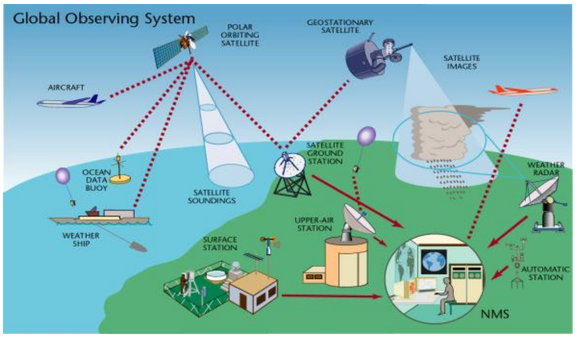
The Course of
Meteorological Instrumentation and Observations



MUSTANSIRIYAH UNIVERSITY
COLLEGE OF SCIENCES
ATMOSPHERIC SCIENCES DEPARTMENT
2018-2019
Dr. Sama Khalid Mohammed
SECOND STAGE

Welcome Students! ☺

TO LECTURE ONE

Principles of Measurement and Instrumentation

What are covered in this course?

1. Data Processing
2. Temperature measurement
   - Basic principles
   - Sensor types
   - Response time
3. Pressure measurement
   - Basic principles
   - Sensors
4. Moisture measurement
   - Moisture Variables
   - Basic Principles
   - Sensors
5. Precipitation measurement
   - Rain gauges
   - Radars for precipitation
6. Wind measurement
   - Mechanical method
   - Electrical method
7. Radiation
   - Basic principles
   - Sensors
8. Clouds measurement
9. Upper atmosphere measurement
10. Weather radar
11. Satellite observations
12. Weather Maps and how to represent Weather Phenomena

Meteorological observations are made for a variety of reasons:

- ❑ for the real-time preparation of weather analyses, forecasts and severe weather warnings,
- ❑ for the study of climate,
- ❑ for local weather dependent operations (for example, local aerodrome flying operations,
- ❑ construction work on land and at sea),
- ❑ for hydrology and agricultural meteorology,
- ❑ for research in meteorology and climatology.




OBSERVING PARAMETERS

PARAMETER	SENSOR	UNIT	MEASURING RANGE
Wind speed	Anemometer	m/sec, knot	0..75 m/sec
Wind direction	Wind vane	Degree	0..360 o
Air temperature	Thermometer	o C	-60 o C..+60 o C
Wet bulb temp.	Thermometer	o C	0...+40 o C
Dew point	Thermometer	o C	-60 o C...+50 o C
Rel. Humidity	Hygrometer	%	0%...100%
Soil Terre. Temp.	Thermometer	o C	-60 o C...+70 o C
Soil temp.	Thermometer	o C	-50 o C...+70 o C
Soil moisture	Moisture sensor	% H_2O	Undefined

OBSERVING PARAMETERS

PARAMETER	SENSOR	UNIT	MEASURING RANGE
Pressure	Barometer	hPa	600....1100 hPa
Precipitation	Pluviometer	mm	Unlimited
Snow depth	Depth sensor	cm	0..1000 cm
Evaporation	Evap. Pool	mm	0...100 mm/day
Global radiation	Pyranometer	Watt/m2	0...1500 W/m2
Direct radiation	Pyrheliometer	Watt/m2	0...1500 W/m2
Diffuse radiation	Pyranometer	Watt/m2	0...1500 W/m2
Net radiation	Pyranometer	Watt/m2	Undefined
Sunshine duration	Heliometer	Hour	120 W/m2 (threshold)

OBSERVING PARAMETERS

PARAMETER	SENSOR	UNIT	MEASURING RANGE
Leaf wetness	Wetness sensor	Kg/m2, capacity%	Undefined
Soil heat flux	Flux sensor	Watt/m2	Undefined
Lightning	Lightning Detector	Count	0....9999
Cloud height	Ceilometer	M, feet	30...25.000 m
Visibility	Transmissometer Forward scatt.	M, km	25....50.000 m
Present weather	Pre. Weat. Sen.	Phenomen a code	----

A **measurement** is a quantity that has both a **number** and a **unit**.

