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Edited by
C.D. Rodgers

M I D D L E

A T M O S P H E R E

P R O G R A M

HANDBOOK FOR MAP

Volume 12

Coordinated Study of the Behavior of the
Middle Atmosphere in Winter (PMP-1)
Workshops: May 11-14, 1982, Boulder, Colorado, USA
April 12-15, 1983, University of Oxford, UK
August 17, 1983, Hamburg, FRG

Edited by

C. D. Rodgers

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Coordinated Study of the Behavior of the Middle Atmosphere in Winter (PMP-1)

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CONTENTS

REPORT ON THE
WORKSHOPS ON COMPARISON OF DATA AND DERIVED
DYNAMICAL QUANTITIES DURING NORTHERN HEMISPHERE WINTERS
(PMP-1 Winters)

1. INTRODUCTION

The PMP-1 working group has held three workshops in order to intercompare middle atmosphere meteorological data from a variety of sources. About 20 scientists from Germany, France, the United Kingdom and the United States took part. The primary aim was to intercompare data on stratospheric and mesospheric temperatures from a variety of sounding systems in order to characterise the differences, to understand the reasons for them, and to help users of the data to understand how these differences will affect derived quantities such as heat and momentum fluxes which are significant in studies of stratospheric dynamics. The first workshop was held at the National Center for Atmospheric Research in Boulder, Colorado from 11 to 14 May 1982. Preliminary comparisons were made, and a strategy mapped out to make more detailed and quantitative comparisons. The second PMP-1 workshop was held in the Department of Atmospheric Physics at the University of Oxford from 12-15 April 1983. This was a working meeting; all the data were available in the Department's computer, together with a utility program to access it, and make comparisons and plots, both of the basic data and of derived quantities. The third meeting, to finalise this report, was held in Hamburg on 17 Aug 1983.

It is important that users of these data should understand their nature and limitations, especially with regard to derived products. Consequently this report includes a large number of diagrams, rather than a few selected cases, in order to help the user draw his own conclusions.

In order to put some bounds on the number of possible comparisons, however, a decision was made to concentrate on a small number of dates. The three dates chosen for the first workshop were extended to eight, including both quiet and disturbed days. A list of dates, and the data available for each one, is given in Table 1.

Table 1. Data sets available for the comparison.

Day no.	Date	DATA AVAILABILITY						Brief Description
		SAMS	LIMS	SSU	NMC	Berlin	ECMWF	
1	2 Jan 79	Y	Y	Y	Y	Y	N	pre-warming
2	26 Jan 79	Y	Y	Y	Y	Y	N	wave 1 warming
3	26 Feb 79	Y	Y	Y	Y	Y	Y	wave 2 warming
4	2 May 79	AB	Y	N	Y	B	N	quiet
5	14 Jun 80	Y	N	Y	Y	Y	Y	quiet
6	5 Nov 80	Y	N	Y	Y	Y	Y	offset vortex undisturbed
7	5 Feb 81	Y	N	N	Y	Y	Y	wave 1 warming
8	8 Feb 81	Y	N	Y	B	Y	Y	wave 1 warming

Y = data available; N = data not available ; A = average of 1 May and 3 May ;
B = became available after the second workshop

2. DESCRIPTION OF DATA SOURCES

2.1 In situ data

The in situ data were from radiosondes and a few rockets. Mapped products of temperature and height based on the radiosondes were available from the National Meteorological Center (NMC) of the United States, the European Centre for Medium-Range Weather Forecasting (ECMWF) and the Free University of Berlin. The NMC analyses are the operational product, and have not been reanalysed after the fact. In the range 70 to 10 mb they are only valid north of 20 N. The NMC analyses at 100, 70, 50, 30, and 10 mb and the ECMWF analyses of 100, 50, and 30 mb are based on an optimal interpolation, using only conventional data.

The Berlin analyses are a research product, analysed subjectively after all data, including rocketsondes, have been received. The analyses are built up hydrostatically from the 50 mb level, giving much weight to the vector winds (and shear winds), assuming geostrophic conditions. An attempt is made to make the maps consistent in time and space and the reanalysis of certain fields is possible if, e.g. a warming develops over a data-sparse region. For the 10 mb level also "off-level data", i.e. significant points of winds and temperatures between 15 and 11 mb, are used in the analyses after the respective extrapolation up to the 10 mb level. For all stations, 00 Z and 12 Z reports are plotted and considered, but the analysis is made for 00 Z.

A typical example of the data coverage at the 10 mb level is shown in Figure 1, where the 10 mb isotherms as analysed by Berlin are shown, together with all available radiosonde data between 15 and 10 mb for 00 Z, 26 February 1979. The reports for 12 GMT of 25 February are added in data-void regions.

2.2 Satellite data

The satellite data were from the Nimbus 7 experimental satellite, and the NOAA-5, TIROS-N and NOAA-6 operational satellites. The instruments used were LIMS, SAMS, VTPR and TOVS.

The LIMS is a limb scanning IR radiometer, which flew on Nimbus 7 and provided temperatures from 100 to 0.05 mb. Radiation emitted by the 15 micron bands of carbon dioxide was measured in 2 spectral channels, from which the temperature was inferred as a function of pressure, using an iterative retrieval scheme (GILLE and RUSSELL, 1984). The vertical field of view (FOV) is 2 km, leading to high vertical resolution. The thickness between standard pressure levels was calculated, and added to the FGGE 100 mb height to give height fields. The gridding used a Kalman-filter on data around latitude circles, giving maps for 00 Z. The use of detectors cooled by a solid cryogen limited its life to 7 months.

SAMS is an IR limb scanning gas correlation radiomete on Nimbus 7 (DRUMMOND et al., 1980). Temperature is derived as a function of pressure from measurements of 15 micron radiance in 4 spectral channels, along the orbital track using a sequential estimation approach to determine 8 eigenfunction coefficients. The gridding used interpolation between measurements made at a given latitude. The vertical FOV is 8 km.

The NOAA-5 Vertical Temperature Profile Radiometer (VTPR) (McMILLIN et al., 1973) and the TIROS N Height Resolution Sounder (HIRS) are nadir viewing IR sounders. HIRS, together with the Microwave Sounder Unit (MSU) and the Stratospheric Sounder Unit (SSU), form the TIROS Operational Vertical Sounder (TOVS) (SMITH et al., 1979; SMITH and WOOLF, 1976). Vertical temperature profiles and thicknesses in the troposphere and stratosphere are derived using latitudinally and seasonally varying regression coefficients. These data are

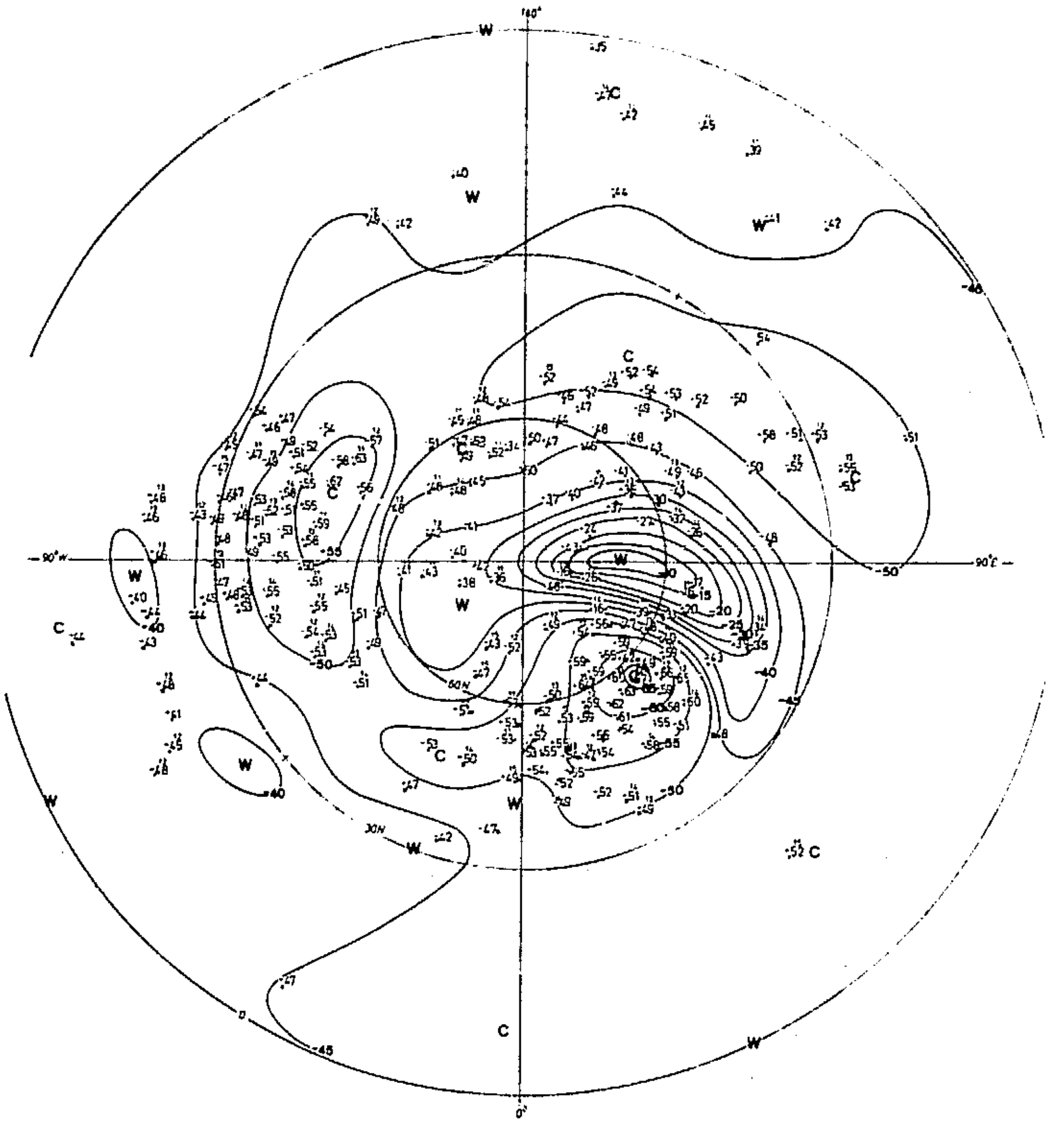


Figure 1. 10-mb isotherms (deg C) for 26 February 1979, 00 Z. All available radiosonde reports are plotted: x denotes reports from 25 Feb, 12 Z; small numbers indicate the pressure level of reports reaching only to levels between 15 and 11 mbs, respectively.

Table 2. NMC and SSU spacecraft and analysis usage.

Day	NMC Spacecraft/Instrument		SSU Spacecraft	Zoned Coeffs	100 mb Field	Analysis Time	Channels Used
1	NOAA-5	VTPR	TIROS-N	NO	FGGE	00Z	25,26
2	NOAA-5	VTPR	TIROS-N	NO	FGGE	00Z	25,26
3	TIROS-N	TOVS	TIROS-N	NO	FGGE	00Z	25,26
4	TIROS-N	TOVS					
5	NOAA-6	TOVS	NOAA-6	YES	NMC	12Z	1-3,24-27
6	NOAA-6	TOVS	NOAA-6	YES	NMC	12Z	""
7	NOAA-6	TOVS					
8	NOAA-6	TOVS	NOAA-6	YES	NMC	12Z	""

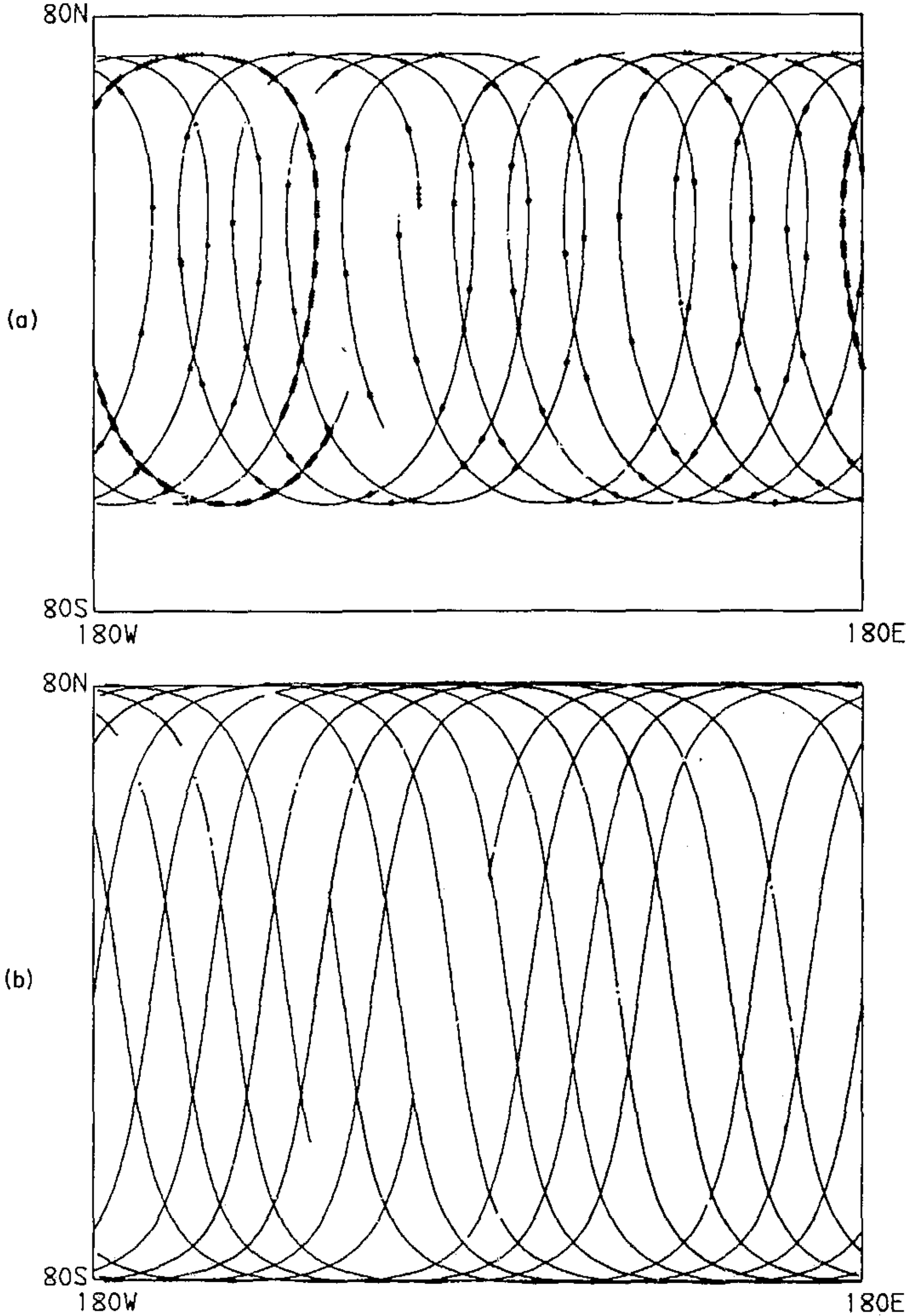


Figure 2. Illustrating the geographical coverage of remote sounders: (a) Tangent point track for SAMS, 26 Jan 79. (b) Subsatellite track for the same day. The scales are linear in latitude and longitude. The small crosses mark calibration sequences.

used in the NMC maps above 10 mb, with VTPR being used through 23 February 1979 and TOVS from 25 February on.

The SSU is a nadir veiwing pressure modulated IR radiometer. The SSU radiances are used operationally by NMC, but independent retrievals are also carried out by the UK Meteorological Office on a nonoperational basis, using a different regression method. For the 1978/9 winter, radiances were available for retrieval only from channels peaking at 15 and 5 mb; information from an additional, higher level is available in later instruments in the NOAA series. Details are given in Table 2. The retrieval determines thickness from 100 mb with regression coefficients, which do not vary with latitude or season for early 1979; this modification was introduced in June 1979.

Satellite data coverage is generally more regular and uniform than that for in situ soundings. Measurements are made at two fixed local times each day for any particular latitude, typically 2 pm and 10 pm for SAMS and LIMS, 8 am and 8 pm for NOAA-6, and 4 am and 4 pm for TIROS N. The geographical coverage is determined by the suborbital or the tangent point track. There are typically 13 measurements at any one latitude each day in each of the ascending and descending parts of the orbit. As an illustration, the tangent track is shown for SAMS for 26 Jan 79 in Figure 2(a). The tangent track for LIMS is qualitatively similar, but extends further north and south. The suborbital track for Nimbus 7 is also shown in Figure 2(b). This is qualitatively similar to the data coverage for all nadir sounders. The coverage in latitude is not complete; details are given in Section 8.2.

3. ERROR SOURCES

The exact state of the stratosphere is something that we can never know. We can only compare different types of measurements and try to understand the differences between them in order to arrive at a best estimate given all the available information. Each measuring system has its own kinds of problem. In the case of satellite remote sounding we can classify the errors into the following rough groups:

(a) Calibration: Are the measured radiances right?

(b) Transmittances: If we knew the actual state of the atmosphere, could we calculate the radiances correctly?

(c) Retrieval: How does the process of solving the equation of transfer:
  (i) smooth actual structures?
  (ii) introduce fictional structures, both random and systematic?

(d) Sampling: Does the distribution of sampling points in space and time ignore or enhance significant variations in the temperature distribution?

(e) Analysis: Does the scheme by which the measurements are interpolated onto a standard synoptic grid introduce errors?

All the above factors introduce errors into the measured temperature fields. When these fields are used to derive other quantities such as thicknesses, heights, winds or transports, the errors may be enhanced.

In the case of radiosondes and rockets, items (b) and (c) do not apply, but the other categories are still relevant.

We must consider the question of how we can distinguish and quantify the various sources of error by making comparisons between the data. The quantities that we can compare include pressure surface maps, vertical cross sections along a specified line (e.g. latitude or longitude), and cross sections of zonal means and wave number components of the following quantities:

(a) Temperature
(b) Thickness
(c) Heights of pressure surfaces
(d) Geostrophic wind
(e) Fluxes of heat and momentum

We cannot clearly separate errors due to calibration because all the remote sounders use different spectral regions and scanning systems so that radiances cannot be compared. The nearest we can get to the ideal of comparing radiances is to compare (for example) SSU and HIRS radiances with those which might be computed from the retrieved temperature fields of the other instruments, using appropriate weighting functions. This has been done with some success for SAMS and SSU by BARNETT and CORNEY (1984) but was too major a task to be repeated by this workshop for all the available cases. Comparisons of thicknesses are perhaps the closest we can get to comparing radiances, because this eliminates to some extent the fine vertical scale structures, real or unreal.

Fields of temperature or thickness in time and space are perhaps the most straightforward for comparison purposes as these are the quantities closest to the original data which all the observing systems produce in common. Derived quantities beyond this stage involve further operations on the data, thus introducing further differences if carried out by different methods. In this study, all the derived quantities have been computed by the same (very simple minded) method, so that the differences are a consequence of data differences only.

Comparisons may be made numerically, in terms of mean and rms differences, or graphically in terms of maps. Both approaches are used here, as they give different kinds of information. Numerical values are required to determine whether the differences are really important, and to find broadly where the errors are largest. Maps and cross sections help to pinpoint some of the reasons for differences in terms of the way the measurements are made.

Differences may be random or systematic, but usually are somewhere in between. There is generally a coherent distribution of difference, clearly related to the distribution of the quantity being measured, but not consistently so. Some systematic differences on a global scale can be seen in comparisons on undisturbed days; other structure-related differences can be seen on disturbed days.

4. TEMPERATURE COMPARISONS BETWEEN ROCKETSONDES, LIDAR AND SATELLITE SOUNDERS

4.1 Statistical comparisons between rocketsondes and satellites

The three satellite sounders involved in this study have been compared on a statistical basis with rocketsonde measurements. The main conclusions of these studies are summarised here.

(a) LIMS data have been compared during the period from October 1978 to May 1979 with the data of 10 rocket stations (GILLE et al., 1984, and Figure 3). In general below 1 mb the mean difference between rockets and LIMS is less than 2 K and not statistically significant. Above 1 mb rockets are on the average warmer than LIMS. The maximum difference may reach 5 to 10 K at middle latitudes (White Sands, 32 N) and high latitudes (Fort Churchill, 58 N) when at low latitudes (Ascension Is, 8 S) the difference is below 3 K, not significant at the 95 percent confidence level.

(b) SSU data have been compared during the period July 1980 to July 1981 with the data of 10 US and 3 USSR rocket stations (Figure 4, from NASH and BROWNSCOMBE (1983)). Significant differences appear for the 3 channels 25, 26 and 27. For US rocketsondes the agreement at middle and high latitudes is within 2 K but at low latitudes rocket data are up to 5 K warmer than SSU, especially at Ascension Island (8 S). The trend with latitude of these differences is larger than the known uncertainties of the SSU data. SSU is always warmer than the USSR rocket data with a maximum in channel 27 from 3 to 5 K.

(c) SAMS and SSU data have been compared from January 1980 to February 1981 with the data from 3 US rocket stations (BARNETT and CORNEY, 1984). In general SAMS and SSU agree within 2 K. The comparison with rocketsondes shows the same trends with latitude for SAMS and SSU. At Primrose Lake (55 N) the agreement is quite good (Figure 5) but at Ascension Island rocket data are up to 5 K warmer than SSU and up to 4 K warmer than SAMS in the 5 - 1 mb layer.

(d) NMC stratospheric data have been compared with rockets for the period September 1978 to September 1981 by GELMAN et al. (1982). Figure 6 shows contours of a correction derived from the zonal mean of rockets minus NMC for four separate periods. The data used in this report do not include this correction. Figure 7 shows the rms difference for the same periods.

4.2 Comparisons between lidar and satellite

A comparison has been made between 61 temperature profiles from December 1982 to March 1983 obtained with the lidar station of the Observatory of Haute-Provence (44 deg N) and the brightness temperature of channel 27 of SSU above the lidar station deduced from the daily maps published by the Metorological Office (Figure 8 from HAUCHECORNE (1983)). High resolution lidar profiles have been integrated in altitude taking into account the weighting function of channel 27. On average the lidar is 1.5 K warmer than SSU with a 2 K standard deviation. The agreement is quite good considering that variations of temperature as large as 25 K occurred during that period. A more sophisticated comparison, using rough data of SSU above the lidar station, will be performed in the next few months.

4.3 Conclusion

The temperature differences between rocketsondes and satellite sounders are often less than 2 K to 3 K and are not statistically significant, but in some cases (high stratosphere at low latitudes for SSU and SAMS and mesosphere at

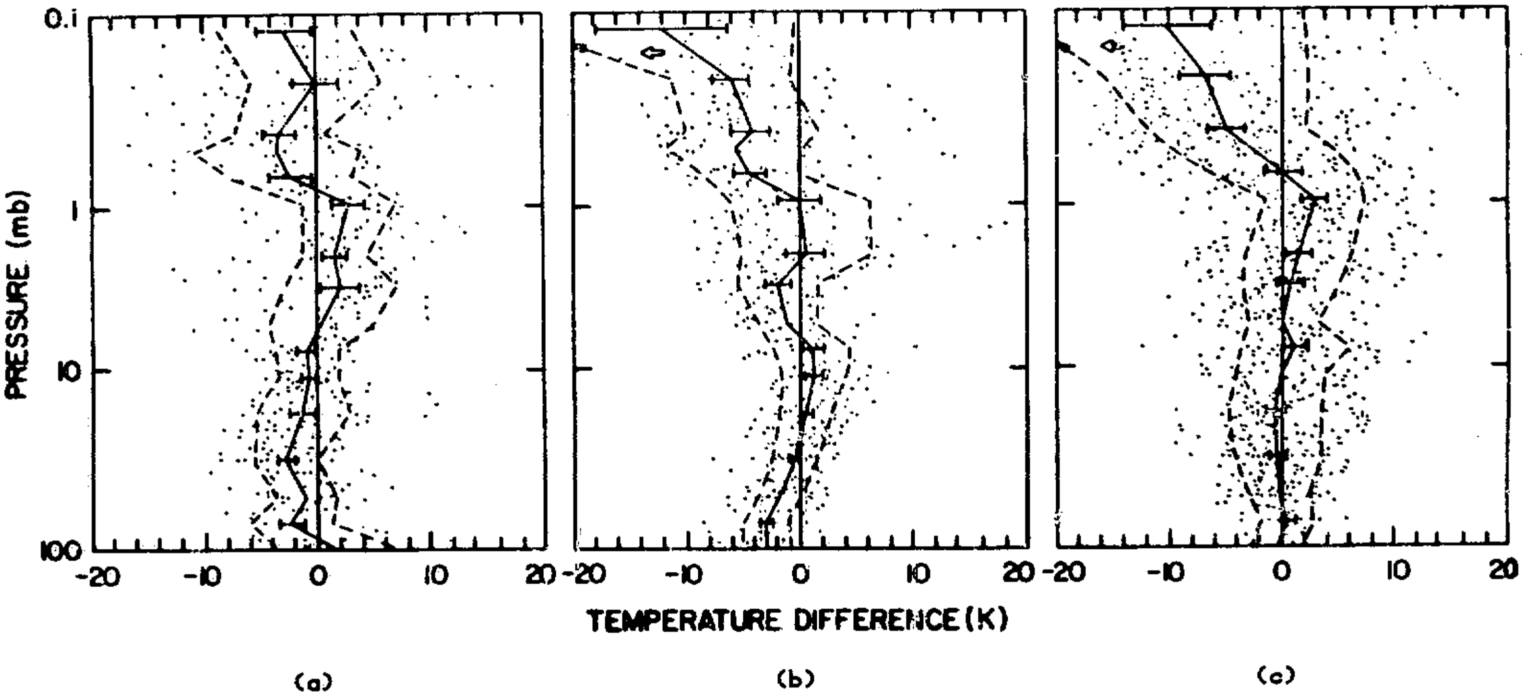


Figure 3. Statistics for comparisons between LIMS and rockets. Points show all individual measurement differences, solid line is mean difference, bars show standard deviation of the mean, and dashed lines indicate $\pm 1\ \sigma$ of differences; (a) 8 profiles at Ascension Island (8 deg S); (b) 11 profiles at White Sands (32.4 deg N); (c) 16 profiles at Ft. Churchill (58.7 deg N).

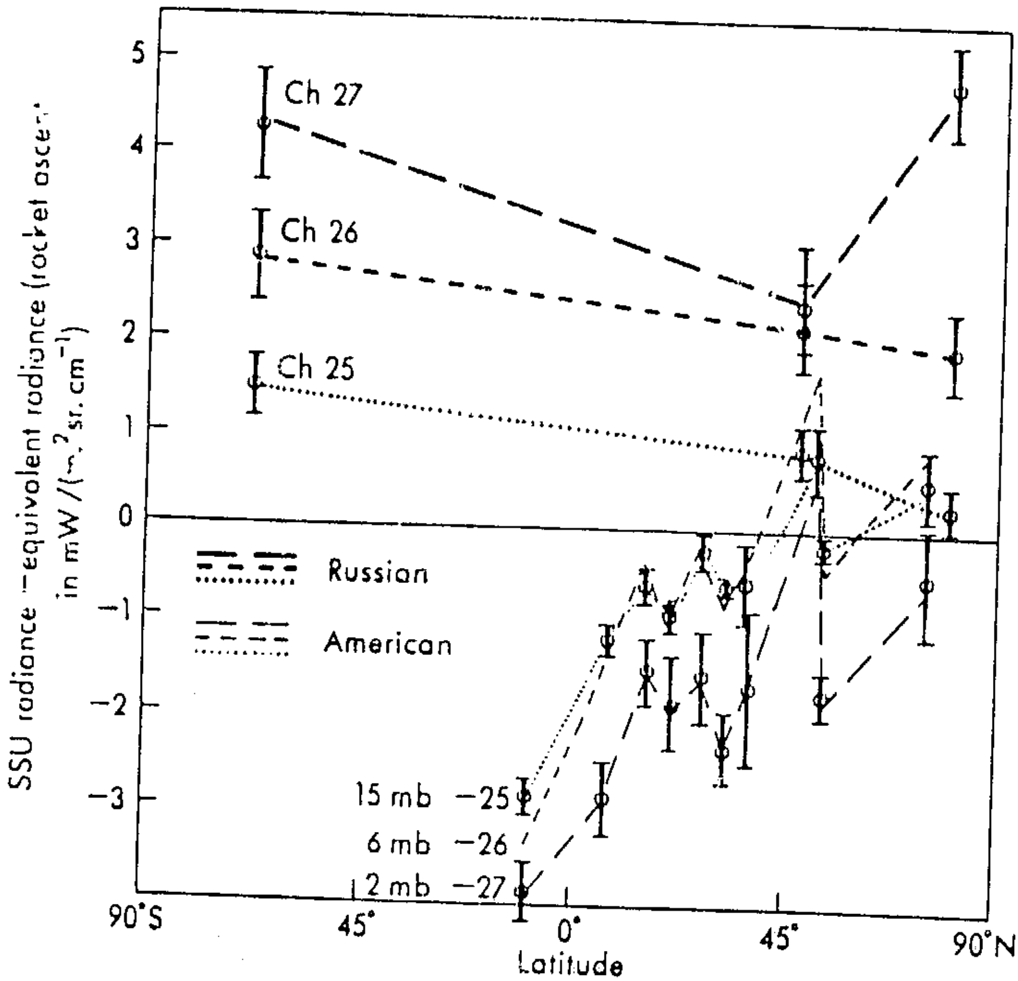


Figure 4. Difference between radiance measured by NOAA-6 satellite overpass and that calculated from rocketsonde ascents July 1980 to July 1981.

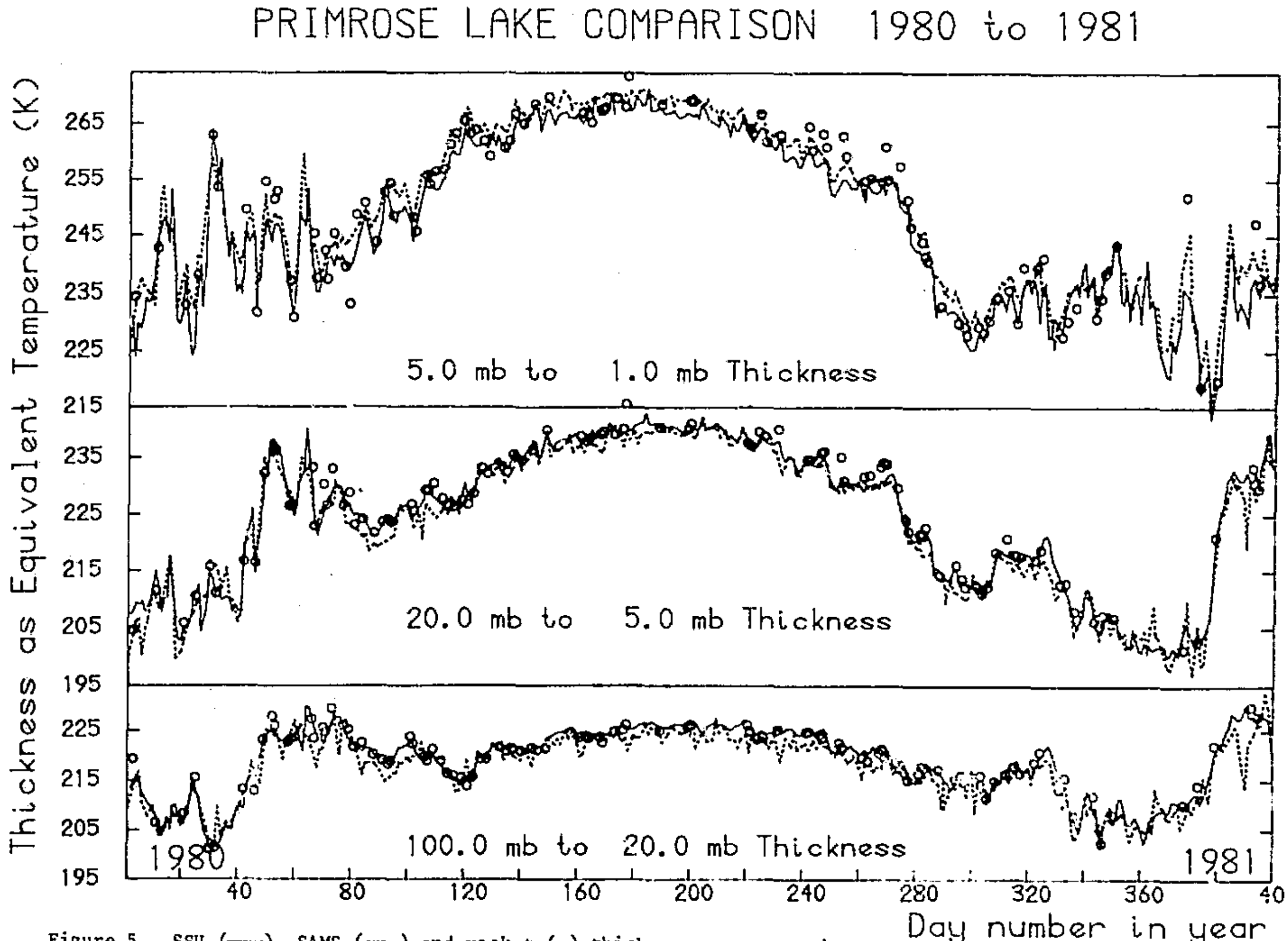
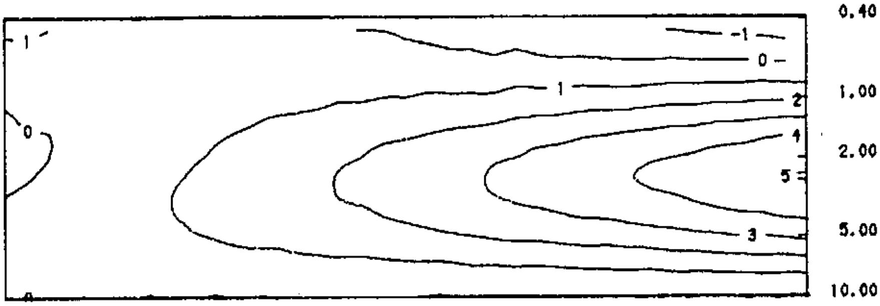
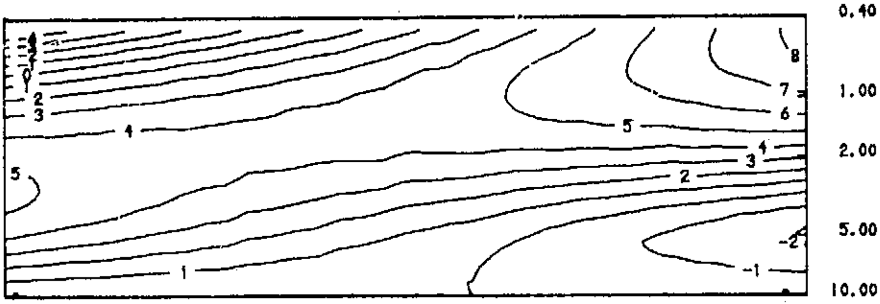


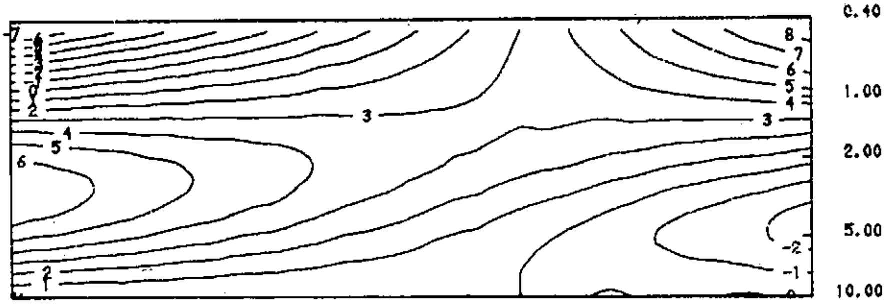
Figure 5. SSU (——), SAMS (---) and rocket (o) thicknesses expressed as equivalent layer mean temperature over Primrose Lake rocket station (55 deg N, 110 deg W).



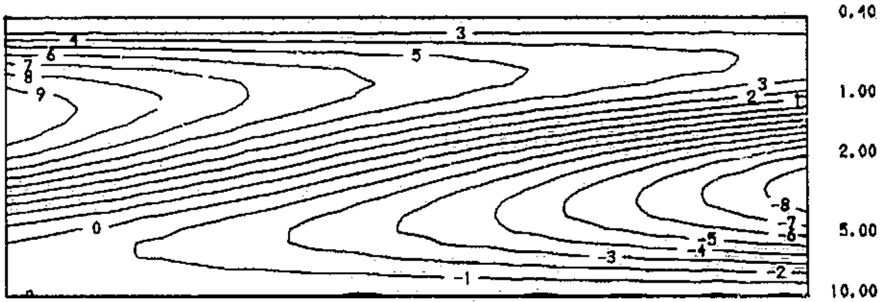
(a) 24 Sep 78 - 22 Feb 79 VTPR



(b) 25 Feb 79 - 20 Jan 80 TIROS N SSU



(c) 21 Jan 80 - 16 Oct 80 NOAA6 SSU



(d) 17 Oct 80 - 1 Sep 81 NOAA6 TOVS

Figure 6. NMC temperature adjustments to be added to uncorrected data.

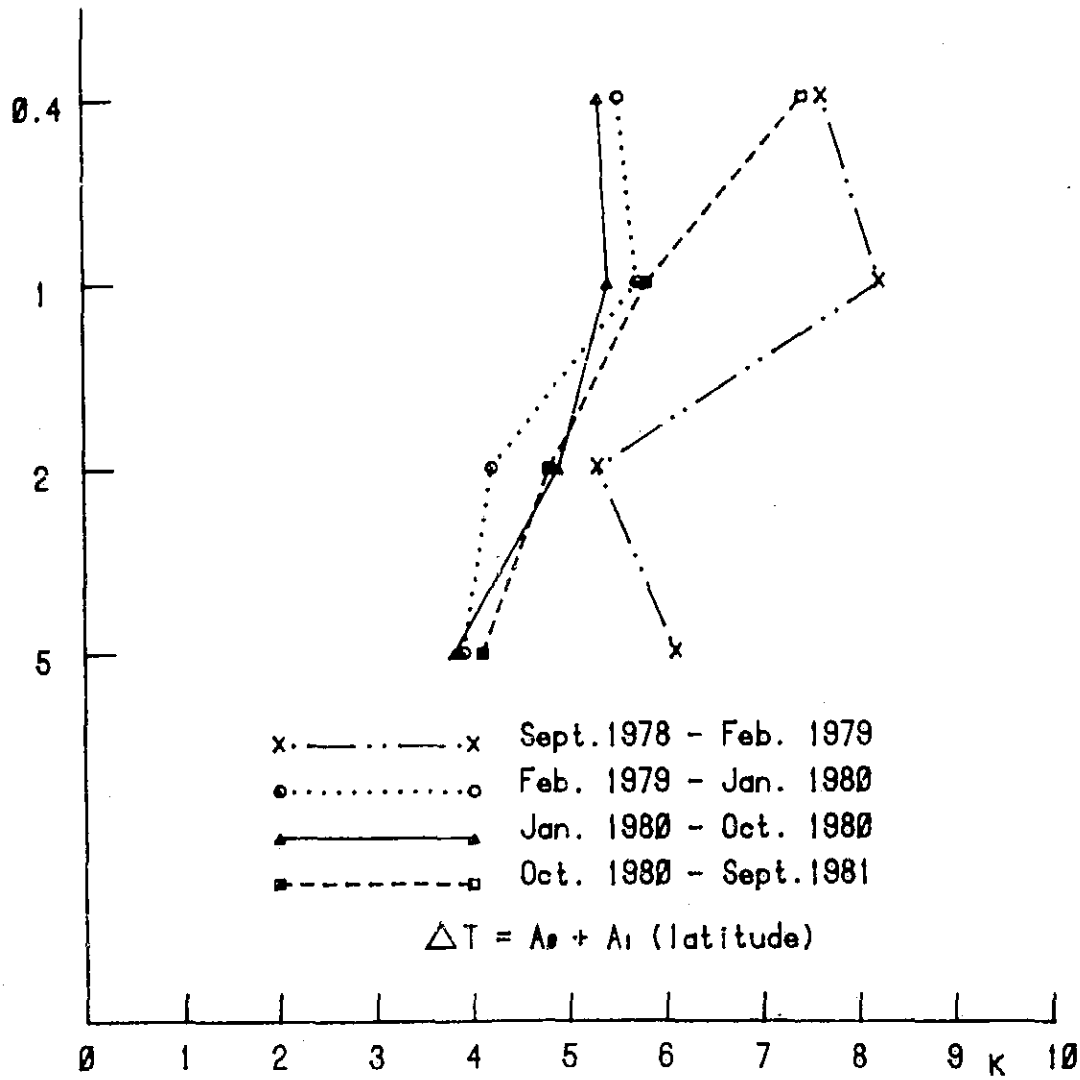


Figure 7. RMS difference between NMC profiles and rocket data.

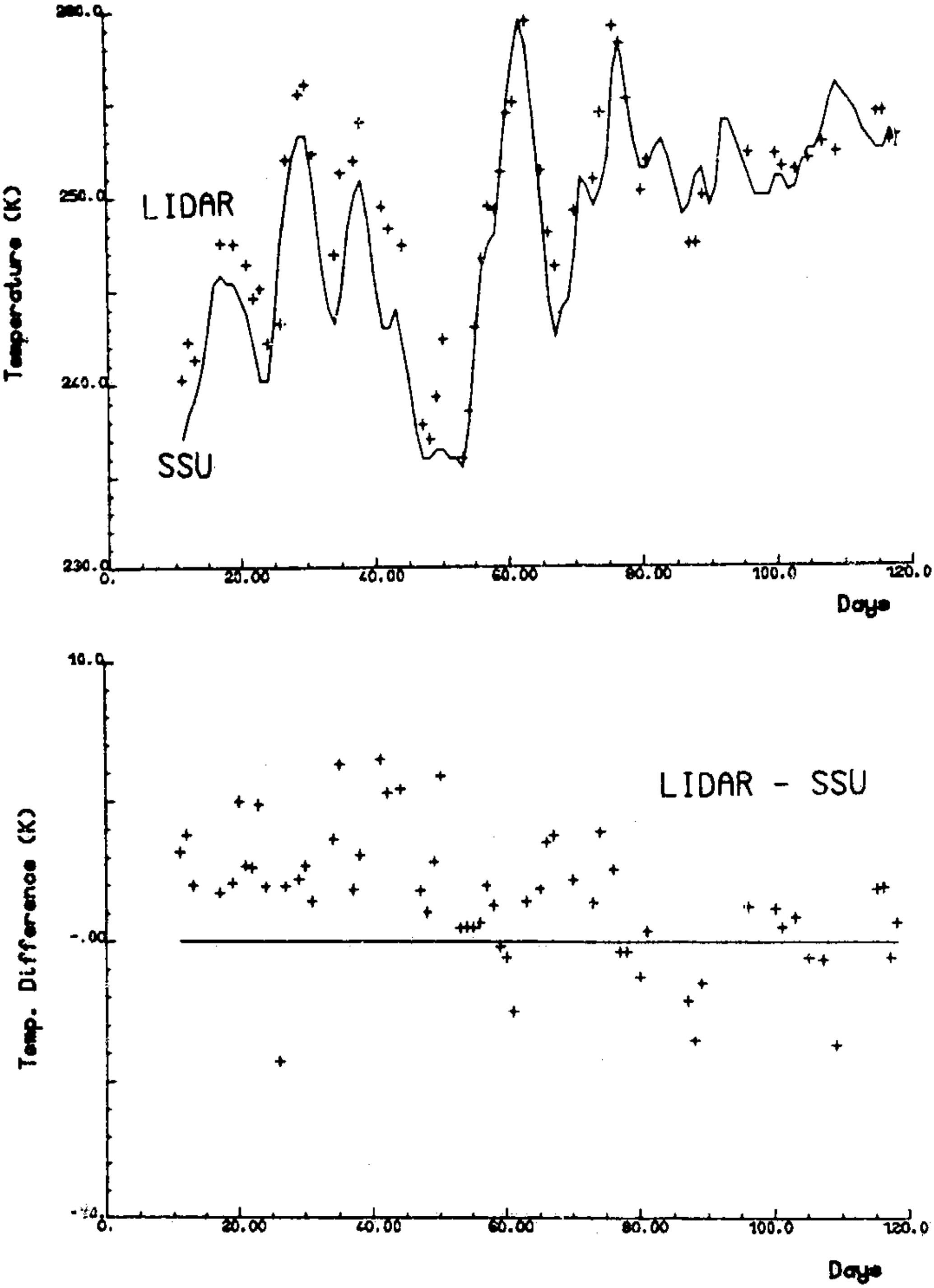


Figure 8. Difference between SSU channel 27 radiances and synthetic radiances computed from Haute-Provence lidar temperature profiles.

middle and high latitudes for LIMS) differences as large as 5 to 10 K are observed. More studies are necessary to understand if these differences are due to systematic errors of one of the methods or differences in spatial and time resolution. The first comparison between satellite and lidar data shows that this new technique may give a better understanding of the causes of the differences.

5. THICKNESS AND TEMPERATURE

5.1 Thickness maps

As has been discussed above, one difficulty of comparing height fields as determined from the various experiments is that they are all built up from a base level. Unfortunately, this base level is not common and an extra dimension of uncertainty is thus added. Therefore, we present here comparisons of the basic thickness fields which represent the "average" temperature field between pressure levels. In this case, this involves a "degradation" of the high resolution temperature retrievals, but on the other hand provides the basic information that enters into the height charts.

After careful consideration of the available data, we discuss below the comparisons for the following levels in mb: 100-50, 100-10, 50-10, 10-5, 5-2, 2-1, 1-0.4, and 0.4-0.1. For each layer we present a few elements of comparison and at the end provide an overall impression. The maps are given in Appendix A1.

5.1.1. 100-50 mb

Day 1: (2 Jan 1979) SAMS-LIMS-NMC
The polar low value of NMC is considerably lower than that for LIMS, 384 vs about 416 dam, and the ridge value is greater, 464 vs about 448, resulting in a substantially larger gradient in the NMC chart. While SAMS shows a tendency toward the lower pole value, the ridge is not as great. We note also the generally smoother LIMS and SAMS charts compared with NMC. Also, SAMS does not portray the secondary ridge at about 90 W.

Day 2: (26 Jan 1979) SAMS-LIMS-NMC
Again, NMC central low value is about 16 dam lower than LIMS, which combined with about 8 dam higher value in the polar ridge results in a substantially enhanced gradient. LIMS contouring appears smoother than NMC and while there is some evidence of detail in the tropics, the NMC data seem overdone. The SAMS ridge value agrees with LIMS, but the lack of data in the pole region limits the detail of the comparisons.

Day 3: (26 Feb 1979) LIMS-SAMS-ECMWF-NMC
Of the 4 charts, NMC appears the coarsest, with many small details not evidenced in the others. In mid-to-high latitudes, the ECMWF and NMC look very similar with larger horizontal gradients than evidenced by LIMS and SAMS.

Day 4: (2 May 1979) SAMS-LIMS-NMC
The first and foremost impression is the relative smoothness of LIMS and SAMS versus NMC with the latter very fragmented. If we examine individual contours, such as the 448, we see that LIMS and NMC are very similar in pattern but that SAMS does not catch the additional trough and ridge at about 90 W. For the 432 contour, however, we see that both LIMS and SAMS are very circumpolar compared to that of NMC.

Day 5: (14 Jun 1980) SAMS-NMC-ECMWF
The overall patterns appear similar although some points of difference occur. The central ridge is slightly greater in the ECMWF map and the troughs over Europe and North America have more amplitude. SAMS appears more circumpolar and does not quite depict the trough amplitude of the others.

Day 6: (5 Nov 1980) SAMS-NMC-ECMWF
In general the maps appear very similar. The ECMWF shows slightly greater ridging over western North America, but the trough over the western North Atlantic seems of greater amplitude in NMC. SAMS is considerably more

fragmented and seems somewhat lower overall.

Day 7: (5 Feb 1981) SAMS-NMC-ECMWF
Again, similar patterns prevail in this case for NMC and the ECMWF with NMC indicating the greater values in the polar areas. SAMS does not seem to depict the trough ridge structure in sufficient magnitude, although it is in evidence.

Day 8: (8 Feb 1981) SAMS-NMC-ECMWF
The overall patterns between NMC and ECMWF agree quite well with the NMC trough slightly lower. SAMS seems to show very little of this detail.

Overall impressions

1. NMC, in general, shows more detail or fragmentation than other charts, especially LIMS and SAMS.

2. NMC and ECMWF agree quite well, on average.

3. LIMS gradients in polar area appear diminished compared to the other charts.

4. SAMS does not, in general, depict quite the details of the others.

5.1.2 100-10 mb

Berlin maps were not available for 100-10 mb thickness, but for the purpose of comparison, they have been constructed by subtracting the SSU 100 mb field from the Berlin 10 mb height.

Day 1: (2 Jan 1979) SAMS-LIMS-NMC-SSU
Pattern between LIMS and SSU very similar in values and smoothness of analysis. SSU values in the polar trough are slightly lower and in the midlatitude ridge slightly higher than LIMS indicating a slightly greater gradient.

The NMC chart is more structured and fragmented than the others, but the central trough value is in good agreement. Over Europe, however, the ridge is much lower than the others, 1504 versus 1536, and also the extent of the 1472 contour over North America is not as great as the other analyses. SAMS, also does not appear as smooth as LIMS and shows considerably lower ridge that agrees more with NMC.

Day 2: (26 Jan 1979) Berlin-SAMS-LIMS-NMC-SSU
The patterns between Berlin, LIMS and SSU, as above, are very similar in overall values and smoothness. Over the Pacific, however, LIMS portrays a very broad ridge while Berlin and SSU show a slight trough. Also, LIMS shows more detail and structure in tropical regions where the gradient is very flat.

NMC seems to agree with Berlin and SSU in the trough over the Pacific and overall, indicates similar patterns to the others. The 1408 value over North America seems overdone as do the fragmented values in low latitudes. SAMS seems to show a basically similar structure to the others, but the lack of data in the polar region inhibits comparisons.

Day 3: (26 Feb 1979) SAMS-LIMS-NMC-SSU
Overall, the pattern of LIMS and SSU agree, but the LIMS ridge value is about 1600 compared to the SSU 1632. Over North America, on the other hand, LIMS seems lower than SSU, but only by less than 8 dam so that the net LIMS gradient is smaller than SSU.

NMC is, again, very fragmented compared to the others, especially in lower latitudes. In higher latitudes NMC appears about 32 dam lower overall, than the others although the tropical values of about 1440 are in general agreement.

SAMS shows the same general pattern as the others with somewhat less detail. Interestingly, the 1440 line in lower latitudes agrees with NMC versus the others which carry it further equatorward.

Day 4: (2 May 1979) SAMS-LIMS-NMC
In addition to the obvious element that the LIMS is considerably smoother than NMC, the maps are very different in detail. The NMC 1504 contour, for example, does not exhibit the wraparound structure toward the Atlantic that LIMS does and the tropical values are about 1456 compared with LIMS' 1472. The structure over the North American region is not dissimilar, in principle, with the trough and the double-ridge structure shown in both, but that in LIMS is more well defined. SAMS does indicate a wraparound structure, but not the double ridge structure over North America. Again, the lack of high latitude data inhibits comparison in this region.

Day 5: (14 Jun 1980) SAMS-NMC-Berlin-SSU
Overall agreement between the two analyses is quite reasonable, although NMC shows more amplitude in the wave structure and also shows a separate trough over Eurasia. SSU indicates 1456 in the low latitudes which is somewhat lower than NMC. Berlin indicates somewhat less amplitude of the wave features than either NMC or SSU and SAMS shows a very fragmented structure with only the ridge over the North Atlantic.

Day 6: (5 Nov 1980) SAMS-NMC-SSU-Berlin
The major difference, apart from the relative smoothness of the SSU map, is that in both the central trough and ridge the NMC is higher by 32 to 16 dam, respectively. Also, NMC depicts a secondary trough over western Russia extending southwestward which does not seem to to have a counterpart is SSU. Berlin shows elements of both of the above with the same general pattern. SAMS is very fragmented.

Day 7: (5 Feb 1981) SAMS-NMC-Berlin
NMC and Berlin show very similar patterns with the NMC trough lower than that for Berlin. SAMS is very much smoother than the others with no indication of the midlatitude troughs in the Pacific and Eurasia. It is hard to tell if the relatively high trough value is due to retrieval or is simply due to missing data.

<u>Overall impressions</u>

1. NMC, as for the 100-50 mb layer, shows more detail or fragmentation than the other charts.

2. While individual charts may show strong differences, in general the thickness patterns appear quite consistent.

3. As for the 100-50 mb layer, the LIMS gradients in the polar areas appear diminished compared to others.

4. SAMS seems to show a basically similar structure to the others, but does not have values in the polar region which can result in some pattern differences that are misleading. SAMS, however, in general does not depict the detail of the others.

5.1.3 50 - 10 mb

Day 1: (2 Jan 1979) LIMS-SAMS-NMC-Berlin
NMC and Berlin charts appear very similar even to the pinching effect of the 1056 contour towards Russia. In contrast, neither LIMS nor SAMS show any indication of this pinching and both show a ridge 32 dam higher than the others. Interestingly, both LIMS and NMC show evidence of a secondary ridge toward North America that is less well defined in the other two. Finally, SAMS indicates a lower central trough of 896 compared to all the others' value of 928. The result is that both LIMS and SAMS indicate larger gradient than NMC and Berlin.

Day 2: (26 Jan 1979) LIMS-SAMS-NMC-Berlin
All four charts, basically, show the same trough-ridge wraparound structure. Berlin, however, shows a somewhat higher ridge, 1152, versus the others' 1120 and the trough center (928) is closer towards Russia. NMC splits the difference on this point with a double trough structure. Note that Berlin, even with the higher ridge, does not wrap the ridge around toward Europe as do LIMS, NMC and to a lesser extent SAMS.

SAMS seems to show the same basic structure as the others, but the trough pattern is very diffuse with quite a bit of noise in the data.

Day 3: (26 Feb 1979) LIMS-SAMS-NMC-Berlin
With respect to the pattern, NMC indicates a trough extending southward toward Europe which is more than LIMS or SAMS and not quite as extensive as Berlin. Within the central ridge and the North America trough, NMC values appear about 32 dam lower than the others.

SAMS shows similar structure, but appears very noisy compared to other charts. The trough over North America is very amorphous and the European trough, while of proper magnitude, does not push into the ridge at higher latitude.

LIMS ridge value of 1152 is the greatest of the series which results in largest gradients in polar area.

Day 4: (2 May 1979) SAMS-LIMS-NMC-Berlin
As for the other layers for this day, LIMS shows a much smoother pattern than NMC. This latter fragmentation makes the charts difficult to compare, but we can discern a basic resemblance of the double trough with the ridge pushing in over the pole. In lower latitudes, NMC shows pockets of trough-ridge structure that look somewhat unrealistic. Berlin is smoother, but has overall resemblance to NMC while SAMS does not wrap the 1056 line around as a separate feature over North America. We note that both SAMS and LIMS have the 1072 contour over Russia.

Day 5: (14 Jun 1980) NMC-SAMS-Berlin
Berlin shows a very circumpolar strucuture ompared to NMC and a slightly greater ridge value. Interestingly, the closed 1040 contour over Russia exists on both charts, but elsewhere the NMC wave amplitude is quite large compared to Berlin.

SAMS is very noisy and fragmented and while it seems to show a circumpolar pattern, it is very difficult to separate the noise from the signal.

Day 6: (5 Nov 1980) NMC-SAMS-Berlin
NMC and Berlin indicate a similar basic structure with, however, some differences. The trough over Europe in the NMC chart is not as extended as Berlin's, but the ridge over North America is more extensive. Also, the pinched ridge structure over North America and the Atlantic is not evidenced in the

Berlin map though it does seem to appear in SAMS.

SAMS is, again, very noisy but the overall map pattern appears very similar to NMC. One difference is the lack of a closed 1040 contour trough over the western Pacific.

Day 7: (5 Feb 1981) NMC-SAMS-Berlin
NMC and Berlin show basically the same trough and wraparound ridge pattern, but the NMC centers are about 32 dam lower than Berlin.

SAMS is less noisy than previous maps and shows very similar pattern to the others although the cutoff of data at high latitudes restricts discussion of the wraparound structure.

Day 8: (8 Feb 1981) SAMS-NMC-Berlin
With no SAMS data in the polar area, it is difficult to examine significance of differences at higher latitudes. SAMS, however, does not seem to catch the wraparound ridge very well nor the pinching effect over Europe. NMC ridge is greater than the others toward North America, and shows a stronger trough over the Pacific.

Overall impressions

1. Basic agreement on patterns quite favourable.

2. LIMS generally smoother than NMC.

3. SAMS, for this layer, seems somewhat noisy and while it is able to discern the broad pattern quite well, it does not seem to catch the detailed structure of the others.

5.1.4 10-5 mb

Day 1: (2 Jan 1979) LIMS-SAMS-NMC-SSU
All four maps show, basically, similar structure with the major differences in the magnitude of the low and high centres, i.e. no two maps agree in both areas. The NMC maps, however, seem different in two areas (1) the ridge is not as well defined as in the other data sets and (2) there is no evidence of a ridging over North America that appears on the others. LIMS shows largest gradient.

Day 2: (26 Jan 1979) LIMS-SAMS-NMC-SSU
All four maps, again, indicate the same pattern and all indicate about the same value in the low centre. The ridge value, however, ranges from about 512 dam for LIMS to about 488 dam for NMC with SAMS and SSU in between at 496. Interestingly, NMC has a bit more small-scale wave amplitude that does not appear on the other charts.

Day 3: (26 Feb 1979) LIMS-SAMS-NMC-SSU
The overall pattern at high latitudes is similar, but with important differences. The NMC polar ridge is the lowest of the group, 504, and centred about 10 deg latitude further south than the others. We note that the LIMS ridge, as for the previous chart, is the highest of the group, 528, but in this case the Pacific ridge is high as well.

Both NMC and SAMS indicate low latitude structure that is not evident in the others.

Day 4: (2 May 1979) LIMS-SAMS-NMC
Once again, the NMC map for this particular day is very noisy and

fragmented such that it is hard to detect the overall pattern in comparison to LIMS, although the basic trough-double-ridge structure does appear in both. SAMS appears less smooth than LIMS and it is interesting that the ridge over Eurasia agrees better with NMC.

Day 5: (14 Jun 1980) NMC-SAMS-SSU

Superimposed on the circumpolar structure are some features of interest. NMC and SSU indicate a common trough over western Europe with NMC of greater amplitude, but NMC has a flattening of the contours over Russia with no apparent counterpart in SSU. SSU, on the other hand, shows a small trough over eastern Russia that is not indicated in NMC.

SAMS contours are somewhat jagged and noisy and while there is some evidence for the flattening of the contours over Russia, there are no indications of the waves over western Europe or eastern Russia.

Day 6: (5 Nov 1980) NMC-SAMS-SSU

The prominent feature in all charts is the polar low with the wraparound trough over the Pacific toward Russia. While NMC and SSU place this at about the same region, SAMS is a bit weaker and 10 deg further north. In addition, NMC indicates considerably more small-scale wave structure than the others. Note that only NMC places a closed contour over Russia.

Day 7: (5 Feb 1981) NMC-SAMS

Both charts indicate substantial fragmentation, but with a polar high wrapped around by the midlatitude trough. Over the Atlantic, SAMS shows the low to be sharper and protruding into the ridge extension more than does NMC. This is distinct from previous discussions which have tended to show SAMS with less overall structural detail. In this regard, over Russia, SAMS indicates less detail than does NMC and over Europe the closed low shown on the NMC chart is not apparent in SAMS.

Day 8: (8 Feb 1981) SAMS-SSU-NMC

The three maps show similar wraparound structure with SSU the most gradient, SAMS somewhat diffuse and NMC somewhat fragmented.

<u>Overall impressions</u>

1. Basic pattern comparisons quite favourable.

2. The "noise" in SAMS, overall, seems to be diminished in this layer and we begin to see it pick up detail not usually seen at lower layers.

5.1.5 <u>5-2 mb</u>

Day 1: (2 Jan 1979) LIMS-SAMS-NMC-SSU

The basic trough-ridge structure is maintained in the four analyses although with some differences. NMC major closed centres are lower than those of SSU by about 18 dam, but otherwise the maps look similar save for the tropics where NMC presents more detail.

LIMS ridge is the maximum of the series which is then reflected in the overall bulging towards Russia. SAMS is a bit noisier than the others and does not wrap the 656 line around quite as far as NMC or SSU.

Day 2: (26 Jan 1979) LIMS SAMS-NMC-SSU

Between NMC and SSU, NMC does not seem to depict several of the major features shown by SSU such as the double trough structure over North America and eastern Russia as well as the secondary ridge over the Atlantic.

LIMS pattern is in overall agreement with SSU and, again, the gradient in the high latitudes is greatest in LIMS. SAMS seems conservative in the troughs and shows no evidence of the secondary ridge.

Day 3: (26 Feb 1979) LIMS-SAMS-NMC-SSU
The general impression is rather favourable for the four data sets with all showing the pronounced wave 2 structure. Within this overall agreement we note that NMC is a bit conservative compared to SSU although the secondary ridge is a bit sharper in structure.

LIMS values seem high overall by about 16 to 32 dam with the largest gradient of the four. Some structure appears at low latitudes, but this is in an area of flat gradient. In the case of SAMS, the basic pattern exists, but is somewhat vague in that the ridge structures exist, but they do not penetrate far enough north.

Day 4: (2 May 1979) LIMS-NMC-SAMS
Overall pattern comparison is quite good, however LIMS is generally higher by 8 to 14 dam with the largest gradient. Also the ridge over Russia is about 30 deg further west in LIMS than NMC and some additional structure appears in LIMS especially at lower latitudes.

Day 5: (14 Jun 1980) SAMS-NMC-SSU
SAMS, as previously, has a bit more noise in the system with this very evident at lower latitudes. On top of the basic circumpolar pattern it is interesting that NMC and SAMS indicate a ridging effect toward Europe not evident in SSU, but that NMC and SSU suggest a small trough over the Pacific not seen in the SAMS data.

