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CALCULATION OF THICKNESSES FROM SATELLITE TEMPERATURE RETRIEVALS OVER HIGH GROUND

by

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CALCULATION OF THICKNESSES FROM SATELLITE TEMPERATURE RETRIEVALS OVER HIGH GROUND

1. INTRODUCTION

Inspection of plotted charts of geopotential thickness obtained from Met.O.19's HERMES system for processing locally-received TOVS (TIROS Operational Vertical Sounder) data has suggested that large errors sometimes occur over moderately high ground (e.g. Scandinavia). This paper examines the problem as it occurs in the original Madison export package implemented by Met.O.19. It identifies an error in the implementation of the export package algorithms which will affect any group which uses the software without provision of surface data from another source. When surface data are not available, the problem manifests itself as an error in the conversion of the retrieved temperature profile into a thickness profile, and this accounts for the major part of the observed anomalies. An alternative algorithm is derived.

2. THEORY

If we have a retrieved temperature profile at standard pressure levels, then the geopotential thickness of the layer between 2 adjacent standard levels away from the earth's surface is simply given by integrating the hydrostatic equation:

$$\Delta z_{p_1}^{p_2} = \frac{R}{g} \overline{T}_v \ln\left(\frac{p_1}{p_2}\right), \qquad \ldots 1$$

where p_1 and p_2 are the pressure of the lower and upper levels respectively,
$\Delta z_{p_1}^{p_2}$ is the thickness between these pressure levels,
R is the gas constant and g the gravitational acceleration such that $R/g = 29.27$ gpm.K^{-1},
and $\overline{T}_v$ is the mean virtual temperature of the layer.

Assuming a virtual temperature lapse rate which is constant in ln(p):

$$\Delta z_{p_1}^{p_2} = \frac{R}{2g} \left\{ (T_v)_1 + (T_v)_2 \right\} \ln\left(\frac{p_1}{p_2}\right), \qquad \ldots 2$$

where $(T_v)_1$ and $(T_v)_2$ are the virtual temperatures at levels p_1 and p_2 respectively.

This is the method used in the Madison export package routine, HT, to convert the retrieved temperature profile at standard levels to a geopotential thickness profile (although the Madison routine uses a value of $R/g = 29.2898$ gpm.K^{-1}).

If the surface pressure has a value which lies between p_1 and p_2, then a different relation applies:

$$\Delta z_{p_1}^{p_2} = \Delta z_{p_1}^{p_s} + \frac{R}{2g}\left\{(T_v)_s + (T_v)_2\right\} \ln\left(\frac{p_s}{p_2}\right) \quad \ldots 3$$

where p_s and $(T_v)_s$ are the pressure and virtual temperature at the surface.
and $\Delta z_{p_1}^{p_s}$ is the height of the surface above pressure level p_1.

If p_1 = 1000 mb and (as is assumed in the current scheme) $z_{p_1} = 0$ (i.e. sea level pressure = 1000 mb), then $\Delta z_{p_1}^{p_s}$ is the surface elevation which can be obtained from the topography data set.

Now,

$$\frac{R}{2g}\left\{(T_v)_s + (T_v)_2\right\} \ln\left(\frac{p_s}{p_2}\right)$$
$$= \frac{R}{2g}\left\{(T_v)_s + (T_v)_2\right\}\left\{\ln\left(\frac{p_1}{p_2}\right) - \ln\left(\frac{p_1}{p_s}\right)\right\}$$
$$= \frac{R}{2g}\left\{(T_v)_s + (T_v)_2\right\}\left\{\ln\left(\frac{p_1}{p_2}\right) - \frac{\Delta z_{p_1}^{p_s}}{(R/g)\,\overline{T}_v'}\right\}, \quad \ldots 4$$

where $\overline{T}_v'$ is an assumed mean virtual temperature below the surface. The appropriate value for $\overline{T}_v'$ is not obvious but it may be argued that we should assume a temperature profile down to 1000 mb which, if the atmosphere existed to this level, would give the same radiances as those actually measured over the elevated surface. Examination of the radiative transfer equation shows that such a profile is isothermal below level p_s with a temperature equal to the true surface temperature. This is illustrated in figure 1. Therefore, to derive thickness, we take the retrieved temperature for 1000 mb, calculate the corresponding virtual temperature and apply it as the virtual temperature at level p and for the layer below. Thus, applying equation 4 to equation 3 and substituting $(T_v)_1$ for $\overline{T}_v'$, we obtain,

$$\Delta z_{p_1}^{p_2} = \Delta z_{p_1}^{p_s} + \frac{R}{2g}\left\{(T_v)_1 + (T_v)_2\right\}\left\{\ln\left(\frac{p_1}{p_2}\right) - \frac{\Delta z_{p_1}^{p_s}}{(R/g)\,(T_v)_1}\right\}. \quad \ldots 5$$

