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On the relationship between extra-terrestrial radiation and surface pressure

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Abstract: The surface pressure of an Antarctic station displays two minima, one in spring, the other in autumn. It is believed that these minima are caused by radiative forcing, as the gradient of the extra-terrestrial radiation is largest during the two equinoxes. The best correlation ($r = 0.85$) was obtained when the pressure lagged the radiation gradient by ten days.

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Introduction

In 1980, automatic weather stations (AWS), reporting over satellite (Argos system), were placed in Eastern Antarctica (e.g. Stearns & Wendler 1988). Surface climatological data have been obtained from these stations for more than a decade. One of our AWS is located 5 km from the coastline at 66.7°S, 139.8°E. The area is snow covered all year, the winds are of katabatic origin, strong and changing little in direction throughout the year and the temperatures are relatively mild for Eastern Antarctica. A temperature below -40°C has never been observed in more than 10 years of observations. This is in contrast to an AWS some 1080 km inland at an altitude of 3280 m (Dome C), where an AWS measured an absolute minimum of -84.6°C.

Results

The atmospheric pressure displays a semi-annual variation with a main maximum in summer (January and December), and there is a secondary maximum in midwinter (June). As can be seen from Fig. 1, the minima occur in the intermediate seasons, the spring one (September) being more pronounced than that in autumn. This semi-annual variation in atmospheric pressure has been described previously (e.g. Schwerdtfeger & Prohaska 1956, Schwerdtfeger 1960, van Loon 1966, 1967) and modelled by Meehl (1991). The above authors suggested that the gradient of latitudinal cooling or heating of the atmosphere and surface initiates a circulation. The intensity of this circulation is dependent on the meridional gradient of heating or cooling. Further, the depth of the circumpolar trough, which surrounds Antarctica, can be

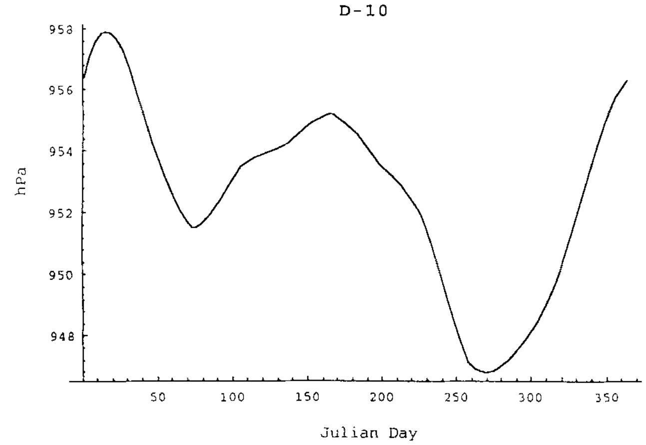

Fig. 1. The annual course of surface pressure as observed at 66.7°S, 139.8°E, derived from observations of an automatic weather station. The pressure was 33.7 hPa less than the mean value for 65°S, as the station was located 240 m a.s.l.

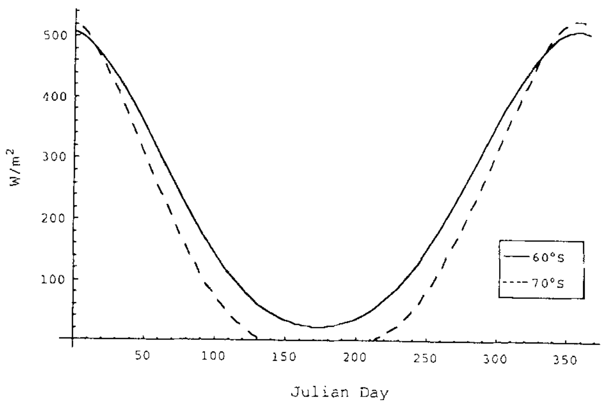

Fig. 2. The annual course of the extra-terrestrial radiation for 60°S and 70°S (solid line 60°S, broken line 70°S). Note, that the radiation becomes zero around midwinter at 70°S, as we are poleward from the Antarctic Circle. Note further, that around midsummer, the ET radiation at 70°S surpasses the one at 60°S, an effect of the longer daylength.

