HADLEY CENTRE
FOR CLIMATE PREDICTION AND RESEARCH

Development of a Stratosphere-Troposphere Data Assimilation System

by

R. Swinbank

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CLIMATE RESEARCH TECHNICAL NOTE

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INTRODUCTION

In order to study the dynamical coupling between the stratosphere and troposphere, one needs to develop a system to analyse the mix of observations available in the middle and lower atmosphere. A data assimilation scheme with this capability is currently being developed at the UK Met Office; it will be used to analyse observations from the Upper Atmosphere Research Satellite (UARS), which is to be launched this September.

THE ASSIMILATION SYSTEM

The stratosphere-troposphere assimilation system has been developed from the new Met Office data assimilation scheme for operational weather forecasting (Lorenc et al, 1991). The numerical model used in the assimilation system is a global primitive equation model, with a split-explicit time integration scheme. It incorporates a comprehensive range of physical parametrization schemes. It uses a hybrid vertical coordinate system, with terrain-following model levels at low levels, gradually changing to pressure levels in the stratosphere.

For these experiments, the model's vertical coverage extends from the earth's surface to above the stratopause; this configuration of the model is illustrated in Figure 1. By including the troposphere as well as the stratosphere, the model avoids any problems resulting from artificial lower boundary conditions. The use of a numerical model as an integral part of the assimilation system also provides the constraint that the analysed dynamical fields are in realistic balance with one another.

Observations are assimilated into a numerical forecast model to produce global analyses. The observations used as input to the assimilation are essentially the same as those used for operational weather forecasting i.e. the World Weather Watch network of surface and upper air observations and satellite data. Once the Upper Atmosphere Research Satellite is launched, data from that satellite will also be assimilated (initially temperature and wind observations will be analysed, and, in the longer term, chemical data will be assimilated too).

Figure 2 illustrates the flow of data through the assimilation system. Observations are acquired from the Met Office Synoptic Data Bank (or from the UARS Central Data Handling Facility), and reformatted for processing on the Cray Y-MP. The observations are quality-controlled by comparing them with model 'first-guess' fields from a previous forecast, and with neighbouring data. The observations are then assimilated using the Met Office "analysis correction" scheme. Analysed fields from the model can then be used as the basis for further scientific study. An "observation processing dataset" (OPD) is also compiled; this permits a statistical evaluation of the assimilated fields.

STRATOSPHERIC WARMING CASE STUDY

As part of the initial tests of the stratosphere-troposphere model and the assimilation system, several experiments have been run for a period in mid-February 1989 when a sudden stratospheric warming occurred. The initial data for these experiments were derived from a blend of the Met Office operational analysis and the Met Office SSU analysis, both for 12 GMT on 15th February; the resulting interpolated analysis (at 10 mb) is shown in Fig 3a.

Temperatures and winds at 10 mb from a five-day forecast from this data are shown in Fig 3b with the verifying SSU analysis in Fig 3c. During the forecast period, the polar vortex has split in two and marked warming has occurred over the Greenland region. The model has given a good forecast of the vortex-splitting, although there are some significant differences in the temperature field. The temperature in the SSU analysis is derived from the geopotential thickness between pairs of pressure levels, (eg. 20 mb and 5 mb), so it will only show up deep features. It is quite possible that the forecast has generated some shallow features in the temperature fields that are more realistic than the SSU analysis.

Starting from the same initial data, observations have been assimilated for a period of 24 hours, giving the analysis shown in Fig 3d. Although the polar vortex (indicated by the wind fields) has not changed much, the temperature field clearly shows the beginnings of the warming. A four-day forecast was then run from this analysis; the results shown in Fig 3e can be compared with Figs 3b and c. The forecast results are in fact very similar to Fig 3b, but there is some improvement in the flow at high latitudes. Both forecasts were also run on for another five days, after which time they had both developed significant evolution errors. To conclude, there was only a slight improvement from running from the assimilated data.

ASSIMILATIONS FOR JANUARY 1991

As a "dry run" for the UARS data assimilation, we are currently assimilating observations from January 1991 on a routine basis. Figures 4a, c and e show analyses of geopotential height and wind at 100 mb, 10 mb and 1 mb for 4th January produced by this assimilation run. The equivalent SSU analysis fields are given in Figs 4b, d and f. Note that the 100 mb SSU height field is interpolated from the operational analysis, and fields at other levels are derived by adding on thicknesses derived from the SSU retrievals; the winds are geostrophic.

The two sets of analyses are very similar. The SSU height fields tend to be rather smoother, and there are some minor differences in the maxima and minima. The winds fields appear more realistic in the assimilated data than in the SSU analyses; they are largely generated by the model, rather than constrained to be geostrophic. It should also be borne in mind that the SSU analysis is based solely on data from the NOAA polar orbiters (above 100 mb), whereas the assimilation can take into account a multitude of different observation types.

The fit of the assimilated temperature fields to temperature observations is shown in Fig 5. The root mean square difference between the analysed and observed values is around 1K, slightly more at high levels, near the surface and around the tropopause.

CONCLUSIONS

This paper gives some initial results from the stratosphere-troposphere data assimilation system. It has been shown that the numerical model is capable of forecasting sudden stratospheric warmings, illustrating the dynamical coupling between the model troposphere and stratosphere. It has also been demonstrated that the system can sucessfully assimilate the observations currently available, indicating its ability to analyse data from UARS when they becomes available.

REFERENCES

A.C. Lorenc, R. S. Bell and B. Macpherson (1991) - The Meteorological Office analysis correction data assimilation scheme. Q. J. R. Meteorol. Soc. 117, 59-89.

FIG 1

UNIFIED MODEL

New model for both forecasting and climate research.

Developed from current models.

