

**World Meteorological Organization**



**Institute of Agrometeorology and Environmental Analysis for  
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Regional Meteorological Training Center**

**Manual on Instrumentation and  
Operations for Automatic Weather  
Stations for Agrometeorological  
Application**

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## **Manual on Instrumentation and Operations for Automatic Weather Stations for Agrometeorological Application**

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*This document was prepared to education purpose, with examples and exercises, using trademarked names and symbols. This is due to the necessity of explain technical operations and it doesn't implicate any preference by the authors.*

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**MANUAL ON INSTRUMENTATION AND OPERATIONS FOR  
AUTOMATIC WEATHER STATIONS FOR  
AGROMETEOROLOGICAL APPLICATIONS**



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## - INTRODUCTION -

### **Purposes of the Guide**

In the past twenty years the world of applied meteorology, climatology and environmental monitoring changed in a radical way. Experts trained in the knowledge and techniques and this process is already under way. The fields where the changes were more relevant are electronics, computer science, telecommunications, space science. Nowadays an applied meteorologist should deal with a large number of tools ranging from automatic weather stations to geographical information systems, from satellite pictures to information technologies as Internet. The ability to manage all these techniques together and to apply them to the data collecting, archiving and processing according to a logic chain allows delivering to the users new products with a higher added value. At the same time the impact of man activities on the planet, the globalization of trades and policies, the huge increase of world population open new scenarios. Close to the preoccupations for the food availability and health situation of a large part of mankind there is now a new attention to the environmental impacts of many industrial practices and to the sustainability of some activities as agriculture, fisheries, forestry.

The United States Conference of Rio de Janeiro and recently of Kyoto are the clear signal that there is a new political recognized dimension of the world social, economic and environmental strategies.

In this perspective new areas of intervention as in the case of climatic impacts and climate prediction should give in the future fruitful results.

All these aspects, technological and political ask for new capacities building at level both of scientists and of public services concerned with the natural resources management.

This manual would be a modest contribution to the bringing technicians up to date and to give them some of the tools that should help to reply to new exigencies.

Peace and welfare should come also from a common effort to manage to manage in a better way, scientifically based, our world and save at the same time traditions and cultures of various communities!

The plan of the guide is conceived to allow the user to plan, buy, install, maintain automatic weather stations jointly with the first data processing concerning data quality assessment, data organization and editing.

This guide should be usefully completed with the lecture of the *Guide to Computer Science Application in Agrometeorology*, of the same authors. In a time where in many parts of the world the evidence of climatic anomalies is under way, the importance of reliable observation is increasing. To the efforts of the W.M.O. and of the authors there is a need for an effort of the users to develop a new professionalism and to look around to a world that is rapidly changing!!

### **Note about the Manual**

At the end of each chapter there is a bibliography appendix. In the text a number in square brackets relates to the bibliography cited. In the text you could find also a word in square brackets. It relates to the Internet pages cited. In the chapter 10 there are the Internet addresses related to each chapter.

## ACKNOWLEDGEMENTS

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## 1. SENSORS

### 1.1) Temperature

The temperature indicates the thermal energy possessed by a given body, in others words it is a measure of kinetic energy of the molecular that constitute the considered substance. The temperature can be expressed in different ranges depending of the value assigned at the reference points such as the fusing ice and the boiling water. In the Celsius range ( $^{\circ}\text{C}$ ) the first reference is  $0^{\circ}\text{C}$  and the second is equal to  $100^{\circ}\text{C}$  (at 1013 mbar air pressure). In the Fahrenheit range ( $^{\circ}\text{F}$ ) the two references above mentioned become, respectively,  $32^{\circ}\text{F}$  and  $212^{\circ}\text{F}$ . In the Kelvin range (K) the triple point of water is  $273.16^{\circ}\text{K}$  and the point of boiling water is  $373.16^{\circ}\text{K}$ . This last range is adopted by the International System of Units. It is also called absolute temperature.

#### 1.1.1) Thermocouples

A thermocouple is made of two wires of dissimilar metals that are welded together. The reference junction is typically part of the instrumentation and the opposite junction is called the sensing junction. When the sensing junction is heated, the opposing metals create a known thermoelectric effect proportional to the temperature difference between the two junctions. By compensating for the known temperature of the reference junction, the temperature at the sensing junction can be determined. Different calibration types provide differing thermoelectric effects for differing temperatures and environments. Because of the cold point compensation and special extension wires, designing thermocouples into systems can be complicated.

Figure 1 shows the couple of wires with different thermoelectric potential joined in two points, one called “sensible junction” and the other, maintained at a fixed temperature (in the proper thermocouple readers by an electronic circuitry), called “reference junction”. In this conditions an electric current is produced proportionally to temperature difference between the two junctions. By a voltmeter we can measure the corresponding voltage. The most utilized couples of conductors are copper-constantan, iron-constantan, chromel-constantan with thermoelectric potential of  $40\ \mu\text{Volt } ^{\circ}\text{C}^{-1}$  around. The modern data-loggers have proper input channels for this kind of sensors.

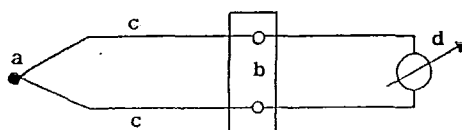


Figure 1. Thermocouple. **a)** Sensible junction, **b)** Reference junction, **c)** Conductors (dissimilar materials), **d)** Voltmeter

The advantages of these transducers are the small size and the fast time response to temperature's variation, and one of the most frequent utilization is for differential measurements (i.e. in temperature profile or in ecophysiology studies for Heat Pulse Velocity measurement technique [1]). This sensor gives a low voltage output and requires accurate data-logger with at least 10  $\mu$ Volt resolution. [2]

Various combinations of materials have been recognized. The noble metal combinations most frequently used include platinum-30% rhodium/platinum (type B), platinum-13% rhodium/platinum (type R), and platinum-10% rhodium/platinum (type S). The thermocouples that are commonly used include chromel-constantan (type E), iron-constantan (type J), chromel-alumel (type K), and copper-constantan (type T).[3]

### 1.1.2) Thermistors

Thermistors are resistive devices made up of metal oxides that are formed into a bead and encapsulated in epoxy or glass. Thermistors generally have a negative temperature coefficient; the resistance decreases as temperature increases. While thermistors are very sensitive, they are typically non-linear and have a limited temperature range.

The thermistors are constituted of semiconductor material, and a temperature increment of 1°C determine a resistance decrease of 5% around; the relationship between temperature and resistance is expressed by the formula:

$$R_t = R_{t0} \exp B(1/T - 1/T_0) \quad (\Omega)$$

Where  $R_t$  is the resistance at the absolute temperature  $T$  (K),  $R_{t0}$  is the resistance at the absolute temperature  $T_0$  (K) (generally  $T_0=298.16\text{K}$ ) e  $B$  is a constant with 4000 ohm value around depending on the utilized material. with thermistors inserted on wheatstone bridges (see chapter below), we have a good linearity in the range of  $-10\div+40^\circ\text{C}$ . The electric output varies between 250 and 500mV  $^\circ\text{C}^{-1}$  Thermistor elements are typically less expensive than RTD elements (see chapter below). They have high resistance that equates to high sensitivity, and provide a

larger voltage drop over a specific temperature using the same measuring current. Self heating is more problematic with a thermistor due to its small size. Thermistors are best suited for low cost applications over limited temperature ranges

### 1.1.3) Thermoresistances

Platinum RTDs are sensing elements that are made of pure platinum wire coil encapsulated in ceramic or glass (wirewound) or a thin film deposited on a ceramic substrate (thinfilm). Platinum RTDs have a positive temperature coefficient, the resistance increases as temperature rises in a known and repeatable manner. Their linearity and long term stability are very good features for environmental applications. Thin film elements are utilized for specific applications such as leaf surface temperature measurements in ecophysiology studies.

These sensors vary their resistance depending on the temperature according to the law:

$$R_t = R_0 + \alpha T$$

Where  $R_t$  is the resistance value (ohm,  $\Omega$ ) at the temperature  $T$  ( $^{\circ}\text{C}$ ),  $R_0$  is the resistance at the reference temperature  $T_0$  ( $^{\circ}\text{C}$ ) (generally  $0^{\circ}\text{C}$ ) and  $\alpha$  is the temperature coefficient ( $\Omega \text{ } ^{\circ}\text{C}^{-1}$ ) that is a function of the material and  $R_0$ . The platinum thermoresistances are the most diffuse and normally have the following characteristics:

$$R_0 = 100 \text{ } \Omega \text{ (at } 0^{\circ}\text{C)}, \text{ where } \alpha = 0.385 \text{ } \Omega \text{ } ^{\circ}\text{C}^{-1} \text{ and are called PT100.}$$

Normally the platinum wire is included in a protective glass capsule from which exit two conductors for the electrical connection. If the reading is done far from the measure site (i.e. few meters to tens of meters) it is advisable to realize a 4 wires connection. A current power supply is applied on a couple of wires and the signal is read on the other couple of wires (see 4 wire connection below).

Additional resistance in extension leadwire will change the true resistance value of the sensor and alter the readings in the controls. The additional resistance is mainly related to the distance between the controls and the sensors, and the ambient temperature of the leadwire. The resistance in the leadwire increases as ambient temperature increases (general rule: if possible don't expose the wires to direct sunlight). Leadwire error can have a significant effect on your actual readings, especially with small gauge wire over long runs. Particularly for long lead runs, a 2 wire connection is inadvisable for additional resistance. There are solutions to canceling leadwire resistance with 3 and 4 wire circuits. Below are

examples of circuits that can be implemented in the acquisition systems in RTD connections:

### Two Wire Circuit

The figure 2 shows a two wire RTD element connected to a typical Wheatstone bridge circuit.  $E_s$  is the supply current by the system,  $E_o$  is the output current,  $R_1$ ,  $R_2$ ,  $R_3$  are fixed resistors and  $R_t$  is the RTD sensor. In this circuit, lead resistance  $L_1$  and  $L_2$  add directly to  $R_t$  (then suitable only for short wires).

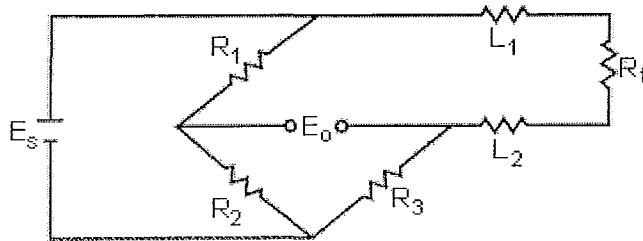


Figure 2. Two wire circuit

### Three Wire Circuit

This circuit provides identical measuring current through  $L_1$  and  $L_3$  across two separate arms of the bridge so that their resistance cancels each other. The two common lead wires,  $L_2$  and  $L_3$  are typically the same color for identification.

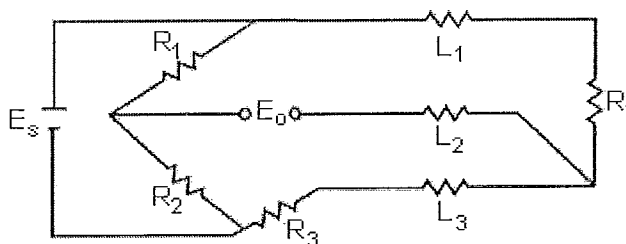


Figure 3. Three wire circuit

### Four Wire Circuit

Four wire circuits provide the best performance for alleviating leadwire resistance errors. The most common data acquisition systems circuit drives a constant current through two leads and the measures the current change across the remaining two leads. Often specific channels are used for this kind of connections. The only source of error is the variation in the measuring current.

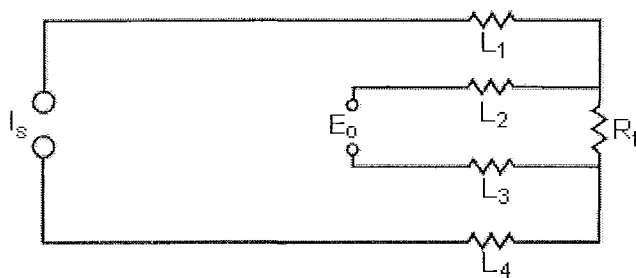


Figure 4. Four wire circuit

Platinum RTDs are powered sensors. That is, a thermoresistance sensor uses a measuring current to calculate the temperature change. As a constant current is supplied to the element, changes in temperature change the sensor resistance and consequently the output current to the instrumentation. Because the sensors are resistive devices, they generate heat in addition to the temperature they are measuring. Self heating needs to be taken into account in thermoresistance sensors to maintain self generated heat a negligible factor. The measuring current used for the RTDs should not exceed 2mA. However when you configure a data-logger for resistance acquisition, it normally has different power current values depending on the magnitude of the resistance, or automatically it choice the correct current value. [A]

#### 1.1.4) Integrated sensors

These are a semiconductor transducers temperature-current; the current drained by these probes is proportional to the temperature. The measure range for these sensors is  $-55^{\circ}\text{C} \div +150^{\circ}\text{C}$  but they required a compensation circuitry to linearize the output signal and in any case the best linearization cannot reach  $\pm 0.5^{\circ}\text{C}$ .

#### 1.1.5) Linearized Thermistors

These probes consist of two series connection thermistor mounted in a unique capsule; in the mounting kit we associate two resistance of known value depending the range which the measures have to cover. We can then have three temperature range of  $-5 \div +45^{\circ}\text{C}$ ,  $0 \div +100^{\circ}\text{C}$ ,  $-30 \div +50^{\circ}\text{C}$ . Its sensitivity is less then others traditional thermistors but is greater than a PT100 ( $39 \Omega/^{\circ}\text{C}$  for  $R_0$  value equal to  $5.6 \text{ k}\Omega$ ) thermoresistance. Keeping in account the maximum uncertainty of nominal value of  $R_0$  and of the temperature coefficient they can reach an error of  $1^{\circ}\text{C}$  at  $+50^{\circ}\text{C}$ . This can be negligible for some applications in which we could

be involved. A disadvantage is due to the high resistance values reached by these sensors that sometimes cannot be directly connected to all types of data-loggers.

## **1.2) Air Humidity**

The air humidity is the atmospheric water vapor content, characterized by determined values of air temperature and air pressure. The air humidity directly influences plant's life regulating its evapotranspiration rate (and consequently its energy balance), and in some particular micrometeorology conditions this factor can favor parasitic diffusion. The water vapor, as others atmospheric gases, contribute to the total pressure definition of this mix of gas. For each air temperature value exist a maximum partial pressure vapor value. This is called partial saturated vapor pressure and it is related to the air temperature by the relationship:

$$e_s = 0.61078 \cdot \exp(17.269 T / (T + 237.3))$$

Where  $e_s$  (kPa) is the partial saturated vapor pressure,  $\exp$  is the Neperian logarithm base (2.7181) and  $T$  (°C) is the air temperature. The air humidity conditions can be expressed in different ways:

- Absolute humidity, it is the atmospheric water vapor content expressed as partial vapor pressure or density ( $\text{gm}^{-3}$ ).
- Relative humidity, express the ratio between saturated vapor ( $e_s$ ) and the effective vapor pressure ( $e_a$ ). The unit is the percentage (%).
- Saturation deficit, is the difference between saturated vapor pressure  $e_s$  and the effective pressure,  $e_a$
- Dew point, is the temperature value which a given air volume have to reach to produce condensation

For air humidity measurements can be employed different kind of sensors; the most employed are the hygrometric sensors, the psychrometric sensors and dew-point sensors.

### **1.2.1) Hygrometric sensors**

In the resistive transducers such as some hygroscopic salts, (like the lithium chloride), the electric resistance variation induced by the humidity absorbed by the surface is measured. Some problems with these sensors can be due to the dust or pollen deposition on the sensor surface, or for pollutants substances action. Moreover another kind of problem is related to the hysteresis effect both in wetting and drying measure phases.

Capacitive humidity sensors can utilize the ability of thin film polymers to vary their dielectric constant, in a linear relationship, to the amount of water vapor present in air or gas. High sensitivity, good accuracy and the repeatability are good features for agrometeorological applications. The elements are manufactured using polymer coating and metal sputtering techniques. A certain amount of polymer film is deposited on silicon, glass or a plastic substrate. Vapor deposited gold or platinum is used as an overcoating to protect the polymer film. Leads are bonded to the elements resulting in miniature sensors that may be incorporated in small probes. These sensors provide a wide measurement range 0-100% RH with  $\pm 2\%$  accuracy between 5-95% RH.

### 1.2.2) Psychrometric sensors

For the aspirated psychrometer two temperature sensors of same type are mounted inside separate tubes that are double-walled and covered with reflective aluminum or coated by white reflectance paint to minimize radiation errors. In the psychrometer the air humidity is determined from the psychrometric equation that allow to derive from dry bulb temperature ( $T_d$ ) and wet bulb temperature ( $T_w$ ), the  $e_s$  (saturated vapor pressure) and  $e_a$  (actual vapor pressure) parameters: The effective vapor pressure is then:

$$e_a = e_{sw} - \gamma (T_d - T_w)$$

Where  $\gamma$  is the psychrometric constant ( $66 \text{ Pa}^\circ\text{C}^{-1}$ ) and  $e_{sw}$  is the saturated vapor pressure at the wet temperature ( $T_w$ ) calculated from:

$$e_{sw} = 0.61078 \exp (17.269 T_w / (T_w + 237.3))$$

The wet bulb is kept moist by a tightly woven cotton wick extending into a reservoir of deionized water (or by a ceramic porous capsule inserted in a reservoir of deionized water). [4] Both temperature bulbs have to be shielded from sunrays and during the measure exposed to an airflow of 5 m/s around (W.M.O. suggest an airflow from  $2.5 \text{ ms}^{-1}$  and not greater than  $10 \text{ ms}^{-1}$ ) otherwise the psychrometric constant has modified.

Table 1 shows the air humidity values calculated from the measure of the dry and wet bulb.

Difference between Dry bulb and Wet bulb readings (°C)

Dry bulb Tmp	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
50	97	94	92	89	87	84	82	79	77	74	72	70	68	66	63	61
49	97	94	92	89	86	84	81	79	77	74	72	70	67	65	63	61
48	97	94	92	89	86	84	81	79	76	74	71	69	67	65	62	60
47	97	94	92	89	86	83	81	78	76	73	71	69	66	64	62	60
46	97	94	91	89	86	83	81	78	76	73	71	68	66	64	62	59
45	97	94	91	88	86	83	80	78	75	73	70	68	66	63	61	59
44	97	94	91	88	86	83	80	78	75	72	70	68	65	63	61	58
43	97	94	91	88	85	83	80	77	75	72	70	67	65	62	60	58
42	97	94	91	88	85	82	80	77	74	72	69	67	64	62	59	57
41	97	94	91	88	85	82	79	77	74	71	69	66	64	61	59	56
40	97	94	91	88	85	82	79	76	73	71	68	66	63	61	58	56
39	97	94	91	87	84	82	79	76	73	70	68	65	63	60	58	55
38	97	94	90	87	84	81	78	75	73	70	67	65	62	59	57	54
37	97	93	90	87	84	81	78	75	72	69	67	64	61	59	56	54
36	97	93	90	87	84	81	78	75	72	69	66	63	61	58	55	53
35	97	93	90	87	83	80	77	74	71	68	65	63	60	57	55	52
34	96	93	90	86	83	80	77	74	71	68	65	62	59	56	54	51
33	96	93	89	86	83	80	76	73	70	67	64	61	58	56	53	50
32	96	93	89	86	83	79	76	73	70	67	64	61	58	55	52	49
31	96	93	89	86	82	79	75	72	69	66	63	60	57	54	51	48
30	96	93	89	85	82	78	75	72	68	65	62	59	56	53	50	47
29	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	46
28	96	92	88	85	81	77	74	70	67	64	60	57	54	51	48	45
27	96	92	88	84	81	77	73	70	66	63	60	56	53	50	47	44
26	96	92	88	84	80	76	73	69	66	62	59	55	52	49	46	42
25	96	92	88	84	80	76	72	68	65	61	58	54	51	47	44	41
24	96	91	87	83	79	75	71	68	64	60	57	53	50	46	43	39
23	96	91	87	83	79	75	71	67	63	59	56	52	48	45	41	38
22	95	91	87	82	78	74	70	66	62	58	54	51	47	43	40	36
21	95	91	86	82	78	73	69	65	61	57	53	49	45	42	38	35
20	95	91	86	81	77	73	68	64	60	56	52	48	44	40	36	33
19	95	90	86	81	76	72	67	63	59	55	50	46	42	38	34	31
18	95	90	85	80	76	71	66	62	58	53	49	45	41	36	32	29
17	95	90	85	80	75	70	65	61	56	52	47	43	39	34	30	26
16	95	89	84	79	74	69	64	60	55	50	46	41	37	32	28	24
15	94	89	84	78	73	68	63	58	53	49	44	39	35	30	26	21
14	94	89	83	78	72	67	62	57	52	47	42	37	32	28	23	18
13	94	88	83	77	71	66	61	55	50	45	40	35	30	25	20	16
12	94	88	82	76	70	65	59	54	48	43	38	32	27	22	17	12
11	94	87	81	75	69	63	58	52	46	41	35	30	25	19	14	9
10	93	87	81	74	68	62	56	50	44	38	33	27	22	16	11	5
9	93	86	80	73	67	61	54	48	42	36	30	24	18	13	7	2
8	93	86	79	72	66	59	52	46	40	33	27	21	15	9	3	
7	93	85	78	71	64	57	50	44	37	31	24	18	11	5		
6	92	85	77	70	63	55	48	41	34	28	21	14				
5	92	84	76	69	61	53	46	39	31	24						
4	92	83	75	67	59	51	44	36								
3	91	83	74	66	57	49										
2	91	82	73	64												
1	90	81														

Subtract the Wet bulb reading from the Dry bulb reading. Note the difference along the top line. Follow this column down until the level with the Dry bulb reading for the percentage humidity.

### 1.2.3) Dew-point sensors

The dew-point sensors measure the temperature that corresponds to a dew formation on an artificially cooled surface (i.e. by current passage generating a Peltier effect). Some problems can be due to the identification of dew formation instant (then of the temperature measure); at this purpose photoelectric systems are employed. A beam lightening directly the specular surface (in which will take place the drop formation); when the dew appears the diffuse light reach a transducer, that actives the instantaneous temperature measure.

### 1.3) Soil Humidity

Soil water availability is an essential condition for plants life, then the knowledge of this parameter is very important but the measurements techniques still presents many difficulties.

Soil water content can be express in different ways:

- As percent of soil weight or volume
- Described as energy relation between soil energy suction and water availability.

From the soil-plant-atmosphere system interaction aspect, the last approach is the most interesting, because it can well describes the energy in which the water is hold by the terrain particles. This gives us an idea about the work of the root system in absorbing water. Following measure methods are described:

- ❖ Neutron method
- ❖ Time domain reflectometry method
- ❖ Tensiometer method

Soil moisture parameter is characterized of high spatial variability, and these above mentioned methods give a punctual measure of soil moisture, then as high samples numbers we are able to collect as the estimation accuracy will improve.

#### 1.3.1) Neutron Probe

It is based on the principles of neutron thermalization. Fast neutrons emitted by an Americium<sub>241</sub>-Beryllium radioactive source are thermalized (slowed) by hydrogen in the test sample. These slowed neutrons are detected, and counts are displayed in direct proportion to the water content of the sample. Since the gauge measures hydrogen in water as well as other compounds, a careful calibration is needed for individual soils and other test material to isolate water. Normally the instrument models can read moisture content directly and has the additional ability to store

data and download data to a computer via serial port, including both the gauge and the console. This contains a microprocessor that allows the instrument to compute and display the moisture content. The display is in different units such as kilograms per cubic meter, volume percent, count ratio, millimeters per meter and so on depending on the manufacturer. The readings are obtained by dropping a probe down an access tube to a desired depth. Tubing is used to line an augered hole to access a sample at a desired depth. The tubing protects the probe from direct contacts with the soil and provides access to repetitive tests.

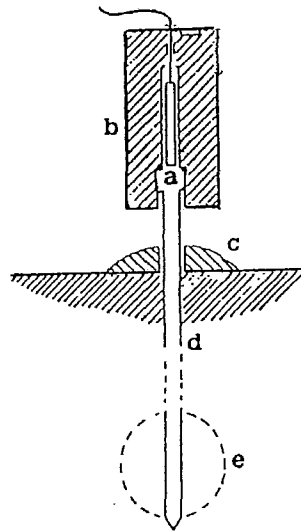


Figure 5. Neutron probe. a) Running probe, b) console, c) sealing access tube, d) access tube, e) sample volume

The memory contain factory calibration coefficients to transform the counts in the specified unit, but this can give only an approximation value of tests soil water contents. With a specific soil test calibration [5], the effective soil water content (expressed as % on the volume) is well estimated and lets accurate and fast routine readings. Some disadvantages of this method are:

- surface measures are not permitted because they can be affect by the air hydrogen contents, and above all for safety operations (the first measure can start with the gauge at a depth of 20cm around).
- Some less or more complicate restrictions about radioactive material are present depending on the country. This can be a difficulty for a field utilization (i.e. the permission for transport from laboratory to the experimental field).
- Experimental field change, means a new calibration procedure for the neutron probe

### 1.3.2) Bouyoucos probes

One of the most common methods of estimating matric potential is with gypsum or porous blocks. The device consists of a porous block containing two electrodes connected to a wire lead. The porous block is made of gypsum or fiberglass. When the device is buried in the soil, water will move in or out of the block until the matric potential of the block and the surrounding soil are in equilibrium. The electrical conductivity of the block is then read by the acquisition system. A calibration curve is made to relate electrical conductivity to the matric potential for any particular soil. Using of a porous electrical resistance block system offers the advantage of low cost and the possibility of measuring the same location in the field throughout the season. The block works over the entire range of soil water availability.

The disadvantage of the porous block system is that each block has different characteristics and must be individually calibrated. The main disadvantage of the gypsum block is that the calibration changes gradually with time, limiting the life of the block; gypsum blocks can have an expected lifetime of at least two years providing the soil salinity is less than 1%. For adverse conditions and for very long observation periods, the inert calcium silicate block should be used. The greater problems occur in high soil water content conditions, because the hysteresis of the sensors became high. The signal output can be in Hz, then a proper data-logger or a converting circuit Hz -> DC voltage can be required. Some expected features for these sensors should be:

- Robust Design
- High Stability
- Corrosion Resistant
- Gypsum or Calcium Silicate Blocks
- Low Power Consumption

Possible applications in agronomy:

- horticulture and greenhouses (but frequent water supply induce a very high water content on the plant's substrate, then critical operative range for the probes);
- soil moisture extraction crop studies;
- irrigation management.

### 1.3.3) Tensiometers

Tensiometer can directly measure the soil water potential. A thin tube composes it with replaceable porous ceramic sensing tip at the bottom extreme. Upper water reservoir with jet-fill button needs to remove accumulated air in the tube with one stroke. In the mechanical series a Bourdon vacuum dial gauge gives the potential indication by a 0-100 centibars graduated manometer.

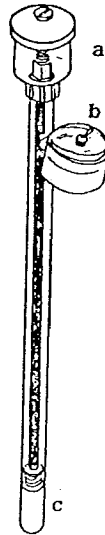


Figure 6. Mechanical tensiometer: a) Reservoir, b) manometer, c) porous ceramic tip

The gauge is inserted in the soil at the desired depth and we wait until steady conditions are reached between porous tip water content and soil water. As the soil dries water in the sensor's column is recall and the manometers will indicate the related depression. Now an electrical switching version sensor is also available, and it is directly connectable to a data-logger for repetitive data collecting. These tensiometers are very similar to the others: they have a ceramic cup, a transparent shaft filled with deionised, degassed water, and a strain gauge that measures soil suction directly (range 0 to -85 kPa). They require calibration.

Some disadvantages of this method are:

- small measure range from 0 to 100 centibars (0÷85 for electronic type)
- water reservoir refilling is needed
- spatial distribution measurements required an expensive purchase of a lot of sensors

### 1.3.4) Time Domain Reflectometry (TDR)

This technique allows nondestructive measurement of volumetric water content in soils and other materials, permitting a continuous measurement (i.e. sensor connected to a data-logger) without taking samples.

The Time-Domain-Reflectometry is being developed to measure the dielectric constant (water = 81, compared to a small one of materials e.g. -soil = <5). The dielectric constant can be determined by the travel time  $c$  of an electromagnetic wave in the material. The travel time is only dependent on two material constants, the dielectric constant and the magnetic permeability.

The travel time of the electromagnetic pulse is dependent on the length of the parallel rods embedded in the porous medium and the water content in the medium (the soil). With this technology it is possible to measure the transmit time with a good resolution. Since this amplitude is attenuated by the electrical conductivity of the medium, it is also possible to derive the bulk soil conductivity and therefore the salinity content in the soil.

The probes can look as that shows in Fig. 7, and they cover an electrical field as shows in Fig. 8 (courtesy of IMKO GMBH)

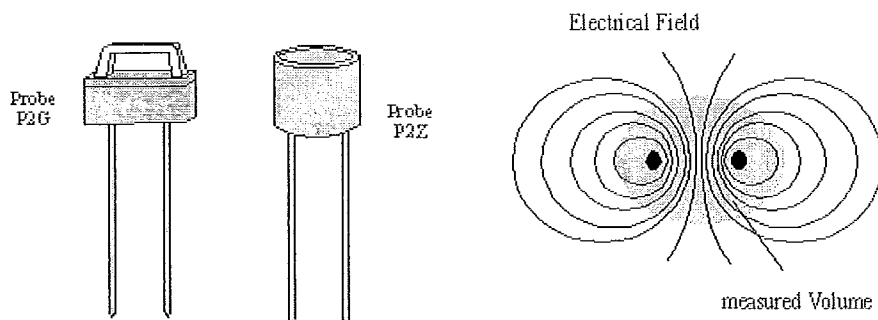


Figure 7. TDR probes.

Figure 8. Electrical field

It is possible to have also a TDR Probe with Access Tube. Two metal shells, which act as electrical transmission lines, are build round the cylindrical body of the tube probe. The device generates a high-frequency pulse (up to 1GHz) which propagates along the metal shells generating an electromagnetic field around the probe. At the end of the shells, the pulse is reflected back to its source. The resulting transit time (10ps...2ns) can be measured and the propagation velocity, which is primarily dependent on the water content, can be determined. The volumetric water content is then calculated by the velocity and is send as analog signal to a data-logger. The penetration depth of the measurement field into the soil can be up to 100mm. In comparison to the capacitance method, the TDR-technique is mostly independent of soil type and salinity. The measurement range

extends up to 70% water content and therefore an accurate measurement is possible also in clayey soils and in soils where fertilizers are used. Because of the simple handling, and without radioactive sources, the tube probe would be a good alternative to the above mentioned neutron probe technique. [B]

Some disadvantages of this method are:

- difficulty measurements in stoned or stratified soils for lines guides insertion
- calibration for each testing fields is advised
- plants treatments can halter salinity concentration in the soil (specially in the firsts layers), than the probe's response
- in the last years this technique has become cheaper then in the past, but to have a sufficient samples measurements number, the method result expensive

#### **1.4) Air Pressure**

The atmospheric pressure on a given horizontal surface is the force per unit area exerted on that surface by the weight of the atmosphere above. The international system unit of pressure is the Pascal, defined as the 1 Newton force on  $1\text{m}^2$  ( $1\text{Pa}=1\text{Nm}^{-2}$ ). Some others units are unfortunately still in use such as mercury millimeter (mm/Hg), water meters (m H<sub>2</sub>O), atmosphere, bar (most utilized is his submultiple: mbar).

Some atmospheric pressure instruments including the electronic signal output models have a mechanical transducer with different characteristics, in which known surface acts a force. When this force is not equalize by a similar pressure on the other surface a sensible element deformation is induced, transmitted to a second transducer that convert this impulse in an electronic signal. The air temperature conditions can affects the measurements made with these sensors, and it is advisable to use immune temperature electric transducers (i.e. potentiometric transducer). The local height above sea level must be known and used as an offset to provide relative atmospheric pressure. Depending on the transducer employed we can classify the following pressure sensors:

- Capacity sensors
- Inductivity sensors
- Piezoelectric sensors
- Potentiometric sensors
- Resistivity sensors
- Semiconductor sensors

#### **1.4.1) Capacity sensors**

Membrane torsion induces a capacitance plate movement including in a measure bridge, which is in equilibrium at zero pressure value. It can be a symmetrical ceramic capsule, which deforms proportionally to applied pressure. Electrodes on the inside surfaces of the ceramic capsule create a variable capacitor. As pressure exerted increases, the electrodes move closer to each other, increasing the capacitance. This is detected and converted to a linear DC signal and acquired.

These sensors can presents some practical problems relative to time constant and hysteresis characteristics.

#### **1.4.2) Inductivity sensors**

The induction coil value varying in response to the pressure oscillation, which modify the membrane (of ferromagnetic material) position placed near of the winding. In these sensors the environmental effects compensation is difficult, especially for air temperature, and a complicated circuitry is needed.

#### **1.4.3) Piezoelectric sensors**

These transducers operate according to the piezometric principle: a resistive film is deposited on a slice of silica to form a measure bridge; as the pressure changes, the slice will deform and consequently changes the system's resistance. Some models mount a special thermal compensation system that significantly reduces the measure errors.

#### **1.4.4) Potentiometric sensors**

In these devices a transducer mechanical movement (Bourdon tube or capsule) is amplified and operates on a potentiometer (this is a variable electrical resistance that varies his value depending on a cursor position on a wiping contact).

#### **1.4.5) Resistivity sensors**

Conductivity characteristics of some materials like carbon dust, rare soils mixture etc. varies depending to the pressure variations. His characteristic can be exploit and an electrical signal is obtained.

Another type or resistivity sensor utilizes the strain gauge transducer. These digital sensors have been designed as reliable and stable sensors for environmental and meteorological monitoring applications. They have minimal power drain (approximately 4mA). These sensors should be housed inside a radiation shield,

as the calibration of barometric pressure sensors changes with temperature; the temperature coefficient of each sensor should be determined by the factory and specified in the calibration certificate. It is recommended that air temperature should also be measured in the same sensor shelter.

#### **1.4.6) Semiconductor sensors**

Some silicon crystals vary its conductivity depending on the pressure variations applied.

All sensors measure pressure with respect to some other pressure such as a vacuum, atmospheric pressure or some other pressure defined by the user. Absolute - pressure sensors have a backside cavity which is sealed at a reference (vacuum); therefore all measurements are made versus a vacuum. These are useful in applications such as those measuring atmospheric pressure.

Differential - pressure sensors have two ports and measure a pressure versus another pressure or the difference between the front port and the back port pressures.

These sensors are basis on a strain gage consisting of a Wheatstone bridge on a thin silicon diaphragm. The bridge is implanted into the silicon in such a way that when pressure is exerted, two resistors go up in value and two go down. As pressure against the diaphragm cause it to deflect, the resistors change in value and the output voltage increases ( $V=I \times R$ ).

These sensors will require a power source such as a current or voltage excitation source. In addition, some type of amplification could be required.

When using low cost uncompensated devices, the customer will probably require some type of compensation and calibration depending on temperature range and accuracy requirements of the application. [C]

#### **1.5) Solar Radiation**

Solar radiation is one's of the most important parameters for environmental plant characterization. It represents primary matter production process energy source and affects many others mechanism, which regulates plants developing phases and plants communities relationship.

With **radiation flux** term we refer to a radiant power in the spectral range of 200 nm up to 100  $\mu\text{m}$ . These values depends on the fact that wavelengths under 200 nm haven't any biological effect because they are filtered by the atmosphere. The

upper value is choosing for the same reason. The measure unit of the power is Watt (W).

The radiant power that reach a surface is called **irradiance** and it is defined as a radiative flux referred to a given surface unit. The measure unit for this parameter is the watt per square meter ( $\text{Wm}^{-2}$ ).

The correspondent of irradiance referred to the energy flux released by a body per unit of solid angle (steradian, sr) is called **radiance**; the unit is  $\text{Wm}^{-2} \text{sr}^{-1}$ .

Measurement instrumentation of radiation can operate by temperature variation of a sensible element (thermopile) or by the photon flux measure of electromagnetic transducers (photocell). The first one's operate on a broadband from the UV region to the microwaves. They are constitutes of an heat sensible element that absorbs the radiation and of a thermistor sensor with a temperature compensation circuitry. The increasing temperature respect to the thermistor sensor measure is an incident radiation function.

### 1.5.1) Thermopile

In the thermopile sensors the temperature sensible element comprises a multi-junction thermocouples (i.e. copper-constantan) to give a greater voltage signal, which is temperature compensated to have a response essentially independent of ambient temperature. The thermopile has the advantage of a quite rugged construction and resist to mechanical vibration. Its surface is covered of a special black coat. Some thermopiles have a rectangular shape: in this case is better to displace the sensor with the longer side of the thermopile aligned to the East-West axis. This for an uniform heating of the transducers. With circular thermopiles we don't obviously have this effect.

### 1.5.2) Photocell

Photoelectric characteristic effect of some materials such as the selenium and silicon is exploit. They convert incident radiant energy directly in electric energy also with low radiation levels. Selenium photocells are particularly sensible in UV region near the visible, while silicon photocell cover a range from the visible region to near infrared (near IR). Particular silicon photocells can cover near UV region also. These low-cost sensor are suitable for high measurements points number of global and diffuse radiation, or for statistical studies of solar radiation distribution (i.e. in the vegetation). Moreover by specific bandpass interference filters particular frequency ranges are available, such as P.A.R. range (Photosynthetically Active Radiation, in the 400 to 700 nm waveband), or for light quality studies.

The photocells cannot be suitable for net radiation measurements, because they are not sensible to the thermal infrared.

### 1.6) Wind Speed

The wind can be defined as large air mass flow motion due to pressure gradient. This air transport has big influences on the plant's life because modify their micrometeorological and biological conditions. In the first case the wind affects others meteorological parameters like air temperature, air humidity, evaporation, gas concentration and so on. In the second case the wind it's a vehicle of pollen, seeds, insects, spores etc.

For a complete wind characterization, the intensity (along the three-axis distribution) and direction need to be measured.

Different types of anemometers can make wind speed measures:

- Cup anemometer, that measures kinetic air energy
- Heat anemometer, that measures the running air cooler effect
- Sonic anemometer
- Doppler anemometer

#### 1.6.1) Cup Anemometer

These sensors employed some devices as cup or propeller that reaches kinetic balance with the surround air.

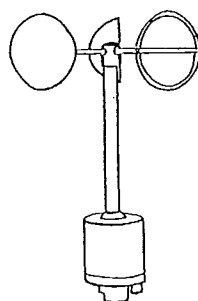


Figure 9. Cup anemometer.

The Cup anemometer showed in Figure 9, is constituted of three cups with different shapes: conic or semispherical, with different diameter depending on the desired sensibility. They are connected to a vertical axis that convert horizontal air flow in a rotation motion (a couple of upper and lower stainless ball bearings are mounted) received by a signal generator. This can operates by two types of transducers: tachometer or photoelectric. In the first case the tachometer generator

produces an analog DC voltage directly proportional to wind speed. In the second one a rotary shutter turns with the rotor spindle and interrupts the light from an internal lamp, activating a photoelectric switch once per revolution of the rotor. A powered circuitry converts these pulses in a DC voltage. Both transducers can be then connected to a data-logger. Some data-logger can directly acquire the frequency signal (Hertz).

The first type of transducers is surely more rugged, but it has higher threshold than the second does. Another common error source for both sensors is due to the distant constant, that is the passage of wind (expressed in meters) required for the output, to indicate 63 per cent of step-function change of the input speed. This parameter could not exceed 2.5 meters. The time constant is the time required for a device to detect and indicate about 63 per cent of a step-function change. The response is such that about 95 per cent of a step-function change would be indicated in a period equal to three times constant.

A disadvantage of cup anemometers is their tendency to overestimate a fluctuating wind speed. This is because the cup accelerates more rapidly with an increase in wind than it decelerates in a falling wind. The degree of over-estimation can be as large as 20% and is most serious when the period of the wind velocity fluctuation is short and the mean velocity is low. [6]

### 1.6.2) Hot wire Anemometer

A hot-wire anemometer is a thermal transducer that is capable of sensing point flow velocity through temperature variation, using an heated resistance wire. The sensor of the typical hot wire probe is a wire, usually made of Tungsten or Platinum.

The probes are constant temperature anemometers, which means that the circuitry provides a sensor heating current that varies with the wind velocity in order to maintain a constant sensor operating temperature (i.e. 150°C or 125°C). As the air velocity increases, the rate of cooling of the sensor will also increase. Then the heating current will have to be increased to maintain the desired operating temperature. The amount of power being supplied to the probe can be related to the air velocity by a linear relationship.

These sensors are generally quite fragile, and they are most often used for boundary layer profile measurements and other tests in which turbulence intensity is of particular importance. Their speed threshold is very low (~ 0.15 m/s)

### 1.6.3) Ultrasonic Anemometer

### Measuring Principle

Short pulses of ultrasonic sound are exchanged on three different directions by couples of sound probes, which are used alternately as transmitting and receiving units.

The sound velocity derived by traveling time of the ultrasonic pulses is composed of the sound propagation of the motionless air itself, i. e. the wind speed parallel to the trajectories of the ultrasonic pulses. Combining the sound velocities of different propagation directions, the 3-dimensional wind vector can be determined. [D]

The anemometer consists of a sensing head with transducers arranged in some pairs, surmounting a box electronic base enclosure. The electronic circuitry provide all ultrasonic processing and vector computations required to compute the wind speed and direction. Each pair of transducers acts alternately as transmitter and receiver, sensing pulses of ultrasound between themselves. By arranging three pairs of transducers in different orientations, the direction and magnitude of the incident airflow may be derived.

The formula can be write as:

$$\Delta T = \frac{2LV \times \cos \sigma}{U^2 - V^2}$$

Where L is the distance between transmitter and receiver,  $\sigma$  is the angle included between wind direction and sound direction.

This instrument have many advantages like a very low speed threshold (0.02 m/s), measure both vertical and horizontal wind components and wind direction, but it's cost is still high. Here is an example of technical specifications:

Ultrasonic sampling rate	80/second
Data Output rate	1/second
Power requirement (heating disabled)	9 ÷ 30 VDC 60 mA
Power requirement (heating enabled)	9 ÷ 30 VDC 250 mA max
Wind speed range	0 ÷ 60 m/s
Wind speed accuracy	< 30 m/s ± 3%
	> 30 m/s ± 5%
Resolution	0.01 m/s
Wind speed offset	0.02 m/s
Direction Accuracy	< 30 m/s ± 2°
	> 30 m/s ± 4°

*(Mod. Basic Solent by Gill Instruments Limited)*

#### 1.6.4) Doppler Anemometer

The best way to describe Doppler shift is to consider an example. As a train, blowing its horn, approaches you at a constant speed, the sound of the horn will be of a slightly higher pitch. As the train passes by, the pitch lowers. If the train were not moving, the sound would be of a pitch somewhere between the higher one and the lower. This is the frequency shift. The speed of the train, in the approaching case, is adding to the speed the sound wave of the horn. In the other case, the speed of the train is subtracting from it. With a higher speed, the wavelength is reduced. With a lower speed it is increased. Doppler described the frequency shifted analytically as,

$$\omega = k(u \pm c_0)$$

where  $k$  is the wave number of the source wave,  $u$  the speed of the interfering media, and  $c_0$  the fundamental speed (i.e. speed of light for electromagnetic waves, speed of sound for acoustics).

In this approach, when there is no interference,  $u$  is zero and the shifted  $[\omega]$  simply equals the original. When there is some speed  $u$ , the frequency varies monotonically with that change in speed giving us a proportional frequency shift,

$$\omega_{\text{shifted}} - \omega = k(u \pm c_0) - kc_0$$

The difference between the two frequency shifts is just,

$$\Delta\omega = \pm ku \quad [7]$$

Doppler Anemometers can be of two types: sonic or optic.

When a radar target is moving, the returned signal is shifted in frequency from that which would be returned from a stationary target. The change in frequency of the returned signal, called the Doppler shift is very small but can be measured by the proper sensor. It requires a radar to transmit pulses in very stable manner. The  $\Delta F$  due to the speed moving of the receiver or of the transmitter or both will be sum to the propagation speed of the waves emitted. If the transmitter and receiver distance decrease the frequency increase, while if the distance increase the frequency decrease. The wind speed can be calculated by the formula:

$$V = \frac{\Delta F}{F} \frac{U}{2} \frac{\sin \Theta}{2}$$

Where:

$U$  = Speed of sound or laser ray propagation

$\Delta F$  = Frequency variation

$F$  = Transmission frequency

$\Theta$  = Transmitter-receiver angle

This instrumentation is generally complex and quite delicate, characteristics that contribute to increase their cost; the possible use can be:

- a) The determination of the radial component of wind speed and direction at various heights, with detailed information also in vertical wind, maximum wind speed
- b) Identification of sharp wind shifts and measurements of their speed and direction
- c) Early identification of extreme events as storm phenomena or tornadoes

### **1.7) Wind direction**

The windvane sensor has a balanced vane assembly (it can have many shapes depending on the manufacturer) which rotates on double sealed stainless ball bearings and is coupled to a precision potentiometer (a variable resistor having two or three terminals and a movable wiper. Precision potentiometers can be used to create a variable resistance proportional to angular or linear displacement). With constant voltage applied to the potentiometer, the signal output is proportional to the angular position of the vane and sent to a data-logger. As wind direction has an high variability an angular resolution of  $10^\circ$  is sufficient. Note that windvane installation needs a compass to set the zero signal to north direction ( $0^\circ$  or  $360^\circ$  angle) and, turning clockwise,  $90^\circ$  for east direction,  $180^\circ$  South direction and  $270^\circ$  West direction. Be careful when you connect it to the data logger: an inversion of the signal wires could invert this response!

As for the anemometers we have to take care on the cleaning of rotation parts, specially the ball bearings, to avoid measurements failures. A different acquisition for this variable is needed, because the high variability and frequency distribution angle calculation. In fact a simple average value gives an error. For example if  $10^\circ$  and  $350^\circ$  values are considered, the main wind direction is certainly North but the average gives  $180^\circ$  (south direction): for example if angular position values falling in the fourth quadrant ( $270^\circ \div 360^\circ$ ), we consider:  $-(360^\circ - 350^\circ) = -10^\circ$ .

The average with the value  $10^\circ$ , gives correctly  $0^\circ$  (North direction).

## WIND DIRECTION

Table 2 - Wind direction - Compass Point Equivalent

Compass	Exact Equivalent in	Code Figure
Calm	-	00
N by E	11.25	01
NNE	22.5	02
NE by N	33.75	03
NE	45	05
NE by E	56.25	06
ENE	67.5	07
E by N	78.75	08
E	90	09
E by S	101.25	10
ESE	112.5	11
SE by E	123.75	12
SE	135	14
SE by S	146.25	15
SSE	157.5	16
S by E	168.75	17
S	180	18
S by W	191.25	19
SSW	202.5	20
SW by S	213.75	21
SW	225	23
SW by W	236.25	24
WSW	247.5	25
W by S	258.75	26
W	270	27
W by N	281.25	28
WNW	292.5	29
NW by N	303.75	30
NW	315	32
NW by N	326.25	33
NNW	337.5	34
N by W	348.75	35
N	360	36
Variable	-	99

**1.8) Rainfall**

Precipitation is defined as the liquid or solid products of the condensation of water vapor falling from clouds or deposited from air on the ground (Rain, hail, snow, dew, and hoar frost and mist precipitation). Even if snow and hail precipitation has an important role on agricultural and forestry studies, here are described the most common rainfall gauge. The rainfall is expressed in millimeters (mm), fall in a specified time interval on a horizontal surface, and for it's measure the amount of water caught by the gauge (with standard orifice measures) is utilized.

### 1.8.1) Pluviometer

In the common pluviometers (Fig. 10) water is brought to a tipping bucket system through a conveyor.

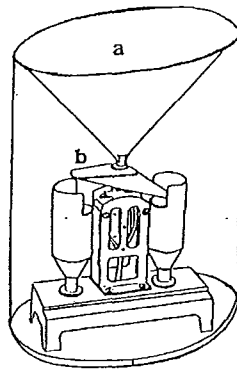


Figure 10. Pluviometer: a) standard receptacle, b) Tipping bucket

The rain gauges can have stainless steel housing or rugged UV plastic, whilst in some cases the collector cones are Teflon coated to allow water droplets to dribble down inside even in case of very light rain drizzle. The measurement device is composed of a double chamber connected to a magnet that operates one reed switch which generates impulses that can be counted by an external meter (data logger provides a digital input signal) with a measurement resolution of 0.1, 0.2 or 0.5 mm/pulse. For sites with sub-zero temperatures, thermostatically heated models are available (they completely melt the snow, even at extreme temperatures). Some errors could occur in extreme events like hot temperatures (i.e. fast evaporation of deposited water on the collector walls or bucket), high rainfall intensity (i.e. splashing of raindrops from or into a gauge), high wind speed, and air turbulence conditions (i.e. blowing of snow from or into the gauge)

Another problem is related to the rain distribution's high random variability (especially comparing small time intervals), that involves considering the representativity of the measure. To study this parameter distribution over a large area, many measure points have to be installed depending on the homogeneous areas identified.

### 1.8.2) Meteorological Radar

The estimation of wide rainfall distribution is generally a difficult problem because of its high variability. Traditional rain gauge networks, even when densely installed, can only provide singular measures of rainfall fields and rarely they could give a real-time response.

The distribution and intensity of precipitation can be measured using weather radar which operate in the 3 to 10 cm wavelength range, and the most advantage

of using radar for precipitation measurement is the coverage radar provides over a large area with high spatial and temporal resolution. Radar can provide remote rainfall estimates for time intervals as small as 5 min and spatial resolutions as small as 1 km<sup>2</sup>. There are some problems as to the correct measurement of radar reflectivity and in the calibration procedures that are required to transform measurements of the electromagnetic radar echo into rainfall rates. This “calibration” requires a preliminary observation of radar measurements against rain gauge response. A transmitter produces an electromagnetic radiation of a known power and at a given frequency. The radiation is emitted along a narrow radial beam from the radar antenna, which also receives that part of the beam scattered back by the raindrops or the flakes. A receiver detects the back-scattered radiation, amplifies it and converts the microwave signal to a low-frequency signal, which is related to the properties of the hydrometeors. [8]

In practice meteorological targets are seldom visible to a radar at ranges beyond 300 km, whilst the intensity of precipitation falling upon the ground cannot be reasonably assessed with any pretence of accuracy at ranges above 100 km. [9]

### **1.8.3) Rain drop energy sensor (Impactometer)**

This particular sensor, called impactometer, is suitable for measuring the energy or momentum released by drops rainfall (or others precipitation such as hail) to a known surface in a preset time interval. A piezoelectric sensor supplies a signal that is numerically integrated by a microprocessor-based circuit; drift problems arising from the use of analog integrators are eliminated. If properly calibrated, the impactometer can measure rainfall intensity too (that is, it works like a rainfall intensity meter) and give an indication of rainfall erosive capability. The upper sensor surface is slightly convex sintered bronze, to reduce drops splashing and avoid water stagnation. When raindrops strike the sensitive surface, they release energy which is transmitted to a piezoelectric impact transducer and then sent to an integrator that produces a proportional voltage depending to the energy collected in a preset time (i.e. 1 minute). The microprocessor performs the integration of the signal during this interval and when the preset time elapses a pulse resets the integrator, and a new measurements cycle start. [10]

## **1.9) Evaporation**

Measurements of this parameter is important because can help farmer’s decisions on irrigation scheduling, particularly in arid and semi-arid zones. But truly representative measurements, from free water surfaces or from the soil and of

transpiration by vegetation, are difficult to obtain. For this reason estimating meteorological methods have reach large interest (i.e. Penman equation).

The unit of time is normally a day and the evaporated amount of water is expressed in millimeters (mm).

### 1.9.1) Evaporimeters

The term evaporimeter is applied to a number of devices by which the water loss from a standard saturated surface is measured. Normally we refer to the evaporation from free water surface in a pan, because it's the widely used (particularly the class A pan with dimensions of 25.4 cm deep and 120.7 cm in diameter).

Good resolution measurements are reached by connecting the float to a potentiometer. This is a resistor having a sliding contact (in the windvane we have rotation potentiometer, while in this case it run on a linear track); it is opportunely powered (i.e. 1, 2, 5, 12 VDC depending on the data-logger voltage input range) and it operates as voltage divider. Every level variation changing the voltage crossing the potentiometer, which value indicates the amount of variation, if the level decreases (evaporation) or increases (rainfall) (Fig. 11).

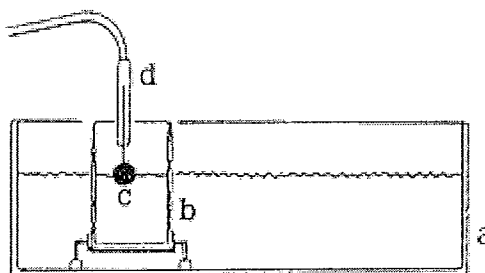


Figure 11. Evaporimeter

- |          |                        |
|----------|------------------------|
| a) tank  | b) protective cylinder |
| c) float | d) sensor level        |

The float is put on a protective cylinder to avoid wind influence on the water level measurements. The tanks and the protective cylinder are made of stainless steel and in a numbers of areas a wire-mesh is required to prevent water loss by birds and animals. This can interfere because reduce evaporation loss, by partly shielding the wind and solar radiation effects on the water surface (see chapter 4).

### **1.9.2) Lysimeters**

A lysimeter is a device measuring water quantity. Essentially, a lysimeter isolates a "block" of soil from its surrounding so its water balance can be measured, particularly what percolates beneath. The area of the lysimeter should be of different dimension (i.e. a 3 m by 3 m by 2.3 m deep soil box, or 1m by 1m by 1 m). Depending on the crop it permits different spaced rows plants to be grown on the lysimeter. Evapotranspiration can be measured to about 0.03-0.05 mm (<0.001 inch) over 1/2 to hour long time periods depending on wind conditions.

Water balance equation, applied to a given surface in a determined time interval can be written:

$$Pr + I = Pe + \Delta U + Ru + ETR$$

Where:

Pr = precipitation, influx;

I = irrigation, influx;

Pe = percolation, outflow;

dU = soil water content variation in a specific time interval, can be positive (water store up) or negative (water loss);

Ru = surface runoff, that can be positive or negative if the water go away (outflow) or incoming to the considered zone (influx);

ETR = evapotranspiration, outflow;

Evapotranspiration can be estimating by others water balance equation terms. Soil water content variation can be measured by a bucket system mounted under the lysimeter block; in this case we talk about the weighing lysimeter. In another kind of lysimeter the water loss is restore to maintain the groundwater level constant. Evapotranspiration is estimated from the water amount restored.

### **1.10) Leaf wetness**

This parameter is essentially used in predicting plant disease models. The sensor could be included in a standard agrometeorological station or for micrometeorological applications. In pocket system including a small data-logger, with other's proper sensors such as air temperature, air humidity, pluviometer, solar radiation and so on. (The type of sensors depend on the simulation model employed). Some advantages using this technique are:

- Aids in disease prediction
- Eliminate unnecessary spraying expense
- Rationalize plants treatment
- Growers benefit by eliminating costly pesticide applications and marketing a higher quality commodity.

