TOVS DATA PROCESSING AT THE HYDROMETEOROLOGICAL CENTRE OF RUSSIA

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1. INTRODUCTION

A most important purpose of the satellite sounding program in HMC is to improve the numerical weather forecast by means of effective incorporation of sounding products (in particular TOVS-derived sounding products) into regional or hemispheric objective analysis scheme, see (Bagrov et al, 1990). Considerable efforts have been made during last three years to install the software package for TOVS data operational processing and to increase the accuracy and the spatial resolution (if possible) of satellite retrievals.

As a result the operational TOVS data processing scheme has been designed and implemented at HMC in 1990. The scheme (which we call briefly HMCTPP-1-Hydrometeorological Centre TOVS Processing Package, version 1) provides local area TOVS data handling in operational mode and production of temperature and humidity profiles, the estimates of cloud coverage parameters. Along with this scheme a refined version of HMCTPP has been developed (HMCTPP-2) which permits to "inverse" satellite data with maximum horisontal resolution corresponding to one pixel of HIRS/2. Section 2 of this paper reviews briefly the HMCTPP processing schemes and the main modifications and changes which have been brought to the original one (Uspensky e.a., 1990). In subsection 2.2 we discuss in some detail the choice of appropriate first guess for the retrievals. The results of HMCTPP products accuracy evaluation obtained in trials with real data are presented in section 3. Some unresolved problems are outlined in section 4.

2. TREATMENT OF TOVS DATA

2.1. General description

The first version of software for TOVS processing has been designed on the base of " TOVS Export Package ", excepting the software for preprocessing of TOVS data, which is original, see (Uspensky et al, 1990). Description of basic algorithms can be found in (Uspensky, Tretjakov, 1989).

Raw TOVS data in TIP form are acquired directly by reception facilities (HRPT receiving ground-station C.I.R.) and injected into PC, which is connected to C.I.R. The preprocessing of raw data is performed on PC AT . The handling of preprocessed data (inversion of radiances and retrieval of atmospheric parameters) is made on COMPAREX computer using first-guess information from the HMC data base. The HMCTPP schemes are linked with the HMC data base and the final product of processing is incorporated into it. The processing of local area TOVS data enables us to obtain the satellite estimates of vertical temperature T (p) and humidity q (p) profiles (in terms of mixing ratio) for the European part of Russia with spatial resolution corresponding to the 3x3 HIRS/2 pixels assembly size (HMCTPP-1) or one pixel size (HMCTPP-2).

The experiments with the first version of TOVS processing scheme highlighted a number of deficiencies and weaknesses of it. Therefore the design of the HMCTPP-1 required some modifications and refinements of algorithms. The most essential modifications and improvements of original algorithms and software concern:

- modification of the first guess preparation for retrieval procedures;
- incorporation the revised version of "radiance correction" procedure for data adjustment based on the analysis of residuals according to (Plokhenko, Uspensky, 1987);
- changes in the algorithm of the estimation of inverse

problem solution.

One of the main new features of the HMCTPP-1 scheme consist in using the 12h numerical weather forecast profiles $T^f(p), q^f(p)$ as the first guess in satellite radiances inversion. We construct first-guess profiles $T^o(p)$ combining $T^f(p)$ up to 100hPa with results of objective analysis T(p) for preceding date and layer between 100 and 10hPa (24h inertial forecast); profiles $q^o(p)$ are formed using $q^f(p)$ for troposphere and "climatological" estimates $q^c(p)$ for more high levels.

The processing scheme HMCTPP-2 which has been implemented into operational practice in summer 1992 provides the retrieval of atmospherical parametres for every second pixel of every HIRS/2 scanline. It enables to obtain the sounding products with spatial resolution of order 40 km in subsatellite point.

The scheme HMCTPP-2 has some minor changes which have been brought to the HMCTPP-1. They concern:

- a new test for evaluation of quality and consistency of measurements in HIRS/2, MSU channels based on radiative transfer forward model calculations;
- modified algorithm for the calculation of the first derivative $dJ(\nu)/dq$, where $J(\nu)$ is radiance;
- derivation of sounding products in cloudy conditions on the base of HIRS/2 measurements (over the clouds).

To conclude this section note that in parallel with development and using operational TOVS processing scheme the work is continued in porting of the HMCTPP code to the PC environment.