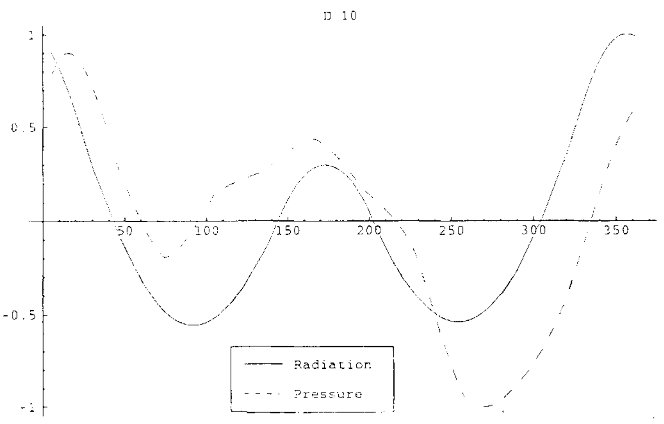

Fig. 3. The normalized annual course of surface pressure as observed at D10 (66.7°S, 139.8°E) (broken line), and the gradient of the extra-terrestrial radiation at the top of the atmosphere between 70°S and 60°S (solid line). For the normalization the mean annual values were set to zero, and the maximum deviation from this value was set to one. Note the similarities of the two curves.

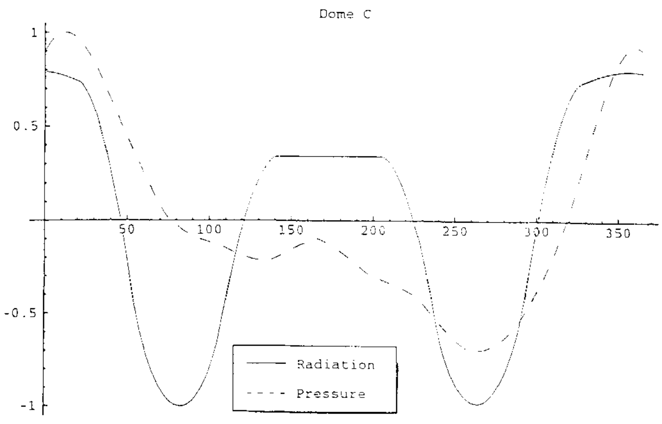

Fig. 5. The normalized annual course of surface pressure as observed at Dome C (74.5°S, 123.0°E) (broken line), and the gradient of the extra-terrestrial radiation at the top of the atmosphere between 70°S and 80°S (solid line). For the normalization the mean annual values were set to zero, and the maximum deviation from this value was set to one. Note, that the two curves are quite dissimilar.

taken as an index of the strength of this circulation.

The extra-terrestrial radiation (ET) for 60°S and 70°S is presented in Fig. 2. The ET radiation is the radiation that would be received from the sun on a horizontal surface with no atmosphere present. It represents, of course, only the solar constant multiplied by sinα, where α is the solar elevation. These values are integrated over each day and then plotted in the figure. No corrections for Earth–Sun distance have been applied. It can be seen from the figure that, for most of the year, the radiation is higher at the lower latitude (60°S). Only around midsummer does the longer daylength at 70°S overcompensate for the lower elevation angles of the sun, and during this time the ET radiation increases when going polewards. Further, the figure shows that the radiation becomes zero around midwinter at 70°, as the station is poleward of the Antarctic circle, and the sun stays steadily below the horizon during this time.

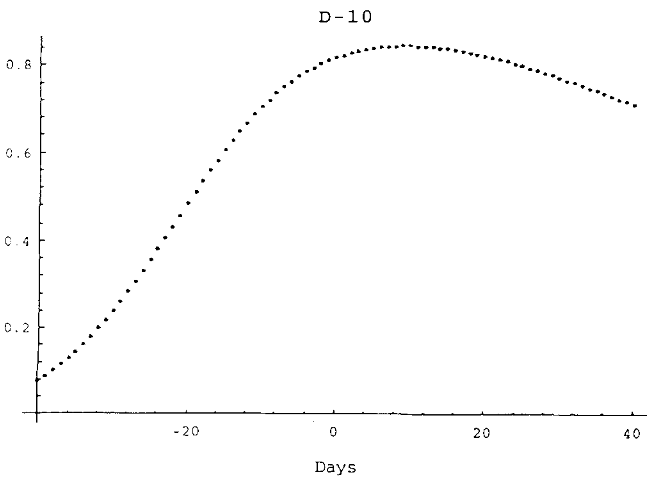

Fig. 4. The correlation coefficient between atmospheric surface pressure and radiative forcing for different time lags in days. Note, that the highest correlation was obtained when the pressure lagged the radiative forcing by 10 days.

