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Behavior of Kelvin waves for two low latitude stations

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The wind profiles of Jakarta (Indonesia) and Hyderabad (India) have been analyzed from the radiosonde data for 12 months (January to December 2019) and the data have been used to investigate the behavior of Kelvin waves in the equatorial atmosphere. A non-dispersive wave of zonal wind easterlies are recorded between 15 and 25 km altitude in January over the Jakarta region with zero perturbation of meridional wind velocity at the same altitude. Similar pattern with less magnitude of easterlies has also been recorded over Hyderabad region at the same period. This might be an apparent evidence for the decay of Kelvin waves as they move away from the equator and the two regions have a nearly opposite trend of wind profiles. Further effect of Kelvin waves on the atmospheric pressure has been investigated for both the regions at three different altitudes including 5, 15 and 25 km, respectively. The observed effect indicate the existence of kelvin waves depend on the decrease of pressure. Therefore, there is nearly four months interval for the shifting of an intertropical conventional zone (ITCZ) from Jakarta to Hyderabad latitude.

Keywords: Comparison, Hyderabad, Jakarta, Kelvin Waves, Radiosonde

1 Introduction

The waves trapped at the equator are called equatorial waves. These waves have always been propagating in the vertical and longitudinal direction. They can rapidly decay away as they move from the equator[1] and they are responsible for balancing the earth's Coriolis Effect. The waves exist both over the ocean and in the earth's atmosphere. The tropical atmosphere equatorial waves play a vital role in the atmospheric dynamics such as Madden Julian oscillation (MJO), Quasi-Biennial Oscillation (QBO) and El Nino, etc. The atmospheric equatorial waves can be generated by many physical processes like diabatic heat release due to cloud formation, whereas, anomalous changes in the potential or direction of the trade winds in the ocean generate atmospheric equatorial waves[2]. The waves are also dependence on the velocity, period, and direction of propagation. Furthermore, equatorial waves can be classified into following, equatorial gravity waves, equatorial Rossby waves, mixed Ross by-gravity waves, and equatorial Kelvin waves. The equatorial gravity waves have the shortest periods while the Ross by waves have the longest periods. These waves propagate in an eastwards direction and carry energy with them. The emphasis here is the equatorial Kelvin waves. According to Matsuno[1] the waves exist at the equatorial beta plane, Yani[3] observed westward-moving waves in the stratosphere in the same region as Matsuno. Later Wallace[4] observed eastward propagating mixed Ross by gravity wave for few weeks.

Mixed Rossby waves gravity waves are generated due to lateral forcing from mid latitudes of meridional propagation of large scale revealing the mean zonal velocity more than the disturbance observed with phase velocity and the mean zonal wind velocity carries energy toward equator. The space-time spectrum analysis on equatorial wind disturbance reveals mixed Ross by gravity waves with a global zonal period of 5 days and wave number of four[5]

The other excitation mechanism involved is atmospheric force heating. Equatorial waves are described as heating response by cumulus convection. Most theories have not considered the mechanism of excitation disturbances caused bythe heating[6]. Therefore, it could be observed that the atmospheric response might be due to diabatic heating from the white frequency spectrumin the troposphere and the observed discrete frequency components of Kelvin

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waves existed according to the altitude structure of the heat source. Furthermore, Salby[6] reported the response of the atmosphere to stochastic heating and evaluated two different types of wave generation. The first type of waves propagate vertically and the other type is a normal mode that horizontally spreads, it is also horizontally concentrated near the excitation field. They have also shown that, the dominant wavelength of the latter waves is influenced by effective depth of heating and it is in sensitive by the height distribution of heat source when the depth of the excitation layer is the same. However, it is difficult of indan exact profile of the source of heating the equatorial atmosphere. Mass continuity from coordinated observations of horizontal wind velocity fields from several stations using radiosonde observation at the Indonesian Islands might reveal some clear perspective.

In the tropical troposphere, Madden[7] have detected an oscillation of zonal winds, which is often known as the “Madden-Julian oscillation” (MJO). The MJO is confined within the troposphere and is a large-scale cloud cluster moving eastward from the Indian Ocean to West Pacific. Analyzing cloud data with Geostationary Meteorological Satellite showed that a super cloud cluster propagated eastward[8].