The routine HT obtained from the original Madison export package uses an algorithm which can be represented by an equation of the same form:

$$\Delta z_{p_1}^{p_2} = \Delta z_{p_1}^{p_s} + \frac{R}{2g}\left\{(T_v)_1 + (T_v)_2\right\}\left\{\ln\left(\frac{p_1}{p_2}\right) - \frac{\Delta z_{p_1}^{p_s}}{(R/g)(T_{SFC} + \Delta z_{p_1}^{p_s}/400)}\right\}, \quad \ldots 6$$

where T_{SFC} is intended to be the best estimate of the virtual temperature at the surface and $\Delta z_{p_1}^{p_s}/400$ represents the effect of a lapse rate below the surface of 5 K.km . This expression would be reasonably good (and perhaps better than equation 5) if T_{SFC} were reasonable. However T_{SFC} is actually obtained using a dummy routine which sets the surface air temperature to 293 K always! (It was the intention of the software's originators that users should supply their own routine to provide surface data from another source.) By comparing equations 5 and 6 it can be seen that large discrepancies arise when $\Delta z_{p_1}^{p_s}$ becomes large and T_{SFC} is significantly different from $(T_v)_1$. Therefore the worst discrepancies will occur over high ground in winter.

3. CASE STUDY

An experiment has been conducted for an occasion on which the discrepancy described above should be large: over the Scandinavian plateau (mean elevation ~700 m) on 5 December 1981. The 1000-500 mb thicknesses, derived using first the Madison algorithm (equation 6) and then the new algorithm (equation 5) as a basis for the routine HT, have been examined (figures 2 and 3 respectively). It can be seen that the anomalous ridge over Scandinavia has been removed giving better agreement with the conventional data (figure 4). Also 2 rogue points over Italy have been adjusted to give reasonable values. As expected, other small changes have occurred over land but values over sea are unchanged.

This is not an isolated example of the problem encountered with the old algorithm; the anomalous ridge over Scandanavia was a persistent feature in December 1981, and similar effects have been noted elsewhere from time to time.

4. DISCUSSION

In the absence of independent surface data, the new algorithm represented by equation 5 appears to be an improvement both on theoretical grounds and as demonstrated by the experiment. However it is not the only possible way of representing the temperature profile in the lower layers for the purpose of computing the thickness. For example, because a regression-based retrieval is unlikely to yield the type of profile shape shown in figure 1, there are grounds for representing this layer with a modest lapse rate. This would give a slightly different version of equation 5 but it would probably yield comparable results. Either is expected to be superior to equation 6 unless the latter is used with a reasonable value of T_{sfc}.

The arguments presented here should apply quite well in cases of "moderately high ground" (perhaps for mean surface elevations up to 1000 m). Over very high ground the results cannot be expected to be as good, since a larger layer of atmosphere is "missing" and the validity of a regression-based retrieval is then questionable.

Figure 1 Representation of the temperature profile for calculation of thickness over high ground

