The TMS Retrieval Algorithm: Preliminary Results for the Whit-Sunday Severe Storm Event

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1. Introduction

The TMS – **T**ypical shape function **M**aximum a posteriori **S**imultaneous – physical retrieval algorithm is an optimal estimator which utilises pattern recognition in both the *a priori*, and radiance domains to establish "appropriate" retrieval constraints. The radiative processes are formulated in terms of a simultaneous model, so both temperature and water vapour information in the measurements are properly utilised by the retrieval estimator (Uddstrom and Wark 1985, Uddstrom 1988a, Uddstrom 1988b). The software, which implements the TMS concepts, is compatible with the International TOVS Processing Package retrieval algorithm's input and output file structures, and may be embedded within that package.

In this paper, some of the features of the TMS algorithm will be demonstrated through application of the scheme to one of the International TOVS Study Conference (ITSC) case study data sets. However, interpretation of the resulting, preliminary, analysed fields is necessarily subjective since no "ground truth" information was available.

2. The TMS Algorithm

The theoretical development of the TMS retrieval estimator has been fully described in Uddstrom (1988a) and will not be discussed here. Instead, in this section, some practical considerations will be noted, especially in regard to the problem of incorporating airmass dependent radiative transfer equation errors. Particulars of the case study retrieval algorithm are given.

The TMS software is entirely compatible with the ITPP file structures, but it does utilise rather more *a priori* information than that used by the ITPP retrieval algorithm. These auxiliary (*a priori*) data, such as the TSF mean profiles and their covariance matrices, the radiance discrimination, de-clouding and radiative transfer correction equations, together with various error statistics, are all stored in a single file, equation data base, which is both satellite and time specific. However, apart from these data, which are computed off line, currently, no other auxiliary information is specifically required by the retrieval algorithm.

Retrievals may be computed at any chosen spatial resolution (relative to the instantaneous field of view (ifov) size) and with any desired set of HIRS and MSU measurements. Also, they may be computed from cloudy or cloud-cleared radiances and from either limb corrected or non limb corrected data. Although in principal the retrieval estimator need only be applied to the data vector once, because of the problem of clouds, it is in fact applied at least twice. The purpose of the initial retrieval being to establish the cloud characteristics, while in the final retrieval, more channels are used and accordingly a more accurate result computed.

a. *Initial Retrieval*

Because the TMS pattern recognition algorithm selects a first guess atmospheric class based primarily on profile shape rather than absolute radiance temperature, the first guess profile may not be used to establish cloud characteristics. Therefore the initial retrieval passes of the estimator establish an improved initial estimate of the temperature profile, for the express purpose of establishing the characteristics (pressure and fraction) of clouds in a retrieval box (i.e. some selection of ifovs). Accordingly, the radiance discrimination and retrieval equations are derived from channels which are not expected to be cloud contaminated, or have been cloud cleared by TSF (Typical Shape Function) dependent cloud clearing prediction equations (see Uddstrom, 1988a).

The following sequence of events occur during the initial retrieval.

- *RTE model errors:* Because it is known that there are apparent "errors" in the forward radiative transfer equation (rte) model, and because all *a priori* data are formulated in terms of that model, the measured data must be corrected to their model equivalents. Further, since these corrections are known to be air-mass dependent (Uddstrom 1988b, Kelly and Flobert 1988), the problem of rte error correction is approached as follows.
  - All channels required for radiance discrimination (to select the TSF class of the atmosphere) are corrected by the delta method, where the deltas have been computed from coincident soundings within the region of interest, i.e.

$$\hat{\mathbf{T}}_{rte} = \mathbf{T}_{sat} + \boldsymbol{\delta}_{reg}. \tag{1}$$

    Where $\mathbf{T}_{sat}$ is the vector of satellite radiance temperature measurements, $\boldsymbol{\delta}_{reg}$ the vector of regionally dependent delta corrections, and $\hat{\mathbf{T}}_{rte}$ is the resulting rte estimate of the observation vector.
  - The radiance discrimination equations are applied to the data and the most probable TSF atmospheric class found. The data are then re-corrected using TSF dependent deltas, and another radiance classification performed, i.e.

$$\hat{\mathbf{T}}_{rte} = \mathbf{T}_{sat} + \delta_{TSF} \quad (2)$$

Where all quantities have the same meanings as expressed above, except that δ_{TSF} is the vector of TSF dependent delta corrections. If, after this correction, the atmosphere is classified into a different TSF class, the data are re-corrected, and the classification process repeated. This sequence is continued until a stable classification occurs, otherwise the data are rejected. Fortunately, data are rarely rejected due to an unstable classification.

