Lesson 4:
GROUND-BASED WEATHER STATIONS

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CONTENTS

Ground-based stations

A **ground-based station** is a facility, either on land or sea, with instruments and equipment for measuring atmospheric properties.

Ground-based weather station

Provide information for weather forecasts and to study the weather and climate
Typical variable:
temperature, humidity, wind speed, wind direction, solar radiation and precipitation amounts.

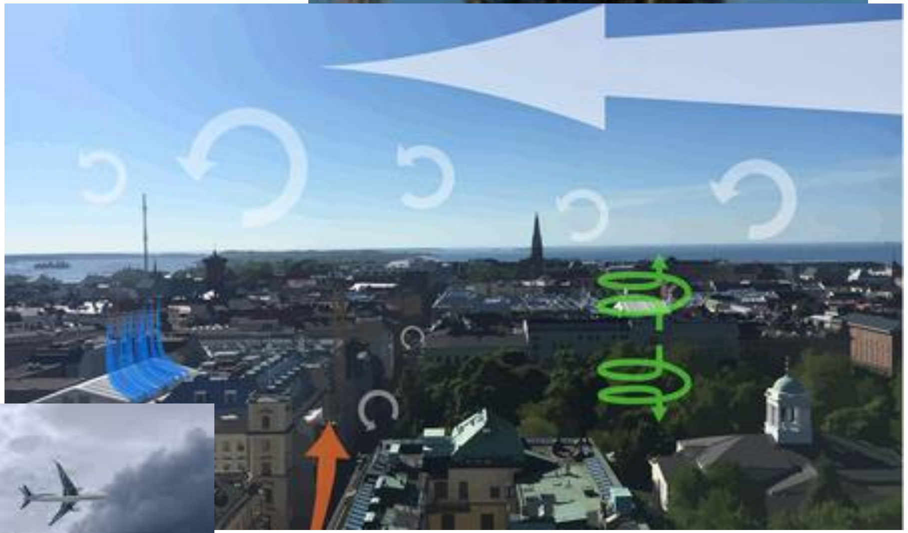
Ground-based air quality station

Measure systematically concentrations of pollutants in ambient air.
Typical variables:
Particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), ozone (O_3),

Ground-based weather stations

Applications:

- ❖ Validating air quality models
- ❖ Pollutant dispersion
- ❖ Urban meteorology
- ❖ Sea/land/lake breeze regime
- ❖ Microeolic energy
- ❖ Agricolture
- ❖ Aviation



Ground-based weather stations

The basic indicators that are received from weather stations include:

- 2m air temperature
- Maximum of 2m air temperature
- Minimum of 2m air temperature
- Water vapour pressure
- Relative humidity
- 10m mean wind speed
- 10m mean wind direction
- Downward directed solar radiation measured at earth's surface (global radiation)
- Duration of sunshine
- Sum of precipitation
- Snow depth
- Total cloud cover

Air temperature (1)

Is the measurement of the temperature at a height above the ground between 1.25 m and 2 m.
This value is always measured by a **thermometer** in a shelter designed to protect the thermometer from solar radiation, heat radiation from the ground and sky and any precipitation.
It must both protect the sensor from radiation and allow free air circulation.