The sensor can be deployed as well as in various plant copy positions to provide better leaf wetness information. Different sensor's exposition and slope would be desirable to take in account every leaf's position. Leaf wetness data could be presented as a logic values between 0 (dry) and 1 (wet), or by wetting percentage (0%=dry and 100%=wet). In the first case digital data input will be necessary in the data-logger configuration.

These sensors can have many shapes. One type is showed in Figure 12

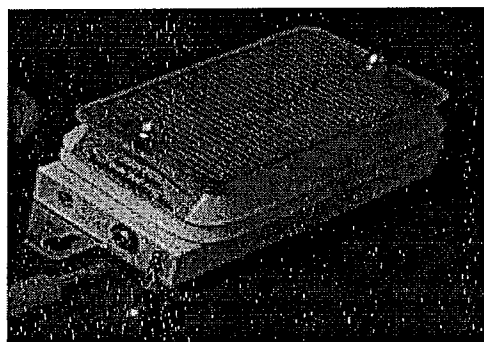


Figure 12. Leaf wetness sensor (*from Spectrum Technologies Inc.*)

The transducer look like a board with a gilded copper resistance that varies it's output values depending on water drops presence on it' surface.

For growers who don't have a personal computer or an agrometeorological station, complete systems (pocket portable size also) have been developed. They can accurately measures and displays some parameters, such as growing degree days and chilling hours using the same standard degree day calculations current pest models are based on. They require a protective weather enclosure.

The maintenance foresees periodically sensor's surface cleaning by isopropyl alcohol.

### **1.11) Soil heat Flux**

This sensor measures the conductive heat flux in the medium (generally the soil, but also for heat transmission monitoring in wall roads and bridges) in which it is inserted. It consist of a plate with two stainless steel faces (plastic types are also available), which contains a differential thermometer transducers type Thermopile, sealed in a phenolic core. This parameter is useful in agrometeorology for soil energy balance studies (particularly for some estimation methods of evapotranspiration).

Additional features: high output; low resistance; temperature independent; no power required; linear calibration.

Figure 13 shows two types of heat flux plates.

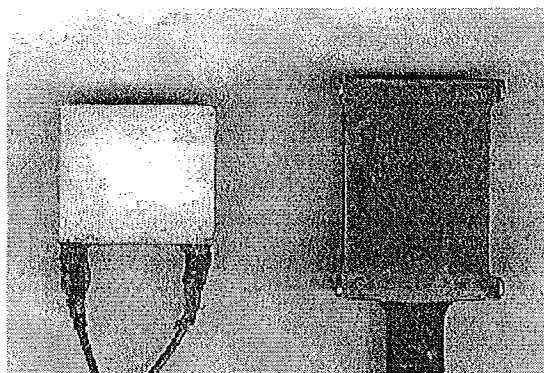


Figure 13

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- 
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```

                                surf3d_1a.kriging.ave
' Name   : Surf3D_1a.Kriging
' Title  : Create a surface from a multipoint shape by UNIVERSAL1 K
RIGING
' Description : Perform a Kriging interpolation by variable radius
.
' Requires : an active Multipoint shape active

theView = av.GetActiveDoc
theT ="Kriging"
'
if (theView.GetUnits = #UNITS_LINEAR_UNKNOWN) then
MsgBox.Error("No map units set for the current view" + NL +
             "Map units must be set before calculating a semivario
gram"
             + NL + "Set map units first and try again", theT)
return Nil
end
'
theTheme = theView.GetActiveThemes.Get(0)
'
theTempFieldList = theTheme.GetFtab.GetFields
theFieldList = {}
for each theField in theTempFieldList
    if(((theField.GetName="shape") Or (theField.GetName = "Ar
ea") Or
      (theField.GetName = "Perimeter")).Not) And ((theField.IsTy
peNumber) Or
      (theField.IsTypeString))) then
        theFieldList .Add(theField)
    end
end
'
if((theFieldList.Count = 0) Or (theFieldList.Count = Nil)) then
    MsgBox.Error("There are no appropriate fields in theme.",th
eT)
    return Nil
end
'
theZ = MsgBox.Choice(theFieldList,"Select a field to interpolate",
theT)
if(theZ = Nil) then
    theContinue = MsgBox.YesNo("You haven't chosen a field fro
n the list, continue ?",theT, TRUE)
    if(theContinue.Not) then
        return Nil
    end
end
theZ = MsgBox.Choice(theFieldList,"Select a field to interpolate",
theT)
if(theZ = Nil) then
    MsgBox.Error("You haven't chosen a field from list" + NL +
NL +
                "Bailing...",theT)

```

```

                                surf3d_1a.kriging.ave
return Nil
end
end
'
theYesUseBarrier = MsgBox.YesNo("Use a line theme as barrier theme
?" + NL
                                + "Note: using barriers significantly" + NL +
                                "extends processing time",theT,FALSE)
if( theYesUseBarrier) then
    theFThemes = {}
    for each theTheme in theView.GetThemes
        if(theTheme.Is(FTHEME)) then
            theFThemes.Add(theTheme)
        end
    end
    end
    theLineThemes.={}
    for each theTheme in theFThemes
        theFtab = theTheme.GetFtab
        theShapeF = theFtab.FindField("shape")
        theValue = theFtab.ReturnValue(theShapeF,0)
        if(theValue.GetDimension = 1) then
            theFtab.SetName(theTheme.GetName)
            theLineThemes.Add(theFtab)
        end
    end
    end
    if((theLineThemes <> Nil) And (theLineThemes.Count > 0)) t
hen
        theBarrier = MsgBox.Choice(TheLineThemes,"Choose b
arrier theme:",theT)
        if(theBarrier = Nil) then
            MsgBox.Error("You haven't chosen a barrier
theme."+
                        NL + NL + "Bailing...",theT)
            return Nil
        end
    else
        MsgBox.Info("No line themes in the current view" +
NL +
                    "Barrier option set to No Barriers",theT)
        theBarrier = Nil
    end
else
    theBarrier = Nil
end
'
' inizializzazione variabili di lavoro
theMapex = Rect.Make(0@0,1@1)
theCellSize = 1
' Set MapExtent e Cellsize
theAE = AnalysisPropertiesDialog.Show(theView,FALSE,"Set MapExtent
and Cellsize")
if(theAE = NIL) then exit end

```

surf3d\_1a.kriging.ave

```
theAE.Activate
'
' leggo la cellsize e il mapex
'
theAE.GetCellSize(theCellSize)
theAE.GetExtent(theMapex)
'
' Determinazione raggio di ricerca
'
TheD = MsgBox.Input("Radius Distance (recommend NIL) :",theT,"Nil"
)
Ac = MsgBox.Input("Radius Count (recommend 12-15) :",theT,"12").As
Number
if(TheD = "Nil") then
    theRadius = Radius.MakeVariable(Ac,Nil)
else
    d = TheD.AsNumber
    theRadius = Radius.MakeVariable(Ac,d)
end
end
'
theYesCreateVarGr = MsgBox.YesNo("Create output variance grid",the
T,TRUE)
if(theYesCreateVarGr) then
    aVarFN = av.GetProject.GetWorkdirMakeTmp("v_uld","")
else
    aVarFN = Nil
end
end
'
' definizione sistema di interpolazione
'
theInterp = Interp.MakeKriging(#KRIGING_UNIVERSAL1,theRadius,theBa
rrier,aVarFN)
'
' definizione della proiezione e del campo contenente la quota
'
thePrj = theView.GetProjection
theDEM = Grid.MakebyInterpolation(theTheme.GetFTab,thePrj,theZ,the
Interp,{theCellSize,theMapex})
if(theDEM.HasError) then
    MsgBox.Error("Severe Fault into output grid","PANIC !!!")
    return nil
end
end
'
' memorizzazione DEM
'
aFN = av.GetProject.GetWorkDir.MakeTmp("surf","")
theDEM.Rename(aFN)
theNewTheme = GTheme.Make(theDEM)
theView.AddTheme(theNewTheme)
```

surf3d\_1a.kriging.ave

## 2) DATA ACQUISITION SYSTEM

### 2.1) Data-Logger

The sensors can be describe as transducers that convert the variation of a physics quantity (temperature, humidity, solar radiation, etc.) in a proportional electric signal; this signal can then be sent to an acquisition system and stored as data, subsequently available for an eventual processing. These devices are called Data-Logger. They record the output from the sensors (using a specific measure unit) at regular time interval (or events occurrence). They normally allow a first data elaboration such as: averages calculation, algebraic operation within different channels or by constant factor previously defined in the program, minimum and maximum values indication, alarm relay output activation, etc....[1]

The storage digital supports can be of different types depending on the data-logger features and if a remote acquisition device is present.

This kind of memorization is well suitable for meteorological and agrometeorological stations that needs a continuous data acquisition. An Analog to Digital Converter (ADC) take the analog signal deriving from the transducers converting them in digital binary format, then the elaboration happens on numeric values and not on analog signals. The acquisition system reading resolution is hardly affects by the bits number of the ADC (8, 16, 17 bits), that is the levels number in which the analog signal is divided. This acquisition type allows fast data analysis, and the real-time can be obtained for example by remote data transmission. An online Personal Computer (PC) allows data storage in a very small size support such as solid state memory, hard disk or floppy disk; these constitute a database archive with very little physical dimension.

Some data-loggers are furnished of a display for immediately visualization of data or general status system information (battery life remain, memory available, etc.)

### 2.2) Data-Logger programming

The modern data-logger are generally given with it's own software that allows you to define the channels number, the sensor type, the acquisition time interval and so on. Once the program has been developed, a file is saved on a disk or as a hard copy. Editing features allow the user to scan each sensor or block of sensors, apply calibration factors and calculate maximum, minimum, averages or simply sample and store the data in final memory. Some other advanced data-logger can be fully programmed to obtain standard deviations, arithmetic functions, wind direction frequency calculation, and drive other devices by special

control output channels. By a personal computer many facilities are provided for programming data-logger, checking its operation and the status of sensors, starting and stopping logging, setting and initiating dial-up for operation via modems, and collecting data. Generally last version of data-logger software are more easy to use than in the past even by users with no much experience of computer. A useful sensor library is available for some data-logger (i.e. Delta-T Devices) that allows raw voltage, range and appropriate unit conversion of wide number of transducers as thermocouples, thermistors, Pt100 probes. In advance the user can added its own sensors, setting the range and conversion factor and stores it in a sensor library.

#### DELTA-T mod. DL2 Data-Logger<sup>1</sup>

Here is an example of data logger set-up for three air temperature sensor (type PT100 thermoresistance), mounted for a temperature profile (at 3 different heights) in open field in Florence, Italy.

This table of the software shows some logging parameters. The first column is the sensor's code (in this case PT2, PT3, PT4 codes are assigned by our technicians because the sensors set-up and calibration was perform ourselves); the manufacturer give a list of standard sensor that the user can directly recall from the proper menu page. The second column shows the Label (in this case L1, L2, L3 means Level 1, Level 2 and Level 3 of air temperature profile) In the Sample column the period between each reading is reported: the software allows different time intervals from 1s to 24h. The Compress column shows the data compression interval, in this case 5 m. The logger stores the values every 5 minutes (in this case it stores the average calculates on 10 samples). "A" means Average, and it is the value that will be written in the data file by the logger. The user could choice also the Maximum or the minimum value. The columns TRIG 61-62 and Control Output can active relays or channel(s) logging for particular applications.

Following are shown two pages of Delta-T configuration menu: The first one gather the information about logging parameter and the second specify the sensor characteristics for the input channels.

---

<sup>1</sup> Names are necessary to report factually on available data; however, the C.N.R.-I.A.T.A. neither guarantees nor warrants the standard of the product, and the use of the name by C.N.R.-I.A.T.A. implies no approval of the product to the exclusion of others that may also be suitable.

```

+ LOGGING PARAMETERS -----+
| SENSOR      TIMED INTERVALS TRIG/ Auto Cold CONTR. OUTPUT
| Code  Label      Sample Compress  61 62  range  jcnct  Ch Threshold
|-----|-----|-----|-----|-----|-----|-----|
33                                           33
34                                           34
35                                           35
36 PT2  L1          30s    5m A          F          36
37 PT3  L2          30s    5m A          F          37
38                                           38
39                                           39
40                                           40
41 PT4  L3          30s    5m A          F          41
42                                           42
43                                           43
44                                           44
    
```

```

+----- (ctrl) <- -> PgUp/Dn A..9 f7:SnsrLst ESC -----
+ Sensor code -----|Enter a code from
the sensor list, to copy sensor characteristics from the | sensor list to this
channel. You can press f7 to display the sensor list. | <space> to cancel this
channel. | To specify a new sensor,
enter a new code and fill in sensor details. |
----- LFW1 input card required
    
```

The auto range field can be Auto or Fixed (Auto range is calculated by the software depending on the sensor's characteristics, the Fixed range is set by the user). The cold junction column regards thermocouple sensors connection.

By pressing CTRL + -> the rest of table is shown (see table below) and the others parameters are visualized: the R means Resistance sensor; 2000  $\mu$ A is the excitation current suitable for these resistance sensors (In this case the software directly set the proper excitation current to avoid self-heating effect).

```

+ SENSOR CHARACTERISTICS -----+
| SENSOR  UNITS  CONVERSION  VALID RANGE  Thrm
| Code sig  $\mu$ A Base Eng'ng Factor Offset  Minimum Maximum  -cpl
|-----|-----|-----|-----|-----|
33                                           33
34                                           34
35                                           35
36 PT2  R 2000 ohm deg C .3885 20.654 -10.00 50.00
37 PT3  R 2000 ohm deg C .389 20.514 -10.01 50.01
38                                           38
39                                           39
40                                           40
41 PT4  R 2000 ohm deg C .389 20.463 -10.01 50.01
42                                           42
43                                           43
44                                           44
    
```

```

+----- (ctrl) <- -> PgUp/Dn A..9 f4:SaveSnsr f7:SnsrLst ESC -----
+ Sensor code -----|Enter a code from the
sensor list, to copy sensor characteristics from the | sensor list to this channel.
You can press f7 to display the sensor list. | <space> to cancel this channel.
|| To specify a new sensor, enter a new code and fill in sensor details. |
----- LFW1 input card required
    