- *Retrieval:* Given the corrected measured radiances and TSF class of the atmosphere, a retrieval is computed and the cloud fraction and cloud top pressure estimated. This step may be iterated, in order to improve these estimates.

- *Further rte model error correction:* Once the cloud pressure is established, via the multispectral CO_2 absorption method of Menzel et al. (1983), it is possible to determine whether the rte model error estimates can be improved though the use of the regression method of Uddstrom 1988b, or the rotated regression method of McMillin et al., 1989. If the correction predictors are not cloud contaminated, then the measured data are corrected using one of these regression methods. The form of the adjustment is,

$$\hat{\mathbf{T}}_{rte} = \mathbf{D}_{TSF}\mathbf{T}_{sat} + \mathbf{C}_{TSF} \quad (3)$$

  where $\mathbf{D}_{TSF}$ and $\mathbf{C}_{TSF}$ are respectively the regression coefficient and constant matrices derived from some dependent TSF class samples.

  Further, it may also be possible to improve the radiance discrimination, by using a set of equations which include channels that might be cloud contaminated. If the cloud sensitive channels in these enhanced equations are found to be cloud free, then the atmosphere is re-classified and the rte model error correction – radiance discrimination cycle repeated until a stable TSF classification is found, or the data are rejected.

b. Final Retrieval

Once the TSF class of the sensed atmosphere is established, together with an estimate of the closeness of the measured atmosphere to the particular chosen TSF class; a decision can be made as to whether it is worth proceeding with a full retrieval. If a full retrieval is possible, then it may be computed using either cloudy or de-clouded radiances.

Again, the retrieval algorithm is in general iterated, and the improving cloud parameter estimates (if the cloudy radiance method is used) fed back into the rte error correction and radiance classification algorithms.

c. *Other Issues*

Uddstrom (1988a) noted that even thickness retrievals are sensitive to errors in the surface pressure estimate used by a physical retrieval algorithm. Over oceanic regions, the mean sea level pressure may be very much greater than 1000 hPa (the bottom level of the NESDIS rte model), with the effect that a warm bias will be introduced into retrievals, unless some account is taken of the radiation emitted by the layer lying below the 1000 hPa surface. The TMS software has been written so as to take advantage of a mean sea level pressure (mslp) prognosis for data time, if available. However, if no mslp data are available, a surface pressure is estimated from the TSF surface statistics and mean retrieval box elevation. Regardless, all radiative transfer calculations integrate down to the specified lower surface.

3. Case Study Data

Results from application of the TMS algorithm to the ITSC case study data set for the Whit-Sunday severe weather event over Southwestern France (7 June 1987), will now be demonstrated. The case study data set consists of three orbits of NOAA 10 data, but results will be shown only for the orbit immediately prior to the storm events. It should be noted that in this application, it has been necessary to use *a priori* constraints derived from a southern hemisphere climatology, since no northern hemisphere data were available. The radiative transfer equation error equations and deltas have been computed from an eight month sample of NOAA 10 and radiosonde collocations provided by Dr L. McMillin of NESDIS (no data for the period of the storm were included in this sample).

a. *A priori Constraints*

A radiosonde data sample (of 7000 profiles) from the Australian, south-west Pacific, New Zealand and Antarctic, and December, were combined to form a climatology of possible *a priori* atmospheres. After TSF classification, 12 classes of atmosphere were identified, and from these samples the TMS constraints computed.

The initial retrieval radiance (Bayesian) discriminant function channels used were; HIRS 1 and 2, and MSU 2, 3 and 4. The enhanced discriminant function adds HIRS channel 4 to this list. The de-clouding regression equation predictors are HIRS channels 1, 2, 3 and MSU channels 2, 3, and 4, while all HIRS channels lying below channel 3 are predictands. Regression (equ. 3) rte model error equations were computed for HIRS channels 1, 2, 3, 4, 5, 15 and 16 and MSU channels 2, 3 and 4. Delta (both TSF and regional) corrections were computed for all channels.