Day 6: (5 Nov 1980) SAMS-NMC-SSU
There is overall agreement in map structure although SAMS seems to have too much detail in the tropical region. All three maps' central value appear consistent, however, we note that the trough toward Russia in NMC at high latitudes is about 30 deg further west than in SSU and is missing altogether in SAMS.

Day 7: (5 Feb 1981) SAMS-NMC
With SAMS missing at higher latitudes it is not clear what value to ascribe to the ridge, but we note that the location seems quite consistent as is that of the trough.

Day 8: (2 Feb 1981) SAMS-SSU-NMC
The basic trough-ridge pattern of the three charts is quite comparable though SAMS seems a little underplayed. The ridge structure seems consistent over Europe, but the SAMS trough over the North Atlantic is relatively weak and less well defined.

Overall impressions

1. LIMS gradient at high latitudes generally higher than others.

2. Noise in SAMS seems better at this layer than lower layers with noise mainly evident in tropics.

3. SAMS, as previously, seems capable of determining gross pattern, but seems to miss detail.

4. NMC on 26 January 1979 is very vague, but this problem seems limited to this one day.

5.1.6 2-1 mb

Day 1: (2 Jan 1979) LIMS-SAMS-NMC-SSU
NMC and SSU show similar structure, but NMC is conservative on the high and low values by about 8 dam. Similarly, NMC values in tropics appear about 8 dam higher than SSU.

LIMS trough value agrees with SSU, but ridge is about 32 dam higher resulting in larger gradient. We note, in addition, the closed 544 LIMS contour over the mid-Pacific with an associated ridging toward the pole with only a weak suggestion of this in the others. SAMS polar centres are higher than SSU, but gradient is similar.

Day 2: (26 Jan 1979) LIMS-SAMS-NMC-SSU
The NMC map centres are about 8 dam higher than those of SSU, and NMC does not indicate the secondary ridge over the North Atlantic.

LIMS values tend to be larger than those of SSU by about 8 dam but do not portray the polar ridges with nearly the detail as either SSU or NMC. In this regard, SAMS is similar to LIMS.

Day 3: (26 Feb 1979) LIMS-SAMS-NMC-SSU
The general comparison of the NMC and SSU charts is very favourable although NMC does not quite get the magnitude of the ridge structure that SSU does. Interestingly neither LIMS nor SAMS develop these ridge structures to the extent of NMC or SSU although they do give an indication of their existence. Also note that the LIMS ridge value is not overdone compared to SSU.

Day 4: (2 May 1979) SAMS-LIMS-NMC
LIMS appears very fragmented compared to the others. SAMS does not catch the ridge structure over Europe or the trough over Russia, but NMC does not quite portray the ridge extension over the North Altantic.

Day 5: (14 Jun 1980) SAMS-NMC-SSU
Basic circumpolar pattern with small trough in South Atlantic although the latter is caught to various degree.

Day 6: (5 Nov 1980) SAMS-NMC-SSU
Basic pattern agreement very good with trough and ridge delineation quite close.

Day 7: (5 Feb 1981) SAMS-NMC
Fairly good agreement on the trough, but the ridge in SAMS is somewhat diffuse and less well defined.

Day 8: (8 Feb 1981) SAMS-NMC-SSU
Very good pattern agreement between NMC and SSU although NMC trough is not as low. SAMS ridge is ill defined.

Overall impressions

1. LIMS has tendency toward high side, but not as clear as lower layers.

2. SAMS tends to have difficulty capturing polar ridge structure.

5.1.7 1-0.4 mb

Day 1: (2 Jan 1979) LIMS-SAMS-NMC
The maps are quite different, overall, though some areas of mutual agree-

ment exist. NMC does not depict the LIMS secondary trough over Russia and wraps the trough around where LIMS wraps the ridge. Within the polar ridge, the difference is 40 dam with LIMS the greater.

SAMS does depict the Russian ridge and trough, but does not seem to push the North American trough to as high a latitude as either LIMS or NMC.

Day 2: (26 Jan 1979) LIMS-SAMS-NMC
The trough and double ridge structure is caught by both LIMS and SAMS although SAMS does not catch a secondary trough over Europe and the highest latitude ridge is about 16 dam lower than that of LIMS.

NMC is very disparate from both LIMS and SAMS with the trough-ridge structure reversed in sign.

Day 3: (26 Feb 1979) LIMS-SAMS-NMC
There is some general agreement among the three maps, but with also certain strong points of disparity. NMC shows a pronounced wave 2 pattern compared to LIMS and SAMS wave 1, i.e. the secondary ridge over North America is not indicated on the latter charts. On the other hand, LIMS does put a secondary ridge over the North Pacific which neither SAMS nor NMC emulate.

Concerning the primary ridge, SAMS is lower than the others by about 16 dam and does not extend toward the pole as much as the others.

Day 4: (2 May 1979) LIMS-NMC-SAMS
As for a previous day, the LIMS ridge becomes an NMC trough plus NMC discerns midlatitude structure not observed by LIMS. SAMS contours very much smoother than LIMS in high latitudes, but contours somewhat noisy in low latitudes.

Day 5: (14 Jun 1980) SAMS-NMC
The basic structure of the two maps is very similar even to the trough over the eastern Pacific. SAMS, however, is much higher in central value approaching the pole and does not depict the additional trough toward the North Atlantic.

Day 6: (5 Nov 1980) SAMS-NMC
Taking into consideration the lack of high latitude SAMS data, the two maps appear quite compatible. NMC troughs appear about 8 dam higher than SAMS, but overall the agreement is good.

Day 7: (5 Feb 1981) SAMS-NMC
Again we see very good agreement between the maps. NMC does depict a ridging effect towards Russia that is only hinted at in the SAMS and also shows more structure in the flat gradient of the tropics.

Day 8: (8 Feb 1981) SAMS-NMC
Overall pattern comparison quite reasonable, but SAMS shows little indication of high latitude ridge over Europe.

<u>Overall impressions</u>

1. LIMS tendency is to be high in the ridges.

2. NMC on several days has reversed trough-ridge structure compared to both SAMS and LIMS.

3. Over the last three SAMS-NMC comparisons, these two data sets show very good agreement.

5.1.8 0.4 - 0.1 mb

Day 1: (2 Jan 1979) LIMS-SAMS

There is generally favourable agreement of the two maps with a central high bordered by two closed low structures. The LIMS is lower in the troughs by about 32 dam with the central value of SAMS uncertain due to the lack of data toward the pole.

Day 2: (26 Jan 1979) LIMS-SAMS

Again, there is basically good compatibility between the patterns. Interestingly, for this day the LIMS trough is higher than that for SAMS by about 32 dam.

Day 3: (26 Feb 1979) LIMS-SAMS

After taking into consideration the lack of SAMS information in the polar area, we see very similar patterns with a central trough, a ridge wrapped around the Atlantic and a second ridge toward western Russia. The values seem to be within about 8 dam. Towards the tropics, the noise of both systems increases so that it becomes difficult to make statements of comparison.

Day 4: (2 May 1979) LIMS-SAMS

LIMS is more fragmented than SAMS with far more small-scale structure.

Overall impressions

There is, generally, very good agreement between the two data sets.

5.1.9 Summary

While we have seen from the above that individual chart comparisons may show strong differences, certain general patterns have emerged.

100-1 mb

1. Within the six layers from 100 to 1 mb, the general patterns of all the data sets are generally quite consistent.

2. NMC, in the lower layers especially, shows more detail or fragmentation than the other charts, particularly LIMS.

3. LIMS gradients in high latitudes seem smaller than the others up to about 50 mb, but switches to being greater than the others from 10 to 2 mb.

4. SAMS appears to show additional "noise" that diminishes with altitude. Overall, SAMS compares quite well with the others on the broad pattern, but does not seem to depict the structural detail as well as the others.

1 - 0.1 mb

1. Above 1 mb, the comparisons between LIMS and SAMS are quite favourable although some differences can occur.

2. From 1-0.4 mb, NMC indicates several days with reversed trough-ridge structure compared to both LIMS and SAMS. However, over the last 3 comparisons, SAMS and NMC show very good agreement.

5.2 Temperatures

Comparing zonal mean cross sections of the different data sets can highlight the spatial variation of systematic differences between them in more detail than the zonal mean statistics. We might expect on undisturbed days the systematic differences would be clearer than on disturbed days, and that differences due to misrepresentation of structures seen on disturbed days would be more clearly found by examining the patterns seen in the full 3-D distributions, using both horizontal maps and vertical cross sections.

5.2.1 Zonal means

The zonal mean cross sections described in this section will be found in Appendix A2.

(a) SAMS and LIMS

2 May 1979 is the only quiet day available for this comparison. The features seen in the SAMS-LIMS difference, Figure 9, are reproduced qualitatively in the undisturbed parts (low and midlatitude) of comparisons for the other days, namely SAMS is cooler by around 4 - 5 K at 1 mb, and by 2 - 3 K at 10 and 70 mb, but is close to LIMS between these levels, apart from a small region at 30 mb 0 - 10 N where SAMS is warmer by 2 - 3 K. The large difference above 0.4 mb, reaching 20 K (SAMS warmer) at 0.1 mb does not appear on 26 Jan 1979 and 26 Feb 1979, but does to a smaller extent on 2 Jan 1979. On 2 May SAMS also shows a relatively thick stratopause region compared with LIMS. The differences on this date are probably due to SAMS being in an operating mode (for technical reasons) which does not give good quality high altitude data.

On 2 January the region of LIMS colder than SAMS above 0.3 mb in middle latitudes, reaches an extreme value of 14 K. This is in a region where the LIMS shows a deep dip in the isotherms. For instance, the 240 K isoline drops from approximately 1.2 mb at the equator to 3.6 mb at 36 deg north, then rises to .1 mb at 68 deg north. SAMS isotherms also dip, but not as deeply, and are more widely spaced.

Noting these regions of larger difference should not obscure the point that mostly the differences are small, i.e. less than 2.5 K for the most part, and less than 5 K almost everywhere.

(b) Berlin, NMC, ECMWF

The radiosonde analyses agree to better than 2 K almost everywhere, except that NMC is up to 6 K cooler than Berlin at the pole on 2 May, and ECMWF is generally 4 K cooler than NMC and Berlin at 30 mb 0 - 30 N.

(c) NMC and SAMS/LIMS

There are larger differences between NMC temperatures and either LIMS or SAMS than there are between LIMS and SAMS themselves. The reader is reminded that two different instruments on different satellites were involved in NMC data, the VTPR on NOAA-5 for 2 January and 26 January, 1979, and the SSU of the Tiros Operational Vertical Sounder (TOVS), on TIROS N, on 26 February and 2 May, 1979, and the SSU on NOAA-6 for the remaining four dates. Additionally, the data from channel 27 of the TIROS N SSU could not be used. Since its weighting function centred at 2 mb, the SSU performance in the upper stratosphere was severely compromised. Results for the first four days are not representative of later periods.

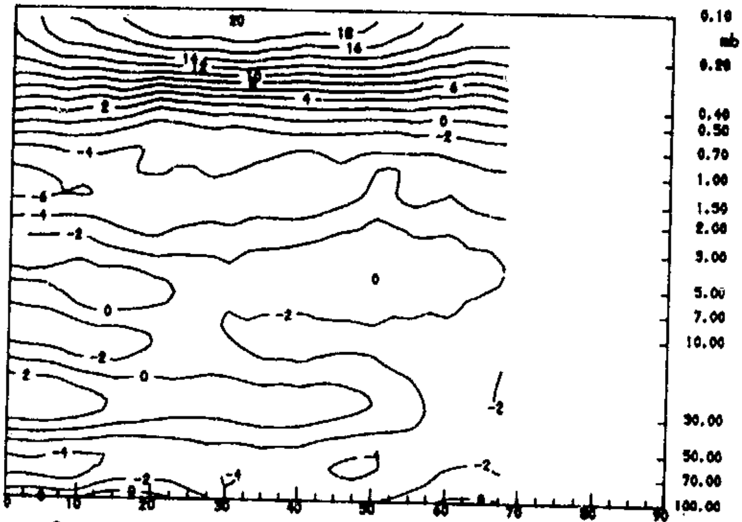


Figure 9. SAMS-LIMS zonal mean temperature, 2 May 1979.

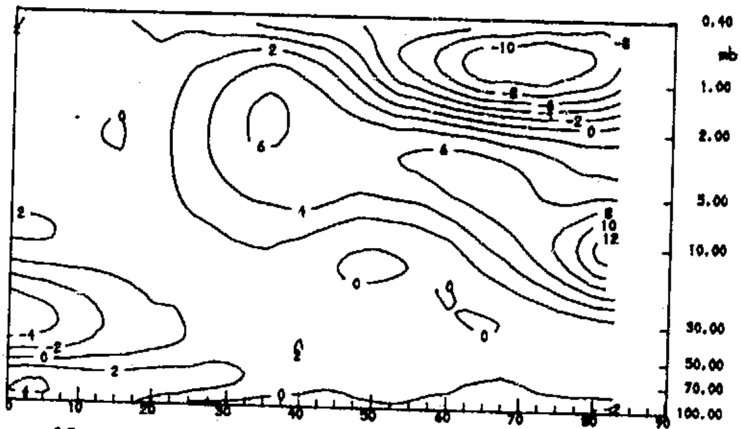


Figure 10. LIMS - NMC zonal mean temperature, 26 Jan 1979.

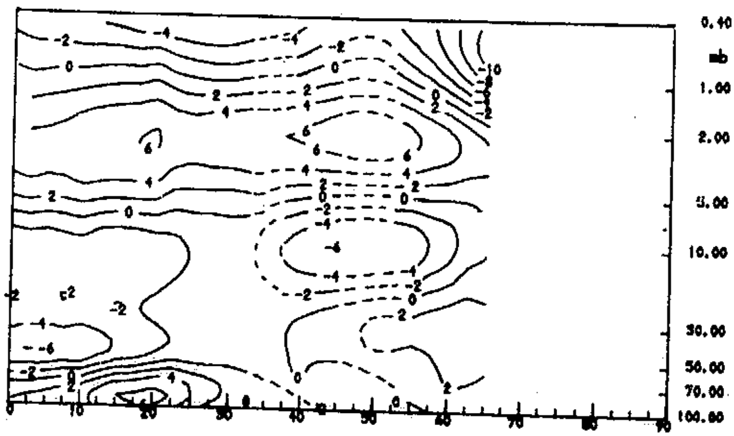


Figure 11. SAMS - NMC zonal mean temperature, 26 Feb 1979.

Restricting attention to the region above 10 mb, on days 1 and 2 there is generally agreement within 2 K from 10 - 1 mb below 30 deg latitude, and at 10 mb up to 45 deg north. This is illustrated by the LIMS minus NMC for 26 January, shown in Figure 10. NMC cross sections for these days appear to be 5 - 8 K cooler than SAMS/LIMS at 2 mb in midlatitudes (40 deg), with the cold region extending poleward, and downward at high latitude compared to LIMS. Temperature adjustment factors published by GELMAN et al. (1982) are in the sense of reducing the differences by 2 - 4 K. NMC temperatures at 0.4 mb and to a lesser extent 1 mb are cooler than LIMS and SAMS on 2 January, when they are warm, and warmer on 26 January, when they are cool. This suggests that the regression retrieval may not follow the large temporal variations in atmospheric temperature in this region.

Some of the same features occur on days 3 and 4, when comparisons were made with results derived from the SSU instrument. Figure 11 shows the SAMS minus NMC differences for 26 February. Agreement with LIMS/SAMS below 30 deg latitude is generally within 4 K, with NMC cooler. LIMS/SAMS results are again warmer by 5 - 7 K at 2 mb and 45 deg north. There is another region of large difference from LIMS at high latitudes. On 26 February, during the warming, LIMS temperatues are above normal in the stratosphere, but cooler in the mesosphere. The SAMS results support LIMS in the mesosophere, but do not extend poleward far enough to confirm the warm region near 5 mb. The NMC temperatures are higher than LIMS in the mesosphere and lower in the stratosphere.

Similarly, in May the NMC temperatures are now lower than the LIMS/SAMS stratopause temperatures, which have increased with the coming of summer. Use of the temperature corrections would improve some of the comparisons, but degrade others. These characteristics again may indicate that the regression retrievals, especially without channel 27, do not follow the temperature variations, notably under disturbed winter conditions.

(d) SAMS/LIMS and radiosondes

The differences here are generally less than 3 K, but no clear pattern emerges, except that there is a tendency for the difference between SAMS and the radiosondes to be greater at 30 mb than at 50 or 10 mb by up to 5 K in low to middle latitudes. The absolute value of the difference varies from case to case, but is presumably related to the smaller lapse rate seen by SAMS between 30 and 10 mb, when compared with other data sources.

5.2.2 Comparisons of temperature maps

The temperature maps discussed in this section will be found in Appendix A3.

Day 1: (2 Jan 1979)
This day is relatively undisturbed at the lower levels, but has a large (28 K amplitude) wave 1 disturbance in the higher levels, peaking about 2 - 3 mb. At 30 and 10 mb there is a cold region over the pole, with a warm region in the Eastern Hemisphere around 50 - 60 N. At 0.4 mb the warm region is over the pole. The LIMS cross section at 90 E/90 W shows a sloping "pancake" of warm air over the polar cap (see Figure 12) which has been joined subjectively over the pole.

At 30 mb the Berlin and NMC maps see the warm region split into two centres. There is a slight indication of the splitting in the LIMS map, but none in the SAMS map. However the SAMS 100 mb map sees the splitting. At 10 mb the warm region is relatively weak in Berlin and NMC compared with LIMS and SAMS. At 1 and 0.4 mb LIMS and SAMS show general agreement, whilst NMC gives what looks like a smoothed version of the 1 mb map, but is completely different at

0.4 mb. It has the 255 K contour in roughly the same place, but it surrounds a cool area, not a warm area.

The differences at 30 and 10 mb are consistent with the inherent low vertical resolution of the satellite data, with SAMS being lower than LIMS. The radiosonde data show clearly that the analysis at 10 mb cannot be changed very much in the 90 E/50 N region from that given by Berlin or NMC. If the warm layer seen on the cross section is sharply bounded in its lower side, and confined to the region above 10 mb, then the Berlin and NMC maps will not show it, but the SAMS and LIMS 10 mb maps will be affected, and SAMS will be more affected because of its poorer vertical resolution. In Figure 12 the warm region can be seen just penetrating 10 mb at 55 - 60 N in the LIMS cross section, but there is no sign of it in the Berlin cross section.

Day 2: (26 Jan 1979)

This day is much more disturbed at 30 and 10 mb than day 1, with a 25 K wave 1 disturbance peaking at 65 N and 30 mb, but there is better qualitative agreement between the satellites and radiosondes, which is even noticeable in the statistics of numerical differences (Table 3). However if difference maps are examined, differences of up to about 15 K are found, associated with the placing of the steep horizontal temperature gradient. The only qualitatively obvious point of difference is in the shape of the cold region in the NMC maps.

At 1 and 0.4 mb, SAMS and LIMS are in reasonable agreement, but NMC is totally different, as was the case for the day 1 0.4 mb map.

The improved agreement at lower levels may be due to the different structure of the temperature distribution, which is much less a strongly sloping system, rather more a change of phase. The 0.4 mb structure is similar to the 10 mb structure, but inverted. In this case we would expect changes in vertical resolution to affect horizontal maps much less.

Day 3: (26 Feb 1979)

This day is characterized in the upper atmosphere by significant and changing wave activity with height. At the 100 mb level there is a broad vortex centered about the pole. This situation changes to a wave number 2 at 50 mb with vortices centered at 50 N, 260 E and 60 N, 50 E. The position and intensity of the vortices change with altitude both in latitude and longitude creating strong horizontal and vertical gradients which complicate both remote sensing measurement interpretation and map analyses using conventional data. The vortices weaken at about the 7 mb level and merge to a single pole-centered vortex at 1 mb with mild gradients at that level and higher.

At 30 mb the radiosonde analyses (Berlin, NMC and ECMWF) agree well everywhere, well within 5 K except for a small region of up to 10 K over the pole and at 90 E, 60 N when the horizontal temperature gradient is largest. Berlin is warmer than the other two. SAMS and LIMS agree well with Berlin except in this same region, with SAMS 20 K warmer and LIMS 18 K warmer at 80 E, 60 N.

At 10 mb SAMS and LIMS are 15 K warmer than Berlin at around 60 E, 60 N and 15 K cooler at 90 E, 60 N, again corresponding to the steepest temperature gradient. The NMC map looks odd in comparison with the others; examination of the difference from Berlin (Figure 13) shows a localised area of up to 30 K difference at 90 E, 70 - 80 N, and a few other "bull's-eyes" of 10 K amplitude at other places on the map, which may indicate a quality control problem with the NMC analysis. LIMS and SAMS differ by less than 5 K in most places, with isolated areas of 10 K, only loosely associated with the shape of the field.

LIMS and SAMS are in very good agreement at 0.4 and 1 mb with maximum

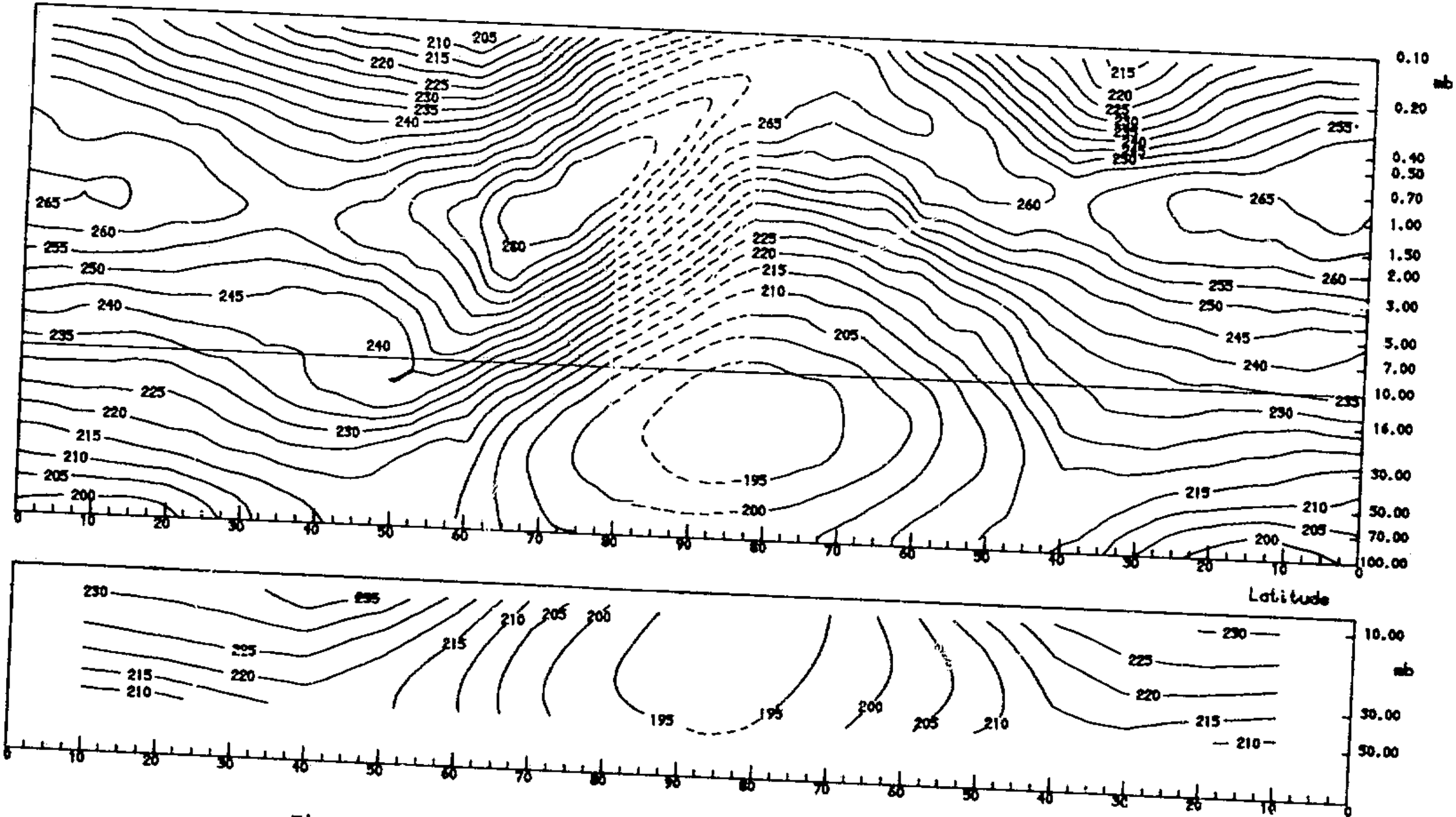


Figure 12. LIMS (top) and Berlin (bottom) temperature cross section, 2 Jan 1979, from 90 E to 90 W across the North Pole.

Table 3. Comparison of 100 mb height fields (decametres).

Day	Mean difference							R.M.S. difference						
	LS	LN	LE	SN	SE	NE	EE	LS	LN	LE	SN	SE	NE	EE
1	0.1	2.0		1.9				2.2	4.6		4.4			
2	0.1	4.2		4.9				2.2	13.9		13.5			
3	0.2	1.4	-0.1	1.4	-0.3	-1.6	-1.2	2.1	4.9	2.4	4.4	1.7	4.5	3.4
4		0.3							3.7					
5				0.0	3.9	3.9	-0.6				0.3	2.3	2.3	1.8
				0.0	3.1	3.1	0.6				0.3	1.9	1.9	3.0
7						1.6	0.8						3.8	6.2
8				0.0	1.6	1.7	-1.2				0.5	2.3	2.2	4.2

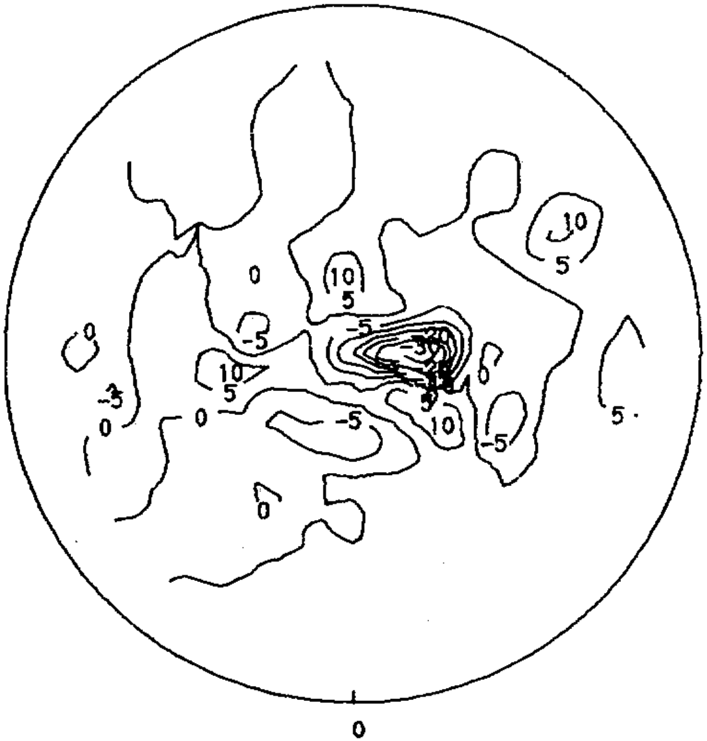


Figure 13. NMC - Berlin 10 mb temperature, 26 Feb 1979.

Figure 14. SAMS - LIMS 30 mb temperature, 26 Feb 1979.

differences less than 5 K everywhere except in a few small geographic regions near the highest measurement latitude. In these regions, the differences are approximately 7 K.

NMC at 0.4 and 1 mb agrees with SAMS and LIMS to about 5 K in low latitudes, but is up to 20 - 25 K warmer in polar regions in the eastern hemisphere.

There are no major problems with the SAMS/LIMS comparisons for February 26, 1979. For the most part, differences are small at all levels with a few exceptions noted above. The largest differences occur near the poles and near the locations of the two vortices associated with the warming. While differences are large in these areas, they are not considered an important problem since they are concerned to a rather narrow geographic region.

The most significant satellite experiment differences appear in meridional cross sections, particularly for the 100 E longitude which passes through a region of rather sharp horizontal and vertical temperature gradients. Figures 15a and 15b show these cross sections. Note that overall features are in agreement, i.e. a downward sloping stratopause with increasing latitude, the presence of a sharp horizontal gradient below 5 mb, and downward sloping temperature surfaces below 5 mb with increasing latitude northward. However, the slopes are quite different in the transition region northward of about 45 N. This area is confined to a rather narrow altitude and latitude range, and in itself, is not considered a major problem. The other data sources also have difficulty in defining the temperature behaviour in this region.

The Berlin analyses for example, show no temperature decrease (Figure 15c), while NMC results show a slope downward in fair agreement with the satellite results below about 30 mb; but they also show an upward slope for levels above 30 mb in opposition to the satellite-derived picture.

A major difference can also be seen in the cross section around a latitude circle at 62.5 N (Figure 16), especially in the region around 60 - 100 E, when Berlin shows a very steep vertical temperature gradient. LIMS and SAMS also show this gradient, but less steeply, consistent with the poorer vertical resolution of the satellite instrument.

In such atmospheric situations, missing or sparse data can lead to problems in the mapping and gradients can lead to errors in remotely sensed results if they are not properly included in the retrieval. LIMS and SAMS had vastly different vertical resolutions (2 km for LIMS, 10 km for SAMS) and LIMS processing included gradient corrections while SAMS processing did not. These factors can explain up to 5 K for normal atmospheric gradients. For this day, larger effects could result however due to the steep gradients associated with the vortices. This is suggested by the LIMS/SAMS difference associated contours which look much like the vortices (see Figure 14). This type of difference could also occur if the locations of the vortices are slightly displaced for the two experiments due to azimuth errors, for example.

The fact that the temperature slopes defined by the various data sets are so different for the 100 E cross section (Figure 15) and not so different for the other meridians studied also suggests that the problem is associated with the gradients created by the vortices. Still another point that supports this conclusion is the fact that the slope differences and the horizontal map differences are largest in the range 50 mb to 10 mb which is where the wave number two condition existed. Some of this behaviour could be studied by degrading the LIMS resolution to the SAMS size and repeating the comparisons. Also, the map analyses using conventional data should be reviewed in light of effects caused by the vortices.

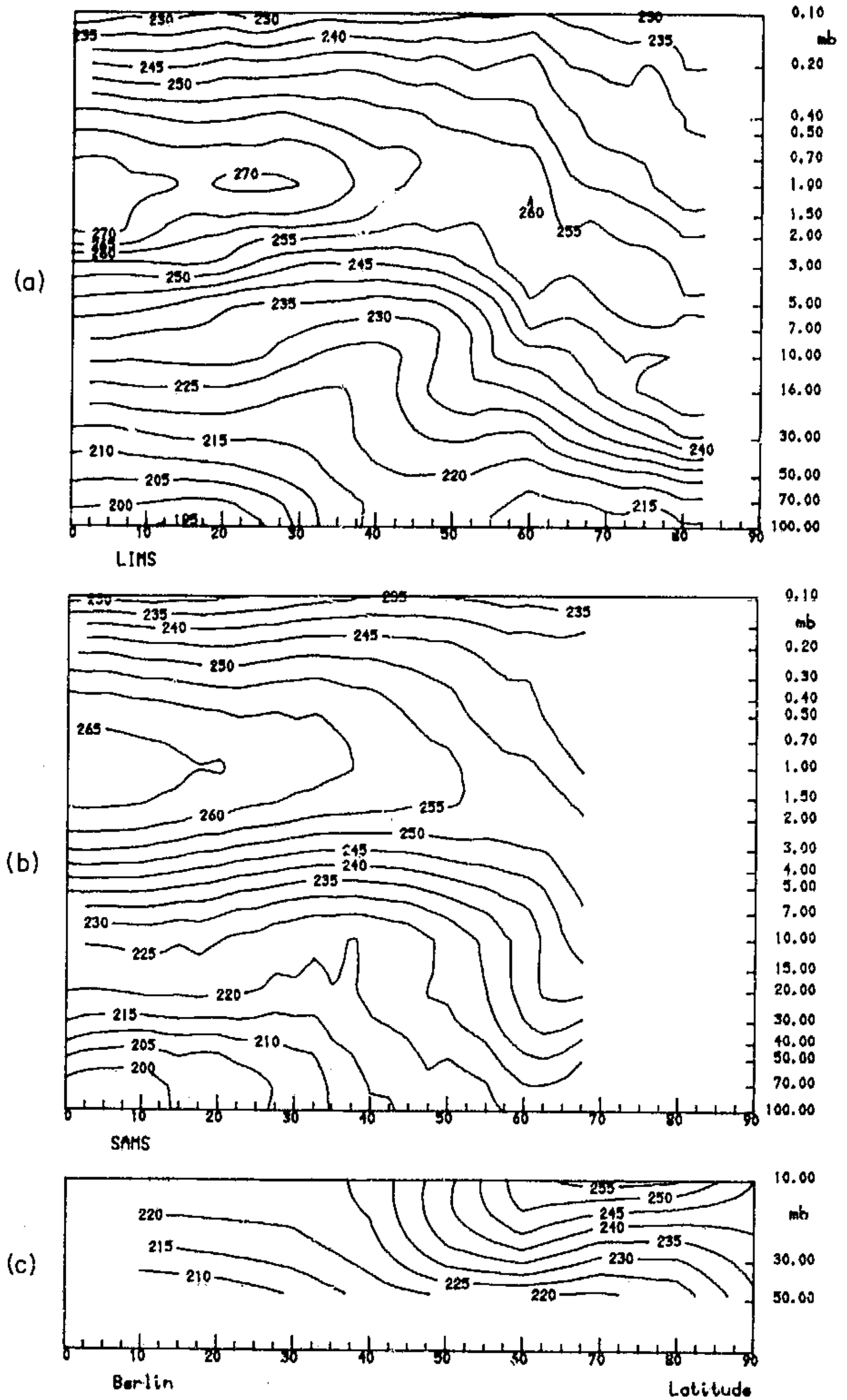


Figure 15. Temperature cross sections at 100 E, 26 Feb 1979.

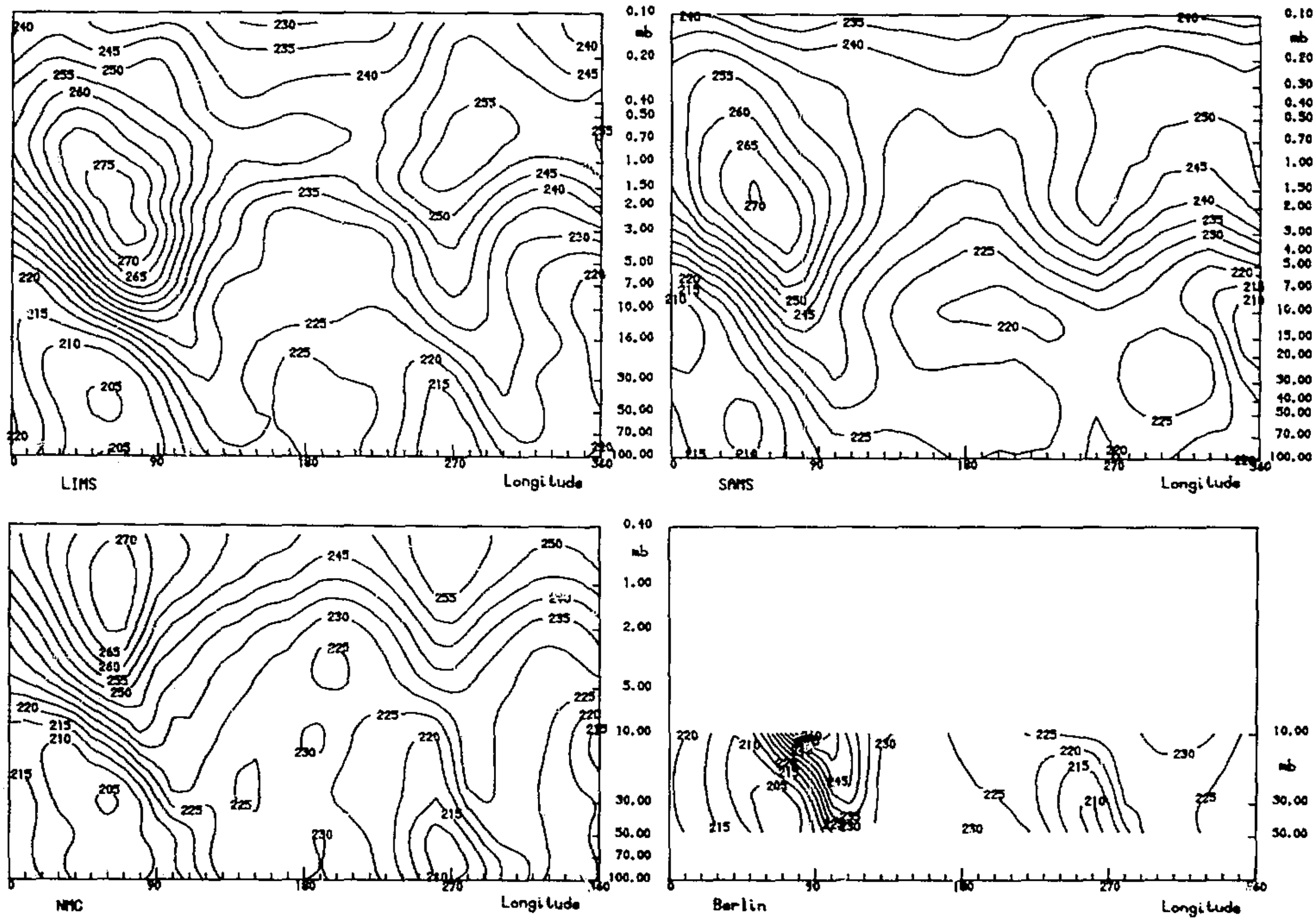


Figure 16. Temperature cross sections around 62.5 N, 26 Feb 1979.

Day 4: (2 May 1979)

This is an undisturbed day with very flat temperature fields. At 30 mb all four maps show only 220 and 225 K contours, and have the main highs and lows in roughly the same place. Much the same is true of 10 mb, although the SAMS contours show "zig-zags" and the NMC contours show "blobs" -- these seem to be features of their respective analysis schemes.

At 1 and 0.4 mb SAMS and LIMS show the polar region to be warm, whilst NMC shows it cold -- this is a clear feature on the zonal mean cross section also.

Day 5: (14 Jun 1980)

Like day 4, this day is undisturbed, but here there are significant zonally symmetric temperature gradients across the maps. SAMS and NMC show their familiar zig-zags and blobs, ECMWF also shows a fine scale structure on the contours which is not reflected in other data. Again the differences are more clearly seen in the zonal mean (Section 5.2.1). At 1 and 0.4 mb NMC shows smaller horizontal gradients than SAMS.

Day 6: (5 Nov 1981)

These data show a strong offset cold centre at lower levels, with some change to wave two about 1 mb. In the lower stratosphere, differences are up to 8 K between all data sources, with no clear picture, and zonal mean differences are up to 4 K. At 1 mb SAMS and NMC show rather similar patterns, but with SAMS about 4 K warmer at mid and low latitudes. At 0.4 mb, there is little similarity between SAMS and NMC, SAMS shows a simple wave 2 pattern, whilst NMC shows a flatter and rather complicated field.

Day 7: (5 Feb 1981)

This was a day of very large amplitude wave 1 and very large horizontal temperature gradients.

At 30 mb differences are generally about 2 K in the zonal mean, but up to 12 K at 90 N (ECMWF - NMC) where the temperature gradient is greatest. At 67 N, SAMS is 8 K warmer than the other analyses, which agree with each other.

At 10 mb NMC shows "blobs" compared with Berlin, with one blob at 60 E, 65 N giving NMC 24 K warmer. The detailed shapes of the warm and cold areas differs between SAMS, Berlin and NMC.

At 1 mb SAMS and NMC are in qualitative agreement, but with numerical differences up to 8 K. As before, the NMC 0.4 mb map is very different from SAMS in detail.

5.3 Statistics of differences

Statistics have been prepared for temperature and thickness only. Of the many parameters which could be calculated, two were chosen as being most likely to give information about the nature of differences. These are:

(a) Mean difference of temperature at a given level, or of thickness between a pair of levels, giving a measure of the overall systematic difference. The average is taken over the region of overlap between the data sources being compared and on a latitude-longitude grid, rather than area-weighting. The numbers are therefore not strictly comparable between pairs of instruments, but nevertheless give a useful overall impression.

(b) rms differences between the departures of fields from their individual zonal means. This compares the accuracy with which each system describes the patterns of temperature and thickness.

In the tables, the following notation is used to identify data sources:

A: SAMS
L: LIMS
S: SSU
N: NMC
B: Berlin
E: European Centre.

The notation, e.g. AL, means SAMS minus LIMS, whilst EE means European Centre 00Z - 12 Z. In comparisons with European Centre data, the appropriate one of the available pair has been used, where this matters.

(i) 100 mb heights

No satellite system measures geopotential heights but some base level is needed in order to compute geostrophic winds. Each data source has used a different base level, so it was felt worthwhile comparing height at one pressure level. The 100 mb level was chosen because it should be the best level of those we have for radiosonde analyses. Table 3 gives mean and rms differences in dam for those cases where comparison is possible. With the possible exception of day 2 NMC, all the differences are small compared with the thickness differences to be discussed below. There is some small component of difference due to interpolation onto a common grid. For example, SSU and NMC for days 5, 6 and 8 use the same data, but show a small difference.

These numbers should be divided by approximately 15 to give percent values for comparison with Tables 4 and 5. The column EE will contain differences due to the change in the atmosphere in 12 hours together with a contribution to the irreducible analysis error.

Data Source	100 mb height field used
NMC	NMC analysis
Berlin	Berlin analysis
ECMWF	ECMWF analysis
SSU	Days 1-4: FGGE; Days 5-8: NMC
LIMS	FGGE
SAMS	None used; only thickness provided.

(ii) Thicknesses 100 - 10 mb

Three thicknesses have been compared in this part of the atmosphere, 100 - 50 mb, 50 - 10 mb, 100 - 10 mb, with the expectation that 100 - 10 mb will provide better comparisons. Differences have been expressed as percent of total thicknesses, to aid comparison between the layers. Both satellite and radiosonde analyses are available in this region.

The mean differences (Table 6) show fair consistency between days for each comparison, but no clear pattern emerges. The rms differences (Table 7) give the impression that satellite-satellite (SS) comparisons and radiosonde-radiosonde (RR) comparisons are better than satellite-radiosonde (SR) comparisons, and that less disturbed days (4,5,6) give better comparisons than more disturbed days (1,2,3,7,8). This is borne out by making rough averages of all the numbers in the table under these categories:

Table 4. Thickness rms difference (percent).

Day	Press	AL	AS	LS	AN	SN	LN	AB	LB	AE	LE	NB	NE	EE
1	100 50	1.4			2.0		1.4							
2		1.4			2.3		1.6							
3		1.3			2.2		1.7			1.7	0.9		1.4	0.8
4		0.9			1.4		1.0							
5					1.1					1.2			0.7	0.4
6					2.0					1.9			0.9	0.5
7					2.8					2.5			1.3	1.2
8					2.6					2.3			1.4	0.9
1	100 10	0.6	0.9	0.7	1.1	1.4	1.0							
2		0.8	0.7	0.7	1.1	0.9	0.9							
3		1.0	0.8	1.1	1.6	1.8	1.3							
4		0.4			0.7		0.5							
5			0.4		0.5	0.4								
6			0.7		0.9	0.6								
7					1.3									
8			0.9		0.9	0.8								
1	50 10	0.5			1.3		1.4	1.3	1.3			0.9		
2		0.9			1.1		1.0	1.1	1.1			1.1		
3		1.1			1.6		1.3	1.4	1.3			1.0		
4		0.3			0.7		0.6	0.6	0.5			0.6		
5					0.6			0.4				0.4		
6					0.8			0.8				0.6		
7					1.1			1.1				1.1		
8					1.2			1.0				0.9		

Table 5. Thickness mean difference (percent).

Day	Press		AL	AS	LS	AN	SN	LN	AB	LB	AE	LE	NB	NE	EE
1	100	50	-0.9			0.2		1.1							
2			-0.5			0.6		1.1							
3			-0.5			0.5		0.9			0.2	0.4		-0.3	-0.2
4			-1.8			-0.1		1.5							
5						-0.8					-0.8			-0.2	0.1
6						-1.3					-1.6			-0.4	-0.1
7						0.2					-0.9			-0.4	0.1
8						-0.1					-0.3			-0.6	0.3
1	100	10	-0.7	-1.1	-0.3	-0.3	0.7	0.4							
2			-0.6	-0.9	-0.4	-0.2	1.3	0.6							
3			-0.6	-1.1	-0.6	-0.2	1.5	0.7							
4			-0.9			0.2		0.9							
5				-0.4		-0.1	0.3								
6				-0.6		-0.5	-0.4								
7						0.0									
8				-0.1		-0.2	-0.1								
1	50	10	-0.7			-0.5		0.1	-0.3	0.2			0.0		
2			-0.7			-0.6		0.4	-0.3	0.5			-0.1		
3			-0.7			-0.4		0.6	-0.5	0.5			-0.4		
4			-0.5			0.3		0.7	0.0	0.4			-0.4		
5						0.1			0.0				-0.2		
6						-0.6			-0.5				-0.2		
7						-0.1			-0.1				0.7		
8						-0.2			0.0				-0.3		

Table 6. Mean temperature differences.

Day	Press	AL	AN	LN	AB	LB	AE	LE	NB	NE	BE	EE
1	100	1.6	1.6	-0.4								
2		2.1	2.2	-0.2								
3		1.8	1.2	-0.7			0.5	1.3				-0.1
4		-0.9	-0.8	-0.3								
5			-4.8				-3.7			1.1		0.1
6			-3.1				-2.9			0.2		0.0
7			-1.6				-0.4			1.7		0.1
8			-1.9				-0.9			0.9		0.4
1	50	-2.1	-1.5	0.5	-0.6	1.3			0.5			
2		-1.6	-1.1	0.6	-0.4	1.2			0.3			
3		-1.4	-1.1	0.5	-0.1	0.9	0.2	0.6	-0.1	-1.1	-0.8	-0.7
4		-3.0	-1.6	1.4	-1.0	0.8			-1.3			
5			-0.7		-1.2		0.8		-0.6	1.0	1.5	0.1
6			-3.3		-3.4		-2.6		0.0	0.4	0.2	-0.1
7			-0.8		-0.5		-1.8		0.3	-2.0	-2.4	-0.2
8			-1.2		-0.9		-2.6		-0.3	-2.4	-2.3	0.7
1	30	-0.8	-0.9	-0.2	-0.4	0.6			0.3			
2		0.0	-0.5	-0.2	-0.1	0.4			0.3			
3		0.4	-0.2	0.1	0.6	0.8	1.9	1.6	-0.6	0.4	0.3	-1.0
4		0.4	1.0	0.6	0.4	0.1			-1.2			
5			2.8		2.8		5.9		-0.5	2.2	2.3	-0.1
6			0.5		0.2		2.6		0.0	1.3	0.8	0.1
7			1.4		1.3		-2.0		1.3	-3.6	-4.6	-0.7
8			0.8		1.0		-2.4		-0.8	-2.8	-1.8	0.8
1	10	-2.0	0.3	2.4	1.1	3.1			1.0			
2		-3.6	-2.0	3.0	-1.2	2.6			-1.4			
3		-5.4	-3.2	3.4	-3.5	2.4			-2.2			
4		-2.6	-0.9	3.2	0.6	2.4			-0.9			
5			-3.6		-2.3				0.3			
6			-4.1		-3.0				0.2			
7			-4.0		-3.0				0.4			
8			-3.0		-2.1				-0.9			

Table 7. Temperature rms differences.

Day	Press	AL	AN	LN	AB	LB	AE	LE	NB	NE	BE	EE
1	100	3.4	4.3	2.2								
2		3.4	3.9	2.3								
3		3.1	4.0	2.3			3.6	1.8				1.4
4		2.4	2.6	1.8								
5			2.8				2.7			1.2		1.0
6			3.7				3.7			0.9		1.2
7			4.5				5.2			2.2		1.9
8			4.6				4.4			1.3		1.6
1	50	2.3	3.1	1.5	3.0	1.8			1.9			
2		2.3	3.0	1.8	2.8	2.0			1.9			
3		2.9	3.7	2.0	3.7	2.4	3.7	1.8	2.5	1.8	1.8	2.2
4		1.5	2.2	1.3	2.0	1.0			1.6			
5			1.8		1.6		1.9		1.1	1.2	1.2	0.9
6			3.2		3.2		3.4		1.3	1.3	1.4	1.1
7			4.0		4.5		3.9		2.8	2.4	2.4	2.1
8			3.8		3.2		3.2		2.0	2.2	2.0	1.8
1	30	1.5	2.3	1.8	2.9	2.3			2.0			
2		2.1	2.7	1.7	2.6	2.1			2.1			
3		2.7	3.3	2.1	3.9	3.3	3.8	3.0	2.4	2.4	2.1	2.1
4		1.1	1.6	1.3	1.4	1.1			1.5			
5			1.3		1.3		1.3		1.2	0.9	1.1	0.6
6			1.9		2.2		2.2		1.1	1.2	1.6	0.8
7			2.7		3.9		2.7		2.5	2.2	3.0	2.0
8			2.3		2.8		2.0		2.3	2.2	2.8	1.7
1	10	2.5	5.4	5.6	4.4	4.5			2.7			
2		2.7	3.1	3.2	4.1	3.5			3.7			
3		2.6	4.1	4.2	4.9	4.6			5.1			
4		1.2	2.0	2.3	2.3	2.2			2.0			
5			2.2		1.8				2.2			
6			2.2		2.5				1.7			
7			2.6		4.6				5.0			
8			3.9		4.2				3.7			

	SS	SR	RR
Quiet	0.5	0.9	0.6
Disturbed	0.9	1.5	1.1

These percentage figures should be multiplied by about 2.5 for comparison with temperatures in the next section..

(iii) Temperatures 100 - 10 mb

Temperatures have been compared at four levels in this altitude range, 100, 50, 30 and 10 mb. As is to be expected, these comparisons show the same features as the thicknesses. The summary table for the rms differences in this case is:

	SS	SR	RR
Quiet	1.5	2.2	1.3
Disturbed	2.6	3.3	2.6

(iv) Thicknesses 5 - 0.1 mb

In this part of the atmosphere, only satellite data are available for comparison of maps. Some points can be extracted from Table 8:

*The quiet/disturbed effect is clearly visible in the rms values.

*The difference between SSU and NMC (on days 3-8) which are based in part on the same data, is not strikingly better than any of the other differences.

*The change from VTPR to TIROS-N shows to some extent in the NMC days 1 and 2 comparisons in the 1 - 0.4 mb layer.

(v) Temperatures 5 - 0.1 mb

As SSU does not retrieve temperatures, only three instruments are available in this section. The main points in Table 9 are:

*The increasing error with height of the NMC data on days 1 and 2.

*The erratic behaviour of the mean difference between SAMS and LIMS at 0.1 mb.

Both of these can be seen in the cross sections and maps described in Sections 5.1 and 5.2.

Table 8. Thickness statistics above 10 mb.

Day	Press		Mean AL	Mean AS	Mean LS	Mean AN	Mean SN	Mean LN	R.M.S. AL	R.M.S. AS	R.M.S. LS	R.M.S. AN	R.M.S. SN	R.M.S. LN
1	10	5	-0.9	-0.3	0.5	-0.2	0.4	0.7	1.1	1.2	1.4	2.0	1.1	2.2
2			-1.5	-0.4	1.1	-0.6	0.6	1.4	0.9	1.1	1.0	1.4	0.8	1.4
3			-1.9	-0.9	1.3	-0.8	0.6	1.7	1.0	1.0	1.2	1.4	1.1	1.7
4			-0.8			0.5		1.0	0.4			0.5		0.6
5				-1.2		-1.0	0.0			0.5		0.6	0.4	
6				-1.1		-1.6	-0.2			0.5		1.7	1.7	
7						-1.4						2.2		
8				-1.0		-0.9	0.9			1.2		1.8	2.2	
1	5	2	-0.4	1.1	1.3	0.6	0.1	1.2	0.9	0.8	1.2	1.2	0.9	1.6
2			-0.6	1.1	1.7	0.7	-0.1	1.4	1.3	1.1	1.2	1.5	1.3	1.9
3			-0.4	1.4	2.0	1.6	0.0	2.0	1.2	0.9	1.0	0.8	1.0	1.6
4			-0.7			1.1		1.8	0.4			0.3		0.5
5				0.8		1.5	0.6			0.4		0.6	0.3	
6				0.8		0.4	0.4			0.5		0.6	0.4	
7						0.5						1.2		
8				1.0		0.4	0.7			0.9		0.9	0.7	
1	2	1	-1.0	1.5	2.6	0.5	-0.8	1.7	1.0	1.1	1.5	1.1	0.9	1.9
2			-1.0	1.4	1.9	0.0	-1.2	0.6	1.3	1.8	1.7	1.9	1.5	1.9
3			-1.2	1.1	1.6	1.2	-0.3	1.4	0.9	1.5	1.4	1.1	1.0	1.3
4			-1.9			0.7		3.0	0.3			0.5		0.6
5				1.0		1.4	0.6			0.4		0.5	0.3	
6				0.9		1.0	-0.1			0.5		0.6	0.4	
7						1.6						0.7		
8				1.5		1.5	-0.2			0.8		0.6	0.8	
1	1	0.4	-1.3			-0.1		1.8	1.0			2.1		2.3
2			-1.1			-1.1		-0.5	1.1			3.3		3.4
3			-1.5			-1.1		-0.6	0.7			1.3		1.6
4			-1.0			-0.5		1.3	0.4			0.4		0.5
5						-1.1						0.4		
6						-0.3						0.6		
7						-0.4						1.3		
8						-0.2						1.3		
1	0.4	0.1	0.8						1.3					
2			-0.2						1.4					
3			0.3						0.9					
4			4.5						0.6					

Table 9. Temperature mean differences above 10 mb.

		Mean			R.M.		
Day	Press	AL	AN	LN	AL	AN	LN
1	5	-1.4	0.4	2.0	2.6	4.0	4.4
2		-2.3	0.9	3.8	2.6	3.9	4.6
3		-2.0	1.3	4.4	2.4	2.8	4.0
4		-0.3	2.4	2.2	1.1	0.8	1.4
5			0.8			1.5	
6			-3.4			1.3	
7			-3.1			3.1	
8			-2.7			2.6	
1	2	-1.1	2.1	3.8	2.4	2.4	3.5
2		-1.1	2.1	2.9	2.9	4.1	4.2
3		-0.8	5.1	4.6	2.7	2.4	2.5
4		-3.4	2.6	6.6	1.1	1.4	1.6
5			5.1			1.6	
6			3.5			1.4	
7			5.4			1.9	
8			4.7			1.2	
1	1	-2.9	-0.3	2.8	2.7	3.8	5.7
2		-3.0	-3.3	-1.9	3.1	6.8	6.4
3		-4.0	-0.2	0.9	1.9	3.3	3.9
4		-4.6	-0.2	6.0	1.0	1.4	1.5
5			0.4			1.3	
6			2.1			1.5	
7			3.3			2.4	
8			3.3			2.5	
1	0.4	-2.5	-2.5	3.2	2.7	7.8	7.6
2		-1.8	-3.8	-2.7	3.3	10.5	11.6
3		-1.4	-5.7	-6.0	1.7	3.3	3.7
4		1.7	-2.2	-1.8	1.4	1.0	1.4
5			-6.0			1.2	
6			-4.3			3.5	
7			-7.4			3.5	
8			-7.2			2.9	
1	0.1	7.9			4.7		
2		2.5			3.8		
3		-0.6			3.0		
4		17.5			1.9		

6. TEMPERATURE WAVE STRUCTURE

The temperature fields were Fourier analysed into a zonal mean and 6 waves. However, because of the large number of possible comparisons, only waves 1 and 2 were studied. The data for this section will be found in Appendix A4.

6.1 Wave 1

Day 1: (2 Jan 1979)
Both SAMS and LIMS found a double maximum at about the same place: 2 - 3 mb at 70 N and 0.1 mb at 60 N. LIMS found about 28 K for both maxima and SAMS found 28 K for the lower and 23 K for the upper maxima. There were marked minima of approximately 2 K at approximately 0.5 mb. The phases were in good agreement. The NMC field showed the lower peak (maximum value 21 K) but the measurements do not reach 0.1 mb and the upper peak was not seen by the NMC as expected. NMC amplitudes did not cut off as rapidly above the lower peak as SAMS and LIMS. There was some discrepancy in the low stratosphere: at 10 mb SAMS and LIMS are 20 K at the peak at 60 N whereas Berlin reached about 12 K and NMC only 10 K. There was, however, good agreement with the phase at this level.

Day 2: (26 Jan 1979)
Again LIMS and SAMS found a double peak of 25 - 26 K each, in remarkably good agreement; the minimum between was approximately 4 K at 1.5 mb for each. The NMC analysis showed a single maximum (23 K) in good agreement with SAMS and LIMS but decaying more slowly above and showing no sign of increasing above 1.5 mb. SAMS and LIMS showed a westward tilt with increasing height at all levels, whereas NMC did below 1 mb but an eastward tilt above. Berlin found the same lower peak as the others with good amplitude (26 K) phase agreement.

Day 3: (26 Feb 1979)
Amplitudes were about half as strong on this day. NMC showed a double peak with maxima of 14 K at both 2 mb and 70 mb at 70 - 75 N. LIMS found similar peaks although the top one was slightly stronger (16 K) and the lower slightly weaker (12 K). SAMS found rather weaker amplitudes than NMC or LIMS, although comparison at the maxima is not possible because they were further north than SAMS views. ECMWF and Berlin found a lower peak in good agreement with the NMC.

Day 4: (2 May 1979)
Amplitudes were just a few degrees, but there was very encouraging agreement. LIMS, SAMS and NMC found a peak at about 35 N, 2 mb with an amplitude of 3 - 4 deg and phase of approximately 300 E. However, NMC found a sharp maximum of 4.5 deg at 10 mb, 67 N not seen by the other sensors. Berlin had amplitudes of up to 2.5 K and did not show the strong maximum found by NMC.

Day 5: (14 Jun 1980)
Again amplitudes were small (up to 5 K). NMC and ECMWF found a 3 - 4 K maximum at approximately 70 mb, 30 N. There is some trace of it on Berlin and SAMS in the same phase. However SAMS shows values of 2 - 3 K at approximately 70 mb, 30 - 70 N; these are generally twice as large as shown by other measurements. NMC finds a broad maximum of 3 K at 30 N 2 mb, compared with SAMS values of 0.5 K here.

Day 6: (5 Nov 1980)
SAMS shows a marked double peaked structure with maxima at 65 N, 10 and 0.1 mb, of 11 K and 8 K, respectively. NMC finds a similar lower peak but shifted higher and southward. However SAMS phases tilt uniformly westward with height, whereas NMC phases do the same below 1 mb but tilt eastward above. In the stratosphere the phases agree well. Berlin and ECMWF agree well with NMC and SAMS.

Day 7: (5 Feb 1981)

SAMS and NMC both show a double peak. All analyses are in good agreement. The Berlin maximum amplitude (34 K) is substantially larger than SAMS or EMCWF (24 K), while NMC lies between (28 K). Each of the lower maxima are at 30 mb about 70 N.

Day 8: (8 Feb 1981)

SAMS and NMC show a double peak of 16 - 18 K in each case with phases in good agreement. The lower peak is also found by Berlin and ECMWF with similar amplitude and phase.

6.2 Wave 2

Day 1: (2 Jan 1979)

Both SAMS and LIMS showed double maximum of 8 - 10 K at 60 N, 10 mb and 0.4 - 0.2 mb, with a marked minimum (1 K) between and very similar phases. However NMC was totally different with a single maximum at about 4 mb, 65 N of 5 K; this is near the level where SAMS and LIMS show a maximum. Berlin amplitudes show a maximum at about 45 N and between SAMS/LIMS and NMC in value. It should be remembered that amplitudes were much less than for wave 1 (25 K) on this day.

Day 2: (26 Jan 1979)

Again SAMS and LIMS showed a similar double peaked structure (6 - 10 K maximum amplitude compared with 25 K for wave 1) with the LIMS a little stronger. NMC amplitudes were also about this size (up to 5 K) but their pattern did not resemble SAMS or LIMS. It was not clear how the Berlin fitted in: it seems to resemble NMC most closely.

Day 3: (26 Feb 1979)

There was fairly good agreement. A large peak at about 3 mb, 55 - 60 N, was found by LIMS, SAMS and NMC, with amplitudes of 17, 13, and 12 deg, respectively. SAMS and LIMS showed the amplitude falling uniformly below. However NMC, Berlin and ECMWF found values of 8 - 9 K at 50 - 100 mb compared with SAMS (approximately 4 K) and LIMS (6 - 7 K).

Day 4: (2 May 1979)

As for wave 1, amplitudes were weak (2 - 3 K). Amplitudes are in reasonable agreement and where amplitudes exceed 1 K phases are also in good agreement.

Day 5: (14 Jun 1980)

Values rarely reached 1.5 K and were too small for useful comparison, except to note that they were all this small.

Day 6: (5 Nov 1980)

Maximum values were 4 - 5 K (at 40 N, 0.7 - 1 mb) with SAMS and NMC agreeing remarkably well in amplitude but differing by 30 deg in phase. The wave tilted westward with height below this peak in both cases and also above for SAMS but eastward for NMC. Amplitudes were just 1 - 2 deg in the low stratosphere, but Berlin ECMWF were consistent with SAMS and NMC.

Day 7: (5 Feb 1981)

There was strong wave number 2, up to 9 K, but 1/3 the size of wave 1. There was a double peak with SAMS and NMC agreeing well. The bottom of the lower peak also appeared in the 10 mb Berlin data but there was also another peak of 10 K not seen on the other analyses at 70 N, 30 mb.

Day 8: (8 Feb 1981)

Up to about 2 mb there was good agreement between all fields. This region includes a maximum of approximately 12 K at 10 mb. However NMC shows a second strong maximum at 1 mb of 8 K, whereas the SAMS shows a minimum at this level (2 K) but a maximum (4 K) at 0.2 mb, 65 N.

