Lecture 22

Intraseasonal variation and intraseasonal oscillations
We have seen that fluctuations between active spells and weak spells or breaks is an important feature of the intraseasonal variation of the monsoon.

The other important feature of the intraseasonal variation of the monsoon is northward propagations of the cloud band/rainbelt from the equatorial regions onto the Indian region.
Northward propagations

We have seen that these northward propagations are a basic feature of the variation of the cloud bands/rain-belts in every summer monsoon season irrespective of whether it is a good monsoon season or a drought.

These propagations are coherent across the Indian longitudes.
Variation of the location of the cloud band at 90°E during June-September of 1973, 1974, 1975
Variation of the cloud-bands along $70^0, 80^0, 90^0$E during June-September 1975

Note that the northward propagations are coherent across $70^0$-$90^0$E
We have also seen that seasonal transitions—from spring to summer as well as summer to autumn are characterized by northward propagations (next slide).

Such propagations also play an important role in the revival of the monsoon from breaks.
Seasonal Variation of the TCZ/Cloud band

Daily Outgoing Longwave Radiation

90°E

[Graph showing daily outgoing longwave radiation with seasonal variation]
• These propagations occur at intervals of 2 to 6 weeks, except in the case of transition seasons when they can occur in rapid succession.
They imply significant correlation (with a lag of one or two weeks) of precipitation over a latitudinal belt to the precipitation to the latitudinal belt to the north.
• We have seen that if for some reason the northward propagations are suppressed in the onset phase, it leads to a hiatus in the progress of the monsoon.
• If the mechanisms leading to these propagations is understood and models can simulate and predict them, they could be the basis for predictions of important phases of the monsoon such as the onset phase and revival from breaks.
We have noted before that two distinct approaches have been adopted in the study of intraseasonal variation. In the first, the more traditional approach, the focus is on special events such as breaks in the monsoon or special features of some systems such as the propagation of the TCZ. The major features of these events are studied with analysis of data and attempts are made at their simulation by models in order to understand the underlying mechanisms.
In the second approach, which is the one adopted in most of the recent studies, the variation is viewed as a superposition of waves/modes or spatial patterns, which are called intraseasonal oscillations (ISOs).

Structure and evolution of these modes is investigated in detail for further understanding and generating predictions.
ISO: Observations
The important timescales of variation of rainfall over the Indian region during the summer monsoon have been identified in the past three decades as the 10–20 day and the 30–50 day scales, in addition to the synoptic scale. Peaks corresponding to these scales are clearly seen in the spectra of rainfall and wind. The 30-50 day mode is seen over a large part of the tropics and is called the Madden-Julian oscillation (MJO).
Rainfall Indian region: 75°E – 85°E, 15°N-25°N

850hpa zonal wind anom Arabian sea 55-65E, 5-15N

850hpa zonal wind anom Bay of Bengal 85-90E, 10-15N

850hpa mer. wind anom 80-85E, 0-5N

15 days, 40 days
INDIAN OCEAN OLR SPECTRA

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**EIO**

![Spectrum graphic for EIO](image)

**BoB**

![Spectrum graphic for BoB](image)
Rainfall (GPCP)

Summer average wavelet spectra for GPCP daily rainfall 1997-2004
Note the absence of a peak around 40 days.
Madden–Julian oscillation (MJO)

• The Madden–Julian Oscillation (MJO), named after its discoverers, is the largest element of the intraseasonal (super-synoptic) variability in the tropical atmosphere.
• It is a large-scale coupling between atmospheric circulation and tropical deep convection. Rather than being a standing pattern (like ENSO) it is a traveling pattern,
propagating eastwards at approximately 4 to 8 m/s, through the atmosphere above the warm parts of the Indian and Pacific oceans. This overall circulation pattern manifests itself in various ways, most clearly as anomalous rainfall.