Some TSF dependent delta corrections derived from the NESDIS collocation sample are presented in Fig. 1. Here, class identifiers 11 and 12 refer to tropical atmospheres, classes 21, 22, 23, 41, 421 and 422 to mid-latitudes atmospheres, and classes 311, 312, 313 and 32 are more typical of sub-antarctic or antarctic atmospheres. As noted previously by Uddstrom (1988b) and Kelly and Flobert (1988), there would appear to be an air mass dependence in these correction terms.

The regional delta corrections used, are given in Table 1.

TABLE 1: Delta corrections computed for the region 35°W → 25°E, and 70°N → 25°N, from NOAA 10 collocation data for months April and August.

	HIRS												MSU		
	1	2	3	4	5	6	10	11	12	14	15	16	2	3	4
Delta (K)	0.18	0.14	0.99	0.15	0.57	0.68	0.18	0.41	0.65	0.62	2.04	0.32	-0.25	0.78	0.96

b. *The Synoptic Situation*

The nature of this particular event has been described by Scott et al. (1988) (now referred to by the initials SC). The essential points of the progression of events are that during the afternoon of June 7 1987, a very active squall line with extremely gusty winds moved over Southwestern France, causing the loss of several lives. AVHRR imagery, from the pass at 0900 UTC (7 June) indicates that, associated with a developing frontal wave over the Bay of Biscay, there is a region of strong convective activity south of Brittany.

c. *Retrieval Results*

Because of the absence of verifying analyses, the discussion on the results for this particular case study, must at this point, be rather subjective. Also, it should be noted that the ITPP compatible form of the retrieval algorithm is still in a "check out" phase of development.

1) The retrieval algorithm specification

The retrieval fields presented here have all been computed from limb corrected data. An mslp analysis was inferred from the results given in SC for 1200 UTC on 7 June 1987. For the initial retrieval the TMS estimator was executed twice, using HIRS 1, 2 and 3, and MSU 2, 3, and 4 channels on the first pass, and HIRS channels 1, 2, 14, 15 and 16, and MSU channels 2, 3 and 4 on the second. The final retrievals were computed by an the estimator (also executed twice), using HIRS channels 1, 2, 3, 8, 10, 12, 13 ,14, 15, and MSU channels 2, 3 and 4 on the first pass and HIRS 1, 2, 3, 4, 5, 7, 8, 12, 13, 14, 15 and MSU 2, 3 and 4 during the second. All observations with a radiance discrimination posterior probability greater than 0.25 were used to provide retrievals.

Without filtering, the resulting data were analysed on to a 30 by 44 grid over the map region (see Fig. 2), using a simple Cressman successive corrections method. A zonal field is used as the first-guess for the analysis, so it might be expected that the resulting analyses will be rather poor near the data boundaries. The analysed fields were lightly smoothed using a 25 point Bleck filter.

2) Height fields

The 1000 hPa and 500 hPa height fields are given in Fig. 2. From the 1000 hPa field it is evident that the essential features of the mslp field have been captured by the retrieval algorithm (even though the mslp field was bogused into the retrieval algorithm on only a 7 by 10 grid, covering the same area as the final analysis grid). The 500 hPa field has been overlaid with an analysis of the posterior probability (P) from the TSF radiance classification. The heaviest shading pattern reflects those regions where the *a priori* statistics least well matched the observed radiances (i.e. $P < 0.6$). It is comforting to note that changes in the posterior probability do not apparently introduce "mesoscale" trough or ridge features into the analysis.

The 500 hPa field is not dissimilar from the analysis given in SC for 1200 UTC, except for a region north of the British Isles. Of course, this field is clearly very dependent upon the mslp field used. There would appear to be a region of convergence over Brittany, together with some evidence of ridging in the location of the frontal wave (as identified from the AVHRR imagery given in SC).

3) THICKNESS FIELDS

The 1000–500 hPa, 1000–850 hPa, and 850–500 hPa thickness fields are presented in Fig. 3. Over the 1000–500 hPa field, the retrieved cloud top pressure is also plotted (for those retrievals that satisfied the various retrieval constraints). The developing shortwave trough/ridge feature over the Bay of Biscay is clearly evident in the 1000–500 field, as is the advection of cold air in behind the main centre of the low to the East of the British Isles. The 1000–850 hPa field indicates that the trough has a cold tongue reaching down to the coast of Northern Spain, and a strong thermal gradient exists across the Bay of Biscay. There would also appear to be a weak ridge, west of Portugal, in the main trough feature. Unfortunately, there is no apparent evidence for such a feature in the AVHRR image for this orbit (given in SC). Also, there is a warm bias in the TMS retrieved 1000—500 thicknesses (and probably other layers too), relative to the equivalent field given in SC.

