THE PHYSICAL RETRIEVAL TOVS EXPORT PACKAGE

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1. Introduction

The satellite sounding radiance data received at the University of Wisconsin is converted into meteorological parameters using a physical solution of the radiative transfer equation, rather than empirical regression, in order to account for the influences of surface variables (i.e., terrain elevation, emissivity, and temperature) in the profile solutions and to permit the infrared data to be utilized for overcast as well as clear or partly cloudy sky conditions. These attributes of the physical solution are particularly important for the CIMSS applications of the data to real-time mesoscale weather analysis and forecasting for the North American region.

The initial "TOVS Export Package" developed by the CIMSS, and made available to numerous direct readout data users, has been modified to include the physical retrieval algorithm. As in the previous version, the new package produces temperature and moisture profiles from a 3 x 3 array of HIRS radiances and spatially interpolated MSU observations. Thus, the resultant linear resolution and spacing is about 75 km. In addition, the new Physical Retrieval TOVS Export Package provides a measure of total ozone concentration based upon the stratospheric carbon dioxide and ozone channel (emission to space) radiance observations. Advantages of the physical retrieval algorithm over the prior statistical regression method are:

a. surface parameters such as skin temperature, emissivity, and elevation are treated as variables and therefore accounted for explicitly in the profile solutions;

b. the reflected solar contribution to the shortwave window channels is determined and accounted for in the solution for surface temperature;

c. the effect of clouds on the infrared channel observations is determined, thereby permitting the use of an optimum number of infrared observations under all cloud conditions;

d. the radiance data is not "limb-corrected", thereby eliminating a potential source of error in the data processing (the preprocessor (PROGRAM TOVPRE) now permits the user to specify whether or not limb corrections are to be made);

e. the solutions are in no way related to radiosonde data so that their accuracy is much more independent of geographical location and observation time than statistical regression solutions (with the exception of the regression first guess option).

In this paper, prepared for the participants of the First International TOVS Study Conference, the physical algorithm is presented, its performance on the Alpex and Tasman Sea NOAA-7 orbits chosen for the conference is described, and the documentation needed to implement the new software is given.

2. Physical Retrieval System

This document assumes the reader is already familiar with the observational characteristics of the TOVS; if not, the reader is referred to the articles provided in the bibliography. As a quick review, Table I shows the characteristics of the TOVS (HIRS and MSU) channels. Figure 1 shows a schematic of the TOVS Physical Retrieval Processing System. The ingest, calibration, and earth location are the same as given in the original version. In the physical retrieval system there is no need to angle or "limb-correct" the measurements since the weighting (i.e., atmospheric transmittance) functions can be computed for the angle of observation as described in section 2 i.

a. First guess profiles

The physical retrieval algorithm solves for a departure of the true atmospheric temperature, moisture, and ozone profiles from a "guess" condition as a function of the departure of the observed radiances from those calculated for the "guess" profiles. The guess options included are: a latitude and time interpolation of the ten "Standard Atmospheres" (one for each of five latitude zones in winter and summer), by regression estimates from the non-cloud-contaminated radiances (microwave and stratospheric infrared); estimates produced by a dynamical forecast model. The first two options are available in the physical retrieval export package; since accessing forecast-model output is highly machine- and installation-specific, each user must provide his own interface.

b. Selection of "clearest" radiances

The profiles are produced from 3 x 3 arrays of 26 kilometer resolution HIRS fields-of-view (the courser resolution microwave data having been interpolated to the HIRS locations). The "clearest" observations are selected on the basis of the 11 μm window channel brightness temperature being within 3°K of the maximum observed amongst the 9 measurements. The average of all the "clearest" observations is generated for the sounding retrieval process. For the microwave channels and the stratospheric sounding infrared channels, the average is taken over all nine fields-of-view without regard to the 11 μm window brightness temperature. A check is made to determine whether the "clearest" observations are too cloud contaminated to afford an accurate profile retrieval. Using the 11 μm brightness temperature and the "guess" temperature profile, if the former is colder than the guess 500 mb temperature no retrieval is attempted. This check also safeguards against the use of precipitation attenuated microwave observations in the profile solutions.

c. Surface data

The accuracy of the retrieved profiles can be affected significantly through the use of surface data. The surface parameters required for radiative transfer calculations are surface pressure, surface skin temperature, and surface emissivity. The "shelter" temperature and humidity are desired as constraints on the retrieved temperature and humidity profiles.

(i) pressure

Surface pressure is computed hydrostatically using an estimated 1000 mb height, an estimated 1000 mb temperature and assumed lapse rate of 5°C/km, and an estimate of the surface elevation for the radiance observation location. That is

$$P_s = 1000 \text{ EXP } \quad - \frac{g}{R} \int_{Z_{1000}}^{Z} \frac{dZ}{T_{1000} + \gamma(Z - Z_{1000})} \quad (1)$$

Where g is gravity, R is the gas constant for air, and γ the assumed lapse rate. The 1000 mb height and temperature are estimated from either an analysis of station observations reduced to the 1000 mb level, a forecast (as in the case of first-guess generation, the user must provide the interface to such data), or climatology. The height of the observed surface is obtained from 10 nautical miles horizontal resolution topographical data (this high-resolution topography is, at present, available for the Northern Hemisphere only: elsewhere, the previously supplied 60 nautical mile resolution information must be used). The elevation for each HIRS field-of-view is obtained through a field-of-view response weighting, and subsequently the elevation for each field-of-view is spatially averaged in the same manner as the radiances themselves, as described in (2b).

(ii) air temperature and humidity

The surface air temperature is estimated from an analysis of station observations reduced to 1000 mb by using the assumed lapse rates for the reduction to 1000 mb and the actual height of the observed topography. Surface humidity is estimated from an analysis of surface dewpoint depression. If station data is not used, then the surface air temperature and dewpoint are left as unknowns in the profile retrieval process.

(iii) skin temperature

The surface skin temperature is estimated from both longwave (11 µm) and shortwave (3.7 µm and 4.0 µm) window channels of the HIRS. During the day, the shortwave windows must be corrected for reflected sunlight contributions prior to the surface temperature retrieval. Assuming that the surface reflectivity is constant within the 3.7 - 4.0 µm region it can be shown (Smith, 1980) that

$$\frac{R(3.7\mu m) - B(3.7\mu m, T_B)}{R(4.0\mu m) - B(4.0\mu m, T_B)} = \frac{B(3.7\mu m, T_{SUN})}{B(4.0\mu m, T_{SUN})} = K \qquad (2)$$

provided that the atmospheric transmittance is the same for both spectral channels. In (2), R is the observed radiance for HIRS window channel, B the Planck radiance, and T_{SUN} is the effective radiating temperature of the sun, assumed to be 5800°K. The only unknown in (2) is the effective radiating temperature of the earth-atmosphere for the 3.7 - 4.0 μm region, T_B. Rearranging (2) gives

$$f(T_B) = KB(4.0\mu m, T_B) - B(3.7\mu m, T_B) = KR(4.0\mu m) - R(3.7\mu m) \qquad (3)$$

Thus, $f(T_B)$ is calculated once and for all, and tabulated to permit rapid determination of T_B from actual observations of R(4.0 μm) and R(3.7 μm) observations (Channels 18 and 19 of Table 1).

The effective surface temperature for the 4.0 μm and 11 μm regions is then calculated from the observed (solar corrected) brightness temperatures using the relation

$$T_S = T^n_S + \frac{T_B - T^n_B}{\tau(p_o)} \qquad (4)$$

where T_B^n refers to the brightness temperature computed for a "guess" surface temperature, T_S^n, and atmospheric temperature and moisture profile condition, and $\tau(p_o)$ is the transmittance of the atmosphere above the surface pressure level, p_o. Equation (4) is derived from a form of the radiative transfer equation in which the Planck radiance dependence upon temperature is linearized using a first order Taylor expansion. Since (4) is not exact, the solution is iterated several times until $|T_S^{n+1} - T_S^n| < 0.01°K$. The initial value for T_s is obtained from the "split window" approximation, $T_s^{(0)} = T_B(11\ \mu m) + 0.5[T_B(11\ \mu m) - T_B(8\ \mu m)]$. As shown in Figure 1, the temperature and moisture profiles used for the final determination of T_s are provided by the microwave brightness temperatures and HIRS water vapor channel radiances as described later. The longwave (11 μm) and shortwave (4 μm) surface temperature values are checked for consistency and used to diagnose the presence of cloud contamination. Provided the results are reasonable for cloudfree sky conditions, they are used separately for the calculation of longwave (15 μm) and shortwave (4.3 μm) radiances in the infrared temperature profile retrieval process. The differences between the two surface temperatures are attributed to surface emissivity differences for the two spectral regions.

(iv) microwave emissivity

Unlike the emissivity of the earth's surface at infrared wavelengths, the surface emissivity at microwave frequencies can depart drastically from unity, depending upon surface moisture conditions. Thus, the surface emissivity must be determined and used explicitly in the calculation of outgoing radiance. The microwave "window" channel at 50 GHz (Table I) was included in the TOVS specifically for determining the effects of surface emissivity and liquid water on the microwave sounding channel radiance. It can be shown that the surface emissivity, ε_s, is given by the expression

$$\varepsilon_s = \frac{T_B + \int_o^{p_o} T(p) \left[1 + \frac{\tau^2(p_o)}{\tau^2(p)} \frac{d\tau(p)}{dp} \right] dp}{T_s \tau(p_o) + \int_o^{p_o} T(p) \frac{\tau^2(p_o)}{\tau^2(p)} \frac{d\tau(p)}{dp} dp} \tag{5}$$

where $\tau(p)$ is the transmittance of the atmosphere above pressure level p. For the microwave window region (50 GHz), the atmospheric (integral) quantities are small compared to the observed brightness temperature and surface term; thus the result is weakly dependent upon the temperature profile condition assumed. If a poor first guess temperature profile condition is used (e.g., climatology) the entire surface emissivity and microwave temperature profile retrieval process is repeated.

d. Microwave temperature profile retrieval

The temperature profile is calculated from the microwave brightness temperatures observed in MSU channels 2,3, and 4, using the iterative solution (Smith, 1970)

$$T^{n+1}(p) = T^n(p) + \frac{\sum_{i=2}^{4} [T_B(\nu_i) - T_B{}^n(\nu_i)] W(\nu_i,p)}{\sum_{i=2}^{4} W(\nu_i,p)} \tag{6}$$

where $T_B{}^n$ is the brightness temperature calculated from the temperature profile $T^n(p)$, and $W(\nu_i,p)=d\tau(\nu_i,p)/dp$. In the calculation of $T^n(p)$, the surface emissivity calculated from the 50 GHz brightness temperature measurement, the surface temperature given by the HIRS 8 μm and 11 μm brightness temperatures using the "split window" approximation, and the surface pressure obtained from the high resolution topographical data are used as boundary conditions. The solution for T(p) is iterated until the condition

$$|T_B{}^n(\nu_i) - T_B{}^{n-1}(\nu_i)| < 0.05°K$$

is satisfied for all channels. If surface air temperature observations are being used, the profile below the 700 mb pressure level is adjusted in a linear fashion to blend into the observed air temperature at the surface.

e. Initial water vapor profile estimate

The initial profile of water vapor is derived using the mean relative humidity solution given by Smith and Zhou (1980). Assuming the relative humidity is constant within each layer sampled by the HIRS water vapor channels (10, 11, and 12), then

$$Rh[(p(\nu_i,p)] = Rh^\circ EXP \frac{R(\nu_i)-R^\circ(\nu_i)}{\int_o^{p_o} W^\circ(\nu_i,p)dp} \tag{7}$$

where $p(\nu_i)$ is the pressure level of maximum water vapor sensitivity for the water vapor channel ν_i, Rh° is a guess layer relative humidity value (a value of 0.5 is used initially), $R^\circ(\nu_i)$ is the radiance calculated for the guess humidity condition, and $W^\circ(\nu_i)$ is the water vapor weighting function given by

$$W^o(\nu_i,p) = g\ \frac{U^o(p)}{q^o(p)}\ \frac{\partial\tau(\nu_i,p)}{\partial p}\ \frac{\partial B(\nu_i,T)}{\partial p}$$

where $U^\circ(p)$ is the integrated precipitable water above the pressure p, and $q^\circ(p)$ is the mixing ratio as implied by the guess relative humidity condition, and the atmospheric temperature profile (which, at this point, has been derived from the MSU brightness temperature observations). For the HIRS water vapor channels 10, 11, and 12, the pressures of maximum sensitivity are assumed to be 800, 600, and 300 mb, respectively. Given these three relative humidity values from (7) a profile of relative humidity is constructed by linear interpolation with respect to pressure. If surface data is available, it is used to interpolate between the surface and the 800 mb level, otherwise the relative humidity is assumed to be constant below the 800 mb level. The relative humidity above 300 mb is also assumed to be constant. The solution given by (7) is repeated after the infrared brightness temperatures are used to derive an improved estimate of the temperature profile, using the relative humidity values obtained initially. Although the layer mean relative humidity approximation is not an exact simultaneous solution for the relative humidity profile from the three water vapor channel radiances, it is a stable approximation in that the influence of cloud or measurement errors is minimal.

It should be noted that, even if the atmosphere is cloudy, a relative humidity profile is derived. In this case, the solution is produced by using the microwave temperature profile and the 11 μm brightness temperature to estimate the cloud pressure and temperature. These cloud parameters are then used in the calculation of $R^o(\nu_i)$. The relative humidity results below the cloud level are a consequence of linear interpolation between the relative humidity sensed above the cloud level and the observed surface value.

f. Infrared temperature profile retrieval

After deriving the water vapor profile, the surface skin temperatures for the short and long wavelength temperature sounding channels are obtained by iterating (4). These together with the microwave-specified temperature profile are used to calculate the "expected" values of the brightness temperatures observed in the 4.3 μm and 15 μm temperature sounding channels (Table I). If the visible channel reflectance is less than 25% and the longwave surface temperature is greater than a threshold of five degrees below the observed or microwave retrieved surface air temperature, then <u>all</u> the infrared channels are presumed to be free of cloud contamination, and are used in the temperature profile retrieval process. If the "clear test" fails, then an attempt is made to determine which of the infrared channels are free of cloud contamination. By assuming that clouds always reduce the brightness temperatures by a magnitude dependent upon the transmissivity of the spectral channel, all channels of equal or greater opacity than a given channel are presumed to be clear if the deviation between the observed and calculated brightness temperature for that channel is greater than or equal to zero. If HIRS channel 7 satisfies this criterion, all shortwave and longwave channels are presumed to be unaffected by the cloud and used in the retrieval process. If, however, this criterion is not satisfied by channel 7, then only the longwave channels satisfying the criterion are used; the shortwave channels are not used because of the difficulty in accurately correcting these measurements for cloud-reflected sunlight contributions.

Having determined the infrared channels unaffected by cloud contamination, the temperature profile is given by the iterative solution

$$T^{n+1}(p) = T^n(p) + \frac{\sum_{i=1}^{m} [T_B(\nu_i) - T_B{}^n(\nu_i)]W(\nu_i,p)}{\sum_{i=1}^{m} W(\nu_i,p)} \qquad (8)$$

where m is the number of cloud free infrared channels and the weighting function is given by the relative contribution function

$$W(\nu_i p) = \frac{B[\nu_i, T^n(p)]}{R(\nu_i)} \frac{d\tau(\nu_i,p)}{dp}$$

If any longwave channel, ν_i, is presumed to be cloud contaminated, then $T_B{}^n(\nu_i)$ is presumed to be equal to $T_B(\nu_i)$ in equation (8), in order to blend the solution into the microwave retrieval below the cloud level. The iteration is terminated as soon as the criterion

$$T_B{}^n(\nu_i) - T_B{}^{n-1}(\nu_i) < 0.05°K$$

is satisfied for all channels. The temperature profile retrieved from the infrared brightness temperatures, using the microwave result as the initial guess, is the "final" estimate.

g. Final water vapor profile estimate

The final water vapor profile is calculated using (7) with the infrared temperature profile and the final surface temperature estimates being used in the calculation of $R^\circ(\nu_i)$ and $W^\circ(\nu,p)$. The Rh° values are taken as the estimates initially derived on the basis of the microwave temperature profile.

h. Ozone retrieval

The total ozone concentration is retrieved from the ozone channel brightness temperature using the method of Ma, Smith, and Woolf (1984). In a manner analogous to the water vapor solution, the ozone concentration is given by the inverse solution of the radiative transfer equation,

$$O(p_o) = O^o(p_o)\,\mathrm{EXP}\;\frac{R(\nu_i) - R^o(\nu_i)}{\int_o^{P_o} W^o(\nu_i,p)\,dp} \qquad (9)$$

where ν_i is channel 9 (Table I) and

$$W(\nu^o,p) = g\,\frac{O^o(p)}{m^o(p)}\;\frac{\partial\tau^o(\nu_i,p)}{\partial p}\;\frac{\partial B(\nu_i,T)}{\partial p}$$

O(p) is the ozone concentration profile, and m(p) is the ozone mixing ratio profile. The initial ozone mixing ratio and concentration profile is obtained using regression relations developed from a large sample of ozonesondes and radiances for the stratospheric HIRS channels (1-4) synthesized by radiative transfer calculations, from the ozonesonde temperature profile data. Thus the temperature profiling channels are used to specify the gross vertical structure of the ozone profile (via temperature-ozone correlation), and the ozone channel radiance is used to estimate the absolute magnitude of the total concentration. If a cloudy condition prevails, the surface pressure used in (9) is the cloud pressure determined from the 11 μm window brightness temperature and the final temperature profile.

i. Calculation of transmittances

An essential ingredient of any physical retrieval scheme is the availability of accurate and computationally efficient ("fast") procedures for calculating profiles of atmospheric transmittance in the various spectral intervals represented by the infrared (HIRS) and microwave (MSU) sounding channels. These procedures must account for variations in spectral response, atmospheric composition and state (temperature and moisture dependence), and departure from vertical viewing (slant path or zenith-angle dependence).

The requirement for computational speed precludes the employment, in routine processing, of so-called "exact" (in the spectroscopic sense),or line-by-line, methods. Therefore, models have been developed (McMillin and Fleming, 1976; Fleming and McMillin, 1977; Weinreb and Neuendorffer, 1973; Weinreb et al., 1981) to satisfy the dual requirements of speed and accuracy--the latter being defined in terms of degree of agreement with exact calculations. The first three references cited above describe the algorithms developed for the infrared; the first relates these specifically to HIRS, and also discusses the method used with MSU.

When the design decision was made to apply the physical retrieval algorithm to non-limb-corrected TOVS data, it was determined that the existing MSU transmittance model would not suffice. For an arbitrary scan angle, it entails calculation of transmittance profiles for a number of angles, followed by convolution with the antenna gain pattern--a computationally costly process. Therefore, a variation of the model was developed, in which a separate set of regression coefficients, relating absorption to temperature and moisture, is generated for each of six equally spaced scan angles. The influence of the antenna pattern is incorporated into the absorption profiles used for the regression. Coefficients for arbitrary scan angles are obtained dynamically by linear interpolation. The model has been verified by comparing antenna temperatures calculated from "exact" and regression-estimated transmittance profiles; agreement is very good.

Transmittances for the ozone retrieval are computed using the method of Gruenzel (1978), with contributions from water vapor lines and continuum obtained by the procedures described in Weinreb, et al. (1981).

The transmittances are adjusted in order to minimize differences between observed and calculated radiances. The adjustments are made assuming that

$$\ln\tau(\nu_i p) = \gamma(\nu_i)\ln\hat{\tau}(\nu_i, p)$$

where $\gamma(\nu_i)$ is the adjustment factor and $\hat{\tau}(\nu_i, p)$ is the unadjusted transmittance. The adjustment factors have been determined on the basis of a very large sample (several thousand) of "coincident" radiosonde and radiance observations. The γ's are calculated so as to minimize the RMS difference between observed and calculated radiances for all atmospheric conditions and latitude zones. The values assumed for all NOAA satellites in the TOVS Export Package are given in Table 2.

3. Results From NOAA-7 ALPEX Orbits

The Physical Retrieval Export Package was applied to the NOAA-7 orbits chosen for the TOVS Study Conference. The program options used were "Regression Guess" and "With Surface Data". The regression coefficients used were the NESDIS operational for the overcast cloud (Path 3) condition. The surface data was obtained from station reports for the ALPEX orbits and from Australian Bureau of Meteorology analyses for the Southern Hemisphere orbits. The effect of the different program options upon the results are discussed in section 5 of this report.

The actual retrieval values and radiosonde data for the Alpex orbits are given in an Appendix. Also, the retrieval values and contour analyses for the Southern Hemisphere orbits chosen for the Study Conference are given in an Appendix. The geopotential thickness values are for the layers specified in the Study Conference invitation and are given in decameters.

In this section we present comparisons of the various TOVS geopotential thickness analyses with those of radiosonde data produced by the European Center for Medium range Weather Forecasting (ECMWF) for the ALPEX orbits. The analysis of the TOVS retrievals is produced by Barnes interpolation (Barnes, 1973) at a spatial resolution of 75 Km. The ECMWF analyses are based on optimal interpolation (Bengtsson, 1981) at a spatial resolution of 200 Km. The different resolutions are consistent with the different horizontal spacings between TOVS and Radiosonde sounding data (see the Appendix).

Figures 2-6 show the analysis comparisons for geopotential thickness. As may be seen from these figures, the patterns of the two different analyses produced from TOVS (SAT) and from Radiosonde (ECMWF) data are nearly identical, however, there are significant differences in the horizontal scale and gradients resolved by the two data/analysis systems. In particular, smaller horizontal scales seem to be resolved in the TOVS analyses. For example, the shortwave ridge in the 1000-700 mb thickness along the east-coast of Spain in the 03Z TOVS analysis (Figure 2c). Also, the amplitude of the trough and ridge axes over the Oceanic areas are definitely greater in the TOVS analyses; for example, the ridge axis over the ocean between Spain and England in the 1000-500 mb thickness at 03Z on 5 March (Figure 3c). On the other hand, at upper tropospheric levels there is a definite weakening of the horizontal gradient of TOVS derived thicknesses relative to the radiosonde data. For example, the horizontal gradient of the 300-100 mb thickness across Italy for 00Z on 5 March is about 180 meters for the ECMWF analysis, compared to about 90 meters for the SAT analysis. The magnitude of the high over the Mediterranean also differs by about 40 meters, the SAT analysis being weaker than the ECMWF analysis. The loss of horizontal resolution of the TOVS soundings relative to radiosondes with altitude is due to the loss of vertical resolution of satellite soundings with increasing altitude. The relatively low vertical resolution of the satellite soundings in the tropopause region leads to large bias and relative differences with radiosonde observations (section 4).

Figure 7 shows the twelve hour change of precipitable water above 1000, 700, and 500 mb levels as retrieved from the TOVS data. One can see good continuity with time and with the thickness patterns displayed in Figures 2-6.

