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Observational study of pre-monsoon thunder events over Delhi and Guwahati region

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Abstract

Thunder events are common during pre-monsoon season (March -May). In this paper thunder events of Delhi and Guwahati for the month of May and April have been analysed with Global Navigation Satellite System (GNSS) derived precipitable water vapour and Moderate Resolution Imaging Spectroradiometer (MODIS) derived Aerosol Optical Depth (AOD) at 550 nm data. It is observed that GNSS derived precipitable water vapour have the potential to nowcast or characterize the mesoscale event. In all cases the AOD and Integrated Precepitable Water Vapour (IPWV) increases before the thunder event which accompanied with duststorm and consequently increase the aerosol loading in the atmosphere. The rate of increase of IPWV ($\frac{d}{dt}(IPWV)$) is observed approximately 3-4 mm /hour during the convective initiation and relative increase of AOD is 150-300 %. The various thermodynamic parameters of radio-sounding to understand better the thunder activity are also highlighted in the paper.

Keywords: AOD, IPWV, thunder events and Pre-monsoon

Introduction

In Pre-monsoon season (March -May) meso-scale (like thunder or duststorm) and synoptic scale phenomena (like cyclones) are the main weather events. Due to local heating dry and moist air condenses and thunder event is developed in association with the dust if availability of moisture is less. Due to this transition the value of AOD and IPWV changes drastically before and after the occurrence of the events. The convection builds up 2 to 3 hours prior to the thunder events. Similarly, the AOD values also changes drastically. Hence, Satellite data sensors play vital role in synoptic or mesoscale system analysis and aerosol influx especially during pre-monsoon season**.** Satellite provides the cost effective way of monitor the AOD distribution locally as well as over large areas. In this paper, Moderate Resolution Imaging Spectroradiometer (MODIS), AOD data has been utilized to study the pre-monsoon thunder events. For improving the quality of retrieval of MODIS, AOD a cloud mask is developed by Ackerman *et al.* (1998). The cloud mask uses a series of cloud detection tests to determine which pixels are cloudy and which are clear. Clouds generally have higher reflectance and lower temperature than the surface, thus the algorithm looks for cloud-surface contrast in the infrared channels near 2.1 mm. The algorithm assumes a general type of surface (coast, desert, land, or water) based on US Geological Survey and other ecosystem data sets. Errors in the cloud mask can result from surfaces that have high reflectance which decreases the surface-cloud contrast, from very dense high aerosol plumes that appear like clouds, from cloud edges resulting in partially cloudy pixels, and from errors in the surface model. Each non-cloudy pixel is then further screened in the aerosol algorithm described by Kaufman and Tanre (1998) by estimating errors in the optical depth in non-arid regions (such as the eastern US) to be $\Delta\tau_a$=0.05 7 0.2 τ_a. Random errors have been reported to be from uncertainty in the surface reflectance (5-20%), instrument calibration (2-5%), screening including removal of pixels using the 10-40% filter (0-10%), and from uncertainty in the use of the models (10-20%) (Kaufman and Tanre, 1998; Chu *et al.,* 2003). The MOD04 AOT values have a documented retrieval error of 25% at τ = 1 over land and 8% at τ = 1 over ocean, and further extensive validation (Chu *et al.,* 2003) has shown that one-third of the values retrieved in each pass lie even outside these error bounds, due to sub-pixel cloud and water contamination. AOD and IPWV showing the same trend it may be due to possibility of the hygroscopic growth of aerosols. This type of trend reported earlier also (Chatterjee, 1985; Krishnamoorthy *et al.,*1998; Gupta *et al.,* 2003; Pandey & Vyas, 2004).

AOD distribution during pre-monsoon affects cloud formation, and hence the rainfall distribution, which is found to be prominent in last 4 years (Prasad *et al.,* 2004). The aerosols, varying in size from a few micrometres to a few millimetres, are important for the radiation budget of the earth-atmosphere system (Charlson *et al.,* 1992; Andreae, 1995; Jayaraman *et al,* 1998). These particles act as nuclei for condensation of water vapour leading to rain precipitation. Aerosols originate from a variety of natural and anthropogenic sources and thus exhibit a great variability in both space and time. Data from the Multi-angle Imaging Spectroradiometer (MISR) instrument on NASA's Terra spacecraft have been used in a groundbreaking new university study that examines the concentration,

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Table (1a). Thunder event observed over Delhi during the month of May, 2007

Date	Commencing time	Ending time	Duration (minute)	Rainfall (mm)
02-05-07	1255 IST	1400 IST	065	
02-05-07	1525 IST	1615 IST	040	5.3
06-05-07	1505 IST	1550 IST	045	
06-05-07	1740 IST	1750 IST	010	8.2
07-05-07	0845 IST	0910 IST	025	0.0
10-05-07	2010 IST	2120 IST	070	8.4
11-05-07	1940 IST	2140 IST	120	25.4
16-05-07	1815 IST	0055 IST	160	21.3
17-05-07	0335 IST	0850 IST	315	0.0
19-05-07	1824 IST	2000 IST	096	0.4
25-05-07	1920 IST	2140 IST	140	
26-05-07	1620 IST	1750 IST	090	
26-05-07	2015 IST	2100 IST	045	

distribution and composition of aerosol pollution over the Indian subcontinent (ScienceDaily, Sep. 9, 2010;

Table (1b). Thunder event observed over Delhi during the month of May, 2008

Date	Commencing time	Ending time	Duration (minute)	Rainfall (mm)
04-05-08	2100 IST	2105 IST	005	Trace
04-05-08	1932 IST	2145 IST	133	1.0
10-05-08	0015 IST	0130 IST	075	0.0
11-05-08	0655 IST	0715 IST	020	
11-05-08	0800 IST	0830 IST	030	3.4
14-05-08	1006 IST	1140 IST	094	9.6
15-05-08	0330 IST	0400 IST	030	9.6
15-05-08	0900 IST	0930 IST	030	0.0
17-05-08	1910 IST	0340 IST	580	7.7
19-05-08	0002 IST	0455 IST	453	2.7
19-05-08	0910 IST	0950 IST	040	
19-05-08	1005 IST	1135 IST	090	
20-05-08	0446 IST	0700 IST	256	7.3
20-05-08	0855 IST	0955 IST	060	24.7
22-05-08	0910 IST	1030 IST	080	35.1
22-05-08	1840 IST	0130 IST	350	36.4
26-05-08	1000 IST	1005 IST	005	
31-05-08	1615 IST	1945 IST	030	Trace
31-05-08	2005 IST	2130 IST	085	0.2

