Characteristics of Tropical Convection in the Indian Monsoon System

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Objective

To characterize the vertical velocity field in tropical convection in the Indian monsoon system using Indian MST Radar. Characterization of storms include the number of cores, life time or size of the core (in terms of overpass time), convection core height, magnitude of vertical air motion, and shape of the cores, in each category for both updraft and downdraft cores.

Database and Methodology

The MST radar data during the passage of 60 convective storms chosen from 11 years of observations. Various stages of convection such as shallow, deep and decaying convection are discerned from MST radar time-intensity plots of vertical air velocity. The convective core is defined as the region in which contiguous measurements of vertical velocity should exceed. 1 (≤ -1) ms^{-1} for updraft and downdraft core respectively.

Shallow convection - the core top confines to less than 6 km. Deep and Decay convection - the cores extend to higher altitudes sometimes penetrates the tropopause (typically ~17 km at Gadanki). In deep convection, acceleration of the air motion should exist above the freezing level, and in the transition region, subsidence or up- and down-draft couplet should be present

Figure (1a) depicts the classical conceptual model of MCS structure: active convection (2215-2255 LT) with intense updrafts with amplitudes in excess of 6 m s-1, transition region (2255-2315 LT) with predominant downdrafts for most part of the troposphere, and trailing stratiform rain (after 2315 LT) with gentle up-down draft couplet. The lower tropospheric (below 5 km) downdrafts observed in the later part of convection and in the stratiform regions are the result of evaporation and melting of raindrops below the freezing level (= 4.85 km).

A deep updraft core flanked by a downdraft core can be seen during 1420 – 1430 LT is shown in figure (1b). A shallow updraft core is also apparent in the figure at around 1415 LT. Lagging behind the deep convection are a group of two shallow updraft cores (1455-1510 LT) and a shallow updraft core at 1545 LT. The intensity of the drafts is about 6 m s^{-1} in all the cores.

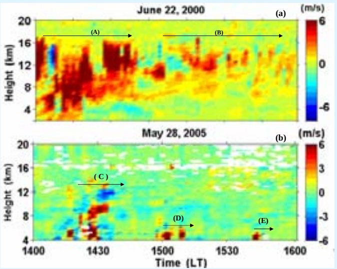

Figure 1: Height time intensity plots of vertical velocity on (a) 22 June2000, (b) 28 May 2005 illustrating different types of convection. 'A', 'C', indicates deep ,'D','E', indicates shallow, and 'B' indicates the decay stages of convection, respectively.

Magnitude of cores

Warm rain processes dominate the shallow convection, therefore, the maximum magnitude is also seen below the freezing level in figure 2(a).

In deep convection (figure 2b) descent is seen in the lower troposphere and ascent is seen in the middle and upper troposphere. The descent in the lower troposphere could be due to rain evaporation and precipitation loading. The ascent in the upper troposphere could be due to the latent heat release during glaciation & vapor deposition.

The vertical velocity in the decay system (figure2c) does not show any skewness and updrafts and downdrafts are seen equally at most of the heights. Among the three types, the distribution is much narrower in decaying convection. The magnitude of the vertical air motion is found to be larger in deep convective systems than in other categories.

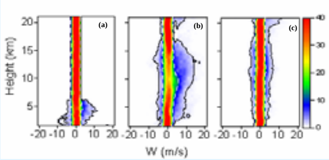

Figure 2: CFAD for vertical air motions corresponding to (a) shallow, (b) deep and (c) decay stages of convection, with 90 (dashed line) and 99 (solid line) percentile lines embedded on it.

Composite w of cores

The distribution of vertical air motion in the shallow convection (figure 3a) is skewed towards negative (positive) velocity side in the lower few km (above 2.5 km) of the troposphere. The magnitude of the up- (down-) draft is reaching as high as 12 (10) m s-1 at around 4 (2) km. The average *w* profile shows downward (upward) motion of the order 0.5 (0.9) m s-1 at 1.8 (4.5) km.

The mean of the vertical air motion distribution for deep convection (figure 3b) shows descent in the lower troposphere (below 3 km) and ascent in the middle and upper troposphere. The composite profile shows a single ascent peak in the middle troposphere (~10 km) similar to that observed in the western Pacific. In contrast, the composite profiles in GATE and DUNDEE campaigns show a double-peaked structure with the low-level peak at around 2-3 km and the upper peak at around 8 km.

