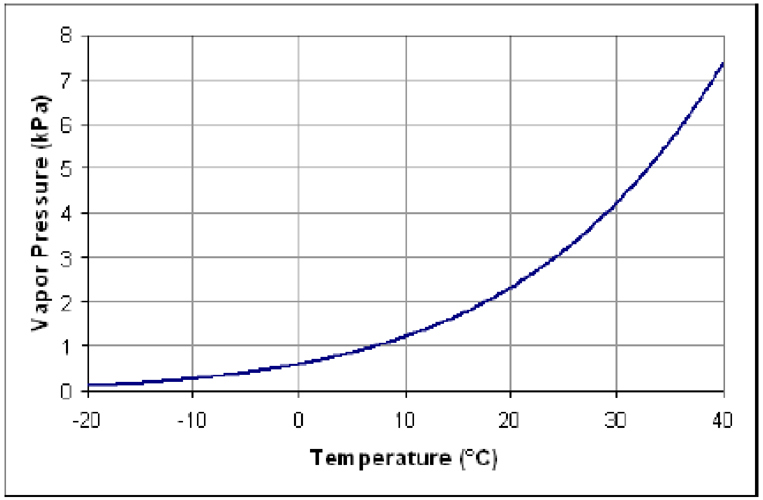
Precipitation

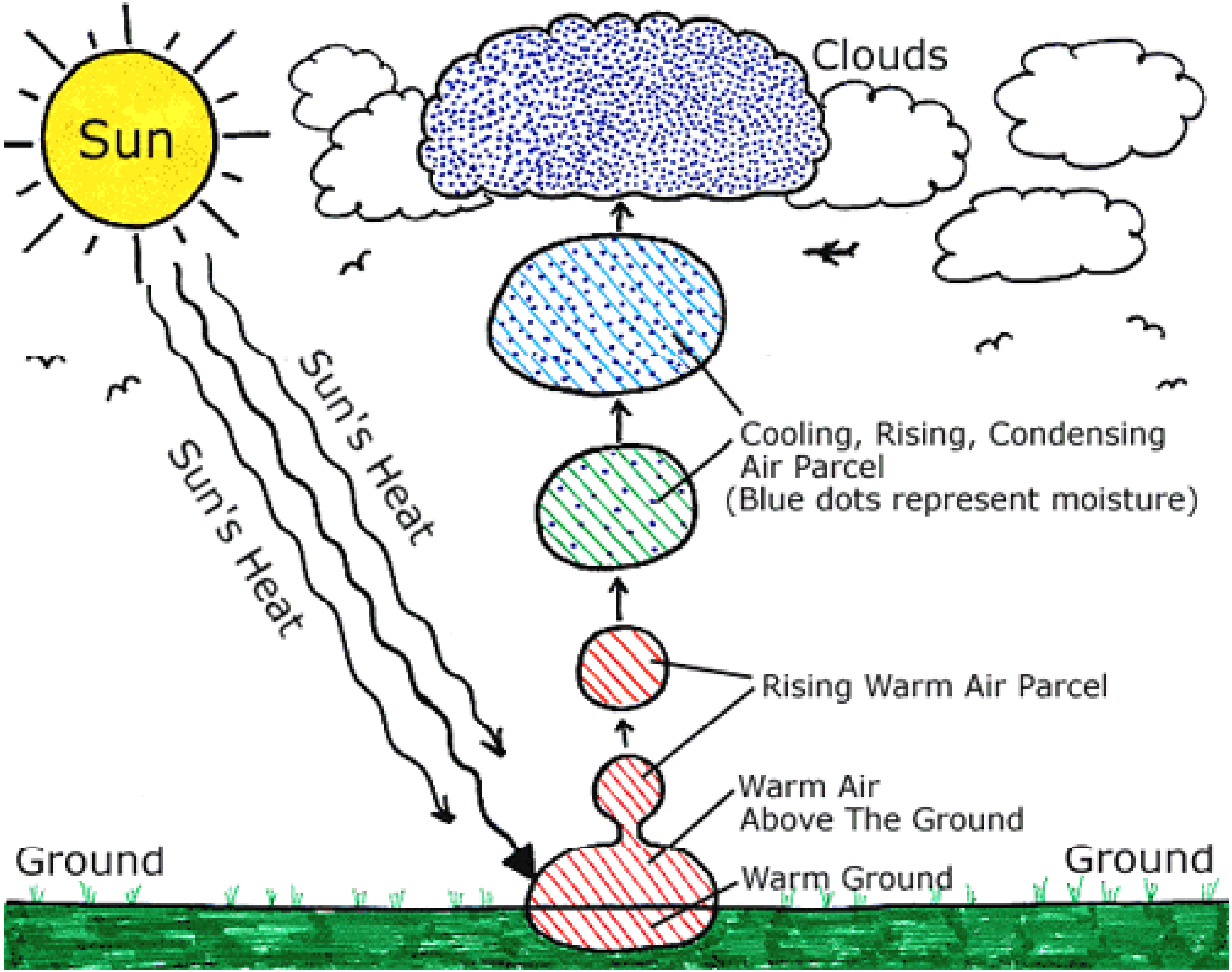
•All forms of moisture emanating from the clouds and all forms of water like rain, snow, hail and sleet derived from atmospheric vapors, falling to the ground.



- The amount of water vapor that the atmosphere can carry (the saturation vapor pressure) is a function of temperature.

- Having water vapor in the atmosphere is a necessary but insufficient condition for precipitation. There must also be a mechanism to promote uplift, cooling and condensation.

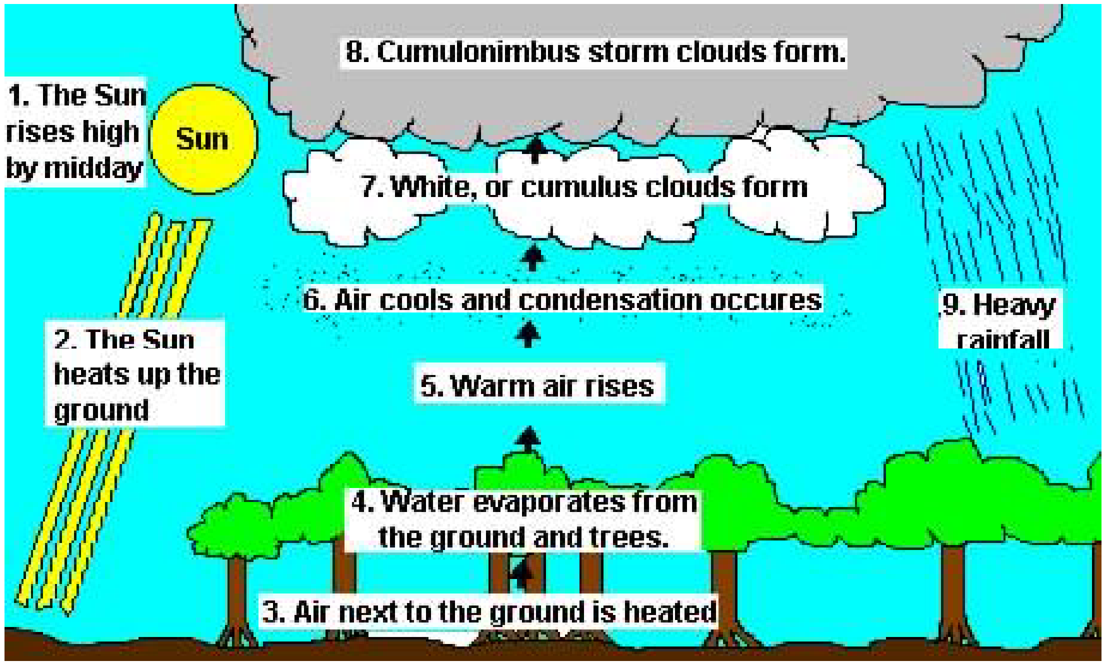
Formation of Precipitation



Sun
Clouds
Sun's Heat
Sun's Heat
Cooling, Rising, Condensing
Air Parcel
(Blue dots represent moisture)
Rising Warm Air Parcel
Warm Air
Above The Ground
Ground
Warm Ground
Ground

- **Mechanism of Cooling**

  When the air ascends from near the surface to upper levels in the atmosphere, pressure reduction takes place. Due to this pressure reduction air crosses through the colder layers and this is the only mechanism capable of producing the degree and rate of cooling needed to account for heavy rainfall.



- **Condensation of Water Vapor**

Condensation of water into cloud droplets takes place on *condensation nuclei* or *hygroscopic nuclei* having affinity for water.

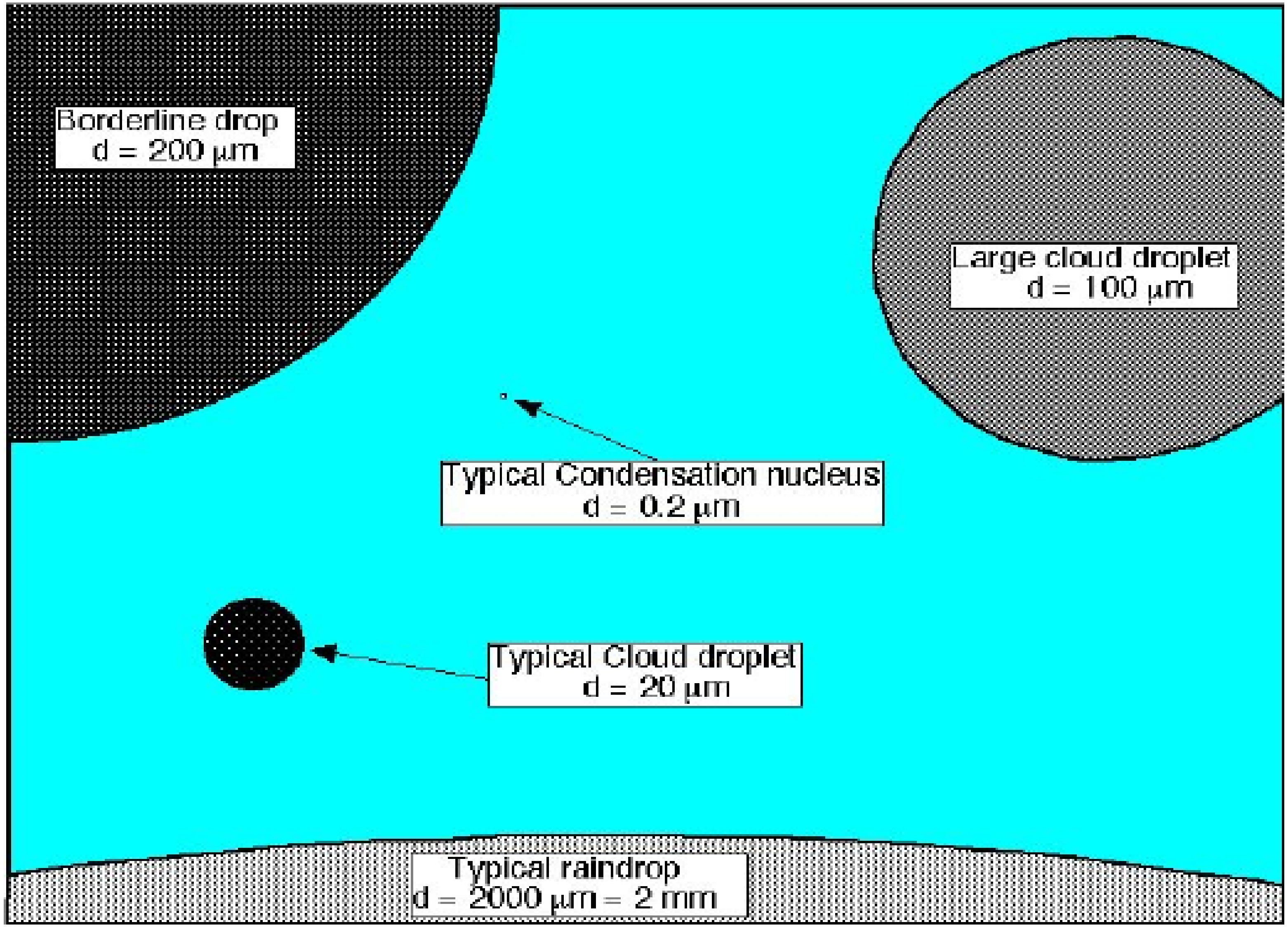
The source of these condensation nuclei is the particles of dust, sea salt or such products of combustion of certain sulfurous and nitrous acids.