```

The conversion factor and the offset allow direct conversion from base unit (ohm) to the Engineering unit (deg °C). The range interval is  $-10\pm+50$  °C: this is roughly the normal range for air temperature at Florence, Italy. For colder or hotter sites is best to use an air temperature range from  $-20$  up to  $50$  or  $55$  °C.

An example of the data output is shown on the table below:

DELTA-T LOGGER  
PROFILE

03/07/97 11.24

26/02/98 10.53

TIMED

Channel number	3	36	37	41
Sensor code	3	PT2	PT3	PT4
Label	3	L1	L2	L3
Unit	3	deg C	deg C	deg C
Minimum value	3	-5.81	-4.74	-4.75
Maximum value	3	23.103	21.645	21.623
16/01/98 12.30	3	9.12	8.59	8.52
16/01/98 12.35	3	9.19	8.7	8.57
16/01/98 12.40	3	9.25	8.79	8.73
16/01/98 12.45	3	9.46	9.09	9.15
16/01/98 12.50	3	9.75	9.43	9.41
16/01/98 12.55	3	9.98	9.62	9.57
16/01/98 13.00	3	10.11	9.59	9.65
16/01/98 13.05	3	10.27	9.57	9.72
16/01/98 13.10	3	10.34	9.68	9.8
16/01/98 13.15	3	10.25	9.59	9.72
16/01/98 13.20	3	10.06	9.45	9.48
16/01/98 13.25	3	9.89	9.38	9.35
16/01/98 13.30	3	9.71	9.31	9.23

### 2.3) Data storage

The new technologies have improved the memory capability of instrumentation and reduced it in a very small component. The follow storage components are a non-exhaustive list because of continuous progress in this science. The size and memory's capacities are continuously changing than fixed parameters cannot be given.

Modules reliability is also improved but after data retrieval operation, a copy of the new data-set to a different support (like floppy disk or Compact Disk) is always necessary, to avoid gap in the database for different causes like: magnetic support failures, temperature effects, or user's errors in data processing. Make the copy before any other operation.

Data recorded by modern loggers is generally stored in RAM chips inserted on the data-logger's main board. The logger should have sufficient RAM to store all data that is likely to accumulate in the period between two data

retrieval operations. When calculating the amount of RAM required for your purpose note how many bytes requires each reading and how many installed RAM you have.

For example if you have 128kbytes of installed RAM available and you will be recording data on 20 channels at 5 minutes intervals, the Ram will be sufficient for an data recorded period of:

$$\frac{128000 * 5}{2 * 20} = 16000 \text{ minutes, (approximately, 11 days)}$$

Where 128000 are the available bytes, 5 is the time acquisition interval express in minutes, 2 is the bytes required for each reading (depending on the type of data-logger), and 20 is the channel's number.

### 2.3.1) Solid state memory

#### Data Storage with Storage Modules

You can increase the storage space for your data-logger by attaching a solid state storage device. Many storage modules are available, (i.e. for data-logger Campbell mod. CR10x the SM192 or the SM716, which store 192,000 bytes or 712,000 bytes of data, respectively). For even more storage, add multiple storage modules. Any of our storage module devices can be left at a site or carried to each site to "milk" the data from the data-logger.

This component is the most use in the data-logger storage module. They are normally utilized for both program and data storage, and they occupy e very small place (see following "state of art" chapter). The principal characteristics are:

- When the memory is full some data-logger can stop logging (fill and stop) or to continue data logging overwriting oldest data (wrap around)
- Solid state memory can be reutilize many times, so its own results very cheap

### 2.3.2) PC card

If the application has high data storage requirements or requires very fast data logging, a memory card or hard drive is a simple solution. In some data-logger simply plugging a rugged, front-loading "credit card-sized" module into the proper drive slot on the device installed, users can access substantial mass memory and/or perform real-time data logging. The PC Card standard (formerly referred to as PCMCIA) has rapidly emerged because its use in laptop computers

and provides a highly reliable, cost-effective standard for program and data storage.

### **2.3.3) Magnetic tape**

This represents a kind of memorization support quite out-of-date. The memorization unit is often fragile and not useful for extreme outdoor conditions use, but is still in use when the on board memory of data-logger is insufficient for some particular applications that required supplemental memory capacity. There are same other limitations like:

- It needs a tape reader with a proper software
- Only high quality tapes recorder states extremes environmental conditions, this means high costs to install a rough and reliable tape-recorder.
- If proper display is not installed we don't have data visualization, then malfunction operations cannot be detected till tape reading operation.

### **2.3.4) Hard disk**

For those applications where a wire link or a telephone line is available, modem is suitable to offload data directly to a computer hard disk. Hard disks are available with a capacity up to 3-4 Gigabytes but these values are continuously upgraded. Meteorological data stored are immediately suitable for software's applications.

## **2.4) Data retrieval**

### **2.4.1) Personal Computer connection**

The personal computer is become fundamental for many applications, especially in meteorological data management and processing. It is also necessary for data acquisition and communication with others devices, such as data-logger. In the last years some standards components were proposed for data exchange between different devices: the most common standard is the RS232. Data-logger program and data collection can be carried out via RS232 serial port. This is a specification of the Electronic Industries Association defining a standard serial data interface. A standard interface between a computer input/output port and a peripheral device. This allows direct connection to the user's own computer, to printers and data recorders, or remote connection over private or public telecommunication networks via line drivers and modems.

The most common serial line standard RS-232 specifies the gender and pin use of connectors, but not their physical type.

The standard classifies equipment as either Data Communications Equipment (DCE) or Data Terminal Equipment (DTE). A DCE RS-232 interface should have a female connector and should transmit on pin two and receive on pin three. DTE (i.e. the personal computer) should have a male connector and should transmit on pin three (TD) and receive on pin two (RD). Originally DCE was a modem (now can be any device, e.g. Data-logger) and DTE was either a computer or a terminal. It is not uncommon though to find equipment with the wrong sex connector and/or with pins two and three the wrong way round, requiring the insertion of a cable or adapter wired as a gender mender or null modem. When you buy a data-logger ask for the proper RS232 cable and for a gender mender if necessary (it is a cable connector adapter with either two male or two female connectors on it, used to correct the erroneous distinction between DTE and DCE). Used especially for RS-232C parts in either the original D-25 (a cable connector with 25 pins) or the IBM PC's D-9 (9-pin) connector.

The following table shows the interface signals (or pin-out) for 9-pin and 25-pin connectors (when used for asynchronous data). Signal names are relative to the DTE (the transmit data signal is data from the DTE). [A]

DB-25 Pin Number	DB-9 Pin Number	Pin Name	Direction		Pin Function
			DTE	DCE	
2	3	TxD	->		Data transmitted from DTE to DCE (for example, from PC to modem)
3	2	RxD	<-		Data received from DCE to DTE (from modem to PC)
4	7	RTS	->		DTE requests permission to send data to modem
5	8	CTS	<-		DCE grants permission to send
6	6	DSR	<-		DCE indicates that it is operational (the modem is powered on)
7	5	Signal ground	<->		Common ground reference
8	1[a]	DCD	<-		DCE indicates that it is receiving carrier from remote modem
20	4	DTR	->		DTE indicates that it is operational (powered on)
22	9(a)	RI	<-		DCE indicates that the phone is ringing

Footnotes:

(a) Some DB-9 to DB-25 adapters do not connect these signals, thus providing hours of rewarding troubleshooting practice for lucky people.

#### 2.4.2) Memory card

The PCMCIA (PC Memory Card Industry Association) sets the standards for 68-pin memory and I/O cards and describes physical and electric characteristics of PC cards. PCMCIA specifies three different card types: Type I, Type II and Type III. They differ only in thickness size, while for computer's connection they use the same 68-pin connector. The thickness are respectively of 3.3 mm, 5 mm, and 10.5 mm. The PC Card Type I is normally utilized for memory expansion: Flash, RAM, OTP (One Time Programmable) and EEPROM (Electrically Erasable Programmable Read Only Memory) have this format.

Flash RAM memory card feature is ideal for archival, installation and maintenance of motion control programs on the plant floor. Flash RAM memory cards (4 to 85 megabytes) feature "write speeds" approaching conventional disk drives with RAM-drive "read speeds".

SRAM memory (Static RAM memory chips). These chips allow individual bytes of data to be updated, and typically read and write at high speed. SRAM requires a power source to maintain the data stored in it. If power is lost, data is lost.

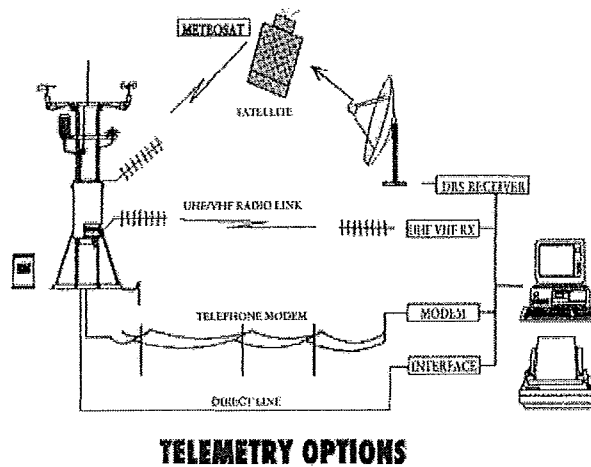
The SRAM memory cards (1, 2 & 4 megabytes) are generally battery-backed, and feature RAM-drive "read" and "write" speeds. Battery life is four years, not counting the time that power is applied to the card. The PC Card standard insures data reliability, and memory wouldn't survive with the battery removed from the card. SRAM is ideal for dynamically changing information where the fastest real-time performance is important.

PC Card hard disks provide large amounts of additional data storage for specialized needs for user program and data storage.

#### 2.4.3) Remote Transmission of data

It is possible to install weather stations with remote transmission device, that allow the operator to directly interrogate data-logger from the laboratory or from the place where the PC is installed, in order to check sensor functioning and recall storage data.

In figure 14 some remote transmission options are showed:



There are different ways for telecommunications options.

#### 2.4.3.1) Radio

##### -Radio Telemetry

A PC can communicate with a lot of data-loggers on a single frequency. Transmission distances are typically 25 miles (40 km around) line-of-sight for UHF or VHF radio (end-users must acquire their own FCC-approved frequency). Repeaters can serve to extend transmission distances. Important: ask to the agent to determine appropriate antennas and siting requirements. Some devices require less power and do not need for a license, but transmission distance and number of sites may be limited. Radio device regulations vary by country, and difficult in license expiration or sever's rules can be an obstacle. Before the purchase check with your local administration and/or your international sales representative for information on compatibility.

#### 2.4.3.2) Modem

##### Modem

A modem package is the easiest link for communicating with one data-logger over longer distances. This system uses a modem at both PC and data-logger, and a two twisted-pair cable for a direct connection. (i.e. the SRM-5A of Campbell Scientific can operate at 9,600 baud up to 6.2 miles using 19-gauge cable, or up to 7.6 miles at 1200 baud).

#### 2.4.3.2.1) *Dedicated or commutated phone line*

##### - Telephone

A Telephone Modem at the data-logger enables a PC with a compatible modem to contact the data-logger at any time. It can operate at different baud rate, at extreme temperatures, and has a low quiescent current drain. All telecommunications functions are supported.

Telephone device regulations may vary by country. Check with your local international sales representative for information on compatibility. [B]

#### 2.4.3.2.2) *Cellular phones*

The Cellular Phone System makes it possible to interrogate a Data Logger when no telephone line is available at the site. This is especially useful when the logging system is temporary or must be moved regularly. This system includes a cellular transceiver, cellular connector, detachable handset, roof-mounted antenna and the proper cable. For these devices an high capacity power supply is recommended. [C]

Remember that the Cellular Telephone package allows telecommunication only in areas served by cellular telephone companies. In remote locations without auxiliary power, the data-logger can turn on the cellular transceiver at set times to save battery power.

#### 2.4.3.2.3.) *Satellite*

For remote one-way data transmissions, use either the GOES or Argos satellite systems. Restrictions apply to the type of applications allowed for these networks, and the amount and timing of data transfers.

Normally you can set special calculations, custom transmission formatting, etc.

##### -Applications

- Remote data collection in locations where no traditional communication channels are available and real time data is required.
- Solar panels, batteries and an antenna combined with this data-logger and transmitter will allow users to access the GOES satellites
- bringing real time data to the user.

##### Helpful information

Always make a power budget calculation before the battery and solar panel chosen for a particular site. Batteries must be selected to operate over the

intended temperature range and provide the current for periods of transmitting. Always include extra margin in the capacity of the battery to account for extended periods of no solar panel charging. Careful selection of the antenna type is crucial to the success of the installed site.

Table 3. Here are reassumed some features of different remote transmission devices. [D]

Communications	Description/Advantages
Direct Dial Telephone	Direct dial telephone systems use standard telephone services for data communications. Data rates of 1200 baud and up are supported. Speech and data modes supported. Manage the entire system from a central station.
Cellular	Some or all the stations in a network can use cellular communications to reduce installation costs and still keep all the features of direct dial telephone.
Dedicated Lines	Dedicated lines are provided by the customer or phone company, for point to point or multipoint communications. Dedicated lines provide the highest data throughput of all communications.
Radio	communications are two way systems where high throughput is required or telephone service is not available or practical.
LOS Radio Modem Base Station	Use this modem with a PC and Sutron's PCBASE2 software to make a complete master station. Separate models are offered for dedicated lines and LOS radio.
GOES	Satellite communications using Geostationary satellites are great for very remote locations. GOES is the system of Geostationary satellites covering the western hemisphere. The transmit power is low enough to allow simple stations with small batteries and solar panels.
GOES Direct Readout Ground Station (DRGS)	The GOES receive station allows a central station to receive any field station transmitting to GOES satellite. Direct reception is a must for any system handling time critical data.
METEOSAT	METEOSAT is the geostationary satellite above Europe and Africa. METEOSAT supports low cost DCPs and low cost receiver stations.
INSAT Satellite	INSAT is the geostationary satellite above India.
Brazilian SCD Satellite and ARGOS.	The Brazilian SCD satellites are in a low-earth orbit. They are ideal for one-way and Argos messaging from remote locations.
GMS and Other Satellites	GMS is the geostationary satellite above Asia.
ORBCOMM	ORBCOMM is a new communications service offering two way digital communications over a wide area. It offers features not available in any other satellite system.

BIBLIOGRAPHY

- [1] Fritschen, L.J., and Gay, L.W. Environmental Instrumentation, 1979, Springer-Verlag, New York, USA

### 3) STATE OF THE ART AND AVAILABLE INSTRUMENTATION

In the last years many factories have improved their products; this allow the researchers, the technicians, and operators to make measure with high speed in quite simple way and with many options depending on the field of application.

Generally the instrumentation is became modular, light, and housed in a very small modules. In this chapter you will find a brief example of some products useful for many field measurements, both for meteorological and ecophysiological studies.

When you decide to buy an agrometeorological station the first step is to plane the exact configuration (the type of sensors, the amount of memory of the data-logger, the power required, etc.). Normally we can ask to someone already involved in this studies (i.e. researchers, technicians of public services, Universities, and so on), or directly call the agents of your country. Because of the particular subject it's not easy to look for this instrumentation. Actually one of the purposes of this guide is to gather Names and addresses of different Company and Institutions, that could furnish useful information.

When you contact the agent, you could ask about a complete station (data-logger plus sensors, wires, software, power device, must, sensor's brackets, etc.) or for one or more items (i.e. the data-logger only).

If you already have a Personal Computer ask to the agent about the compatibility with that data-logger, and its software.

If you decide to configure yourself the agrometeorological station, keep clear in mind that you have to provide all the instrumentation and the accessories. In other words you must check the compatibility of your data-logger with the sensors, you have to program the acquisition system, provide the mounting tools for the sensor, the mast for data-logger, the box for the battery, arrange the power supply for the system, etc.

If you are confident with these tools, it could result a less expensive solution. It depends also on the number of stations that you have to set-up.

Always ask for the estimation costs to different company, trying to obtain comparable preventives (i.e. similar sensors configuration, data-logger with a minimum amount of channels and available memory, etc.).

Remember to get guarantees from the agent about:

- the speed and the cost of delivery of the instrumentation
- the list of sensor's accessories like signal cable, mounting bracket, instructions for the connection to your data-logger, etc.
- the replacement parts availability
- the velocity of intervention in case of damages

Today the new technologies in telecommunication give us another fast search tool as a source of information: Internet. (In the chapter 7 you will find more description about it).

In this chapter we list some products of different manufacturers, but it couldn't be a complete review about the instrumentation. Therefore the instrument's production is continuously updated, and new products are often proposed to satisfy the user's requests.

### 3.1) Data-logger

#### Campbell Data-logger

The Campbell Company has many type of data-logger with different tools. The CR data-loggers series allow many options for the users. For example the CR10X consists of a measurement and control module and a detachable wiring panel. A detachable keyboard/display (the CR10KD) may be used with any number of different stations in a CR10X network. The CR10X is powered by eight alkaline "D" cell batteries (BPALK) or a sealed rechargeable battery (PS12LA). The CR10X includes non-volatile 60k data area, non-volatile 16k program area, 16k for user-stored programs, battery-backed clock, and a greatly enlarged instruction set for virtually any programming option ever offered on its predecessor, the CR10. Power consumption and packaging are optimized in the CR10X making it our most cost-effective data-logger for unattended network applications.

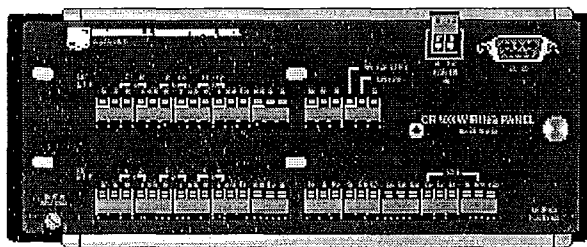


Figure 15. Campbell data-logger

PC208 for DOS supports the CR10, CR10X, 21X, and CR7 data-loggers and works with a wide variety of communication links, such as:

- Direct connection (up to 50 feet)
- Short haul modem (hard wired within a few miles)
- Telephone (including cellular)

- Radio telemetry (UHF and VHF frequencies); also includes spread spectrum radios
- Multidrop modem (coax)
- Solid State Storage Modules and PCMCIA cards

Figure 16 shows software's communication page of the data logger.

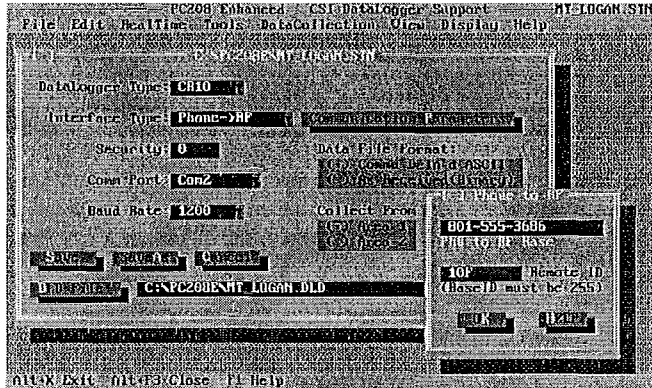


Table 4. Datalogger Comparison Table

Use this table to compare Campbell Scientific dataloggers.

Parameter	CR500	CR10X	21X	CR23X	CR7	CR9000
Differential Analog Channels (a)	2	6	8	12	14 per 723 Card or 723T Card	14 per 9050 Card or 9055 Card
Maximum Input Voltage (b)	± 2500 mV	± 2500 mV	± 5000 mV	± 5000 mV	± 5000 mV (726 Card) ± 50 V (723 Card)	± 5000 mV (9050 Card) ± 50 V (9055 Card)
Analog Voltage Res.	to 0.33 µV	to 0.33 µV	to 0.33 µV	to 0.33 µV	to 50 µV	to 0.76 µV
A/D Bits	13	13	14	15	16	16
Input Impedance	20 Gohm	20 Gohm	200 Gohm	20 Gohm	2.5 Gohm	2.5 Gohm
Input Bias Current	± 9 nA	± 9 nA	± 2 nA	± 10 nA max	± 100 pA	± 3 nA typ.
Scan Interval (c)	8 Hz	64 Hz	80 Hz	100 Hz	80 Hz	100,000 Hz
Burst Mode	N/A	750 Hz	1000 Hz	1500 Hz	N/A	100,000 Hz
Pulse Channels (d,e)	2	2	4	4	4 per 724 Card	12 per 9070 Card
Excitation Channels (e)	2 (f)	3	4	4	8 per 725 Card	10 per 9060 Card
Excitation Voltage (g)	± 2500 mV	± 2500 mV	± 5000 mV	± 5000 mV	± 5000 mV	± 5000 mV
CAO Channels (e)(h)	0	0	2	2	2 per 725 Card	6 per 9060 Card
Digital Ports (e)(i)	1 output	8 I/O	6 output	8 I/O	8 output per 725 Card	8 output per 9060 Card 16 output per 9070 Card
Voltage Requirements	9.6 to 16 VDC	9.6 to 16 VDC	9.6 to 15 VDC	9.6 to 15 VDC	9.6 to 15 VDC	9.6 to 15 VDC
Memory	CR500	CR10X	21X	CR23X	CR7	CR9000
Program Memory	16K Flash	16K Flash	1K	16K Flash	1.8K	256K Flash
Data Values Stored	24,000	62,280	19,296	500,000	18,396	Table Format
Current Drain	CR500	CR10X	21X	CR23X	CR7	CR9000
Quiescent	1 mA typical	<1.5 mA typical	1 mA	2 mA display off	3.5 to 6.0 mA typical	N/A
Processing	13 mA	13 mA	25 mA	45 mA	16 mA	750 to 1000 mA typ.

Measurement	46 mA	46 mA	60 mA	70 mA	100 mA	750 to 1000 mA typ.
Temperature Range	CR500	CR10X	21X	CR23X	CR7	CR9000
Standard	-25 to +50 C	-25 to +50 C	-25 to +50 C	-25 to +50 C	-25 to +50 C	-25 to +50 C
Extended	-55 to +80 C	-55 to +80 C	-55 to +80 C	-55 to +80 C	-40 to +70 C	-40 to +70 C
Dimensions	CR500	CR10X	21X	CR23X	CR7	CR9000
Size (inches)	8.4 x 1.5 x 3.9	9.0 x 3.5 x 2.9	8.2 x 6.0 x 3.5	9.5 x 7.0 x 3.8	20 x 13 x 10	18 x 14 x 9
Size (cm)	21.3 x 3.8 x 9.9	22.9 x 8.9 x 7.4	20.8 x 15.2 x 8.9	24.1 x 17.8 x 9.6	50.8 x 33.0 x 25.4	45.7 x 34.3 x 22.9
Weight	1.0 lbs (0.4 kg)	1.5 lbs (0.68 kg)	6.5 lbs (3.0 kg)	8.3 lbs (3.8 kg)	40 lbs (18.2 kg)	40 lbs (18.2 kg)

- (a) Each differential channel can be configured as 2 single-ended channels; expandable with multiplexers.
- (b) Precision 2:1 and 10:1 voltage dividers are available to extend these ranges.
- (c) One measurement with data transfer without interruption.
- (d) Switch closure, high frequency square wave, or low-level AC sine wave.
- (e) Expansion peripherals are available, see SDM literature.
- (f) Port C2/P3 is input only and can be software configured as an SDI-12 port, a binary input, or as a switch closure counter (40 Hz maximum).
- (g) All excitation and CAO (Continuous Analog Output) channels can be individually programmed as outputs by the end-user.
- (h) CAO channels can be programmed to hold a constant value or vary with the magnitude of a measurement.
- (i) 0 V low, 5 V high; the CR500, CR10X, and CR23X have ports that are configurable for interrupt subroutines.

[A]

### LI-COR Data-logger

The LI-1000 combines simple operation, compact size, and 10 channel logging capability to produce an instrument that is both powerful and easy to use. A wide variety of sensors can be used with the LI-1000 including LI-COR radiation sensors, LI-COR air and soil temperature sensors, thermocouples, thermopile pyranometers, and many meteorological sensors. Menu driven software allows the LI-1000 to be quickly configured to meet your application. The flexibility of the software allows the LI-1000 to be operated as either a simple meter or as a data logger.

### LI-1000 Specifications

- Keyboard Sealed, 24 key tactile response keypad
- Display One line, 16 character alphanumeric LCD
- Internal Memory 32K bytes RAM
- Power Requirements Six alkaline "D" batteries
- External Power 108-126/216-252 VAC AC Adapter (part #1000-02)
- Enclosure Rugged O-ring sealed, weatherproof polycarbonate case
- Operating Temperature -25 to 55 ° C (0 to 100% RH)

- Dimensions 21L x 11.4W x 6.9cm D (8.3L x 4.5W x 2.7" D)
- Weight 1.6 kg (3.5 lbs) with batteries

#### Analog Inputs:

##### Current Inputs

- Eight channels; two sealed BNC connectors and six channels accessed directly through a 37 pin D connector or by connecting an available terminal block

##### Voltage Inputs

- Six single-ended channels accessed directly through a 37 pin D connector or by connecting an available terminal block.
- Channels 1 and 2 may also be configured for voltage measurement by placing an impedance resistor in the sensor cable.

##### Pulse Counting Inputs

- Two pulse counting channels. Switch closure to ground (200 hz); external signal driving (1Khz). Inputs have hysteresis so there is no minimum rise time.

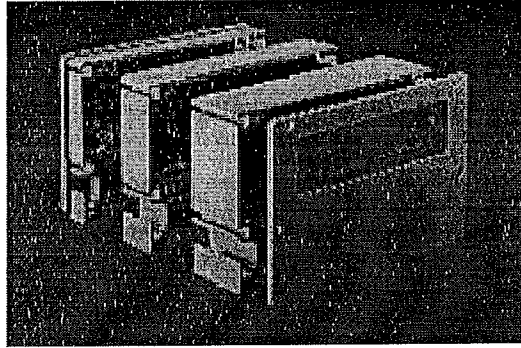
Table 5. Range Selection: Autoranging or software selectable:

<b><i>Voltage Ranges</i></b>	<b><i>Resolution</i></b>
1 : ±20 millivolts	2.5 microvolts
2 : ±200 millivolts	25 microvolts
3 : ±2.0 volts	0.25 millivolts
4 : ±20.0 volts	2.5 millivolts
<b><i>Current Ranges</i></b>	<b><i>Resolution</i></b>
1 : ±200 nanoamps	25 picoamps
2 : ±2 microamps	0.25 nanoamps
3: ±20 microamps	2.5 nanoamps
4: ±200 microamps	25 nanoamps

[B]

#### Delta-T Device

The DL3000 is a modular Data-logger that recognizes many of the common meteorological sensors. It can be easily upgrade in the channels number and in memory capacity. The data-logger is sold with a processor module with memory expansion, + analogue module. Output and digital inputs are available even in the basic configuration. A tutorial kit, the configuration software and RS232 cable were also given with the instrument. It can record data on RAM modules or on a PCMCIA card (with card board option) or send data by remote interrogation.



The figure 17 (above) shows DL3000 Data-logger from Delta T Devices. It is a modular, expandable data-logger. The menu driven logger software makes the DL3000 easy to use and program.

Data-logger Specifications:

- 17 Bit Resolution
- 40 Readings per Second
- 24 to 384 inputs, the basic logger comes with a 12/24 input card.
- Powerful programming language to setup thresholds, triggers, calculations or controlled outputs.
- 4 Latched Digital Outputs
- Weather-proof enclosure.
- PCMCIA Memory card module.
- Memory for 42,000 readings expandable to 455,000 readings.
- -40 C to +70 C Operating Range

[C]

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Sutron DCPs, RTUs and Data Recorders

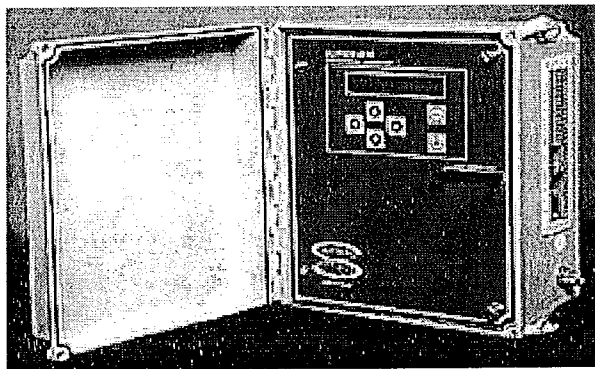


Figure 18. Sutron Data-logger

Sutron introduces two new models to round out our product line. The model 8210 is an advanced 8200 with dual-communications capabilities and PCMCIA. The

model 8400 is a stand-alone stage precipitation recorder designed to replace mechanical recorders. Below there are the features of each type of data recorder/transmitter.

Table 6. Feature Comparison

Feature	8200	8210	8400	9000
Built-in Memory	128KB expandable to 380KB	128KB expandable to 380KB	12,000 readings expandable to 50,000 readings	8KB standard, expandable to 512KB
Keys	6 keys built-in	6 keys built-in	3 keys built-in	use Laptop
Setup	Menu	Menu	Menu	SDL program
Programming	TINY-BASIC	TINY-BASIC	NO	SDL
Feature	8200	8210	8400	9000
Sensors	8 analog, 5 counter or 2 quadrature, 1 counter, SDI-12	8 analog, 5 counter or 2 quadrature, 1 counter, SDI-12	Shaft encoder tipping bucket SDI-12	Optional 23 analog, 4 counter, RS232, SDI-12
Display	16 character LED	16 character LED	20 character LCD	Optional
GOES/SATELLITE	Optional	Optional	NO	Optional
Telephone	Optional	Optional	External	Optional
Cellular	Optional	Optional	External	Optional
Feature	8200	8210	8400	9000
Speech	Optional	Optional	NO	Optional
Memory Card	Proprietary 64KB	PCMCIA 256KB, 1MB	PCMCIA 256KB, 1MB	NO
Dual Communications (e.g. GOES and Phone)	External	YES	NO	YES
Controls	1	20 I/O	NO	Optional
RS232	YES	YES	YES	YES

Table 7. Summary

Model	Description
8200-0014	8200A Data Recorder
8210-0014	8210A Data Recorder
8200-1000	INSAT Satellite Transmitter
8200-2000	METEOSAT Satellite Transmitter
8200-3000	Telephone Speech Modem
8200-4000, 6000	UHF/VHF Radio Modem
8200-5000	GOES Satellite Transmitter
8200-8000	ORBCOMM Satellite Transmitter
8200-9000	SCD-1/ARGOS Transmitter
8111-7000	Cellular Communications Options
8210	Ordering Guide
8400-1001	8400 Digital Data Recorder
8400-2001	SDI Data Recorder
9000-0000	9000 Remote Terminal Unit
9000-0305, 0307, 0300, 0303	9000 Telemetry Modules
9000-0101, 0400, 0500	9000 General Purpose Modules

### Onset Computer Corporation

This company makes data loggers that you have to assemble by the help of an Electronic Engineer or an Electronic Technician. In addition you have to program it by a proper software.

Onset's Tattletale Flash eXpress data logger/controller engine, the TFX-11, is the ideal choice for embedded data acquisition or control applications with one or more of the following requirements; portability, prolonged field deployment, fast sampling over multiple channels, small size and weight, low power, non-volatile data storage, and battery-backed real time clock. The TFX-11 (Figure 19), programmed with TFBASIC, enables the user to quickly develop and implement custom solutions to the most challenging data acquisition or control tasks.

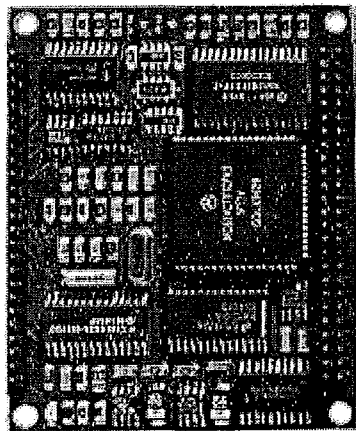


Figure 19. Onset data-logger TFX-11

#### TFX-11 Features . . .

- Easy to use-program in TFBASIC
- Tiny-only 2 x 3 x 0.5 inches; weighs one ounce
- Powerful yet flexible-68HC11 main processor with PIC 16C62 coprocessor
- 3.2KHz sampling rate
- Low power drain-less than 50 $\mu$ A typical
- 11 analog channels, 12-bit, resolution
- 8 analog channels, 8-bit, resolution

[D]

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### 3.2) Sensors

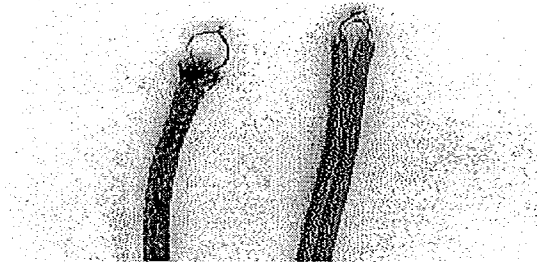
As the sensors features are improved in the last years, in terms of accuracy, reliability, spare parts availability and design. Beside the traditional meteorological sensor's factory, many manufacturer (especially in United States, Japan, Europe and Australia) begin their activity thanks to a large diffusion of construction techniques. For this reason we can find sensors with varies

characteristics on shape, size (following however the W.M.O. advice), or designed for particular applications and so on.

Here is a list (very partial list, of course) of some sensors of modern conception, with some typical technical specifications, founded by bibliography research, pull from their manuals or available on internet Companies pages. We have not any preference for the sensors type or the factory mentioned in this manual, but it's would be only a practical help and an example for the users. On the proper appendix we provide some addresses (Internet addresses also) of centers, manufacturers and some others organizations, involved in doing measurements and experienced on agrometeorological sensors management.

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### Temperature:



The figure 20 (above) shows two thermocouples by the Omega Company. [E]. The left type is a copper-constantan thermocouple with special limits of error. It is useful for air temperature measurements. In the right side there is a copper-constantan thermocouple with a worst accuracy than the other one (0.6 °F at 199.9 °F). Both of them are “T” thermocouples. The copper is the blue wire (positive terminal on the data-logger’s channel) and the constantan is the red wire (negative terminal on the data-logger’s channel)

#### Thermocouple Advantages.

\*Extremely high temperature range

Thermocouples can be rated as high as 1700C

\*Ruggedness

The inherent simplicity of thermocouples allow them to withstand extreme shock and vibration.

**\*Small size/fast response**

Thermocouples with exposed or grounded junctions offer nearly immediate response to temperature changes.

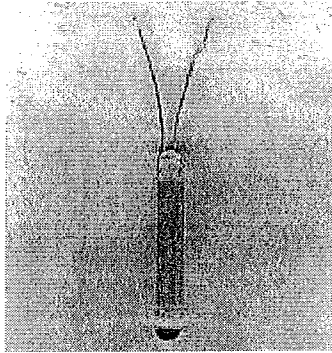


Figure 21

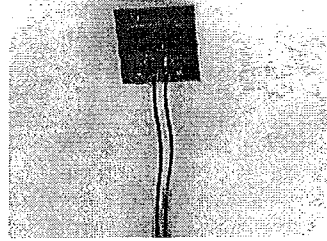
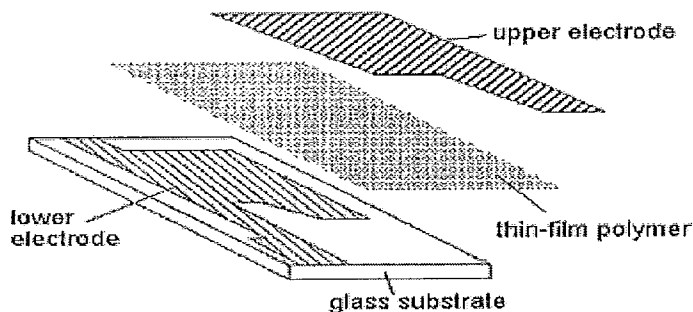


Figure 22

The figures above show two types of thermoresistance. The left one is a platinum thermoresistance type PT100 (100 ohm = 0 °C). It is encapsulated in a glass protection. The right figure shows a thermoresistance for surface measurements (i.e. plant's leaves). The sensor could be furnished in its original configuration with two wires. For long distance we should sold a pair of wires at each terminal. This way we can connect four wires (see chapter 1) to the proper channel of the data-logger, or to a suitable reader.

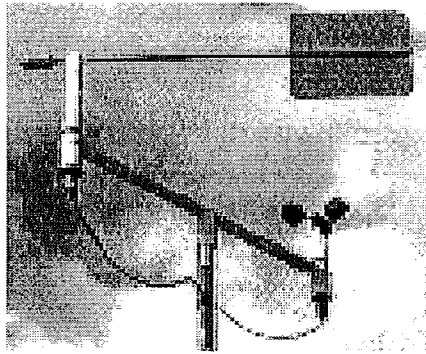
Humidity

The figure 23 (below) shows a schematic diagram of a capacitive thin-film humidity sensor



The principle of humidity measurement is the same in both the HUMICAP® and INTERCAP® sensors. The thin polymer film either absorbs or exudes water vapor as the relative humidity of the ambient air rises or drops. The dielectric properties of the polymer film depend on the amount of water contained in it: as the relative humidity changes, the dielectric properties of the film change and so the capacitance of the sensor changes. The electronics of the instrument measure the capacitance of the sensor and convert it into a humidity reading.

[F]

Wind:

For traditional separate wind speed and direction sensors, consider Model 12005 MicroVane & 3-Cup Anemometer Gill, by RM Young. (Figure 24, above)

Technical characteristics, wind speed:

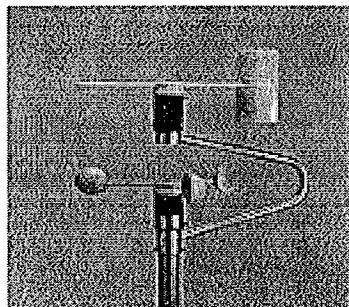
- Range 0-50 m/s
- Gust survival 60 m/s
- Threshold 0.5 m/s generator; 0.3 m/s photochopper
- Cup wheel distance constant 2.3 m

Technical characteristics, wind direction:

- Azimuth 360° mechanical, 355° electrical (5° open)
- Range 0-50 m/s
- Gust survival 60 m/s
- Threshold 0.4 m/s at 10° displacement; 0.7 m/s at 5° displacement

[G]

---



The tacho-anemometer shown in Figure 25 (above) is a sensor for measuring wind speed. It comprised a light alloy transducer protected by polyurethane paint. The tachymetric system is fitted inside. This consist of a seventy-two notch rotating disc with optoelectronic reading. The electrical signal is made up of a series of pulses with frequencies that are proportional to the speed of the rotor fitted on the

sensor transducer. In the heated versions, a thermostat controls a heater that keeps the rotor moving effectively in case of freezing.

Table 8. Features

Descriptions	C500S	C100S
Range	0-60 m/s	0-60 m/s
Threshold	0,25 m/s	0,25 m/s
Accuracy	1,5%	1%
Linearity	0,5%	0,5%
Delay	*	4,5 m
Resolution	0,1 m/sec.	0,1 m/sec.
Load resistance	Max. 500 Ohm	-
Power consumption	Max. 0,5 Watt	Max. 20 mA
Operative temperature	-30° + 70°C	-30° + 70°C
Transducer	Optoelectronic	Optoelectronic
Protection	IP65	IP65
Protection against electric discharge	Tranzorb and "gas discharge" units	-
Material	Anodized aluminum protected with polyurethane paint	Anodized aluminum protected with polyurethane paint
Weight	780 gr	720 gr
Connection	7 pins connector, IP-65 protection	7 pins connector, IP-65 protection
Connection cable	6-wire+shield cable not included L.= 10, 25, 50, 100 mt	6-wire+shield cable not included L.= 10, 25, 50, 100 mt
Mounting	on meteo pole Ø 48,5/50 mm	on meteo pole Ø 48,5/50 mm

The gonioanemometer is a wind direction sensor. It comprises a light alloy transducer containing the gonioanemometric system. This system consist of a potentiometer that provides resistance proportional to the direction the wind is blowing in. The "0°" (North) position reference of the potentiometer is shown by a red protrusion fitted to the body of the sensor. In the heated versions, a thermostat controls a heater that keeps the rotor moving effectively in case of freezing. The sensor consists of the transducer (see "Versions"), vane flag rotor (code DNA017) and connection cable (see "Accessories").

Table 9. Features

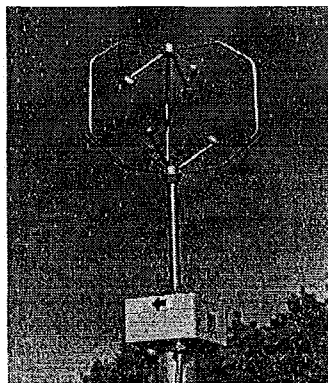
Descriptions	C500D	C100D	C110D
Range	0-360 <)	0-360 <)	0-540<)
Threshold	0,3 m/s	0,3 m/s	0,3 m/s
Accuracy	1,5%	1%	1%
Linearity	0,5%	0,5%	0,5%
Resolution	Not measurable	Not measurable	Not measurable

Wave lenght	l = 4 m wind path for one completed oscillation	l = 4 m wind path for one completed oscillation	l = 4 m wind path for one completed oscillation
Lenght of delay	1,1 m Wind path to reach an reading equal to 50% of the actual change in direction	1,1 m Wind path to reach an reading equal to 50% of the actual change in direction	1,1 m Wind path to reach an reading equal to 50% of the actual change in direction
Damping *	0,4	0,4	0,4
Load resistance	Max. 500 Ohm	-	-
Power	Max. 0,5 Watt	-	-
Operative temperature	-30° + 70°C	-30° + 70°C	-30° + 70°C
Transducer	Wirewound low-torque potentiometer(0-355°)	Wirewound low-torque potentiometer(0-355°)	Wirewound low-torque potentiometer(0-355°)
Protection	IP65	IP65	IP65
Protection against electric discharge	Tranzorb and "gas discharge" units	-	-
Material	Anodized aluminum protected with polyurethane paint	Anodized aluminum protected with polyurethane paint	Anodized aluminum protected with polyurethane paint
Weight	870 gr	720 gr	770 gr
Connession	7 pins connector, IP-65 protection	7 pins connector, IP-65 protection	7 pins connector, IP-65 protection
Connection cable	6 wire + shield cable not included. L.= 10, 25, 50, 100 mt.	6 wire cable not included L.= 10, 25, 50 mt.	6 wire cable not included L.= 10, 25, 50 mt.
Mounting	on meteo pole Ø 48,5/50 mm	on meteo pole Ø 48,5/50 mm	on meteo pole Ø 48,5/50 mm

[H]

### Sonic Anemometer

Figure 26 (below): Sonic anemometer



Features:

- Accurate wind and turbulence measurements by solid state sensor
- Evaluates complete 3-D wind information

- Unattended long term operation due to non moving parts
- Reliable operation even in extreme weather conditions
- Built-in self test
- Different sensor heads optimized for a wide range of applications
- Deicing capability by sensor head heating
- On-line calculation of turbulence parameters
- Synchronized sampling of external analog signals (Eddy-correlation)
- Measuring range 0 .-. 60 m/s
- Sampling rate 0.1 .-. 40 Hz
- Digital (RS232 or RS422) and/or analog output
- Instantaneous or averaging mode selectable
- On-site calibration routine

#### Benefits of the Ultrasonic Wind Sensor

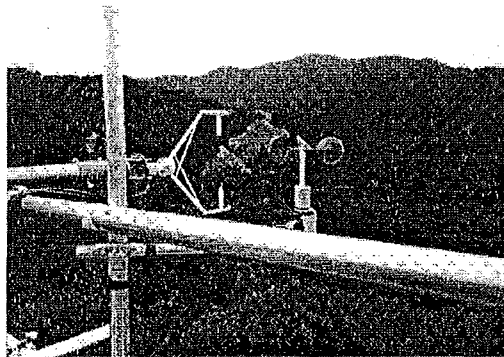
Moving parts of conventional wind sensors often cause problems due to the mechanics inside which require considerable effort of continuous maintenance and system check. Furthermore vertical wind components or high wind speeds lead to unacceptable deviation from the true wind data. Inertia masses of the sensor contribute to these errors (threshold and overspeeding). The system can be operated in instantaneous or averaging mode with adjustable sample rates and averaging intervals. A north alignment correction and the optional available sensor head heating upgrades the system to an easy-to-use long term measuring tool for monitoring of the atmospheric wind flow even under severe conditions.

[I]

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One dimensional ultrasonic anemometer and microanemometer with three cups. On the wasteland in the slope opposite, a thermal imager is installed (impossible to recognize), which can obtain information on the surface temperature distribution. This information is an important variable in the study of the water budget and energy from the bio-surface. In the background is the north slope of Mt. Sanage.

Figure 27. Sonic and cup anemometer



[J]

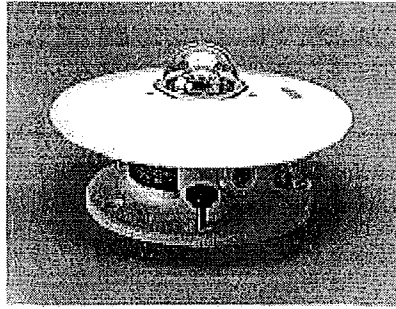
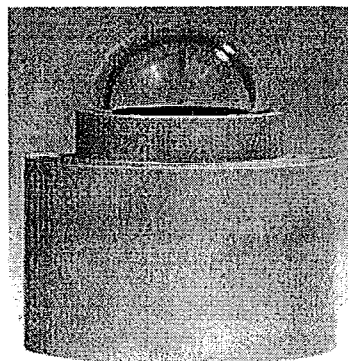
Solar radiation:

Figure 28. Model PSP - Eppley

The Precision Spectral Pyranometer is a World Meteorological Organization First Class Radiometer designed for the measurement of sun and sky radiation, totally or in defined broad wavelength bands. It comprises a circular multi-junction wire-wound Eppley thermopile. Its receiver is coated with a Parson's black lacquer (non-wavelength selective absorption). This instrument is supplied with a pair of removable precision ground and polished hemispheres of Schott optical glass. Both hemispheres are made of clear WG295 glass which is uniformly transparent to energy between 0.285 to 2.8 $\mu$ m. For special applications, other dome hemispheres are available. Included is a spirit level, adjustable leveling screws and a desiccator which can be readily inspected. The instrument has a cast bronze body with a white enameled guard disk (shield) and comes with a transit/storage case. A calibration certificate traceable to the World Radiation Reference and a temperature compensation curve is included. [K]

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Figure 29. Kipp & Zonen Pyranometer



The CM 3 is an ISO-classified Second Class pyranometer. The precision optical glass dome acts as a filter, with a spectral bandpass that permits the full solar spectrum to pass through to the sensor. The glass also protects the sensor from the elements.

The sensor is a high-quality blackened thermopile. Heating of the sensor by incoming solar radiation produces a signal in the microvolt range. Each pyranometer has its own calibration factor which is a direct function of the output voltage per W/m<sup>2</sup> solar radiation. Each pyranometer is provided with a calibration factor certificate. The pyranometer requires no external power source.

### Specifications of CM 3

Response time 95% zero offsets	18 seconds
200 W/m <sup>2</sup> thermal radiation	< 15 W/m <sup>2</sup>
5 K/h change in ambient temperature	4 W/m <sup>2</sup>
non-stability	< 1% change/year
non-linearity	±2.5% (<1000 W/m <sup>2</sup> )
directional error	<±25 W/m <sup>2</sup> at 1000 W/m <sup>2</sup>
Spectral Sensitivity	± 5% (305-1500 nm)
temperature dependence of sensitivity	6% (-10 to +40°C)
tilt response	<±2%
Sensitivity	10-35 μV/Wm <sup>-2</sup>
Impedance	79-200 Ohm
Operating temperature	-40 to +80°C
spectral range 305-2800 nm	(>50% points)

[L]

### Net Radiometer

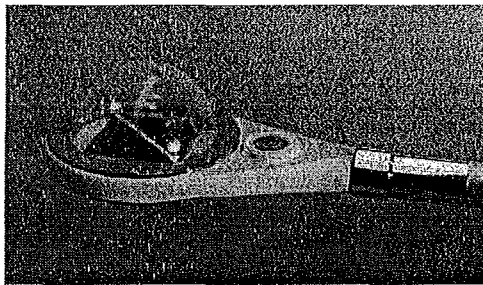


Figure 30. CN1-R Net Pyrradiometer

The Middleton CN1-R is a net radiometer for balance measurement of solar and reflected radiation (0.3 to 60μm). It indicates the net total radiation flux (solar, terrestrial, and atmospheric) downward and upward through a horizontal surface, and is suitable for solar energy studies in agriculture and meteorology.

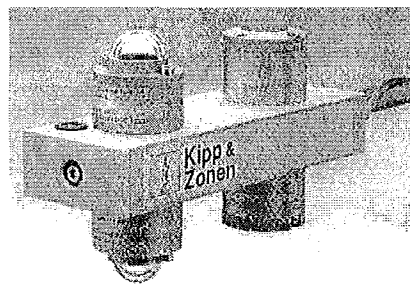
#### Technical Characteristics:

- Fast-response thermopile sensor.

- Equal shortwave and longwave sensitivity.
- Equal upward and downward sensitivity.
- Polythene domes shielding sensor have minimal selective absorptency.
- No total-loss air supply required.
- Light weight.
- Bubble level on head.
- Compact size: 80mm diameter head; 600mm handle.
- Semi-rigid domes stay inflated.
- Desiccated and sealed.
- Durable cast epoxy head, painted in white polyurethane.

[M]

Figure 31. CNR1 Net Radiometers



For accurate measurement of the solar and far infrared radiation balance. The CNR1 Net Radiometer is ideal for the analysis of the solar and far infrared radiation balance.

Incorporating four individual sensors of equal sensitivity (two pyranometers for measuring the incoming and reflected solar radiation, and two pyrgeometers for measuring the incoming and outgoing far infrared radiation). The CNR1 can provide, in addition to net radiation measurement, other important parameters including solar radiation, far infrared radiation, albedo, energy balance, and soil surface/sky temperature measurements.

Features:

- Built-in Pt-100 temperature sensor for accurate temperature measurement
- Internal heating element for the elimination of frost or dew deposition
- Spirit level for convenient leveling
- Robust & weather resistant housing requiring minimal maintenance

The rugged and versatile design of the CNR1 will provide years of quality performance under varying atmospheric and environmental conditions, as well as improved measurement accuracy when compared to other net radiometers.

Applications

Macam offers four ranges of light detectors for use with both their portable and laboratory radiometers. Sealed detectors are used in continuously monitoring environments. Small pre-amplifiers are fitted to the ultra-violet detectors for connection to data loggers. The detectors are supplied in an aluminum housing with dynode chain and connectors. [N]

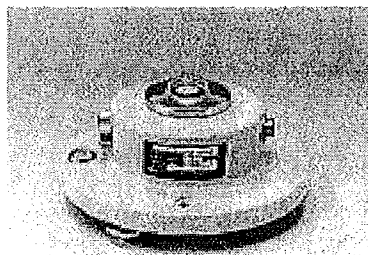
Figure 33. Radiometer and Tube Solarimeter (bottom) (Lengths, 990mm and 970mm respectively)



Tube Solarimeters, type TSL, are used to measure solar radiation in crop growth studies. They are permanently installed throughout the growing season, and may be used outdoors or in glasshouses.

Tube Net Radiometers are used to make comparative measurements of net radiant heat flux in crops and plant canopies, where the distribution of radiant energy is non-uniform. Tubes are mounted horizontally and parallel to each other. One tube, or a dome net radiometer, is mounted above the canopy to provide a reference. A polythene cover protects the element; a supply of dry air (i.e. Delta-T Purging Kit type PK) or dry gas is required to inflate the cover and keep it free from condensation. [C]

#### UV-B RADIATION



UV-B Radiometer MS-210W (For meteorological and materials weathering purposes), and MS-210D (For medical and biochemical purposes. Figure 34

(above). It is well known that UV-B is closely related to the causes of skin cancer and cataracts).

UV-B radiation reaching the ground accounts for only about 0.2% of the total radiation, and the angular and spectral distribution are strongly dependent on atmospheric parameters, including dependence on temperature changes of more than 50 deg.C. In order to get a precise measurement of the UV radiation, it is necessary to cut out the radiation longer than 0.315micron (representing a 99.8%), at particular angular and spectral parameters.

#### SPECIFICATIONS

- Sensitivity: approx.  $9 \mu\text{V}/\text{Wm}^{-2}$ .
- Impedance: approx. 650 Ohms.
- Temperature Dependence:  $\pm 1\%$  over ambient temperature range -20 to  $+40^\circ\text{C}$  (temperature compensation of sensitivity can be supplied over other ranges at additional charge).
- Linearity:  $\pm 0$
- Temperature response:  $\pm 1.8\%$  (within -20 to  $40^\circ\text{C}$ )
- Directional response:  $\pm 10\%$  (within 0 to  $80^\circ$ .)
- Spectral range: MS-210W 280 to 315 nm  
MS-210D corresponds to erythema
- Accuracy:  $\pm 10\%$   
.5% from 0 to  $2800 \text{ Wm}^{-2}$ .
- Response time: 1 second (1/e signal).
- Cosine:  $\pm 1\%$  from normalization 0- $70^\circ$  zenith angle;  
 $\pm 3\%$  70- $80^\circ$  zenith angle.
- Mechanical Vibration: tested up to 20 g's without damage.
- Calibration: integrating hemisphere.
- Size: 5.75 inch diameter, 3.75 inches high.
- Weight: 7 pounds.
- Orientation: Performance is not affected by orientation or tilt.

[N]

Figure 35. UVB1 Yankee Environmental Systems

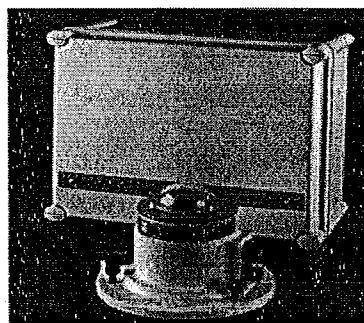


Table 10. UVB-1 Specifications

Characteristic	Description
Spectral response	280 to 320 nm
Cosine response	±5% for 0 - 60 degree solar zenith angle
Sensitivity	1.97 (watt/m <sup>2</sup> )/volt of total UV-B irradiance
Output signals	0 to 4 VDC, low impedance (single-ended) output for each channel
Operating temperature	Thermally regulated for operation over an ambient temperature range of -40°C to +40°C; an internal YSI #44011 monitor thermistor (100 KΩ @ 25 °C) is also provided (See Appendix A for the resistance versus temperature characteristic of the thermistor.)
Response time	Approximately 0.1 second
Power requirement	-12 VDC @ 5 mA; +12 VDC load varies with ambient temperature: 120 mA at +20 °C, 500 mA at -40 °C; the maximum allowable supply voltage range is 11 to 14 VDC
Electrical connections	Amphenol #165-15 weatherproof connector, and mating connector, Amphenol #165-14, prewired with 32 feet (10 meters) Belden cable; the opposite end is terminated in pigtail leads for a terminal board or connector, as specified
Size	5.06" (12.9 cm) high; 5.75" (14.6 cm) diameter base
Weight	3 lb. (1.3 kg)

[O]

### Soil Moisture Sensors

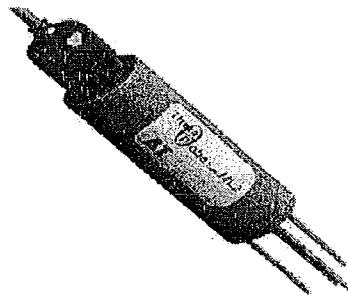


Figure 35. ThetaProbe type ML2

± 2% soil moisture (± 0.02 m<sup>3</sup>.m<sup>-3</sup>)

Interchangeable sensors

Stable, robust and maintenance-free

ThetaProbes feature a new technique that matches TDR accuracy without its expense, or susceptibility to set-up errors. Simply insert a probe into the soil, connect to a single analogue channel on your data logger or meter, provide 7-15V dc power at 33mA and within seconds you can be logging soil moisture.

After a single two-point gravimetric calibration, all ThetaProbes will meet their full accuracy specification for your particular soil (or other medium). The probes show some saline response, but this reduces as the salinity increases and they may be used with confidence even in very saline soils.

The probes are very durable - the rods are 60 mm long, made of resilient, solid stainless steel, and can be unscrewed and replaced if necessary. All exposed materials are either stainless steel or durable plastic, and the probes are fully sealed, so they can safely be buried. Optional extension tubes are available for convenient placement and removal when burying at depth.

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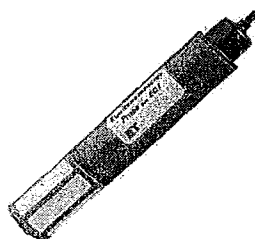
#### Equitensiometer type EQ1

0 to -1000 kPa

No maintenance

Simple data logger connection

No frost damage



The Equitensiometer shown in Figure 36 (above) is an accurate, maintenance-free sensor for measuring soil matric potential. It makes clever use of the latest generation of soil moisture sensor, the ThetaProbe, to derive readings of soil matric potential without any of the familiar tensiometer problems.

The sensor comprises a ThetaProbe embedded into a specially formulated matric material. The water content of this material rapidly reaches equilibrium with the matric potential of the surrounding soil, and the absorbed water is detected by the ThetaProbe. [C]

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### **3.3) Integrated logger and transducer systems**

Many applications require fast measure system set-up and unattended data acquisition even for short time period. Some companies have introduced very small devices that include few small meteorological sensors (i.e. air temperature and humidity), the circuitry, a small chip as data-logger and the memory for data acquisition. Even inexperienced operators can decide to start the logging by a simple PC software that manage the operations of start logging, data retrieval, data conversion in common format etc.

As an example Onset Computer Corporation introduces four new HOBO loggers for unattended data recording and the new pocket-sized HOBO Shuttle for convenient data retrieval. The new HOBO H8 Family of data loggers consists of four models: single-channel temperature, 2-channel temperature/humidity, 2-channel temperature/external, and 4-channel temperature/humidity/light intensity/external. The reusable HOBO loggers take up to 7,944 time-stamped measurements and have a one year user-replaceable battery. Connect the HOBOs to a PC and use the BoxCar Pro software for easy launch, readout, graphing and data export. Use the optional HOBO Shuttle for offload and restart of up to 60 loggers -- then transport the data back to the PC for viewing and analysis.

This kind of loggers are ideal for many purposes like preliminary studies for agrometeorological station installations, troubleshooting systems, monitoring facilities and warehouses, evaluating energy usage, tracking conditions during transportation, monitoring museum environments, and much more. To operate the HOBO loggers, simply connect the loggers to a PC with the provided cable and use the software to select logging frequency, length of deployment, and starting time. Disconnect the HOBO and place these tiny loggers (2.4"x1.9" x0.8" – 6x4.8x2 cm) in the desired locations for up to one year. Use the HOBOs to record temperature from -4°F to +158°F (-20°C to +70°C), relative humidity from 25% to 95% RH, dew point and light intensity from 2 to 600 lumens/ft<sup>2</sup> (. The external input accepts an external temperature sensor or a 0 to +2.5 DC voltage. The HOBO's non-volatile EEPROM memory saves data even if the battery is removed.

Reconnect the HOBOs to a PC or laptop to easily view data and graphs by its software. Export data to popular spreadsheet packages for further analysis. [D]

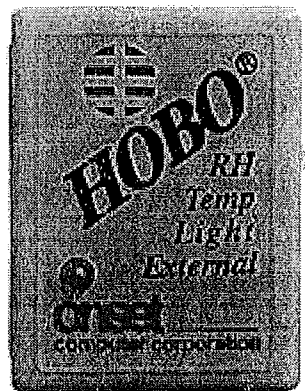


Figure 37. Hobo integrated data-logger

Figure 38. HT1: Humidity-Temperature Data Logger-Rotronic.



- » Integral probe
- » 0..100 %RH
- » -40..158° F / -40..70°C
- » 2 x 8,000 data points (up to 388 days)
- » Humidity field calibration with certified standards
- » Splash proof

[P]

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### **3.4) Low-cost AWS of A.M.F. & C.N.R. - I.A.T.A.**

Station model MINIMETEO-1

This system was developed by the Applied Meteorology Foundation and the National Council Research of Florence – Italy, for weather and agrometeorological measurements, with particular features of reliability and accuracy for many purposes in research and industrial applications.

#### **3.4.1) Data-logger**

The weather station supports the main meteorological parameters sensors with 0÷5 Volts output, like: temperature and air humidity, soil temperature, global solar radiation, wind speed, wind direction, leaf wetness, rainfall. They are connected to a data-logger (with 8 analog channels, 11 digital channels with I/O functions and an input counter channel for rain gauge) contained in a rugged box

(IP56 protection class) where the main board of data logger and the electronic of the sensor are placed.

The memory capacity of the system is 480 Kb and data storage depends both on channel numbers and acquisition frequency.

The data logger program and data retrieval are performed by the specific D.O.S. environment software and an RS-232 interface port.

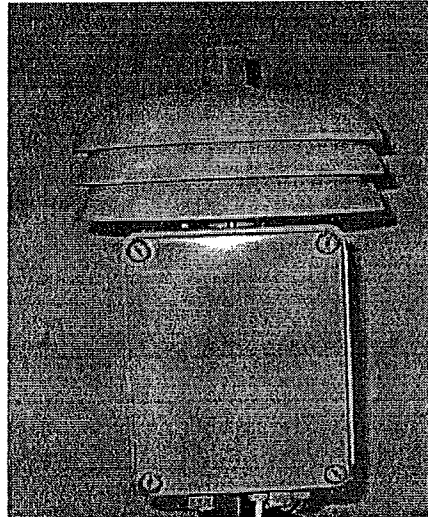


Figure 39. IP56 Protection case of data-logger and sensor shield

### 3.4.2) Sensors

#### Technical Characteristics

##### *Air temperature*

Sensor type	Integrated sensor
Power requirement	12 VDC
Measuring range	-20 ÷ +70 °C
Output voltage	0÷5 VDC
Operating temperature range	-25 ÷ +105 °C
Accuracy (typical/max)	±0.5/1°C
Sensitivity	55 mV/°C

##### *Soil temperature*

Sensor Type	integrated sensor
Power requirement	12 VDC
Measuring range	-20 ÷ +70 °C
Output voltage	0 ÷ 5 VDC
Operating temperature range	-25 ÷ +105 °C
Accuracy (typical/max)	±0.5/1°C

Sensitivity 55 mV/°C

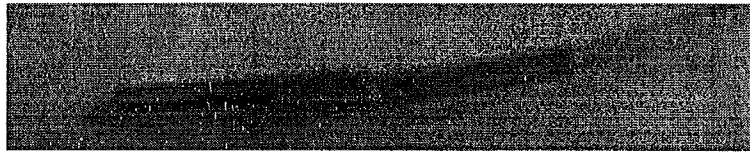


Figure 40. Soil temperature sensor (Integrated sensor)

*Air humidity*

Sensor Type	Capacitance sensor
Power requirement	12 VDC
Measuring range	10 ÷ 90 %
Output voltage	0 ÷ 1 VDC
Resolution	1%
Operating temperature range	0 ÷ +85°C
Accuracy	< 5%
Operative Range	0÷100%
Sensitivity	10 mV/%

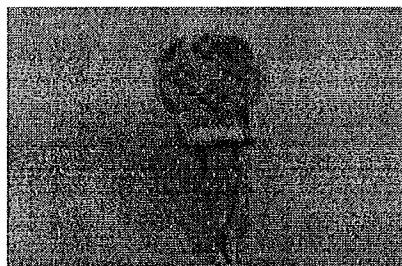


Figure 41. Philips air humidity sensor

*Solar radiation intensity*

Sensor Type	Silicon photocell sensor
Power requirement	12VDC
Measuring range	0 ÷ 1400 W/m <sup>2</sup>
Output voltage	0 ÷ 1400mV
Operating temperature range	-25 ÷ +75 °C
Sensitivity	1mV/Wm <sup>-2</sup>
Spectral range	400 ÷ 1100 nm
Linearity	< 5%

*Wind speed*

Sensor Type	reed switch
Power requirement	12VDC
Measuring range	0.9÷40 m/s

Output voltage	0÷5 VDC
Operating range	0÷78 m/s
Accuracy (typical/max)	±5%
Sensitivity	124.9 mV/ms <sup>-1</sup>

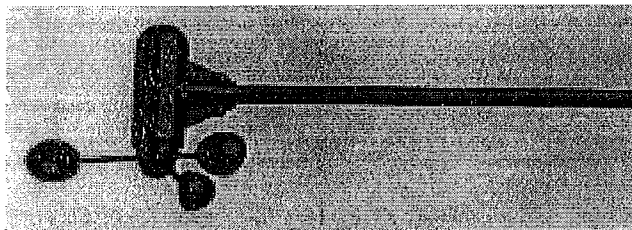


Figure 42. Wind speed sensor (Davis instr.)

*Wind direction*

Sensor Type	two wire potentiometer
Power requirement	12VDC
Measuring range	0÷360°
Output voltage	0÷5 VDC
Resolution	1°
Accuracy (typical/max)	±7°
Sensitivity	13.9 mV/deg

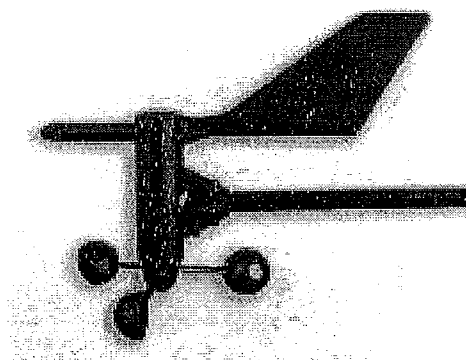


Figure 43. Wind speed and wind direction (Davis Instr.)

*Rain gauge collector*

Carefully designed to meet the guidelines of the World Meteorological Organization, our self-emptying, tipping-bucket design is exceptionally accurate. Available in two models: one measures in 0.01inch, the other in 0.2mm. Ruggedly built for minimal maintenance.



Figure 44. Raingauge (Davis Instr.)

Power requirement	5VDC
Output voltage	pulse
Accuracy (typical)	±2%
Resolution	0.2 mm

*Leaf wetness*

Power requirement	12VDC
Output voltage	0V leaf dry ÷ 5V leaf wet

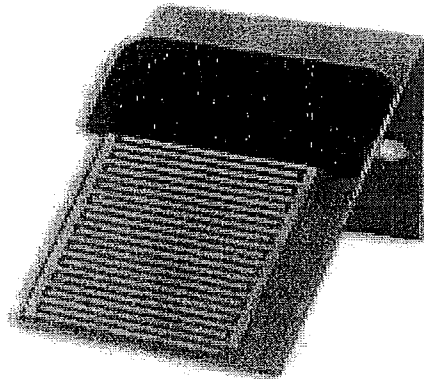


Figure 45. Leaf wetness sensor

*General features*

Max Current draw	35 mA
Car Battery life (60Ah)	around 71 days (60Ah/0.035A/24h=71.4d)

[Q]



#### 4) UTILIZATION AND MAINTENANCE OF AUTOMATIC AGROMETEOROLOGICAL STATIONS

##### General note

In the following chapter we'll give you some practice information about the installation and maintenance of weather station.

The first step is to plane a preliminary visit to the installation site, to decide the mounting structure type and to see if some specific devices are necessary to install the sensors. Some photos are also recommended. After that you have to prepare the mast in your laboratory, checking all mechanical part and trying to connect the sensor and data logger to the mast. Sometime are also necessary some operation in the installation area, for example to build an enclosure around the weather station or a plinth for the mast.

When the mast is ready you have to connect the sensor and the power supply to the data-logger. Is better if you check the complete system before starting the field installation. If you have some reference instruments (to measure air temperature, air humidity or solar radiation, etc.) you can put these near the weather station for some days to check if all the sensors output are correct.

If you assemble the complete system in your laboratory you are quite sure that, during the field installation you'll have all tools that you need.

At the beginning of field installation you have to check that the devices weren't damaged during the shipment and that the package is complete. More detailed information about the installation of each sensor are shown in the following paragraphs.

The primaries things required for the AWS field installations, are reassumed in this "check list" (anyone can added or erase one item or more, depending on the instrumentation and the tools required):

- ✓ Portable multimeter
- ✓ Compass (for vane anemometer and solar sensor positioning)
- ✓ Site map or Global Positioning System (G.P.S.) for the estimation of the coordinates of the AWS
- ✓ Altimeter (or a map with accurate contour)
- ✓ Bubble-level (for solarimeter, raingauge, evaporimeter, anemometer positioning)
- ✓ Meter
- ✓ Staircase
- ✓ Screwdriver for sensors terminal board
- ✓ Screwdriver for "philips" screw (small, medium and big size)
- ✓ Screwdriver for normal screw (small, medium and big size)
- ✓ Wire stripper
- ✓ Wrench series (metrics or inch size)

- ✓ Screw series (usually all devices are equipped with own screw but is better if you have a small series of screw during the field installation)
- ✓ Combination pliers
- ✓ Electronic nippers
- ✓ Monkey wrench
- ✓ Hammer
- ✓ Cutter
- ✓ Portable gas solder plus tin.
- ✓ Lithium grease (or silicon grease) for screws protection
- ✓ Silicone rubber
- ✓ Electrical tape
- ✓ Self bonding electrical tape
- ✓ Hacksaw
- ✓ Portable lamp
- ✓ WD-40 or CRC spray oil
- ✓ Electrical terminal box
- ✓ Hoe (to install soil sensor)
- ✓ Sensors with calibration form and/or manual
- ✓ Data-logger with manual and PC interface RS232 cable (if necessary)
- ✓ Gender connector for RS232 interface (if necessary)
- ✓ Portable Computer (Check the voltage of batteries first)
- ✓ Connection cable between sensors and Data-logger
- ✓ Battery for instrumentation power supply
- ✓ Battery → Data-logger cable
- ✓ Waterproof box for battery and data-logger recovery
- ✓ Piles and mounting brackets plus corner joints for sensors, data-logger and solar panel (if present)
- ✓ Stainless steel ties
- ✓ Wire rope plus chucks for sensor's pipe cross bracing.

#### **4.1) Agrometeorological station location**

We briefly reassume W.M.O (World Meteorological Organization) disposition to distinguish following categories of agro-meteorological stations [1]:

a) Principal agro-meteorological station:

Instrument's features, observations range and frequency, in both meteorological and biological fields, and professional technicians allow to extract high quality information for entire countries or regions.

b) Ordinary agro-meteorological station:

it furnishes routine measurements both meteorological and biological, and may be equipped to assist in research into specific problems. In general observation will be related to the local climatic regime of the station.

c) Auxiliary agro-meteorological station:

it furnishes meteorological and biological information. The meteorological information may include soil temperature, soil moisture, potential

evapotranspiration, leaf wetness and so on. Plant phenology and diseases risks information can be includes.

d) Agro-meteorological station for specific purposes:

this is a station set-up for temporary or continuous measurements of one or more elements regarding specified.

Station site should be (depending on the purposes) in level position and free from obstructions. Crop cover (if any) have to be representative of the zone and cut at proper frequency to keep it uniform and to don't affect measurements.

Trees, hedges or building should not be closer than eight or ten times their height.

Keep care on partial sensor shadowing by objects or sensor's arm or support (especially at sunset and sunrise), considering daily or seasonal solar trend.

The site has to be representative but no subject to cold air drainage, near ponds or swamps, rivers, or locations with frequent flooding.

Accessibility to the station has to be taking in account for future operations and instrumentation maintenance.

Take care about possible damage due to animals (e.g. water's evaporimeter protection) actions.

W.M.O. give also indications about the parameters measurements accuracy for agricultural meteorology purposes (Table n° 11):

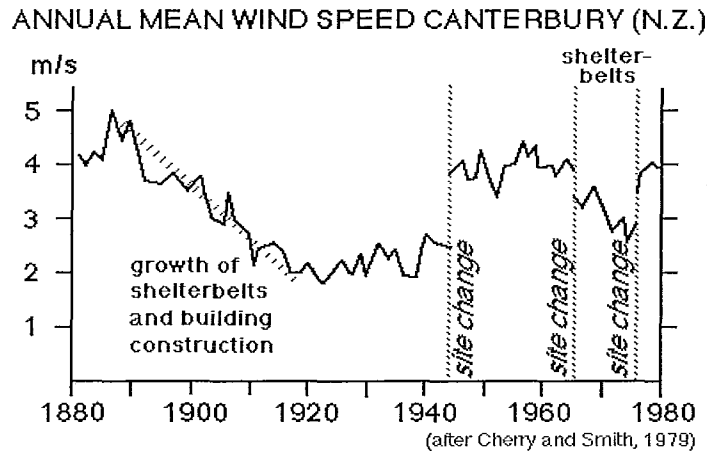
Table 11: Accuracy requirements for surface measurements

<b>PARAMETER</b>	<b>Accuracy for agrometeorological measurements</b>
<b>TEMPERATURE</b>	
Dry bulb	$\pm 0.1$ °C Time constant not > 1 minute
Extremes (Max and min)	$\pm 0.5$ °C
<b>HUMIDITY</b>	
Wet bulb	it depends on the purpose
Relative Humidity	$\pm 1\%$
Dew-Point	$\pm 0.1$ °C
Vapor Pressure	Equivalent to $\pm 0.1$ °C in dew-point
<b>WIND</b>	
Direction	$\pm 10\%$ mean value over 2 minutes periods are required
Speed	$\pm 10\%$ above $1 \text{ m s}^{-1}$
<b>RAINFALL</b>	
Total amount between 2 observations	0.2 mm up to 10 mm $\pm 2\%$ for large amount
Intensity	$\pm 5\%$ over periods of 15 minutes
Depth of Snow	$\pm 10\%$ of the absolute value
<b>EVAPORATION</b>	

Pan evaporation	± 0.1 mm up to 10 mm
Evaporation	± 2% for large amount
RADIATION	
Sunshine duration	± 0.1 h for each hour
Solar Radiation	± 1 MJ m <sup>-2</sup> d <sup>-1</sup>
Net Radiation	± 0.4 MJ m <sup>-2</sup> d <sup>-1</sup> up to 8 MJ m <sup>-2</sup> d <sup>-1</sup> (amount over 24 hours) ± 5% above 8 MJ m <sup>-2</sup> d <sup>-1</sup>

Besides the instrumentation, that can be automatic or not, the quality of the observations depend much on its immediate surroundings. Figure 46 shows as an example that the upwind distance (fetch), required for air to assume equilibrium with the terrain, is much longer than people tend to expect.

Figure 46 (below). Fetch F (in m) needed at height z for flow adaptation to roughness z



This shows that a long data series can be disastrously inhomogeneous, even from a conscientiously-managed weather station. In this particular case, the cause was change in surroundings, to which wind is very sensitive as was shown. However, many other possible sources of inhomogeneity exist for all parameters. Instrumentation may have changed, or the station location may have been moved, or the temperature measurement height may have been modified from e.g. 1.2 m to 2 m.

Concerning agro-meteorological station representativity this is a universal quality like accuracy, a fixed attribute of some (well-executed) observation. Rather, it depends both on the properties of the parameter (radiation, precipitation, wind) and on the application scales. Then first question we have to do yourself is: What station is representative for?.

Representative observation requires good and well-placed instruments, but is not the same as measurement accuracy. Important other aspects are observation location, and sampling frequency. [2]

Station should be identified by his position (especially for Network set-up), that is by the latitude, the longitude and altitude. This can be done by local map with adequate scale like 1:10000 (1cm is equal to 10000 cm) or 1:25000, with an accurate contour indication. In the last years the use of G.P.S. (Global Positioning System) has been introduced also for this purpose.

GPS was fundamental develop to operated by the U.S. military.

The system consists of the GPS satellites. These space vehicles (SVs) send radio signals from space. The GPS Operational Constellation consists of 24 satellites: 21 navigational SVs and 3 active spares orbit the earth in 12 hours orbits. These orbits repeat the same ground track (as the earth turns beneath them) once each day. This constellation provides the user with between five and eight SVs visible from any point on the earth.

A Master Control station located at Falcon Air Force Base in Colorado (with other stations around the world) measure signals from the SVs which are incorporated into orbital models for each satellites. The models compute precise orbital data (ephemeris) and SV clock corrections for each satellite. The Master Control station uploads ephemeris and clock data to the SVs. The SVs then send subsets of the orbital ephemeris data to GPS receivers over radio signals.

The user's device consists of the GPS receivers that convert SV signals into position, velocity, and time estimates. Four satellites are required to compute the four dimensions of X, Y, Z (position) and Time. GPS receivers are used for navigation, positioning, time dissemination, and other research.

A more precise positioning is possible using GPS receivers at reference locations providing corrections and relative positioning data for remote receivers (useful for surveying, geodetic control, plate tectonic studies, etc.). [3]

Here's how GPS works in five logical steps:

- 1.The basis of GPS is "triangulation" from satellites.
- 2.To "triangulate," a GPS receiver measures distance using the travel time of radio signals.
- 3.To measure travel time, GPS needs very accurate timing which it achieves with some tricks.
- 4.Along with distance, you need to know exactly where the satellites are in space. High orbits and careful monitoring are the secret.
- 5.Finally you must correct for any delays the signal experiences as it travels through the atmosphere.

[A]

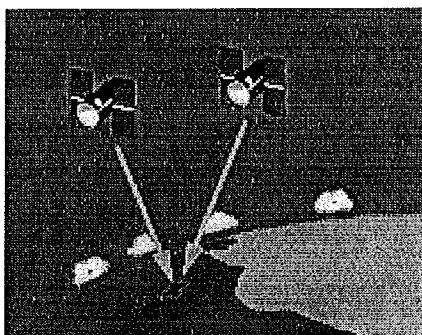


Figure 47. GPS scheme [A]

#### **4.2) Sensors employment**

This paragraph relates on some considerations over sensor's employ for some principal meteorological parameters for agriculture:

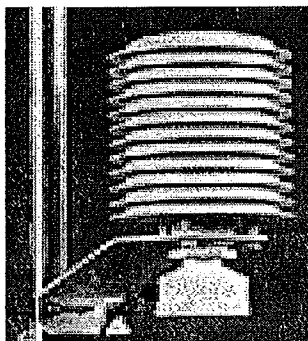
- Temperature
- Air Humidity
- Wind Intensity
- Wind Direction
- Rainfall
- Radiation
- Evaporation
- Soil heat flux
- Soil moisture

Most part of these considerations relates to the specific W.M.O. publication [4].

##### **4.2.1) Air temperature**

Thermometer's indication can be affected both from solar radiation and from longwave radiation (thermal infrared) emitted by clouds, soil, or any object positioned near the sensor. These influences can be avoided shadowing the sensor by a double shield mounted around, permitting free air ventilation.

Figure n° 48. Double shield



This is useful for sensor's protection against rain (with an alteration on temperature measurements), hail, and other mechanic interventions. This double shield reduces effects of thermal radiation, be care to avoid contact within it and the sensor, and free air circulation is allowed. Artificial air aspiration can be induced by law drain current fan and the air speed has to be maintained in a range of 2.5 to 10 m s<sup>-1</sup>. Take care on the direction of air circulation: the air have to be aspirated from the sensor to the fan, and not vice versa, to avoid temperature alteration due to electrical motor heating.

Standard sensor's height should be 1.25 up to 2.00 m around from ground surface. It has to be situated free from trees or building, and generally hollow or soil depression, or hard slope soil installations have to be avoided (except for particular temperature inversion studies).

With periodic snow presence, the sensor's height has to be modified depending the snow depth, to maintain a constant distance from the surface.

Sensor's shield should be periodically cleaned to reflect the most part of incident radiation.

#### 4.2.2) Soil temperature

Soil temperature sensors have to be introduced in a seal hard protection, to improve their mechanic resistance. This protection must have a small size to avoid temperature integration over a large area, this is an important feature especially in soil temperature profile measurements.

Be careful on the full contact between the probe and the soil around. It has to be primary considered in the installation.

#### 4.2.3) Air humidity

##### PSYCHROMETERS

- Based on two temperatures (wet and dry bulb) measure, cares described on the precedent paragraph have to be followed.
- Air flux speed through the temperature bulbs has to be maintained at 2.5 up to 10 ms<sup>-1</sup>.
- In high altitude installation, air flux has to be more fast cause low air density.
- Care on water reservoir refilling and cotton gauze cleaning, have to be take in account for wet bulb probe. The instrument's height should be 1.25 up to 2 m from the ground surface.
- Temperature's probe has to be of the same type.

- Take care at the installation to the woven cotton wick cleaning and probe's contact with it.
- Distilled water has to be used for reservoir refilling.
- Using non-aspirated psychrometers, proper tables have to be considered. In fact normal tables referring to temperatures measurements made with an air flux of  $3 \text{ m s}^{-1}$  around.
- Psychrometric equation can be use when the psychrometric factor is known; generally we consider a value of  $0.66 \text{ mbar } ^\circ\text{C}^{-1}$ , with an air flux between 3 up to  $8 \text{ ms}^{-1}$  and 1013.25 mbar of pressure. With a different pressure the given value have to be multiply for  $P/1013.25$  where P is the real atmospheric pressure (mbar). Errors due to pressure variation are always negligible ( $\pm 1.5\%$  for  $\pm 30$  mbar variation).
- Errors can be also due to ice formation on wet bulb.

#### 4.2.4) Soil humidity

##### HYGROMETERS

- These sensors have low cost and an easy employ, but low accuracy; in advance they are greatly affected by physical-chemistry soil characteristics in which they operate. They than requires a calibration procedure for each kind of soil.
- Sensor's installation determines an alteration in the soil's structure, than a stabilization time is required before starting measure.
- Gypsum blocks are the low expensive probes but problems are due to their duration (for gypsum deterioration), and with high soil moisture the sensor indicate constantly 100% of the range.

##### TENSIOMETER

- This instrument gives an accurate soil water potential response but in a very short operative range ( $0 \div 800$  mbar), and a frequent reservoir refilling is required especially during dry season.
- Sensor's installation requires a drill with a slightly low diameter than the tensiometer, to assure a good adherence with the soil around. An hole too small can determine the ceramic porous tip damages.

##### TDR (Time Domain Reflectometry)

The probe can have different size and shape depending on the soil type and the measures depth. During the installation care on soil and probe complete contact,

have to be done. As for others sensors, is better to wait for soil structure recover around the probe. For best results a calibration procedure is recommended: the water content is estimated taking a definite volume of substrate and measuring its fresh weight and the dry weight (obtained keeping the sample at 105 °C to constant weight). Samples at different soil's water content have to be taken to improve the calibration reliability.

The soil salinity content is another problem, because the probe's response can be affected by this. The problems increase when some plant's treatments could change soil salinity content. In this case data collect before the treatment could be not compares with the data set collect after the treatment (better, a certain delay time after treatment depending on soil permeability and measure's depth).

#### **4.2.5) Air pressure**

General rules for air pressure sensor's installation are the following:

- the sensor don't have to be exposed to the direct sunlight (cover with a reflectance shield)
- the transducer could be connect to the external atmosphere by a filtered tube that avoid too fast pressure variations due to gust wind
- firmly stop the sensor to avoid vibrations
- The site's height has to be known in order to enable barometer readings taken at different altitudes to be compared; it is then firstly necessary to reduce them to the same level.

#### **4.2.6) Solar radiation**

- For any flux radiation standard measurements, the sensor must be installed far from buildings, trees, or objects that can affects the values in some day's hours. The distance depends also on obstacle's color that can reflect radiation on the sensor's surface.
- Light sources proximity has to be avoided.
- Artificial shadow risks are greater at sunset and sunrise time. Obstacles don't have to cover the incoming radiation for more than 0.5 steradian.
- Take care on sensor's dome cleaning, and dew or hoarfrost deposition have to be removed (heater fan can be installed); condense can be avoided by a silica-gel capsule installed in the sensor and periodically replaced.
- Since all radiation fluxes are defined respect to an horizontal plane, the sensor must be positioned with the indication of a bubble level.

- In fixed installations the wires from the sensor to the data-logger, should be positioned underground to avoid possible thermoelectric potentials influences.

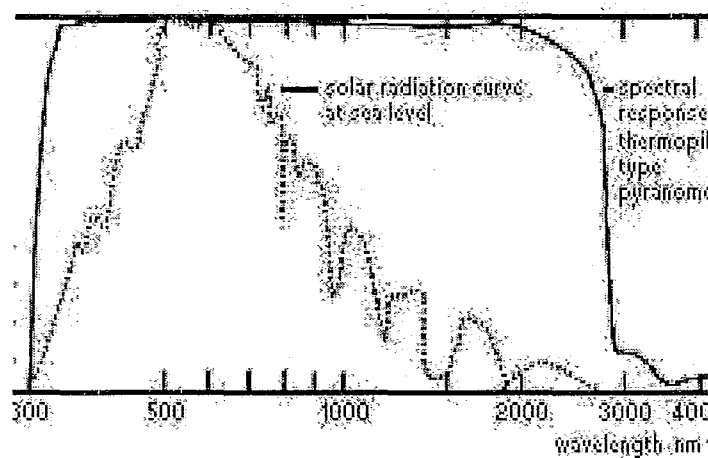
#### 4.2.6.1) Global solar radiation

This is the sum of direct radiation and diffuse radiation from varies atmosphere's components. The measure is made by sensors called pyranometers (or solarimeters), based on temperature variation measure of a transducer, thermopile, due to the incident radiation. These instruments normally have a built-in temperature sensor to compensate ambient temperature oscillations. Adsorbing surface is black coated and protected by two concentric domes: the internal one is made of glass and allows radiation penetration in the range from 295 to 2800 nm. The external one is normally transparent or filtered to obtain different sensitivity wavelengths.

The large part of pyranometers utilize a Moll-Gozczymsky thermopile; such sensors have to be oriented with the line constitute by the thermopile junctions in east-west direction (azimuth regulation). Thermopiles with circular junction's disposition obviously don't need any orientation.

If possible, sensor's connector has to be exposed to the north to avoid heating effects by the direct sunlight that can generate thermoelectric potentials on pin's connector.

Figure 49 shows the spectral response of a thermopile type pyranometer



#### 4.2.6.2) Diffuse solar radiation

The main care regarding the shading ring position. It is mounted on two rails oriented parallel to the Earth's axis, in such a way that the center of the ring coincides with the pyranometer during the equinox.

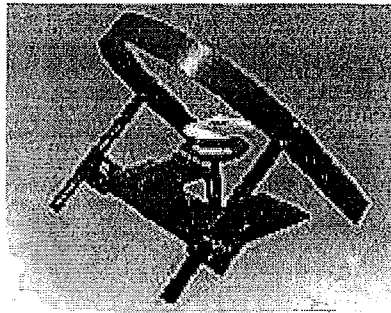


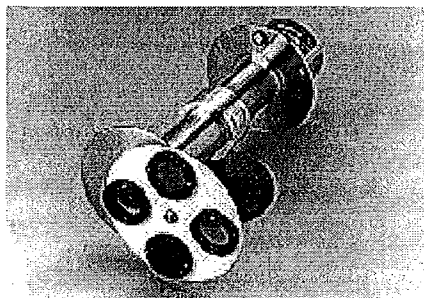
Figure 50: sensor for diffuse radiation (courtesy of Eppley Lab.)

The shadow Ring has to be designed to protect the pyranometer sensor from direct radiation, measuring diffuse radiation from the sky. Naturally the ring will also intercept some of the diffuse radiation from the sky. Correction is necessary to compensate for this. The diameter of the ring could range from 0.5 to 1.5 m and the ratio of the width ( $b$ ) to the radius ( $r$ ),  $b/r$  from 0.09 to 0.35. The regulation of the ring position to the solar declination is made by sliding it along the rails, because they have to form by the horizontal plane an angle equal to the site's latitude, (check the ring position every 15 days around).

#### 4.2.6.3) *Direct solar radiation*

The sensor utilized for the measure of this quantity is the pyrheliometer. It is delicate and direct radiation measurements are quite complicated. It is advisable to perform this in days with calm of wind.

Figure 51 (below) shows a Pyrheliometer (courtesy of Eppley Lab. Inc.).



To improve data's reliability the measure interval can be of 15 up to 20 minutes collecting 10 measures at least. Particularly care has to be taken on sensor's alignment respect solar beam: this has to be correct before each measure.

If particular precision is not required direct radiation can be estimated from global and diffuse radiation difference by the equation:

$$I = (G-D)/\sin h$$

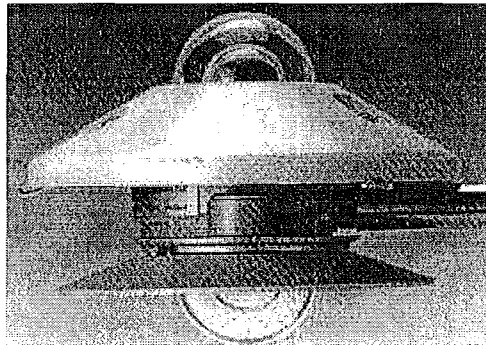
Where

- I = net radiation
- G = global radiation
- D = diffuse radiation
- h = solar elevation

#### 4.2.6.4) *Outgoing solar radiation*

- The pyranometer's height should be 1 up to 2 meters over the examining surface.
- In case of grass cover it has to be maintain at constant height.
- If snow presence occur in studied surface, the sensor's height has to be modified depending on the snow's depth. The ratio between outgoing radiation and the incoming radiation is defined Albedo.

In Figure 52 (below) an albedometer (courtesy of Kipp & Zonen) is showed.



#### 4.2.6.5) *Net radiation*

- The net radiometer has to be maintain at 2 meters above the ground surface in horizontal plane (normally a bubble level is present on the instrument).
- Dome's transparency depletion to the thermal infrared is due to polythene oxidation, and its substitution every six months around (depending on environmental conditions) is recommended.
- In some sensors type the dome tension is maintain by a constant dry air flux, that must have a proper regulation

- A good gas exchange assure the compensation from different inferior and superior plate's convection coefficients; avoid also an excessive air flow that could transport away the heat from the plate and lower the correct value.
- Because the transducer is a thermopile follow the instruction for sensor positioning described in the paragraph of global radiation.
- In the sensors without air flux exchange a capsule of silica-gel, connected to the ambient under the domes, should be periodically replaced

#### 4.2.6.6) *Photosynthetically Active Radiation (P.A.R.)*

PAR radiation or Photosynthetically Active Radiation is radiation in the 400-700 nm region of the solar spectrum, i.e. radiation that is utilized by plants for photosynthesis process, then it is an important parameter in agronomy science. There are many sensors realized to measure this kind of parameters; most of them utilize a silicon photocell transducer.

We can use also some pyranometers to estimate PAR, based on the fact that the ratio between PAR and total solar radiation (which is measured by a pyranometer) is rather constant. [5] Pyranometers can be used as PAR sensors. In fact, estimating Photosynthetically Active Radiation from a pyranometer output is rather accurate. This is because some pyranometers can have a much better cosine response and a better temperature dependence than commercially available PAR sensors.

Under "blue sky" conditions, each measured  $W/m^2$  contains  $4.24 \mu mol/s/m^2$  PAR radiation (in 400 to 700 nm range). Under "diffuse" conditions this ratio is 4.57. Taking 4.40 as an average only  $\pm 5\%$  inaccuracy is to be expected from this estimation.

From  $W/m^2$  (pyranometer signal) multiply by 4.40 to get  $\mu mol/s/m^2$  (PAR). [6]

Because of the cheaper cost of silicon photodiode sensors, they can be well suitable for P.A.R. spatial distribution measurements inside crop vegetation.

#### 4.2.6.7) *Sunshine duration*

The automatic recording sensors are curved triangular element shape for good directional response, correlates with Campbell-Stokes sunshine recorder. Both direct and diffuse lights are utilized to avoid bright-cloud error. The instrument is composed by bimetallic sensor elements with a variable number of contacts. These only close when elements are under direct sunshine.

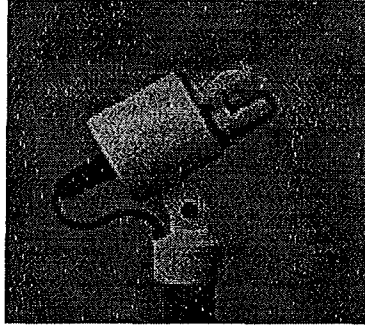


Figure 53. Sunshine duration sensor (courtesy of Lastem)

As others radiation sensors, is fundamental to care on glass cleaning.

For sensor's installation some regulation have to be done:

- I) horizontal sensor's leveling;
- II) The site should provide an uninterrupted sensor's view of the sun for the entire year;
- III) The recorder should be firmly fixed to a rigid support.

The sensors are calibrated for solar radiation levels higher than a preset threshold; the Commission for Instruments and Methods of Observations recommended the use of  $120 \text{ W m}^{-2}$  as this threshold when using a pyrheliometer as a standard, with the sun near the horizon as a source.

#### 4.2.6.8) *UV-B radiation*

The installation's procedures are very similar to the others radiation sensors. The spectral response depends on the measure purpose. (i.e. to study biological effects we will use a sensor which match the DNA or Erythema absorption curve; for material deterioration studies a sensor that match meteorological UV-B curve will be used).

#### A brief note on UV-B measurements

The continuous decrease of stratospheric ozone layer is producing an increase in solar ultraviolet radiation on the earth's surface. This increase in UV radiation could affect some biological processes on the earth.

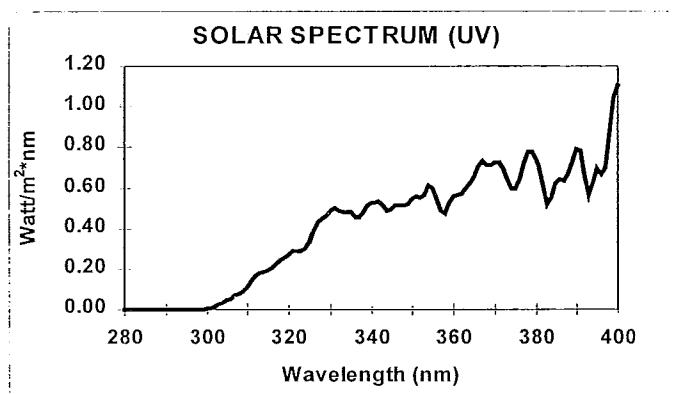
The measurement of ultraviolet (UV) light is a much more difficult task than the measurement of visible. The visible spectrum is defined generally to range from 400 nanometers (nm) to about 700 nm. The part of the near UV spectrum that has

a major effect on living things is divided into three general regions. From 320 to 400 nanometers is called the UVA region, 280 to 320 nanometers is the UVB and 280 and less nanometers is called the UVC region.

Measurements of UV are difficult and there are few good quality measurements of UV; this is because of the high slope of the spectrum in the UV region and because calibration standards in this spectral region are imperfect. In particular it is very difficult to determine the UV trend in a long time period because there are many factors other than ozone, which affect the UV. UV measurements could be performed by means two type of instruments: broadband radiometers and spectroradiometers.

Broadband radiometers are used to obtain the total energy over a broad range of wavelengths in the UV band; with broadband radiometer it is possible to obtain a continuous series of data over time. Spectroradiometers are able to measure the energy content of the light for each nanometer, to build up a detailed spectrum.

Figure 54: Solar spectrum measured by means a spectroradiometer



The shorter wavelengths (UVB) are more dangerous (in terms of biological effect) but they are not much present, while the response to the longer UVA is not as severe but there is just much more of it. The result is that both the UVB and the UVA portions of the spectrum should be studied. To study the biological effect of UV radiation, broadband radiometers have been very carefully designed to react in the same manner as some biological processes. For example some radiometers measure the biological effective UV radiation in terms of plant damage, of erythema induction, of photosynthesis inhibition, etc. These radiometers have a spectral curve response, which approximate the spectral curve of sensitivity of specific biological process.

### Choice of UV-B radiometer

Today it is possible to use many models of UV-B radiometers. What are the characteristics that we have to take into account in choosing the more appropriate radiometer for our use?

First of all it is important to know the spectral response of the sensor; it depends primarily from the application of measured data. For example if we are interested to measure UV-B radiation to study the possible impact on human health it could be necessary to use broadband radiometers with spectral response which approximate the spectral curve of sensitivity of human skin (Erythematous Action Spectrum).

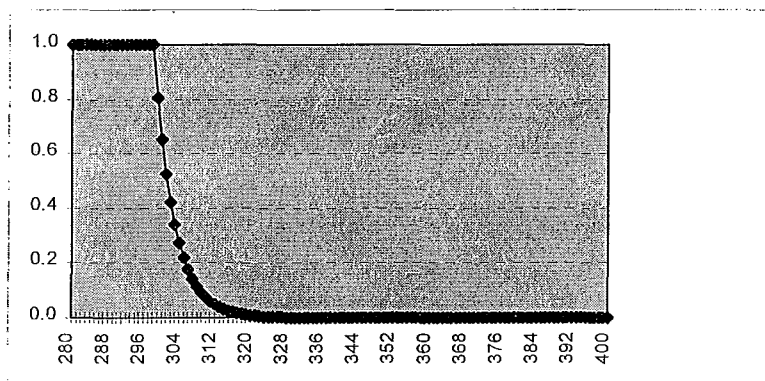


Figure 55. Erythematous Action Spectrum

In the figure 55 it is represented the Erythematous Action Spectrum [7] [8]. Radiometers with spectral response close to this action spectrum measure UV-B radiation taking into account the high deleterious effects of short UV-B wavelength (in other terms the solar irradiance is weighted to consider the different deleterious effects of irradiance at different wavelengths). Using irradiance weighted with erythematous action spectrum it is possible to convert the data in terms of UV-Index; the UV-index is an internationally adopted index to express the risk consequent to solar exposure. It is calculated as the ratio irradiance ( $\text{mWatt/m}^2$ )/25 and it can vary between 0 (minimum value of risk) to about 12 (maximum value of risk).

There are also UV-B radiometers with spectral response similar to other biological process action spectra and UV-B radiometers for meteorological application, which don't make any weighting of measured irradiance.

Some other technical characteristics to consider in choosing appropriate broadband UV-B radiometer are the wavelength range, the temperature range, the cosine response and also the power supply and the output signal; in fact it is

necessary to choose the radiometer compatibly with power supply and data logger characteristics.

Each UV radiometers need of periodical calibrations; it is possible to re-calibrate the sensor sending it directly to the manufacturer, or by means intercomparison campaigns by using reference instruments.

#### 4.2.7) Wind speed

- The sensor has to be place in horizontal level
- For meteorological purposes the anemometers have to be placed at 10 m from the ground surface, taking in account eventual obstacles present near the site (they have to be far from the sensor ten times respect their height).
- For agronomy studies the general sensor's disposition is 2 m height, from the ground.
- For cup anemometers the two ball bearings are the parts that required more maintenance because dust or ice deposition. Take care on balls bearing dismount and accurate cleaning. They have to be correctly realigned to avoid friction. Use only appropriate solvent cleaner (it mustn't leave any deposition on the ball bearings)

#### 4.2.8) Wind direction

- To install this sensor the same rules given for the anemometers can be follow.
- The compass is required to position the zero value (or the 360° value) corresponding to the north, the 90° value to the east clockwise and so on. Check directly in the field this output, moving the transducer on each point.
- Utilizing potentiometric sensors take care on power positive + and negative – connection, because the correspondence above mentioned become inverted (anti-clockwise increment, see the point above).
- This parameter is extremely variable, instant for instant, and to obtain a prevalent wind direction high instantaneous values number is necessary. If a recent data-logger version is available a lot of data can be stored in the RAM and reassumed in a unique dominant frequency value calculated for the relative time interval.
- Take care on the oscillations around zero value, because potentiometric's cursor can fall on its dead angle (it should not be greater than 3°) and give erroneous signal.

- Take care when measuring the resistance on the potentiometer that the test current does not exceed the maximum potentiometer current. Choose also the correct voltage supply to match the data-logger's voltage range.

#### 4.2.9) Rainfall

- Rainfall gauges have to be positioned on horizontal stable surface, that can be covered by grass or gravel layer. Avoid hard surfaces like cement for possible raindrops jumping
- Errors in rainfall measurements are often due to raindrops deposition on internal sensor's surface, or partial evaporation of accumulated water in the bucket and of raindrops splashing from or into the gauge.
- Horizontal gauge's level position has to be regularly checked. To reduce wind disturbs vegetation hedge can be plant around the sensor, taking care that its height be maintained at the same level of gauge orifice by frequent clipping.
- In general objects should not be closer to the gauge than a distance twice their height above the gauge orifice. Direct solar radiation can be also an error's source and normally gauge's external surface is white reflectance painted.

#### 4.2.10) Evaporation

##### A PAN EVAPORIMETER

The sensors in situated inside a water tank sunken, and its body can be set up below the ground level or above ground (e.g. on wood pallet). Pans installed above the ground are inexpensive and easy to install and maintain, and they stay cleaner than sunken tanks. The water contains in the above ground pan is losses fast than the tank installed below the ground for radiant energy intercepted by the sides.

Normally we refer to the evaporation from free water surface in a pan, because it's the widely used (particularly the class A pan with dimensions of 25.4 cm deep and 120.7 cm in diameter). It is fill up to 5 cm from the upper limit (this level cannot be exceed because a discharge valve is present), and water's level shouldn't decrease less than 50 mm respect the maximum level.

- The water level sensor is often an hookgauge. This is mounted in a stilling well (situated on the middle part of the tank) in order to breaks any ripples that may be present in the tank.

- Inspections could pay attention on eventual leaks and water's cleaning operations. The maintenance interval depends on weather conditions, field treatment around the sensor such as grass cutting or soil tilling that can produce a sediment of dust, stem, foliage and so on. The addition of a small amount of copper sulfate, or some other suitable algacide, in the water should restrain the algae's growth. Using this products take care on water evaporation rate alteration.
- The plot should be fenced to protect the instrument (this is could be valid for any instrument's installation) and to prevent animals from interfering with the water level.
- A metal lath lean on the tank can be suitable. Errors due to its presence should be known. For example a metal lath with an hexagonal pattern of 25 mm side size, framed in steel bar of 8 mm width, experimented for two years in three different places, gave a constant 10% reduction of the evaporation rate.
- Evaporation stations should be located free from obstruction such as trees, building or instrument shelter. They should not be closer than four times their height above the pan.
- Air and water temperature, wind speed and rainfall, measured at the pan's level, are sometime set-up to improve the evaporation estimation.

#### **4.2.11) Leaf wetness**

This sensor is useful in micrometeorological instrumentation set-up, especially for plant disease studies. It has to be installed with a proper slope and exposition, to be representative of the plants foliage distribution. The sensor's height displacement and the probable shadow effect due to the plants, have to be considering when the installation takes place. The sensor could be constituted by a single surface. In this case it couldn't be sufficiently representative if mounted alone, and is better to mount more than one sensor to simulate different leaves disposition.

There are some sensors constitute of two plates cross-mounted in order to simulate an "average" plant's leaves distribution.

#### **4.2.12) Soil heat flux plate**

These sensors have to be introduced in the soil at the desired depth. Generally the deep of insertion is 5÷10 cm around, from the soil surface. As for soil temperature sensors, is important to pay attention for a good adherence of the

soil to the sensor's surfaces. It is better to consider the measurements after a certain time, to await for soil's settlement around the sensor. The sensors are furnished waterproof and resistant to a mechanical shock for their particular utilization, but a film of special transparent protective lacquer can improve these characteristics and preserve cable corrosion (especially at the sensor's connection point in the soil).

The heat flux transducer should be installed level in the soil. Make sure that there is good thermal contact between the soil and both top and bottom transducer surfaces. It is not advisable to place the transducer too close to the soil surface. This may impede moisture migration and the soil above it may dry quicker than adjacent soil. Resulting heat flow measurements would not be representative of the adjacent soil.

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```

surf3dl.generalizefeatures.ave
' Name: Surf3D_1a.GeneralizeFeatures
'
' Title: Removes unneeded vertices from selected features
'
' Topics: GeoData
'
' Description: Simplifies the shapes in a shapefile that is creat
ed from
' the selected features for each active polyline or polygon theme.
This
' script is used to generalize, or weed out, vertices that do not
add
' to the desired level of detail in the definition of the shape ge
ometry. A
' tolerance is specified to check whether or not vertices should b
e
' retained.
'
' This script is a simple implementation of the Douglas - Peucker
' algorithm used in ARC/INFO and PC ARC/INFO. It should be used a
s
' a button in a View GUI.
'
' A few thoughts to consider:
'
' 1. The script first creates a new shapefile for selected featur
es of
' an active theme. The new shapefile is added to the view. The o
riginal
' theme is not changed.
'
' 2. This script will reduce the quality of the data. Any metada
ta for
' the themes should state that the data has been modified.
'
' 3. Results are very dependent on the polygon geometry. Shapes
' created from adjacent polygons may no longer be coincident. The
y
' may overlap, or leave a sliver. Proceed with caution.
'
' 4. Results are very dependent on the polyline geometry. While
the
' shape endpoints are maintained, interior points may be eliminate
d.
' Other shapes in a network that may begin or end at an interior v
ertex
' may now be dangling. A complex shape may cross itself after bei
ng
' generalized. Proceed with caution.
'
' 5. The only check on the resulting geometry is to be sure a pol
ygon

