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An account of low level wind shear over Chennai airport - Part I : Observation and forecasting aspects

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सार – निम्न स्तर पवन अपरूपण (एल. एल. डब्ल्यू. एस.) विमानन के लिए एक आपदा है। चैन्ने हवाई अडडे में वर्ष 1987 से 2007 (1992 और 1993 की अवधि की रिपोर्ट के आँकड़े विश्लेषण के लिए आसानी से उपलब्ध नहीं है) तक विमानन कार्मिकों द्वारा रिपोर्ट किए गए एल. एल. डब्ल्यू. एस. के मामलों का विस्तारपूर्वक विश्लेषण किया गया है। एल. एल. डब्ल्यू. एस. की घटना के होने के अधिक अनुकूल समय/अवधि के आँकड़ तैयार किए गए हैं जिससे मौसम की अद्यतन रिपोर्ट में एल. एल डब्ल्यू. एस. चेतावनी जारी की जा सकती है। एल. एल डब्ल्यू. एस. के रिपोर्ट किए गए मामलों के रिचर्डसन नम्बर और टरब्यूलेंस इंडेक्स (टी. आई.) का आकलन किया गया है और इन तापगतिकीय सूचकांकों की क्षमताओं के आँकड़ें रिकॉर्ड किए गए हैं। सक्रिय सामान्य/ भीषण एल. एल डब्लयू. एस. के मामले भी देखे गए है, जो 10 घंटे से भी अधिक समय तक रहे, जबकि ऐसा माना जाता है कि एल. एल डब्ल्यू. एस. कम समय तक रहने वाली परिघटना है। इस शोध पत्र में समुचित चेतावनी नीति तैयार करने के लिए विस्तृत एल. एल डब्ल्यू. एस. आँकड़ा आधार तैयार करने की आवश्यकता के बारे में बताया गया है।

ABSTRACT. Low level wind shear (LLWS) is an aviation hazard. LLWS cases reported by the air crews over Chennai airport from 1987 to 2007 (barring 1992 and 1993 during which period no report is readily available for analysis) have been analysed threadbare. The most favourable time / period of occurrence of LLWS have been documented which has prophylactic value to issue LLWS alert in current weather reports. Richardson number and turbulence index (TI) have been computed for the reported cases of LLWS and the efficacies of these thermodynamical indices have been documented. There were cases of active moderate / severe LLWS cases lasting even beyond 10 hrs duration in contrary to the general belief that LLWS is a short lived phenomenon. The urgency / necessity of having a sizeable LLWS database to devise a suitable warning strategy have been highlighted.

Key words – Chennai airport, low level wind shear, Richardson number, Turbulence index, Doppler Weather Radar, METAR, Three dimensional shear.

1. Introduction

Wind shear is the change in wind, in direction or speed or both, over a short distance either laterally or vertically. In operational aviation meteorology, the most common definition for wind shear is an abrupt change in direction and/or velocity of wind. The wind shear may be associated with thunderstorms, temperature inversions or surface obstructions and fronts in extra-tropics. The most hazardous form of wind shear is that encountered in thunderstorms. The severe, sudden wind changes can exceed the performance capabilities of many sophisticated aircraft. There have been numerous documented cases of aircraft mishaps associated with wind shear [Fujita and Caracena, 1977; Federal Aviation Administration (FAA), 1979; DiMarzio *et al*., 1979; International Civil Aviation Organisation (ICAO), 1983]. The vectorial change in wind often create eddies, swirls of air which cause turbulence. The performance of an aircraft (more specifically the touch-down, landing and take-off phases of operation) is affected by the change in wind direction or velocity or both. While the wind shear observed in vertical or lateral directions in the boundary layer during the landing / take-off phases of aircraft operations often end up in a aircraft incident or accident (Fujita and Caracena,1977; Fujita, 1980), the same during cruising phase at higher altitudes may result in drastic losing of altitude, inconvenience to the passengers by way of turbulence.

Wind shear of magnitude as high as 417 × 10^{-3} s^{-1} (25 ms^{-1} in the first 60m a.g.l) have been documented [International Civil Aviation Organisation (ICAO), 1983]. These strong shears are often associated with gust front from thunderstorms. Though an aircraft can recover from the loss of altitude due to strong shears encountered at higher altitudes, considerable loss of altitude leading to

TABLE 1

Observation of low level wind shear by air crews over Chennai airport, 1987-2007 (except the no data period 1992-1993)

Year	Wind shear reported by aircrews during the time interval (UTC)								Total
	A	B	C	D	E	F	G	H	
1987	1	2	4	3	3	4	1	0	18
1988	0	3	2	2	2	3	0	0	12
1989	1	1	3	1	4	3	0	0	13
1990	1	3	3	2	5	2	2	0	18
1993	1	2	0	1	0	0	1	0	5
1994	0	0	0	0	2	0	1	0	3
1995	0	0	1	1	1	3	1	0	7
1996	0	0	1	0	0	0	1	0	2
1997	1	5	3	1	10	7	1	0	28
1998	9	2	4	1	4	2	0	2	24
1999	3	1	0	1	4	2	1	1	13
2000	1	1	3	2	5	3	1	1	17
2001	0	4	0	1	2	5	0	0	12
2002	0	0	0	2	3	10	0	3	18
2003	0	5	1	1	1	1	0	1	10
2004	0	0	1	1	0	1	0	0	3
2005	1	0	0	1	0	0	1	1	4
2006	0	0	0	1	0	1	0	1	3
2007	1	1	3	1	1	2	1	1	11
Total	20	30	29	23	47	49	12	11	221

Note : A : 0000-0300 UTC; B : 0300-0600 UTC; C : 0600-0900 UTC; D : 0900-1200 UTC; E : 1200-1500 UTC; F : 1500-1800 UTC; G : 1800-2100 UTC; H :2100-2400 UTC.

aircraft incidents / accidents may occur when wind shear occurs at lower atmosphere in view of non-availability of space and time for the pilot to act. Hence, the pilot is expected to detect, predict and avoid severe wind shear conditions as the airplanes may not be capable of safely penetrating through all intensities of low level wind shear (LLWS). Hence a pilot accords much importance to LLWS rather than the wind shear experienced at higher levels albeit he avoids it at all levels for a safe and smooth air navigation.

ICAO (2004) envisages the observation of LLWS by the air crews and reporting the same to the local air traffic services as in-flight report so that subsequent flights can be warned. The life time of the shear is very minimum (say a maximum of few minutes) but its catastrophic effect is very high. As the exploration of vertical atmosphere is limited to two observations every day through radio sonde/radiowind (RS/RW) technique, prediction of wind shear to a reasonable degree of accuracy is somewhat limited. Hence the in-flight report on wind shear serves not only as the basic input for the meteorologists to issue trend forecast for the next few hours but also serves as a database to devise a warning strategy when sufficient input is received for the air field concerned. The utility of Doppler Weather Radar (DWR) to issue wind shear alert has been well documented in literature (see for example, Browning, 1982; Wilson *et al*., 1984; Eilts, 1987; Doviak and Zrnic, 1992, Fujita, 1990; Sauvageot, 1992; Lau *et al*., 2002; Cheng, 2002; Raghavan, 2003; Suresh, 2004, 2006 and 2007; among others).

An attempt has been made in this study to tabulate the available in-flight wind shear reports with a view to identify the most favourable period during which wind shear is active over Chennai airport. The most favourable cause for wind shear also has been studied using RS/RW data. The analysis, it is hoped that, will have prophylactic value for the operational aviation meteorologists to issue LLWS alert and TREND forecast in the current weather reports (METARs and SPECIs).

2. Data used

The in-flight LLWS reports that were received during 1987-2007 (barring 1992 and 1993 during which period no LLWS report is reaily available) have been analysed in this study. The low level 0000 and 1200 UTC upper air data have been collected from Chennai RS/RW station for the same period to work out the Richardson Number, turbulence index and instability condition of the lowest atmosphere. A state-of-the art DWR has been put into operation use w.e.f 20th February 2002 at Cyclone Detection Radar station of IMD, Chennai. The Chennai DWR data from 2002 to 2007 have been thoroughly analysed for the reported wind shear periods.

