TECHNICAL MEMORANDUM

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Monthly report on ECMWF's operational model's performance

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This is the third report on model performance. The previous reports have been published as Technical Memoranda No. 9 and No. 10, 1979.

For this month, the discussion will be broadened to include a synoptic review, discussion of some forecast cases and verifications over Europe in addition to nearly-hemispheric (20° - 90° N) verifications, model-atmosphere comparative energetics and large-scale systematic errors. The report will be divided into four sections.

1. Synoptic evaluation
2. Verification statistics
3. Hemispheric energetics and systematic errors
4. Special topics

The last two sections will remain very similar in both content and format to the previous reports.

For the months of September and October, we have seen similarities in our diagnostics of the behaviour of the operational model. We have also been able to note differences. The results for November again show similarities in behaviour with those of the previous months but major new differences are also apparent. This should make us aware that any generalization at this stage is presumptuous. We shall nevertheless try to do just that in certain cases with the general assumption that such generalizations may serve as useful working hypotheses for model improvement.

The month of November includes 21 forecast cases. For the description of the content of the Figures in Section 3 and 4, we refer the reader to previous reports.

1. SYNOPTIC EVALUATION

1.1 Circulation pattern over Atlantic and Europe in November

At the beginning of November 1979 a ridge extended from the Iberian peninsula over western Europe into Scandinavia, with upper troughs over the North Atlantic and over central and S.E. Europe. During the first week of the month this situation changed considerably. There was an overall pressure rise south of 50 ^{o}N and a weakening of the two troughs, leaving two cut-off lows, one over the Mediterranean, the other over the Atlantic. A frontal zone between Newfoundland and western Europe became established and in the westerly flow short wave cyclogenesis penetrated into northern and central Europe, where a large wave trough was situated. This circulation pattern showed little change until the middle of the month. After this the Atlantic high strengthened and the European trough extended meridionally, and then disrupted leaving once again a cut-off low in the Mediterranean, with north westerly flow over western Europe (see Section 1.2 for 18 November). The long waves now changed position. A trough over Newfoundland developed into the Atlantic and there was intense warm air advection over western and northern Europe, with a ridge of high pressure developing over these areas within just three days. The Atlantic trough became stationary and for the rest of the month high pressure over south-western Europe was the dominant feature with a very mild westerly flow over Britain and the North Sea into central Europe.

1.2 Review of some ECMWF forecasts in November

The following examples of ECMWF 10-day forecasts illustrate the behaviour of the model during two periods of the month: (i) the stable westerly flow across the Atlantic at the beginning of the month; (ii) a week in the second half of November which includes two major changes in the circulation over Europe.

(i) Forecasts verifying on 8 November 1979

Fig. 1 shows the 1-day forecast from 7 November, 2-day forecast from* 6 November up to the 10-day forecast from 29 October, i.e. all verifying on 8 November. As described above this date falls into the period characterised by a pronounced zonal flow extending from North America over the Atlantic into central Europe. Embedded into the flow are short wave features which are travelling eastwards without gaining much amplitude. Up to the 7-day forecast, a good indication of the large-scale circulation pattern is given although from D + 4 the detail of the positions of the short wave troughs and ridges is not correct. This is a feature which is observed for forecasts during this sort of circulation regime. This is in accord with current thinking and ideas that reliable information about rapidly moving short waves in a stable westerly flow cannot be expected further than three or four days into the forecasts.

On the 8-day forecast from 31 October and 10-day forecast from 29 October the strength of the frontal zone over the Atlantic is overestimated and it extends too far south into Europe. Guidance taken from these forecasts would have been misleading.

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*At present, forecasts are only made 5 times a week (Sunday to Thursday). Thus, the 5-day forecasts from Saturday, November 3 and the 6-day forecast from Friday, November 2 are not available.

(ii) Forecasts verifying on 18 November 1979 and 21 November 1979

Figs. 2 and 3 are examples of how the model coped with major changes in the circulation pattern. By 18 November the previous zonal flow across the Atlantic had been replaced by a more meridional type of circulation with pronounced troughs over Newfoundland and Europe. This was indicated clearly in the 5-day forecast from 13 November 1979 (Fig. 2). The cut-off low over the Mediterrean is correctly represented at 500 mb and at the surface (not shown). In ECMWF experience the predicted surface pressure distribution becomes less reliable around two days before the predicted upper air pattern finally deteriorates. This is the case for the 6-day and 7-day forecasts from 12 and 11 of November respectively; the 500 mb charts at least indicate the major change in the circulation type but fail to describe the phase of the important broad scale features or their strength. The corresponding surface charts gave somewhat misleading information.

Three days later on 21 November the situation had changed again (Fig. 3). Between Ireland and Scotland the frontal zone had become very pronounced extending far into Northern Europe; a belt of high pressure extended from the Azores into the USSR.

Although the forecast from 13 November was successful in predicting the cut-off over the Mediterranean (Fig. 2), the model could not cope with the second major change in the circulation pattern during the later stage of this forecast. Little useful information could be obtained from the 8-day forecast (Fig. 3) verifying on 21 November. The penetration of the westerly flow across much of Europe in the 7-day forecast from November 14, and even the 6-day forecast from November 13 breaks down the ridge over the North Sea too quickly.

2. VERIFICATION STATISTICS

2.1 Hemispheric scores

Figs. 4,5,6 and Table 1 give the standard objective scores. When comparing the scores of September, October and November, we note a relative improvement from month to month, but November scores are particularly better. Judging from the anomaly correlation coefficients (ACC) an increase in predictability (the predictability limit being defined as the intersection of ACC's with the 0.6 level) of about one day for both heights and temperatures is observed from October to November. For the standard deviations (labelled RMS), the ratio to the persistance (a better indicator apparently than the ratio to the norm) also indicates a big improvement. Because the scores at day 6 in November are comparable to the ones at day 5 in previous months, we felt obligated to extend Table 1 to 144 hours.

The study of the wave decomposition of the objective scores indicates that the improvement is coming from all wave numbers but especially from the long waves (1-3) and to a lesser extent from the medium waves (4-9) while the zonal part is if anything worse than in the other months. The really high predictability of waves 1-3 in the month of November is best illustrated by Table 2 which reproduces the results of Table 1 but for these wave numbers only. Here we have equally good scores for heights and temperatures and for example correlations of 0.60 for the 500 mb heights and 0.62 for the 850 mb temperatures after 6 days!

		FORECAST LENGTH (HRS)	12	24	36	48	60	72	84	96	108	120	132	144
HEIGHTS	RMSE (m)	1000-200	21	28	37	46	54	63	72	81	89	96	103	111
		500	19	26	35	45	54	63	73	82	89	96	103	111
		1000	19	26	35	41	46	52	58	63	67	71	76	81
	ACC (%)	1000-200	98	97	95	92	90	86	81	77	72	66	61	55
		500	99	97	95	93	90	86	82	77	72	67	62	56
		1000	96	94	90	87	83	79	74	69	64	60	54	49
TEMPERATURE	RMSE (0.1 °C)	850-200	12	16	19	23	26	30	33	36	38	41	43	45
		500	10	14	17	21	25	29	32	36	38	41	43	45
		850	14	19	23	27	31	34	37	41	44	46	48	50
	ACC (%)	850-200	96	93	90	87	83	78	74	69	64	58	53	48
		500	97	95	93	89	85	80	75	70	64	58	53	47
		850	96	93	90	86	83	79	75	70	65	61	57	52

Table 1. RMSE and ACC for heights and temperatures. November 1979 (21 cases)

		FORECAST LENGTH (HRS)	12	24	36	48	60	72	84	96	108	120	132	144
HEIGHTS	RMSE (m)	1000-200	14	18	25	31	37	43	48	54	59	64	68	74
		500	13	17	24	31	37	43	48	54	58	63	67	73
		1000	14	17	25	28	33	36	41	43	46	48	52	56
	ACC (%)	1000-200	98	97	95	93	91	87	84	80	76	71	65	59
		500	99	98	96	93	91	88	85	81	77	72	67	60
		1000	96	95	90	88	85	81	75	69	63	58	50	42
TEMPERATURE	RMSE (0.1 °C)	850-200	7	9	11	13	16	18	19	22	23	25	26	28
		500	6	8	10	12	15	17	19	21	23	25	26	27
		850	9	10	14	16	18	20	22	25	26	28	29	30
	ACC (%)	850-200	97	95	93	90	87	84	81	77	73	68	63	58
		500	98	96	94	92	88	84	81	78	73	68	63	58
		850	96	95	92	90	87	84	81	78	74	70	67	62

Table 2. RMSE and ACC for heights and temperatures. November 1979 (21 cases), 1-3 wavenumbers

2.2 Objective verification for the European Area

The numerical forecasts of the ECMWF grid point model are operationally verified in a limited area covering Europe and the eastern part of Atlantic, defined by latitudes 35 ^{o}N - 75 ^{o}N and longitudes 20 ^{o}W - 50 ^{o}E with the latitude/longitude resolution of 5 degrees. The objective verification scores used are conventional: the correlations coefficient between forecast and analyzed changes from the initial state (tendency correlation coefficient) and the standard deviations for the forecast error and for the persistence forecast error.

The verified parameters are the geopotential height and temperature at six standard levels, 1000, 850, 700, 500, 300, and 200 mb. The ECMWF analyses are taken as verifying analyses. The standard deviation of forecast error is also compared to the climatological normal values.

Fig. 7 shows the individual scores of the 3-day and 6-day forecasts of 500 mb height including correlation coefficient and standard deviation of forecast error. The first forecast period from 7 to 8 November was reasonable, but during the next period from 11 to 15 the forecast initiated from 14 November had failed by day 6. The development of a ridge over the western part of the verification area between days 4 and 6 of this forecast from 14 November was not correctly predicted. The third period from 18 to 22 was extremely good, while the period from 25 to 29 had again a larger variability in the prediction skill.

Figs. 8 and 9 show the monthly mean values for the tendency correlation coefficients at different levels. The correlations decrease most sharply between about days 2 and 6. The objective verification scores for November indicate that the November forecasts were significantly better than the October forecasts at all levels to around forecast day 5. The standard deviations of height (Figs. 12 to 14) show the forecast error increasing quite linearly up to day 6 or 7 and more slowly thereafter at the lowest levels. At the lower levels the forecast error nearly reaches the persistence error (shown dashed) at day 6. The forecast error reaches the normal curve also at day 6 at 850 mb, but not until after day 8 at higher levels. The quasi-stationary nature of the circulation in the area during much of the month, noted in the synoptic review of Section 1, is reflected in the relatively slow growth of the persistence scores.

Figs. 10 and 11 show the standard deviations of temperature. The forecast error remains below the normal curve until after day 8 at all levels except 200 mb, i.e. near the tropopause.

3. HEMISPHERIC ENERGETICS AND SYSTEMATIC ERRORS

3.1 Zonally averaged energetics

Figs. 15 to 26 (Figs. 4 to 15 in previous reports) give comparisons, for the forecast period 7 - 10 days, of the main energetic terms between model and reality (NOV vs OBS). The tendency for the model to produce excessive KE in the zonal component and to be deficient in eddy KE in upper atmospheric levels is maintained. As in October, the relative discrepancy increases with wave number. In September the biggest discrepancy was in the wave number band 1-3. Concerning the excess zonal KE, it is worthwhile mentioning that the overall integrated value of zonal KE is but only very slightly overestimated, while the difference between maximum values are relatively large: a fact which can only be explained by excessive confinement of the mean jet. Another problem mentioned in previous reports concerned the shift to the north of the mean jet by a few degrees of latitudes in September, almost unnoticeably in October. In November, however, as will be shown also in other graphs, later on (Fig. 30 and Sect. 4.2) the northward shift is by nearly 15 degrees and has become one of the most noticeable features. The problem shows up very clearly, in the conversion term CK where the observed low latitude (25 ^{o}N) main negative centre has been deemphasized in the forecast model in favour of the more northern (40 ^{o}N) centre where only a weak positive centre exists in reality. Underestimation of zonal (below 500 mb) and eddy (entire atmosphere) AE also appears as a persistent model defect, while representations of CA, UV and TV is acceptable.

3.2 Tropospheric spectra

Looking at the spectra of total tropospheric kinetic energy and height at 500 mb, (Figs. 27 - 29), we note again the model tendency to be deficient at most wavenumbers but particularly at high wave numbers. On the other hand the forecast spectra at low ($\leqslant 5$) wave numbers are in reasonably good agreement and provide a better fit to the observations than for the previous months. An interesting aspect of these spectra is perhaps the monthly evolution of the observed spectra themselves. From September to November, the observed KE spectra, for example, show a marked increase in KE in wave numbers 4-6 compared to only a slight increase in wave numbers 1-3, a decrease in wave numbers 8 - 9, and unchanged values for wave numbers 7 and 10-20. In September, the KE field is dominated by the larger scales 1-3 with relative maxima at wave numbers 5 and 8. In November, the KE field has become dominated by scales 4-6 and is much smoother than in previous months. Vertical distribution of kinetic energy is discussed in Sect. 4.4.

3.3 Zonally averaged, zonal wind and temperature deviations (Fig. 30)

The large mid-latitude error in zonal wind for November which, unlike for September and October, extends to the earth's surface is perhaps the most surprising aspect of the November results, in view of the fact that the temperature error has remained relatively unchanged or has even diminished in the tropics and mid-latitudes. Hence the error must have a large barotropic component and be related largely to a dynamic rather than thermodynamic deficiency. The most straightforward explanation for the mid-latitude near surface wind error is insufficient effective surface drag coefficients. This explanation is supported by other diagnostics and appears confirmed by experiments in the Research Department. The high-latitude wind error is related to errors in the thermal field and could be attributed to excessive high surface temperature near the pole. It is also interesting to note the important change (diminution) of the temperature error in the stratosphere.

3.4 <u>Geographical distribution of the errors (Figs. 31 - 36)</u>

A comparison of the observed and forecast (day 10) mean 500 mb height fields for November show general trends similar to the ones described for September and October: a tendency for the predicted flow to become increasingly zonal and more confined in the mid-latitude. Also the Pacific jet stream extends too far east. The Atlantic jet stream is displaced eastward and fails to curve northward in the middle of the Atlantic. Ridging over western North America is particularly weakened. Some troughs show large eastward displacement during the 10-day forecast period as well as loss of amplitude (see also Sect. 4.3). While the amplitude of the errors at 500 mb has not greatly increased between September and November, their scale has gradually changed: predominantly large (wave number 1-3) in September, more zonal and medium (wave number 4-9) in November, with for October an intermediate situation. The lack of amplitude of the mean flow at intermediate scales is further substantiated in Sect. 4.6).

The comparison of the observed and forecast (day 10) mean 1000 mb height fields confirms the tendency of the model to produce depressions near the Aleutians and Iceland, which are not only too deep but also extend too far to the east. Consequently, the main negative error centres are situated over the western portion of both North America and Europe. At 1000 mb, the errors have increased considerably from September to November. They also present a large zonal component in November.

The 850 mb temperature error pattern has remained fairly consistent from month to month over the continental masses: with the exception of the Polar and Hudson Bay regions which are too warm, continental masses are generally too cold, particularly south of 30 ^{O}N and over the western portion of North America and Europe. The Himalayan region is also too cold (extrapolated values).

4. SPECIAL TOPICS

4.1 Vertical structure of the forecast error

Figs. 37 and 38 are time-height diagrams of the anomaly correlation coefficients for heights and temperature respectively. The comparison of both pictures confirms the fact that, globally, the temperature predictability is about one day less than for heights. But an interesting feature is that (for the troposphere) the quality of the height forecast decreases when going down, the reverse being true for temperature. As a result heights and temperatures have similar skill scores in the lower part of the atmosphere. The waves most responsible for this differentiation process are the long waves.

4.2 North-south profiles. Shift of the subtropical jet

Figs. 39 to 41 show the time evolution of several north-south profiles. From the 300 mb wind profile, we can immediately notice a dramatic northward shift of the sub-tropical jet (by about 15^{O} between day 7 and 10) and its intensification. The wind field error is then the one discussed in Sect. 3.3. Perhaps of some interest is the fact that the model wind profile at day 7-10 resembles those seen in September and October. And in October the jet position was about right although the jet itself was too intense. In September both position and intensity were about right. This and the discussion of systematic errors (Sect. 3.4) suggest that the model may have a preferred mean jet position and a tendency to intensify and confine it at least up to day 10. Depending on the real situation, this gives acceptable or totally wrong results. A rapid deviation from reality in certain cases toward a preferred position might be possible if, as suggested in Sect. 3.3, the effective level of surface drag is too low.

The 850 mb temperature profile clearly shows a general mean cooling of the lower troposphere below 70 ^{O}N.

4.3 Eastward drift of 500 mb troughs

Fig. 42 shows the time evolution of the mean 500 mb height field in comparison with reality (Fig. 31; Fig. 42 for day 2 can be used for comparison purposes) as a complement to our discussion on systematic errors (Fig. 3.4). A feature of interest is the trough situated over central U.S. at day 2 which drifts gradually in the forecast to reach the East Coast by day 10.

4.4 Energy spectra at different pressure levels

The spectra of KE at different pressure levels for three forecast periods is shown in Figs. 43 to 48. In Sect. 3.2 we saw that the mean tropospheric energy spectrum was of good quality in both medium and long waves up to day 10. Here we show that, in spite of the improvements over September and October, in this diagnostic, the systematic differences at different pressure levels noted for October remain. Note the different scales in the graph for upper and lower levels.

4.5 Time evolution of the energetics

Fig. 49 show that total KE slowly decreases with time in spite of an increase in the zonal part. Medium scales (4-9) loses KE most rapidly after 3 days.

Total AE (Fig. 51) loss occurs very early in the forecast. Zonal AE increases after 3 days but eddy AE decreases more rapidly also after 3 days. CA (Fig. 52) is initially (0-6 days) larger than observed and smaller thereafter. CK (Fig. 50) is (negatively) larger than observed. In more detail (Fig. 52, 54 and 17,18) this seems related to the over development of a mean centre of activity to the north of the original or observed one and further down in the atmosphere. The new centre progressively takes over wrongly the main energetic role.

4.6 Mean flow spectra

As mentioned in Sect. 3.4, Fig. 55 shows the increased importance of medium scale deficiencies in standing energy in relation to the larger scales from September to November. It also supports the fact that eddy KE deficiencies are mostly in the "stationary" part of the flow.

4.7 Lower troposphere cold pools over Europe in October forecasts

Cold outbreaks over Europe in northerly situations in Autumn forecasts have shown 850 mb temperatures which appeared to be rather low. Fig. 56 is an example of a cold outbreak observed near 50 ^{O}N 75 ^{O}E, with forecast positions of this 850 mb minimum temperature also shown. Note that the forecast temperatures were 5 to 6 K lower than the observed.

Individual forecast cold pools cannot always be associated with verifying analyses, but the distribution of cold outbreaks can be tabulated. Table 3 shows the analysed cold outbreaks on the Atlantic and European maps east of 10 ^{O}W and south of 60 ^{O}N for the month of October.

Minimum Temperature	Latitude	Longitude	Date
$-10^{\circ}C$	$57^{\circ}N$	$78^{\circ}E$	79/10/06
$-11^{\circ}C$	$58^{\circ}N$	$62^{\circ}E$	79/10/09
$-12^{\circ}C$	$50^{\circ}N$	$75^{\circ}E$	79/10/13
$-12^{\circ}C$	$50^{\circ}N$	$32^{\circ}E$	79/10/28
$-16^{\circ}C$	$54^{\circ}N$	$62^{\circ}E$	79/10/28
$-17^{\circ}C$	$54^{\circ}N$	$60^{\circ}E$	79/10/31

Table 3. Analysed minimum temperatures, positions and dates of cold outbreaks over Europe in October.

Table 4 shows the number of forecast outbreaks for the same area which had minimum temperature less than $-12^{\circ}C$ for October 1-15, and less than $-16^{\circ}C$ for October 16-31. A total of 11 forecasts were made in the period October 1-15 and 12 in the period October 16-31, so that 110 and 120 850 mb temperature fields were inspected for cold outbreaks for the two periods, respectively. Thus, approximately one 850 mb forecast chart in three had a cold outbreak with minimum temperatures lower than the lowest temperatures observed in the area at that time of year.

It appears that this cooling is a combined adiabatic and radiative effect which is not balanced by a compensating diabatic heating in the model.

Min. Temp. (°C)	FORECAST DAY D+1 to D+3	D+4 to D+6	D+7 to D+10	TOTAL
-13	3	2		5
-14	2	3	1	6
-15	1	3		4
-16	1	2	3	6
-17	3	2	2	7
-18	2	4		6
-19		1		1
-20		1		1
TOTALS October 1-15	12	18	6	36

-17			4	4
-18	4	3		7
-19	2	1	5	8
-20			1	1
-21	1	1	1	3
-22	1	1		2
-23				0
-24			1	1
-25	1	1		2
-26			1	1
TOTALS October 16-31	9	7	13	29

Table 4. Forecast minimum temperatures for forecasts made October 1-15 (upper table) and October 16-31 (lower table) for cold outbreaks over Europe.

4.8 A seasonal summary (September to November)

We have noted a tendency for the model to underestimate both total KE and AE. Considerable AE is lost in the initial stages of the forecast (0-3 days) in all parts of the spectrum. Thereafter total AE remains stationary with more zonal AE being produced than observed balanced by continued loss of eddy AE. Related to this problem, we have noted a general cooling of the lower troposphere at low and middle latitudes, the cooling being more pronounced over continental masses, at all longitudes south of 30 ^{o}N and principally over the western portion of both North America and Europe in the middle latitudes. Total KE loss is gradual during the forecast. Some zonal KE is lost early in the forecast but thereafter it increases at the expense of eddy KE. Loss of eddy KE starts at the higher end of the spectrum and in the upper atmospheric levels with apparent transfer from upper to lower levels which tend to retain more eddy KE than observed throughout the forecast at least in some part of the spectrum.

While in September, the KE deficit was more pronounced in larger scales (1-3), October showed an equally strong deficit in wave numbers 4-6 and November showed a more pronounced deficit in medium scales (4-6). It is interesting to note that the observed spectra themselves had more energy in large scales (1-3) in September, near equipartition in October and peaked in medium scales (4-6) in November.

A look at the KE spectrum of the mean flow leads us to believe that most of this deficit is due to the "stationary" part of the flow. It should also be noted that the wave number 3 component kept being underestimated by a large percentage for all three months. These observations agree reasonably well with the pattern of mean errors in the 500 mb height field between 80^{o} and 60^{o} N.

We have noted the tendency for the model in the later stages of the 10-day forecast to position the mean jet near 45 ^{O}N and to exaggerate its intensity and confinement. When compared to reality, the problem has become more serious from September to November as the mean circulation intensified and the observed mean jet became broader and shifted its maximum towards the south. Accordingly the zonal component in both the 1000 mb and 500 mb error pattern was observed to amplify from September to November.

We would like to emphasize the tendency for the model to produce an excessive mean circulation near the surface as demonstrated by 1000 mb KE spectra and, mean height maps. It is believed that insufficient effective drag is responsible for this problem.

Lack of "stationary" KE energy at the lower end of the spectrum, in particular wave number 3, combined with the observed eastward drifting of "stationary" 500 mb troughs, particularly obvious over North America in November and insufficient ridging over the Rockies all point to insufficient "stationary" forcing. A contribution to this error is believed to be due to "incorrect topography".

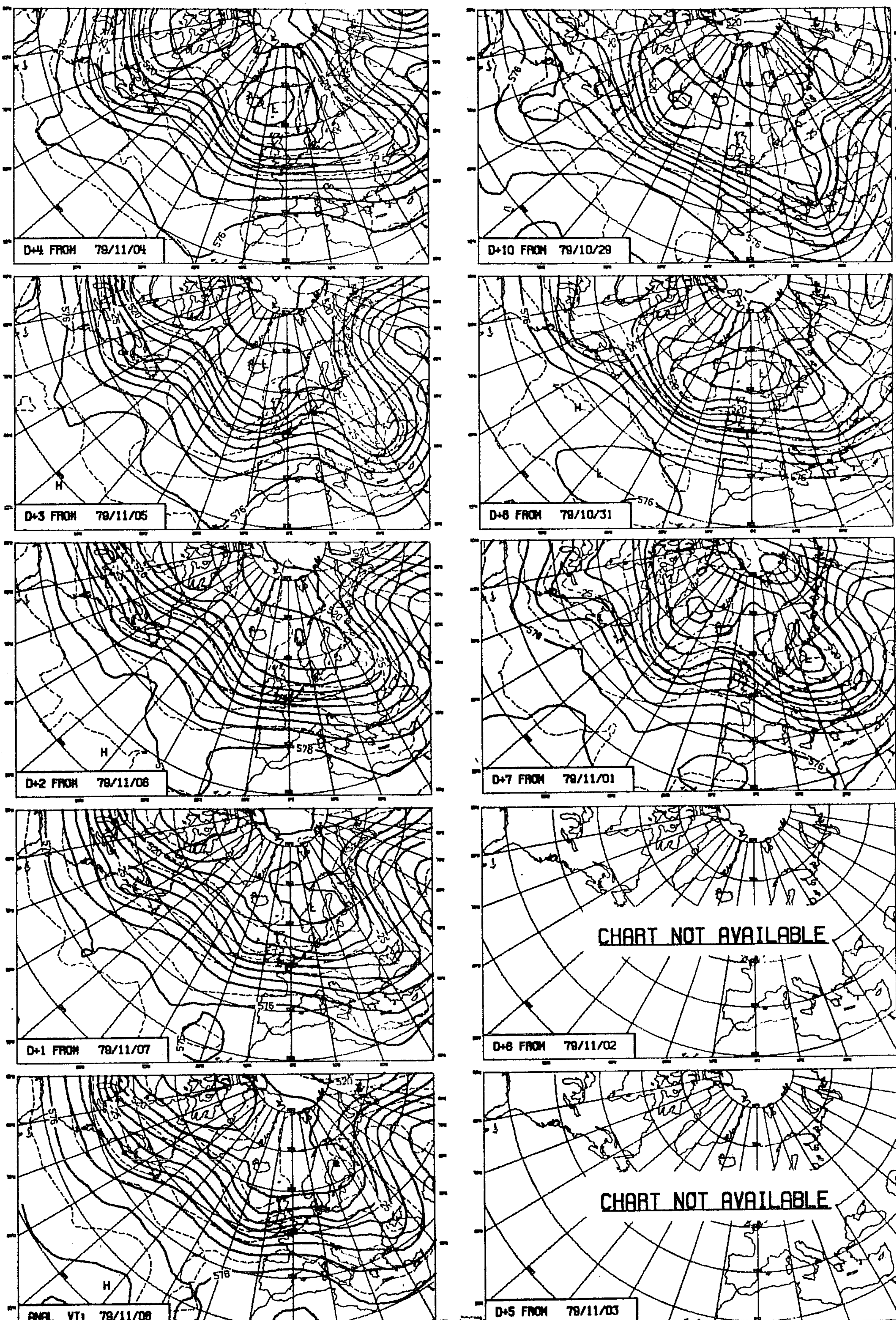


Fig. 1 ECMWF 500 MB ANALYSIS FOR 12Z 79/11/08 AND FORECAST FIELDS VERIFYING AT THAT TIME

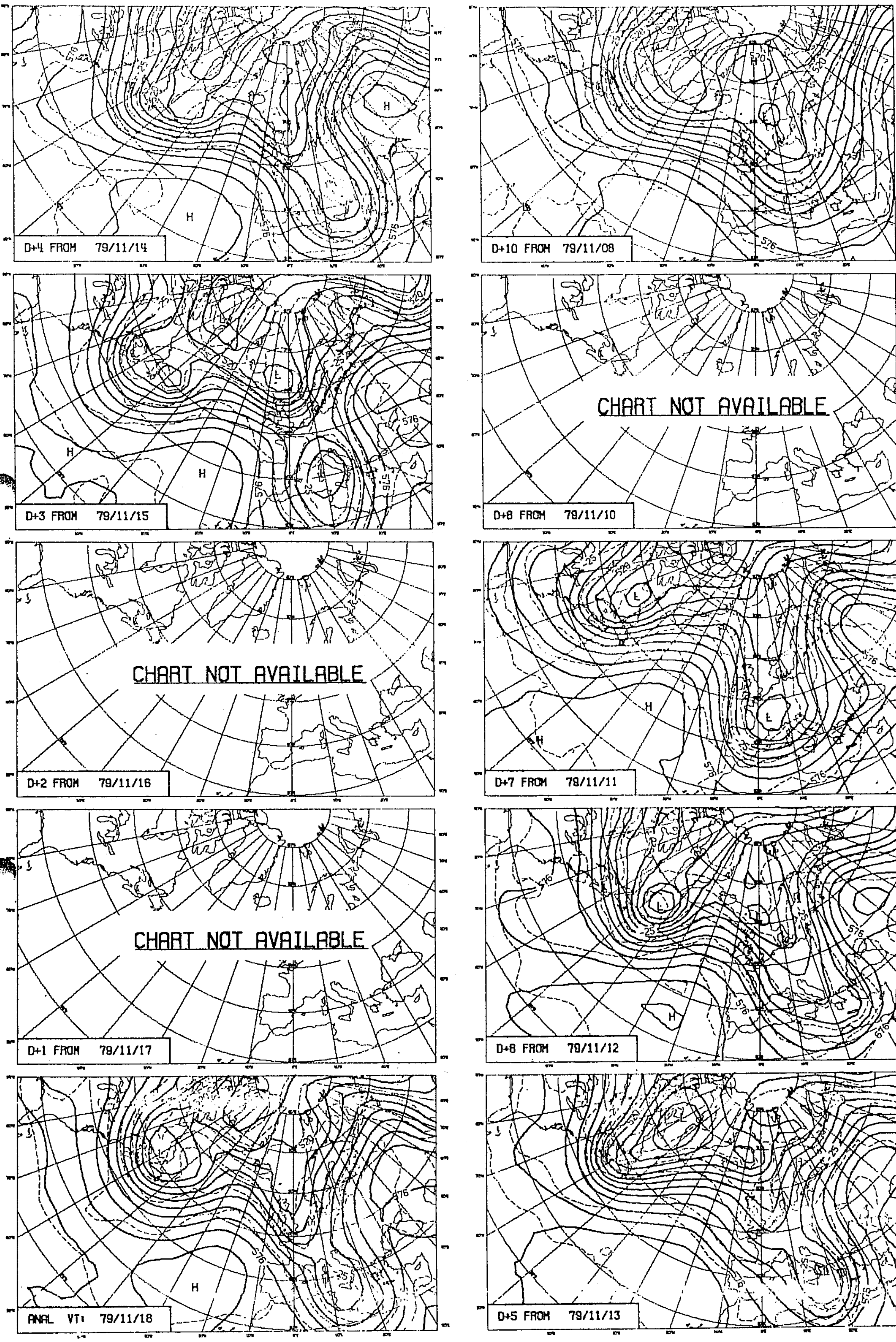


Fig. 2 ECMWF 500 MB ANALYSIS FOR 12Z 18/11/79 AND FORECAST FIELDS VERIFYING AT THAT TIME
CONTOUR INTERVAL 8DAM(THICK LINES), 5K(DASHED LINES)

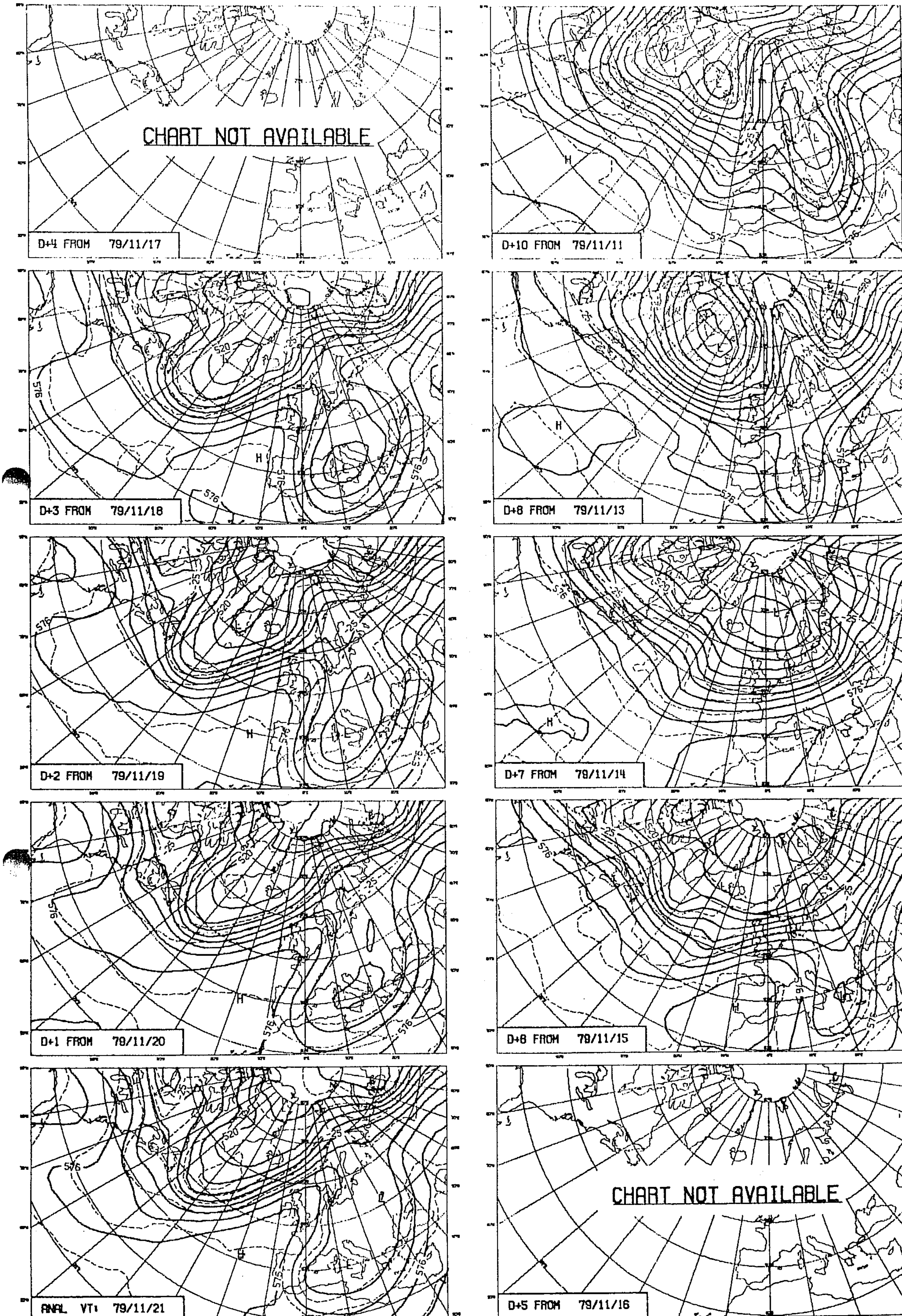


Fig. 3 ECMWF 500 MB ANALYSIS FOR 12Z 21/11/79 AND FORECAST FIELDS VERIFYING AT THAT TIME
CONTOUR INTERVAL 8DAM(THICK LINES), 5K(DASHED LINES)

