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The ionospheric F2 region winter anomaly and its dependence on solar activity in the northern and southern hemispheres

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RESUMEN

En este artículo se estudia la dependencia de la anomalía de invierno de la región F2 de la ionosfera con la actividad solar. Se realizó un estudio estadístico con datos de dos sondadores ionosféricos del hemisferio norte y dos del hemisferio sur. Se consideraron las medianas mensuales de foF2 para un mes de verano y uno de invierno, para un año de alta actividad solar (1980) y un año de baja actividad (1975). La anomalía de invierno está siempre presente en el hemisferio norte mientras que está presente sólo ocasionalmente en el sur. El análisis estadístico muestra que el comportamiento de la región F2 es diferente de un hemisferio a otro. Los resultados para el hemisferio norte presentan porcentajes de la variabilidad explicada desde un 82 a un 85% a la noche y de un 60 a un 83% al mediodía. A la noche, para el hemisferio sur, la variabilidad explicada oscila entre un 63 y un 77%. Sin embargo, al mediodía, la necesidad de buscar otras variables explicativas se hace evidente ya que sólo se explica el 28 y el 45% de la variabilidad de $\Delta f_oF2(12)$. Proponemos que estos resultados podrían estar conectados con la anomalía geomagnética del Atlántico Sur, con una menor altura para los puntos especulares lo que da lugar a un aumento de la precipitación de partículas atrapadas en una atmósfera más densa. Así, el calentamiento sería mayor en la región del Atlántico Sur, inhibiendo la convección desde el verano del norte al invierno del sur.

PALABRAS CLAVE: Anomalía de invierno, región F2, ionosfera, partículas atrapadas.

ABSTRACT

Data from two ionospheric sounders each from the northern and southern hemisphere, are used for a statistical analysis of foF2 monthly medians for summer and winter and high and low solar activity. The winter anomaly is always present in the northern hemisphere and only occasionally in the southern one. Statistical results suggest that the F2 region behaviour is different from one hemisphere to the other. In the northern hemisphere explanatory variability is 82 to 85% at night and 60 to 83% at noon. At night, in the southern hemisphere, the explained variability oscillates between 63 and 77%. However, at noon, it becomes necessary to look for other explicative variables since only 28 to 45% of the variability of $\Delta f_oF2(12)$ is explained. These results may be due to the South Atlantic geomagnetic anomaly, lowering the geomagnetic mirror points and enhancing trapped particle precipitation in the denser atmosphere. Thus, heating should be larger in the South Atlantic region, inhibiting convection from the northern summer to the southern winter.

KEY WORDS: Winter anomaly, F2 region, ionosphere, trapped particles.

INTRODUCTION

The ionospheric F2 region winter anomaly has been discussed by many authors. Noon maximum electronic density values tend to be greater in winter than in summer. Winter anomalies are directly connected with solar activity. This may be considered as a good example of the close dependence between solar and atmospheric phenomena. The anomaly is always present in the northern hemisphere, but is usually absent in the southern hemisphere during periods of low solar activity.

Torr and Torr (1973, 1980) and Rishbeth (1989) suggest that winter anomaly may be due to neutral composition changes in the F region. Such changes may be due to a change in the O/N_2 ratio. An increase in the O/N_2 ratio could be caused by convection of atomic oxygen from the summer to the winter hemisphere. This could be associated to seasonal variations in thermospheric winds (Roble *et al.*, 1977; Roble, 1983; Rich, 1985).

In this paper, the dependence of the winter anomaly on solar activity is examined for different latitudes and longitudes. Also, nocturnal behaviour is examined. Evidence of different behaviour in the two hemispheres will be established, and some suggestions about the origen of the winter anomaly will be proposed.

SOLAR ACTIVITY AND THE WINTER ANOMALY

Ionospheric sounding data from Dourbes and Wakkanai, in the northern hemisphere, and Canberra and Port Stanley in the southern hemisphere are used (Table 1). All observatories are located at middle latitude stations.

Figures 1 and 2 show the monthly median values foF2 - F2 layer critical frequency - in January and July. We are showing data for high (1980) and low 1975 solar activity. (1975) The yearly means of the monthly mean sunspot

Table 1

Ionospheric Observatories

Stations	Geogr.	Geomag.	Geogr.	Geomag.
	Latitude		Latitude	
Northern Hemisphere				
Dourbes	50.1	51.7	4.6	88.9
Wakkanai	45.4	35.5	141.7	-152.7
Southern Hemisphere				
Port Stanley	-51.7	-40.6	-57.8	10.3
Canberra	-35.3	-43.7	149.0	-134.2

numbers are 15.5 for 1975 and 154.6 for 1980. In the Northern hemisphere the winter anomaly is always present in both stations, while in the southern hemisphere it is present only in Canberra at solar maximum. These data may be compared with those of other authors (for instance, Torr and Torr, 1973).