2.2. Choice of the first guess.

It is now well recognized that the accuracy of satellite sounding products depends strongly on the quality of apriori information used in "inversion" of satellite data and, in particular, on the quality of first guess solution. Due to nonlinearity and ill-posesness of original inverse problem there are rather close relations between the information content of satellite data (also the information content of retrievals) and the quality of the first guess.

The information content of satellite data and the quality of apriori information (first guess) are the main factors which define the information content of retrievals or its accuracy characteristics (systematic and random components of error).A brief discussion on this topic is given below.Let us consider the following linear model of satellite measurements: $v = Fx + e$. Here y is a result of measurements, x is a vector of unknown parameters, F is a matrix approximating the forward radiative transfer operator and e are the errors with known covariance matrix S .Starting from first guess solution with known covariance matrix (DO) of first guess errors the minimum variance solution (the best linear estimator) can be obtained in the form

$$\hat{x} = ((DO)^{-1} + M)^{-1} * F^T * S^{-1} * y, \quad D(\hat{x}-x) = ((DO)^{-1} + M)^{-1},$$

where $M = F^T * S^{-1} * F$ is information matrix, see, for example, (Eyre e.a., 1986), (Uspensky, 1990). The information content of v with respect to x can be defined through invariants (eigen values) of matrix $U = (DO) * M$. More simple (but not invariant) quantitative measure of information content is the following value: $R(x(k)) = (var(x(k)) - var(\hat{x}(k)-x(k)))/var(x(k))$, where var(x(k)) is the variance of x(k), $var(\hat{x}(k)-x(k)) = (D\, x(k)-x(k))$. The empirical estimates of R(T), R(q) are presented in section 3. The difference $d = \hat{x}-x$ can be written as

$$d = (I - C * F) * (x^o - x) + C * e = d(sys) + d(rnd),$$
$$C = ((DO)^{-1} + M)^{-1} * F^T * S^{-1}.$$

The systematic component $d(sys) = (I - C * F) * (x^o - x)$ or bias depends on (x^o-x) through operator $(I - C*F)$, where $C*F$ is averaging operator. The operator $(I - C*F) = (I + (DO) * M)^{-1}$ is not shrinking. Employing the definition $x^o = B * x$ the value d(sys) can be written as d(sys) = (I - C*F) * (I-B) * x . It follows from this: ‖d(sys)‖ = ‖I - C*F‖ * ‖I-B‖ * ‖x‖ . Hence it is possible to reduce the norm ‖d(sys)‖ reducing ‖I - B‖. The reducing of the last value is reached by the choice of "excellent quality" first guess.

It is reasonable to note that the useful quantitative measure of systematic error (called the vertical resolution measure) is defined in (Backus, Gilbert, 1968; Conrath, 1972). This quantity similar to ‖I-C*F‖ depends on the behaviour of operator C*F . The estimates of quantities like ‖I - C*F‖ are obtained in (Uspensky et al, 1984) for different measurement schemes. To summarize this section the information content and accuracy characteristics of retrievals depend on appropriate choice of first guess.

3. RESULTS OF OPERATIONAL RETRIEVAL ERROR ANALYSIS

Here we summarize the results of systematic comparisons of the satellite sounding products (temperature and humidity profiles) with collocated RAOB data.The assessment of retrievals quality has been performed using several sets of real data corresponding autumn period of 1990 for HMCTPP-1 and the period August - December 1992 for HMCTPP-2.

The accuracy estimates for HMCTPP products are given in (Plokhenko, Uspensky, 1992). Some of these estimates have been produced in the HMC laboratory of objective analysis using technique from (Tsyrulnicov,1990). The satellite estimates for profiles T , q and heopotential thickness H (relative to 1000 hPa) were compared with RAOB data.The mean distance between positions of satellite and radiosonde measurements is 140 km,the maximum time difference is 6 hours. The derivation of $\hat{H}$ is based on spline-quadrature solution of hydrostatic equation (using profiles $\hat{T}$).The comparisons have been done for retrievals at 6 dates in autumn 1990 (10.09; 17.09; 16.10; 29.10; 06.11; 10.11). Total number of realisations is 2183.

In parallel with comparisons of satellite and RAOB data analysis of first guess accuracy has been performed. The basic statistics (mean biases(b),standard deviations ,RMS differences(rms) for retrieved profiles (with subscript "I") at 6 levels and for first guess profiles (with subscript "II") are given in table 1.