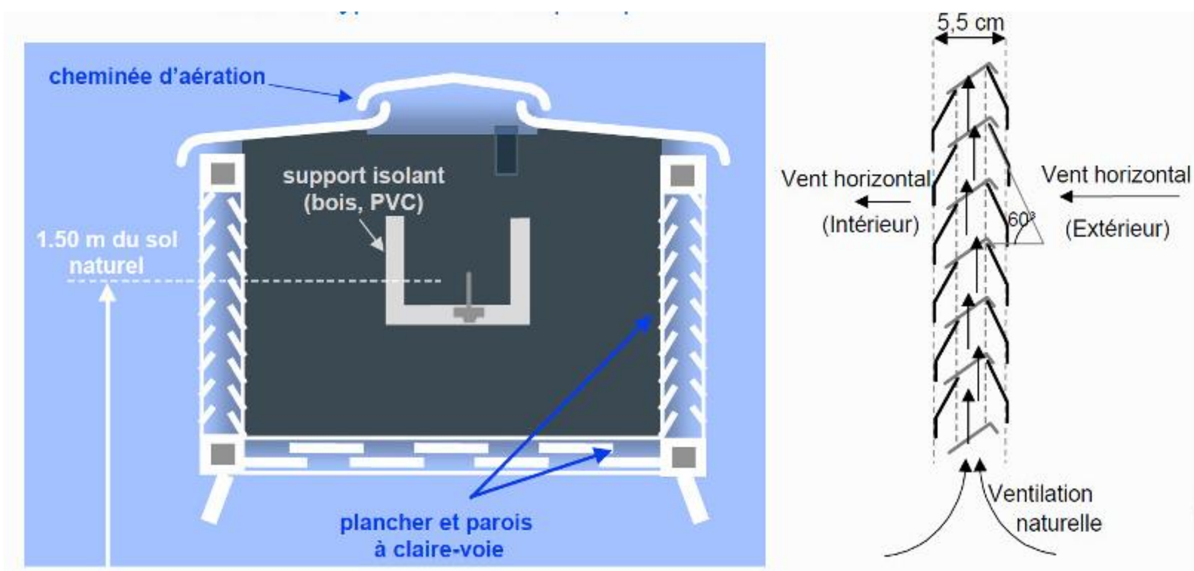
A forced ventilation shelter is theoretically better than a natural ventilation shelter but…

- it requires energy for its motor and the assurance that the ventilation is active
- it must be designed to avoid deposits or water retention
- its cost is also higher
- it requires changes in measurement technology that could cause a break in climate measurement series

Air temperature (2)

The shelter should be at a temperature close to that of the air: it is white. Unfortunately, it is never completely neutral and is the main cause of error in air temperature measurement.
Under conditions of high solar radiation and poor ventilation (<1 m/s), errors greater than 1 °C are possible.
The most commonly used electronic thermometers are platinum wire resistance thermometers.

Its stability over time is very good, a calibration every 5 years may be sufficient.



Hygrometric measurements

To characterize the hygrometric state of the atmosphere, meteorologists use several parameters, which are not independent of each other.

- **Mixing Ratio** *r* [g/kg]: ratio of water vapour mass to dry air mass
- **Vapour Pressure** *e'* [hPa]: partial pressure of water vapour in the air; the saturation vapour pressure is noted e'_w, it is an increasing function of temperature (hot air can contain more water vapour than cold air);
- **Dew Point Temperature** *Td* [°C]: temperature at which a mass of humid air must be cooled to reach saturation;
- **Relative Humidity** *RH* in relation to liquid water, expressed as % : ratio between the vapour pressure e' and the saturation vapour pressure e'_w.

Vapour pressure

One of the oldest methods for measuring the hygrometric state of the atmosphere is to use a **psychrometer**.

It is composed of 2 thermometers: the first measures the temperature t of the dry air, the second the temperature t' of a wet thermometer using a wick dipped in a water tank.
Evaporation cools the wet thermometer and is more intense when the air is dry.

$e'_w - e' = Ap(t-t')$,
p atmospheric pressure
A psychrometric constant depending on the geometry and on the ventilation of the sensor (which should be at least 2 m/s).

The naturally ventilated psychrometers used in the past under shelters were not very accurate.
It is preferable to used forced ventilation.
It requires a positive temperature for continuous operation.

Relative humidity

The most common **hygrometers** are small cells, similar to electrical capacitors, whose capacity depends on the relative humidity of the air.
The dielectric is a polymer film sensitive to water vapor.
For meteorological use, the sensors must withstand a water vapor saturated atmosphere and operate over a wide temperature range.