In the stratosphere the quasi-biennial oscillation (QBO), with the period of 26-28 months has been observed[9]. Vertical transport of momentum and energy by equatorial waves is thought to be a key mechanism for the QBO. Holton[10] hypothesized that the wind reversal is due to thermal damping of vertically propagating mixed Rossby-gravity and Kelvin waves. Hence, an analysis of the QBO in a three-dimensional model[10] has shown that westward propagating gravity waves are coupled with precipitation and are important in generating the easterly phase of QBO. While the westerly phase of QBO seemed to be maintained by both Kelvin waves and eastward propagating gravity waves. Thus, the upward momentum flux from equatorial Kelvin and gravity waves are estimated using radiosonde data from balloons launched at Singapore and concluded that the momentum flux of short period (1-3 days) gravity waves is three times larger than that of Kelvin waves in the westerly shear of QBO[10].

2 Methodology

The VaisalaRS-80 rawinsonde with the omega navigation system, and TA/TX-1000 balloons provided by TOTEX, where the TX-1000 was developed especially for a launch in a tropical region. The payload sensors send the data every two seconds, with altitude spacing around 10 m, and averaged in a layer with a thickness of 150 m. The 150 m height resolution for all atmospheric data such as wind velocity, atmospheric pressure, temperature, and relative humidity is sufficient to resolve the dominant atmospheric waves[11]. Balloons were launched two times every day at 00Z and 12Z (Indonesian standard time, which precedes universal time by 7 hours). To avoid balloon bursts, caused by the cold temperature near the tropopause at night, the morning launching at 00ZLT was sometimes delayed. However, in this study assuming that data have an even time interval of 12 hours during the whole observation period, a total of 510 balloons were launched in 12 months with two major interruptions during November 2019, and 368 balloons (72%) reaching to an altitude of 29 km observed the whole range of troposphere and the minimum and the maximum height reached by the balloon is 12 to 29 km respectively.

High-resolution GPS radiosonde (Meisei, Japan, make RD06G) balloons were launched almost regularly from Begumpet, Hyderabad January 2019 to December 2019 around 00Z i.e., 05:30 IST and 12 Z i.e., 17:30 (IST = UT + 05:30 h). The total number of soundings during the year is 614. The net weight of the Radiosonde balloon is 750 g (Sonde: 150 g and Totex balloon). The dimensions of the Sonde are 100 (W) × 60 (H) × 92 (D) mm. The balloon carrier’s sensor measures pressure temperature, relative humidity, wind direction, and wind velocity and reaching an approximate altitude of 30 km for the entire year. The balloon moves with an average velocity of 5 ms^{-1} and sends the data from the transmitter to receiver between 1000 hPa to 10 hPa. The negative temperature coefficient thermistor is used to measure temperature. The response time for the humidity (capacitance-based thin polymer) is 1s or less at 1000 hPa and 25 °C and it takes 10 s for a step-change from 20 % to 90 % RH, respectively. The minimum altitude reached by the balloon is 18 km. The minimum altitude is depending upon the season. During the monsoon season, it reaches the minimum altitude.

3 Results and Discussion

3.1 Wind velocities

Hyderabad (India) and Jakarta (Indonesia) are selected for this study because these two regions are close to the equator where the Kelvin wave exists and

Jakarta is a reference station because it is located very close to the equator.

The monthly mean of zonal wind profile up to 30km altitude over Jakarta and Hyderabad using radiosonde observation are shown in Figs 1 and 2, respectively. In Jakarta, it is found that from February to December easterlies are prevailing up to 15 km altitude and westerlies were observed in January up to 7 km altitude. In addition, westerlies are dominating easterlies within 15 to 26 km altitude with decreasing magnitude from March to December, while January to March easterlies is found[12]. Above 26 km altitude easterlies are observed except for January and it is approximately equal to zero for February and March.

The wind profile over Hyderabad is shown in Fig. 2 it is observed that westerlies are prevailing from January to May up to an altitude of 20 km while from June to September westerlies are recorded upto 5 km altitude before it gradually turns eastwards in December. The westerlies are dominant for January and February above 20 km altitude. It is quite calm at higher altitude for March and April whereas easterlies are observed above 5 km altitude for the rest of the months. The wind profile for the two regions of Hyderabad and Jakarta showed an approximate opposite trend, when winds are easterlies for Jakarta, it is westerlies for Hyderabad and vice versa.

