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OFFICE NOTE 176

Use of Ship Surface Air Temperatures in the Flattery Height/Wind Analysis

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1. Introduction

Close scrutiny of a single analysis by Phillips, et al. (1977) revealed several problems with both the observed data and the Flattery analysis procedure used for NMC operational analyses and in the 6-hour data assimilation cycle. A solution to one of the problems is discussed in this note. The problem is that the Flattery analysis produces incorrect low-level thickness temperatures over oceanic areas. More specifically, the one case study showed the low-level thickness temperatures to be too cold in the northwestern Pacific when compared to observed ship temperatures. A solution to this problem consists of making better use of observed ship surface air temperatures.

2. Procedure for using ship temperatures

Current practice is to withhold observed surface temperatures from the Flattery height/wind analysis. Surface temperatures are used in the Flattery temperature analysis, which gets its first guess from thickness temperatures derived from the height analysis. However, in the 6-hour data assimilation cycle the initialization procedure for the global model does not make use of temperatures from this quasi-independent temperature analysis. Such practice is intentional and has merit; it avoids initializing the model with heights and temperatures which may be hydrostatically inconsistent with one another. Unfortunately, such practice also prevents ship surface air temperatures from contributing to the analysis in areas already poor in high quality data.

A procedure has been devised and tested for including these temperature observations in the height/wind analysis for both operational analyses and the data assimilation cycle. It consists of deriving a height sounding at each surface ship observation location based upon the ship report and upon the first guess field. The sounding is constrained to have low level thicknesses compatible with the reported ship temperature and compatible with the first guess 700-mb temperature. In addition, the heights above 700 mb are required to preserve the thickness structure of the first guess. In other words, if the low-level thicknesses are adjusted to reflect the ship observation, the upper level heights are likewise adjusted to preserve the first guess thickness structure above 700 mb. A 1000-mb height is not included as part of the sounding; instead an observation of zero height is inserted into the analysis at the pressure reported by the ship at sea level. Such a procedure is not new; reported ship sea level pressures have always been inserted into the Flattery analysis in such a manner.

Finally, a two-level temperature sounding is generated at each ship observation location for use in the quasi-independent temperature analysis. The levels included are 1000 mb and 850 mb. These temperatures are obtained by interpolating linearly in $\ell n\ p$ using the reported surface ship temperature and the 700-mb guess temperature, interpolated horizontally to the ship's location. These temperatures are generated for use in the temperature analysis but would not impact the data assimilation cycle in any way.

The detailed procedure for constructing pseudo-soundings from surface ship reports goes as follows (refer to Fig. 1):

1. Interpolate horizontally the 700-mb guess temperature (T_{700}) and the 700-50 mb mandatory level guess heights $(Z_{700}, Z_{500}, \ldots, Z_{50})$ to the ship observation location.

2. Interpolate linearly in ℓn p using T_{700} and the reported ship temperature (T_{SFC}) to get a 1000-mb temperature (T_1), an 850-mb temperature (T_2), a midpoint temperature between the surface and 850 mb (T_{M1}), and a midpoint temperature between 850 and 700 mb (T_{M2}).

3. Using the hydrostatic formula and the two midpoint temperatures from 2., compute a thickness between surface and 850 mb (ΔZ_1) and between 850 and 700 mb (ΔZ_2).

4. Construct 850-50 mb mandatory level heights:

$$Z^o_{850} = \Delta Z_1$$

$$Z^o_{700} = \Delta Z_1 + \Delta Z_2$$

$$Z^o_{500} = Z_{500} + \left(Z^o_{700} - Z_{700}\right)$$

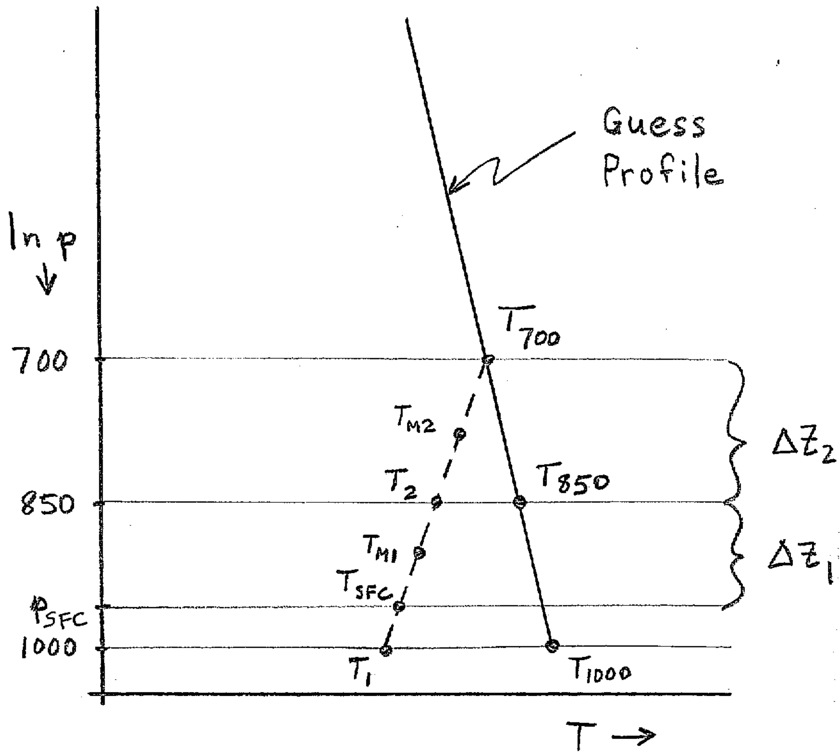
$$Z^o_{400} \quad Z_{400} + \left(Z^o_{700} - Z_{700}\right)$$

$$\vdots$$

$$Z^o_{50} = Z_{50} + \left(Z^o_{700} - Z_{700}\right)$$

The pseudo-sounding then consists of temperatures at 1000 and 850 mb (T_1 and T_2) and heights at all standard levels up to 50 mb except for 1000 mb $(Z^o_{850}, \ldots, Z^o_{50})$. In addition, the reported sea level pressure is used in the height/wind analysis (zero height inserted at the reported sea level pressure).