With the best models the measurement uncertainty is close to 3%, but in general it is difficult to guarantee an uncertainty of less than 5% after a certain period of use under variable temperature conditions.
These hygrometers are often accompanied by a Pt100 temperature sensor, which can also be used internally by the sensor to correct thermal drifts. It is important to measure these 2 parameters under the same shelter, in order to be able to calculate the other hygrometric parameters (e', Td, etc).

Surface wind

Wind speed is a three-dimensional vector quantity, but in meteorology we are mainly interested in its horizontal projection.
Its high temporal variability has led to the definition of standard parameters: 10-minute averaged value, gusts defined as extreme values over a period of 3s measured over the previous 10 minutes.
The sampling frequency for measurements recommended by the WMO is 4 Hz and should not fall below 1 Hz.

The uncertainty desired by the WHO being 10% for speeds and 5° for directions.

The surface wind is measured at a conventional height of 10 m, which is in fact a compromise between a height sufficient to minimize the effect of buildings or nearby vegetation and the need not to impose excessive installation and access constraints. The installation should be at a distance of at least 30 times the height of the surrounding obstacles.

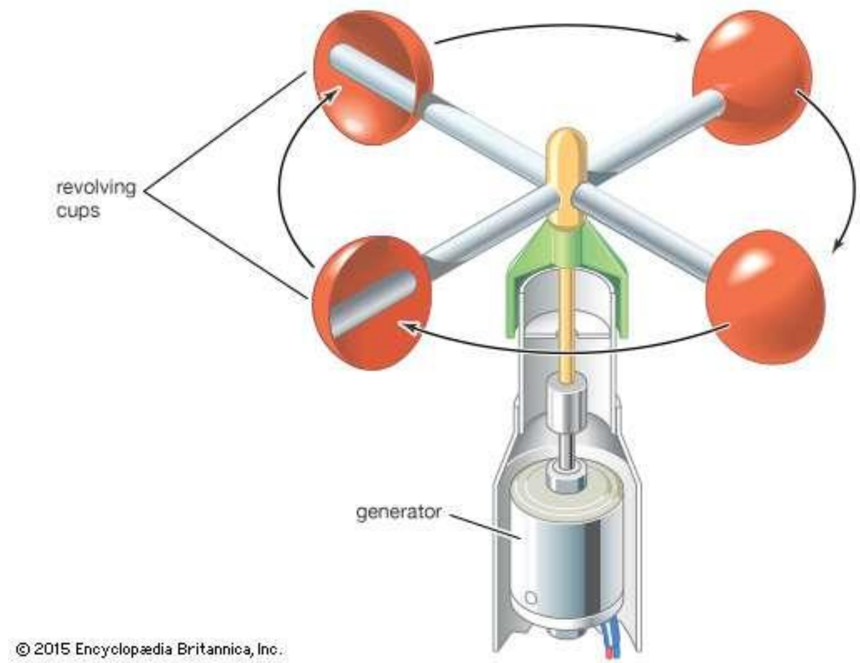
Rotary anemometer

The most common instruments are still **cup or propeller anemometers**.

They now have an optical transducer to count the number of revolutions and fractions of revolutions.

Their response is determined by the shape of the cups and therefore does not necessarily require initial or periodic calibration.

However, to measure light winds, ball bearings must be maintained or regularly changed, to ensure a sufficiently low starting threshold (typically between 0.5 and 1 m/s). They are associated with a weather vane, whose flag is oriented in the wind bed.



Ultrasonic anemometer

Three or four **ultrasonic transceivers** are coupled 2 to 2.

The propagation time of sound from the transmitter to the receiver is measured first in one direction and then in the opposite direction by inverting the transmitter and receiver. The difference between the 2 propagation times eliminates the speed of sound and gives the wind speed in the axis of the transmitter/receiver pair. The combination of the various transmitter/receiver pairs allows the calculation of wind speed and direction, sometimes even its vertical component.

