Sharp Depletion of Absolute Humidity associated with Squall over Kolkata (22°34′N, 88°26′E): A Possible Method of Forecasting Squall.

U. Saha, M.Sc.[1]**; S.K. Midya, Ph.D.**[1]***; H. Sarkar, Ph.D.**[2]**; and G.K. Das, M.Sc.**[3]

[1]Department of Atmospheric Science, University of Calcutta,
51/2 Hazra Road, Kolkata-700019, West Bengal, India
[2]Centre for Microwave and Millimeter Wave Research and Training, Institute of Radio Physics and Electronics, University of Calcutta, 92 A. P. C. Road, Kolkata- 700009, West Bengal, India
[3]Regional Meteorological Centre, Kolkata, West Bengal, India

E-mail: drskm2011@gmail.com*****
upalsaha22@gmail.com

ABSTRACT

The paper presents the nature of the variation of absolute humidity of the atmospheric medium with time before, during, and after the onset of squall with thunderstorms, only squall event, squall but no thunderstorm days, and normal days having no squall or thunderstorm over Kolkata, West Bengal, India (22°34′N, 88°26′E) during the pre-monsoon period. A critical analysis shows that a sharp depletion of the atmospheric absolute humidity takes place before the onset of squall occurrences which can be a possible method for forecasting the phenomena. Possible explanations are also offered for the said occurrence.

(Keywords: absolute humidity, squall, thunderstorm, pre-monsoon, forecast).

INTRODUCTION

Forecasting mesoscale phenomena have been a challenge to atmospheric scientists since imposing boundary conditions to mathematical equations of mesoscale phenomena (e.g. thunderstorms) are not permitted due to the comparable values of zonal and meridional components. Hence, forecasting these phenomena numerically has been a serious and tedious job.

It is well-known that the threat level of only thunderstorm is lesser than those associated with squall. The high-velocity winds in reality are aviation-hazards while aircraft is in flight and very dangerous during landing. A squall is a sudden, sharp increase in wind speed which is associated with thunderstorms or heavy rain showers. Thus, squalls refer to an increase in the sustained winds over a short time interval, usually occurring in a region of strong mid-level height falls, or mid-level tropospheric cooling, which force strong localized upward motions at the leading edge of the region of cooling, which then enhances local downward motions just in its wake. These high velocity winds whose speed increases by at least three stages on the Beaufort scale – the velocity rising to force 6 (22-27 knots / 41-47 kmph) or more and lasting for at least one minute in duration.

Currently, the squall forecasting efficiency is not high enough. This can be partially explained by the fact, as given by Vasil'ev, et al. [1], that the squalls are mainly missed by the sparse observational network, low accuracy of measurements, and indirect estimation of wind speed, as well as higher complexity of the process, its parameterization, and a whole complex of factors which cause formation of squalls. Radar reflectivity in squalls is usually greater at the level of precipitation than that of crystallization initiation and mass crystallization. If the radar reflectivity at the third level is not available, the reflectivity at lower levels should be used in squall forecasting, shown by Ananova, et al. [2].

All the squall lines form in a conditionally and convectively unstable atmosphere which is characterized by strong vertical shear and turning off the shear vector with height at low levels, and weaker shear and only slight turning aloft. There is more variability in the environmental hodographs aloft than at low levels, observed by Bluestein and Jain [3]. Besides Mitra [4] mentioned that there is a close relation between barometric height, tropospheric weather and ionospheric parameters of the upper atmosphere. It was observed that minimum height of F region and average E ionization tend to follow the variation of barometric height.

The fall in surface temperature and increase in relative humidity with thunderstorm is a normal trend. Midya, et al. [5] presented the nature of the variation of refractive index of atmospheric medium with time and altitude before, during and after the onset of thunderstorms over Gangetic West Bengal during the pre-monsoon period showing that a sharp depletion of the atmospheric refractive index taking place before the onset of Nor'westers.

A squall line is defined operationally as any line or narrow band of active thunderstorms. Moreover, the squall lines are generally observed to last several hours. These two basic features sharply distinguish the squall line from the more commonly observed mode of precipitating cumulus convection in which rain showers are widely scattered and intermittent, given by Rotunno, et al. [6].