Hybrid vertical coordinate;
pressure at model level k is:
$p_k = A_k p_0 + B_k p_s$

Version for stratospheric assimilations with enhanced vertical resolution

horizontal grid: 2.5° latitude
by 3.75° longitude (global)
42 levels up to 0.25 mb (58 km)

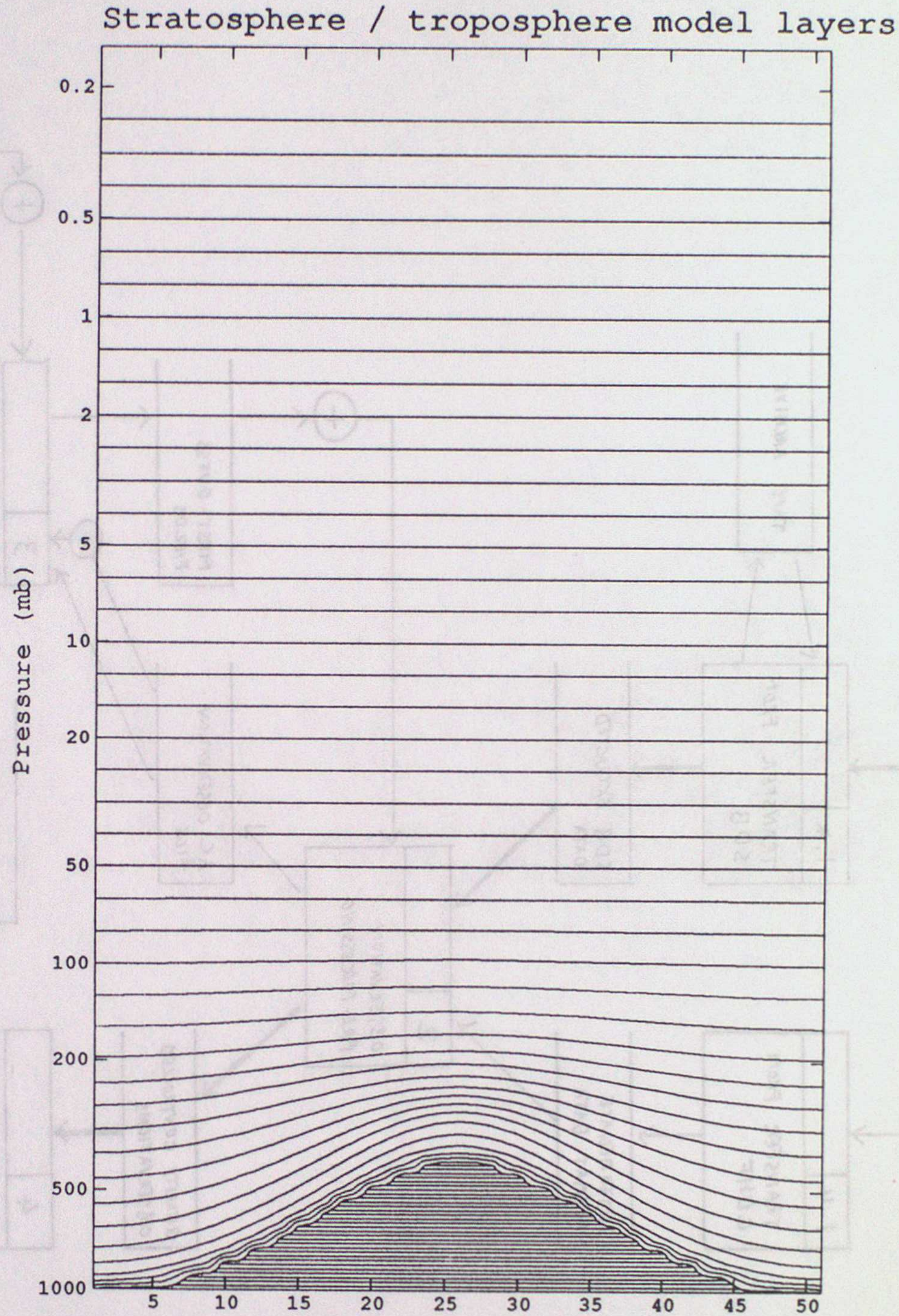
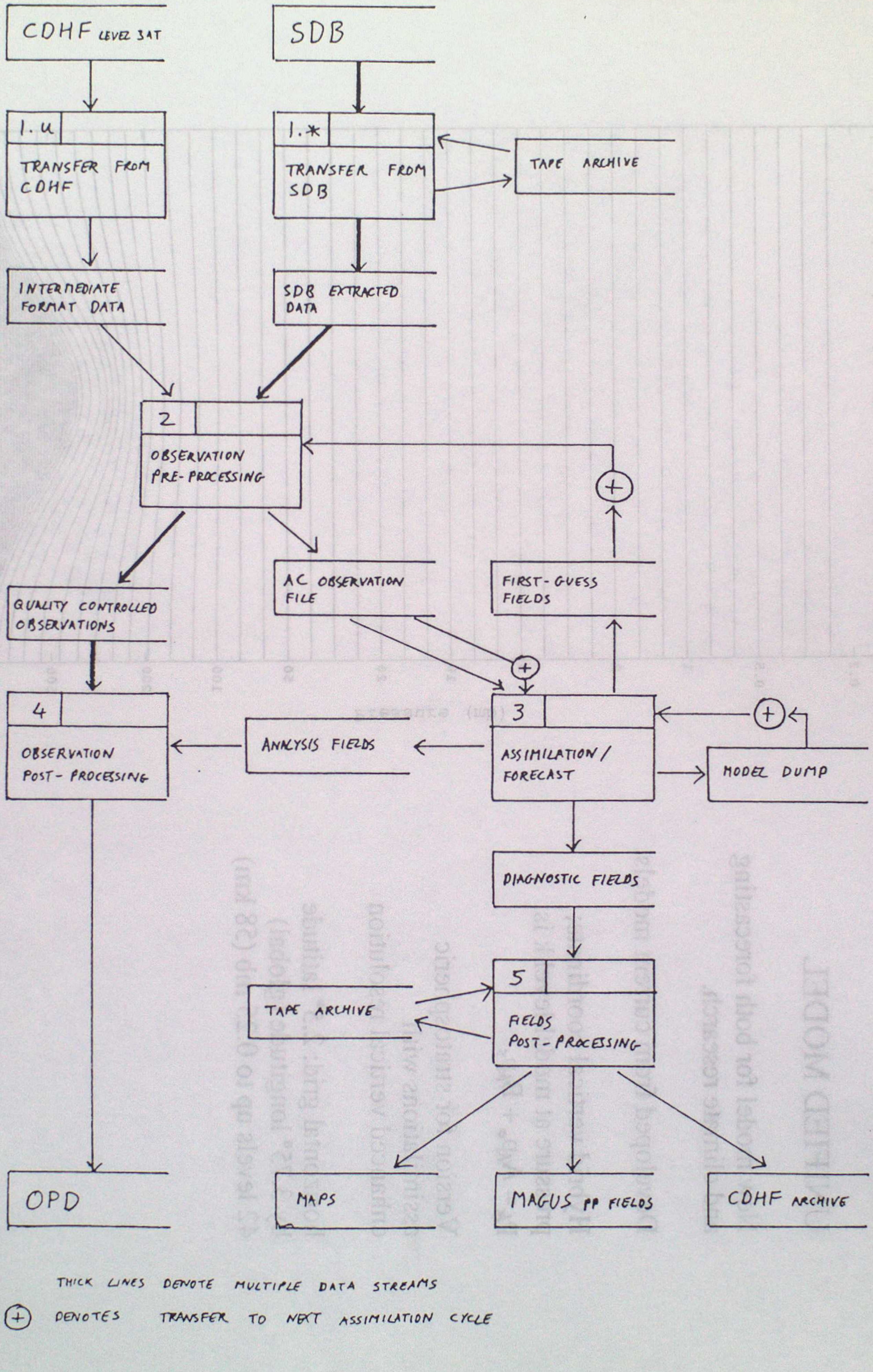


