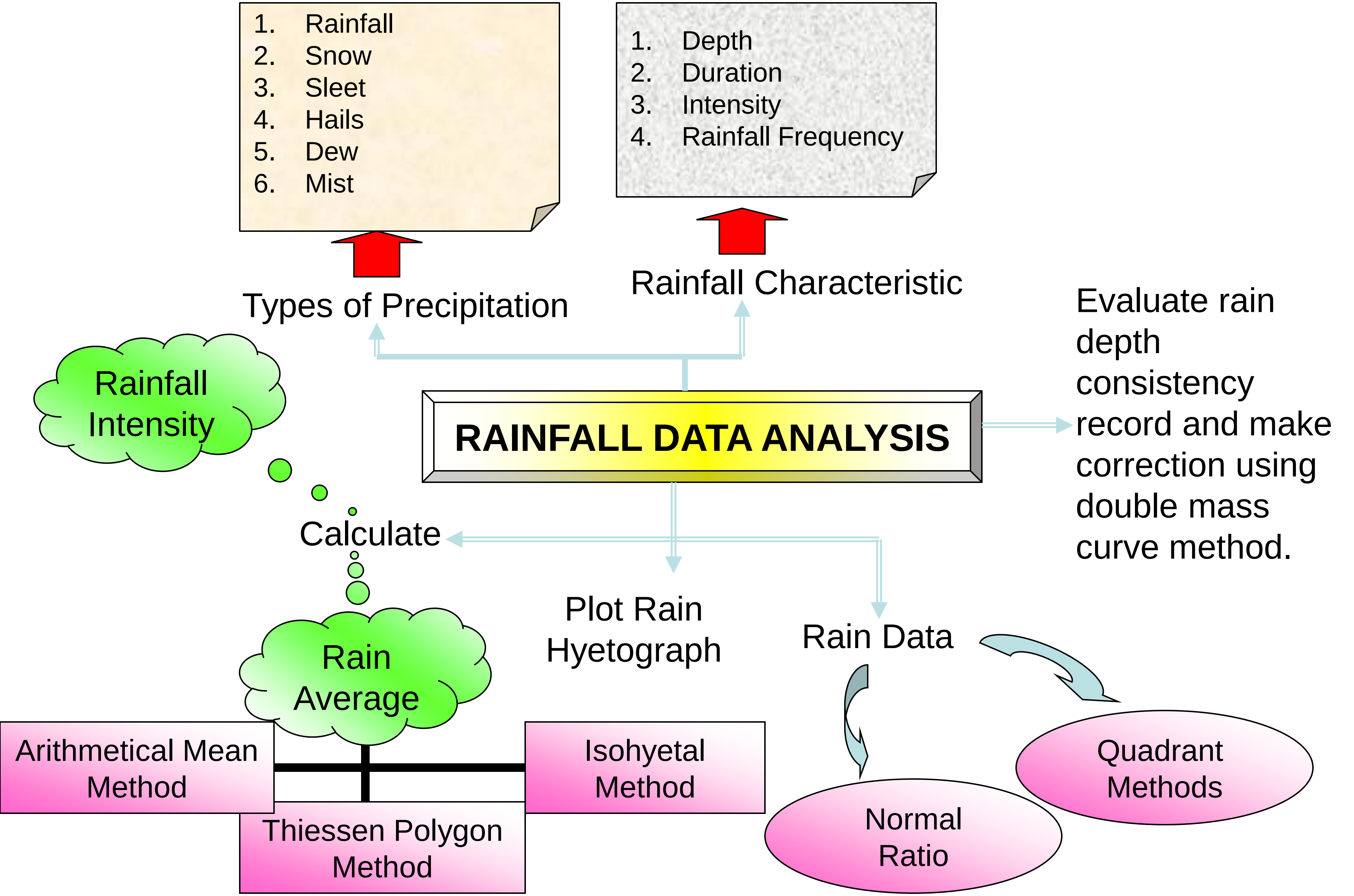


1. Rainfall
2. Snow
3. Sleet
4. Hails
5. Dew
6. Mist
1. Depth
2. Duration
3. Intensity
4. Rainfall Frequency
Types of Precipitation
Rainfall Characteristic
Evaluate rain depth consistency record and make correction using double mass curve method.
Rainfall Intensity
RAINFALL DATA ANALYSIS
Calculate
Plot Rain Hyetograph
Rain Data
Rain Average
Arithmetical Mean Method
Isohyetal Method
Thiessen Polygon Method
Quadrant Methods
Normal Ratio

PRECIPITATION

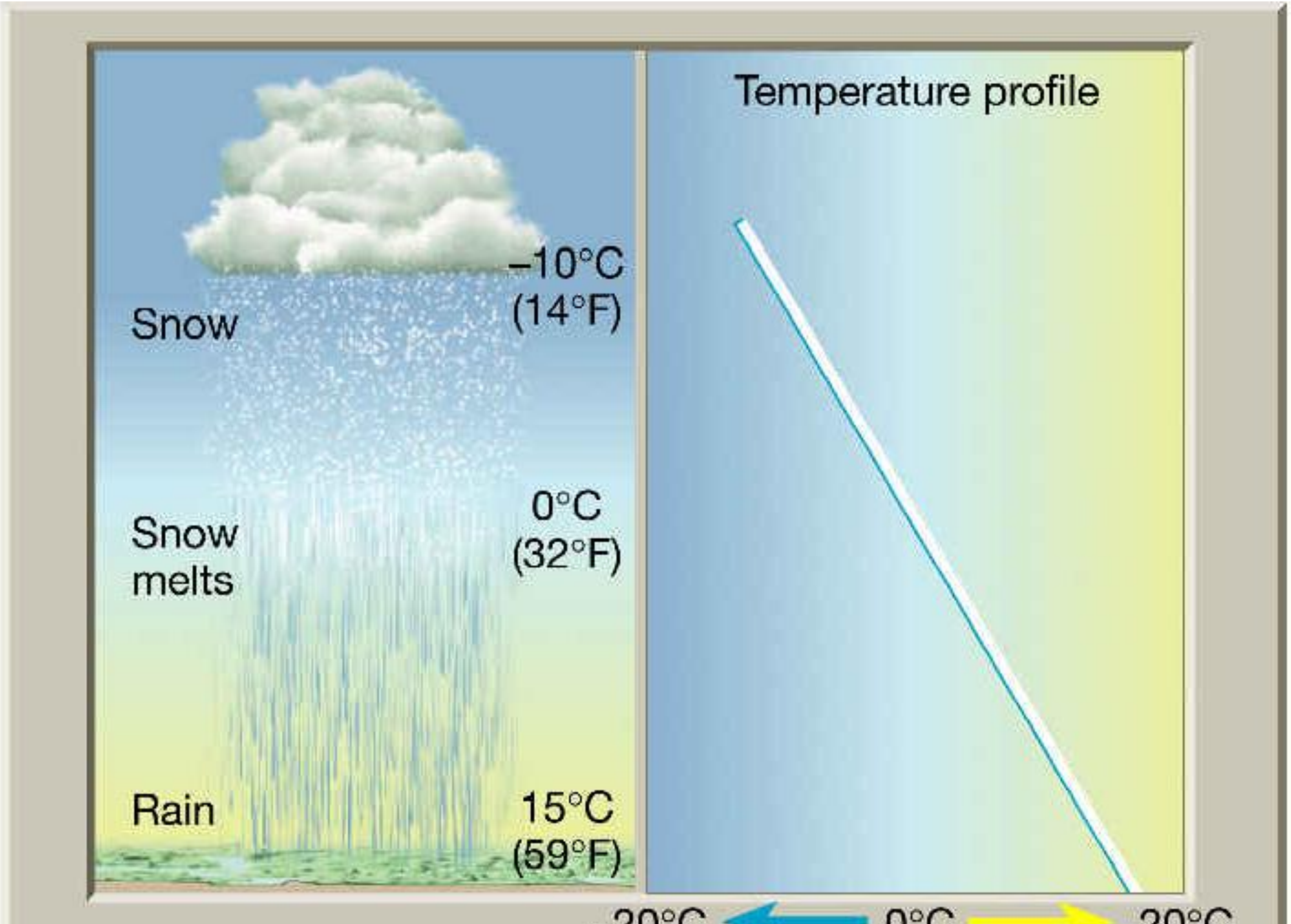
- is any dump or deposition in solid or liquid form that originated from the atmosphere.
- Most come from the sea.
- occurs when water vapor cools.
- When the air reaches saturation point (also know as condensation point and dew point) the water vapor condenses and forms tiny droplet of water.
- Precipitation form a 0.001% of the world’s water resources

Types of Precipitation

- **HORIZONTAL PRECIPITATION**
  - Water vapour become frozen near the surface or directly on the surface
  - Example : dew and fog
- **VERTICAL PRECIPITATION**
  - Water vapour become freezing on the air and fall to the earth
  - Example : rain and snow

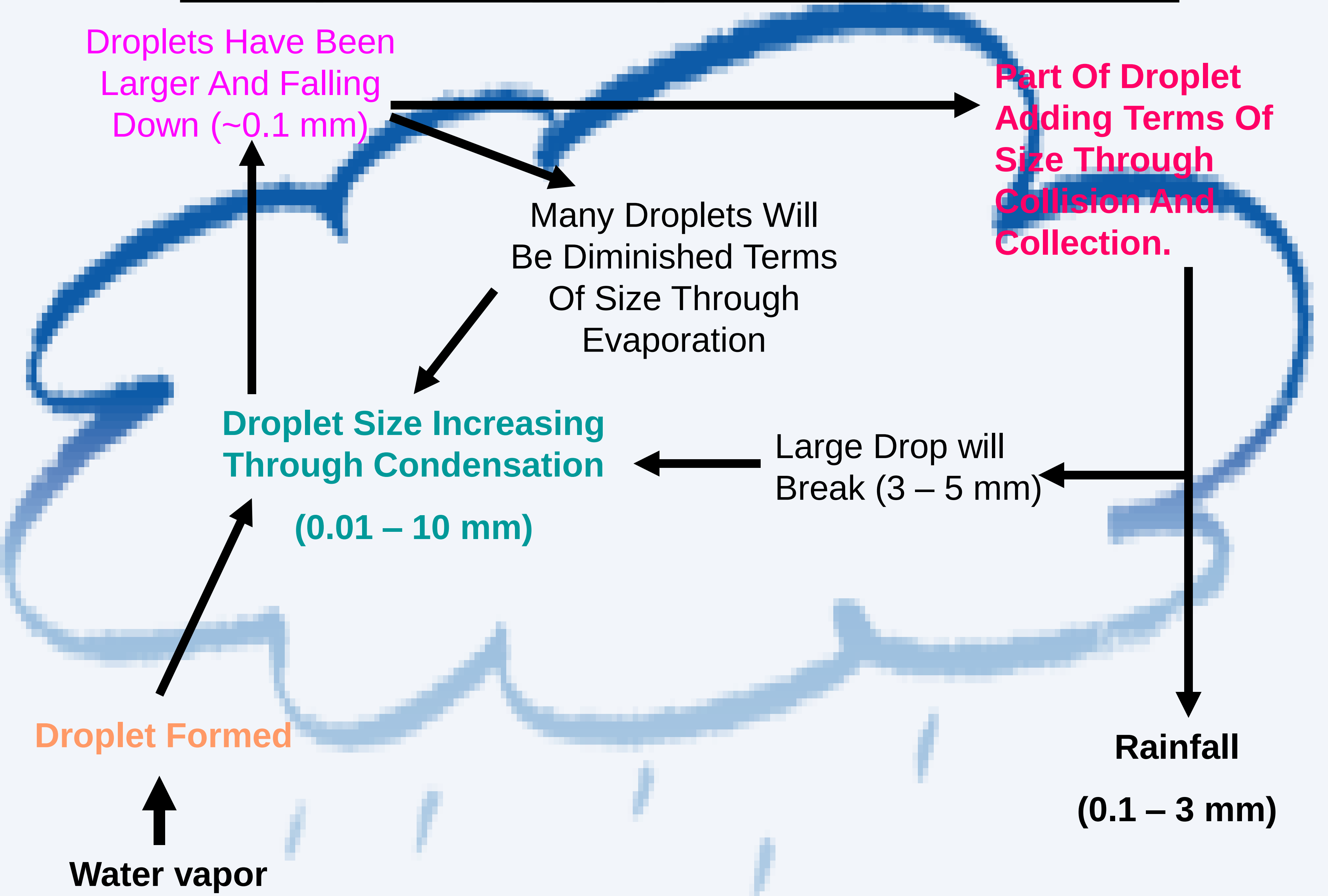
RAINFALL

- Rain is the major from precipitation in the form of water drops sizes greater than 0.5 mm.
- The maximum sizes of rain drop is about 6 mm based on the intensity, rainfall is classified as light rain (>2.5mm - 5mm/hr), moderate rain (2.5 – 7 mm/hr) and heavy rain (>7.5mm/hr)