Table 1

The satellite ($\hat{T}$, $\hat{q}$) and first guess (T^{o}, q^{o}) profiles versus RAOB data

P (gPa)		10.09.90, N = 383					Total sample, N = 2183			
		$b(I)$	$s.d.(I)$	$b(II)$	$s.d.(II)$	$R(x(k))$	$rms(I)$	$rms(II)$	ρ	rms
	H	- 7	12(14)	-	-	-	13	-	-	19
850	T	0.48	1.57	0.78	1.61	0.15	2.4-0.3	2.5-0.3	0.02	3.1
	q	1.09	3.80	1.03	3.90	0.16	2.6-1.0	3.1-1.0	0.08	-
	H	0	18	-	-	-	20	-	-	29
700	T	1.89	1.57	2.10	1.85	0.39	2.4-0.2	2.4-0.3	0.12	2.5
	q	-0.56	2.92	-0.49	2.97	0.13	3.4-1.0	3.3-1.1	0.15	-
	H	18	28(33)	-	-	-	34	-	-	40
500	T	1.58	1.56	1.05	1.63	0.20	2.1-0.2	2.1-0.2	0.19	2.6
	q	-2.96	1.48	-2.99	1.49	0.08	1.8-0.7	1.9-0.7	0.04	-
250	H	50	43(66)	-	-	-	59	-	-	58
	T	2.16	2.97	2.00	2.98	0.06	2.0-0.3	2.7-0.3	0.07	2.5
100	H	79	65(102)	-	-	-	74	-	-	65
	T	1.57	1.65	0.28	1.67	0.11	1.9-0.1	1.5-0.1	0.09	2.7
50	H	103	62(120)	-	-	-	100	-	-	81
	T	2.20	1.56	0.30	1.76	0.34	2.0-0.2	1.8-0.2	0.23	2.2

They concern two samples: first for one date (10.09.90) and second for all 6 dates. The values of informativities R(T),R(q), introduced in subsection 2.2,are also shown in table 1.Together with described values we present in the last column of table 1 the values of RMS errors for SATEM data (heopotential heights H and temperature profiles T) which are regularly received through GTS. SATEM data relate to 3 dates of november 1990.

Analysis of table 1 shows that the accuracy characteristics of retrievals and first guess are close to each other. Improvement of rms errors for satellite products is insignificant or absent in statistical sense. The values of standard deviations, are a bit smaller than analogous values for T^f, q^f. It leads to the conclusion (in frame of above discussion) that the information content of satellite retrievals is small but positive ($R(T)>0, R(q)>0$); in other words we have a very marginal positive impact of satellite measurements for the temperature and humidity soundings, see also (Baker e.a., 1990), (Eyre e.a., 1986). The enhancement of rms values at level higher than 500 hPa is explained by the growth of mean biases . The most probable cause for this consists in the quality of radiative transfer forward model calculations and presence of some disturbing factors. According to table 1 the accuracy of "standard" SATEM data is close to accuracy of HMCTPP-1 data. For the lower levels the HMCTPP-1 products are a little better but for the upper levels they are poorer than SATEM data due rather big biases.

The values of RMS differences between satellite retrievals $\hat{T}$ produced by HMCTPP-2 and RAOB data T are presented in table 2 for several months 1992.

Table 2.

Temperature retrievals statistics for August - December 1992
RMS differences between collocated satellite retrievals and RAOB data

level(hPa) \ month	8	9	10	11	12
1000	3.7	4.3	6.3	4.1	4.1
850	2.3	2.4	4.5	3.1	3.0
700	1.5	1.9	2.5	2.5	2.0
500	1.5	1.6	2.6	2.4	2.1
400	1.7	1.8	3.1	2.7	2.6
300	1.9	1.9	2.7	2.5	2.4
250	2.8	2.4	2.9	2.9	2.8
200	2.7	2.5	3.0	3.1	2.6
150	1.7	1.8	2.1	1.8	1.9
100	2.2	2.4	2.2	2.6	2.3
70	2.1	1.7	2.7	2.8	2.7
50	2.3	1.8	3.5	3.2	3.4
30	2.9	2.4	3.5	3.0	4.0
20	2.9	2.7	3.5	4.1	4.2

The total number of pairs (retrieval, RAOB) exceeds 300 for every month. The maximum distance for comparisons is 1° while the maximum time difference is 6 hours.