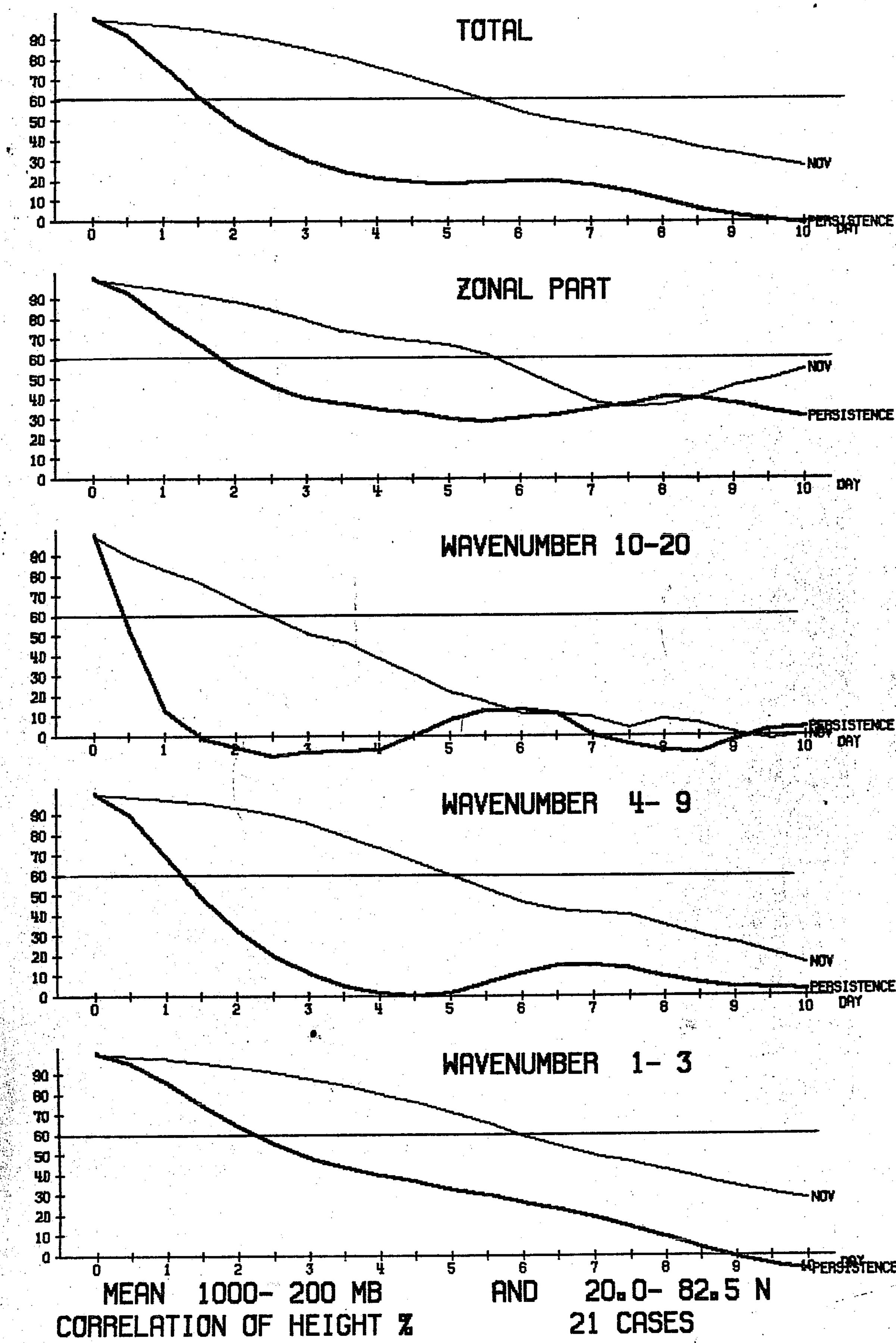

TOTAL
ZONAL PART
WAVENUMBER 10-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
NOV
PERSISTENCE
DAY
0 10 20 30 40 50 60 70 80 90
0 1 2 3 4 5 6 7 8 9 10
MEAN 1000- 200 MB AND 20.0- 82.5 N
CORRELATION OF HEIGHT % 21 CASES

Fig. 4

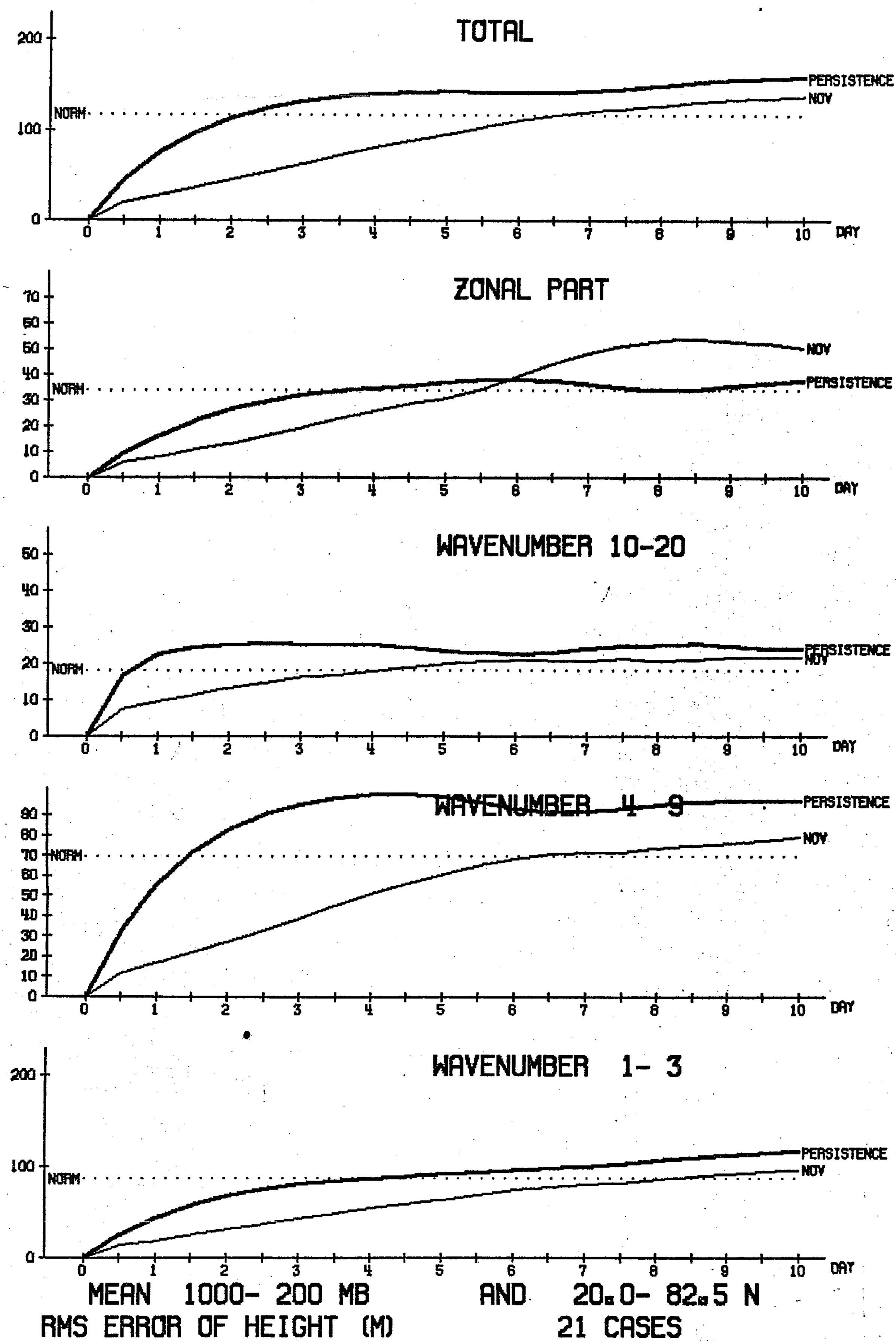
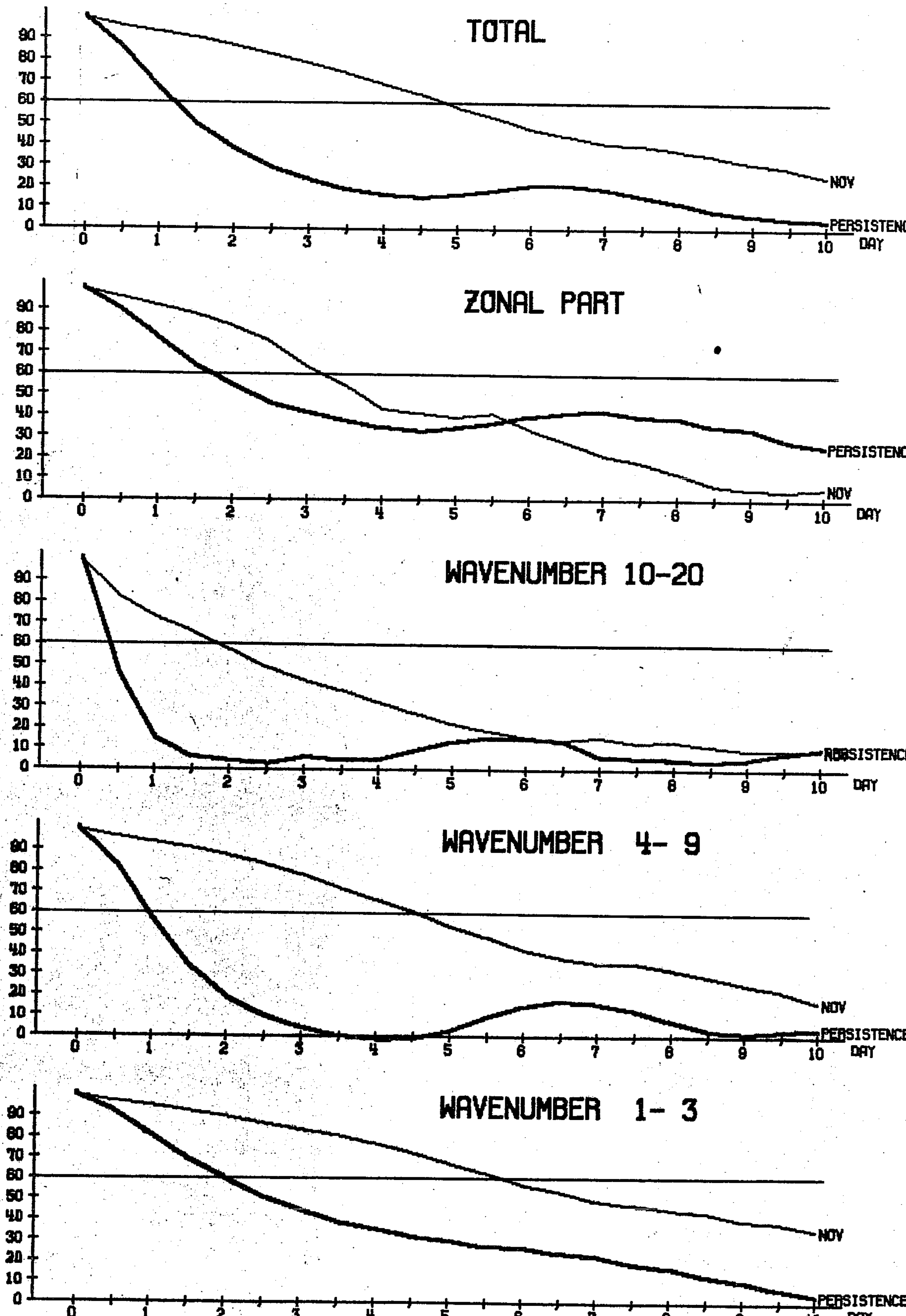

TOTAL
PERSISTENCE
NOV
NORM
DAY
ZONAL PART
WAVENUMBER 10-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MEAN 1000- 200 MB AND 20.0- 82.5 N
RMS ERROR OF HEIGHT (M) 21 CASES

Fig. 5



MEAN 850- 200 MB AND 20.0- 82.5 N
CORRELATION OF TEMPERATURE %, 21 CASES

Fig. 6

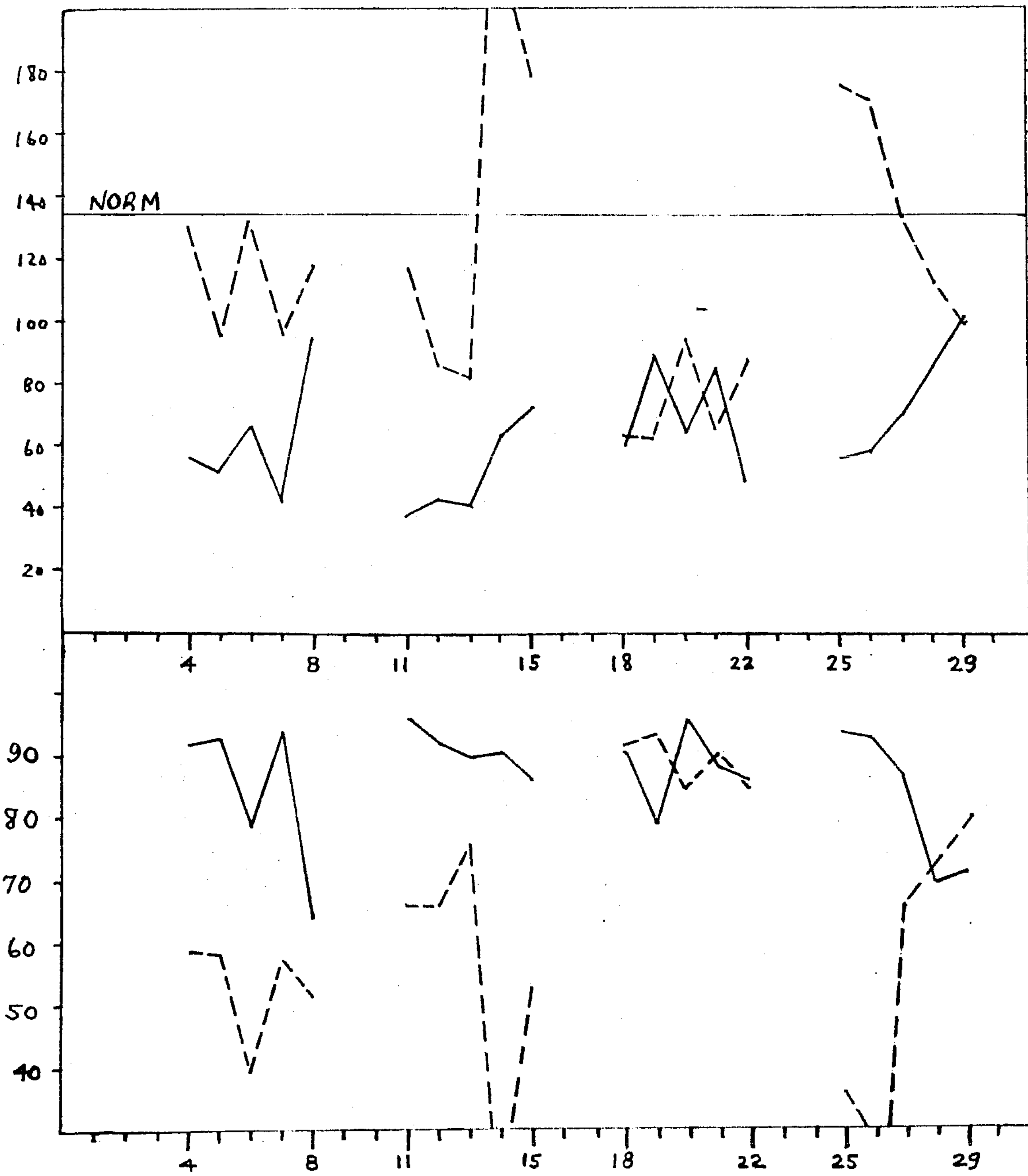


Fig. 7 Daily 500 mb height RMS errors in meters (top) and tendency correlation in % (bottom) for forecast days D+3 (solid lines) and days D+6 (dashed lines) for the month of November 1979 over the European Area.

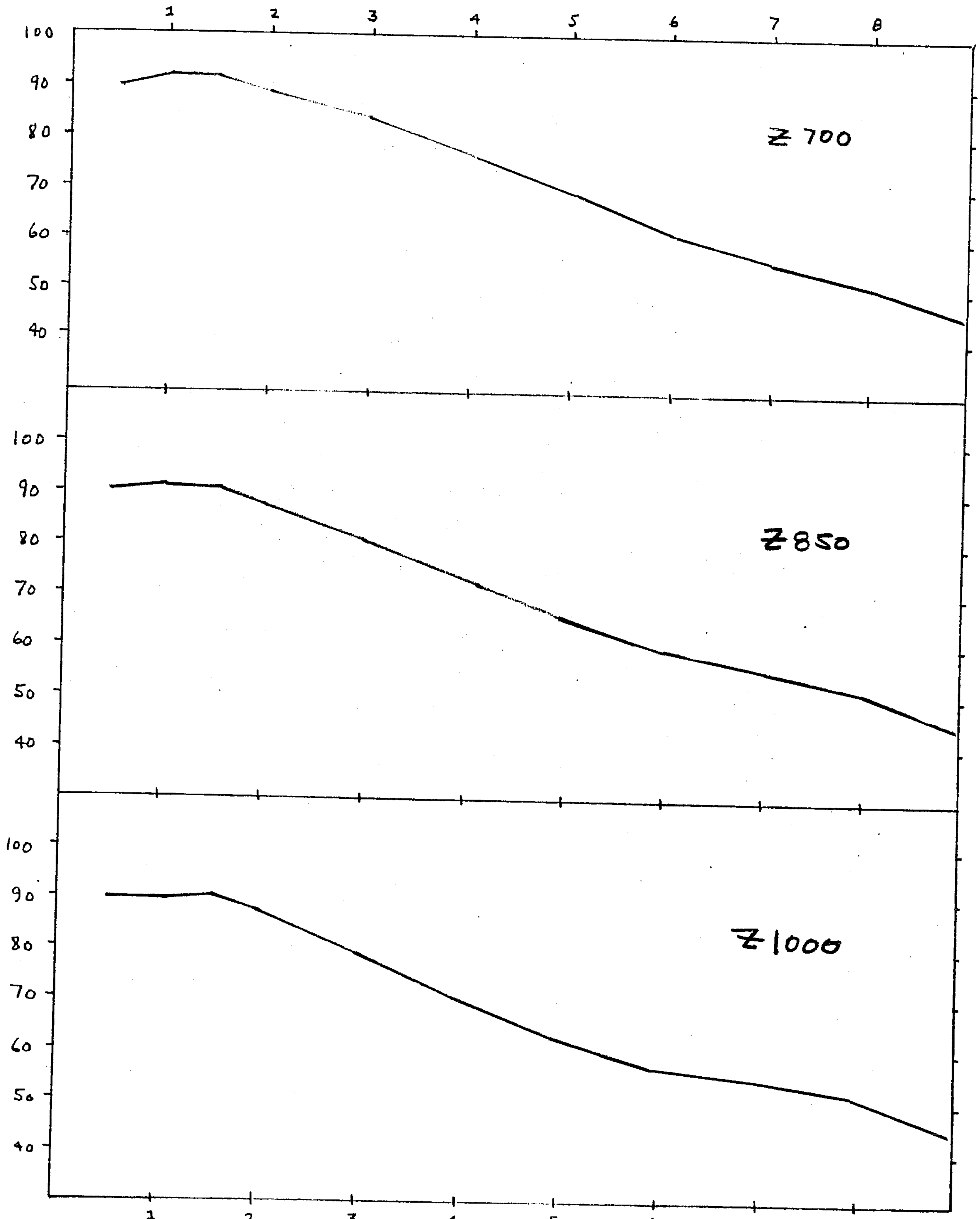


Fig. 8 Average correlation of height changes versus forecast length (in days) at 700, 850 and 1000 mb for the month of November 1979 over the European Area.

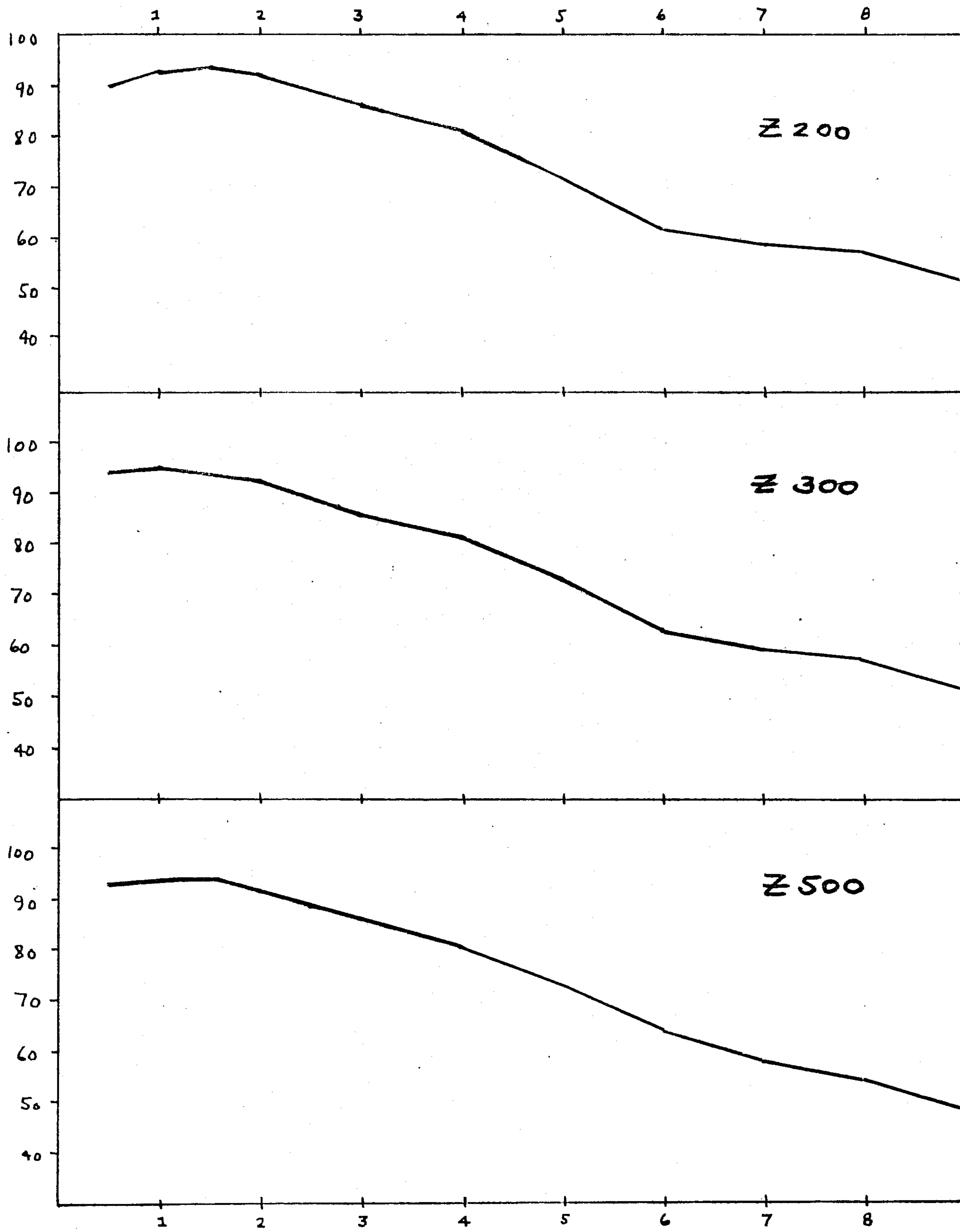


Fig. 9 Same as Fig. 8 at 200, 300 and 500 mb

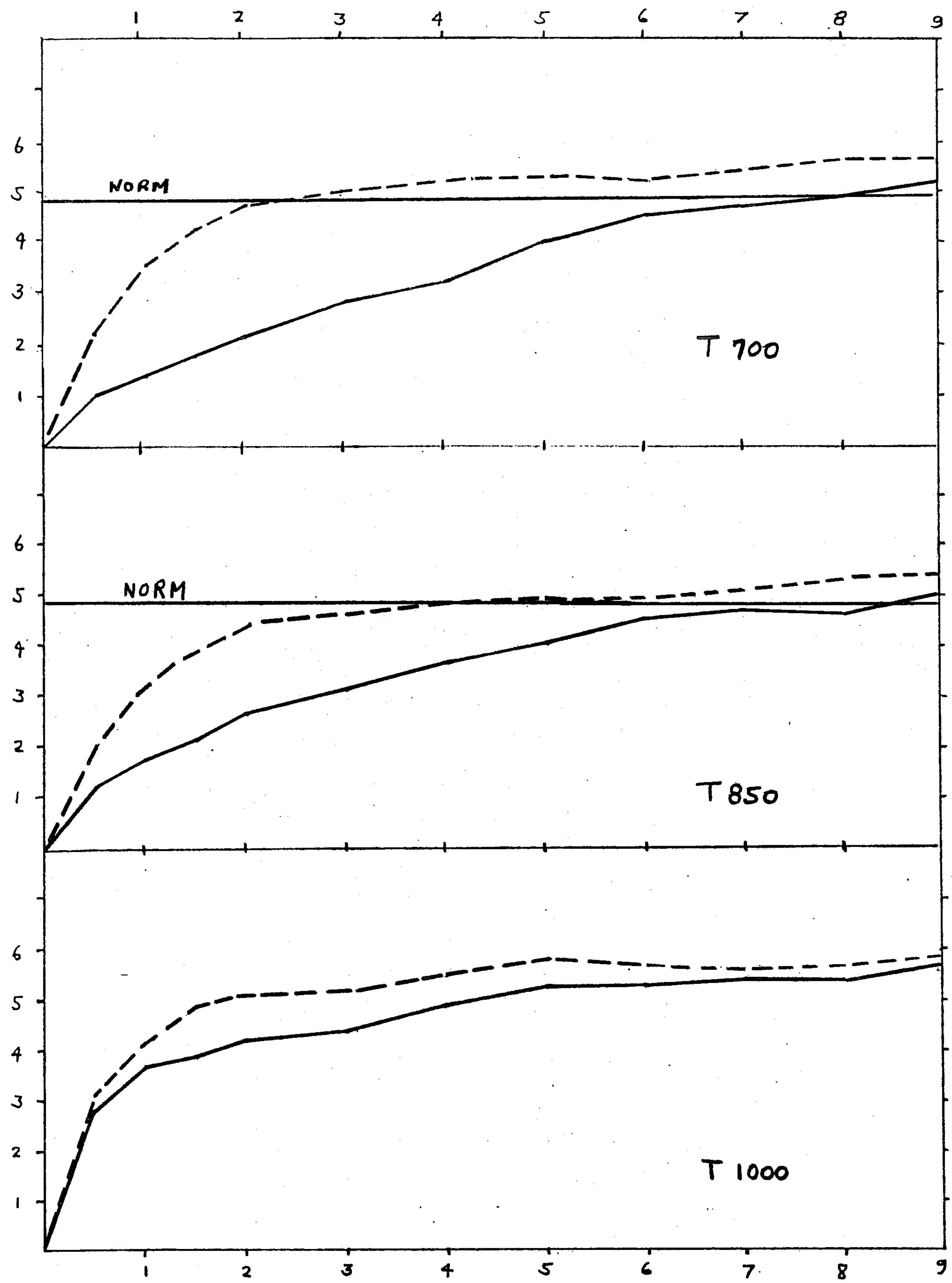


Fig.10 Average RMS errors of temperature (^{o}C) versus forecast length (days) at 700, 850, and 1000 mb for the month of November 1979 over the European Area.

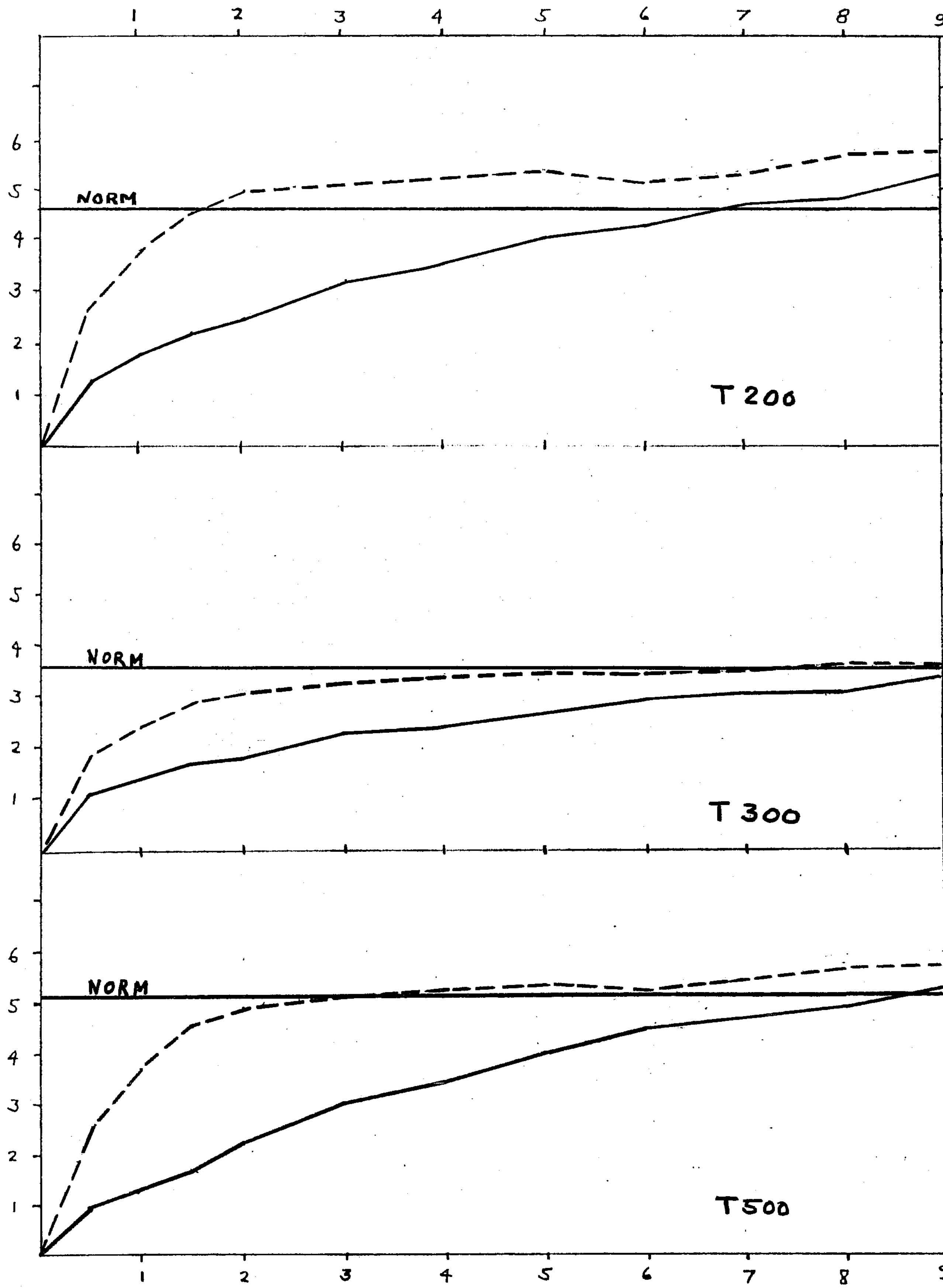


Fig.11 Same as Fig. 10 at 200, 300 and 500 mb

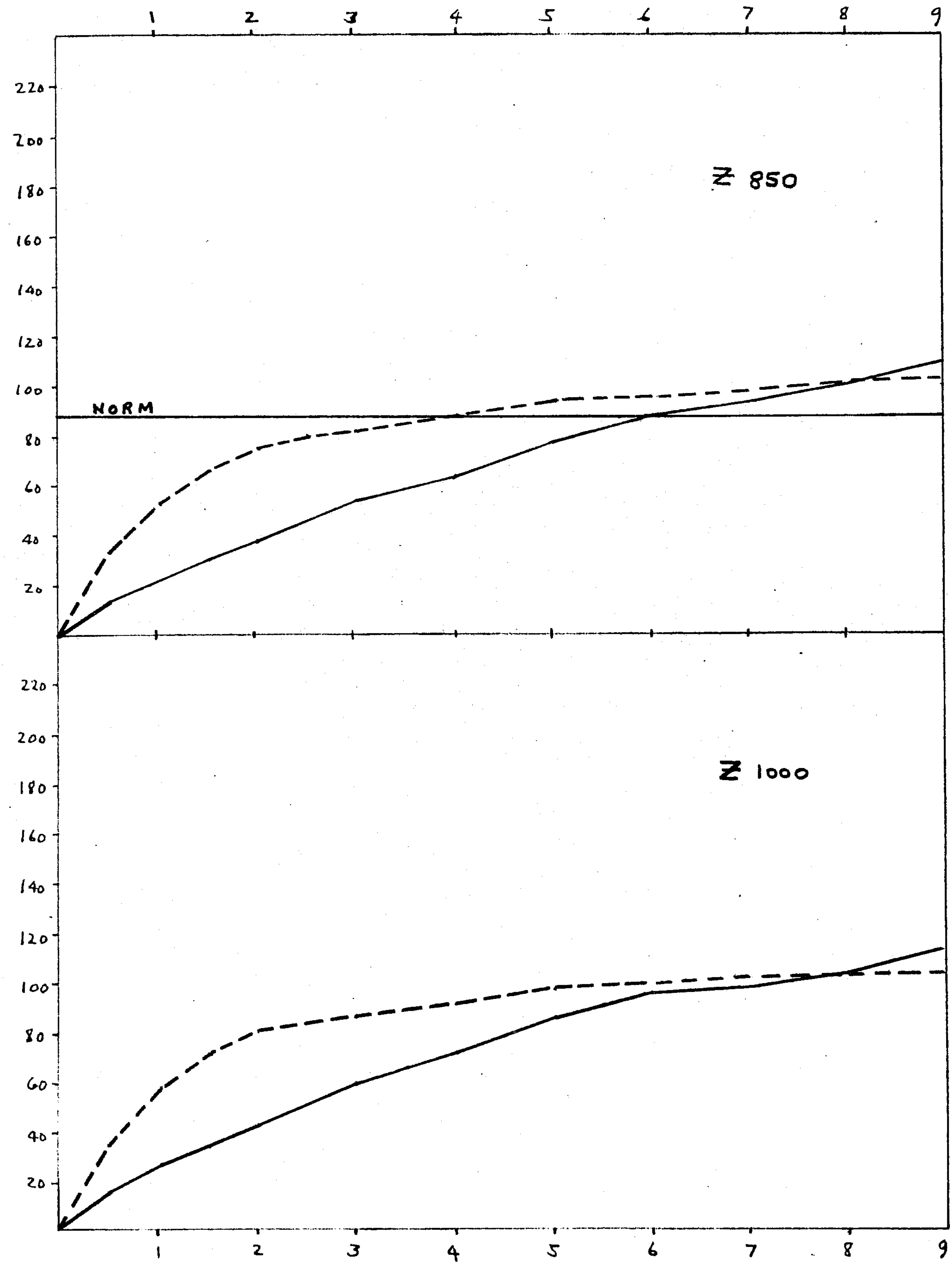


Fig. 12 Average RMS errors of height (m) versus forecast length (days) at 850 and 1000 mb.