In the 850–500 hPa layer, only the general features of the trough/ridge feature over the Bay of Biscay are evident, but there is a deep layer of convergence south of Brittany.

4) TEMPERATURE FIELDS

Fig. 4 displays the retrieved 850 hPa and 500 hPa temperature fields, together with the 700 hPa temperature and height fields. It is immediately obvious from the temperature data (Fig. 4(a)) that over the Bay of Biscay, there is pool of cold air (-24°C) overlaying warm air, presumably, enhancing the convection due to convergence. The region of sharpest temperature gradient lies close to the vortex centre associated with the frontal wave, as portrayed in the associated AVHRR imagery (in SC).

The advection of cold air at 700 hPa, over the Bay of Biscay, from the trough is clearly evident from the overlaid temperature and height fields.

4. Discussion

The purpose of this paper has been to bring the TMS physical retrieval algorithm to the attention of the TOVS community, although proper estimation of its worth must await further analysis.

Because of the nature of the *a priori* data requirements of the TMS algorithm, as implemented at the New Zealand Meteorological Service (NZMetS), it might be expected that it will perform better on a Southern Hemisphere case. When the AMEX case study data are available, a full analysis of the performance of the algorithm will be possible. In particular the TMS fields will be used to diagnose the vertical motion field, for comparison with GMS imagery. This should prove a sensitive test of the TMS retrievals.

Assuming continued satisfactory results from testing of the TMS algorithm, it will be implemented operationally at the NZMetS toward the end of 1989.

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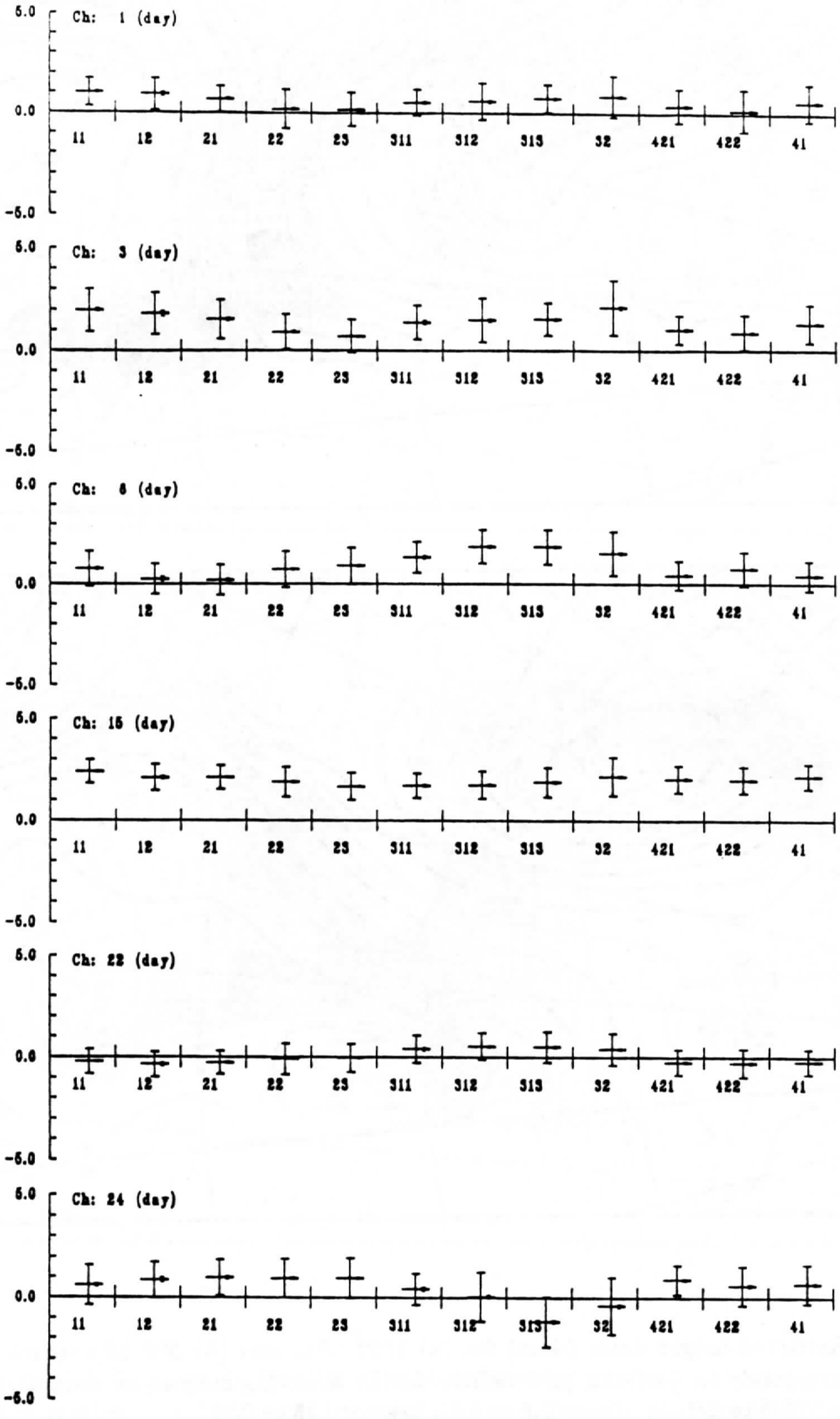


