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Antarctic 500 hPa heights and surface temperatures

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The conservative shape of temperature profiles in the lower troposphere above the Antarctic ice sheet makes the surface temperature, t_s, an effective independent variable for estimating the height of the 500 hPa surface above automatic weather stations (AWS). In place of regression equations for the thinning of the surface/500 hPa layer (produced by negative layer mean temperatures, $\bar{t}$) as a dependent variable, an alternative approach examined here uses the layer mean temperature itself as a dependent variable. It is shown that this eliminates systematic differences between the regression parameters for radiosonde stations at different elevations, and should validate a single set of parameters for a wide range of AWS sites.

Introduction

The surface elevations of the East Antarctic ice sheet make 500 hPa the lowest standard constant pressure level that does not intersect the ice sheet. Along the Antarctic coast, pressures in the free atmosphere are reasonably well defined by regular radiosoundings, but in the interior one upper air station only is currently operating (Amundsen-Scott at the pole). It is then fortunate that a procedure for refining the 500 hPa analyses with the observations from automatic weather stations now operating on the ice sheet has been found by Phillpot (1991). A modified version was used by Radok and Wendler (1991) and is explored more fully in this note.

Statistics of the surface/500 hPa layer thickness above the interior of Antarctica

The height of the 500 hPa constant-pressure surface is determined by the mean temperature, $\overline{T}$ (°K), of the layer between the surface elevation, E (with pressure p_s), and the 500 hPa level, as

$$Z = E + \overline{T}(R/g)\ln(p_s/500) \qquad \ldots 1$$

where R is the specific gas constant and g is the acceleration of gravity; g/R = 0.034°C/m is the vertical temperature lapse rate in a constant-density atmosphere.

With $\overline{T}$ (°K)=273+t(°C) the layer thickness $\Delta Z = Z - E$ becomes $\Delta Z = \Delta Z_0 + \Delta Z_t$ where $\Delta Z_0 = 8029 \ln (p_s/500)$ depends on surface pressure only, and $\Delta Z_t = (\bar{t}/0.034) \ln (p_s/500)$ is the thickness correction for the (usually negative) layer mean temperature, $\bar{t}$(°C). Phillpot (1991) showed that ΔZ_t is strongly correlated with the surface temperature, t_s. His linear regression equations (in terms of dekameters, dam) for five IGY stations are reproduced in Table 1(a), together with root mean square deviations from the regression lines ('standard deviations', sd). The slope parameters, m_1, exhibit a systematic decrease with increasing elevation. From a similar though less regular decrease in the standard deviations, Phillpot argued that the use of the $\Delta Z_t/t_s$ regressions for height estimates of the 500 hPa surface should be limited to stations above 2500 m which have standard deviations less than 2 dam; then (Gaussian) errors would be expected to exceed ±2*sd* = ±4 dam in fewer than five per cent of all cases.

Radok and Wendler (1991) pointed out that the $\Delta Z_t/t_s$ regression reflects the tendency of vertical temperature profiles over the ice sheet to preserve their shape as they translate with changing surface temperatures. A more uniform relationship

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should then exist between the surface temperature, t_s, and the layer mean temperature, $\bar{t}$, itself. For the same stations and three sea-level stations, $\bar{t}/t_s$ regression equations have been computed with the data extracted from IGY upper air soundings for 1958 and kindly made available to us by Henry Phillpot. Their parameters and error standard deviations are given in Table 1(b), (i) and (ii); they exhibit no systematic dependence on elevation and are more uniform than those in Table 1(a). This is further demonstrated by Fig. 1 which shows probability ellipses (cf. Bartels 1932) enclosing the individual $\bar{t}/t_s$ pairs observed during 1958 which fell within ± 1.65 standard deviations from the regression lines (representing 90 per cent of their (Gaussian) distributions).

Figure 1 suggests that the all-station $\bar{t}/t_s$ relationships, listed in Table 1(b)(iii), are broadly valid for a wide range of surface elevations, extending even down to sea level. When such an all-station regression is used for finding the thickness corrections, ΔZ_t, their error standard deviations are obtained by multiplying the all-station standard deviation with ln $(P/500)/0.034$, where the P are representative surface pressures. As an illustration, the specific values of P given in Table 1(b)(i) convert the $\bar{t}/t_s$ standard deviations of the five ice-sheet stations into Phillpot's estimates given in Table 1(a). Furthermore, Fig. 2 shows standard errors of ΔZ_t to be expected for increasing surface pressures (and hence layer thickness) from the all-station $\bar{t}/t_s$ standard deviations of Table 1(b)(iii).