The pseudo-soundings are then used in the height/wind analysis just like any other soundings with one exception. Heights above 700 mb are inserted only on the first six scans through the data. (Nine scans are performed in all.) In the absence of other data types, the influence of the pseudo-soundings will be well established after six scans. If other data types are present, removal of the ship-generated soundings above 700 mb for the last three scans allows these other data to be analyzed for in preference to the pseudo-soundings. Ship-generated pseudo-soundings receive the same relative weight in the analysis scheme as remote sounding data.



Guess
Profile
ln p
700
850
p_{SFC}
1000
T_{700}
T_{M2}
T_2
T_{850}
T_{M1}
T_{SFC}
T_1
T_{1000}
ΔZ_2
ΔZ_1
T →

Figure 1.

3. Testing the use of ship temperatures

The effectiveness of using reported surface ship air temperatures to improve the low level thickness analysis was tested by cycling for 24 hours both with and without ship-generated soundings, employing a 6-hour update interval. The time period was 0000 GMT 2 February to 0000 GMT 3 February 1976. Codes for the Flattery analysis and 9-layer prediction model were the same as those used for the winter data systems test (DST-6). Both the experiment with ship temperatures (referred to as SHPBOG) and the one without (referred to as CONTROL) began from the same global first guess valid at 0000 GMT 2 February 1976. Thereafter the two experiments cycled independently of one another. Both experiments included all observational data from the operational data base except that remote sounding data were excluded from the Northern Hemisphere. None of the DST-6 experimental data types were used in this test except for a few special aircraft reports from wide-bodied aircraft and constant pressure level balloon observations in the Southern Hemisphere.

The evaluation of this experiment will focus on the analyses produced at the end of the 24-hour assimilation period (0000 GMT 3 February). Portions of the resultant surface temperature analyses are depicted in Figs. 2 and 3. These temperature fields were derived solely from the height analyses using a routine operational procedure. The procedure consists of applying a three-point difference formula to standard layer thicknesses to obtain standard level temperatures and then extrapolating or interpolating in the vertical to the surface. Fig. 2 depicts an area between 25° and 55°N which extends from 160°E to the west coast of North America. Fig. 3 shows the same latitudinal strip for the Atlantic ocean region. Both SHPBOG and CONTROL analyses are shown. Superimposed on the SHPBOG analysis for both the Pacific and the Atlantic regions is a plot of the observed surface ship air temperatures which were used to generate pseudo-ship observations.

It is clear that the SHPBOG surface temperature analysis fits the ship surface temperature data more closely than does the CONTROL analysis. The same conclusion can be drawn from the statistical verification of each analysis against reported ship temperatures. Such verifications are tabulated in Table 1 for the same areas and for the same ship reports shown in Figs. 2 and 3. It is also evident from the statistics that the SHPBOG analysis has a substantially smaller cold bias than does the CONTROL experiment.

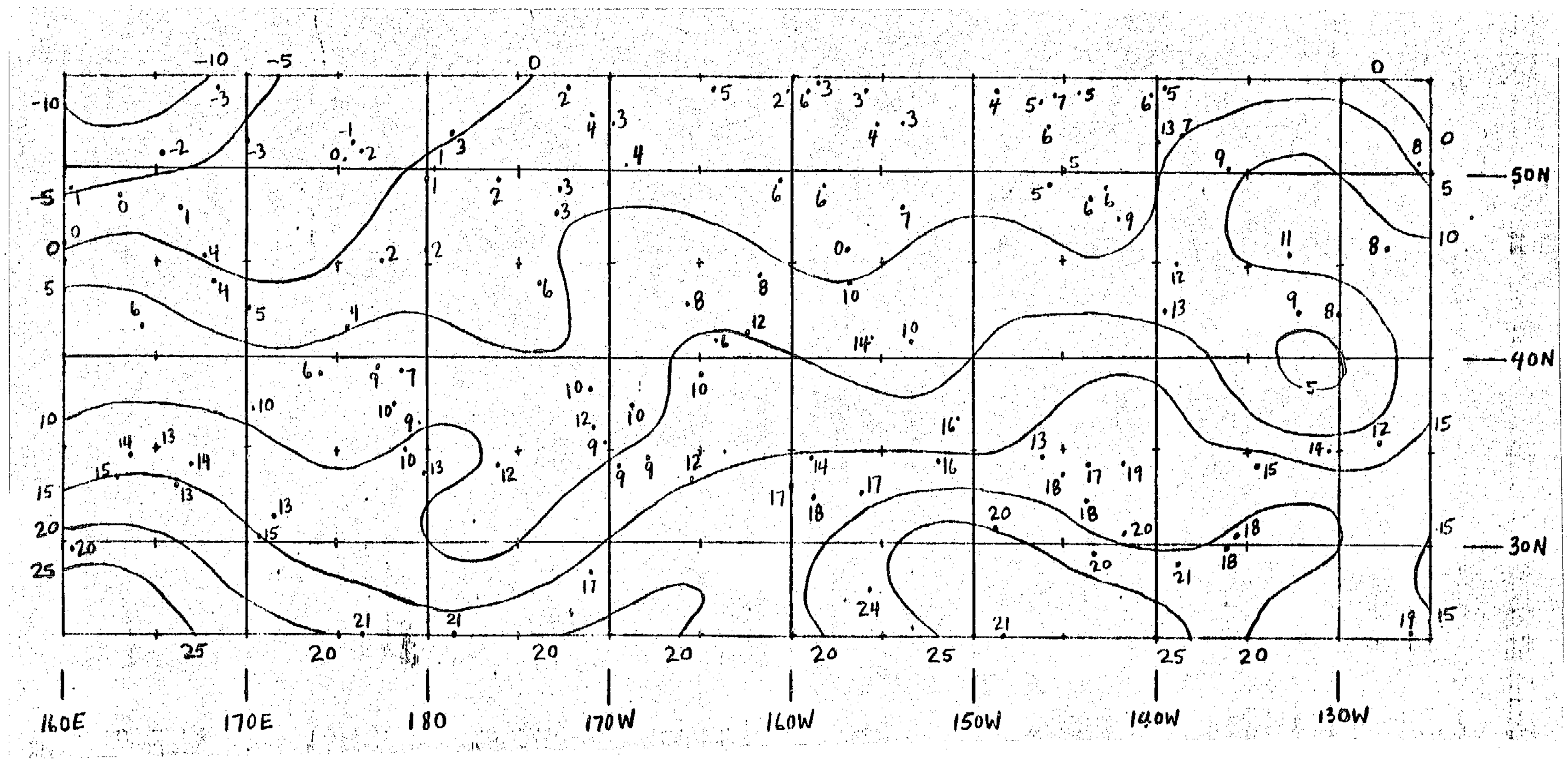


Fig. 2a. SHPBOG surface temperature analysis. 0000 GMT February 3, 1976.