Again the comparison with ENSO is instructive, since their local effects on Peruvian fisheries were discovered long before the global structure of the pattern was recognized.
• The MJO is characterized by an eastward progression of large regions of both enhanced and suppressed tropical rainfall, observed mainly over the Indian Ocean and the Pacific Ocean.
• The anomalous rainfall is usually first evident over the western Indian Ocean, and remains evident as it propagates over the very warm ocean waters of the western and central tropical Pacific.
• This pattern of tropical rainfall then generally becomes nondescript as it moves over the cooler ocean waters of the eastern Pacific (except over the
region of warmer water off the west coast of Central America) but occasionally reappears at low amplitude over the tropical Atlantic and higher amplitude over the Indian Ocean. The wet phase of enhanced convection and precipitation is followed by a dry phase. Each cycle lasts approximately 30–60 days. Because of this pattern, The MJO is also known as the 30–60 day oscillation, 30–60 day wave, or intraseasonal oscillation.
Madden Julian Oscillation (MJO)

Schematic large scale features of the life cycle from top to bottom
Typical Variables Used for MJO Analysis

- Cloudy
  - Low OLR
- Clear
  - High OLR
- Rainfall
- U200
- U850
Schematic depiction of the large-scale wind structure of the MJO.
Intraseasonal Time Scale: ~40-60 days

Planetary-Scale: Zonal Wavenumbers 1-3

Convection has multi-scale structure

Tendency to be Equatorially Trapped

Strong Seasonal Dependence:
NH Winter: Eastward Propagation
NH Summer: ~Northeast Propagation

Significant interannual Variability
• Northern winter MJO

• Composite rainfall maps derived from merged satellite and in-situ measurements are separated by 10 days.

• Rainfall anomalies propagate in an eastward fashion and mainly affect the Tropical eastern hemisphere.
- Northern summer MJO
- Composite rainfall maps derived from merged satellite and in-situ measurements are separated by 10 days.
- Rainfall anomalies propagate in a northeast fashion and mainly affect the Tropical eastern hemisphere.
• The MJO undergoes a strong seasonal cycle in both its strength and latitudinal locations.
• Its primary peak season is austral summer/fall when the strongest MJO signals are immediately south of the equator; the second peak season is boreal summer when its strongest signals are north of the equator.
• The synoptic scale disturbances move westward while the large scale convection in which they are embedded move eastward as MJO.
Westward moving synoptic signals

(a) zonal wind at 850 hPa

(b) precipitation

Eastward moving MJO

Longitude averaged over 10N–10S Longitude
• Over the Indian region, the 10-20 day mode is associated with westward propagations and 30-50 day mode with northward propagations.

• We have seen that the onset phase comprises northward propagation of the TCZ from the equatorial Indian Ocean onto the monsoon zone and westward propagation of systems from the Bay across the monsoon zone.
We have also seen that revival from breaks occurs either by westward propagations of the systems from the Bay (which can often be attributed to westward propagations of systems from the West Pacific), or by northward propagation of the equatorial TCZ.

Thus both modes are important components of the monsoon and its variability.
Interannual variation

India

Australia

79

88

96
Mechanisms of intraseasonal variation

• Major features: A: Fluctuations between active spells and weak spells/breaks
• B: Northward propagation of the TCZ at intervals of 2-6 weeks
• An in-depth discussion of the mechanisms believed to be responsible for these features, requires a detailed exposition of the model studies which is beyond the scope of these lectures.
• Here, I shall only elucidate the processes believed to be important. However, references to the large number of reviews are also provided.
Occurrence of active-weak cycles is found to be a ubiquitous feature of the TCZ, although the time scales vary in different regions. For example, active spells tend to be of shorter duration over the African region (10°E) than the Indian monsoon zone during the northern hemispheric summer (Gadgil and Srinivasan 1990).
Variation of OLR for the region 90°E (01DEC-28FEB)

- 2012
- 2011
- 2010
- 2009

Legend:

160 180 200
DJF
70°W
Over the Indian longitudes, there are two favourable locations for the TCZ, one over the Indian monsoon zone and the other over the warm waters of the equatorial Indian Ocean. Northward propagations of the TCZ from the equatorial Indian ocean to the Indian monsoon zone occur at intervals of 2 to 6 weeks with a dominant time-scale of about 40 days.
• Gadgil & Srinivasan (1990) showed that bimodality (existence of two favourable zones) is a special feature of the Asian summer and winter monsoon regimes. While poleward propagations of the TCZ are occasionally seen over other regions, they appear to be a basic feature of the TCZ variation only over the Asian summer monsoon zone.
Thus we expect the mechanisms leading to active-weak cycles to be related to the intrinsic features/dynamics of the TCZ such as cloud-radiation feedbacks. On the other hand, special features of the Asian monsoon zone are likely to be important in poleward propagations of the TCZ.
Fluctuations of the TCZ