Condensation occurs when the temperature is ≤ the dew point T_d

Typical CN = 0.2 µm

Typical cloud droplets are 20-100 µm

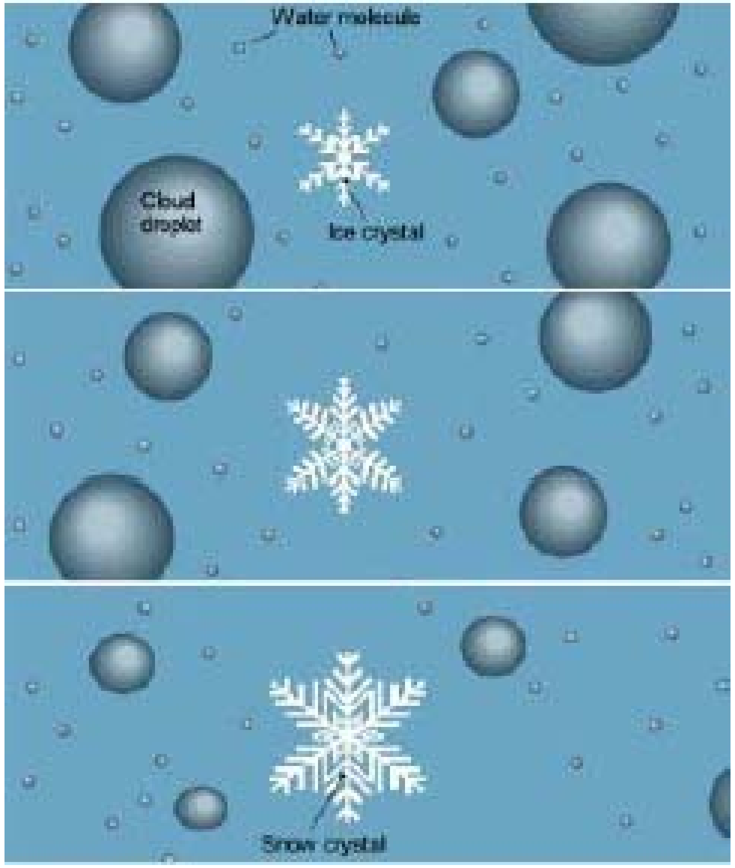
Relative sizes of CCN, cloud droplets and rain droplets



- **Growth of Cloud Droplets**

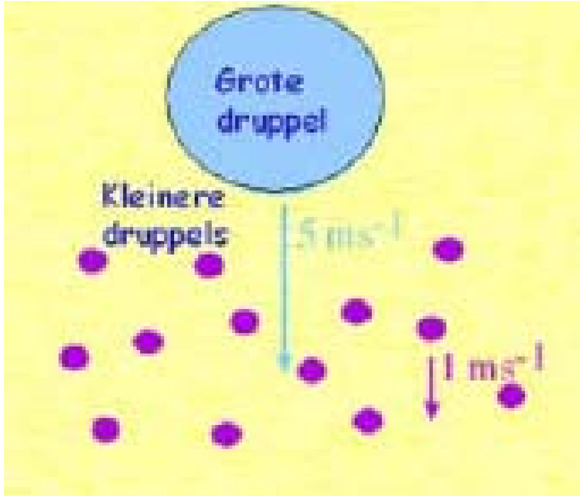
  Bergeron-Findeisen theory: If ice and supercooled water droplets exist together in a cloud, the ice crystals grow at the expense of water droplets, the reason being that the saturation vapor pressure over ice is lower than over water.

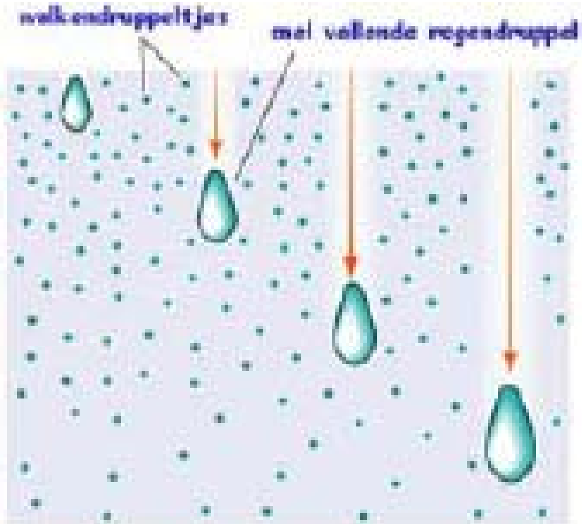
  Solid precipitation that falls may (or may not) melt at a lower, warmer atmospheric level to become rain.



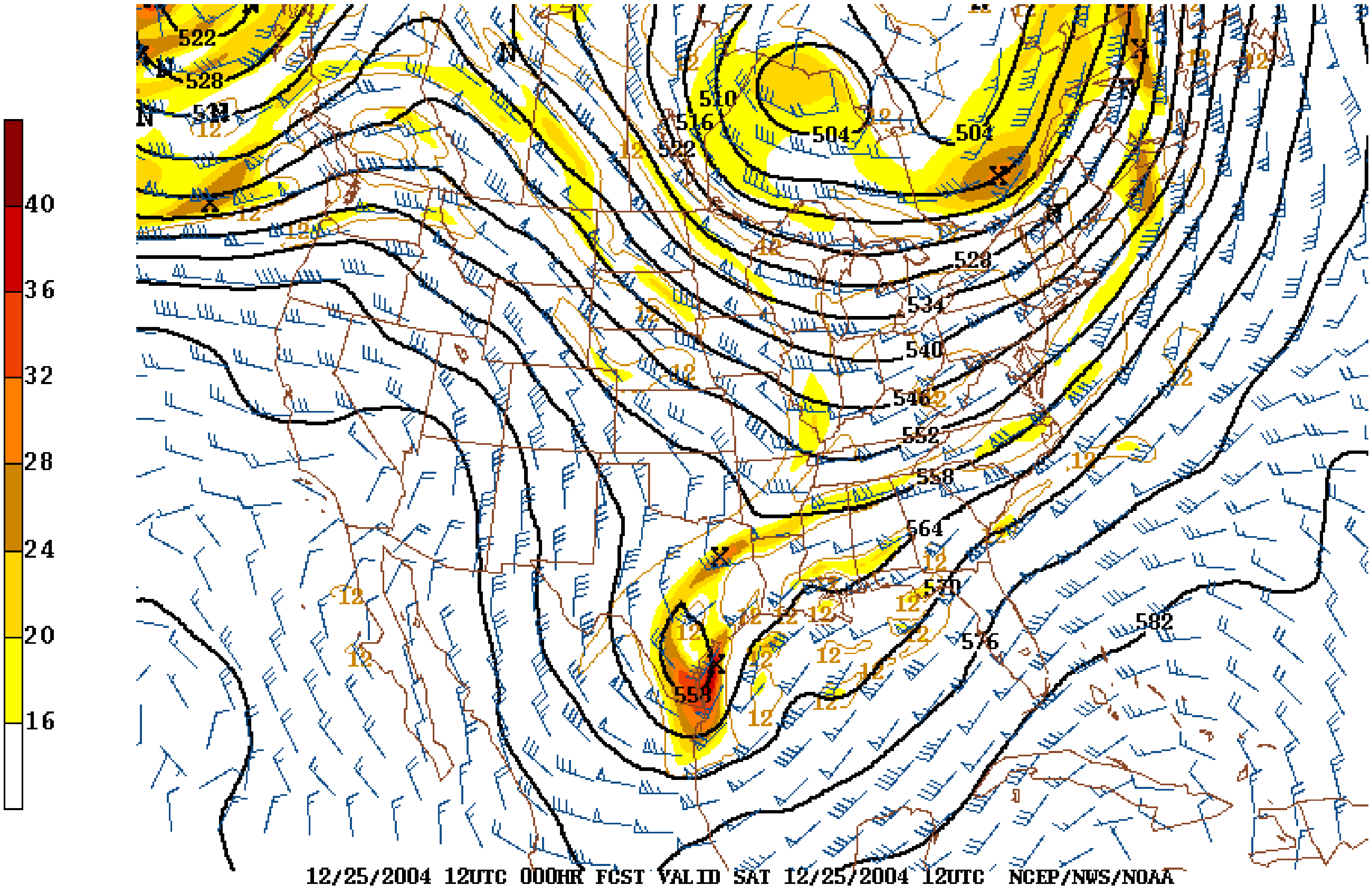
Coalescence Occurs in warm (liquid) clouds.

Falling droplets have terminal velocities directly related to their diameter, such that the larger falling drops overtake and absorb smaller drops, the smaller drops can also be swept into the wake of larger drops and be absorbed by them.

