Advanced Agro-Hydro- Meteorology

A MSc course for students of Atmospheric Sciences

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Lecture 2: Precipitation (Part 2)

3.1 Precipitation systems

- We know that water vapour in the atmosphere may be condensed to form clouds when the air is lifted. Cloud particles may then grow by various processes to form precipitation. The atmospheric motions which produce the lifting necessary to trigger these processes are organized on various scales as shown in Table 3.1.

Table (3.1) Scales of precipitation systems

	Precipitation system	**Description**	**Horizontal scale (km)**	**Vertical velocity (cm s^{-1})**
1	Localized convection	Precipitation from single clouds or from convective cells within larger scale systems. They may occupy a large depth of the atmosphere, in which case they are referred to as *thunderstorms*	$10^{0.5}$	10^{2}
2	Mesoscale precipitation area (MPA)	Cluster of convective cells	$10^{1.5}$	10
3	Mesoscale rain band	Convective cells occurring in lines, sometimes almost two-dimensional	Width $10^{1.5}$ Length 10^{2}	10
4	Synoptic scale precipitation systems	Mid-latitude depressions	Width 10^{2} Length 10^{3}	1
5	Tropical storms	Known as hurricanes in the southern part of the North Atlantic, cyclones in the northern part of the Indian Ocean, typhoons in the southwestern part of the North Pacific, and willy-willies in the north-east of Australia	Radius $10^{1.5}$	10^{2}

3.1.1 Localized Convection

- If the atmosphere is unstable then vertical motion will occur, giving rise to condensation of water vapor and the formation of cloud.
- The development of convection may be controlled either by boundary layer characteristics (microscale) or by atmospheric synoptic situations. The same effect may be produced by air forced to rise over hills. Such clouds grow to a height of several kilometres in 20–40 minutes, producing rain of intensity dependent upon the depth of the cloud.

- The vertical velocity will be dependent upon the difference between the environmental lapse rate and the SALR. If this difference is large, then the vertical motion will be large, and a small shower cloud may develop rapidly to a height of around 10 km, becoming a thunderstorm (mostly with lightning).
- Within thunderstorms, hail may be produced by precipitation particles sweeping up supercooled droplets in an updraught until they are of such a size that they fall out of the updraught.
- Two main types of thunderstorms have been identified: multi-cell storms and supercell storms. Most storms fall into the multi-cell category. They consist of several cells (clouds) at different stages of development at any one time. New cells may form where the outflow regions from other cells intersect. The air of the downdraught spreads out laterally.
- The supercell storms have a structure, which consists of a single storm-scale circulation comprising one giant updraught–downdraught pair. Either of these types of storm may produce a tornado, a region a few kilometers wide or less of high rotation (winds in excess of 322 km/h) and low pressure visualized as a funnel cloud. Rainfall may be very heavy, although usually of short duration. Thunderstorms occur in temperate and tropical regions throughout the world.

3.1.2 Mesoscale precipitation systems

- Several thunderstorms may be grouped together within a mesoscale convective complex (MCC). The timescale is much longer than one hour, the lifetime of the individual cumulonimbi comprising the system. A typical timescale of an MCC in mid-latitudes is around three hours. MCCs are represented as squall lines when near linear.
- The precipitation area is continuous and larger than precipitation from any individual storm.
- In the early stages of development the MCC is very convective, and the rainfall is dominated by that produced by the individual cells. However, as the MCC develops, lifting on a larger scale occurs.

3.1.3 Mid-latitude depressions

- Although thunderstorms produce large amounts of rainfall in mid-latitudes at any one place, they are quite rare. Most of the rainfall originates from low pressure systems termed depressions.
- Rain from stratiform (layered) cloud is associated with the warm front, and rain from convective cloud and thunderstorms is associated with the cold front. The basis of a dynamical description of the depression is the release of energy in sloping (baroclinic) convection (Figure 3.1).

