Atmospheric Observing Systems

Observing System Classifications

Observing systems can be classified in several ways:

One useful distinction is:

a) in-situ sensing – sensor of the instrument is immediately adjacent to the volume of air being sampled

b) remote sensing – sensor measures a volume of air that is some distance away (satellite, radar, human eye, etc)

- Note that sensor is only one part of the instrument. Instrument can include data processing/acquisition system. The sensor of an in-situ observing system is the part of the instrument that converts the atmospheric state into some quantifiable signal (such as voltage). The sensor may be only one small and relatively inexpensive part of the obs system, e.g., a $20 thermocouple attached to a $1500 datalogger. It may be located some distance away from the rest of the instrument

Characteristics of observing systems

- Resolution – smallest detectable change of output. For a digital instrument this is the last decimal place
- Sensitivity – change in output for a certain change in input; e.g. for an electrical measurement of temperature this could be volts per degree
- Accuracy – the correspondence of an instrument's measurement to some accepted standard, as a representation of "truth"
- Precision – ability to replicate measurement of a specified condition

Ability of an instrument to adjust its indications to a changing environment can be important. This is especially the case for turbulence measurements, where we are interested in measuring rapid fluctuations

For many instruments, this is reflected in the time constant. Given an impulsive change Δy of the measured condition, the indicated measurement $y_I(t)$ gradually approaches the new value y. The time constant τ is then the time required to reduce the deviation to a fraction 1/e of its original value, i.e.,

$$[y - y_I(t)]/\Delta y = 1/e.$$

Then in general the relation between the true and indicated values at time t will be:

$$y - y_I(t) = \Delta y\, e^{-t/\tau}$$

Requirements for Mesoscale Networks

- Resolution – both temporal and spatial (horiz and vert). Present twice-daily network is good enough for synoptics but marginal or inadequate for mesoscale. Effective resolution is greatly improved by a regular distribution of stations. "clustering" of stations greatly reduces the resolution (sometimes there are good reasons for clustering that outweigh this consideration)

- Representativeness – Since observations are separated by some finite difference, they usually are implicitly assumed to be a representative sample of some finite region. This assumption may be violated when the atmosphere contains large gradients or when there are coherent structures. This depends on the ultimate use of sounding data: e.g., a sounding ascending in a thunderstorm updraft can be good (if we are studying t.storms) or bad (if our goal is to do a regional analysis).

- Data Quality – the data quality must be adequate for the intended purpose: this often varies depending on our goal. For example, slow-response instruments would be inadequate for turbulence studies but may be quite satisfactory for mapping max/min temperatures

One frequently encounters obs or mini-networks operated by various public or private concerns that are not part of the standard NWS/FAA/military obs network. The quality of these data must be carefully evaluated: sometimes very good, sometimes poor. Often the agency lacks funds, expertise, and/or motivation to properly set up and maintain the instruments

Sounding systems

- For the moment, we will discuss only in-situ sounding systems. Later we will discuss remote sensing techniques for atmospheric soundings.
- Recall that in-situ techniques can only measure a volume of air immediately adjacent to the sensor. Thus, the sensor must be transported by some means to the location (height) where we require a measurement. Perhaps the most familiar type of in-situ sounding is the radiosonde. This is an instrument package carried aloft by a free-flying balloon. Radiosondes are the basis for the standard upper-air observing network

Requirements for radiosondes:

- Accuracy sufficient to provide useful measurements
- Low cost since the sondes are usually expendable (i.e. not recovered or re-used)
- Light weight so that the sonde does not pose a hazard to people or property when it falls.

Sonde instruments accuracy

- Temperature – thermister (rod or bead) ≈ 0.1-0.5 C.
- Humidity – carbon hygrister or thin film capacitor. Errors are fairly large (several %). Tends to read < 100% in saturated conditions
- Pressure – aneroid with commutator switch (like a small circuit board). Closes different contacts depending on the pressure. Accurate to 1-2 mb

Sounding position and movement

- The vertical location of the sonde is found by integrating the hydrostatic approximation as represented by the thickness equation

  $\Delta z = R_d T_v / g \ln(p_0/p_1)$
- The accuracy of the heights is affected mainly by systematic biases in the (virtual) temperature.

- The horizontal location usually is found by some radio means; either a tracking system or a navigation system. Common systems include:

WBRT (or GMD) – special tracking antenna that locks onto the signal from the radiosonde antenna

Omega – uses signals from the Omega navigation system transmitters. More accurate than WBRT and doesn’t require a special antenna for tracking

CLASS – similar to Omega but uses signals from the LORAN-C navigation system. CLASS = Cross-chain LORAN Atmospheric Sounding System; LORAN = Long Range Navigation. Standard NCAR sounding at present. Accurate and simple to operate

GPS – satellites with global coverage.

Wind speed

- Wind speed is found by finite difference approximation $\Delta x/\Delta t$. Usually accurate to 1-2 m/s. Larger errors in regions of larger wind gradients (jets).

Other types of in-situ soundings

- Dropsondes (dropwindsondes) – essentially the same as radiosondes except they are dropped from aloft by aircraft
- Tethersondes – these are again instrument packages very similar to radiosondes except that the balloon is captive rather than free-flying. The balloon and instrument package are at one end of a tether line and the other end of the line is let out or reeled in by a winch.

  Since the height of the balloon is controllable, tethered balloons can be very useful for boundary layer measurements. They become unstable in high winds.
- Kites – once more, essentially a radiosonde package but carried aloft by a kite.

- Pilot balloons (PIBALS) usually visually tracked using a theodolite. Single or double theodolite. Balloon has no instruments thus height must be measured or assumed.
- Research Aircraft – very versatile; can carry a large complement or sophisticated instruments. Can measure in both horizontal and vertical. Expensive, prohibiting routine use
- Commercial Aircraft – Two programs exist for using commercial aircraft to make meteo measurements:

  ACARS (Aircraft Communication Addressing and Reporting System) – measurements of wind speed and direction, temp. Vertical resolution usually 2000 ft (600m) but some aircraft are equipped to measure at finer resolution

CASH (Commercial Aviation Sensing of Humidit)

TAMDAR was also a program for a while (not now?)

These can provide useful data but measurements are dictated by commercial operations, not scientific or forecasting requirements

Pilotless aircraft – remote controlled or pre-programmed “drone” aircraft (now called UAS – unmanned aviation systems). Potentially cheaper than (manned) research aircraft; safer.