Finally, Figure 8 shows the total ozone retrieved from the NOAA-7 TOVS observations for 4 and 5 March, 1982. Unfortunately, the ground truth data was not available to verify the absolute accuracy of these retrievals. Of particular interest is the very rapid movement of the high ozone center over the English channel at 13Z on 4 March to the Mediterranean at 03Z on 5 March. This movement, and in fact the entire ozone pattern, is highly correlated with the patterns and time displacements seen in the 300-100 mb thickness shown in Figure 6. This correlation is presumably due to the relation between ozone concentration and geopotential thickness in this layer to tropopause height and temperature. High stratospheric ozone concentrations should be associated with low tropopause height and low tropopause height are associated with warm tropopause temperatures or geopotential thicknesses. Thus, there is a strong positive correlation between the geopotential thickness of the tropopause layer (i.e., 300-100 mb) and the stratospheric ozone concentration. This correlation is clearly seen in the TOVS retrievals (compare Figures 8 and 6).

4. Error Statistics

Figure 9 presents bias and standard deviations between the analyses of TOVS retrieved temperatures and radiosonde temperature observations (ECMWF) as well as the bias and standard deviations of each of these analyses with respect to actual radiosonde observations. Because of occasional large digital transmission errors in the radiosonde data, observations which exceeded 2° (Figure 9c) or 5° (Figure 9d) deviation from the ECMWF analysis were discarded from the error statistics. No filtering of TOVS data was performed. The reader is reminded that the TOVS retrievals were produced using a stratospheric HIRS and MSU channel regression "first guess" and incorporated surface data. The TOVS and ECMWF analyses were performed with grid spacings of 75 km and 200 km, respectively.

As may be seen by comparing Figure 9(b) with 9(c) or 9(d), the bias and standard deviations between radiosonde observations and the TOVS and ECMWF analyses are comparable, except in the tropopause regions. This result is somewhat surprising since the TOVS analyses are completely independent of the radiosonde data whereas the ECMWF analyses are completely dominated by radiosonde observations over the European region studied. One explanation for the comparability of the magnitudes of the standard errors is (a) the lack of small horizontal scale detail in the ECMWF analyses (i.e., horizontal smoothing) and (b) the inherent vertical smoothing of the TOVS profiles relative to radisonde observations. The much larger bias error in the TOVS retrievals in the tropopause region merely demonstrates that vertical smoothing is more detrimental than horizontal smoothing in this region of sharp vertical temperature variation. The combination of the error statistics shown in figure 9 indicate that the TOVS level temperature retrieval errors are generally less than 2°C. Errors in thickness temperatures should be less than the error of level temperature values because of the vertical smoothing inherent in the TOVS retrievals.

5. Impact of Profile Guess and Surface Data

The influence of profile first guess and surface data options of the retrieval program were studied using the western orbit of 4 March, 1982. Figure 10 shows the bias and standard deviations of the TOVS level temperature values with respect to the ECMWF analyses for four different program options; (a) regression guess with surface data, (b) climate guess with surface data, (c) regression guess without surface data, and (d) climate guess without surface data. As may be seen, the main influence of the various options is upon the bias error distribution of the retrievals. The major influence of surface data is below the 700 mb level where standard deviation and bias error improvement of more than 1°C can be seen. The influence of the profile first guess (regression vs. climate) seems to greatly impact the bias error for the case where surface data is utilized. This may be due to the structure differences created by blending the "first guess" profile into the surface observations. Surprising is the fact that without surface data (Figures 10c and 10d), little difference is produced by the profile first guess. Comparisons of horizontal analyses of the level temperatures for the various first guess options (not shown) revealed little difference in the patterns but significant differences in the absolute temperature values as suggested in Figure 10. The authors believe that the most reliable retrievals are produced for the regression guess with surface data option. Certainly, surface observations are extremely valuable when dealing with complex terrain conditions.

6. Summary and Future Improvements

The physical retrieval "Export Package" has been described. Analyses of its performance on the NOAA-7 orbits chosen for the TOVS study conference indicate satisfactory performance. A major improvement yet to be implemented is the use of full resolution AVHRR data to better define surface skin temperature and to account for the influence of clouds upon the TOVS sounding channel radiances. An effort is now underway at the CIMSS to implement the AVHRR option to the TOVS sounding processing system.

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Channel Number	Channel Central Wavenumber	Central Wavelength (μm)	Principal Absorbing Constituents	Level of Peak Energy Contribution	Purpose of the Radiance Observation
1	668	15.0	CO_2	30 mb	Temperature Sounding. The 15 μm band channels provide better sensitivity to the temperature of relatively cold regions of the atmosphere than can be achieved with the 4.3 μm band channels. Radiances in Channels 5, 6, and 7 are also used to calculate the heights and amounts of cloud within the HIRS field of view.
2	679	14.7	CO_2	60 mb	
3	691	14.5	CO_2	100 mb	
4	704	14.2	CO_2	250 mb	
5	716	14.0	CO_2	500 mb	
6	732	13.7	CO_2/H_2O	750 mb	
7	748	13.4	CO_2/H_2O	900 mb	
8	898	11.1	Window	Surface	Surface Temperature and cloud detection.
9	1028	9.7	O_3	25 mb	Total Ozone concentration.
10	1217	8.3	H_2O	900 mb	Water Vapor Sounding. Provide water vapor corrections for CO_2 and window channels. The 6.7 μm channel is also used to detect thin cirrus cloud.
11	1364	7.3	H_2O	600 mb	
12	1484	6.7	H_2O	400 mb	
13	2190	4.57	N_2O	950 mb	Temperature Sounding. The 4.3 μm band channels provide better sensitivity to the temperature of relatively warm regions of the atmosphere than can be achieved with the 15 μm band channels. Also, the short-wavelength radiances are less sensitive to clouds than those for the 15 μm region.
14	2213	4.52	N_2O	850 mb	
15	2240	4.46	CO_2/N_2O	700 mb	
16	2276	4.40	CO_2/N_2O	600 mb	
17	2361	4.24	CO_2	5 mb	
18	2512	4.0	Window	Surface	Surface Temperature. Much less sensitive to clouds and H_2O than 11 μm window. Used with 11 μm channel to detect cloud contamination and derive surface temperature under partly cloudy sky conditions. Simultaneous 3.7 μm and 4.0 μm data enable reflected solar contribution to be eliminated from observations.
19	2671	3.7	Window	Surface	
20	14,367	0.70	Window	Cloud	Cloud Detection. Used during the day with 4.0 um and 11 um window channels to define clear fields of view.

MSU	Frequency (GHz)	Principal Absorbing Constituents	Level of Peak Energy Contribution	Purpose of the Radiance Observation
1	50.31	Window	Surface	Surface Emissivity and Cloud Attenuation determination.
2	53.73	O_2	850 mb	Temperature Sounding. The microwave channels probe through clouds and can be used to alleviate the influence of clouds on the 4.3 μm and 15 μm sounding channels.
3	54.96	O_2	500 mb	
4	57.95	O_2	100 mb	

TABLE 1. Characteristics of TOV Sounding Channels

Table 2. Transmittance - adjustment exponents ("gammas") for use in SUBROUTINE TAUGAM

HIRS Channel	HIRS Gamma	MSU Channel	MSU Gamma
1	1.069	1	1.000
2	0.942	2	1.019
3	1.108	3	0.999
4	1.031	4	0.899
5	0.972		
6	0.965		
7	0.909		
8	1.000		
9	1.000		
10	1.120		
11	1.032		
12	1.035		
13	1.115		
14	1.028		
15	1.057		
16	1.002		
17	1.480		
18	1.000		
19	1.000		

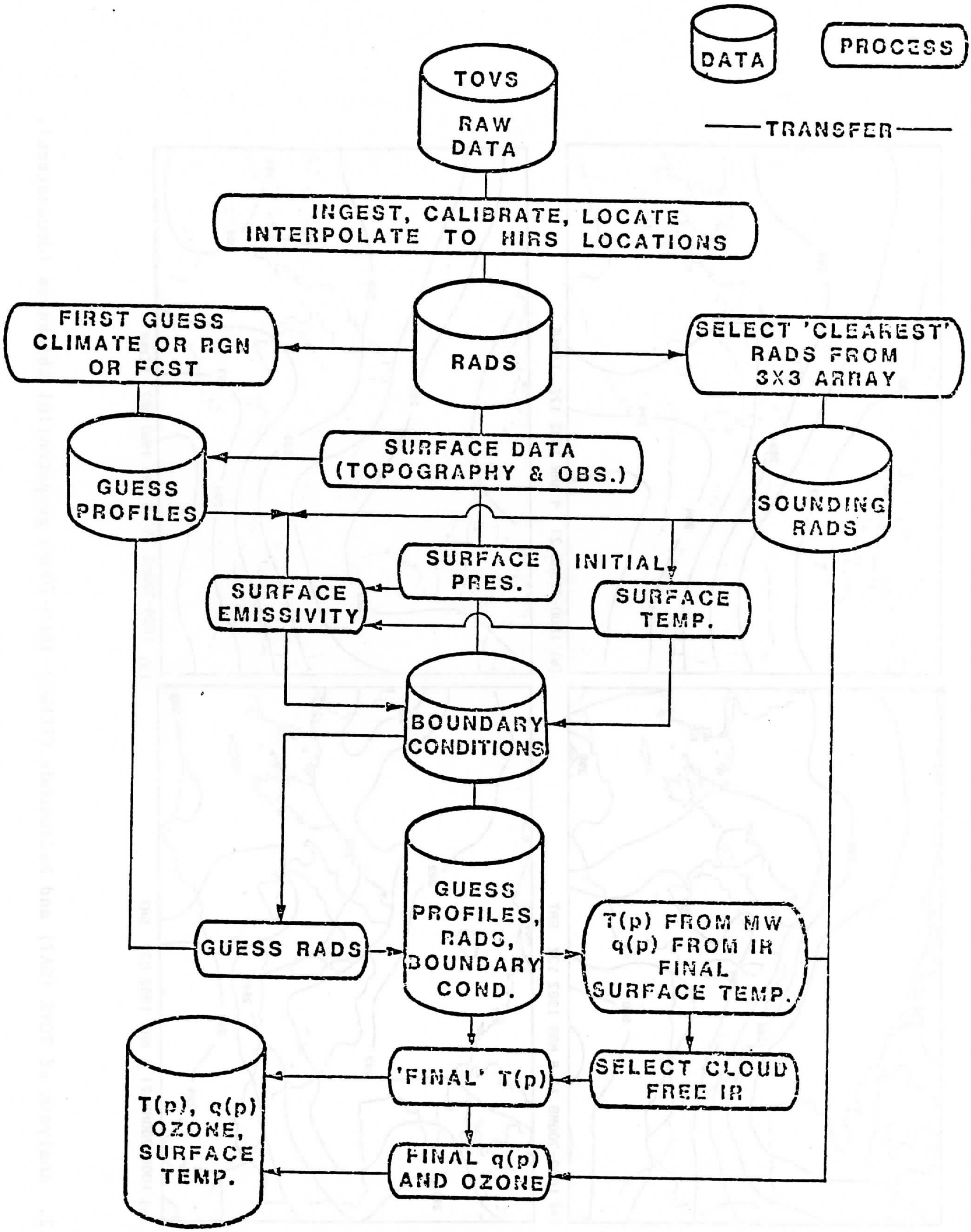


Figure 1. Schematic of the TOVS Physical Retrieval Processing System.

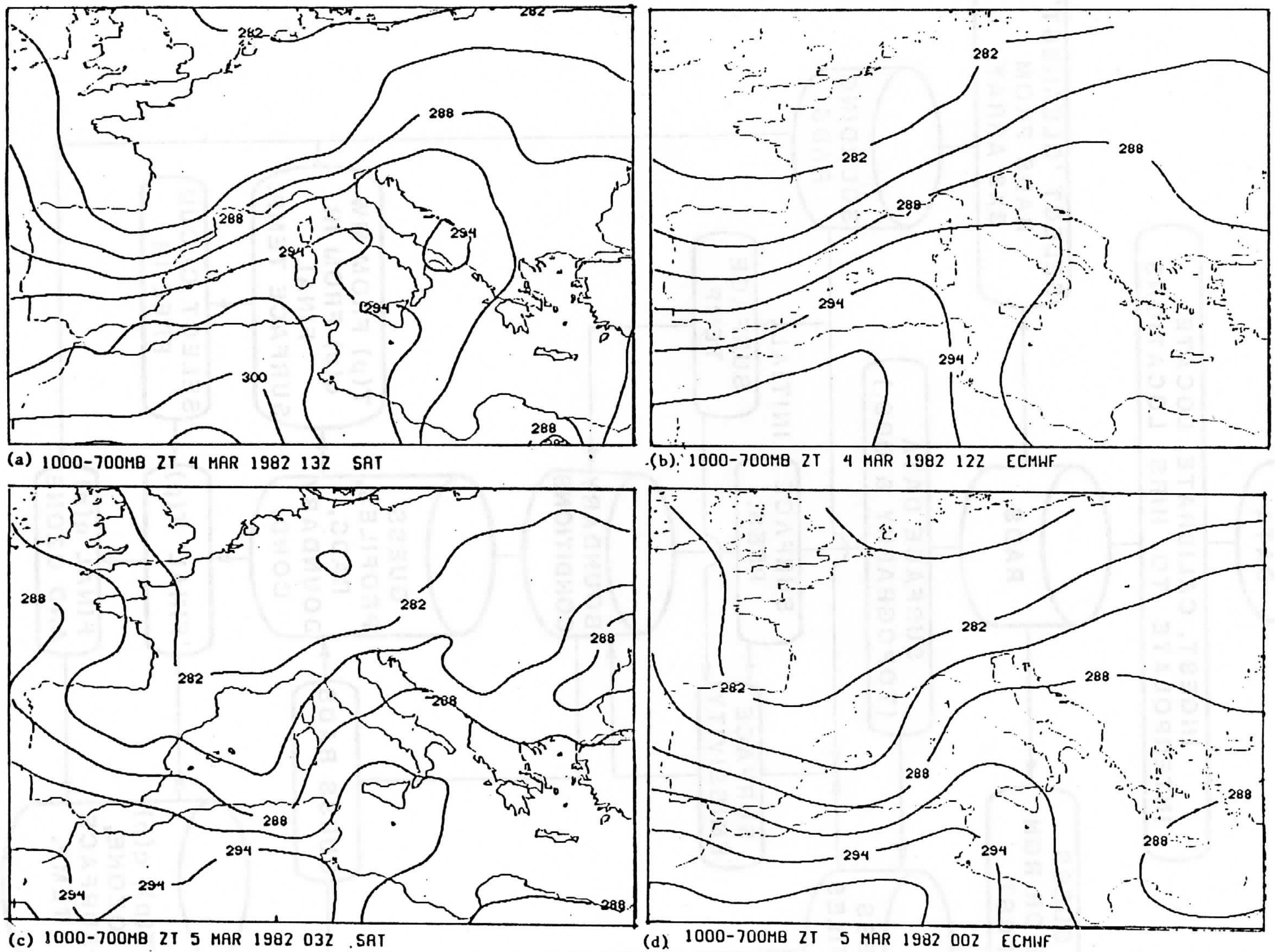


Figure 2. Analyses of TOVS (SAT) and Radiosonde (ECMWF) 1000-700mb geopotential thickness (decameters).

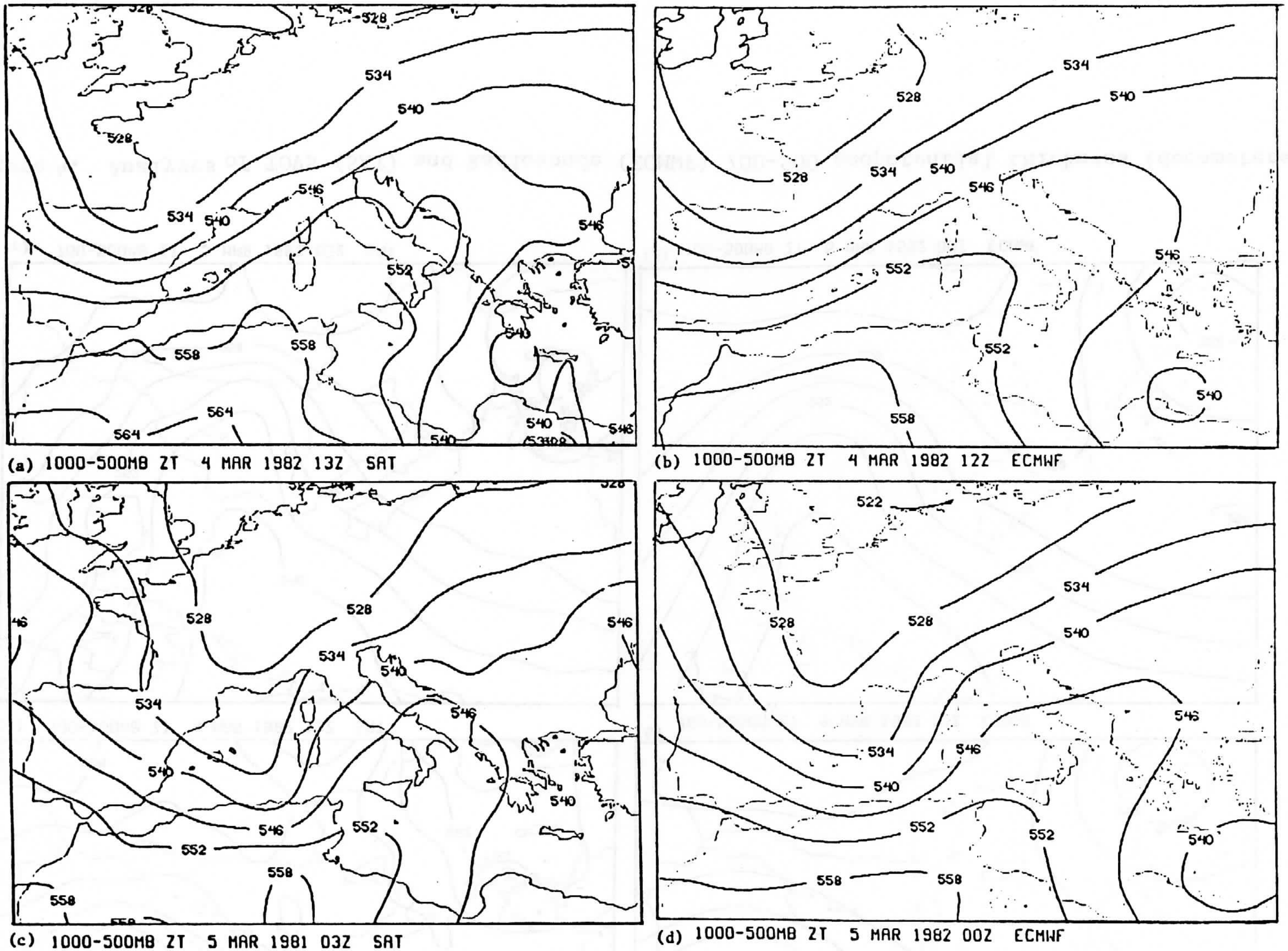


Figure 3. Analyses of TOVS (SAT) and Radiosonde (ECMWF) 1000-500 mb geopotential thickness (decameters).

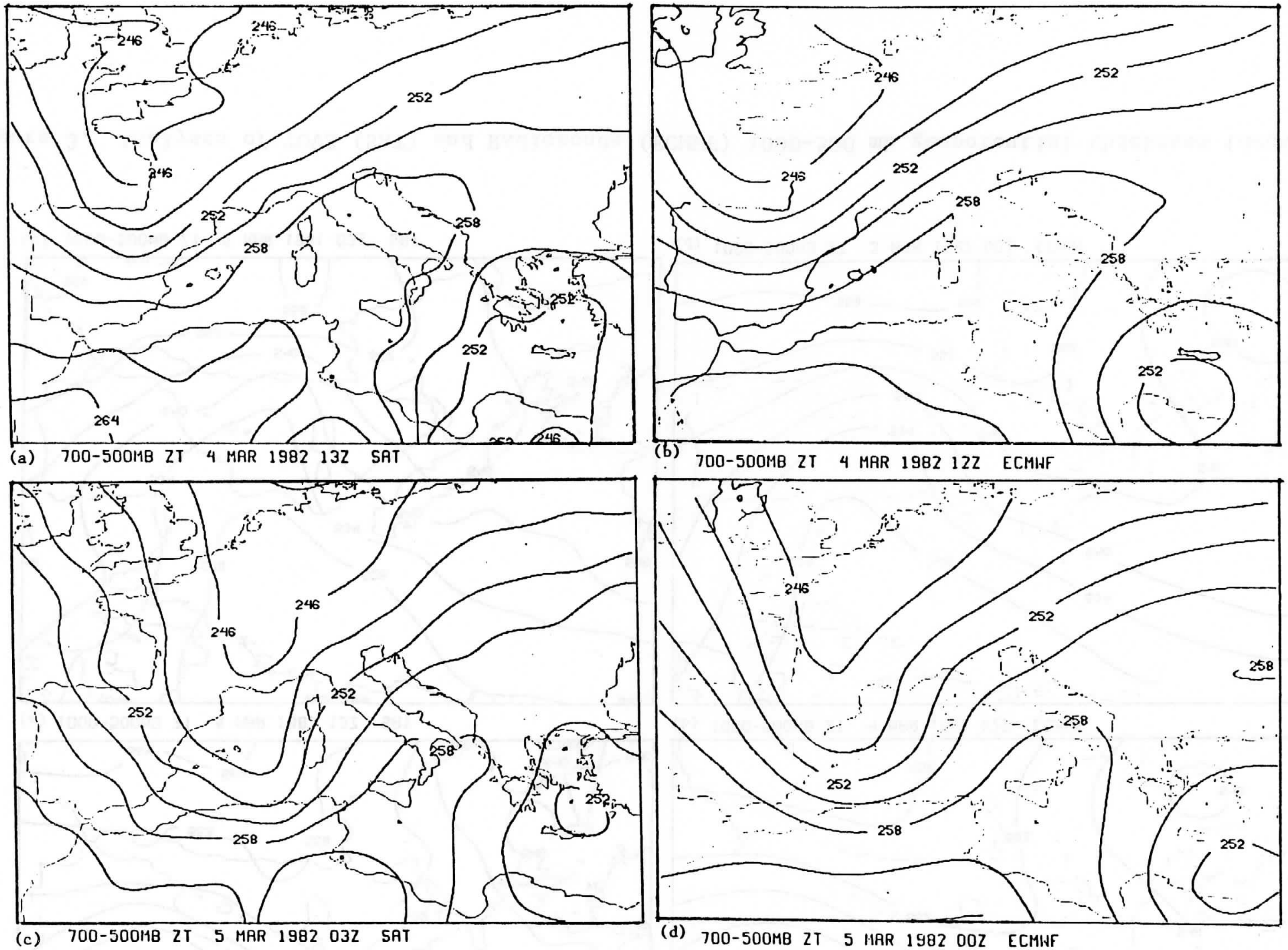


Figure 4. Analyses of TOVS (SAT) and Radiosonde (ECMWF) 700-500 geopotential thickness (decameters).