From table 2 we can see that the RMS errors are changing with time. Apparently this fact is caused by such reasons as: - different sounding conditions (clear or cloudy atmosphere); - variations of the first guess accuracy; - sample effects. It is also noteworthy that the accuracy characteristics are better and more stable for summer and early autumn dates.

The accuracy characteristics in tables 1,2 are based on the comparisons of pixel-averaged quantities with the pointwise measurements. It seems reasonable to obtain supplementary data on the satellite retrievals quality and informativity comparing the charts (fields) of retrievals with the first guess fields at standard levels. Examples of such fields are presented in (Plokhenko, Uspensky, 1992) for HMCTPP-1 scheme. The analysis of these data shows that: - the satellite retrievals fields are rather smooth; - the structure of cloud picture is similar to the structure of cloud amount chart; - the T fields are rather close to T fields, excluding some limited zones.

In this paper we show the examples of T fields at levels 850, 500, 250 hPa (fig.1-3) and q fields at levels 850, 500 hPa (fig.4,5). The retrievals T, q for 04.02.1993 are derived from NOAA-11 data using HMCTPP-2 scheme. The RAOB data are also shown at fig.1-5. These examples demonstrate that the similarity between two kinds of data takes place (spatial structure of both fields are similar).

The comparison of products of both described schemes demonstrate that the HMCTPP-II fields contain some new structure peculiarities. The discrepancies between both kinds of data were identified to be main the result of different space resolution. But the potential improvement over temperature and humidity data profiling accuracy due to HMCTPP-2 using is questionable and data validation should be performed through assimilation experiments in mesoscale numerical weather forecast models.

4. CONCLUSIONS AND FUTURE WORKS.

The activity described before has led to the development of TOVS data processing scheme HMCTPP-1. The operational application of this scheme in HMC is in progress now. With regard to the future development of the operational TOVS processing system it is intended:

1). To modify the procedure of cloud-clearing and estimation of cloud parameters on the base of increasing the number of analysed HIRS/2 channels;

2). To incorporate the new procedures of models correction and adjustment with explicit dependance on angular distances of the observations from satellite nadir;

3). To consider the effects of surface emissivity;

4). To utilize as the first guess the results of regional numerical weather forecast with enhanced space resolution and with constraints (error covariances).

