

OBJECTIVE ANALYSIS OF WIND MEASUREMENTS WITH AUTOMATIC WEATHER STATION AND AN INDIGENOUS HIGH WIND SPEED RECORDER DURING INDIAN NORTHEAST MONSOON 2009

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ABSTRACT

Indian North East Monsoon(NEM) season (Oct - Dec) is characterised by strong easterly winds and formation of cyclonic storms in the Bay of Bengal. An indigenous High Wind Speed Recorder(HWSR) specially designed to withstand the winds experienced in coastal areas prone to cyclonic storms was installed in Oct 2009 at Chennai(13°N/ 80.25°E) at a height of 15 m a.g.l. A potentiometric wind vane and a cup generator anemometer record and log continuous measurement of wind direction and speed in the data logger and display the values in a TFT display. Two and ten minutes vector wind averaged output is also displayed in a round-display. A state-of-art satellite-based Automatic Weather Station(AWS) located few metres away, has a Gill ultrasonic wind sensor installed at 10 m height as recommended by WMO. Hourly vector averaged wind speed and wind direction are available from the AWS.

During the northeast monsoon season of 2009, a cyclonic storm "Phyan" formed (11.0°N / 72°E) in the Arabian Sea during 7-12 Nov 2009 and another cyclonic storm "Ward" occurred (6.5 °N / 88°E) in the Bay of Bengal during 10-15 Dec 2009. These two cyclonic disturbances brought copious rainfall to Chennai (13 °N / 80.25°E). Signatures of the variations in wind direction and speed associated with both the cyclonic disturbances of Bay of Bengal during NEM 2009 as recorded by AWS, High Wind Speed Recorder, Dines Pressure Tube Anemograph are depicted to highlight the inherent differences brought out by various sensing elements with varying accuracy.

Validation of observations from new technology with the existing conventional instruments is essential and crucial in convincing the weather forecasters about the dependability on automated electronic equipments. In order to establish the conformity of algorithms and sampling methods of automated measurements with climatology and persistence, statistical analysis helps a great deal. Hence an objective analysis has been made on the variability in u and v components of wind as measured by both the modern observing techniques. Spectral analysis of the wind has been made and the Markov red noise spectrum has been derived to obtain the periodicity in wind which shows clearly the diurnal variation pattern for a coastal station like Chennai. In addition the presence of a 5-6 days low frequency oscillation in wind pattern in accordance with the established 5 days pressure oscillations has been analysed.

Introduction

The Indian North East Monsoon(NEM) season is a small scale monsoon which brings copious rainfall to the states located in the southern peninsular India. Tamil Nadu state, for which Chennai(13°N/80.25°E), is the capital city and the station of the proposed study, receives about 47% of its annual rainfall during NEM season, the normal rainfall of the season being 43 cm. The onset sets in with reversal of winds from south westerlies to north easterlies during October and increased rainfall activity. On an average 2-3 cyclonic disturbances occur during the season in association with an active monsoon surge.

Modern state-of-art technology supplement the weather forecaster in his operational duties. A network of 125 satellite-based Automatic Weather Stations(AWS) is functional since 2007 in India Meteorological Department(IMD). Hourly meteorological data from these AWS are utilised for weather forecasting in addition to the data from the already well-established conventional, manual surface observatories. Under the modernisation phase the work of installation and commissioning 550 AWS and 1350 Automatic Rain Gauge(ARG) stations is nearing completion. More are planned in the next five years. Availability of uninterrupted, reliable and accurate hourly data from the unmanned AWS is an additional advantage of the AWS. One limitation is that the equipments need periodic preventive maintenance which has to be ensured for reliable and continuous data availability. An AWS is functional at Chennai since Mar 2007 and data quality from the AWS is very good.

Indigenous digital High Wind Speed Recorders(HWSRs) designed in-house were commissioned during the year 2009 in a few stations along the east coast of India, which are prone to cyclonic storms and its associated wind speeds. Sensors manufactured by IMD, like potentiometric wind vane and cup generator anemometer for wind direction and wind speed respectively are interfaced with the HWSR. The HWSR sensors are installed in the top floor of a building around 15 m from ground level and wind direction and speed measured by the High Wind Speed Recorder are logged in one minute intervals based on the sensor output which is continuously logged in a data logger and displayed in the Duty Officer's room in Area Cyclone Warning Research Centre(ACWC), Regional Meteorological Centre, Chennai. The HWSR was installed during first week of Oct 2009 and operational data w.e.f 8 Oct 2009 onwards is available.

Background

In the case of AWS, wind speed and direction measurements are done with the Gill ultrasonic wind sensor mounted a height of 10m as per WMO guidelines. A typical AWS site is shown in Fig.1. Three minute vector averaging of samples taken every second (180 samples) prior to the top of the hour gives the wind speed and direction at full hour UTC. The range of measurement for wind speed is 0-116 knots with an accuracy of $\pm 2\%$ (at 23 knots) and $\pm 3^\circ$ (at 38 knots) in the measuring range of 0-359° for wind direction. Ultrasonic wind sensors due to the lack of moving parts and zero threshold are appropriate for long term use in exposed automatic weather stations and weather buoys whereas the accuracy and reliability of traditional cup anemometers are adversely affected by salty air or large amounts of dust.

The HWSR consists of a data logger, a Serial to VGA converter called Viewmet, a TFT touch panel for continuous graphical display of wind direction and speed and a 36-point round LED display for distant monitoring of wind. User-friendly menu driven options facilitate easy operation.

In addition, print-outs can be taken of the daily profile of wind. Block diagram of the HWSR is shown in Fig.2.

In addition, the Dines Pressure Tube Anemograph(DPTA) which is a conventional instrument used since the 1980s and which is becoming obsolete is functional at RMC Chennai and is also co-located with the HWSR. The continuous recording of the instantaneous value of wind speed and wind direction on a single chart is done so that the wind is completely described as vector quantity. Wind direction is measured and recorded by means of a wind vane and a mechanical twin pen recorder. Wind speed is measured by means of a pitot static tube and recorded by a sensitive float manometer. The DPTA has a threshold of 1 knot.



Fig.1 A typical AWS site

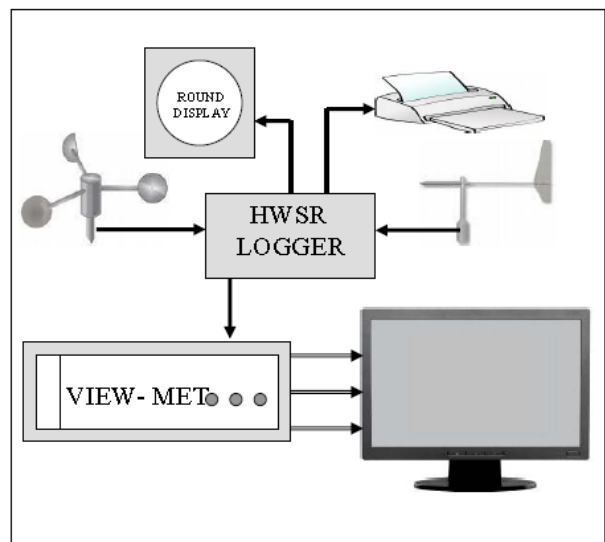


Fig. 2 Block diagram of High Wind Speed Recorder

Data and methodology

Hourly wind direction and wind speed available from the AWS at Chennai has been taken up for this study for the period 1 Oct – 31 Dec 2009. In addition, the one minute interval data from HWSR for the period 8 Oct - 31 Dec 2009 has been utilised. To maintain uniformity while comparing samples from both types of wind monitoring systems, the one minute interval data of HWSR has been averaged to hourly data for all the days. The zonal (u) and meridional (v) components of wind have been derived and has been used for the power spectral analysis to study the periodicity, if any, manifested by the wind data of a coastal station like Chennai during northeast monsoon season 2009.