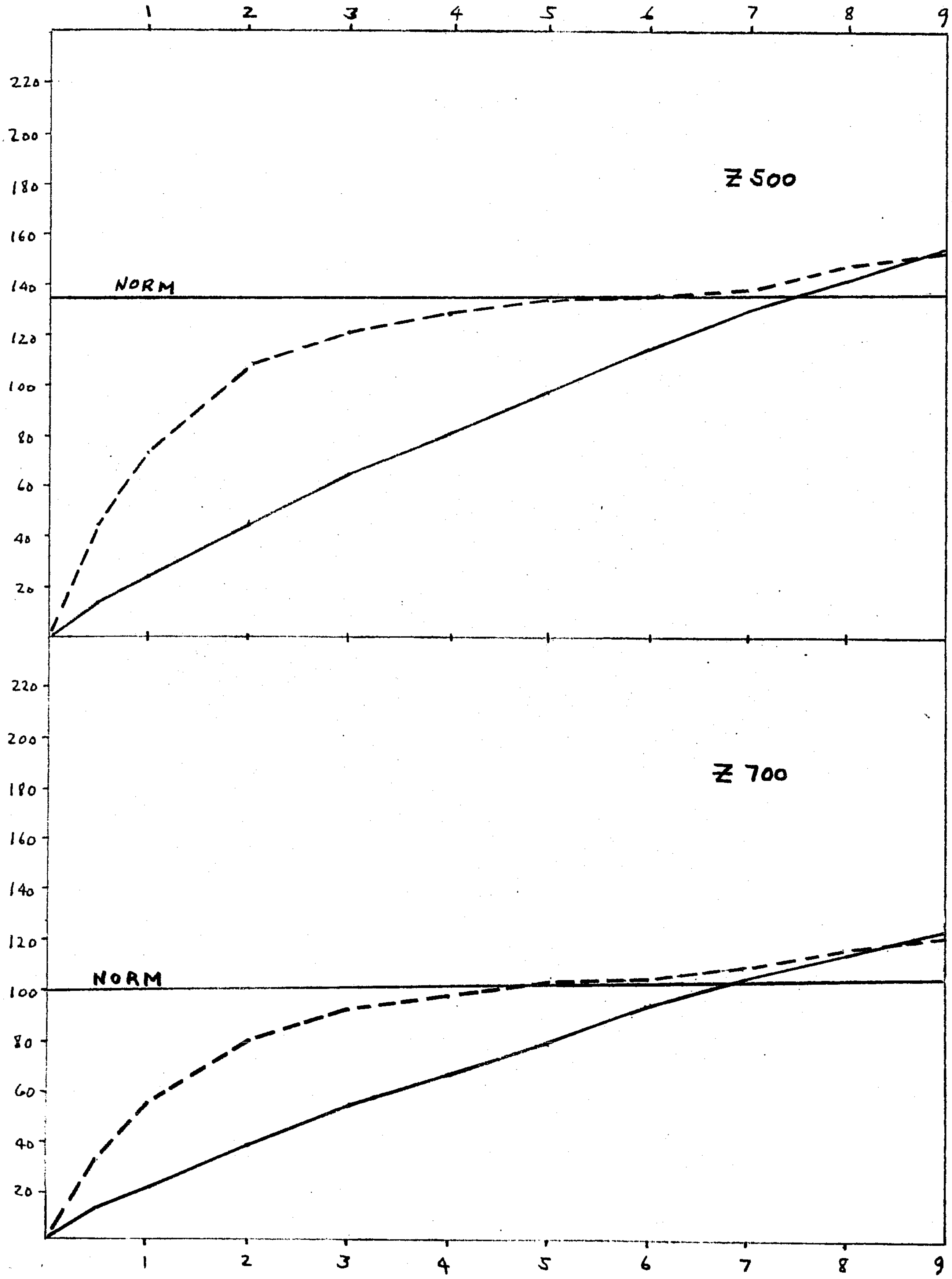


Fig.13 Same as Fig. 12 at 500 and 700 mb

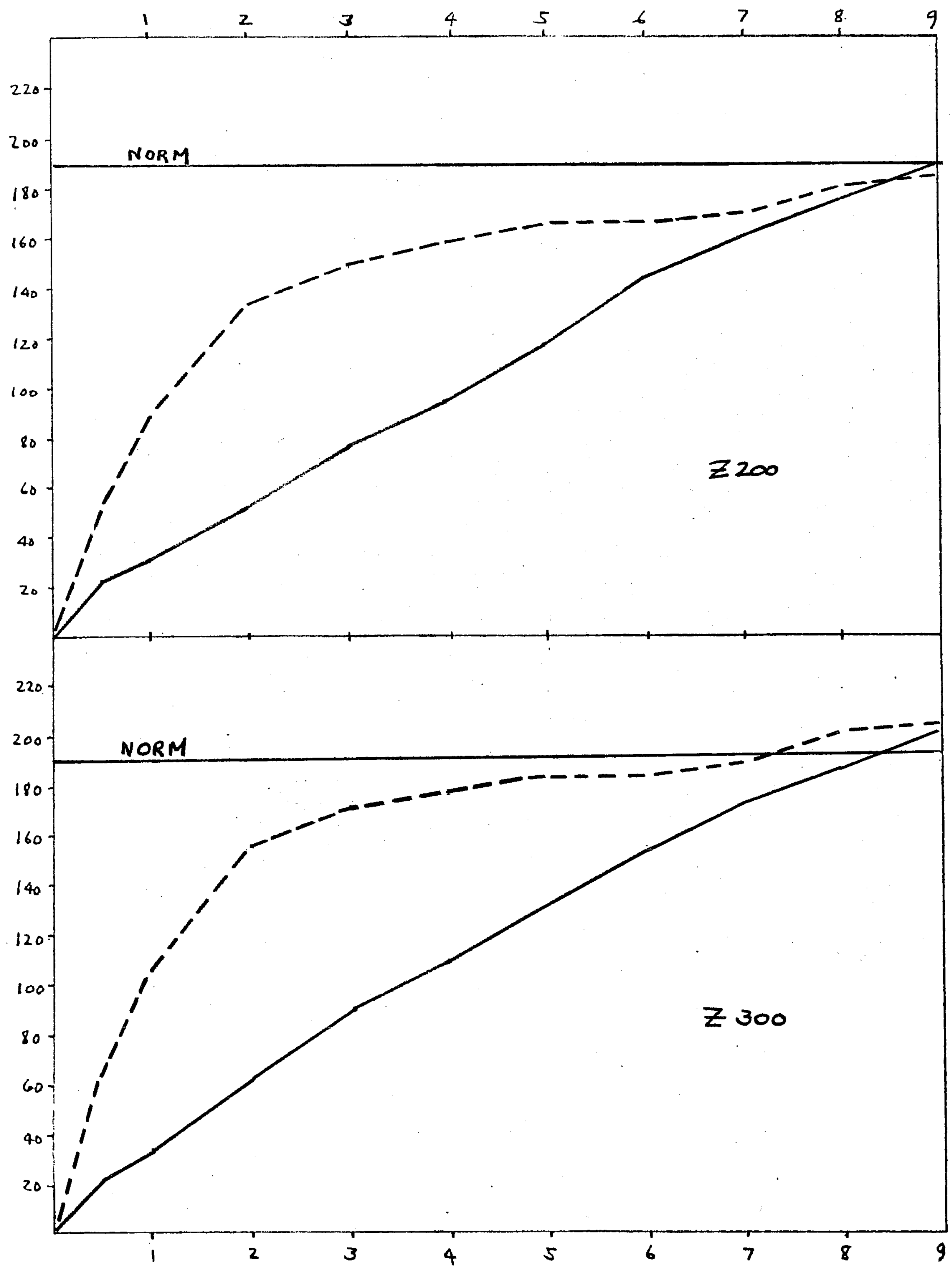


Fig.14 Same as Fig. 12 at 200 and 300 mb

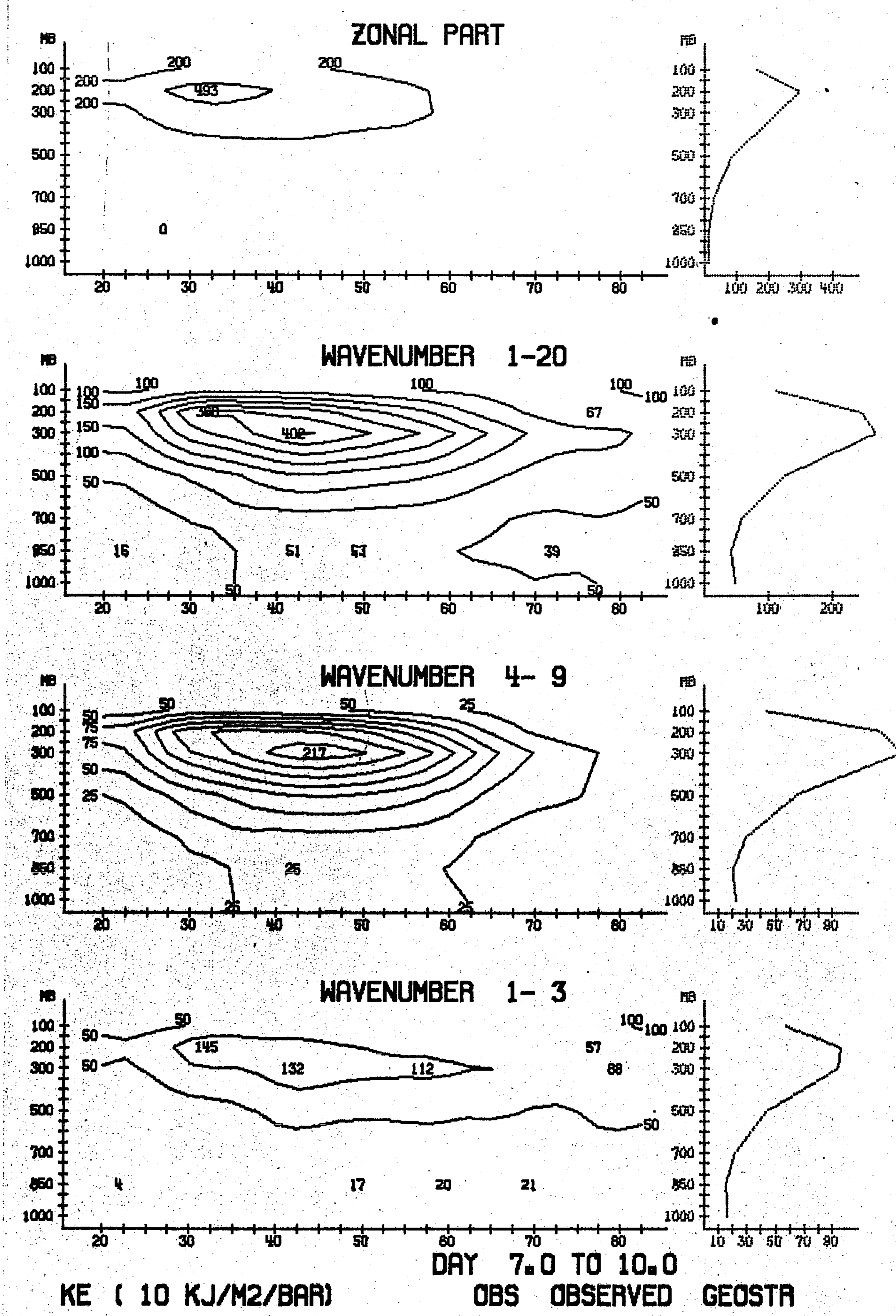

ZONAL PART
WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
DAY 7.0 TO 10.0
KE (10 KJ/M2/BAR)
OBS OBSERVED GEOSTR

Fig. 15

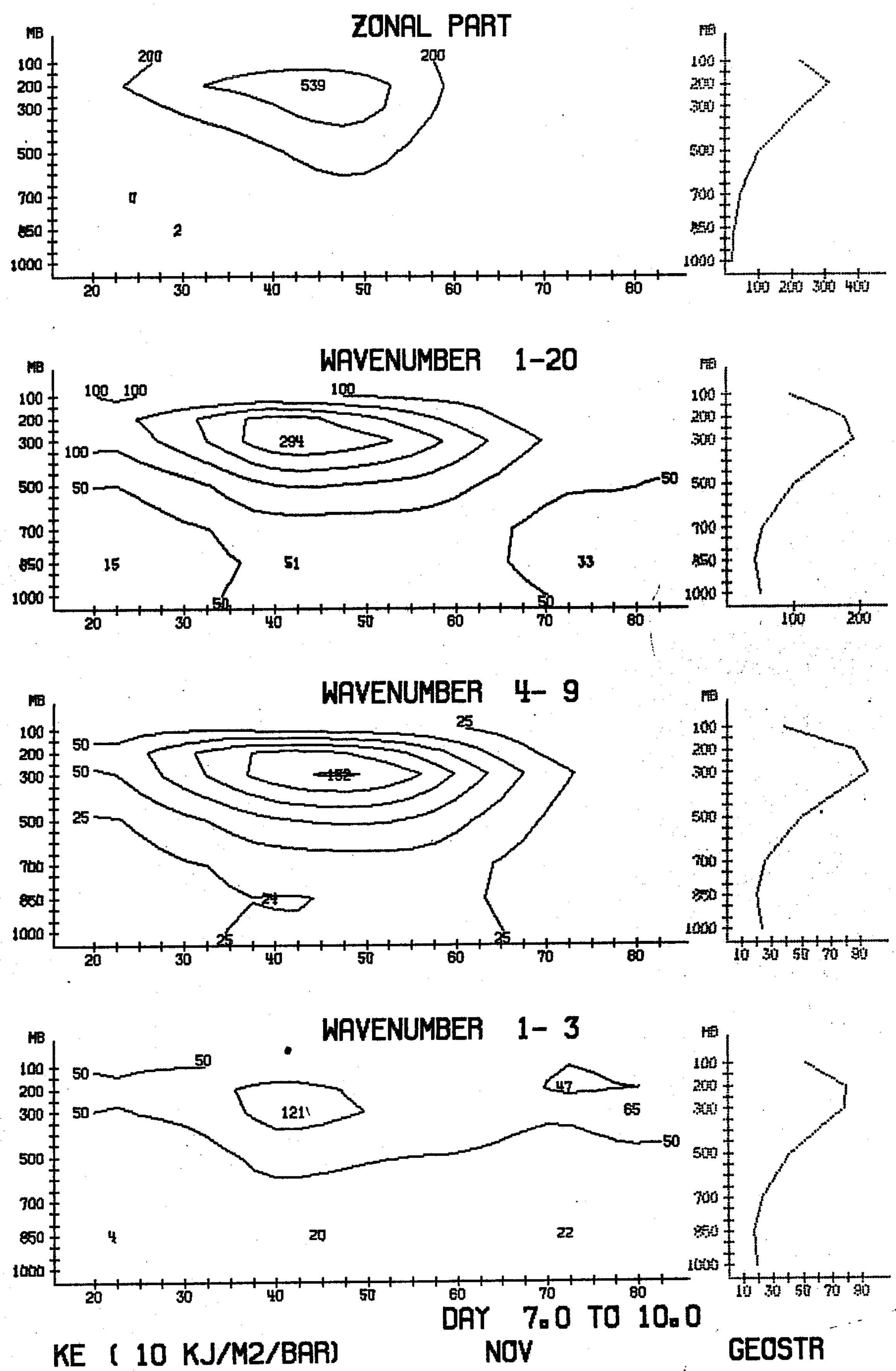

ZONAL PART
WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
DAY 7.0 TO 10.0
KE (10 KJ/M2/BAR)
NOV
GEOSTR

Fig. 16

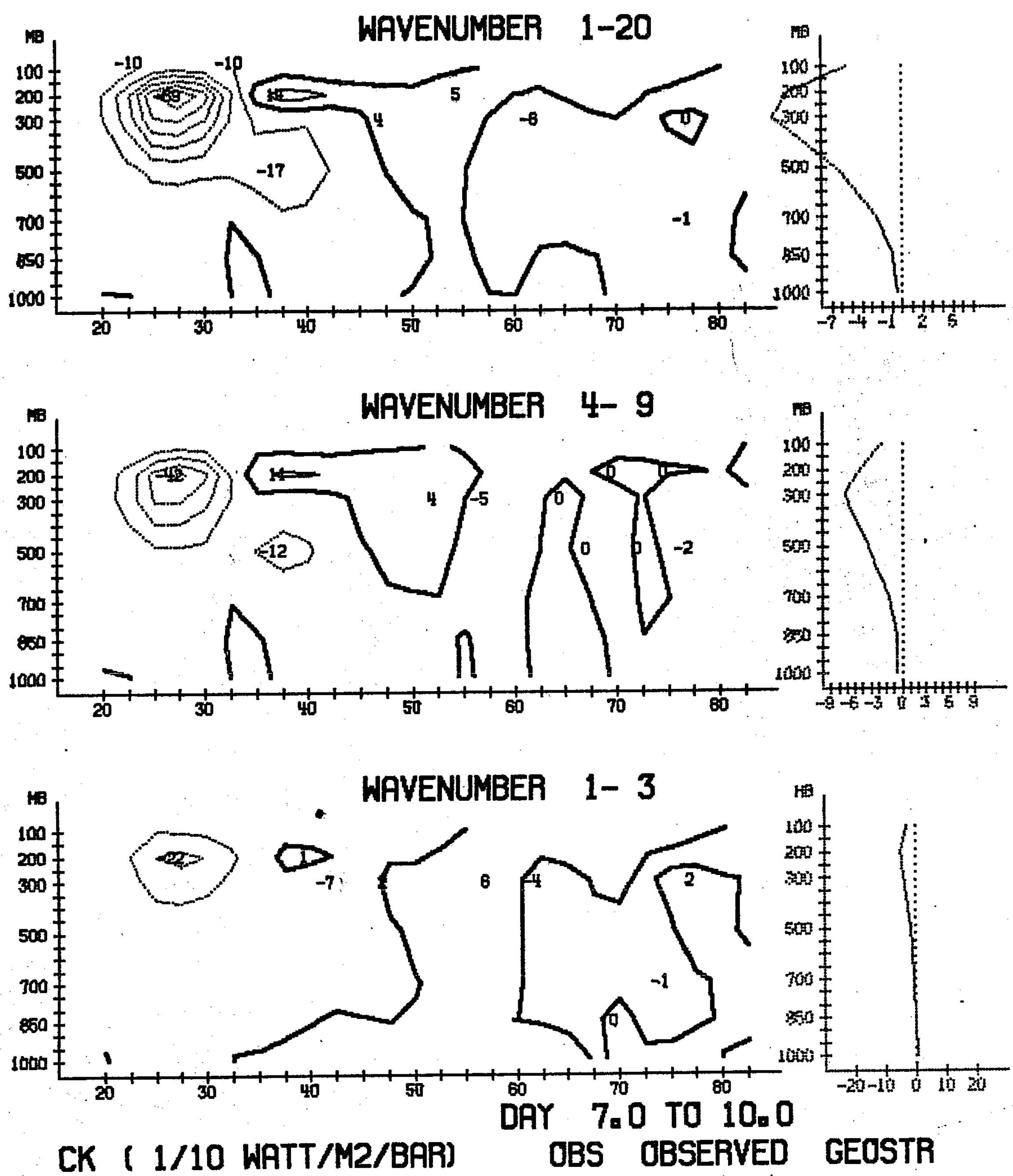

WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
DAY 7.0 TO 10.0
CK (1/10 WATT/M2/BAR) OBS OBSERVED GEOSTR

Fig. 17

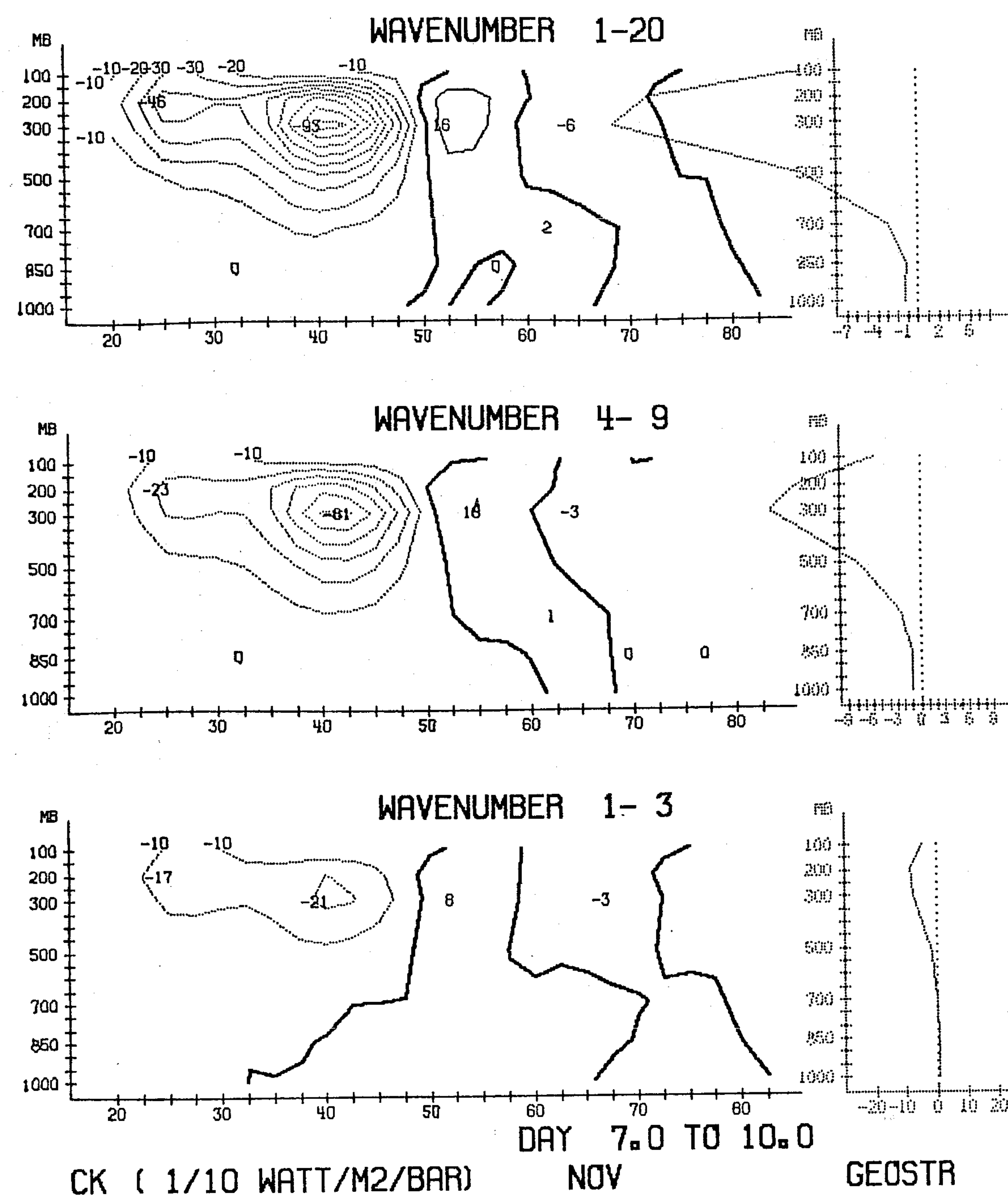

WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
DAY 7.0 TO 10.0
CK (1/10 WATT/M2/BAR)
NOV
GEOSTR

Fig. 18

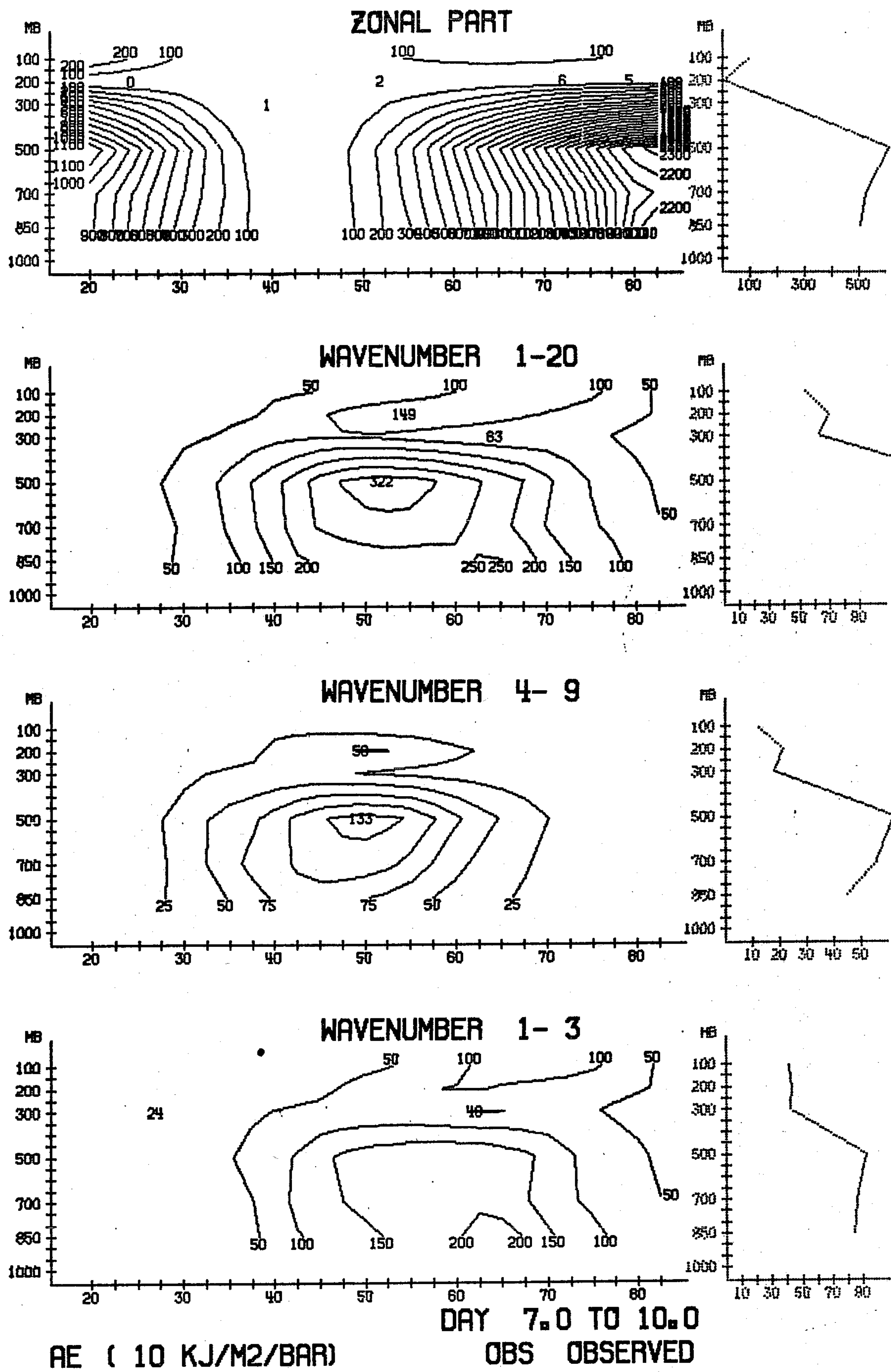

ZONAL PART
WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
DAY 7.0 TO 10.0
AE (10 KJ/M2/BAR)
OBS OBSERVED

Fig. 19

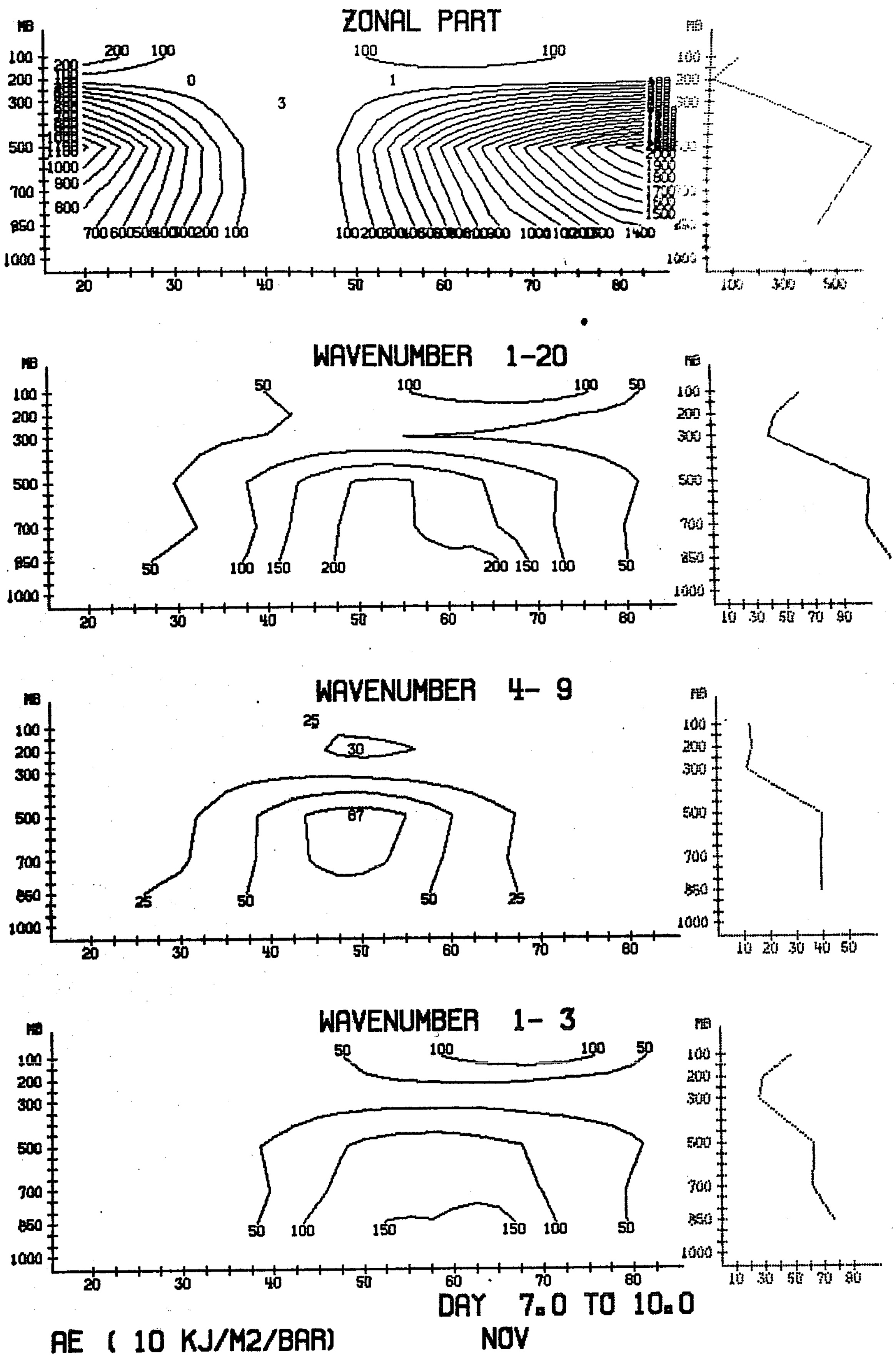
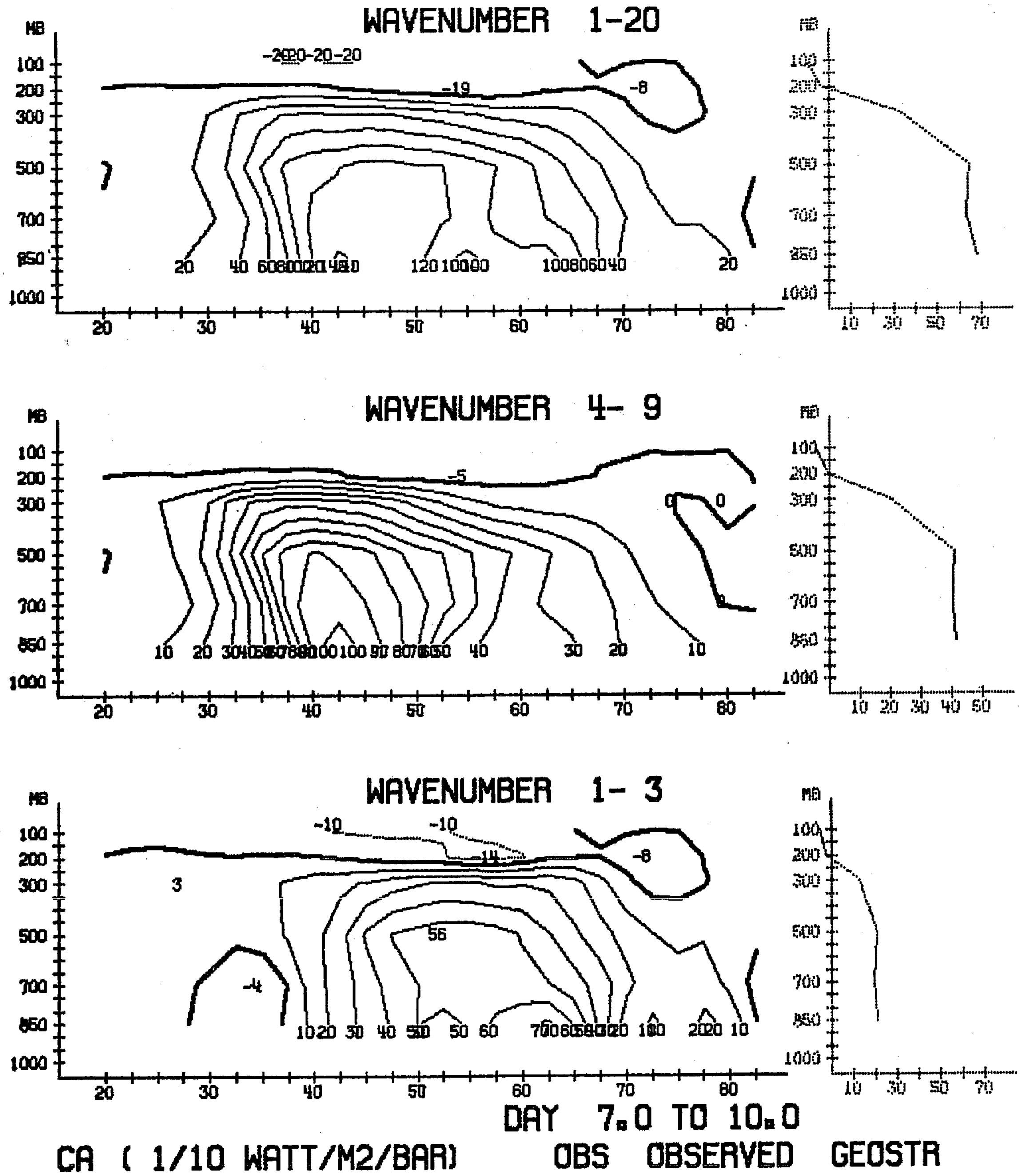

