Wind steadiness up to 35 km and its variability before the southwest monsoon onset and the withdrawal

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सार – इस शोध पत्र में मुख्यत पवन अपरिवर्तिता कारक (डब्ल्यू. एस. एफ.), एक मात्र प्राचल जो ऊँचाई, पवन गति और पवन दिशा पर निर्भर करता है, के माध्यम से पवन की दिशा की परिवर्तिता को प्रस्तुत करने के लिए मात्रात्मक विधि के बारे में बताया गया है। इसका उपयोग केरल में दक्षिण पश्चिम मॉनसून (द. पू. मॉनसून) के आरंभ और वापसी के संबंध में पूर्वानुमान प्राचल के लिए किया जा सकता है। इस संबंध में पुरानी जानकारी के लिए TERLS (8° 32′ उ. ⁄ 76° 52′ पू.) में 35 कि. मी. तक पवन की जलवायविकी की एक संक्षिप्त रूपरेखा पर चर्चा भी की गई है। व्युत्पन्न डब्ल्यू. एस. एफ. जलवायविकी से पता चला है कि उष्णकटिबंधीय पूर्वी जेट (टी. ई. जे.) के फलस्वरूप द. पू. मॉनसून के दौरान 12.5 कि. मी. से 18 कि. मी. के बीच के क्षेत्र में अधिकतम डब्ल्यू. एस. एफ. है। वार्षिक डब्ल्यू. एस. एफ. की उर्ध्वाधर परिवर्तिता से सुचिन्हित चार स्तरीय संरचना के लिए बने पवन पुष्पचित्र किसी विशेष स्तर के लिए प्रभावी दिशा द्वारा डब्ल्यू. एस. एफ. को योगदान देते हैं। प्रत्येक उपलब्ध रेडियो पवन प्रोफाइल (0530 और 1730 बजे भा. मा. स.) के लिए तिरूवनन्तपुरम में 12.5 से 18 कि. मी. के बीच के क्षेत्र के लिए डब्ल्यू. एस. एफ. मान का आकलन किया गया और यह पता चला कि आरंभिक घटना और द. पू. मॉनसून से पहले 80% से अधिक डब्ल्यू. एस. एफ. के अनुरक्षण से द. प. मॉनसून का पहले आगमन हो जाता है और इससे विपरीत स्थिति में देर से आगमन होता है। 80% के मान से डब्ल्यू. एस. एफ. में देर से ⁄ जल्दी कमी होने तथा उसके उपरांत और कमी होने के कारण द. प. मॉनसून की देर से ⁄ जल्दी वापसी होती है।

ABSTRACT.   This paper brings out mainly on the quantitative approach to delineate wind direction variability through Wind Steadiness Factor (WSF) - a single parameter which depends on height, wind speed and wind direction. This can be used as a prognostic parameter for the onset and withdrawal of south west monsoon (SW Monsoon) over Kerala. A brief sketch on wind climatology up to 35 km over TERLS (8° 32′ N / 76° 52′ E) is also discussed to have a background knowledge. From the derived WSF climatology, it is seen that the region between 12.5 km to 18 km is of highest WSF during the SW Monsoon due to the Tropical Easterly Jet (TEJ). Vertical variation of annual WSF has shown well demarcated four layered structure and the wind rose constructed for each layer provides the contribution of WSF attributed by the dominant direction for that particular layer. A WSF value was estimated for the region between 12.5 km to 18 km over Thiruvananthapuram for each available rawin profile [0530 and 1730 hrs (IST)] and inferred that an early incidence and maintenance of WSF well above 80% prior the SW Monsoon supports an early SW Monsoon onset and reverse for a late onset. A late/early WSF decrease from a value of 80% followed by systematic further decrease is associated with late/early withdrawal of the SW Monsoon.

Key words – SW monsoon, Onset, Withdrawal, Wind steadiness factor, Monsoon low level jet, Tropical easterly jet, Sub tropical westerly jet, Stratospheric easterly jet, Wind rose, Mean resultant wind speed, Mean scalar wind speed.