Let us now compare the statistics of data from 1965 to 1989 (that is, 25 years) at Dourbes and data from 1965 to 1987 (23 years) at Wakkanai, with data from 1965 to 1981 (17 years) at Port Stanley, and data from 1965 to 1991 (27 years) at Canberra. January and July noon and midnight monthly medians values are used. These values may reflect the average daily behaviour in the northern winter and summer. The equation

$$\Delta foF2(12) = foF2(12)_{January} - foF2(12)_{July} \quad (1)$$

defines the anomaly at noon, and

$$\Delta foF2(00) = foF2(00)_{January} - foF2(00)_{July} \quad (2)$$

defines the behaviour at midnight.

The nocturnal behaviour study has been considered also of interest, in spite of the fact that the winter anomaly is an essentially diurnal phenomenon.

At each station (Dourbes, for instance), we have 25 values of $\Delta foF2(12)$ and 25 values of $\Delta foF2(00)$ for

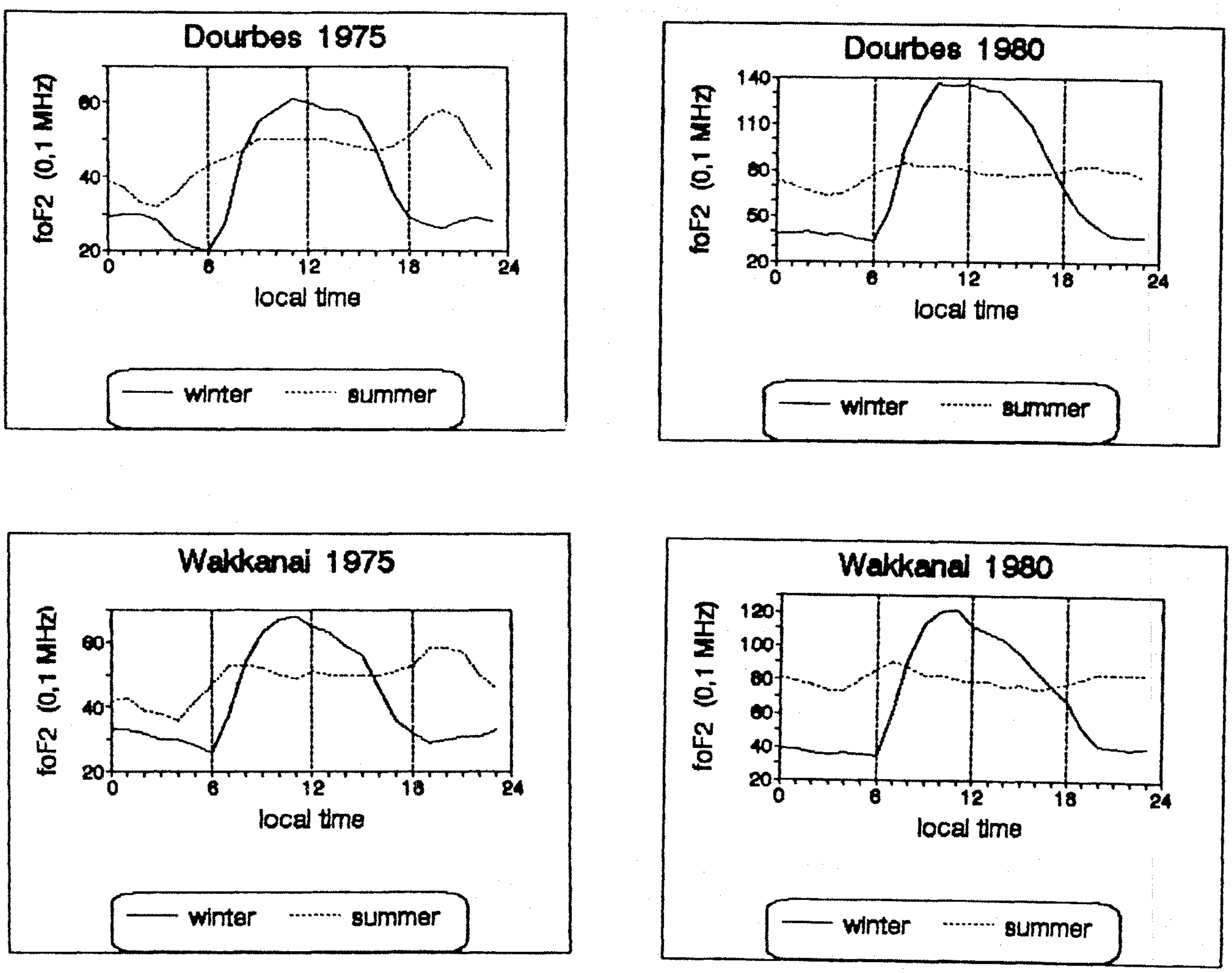

Fig. 1. Monthly median of foF2 versus local time for two middle latitude stations from the northern hemisphere. July and January months reflect the summer and winter behaviour, respectively, at solar maximum, 1980 and solar minimum, 1975. Between about 08.00 hs. and 17.00 hs., winter foF2 values are larger than summer values.