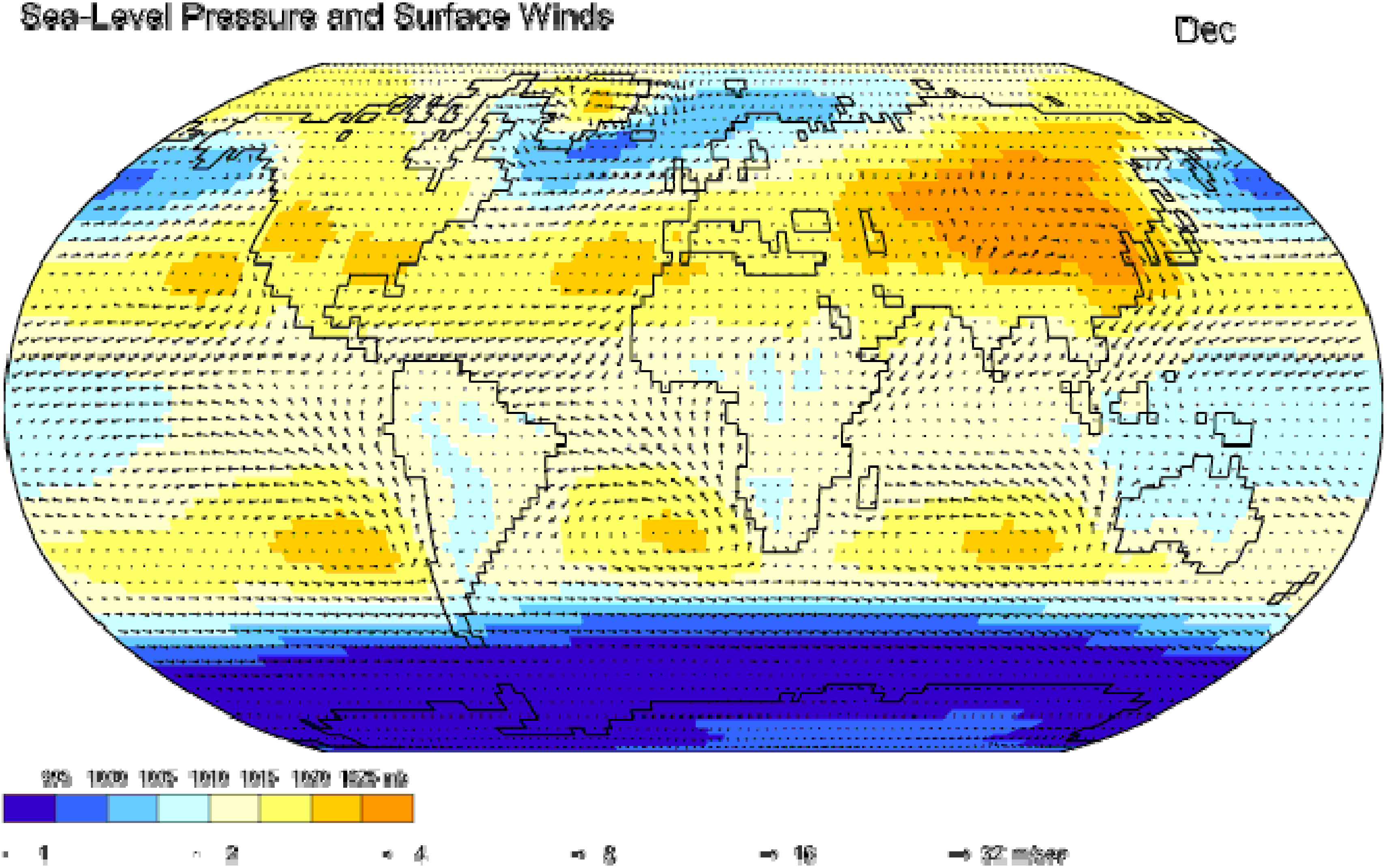




Moisture Accumulation



Sea-Level Pressure and Surface Winds



Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

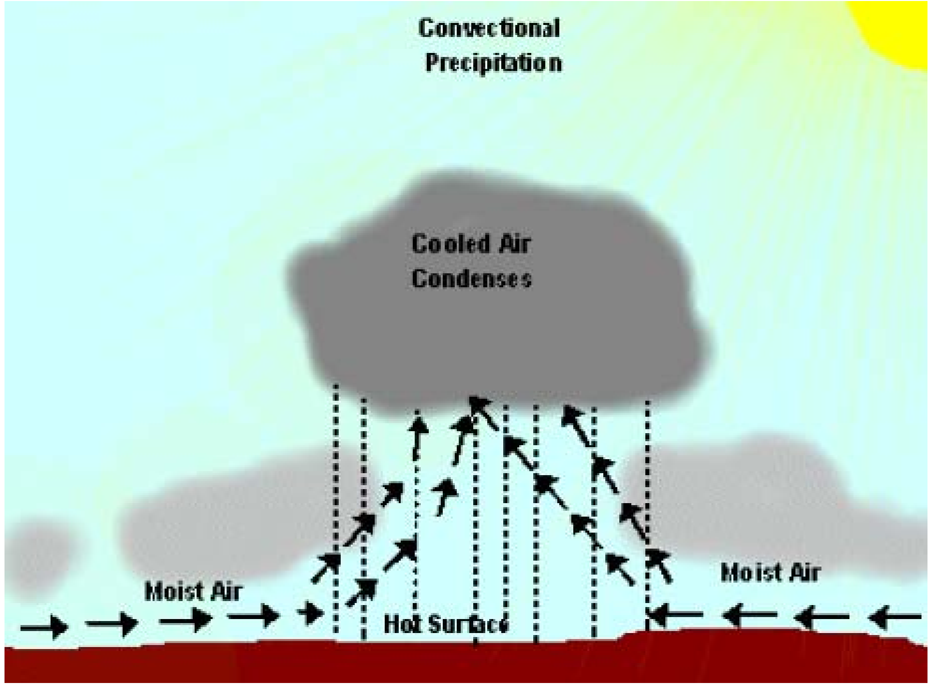
Moisture accumulation

- Heavy rainfall amount over a river basin exceeds by far the amount of water vapor at the atmospheric volume vertically above the basin at the beginning of the rainfall.

- Clearly there must be a large net horizontal inflow of water vapor into the atmosphere above the basin area. This process is called **convergence**, which is defined as the net horizontal influx of air per unit area.

Types of Precipitation

The air close to the warm earth gets heated and rises due to its low density, cools adiabatically to form a cauliflower shaped cloud, which finally bursts into a thunder storm.



Convective precipitation tends to be localized.
Keys to convective storm development are low atmospheric stability and ample atmospheric water vapor.

The stronger the decrease in temperature with height (the more negative the environmental lapse rate), and the more water vapor that is available, the more favourable the conditions for convective storms.

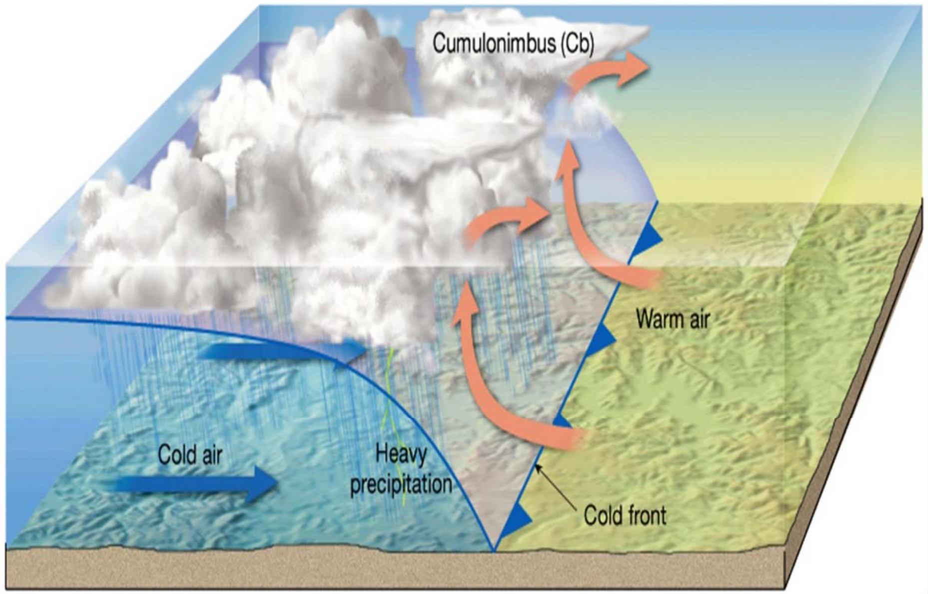
- When two air masses due to contrasting temperatures and densities clash with each other, condensation and precipitation occur at the surface of contact called **Frontal Precipitation**.

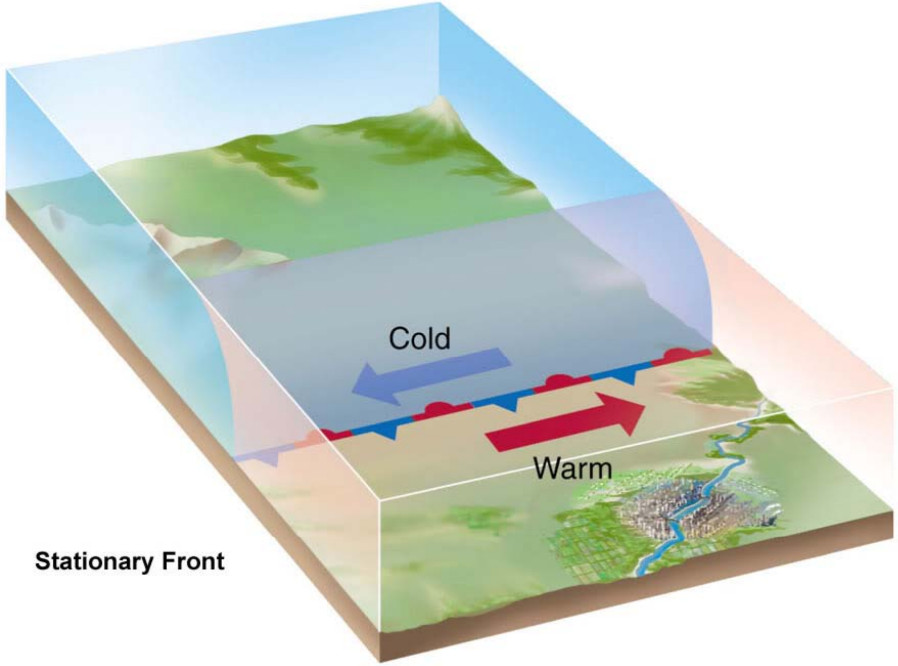
- This surface of contact is called a ‘front’ or ‘frontal surface’.
- If a cold air mass drives out a warm air mass’ it is called a ‘cold front’ and if a warm air mass replaces the retreating cold air mass, it is called a ‘warm front’.