1.   Introduction

A description of the steadiness of the wind direction is desirable in dispersion problems. Studies are available to quantify the oscillations associated with wind direction for engineering applications. Early studies in this area were contributed by Singer, 1967, where a trigonometric transformation is used to linearise the variation of constancy with the mean angular range of direction and the function was designated as steadiness. Methodologies were also developed for estimating standard deviation of wind directions. A comparison of three methods for
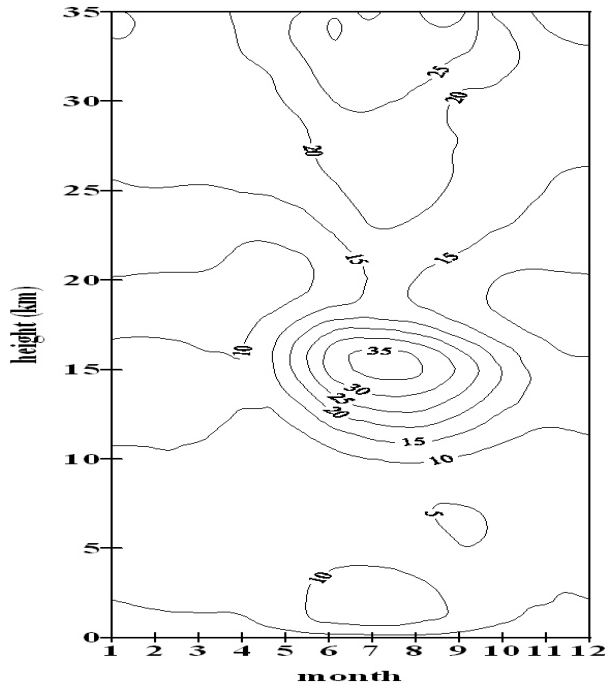
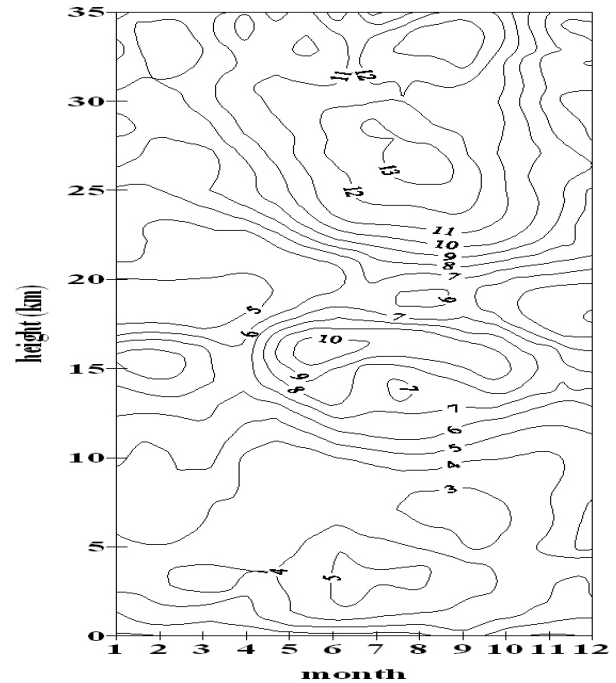**Fig. 1.** Mean scalar wind speed (m/s)

Fig. 2. Standard deviation of scalar wind (m/s)

calculating the standard deviation of the wind direction was evaluated by Turner, 1986. In the horizontal wind variability studies over Sriharikota, the reciprocal relation between wind direction steadiness and standard deviation of wind directions are emphasised (Namboodiri, 2000). Studies on steadiness in wind direction were mostly seen in boundary layer meteorology for its potential applications in dispersal modelling as well as wind modelling demands. In Aviation, Ballistic and Aerospace Meteorology fields, structure of wind steadiness factor can find suitable mandatory requirements in firing of rifles, artillery or missiles or the bomb droppings, in rocket fragmentation analyses and flight enroute decisions.

In this paper the simplest quantified approach to delineate wind direction variability through wind steadiness factor computation up to 35 km over Thumba (8° 32′ N / 76° 52′ E), Thiruvananthapuram, India is carried out. Climatological wind characteristics up to 35 km are also discussed to provide background knowledge. Wind steadiness climatology over Thumba and steadiness factor variations between 12.5 km to 18 km before the south west monsoon (SW Monsoon) onset and withdrawal over Kerala are analysed.

2.   Data and methodology

To generate the thirty-five year climatological depictions rawin wind data up to 35 km over Thumba

Equatorial Rocket Launching Station (TERLS) is used. Weekly high altitude balloon ascents at 1400 hrs (IST) have been made regularly from Thumba to collect wind data at 1 km altitude interval since 1970. To assess wind steadiness factor features in association with onset and withdrawal of SW Monsoon, daily rawin data [0530 and 1730 hrs (IST)] from the India Meteorological Department (IMD), Thiruvananthapuram which is situated about 8 km east of TERLS was employed. Daily weather bulletin from IMD, Thiruvananthapuram was utilized in order to get onset and withdrawal dates of SW Monsoon and also to assess associated weather features.