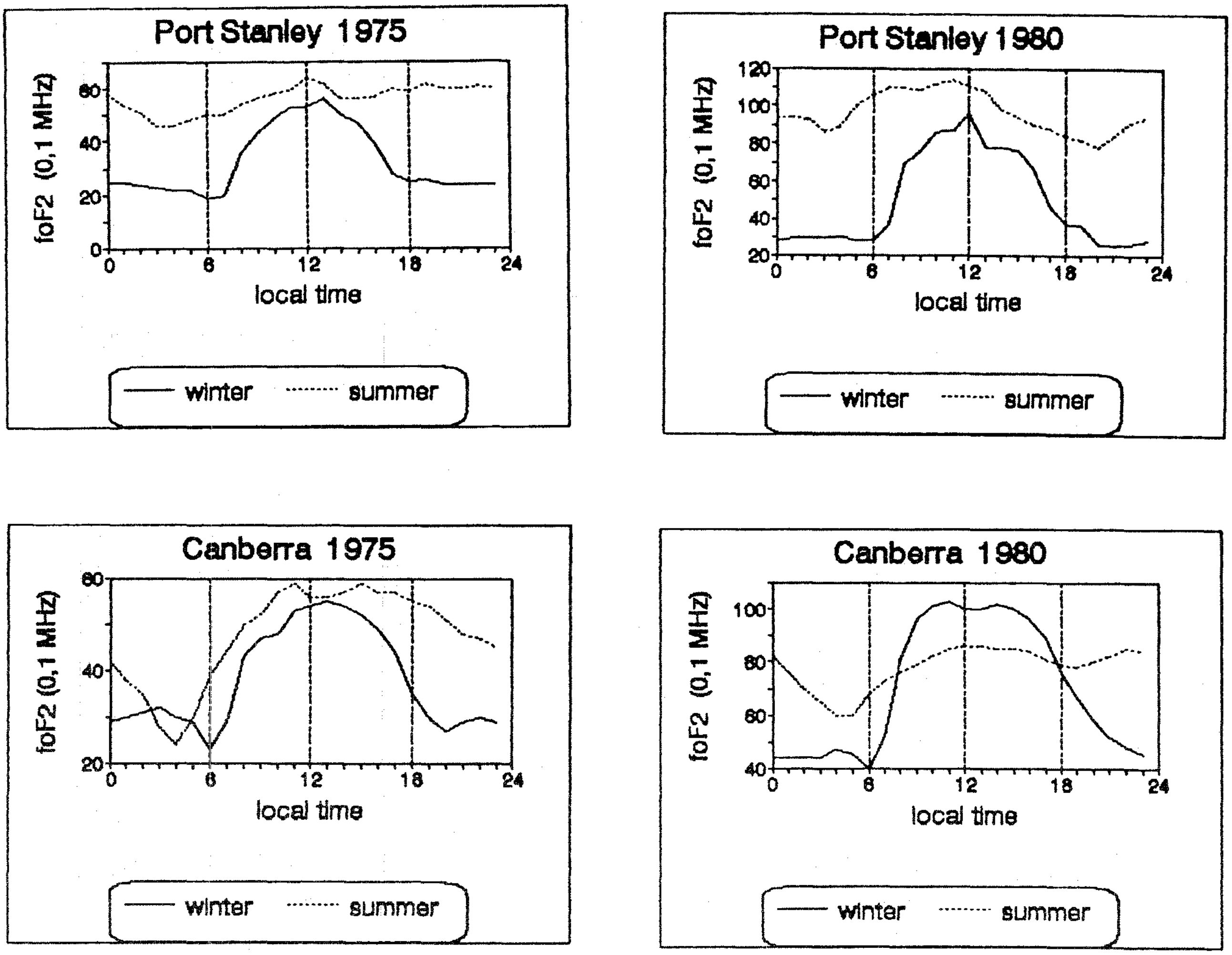

Fig. 2. Monthly median of foF2 versus local time for two middle latitude stations from the southern hemisphere. January and July months reflect the summer and winter behaviour, respectively, at solar maximum, 1980 and solar minimum, 1975. Port Stanley summer values are larger than winter values, showing that the winter anomaly is not present. It is present at Canberra, 1980.

carrying out our statistical study. We fit a multiple linear regression model of the form

$$Y = \beta_o + \Sigma\beta_i X_i$$

to each set of data. The multiple correlation coefficient is R, and R^2 is the proportion of the variability of the dependent variable $\underline{Y}$ explained by the independent variables $\underline{X_i}$ (Johnston, 1979). When only one explanatory variable is retained, the result becomes a simple regression, where R is the simple correlation coefficient.

The dependent variables are ΔfoF2(00) for nocturnal behaviour, and ΔfoF2(12) for noon behaviour. The proposed independent variables (that is, the possible explanatory variables) are the solar activity S, given by the monthly mean sunspot numbers Sp (the averages between January and July); Δh'F, where h'F is the F layer virtual height, and ΔhpF2, where hpF2 is the approximate value of the electronic concentration peak altitude as obtained from the M(3000)F2 parameter. The "Δ" symbol has an analogous meaning to that given at ΔfoF2 in equations (1) and (2).

The values for R and R^2 at noon and at night for each station are showed in Table 2. The explanatory variables are also shown .

Thus, for Wakkanai at night, when only solar activity Sp is considered, we obtain $R^2 = 0.82$, saying that 82% of the variability in ΔfoF2(00) is explained by Sp. However, multiple regression on both Sp and Δhp(00) yields $R^2 = 0.85$, which means that 85% can be explained by two variables.

Scatter diagrams of ΔfoF2 versus solar activity for the northern hemisphere (Figure 3), and for the southern hemisphere (Figure 4) are also shown.

Note that the correlation changes sign from day to night and from one hemisphere to the other (Figures 3 and 4). This is due to the way in which winter anomaly has been defined.