In addition, the hourly wind data from DPTA of Chennai as recorded during the two cyclonic storms “Phyan” and “Ward” which occurred in the north Indian Ocean (Bay of Bengal and Arabian Sea) during Nov and Dec 2009 has been compared with the data of the same period from AWS and HWSR. The inherent differences and limitations in measuring techniques which induce bias in wind measurements between the three methods has also been discussed and results presented. Variability in rainfall at Chennai associated with change in wind pattern during the passage of a cyclonic disturbance is also depicted. The conventional surface observatory co-located with the AWS had recorded 887.2 mm of rainfall during Oct-Dec 2009 and the AWS had recorded 897.5 mm. As such, the present study is limited to NEM season of Chennai, with

observations by new technology which will be a replacement to conventional methods of observation and hence the long term aspects need to be studied in-depth with more years of data from the same observing systems.

Onset of northeast monsoon (Oct-Dec) 2009

Preceding the onset of northeast monsoon in October, reversal of low level winds (850 hPa) from westerlies to easterlies took place around 10-11 October as is the normal feature but the surface level winds were westerlies during 8-17 Oct 2009. As the withdrawal of southwest monsoon was very much delayed (It withdrew from the entire country on 22 October only) westerly anomalies prevailed during most part of the month and easterlies at lower levels did not strengthen to the extent expected. Most of the coastal stations reported rainfall on 28th and 29th October and Chennai (the place of study) reported 14 cm of rain. Chennai Airport located at a distance of 17 km from Chennai recorded 6 cm of rain. Onset of northeast monsoon was declared on 29th October. Subsequently, two cyclonic storms occurred in the north Indian Ocean, one in Arabian Sea and the other in Bay of Bengal during Nov and Dec 2009 respectively. The tracks of both the storms are shown in Fig.3 which has been obtained from the Cyclone e-Atlas database of IMD.

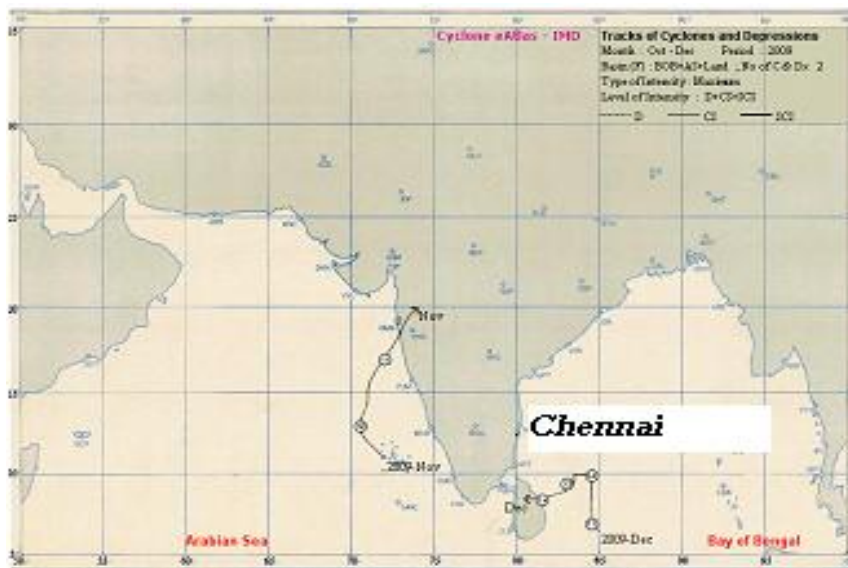


Fig.3 Tracks of Phyan and Ward cyclonic storms (Nov-Dec 2009)

Cyclonic storms of Nov and Dec 2009

a) PHYAN (4-10 Nov 2009)

In association with active northeast monsoon surge, a low pressure area formed over Comorin area on 7th November, 2009. It intensified into a deep depression at 0830 hrs IST and into a cyclonic storm 'Phyan' at 2330 hrs IST of 10th November, 2009. Continuing its north-northeastward movement, the cyclonic storm. 'Phyan' crossed north Maharashtra coast between Alibag and Mumbai between 1530 and 1630 hrs IST of 11th November. It weakened into a well marked low pressure area over north Madhya Maharashtra and neighbourhood at 0530 hrs IST of 12th November 2009. The rainfall recorded at Chennai during the season including that during Phyan and Ward is shown in Fig. 4. The satellite pictures of cyclonic storm Phyan taken by Indian satellite Kalpana-I on 9th and 10th Nov 2009, are shown in Fig.5

