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STRATOSPHERIC TEMPERATURES DURING AASE: RESULTS FROM STRATAN

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Abstract. Comparisons of temperatures from the research analysis system STRATAN to radiosonde data, Meteorological Measurement System (MMS) data, and the National Meteorological Center (NMC) analyses are presented for the Airborne Arctic Stratospheric Expedition (AASE). The STRATAN analyses show consistent quality throughout AASE. The comparisons to MMS show that STRATAN more accurately represented low temperatures than NMC. This, coupled with forecast quality, show that STRATAN temperature fields are a valuable tool for diagnosing and forecasting polar stratospheric clouds.

Introduction

STRATAN is a research analysis system under development at NASA Goddard. It uses forecast/assimilation techniques to produce global analyses of temperature, geopotential height, and winds on a 4° × 5° grid on standard pressure levels (1000 to 0.4 hPa) at 6 hour intervals. The analysis is a three-dimensional optimal interpolation at and below 50 hPa, two-dimensional above. The analysis technique is described in Baker et al. [1987] and Takano et al. [1987]. Applications to stratospheric transport are described in Rood et al. [1989] and Kaye et al. [1989, 1990]. Documents detailing wind analyses produced by STRATAN are in preparation.

This paper presents temperature analyses between 150 and 30 hPa over an area roughly defined by Norway, Greenland, and Iceland. Comparison to radiosondes are presented for all the days from 1 January 1989 until 15 February 1989. Comparisons of temperatures from STRATAN to the Meteorological Measurement System (MMS) aboard the ER-2 are presented for all flight days except 30 January. Similar comparisons to the MMS are given for the National Meteorological Center (NMC) operational data set. These comparisons cover the entire period of the Airborne Arctic Stratospheric Expedition (AASE). Comparisons to Antarctic data have not been performed. Since Arctic and Antarctic winter stratospheric conditions are substantially different, the following results should not be generalized to the Southern Hemisphere.

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Data Source and Treatment

The basic data set used in the STRATAN analyses for AASE are obtained from NMC via electronic link. STRATAN analyzes geopotential height and wind observations in a multivariate fashion. The observation set includes surface land and ship observations, rawinsondes, aircraft observations, and cloud track winds. Satellite temperature profiles derived by NESDIS (National Environmental Satellite Data and Information Service) from the Tiros Operational Vertical Sounder (TOVS) are also used. This is the same base data set used in the NMC analysis.

Data are prioritized with respect to their error characteristics. In the optimal interpolation analysis, observational and representation errors are assigned to each observation type. These errors define a priority system (i.e. data with lower errors will more strongly influence the analysis than data with larger errors). Since radiosonde data is considered a more accurate routine measurement of atmospheric temperatures, it is given smaller observational errors than satellite data.

Both radiosonde and satellite data are subjected to quality control procedures before being assimilated. Radiosonde heights and temperatures are compared for hydrostatic consistency. Satellite layer mean temperatures are converted hydrostatically into layer thicknesses. The height of the reference pressure level for the satellite sounding (usually 1000 or 850 hPa) is taken from the model 6 hour forecast. Thicknesses are then integrated above the reference level to produce heights at standard levels.

A proximity elimination is performed on all data available for an analysis. Data that are geographically within 0.5 degree of each other are subject to elimination based on the predetermined accuracy hierarchy. Radiosonde data are always kept over other data types; other data are kept or deleted according to their relative ranking among the nearby data.

Data are then compared to the first guess (the forecast) interpolated to the observation location. This is the gross check. Data that are different from the first guess by more than a specified amount are flagged as 'suspicious.' For geopotential heights, this cutoff value increases with altitude, decreases in the tropics, and is independent of data type. Data may also be flagged as suspicious by the data producer. These data are treated the same as data flagged by the analysis quality control procedure. No attempt is made to use data flagged as 'bad' by the producer.

Suspicious data are compared to nearby good data values via a proximity check. If the difference between a suspicious observation and the first guess is within the gross check cutoff value of the average difference between the neighboring good data and the first guess, then the suspicious data is re-accepted into the analysis. If suspicious data fails a proximity check or if there are fewer than three nearby good observations, then the suspicious observation is rejected.