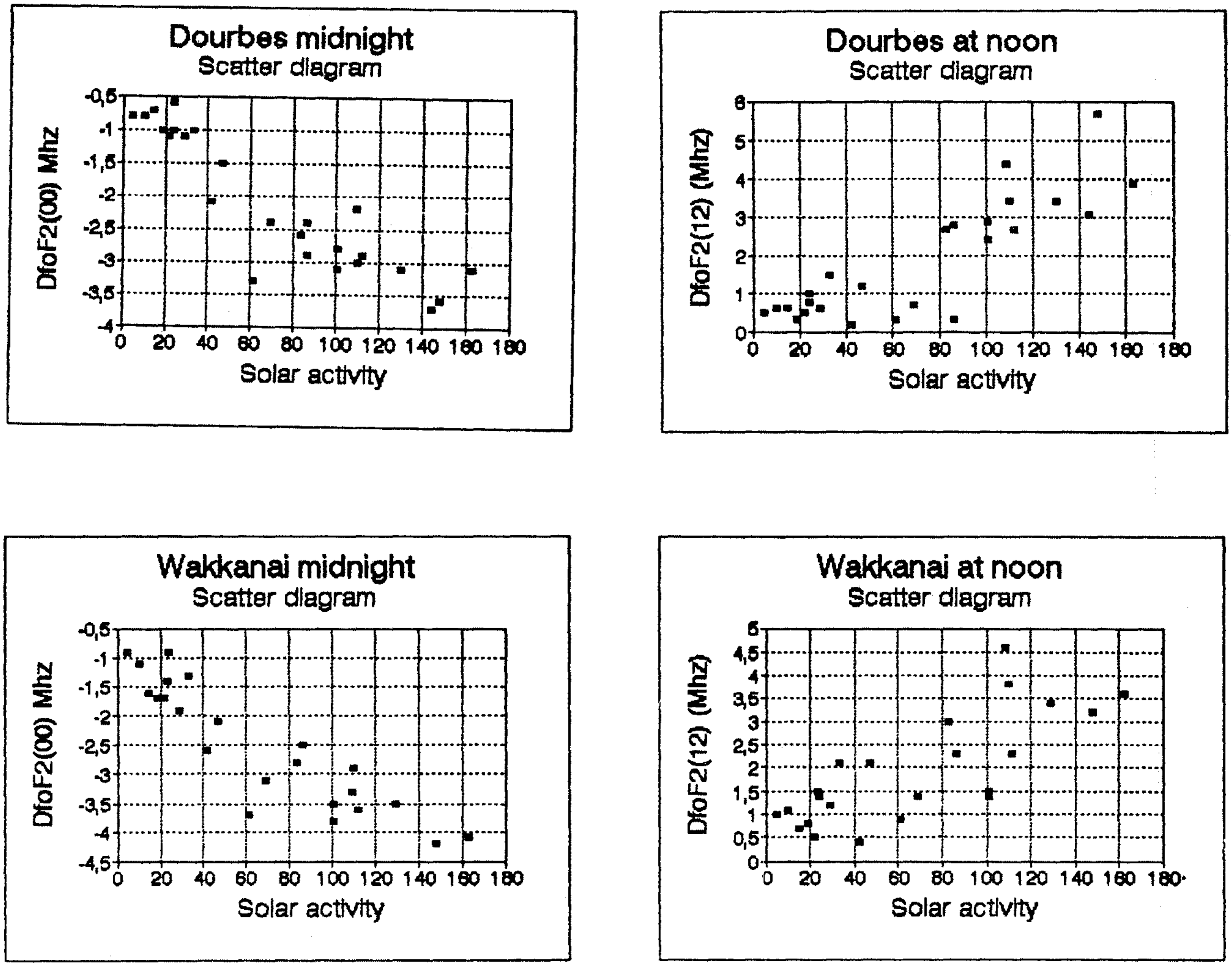

Fig. 3. Scatter diagrams for foF2(00) and foF2(12) versus solar activity for Dourbes (25 data years, above) and Wakkanai (23 data years, below). Both stations are in the northern hemisphere and have similar latitudes. The nocturnal adjustment is better than the diurnal. Wakkanai, at noon, shows the largest dispersion.

Table 2

Solar Activity Dependence

	MIDNIGHT		
	Simple L. Reg.		Multiple L. Reg.
Station	R	R^2	R^2 Exp. Var.
Dourbes	- 0.91	0.82	Sp
Wakkanai	- 0.91	0.82	0.85 Sp, Δhp
Canberra	0.80	0.63	Sp
Pt. Stan.	0.88	0.77	Sp
	NOON		
	Simple L. Reg.		Multiple L. Reg.
Station	R	R^2	R^2 Exp. Var.
Dourbes	0.85	0.72	0.83 Sp, Δhp
Wakkanai	0.77	0.60	Sp,
Canberra	-0.60	0.35	0.45 Sp, Δhp
Pt. Stan.	0.52	0.28	Sp

DISCUSSION

The F2 region behaviour differs from one hemisphere to the other. The differences are important and can be measured. The winter anomaly in the northern hemisphere at night can be satisfactorily explained by solar ionization alone, and is a function of solar activity. Correlation coefficients higher than 0.9, and explained percentages from 82 to 85% (Table 2), suggest that other explanatory variables are not required. For noon results, with 83% explained variability at Dourbes and 60% at Wakkanai, we could think that our working method might be effective.

In the southern hemisphere (Table 2), on the other hand, the results are less conclusive. The ΔfoF2(00) variability is between 63% and 77% at night, but at noon it is below 50%.Thus, the solar ionization is insufficient to explain ΔfoF2(12) variability at noon. The southern winter anomaly seems less dependent on solar activity that the northern.