ZONAL PART
WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
DAY 7.0 TO 10.0
AE (10 KJ/M2/BAR)
NOV

Fig. 20



WAVENUMBER 1-20
MB
100
200
300
500
700
850
1000
20
30
40
50
60
70
80
-19
-8
WAVENUMBER 4- 9
-5
0
WAVENUMBER 1- 3
-10
3
56
-4
-8
DAY 7.0 TO 10.0
CA (1/10 WATT/M2/BAR) OBS OBSERVED GEOSTR

Fig. 21

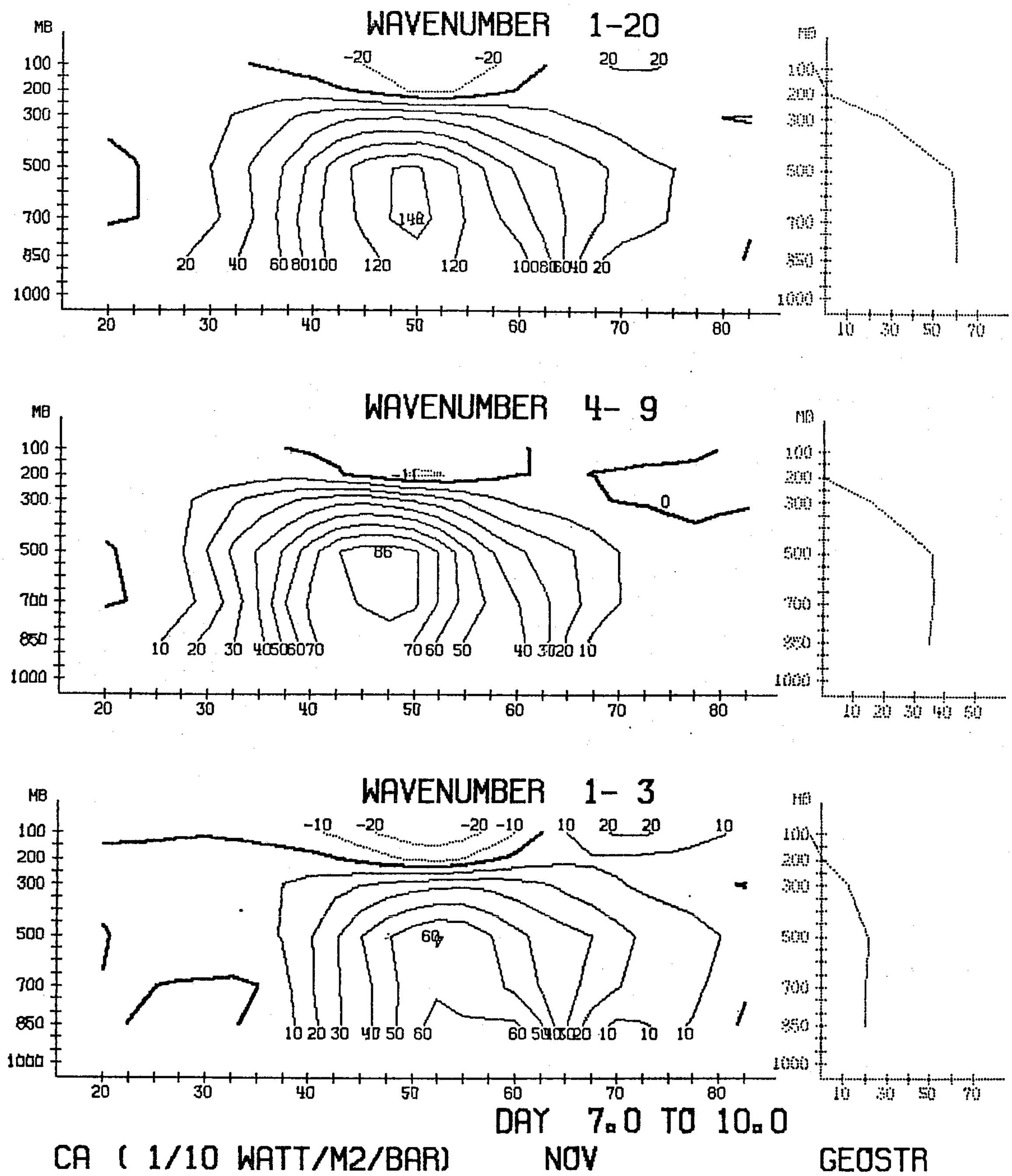

WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
DAY 7.0 TO 10.0
CA (1/10 WATT/M2/BAR)
NOV
GEOSTR

Fig. 22

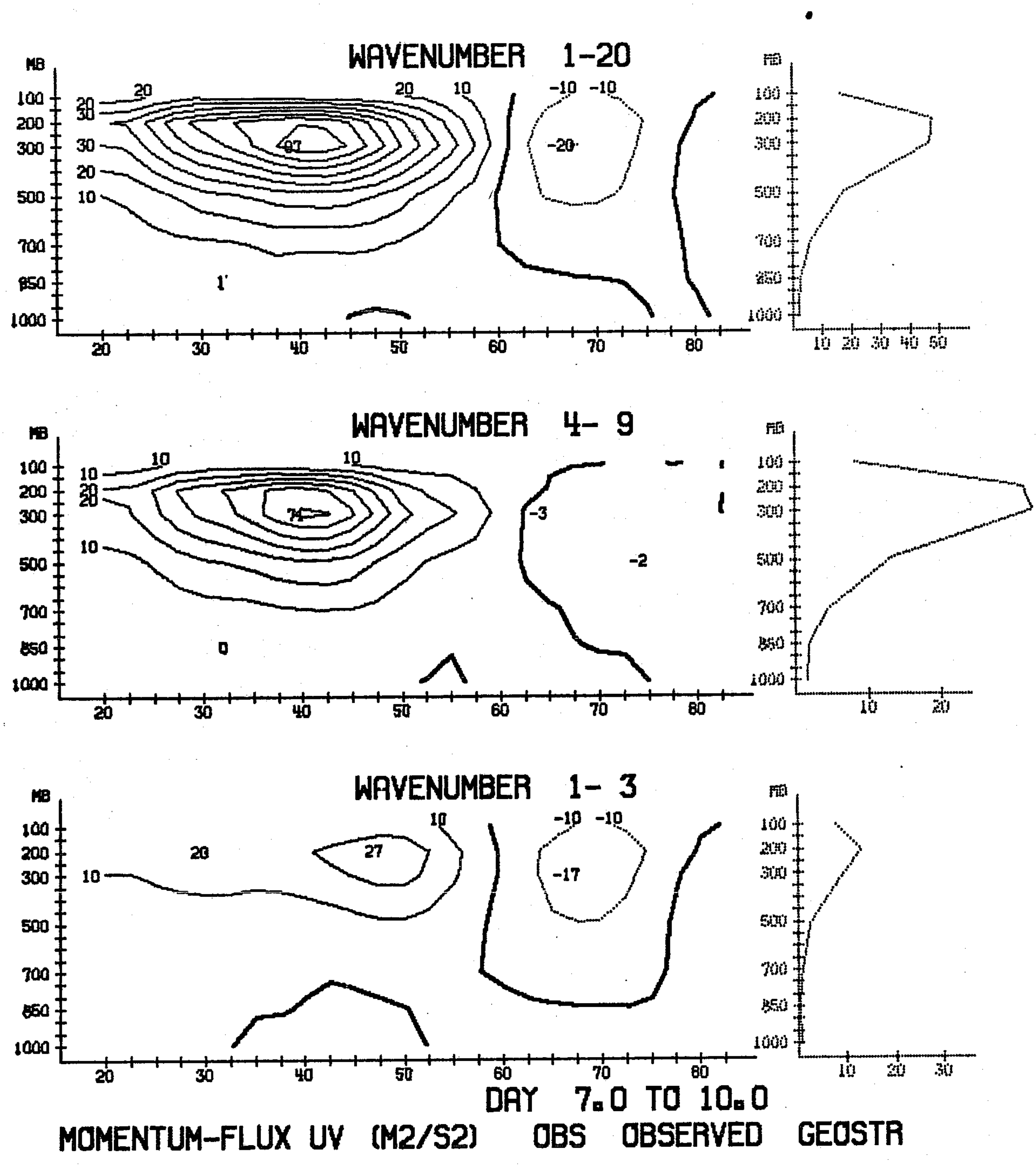

WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
DAY 7.0 TO 10.0
MOMENTUM-FLUX UV (M2/S2) OBS OBSERVED GEOSTR

Fig. 23

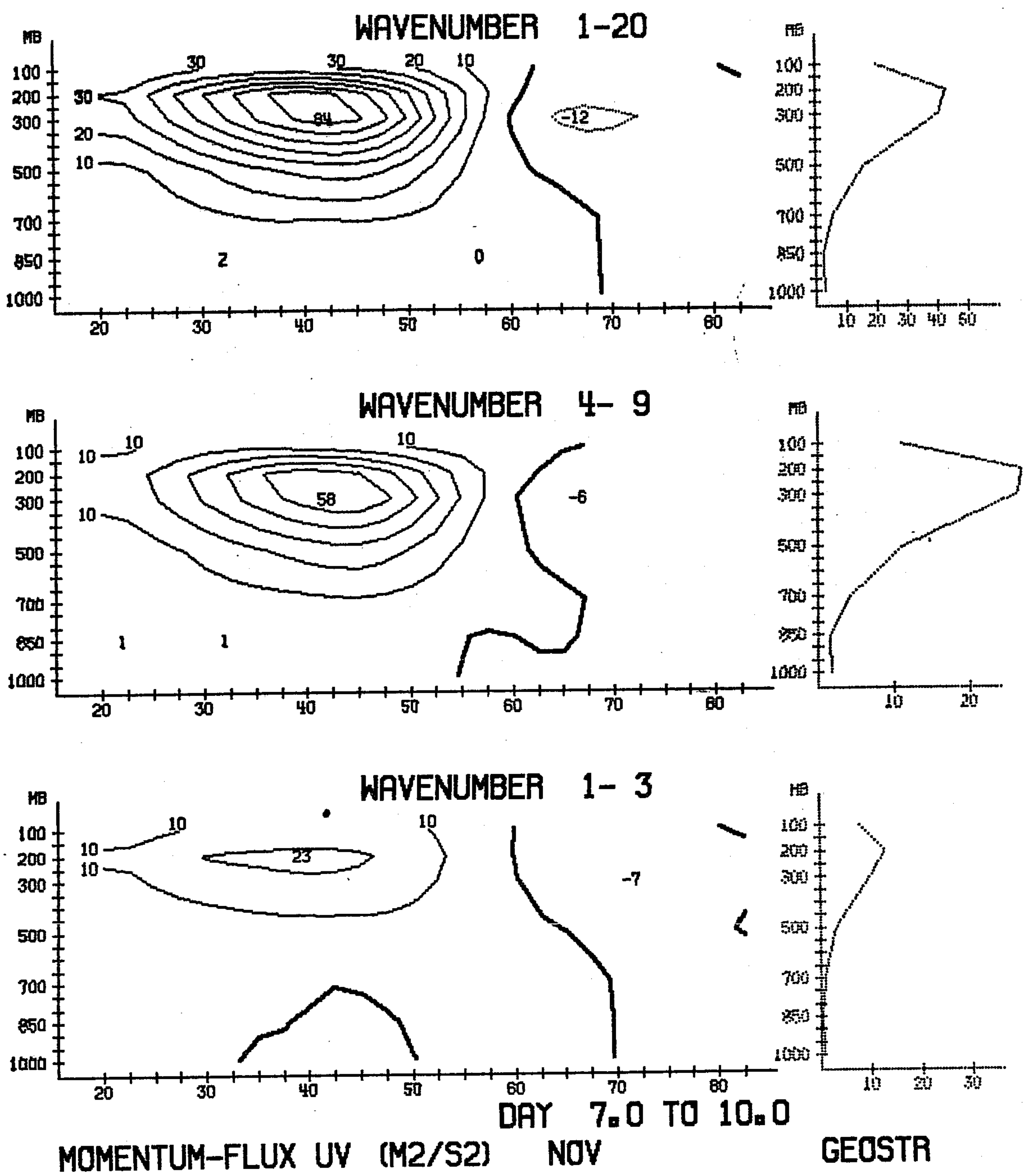
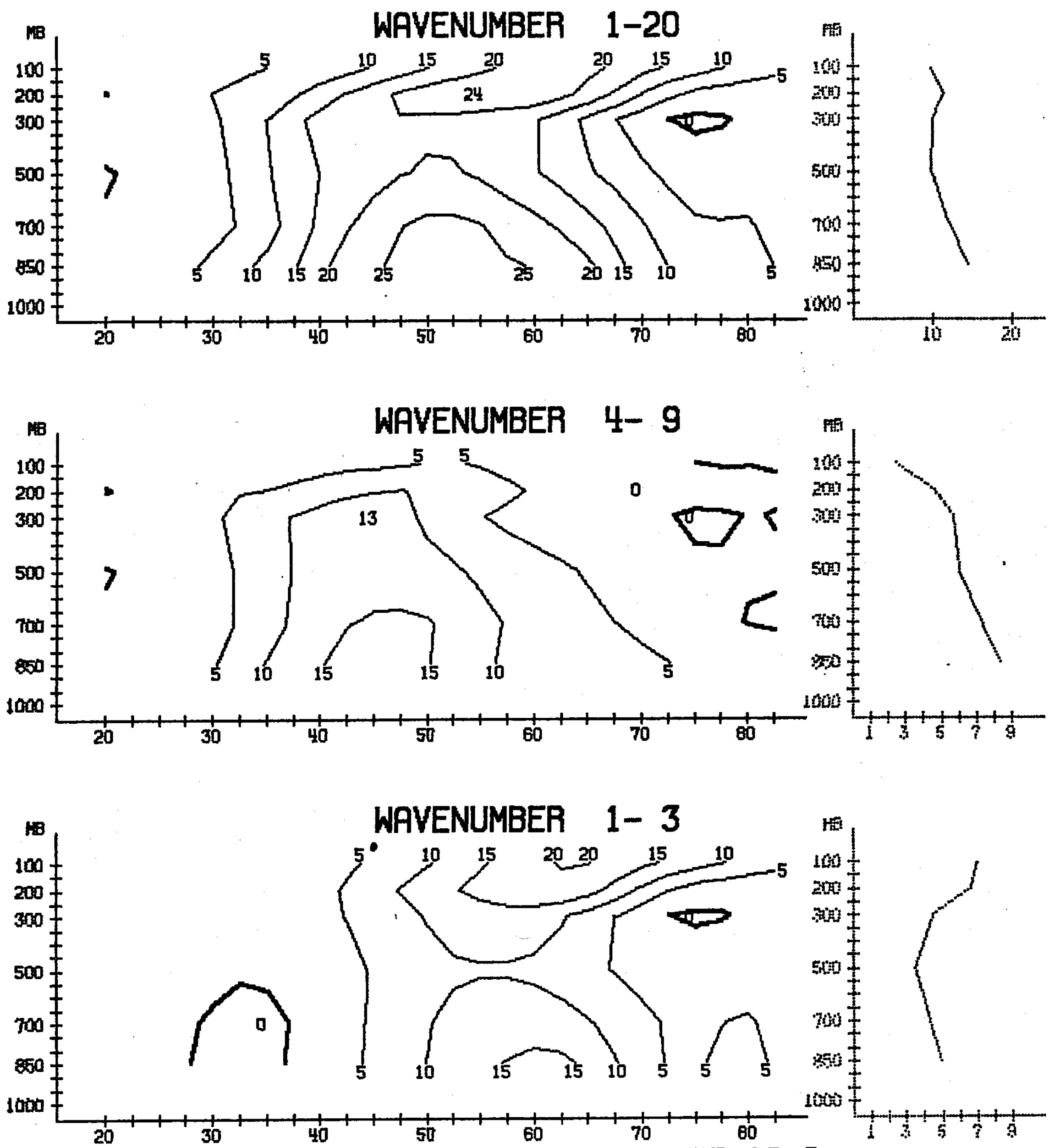

WAVENUMBER 1-20
MB
100
200
300
500
700
850
1000
30
20
10
84
-12
2
0
20
30
40
50
60
70
80
10 20 30 40 50
WAVENUMBER 4- 9
58
-6
1
WAVENUMBER 1- 3
23
-7
DAY 7.0 TO 10.0
MOMENTUM-FLUX UV (M2/S2) NOV
GEOSTR

Fig. 24



DAY 7.0 TO 10.0

SENSIBLE HEAT-FLUX TV (K*M/S)BS OBSERVED GEOSTR

Fig. 25

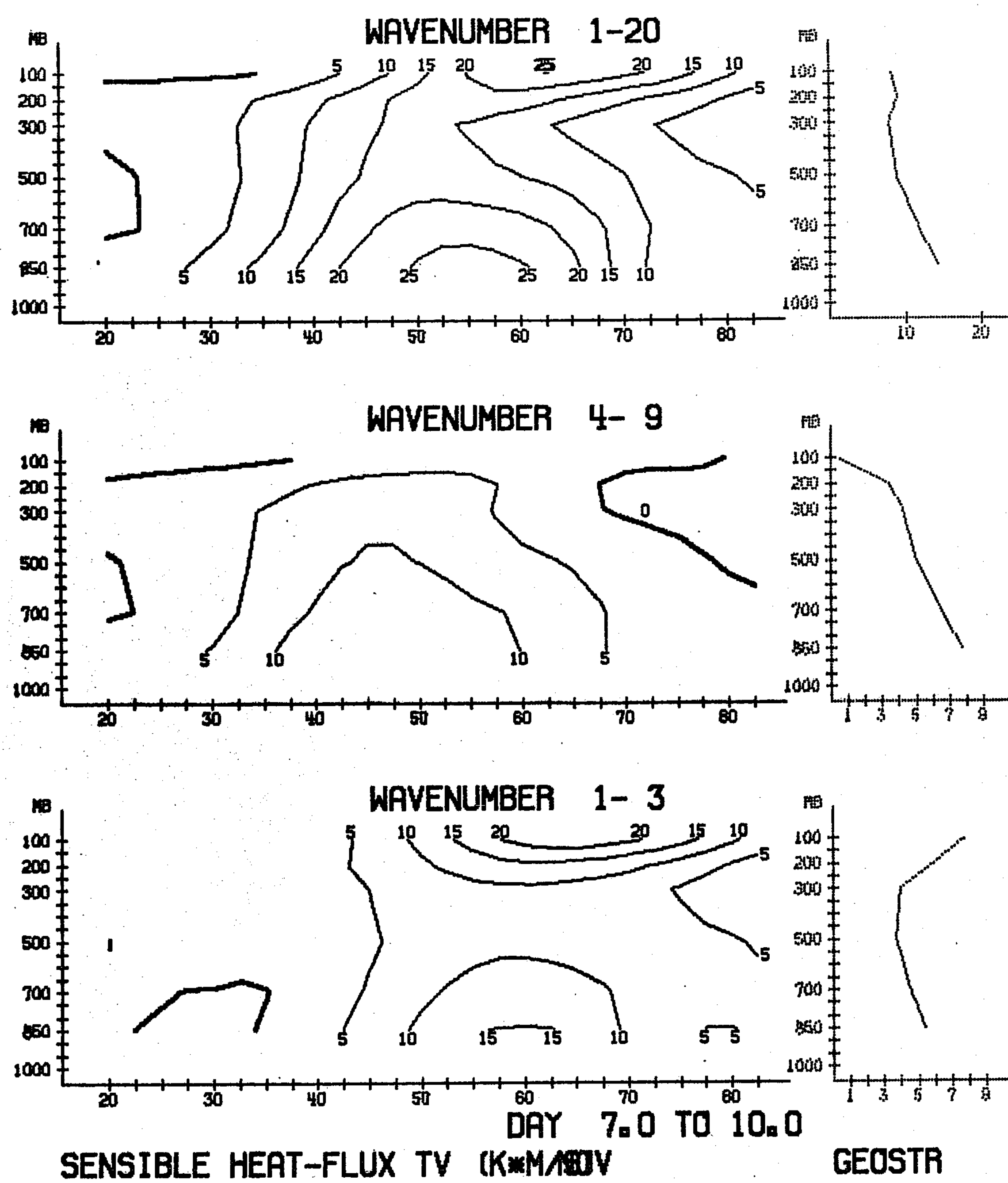
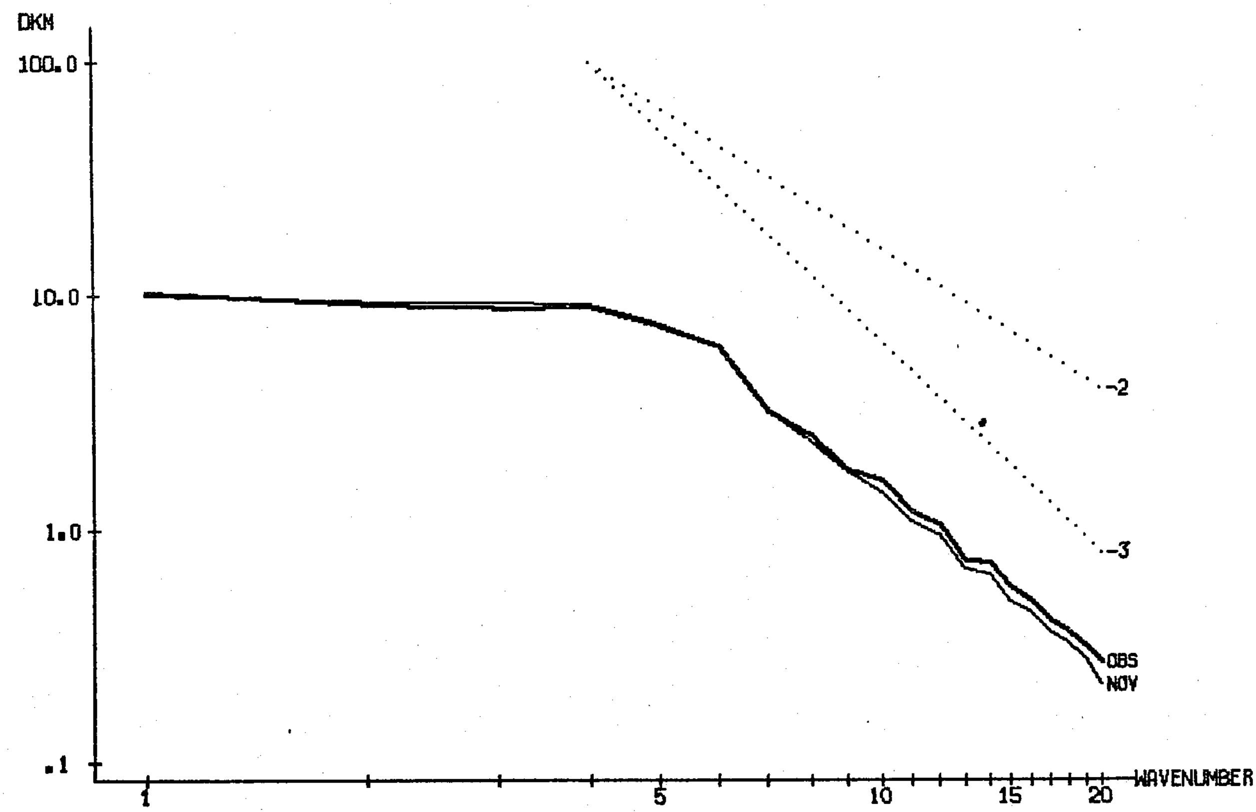
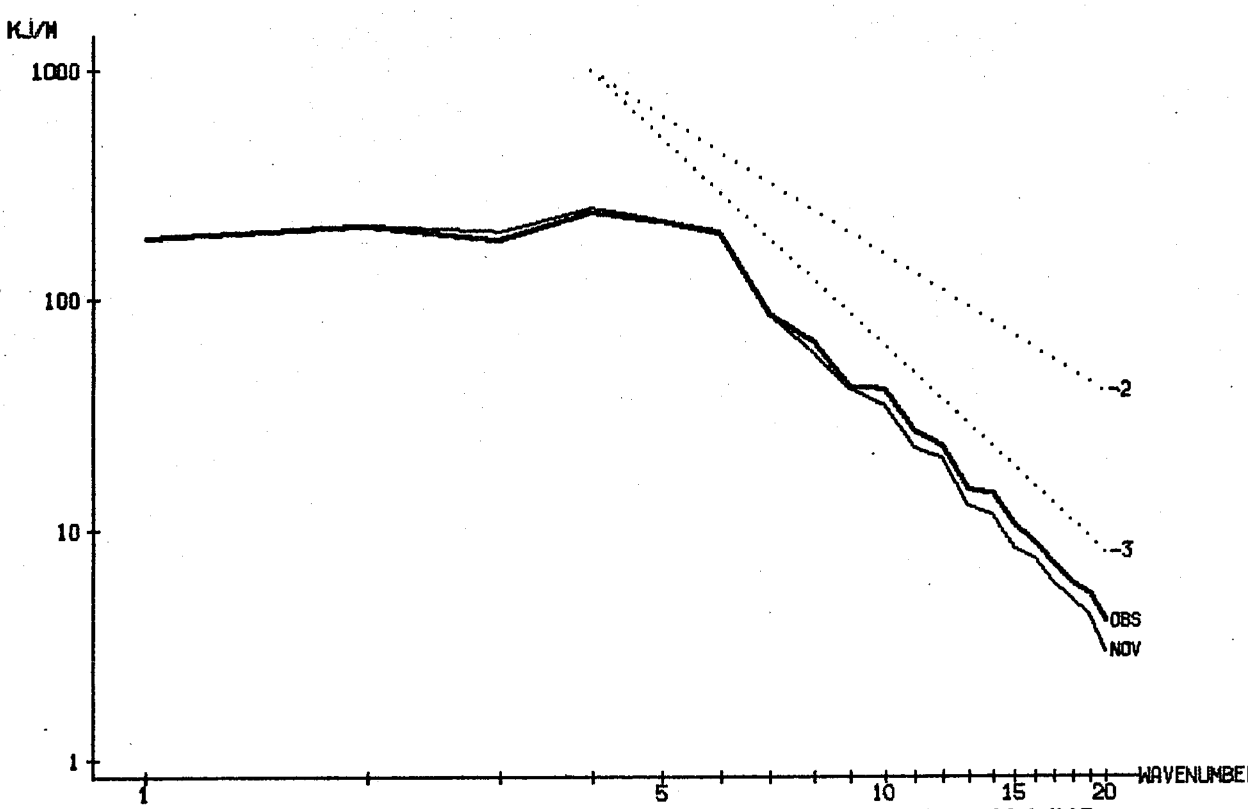

WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
DAY 7.0 TO 10.0
GEOSTR

Fig. 26



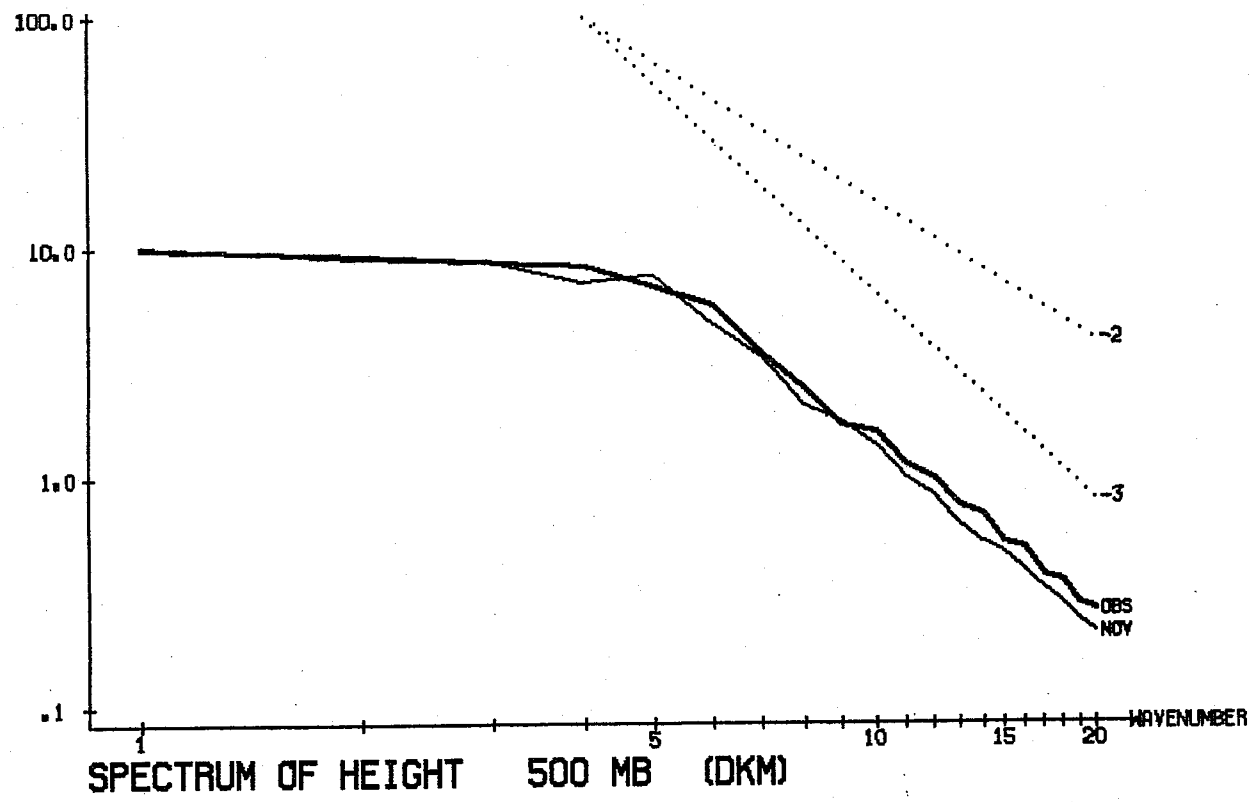
SPECTRUM OF HEIGHT 500 MB (DKM)



SPECTRUM OF KINETIC ENERGY TROPOSPHERE KJ/M2

DAY 0.0 TO 3.0 MEAN BETWEEN 40.0 AND 60.0 GEOSTR

Fig. 27


100.0
10.0
1.0
.1
-2
-3
OBS
NOV
WAVENUMBER
1
5
10
15
20
SPECTRUM OF HEIGHT 500 MB (DKM)