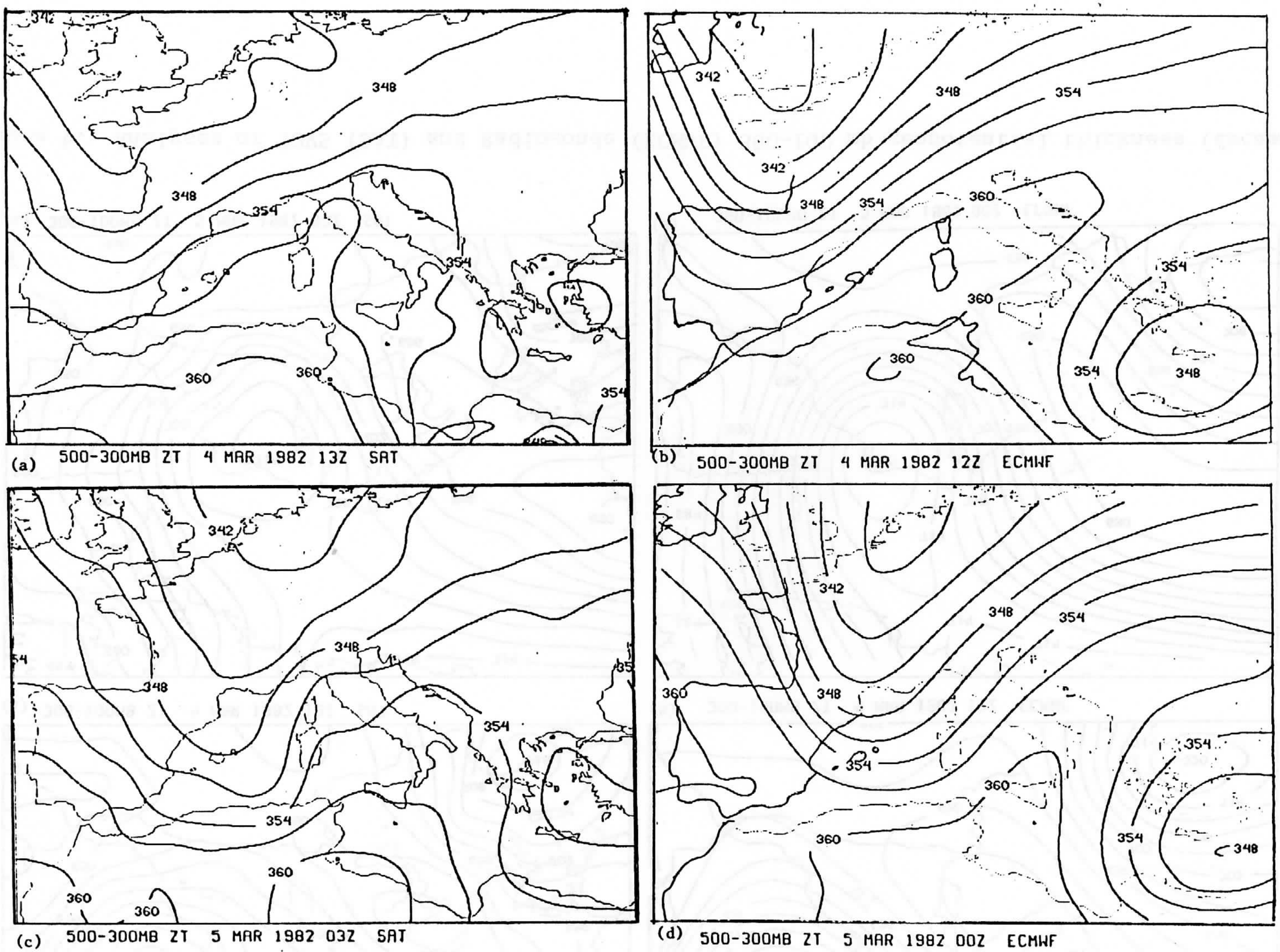


Figure 5. Analyses of TOVS (SAT) and Radiosonde (ECMWF) 500-300 geopotential thickness (decameters).

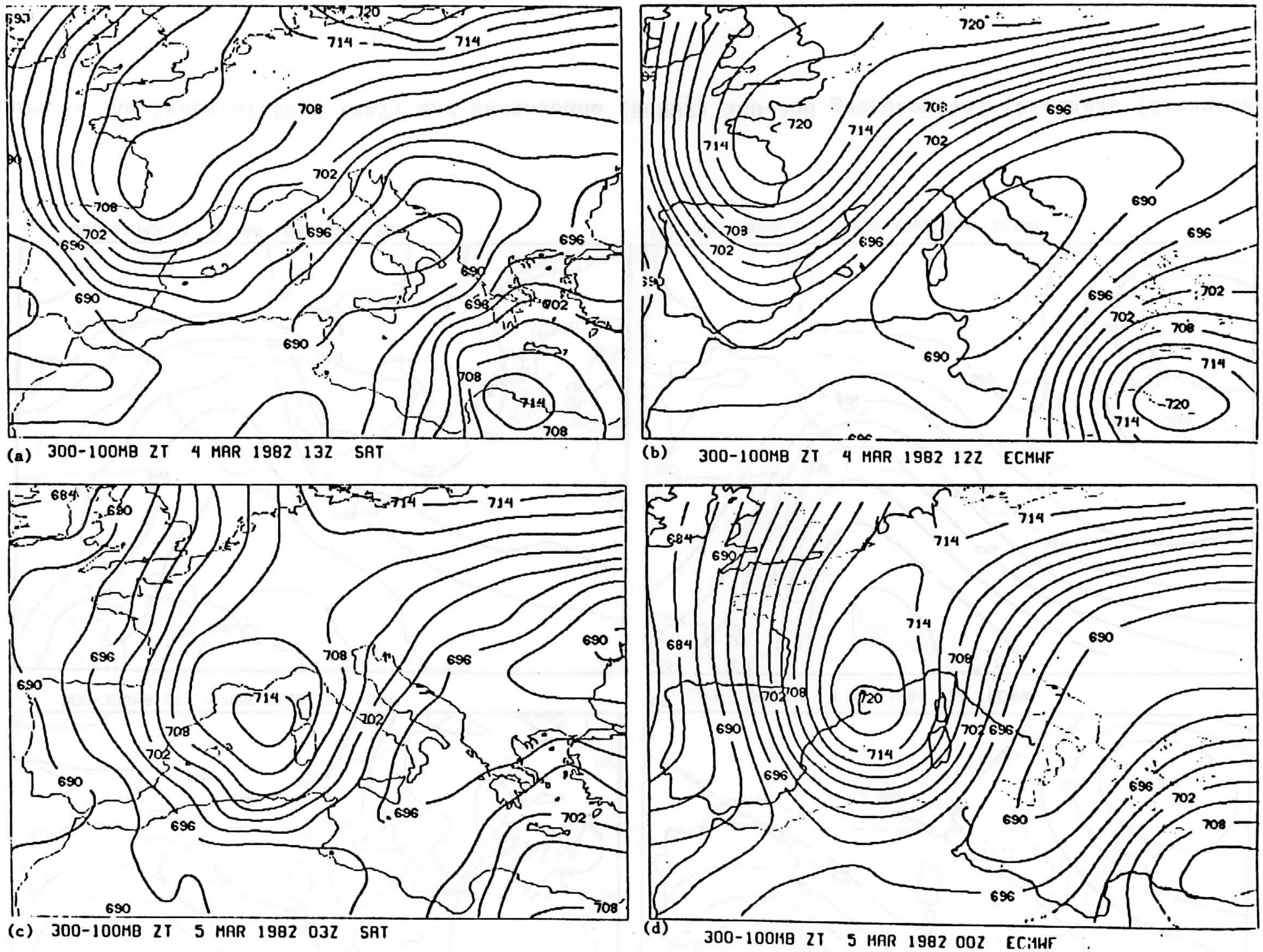


Figure 6. Analyses of TOVS (SAT) and Radiosonde (ECMWF) 300-100 mb geopotential thickness (decameters).

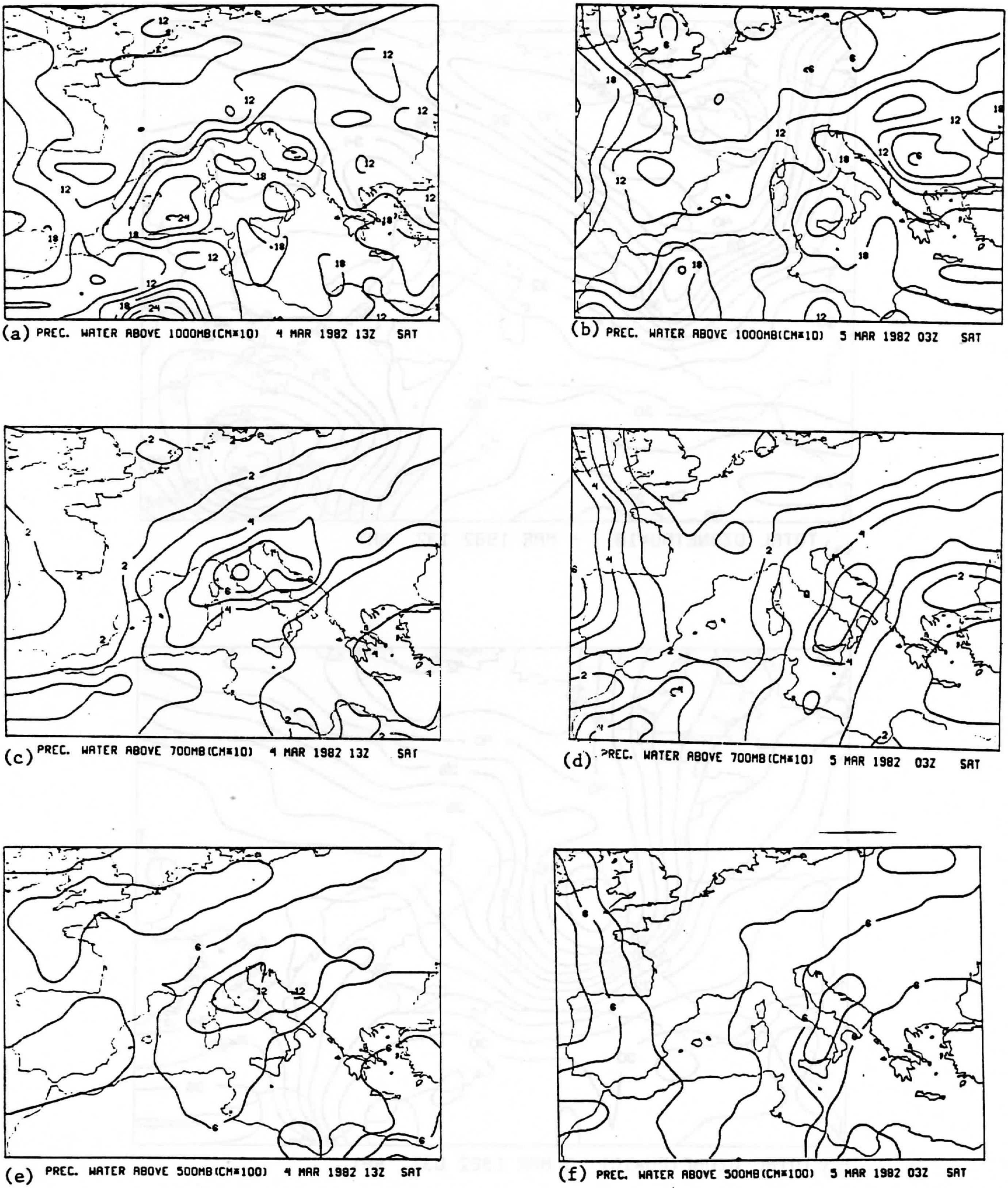
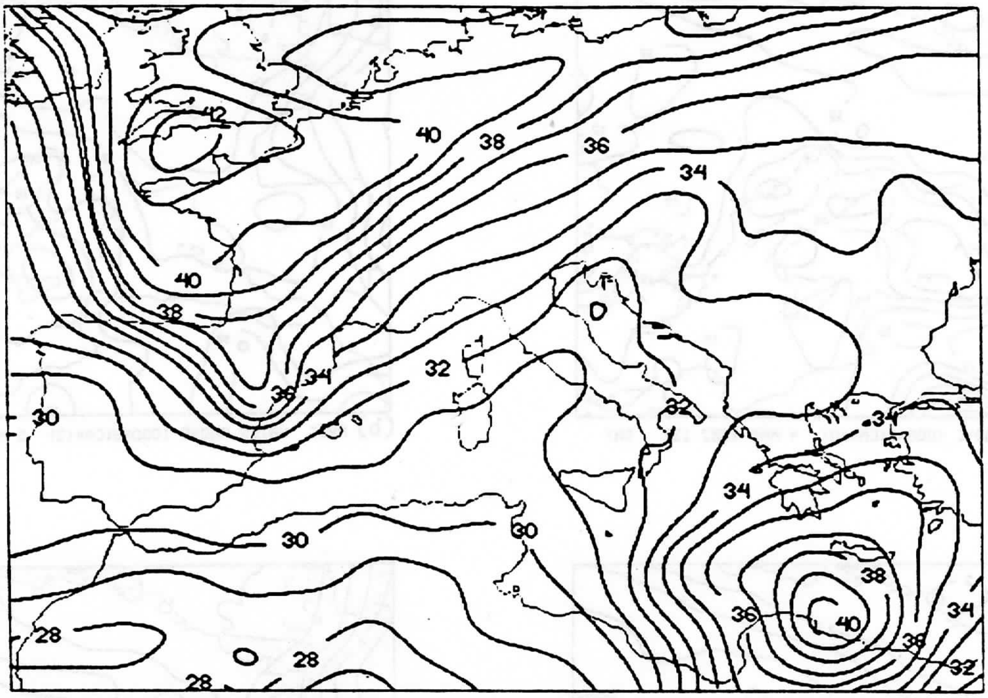
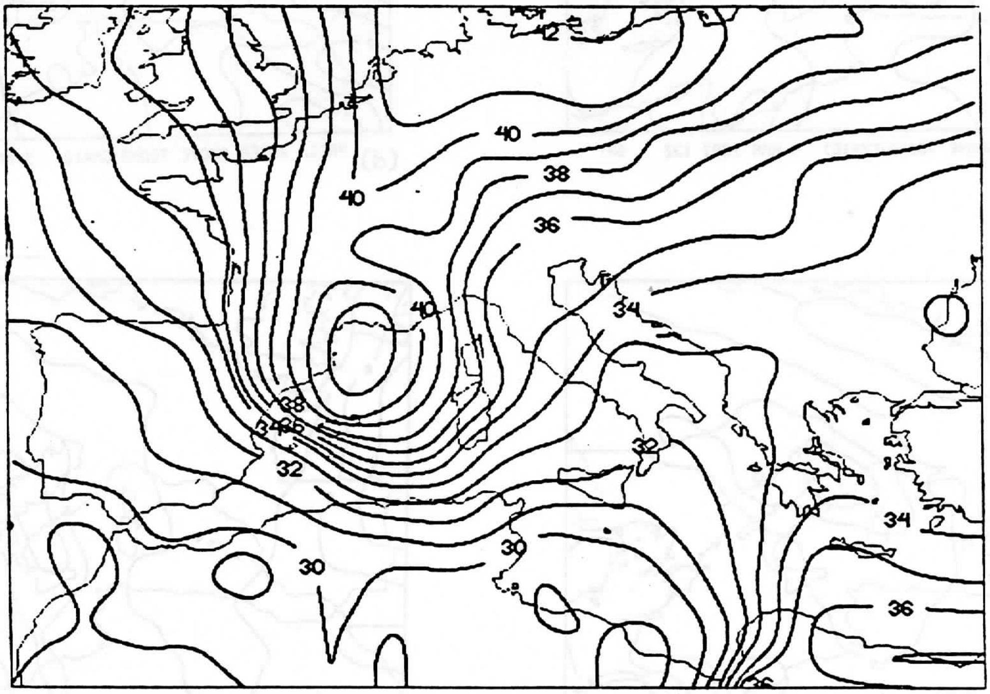


Figure 7. Analyses of TOVS (SAT) Total Precipitable Water for the Atmospheric Column above (a) and (b) 1000 mb, (c) and (d) 700 mb, and (e) and (f) 500 mb.



(a) TOTAL OZONE(DU*10) 4 MAR 1982 13Z SAT



(b) TOTAL OZONE(DU*10) 5 MAR 1982 03Z SAT

Figure 8. Analyses of TOVS (SAT) Total Ozone Concentration (deca-Dobson units) for (a) 4 March and (b) 5 March, 1982.

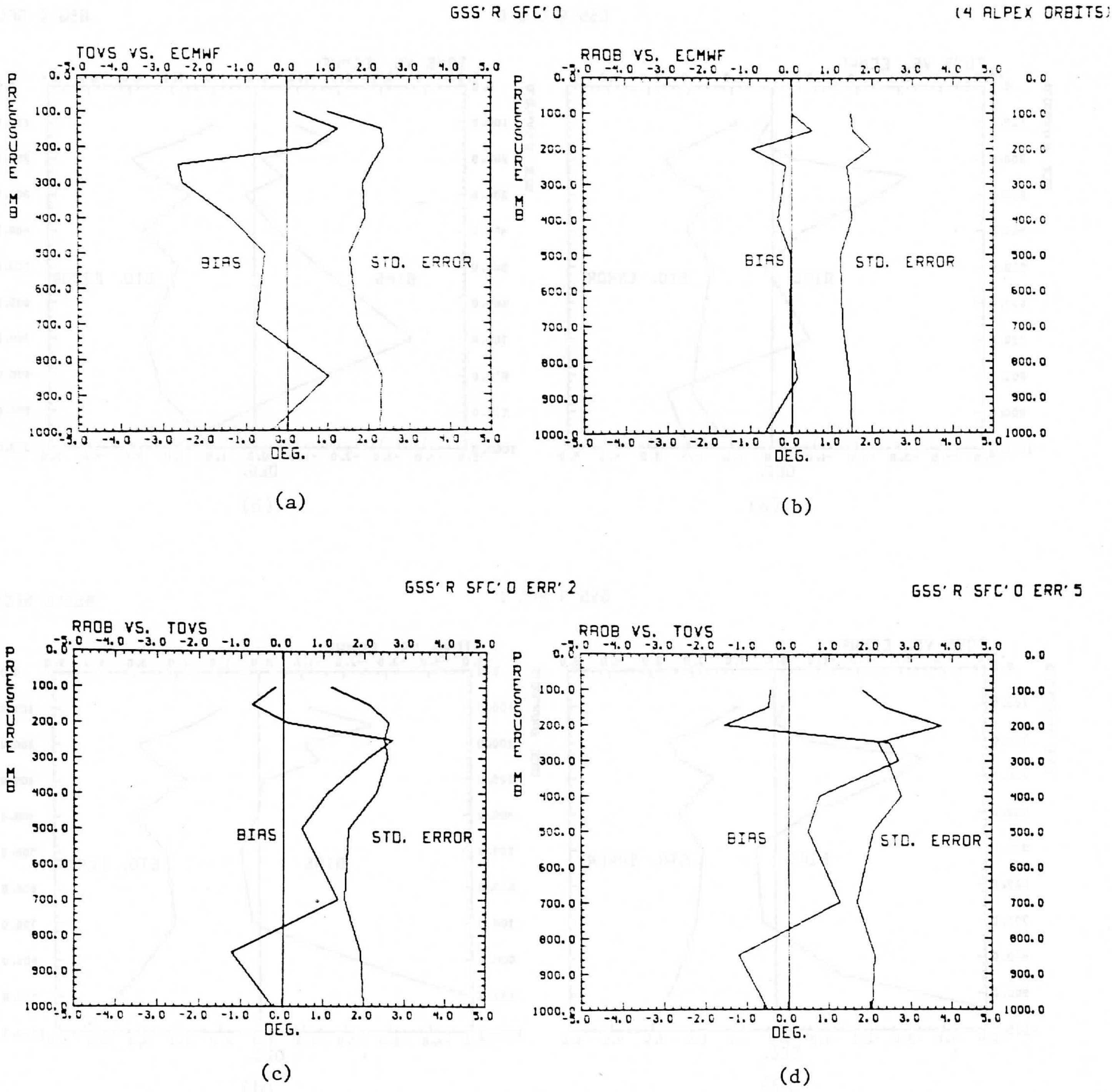


Figure 9. Bias and Standard Deviation (Errors) between TOVS, ECMWF analyses and radiosonde observations of level temperatures. Radiosonde used in figures (c) and (d) were within 2°C and 5°C of the temperature of the ECMWF analyses.

