Long period atmospheric oscillations in the troposphere and lower and middle stratosphere over Hyderabad

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The monthly mean values of zonal and meridional winds for seventeen years over a tropical station, Hyderabad (17.2° N; 78.2° E) have been used to study the characteristics of long period atmospheric oscillations, the QBO, AO, SAO and TAO, in the altitude range 7-32 km. Since the period of the data includes two solar maxima and one solar minimum, the solar activity effects on various atmospheric parameters have been investigated. The annual oscillation in zonal wind is found to be strongly correlated with solar activity, whereas the prevailing zonal wind shows poor correlation. The correlation of solar activity with meridional wind parameters is also found to be very poor. The period of QBO and its heights of maxima are found to be affected by solar activity variation, whereas its amplitude is not.

1 Introduction

It is well established that long period oscillations like the quasi-biennial oscillation (QBO), annual oscillation (AO), semi-annual oscillation (SAO) and ter-annual oscillation (TAO) dominate the tropical middle atmosphere. As the atmosphere of the earth is mostly solar dependent, various phenomena in the middle atmosphere are found to be affected by solar variability. The QBO is reported to show variability from cycle to cycle in its period and amplitude. The coupling of the wind system with the 11-yr solar cycle has been subjected to various investigations. Some of the studies show contradictory results making the subject still controversial. Most of these reports are from mid-latitude stations and results from tropical latitudes are very sparse. In the present study, we have made a detailed analysis of the long period oscillations and the solar activity variation of wind parameters considering data from a tropical station, Hyderabad (17.2° N, 78.2° E).

2 Data and method of analysis

Extensive wind data have been collected by the National Scientific Balloon Facility of the Tata Institute of Fundamental Research (TIFR), Hyderabad, jointly with the India Meteorological Department (IMD), Hyderabad, for the past two decades by using a special type of rubber and polyethylene balloon capable of reaching up to an altitude of 40 km. The data collected over 17 years (1977-1993) in the altitude range of 7-32 km have been utilized for the present study. Wind velocity components have been derived by using raw data consisting of range, elevation and azimuth of the balloon at 1 min interval. Generally, there are a few flights every month. Altitude profiles of zonal and meridional winds given by these flights have been averaged to obtain monthly mean profiles. The TIFR restricts balloon flights during monsoon season. Data for such missing months between 1984 and 1993, over Hyderabad, have been obtained from India Meteorological Department, Pune. Very few data gaps which were still left over have been filled by spline interpolation to obtain a continuous data set of 204 months. Monthly break-ups of balloon ascents are shown in Table 1.

The continuous data sets of zonal and meridional winds, so obtained, have been Fourier transformed to identify the dominant long period oscillations in the troposphere and lower and middle stratosphere. To obtain quantitative information about these oscillations, the data sets have been subjected to harmonic analysis with least square fitting, assuming that the oscillations consist of AO, SAO, TAO and QBO. The periods of AO, SAO and TAO have been taken as 12, 6 and 4 months, respectively, whereas the period of QBO has been varied between 22 and 34 months to get the best fit.

To study the solar activity dependence of the...
amplitude of these long period oscillations, the long zonal and meridional wind data sets have been divided into three periods (1978-1982), (1983-1987) and (1988-1993), with average sunspot numbers as 132, 35 and 129, respectively, i.e. covering two high activity periods and one low activity period which will henceforth be referred to as HA1, LA and HA2. Harmonic analysis was then carried out for each group separately to find the amplitudes of these oscillations. We have also calculated cross-correlation coefficients of the yearly averaged sunspot numbers and $F_{10.7}$ cm solar flux with the prevailing wind and the amplitude of AO.

3 Results and discussion

Figure 1 shows FFT spectra of the zonal winds for two particular heights. It is found that AO dominates the troposphere, having maximum amplitude near 12-14 km, whereas QBO starts becoming prominent in the lower stratosphere, maximizing near 29-30 km.

3.1 Annual oscillation

The annual oscillation (AO) dominates the high latitude middle atmosphere, which can be attributed to the annual cycle of solar insolation. The maximum amplitude of the annual cycle is observed at 80°N or S in the temperature data and a marked hemispheric difference is observed. Large longitudinal asymmetry has also been established in AO over the tropics. Even though the amplitude of AO is comparatively small at low latitudes, it is found to be quite significant in both zonal and meridional winds. Figure 2 shows the height variation of the amplitude of AO and QBO in zonal wind and AO in meridional wind. Maximum amplitudes of the order of 19 m/s and 3 m/s are observed between 12 and 14 km in zonal and meridional winds, respectively. Average phase variation of AO and QBO with height are depicted in Fig. 3. The amplitudes of AO in the zonal wind obtained by Nagpal et al. for Thumba, Shari and Balasore were 18 m/s, 22 m/s and 26 m/s, respectively. Reddy et al. also observed similar results. The AO phase (time of maximum westerly wind) is found to decrease slowly with height as shown in Fig. 3, which is comparable to those observed by others.