FIG. 2

STRATOSPHERIC DATA ASSIMILATION SYSTEM

TOP LEVEL DATA FLOW DIAGRAM



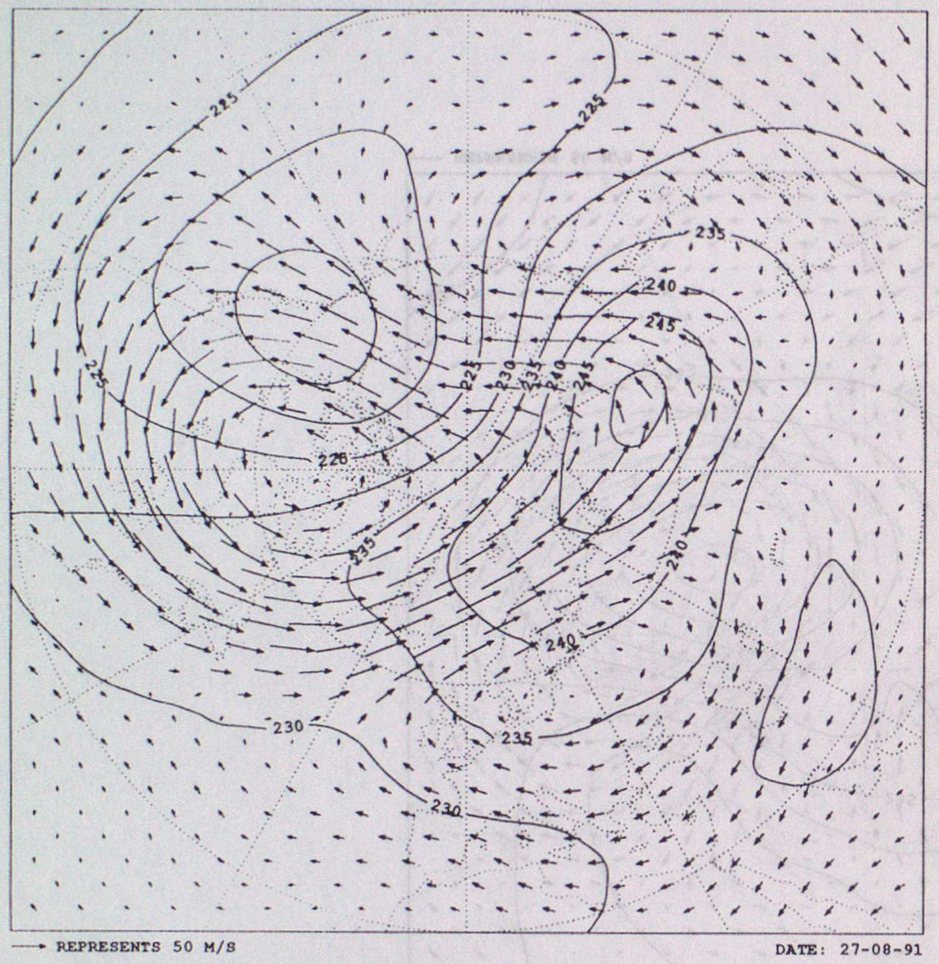
THICK LINES DENOTE MULTIPLE DATA STREAMS

(+) DENOTES TRANSFER TO NEXT ASSIMILATION CYCLE

FIG. 3

Initial data for experiment
Temperature and wind vectors
VALID AT 12Z ON 15/2/1989   DATA TIME 12Z ON 15/2/1989
LEVEL: 10 MB

a



Forecast from interpolated data
Temperature and wind vectors
VALID AT 12Z ON 20/2/1989   DATA TIME 12Z ON 15/2/1989
LEVEL: 10 MB   T+120

b

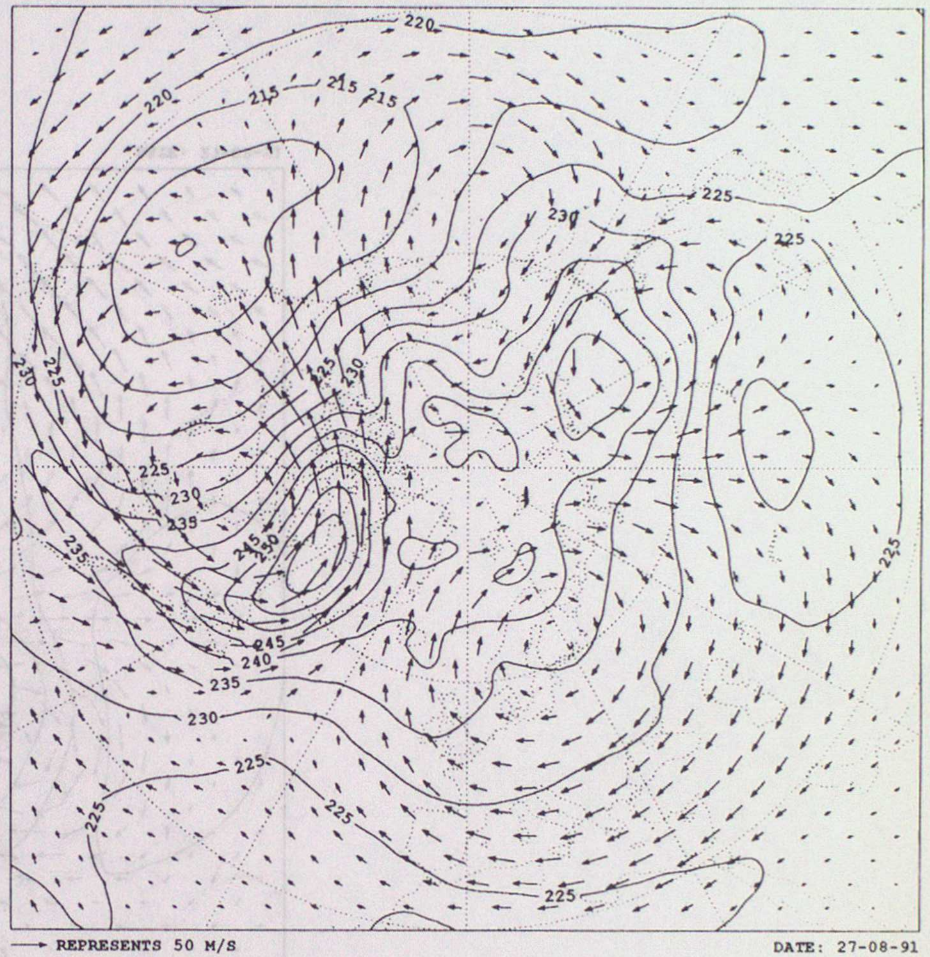


FIG 3

Verifying SSU analysis
Temperature and wind vectors
VALID AT 12Z ON 20/2/1989
LEVEL: 10 MB