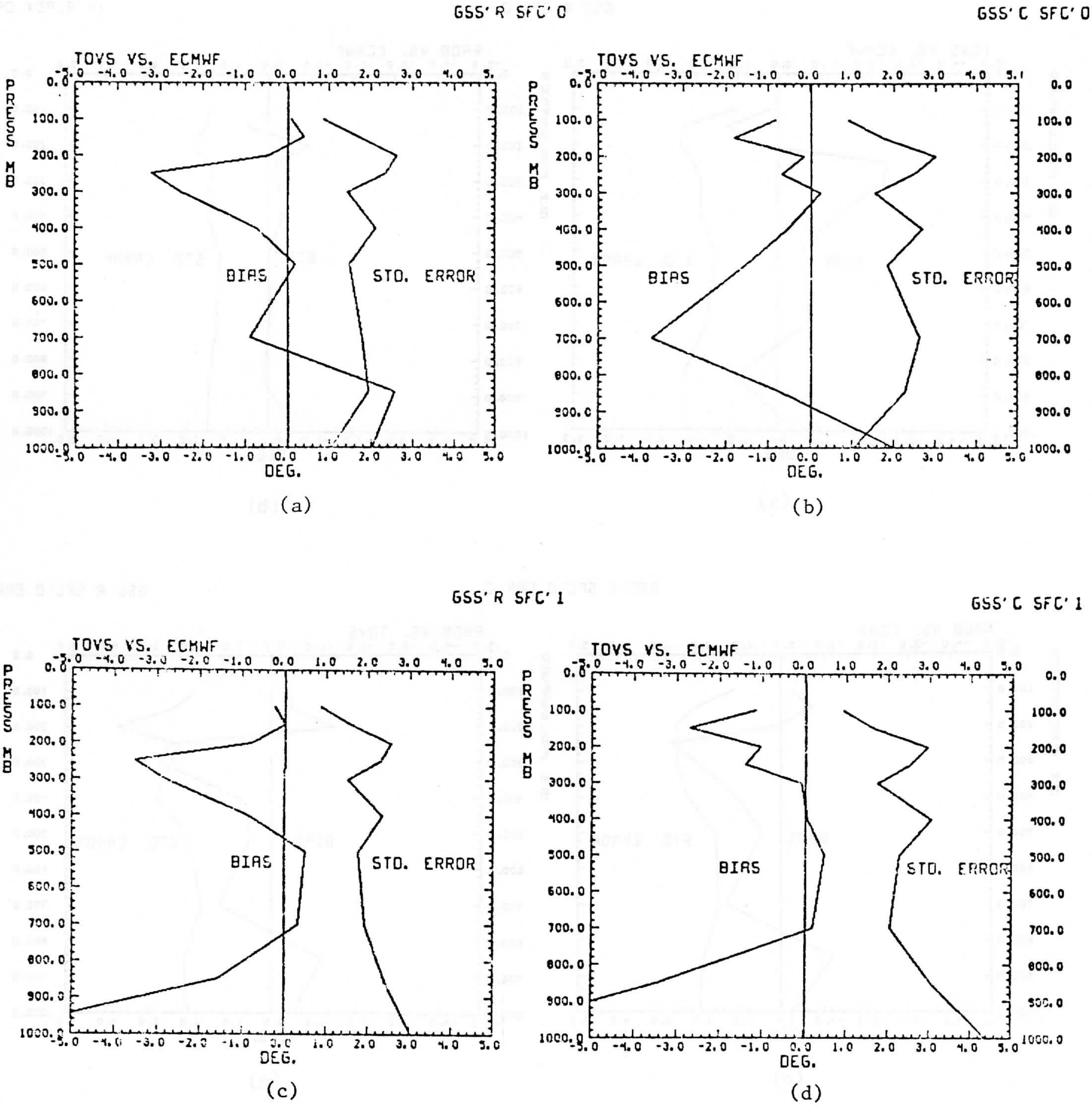
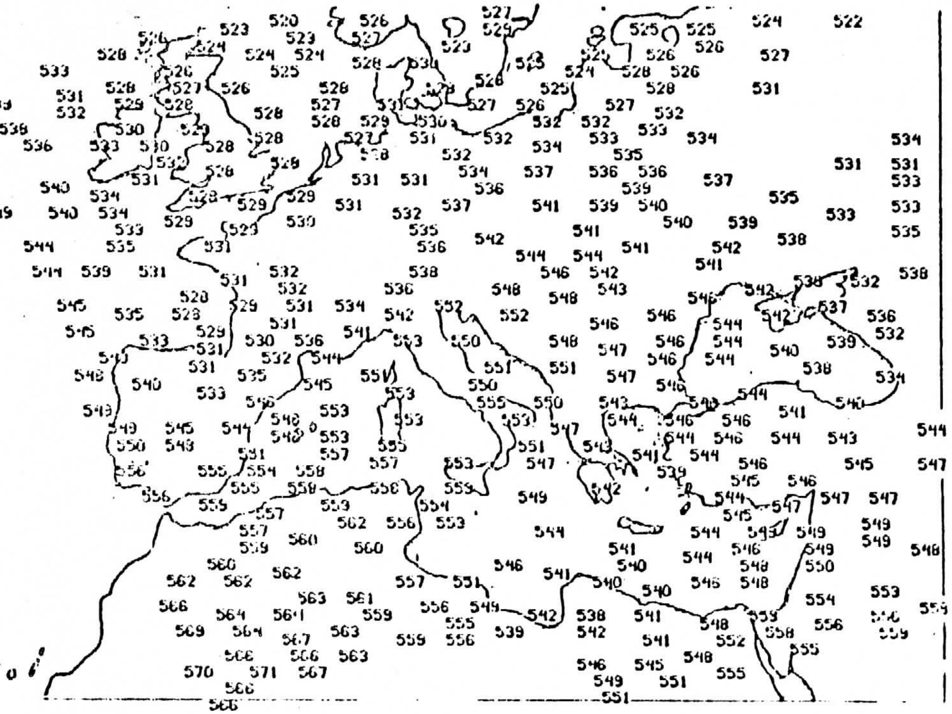


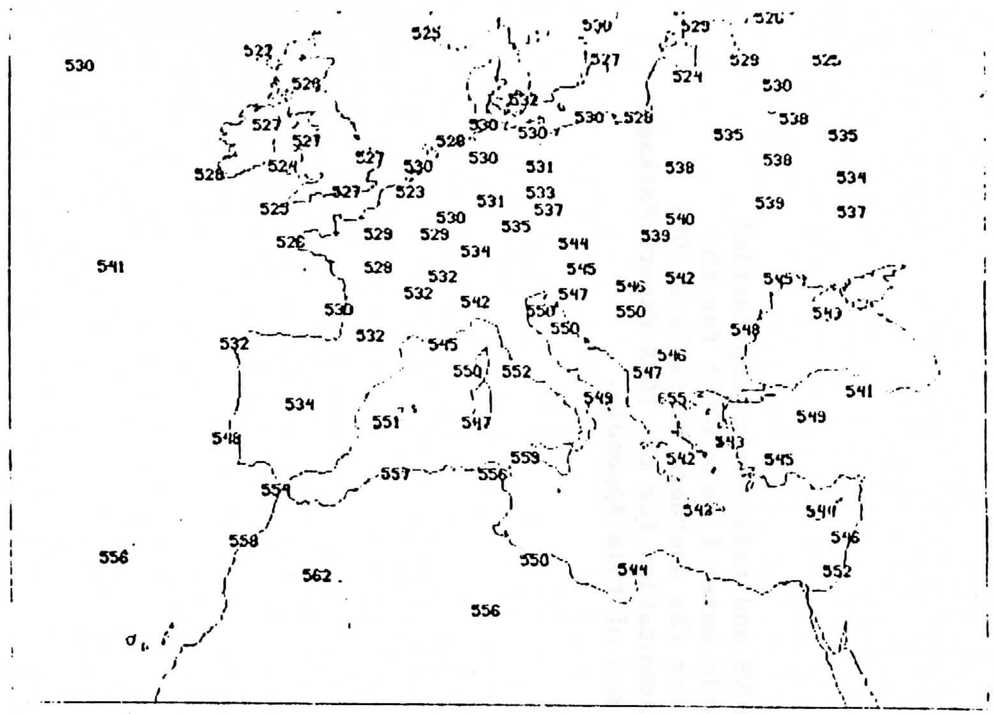
Figure 10. Bias and Standard Deviations between ECMWF analyses of radiosonde data and TOVS level temperature values produced for four different program options. (a) regression guess with surface data, (b) climate guess with surface data, (c) regression guess without surface data, (d) climate guess without surface data.

Appendix to Smith et al

The following pages contain plots of TOVS and radiosonde geopotential thickness (decameters) and precipitable water (cm x 100) for the TOVS Study Conference NOAA-7 orbits. For the southern hemisphere, TOVS data and analyses are also given. Documentation for the TOVS Export Package software and data are included at the end of this Appendix.



1000-500MB ZT 4 MAR 1982 13Z



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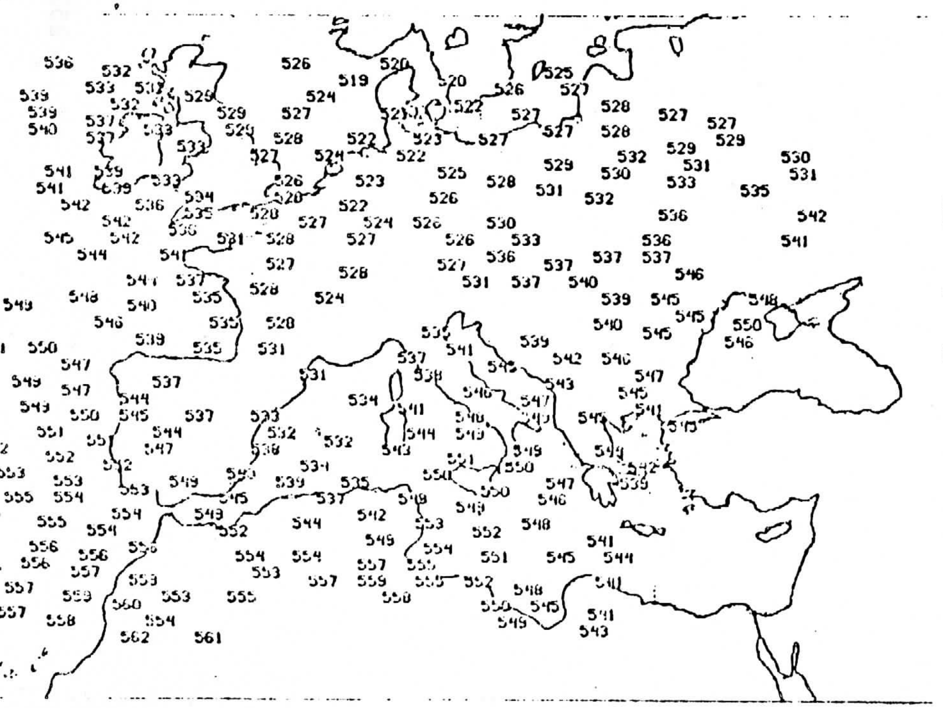

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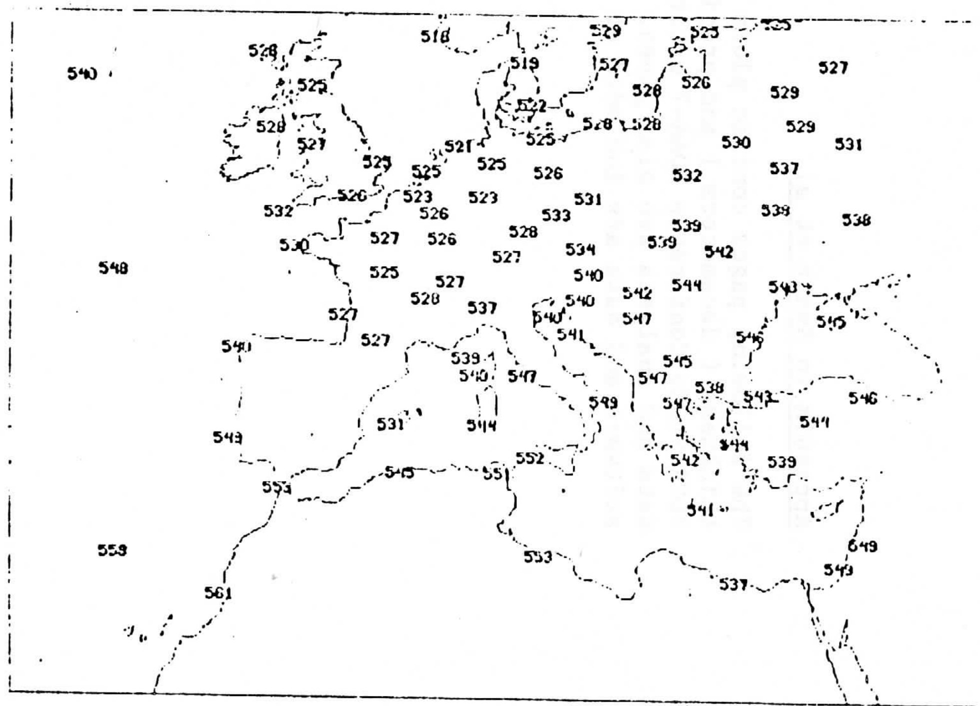

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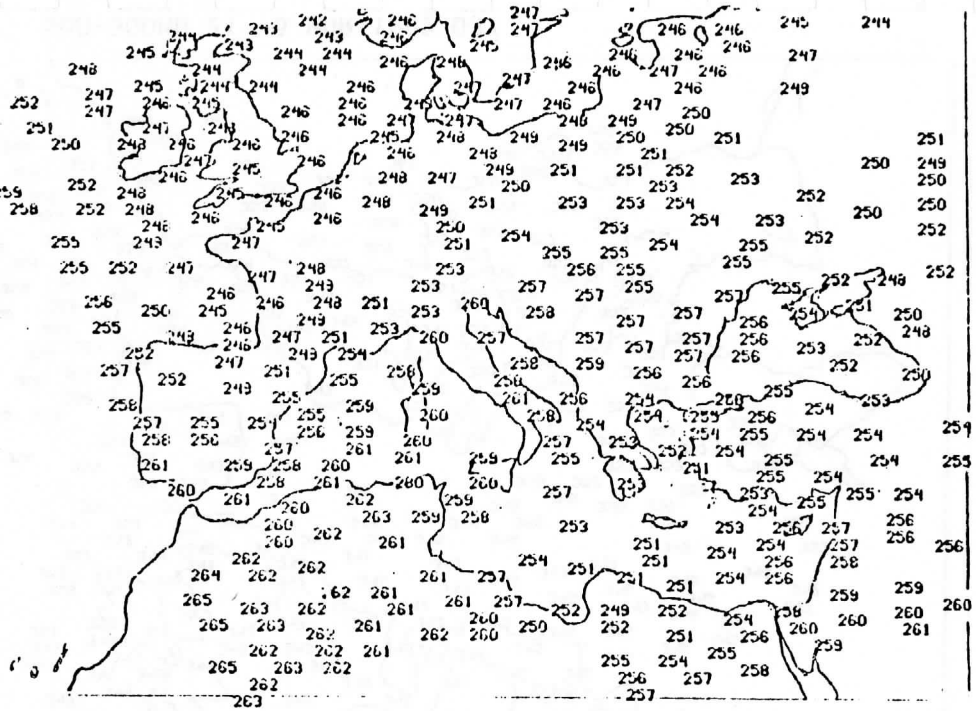

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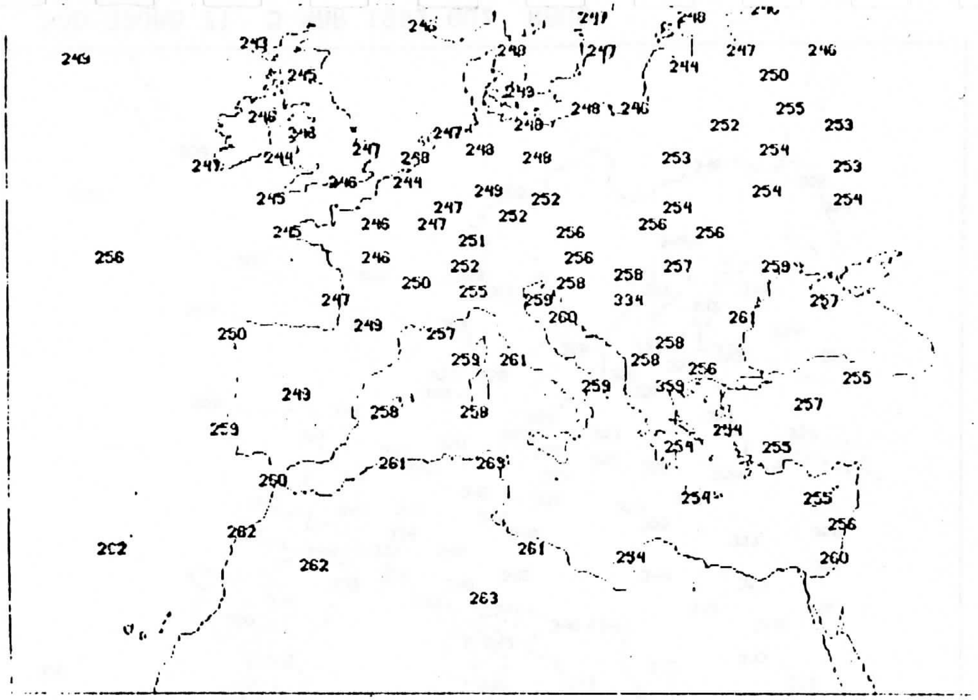

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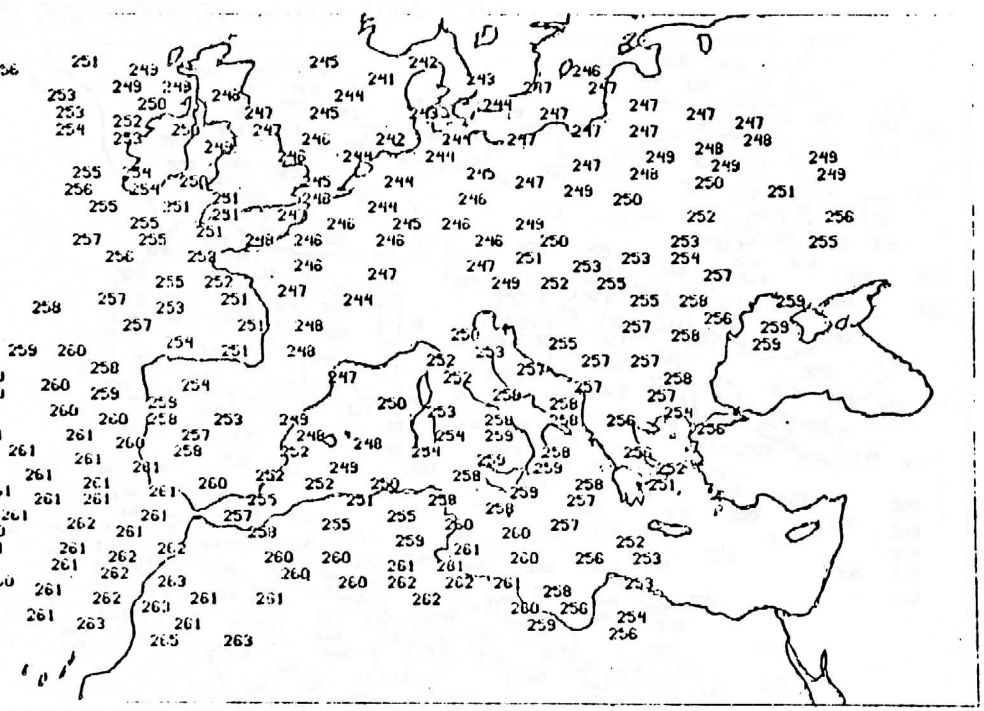

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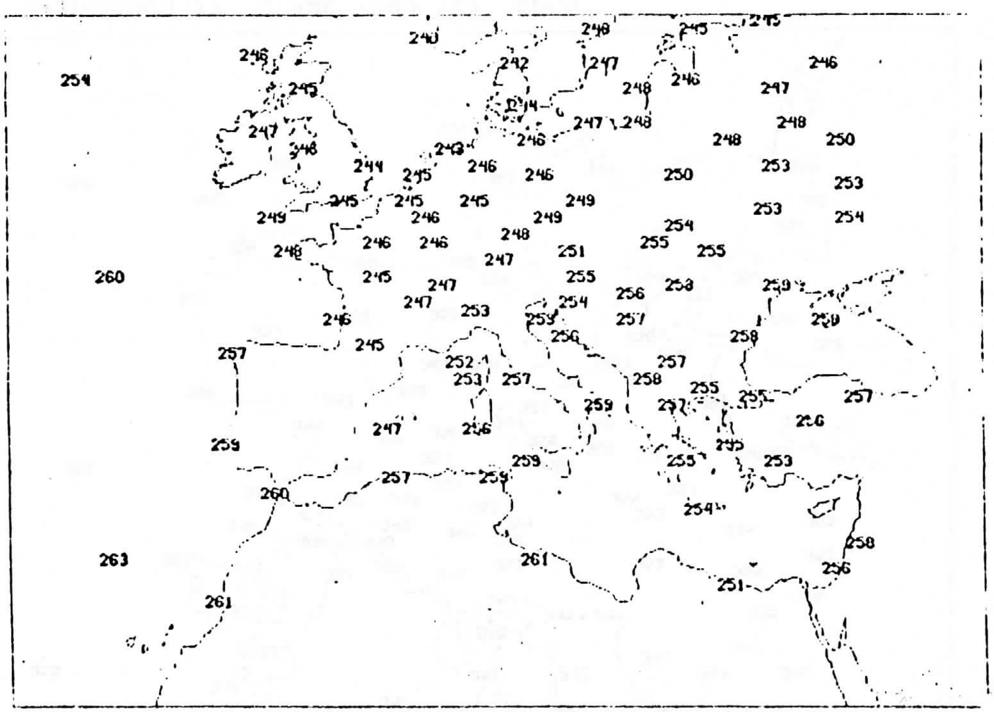
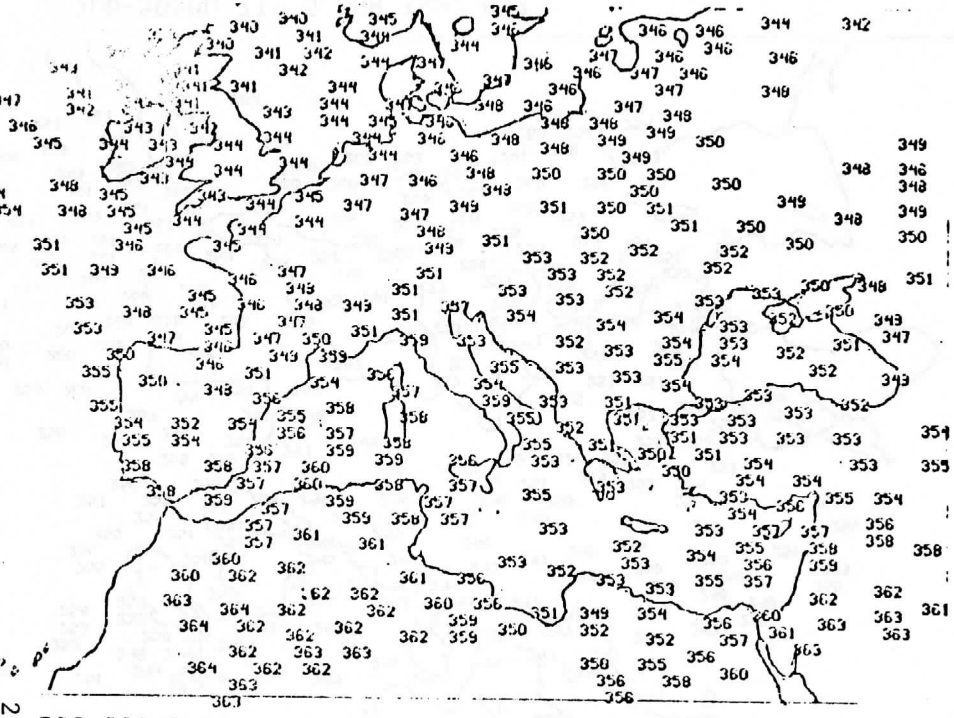


700-500MB ZT 5 MAR 1982 00Z RAOB



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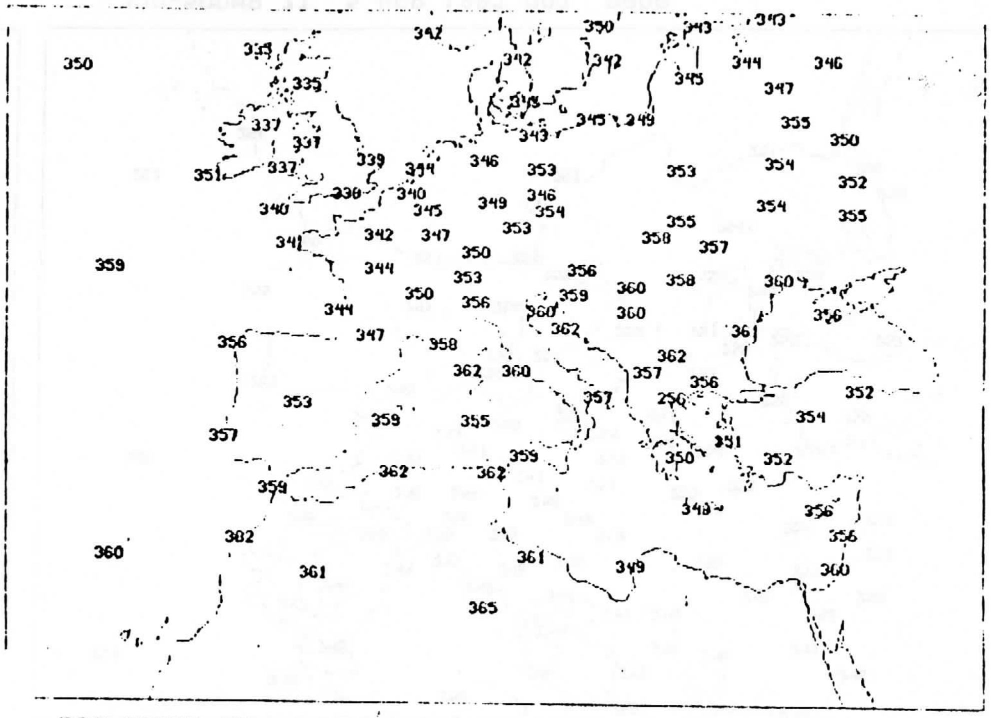