2.34 g **36.1 mL** **996 hPa**

Measurements are fundamental to the experimental sciences. For that reason, it is important to be able to MAKE measurements and to *decide* whether a measurement is CORRECT.

We can make these observations in two ways:

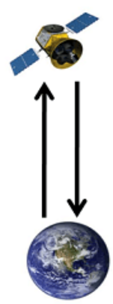
In situ measurement

- measurements obtained through direct contact with the respective object (basically you take measurements of the parameters right were you are)
- they measure the parameters from where they are located at that moment, Surface (stations, ships, or, buoys), or upper-air(rockets; balloons, and aircrafts)

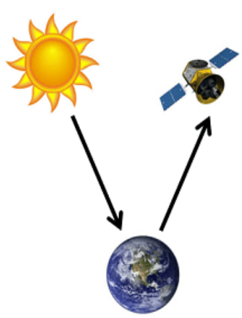
Remote sensing measurement

- acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing devices that are wireless, not in physical or intimate contact with the object.
- It has two types: active and passive remote sensing

Active remote Sensing: Makes use of sensors that detect reflected responses from objects that are irradiated from artificially-generated energy sources, such as radar(send out radiation, hoping to get it back to analyze it).



Active remote sensor



Passive remote sensor

Passive Remote Sensing: Makes use of sensors that detect the reflected or emitted electro-magnetic radiation from natural sources (wait for radiation to come to them so that they can analyze the data)

Steps needed to make measurements for a specific application:

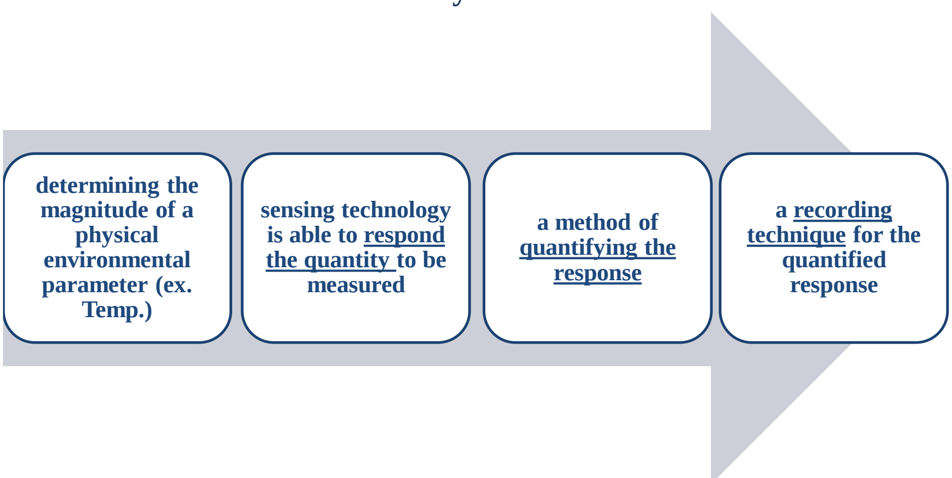
1. Define and research the problem (literature review is advised).
- What parameters are required and what must be measured.
- What is the frequency of the observations that will be required?
- How long will the observations be made?
- What level of error is acceptable?

2. Know and understand the instruments that will be used (consider cost, durability, and availability).

3. Apply instruments and data processing (consider deployment, and data collection).

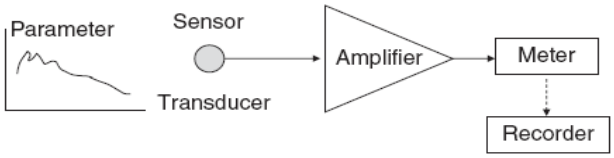
4. Analyze the data (apply computational tools, statistics, etc..).