C

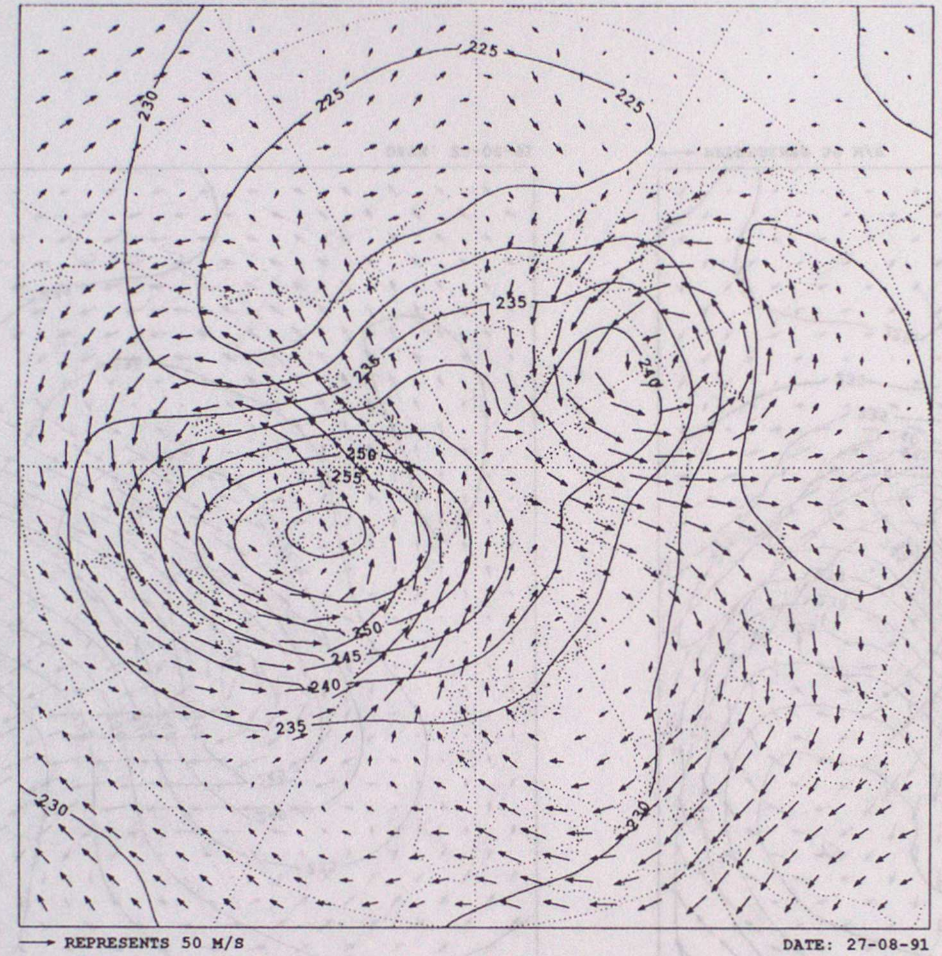
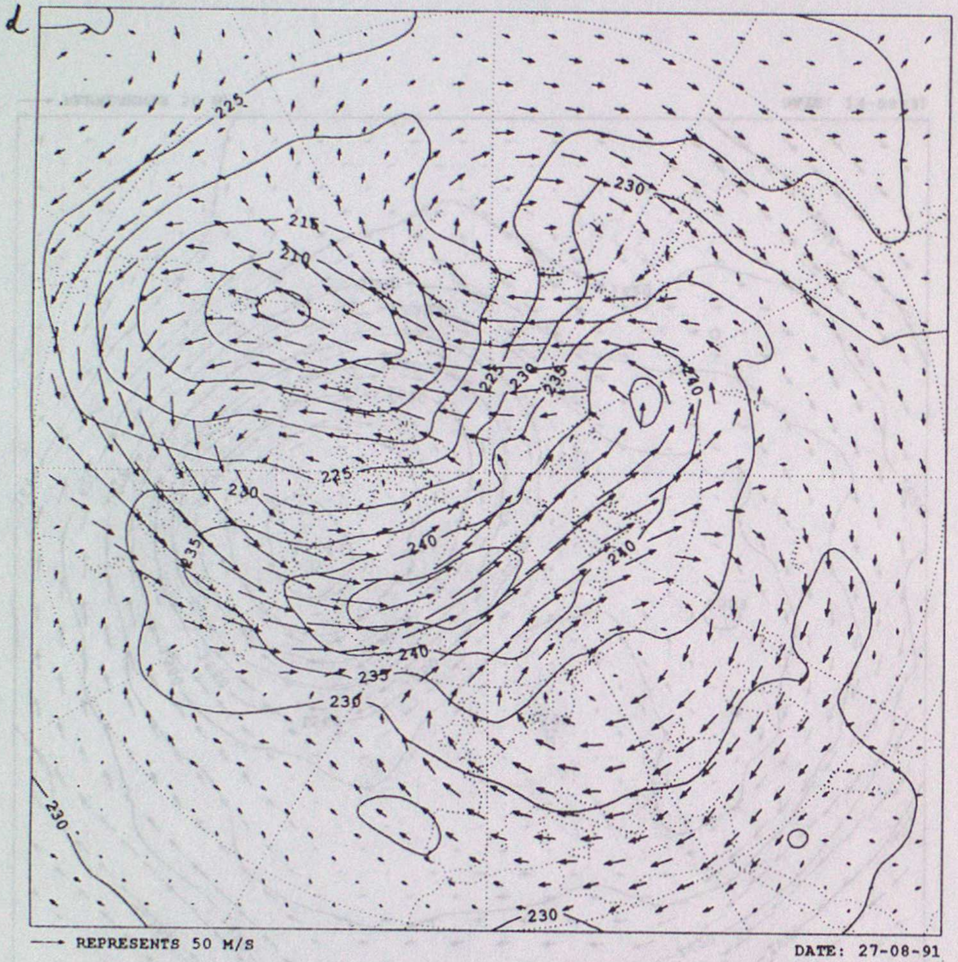