- If the two air masses are drawn simultaneously towards a low pressure area, the front developed is stationary and is called a ‘stationary front

Cold front

Source: Lutgens and Tarbuck, 2004

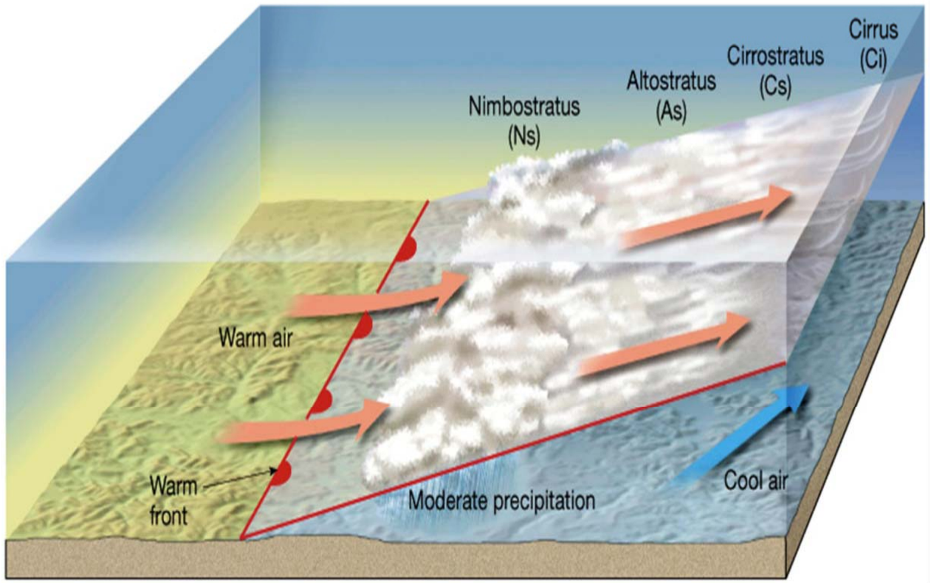




Stationary Front

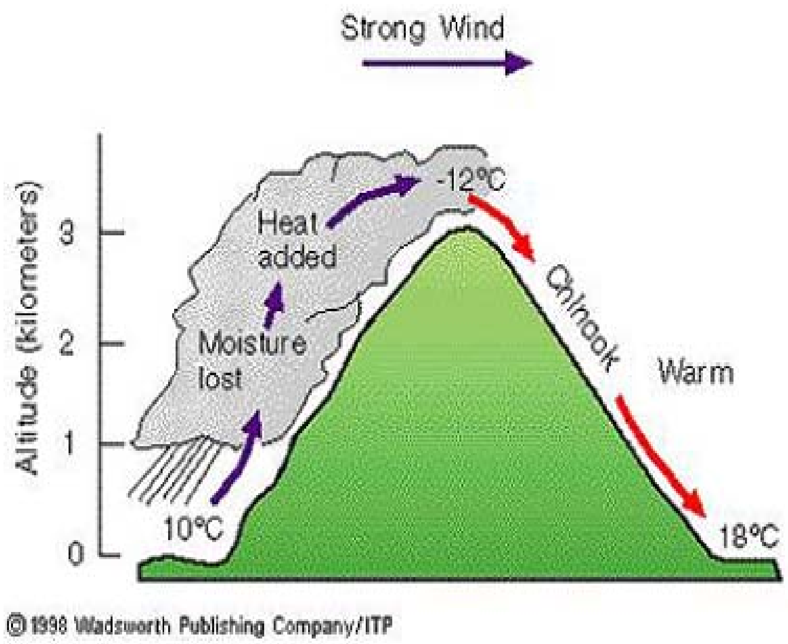
Warm front

Source: Lutgens and Tarbuck, 2004



- **Orographic precipitation** results from ascent of air over a mountain barrier, resulting in adiabatic cooling, condensation and precipitation on the upwind side of the barrier. The leeward side experiences a rain shadow.

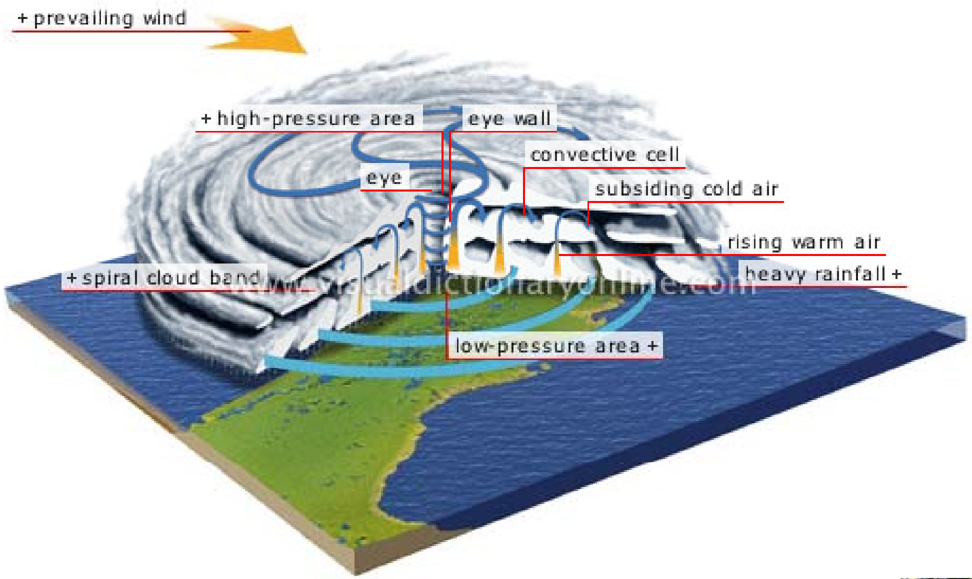
- As it descends on the leeward side, it warms at the adiabatic lapse rate, and arrives at a higher temperature than it had before the ascent process. These warm, leeside conditions are often associated with strong gusty winds called **chinooks.**

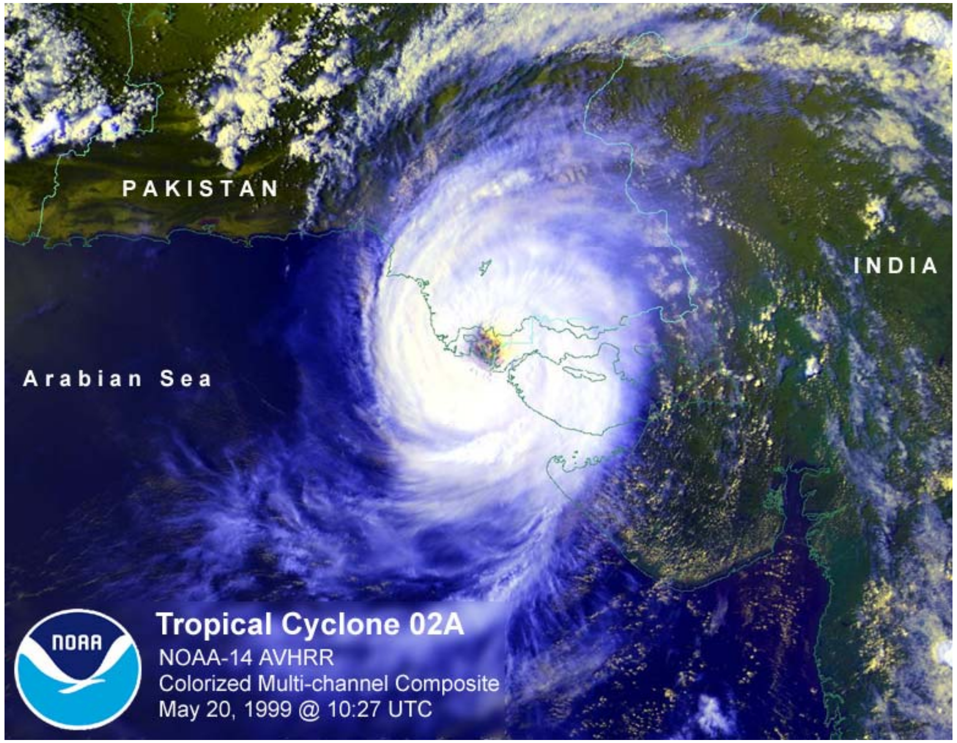


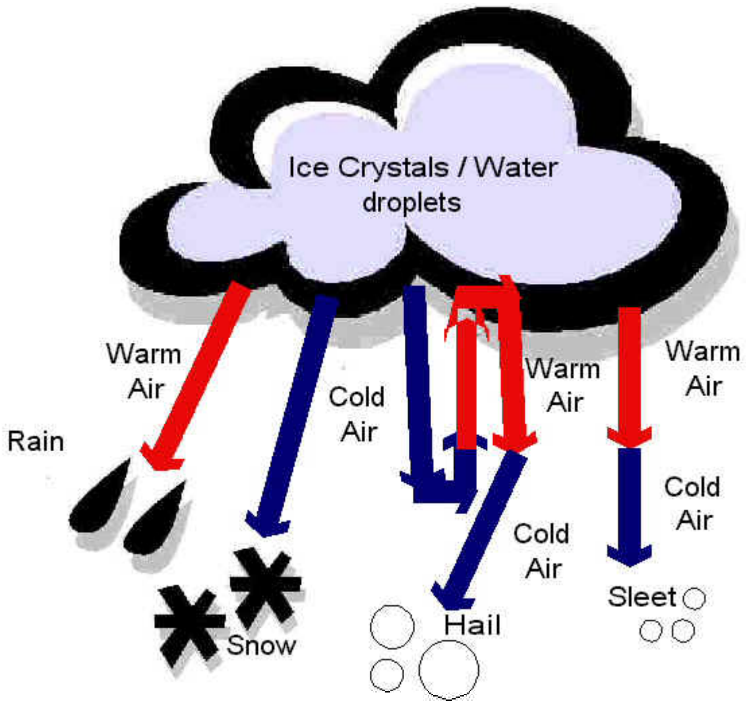
- **Cyclonic precipitation** is due to lifting of moist air converging into a low pressure belt, i.e., due to pressure differences created by the unequal heating of the earth's surface.

- Here the winds blow spirally inward counter clockwise in the northern hemisphere and clockwise in the southern hemisphere.

- There are two main types of cyclones—tropical cyclone (also called hurricane or typhoon) of comparatively small diameter of 300-1500 km causing high wind velocity and heavy precipitation, and the extra-tropical cyclone of large diameter up to 3000 km causing wide spread frontal type precipitation.


+ prevailing wind
+ high-pressure area
eye wall
convective cell
eye
subsiding cold air
rising warm air
+ spiral cloud band
heavy rainfall +
low-pressure area +
www.visualdictionaryonline.com

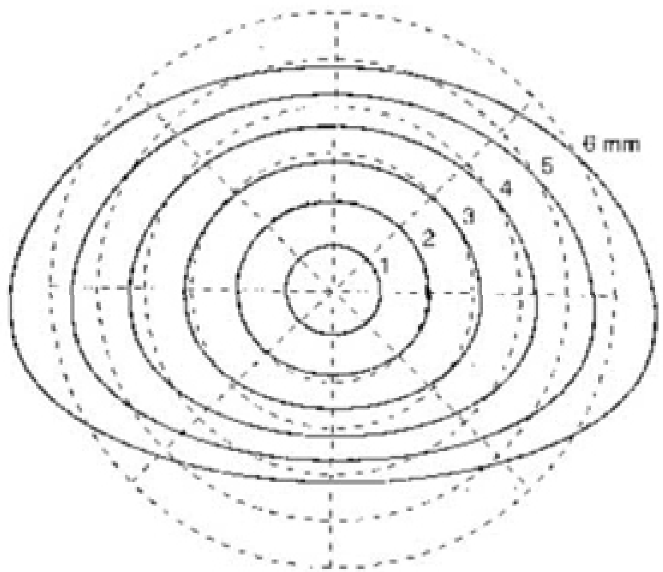

PAKISTAN
INDIA
Arabian Sea
NOAA
Tropical Cyclone 02A
NOAA-14 AVHRR
Colorized Multi-channel Composite
May 20, 1999 @ 10:27 UTC



Forms of precipitation

- **Drizzle**
  - These are the minute particles of water at start of rain. These consist of water drops under 0.5 mm diameter and its intensity is usually less than 1.0 mm/hr.
  - Their speed is very slow and we cannot even feel them. Therefore they cannot flow over the surface but usually evaporate.