The number of radiosonde observations decreases rapidly with height, and the stratospheric sonde data is sparse. This is especially true in winter at polar latitudes because the balloons burst in the cold temperatures. Furthermore, the accuracy and precision of the sondes decreases with altitude [Nash and Schmidlin, 1987]. Therefore, the satellite data assume a dominant role in the middle to upper stratosphere. By 10 hPa essentially all of the data going into the analysis is satellite data. The satellite data also plays a dominant role in radiosonde sparse lower stratospheric regions (e.g. over oceans and much of the southern hemisphere). No satellite data are used below 100 hPa over land because they adversely affect the radiosonde data.

Since geopotential heights and winds are analyzed, temperatures are hydrostatically derived from heights and interpolated to standard pressure levels. Therefore, temperatures should be considered as a diagnostic field of the analysis. STRATAN temperatures will be compared to the actual observed radiosonde temperatures. Comparisons of STRATAN layer mean temperatures (derived directly from the analyzed heights) to other layer mean measurements are better, since interpolation effects are removed.

Results

Radiosonde stations used in this study are listed in Table 1. Figure 1a shows temperature and layer mean temperature from Barentsburg on Spitzbergen Island on 25 January 1989 at 12 GMT. Also shown are the same quantities from the closest STRATAN grid point. This figure characterizes STRATAN's performance. Largest errors are near the tropopause (250-300 hPa) where STRATAN cannot resolve the sharp lapse rate change. In general, STRATAN faithfully represents the sonde data with the largest differences correlated with abrupt changes in lapse rates. These abrupt changes occur at the tropopause, but may also result from gravity waves and measurement errors.

Table 1. Radiosonde - STRATAN differences (K), RMS difference in brackets.

Norway	150 hPa	50 hPa
Sola (59°N, 6°E)	−0.09(2.27)	+0.33(2.10)
Orland III (64°N, 10°E)	−0.29(1.37)	−0.01(1.78)
Bodo VI (67°N, 14°E)	+0.21(1.48)	+0.56(1.89)
Bjornoya (75°N, 19°E)	−0.12(1.04)	−0.63(1.34)
Barentsburg (78°N, 14°E)	+0.39(1.61)	−0.37(1.79)
Total Observations	+0.01(1.61)	+0.02(1.83)
Greenland/Iceland	**150 hPa**	**50 hPa**
Narssarssuaq (61°N, 45°W)	+0.09(1.10)	+0.28(2.23)
Keflavik (64°N, 23°W)	+0.09(1.21)	−0.04(1.88)
Angmagssalik (66°N, 38°W)	+0.00(1.29)	−0.94(2.13)
Egedesminde (69°N, 53°W)	+0.14(0.88)	−1.41(2.13)
Scoresbysund (70°N, 22°W)	+0.04(0.99)	−0.48(1.66)
Jan Mayen (71°N, 9°W)	+0.20(1.12)	+0.02(1.83)
Danmarkshavn (77°N, 19°W)	+0.11(0.99)	−0.57(0.71)
Total Observations	+0.09(1.09)	−0.33(2.00)

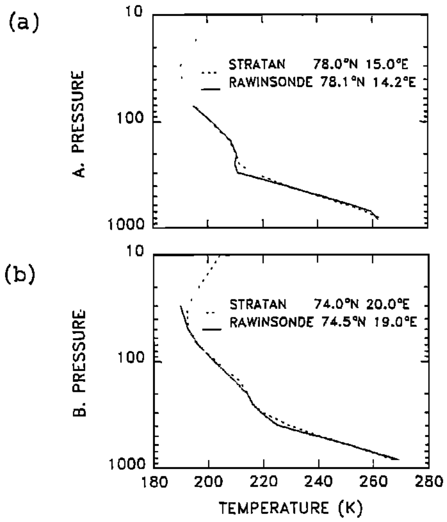

Fig. 1 Radiosonde profiles (solid lines) from Barentsburg on Spitzbergen Island for 25 January 1989 (A, top), and Bjornoya for 28 January 1989 (B, bottom). The nearby STRATAN profiles are also shown (dashed lines).

Figure 2 presents time series of differences between sonde temperatures and STRATAN temperatures interpolated to station sites. The sonde data contains all available data, including which have been rejected in the quality control algorithm (see previous Section). The figure is partitioned into Norwegian and Greenland/Iceland (G/I) stations (see Table 1) at both 150 hPa and 50 hPa.

The time series at 150 hPa for both G/I and Norway show temperature differences uniformly distributed around 0.0 with biases less than 0.1 K (biases and RMS deviations for each station are listed in Table 1). The G/I stations show less scatter than the Norwegian stations with root mean square (RMS) differences of 1.09 K as compared to 1.61 K. Comparisons between sondes and STRATAN are similar at 200 and 100 hPa.