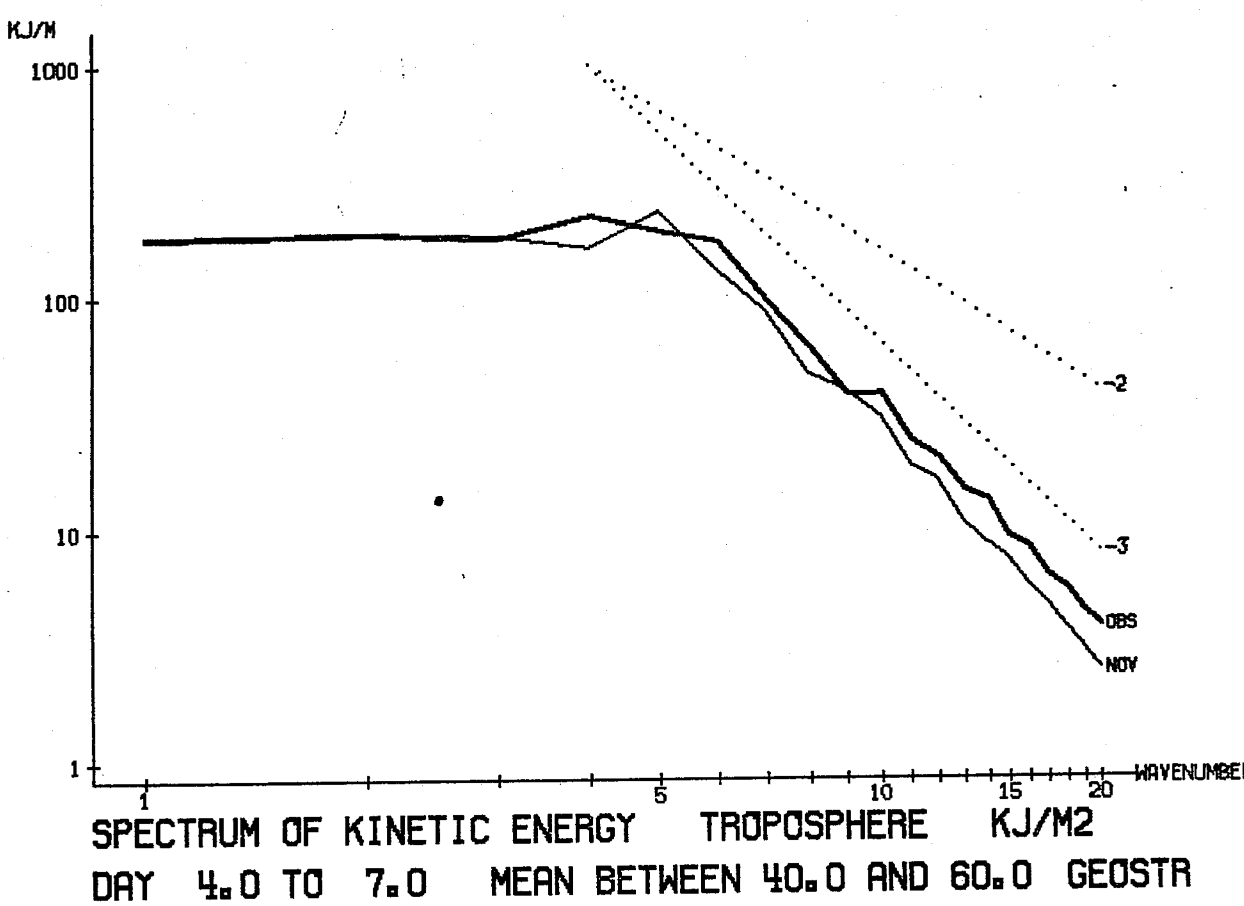
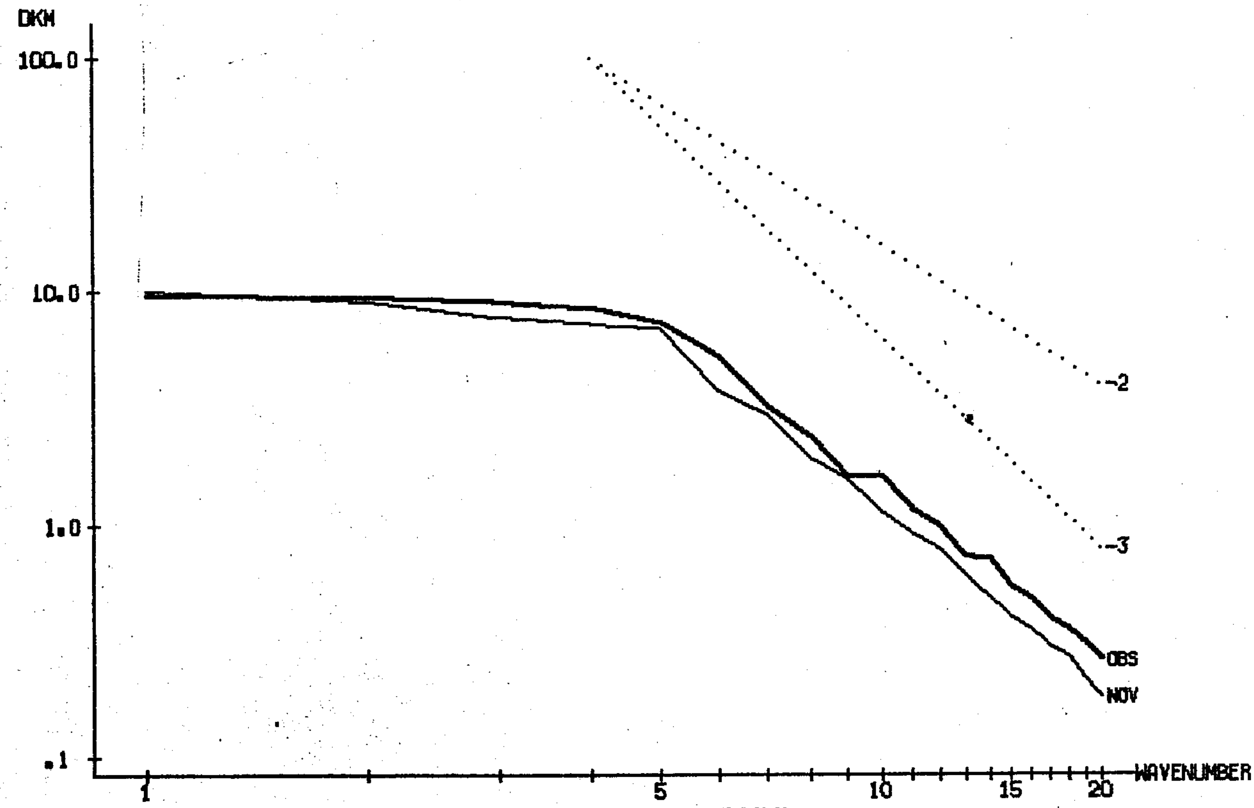
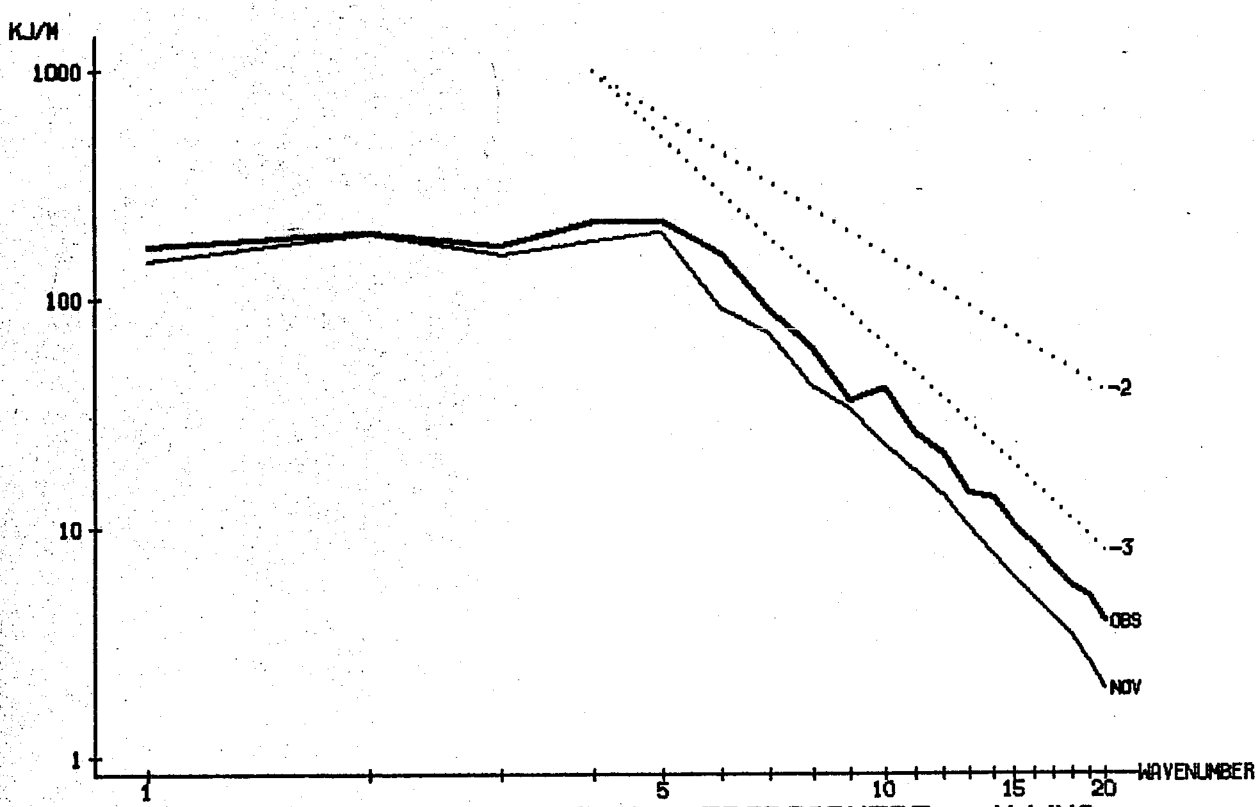

KJ/M
1000
100
10
1
-2
-3
OBS
NOV
WAVENUMBER
1
5
10
15
20
SPECTRUM OF KINETIC ENERGY TROPOSPHERE KJ/M2
DAY 4.0 TO 7.0 MEAN BETWEEN 40.0 AND 60.0 GEOSTR

Fig. 28



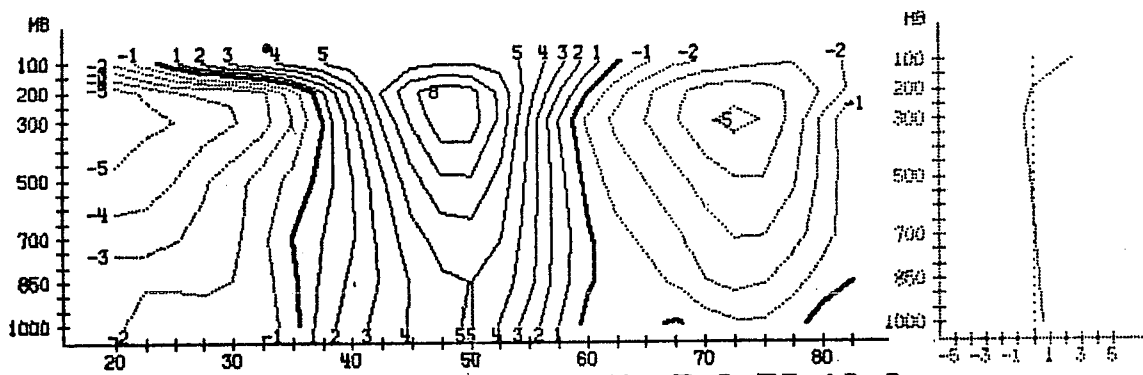
SPECTRUM OF HEIGHT 500 MB (DKM)



SPECTRUM OF KINETIC ENERGY TROPOSPHERE KJ/M2

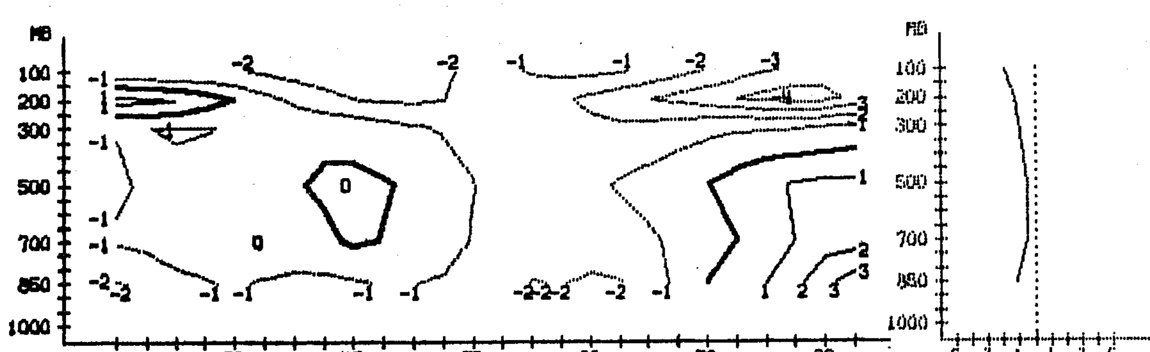
DAY 7.0 TO 10.0 MEAN BETWEEN 40.0 AND 60.0 GEOSTR

Fig. 29



DAY 7.0 TO 10.0

ZONAL MEAN OF U DEVIATION FROM OBSERVED GEOSTR



DAY 7.0 TO 10.0

ZONAL MEAN OF T DEVIATION FROM OBSERVED

Fig. 30

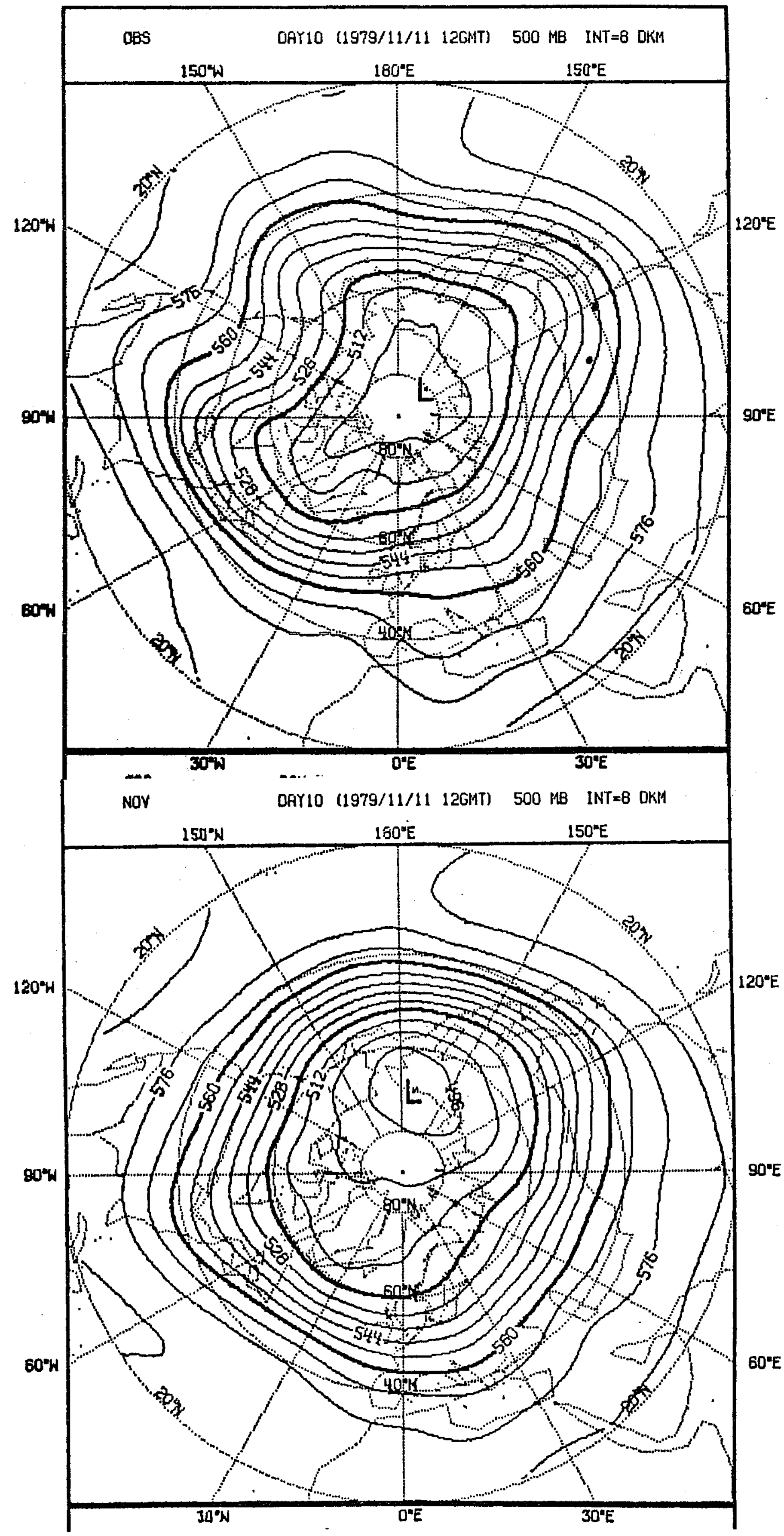

OBS
DAY10 (1979/11/11 12GMT) 500 MB INT=8 DKM
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E
20°N
40°N
60°N
80°N
576
560
544
528
512
L
NOV
DAY10 (1979/11/11 12GMT) 500 MB INT=8 DKM
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E
20°N
40°N
60°N
80°N
576
560
544
528
512
496
L

Fig. 31

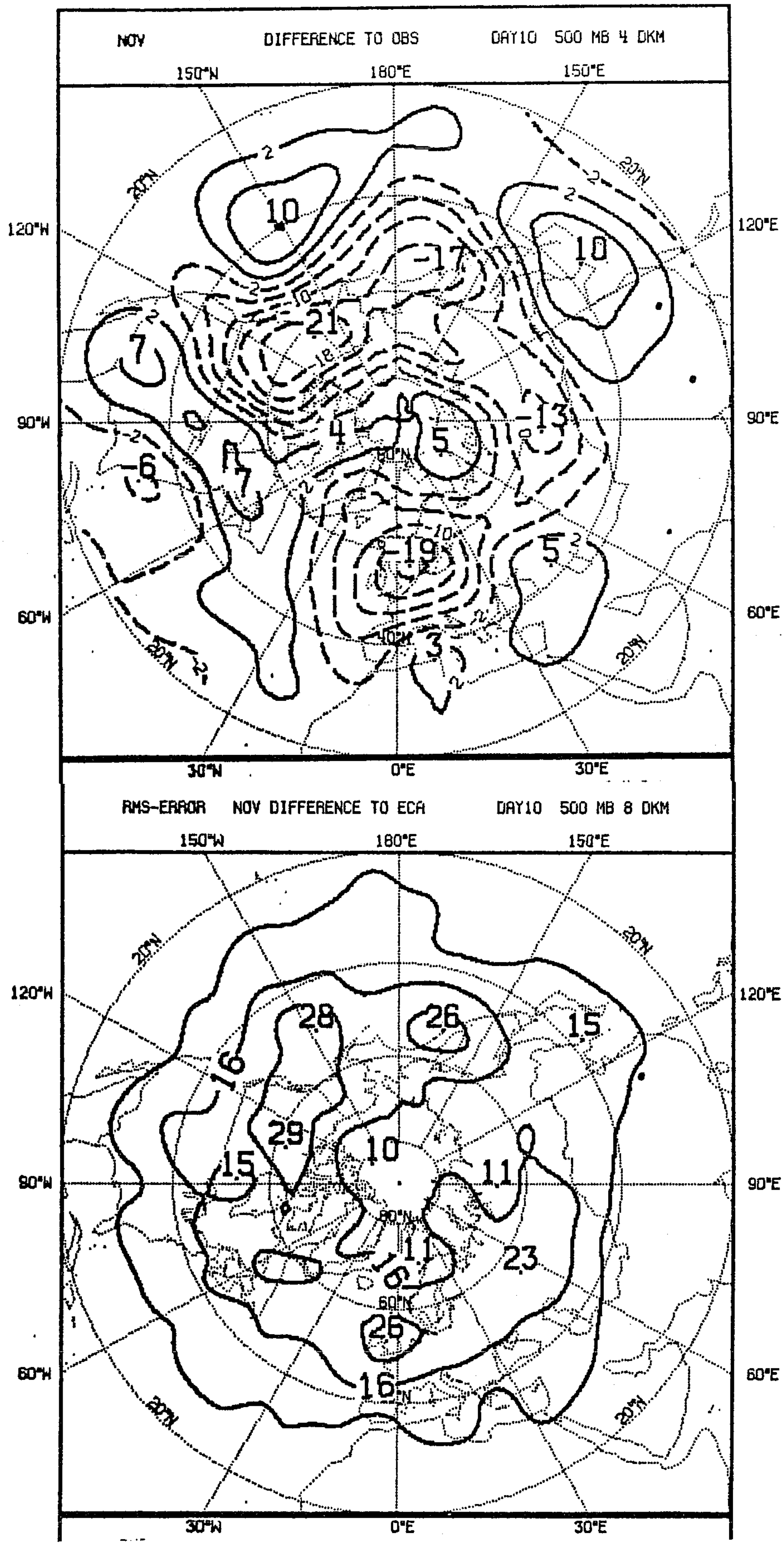

NOV
DIFFERENCE TO OBS
DAY10 500 MB 4 DKM
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E
20°N
80°N
10
-17
10
-21
7
-4
5
-13
-6
7
-19
5
3
2
-2
-10
RMS-ERROR NOV DIFFERENCE TO ECA
DAY10 500 MB 8 DKM
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E
20°N
80°N
60°N
28
26
15
16
29
10
11
15
11
23
16
26
16

Fig. 32

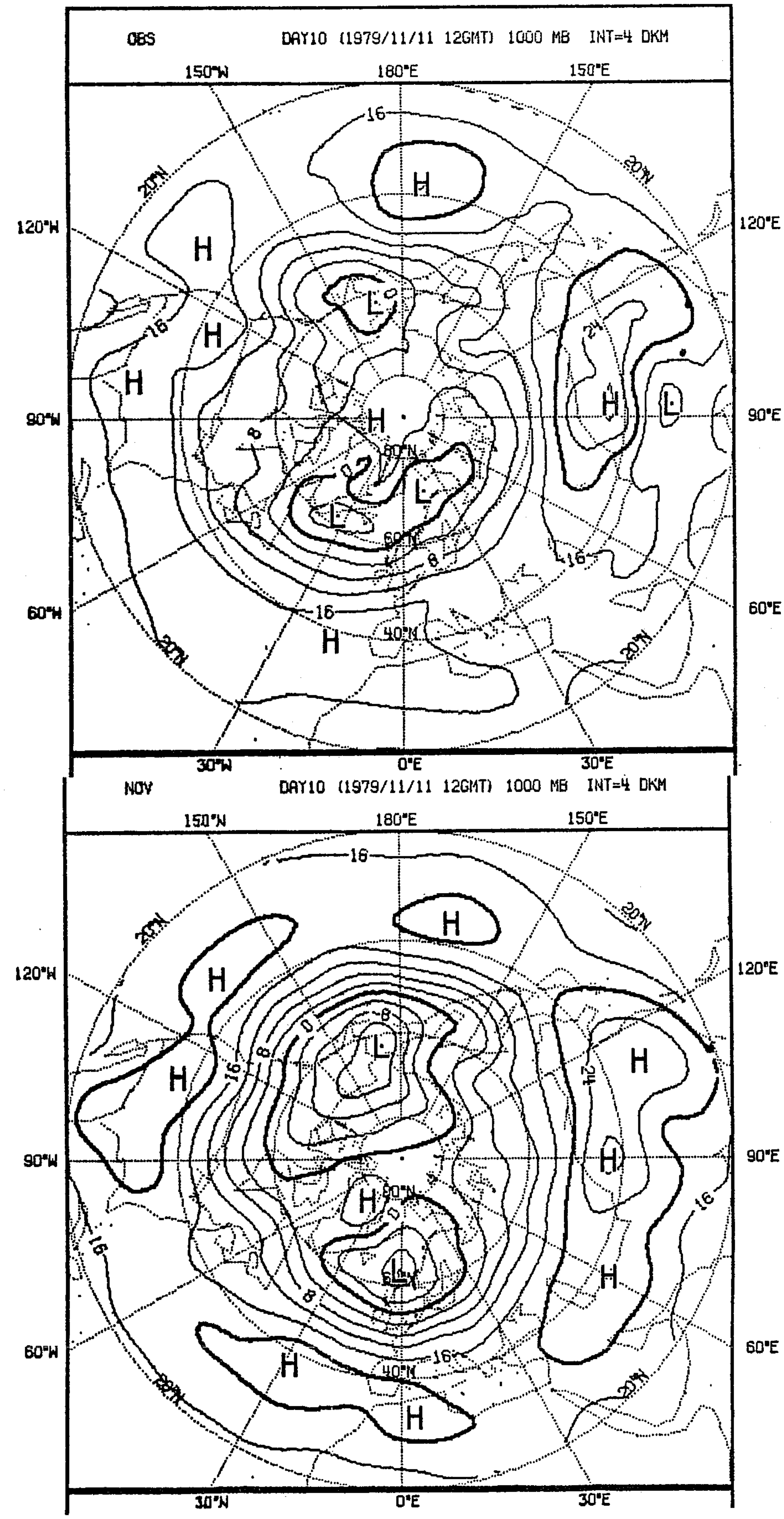
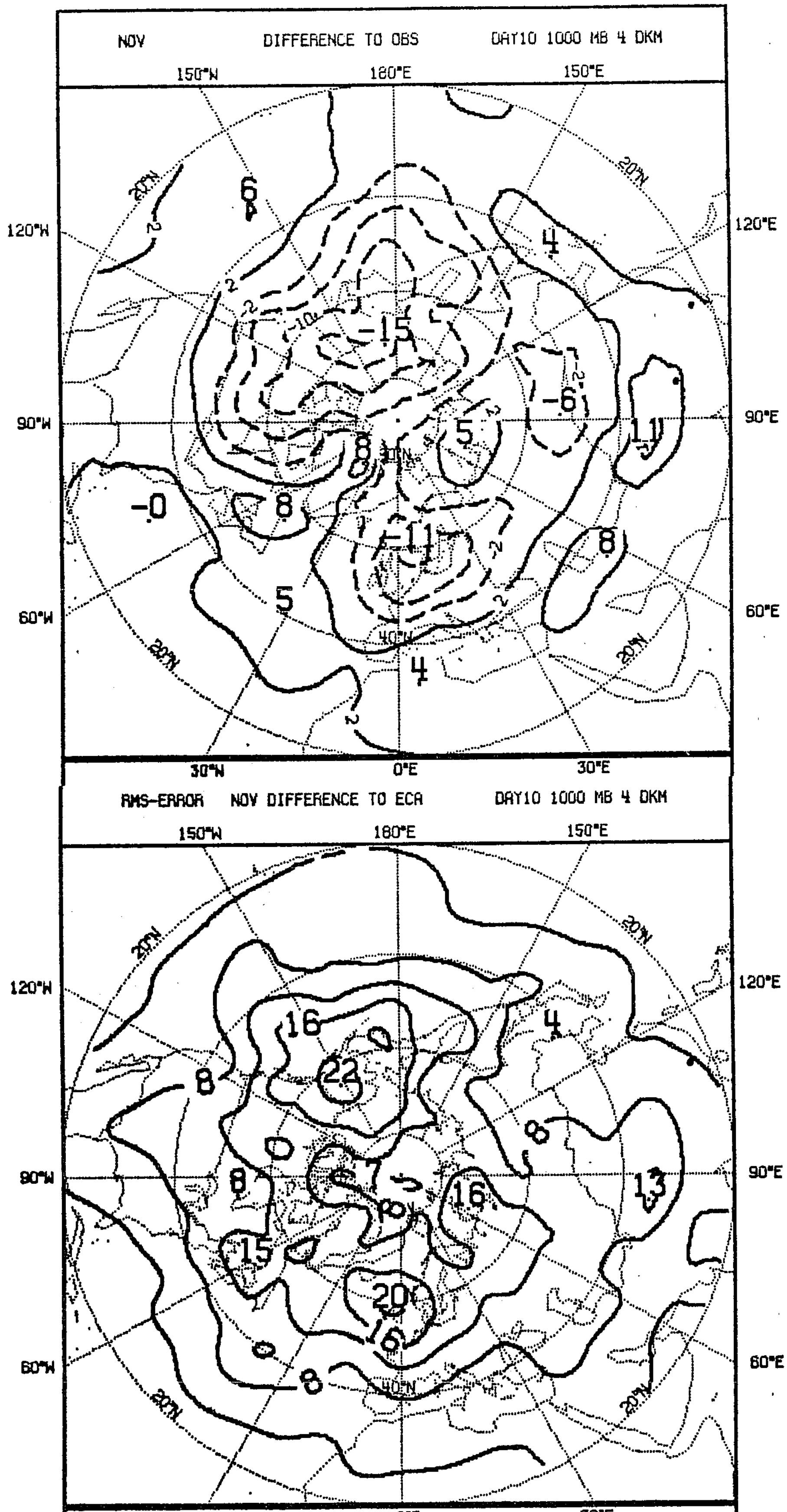

OBS
DAY10 (1979/11/11 12GMT) 1000 MB INT=4 DKM
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E
NOV
DAY10 (1979/11/11 12GMT) 1000 MB INT=4 DKM
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E

Fig. 33



NOV
DIFFERENCE TO OBS
DAY10 1000 MB 4 DKM
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E
RMS-ERROR NOV DIFFERENCE TO ECA
DAY10 1000 MB 4 DKM
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E

Fig. 34

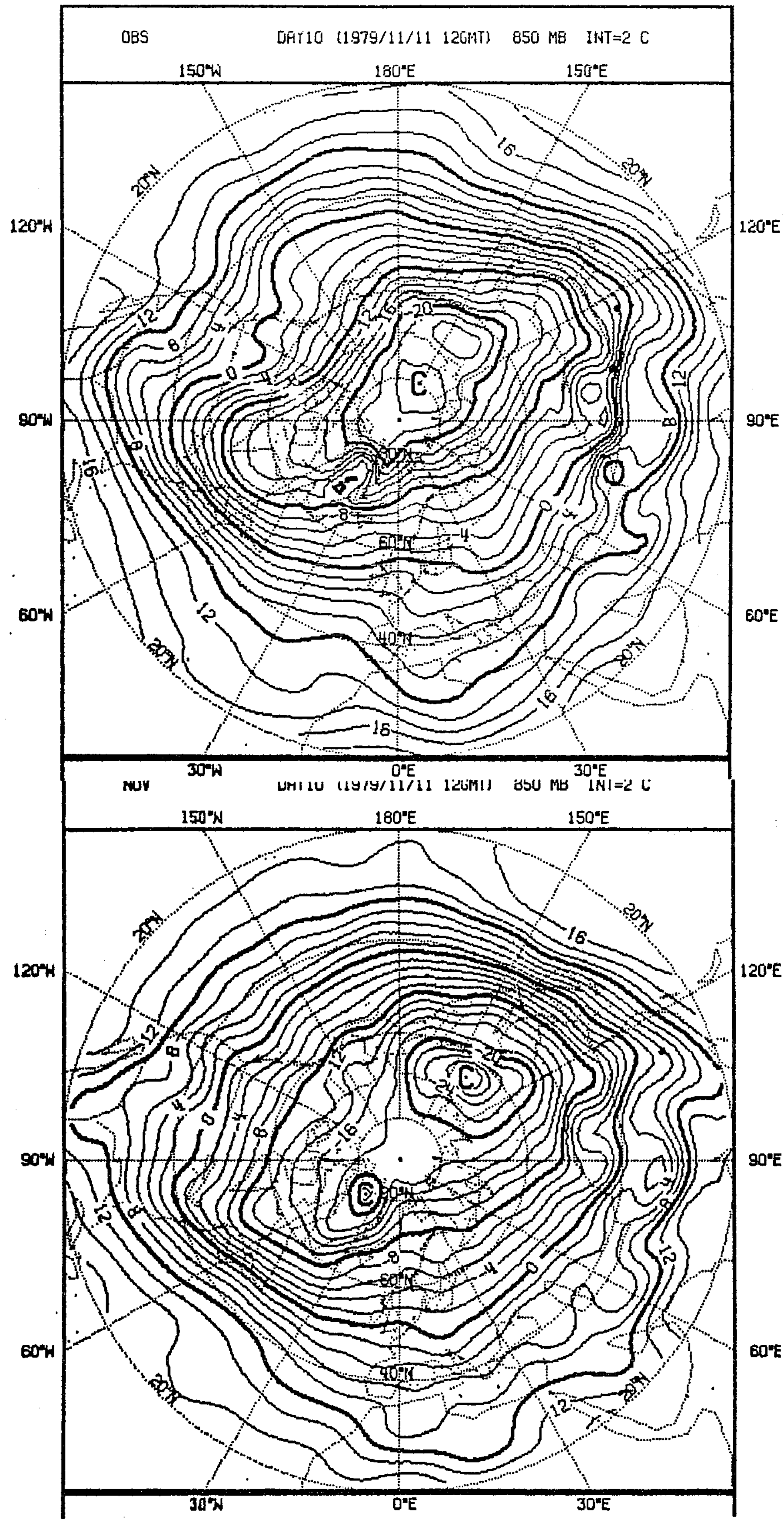
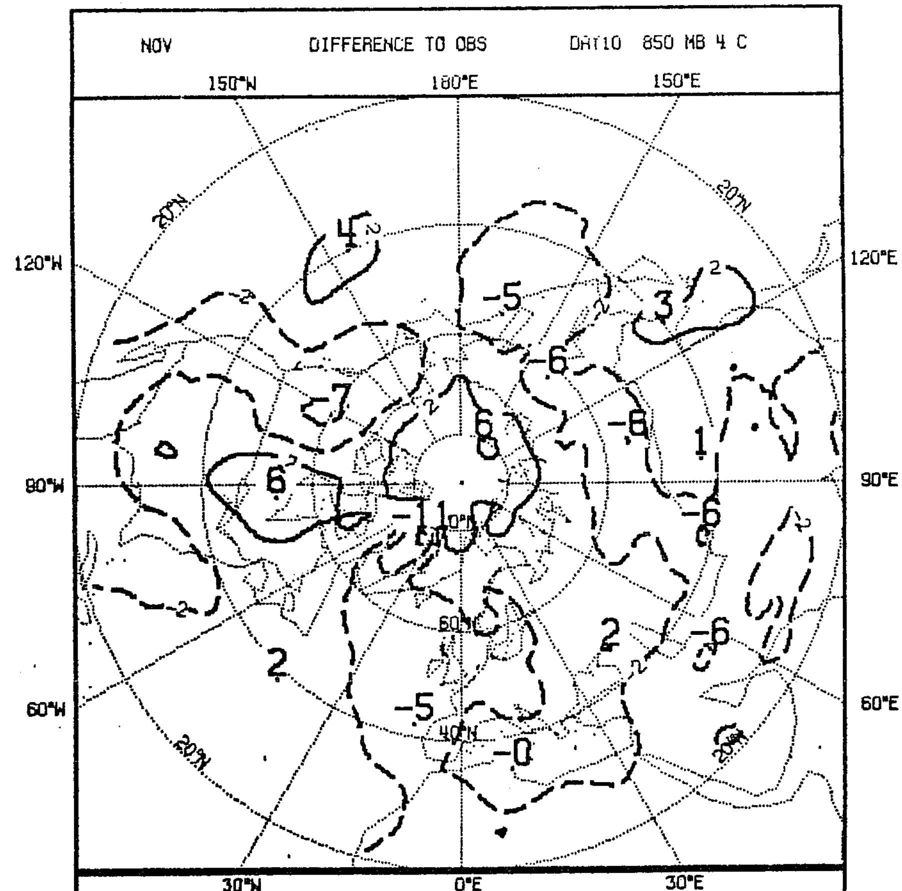