```

```

                                surf3d1.generalizefeatures.ave
' has not collapsed completely by removing too many vertices. If
so,
' the shape will revert to the original.
'
' 6. This script does not recalculate areas, perimeters, or lengths.
' They may have changed as the shapes are simplified. The
' "CalculateAreaPerimeterLength" sample script can be used to update
the
' the values.
'
' Requires: A View with at least one active polyline or polygon theme.
'
' Self:
'
' Returns:

' Get the view and its projection

theView = av.GetActiveDoc
thePrj = theView.GetProjection
if (thePrj.IsNull) then
    hasPrj = false
else
    hasPrj = true
    thePrj = theView.GetProjection
end

' Get active themes

theThemes = theView.GetActiveThemes

if (theThemes.Count < 1) then
    MsgBox.Error("Please make a polyline or polygon theme active","*
** Error **")
    exit
end

' Process each active theme

for each t in theThemes

    ' Check that the theme is of the correct type

    if (t.Is( FTHEME).Not) then
        MsgBox.Error (t.GetName++"is not a polyline or polygon theme",
"*** Error ***")
        continue
    end
end

```

```

        surf3d1.generalizefeatures.ave
theClassName = t.GetFTab.GetShapeClass.GetClassName
if ((theClassName = "Polygon").Not and (theClassName = "Polyline
").Not) then
    MsgBox.Error (t.GetName++"is not a polyline or polygon theme",
"*** Error ***")
    continue
end

' Get a tolerance in (distance units) to be used (must be > 0)

theTol = 0
theMUnits = theView.GetDisplay.GetUnits
theDUnits = theView.GetDisplay.GetDistanceUnits
theUStr = Units.GetFullUnitString(theDUnits).LCase
while ((theTol <= 0) or (theTol.AsString.IsNumber).Not)
    theTol = MsgBox.Input("Positive tolerance value (in "+theUStr+
        ") for theme"++t.GetName,"Tolerance",theTol.AsString)
    if (theTol = NIL) then exit end

    if (theTol.IsNumber) then
        theTol = theTol.AsNumber
    end
end
theTol = Units.Convert(theTol,theDUnits,theMUnits)

' Get the name for a new theme, from View.Export script

def = av.GetProject.MakeFileName("theme", "shp")
def = FileDialog.Put(def, "*.shp", "New file for simplified "+ t
.getName)

if (def = NIL) then return nil end

' Create a new shapefile theme, from View.Export script

tbl = t.GetFTab
shpfld = (tbl.FindField("Shape"))
if (shpfld.IsVisible.Not) then
    shpfld.SetVisible(shpfld.IsVisible.Not)
    WasNotVisible = TRUE
else
    WasNotVisible =FALSE
end

' This will only export the selected shapes, if any have been se
lected

av.ShowMsg("Creating new shape file from"++ t.GetName)
anFTab = tbl.Export(def, Shape, tbl.GetSelection.Count > 0)
anFTab.SetEditable(true)

if (WasNotVisible) then

```

```

        surf3d1.generalizefeatures.ave
    shpfld.SetVisible(FALSE)
end

' Find the shape field

theSField = anFTab.FindField("Shape")

' Set up status bar

av.ShowMsg("Generalizing new shapes from theme"++ t.GetName)
theSize = anFTab.GetNumRecords

' Initialize counters for reporting

count = 0
oldCount = 0
newCount = 0

' Process each shape

for each r in anFTab

    av.SetStatus(100*count/theSize)

    ' Retrieve shape

    if (theClassName = "Polygon") then
        theOShape = Polygon.MakeNull
    else
        theOShape = Polyline.MakeNull
    end
    anFTab.QueryShape(r,theView.GetProjection,theOShape)

    ' Make a list for collecting the new set of point lists

    theNShape = List.Make

    ' Process each list in the ListofListofPoints

    for each p in theOShape.AsList

        ' Make a list for collecting the vertices to keep

        theNList = List.Make

        oldCount = oldCount + p.Count

        ' Set up stack for holding a set of lists of form {index,poi
nt}

        theStack = Stack.Make

```

```

                                surf3dl.generalizefeatures.ave
' Add first point to the list being assembled, and make it the anchor

theAnchor = p.Get(0)
if (hasPrj) then
  theNList.Add(theAnchor.ReturnUnProjected(thePrj))
else
  theNList.Add(theAnchor)
end
aIndex = 0

' Add last point to stack

fIndex = p.Count - 1
theStack.Push({fIndex,p.Get(fIndex)})

' Process the points with the Douglas - Peucker approach
while (theStack.IsEmpty.Not)
  ' Process from Anchor (beginning) to Floater (top of stack
)

  fIndex = theStack.Top.Get(0)

  ' Create graphic shape for comparing distances
  theVect = Line.Make(theAnchor,theStack.Top.Get(1))

  ' Initialize values for comparison

  theMax = theTol
  mxIndex = 0

  ' Find distance

  for each i in (aIndex + 1) .. (fIndex - 1) ' process middle points

    dist = theVect.Distance(p.Get(i))

    ' Check against previous maximum

    if (dist >= theMax) then ' this point is out of the tolerance
      theMax = dist
      mxIndex = i
    end

  end

  ' If a vertex is found outside the current tolerance corri

```

```

dor,
    ' push it onto the stack

    if (mxIndex > 0) then 'a new floater has been found
        theStack.Push({mxIndex,p.Get(mxIndex)})
    else ' add floater to the list for the new shape and move
forward
        if (hasPrj) then
            theNList.Add(theStack.Top.Get(1).ReturnUnProjected(the
Prj))
        else
            theNList.Add(theStack.Top.Get(1))
        end

        ' Make the floater the new anchor

        theAnchor = theStack.Pop.Get(1)
        aIndex = fIndex

    end

end

' Check for collapsed polygons

if ((theNList.Count < 4) and (theClassName = "Polygon")) the
n
    ' Revert to original polygon
    if (hasPrj) then
        theNList = List.Make
        for each pt in p
            theNList.Add(pt.ReturnUnProjected(thePrj))
        end
    else
        theNList = p
    end

end

' Finish up individual lists

newCount = newCount + theNList.Count
theNShape.Add(theNList)

end

' Finish up the shape

if (theClassName = "Polygon") then
    theNShape = Polygon.Make(theNShape)
else
    theNShape = Polyline.Make(theNShape)

```

```
                surf3d1.generalizefeatures.ave
end
anFTab.SetValue(theSField, r, theNShape)
count = count + 1

end

' Clear status message

av.ClearMsg
av.ClearStatus

' Report on counts of old and new theme

MsgBox.Info("The old theme with"++ oldCount.AsString ++
            "vertices has been generalized to"++
            newCount.AsString++"vertices", "Results")

' Create a theme and add it to the View

anFTab.SetEditable(false)
fthm = FTheme.Make(anFTab)
theView.AddTheme(fthm)

end

' Bring the View to the front

theView.GetWin.Activate
```

## 5) INSTRUMENTATION POWER SUPPLY AND PROTECTION

### 5.1) Power supply

#### 5.1.1) Main power supply – No-break power

Main power rarely its easy to reach on open-field or in wood site. If available it is often near buildings or structures, where normally weather measures have not to be taken because they aren't representative of the natural site.

Moreover even if a distribution substations is available, they often don't guarantee a regular power supply, because are terminal stations.

In this case a no-break power systems should be requested. These are constituted of a power source, a battery and an inverter with an onboard system's protection. In this way the power supply should be continuously available, except for hard and fast line over-voltage. In this case the first device that can be damage is really the no-break system and probable others devices connected. Buying an inverter take care on the voltage output that must have sinusoidal wave with a distortion less than 3%, because a large part of inverters give a "square" wave voltage which can damage electronic circuitry, specially digital electronic.

Room air conditioning, when necessary, can added others problems to main voltage line. This have to give sufficient energy specially when the conditioner turn on, in order to don't produce line interruption or voltage oscillation. Every devices must have a good earth connection, to reject spurious signals coming from main's wires or from the shield of the sensor's cable. Frequently inadequate earth's connection can cause instrument's damages or malfunctions.

There are various methods of earth grid that can be installed to achieve a satisfactory earth resistance. Normally an efficient earthing system, well dimensioned for power requirements and measure net extension, is able to safe the installed instrumentation. This can made by traditional methods such as driven rods, tapes, plates or pipes.

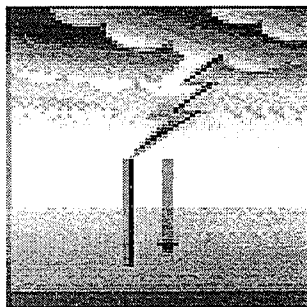
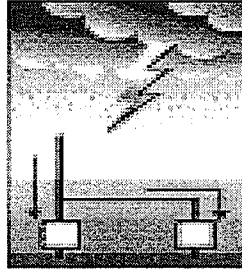


Figure 56. single rod system (courtesy of Global Lightning Technologies)

These passive conductors enable an electrical fault to travel down to the earth, therefore passive conductors in poor soil conditions will result in inadequate earthing protection. In this case we can apply some earth compound to fill the cavity of each rod.

An often overlook aspect of proper earthing is the effect of normal soil movement. Weather conditions and surrounding environmental fluctuations contribute to the expansion and contraction of soil. During periods of dry weather,



the soil will often become loose and non-conductive. If a desired resistance is not achieved with a single rod then additional rods need to be installed. Each rod can be connect to the other using flat copper tapes and clamps. [A]

Figure 56. multiple rods system (courtesy of Global Lightning Technologies)

Some systems have been designed with a special soil to electrode interface that expands and contracts accordingly. This enables the electrode to maintain constant contact with the surrounding soil and ensure a proper moisture level regardless of fluctuations in weather or environmental conditions.

Sometimes either an efficient earthing system cannot preserve against any accident, then auxiliary protection can be installed such as Over Voltage Protection (OVP) devices. These employs Zener components, that well operates in fast transient voltages induced by igneous meteor.

Although field discharge rarely directly strikes instrumentation, for its impulsive origin can produce high voltage transients on the cable conductors, up to kVolts order, also if it has been lighted 20 or more kilometers far from power line. We can avoid this inconvenient renouncing to the main power and arranging autonomous power generators.

### 5.1.2) Battery power supply – Solar panel

The common generators place many problems such as: fuel reservoir short autonomy, noise disturbing, dangerous no-stop functioning especially in wood test sites and during hot season.

Normally recent weather stations installations foresee a battery supply. These can be periodically recharged in laboratory, or charged directly on the site by a solar panel (when solar radiation energy is available). The photoelectric panels can restore the current lose by the battery, with a direct solar energy conversion. This allows long-term operations of the installed instrumentation. Besides problems due to main power disturb and over-voltage transient long the cable are avoided.

Silicon is the raw material used to make solar cells. There are three main types:

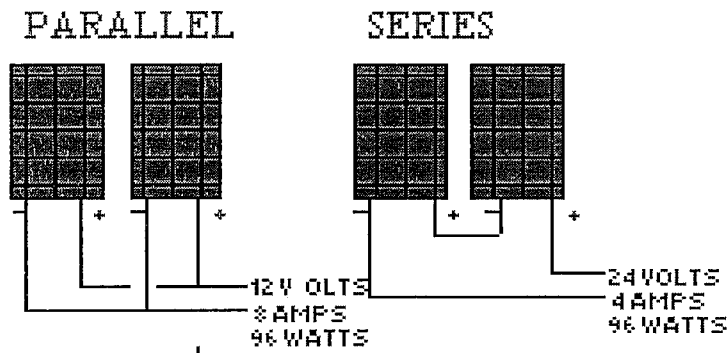
1. Monocrystalline or single crystal cells. The first generation of solar cells excellent conversion rate (12 - 16%);
2. Polycrystalline cells lower production costs, requiring less energy to make 11 - 13% conversion efficiency;
3. Amorphous a more recent technology (mid-70's) lower production costs, but unfortunately also lower efficiency (8 - 10%), This process can use very thin layers of amorphous silicon (0.3 - 1.0 microns compared to 500 microns for the other types).

A single solar cell always produces a voltage of approximately 0.5 volts, regardless of its size. For higher voltages, you have to connect individual cells in series to add their voltages. The larger the solar cell, the greater the current will be. Current is measured in amperes (A). You can also connect cells in parallel to increase current. The most common solar panels are for 12 V applications. To reach that voltage, 24 cells would be sufficient, but for charging batteries and in order to compensate for voltage drops due to various factors, a panel normally contains between 28 and 40 cells for a higher voltage. When You buy a solar panel be sure that it could deliver more than 12 volts to charge a 12-volt battery (if it is the voltage required). Voltage can drop for several reasons:

At high temperatures. (it could appear strong but solar panel works less well when it's very hot! In tropical climates, choose higher voltage panels.) as a result of long wires it's important to keep your wiring between your panels and other parts of your installation as short as possible. Diodes can also cause small voltage losses (these components are useful to prevent battery's discharge when the sun is absent). A panel that produces 2 amperes sends twice as many electrons as a one-ampere panel. When talking of solar panels, you usually refer to their power (measured in watts).

$$\text{VOLTS} \times \text{AMPERES} = \text{WATTS}$$

A 12-volt (VDC) panel producing 4 amperes (A) of current has 48 watts of power. Panels can be connected in series or in parallel. If you take two of these 48 watt (W) panels, you can connect them in series, adding their voltage, with no change in current (A), the result is 24 VDC at 4 A (96 watts). You can also connect them in parallel, the voltage stays the same, but you add the current (A), which gives you 12 VDC at 8 A, but still 96 W as in the case above (Figure 57, below). [C]



## 5.2) Instruments protection

### 5.2.1) Environmental class quality

Open-field's measurements always presents difficulties due to instrument's reliability. Generally modern sensors and data-loggers are constructed with proper materials utilization, solving successfully great part of those aspects.

Sometimes manufacturers can utilize some components with an insufficient operating temperature range (that is from 0°C to 70 °C, industrial range); this means that the reliability degree mentioned on the technical sheet can be modified. Most of damages concern analog devices with electromechanical components such as printers and tape recorders.

For critical environment conditions special components are available. These relate to military rules construction that allow operating ranges of -55°C up to 125°C for temperature and up to 90% for the humidity. Obviously they are more expensive.

Example of Rules for Italy.

In Italy the D.L. of the 1st March 1945 in Art. 4 entrusts to the National Research Council, CNR, the task of compiling "regulations for the acceptance, testing and unification of various materials, instruments, equipment, machinery

and accessories for technical and scientific use, as well as regulations for the creation, testing and protection of plants and constructions". By means of its own technical bodies and other organizations connected to it such as the Italian Electrotechnical Committee, CEI, which deals with electrotechnical and electronic affairs, and the Italian National Unifications Organization, UNI, which deals with all other industrial sectors. CNR oversees the publication of regulations concerning measuring methodologies and the meteorological characteristics of instruments.

CEI regulations which, based on law 186 of the 1st March 1968, are legally valid, keep track of publications from international organizations. In particular, following upon D.M. 15.12.1978, CEI was asked to take part in EEC studies leading to unified technical regulations as laid down in the Community Directive CC/73/23 incorporated in Italy by law 791 of the 18th October, 1977. These are carried out by CENELEC (European Committee for Electrotechnical Regulations) of which CEI is the Italian member.

The international organs set up to prepare and publish regulations are the IEC (International Electrotechnical Commission) and the ISO (International Standard Organization).

Between these two organizations there is an agreement whereby IEC take care of international regulations in the fields of electrical engineering and electronics, while the ISO takes care of the other areas. IEC and CENELEC publications are also available from CEI.

#### Classification of Environments

The IEC has classified environments by identifying with two letters that change according to the parameter they take into consideration, and a number which indicates the intensity of the effect of the parameter (Table 12). Tables 13, 14, 15 contain classifications that refer to solid bodies, water and temperature.

*Table 12 - IEC initials referring to the most interesting environmental parameters in the fields of agriculture and forestry.*

AA	Temperature of the environment
AD	Water
AE	Solid bodies
AF	Corrosive or contaminating substances
AG	Mechanical stress
AH	Vibrations
AK	Flora
AL	Fauna
AM	Electromagnetic and electrostatic influences
AN	Solar radiation
AQ	Atmospheric discharges

Table 13 - Presence of solid bodies

Letters	Environment characteristics	Example
AE1	Negligible dusts presence and solid bodies of small size	Buildings, offices, schools, public locals
AE2	Small bodies with minimum obstructed not less than 1 mm	Machines rooms, big kitchens, factories, yards
AE3	Very small bodies with obstructed not less than 1 mm	Children's rooms, textile factories
AE4	Negligible dusts quantities	Thermal coal power plant, cement factories, granaries, wood workmanship

Table 14 - Presence of water

Letters	Environment characteristics	Example
AD1	Negligible water presence	Dry ambient, occasionally moist, but with good air circulation
AD2	Dew vertical falling probability	Moist ambient, dew formation possibilities
AD3	Atomization water falling with inclination not > 60	Falling water wet walls and ground in a thin layer
AD4	Water's sprinkles in any directions	Weather exposed ambient
AD5	Water's throws possibilities	Local with normal utilization of water's throws (e.g. car washing rooms)
AD6	Water's waves occurrence	Sea environments like benches, harbor, etc.
AD7	Submersion possibilities with temporary floods	Occasionally water waves up to 150 mm over instrument's case
AD8	Total and permanent submersion	Underwater environments, swimming pool, etc.

Table 15 - Environment Temperature

Letters	Environment characteristics	Example
AA1	Refrigerators temp. (-60°C ÷ +5°C)	Refrigerators stations
AA2	Very cold (-40°C ÷ +5°C)	“ “
AA3	Cold (-25°C ÷ +5°C)	“ “
AA4	Temperate (-5°C ÷ +40°C)	Showers, thermal power stations, vapor and warm water stations production, sauna etc.
AA5	Hot (+5°C ÷ +40°C)	“ “
AA6	Very hot (+5°C ÷ +60°C)	“ “

Classification of housings

Another important classification for the users who has to establish whether a certain piece of apparatus can be used (or cannot be used) in a certain

environment, concern the housings that have to protect the apparatus. This classification gives indications against accidental contacts with foreign bodies (Table 16) and against water infiltration (Table 17).

*Table 16 - Code IP: Degree of protection against accidental contacts and foreign bodies*

Figure	Denomination	Area of protection-explanation
0	No protection	No particular protection against direct contacts. No protection against extraneous bodies
1	Extraneous big size bodies protection	Accidental contacts of great surfaces protection, but no protection against voluntary access. Protection for extraneous bodies $\varnothing > 50$ mm
2	Extraneous medium size bodies protection	Finger's contacts protection. Protection for extraneous bodies $\varnothing > 12$ mm
3	Extraneous small size bodies protection	Tool's and wires contacts protection. Protection for extraneous bodies $\varnothing > 2.5$ mm
4	Extraneous granular bodies protection	Tool's and wires with thickness $> 1$ mm contacts protection.
5	Dust's deposition protection	Full protection of internal mobile parts or powered contacts. Protection for harmful dust deposition
6	Dust incoming protection	Full protection of internal mobile parts or powered contacts. Protection for dust penetration

This classification uses the letters IP followed by two numbers: the first indicates the protection degree against accidental contact with foreign bodies, the second number refer to the protection against the water.

*Table 17 - Code IP: degree of protection against water.*

Figure	Denomination	Area of protection-explanation
0	No protection	Any particular protection
1	Vertical water falling protection	Vertical water's drops have not to have harmful effects
2	Oblique water falling protection	Oblique falling water's drops with an angle from $15^\circ$ up to $90^\circ$ have not to have harmful effects
3	Water vapor protection	Oblique falling water's drops with an angle from $60^\circ$ up to $90^\circ$ have not to have harmful effects
4	Water sprinkles protection	Water's drops falling in any direction have not to have harmful effects.
5	Water throw protection	Water throw from a conductor have not to have any harmful effects
6	Flood protection	For temporary flood (e.g. sea floods) water's penetration have not to have harmful effects
7	Occasionally submersion protection	For given weather and pressure

		conditions, no water penetration have to happen in harmful quantity.
8	Submersion protection	No water penetration in harmful quantity

Classification of apparatus regarding the environment

An IEC publication (n. 654-1 of 1979) subdivides instruments and apparatus into four classes in relation to the operational and storage conditions they can withstand. This classification also establishes the limits of concentration for various contaminants in the air.

*Class A: apparatus needing air conditioning*

In the environments in which they operate temperature and humidity are controlled within narrow limits. A system of air circulation with forced filtering reduces the quantity of dust and chemical contaminants. In the case of failure in the air conditioning apparatus, service conditions may approach limits as described for class B.

A defective functioning of conditioners or the introduction of material from storage areas maintained below the condensation point in air conditioned environments, may actually cause condensation. Condensation only occurs for short periods.

*Class B: apparatus needing heated and/or cooled environments*

In the environment in which they operate atmospheric conditions are maintained within determined limits, but the automatic maintenance of temperature and/or humidity may be absent. Condensation may occur for short periods, especially when relative humidity is high.

*Class C: apparatus needing protected areas*

The apparatus needs protection from direct sunlight, wind, rain and falling bodies. In most cases refrigeration or heating plants are not needed; ventilation is natural. Minimum temperatures approach the environmental minimum; maximum temperatures may exceed the environmental maximum, while condensation is withstood for short periods.

*Class D: apparatus that can operate outside*

This equipment is not protected at all from atmospheric conditions, including sun, wind, and rain and contaminating substances. In the environment in which they operate swift variations in temperature may occur. Variations in equipment temperature may take place even more quickly. For example, a piece

of equipment exposed to direct sunlight might be cooled suddenly by rain. Condensation is withstood even for long periods of time.

*Table 18 - Operational conditions for storage established by the IEC publication 654-1 of 1979*

Environmental class

Operational conditions	A	B	C	D
Temperature (°C)	15 to 30	5 to 50	-25 to 55	-40 to 85
Relative humidity (%)	20 to 80	5 to 95	5 to 100	5 to 100
Maximum water content In kg/kg of dry air	0.022	0.028	0.028	0.05
Atmospheric Pressure (kPa)	70 to 108			

Storage Conditions	A	B	C	D
Temperature (°C)	-40 to 70	-40 to 85	-40 to 85	-55 to 100
Relative humid.(%)	0 to 100*			
Atmospheric pressure (kPa)	20 to 108			

\* Conditions that cause condensation for long periods are not consented

Examined contaminants

Hydrogen sulfide (H <sub>2</sub> S) ppm	≤ 0.1	≤ 0.1	≤ 10	< 25
Sulfur dioxide (SO <sub>2</sub> ) ppm	≤ 0.1	≤ 0.1	≤ 5.0	< 10
Chlorine (Cl <sub>2</sub> ) ppm	≤ 0.01	≤ 0.1	≤ 1.0	< 5.0
Ammonia (NH <sub>3</sub> ) ppm	≤ 0.05	≤ 1.0	≤ 50.0	< 100
Nitric oxide (NO, NO <sub>2</sub> , N <sub>2</sub> O <sub>2</sub> ) ppm	≤ 0.01	≤ 1.0	≤ 5.0	< 10
Oxidizers (O <sub>3</sub> and others) ppm	≤ 0.05	≤ 0.05	≤ 0.1	< 0.5
Carbon monoxide (CO) ppm	≤ 10.0	≤ 25.0	≤ 50	< 100
Hydrocarbons, ppm	§	§	≤ 50	< 25
Dust g/m <sup>3</sup>	≤ 100		≤ 200	≤ 200

Sensors, data-loggers and the associated electronics have obviously to belong to D class.

Some data-loggers are contained in waterproof case (C class), and with some cares can be installed on open field. Some others are still realized in B class then a proper protection have to be made before open-field installation.

### 5.2.2) Over-transient voltage protection

Lightning, electrostatic discharge and inductive load switching can produce electrical transient pulses characterized by high  $dv/dt$  ratio (voltage/time) that can cause electronic component and system failures (i.e. data-logger [1]). Therefore, to be effective, transient voltage suppression (TVS) devices must activate before the system's components react to transient pulses. The device must be capable of dissipating the transient energy while clamping the voltage to a safe level. This is usually done with TVS devices that limit the overvoltage rise and reject the transient away from protected components, usually to ground. Today transient overvoltage protection consists of metal oxide varistors (MOVs), or solid state devices (TVS diodes and TVS thyristors).

MOVs are devices composed of ceramic-like material usually formed into a disc shape. High transient capability is achieved by increasing the size of the disc. Typical sizes range from 3 to 20mm in diameter. MOVs turn on in a few nanoseconds and have fairly high clamping voltages, ranging from approximately 30V to 1.5kV.

TVS thyristors are solid state devices capable of handling very high pulse currents. These devices respond in nanoseconds and have operating voltages that start at about 28V and up. [B]

### BIBLIOGRAPHY

[1] Benincasa F., Fasano G., Materassi A. Protezione dei sistemi di acquisizione dati contro le scariche elettriche. Rivista di Ingegneria Agraria. 1987, 3, 144-149

## 6) SENSORS CALIBRATION

### 6.1) Calibration principles

The calibration is defined as the process that determines the correlation between output sensor signal and measures (UNI 4546 definition).

The calibration's aim is to determine the metrological characteristics of the instruments, and list them in a calibration form.

Calibration process takes place in the factory before user's applications, and it has to be generally repeated at regular intervals during the life of instrument due to:

- End of expiration date of validity calibration form established by the factory or fixed by particular norm of the instrument.
- During instrument's utilization, an influence quantity reach values over safety range. The influence quantities affect the measures but not alter the parameter we are measuring; they affect the relation between output signal and the measuring parameter.
- If the measuring parameter is extremely over-ranged the instrument need to be recalibrate. The manufacturing give the safety limits that is not possible cross-over without instrument's damages risk on it's calibration or functioning.
- When a non-operative instrument is affects by quantity influence that reach external values of storage range.

#### 6.1.1) Sensors comparison calibration

The methodologies described allow the user to calibrate his sensors, provided he has a reference standard sensor (with best characteristics then the calibrating sensor); the following procedures will relate to comparison calibration.

Absolute calibrations are performing in a specialized laboratory qualified to issue proper certification referring to standard physics quantities.

As above discuss is then evident that a reference standard have not to be use for routine measures, because it would fall in one's of the conditions that will require a recalibration. Obviously the reference sensor will have to be periodically recalibrate but with different time interval.

In the comparison calibration it's suggested to use a reference sensor with metrological characteristics of a greater order than the calibrating sensor. For example if we want to calibrate a sensor with 0.1 precision (that is with the 0.1 real value), the uncertainty of reference standard cannot exceed the 0.01 value.

#### 6.1.2) Calibration uncertainty

We have to be careful to don't confuse the accuracy with the resolution. Especially in digital instrument these misunderstanding could be easy

Normally last digit indicates the resolution, not the precision: an instrument with two decimals (.00) discriminates two values: they could differ of .01 at least. This is not necessary the accuracy of the two values (that is, .01, is their maximum departure from true value).

Commonly the last digit is uncertain, and it is only a part of the instrument's uncertainty. Actually we have to consider the maximum statistic excursion between the true value and the output value. At this purpose the manufacturers give the accuracy as:

$\pm(1 \text{ digit, the last,} + X\% \text{ of the range or of the value measured})$

Where X is an uncertainty value that is not exceeded with a 68% of probability.

For greater certainty we should have:

$\pm(1 \text{ digit} + 2X\%)$  gives a 95% of probability

$\pm(1 \text{ digit} + 3X\%)$  gives a 99.7% of probability

For example calibrating a sensor with a 1/10 of accuracy in the range of 0÷10 by a 4 digit instrument with a span of 99.99 and an accuracy of  $\pm(1 \text{ digit} + 0.1\% \text{ of the span})$  the uncertainty for any value is:

$$\pm(0.01 + 0.1) = \pm 0.11$$

The value fall (at 68% of probability), in an interval of uncertainty of 0.22, broadly over 0.1. Then this instrument cannot be useful for calibration accuracy of 0.1 and neither an instrument with a digit more (greater resolution and same accuracy):

$$\pm(0.001 + 0.1) = \pm 0.101$$

Because the interval of uncertainty obtained, 0.202, is greater than 0.1.

Using an instrument with same characteristics and a span similar to our range of measures, the accuracy improve (This could be a general criteria; best measurements are made near the span). With a span of 9.99, an accuracy of  $\pm(1 \text{ digit} + 0.1\% \text{ span})$ , the uncertainty is  $\pm(0.01 + 0.01) = \pm 0.02$ , that is the true value at 68% of probability fall in an interval of uncertainty of 0.04, inferior respect 0.1. This instrument could then be utilized for a calibration with an accuracy of 0.1. Either it guarantee a 0.1 accuracy with a certainty of 99.7%:

$$\pm(0.01 + 3 \pm 0.01) = \pm 0.04$$

thus a range of uncertainty of 0.08, less than 0.1.

### 6.1.3) Methodology

The primary operation concerning on the reference sensor choice:

- I) It has to operate the same transduction<sup>(\*)</sup> of the sample sensor (i.e. to calibrate a thermoresistance we will use a reference thermoresistance and not a thermocouple and vice versa, in order to don't have different interference by influence quantities).
- II) It must have better metrology characteristics respect to the calibrating sensor:
  - better accuracy
  - better resolution
  - wider or equal operating range
  - greater or equal time response (for time response studies only, we need for a reference sensor with smaller time response)
  - smaller hysteresis

#### General note

If we don't have a sensor with this characteristics provide at least a sensor with same features, that you keep in your laboratory. You can periodically make comparison between the sensor mounted on the station and the "reference" sensor. Take in account that is not a calibration but a good check procedure.

After this choice we dispose the reference sensor and the calibrating sensor(s) in the same conditions.

We consider the meteorological parameter variation (natural variation or artificially induced variation) from the extreme range points (zero or span) for the sensor observed, step by step (normally 1/10 of range). These are the calibration points.

For each point the reference sensor output signal have to be steady (then also the calibrating sensor that should have a less time response).

We read the "real value" of physics quantity in steady conditions, from the reference instrument, then the reading of the calibrating sensors.

---

(\*) Sensors submitted to a physic quantity which they are sensible, give a proportional electric output. This process is called transduction.

Subsequently we set next value of the physics quantity (if we have a system to induce a variation of the meteorological parameter) following this procedure up to other extreme of the range

To highlight the calibrating sensor hysteresis (if present) we repeat in reverse mode the entire calibration, to the other extreme of the range.

For most calibration systems the passage between two set-points happens as an asymptote trend. (Figure 32.a), while in other cases this passage has a trend characterized by overshoots. When the physic quantity reach the given value it doesn't stops, but oscillates around the set-point. This oscillation diminishes after a certain time (from some minutes to some hours, Figure 32.b). If an overshoot causes an over-range the sensor could be damaged.

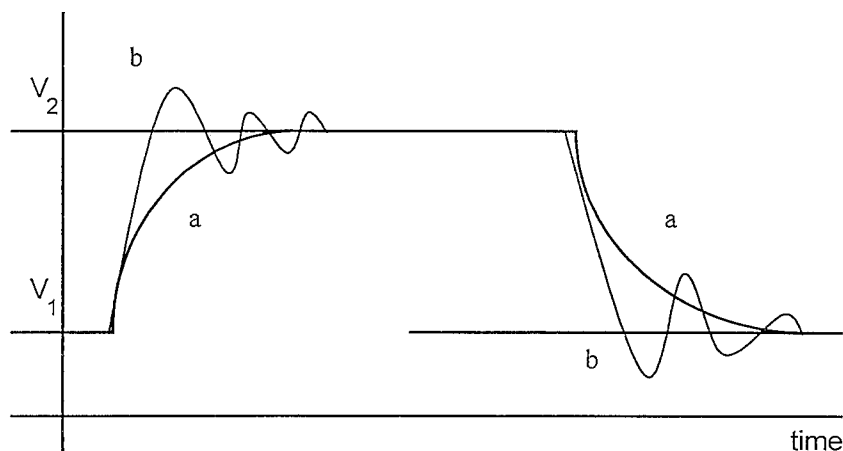


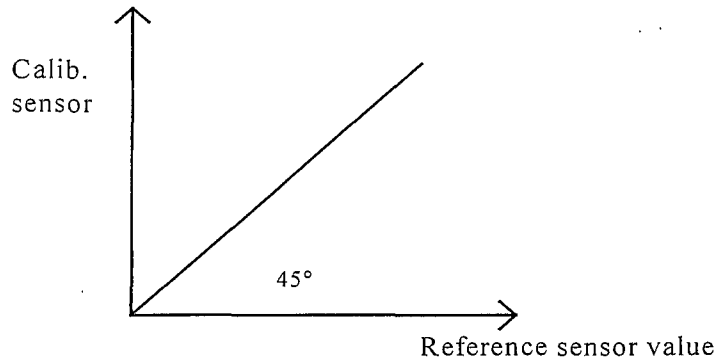
Fig. 58: the passage between two set-points ( $V_1$  and  $V_2$ ) can have a trend like asymptote (curve a) or an overshoot trend characterized by damped oscillations (curve b).

#### 6.1.4) Calibration response curves

The calibration points allows the operator to make two graph type:

- I) Reference sensor value Vs sample (calibrating) sensor value
- II) Input quantity Vs sample sensors output quantity

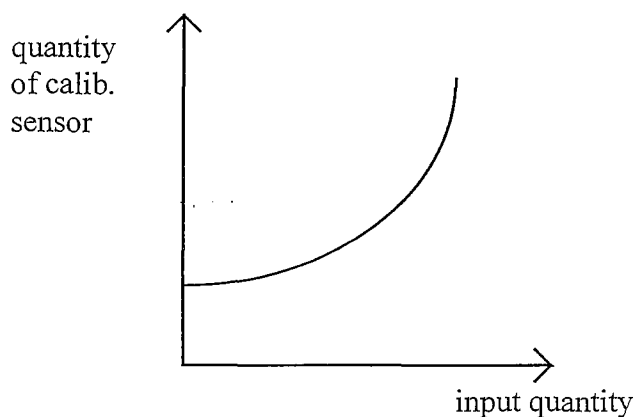
In the first case, provided an ideal sensor response (i.e. reference and calibrating sensors have same output signal), the linear trend is well described on two Cartesian axis with 0 value on the origin and the response line with a slope of  $45^\circ$ . (Figure 59).



*Fig. 59: Linear (Ideal) calibration response when both calibrating and reference sensors given the same output.*

This graphic can be obtained when both reference and calibrating sensors have same characteristics and are connected to the same reader, to reduce possible differences between them. For example in thermoresistance calibration both sensors are connected to an ohm ( $\Omega$ ) meter that gives an ohm reading, or to a reader system that directly convert the signal in a temperature value.

This graphic allows highlight the linearity, the hysteresis, the accuracy, and the resolution of calibrating sensor respect to the reference sensor. The second graphic type is drawn when different reader systems for reference sensor and calibrating sensor are used. For example in thermoresistance calibration we can use an ohm's meter for the calibrating sensor and a thermometer as reference sensor or vice versa (it is rare because references sensors normally has it's own reader system). A graphic not necessarily linear or with the origin different from zero would be obtained. (Figure 60)



*Figure 60: Response calibration curve for reference and calibrating sensor with different quantity output.*

The calibrating sensor's accuracy could be immediately obtained respect to the reference sensor.

### 6.1.5) Time response

Sensor's time response can be relieved in two ways:

- I) As a response due to a physic quantity step variation
- II) As a response due to a physic quantity ramp variation

A step variation is the passage from a value to another, in a time interval tenting to zero (Fig. 61, curve a); a ramp variation is the linear and gradual passage through two values (Fig. 61, curve b).

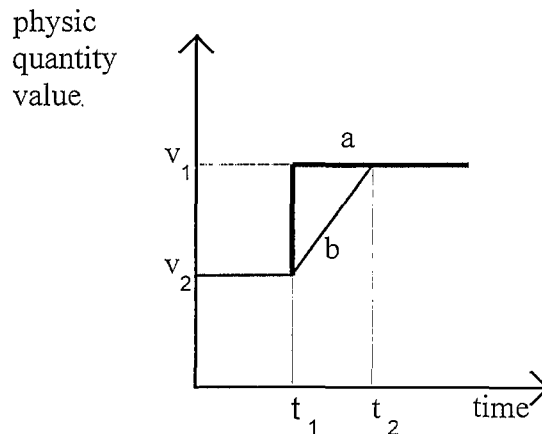


Figure 61 : Passage from  $V_1$  to  $V_2$  value of the physic quantity takes place as a step, a curve, or as a slope, b curve.

The first is the simplest method but sometime the sensor's step variation is difficult to induce and we are forced to employ the second one.

We can demonstrate as time response is independent from  $V_1$  and  $V_2$  values, and from their difference,  $V_2 - V_1$ , (Figure 61). An exception for the anemometers will be explained in paragraph 7.2.5.

In the step time response the reference sensor doesn't has particular characteristics. Two sample reference sensors of the same physics quantity with known value are needed, and theirs function (since two of them are required), is to indicate the two samples values.

Time response calibration requires the knowledge of the transduction function of the sensor (Fig. 33 o 34), therefore the calibrating sensor is put in a well contact with the first sample sensor till steady conditions are reached, and the output value is read. In a short time (possibly tenting to zero) the calibrating sensor is put in contact with the second sample sensor and the elapsed time necessary to reach the 90% of physics quantity variation is measured. This is the time response.

The sensor's time constant is instead defined as the elapsed time necessary to give the indication of 63% of the variation. The time response is 2-3 time greater than the time constant (\*).

For example to measure the time response of a thermometric sensor, we take it in free air, measuring the temperature value,  $T_a$ , then dip it in a thermostatic bath set at the temperature,  $T_b$ , that differ from air temperature. The time employed by the sensor to pass from  $T_a$  to  $T_a+0.9*(T_b-T_a)$  is the time response. (Figure 62).

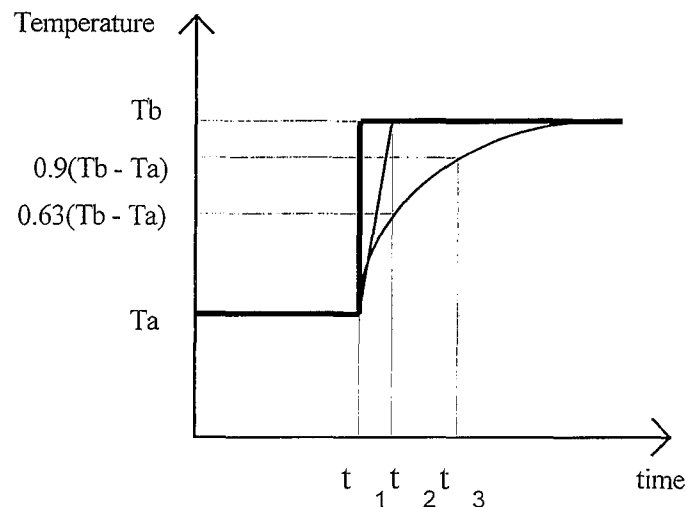


Figure 62: The time required by the sensor ( $t_3 - t_1$ ) to pass from  $T_a$  to  $T_a+0.9 \cdot (T_b - T_a)$  is the response time. The time interval ( $t_2 - t_1$ ) to pass from  $T_a$  to  $T_a+0.63(T_b - T_a)$  is called time constant and we can graph it as shown in the figure, drawing the tangent of sensor's response curve at the time  $t_1$ .

(\*) Referring to figure 35, with  $V_1$  e  $V_2$  respectively as start values and final values of the physics quantities, the raising exponential trend,  $v$ , indicated by the sensor is express as:

$$v = (V_2 - V_1) \cdot \left(1 - e^{-\frac{t}{\tau}}\right) + V_1$$

with  $\tau$  as time constant. After time interval equal to time constant  $t=\tau$  the sensor's value is:

$$v = (V_2 - V_1) \cdot 0,6321 + V_1$$

That is after a time interval equal to the time constant the value  $v$  is raised, respect to the initial value, of 63.21% of the  $(V_2 - V_1)$  value. Time constant definition is: *the time required for a sensor to indicate a variation of 63% of the quantity.*

We define *time response*,  $tr$ , as *the time required for a device to detect and indicate 90% of variation.*

$$v = 0,9 (V_2 - V_1) + V_1;$$

therefore:

$$0,9(V_2 - V_1) + V_1 = (V_2 - V_1) \cdot \left(1 - e^{-\frac{tr}{\tau}}\right) + V_1$$

then  $tr = 2,3026 \tau$

By this method the samples physics quantity values measured by the reference sensor can be not strictly evaluate, because time response is independent from them.

In the same way we can proceed keeping in shadow conditions a solarimeter, then rapidly exposed it to the light. More difficulties we have with hygrometric sensors (for the difficulty in the passage through two different humidity samples) or with a heat flux sensor.

With particular sensors it's easier to operate by a constant change. In this case the reference sensor have to follow all the range's evolution of the quantity, possibly without any delay, then it has to have a very small time response. For example in thermoresistance time response analysis we could use a thermocouple as reference sensor. In this case the different conception of the two sensors don't affect the time constant.

Operating by a constant change the calibrating sensor (with known transduction function) and the reference sensor are submitted to the same variation of physic quantity. When both sensors have exceeded the transitory temporary phase we measure  $V$  values at the instant  $t_1$  take by the reference sensor. Then we measure the time interval  $(t_2 - t_1)$  of the sensor we are calibrating (Figure 36); this is the sensor's time constant.

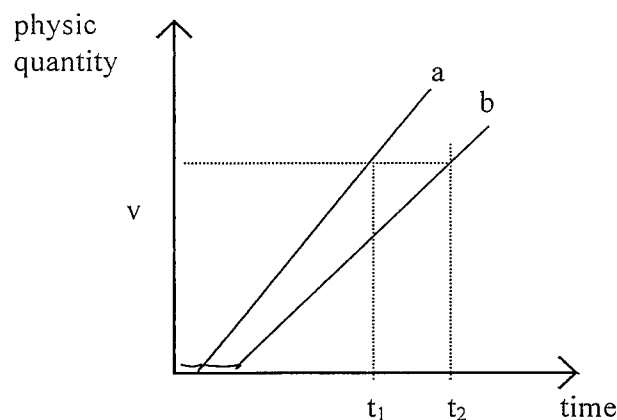


Figure 63: Curve a, gradual trend for the physics quantity measured by reference sensor. Curve b, gradual trend for the physics quantity measured by calibrating sensors. When transitory phase for both sensors is completed, we calculate the time response of the calibrating sensor measuring the time interval in which the sensors indicate a value taken in advance by the reference sensor.

## 6.2) Sensors calibration

### General note

In this paragraph some calibration procedures will be described. Obviously calibration systems and reference sensors are expensive and difficult to maintain. Normally we find these instrumentation to specialized laboratories.

However the operator could organize a set of “reference sensors” for each parameter measured at the agrometeorological station(s). It could be a first step in checking the data collected.

For example with a suitable solarimeter as a “reference sensor”, we can check the response of the sensor mounted on the station. We can acquire the data of both sensors for one or more days to draw a response at different sun’s heights, or in different irradiation conditions. This periodic check could be planed for each sensor of the stations that you have installed. This procedure could give very useful information. In case of strange trend or unexpected differences between the sensors, you can decide to dismount the sensor and bring it to a proper laboratory for a recalibration.

### 6.2.1) Air temperature

To calibrate a temperature’s sensor a thermostatic bath with range of at least  $-10^{\circ}\text{C}$  to  $50^{\circ}\text{C}$  is required.

The antifreeze liquid has to be added to the water inside the bath for measures below  $0^{\circ}\text{C}$ . The thermostatic bath has to include an agitator to homogenize liquid’s temperature.

To assure thermal condition uniformity, the sensors are inserted in a metal block with higher inertia than the liquid.

On this block, built of high conductive material (copper or aluminum), some holes that fit sensor’s size are made, to insert the reference transducers and the calibrating transducer(s) (Figure 64).

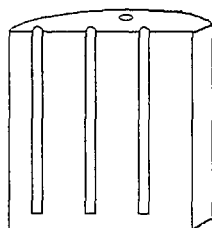


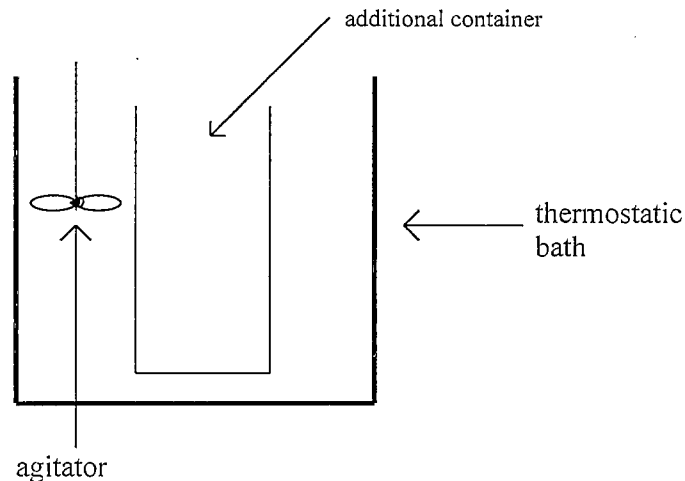
Figure 64: Metal block (section view)

To improve sensor's touching between the block walls and the sensors, these are covered by silicon grease that eliminate air space and favors thermal exchanges.

To reduce thermostatic temperature controller oscillations, is better to introduce the block not directly in the main bath tank but in an additional container filled of same thermostatic liquid. (Figure 38).

Time required for will result longer, but the measure's stability certainly will improve.

Figure 65 (below) shows a thermostatic bath tank with additional smaller tank



### 6.2.2) Air humidity

Air humidity sensor's calibration results long and complex. The main difficult is to obtain a "physic sample", or better to maintain in a given air ambient, the temperature value and the water vapor concentration, that we can modify over all sensor's operating range.

At this purpose hygrometric chamber have been proposed. The air humidity regulation is based on the dew-point temperature control.

Inside the chamber we dispose the sensors (reference sensor and calibrating sensor) and outside the chamber the air is treated, passing through water saturated filter kept at the dew-point temperature, then heated at the right temperature by a heater system.

All the system can be managed by a microprocessor that compare the air and dew point temperatures, so it drives the temperature control sensors respectively sited after the humidity system and after the heater.

The advantage of this system consists in using a temperature sensor instead a humidity sensor as control. The first one has generally better features regarding the accuracy, the sensitivity and repeatability.

Simpler methods are based on the use of specific saline saturated solutions, kept in a sealed box in order to obtain different gas water vapor concentrations values. For example lithium chloride (12%), magnesium chloride, sodium chloride (75%), magnesium nitrate, potassium nitrate, potassium sulfate (97%) solutions can be used. If we are able to vary the solution's temperature, a large humidity range could be obtained. The advantage of this method is that a reference sensor is not required.

We prepare a little container (with the specific solution) easy to seal, in which we introduce the calibrating sensors. To assure the solution saturation we let deposit at the bottom of the container some millimeters of the proper salt.

The solution level has to be left at about half height of the container, and the sensor must not be in touch with the free liquid solution.

We insert the sensor and we seal the container, than we arrange the system in a thermostatic bath. (Figure 39).