FIG. 3

After 24 hours of data assimilation
Temperature and wind vectors
VALID AT 12Z ON 16/2/1989 DATA TIME 12Z ON 16/2/1989
LEVEL: 10 MB

d



Forecast from stratospheric assimilation
Temperature and wind vectors
VALID AT 12Z ON 20/2/1989 DATA TIME 12Z ON 16/2/1989
LEVEL: 10 MB T+96

e

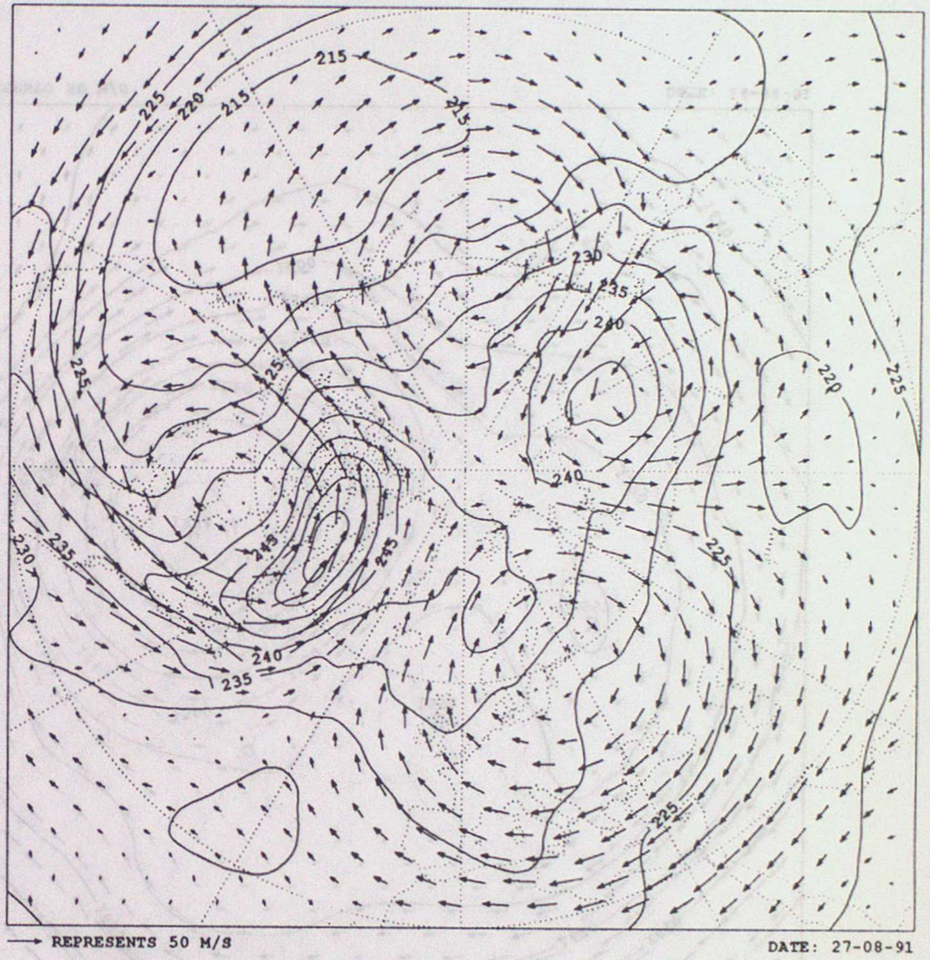
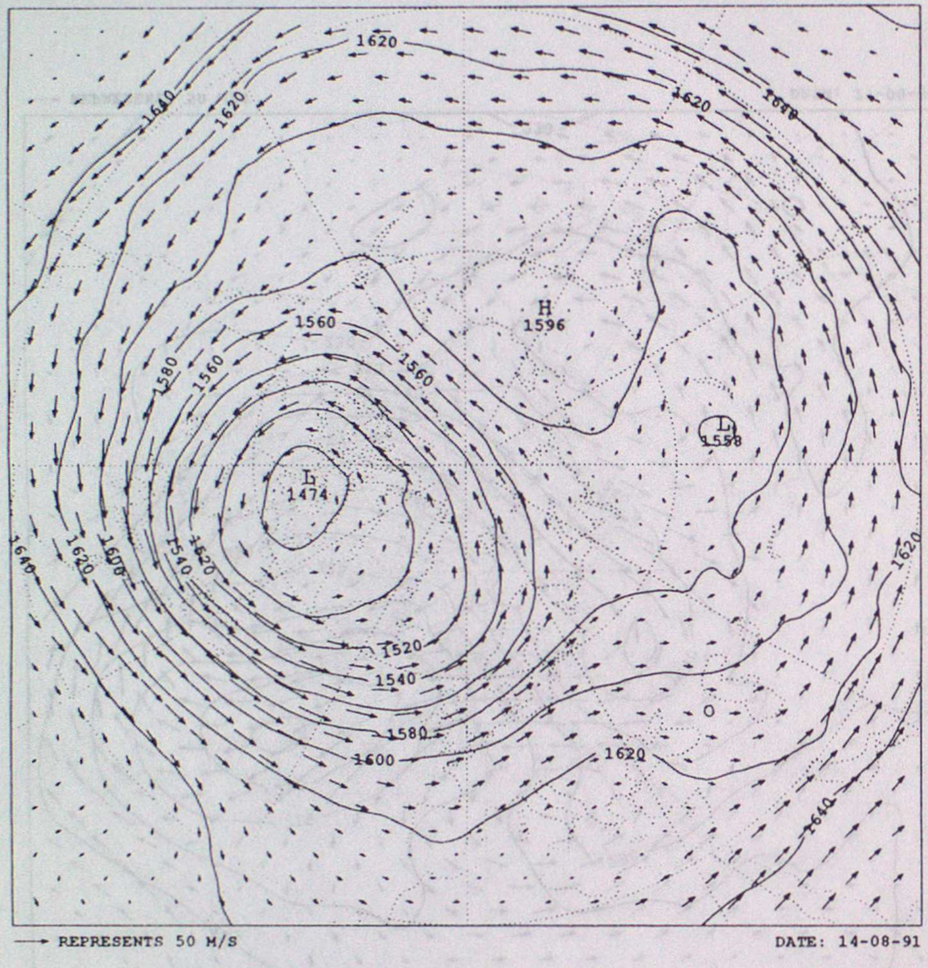