Table (1c). Thunder event observed over Delhi during the month of May, 2009

Date	Commencing time	Ending time	Duration (minute)	Rainfall (mm)
05-05-09	1745 IST	1915 IST	090	Trace
10-05-09	1522 IST	1545 IST	023	11.2
22-05-09	1405 IST	1445 IST	040	1.0
23-05-09	2000 IST	2135 IST	095	0.9
25-05-09	2100 IST	2315 IST	135	5.1
31-05-09	0217 IST	0655 IST	278	43.4
31-05-09	0800 IST	0900 IST	060	

http://www.sciencedaily.com/releases/2010/09/100908142739.htm). The study documents the region's very high levels of natural and human-produced pollutants, and uncovered surprising seasonal shifts in the source of the pollution. Dey and Larry Di Girolamo.(2010), observed from MISR data that densely populated Indian subcontinent has poor air quality and lacks on-the-ground pollution monitoring sites. The air quality

Table (2). Thunder event observed over Guwahati during the month of April, 2008

Date	Commen-cing time	Ending time	Duration (minute)	Rainfall (mm)
02-04-08	0600 IST	0800IST	120	6.2
03-04-08	2100IST	2300IST	120	12.8
12-04-08	2200IST	2330IST	090	19.0
13-04-08	1930IST	2330IST	240	12.7
15-04-08	1600IST	1730IST	090	5.8
24-04-08	1130 IST	1530 IST	240	8.0
28.04.08	2100IST	2330IST	150	26.2
29.04.08	2000IST	2130IST	090	9.6
30.04.08	2200IST	2300IST	060	17.0

during the pre-monsoon season is notoriously bad as these winds carry an immense amount of dust from Africa and the Arabian Peninsula to India. In northwest India the pre-monsoon season 'hot weather period' is known for intense convective activity over land areas. Thunderstorm developed due to intense convective activity is accompanied with moderate /severe squalls. The convective duststorms are locally called "aandhi's". These storms are characterized by downdrafts of thunderstorms or squall lines that are so intense that they blow up dust walls on the ground as far as 30 km from the main thunderstorm and over northwest India mainly in afternoon hours (Joseph *et al.,*1980, Joseph, 1982). Table 1(a-c) shows the thunder events of Delhi for the month of May of year of 2007, 2008, 2009. Thunder events for the month of April 2008 for Guwahati is given in Table 2. Various sounding indices derived from the radio-sonde data, are given in Table 3 (a-c) and their description is given in appendices (A-D). The variation thermodynamic parameters along with IPWV derived from GPS data at Delhi using Gamit 10.3.2.1 MIT, USA software **(**King & Bock, 1997) are shown in Figs {5-7 (a-e)}. The pressure diurnal variations shows negative interrelationship with the approach of the system.

Data and methodology

The upper air sounding data has been taken from the global web-site: http://weather.uwyo.edu/upperair/

Aerosol Optical Depth (AOD) over land (MOD08/MYD08) data used in the study for Delhi and Guwahati has been retrieved from the global data link: http://disc.sci.gsfc.nasa.gov/giovanni

Global positioning system (GPS) Integrated Precipitable Water Vapour (IPWV), data used for the year 2008 and 2009 is being processed at Satellite Division, Mausam Bhawan, Lodi Road, New Delhi. The pressure, temperature and humidity data used for the study is taken from GPS stations at Delhi and Guwahati. Aerosol optical

Table 3 (a). Various thermodynamic instability parameters on 18th to 20th May, 2008

Indices	18May		19May		20May	
	00UTC	12 UTC	00UTC	12 UTC	00UTC	12UTC
Total Totals Index	52.39	57.20	48.40	43.80	49.00	47.16
Showalter Index	-02.34	-05.60	-00.80	03.39	-01.42	-00.16
Lifted Index	05.37	-08.48	02.38	-04.28	-00.50	-05.05
K Index	35.78	14.30	32.30	27.70	34.10	32.67
CAPE (J/Kg)	00.00	2369.00	516.56	40.07	100.87	1588.42
Bulk Richardson No	00.00	82.00	56.74	57.92	00.27	29.55

Table 3 (b). Various thermodynamic instability parameters on 04th to 06th May, 2009(case1)

Indices	04May		05May		06May	
	00UTC	12UTC	00UTC	12 UTC	00UTC	12UTC
Total Totals Index	52.00	56.00	45.20	59.00	44.40	47.80
Showalter Index	-02.18	-03.59	02.62	-07.16	03.35	01.20
Lifted Index	-00.20	-03.14	01.47	-06.19	-01.69	00.80
K Index	31.30	42.20	24.10	38.30	-13.10	31.30
CAPE (J/Kg)	497.17	526.27	72.00	1697.97	138.00	233.47
Bulk Richardson No	75.19	116.36	01.43	25.16	02.96	08.20

Table 3 (c). Various thermodynamic instability parameters on 30th May to 01th June, 2009(caseII)

Indices	30May		31May		01June	
	00UTC	12UTC	00UTC	12 UTC	00UTC	12UTC
Total Totals Index	50.20	56.60	49.40	56.00	44.80	48.60
Showalter Index	-03.05	-06.47	-02.80	-06.67	00.51	-01.73
Lifted Index	-01.62	-10.68	-00.31	-08.13	-01.77	-01.26
K Index	30.30	40.10	36.30	40.90	33.10	33.70
CAPE (J/Kg)	298.09	2277.59	65.16	2338.93	482.98	161.67
Bulk Richardson No	48.35	59.88	01.71	35.66	63.17	01.31

thickness (AOD) is a measure of extent of attenuation of electromagnetic radiation (due to scattering and absorption) when it passes to atmosphere and is dependent on wavelength.

$$I_{\lambda s} = I_{\lambda 0} e^{-\tau}$$

Where, $I_{\lambda s}$ is the intensity after penetration and $I_{\lambda 0}$ is the incident intensity and τ is the optical thickness or optical depth (non-dimensional). Thus, AOD is an indicator of aerosol loading in the atmosphere as the higher the aerosol content, e.g. soot or smoke particles, the larger the attenuation. Normally, we take AOD values >1.0 as definite thick haze and 0.6-1.0 as probable haze.