Instruments and measurement systems



- **Closely related is the need to <u>evaluate</u> how well the quantity has been measured, <u>to provide an assessment of the associated uncertainty.</u>**

The <u>sensor</u> responds to the specific parameter measured.
(In some cases, energy exchange by a <u>transducer</u> may also be required, to convert the sensor's response into something which can be more conveniently measured.)
An <u>amplifier</u> is used to increase the magnitude of the changes produced by the sensor. Amplifiers operate on a variety of principles, for example mechanical, chemical, optical or electronic. As well as increasing the signal, an amplifier usually increases other random variations (noise) present as well.
The <u>meter</u> provides the final readout in terms of a magnitude, and can be digital or analogue.
A <u>recording</u> device of some form may be attached to the meter, such as a chart recorder, a computerized logging system or, more simply, an observer with a notebook.



Term	Explanation
Parameter	The variable physical quantity to be measured, such as pressure, temperature, speed, time.
Sensor	A device which responds directly in some way to changes in the parameter to be measured. For example, the rotating cups on a cup anemometer.
Transducer	An energy transfer device to convert the response of a sensor into another quantity, which can be more conveniently measured (e.g. to an electrical signal) or recorded. In some instruments, such as a photovoltaic light meter, the functions of sensor and transducer are combined.
Amplifier	This magnifies a small change, for example turning a small voltage change into a larger voltage change; amplifiers are, however, not necessarily electronic.
Gain	The ratio of the output signal amplitude to the input signal amplitude of an amplifier stage.
Meter	This measures and displays the output from a transducer or sensor (meters are often electrical, in that they display a voltage, but may also be mechanical).
Recorder	A device employing a retrieval method (paper, film, electronic etc.) by which a series of successive meter readings can be preserved.

Descriptions of parts of an instrument

General Concepts: Understanding measurement:

Accuracy
Definition and how to achieve it

The ability of the instrument to measure a quantity with little or no deviation among measurements (Accuracy is how close the measurement is to the true value of the variable). Accuracy is determined by the combination of **random and systematic** errors in the instrument

To achieve accuracy: take the readings as carefully as possible, repeat the measurements at least three times, look out for anomalous results – odd ones which don't fit the trend / pattern, and repeat a measurement if necessary.

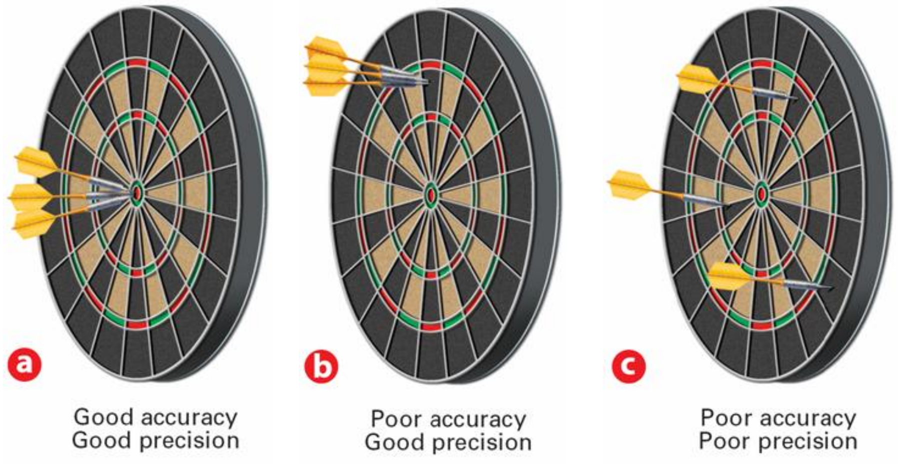
General Concepts: Understanding measurement:

Precision Definition and how to achieve it

refers to how close together a series of measurements are to each other.

in repeated trials, it is able to give the same output response for the same value of the input parameter. Precision is therefore determined by the **systematic error** in the instrument remaining constant

Accuracy – closest to TRUE Value
Precision – repeated Same Value



Precision versus accuracy

As an example: let us say I have two digital clocks in front of me. One says the time is 10:23:46, the other says it is 10:19. The first is very precise, but is it accurate?
Both clocks show different times and clearly one must be wrong.
If I were to check the time using a third source of known accuracy, perhaps a radio-controlled clock, and found that at the time I observed the clocks, the exact time was 10:18:46, then it is apparent that although the first measurement is precise, it is not accurate.
The second measurement is less precise, but it is more accurate.