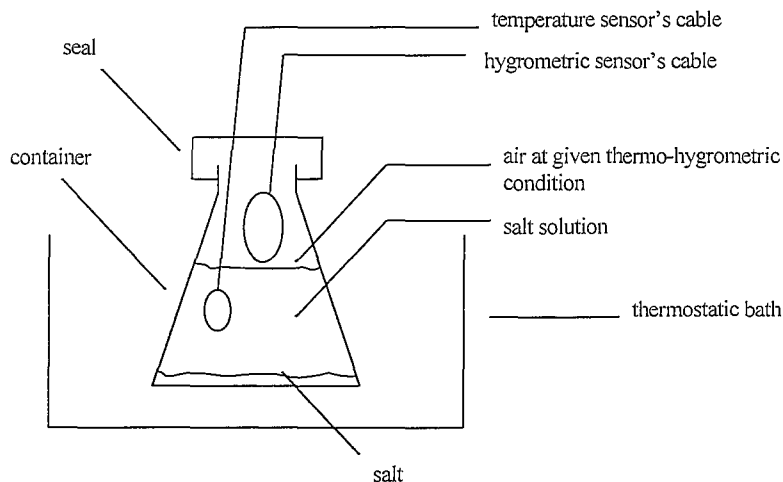


Figure 66: Calibrating sensor's disposition in a salt solution container

An air temperature sensor (accuracy of  $\pm 0.1$  °C) is introduced to check this parameter. Without air temperature control is better to wait about two or three hours after the control bath have reached the temperature set.

Table 19 shows some salt solutions with respective values of relative humidity obtainable at different temperature.

Table 19.

Relative humidity (%) of a saturated salt solution at different temperatures (°C). 1, lithium chloride; 2, magnesium chloride; 3, sodium dichromate; 4, magnesium nitrate; 5, sodium chloride; 6, ammonium sulfate; 7, potassium nitrate; 8, potassium sulfate.

T (°C)	1	2	3	4	5	6	7	8
0	14.7	35.0	60.6	60.6	74.9	83.7	97.6	99.1
5	14.0	34.6	59.2	59.2	75.1	82.6	96.6	98.4
10	13.3	34.2	57.9	57.8	75.2	81.7	95.5	97.9
15	12.8	33.9	56.6	56.3	75.3	81.1	94.4	97.5
20	12.4	33.6	55.2	54.9	75.5	80.6	93.2	97.2
25	12.0	33.2	53.8	53.4	75.8	80.3	92.0	96.9
30	11.3	32.8	52.5	52.0	75.6	80.0	90.7	96.6
35	11.7	32.5	51.2	50.6	75.5	79.8	89.3	96.4
40	11.6	32.1	49.8	49.2	75.4	79.6	87.9	96.2
45	11.5	31.8	48.5	47.7	75.1	79.3	86.5	96.0
50	11.4	31.4	47.1	46.3	74.7	79.1	85.0	95.8

### 6.2.3) Air pressure

The procedures are quite simpler in electronic transducer calibration, because generally an air flux with known pressure can be injected to the sensor. To produce this air samples with a pressure range from 850 to 1050 mb proper sealed cylinder is employed.

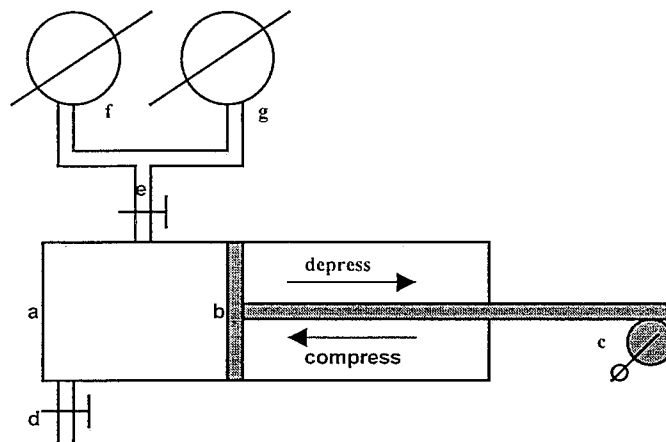


Figure 67. System diagram for air pressure samples production (in a barometric range): a) cylinder, b) piston, c) piston motion system, d) valve cylinder-ambient, e) cylinder valve between reference sensor and calibrating sensor (f, g).

Inside the cylinder a piston can run to obtain different air pressure values, measured by a reference sensor connected to the calibrating sensor's room.

## 6.2.4) Solar radiation

### *Global and diffuse pyranometer*

The calibration has the aim to determine the transducer's response curve and the sensor's factor (that is the proportional factor of voltage  $V$  produced by the thermopile or photocell and the incoming radiation  $G$  at different sun's heights  $h$ ):

$$K(h) = \frac{V}{G} \quad (1)$$

The greater error's source is represented by the sun position, because the sensor's factor is constant only for solar angle over  $35^\circ$  around, while it varies for minor solar angles (it can increase or decrease depending on the sensor type).

Provided that all radiative fluxes are related to a horizontal plane, it's very important the sensor's leveling.

Calibration measurements have to be made during sunny day with clear sky conditions.

Pyranometers can be "on-field" calibrated by comparison with a reference pyranometer, or better by a pyrliometer for direct radiation measure  $I$ , and measuring global radiation  $G$  and the diffuse radiation  $D$  by the calibrating sensor.

The relation between these quantities is:

$$G = D + I \text{ sen } h \quad (2)$$

between non-shielded and shielded pyranometer output voltage (\*) ( $V_{\text{global}}$  and  $V_{\text{diffuse}}$ ), the pyrliometer output ( $I$ ), and the pyranometer calibration factor ( $K$ ), the following relation exist (obtained by 1 and 2):

$$K = \frac{V_{\text{global}} - V_{\text{diffuse}}}{I \text{ sen } h} \quad (3)$$

Measuring global and diffuse radiation fluxes by the same sensor a shift time error occurs, but it can be very small if a reference pyranometer for diffuse radiation measure is available.

In this case relations (1) and (2) give:

$$K(h) = \frac{V_g}{\frac{V_d}{K_d} + I \text{ sen } h} \quad (4)$$

---

(\*) These two measures have to be done in extremely short time otherwise solar conditions could change.

Where:

$V_d$  e  $K_d$  are respectively the voltage output of reference sensor and its (transducer) sensor factor.

In both cases (equation 3 and 4) the sun's height during the reading has to be known; this is calculate by the relation:

$$\text{sen } h = \text{sen } \phi \text{ sen } \delta + \cos \phi \cos \delta \cos H \quad (5)$$

Where:

- $\phi$  is the latitude
- $\delta$  is the sun declination, that is the angle between the ideal line of sun-earth, and the equatorial plane
- $H$  is the local hourly angle.

Anyway measuring at different daytime global and diffuse solar (that is at different solar elevation),  $K(h)$  can be obtained. For reliable results measurements have to be taken for every season.

### *Albedometer*

Albedometers can be calibrated, as the others sensors, by comparison against precision sensors, or by the methodology described for pyranometers.

Obviously because the instrument is composed of two radiometers the calibration procedure is repeated for both sensors. For the sensor turned to the ground surface, the solar coefficient trend for  $h$  variation shouldn't be determined, because it never measures direct radiation.

We can consider a good sensors calibration response when the sensors which compose the albedometer given an output, at same radiation, that not differ more than 2-3 %; otherwise a software correction on the logger should be introduced to homogenize the output signals.

### *Net Radiometers*

These instruments have two sensible surfaces which don't belong to two sensors, as for the albedometers; they include a thermopile sensor with both the sides sensible, and the signal output is the difference between the solar incoming radiation and the outgoing radiation emitted by the earth's surface. (Figure 68).

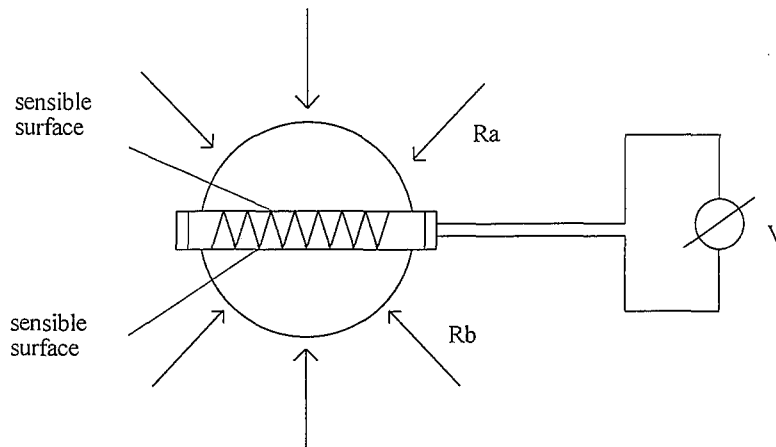


Figure 68 Net radiation sensor: the thermopile transducer between the upper and the lower surfaces gives a voltage  $V$ . It is proportional to the difference between the incoming solar radiation  $R_a$  and the outgoing radiation  $R_b$ .

Visible range calibration can be performed by a reference net radiometer comparison for both surfaces. While a surface is exposed to the light, the opposite has to be exposed to a thermostatic bath as reference temperature object (because this instrument also covers thermal longwave radiation). It is important to repeat this procedure for both surfaces taking care on light's infiltration in the thermostatic bath.

As for the albedometers, if the output voltage of the two faces differs more than 2-3% at same radiation, signal output has to be corrected.

### **Sunshine sensors**

The sunshine duration sensors are based on the signal produced by one or more photocells. The presence of the sun is determined by the overpass of a fixed threshold in term of solar radiation. The set of this threshold value is the lonely regulation to check ( $120 \text{ W m}^{-2}$ ).

### **6.2.5) Wind speed**

For wind parameter the speed and the direction have to be considered.

#### **WIND SPEED**

Anemometer's calibration takes place in devices called wind tunnels by a reference sensor comparison. These tunnels should have a section twice than the calibrating anemometer dimension, and they have to produce a constant airflow for 2 minutes at least.

A typical calibration device includes a tunnel 3 meters long with a 1m diameter around. An aspirator fan and a filter are placed at the tunnel's extremities. A constant voltage drives fan's motor with variable frequency, to

## WIND DIRECTION

For these sensors we observe the response trend due to a step variation of wind direction. We can follow the anemometer's constant distance determination procedure, introducing the windvane in the wind tunnel with the vane locked in orthogonal sense respect to the airflow direction.

Sensor's signal output, if recorded on paper as analog signal, will have a damp oscillating trend. We can estimate the equivalent distance (or wave length) and the damping ratio which is related to the sensor's time response.

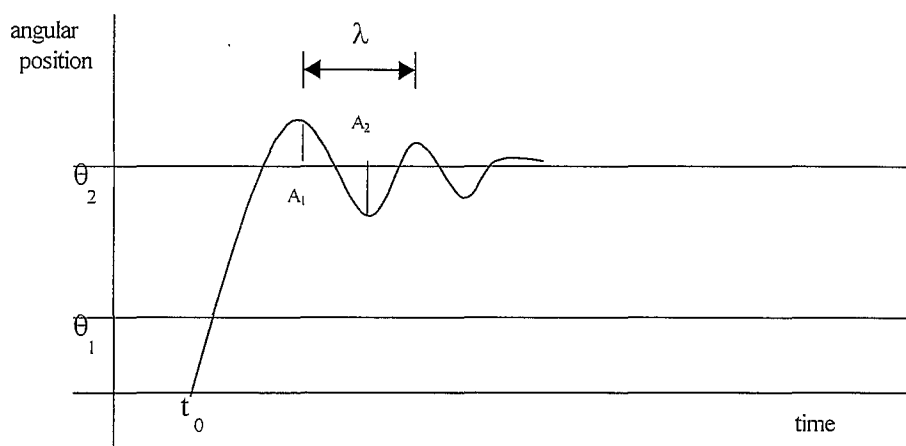


Figure 72:  $\lambda$  indicates the equivalent distance (or wave length);  $A_2 / A_1$  indicates the damping ratio

### 6.2.6) Rainfall

For any raingauge type the most important factor to determine, is the water quantity related to the area of a given collector that produce an unit increment of rainfall. The variation of this parameter is normally due to dirt deposition in the bucket or to a pivot bucket turnover oxidation.

This controls consist on weight measures (e.g. tipping bucket) or volume measures (e.g. sensor level pluviometer), of the minimum water weight or volume amount that cause an unit rainfall increment; knowing the gauge's collector diameter the rain height (millimeters) can be related to the considered water weight or volume.

#### *Snow, hail, dusts and fines rainfall.*

No general indication can be done because these instruments can be significantly different.

### 6.2.7) Evaporation

Referring to this quantity the water level variation measure system have to calibrated.. Because many transducers can be utilized (potentiometers, differential transformer, ultrasound, etc.) it is difficult to give general indications.

For potentiometric systems one of the principal parameters to take in account is the resolution; actually the potentiometers normally have a good resolution, but this can decrease because the cursor of the electrical resistance produce friction effects. Until the water level doesn't change of certain quantity the cursor cannot move from the old position.

Differential transformer sensors don't have any element in touch, then the friction problems are solved. The response curve has to be checked because at the range extremity it could not be linear.

For the ultrasound sensors the temperature coefficient has to be considered, because temperature's variations can greatly affects the measurements.

### 6.2.8) Heat flux plate

For the heat flux sensors, beyond a comparison calibration, different methods were proposed. The simpler methods are based on the apparatus that produces a known constant heat flux trough a layer. The heat flux plate is placed in an appropriate porous medium with a known thermal conductivity similar to the soil (i.e. dry sand, glass bead, etc.), in contact with an heater powered with a known amperage:

$$q = R I^2 \quad (7)$$

Where:

- R is the electrical resistance of the heater (ohm)
- I is the electrical current trough the heater (A)

The main problem is to produce a constant heat flux in one direction through the medium up to the transducer. Normally the apparatus was contained in an insulated box to minimize heat losses (Figure 73).

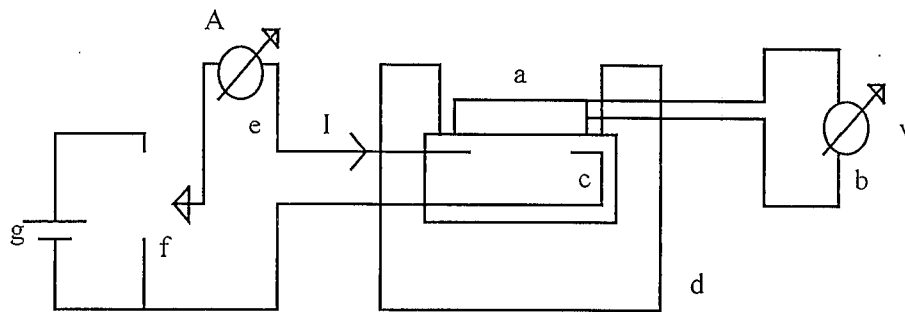


Figure 73: a, heat flux; b, voltmeter that measures the output voltage from the transducer; c, heater; d, insulating material that avoid heat losses; e, amperometer that measure the current through the heater; f, potentiometer to vary the current trough the heater; g, electrical power of the heater.

the equation, here showed is:

$$q = K V \quad (8)$$

by the calibration we want to determine the coefficient K that relates q to V.

We send increasing values of current (and subsequently decreasing values). By the equation (7) the power dissipated is estimated. For each point, the voltage produced by the thermopile is measured by a voltmeter. By the equation (8) we obtain the coefficient K for each couple of values (q, v), then we can graph the calibration curve  $q = f(v)$  that is a line that pass through the origin.

#### CALIBRATION APPENDIX

Here are some examples of calibration procedures for meteorological sensors, executed in our laboratory at the CNR-IATA by the staff of the Eng. Fabrizio Benincasa with the technical support of field assistants Alessandro Materassi and Gianni Fasano

#### TEMPERATURE

Temperature sensor calibration, with a thermostatic bath mod. Julabo Paratherm FT1 Electronic, by the comparison against a reference sensor types (PT100).

#### Technical characteristics

##### Thermostatic bath

Dimension : 130x140x100 mm  
 Temperature range : -10 ÷ 130 °C

Temperature stability inside the stilling well :  $\pm 0.1$  °C  
 Reader accuracy :  $\pm 0.05$  °C  
 (PT100 + multimeter HP3456A)

*Reference PT100*  
 Accuracy :  $\pm 0.05$  °C

*Reader system Multimeter HP3456A*  
 Resolution :  $> 0.001$  °C  
 Accuracy :  $\pm 0.003$  °C

### Calibrating Sensor: Tempsistor

$R_T$  - Tempsistor resistance value at the temperature  $T$

$$R_T = R_0 + \alpha (T - T_0)$$

*Nominal values*

$T_0 = 25$  °C

Reference temperature

$R_0 = 10$  k $\Omega$

Resistance value of tempsistor sensor at reference

sensor  $T_0$

$\alpha = 83.14$   $\Omega$ °C<sup>-1</sup>

Temperature coefficient

Obs N°.	Temperature °C	Tempsistor R5 k $\Omega$
1	0.48	8.002
2	9.95	8.783
3	14.99	9.237
4	19.80	9.655
5	25.20	10.087
6	29.04	10.401
7	34.55	10.840
8	39.58	11.259

*Values calculated by linear regression*

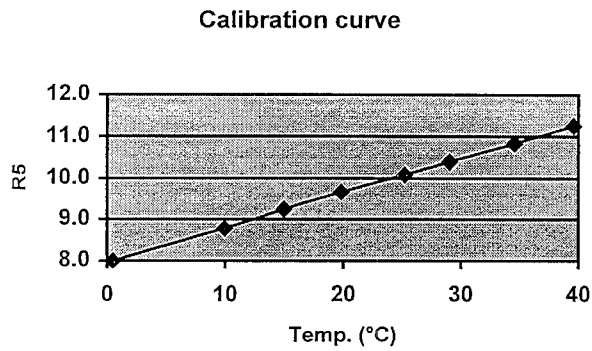
$$R_T = R_0 + \alpha T$$

with

$$T_0 = 0$$
 °C

$$R_0 = 7973.36$$
  $\Omega$

$$\alpha = 83.44$$
  $\Omega$ °C<sup>-1</sup>



## SOLAR RADIATION

Laboratory calibration of a radiation sensor (photocell solarimeter) by an optical bench device.

### Technical characteristics of optical bench

#### *Radiation source*

Xenophot Longlife Osram Lamp mod. HLX 64642 24V 150 W

#### *Measure instrument* Molelectron Radiometer mod. PR200

Maximum spectral range band : 230 ÷ 3200 nm

Field of view : 0.1 Sr

Resolution : 6 nW

Linearity : 2 % up to 50 mW/cm<sup>2</sup>  
5 % up to 200 mW/cm<sup>2</sup>

### Calibrating Sensor: Silicon photocell solarimeter

Turning the solarimeter plane respect to the light beam coming from the optical bench radiation source, the sensor's signal is measured  $V(h)$  at various angles; with a known reference radiation intensity of the source  $I$ , the radiometric coefficient for each angle could be determined:

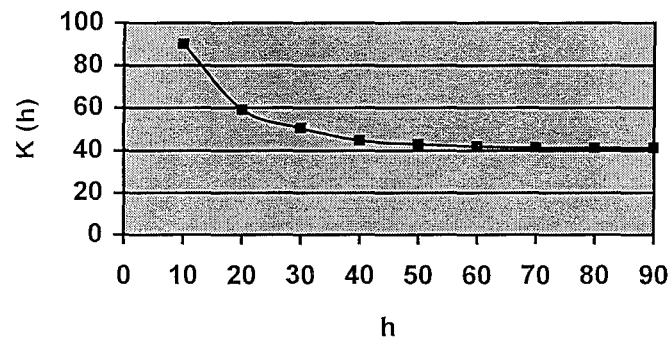
$$k(h) = \frac{V(h)}{I \sin h}$$

N° Obs.	Angle h degree	k(h) $\mu\text{V}/\text{Wm}^{-2}$
1	10	90.22
2	20	59.23
3	30	50.63
4	40	44.80
5	50	42.92
6	60	41.84
7	70	41.41
8	80	41.35
9	90	41.26

*values determined by non-linear regression*

$$k(h) = 42.263 (1 + 3.008 e^{-0.0978 h})$$

### Radiometric coefficient



### WIND SPEED

Anemometer's calibration by a C.N.R.-I.A.T.A. wind tunnel by comparison with a reference sensor.

### Technical characteristics

C.N.R.-I.A.T.A. wind tunnel

Speed range : 0 ÷ 12 m/s

Dimensions (cylinder section) :  $\varnothing$  600 x 1000 mm

Speed driver : By a Kasuga inverter mod. KVFS215ES

Wind rectified filters at the end and at the bottom side of the tunnel conformed to the UNI rules

*Reference propeller anemometer mod. Airflow EDRA 6*

Accuracy :  $\pm 1\%$  of span  
 Wind speed selectable Ranges :  $0 \div 1$ ,  $1 \div 5$ ,  $5 \div 25$  m/s

### Calibrating sensor: Optoelectronic cup anemometer

$$V_m = F_{out} / K_c$$

Where:

- $V_m$  - Wind speed (calibrating anemometer)
- $F_{out}$  - Frequency output (calibration anemometer)
- $K_c$  - calibration constant

Obs N°.	W.S. (m/s)	Fout (Hz)
1	0.0	8.002
2	1.0	16.05
3	2.0	37.15
4	3.0	58.80
5	4.0	79.50
6	5.0	100.80
7	6.0	123.65
8	7.0	143.25

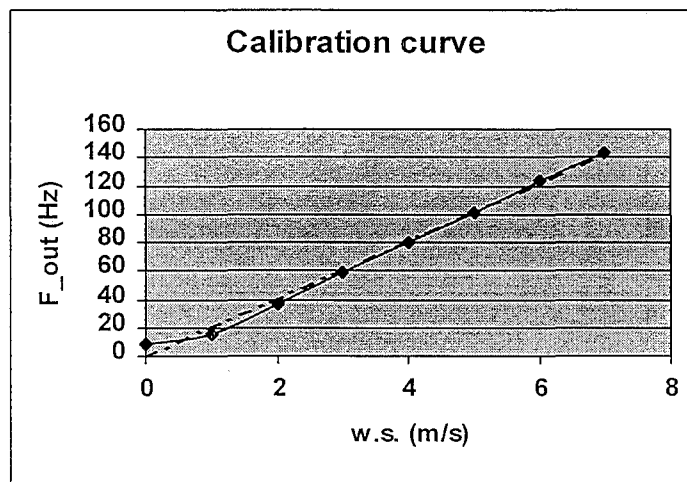
w.s. – Wind speed (reference anemometer)

*Values determined by linear regression*

$$F_{out} = 20.225 \text{ W.S.}$$

$$\text{Then } K_c = 20.225 \text{ Hz m}^{-1} \text{ s}$$

$$V_m = F_{out} / 20.225 \quad [\text{m/s}]$$



**Linearity error**

$$\Delta V = |V_m - W.S.|$$

Obs N°.	W.S. (m/s)	V <sub>m</sub> (m/s)	V <sub>m</sub> - V.V. (m/s)
1	0.0	0.00	0.0
2	0.96	0.67	- 0.29
3	2.0	1.79	- 0.21
4	3.0	2.82	- 0.18
5	4.0	4.00	- 0.00
6	5.0	5.03	- 0.03
7	6.0	6.03	- 0.03
8	7.0	7.14	- 0.14

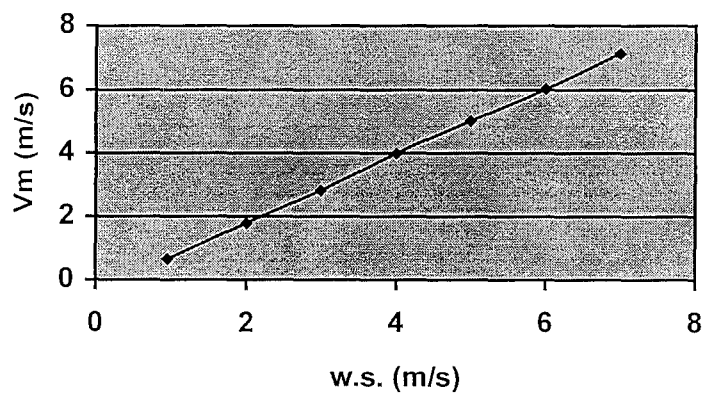
W.S. - Wind speed (reference anemometer)

V<sub>m</sub> - Wind speed (calibrating anemometer)

*Linearity error*

$$\Delta V \text{ max} = 0.29 \text{ m/s}$$

$$\Delta V \text{ [referred to the Span value of . (7 m/s)]} = \pm 4.14\%$$

**Linearity error****PRECIPITATION GAUGES****Rain intensity calculation**

For rain intensity determination an ideal water cylinder above the gauge having same collector diameter is considered. The “rain cylinder” has a volume equal to the rain collected at the specific event.

*Technical data*

D – Collector’s diameter	:	160 mm
P – Container’s weight with water	:	517 g
T – Container’s tare	:	106 g
$\delta$ - Specific weight of the water	:	1 g cm <sup>-3</sup>
d – Event’s duration	:	75 min

*I – rain intensity* : ? mm/h

**Result**

$$\text{Water weight} = P - T = 517 - 106 = 411 \text{ g}$$

$$\text{Volume} = \text{weight} / \delta = 411 \text{ cm}^3 = 411000 \text{ mm}^3$$

$$\text{Section} = \pi (D/2)^2 = \pi 80^2 = 20106.19 \text{ mm}^2$$

$$\text{Rain height} = \text{Volume} / \text{Section} = 411000 / 20106.19 \approx 20.4 \text{ mm}$$

$$d = 75 / 60 = 1.25 \text{ h}$$

$$I = \text{Rain height} / \text{event duration} = 20.4 / 1.25 \approx 16.3 \text{ mm/h}$$

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## 7) DATA ANALYSIS AND ARCHIVING

### 7.1) Data validation

The first thing to do after we have collecting last data is to put them in a file and check their quality. Some data-logger provides directly to mark wrong data by “flag” written in the data fields associated at each channel (i.e. Delta-T Data-Logger). However we can begin simply watching last data set retrieved and verify the range expected for each parameter based on the operator experience; this is obviously only an empirical method and it is possible if we have to manage one or few stations. For this purpose we can operate at different validation levels: we can compare data acquired with given parameter (i.e. range, percentage time variation, total sum etc) or comparing historical data (at least ten years) of that station (if there are any). Data spatialisation technique could be utilized.

#### **7.1.1) Values range check and time-based verification**

We take in account some criteria for the first validation type: to give validate data rapidly available; to mark data that are surely wrong; to perform it in automatic way. We can follow essentially two lines: the first is the range control in which all parameters are compare with fixed or variable values. This allows you to highlight only macroscopic errors. For example the air temperature is compared with range limits that vary depending on year’s month, the station’s height and latitude. These limits can be obtained from the historical data if available.

The second is theoretical value control. Some parameters can be compared with theoretical values estimated by suitable formula. For example the solar radiation values can be compared, on daily or hourly scale, by the estimated solar radiation flux on the external atmosphere. The sunshine duration can be compared with the astronomic sunshine duration corresponding to the station latitude.

Another control level can be performed every day in order to verify congruence between measured data at different time and daily summarization data (totals, minimum, maximum, etc.). Particularly could be performed the following controls:

- an internal congruence, in which we verify different parameters coherence related to the same temporal period (i.e. minimum temperature and daily maximum and hourly temperature),
- a temporal congruence in which is verify the evolution consistency of parameter by comparison of two subsequent instants measures. The validation reports can be utilized to active station maintenance when required.

A third level of validation can be realized with the objective to characterize sensors trend or systematic errors and to check global quality of data measured. The validation essentially consists on a visual analysis of graphed data representation. The operator that examines graph data can decide to produce some other output depending on the results of preliminary analysis. For example are typically produced time series for air temperature (at different high levels if more sensors are present), air pressure, wind speed, relative humidity, or scatter diagrams of global solar radiation as percentage of maximum theoretical radiation value at the external limit of the atmosphere. When some anomalies is evidencing the operator can mark suspect data by a flag and active an intervention to the station.

**7.1.2) Historical data series comparison (statistical method)**

In order to improve the quality of the control the best way to check meteorological data is to compare them with the values derived from historical data series. This approach foresees an experience on the utilization of statistical software package, and is essentially applied to climatological historical series. It's based on statistical estimation of climatological characteristics of measured parameters, for "normal" condition definition and anomalies or extremes events evaluation. This validation is applied in different way depending of the statistical characteristic of meteorological variable. For example the maximum or minimum daily temperature can be verified by following sequence:

A) Interannual variability check:

For each day of year are calculates climatic daily data  $T_i$  ( $i=1, \dots, 365$ ), by the formula:

$$T_i = \frac{\sum_{Y=1}^N \sum_{d=1}^{i+15} t_{dy}}{N * 31} \dots\dots\dots i = 1, \dots, 365$$

Where N is the number of the available years of data

The daily interannual variability ( $i=1, \dots, 365$ ) is then estimated by the formula:

$$\sigma_i = \sqrt{\frac{\sum_{y=1}^N \sum_{d=1}^{i+15} (t_{dy} - T_i)^2}{N * 31}} \dots\dots\dots i = 1, \dots, 365$$

Each daily data is then compare with the following threshold values:

$$T_i - 3 * \sigma_i \leq t_{i,y} \leq T_i + 3 * \sigma_i \dots\dots\dots i = 1, \dots\dots, 365; y = 1, \dots\dots, N$$

The data out of this limits can be temporary marked as suspects and subordinate to a control by closest stations data (described later in the text).

B) Daily variability check

In this case are estimated daily climatological values of increments between a day and their subsequent day  $\Delta_i$  ( $i=1, \dots\dots, 365$ ) by the formula:

$$\Delta_i = \frac{\sum_{y=1}^N \sum_{d=1-15}^{i+15} (t_{dy} - t_{dy-1})^2}{N * 31} \dots\dots\dots i = 1, \dots\dots, 365$$

Where N is the number of the available years of data.

The daily increments interannual variability  $\delta_i$  ( $i=1, \dots\dots, 365$ ) are estimated by the formula:

$$\delta_i = \frac{\sum_{y=1}^N \sum_{d=1-15}^{i+15} ((t_{dy} - t_{dy-1}) - \Delta_i)^2}{N * 31} \dots\dots\dots i = 1, \dots\dots, 365$$

Every measured daily value  $t_{i,y}$  are then compared with the previous daily data measured:

$$\Delta_i - 3 * \delta_i \leq t_{i,y} - t_{i,y-1} \leq \Delta_i + 3 * \delta_i \dots\dots\dots i = 1, \dots\dots, 365; y = 1, \dots\dots, N$$

In this controls are not utilized previous marked suspect data. Data that fall out of these limits are temporary “flagged” and verified by closest weather stations data.

C) Spatial variability check

For each day and for each weather station are estimated the climatic values of differences between recording data of given station and the closest stations

$\Psi_i$  ( $i=1, \dots\dots, 365$ ), by the formula:

$$\Psi_i = \frac{\sum_{s=1}^M \sum_{y=1}^N \sum_{d=1-15}^{i+15} (t_{dy} - t_{dy(s)})}{N * M * 31} \dots\dots\dots i = 1, \dots, 365; s = 1, \dots, M$$

Where N is the number of the available historical series of yearly data and M the number of available closer stations. The area dimension choice for data Spatialisation depends on the given meteorological data behavior. For each station and for each day of year, interannual variability of daily differences between different stations are then estimated,  $\Psi_i = (i=1, \dots, 365)$ , by the following algorithm:

$$\Psi_i = \frac{\sum_{s=1}^M \sum_{y=1}^N \sum_{d=1-15}^{i+15} ((t_{dy} - t_{dy(s)}) - \Psi_i)^2}{N * M * 31} \dots\dots\dots i = 1, \dots, 365; s = 1, \dots, M$$

Only daily data  $t_{i,y}$  highlighted as suspects by previously controls (A and B points) are then verified by the formula:

$$\Psi_i - 3 * \Psi_i \leq t_{iy} - t_{iy(s)} \leq \Psi_i + 3 * \Psi_i \dots\dots\dots i = 1, \dots, 365; s = 1, \dots, M$$

The values that fall out of these limits are definitely marked as wrong data.

Agrometeorological data need to be controlled by trained technicians; they can operate by graphic and numeric data representation to recognize some error or anomalies; they can utilize the automatic application of specified algorithm, to make a first selection of the stored data. [1]

**7.2) Data process**

**7.2.1) Time unit (hour, day, decade, month, year...)**

The first thing to do in data processing is to take in account the spatial and time distribution of specified meteorological parameter. At this purpose we have to choice the proper range for the objectives we have to work on.

If we want to study the probability of frozen risk in vineyard zone, the time range for the minimum air temperature would be daily based, because a longer time could hide the phenomena. For the spatial range studying an uneven morphology vineyard land we have to evaluate some criteria to assign minimum air temperature to the different fields, with different morphological characteristics (slope, exposure, high, etc) respect the weather station(s) position.

If we want to characterize rainfall distribution of a specified area related to the time variability, the decade temporal range will be necessary in order to avoid the high dispersion of this phenomenon (i.e. if we directly considered daily data).

For some study of soil erosion, daily rainfall data may not be sufficient, but hourly rainfall intensity value will be necessary because the erosion phenomena depends hardly on the kinetic energy of drops, then the time interval elaboration will have to be short. [2]

Table n° 20 - Time interval elaboration

<i>Parameter</i>	<i>Day</i>	<i>Decade</i>	<i>Month</i>	<i>Year</i>
Frozen risk	*			
Start of vegetative season	*	*		
Soil erosion				*
Cryptogam infection risk	*	*		
Water stress risk	*	*		
Climatic classification			*	*
Environmental pollution	*			
Micrometeorology	*			
Irrigation	*			
Crop models			*	

**7.2.2) Data processing choice**

One of the instruments for the agrometeorology investigation is the statistic. By statistical processing of meteorological data, an accurate characterization is allowed for many applications. We can talk about a descriptive statistics and on inferential statistics. The first describes population characteristics. This is performing through some operations sequence: statistic sample identification, data organization and graphic visualization, population's characteristic parameter determination, and distribution law definition.

The inferential statistic treats on sample's representativity, population's parameters estimation from sample's analysis, comparison against others samples, correlation with others data, etc.

We can define a statistic population when every population's values are determined by the same cause. Different values are then the result of random variation, which is not systematic. For example the daily maximum temperature values of the month of January 1992 for a given station, do not constitutes a statistical population because the temperature greatly depend on solar radiation. This is not a fixed parameter because solar angle changes during the month then temperature's values would not have the same probability to assume the same value. The use of mean parameter to describe

the characteristics of the month of January is then a filter operation to reduce temporal series to a unique value, rather than a position index of statistic population.

Instead thirty years values of maximum temperature of 1 January in Florence (Italy), is a statistic population. A sample is a random extraction of some population's values, and its characteristic parameter's analysis allows an estimation of the population's characteristics.

In practical application we generally work with samples. The most frequent statistical population in climatology are the historical series, that is the whole data belongs to a temporal series for a defined time interval; e.g. thirty years data of mean temperature of February month, the total amount of rainfall for fifty years, etc....[2]

### 7.2.3) Agroclimatological processing

The climatological analysis for agrometeorology applications has to highlight its relationships with biological phenomena and their dynamic trend. Meteorological data can be classified as:

- Qualitative; they refer to a condition's occurrence and not to the condition's type, e.g. days with rain, clear sky day, overcast days, hoarfrost presence, stormy days,....
- Quantitative; they refer to events revealed with a measurable intensity, and they can be distinguish between:
  - Discrete; this phenomena, like the rain, have an initial and a final point and can be defined in a time interval
  - Continuous; this phenomena, like the temperature or that is described by a certain value always different from zero (in this case from the absolute zero value)

In the reports the qualitative parameters are expressed as frequencies (i.e. rainy days number, frost, etc.) The discreet parameters are described as totals (radiation, evaporation, rainfall); the continuous characters are represented as averages, like the mean daily temperature, the mean monthly temperature, the air pressure, the absolute and relative humidity, etc.

Meteorological data are organized in the above mentioned form and processed to highlight their trend (see paragraph before for example of statistical population). When a statistical population is defined, like the historical series of twenty consecutive years of mean air temperature in Florence (Italy) for the 1 December, it can be organized for successive elaboration by graphic visualization or frequency table. For example a frequency table (Table n° 21) is obtained dividing the statistic population in contiguous class, and for each class the number of values falling in the interval is assigned. The class range choice is very important in order to avoid information's loss or an excessive variability (too small class). To define the class number an empiric rule is applied

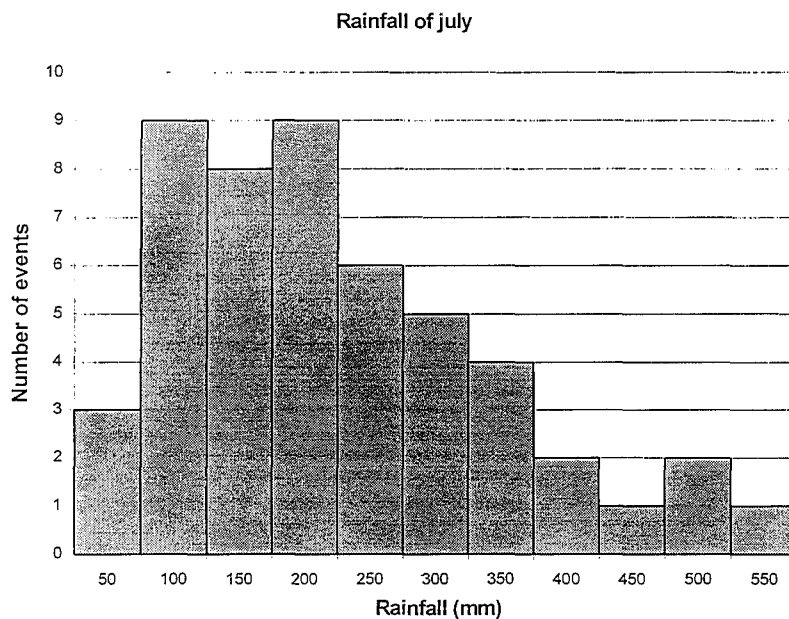
(Sturges rule), this define on the base of observations number of a series, n, the minimum number of class, k:

$$k = 1 + \frac{10}{3} \text{Log}_n$$

Table n° 21 - Total Rainfall frequency table for July

Class	Frequency
From 0 to 49 mm	3
From 50 to 99 mm	9
From 100 to 149 mm	8
From 150 to 199 mm	9
From 200 to 249 mm	6
From 250 to 299 mm	5
From 300 to 349 mm	4
From 350 to 399 mm	2
From 400 to 449 mm	1
From 450 to 499 mm	2
From 500 to 549 mm	1

When the number of class is estimated, the extreme value is divide by the given number of class in order to define theirs range. The frequency table can then be express in graphic mode as shown in the Figure n° 74 (below).



The graphic has in the x-axis the values of the class, and in y-axis the frequency. The class limits define the base of the rectangles which height is equal to the observation's frequency falling in that interval.

From the frequency table the cumulated frequency table could be obtained; that is each class includes the preceding class and their frequency value, until the last class includes all the frequency values of the others intervals. (Table n° 22)

Table n° 22: Cumulated frequency table

Class	Frequency
Less than 50 mm	3
Less than 100 mm	12
Less than 150 mm	20
Less than 200 mm	29
Less than 250 mm	35
Less than 300 mm	40
Less than 350 mm	44
Less than 400 mm	46
Less than 450 mm	47
Less than 500 mm	49
Less than 550 mm	50

Moreover from the frequency table the empirical distribution table can be obtained (Table n° 23). The observations are organized in ascending order with its own order number, m. The probability, p, that a value (or inferior values) can occur is given by the formula:  $m/n+1$  where n is the total number of observations. This way subtracting the probability values for two desired values, the probability that a value will fall in that interval can be estimated.

Table n° 23: Cumulated empirical distribution

m	v	P	m	v	P	m	v	P	m	v	P
1	1	.019	13	100	.255	26	173	.510	38	261	.745
2	26	.039	14	111	.274	27	179	.529	39	289	.765
3	41	.059	15	117	.294	28	196	.549	40	295	.784
4	52	.078	16	126	.314	29	198	.568	41	303	.804
5	58	.098	17	130	.334	30	200	.588	42	308	.824
6	66	.118	18	134	.353	31	200	.608	43	320	.843
7	69	.137	19	145	.372	32	210	.628	44	339	.863
8	72	.155	20	149	.392	33	227	.647	45	365	.882
9	74	.177	21	150	.412	34	241	.666	46	368	.902
10	75	.196	22	153	.432	35	244	.686	47	438	.922
11	85	.216	23	155	.451	36	256	.706	48	456	.941
12	86	.235	24	159	.471	37	260	.726	49	490	.961
			25	162	.490				50	517	.981

### Agro-climatic processing

Computer science applications in agrometeorology and climatology are become indispensable to an effective utilization of the collected data. Real-time information and forecasting, the news frontiers of the environmental sciences, needs of powerful instruments, more and more based on the mathematics and electronics tools. From the

data acquisition to the diffusion of the results, the communication between the instrument occur in numeric (digital) format and all the passages are controlled by specific software. Nowadays the technical operators shall be able to use these instruments and the relative software, staying informed on the new products that are increasingly upgraded and strengthened.

A synthetic list of the software commonly used for agro-climatological data processing, with examples of the possible applications, is give below.

The disposable packages are gathers into five big groups, on base of the own principal functions:

- **Database** - allows the data storage and management;
- **Spreadsheets** - useful for the data evaluation and graphical representation;
- **Statistical software** - indispensable for deepen statistical analysis;
- **Data Spatialisation** - software for spatial analysis;
- **Image processing** - mainly used for aerial and satellite image processing;
- **Geographic Information Systems** - complex packages for a complete management of all the layers existing on the territory.

**Database** - The enormous quantity of data collected by the numerous existing data sources (meteorological and agro-meteorological stations, satellite, radar etc.) required specific software, able to optimize the use of the space in the hard disk, guaranteeing a rapid access to the archive and a good first data management.

Many commercial database has been developed, like dBase III, Access, FoxPro, Paradox, Clipper, Oracle etc. Besides these commercial software, specific database has been realized for meteorological and climatic applications, as Clicom, Spatial Database, Teleform, and DRS.

**Spreadsheets** - The data organized in the database files require further graphical and statistical elaboration, for extraction of the desired information. This is one of the most important points for providing reliable evaluation of actual conditions and to foresee the future trend of the main parameters. Standard graphical and statistical analyses are performed with commercial software, which is rarely complete for all the aspects involved in an agrometeorological evaluation. Packages as Lotus 1-2-3<sup>®</sup>, Excel<sup>®</sup> and Qpro<sup>®</sup>, may be used for this purpose, providing simples tools for the organization and evaluation of the data, with same graphical an statistical possibility. The most common operations can be automated, realizing personalized macros and rationalizing the routine activity.

**Statistical software** - Statistical analysis of the data are absolutely necessary for agro-climatological applications, mainly for the evaluation of the data validity before the diffusion and for the extraction of the desired information. All the packages allow these two operations, but the use of the statistical functions requires the knowledge of the relative principles. Many statistical packages are used for these purposes: Axum, DataDesk, Genstat, Instat, JMP, Minitab Statistical Software, NCSS, S-Plus, SPSS, Statgraphics, Statit, XploRe, etc.

**Data Spatialisation** - The climatic parameters have usually continuous variations in the territory, in the time and in the space, that are rarely possible to describe with punctual representations. Nevertheless, the data collected on the territory has usually exact references: position of the stations, sample points, areas of study etc. This geographical positioning make difficult the attribution of the available information to the other points of the territory. The knowledge of the physic principles of agrometeorological parameters and of their spatial trend allows the estimation of lack values. Statistical methods used for the spatial data analysis are different by those of the conventional statistics, which are based on random, independent variables that assume zero continuity and do not allow the extension of the data values. Geo-statistic assumes that each point is correlated to the nearby ones and this continuity is used for the estimation of lack values. The study of the data trend is realized with suitable methods selected according to the statistic characteristics of the studied parameter that can produce different estimated values.

This assignment is facilitate by software for the data spatial analysis, like Matlab and Surfer, or by specific functions introduced in the more complex software, like the Geographic Information Systems.

**Image processors** - The contribution of over twenty years of activity in the sector of the earth sciences of the remote sensing techniques has determined a close link between the agrometeorological station network and many different instruments of remote sensing. The use of these techniques can provide reliable information on the territory with an increasing of the spatial definition. The sensors most widely used for environmental applications are cameras and scanners operating in the visible and in the infrared spectral regions, that provides images of great dimensions. Image processing is therefore necessary for many important applications, like the evaluation of land cover or land use, pollution monitoring and territorial characterizations. Specific software, for Work- Station or PC needs to extract the necessary information from the frames and to produce readable output maps.

**Geographic Information System (GIS)** - All the data available on the territory may be combined together in the GIS, which allows many different operations with all the information layers created. A GIS is a computer-assisted system for all the operations concerning geographic data and the production of territorial maps. These software are becoming essential tools to understand the process of global change and the planning of new strategies. Different maps and satellite information sources can be integrated to simulate the interactions of complex natural systems. Many GIS packages are commercialized: ARC/INFO, PC ARC/INFO, ArcCad, ArcView, Erdas, Er Mapper, Grass, Idrisi, MAP, etc.. The GIS helps greatly the management and analysis of large volumes of data, allowing a best understanding of terrestrial processes and management of the human activities.

Introducing in the GIS specific models, like that for simulations, land use planning and yield forecasting, is possible the realization of a global support system for the agrometeorological services.

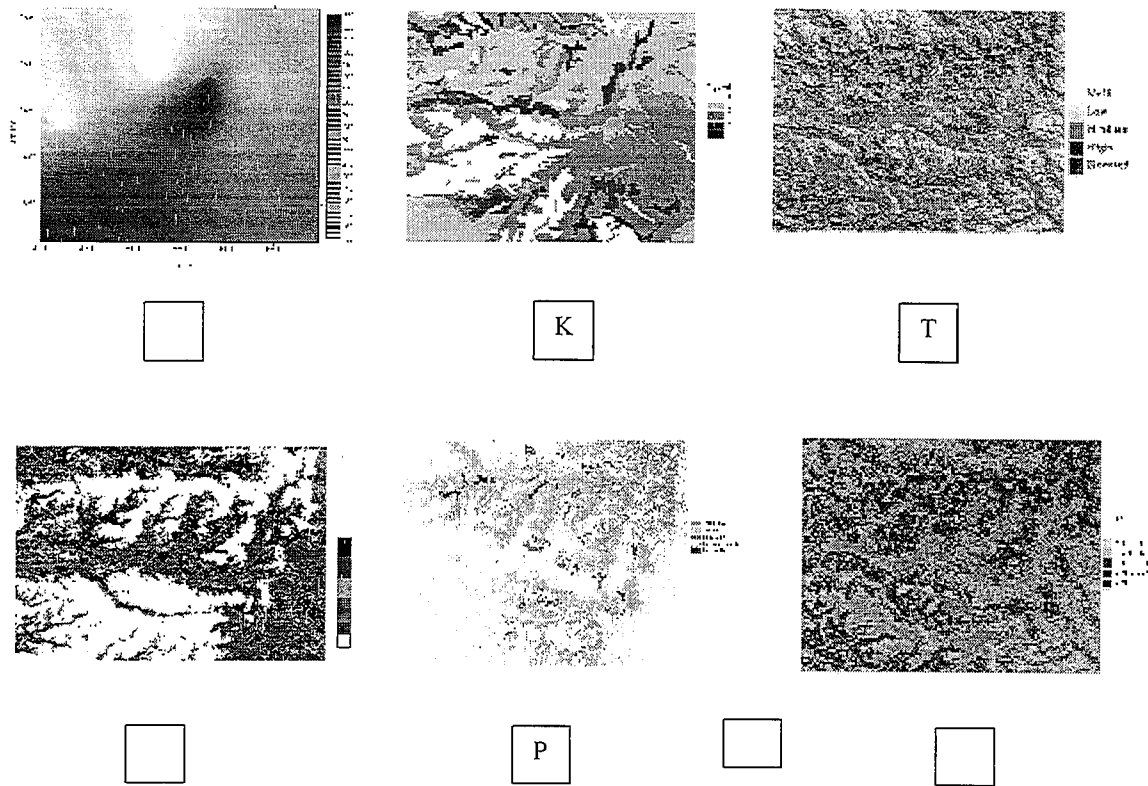
### **Example of application**

A simple example of possible procedure for the use of the information collected by the network of instruments distributed on the territory, with a synthetic description of the role played by each software package, is showed. The example is extracted from a study carried out by the Ce.S.I.A., for the PEICRE Project, in the department of Keita (Niger). In the studied area the terrain is heavily subjected to erosion phenomenon and the evaluation of this aspect became one of the more important factors for the land suitability. The evaluation of the erosion hazard by means of RUSLE model requires the use of many information layers, like climatic erosivity (R), soil erodibility (K), territorial morphology (T), cover management (C), supporting practices (P). In fact, for this equation, the soil loss (A) express in t/ha per years is:

$$A = R * K * T * C * P \quad (1).$$

The data collected by the information layers are organized in a *database*, that allows an easy consultation and updating of the archives, that are numeric, graphic, texts and images.

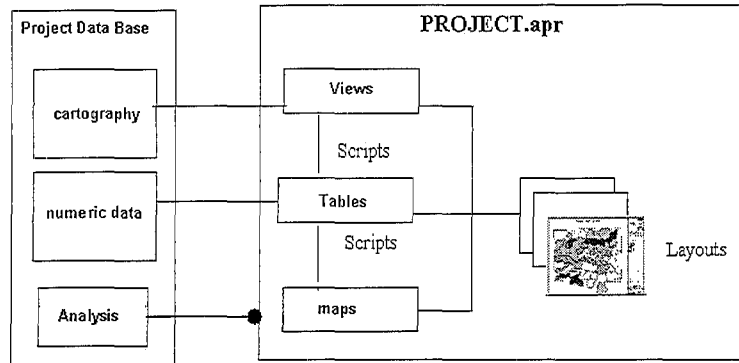
Figure 75. Scheme of different informative layers



Each informative layers is realized starting from different data and required different processing:

- R is realized using numeric rainfall data and require statistical and spatial analysis;
- K is produced by means of digitalization of existing soil cartography and attribution of specific erodibility factors to the polygons;
- T is an index, which describe the contribution of the water flow to the erosion and is calculated from a DEM (Digital Elevation Model). In this case are necessaries many complexes mathematics procedures for the realization of the DEM using digitalized level curves;
- C this is a map extracted from satellite image processing;
- P is give by ground detection and transfer of the data (position, dimension, configuration etc.) to a digital format.

All the information collected by the project are organized in a *Geographic Information System* (GIS) and has been available, for further applications: strategies planning, simulations of different events, etc. (Figure 76, below). [3]



#### 7.2.4) Data visualization

Data representation can be done by graphics or data table in different ways.

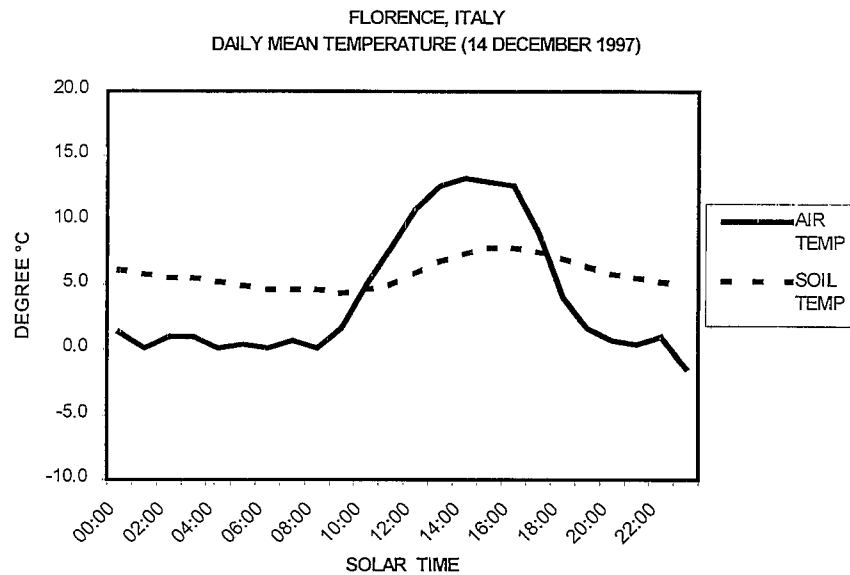
The linear graphics, histograms, XY graphics, dispersion graphics, etc represent the most common graphics. Linear graphics are normally utilized for parameter's value representation, e.g. annual rainfall Vs time, in this case the time interval is the year. The histograms are applied to data gather in class as distribution representation; on the x-axis there are the class values and on the y-axis the absolute or the percent frequency. XY graphics are utilized to highlight the relation between an independent variable with a dependent variable; in a short time they allow correlation degree evaluation of the variables compared and their relationship. Dispersion diagrams are utilized to compare for three variables, two on the y-axis and the third identified as a label for each point. For example they are used to define the relationship of sunset air temperature against dew-point, or to study the relation between the sunset minimum air temperature and the occurrence of minimum air temperature less than 0 °C on the next day.

Numeric data table can reassume, by proper processing, the weather conditions of a site for a defined time interval. This kind of representation doesn't allow an immediate evaluation of the parameter's trend. Normally data table are use to give the results of data elaboration or for an easily consultation of different parameters.