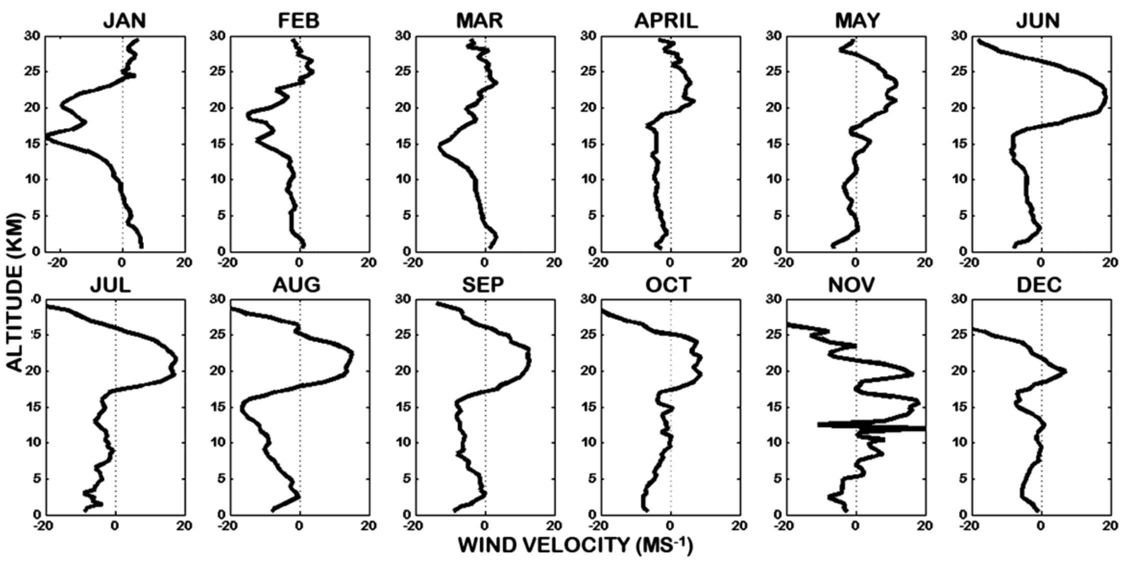

Fig. 1 — Zonal wind velocity of Jakarta for the year 2019.

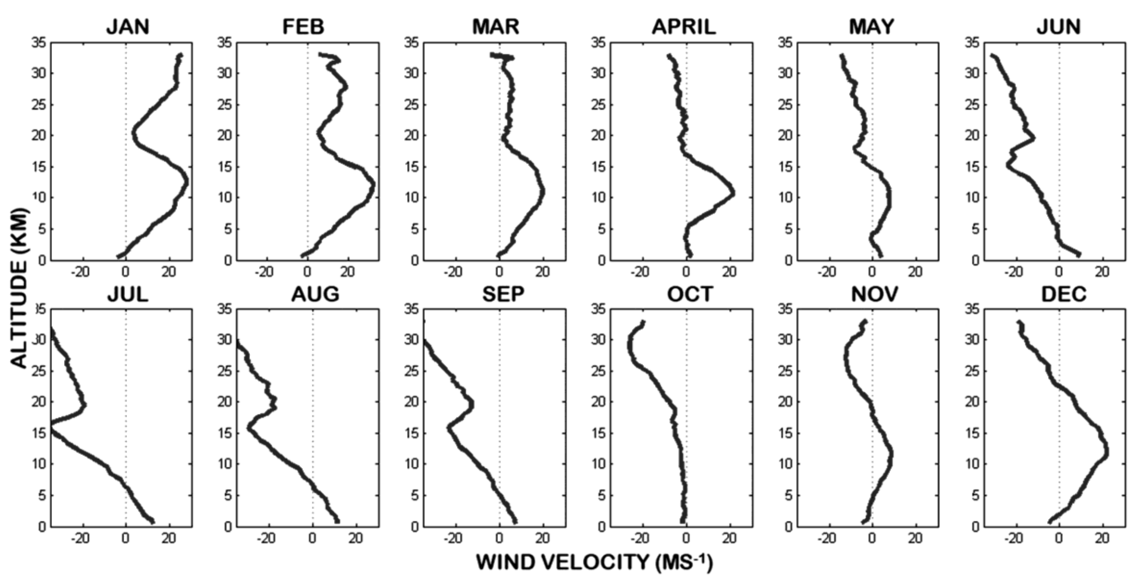

Fig. 2 — Zonal wind velocity of Hyderabad for the year 2019.