3.   Result and discussions

3.1.   *Climatology up to 35 km*

Prominent features on the mean scalar wind speed are as shown by Fig. 1. Below 10 km altitude, the mean scalar wind is less than 10 m/s through out the year with a closed contour maxima in the altitude between 1 to 4 km in association with Monsoon Low Level Jet (MLLJ). In the upper troposphere, mean scalar wind started peaking to a value of 35 m/s in the core of the Tropical Easterly Jet (TEJ) at 15 km, which is a feature during the SW monsoon. Well marked maxima are not seen in the height region of Sub Tropical westerly Jet (STJ) during its activity period from December to April through January. During the same period, winds of variable direction are noticed generally through out the atmosphere by
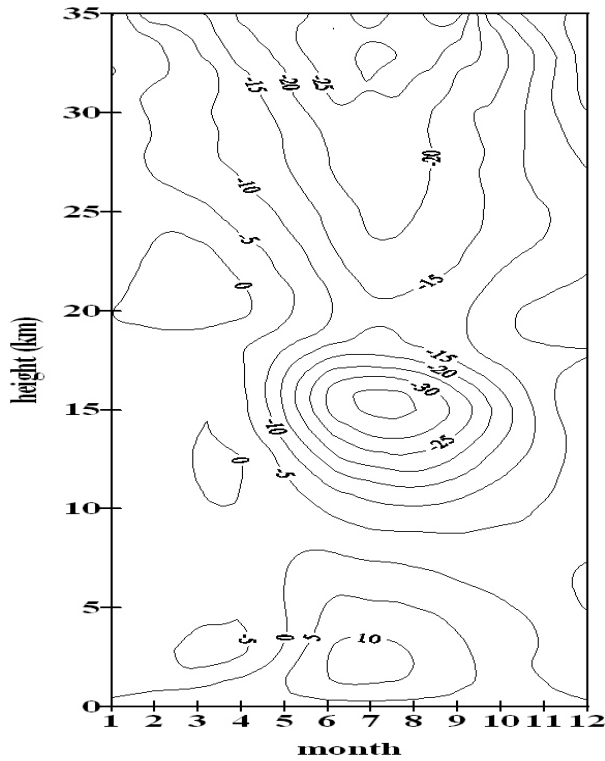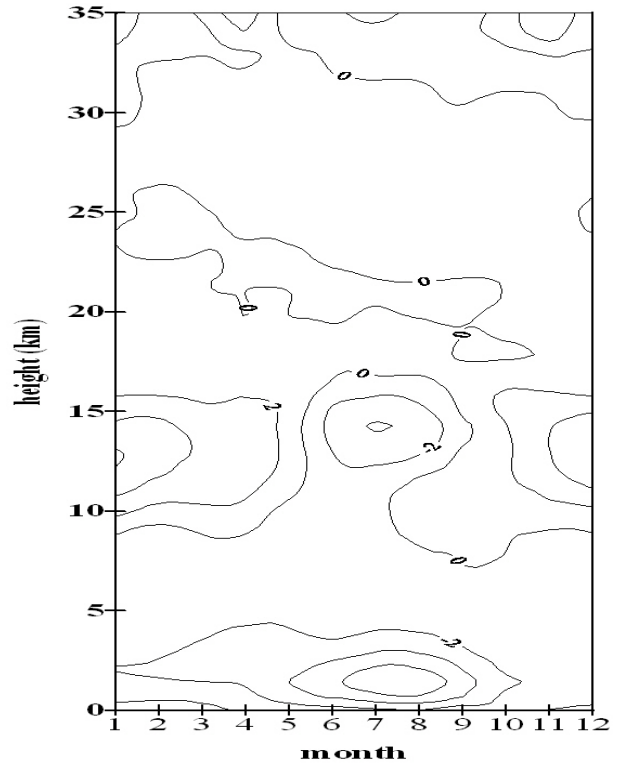
Fig. 3. Mean zonal wind component (m/s)

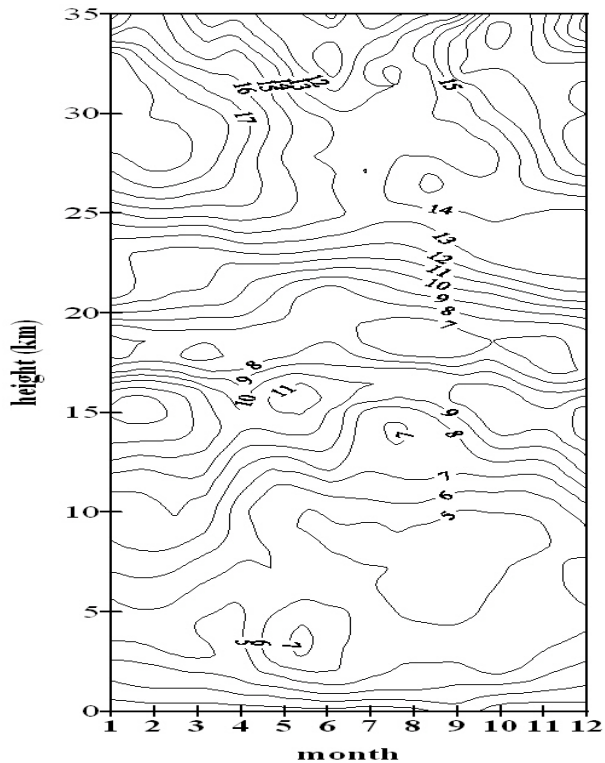**Fig. 5.** Mean meridional wind component (m/s)

Fig. 4. Standard deviation of zonal wind component (m/s)

comparing the mean scalar wind with zonal wind, meridional wind and wind steadiness factor features. Above 30 km, a defined maxima of mean scalar wind of the order of 25 m/s is observed in connection with Stratospheric Easterly Jet (SEJ) which has its peak activity during the SW monsoon. Standard deviations of scalar wind observations (Fig. 2) show maximum value 5 m/s, 9 m/s and 13 m/s in the region of MLLJ, TEJ and SEJ.

