FOPA 12

Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 59, No. 12, pp. 1405–1410, 1997

1364–6826/97 $17.00+0.00

Pergamon

PII: S1364–6826(96)00178–2

Solar activity variations of meridional winds over King George Island, Antarctica

Manuel A. Arriagada,[1] Alberto J. Foppiano*[2] and Michael J. Buonsanto[3]

[1]Universidad del Bío-Bío, Casilla 5-C, Concepción, Chile; [2]Departamento de Física de la Atmósfera y del Océano, Universidad de Concepción, Casilla 4009, Concepción, Chile; [3]Massachusetts Institute of Technology, Haystack Observatory, Westford, U.S.A.

(*Received in final form* 30 *May* 1996; *accepted* 26 *November* 1996)

Abstract—Diurnal variations of the magnetic meridional component of thermospheric neutral winds are derived for King George Island (62.2°S; 58.8°W). Calculations are made using a servo theory based algorithm. Input values are F-region peak heights determined from ionosonde data using a well known empirical equation. Ionosonde data correspond to conditions of low geomagnetic activity and both low and high solar activity level for all seasons. These diurnal variations are compared with corresponding variations calculated with the HWM90 model, and solar activity trends of the mean value and diurnal amplitude are examined. © 1997 Elsevier Science Ltd

INTRODUCTION

The dependence on solar activity level of the magnetic meridional component of thermospheric neutral winds has been studied for several years, using results from both thermospheric theoretical and empirical models. However, there are still uncertainties as to whether solar activity trends found in diurnal mean wind velocities and in diurnal variation amplitudes by different methods are consistent with each other (e.g. Hedin *et al.*, 1994). Further, most results relate to northern hemisphere locations (Buonsanto, 1990, 1991). Southern hemisphere results published by Titheridge, 1993, 1995b, are for conditions of high and low solar activity, but correspond to locations away from the geographic longitude sector where the so called South Atlantic Anomaly (SAA) of the geomagnetic field is observed, where particular effects may be expected. Results for Southern South America, published by Canziani *et al.*, 1990, 1992 and Giraldez and Canziani, 1992 are derived only from data observed during 1984, and therefore do not allow the solar activity level trend to be obtained. This article examines the solar activity level trends found in winds corresponding to conditions of low geomagnetic activity level, derived from ionosonde data, for a mid-latitude station in the southern hemisphere located close to the SAA longitude sector.

*Author to whom correspondence should be addressed.

DATA AND MODELS

Diurnal variations of the magnetic meridional component of thermospheric neutral winds have been derived for King George Island (62.2°S; 58.8°W geographic, −51.4°; 9.0° geomagnetic), corresponding to the ten geomagnetically quietest days (daily $Ap < 10$) of June, September and December of 1986 and 1989, relating to conditions of low ($F_{10.7}$ flux < 72.1) and high ($F_{10.7}$ flux > 163.2) solar activity level. Values were determined using the servo model (SM) (Buonsanto *et al.*, 1989) and they are compared with those given by the horizontal wind model (HWM) (Hedin *et al.*, 1991).

For servo model variations F-region peak heights were first determined for each day using a well known empirical equation (Bradley and Dudeney, 1973; Eyfrig, 1974) with foF2, M(3000)F2 and foE values scaled from hourly ionograms. When foE was not observed, it was calculated from a modified version of the CCIR formula (Buonsanto and Titheridge, 1987). Electric field effects were taken into account using the Richmond *et al.*, 1980 electric field model. Then hourly means from the 10 values were computed and winds derived using these mean heights. Winds were also derived reducing the servo peak heights by an amount that decreases linearly from about 18 km just after sunrise to zero at 15.00 L.T. This minimises the failure of the SM method to account properly for the sudden onset of production at that time as suggested by Titheridge, 1995a. A 3 h running mean smoothing was then applied to both sets of wind velocities to reduce oscillations of periods less than about 2 h. An estimation of wind velocity errors was computed for each hour, as twice the difference between wind velocities calculated for mean heights plus a standard deviation and those for mean heights. Heights reduced by a standard deviation were not used because the corresponding derived daytime-poleward winds are considered unreasonably high, particularly during winter. Mean wind velocity errors representative of night-time and daytime were then computed for June and September only because there is no true night-time during December (summer).

Single HWM variations for each month were calculated so as to correspond to conditions of mean *Ap* and mean $F_{10.7}$ flux for the 10 days included, and assigned to the 15th of the month, since changes of temperature and composition within a month were considered smaller than those related to geomagnetic and solar activity levels.

RESULTS

Diurnal variations are shown in Fig. 1, while solar activity trends of diurnal mean wind and of diurnal variation amplitude are presented in Table 1.