We have seen that deep clouds owe their existence to the presence of vertical moist instability/CAPE. Initially the presence of clouds will lead to intensification of the organized convection leading to an active phase. However, CAPE gets depleted in active phases because of the mid-tropospheric heating by the clouds and surface cooling because of rainfall and less radiation reaching the surface.
Thus there is a negative feedback between the organized convection and vertical stability which leads to the weakening and eventual demise of the system. Once the system disappears, CAPE builds up (recharge) and convection can be triggered if the dynamical conditions are favourable.
• Fluctuations in the intensity of the TCZ have been attributed to such feedbacks of the dynamical-thermodynamical system characterizing the TCZ. Sikka and Gadgil (1980) suggest the following “In a simplified form the action of the clouds may be represented as follows: Initially when the ITCZ is getting established near the radiative source, we expect a positive
feedback from clouds because the latent heat released in the clouds leads to the intensification of the ITCZ by CISK (Charney and Eliassen, 1964). However, over long time scales, the negative effect of increased albedo dominates the positive effects of increased absorption of longwave radiation and a negative anomaly of the radiative heat flux will appear.”
As suggested by Monin (1972, p. 112) as a result of this negative anomaly- -”The surface of the ocean (in our case of the moist continent) will cool and begin to cool the atmosphere; downward motions will develop in the atmosphere and the clouds will begin to disappear. With a decreased amount of clouds the ocean (again, land in our case) will undergo an increased warming, the conditions with which we began will be established and the whole process repeated.” Such a process could lead to fluctuations between active and weak spells in the monsoon.
• Krishnamurthy and Bhalme (1976) attribute the prominent 10-15 day periodicity they found in the fluctuations of all the components of the monsoon system they studied, including rainfall, to the mid-tropospheric warming associated with clouds.

• Thus, it appears that the fluctuations of the TCZ and (hence) the monsoon could arise from feedbacks involving clouds.
The first observational experiment over the Indian seas under the Indian Climate Research Programme (ICRP) was BOBMEX, conducted during July-August 1999 (Bhat et al. 2001). During BOBMEX, high-resolution measurements of the vertical profiles of temperature and humidity, from which reasonable estimates of CAPE/vertical moist stability could be obtained, were made over the north Bay.
The composite profiles of temperature and specific humidity for active and weak phases of convection over the Bay from these observations (are consistent with the theory that vertical moist instability/CAPE builds up in the weak phases and gets depleted in active phases.)
A surprising observation was the short time required for recovery from the low values characterizing active spells. It was found that CAPE decreased by 2-3 kJkg$^{-1}$ during convective episodes but recovered in 1-2 days. The quick recovery of CAPE suggests that the thermodynamic conditions become favourable for convection within 2 days of its cessation. After that, dynamical conditions determine when the next active spell commence.
• Stephens et al. (2004) consider the intraseasonal oscillation (over the tropical oceans) to comprise three phases, i.e.

• (i) destabilization phase in which the instability of the atmosphere builds up through radiative cooling of the upper atmosphere, surface warming and development of shallow boundary layer cumulus clouds,
• (ii) convection phase with heavy precipitation, cooling of the surface and moistening of the upper troposphere, in which the instability decreases rapidly, and

• (iii) the restoring phase in which strong winds keep the surface cool and high clouds associated with high humidity stabilize the atmosphere. Webster et al. (2002) report observation of these three phases during JASMINE.
The analysis of observations by Kempball-Cook and Weare (2001) has shown that after the passage of a Madden-Julian Oscillation, mid-level moist static energy builds up with a drying of the mid-troposphere (‘charging’) and this energy is consumed during the passage of a Madden-Julian Oscillation (the discharge).
Northward Propagations

- Northward propagations of cloud bands during April-October emanate from the equatorial Indian Ocean, culminate in the monsoon zone or the head Bay and are characterized with speeds of about 1° per day.