Among the three convection categories, the distribution is much narrower in decaying convection. The mode of vertical velocity distribution in decaying convection (figure 3c) doesn't show any noticeable skew ness, rather the distribution show both up- and down- drafts nearly equally at most of the altitudes. The maximum strength of the vertical air motion (in both up- and down- draft cores) in the decaying category is found to be about 5 m s^{-1}.

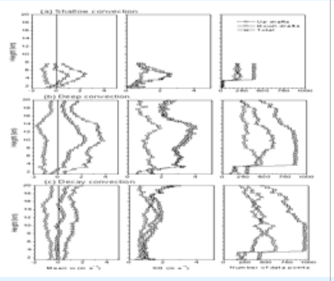

Figure 3. The mean of the vertical velocity distribution, standard deviation (SD) and the number of valid data points.

Size of core

The shallow cores (figure 4a) is short lived with 85% of the cores have an overpass time of less than 10 minutes. The median overpass time for downdraft cores (7 min) is slightly more than that of updraft cores (4 min). The updraft cores in the deep convection (figure 4b) seem to have a wide range of lifetimes (rather overpass time); a few of them are short-lived, while many of the systems have an overpass time longer than 10-15min. . The downdraft cores are found to be relatively short lived with a major fraction of the cores have an overpass period less than 10 min.

The overpass duration for updraft cores in decaying convection (figure 4c) is relatively moderate (~10-15 min).

The size of updraft cores have shown increasing trend with height, at least up to the middle troposphere (measurements are limited in height in MR99, and Lemone and Zipser 1980), at all the locations. The core size of downdraft cores is smaller than updraft cores at all the locations, and most importantly, the size of updraft and downdraft cores over Gadanki is bigger than those observed over Darwin and in GATE campaign.

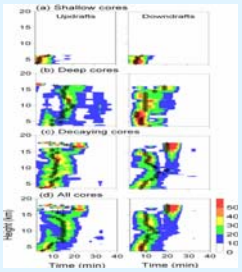

Figure 4.The CFADs for duration of the core is plotted separately for up- and down- draft cores corresponding to the shallow, deep and decaying categories.

Shape of core

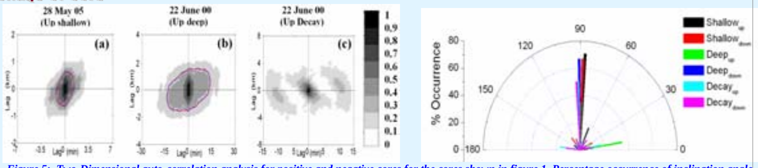

Figure 5: Two-Dimensional auto-correlation analysis for positive and negative cores for the cores shown in figure 1. Percentage occurrence of inclination angle of the cores for shallow, deep and decay stages of convection.

The 2D autocorrelation plot for updraft cores in shallow convection on 28 May 2005 (figure 5a), shows an erect and narrow structure, which is short lived. The core is limited in height as well as in time exemplifying the shallowness of the system About 70% of both up- and down-draft cores show slopes close to 90º.

The deep updraft core on 22 June 2000 (figure 5b), depicts an erect structure within a tilted structure, The deep-downdraft cores (not shown as a separate figure have shown an erect structure. During deep convection, the vertical updraft cores exhibit variety of structures, from very low inclination (0-20º) (35%) to somewhat inclined (30%) to erect (35%), while 70% of downdraft cores show slopes close to 90º.

The cores in the decaying category on 22 June 2000 (figure5c) resulted a peculiar structure, as shown. It shows, the cell splits into three distinguished cells, perhaps due to the presence of strong up and down draft couplet in the decaying convection. In decaying convection, 50% of up- and down- draft cores exhibit erect structures and considerable percentage (16% for updraft cores and 9% for downdraft cores) of cores shows very low inclination angles (0-20 º)

Height of core

In shallow convection (figure 6a), 70% of the storm tops (both updraft and downdraft) are just below 6 km. Warm rain processes occur in the shallow convection. Therefore, the core-tops in this category remained below 6.5 km.

In deep convection (figure 6b), the updraft core has a broad peak around 7-8 km, while the downdraft core has a bimodal distribution: one peak at 4-6 km and another at 7-8 km.The peak in core-top distribution around 5 km may be associated with the subsidence induced by the melting and evaporation of rain and drop loading at and below the freezing level. It is interesting to note that 3% of updraft core-tops reached the lower stratosphere (above 17 km).