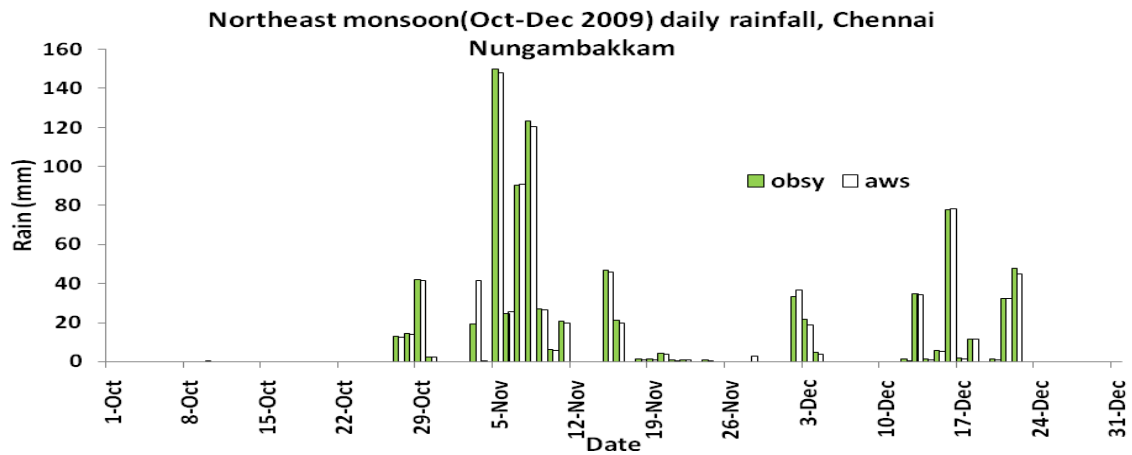


Fig.4 Northeast monsoon 2009 rainfall of Chennai

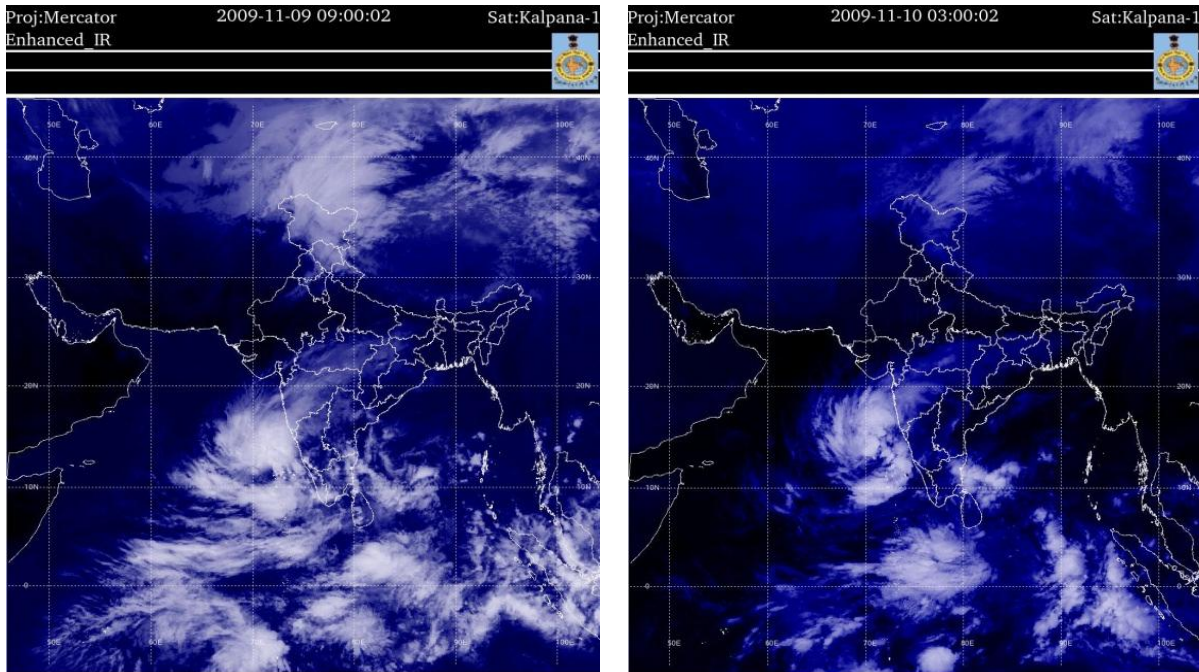


Fig.5 Indian satellite Kalpana-1 pictures of cyclonic storm Phyan on 9th and 10th Nov 2009

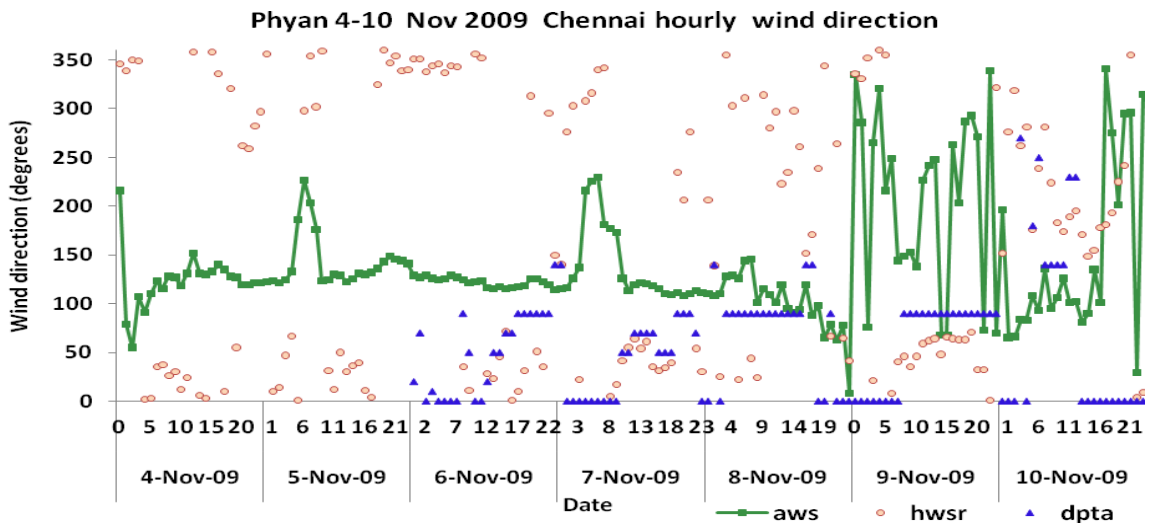


Fig. 6(a) Hourly wind direction as recorded by AWS, HWSR and DPTA during Phyan

Due to the cyclonic circulation and its associated clouding over Chennai the surface wind direction prevailing during the time of Phyan was easterly to southeasterly as recorded by AWS. The variations as recorded by HWSR, DPTA and AWS are shown in Fig.6(a). The sharp changes in wind direction manifested by ultrasonic sensor of AWS have not been captured by the mechanical sensors of HWSR and DPTA. However, majority of the observations are in congruence with each other though slightly underestimated by DPTA in almost the entire period of Phyan. Other possible reasons in reporting the same direction for many hours by DPTA can be attributed to the lag in the response of the twin pen recorder.

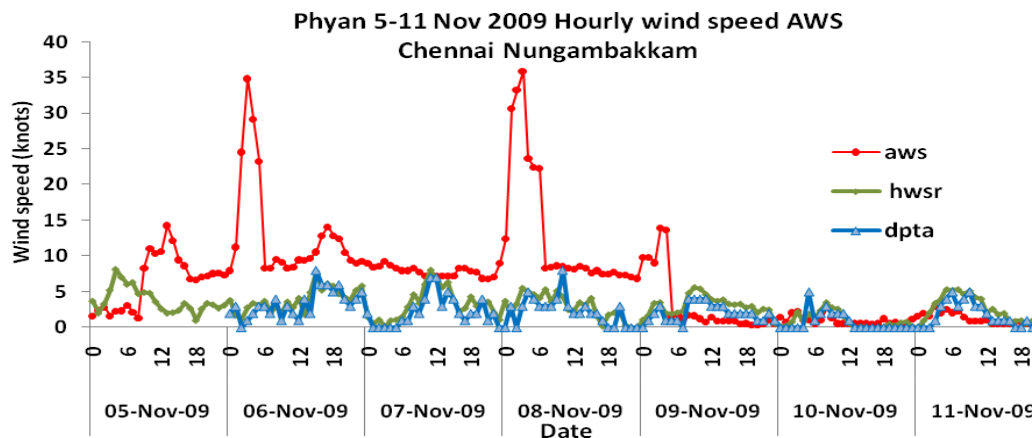


Fig. 6(b) Hourly wind speed as recorded by AWS, HWSR and DPTA during Phyan

Fig. 6(b) shows the pattern in hourly wind speed as recorded by AWS, HWSR and DPTA. Human observations noticed at the time of Phyan at Chennai as per Beaufort's scale of estimating winds, indicate experiencing very strong gusty winds during few occasions on the days of Phyan. It is probable that the AWS has been able to catch the signatures of such spells while averaging the wind the top of the UTC of observation. Since the one minute samples of wind recorded by HWSR are averaged, any possible peak in wind speed would get smoothed and hence not been depicted in the hourly average. It is noteworthy that HWSR and DPTA recorded wind speeds are highly correlated with each other and it appears that AWS wind speed is overestimated. But after 9th Nov, it is interesting that all the three observations are synchronous.

b) WARD (10-15 Dec 2009)

A cyclonic storm (T3.0), 'WARD' (10-15 December) developed over the south Bay of Bengal and crossed northeast Sri Lanka coast, close to south of Trincomalee as a deep depression between 0800 and 0900 UTC of 14th December 2009. It weakened into a well marked low pressure area over north Sri Lanka at 0300 UTC of 15th December. It then emerged into Gulf of Mannar and became insignificant on 16th December.