6.3 Discussion

SAMS and LIMS seem to agree reasonably well for both waves 1 and 2 at all levels between 100 and 0.1 mb, as do the radiosonde-based analyses between 100 and 10 mb, except possibly on the quiet days 4 and 5.

The main discrepancy concerns NMC above about 5 to 2 mb, where both the amplitude and phase seem to be more related to the structure below than the structure shown by SAMS and LIMS. For example, the phase above 1 mb often seems to be a reflection of the phase below 1 mb, e.g. Day 1 wave 2, Day 2 waves 1 and 2, Day 6 waves 1 and 2, Day 7 wave 2, Day 8 wave 1. On days 3 and 4 the phase is independent of height in this region. This may be indicative of the retrieval above 2 mb being dominated by regression with levels below. This observation is consistent with the features seen in the mapped comparisons in Section 5.2.

7. DERIVED QUANTITIES

The derived quantities compared in this section are:

(7.1) zonal mean wind
(7.2) amplitudes of geopotential height for waves 1 and 2
(7.3) eddy momentum fluxes
(7.4) eddy heat fluxes

The calculations were carried out by the same very simple procedure for all data sources. Horizontal derivatives for geostrophic winds were computed from first differences on the 2.5 x 10 deg grid. Fluxes of momentum and heat were calculated as the sum of the first six wave numbers of $\overline{u'v'}$ and $\overline{v'T'}$. It should be borne in mind when making comparisons that the procedure of differencing without smoothing will amplify both small scale structure and noise. The SAMS data set has been tied to the Berlin 30 mb surface for the purpose of computing all the derived quantities. The account concentrates on the principal differences between the analyses so that not all analyses are discussed in the comparison for a given day.

7.1 Zonal mean winds

Latitude-height cross sections of the zonal mean wind are presented in Appendix A5.

Day 1: (2 Jan 1979)
Below 1 mb poleward of 30 N, the agreement between all of the compared fields appears quite good. The major differences occur in the location and extent of the low latitude easterlies. Despite the good qualitative agreement, there are significant differences in both the horizontal and vertical gradients of U in some regions. This characteristic is observed in all of the days examined in this study. Further derived quantities which depend on those gradients will probably agree less well than the U fields themselves.

Day 2: (26 Jan 1979)
There is a general similarity in structure between the LIMS and SSU wind fields. However, at high latitudes the SSU field has stronger easterlies which penetrate much lower. The NMC pattern is substantially different with no high latitude easterlies. At lower latitudes there is a much tighter and more intense jet than is present in either the LIMS or SSU fields.

Day 3: (26 Feb 1979)
In spite of the limited data coverage of SAMS for this day, there is good agreement with both LIMS and SSU at high latitudes, but relatively poor agreement at low latitudes below 10 mb. In contrast, the NMC analysis has weaker easterlies at 70 N and westerlies at very high latitudes not seen in the LIMS, SAMS, or SSU fields.

Day 5: (14 Jun 1980)
The SSU and NMC wind fields are in general agreement poleward of 40 N. Both fields have a low latitude jet extending downward to 100 mb. However, at lower latitudes the agreement is poorer with substantially stronger horizontal gradients in the NMC field. The SAMS data display extreme "roughness" in the meridional direction that makes comparisons difficult.

Day 6: (5 Nov 1980)
Again, SSU and NMC fields tend to show better agreement at higher latitudes where gradients in the winds are markedly different. The SAMS field also tends to agree with that of NMC below 2 mb.

Day 8: (8 Feb 1981)

The NMC and SSU fields are quite different for this day with substantial differences at both high and low latitudes. The SAMS field again displays a roughness that makes comparison more difficult but there is some agreement with NMC with respect to the easterlies centered at approximatley 72 N.

Summary

There appears to be a tendency for LIMS, SSU, and SAMS wind fields to agree better with one another than with those of NMC. This is not true for all of the days examined, however. In general, agreement of the fields is better at higher latitudes (poleward of 40 N). At lower latitudes the agreement tends to be much worse, and gradients (both horizontal and vertical) are often very different among the different data sources. The obvious implication is that further derived quantities (e.g. Eliassen-Palm flux and potential vorticity) will probably exhibit greater differences among the several sources. Of course, it should be borne in mind that these conclusions are based on examination of a very limited portion of the available data. However, the widely varying level agreement seen in these data suggest care in selecting a data source and ensuing interpretation based on derived dynamic quantities.

7.2 Amplitude of geopotential height waves 1 and 2

Latitude-height cross sections of the amplitude of zonal harmonics one and two of the geopotential height are presented in Appendix A6.

Day 1: (2 Jan 1979)

Wave 1 - There is very good agreement between LIMS and SAMS. The SSU field agrees reasonably well with LIMS/SAMS below 2 mb, but amplitudes at 2 mb and above are somewhat lower for SSU. The NMC field has a similar structure, but amplitudes at upper levels are even smaller than for SSU.

Wave 2 - There is reasonable agreement between LIMS and SAMS both in general structure and peak amplitude. Agreement becomes poorer at lower latitudes. The SSU structure is rather different from LIMS/SAMS south of 50 N, but peak amplitudes are in agreement. The NMC field is quite different from LIMS, SAMS, and SSU at all latitudes, and peak amplitudes are 50 percent lower.

Day 2: (26 Jan 1979)

Wave 1 - There is very good agreement between SSU and NMC fields. Similarly, LIMS and SAMS agree very well. The NMC/SSU fields agree well with those of LIMS/SAMS, except that the maximum for the latter fields occurs somewhat lower and slightly poleward than the former.

Wave 2 - Agreement between SSU and LIMS results is moderate, but those of SAMS and NMC are rather different from each other, as well as from SSU and LIMS.

Day 3: (26 Feb 1979)

Wave 1 - The analyses for all of the sources are in accord. Wave 1 amplitudes are reduced somewhat at this time during the large wave 2 major stratospheric warming episode that occurred at this time.

Wave 2 - The SAMS analysis is rather different from that of the other sources. LIMS and SAMS agree with each other, while NMC has a different vertical structure and larger amplitude at 10 mb. SAMS, NMC, and Berlin have peak amplitudes for wave 2 at 10 mb, 50 percent larger than LIMS or SSU.

Day 5: (14 Jun 1980)

Wave 1 - There is fair agreement between SSU, NMC, and ECMWF analyses for wave 1, but the Berlin analysis has a different structure at low latitudes. The SAMS pattern exhibits very different values and structure.

Wave 2 - All of the analyses differ substantially.

Day 6: (5 Nov 1980)
Wave 1 - The different analyses are all in reasonable agreement.

Wave 2 - The general structure is somewhat similar for all of the sources, but actual values differ significantly from each other.

Day 7: (5 Feb 1981)
Wave 1 - There is reasonable agreement between all of the analyses except the peak amplitude at 10 mb is about 20 percent higher in the Berlin results.

Wave 2 - There is fair agreement between SAMS and NMC.

Day 8: (8 Feb 1981)
Wave 1 - The comparison is favourable for all of the sources.

Wave 2 - SAMS and SSU exhibit reasonable agreement in their general structure, but peak amplitude at 2 mb is 50 percent larger for SSU.

Summary

Generalizations with respect to agreement between the various sources are much more difficult to make for the geopotential height wave amplitude comparisons than for the derived winds. Agreement between the various results tends to be better for wave 1 than for wave 2, as one might expect. However, the reader must again be cautioned that these comparisons are based on an extremely small subset of the available data.

7.3 Eddy momentum flux

Latitude-height cross section of eddy momentum flux are presented in Appendix A7.

Day 1: (2 Jan 1979)
Both the structure and the magnitudes are quite different for the fields of eddy momentum flux. Particularly noticeable are the negative values above 2 mb. The NMC distribution has large negative values poleward of 50 N. LIMS has even larger negative values, but poleward of 70 N. SAMS has an isolated region between 50 - 55 N with large negative values.

Day 2: (26 Jan 1979)
The structure of the LIMS and SSU fields are similar with the maximum at the same location, but LIMS values being larger. The NMC pattern differs considerably with large negative values at high latitudes that are not present in the other analyses. The magnitude of the NMC positive maximum agrees with that of LIMS, but the NMC maximum is higher and more equatorward.

Day 3: (26 Feb 1979)
The fields are rather dissimilar. The negative values around 80 N and 10 mb shown by SSU are not present in the other analyses. Negative values are present in the ECMWF field at high latitudes below 30 mb, but these are considerably larger than for SSU.

Day 5: (14 Jun 1980)
There is fair agreement between ECMWF, NMC, and SSU below 30 mb, but Berlin does not have the large negative values shown by these analyses. Very different

structures for SAMS, NMC, and SSU exist at higher levels.

Day 6: (5 Nov 1980)
There is fair agreement among SSU, NMC, and Berlin. A common feature of all these fields is the negative maximum between 70 - 80 N in the lower stratosphere.

Day 7: (5 Feb 1981)
SAMS and NMC have rather different patterns. In the lower stratosphere NMC has a very large negative maximum at 80 N and 10 mb which is not present in the Berlin results.

Day 8: (8 Feb 1981)
There are major differences in the analyses with SSU showing large negative values at high latitudes, whereas the Berlin results show large positive values. SAMS and SSU have very different structures around 60 N.

Summary

Based on this limited examination of these data, there seem to be more differences than similarities in the fields of eddy momentum flux. Obviously, the interpretation of a particular dynamical situation could vary signifcantly in some instances depending on which source of data was used. Thus, independent analyses using several data sources may be invaluable.

7.4 Eddy heat flux

The latitude-height cross sections of eddy heat flux are presented in Appendix A8. Temperatures were not derived from the SSU data, so SSU comparisons for heat flux are not included in the ensuing discussion.

Day 1: (2 Jan 1979)
There is reasonable agreement between LIMS and SAMS. Although the SAMS data coverage for this day extends only to 68 N, the structure and magnitude of the eddy heat flux distribution tends to confirm the maximum shown by LIMS around 72 N at 2 mb. In contrast, the NMC peak value is 30 percent lower and occurs higher and more equatorward.

Day 2: (26 Jan 1979)
There is good agreement of the general structure at the latitudes poleward of 50 N for LIMS, SAMS, and NMC, although the magnitude of the LIMS maximum is less and occurs lower in altitude. All three sources also indicate a negative maximum near 47 N, but the LIMS values are much the largest.

Day 3: (26 Feb 1979)
NMC and LIMS are in fair agreement, but again differ in the position of the maximum. The vertical structure of the SAMS distribution is quite different. Berlin has much larger values at 10 mb than the other analyses.

Day 5: (14 Jun 1980)
The analyses are all very different.

Day 6: (5 Nov 1980)
While there is fair agreement between SAMS, Berlin, and NMC, the ECMWF peak values are further poleward.

Day 7: (5 Feb 1981)
Peak values at 10 mb are considerably larger for Berlin than for other analyses. There are some similarities between the SAMS and NMC structures, but the position of the maximum differs considerably.

Day 8: (8 Feb 1981)

The Berlin and ECMWF results are in reasonable agreement. The SAMS data coverage at higher latitudes is extremely limited, but seems consistent with the Berlin/ECMWF results. All data sources show the sign of the heat flux changing between 5 Feb and 8 Feb as the warming progresses.

Summary

The conclusions with respect to the eddy heat flux are identical to those arrived at for the eddy momentum flux in that there are more differences than similarities.

7.5 Conclusions and recommendations

The intercomparison of the basic temperature data and the derived thickness was generally quite encouraging in that substantial agreement was seen. However, the "agreement" is subjective and should be kept in mind if these data are to be used to calculate further derived quantities which may depend on both horizontal and vertical gradients. The present study revealed that substantial differences could exist between the same dynamical quantity derived from the several data sources. The differences were in general structure, the magnitude, the sign, or some combination thereof. This is particularly true during the disturbed periods when spatial gradients of the meteorological variables are large. Large differences also can exist during quiet periods (such as summer) when the departures from zonal flow are small. No systematic tendency was observed for quantities derived from one data source to disagree with those derived from other sources.

Until such time as improvement in this situation exists, caution must be exercised in interpretation of diagnostic studies based upon observational data of the upper atmosphere. Large errors may result in quantities involving higher order differentiation, such as divergence of Eliassen-Palm flux and Ertel potential vorticity. Independent analyses of the same phenomena using different sources of data are necessary.

It would be of help for future intercomparisons of satellite data if some indication were provided of the extent to which the derived fields on successive days satisfied the zonal mean momentum and thermodynamic equations. This could be done by comparing the mean meridional circulation required to satisfy the zonal mean momentum equation with that required to satisfy its thermodynamic counterpart, the latter containing an estimate of the radiative contribution. This might provide some indication on a given day whether one analysis was better than another (recognizing additional errors due to the radiative contribution and any unresolved motions of dynamical importance). A major difficulty with the present intercomparisons was that no objective criteria were available with which to assess the analyses from the different data sources.

Instead of taking a sequence of days for comparison which are widely separated in time, it will be of value to examine the temporal continuity of dynamical quantities from analyses on successive days (perhaps for a period leading up to a stratospheric warming with conditions comparatively undisturbed initially). A comparison of diagnostic analyses based on independent data will highlight areas where caution is needed when presenting arguments concerning interpretation of particular dynamical events.

8. SUMMARY AND CONCLUSION

The emphasis in this report has been to identify problems with the available data set on stratospheric temperatures and heights, and to indicate how they can be dealt with. The reader should not come to the conclusion that the data are useless as a consequence of this emphasis. There is a tremendous amount of information in the data sets; much useful work on the dynamics of the stratosphere has already been done, and there is considerable potential for further studies. However the user should be aware of the nature of the data and their limitations so that a reasonable assessment can be made of the validity of any conclusions he might come to.

We have concentrated on disturbed winter days, which are the hardest to get right in detail, but are worth the effort because they contain the interesting dynamics. Long term means will give more information on systematic errors, so we are planning to carry out further studies in this area.

The study has identified a number of general points and some problem areas associated with individual data sources.

8.1 General points

(a) Random and systematic differences. Systematic differences in thickness and temperature show moderate consistency for any pair of data sources at any given level, but there is no clear overall pattern as there is in the case of random differences. Typical values are around 0.5 percent for thickness and 1 K for temperature. Details are given in the tables in Section 5.3.

We have defined random differences to mean rms values of the departure from the zonal mean difference. Here there is a clear pattern in that satellite soundings agree with each other, and radiosonde analyses agree with each other, with rms values of around 0.5 percent for thickness and 1.5 K for temperature in both cases on quiet days, but the difference between satellites and radiosonde analyses is larger, being about 1 percent and 2.2 K, respectively. On disturbed days the pattern is the same, but the values are larger by a factor of 1.5 to 2.

(b) Signal to noise. We have not yet carried out a systematic study of the signal-to-noise ratio, i.e. the ratio of the rms departure of a field from its zonal mean compared with the same rms for differences between data sources. It is not very clear how meaningful the concept is. As an example, consider the comparison between SAMS and LIMS 10 - 5 mb thickness for 1 Jan 1979. The rms difference is 5 dam, yet the rms for the field itself is 20 dam, so the signal-to-noise ratio is only 4. Yet this is qualitatively a good agreement. For undisturbed conditions, signal to noise is often less than unity, yet there is still useful information in the data.

(c) Vertical resolution effect in satellite retrievals. The vertical resolution of a radiosonde is high, it depends only on the response time of the temperature sensor and the rate of ascent of the balloon. The basic vertical resolution of the satellite instruments is much poorer, being around 2 - 3 km for LIMS, 8 - 10 km for SAMS and 10 - 15 km for the nadir sounders. The retrieval process does not recover a high resolution profile from the radiances, the retrieved temperature at any one pressure level is made up of contributions from a range of heights in the actual atmosphere. This has a significant effect which can be seen both in the vertical cross sections and the horizontal maps. A region of very high vertical temperature gradient as seen by the radiosonde analyses, such as the lower side of a descending warm region during a stratospheric warming, e.g. Figure 16, is seen much less clearly by LIMS, SAMS and VTPR, all of which see a much smaller temperature gradient. There is a secondary effect on the horizontal maps, because the vertical spreading of the temperature profile will effectively 'mix' maps at different levels. A clear example of this is 2 Jan 1979 (Figures 12 and A3.1) where a warm region which is probably entirely above 10 mb affects the LIMS and SAMS 10 mb maps by moving the warm centre at 10 mb considerably towards the pole relative to its position seen by the Berlin analysis.

Derived quantities which are linear functions of the temperature field, including thickness, height, geostrophic wind, and wave amplitude will be affected in exactly the same way as the original temperature field — they will be smoothed in the vertical. However, quantities which are nonlinear functions of the temperature field, such as heat and momentum flux, will be affected in a much more complicated way.

(d) Time evolution problems. The field being measured is varying with time, and each of the data sources analyses the field using a different method, giving different treatments of the time evolution. Berlin maps are for midnight, using data from both sides of the synoptic hour. NMC maps are for noon, using only data before the synoptic hour. SAMS maps are 24-hour averages, biassed by the pattern of data acquisition, and LIMS maps are for midnight, using Kalman filtering to interpolate to the synoptic hour, thus using data on both sides of the nominal time. The European Centre have provided maps for both midnight and noon. The difference between these is an rms of 0.5 - 1 K in quiet situations and 1.5 - 2 K in disturbed situations, averaged over the hemisphere, giving an estimate of a typical error that could be assigned to time evolution.

(e) Sampling problems. Satellite sounders and radiosondes sample the atmosphere in different ways, giving different kinds of bias. Radiosondes are sparse over the ocean, giving a geographical bias in the error term. Satellite sounders are sun synchronous so that diurnal variations such as tides are not seen. A fixed bias between satellites in different orbits may be due to this cause.

(f) Vertical range of satellite data. There is a clear tendency in the comparisons for the NMC retrievals to differ markedly from SAMS and LIMS above some level which varies from about 5 mb for the early dates to 1 or 2 mb for the later dates. This corresponds approximately to the peak of the top weighting function of the instrument in use at the time. The conclusion seems to be that for nadir sounders, retrievals should not be made above the peak of the top weighting function, especially if a regression method is being used. With limb sounders, there is no clear top weighting function, signal/noise just fades away with height, so there is no clear cutoff level.

(g) Gradient problem for limb scanners. A limb scanner sees from a very long quasi-horizontal path through the atmosphere, significant amounts of radiation coming from a region around 500 km long, rather than just from the neighbourhood of the tangent point. At an altitude where the path through the limb is becoming optically thick, the radiation reaching the instrument no longer comes from a region centred on the tangent point, but from somewhere closer to the spacecraft by some hundreds of km. When there are strong horizontal gradients in the atmosphere, these will be smoothed out and/or misplaced, e.g. Figure 16. The LIMS retrieval allows for this effect to some extent by estimating the gradient using a map derived from a preliminary retrieval and adjusting the radiance to allow for the effect. The SAMS retrieval does not allow for the effect at all.

8.2 Problems associated with individual data sources

(a) Radiosondes. The Northern Hemisphere radiosonde network consists of about 650 stations of which only about 400 reach the 100-mbar level and fewer reach much above that level, especially during the winter months.

Evaluations of data compatibility between observations from different types of instruments is one of the greatest problems facing the stratospheric analyst. We know much more about the compatibility than we do of the accuracy, since the former can be tested in an empirical fashion. Stratospheric radiosonde errors can be quite substantial above 100 mb and mainly stem from systematic instrumental response to solar and long-wave radiation. Each instrument (and there are more than 15 used globally) reacts differently. Unless the temperature and height fields are adjusted to ensure observational compatability, stratospheric analysis becomes nearly impossible. Errors can be adequately defined through day-night data studies, which show the mean temperature/height differences for large numbers of observations. These differences have been shown to depend heavily on the solar angle of the daytime report.

NMC is an operational product, and as such cannot make use of late data and future time evolution to improve an analysis. Furthermore, problems due to quality control will remain in the data set, and cannot be removed at a later stage. An example might be the NMC 10 mb temperature map for 26 Feb 1979 (Figure A3.3). But even with the more careful treatment afforded by the Berlin analysis, it may be impossible to catch rapid temperature changes which start in the higher altitudes above the 10 mb level. This may be the reason for the large differences on 2 Jan 1979. Obviously the warming could be followed much better when fully developed.

(b) LIMS. The main problem we have identified with LIMS data is the underestimation of both horizontal and vertical gradients, when these are particularly large, such as during stratospheric warmings. This is largely due to the vertical resolution of the instrument (2 - 3 km), its resolution along the line-of-sight resolution (500 km), and the incompletely corrected horizontal shift of the horizontal weighting function. Useful data cover the period 25 Oct 1978 to 28 May 1979, latitude range 64 S - 84 N, and altitude range 15 - 70 km.

(c) SAMS. The main problems we have identified with SAMS data are the same as LIMS, except that the vertical resolution is 8 - 10 km and the horizontal shift problem has not been corrected at all. The vertical structure shows a systematic error when compared with LIMS which may be due to the use of an eigenvector representation for the profile, but this is not certain. The horizonal structure shows noise, especially at low levels,which appear as 'blobs' on the scale of 2.5 deg latitude x 20 deg longitude, i.e. the retrieval interval and the orbit spacing.

Useful data cover the period Jan 1979 to Nov 1982, with some data outside the period, latitude range is 50 S to 70 N, and altitude range from 15 - 70 km.

(d) SSU. The main problems we have identified with the SSU data are its inherently low vertical resolution and the loss of channel 27 on TIROS-N, which restricts the height range for this period. Temperature retrievals are not provided by the SSU teams on the reasonable grounds that the vertical resolution only justified thickness retrievals.

In spite of the fact that height maps for the upper stratosphere derived from the SSU radiances are much better than the maps derived only from rocketsondes (as done by the USSR) there are still systematic errors, especially during stratospheric warmings. There should be further studies to overcome these problems, because the SSU is the only stratospheric data source which will be routinely available in the future.

Useful data cover the period from Oct 1978 to the present. The latitude range is 80 S to 80 N and altitudes up to 50 km.

(e) NMC satellite data. NMC data above 10 mb are based almost entirely on satellite data. The main problems we have found with these data are:

(i) The regression retrievals have been taken too high. Data above the peak of the highest weighting function are not very clearly related to the atmosphere at that height.

(ii) The data are designed as an operational product, not a data set for scientific research. There are changes of satellite and changes of processing methods which make it nonuniform in quality.

(iii) The data originally supplied show changes of systematic error when satellites change. Corrections need to be made to adjust this, based on rocket comparisons.

(iv) The regression coefficients have become more uncertain with the loss of rocket stations, especially at high latitudes.

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APPENDIX A: AN EXTRACT FROM THE BASIC DATA SET

A.1 Thickness maps:
- 100 - 50 mb
- 100 - 10 mb
- 50 - 10 mb
- 10 - 5 mb
- 5 - 2 mb
- 2 - 1 mb
- 1 - 0.4 mb
- 0.4 - 0.1 mb

A.2 Zonal mean temperature cross sections

A.3 Temperature maps:
- 30 mb
- 10 mb
- 1 mb
- 0.4 mb

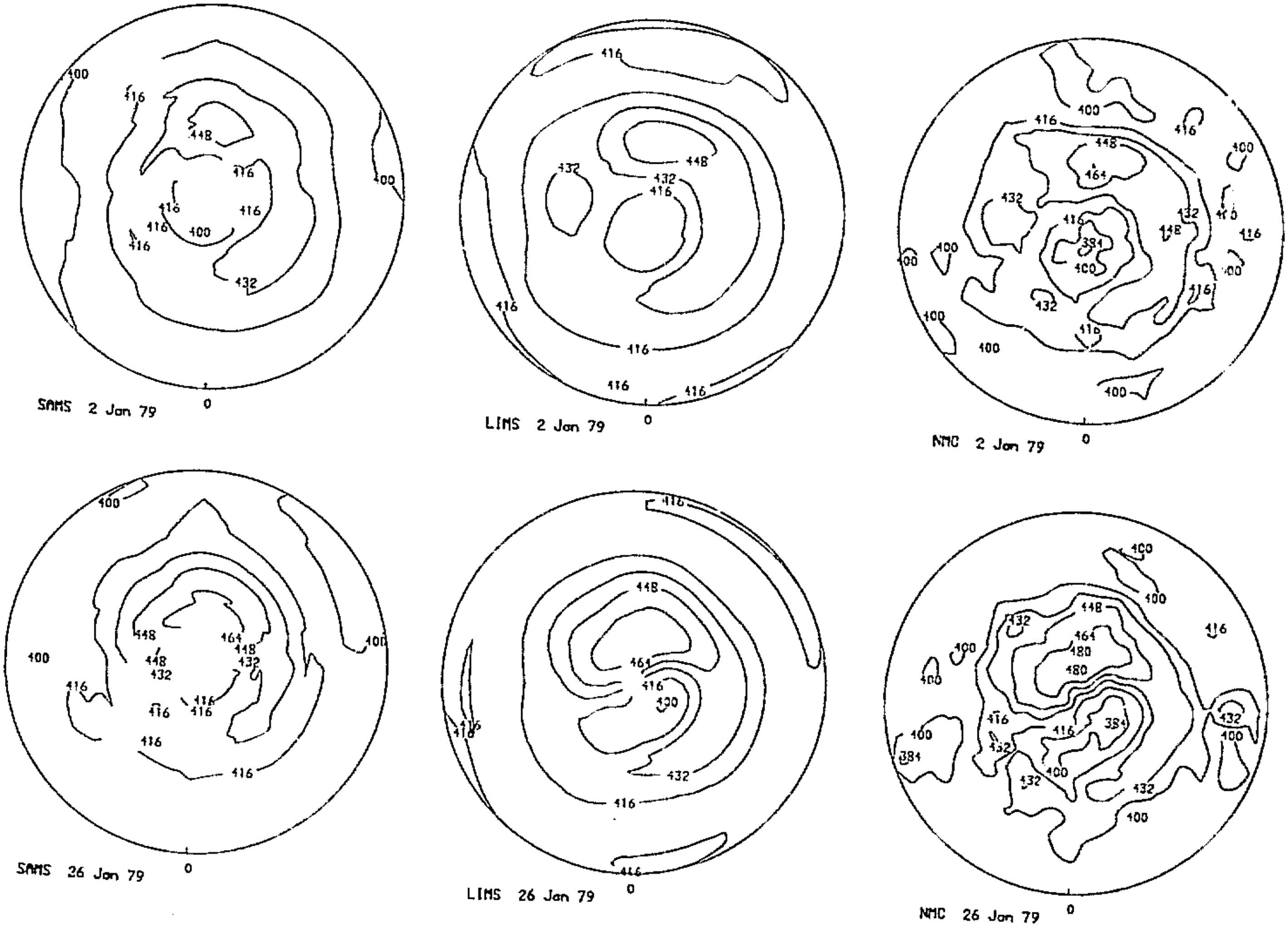
A.4 Temperature wave 1 and 2 cross sections
Amplitude and Phase

A.5 Zonal mean U wind cross sections

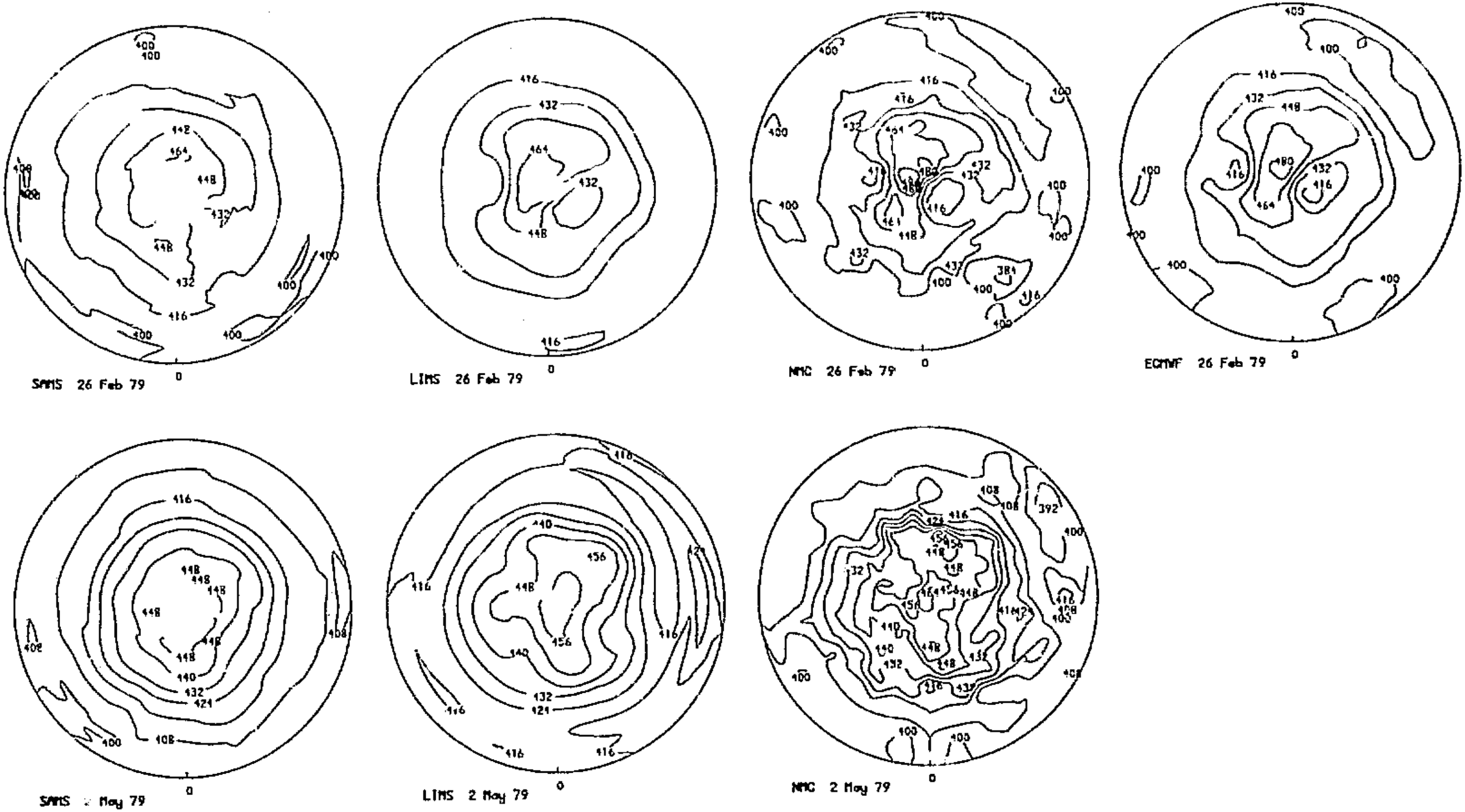
A.6 Geopotential height waves 1 and 2
Amplitude and Phase

A.7 Momentum transport m^2/s^2

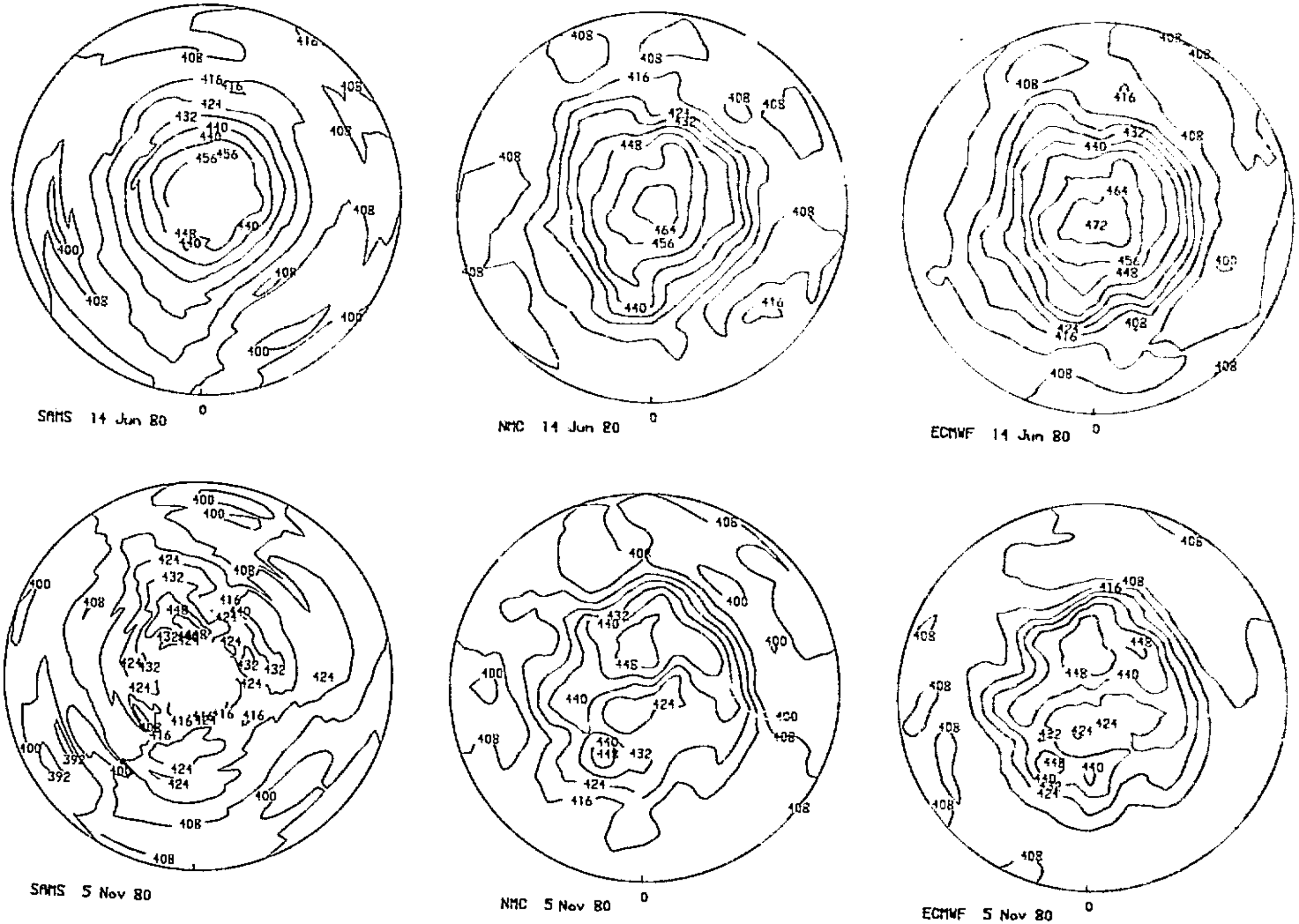
A.8 Heat transport K m/s



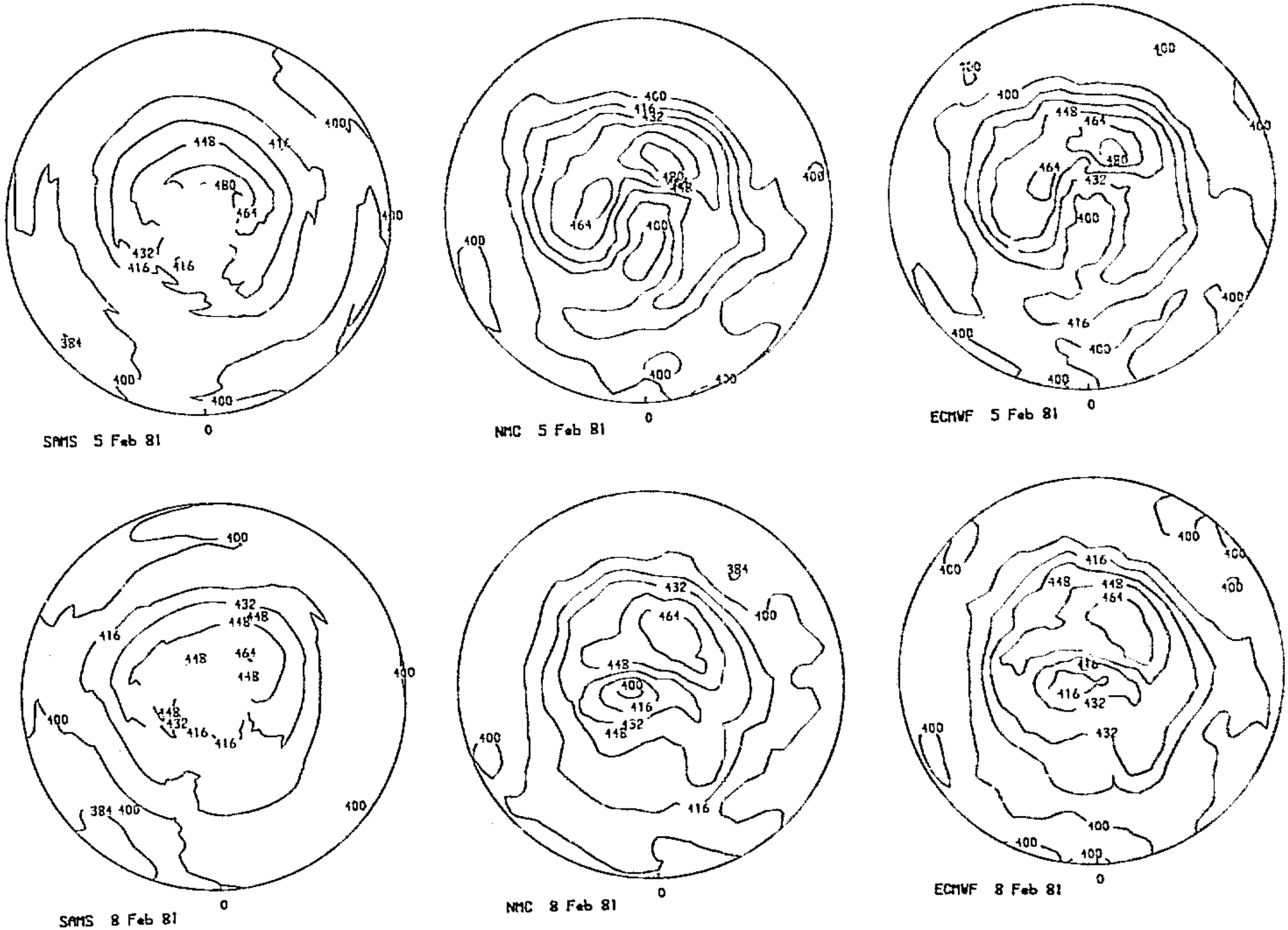
A1.1 100 - 50 mb thickness, decametres.



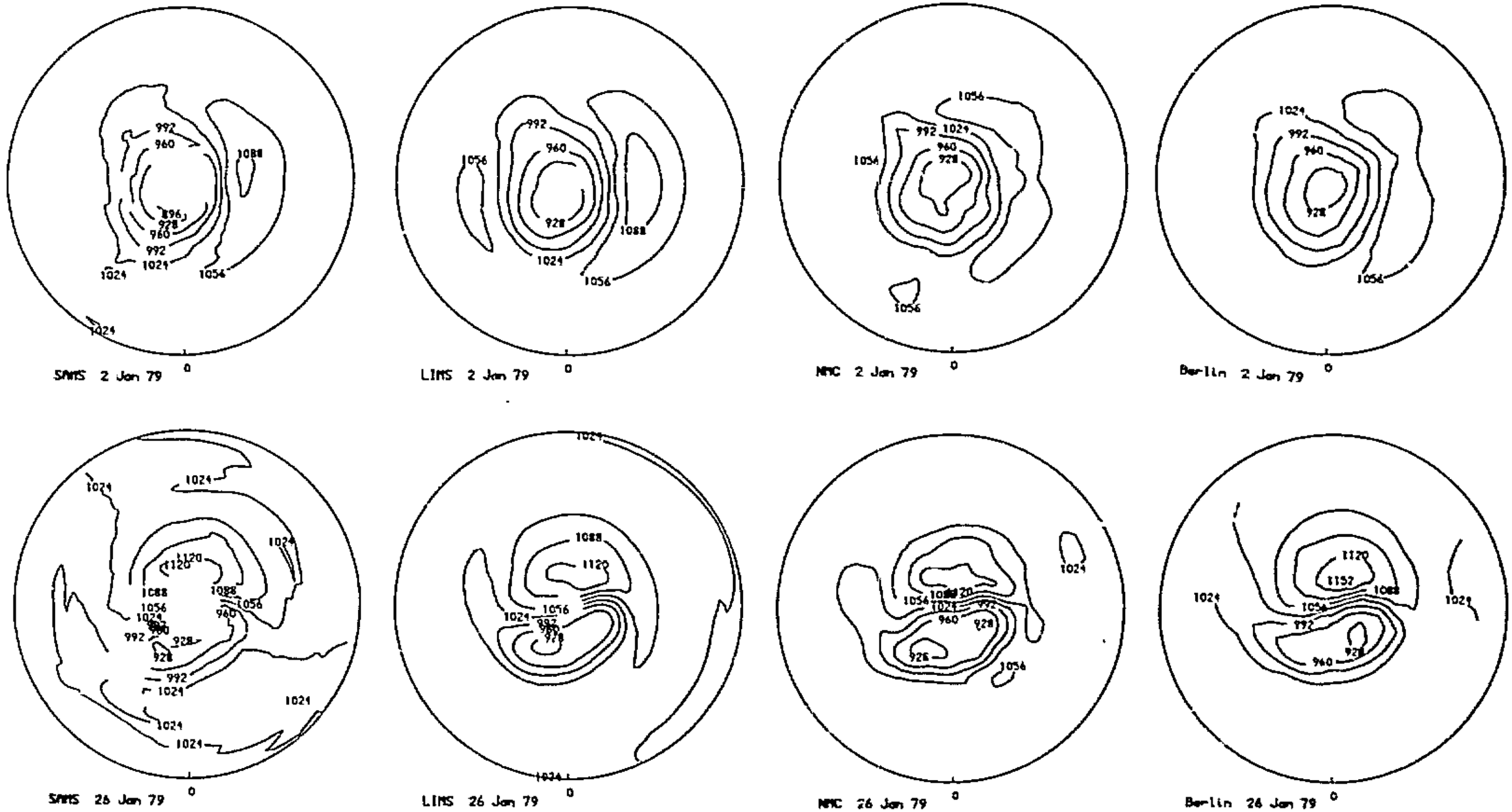
A1.2 100 - 50 mb thickness, decametres.



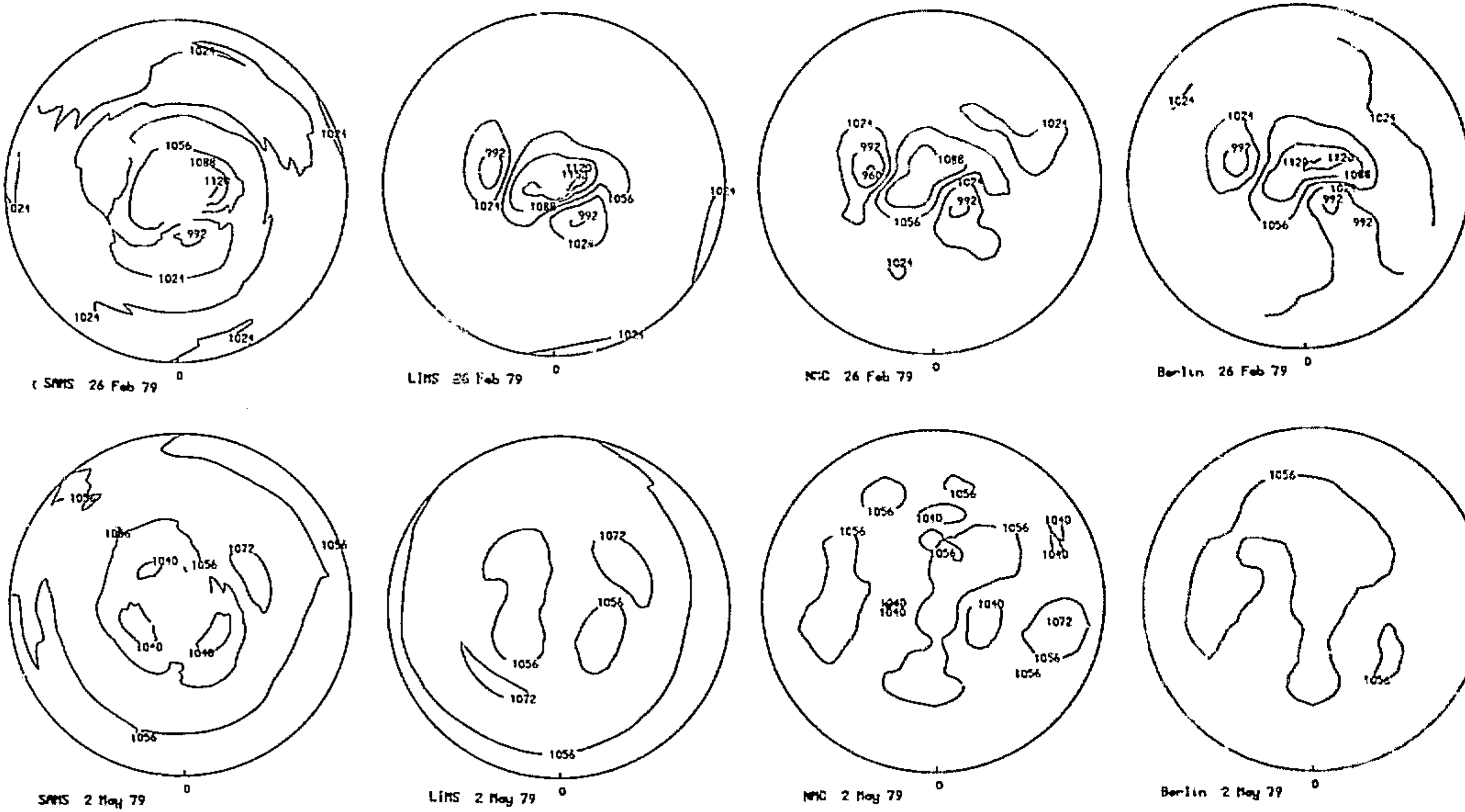
A1.3 100 - 50 mb thickness, decametres.



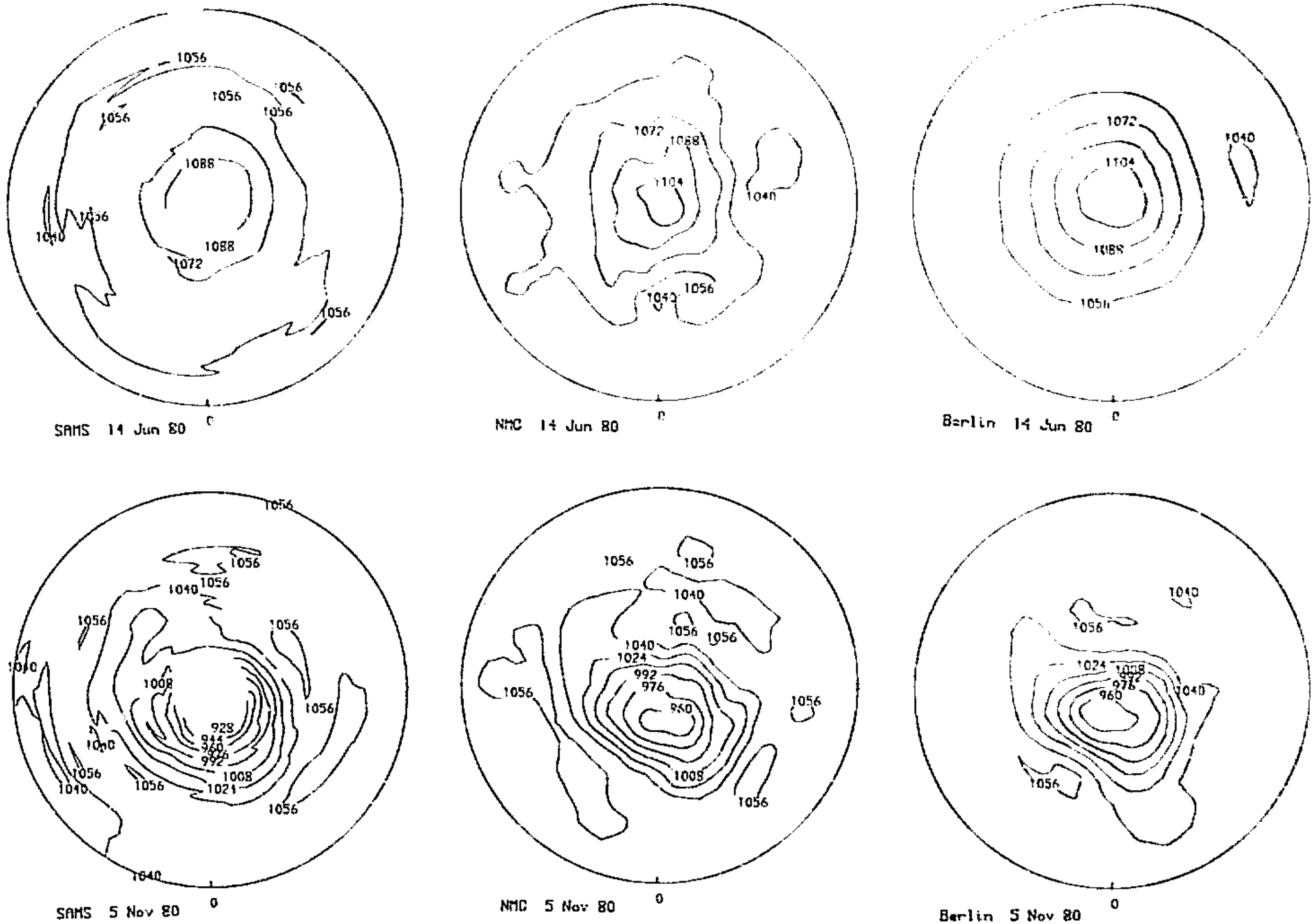
A1.4 100 – 50 mb thickness, decametres.



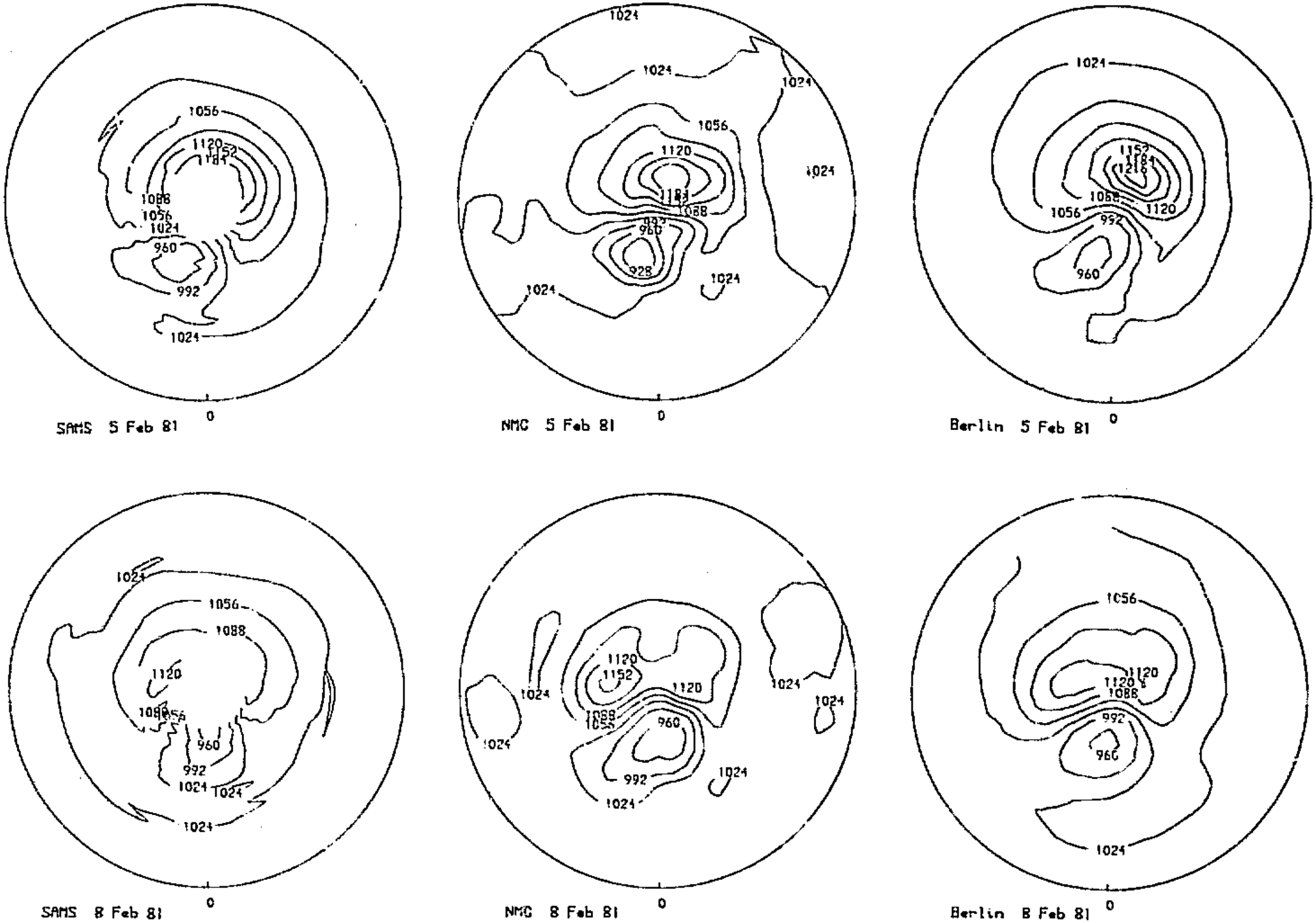
A1.5 50 - 10 mb thickness, decametres.



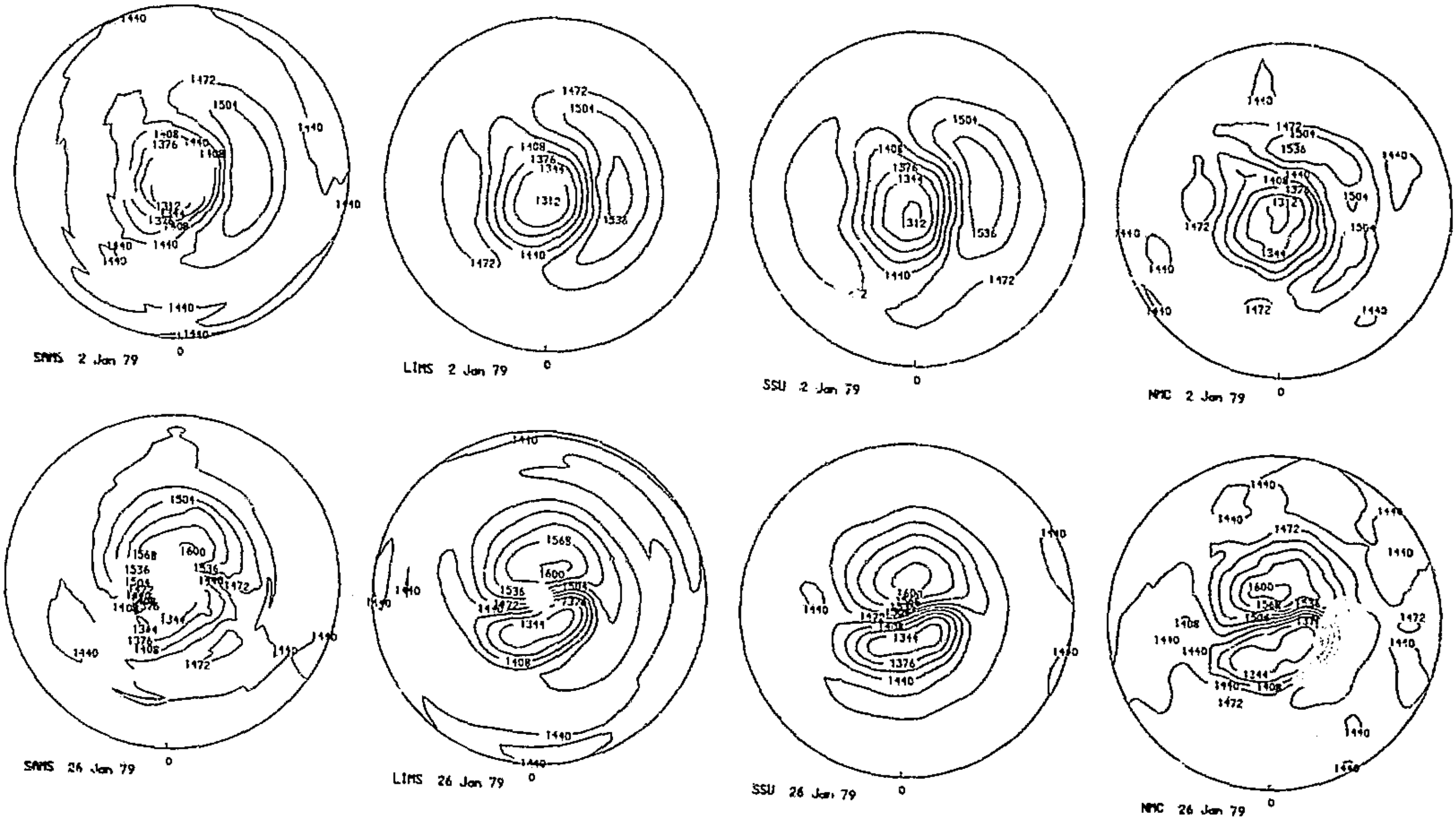
A1.6 50 - 10 mb thickness, decametres.



A1.7 50 - 10 mb thickness, decametres.

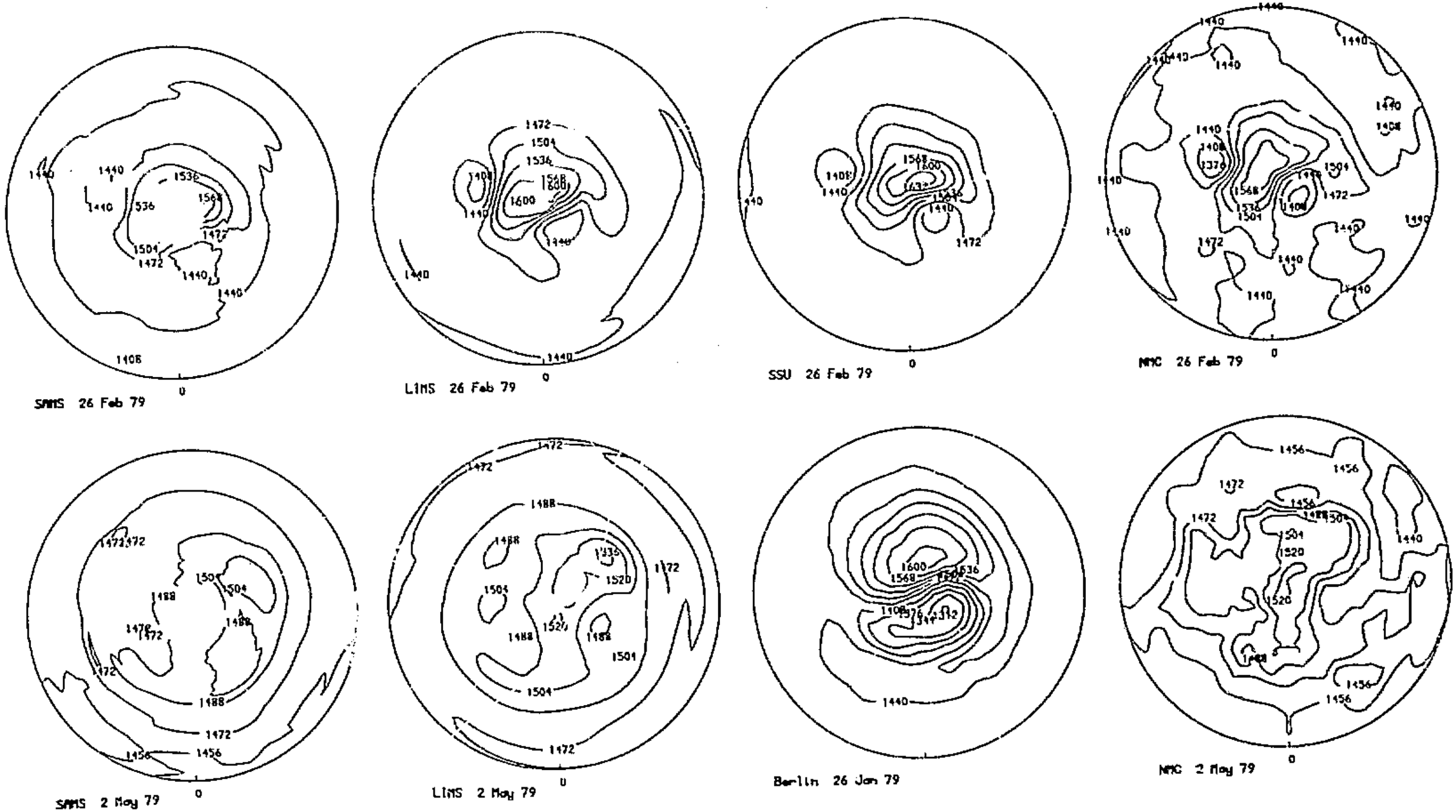


A1.8 50 - 10 mb thickness, decametres.