These static sensors require little maintenance and servicing.

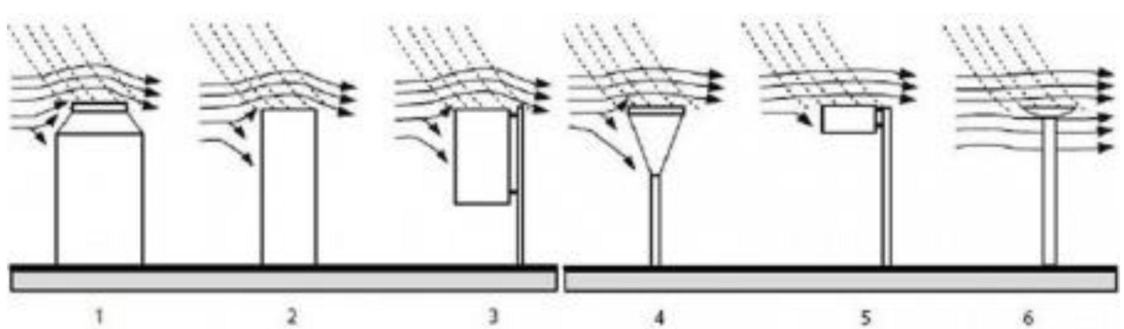
They can be heated more easily than rotating anemometers for icing or freezing conditions.

Precipitation

Precipitation amounts mainly include water falling from the sky in liquid or solid form, but also deposits in the form of dew, ice, etc. The measurements are expressed as the height of water, expressed in mm.

The main difficulty for measuring precipitation is <u>the correct capture of precipitation by a defined surface</u>. In the absence of wind, the particles fall vertically. But in the presence of wind, the air streams are deformed by the rain gauge itself, so that vertical drafts are created depending on the shape of the rain gauge. This results in a capture failure that depends on wind speed and rain gauge shape.

The underestimation is typically about 10% for a wind speed at the 5 m/s rain gauge, about 25% for a 10 m/s wind and 80% for snow.



Rain Gauges

The simplest rain gauges are graduated containers that collect water and require manual reading.

For automatic measurements, the most common rain gauges use tipping buckets, placed under a collection cone, which switch alternately when filled.

The resolution of the measurement is then given by the collection surface and the mass of water tilting a bucket, for example 0.2 mm for a 20 g bucket and a 1000 cm^2 surface.

For the measurement of solid precipitation a heating is necessary, but it increases the capture deficit!

There are also rain gauges that weigh the mass of a collection pot, which can also measure solid precipitation with brine in the pot. A large pot capacity is required to avoid overflows, but these devices can be more accurate and have a better resolution than rain gauges with buckets.

Snow height

The water level equivalent to a snowfall is typically measured by a heated rain gauge, with a large underestimation in the absence of a wind screen.

There are also snow height sensors, either ultrasonic (measurement of the round trip time of a sound wave reflected on the snow surface) or using a laser (measurement of distance by phase shift of a laser beam modulated at several frequencies). Their resolution/incertitude is in the order of cm.

Optical sensors

There are optical rain gauges: a light beam is emitted to a detector that analyses the signal drops associated with the passage of particles falling into the beam.
More sophisticated models are disdrometers, which analyze the size and velocity of particles and thus provide a distribution of the number of particles detected into size and falling velocity classes. The intensity of precipitation is then calculated.

Solar radiation

The measurement of global solar radiation on a horizontal plane, in a wavelength range from 0.3 mm to 3 mm, is carried out using a **pyranometer**, a device that uses a thermopile between the receiving surface of a black body and the body of the device.
Direct solar radiation is measured with a **pyrheliometer**, which also uses a thermopile, but continuously oriented in the direction of the sun.
The exposure time is defined and measured as the time during which the direct solar radiation is greater than 120 W.m-2.
Some measurements of solar UV radiation are sometimes made with a specific UV pyranometer.