GPS IPWV retrieval

GPS based total delay in the Zenith direction is estimated with the help of observational data. The total delay in zenith direction (ZTD) is the sum of two parts; dry delay in zenith direction called zenith hydrostatic delay (ZHD) and wet delay, which is known as zenith wet delay (ZWD). ZTD values are estimated from the observation file getting from the GPS receiver of each site by measuring the pseudo range or phase delay methods. The brief computation procedure of estimation of Integrated Precipitable Water Vapour (IPWV) is given below:

$$ZTD = ZHD + ZWD$$

ZHD values are more sensitive to station level pressure and temperature and calculated by the following formula:

$$ZHD = 0.00278 * P_s * \{1 + 0.0026 * \cos(2\phi) + 0.00000028 * H_s\}$$

Where, Ps =Station level pressure in milibar

Hs = Surface height above geoid in Km

ϕ = Latitude of the station

$$PWV = K * ZWD$$

Where,

$$K = \{10^{-6}(\frac{k_3}{T_m} + k'_2)R_v\rho\}^{-1}$$

ρ = Density of water in Kg/m^3

R_v=Water vapour gas constant

Where,

$$k'_2 = (17 \pm 10) K mb^{-1}, k_3 = (3.776 \pm 0.004)10^5 K^2 mb^{-1}$$

T_m= Weighed mean temperature of the atmosphere is given by

T_m=55.8(^{0}K)+0.77*T_S(^{0}K)

Ts = Surface temperature

ZHD values can be modelled properly and ZWD values cannot be modelled properly due to its in homogeneity in space and time. The final output product of precipitable water will be in mm.

Results and discussions

Convective activities are common in pre-monsoon season over most of the parts of Indian subcontinent. In this paper, the convective activity events AOD and GPS derived IPWV of Delhi for the months May, 2007-08 & 09 and April, 2008 for Guwahati have been analysed. The MODIS derived AOD is available at single wavelength, 550 nm. *Fig.*s marked (a) are MODIS derived AOD and those marked (b) are GPS derived precipitable water vapour respectively. The AOD values are daily averaged values and peaks observed in the Figs {1-7 (a)} are the representation of high increase of AOD on that Day. Similar increase is noticed in IPWV values Figs {1 -7 (b)} also. The availability of daily mean AOD data from MODIS limits the nowcasting capability but it captures the events well and an increase of the order of 150 to 300 % in AOD represents a thunder event. The brief details of the events are given in Tables 1(a-c) & 2 for Delhi and Guwahati respectively. It is clear from the events, given in the Tables 1 (a-c) & 2, that AOD as well as Precipitable water shows increasing trend before the thunder activity and decreasing after the event is over. The possible reason may be due to increase the hygroscopic nuclei in the atmosphere and washed out after the rain and AOD decreases thereafter removal or spatially redistribution of aerosols. Van den Heever *et al.* (2005) found that

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Fig.. 1 (a). Aerosol optical depth (AOD) of Delhi from MODIS for the Month of May, 2007 at 550 m

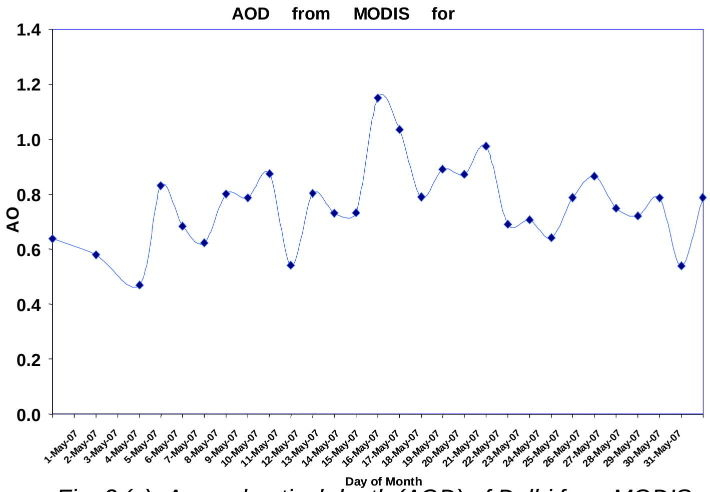

Fig. 1 (b). IPWV (mm) from GPS of Delhi for May, 2007

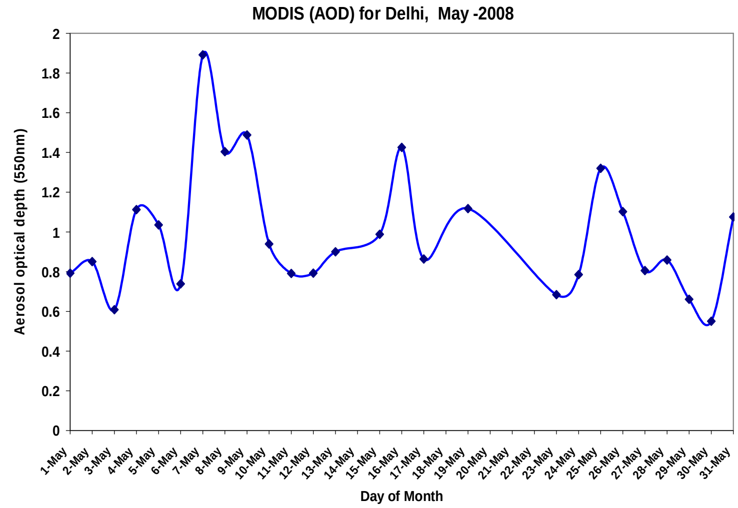

Fig. 2 (a). Aerosol optical depth (AOD) of Delhi from MODIS for the Month of Mav. 2008 at 550 nm