At Port Stanley the ΔfoF2(12) variability is correlated

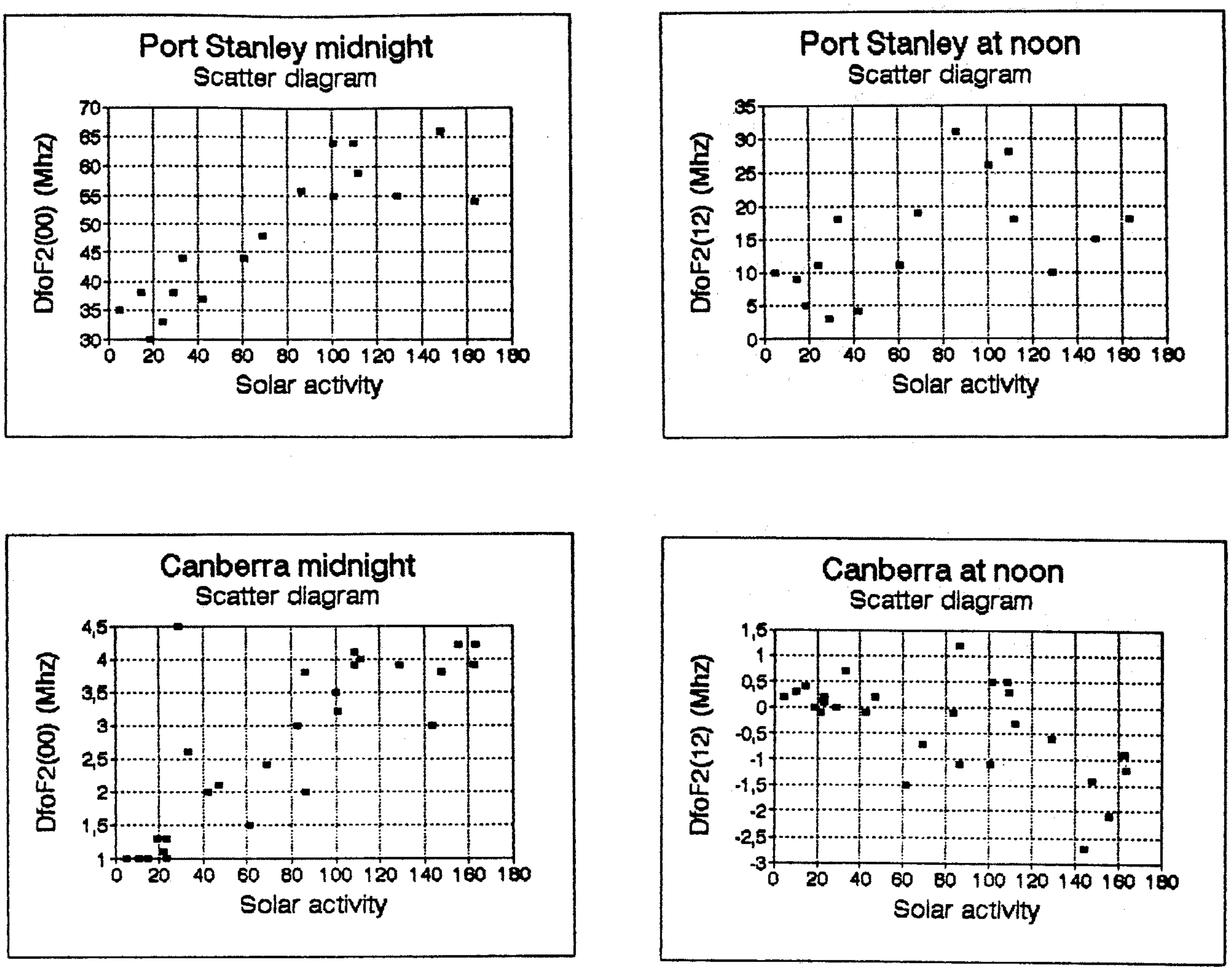

Fig. 4. Scatter diagrams for foF2(00) and foF2(12) versus solar activity for Canberra (27 data years, above) and Port Stanley (17 data years, below). Both stations are in the southern hemisphere and have similar latitudes. The nocturnal adjustment is better than the diurnal. Port Stanley, at noon, shows the largest dispersion.

with solar activity at the level of 28% and in Canberra of 35%. We propose that these results are connected to the lower altitude of the electron mirror point in the southern hemisphere. The geomagnetic field is abnormally weak in the region of the South Atlantic geomagnetic anomaly. Particles precipitation from the radiation belts, and the resulting heating, would be larger in the southern hemisphere, thus increasing convection to the northern winter and inhibiting convection to the southern winter.

This extra source of ionization would act fundamentally in the southern summer, favouring the transport of air rich in atomic oxygen to the northern winter. Note that R^2 values at noon are higher at Dourbes than at Wakkanai, suggesting transport from the South Atlantic sector. In conclusion, when explaining the F2 region winter anomaly in the southern hemisphere, the geomagnetic field must be taken into account.

The Δh'F variable has little weight. If included in the regression equation, it adds little to improve the regression as measured by the multiple correlation coefficient. On the other hand, ΔhpF2 does appear as an explanatory variable in the model for Dourbes at noon, Wakkanai at night and Canberra at noon. The significance levels of this variable are lower than for the Sp solar activity,which is the most important variable in this problem.

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