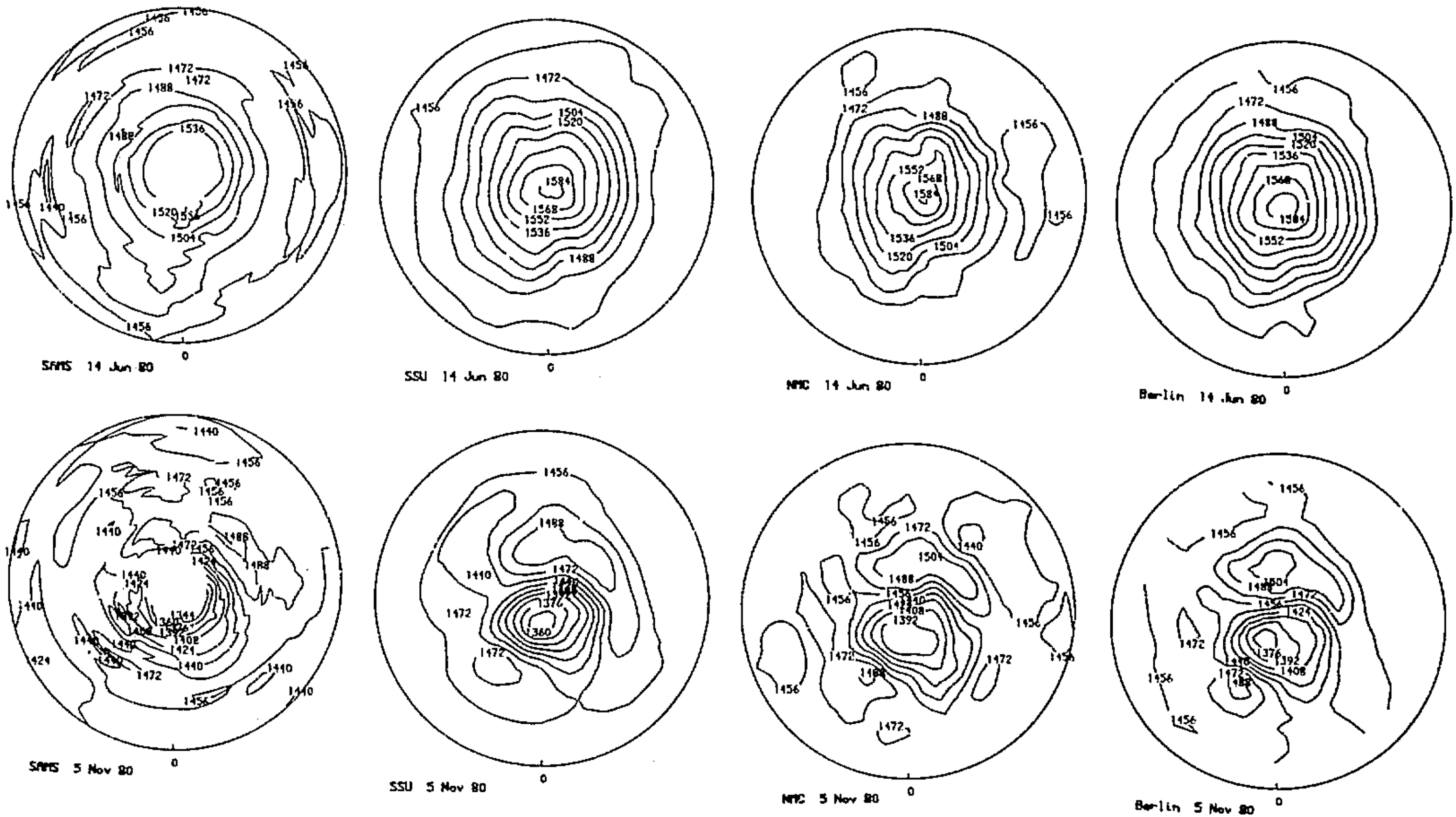


Berlin 26 Jan 79;
see next page

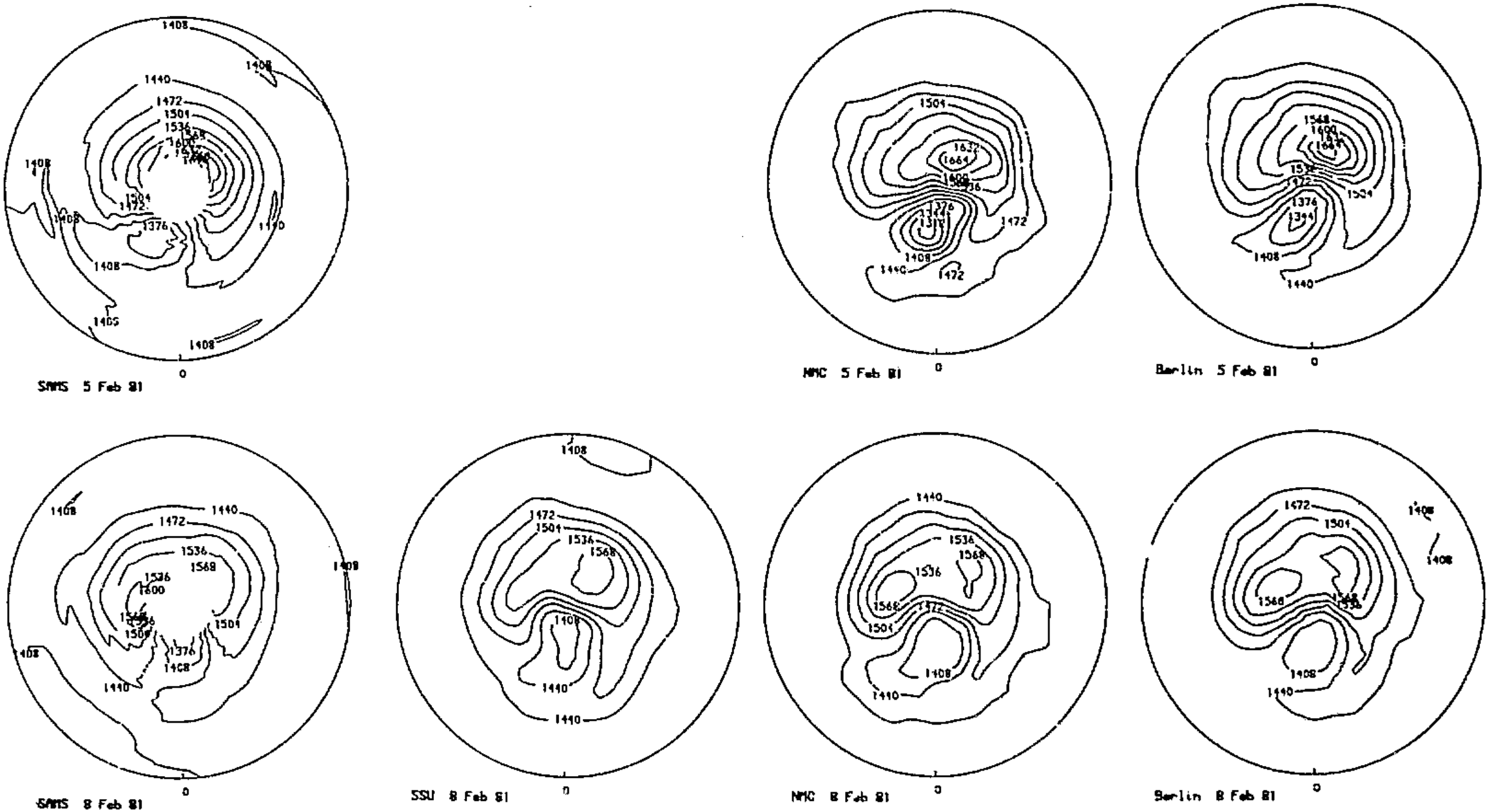
A1.9 100 - 10 mb thickness, decametres.



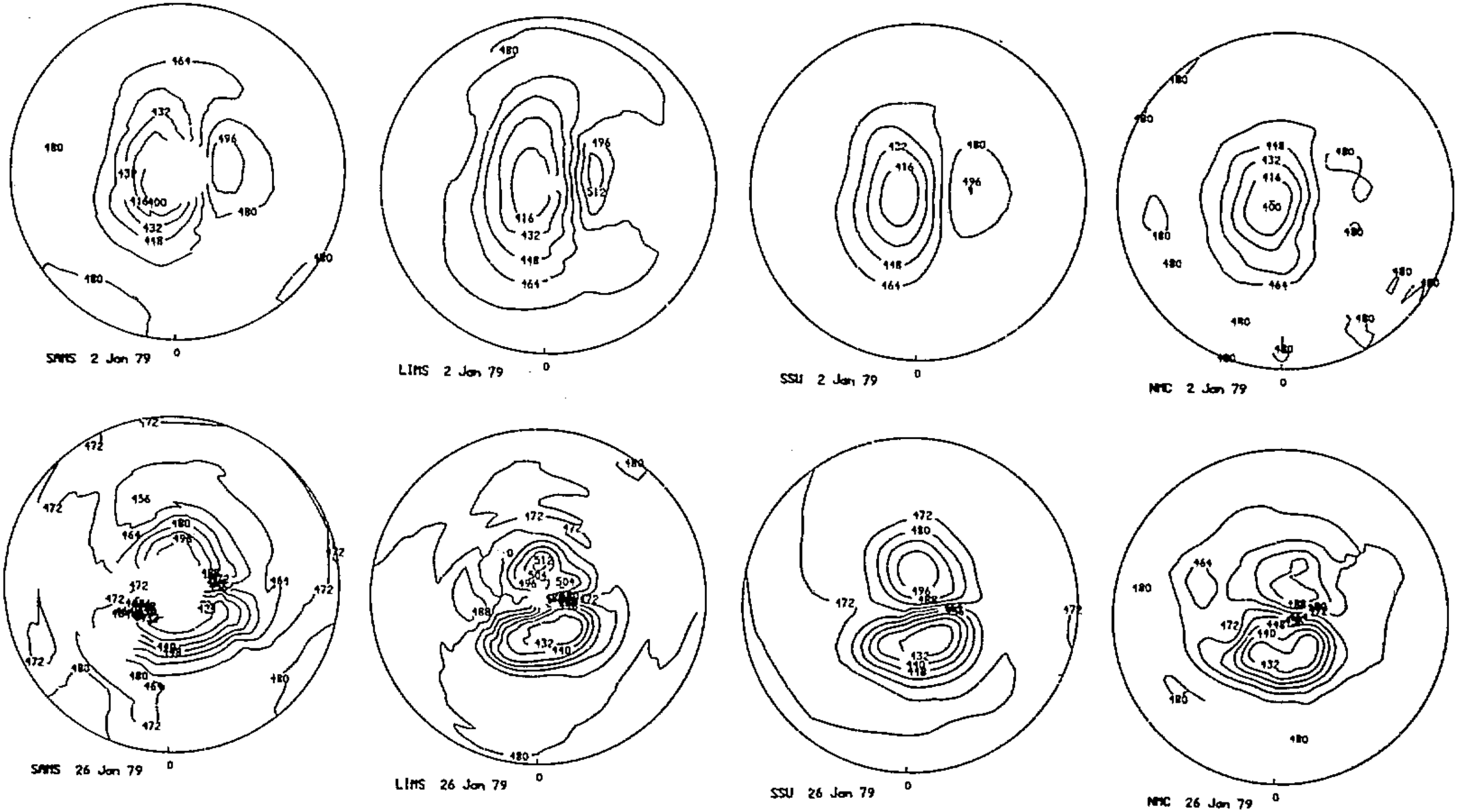
A1.10 100 - 10 mb thickness, decametres.



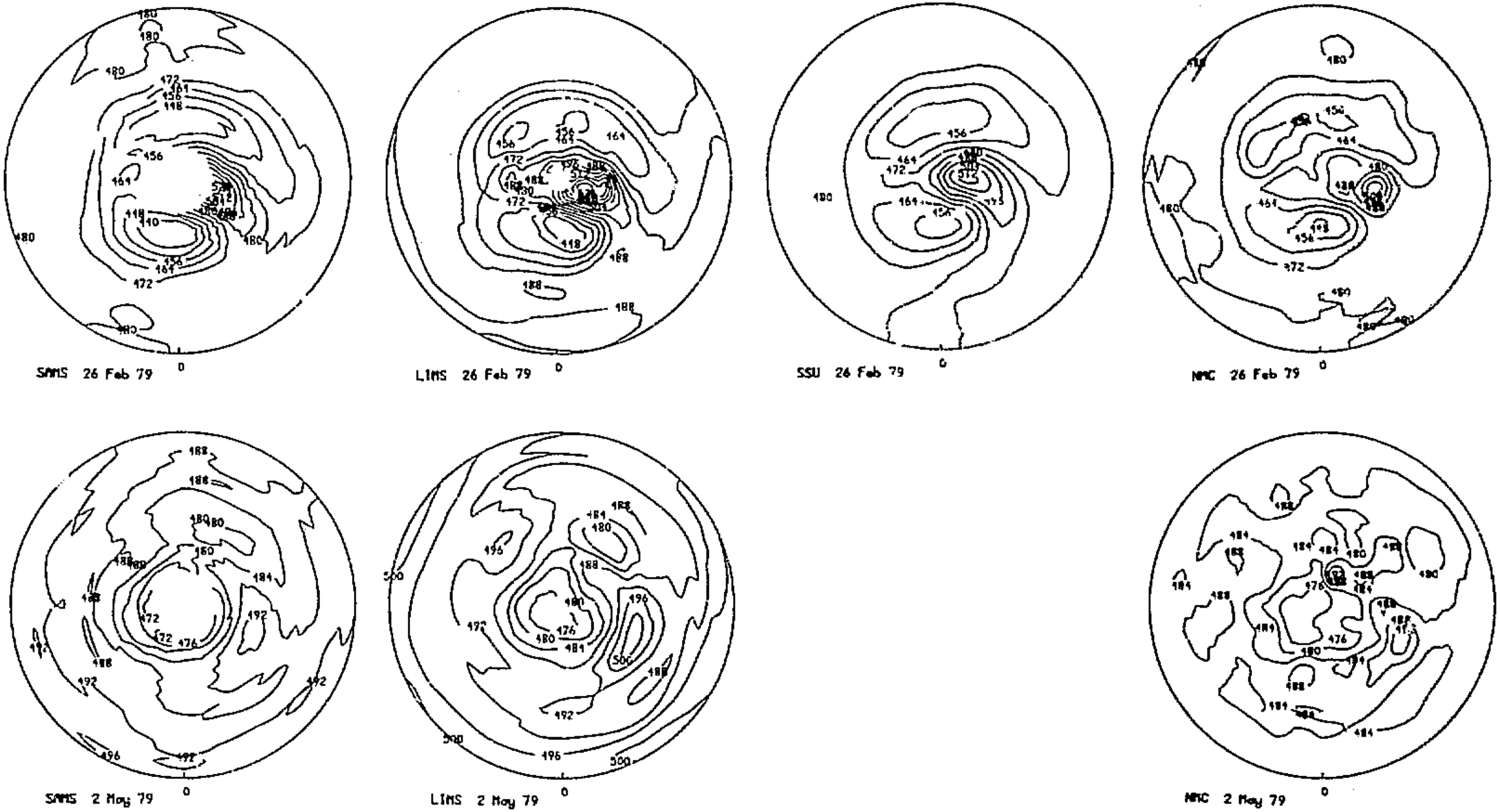
A1.11 100 - 10 mb thickness, decametres.



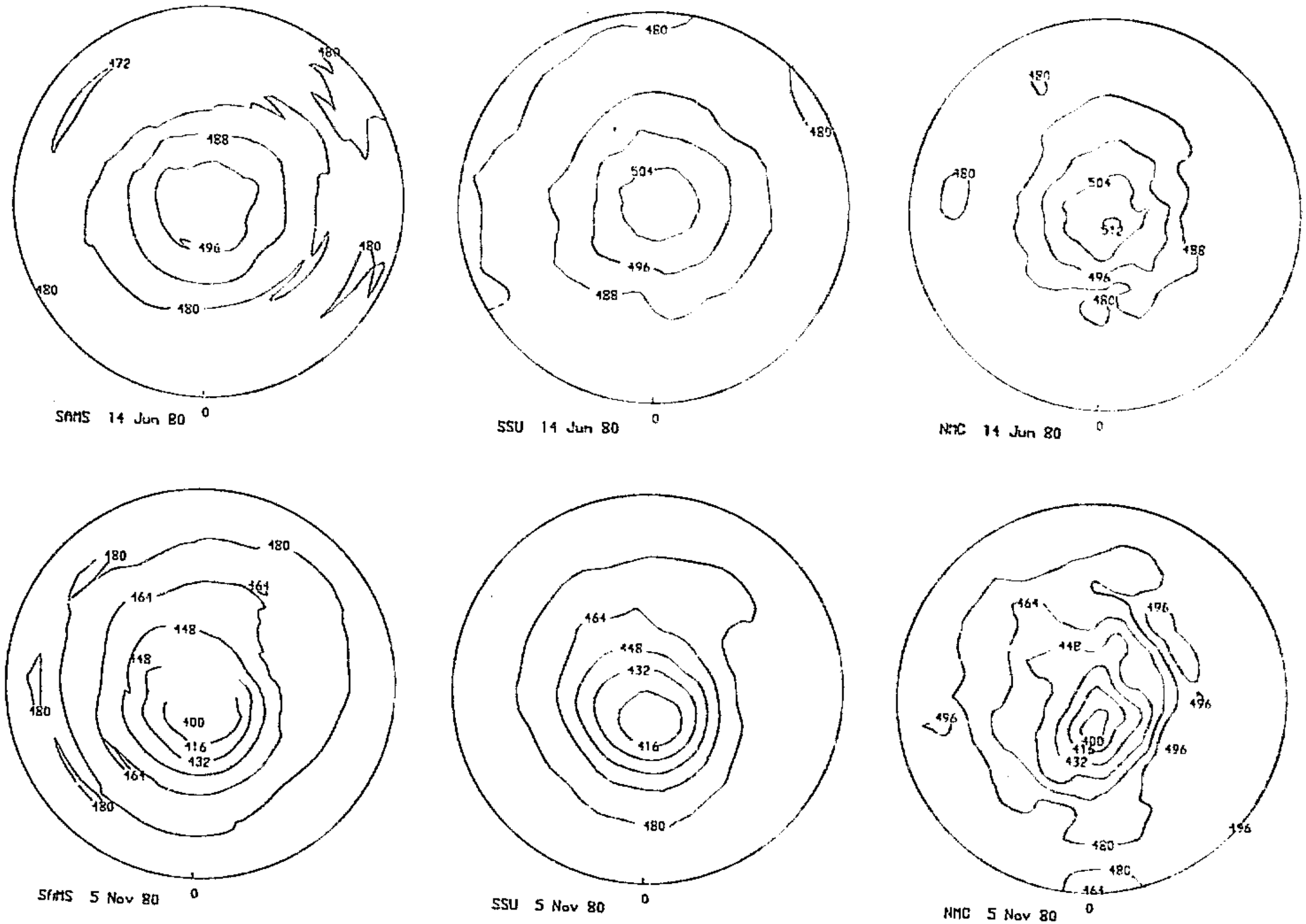
A1.12 100 - 10 mb thickness, decametres.



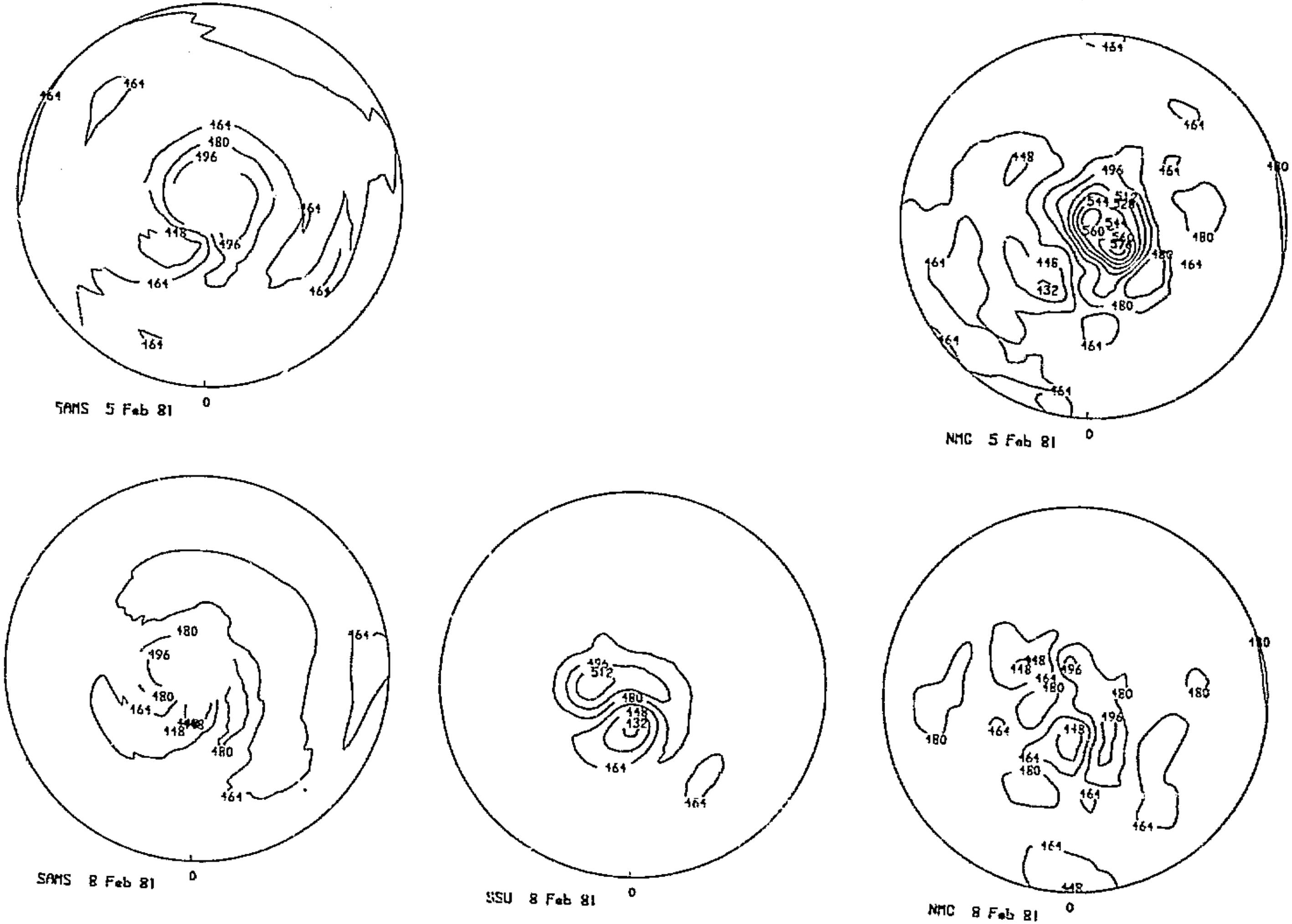
A1.13 10 - 5 mb thickness, decametres.



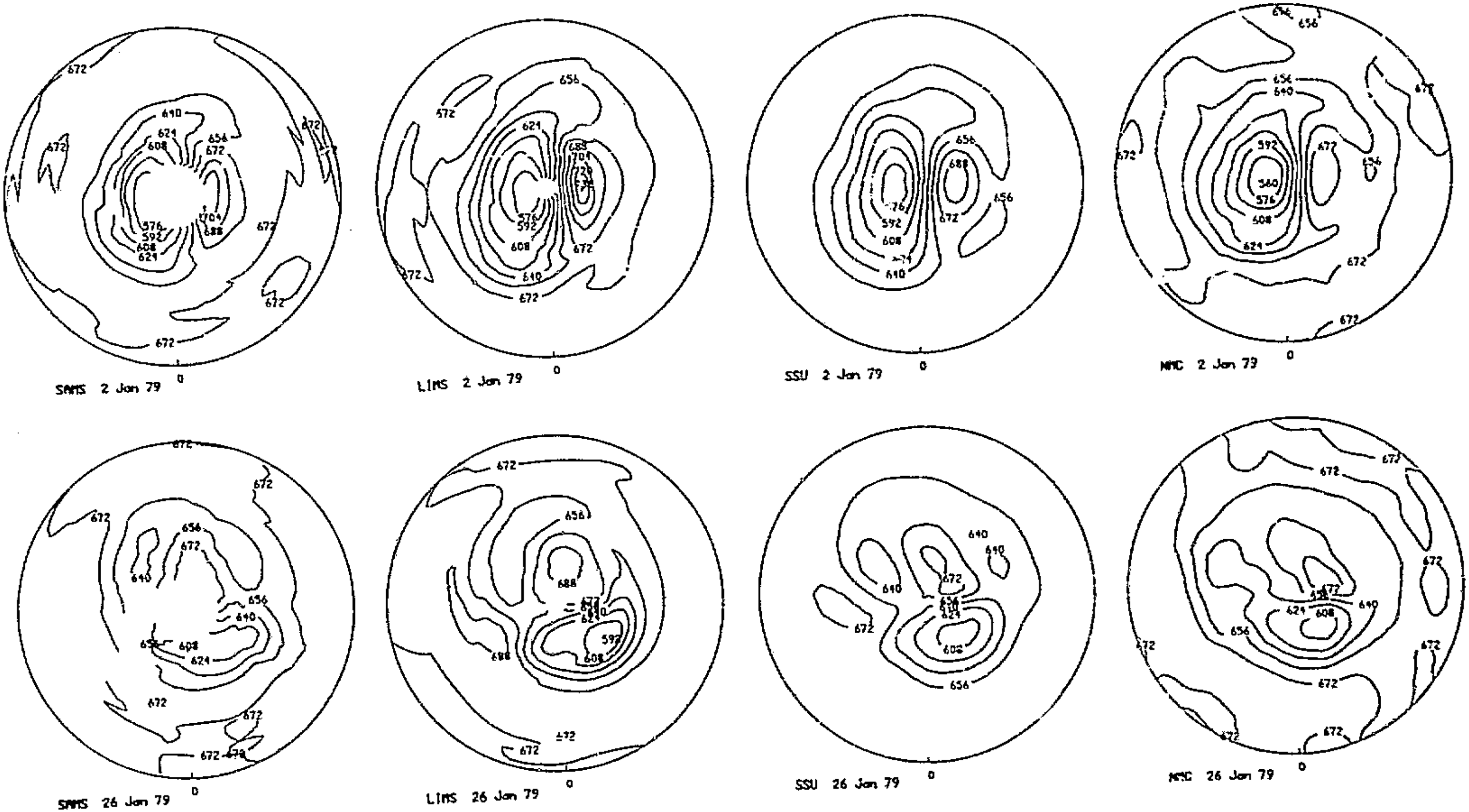
A1.14 10 - 5 mb thickness, decametres.



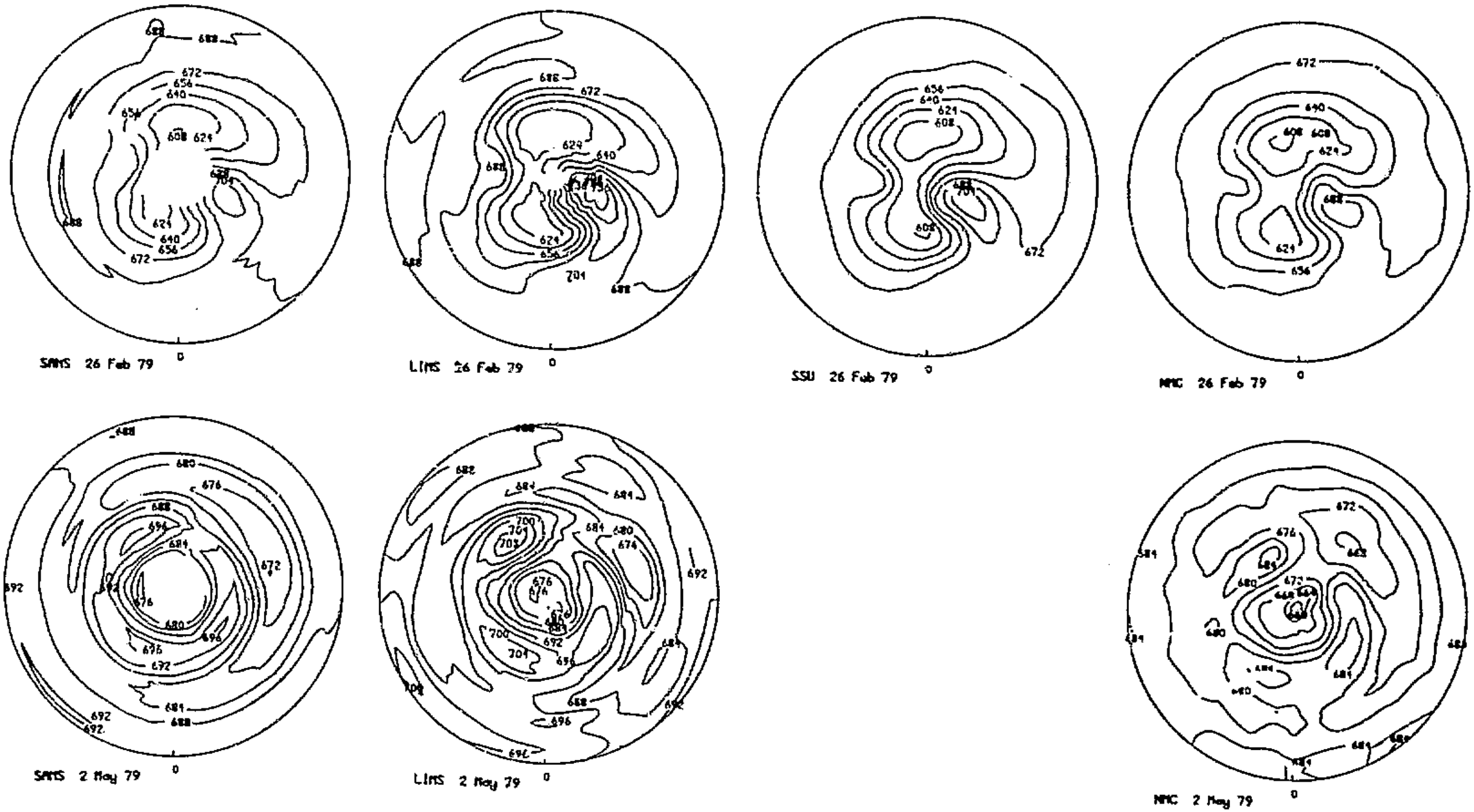
A1.15 10 - 5 mb thickness, decametres.



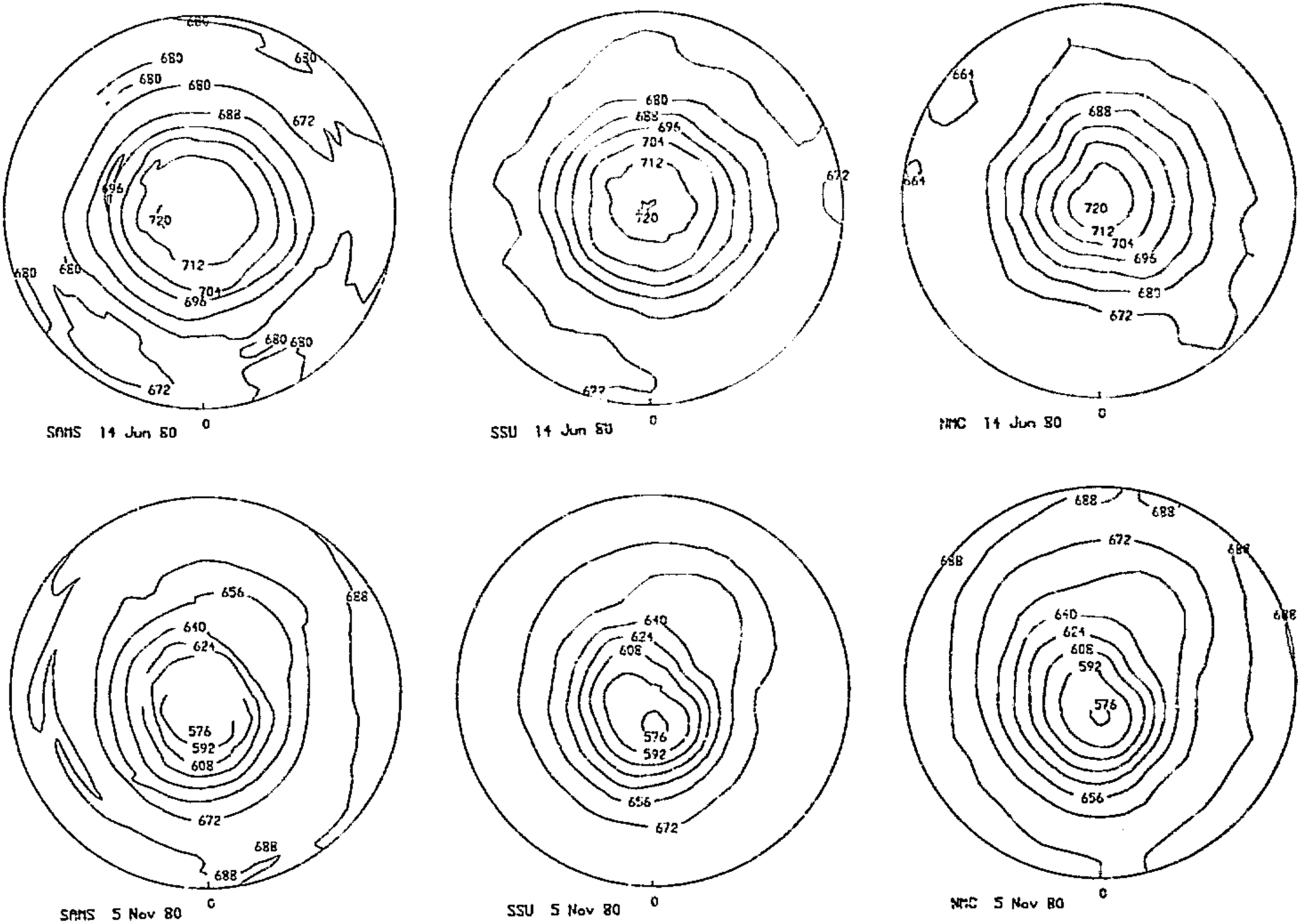
A1.16 10 - 5 mb thickness, decametres.



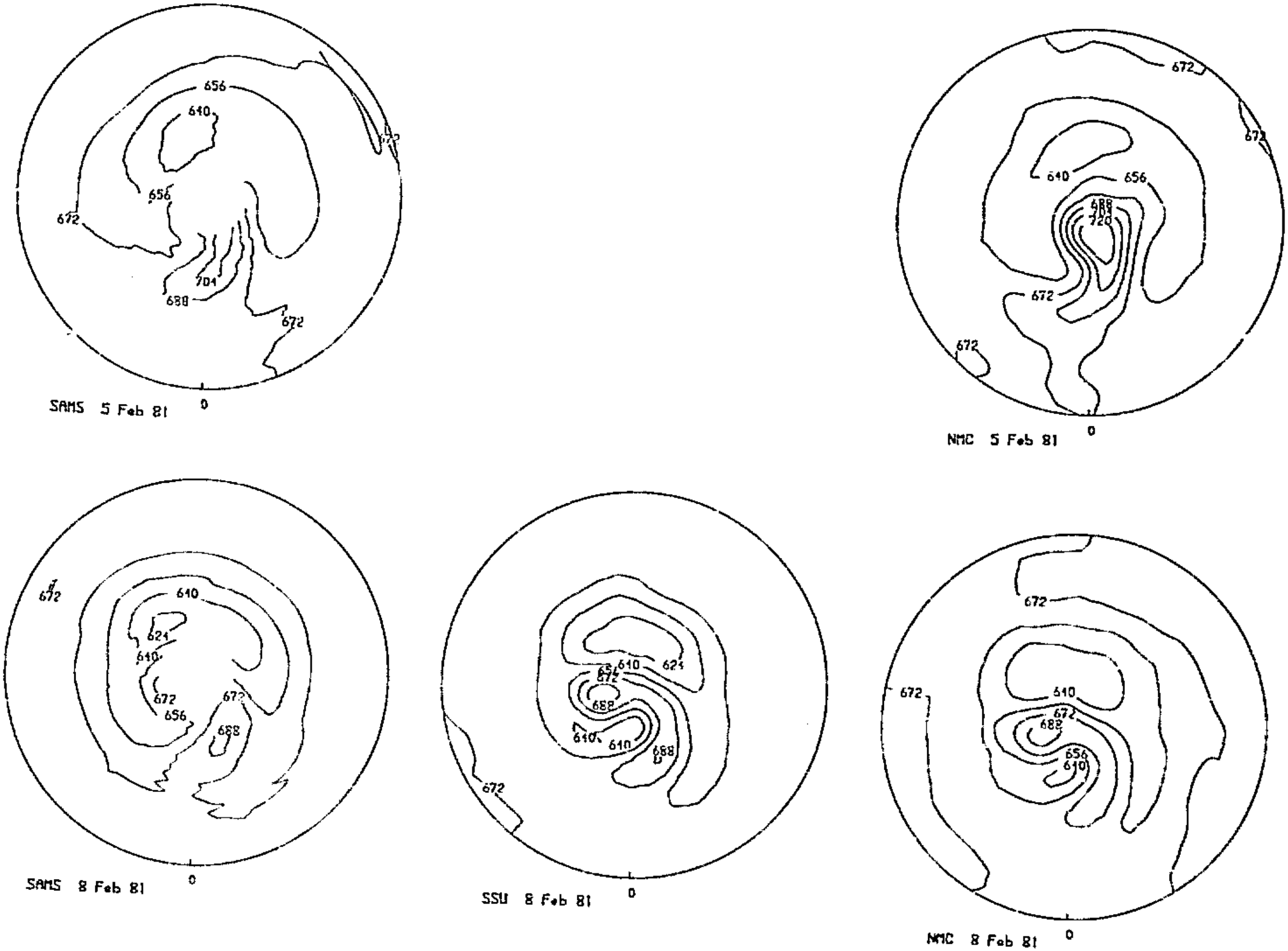
Ai.17 5 - 2 mb thickness, decametres.



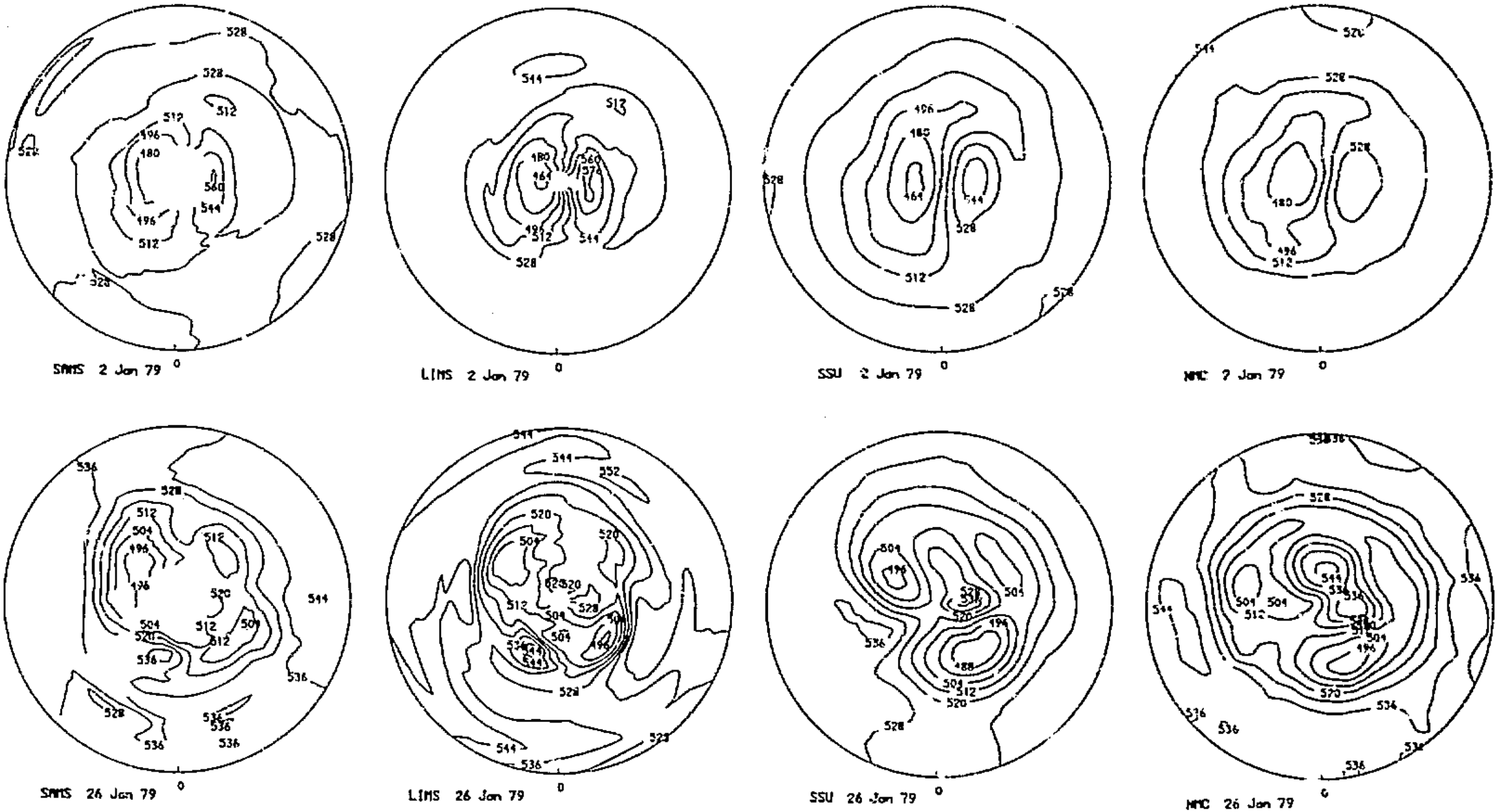
Al.18 5 - 2 mb thickness, decametres.



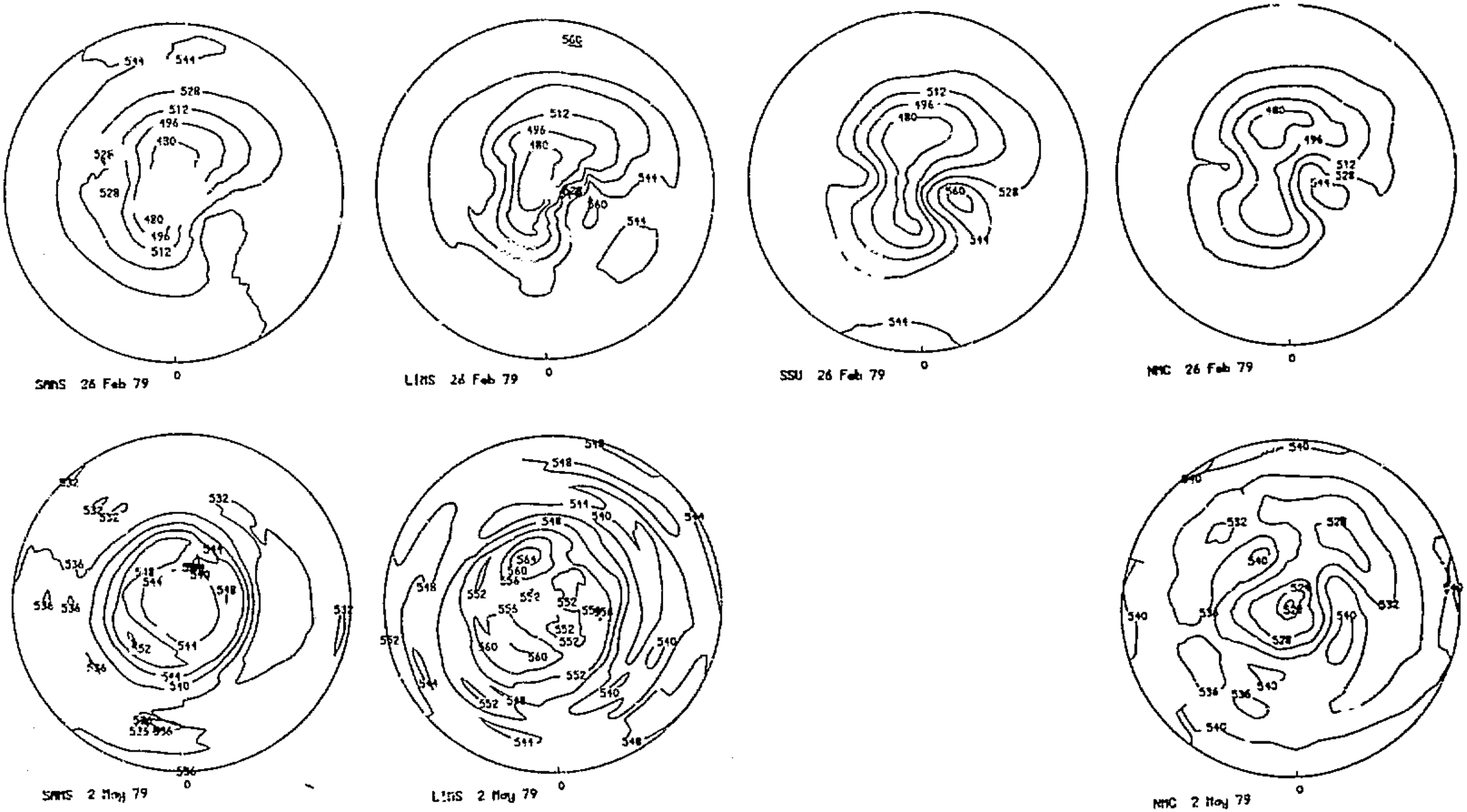
A1.19 5 - 2 mb thickness, decametres.



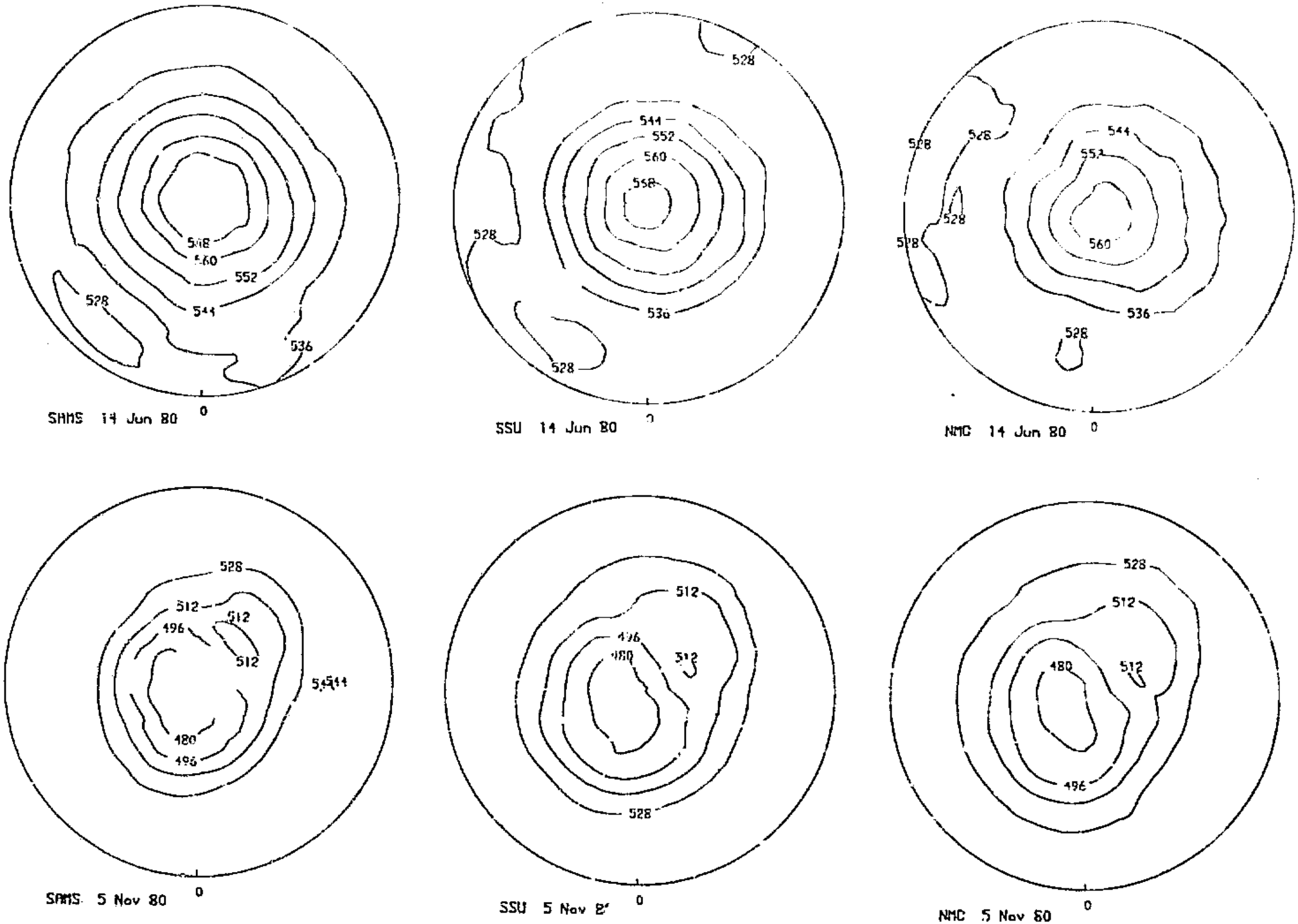
A1.20 5 - 2 mb thickness, decametres.



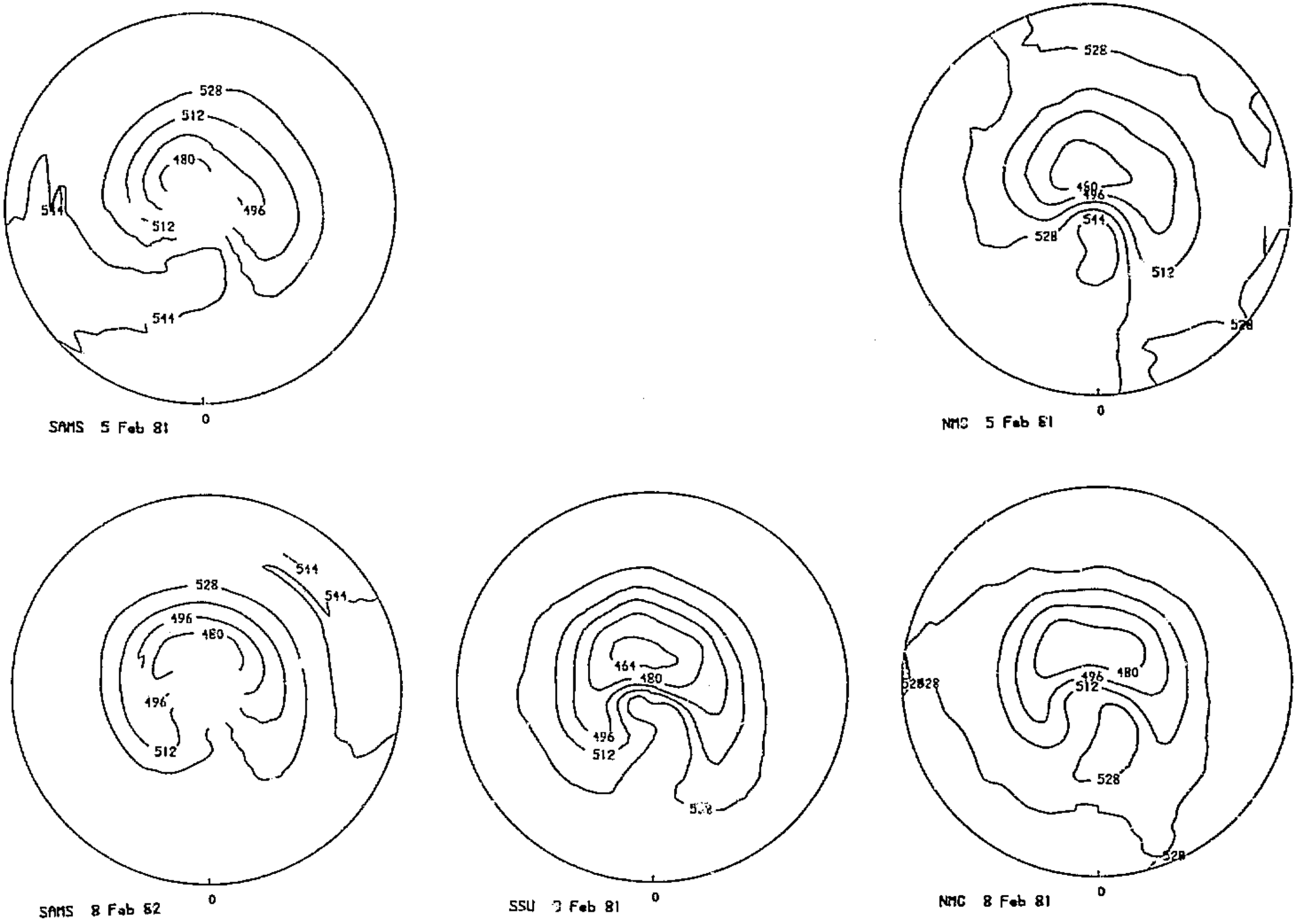
A1.21 2 - 1 mb thickness, decametres.



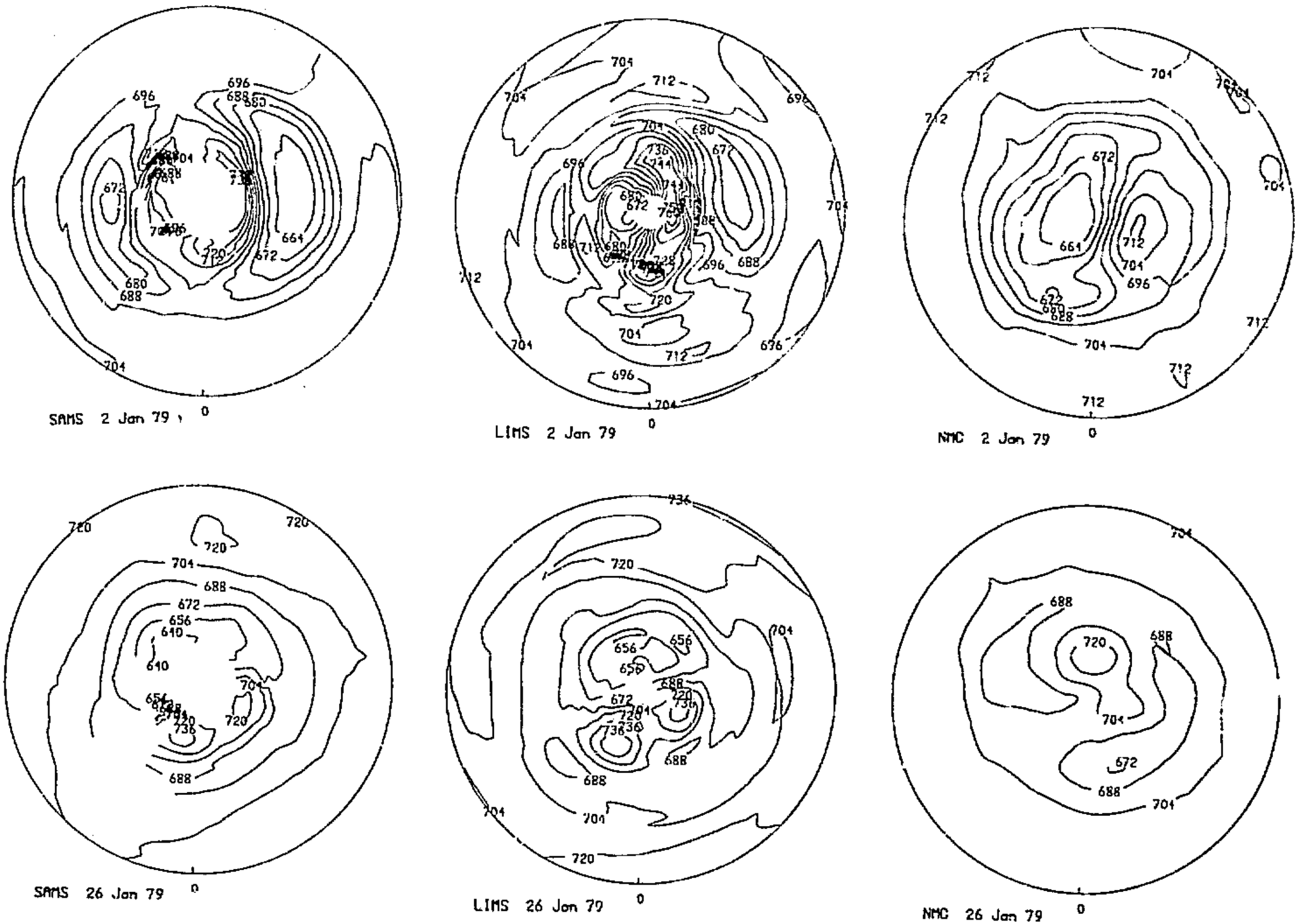
A1.22 2 - 1 mb thickness, decametres.



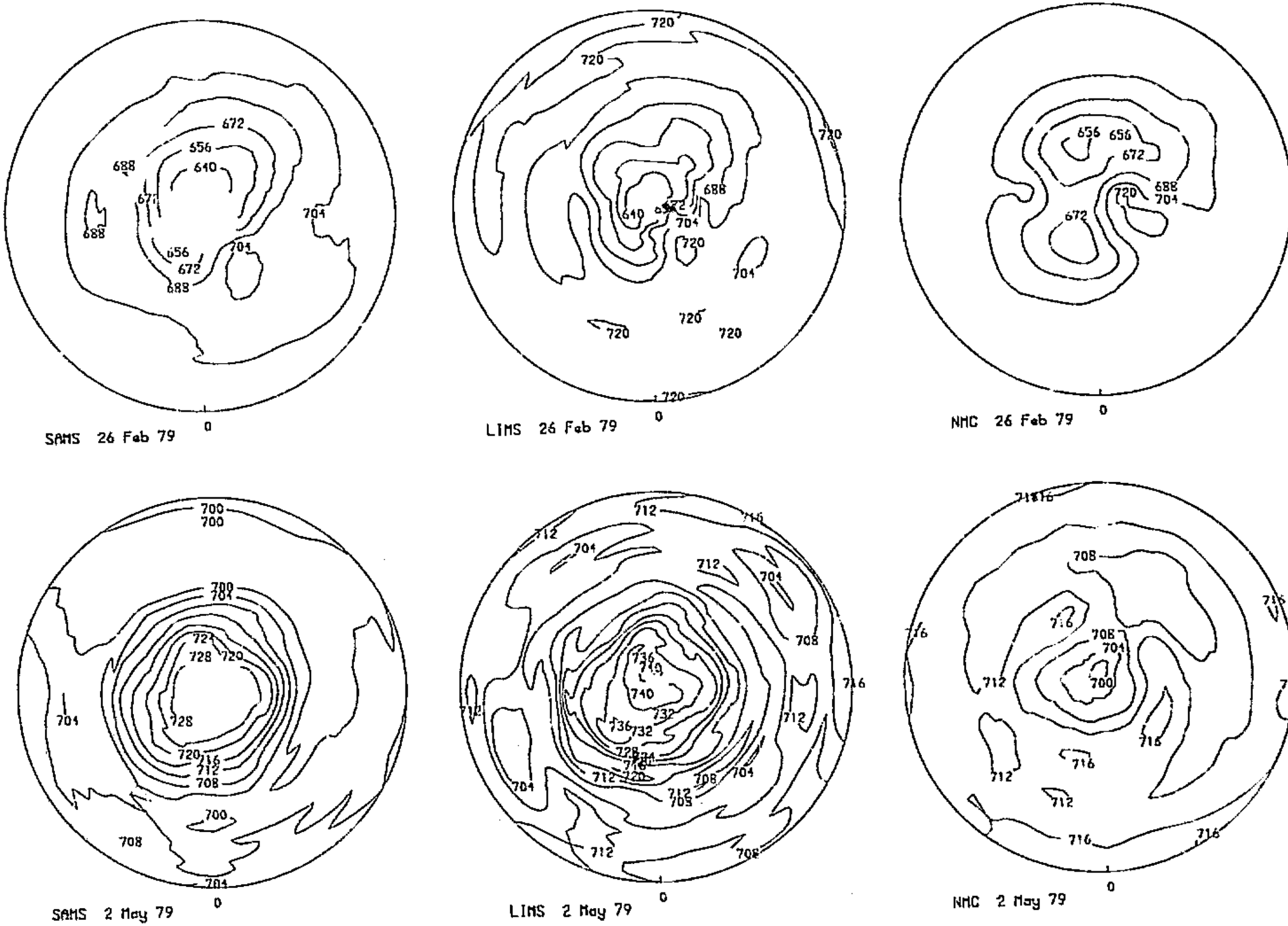
A1.23 2 - 1 mb thickness, decametres.



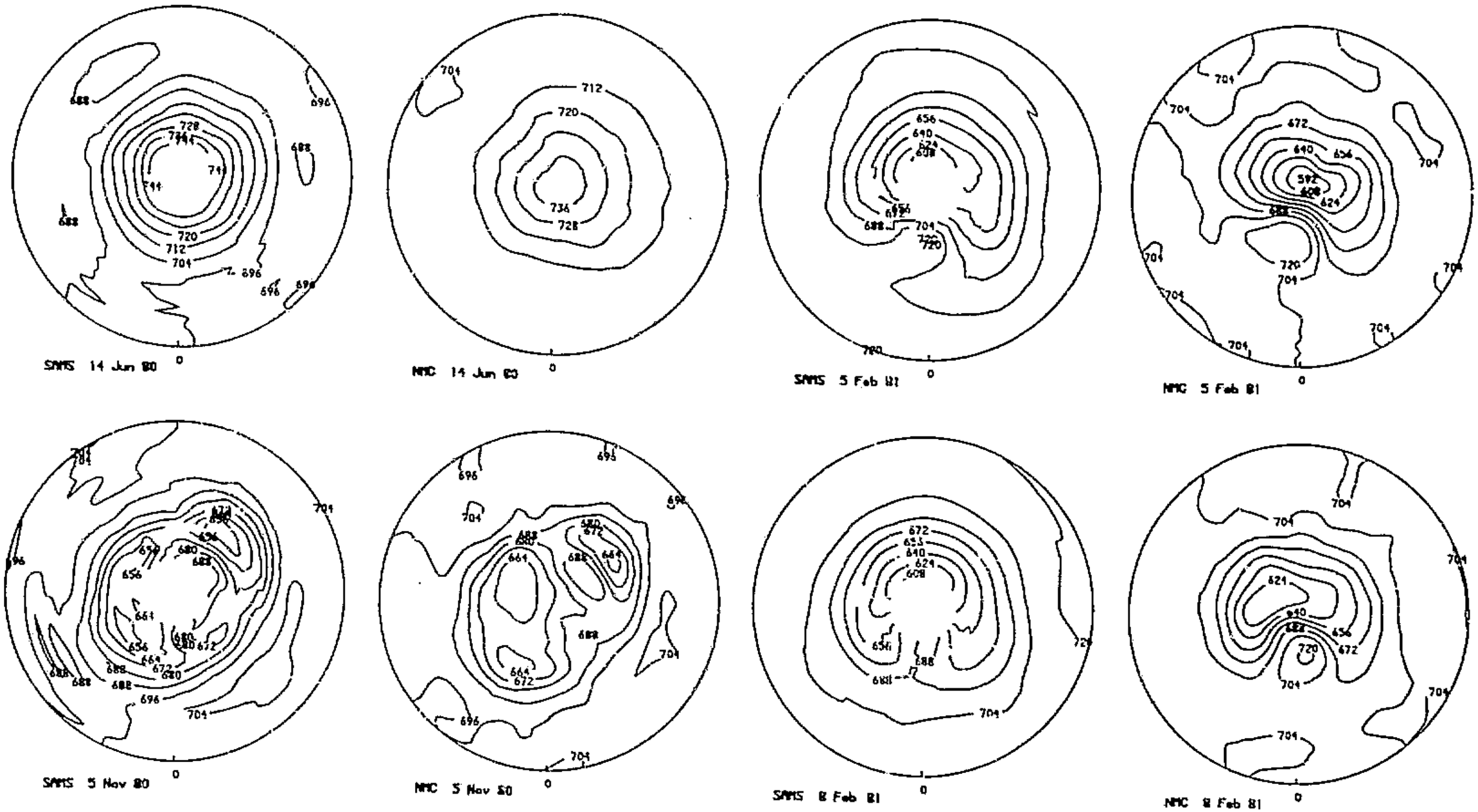
A1.24 2 - 1 mb thickness, decametres.