The main features of this cyclone are as follows.

- (i) Cyclone, 'WARD' followed a rare track, as it moved initially in a northerly direction and then moved west-southwestwards across Sri Lanka.
- (ii) It was a slow moving system, as it travelled at the average rate of 200 km per day (8 km per hour).
- (iii) It weakened into deep depression over the sea before the landfall.

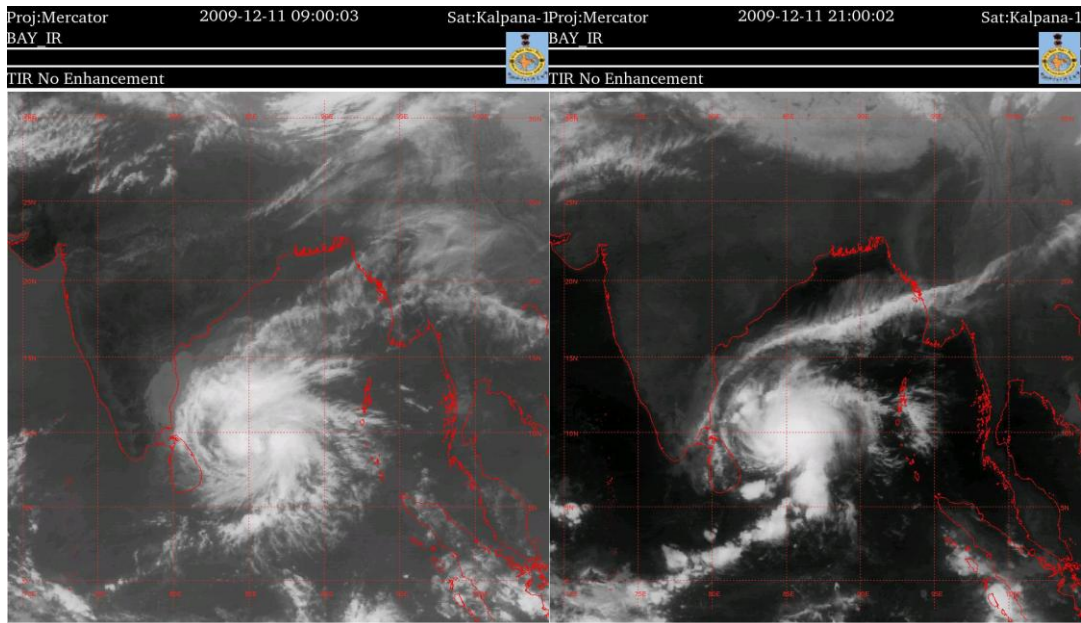


Fig.7 Satellite pictures of Ward on 11 Dec 2009 at 09 & 21 UTC

In association with the cyclone Ward, the northeast monsoon was vigorous over coastal Tamil Nadu and Puducherry during 13th-16th Dec 2009. Widespread rainfall with isolated heavy to very heavy falls occurred during this period. The satellite pictures taken on 11th Dec are shown in Fig.7. which show the cyclonic circulation along with the spiral bands which gave rainfall to Chennai ranging from 10 mm to 80 mm during 11-16 Dec 2009 during its movement in a westerly to southwesterly direction towards Sri Lanka.

Maximum surface wind of 55-65 kmph (25-35 knots) gusting to 75 kmph(40 knots) was predicted for Tamil Nadu and Puducherry coast based on observation of 0000 UTC of 11th December. The maximum wind was about 45 kmph (24 knots) reported by Pamban in coastal Tamil Nadu on 15th morning due to weakening of the system. However the wind speed was reduced in prediction considering the weakening of the system subsequently based on observation of 0900 OTC of 14th December 2009.

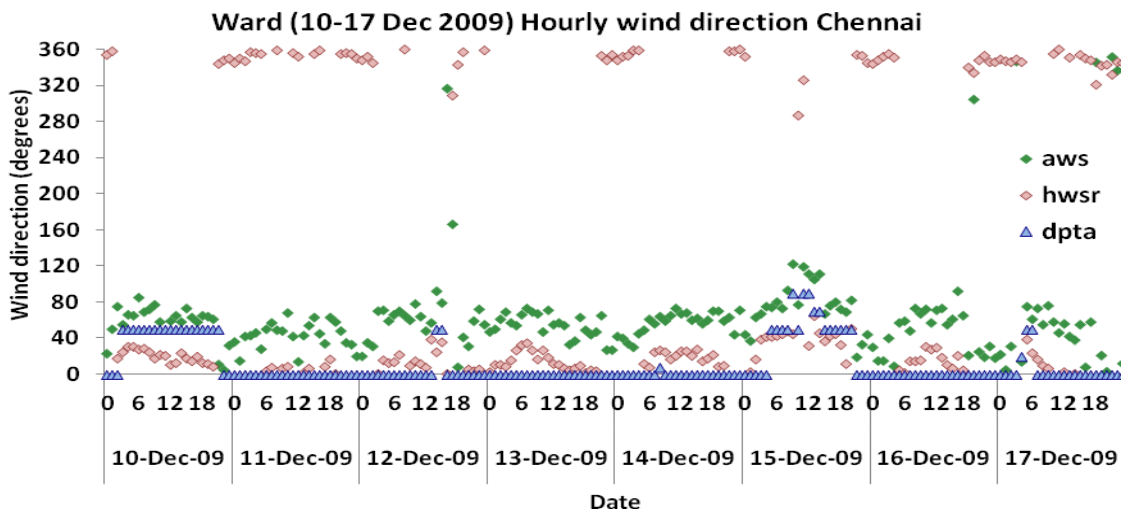


Fig.8(a) Hourly wind direction during Ward as recorded by AWS, HWSR and DPTA

The wind directions as recorded by AWS, HWSR and DPTA shown in Fig.8(a) indicate clearly predominant easterlies as is the prevailing wind during northeast monsoon season. The cyclonic circulation associated with “Ward” also shows the enhancing the easterly inflow of winds. Fig.8(b) depicts the hourly wind speed recorded by all the three systems which is in close agreement in contrast to the variation seen in the wind speeds during “Phyan”. AWS recorded wind speeds are underestimated during “Ward” contrary to that recorded during “Phyan” where higher speeds are reported.

