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Identification of convective/stratiform dominance over surface rainfall

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सार – इस शोध पत्र में भारत के कुछ चुनिंदा स्टेशनों तथा भूमंडल के कुछ अन्य स्थानों पर होने वाली धरातलीय वर्षा को प्रभावित करने वाले स्तरण/संवहनीय प्राबल्य की विशेषताओं का पता लगाने के लिए ऊपरितन वायु मौसम विज्ञानिक तत्वों जैसे:- मेघ द्रव जल (सी एल डब्ल्यू), वर्षा जल (पी डब्ल्यू) और गुप्त ऊष्मा (एल टी), का धरातल से 18 कि.मी. तक की ऊँचाई तक रिकार्ड किए गए डेटा, का विश्लेषण किया गया है। इस अध्ययन के लिए उपयोग में लिए गए आँकड़े हैं - मेघ द्रव जल, वर्षा जल, गुप्त ऊष्मार वर्ष 1999-2002, 2007 एवं 2008 की अवधि में ऊष्णंकटिबंधीय वर्षा मापन मिशन उपग्रह (टी आर एम एम) माइक्रोवेव इमेजर (टी एम आई) 2 A 12 डेटा उत्पाद से प्राप्त किए गए वर्षा आँकड़े, उष्णकटिबंधीय वर्षा मापन मिशन उपग्रह में लगाए गए 2 A 23 वर्षा रेडार (पी आर) से वर्ष 1999-2002 की अवधि में प्राप्त किए गए ब्राइट बैंड हाईट और हिमांक स्तर की ऊँचाई। इसमें वर्षा जल, गुप्त ऊष्मा और मेघ द्रव जल के उर्ध्वाधर प्रोफाइलों को दर्शाया गया है। इसमें दो नए प्राचलों अधिकतम मेघ द्रव जल की ऊँचाई (एच पी सी एल) और एच पी सी एल पर वर्षा जल को शामिल किया गया है। एच पी सी एल को ऊँचाई के रूप में परिभाषित किया गया है जिसमें मेघ द्रव जल इसकी ऊँचाई को दर्शाता है। ऐसा पाया गया है कि उर्ध्वाधर स्तंभ में गुप्त ऊष्मा का अवशोषण एवं निकास, एच पी सी एल पर वर्षा जल का मान तथा गुप्त ऊष्मा अवशोषण शीर्ष के स्तर धरातलीय वर्षा के स्तरण/संवहनीय प्रभाविता की व्याख्या करने में सक्षम हैं।

ABSTRACT. In order to find out the characteristics of stratiform/convective dominance over surface rainfall, upper-air meteorological elements like cloud liquid water (CLW), precipitation water (PW) and latent heat (LH) have been analysed from the surface to a height of 18 km, for a few selected stations in India and a few other global locations. The data required for the study are the CLW, PW, LH and rainfall data from the data product 2A12 of the Tropical Rainfall Measuring Mission satellite (TRMM) Microwave Imager (TMI) for the period 1999-2002, 2007 and 2008; bright band height (BBH) and freezing level height (HFL) data from 2A23 of the Precipitation Radar (PR) onboard TRMM for the period 1999 - 2002. Vertical profiles of PW, LH and CLW have been presented. Two new parameters, called height of peak cloud liquid water (HPCL) and precipitation water at HPCL have been introduced. HPCL is defined as the height where CLW shows its peak. It is found that absorption and evolution of LH along the vertical column, PW values at HPCL and the level of LH absorption peak are able to explain stratiform/convective dominance over surface rainfall.

Key words – Peak cloud liquid water level, Latent heat, Convective rainfall, Stratiform rainfall.

1. Introduction

Understanding the mechanism of stratiform and convective precipitation is necessary in the context of cloud microphysics. Stratiform precipitation originates from stratiform clouds, *viz.*, nimbostratus, while convective precipitation occurs in convective clouds, *viz.*, cumulonimbus and cumulus (Tokay and Short, 1996). However, studies show that stratiform rainfall may occur in mesoscale convective systems (MCSs) (Schumacher and Houze, 2003a); and convective rainfall may be present within a stratiform precipitation also (Houze, 1993; Gregory *et al.*, 1990; Matthew *et al.*, 2000). During the development stage of a convective cloud, convective precipitation is dominant. However, when a convective cloud matures and finally decays, the stratiform precipitation replaces the convective precipitation (Shen *et al.*, 2012). A study (Schumacher and Houze, 2003b) shows that if the precipitation falls from young and active region, *i.e.*, the region of strong vertical motion, then it is called a convective precipitation, while if the precipitation falls from an old and less active convective region, *i.e.*, region of weak vertical air motion, then it is said to be a stratiform precipitation.

The convective and the stratiform precipitation are also differentiated on the basis of vertical distribution of latent heating and the growth mechanism of precipitation particles (Schumacher and Houze, 2003b). It is found that the vertical profile of latent heat (LH) is different for the two types of precipitation (Steiner and James, 1998). A stratiform precipitation is found to cool the lower troposphere and heat the upper troposphere, while in case of a convective ppt, heat is distributed throughout the troposphere (Schumacher and Houze, 2003b). The peak of the latent heat profile in a stratiform cloud occurs in the upper part of the cloud, while in case of the convective cloud, it occurs in the lower part of the cloud (Tokay and Short, 1996). In a convective cloud, the rain drops grow basically by accretion, while in stratiform precipitation, the drops grow by condensation/deposition (Houze, 1997).

A convective precipitation consists of a larger number of small to medium sized drops as compared to the drops in case of stratiform precipitation at the same rainfall rate (Tokay and Short, 1996). The rainfall intensity from a stratiform cloud is also less as compared to a convective precipitation (Emmanouil, 2004; Shen *et al.*, 2012). Stratiform rain is characterized by weak updraft in the lower troposphere, and moderate updraft in the middle and upper troposphere, while the convective rain is associated with strong updraft throughout the troposphere (Houze, 1997). Horizontal reflectivity gradient is stronger in convective rain than in stratiform rain. Stratiform precipitation is found to be associated with a prominent bright band structure below the freezing level when snowflakes start melting (Battan, 1973; Houze, 1993). In the case of convective precipitation, the bright band structure is missing because of large scale mixing of different particles (Battan, 1973). Because of strong updraft, the hydrometeors in a convective cloud are carried upward and they continue to grow until they become heavy enough to continue being carried upward, after which they fall down as precipitation (Tokay and Short, 1996).

Studies show that convective clouds associated with thunderstorms may reach a height above 10 km (Battan, 1973). A study shows that if the presence of a bright band is associated with turbulence above the melting level, then it is a mixed stratiform/convective case; otherwise it is stratiform precipitation (Rao *et al.*, 2008). On the other hand, if there is no bright band and hydrometeors are not found above the melting level, then it is a case of shallow convection, while the presence of hydrometeors above the melting level when no bright band is present, is a case of deep convective precipitation (Rao *et al.*, 2008).