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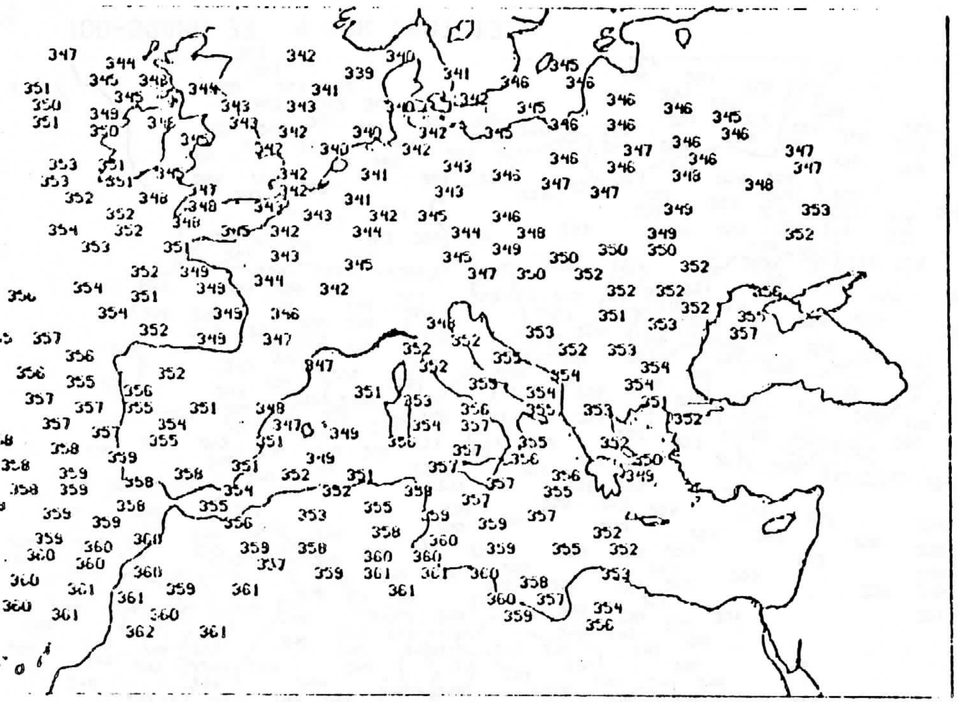

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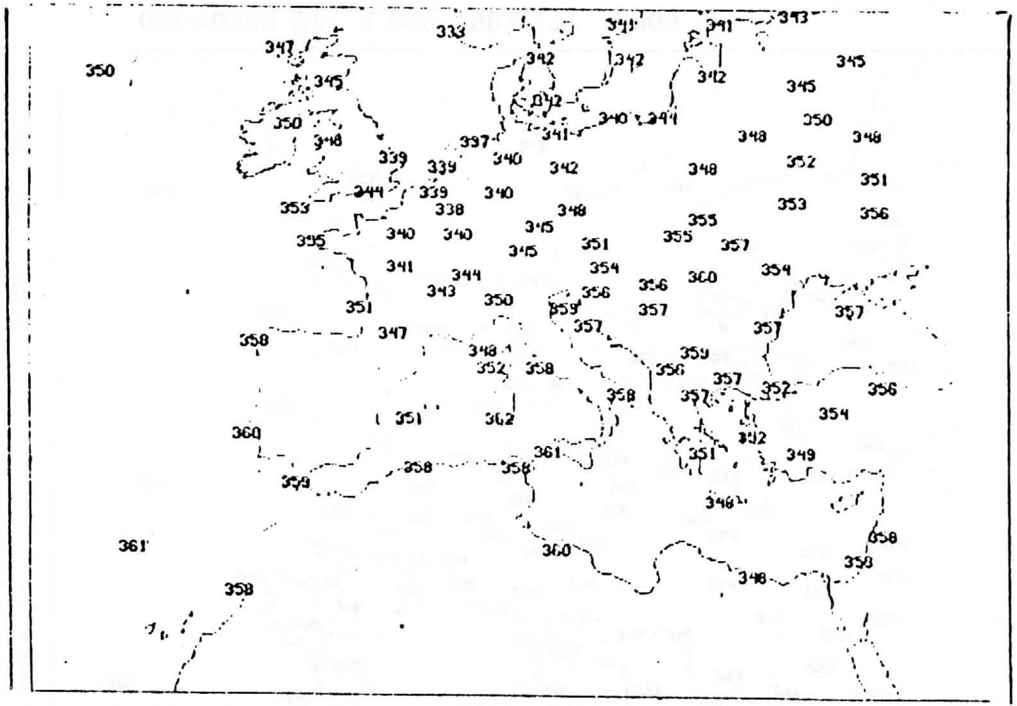

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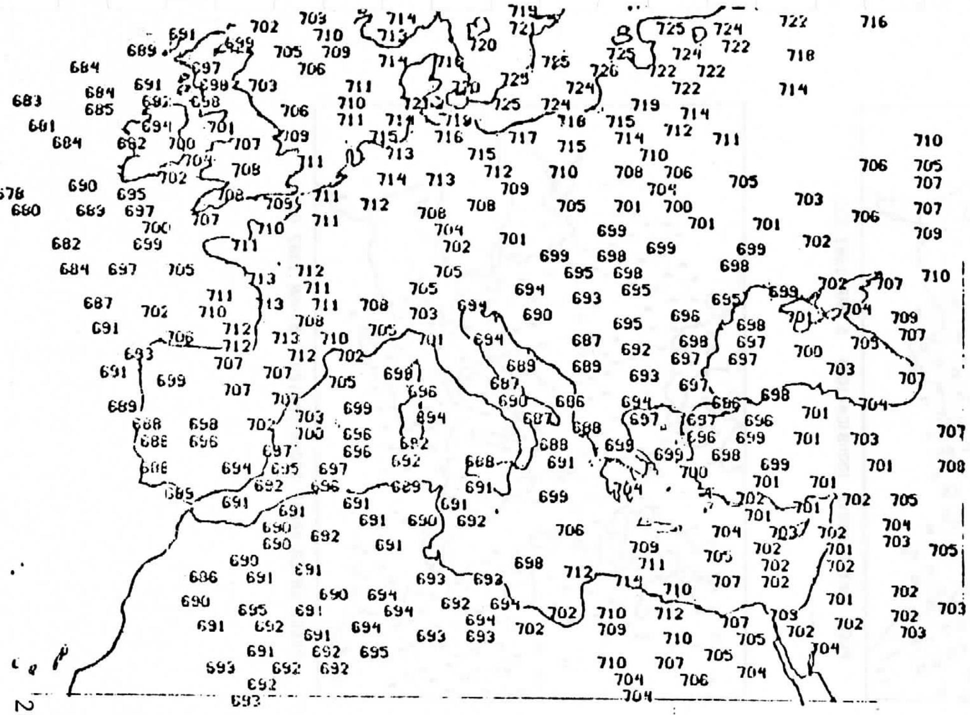

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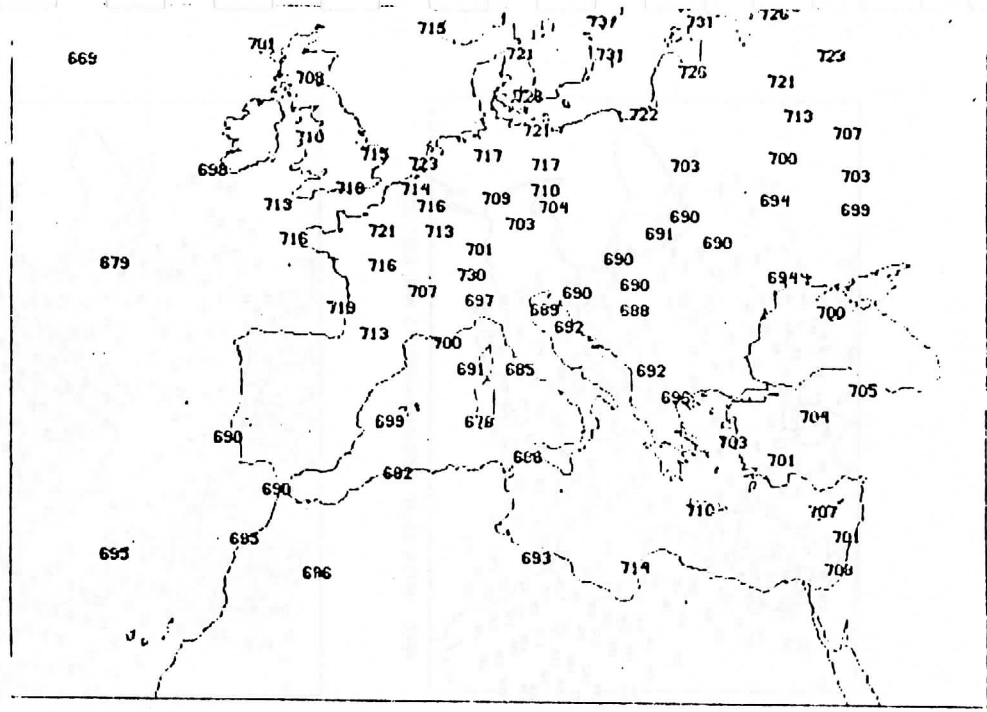

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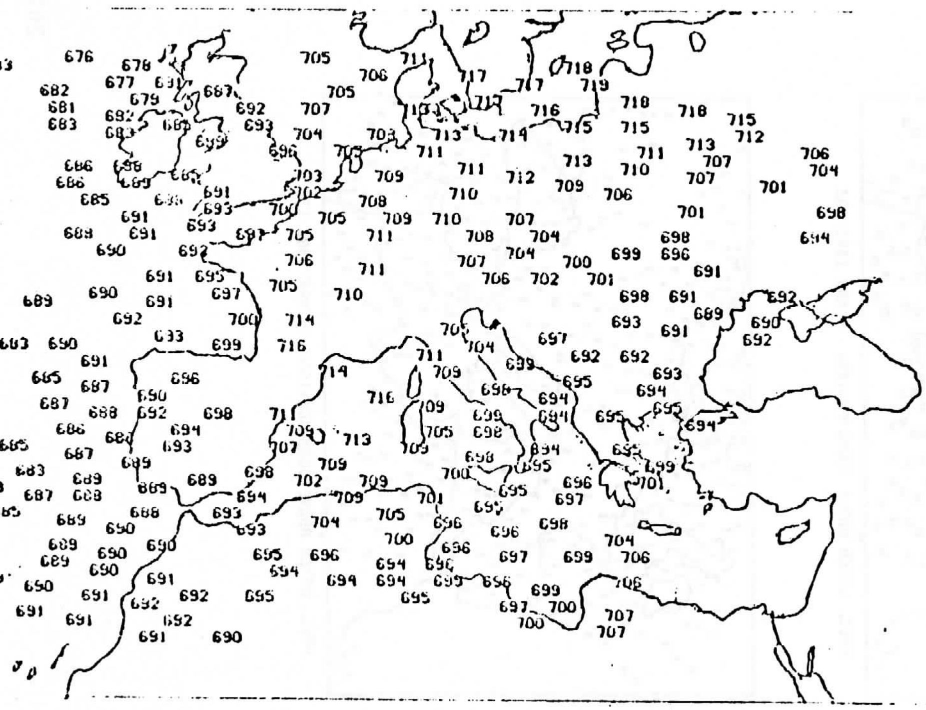

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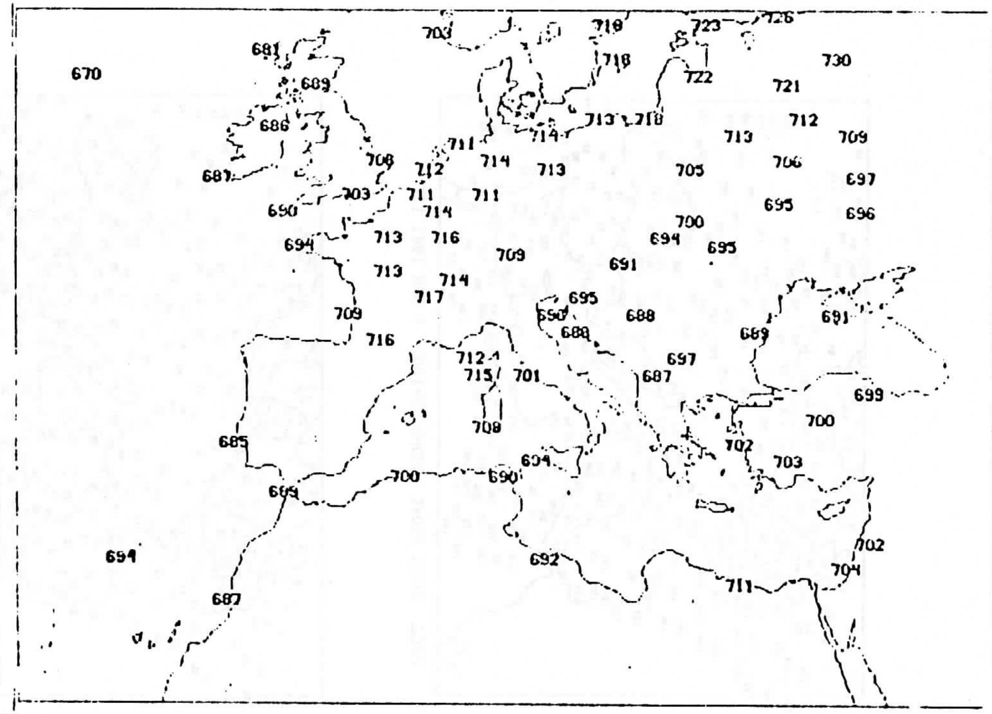

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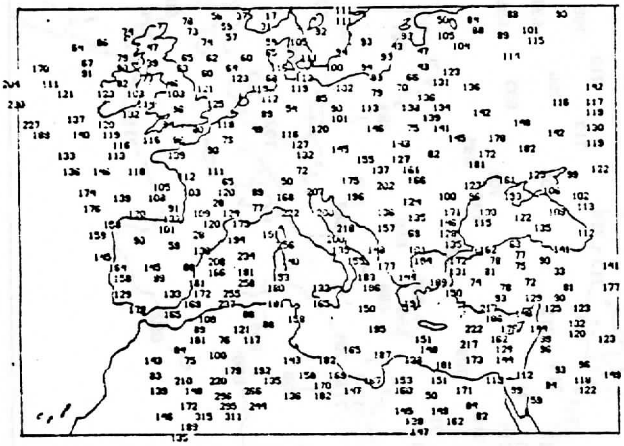
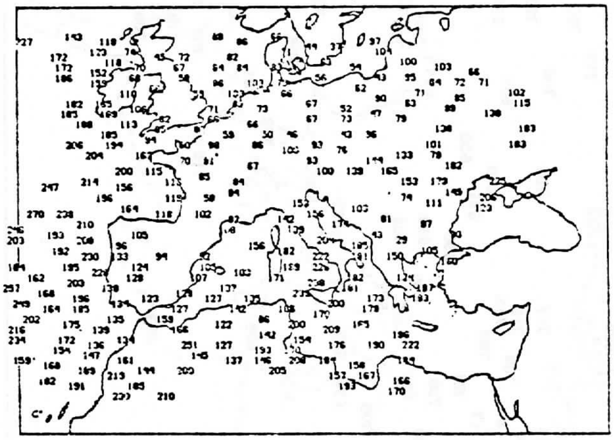


PREC. WATER ABOVE 1000MB(CM*100) 4 MAR 1982 13Z



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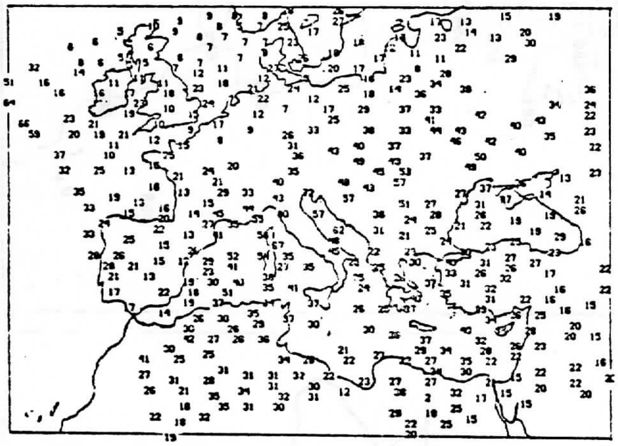

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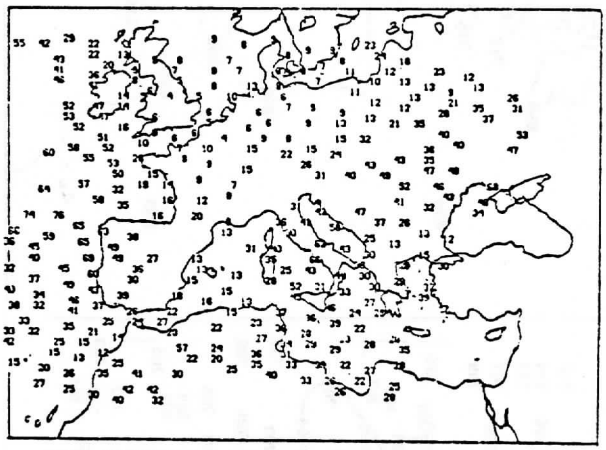
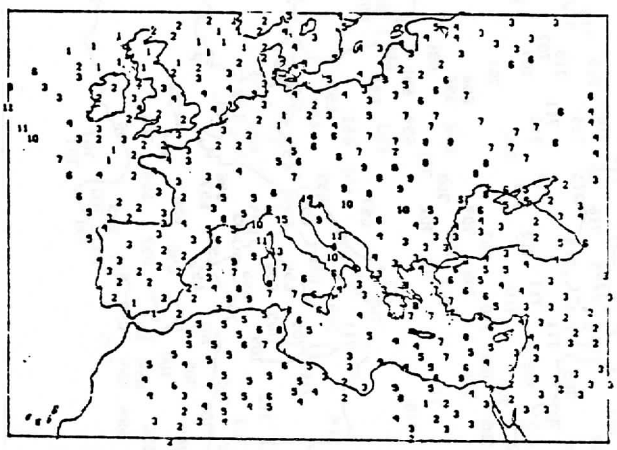


PREC. WATER ABOVE 700MB(CM*100) 5 MAR 1982 03Z



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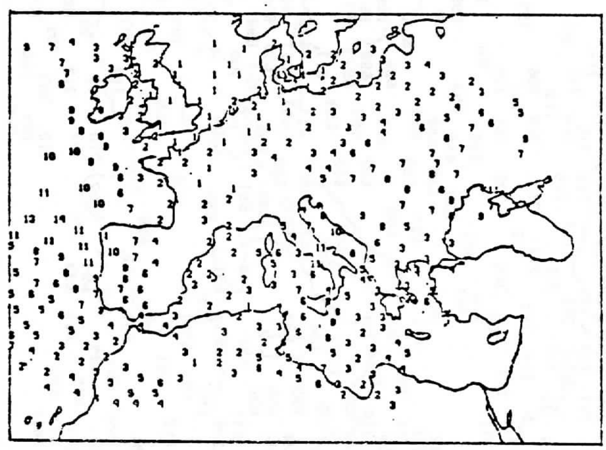
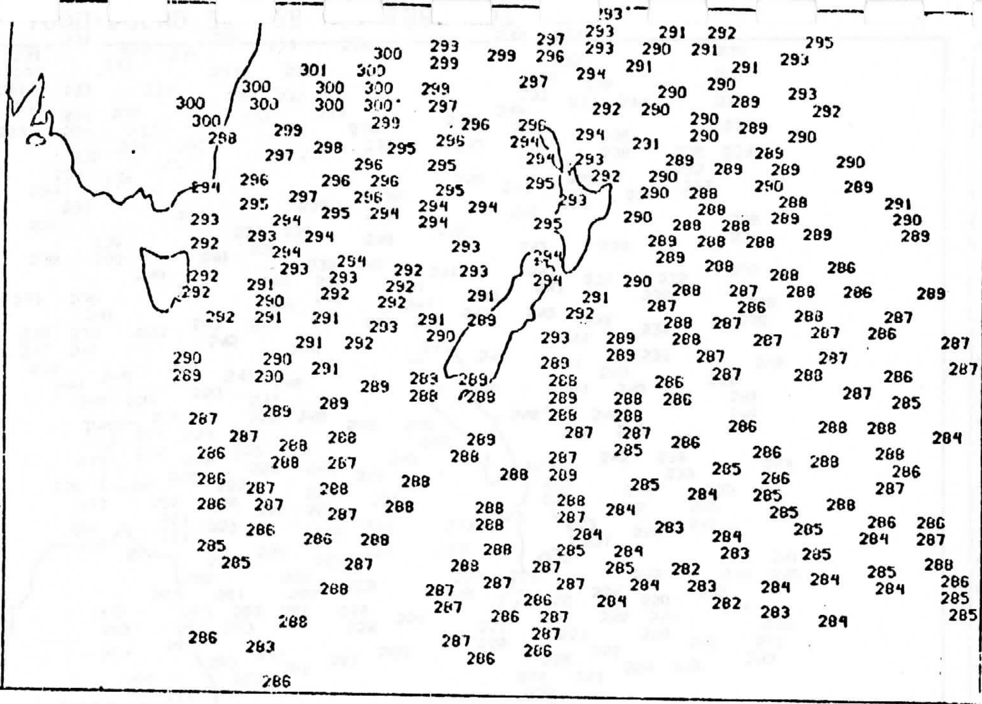
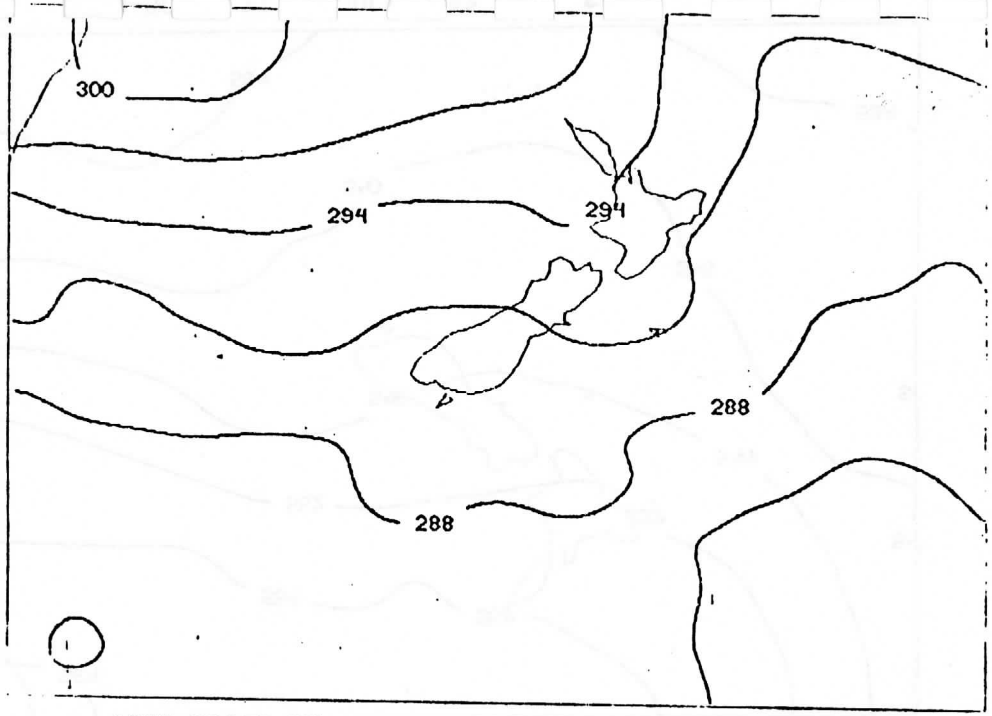