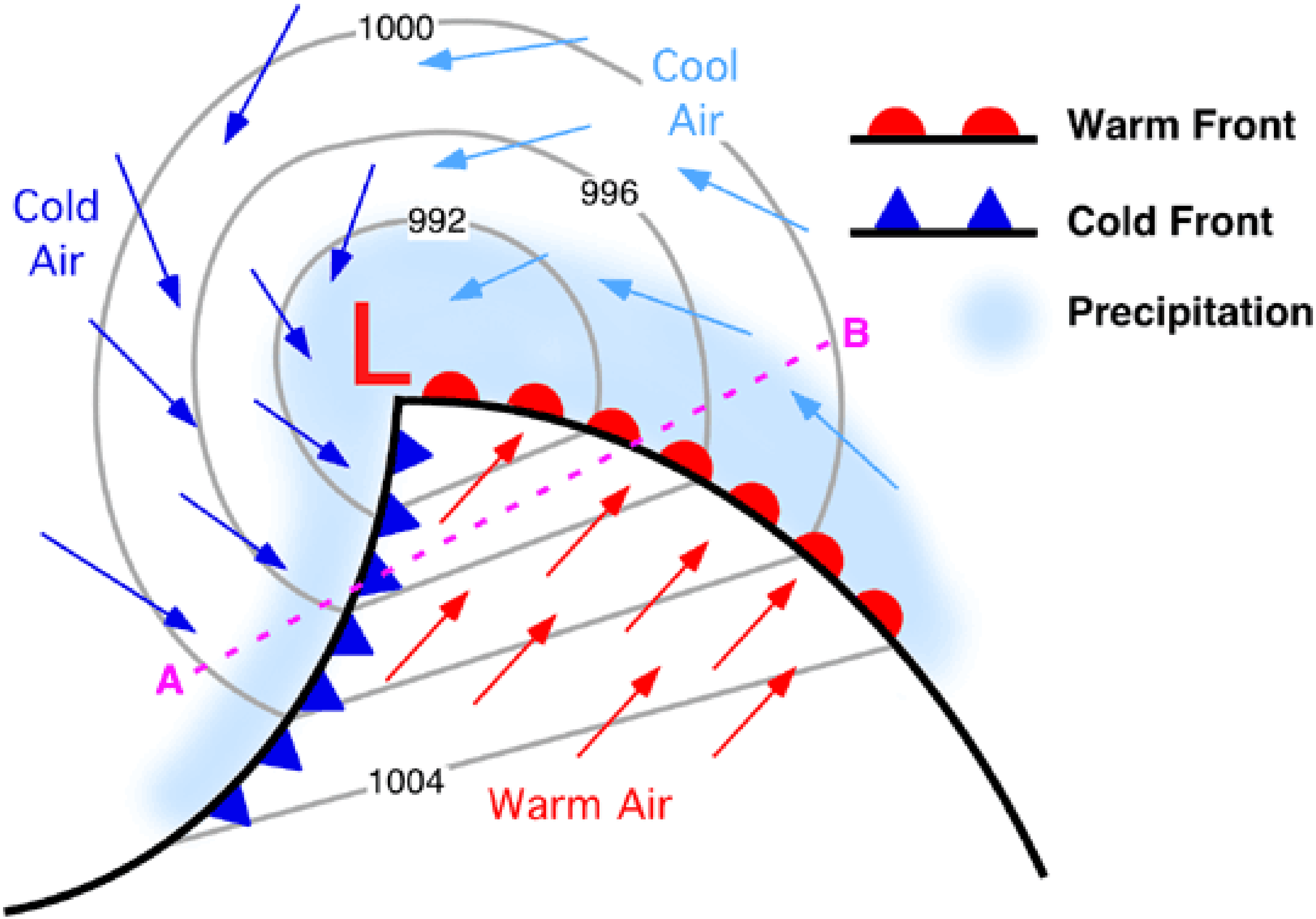

Temperature profile
–10°C
(14°F)
Snow
0°C
(32°F)
Snow
melts
Rain
15°C
(59°F)
–20°C
(–4°F)
0°C
(32°F)
20°C
(68°F)