Visibility

Visibility is the greatest distance at which a black object of appropriate size can be seen and identified during daylight hours on the background of the sky on the horizon. In the case of night observations, this is the distance at which this object could be seen and identified if the general illumination increased until it reached normal daylight intensity.

For aeronautical use, account is taken of the distance of perception of light sources, which requires taking into account the background luminance of the sky: a light source is more easily visible on a dark background than on a light background.

The aerosol extinction coefficient, or AOD, is measured mainly by scatterometer, which measure the lateral diffusion of light emitted by the sensor into a small volume of air in front of the sensor.

Their range ranges from a few meters to more than 10 km, with an uncertainty of about 10 to 20% of the measured value.

Cloud altitude and extent

The altitude above the ground at the cloud base is measured with a **cloud rangefinder**.

It is a small LIDARA that measures the backscatter profile of the atmosphere vertically from the sensor. The presence of a cloud results in a sudden increase in this backscatter profile, which is a good mark of its base.

Their range often reaches 7000 m, although their ability to detect cirrus clouds is not very good.

Algorithms are used to combine observations from one or more cloud rangefinders to determine the extent and height of cloud layers over a site.

These algorithms assume that the movement of clouds over the sensor allows their extent to be estimated. Observations over the last 30 minutes are used for the calculation.

Measurement uncertainties

Meteorological measurements are difficult because the measurement is not carried out under well-controlled environmental conditions (as in a laboratory).

- **Instrumental errors**: characteristics of the instruments. They are usually published by the manufacturer, sometimes with an indication of some influencing factors, which have been tested in the laboratory.

E.g. hygrometer: characteristics that are subject to a significant temperature influence between -20°C and +40°C.

- Those related to **maintaining** (or not maintaining) the sensor under nominal operating conditions.

E.g. frequency of sensor cleaning and calibration.

- **Environmental errors**: the environment close to the measurement and the exposure of the instruments have an important influence on the representativeness of the measurement and therefore on the uncertainty that can be assigned to its meaning.

Installation in urban environments

1- **Thermometer and hygrometer**: must be positioned between 1.7 and 9.5 meters above the ground and at least 4 meters away from vertical obstacles. If installed above a roof, instruments are located at least 2 meters above the level of the tiles, so as to limit the effect of the heat released by the buildings on the recorded values.
Furthermore, both instruments require a so-called "sun screen", i.e. a special protection that allows the thermometer and hygrometer to remain sheltered from direct sunlight, so that it is possible to install the weather station in full sun without the risk of detection of unreal values of temperature and humidity.

2- **Rain gauge**: must be at the same height level as the thermometer/hygrometer. It is essential that the nearest buildings are at least 10 meters away or that in any case the rain gauge is free of obstacles within this distance so that the mouth of the rain gauge does not receive less rain than it actually falls;

3- **Anemometer**: must be positioned 10 meters above the ground and at least 10 meters away from vertical obstacles, or in any case in the most open position possible so that the wind arrives easily to instruments without interference;

4- **Pyranometer**: must be positioned in the sunniest possible spot, so that it receives the sun's rays well and for as long as possible during the day.

Installation in rural environments

1- **Thermometer and hygrometer**: must be positioned between 1.7 and 2.0 meters above the ground, possibly on natural grass and at least 10 meters away from buildings;

2- **Rain gauge**: must be at the same height level as the thermometer/hygrometer and away from vertical obstacles at least 10 meters;