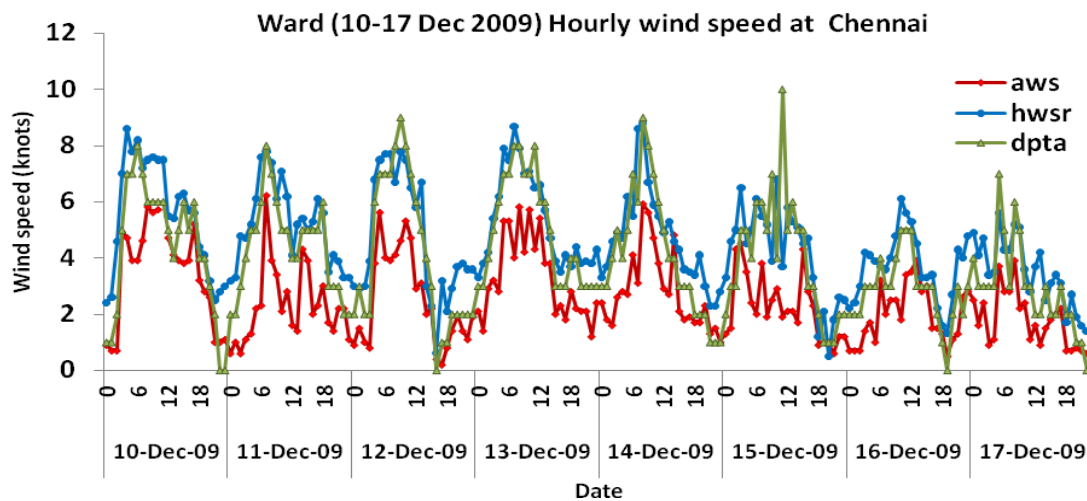


Fig. 8(b) Hourly wind speeds as recorded by AWS, HWSR and DPTA

Inherent instrumental errors and microclimatic fluctuations around the sensor coupled with the influence due to the synoptic circulation can be attributed as reasons for such contrasting variations shown by the same sensors. In-depth study on the aspects which cause such deviations needs to be done.

Power spectral analysis

Variation of wind in association with the synoptic scale systems could be seen from the analysis of wind during both Phyan and Ward. The surface level wind has in fact shown significant change during both the cyclonic disturbances, Phyan and Ward though they were located at a considerable distance from the station. For the analysis of the time series of such rapidly fluctuating elements, power spectral analysis is a widely accepted technique to separate signals from noise. Power spectral analysis using Blackman and Tukey’s Procedure (WMO, 1966) brings out the prominent periodicities in the fluctuations of meteorological elements. Various authors like Raghavendra(1974), Bhalme(1972), Parthasarathy(1976), Raj(1989), Lal(1992), Subramanian(1992) have studied the trends and periodicities in rainfall for different regions by spectral analysis. 5-6 days oscillations in pressure gradients over India during the SW monsoon has also been analysed by Bhalme et al (1975).

To find out statistically the persistence of the series month-wise analysis is performed for both AWS and HWSR-derived hourly u and v components of wind. The time series of wind during Oct-Dec 2009 showed persistence of “Markov” type by virtue of its first serial correlation coefficient being significant and so the “red noise” spectrum was used to determine the significant peaks. A Fortran program was utilised to derive the monthwise autocorrelations and spectral densities. The total number of samples utilised are provided in Table 1.

Spectral analysis details (Oct – Dec 2009)		HWSR				AWS			
		Oct *	Nov	Dec	OND combined	Oct	Nov	Dec	OND combined
No. of observations (N)		576	720	744	2040	744	720	744	2208
Lag for no. of accs(m)		192	240	248	680	248	240	248	736
Degrees of freedom (n)		5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Limiting values of Chi-square	5%	11.88 ; Factor for Markov persistence (Chi-square/n) : 2.16							
	10%	9.99; Factor for Markov persistence (Chi-square/n) : 1.82							

* Data is from 8 Oct 2009 as installation of HWSR was done only during 1-6 Oct 2009

Table 1 Matrix of the samples used in spectral analysis

Results and discussions

a) HWSR - Autocorrelation coefficients(ACC) and spectral densities

The autocorrelation coefficients computed for each of the month for both zonal(u) and meridional (v) components are plotted against the lag which is one hour between two observations. This is called the correlogram of the series. The correlograms derived from HWSR data are plotted month-wise and shown in Fig.9(a to d).