(a) Rain

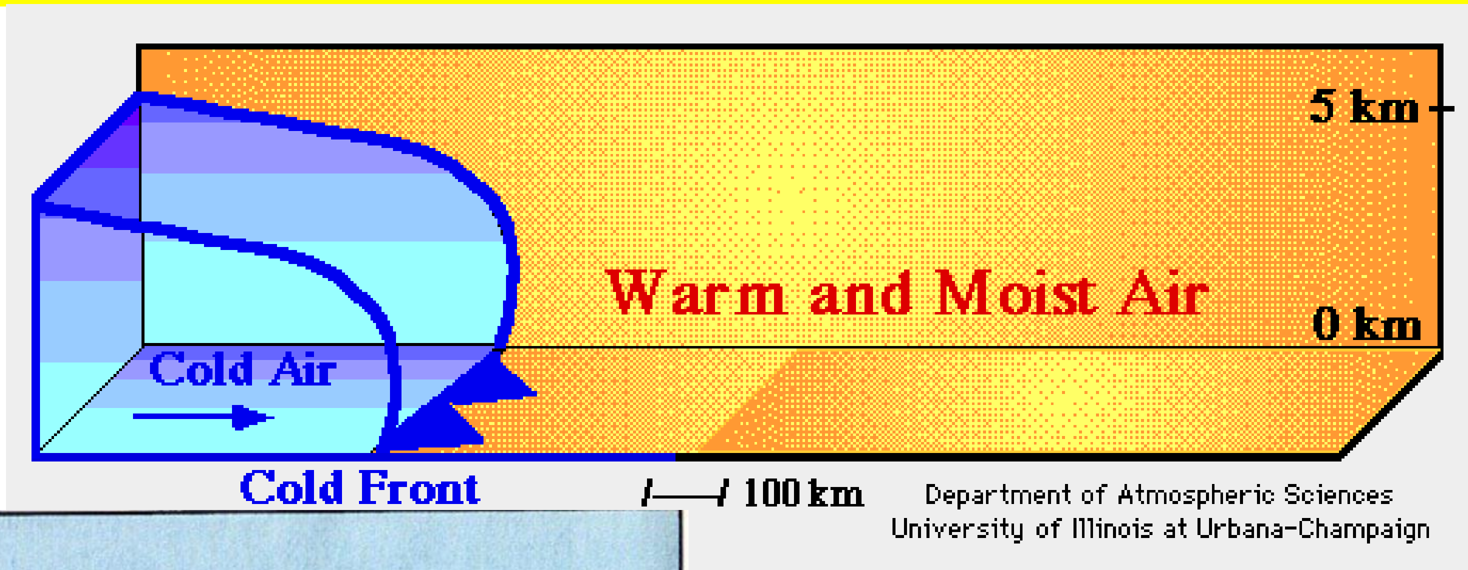
Precipitation (Rain) Formation Process

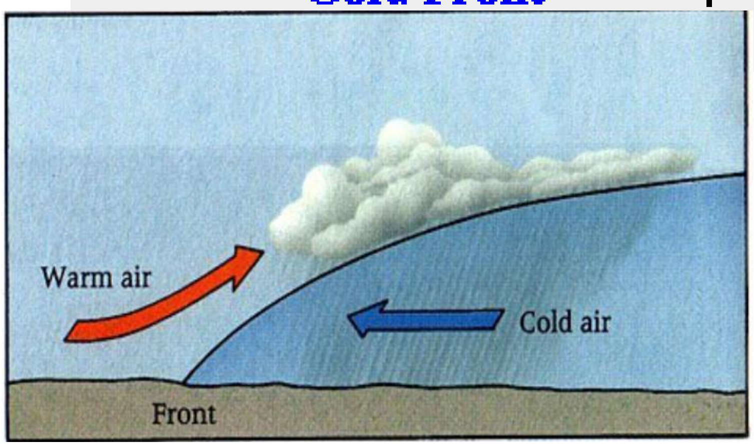


CYCLONE RAIN



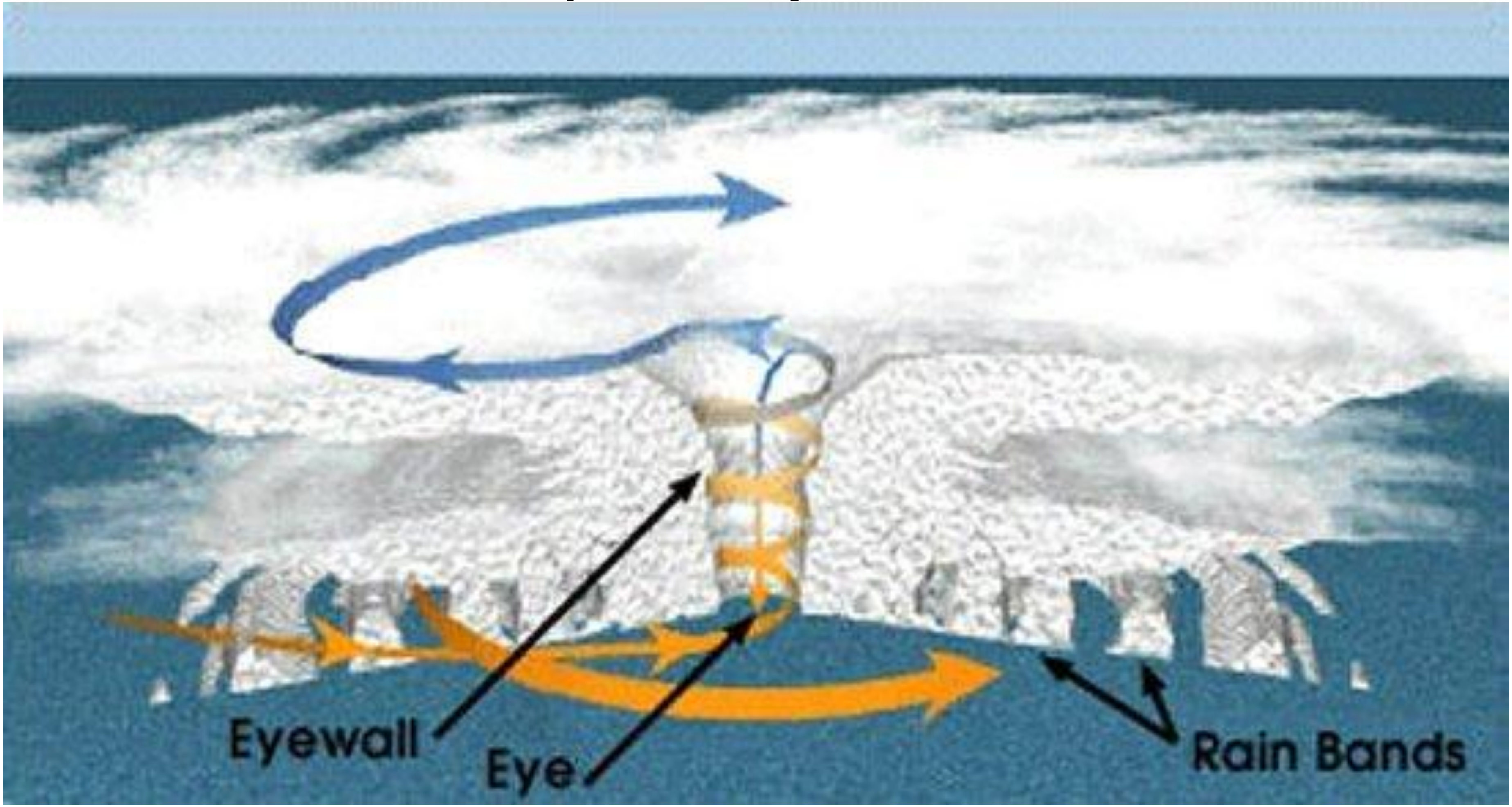
CYCLONE RAIN





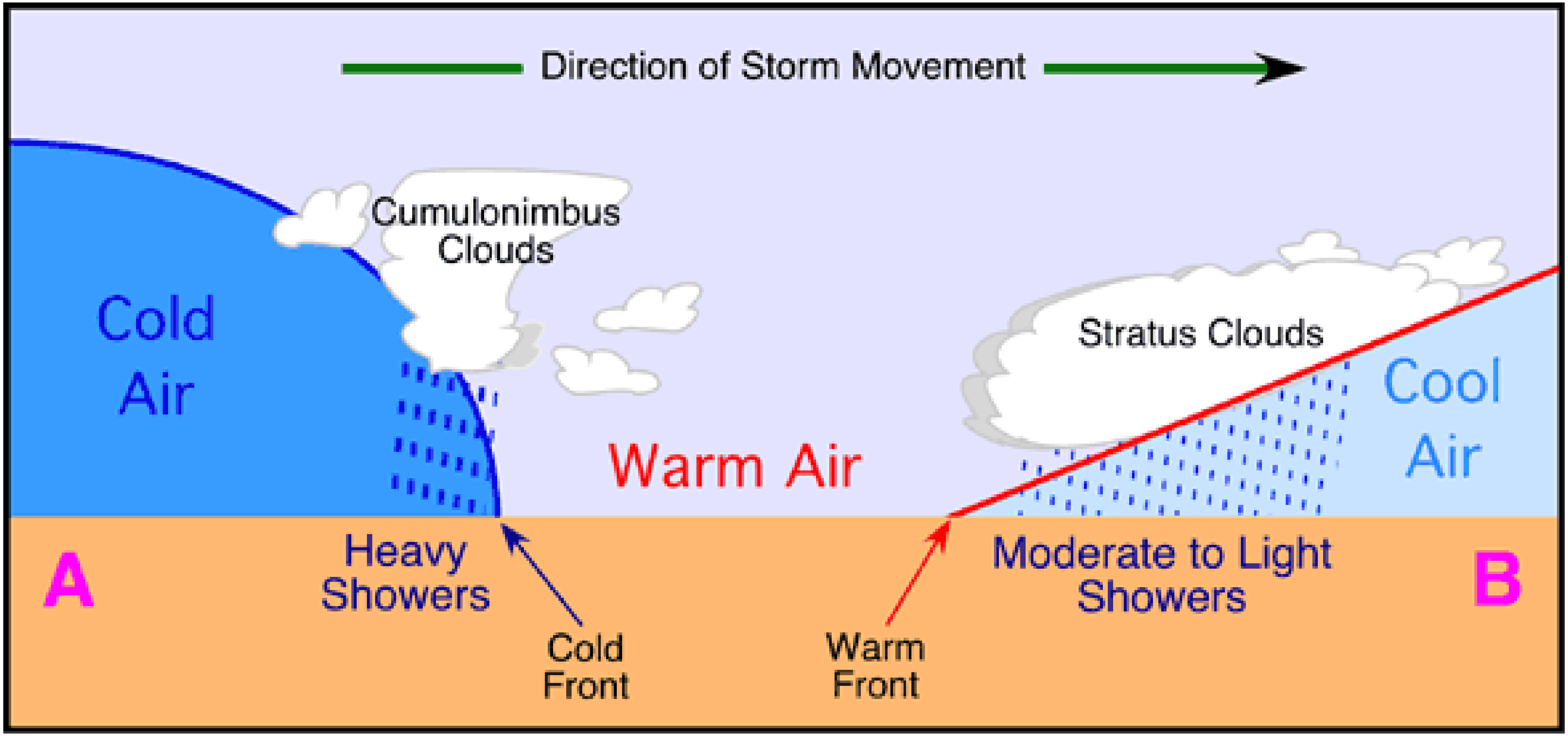
Stage 1	:	An area of warm air meets and area of cold air
Stage 2	:	The warm air is forced over the cold air.
Stage 3	:	Where the air meets the warm air is cooled and water vapour condenses
Stage 4	:	Clouds form and precipitation occurs

Hurricane & Tropical Cyclone Formation



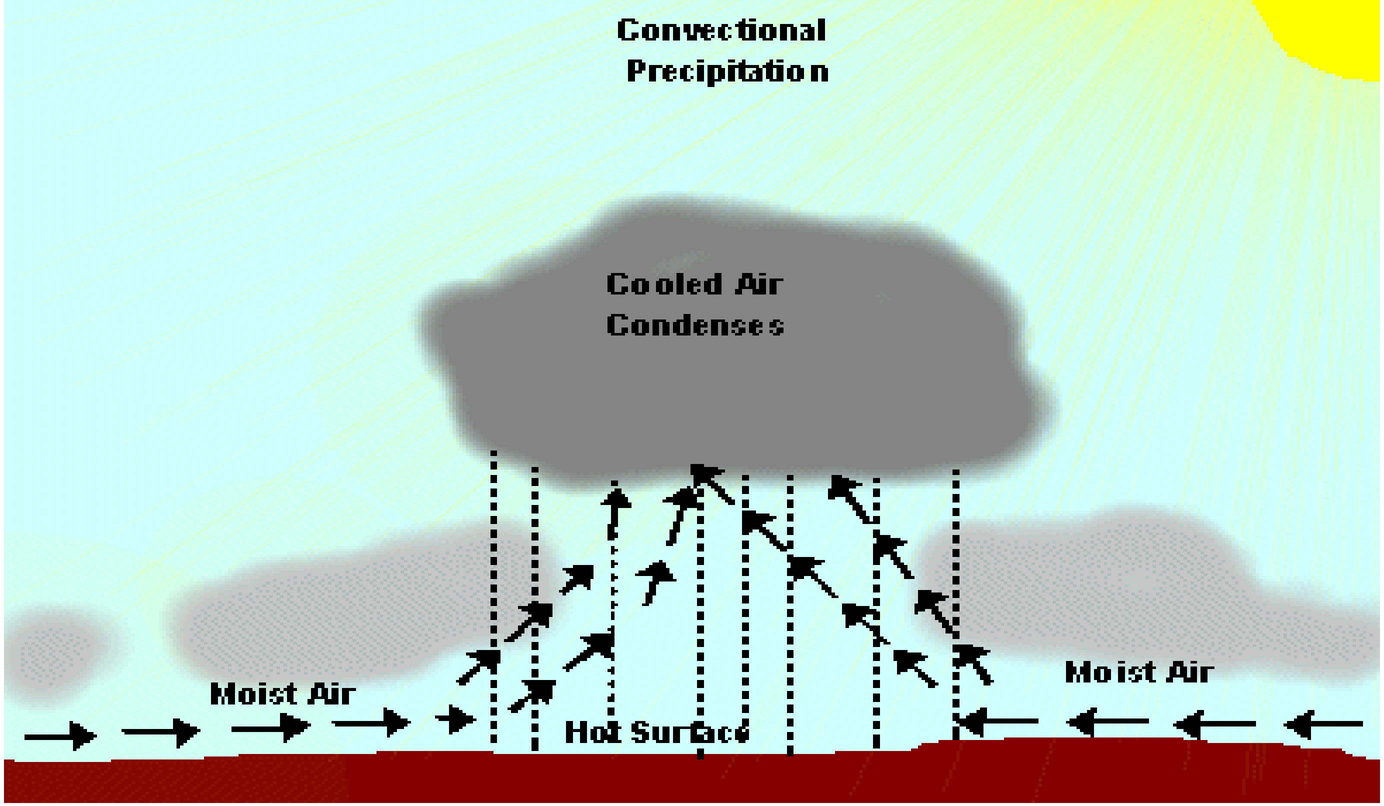
Fully formed tropical cyclone with an eye, eyewall, and circulating rain bands

CONVECTIONAL RAIN



CONVECTIONAL RAIN/ HUJAN PEROLAKAN

- Convectional precipitation results from the heating of the earth's surface that causes air to rise rapidly. As the air rises, it cools and moisture condenses into clouds and precipitation. This type of precipitation is common in the prairie provinces.



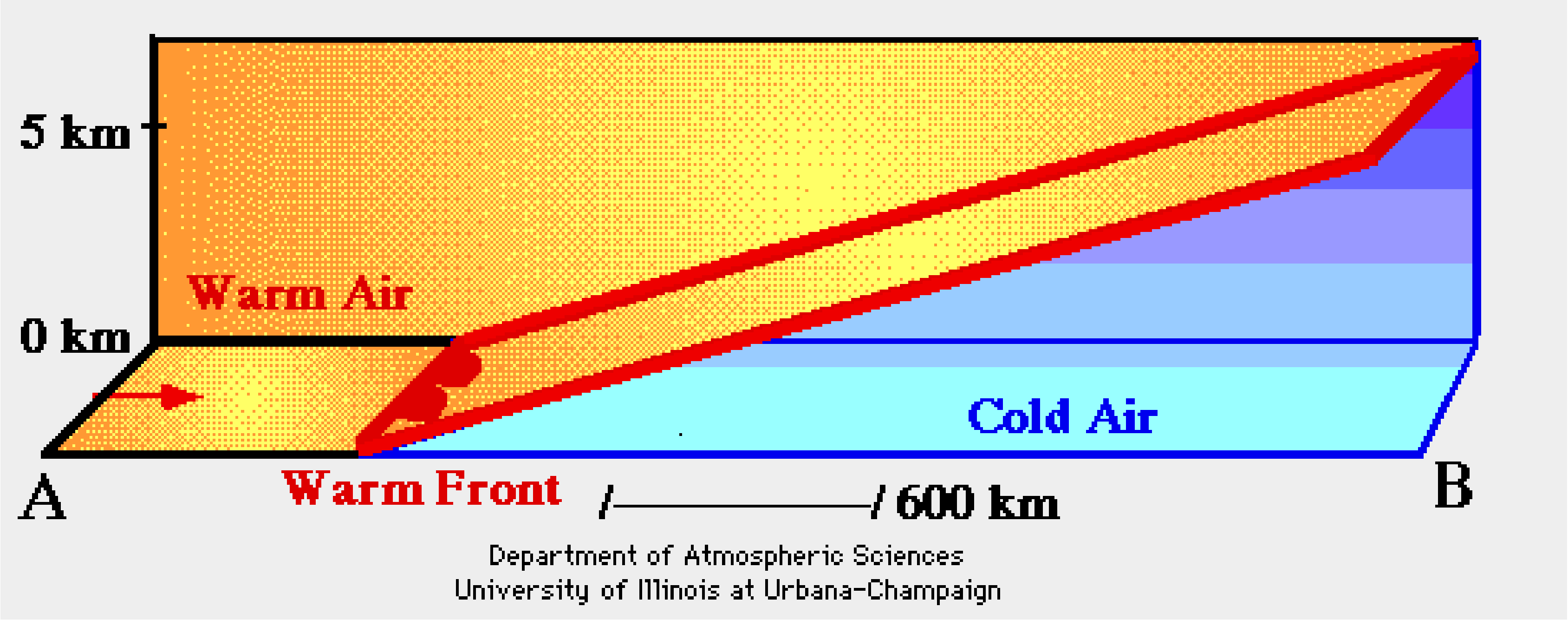
Stage 1 : The sun heats the ground and warm air rises

Stage 2 : As the air rises it cools and water vapour condenses to form clouds

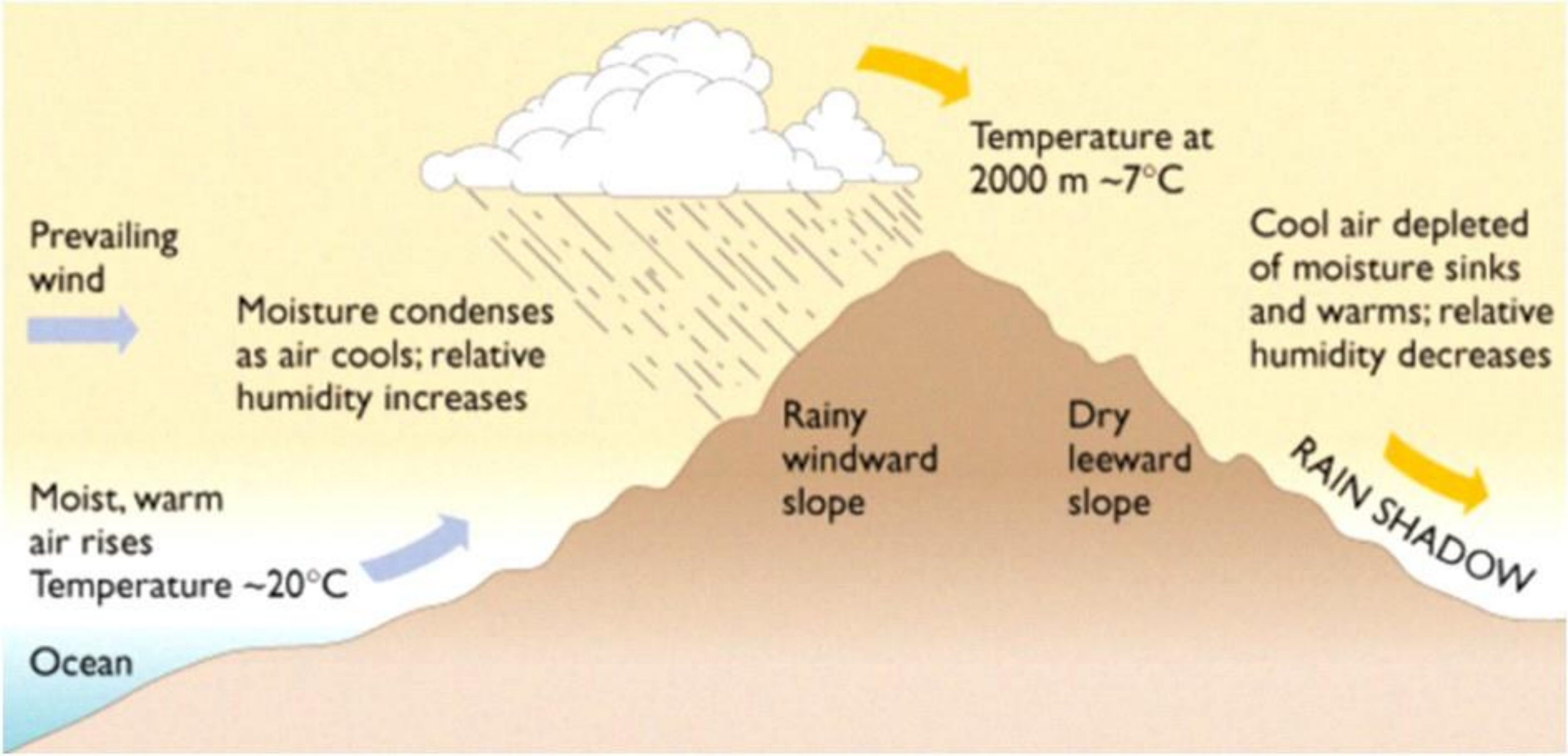
Stage 3 : When the condensation point is reached large cumulonimbus clouds are formed

Stage 4 : Heavy rain storms occur. These usually include thunder and lightening due to the electrical charge created by unstable conditions.