OBS
DAY10 (1979/11/11 12GMT) 850 MB INT=2 C
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E

Fig. 35


NOV
DIFFERENCE TO OBS
DAY10 850 MB 4 C
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E

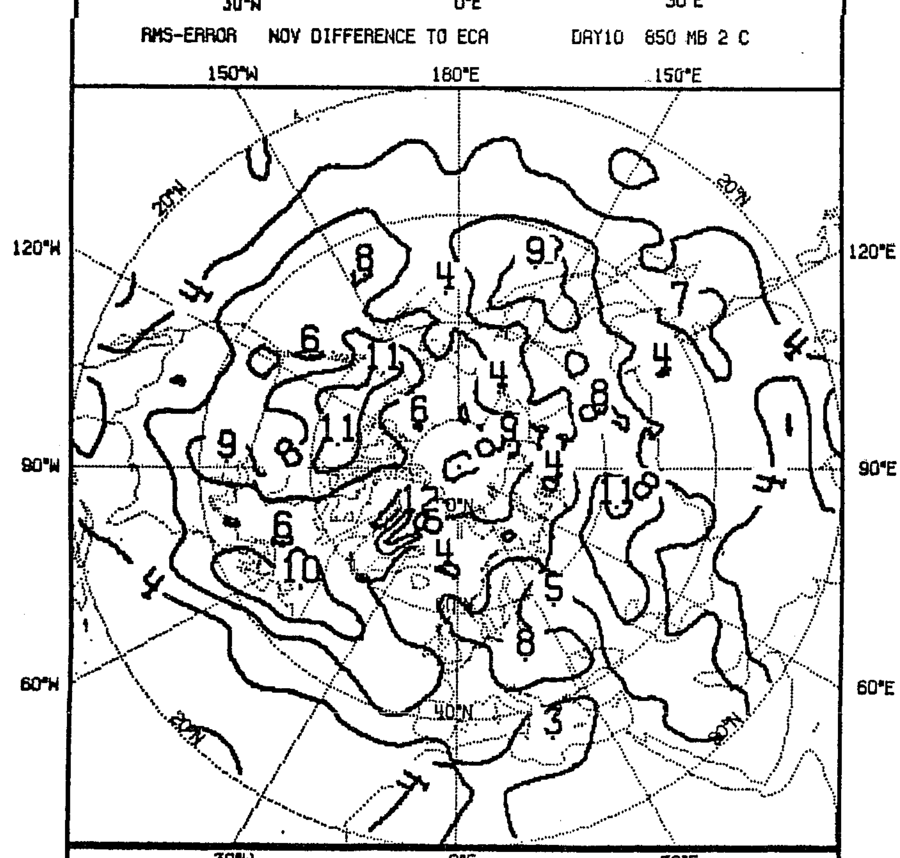

RMS-ERROR NOV DIFFERENCE TO ECA
DAY10 850 MB 2 C
150°W
180°E
150°E
120°W
120°E
90°W
90°E
60°W
60°E
30°W
0°E
30°E

Fig. 36

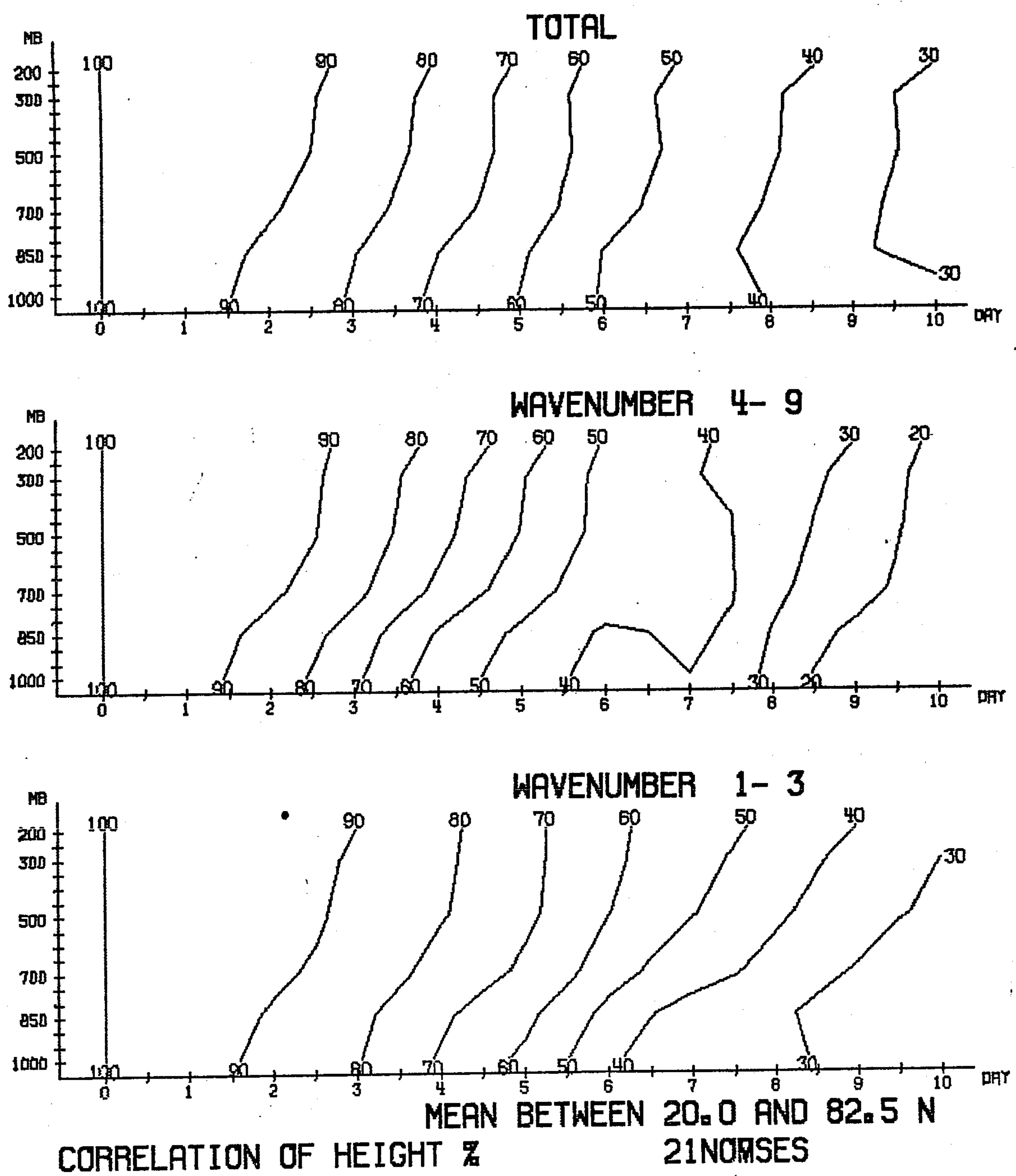

TOTAL
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
200
300
500
700
850
1000
DAY
100
90
80
70
60
50
40
30
20
MEAN BETWEEN 20.0 AND 82.5 N
CORRELATION OF HEIGHT %
21NOMSES

Fig. 37

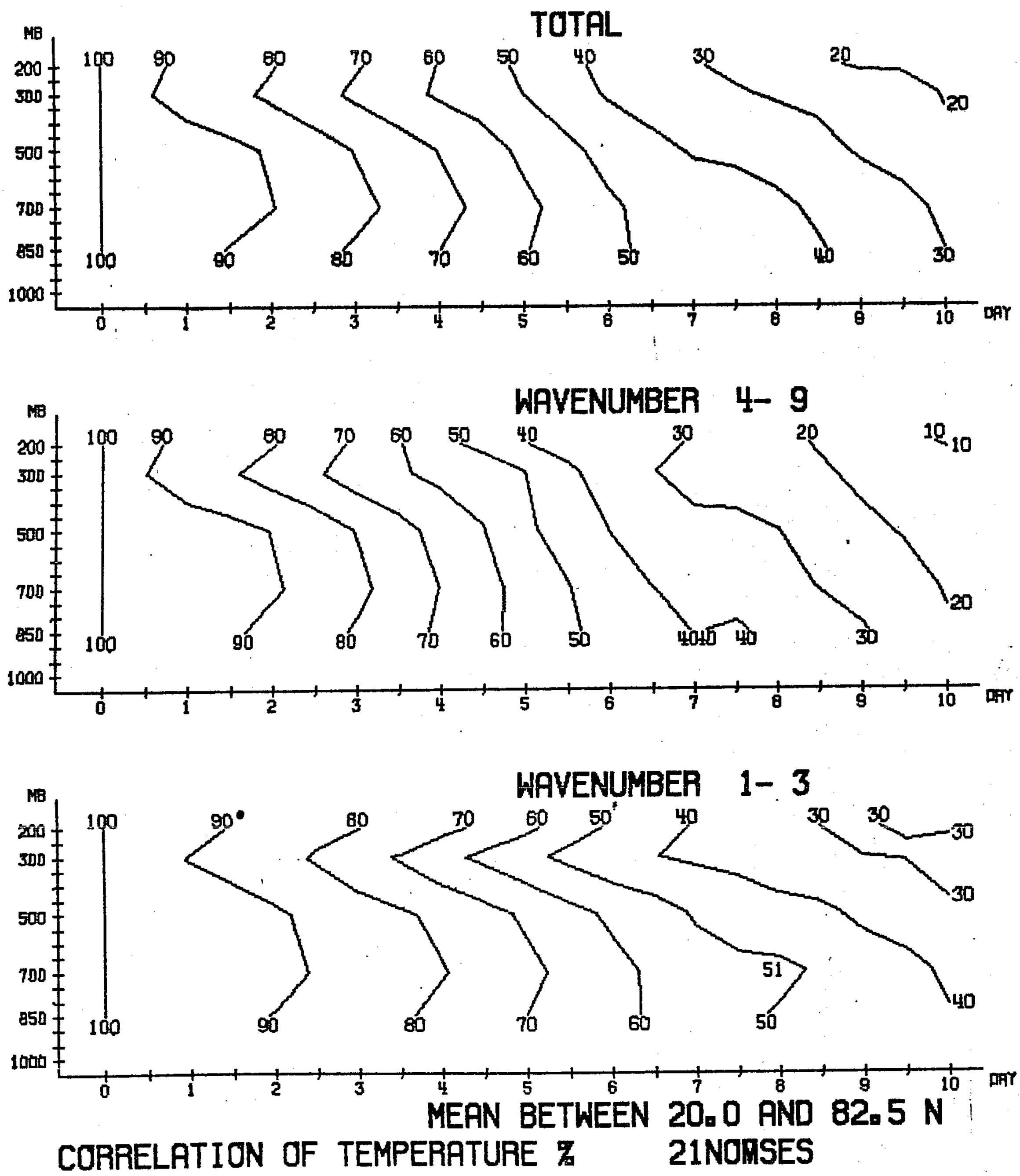

TOTAL
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
200
300
500
700
850
1000
DAY
0 1 2 3 4 5 6 7 8 9 10
MEAN BETWEEN 20.0 AND 82.5 N
CORRELATION OF TEMPERATURE % 21NOMSES

Fig. 38

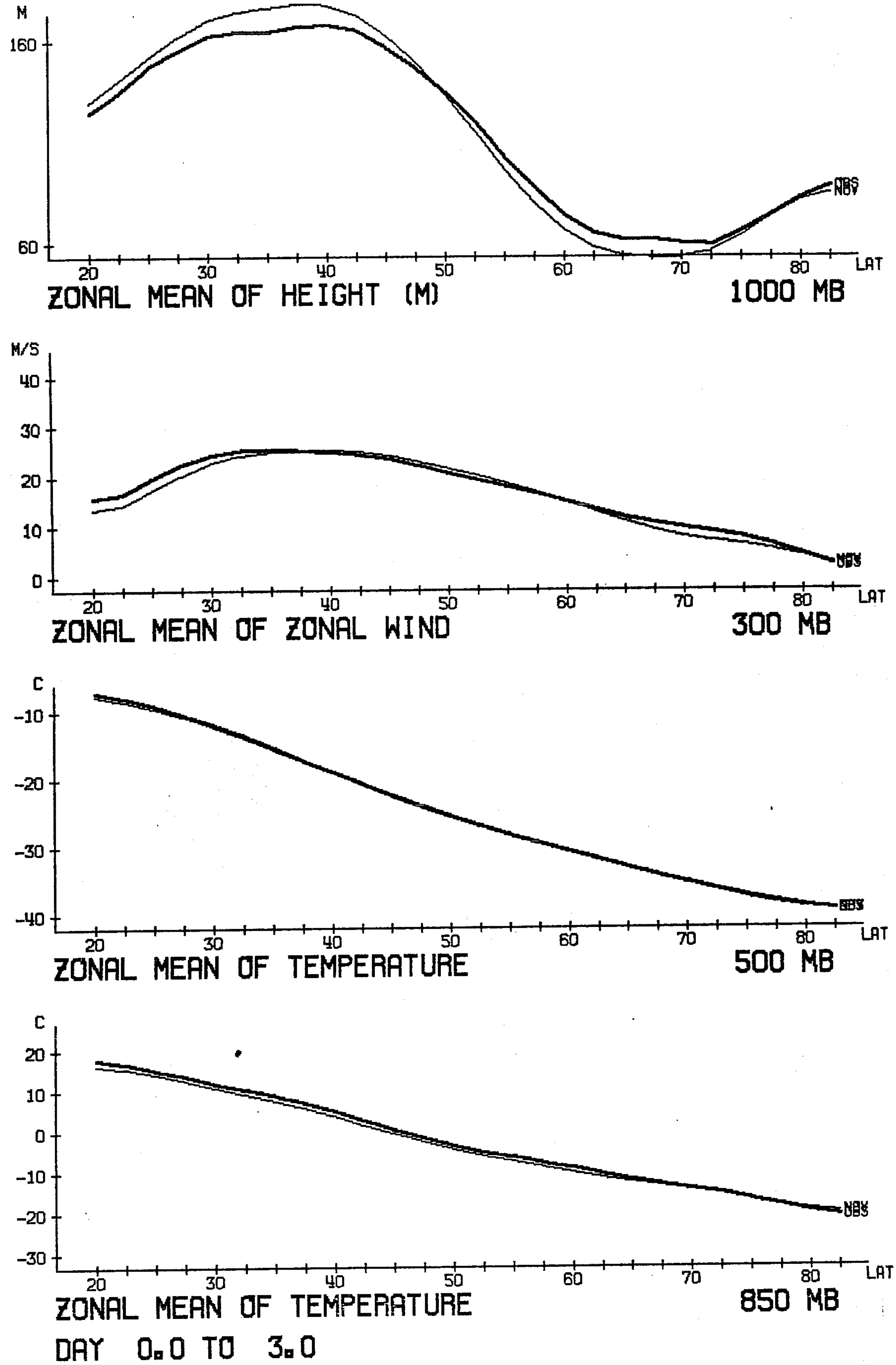
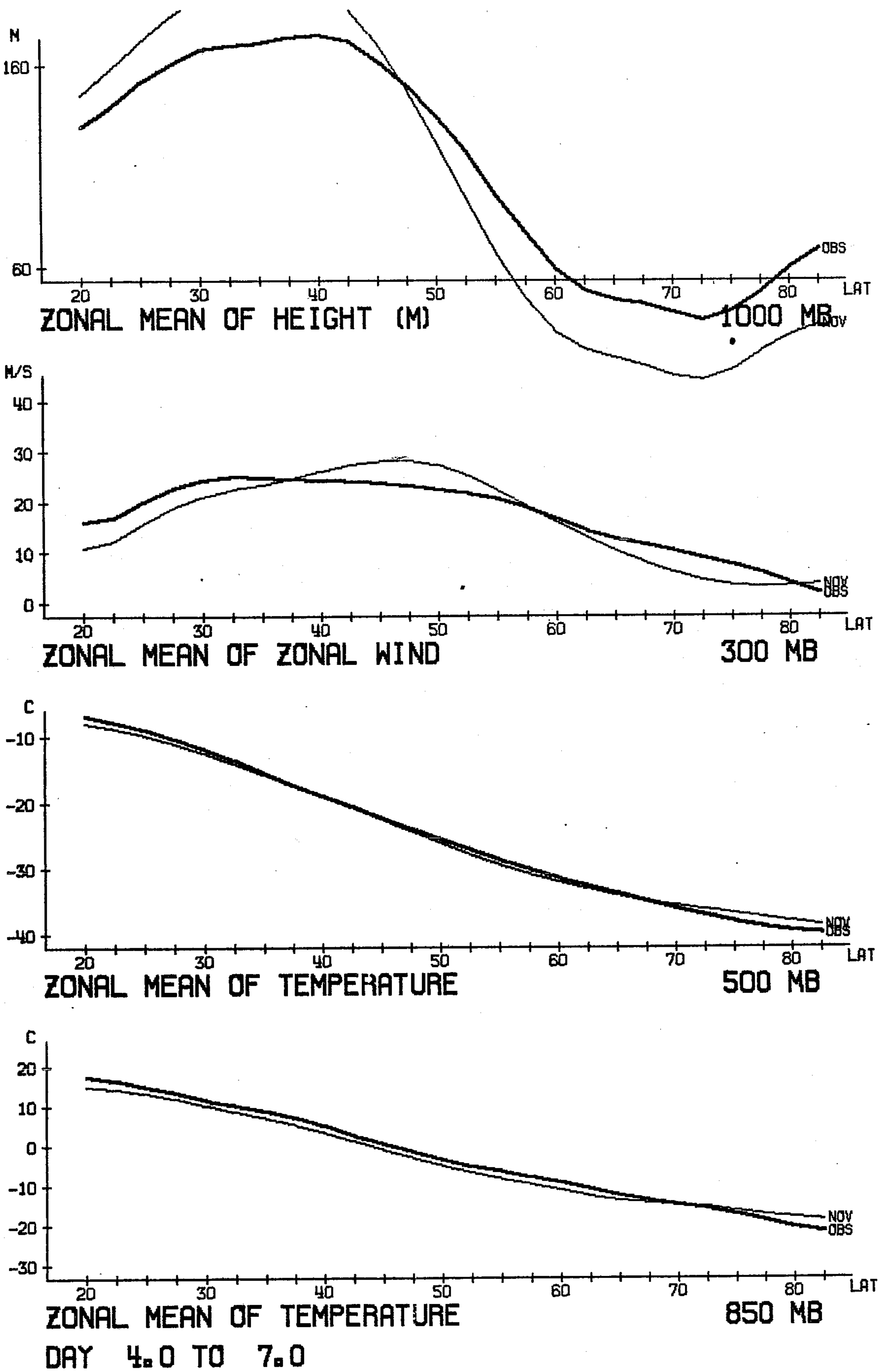

M
160
60
20 30 40 50 60 70 80 LAT
ZONAL MEAN OF HEIGHT (M)
1000 MB
M/S
40
30
20
10
0
20 30 40 50 60 70 80 LAT
ZONAL MEAN OF ZONAL WIND
300 MB
C
-10
-20
-30
-40
20 30 40 50 60 70 80 LAT
ZONAL MEAN OF TEMPERATURE
500 MB
C
20
10
0
-10
-20
-30
20 30 40 50 60 70 80 LAT
ZONAL MEAN OF TEMPERATURE
850 MB
DAY 0.0 TO 3.0

Fig. 39



M
160
60
20 30 40 50 60 70 80 LAT
OBS
NOV
ZONAL MEAN OF HEIGHT (M)
1000 MB
M/S
40
30
20
10
0
20 30 40 50 60 70 80 LAT
NOV
OBS
ZONAL MEAN OF ZONAL WIND
300 MB
C
-10
-20
-30
-40
20 30 40 50 60 70 80 LAT
NOV
OBS
ZONAL MEAN OF TEMPERATURE
500 MB
C
20
10
0
-10
-20
-30
20 30 40 50 60 70 80 LAT
NOV
OBS
ZONAL MEAN OF TEMPERATURE
850 MB
DAY 4.0 TO 7.0

Fig. 40

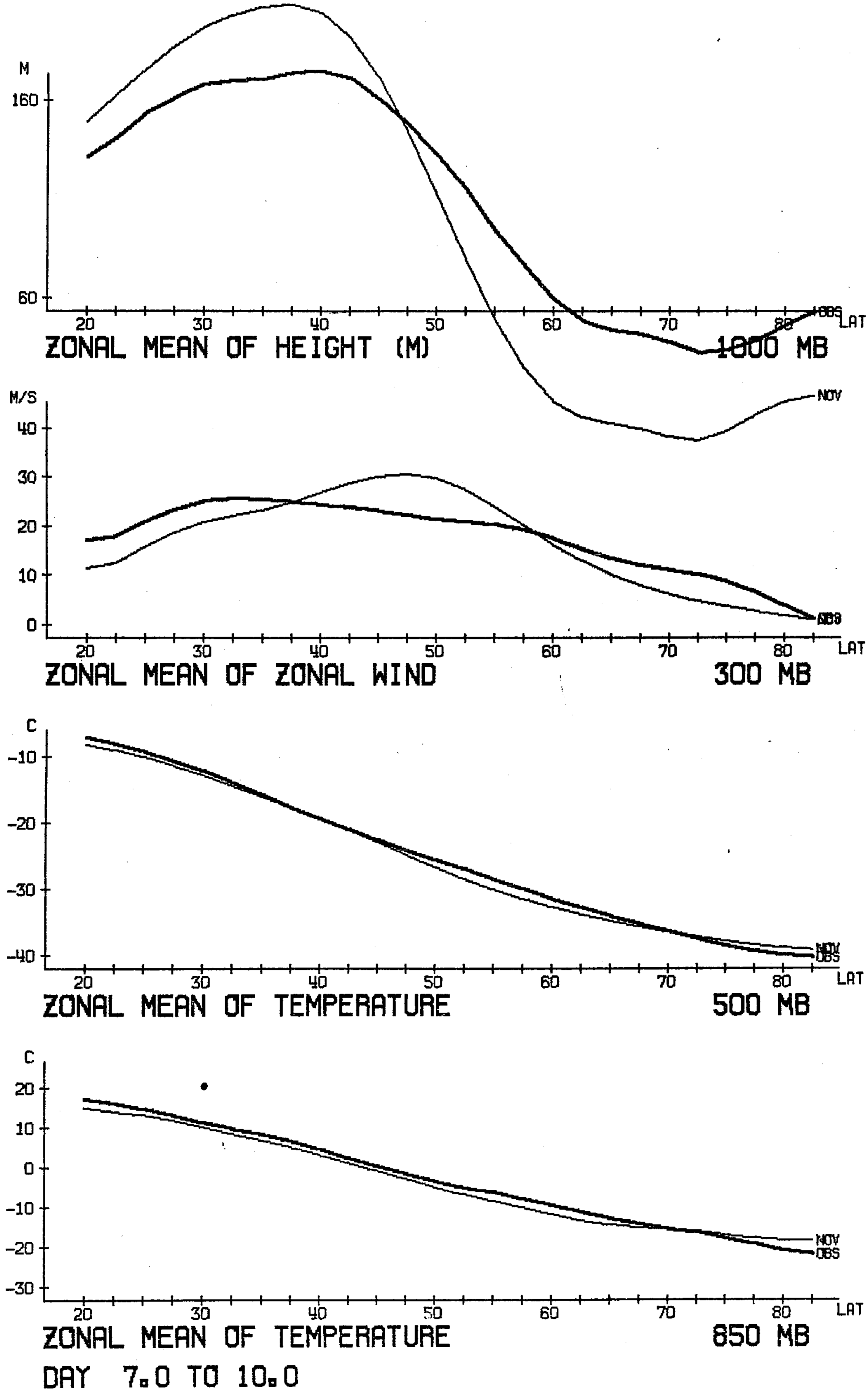

M
160
60
20 30 40 50 60 70 80
OBS
LAT
ZONAL MEAN OF HEIGHT (M)
1000 MB
NOV
M/S
40
30
20
10
0
OBS
LAT
ZONAL MEAN OF ZONAL WIND
300 MB
C
-10
-20
-30
-40
NOV
OBS
LAT
ZONAL MEAN OF TEMPERATURE
500 MB
C
20
10
0
-10
-20
-30
NOV
OBS
LAT
ZONAL MEAN OF TEMPERATURE
850 MB
DAY 7.0 TO 10.0

Fig. 41

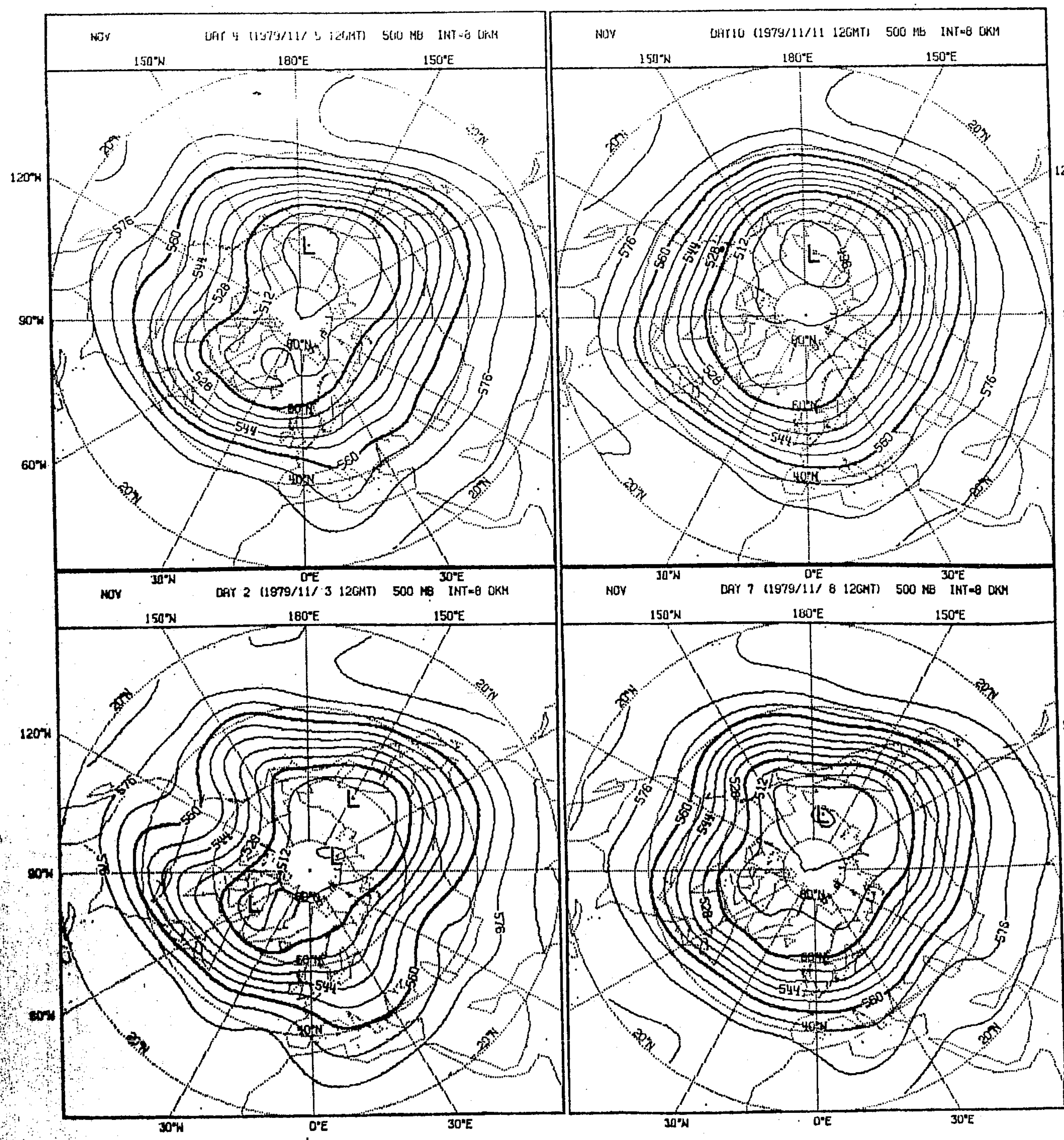
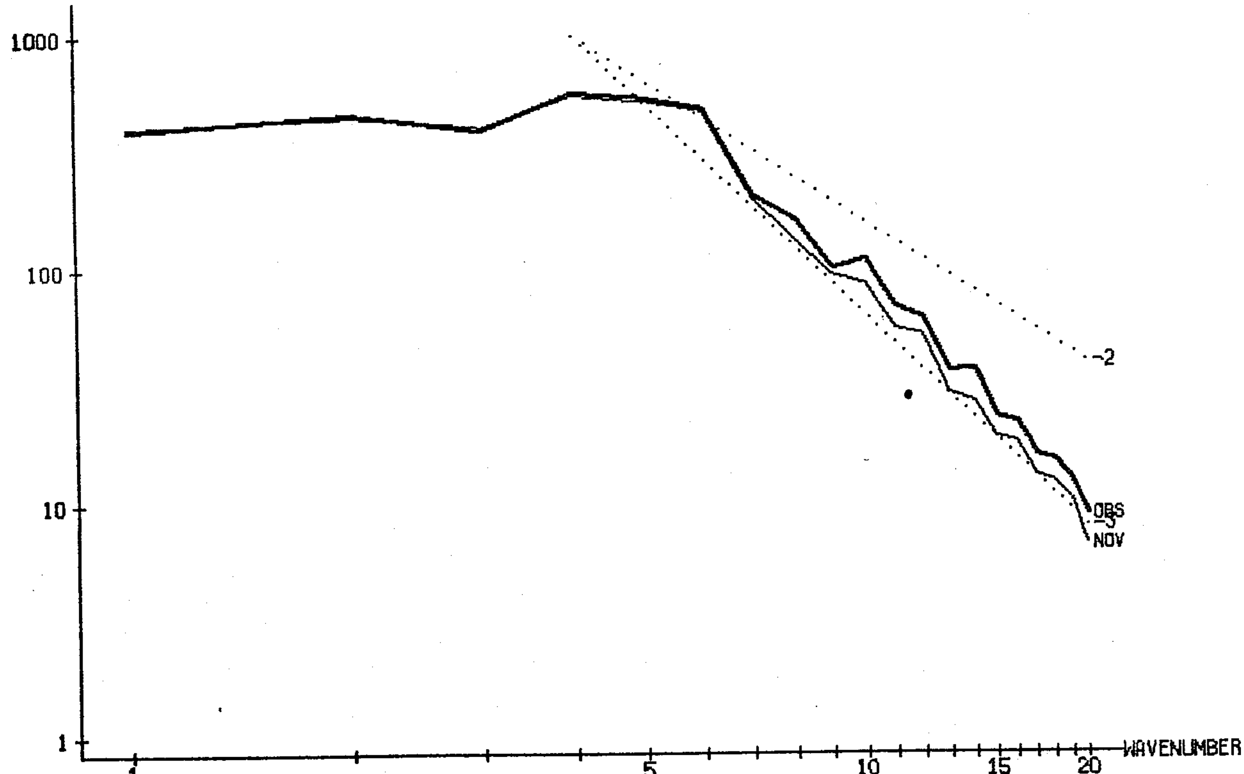
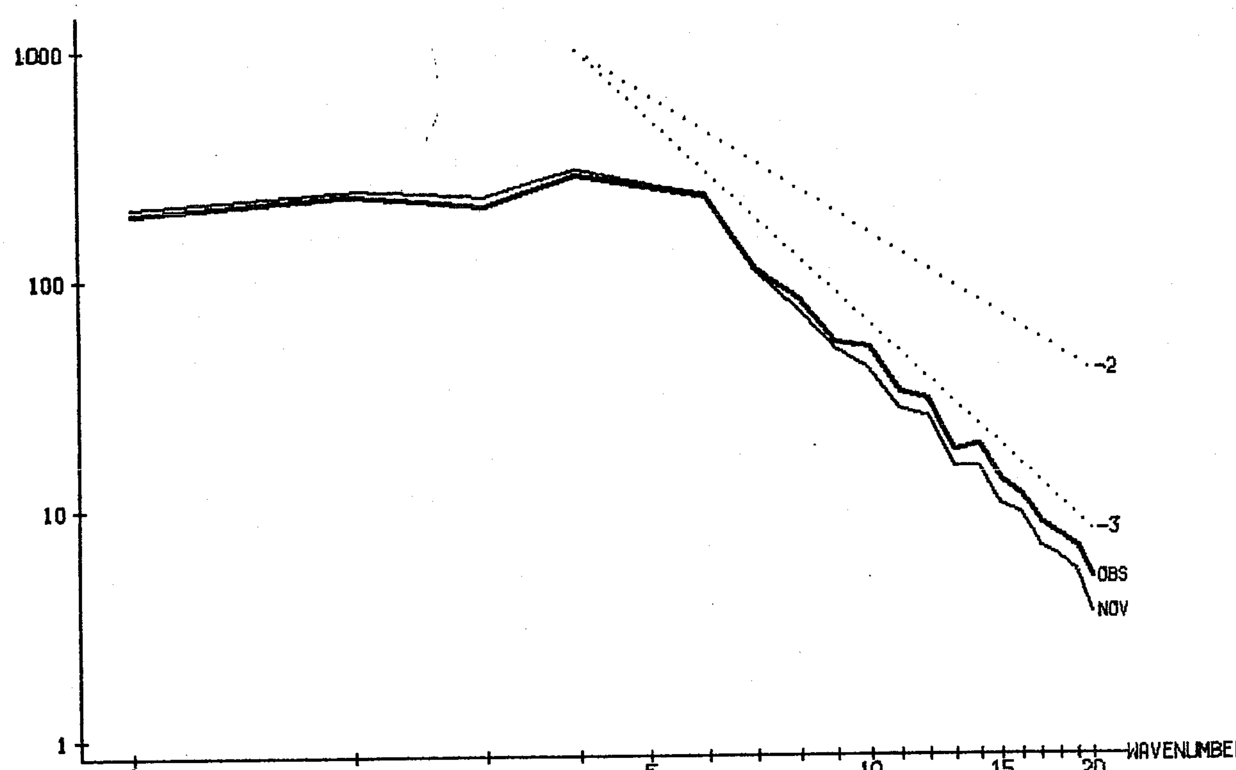