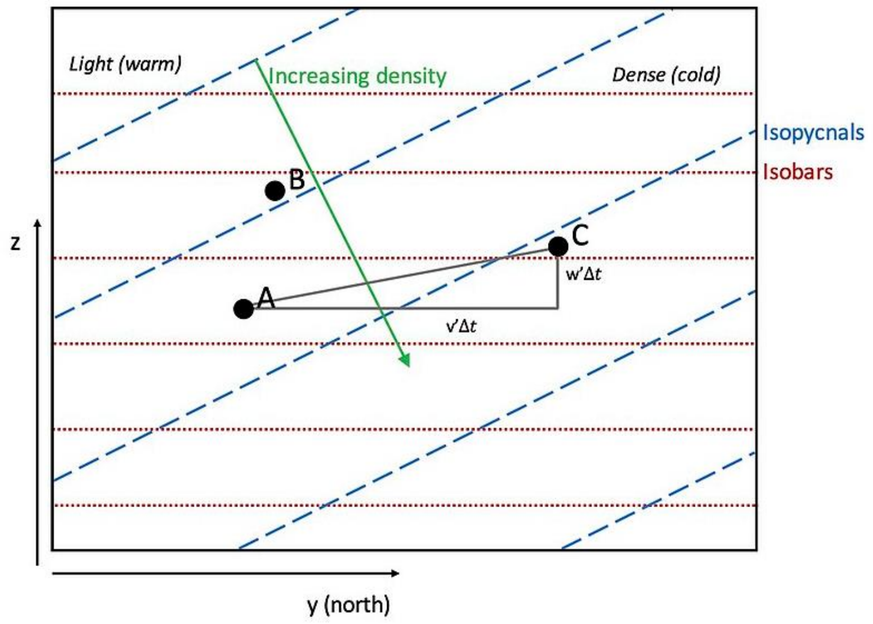

Figure (3.1) A Baroclinic fluid with sloping isopycnals (lines of the same density), intersecting with isobars. Small perturbations (B and C) from the original state (A) are shown and used to explain the process of sloping convection. For perturbations from A to B, a relatively dense fluid parcel is surrounded by lighter fluid, so the fluid parcel will sink back to location A (static stability). When a fluid parcel at A is perturbed to location C, the parcel is surrounded by relatively dense fluid and it will continue to rise further. Small perturbations now grow into larger ones (sloping convection).

- Figure 3.2 shows the lifetime of a depression based upon microwave radiometer data from an open wave through a mature stage to an occluded stage.

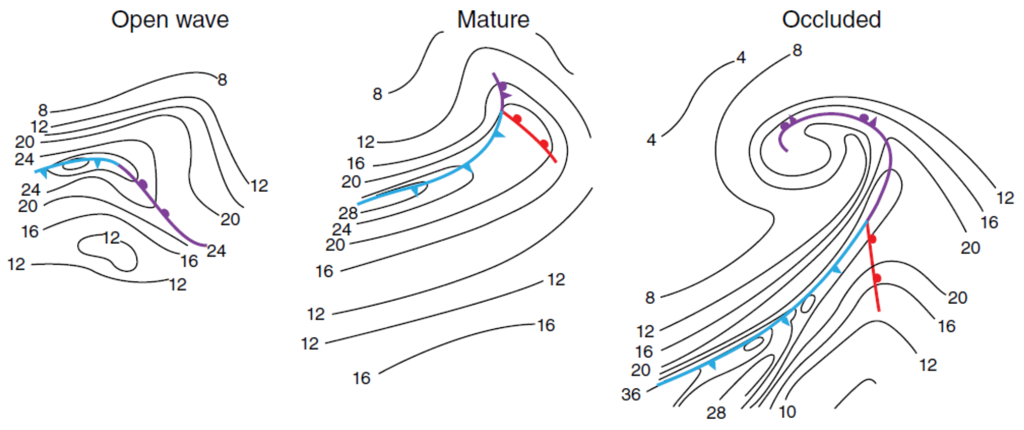

Figure (3.2)

- The dry air behind the cold front often overrides the *warm conveyor belt* (WCB) in the region shown in Figure 3.3. This causes the air to become unstable if it is ascending, with the result that convection is released in small cells at mid-levels known as generating cells.