Variation shape

There is a significant change in the variation shape from low to high level of solar activity for SM results. For all seasons at low solar activity level, the wind changes from maximum equatorward velocity to maximum poleward velocity in less time than that for the corresponding change from poleward to equatorward. This feature is not present at high solar activity level. By contrast, HWM variation shapes (not mean winds or variation amplitudes) which are similar to SM variations for low solar activity, do not change significantly with increasing solar activity level.

SM and HWM results show that, though the day time interval for which poleward wind is observed decreases from winter to summer for both low and high solar activity level, these time intervals are larger for high solar activity level. This feature derives from the fact that the morning hour for which no wind is observed tends to occur later and the afternoon hour tends to occur earlier for low solar activity level.

Mean wind

SM winds are mainly poleward, with the mean velocity decreasing from winter to summer for both low

Table 1. Thermospheric neutral winds (magnetic meridional component) at King George Island (KGI: 62.2°S; 58.8°W geographic, −51.4°; 9.0° geomagnetic) and Invercargill (I:42.9°S, 176°E geographic, −46.6°; 257° geomagnetic)

Station	Model	Season	Low solar activity level ($F_{10.7}$ flux < 72.1 for KGI and = 75 for I)				High solar activity level ($F_{10.7}$ flux > 163.2 for KGI and = 150 for I)			
			Mean (m/s)		Amplitude (m/s)		Mean (m/s)		Amplitude (m/s)	
KGI	Servo model	Winter (June)	−40	(−22)	265	(183)	−65	(−56)	267	(267)
		Spring (September)	−17	(3)	188	(127)	−23	(−18)	100	(100)
		Summer (December)	6		155		−1		58	
	HWM90 (Hedin *et al.*, 1991)	Winter (June)	40		196		−28		209	
		Spring (September)	59		219		2		204	
		Summer (December)	75		194		30		194	
I	Titheridge (1993)	Winter	−25		168		−15		128	
		Spring	−27		118		−13		105	
		Summer	5		73		1		78	

Values in brackets correspond to values determined including correction from sunrise to 15.00 L.T. Titheridge, 1995a.