- **Rain**
  - The size of drops in this case is more than 0.5 mm and less than 6.25 mm in diameter.
  - It can produce flow over the ground and can infiltrate and percolate.
  - Both the duration as well as rate of rainfall are important.
  - If the rainfall per unit time is greater than the rate of infiltration, the rain water can flow over the surface of earth.

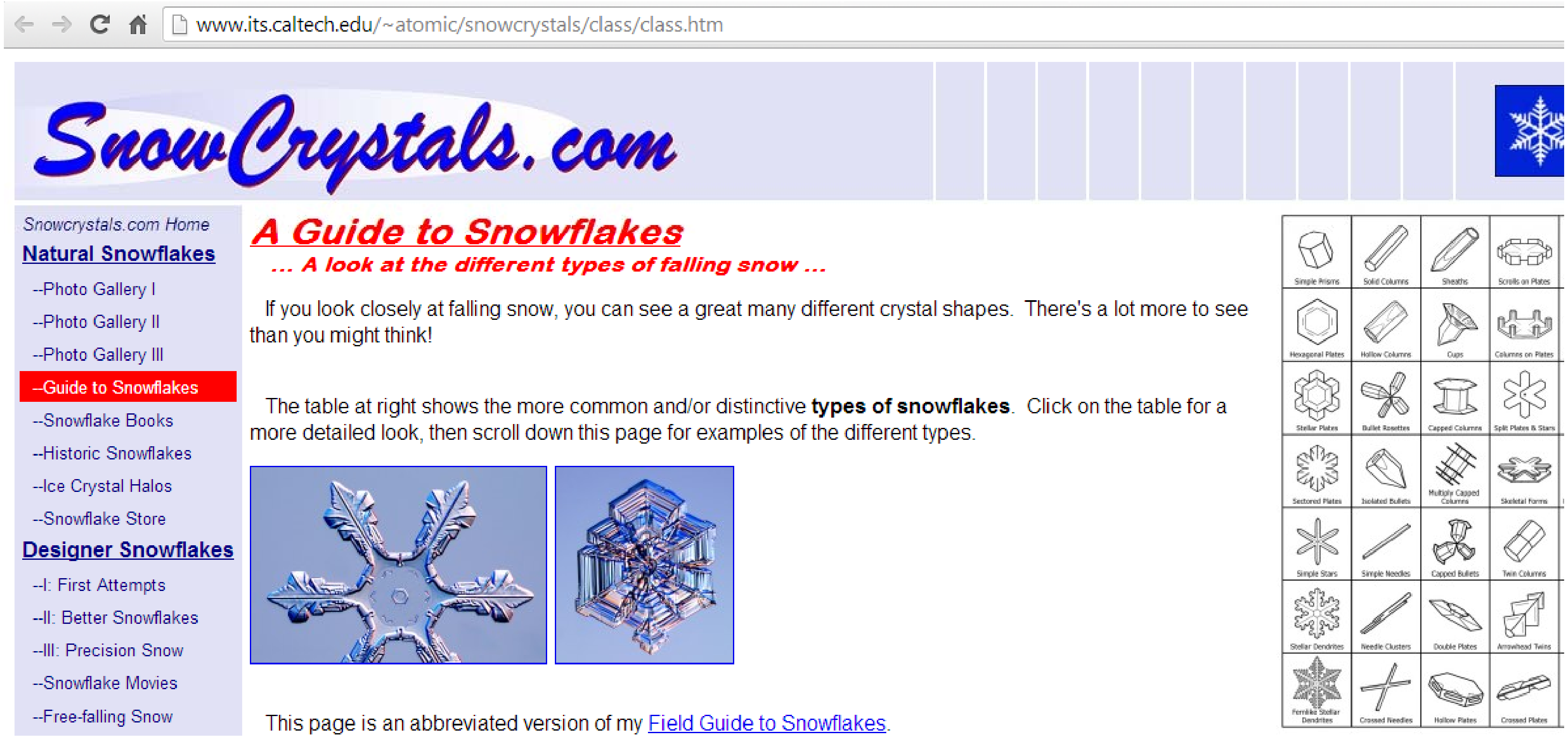


- **Glaze**
  - It is the ice coating formed on drizzle or rain drops as it comes in contact with the cold surfaces on the ground.

- **Sleet**
  - Sleet is frozen rain drops cooled to the ice stage while falling through air at subfreezing temperatures.

- **Snow**
  - Snow is precipitation in the form of ice crystals resulting from sublimation i.e. change of water vapor directly to ice.
  - A number of snow crystals fuse together to form a snow flake.

On CALTECH (California Institute of Technology)



- **Hail**
  - Hail is the type of precipitation in the form of balls or lumps of ice over 5 mm diameter formed by alternate freezing and melting as they are carried up and down by highly turbulent air currents

Precipitation Measurement

- The amount of precipitation means the vertical depth of water that would accumulate on a level surface, if the precipitation remains where it falls. It is usually measured in units of depth (inches, mm, cm etc).

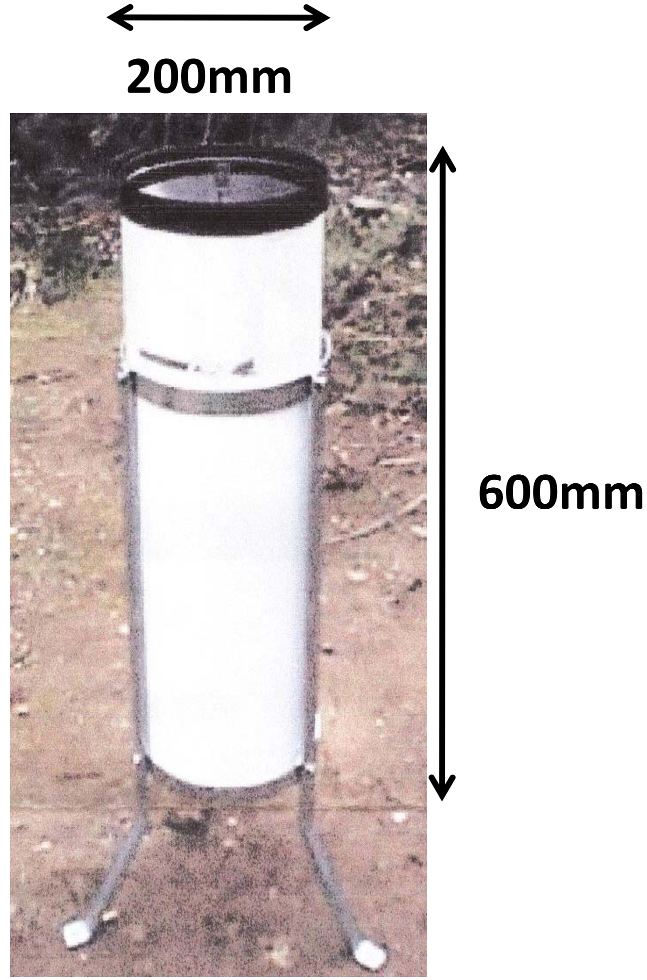
- Amount of precipitation per unit time is called the intensity of precipitation or rate of precipitation

- Precipitation is measured by a network of rain gauges which may either be of non-recording or recording type.

- The US Weather Bureau Non-Recording Rain Gauge.

- When snow is expected both the collector and tube is removed then.

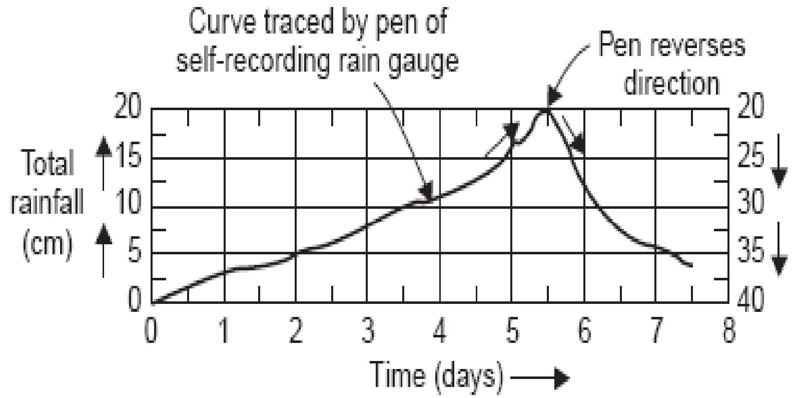
- The inside measuring tube has a cross sectional area 1/10th of the collector, so that 2.5 mm rain fall will fill the tube to 25 mm depth.



Recording Rain-gauges

- This is also called self-recording, automatic or integrating rain gauge.

- It has an automatic mechanical arrangement consisting of a clockwork, a drum with a graph paper fixed around it and a pencil point, which draws the mass curve of rainfall



Mass curve of rainfall

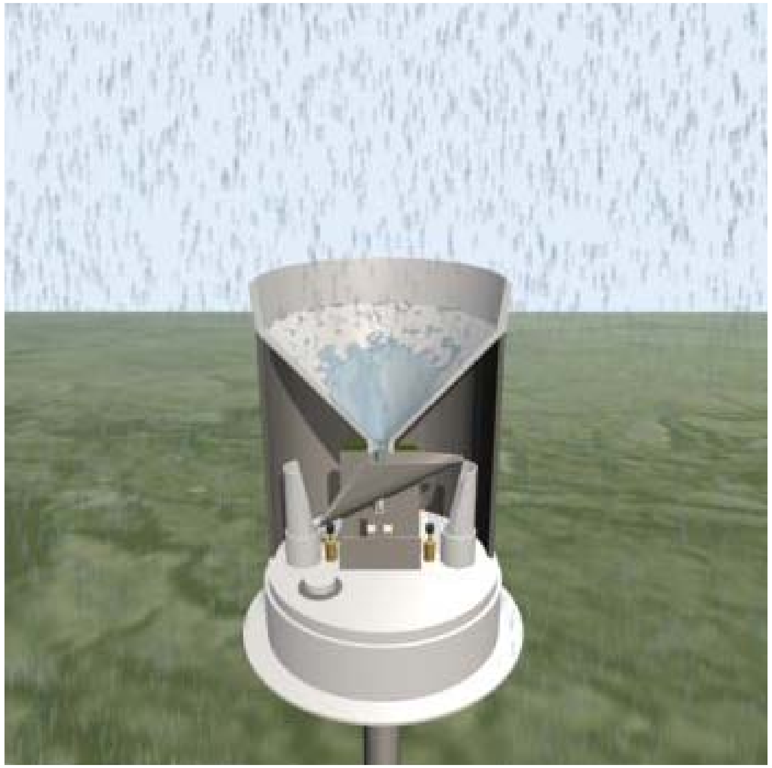
- The gauge is installed on a concrete or masonry platform 45 cm square in the observatory enclosure.