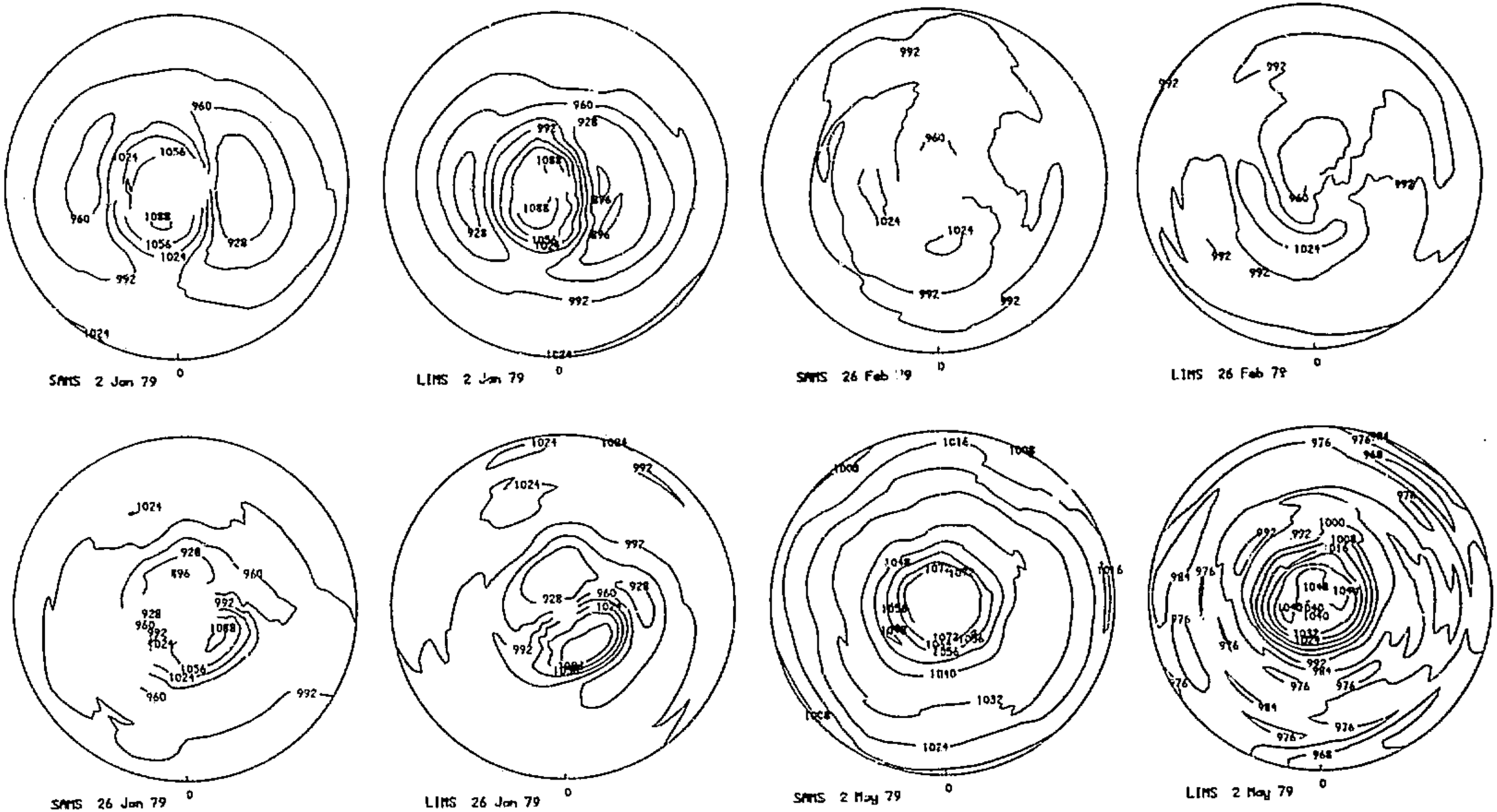
A1.25 1 - 0.4 mb thickness, decametres.



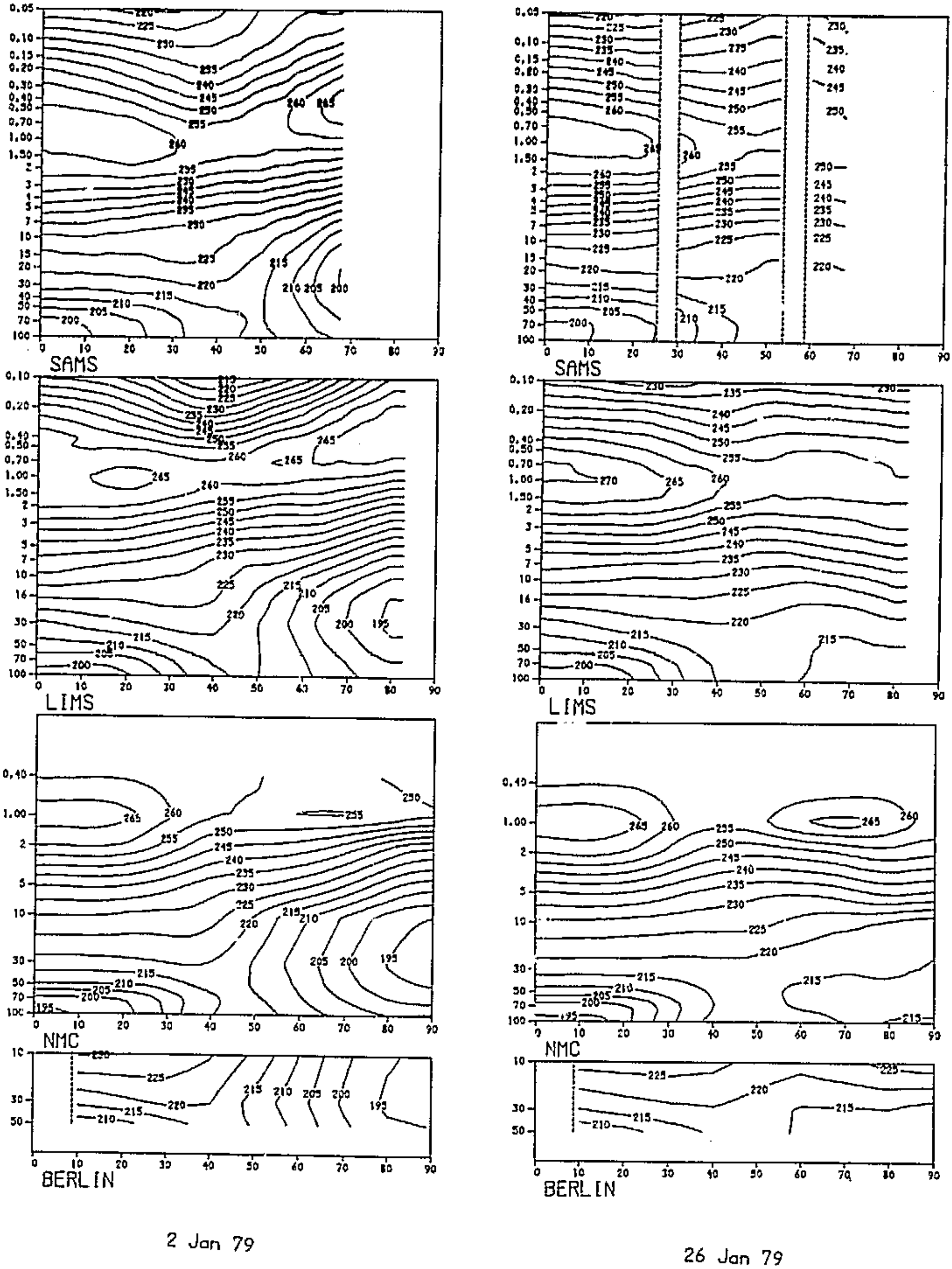
A1.26 1 - 0.4 mb thickness, decametres.



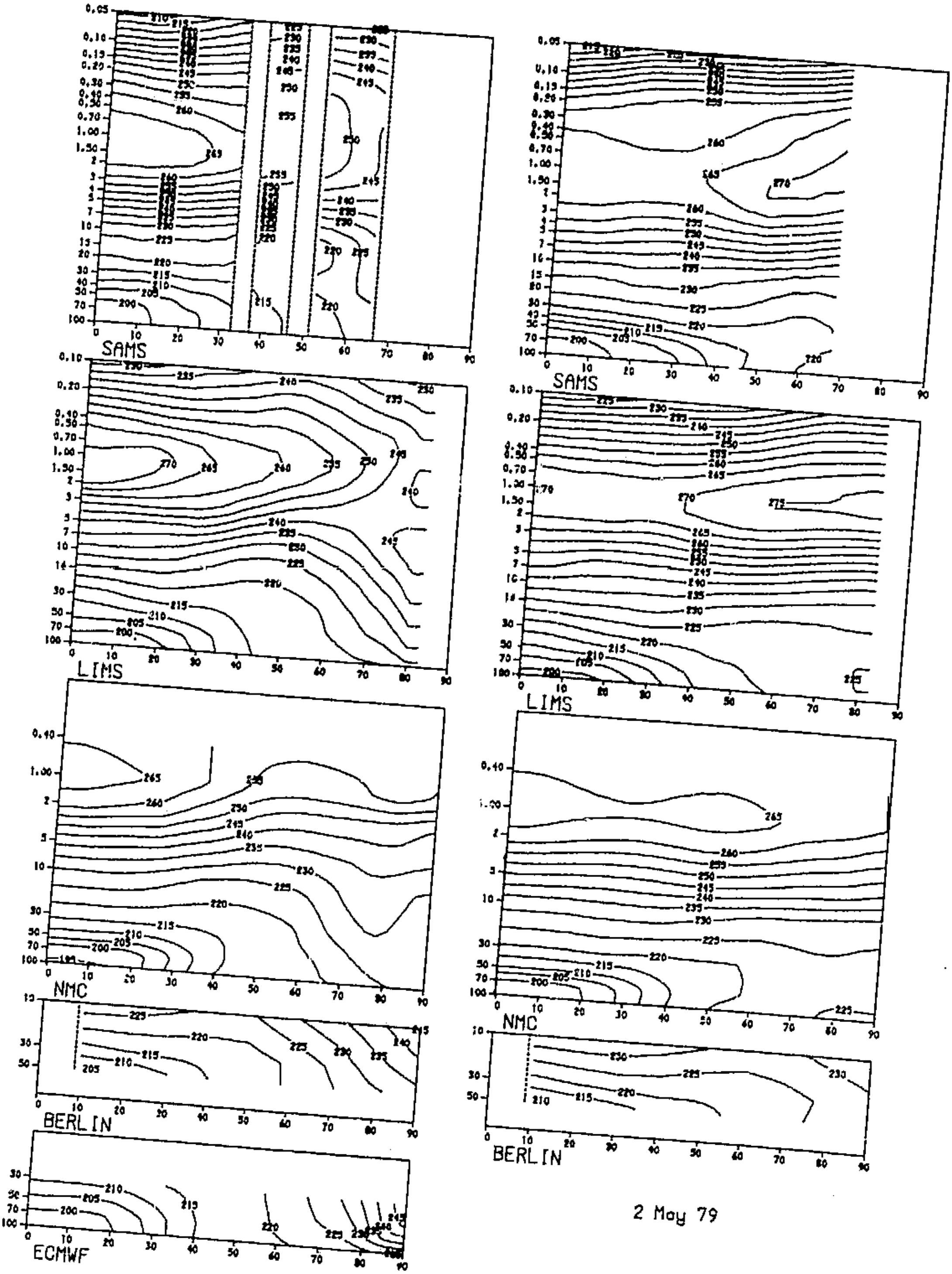
A1.27 1 - 0.4 mb thickness, decametres.



A1.28 0.4 - 0.1 mb thickness, decametres.



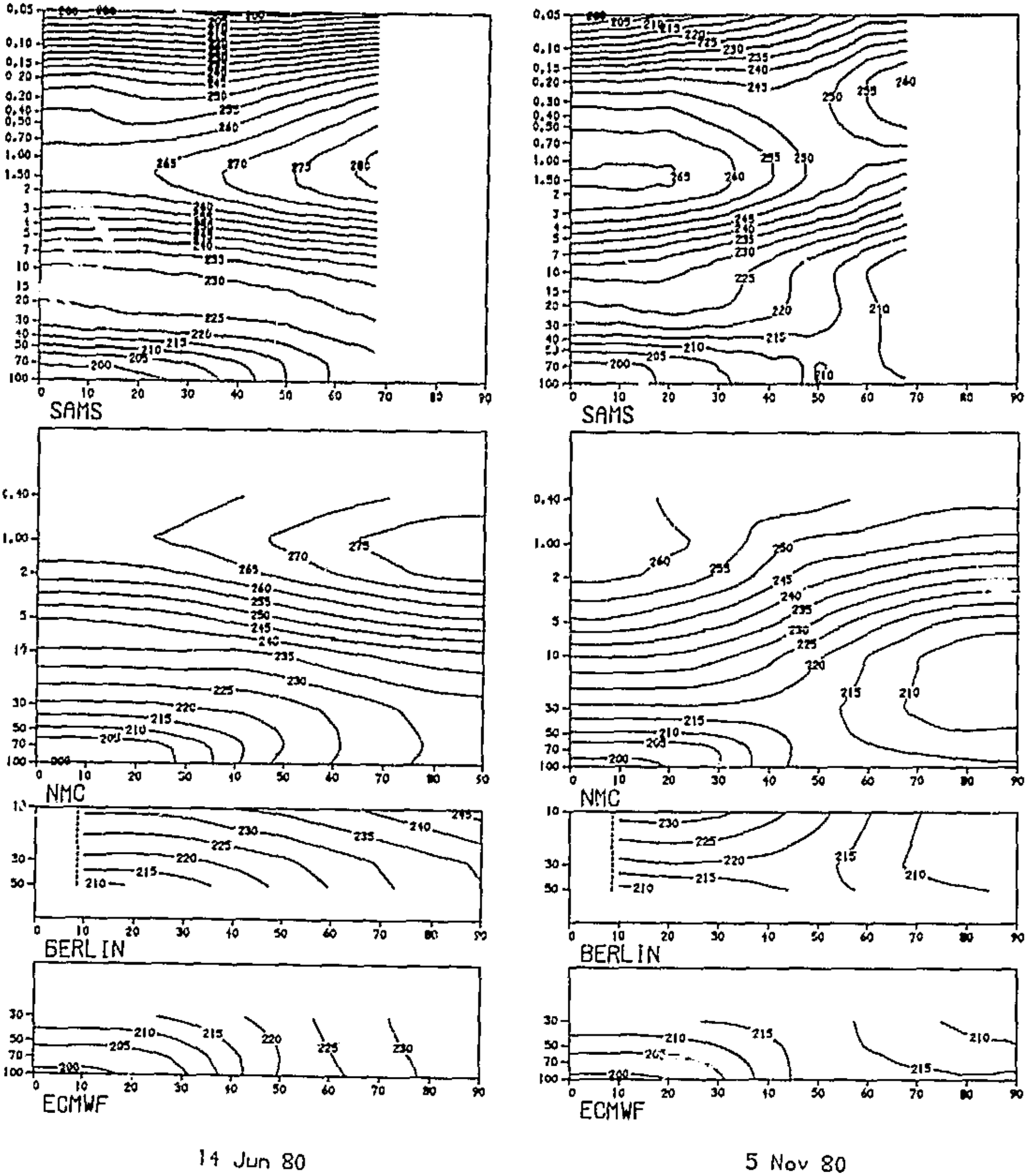
A2.1 Zonal mean temperature cross sections.



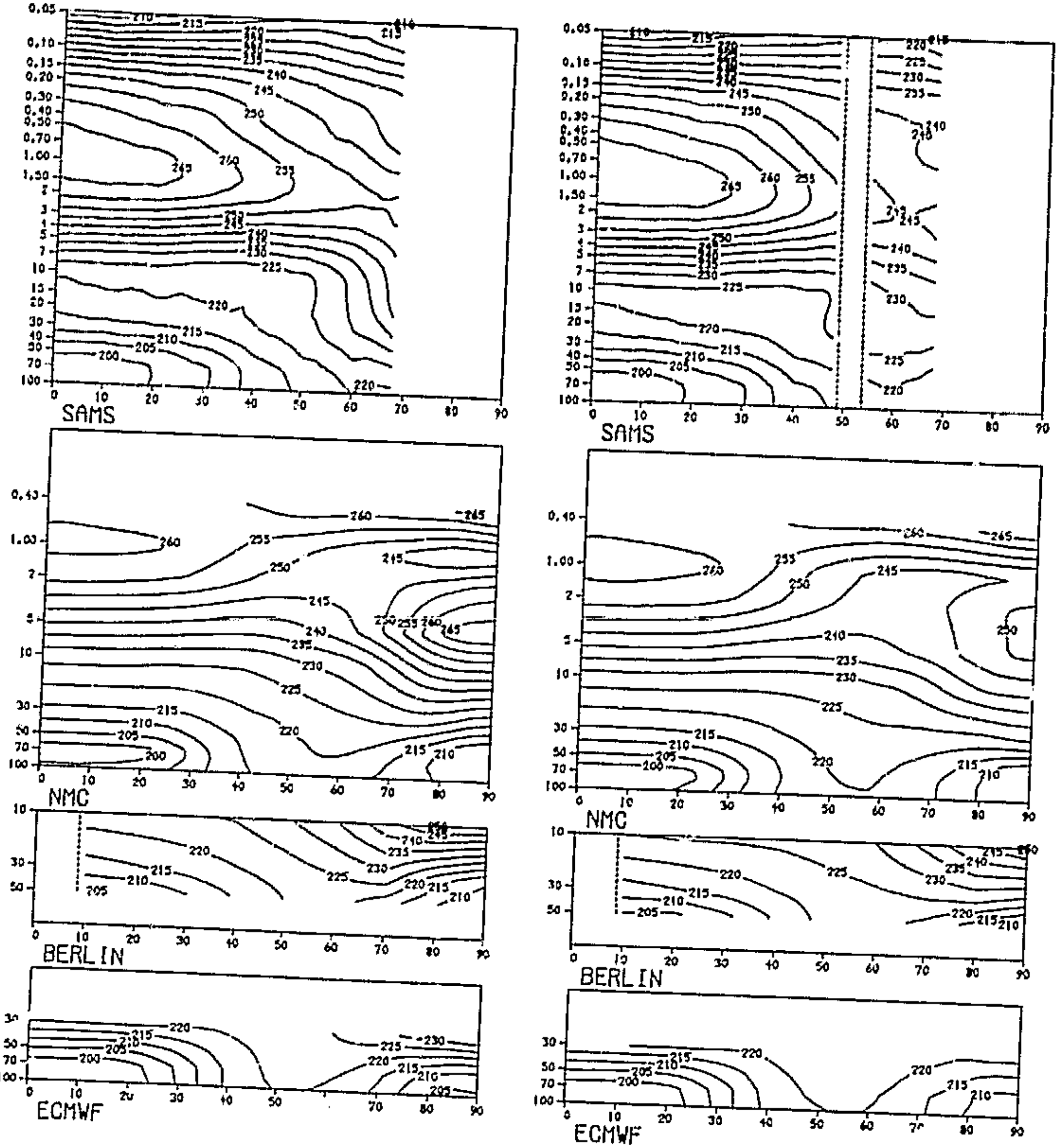
26 Feb 79

2 May 79

A2.2 Zonal mean temperature cross sections.



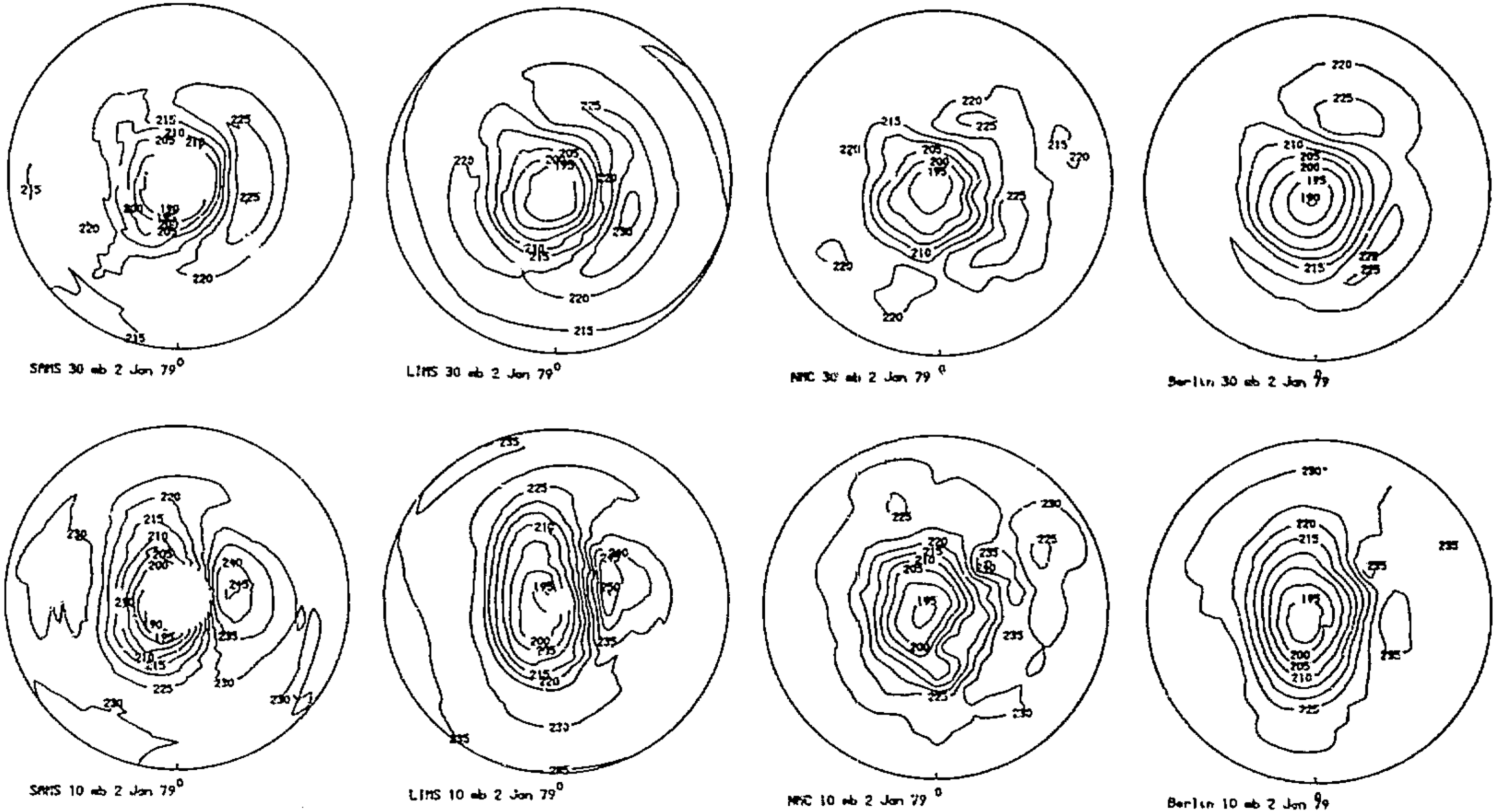
A2.3 Zonal mean temperature cross sections.



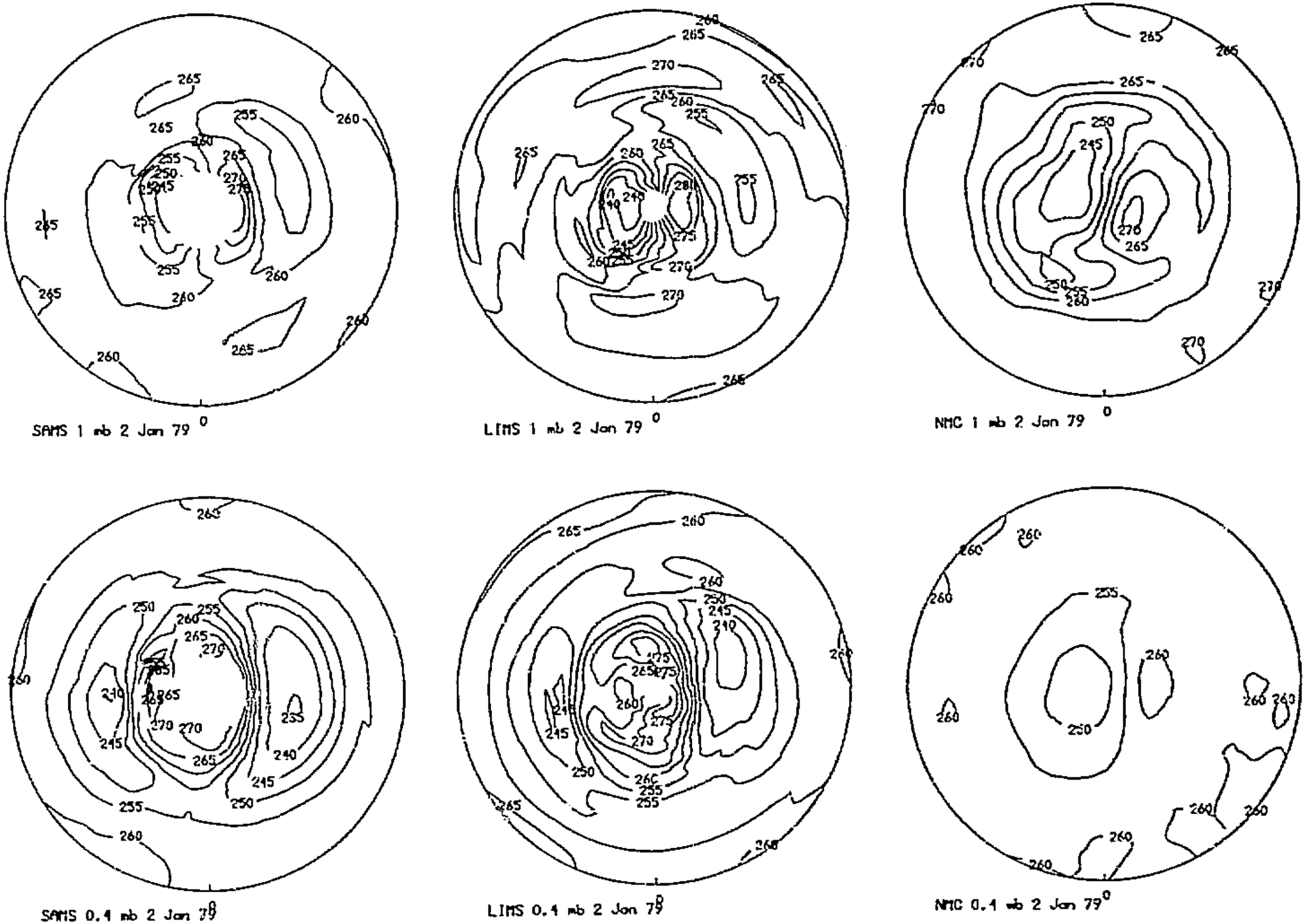
5 Feb 81

8 Feb 81

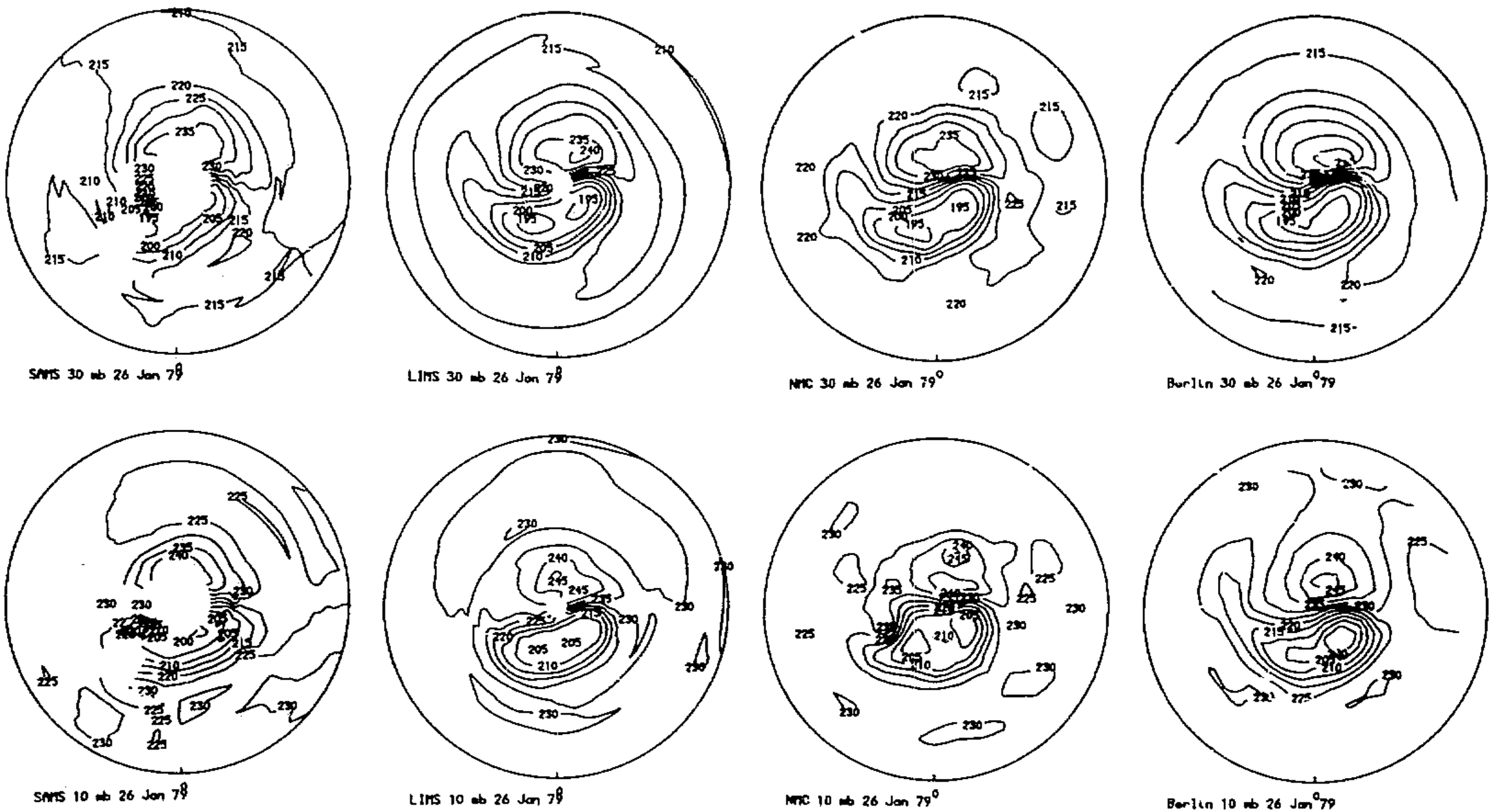
A2.4 Zonal mean temperature cross sections.



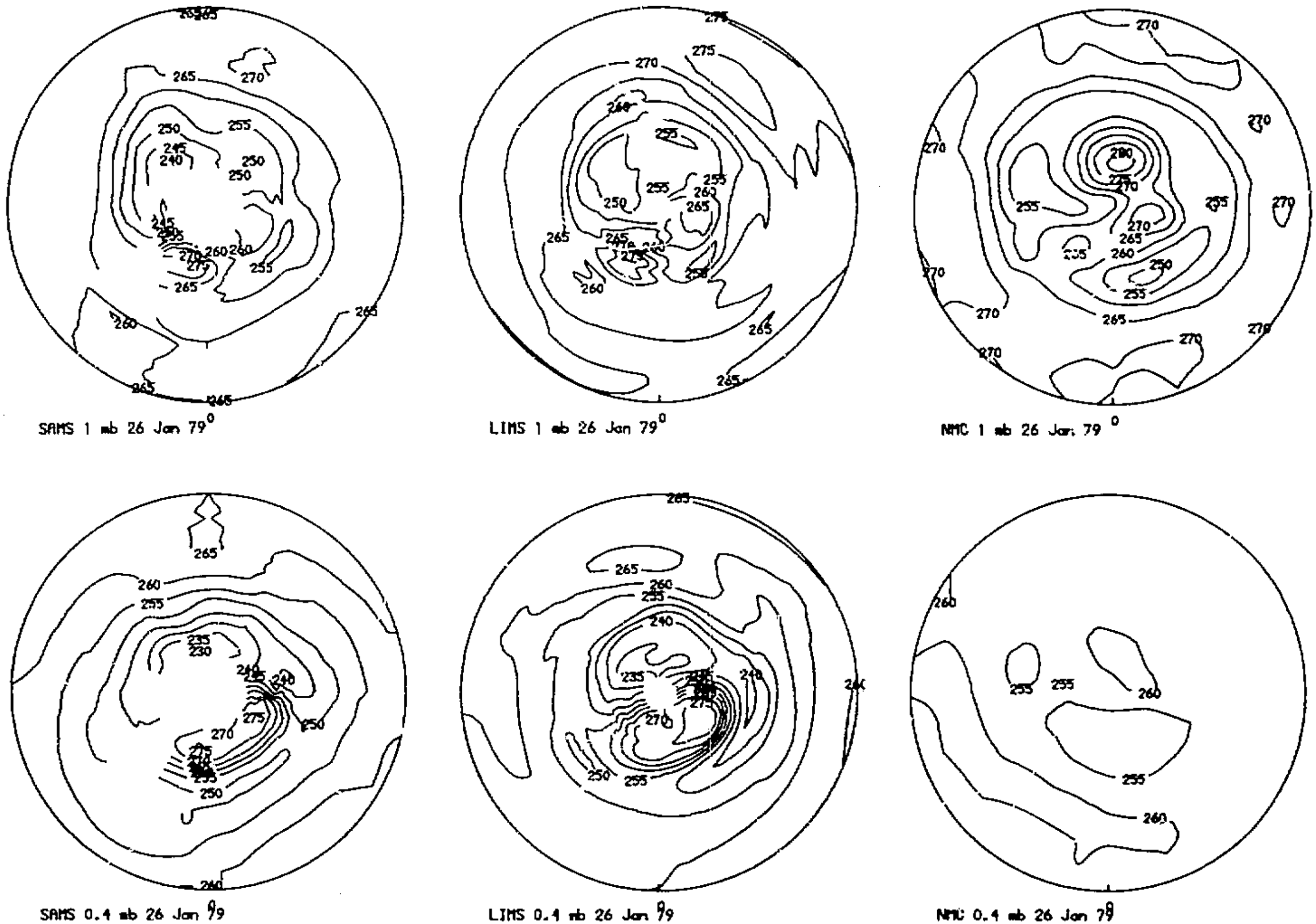
A3.1 Temperature maps.



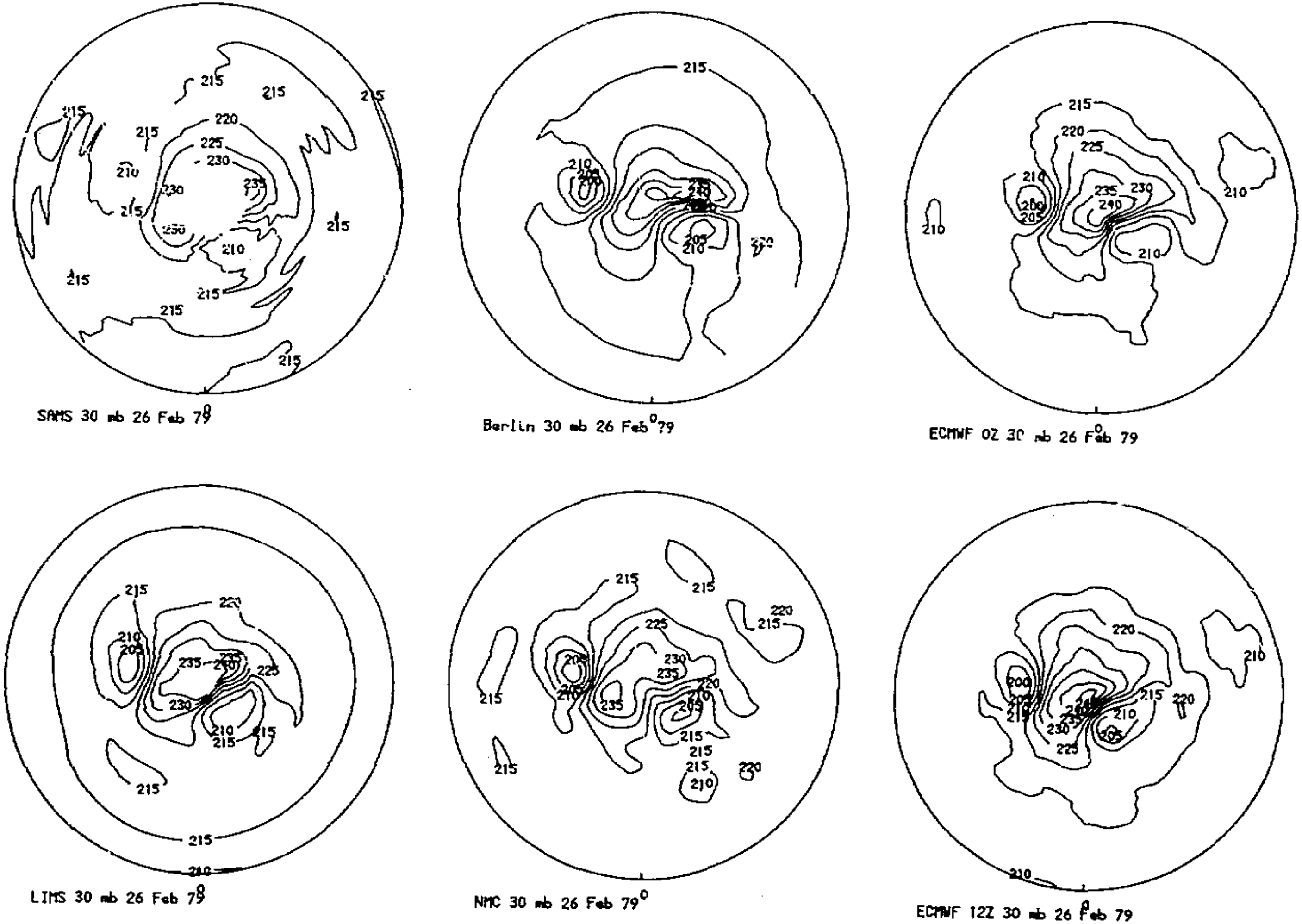
A3.2 Temperature maps.



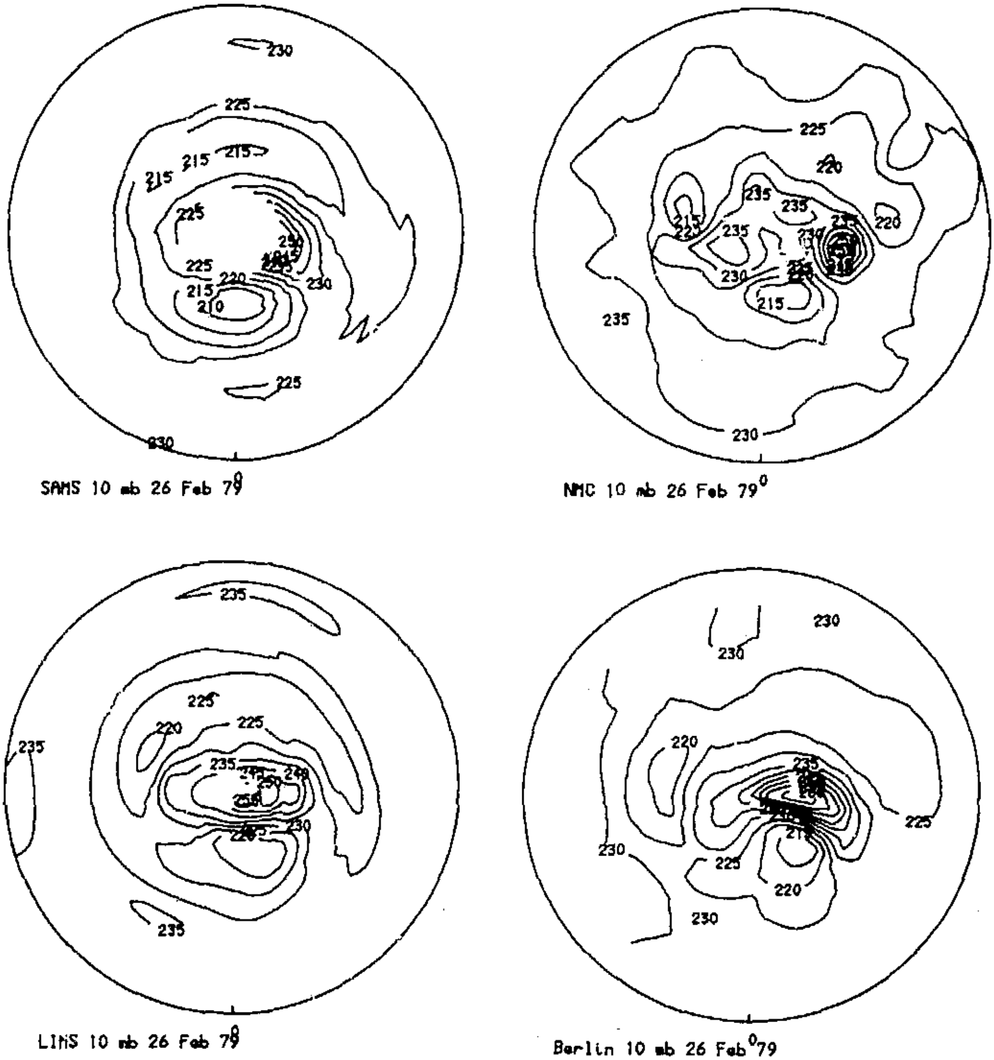
A3.3 Temperature maps.



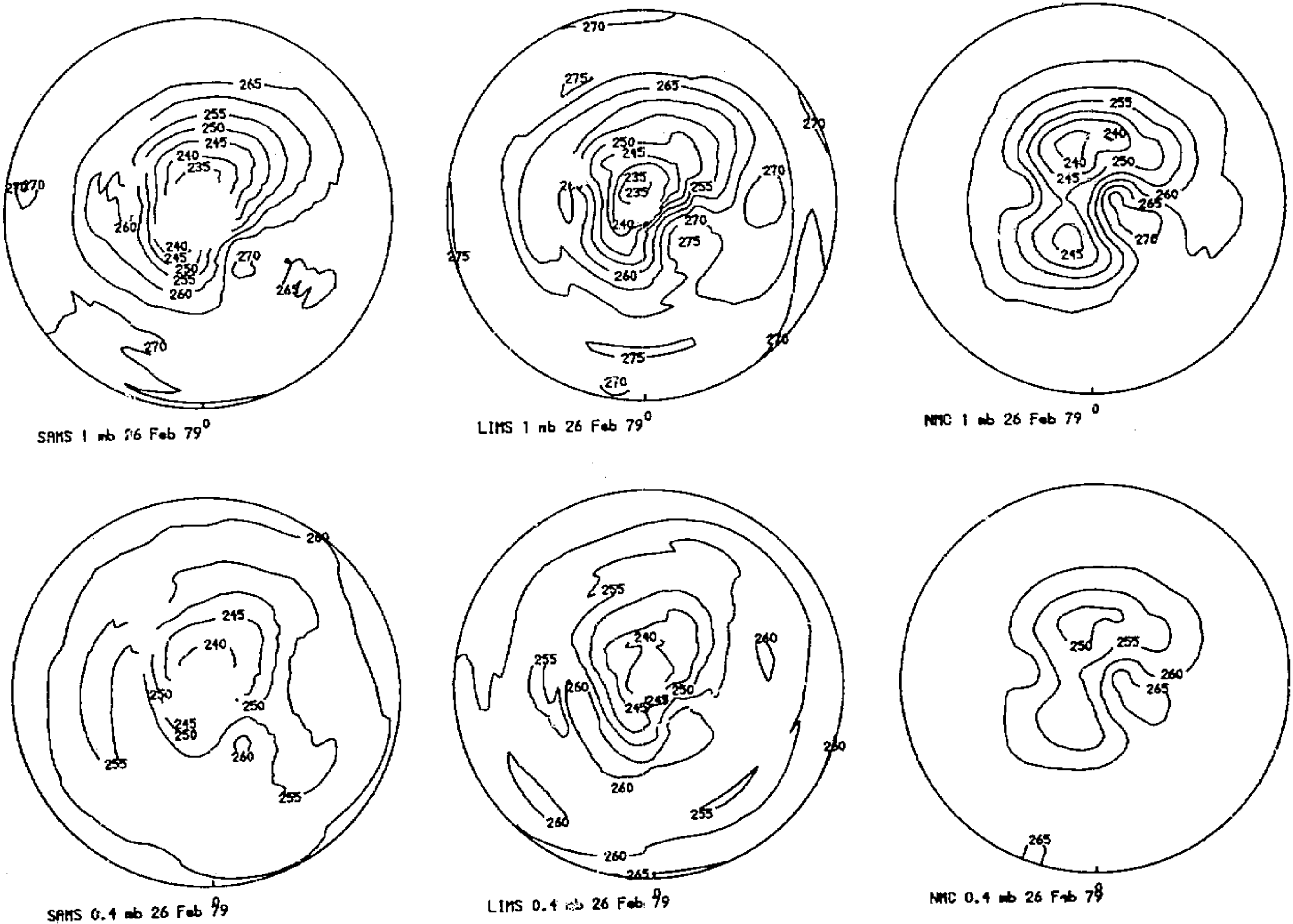
A3.4 Temperature maps.



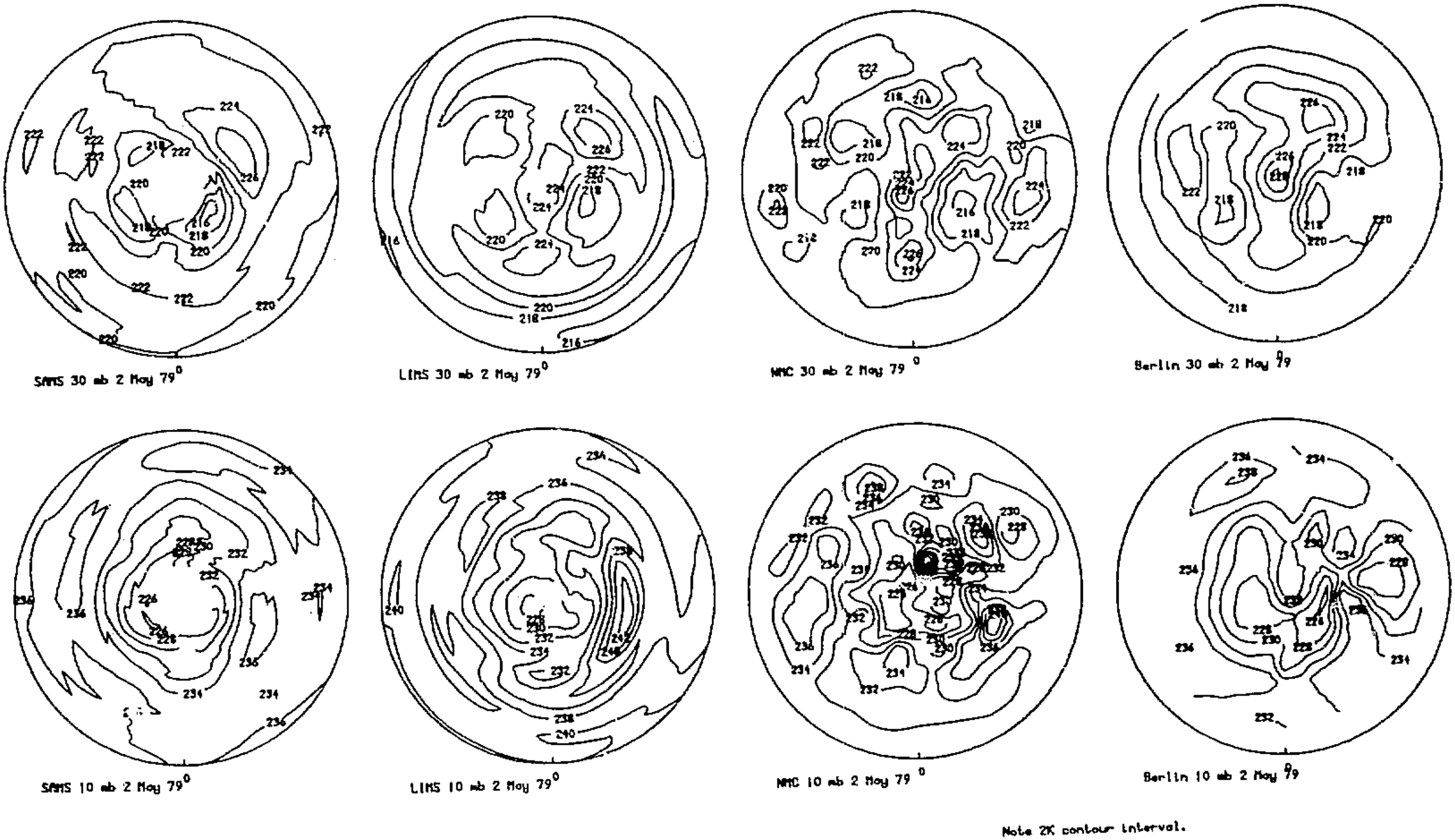
A3.5 Temperature maps.



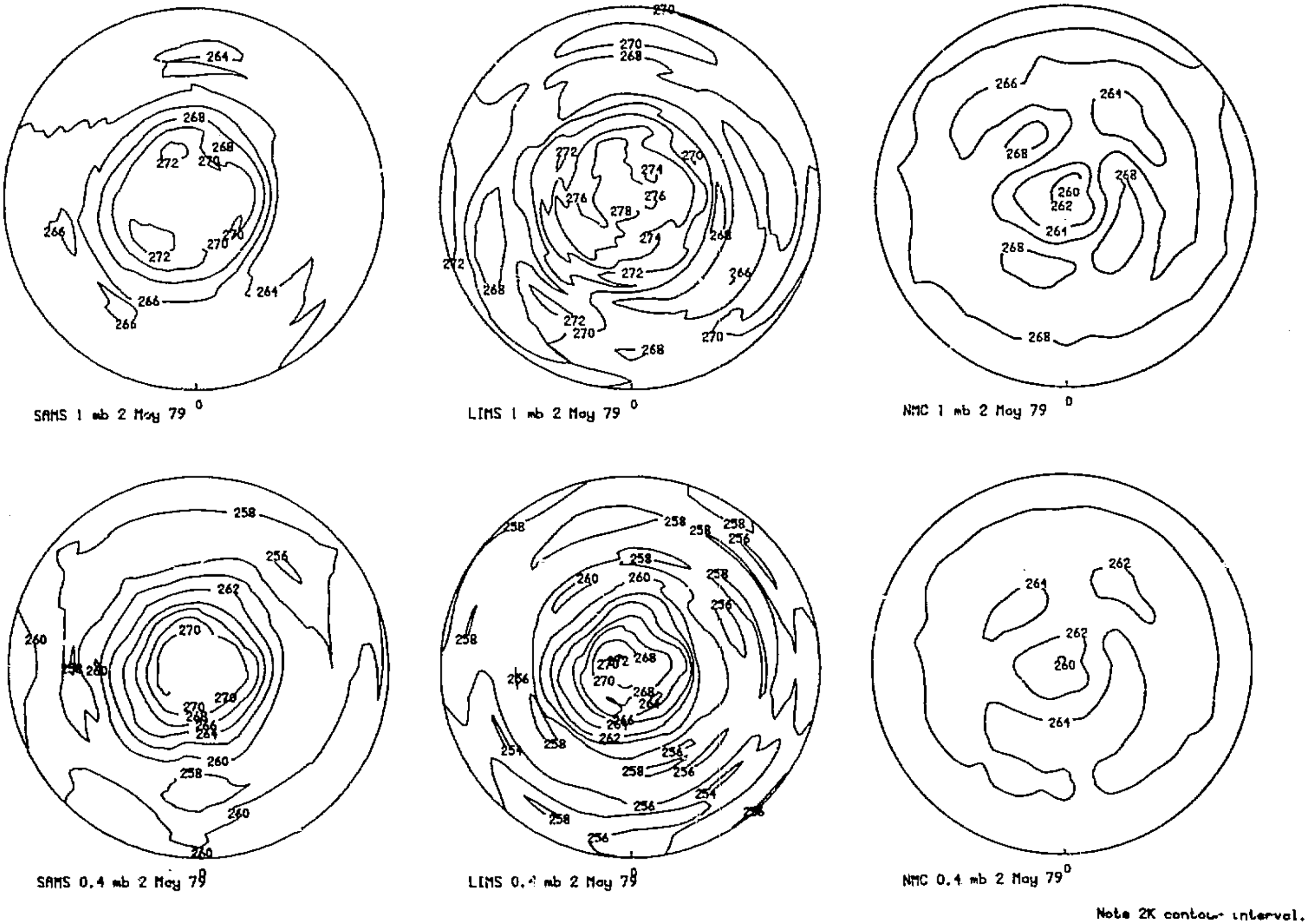
A3.6 Temperature maps.



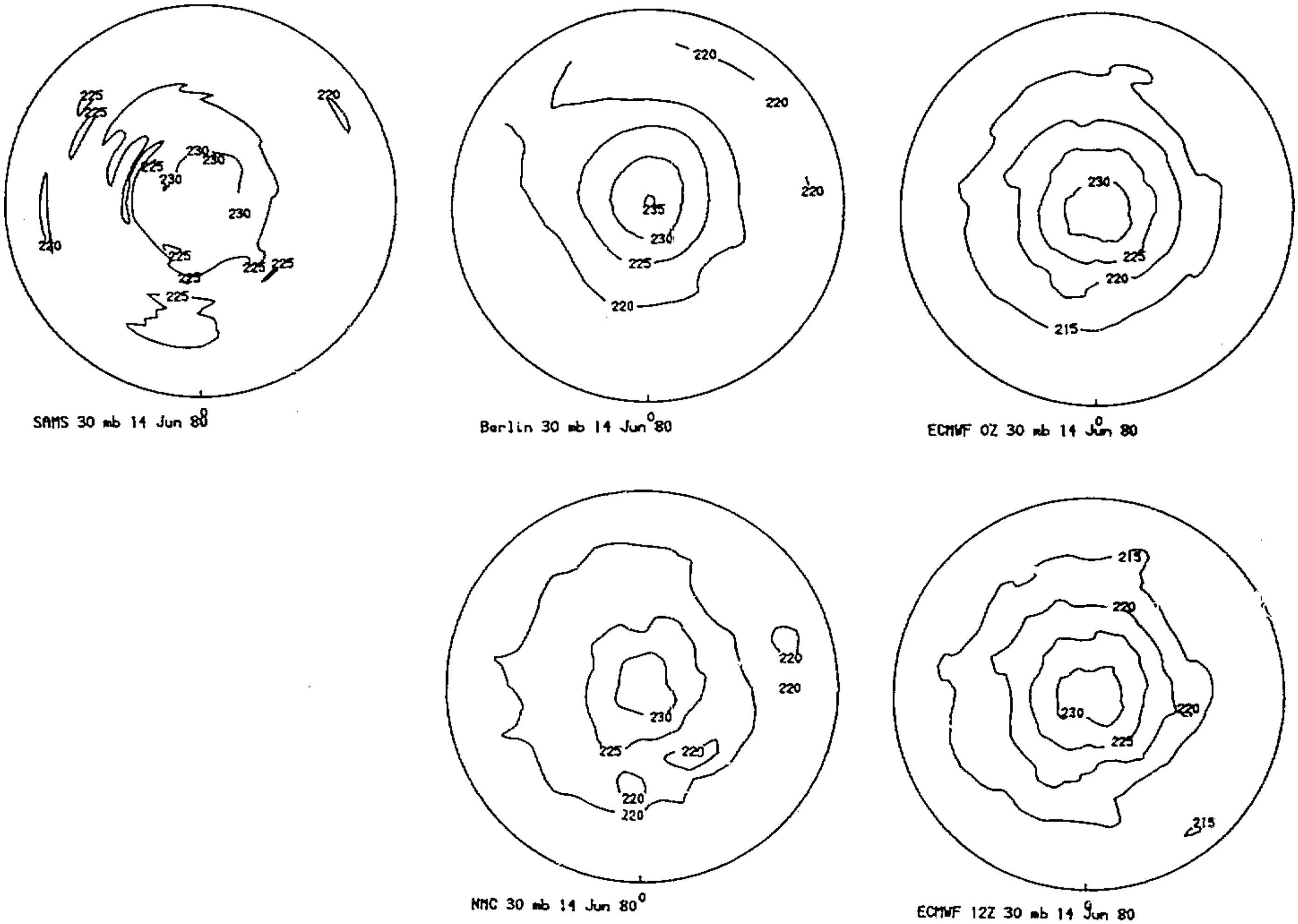
A3.7 Temperature maps.



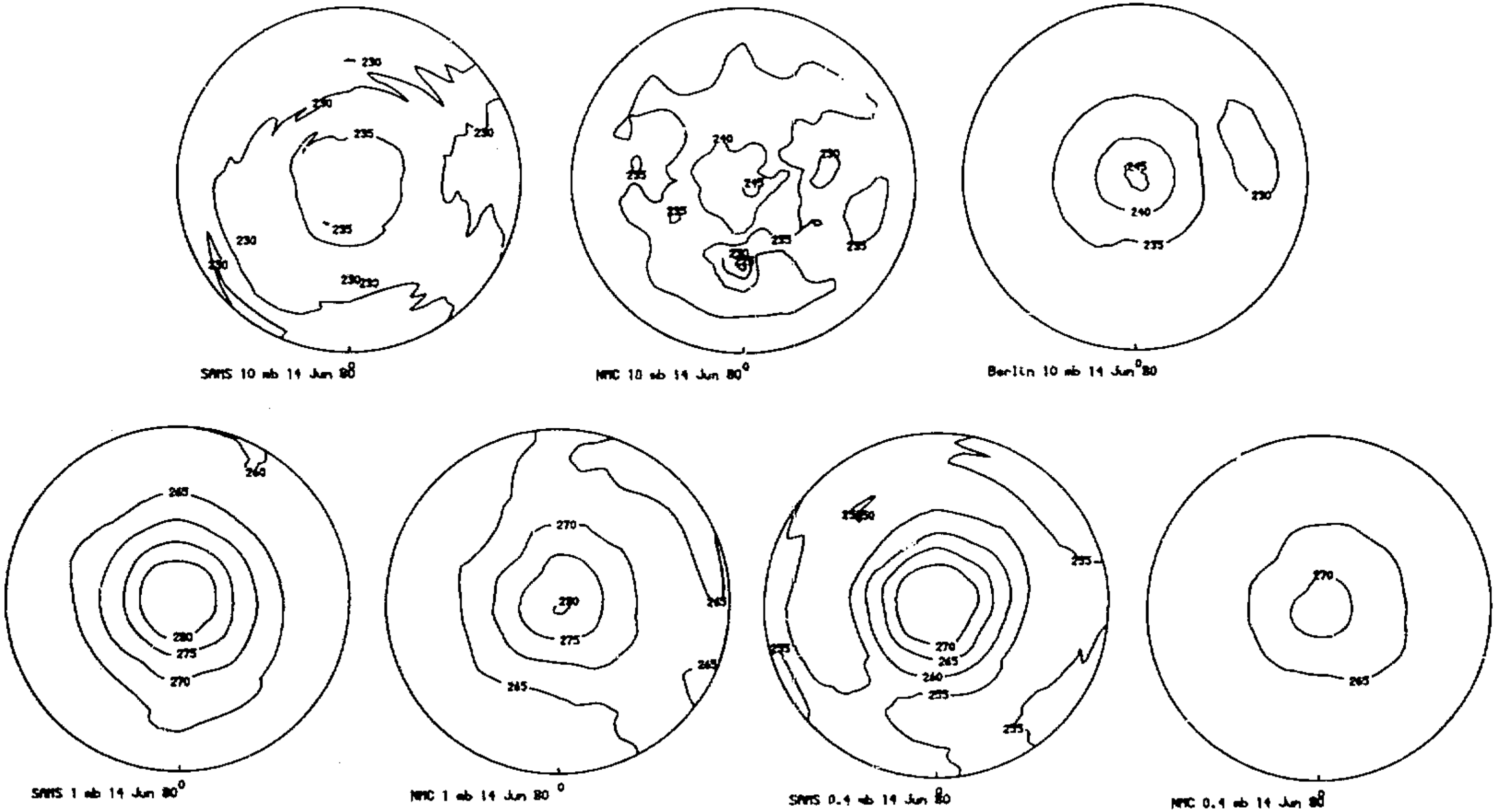
A3.8 Temperature maps.