The convective and stratiform discrimination scheme of the TRMM is based on the differences of brightness temperature depending upon the polarization status of the channels used in TMI (Olson *et al.*, 2001). The difference in brightness temperature between the horizontally and vertically polarized 85.5 GHz channels is found to be of the order of 5 k or greater in stratiform rainfall. In convective rainfall, however no such differences were found out with respect to the polarization state.

Another way of stratiform- convective precipitation demarcation in the TRMM data is based on the horizontal variations of liquid phase and ice phase precipitation (Churchill and Houze, 1984). A stratiform precipitation is associated with a relatively weak and uniform horizontal updrafts and downdrafts. It shows uniform horizontal distribution of precipitation. A convective precipitation, on the other hand, is characterized by a greater horizontal gradient of precipitation and strong and non uniform updrafts and downdrafts.

Convective clouds have been reported to have more liquid water than that in stratiform clouds (Taylor and Ghan, 1992). The existence of a large number of super-cooled water drops is found in the convective cloud (Rosenfeld and Woodley, 2000).

Cloud liquid water (CLW) is the amount of liquid water per unit volume of air. It is also named as LWC or total cloud liquid water (NASA, 2011). It is expressed in g/m^3 or g/kg. CLW is of immense importance in producing rain by cloud-seeding technique. A study shows that above the freezing level, the super cooled CLW is lower. But at times, it can be fairly large, posing aviation hazards (Curry and Liu, 1991). Super-cooled water drops present in the atmosphere above the 0º C level give rise to ice deposition on the exposed surfaces of an aircraft, thereby posing a hindrance to aircraft lift. Thus, knowledge of CLW is also very important for aviation related operations. The attenuation caused by CLW in the microwave region is proportional to CLW and the frequency (Hogan *et al.*, 2005; Sarkar and Kumar, 2007). CLW over the ocean is found to be correlated with precipitation (Bhattacharya *et al.*, 2012). A study (Chakraborty and Maitra, 2012) shows that CLW exhibits seasonal variation.

It is found out that the water vapour is one of the key factors for the formation of convective clouds (Battan and

Kassander, 1960). The amount of water vapour available in the atmosphere is an important parameter as it provides information about the latent heat released and absorbed at different levels, and it also provides insight into the condensation processes. Moreover, water absorbs both long-wave and short-wave radiations. Thus, in turn, it influences the albedo and the emissivity of the cloud (Taylor and Ghan, 1992), thereby contributing a major role to the radiation budget of the Earth-atmosphere system. Total precipitation water is also found to be an important component to produce rainfall (Battan and Kassander, 1960). Precipitation water (PW) (TRMM Data Users Handbook, 2001) is the actual amount of moisture that has precipitated as rain, while precipitable water is the amount of precipitation that would fall on ground if the entire water vapour in the vertical column would condense (Max, 2001). The present paper deals with the precipitation water measured by the Tropical Rainfall Measuring Mission Satellite (TRMM).

LH is well known to affect the Earth's radiation budget, and in turn, the global circulation, which governs the weather systems (Taylor and Ghan, 1992). Latent heat is that part of diabatic heating that is either released or absorbed as a result of phase change of water (Tao *et al*., 2006). Thus, CLW, LH and PW appear to be very important factors influencing cloud formation and demand careful analysis.

In this paper an attempt has been made to study the CLW, PW and LH available at different levels in the atmosphere over a few selected stations in India and a few other global locations. Efforts have been made to find out whether any correlations exist between the height of the levels and these parameters, and to find out possibility of a functional relationship between them, if any. The values of PW, LH, CLW and level height have been fitted to different models, *i.e.*, cubic, linear, quadratic, power, exponential, sigmoid curve, logarithmic, growth, inverse, logistic and compound. The validity of the relationship is judged by F test at a 5% level of significance. An *F*-test is done to identify the model that best fits the population from which the data were sampled (*F* test, 2014). The primary aim of this paper is to find out the characteristics of stratiform/convective dominance over surface rainfall, *i.e.*, the conditions under which convective/stratiform rainfall contributes more to surface rainfall. In order to characterize the above dominance, three parameters have been introduced as follows :

(*i*) The height at which the LH absorption peak occurs in a particular event,

(*ii*) Total LH along the entire profile from the surface up to 18 km and

(*iii*) PW value at the height of peak cloud liquid water (HPCL). It is found that these parameters are able to characterize the above dominance very well, except for a few cases. The authors also aim to find out which type of rain (convective/stratiform) occurs in a particular place. In addition, rainfall from stratiform and convective clouds has been obtained from the data product 2A12 onboard the TRMM over a few stations. The 2A12 provides daily convective rainfall and surface rainfall. The stratiform rainfall is obtained by subtracting the convective rainfall from the surface rainfall.

2. Data and methodology

The data required for this study are CLW, PW, LH and rainfall data from the data product 2A12 (TRMM, 1998a) of the TRMM microwave imager (TMI) onboard the Tropical Rainfall Measuring Mission satellite (TRMM) for the period 1999-2002, 2007 and 2008; bright band height (BBH) and freezing level height (HFL) data from 2A23 (TRMM, 1998a) of the Precipitation Radar (PR) onboard TRMM for the period 1999-2002 for a few selected stations of the Indian subcontinent namely, Mumbai (18.55° N, 72.54° E), Panjim (15.3° N, 73.55° E), Chennai (13.03 ° N, 80.74° E), Trivandrum (8.29° N, 76.59° E), Kakdwip (21.47° N, 87.87° E), Puri (19.48° N, 85.88° E), Karaikal (10.92° N, 79.89° E), Machilipatnam (15.98° N, 81.32° E), Mangalore (12.83° N, 74.77° E), Vishakhapatnam (17.61° N, 83.81° E) and a few other global locations, namely the East China Sea (30° N, 123° E), Mozambique (17.8° S, 38.18° E), the Pacific Ocean (17° S, 164° W), Costa Rica (9.18° N, 85.43° W), the Indian Ocean (0, 90° E) and Taiwan (25° N, 121° E). It is noteworthy that the above geo locations chosen are over the oceans closest to the stations mentioned. For example, "station Puri" implies the geo location over the ocean closest to Puri. It is noteworthy that the data product 2A23 for the years 2007 and 2008 data were not included, because 2A12 and 2A23 data for the same orbit number were not available during this period.

The TRMM Microwave Imager (TMI) onboard the TRMM satellite measures the brightness temperature (TB) of the radiation emitted by the target, *i.e.*, the hydrometeors present in the atmosphere. TRMM 2A12 algorithm is basically an ocean algorithm (Wentz and Spencer, 1998) which uses TB as input based on a relationship between TB and the outputs, *i.e.*, columnar water vapour PW, columnar cloud liquid water CLW, rainfall rate R and effective radiative temperature Tu, and estimates these outputs at 14 vertical levels starting from the Earth's surface up to a height of 18 km. Radiative transfer shows that there is a direct relationship between the brightness temperature (TB) and the atmospheric transmittance due to liquid water (TL) (Wentz and

Spencer, 1998). TL, in turn, depends on the columnar water of the rain cloud, and the effective radiative temperature Tu depends on the height from where the radiation is emitted, and whether the radiative backscattering by large ice particles is present.