- The gauge is so installed that the rim of the funnel is horizontal and at a height of exactly 75 cm above ground surface.

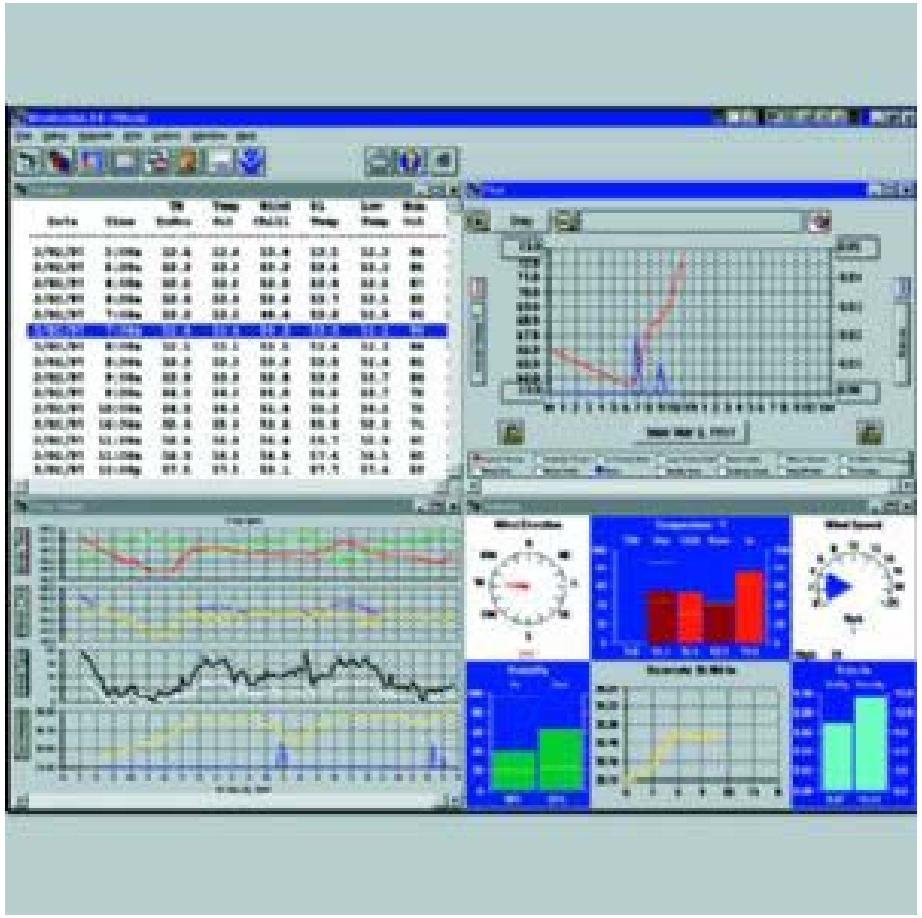
- There are three types of recording rain gauges—tipping bucket gauge, weighing gauge and float gauge.

- **Tipping bucket rain gauge.** This consists of a cylindrical receiver 30 cm diameter with a funnel inside. Just below the funnel a pair of tipping buckets is pivoted such that when one of the bucket receives a rainfall of 0.25 mm it tips and empties into a tank below, while the other bucket takes its position and the process is repeated.

1662 First Tipping Bucket Raingauge



Sir Christopher Wren, England (1632-1732, aged 90)



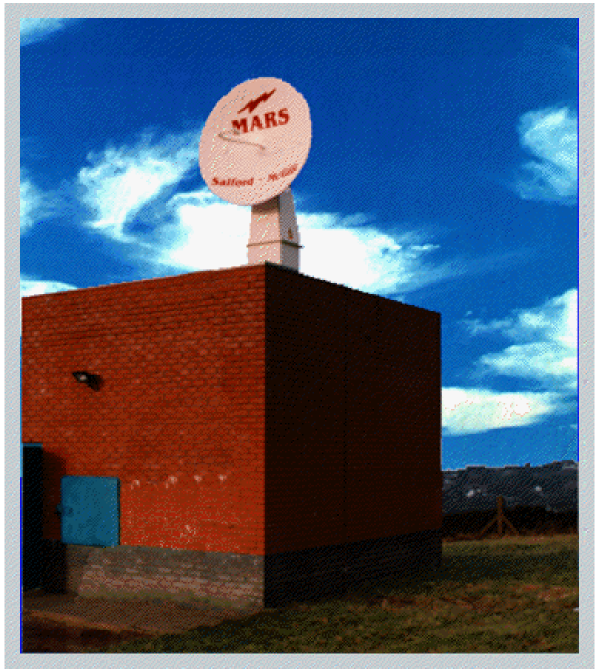
Snow-Telemetry (SNOTEL)

Areal Rainfall

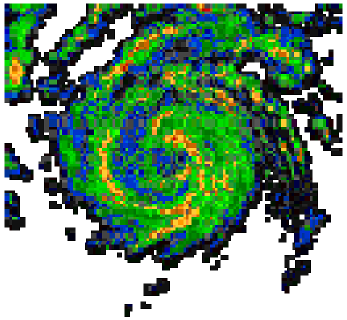
Non-uniform

Radar

RAdio Detection And Ranging



Transmitter →



NOAA

Receiver ←

$$Z \approx \int D^6 N(D)dD$$

$$R \approx \int D^{3.67} N(D)dD$$

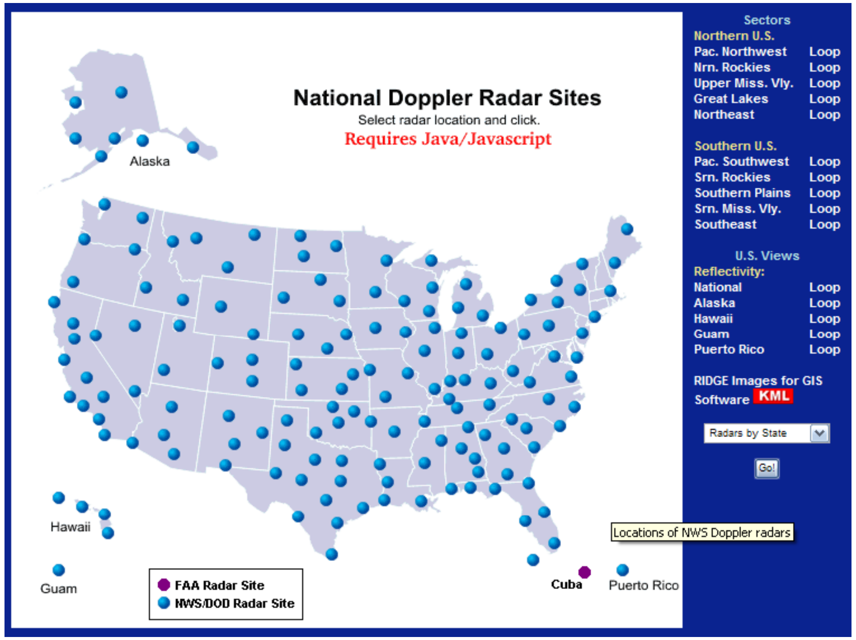
⇒ $$Z = aR^b$$

Source: www2010, Univ. of Illinois

Doppler weather radar

NEXRAD Next-Generation Radar

NEXRAD



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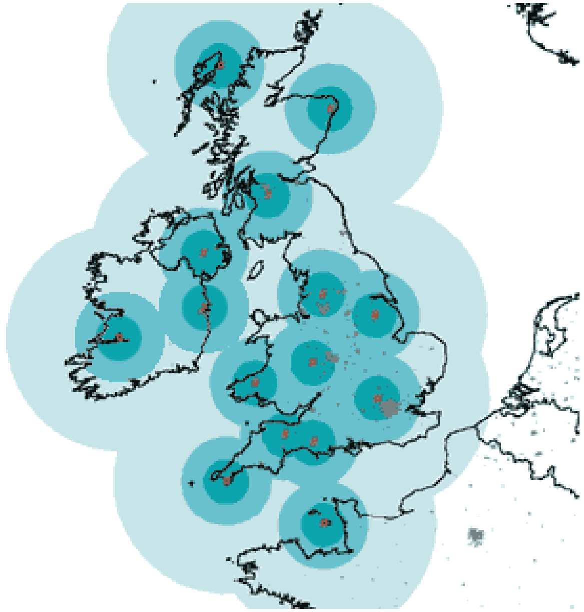
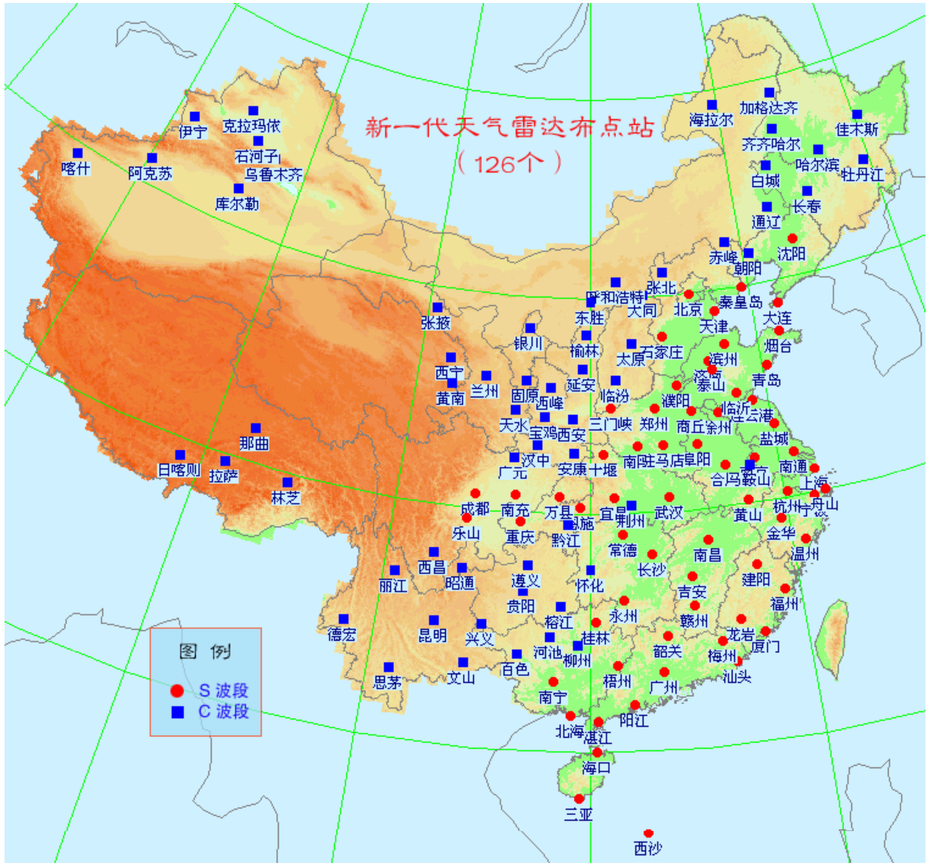
UK weather radars