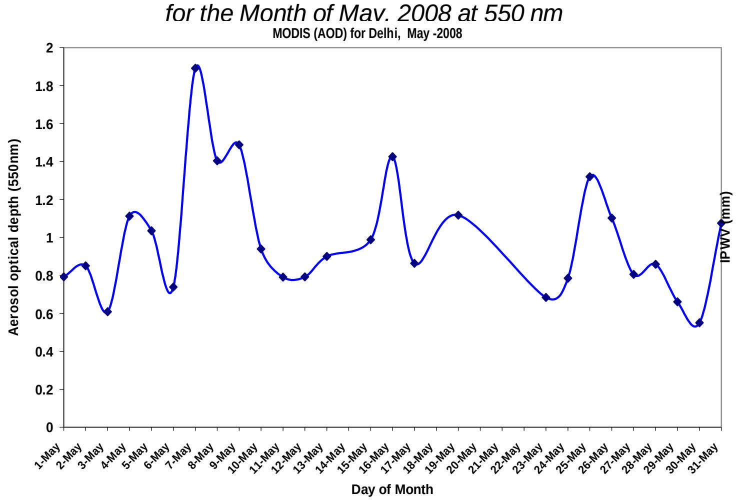

Fig. 2 (b). IPWV (mm) from GPS of Delhi for May, 2008

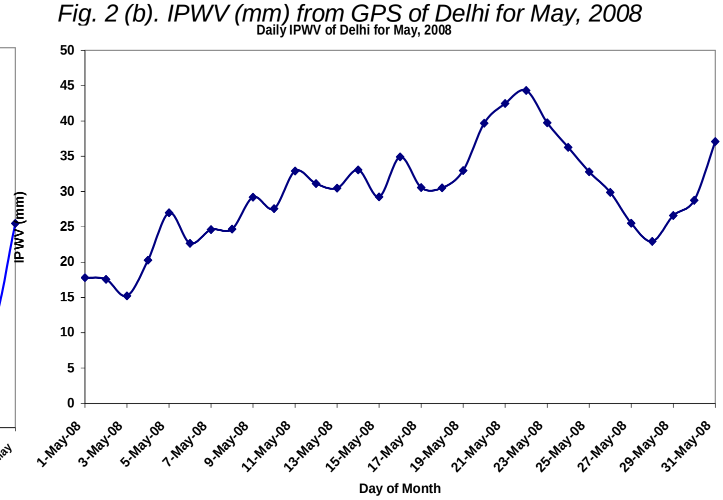

Fig. 3 (a). Aerosol optical depth (AOD) of Delhi from MODIS for the Month of May, 2009 at 550 nm

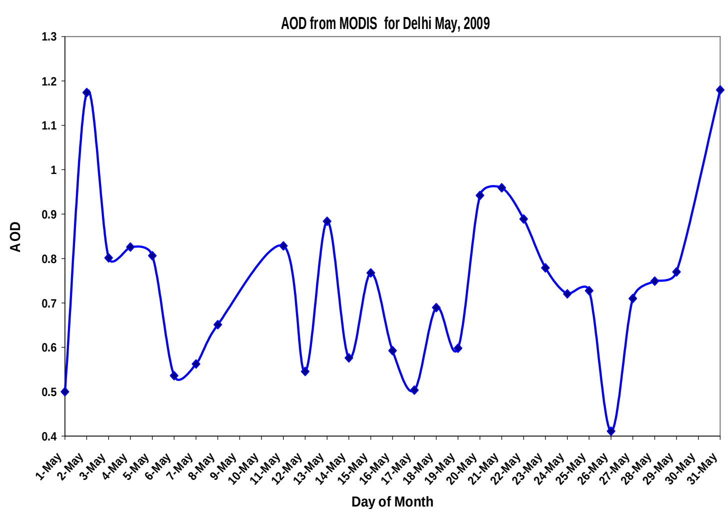

Fig. 3 (b). IPWV (mm) from GPS of Delhi for May, 2009

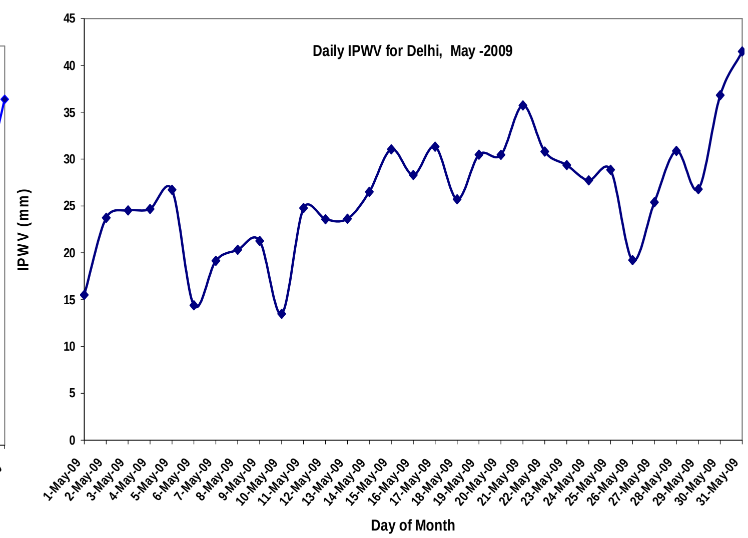

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Fig. 4 (a). Aerosol optical depth (AOD) of Guwahati from MODIS for the Month of April, 2008 at 550 nm