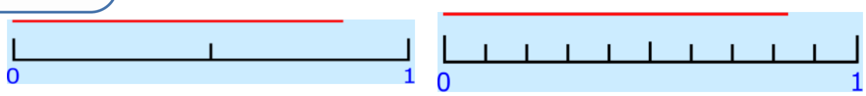
General Concepts: Understanding measurement:

Sensitivity of the Instrument

-Is the quantitative response to the change, which is the ratio of the response in the instrument to a unit change in the parameter sensed.

-This is the change occurring in the output from the complete instrument (i.e. sensor + transducer + amplifier), in response to a unit change in the parameter sensed.

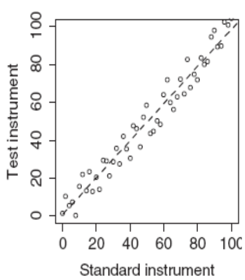
A <u>more sensitive</u> instrument will lead to more precise measuring, because there are more divisions to assist in reading the scale.



Sensitivity of the Instrument

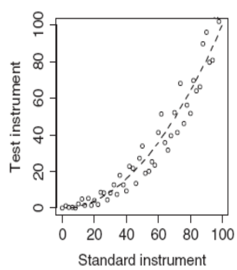
Linear Response

the sensitivity will be the same no matter how large or small the value of the parameter, yielding a straight line relationship between variations in the parameter and the instrument's response



Non-linear Response

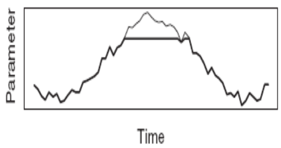
the sensitivity varies with the parameter sensed

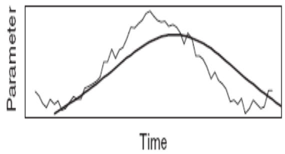


Factors which can influence an instrument's response to variations in the parameter sensed : If the instrument is unable to measure over the full range of the possible values of the parameter, it is said to have insufficient dynamic range, and there will be no further variation measured even if there are continued variations above this maximum. The instrument is then said to be saturated, and the only information it provides is that the parameter is greater than or equal to the instrument's maximum value, with an indication of for how long the saturation condition persists.

An instrument may also not be able to follow rapid variations in the parameter sensed, because of a limited time response.

1. Rapid changes in the parameter become smoothed out by the instrument and so are not determined,
2. There may also be some delay in the changes being registered



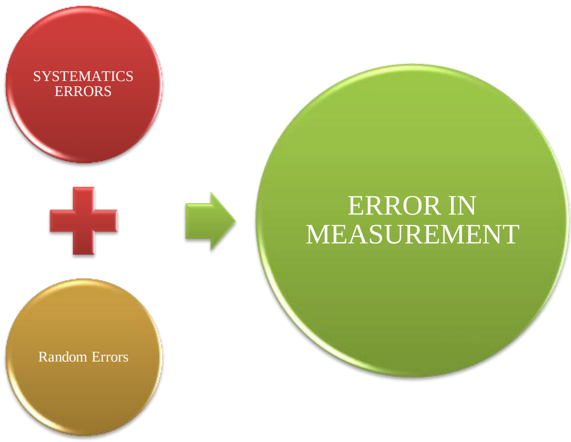


Measurement quality

- Calibration: is a comparison between an instrument of unknown response and another instrument whose accuracy is known, it provides a test of the instrument's response against known values of the parameter sensed, or at least values of the parameter which are themselves known to an acknowledged level of uncertainty.
- The successive comparison of a poorer instrument with a better instrument leads to the need for a calibration standard. In general, such standards, reference instruments are maintained by national standards laboratories. These are essentially the primary standards, from which secondary standard instruments are calibrated and distributed to other laboratories.
- There are also 'absolute' instruments which can be self-calibrating, through permitting a comparison with other physical quantities independently defined.

Calibration of an instrument will reveal the uncertainties (or errors) associated with its measurements.
Error -is the difference between the actual value of a quantity and the value obtained in measurement.
Acutal value– standard or reference of known value or a theoretical value.