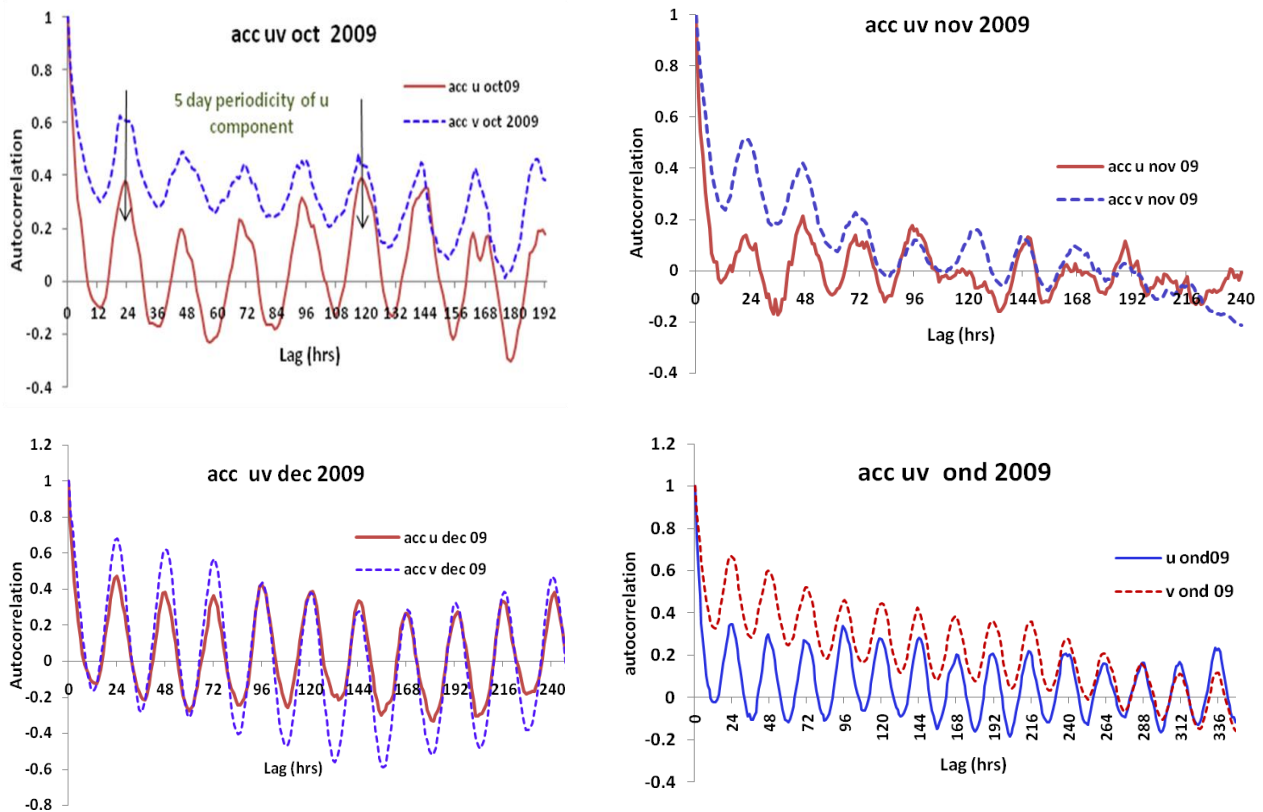


Fig.9 (a to d, left to right) Autocorrelation using HWSR data Oct-Dec 2009

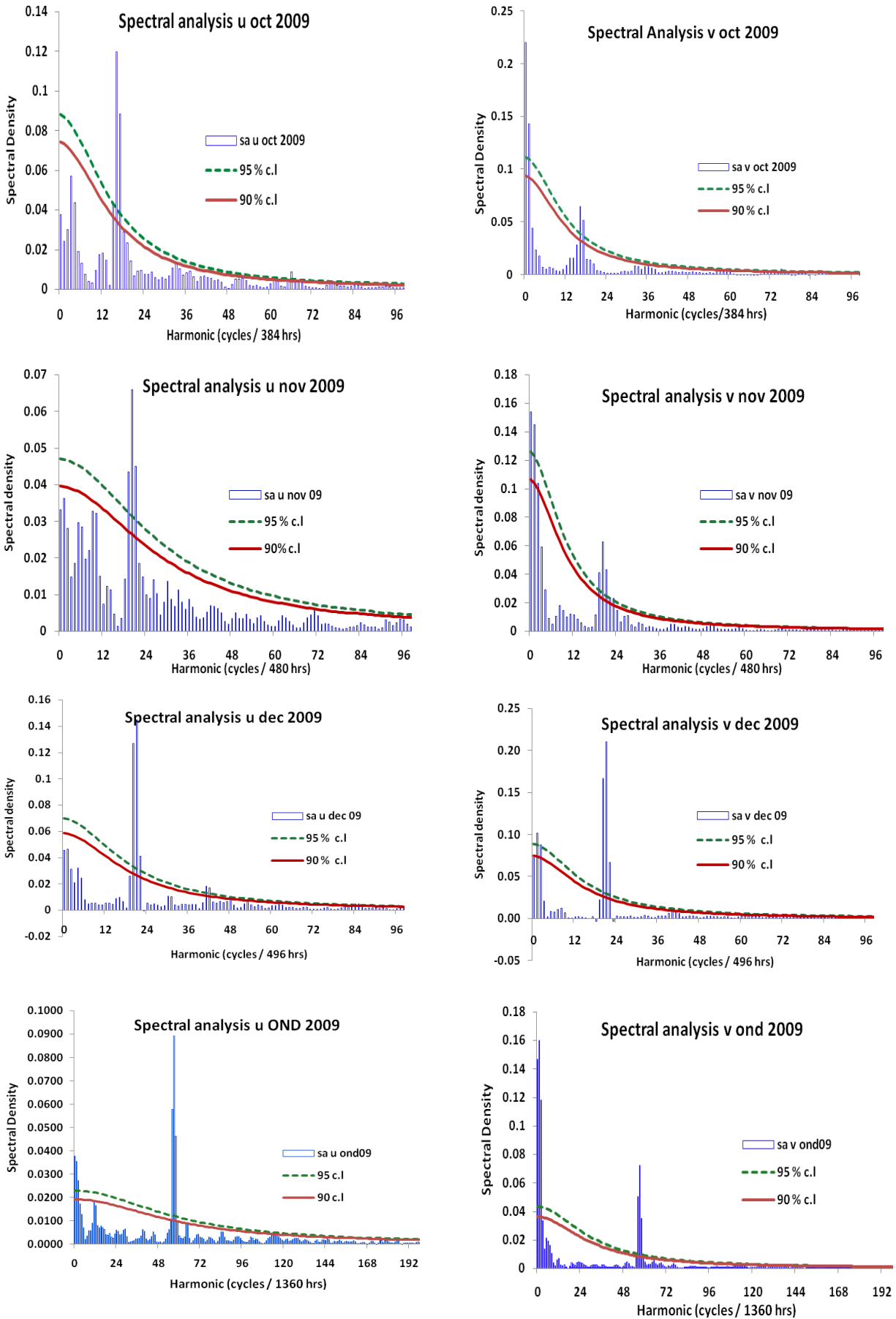


Fig. 10 (a to h, from left to right) Spectral analysis of month-wise u and v components of wind using HWSR data of Oct-Dec 2009

- i) **Oct** : The sinusoidal oscillations imply the clear diurnal variation in wind pattern normally felt in a coastal station like Chennai. Both the zonal and meridional components show consistent variation though u component shows a negative autocorrelation also while v is mostly positive. When the correlogram of Oct 2009 in Fig.9a is analysed jointly with the spectral analysis of Oct 2009(as in Fig.10a), it is observed that there is a low period oscillation of 5 days which is clear only from the variation of the autocorrelation coefficient of the u component and not from the spectral density. Though the spectral densities are concentrated in the first few harmonic cycles, the 5 day periodicity is more evident from the correlogram. The 90% and 95% confidence limits(c.l) indicate a clear periodicity of 24 hrs at the 16th harmonic cycle as in Fig.10a. The spectral analysis of v component (Fig.10b). also indicates a peak for 24 hr periodicity whereas five day periodicity is not marked.
- ii) **Nov** : The correlogram (as in Fig.9b) of u and v components of Nov 2009 shows a waning type of distribution with accs slowly tending to zero gradually with considerable distortion in the sinusoidal pattern of the u component, consequent to the reversal in wind pattern for few hours during the existence and movement of the storm. It may perhaps be attributed to the cyclonic storm “Phyan” of 4-10 Nov. The five day periodicity of u component is feeble in Nov whereas it is significant in the v component(Fig.10d) through clustering and peaking of spectral densities above the 90% c.l in the first few harmonic cycles. The 24 hr periodicity of u and v is manifested clearly (Fig.10 c&d).
- iii) **Dec**: The correlogram of u and v components(Fig.9c) of Dec shows an almost in phase oscillation of both u and v in spite of the “Ward” storm of 10-Dec. The variations in wind direction and speed as in Fig.8(a & b) are direct manifestations of the almost synchronous oscillations of u and v which is distinct for Dec and not observed in Oct and Nov. The spectral analysis of u and v of Dec(Fig.10 e&f) indicates the clear 24 hrs periodicity in both components.
- iv) **Oct-Dec** : The correlogram of the whole time series of the season (Oct – Dec) shown in Fig.9(d) has a smoothed sinusoidal oscillation with the v component being more significant than u. The spectral analysis (Fig.10 g&h) shows a 5 day periodicity just below the 90 % c.l which was originally manifested in the spectral analysis of u component of Oct in Fig.10(a). the 24 hr periodicity is however very clear from the spectral peaks of both u and v for the entire series.

b) AWS - Autocorrelation coefficients(ACC) and spectral densities

- i) **Oct** : The correlogram of uv of Oct 2009 (Fig.11a) derived from AWS shows some amount of 5 day periodicity through the u component, though it is completely absent in the spectral analysis(Fig. 12a). There is a predominance of v component during Oct as derived from acc of Oct HWSR data whereas the acc is less for v as seen from AWS data. The 24 hr periodicity is evident from the spectral analysis(Fig.12 a & b) of u and barely manifested in the v component during Oct.
- ii) **Nov**: The acc of uv of Nov 2009 (Fig.11b) as derived through AWS data does not show any type of sinusoidal oscillation whereas HWSR-derived acc also showed some amount of distortion,though not so significant as that of AWS. It may be analysed from Fig.6(a & b) that

the variation in wind speed was less than 10 knots during the time of “Phyan” as recorded through HWSR and DPTA whereas AWS showed wind speeds greater than 10 knots shooting up to even 35 knots on two occasions. The wind direction recorded by AWS during the same period was easterly to southeasterly and HWSR and DPTA did not show similar such consistent pattern. These might be contributing factors to the aperiodic pattern in acc during Nov.