17

Weather radar network in China



Doppler Weather radar 126

Radar Network of PMD

10-cm Doppler Radars

1- Lahore

2- Mangla

QPM Radar

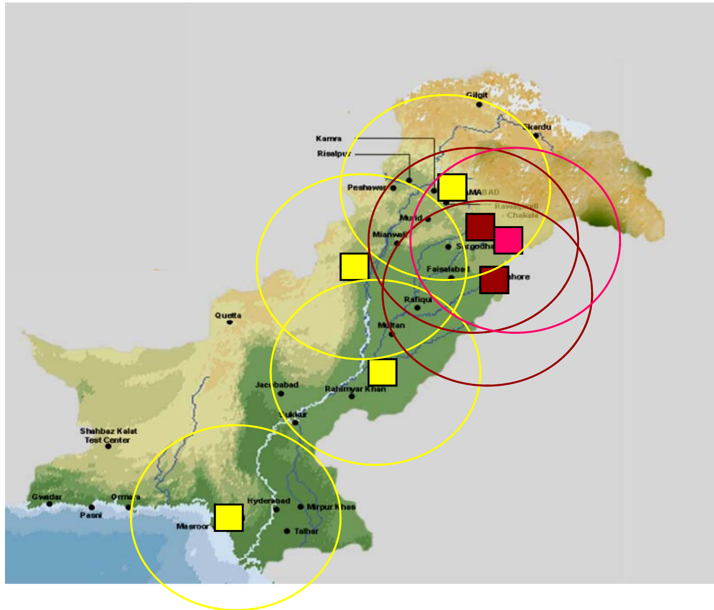
1- Sialkot

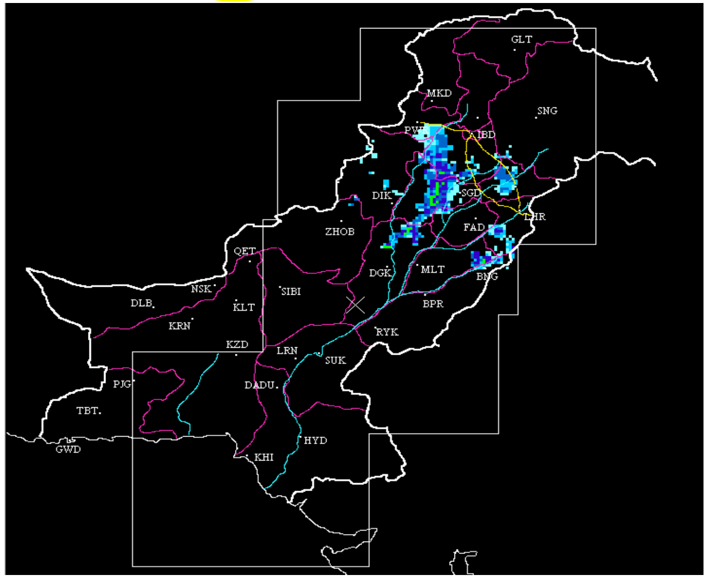
5-cm Wx. Surveillance Radars

Islamabad, D.I.Khan

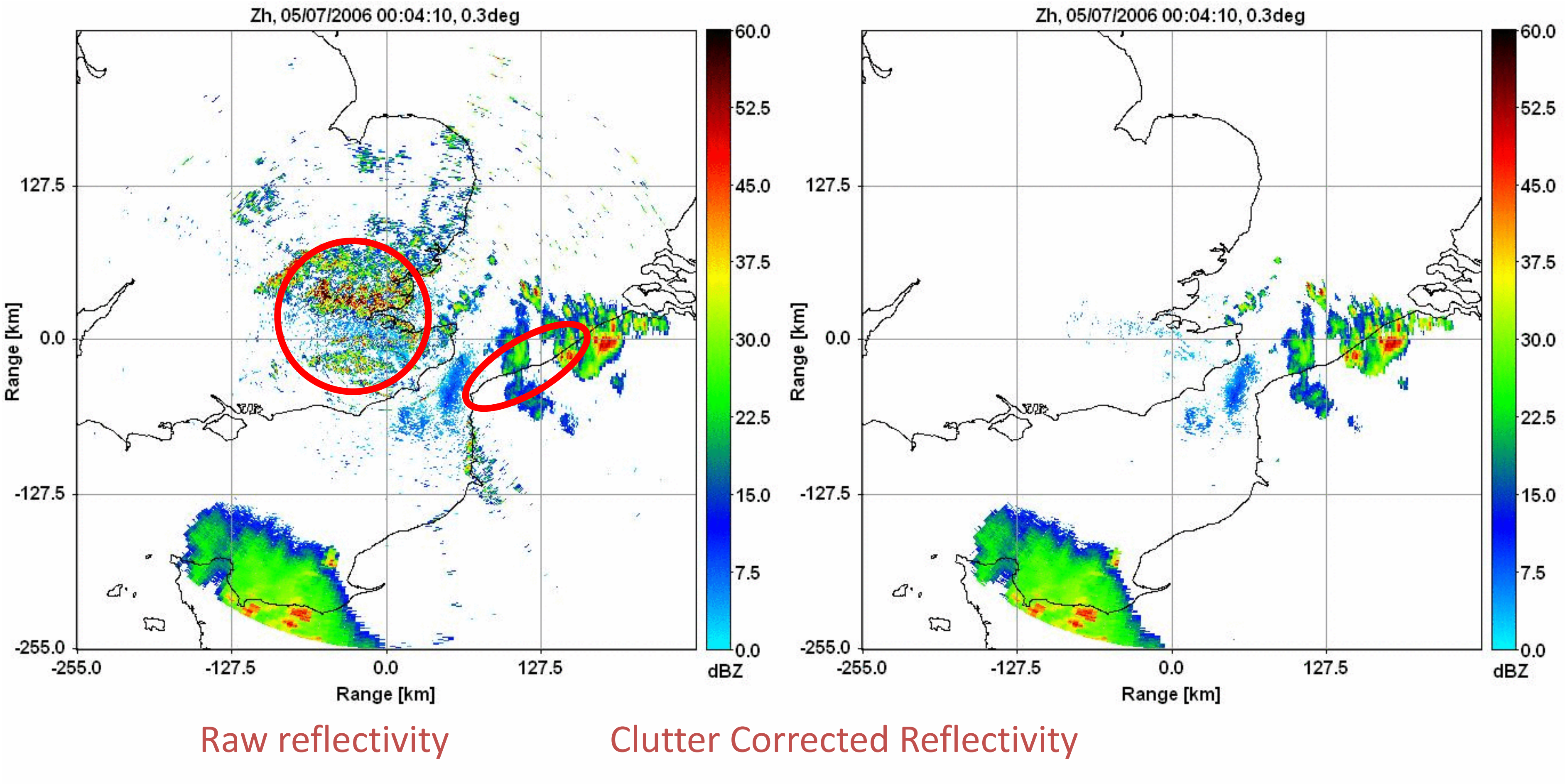
Rahim Yar Khan

Karachi

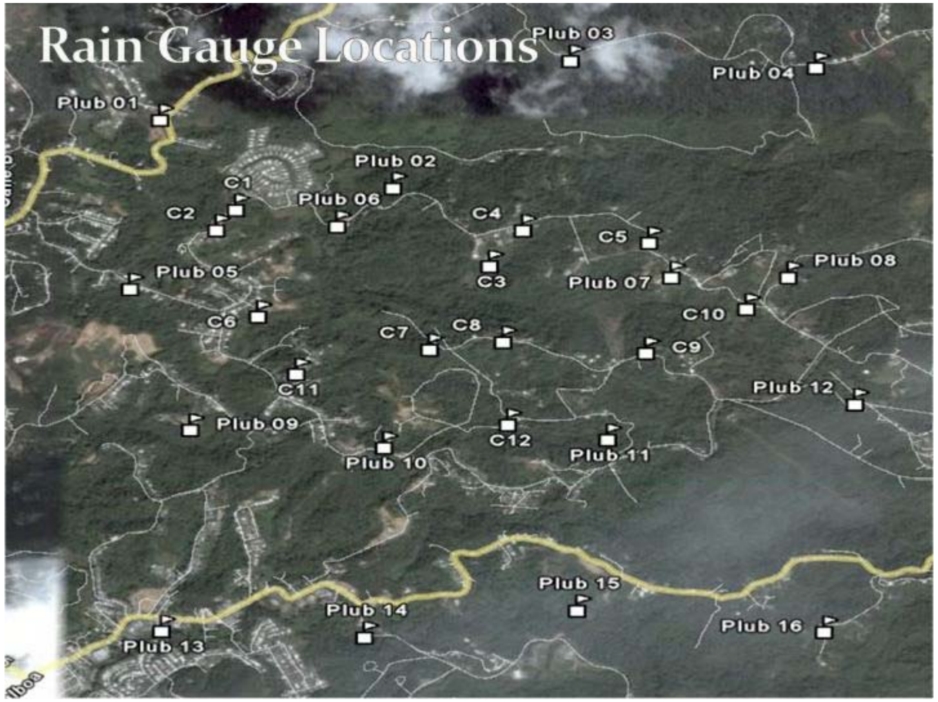




Clutter removal using a Bayes classifier



Clutter = Non-precipitation echoes such as echoes from the ground, sea, ship, airplanes



Rain Gauge Network

- In comparatively flat regions of Temperate (Latitudinal range 40° and 60/70° e.g. Ireland), Mediterranean (Latitudinal range 30^0 and 45^0 e.g. Most part of Europe) and Tropical Zones (Latitude range $5^0/10^0$ to 35^0e.g. Amazon)

- Ideal is at least one station for 230 – 345 sq. miles. However one station for 345 – 1155 sq. miles is also acceptable.

- In mountainous regions of Temperate, Mediterranean and Tropical Zones, Ideal is at least one station for 35 – 95 sq. miles. However one station for 95 – 385 sq. miles is also acceptable.

- In arid (Saudi Deserts) and polar zones, one station for 575 – 3860 sq. miles is acceptable

Analysis of Precipitation data

- **Point Data Analysis**
  - Point precipitation data refers to precipitation of a station.
  - This data could be in form of hourly record, daily record, monthly precipitation or annual precipitation.
  - Data continuity and consistency of a rain gauge should be checked first.

Reasons for Missing Precipitation Record

- Absence of the observer
- Instrumental failures.
- Hence missing data has to be estimated
- There are two methods for estimation of missing data.
  - Arithmetic mean method.
  - Normal ratio method.
- The gauging station whose data is missing is called **interpolation station** and
- The gauging stations whose data are used to calculate the missing station data are called **index stations.**

- If the normal annual precipitation of the **index stations** lies within $\pm$**10%** of normal annual precipitation of **interpolation station** then we apply arithmetic mean method to determine the missing precipitation record otherwise the normal ratio method is used for this purpose.

- Consider that record is missing from a station 'X'.

- Now let,

  N = Normal annual precipitation. (Mean of 30 years of annual precipitation data)

  P = Storm Precipitation.