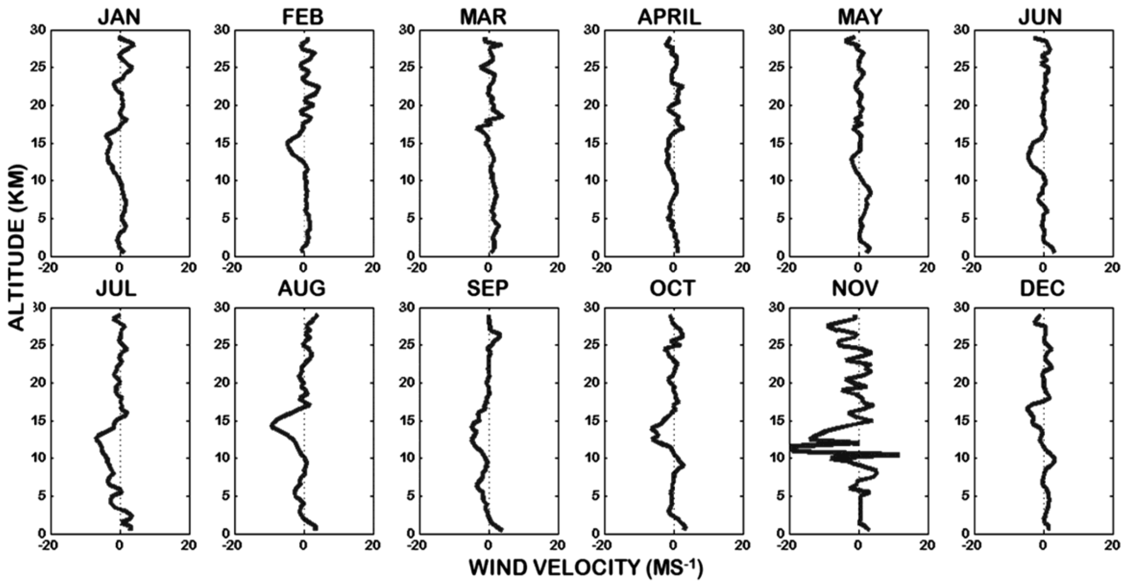

Fig. 3 — Meridional wind velocity of Jakarta for the year 2019.

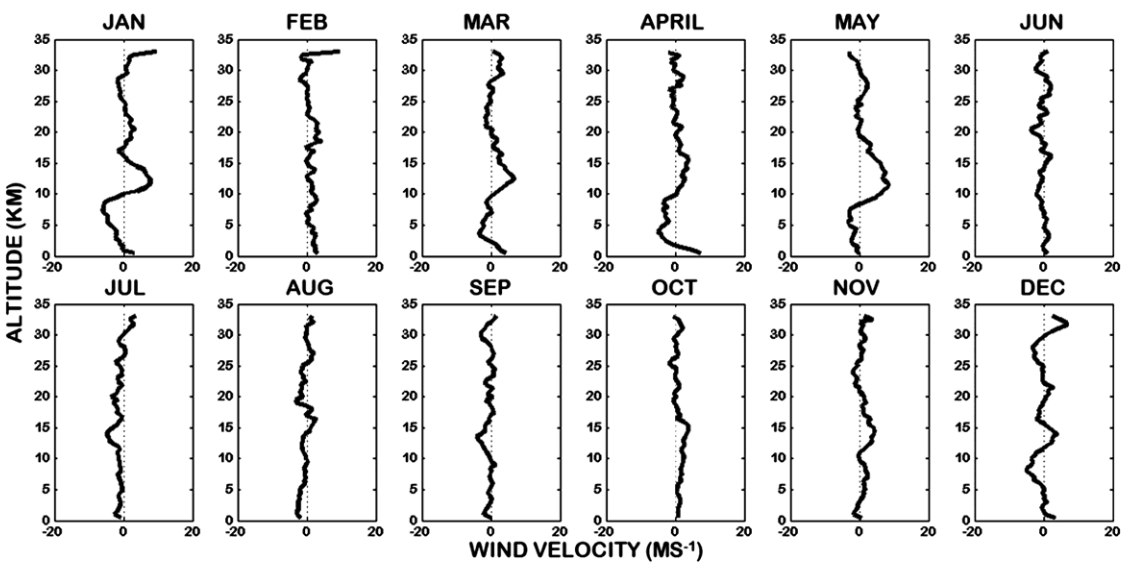

Fig. 4 — Meridional wind velocity of Hyderabad for the year 2019.