In order to retrieve rainfall rate R, at first TL is retrieved. Next, from the retrieved TL at 19 and 37 GHz, the beam filling effect is estimated (Wentz and Spencer, 1998). After applying beam filling correction, the attenuation due to liquid water is estimated. Next, by using Mie theory and by using a power law relation between the attenuation and columnar rainfall rate (vertically averaged rainfall rate times columnar height), the latter is found out. Next, by dividing the columnar rainfall rate by the rain height, the vertically averaged rainfall rate, which is assumed to be the surface rainfall rate, is found out (Wentz and Spencer, 1998).

The Goddard Profiling Algorithm is used to retrieve the latent heat profile from TRMM (Olson *et al*., 1999; Olson *et al*., 2006; Yang *et al*., 2006; Tao *et al*., 2006) by using the equation

$$Q_1 = \pi\left(\frac{\partial\theta}{\partial t} + v.\nabla\theta + W\frac{\partial\theta}{\partial x}\right) \tag{1}$$

$$Q_2 = -\frac{L_v}{\mathrm{C_p}}\left(\frac{\partial q_v}{\partial t} + V.\nabla q_v + W\frac{\partial q_v}{\partial z}\right) \tag{2}$$

Where Q_1 is the apparent heat source and Q_2 is the apparent moisture sink of a large scale system. Π is the non dimensional pressure given by:

$\pi = (P / P_{00})^{R/Cp}$

where,

P is the pressure at a particular altitude,

P_{00} is the reference pressure, *i.e*., 1000 hPa,

θ is the potential temperature,

W is the vertical velocity,

V is the horizontal wind vector,

q_v is the mixing ratio of water vapor,

$\mathrm{C_p}$ is the specific heat of dry air at constant pressure,

$\mathrm{L_v}$ is the latent heat of condensation and

R is the gas constant for dry air.

Considering the contribution of cloud effects estimated by Goddard Cumulus Ensemble (GCE) model (Soong and Tao, 1980; Tao and Soong, 1986; Simpson and Tao, 1993), equations (1) and (2) can be modified to,

$$\begin{aligned} Q_1 = {} & \pi\left(-\frac{1}{\rho}\frac{\partial\rho w'\theta'}{\partial z} + D_\theta\right) + \frac{L_v}{\mathrm{C_p}}(c - e_c - e_r) + \\ & \frac{L_f}{\mathrm{C_p}}(f - m) + \frac{L_s}{C_p}(d - s) + Q_R \end{aligned} \tag{3}$$

$$\begin{aligned} Q_2 = {} & \frac{L_v}{\mathrm{C_p}}\left(-\frac{1}{\rho}\frac{\partial\rho w' qv'}{\partial z} - D_{qv}\right) + \frac{L_v}{\mathrm{C_p}}(c - e_c - e_r) + \\ & \frac{L_s}{\mathrm{C_p}}(d - s) \end{aligned} \tag{4}$$

where,

ρ is the air density,

L_f is the latent heat of fusion,

L_s is the latent heat of sublimation,

C is the rate of condensation,

e_c is the rate of evaporation of cloud droplets,

e_r is the rate of evaporation of rain droplets,

f is the rate of freezing of rain drops,

m is the rate of melting of snow and graupel/hail,

d is the rate of deposition of ice particles,

s is the rate of sublimation of ice particles,

w' is the vertical wind deviation from the horizontal mean value,

θ' is the deviation of the potential temperature from the mean value

q'_v is the deviation of mixing ratio from its mean value,

Q_R is the cooling/ heating rate associated with radiative process and

D_θ & D_{qv} are the subgrid scale turbulence terms which are negligibly small compared to other terms.

Equation (3) and (4) respectively represents cloud heating effects and cloud drying effects. First term of R.H.S of equation (3) is the vertical eddy heat convergence and the first term of R.H.S of equation (4) is the moisture field convergence. Equation (3) reduces to,

$$\begin{aligned} Q_1 - Q_R = {} & \pi\left(-\frac{1}{\rho}\frac{\partial\rho w'\theta'}{\partial z} + D_\theta\right) + \frac{L_v}{\mathrm{C_p}}(c - e_c - e_r) + \\ & \frac{L_f}{\mathrm{C_p}}(f - m) + \frac{L_s}{C_p}(d - s) \end{aligned} \tag{5}$$

$$\begin{aligned} Q_1 - Q_R = {} & \pi\left(-\frac{1}{\rho}\frac{\partial\rho w'\theta'}{\partial z} + D_\theta\right) + \frac{L_v}{\mathrm{C_p}}(c - e) + \\ & \frac{L_f}{\mathrm{C_p}}(f - m) + \frac{L_s}{C_p}(d - s) \end{aligned} \tag{6}$$

where,

$$\bar{e} = \bar{e}_c + \bar{e}_r$$

$\bar{e}_c$ is the horizontal area averaged rate of evaporation of cloud droplets,

$\bar{e}_r$ is the horizontal area averaged rate of evaporation of rain drops and

$\bar{e}$ is the horizontal area averaged rate of evaporation due to cloud droplets and rain drops.

In the cloud ensemble model, the horizontal area is one grid scale which contains several cumulus clouds and which can be considered as a subset of a large-scale system.

The values of

$$\left[\frac{L_v}{\mathrm{C_p}}(c - e) + \frac{L_f}{\mathrm{C_p}}(f - m) + \frac{L_s}{C_p}(d - s)\right]$$

are the latent heat values found out at 14 vertical levels (Tao *et al*., 2006).

The CLW, PW, LH, convective rainfall and surface rainfall values obtained from version V6 of the data product 2A12 (TRMM, 1998a) of TRMM in Hierarchical Data Format (HDF) have been converted to readable form, taking account of the surface flag. A surface flag“0” corresponds to data recorded over ocean and a surface flag “1” denotes data recorded over land, while a surface flag “2” denotes data recorded over coast. In this paper data corresponding to surface flag “0” only have been considered as 2A12 data product (TRMM, 1998a) is valid over ocean only (TRMM, 1998b). BBH and HFL values obtained from version V6 of data product 2A23 (TRMM, 1998a) of TRMM in HDF have been converted to readable form, taking account of the rain type flag (TRMM, 1998b).

The values of daily CLW, PW and LH over a particular station are noted at various levels for each rainy event as obtained from 2A12 (TRMM, 1998a). The TMI records these values at each pixel at 14 vertical levels in the atmosphere. These vertical levels are described in Table 1. It is noteworthy that the TRMM algorithm does not permit the recording of the CLW, PW and LH in non-rainy conditions (personal communication with TRMM algorithm team). In order to distinguish between convective/stratiform dominance over surface rainfall, the value of PW at HPCL is noted and compared with the daily maximum PW. It is found out that the PW at HPCL is able to characterize convective/stratiform dominance. The level at which the LH absorption peak occurs is also noted. Moreover, the total LH along the entire profile is estimated for each day over a station. It is noteworthy that the study includes only those rainfall events which have been recorded by the TRMM. Several other rainfall events have been overlooked as there were no TRMM passes at that time. Moreover, PR missed to record several BBH data. Those cases are marked as “- 9999” in 2A23 data (TRMM, 1998a).