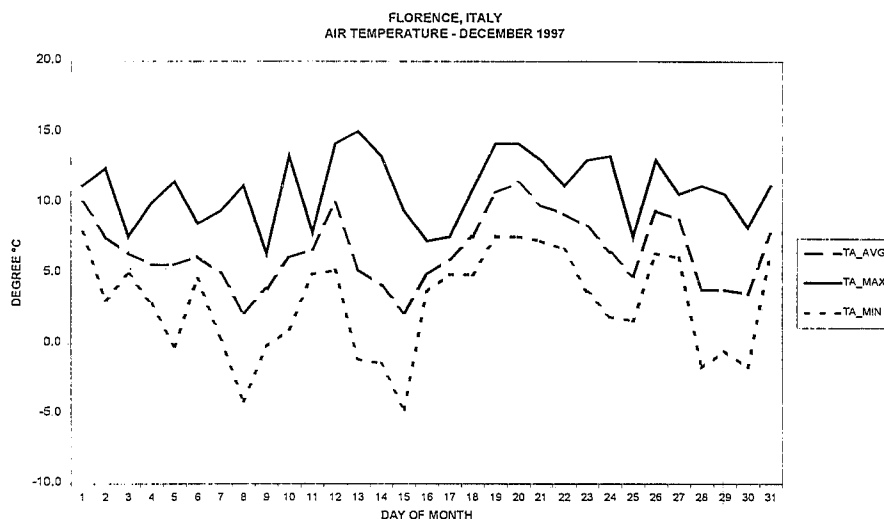
Some tables should report the minimum or maximum value of air temperature, or the critical threshold value reached by one or more parameters (frozen risk, air temperature less than 0°C; mm of rainfall for a specific event, the duration of leaf wetness at critical values for plant's disease risk)

##### 7.2.4.1) Graphic display

For daily temperature a graphic as that shown in Figure 77 (below) can be explicative of its trend, air and soil temperature (at 5 cm deep) can refer to the same range:

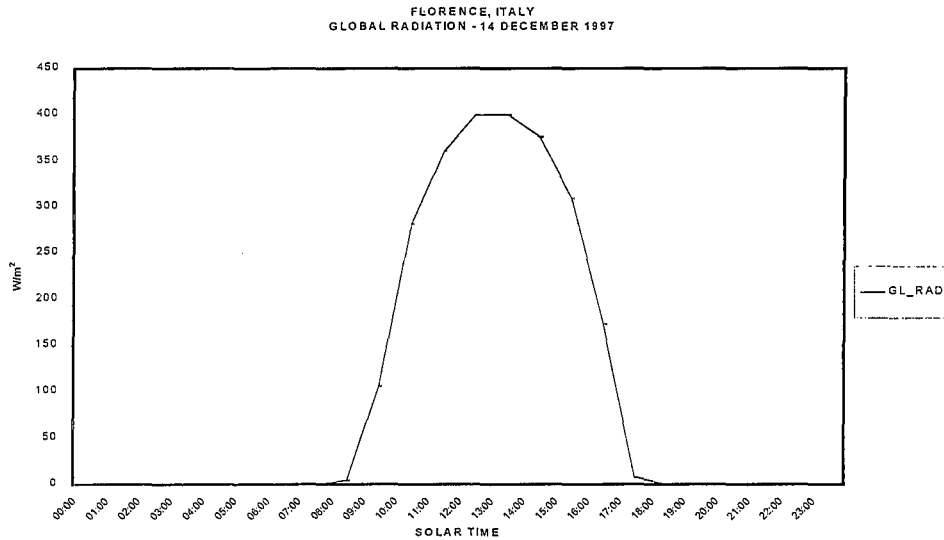


For monthly trend raw data (in this case the time interval is an hour) can induce confusion, then the mean values are used as a filter. Daily mean air temperature and maximum and minimum air temperature values can be shown as in Figure 78:

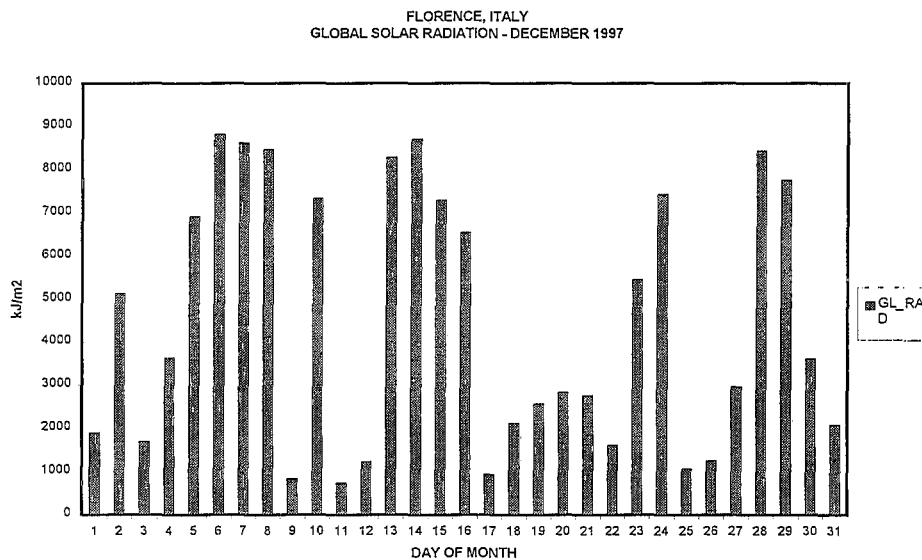


The temperature in y-axis range should have the same range (from  $-10^{\circ}\text{C}$  to  $20^{\circ}\text{C}$ ), and the graph has to report useful information for the users. The measure unit employed; the legend for parameter explanation (min or max or mean value), the graph title could include the station location and any useful comment.

This kind of graph could also describe the global radiation trend. In this case the unit for daily trend and monthly trend change, because the daily radiation unit should be expressed in  $J\ m^{-2}$  (especially their multiples: kJ and MJ), while the daily trend can be expressed in  $W/m^2$  as shown in Figure 79 (below):



Monthly trend could be described by a histogram graph that can look as that shown in Figure 80 (below):



In this case the daily radiation amount expressed in  $kJ/m^2$  is estimated from the hourly data. We assume that the mean value expressed in  $W/m^2$  is equal for every second in the hour ( $W=J\ s$ ). For example the data at 12 a.m. of 14 December of global radiation is  $400\ W/m^2$ ; we multiply this value for 3600 (the seconds in an hour) and we estimate the amount of J in this hour, then we divide by 1000 to obtain the  $kJ/m^2$ . This procedure is repeated for each hourly radiation value, then we sum all the values to have

the daily global radiation amount. Obviously a shorter acquisition time interval than an hour (e.g. 20 minutes or 30 minutes) can reduce the estimation error.

For the 14 December the raw data radiation ( $W/m^2$ ) and the equivalent hourly amount express in  $kJ/m^2$  are showed in table n° 24a:

Table 24a.

Time	$W/m^2$	$kJ/m^2$
00:00	0	0
01:00	0	0
02:00	0	0
03:00	0	0
04:00	0	0
05:00	0	0
06:00	0	0
07:00	0	0
08:00	4	14.4
09:00	106	381.6
10:00	282	1015.2
11:00	361	1299.6
12:00	400	1440
13:00	400	1440
14:00	376	1353.6
15:00	310	1116
16:00	173	622.8
17:00	8	28.8
18:00	0	0
19:00	0	0
20:00	0	0
21:00	0	0
22:00	0	0
23:00	0	0
Daily Total ( $kJ/m^2$ ) →		8712

Monthly rainfall and evaporation amount can be represented by histogram graphics type.

The wind speed and wind direction can be represented in different ways. The raw data for wind speed are expressed in meters per second ( $m/s$  or  $ms^{-1}$ ). The daily amount can be express either in mean wind speed ( $m/s$ ) or in total wind run through the measure's site from any direction (express in m or km). For a daily representation of wind speed and direction, we calculate the frequency for each direction interval (we can consider eight sectors of  $45^\circ$  width). In the example below for any hourly value we associate the wind speed. For each sector we calculate the amount of wind run. In the column "Direction sector" the value -9999 indicates missing values, while the value 600 is assigned to those wind direction values, corresponding to a wind speed of zero

ms<sup>-1</sup>, that are not considered. To obtain the north direction values, the sector's frequencies of -9999 to 22.5 and 337.5 to 360 sectors are sum. The hourly wind run is obtained by multiply the value in ms<sup>-1</sup> for 3600 (the seconds in a hour), then dividing for 1000, to obtain the km.

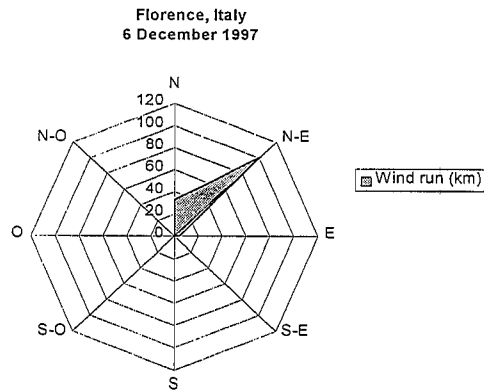
Figure 81 shows the graph (Radar graph type) of wind speed. It has the wind run (or total wind) in the y axis (or series axis) and the cardinal points as x axis (or category axis).

Table 24b shows wind speed and wind direction data (plus the frequency classes and corresponding wind run values).

Table 24b: Wind speed and wind direction values

Day	Hour	Wind Speed (m/s)	Wind Dir. (degree)	Dir. sectors	Data (freq)	Total wind (km)
06-dic-97	00:00	1.0	42	-9999	0	
06-dic-97	01:00	0.4	195	22.5	6	N 32.4
06-dic-97	02:00	0.4	196	67.5	15	N-E 102.24
06-dic-97	03:00	0.4	0	112.5	1	E 4.32
06-dic-97	04:00	0.8	8	157.5	0	S-E 0
06-dic-97	05:00	1.0	32	202.5	1	S 2.88
06-dic-97	06:00	1.2	68	247.5	0	S-O 0
06-dic-97	07:00	1.0	27	292.5	0	O 0
06-dic-97	08:00	1.0	0	337.5	0	N-O 0
06-dic-97	09:00	1.4	25	360	0	0
06-dic-97	10:00	1.8	38	600	0	0
06-dic-97	11:00	2.5	38			
06-dic-97	12:00	2.9	30			
06-dic-97	13:00	3.3	40			
06-dic-97	14:00	2.5	20			
06-dic-97	15:00	2.9	16			
06-dic-97	16:00	2.7	35			
06-dic-97	17:00	2.0	30			
06-dic-97	18:00	1.6	28			
06-dic-97	19:00	1.8	24			
06-dic-97	20:00	1.8	28			
06-dic-97	21:00	2.0	41			
06-dic-97	22:00	1.6	25			
06-dic-97	23:00	1.4	4			

Figure 81 (below). Radar graph type



#### 7.2.4.2) Numeric (data table)

Below an example of a numeric table representation for monthly data is shown. Some column shows the parameter's value of 8, 14 and 19 hour that are given by the W.M.O as representative day's hours. The table should report the name of the organization that issued the data table and fundamental information about site location (such as the coordinates and the height). References about the responsible for the station and for bulletin emission can be useful for the users, which would acquire useful information or require meteorological data.

### **7.3) Data format**

Generally devices such as Data-loggers or weather instruments can output data in standard ASCII (American Standard Code for Information Interchange) format or in some other standard format like binary or hexadecimal codes. Normally the instrument's software provides a file conversion tool to allow the user to import data in database or spreadsheet for successive manipulation.

#### **7.3.1) Binary**

This is file format for digital data encoded as a sequence of bits (a bit is the smallest unit of information that a computer can work with. Each bit is either a one or a zero.

The personal computers utilize the binary numeric system (base 2). The byte (a memory unit that contain a single ASCII character) is a number constitute by 8 binary figures; e.g.  $11010110_2$ . Each digit is called bit. The subscript 2 means binary format (in base 2) while the subscript 10 means decimal format (in base 10). In the decimal format ten digits are used, from 0 to 9; in binary format two digits are used, 0 and 1. A file written in binary format contains information that is not displayable as characters. Software capable of understanding the particular binary format method of encoding information must be used to interpret the information in a binary formatted file. Binary formats are often used to store more information in less space than possible in a character format file. They can also be searched and analyzed more quickly by appropriate software. A file written in binary format could store the number "7" as a binary number (instead of as a character) in as little as 3 bits (i.e., 111, that is:  $1*2^2+1*2^1+1*2^0=4+2+1=7$ ), but would more typically use 4 bits (i.e., 0111). Binary formats are not normally portable however (in computer usage, a file or program is "portable" if it can be used by a variety of software on a variety of hardware. Numeric data files, written as plain character format files are fairly portable). Software program files are written in binary format. [A]

#### **7.3.2) Hexadecimal**

Some software as a compromise between the users and the hardware utilizes the hexadecimal format. The "hex", base 16, is a number representation using the digits 0-9, with their usual meaning, plus the letters A-F (or a-f) to represent hexadecimal digits (or "hexits") with values of (decimal) 10 to 15. The right-most digit counts ones, the next counts multiples of 16, then  $16^2 = 256$ , etc..

For example, hexadecimal BEAD is decimal 48813:

digit	weight	value
B = 11	$16^3 = 4096$	$11 * 4096 = 45056$
E = 14	$16^2 = 256$	$14 * 256 = 3584$
A = 10	$16^1 = 16$	$10 * 16 = 160$
D = 13	$16^0 = 1$	$13 * 1 = 13$
		-----
		BEAD = 48813

Hexadecimal is more succinct than binary for representing bit-masks, machines addresses, and other low-level constants but it is still reasonably easy to split a hex number into different bit positions, e.g. the top 16 bits of a 32-bit word are the first four hex digits. Some data-logger's software (i.e. Delta-T) allow a data retrieve in hexadecimal code, to save space on the disk and to improve data retrieve speed. [B]

### 7.3.3) ASCII format

A character-encoding scheme used by many computers. The ASCII standard uses 7 of the 8 bits (a byte) to define the codes for 128 characters. Example: in ASCII, the number seven is a treated as a character and is encoded as: 00010111. Because a byte can have a total of 256 possible values, there are additional 128 possible characters that can be encoded into a byte, but there is no formal ASCII standard for those additional 128 characters. Most IBM® compatible personal computers do use an IBM "extended" character set that includes international characters, line and box drawing characters, Greek letters, and mathematical symbols. [A]

### 7.3.4) Commercial and specific software data storage

Different software can be useful for data storage. DBIII® for D.O.S.® environment (Disk Operating System) is one's of the widely utilized for this purpose. This is an old version of DB software, but the base organization is similar for most of these programs. Data table 9 shows one record of the database visualized in the edit mode of the program. The Database is defined as one or more large structured sets of persistent data, usually associated with software to update the data. A simple database might be a single file containing many records, each of which contains the same set of fields where each field is a certain fixed width. [B]

Every column must have the title (e.g. Data, Hour, TA for air temperature and so on). The record below relates to the hourly data of midnight for an agrometeorological station placed in Florence, Italy. Sensors are "interrogate" by the data logger every two minutes, then the hourly (mean, sum or dominant frequency) data are stored.

```

DATE          01/12/97
HOURL         00:00
PP_mm        0.0
WS_m/s       1.2
WD_°         337
TA_°C        10.6
TS_°C        11.2
SD_min       -9999
RH_%         78
SR_Wm-2      0
EV_mm        -9999
    
```

```

EDIT  |<C:>|      DEC97      |Record: 1/744  |  |Num
    
```

The record is composed of:

The data (December the first); hour (00:00), rainfall (hourly total), wind speed (hourly mean value), wind direction (hourly dominant frequency, calculated by an algorithm directly by the logger), air and soil temperature (mean value), sunshine duration (minutes, but the -9999 code means that the sensor is not connected), relative humidity (hourly mean value), solar global radiation (hourly mean value), evaporation (total mm amount, but the sensor is not connected because the water evaporation amount is negligible in this period).

At the end of the page some information are given: Edit, for EDIT mode operations, <C:> is the active computer's data drive, DEC97 is the filename (December 1997), 1/744 is the record number (in this case the cursor is positioned on the record number 1, and the entire file consists of 744 records), Num is the field type (in this case the cursor is positioned on a numeric field).

In BROWSE mode multiple records can be displayed:

```

DATE---  HOUR--PP_mm-WS_m/s-WD_°  TA_°C-TS_°C- SD_min RH_%-SR_Wm-2 EV_mm
01/12/97 00:00 0.0  1.2  337  10.6  11.2 -9999  78  0  -9999
01/12/97 01:00 0.0  1.6  343  10.3  11.2 -9999  75  0  -9999
01/12/97 02:00 0.0  1.0  326  9.7  11.2 -9999  79  0  -9999
01/12/97 03:00 0.0  0.6  328  9.1  10.9 -9999  85  0  -9999
01/12/97 04:00 1.0  1.0  335  8.5  10.9 -9999  90  0  -9999
01/12/97 05:00 0.0  1.0  326  7.9  10.9 -9999  94  0  -9999
01/12/97 06:00 0.0  1.0  340  8.2  10.9 -9999  88  0  -9999
01/12/97 07:00 0.0  1.0  322  8.8  10.6 -9999  85  0  -9999
01/12/97 08:00 0.0  1.0  344  8.8  10.6 -9999  85  0  -9999
01/12/97 09:00 0.0  0.8  347  9.4  10.6 -9999  81  16 -9999
01/12/97 10:00 0.0  1.2  346  10.0 10.6 -9999  78  39 -9999
    
```

```

BROWSE  |<C:>|      DEC97      |Record: 1/744  |  |Num
    
```

The first line corresponds to the record above shown. The first row has to report the field title (name of the variable). This way the software can perform a multitude of operation: find a given value, extract records that match one or more conditions, and so on.

The field can contain any character, and the software provides four field's type: Data (for data and hour field), Numeric, Character (for alphanumeric field) and Memo (a particular text field to include comments relative to the record). The software permits easy data exchange with the most diffuse software. Generally standard ASCII files represent the safest way. By this option the same database can be organized on spreadsheet software such as LOTUS 1-2-3<sup>®</sup>. This allows graphic elaboration and some simple data processing (linear regression between two variables or values frequency distribution). Spreadsheets don't be normally used for data storage. The file DEC97 saved as .DBF file (the suffix for DBIII<sup>®</sup> files) is smaller than a .WK\* files (the suffix for lotus files where \* indicate the release's number. In this example a LOTUS 1-2-3<sup>®</sup> version number 2 is utilized).

File	Extension	Size (Kbytes)	date	hour
DEC97	DBF	47.289	22/01/98	14.36
DEC97	WK1	138.654	22/01/98	14.39
DEC97	XLS	99.328	22/01/98	14.41
DEC97	MDB	184.416	22/01/98	14.45

The size of .DBF is smaller than .WK\* files. On the list appears also another file type with .XLS suffix. This identifies an EXCEL<sup>®</sup> file. This is a spreadsheet that runs under WINDOWS<sup>®</sup> environment, one of the most diffuse operative environments. The EXCEL (in this case a version 7 for WINDOWS<sup>®</sup> 95 is utilized) file's size is smaller than the .WK\* file, but greater than DBIII<sup>®</sup> file (in this example an old version 1 for D.O.S. is utilized). The last file refers to the software ACCESS<sup>®</sup>. This is a Microsoft<sup>®</sup> DataBase that runs under WINDOWS<sup>®</sup> environment. As we can see it is the greatest file, because the software allows many database's manipulation with user-friendly commands, e.g. ipertext field column import, multimedia field management (i.e. figures, sounds), easy data filter and extraction, fast connection with others software.

Extracting and importing data through different software don't change so much their appearance (meteorological data have to be always organized as database), but the frame around. In the newest software many options are shown and easy to active by windows-command menu.

#### 7.4) Data diffusion

Agrometeorology studies had greatly improved in last years for two main reasons: the progress on the computer science and on the telecommunications. New hardware and software availability and the possibilities of fast and wide data and

agrometeorological elaboration distribution, allows a new interest on the agrometeorology applications.

The information furnished and the way to diffuse them can be widely different depending on the country, on the scale (from a region to the basin), on the crops, on the season and so on.

Generally Regional Services or Local Administrations manage this kind of information, but also private organizations are developing agrometeorological bulletins.

These services can be free or available after a subscription (its cost normally depends on the amount of information required).

Lets take as an example the work done in the early warning in Niger based also on the SISP module of yield prediction (Système Intégré de Suivi et Prévision – Yield Forecast And Monitoring Integrated System). As it is understandable, all the actions undertaken by this system have in the production of the periodical bulletin their most important (operative) aims.

The bulletin is the result of the work to produce critical information realized by the different Services. It is produced under the responsibility of the GTP (Pluridisciplinary Work Groups) of the National Early Warning System. It has a decade frequency and handles agro-hydro-meteorological information which can be described as follows:

- meteorological situation
- pluviometric situation
- agrometeorological situation
- phenological situation and on-going cultural operations
- hydrological situation
- phytosanitary situation

In addition, since 1993, the decadal bulletin also produces information on:

- suitable agrometeorological strategies based on local meteorological conditions
- the stabilization of the sowing dates and the probable length of the growing season for the different regions of the country
- indications on the drought risks periods during the growing season
- graphics and tables for the comparison of the most important parameters to appreciate the evolution of the agricultural campaign

This information is diffused as paper bulletin (at now), that includes a number of notices useful for the peasants to take decisions about their cultural operations and preventive actions to protect their crops. Those notices are produced by a great amount of data management operated by the National Meteorological Direction in collaboration with the Agricultural Direction and permitted by the use of several utilities among

which the SISP. The data management is preceded by the collection of data from the network of the monitoring of agricultural campaign and is divided in two steps:

1. tendency indicators generators describing the evolution of the agricultural campaign; such indicators are

- the probable period of the beginning of the agricultural campaign for each locality
- the probable period of the end of the growing season
- the average length of the growing season
- the rainfall amount
- the rainfall amount for the following decades
- the satisfaction rate of the water needs of the crops
- the water stocks available in soil
- the occurrence of consecutive dry days
- at the end of campaign, the yield prediction of crops

2. utilization of the those indicators or parameters to elaborate each decade the following information:

- statistical elaboration on the basis of the probable rainfall and cartography
- comparison of the on-going rainfall with the normal rainfall (based on historical series) and cartography
- values tables of decade rainfall and their probability at 25, 50 and 75% from May to October
- description of the simulated cycles for each station of the network

The comments are prepared on the basis of this very rich graphic and software support which permits careful and analytical observations; even the edition of the bulletin is thus quick and simple so that it serves the peasants with complete information in the opportune moment. [4]

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Here is instead an example of a private United States company profile (Agricultural Weather Information Service Inc., [C]) that furnish some products for almost all American's states:

Agricultural Weather Information Service Inc.

We produce forecasts and data products for every major commodity produced in each state. Here is a sample of the topics available for California. Below are a few examples of our basic Ag Weather Forecasts, products for those growing field crops, forecasts for managing animals, some of our IPM (Integrated Pest Management) products, our frost/freeze forecasts, and AWIS ag data products.

## AG WEATHER FORECASTS

A good basic ag weather forecast is essential for making many decisions on the farm. Most forecasts are available in tabular and graphic formats. Here's just a few examples: 7-Day temperature forecast tables and maps are made twice each day and are available for 5,200 locations. 7-Day rain probability forecast tables and maps help plan irrigation and haymaking. Detailed maps of rain chances for every county are also available as well as regional forecasts of rainfall amounts.

### Example of agricultural weather forecast

Forecast For Southeast Iowa

Average Value -----	Thursday 03/20/97 -----	Friday 03/21/97 -----
Lowest Relative Humidity %	54	42
Hours of Sunshine	6	4
Morning Wind Dir/Speed MPH	NW/09	W/14
Afternoon Wind Dir/Speed	W/09	NW/21
Pan Evaporation (Inches)	0.11	0.12
Drying Potential	MODERATE	MODERATE
Solar Radiation (Watt-Hrs/SQ M)	3727	3291
Dew/Frost Intensity/Dryoff	NA	NO DEW/FROST
Nighttime Precip Amount 6PM - 6AM	NA	0.00
Likelihood of Precip 6PM - 6AM	NA	UNLIKELY
Daytime Precip Amount 6AM - 6PM	0.00	0.00
Likelihood of Precip 6AM - 6PM	UNLIKELY	UNLIKELY

(Copyright 1997: Agricultural Weather Information Service, Inc.)

Examples of hourly maps of weather parameters of special interest to agricultural users:

- Temperature analysis for the United States
- Current relative humidity
- Dew point temperature
- Wet bulb temperature
- Wind Vectors show the wind speed and direction it is blowing
- Wind Streamlines indicate where the air is coming from

FIELD CROPS (corn, cotton, soybeans, peanuts, etc.)

Forecasts and data products cover all row crops from planting to harvest. Thanks to many years of research, there are weather-based management tools to help you manage corn, soybeans, cotton, peanuts, and other field crops. We tabulate Growing Degree Days (GDD) for every common base in table and map formats.

As your crop grows, we can help you decide when to:

- irrigate based on recent evaporation rates
- schedule irrigation based on forecast rainfall
- spray based on winds

When harvest comes, AWIS can help determine the best times:

- for harvesting cotton , corn, peanuts, and other crops
- aerating corn sorghum, and soybeans

Degree Day Forecast For ILLINOIS

(Base 50 Degrees F.) ... Units Above Max Cap = 86, Min Cap = 50

Produced at 525 PM CDT on Mon Jun 8 1999

STATION	Tue 6/ 8	Wed 6/ 9	Thu 6/ 8	Fri 6/ 9
Aledo	20	18	21	17
Belleville	22	15	23	18
Bentley	15	17	22	15
Brownstown	23	18	20	18

ANIMAL  
MANAGEMENT

Heat stress is a major problem for poultry and livestock that results in major economic losses and consumer concerns. AWIS forecasts can help you manage your animals! Our regional 6-10 Day Outlook can indicate an impending hot spell, allowing you time to get your animals to market. For routine animal management, we offer the:

- regional livestock heat stress index maps and the Livestock
- Safety Index category maps
- livestock heat stress forecast and the heat stress forecast for poultry
- Other information for haymaking and temperature forecasts are also available.

INTEGRATED PEST  
MANAGEMENT

Integrated Pest Management (IPM) is used to manage pests such as insects and diseases with minimum economic and environmental impact. AWIS has worked with university researchers to develop IPM products for:

- potato late blight WISDOM model
- tomato expert system called TOM-CAST
- peanut leafspot using the AU-Pnut system
- peanut leafspot using the Jensen-Boyle model
- others can be implemented on request

TOM-CAST Expert System

Total Severity Units

From Last Spray Date to: 04/06/97

IF YOUR LAST SPRAY DATE	TOTAL SEVERITY UNITS	IF USING CHEMICAL A	IF USING CHEMICAL B
was: 03/25/97	15	NO SPRAY	SPRAY
03/26/97	13	NO SPRAY	NO SPRAY
03/27/97	12	NO SPRAY	NO SPRAY

## AG DATA PRODUCTS

AWIS maintains one of the most extensive near real time ag weather databases anywhere! We collect data from nearly 3000 locations around the nation. Some of the products available include:

- daily ag data report
  - rainfall summary for the last 7, 30, and 60 days plus year-to-date
  - detailed rain totals by location
  - monitoring dormancy with chill hours
- 

Here is an example of the organization of an agrometeorological service of Tuscany Region in central Italy [D]. It belongs to the regional administration and gives some prices for particular output.

### STRUCTURE

- The agrometeorological sensing network
- The meteorological radar
- The data acquisition and processing center
- The meteorological Office

### PRODUCTS OF THE SERVICE

- Agrometeorological data
- Meteoclimatic studies and elaboration
- Weather forecast

The Regional Agrometeorological Service of Tuscany (R.A.S.) was set up ten years ago in order to satisfy the demand of agrometeorological information expressed by technical assistance in agriculture.

The Service is managed by A.R.S.I.A. (Regional Agency for Innovation and Development in Agricultural and Forestry sectors), of which represents one of the specialized facilities for technical support and assistance to agricultural and forestry sectors (and others sectors as hydrogeologic and civil protection, mass media, tourism etc).

The Service is structured into an operative office and a local sensing structure distributed on the territory and made up of an agrometeorological network, a meteorological radar and three local data acquisition centers called Front End Unit (F.E.U.).

#### *The agrometeorological sensing network*

The agrometeorological sensing network is composed of 105 electronic automatic weather stations spread throughout Tuscany and gathering continuously different parameters such as quantity and intensity of precipitation, air and ground temperature, humidity, solar radiation, wind intensity and direction, atmospheric pressure etc.

Only 6 stations of the network are currently equipped with ten-meters high anemometers according the standard of the World Meteorological Organization (W.M.O.)

The electronic stations work non-stop with the power supply provided by solar panels; they are preset to record the data in digital format, to store them into memory cassettes and above all to transmit them to the acquisition centers by a radio device installed in each unit.

The radio transmission is carried out with a radio linkage, feasible thanks to a set of repeaters located on the main peaks of the region, that also allows the interrogation and programming of the stations and of the sensors from the operative center of Pisa.

Essential part of the whole sensing network is meteorological radar installed in the southern part of Tuscany (Colline Metallifere area) which, after the current experimental period, will make possible weather nowcasting in the whole region. The integration of the data and radar images with the information acquired by the weather stations will allow testing and verifying the reliability and efficiency of the whole sensing system

#### *The meteorological radar*

The radar installed by A.R.S.I.A. in southern Tuscany, in collaboration with Ce.S.I.A. (Center for Informatics Application in Agriculture) - Accademia dei Georgofili and LaMMA (Laboratory for Meteorology and Environmental Modelling [E]), is the first meteorological system aimed at supporting agricultural, civil and social activities in Tuscany. Its operative capacity (range of 50-60 km) will allow to forecast and follow the meteorological conditions and phenomena, in almost the whole region, with particular reference to rainfall measuring, thunderstorms and whirlwinds tracing etc. The products elaborated by the radar will help the Service start a nowcasting activity essential for civil protection purposes and issue of meteorological warnings.

#### *The data acquisition and processing system*

It represents the core of the operative center being able to acquire, process and distribute all the agrometeorological and meteorological data coming from both the sensing network and the main national and international meteorological Offices.

At fixed hours and twice a day, the acquisition system automatically interrogates the sensing units and the acquired data update the data archives of the processing center. The format of the data bank has been selected and designed by the Service, using the SQL standard language in order to allow a complete data exchange between the central archives and the archives of other users.

#### *The meteorological office*

The Meteorological Office daily prepares different types of weather reports and provides the users with all the meteorological information detailed for the regional territory.

The Office is equipped with the main facilities necessary to acquire the main meteorological data and to follow the evolution of the meteorological situation in the short and medium term.

The issue and elaboration of the information are carried out by processing the weather maps and data daily received from the main European Meteorological Centers and from some Limited Area Model (L.A.M.) tailored to the meteo-climatic and orographic characteristics of Tuscany.

## THE PRODUCTS OF THE SERVICE

### *Agrometeorological data*

In the data bank of the operative center are stored both hourly and daily data easily accessible and processable according specific requests.

The hourly data allow highlighting the evolution of particular phenomena interesting the agricultural and the environmental resources protection fields.

These data are used in agriculture to assess the duration of some agrometeorological parameters such as wet foliage and relative humidity, or to know the characteristics and values of some events such as frosts, heavy rainfalls, gusts etc.

In the fires and arsons prevention activity the data allow to know the daily variation of the dominant regional winds mainly interesting for the coastal and mountain areas.

The daily data, obtained by post-processing the hourly ones, allow a more immediate picture of the climatic trend and are helpful to the technicians in order to estimate some agrometeorological parameters such as the global rainfall or the evaporated water, whose knowledge is essential to rationalize watering operations.

### *Meteoclimatic studies and elaboration*

The meteoclimatic studies serve to know the climatic characteristics of the region and the distribution of the main meteorological parameters such as temperature, rainfall and winds over longer periods.

In addition to these studies the Service issues agrometeorological elaboration, valid for weeks, months and years are mainly used to support the technical assistance in agriculture, to implement and test agrometeorological models etc.

Both these products are used for different purposes such as request for weather-related damages to the crops, planning in the forestry fields, etc.

### *The weather forecast*

The weather forecast is represented by a set of different weather reports issued by the Service daily or on occasion of foreseen severe and potentially dangerous meteorological events.

The reports, always detailed for the regional territory, have a different validity and contain different foreseen meteorological information and phenomena such as sea and sky state, temperature, heavy rainfall, storms, frost, hail, fog etc.

## DISSEMINATION OF THE PRODUCTS

The products are disseminated with different means:

### Fax

All the users can receive the products directly by a fax machine.

For further information about the modalities of receiving the products please contact the staff of the Service at the phone number 0039-50-8006220 or at the fax number 0039-50-503220.

### Fax on demand

By the end of 1997 a device for the automatic dissemination of the information (by both answering machine and fax) will be available at the operative center.

In order to obtain the information the user will have to dial the number 0039-50-8006222 and to follow the prerecorded indications.

The activation of the service will be communicated by means of the other dissemination devices

#### Phone

The staff of the Service is available to provide every phone information about meteorological situation and about all the products, during working hours (8.30 a.m. - 16.30 p.m.), from Monday to Friday.

#### Internet

The general weather report for Tuscany (valid for 7 days) is available free at the following address: "<http://www.arsia.toscana.it>"

The report is updated 5 times a week (from Monday to Friday) but currently only in Italian.

#### E-mail

The dissemination of the products can be carried out, on request, by E-mail; the personnel of the Service can be contacted at the following address: "[meteoarsia@cpr.it](mailto:meteoarsia@cpr.it)"

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### 7.4.1) Weather report

Every information about weather conditions can be very useful for people and organizations that manage open-air activities: farmers, transports on-line services information (for roads, airports, harbors...), open air activities planning, tourism...

Our interest concern agricultural aspects, then examples of weather reports for agronomy activities are given. Here is an example of weather bulletin of the Kenya Meteorological Department [F]

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**CROP AND WEATHER REVIEW BULLETIN DEKAD: 32 11-20 NOV 1996  
ISSUED BY THE KENYA METEOROLOGICAL DEPARTMENT P.O.BOX  
30259  
NAIROBI, KENYA**

#### IMPACTS OF WEATHER ON CROPS AND PASTURE

##### HIGHLIGHTS

There has been a general late start of the growing season in most parts of the country, especially in the Central and Eastern provinces. The southern parts of Nyanza, Central Rift Valley and Coast provinces had early start. The Rift Valley and Western provinces, however, have continued to experience a continued poor season, as rainfall has to date remained below normal.

Maize crop which is being harvested and stalked in the fields in some Rift Valley districts of Uasin Gishu and Trans-Nzoia are unlikely to suffer severe damage as the rainfall amounts being recorded are low.

In the Eastern province which had a general late start of the growing period, normal to above normal rainfall was recorded during the period under review. High rainfall realized during the 1st 20 days of the month has improved the conditions of the growing season, thus supporting crop germination and development of pasture. The late onset will need to be accompanied by continued rainfall to minimise chances of the crops being left to wither in their vegetative stage. Experience has shown that these districts are not favoured by late start of the growing season as this normally leads to early cessation of rainfall hence poor harvests. Keen monitoring of rainfall performance during the remainder of the season is absolutely necessary (given the current late start) especially in the low lying districts of Machakos, Makueni, Mwingi and Kitui which normally rely on the short rains. Performance of pasture in the Northern districts of Marsabit, Isiolo and Moyale seen to have improved with improved rainfall.

In the Southern parts of Nyanza province including Kisii, Nyamira and Kuria districts early onset together with above normal rainfall reported during the period under review are expected to increase significantly yield prospects of maize in the lower parts of these districts. Harvesting of beans needs to be hastened in order to minimise on farm losses.

North Eastern districts of Garissa, Wajir and Mandera including the northern parts of Rift Valley (Turkana and Baringo districts) has had late onset coupled with below normal rainfall. This does not augur well for pasture and replenishment of watering points for livestock and consequently animals are likely to continue suffering from lack of adequate pasture and water. The situation may be alleviated as we approach mid November when rainfall intensities are expected to reach their maximum values. Areas in these districts (including Moyale, Isiolo, and Marsabit districts of Eastern province) which practice speculative agriculture have continued to suffer as germinated crops withered due to lack of moisture and may require resowing. Resowing may not help the dire situation as the season has already progressed and is expected to only benefit pasture.

In the Central Province, the onset of the season was late as in other districts, however, during the period under review rainfall was above normal except in low lying areas of Nyeri. The sown crops are expected to continue doing well but in some fields in Nyeri resowing may be necessary. Vegetables in the province are expected to benefit much from the current high rainfall.

Coastal districts had normal onset. Ample moisture reserves are expected to give good yield prospects in the province, however;

There has been mixed performance of rainfall during the period under review in the Coast province showing a decline as we move northwards. On the whole season has been a normal one in Kwale, Mombasa and Kilifi districts. Taita Taveta which saw a late onset of the rains hence late start of the growing season started showing an improved performance during the 1st 20 days of the month with above normal falls being recorded. This situation is expected to support the germinated crops due to the present ample moisture. The seasonal performance will require keen monitoring as during the next 20 days as the case is in the low lying districts of Eastern province. In Tana River and Lamu districts the season has been poor since when it started. The poor seasonal behavior is not conducive to sustenance of quality pasture but with peak values

of rainfall being expected from the mid of November to the end then the situation may be alleviated. The crops in these districts are expected to perform poorly.

Table 25. Data table for November

STATION	PRECIPITATION			MEAN AIR TEMP	SOIL TEMPERATURE			RADIATION	SUNSHINE DURATION	WIND SPEED	RH	PAN EVAP	PET Ep
	Actual	Normal	(%) Dep. From Normal	(°C)	5 Cm	10 Cm	20 Cm						
Kakamega	23.8	36.6	-35	20.9	24.1	23.0	*	*	*	0.9	71	42.8	*
Kisii	43.7	71.8	-39	20.0	21.4	21.3	21.4	*	*	1.8	70.8	47.7	*
Kisumu	0.9	38.5	-98	23.8	28.2	28.7	27.6	*	*	1.3	61.7	*	*
Lodwar	0.0	1.6	-99	28.7	*	*	*	24.3	*	3.3	45.8	110.5	*
Kitale	3.8	34.1	-89	18.6	21.3	21.6	21.8	22.8	*	0.8	70.6	34.8	*
Eldoret	1.3	19.3	-93	*	20.9	19.5	20.2	22.9	*	2.4	*	59.7	*
Nakuru	21.5	26.6	-19	17.2	18.3	19.7	20.3	24.3	*	0.7	75.8	36.6	*
Kericho	0.5	32.7	-98	16.8	18.9	19.1	18.9	19.9	*	0.8	81.6	34.5	*
Narok	1.9	15.8	-88	16.8	24.6	22.2	22.0	17.4	*	2.5	81.1	55.1	*
Nyeri	20.0	47.0	-57	18.1	22.1	22.0	22.4	16.8	*	0.8	79.5	29.5	*
Thika	0	22.3	-100	*	29.6	27.7	27.3	25.4	10.0	1.4	*	*	*
Dagoretti	106.6	37.7	-183	17.4	21.1	19.7	20.5	14.5	*	1.8	73.9	*	*
Marsabit	35.3	29.3	21	19.6	22.8	23.3	24.4	14.2	*	*	79.5	*	*
Meru	138.4	99.7	39	18.2	21.9	22.0	21.9	17.7	*	0.9	87.3	*	*
Embu	*	69.1	*	*	*	*	*	*	*	*	*	*	*
Katumani	100.6	40.4	149	18.4	22.7	22.5	*	16.2	*	1.6	83.5	*	*
Makindu	95.3	58.7	62	22.6	*	*	*	17.0	*	2.5	72.6	*	*
Moyale	40.3	38.3	5	23.1	29.1	28.5	27.0	17.0	*	2.2	70.9	*	*
Mandera	4.0	9.5	-58	29.8	*	*	*	18.2	*	1.9	52.2	*	*
Wajir	053.0	21.1	151	28.4	*	*	*	21.7	*	1.9	61.0	*	*
Garissa	26.8	35.6	-25	29.5	*	*	*	*	*	1.7	58.7	59.8	*
Lamu	*	60.9	*	27.3	*	32.2	32.1	*	*	1.2	78.5	*	*
Malindi	*	11.7	*	*	*	*	*	*	*	*	*	*	*
Mombasa	35.8	23.5	52	26.2	29.3	29.4	29.6	21.6	7.5	1.3	84.7	46.3	42.0
Voi	94.9	32.3	194	25.1	*	*	*	20.0	*	1.3	70.7	54.4	*
Msabaha	*	28	*	*	*	*	*	*	*	*	*	*	*
Mtwapa	18.6	28.1	-34	25.9	32.9	32.4	31.1	21.4	*	0.5	93.0	50.6	*
Kabete	88.9	43.4	105	16.8	19.9	19.0	19.9	11.9	*	1.8	85.5	*	*
Nyahururu	4.2	21	-80	13.9	23.3	21.5	17.6	*	*	1.3	82.3	*	*
JKIA	77.4	30.1	157	18.9	*	*	*	14.5	*	3.4	78.5	38.2	*
Mwea	69.1	62.4	11	21.9	27.0	26.0	26.3	22.2	6.2	1.5	84.4	49.1	42.9
Wilson	*	33.6	*	*	*	*	*	*	*	*	*	*	*

All parameters are decadal averages, except Rainfall, PAN and PET.

Legend: \* stands for missing data; PET: Potential Evapotranspiration; PAN: Pan Evaporation

#### 7.4.2) Telefax

Weather and agrometeorological reports can be distributed in different ways. The telefax can be useful because is widely utilized in many countries and the technique can offer interesting optional that allows your customers or employees to have access to

you 24 hours a day, 7 days a week. It allows you to automate repetitive daily tasks (i.e. report delivery).

*Fax-on-Demand* - callers retrieve documents from a stored document database. Access to the information is from a touch tone telephone via voice prompted menus. Documents are then faxed back within minutes to the callers fax machine.

*Fax Broadcast* - Send a document to a list of fax machines. These fax documents can be sent during off-hours, therefore saving on long distance charges.

*Fax Store and Forward* - similar to a voice mailbox. A fax can be stored in an individual mailbox and be retrieved or forwarded to any fax machine at the owner's discretion. [G]

### 7.4.3) Television

The weather forecast is by now a typical television program. Many services utilize this media for people advice and information's distribution. Because its very large use some specific channels were found for weather information.

In some countries special pages are available by an agreement with the State television network or local private network, in order to inform people about extremes events (flood probability, heavy rain, fog...) or to distribute agrometeorological advises.

*Example:*

*Televideo's management*

Televideo is the name of the teletext service activated by RAI (Italian National Television) in 1984.

Today it has become a medium, which is widely utilized by over half of the Italian households. As an interesting mix of broadcast television and computer technology, Televideo has an important role in the media context and has become part of the Italian way of life. From the initial 300 pages broadcast in 1984, Televideo's range of services has increased progressively, taking it to the top of the European teletext category. Televideo currently broadcasts over 2.000 pages, divided into "static" pages (which, once they are selected by the viewer remain fixed on the screen until the next selection) and "sub-pages" (sets of pages which cycle automatically on the screen at 20 second intervals). Televideo is transmitted 24 hours a day, 7 days a week. It has then taken an important role and can rely on a non-stop information source.

Televideo provides information which covers five major areas:

- 1.news
- 2."service" information on a national basis
- 3."service" information on a regional basis
- 4.subtitles for the deaf
- 5.telesoftware.

#### 7.4.4) Internet

In this paragraph there is the definition and the description for this powerful tool. Also this guide gather much information thanks to this new way of communication. It is a kind of the world's showcase where you can find new products and interact with other people.

What is INTERNET?

On October 24, 1995, the FNC unanimously passed a resolution defining the term Internet. This definition was developed in consultation with the leadership of the Internet and Intellectual Property Rights (IPR) Communities. [H]

The Federal Networking Council (FNC) agrees that the following language reflects our definition of the term "Internet".

"Internet" refers to the global information system that:

- (i) is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons;
- (ii) is able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) suite or its subsequent extensions/follow-ons, and/or other IP-compatible protocols; and
- (iii) provides, uses or makes accessible, either publicly or privately, high level services layered on the communications and related infrastructure described herein."

In practical terms it is a network that interconnects networks, and allows communications between different worlds by an unbelievable computers cobweb. The ways to connect two or more network are:

- telephone lines, switched or dedicated
- optical fibers
- radio frequency

If a telephone line is used (the common way) to connect to Internet, a modem is needed. This is a device that sends and receives computer's data, converting them from digital to analog format and vice versa.

If we think about Internet as a road system, the network connection can be compares to a road that can run some traffic volume at certain speed.

In Internet there are different speed connections that can produce, in some situations, traffic problems. The fastest highways are called backbones. The original backbone was founded in 1969 and named ARPAnet. The main backbone today is that of United States Federal Gouvernement and that of NSFNET (National Science

Foundation); it is available for public administration, research and University organizations. Parallel, commercial providers were established the CIX (Commercial Internet Exchange), separate from NSFNET and utilized for commercial information exchange without any restriction.

---

"Internet" describes a massive worldwide network of computers. The word literally means a "network of networks", and is made up of smaller regional networks scattered though-out the world. On a given day, it connects around 20 million users in approx. 50 countries.

So it's an international community of people who share information and communicate. For the user, the Internet is a vast collection of resources - people, information and multimedia.

### History

The birth of the Internet is linked to the cold war. It was the answer to the problem of how to communicate in the aftermath of a nuclear attack. What was needed was a communication network in grid form so that there would always be more than a single line of communication.

This idea grew into what we today know as the Internet.

### WWW.

The World Wide Web (WWW) is mostly used on the Internet, but they are not the same things. The Web refers to information, whereas the Internet refers to the physical network of cables and computers. The WWW uses the Internet to send documents between computers users internationally.

As in the case of the Internet, no one body owns the WWW. People are responsible for the documents they author and make available publicly on the web.

### What's this E-mail?

It takes days to send a letter around the country and weeks sometimes to go around the world. To save time and money more people turn to electronic mail. Its fast, its easy and its cheaper than the post office, allowing you to quickly and easily communicate with millions of people around the world any time of the day or night, for the cost of a local telephone call. So, in simple terms, e-mail is an electronic message sent from one computer to another. You can send or receive personal and business - related messages together with attachments, which could include documents, pictures or even computer programs.

### I'm on the Internet - Now What?

The Internet is where you go to get information, but you need to Search for the stuff you need. There are two ways to do this; either you put in the URL in the location

bar (this is when you know the exact site address), or you start searching, using one of the search engines. You can type one or more keywords and the search engine list some addresses that match such keywords..

What you need to get connected:

- Computer with 486 processor or higher
- 8 MB RAM is recommended as a minimum
- Modem normally 14.4 KBPS (A 33.6 KBPS modem is recommended, and in most areas)
- Telephone connection
- An account with a server
- Software for access, e - mail and web browsing.

Your account with us will give you:

- A local phone number to dial in.
- An e - mail address ( e.g. yourname@eureka.lk )
- Your account is protected by:
- A login password
- An e - mail password
- Customer support
- Phone in
- Site visit
- Online usage information (Test page. Try Customer Service if it fails to work!)
- Internet Tutorial

#### Value Added Services

##### FTP Software

File transfer protocol, software installed so that you can download large files without the risk of cut off problems. Installed free of charge with all Eureka packages.

[1]

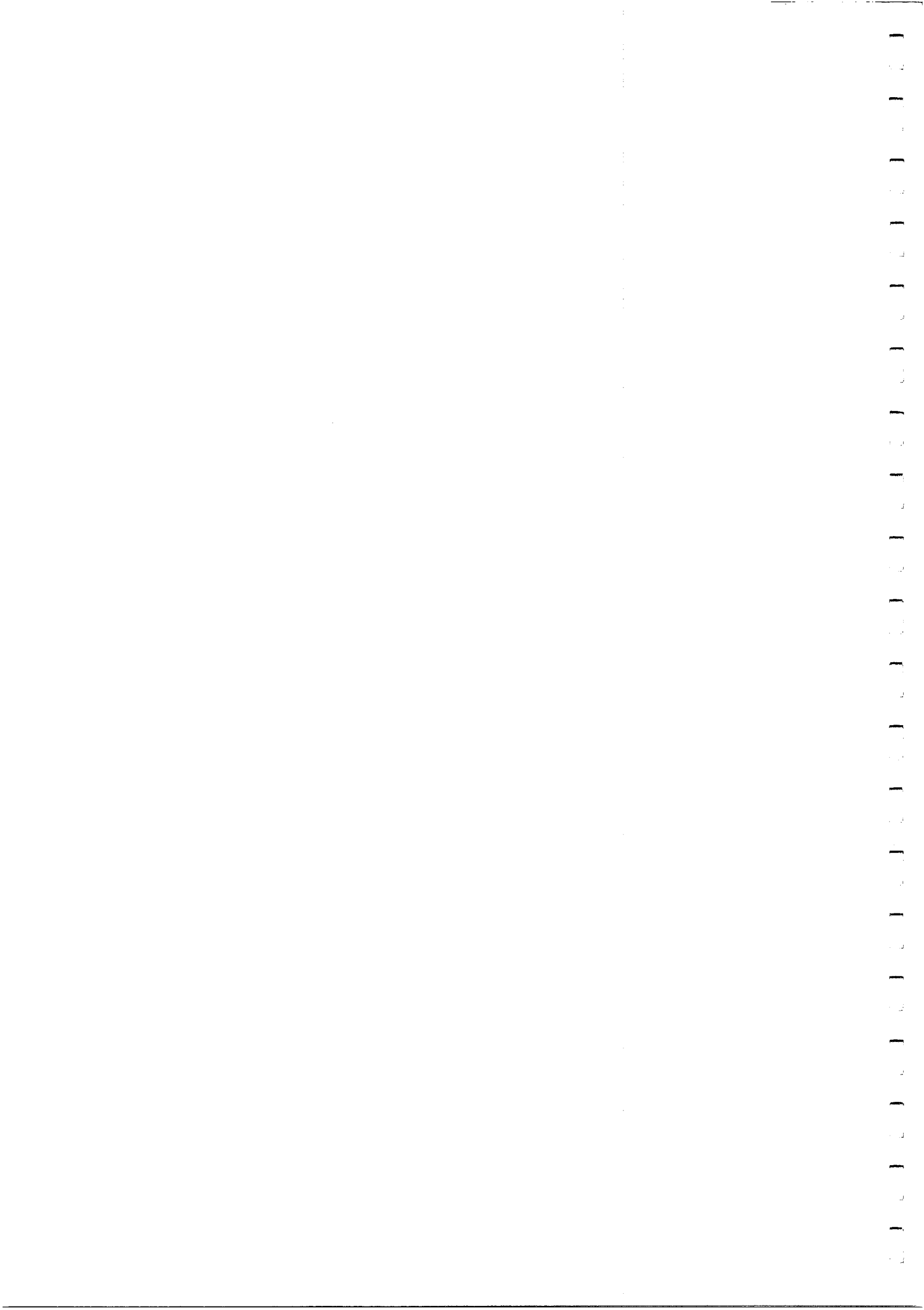
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## 8) EXAMPLES OF INSTALLATIONS FOR SPECIFIC PURPOSES

### 8.1) Dimensioning of solar panel power for agrometeorological station

When a weather station powered by a battery and recharged by solar panel is installed, we have to take in account the power drain by the system such as data-logger, sensors (if they required power), fan aspirator for temperature or humidity sensors, etc.

As an example solar panel dimensioning is estimated by radiation data of three sites in Italy: Milano, Roma, Crotone. The first city, Milano, is in the northern part of Italy, the second in the middle Italy and the third in the southern side of Italy. (Solar radiation data of the Italian Aeronautical Weather Service).

At these latitudes the minimum amounts of solar radiation over a plane of 45° slope ( $I_0$ ), are recorded in the month of December. The values are:

MILANO	1003Wh/m <sup>2</sup> d <sup>-1</sup>
ROMA	1839Wh/m <sup>2</sup> d <sup>-1</sup>
CROTONE	2137Wh/m <sup>2</sup> d <sup>-1</sup>

The 45° angle represent the common solar panel inclination.

To convert Wh/m<sup>2</sup> d<sup>-1</sup> to kJ/m<sup>2</sup> d<sup>-1</sup> multiply for 3.6 factor: 1 Wh/m<sup>2</sup> d<sup>-1</sup> = 3.6 kJ/m<sup>2</sup> d<sup>-1</sup>

If the average power drain of the device is 100mA at 12Vdc for 24 hours, we obtain a value of 28.8 Wh d<sup>-1</sup> (0.1A/12Vdc\*24h=28.8 Wh d<sup>-1</sup>).

If we consider a battery's efficiency of 60%, the solar panel should furnish 40 Wh d<sup>-1</sup> to the accumulator ( $W_0$ ).

The photovoltaic cell's average efficiency is considered equal to the maximum value of 12% for active silicon's surface unit.

The total active solar panel surface should then be:

$$\text{Solar Panel Surface (m}^2\text{)} = W_0 / (0.12 * I_0)$$

that is for:

MILANO	40/(0.12*1003)=0.33m <sup>2</sup>
ROMA	40/(0.12*1839)=0.18m <sup>2</sup>
CROTONE	40/(0.12*2137)=0.16m <sup>2</sup>

If you have the daily radiation expressed in kJ/m<sup>2</sup> d<sup>-1</sup>, you have to refer the value to an inclination plane of 45° dividing by the cosine of the angle, cos 45° = 0.707. Then you can convert it in Wh/m<sup>2</sup> d<sup>-1</sup> multiplying by the factor 0.27778.

Obviously this kind of application required an historical series of global radiation data (or an estimation if radiation data are unavailable).

### 8.2) Installation of air temperature profile study

This study foresees a different number of sensors depending on the heights which the temperature measurements are required.

Normally a logarithmic sensor's distribution along the vertical profile is the best way to perform this measure.

The limit for the closest sensor to the ground and the upper sensor's height depend on the soil cover and on the crop studied.

In this example three sensors at 0.05, 0.5 and 3 m are installed for surface temperature profile.

The sensor's set-up consists of a data-logger that scans three sensors (type PT100) every 30 seconds, and acquires the mean value every five minutes. These intervals could differ depending on the subjects of measurements. The sensors are included in a double concentric shield, to avoid direct sunlight effects. The sensors are non-ventilated.

The data-logger employed is a Delta-T logger mod. DL2. It has a specific board for 4 wire sensors acquisition. Each sensor was calibrated in laboratory and introduced in a thin steel capsule to protect against shock. This reduces also too fast fluctuations of temperature measurements.

Logger configuration is shown in chapter 2.2, and the constants are obtained by calibration against a reference sensor in a thermostatic bath. The range (suitable for Southern Europe latitudes) is  $-10 \div +50^{\circ}\text{C}$ .

In this kind of study we measure very low differences of air temperature, so we need temperature sensors with an accuracy of  $0.1^{\circ}\text{C}$  and a resolution of  $0.01^{\circ}\text{C}$ . Normal temperature sensors (i.e. for standard agrometeorological stations) with an accuracy of  $0.3^{\circ}\text{C}$  are then not suitable.

### 8.3) Installation for wind erosion studies

Deflation refers to the entrainment and transportation of soil particles and other materials by wind. In this process the soil particles are detached, transported, and deposited by wind action. Soil loss from a watershed due to wind depends on surface roughness; surface moisture of the soil; type; variety, and condition of vegetation; direction and velocity of the wind; and, in case of cultivated fields, the cloddiness of the soil [1]. Wind erosion is significant in arid and semiarid areas;

the detaching capacity of wind is function of the shear stress exerted by the wind and the size of soil grain:

$$D = f(U^*)^2$$

Where D is the detaching capacity in  $\text{g cm}^{-2} \text{ sec}^{-1}$ ,  $U^*$  is the shear velocity in  $\text{cm sec}^{-1}$ . Particles in the size range of 0.1÷0.15 mm are easily detached, and soils in the range of 0.05÷0.5 can be detached if wind velocity is great enough. Normally, particles above 1mm in diameter are not detached by winds even up to 16.5 m/sec. (USDA 1968; Troeth et al. 1980; Bagnold 1965)

Some authors proposed estimation methods for soil moisture by meteorological measurements, to predict the amount of soil loss by the wind. Fryrear et al. [2] utilized the following field instrumentation for the measure and the analysis of soil loss, in a typical uniform field with a well defined non-eroding boundary:

Meteorological instruments:

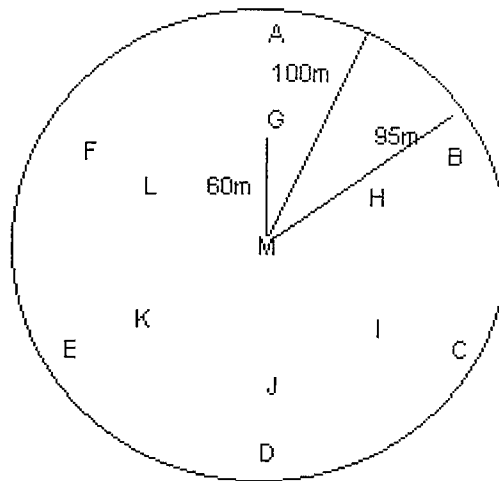
- four anemometers, 0.2, 0.5, 1.0, 2.0 m
- two air temperatures, 0.2, 2.0 m
- one solar radiation
- one soil temperature, -0.02 m
- one wind direction, 2.5 m
- one tipping bucket rain gauge
- one relative humidity sensor

Erosion samplers:

- 14 clusters BSNE suspended soil particles samplers at 0.05, 0.10, 0.20, 0.5, 1.0 m above the soil surface
- one surface creep soil flux sampler (0.0 to 0.003 m height, 0.005 m wide opening) with saltation (0.003 to 0.02 m height)
- one weighing BSNE dust sampler at 0.02 m height
- one SENSIT (threshold) 0.02 m height. This piezoelectric quartz crystal sensor counts particles impacts, and allows to determine the onset and the cessation of the saltation. This parameter is useful because most models require an accurate estimation of the threshold condition and erosion duration.