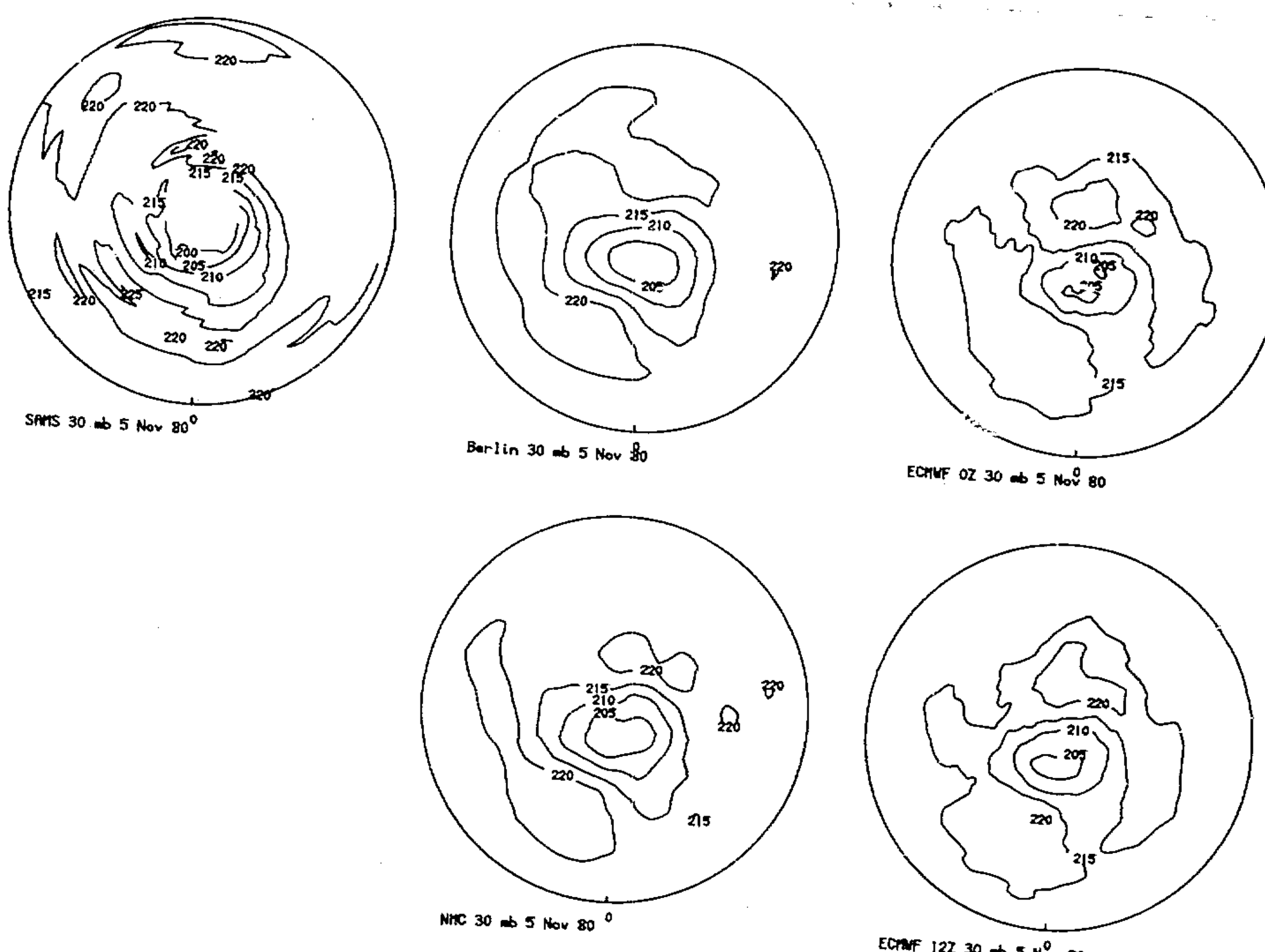
A3.9 Temperature maps.



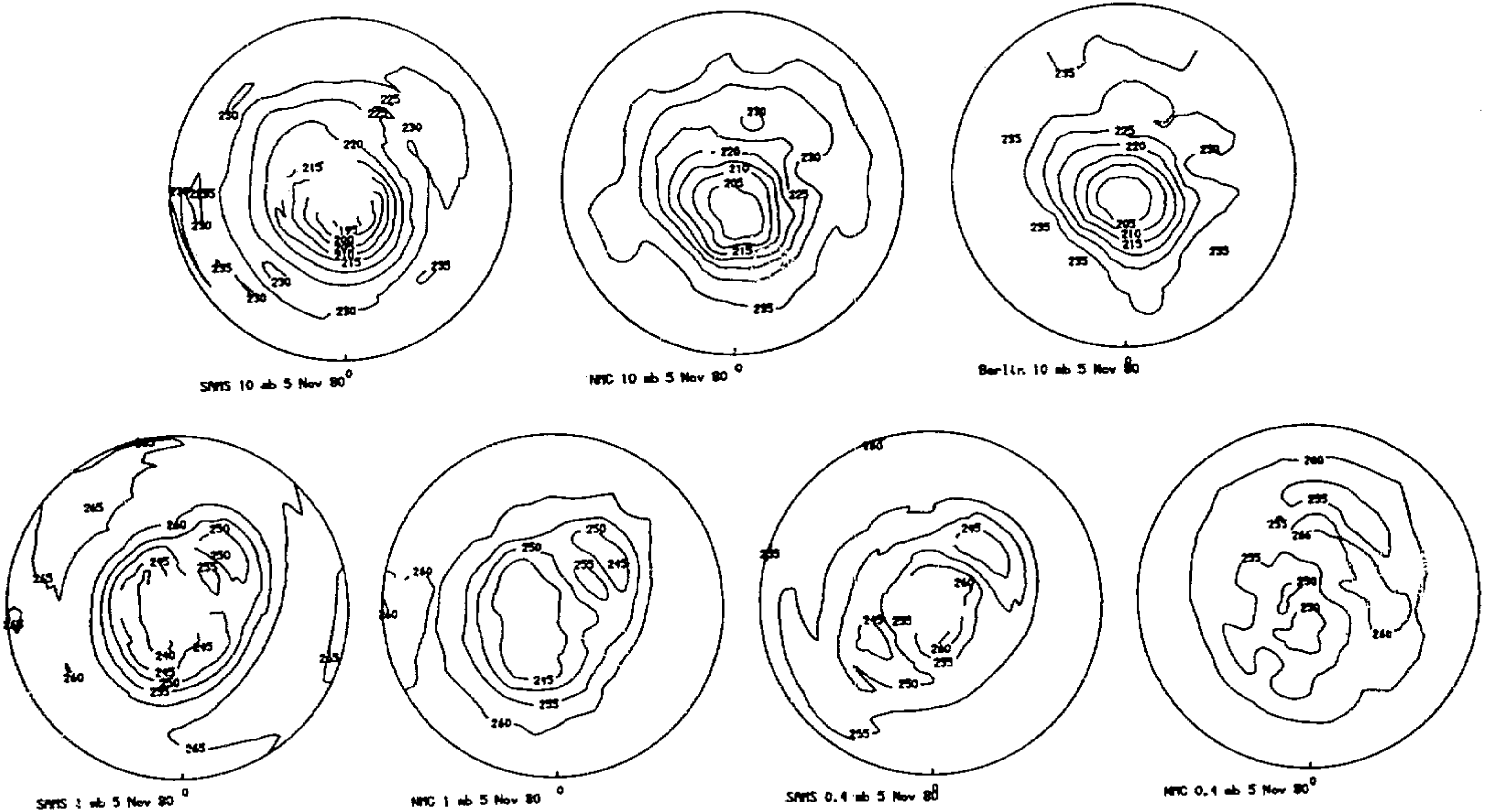
A3.10 Temperature maps.



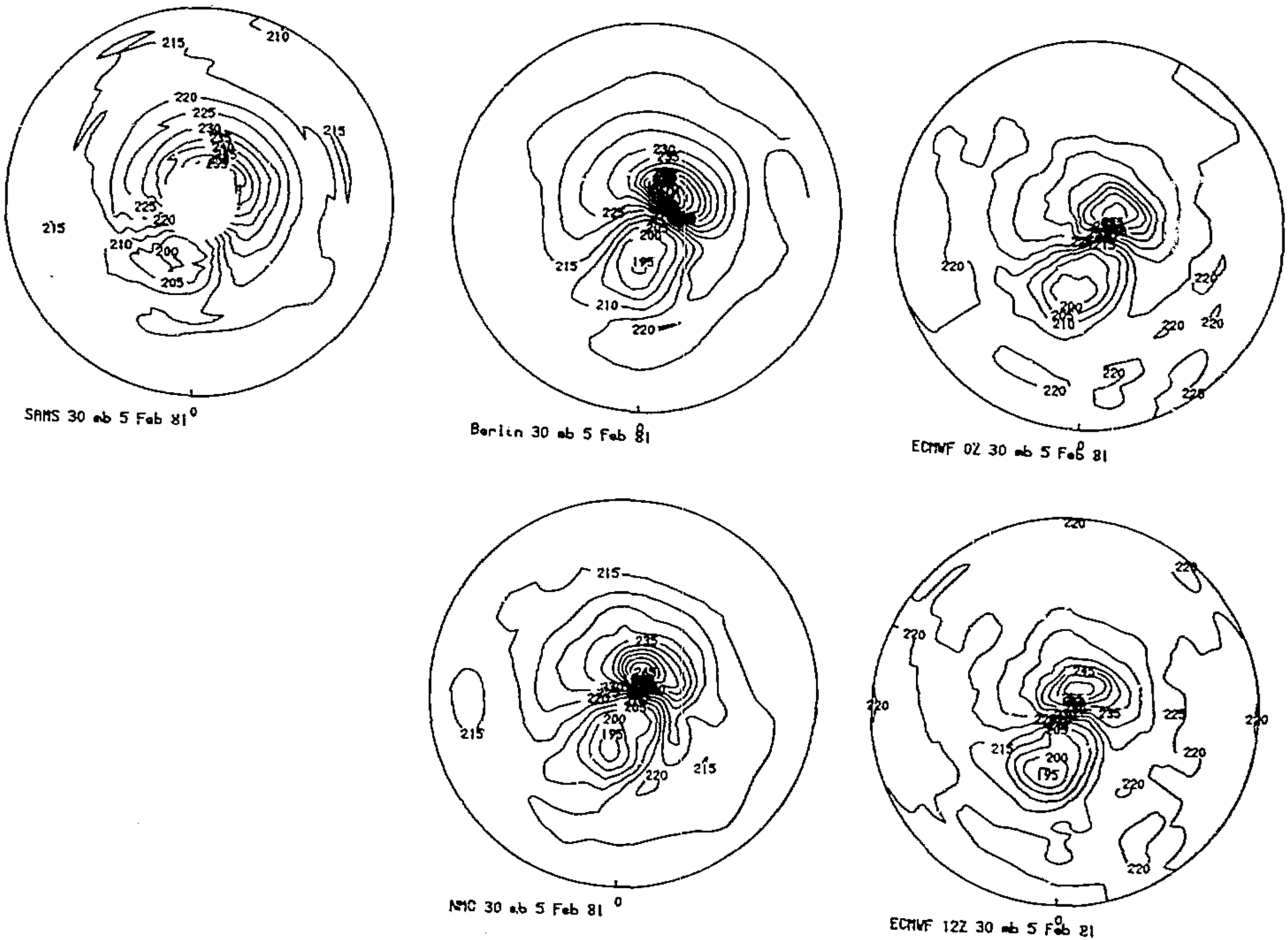
A3.11 Temperature maps.



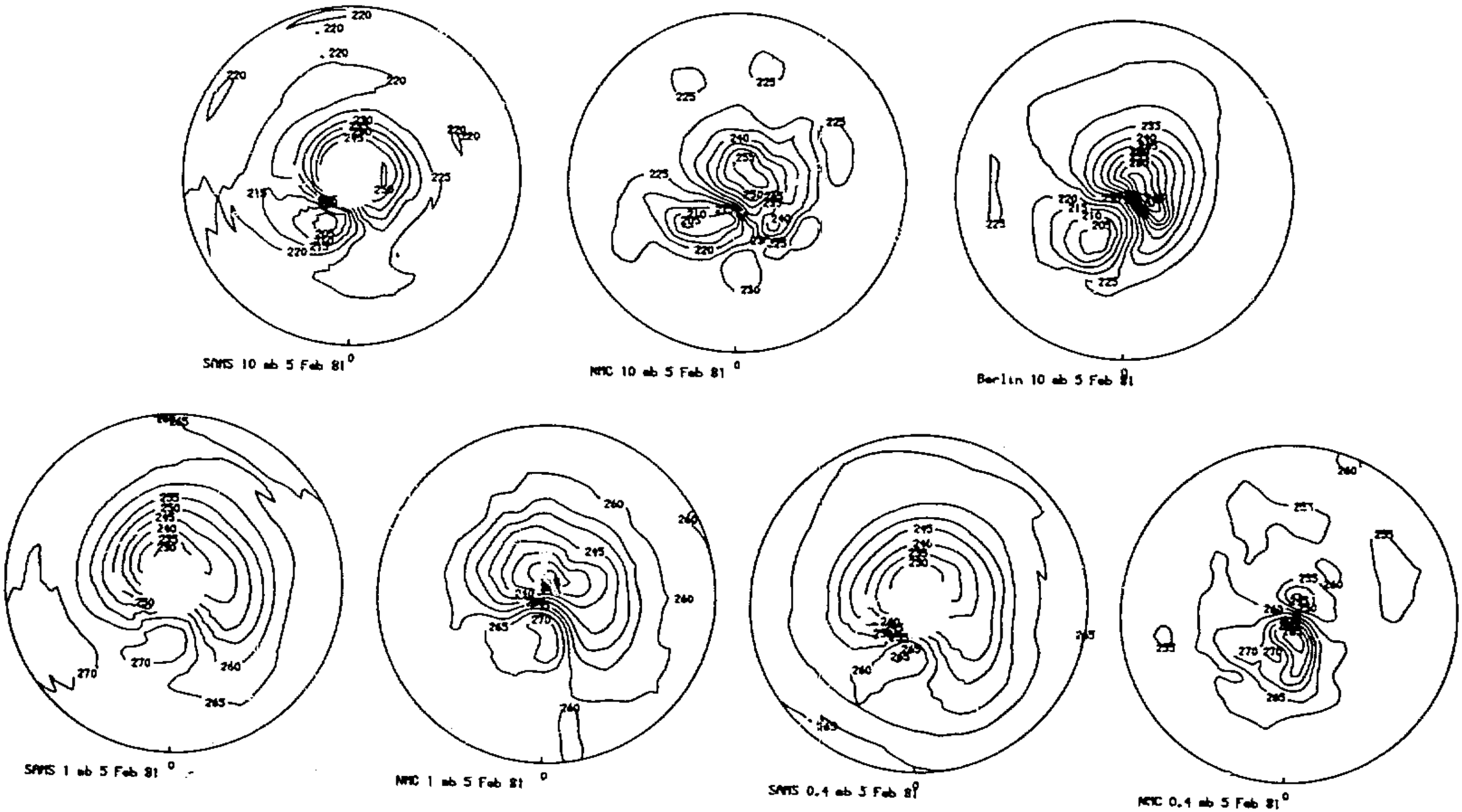
A3.12 Temperature maps.



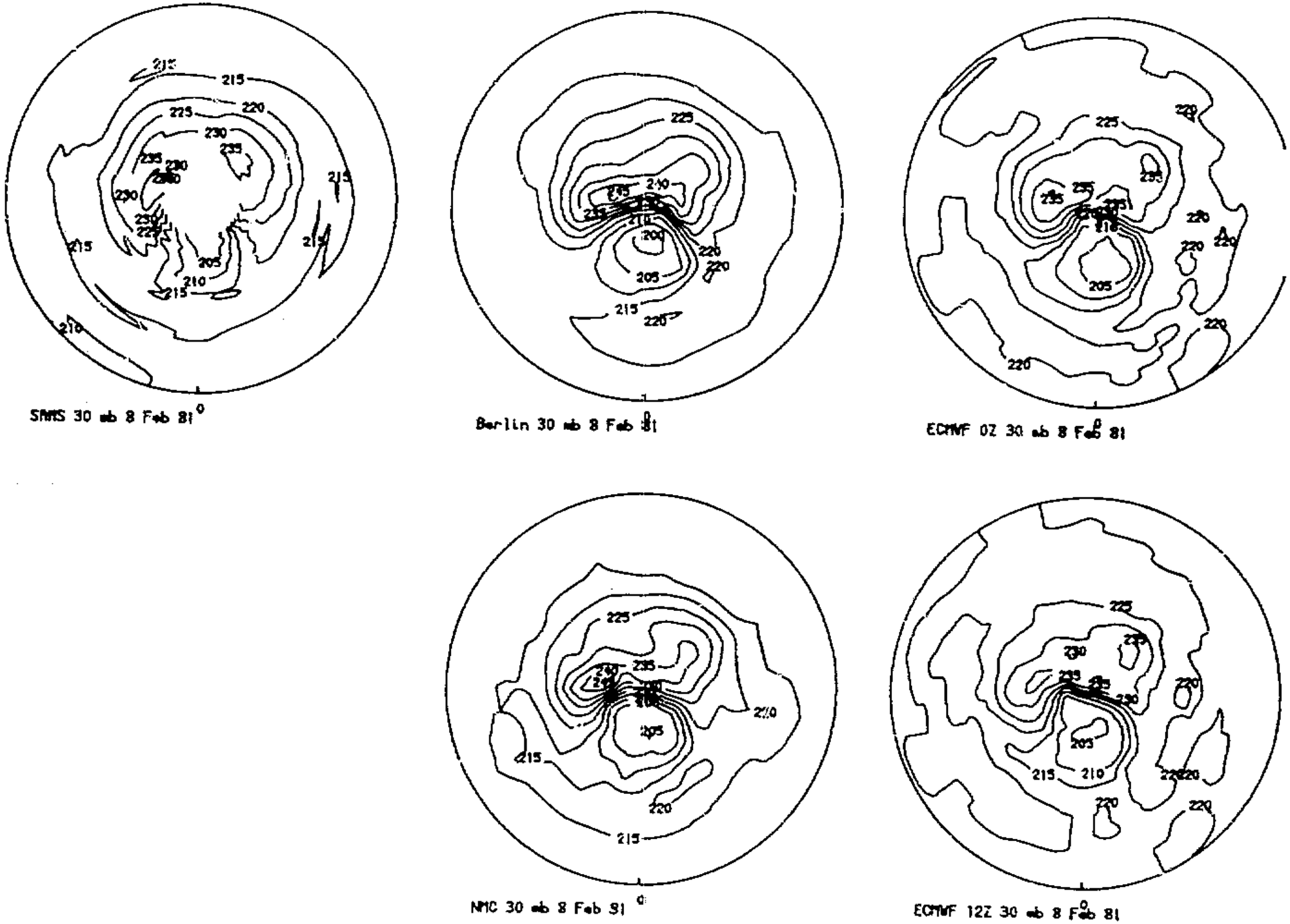
A3.13 Temperature maps.



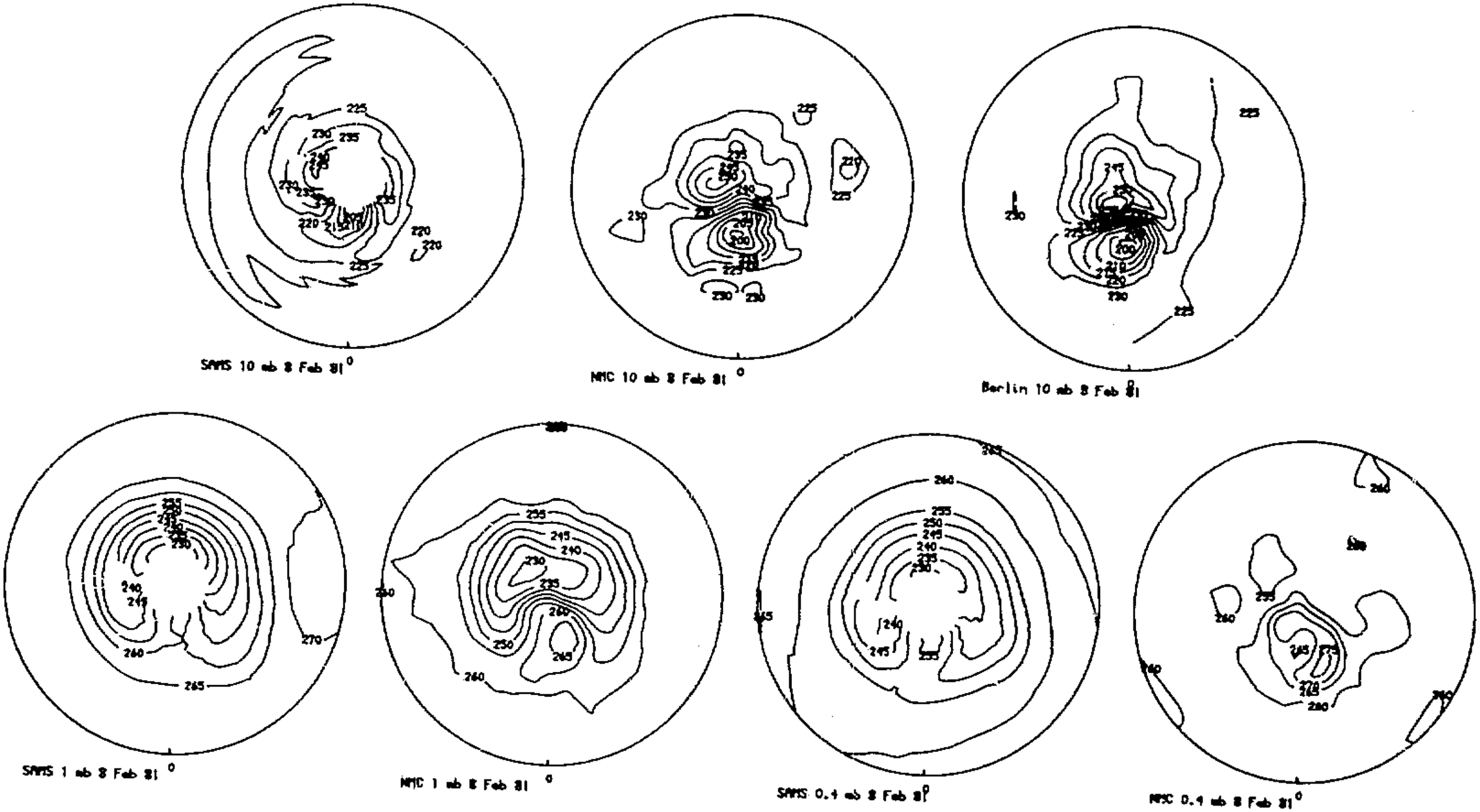
A3.14 Temperature maps.



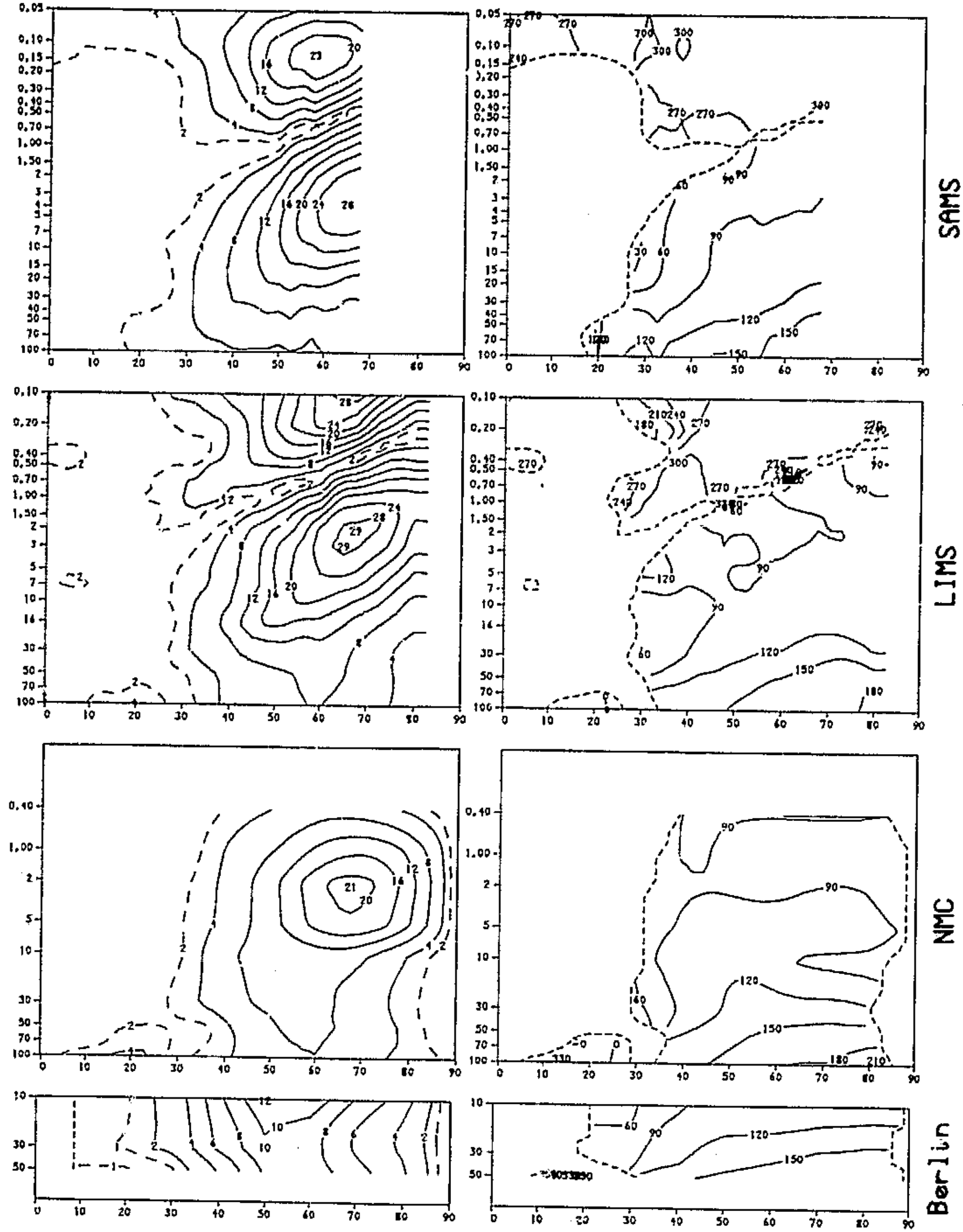
A3.15 Temperature maps.



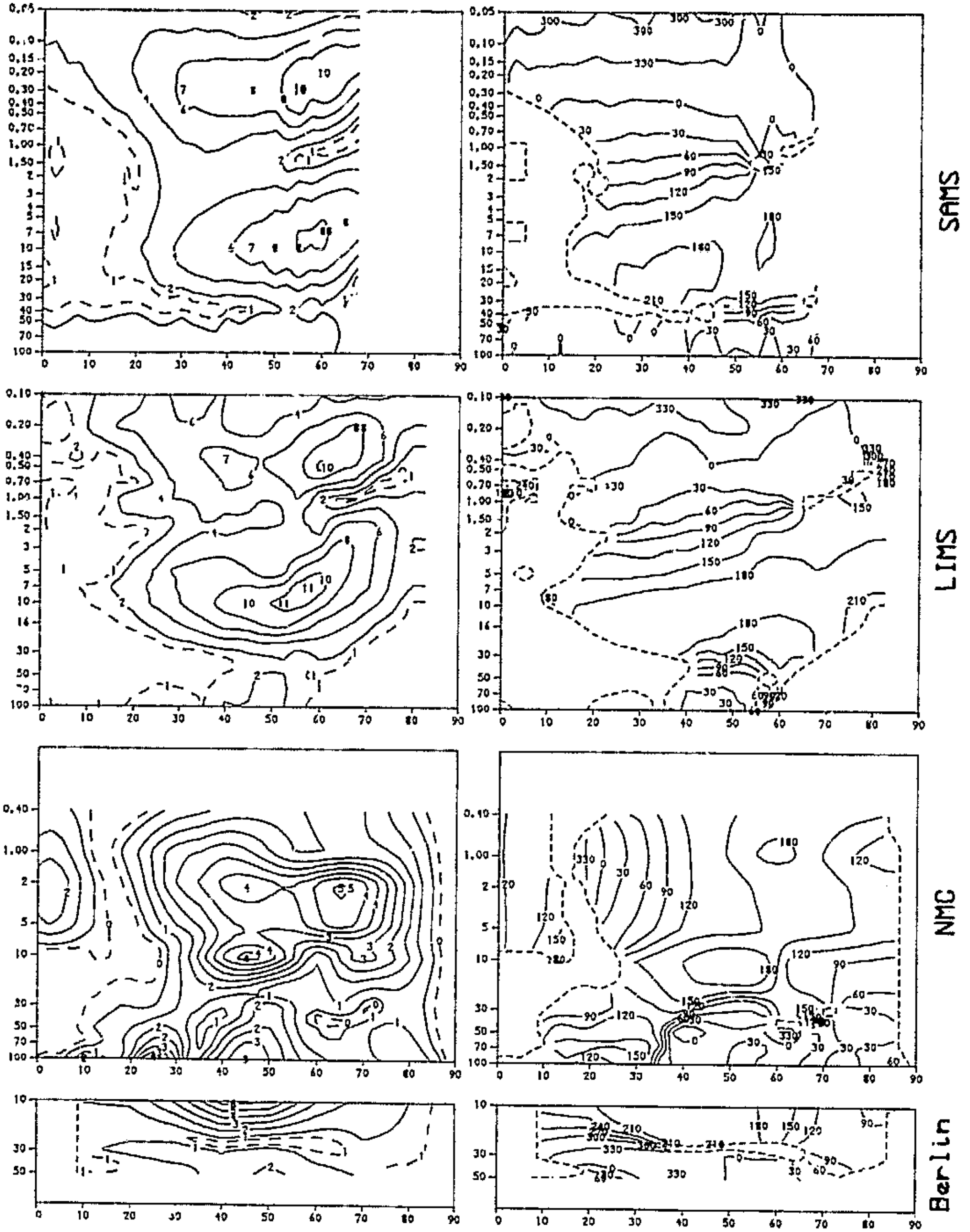
A3.16 Temperature maps.



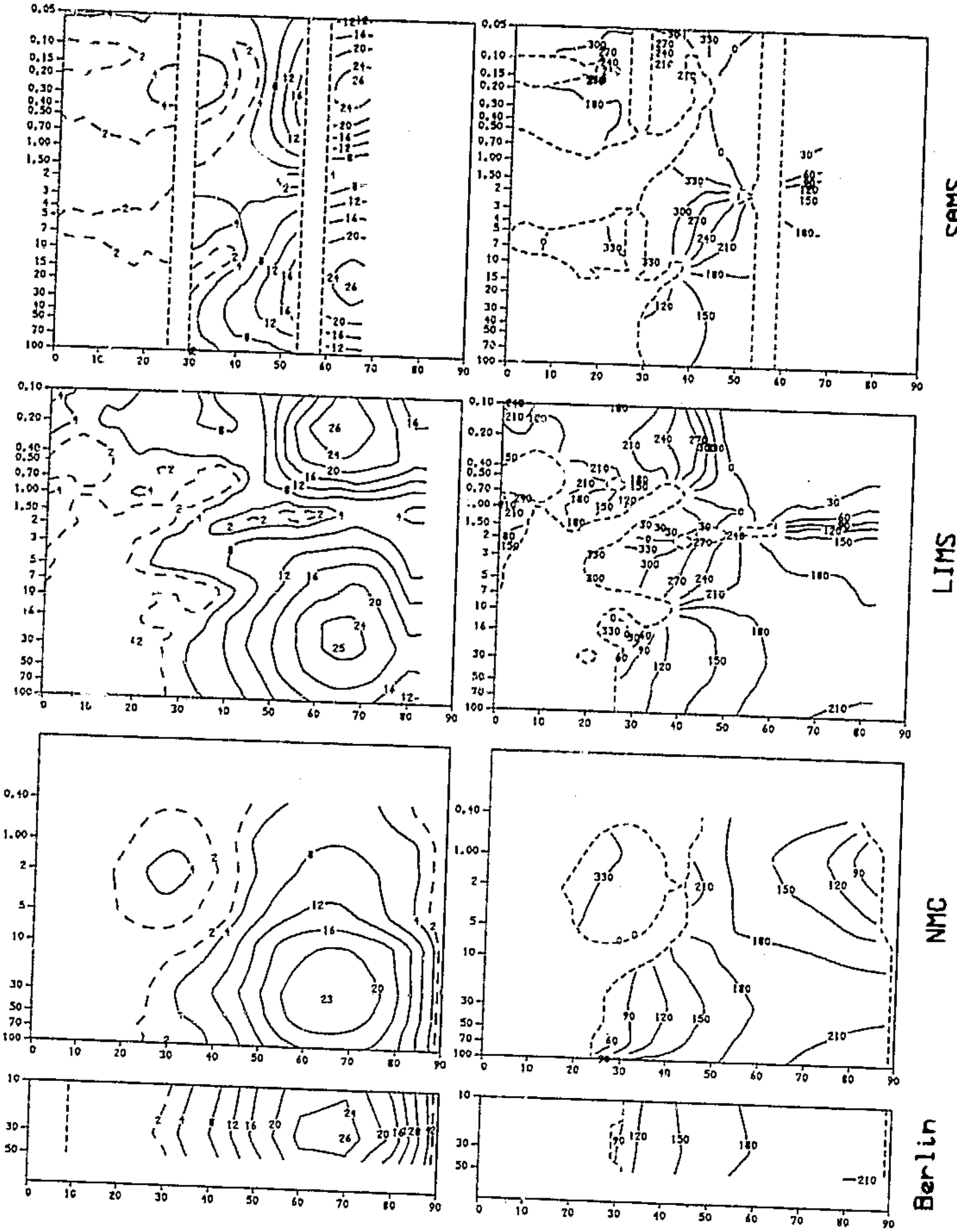
A3.17 Temperature maps.



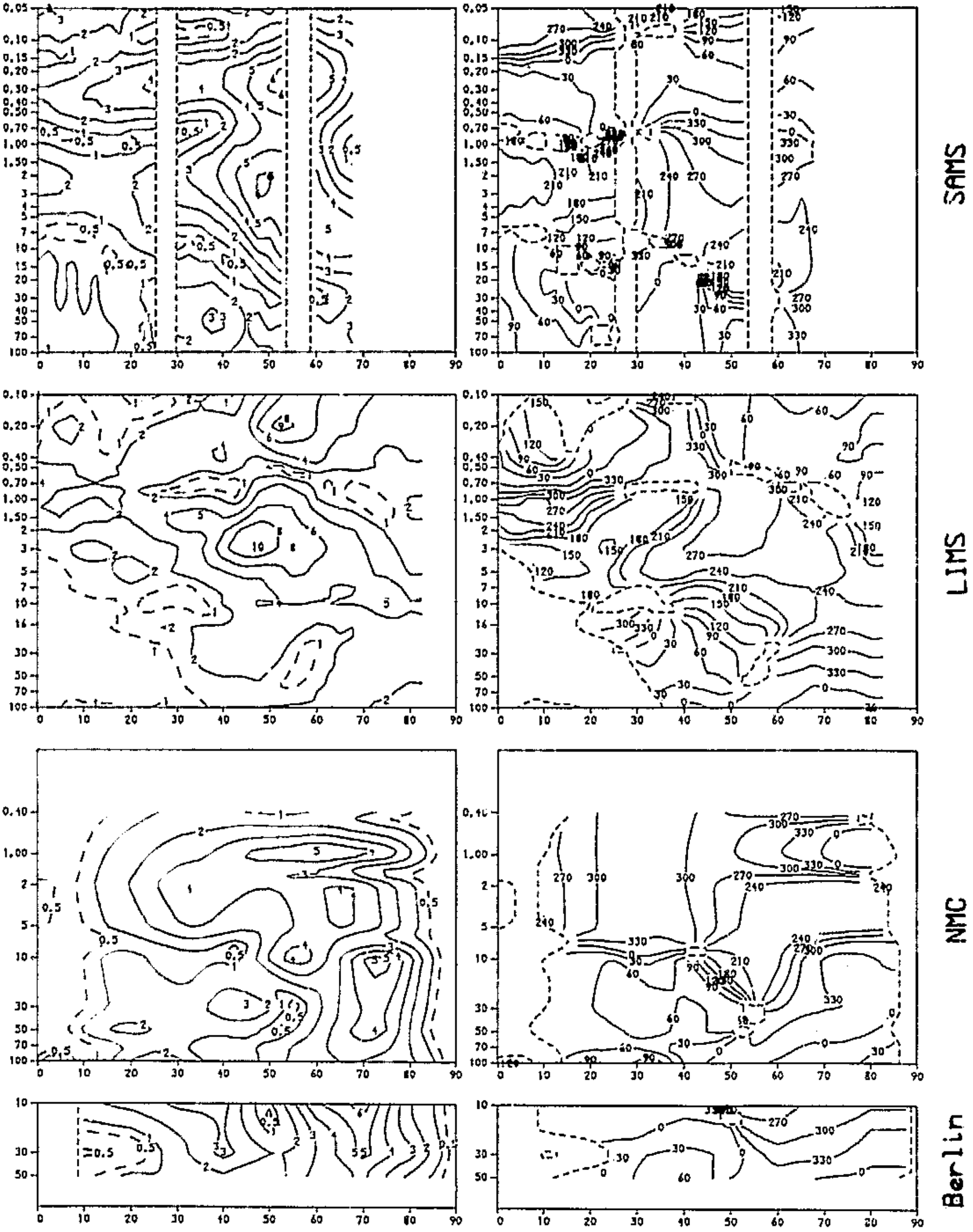
A4.1 Temperature wave 1 amplitude and phase, 2 Jan 79.



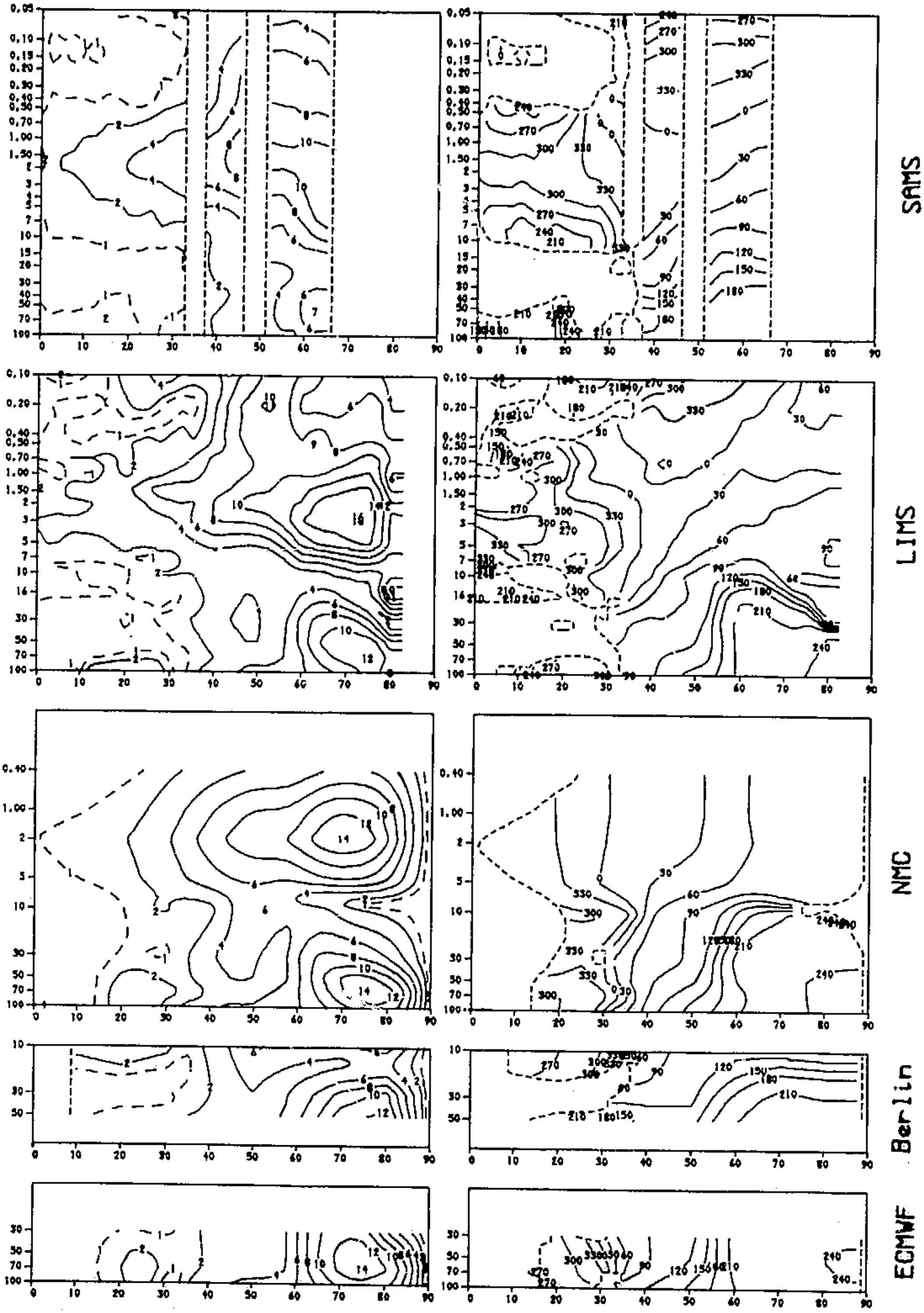
A4.2 Temperature wave 2 amplitude and phase, 2 Jan 79.



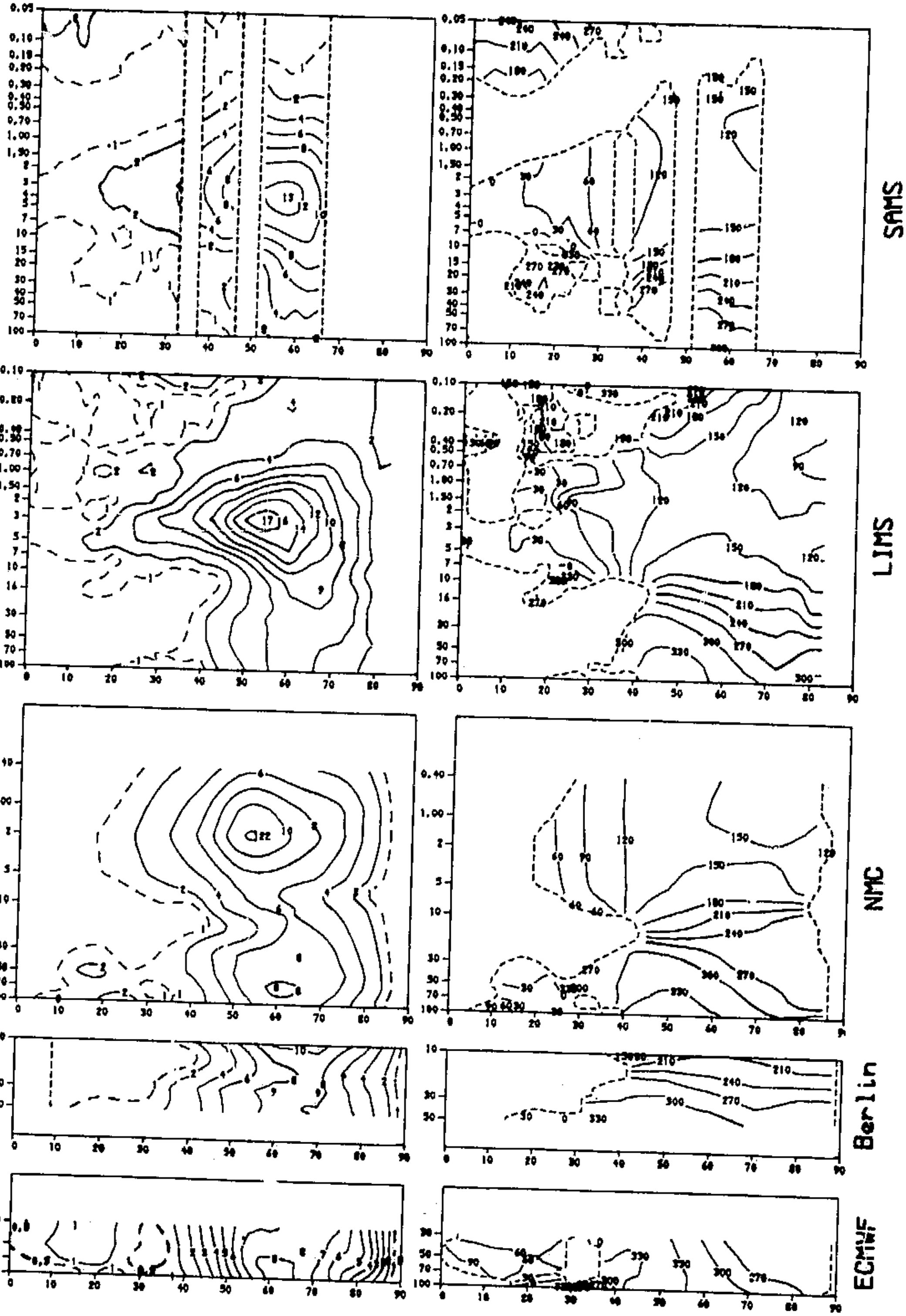
A4.3 Temperature wave 1 amplitude and phase, 26 Jan 79.



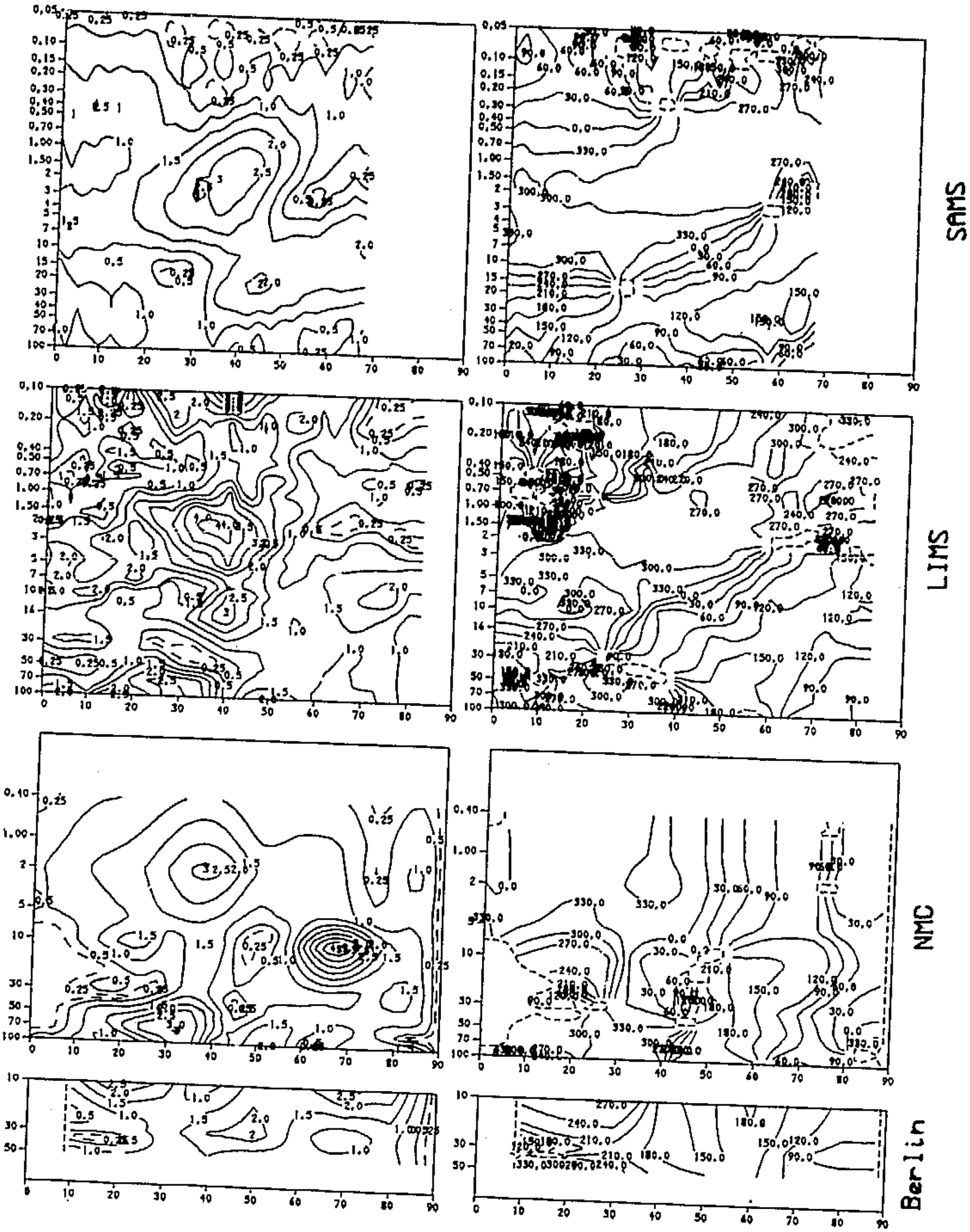
A4.4 Temperature wave 2 amplitude and phase, 26 Jan 79.



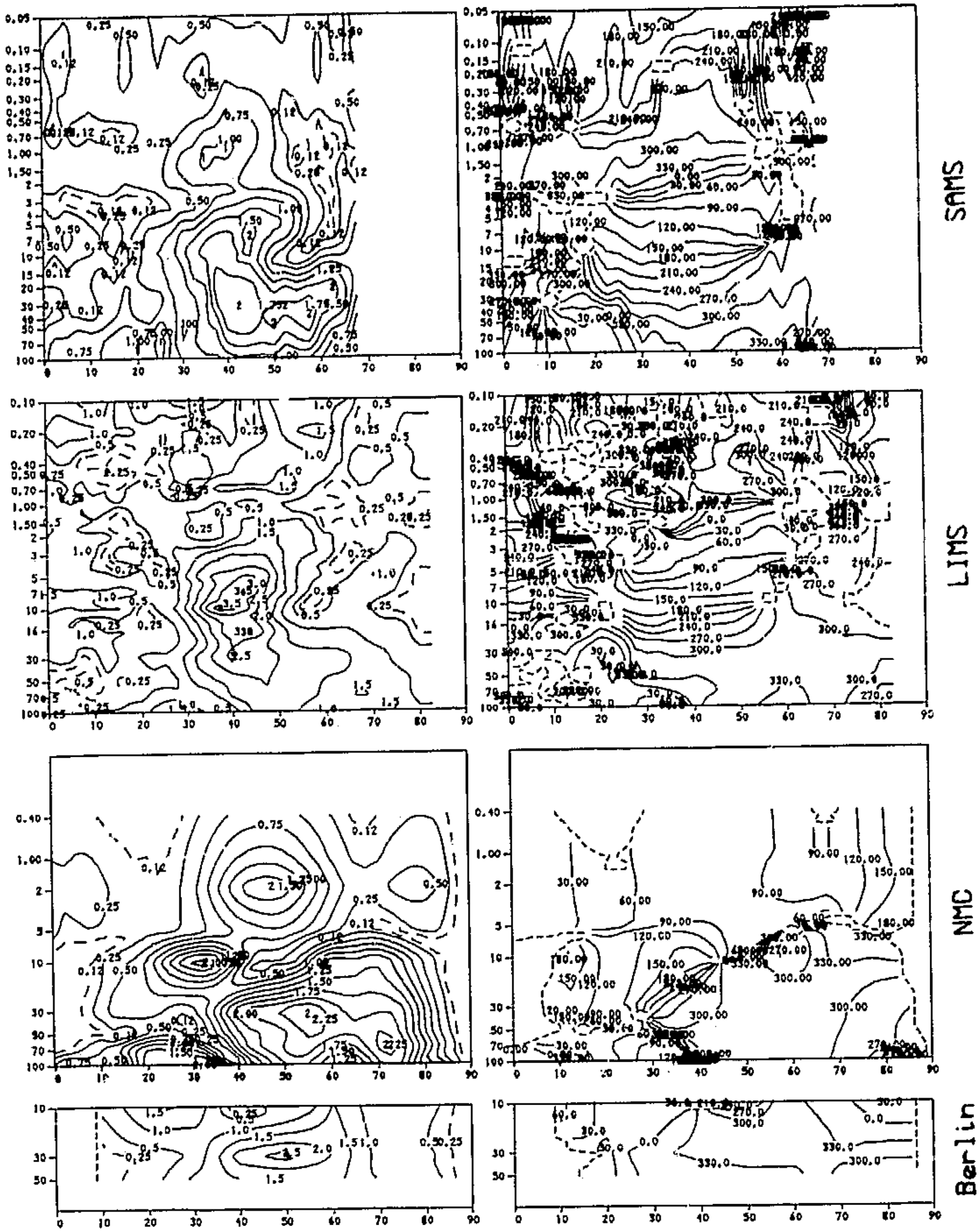
A4.5 Temperature wave 1 amplitude and phase, 26 Feb 79.



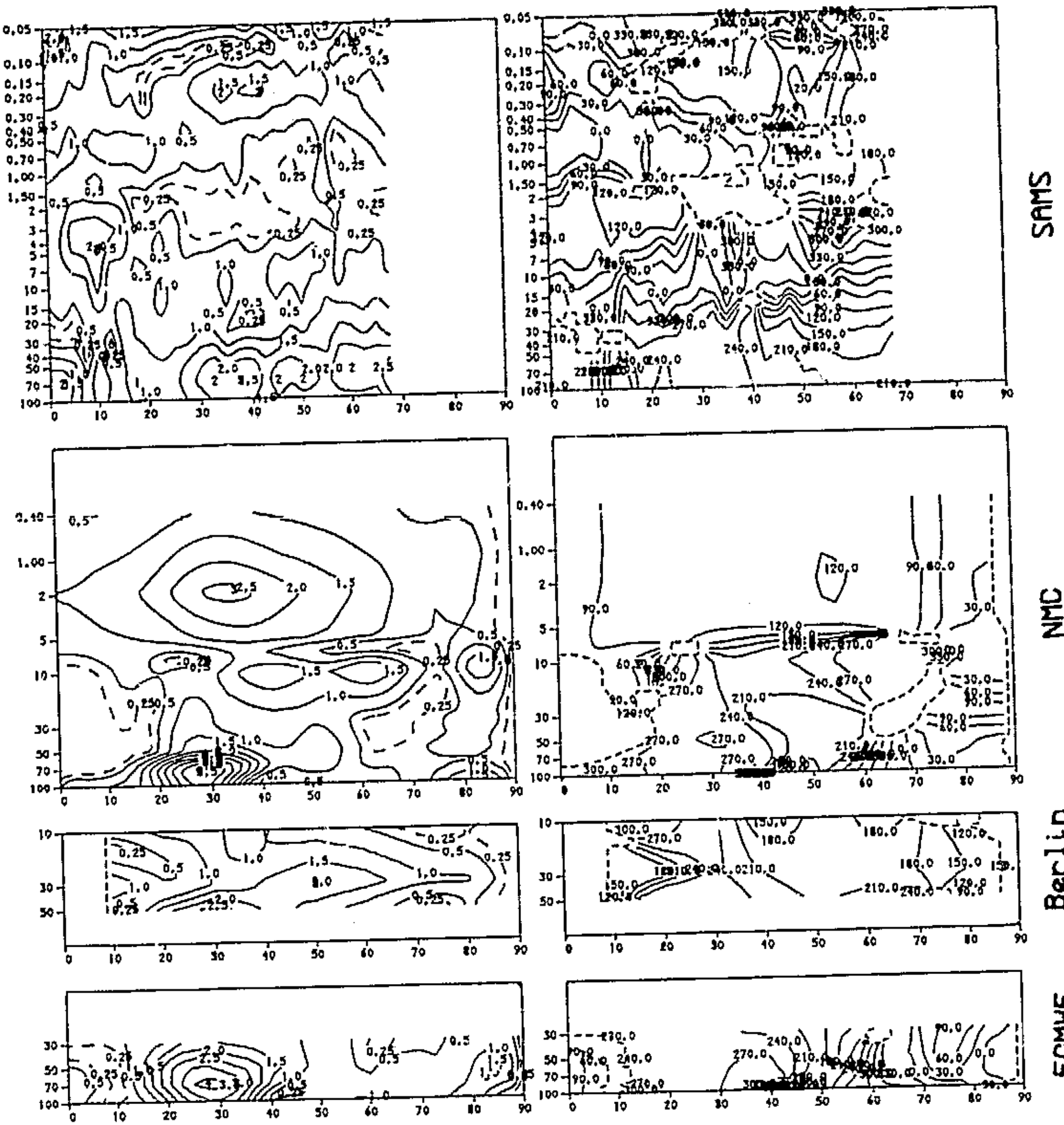
A4.6 Temperature wave 2 amplitude and phase, 26 Feb 79.



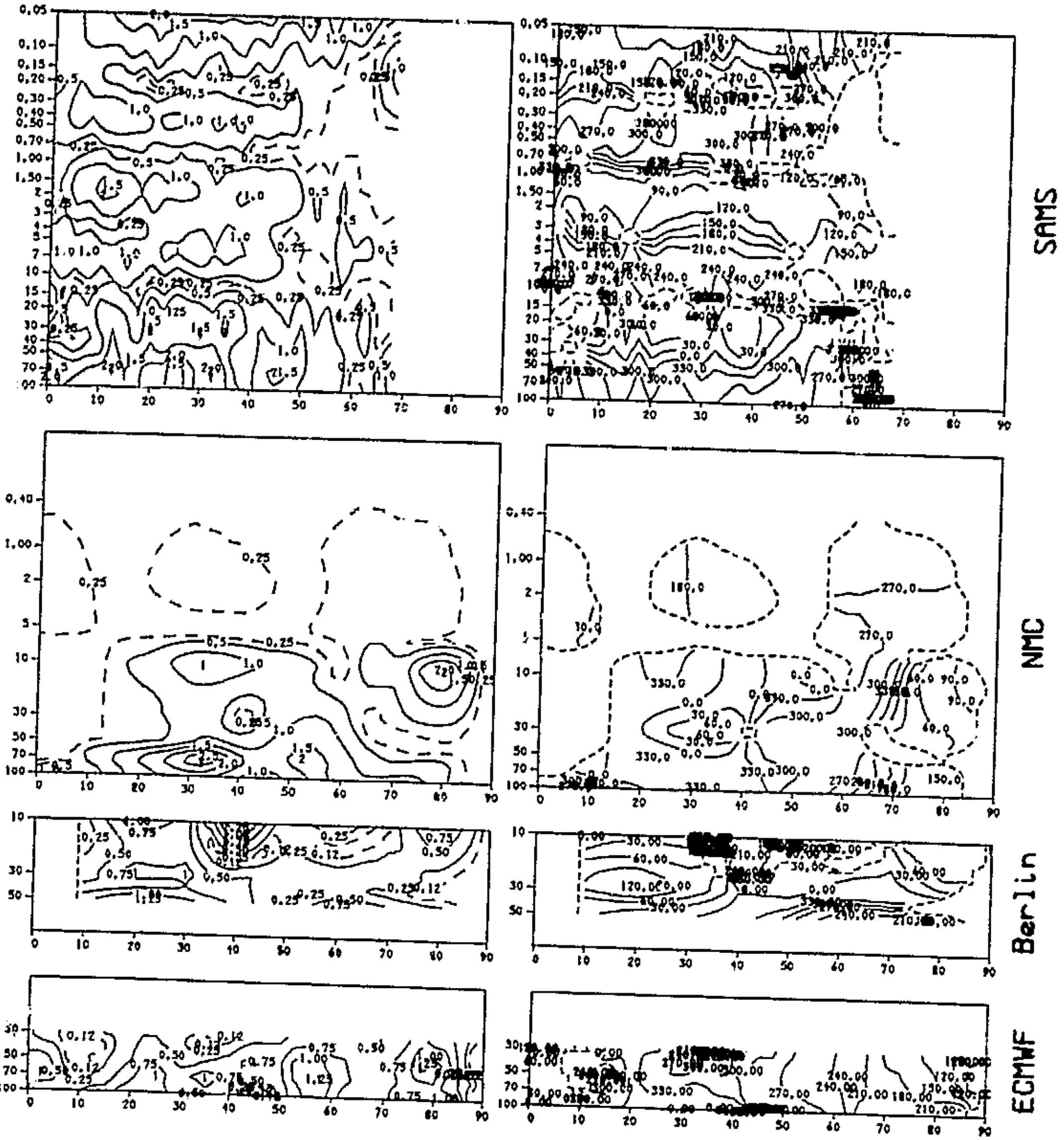
A4.7 Temperature wave 1 amplitude and phase, 2 May 79.



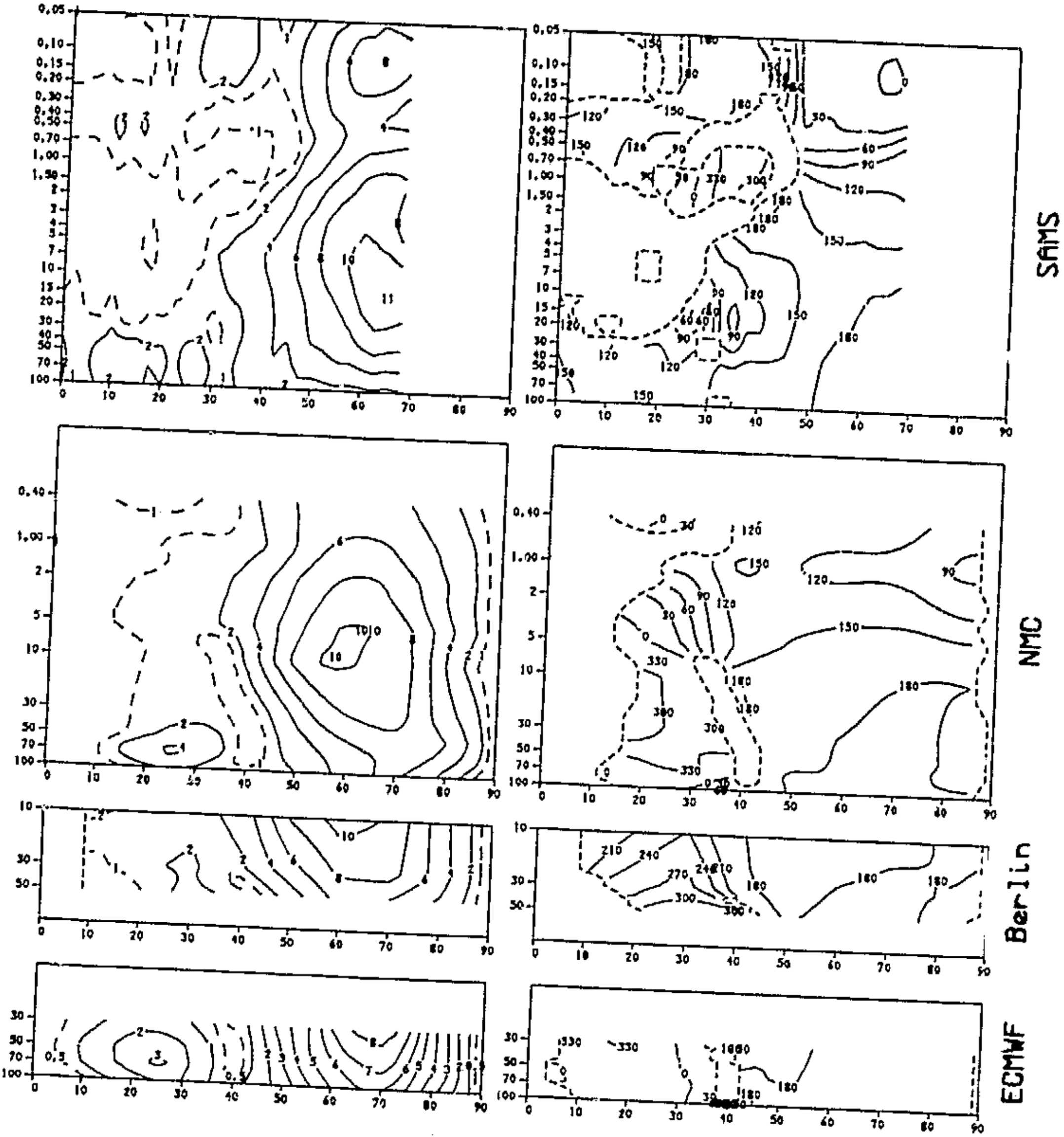
A4.8 Temperature wave 2 amplitude and phase, 2 May 79.



