Long-Period Waves in Mesospheric Winds at Saskatoon (52°N)

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Long-period variations of winds observed by the radio reflection technique at Saskatoon, from 65 to 110 km, 1969–1975, show some significant differences from the CIRA 1972 model. The maximum amplitude of the annual wave below 80 km is found to be only 22 m s^{-1} , while CIRA shows 45 m s^{-1} at this latitude. The semi-annual wave below 75 km at Saskatoon has an amplitude only half that of CIRA. Its phase shows a constant downward propagation from 118 to 70 km at 8 km month^{-1} . No appreciable terannual wave was found at Saskatoon, but a weak 3-month wave shows the same phase progression pattern as for the semi-annual. A QBO is found at Saskatoon with amplitude of 10 m s^{-1} above 100 km.

1. Introduction

Wind measurements in the mesosphere have been far less numerous than in the stratosphere below or in the lower thermosphere above. Rawinsondes and small meteorological rockets provide relatively detailed wind data below about 65 km, while meteor-wind radars routinely provide data from about 90 to 105 km at several stations globally. As a result, knowledge of the circulation patterns from 65 to 90 km has been largely based on a relative handful of rocket grenade experiments (CIRA, 1972). The wind measurements made at Saskatoon (52°N, 106°W) by the radio reflection technique (GREGORY and STEPHENSON, 1972), extending from about 65 to 118 km, are thus of special interest as they help connect knowledge of the wind fields of the stratosphere and lower thermosphere. The vertical resolution of the data is 3 km and data can be taken at 5-min intervals. Observations from 1969 to 1976 have now been summarized and some of the results of their periodic variations of longer than one month are given here. The features of the quasi-biennial and first four harmonics of the annual wave are summarized next.

2. Quasi-Biennial Oscillation (QBO)

A QBO in zonal wind speed in the lower thermosphere has been noted by SPRENGER *et al.* (1975) and in the airglow of the lower thermosphere by FUKUYAMA (1977). The QBO in thermospheric wind is also apparent in the 12-month running means of meteor wind data at Adelaide (35°S) and in radio winds at Saskatoon (BELMONT *et al.*, 1977). Adelaide data are from Elford (private communication, 1977).

Fig. 1. Periodic analysis results at Saskatoon, based on monthly mean local noon data February 1969–January 1976; 26-month QBO.

In order to estimate the amplitudes and phases (time of maximum eastward speed) of the QBO and of the first four harmonics of the annual wave, periodic analysis of monthly mean zonal wind speed was made using the technique of BELMONT and DARTT (1973). Tests with sinusoidal waves having periods ranging from 20 to 35 months showed that a 26-month period most reduced the variance and gave the smallest RMS amplitude errors for this period of record. Vertical profiles of the amplitude and phase of the 26-month QBO are given in Fig. 1. Below 118 km, QBO amplitudes range from 1 to 7 m s^{-1} , in good agreement with SPRENGER *et al.* (1975) who report amplitudes of about 3 m s^{-1} at 90–95 km near 53°N. The phase of the QBO is highly variable, and perhaps the only reliable feature is a 180° shift between 94 and 97 km. The available data on QBO at these levels are summarized below:

	Lat.	Record	Alt (km)	Pd (mo)	Ampl (m s^{-1})
Berlin (Sprenger)	54°N	1957–1972	90–95	22 (19–24)	3 (1–15)
Japan (Fukuyama)	43°N	1957–1970	~95	28	—
Adelaide	35°S	1966–1972	84–105	22	5 (1–10)
Saskatoon	52°N	1969–1976	65–120	26	4 (1–10)
GROVES (1973)	50°N	1962–1969	60	32	7

3. Annual Wave

Monthly mean profiles of the zonal wind speed (u) are shown in Fig. 2. There are no noteworthy changes from the results of GREGORY and MANSON (1975), which are based on data from 1969–1973, although the two additional years of data used here doubles the number of hourly medians at most levels. The annual wave is clearly seen in Fig. 2 and has a phase reversal near 100 km with winter westerlies below and summer westerlies above that level. In the overlap region of these two annual waves, i.e., from 90 to 100 km, a semiannual wave is presented as there are four reversals per year. The semiannual and shorter period waves are not easily seen by inspection at other levels.

It is interesting that a jet of winter westerlies is not found in the lower mesosphere in Fig. 2. As the mean speed in the jet is over 60 m s^{-1} both from rocketsonde data (BELMONT *et al.*, 1975) and grenade data (THEON *et al.*, 1973), the relatively

Fig. 2. Monthly mean zonal wind speeds (m s^{-1}) at local noon at Saskatoon, 1969–January 1976. Striped winds are from the west.

small winter speeds below 80 km in Fig. 2 require explanation. There are several possible causes:

1) There may be a bias toward low speeds in the radio reflection technique. The good agreement between rocketsonde and radio winds found by VINCENT *et al.* (1977), does not suggest any bias however.