The monthly mean of the meridional wind profile of Radiosonde data over Jakarta and Hyderabad are presented in Figs 3 and 4, respectively. For Jakarta, January, February, June, July, August, September, and October the winds are northerlies with an approximate velocity of 5 m/s between 10 and 15 km altitude, and not much variation is observed for the rest of the months. In the case of Hyderabad, the southerlies are noticed in January and May and it is calm for the remaining months.

3.2 Kelvin waves

The Kelvin waves are defined as a disturbance in the equatorial atmosphere to balances the earth Coralie's force. They are unidirectional and decay in a gaussian manner from the equator and always propagate eastwards[13] whereas, the meridional perturbation is zero[14]. To study the behavior of these waves both zonal and meridional winds are evaluated for Jakarta and Hyderabad as presented in the previous section. In case of Jakarta, the zonal winds are easterlies below 15 km with less magnitude throughout the year and 16 to 25 km for January, February and March, respectively. On the other hand, westerlies are found from April to December with decreasing magnitude of wind velocity moreovere above 25 km the winds are easterlies for the same

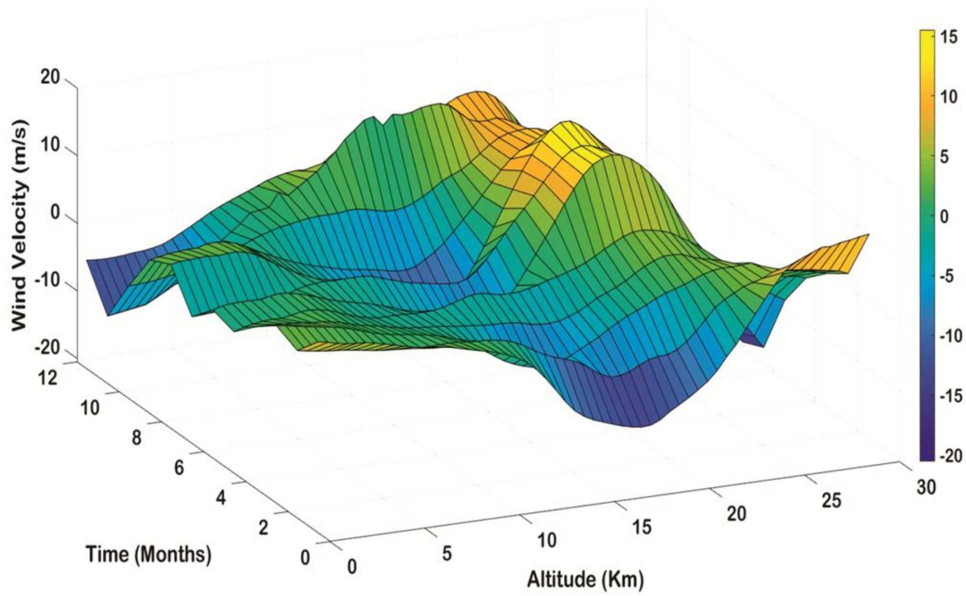

Fig. 5 — Zonal wind velocity of Jakarta for the year 2019.