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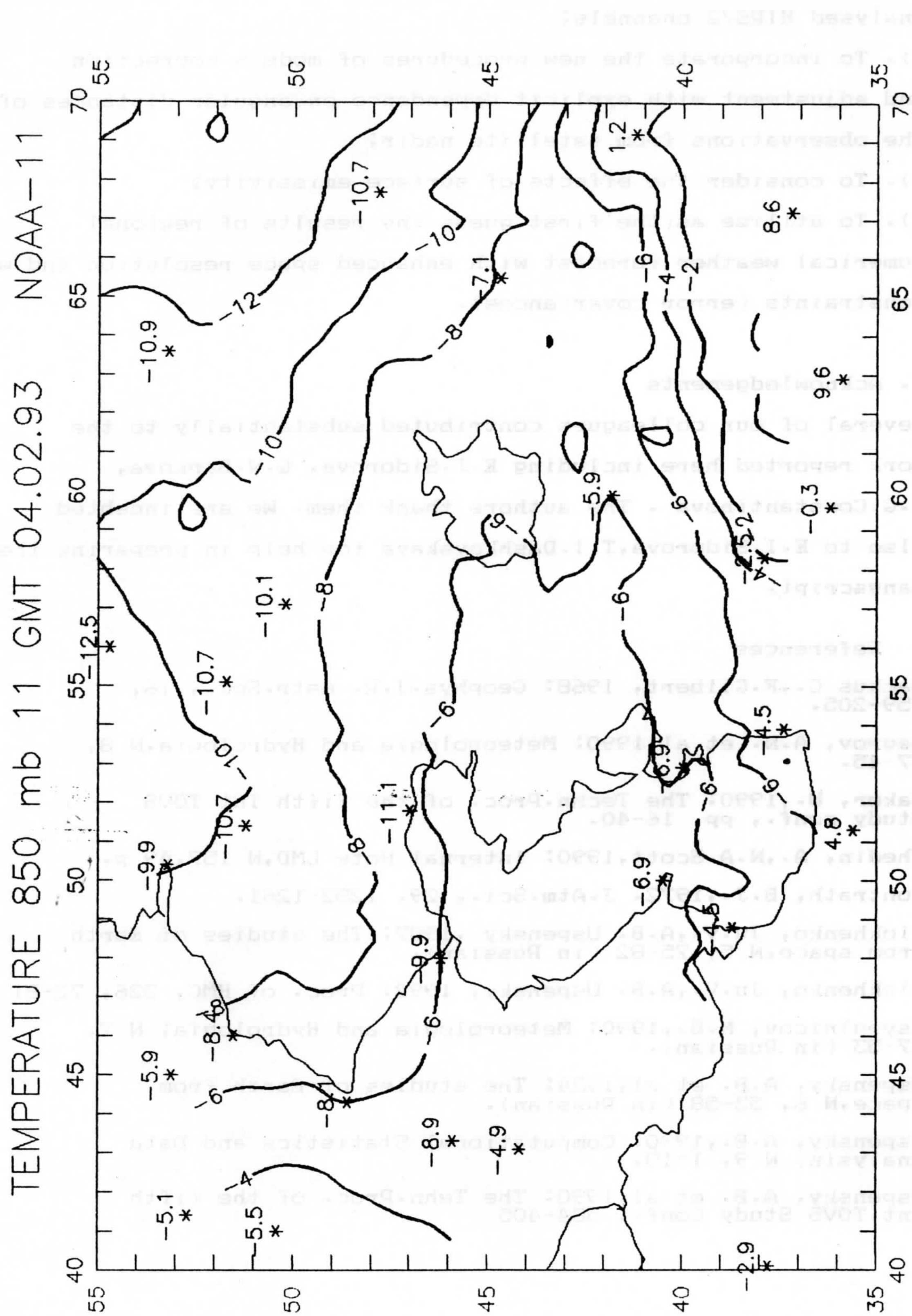
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