TABLE 1

Vertical profile

14 Vertical profiling layers		14 Vertical heating levels	
Layer index	Layer height (km)	Level index	level height (km)
1	Surface - 0.5	1	0
2	0.5 - 1.0	2	1.0
3	1.0 - 1.5	3	2 .0
4	1.5 - 2.0	4	3 .0
5	2.0 - 2.5	5	4 .0
6	2.5 - 3.0	6	5 .0
7	3.0 - 3.5	7	6 .0
8	3.5 - 4.0	8	7 .0
9	4.0 - 5.0	9	8 .0
10	5.0 - 6.0	10	9 .0
11	6.0 - 8.0	11	10 .0
12	8.0 - 10.0	12	12 .0
13	10.0 - 14.0	13	14 .0
14	14.0 - 18.0	14	16 .0

3. Results and discussion

The authors have performed this study based on an assumption that CLW, PW and LH are the key factors in producing rain; and eventually, the features of convective and stratiform dominance over surface rainfall are expected to reflect in the dialogue between these parameters. Thus, at first, the authors have made an attempt to study the CLW, PW and LH at different layers (Table 1) of the atmosphere (TRMM, 1998b) starting from surface up to 18 km on each day when TRMM had recorded rainfall over the stations during 2007-2008.

3.1. *Interrelationship between CLW, PW, LH and height*

The study shows that there exists significant correlation between the altitude and CLW, PW, LH [Figs. 1 (a-c) respectively].

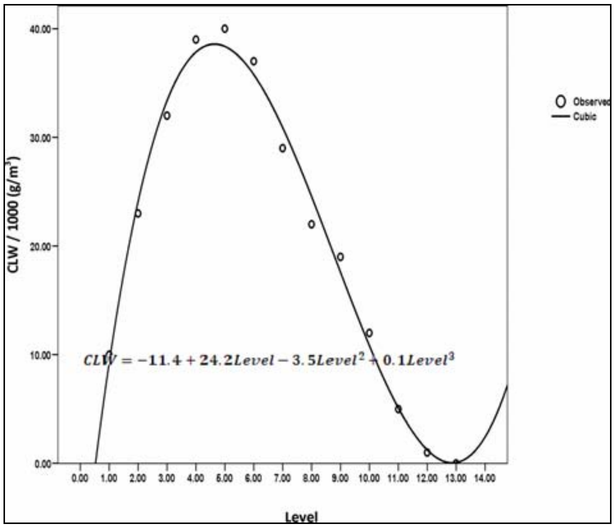

Fig. 1(a). Variation of CLW with height over Karaikal on 25 November, 2008

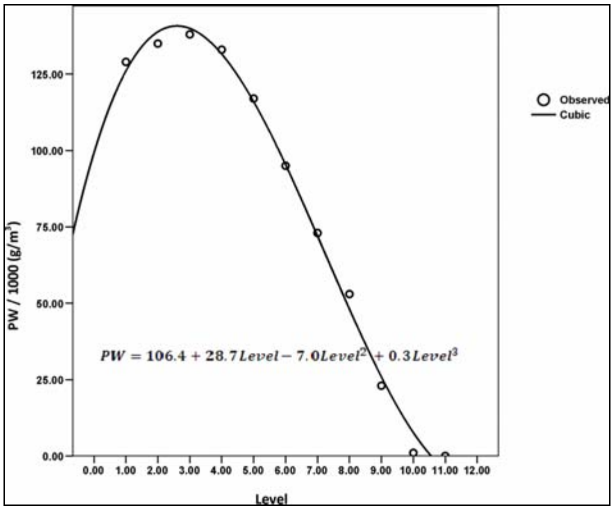

Fig. 1(b). Variation of PW with height over the Pacific Ocean on 1 March, 2008

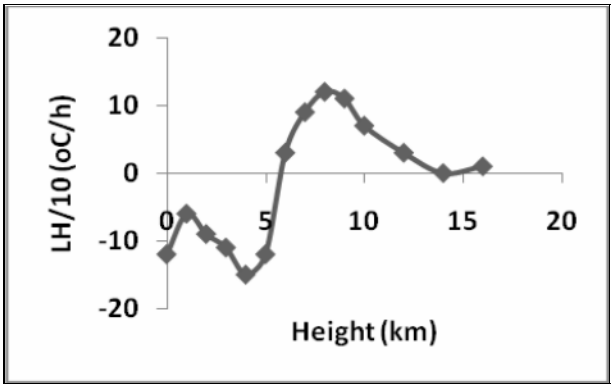

Fig. 1(c). Variation of LH with height over the East China Sea on 21 September, 2007

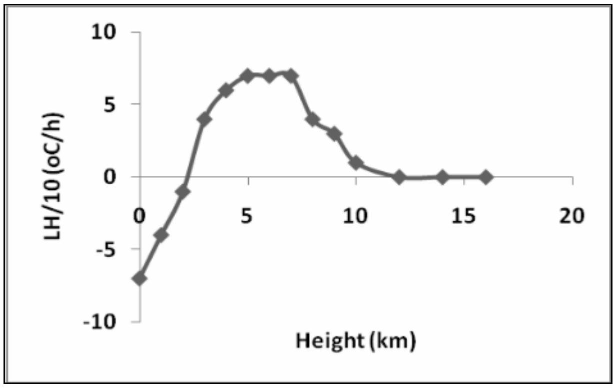

Fig. 1(d). Variation of LH with height over the East China Sea on 12 January, 2007

3.1.1. *Occurrence of peak CLW*

Various meteorological elements over Kakdwip during 2007-2008 are shown in Table 2. The occurrences of peak CLW are also shown in Table 2. The meteorological elements over other stations are not shown in this table. It is found from this table that CLW shows its peak mostly at the 6th/7th level, *i.e.*, at 2.5 to 3.5 km; sometimes the CLW peak occurs at the 9th level, *i.e.*, at 4.0 to 5.0 km; the 3rd level, *i.e.*, at 1.0 to 1.5 km; 5th level, *i.e.*, 2.0 to 2.5 km; 4th level, *i.e.*, 1.5 to 2.0 km and 8th level, *i.e.*, 3.5 to 4.0 km. It is found that over the stations studied, the CLW reaches its peak at 2.5 to 3.5 km in 72.3% cases on an average, over Indian stations. At most of the individual stations the occurrence is still higher, that is over Machilipatnam in 2007 in 92.3%; Puri in 2007 in 81.6% and over Panjim in 2008 in 81.6% cases, etc. Over the Indian Ocean (0º, 90º E), Mozambique, the East China Sea (30º N, 120º E), the Pacific Ocean (17º S, 164º W), Taiwan and Costa Rica, HPCL occurs at the 6th/7th level in 86.8%, 87.5%, 88.5%, 89.7%, 90.7% and 61.2% of cases, respectively (figures not shown).