iii) Dec: The acc of v component(Fig.11c) is underestimated compared to that shown by HWSR during Dec. However the oscillation is periodic. The spectral density of u and v components(Fig.12e&f) show 24 hr periodicity and the v component of Dec shows a spectral density for 5 day periodicity also which was not manifest through HWSR data.

iv) Oct-Dec : Fig.11d shows the acc of the combined time series of all the three months. The acc of v component reduces to zero for every subsequent lag whereas sinusoidal oscillation is shown in the u component. Reverse is the case with data of HWSR-derived data v component of the series was of higher acc than u component. The reasons for such a reversal needs to be studied in-depth. Fig.12 (g&h) show the spectral densities of u and v for the entire time series wherein u component reflects the 24 hr periodicity whereas the v component just shows the periodicity at 90% c.l.

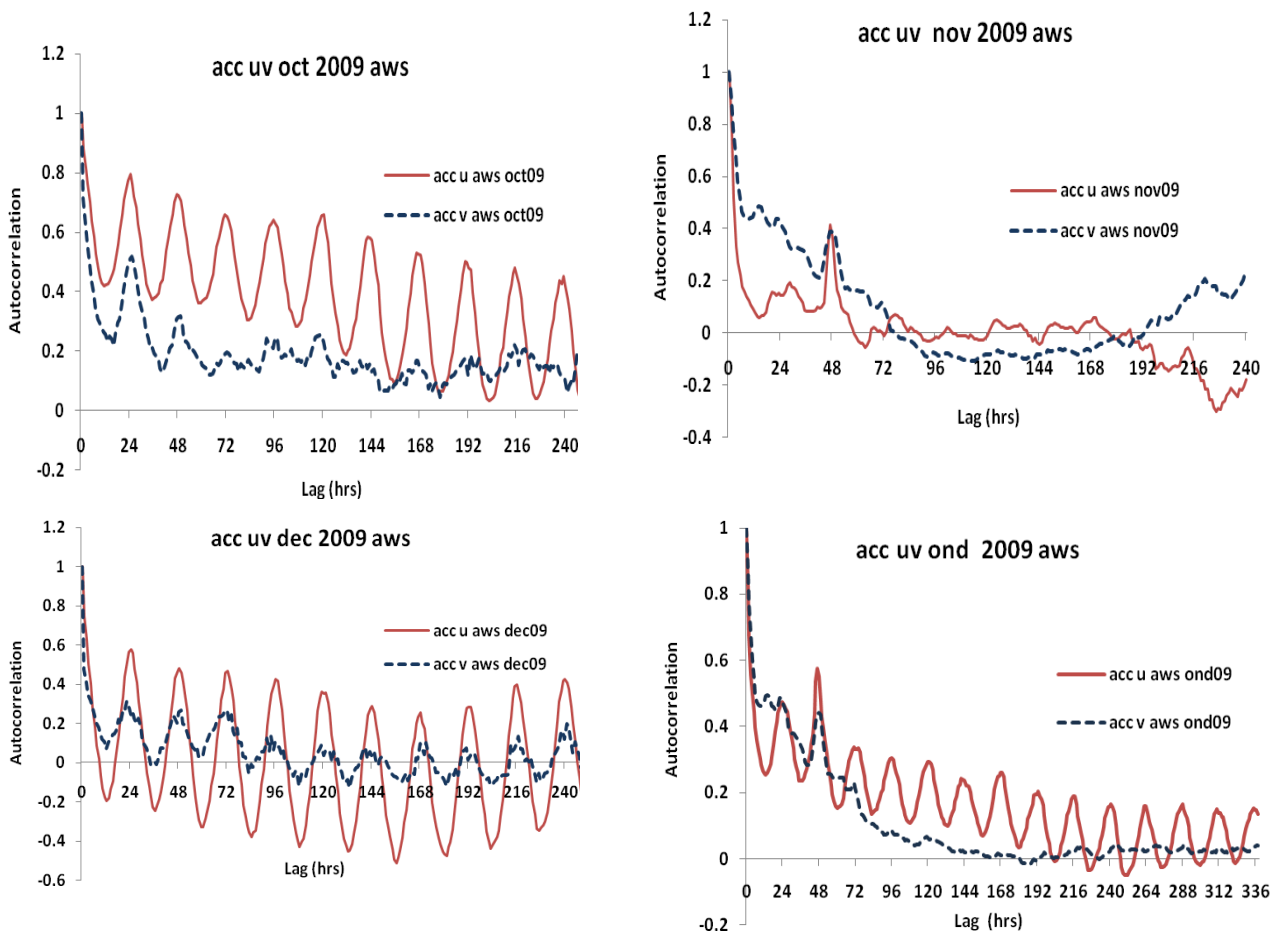


Fig. 11 Autocorrelation of u and v wind components using AWS data Oct – Dec 2009

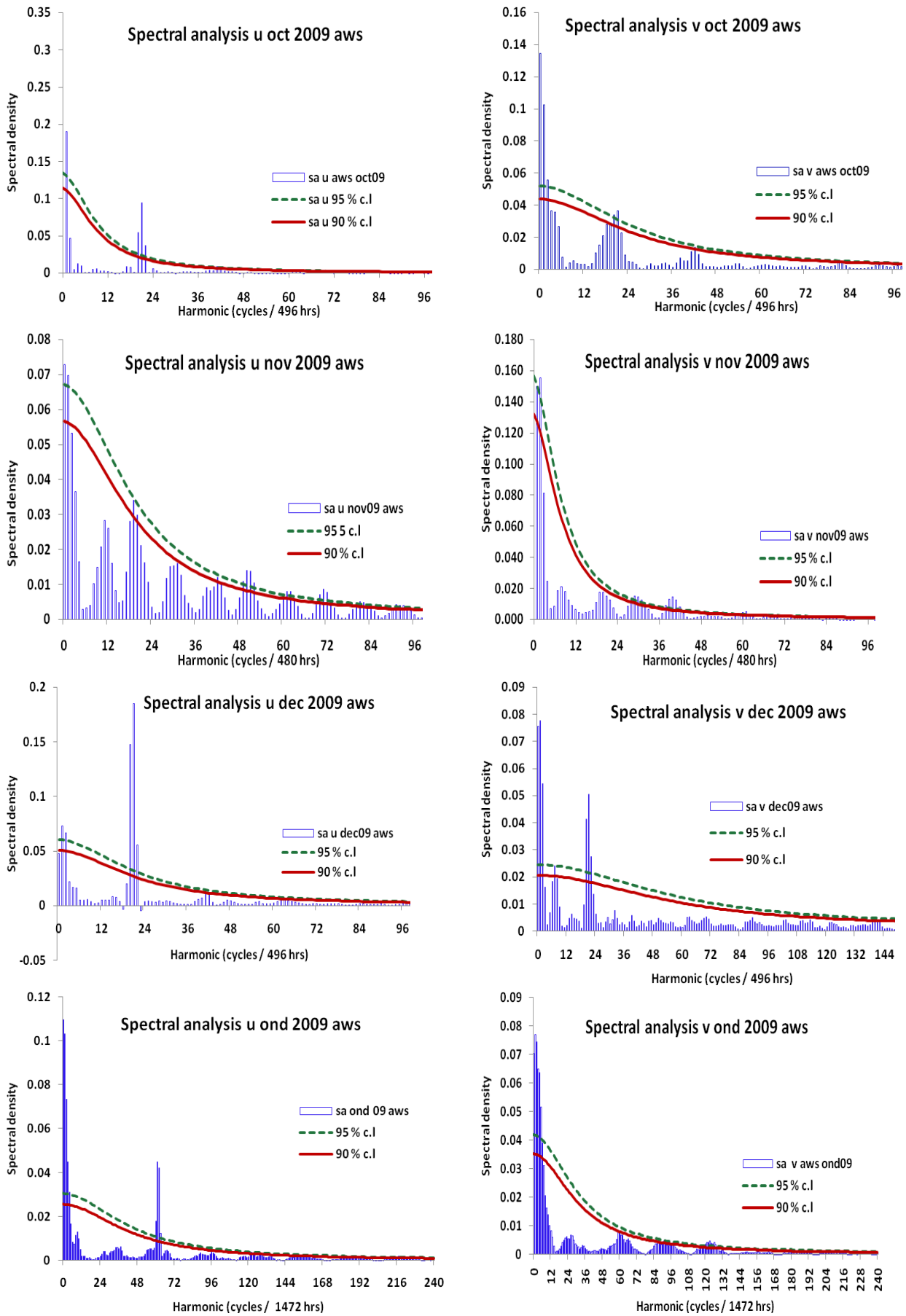


Fig. 12 (a to h, left to right) Spectral analysis of u and v wind components using AWS data Oct-Dec 2009

Decadal averages

Ten day(decadal) averages of the u and v components derived from wind direction and speed recorded through HWSR and AWS is depicted in Fig.13(a) and (b). The zonal and meridional components clearly indicate the southwesterly winds before onset of NEM and the gradual shift to northerly and easterly wind components which is characteristic of the monsoon season. A clear-cut transition in winds is seen in Fig.13(b) of AWS data during the period of Phyan where higher wind speeds were reported. No such difference is seen in the HWSR derived data though a minor change is seen during the period 10-19 Nov in HWSR data. In general, it may be inferred that the decadal averages of u and v conform to the established persistence in the zonal and meridional components of wind during the northeast monsoon season 2009.