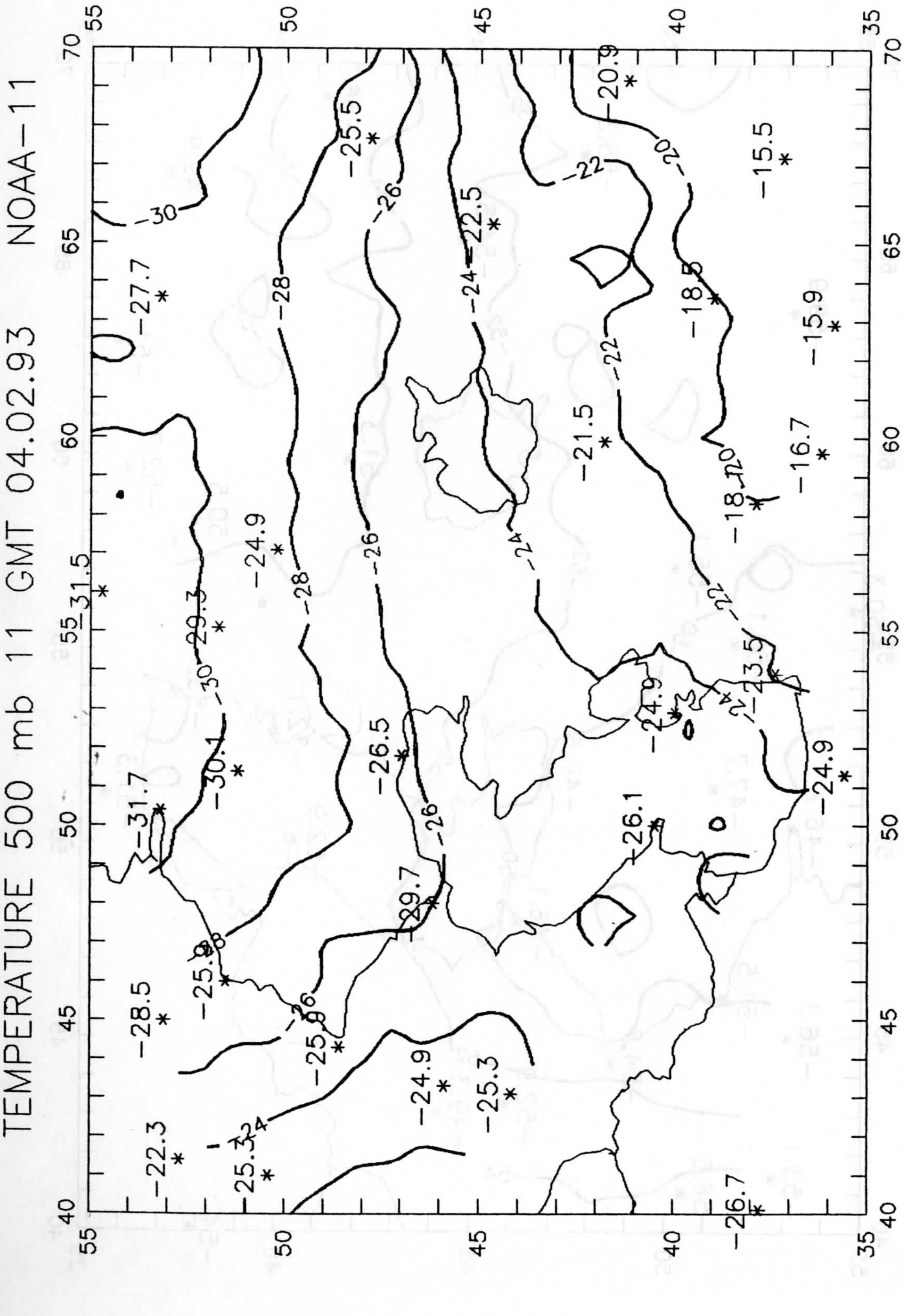
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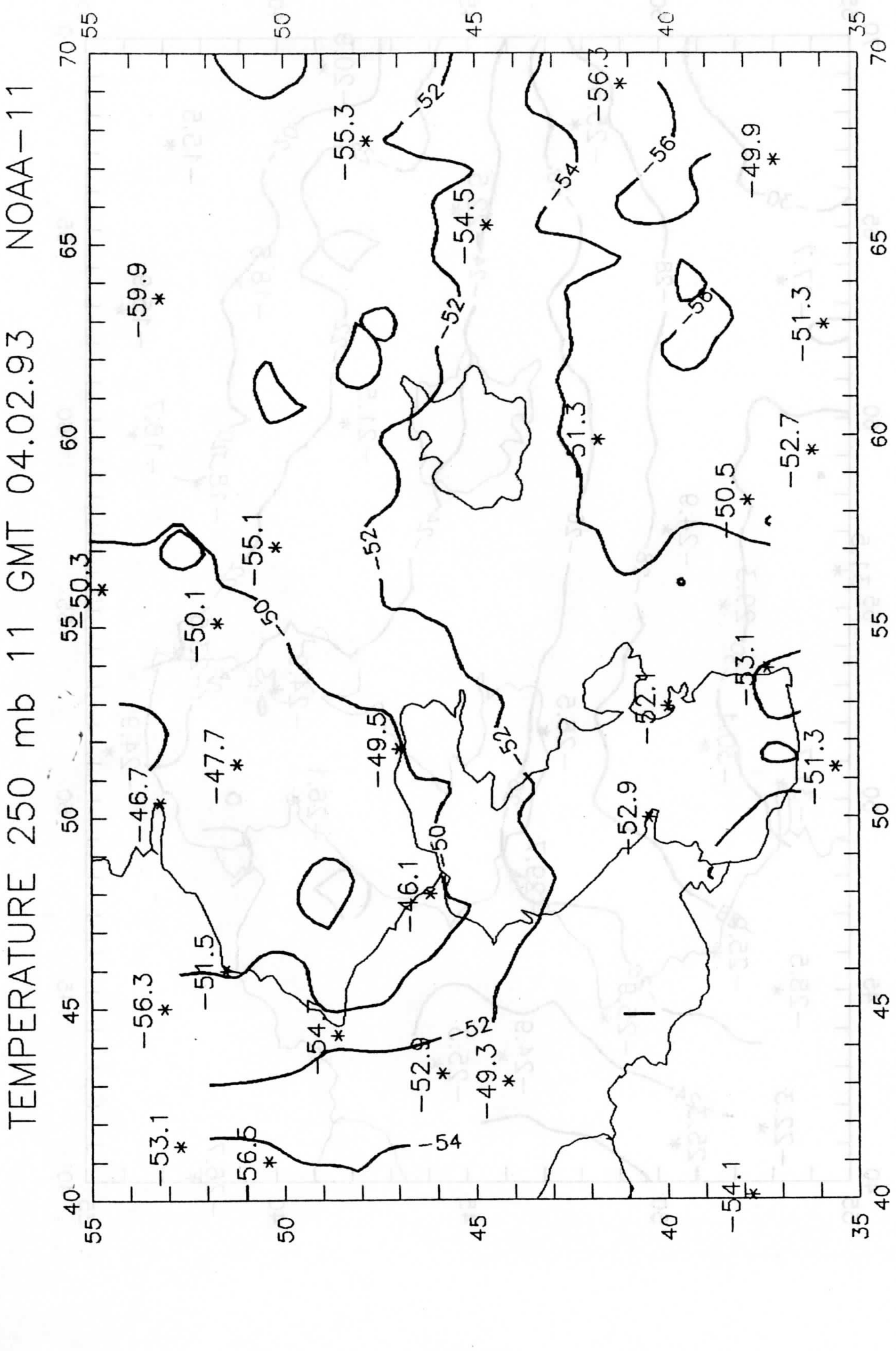