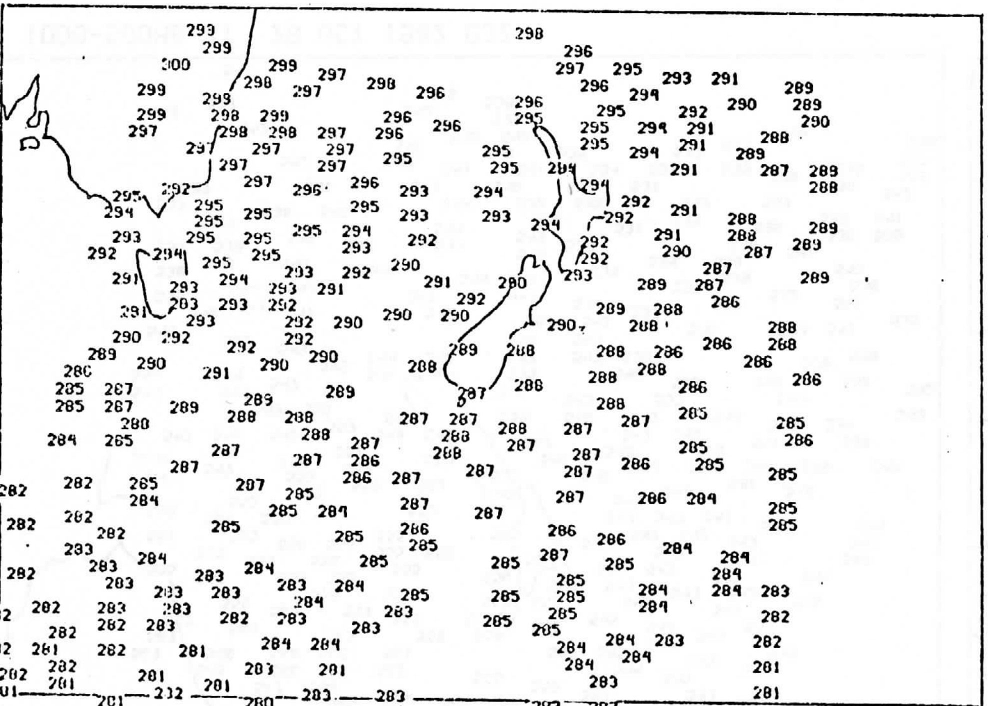
PREC. WATER ABOVE 500MB(CM*100) 5 MAR 1982 03Z



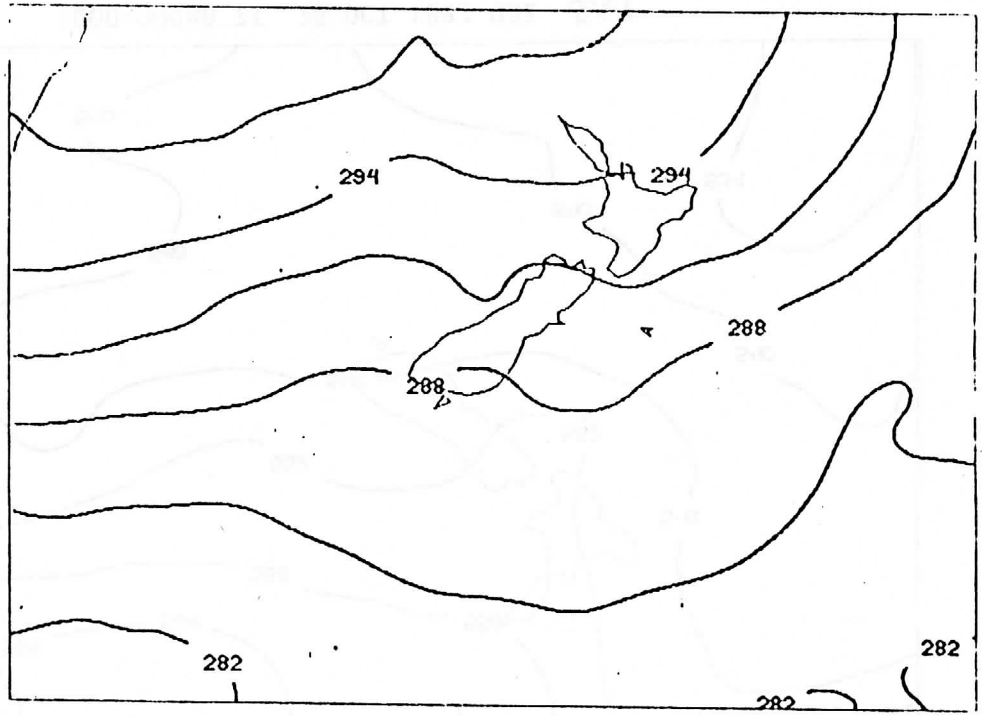
1000-700MB ZT 28 OCT 1982 03Z



1000-700MB ZT 28 OCT 1982 03Z SAT



1000-700MB ZT 28 OCT 1982 15Z



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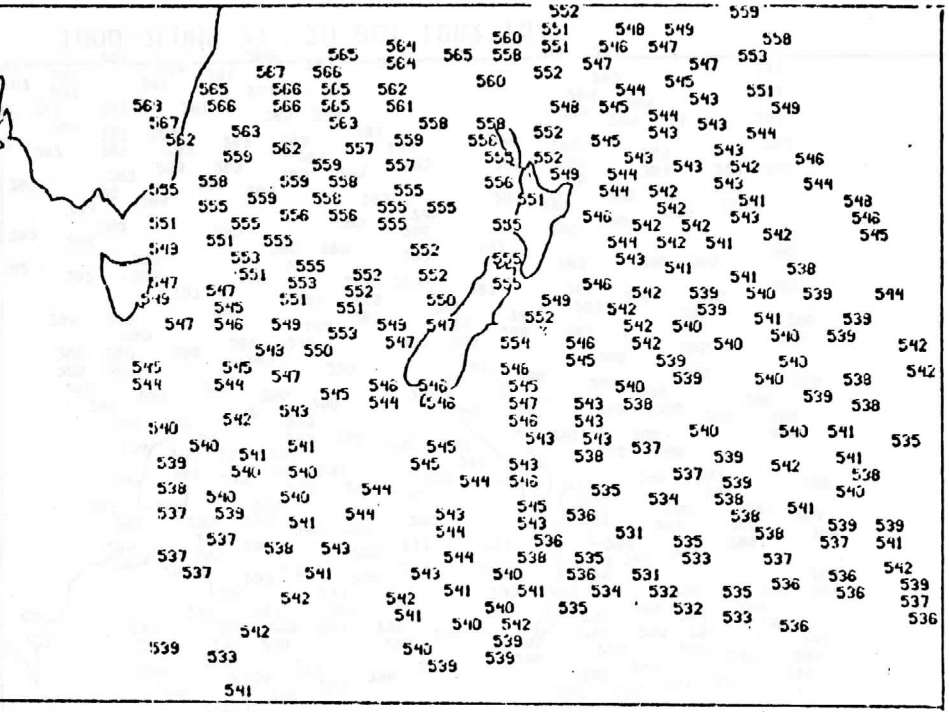

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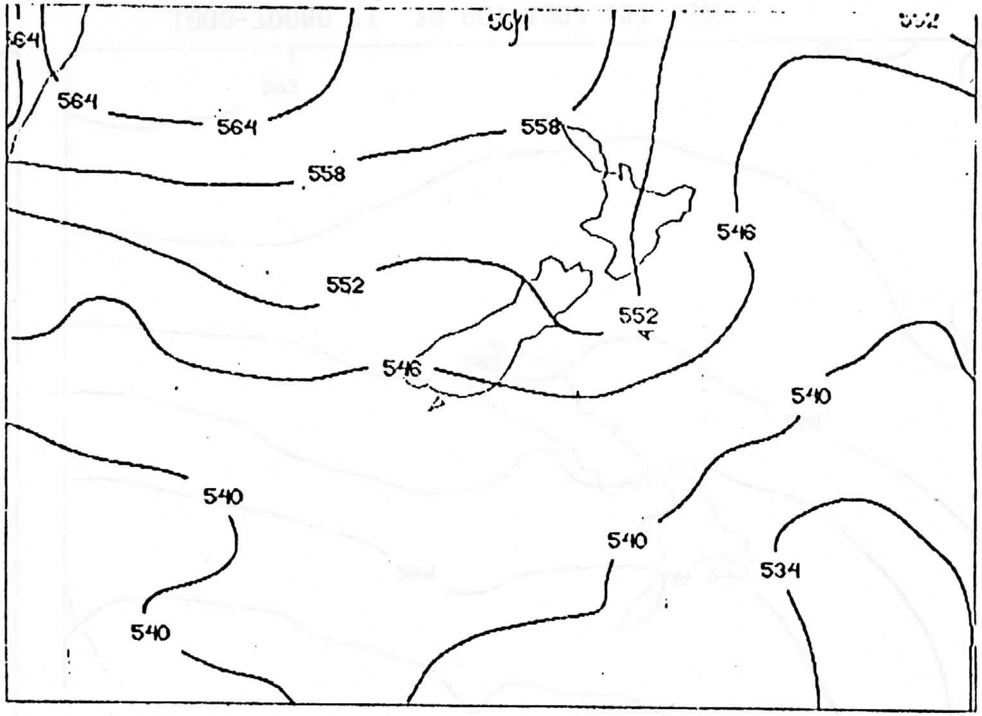

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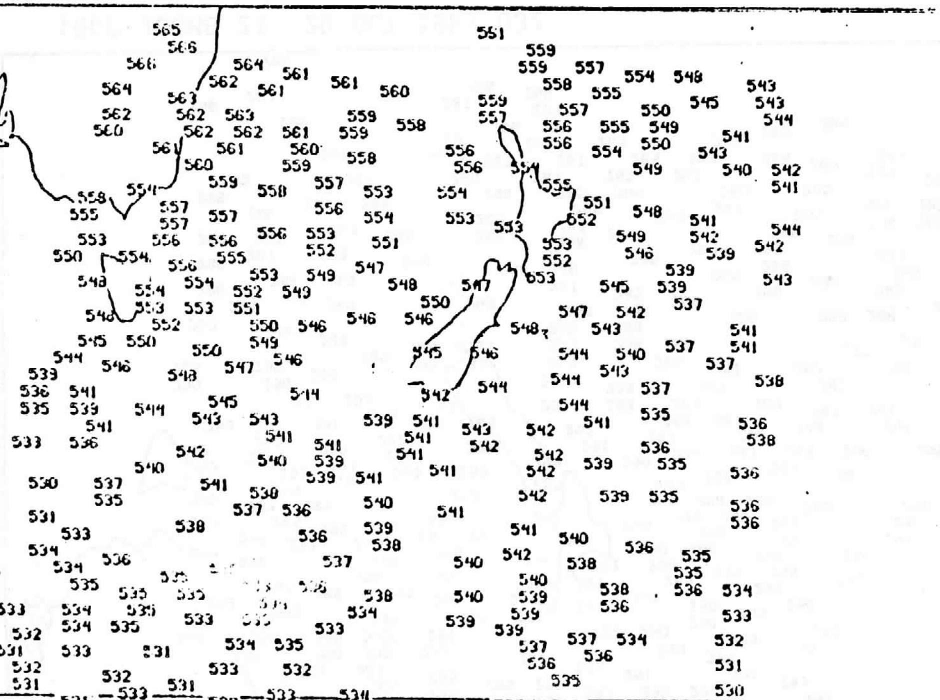

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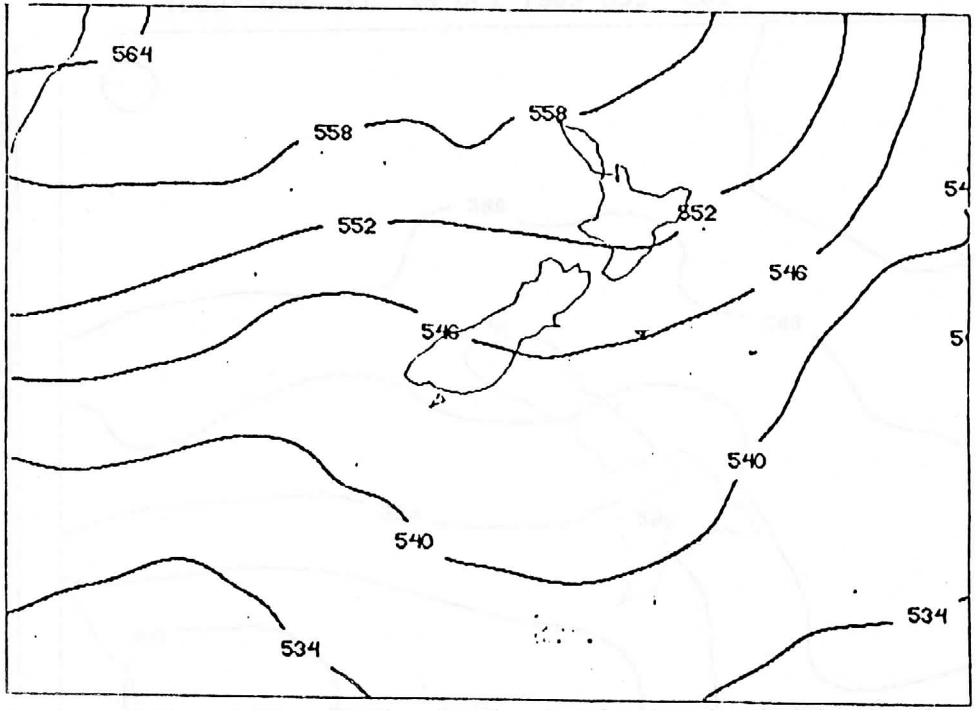
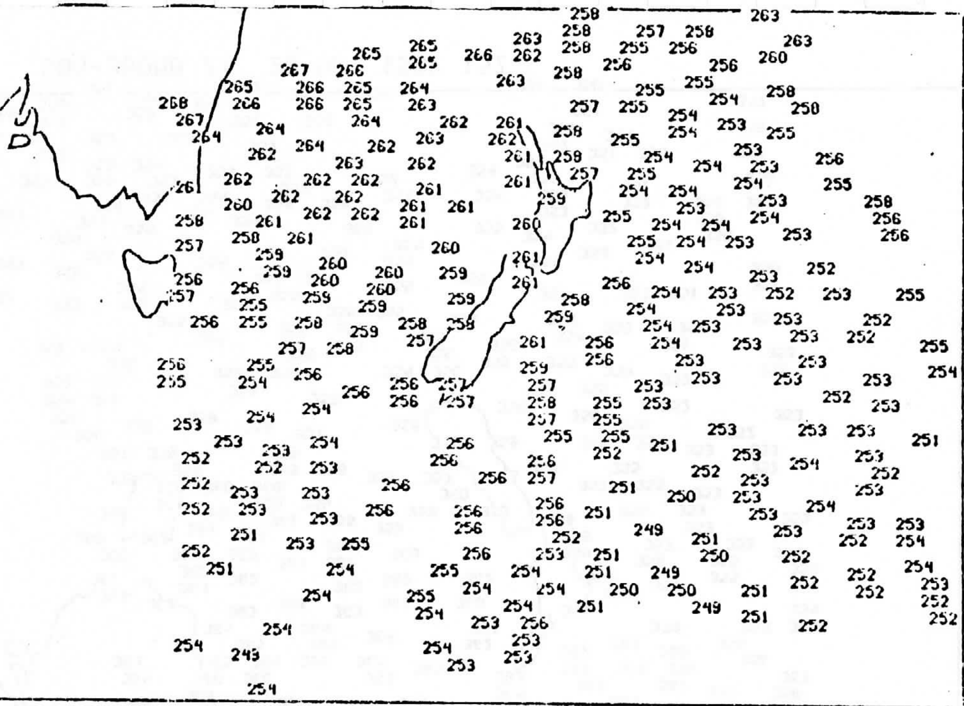


1000-500MB ZT 28 OCT 1982 15Z SAT



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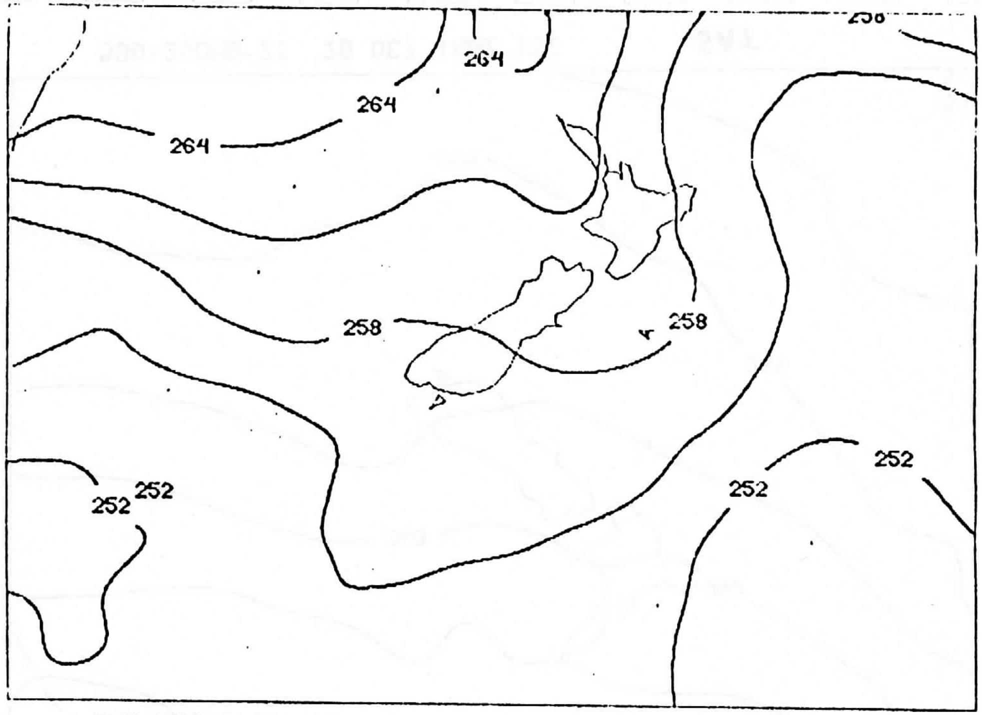

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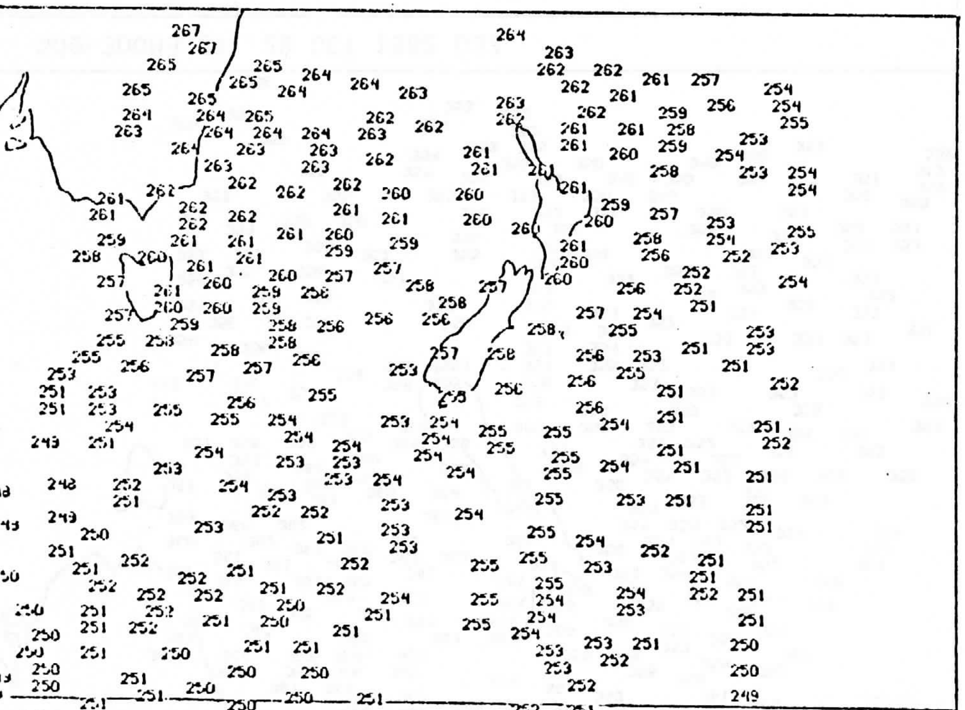