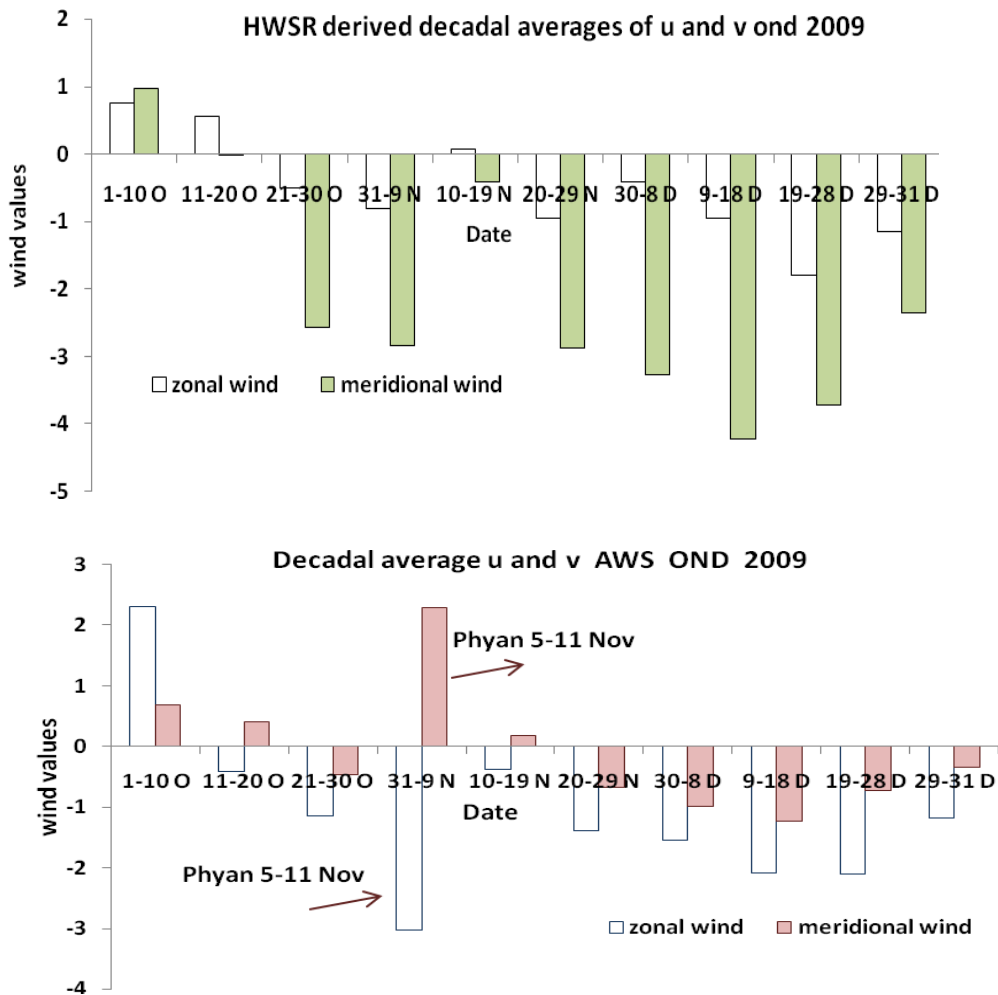


Fig.13 (a) and (b) Decadal averages of u and v as derived through HWSR and AWS for Oct-Dec 2009

Conclusions

The spectral analysis of the HWSR data of Oct-Dec 2009 shows interesting patterns synonymous with the established climatological persistence and periodicity in wind pattern over Chennai. For the u and v wind components, the analysis revealed at 95 % and 90% confidence limits that the power concentration is significant at 24 hrs, which is manifested in all the three months.

The fluctuations noticed in the correlograms of u and v components of HWSR-derived data may be due to systematic oscillations or due to any aperiodic variation during the onset phase of northeast monsoon or due to the effect of cyclonic circulations in the vicinity of the station under study. The clustering of spectral densities near about 5-6 days periodicity indicated in Oct in the zonal component appears to be due to the 5-day pressure oscillations over tropics as has been established by Bhalme et al (1975). The feeble indication of the same in Nov and Dec The performance of the automated equipments during Oct-Dec 2009 alone has been brought by this analysis and since the study pertains to only a single season, no generalisation can be made. In-depth study for annual variations needs to be undertaken with data of more number of years.

However, validation of the data in conformity to the conventional methods has been done through the results of this study which indicate persistence with climatology. Dependability has increased and transition to new sensor technology is possible by convincing the weather forecaster of the advantages of automation and user-friendly outputs available from such equipments. All electronic equipments need proper preventive maintenance and while it is ensured, accuracy of data is also enhanced.

Acknowledgement

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