

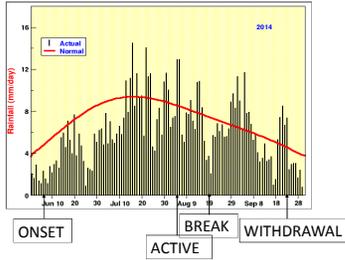


The life cycle of a monsoon season viewed from TRMM, GPM, CLOUDSAT and Reanalysis data sets

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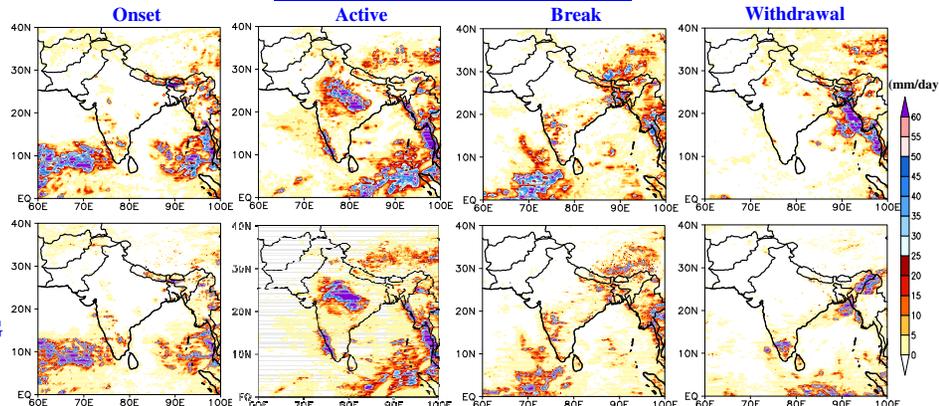
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INTRODUCTION:



- This study illustrates clouds, precipitation, surface energy balance, evolution of moist static energy, transitions of soil moisture, moisture fluxes and the energy exchanges between the rotational and the divergent kinetic energy during the life cycle of a monsoon season. The features in a life cycle include onset, active, break, revival and the withdrawal phases of the monsoon. The TRMM, GPM, CLOUDSAT data sets along with the reanalysis products examine typical features during these phases.
- The box (20-27.5 °N and 75-82.5 °E) over central India is chosen for earth radiation budget analysis.

PHASES OF THE MONSOON

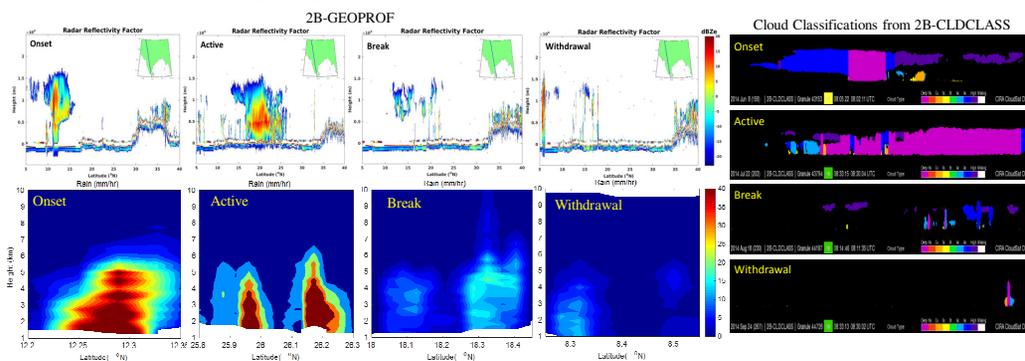


TRMM

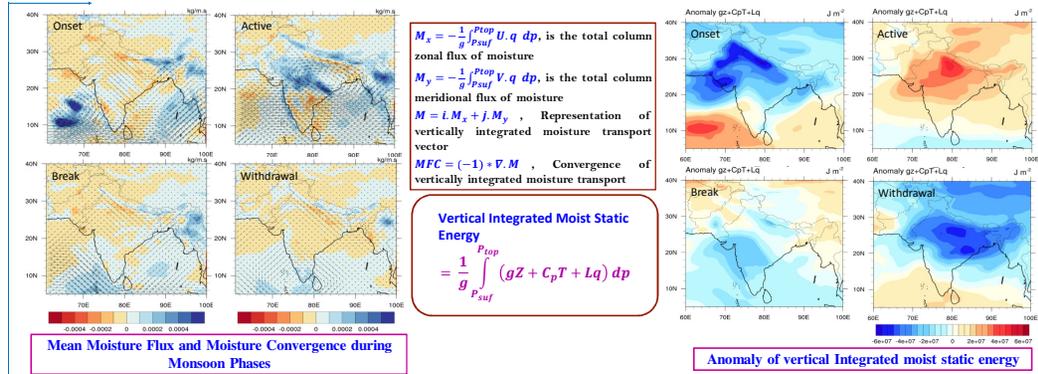
GPM/IMERG

- The TRMM and GPM based rains (mm/day), for individual days, during the monsoon phases for 2014 are quite similar.