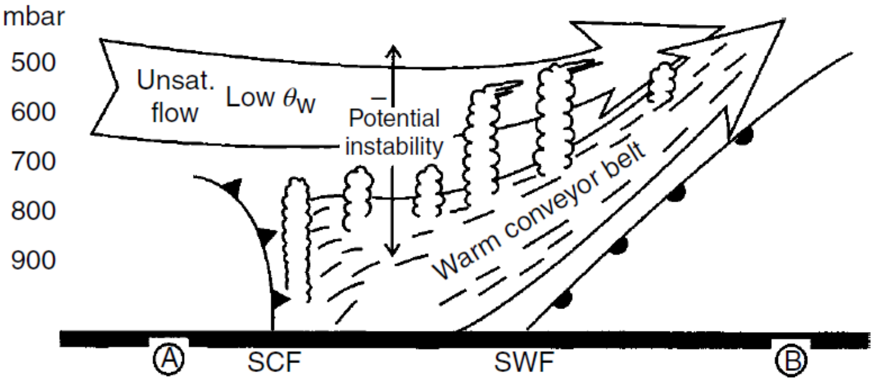

Figure (3.3)

- These cells tend to occur in clusters and give rise to mesoscale precipitation areas (MPAs) which can produce moderate or heavy rainfall. This rainfall is produced by what is known as a seeder–feeder mechanism. Ice particles from the generating cells fall into lower level frontal cloud and act as natural seeding particles, causing a rapid growth of precipitation particles (See Figure 3.4).

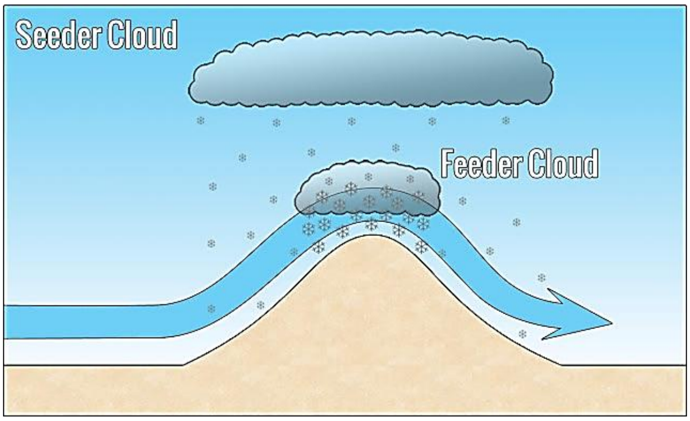

Figure (3.4)

- Rainfall totals from mid-latitude depressions are not generally large, although heavy rain may occur from thunderstorms developing on the cold front. Nevertheless, the precipitation often occurs steadily over long periods, particularly over hilly areas.

3.1.4 Tropical storms

- One favoured area for the formation of tropical cloud clusters is the Inter-Tropical Convergence Zone (ITCZ) located close to the equator. Here the north-east trade winds of the northern hemisphere converge with the south-east trade winds of the southern hemisphere.
- A small fraction of clusters develop into hurricanes (cyclones or typhoons). Heavy precipitation occurs in the main cloud band known as the eye wall band and other bands, although lighter precipitation does occur between them. An example of the cloud pattern associated with a hurricane is shown in Figure 3.5. The boundary layer may play an important role in the intensification of these systems.