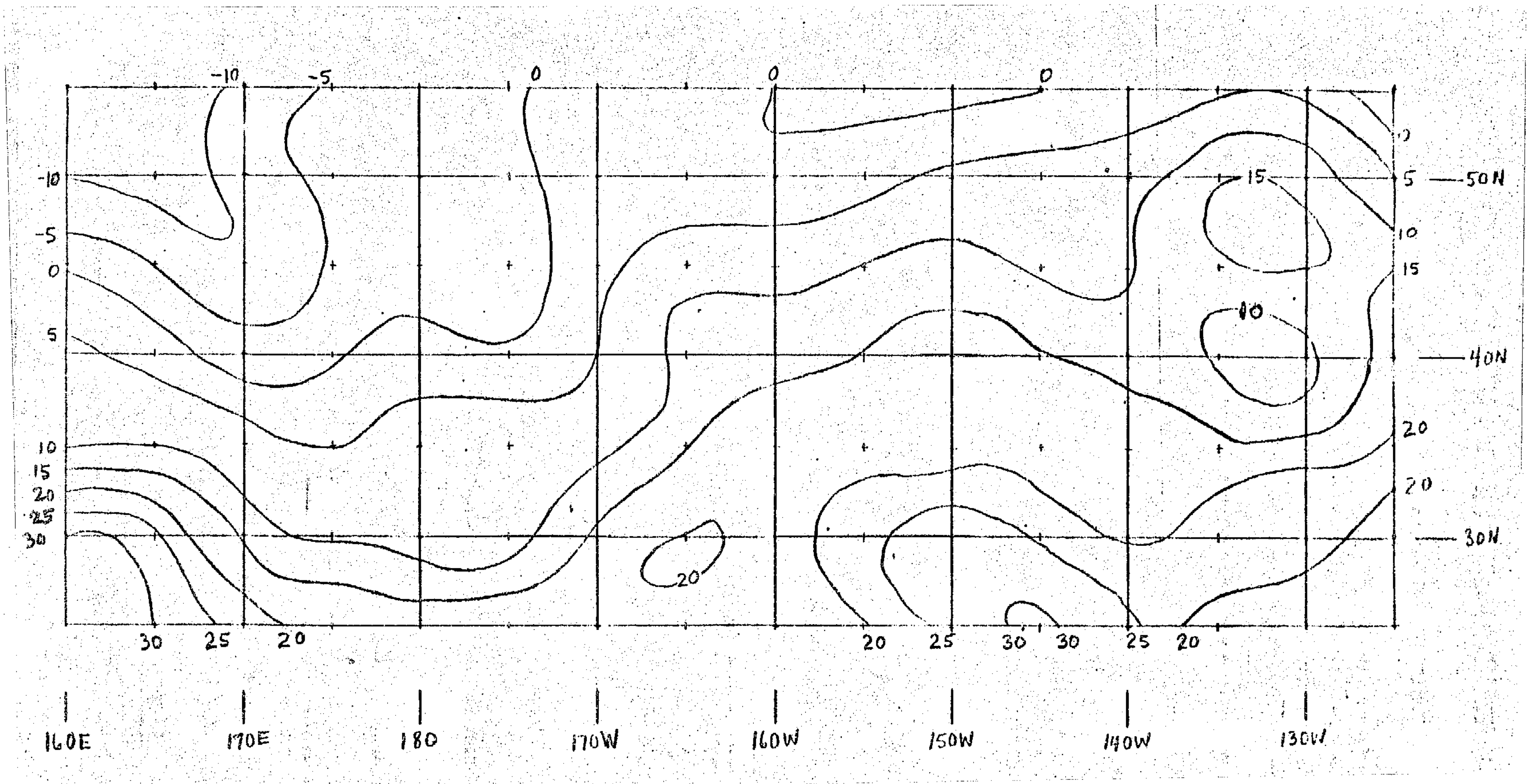


Fig. 2b. CONTROL surface temperature analysis. 0000 GMT February 3, 1976.

Table 1. Surface temperature analysis errors verified against reported surface ship temperatures. 0000 GMT 3 February 1976.

Experiment	Area	Error (^{o}C) Average	RMS	Standard Deviation	Number of Reports
SHPBOG	Atlantic	-1.0	2.7	2.5	70
CONTROL	Atlantic	-2.1	4.5	4.0	70
SHPBOG	Pacific	-1.1	2.7	2.5	119
CONTROL	Pacific	-1.5	4.5	4.2	119

Nevertheless, the SHPBOG surface temperature analysis does have a cold bias in both the Pacific and Atlantic. It appears that two small areas in the Pacific and two small areas in the Atlantic are largely responsible for this bias.

Consider the Pacific region first (Fig. 2a). The extreme northwest corner of the grid has a cold bias which is caused by the influence of a very cold air mass over Kamchatka. The east coast of Kamchatka is located near the northwest corner of the Pacific grid (160E, 55N). Land surface temperatures are not used in the analysis of heights, but cold thicknesses from radiosonde height reports do impact the height analysis.

The second area of cold bias is 140-160W between 40 and 50N. Part of the bias may have been caused in this area by what looks like an erroneous 0^{o}C report at about 46N, 157W. At present surface temperature observations are subjected to a rather loose gross check. Any report outside the -10^{o}C to +30^{o}C range is considered erroneous and excluded from the analysis. A future modification will compare each report to the sea surface climatological temperature at the observation location. Reports deviating from climatology by more than a pre-specified amount will be excluded. Such a scheme probably would have removed the 0^{o}C report mentioned above.