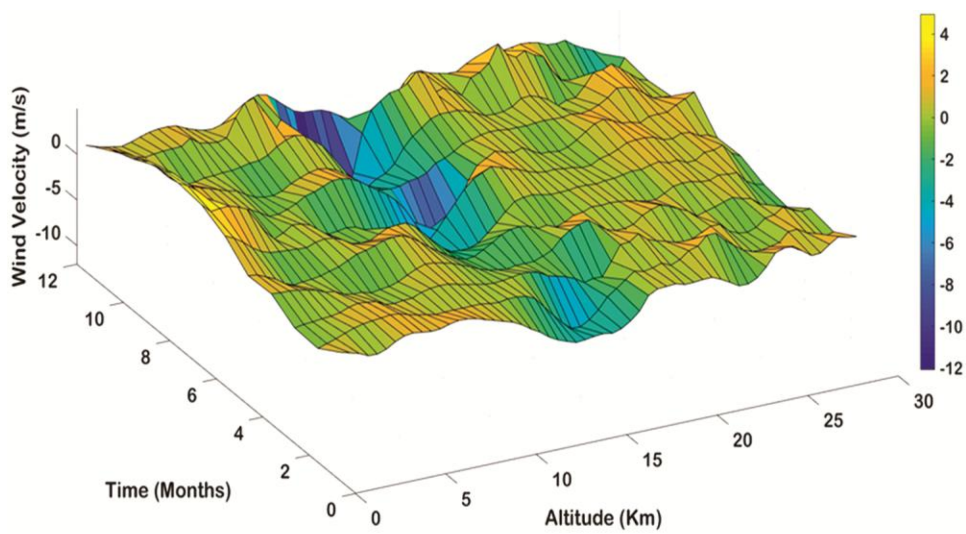

Fig. 6 — Meridional wind velocity of Jakarta for the year 2019.

period[15]. Further observation showed dramatic changes for January when the easterlies are dominating westerlies between the altitude of 11 to 25 km and westerlies are prevailing for the remaining altitudes. But in the case of January for Hyderabad, the westerlies had a very less magnitude of zonal wind velocity at the same altitude. Therefore, an approximate opposite trend revealed between the Hyderabad and Jakarta.

The detrended and smoothed data of zonal and meridonal wind for Jakarta region is presented in Fig. 5. The wave-like pattern is observed similar to non-dispersive wave of easterlies and at the same instant the meridional purtubation is approximately equal to zero as shown in Fig. 6 this results shows the existence of kelvin waves over Jakarta in January[16].

The detrended and smoothed data of zonal and meridonal winds for the Hyderabad region is traced in Figs 7 and 8. The easterlies are noted in January from 15 to 25 km Altitude with less wind velocity as compared to the Jakarta region and the meridional perturbation is zero at the same altitude. These observations reveal that Kelvin waves are decaying as they move away from the equator (Hyderabad is a high latitude station relative to Jakarta). The meridional winds for Jakarta and Hyderabad are

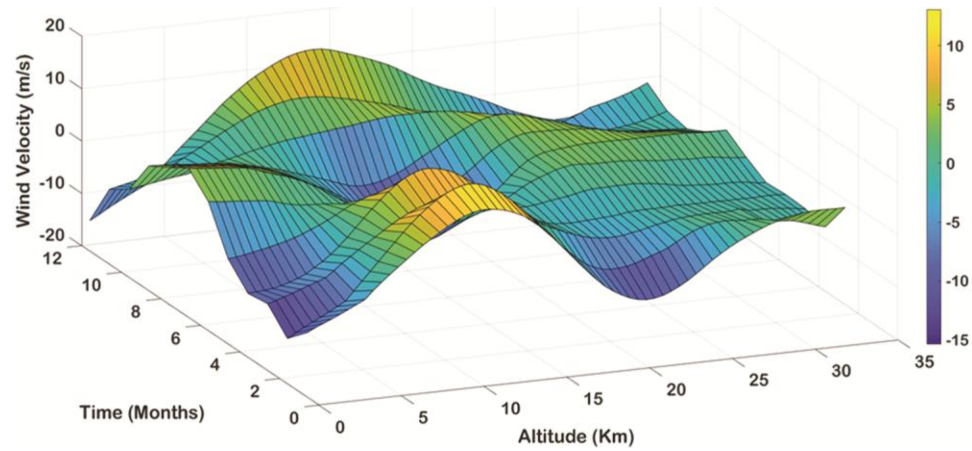

Fig. 7 — Zonal wind velocity of Hyderabad for the year 2019.