3.1.2. *CLW versus height*

The knowledge of the variation of CLW with height is very much essential in aviation. Above the freezing level, if super cooled cloud liquid water exists, it becomes hazardous to aviation (Tokay and Short, 1996). The super cooled liquid water freezes on the wings of an aircraft, thereby increasing possibility of accidents. Moreover, the altitude variation of CLW gives an insight into the type of

TABLE 2

Meteorological elements over Kakdwip during 2007-2008

Station	Date	Convective rainfall (mm/h)	Stratiform rainfall (mm/h)	Surface rainfall (mm/h)	Total CLW/ 10^3 (g/m^3)	HPCL	PW at HPCL /10^3 g/m^3	Max PW /10^3 g/m^3	Total PW /10^3 g/m^3	Level at which LH absorption is maximum	Total LH /10 °C/h	Dominance over surface rainfall
Kakdwip	28 Apr, 07	0.04	0.05	0.09	56	6,7	10,11	11	78	NA	0	Stratiform
	14 May, 07	0.02	0.03	0.05	56	6,7	5,6	7	48	NA	0	Stratiform
	8 Jun, 07	0.58	2.39	2.97	193	3	197	205	1750	5	-20	Stratiform
	29 Jun, 07	0.21	0.68	0.88	108	7	67	68	574	6	-14	Stratiform
	3 Jul, 07	0.04	0.22	0.26	41	7	33	36	266	6	-14	Stratiform
	4 Jul, 07	0.15	0.82	0.97	67	3,4	70,72	86	690	6	-25	Stratiform
	5 Jul, 07	0.54	2.90	3.44	197	9	155	243	2066	5	-9	Stratiform
	6 Jul, 07	0.04	0.07	0.11	71	7	12	13	98	6	-4	Stratiform
	15 Jul, 07	0.15	0.52	0.67	82	7	58	59	483	6	-15	Stratiform
	16 Jul, 07	0.28	0.64	0.92	141	7	64	65	539	surface	-9	Stratiform
	23 Jul, 07	17.03	2.17	19.2	1528	9	538	941	7749	surface	1023	Convective
	26 Jul, 07	0.11	0.19	0.29	101	7	29	29	223	1,5,6	-10	Stratiform
	28 Jul, 07	0.16	0.69	0.85	70	7,8	76,73	76	594	5,6	-17	Stratiform
	5 Aug, 07	0.04	0.06	0.1	77	7	13	14	100	NA	0	Stratiform
	12 Aug, 07	20.28	2.78	23.1	1324	9	829	1219	10487	surface	1156	Convective
	17 Aug, 07	0.66	3.54	4.2	241	9	194	307	2584	3	28	Stratiform
	18 Aug, 07	3.34	5.70	9.04	500	9	316	566	4633	surface	137	Stratiform
	20 Aug, 07	0.20	0.50	0.71	111	7	56	56	466	surface	-12	Stratiform
	5 Sep, 07	0.34	1.87	2.2	135	3,9	152,96	171	1385	5	-11	Stratiform
	8 Sep, 07	0.09	0.17	0.27	94	7	29	29	222	6	-11	Stratiform
	21 Sep, 07	0.15	0.28	0.42	104	7	37	37	291	1	-8	Stratiform
	22 Sep, 07	0.42	1.98	2.4	167	9	106	165	1429	5	-18	Stratiform
	24 Sep, 07	0.64	3.24	3.88	234	9	172	269	2303	3	-3	Stratiform
	7 Oct, 07	0.07	0.14	0.21	84	6,7	23,26	26	194	5,6	-11	Stratiform
	17 Oct, 07	0.03	0.04	0.07	57	7	8	9	64	NA	0	Stratiform
	2 Nov, 07	0.12	0.22	0.34	100	7	31	31	247	1,6	-8	Stratiform
	15 Nov, 07	2.23	0.96	3.19	611	7	122	186	1303	surface	59	Convective
Kakdwip	20 Mar, 08	4.92	4.15	9.07	717	8,9	339,184	517	3904	surface	217	Convective
	1 Apr, 08	0.06	0.17	0.24	67	3	21	30	188	4	-3	Stratiform
	27 Apr, 08	0.03	0.04	0.07	58	6,7	9,11	11	74	NA	0	Stratiform
	4 May, 08	0.12	0.25	0.36	76	7	41	41	291	5,6	-10	Stratiform
	6 May, 08	0.07	0.13	0.21	69	6,7	23,26	26	181	5,6	-8	Stratiform
	9 Jun, 08	0.72	3.63	4.35	253	9	194	310	2628	3,4	26	Stratiform
	10 Jun, 08	0.05	0.08	0.13	80	7	16	16	119	6	-6	Stratiform
	16 Jun, 08	0.06	0.16	0.22	87	6,7	24,26	28	211	6	-10	Stratiform
	17 Jun, 08	0.37	1.83	2.2	144	9	102	157	1340	5	-22	Stratiform
	26 Jun, 08	0.09	0.17	0.26	95	7	25	26	208	6	-10	Stratiform
	27 Jun, 08	0.16	0.39	0.55	100	7	47	47	389	6	-11	Stratiform
	30 Jun, 08	0.07	0.12	0.19	91	6,7	20,22	22	166	5,6	-8	Stratiform
	6 Jul, 08	0.17	0.70	0.87	80	7,8	73,74	74	606	6	-18	Stratiform
	14 Jul, 08	0.14	0.29	0.43	103	7	39	39	311	1,6	-9	Stratiform
	30 Jul, 08	0.10	0.28	0.38	77	7	39	41	319	6	-11	Stratiform
	31 Jul, 08	0.08	0.19	0.27	85	6,7	27,30	31	239	6	-10	Stratiform
	11 Aug, 08	0.14	0.24	0.38	109	7	32	32	258	1,6	-9	Stratiform
	19 Aug, 08	0.06	0.11	0.17	82	6,7	15,16	17	135	6	-6	Stratiform
	4 Sep, 08	11.24	1.05	12.3	76	5	574	613	4835	surface	650	Convective
	9 Sep, 08	0.05	0.06	0.11	92	6,7	11,12	12	91	5,6	-4	Stratiform
	14 Sep, 08	0.10	0.20	0.29	102	7	29	30	234	6	-10	Stratiform
	15 Sep, 08	7.10	1.00	8.05	77	7	285	419	3039	surface	289	Convective
	17 Sep, 08	0.12	0.24	0.36	60	7	35	35	277	6	-9	Stratiform
	18 Sep, 08	0.05	0.09	0.14	99	6,7	14,15	16	121	6	-7	Stratiform
	21 Sep, 08	0.03	0.06	0.09	96	6,7	12,13	14	101	NA	0	Stratiform
	24 Sep, 08	11.24	1.05	12.3	67	5	574	613	4835	surface	65	Convective
	25 Sep, 08	0.13	0.28	0.4	58	7	36	36	297	6	-11	Stratiform
	25 Oct, 08	0.14	0.35	0.49	76	7	42	43	351	6	-12	Stratiform

cloud formed, for instance, cirrus contains much less water than the stratus. Variation of CLW with height over Karaikal is shown in Fig. 1(a) (figures for other stations and cases are not shown). It is found from this figure that with increase in height CLW first increases reaches its peak and then gradually decreases with increase in height. CLW is found to bear a cubic relationship with height in most of the cases at all the stations. Sometimes it shows a quadratic relationship over Indian stations alone (figures not shown), *viz*., a quadratic relationship is found over Chennai, Machilipatnam, Kakdwip, Mumbai, Mangalore, Trivandrum, Panjim and Puri in 2.8, 10.2, 7.0, 6.2, 4.7, 3.5, 6.4 and 2.6% cases, respectively. Over Vishakhapatnam and Karaikal a quadratic relation was never seen between the CLW and height.