The core-top characteristics of decaying convection (figure 6c) are similar to that of deep convection, except for the height of the broad peak. The peak in the updraft core-top distribution in the decaying convection is seen at a slightly higher altitude than in deep category.

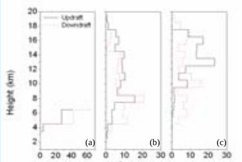

Figure 6: Percentage occurrence of core top for (a) shallow, (b) deep, and (c) decay stages of convection.

Identification of Wet and Dry spells

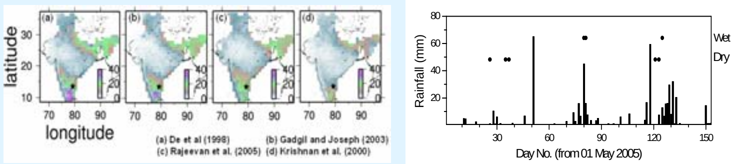

Figure 7: (a) Spatial distribution of rainfall fraction (in %) in all India break periods, (b) Day to day variation of accumulated rainfall during the period 01 May – 30 September 2005. The symbols on the figure represents the days in which convection occurred. The convective systems in wet and dry spells are shown separately.

Figure 7a shows the spatial distribution of rainfall fraction (in %) in break periods defined by De et al. (1998), Gadgil and Joseph (2003), Rajeevan et al. (2006) and Krishnan et al. (2000).Rb is very small in the entire central and north India in addition to the west coast of south India. Rainfall fraction increases, primarily, in two regions: southeast peninsular and northeast India. The Rb is about 20-40% depending on the region with larger values in the southern part of the southeastern peninsular region). The period is termed as active (or wet) if the rain is seen nearly continuously on all days during the period. Any convective event occurred during that period is considered as associated with wet spell. If convection occurs only on a particular day in a period of mostly dry weather (no rainfall), then the convection event is treated as associated with the break (dry) spell.

Magnitude of W in wet & dry spell

The distribution of *w* corresponding to shallow cores (figure 8a) in both monsoon regimes (dry and wet) shows weak to moderate velocities with about 75% of *w* are between ± 2 m s-1. The distribution is slightly wider in the dry spell than in wet spell with stronger updrafts predominantly seen only in the dry spell. The composite *w* for wet spell is weaker than that for dry spell.

The distribution is wider in the lower troposphere and upper troposphere for dry spell, while it is wider only in the upper troposphere and lower stratosphere for wet spell during deep convection (figure 8b). In both the spells, intense updrafts of the order of 10-12 ms-1 are seen, while the downdraft magnitudes are relatively smaller. The composite *w* for wet spell is nearly zero up to an altitude of 5 km, increases to ~3 m s-1 in the height region 10-14 km and then decreases to < 1 m s-1 above 18 km. The composite *w* for the dry spell, on the other hand, shows descending motion below 3 km and ascending motion above it.

The *w* distribution for decaying convection (figure 8c) in both the monsoon regimes is narrower in comparison with that of for shallow and deep convection categories. The drafts are weaker in decaying convection than in other two categories, with *w* values lying mostly within -4 to 6 ms-1. The *w* distribution for dry spell is narrower than that for wet spell.

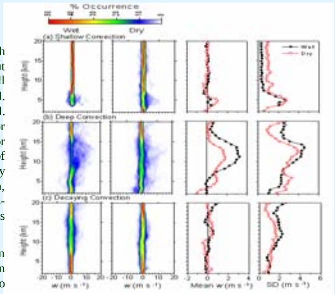

Figure 8: The Contour Frequency by Altitude Diagrams (CFAD) for w corresponding to (a) shallow convection, (b) deep convection, and (c) decaying convection, in wet and dry spells. Corresponding composite w and their standard deviation profiles as a function of altitude are also shown in the figure (right panels).

Composite W in wet & dry spell

The composite *w* profiles in figure 9 show weaker velocities up to an altitude of 7 km and strong ascending motion above it. All the composite *w* profiles show peak values in the upper troposphere (at around 13 km).

Interestingly, many of the composite profiles for dry spell not only show the bimodal distribution, but also the location of the peaks in the distribution are strikingly similar. All dry composites show downward motion below 3.5 km, consistent with the composite of all events in the dry spell.