In the Atlantic (Fig. 3a) the surface temperature analysis has a cold bias in the northwest corner of the grid. Again, as in the Pacific, the bias is related to something that is occurring over land. At analysis time, a deep (952 mb) surface low was centered at about 53N, 67W. This storm had deepened rapidly as it moved northward along the east coast of North America during the previous 24 hours. The forecast model did not predict this rapid deepening. As a result, most of the land surface reports in the vicinity of the storm center were rejected as being too far from the first guess at 0000 GMT 3 February. Consequently, the 1000-mb heights were too high (see Fig. 4), and the low level thicknesses too shallow, causing an erroneously cold surface temperature analysis. The CONTROL analysis had a similar problem, although not quite so severe (compare Figs. 3a and 3b); a few land surface

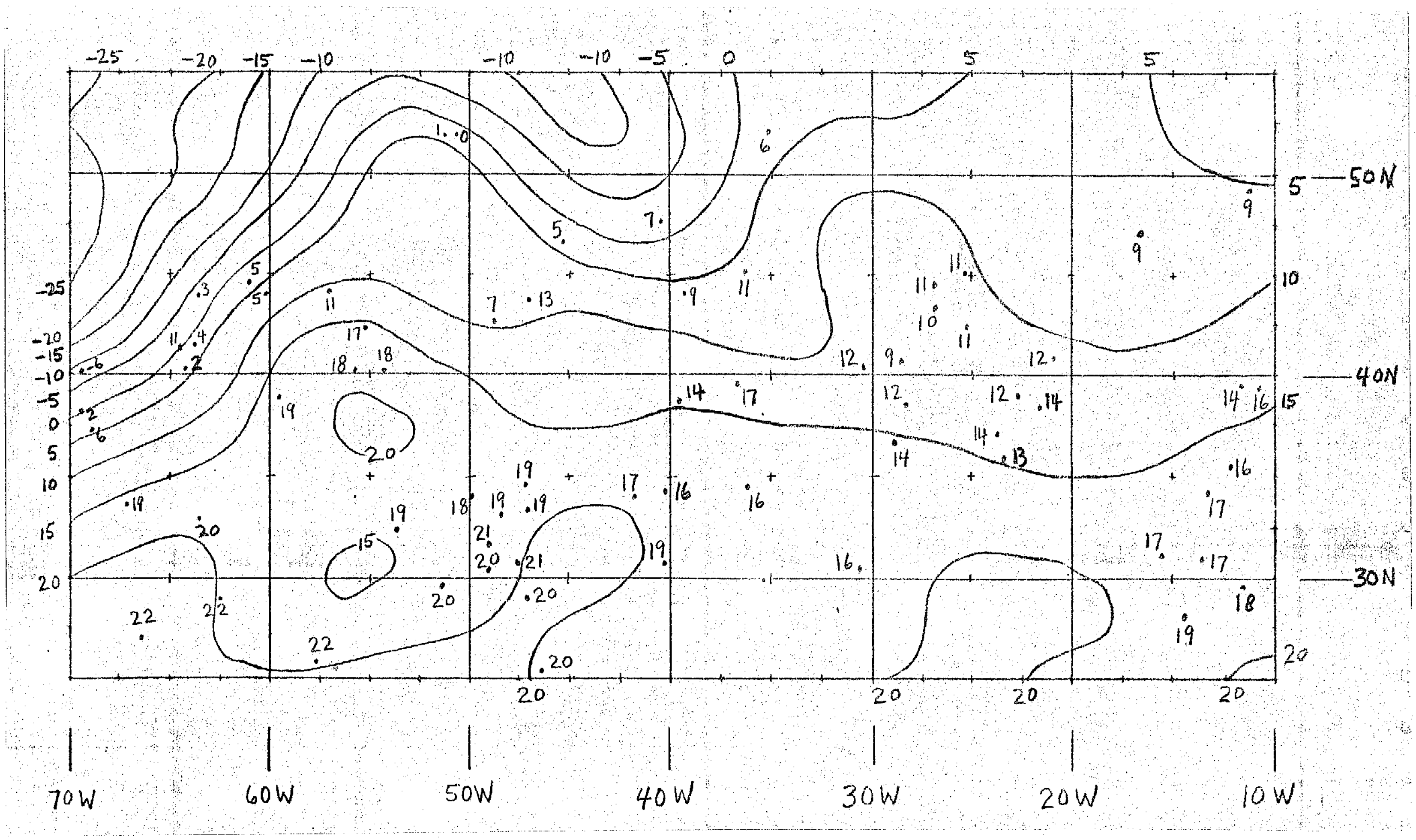


Fig. 3a. SHPBOG surface temperature analysis. 0000 GMT February 3, 1976.