The radiative gradient between 60°S and 70°S can be taken as an indication of the radiative forcing. This radiative gradient, here defined as the ET radiation of 70°S minus that at 60°S and the deviation series of the surface pressure are presented in Fig. 3. For easier comparison, both curves have been normalized in such a way that their mean value is zero, and the extreme deviation from this value was assumed to be one. The agreement between the two curves is astonishingly good. The only major discrepancy between the graphs occurs at the vernal equinox where the surface pressure displays a more pronounced minimum than in autumn. Of course, the radiative gradient at the top of the atmosphere shows no variation between the equinoxes. The intensification of the pressure trough in spring is related to the maximum sea ice extent at this time of the year. The correlation coefficient between atmospheric surface pressure and the gradient of the extra-terrestrial radiation was $r = 0.80$. If we allow time lags, the best coefficient was found when the pressure trailed the radiative forcing by 10 days (Fig. 4); the numerical value was $r = 0.85$. This time lag is relatively short and the atmosphere appears to react quickly to the extra-terrestrial radiative forcing. It should be noted that the correlation coefficients are not symmetrical around the maximum, but show higher values following the maximum. This is caused by the surface energy budget and represents the heat storage term.

However, such a good agreement deteriorates when going

Table I. Amplitudes of annual and semi-annual harmonics of atmospheric pressure and extra-terrestrial radiation gradient.

station	element	1st harmonic	2nd harmonic	units
D 10	radiation gradient	17.8	33.1	W m^{-2}
	atmospheric pressure	2.73	3.12	hPa
Dome C	radiation gradient	10.6	44.7	W m^{-2}
	atmospheric pressure	5.74	4.03	hPa

inland in Antarctica. Dome C is our highest AWS station, located at 3280 m a.s.l. at 74.5°S and 123.0°E. Again, some 10 years of data are available. In Fig. 5 the normalized deviation series of the surface pressure and ET (this time the gradient between 70°S and 80°S) are given. While the radiative forcing displays the strong half-yearly oscillation, which is zero in midwinter due to continuous darkness, the pressure displays only one big summer maximum. There might be a slight indication of a secondary maximum in winter, but it is very weak. The correlation coefficient between the two graphs was only $r = 0.47$. If time lags are allowed, it increased to a maximum of $r = 0.59$ for the atmospheric pressure trailing the radiative forcing by 32 days (not shown).

The differences in the correlation might be explained by the albedo or surface energy budget, respectively. In summer melting occurs in the coastal region and small exposed rock areas exist; furthermore, open water is frequently present during summer; it can occur during any time of the year. In contrast to this, the interior of Antarctica is year-round in the dry snow zone (Giovinetto 1961), with a very high surface albedo (80% or above). Hence, the latitudinal gradient of solar radiation does not have the same importance as at lower latitudes, as most energy is reflected back to space.

In Table I the amplitudes of the annual and semi-annual harmonics of both atmospheric pressure and radiation gradient are tabulated for both sites. It can be seen that the second harmonic is larger for the radiation gradient for both stations, and for atmospheric pressure for the coastal station. However, for atmospheric pressure the first harmonic is dominant for the inland station.

Conclusion

In summary, data from remotely located automatic weather stations in Antarctica have demonstrated that the semi-annual pressure variation is well established near sea level. However, with increasing altitude the variation becomes weaker and, in the interior of Antarctica, hardly a trace remains. It is believed that the atmospheric pressure is an indication of the transport polewards, as the semi-annual pressure variation is well correlated to the gradient of the radiative forcing. The best correlation ($r = 0.85$) was found when the atmospheric pressure trailed the radiative forcing by about 10 days, indicating that the atmosphere has a very short response time to outside forcing. The correlation represents a very good non-trivial relationship showing how the atmosphere reacts to the extra-terrestrial radiation gradient.

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