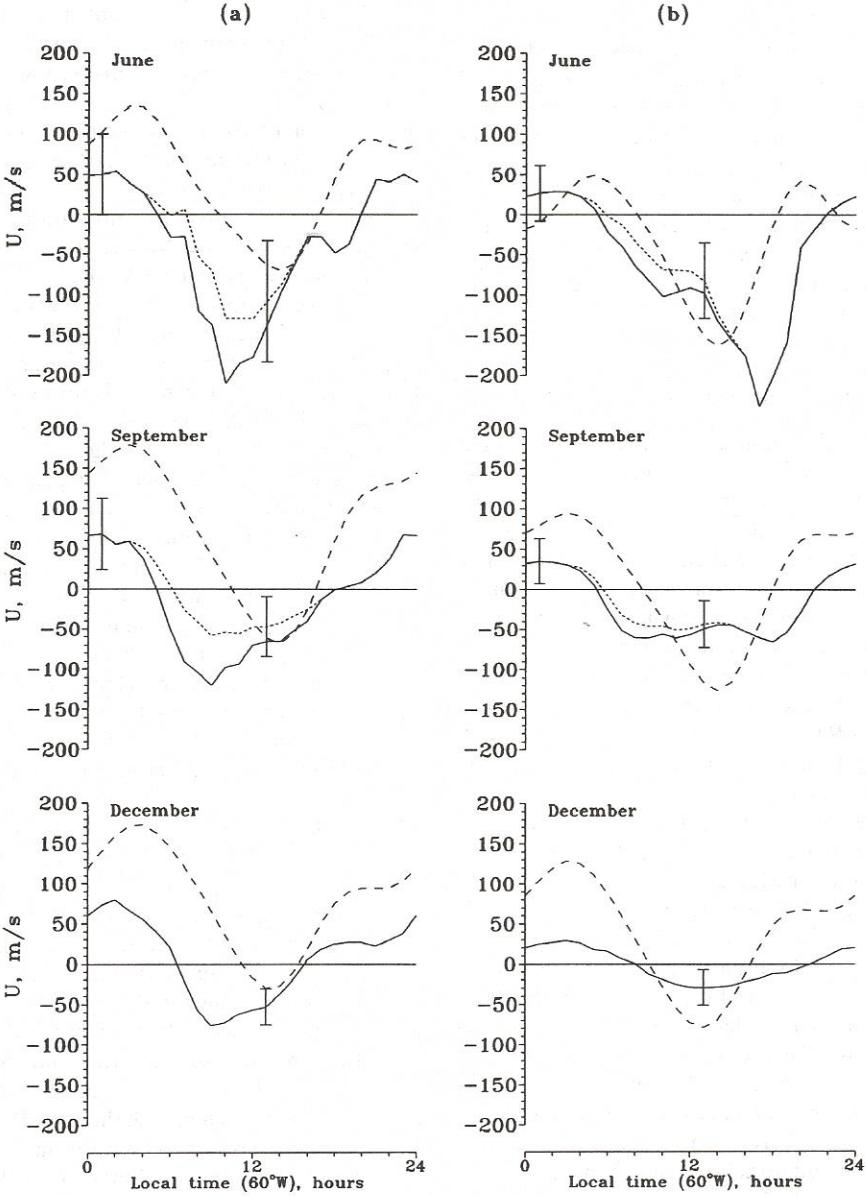

Fig. 1. Diurnal variations of the magnetic meridional component of thermospheric neutral wind velocity (equatorward positive) for King George Island (62.2°S; 58.8°W geographic, −51.4°; 9.0° geomagnetic), corresponding to the 10 geomagnetically quietest days (daily $Ap < 10$) of June (winter), September (spring) and December (summer). (full line) Servo model Buonsanto *et al*., 1989. (dotted line) Servo model including servo peak height reduction Titheridge, 1995a. (dashed line) Horizontal wind model Hedin *et al*., 1991. (a) Low solar activity level, 1986 ($F_{10.7}$ flux < 72.1). (b) High solar activity level, 1989 ($F_{10.7}$ flux > 163.2).

and high solar activity levels, and are greater at high solar activity level, except for summer. By contrast HWM winds are mainly equatorward, with mean velocities increasing from winter to summer for both solar activity levels, and are smaller at the high activity level, except for winter. Further, the rates of change with solar activity level are considerably larger for the HWM results, and are almost the same for all seasons. By comparison, SM rates of change increase from summer to winter.

Variation amplitude

There is a clear amplitude decrease in SM results from winter to summer, and also from low to high solar activity levels for spring and summer, with almost no change for winter. However, when winds are calculated using Titheridge's proposed correction, at low solar activity spring amplitude is smaller than the summer amplitude. Further, the winter amplitudes do increase with solar activity level. By contrast, no significant seasonal or solar activity level effects are seen for the HWM results.

DISCUSSION

Although small sample effects cannot be neglected, there seems to be a significant change in the shape of the diurnal variation of wind velocity from conditions of low to high solar activity level, for all seasons, which may be related to changes in the weight that various processes have on the thermospheric dynamics. This feature is present even when account is taken of the sudden onset of production at sunrise, as suggested by Titheridge (1995a). These shape changes do not appear to be accounted for by empirical models such as the HWM. Nor are they observed in results for Invercargill (42.9°S, 176°E geographic, −46.6°; 257° geomagnetic), for low and high activity level ($F_{10.7}$ flux = 75 and 150, respectively), $Ap = 10$, published by Titheridge, 1993. However, results obtained from ionosonde data for Boulder (40.0°N;105.3°W geographic, 48.7°; 319.0° geomagnetic), September 1975 and 1979 ($F_{10.7}$ flux = 80.0 and 202, respectively), $Ap < 10$, published by Buonsanto (1991), also show a slight shape change of the diurnal variation, the shape for high solar activity level being similar to that observed in King George Island.

While present summer results (December) are consistent with Hedin *et al.* (1994) northern hemisphere results (June), also derived from ionosonde data, that indicate a weak equatorial diurnal mean wind at low solar activity level, with a trend towards even smaller winds at high solar activity, the former are much weaker (less than about 7 m/s as compared with around 25 m/s). The opposite trend is reported by Buonsanto, 1991 for summer months at Boulder during the 1975–1987 interval, namely, mean winds are almost nil at low solar activity level (1976 and 1985/86) and about 30 m/s equatorward at high level (1978 and 1979). However, the HWM mean winds do decrease with increasing solar activity level but are always equatorward (from about 75 to 30 m/s). Present mean winds corresponding to winter conditions (June) are always poleward, being stronger as the solar activity level becomes larger (from about 40 to 60 m/s). Hedin *et al.*, 1994 northern hemisphere winds (December) are mainly equatorward (30 m/s) at low solar activity level, with a trend towards no wind at high solar activity level. By contrast to these two opposite trends, Buonsanto (1991) results do not seem to indicate a clear trend, provided mean winds for the 1984–1985 and 1985–1986 winters are not considered because they are regarded by Buonsanto, 1991 as clearly anomalous. Further, the HWM mean winter winds change from equatorward to poleward as solar activity level increases. Present results for spring also differ from those reported by Buonsanto, 1991 who found equatorward mean winds for most years.

Mean wind velocities determined using the SM method, incorporating Titheridge (1995a) correction, are smaller, the effect being largest at low solar activity. However, this does not modify the conclusion that the winds are stronger at high solar activity for winter and spring. By contrast Invercargill mean winds are weaker for high solar activity.