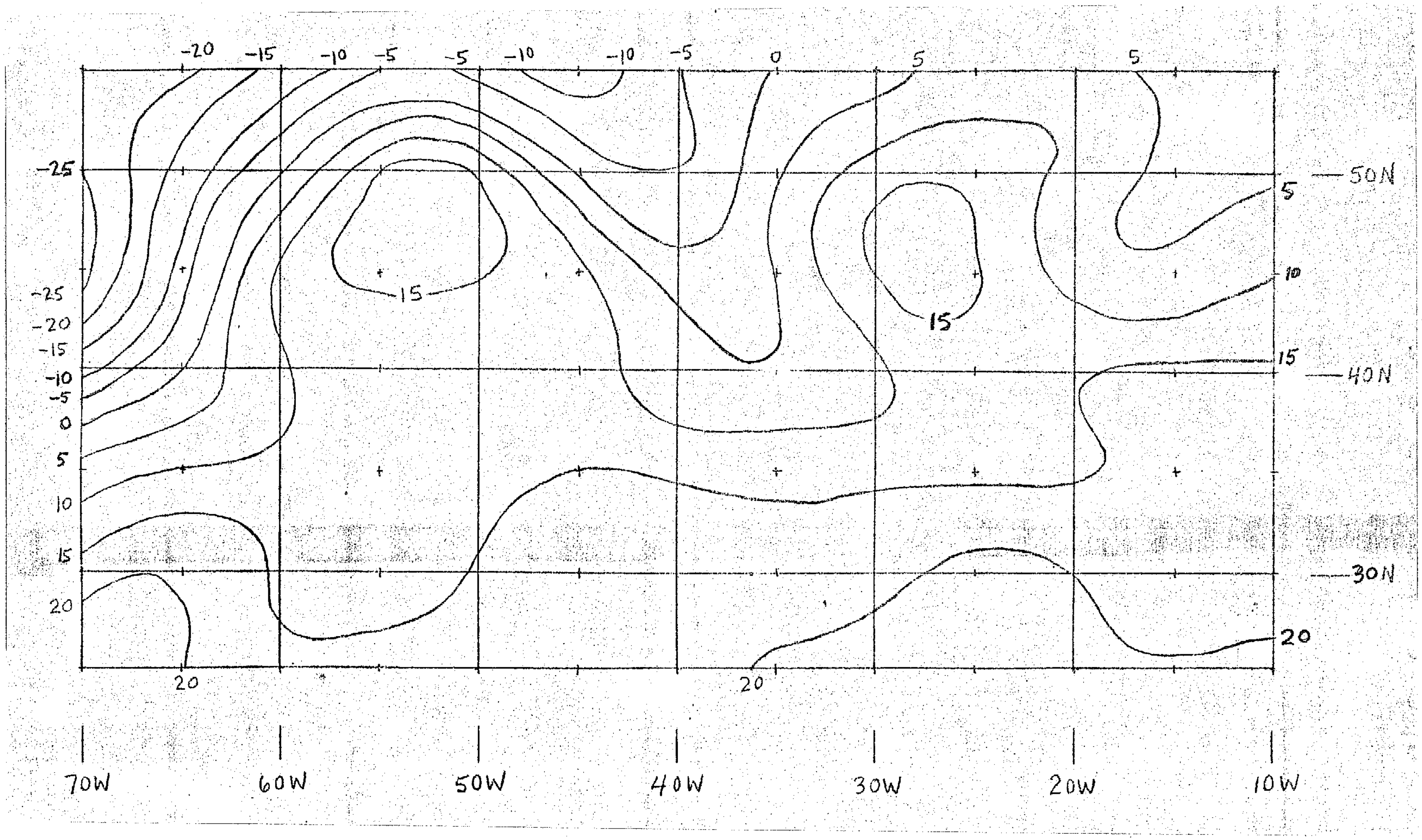
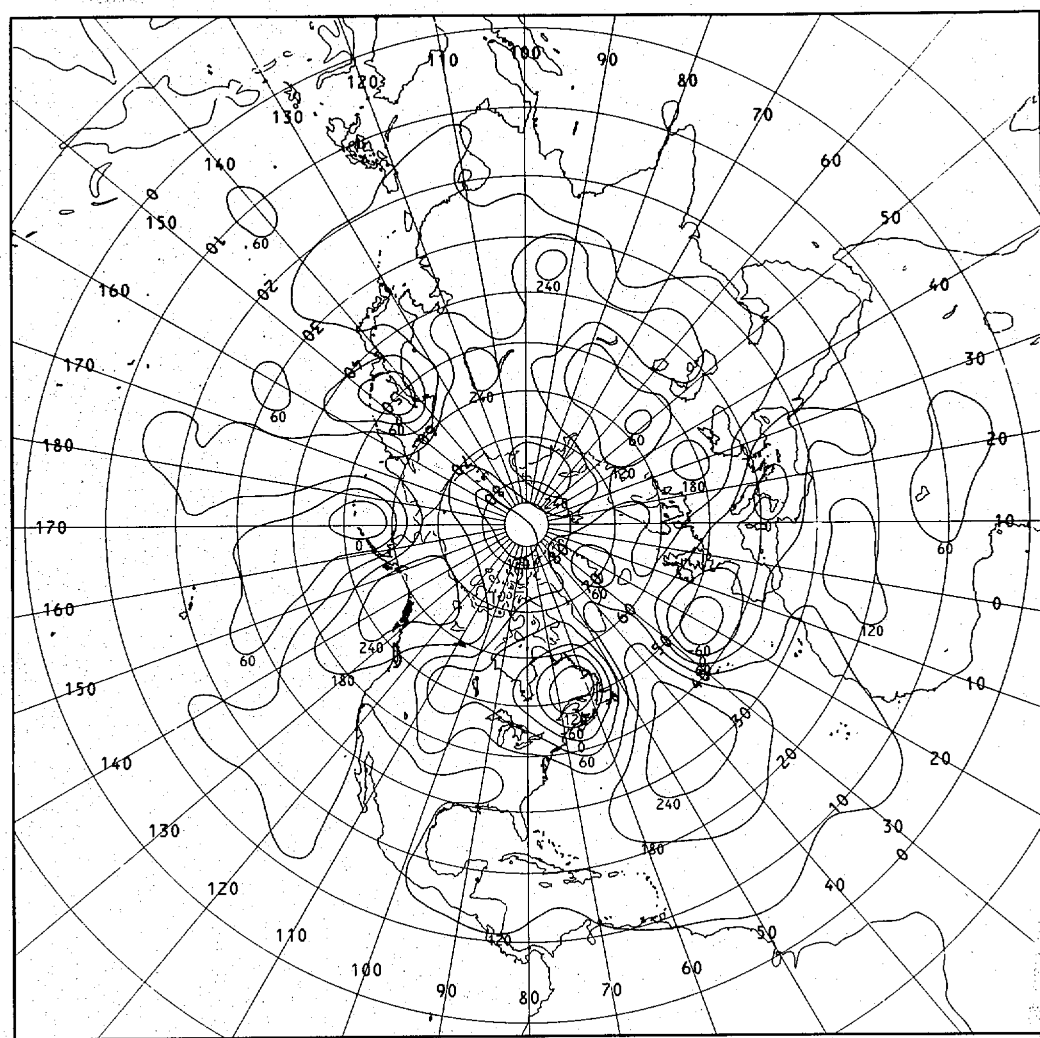


Fig. 3b. CONTROL surface temperature analysis. 0000 GMT February 3, 1976.