CONVECTIONAL RAIN/ HUJAN PEROLAKAN



OROGRAPHIC PRECIPITATION

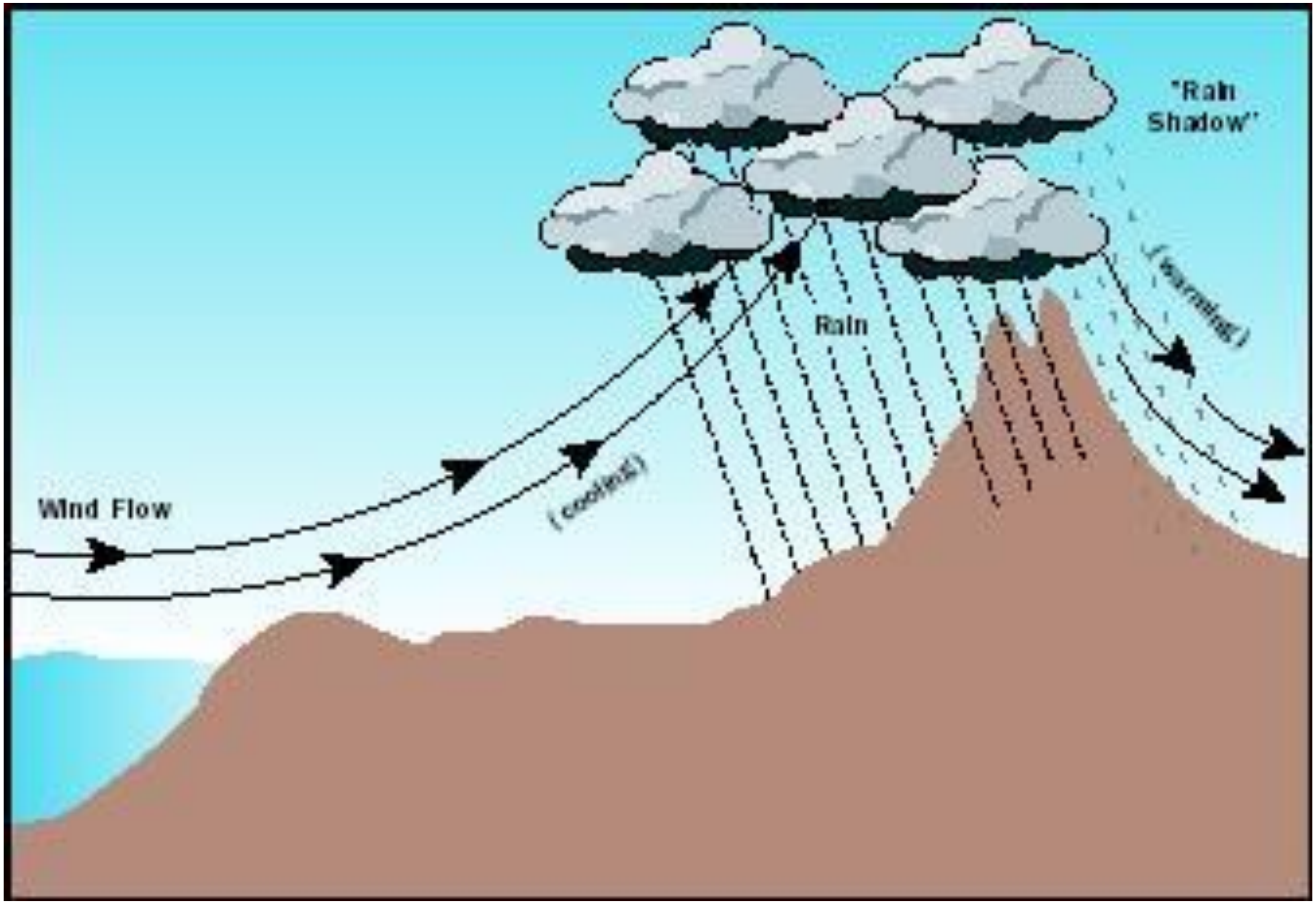


Stage 1 : Warm wet air id forced to rise over high land

Stage 2 : As the air rises it cools and condenses. Clouds form and precipitation occurs.

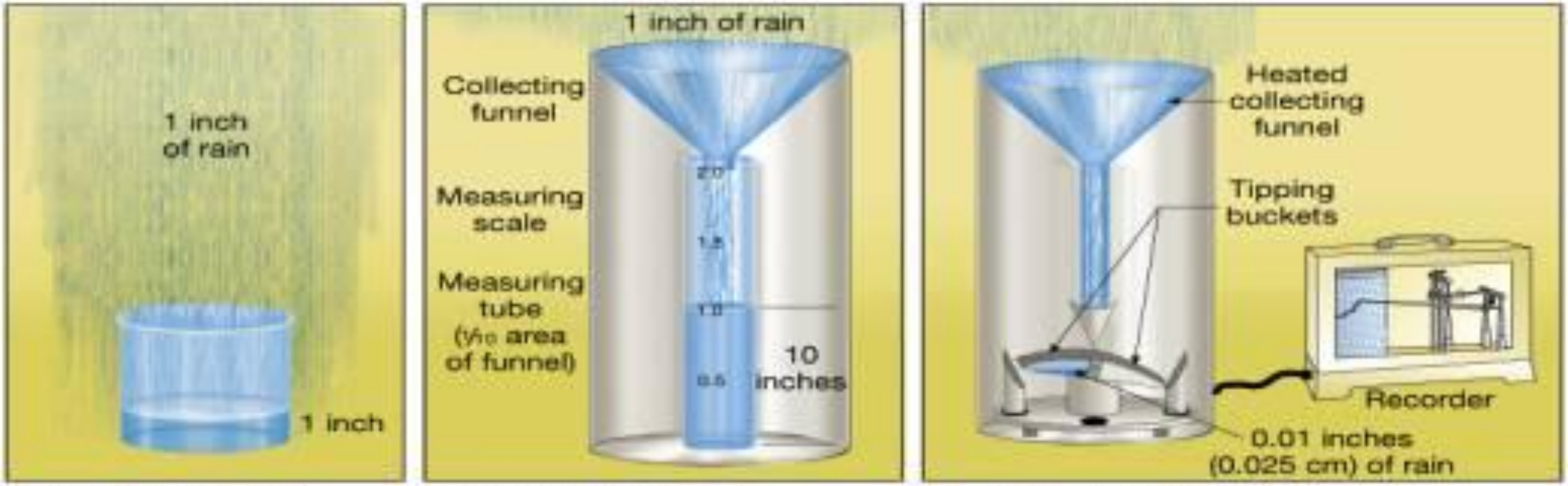
Stage 3 : The drier air descends and warms

Stage 4 : Any moisture in the air (e.g. cloud) evaporates

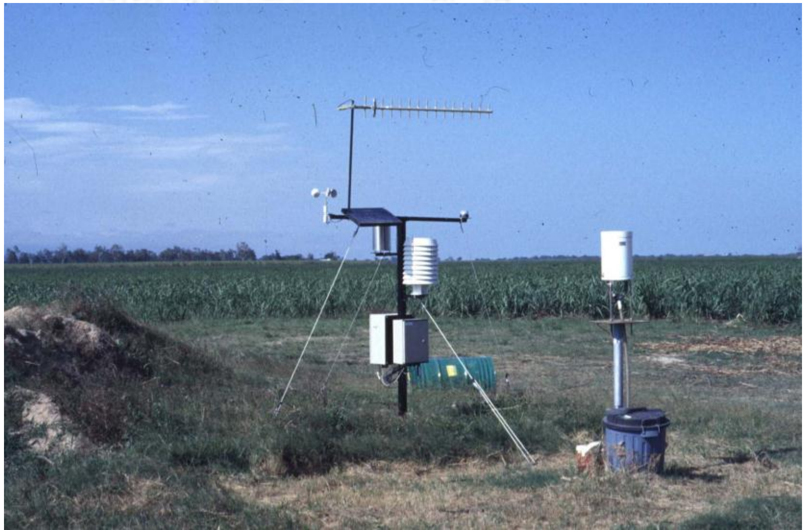


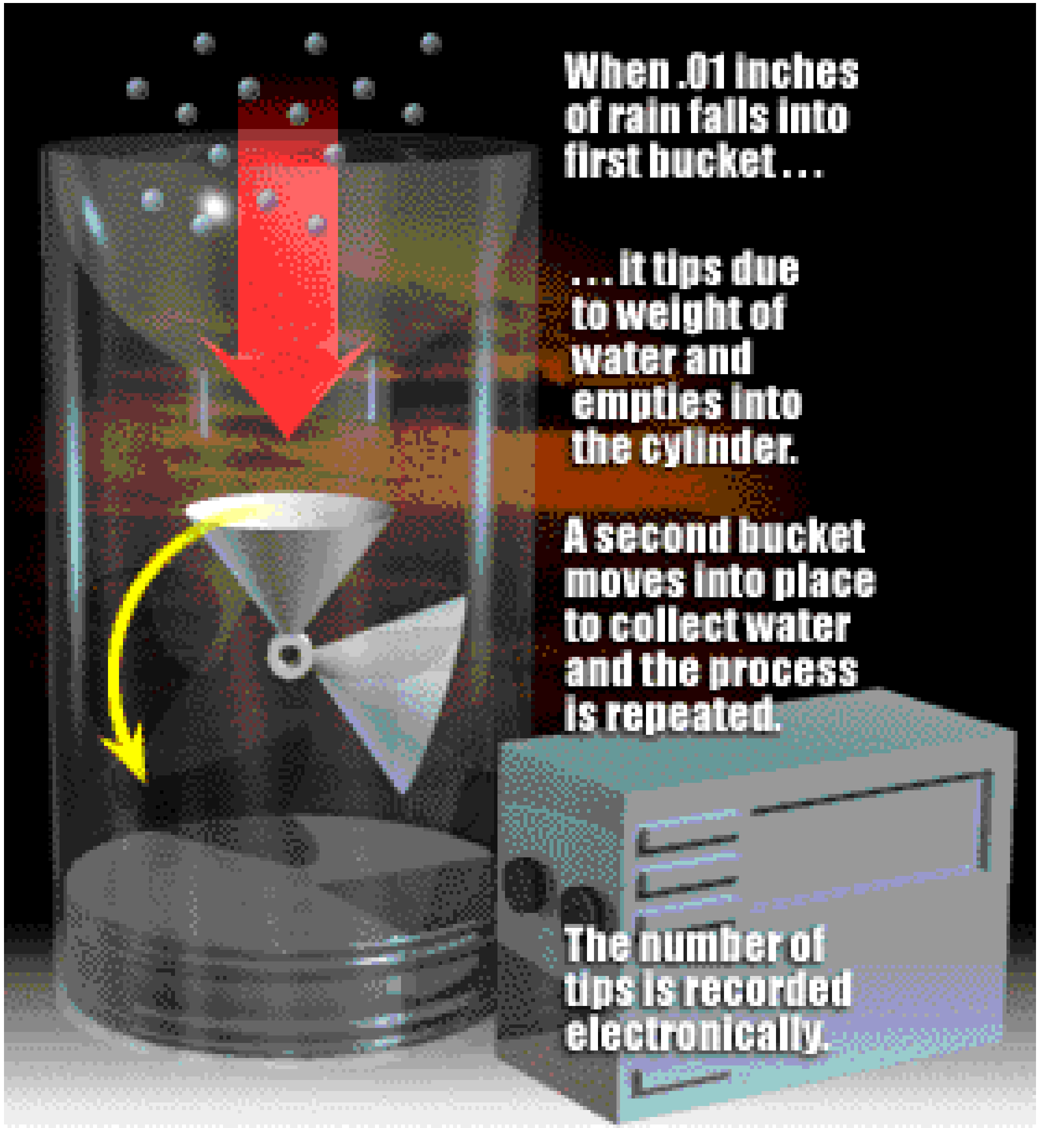
OROGRAPHIC PRECIPITATION results when warm moist air of the ocean is forced to rise by large mountains. As the air rises it cools, moisture in the air condenses and clouds and precipitation result on the windward side of the mountain while the leeward side receives very little