3. Methodology

The in-flight LLWS reports have been critically analysed to identify the most favourable time interval, if any, for the wind shear over Chennai airport. After this analysis, Richardson Number (Keitz, 1959; Colson, 1963; Keller, 1981; Ellrod and Knapp, 1992; Asnani, 1993) have been computed using the 0000 and 1200 UTC RS/RW data to find out the threshold of Richardson number conducive for LLWS. Turbulence Index (TI) as a forecasting tool have been used for forecasting non-convective / clear air turbulence of moderate and severe intensity (see for example, Endlich and Mancuso, 1965; Ellrod and Knapp, 1992, WMO, 1993; ICAO, 2004). Hence TI has been computed for the reported LLWS cases using 0000 and 1200 UTC RS/RW data of Chennai. The radial velocity data obtained from volume scans of DWR have been used to compute the radial, azimuthal, elevation, three dimensional shear for a period at least two hours prior to the reporting of LLWS by the aircrews during 2002-2007.

3.1. *Observation of LLWS*

The incidences of LLWS reported by the aircrews through air traffic controllers have been classified into three hourly time interval and tabulated in Table 1. As per prevailing guidelines (WMO, 1993; ICAO, 2004), LLWS reported by an aircraft may be used as supplementary information in current weather aviation Met. reports (METAR) for the next two hours to alert the air crews. Hence, multiple reports received within two hours of the first report have been considered as a single LLWS incidence. In all 221 cases only had been reported during 1987-2007 barring 1991 and 1992 during which period no data is available for analysis. The LLWS frequency accounts to a meager 0.03% of mean operations per day from Chennai airport as these reports depend upon the interest and working condition of the air crew concerned who is under pressure to safely land / take-off when encountering such wind shear conditions. In other words, though the air crew might have experienced LLWS he might not have reported the same to the air traffic controllers by over sight or might have considered as a routine phenomenon and/or not fit to be reported. Nonetheless, reporting of such in-flight reports over Chennai is quite comparable with those documented in major international airports. For example, Hong Kong international airport which has been assigned special task of issuing LLWS alert by ICAO has recorded 0.14% of mean daily operations during the campaign period (Cheng, 2002).

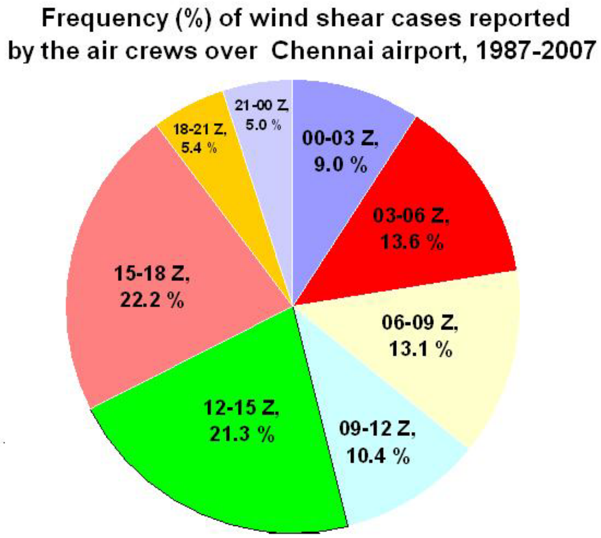


Fig. 1. Percentage frequency distribution of low level wind shear cases reported at different time periods of their observation over Chennai airport, 1987-2007 (barring 1991-1992)

The percentage frequency distribution of LLWS during different time periods of observation have been shown in Fig. 1. From Table 1 and Fig. 1, it can be seen that LLWS were reported at all time periods of the day albeit the maximum number of wind shear incidences have been reported from 1200 to 1800 UTC. As the LLWS reports were considerably decreasing since 2004 in comparison to those reported during the epoch 1997-2002, air lines were periodically reminded through various forums on the necessity and urgency of reporting LLWS during 2005-2007 for devising suitable warning strategies that ultimately may help airline operations.

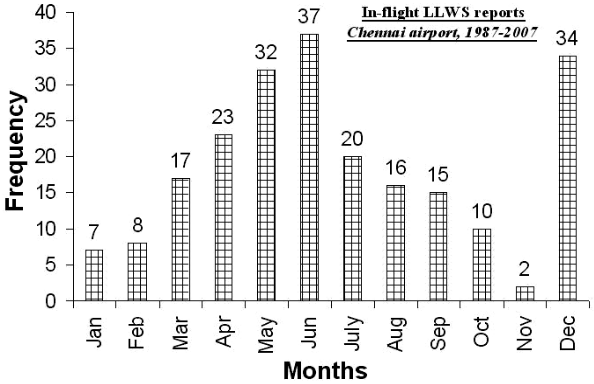


Fig. 2. Month-wise frequencies of low level wind shear reported over Chennai airport during 1987-2007 (barring 1991-1992)

Further analysis of the reported LLWS revealed that maximum number of incidences have been observed during June, December and May while significant number of cases have been reported during March – April and July – September as well. Fig. 2 displays the month-wise LLWS frequency. In contrary to the expectation that least number of LLWS may occur during winter (January – February) when stable atmospheric condition prevails, the least number of cases have been observed during November whence the steady northeast current prevails over Chennai.

3.2. *Predictability of LLWS using Richardson number*

Richardson number (R_i) which is the ratio of static stability of the atmosphere to the square of vertical shear of horizontal wind has been used by various authors to explain the occurrence of turbulence, especially the clear air turbulence (CAT). Mathematically R_i has been defined as

$$R_i = \frac{\frac{g}{\theta}\left(\frac{\partial \theta}{\partial z}\right)}{\left(\frac{\partial u}{\partial z}\right)^2}$$

$$= \frac{\text{Static stability}}{\text{Square of vertical shear of horizontal wind}}$$

TABLE 2

Predictability of low level wind shear over Chennai during 1987-2007 (barring 1991 and 1992) based on Richardson number

Year	Wind shear *vis-à-vis* Richardson number: Predicted correctly	Missed	Total
1987	8	10	18
1988	7	5	12
1989	6	7	13
1990	14	4	18
1993	5	0	5
1994	3	0	3
1995	4	3	7
1996	2	0	2
1997	23	5	28
1998	15	9	24
1999	8	5	13
2000	13	4	17
2001	8	4	12
2002	17	1	18
2003	6	4	10
2004	3	0	3
2005	3	1	4
2006	3	0	3
2007	9	2	11
Total	157	64	221

where θ is the potential temperature, u is the horizontal component of wind and z is the height. Dutton (1971) has viewed the Richardson number as a ratio of the buoyancy resistance to the energy available from the wind shear (Keller, 1990). Richardson number is a dimensionless number. The computed R_i below a critical threshold limit explains the condition favourable for the onset of turbulence since the kinetic energy of unit mass exceeds the static stability of the atmosphere. Literature survey reveals that different threshold values of R_i (such as $R_i < 0.25$, $R_i < 0.5$, $R_i < 0.6$, $R_i < 0.65$ and $R_i < 1.0$) have been considered by various authors to predict the atmospheric turbulence (Keitz, 1959; Colson, 1963; Endlich, 1964; Keller, 1981; Asnani, 1993; Ellrod and Knapp, 1992; to name a few). As the static stability has to be overcome by the kinetic energy, in this paper we have considered $R_i < 1$ as the threshold to diagnostically compare the reported turbulence associated with wind shear.

R_i has been computed using 0000 and 1200 UTC RS/RW data for all those days on which LLWS were reported. The computed R_i was considered for assessing its predictability when the LLWS was reported upto a lead time of ten hours from the RS/RW observation time. However, for reported LLWS cases between 1000 and

TABLE 3

Predictability of low level wind shear through Richardson Number during specified time interval, Chennai airport, 1987-2007 (barring 1991-1992)

	Predictability of Wind shear through Richardson Number during the time interval (UTC)								
Item	A	B	C	D	E	F	G	H	Total
Predicted correctly	10	17	20	13	38	42	8	9	157
Events missed	10	13	9	10	9	7	4	2	64
% of success in prediction	4.5	7.7	9.0	5.9	17.2	19.0	3.6	4.1	71.0

Note : A : 0000-0300 UTC; B : 0300-0600 UTC; C : 0600-0900 UTC; D : 0900-1200 UTC; E : 1200-1500 UTC; F : 1500-1800 UTC; G : 1800-2100 UTC; H :2100-2400 UTC.