As an air parcel ascends, it encounters gradually decreasing temperature in the troposphere (Aguado and Burt, 2010). Hence, the moisture condenses; cloud droplets are formed releasing latent heat of condensation. Hence, as height increases from the Earth's surface, CLW also increases. At a higher altitude between 2.5 and 3.5 km mostly, the CLW reaches its maximum value. After reaching the maximum value, the CLW value falls off with further increase in height. This can be explained as follows: As height further increases, the moisture content inside the air parcel goes on decreasing, resulting in less condensation, and thus less production of CLW. At a very high level, the parcel will be completely depleted of moisture as it has already used up all the moisture in it. Hence very little condensation takes place, resulting in less CLW at very high altitude accompanied by very less LH release. Moreover, beyond the tropopause, the ambient temperature is higher in the stratosphere, as the temperature increases with altitude. Hence, the air parcel becomes stable and further ascent is stopped.

3.1.3. *Occurrence of peak PW*

The occurrence of peak PW over Kakdwip is shown in Table 2. Table 2 shows that over Kakdwip, the PW shows its peak at the 7th and 8th level (3.0-4.0 km) mostly. At times, the peak occurs at the 2nd or 3rd level (0.5-1.5 km) also. Similar results have been observed over other stations (results not shown).

3.1.4. *PW versus height*

Variation of PW with height over the Pacific Ocean (17° S, 164° W) is shown in Fig. 1(b) (figures for other stations are not shown). It is seen that with increase in height, PW first increases, the tail starting from a non-zero value, reaches its peak, and then decreases with further increase in height. PW is always found to bear cubic relations with height over all the stations.

3.1.5. *LH versus height*

Fig. 1(c) shows the variation of LH with height over the East China Sea (30° N, 120° E) (figures for other stations are not shown). It is found that LH mostly shows two peaks: the absorption peak occurs at the lower level and the evolution peak occurs at the higher level. It is noteworthy that Fig. 1(c) represents a stratiform dominance. A stratiform precipitation originates in the older part of a convective cell (Houze, 1997). In the older region of a convective cell, the lower troposphere is dominated by downdraft and the upper part is dominated by weak updraft (Houze, 1997). In the down draft region, the falling water drops may evaporate absorbing latent heat. Hence, the vertical profile of LH in a stratiform precipitation shows –ve LH, *i.e.*, absorption in the lower troposphere. In the upper part of the troposphere, the weak updraft condenses the vapour to CLW, thereby liberating latent heat of condensation. Thus, a crest is found in Fig. 1(c), implying +ve LH in the upper troposphere. The vertical profiles of LH show the same characteristics over all the stations studied (figures for other stations not shown).

Fig. 1(d) shows the variation of LH with height over the East China Sea (30° N, 120° E) for convective dominance (figures for other stations are not shown). Fig. 1(d) shows that the absorption maximum under convective dominance occurs at the Earth's surface. Similar results have been obtained over other stations also. It is further found out that in 98% of cases studied in the year 2007 and about 93% cases studied in 2008, at all levels above the Earth's surface, LH is +ve, implying that LH is evolved at all levels above the Earth's surface (figures not shown). A convective rainfall is associated with strong updraft at all levels (Houze, 1997). Net upward mass transport produces CLW due to condensation of vapour. This liberates latent heat of condensation. Thus, net upward updraft in a convective rainfall produces net latent heating at all levels. However, in about 2% cases of convective dominance in 2007 and about 7% cases in 2008, the vertical profiles of LH show –ve values at the Earth's surface and at the 5th (2.0-2.5 km)/6th level (2.5-3.0 km), implying absorption above the Earth's surface also [Fig. 1(d)]. The reason of this anomaly is yet not known. It is found out from Fig. 1(d) that as height increases, LH increases, reaches its peak, and thereafter decreases with further increase in height. As the air parcel goes up, the water vapour present in it goes on condensing, releasing latent heat. Thus, with increase in height, the LH increases. At a very high level, the water vapour content of the air parcel goes on reducing as most of it is condensed, thereby reducing the latent heat of condensation. Ultimately, at a very high level, the latent heat becomes zero, as the air parcel becomes completely

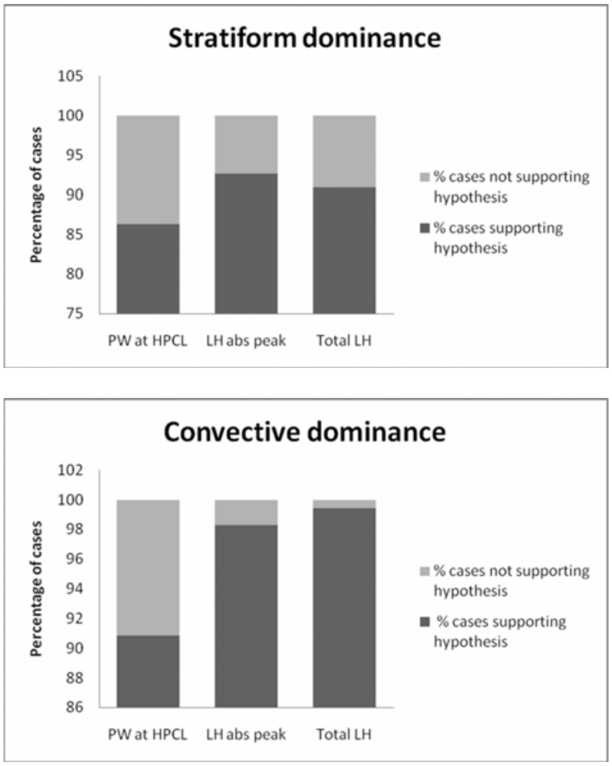

Fig. 2. Percentage of cases explaining stratiform and convective dominance based on individual parameters

depleted of water vapour. Similar results have been noticed over all the stations studied (figures not shown).

3.2. *Identification of convective / stratiform dominance over surface rainfall*

Table 2 shows the height of peak CLW (HPCL), maximum PW, height of LH absorption peak, PW at HPCL and the total PW of each day studied over Kakdwip (results for others stations are not shown).