Application to a South Pole episode

The individual errors during 1958 of the thickness correction estimates for the five ice-sheet stations have been plotted as time series and in general appear to be random, but with occasional trends lasting several days. A typical example for South Pole is presented in Figs 3 and 4. Between 3 and 7

Table 1. Regression equations for estimating the 500 hPa height with surface temperature as independent variable.
(a) Regression equations for the thickness correction
$\Delta Z_t = (\bar{t}/0.034)\ \ln\ (p_s/500) = m_1 t_s + c_1$ (Phillpot 1991)

	Stations				
	Sovietskaya	*Vostok*	*South Pole*	*Pioneerskaya*	*Byrd*
Elevation (dam):	367	350	284	276	153
Soundings (IGY):	277	343	918	130	957
m_1 (dam/°C):	0.19	0.24	0.27	0.36	0.51
c_1 (dam):	−14.71	−14.87	−21.60	−17.60	−25.84
Error sd (dam):	1.76	1.71	2.31	2.12	4.29

(b) Regression equation for the layer mean temperature $\bar{t}$:
$\bar{t} = m_2 t_s = c_2$

	(i) Stations				
	Sovietskaya	*Vostok*	*South Pole*	*Pioneerskaya*	*Byrd*
Soundings (1958):	274	343	580	129	638
m_2(°C/°C):	0.39	0.47	0.36	0.40	0.39
c_2(°C):	−22.9	−19.1	−21.7	−18.7	−20.0
Correlation:	0.86	0.93	0.85	0.80	0.83
Error sd (°C):	3.5	2.3	3.1	2.9	3.3
Pressures P (hPa) giving the ΔZ_t error sds of table 1a (for details see text):	759	684	644	611	600

	(ii) Sea-level stations			*(iii) All-stations $\bar{t}/t_s$ regressions:*			
	McMurdo	*Hallett*	*Wilkes*	*5 ice-sheet stations (1964 soundings)*		*all stations (3494 soundings)*	
Soundings (1958):	535	357	638				
m_2(°C/°C):	0.43	0.37	0.49	*m_2(°C/°C):*	0.42	*m_2(°C/°C):*	0.44
c_2(°C):	−20.9	−20.5	−17.2	*c_2(°C):*	−20.0	*c_2(°C):*	−19.0
Correlation:	0.74	0.71	0.82	*Correlation:*	0.86	*Correlation:*	0.93
Error sd(°C):	3.6	4.0	3.0	*Error sd(°C):*	4.33	*Error sd(°C):*	3.57

Fig. 1 Frequency ellipses (Bartels 1932) enclosing 90% of surface/500 hPa layer mean temperature pairs observed at Antarctic stations during 1958.
--- high-level stations: Amundsen Scott (AS), Vostok (V), Sovietskaya (S).
-·-· intermediate-level stations: Byrd (b), Pioneerskaya (P).
.... sea-level stations: McMurdo (M), Wilkes (W), Hallett (H).
— all stations.

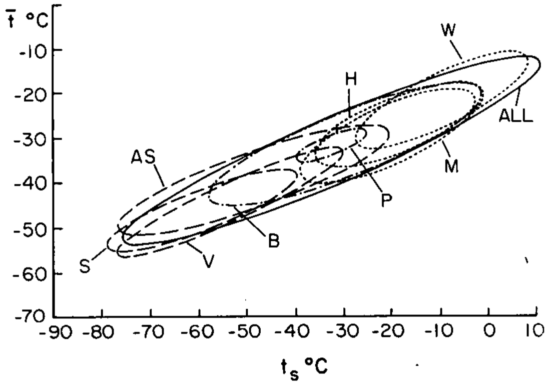


Fig. 2 Standard errors of thickness corrections ΔZ_t (dekametres) calculated with the all-station $\bar{t}/t_s$ regression for 1958 (sd = 3.57°C, full line), and with that for the ice-sheet station data only (sd=4.33°C, broken line).

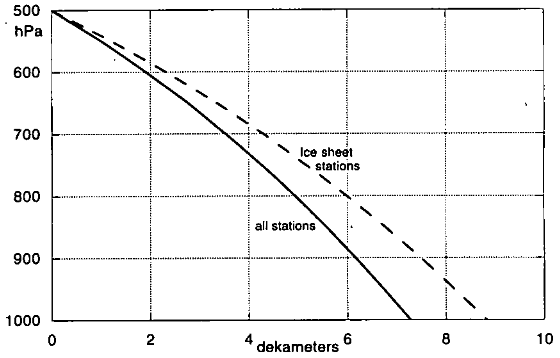


Fig. 3 Surface pressures and temperatures observed at the South Pole, 3 to 7 July 1958.