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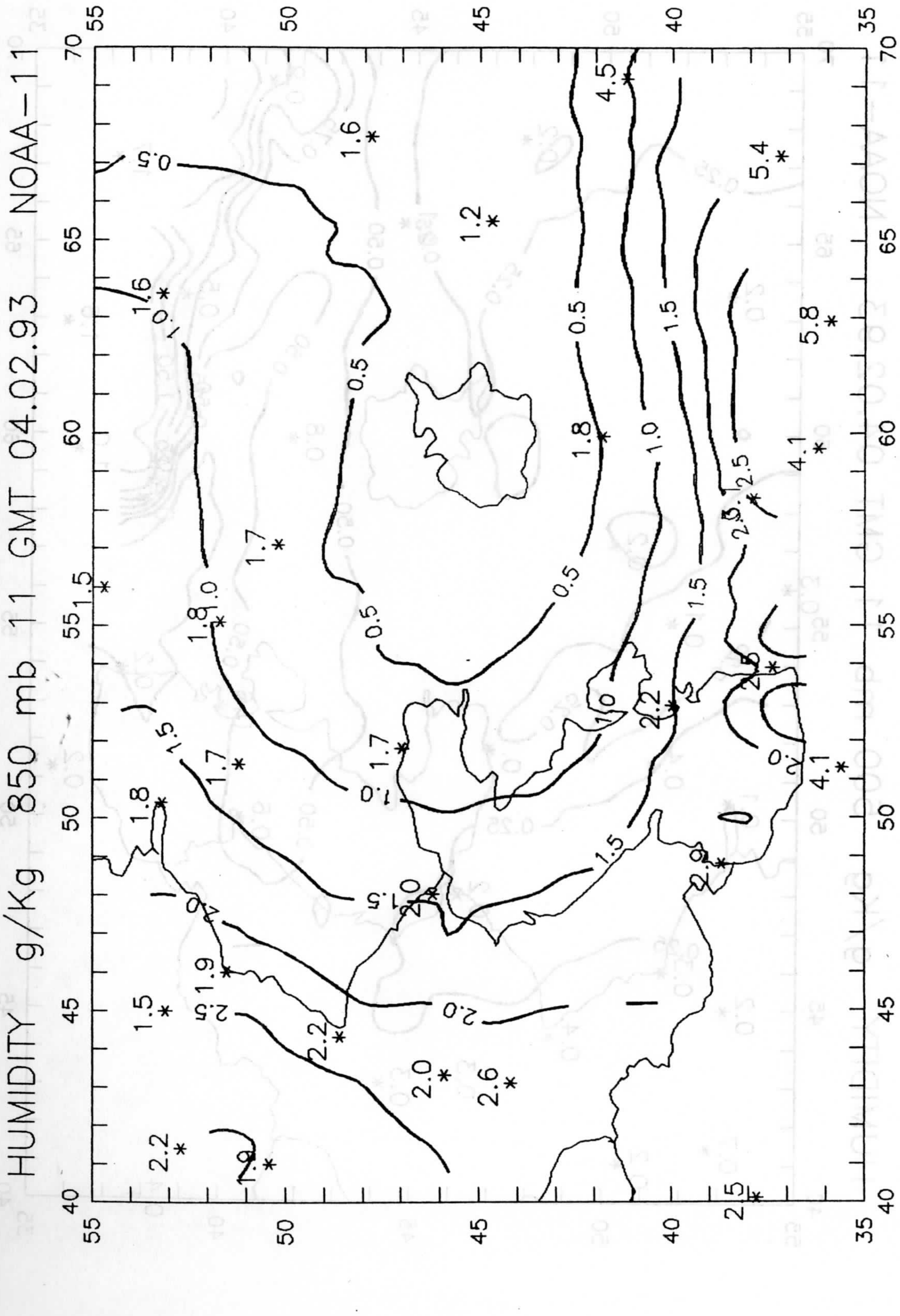