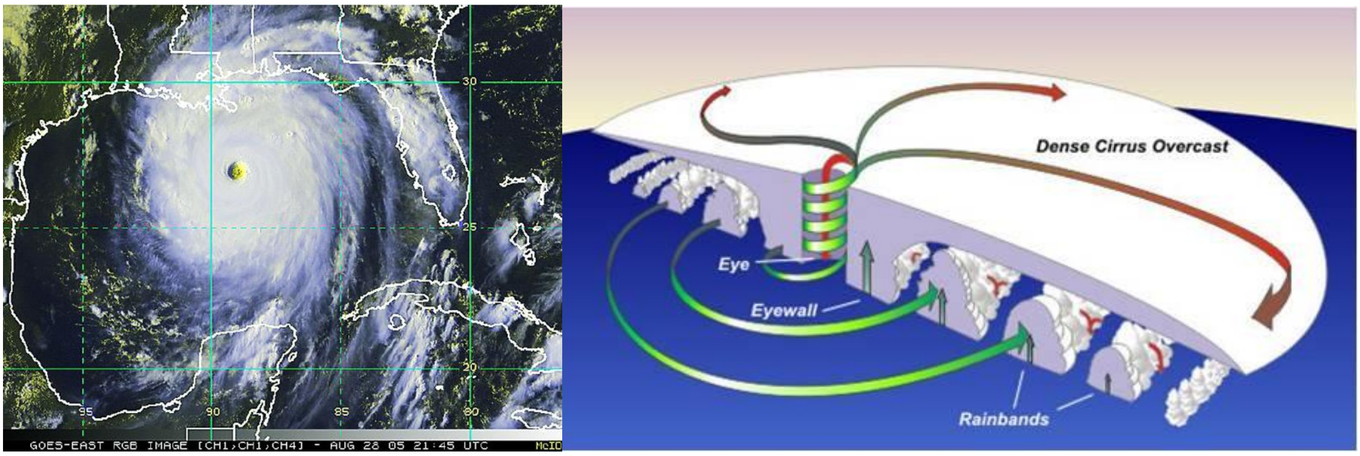

Figure (3.5) (Left) Hurricane Katrina, 28 /8/ 2005; category 5, highest winds 175 mph (280 km h^{-1}), lowest pressure 902 mbar (hPa). (Right) typical vertical structure of tropical depression (hurricane).

- Hurricanes may be symmetric, having a closed eye wall band, or asymmetric, having an eye wall band which is not closed. In a symmetric system the centre of the wind circulation (anticlockwise in the northern hemisphere) is located in the centre of the circle defined by the eye wall boundary. Although hurricanes form over the tropical oceans, the rainfall from them, when they reach land, may be very large indeed.

3.2 Orographic effects on precipitation distribution

- Orography can affect the distribution of rainfall by forcing air to ascend. The ascent may lead to condensation and rainfall (Figure 3.6a), or may result in convection leading to rainfall (Figure 3.6b). A third process is the enhancement of rain over hills from pre-existing clouds as a result of a natural seeding process (Figure 3.6c). Mechanisms (a) and (c) in Figure 3.6 occur in frontal rainfall situations.

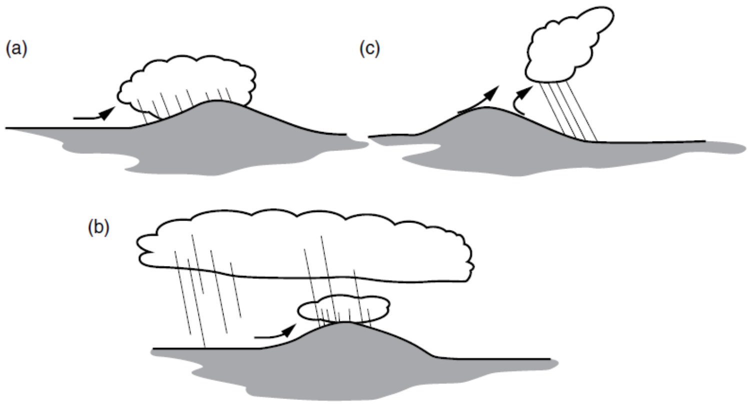

Figure (3.6) Mechanisms of orographic rain generation

- The increase in rainfall over hilly areas is very evident on average annual rainfall maps in mid-latitudes for areas exposed to moist air moving from the sea. Indeed there is almost a relationship between elevation and average annual rainfall amount, although this relationship does vary spatially. In the lee of ranges of hills, descending air (or subsidence) may lead to reduced rainfall in areas known as *rain shadows*.