Mean zonal wind component (Fig. 3) is mainly by MLLJ, TEJ and SEJ with maximum values of the order of 10 m/s, -35 m/s and -30 m/s respectively. The standard deviations in Fig. 4 shows that zonal wind components are less than 10 m/s in general through out the troposphere and between 10 m/s to 20 m/s in the lower and middle stratosphere. Even though the values are very low in the structure of mean meridional wind component (Fig. 5), a mean meridional component value of -6 m/s in the core of the MLLJ establishes the feature of slight West North Westerliness of the Low Level Jet. Also in the core of TEJ, mean meridional flow with a value of the order -3 m/s, depicts the characteristics of TEJ current with a little East North Easterliness. Mean meridional component explains typical east-west orientation in zonal flow which is observed throughout the year in stratospheric levels unlike slight deviation from east west direction observed in tropospheric jet streams. Fig. 6 provides the structure of
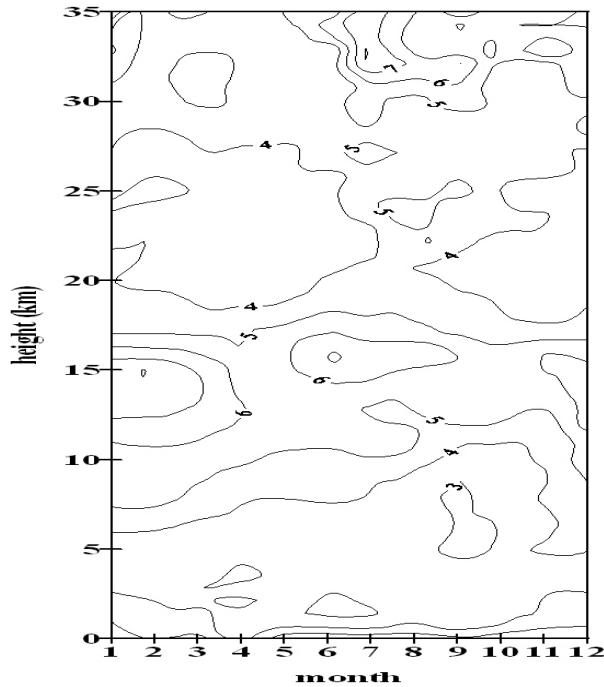
Fig. 6. Standard deviation of meridional wind component (m/s)

Fig. 8. Wind steadiness factor profile derived from all the observations
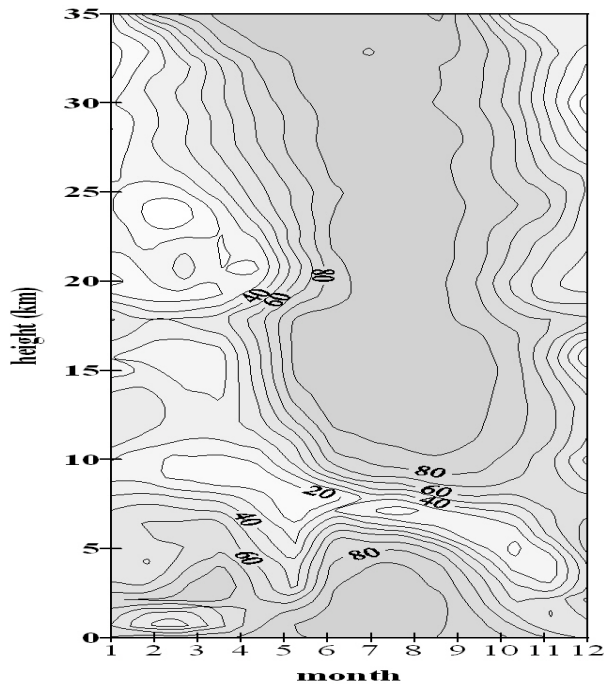