Fig.1. Mean (widest horizontal bar), standard deviation, and standard error (short error bars, attached to the mean) statistics for a selection of NOAA-10 rte δ channel correction estimates (dependent sample), as a function of TSF class.

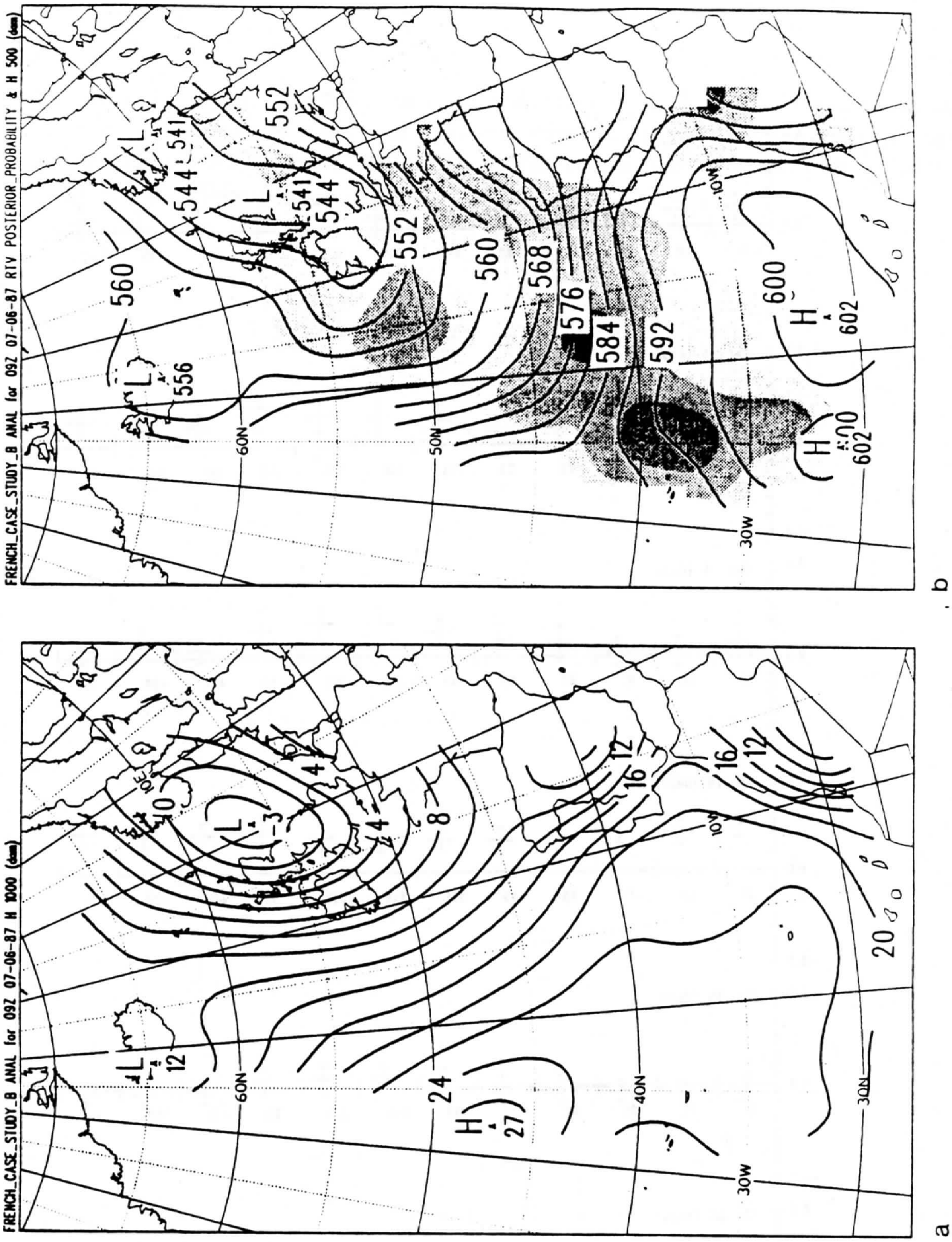


Fig.2. Retrieved height fields (dam) for (a) 1000 hPa, and (b) 500 hPa where the shading corresponds to posterior probabilities in the following ranges; no shading (1.0 to 0.9), light (0.8 to 0.9), medium (0.6 to 0.8), heavy (0.25 to 0.6).