3.3 Topographical effects on precipitation distribution

- Precipitation amount may be increased in coastal areas by the difference in the convergence of air caused by increased friction over the land compared to that experienced over the sea. Differences between land and sea can cause fronts associated with mid-latitude depressions to become *stationary* just off-shore, which can lead to very large falls of precipitation in coastal regions, particularly if the land is hilly. The sea or land breezes associated with air circulation caused by temperature differences between the land and the sea may organize convection such that precipitation amounts can be very much enhanced (Figure 3.7).

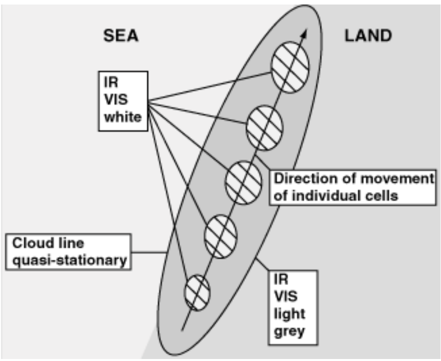

Figure (3.7) Cloud lines are mostly convective in nature, with individual cells often travelling along the coast with the gradient wind, but the whole cloud band appears quasi-stationary for a relatively long period of time.

3.4 Global atmospheric circulation

- The average time that a molecule of water is resident in the atmosphere as vapor or within a cloud is 10-12 days. During this period, the molecule may travel a considerable distance within the atmospheric circulation before being returned to the surface of the Earth as precipitation. Indeed, it is the global circulation of the atmosphere as a whole, which dictates the occurrence of the atmospheric systems outlined earlier and hence the global precipitation distribution.
- The climatological distribution of annual rainfall can be visualized as in Figure 3.8. The precipitation maxima in mid-latitudes are associated with depressions, showers and thunderstorms. In the tropics, the rainfall maximum is associated with cloud clusters and tropical storms.

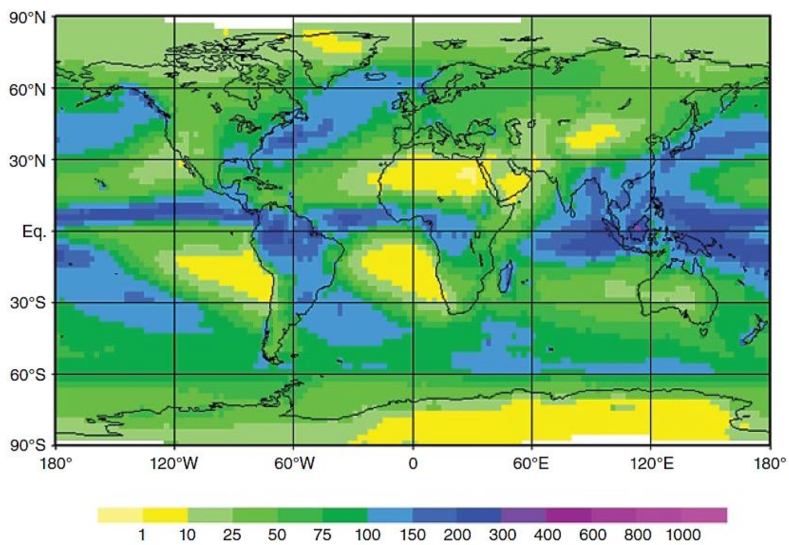

Figure (3.8) Globally averaged annual precipitation 1980–2004 Jan–Dec (mm per month) from the Global Precipitation Climatology Project (GPCP) Version 2