1000.0 MB HGT FOR 000 HRS AFTER 00Z 3 FEB 76 SHPBOG NO SAT

Figure 4.

observations managed to get into the CONTROL analysis. It is not clear why the SHPBOG analysis should be poorer in the low levels than the CONTROL analysis in an area where no ships are reporting. However, it was possible to improve this part of the analysis by rerunning it with a slightly looser tossout limit. The rerun had a low level vortex which was still too shallow but nevertheless closer to reality than either the original SHPBOG or CONTROL analysis.

A second area where the Atlantic SHPBOG surface analysis has a cold bias is in the area around 50N,40W. However, in this area there are not many reports, and only one report (7°C reported at 48N,41W) has a large error (about 8°C). The CONTROL analysis has a bias of about the same magnitude in this region.

The difference between SHPBOG and CONTROL analyzed surface temperature fields is shown in Fig. 5. Differences are contoured using a 2°C contour interval. Negative values indicate lower temperatures in the SHPBOG analysis. The largest difference is associated with the very deep east coast storm discussed above. This difference, as mentioned earlier, is a result of tossing good surface reports. The -6°C difference at 40N between 150 and 155W is a result of the SHPBOG analysis being too cold (perhaps partly due to an erroneous report as mentioned above) and the CONTROL analysis being too warm. Other large differences which fall in the areas shown in Figs. 2 and 3 are clearly more accurately depicted in the SHPBOG analysis.

The SHPBOG surface pressure pattern was virtually identical to that of the CONTROL analysis (not shown). Such a result was expected since both analyses used the same surface pressure observations.

At 500 mb the largest temperature differences were only slightly larger than 2°C. Two such areas occurred (Fig. 6): one in the eastern Pacific and one in the western Atlantic. The largest difference in the two height fields at 500 mb was slightly larger than 60m and occurred in the Pacific (see Fig. 7). Because of the lack of data, it would be difficult to say which analysis is more correct at 500 mb. The SHPBOG 500-mb height analysis is shown in Fig. 8.

The procedure for using ship temperatures was tested on a second case. The second case began from 0000 GMT 22 February. Data were assimilated for 24 hours both with and without ship temperatures as was done for the first case. The second case will not be discussed in detail. The verification of each surface temperature analysis against reported ship temperatures is presented in Table 2. The verification areas are the same as in Table 1.

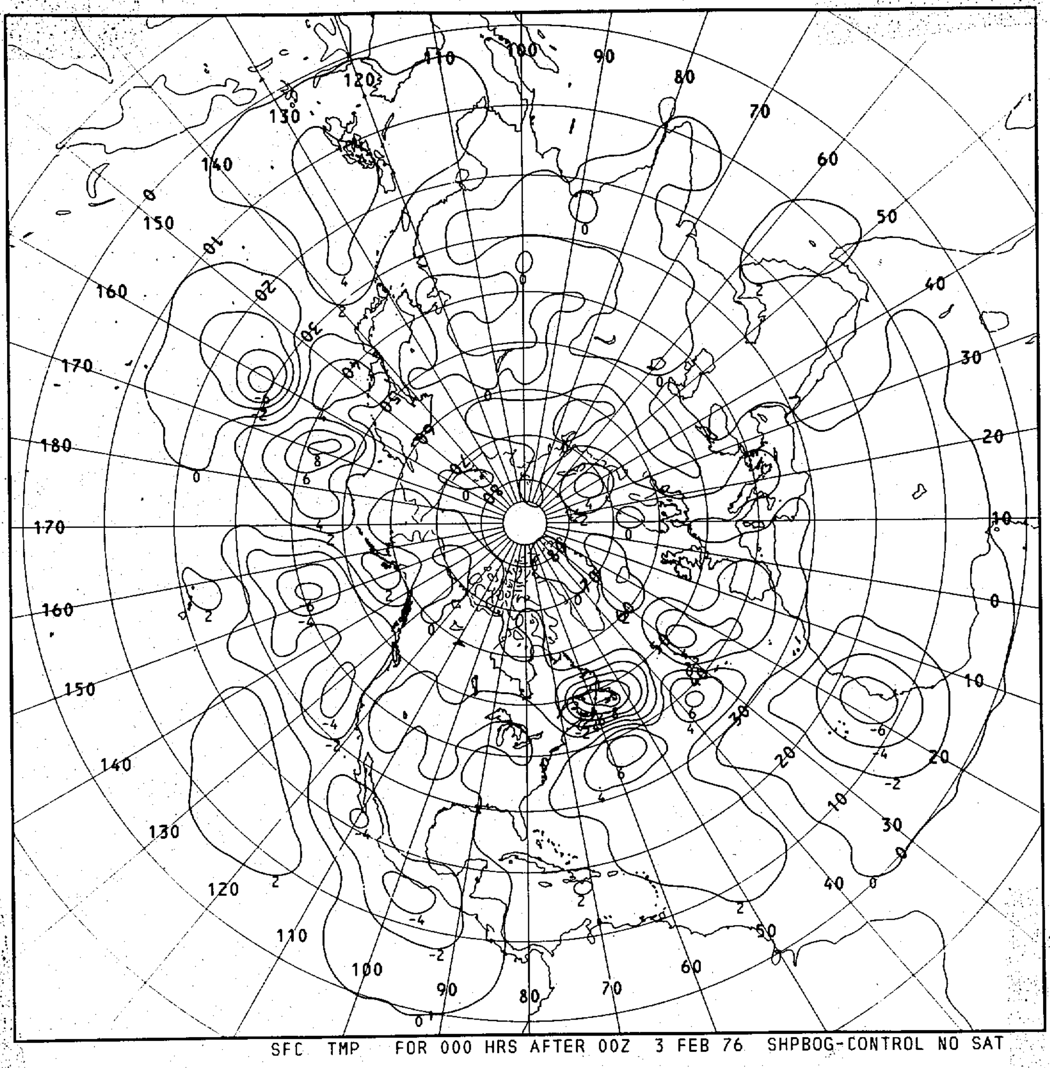


Figure 5.