- At the culmination of each propagation the TCZ persists over the monsoon zone for several days (next slide). Thus there is an active phase of the monsoon at the end of each poleward propagation, in which the TCZ fluctuates over the monsoon zone (around 20°N).
Variation of the cloud-bands along $70^0, 80^0, 90^0E$ during June-September 1975

Note that the northward propagations are coherent across $70^0-90^0E$
- A class of zonally symmetric models, with one continental cap north of 18°N, of increasing complexity has yielded increasingly realistic simulations of the intraseasonal variation of the TCZ over the Indian longitudes during the summer monsoon.

- The first model to simulate poleward propagations of the TCZ was the simple, two-level, zonally symmetric climate model developed by Webster & Chou (1980a, b).
Variation of the TCZ simulated in the model by Webster and Chou (1980)
• However, the simulated propagations were restricted to the region over the continent (whereas the observed propagations are across the equatorial ocean and the continent), and were far more frequent than observed.

• Gadgil & Srinivasan (1990) and Srinivasan et al. (1993) modified the model to incorporate thermal inertia of land and a realistic SST distribution and simulated more realistic propagations across ocean and continent.
• In all these simulations, at the culmination of each propagation, the TCZ over the continent disappeared and another propagation commenced. Thus the active phase of the monsoon at the end of each poleward propagation, in which the TCZ fluctuates over the monsoon zone (around 20°N), was not simulated.

• A realistic simulation of all the important features was obtained by the model developed by Nanjundiah et al. (1992).
Webster (1983) had suggested that hydrological feedbacks leading to cooling of the land surface beneath the TCZ i.e. to a perturbation in sensible heat flux, played an important role in poleward propagations.

Obviously, mechanisms based on hydrological feedbacks cannot explain the propagations over the ocean.
The mechanism of propagation over land and ocean was identified by Gadgil & Srinivasan (1990) and Srinivasan et al (1993).

They showed that northward propagations occurred because of the north-south differential in total heating arising from the north-south gradient in the convective stability and moisture availability which led to the maximum of convective heating being northward of the maximum in the profile of vertical ascent.
• That this mechanism was responsible for the propagations in the model was shown with an experiment in which the convective heating in the model was taken to be independent of the north-south gradient in the convective stability and moisture availability. In that situation, the propagations in the model disappeared completely (next slide).
The same mechanism was shown to operate for the propagations simulated in the model of Nanjundiah et al (1992). The simulation of the active phase with TCZ persisting over the continent at the culmination of the poleward propagation by Nanjundiah et al (1992) was found to be associated with anchoring of the TCZ in the surface trough.
Lau and Lau (1990) studied vorticity disturbances over Bay of Bengal, Philippine Sea and South China Sea. They tried to understand the northward movement in terms of rotation of the horizontal vorticity vector by the equatorward gradient of vertical velocity. They assumed a constant easterly vertical shear. This gives rise to a horizontal vorticity vector.
About the centre of convection, if the upward velocity is higher southward, then it results in ‘lifting’ of the vorticity vector, resulting in a vertical component of vorticity north of the centre of convection. This vertical component of vorticity results in low level convergence north of the convection centre causing convection there and the convection centre moves northwards. The opposite effect occurs to the south of the convection centre and prevents a southward movement.
Different hypotheses for the mechanisms responsible for meridional propagations of cloud systems/TCZ have been reviewed by Goswami (2005) and Nanjundiah and Krishnamurti (2007).
Scale selection and prediction of ISO

- The theories proposed for scale selection and propagating ISOs have been reviewed by Goswami (2005) and Nanjundiah and Krishnamurti (2007). It has been shown that convective coupled wave dynamics involving a Kelvin and Rossby wave can give rise to an intraseasonal oscillation with a time-scale of 30-50 days (Lau and Peng 1990, Wang and Xie 1997).
• Krishnamurti et al. (2003) have shown that interaction of the MJO time scales (characterizing the SST fluctuation) with tropical disturbances arising out of instabilities around the synoptic time scales in the constant-flux and boundary layers leads to a large amplification at the MJO time scales.
Using continuous space-time wavelets, Shanker and Nanjundiah (2004) have shown that the dominant spatial scale related to these latitudinal variations is about 30 degrees and the associated temporal scale is about 30-40 days. Many hypotheses have been proposed for the mechanism of the poleward propagations (for a detailed discussion of these theories see: Gadgil (2003), Goswami (2005), Waliser (2006)).
References

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