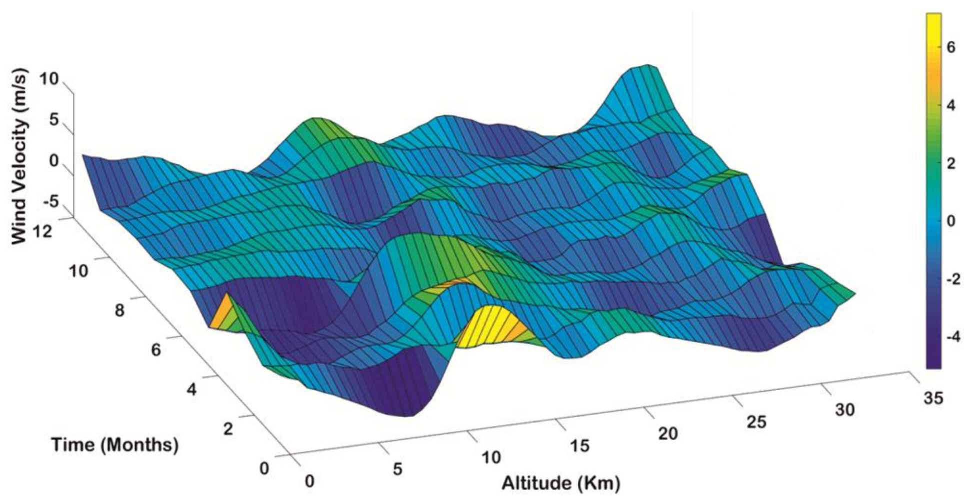

Fig. 8 — Meridional wind velocity of Hyderabad for the year 2019.

moving in opposite directions and it is almost southerly for Jakarta except between the altitude 10 to 15 km and northerly for Hyderabad except 10 to 15 km altitude.

3.3 Atmospheric pressure during Kelvin waves

Pressure on the earth not only changes with altitude but also with the weather. It effects temperature, humidity, wind velocity, and wind direction[17]. The atmospheric pressure variation for the two regions of Jakarta and Hyderabad is studied at three different altitudes 5, 15 and 25 km. From Fig. 9 the atmospheric pressure for Jakarta around 5 km is lowered during the mid-months (July and August) of the year whereas for 15 km and 25 km altitude it shows low pressure in January and December. Figure 10 illustrate the pressure variation for Hyderabad for 5, 15 and 25 km. At 5 km altitude, high pressure exists in the middle months and low pressure in the initial and final months of the year whereas at 15 km and 25 km low pressure exists in the mid months of the year. It is observed that easterlies are strongly correlated with low pressure. Whenever low pressure is generated easterlies are dominating westerlies

3.4 Intertropical convergence zone

A case study by Straud[18] for convective couple Kelvin Waves in the eastern pacific intertropical convergence zone (ITCZ) is presented as observed during 1947 by Pan American Climate Studies (PACS)[19]. The motion of the easterlies between the two stations is due to ITCZ caused by adiabatic heating of the atmosphere due to the spinning of the earth[20,21]. From wind velocity descried in the above section, it is observed that the zonal wind showing easterlies from December to March and for Hyderabad it initiates in June and ends in September

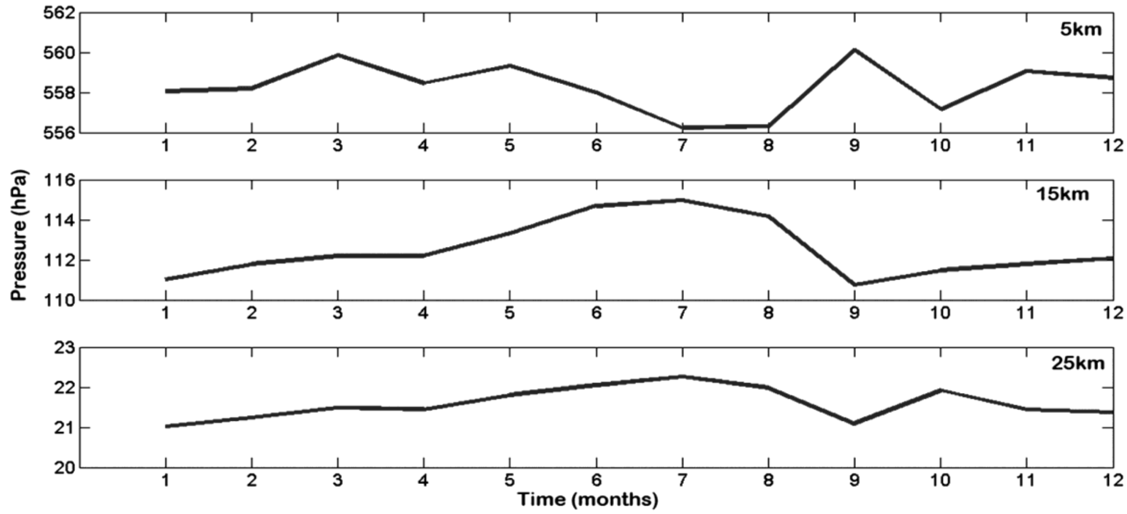

Fig. 9 — Pressure variation for 5 km, 15 km, and 25 km for Jakarta, 2019.