Fig. 7. Wind steadiness factor (%)

the standard deviation of meridional wind component. High standard deviation values of the order of 7 m/s is observed at levels around 12-15 km during December to April. Also in the TEJ region, standard deviation of 6 m/s is observed.
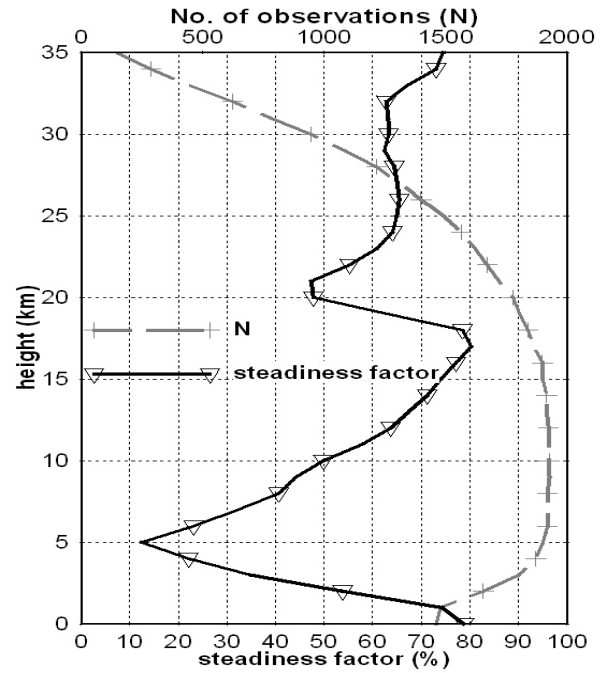
3.2. *Wind Steadiness Factor*

Wind Steadiness Factor (WSF) is a general meteorological analysis technique in order to derive the quantitative estimate of steadiness of wind direction. Steadiness factor (expressed in %) is defined as the ratio of Mean Resultant Wind Speed (MRWS) to Mean Scalar Wind Speed (MSWS) computed as follows.

$$\text{MSWS} = \sum_{i=1}^{N} V_i / N \qquad (1)$$

$$\text{MRWS} = \sqrt{(\sum_{i=1}^{N} u_i / N)^2 + (\sum_{i=1}^{N} v_i / N)^2} \qquad (2)$$

$$\text{WSF (\%)} = (\text{MRWS/MSWS}) \times 100 \qquad (3)$$

Where V_i, u_i, v_i and N are scalar wind speed, zonal component, meridional component and number of observations respectively. Fig. 7 depicts the climatological structure of steadiness factor up to 35 km. Highest steadiness factors are seen in the region of jet streams. In the region of MLLJ, TEJ and throughout the stratosphere steadiness factors are observed with highest values of 90%
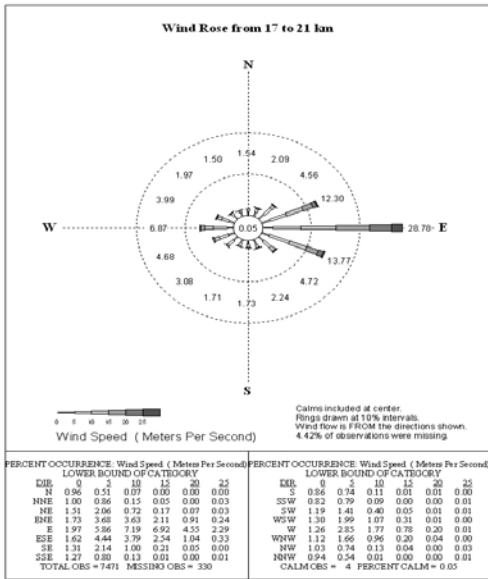
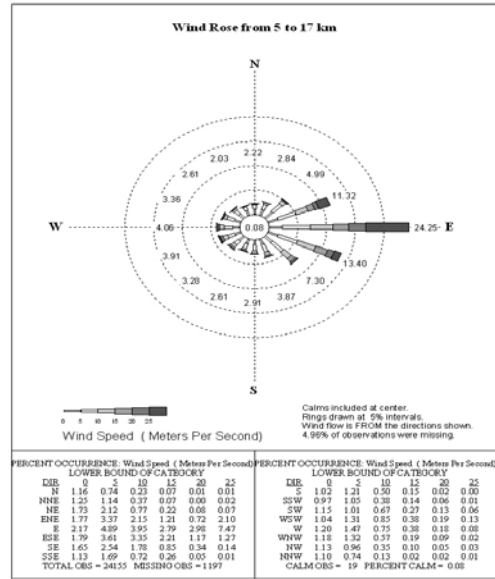**Fig. 9(a).** Wind rose for the region from 0 to 5 km