TABLE 4

Predictability of low level wind shear through Richardson Number in specified layers, Chennai airport, 1987-2007 (barring 1991-1992)

	Layer height (m)						
	< 90	90-150	150-300	300-450	450-600	> 600	Total
Predicted	71	11	29	17	9	20	157
Missed	29	19	11	3	1	1	64
Total	100	30	40	29	10	21	221

1200 UTC, 1200 UTC based R_i was considered and for LLWS cases between 2200 and 0000 UTC, 0000 UTC based R_i was considered as they are good representatives of the prevailing atmospheric conditions during the LLWS. The year-wise predictability of LLWS based on R_i has been tabulated in Table 2.

It can be seen that 71% of the LLWS incidences were predicted by R_i. This predictability gives a good signal that R_i can be used as a tool to issue LLWS warning, as otherwise the national aviation meteorological services currently use the reported observation of a LLWS as supplementary information for the next two hours in their current weather reports (METARs) as per prevailing practice and guidelines of ICAO (WMO, 1993; ICAO, 2004). Though it is generally stated that wind shear is a short lived phenomenon, there are occasions in which wind shear acted for more than 10 hours over Chennai. A typical case will be discussed later in section 5.

All the 157 LLWS correctly predicted by Richardson number have been subjected to further analysis and the results have been summarized in Table 3. It is seen that the maximum predictability was based on 1200 UTC RS/RW data with a lead time up to 6 hours. Incidentally, it may be a matter of interest to note that the frequency of LLWS is also high during the same time interval, *viz*., 1200 – 1800 UTC. The layers in which the LLWS were reported by the air crews and their predictability have been classified and shown in Table 4. It can be seen that 100 out of 221 incidences have been reported in the lowest 300 ft (90m) of the atmosphere. Out of these 100 incidences of LLWS, 71% were predicted using Richardson Number. Of the 29% of the incidences that were missed, no data was available within the lowest 90m for 21% of the cases. This suggests that for predicting LLWS, the forecaster should have the upper air data in the boundary layer at a very fine resolution.

3.3. *Thermally induced turbulence and shear induced turbulence*

Based on elementary thermodynamics, Richardson number can be re-written as follows.

$$R_i = \frac{\frac{g}{\theta}\left(\frac{\partial\theta}{\partial z}\right)}{\left(\frac{\partial u}{\partial z}\right)^2} = \frac{\frac{g}{\bar{T}}\left(\Gamma - \gamma\right)}{\left(\frac{\partial u}{\partial z}\right)^2}$$

where $\bar{T}$ is the layer mean temperature, Γ is the dry adiabatic lapse rate, γ is the environmental lapse rate and θ

TABLE 5

Thermal turbulence and shear induced turbulence in association with low level wind shear as identified using Richardson number over Chennai airport, 1987-2007

	Total frequency of thermal turbulence detected by Richardson number in the layer specified							
	<=30m	31 -90m	91 -300m	301 -600m	>600m	Total thermal turbulence	Shear induced turbulence	Total frequency of turbulence
1987	2	1	1	0	1	5	3	8
1988	1	0	1	1	2	5	2	7
1989	2	0	0	0	1	3	3	6
1990	3	4	2	0	0	9	5	14
1993	0	0	0	0	1	1	4	5
1994	0	0	1	1	0	2	1	3
1995	1	0	0	2	0	3	1	4
1996	0	1	0	0	0	1	1	2
1997	5	4	0	0	1	10	13	23
1998	2	0	0	1	0	3	12	15
1999	1	1	2	2	0	6	2	8
2000	1	1	6	2	0	10	3	13
2001	0	1	3	0	0	4	4	8
2002	0	0	4	3	0	7	10	17
2003	0	0	0	1	0	1	5	6
2004	0	0	1	0	0	1	2	3
2005	0	0	2	0	0	2	1	3
2006	0	0	1	0	2	3	0	3
2007	2	0	1	1	1	5	4	9
Total	20	13	25	14	9	81	76	157

is the potential temperature. The turbulence arisen out of thermal instability (*i.e*., when $\gamma > \Gamma$) is thermally induced and that with high value of the shear [often exceeding 10 $\mathrm{ms^{-1}\ km^{-1}}$, this shear value have been arrived at from 6 kt / 1000 ft mentioned in Endlich (1964), Ellrod and Knapp (1992) and others in the literature] is shear induced. In other words, the negative static stability (numerator of the Richardson Number) explains the thermally induced turbulence and higher magnitude of vertical shear of horizontal wind explains the shear induced turbulence. As per the in-flight reports received, the turbulence associated with wind shear were mostly of moderate intensity but for a few cases of severe intensity. Thermal turbulence and shear induced turbulence over specified layers in the lower atmosphere, as identified based on Richardson number, have been summarized in Table 5.

The most favourable layer for thermal turbulence is 090-300 m. While afternoon thermal plume / convective current could be the cause for the thermal turbulence over this tropical station, the shear induced turbulence could be the result of passing of convective systems and sea breeze over this coastal station in east coast of India. Fig. 3 displays the percentage frequencies of thermal and shear induced turbulence in association with LLWS. It can be clearly seen from the overall frequency that both thermal and shear induced turbulence were active over Chennai in different seasons.

3.4. *LLWS in association with sea breeze*

Sea breeze is one of the cause for the LLWS over a coastal airport (ICAO, 2004; Suresh, 2004; Suresh, 2007). Abrupt change in wind direction (*i.e*.,) the vertical wind-

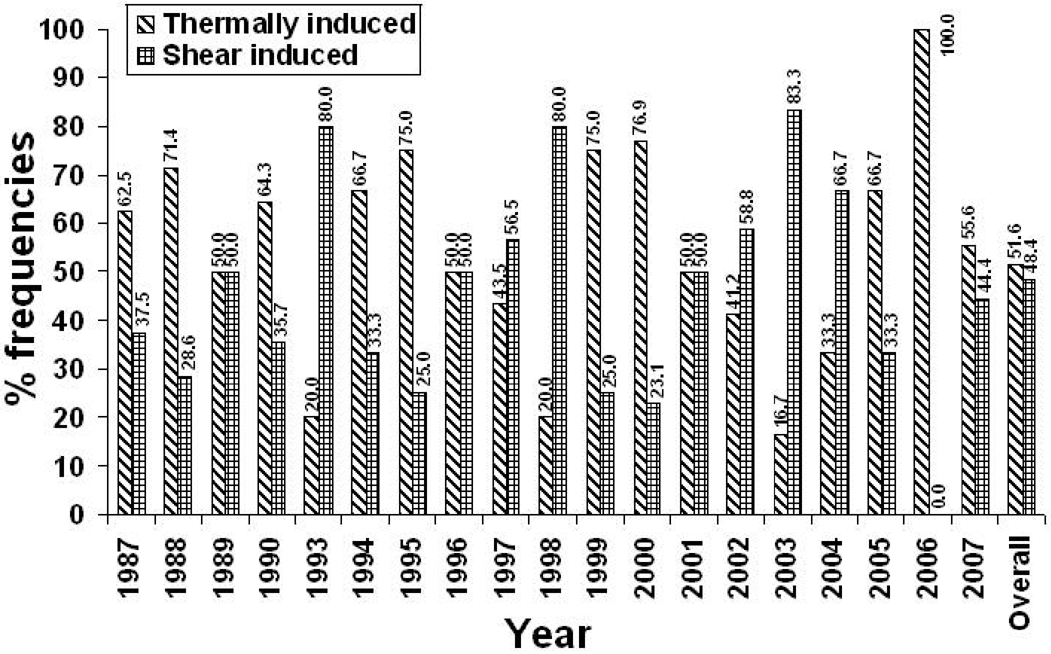


Fig. 3. Year-wise percentage frequencies of thermal and shear induced turbulence in association with low level wind shear over Chennai, 1987-2007 (except 1991-1992)