The temperature, pressure, relative humidity changes during the onset of thunderstorm period causes in homogeneity of the refractive index in the atmosphere, which in some cases may result in anomalous propagation. As a result, there may be chances for super refraction and ducting may occur. These effects mainly occur in almost horizontal propagation paths near the earth's surface. When microwave propagates through the atmosphere, the dipole moment of water vapor molecule will be induced and reorient themselves according to the polarity of propagations. As a result, refractive index of the atmosphere will be changed, as shown by Midya, et al. [5].

Midya, et al. [7] also showed that the sharp depletion of attenuation at 22.235 GHz before the onset of a Nor'wester may be one important observation to forecast thunderstorm over Gangetic West Bengal. This paper presents the sharp depletion of absolute humidity associated with squall over Kolkata (22°34′N, 88°26′E) as a possible method of forecasting the phenomenon. Because these drastic winds in reality are a cause of aviation hazards while aircraft is in flight and are equally very dangerous during landing of the aircraft and thus a reason of serious concern and an important sector to be forecasted.

DATA AND METHODOLOGY

The surface relative humidity data over Kolkata (22°34′N, 88°26′E) is taken from the website http://www.uwyo.edu (University of Wyoming). Liebe [8] presented one empirical equation which is helpful to calculate absolute humidity of a particular squall-event day and non-squall day. To calculate the absolute humidity we consider the atmospheric temperature T (^{0}C) and relative humidity in percentage as input parameters. Using a relative inverse temperature variable (Φ) defined as $\Phi = 300/(T+273.15)$; and water vapor pressure (e) is defined as $e = 2.408 \times 10^8 \times U \times \Phi^4 \times \exp(-22.64\ \Phi)$ in kPa where U represents relative humidity in percentage, we ultimately get the expression for absolute humidity as:

$$V = 7.223 \times e \times \Phi \text{ (in g/m}^3\text{)} \quad \textbf{(1)}$$

We have considered the relative humidity of some particular dates (27.03.2010, 09.05.2010, 24.05.2010, 26.05.2010, 26.04.2010, 02.05.2010) having squall with thunderstorm events for the first three successive dates, only squall event occurring on the next date and thunderstorm but no squall events for the last two dates respectively and a normal day is considered for our analysis to validate the sharp depletion of absolute humidity occurring only before the onset of squall phenomena.

RESULTS AND DISCUSSION

1. Sharp Depletion of Absolute Humidity during Squall with Thunderstorm events:

Atmospheric moisture field is one of the important features for the generation of convective events. Sufficient moisture in the atmosphere is a primary ingredient for severe convection. The high surface temperature and intense convective activities are the characteristics of this pre-monsoon season. Development of convective storms depends on the presence of environmental conditions favorable for the development of deep convection. The essential ingredients for the occurrence of local severe storms are the presence of deep layer instability (convective or potential instability) in a warm and humid air mass, characterized by relatively high surface dew point temperatures, low surface dew point depressions and a relatively 'Lifting Condensation Level' (LCL), high values of Convective Available Potential Energy (CAPE) and low values of Convective – Inhibition Energy (CINE). An increased supply of moisture in the boundary layer by a favourable atmospheric flow coupled with warm air advection in the lower levels and cold air advection in the upper levels helps to enhance and maintain the convective instability, described by Srinivasan, et al. [9].

Figure 1 (a-c) shows the nature of variation of percentage absolute humidity with the time (in I.S.T.) of occurrence of squall associated with thunderstorm events at three different pre-monsoon dates (27.03.2010, 09.05.2010 and 24.05.2010) over Kolkata, Gangetic West Bengal. These figures indicate a sharp depletion of percentage absolute humidity during the event of occurrence. It is due to the fact that prior to the squall with thunderstorm event, there is a sharp fall of humidity in the atmosphere due to convective instability.

Kolkata is a tropical region and its surface is heated by absorbing solar radiation during daytime. Air in contact with the Earth surface begins to rise after absorbing water molecules. When the moist air goes upward, the air parcel expands adiabatically and becomes cooler; as a result of which, clouds are formed. The released latent heat increases the pressure of the upper atmospheric layer. This will create a positive feedback and the system will develop significantly if sufficient moisture is available and a cumulonimbus cloud is formed. At the matured stage, there will be downdraft of cold dry air as the rising warm air-parcel has lost all its moisture after reaching its critical height which depends on its moisture content. The dry and denser air during its downward sinking generates squall at the surface. Before onset of squall, there will be an increase of surface pressure, fall in surface temperature and minimum availability of water vapor occur.