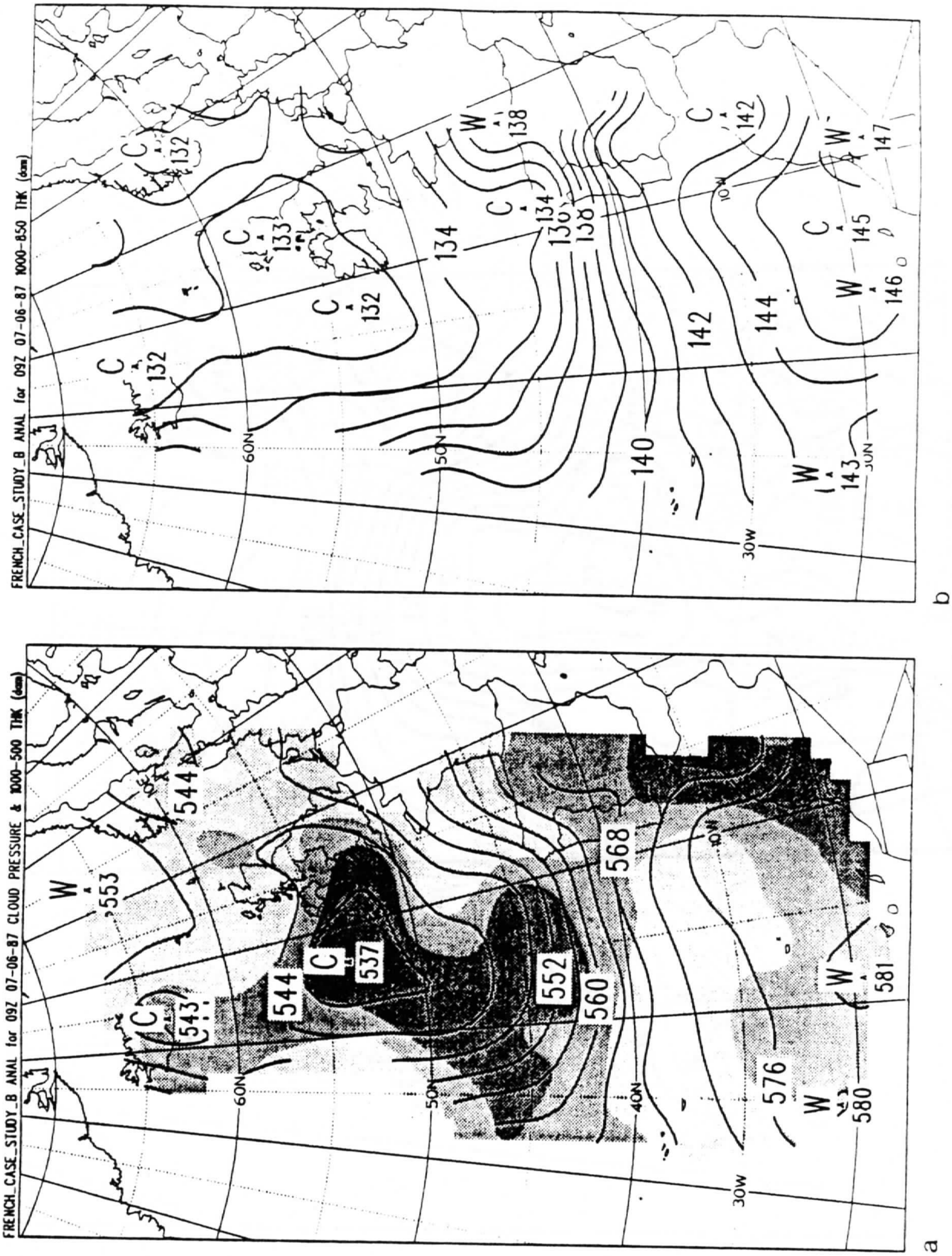