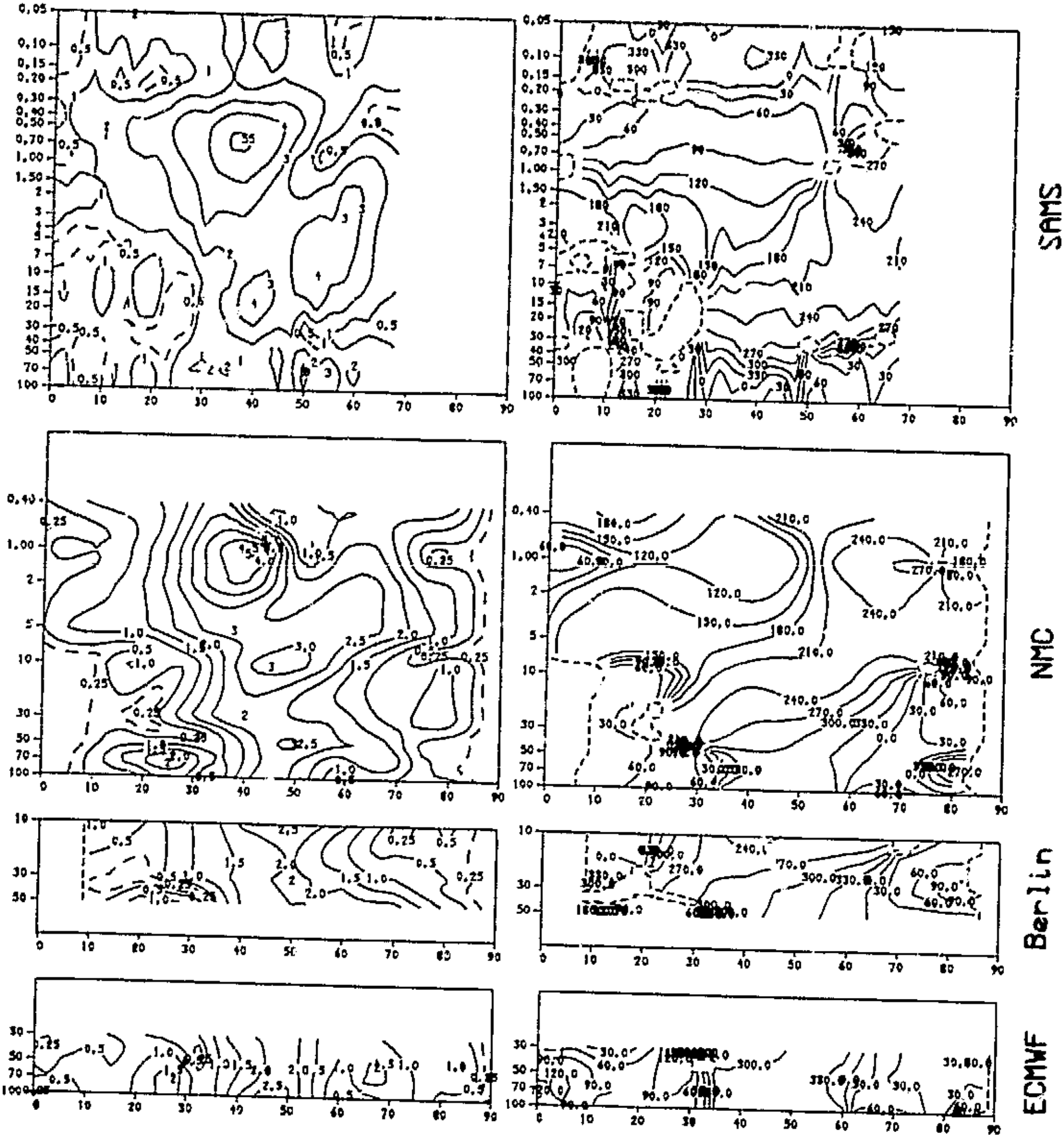
A4.9 Temperature wave 1 amplitude and phase, 14 Jun 80.



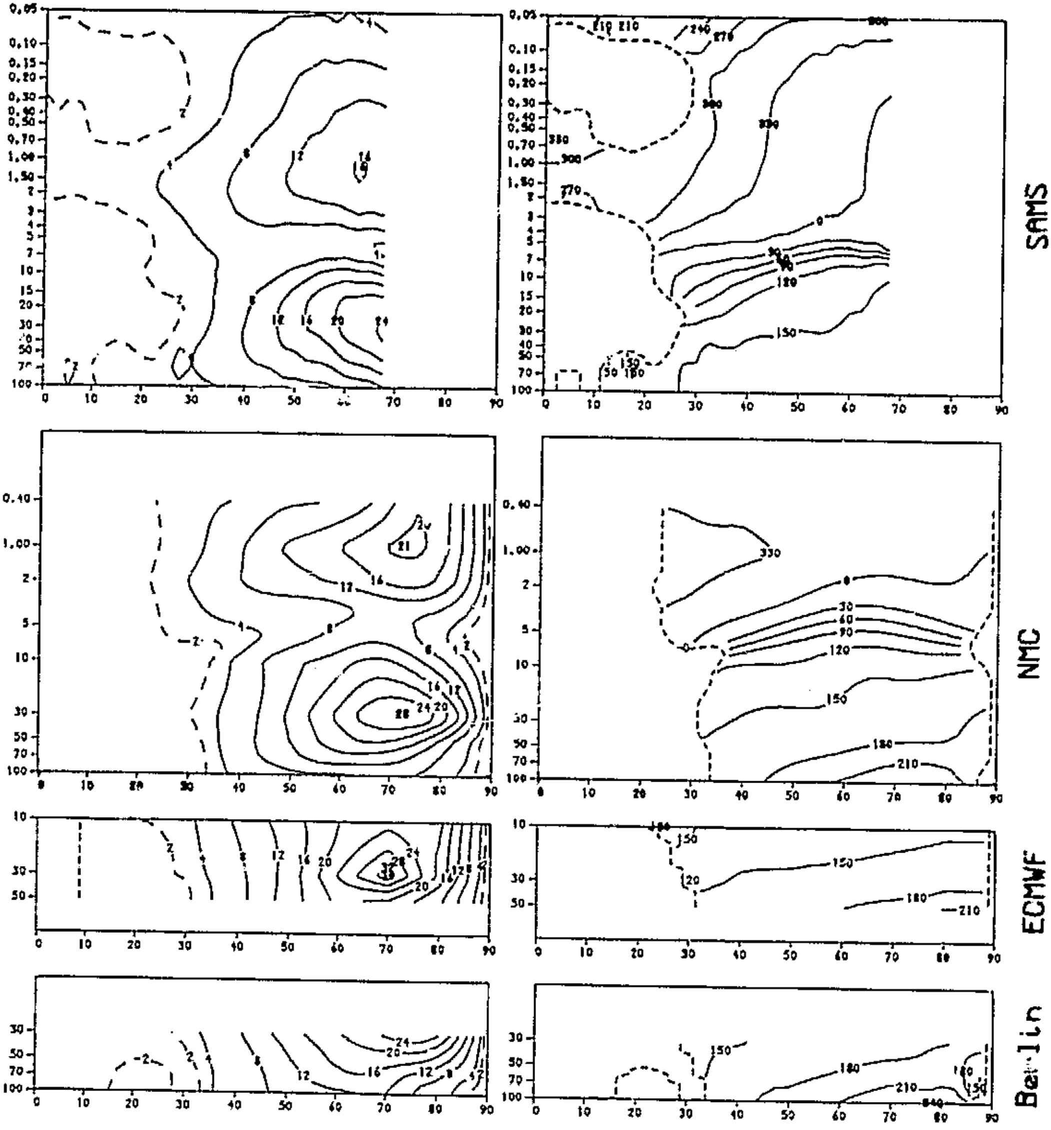
A4.10 Temperature wave 2 amplitude and phase, 14 Jun 80.



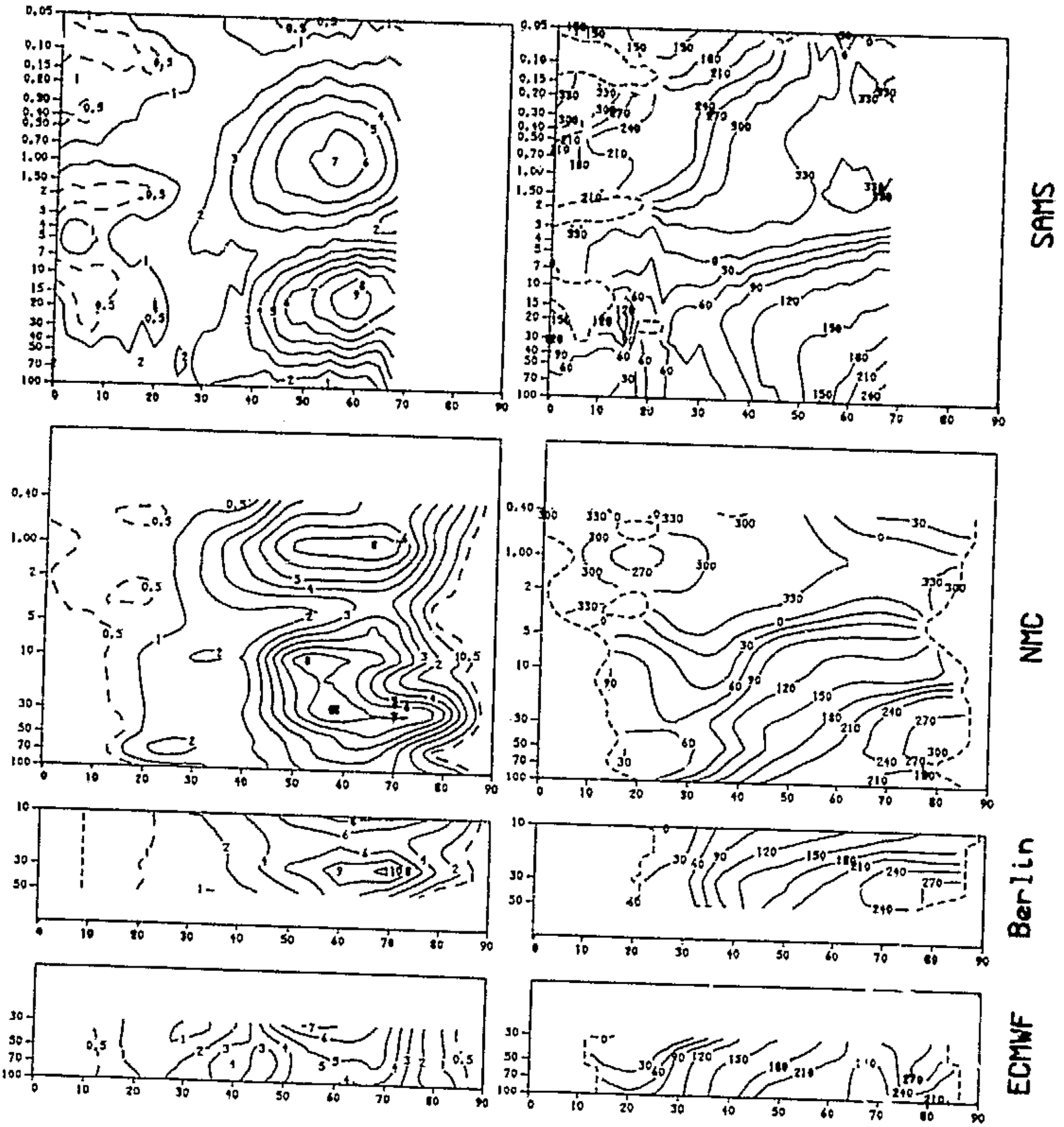
A4.11 Temperature wave 1 amplitude and phase, 5 Nov 80.



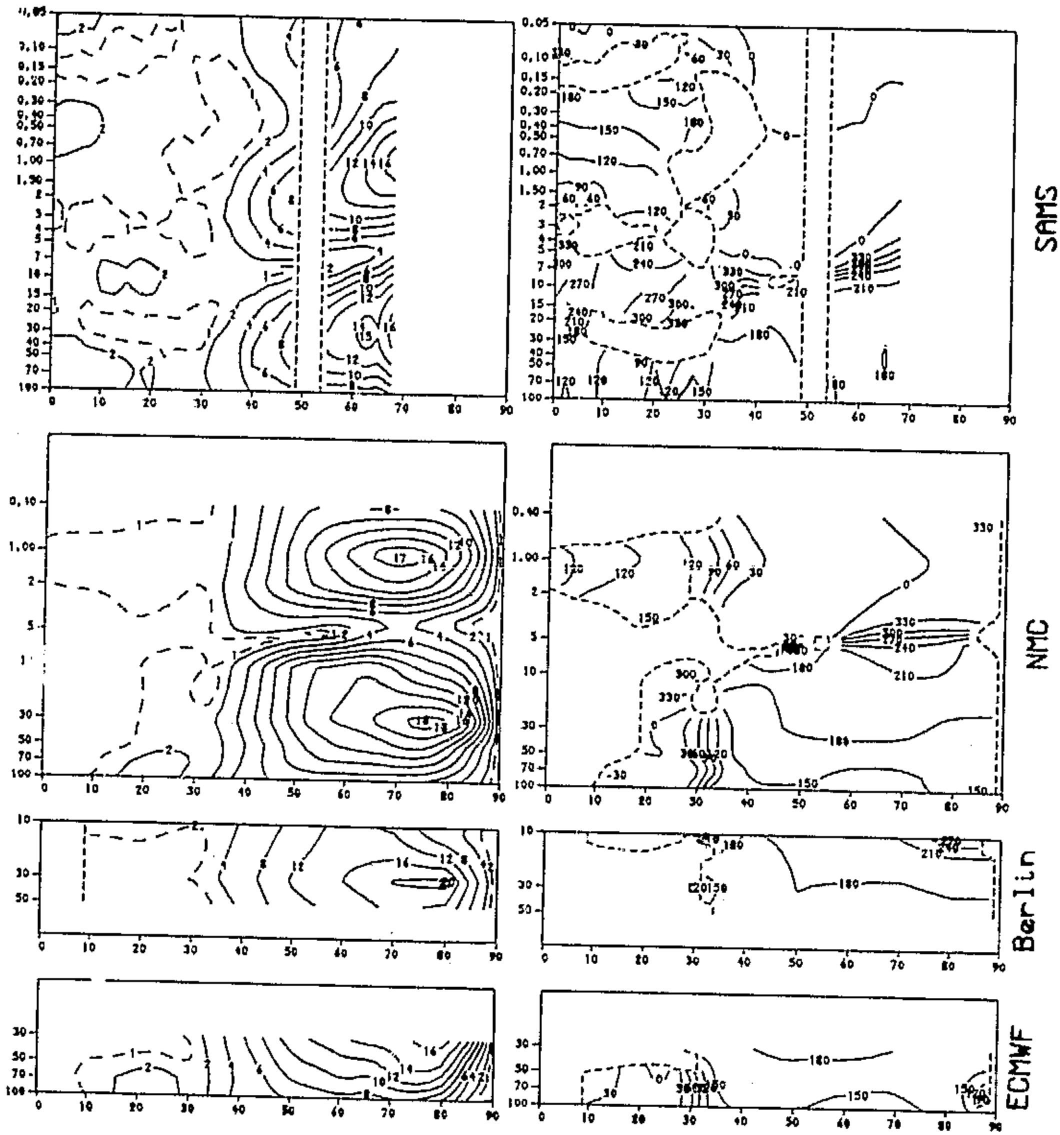
A4.12 · Temperature wave 2 amplitude and phase, 5 Nov 80.



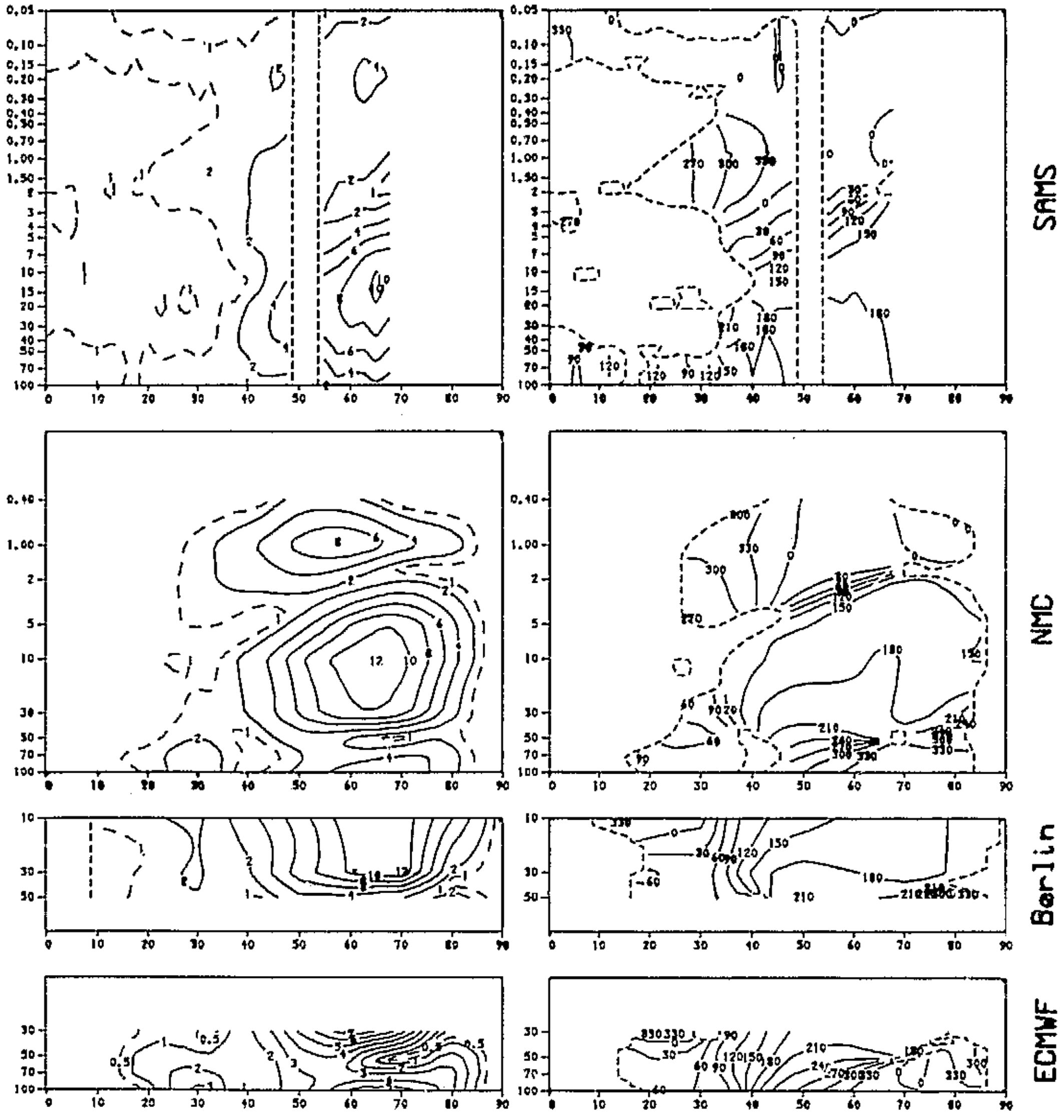
A4.13 Temperature wave 1 amplitude and phase, 5 Feb 81.



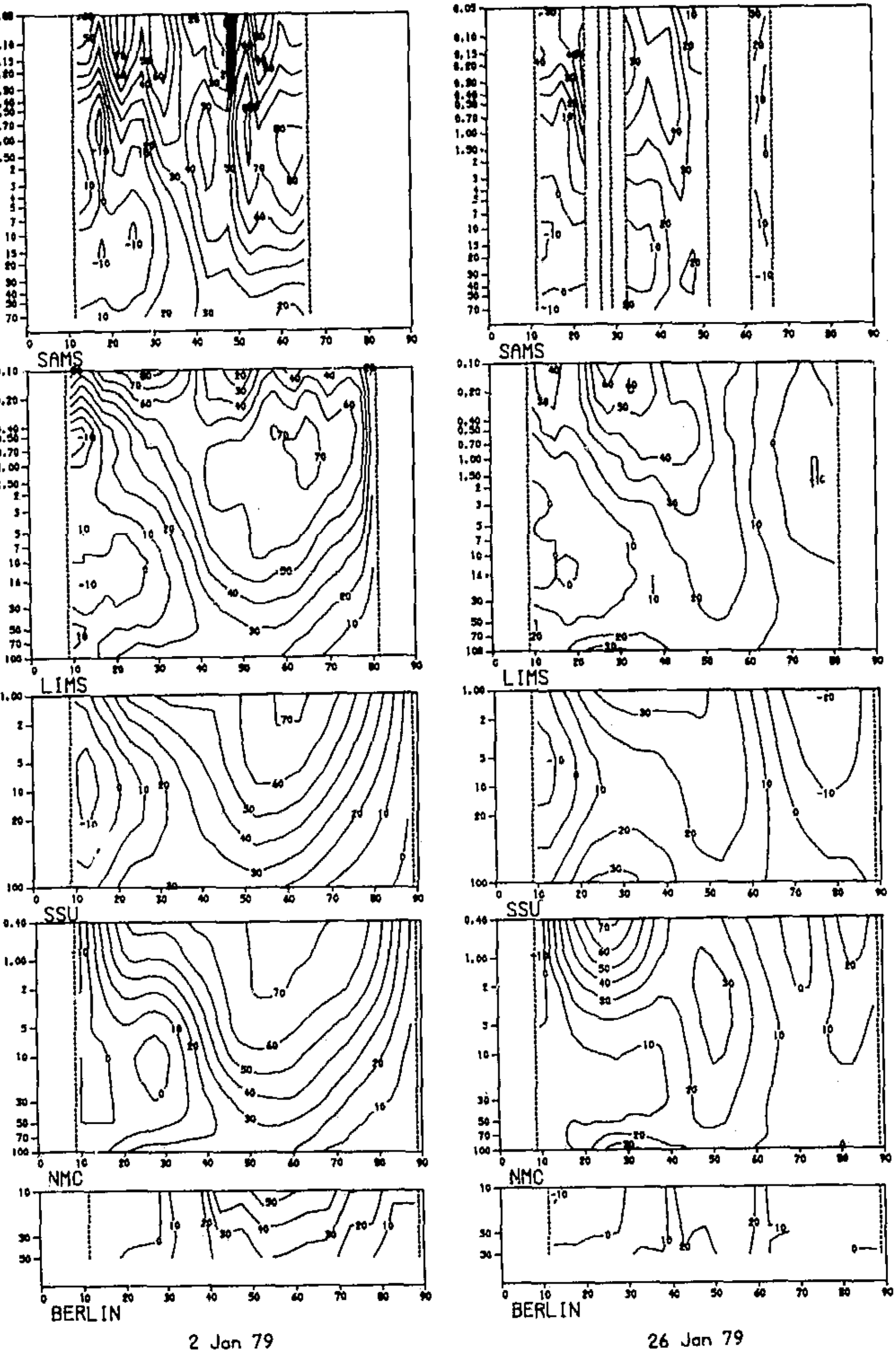
A4.14 Temperature wave 2 amplitude and phase, 5 Feb 81.



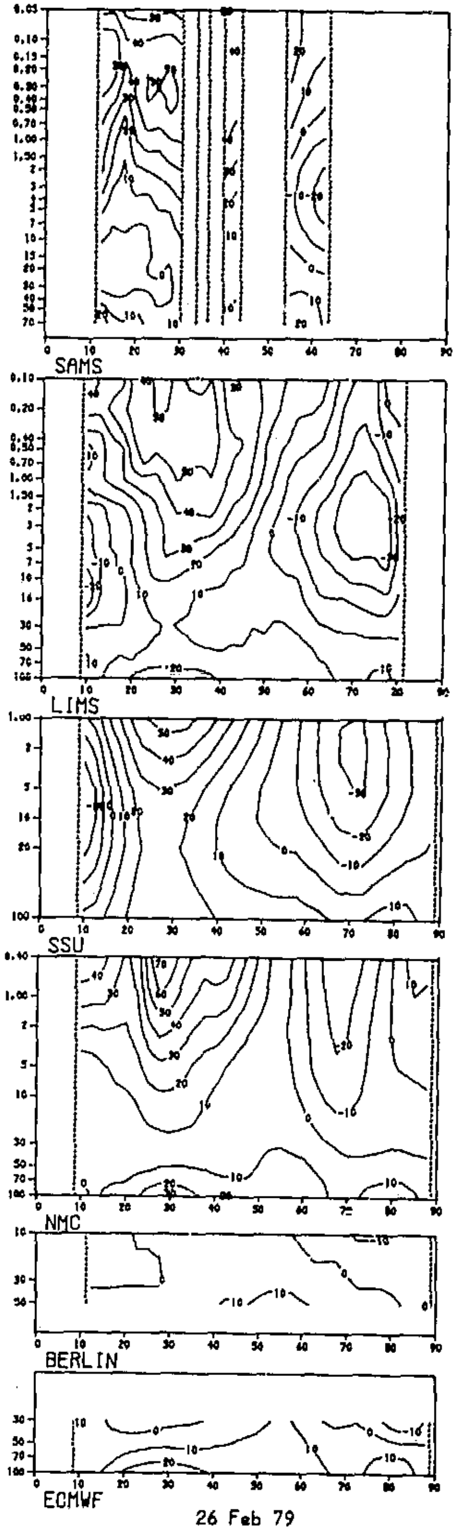
A4.15 Temperature wave 1 amplitude and phase, 8 Feb 81.



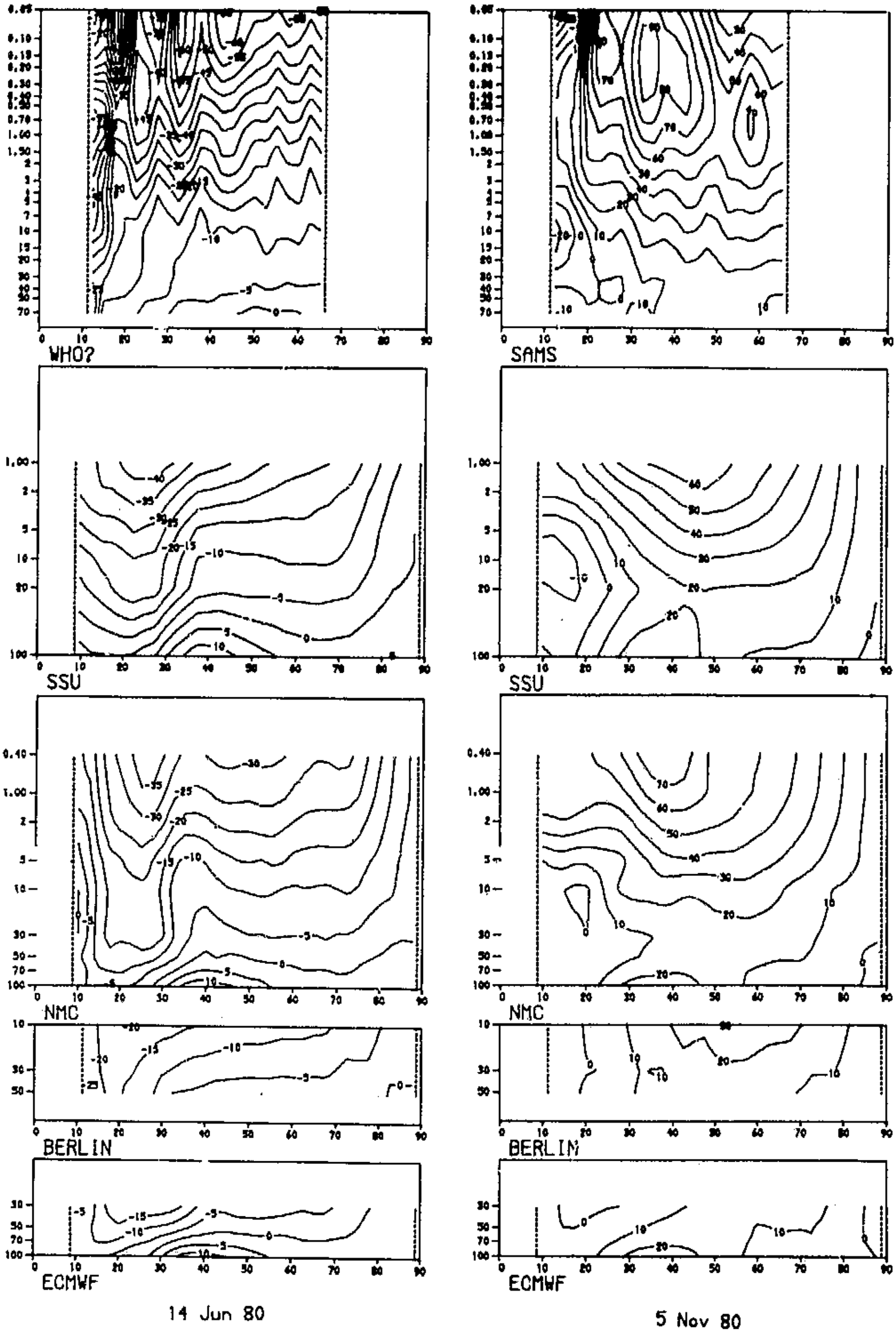
A4.16 Temperature wave 2 amplitude and phase, 8 Feb 81.



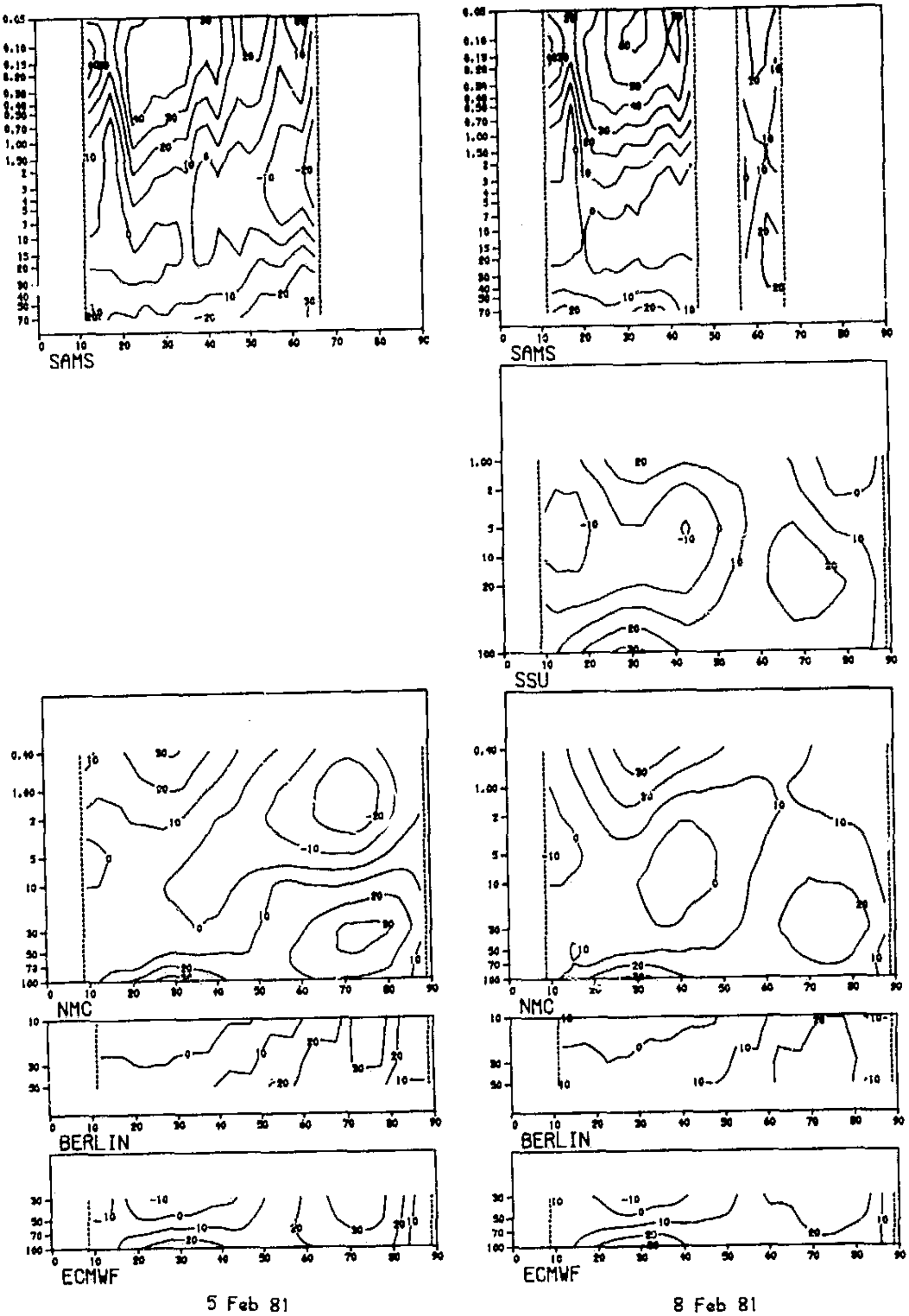
A5.1 Zonal mean geostrophic U-wind.



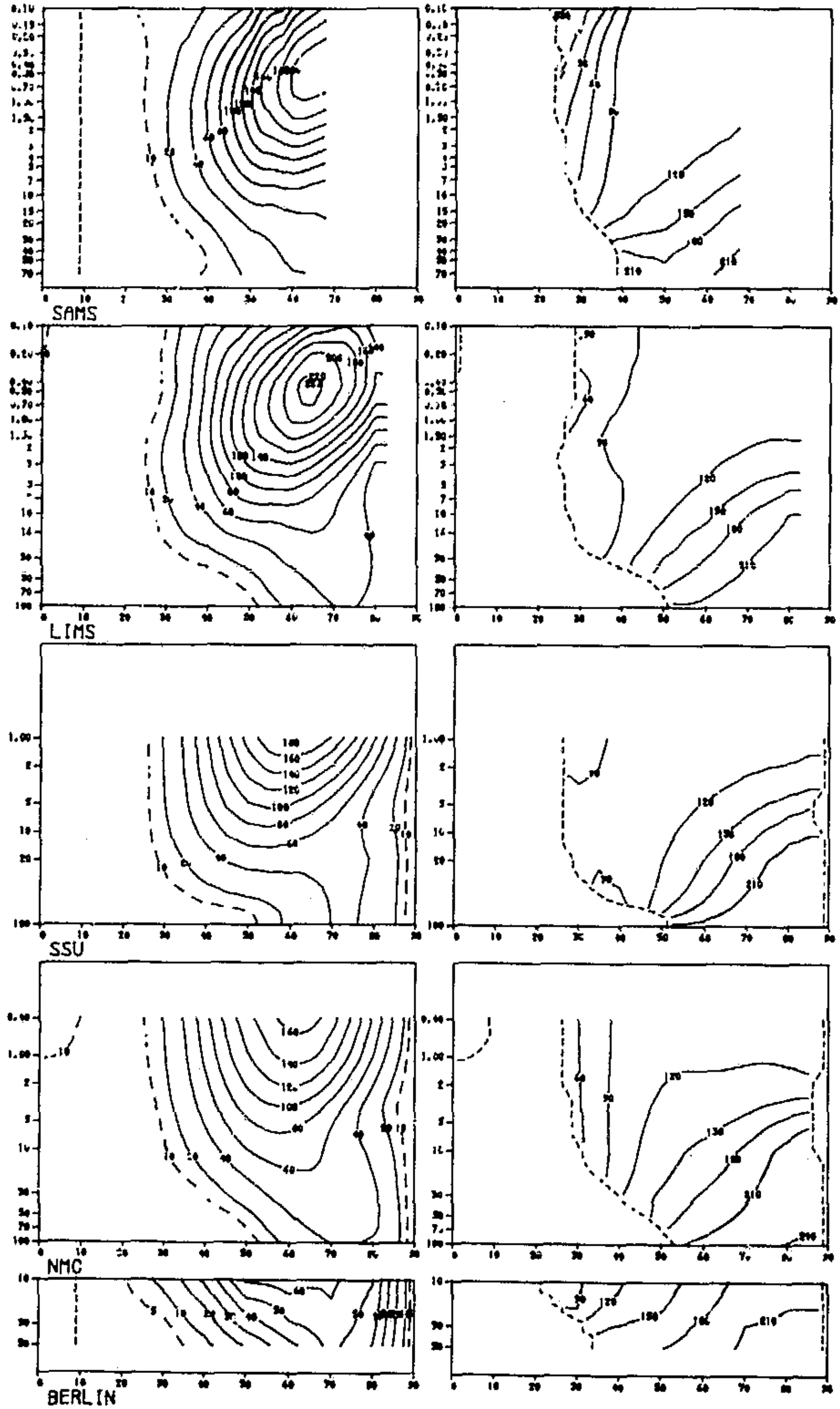
A5.2 Zonal mean geostrophic U-wind.



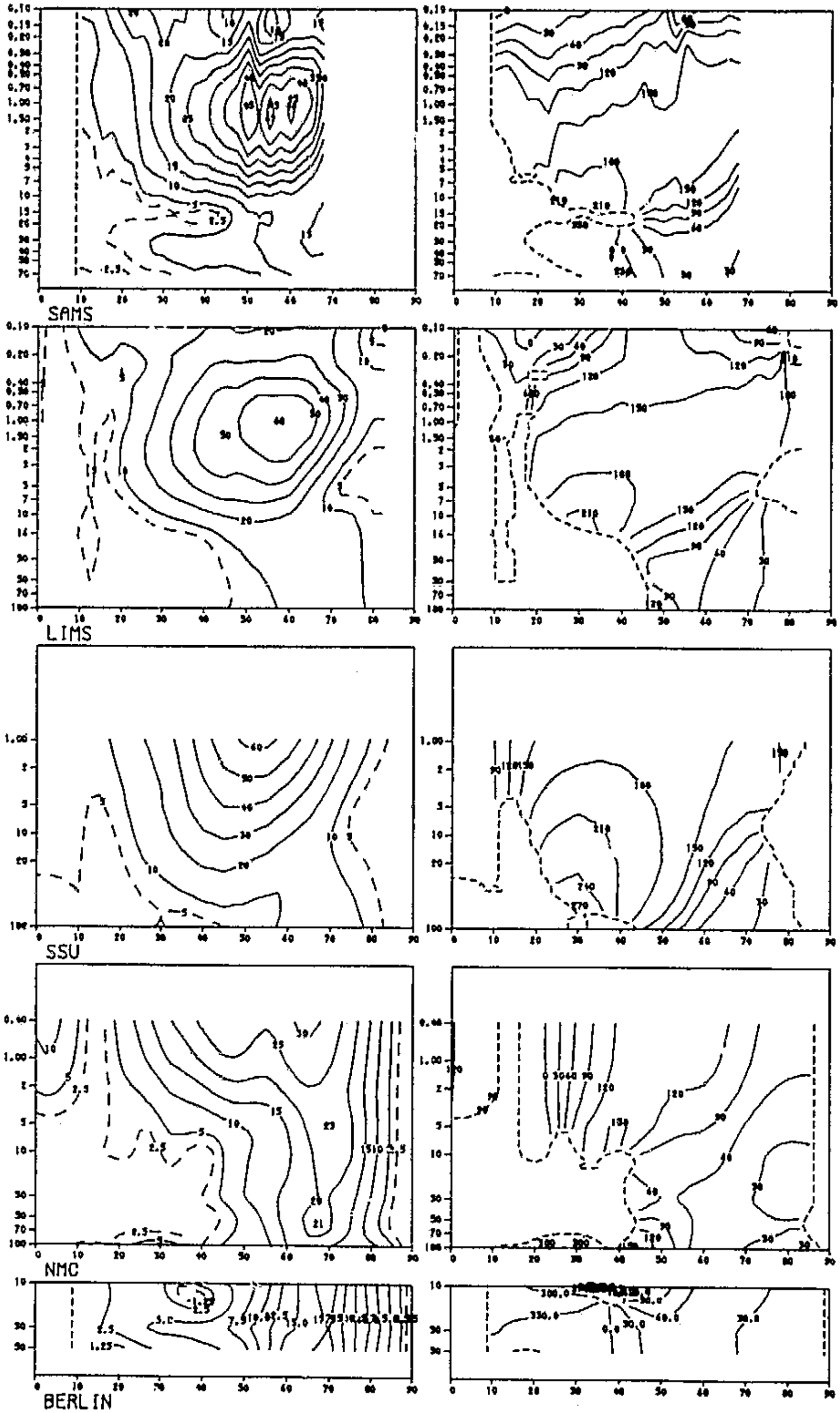
A5.3 Zonal mean geostrophic U-wind.



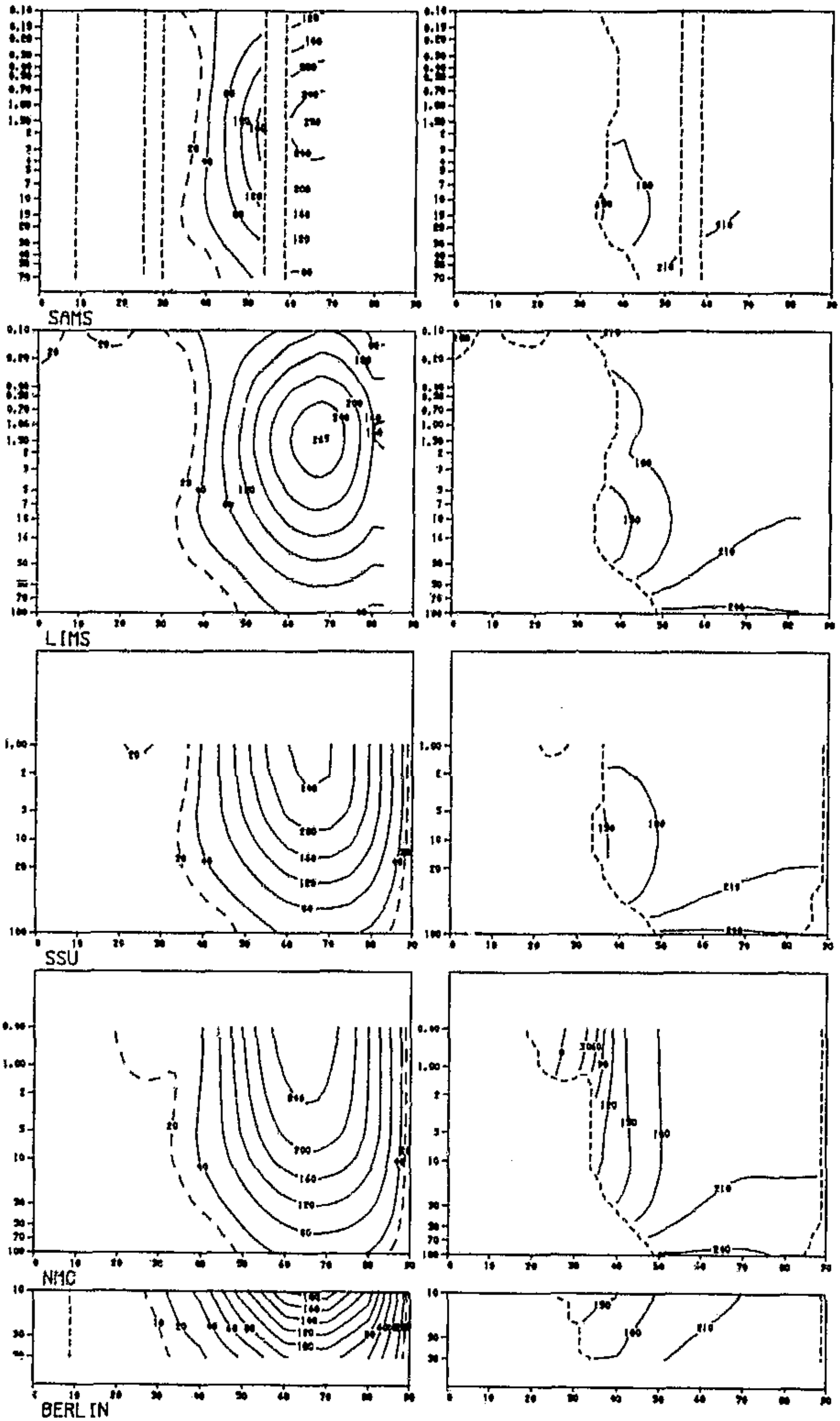
A5.4 Zonal mean geostrophic U-wind.



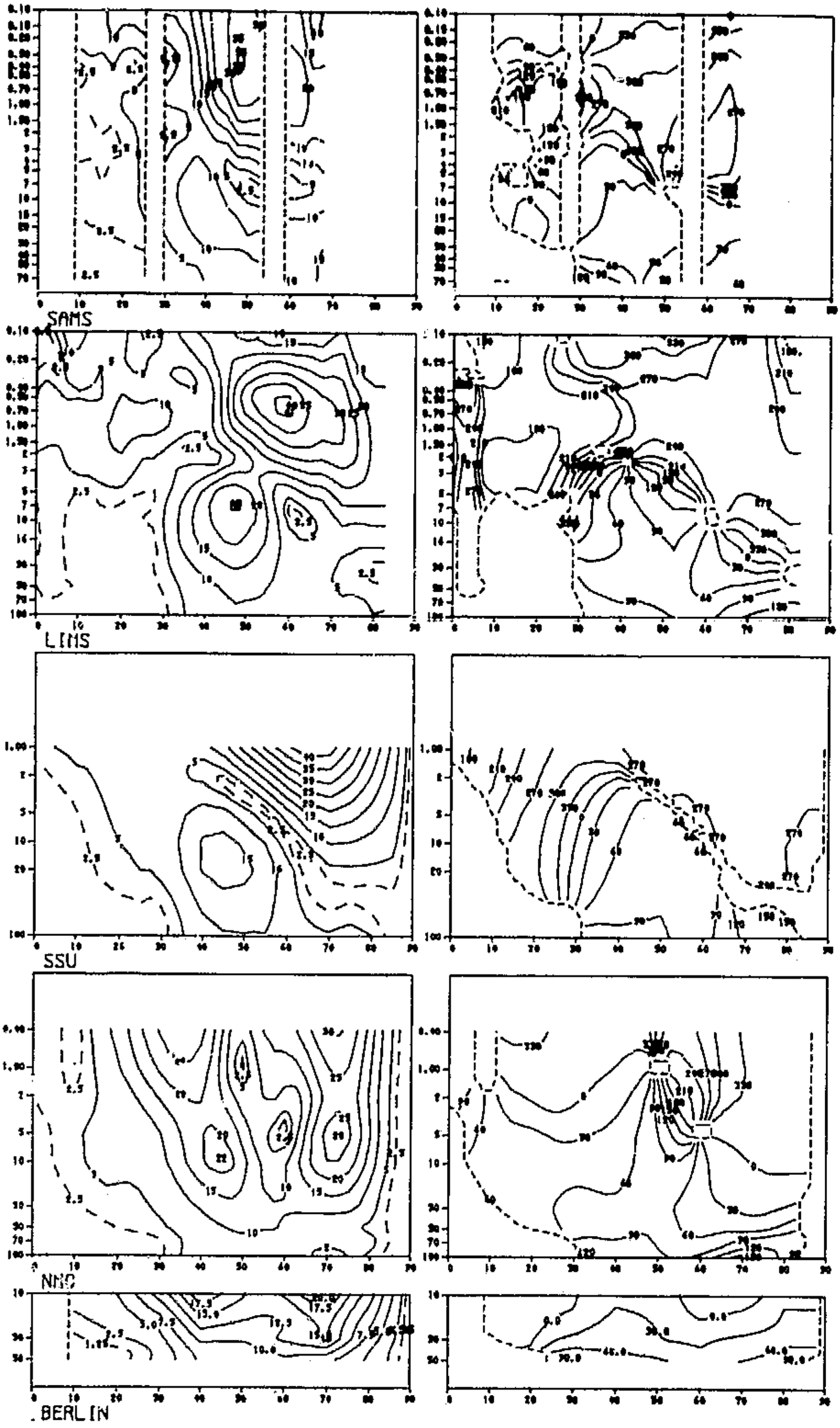
A6.1 Geopotential height wave I amplitude and phase, 2 Jan 79.



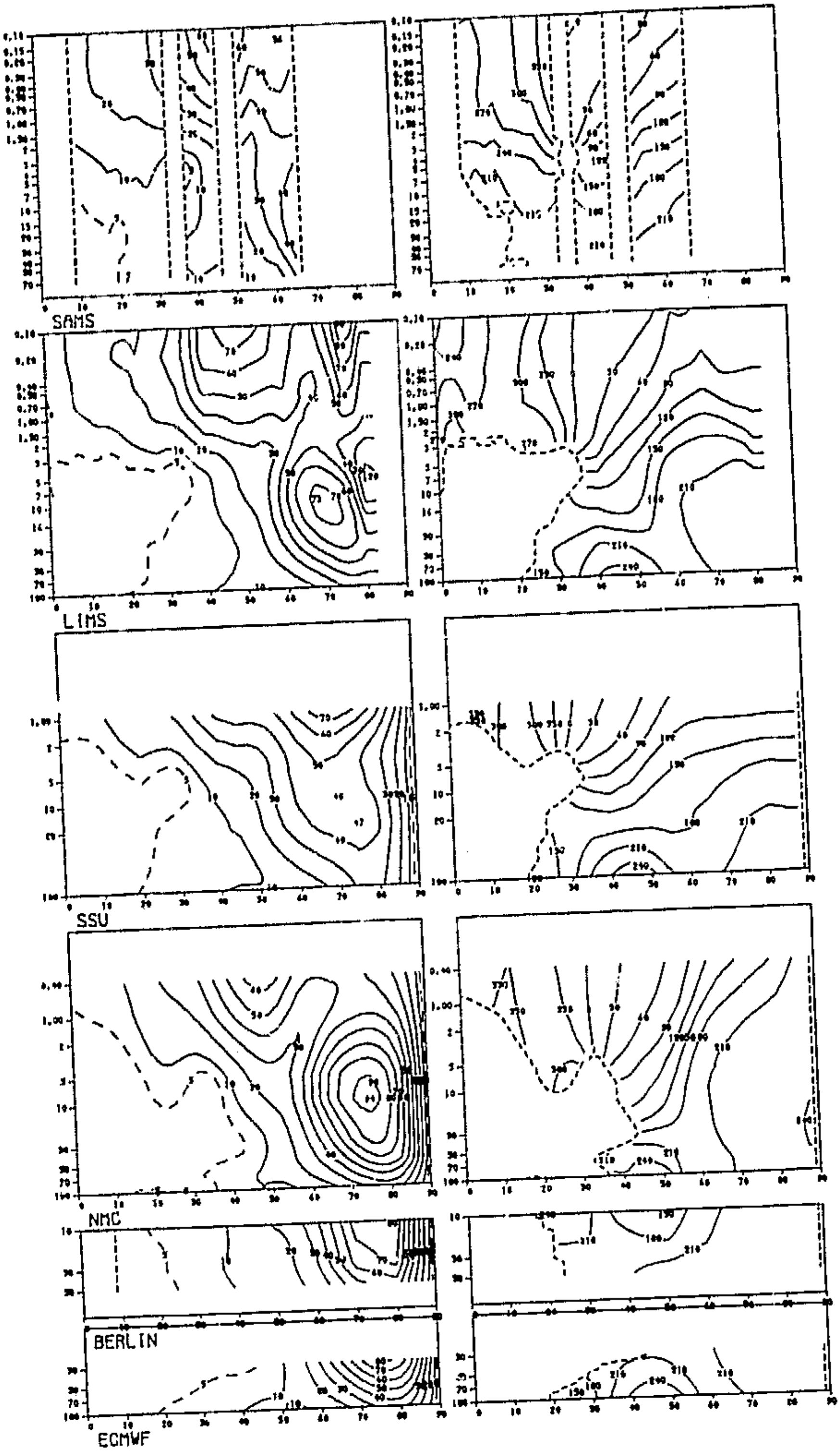
A6.2 Geopotential height wave 2 amplitude and phase, 2 Jan 79.



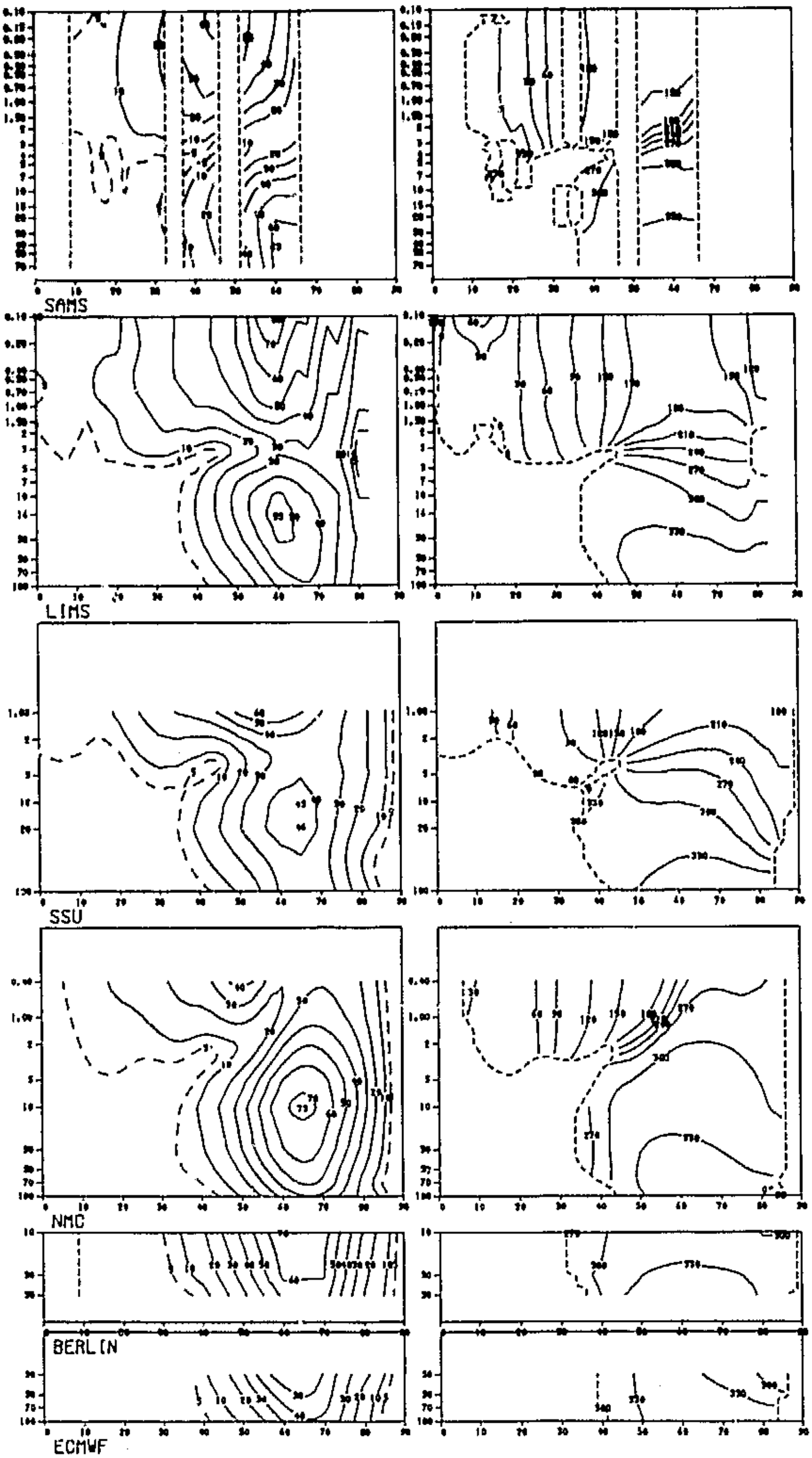
A6.3 Geopotential height wave 1 amplitude and phase, 26 Jan 79.



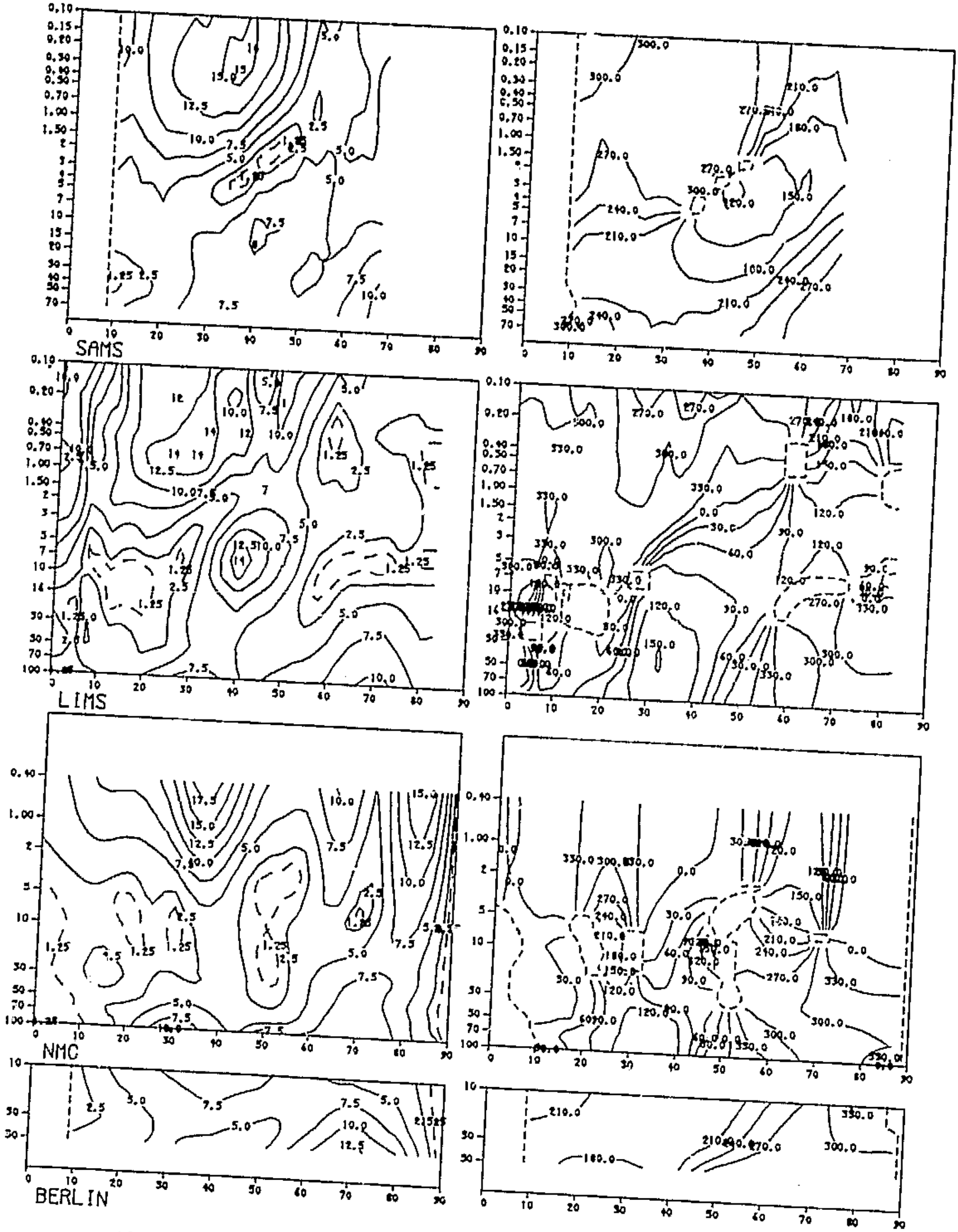
A6.4 Geopotential height wave 2 amplitude and phase, 26 Jan 79.