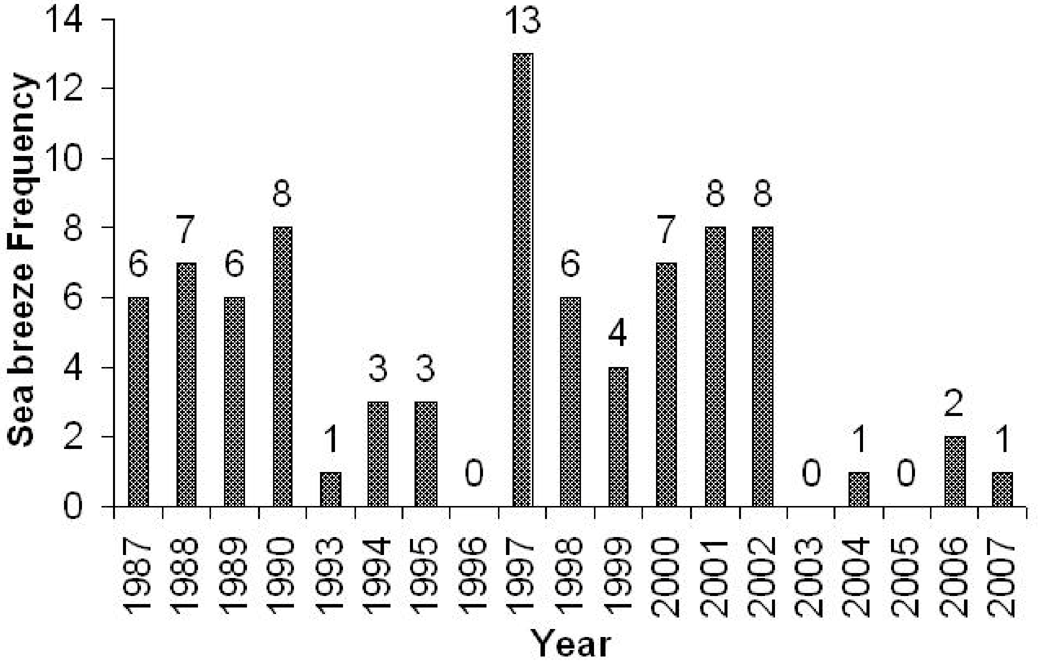


Fig. 4. Year-wise frequency of sea breeze for those dates on which low level wind shear was reported over Chennai airport during 1987-2007 (barring 1991 and 1992)

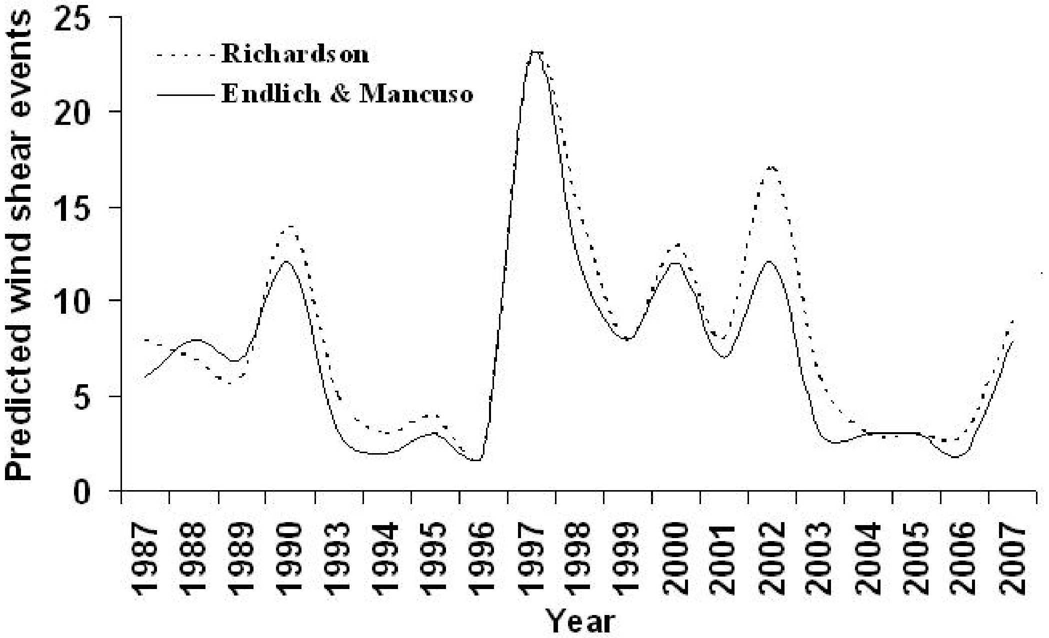


Fig. 5. Plot of predictability of low level wind shear over Chennai airport during 1987-2007 (barring 1991 and 1992) using Richardson number and Turbulence index

shift is conducive for the onset of turbulence (Endlich and Mancuso, 1965; WMO, 1993). The prevailing wind over Chennai during pre-monsoon (March – May) and southwest monsoon season (June – September) from surface to about 3.0 km has a westerly component. However, with the onset of sea breeze the winds at surface and lowest part of boundary layer is replaced by an easterly component of wind. Hence a change of wind direction by more than 120° in juxtaposition with strong wind speed often results in turbulence. As an aircraft flying across a sea breeze front may experience a change in headwind or tailwind, strong sea breeze front may cause LLWS.

Since the zonal flow has a westerly component during mid-March to mid-October over Chennai, the sea breeze front is clearly discernible during this period while during the rest of the year the sea breeze front is not fully discernible as they are superposed with the prevailing easterly winds. Year-wise frequencies of sea breeze for those days on which LLWS was reported have been depicted in Fig. 4. While the sea breeze front was observed on 84 days during the period of this study, the shear induced turbulence was 76 days only (Table 5). The reason for this difference may be attributed to the fact that on a few days either the strength of sea breeze was not sufficient enough to cause the shear induced turbulence or a cumulative effect of both thermal and shear induced turbulence might have prevailed during those days.

4. Turbulence index

Turbulence index (TI) was proposed by various authors to predict the turbulence, especially the non-convective turbulence such as CAT, using the upper air temperature and wind data. One form of TI which has been successfully used over United States was proposed by Endlich and Mancuso (1965). This index takes into account the wind speed, change in wind direction with height and second derivative of temperature change with height. TI is defined as TI = $\left| V\left(\frac{\partial \alpha}{\partial z}\right)\left(\frac{\partial^2 T}{\partial z^2}\right) \right|$ where α is the wind direction (in radians), V the wind speed, z is the height and T the temperature. It has been documented in their study that $\left| V\frac{\partial \alpha}{\partial z} \right|$ had maximum magnitude in the turbulent regions and $\left| \frac{\partial^2 T}{\partial z^2} \right|$ had the largest values over frontal boundaries and in tropopause.

Ellrod and Knapp(1992) have used two types of TI based on numerical weather prediction (NWP) model outputs for forecasting CAT over upper troposphere and stratosphere over the United States. Stretching deformation (DST) and shearing deformation (DSH) were computed to get the resultant deformation (DEF) which is the square root of sum of squares of DST and DSH. The vertical wind shear (VWS) and convergence (CVG) were computed and the turbulent indices were then calculated using the following formulae.

$$TI1 = VWS * DEF$$

$$TI2 = VWS * (DEF + CVG).$$

The authors have claimed that the probability of detection of CAT was between 0.66 and 0.75 and the false alarm ratio was between 0.20 and 0.25. The above formulation have been used by various authors throughout the world since then with mixed rate of success (WMO, 1993). However, as NWP model output data has not been used in this study, the method proposed by Ellrod and Knapp will be attempted later when NWP model output is available at the boundary layer in very fine spatial resolution.