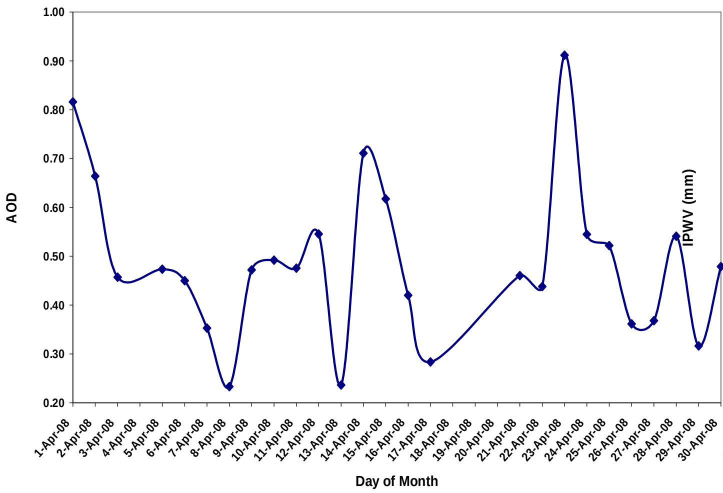

Fig. 4 (b). IPWV (mm) from GPS of Guwahati for April, 2008

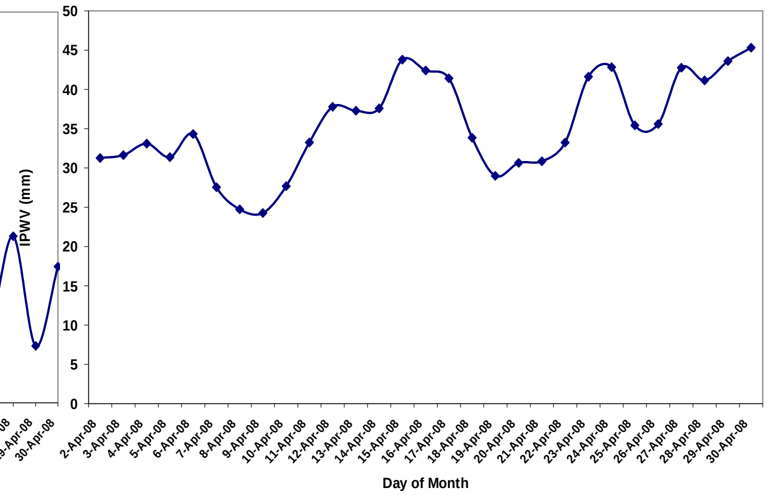

Fig. 5 (a). Daily variation of MODIS derived AOD (17-24 May, 2008) over Delhi

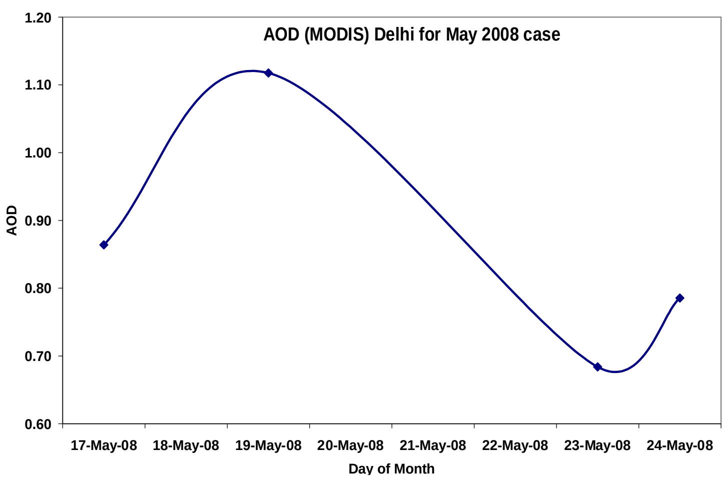

Fig. 5 (b). Diurnal variation of IPWV (18-21 May, 2008) over Delhi

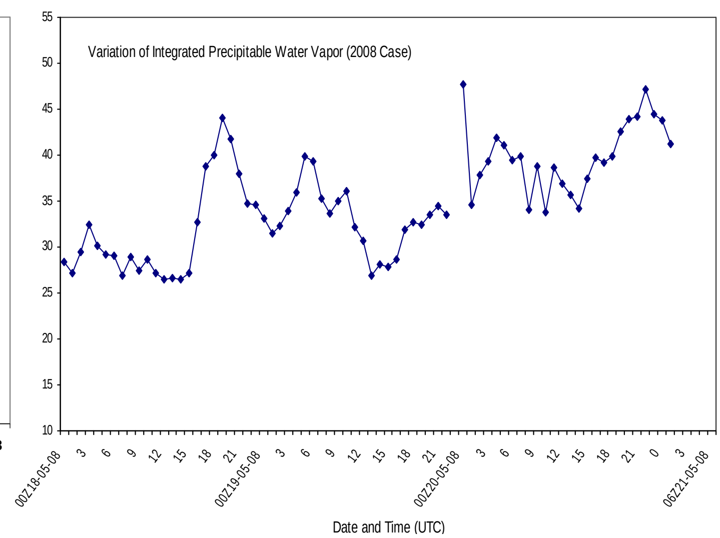

Fig. 5(c). Diurnal variation of Pressure (18-21 May, 2008) over Delhi

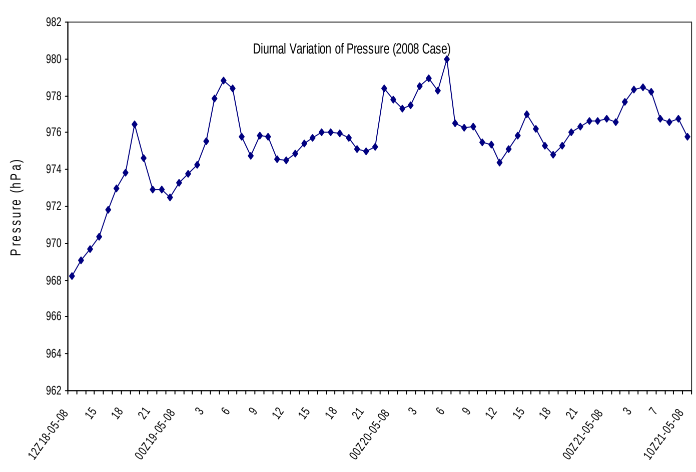

Fig. 5(d). Diurnal variation of Temperature (18-21 May, 2008) over Delhi

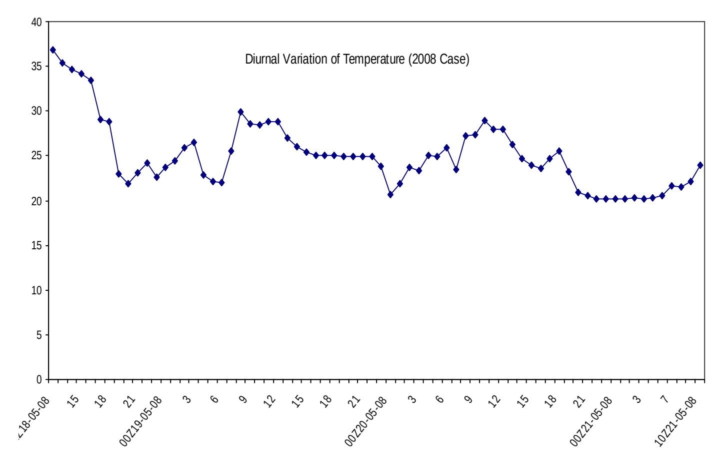

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Fig. 5(e). Diurnal variation of R.H (18-21 May, 2008) over Delhi