NOV DAY 4 (1979/11/ 5 12GMT) 500 MB INT=8 DKM
NOV DAY10 (1979/11/11 12GMT) 500 MB INT=8 DKM
NOV DAY 2 (1979/11/ 3 12GMT) 500 MB INT=8 DKM
NOV DAY 7 (1979/11/ 8 12GMT) 500 MB INT=8 DKM

Fig. 42



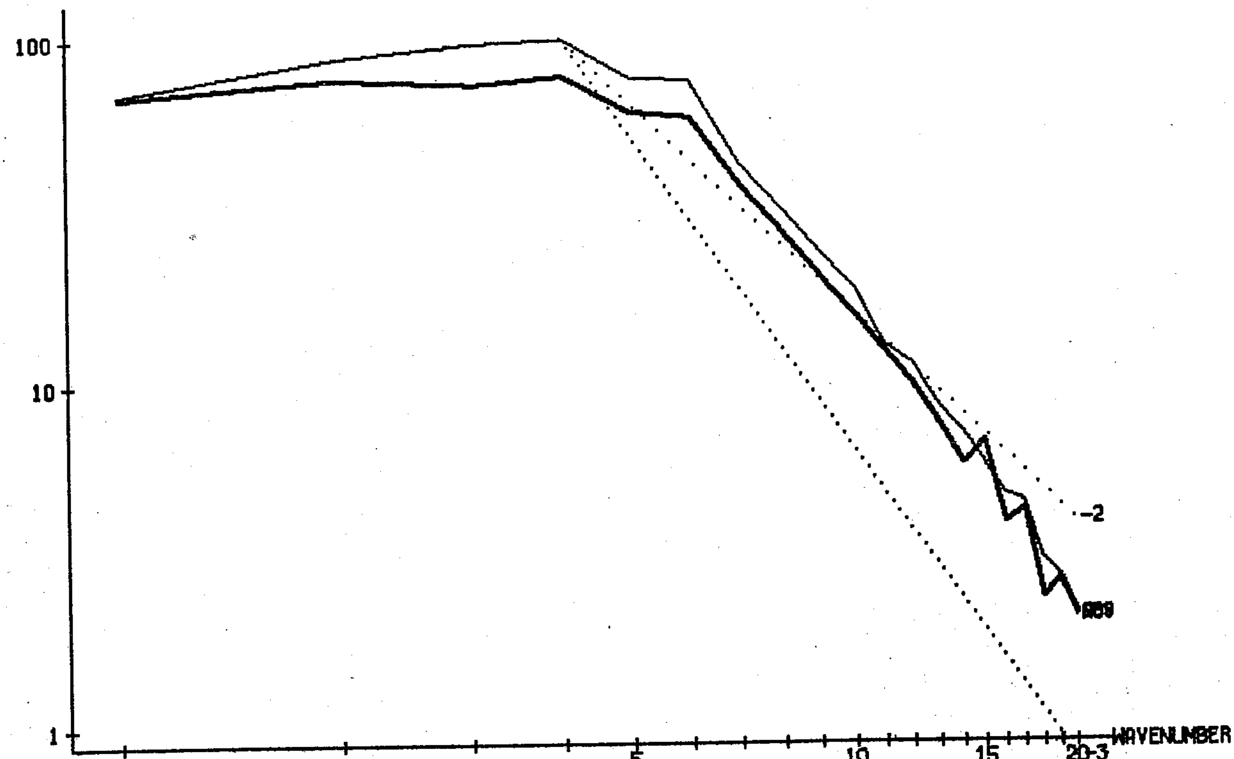
SPECTRUM OF KINETIC ENERGY 300 MB KJ/(M2*BAR)



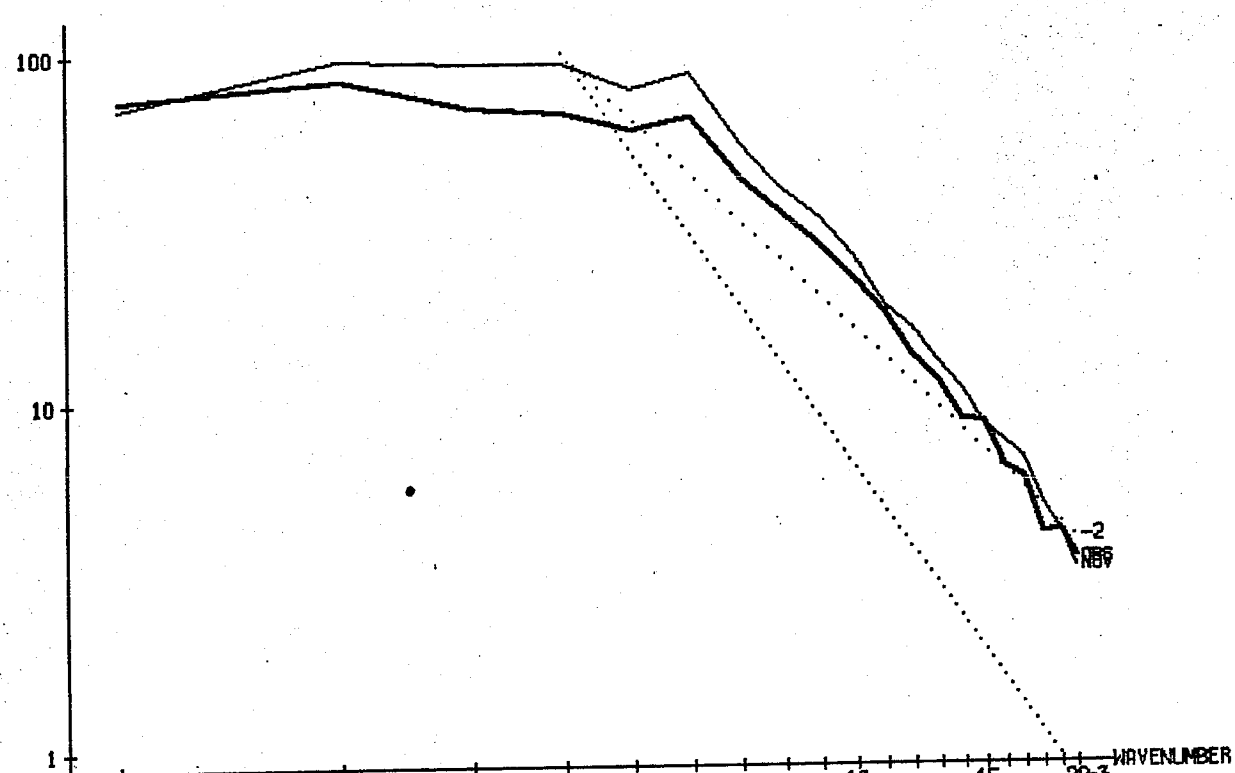
SPECTRUM OF KINETIC ENERGY 500 MB KJ/(M2*BAR)

DAY 0.0 TO 3.0 MEAN BETWEEN 40.0 AND 60.0 GEOSTR

Fig. 43

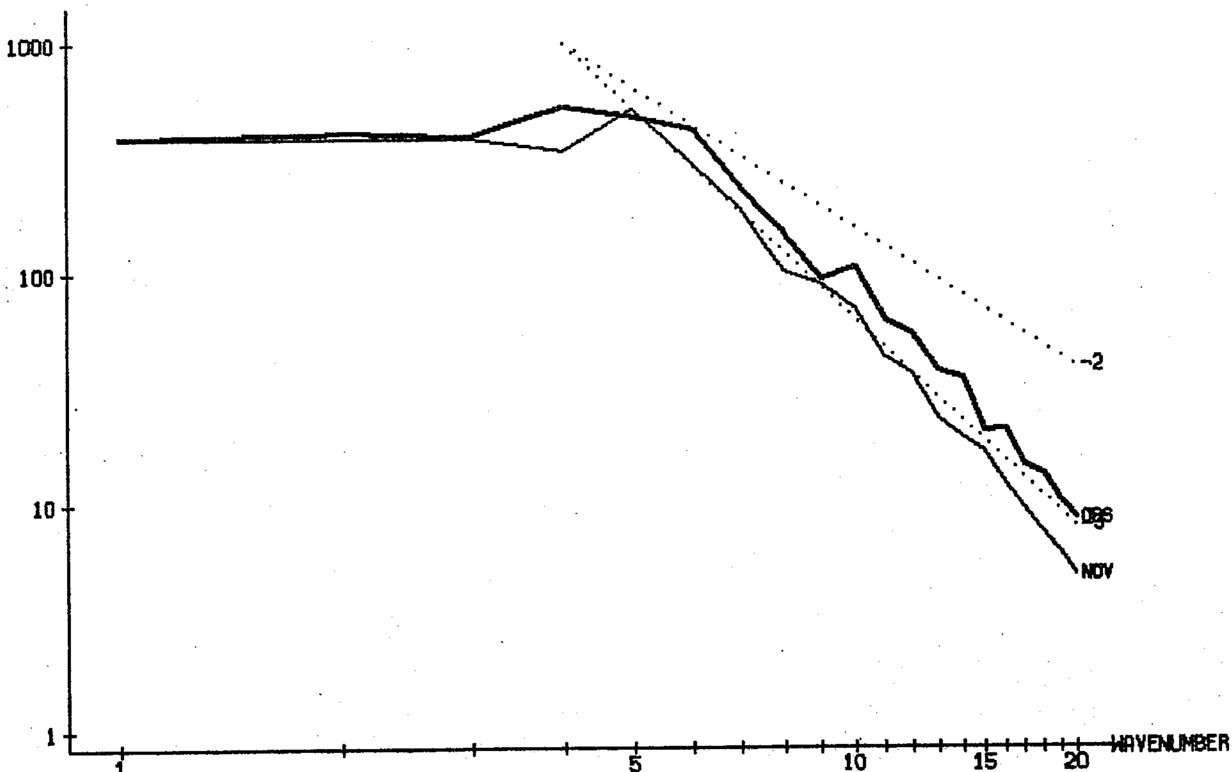


SPECTRUM OF KINETIC ENERGY 850 MB KJ/(M2*BAR)

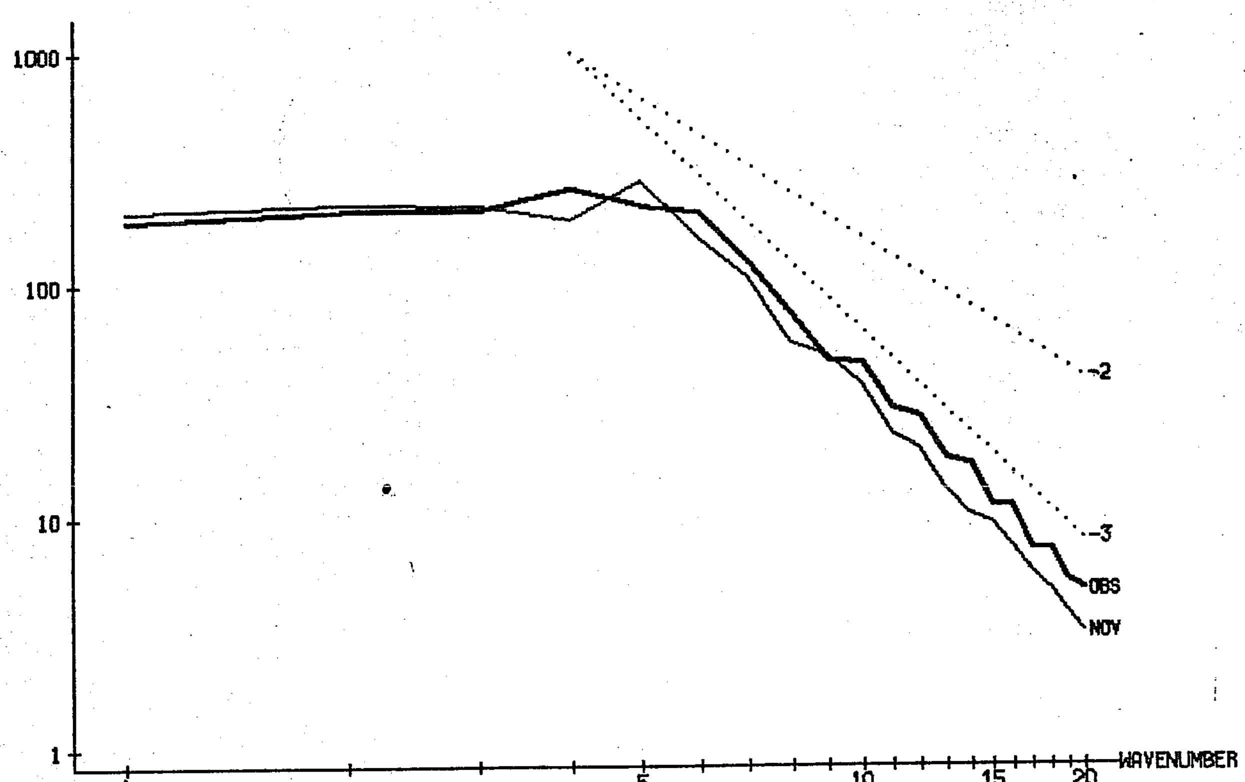


SPECTRUM OF KINETIC ENERGY 1000 MB KJ/(M2*BAR)
DAY 0.0 TO 3.0 MEAN BETWEEN 40.0 AND 60.0 GEOSTR

Fig. 44



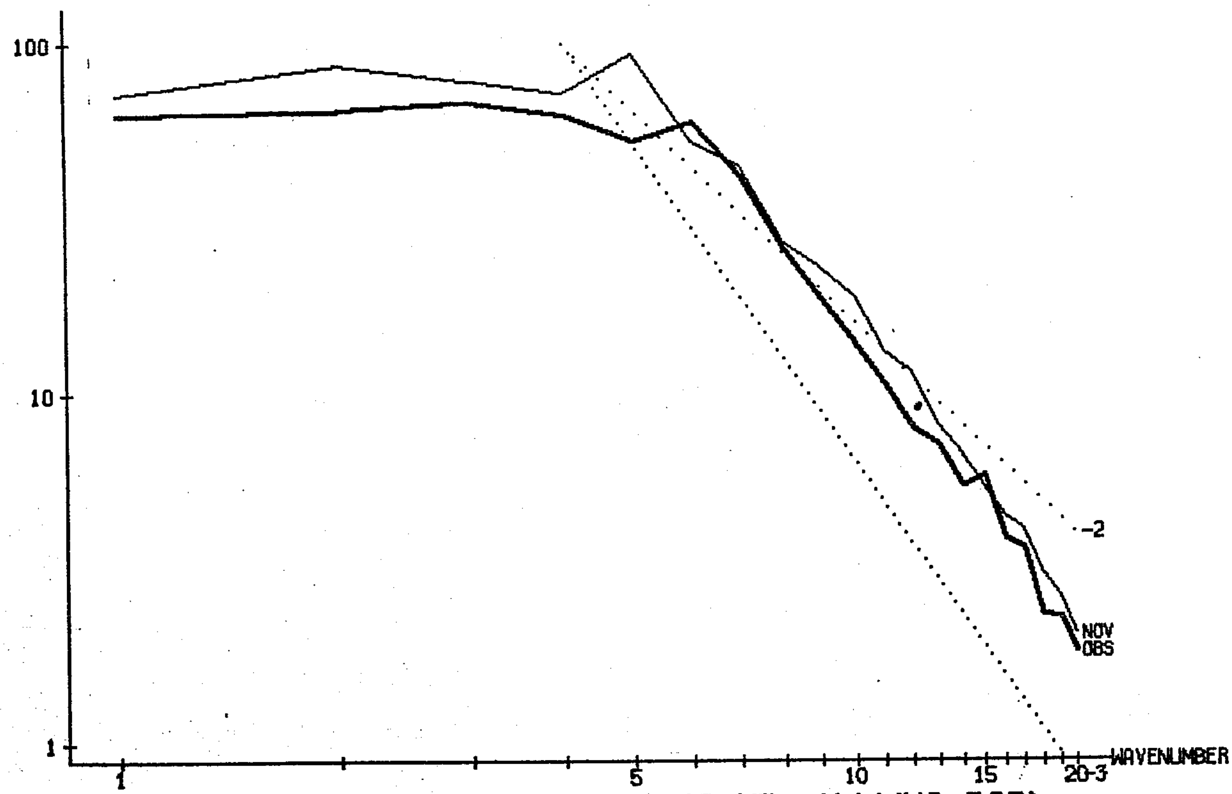
SPECTRUM OF KINETIC ENERGY 300 MB KJ/(M2*BAR)



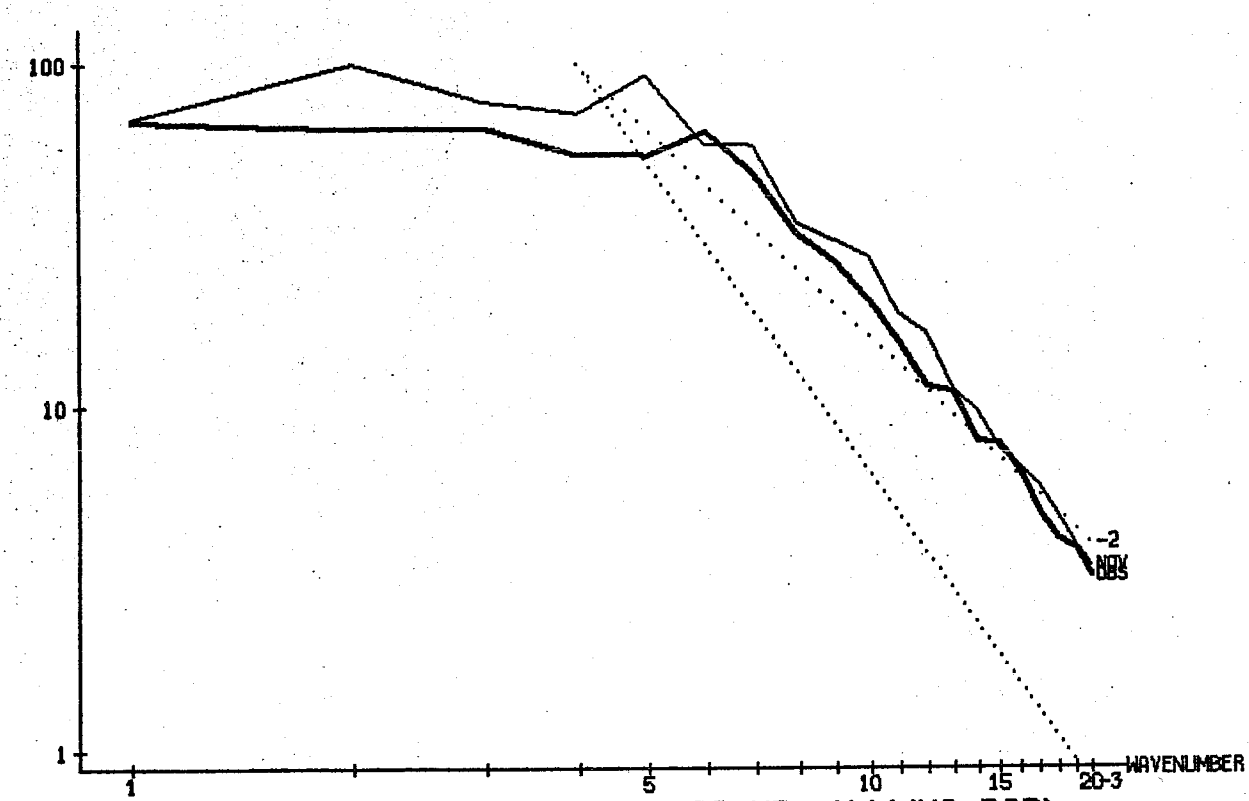
SPECTRUM OF KINETIC ENERGY 500 MB KJ/(M2*BAR)

DAY 4.0 TO 7.0 MEAN BETWEEN 40.0 AND 60.0 GEOSTR

Fig. 45



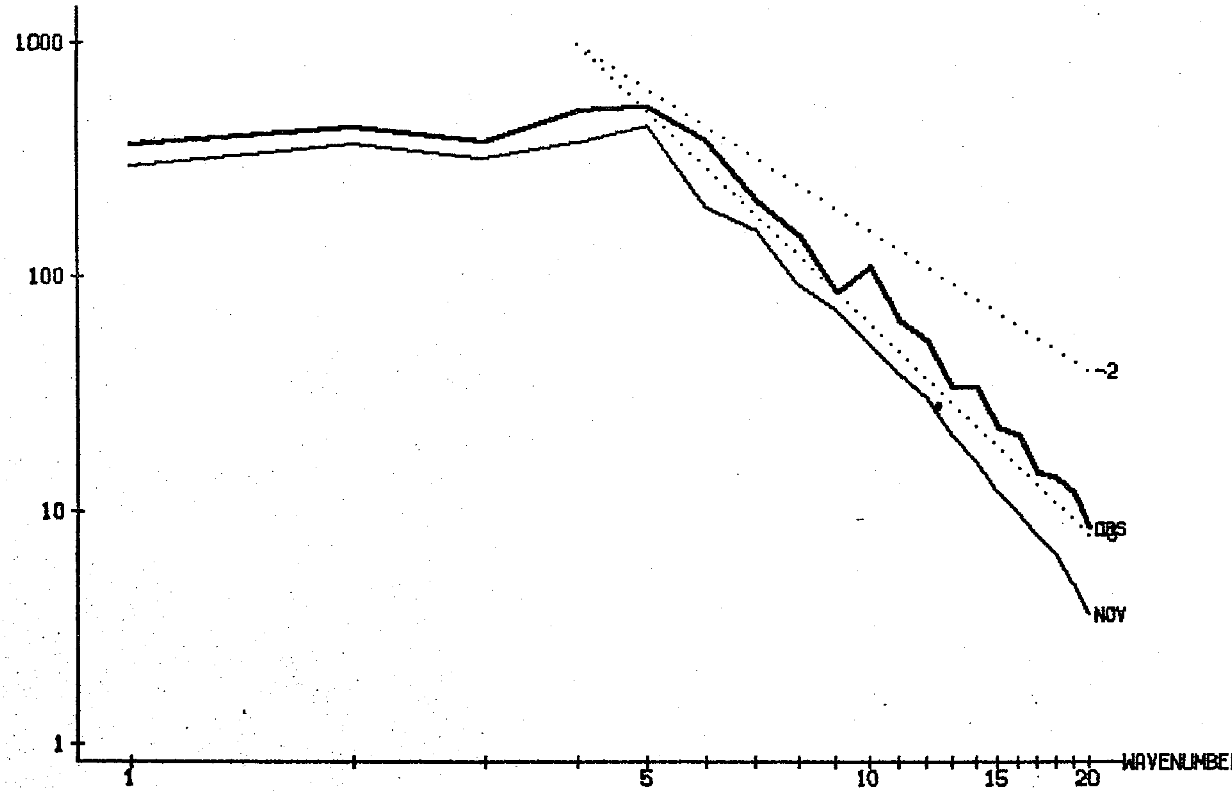
SPECTRUM OF KINETIC ENERGY 850 MB KJ/ (M2*BAR)



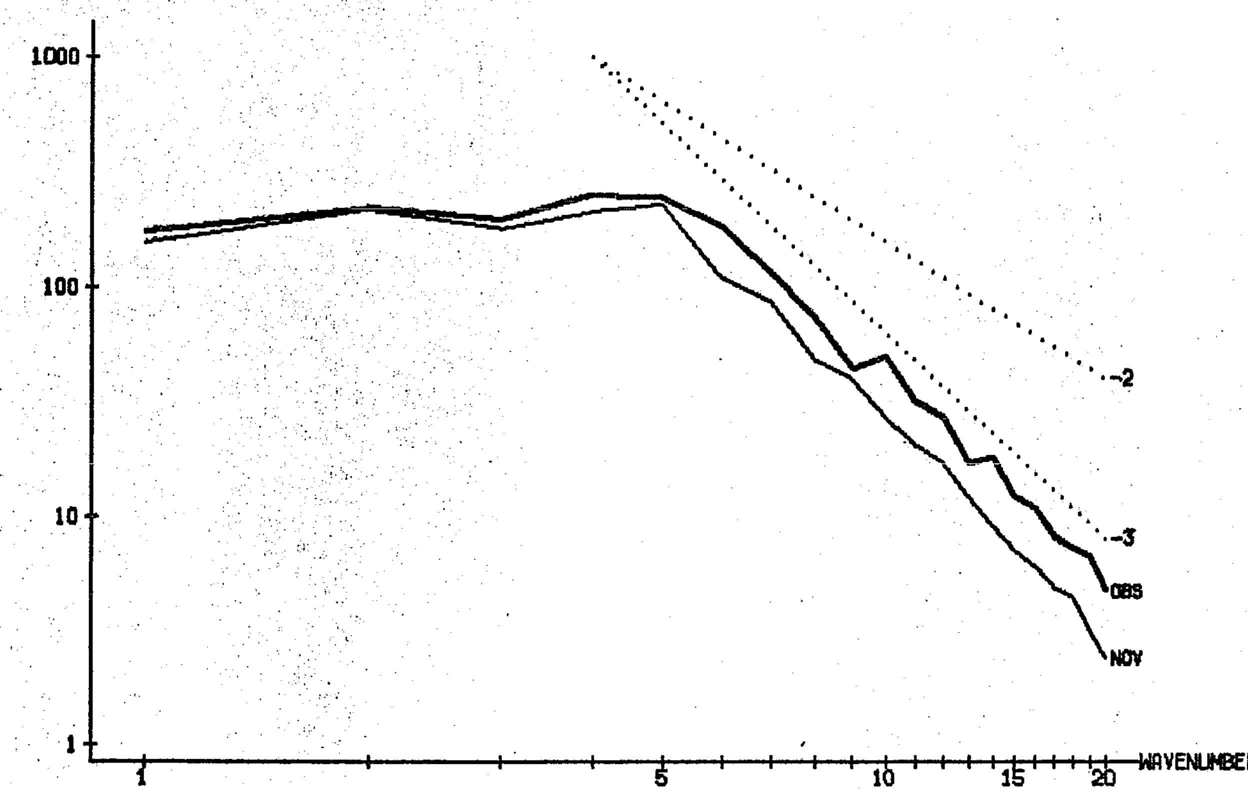
SPECTRUM OF KINETIC ENERGY 1000 MB KJ/ (M2*BAR)

DAY 4.0 TO 7.0 MEAN BETWEEN 40.0 AND 60.0 GEOSTR

Fig. 46



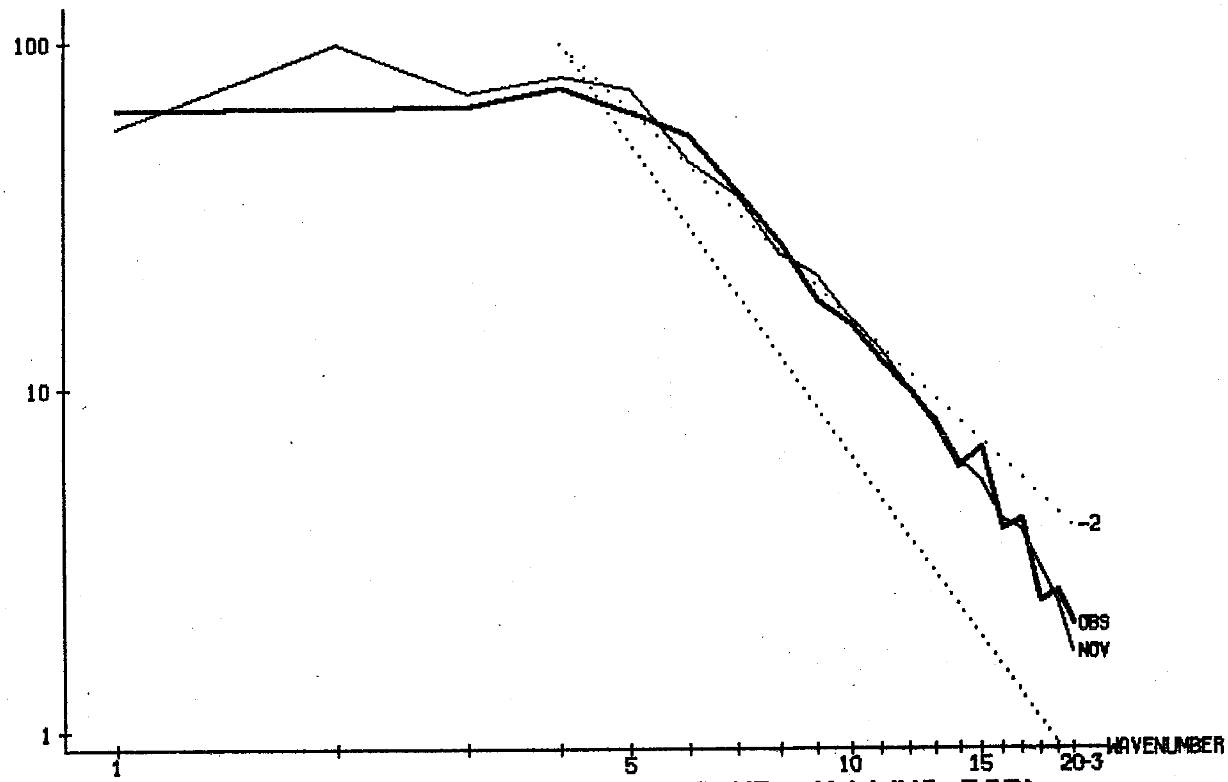
SPECTRUM OF KINETIC ENERGY 300 MB KJ/(M2*BAR)



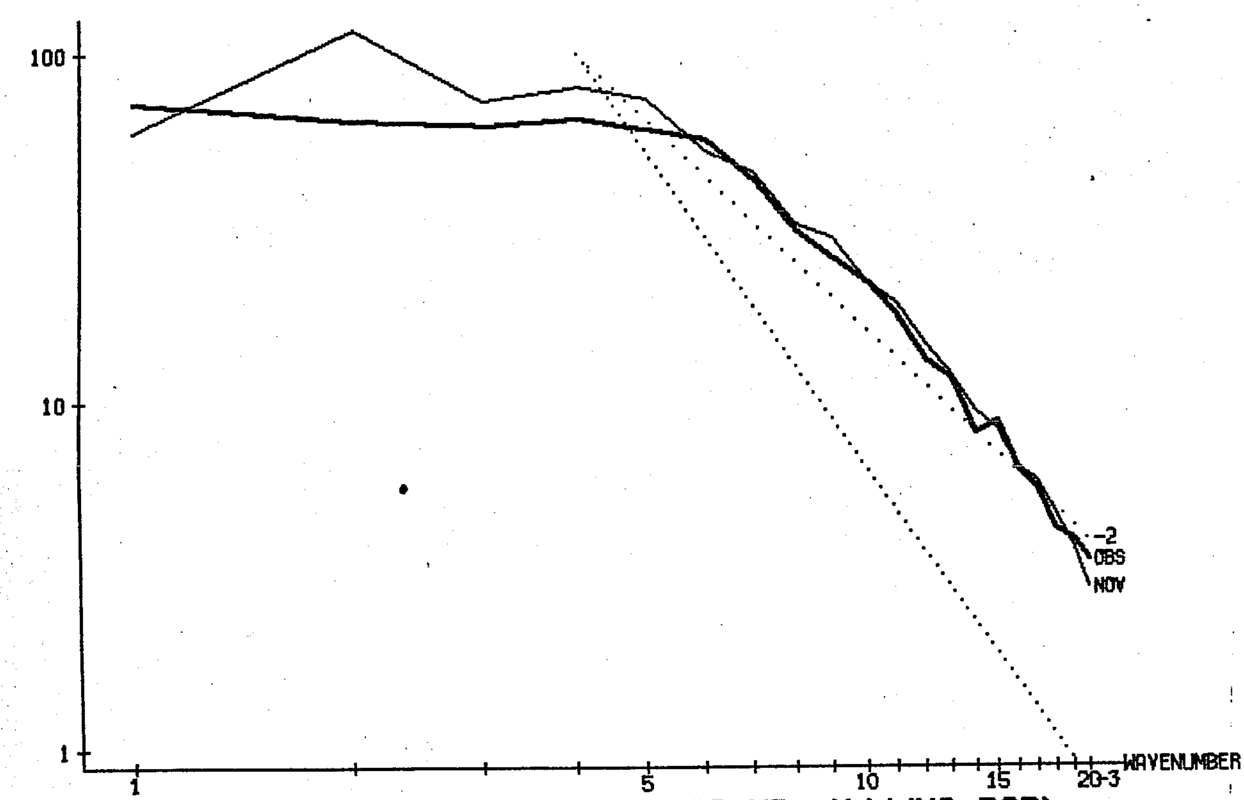
SPECTRUM OF KINETIC ENERGY 500 MB KJ/(M2*BAR)