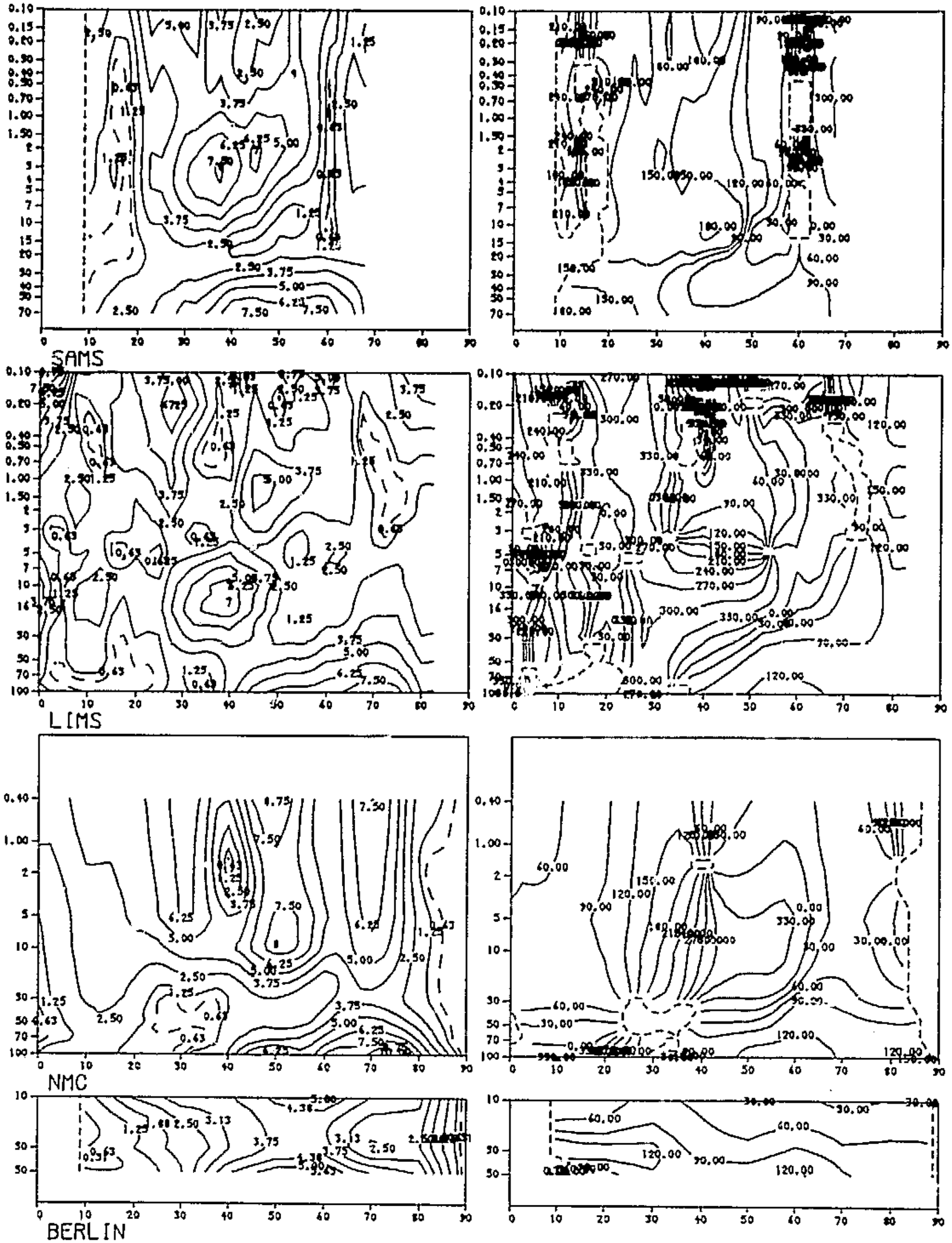
A6.5 Geopotential height wave 1 amplitude and phase, 26 Feb 79.



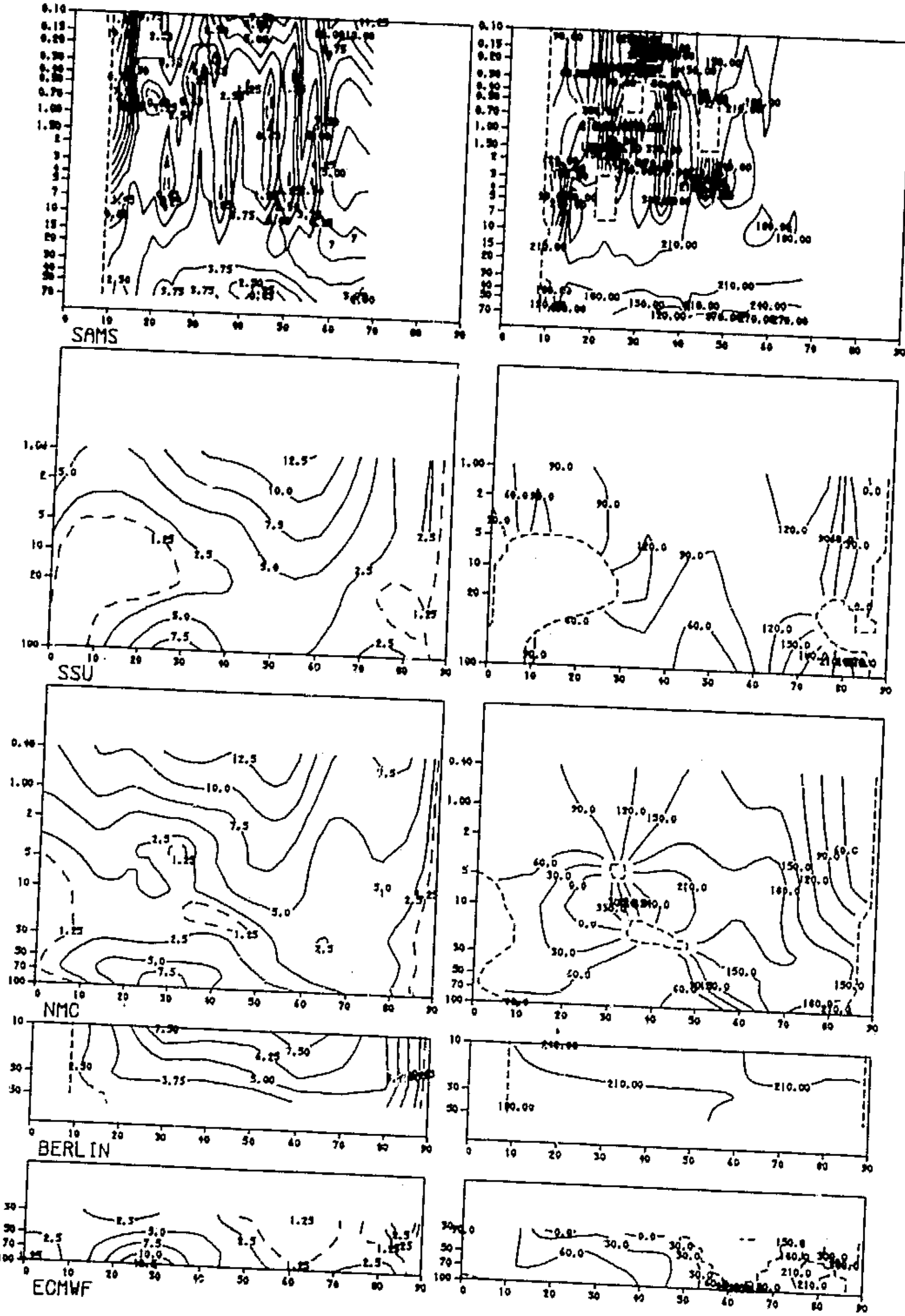
A6.6 Geopotential height wave 2 amplitude and phase, 26 Feb 79.



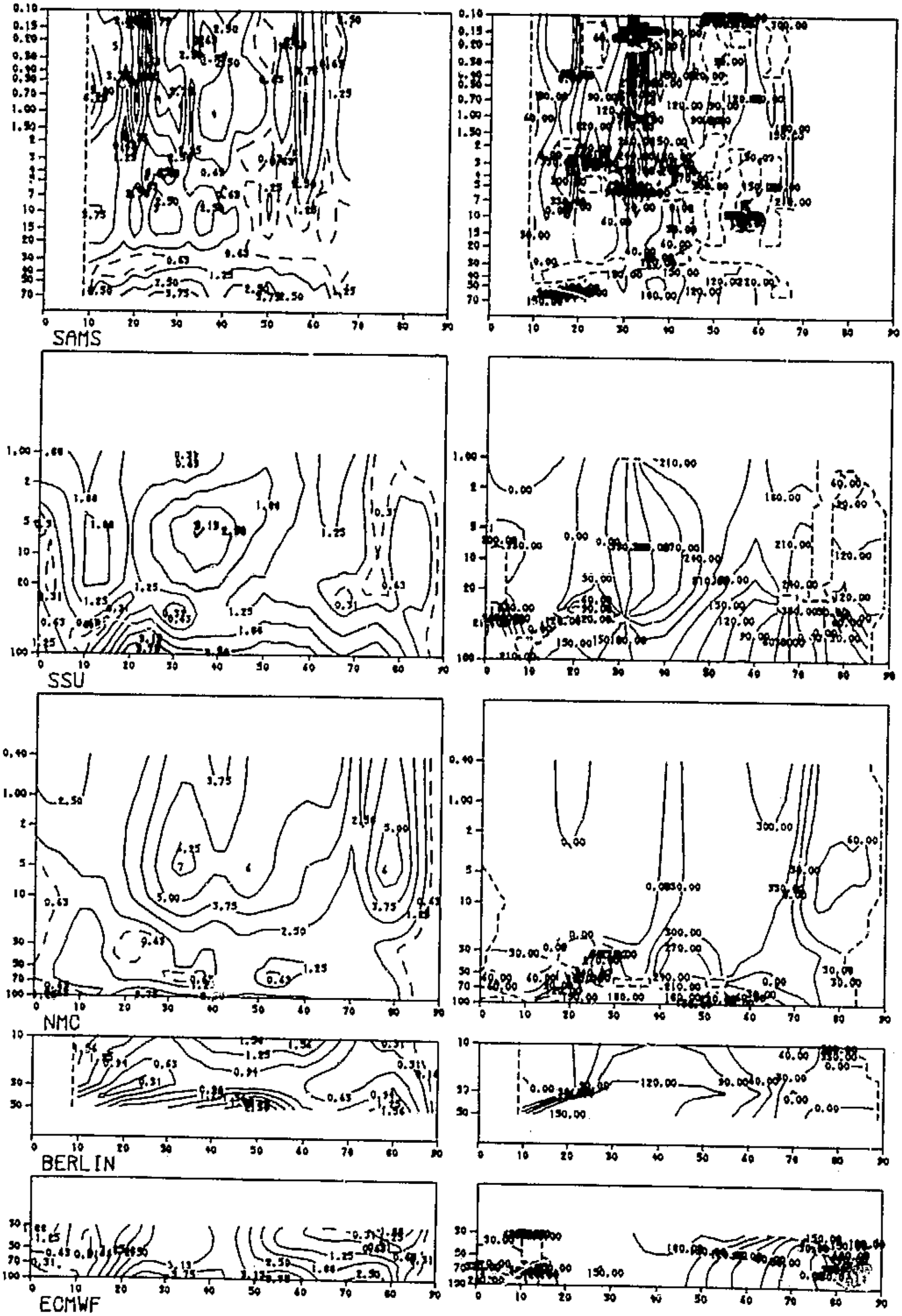
A6.7 Geopotential height wave 1 amplitude and phase, 2 May 79.



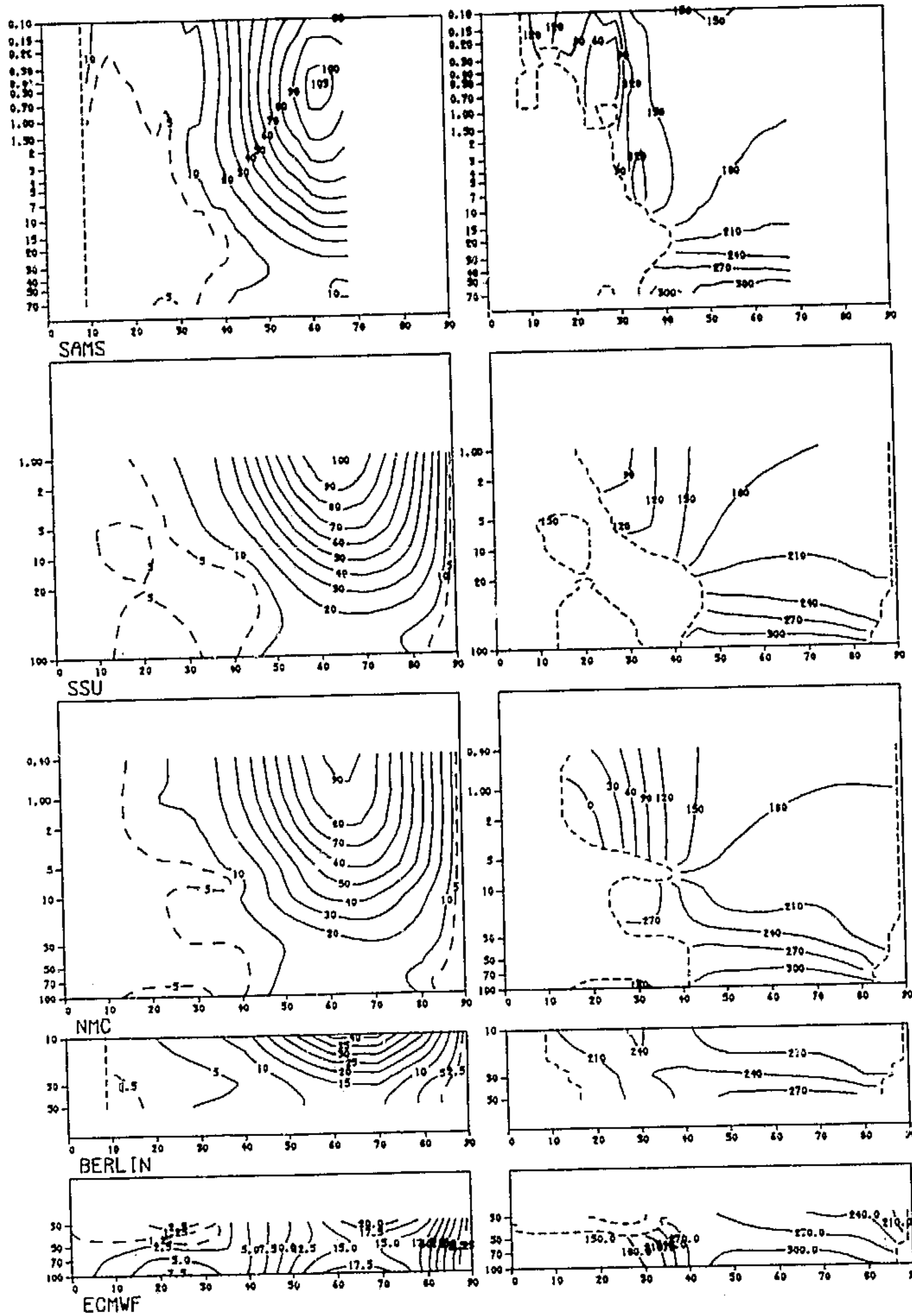
A6.8 Geopotential height wave 2 amplitude and phase, 2 May 79.



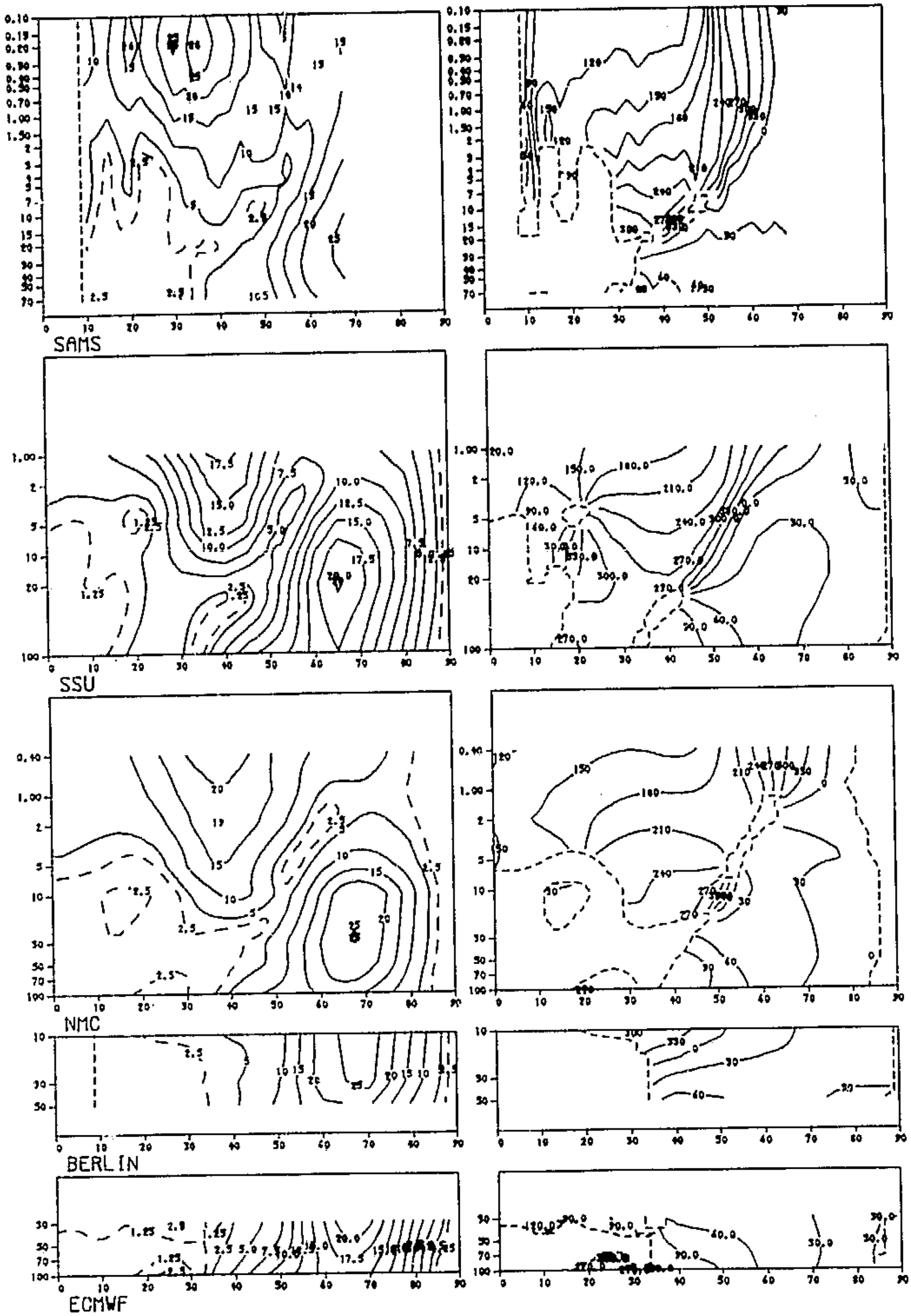
A6.9 Geopotential height wave 1 amplitude and phase, 14 Jun 80.



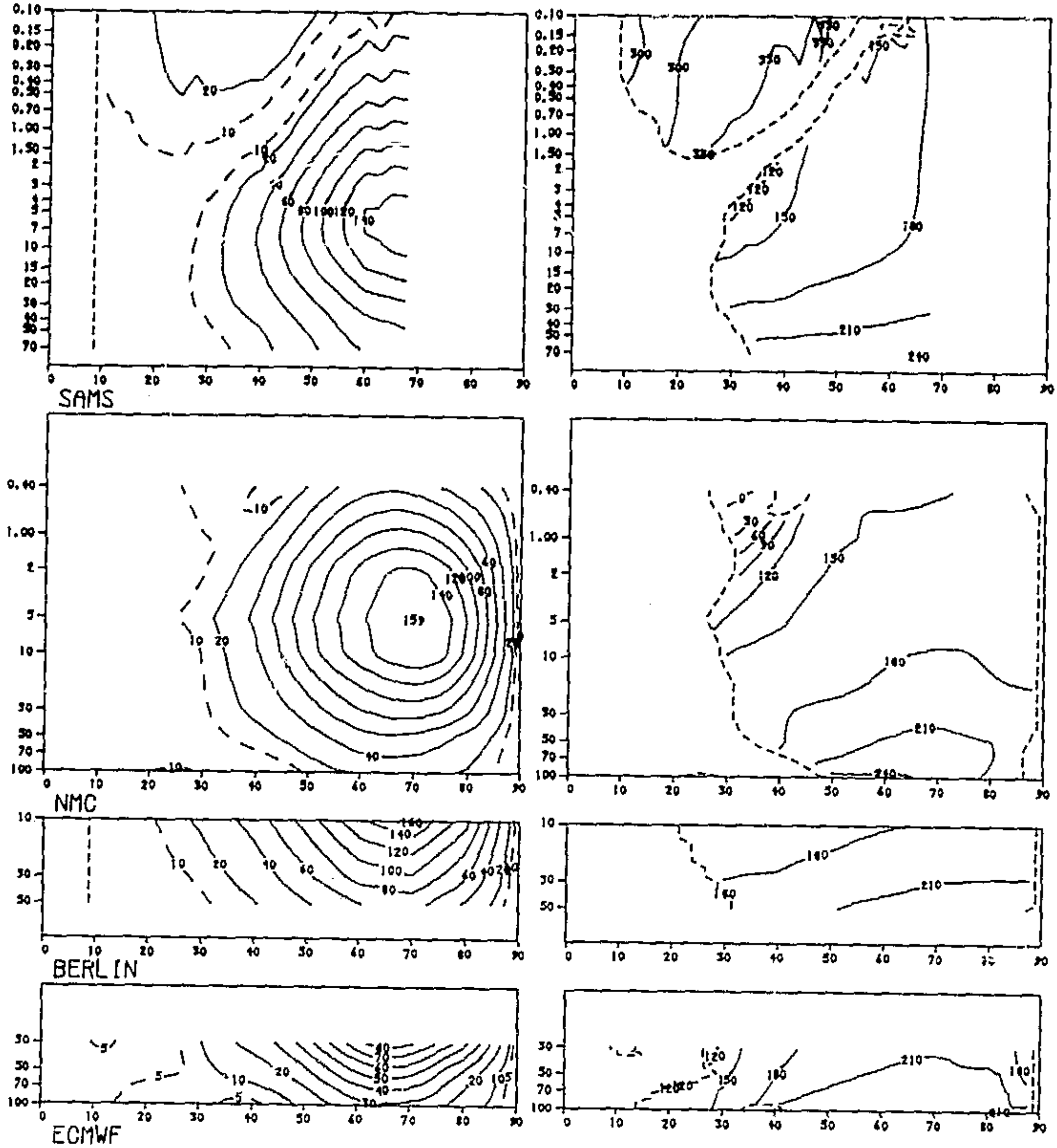
A6.10 Geopotential height wave 2 amplitude and phase, 14 Jun 80.



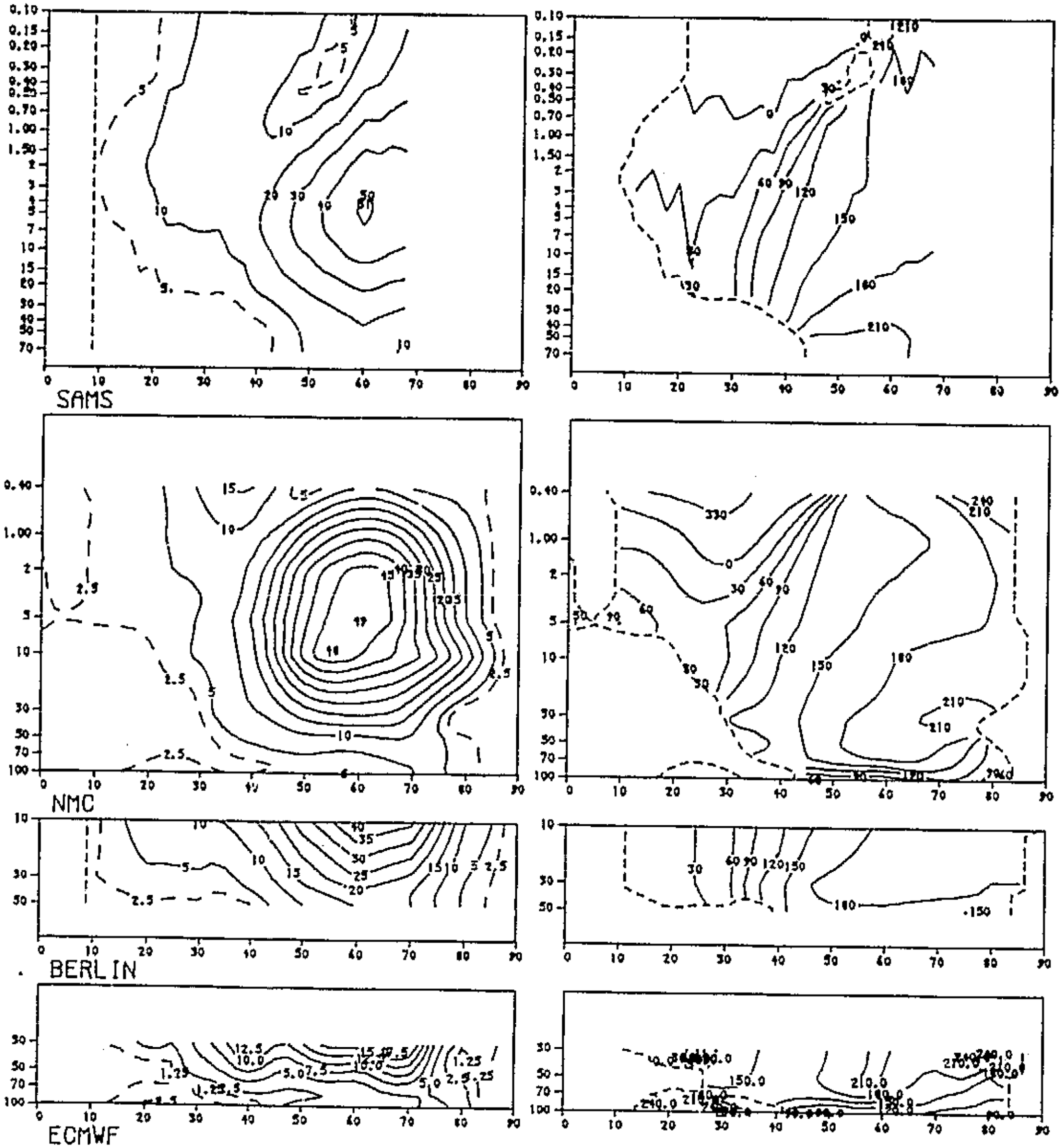
A6.11 Geopotential height wave 1 amplitude and phase, 5 Nov 80.



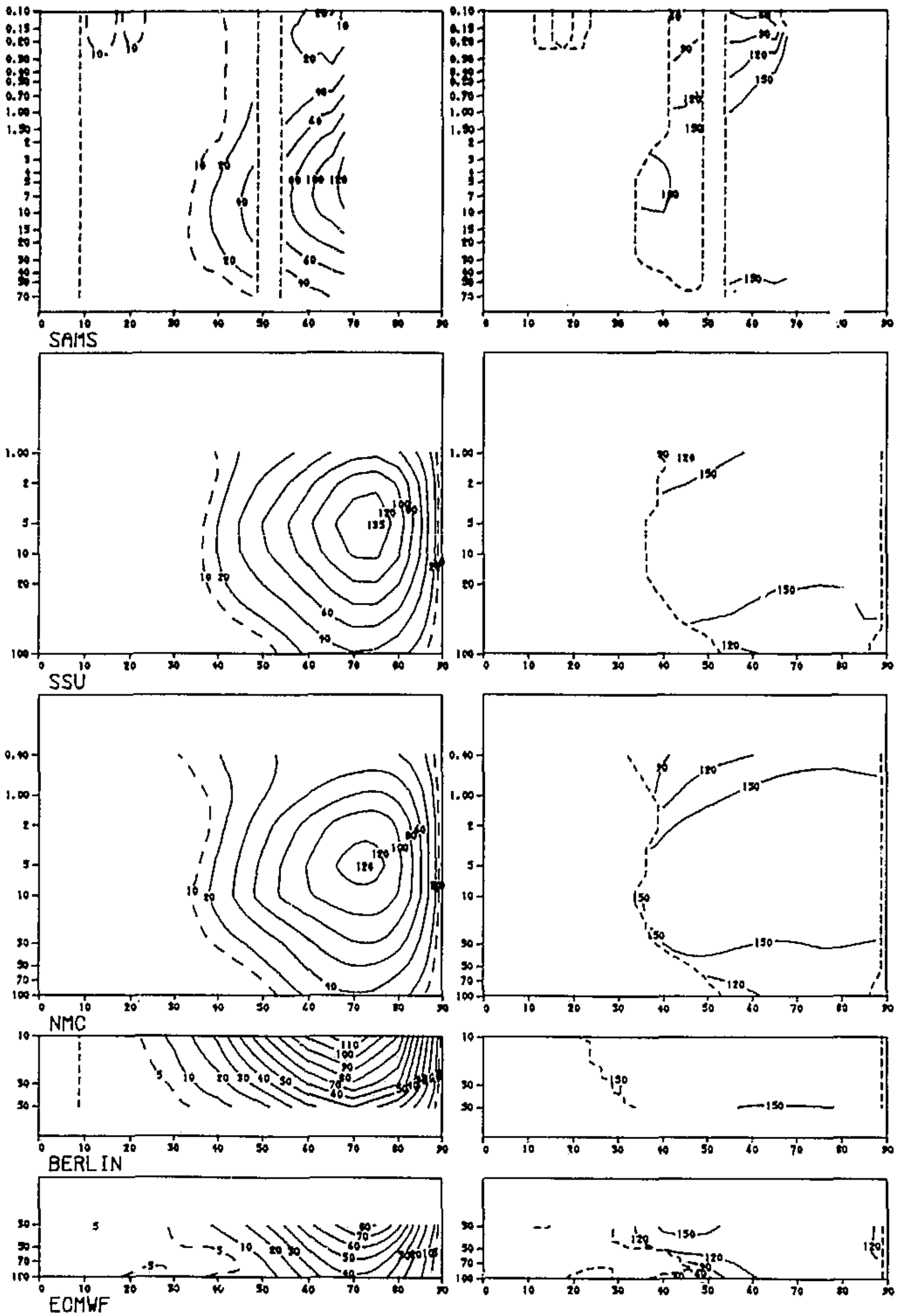
A6.12 Geopotential height wave 2 amplitude and phase, 5 Nov 80.



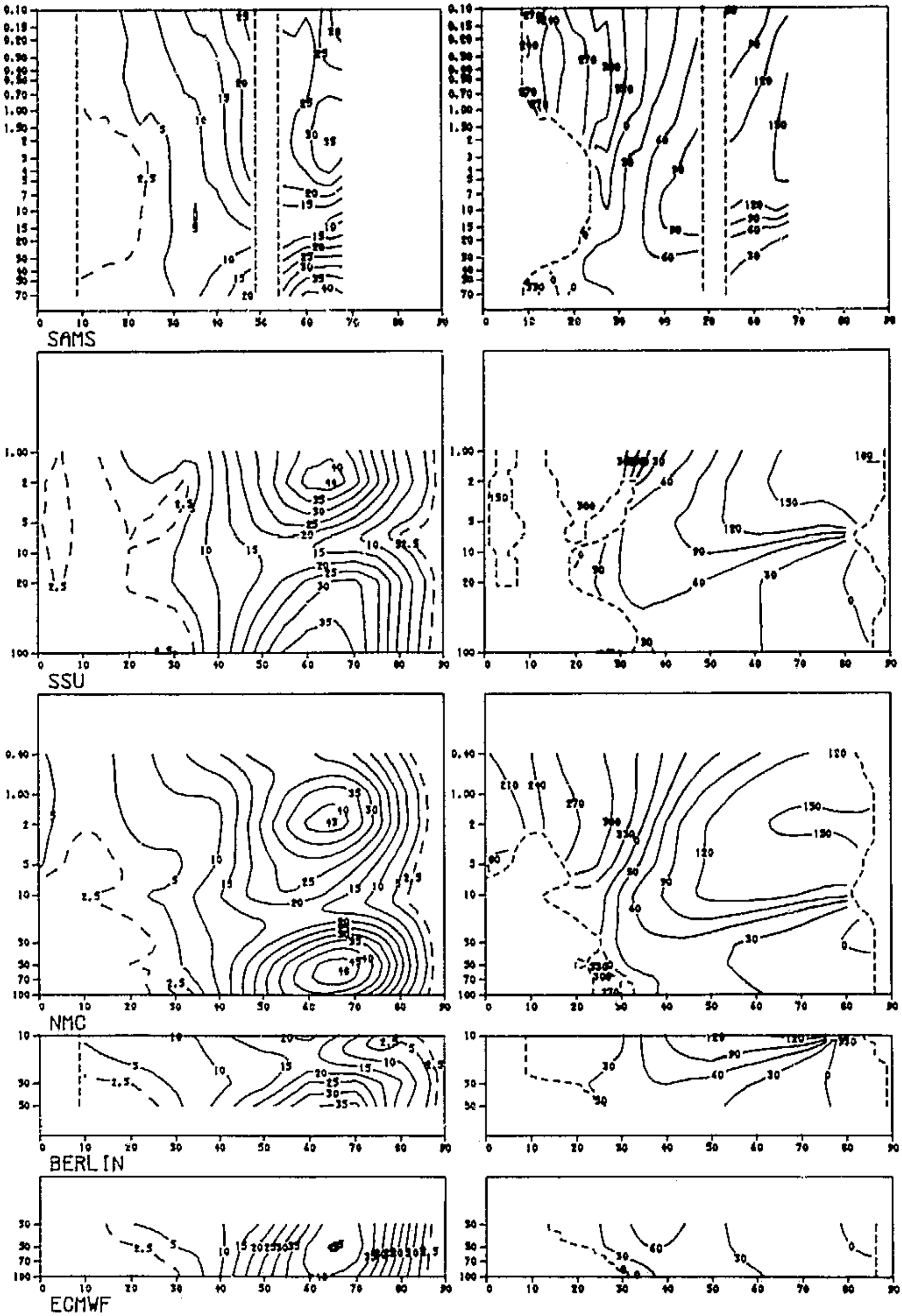
A6.13 Geopotential height wave 1 amplitude and phase, 5 Feb 81.



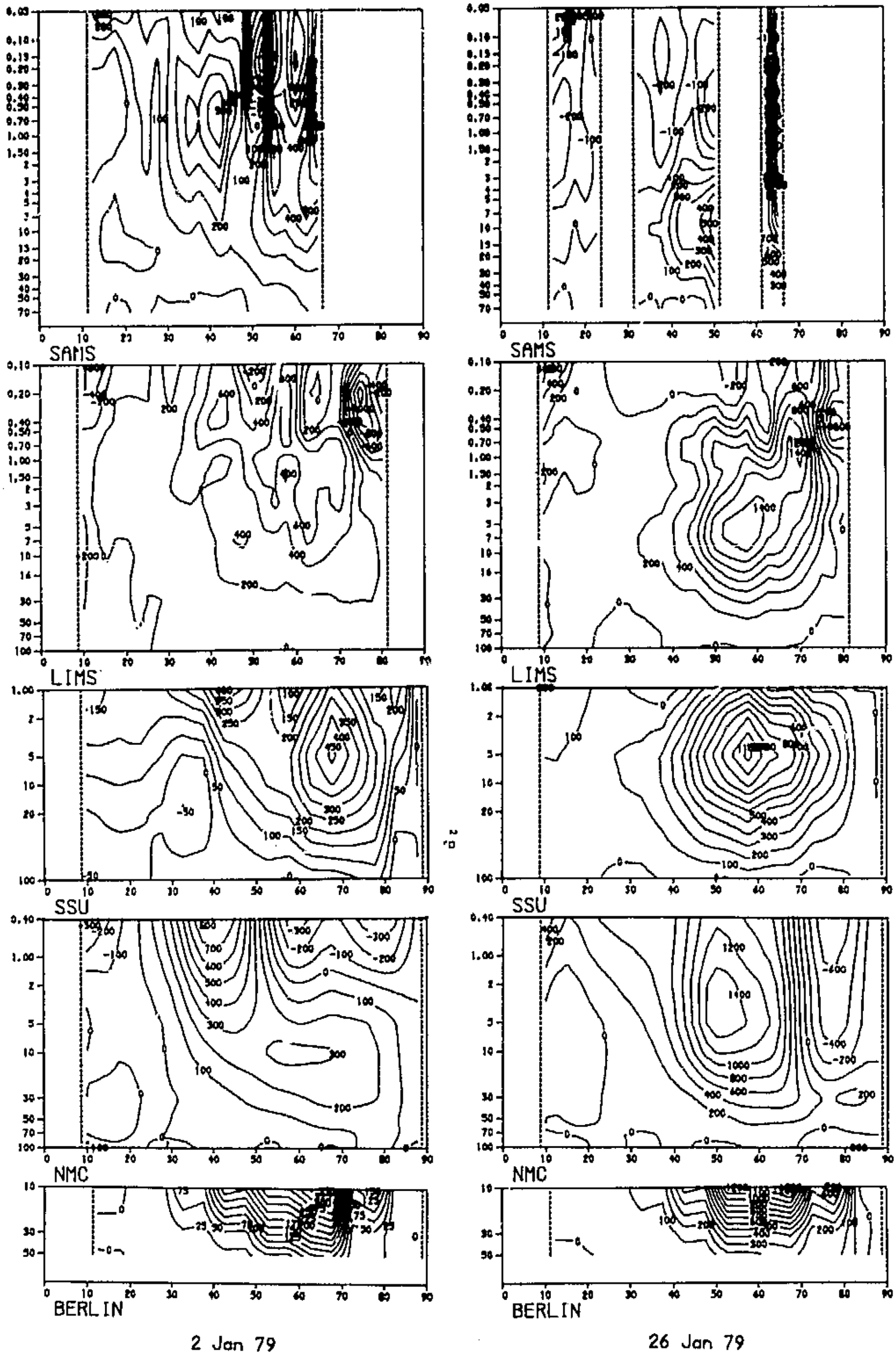
A6.14 Geopotential height wave 2 amplitude and phase, 5 Feb 81.



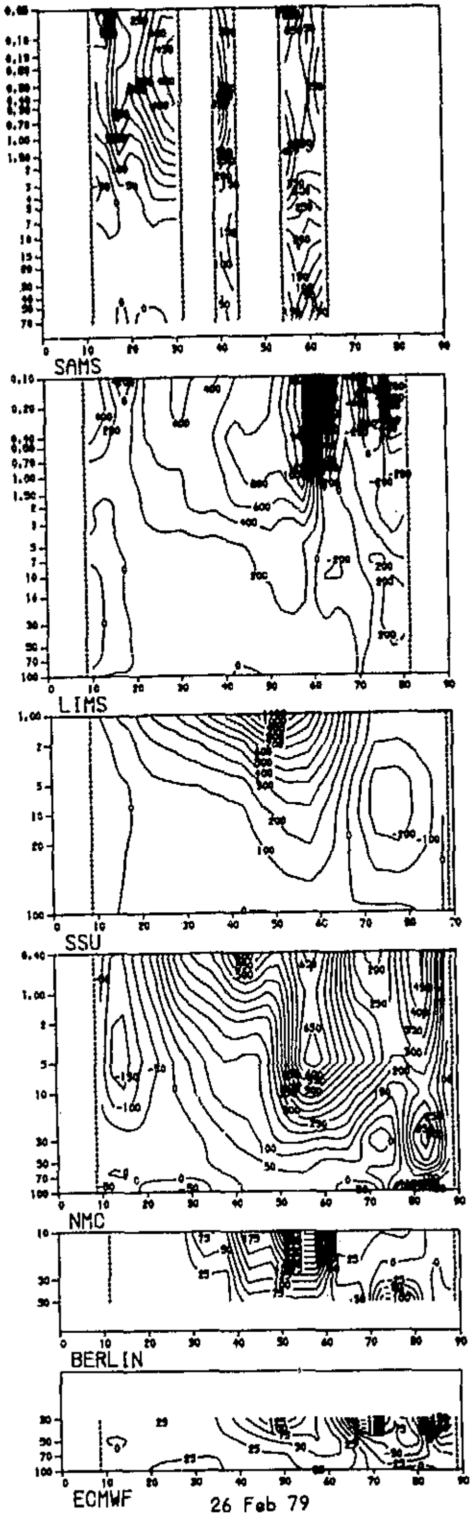
A6.15 Geopotential height wave 1 amplitude and phase, 8 Feb 81.



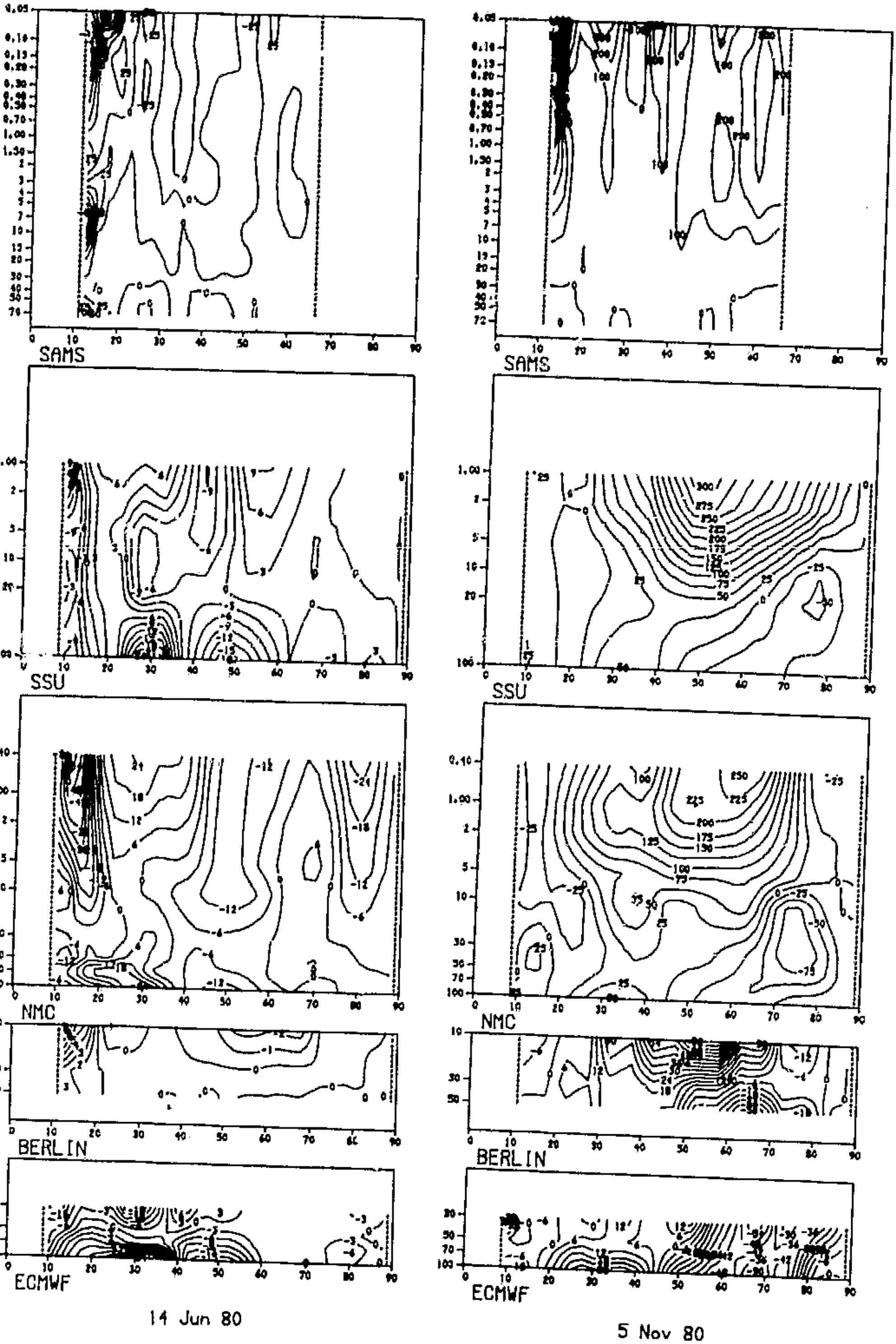
A6.16 Geopotential height wave 2 amplitude and phase, 8 Feb 81.



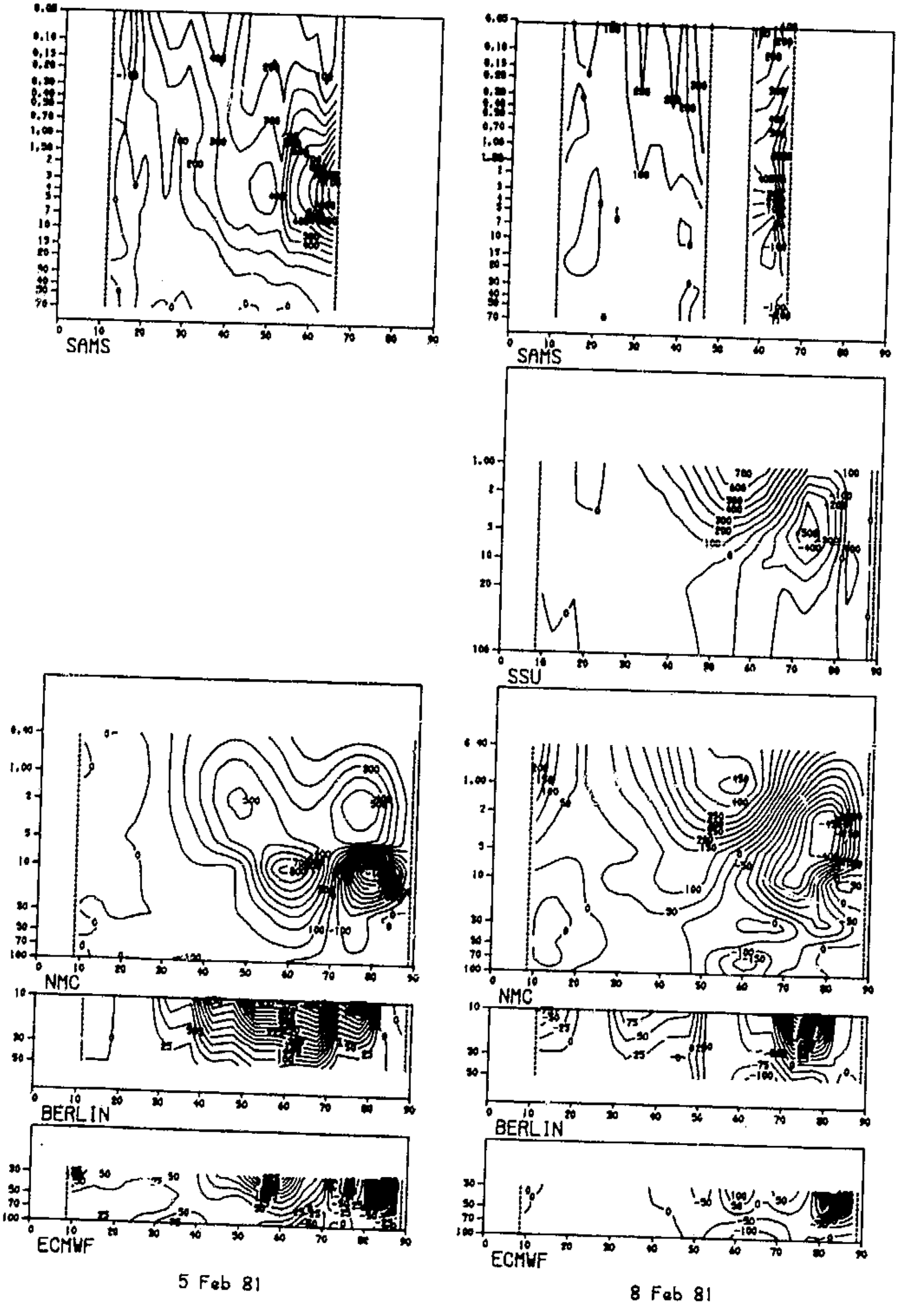
A7.1 Momentum flux.



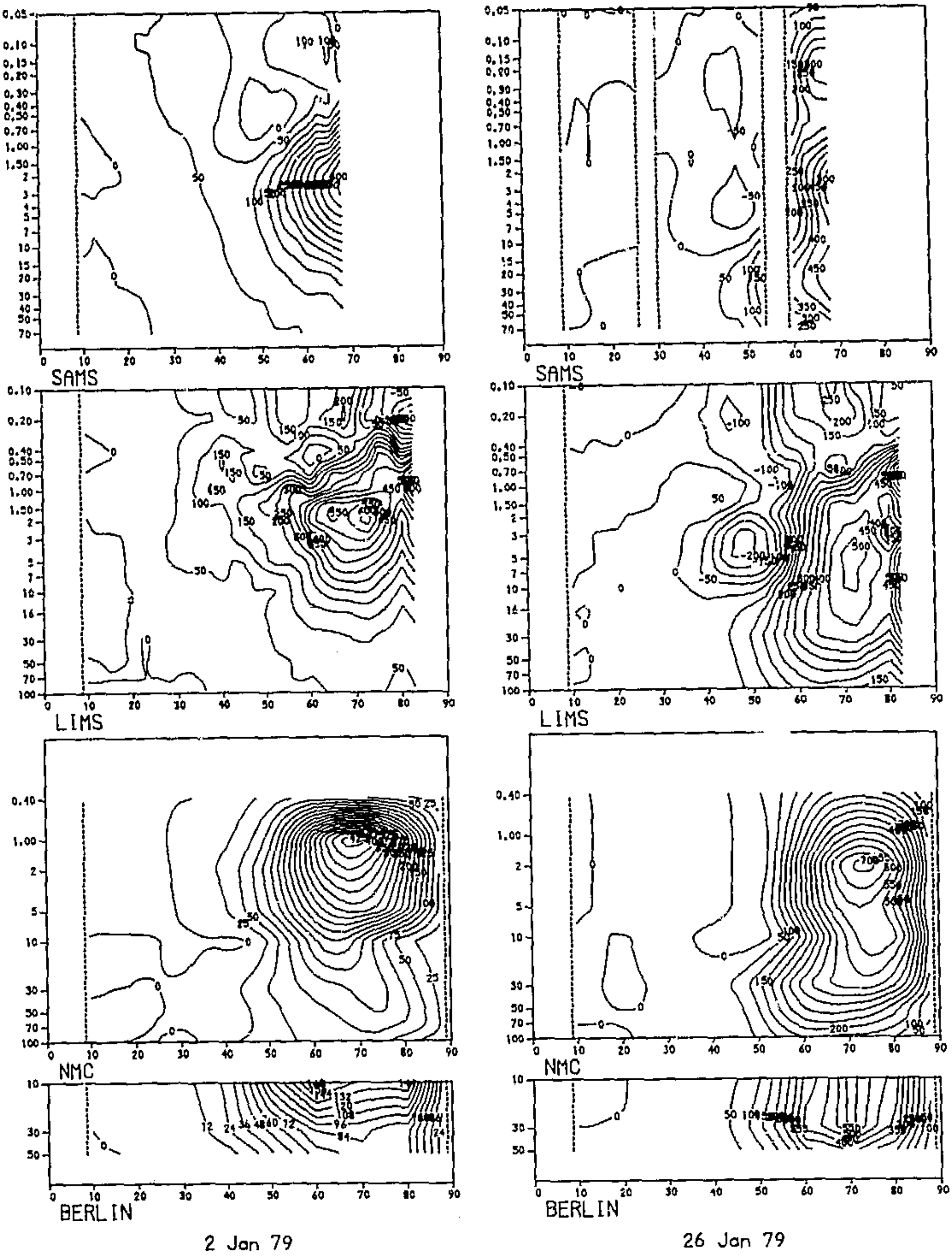
A7.2 Momentum flux.



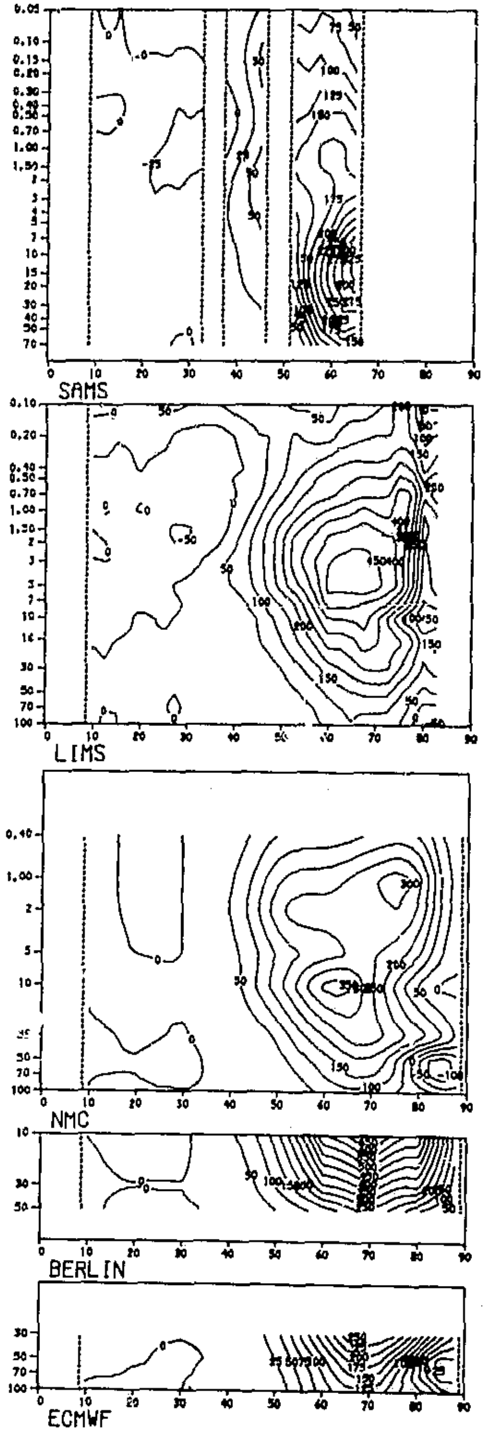
A7.3 Momentum flux.



A7.4 Momentum flux.

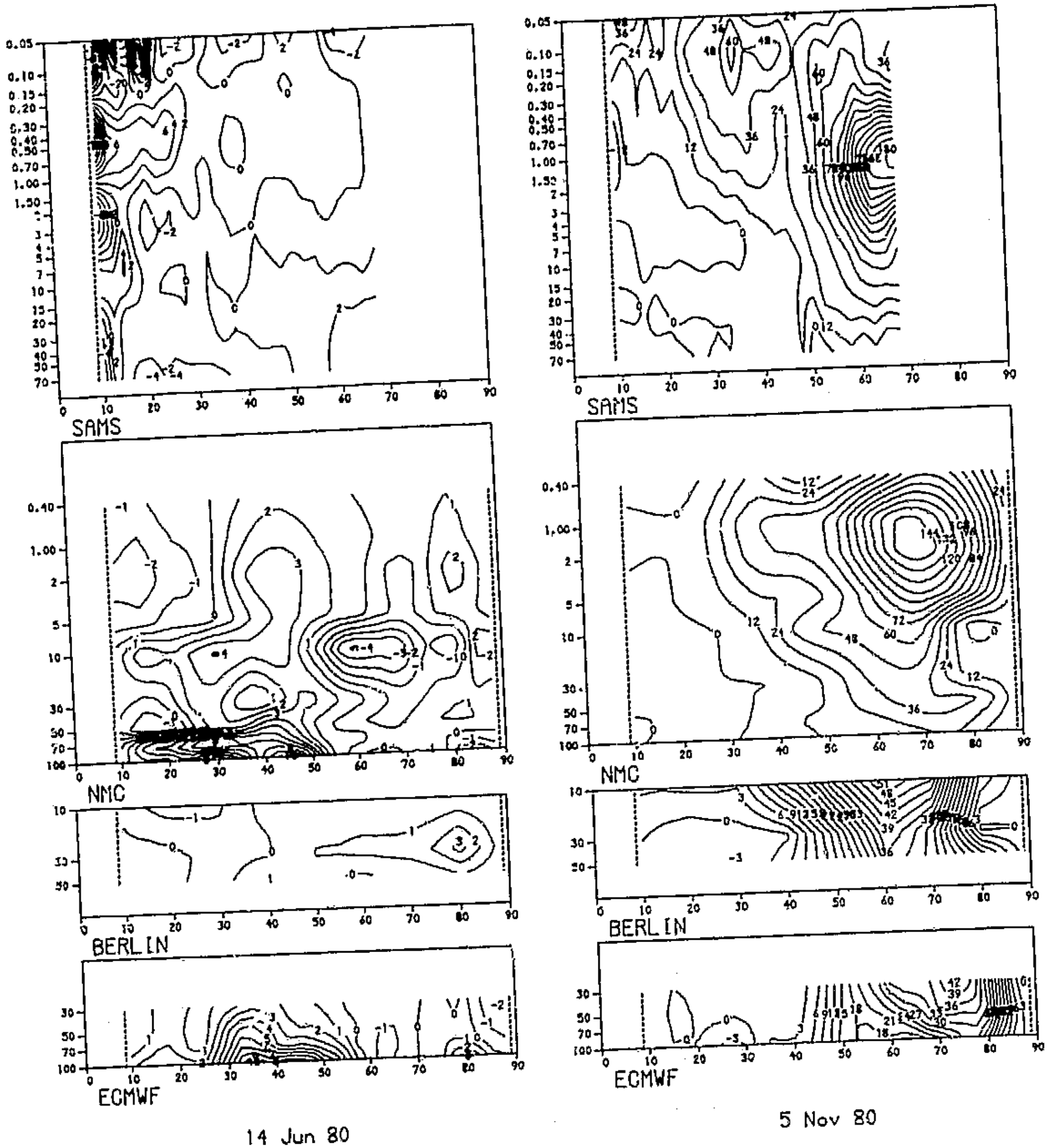


A8.1 Heat flux, K m/s.

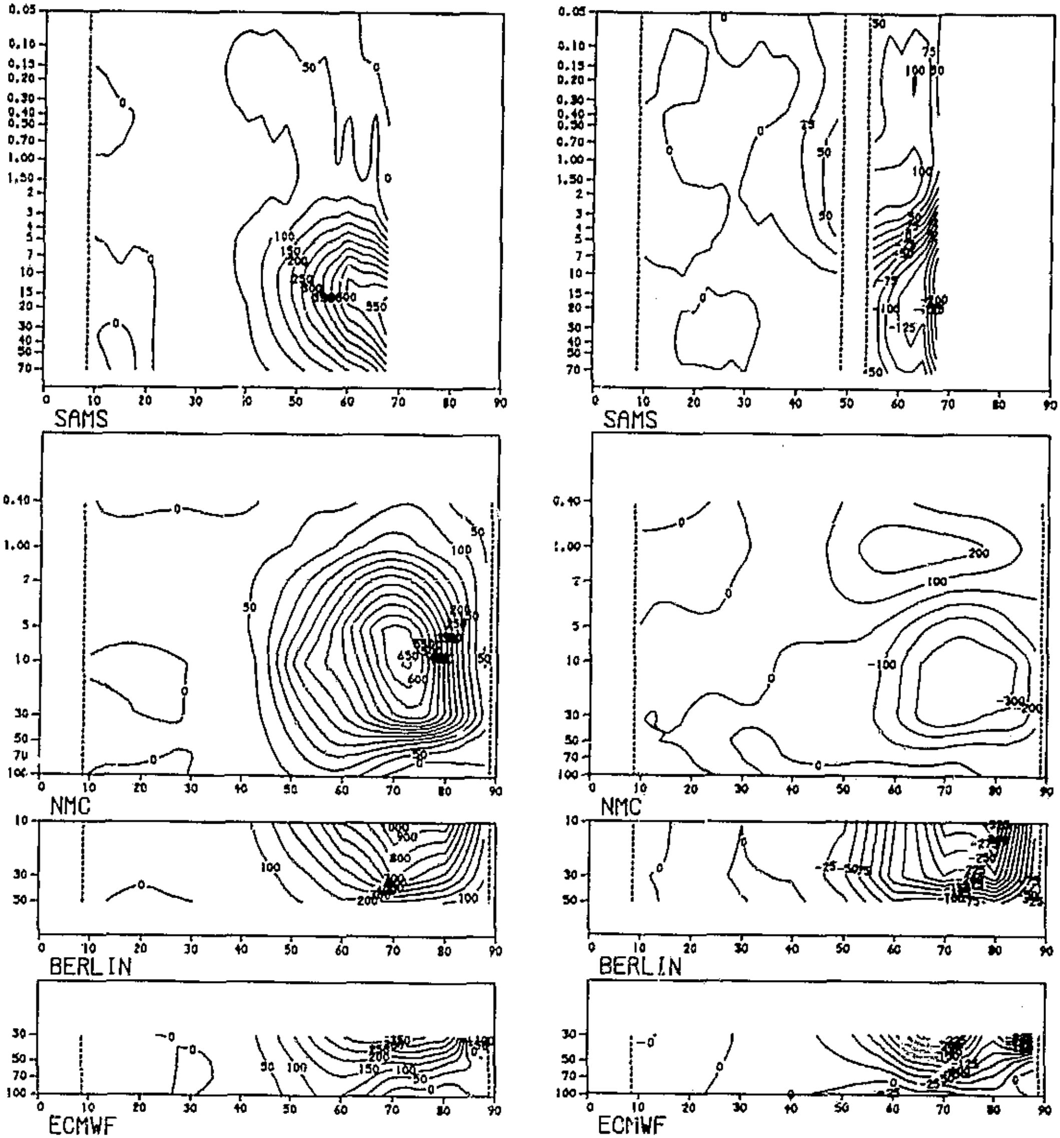


26 Feb 79

A8.2 Heat flux, K m/s.



A8.3 Heat flux, K m/s.



5 Feb 81

8 Feb 81

A8.4 Heat flux, K m/s.

APPENDIX B: ATTENDEES AND CONTRIBUTORS

*J. J. Barnett, Oxford University
M. L. Chanin, Service d'Aeronomie CNRS, Haute Provence
S. A. Clough, U K Meteorological Office
M. Corney, U K Meteorological Office
R. Dickinson, National Center for Atmospheric Research
F. G. Finger, NOAA, National Meteorological Center
R. R. Garcia, National Center for Atmospheric Research
M. A. Geller, NASA Goddard Space Flight Center
*J. C. Gille, National Center for Atmospheric Research
*W. L. Grose, NASA Langley Research Center
D. L. Hartmann, University of Washingon
*A. Hauchecorne, Service d'Aeronomie CNRS, Haute Provence
I. Hirota, Kyoto University
J. R. Holton, University of Washington
E. Klinker, European Centre for Medium Range Weather Forecasting
W. J. Kohri, Drexel University
*K. Labitzke, Meteorological Institute, Free University, Berlin
R. Madden, National Center for Atmospheric Research
J. D. Mahlman, Princeton University
T. Matsuno, University of Tokyo
*J. Miller, NOAA, National Meteorological Center
J. Nash, U K Meteorological Office
*A. O'Neill, U K Meteorological Office
T. N. Palmer, University of Washington
K. Petzoldt, Meteorological Institute, Free University, Berlin
D. R. Pick, U K Meteorological Office
+C. D. Rodgers, Oxford University
*J. M. Russell III, NASA Langley Research Center
M.-F. Wu, Applied Research Corporation

* Co-authors of this report
\+ Editor

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