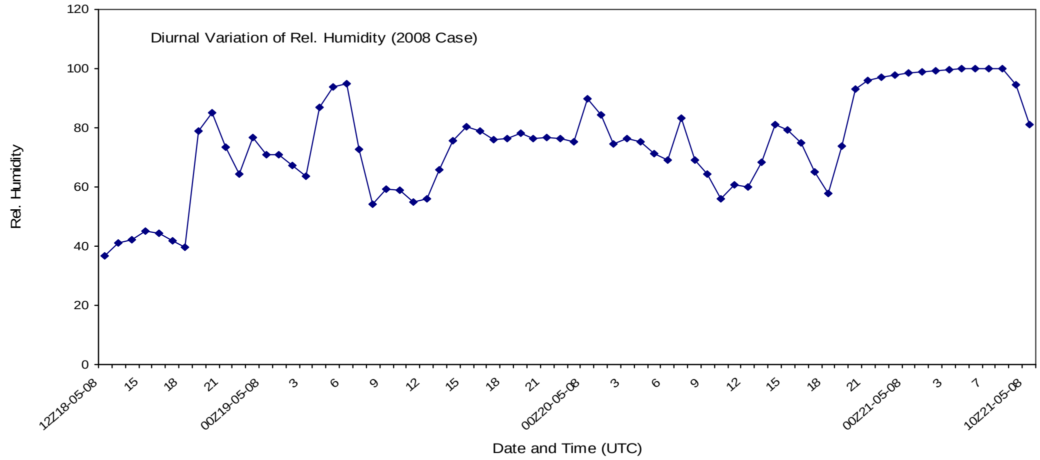


Fig. 6 (a). Daily variation of MODIS derived AOD (04 -08 May, 2009) over Delhi

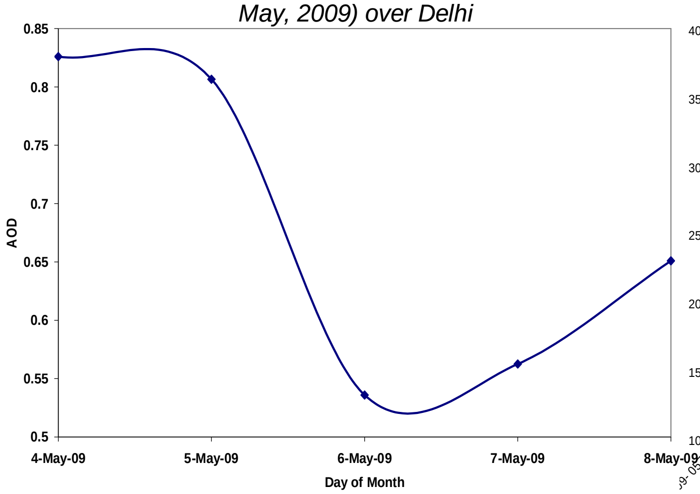


Fig. 6 (b). Diurnal variation of IPWV (04 - 08 May, 2009) over Delhi

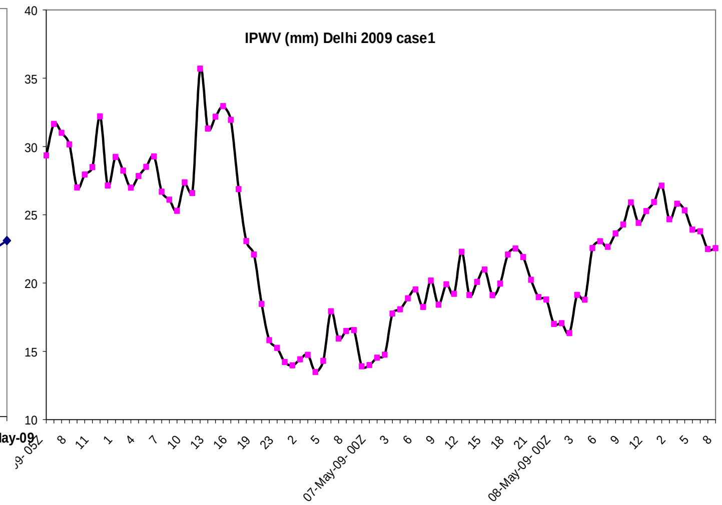


Fig. 6(c). Diurnal variation of Pressure (06-10 May,2009) over Delhi

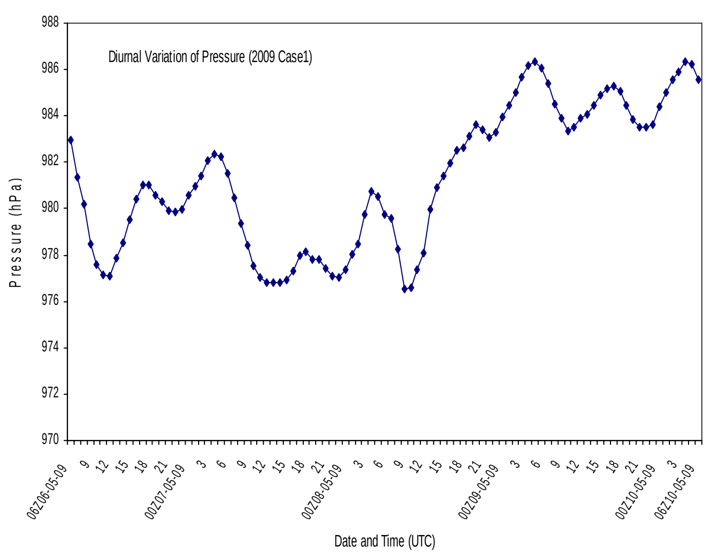


Fig. 6 (d). Diurnal variation of Temperature (06 May-10 June, 2009) over Delhi

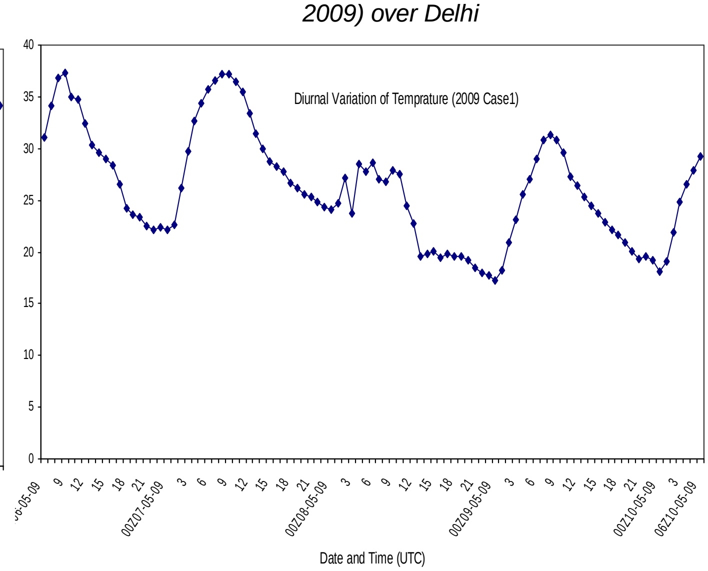


Fig. 6 (e). Diurnal variation of R.H. (30 May-01 June, 2009) over Delhi

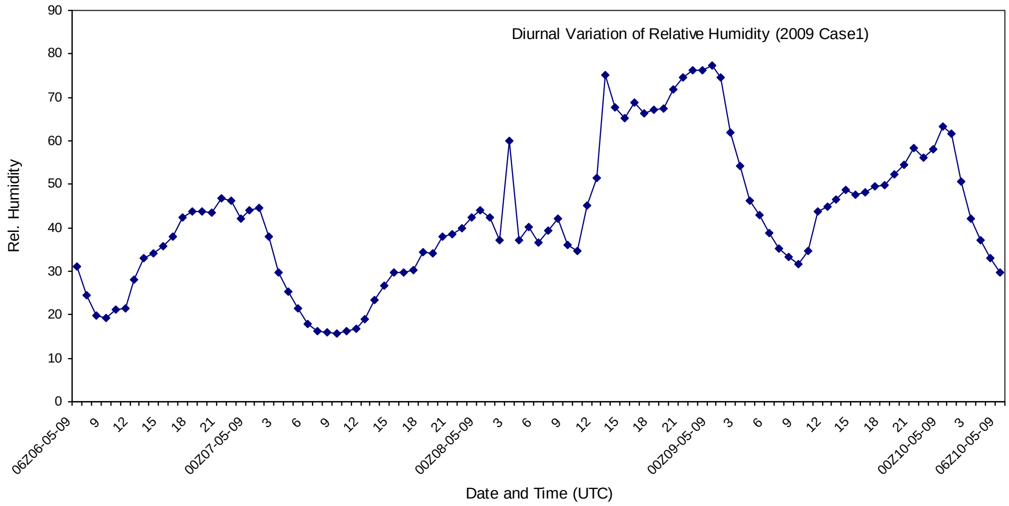


Fig. 7(a). Daily diurnal variation of MODIS, AOD (30 May-01 June, 2009) over Delhi