Between 400 and 200 hPa STRATAN is warm biased by about 1.5 K. Referring to Figure 1a, it is seen that this bias is due to poor resolution of the tropopause. The largest errors at the tropopause are on the order of 5 K, with Figure 1a as an extreme example.

At altitudes higher than 100 hPa, the scatter is larger (Figures 2c and 2d, and Table 1). The bias with respect to the Norwegian stations remains less than 0.1 K, but the G/I stations show a cold bias of 0.3 K. At the end of the mission (days 40-45) the differences between STRATAN and the G/I stations show a period of large cold biases followed by a period of large warm biases. The cause is unknown, but could be related to the wave 2 warming. As the wave 2 develops, there is a dramatic decrease of stratospheric sonde data over eastern Canada, and the effects of this data void would generally propagate towards G/I.

The extreme differences of 5-6 K at 50 hPa are small in number, and can be characterized by two different situations. In the first, the sonde profile shows a jagged struc-

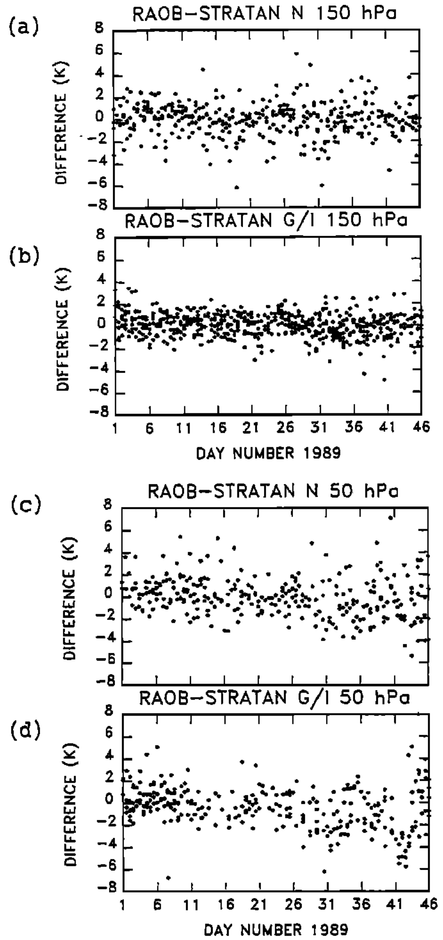

Fig. 2 Time series of STRATAN and radiosonde differences at 150 hPa and 50 hPa in the Norwegian (N) and Greenland/Iceland (GI) regions (see Table 1 for station locations and difference statistics). STRATAN profiles have been interpolated to the station site. a) N 150 hPa. b) GI 150 hPa. c) N 50 hPa. d) GI 50 hPa.

ture with height indicative of either a gravity wave or a low quality measurement. In the second, the sonde profile is either monotonically increasing or decreasing (the usual case, Figure 1b). STRATAN does not show this monotonic behavior, and the STRATAN profile is turning to meet the higher level temperature profile that is defined by the satellite data. A consistent STRATAN characteristic is its inability to represent a temperature minimum at the uppermost altitude of a stratospheric sonde profile. This partially results from the analysis of geopotential thicknesses instead of temperatures.

In general the Figure 2 time series do not show episodes of particularly low quality analyses. There is some indication of drift in STRATAN. The drift occurs in conjunction with a slackening of the number of radiosondes over a region in the stratosphere. This may be due either to model drift or to the analysis drawing closer to the satellite profiles. The drift is currently being investigated. These results suggest that forecast quality is consistent throughout the time period, and show that the analysis is stable and well behaved.

Figure 3 shows a comparison of STRATAN to ER-2 MMS temperatures and NMC to MMS temperatures during AASE. For both STRATAN and the NMC data, ER-2 flight paths were drawn through the analysis grid and temperatures were interpolated to the flight path. Both analyses are independent of MMS and have much coarser spatial resolution. The MMS data are very accurate and comprise the most stringent test of the analyses.