In this paper, TI has been computed based on Endlich and Mancuso (1965) formula for the days on which LLWS had been reported over Chennai airport. While the predictability of wind shear using Richardson number has been made based on the criteria that $R_i < 1.0$ as mentioned earlier, threshold values of $R_i < 0.6$ and $TI > 3 * 10^{-6}$ rad s^{-1} °K m^{-2} have been used as suggested by Endlich and Mancuso. Comparative performance of these two methods has been shown in Fig. 5. It can be seen that the predictability of the reported LLWS was 71% using R_i whereas the same was 61.5% using TI. Though 100% predictability may not be possible using the available coarse time and space resolution 0000 and 1200 RS/RW data, the above methods especially the Richardson number may be used as a tool to issue LLWS alert/warning in view of its efficient predictability.

5. Nowcasting wind shear using DWR

Doppler Weather Radar (DWR) has been used extensively for detecting the wind shear throughout the world (Browning, 1982; Eilts, 1987; Wilson *et al.*; 1984; Fujita, 1990; Passman, 1993; Cornman and Carmichael, 1993; WMO, 2000; Cheng, 2002; Raghavan, 2003; Suresh, 2004). Compared to very coarse time and space resolution of upper air exploration through RS/RW data at 12 hourly interval, the DWR has a very fine time and space resolution sampling especially the lower atmosphere by adopting suitable scan strategies. In other words, the vital data provided by DWR in the lower atmosphere is quite helpful to detect and nowcast LLWS in the boundary layer. Since the DWR gives only the radial velocity, attempts have been made to work out various types of shears such as azimuthal, radial, elevation, combination of all the three called three dimensional shear (3DS) etc using DWR data of Cyclone Detection Radar station, IMD, Chennai by Suresh(2004). 3DS is defined as

$$3DS = \sqrt{\begin{array}{l}(\text{Azimuthal shear})^2 + (\text{Elevation shear})^2 \\ + (\text{Radial shear})^2\end{array}}$$

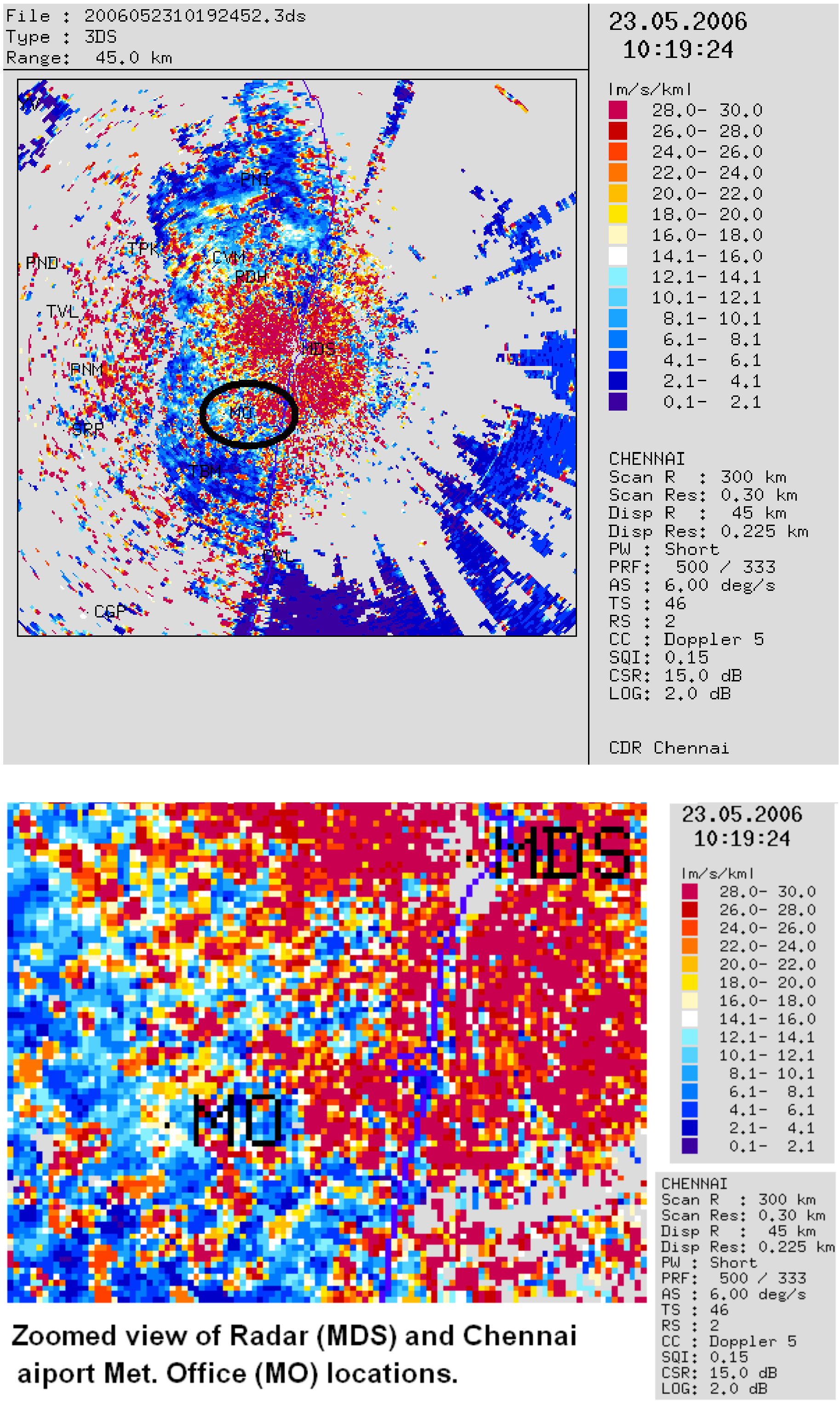
He had observed that 3DS > 16 ms^{-1} km^{-1} can be used to issue wind shear alert over Chennai airport based on the analysis of eight reported wind shear cases during 2001-2002. In view of small sample and also due to some technical limitations, it is understood that this method is yet to be operationalised. Incidentally, it may be mentioned here that Chennai DWR is located at about 16 km away from the Chennai airport and therefore can be used for wind shear alert over Chennai airport.

Wind shear as per literature is a short lived phenomenon but whose effect exceeds the power of an aircraft engine to lose altitude of a few thousands of feet in a few seconds (FAA, 1979). The end result may be a hard landing type of an incident or an accident depending on the altitude at which the LLWS is active and the pilot's presence of mind and judgment capacity to overcome its ill effect (WMO, 1993).

As per procedures laid down by ICAO (2004), LLWS may be issued up to an altitude of 0.5 km or depending on the local requirement by air traffic controlling authority. In Chennai, the upper limit of computing 3DS has been fixed as 0.8 km to comfortably cover the active 3DS areas. This product is generated as a plan view to display maximum value of computed 3DS from the lowest elevation bin up to certain height (0.8 km in Chennai DWR) over each pixel from a volume scan. The presentation is of Cartesian type. The precise height at which the value is displayed may not be readily known to the user. Nonetheless, as the lowest elevation used in Chennai DWR is 0.2°, the product display around Chennai airport (located about 16 km away from DWR in southwest sector) is from 70 to 800 m.

5.1. *Prolonged wind shear over Chennai airport on 23 May 2006*

In a typical case on 23 May 2006, moderate Wind shear was reported between 500 ft (150 m) and 1000 ft (300 m) by a pilot of Air India flight at approach RWY07 at 1555 UTC/23. Figs. 6(a-e) shows a few 3DS product on 23rd and 24th May 2006. Clutter contamination and associated near zero radial velocity around the radar up to 6 km could not be effectively filtered by the hardware parameters such as Clutter to Signal Ratio (CSR) and Signal Quality Index (SQI) selected in the scan strategy. Hence, 3DS computation based on radial velocity close to



File : 20060523101924 52.3ds
Type : 3DS
Range: 45.0 km

23.05.2006
10:19:24

|m/s/km|
28.0- 30.0
26.0- 28.0
24.0- 26.0
22.0- 24.0
20.0- 22.0
18.0- 20.0
16.0- 18.0
14.1- 16.0
12.1- 14.1
10.1- 12.1
8.1- 10.1
6.1- 8.1
4.1- 6.1
2.1- 4.1
0.1- 2.1

CHENNAI
Scan R : 300 km
Scan Res: 0.30 km
Disp R : 45 km
Disp Res: 0.225 km
PW : Short
PRF: 500 / 333
AS : 6.00 deg/s
TS : 46
RS : 2
CC : Doppler 5
SQI: 0.15
CSR: 15.0 dB
LOG: 2.0 dB

CDR Chennai

23.05.2006
10:19:24

|m/s/km|
28.0- 30.0
26.0- 28.0
24.0- 26.0
22.0- 24.0
20.0- 22.0
18.0- 20.0
16.0- 18.0
14.1- 16.0
12.1- 14.1
10.1- 12.1
8.1- 10.1
6.1- 8.1
4.1- 6.1
2.1- 4.1
0.1- 2.1

CHENNAI
Scan R : 300 km
Scan Res: 0.30 km
Disp R : 45 km
Disp Res: 0.225 km
PW : Short
PRF: 500 / 333
AS : 6.00 deg/s
TS : 46
RS : 2
CC : Doppler 5
SQI: 0.15
CSR: 15.0 dB
LOG: 2.0 dB

Zoomed view of Radar (MDS) and Chennai aiport Met. Office (MO) locations.