There are 2 main types of error:



Systematic errors are biases in measurement which lead to the situation where the mean of many separate measurements differs from the actual value of the measured attribute.

Systematic errors: (a) constant, or (b) varying depending on the actual value of the measured quantity.

- When they are constant, they are simply due to incorrect zeroing of the instrument (when the measuring instrument does not start from exactly zero).
- When they are not constant, they can change sign.

- A common method to remove systematic error is through
- calibration of the measurement instrument.

Random errors

1. Random errors arise from unknown and unpredictable variations in condition.

2. It fluctuates from one measurement to the next.

3. Random errors are caused by factors that are beyond the control of the observers. They can cause by personal errors such as

- **human limitations of sight and touch.**
- **lack of sensitivity of the instrument: the instrument fail to respond to the small change.**
- **natural errors such as changes in temperature or wind, while the experiment is in progress.**
- **wrong technique of measurement.**

5. One example of random error is the parallax error.

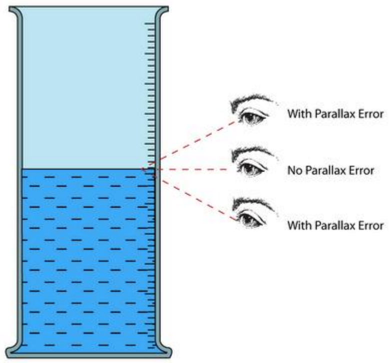
Random error can be reduced by

- taking repeat readings

- find the average value of the reading.

Parallax error

A parallax error is an error in reading an instrument due to the eye of the observer and pointer *are not in a line perpendicular to the plane of the scale.*



How to express errors:

- **Absolute Error = |Measured Value- Actual Value |**
- **Relative Error = Absolute Error / Actual Value**
- **Percentage Errors = Relative Error x100%**

Fundamentals Data processing concepts

A. Simple statistics

B. Significant figures

Simple statistics

Averaging

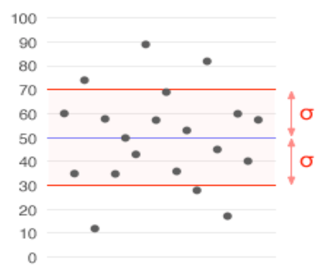
$$\bar{x} = \frac{1}{n}[(x(1) + x(2) + ... + x(n)] = \frac{1}{n}\sum_{t=1}^{n} x(t)$$

Variance

$$\sigma_x^2 = \overline{x'^2}$$

Standard deviation

$$\sigma_x = \sqrt{\overline{x'^2}}$$



covariance

$$\overline{x'y'} = \frac{1}{n}\sum_{i=1}^{n} \overline{x'(i)y'(i)}$$

Correlation coefficient

$$\gamma_{xy} = \frac{\overline{(x'y')}}{\sigma_x \sigma_y}$$

EXPRESSING ACCURACY AND PRECISION

Mean (average) Percent error	accuracy
Range Deviation Standard deviation Percent coefficient of variation	precision

Significant Figures (Sig Figs) = **Known** + **ESTIMATE**

The **significant figures** in a measurement include all of the digits that are **known**, plus a last digit that is **estimated**.

Significant Figures relate to the **certainty** of a measurement – The **PRECISION** of the measurement

<u>Precision</u> = Same REPEATABLE Value (Certainty)

More Sig Figs = more certainty = greater <u>precision</u>

a Measured length = _ **1 sig fig (.<u>6</u> is the estimate)**

b Measured length = _ **2 sig figs (.0<u>1</u> is the estimate)**

c Measured length = _ **3 sig figs**

Most <u>certainty</u> and greatest PRECISION

Which measurement has the most <u>certainty</u> and greatest PRECISION?

Rules for Counting Significant Figures - Details

- <u>Nonzero integers</u> always count as significant figures.

  - 3456 has
  - 4 sig figs.

Rules for Counting Significant Figures - Details

- Zeros
- - Leading zeros do not count as significant figures.

  - 0.0486 has
  - 3 sig figs.

Rules for Counting Significant Figures - Details

- Zeros
- - Captive zeros always count as significant figures.