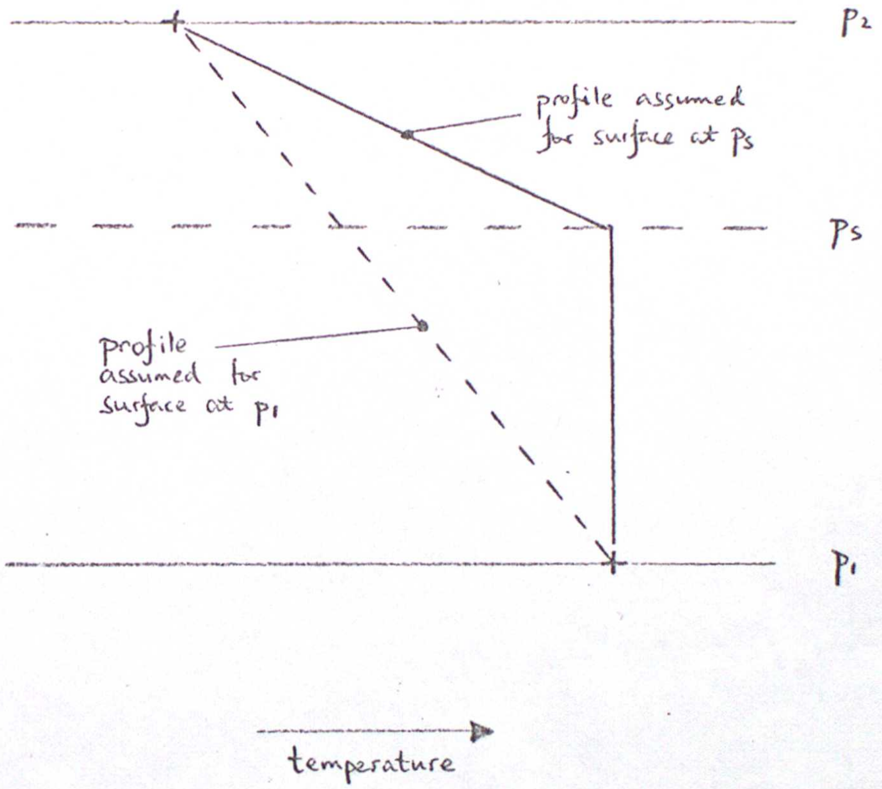

Figure 2 : Retrievals with old algorithm

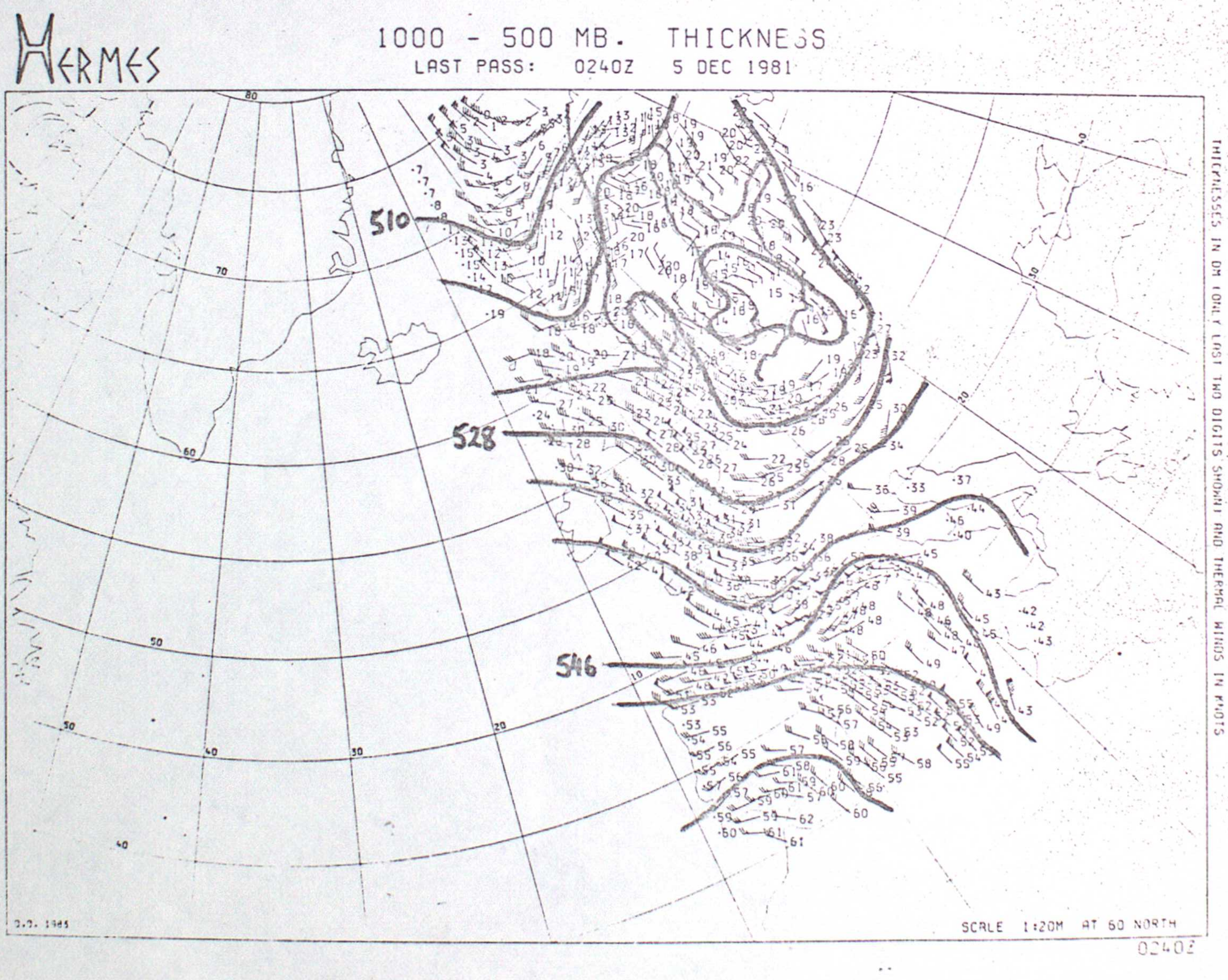

Figure 3 : Retrievals with new algorithm