Fig. 6(a). Three Dimensional Shear (3DS) at 1019 and 1049 UTC/23 May 2006. Chennai airport located at 16 km SW of Radar has been marked MO in the figure and encircled and the Radar has been marked as MDS in the plot. The display range is 45 km and display (pixel) resolution is 0.225 km. Zoomed view of Chennai airport (MO) and Radar site (MDS) has been shown in the bottom figure

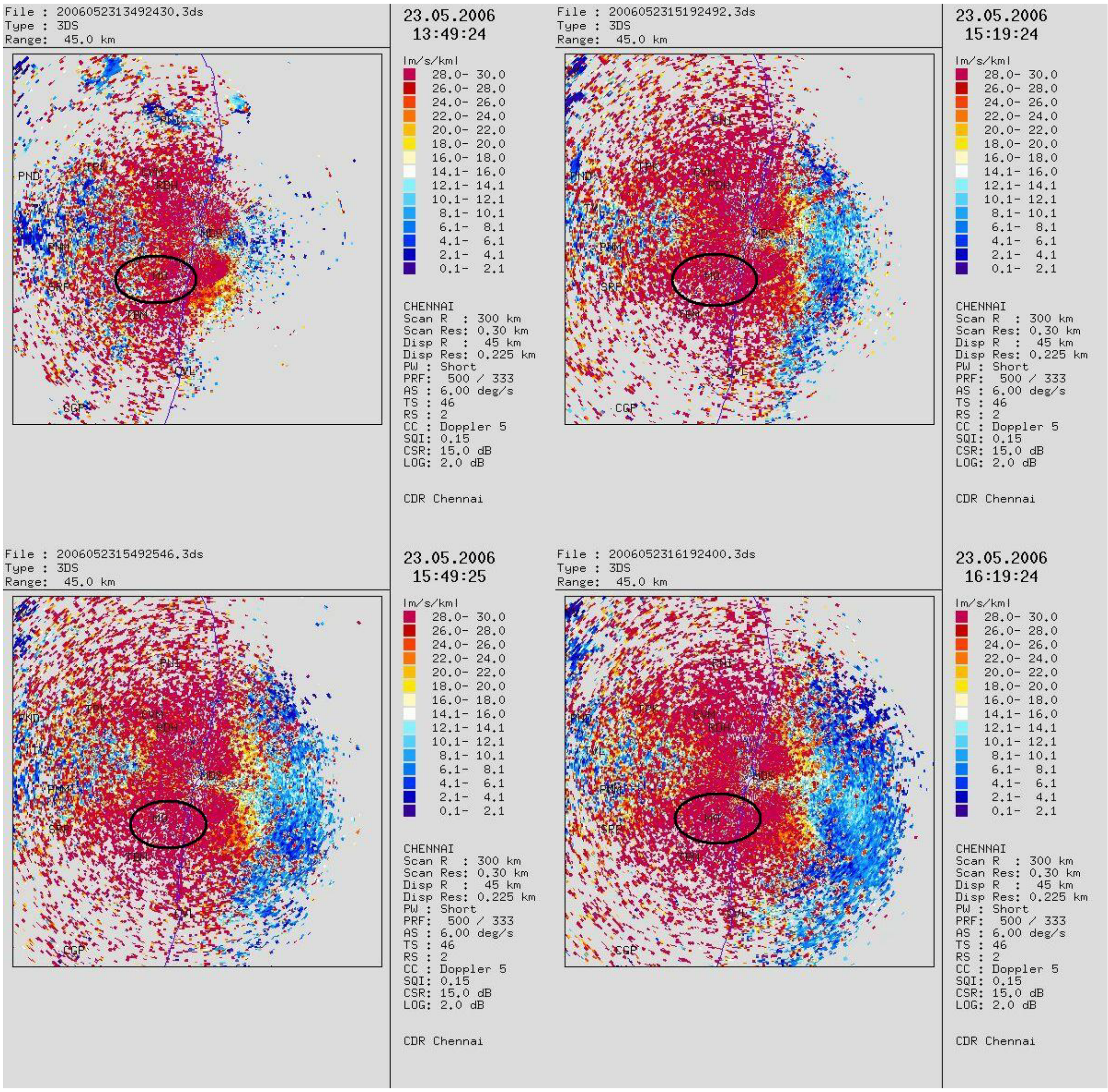


Fig. 6(b). Three Dimensional Shear (3DS) at 1349, 1519, 1549 and 1619 UTC / 23 May 2006. Chennai airport is located at 16 km SW of Radar (marked MO in the figure and has been encircled)

the surface (from some of the non-moving objects around the radar) and the actual measurement at higher altitude vertically above these pixels resulted in high values around the radar site. As such the high 3DS values around the airport up to 6 km may be considered as noise and discarded. Nonetheless, the Chennai DWR can be thought of as a terminal Doppler Weather Radar (TDWR) for Chennai airport (16 km southwest of DWR) as the 3DS can be computed to cover an altitude of 800 m over and around the vicinity of the airport.

As per DWR Chennai observations, 3DS around the vicinity of airport was well above 16 m s^{-1} km^{-1} from 1019 UTC over a few locations. It can be seen that while large area in and around Chennai city had 3DS values more than 24 ms^{-1} km^{-1}, north to east and southern sector of Radar has 3DS values in excess of 16 ms^{-1} km^{-1} [Fig. 6(a)]. It may also be noted that the prime runway (RWY) in operation on 23rd May was RWY 07 / RWY 25. The shear magnitude exceeded 28 m s^{-1} km^{-1} and covered a vast area of about 10 km radius circle around the airport