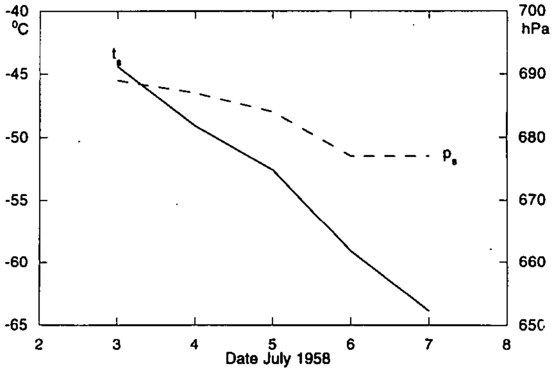
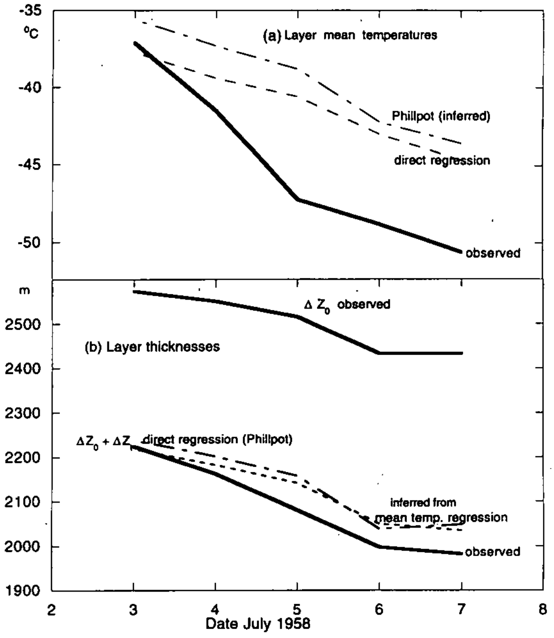


Fig. 4 Observed surface/500 hPa layer mean temperatures (a) and thickness (b, heavy lines), and regression estimates.



July 1958, a 12 hPa drop in surface pressure and surface temperature decrease of almost 20 degrees (Fig. 3) reduced the actual thickness of the surface/500 hPa layer by 24 dam (cf. Fig. 4(b)). The error of the thickness correction (the difference from the ΔZ_0 curve) directly estimated with Phillpot's regression equation for the South Pole (Table 1(a)) was negative throughout, with a maximum of −6.6 dam on 7 July, whereas the thickness correction calculated with the $\bar{t}/t_s$ regression equation for South Pole in Table 1(b) started with a positive 1.2 dam error on 3 July and became −4.6 dam by 7 July. These differences are explained in part by the slightly different datasets used to estimate the regression parameters, but Fig. 4(a) shows that all the directly estimated layer mean temperatures are more realistic than those inferred from Phillpot's ΔZ_1 values.

During this episode the 500 hPa charts for the IGY (South African Weather Bureau, undated) show the South Pole to have been located between a persistent 500 hPa trough flanking Antarctica in the western hemisphere and a high centered at 80°S, 70°E, which temporarily strengthened on 4 July. At the 500 hPa level, NNW winds started on 2 July, weakening after 4 July; strong katabatic surface winds from NNE prevailed between 2 and 6 July. According to Stone and Kahl (1991), this type of persistent cold-air drainage from the high plateau in cloudless conditions is one of the characteristic climatic modes encountered at the South Pole; at least on this occasion the associated strong cooling of the lower troposphere escaped notice by the surface temperature regressions.

Conclusion

According to Hutchinson (1995), analyses of the 500 and 700 hPa topographies in preparation for three special observing periods of the First Regional Observing Study of the Troposphere (Bromwich and Smith 1993), are being supplemented with the Phillpot procedure. In that procedure the surface pressure, p_s, is assigned two different roles: it determines the exact value of the thickness, ΔZ_0, and also forms an implicit part of the dependent regression variable, ΔZ_1. By contrast the $\bar{t}/t_s$ procedure described here used the same observed factor ln $(p_s/500)$ for both ΔZ_0 and ΔZ_1. This should yield more accurate estimates of the total thickness, ΔZ, which moreover can be expected to involve the same regression parameters for a considerable range of elevations. The ample data now available for Amundsen Scott and Vostok could thus be used to refine the parameters of the $\bar{t}/t_s$ regression and to determine their seasonal variation, in order to obtain the full benefits of Henry Phillpot's discovery for synoptic analyses over Antarctica.

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