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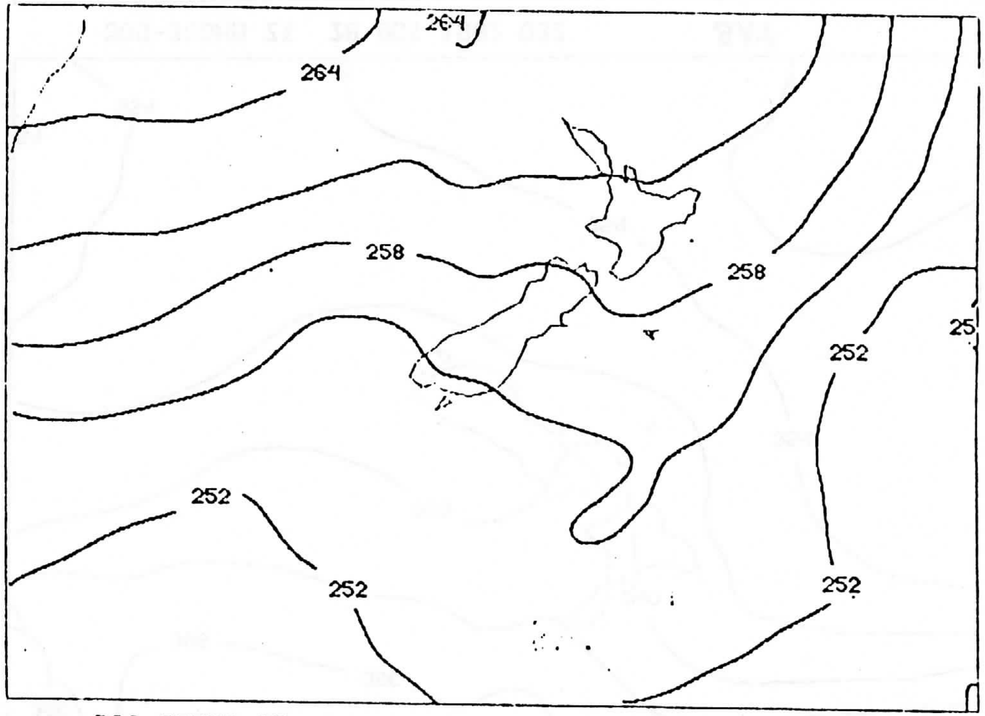
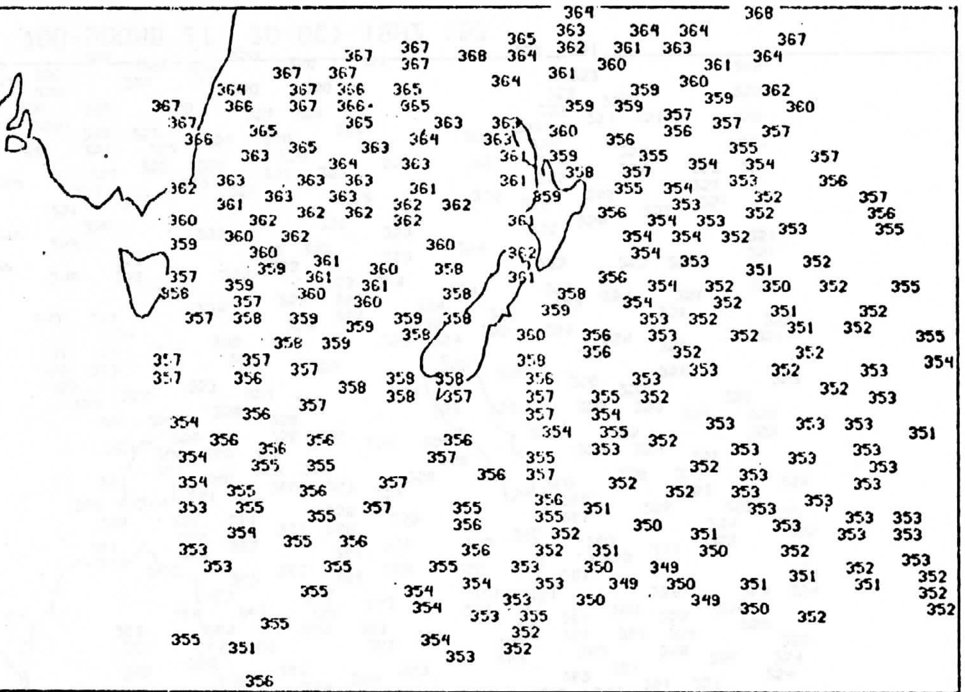
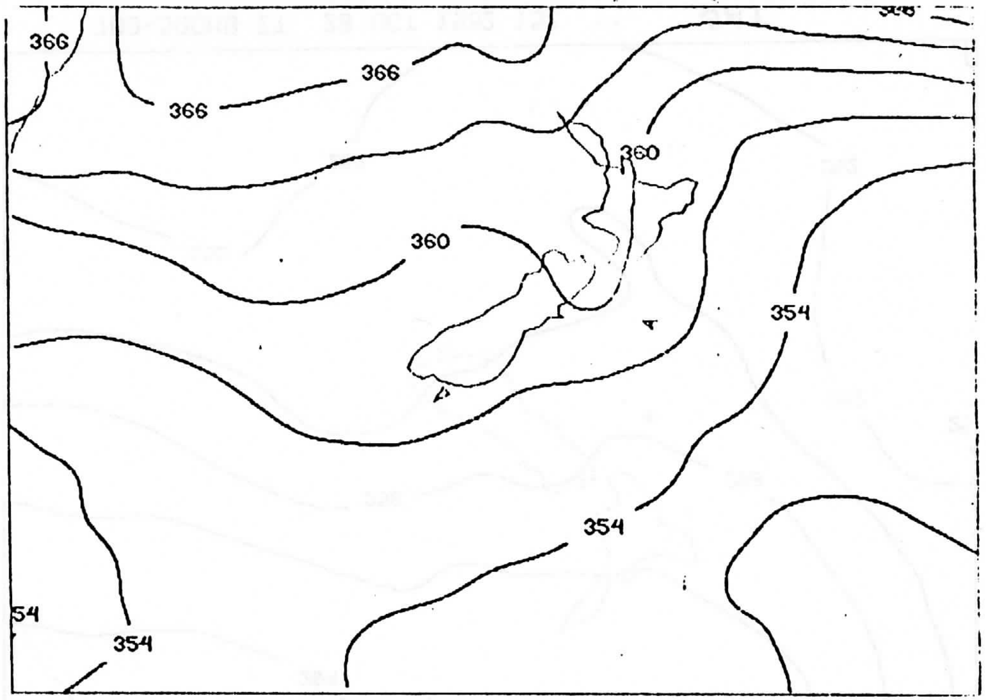


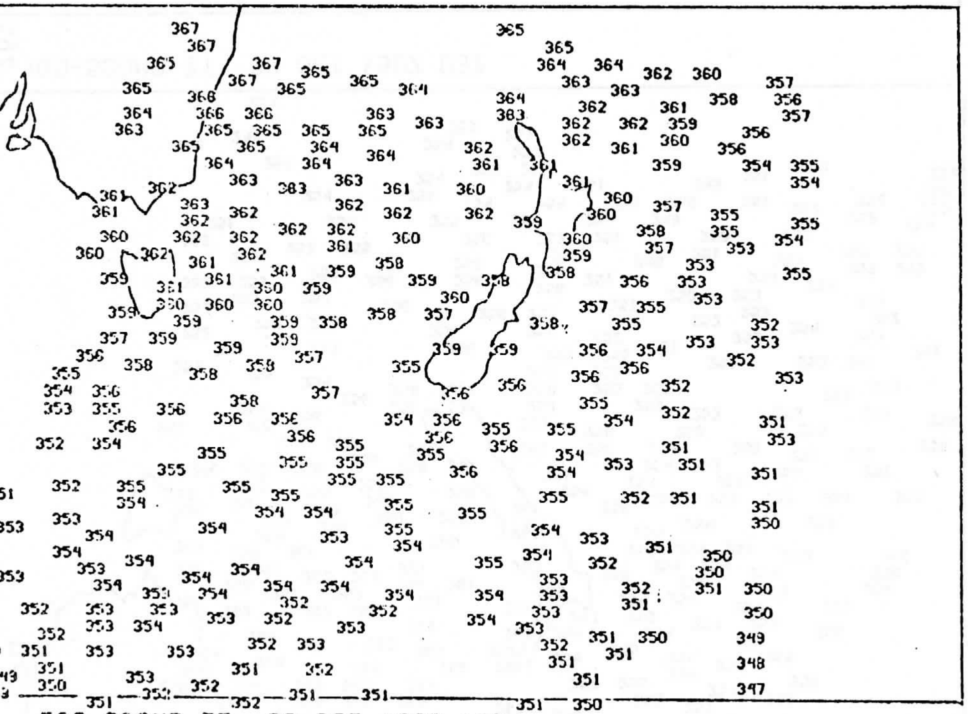
700-500MB ZT 28 OCT 1982 15Z SAT



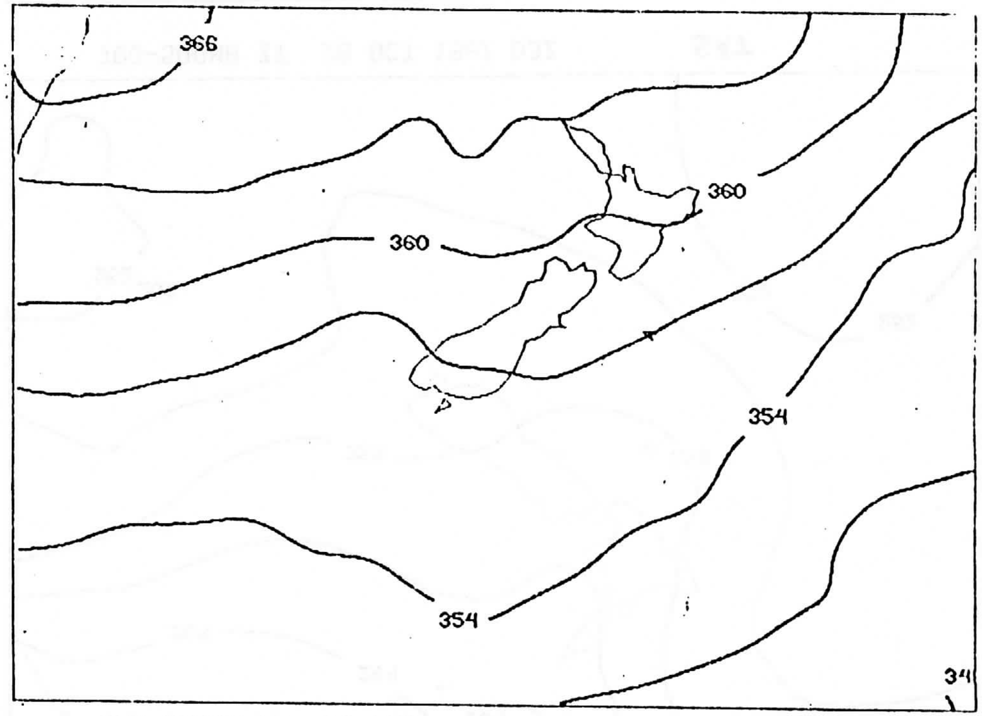
500-300MB ZT 28 OCT 1982 03Z



500-300MB ZT 28 OCT 1982 03Z SAT



500-300MB ZT 28 OCT 1982 15Z



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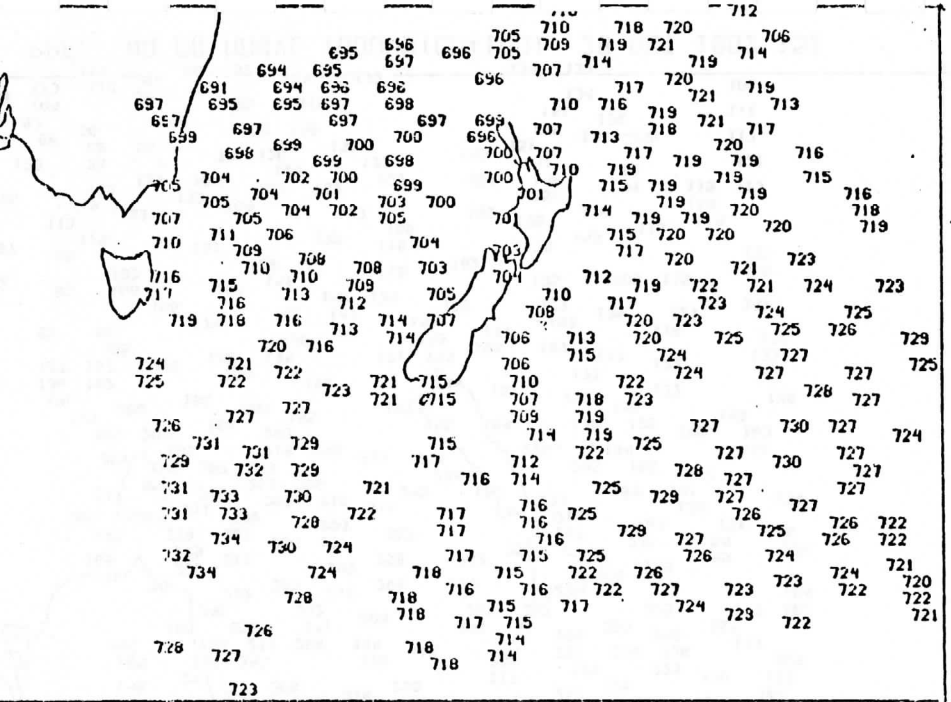
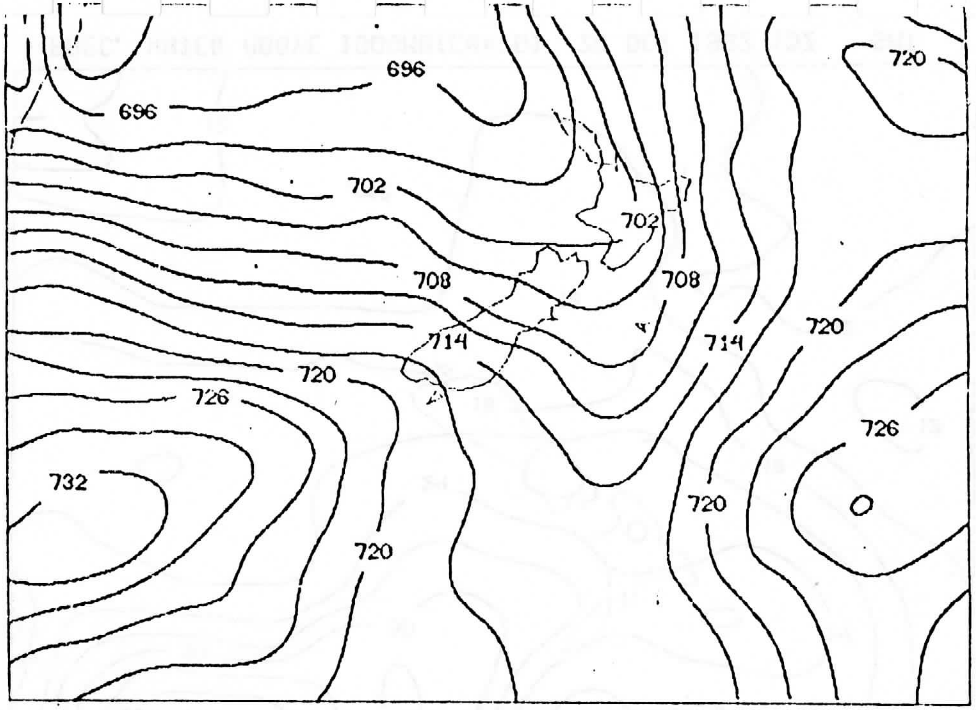


300-100MB ZT 28 OCT 1982 03Z



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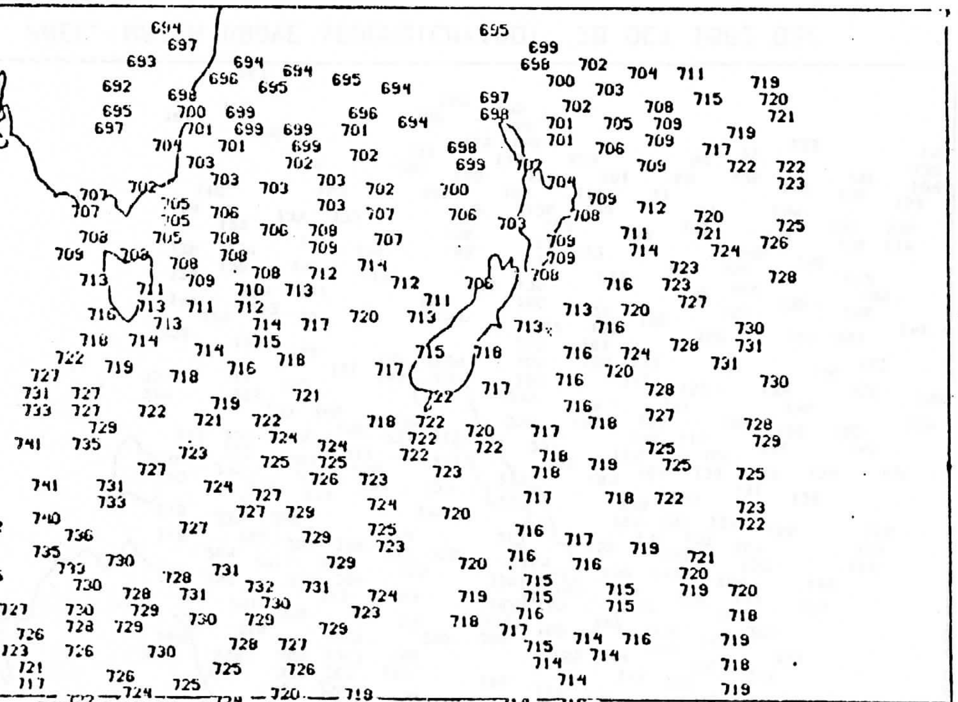

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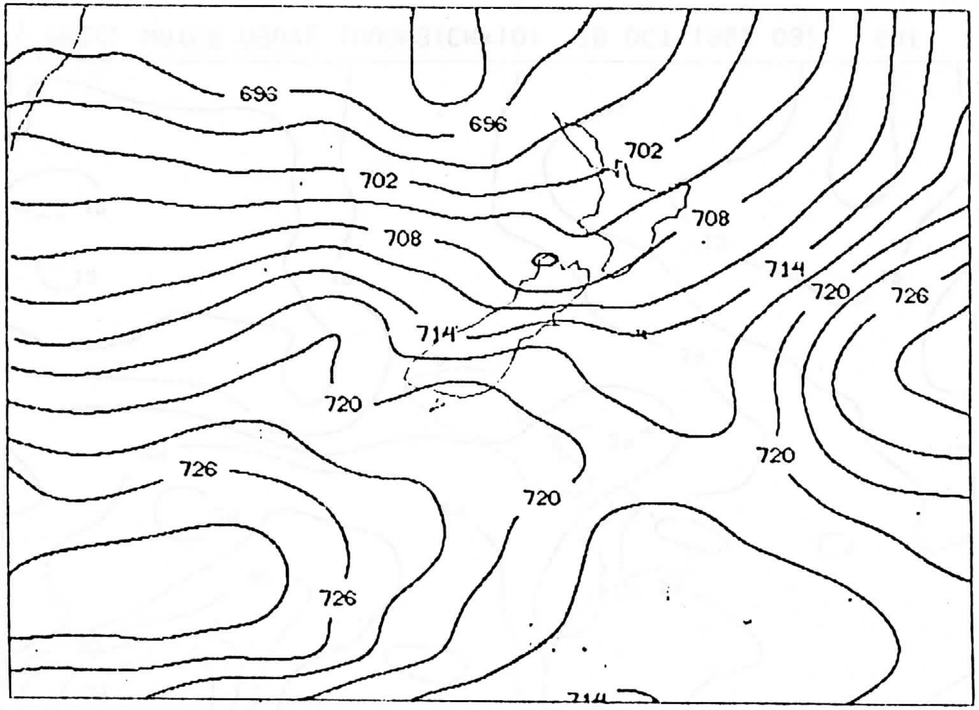

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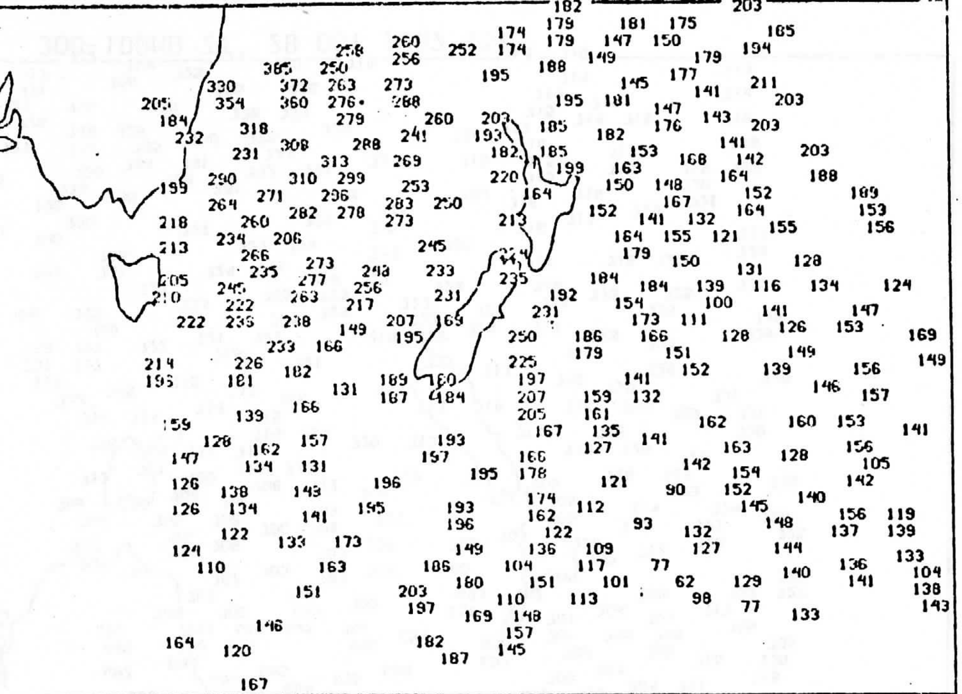
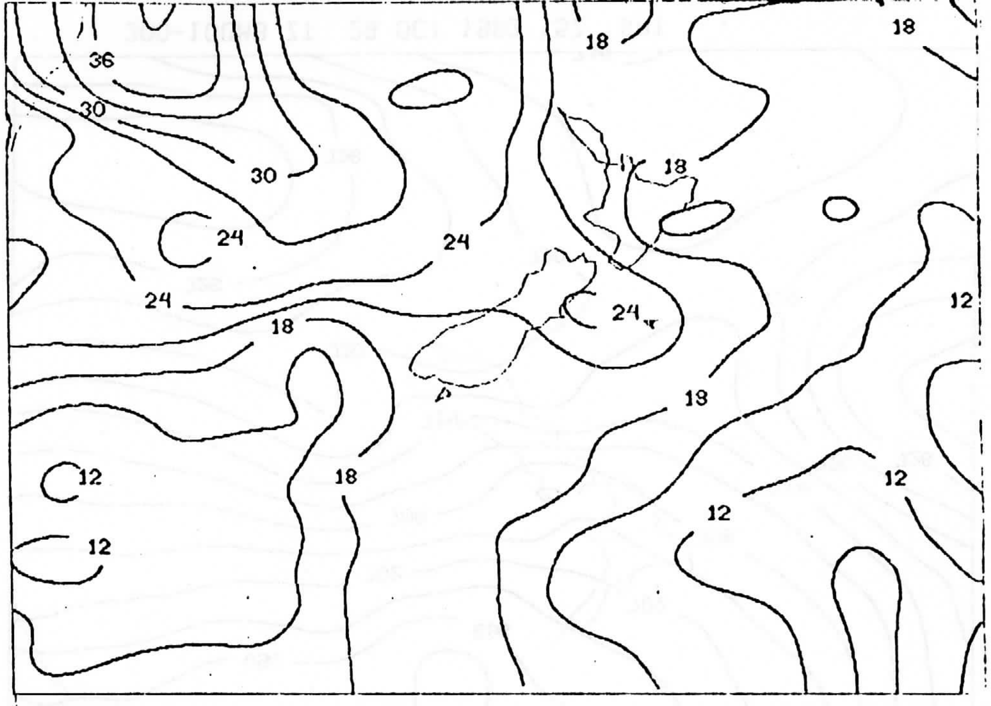