Table 1 - Monthly break-up of balloon ascents during 1977 - 1993

<table>
<thead>
<tr>
<th>Alt. (km)</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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</thead>
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<tr>
<td>10 km</td>
<td>115</td>
<td>112</td>
<td>112</td>
<td>114</td>
<td>181</td>
<td>169</td>
<td>186</td>
<td>176</td>
<td>155</td>
<td>58</td>
<td>81</td>
<td>94</td>
</tr>
<tr>
<td>15 km</td>
<td>110</td>
<td>107</td>
<td>112</td>
<td>113</td>
<td>168</td>
<td>157</td>
<td>171</td>
<td>167</td>
<td>135</td>
<td>58</td>
<td>80</td>
<td>93</td>
</tr>
<tr>
<td>20 km</td>
<td>93</td>
<td>105</td>
<td>101</td>
<td>112</td>
<td>137</td>
<td>128</td>
<td>143</td>
<td>124</td>
<td>112</td>
<td>58</td>
<td>79</td>
<td>93</td>
</tr>
<tr>
<td>25 km</td>
<td>76</td>
<td>98</td>
<td>97</td>
<td>101</td>
<td>98</td>
<td>92</td>
<td>73</td>
<td>72</td>
<td>65</td>
<td>58</td>
<td>67</td>
<td>85</td>
</tr>
<tr>
<td>30 km</td>
<td>56</td>
<td>85</td>
<td>94</td>
<td>85</td>
<td>52</td>
<td>46</td>
<td>41</td>
<td>34</td>
<td>24</td>
<td>55</td>
<td>60</td>
<td>81</td>
</tr>
</tbody>
</table>
3.2 Quasi-biennial oscillation

No evidence exists for truly periodic atmospheric oscillations apart from diurnal and annual components and their harmonics. The oscillation which comes closest to periodic behaviour is the QBO in the mean zonal wind of equatorial stratosphere, with a period varying from about 22 to 30 months. Vertically propagating equatorial Kelvin and Rossby-gravity waves provide the zonal momentum sources necessary to drive QBO. Holton and Lindzen have successfully explained different observed features of the QBO.

In recent years, QBO in the zonal wind has gained a lot of importance and is considered to control both lower and upper atmospheric dynamics and chemistry. Kane confirmed the presence of QBO in ionospheric parameters such as $f_E$, $f_F2$, $h_mF2$, etc. Recently Saji Abraham et al. investigated long-term variations in ionospheric absorption data over Delhi, and found a remarkable anti-correlation between the QBO in wind data at 28 km (Thumba) and absorption data at the mesospheric level. There are also several studies relating the lower stratospheric QBO and EL Niño events.

Results of the present study of amplitude and phase variations of this important oscillation over Hyderabad are shown in Figs 2 and 3. Horizontal bars show the standard deviations of wave amplitude and phase. It is observed that the QBO amplitude starts becoming prominent above 18 km and maximizes at 29 km (9 m/s) with a period of 29 months. The QBO amplitude is found to decrease systematically with latitude. Nagpal et al. found the amplitudes of QBO to be 20 m/s, 10 m/s and 4 m/s for the stations Thumba, Shar and Balasore, respectively. The heights of peak QBO amplitude as observed by them were 28 km, 33 km and 37 km, respectively. Sasi et al. have shown that QBO in the zonal wind at Trivandrum (8.5°N) is well defined and cycles are easily identifiable, whereas it is not so well pronounced for an extra tropical station like Balasore (25.1°N). Figure 4 shows a time-series of zonal wind velocities at different heights. Thirteen-point running average has been taken to smooth the data and to filter out short period oscillations. Downward phase propagation can be seen from the height variation of westerly maxima.

3.3 Semi-annual oscillation and ter-annual oscillation

The amplitudes of SAO and TAO in the troposphere and lower and middle stratosphere are found to be quite insignificant as reported by earlier workers and hence not been considered for further analysis.

3.4 Solar activity dependence of wind components

The solar activity dependence of AO, QBO and prevailing wind has been studied using the method described earlier. The results of harmonic analysis show higher AO amplitude in the zonal wind during high activity periods HA1 and HA2 having amplitudes of the order of 25 m/s and 26 m/s, respectively, compared to its value during LA (15 m/s). The height of maximum AO amplitude is also found to vary with solar activity having altitudes of 14 km and 13 km during HA1 and HA2 and as low as 10 km during the LA period. The AO component in meridional wind did not show any regular variation with solar activity.