2. Sharp Depletion of Absolute Humidity during only Squall event:

Figure 2 shows the nature of variation of percentage absolute humidity with the time (in I.S.T.) of occurrence of squall event at a pre-monsoon date (26.05.2010) over Kolkata, Gangetic West Bengal. It indicates a sharp depletion of percentage absolute humidity during the severe squall event.

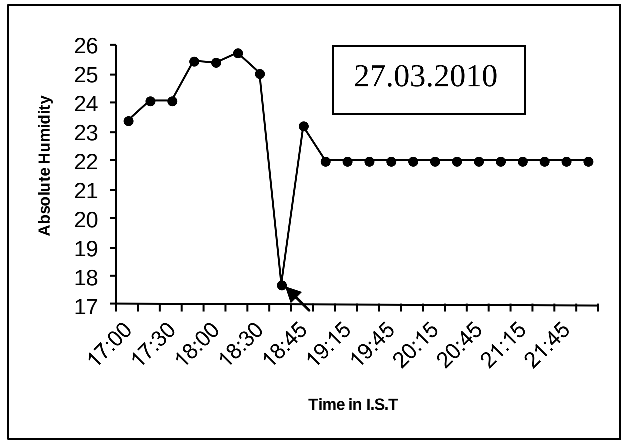

Figure 1 (a)

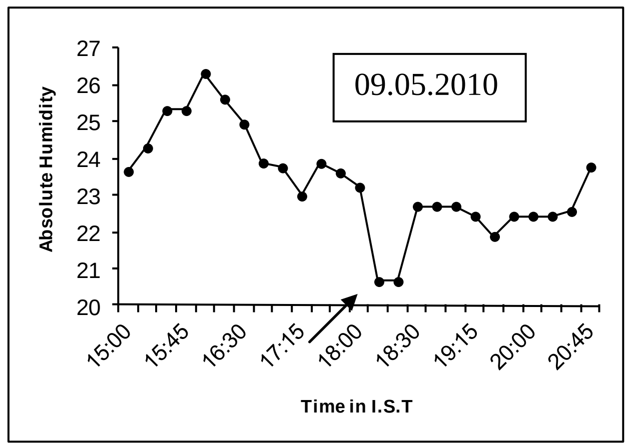

Figure 1 (b)

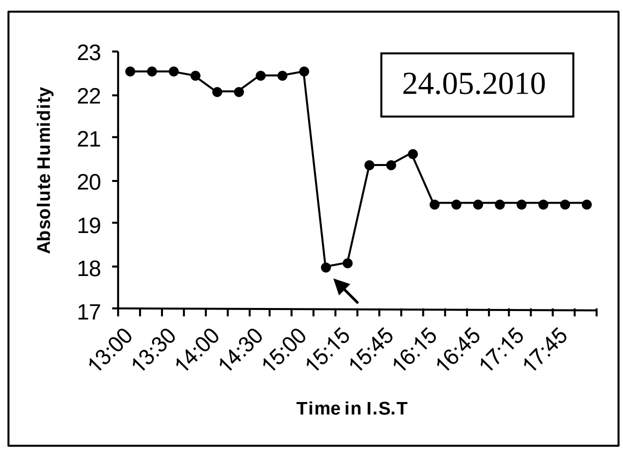

Figure 1 (c)

Figure 1: Sharp depletion of absolute humidity during squall with thunderstorm events (Arrow mark indicates the time of onset of squall).

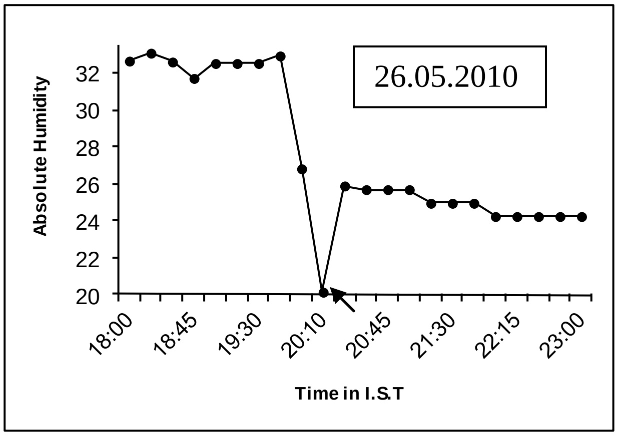

Figure 2: Sharp depletion of absolute humidity during only severe squall event (Arrow mark indicates the time of onset of squall).