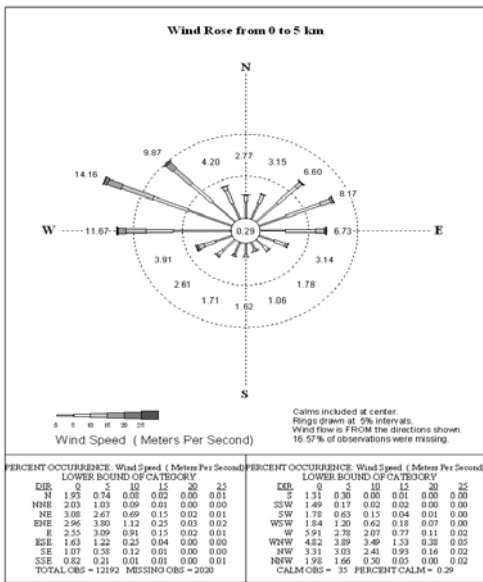**Fig. 9(c).** Wind rose for the region from 17 to 21 km

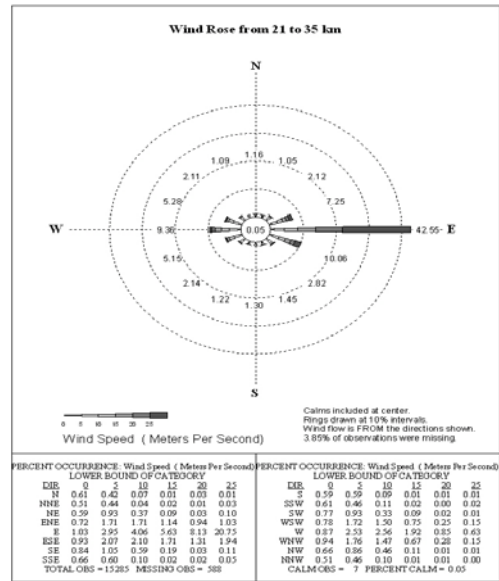**Fig. 9(b).** Wind rose for the region from 5 to 17 km

Fig. 9(d). Wind rose for the region from 21 to 35 km

in SW Monsoon. A transition layer of low steadiness factor (20%) is noticed from 10 km level in January, which is slowly percolating down to 5 km in November. Steadiness factor above 10 km during January to April show lowest values of the order of less than 40% up to 35 km.

The vertical profile structure of annual wind steadiness factor is constructed by using all the data points available at every km and presented in Fig. 8. Number of points considered to derive each km steadiness factor also incorporated in this figure. Salient feature of this depiction is that, there is an excellent systematic steadiness factor profile variation over the station, which can be well demarcated by a four layered structure *viz.*, (*i*) Layer - 1 from 0 to 5 km, in which steadiness factor slowly
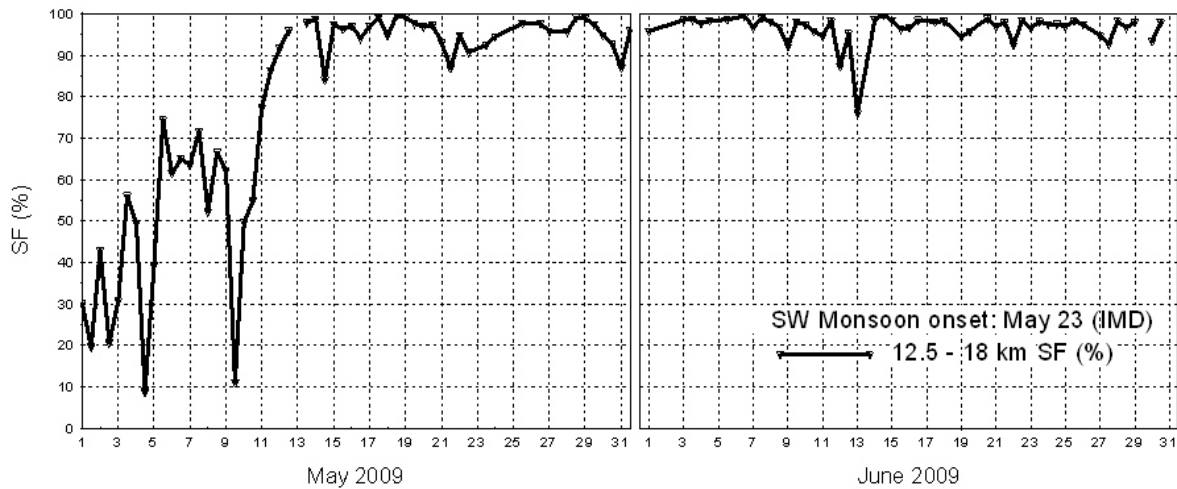
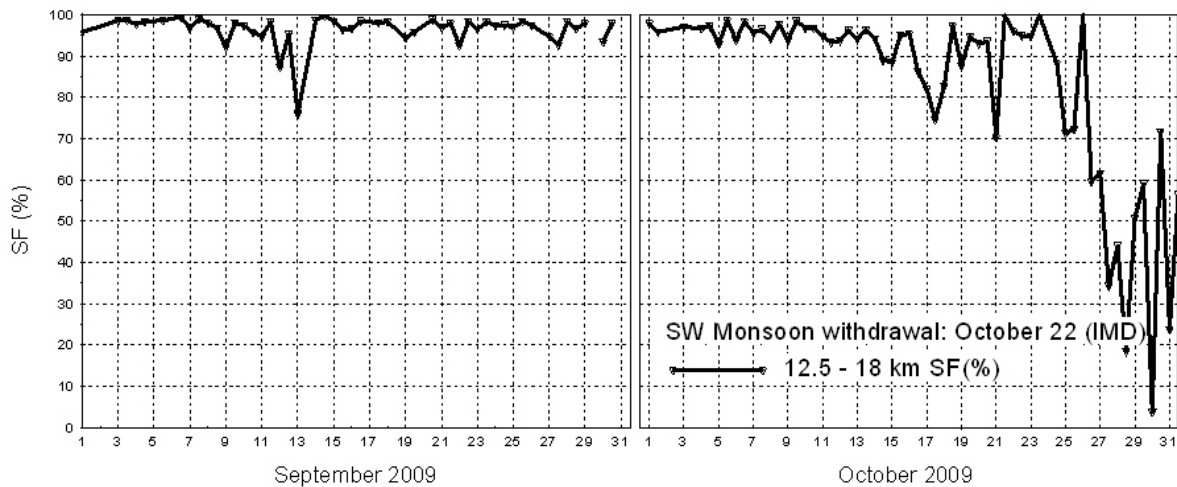**Fig. 10(a).** Wind steadiness factor in May and June 2009