Figure 5 shows the height variation of the AO and QBO amplitudes for the different periods HA1, HA2 and LA. The amplitude of QBO also shows appreciable variability with solar activity particularly at higher altitudes. The period of QBO is found to be longer in high activity periods, being around 30 and 29 months, compared to 22 months during the low activity period. The corresponding height of the QBO amplitude peak is 29, and 30 km for HA1 and HA2 and 33 km for the LA period. Sasi et al. analyzed wind data over Trivandrum and showed that the standard deviation of maximum easterly amplitude was more than that of the westerly maximum, indicating greater variation from cycle to cycle. They found that the mean period of the westerly regime was longer than that of easterly regime except at altitudes.
from 15 to 18 km where the easterly period was longer. Similar analysis for the station, Balasore, showed an increasing trend of QBO amplitude with height. The mean periods at Balasore were nearly the same as those of Trivandrum in the altitude range 25 - 34 km, whereas above 34 km and below 25 km the easterly and westerly periods were shorter than 12 months in contrast to the behaviour at Trivandrum where they remained longer than 12 months in the altitude range 15 - 42 km.

To study the cross-correlation coefficients between the solar parameters and AO, harmonic analysis has been carried out for individual year's data. The amplitudes of AO, so obtained, have been averaged over a slab of 8 km (between 10 and 17 km) which is the e-folding depth around the height of maximum AO amplitude. The cross-correlation coefficients (r) between the AO amplitudes and sunspot numbers ($R_c$) and $F_{10.7}$ cm solar flux are 0.78 and 0.75 for zonal wind and 0.26 and 0.20 for meridional wind, respectively. To consider the statistical significance of these correlation coefficients, $t$-tests have been carried out. A $t$-test for the significance of $r$ is given by

$$t = r \sqrt{\frac{n-2}{1-r^2}}$$ ...

which has $n-2$ degrees of freedom. The $t$ values obtained for the zonal wind case are 4.44 and 4.80 and those for the meridional wind are 0.80 and 1.05. The critical value for $t$ with 15 degrees of freedom and at 0.01% level of significance is 2.947. Because the test statistics (zonal wind AO) fall into the upper critical region, it is concluded that there is a real correlation between the amplitude of AO in the zonal wind and $R_c$ and $F_{10.7}$ cm solar flux, whereas the correlation of the amplitude of AO in meridional wind and the solar parameters are not significant. Figure 6 shows the AO amplitudes for each year (both zonal and meridional), for the 8 km height-slab average, between 1977 and 1993 with the corresponding values of sunspot number and $F_{10.7}$ cm solar flux.

To study the correlation of prevailing wind with solar parameters, two height regions (average 10-15 km and 25-30 km) have been considered. The values of cross-correlation coefficients of zonal and meridional prevailing winds with $R_c$ for the first and second slabs are 0.21, -0.18 and 0.26, -0.29 respectively. Results of $t$-tests carried out in a similar manner as mentioned earlier, show that the correlations are not significant. Greisiger et al., Babajanov et al. and Namboothiri et al. studied solar activity variations of wind parameters for upper atmosphere over mid-latitude stations. Their results are contradictory in nature. Similar studies for lower atmosphere and low latitude stations are not available for comparison with the present work.

3.5 Energy density of AO with altitude

The energy density of AO has been calculated using the average density ($\rho$) from the atmospheric model given by Sasi and Sen Gupta for Indian stations lying between 0° and 15°N following the standard relation

$$E = \frac{1}{2} \rho V^2$$

and

$$V^2 = V_z^2 + V_m^2$$ ...

where, $V_z$ and $V_m$ are the mean values of zonal and meridional amplitudes of AO obtained by harmonic analysis. Figure 7 shows the altitude variation of energy density of AO over Hyderabad. The energy density is found to increase rapidly till about 10 km
and then to decrease sharply. Most of the energy appears to be confined in the troposphere below the tropopause level. There is an indication that very little energy is leaked through the tropopause and gets dissipated thereafter.

4 Summary and conclusions
The results obtained in the present study of oscillations and the solar activity dependence of wind parameters using 17 years (1977-1993) wind data in the altitude range of 7 - 32 km for a tropical station can be summarized as follows:

(i) Strong AO component is observed in both the zonal and meridional winds at an altitude between 12 and 14 km, being of the order of 19 m/s and 3 m/s, respectively.
(ii) The AO is found to become stronger with solar activity. The amplitudes of AO in the zonal wind shows a strong positive correlation with the \( F_{10.7} \) cm solar flux and \( R_z \) numbers. The height of maximum AO amplitude is also found to vary with solar activity, being higher for the high activity periods and lower for the low activity period. The meridional wind shows poor correlation with solar activity.
(iii) The QBO amplitude in the zonal wind maximizes at 29 km. The amplitude and period of QBO are observed to be 9 m/s and 29 months, respectively. The amplitude of QBO is not observed to get affected by the variation in solar activity. The period of QBO is found to be longer in high activity periods, whereas the height of maximum QBO is more in the low activity period.

(iv) No clear trend of solar radiation dependence of the prevailing wind was observed in the present study. This may be due to the short length of the data set. Data from a number of tropical stations over more solar cycles should be studied to confirm the relation of the prevailing wind with solar activity.

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