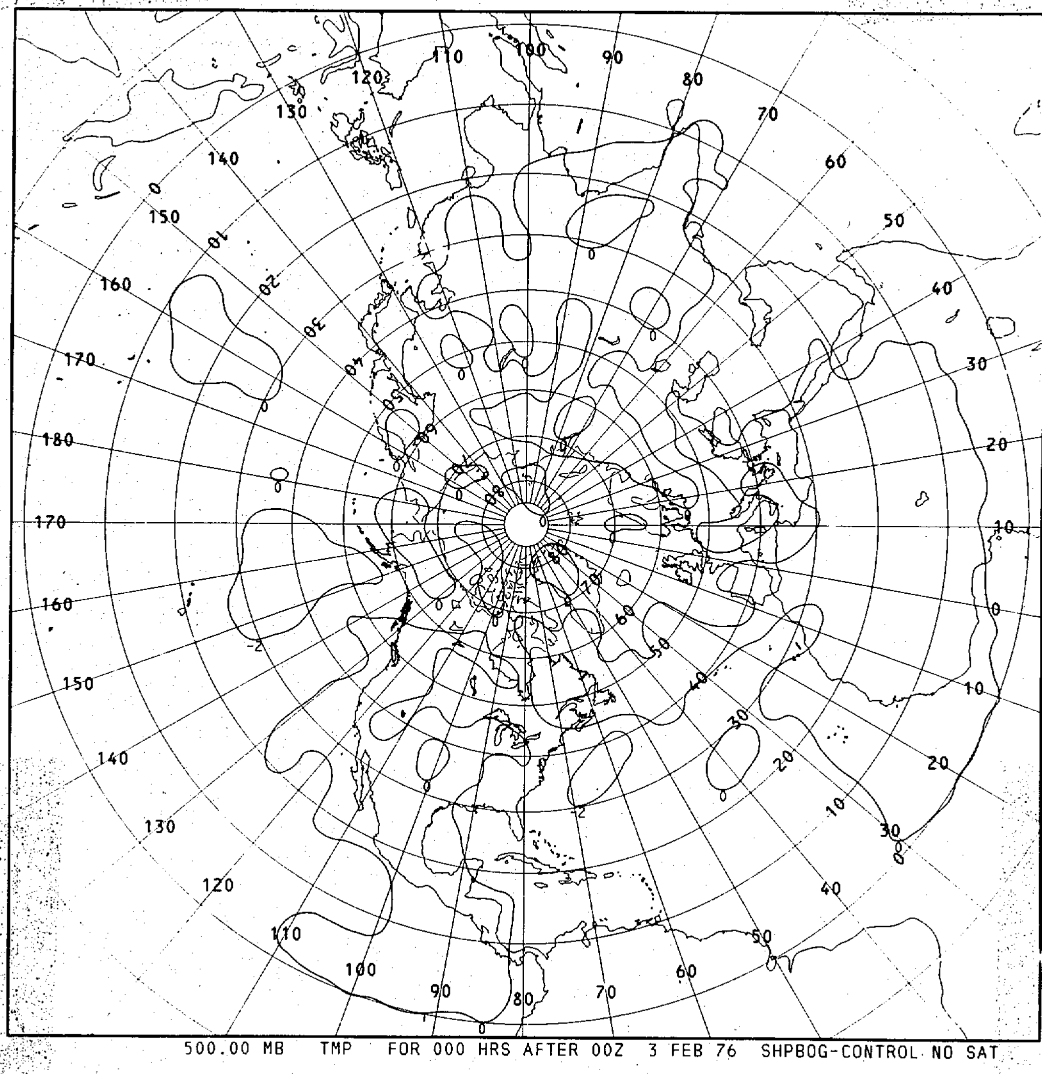

500.00 MB TMP FOR 000 HRS AFTER 00Z 3 FEB 76 SHPBOG-CONTROL NO SAT

Figure 6.