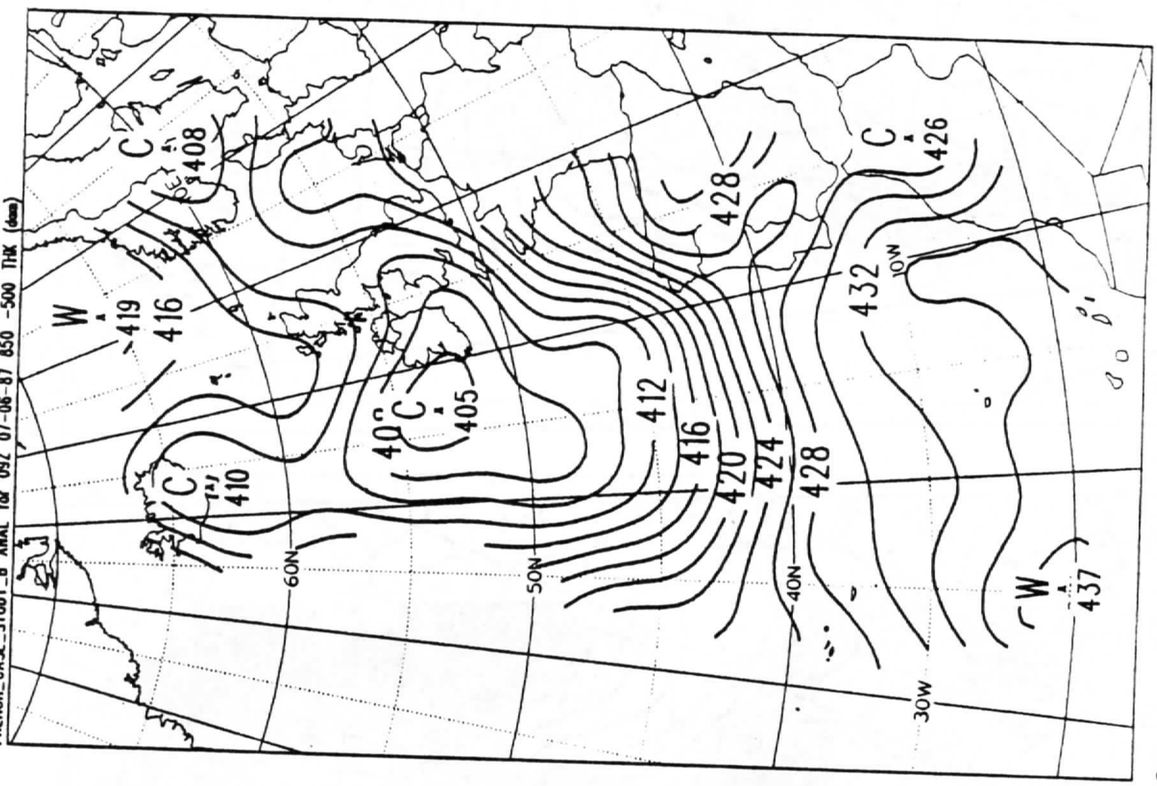