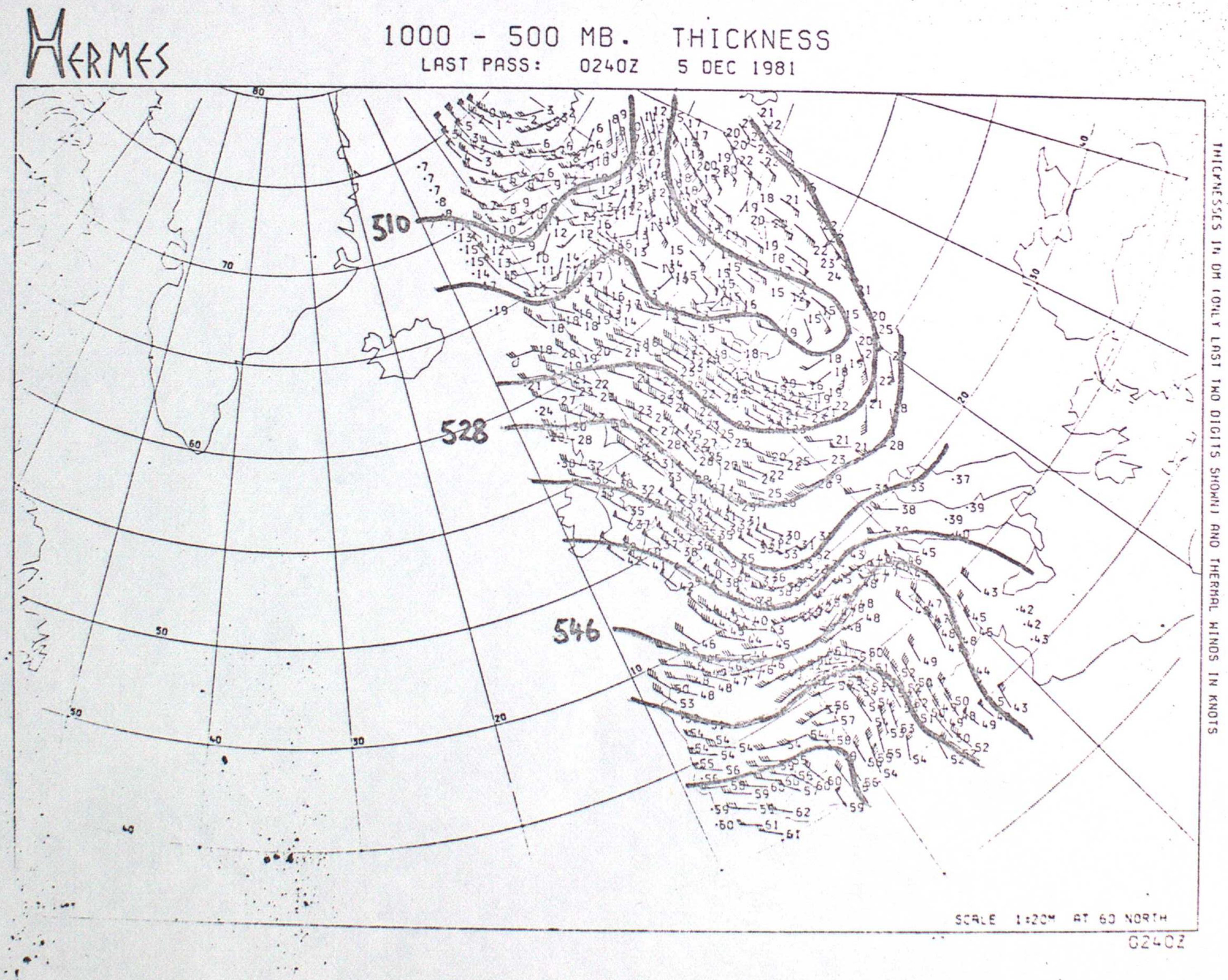

Figure 4 : Conventional data

1000 - 500 MB THICKNESSES AND THERMAL WINDS
00Z 5 DECEMBER 1981 (SATEMS AND R/S)