Fig. 10(b). Wind steadiness factor in September and October 2009

decreases from 80% to 12%, (*ii*) Layer-2 from 5 km to 17 km in which the steadiness of wind shows a steady increase from the lowest value to the highest value of 80 %. (*iii*) A narrow layer-3 compared to all the other 3 layers is observed from 17 km to 20 km where the steadiness factor decreased from 80 % to a medium value of 50 % and (*iv*) Above 21 km, steadiness factor is almost constant with values around 70% (layer-4).

3.3. *Wind roses for the WSF layers*

We have constructed wind roses (the conventional method of representing percentage frequency of winds in a specific direction for different speed classes) for the above described four specific layers in the annual wind

steadiness factor profile [Figs. 9(a-d)]. For the construction of wind roses, all the available speed and direction data at every km interval are used for each layer. Four wind roses are constructed on percentage occurrence of wind speed for different speed classes at 16 compass points. The wind rose diagram along with the computed table inset provides an over all idea about the wind structure (both in speed and direction) in a year at different atmospheric layers over the station and the contribution of wind steadiness attributed by the dominant wind direction.

Fig. 9(a) depicts the wind rose for 0 to 5 km atmospheric region. WNWly winds are observed with maximum occurrence with a frequency of 14.16 %. In the atmospheric layer from 5 to 17 km, easterly winds with

TABLE 1

Prominent date of wind steadiness change before the SW Monsoon onset and withdrawal along with onset and withdrawal dates

Year	Date from which systematic increase in SF (%) is observed	Date of onset of SW Monsoon	Date from which systematic decrease in SF (%) is observed	Date of withdrawal of SW Monsoon
2000	May 19	June 01	October 11	October 25
2001	May 7	May 23	No data	October 16
2002	May 5	May 29	October 8	October 25
2003	May 7	June 08	September 30	October 15
2004	April 25	May 18	September 27	October 18
2005	May 26	June 05	September 21	October 11
2006	May 06	May 26	September 25	October 17
2007	May 17	May 28	October 12	October 22
2008	May 08	May 31	No data	October 15
2009	May 11	May 23	October 14	October 22

maximum of 24.25 % contributed by all the speed classes [Fig. 9(b)]. Also greater than 25 m/s events are maximum from the east with a frequency of 7.47 %, which may be attributed to the sharp easterly TEJ component in the SW monsoon. The wind rose which represents the narrow layer from 17 km to 21 km, shows easterly dominance with 28.78 % as in Fig. 9(c). The notable features in Fig. 9(d) which represents the 21 to 35 km layer is the predominance in easterly winds with a frequency of 42.55 %. The most dominant frequencies in 5 to 17 km, 17 to 21 km and 21 to 35 km are 24.25 %, 28.78 % and 42.55 % respectively which further ascertain the fact of SEJ as the most persistent phenomena in comparison with TEJ or conclusion can be drawn as most of the time stratospheric levels are under the influence of easterlies.