Fig.3. Retrieved thickness fields (dam) (a) 1000-500 hPa, overlaid with cloud top pressure patterns where: no shading implies the cloud top pressure is less than 500 hPa; light, that it lies in the range 500 to 700 hPa; medium, in the range 700 to 850 hPa; and heavy, greater than 850 hPa. (b) 1000-850 hPa, (c) 850-500 hPa.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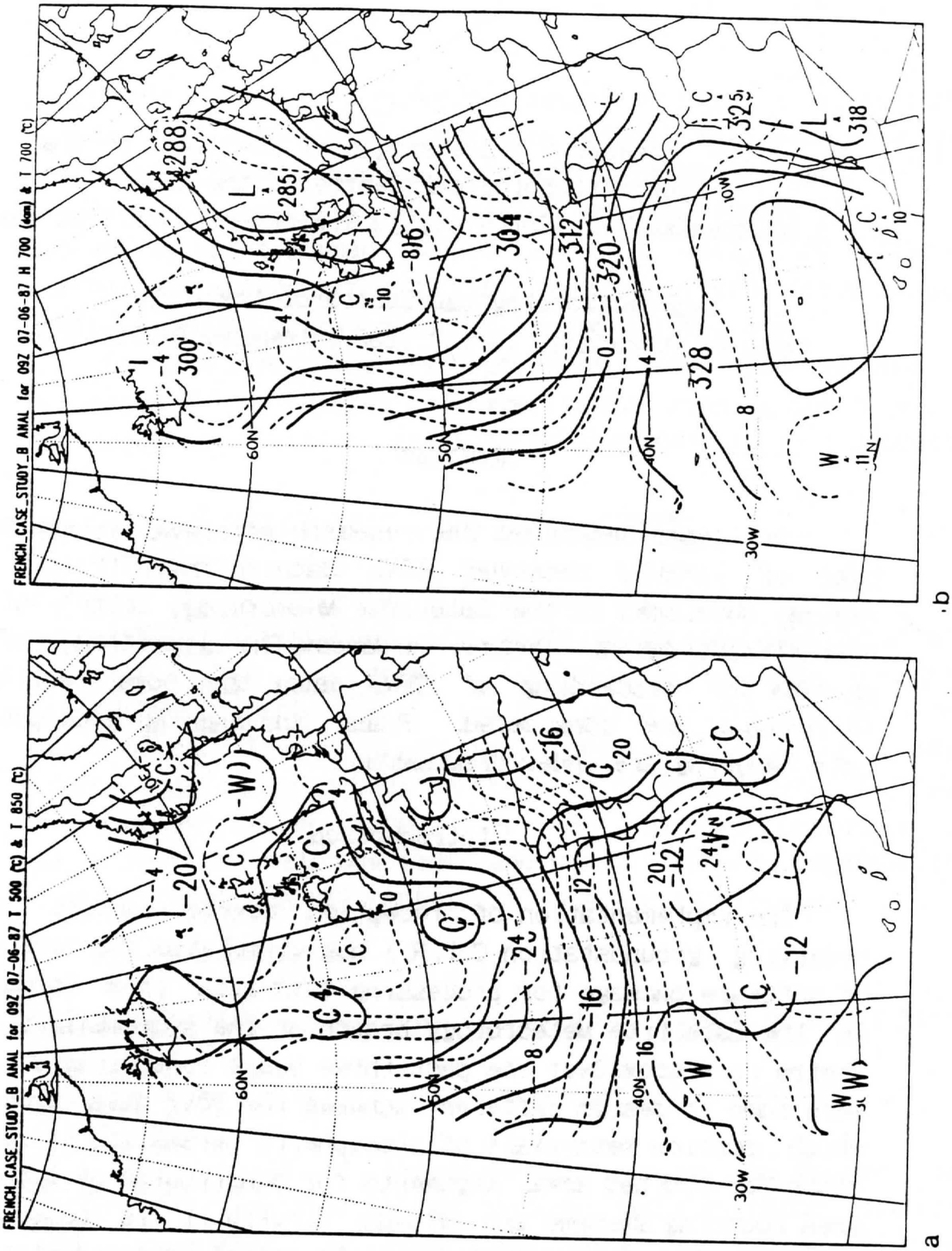

Fig.4. (a) The retrieved 500 hPa temperature field (solid line) and 850 hPa temperature field (dashed line), (b) the 700 hPa temperature and height fields.

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