DAY 7.0 TO 10.0 MEAN BETWEEN 40.0 AND 60.0 GEOSTR

Fig. 47



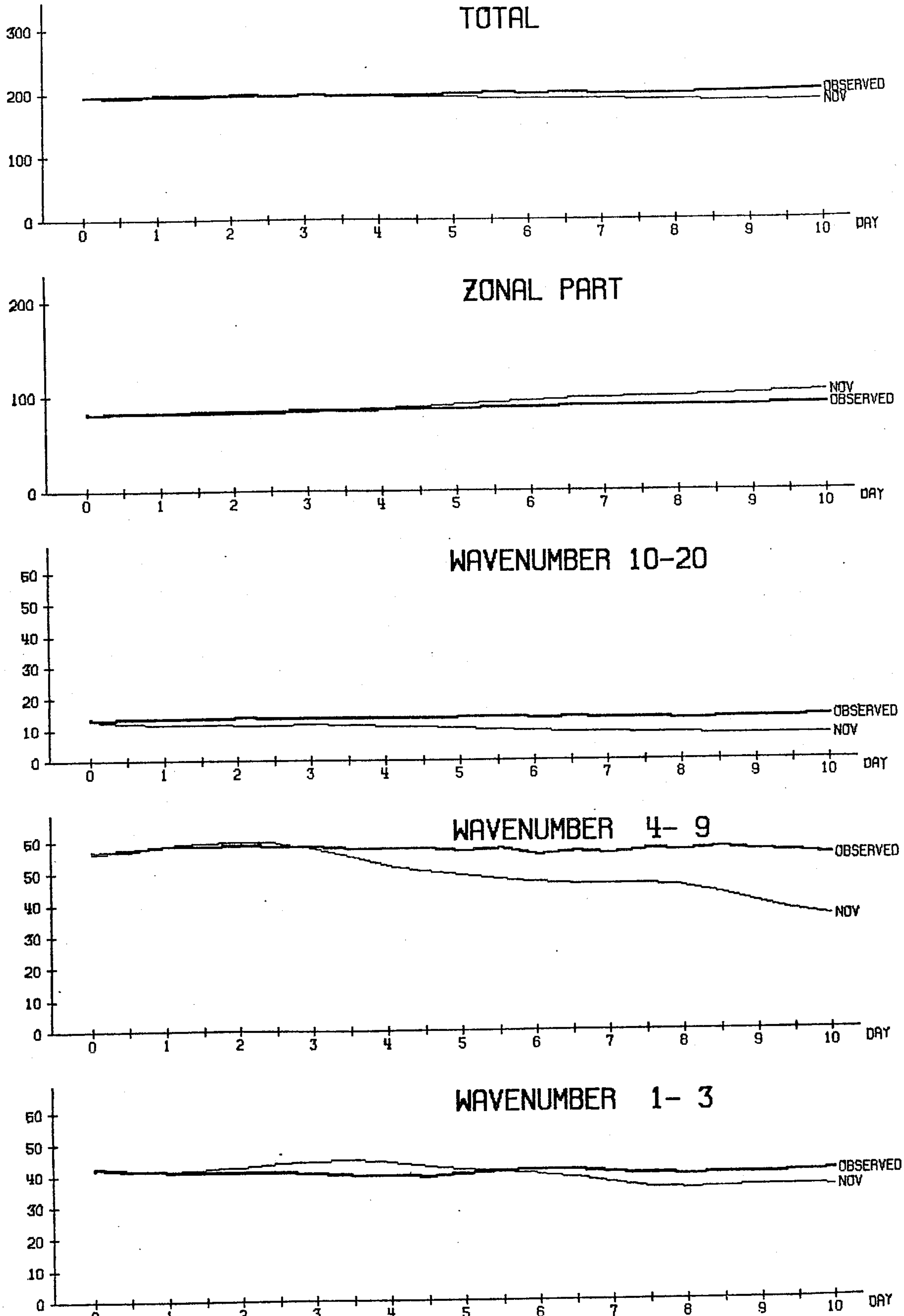
SPECTRUM OF KINETIC ENERGY 850 MB KJ/(M2*BAR)



SPECTRUM OF KINETIC ENERGY 1000 MB KJ/(M2*BAR)

DAY 7.0 TO 10.0 MEAN BETWEEN 40.0 AND 60.0 GEOSTR

Fig. 48



INTEGRAL 1000- 200 MB AREA MEAN 20.0- 82.5 N
KE (10 KJ/M2) 21 CASES GEOSTR

Fig. 49

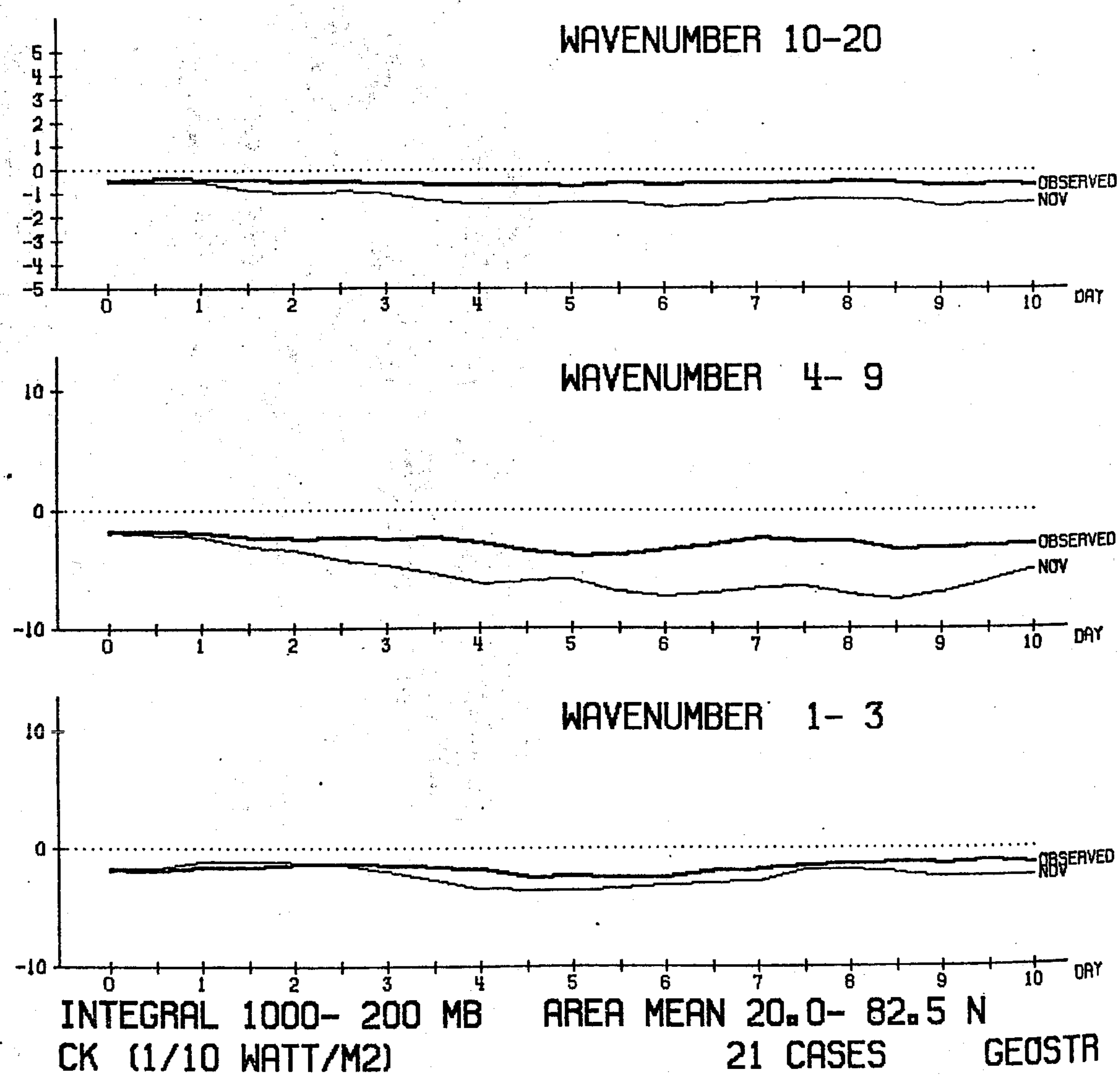

WAVENUMBER 10-20
6
4
3
2
1
0
-1
-2
-3
-4
-5
OBSERVED
NOV
0 1 2 3 4 5 6 7 8 9 10
DAY
WAVENUMBER 4- 9
10
0
-10
OBSERVED
NOV
0 1 2 3 4 5 6 7 8 9 10
DAY
WAVENUMBER 1- 3
10
0
-10
OBSERVED
NOV
0 1 2 3 4 5 6 7 8 9 10
DAY
INTEGRAL 1000- 200 MB AREA MEAN 20.0- 82.5 N
CK (1/10 WATT/M2) 21 CASES GEOSTR

Fig. 50

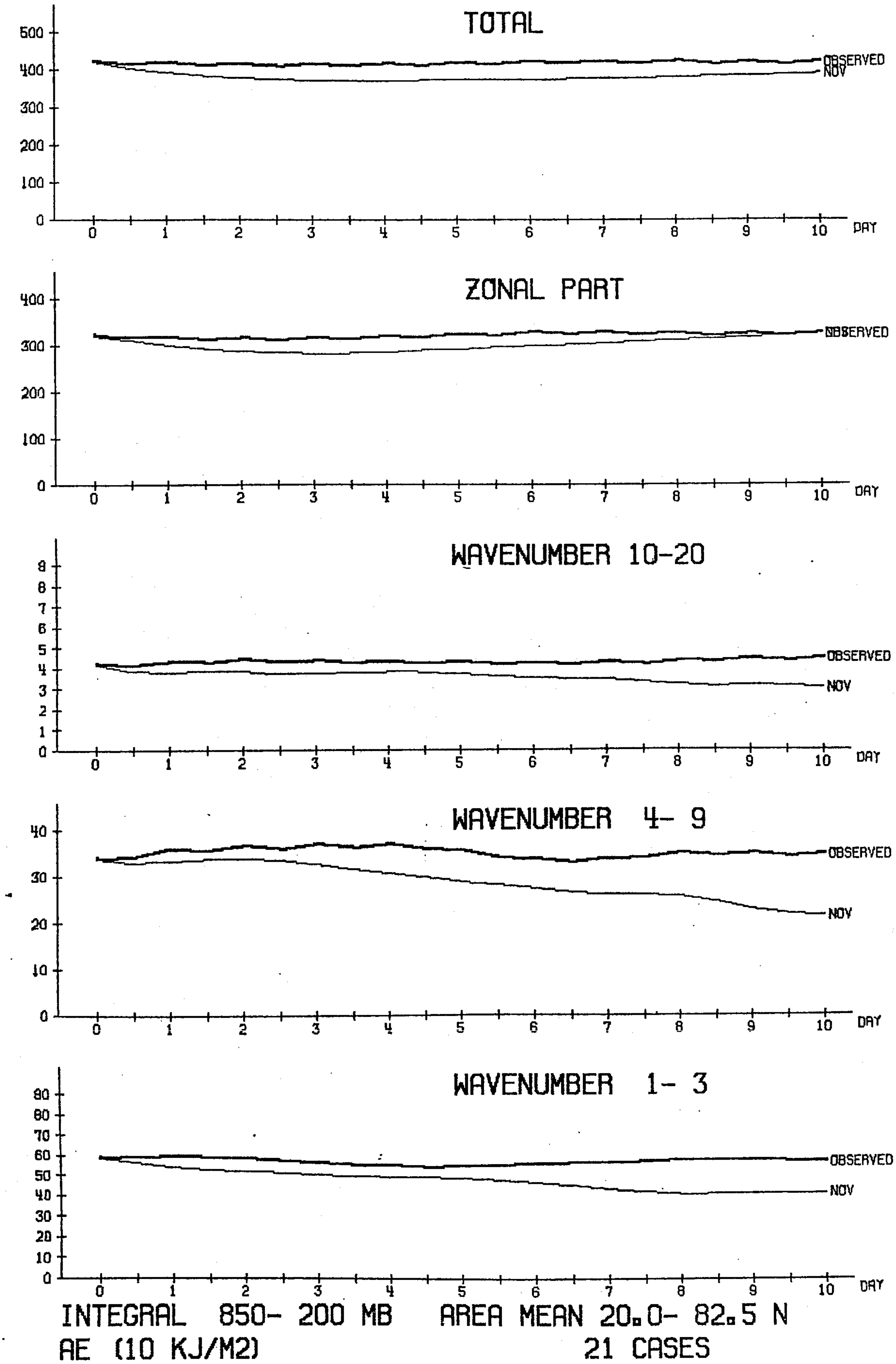

TOTAL
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 DAY
OBSERVED
NOV
ZONAL PART
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 DAY
OBSERVED
WAVENUMBER 10-20
9
8
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 DAY
OBSERVED
NOV
WAVENUMBER 4- 9
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 DAY
OBSERVED
NOV
WAVENUMBER 1- 3
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 DAY
OBSERVED
NOV
INTEGRAL 850- 200 MB AREA MEAN 20.0- 82.5 N
AE (10 KJ/M2) 21 CASES

Fig. 51

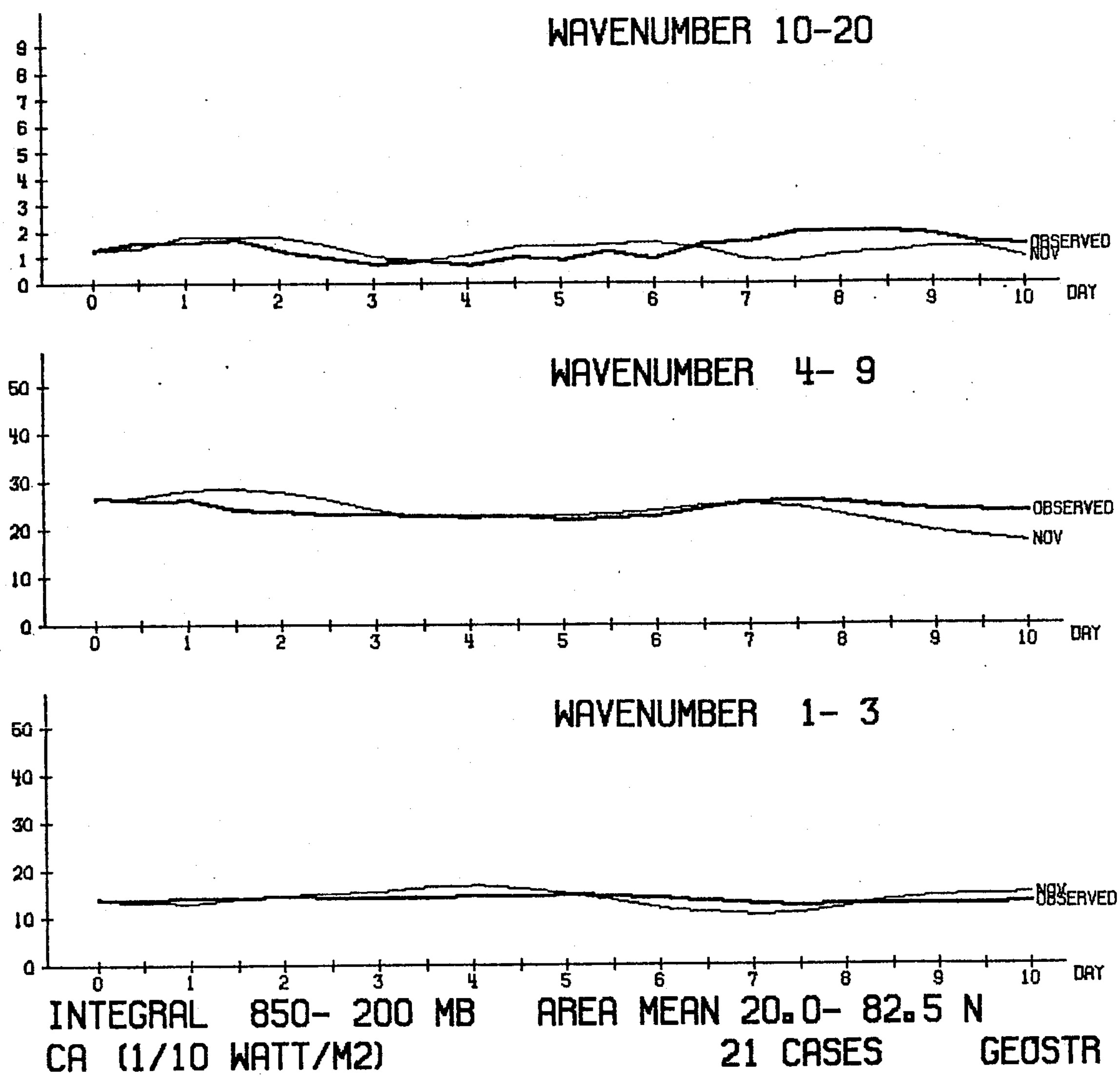

WAVENUMBER 10-20
OBSERVED
NOV
DAY
WAVENUMBER 4- 9
OBSERVED
NOV
DAY
WAVENUMBER 1- 3
NOV
OBSERVED
DAY
INTEGRAL 850- 200 MB AREA MEAN 20.0- 82.5 N
CA (1/10 WATT/M2) 21 CASES GEOSTR

Fig. 52

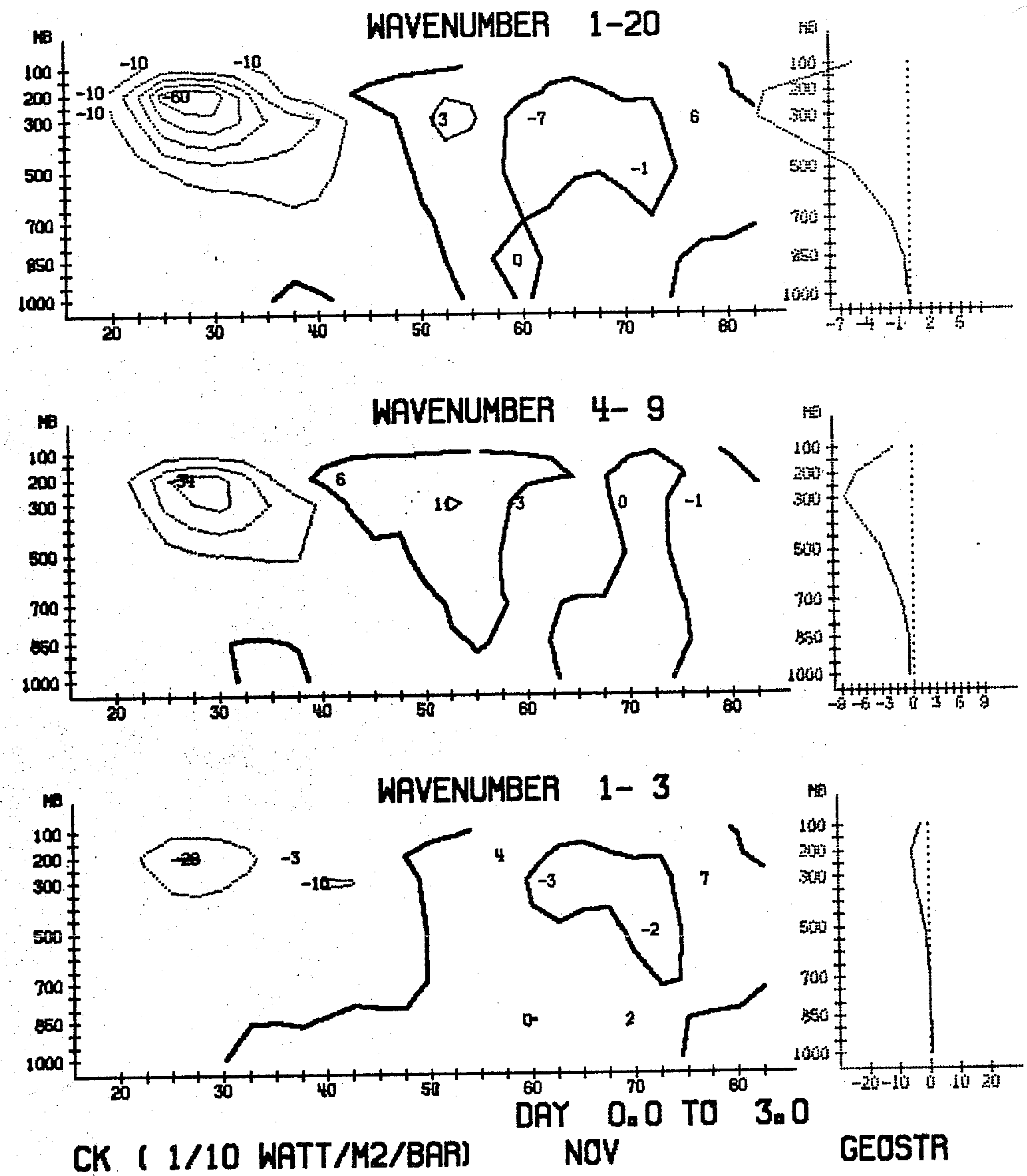

WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
DAY 0.0 TO 3.0
CK (1/10 WATT/M2/BAR)
NOV
GEOSTR

Fig. 53

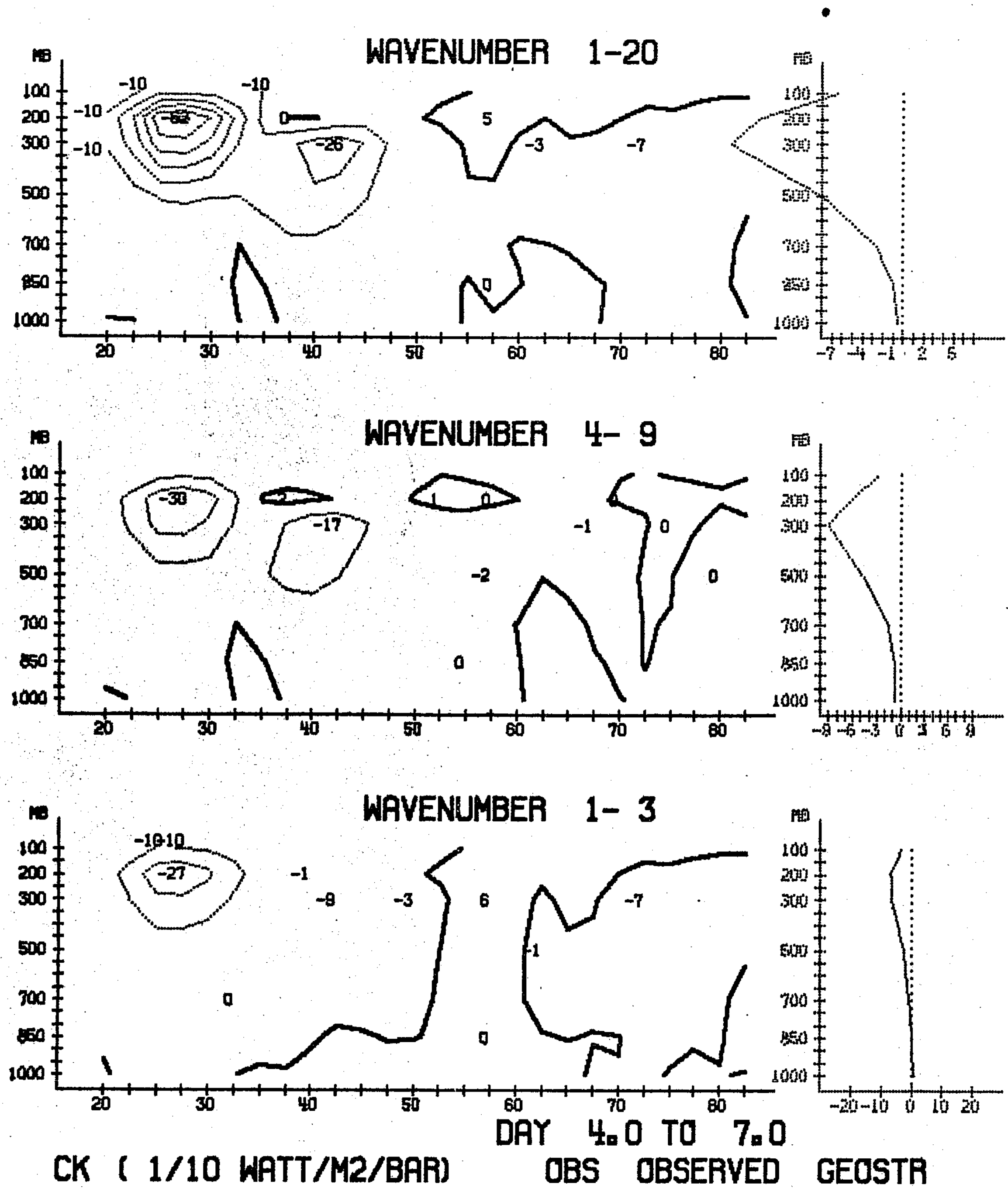

WAVENUMBER 1-20
WAVENUMBER 4- 9
WAVENUMBER 1- 3
MB
DAY 4.0 TO 7.0
CK (1/10 WATT/M2/BAR) OBS OBSERVED GEOSTR

Fig. 54

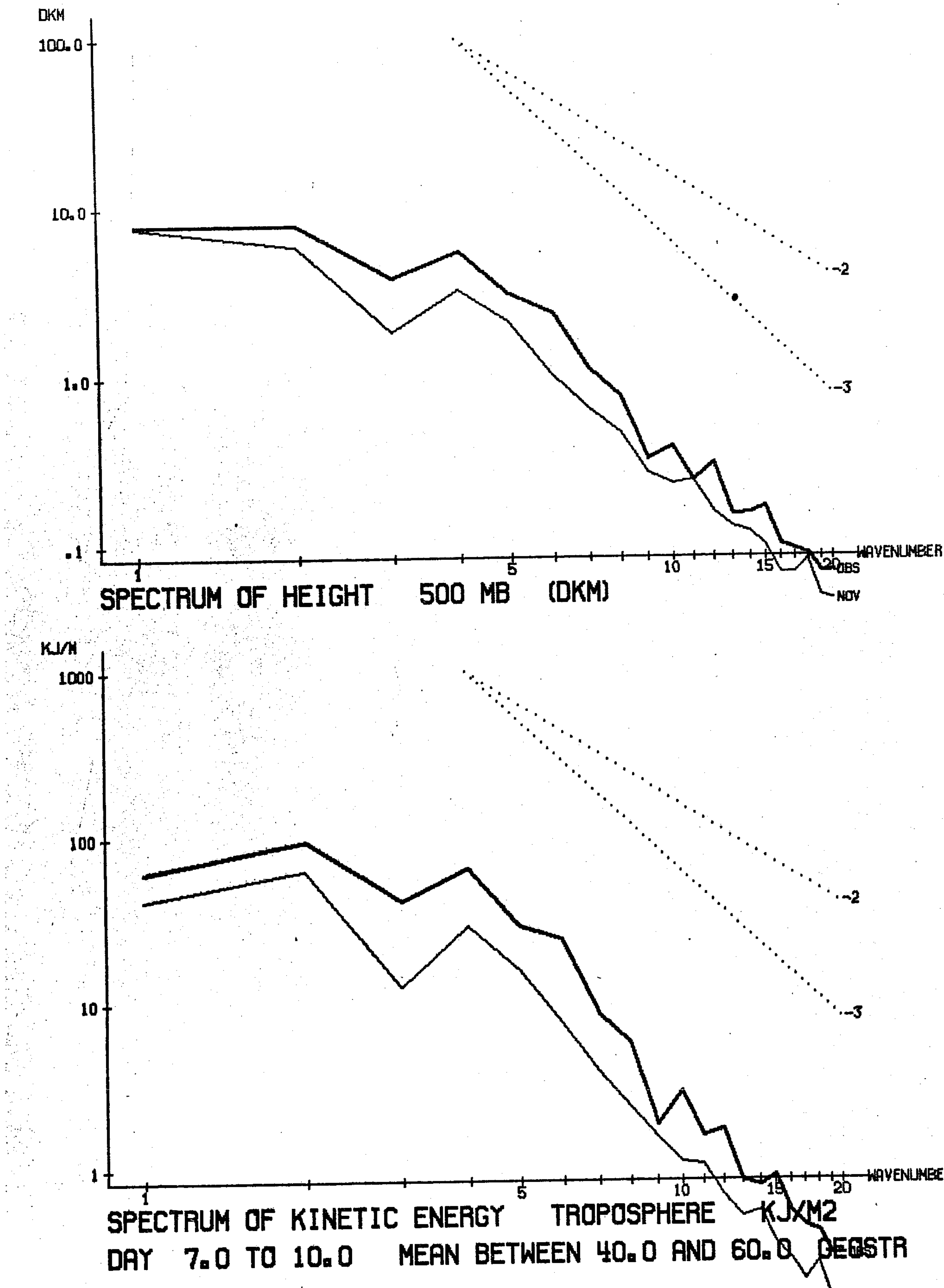

DKM
100.0
10.0
1.0
.1
-2
-3
WAVENUMBER
1
5
10
15
20
OBS
NOV
SPECTRUM OF HEIGHT 500 MB (DKM)
KJ/M
1000
100
10
1
-2
-3
WAVENUMBER
1
5
10
15
20
SPECTRUM OF KINETIC ENERGY TROPOSPHERE KJ/M2
DAY 7.0 TO 10.0 MEAN BETWEEN 40.0 AND 60.0 DEGSTR
NOV

Fig. 55

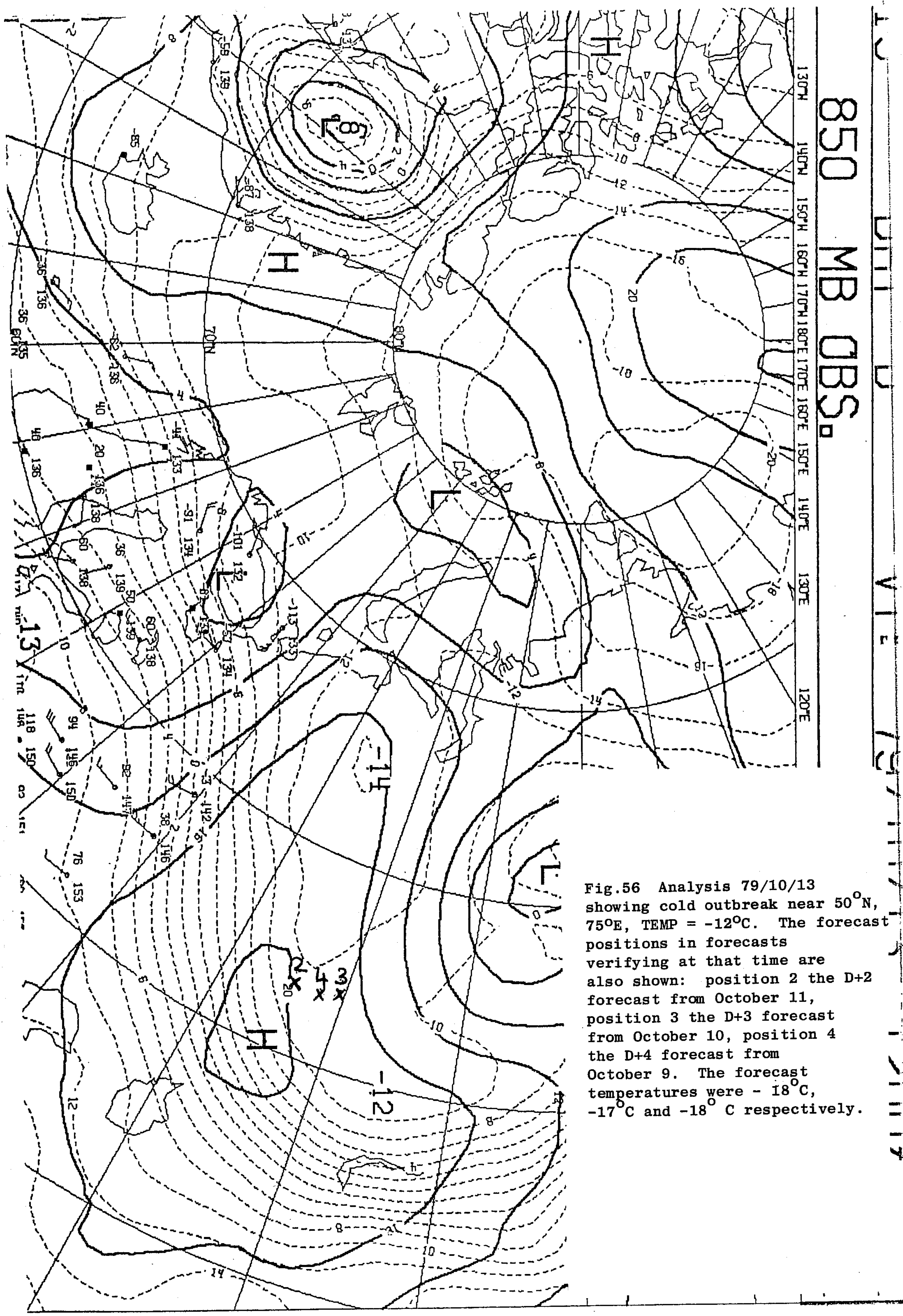


Fig.56 Analysis 79/10/13 showing cold outbreak near 50°N, 75°E, TEMP = -12°C. The forecast positions in forecasts verifying at that time are also shown: position 2 the D+2 forecast from October 11, position 3 the D+3 forecast from October 10, position 4 the D+4 forecast from October 9. The forecast temperatures were - 18°C, -17°C and -18° C respectively.