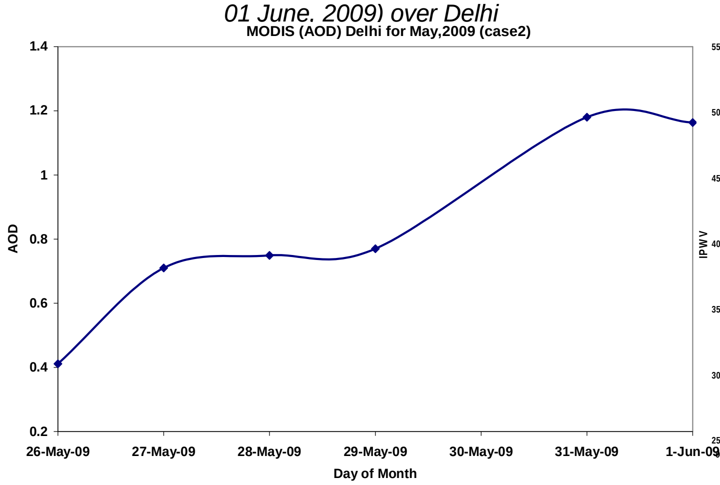


Fig. 7 (b). Diurnal variation of IPWV (30 May-01 June, 2009) over Delhi

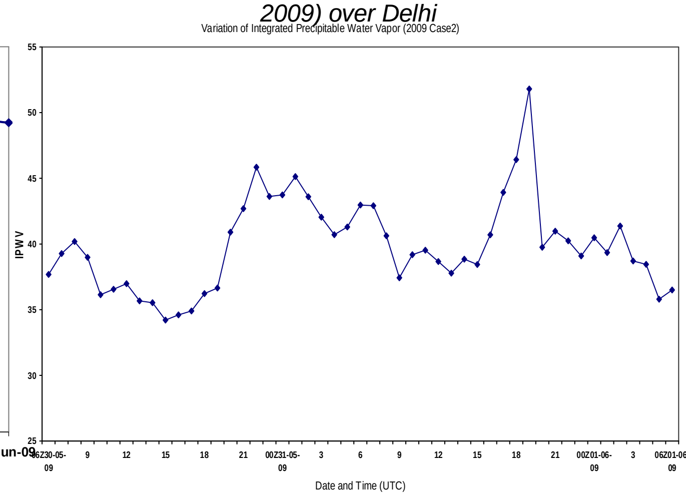


Fig. 7 (c). Diurnal variation of Pressure (30 May-01 June, 2009) over Delhi

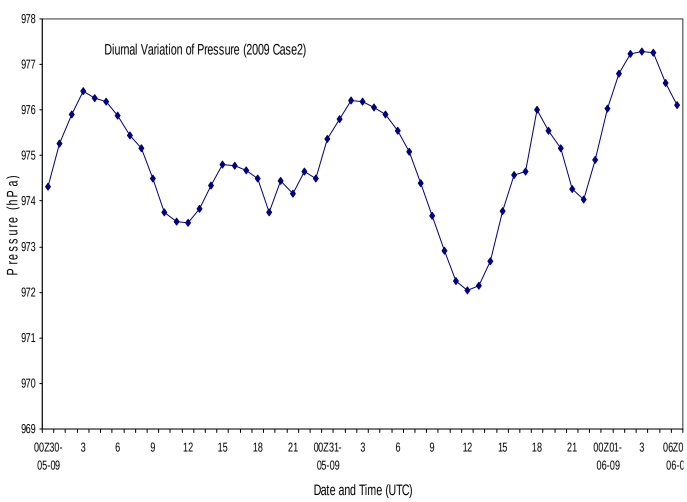


Fig. 7 (d). Diurnal variation of Temperature (30 May-01 June, 2009) over Delhi

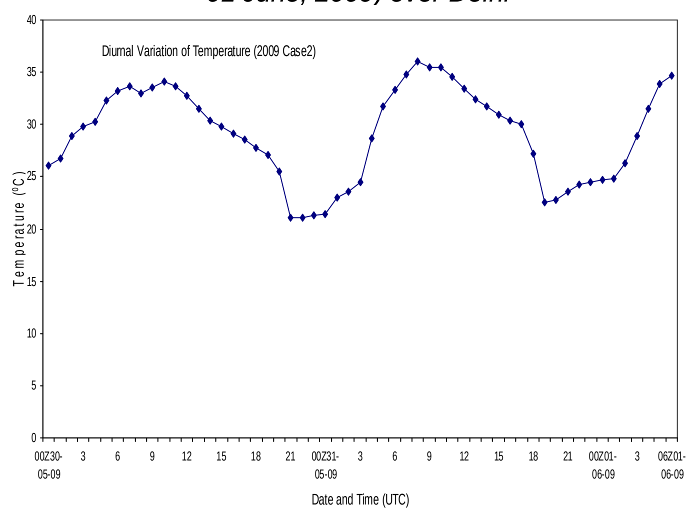
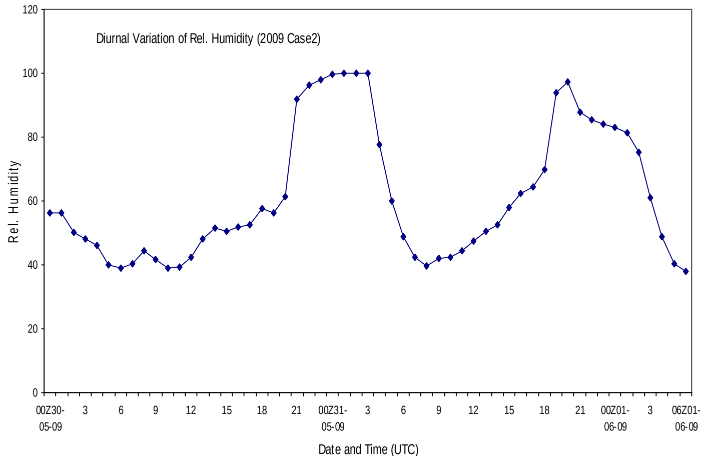


Fig. 7(e): Diurnal variation of R.H (30 May-01 June, 2009) over Delhi



increasing aerosol concentrations can enhance horizontally-averaged convective updraft strength.

Case studies of Delhi region

Three case studies of Delhi are isolated thundershowers during the pre-monsoon season. The convection building up starts at-least two hour prior to the events this is clearly evident by the trend of IPWV in 2008 and 2009 case1 and 2009 case2, which are shown in Figs. {5,6,7 (a-e)} respectively. The scavenging was found to be dependent on the particle size distribution; the larger, super micron particles were found to be removed faster during the first shower itself, even though it was of only moderate intensity, resulting in about a 64% decrease in the columnar mass loading (Saha & Krishna moorthy, 2004). The possible threshold value of IPWV noticed for the thunder event cases, which could provide rain during the month of May, is more than 35 mm and 38 for Delhi and Guwahati respectively. Changes noticed in other meteorological conditions like, relative humidity (~ 70 % increase), pressure (drop ~ 5 hPa in 2 to 3 hours), temperature (drop 5 -6 ^{0}C during 1 or 2 hours) and IPWV (~ 3 to 4 mm per hour). The possible increase of AOD is approximately 150-300 % during the time of thunder event which accompanied with duststorm. By monitoring hourly IPWV rate data at the observation site can be used, as an important tool for nowcasting the future thunder events as it shows an increase 2 -3 hours prior to the event.

Thermo -dynamical instability parameters

Convective available potential energy (CAPE) which represents the positive area in T-Θ gram, measures the total energy available to generate thunderstorms. The greater CAPE value, greater will be the energy available for thunderstorm generation.

The Lifted Index (LI) is simply the temperature difference between the environment and an ascending air parcel at the 500mb pressure level. A negative value indicates a parcel warmer than the surrounding environment, thus positively buoyant and favours the thunder events. GPS derived IPWV at observation site will tell about the moisture availability which could give the precipitation if other instability parameters permit or sufficient triggering will present. Atmospheric instability is essential to generate sufficient updrafts and support the mesoscale activity.