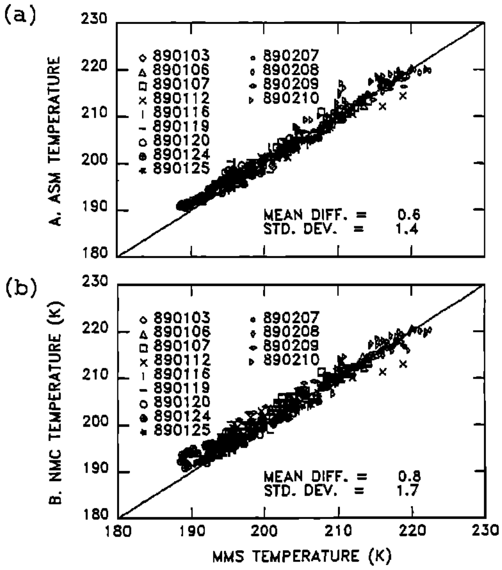

Fig. 3 Comparison of temperatures from the Meteorological Measurement System (x-axis) to a) STRATAN (top) and b) NMC (bottom). Symbols represent flight days given in legend.

Analyses for 30 January were eliminated because of data problems. A transmission failure in the electronic link caused most of the observations for 29 January to be lost without possible recovery. Because of the lack of data the assimilation system experiences a startup period. Hence, the analyses for 30 January were poor and were not used in this investigation.

Both analyses do a credible job representing the MMS measurements, but are slightly biased relative to MMS (see Figure 3). The bias and the standard deviation of STRATAN are smaller than in the NMC data. The reduced spread in STRATAN is particularly evident at low temperatures. The stratospheric NMC data (above the 70 hPa level) are currently model independent [Newman et al., 1989]. Future NMC plans to extend their global data assimilation to 10 hPa should bring STRATAN and NMC into better agreement.

A result of potential importance is the performance of STRATAN at low temperatures. Accurate forecasts and measurements of temperature are necessary to locate areas where polar stratospheric clouds (PSCs) are expected. In figure 3, STRATAN is colder than NMC at low temperatures, and STRATAN is closer to MMS. In order to further investigate the capability of the STRATAN system to impact PSC determination, forecast experiments were run for 9 January.

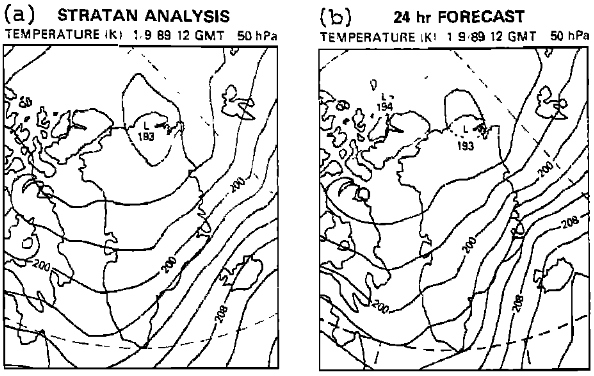

Fig. 4 STRATAN analysis (a) and 24 hour forecast (b) in the AASE operations sector at 50 hPa on 9 January 1989.

The United Kingdom Meteorology Office (UKMO) analysis in the AASE archive data set shows cold temperatures (< 195 K) over much of Greenland at 12 GMT on 9 January. PSC's were expected in this region, but DC-8 measurements found no clouds [McCormick et al., 1990]. Figure 4 shows the 24 hour STRATAN forecast and analysis. Both the forecast and analysis show only a small region north of Greenland where PSC's might be expected (T < 195 K is shaded, predicted minimum is 193.4 K). STRATAN is 5 K warmer on the 50 hPa surface than the UKMO analysis on this day. At 30 hPa the differences are larger with the UKMO analysis showing a closed 190 contour and STRATAN showing no temperatures below 192. The 48 hour STRATAN forecast shows only a slight degradation of the prediction of temperature minima.

Summary and Conclusions

STRATAN temperature analyses investigated during AASE show good agreement with radiosonde and MMS data. There are no periods where STRATAN abruptly fails, though notable problems on 30 January follow the 29 January data void. This suggests that the forecast quality is consistent throughout the mission.

Differences between STRATAN and NMC temperatures are small, with some indication that STRATAN analyses are improved. Warm biases are found between STRATAN and NMC at the tropopause and above 50 hPa where sonde temperatures monotonically decrease. Stratospheric biases are due to assimilation of layer mean temperatures and the influence of satellite profiles in data sparse areas. Techniques used in the NMC analysis assure good agreement with the sonde temperature data at all altitudes.

These comparisons suggest that STRATAN currently produces Northern Hemisphere stratospheric temperature analyses comparable in quality to any available. The wind analyses through the entire depth of the stratosphere are unique to the system, and generate high quality transport calculations. Future improvements in the treatment of the upper boundary, analysis procedure, data checking, and forecast initialization should assure a measurable increase in analysis quality.

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