Table 2 also shows the stratiform rainfall, convective rainfall, surface rainfall of the day and dominance of convective/stratiform rainfall over surface rainfall. The analysis shows that under convective dominance, the parameters introduced in section 1 satisfy certain conditions which are different in case of stratiform dominance. It is described below. It is found out from Table 2 that the dominance of convective rain over surface rainfall is always associated with (*i*) LH absorption peak at the Earth's surface (*ii*) resultant evolution of heat along the vertical column above the surface of the earth up to 18 km and (*iii*) whenever convective dominance exists, the PW value at HPCL is far less than the maximum PW value of the day. The stratiform dominance over surface rainfall, on the other hand, is found to be associated with (*i*) a net absorption of heat along the vertical column, or zero evolution of heat, (*ii*) the absorption peak being found at a much higher level; far above the surface and (*iii*) a very high PW value at HPCL, almost or exactly equal to the highest PW of the day. Similar results have been observed over all the stations studied as shown in section 3.3.

It is further found out that a convective dominance over surface rainfall is characterized by very high columnar CLW and PW values from the surface up to 18 km above, while a stratiform dominance is characterized by less columnar CLW and PW values (Table 2). This table further shows that the PW at HPCL is a very good indicator of surface rainfall. In a month/ year, the maximum PW at HPCL is associated with the highest rainfall of the month/ year and the minimum PW at HPCL in a month/year, represents the minimum rainfall of the month/year. The data over other stations also show similar results (results not shown).

3.3. *Validity of the conditions characterizing convective/stratiform dominance over surface rainfall*

Fig. 2 shows how well the above three conditions explain the dominance. It is found from Fig. 2 that a convective dominance is explained on the basis of LH absorption peak, PW value at HPCL and the total LH along the entire vertical column in 98.28%, 90.86% and 99.43% cases respectively. Similarly, a stratiform dominance is explained by the LH absorption peak, PW value at HPCL and total LH in 92.65%, 86.31% and 90.92% cases respectively.

It is further found out that the dominance of stratiform and convective rain over surface rainfall is explained on the basis of all three conditions in 83.08% cases. Moreover, at least two conditions out of the three explain the above dominance in 93.1% cases. In 1.3% cases an absolute discrepancy is found, *i.e.*, none of the conditions explains the above dominance. It is further to note that when the HPCL was at 9th level, at least two conditions explained the dominance in 64.04% cases, while the same was explained in 66.67%, 84.7% and 90% cases when the HPCL was found at 5th, 4th and 3rd level respectively. No discrepancies were found when HPCL occurred at the 8th level.

3.3.1. *Indian subcontinent*

Table 3(a) shows the validity of the three conditions characterizing the convective / stratiform dominance over

TABLE 3(a)

Validity of the hypothesis over Indian stations

Total no of cases studied	*No of cases explained and %	HPCL	No of times HPCL occurred at the level and % of occurrence	Percentage of cases explained	
				**V3	**V2
669	621 (92.83%)	6/7	492 (73.54%)	98.3	98.4
		9	89 (13.3%)	80.7	79.6
		8	67 (10.01%)	100.0	100.0
		3	26 (3.89%)	84.6	92.4
		4	18 (2.69%)	50.0	83.4
		5	21 (3.14%)	47.6	63.6

*At least two conditions out of three valid
**V3-Hypothesis valid by all 3 conditions
**V2-Hypothesis valid by at least 2 conditions

TABLE 3(b)

Validity of the hypothesis

Station	Total number of cases	Number of cases hypothesis valid	Number of convective cases	*V2 Convective	*V3 Convective	Number of stratiform cases	*V2 Stratiform	*V3 stratiform
Mozambique	16	16(100.0%)	3	3(100.0%)	3(66.7%)	13	13(100.0%)	12(92.3%)
East China Sea	26	23(88.5%)	4	4(100.0%)	4(100.0%)	22	19(86.4%)	15(68.1%)
Costa Rica	49	48(97.9%)	13	12(92.3%)	8(61.5%)	36	32(88.8%)	26(72.2%)
Indian Ocean	38	38(100.0%)	6	6(100.0%)	5(83.3%)	32	32(100.0%)	30(93.8%)
Pacific Ocean	29	26(89.7%)	6	5(83.3%)	4(66.6%)	23	21(91.3%)	19(82.6%)
Taiwan	43	40(93.02%)	7	7(100.0%)	6(85.7.%)	36	33(91.7%)	31(86.1%)

*V3 - Hypothesis valid by all 3 conditions
*V2 - Hypothesis valid by at least 2 conditions

Indian stations and percentages of occurrence of peak CLW at various levels. Table 3(a) further shows the percentage of explained dominance when HPCL occurred at various levels. It is found from this table that HPCL mostly occurred at the 6/7 level. At times, it also occurred at the 9th, 8th, 3rd, 4th and 5th level. It is found that whenever HPCL was at the 6th/7th level, *i.e.*, at 2.5 to 3.5 km, all the three conditions satisfied the dominance in 98.3% cases. It is further found that when the HPCL had occurred at the 8th level, no discrepancies were found, *i.e.*, dominance of convective/stratiform rain over surface rainfall was characterized by all the three conditions. However, when the HPCL occurred at the 9th, 5th, 4th and 3rd level, the dominance was explained on the basis of all the three conditions in 80.7%, 47.62%, 50% and 84.6% of the cases respectively. It is further found from Table 3(a) that the dominance is identified based on these conditions in 621 cases out of 669 cases studied, *i.e.*, in about 92.8% of cases.

Also, it is found out that over Indian stations, in no cases of convective dominance, any discrepancies were found. This observation is found in all cases of convective dominance, irrespective of HPCL. It is found that these conditions characterize convective/stratiform dominance over Chennai, Kakdwip, Karaikal, Machilipatnam, Mangalore, Panjim, Puri, Vishakhapatnam, Mumbai and Trivandrum in 91.7%, 96.4%, 83.0%, 94.0%, 88.6%, 97.3%, 93.1%, 87.2%, 87.7% and 98.1% of cases, respectively (not shown in the table). Thus the study shows that the three conditions as mentioned above are generally valid and the discrepancies are found in very few cases.

TABLE 4

Occurrence of convective and stratiform rainfall

Station	Year	Percentage of occurrence		Percentage of contribution	
		Convective rainfall	Stratiform rainfall	Convective rainfall	Stratiform rainfall
Chennai	2007	30.0	70.0	58.06	41.94
	2008	15.79	84.21	74.19	25.81
Kakdwip	2007	11.11	88.89	53.36	40.64
	2008	13.33	86.67	67.61	32.39
Karaikal	2007	6.25	93.75	28.5	71.51
	2008	32.26	67.74	49.15	50.85
Machilipatnam	2007	19.23	8.77	77.01	22.99
	2008	4.17	95.83	30.88	69.12
Mangalore	2007	22.22	77.78	59.01	40.99
	2008	31.25	68.75	66.85	33.16
Panjim	2007	19.36	80.65	74.21	25.80
	2008	20.41	79.59	70.32	29.68
Puri	2007	9.38	90.63	48.84	51.16
	2008	14.29	85.71	57.42	42.59
Vishakhapatnam	2007	8.33	91.67	27.59	72.41
	2008	20.83	79.17	58.45	41.55
Mumbai	2007	17.65	82.35	60.17	39.83
	2008	6.45	93.55	33.81	66.19
Trivandrum	2007	40.0	60.0	71.24	28.76
	2008	25.0	75.0	69.28	30.71
East China Sea	2007	3.45	96.55	36.26	63.74
	2008	9.68	90.32	53.87	46.13
Africa	2007	31.82	68.18	75.09	24.91
	2008	18.75	81.25	66.16	33.84
Costa Rica	2007	20.00	80.00	50.76	49.18
	2008	32.14	67.86	68.78	31.22
Indian Ocean	2007	23.08	76.92	66.67	33.33
	2008	26.47	73.53	74.41	23.59
Pacific Ocean	2007	29.03	70.97	69.80	30.21
	2008	17.65	82.35	48.19	51.82
Taiwan	2007	12.82	87.18	52.95	47.05
	2008	10.26	89.74	43.29	56.71