The magnitude and the variability of the descending motion are also large, varying by 2 m s-1. Contrastingly, the composites in the wet spell do not show any preferential direction of motion in the lower troposphere. The composites are weaker in dry spell above 15 km, where as wet composites show considerable values of *w* up to an altitude of 20 km. Further, large (small) variability is seen between composite *w* profiles for wet (dry) spell above 17 km.

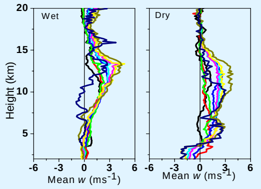

Figure 9: Vertical variation of composite w for deep cores in wet and dry spells. Each profile is a composite of one convection event.

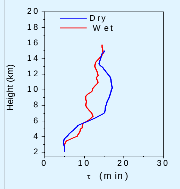

Figure10:Altitude variation of the median overpass duration of the cores (t) in wet and dry spells.

It is apparent from figure 10 that the overpass time generally, increases with altitude in both wet and dry spells. In the middle and upper troposphere (between 7 and 14 km), the t is larger for the cores in the dry spell. Below 4 km, the median core-size is small (1.5-2 km) and is nearly equal (within 500 m) in both the monsoon spells. The median core size, however, increases by a factor of 2 in the middle and upper troposphere and also varies considerably from dry spell to wet spell. The median core size in dry spell (5-6.5 km) is about 1-2 km larger than that in the wet spell (4-5 km) in the middle troposphere (6-12 km).

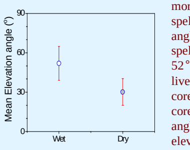

Figure 11: Mean elevation angle for deep updraft cores in dry and wet spells.

The cores in dry spell are more inclined than in wet spell. The mean elevation angles of cores in dry and wet spells are 30°±32° and 52°±39°, respectively. Long-lived convection (or bigger cores), generally, produces cores with small elevation angles. The observed smaller elevation angles in the dry spell are, therefore, consistent with the size of the cores (bigger) seen in the dry spell

Height of core in wet & dry spell

The peak in the distribution for updraft cores in dry phase is at a slightly lower (by 1-2 km) altitude than that in the wet phase as shown in figure 12. The percentage occurrence in both phases, generally, increases with altitude and the maximum occurrence of core-top altitude is found in the upper troposphere.

More than 15% of cores reached the lower stratosphere (above 17 km) in the wet phase of the monsoon. The occurrence of the cores above the tropopause in dry phase is relatively less (8%)

The core-top height distribution for updraft cores in the decaying convection is similar to that of in deep convection, with cores in the wet spell reaching greater heights than in dry spell. Downdraft core-top distribution for decaying category is however flat with no clear-cut peaks (except for the upper tropospheric peak in the wet spell) in both phases of the monsoon. .

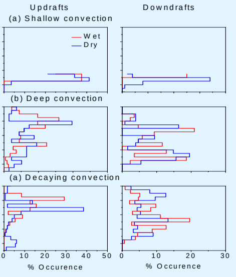

Figure 12: Percentage occurrence of convection height in wet and dry phases of monsoon corresponding to (a) shallow, (b) deep and (c) decay stages of convection.

Summary and Conclusions

- **Negative cores are ubiquitous in all types of convection over Gadanki. They exist at all heights neighboring updraft cores. They show more coherence than the updraft cores.**
- **Shallow convection: Cores are short lived and mostly erect in nature. vertical velocity and core top height distribution show peak values just below the freezing level.**
- **Deep convection: Cores are long lived and considerable percentage of storms are inclined. Vertical velocity and core top height distributions show peak values in the upper troposphere. Nearly 3% of the convective cores crossed the tropopause. Low level descent and high level ascent is observed.**
- **Decaying convection: Cores are long lived, mostly erect, more downdraft cores, mean vertical air motion show wavy structure, upper tropospheric peak in core top height distribution. The draught distribution is narrower than the shallow and deep convection.**
- **The vertical air motion is larger in wet phase than in dry phase. The composite *w* profile shows single and bimodal distribution in wet and dry spells respectively.**
- **The core top height distribution shows that the cores reach higher altitude in wet phase. The results clearly shows that the storms are more intense in wet phase than in dry phase of the Indian monsoon.**