For academic interest it is worthwhile to study about the TEJ over India. It is more commonly known as Easterly Jet Stream, because it is found in the zonal easterly wind belt of the tropics. It is found at a mean height of about 14 to 15 km above msl. It is prominent in the SW Monsoon and becomes very weak in the winter. In July average core speed may vary from 30 to 40 m/s, but on occasions winds up to 50 to 60 m/s may be encountered. The TEJ axis average location in July-August is near 15° N over the Indian area. Elsewhere there are large breaks, the core velocities are falling to very low values. In winter, the TEJ becomes very weak and only moderate easterly winds found a little to the south of the equator. The changes in the location and intensity are intimately connected with the changes in the Indian seasons. In the Indian region, the disappearance of the Sub Tropical westerly Jet (STJ) over India and the appearance of TEJ practically coincide with the onset of

the SW monsoon. Again, the withdrawal of the SW monsoon is associated with the southward shifting of the STJ in to the northern parts of India.

3.4. *WSF before, during and withdrawal of SW monsoon*

From the climatological structure depicted in Fig. 7, it is understood that the region between 12.5 km to 18 km is influenced by the highest steadiness values attributed by the TEJ. WSF computation within a specific regime (12.5 to 18 km) provides, a single value parameter which is a function of three parameters-height, wind speed and wind direction. This effectively gives a quantitative estimate on current depth, intensity and orientation of the TEJ. Systematic increase of direction steadiness to more than 80 % can be seen while nearing towards the onset of SW monsoon and systematic decrease when we approach SW monsoon withdrawal. MSWS and MRWS are computed between the layer 12.5 to 18 km region by taking all the available data points for (May, June) and (September, October) for onset and withdrawal of SW Monsoon (2000-2009) signatures respectively. Wind steadiness factor is computed by taking 0530 and 1730 hrs (IST) Rawin ascents consecutively for the region between 12.5 to 18 km. For the year 2009 [Figs. 10(a&b)] show daily wind steadiness factor values (time series graphs) from which it is seen that the feature of high steadiness of the order more than 80 % is maintained from May 11, 2009 onwards and the onset of SW monsoon over Kerala was declared by IMD as on May 23, 2009. Abrupt decrease in wind steadiness is observed from 80 % from October 14, 2009 onwards and the withdrawal date of SW monsoon was announced as on October 22, 2009. Similarly

different onset and withdrawal dates are delineated by observing the critical point or the point of inflection for higher steadiness values and lower steadiness values in time section plots and are provided in Table 1 for the year 2000 to 2009. From the analyses, it is understood that an early incidence and maintenance of wind steadiness values well above 80 % prior the SW monsoon supports an early SW monsoon onset (exception in 2003) and reverse for late onset. The predictive potential inference for onset and withdrawal of SW monsoon is carried out by using the rawin data of IMD, Thiruvananthapuram. Confirmation of the result was done by using weekly once rawin data over Thumba. The exceptional nature which was observed in 2003, may be the result of the low pressure influence in the Bay of Bengal in May 2003 and there by interruption in the monsoon flow field. Pre-monsoon rainfall activity was observed between 05 to 07 May, 2003 over Kerala and the occurrence was in most of the places over Kerala on 06 May, 2003 (Daily weather bulletin, IMD). These two observations are ascertaining the fact of a tending early onset of SW monsoon, but interruption in monsoon flow attributed by the low pressure formation in the Bay. A late / early wind steadiness factor decrease from a value of 80 % followed by systematic further decrease may associated with a late/early withdrawal of SW Monsoon.

4. Conclusions

The following conclusions can be drawn from the study.

(*i*) The climatological structure of wind has shown features of MLLJ, TEJ and SEJ with mean scalar values of the order of 10 m/s, 35 m/s and 25 m/s with standard deviations 5 m/s, 9 m/s and 13 m/s respectively in the jet core region.

(*ii*) Mean zonal wind field depiction has provided values 10 m/s, -35 m/s and -30 m/s correspond to MLLJ, TEJ and SEJ. Standard deviations were less than 10 m/s in the troposphere and between 10 m/s to 20 m/s in the lower and middle stratosphere.

(*iii*) Very low values were observed in mean meridional winds and from these values, the West North Westerliness of MLLJ and East North Easterliness of TEJ characteristics were investigated and typical East-West flow in the stratosphere.

(*iv*) MLLJ, TEJ and SEJ are associated with highest WSF values of 90 %. Vertical profile of annual WSF has shown a very systematic four layered structure, *viz.*, 0 to 5 km, 5 to 17 km, 17 to 21 km and above 21 km. Over all idea about the wind speed and direction was depicted through wind roses at various layers and conclusions were drawn as most of the time stratospheric levels are under the influence of easterlies unlike tropospheric levels.

(*v*) A WSF value was estimated for the region between 12.5 km to 18 km over Thiruvananthapuram for each available rawin profile [0530 and 1730 hrs (IST)] and inferred the predictive potential as an early incidence and maintenance of WSF well above 80 % prior the SW monsoon supports an early SW Monsoon onset and reverse for a late onset. A late/early WSF decrease from a value of 80 % followed by systematic further decrease is associated with late/early withdrawal of the SW monsoon.

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