FIG 4

Stratospheric assimilation results
Geopotential height and wind vectors
VALID AT 12Z ON 4/1/1991   DATA TIME 12Z ON 4/1/1991
LEVEL: 100 MB

a



SSU analysis
Geopotential height and wind vectors
VALID AT 12Z ON 4/1/1991
LEVEL: 100 MB

b

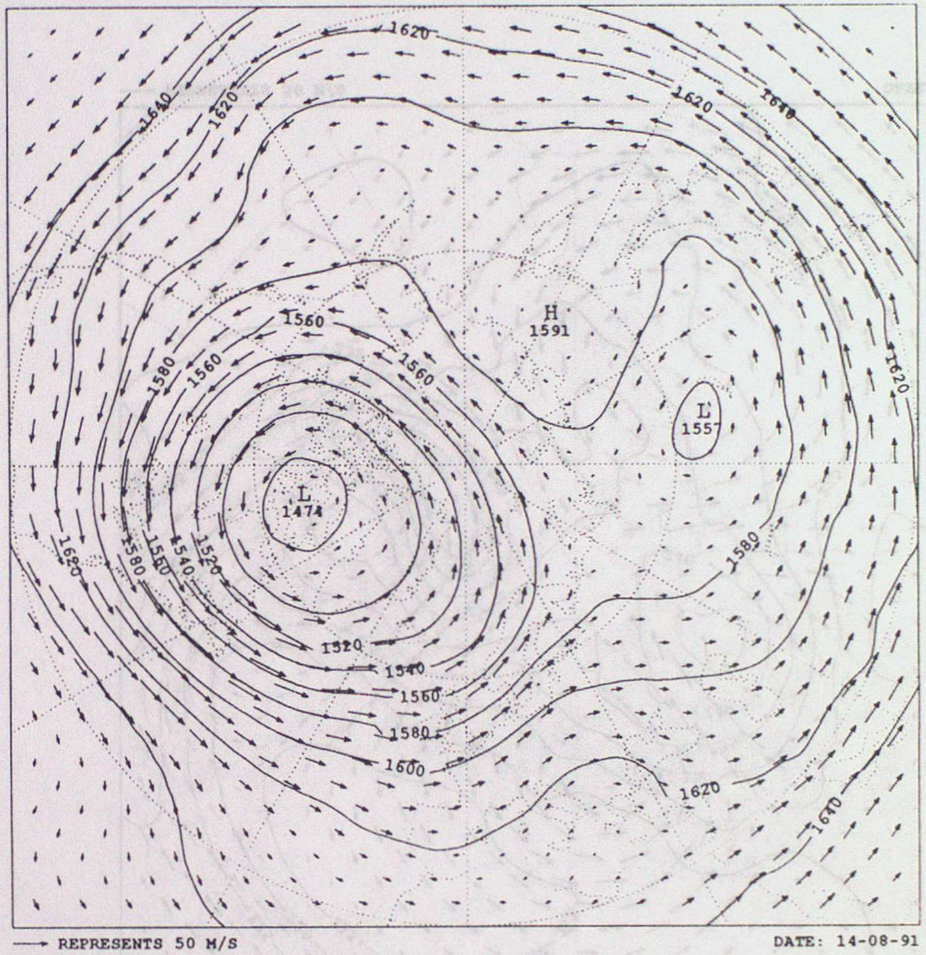
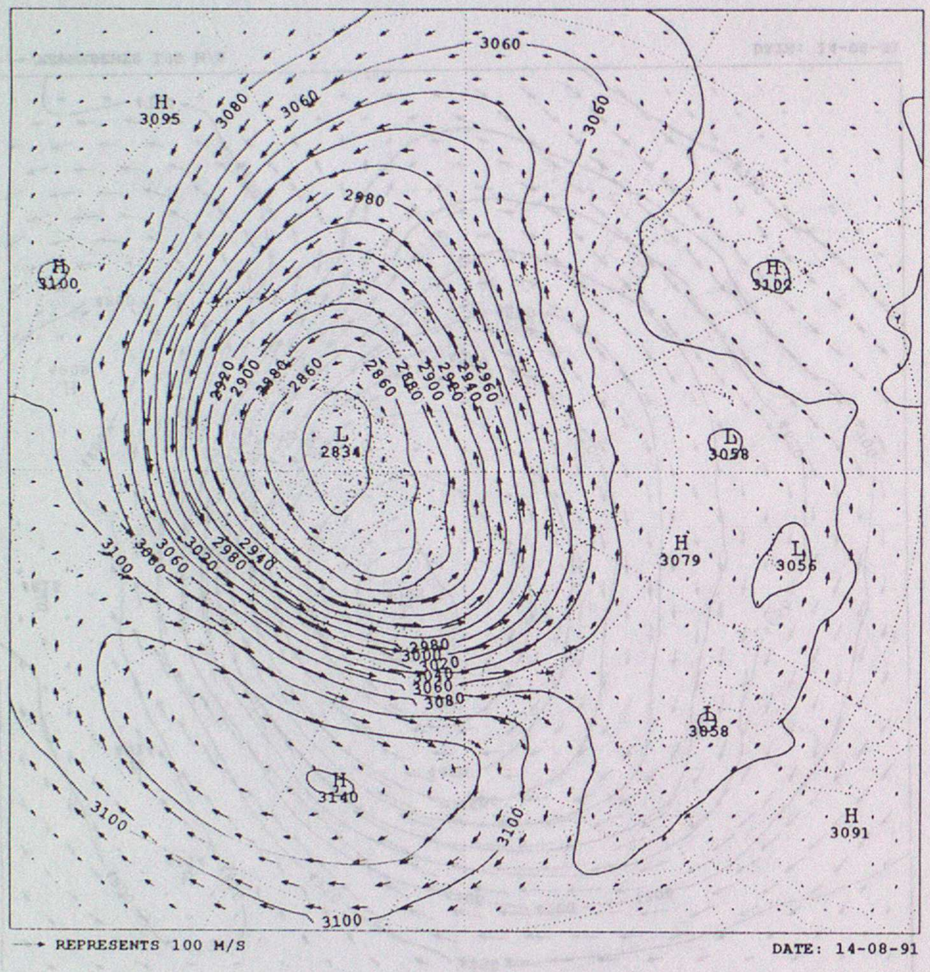