RAIN MEASUREMENT



(a) Simple rain gauge (b) Standard rain gauge (c) Tipping–bucket gauge

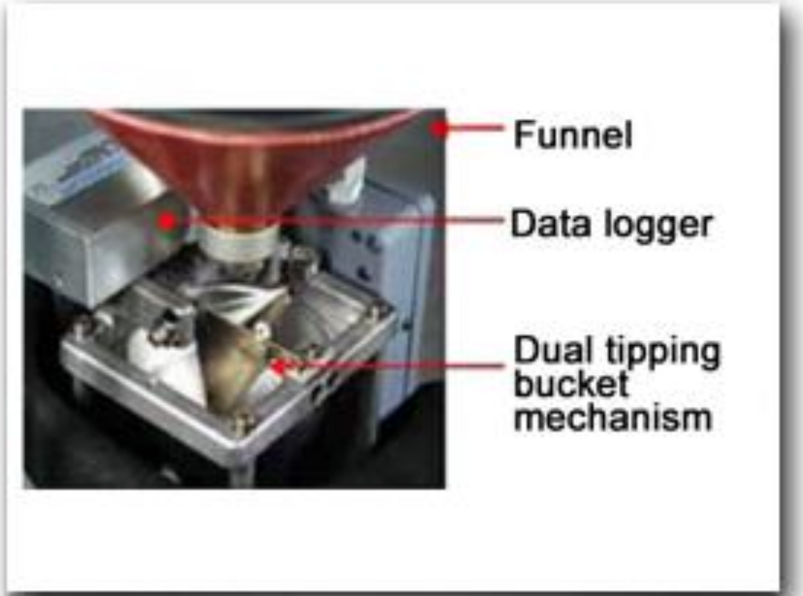




When .01 inches of rain falls into first bucket . . .
. . . it tips due to weight of water and empties into the cylinder.
A second bucket moves into place to collect water and the process is repeated.
The number of tips is recorded electronically.

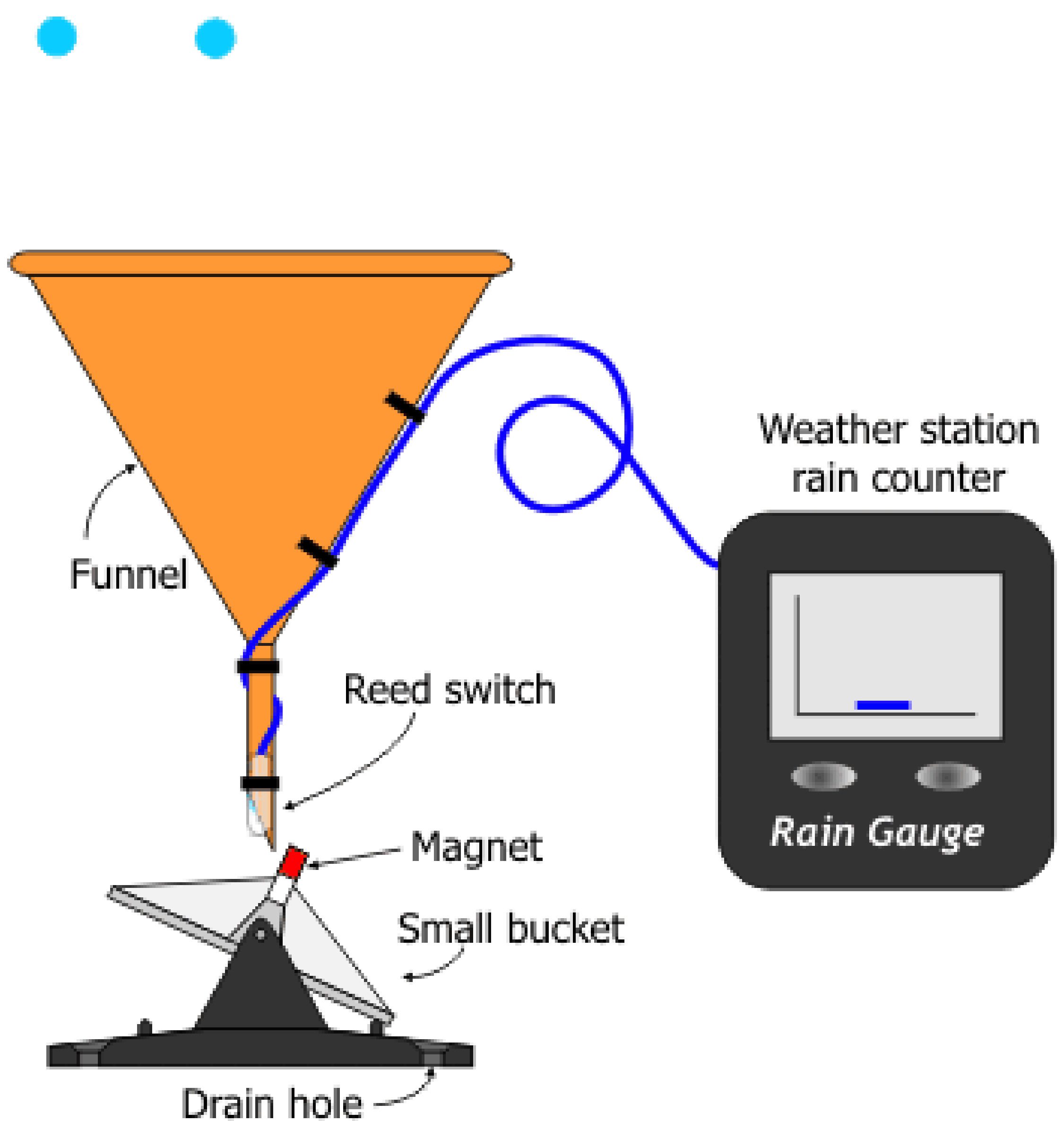
RAIN MEASUREMENT

Modern Tipping Bucket Rain Gauge
(Casella)



A commercial tipping bucket rain gauge
(Lambrech GmbH)


MyTeleLogger
1
2
3
SAVE
4
5
6
LOG
7
8
9
CHECK / EDIT
RESET
0
ENTER
NEXT
SRAM CARD
COMM PORT
TCK e-Solutions Sdn Bhd
www.tck.com.my
ALAT PENYUKAT HUJAN
DATA LOGGER
(RF 14)



Weather station
rain counter
Funnel
Reed switch
Magnet
Small bucket
Drain hole
Rain Gauge

Placement of Rain Gauges

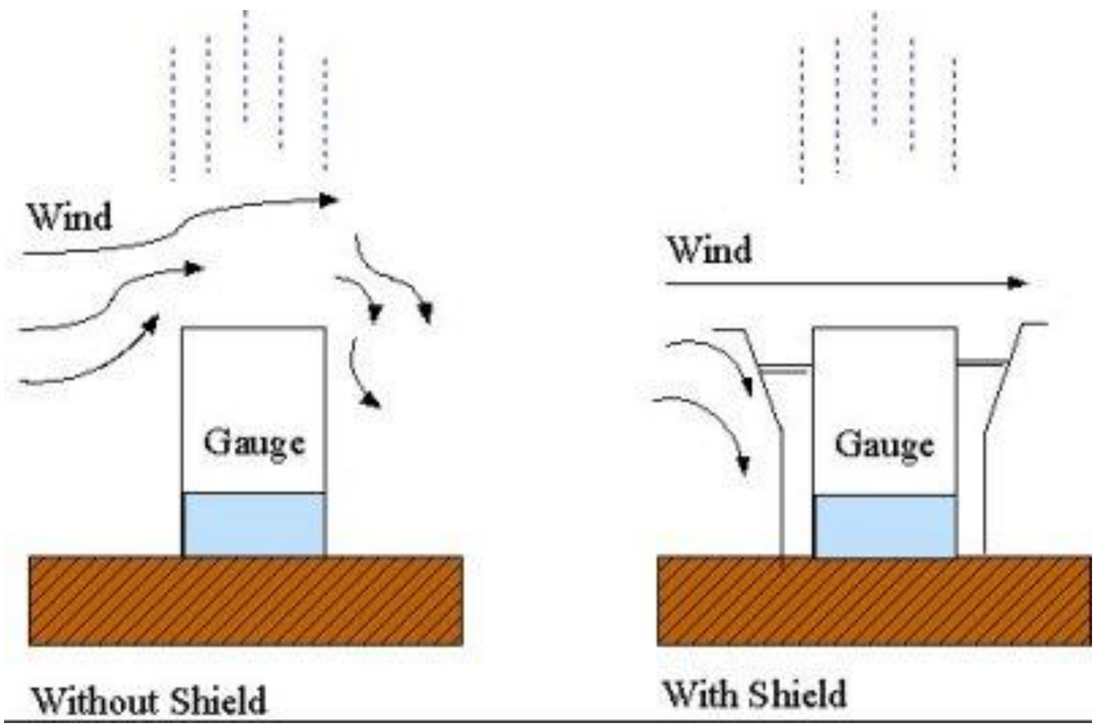
Gauges are affected by wind pattern, eddies, trees and the gauge itself, therefore it is important to have the gauge located and positioned properly.

- 1m above ground level is standard -
all gauges in a catchment should be the same height

- 2 to 4 times the distance away from an isolated object (such as a tree or building) or in a forest a clearing with the radius at least the tree height or place the gauge at canopy level

Placement of Rain Gauges

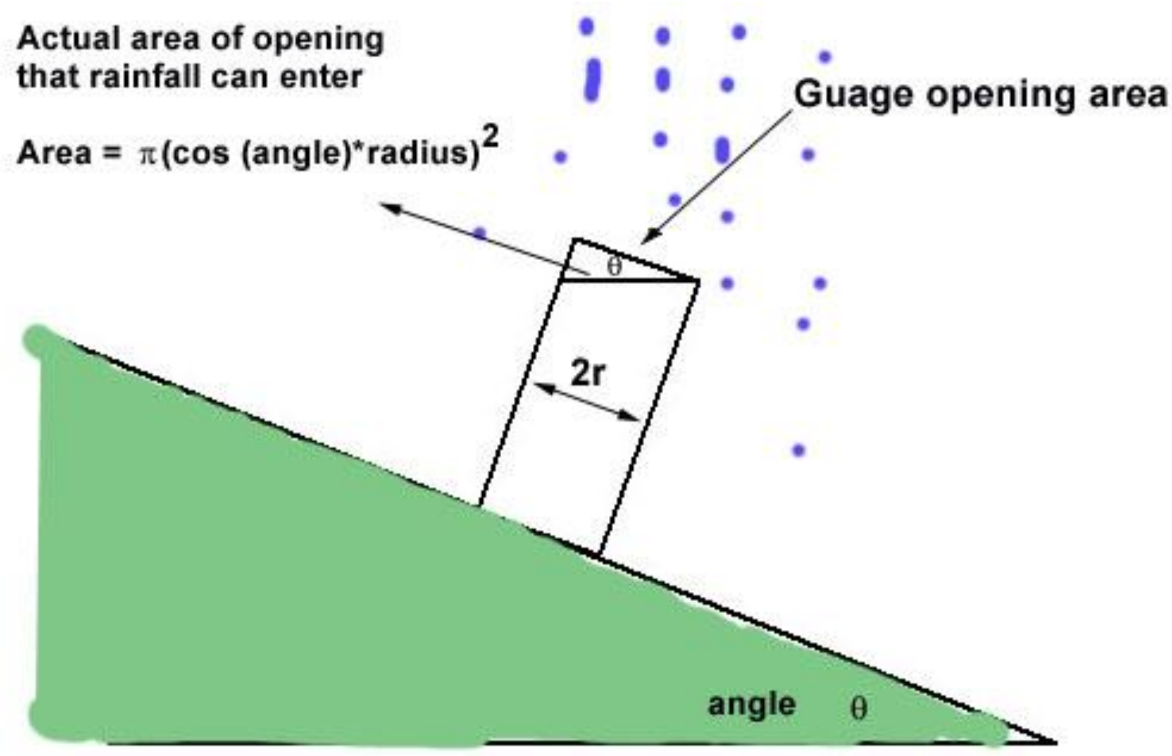
- shielded to protect gauge in windy sites
- or if obstructions are numerous they will reduce the wind-speed, turbulence and eddies.