Initiation of deep convection associated with Nor'wester can be connected to the favorable thermodynamic environment, created by synoptic scale flow, and sufficient lift, usually provided by mesoscale process, shown by Srinivasan, et al. [9].

Ghosh, et al. [10] analyses the horizontal moisture discontinuity line, and zones of moisture concentration have been identified by analyzing the horizontal distribution of moisture. As the moisture is an important ingredient in the development of severe thunderstorm, it is expected that the evolution of atmospheric moisture field in lower as well as mid-upper levels during the pre-storm hours itself contains some useful signatures of convective initiation. At least two mechanisms operate in moving thunderstorm for the sudden drop of absolute humidity during the onset of a thunderstorm over a station and these mechanisms may be explained as the turbulence produced at the leading edge of the wind front mixes dry air at the top resulting in a drop in surface moisture and also in the initial stage of downdraft, the air is evaporating and thus cooled but devoid of any moisture, given by Midya and Sarkar [11].

Ghosh, et al. [10] also analyzed the vertical and horizontal distributions of moisture in initial outbreak of Nor'wester. The low-level moist air and mid-tropospheric dry air create a convectively unstable pre-storm environment (Srinivasan, et al. [9]; Doswell [12]-[13]). Srinivasan, et al. [9] found that convective (also known as potential instability) and conditional instabilities are the pre-conditions for the development of Nor'wester or squall event.

3. Variation of Absolute Humidity during Squall but no Thunderstorm events:

Figure 3 (a-b) shows the nature of variation of percentage absolute humidity with the time (in I.S.T.) of occurrence of squall but no thunderstorm events at two different pre-monsoon dates (26.04.2010 and 02.05.2010) over Kolkata, Gangetic West Bengal. These figures indicate no indicative sharp depletion of absolute humidity prior to the event of occurrences rather a depletion of absolute humidity during the squall event. The variation of vertical distribution of moisture determines the conditional and convective instabilities. Severe convective events are associated with the strongest vertical motions observed in any atmospheric phenomenon.

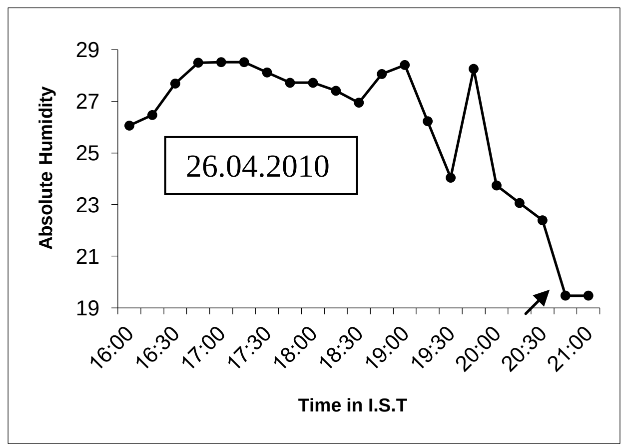

Figure 3 (a)

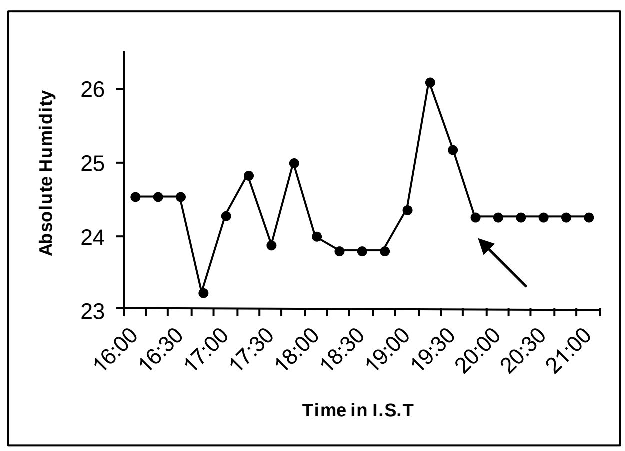

Figure 3 (b)

Figure 3: Variation of absolute humidity during squall but no thunderstorm events (Arrow indicates the time of onset of squall).