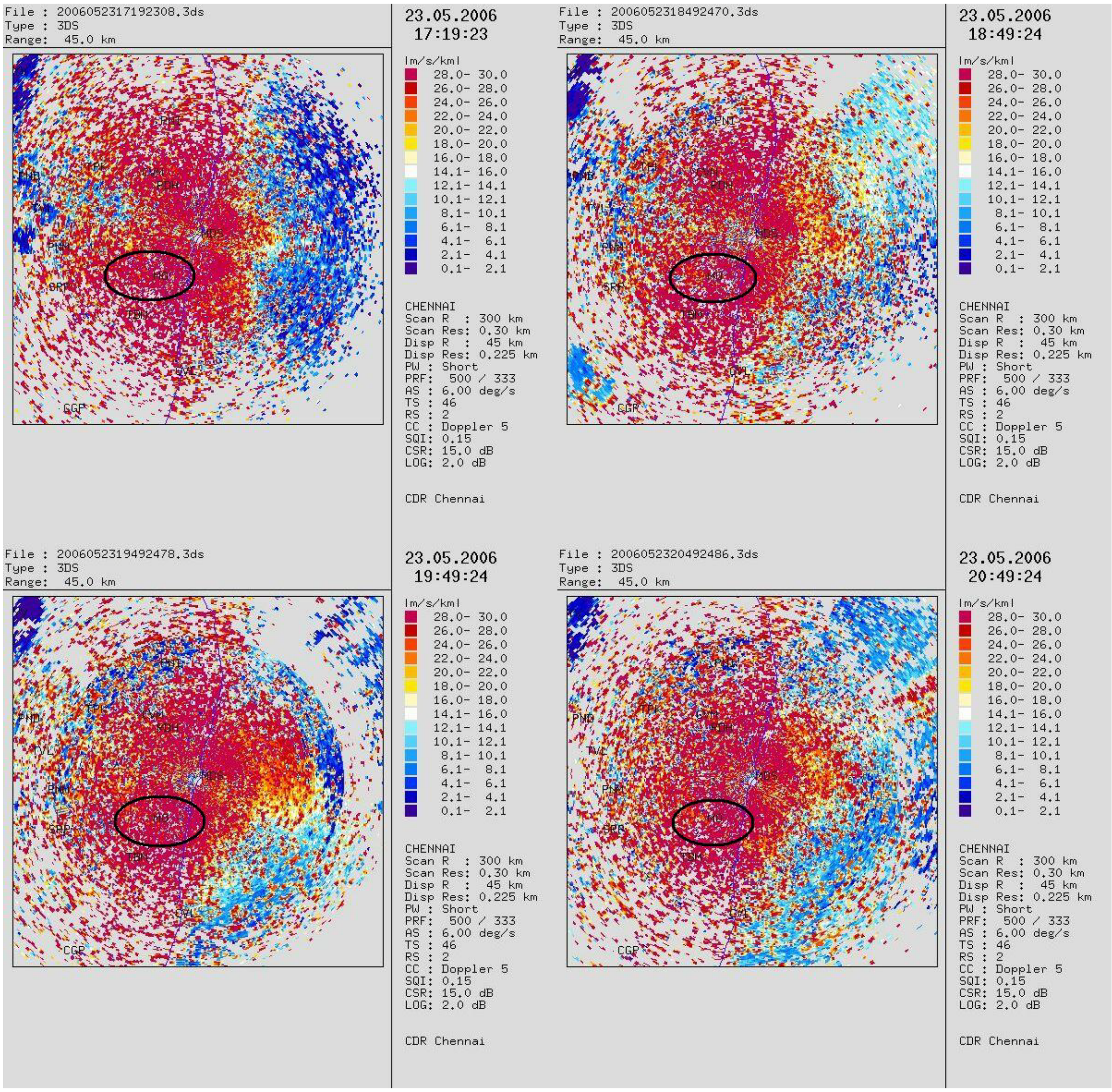
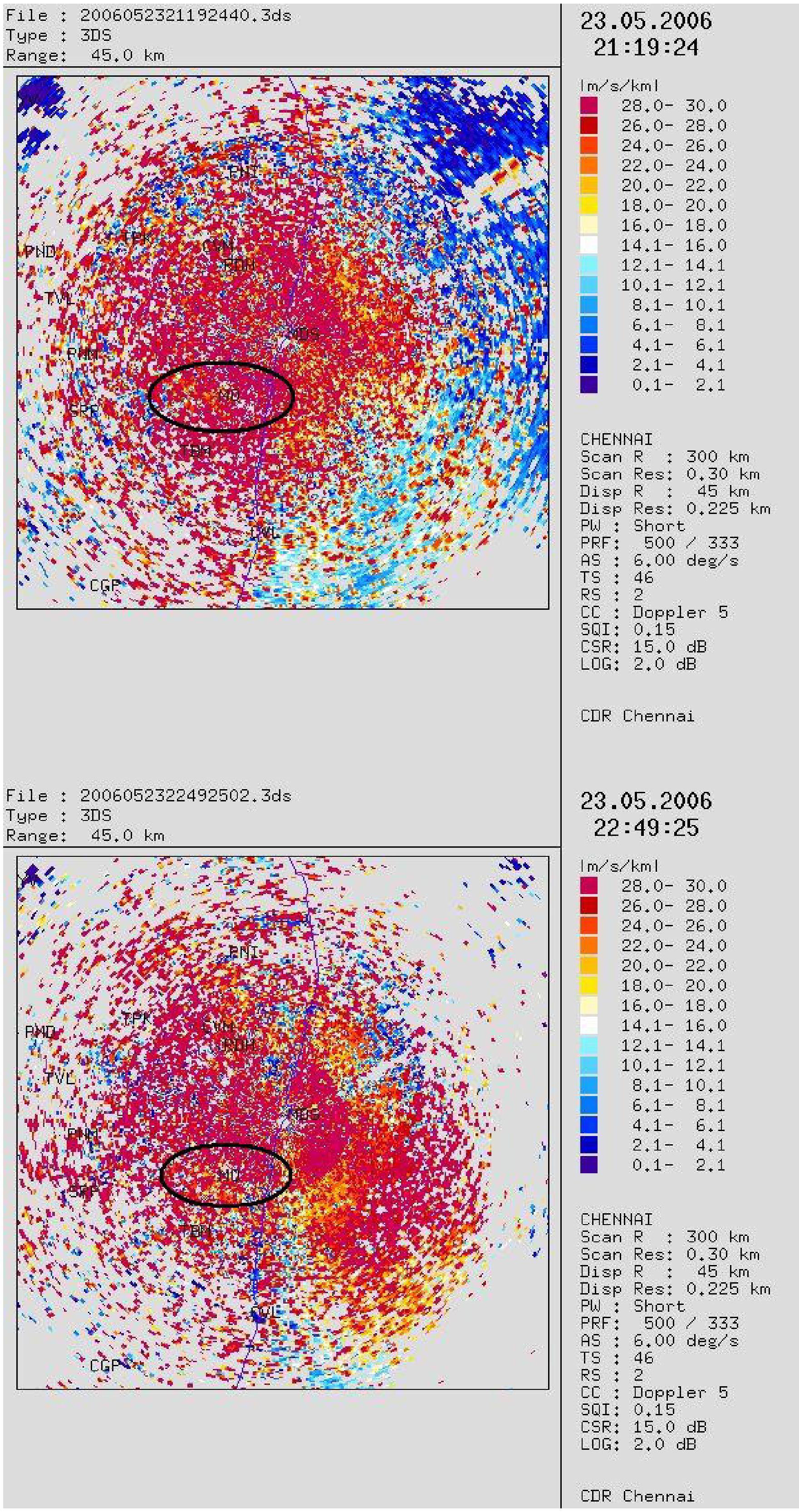


Fig. 6(c). Same as in Fig 6(b) but for time of observation at 1719, 1849, 1949 and 2049 UTC/23 May 2006

from 1349/23 [Fig. 6(b)]. Over the RWY ends, 3DS values higher than 30 m s^{-1} km^{-1} could be seen from 1719 UTC/23 to 2049 UTC/23 [Figs. 6(c&d)].

This increase in shear and areal coverage continued up to 2319 UTC/23. Reduction in strength of shear and areal coverage were noticed from 2349 UTC/23 to 0219 UTC/24 around the airport [Fig. 6(e)]. The vertical wind shear of 10 ms^{-1} km^{-1} is the lower limit for moderate turbulence and 20 ms^{-1} km^{-1} is that for severe turbulence (Endlich, 1964; Endlich and Eclean, 1985; Ellrod 1985 and Ellrod and Knapp, 1992). Hence, it can be inferred from the observation that moderate to severe turbulence from 1019 to 1349 UTC/23 and severe turbulence from 1349 UTC up to 2019 UTC/23 might have prevailed over Chennai airport.