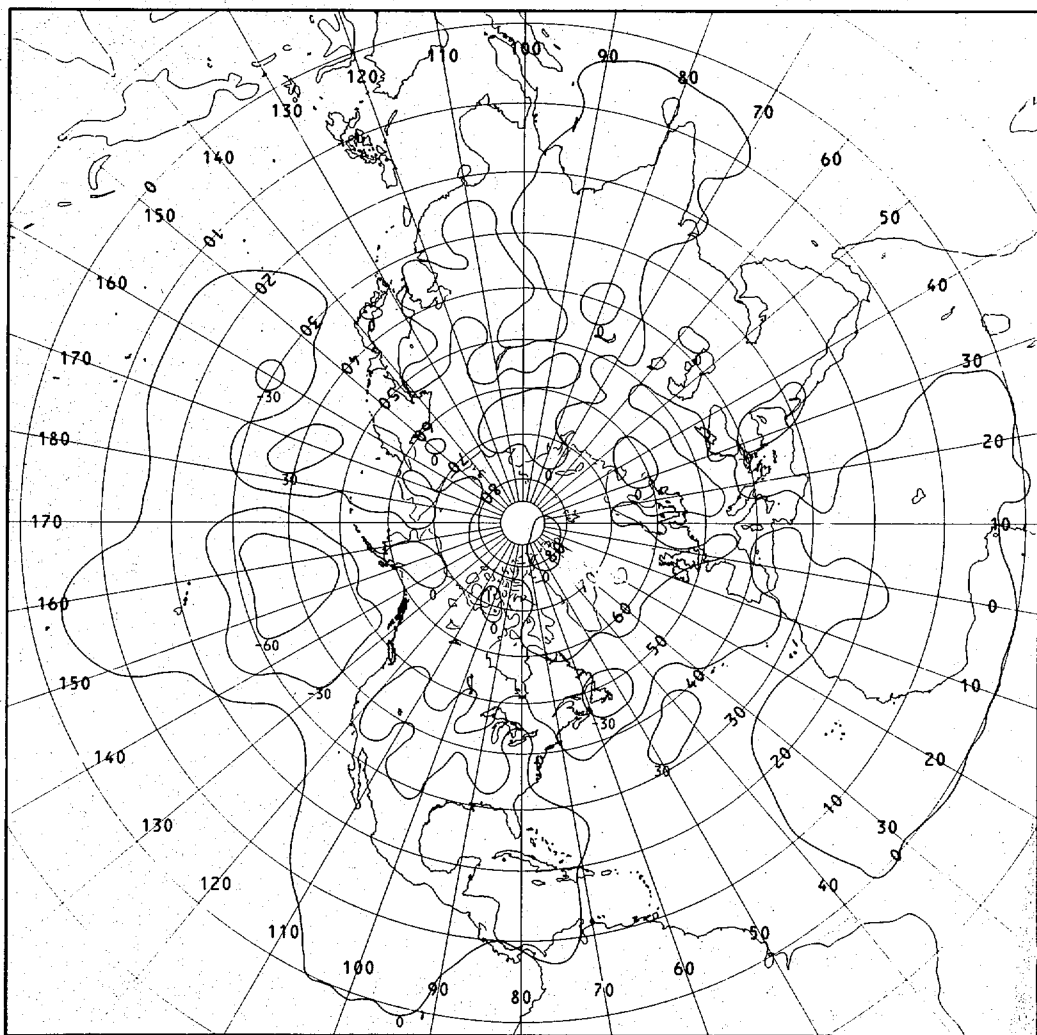

500.00 MB HGT FOR 000 HRS AFTER 00Z 3 FEB 76 SHPBOG-CONTROL NO SAT

Figure 7.

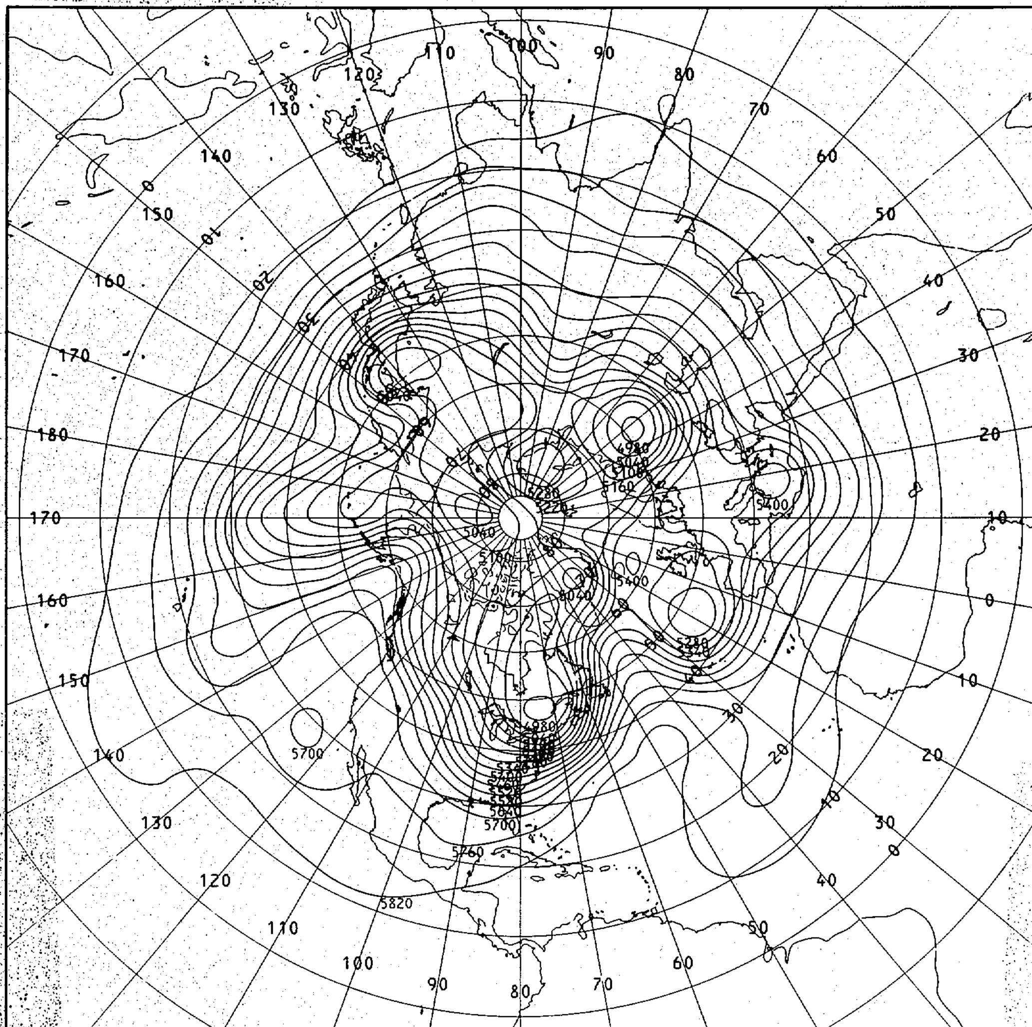


Figure 8.

Table 2. Surface temperature analysis errors verified against reported surface ship temperatures. 0000 GMT 23 February 1976.

Experiment	Area	Error (°C)			
		Average	RMS	Standard Deviation	Number of Reports
SHPBOG	Atlantic	-0.8	3.2	3.1	52
CONTROL	Atlantic	2.8	6.0	5.3	52
SHPBOG	Pacific	-0.7	2.8	2.7	86
CONTROL	Pacific	1.8	9.4	9.2	86

Unlike the first case, the February 23 surface temperature analysis exhibits a positive bias (too warm) when ship temperatures are not used in the analysis. A large reduction in both bias and root-mean-square error results when ship temperatures are used in the height analysis.

4. Summary and Conclusions

A procedure for incorporating ship surface air temperature observations into the Flattery height/wind analysis has been devised. The scheme was tested by cycling for 24 hours for two different test cases. The 9-layer prediction model was updated every 6 hours during each 24-hour period, using the Flattery analysis method. The two cases were run with and without ship temperature data. In both cases, inclusion of surface ship temperatures was found to significantly improve the surface temperature analysis over oceanic regions. Only very slight changes in the temperature analysis occurred above 700 mb when ship temperatures were added to the height/wind analysis. Adding this procedure to the operational Flattery analysis should result in significantly improved low level temperature analyses over oceanic regions.

References

Phillips, N., K. Campana, and M. Mathur, 1977: Data and Analysis Errors on 9 January 1977. NMC Office Note 160.