The validation site plan was organized as in Figure 47, where the points from A to M are the 14 clusters of samplers in a 200 m diameter field.

Figure 82. Measure points location



#### 8.4) Installation for crop water irrigation scheduling

Evapotranspiration estimate is commonly applied in the determination of crop water requirements and in irrigation planning. An accurate prediction of evapotranspiration is essential to evaluate the expected daily water consumption needed for irrigation scheduling. Many methods were proposed for estimating potential or real evapotranspiration, and different sensor's set up and parameters are then required. Integration of different methods can be a good way to improve the final result.

Following some methods collected in a recent review are described. [3]

##### *Measuring Potential Evapotranspiration (ETP)*

##### BLANEY-CRIDDLE METHOD

The relation representing mean value over the given month is (Blaney-Criddle, 1950) [4]:

$$ETP = c[p(0.46T+8)]$$

where:

$ETP$  = potential evapotranspiration for the month considered [ $\text{mm/d}^{-1}$ ]

$T$  = mean daily temperature over the month considered [ $^{\circ}\text{C}$ ]

$p$  = mean daily percentage of total annual daytime hours obtained from Table 1.x for a given month and latitude

$c$  = adjustment factor which depends on minimum relative humidity, sunshine hours and daytime wind estimates

Table n° 26: required sensors for Blaney-Criddle method

Parameters	Sensors
Daily mean air temperature	Thermometer
Daily minimum air humidity	Hygrometer
Daily sunshine duration	Sunshine duration sensor
Daily mean wind speed	Anemometer

### HARGREAVES METHOD

The form of equation used in this method [5]:

$$ETP = 0.0023 \frac{Rg}{L} (Tmg + 17.8)(T \max - T \min)^{0.5}$$

where

$ETP$  = potential evapotranspiration [ $mm \cdot d^{-1}$ ]

$Rg$  = daily solar extraterrestrial radiation [ $J \cdot m^{-2} \cdot d^{-1}$ ]

$T \max$  = daily maximum temperature [ $^{\circ}C$ ]

$T \min$  = daily minimum temperature [ $^{\circ}C$ ]

$Tmg$  = average daily temperature [ $^{\circ}C$ ]

$L$  = latent heat of vaporisation [ $J \cdot Kg^{-1}$ ]

in which:

$$L = (2500.5 - 2.44Tmg)10^3$$

$$Rg = I_0 \frac{24}{\pi} \sin \varphi \sin \delta [Hg - TgHg]$$

where  $I_0$  = hourly solar energy ( $4.87 \cdot 10^6 J \cdot m^2 \cdot h^{-1}$ )

$Hg$  = hour angle to sunset/dawn [rad]

$\varphi$  = latitude [degree]

$\delta$  = sun declination [rad]

$ng$  = number of day from 1<sup>st</sup> January

in which:

$$Hg = \arccos(-Tg \delta Tg \varphi)$$

$$\delta = 23.5 \cos \left[ \frac{360(ng - 172)}{365} \right] \frac{\pi}{180}$$

Table n° 27: required sensors for Hargreaves method

Parameters	Sensors
Daily Maximum air temperature	Thermometer
Daily minimum air temperature	Thermometer
Rainfall	Raingauge

## PAN EVAPORATION METHOD

The form of equation used in this method for Class A pan is:

$$ETP = k_p \cdot Epan \quad 1.4$$

where  $ETP$  = potential evapotranspiration [ $mm \cdot d^{-1}$ ]

$k_p$  = pan coefficient

$Epan$  = pan evaporation and represents the total daily value [ $mm d^{-1}$ ]

Table 28:  $k_p$  coefficient for A pan evaporimeter situated on different soil cover, and for different daily air humidity and wind run conditions (from Dorenboos e Pruitt, 1977).

		Evaporimeter on grass cover			Evaporimeter on bare soil		
Mean RH (%)		Low	Mean	High	Low	Mean	High
		<40	40÷70	>70	<40	40÷70	>70
Wind run (km d <sup>-1</sup> )	Distance from crop cover (m)						
Light (<175)	1	0.55	0.65	0.75	0.70	0.80	0.85
	10	0.65	0.75	0.85	0.60	0.70	0.80
	100	0.70	0.80	0.85	0.55	0.65	0.75
	1000	0.75	0.85	0.85	0.50	0.60	0.70
Moderate (175÷425)	1	0.50	0.60	0.65	0.65	0.75	0.80
	10	0.60	0.70	0.75	0.55	0.65	0.70
	100	0.65	0.75	0.80	0.50	0.60	0.65
	1000	0.70	0.80	0.80	0.45	0.55	0.60
Strong (425÷700)	1	0.45	0.50	0.60	0.60	0.65	0.70
	10	0.55	0.60	0.65	0.50	0.55	0.65
	100	0.60	0.65	0.70	0.45	0.50	0.60
	1000	0.65	0.70	0.75	0.40	0.45	0.55
Very strong (>700)	1	0.40	0.45	0.50	0.50	0.60	0.65
	10	0.45	0.55	0.60	0.45	0.50	0.55
	100	0.50	0.60	0.65	0.40	0.45	0.50
	1000	0.55	0.60	0.65	0.35	0.40	0.45

Table 29. Sensors required for Pan evaporation method

Parameters	Sensors
Daily evaporation	Class A Pan evaporimeter

## PENMAN METHOD

The form of equation used in this method is (Penman 1948) [6]:

$$ETP = ((d \cdot R_n / L) + (\gamma \cdot E)) / (d + \gamma)$$

$$d = (239 \cdot 17.4 \cdot e_s) / ((T + 239)^2)$$

$$R_n = 0.72 R_g - 86$$

$$E = 0.26 \cdot (e_s - e_a) \cdot (1 + 0.4 \cdot u)^2$$

$$e_s = 6.11 \cdot \exp(17.4 \cdot T / (T + 239))$$

$$e_a = e_s \cdot UR, \text{ or } e_a = 6.11 \cdot \exp(17.4 \cdot T_{min} / (T_{min} + 239))$$

where

ETP = potential evapotranspiration [mm d<sup>-1</sup>]

d = derivative of saturation vapor pressure/temperature [hPa °C<sup>-1</sup>]

R<sub>n</sub> = net radiation [cal cm<sup>-2</sup> d<sup>-1</sup>]

R<sub>g</sub> = global radiation [cal cm<sup>-2</sup> d<sup>-1</sup>]

L = latent heat of vaporisation [cal cm<sup>-2</sup> mm<sup>-1</sup>]      59.82 - 0.583 · T

γ = psychrometric constant [hPa °C<sup>-1</sup>]      0.66

E = atmospheric vapor deficit [mm d<sup>-1</sup>]

e<sub>s</sub> = saturation vapor pressure [hPa]

e<sub>a</sub> = actual vapor pressure [hPa]

u = wind speed [m s<sup>-1</sup>]

T = average temperature [°C]

T<sub>min</sub> = minimum temperature [°C]

Examples:

Data required

R<sub>g</sub> = global radiation [cal cm<sup>-2</sup> d<sup>-1</sup>]      500

u = wind speed [m s<sup>-1</sup>]      0.8

T = average temperature [°C]      22

T<sub>min</sub> = minimum temperature [°C]      13

Results:

R<sub>n</sub> = net radiation [cal cm<sup>-2</sup> d<sup>-1</sup>]      274

es = saturation vapor pressure [hPa]	26.4853
ea = actual vapor pressure [hPa]	14.9924
L = latent heat of vaporisation [ $cal \cdot cm^{-3}$ ]	46.994
E = atmospheric vapor deficit [ $mm \cdot d^{-1}$ ]	3.9443
d = derivative of saturation vapor pressure/temperature [ $hPa \cdot ^\circ C^{-1}$ ]	1.5932
ETP = potential evapotranspiration [ $mm \cdot d^{-1}$ ]	5.2780

Table 30. Sensors required for Penman method

Parameters	Sensors
Daily mean air temperature	Thermometer
Daily minimum air temperature	Thermometer
Daily mean air humidity	Hygrometer
Daily net radiation	Net Radiometer
Daily sunshine duration	Sunshine duration sensor
Daily mean wind speed	Anemometer
Daily Rainfall	Raingauge

To estimate the real evapotranspiration the value of ETP should be multiplied for a so-called Crop Coefficient. This value depends on the crop type, on the vegetation stage, etc. Some crop coefficients found on bibliography are reported on the appendix (chapter 9).

### *Measuring Real Evapotranspiration (ETR)*

#### AERODYNAMIC MODEL

The resulting equation gives the value for real evapotranspiration [7]:

$$ETR = \frac{M_w}{R\rho_w} k^2 \frac{(z-d)^2}{(z_1-z_2)} \frac{(e_1-e_2)(u_1-u_2)}{(Tm+273.15)} \frac{K_w}{K_a} \Phi_w^2$$

where

$ETR$  = real evapotranspiration [ $mm \cdot d^{-1}$ ]

$M_w$  = molecular weight of water ( $=18 \cdot 10^{-3} kg \cdot mole^{-1}$ )

$R$  = perfect gas constant ( $=8.314 \cdot J \cdot mole^{-1} \cdot K^{-1}$ )

$\rho_w$  = air density ( $=10^3 kg \cdot m^{-3}$ )

$k$  = Von Karman constant ( $=0.4$ )

$z_1, z_2$  = distance from soil of two height [m]

$d$  = height zero ground ( $=0.63$  m)

$e_1, e_2$  = partial water vapor tension at height  $z_1$  and  $z_2$  [Pa]

$u_1, u_2$  = wind speed at height  $z_1$  and  $z_2$  [ $m \cdot sec^{-1}$ ]

$T_w$  = average between temperature  $T_1, T_2$  [°C]

in which:

$$T_w = \frac{T_1 + T_2}{2}$$

for determination of  $K_w/K_m$  and  $\Phi_w$  there are empirical relationship from the Richardson Number:

$$Ri = \frac{g \frac{(T_1 - T_2)}{(z_1 - z_2)}}{(T_w + 273.15) \left( \frac{u_1 - u_2}{z_1 - z_2} \right)^2}$$

where

$Ri$  = Richardson Number [dimensionless]

$g$  = gravity acceleration ( $9.81 \text{ m} \cdot \text{s}^{-2}$ )

$T_1, T_2$  = dry bulb temperature at height  $z_1$  and  $z_2$  [°C]

Table 31 - Functional relationship between of  $K_w/K_m$  and  $\Phi_w$  and Richardson Number (Pruitt et al., 1973)

Condition	$\Phi_w$	$K_w/K_m$
Stability	$(1+16Ri)^{0.333}$	$1.13(1+95Ri)^{-0.110}$
Instability	$(1-16Ri)^{-0.333}$	$1.13(1-60Ri)^{0.074}$

Table 32: required sensors for Aerodynamic method

Parameters	Sensors
Dry bulb temperature	N° 2 Thermometers (at 2 levels)
Wet bulb temperature	N° 2 Wet Thermometers (at 2 levels)
Wind speed	N° 2 Anemometers (at 2 levels)
Rainfall	Raingauge

### BOWEN METHOD

The resulting equation gives the value for real evapotranspiration [8]:

$$ETR = \frac{Rn - G}{L(1 + \beta)}$$

where

$ETR$  = real evapotranspiration [ $\text{mm} \cdot \text{d}^{-1}$ ]

$Rn$  = net radiation [ $\text{J} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ]

$G$  = heat flux in the ground [ $\text{J} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ ]

$L$  = latent heat of vaporisation ( $2450 \times 10^3 \text{ J} \cdot \text{kg}^{-1}$ )

in which (for neutral condition):

$$\beta = C_p \frac{M_a P T_1 - T_2}{M_w L e_1 - e_2}$$

where

$M_a$  = molecular weight of air ( $29 \times 10^{-3} \text{ Kg} \cdot \text{mole}^{-1}$ )

$M_w$  = molecular weight of water ( $18 \times 10^{-3} \text{ Kg} \cdot \text{mole}^{-1}$ )

$C_p$  = specific heat of air ( $1.01 \times 10^3 \text{ J} \cdot \text{kg}^{-1} \cdot ^\circ\text{C}^{-1}$ )

$T_1, T_2$  = temperatures at height  $z_1, z_2$  [ $^\circ\text{C}$ ]

$P$  = atmospheric pressure [Pa]

$e_1, e_2$  = partial water vapor tension at height  $z_1$  and  $z_2$  [Pa]

Table 33. required sensors for Bowen method

Parameters	Sensors
Dry bulb temperature	N° 2 Thermometers (at 2 levels)
Wet bulb temperature	N° 2 Thermometers (at 2 levels)
Net radiation	Net radiometer
Atmospheric pressure	Air pressure sensor
Heat flux	Heat flux plate
Rainfall	Raingauge

The equation can also be express as follow:

$$ETR = \frac{Rn - G}{L(1 + \beta)}$$

$$\beta = (\rho \cdot C_p \cdot (T_1 - T_2)) / (\chi_1 - \chi_2)$$

$$\chi = ea \cdot (Mw / (R \cdot T))$$

T is express in K (to convert  $^\circ\text{C}$  in K add 273.15)

$$ea = es \cdot UR$$

$$es = 610.78 \cdot \exp(17.269 \cdot T / (T + 237.30))$$

where

$ETR$  = real evapotranspiration [ $\text{cm} \cdot \text{d}^{-1}$ ]

$Rn$  = net radiation [ $\text{cal} \cdot \text{cm}^{-2} \cdot \text{d}^{-1}$ ]

$G$  = heat flux in the ground [ $\text{cal} \cdot \text{cm}^{-2} \cdot \text{d}^{-1}$ ]

$L$  = latent heat of vaporisation  $598.2 - 0.583 \cdot T$  [ $\text{cal} \cdot \text{cm}^{-3}$ ]

(T is  $T_1$  express in °C)

$\beta$  = Bowen ratio

$\rho$  = air density =  $0.001204 [g \cdot cm^{-3}]$  for  $T=20^\circ C$

$C_p$  = specific heat of air =  $0.24 [cal \cdot g^{-1} \cdot ^\circ C^{-1}]$

$T_1, T_2$  = temperatures at height  $z_1, z_2 [^\circ C]$

$\chi_1, \chi_2$  = absolute humidity at height  $z_1, z_2 [g \cdot cm^{-3}]$

ea = actual water vapor tension [Pa]

$M_w$  = molecular weight of water =  $18 [g \cdot mole^{-1}]$

R = gas constant =  $8.314 [J \cdot mol^{-1} K^{-1}]$

es = partial water vapor tension [Pa]

UR = relative humidity [%]

Example [9]:

Data needed:

$T_1$ = temperature at height $z_1 [^\circ C]$	21
$T_2$ = temperature at height $z_2 [^\circ C]$	19.5
UR <sub>1</sub> = relative humidity at height $z_1$ [%]	80
UR <sub>2</sub> = relative humidity at height $z_2$ [%]	67
Rn = net radiation [ $cal \cdot cm^{-2} d^{-1}$ ]	420
G = heat flux in the ground [ $cal \cdot cm^{-2} d^{-1}$ ]	negligible

Results:

es <sub>1</sub> = actual water vapor tension at height $z_1$ [Pa]	2486.7217
es <sub>2</sub> = actual water vapor tension at height $z_2$ [Pa]	2266.6337
ea <sub>1</sub> = actual water vapor tension at height $z_1$ [Pa]	1989.3774
ea <sub>2</sub> = actual water vapor tension at height $z_2$ [Pa]	1518.6446
$\chi_1$ = absolute humidity at height $z_1 [g \cdot cm^{-3}]$	$14.642 \cdot 10^{-6}$
$\chi_2$ = absolute humidity at height $z_2 [g \cdot cm^{-3}]$	$11.235 \cdot 10^{-6}$
L = latent heat of vaporisation [ $cal \cdot cm^{-3}$ ]	585.957
$\beta$ = Bowen ratio	0.2170
ETR = real evapotranspiration [ $cm \cdot d^{-1}$ ]	0.5889

The dimensional equation of  $\chi$  is:  $\chi = ea \cdot (Mw / (R \cdot T))$ , and it can be write :

$\chi = ea \cdot (Mw \cdot (R^{-1} \cdot T^{-1})) = [Pa] [g \cdot mol^{-1}] [J^{-1} \cdot mol \cdot K] [K^{-1}] = [Pa] [g] [J^{-1}]$  this can be express:  $[N \cdot m^{-2}] [g] [N^{-1} \cdot m^{-1}] = [g \cdot m^{-3}] 10^{-6} = [g \cdot cm^{-3}]$

HEAT FLUX METHOD

The resulting equation gives the value for real evapotranspiration :

$$ETR = \frac{Rn - H - G}{L} \quad 1.9$$

where  $ETR$  = real evapotranspiration [ $mm \cdot d^{-1}$ ]

$Rn$  = net radiation [ $J \cdot m^{-2} s^{-1}$ ]

$L$  = latent heat of vaporisation ( $2450 \times 10^3 J \cdot kg^{-1}$ )

$G$  = heat flux in the ground [ $J \cdot m^{-2} s^{-1}$ ]

in which:

$$H = -k^2 \frac{M_a}{R} C_p \frac{P}{T_m} (z - d)^2 \frac{(T_1 - T_2)}{(z_1 - z_2)} (u_1 - u_2) (K_h / K_m) \Phi_m^{-2}$$

where  $k$  = Von Karman's constant (=0.4)

$M_a$  = molecular weight of air ( $29 \times 10^{-3} Kg \cdot mole^{-1}$ )

$C_p$  = specific heat of air ( $1.01 \times 10^3 J \cdot kg^{-1} C^{-1}$ )

$T_1, T_2$  = temperatures at height  $z_1, z_2$  [ $^{\circ}C$ ]

$P$  = atmospheric pressure [Pa]

$z_1, z_2$  = distance from soil of two height [m]

$d$  = height zero ground (=0.63h m)

$u_1, u_2$  = wind speed at height  $z_1$  and  $z_2$  [ $m \cdot sec^{-1}$ ]

$T_m$  = average between temperature  $T_1, T_2$  [ $^{\circ}C$ ]

$R$  = perfect gas constant (=  $8.314 \cdot J \cdot mole^{-1} \cdot K^{-1}$ )

Table 34 - Functional relationship between of  $K_w/K_m$  and  $\Phi_m$  and Richardson Number (Webb, Dyer et al., 1970)

Condition	$\Phi_m$	$K_w/K_m$
Stability	$(1-5.2Ri)^{-1}$	1
Instability	$(1-16Ri)^{-0.25}$	$(1-16Ri)^{0.25}$

Table 35. required sensors for Heat Flux method

Parameters	Sensors
Dry bulb temperature	N° 2 Thermometers (at 2 levels)
Wet bulb temperature	N° 2 Wet Thermometers (at 2 levels)
Net radiation	Net radiometer
Atmospheric pressure	Air pressure sensor
Heat flux	Heat flux plate
Rainfall	Raingauge

### 8.5) Installation for crop protection strategy based on agrometeorological data

Many simulation models can well describe pathogen growth on crops. They can also implement a crop growth model to estimate the percentage of tissues damaged (e.g. Leaf Area Index estimation) [10].

The agrometeorological input parameters often refer to the air temperature and humidity, rainfall, leaf wetness (especially for mushrooms attacks), solar radiation and wind speed.

#### **Downy mildew (*Plasmopara viticola*)**

An example of simulation model (PLASMO) for downy mildew (*Plasmopara Viticola*) disease on grapevine plants, is described. It was developed by the Ce.S.I.A., Florence - Italy, and it is based on agrometeorological observations and few plant's information like the L.A.I. (Leaf Area Index) value at the begin of the season, the shooting data, the first attack date and percentage.

Table 36. sensors required for PLASMO model

Parameters	Sensors
Air temperature	Thermometer
Air humidity	Hygrometer
Leaf wetness	Leaf wetness plate (1 at least, or more if available)
Rainfall	Raingauge

The agrometeorological data are stored every hour (by means of some readings); the sensors have to be installed as close as possible to the plants. The leaf wetness data could be obtained also by means of different sensors, positioned with different exposition to reproduce natural leaves conditions.

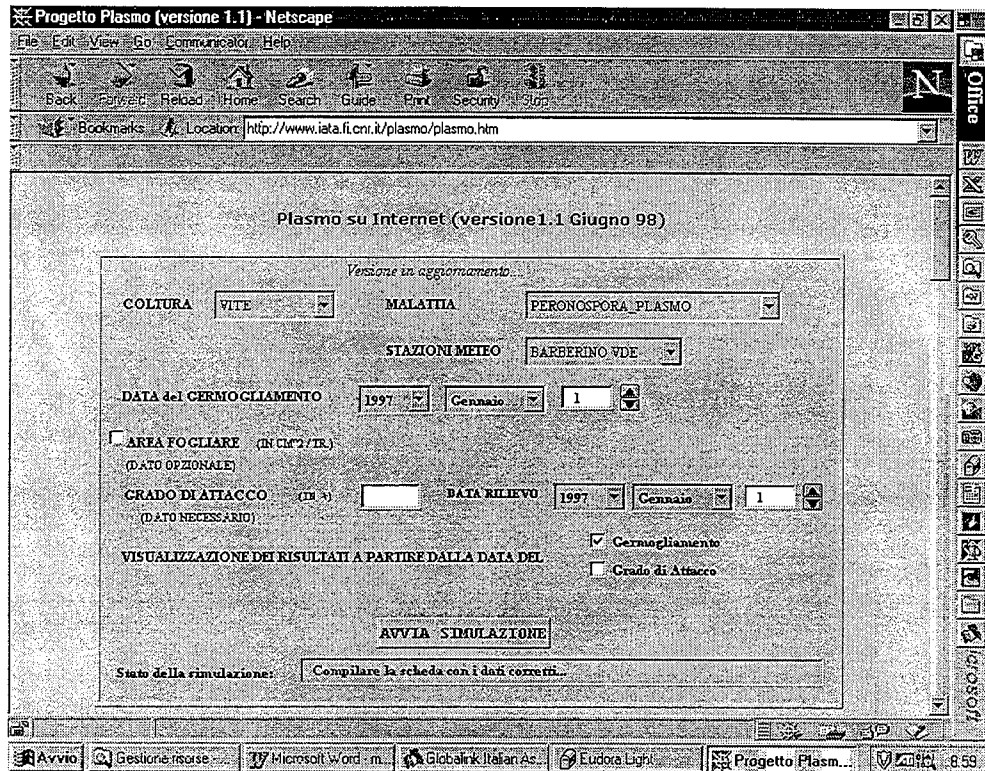
The pathogen needs for its developing of certain conditions in terms of mean daily air temperature, rainfall in the last 24 hours, grapevine sprig length. The model take in account also the leaf wetness duration, and the type of the last spray product employed (especially its persistence on the plant).

By a graphic output the growth of the pathogen generations are showed; when the line that represents this trend cross a given threshold the spray intervention is necessary. If two generation have a near reproduction cycle the product employed

could cover both the attacks, then one treatment is saved (that means an economic and ecological gain due to the rational approach).

The last version of the software run under Internet and the site is linked with some agrometeorological stations. These devices transmit every day the data by modem, then the file which contains the database is continuously upgraded. This way the operator can consult the proper internet page, and check the infection progression.

Figure 83 (below) shows the main page of the model in Internet [A]:



### Desert Locust (*Schistocerca gregaria*)

After the eggs deposition in moist soil, the development is strongly influenced by the temperature. The eggs have an incubation interval of 13 days around, with a minimum of 9 days. At the first stage the eggs have to absorb a water quantity equal to their weight to start the development, which velocity mainly depends on the temperature.

Some authors (J.F. Duranton and M. Lecoq, 1990) have studied this relationship: a table (n° 37) with the daily percentage variation of the embryonic development, related to the daily mean air temperature, is showed (C.O.P.R., 1981):

Table 37. (Extremes values relate to a confidence threshold of 95%)

Mean air	Daily percentage	Incubation duration (days)
----------	------------------	----------------------------

temperature (°C)	development (%)			
	Average	Extremes	Average	Extremes
10	1.0	0.7-1.4	99	70-139
11	1.2	0.9-1.7	83	60-116
12	1.4	1.0-2.0	70	51-97
13	1.7	1.2-2.3	60	44-82
14	1.9	1.4-2.7	51	38-70
15	2.3	1.7-3.1	44	33-60
16	2.6	1.9-3.5	39	29-52
17	3.0	2.2-4.0	34	25-46
18	3.3	2.5-4.5	30	22-41
19	3.8	2.8-5.1	27	20-36
20	4.2	3.1-5.7	24	18-32
22	5.1	3.8-7.0	19	14-26
24	6.1	4.5-8.3	16	12-22
26	7.0	5.2-9.6	14	10-19
28	7.9	5.8-10.7	13	9-17
30	8.6	6.3-11.0*	12	9.16*
32	9.1	6.7-11.0*	11	9-15*
34	9.4	6.8-11.0*	11	9-15*

\* Values corrected for a minimum incubation interval of 9 days.

Rao, Y.R. 1942, observed that the egg-stage duration is ten weeks around for soil average temperature (measured at 10 cm) of 19°C, to two weeks for a corresponding soil temperature of 34°C.

The degree of regularity of these processes has been utilized to provide forecast (e.g. the dates of hatching and of subsequent appearance of swarms), for control operations planning (R.C. Rainey 1963). [12]

After this period start the swarm development composed of five stages. In Sahel region, between June and September the swarm development take thirty days around. The shortest stage is the first and the longest is the fifth. The duration percentage for each of this fifth stages is respectively of: 14, 16, 18, 20 and 32% of total development, that is approximately 5, 5, 6, 7, 11 days for a complete development of 34 days.

Table 38 required sensors for Locust's embryo development studies

Parameters	Sensors
Air temperature	Thermometer
Air humidity	Hygrometer
Soil (or air) temperature	Thermometer (between -5 cm and -10 cm, for soil temperature.)
Rainfall	Raingauge

### 8.6) Installation for UV-B radiation study

The choice of sensor depends on the aim of studies [13]. For biological effects studies a spectroradiometer (very expensive) or a broadband radiometer with an output that match the DNA absorption spectra or the erythema absorption spectra (UV-B<sub>be</sub>, where *be* means biologically effective), will be utilized (Caldwell et Al., 1986). In practice the radiation measured in each nanometer of the UV-B band (280÷320 nm) by a spectrophotometer, is multiply for a factor experimentally determined. These values of coefficients depend on the absorption spectrum of the components studied. In the broadband sensors this modulation is made by interposition of filters over the transducer. The sensor response will have a trend like that showed on figure 55 in the chapter 4.

In experiments on the plants is advisable to associate a measure of P.A.R. flux, and global radiation to investigate the ratio between these solar radiation components.

Table 39: required sensors for UV-B effects for biological studies

Parameters	Sensors
UV-B <sub>be</sub>	Spectroradiometer or at least an UV-B <sub>be</sub> radiometer with weighted response for DNA or erythema absorption spectrum
P.A.R.	P.A.R. radiometer
Global radiation	Pyranometer (400÷1100 nm)

Note that last experiments were conduct in open field. The supplementary UVB radiation to plants is furnished by UVB lamps (Q-Panel, mod. UVB313, USA) [14].

To study the effects of solar radiation on the material aging (e.g. greenhouses plastic material), the sensor will have a normal radiation spectrum response (UV-B meteorological), showed in Figure 84. For these experiments is better to measure also the global radiation and the portion of UV-A radiation (320÷440 nm), because the ratio between these different portions of the spectrum could be a good index.

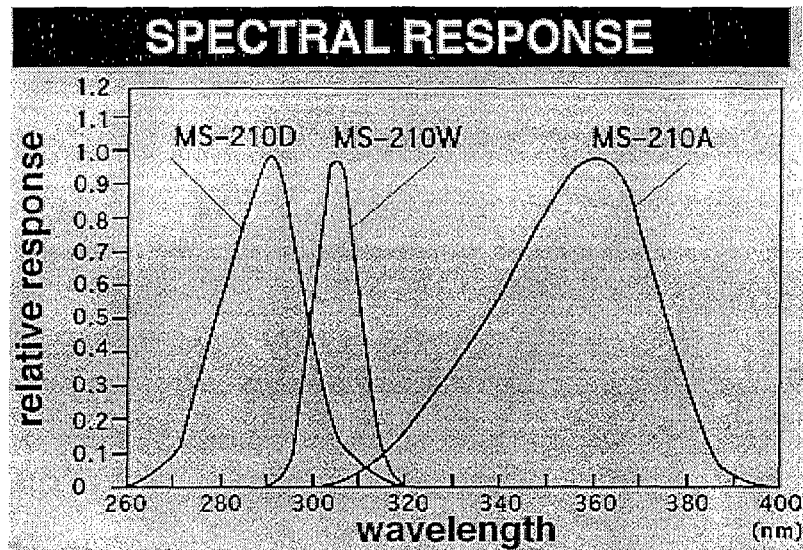


Figure 84. Response for UV-B and UV-B meteorological sensors. The spectral response of D model is fairly close to action spectrum of DNA (Deoxyribonucleic Acid). The W model is for meteorological measurements. (Courtesy of Eko instruments, Japan [B])

Table 40: required sensors for UV-B meteorological studies

Parameters	Sensors
UV-B meteorological	Spectroradiometer or at least an UV-B radiometer with meteorological response
UV-A	UV-A sensor
Global radiation.	Pyranometer (400÷1100 nm)

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## 9) APPENDIX

**9.1) Metrology characteristics of instruments***a) Span*

It is the maximum value of the quantity that the sensor can measure (Figure. 85). Some instruments may have selectable ranges by external command. In a paragraph later, range and accuracy relation will be explained.

*b) Threshold*

It is the lower signal level relieved by the sensor. It couldn't be necessarily equal to the zero value of the measured quantity. (Figure 85).

*c) Range*

Is the interval of the input values in which the instrument give an indication, in other words is the difference between the Span and the Zero. (Figure 85):

$$\text{Range} = \text{Span} - \text{Zero}$$

Often the Zero of the instrument match the quantity's Zero, then the Range and the Span become equals.

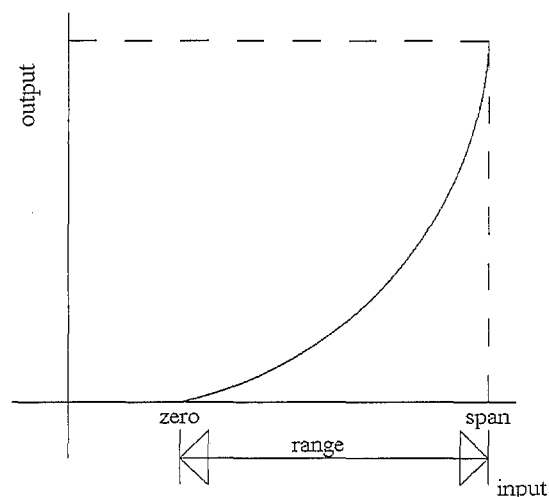


Figure 85 – output - input instrument's characteristic

where:

- Output = instrument's indication (e.g. cursor shift on a graduate range);
- Input = Quantity value measured by the sensor.

The figure shows the Zero, Span, and Range meaning

#### d) *Time response*

Give an indication about the instrument's response speed. That is the time employed by the instrument to detect a 90% of the input quantity variation. The readiness increase as lower is the number that represents it.

#### e) *Stability*

Is the instrument or sensor's property that describes how long they can conserve their characteristics. We can distinguish between short-term stability (e.g. time interval of an hour) and long term stability (e.g. time intervals of weeks or months). This parameter gives an indication about calibration's frequency. In some cases, above all for the sensors, we talk about Drift. This term means the variation, in the time, of the sensor's output signal when the physic quantity, which it is sensible, remain constant. For example some capacitive sensors for air humidity measurements, at high relative humidity values (above 70%) in the first 5 - 10 minutes, indicate the right value (e.g. 85%). As the time goes by, however, they could "drift" and on a time interval of 10 - 15 hours they indicate higher values such as 90% - 100%, even if the air humidity is unchanged.

#### f) *Linearity*

This give an indication about instrument's curve response, that is how the show value-Input value response approach to the ideal line with 45° slope. Generally this parameter is express as % of the Span, and it define a band in which the response curve should be included.

In the figure 86 instrument's response (whole line), is not linear but we can define it linear if we consider as the response the wide band L in which it is contained. Generally instead the L value, the percentage respect to the range is given:

$$L\% = (L/\text{Range}) \times 100$$

This is a desirable instrument's feature since allows a more easy response comprehension (an equation type like  $y = ax+b$  instead  $y = f(x)$  with f generic function of x), and in advance give also an indication about other instrument's features like the sensitivity and the hysteresis. The linearity is greater as lower is the number that represents it.

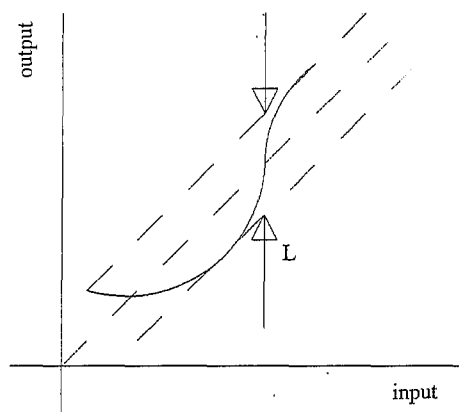


Figure 86

*g) Sensitivity*

Is the ratio between the quantity output variation (for example a value shows on the display) and the correspondent input variation. With linear response the sensitivity is equal for every point of the range, otherwise it can change depending the range value.

Default

$$S = d\_output/d\_input$$

That is constant only if output-input characteristic is linear (Figure 87)

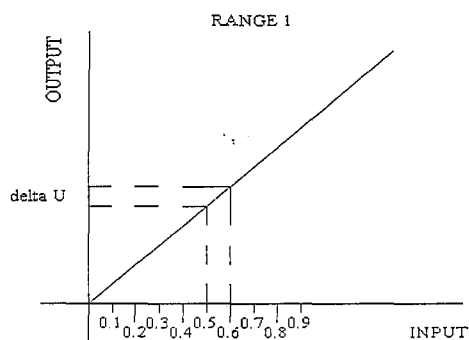


Figure 87a

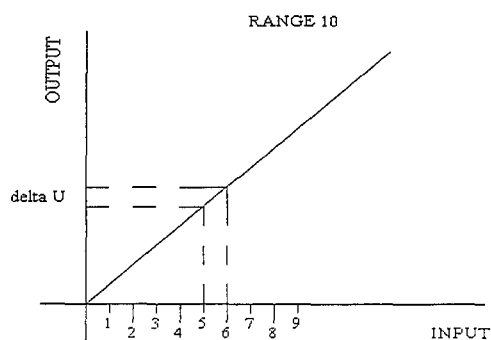


Figure 87b

In the instruments with selectable range the sensitivity varies with the range, that is it decrease as the range increase.

In figure 87/a is drawn an input-output characteristic in the range 1 then tenth are shown on the x axis, while in the figure 87/b we have the same characteristic with range 10 then unit are shown. Considering the  $\Delta U$  output variation that we have for a unit on the x axis it correspond to an input signal variation of 0.1; In the first case we then obtain a sensitivity of:

$$S1 = \Delta U/0.1$$

The same variation  $\Delta U$  is also given for the second case, considering again an unit variation on the x axis, which correspond an input signal variation of 1; The sensitivity in the range 10 is then:

$$S10 = \Delta U/1$$

be  $\Delta U$  equal for both cases, S10 is ten times smaller then S1.

#### *h) Hysteresis*

This is determined by the fact that the instrument's response of the input quantity for increasing values, don't match the response for decreasing values. This is a typical friction effects of mechanical instrumentation but also digital instrumentation (obviously for different causes because any mobile part is present) can have this disadvantage.

For example with increasing values, for friction effects, the cursor in presence of a  $V_0$  input quantity, doesn't cover a  $\theta_0$  angle and doesn't indicate the  $V_0$  value, but it covers the  $\theta_1$  angle indicating the  $V_1$  value (figure 88). Beginning from the end of range and coming back, the cursor with a  $V_0$  input quantity doesn't cover the  $\theta_0$  angle but, for friction effects, stops itself before in  $\theta_2$  position indicating the  $V_2$  value (figure. 88).

The curve obtained from the relation <output value Vs input value> cannot be linear with a  $45^\circ$  of slope, but it would have a trend shows in figure 89. Note that if this relation would be linear, no hysteresis phenomena could be observed.

This systematic error is difficult to evaluate because it changes depending on the value reached.

The hysteresis is quantified as percentage ratio of maximum deviation between the two response curves (obtained by input variations from the Zero to the Span and from the Span to the Zero) and the instrument's range.

$$I\% = (I/\text{Range}) \times 100$$

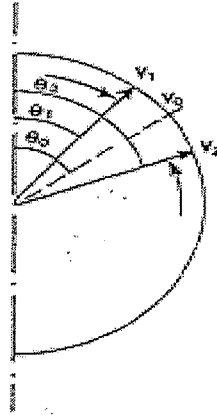


Figure 88

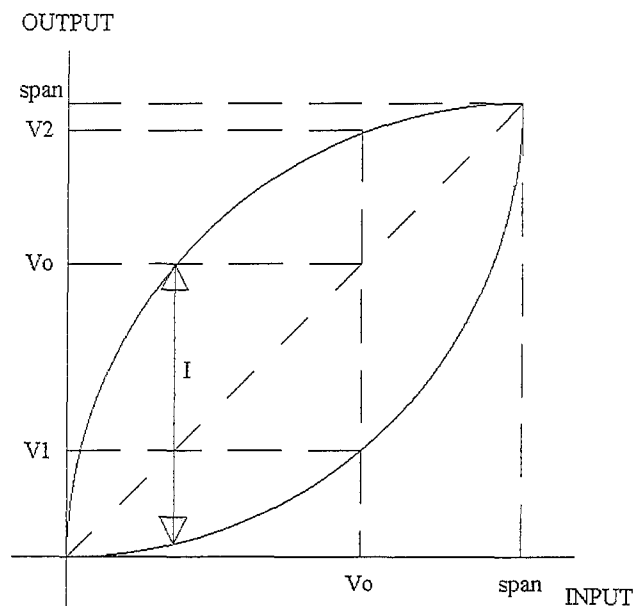


Figure 89

*i) Resolution*

It is the smallest change in the parameter being measured that causes a detectable change in the output of the instrument.

In most part of instrument with mechanical elements frictions or discontinuities can be present, then systematic errors are produced..

The ratio between quantization error and the range is called resolution and it is generally express as percent. Drawing on a graph the input-output relation for an instrument with known resolution, a step trend is obtained like that shows in figure 90 and for the above mentioned definition we have:

$$R\% = (\delta / \text{range}) \times 100$$

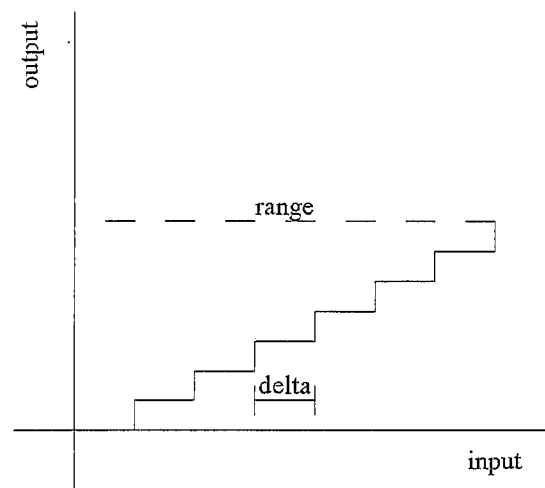


Figure 90

We can see that resolution is always less than 1 and the instrument will be better as smaller is R. In others words the resolution is greater as smaller is the number that describes it.

In practice we call resolution the quantization error, but the resolution is express as a pure number, while the quantization error is express in the measure unit.

Avoid confusion between the resolution and sensibility: the resolution is express as a pure number while sensibility is expressed by the ratio between output quantity and input quantity.

#### 1) Precision

It is defined as the maximum error that the instrument can produce. It is the maximum difference between the true value and the measured value (that cannot be determined but only statistically defined as mean value of infinite measure's number). The precision is greater as smaller is the number that represents it for

example an instruments with a precision of 0.1 is better than an instruments with a precision of 1. For the same instrument this parameter differs depending the Span.

For digital instrument this parameter is given as +/- 1 digit on the maximum representative number, that is for an instrument with four digit and value 2 as span, the maximum number that can be represented is:

$$1.999 \text{ +/- 1 digit}$$

The maximum number's uncertainty is of a unit on the thousandth

$$(\delta = 0.001).$$

If 200 of Span is selected the decimal point move on third position and the maximum visualization number become:

$$199.9 \text{ +/- 1 digit}$$

this is maximum number's uncertainty is of a unit on the tenths:

$$(\delta = 0.1).$$

Note that digital instrument is sometimes defined of **n** digit. In this case **n** display can assume every value from 0 to 9; furthermore others instruments can be of **n** digit and half, that means the digit are  $1+n$  but the first digit can assume only some value (generally 0 and 1).

On the precedent example the instrument can have 2, 20, 200 of Span with 4 digit, but in effect they are 3 digit and half because the first digit can assume only 1 as value.

For analog instruments Precision Class instead precision is given, and it is express as percentage ratio between the precision and the instrument's range:

$$C = (\delta / \text{range}) \times 100$$

For electrical instruments CEI rules (in Italy) foresee following class:

0.05%    0.1%    0.2%    0.3%    0.5%    1%    1.5%    2.5%    5%

For example if an instrument of 1 Class and 10 range gives an indication of 8, the manufacturer guarantee that maximum deviation from the true value is:

$$\delta = (C \cdot \text{range}) / 100 = (1 \cdot 10) / 100 = 0.1 \quad V = 8 \text{ +/- } 0.1$$

if the range is 100:

$$\delta = (C \cdot \text{range} / 100) = (1 \cdot 100) / 100 = 0.1 \quad V = 8 \pm 1$$

We deduce that the choice of instrument's span has to be close as more as possible (if it is available) to the measure range to obtain minimum error.

m) *Accuracy*

Repeating many times the same observation the instrument, for different causes, don't give always the same result, then the mean value have to be considered.

It is the deviation between the mean value and the true value and it is also called *statistical accuracy*. Avoid confusion between accuracy and precision defined in the last paragraph;

the precision is the difference between measured value and the true value. In others terms the precision indicates how the read value approach the true value while the accuracy, that take in account also random errors, indicate how the mean value approach the true value.

n) *Reliability (or repeatability)*

This gives an indication about value dispersion around the mean value.

Making for the same quantity a high number of observations a high number of different values will be obtained. Drawing a graph with the observation values in the X axis and the time's numbers which the values are appeared in the Y axis, a gaussian trend is obtained. The curve width at middle level can be take as reliability index. As larger is this curve as large is the values dispersion around the mean value.

Note that good reliability doesn't means more accuracy because a situation as shown in Figure 91 can be done:

$G_m$  is the mean value while  $G^*$  is the true value. In the first curve we have low number of values dispersion around the mean value. Then the instrument is reliable but it has a low accuracy because  $G_m$  is far from  $G^*$ . The opposite situation is shown in the second curve with a high values dispersion around the mean value (the curve is larger than the first), but  $G_m$  is near  $G^*$  then the instrument result in low reliability but better accuracy.

Because the exact Gaussian curve cannot be drawn because infinite observations would be needed, the reliability (defined as gaussian width) is express as the maximum value (that is in the worst hypothesis the gaussian has that width).

Note that as greater is the gaussian width as lower is the reliability then an instrument is more reliable as lower is the reliability's number represented.

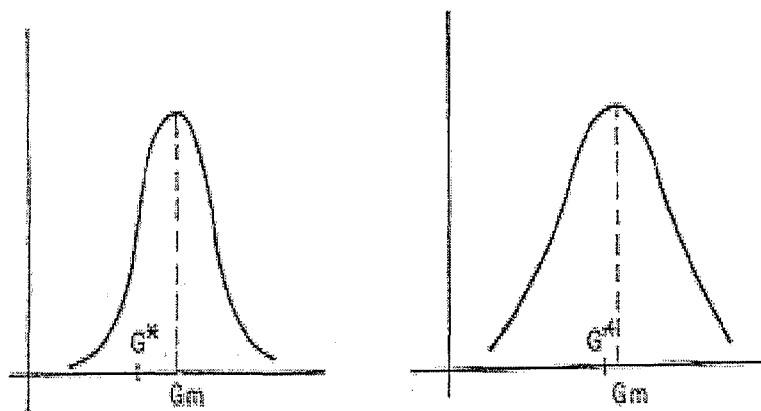


Figure 91

[1] [2]

## 9.2) Instrument's employment features

The main non-metrologic instrument's features are:

- Storage temperature, Operation temperature, Temperature coefficient (they relate to operational environmental conditions)
- Input and output impedance (linked to the sensor's circuitry)
- Reliability (that have statistical feature)

a) *Storage temperature*: defines the temperature's range (e.g.  $-20\text{ }^{\circ}\text{C}$  /  $+60\text{ }^{\circ}\text{C}$ ) in which a not operative instrument can be kept without any damage.

b) *Operative temperature*: defines a temperature range for operatives instrument (e.g.  $0\text{ }^{\circ}\text{C}$ ÷ $+40\text{ }^{\circ}\text{C}$ ). Its range is generally  $40\text{ }^{\circ}\text{C}$  around less than the storage temperature. To avoid temperature's limits over range is better to keep the instrument far from storage and operative critical values; take care on the instrument's operative temperature especially for field applications, where is easy to exit from the prescribed range.

c) *Temperature's coefficient*: indicates the correction to be introduced to the value, when the instrument works in the proper range but not exactly at its calibration's temperature (usually  $20\text{ }^{\circ}\text{C}$ ).

Don't confuse this parameter with the temperature coefficient described for thermometric sensors.

Others coefficient factors relates to the humidity and the pressure but they are less important than the temperature parameter.

d) *Input and output impedance*: they relate to the instrument's circuitry employment; the input impedance is important characteristics for recording and indicator devices (e.g. data-logger and terminals) while the output impedance is an important features for the sensors.

For recording devices the input impedance has to be as large as possible, and vice versa the sensors. They should have a low impedance as possible; good values for input impedance can have a magnitude in hundreds of thousands of  $\Omega$  (in hundreds of  $\text{k}\Omega$ ), while the sensor's impedance could be less than a tens of  $\Omega$ . When this condition its not verified a circuitry called "impedance adapter" (buffer) have to be introduced between the sensor and the instrument.

e) *Reliability – mean life*: the reliability is defined as the operative lifetime probability for a component or a system, for given operating conditions and a determined time period. The reliability concept has become more important in the last years cause the systems complexity. Actually low instrument's reliability increasing maintenance costs, and it cause a damage to the user because its unavailability.

This characteristic hasn't to be confused with the device's quality. The reliability determines the time interval in which the instrument maintains its properties, while its

quality is a measure of the excursion respect to the standard (or to the assigned specifications for the same function).

To explain this difference we can think about a sensor that decrease its performances as the time pass, but it can be utilize for others purposes. A simple breakdown, such as a fuse interruption in a data-logger, constitutes a worst damage for the user that could lose all data after the fuse's interruption.

Statistically the breakdown rate,  $\lambda$ , of the device's components have a trend (relative to the time interval) as shown in fig. 92. The breakdown rate represents the percentage of devices or components damaged in the time unit at the  $t$  instant. This is calculated respect the component's number still operative at that instant:

$$\lambda = \frac{s}{\frac{n}{t}}$$

where:

$s$  = samples' number failure during the test

$n$  = number of samples tested

$t$  = test duration

In the figure n° 92 we can locate three intervals: the initial, of premature mortality, that rapidly decrease by the time, due to manufacturer defect. The central interval, characterized by a break rate quite constant that represent the useful life of the component (here the damages have random origin). Final the senile phase characterized by rapidly damages increasing.

The  $\lambda(t)$  curve is experimentally determined for several components.

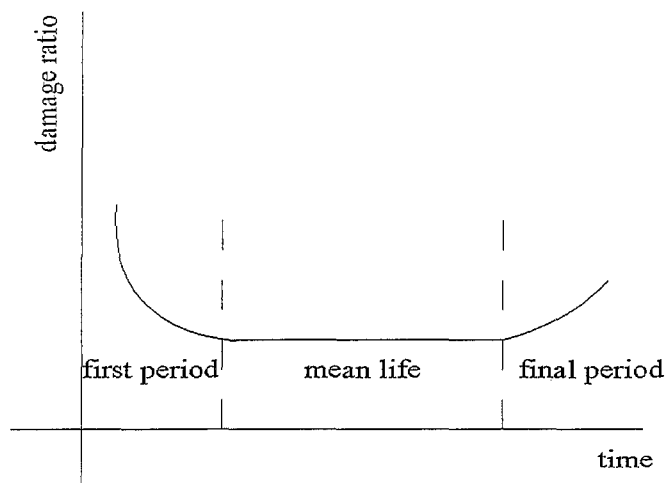


Figure 92

During the central phase of the life,  $\lambda$  is approximately constant. In this case we show that the reliability,  $R(t)$ , is an exponential function of  $\lambda$ :

$$R(t) = \exp(-\lambda t)$$

It represents the probability of the operative life for a given component for the time  $t$ .

The reliability depends on a wide number of factors, even unidentified or measurable, then it has a statistical trend.

Besides the employment hours, the percentage of damages depends on:

- the environmental conditions (high temperature and humidity or too low values of these parameters),
- the circuitry conditions (main power not steady, that is fast and intense over-transient or earth not sufficient),
- the number of -power on- operations of the instrument (high damage's percentage happens during this operation).

Some instruments have a better reliability because they are realized with special components, built following military rules. In fact they are submitted to an artificial aged process that stabilize their characteristics. This procedure induces death of worst components; the damages on the first part of instrument's operations are then avoided.

$$\text{Mean life} = 1/\lambda$$

### 9.3) Conversion table for main measurements units

This paragraph contains some conversion factors collected from bibliography [3] [4] and from Internet [A].

#### Metric prefixes and multipliers

Prefix	Abbreviation	Scientific notation	Decimal notation
tera	T	$10^{12}$	1.000.000.000.000
giga	G	$10^9$	1.000.000.000
mega	M	$10^6$	1.000.000
kilo	k	$10^3$	1.000
hecto	h	$10^2$	100
deca	da	10	10
deci	d	$10^{-1}$	0.1
centi	c	$10^{-2}$	0.01
milli	m	$10^{-3}$	0.001
micro	$\mu$	$10^{-6}$	0.000001
nano	n	$10^{-9}$	0.000000001
pico	p	$10^{-12}$	0.000000000001
femto	f	$10^{-15}$	0.000000000000001
atto	a	$10^{-18}$	0.000000000000000001

#### Irradiance units

<i>Irradiance</i>	<i>To convert to <math>W m^{-2}</math> multiply by:</i>
$mW cm^{-2}$	10.0
$kW m^{-2}$	1000.0
$cal cm^{-2} min^{-1}$	697.8
$Mcal cm^{-2} s^{-1}$	41.868

#### Radiant exposure units

<i>Radiant exposure</i>	<i>To convert to <math>J m^{-2}</math> multiply by:</i>
$J cm^{-2}$	10000.0
$Cal cm^{-2}$	41868.0
$kcal m^{-2}$	4186.8

#### Radiation to equivalent depth of evaporation

<i>Radiation unit</i>	<i>Equivalent (depth in mm)</i>
$1 cal cm^{-2}$	1/59 mm
$1 cal cm^{-2} min$	1 mm/h
$1 mW cm^{-2}$	1/70 m/h
$1 mW cm^{-2} (24 h)$	0.344 mm/day
$1 cal cm^{-2} min (24 h)$	24 mm/day
$1 Joule cm^{-2} min (24 h)$	5.73 mm/day

## Conversion factors for radiometric, photometric and photonic quantities

To convert → on ↓	$W m^{-2}$	$\mu E s^{-1} m^{-2}$	Lux
$W m^{-2}$	1	$217.4 * 10^{-3}$	$424 * 10^{-5}$
$\mu E s^{-1} m^{-2}$	4.6	1	$195.3 * 10^{-4}$
Lux	236	51.2	1

## Conversion coefficients for Kelvin, Celsius and Fahrenheit temperature ranges.

To convert → on ↓	degree K	°C	°F
K	1	$Y=X+273.15$	$Y=(5/9)*(X+459.67)$
°C	$Y=X-273.15$	1	$Y=(5/9)*(X-32)$
°F	$Y=(9/5*X)-459.67$	$Y=(9/5*X)+32$	1

## Conversion factors for speed units

To convert ↓ on →	$m s^{-1}$	$km h^{-1}$	mile $h^{-1}$	kt
$m s^{-1}$	1	0.27778	0.44704	0.51444
$km h^{-1}$	3.6000; 0	1	1.6093	1.8520
mile $h^{-1}$	2.2369; 0	0.62137	1	1.1508
kt	1.9438; 0	0.53996	0.86898	1

(kt = nautical mile per hour); Multiply by the factor in the appropriate cell of the table

Conversion factors for pressure units (S.I. unit  $1 Pa = 1 N m^{-2}$ )

To convert → on ↓	Pascal ( $N m^{-2}$ )	$Kg m^{-2}$ (= $mmH_2O$ )	mm Hg	atm	bar
Pascal ( $N m^{-2}$ )	1	9.8067; 0	1.3332; +2	1.0133; +5	1; +5
$Kg m^{-2}$ (=mm $H_2O$ )	1.0197; -1	1	1.3595; +1	1.0332; +4	1.0197; +4
mm Hg	7.5006; -3	7.3556; -2	1	7.6000; +2	7.5006; +2
atm	9.8692; -6	9.6784; -5	1.3158; -3	1	9.8692; -1
bar	1; -5	9.8067; -5	1.3332; -3	1.0133	1

The number  $n$  after the “,” means that the first number must be multiplied for  $10^n$

## Miscellaneous conversion factors

From	To	Multiply by
atm	$kg/m^2$	$1.0332 * 10^4$
atm	$kg/cm^2$	1.0332
atm	$g/cm^2$	$1.0332 * 10^3$
bar	atm	0.9869
bar	$kg/cm^2$	$1.020 * 10^4$
cal	J	4.184
cal	kWh	$1.1622 * 10^{-6}$

cal	kJ	$4.184 \cdot 10^{-3}$
cal/sec	W	4.184
cal/sec	J/sec	4.184
cal/cm <sup>2</sup> sec	W/cm <sup>2</sup>	4.184
cal/cm <sup>2</sup> sec	kW/m <sup>2</sup>	41.84
cal/cm <sup>2</sup> h	kW/m <sup>2</sup>	$1.1622 \cdot 10^{-2}$
cal/cm <sup>2</sup> h	W/cm <sup>2</sup>	$1.1622 \cdot 10^{-3}$
cal/cm <sup>2</sup> min	kW/m <sup>2</sup>	$6.9732 \cdot 10^{-1}$
cm	in	0.39370
cm	ft	0.03281
cm <sup>2</sup>	in <sup>2</sup>	0.15500
cm <sup>2</sup>	ft <sup>2</sup>	$1.0764 \cdot 10^{-3}$
cm <sup>3</sup>	in <sup>3</sup>	$6.1023 \cdot 10^{-2}$
cm <sup>3</sup>	ft <sup>3</sup>	$3.5315 \cdot 10^{-5}$
erg	cal	$2.3901 \cdot 10^{-8}$
g/cm <sup>2</sup>	atm	$9.6784 \cdot 10^{-4}$
hp	kW	0.74570
hp	cal/min	$1.06936 \cdot 10^4$
J	cal	0.239006
J	erg	107
J	Wh	$2.7778 \cdot 10^4$
J/sec	W	1
J/sec	cal/min	14.3404
J/sec	hp	$1.34102 \cdot 10^{-3}$
kJ	kWh	$2.7778 \cdot 10^{-4}$
kJ/m <sup>2</sup>	cal/m <sup>2</sup>	239.006
kg/cm <sup>2</sup>	atm	0.96784
km	mi	0.62137
km <sup>2</sup>	acres	247.105
km/h	ft/sec	0.9113
kW	hp	1.3410
kW	cal/min	$1.43197 \cdot 10^4$
kW	J/sec	$10^3$
kWh	cal	$0.59326 \cdot 10^4$
kWh	kJ	3600
kW/m <sup>2</sup>	W/cm <sup>2</sup>	0.10000
kW/m <sup>2</sup>	cal/cm <sup>2</sup> sec	0.23901
mi	yds	1760
mi	m	1609.34
mi <sup>2</sup>	km <sup>2</sup>	2.58999
mi <sup>2</sup>	acres <sup>2</sup>	640.0000
mi <sup>2</sup>	ha	258.9988
N	dynes	$10^5$
W	J/sec	1
W/cm <sup>2</sup>	cal/cm <sup>2</sup> sec	0.239045
W/cm <sup>2</sup>	kW/m <sup>2</sup>	10.0000
W/cm <sup>2</sup>	cal/cm <sup>2</sup> min	14.3310
Wh	cal	859.184
Wh	kg m	367.098
Wh	kJ/m <sup>2</sup>	$3.6000 \cdot 10^4$

#### **9.4) Institutions and Companies addresses of agrometeorological interest**

This list of addresses is collected from the "bookmark file" organized during the preparation of this guide. We divided such addresses in three parts:

- Institutions (i.e. Universities, Public Services, Organizations, etc.)
- Utilities (i.e. Internet sites with glossary terms, unit conversion tables, etc)
- Companies (i.e. sensor's manufacturers)

#### **INSTITUTIONS**

<http://www.wmo.ch/index.html>

World Meteorological Organization

Information and Public Affairs Office

41, avenue Giuseppe-Motta - 1211 Geneva 2 / Switzerland

Tel: (041 22) 730 8314/15 - Fax (041 22) 733 2829 - Tlx: 414199A OMM CH

<http://www.fao.org/>

FAO

Viale delle Terme di Caracalla,

00100 Rome, Italy

Tel.: +39(6) 57051

Fax: +39(6) 57053152

E-mail at FAO

Telex: 625852/625853/610181 FAO I

Telegrams: FOODAGRI ROME

<http://www.iata.fi.cnr.it/geniata.html>

C.N.R.-I.A.T.A.