Fig. 6(d) shows the prevalence of 3DS more than 28 ms^{-1} km^{-1} around and over Chennai airport at 2119, 2249 UTC/23. While shear values between 24 and 28 ms^{-1} km^{-1} were noticed at 2319 UTC/23, reduction in area of these high shear values were noticed from 2349 UTC/23 and



File : 2006052321192440.3ds
Type : 3DS
Range: 45.0 km

23.05.2006
21:19:24

CHENNAI
Scan R : 300 km
Scan Res: 0.30 km
Disp R : 45 km
Disp Res: 0.225 km
PW : Short
PRF: 500 / 333
AS : 6.00 deg/s
TS : 46
RS : 2
CC : Doppler 5
SQI: 0.15
CSR: 15.0 dB
LOG: 2.0 dB

CDR Chennai

File : 2006052322492502.3ds
Type : 3DS
Range: 45.0 km

23.05.2006
22:49:25

CHENNAI
Scan R : 300 km
Scan Res: 0.30 km
Disp R : 45 km
Disp Res: 0.225 km
PW : Short
PRF: 500 / 333
AS : 6.00 deg/s
TS : 46
RS : 2
CC : Doppler 5
SQI: 0.15
CSR: 15.0 dB
LOG: 2.0 dB

CDR Chennai

Fig. 6(d). Same as in Fig 6(b) but for time of observation at 2119 and 2249/23 May 2006

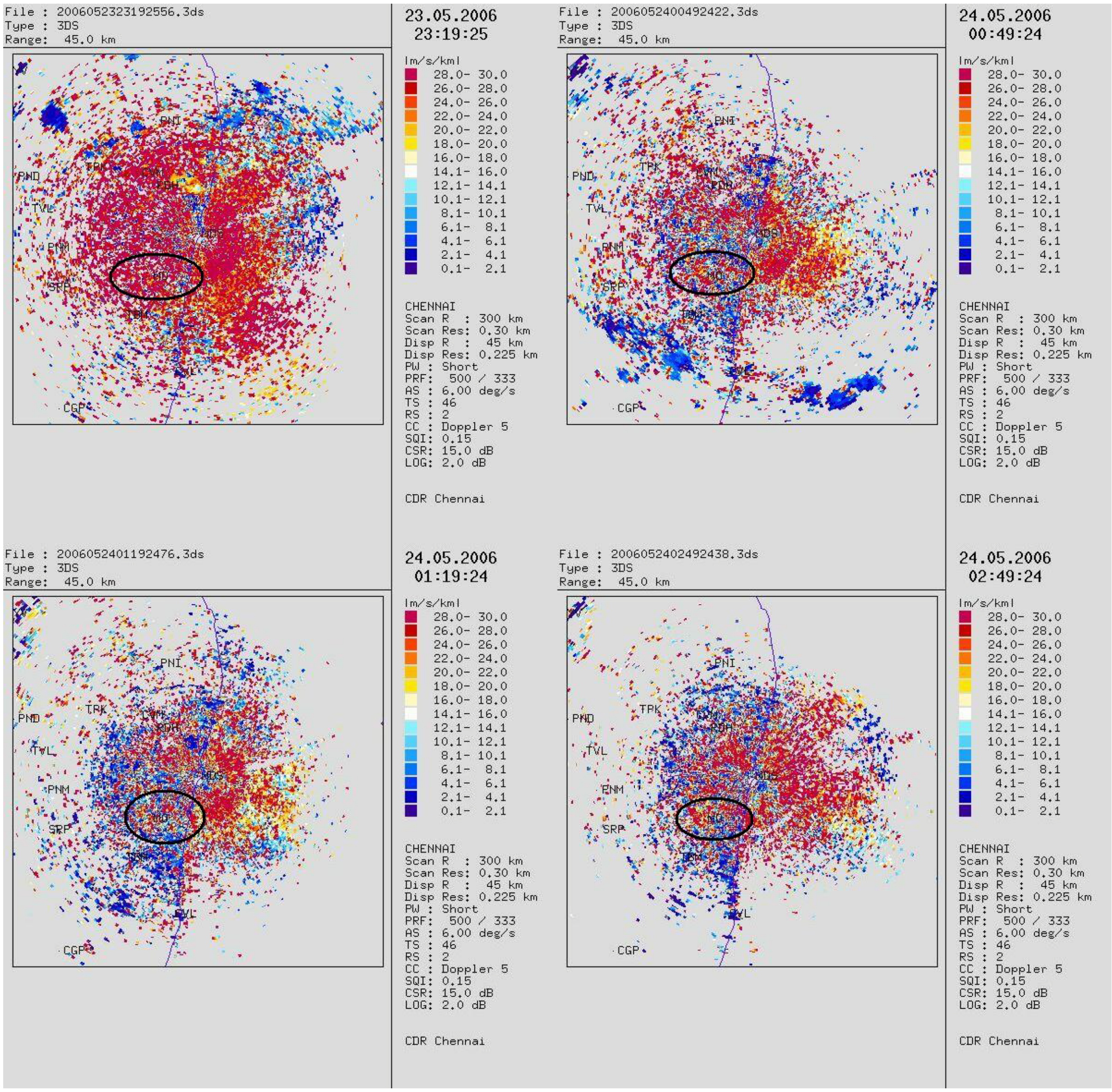


Fig. 6(e). Same as in Fig 6(b) but for time of observation at 2319 / 23 May 2006 and 0049, 0119 and 0249 / 24 May 2006

values got dropped to 18 ms^{-1} km^{-1} at a few places over Chennai airport at 0049 UTC/24 [Fig. 6(e)]. Nonetheless, sporadic shear values in excess of 20 ms^{-1} km^{-1} and values between 18 and 20 ms^{-1} km^{-1} were still seen upto 0249 UTC/24.

But for the single pilot report (PIREP) by M/s Air India at 1555 UTC/23, neither any inflight report had been received on that day by the air traffic controllers nor there were any de-briefing by the pilots to the Met office as per available records. During personal interaction with air crews for not-reporting this sort of high shear value, it is understood that they are habituated with this sort of shear over Chennai airport during pre-monsoon season and/or unable to intimate/de-brief the shear information due to concentration in safe take-off and landing operations.

5.2. *Necessity of feedback from air crews*

This particular case of wind shear on 23/24 May 2006 suggests that wind shear can be active even for nearly ten hours. Under this sort of long duration active wind shear conditions, the current practice of using the reported wind shear as a supplementary information in current weather reports (METAR) for the next two hours may not be sufficient in the context of air safety.

However, unless in-flight report and/or de-brief information about cessation of wind shear condition is received from the air crews, there is no alternative method than to continue the existing practice.

The necessity of feedback from air crews was highlighted through various forums (Suresh, 2004). The current case has been presented to air crews and operational staff members of various airlines operating from Chennai airport during 2006 and 2007 and they were impressed upon the consequences of wind shear related accidents that had been documented elsewhere (Fujita, 1980 and 1990; ICAO, 1983 and 2004). In order to devise a suitable LLWS warning strategy, it was pointed out to them the absolute inevitability of sizeable database on LLWS experienced by the air crews. Whence such a database is made available to the Met. office, analysis based on surface and upper air meteorological data and DWR information can be effective to identify warning threshold(s). Hence, the airline agencies have been kept informed about a similar attempt made at Heathrow airport in the year 1977 (Roach, 1981) prior to the introduction of LLWS warning method from Heathrow airport during 1980s. Aircrews operating from Chennai airport were requested to pass on in-flight reports without fail. Despite these efforts during 2006-2008, the response is not encouraging. However, constant pursuing with airlines is still being made to get a sizeable database.

6. Summary and conclusions

(*i*) Maximum number of low level wind shear (LLWS) cases have been reported over Chennai airport during 1200-1800 UTC and the most favourable period for LLWS is May – June and December. Minimum frequency of LLWS was reported during November when steady northeasterly winds prevail over Chennai.

(*ii*) Richardson number detects 71% of the reported LLWS cases over Chennai. Maximum predictability is during 1200-1800 UTC during which period maximum number of LLWS cases were reported by the aircrews.

(*iii*) Thermally induced and shear induced turbulence were detected in almost 50% in each category.

(*iv*) 45.2% of reported LLWS cases were in the layer upto 090 m a.g.l. Very fine resolution upper level data is needed in the lowest portion of boundary layer (surface / mixed layer) to predict the LLWS.

(*v*) Predictability through Turbulence Index (TI), *viz*., TI $> 3*10^{-6}$ rad s^{-1} °K m^{-2} and $R_i < 0.6$ has 61.5% efficiency in predicting LLWS cases reported over Chennai.

(*vi*) In contrast to the general belief that windshear is a short lived phenomenon, there are cases at which LLWS was active for more than 10hrs over Chennai airport.

(*vii*) It is absolutely inevitable to have sizeable database of LLWS incidences reported by the aircrews to devise a suitable LLWS warning strategy.

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