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By COOK,I.S. and HUNT,R.D.

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IMPROVEMENTS IN THICKNESS RETRIEVALS OBTAINED BY SPECIFYING THE 75 MB TEMPERATURE

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I. S. Cook and R. D. Hunt

Introduction

The maximum probability method of retrieval (ref 1) uses independent climatological data as a constraint on the solution in order to arrive at a temperature profile, given a set of satellite radiance measurements. The fact that an overlap exists between satellite soundings and ground-based measurements in the troposphere and lower stratosphere suggests that ground-based measurements might perhaps be used as a supplementary source of data, and provide a further constraint. This report describes an investigation into the effect on high level thickness retrievals of specifying the 75 mb temperature.

The retrievals were based on the SCR instrument carried by Nimbus E (ref 2). The weighting functions belonged to the A1 channel, and to the "differenced" channels B34, B23, and B12. The respective weighting peaks lie at 60 mb, 8 mb, 5 mb, and 2 mb (approximately). The constraint was imposed via an extra artificial channel with weighting function unity at the level corresponding to 75 mb, but zero elsewhere. A pair of operator matrices was derived for each latitude-season group; one for the real channels alone, the other for the real and artificial channels combined. As the investigation was concerned with a comparison of retrieval errors, a true profile was needed with which to compare the retrieved ones. The measured radiances were therefore derived synthetically, using the weighting functions, from existing rocketsonde profiles. Measured radiances derived in this fashion from rocketsonde data should be close to the values that would actually be measured by an overhead SCR. The artificial channel's radiance was set to the Planck function for the specified temperature. This temperature would in practice be subject to a degree of error. In order to simulate this, a set of random numbers, normally distributed about zero and with standard deviation $2^{\circ}K$, was added to the initial 75 mb temperatures. An appropriate random error was also introduced into each of the "measured" radiances to simulate instrumental noise.

The initial and retrieved profiles were for the purposes of the investigation expressed in terms of the following thicknesses: 300-30 mb, 300-10 mb, 100-30 mb, 30-10 mb, 100-1 mb, and 3-1 mb. The aim was to find, for each thickness, the percentage reduction in retrieval error over a large sample of profiles brought about by the use of a specified temperature.

Technique

The starting point of the technique was a set of temperature profiles obtained from rocketsonde data. The original values were interpolated on to a 50 level system of discrete atmospheric layers with pressures defined by:

$$P_{n+1} = P_o . \exp(-n/5)$$

where $n = 0, 49$

$P_o = 1013.246$ mb

Level 50 has a pressure of 0.0562 mb. All processes from this stage onwards were performed with respect to the 50 level system. The temperature specification acted at level 14, which approximates closely to 75 mb. Level 14 was chosen for three reasons: (1) it is close to the tropopause (at least in lower latitudes), and the temperature might exhibit a greater degree of persistance over a 12-24 hour timescale than at other levels. (2) It is high enough to carry appreciable correlations with mid-stratospheric levels, and (3) it is low enough for reliable ground-based measurements of the temperature to be available. It is also close to a standard radiosonde level (70 mb).

Ref 3 describes the building up of a statistical data bank (based on the 50 levels) from 462 rocket soundings. The operator matrices for the seven latitude-season groups were derived from these statistics. None of the 462 profiles were used as initial profiles in the investigation, however, as it was decided only to use profiles that were independent of the original statistics. A total of 96 independent profiles was chosen - 24 in each of the latitude "bands" 0-30 deg (tropical), 30-50 deg, 50-70 deg, and 70-90 deg (polar). Each profile yielded (1) a set of six initial thicknesses, and (2) a set of radiances (including the

fifth one for the artificial channel). The vector (5 x 1) of "measured" radiances is given by:

$$R - \bar{R} = W(B - \bar{B})$$

where W is the matrix (5 x 50) of weighting functions

B is the vector (50 x 1) of Planck functions

$\bar{B}$ is the climatological mean of B

$\bar{R}$ is the vector of mean "measured" radiances ($\bar{R} = W\bar{B}$)

Each radiance vector was retrieved twice, once via the maximum probability method alone (method A), and once via the maximum probability method constrained by a specified temperature (method B). Two operator matrices were thus required for each latitude-season group. Their general form is:

$$CW^T(WCW^T + E)^{-1}$$

so that the equation solved is:

$$B - \bar{B} = CW^T(WCW^T + E)^{-1}(R - \bar{R})$$

where: W^T is the transpose of W

C is the covariance matrix (50 x 50) of atmospheric Planck functions appropriate to the particular latitude-season group.

E is the matrix of instrumental noise covariances (assumed diagonal).

For method A, matrices R, W, and E correspond to the four real channels only, and are of order (4 x 1), (4 x 50), and (4 x 4) respectively. For method B, the matrices correspond to the combination of the real channels and the artificial one, and are of order (5 x 1), (5 x 50) and (5 x 5). The two operator matrices are of order (50 x 4) and (50 x 5) respectively.