Again consistency is found between the present results for summer (December) and northern hemisphere (June) published by Hedin *et al.* (1994) when the diurnal variation amplitudes are compared, these amplitudes being smaller for the higher solar activity levels. However, much larger absolute values and larger decreasing trends are found here (a change from 190 to 110 m/s as compared with 60 to 40 m/s). By contrast, winter amplitudes (June) do not seem to change with increasing solar activity level, whereas the corresponding Hedin *et al.* (1994) northern hemisphere amplitudes do decrease (from about 70 to 40 m/s), though the absolute values are much smaller. This winter no change and large amplitude feature is also consistent with HWM results, which indicate almost no change also for spring and summer, with amplitudes of about 200 m/s. The present results for all seasons are consistent with those for Boulder, when Fourier decomposition of the diurnal variations is performed, in that the amplitude of the diurnal component decreases and the phase of maximum wind (poleward in both hemispheres) occurs later as the solar activity level increases. This amplitude decrease may probably be related to the greater ion drag for the higher solar activity level as has been previously suggested (e.g. Buonsanto, 1991 and references there in).

Diurnal variation amplitudes determined using the SM method, incorporating Titheridge (1995a) correction, are smaller at low solar activity levels for winter and spring. This means that winter amplitudes now increase with increasing solar activity, and that the rate of amplitude decrease observed in spring is smaller. By contrast, the Invercargill variation amplitude decreases with increasing solar activity level for winter and almost do not change for summer. Only spring solar activity trends for both SM modified and Invercargill results are similar.

Although, as indicated before, the southern hemisphere results reported by Canziani *et al.* (1990, 1992) and Giraldez and Canziani (1992) do not permit a solar cycle dependence to be obtained, they can be considered representative of conditions of low solar activity level and thus compared with the present results for 1986. Values reported for Puerto Argentino (Port Stanley) are used because they correspond to a location within the same longitude sector and nearer geographic and geomagnetic latitudes. The geographic latitudes of other locations are much lower and those for which the geomagnetic latitudes are similar are widely separated in longitude. There are significant differences in the shape of the diurnal variation for all seasons, Puerto Argentino's shapes being consistent with variations for which there are significant semidiurnal and terdiurnal components (they are more 'W' like). Mean winds also differ. They are almost nil for winter at Puerto Argentino (June) and for summer at King George Island (December), otherwise they are poleward at both locations. Seasonal changes of the diurnal amplitudes are similar, the King George Island amplitudes being larger for all seasons.

Finally, though it would be impossible at this stage to qualify effects of the SAA on the prevailing winds, it may be argued that even during geomagnetic quiet intervals some Joule heating related winds created in this 'point' source (as compared with the auroral source 'belt') would compete with those created at high latitudes, particularly for latitudes between these two sources (e.g. Puerto Argentino and King George Island), perhaps explaining some of the differences observed.

CONCLUSIONS

Although small sample effects cannot be ruled out, there seems to be a significant change in the shape of the diurnal variation of wind velocity from conditions of low to high solar activity level, for all seasons, which may be related to changes in the weight that various processes have on the thermospheric dynamics.

There is evidence for SM derived equatorward diurnal mean winds to decrease with increasing solar activity level during summer, which is consistent with the results for some locations in the southern and northern hemispheres, but inconsistent with others. Further, the opposite trend is found in poleward winds for winter and spring conditions, again inconsistent with other southern hemisphere results.

Previously found trends of decreasing amplitude of the diurnal variation with increasing solar activity level for a southern hemisphere location in winter and spring, and for northern hemisphere locations in all seasons, are confirmed only for spring and summer conditions. Although no trend is found for winter, when calculations are performed without incorporating Titheridge (1995a) correction, which is in agreement with HWM model results, an increase of variation amplitude is obtained when this correction is included.

Both diurnal mean wind velocities and diurnal variation amplitude changes with solar activity level, derived using the SM method, significantly differ from those determined using the HWM method.

Significant differences are found between the diurnal variation shape, mean value and amplitude of winds derived for locations in the southern hemisphere, even for the two located within the SAA longitude sector for low solar activity level conditions. It is suggested that these may be related to the relative position of these locations as regards the SAA area and the auroral belt.

Acknowledgements—The Instituto Antártico Chileno made funds and partial logistic support available to buy, install and operate the ionosonde at King George Island. Logistic support was also provided by the Fuerza Aérea de Chile. Comments received from two referees, which led to a significant revision of the text are greatly appreciated. The HWM90 code was kindly provided by the National Space Science Center, Greenbelt, USA. Support for this study was provided by Fondo Nacional de Desarrollo Científico y Tecnológico under Proyecto No. 1940934.

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