FIG 4

Stratospheric assimilation results
Geopotential height and wind vectors
VALID AT 12Z ON 4/1/1991   DATA TIME 12Z ON 4/1/1991
LEVEL: 10 MB

c



SSU analysis
Geopotential height and wind vectors
VALID AT 12Z ON 4/1/1991
LEVEL: 10 MB

d

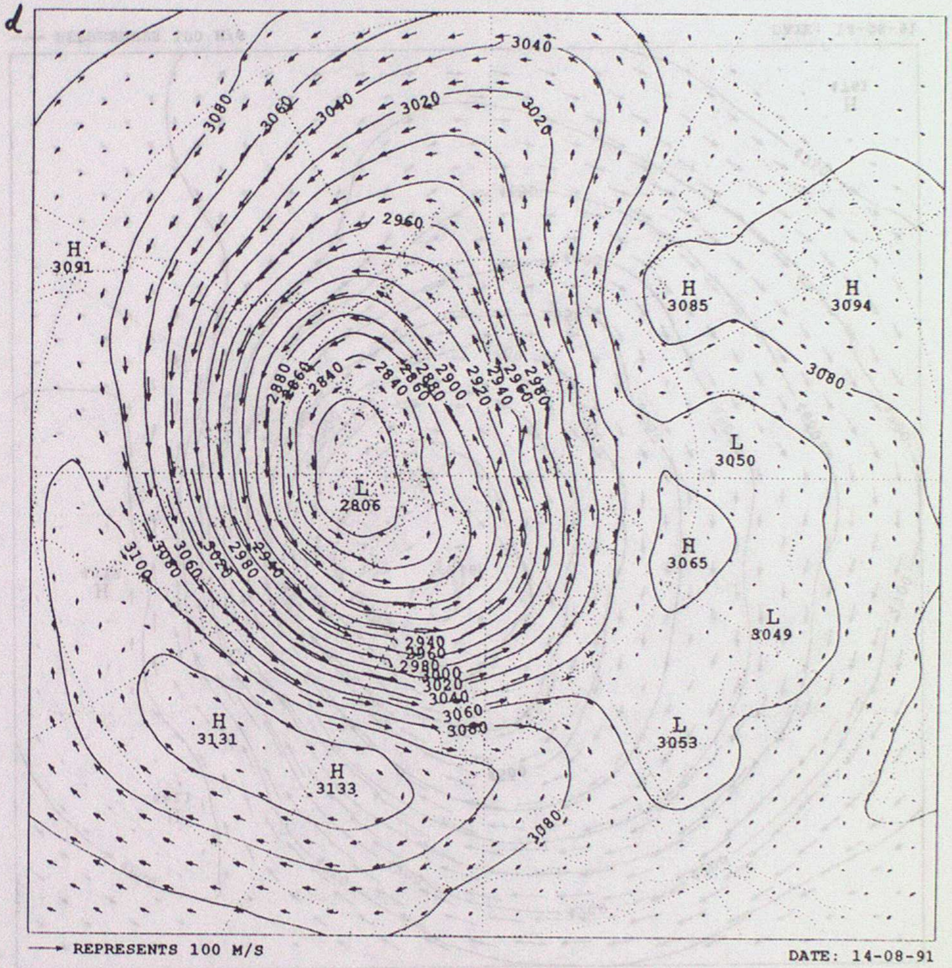
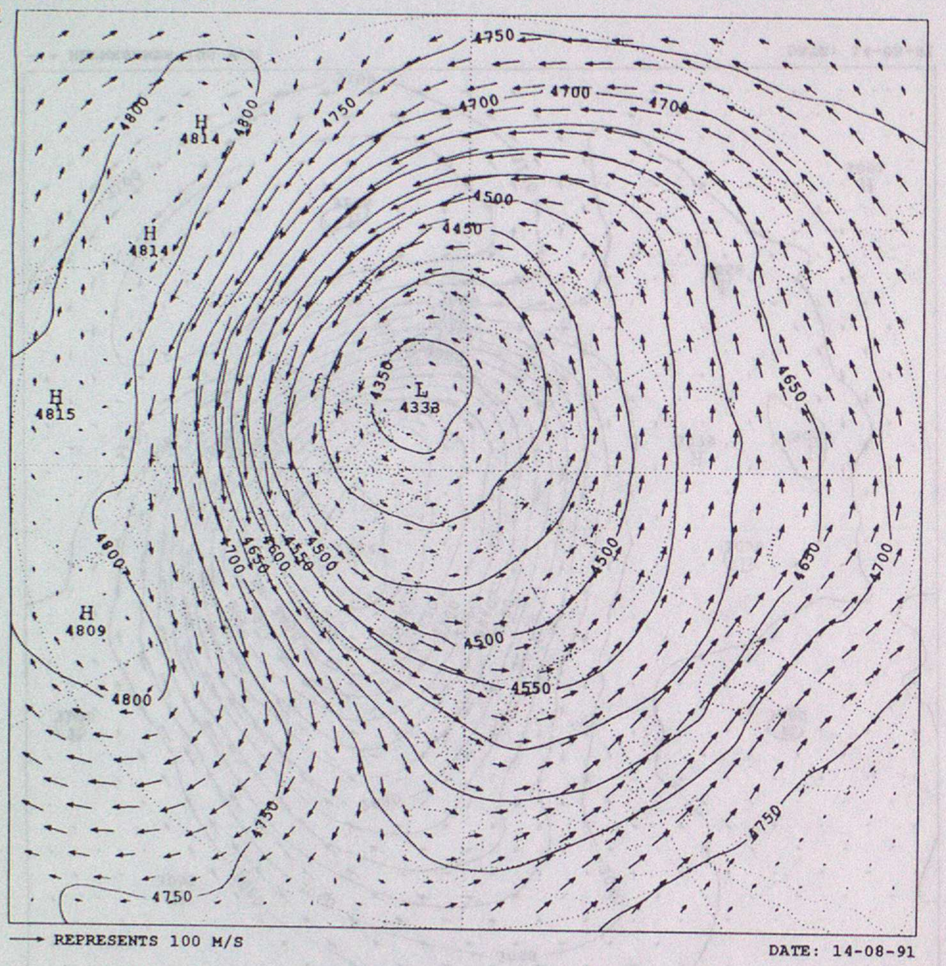