The two profiles retrieved from each radiance set yielded two sets of retrieved thicknesses. Comparison of these with the initial thickness set yielded a pair of thickness retrieval error sets. This may be expressed algebraically as follows:

Consider profile n (where n = 1, S), and let thickness t (where t = 1, 6) have the value H_{tn}. Now, let the corresponding retrieved thicknesses have values H_{tna} (method A) and H_{tnb} (method B). The thickness retrieval errors H'_{tna} and H'_{tnb} are:

$$H'_{tna} = H_{tna} - H_{tn}; \quad H'_{tnb} = H_{tnb} - H_{tn}$$

The original intention was to analyse all 96 profiles as a single sample, and then to compare, for each thickness, the rms retrieval error using method A with the rms retrieval error using method B. The rms thickness retrieval errors ε_{ta} and ε_{tb} over a sample of S profiles are:

$$\varepsilon_{ta} = \sqrt{\frac{1}{S}\sum(H'_{tna})^2} \; ; \; \varepsilon_{tb} = \sqrt{\frac{1}{S}\sum(H'_{tnb})^2}$$

The improvement X_t% in the retrieval of thickness t brought about by the use of method B is:

$$X_t = 100 \left(1 - \frac{\varepsilon_{tb}}{\varepsilon_{ta}} \right)$$

It was decided to make preliminary analyses with the main sample broken down by latitude band into four groups of 24 profiles each. The statistics used to calculate the operator matrices in the polar region were thought to be less reliable than those used to derive the others, mainly because of the small size of the original sample (due in turn to shortage of data). If the preliminary analyses produced ambiguous results for the 70-90 deg band, then these profiles could be removed from the main sample, and a separate analysis carried out using the 72 non-polar profiles. This was, in fact, done.

RESULTS

Fig. 1 shows the results of the preliminary analyses. The columns represent ("P") the rms deviation of the initial profile thickness from the climatological mean, ("A") the rms retrieval error for method A, and ("B") the rms retrieval error for method B. Units are decametres throughout. The final column shows the percentage improvement X_t.

While few valid conclusions can be drawn from the preliminary analyses alone (the 95% confidence limits for significant improvement and significant deterioration are about +30% and - 40% respectively for a sample of 24 profiles), it can be seen that the results in the 70-90 deg band are considerably worse than those in the other latitude bands (see Fig. 2), although the method A retrievals are surprisingly good. This suggests that the polar covariance matrices are not as unrealistic was was thought, but that the particular set of covariances between (1) level 14 and (2) all the levels between 300 mb and 1 mb is rather unrepresentative of the real atmosphere. Method B is particularly susceptible to the latter problem as its success depends on the extent to which an imposed "improvement" at level 14 also improves, because of the covariances, the retrieval at other levels. However, it is not really possible to say whether or not the deterioration would be observed with a more satisfactory original sample. It may be that, for the polar regions, the correlations between level 14 and the other levels are too weak for the corresponding covariances to be able to carry reliable additional information about the overall profile.

Surprisingly, both the 0-90 deg (overall) sample and the 0-70 deg sample (which excludes the polar profiles) show broadly similar results (see Fig. 3) with substantial improvements in the 300-30 mb, 300-10 mb, 100-30 mb, and 100-1 mb thicknesses (all of which include the 75 mb level). For a sample of 72 profiles, the 95% confidence limit for significant improvement is about 20%. No significant improvement or deterioration is observed with either the 30-10 mb or the 3-1 mb thicknesses.

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Thickness	-P-	-A-	-B-	Impr.	
300-30 mb	14.0	8.1	4.2	48% S	
300-10 mb	22.1	10.5	6.3	40% S	
100-30 mb	11.1	6.2	4.2	33% S	0 to 30 deg (tropical)
30-10 mb	11.4	6.4	5.7	12%	
100- 1 mb	32.7	4.6	3.6	21%	
3- 1 mb	13.0	4.7	4.5	5%	

Thickness	-P-	-A-	-B-	Impr.	
300-30 mb	20-5	12.4	8.3	33% S	
300-10 mb	29.0	11.3	5.5	51% S	
100-30 mb	12.3	7.0	5.4	23%	30 to 50 deg
30-10 mb	17.9	7.4	6.2	16%	
100- 1 mb	75.8	13.5	9.4	30% S	
3- 1 mb	30.9	10.8	11.1	-2%	

Thickness	-P-	-A-	-B-	Impr.	
300-30 mb	55.7	14.9	7.5	50% S	
300-10 mb	82.8	15.3	6.4	58% S	
100-30 mb	31.9	5.9	2.3	61% S	50 to 70 deg
30-10 mb	31.4	4.9	6.5	-31%	
100- 1 mb	111.0	6.6	5.6	15%	
3- 1 mb	26.8	10.6	9.6	9%	

Thickness	-P-	-A-	-B-	Impr,	
300-30 mb	33.9	9.2	10.8	-18%	
300-10 mb	53.7	7.6	6.7	12%	
100-30 mb	20.9	4.0	4.5	-11%	
30-10 mb	28.1	5.1	7.6	-50% S	70 to 90 deg (polar)
100- 1 mb	119.4	6.3	5.8	7%	
3- 1 mb	41.9	5.4	7.1	-31%	

S denotes a significant improvement or significant deterioration (95% confidence).

P denotes the rms of the profile thicknesses from the climatological means.

A denotes the rms errors for method A (dm).

B denotes the rms errors for method B (dm).

Fig. 1: Results for each latitude band.

	0-30 deg	30-50 deg	50-70 deg	70-90 deg
sig. improvements:	3	3	3	0
no sig. change:	3	3	3	5
sig. deteriorations:	0	0	0	1

Fig. 2: Comparison of results for different latitude bands.

	Method		
Thickness	-A-	-B-	Impr.
300-30 mb	12.1	6.9	43% S (30%)
300-10 mb	12.5	6.1	52% S (46%)
100-30 mb	6.4	4.1	35% S (28%)
30-10 mb	6.4	6.1	4% (-8%)
100- 1 mb	9.1	6.7	27% S (24%)
3- 1 mb	9.2	8.8	3% (-1%)

Fig. 3: Overall results for the 0-70 deg (non-polar) sample.

S denotes significant improvement. The bracketted percentages represent the corresponding improvements for the 0-90 deg sample (ie including the polar profiles). The rms errors for methods A and B respectively are in decametres.