Showalter Index (SI) provides an estimate of the instability due to the difference between the 500mb temperature and the temperature an air parcel would acquire when lifted from 850mb to 500 mb. It is applied when use of the 850 mb level would be a better representation of atmospheric instability versus the surface based lifted index (e.g. cool surface temperatures). Total -total (TT) index measure of how buoyant the air parcel is due to less dense, moist air in the lower levels. The given case comes under the category of moderate to severe thunder events. K index is used to forecast of mass thunderstorms, In this case, a small dew point depression at 700 mb indicates a possibility for deep convection. If there is no significant moisture at 700mb then there is a greater chance that entrainment of dry air would occur, given a parcel were lifted from beneath the 700 mb level. If entrainment of dry air occurs, the parcel will become less buoyant (Bluestein, 1993). The quantification of available convection and magnitude of shear is expressed in terms of Bulk Richardson number, which is introduced by Weisman and Klemp (1982).Its value greater then 20 favors the convection. The values of sounding indices given in appendices are based on mainly USA environments. For tuning these parameters in Indian scenario, a large number of data sets are required.

Additional influx of natural aerosol particles due to high winds blows during the time of duststom which accompanying thunder also. Probably this will load more hygroscopic type of nuclei into the atmosphere and hence the value of AOD showing increasing trend during the time of thunder activity. For new refinements and better weather prediction we need regulatory measures to see the trends of aerosol concentration in time and its comparison with health and climate data. The influx of MODIS derived AOD also contain the man made pollutants that are hidden in the dust. Even after the rain of any thunder activity in pre-monsoon season the concentration of aerosols is not reduced drastically sometimes. One possible reason may be due to that rain is not the only medium of sinks of these nuclei. By increasing the observational studies we can refine the temporal and spatial distribution of aerosols predicted from models.

Concluding remarks

Water vapour convergence $\{\frac{d}{dt}(IPWV)\}$ acts as a proxy for few hours of time domain and its value increasing 3-4 mm/hour during the convective development of the mesoscale event. Thunderstorm in pre-monsoon season brings out essential rain contribution for the total precipitation. Radio sounding observations are available only twice a day and not fully representative of the local thunderstorm events. Moderate Resolution Imaging Spectroradimeter (MODIS) derived Aerosol Optical Depth (AOD) play an important role in modifying the local environment of the thunder activity. It shows the positive loading before the rainfall up to 150 -300 % increases in its value. This is possibly due to the increase of hygroscopic nuclei in the atmosphere. The decline of AOD after the thunder events, because most of the aerosol scavenge by the rain as the small size (Aitken type) of nuclei easily washed out by the rain. GPS derived IPWV data has a great potential in nowcasting applications as it is an indicator of convective development prior to the at least one or two hours. The sudden change in pressure, temperature and humidity also justify the bad weather occurrence and AOD and IPWV monitoring can acts good proxy to nowcast the event.

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