CLOUDSAT AND TRMM 2A25 RADAR VIEWS



- The CLOUDSAT (2B-GEOPROF and 2B-CLDCLASS) and TRMM 2A25 radar show deep overshooting cumulonimbus reaching almost 16km (tropopause) during the onset phase. During the active phase the nimbostratus and cumulonimbus are dominant. During the break phase weak nimbostratus clouds are still present. The withdrawal phase with drier air from the north-west, lifts the melting layer and still some shallow upper tropospheric convection abounds.



Mean Moisture Flux and Moisture Convergence during Monsoon Phases

Anomaly of vertical integrated moist static energy

Psi-Chi Interaction

The salient terms for the energy exchange from the divergent kinetic energy into rotational kinetic energy is expressed by,

$$\frac{d}{dt} K_\psi = \left[f \nabla \psi \cdot \nabla \chi + \zeta \nabla \psi \cdot \nabla \chi + \nabla^2 \chi \cdot \frac{(\nabla \psi)^2}{2} + \frac{\omega f (\psi \cdot \frac{\partial \chi}{\partial p})}{g} + F_\psi \right] \quad (1)$$

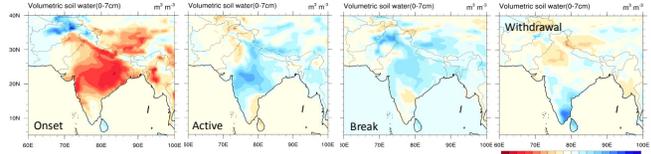
The terms in Eq (1) called the Psi-Chi interaction terms. They are responsible for transferring thermally driven meridional circulation to monsoon eddy.

- According to Krishnamurti and Ramanathan (1982) first two terms are the largest in magnitude.
- Term1 = $f \nabla \psi \cdot \nabla \chi$ and
- Term2 = $\zeta \nabla \psi \cdot \nabla \chi$ where $\zeta = \nabla^2 \psi$.
- $\nabla \psi$ & $\nabla \chi$ measure the gradient of the stream function and velocity potential, their mutual orientation is important.

Mean ($f + \zeta$)($\nabla \psi \cdot \nabla \chi$) from the Psi-Chi interaction

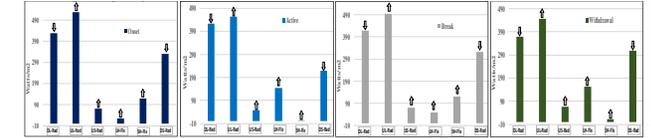
Mean angle between $\nabla \psi$ & $\nabla \chi$ from the Psi-Chi interaction

Transition of Soil Moisture:



- The soil moisture shows a spectacular change from the onset to the active phase.
- The break phase, that follows an active phase, does not exhibit a dryness as high as the onset stage because of the high retention of moisture in the soil.
- The model based surface energy balance during the transitions of the monsoon phases largely reflected the importance of clouds and soil moisture.
- The surface latent heat fluxes increased to values above 100 watts/m² and remained large during the active and even the withdrawal phases, those values were much smaller during the break phase but not as small as in the pre-onset phase. As to be expected the downward short wave radiation was largest during the onset and the break phases.

Earth radiation budget over central India:



CONCLUSIONS:

- Through TRMM, GPM, CLOUDSAT observations and reanalysis products we found that during Monsoon phase transitions deep cumulonimbus clouds prevail whereas in the active monsoon phase the nimbostratus provides the steady heavy rains.
- The reanalysis products and modeling confirms the role of soil moisture and clouds modulating the surface energy balance during phase transitions.
- The large built up of positive values of moist static energy anomaly over most of India indicates monsoonal links to regions outside south Asia.
- The evolution of the exchange of energy from (or to the) the divergent to the rotational kinetic energy has a role in the strengthening (or weakening) of the monsoon circulation.

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