3.3.2. *Stations other than India*

The validity of the conditions characterizing convective/stratiform dominance over stations other than India is described in Table 3(b). It is found that over none of the stations mentioned in Table 3(b), absolute discrepancy was noted. It is further found that these conditions are able to explain the dominance of convective/stratiform dominance over surface rainfall over all these stations, in most of the cases. Table 3(b) further shows that stratiform rainfall is more frequent over these stations than convective rainfall.

3.4. *Discussion on discrepancy*

It is found from Tables 3(a&b) that the three conditions explain the dominance of convective/stratiform rainfall in almost all the cases. However, a few discrepancies are also found. It is seen that over Indian stations the absolute discrepancy was found in stratiform dominance and occurred mostly when HPCL was at the 5th level; and on few days at the 9th level. An absolute discrepancy is defined as the situation when none of the conditions suggested by the authors is found in a particular kind of dominance. For convective dominance, however, there were no absolute discrepancies. Over all stations other than India, the discrepancy was mostly found when HPCL occurred at the 9th level. Moreover, it is found that only in 1.3% cases an absolute discrepancy occurred.

An interesting feature of stratiform rainfall is revealed by the study (table not shown). In existing literature, the freezing-level height has been reported to be the transition height between the ice particles and the liquid phase. Table 2 also supports this fact in most cases of stratiform rain. However, it is found out that (table not shown) BBH often goes high above HFL, indicating that water-coated ice particles do exist above freezing level, implying that in some cases of stratiform rain, the freezing level is not the transition height between pure ice and the liquid phase.

3.5. *Characteristics of convective and stratiform rainfall*

In order to find out the characteristics of stratiform and convective rainfall, the rain type flags and the bright band flags of the data product 2A23 derived from the precipitation radar (PR) onboard the TRMM have been checked for the period 1999-2002. Simultaneous CLW, PW and LH data were obtained from the data product 2A12. In this regard, 2007 and 2008 data were not included, because 2A12 and 2A23 data for the same orbit number were not available during this period. The rain type flags represent the types of rain, *i.e.*, whether the surface rain is stratiform or convective. The bright band flag represents whether a bright band is detected or not, and if detected, it gives the bright band height, *viz.*, "- 1111" represents no bright band, *i.e.*, it represents either a convective case (*i.e.*, no bright band) or bright band was present but not detected. From the rain type flags of 2A23, the confirmed stratiform cases were chosen and the corresponding CLW, PW and LH profiles were noted from 2A12. Similarly, the rain type flags were checked for confirmed convective cases. Then for each such case, the CLW, PW and LH values were noted from 2A12. It is found out that the total columnar CLW and PW are generally more in convective cases than in stratiform cases. This can be explained as follows: convection occurs when the air near the surface gets heated and rises at such a rate that the density of the air medium is changed (Houze, 1997). Under such circumstances, molecular diffusion cannot redistribute the modified density fast enough to maintain equilibrium (Houze, 1997). In order to maintain equilibrium, the air parcel becomes bouyantly unstable and overturns against gravity. When overturning takes places, there is upward mass transport. The sudden and strong updraft condenses the water vapour rapidly, producing very large amount of CLW. Because of strong air motion in the upward direction, the CLW remains floating for a long time in the atmosphere against gravity. This is why the total CLW is high in convective precipitation. In stratiform precipitation, in the older region of the convective cell, the updraft becomes weak. Hence, large amount of CLW is not produced as in the case of convective precipitation from the young, vigorous part of the convective cell. Moreover, the weak updraft in the stratiform part does not allow the CLW to remain floating in the atmosphere for a long time against gravity (Houze, 1997). Hence, in case of a stratiform precipitation, the total CLW is less as compared to the convective precipitation. The latent heat profile for a convective case is also distinctly different from that of a stratiform case [Fig. 1(c&d)].

Table 4 shows the percentage of convective and stratiform events and the amount of rainfall recorded over the stations studied. It is seen that at all stations the frequency of stratiform events is greater than that of convective events, while the contribution of the latter to surface rainfall is greater than that of the former in some stations. However, over some stations, at times, the contribution of stratiform rainfall to total rainfall is more. It has been reported that over the tropics most rainfall events are of stratiform origin, while the contribution of convective rain is greater to surface rainfall (Houze,1997).

4. Conclusions

The characteristics of convective/ stratiform dominance over surface rainfall have been analysed using the meteorological elements like the CLW, PW and LH starting from the Earth's surface up to a height of 18 km above, over a few selected stations in India and a few global locations. The data required for the study have been obtained from the data product 2A12 on board the

Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), for the period 1999-2002, 2007 and 2008. The statistical tools used for this study are linear and non linear regressions. Two new parameters, *viz*., the height of peak cloud liquid water (HPCL) and the precipitation water at HPCL have been introduced in this paper. The study brings out the characteristic features of convective/stratiform dominance over surface rainfall. The study also shows the correlations between CLW, PW and LH with height and establishes the functional relationships between them.

The study shows that mostly, the HPCL exists at 2.5 to 3.5 km, while the peak PW occurs at 3.0 to 4.0 km. The CLW and PW bear cubic relations with height, while the vertical profile of LH in a stratiform cloud generally shows an absorption peak in the lower troposphere and an evolution peak higher up. In a convective cloud, the entire troposphere mostly shows dominance of LH evolution. Over the stations studied, stratiform rainfall is found to be more frequent than convective rainfall, whereas the latter contributes more to the rainfall amount than the former in most of the cases. However, over some stations, at times, the stratiform rainfall is found to contribute more to surface rainfall. A convective dominance over surface rainfall is characterized by LH absorption peak at the surface, a net evolution of LH along the entire vertical column and a very less value of PW at HPCL as compared to the maximum value of the day. A stratiform dominance, on the other hand, is marked by the LH absorption peak far away from the surface, a net absorption or zero evolution of LH along the vertical column and a very high (the highest or close to the highest of the day) PW value at the HPCL. Discrepancy is found mostly when the HPCL occurs at 2.0 to 2.5 km. It is found that whenever the HPCL occurs at 2.0 to 2.5 km, LH absorption peak always occurs at the surface. Though in most of the cases of stratiform rainfall, freezing level is the transition between ice and liquid, at times, the snowflakes may exist at or above the freezing level, marked by higher BBH than HFL. A convective rainfall is found to be associated with a higher total columnar CLW and PW than in case of a stratiform rainfall.

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