Rain gauge with wind guards

Placement of Rain Gauges

- For sloping ground the gauge should be placed with the opening parallel to the ground
- The rainfall catch volume (mm^3) is then divided by the opening area that the rain can enter



Number and Distribution of Gauges

Need to consider:

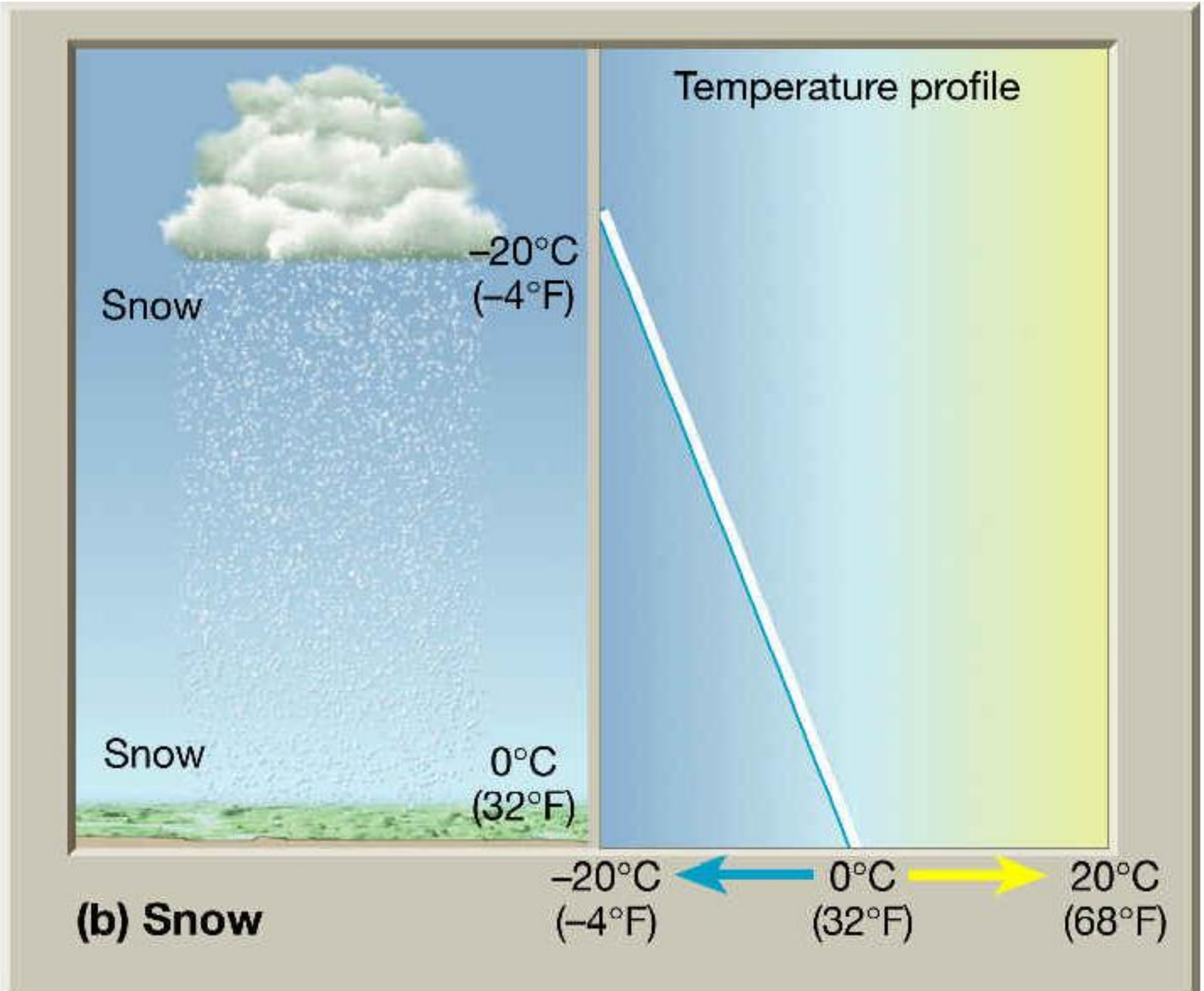
- size of area
- prevailing storm type
- form of precipitation
- topography
- aspect
- season

Number of Gauges

Number of gauges	Size of area
2	16 hectares
3	40 hectares
10	8 km^2
15	16 km^2
50	160 km^2
300	1600 km^2
1000+	16,000 km^2

SNOW

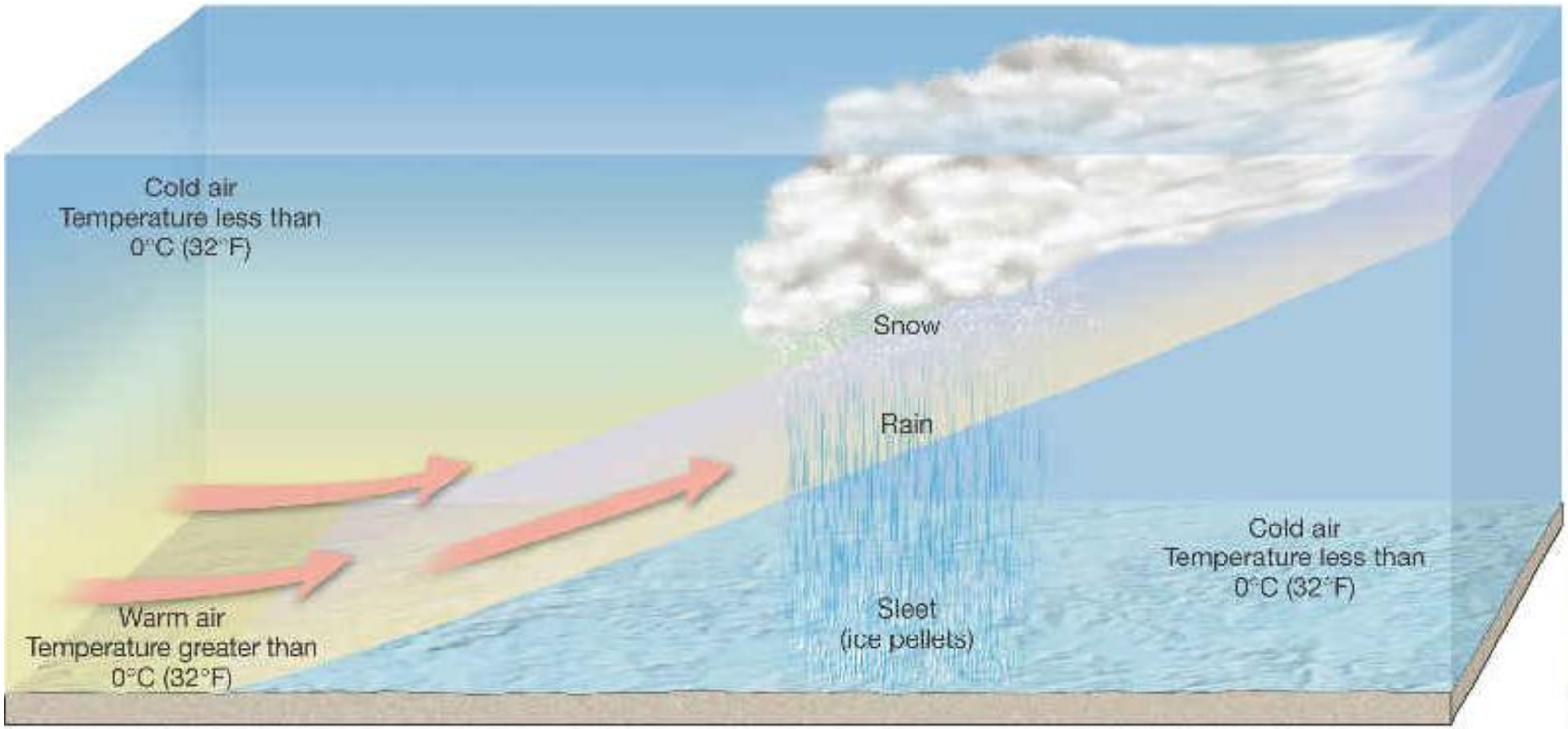
- **Snow is a form of precipitation within the Earth's atmosphere in the form of crystalline water ice, consisting of a multitude of snowflakes that fall from clouds. Since snow is composed of small ice particles, it is a granular material. It has an open and therefore soft structure, unless packed by external pressure. Snowflakes come in a variety of sizes and shapes. Types which fall in the form of a ball due to melting and refreezing, rather than a flake, are known as grapple , with ice pellets and snow grains as examples of graupel. Snowfall amount and its related liquid equivalent precipitation amount are determined using a variety of different rain gauges.**


Temperature profile
Snow
–20°C
(–4°F)
Snow
0°C
(32°F)
–20°C
(–4°F)
0°C
(32°F)
20°C
(68°F)
(b) Snow

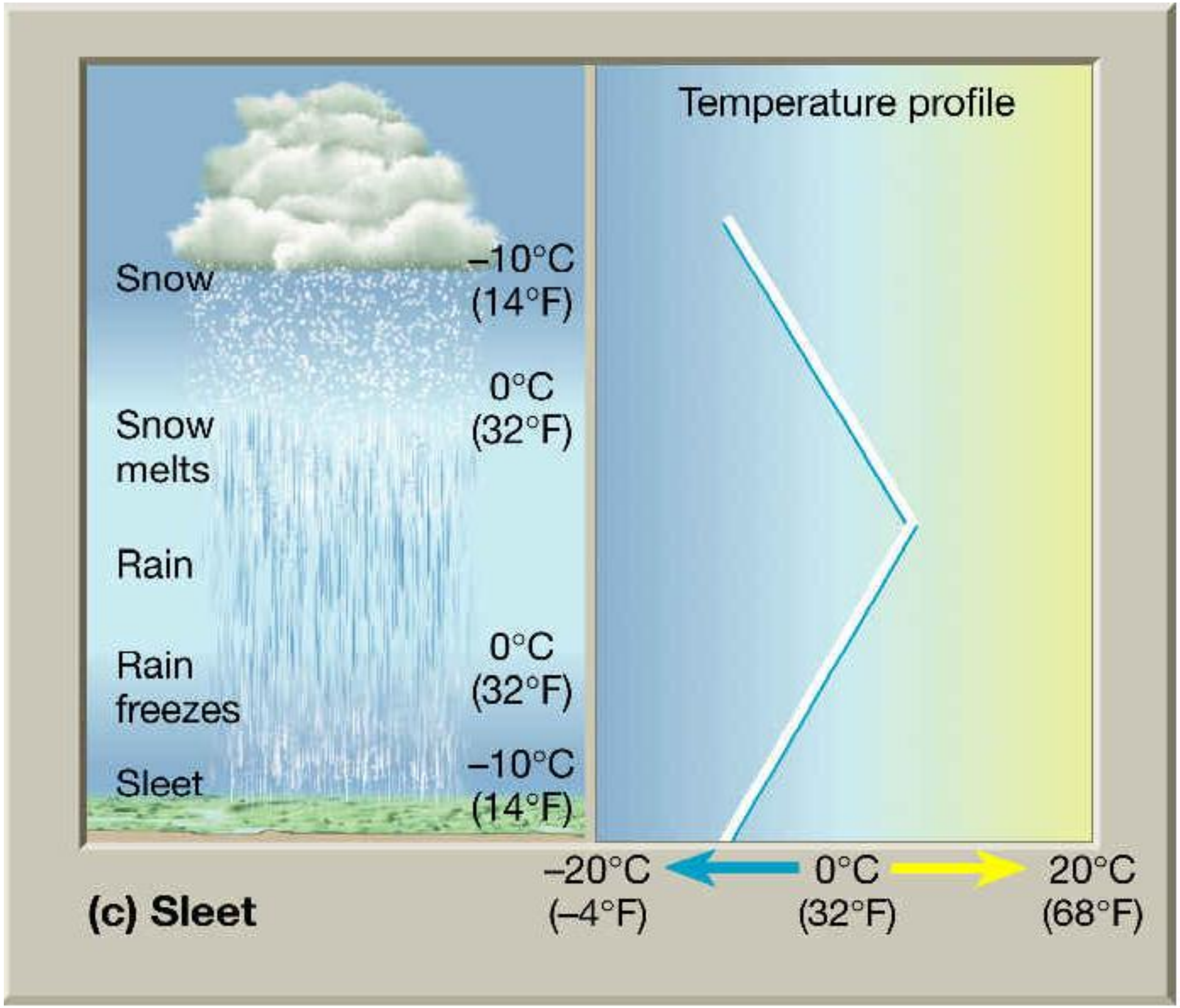
Sleet

- **Sleet** refers to two distinct forms of precipitation:
- Rain and snow mixed, snow that partially melts as it falls. (UK, Ireland and Canada)
- Ice pellets, one of three forms of precipitation in a US-style "wintry mix", the other two being snow and freezing rain. (US)

Sleet



Sleet forms when rain passes through a cold layer of air and freezes into ice pellets. This occurs most often in the winter when warm air is forced over a layer of cold air.