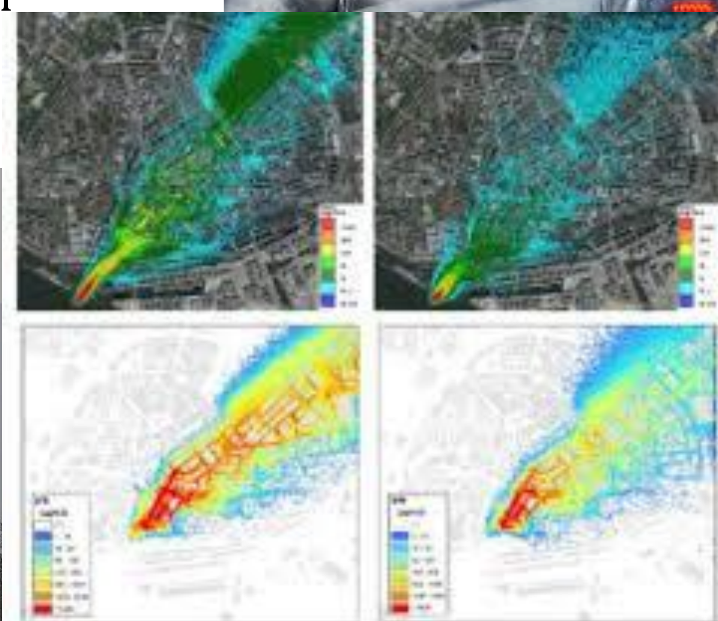
3- **Anemometer**: must be positioned between 2.5 and 10 meters above the ground, or in any case in the most open position possible and at least 10 meters away from vertical obstacles;

4- **Pyranometer**: the same applies in urban environment.

Ground-based air quality stations

Applications:

- Environmental impact assessments
- Personal exposure studies
- Mobile air quality surveys
- Validating air quality models
- Responding to complaints from the public
- Short term fixed monitoring
- Construction Air Quality Monitor
- Smog Monitor



Particulate matter (PM)

PM_{10} and $PM_{2.5}$ are typically measured by a sequential automatic sampling system on filter media that operates with two independent sampling lines.
The mass measurement of the two samples taken is carried out at the same time thanks to the methodology of attenuation β, which allows to reach an uncertainty on the mass measurement data of the order of 10 μg.
Samplers permit to measure the temporal evolution of the mass concentrations of two fractions of airborne particulate matter.

- ❖ chemical characterization
- ❖ evaluation of the losses of volatile compounds during the enrichment phase
- ❖ evaluation of the equivalence between different sampling heads
- ❖ evaluation of bias associated with variations in the particle size cut of the fractionation system
- ❖ evaluation of the reproducibility of the mass measurement

Nitrogen dioxide (NO_2)

Nitrogen dioxide is commonly measured using automatic analysers that run 24 hours a day. The main measuring method is to use a chemiluminescence continuous analyser (chemiluminescence means the emission of light as a result of a chemical reaction).

Air is drawn into the analyser where nitrogen monoxide (NO) is made to react with ozone, to give nitrogen dioxide in a reaction that generates light:

$$NO + O_3 \rightarrow NO_2 + O_2 + \text{light emission}$$

This method doesn't actually measure nitrogen dioxide but calculates the airborne levels of nitrogen monoxide and total oxides of nitrogen (NOx), and then subtracts one reading from the other.
The final results are expressed in parts per billion (ppb) or micrograms per cubic meter of air ($\mu g\ m^{-3}$).

Sulphur dioxide (SO_2)

Sulphur dioxide is usually measured automatically, by a continuous analyzer that uses ultra-violet fluorescence.
The concentration of Sulphur dioxide is calculated by measuring the fluorescent radiation energy produced when the Sulphur dioxide molecules are bombarded by UV radiation inside the analyzer.

This then provides a concentration in air, usually expressed in parts per billion (ppb) or micrograms per cubic meter ($\mu g\ m^{-3}$).

Ozone (O_3)

An ozone monitor operates by pulling an air sample from the atmosphere into the machine with an air pump.
Inside the analyzer, specially produced light is shone through the sample inside a tube, and a measurement of how much light has been absorbed is taken at the other end.
The absorption of light is proportional to the concentration of ozone.