- Let P_x be the missing precipitation for station 'X' and N_x , the normal annual precipitation of this station, N_a, N_b and N_c are normal annual precipitations of nearby three stations, A, B and C respectively while P_a, P_b and P_c are the storm precipitation of that period for these stations.

- Now we have to compare N_x with N_a , N_b and N_c separately. If difference of N_x - N_a, N_x - N_b, N_x - N_c is within 1/10% of N_x then we use simple arithmetic mean method otherwise the normal ratio method is used.

- According to the arithmetic mean method the missing precipitation is given as:

$\frac{1}{n}\sum_{i=1}^{i=n} P_i$ where n is number of nearby stations.

Normal Ratio Method

- According to the normal ratio method the missing precipitation is given as:

$$P_x = \frac{1}{n}\sum_{i=1}^{i=n}\frac{N_x}{N_i}P_i$$

- where P_x is the missing precipitation for any storm at the interpolation station 'X'.

- P*i* is the precipitation for the same period of same storm at the "*i*th" station of a group of index stations and

- N_x and N_i are the normal annual precipitation values for the 'X' and '*i*th' stations e.g. in case of three index stations

$$P_x = \frac{1}{3}[\frac{N_x}{N_1}P_1 + \frac{N_x}{N_2}P_2 + \frac{N_x}{N_3}P_3]$$

- ***Example***
  - Find out the missing storm precipitation of station 'C' given in the following table: (can we apply Simple Arithmetic Mean Method to Approach the Solution?)

Station	A	B	C	D	E
Storm precipitation (cm)	9.7	8.3	----	11.7	8.0
Normal Annual precipitation (cm)	100.3	109.5	93.5	125.7	117.5

Continued…

- **Solution**

In this example the storm precipitation and normal annual precipitations at stations A, B, D and E are given and missing precipitation at station 'C' is to be calculated whose normal annual precipitation is known. We will determine first that whether arithmetic mean or normal ratio method is to be applied.

10% of N_c = 93.5x10/100 = 9.35

After the addition of 10% of N_c in N_c, we get 93.5+9.35=102.85

And by subtracting 10% we get a value of 84.15

So N_a, N_b, N_d or N_e values are to be checked for the range 102.85 to 84.15.

If any value of N_a, N_b, N_d or N_e lies beyond this range, then normal ratio method would be used. It is clear from data in table above that N_b, N_d and N_e values are out of this range so the normal ratio method is applicable here, according to which

$$Px = \frac{1}{n}\sum_{i=1}^{i=n}\frac{N_x}{N_i}P_i$$

Pc= (1/4)(93.5 x 9.7/100.3+ 93.5 x 8.3/109.5+ 93.5 x 11.7/125.7+ 93.5 x 8.0/117.5) = 7.8 cm

- **Example**

Precipitation station "X" was inoperative for part of a month during which a storm occurred. The storm totals at three surrounding stations A, B and C were respectively 10.7, 8.9 and 12.2 cm.

The normal annual precipitation amounts at stations X, A, B and C are respectively 97.8, 112, 93.5 and 119.9 cm. Estimate the storm precipitation for station 'X'.

- Solution

P_a = 10.7 cm	N_a = 112 cm
P_b = 8.90 cm	N_b = 93.5 cm
P_c = 12.2 cm	N_c = 119.9 cm
P_x = ?	N_x = 97.8 cm

10% of Nx = 97.8 x 10/100 = 9.78 cm.

$\therefore$ Nx - Na = 97.8 - 112 = -14.2 cm $\Rightarrow$ More than + 10% of Nx (no need of calculating Nx – Nb and Nx – Nc

So we will use Normal Ratio Method

$\therefore$ Px = (1/3) (97.8 x 10.7/112+ 97.8 x 8.90 /93.5 + 97.8 x 12.2 /119.9)

Px = 9.5 cm

Consistency of Precipitation Data or Double Mass Analysis

- In using precipitation in the solution of hydrologic problems, it is necessary to ascertain that time trends in the data are due to meteorological changes only and not other factors like
- Changes in the gauge location
- Change in surroundings such as
  – Construction of buildings or
  – Growth of trees etc.

- Frequently changes in gauge location are not disclosed in the published record.

- Due to such changes the data might not be consistent.

- The consistency of the record then is required to be determined and the necessary adjustments be made. This can be achieved by the method called the double mass curve technique.

- The double mass curve is obtained by plotting the accumulated precipitation at the station in question along X-axis and the average accumulated precipitation of a number of other nearby stations which are situated under the same meteorological conditions along Y-axis.

- If the curve has a constant slope, the record of station “X” is consistent. However, if there is any break in the slope of the curve, the record of the station is inconsistent and has to be adjusted by the formula.

$$P_a = (S_a / S_o) \times P_o$$

Where P_a = Adjusted precipitation.

P_o = Observed precipitation.

S_a = Slope prior to the break in the curve

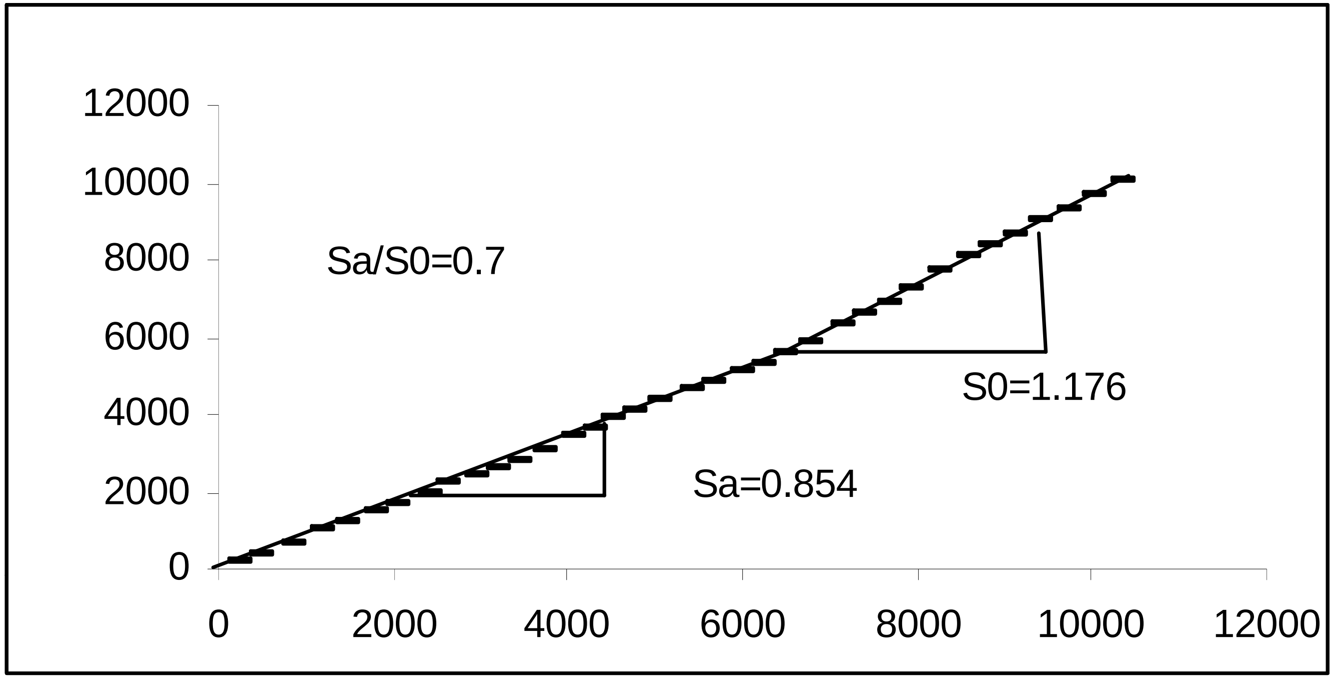
S_o = Slope after the break in the curve.

- All values before break are to be adjusted.

Example: Check consistency of the data given in table below and adjust it if it is found to be inconsistent

Year	Annual precipitation at x (mm)	Mean of annual precipitation of 20 surrounding stations (mm)	Year	Annual precipitation at x (mm)	Mean of annual precipitation of 20 surrounding stations (mm)
1972	188	264	**1954**	223	360
1971	185	228	**1953**	173	234
1970	310	386	**1952**	282	333
1969	295	297	**1951**	218	236
1968	208	284	**1950**	246	251
1967	287	350	**1949**	284	284
1966	183	236	**1948**	493	361
1965	304	371	**1947**	320	282
1964	228	234	**1946**	274	252
1963	216	290	**1945**	322	274
1962	224	282	**1944**	437	302
1961	203	246	**1943**	389	350
1960	284	264	**1942**	305	228
1959	295	332	**1941**	320	312
1958	206	231	**1940**	328	284
1957	269	234	**1939**	308	315
1956	241	231	**1938**	302	280
1955	284	312	**1937**	414	343

- ***Solution***
  - A double mass curve is plotted by taking cumulative of average precipitation of surrounding stations along x-axis and accumulative precipitation of station 'X' along y-axis for which consistency of data is being investigated.



- The correction for slope is applied to readings before break in slope (in time). The calculations are shown in table, below.

Slope of Ist line = Sa = 0.854

Slope of deviating line = So = 1.176

Correction to values (multiplying factor) = 0.854/1.176 = 0.70

- Now regime changes before 1950. So up to 1950 no correction is required. Before 1950 all readings are multiplied by slopes ratio of 0.7 to get corrected precipitation.
- Note that data in latter interval (1973-1950) is considered more authentic so kept in initial reach of the graph.

Table: Adjusted Precipitation

Year	Cummulative Annual precipitation at x (mm)	Cummulative precipitation of 20 surrounding stations (mm)	Corrected Precipitation	Remarks
1972	188	264	188	No correction
1971	373	492	185	
1970	683	878	310	
1969	978	1175	295	
1968	1186	1459	208	
1967	1473	1809	287	
1966	1656	2045	183	
1965	1960	2416	304	
1964	2188	2650	228	
1963	2404	2940	216	
1962	2628	3222	224	
1961	2831	3468	203	
1960	3115	3732	284	
1959	3410	4064	295	
1958	3616	4295	206	
1957	3885	4529	269	
1956	4126	4760	241	
1955	4410	5072	284	
1954	4633	5432	223	
1953	4806	5666	173	
1952	5088	5999	282	
1951	5306	6235	218	
1950	5552	6486	246	

Table: Adjusted Precipitation

Year	Cumulative Annual precipitation at x (mm)	Cumulative precipitation of 20 surrounding stations (mm)	Corrected Precipitation	Remarks
1949	5836	6770	190.8	Precipitation of Station 'X' x0.7
1948	6329	7131	345	
1947	6649	7413	224	
1946	6923	7665	192	
1945	7245	7939	225.4	
1944	7682	8241	306	
1943	8071	8591	272.3	
1942	8376	8819	213.5	
1941	8696	9131	224	
1940	9024	9415	229.6	
1939	9332	9730	215.6	
1938	9634	10010	211.4	
1937	10048	10353	290	