Temperature profile
Snow
–10°C
(14°F)
0°C
(32°F)
Snow
melts
Rain
0°C
(32°F)
Rain
freezes
Sleet
–10°C
(14°F)
–20°C
(–4°F)
0°C
(32°F)
20°C
(68°F)
(c) Sleet

Hails

- Hail is a large frozen raindrop produced by intense thunderstorms, where snow and rain can coexist in the central updraft. As the snowflakes fall, liquid water freezes onto them forming ice pellets that will continue to grow as more and more droplets are accumulated. Upon reaching the bottom of the cloud, some of the ice pellets are carried by the updraft back up to the top of the storm.

Dew

- **Dew** is water in the form of droplets that appears on thin, exposed objects in the morning or evening. As the exposed surface cools by radiating its heat, atmospheric moisture condenses at a rate greater than that at which it can evaporate, resulting in the formation of water droplets.
- When temperatures are low enough, dew takes the form of ice; this form is called frost (frost is, however, not frozen dew).

MIST/ FOG

- **Mist is a phenomenon of small droplets suspended in air. It can occur as part of natural weather or volcanic activity, and is common in cold air above warmer water, in exhaled air in the cold, and in a steam room of a sauna. It can also be created artificially with aerosol canisters if the humidity conditions are right.**

Rainfall Characteristic

- Depth
  - Measurements in high-rainfall
  - Measured in mm @ cm
  - Measured by the hour, day, week, month and year
- Duration
  - The period of time during which rain fell
  - Rain time interval fall measured in minutes and hour
- Intensity
  - Depth of rainfall per unit time
  - Example: 30 mm in 3 hours; intensity = 10mm/hr
- Rainfall Frequency
  - The frequency of rainfall occurred
  - Repeat for the rain
    - This situation can be illustrated by the rainfall that is:

      a) Uniform distribution: suitable for agriculture and reduce erosion
      b) Distribution of single-mode: rainfall in the wet season
      c) Distribution of dual mode

Rainfall Intensity

- Intensity/heavy rain is the depth of rainfall per unit time
- The symbol is “i” and the units are mm/hr @ cm/hr @ in/hr
- Rainfall intensity equation :

$$i = \frac{\text{Depth rainfall}}{\text{Time}}$$

Volume, V = Area x Depth

= m^3 @ ka^3

Rainfall Intensity

Rainfall Intensity

	Intensity inches/hour (cm/hour)	Median diameter (millimeters)	Velocity of fall feet/second (meters/second)	Drops per second per square foot (square meter)
Fog	0.005 (0.013)	0.01	0.01 (0.003)	6,264,000 (67,425,000)
Mist	.002 (.005)	.1	.7 (.21)	2,510 (27,000)
Drizzle	.01 (.025)	.96	13.5 (4.1)	14(151)
Light rain	.04 (1.02)	1.24	15.7 (4.8)	26 (280)
Moderate rain	.15 (.38)	1.60	18.7 (5.7)	46 (495)
Heavy rain	.60 (1.52)	2.05	22.0 (76.)	46 (495)
Excessive rain	1.60 (4.06)	2.40	24.0 (7.3)	76 (818)
Cloudburst	4.00 (10.2)	2.85	25.9 (7.9)	113 (1,220)

Source: Lull, H.W., 1959, Soil Compaction on Forest and Range Lands, U.S. Dept. of Agriculture, Forestry Service, Misc. Publication No.768

Rain Average

Methods used to convert point rainfall values at different rain gauge stations into an average value over a catchment include

- **Arithmetical Average Method**
- **Thiessen Polygon Method**
- **Isohyetal Method**

Arithmetical Mean Method
Thiessen Polygon Method
Isohyetal Method etc

Arithmetic Average Method

- This technique calculates area precipitation using the arithmetic mean of all the point or area measurements considered in the analysis.

$$\bar{P} = \frac{P_1 + P_2 + P_3 + \dots\dots\dots\dots + P_n}{n} = \frac{1}{n}\sum_{1}^{n} P_i$$

$\bar{P}$ = *average precipitation over the catchment area (for a given time period)*

$P_1, P_2, P_3, \dots\dots\dots\dots, P_n$ *are the precipitations in a given time period at stations* 1, 2, 3, ..., *n respectively within the catchment*

Example:

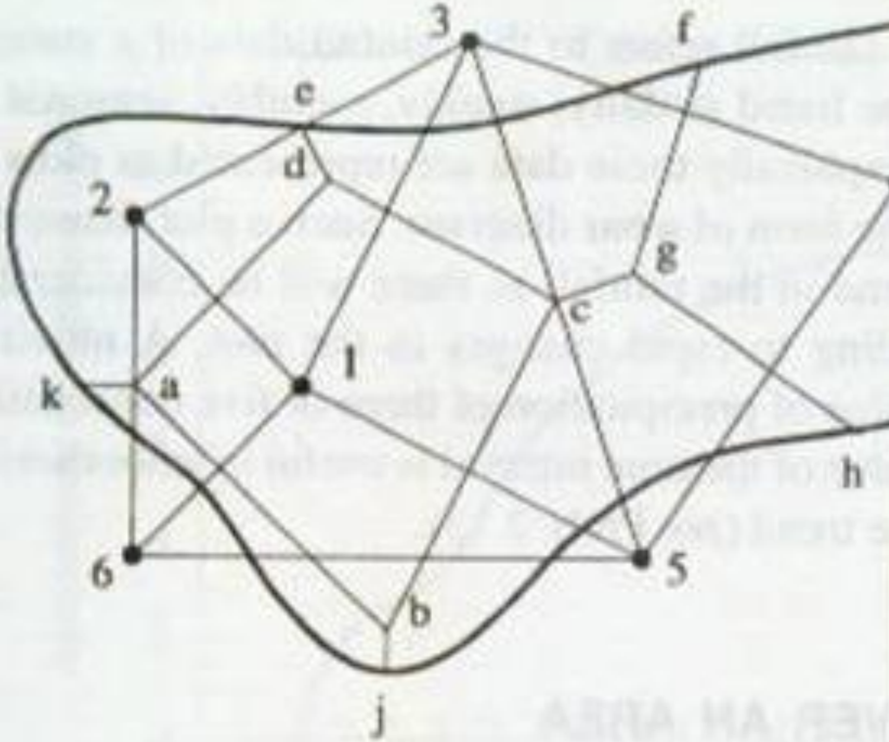
Thiessen Polygon Method

If there are n stations with rainfall values $P_1, P_2, P_3, \ldots\ldots P_n$ *and* $A_1, A_2, A_3, \ldots\ldots A_n$ *are the areas of the respective Thiessen polygons, the average rainfall over the catchment* $\bar{P}$ *is computed as*

$$\bar{P} = \frac{P_1 A_1 + P_2 A_2 + P_3 A_3 + \ldots\ldots\ldots\ldots\ldots\ldots + P_n A_n}{A_1 + A_2 + A_3 + \ldots\ldots\ldots\ldots\ldots\ldots + A_n} = \sum_{1}^{n} P_i \frac{A_i}{A}$$

$\frac{A_i}{A}$ *is called the weightage factor*

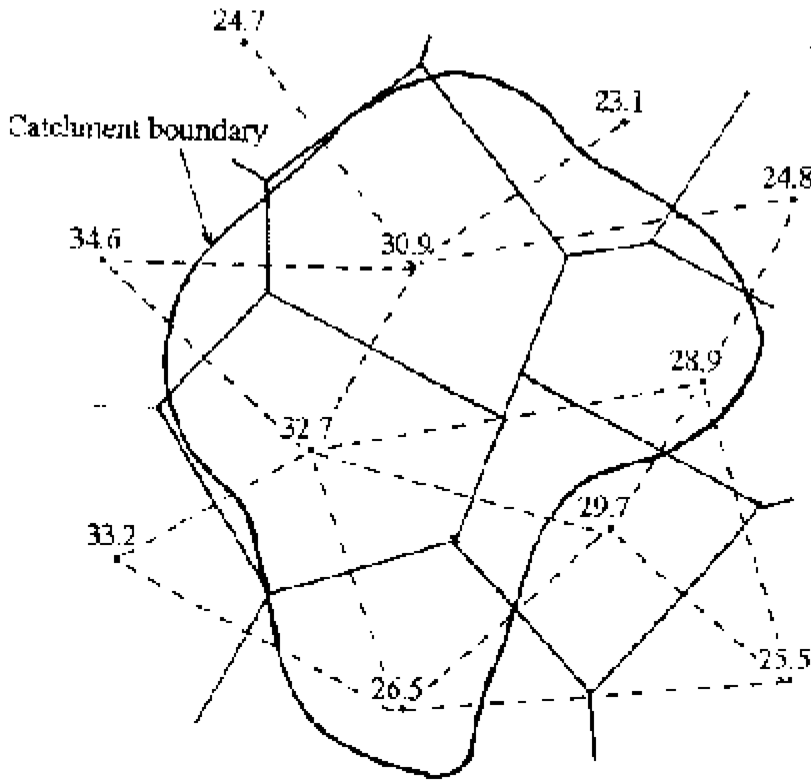
Thiessen Polygon Method



A = total catchment area

Station	Bounded by	Area	Weightage
1	abcd	A_1	A_1/A
2	kade	A_2	A_2/A
3	edcgf	A_3	A_3/A
4	fgh	A_4	A_4/A
5	hgcbj	A_5	A_5/A
6	jbak	A_6	A_6/A

Rainfall Station	A Thiessen Constant (Fractional Area)	B Rainfall in Each Polygon	A*B Weighted average
A	0.144	33.4	4.81
B	0.110	34.2	3.76
C	0.104	33.3	3.46
D	0.133	34.5	4.59
E	0.132	35.0	4.62
F	0.113	37.0	4.18
G	0.064	37.3	2.39
H	0.105	35.5	3.73
I	0.103	35.0	3.60
Sum Total	**1.00**		**35.14**



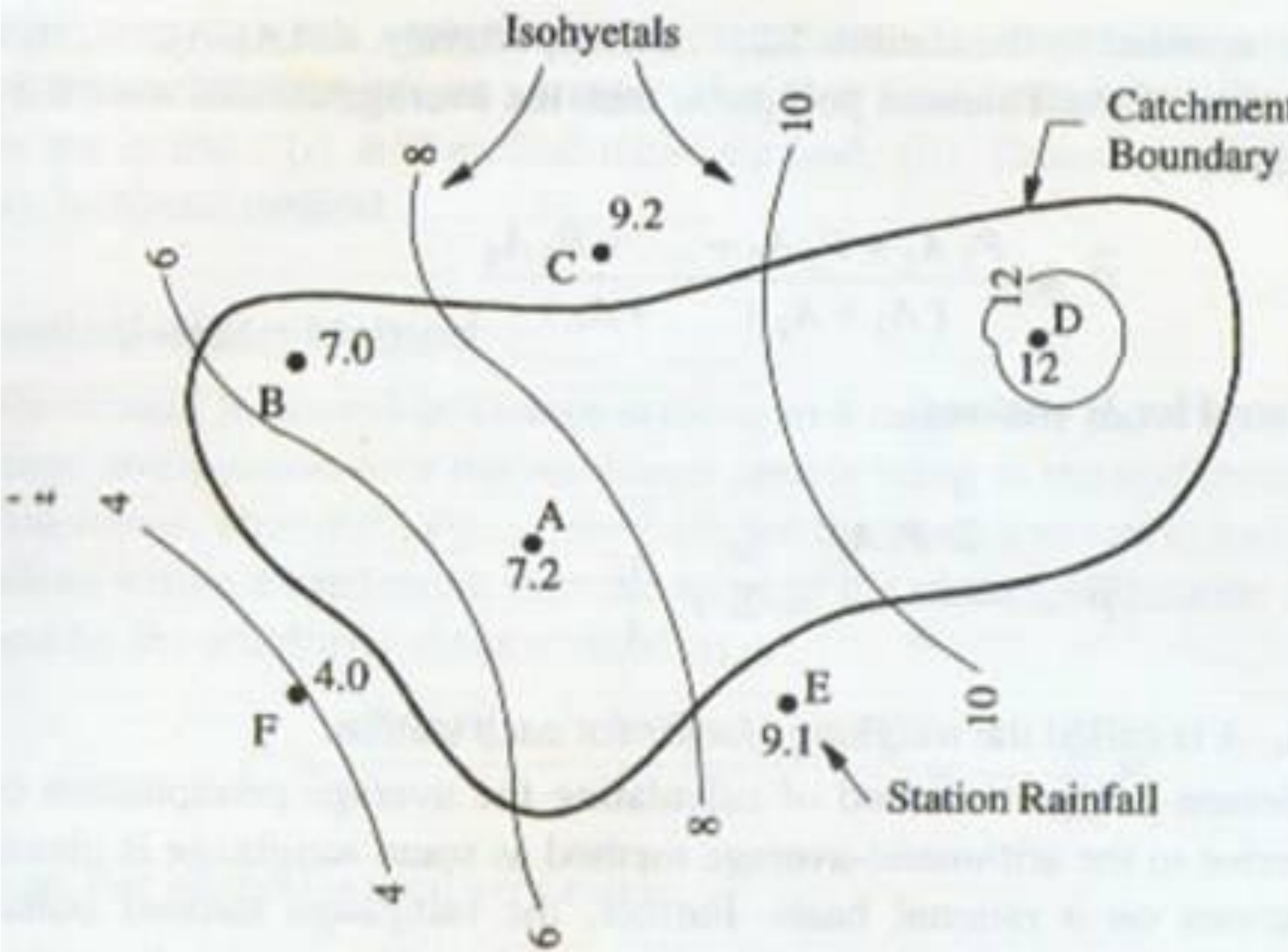
Rainfall (mm)	Area (km^2)	Percent of Total	Area Weighted Rainfall (mm
24.8	0.3	1.2	0.3
30.9	5.6	23.0	7.1
23.1	1.9	7.8	1.8
34.6	0.9	0.4	0.1
32.7	5.3	21.8	7.1
28.9	3.7	15.2	4.4
29.7	2.5	10.3	3.1
26.5	4.1	16.9	4.5
	24.3		28.4

Isohyetal Method

- Isohyet – It is a line joining points of equal rainfall magnitude
- The catchment area is drawn to scale and the rain gauge stations are marked on it
- The recorded rainfall values for which areal average is to determined are marked at the respective stations
- Neighbouring stations outside the catchment are also considered
- Taking point rainfall values as the guide, ishohyets of different rainfall values are drawn (similar to drawing contours based on spot levels)

The area between adjacent isohyets is measured using a planimeter.