FIG 4

Stratospheric assimilation results
Geopotential height and wind vectors
VALID AT 12Z ON 4/1/1991   DATA TIME 12Z ON 4/1/1991
LEVEL: 1.00 MB

e



SSU analysis
Geopotential height and wind vectors
VALID AT 12Z ON 4/1/1991
LEVEL: 1.00 MB

f

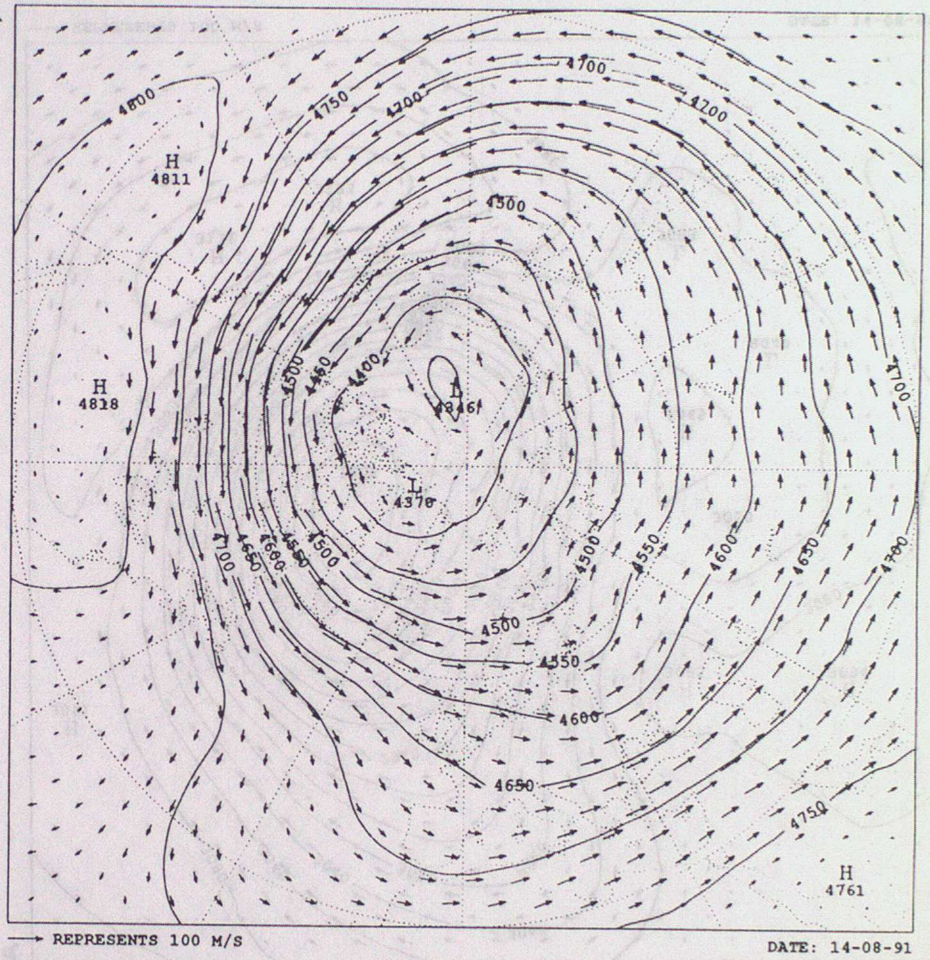
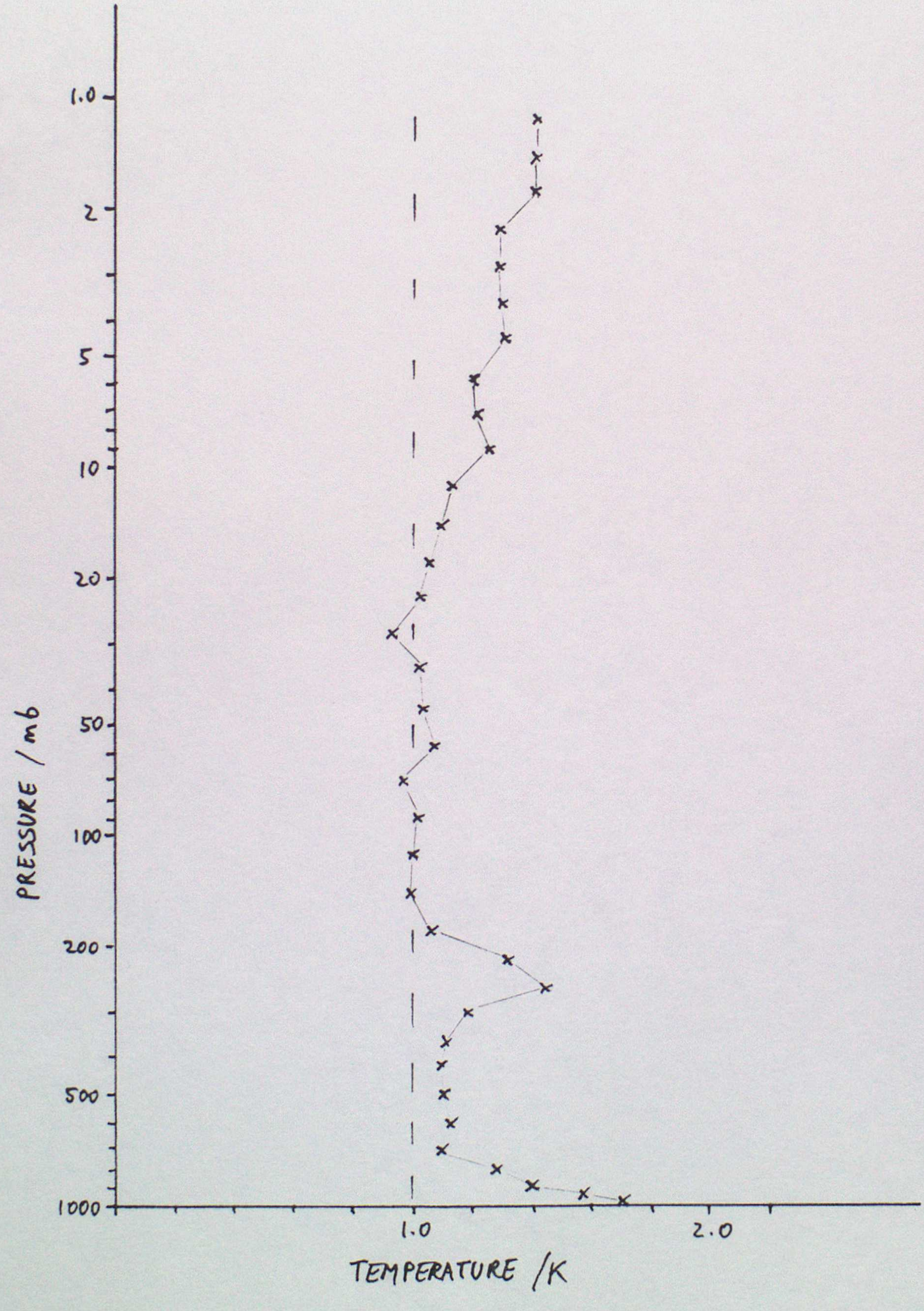


FIG. 5.

ROOT MEAN SQUARE FIT TO TEMPERATURE OBSERVATIONS
12 GMT 1ST JANUARY 1991



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