4. Variation of Absolute Humidity during a Normal Day with no Squall and Thunderstorm events:

Figure 4 show the nature of variation of percentage absolute humidity with the time (in I.S.T.) during a normal day with no squall and thunderstorm events over Kolkata, Gangetic West Bengal. The figure has no such sharp depletion of absolute humidity with time. This validates that the sharp depletion of absolute humidity occurs only before the onset of squall phenomena and not on any normal day having no squall or thunderstorm events.

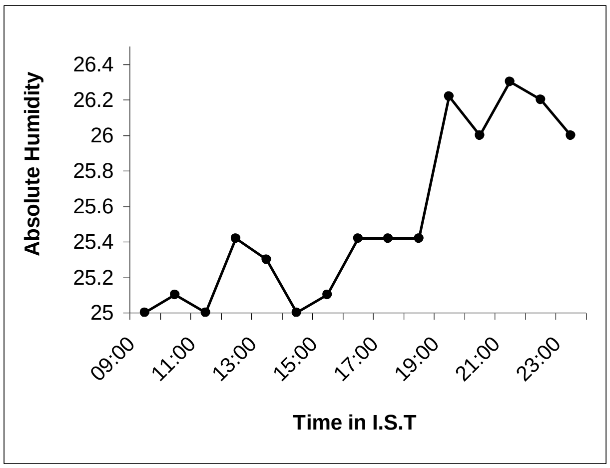

Figure 4. Variation of absolute humidity during a normal day with no squall and thunderstorm events.

CONCLUSION

Mukhopadhyay, et al. [14] and Suresh and Bhatnagar [15] have reported that CAPE does not trigger convection, especially over north-east India, on most of the days during pre-monsoon season despite the presence of large magnitudes. In any case, CAPE does not provide clue to the most likely type of mesoscale organization. In that case, our study will become helpful and may be a possible method in forecasting squall by analyzing the sharp decrease of absolute humidity before the onset of squall over Kolkata, which is due to the decrease of water molecules in vapor state. It may be a helpful forecasting method for the aviation sector, where the flight-hazards created during the flow of high-velocity winds associated with thunderstorm.

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ABOUT THE AUTHORS

Dr. Subrata Kumar Midya, is an Associate Professor in the Department of Atmospheric Science, University of Calcutta and Honorary Associate Professor of Indian Centre for Space Physics, Garia Station Road, Kolkata. He was a reader in Serampore College (University of Calcutta).He acted as Research Guide to three students and they have obtained Ph.D. degrees under his guidance. He has published more than 80 research papers in different refereed journals and a number of research papers are under review or in press. His research interests are airglow emission, ozone depletion, solar physics, earthquake-related problems, and different tropospheric processes.

Mr. Upal Saha, completed his M.Sc. in Atmospheric Sciences from Department of Atmospheric Sciences. He is a Research Scholar at Calcutta University now and pursuing his Ph.D. studies. He had 6 published papers in International and National journals and a number of papers are under consideration for review purposes in different peer-reviewed journals. His research interests are in the areas of solar control on different atmospheric parameters and phenomenon such as Indian summer monsoon rainfall, thunderstorm and lightning occurrences, and the atmospheric chemical kinetics of ozone-related problems.

Dr. Himangshu Sarkar, completed his Ph.D. degree from Javavpur University. He joined as a Research Associate of the Centre for Microwave and Millimeter Wave Research and Training, Institute of Radio Physics and Electronics, University of Calcutta. He has published more than twenty journal papers. His research interests are airglow emission, ozone depletion, solar physics, earthquake-related problems, and different tropospheric processes.

Mr. Ganesh Kumar Das is the Meteorologist Grade-I in India Meteorological Department, Alipore, Kolkata. He had published 5 research papers in national journals and a number of papers are under review in different journals. His research interests are in the areas of atmospheric physics, meteorology, and ozone-related problems.

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