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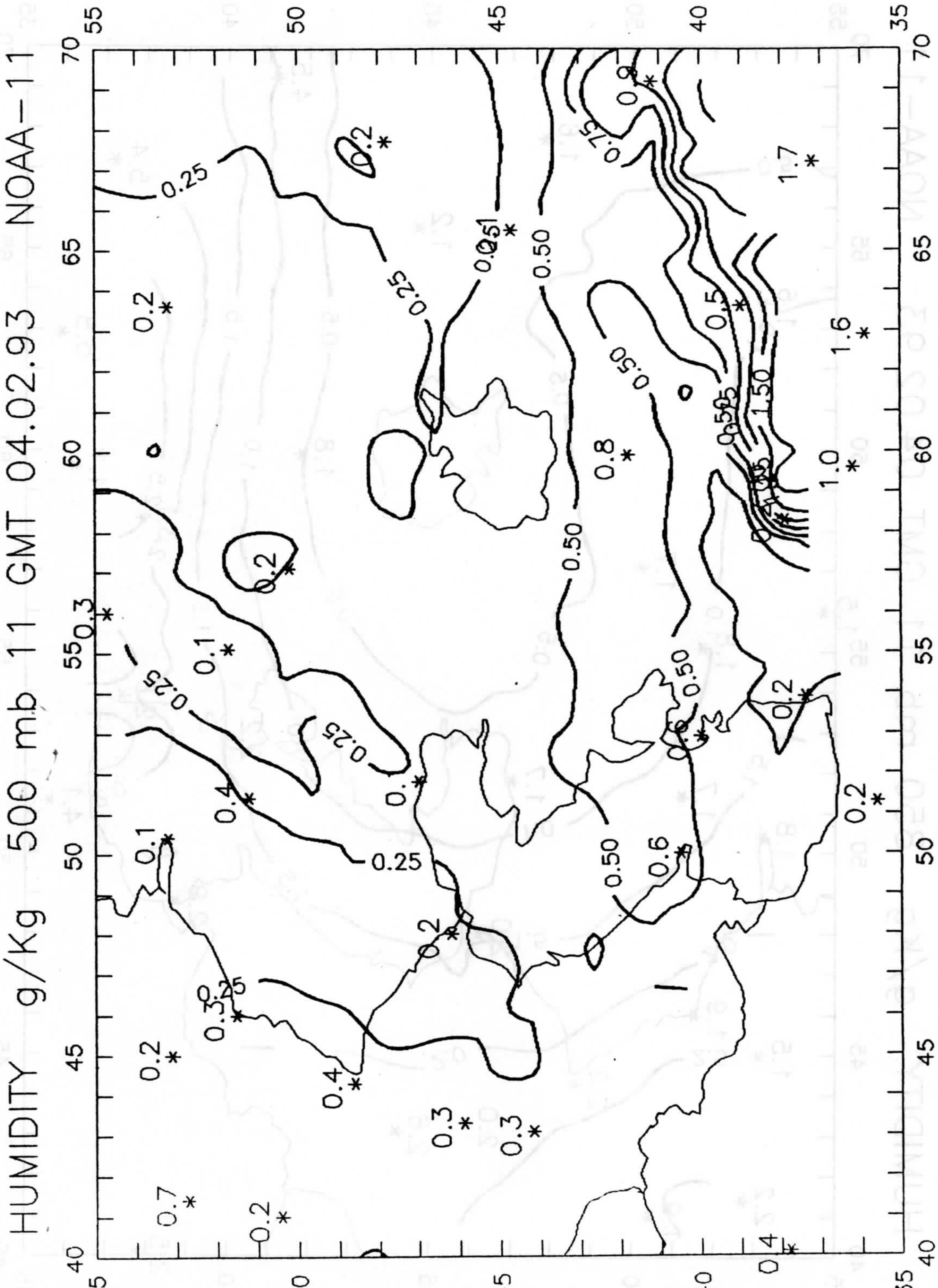
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