  - 16.07 has
  - 4 sig figs.

Rules for Counting Significant Figures - Details

- Zeros
- Trailing zeros are significant only if the number contains a decimal point.

  - 9.300 has
  - 4 sig figs.

Rules for Counting Significant Figures - Details

- Exact numbers have an infinite number of significant figures.

  - 1 inch = 2.54 cm, exactly

RULE-2: Every digit in scientific notation is Significant

47.3	4.73×10^{1}	= 3 S.F
0.0021	2.1×10^{-3}	= 2 S.F
1.200	1.200×10^{0}	= 4 S.F
36	3.6×10^{1}	= 2 S.F
2400	2.4×10^{3}	= 2 S.F
0.0600	6.00×10^{-2}	= 3 S.F
104,000	1.04×10^{5}	= 3 S.F

Sig Fig Practice #1

How many significant figures in each of the following?

1.0070 m → 5 sig figs

17.10 kg → 4 sig figs

100,890 L → 5 sig figs

3.29×10^{3} s → 3 sig figs

0.0054 cm → 2 sig figs

3,200,000 → 2 sig figs

Rules for Significant Figures in Mathematical Operations

- **Multiplication and Division:**
- # sig figs in the result equals the number in the least precise measurement used in the calculation.

- 6.38 x 2.0 =
- 12.76 → 13 (2 sig figs)

Sig Fig Practice #2

Calculation	Calculator says:	Answer
3.24 m x 7.0 m	22.68 m^2	23 m^2
100.0 g ÷ 23.7 cm^3	4.219409283 g/cm^3	4.22 g/cm^3
0.02 cm x 2.371 cm	0.04742 cm^2	0.05 cm^2
710 m ÷ 3.0 s	236.6666667 m/s	240 m/s
1818.2 lb x 3.23 ft	5872.786 lb·ft	5870 lb·ft
1.030 g ÷ 2.87 mL	2.9561 g/mL	2.96 g/mL

Rules for Significant Figures in Mathematical Operations

- **Addition and Subtraction**: The number of decimal places in the result equals the number of decimal places in the least precise measurement.

- 6.8 + 11.934 =
- 18.734 → 18.7 (3 sig figs)

Sig Fig Practice #3

Calculation	Calculator says:	Answer
3.24 m + 7.0 m	10.24 m	10.2 m
100.0 g - 23.73 g	76.27 g	76.3 g
0.02 cm + 2.371 cm	2.391 cm	2.39 cm
713.1 L - 3.872 L	709.228 L	709.2 L
1818.2 lb + 3.37 lb	1821.57 lb	1821.6 lb
2.030 mL - 1.870 mL	0.16 mL	0.160 mL

CONCEPTUAL PROBLEM 3.1

Counting Significant Figures in Measurements

How many significant figures are in each measurement?

a. 123 m

b. 40,506 mm

c. 9.8000×10^4 m

d. 22 meter sticks

e. 0.070 80 m

f. 98,000 m

Guesses only, don't write any of this down YET.

There are rules (hints) to help you in determining the number of significant figures there are in a measurement.

CONCEPTUAL PROBLEM 3.1

Counting Significant Figures in Measurements

How many significant figures are in each measurement?

a. 123 m = 3 S.F

b. 40,506 mm = 5 S.F

c. 9.8000×10^4 m = 5 S.F

d. 22 meter sticks = Unlimited

e. 0.070 80 m = 4 S.F

f. 98,000 m = 2 S.F

Guesses only, don't write any of this down YET.

There are rules (hints) to help you in determining the number of significant figures there are in a measurement.

3.1 Section Quiz

- 1. Which set of measurements of a 2.00-g standard is the most precise?
  - 2.00 g, 2.01 g, 1.98 g
  - 2.10 g, 2.00 g, 2.20 g
  - 2.02 g, 2.03 g, 2.04 g
  - 1.50 g, 2.00 g, 2.50 g

3.1 Section Quiz

- 2. A student reports the volume of a liquid as 0.0130 L. How many significant figures are in this measurement?
- 2
- 3
- 4
- 5