- If isohyets go out of the catchment, the catchment boundary is used as the bounding line. It is assumed that the average value of rainfall indicated by two isohyets acts over the inter isohyetal area
- This method is considered superior to the previous methods when the number of raingauge stations are large


Isohyetals
Catchment
Boundary
10
8
9.2
C
6
12
D
12
7.0
B
4
A
7.2
4.0
F
E
9.1
10
Station Rainfall
8
4
6

If the rainfall values corresponding to the isohyets are $P_1, P_2, P_3, \ldots P_n$ *and* $A_1, A_2, A_3, \ldots A_{n-1}$ *are the corresponding inter isohyetal areas, the average rainfall over the catchment*

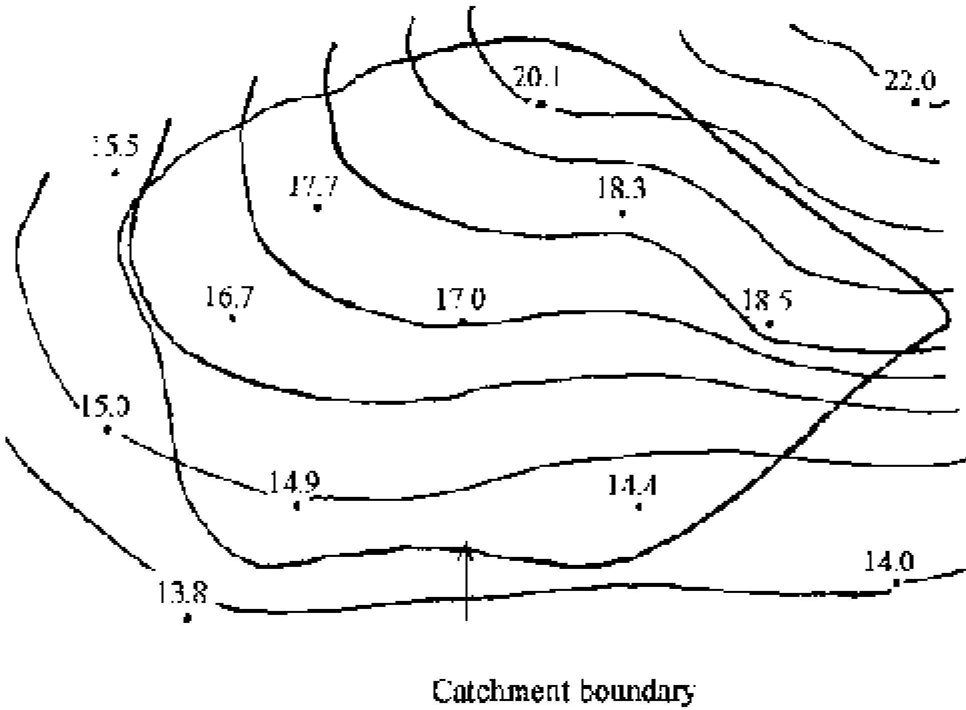
$\bar{P}$ *is computed as*

$$\bar{P} = \frac{A_1\left(\frac{P_1+P_2}{2}\right) + A_2\left(\frac{P_2+P_3}{2}\right) + \ldots\ldots + A_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{A_1 + A_2 + A_3 + \ldots\ldots + A_{n-1}}$$

where, $A_1 + A_2 + A_3 + \ldots\ldots + A_{n-1} = A$

Isohyets Upper	Lower	A Mean Rainfall On Area	B Area Between Isohyets (ha)	A*B Weighted Mean Rainfall
38	37	37.5	130	4875
37	36	36.5	150	5475
36	35	35.5	300	10650
35	34	34.5	450	15525
34	33	33.5	200	6700
Total			**1230**	**43225**

Mean Rainfall = 35.14 i.e. from (43225/1230)



Av. Iso Rainfall (mm)	Area (km^2)	Percent of Total	Area Weighted Rainfall (mm)
14.5	4.0	12.1	1.8
15 5	6.2	18.8	2.9
16 5	7.7	23.3	3.8
17.5	5.8	17.6	3.1
18.5	4.9	14.8	2.7
19.5	3.6	10.9	2.1
20.5	0.8	2.4	0.2
	33.0		16.6

(Increased accuracy can be obtained by weighting by isohyet length in addition to area)

Normal ratio method

Normal ratio method (NRM) is used when the normal annual precipitation at any of the index station differs from that of the interpolation station by more than 10%. In this method, the precipitation amounts at the index stations are weighted by the ratios of their normal annual precipitation data in a relationship of the form:

$$P_m = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{N_m}{N_i} P_i \right)$$

Where:

*P*m = precipitation at the missing location

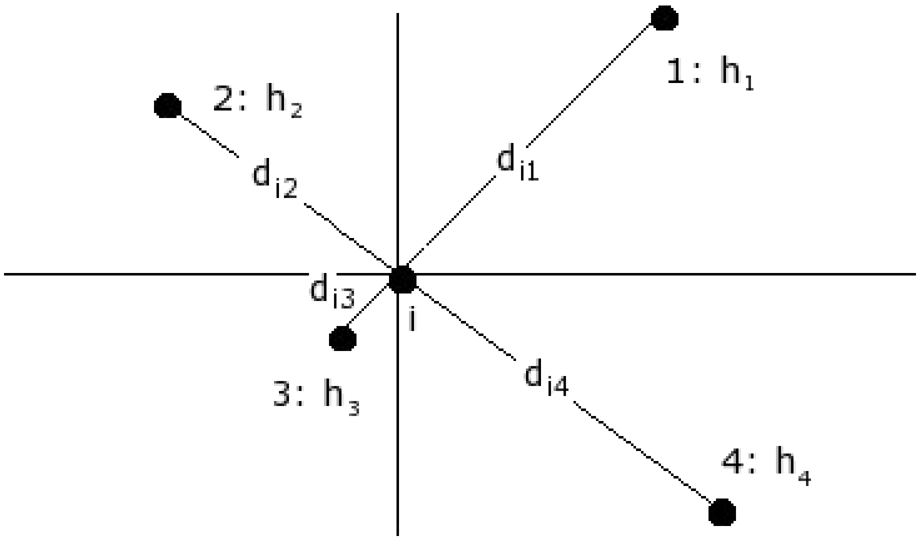
*P*i = precipitation at index station

*N*m = average annual rain at 'missing data' gauge

*N*i = average annual rain at gauge

N = number of rain gauges

is used to calculate quickly the average rainfall for hourly time intervals. The method takes into account the nonlinearity of the rainfall distribution over the basin area. The basin is divided in a network of square elements with a fixed step size. The rainfall is calculated in each node using interpolation, as a function of the measured values at the adjacent stations.



Procedure:

- Divide area around gauge of interest into four quadrants
- Using records at nearest station in each quadrant
- Compute missing precipitation amount:

$$P_m = \frac{1}{\sum_{i=1}^{4} 1/X_i} \left(\sum_{i=1}^{4} \frac{P_i}{X_i} \right)$$

Where:

*P*i = rainfall recorded by gauge *i*

Xi = distance from gauge *i* to missing data point

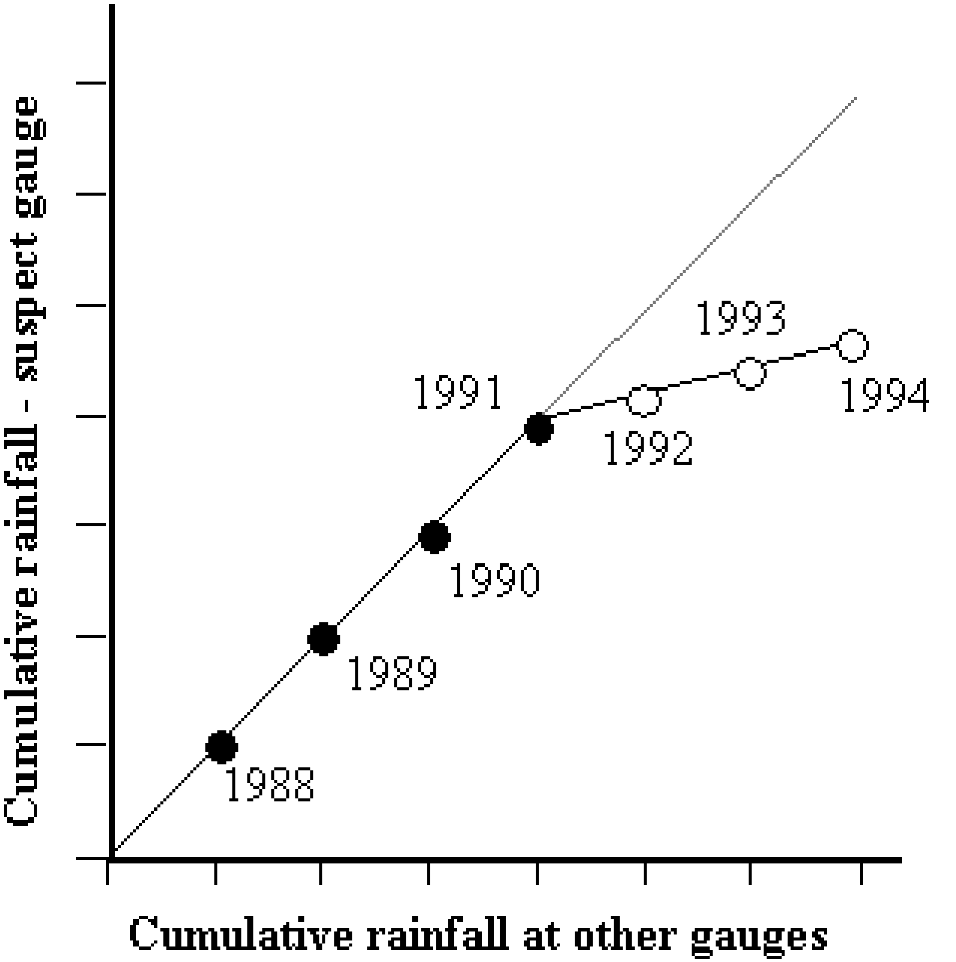
double-mass curve

Consistency of Precipitation Data

A ***double-mass curve*** is used to check the consistency of a rain gauge record:

- compute cumulative rainfall amounts for suspect gauge and check gauges
- plot cumulative rainfall amounts against each other (divergence from a straight line indicates error)
- multiplying erroneous data after change by a correction factor *k* where

$$k = \frac{\text{gradient of line before change}}{\text{gradient of line after change}}$$



- http://gs.riverdale.k12.or.us/~simonc17/panama/
- http://www.geography.hunter.cuny.edu/~tbw/wc.notes/5.cond.precip/sleet_formation.htm
- http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cld/prcp/rnhl.rxml
- http://en.wikipedia.org/wiki/Dew
- http://www.egr.msu.edu/~northco2/BE481/HW1.htm
- http://theconstructor.org/water-resources/mean-precipitation-calculation-over-an-area/4500/
- http://www.aboutcivil.com/measurement-of-precipitation.html
- http://echo2.epfl.ch/VICAIRE/mod_1a/chapt_3/main.htm
- http://www.greenstone.org/greenstone3/nzdl;jsessionid=30A7616109C05E596B19423862F261F1?a=d&c=cdl&d=HASH20df2bee4882705a3d73c1.11.2.np&sib=1&p.s=ClassifierBrowse&p.sa=&p.a=b