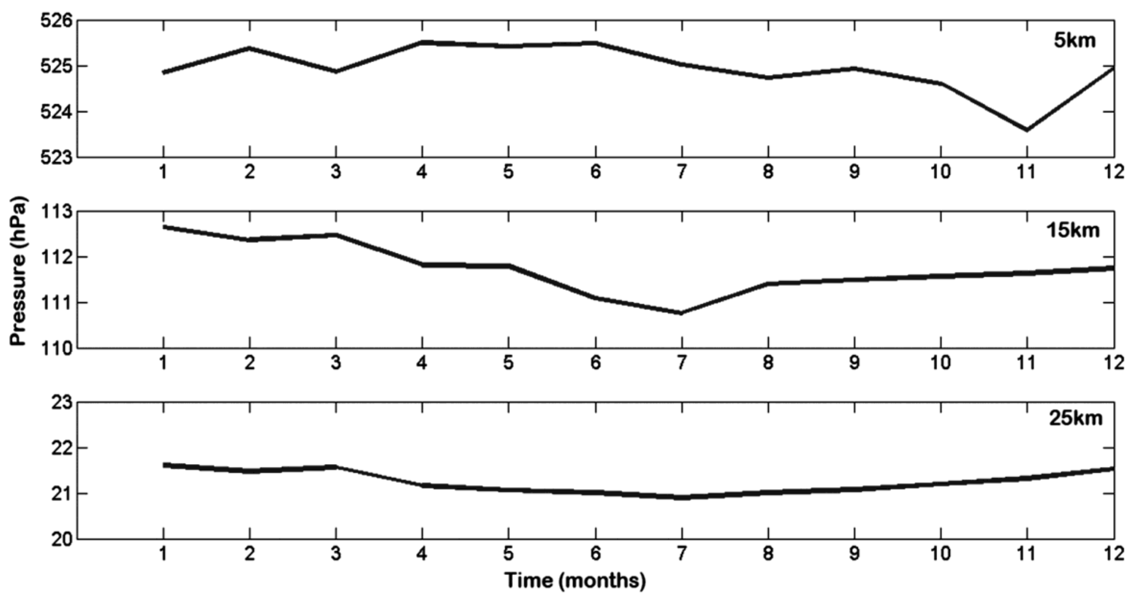

Fig. 10 — Pressure variation for 5 km, 15 km, and 25 km for Hyderabad, 2019.

at the tropopause. The period of existence between these two easterlies of both the regions is four months. Hence it concluded that the ITCZ will take four months to shift from Jakarta latitude to Hyderabad latitude.

5 Conclusion

The wind profiles have nearly reveal an opposite trend between Jakarta and Hyderabad. Thus, when westerlies winds have been recorded over Jakarta, an easterlies winds have to be recorded over Hyderabad and vice versa. In Jakarta, the easterlies wind velocity from January to March with decreasing magnitude at 15 km altitude have been observed. Whereas around 20 km the westerlies winds from May to November have been recorded. In addition, easterlies from June to September with increasing magnitude have been observed at 15km altitude. Wind of high magnitude of zonal wind velocity and zero perturbation of meridional wind velocity is observed while Hyderabad has indicated an opposite pattern. The Gaussian decay of Kelvin waves from the equator to higher latitude is noticed in January over Jakarta and Hyderabad with decreasing magnitude of easterlies from Jakarta to Hyderabad. For both regions, meridional winds are moving in opposite directions, southerly for Jakarta and northerly for Hyderabad except in between the 10 to 15 km altitude. Low atmospheric pressure is noticed for the altitudes where easterlies dominate westerlies such that Jakarta having easterlies from 12 to 25 km in January. At this altitude low pressure exists and below 5 km altitude westerlies are found due to relatively low pressure. A similar reverse pattern is observed for Hyderabad pressure variation. The shifting time of ITCZ from Jakarta to the Hyderabad region is approximately four months.

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