Institute for Agrometeorology and Environmental Analysis for Agriculture

Piazzale delle Cascine, 18

50144 - Firenze - Italy

Tel. +39 55 301422-301504

Fax. +39 55 308910

<http://www.lamma-rtrt.regione.toscana.it/>

Laboratorio per la Meteorologia e la Modellistica Ambientale

(Laboratory for Meteorology and Environmental Modelling)

Via Einstein, 35/b

50100 - Campi Bisenzio - Firenze

Tel. +39 55 897621

Fax. +39 55

<http://159.213.57.69/uvweb/index.html>

COST 713 international action on forecast of UV-B radiation

"European Cooperation in the Field of Scientific and Technical Research"

[grifoni@lamma-rtrt.regione.toscana.it](mailto:grifoni@lamma-rtrt.regione.toscana.it)

<http://www.npl.co.uk/>

National Physical Laboratory  
Queens Road, Teddington, Middlesex, United Kingdom, TW11 0LW  
Telephone: +44 (0)181-977 3222, Fax: +44 (0)181-943 6458  
E-mail enquiries: [enquiry@npl.co.uk](mailto:enquiry@npl.co.uk)

<http://www.meteo.go.ke/>  
The Director,  
Kenya Meteorological Department  
P. O. Box 30259, Nairobi.  
Phone 254-2-567880  
Fax 254-2-567888/9  
E-mail [director@lion.meteo.go.ke](mailto:director@lion.meteo.go.ke)

<http://ss.niaes.affrc.go.jp/pub/hseino/agromet/agromete.html>  
Division of Agrometeorology  
National Institute of Agro-Environmental Sciences  
Email: [hseino@ss.niaes.affrc.go.jp](mailto:hseino@ss.niaes.affrc.go.jp) (Hiroshi SEINO)

<http://www.arsia.toscana.it/meteo/english.htm>  
ARSIA (Tuscany Regional Agrometeorological Service)  
Servizio Agrometeorologico  
Via Pietrapiana, 30  
50121 FIRENZE  
Tel. 055/27551  
Fax 055/2755216

and:

ARSIA  
Servizio Agrometeorologico Regionale  
Via Roma, 3  
56100 PISA  
Tel. 050/800611  
Fax 050/503220  
E-mail: [meteoarsia@cpr.it](mailto:meteoarsia@cpr.it)  
Fax on demand 050/8006222

---

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[INSTRUMENTS] [JOBS] [JOURNALS] [K-12] [MAIL] [MARINE] [METOFFICE]  
[MODELS] [NEWLINK] [NEWS] [ORGS] [PERSONAL] [SAT] [SCHOOLS]  
[SKYWARN] [SOFTWARE] [TELNET] [TORNADO] [UNIV]  
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owens@ugems.psu.edu

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<http://www.soton.ac.uk/~scp93ch/refer/convfact.html>

Unit Conversion

<http://elroy.nmsu.edu/cahe/redtops/h/h-640.html>

Measuring Soil Moisture in Pecan Orchards

Guide H-640

PH 4-205

Esteban Herrera, NMSU Extension Horticulturist

John White, El Paso County Extension Agent

<http://www.eureka.lk/Eurek@Site/FAQ's/FAQ.htm>

What is the Internet ? Go to:

\*Definition \*history \*www \*e-mail \*What you need \*ftp \*Web site (creation + holding) \*Relay Chat \*Leased line \*Mail Servers \*E-2-Fax

<http://www.csr.utexas.edu/tsgc/stars/metgloss.html>

Glossary of Meteorology Terms

<http://www-cmpo.mit.edu/radlab/Glossary.html>

Radar Meteorology Glossary

Most of this glossary is reprinted with the kind permission of Ronald E. Rinehart of the University

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<http://glossary.weather.utande.co.zw/index.htm>

Ministry of Transport and Energy

Department of Meteorological Services

ATTN: (select one of the choices listed below)

PO BOX BE 150

Belvedere

Harare - Zimbabwe

Contact Meteorological Office by Telephone, Fax or Telex

Phone: (263) 4 - 774891/2/5

Fax: (263) 4 - 774890

Telex: 40004 METEO ZW

<http://www.ece.orst.edu/~ece482/lasers/ee48894/pamela/pamprop.htm>

## Laser Doppler Anemometry

Proposal for EE488  
 Department of Electrical Engineering  
 University of Washington  
 by Kelly Doser and Pamela Roper, November, 1994

<http://www.cstv.to.cnr.it/toi/it/toi.html>  
 The Time of Internet by Fabrizio Pollastri  
 Email: [pollastri@cstv.to.cnr.it](mailto:pollastri@cstv.to.cnr.it)

<http://www.meteor.wisc.edu/~hopkins/100hold/a-zehgls.htm>  
 HOPKINS GLOSSARY OF WEATHER TERMS  
 Last update 6 June 1996  
 Edward J. Hopkins, Ph.D.  
 Department of Atmospheric and Oceanic Sciences  
 University of Wisconsin-Madison  
 Email: [hopkins@meteor.wisc.edu](mailto:hopkins@meteor.wisc.edu)

<http://odwin.ucsd.edu/glossary/tc.html>  
 Glossary of Social Science Data and Computer Terms

<http://wombat.doc.ic.ac.uk/foldoc/index.html>  
 FOLDOC - Free On-Line Dictionary Of Computing

<http://info-s.com/gloss.html>  
 Glossaries Info Service  
 Info Service Categories (below only some categories are showed):

- Atmospheric Chemistry and Air Quality Glossary
- Carbon Dioxide and Climates Glossary
- ILC Glossary of Internet Terms
- Computing Terms
- Measurement Glossary
- Meteor Astronomy
- Physics Terms
- Energy Terms
- Remote Sensing Terminology
- Social Science Computing and Data Terms Glossary
- Solar Terrestrial Terms
- Systematic Glossary
- Technical Notation
- Tropical Cyclone and Hurricane Glossary
- Water Quality Association Glossary of Terms
- Water Resource Terms
- Weather Glossaries

<http://www.sowacs.com/sensors/index.html>  
 sowacs.com

The Types of Soil water Content Sensors how they work, some literature on them,  
 where to get them and how much they cost.

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last update : 7 March 1998

<http://res.agr.ca/CANSIS/NSDB/SLC/V2.0/CLAYER/texttr.html>

Texture of mineral layer

(ref: Research Branch, 1976; Expert Committee, 1982)

<http://galaxy.einet.net:80/editors/john-beadles/introgps.htm>

Introduction to GPS Applications

John T. Beadles, Email: [jbeadles@pobox.com](mailto:jbeadles@pobox.com)

<http://wwwhost.cc.utexas.edu:80/ftp/pub/grg/gcraft/notes/gps/gps.html>

Global Positioning System Overview

Peter H. Dana

Department of Geography, University of Texas at Austin.

Send comments and suggestions to: [pdana@mail.utexas.edu](mailto:pdana@mail.utexas.edu).

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<http://nimbus.unbc.ca/envs/201/manf97/manf97.html>

Laboratory Manual for Environmental Studies 201:

Introduction to Atmospheric Science

Peter L. Jackson

Environmental Studies Program

University of Northern British Columbia

Fall, 1997

Acknowledgments:

Parts of the material contained here is derived (with modifications) from course notes of T. R. Oke, of the Department of Geography, University of British Columbia. The material is used here with his permission.

<http://www-cosdis.ornl.gov/FIFE/Datasets/Surface Flux/Eddy Correlation GSFC.html#3>.

FIFE

First ISLSCP Field Experiment (ISLSCP: International Satellite Land Surface Climatology Project)

Contact Information:

ORNL DAAC User Services

P.O. Box 2008

Mail Stop 6407

Oak Ridge National Laboratory

Oak Ridge, TN 37831-6407

Telephone: (423) 241-3952

FAX: (423) 574-4665

Email: [ornl daac@ornl.gov](mailto:ornl daac@ornl.gov)

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Fax: 61-77-254-155

Campbell Scientific Canada

Phone: 403-454-2505

Fax: 403-454-2655

Campbell Scientific Ltd. - Europe

Phone: +44-(0)1509-601141

Fax: +44-(0)1509-601091

<http://www.lsi-lastem.it/>

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Fax 02/95770594

<http://www.traverse.com/commerce/rmyoung/rmyhome1.htm>

Gill

Telephone: 616-946-3980

FAX: 616-946-4772

R. M. Young Company

2801 Aero Park Drive

Traverse City, Michigan 49686 USA

<http://www.eppleylab.com/>

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LABORATORY, INC.

12 Sheffield Avenue, PO Box 419

Newport, Rhode Island 02840 USA

Tel: 401-847-1020 Fax: 401-847-1031

Email: [eplab@mail.bbsnet.com](mailto:eplab@mail.bbsnet.com)

<http://www.carterscott.com.au/>

Middleton Solar Instruments

Telephone +61-3-9388 9811

FAX +61-3-9388 9822

Postal address

Carter-Scott Design

16 Wilson Avenue

Brunswick  
Victoria 3056 - Australia.  
Electronic mail [csd@enternet.com.au](mailto:csd@enternet.com.au)

<http://www.solar.com/>  
Solar Light Co. Inc. Philadelphia, PA 19126  
Phone:(215)927-4206 Fax:(215)927-6347  
Email : [info@solar.com](mailto:info@solar.com)

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Sensor Instruments Co., Inc.  
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Concord, NH 03301  
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Phone 61-7-3203 5066  
Fax 61-7-3881 0019

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EGYPT  
Phone 20-2-401 5321  
Fax 20-2-402 4217

Masibus Process Instruments (P) Ltd.  
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INDIA  
Phone 91-2712-24453  
Fax 91-2712-25457

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ITALY  
Phone 39-6-7984 1028  
Fax 39-6-7984 5254

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Dubai  
UNITED ARAB EMIRATES  
Phone 971-4-62 2728  
Fax 971-4-62 5506

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Livingston  
West Lothian  
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FAX: (UK) 01506 438543

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Imko Micromodultechnik GmbH  
Im Stöck 2 D-76275 Ettlingen  
Telefon +49 7243 592110 Fax +049 7243 90856

<http://env.licor.com/>  
Support Info  
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LI-COR, Inc.  
P.O. Box 4425  
Lincoln, NE 68504

Shipping Address:  
LI-COR, Inc  
4421 Superior Street  
Lincoln, NE 68504

E-Mail Address: [envsales@env.licor.com](mailto:envsales@env.licor.com)  
Web Address: <http://www.licor.com>  
Phone Number: 402-467-3576

Fax Number: 402-467-2819

<http://www.dynamax.com/#6>

Dynamax, Inc.  
10808 Fallstone Rd.  
Suite 350  
Houston, TX 77099  
1-800-727-3570 Domestic Sales  
1-888-396-2628 Service  
1-281-564-5100 Main Office  
1-281-564-5200 Fax

<http://www.specmeters.com/index.htm>

Spectrum Technologies, Inc.  
23839 W. Andrew Rd.  
Plainfield Illinois 60544  
800-248-8873  
815-436-4440  
Fax: 815-436-4460  
E-mail: [specmeters@aol.com](mailto:specmeters@aol.com)

<http://ats.com.au/monitor/>

Monitor Sensors  
7 - 9 Industrial Drive  
Caboolture Qld 4510  
Australia  
Tel: +61 7 5495 7222  
Fax: +61 7 5495 7246

<http://www.netstra.com.au/tain/welcome.html>

Tain Electronics Pty. Ltd. A.C.N. 006 496 706  
10 Rowern Court  
Box Hill North  
VICTORIA 3129  
AUSTRALIA

Phone +61 3 98987366  
Fax +61 3 98997992  
e-mail [tain@emerald.cns.net.au](mailto:tain@emerald.cns.net.au)

<http://www.awis.com/>

Agricultural Weather Information Service Inc.  
1735 E. University Dr., Suite 101, P.O. Box 3267  
Auburn, AL 36831-3267  
United States of America  
(334) 826-2149 (voice) / (334) 826-2152 (fax)

<http://www.eko.co.jp/eko/indexe.html>

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## COMPANY OUTLINE

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Factory/  
1-21-8, Hatagaya, Shibuya-ku, Tokyo 151, Japan  
TEL 81-3-3469-4561 FAX 81-3-3469-5897  
Osaka Office/

Medical Building 3-1-14, Uchiawaji-machi, Chuo-ku,  
Osaka 540, Japan  
TEL 81-6-943-7588 FAX 81-6-943-7286

<http://www.pmp.it/AGinstruments/home.htm>

[aginstru@pmp.it](mailto:aginstru@pmp.it)

International phone: ++39/2/98237487

International fax: ++39/2/98237489

Post/Office Address:

Agostoni - Gabbini snc

Via Delle Industrie, 21

20060 Colturano MI - ITALY

<http://www.ametsoc.org/AMS/>

American Meteorological Society

45 Beacon Street

Boston, MA 02108-3693

Telephone: 617-227-2425

Fax: 617-742-8718

<http://www.iata.fi.cnr.it/convenzioni/fma/fma.htm>

A.M.F. (APPLIED METEOROLOGY FOUNDATION)

Via G. Caproni 8, 50145 FIRENZE Tel. +3955-301422, Fax. +3955-308910

E-MAIL: [zaldei@sunserver.iata.fi.cnr.it](mailto:zaldei@sunserver.iata.fi.cnr.it)

<http://www.delta-t.co.uk/>

Delta-T Devices Ltd 128 Low Road, Burwell, Cambridge CB5 0EJ U.K.

Tel. +44 1638 742922, Fax +44 1638 743155,

E-Mail: [fi42@delta-t.co.uk](mailto:fi42@delta-t.co.uk)

<http://www.davisnet.com/>

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Hayward, CA 94545.

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1-510- 732-9229 from outside USA and Canada

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Email: [webeditor@casella.co.uk](mailto:webeditor@casella.co.uk)

<http://www.rotronic-usa.com/>  
Rotronic Instrument Corp.  
160 E. Main Street, Huntington NY 11743  
Toll Free: (800) 628-7101 Phone: (516) 427-3898 Fax: (516) 427-3902

<http://www.hannainst.com/welcome.htm>  
Hanna Instruments, Inc.  
584 Park East Drive  
Highland Industrial Park  
Woonsocket, RI 02895  
Toll : (800) HANNA-US 426-6287  
Tel: (401) 765-7500  
Fax: (401) 765-7575  
E-Mail: [usa@hannainst.com](mailto:usa@hannainst.com) (USA Sales)  
E-Mail: [latinsales@hannainst.com](mailto:latinsales@hannainst.com) (Latin America Sales)

<http://ats.com.au/monitor/>  
Monitor Sensors  
7 - 9 Industrial Drive  
Caboolture Qld 4510  
Australia  
Tel: +61 7 5495 7222  
Fax: +61 7 5495 7246

<http://www.netstra.com.au/tain/welcome.html>  
Tain Electronics Pty. Ltd. A.C.N. 006 496 706  
10 Rowern Court  
Box Hill North  
VICTORIA 3129 - AUSTRALIA

Phone +61 3 98987366  
Fax +61 3 98997992  
e-mail [tain@emerald.cns.net.au](mailto:tain@emerald.cns.net.au)

<http://www.trimble.com/index.htm>  
North American Offices of Trimble Navigation Limited

Corporate Offices  
645 North Mary Avenue  
Sunnyvale, CA 94086  
Phone: 408-481-8000  
FAX: 408-481-2000

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Environmental Sensors, Inc.

P.O. Box 720698  
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D-40882 Ratingen  
Germany  
Fax: (0)2102-856 80 56  
Phone: (0)2102-856 80 66

<http://www.yesinc.com/product/uvb1-spec.html>

Yankee Environmental Systems, Inc.  
Airport Industrial Park  
101 Industrial Blvd.  
Turners Falls, MA 01376 USA  
Telephone: (413) 863-0200  
Fax: (413) 863-0255  
Email: [info@yesinc.com](mailto:info@yesinc.com)

## 9.5) Julian days table

Day of month	GEN	FEB	MAR	APR	MAG	GIU	LUG	AGO	SET	OTT	NOV	DIC	Day of month
1	1	32	60	91	121	152	182	213	244	274	305	335	1
2	2	33	61	92	122	153	183	214	245	275	306	336	2
3	3	34	62	93	123	154	184	215	246	276	307	337	3
4	4	35	63	94	124	155	185	216	247	277	308	338	4
5	5	36	64	95	125	156	186	217	248	278	309	339	5
6	6	37	65	96	126	157	187	218	249	279	310	340	6
7	7	38	66	97	127	158	188	219	250	280	311	341	7
8	8	39	67	98	128	159	189	220	251	281	312	342	8
9	9	40	68	99	129	160	190	221	252	282	313	343	9
10	10	41	69	100	130	161	191	222	253	283	314	344	10
11	11	42	70	101	131	162	192	223	254	284	315	345	11
12	12	43	71	102	132	163	193	224	255	285	316	346	12
13	13	44	72	103	133	164	194	225	256	286	317	347	13
14	14	45	73	104	134	165	195	226	257	287	318	348	14
15	15	46	74	105	135	166	196	227	258	288	319	349	15
16	16	47	75	106	136	167	197	228	259	289	320	350	16
17	17	48	76	107	137	168	198	229	260	290	321	351	17
18	18	49	77	108	138	169	199	230	261	291	322	352	18
19	19	50	78	109	139	170	200	231	262	292	323	353	19
20	20	51	79	110	140	171	201	232	263	293	324	354	20
21	21	52	80	111	141	172	202	233	264	294	325	355	21
22	22	53	81	112	142	173	203	234	265	295	326	356	22
23	23	54	82	113	143	174	204	235	266	296	327	357	23
24	24	55	83	114	144	175	205	236	267	297	328	358	24
25	25	56	84	115	145	176	206	237	268	298	329	359	25
26	26	57	85	116	146	177	207	238	269	299	330	360	26
27	27	58	86	117	147	178	208	239	270	300	331	361	27
28	28	59	87	118	148	179	209	240	271	301	332	362	28
29	29		88	119	149	180	210	241	272	302	333	363	29
30	30		89	120	150	181	211	242	273	303	334	364	30
31	31		90		151		212	243		304		365	31

### 9.6) Crop Coefficients

Here are shown some crop coefficients found in bibliography. They are employed to estimate the real evapotranspiration from the potential evapotranspiration.

#### CROP COEFFICIENT FOR ALFALFA, CLOVER, GRASS-LEGUMES AND PASTURE

##### Crop coefficient for Alfalfa, Clover, Grass-legumes and Pasture

		Alfalfa	Grass for hay	Clover, Grass-legumes	Pasture
Humid	kc mean	0.85	0.80	1.00	0.95
Light to moderate wind	Kc peak	1.05	1.05	1.05	1.05
	Kc low	0.50	0.60	0.55	0.55
Dry	kc mean	0.95	0.90	1.05	1.00
Light to moderate wind	Kc peak	1.15	1.10	1.15	1.10
	Kc low	0.40	0.55	0.55	0.50
Strong wind	kc mean	1.05	1.00	1.10	1.05
	Kc peak	1.25	1.15	1.20	1.15
	Kc low	0.30	0.50	0.55	0.50

#### CROP COEFFICIENT FOR RICE

##### Crop coefficient for Rice

	Planting	Harvest	First & Second month	Mid-season	Last 4 weeks
<b>Humid Asia</b>					
<i>Wet season (monsoon)</i>	June-July	Nov-Dec			
Light to mod. wind			1.1	1.05	0.95
Strong wind			1.15	1.1	1.00
<i>Dry season</i>	Dec - Jan	Mid -May			
Light to mod. wind			1.1	1.25	1.00
Strong wind			1.15	1.35	1.05
<b>North Australia</b>					
<i>Wet season</i>	Dec - Jan	Apr -May			
Light to mod. wind			1.1	1.05	0.95
Strong wind			1.15	1.1	1.00
<b>South Australia</b>					
<i>Dry summer</i>	Oct	March			
Light to mod. wind			1.1	1.25	1.00
Strong wind			1.15	1.35	1.05
<b>Humid S. America</b>					
<i>Wet season</i>	Nov-Dec	Apr - May			
Light to mod. wind			1.1	1.05	0.55
Strong wind			1.15	1.1	1.00
<b>Europe (Spain, S. France)</b>					

<b>and Italy)</b>					
<i>Dry season</i>	May- June	Sept-Oct			
Light to mod. wind			1.1	1.2	95.00
Strong wind			1.15	1.3	0.04
<b>U. S. A.</b>					
<i>Wet summer (south)</i>	May	Sept-Oct			
Light to mod. wind			1.1	1.1	0.95
Strong wind			1.15	1.15	1.00
<i>Dry summer (Calif.)</i>	early May	early Oct			
Light to mod. wind			1.1	1.25	1.00
Strong wind			1.15	1.35	1.05

## CROP COEFFICIENT FOR AQUATIC WEEDS

### Crop coefficient for Aquatic Weeds and Coefficients for Open Water

Type of vegetation	Humid		Dry	
	light to mod. wind	strong wind	light to mod. wind	strong wind
Submerged (crassipes)	1.1	1.15	1.15	1.2
Floating (duckweed)	1.05	1.05	1.05	1.05
Flat leaf (water lilies)	1.05	1.1	1.05	1.1
Protruding (water hyacinth)	1.1	1.15	1.15	1.2
Reed swamp (papyrus, cattails)				
Standing water	0.85	0.85	0.9	0.95
Moist soil	0.65	0.65	0.75	0.8
Open water	1.1	1.15	1.15	1.2

## CROP COEFFICIENT FOR BANANAS

### Crop coefficient for Bananas

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec			
<u>Mediterranean climate</u>															
<i>First-year crop, based on March planting with crop height 3.5 m by August:</i>															
Humid, light to mod. wind			0.65	0.6	0.55	0.6	0.7	0.85	0.95	1	1	1			
Humid, strong wind			0.65	0.6	0.55	0.6	0.75	0.9	1	1.05	1.05	1.05			
Dry, light to mod. wind			0.5	0.45	0.5	0.6	0.75	0.95	1.1	1.15	1.1	1.1			
Dry, strong wind			0.5	0.45	0.5	0.65	0.8	1	1.15	1.2	1.15	1.15			
<i>Second season with removal of original plants in Feb. And 80% cover by August:</i>															
Humid, light to mod. wind	1	0.8	0.75	0.7	0.7	0.75	0.9	1.05	1.05	1.05	1	1			
Humid, strong wind	1.05	0.8	0.75	0.7	0.7	0.8	0.95	1.1	1.1	1.1	1.05	1.05			
Dry, light to mod wind	1.1	0.7	0.75	0.7	0.75	0.85	1.05	1.2	1.2	1.2	1.15	1.15			
Dry, strong wind	1.15	0.7	0.75	0.7	0.75	0.9	1.1	1.25	1.25	1.25	1.2	1.2			
<u>Tropical climates</u>															
Months following planting:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0.4	0.4	0.45	0.5	0.6	0.7	0.85	1	1.1	1.1	0.9	0.8	0.8	0.95	1.05
Suckering															
shooting															
harvesting															

## CROP COEFFICIENT FOR CITRUS

Crop coefficient for Citrus (Grown in predominately dry areas with light to moderate wind)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Large mature trees providing = 70% tree ground cover												
Clean cultivated	0.75	0.75	0.70	0.70	0.70	0.65	0.65	0.65	0.65	0.70	0.70	0.70
no weed control	0.90	0.90	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Tree providing = 50% tree ground cover												
Clean cultivated	0.65	0.65	0.60	0.60	0.60	0.55	0.55	0.55	0.55	0.55	0.60	0.60
no weed control	0.90	0.90	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Tree providing = 20% tree ground cover												
Clean cultivated	0.55	0.55	0.50	0.50	0.50	0.45	0.45	0.45	0.45	0.45	0.50	0.50
no weed control	1.00	1.00	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95

## BIBLIOGRAPHY

- [1] Benincasa, F., e Zipoli, G., Strumenti e sensori per misure agrometeorologiche. 1990, Manuale tecnico n. 8. CeSIA-Accademia dei Georgofili, Firenze.
- [2] Fritschen, L.J., and Gay, L.W. Environmental Instrumentation, 1979, Springer-Verlag, New York, USA
- [3] Pennycuik C.J., Handy Matrices of unit conversion factors for biology and mechanics. Ed. Edward Arnold, 1974
- [4] Benincasa, F, Maracchi, G, e Rossi P., Agrometeorologia, 1991, Patron editore, Bologna.

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## 10. INTERNET Useful Addresses

### Chapter 1 – Sensors

[A] From Internet page: <http://www.navidec.com/components/thin/wiring.html>

[B] From Internet page:  
<http://www.alive.de/imko/Default.htm>

[C] From Internet page:  
<http://www.exar.com/smi.htm>

[D] From Internet page:  
<http://www.metek.de/usa1.html>

### Chapter 2 – Data acquisition systems

[A] From Internet page:  
<http://www.ora.com/reference/dictionary/>

### Chapter 3 – State of the Art and Available Instrumentation

[A] From Internet page:  
<http://www.campbellsci.com/>

[B] From Internet page:  
<http://env.licor.com/>

[C] From Internet page:  
<http://www.delta-t.co.uk/>

[D] From Internet page:  
<http://www.onsetcomp.com/>

[E] From Internet page:

<http://www.omega.com/index.html>

[F] From Internet page:

<http://www.vaisala.com/www/webcom.nsf?OpenDatabase>

[G] From Internet page:

<http://www.traverse.com/commerce/rmyoung/rmyhome1.htm>

[H] From Internet page:

<http://www.lsi-lastem.it/>

[I] From Internet page:

From Internet page: <http://www.metek.de/usa1.html>

[J] From Internet page:

<http://kikori.uf.a.u-tokyo.ac.jp/Tour/Aichi/huuryoku.html>

[K] From Internet page:

<http://www.eppleylab.com/>

[L] From Internet page:

<http://www.sci-tec.com/kipp.htm>

[M] From Internet page:

<http://www.carterscott.com.au/>

[N] From Internet page:

<http://www.eko.co.jp/eko/indexe.html>

[O] From Internet page:

<http://www.yesinc.com/product/uvb1-spec.html>

[P] From Internet page:

<http://www.rotronic-usa.com/>

[Q] From Internet page:

<http://www.iata.fi.cnr.it/convenzioni/fima/fma.htm>

## **Chapter 4 – Utilization and Maintenance of Automatic Agrometeorological Stations**

[A] From Internet page:

<http://www.trimble.com/index.htm>

## **Chapter 5 – Instrumentation Power and Protection**

[A] From Internet page:

<http://www.glt.com.au/default.htm>

[B] From Internet page:

<http://www.semtech.com/>

[C] From Internet page:

<http://ourworld.compuserve.com/homepages/bhuebner/how.htm>

## **Chapter 6 – Sensors Calibration**

## **Chapter 7 – Data Analysis and Archiviatio**

[A] From Internet page:

<http://odwin.ucsd.edu/glossary/tc.html>

[B] From Internet page:

<http://wombat.doc.ic.ac.uk/foldoc/index.html>

[C] From Internet page:

<http://www.awis.com/>

[D] From Internet page:

<http://www.arsia.toscana.it/>

[E] From Internet page:

<http://www.lamma-rtrt.regione.toscana.it/eng/index.html>

[F] From the Internet page:

<http://www.meteo.go.ke/obsv/cropbul.html>)

[G] From Internet address:

<http://www.voicetech.com/index.html>

[H] From Internet address:

[http://www.fnc.gov/Internet\\_res.html](http://www.fnc.gov/Internet_res.html)

[I] From Internet address:

from: <http://www.eureka.lk/Eurek@Site/FAQ's/FAQ.htm>

## **Chapter 8 – Data Analysis and Archivation**

[A] From Internet address:

<http://www.iata.fi.cnr.it/plasmo/plasmo.htm>

[B] From Internet page:

<http://www.eko.co.jp/eko/indexe.html>

## **Chapter 9 – Appendix**

[A] From Internet page:

<http://www.soton.ac.uk/~scp93ch/refer/convfact.html>

**WORKBOOK FOR AGROMETEOROLOGICAL STATIONS SET-UP**

**INTRODUCTION**

This workbook relates to the “**Manual on Instrumentation and Operations for automatic Weather Stations for Agrometeorological Applications**”.

Some exercises could have more than one answer. W.M.O. gives indication and advises to make good and comparable measurements, and this part of the guide could be utilized to practice with these rules.

**EXERCISE 1**

**AUTOMATIC AGROMETEOROLOGICAL STATIONS INSTALLATION**

Which is the right position(s) for a standard Agrometeorological Weather Station (AWS) installation?

- a) The AWS should not be closer than eight or ten times the height of the surrounding objects (trees, bush, buildings, pylon, etc.).
- b) Soil surface has to be maintained irrigated with homogeneous grass canopy cover.
- c) The AWS should not be closer than five÷six times the height of the surrounding objects (trees, bush, buildings, pylon, etc.).
- d) Soil surface has to be representative of the zone. If a crop cover is present it should reach the upper level of the evaporimeter tank, in order to have a natural radiation shield.
- e) Soil surface has to be representative of the zone. If a crop cover is present it should be cut at proper frequency to keep it uniform.

For an AWS installation in desert zone characterized by high thermal excursion, rare desert storms and gust wind, which is the best sensor's set up?

A)

Sensor's technical characteristics:

	Thermometer	Hygrometer	Anemometer	Rainfall	Radiometer
Range	-10÷+40 °C	10÷90 %	0÷40 m/s		0÷1000 W/m <sup>2</sup>
Accuracy	±0.01°C	±3%	0.5 m/s	5%	1% of range

B)

Sensor's technical characteristics:

	Thermometer	Hygrometer	Anemometer	Rainfall	Radiometer
Range	-10÷+65 °C	5÷100 %	0÷50 m/s		0÷2000 W/m <sup>2</sup>
Accuracy	±0.1°C	±3%	±0.5 m/s <15 m/s ±1 m/s >15 m/s	0.2 mm	2%

C)

Sensor's technical characteristics:

	Thermometer	Hygrometer	Anemometer	Rainfall	Radiometer
Range	-10÷+55 °C	0÷100 %	0÷60 m/s		0÷2000 W/m <sup>2</sup>
Accuracy	±0.3°C	±1%	0.2 m/s	3%	5 %

## EXERCISE 2

### CHOICE OF DATA LOGGER

For the following sensors equipment which is the data-logger that match their output?

A)

	Thermocouple K type	Cup anemometer	Digital pluviometer	Thermopile Radiometer
Measuring range	-250÷1260 °C	0÷40 ms <sup>-1</sup>		0÷1400 Wm <sup>-2</sup>
Sensitivity	39.5µV°C <sup>-1</sup>	25 mV/ms <sup>-1</sup>	Pulse	10µV/Wm <sup>-2</sup>
Resolution	0.1°C	0.1 m/s	0.2 mm	0.1 Wm <sup>-2</sup>
Accuracy	±0.2°C	±1% range	±2%	±1%

B)

	PT100 Thermoresistance	Cup anemometer	Digital pluviometer	Photocell Radiometer
Measuring range	-30÷+70°C	0÷40 ms <sup>-1</sup>		0÷1400Wm <sup>-2</sup>
Sensitivity	100Ω at 0°C + 0.38Ω°C <sup>-1</sup>	62.5 mV/ms <sup>-1</sup>	Pulse	1mV/Wm <sup>-2</sup>
Resolution	0.5°C	0.1 ms <sup>-1</sup>	0.2 mm	1Wm <sup>-2</sup>
Accuracy	±1%	±1% range	±2%	±2%

C)

	Thermocouple T type	Cup anemometer	Digital pluviometer	Thermopile Radiometer
Measuring range	-300÷1100°C	0÷60ms <sup>-1</sup>		0÷1400Wm <sup>-2</sup>
Sensitivity	45μV°C <sup>-1</sup>	20mV/ms <sup>-1</sup>	Pulse	10μV/Wm <sup>-2</sup>
Resolution	0.1°C	0.1ms <sup>-1</sup>	0.2mm	0.5wm <sup>-2</sup>
Accuracy	±0.3°C	±2.5% range	±1%	±1%

Data-logger description:

Data-logger characteristics	A	B	C
Voltage Range	0÷2048mV	0÷1000mV	0÷2500mV
Voltage Resolution	4 μV	1 μV	10 μV
Resistance Range	/	1K÷10KΩ	20÷200Ω
Resistance Resolution	/	5Ω	0.15Ω
Signal acquired	Volt, μA, Pulse	Volt, Resistance, Pulse	Volt, Resistance, Pulse

**EXERCISE 3**

SENSORS CHOICE

Which is the best sensor's configuration for a standard AWS installation?

A	B	C
Air temperature	Air temperature	Air temperature
Air humidity	Air humidity	Soil temperature
Net Radiation	Soil temperature	P.A.R.
Global radiation	Wind speed	Wind speed
Wind speed	Wind direction	Wind direction
Evaporation	Evaporation	Evaporation
Soil heat flux	Global radiation	Soil heat flux
Rainfall	Rainfall	Rainfall

**EXERCISE 4**

DATA ACQUISITION CONFIGURATION

Which is the right sensor's set up for Penman evapotranspiration method:

A)

Parameters	Sensors
Daily mean air temperature	Thermometer
Daily net radiation	Net radiometer
Daily sunshine duration	Sunshine duration sensor
Daily mean wind speed	Anemometer
Daily Rainfall	Raingauge

B)

Parameters	Sensors
Daily mean air temperature	Thermometer
Daily mean air humidity	Hygrometer
Daily global radiation	Radiometer
Daily sunshine duration	Sunshine duration sensor
Daily mean wind speed	Anemometer
Daily Rainfall	Raingauge

C)

Parameters	Sensors
Daily maximum air temperature	Thermometer
Daily mean air humidity	Hygrometer
Daily global radiation	Radiometer
Daily amount of soil heat flux	Heat flux plate
Daily mean wind speed	Anemometer
Daily Rainfall	Raingauge

Which is the best sensors displacement for wind profile studies?:

A)

Parameter	Sensor	Number	Height (m)
Wind speed	Cup Anemometer	3	2.5, 5, 10
Wind direction	Vane anemometer	1	10

B)

Parameter	Sensor	Number	Height (m)
Wind speed	Cup Anemometer	3	0.5, 2, 10
Wind direction	Vane anemometer	3	0.5, 2, 10

C)

Parameter	Sensor	Number	Height (m)
Wind speed	Hot wire Anemometer	3	0.5, 1, 10
Wind direction	Vane anemometer	1	10

Which is the appropriate data acquisition interval for a standard Automatic Weather Station?

A)

Data sampling: 1 s  
Data acquisition interval: 1.5 h

B)

Data sampling: 30 s  
Data acquisition interval: 2 h

C)

Data sampling: 2 min  
Data acquisition interval: 20 min

D)

Data sampling: 1 min  
Data acquisition interval: 30 min

Calculate the maximum time period of data-logger memory capacity with the following configuration:

- each reading requires 2 bytes
- each 8k RAM provides 8192 bytes of memory

and your data-logger configuration is:

- 32k of available memory
- time acquisition interval of 30 min
- 10 active sensor's channels

Which is the correct acquisition configuration for an AWS?

	Time acquisition interval	Air temperature	Air humidity	Wind speed	Wind direction	Rainfall	Evap.	Solar radiation
A	1h	Average	Max value	Total amount	Average	Rain event	Total amount	Max. value
B	30min	Average	Average	Average	Max frequency	Total amount	Instant value	Average
C	10min	Max. value	Average	Average	Average	Average	Average	Average
D	24h	Average	Average	Average	Average	Max. value	Max. amount	Total amount
E	20min	Average	Average	Amount of wind run	Max. frequency	Total amount	Instant value	Average
F	10s	Instant value	Instant value	Max. value	Max. value	Average	Min. amount	Max. value

Where: s = second, min = minute, h = hour

### EXERCISE 5

Which is the correct orientation for a net-radiometer sensor of an AWS?

- 1) South
- 2) North
- 3) South-East

Which is the correct height for a wind speed sensor of an AWS?

- 1) from 1 to 3 meters
- 2) 3 meters
- 3) from 1.25 to 2 meters

Which of these anemometers have the lowest threshold speed?

- 1) Cup anemometer
- 2) Hot wire anemometer
- 3) Propeller anemometer

Which is the correct measure unit for the instantaneous global solar radiation?

- 1)  $\text{cal cm}^{-2} \text{min}^{-1}$
- 2)  $\text{W m}^{-2}$
- 3)  $\mu\text{E m}^{-2} \text{s}^{-1}$

Which is the correct measure unit for the Photosynthetically Active Radiation?

- 1)  $\text{cal cm}^{-2} \text{s}^{-1}$
- 2)  $\text{W cm}^{-2}$
- 3)  $\mu\text{E m}^{-2} \text{s}^{-1}$

A global solar radiation sensor should have a spectral response of:

- 1)  $0.3\div 5 \mu\text{m}$
- 2)  $400\div 700 \text{nm}$
- 3)  $400\div 1100 \text{nm}$

**EXERCISE 6**

Chose the best combination of maintenance time interval for the given sensors? (Put the mark “\*” in the proper cells)

	Time interval	Air temperature (PT100)	Air humidity (capacitive)	Wind speed (cup anem.)	Wind direction	Rainfall (tipping bucket)	Evap. (A pan)	Solar radiation (thermopile with glass dome)
A	3days							
B	7days							
C	15days							
D	1 month							

**EXERCISE 7**

Convert to Kelvin degrees (K):

- 1) 25°C
- 2) 38°C
- 3) -10°C
- 4) 77°F

Convert to °C:

- 1) 44°F
- 2) 78°F
- 3) 300K

Convert to  $W/m^2$ :

- 1)  $0.5 \text{ cal cm}^{-2} \text{ min}^{-1}$
- 2)  $700 \mu E \text{ m}^{-2} \text{ s}^{-1}$
- 3)  $0.741 \text{ kW m}^{-2}$

### EXERCISE 8

#### DATA SUMMARIES PROCESS

Create a daily summary database from raw data below. Define the mask and the first elaboration (Max, Min, Averages, etc.) for the following parameters:

Air temperature, Soil temperature, Wind speed, Rainfall, Evaporation, Wind direction, Air humidity, Global solar radiation

Raw Data:

Date	Hour	Rain (mm)	WS (m/s)	WD (deg)	Tair °C	Tsoil °C	EL Min	RH (%)	Rg W/m <sup>2</sup>	EV mm
01/08/97	00:00	0.0	0.2	220	21.7	28.0	-9999	66	0	55
01/08/97	01:00	0.0	0.2	157	22.0	27.4	-9999	60	0	55
01/08/97	02:00	0.0	0.6	151	22.3	27.1	-9999	62	0	55
01/08/97	03:00	0.0	0.4	145	21.7	27.1	-9999	65	0	55
01/08/97	04:00	0.0	0.4	162	21.4	26.5	-9999	69	0	55
01/08/97	05:00	0.0	0.4	155	20.8	26.5	-9999	71	0	55
01/08/97	06:00	0.0	0.4	154	21.1	26.2	-9999	69	8	55
01/08/97	07:00	0.0	0.4	182	21.7	25.9	-9999	71	67	55
01/08/97	08:00	0.0	0.6	164	22.3	26.2	-9999	67	114	55
01/08/97	09:00	0.0	0.6	209	24.1	26.5	-9999	64	169	57
01/08/97	10:00	0.0	0.6	154	26.8	27.4	-9999	58	388	57
01/08/97	11:00	0.0	0.8	184	28.3	28.3	-9999	49	463	57
01/08/97	12:00	0.0	0.8	195	30.1	29.5	-9999	44	576	57
01/08/97	13:00	0.0	1.0	181	30.4	31.0	-9999	42	561	57
01/08/97	14:00	0.0	0.6	8	31.6	31.9	-9999	37	604	58
01/08/97	15:00	0.0	0.8	301	32.8	32.8	-9999	35	545	58
01/08/97	16:00	0.0	1.0	325	32.2	33.1	-9999	38	357	59
01/08/97	17:00	0.0	2.7	48	28.9	32.5	-9999	50	294	59
01/08/97	18:00	0.0	2.5	42	27.7	31.9	-9999	58	176	59
01/08/97	19:00	0.0	2.4	38	26.5	31.0	-9999	57	47	59
01/08/97	20:00	0.0	2.5	72	25.0	30.1	-9999	60	12	59
01/08/97	21:00	0.0	2.0	102	23.8	29.5	-9999	63	0	59
01/08/97	22:00	0.0	1.8	47	22.9	28.9	-9999	66	0	60
01/08/97	23:00	0.0	1.2	44	22.3	28.3	-9999	69	0	60
02/08/97	00:00	0.0	1.6	13	21.7	27.7	-9999	68	0	60
02/08/97	01:00	0.0	2.0	27	21.4	27.1	-9999	63	0	60

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02/08/97 02:00	0.0	1.4	38	20.5	26.8	-9999	68	0	60
02/08/97 03:00	0.0	1.4	23	19.9	26.2	-9999	67	0	60
02/08/97 04:00	0.0	1.2	14	19.9	25.6	-9999	65	0	60
02/08/97 05:00	0.0	1.2	78	19.9	25.3	-9999	59	0	60
02/08/97 06:00	0.0	0.6	150	19.0	25.0	-9999	64	59	60
02/08/97 07:00	0.0	1.4	102	22.0	25.0	-9999	54	231	61
02/08/97 08:00	0.0	1.2	152	24.7	25.6	-9999	43	349	62
02/08/97 09:00	0.0	2.0	99	25.3	26.8	-9999	38	463	64
02/08/97 10:00	0.0	2.0	114	25.9	28.0	-9999	34	573	64
02/08/97 11:00	0.0	1.8	140	27.4	29.8	-9999	30	659	65
02/08/97 12:00	0.0	1.8	168	28.0	31.3	-9999	28	714	65
02/08/97 13:00	0.0	1.4	202	29.5	32.5	-9999	26	745	65
02/08/97 14:00	0.0	1.0	309	31.0	33.7	-9999	23	710	65
02/08/97 15:00	0.0	0.8	339	31.3	34.0	-9999	22	643	65
02/08/97 16:00	0.0	0.8	311	31.6	34.0	-9999	20	537	66
02/08/97 17:00	0.0	0.8	322	31.6	33.4	-9999	20	427	67
02/08/97 18:00	0.0	0.8	356	30.4	32.5	-9999	21	298	67
02/08/97 19:00	0.0	0.4	284	28.6	31.6	-9999	27	51	67
02/08/97 20:00	0.0	0.8	175	25.9	30.7	-9999	37	8	67
02/08/97 21:00	0.0	1.0	147	25.0	29.8	-9999	38	0	67
02/08/97 22:00	0.0	0.8	144	24.1	28.9	-9999	40	0	67
02/08/97 23:00	0.0	0.4	151	22.0	28.3	-9999	47	0	67

From the daily data of the previous paragraph, calculate potential evapotranspiration by Penman method for both days.

(See chapter 8 on the manual “Manual on Instrumentation and Operations for Automatic Weather Stations for Agrometeorological Applications”)

From the daily average air temperatures of the table, calculate the duration of Desert Locust embryo incubation, beginning from the third day. Which day the percentage reaches the value of 100%?

Day	TA_avg (°C)	rainfall (mm)	daily increase (%)
1	25.3	0	
2	25.3	0	

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3	24	0
4	26	0
5	26.2	0
6	24.8	0
7	25.7	0
8	26.1	0
9	26.5	0
10	27.8	0
11	25.7	0
12	26.8	0
13	25.3	0
14	25	0
15	25.7	0
16	23.6	0
17	22.5	0
18	22.4	2
19	23.6	0
20	24.3	0
21	22.6	2
22	24.1	1
23	24.1	0
24	22.7	0
25	24.4	0
26	23.6	1
27	23.9	0
28	23.2	7
29	20.6	3
30	20.8	0
31	21.8	0

Total --->

**Appendix - RESULTS**

**EXERCISE 1**

Which is the right position(s) for a standard AWS installation?

- a) The AWS should not be closer than eight or ten times the height of the surrounding objects (trees, bush, buildings, pylon, etc.).
- e) Soil surface has to be representative of the zone. If a crop cover is present it should be cut at proper frequency to keep it uniform.

For an AWS installation in desert zone characterized by high thermal excursion, rare desert storms and gust wind, what is the best sensor's set up?

B)

Sensor's technical characteristics:

	Thermometer	Hygrometer	Anemometer	Rainfall	Radiometer
Range	-10÷+65 °C	5÷100 %	0÷50 m/s		0÷2000 W/m <sup>2</sup>
Accuracy	±0.1°C	±3%	±0.5 m/s <15 m/s ±1 m/s >15 m/s	2%	2%

**EXERCISE 2**

CHOICE OF DATA LOGGER

For the following sensors equipment what is the data-logger that match their output?

Sensors equipment	A	B	C
Data logger type	B	C	A

**EXERCISE 3**

Which is the best parameter configuration for a standard AWS installation?

B

Air temperature  
Air humidity  
Soil temperature  
Wind speed  
Wind direction  
Evaporation  
Global radiation  
Rainfall

**EXERCISE 4**

Which is the right sensor's set up for Penman evapotranspiration method:

B)

Parameters	Sensors
Daily mean air temperature	Thermometer
Daily mean air humidity	Hygrometer
Daily global radiation	Radiometer
Daily sunshine duration	Sunshine duration sensor
Daily mean wind speed	Anemometer
Daily Rainfall	Raingauge

Which is the best sensor's displacement for wind profile studies?

A)

Parameter	Sensor	Number	Height (m)
Wind speed	Cup Anemometer	3	2.5, 5, 10
Wind direction	Vane anemometer	1	10

Which is the best data acquisition interval for a standard Automatic Weather Station?

C)

Data sampling: 2 min  
Data acquisition interval: 20 min

D)

Data sampling: 1 min  
Data acquisition interval: 30 min

Calculate the maximum time period of data-logger memory capacity with the following configuration:

$$\frac{8192 \text{ bytes} * 4 * 30 \text{ min}}{2 \text{ bytes} * 10 \text{ channels}} = 49152 \text{ min} / 1440 \text{ (min/d)} = 34 \text{ days around}$$

Which is the correct acquisition configuration for an AWS?:

	acquisition interval	Air temperature	Air humidity	Wind speed	Wind direction	Rainfall	Evap.	Solar radiation
B	30 min	Average	Average	Total amount	Max frequency	Total amount	Total amount	Average
E	20min	Average	Average	Amount of wind run	Max. frequency	Total amount	Instant value	Average

Where: s = second, min = minute, h = hour

**EXERCISE 5**

Which is the correct orientation for a net-radiometer sensor of an AWS?

1- South

Which is the correct height for a wind speed sensor of an AWS?

3- from 1.25 to 2 meters

Which of these anemometers have the lowest threshold speed?

2- Hot wire anemometer

Which is the appropriate measure unit for the instantaneous global solar radiation?

2-  $W m^{-2}$

Which is the correct measure unit for the Photosynthetically Active Radiation?

3  $\mu E m^{-2} s^{-1}$

A global solar radiation sensor should have a spectral response of:

3 400÷1100 nm

**EXERCISE 6**

Chose the best combination of maintenance time interval for the given sensors? (Put the mark "\*" in the proper cells)

	Time interval	Air temperature (PT100)	Air humidity (capacitive)	Wind speed (cup anem.)	Wind direction	Rainfall (tipping bucket)	Evap. (A pan)	Solar radiation (thermo pile with glass dome)
A	3days						*	
B	7days						*	*
C	15days		*	*		*		*
D	1 month	*	*		*			

**EXERCISE 7**

Convert to K:

- 5)  $25^{\circ}\text{C} \rightarrow 298.15$
- 6)  $38^{\circ}\text{C} \rightarrow 311.15$
- 7)  $-10^{\circ}\text{C} \rightarrow 263.15$
- 8)  $77^{\circ}\text{F} \rightarrow 298.15$

Convert to  $^{\circ}\text{C}$ :

- 4)  $44^{\circ}\text{F} \rightarrow 6.67$
- 5)  $78^{\circ}\text{F} \rightarrow 25.55$
- 6)  $300\text{K} \rightarrow 26.85$

Convert to  $\text{Wm}^{-2}$ :

- 1)  $0.5 \text{ cal cm}^{-2} \text{ min}^{-1} \rightarrow 348.9$
- 2)  $700 \mu\text{E m}^{-2} \text{ s}^{-1} \rightarrow 152.18$
- 3)  $0.741 \text{ kW m}^{-2} \rightarrow 741$

**EXERCISE 8**

DATA SUMMARIES PROCESS

Create a daily summary database from raw data below. Define the mask and the preliminary elaboration (Max, Min, Averages, etc.) for the following parameters:

Air temperature, Soil temperature, Wind speed, Rainfall, Evaporation, Wind direction, Air humidity, Global solar radiation

Sample of summary table:

Day	Soil temperature			Air Temperature				Relative Humidity				Wind dir	Total Wind km	Glob. Rad. kJ/m <sup>2</sup>	Rain fall mm	Evp. mm		
	Avg	MAX	MIN	8h	14h	19h	Avg	MAX	MIN	8h	14h						19h	Avg
	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	%	%	%	%	deg			
1	28.9	33.1	25.9	22.3	31.6	26.5	25.3	32.8	20.8	67	37	57	58	S S-E	89.6	15772	0	5
2	29.2	34	25	24.7	31	28.6	25.3	31.6	19	43	23	27	42	S-E	103	23281	0	7

From the daily data of the previous paragraph, calculate potential evapotranspiration by Penman method for both days.

Data required:

- Global solar radiation (cal cm<sup>-2</sup> d<sup>-1</sup>)
- Wind speed (m s<sup>-1</sup>)
- Mean air temperature (°C)
- Minimum air temperature (°C)

We have for the two days the following values:	day 1	day 2
Global solar radiation (kJ/m <sup>2</sup> )	15772	23281
Wind run (km/d <sup>-1</sup> )	89.6	103
Mean air temperature (°C)	25.3	25.3
Minimum air temperature (°C)	20.8	19

To convert kJ m<sup>-2</sup> d<sup>-1</sup> in cal cm<sup>-2</sup> d<sup>-1</sup> divide for 41.868:  
 15772/41.868 = 376.7077 and 23281/41.868 = 556.0571, and we calculate the daily global radiation of the two days. By the formula: Rn=0.72\*Rg-86 we calculate the Rn.

To convert the km d<sup>-1</sup> in m/s multiply for 1000 (km to m) and divide for 86400 (seconds in a day):

$$89.6 * 1000 / 86400 = 1.037 \text{ m/s and } 103 * 1000 / 86400 = 1.192 \text{ m/s}$$

Calculations:	Day 1	Day 2
Rn: net radiation (cal cm <sup>-2</sup> d <sup>-1</sup> )	185.2296	314.3611
es: saturation vapor pressure (hPa)	32.31508	32.31508
ea: actual vapor pressure (hPa)	24.6062	22.00615
L: latent heat flux (cal cm <sup>-2</sup> mm <sup>-1</sup> )	45.0701	45.0701
E = atmospheric vapor deficit (mm d <sup>-1</sup> )	2.835727	3.958437
d: derivative of saturation vapor pressure/temperature (hPa °C <sup>-1</sup> )	1.895758	1.895758
	ETP	3.780791 6.195955
	(mm d <sup>-1</sup> )	

From the daily average air temperatures of the table, calculate the percentage of Desert Locust embryo development, beginning from the third day.

Referring to the table showed in chapter 8 (paragraph i), we can assign a percentage for each day. The seventeenth day we have the 100% of probability of complete development of embryo stage.

Day	TA_avg (°C)	rainfall (mm)	daily increase (%)
1	25.3	0	
2	25.3	0	
3	24	0	6.1
4	26	0	7
5	26.2	0	7
6	24.8	0	6.3
7	25.7	0	6.7
8	26.1	0	7
9	26.5	0	7.2
10	27.8	0	7.8
11	25.7	0	6.7
12	26.8	0	7.4
13	25.3	0	6.4
14	25	0	6.5
15	25.7	0	6.7
16	23.6	0	5.6
17	22.5	0	5.6
18	22.4	2	
19	23.6	0	
20	24.3	0	
21	22.6	2	
22	24.1	1	
23	24.1	0	
24	22.7	0	
25	24.4	0	
26	23.6	1	
27	23.9	0	
28	23.2	7	
29	20.6	3	
30	20.8	0	
31	21.8	0	
		Total ---->	100 %