2) The diurnal and semi-diurnal tides may lead to unrepresentative daily values because the Saskatoon observations in Fig. 2 are all taken at local noon each day. However, the meteorological rockets at Primrose Lake (54°N) close by the radio site, and at Churchill (59°N) are also taken usually within 2 hr of local noon so the tidal effect may not be a significant factor. Grenades, however, were taken at all hours (THEON *et al.*, 1973), but their total number was on the order of 40 for all years combined, at a given station, for a given season. Even if grenades could be said to average out the tidal effect by averaging over many hours, the discrepancy of the radio data with meteorological rockets remains.

Thus, the diurnal tide is included in the noon data used here and seasonal variations of amplitude or phase of this tide may bias the monthly mean noon wind speeds such that the annual wave below about 80 km appears too small. Possible biasing by the diurnal and semidiurnal tides must be taken into account if the present data are used for developing models of the general circulation. Otherwise the resulting models may be dynamically unstable (SCHOEBERL and ZALESK, 1976).

3) If one questions the reliability of the winds derived from the nearest rockets, it would be necessary to explain why other independent rockets also observe the mesospheric jet (West Geirinish).

4) The effect may be real but local to Sub-arctic Canada which is near the maximum activity of the auroral zone. If ionization from particle precipitation leads to enhanced absorption of radiation and heating, to the north of Saskatoon, a reduction in the W-E wind might explain the weak winter westerlies relative to the other longitudes. But again, why are Primrose rocket data not also affected? There are relatively few meteorological rocket observations compared to those by

Fig. 3. As in Fig. 2, for meridional wind speeds. Striped winds are from the south.

Fig. 4. As in Fig. 1, for annual wave.

radio so the rockets may have missed more of the magnetic disturbance, but this seems rather unlikely.

There are no sure answers to the discrepancy at this time, but the problem must be examined more fully when further independent data become available.

The mean monthly noon meridional winds (v) are given in Fig. 3 for completeness. The basic pattern is similar to that of GREGORY and MANSON (1975).

The amplitude of the annual wave (Fig. 4) has a pronounced minimum near 100 km. Below 100 km the phase date is near the winter solstice, and above 100 km it is near the summer solstice. Above 105 km the present amplitudes are slightly larger, and the phase dates about a month later than the corresponding results of GROVES (1972).

4. Semiannual Wave

The amplitude of the semiannual wave (Fig. 5) has three maxima, in agreement with GROVES (1972). The phase dates are also similar to those of Groves, but the very regular pattern of propagation with height is much more evident in the present display and does not seem to have been noted previously. The straight line on the phase diagram (fitted by eye) has a slope of 8 km month^{-1} . If downward phase propagation implies upward energy propagation, then the region of excitation of

Fig. 5. As in Fig. 1, for semiannual wave.

this semiannual wave is near 70 km. BEMONT *et al.* (1975) have hypothesized that particle precipitation effects in the auroral zone influence the radiation field, and hence, thermal and wind fields on a semiannual basis. Recent observational (RANDHAWA, 1976; HEATH *et al.*, 1976) and theoretical (THORNE, 1977) papers lend support to the particle precipitation hypothesis, and the present results could be explained by that hypothesis. However, there could be other explanations for this semiannual wave. For example, the wind reversals associated with mid-winter sudden warmings could induce a semiannual wave with equinoctial phase dates, as found in Fig. 5 near 70 km. However, sudden warmings should induce nearly the same phase at all levels. The non-sinusoidal solar heating at the pole also can induce a semiannual wind variation (DEVORE and VENKATESWARAN, 1977), but the model calculations show no phase variation with height, in disagreement with the results in Fig. 5.

5. Three-month Wave

The 3-month wave can be identified as the second harmonic of the semiannual wave. Although its amplitude (Fig. 6) is less than 5 m s^{-1} at most levels, its phase progression with height appears exactly double that of the semiannual wave. This is apparently the first time an organized 3-month wave has been detected in the mesosphere or lower thermosphere.

Fig. 6. As in Fig. 1, for 3-month wave.

6. Terannual Wave

The terannual wave has amplitudes less than 5 m s^{-1} at most levels and has no clear pattern of phase progression with height, so is not shown here.

7. Conclusions

- 1) A weak QBO exists from 65 to 120 km, which has a phase shift near 95 km.
- 2) The annual wave amplitude shows only 20 ms^{-1} below 88 km and above 105 km, with a pronounced minimum at 100 km where there is a 180° reversal of phase. This is only half the mesospheric amplitude found by meteorological rockets and grenades.
- 3) The semiannual wave has three maxima near 10 m s^{-1} at 70, 97, and 118 km, agreeing with Grove's model. The phase displays a remarkably consistent downward progression of 8 km month^{-1} from 118 km in October to 70 km in April. These dates suggest either the influence of auroral particle precipitation maxima, and consequent effects on ozone, or the influence of heating at high latitudes by sudden warmings in winter, or both. Solar heating at the pole (DEVORE and VENKATESWARAN, 1977) does not render the observed phase variation with height.
- 4) A weak 3-month wave of less than 7 m s^{-1} has double the phase descent rate of the semiannual wave, of which it is the second harmonic. This appears to be the first notice of a 3-month wave.
- 5) No consistent terannual wave phase was observed and amplitudes were less than 5 m s^{-1} .

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