PREC. WATER ABOVE 1000MB(CM*100) 28 OCT 1982 03Z



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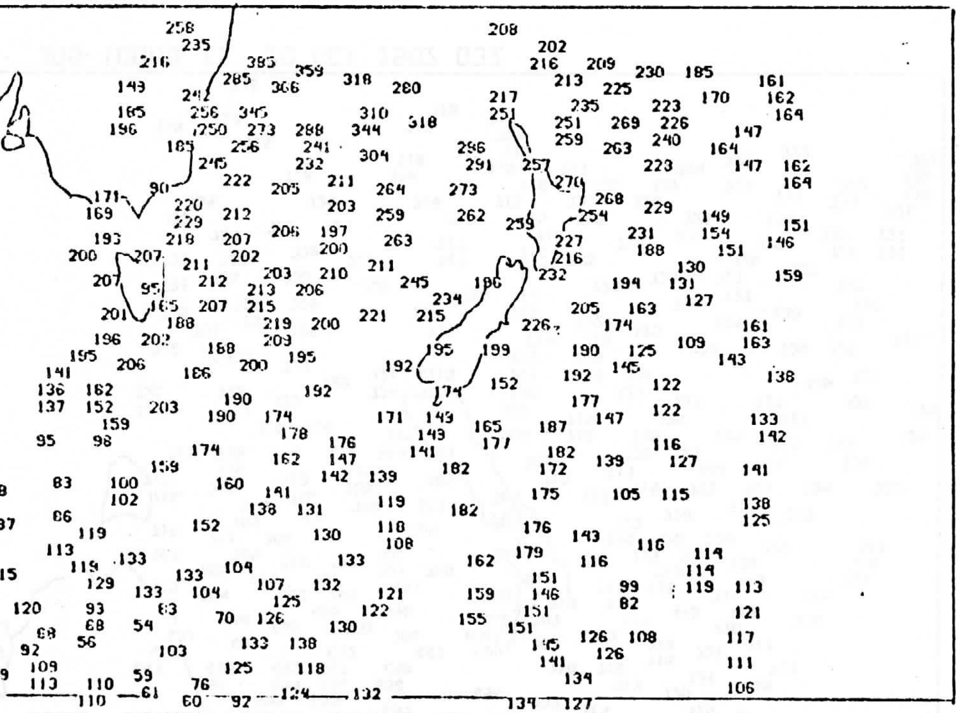

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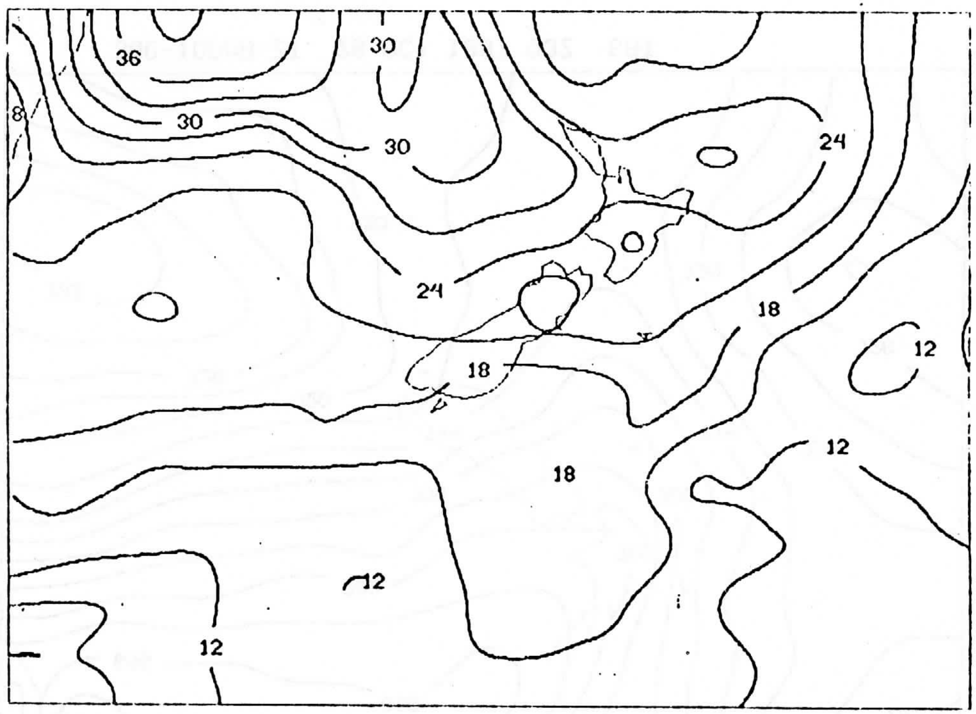

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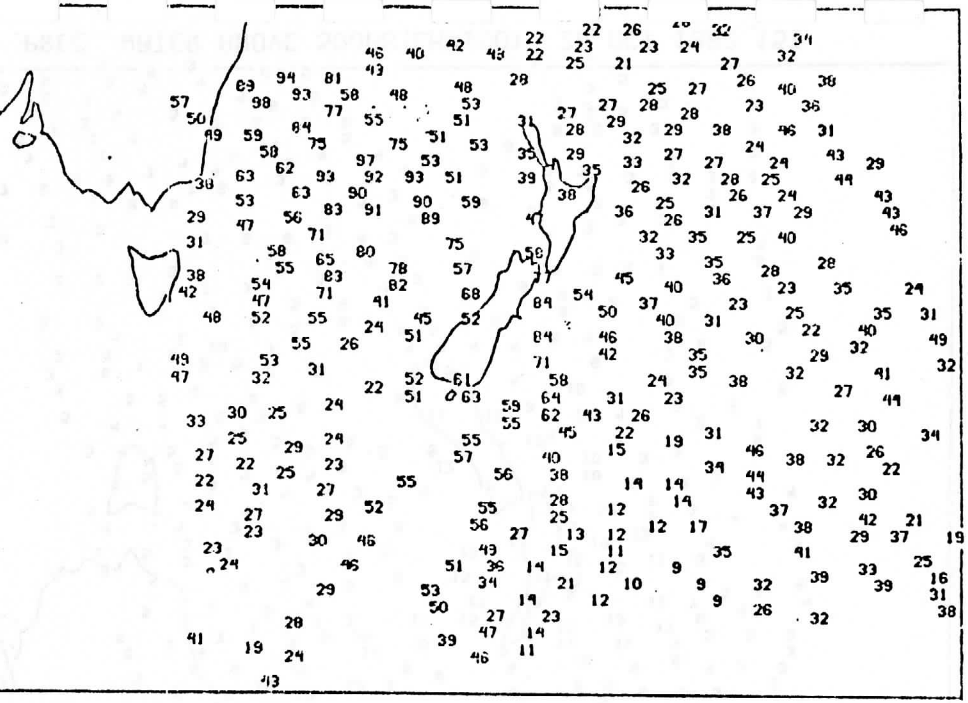

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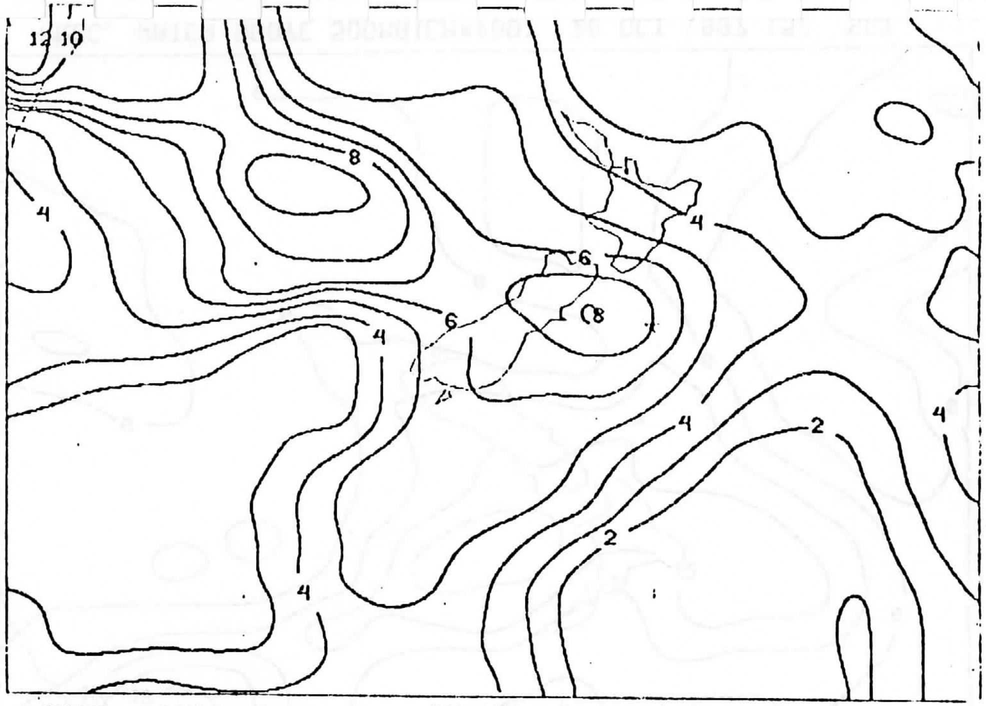

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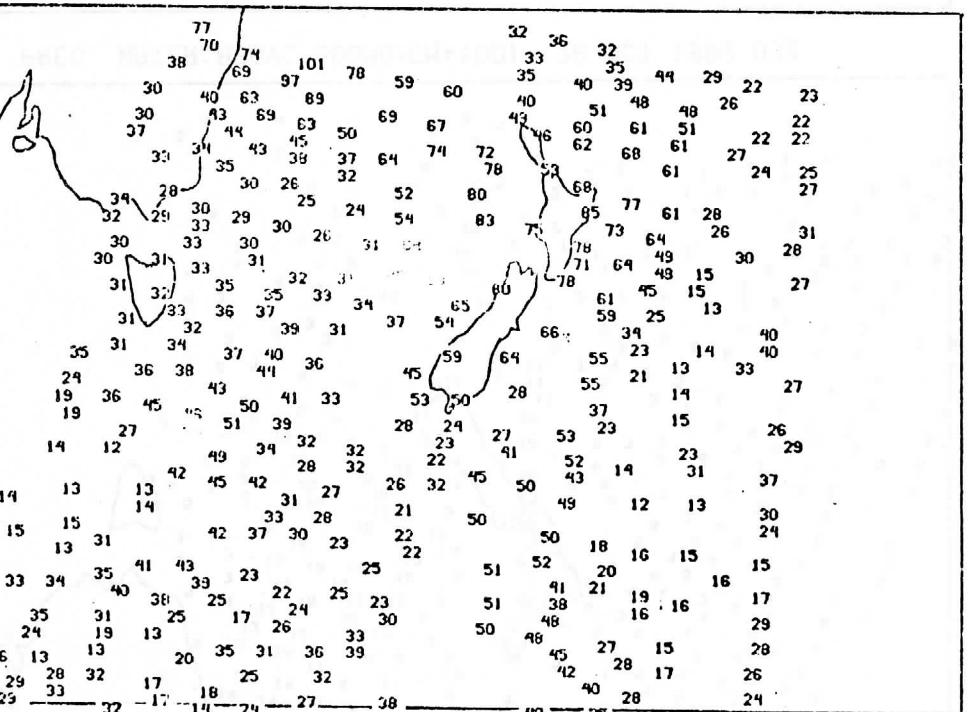

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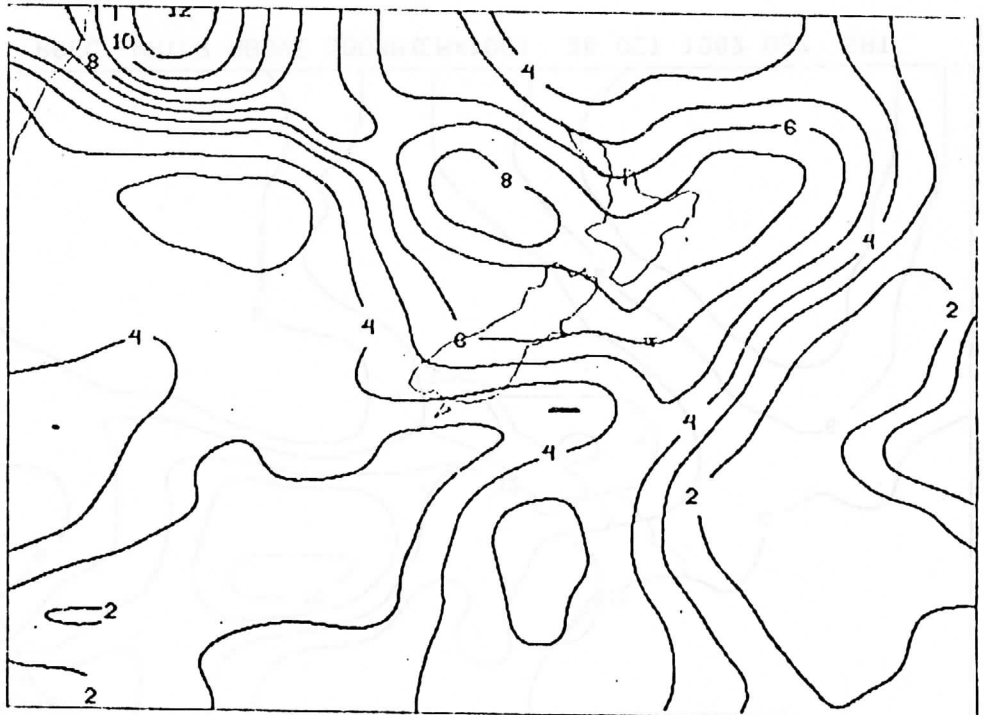

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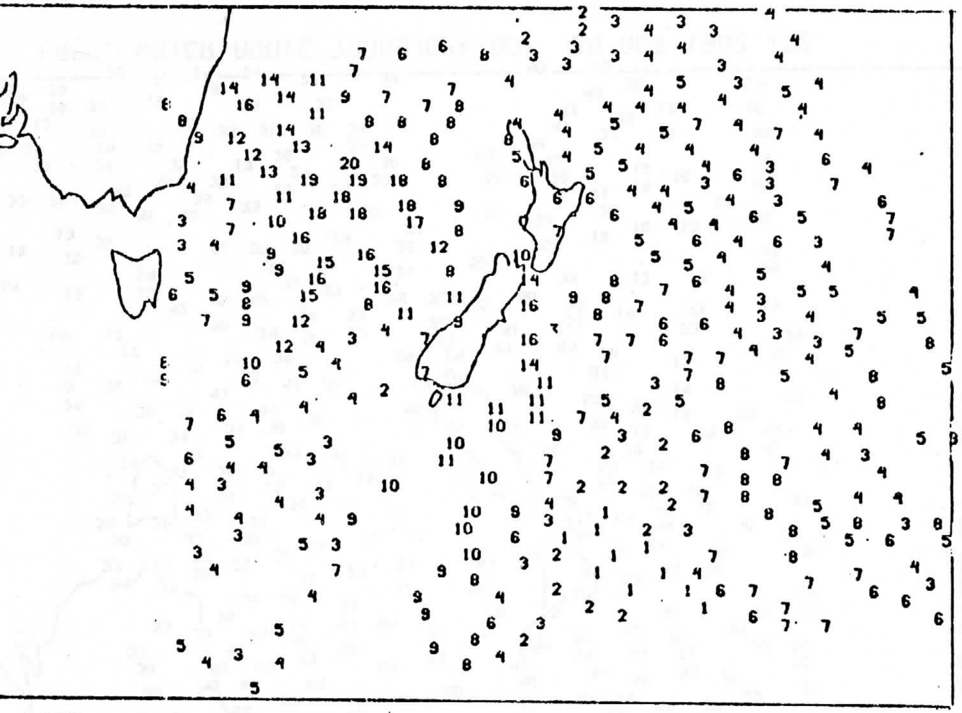

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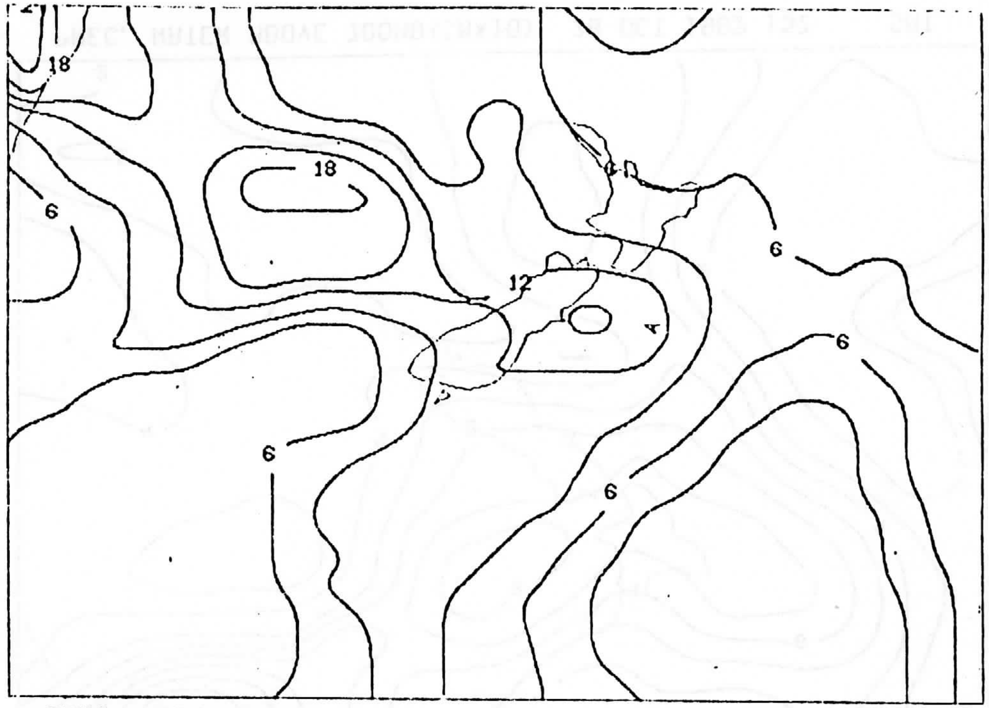

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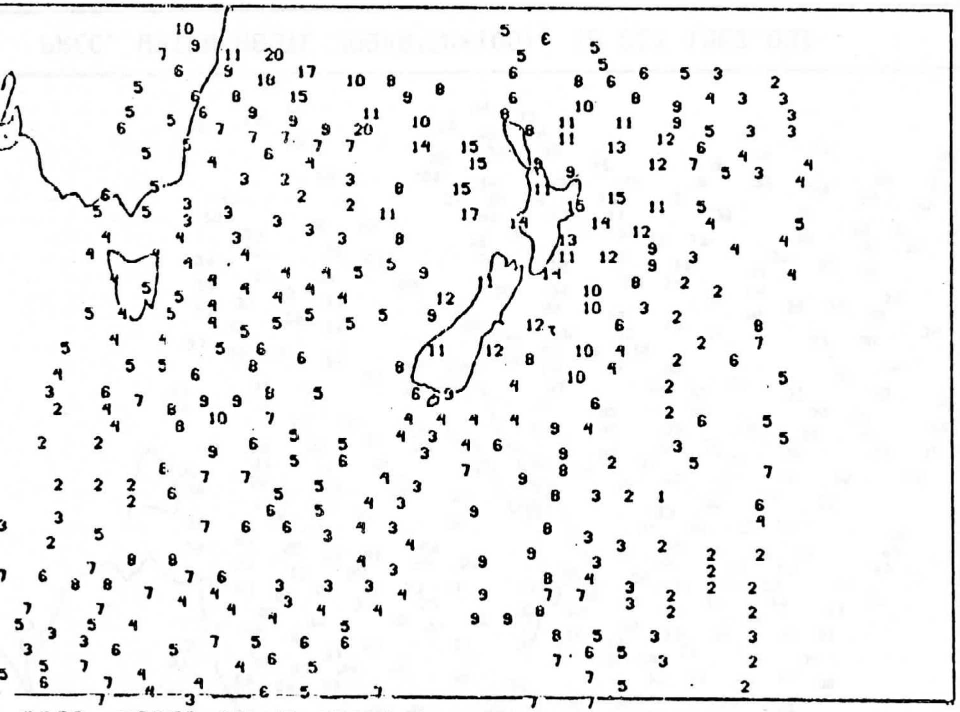

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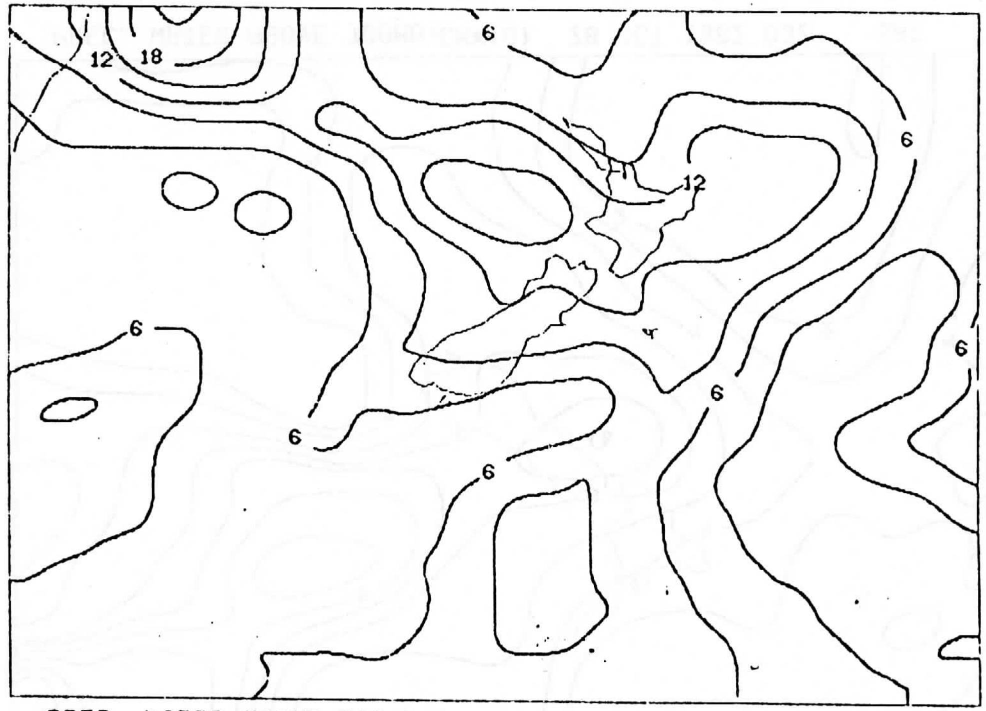

PREC. WATER ABOVE 500MB(CM*100) 28 OCT 1982 15Z SAT

DOCUMENTATION FOR TOVS-EXPORT SOFTWARE/DATA PACKAGE

VERSION OF 24 SEP 83

THIS DOCUMENT DESCRIBES, IN BRIEF OUTLINE FORM, PROCEDURES FOR ESTABLISHING A LOCAL/REGIONAL SYSTEM FOR PROCESSING TOVS (HIRS+MSU) SOUNDING DATA FROM THE TIROS-N/NOAA SERIES OF POLAR-ORBITING SPACECRAFT, USING THE SOFTWARE AND SUPPORTING DATA CONTAINED IN SUBSEQUENT FILES ON THIS TAPE. THE ALGORITHMS AND DATA-PROCESSING TECHNIQUES WERE ORIGINALLY DEVELOPED FOR 'MCIDAS' (MAN-COMPUTER INTERACTIVE DATA ACCESS SYSTEM) AT THE SPACE SCIENCE AND ENGINEERING CENTER OF THE UNIVERSITY OF WISCONSIN IN MADISON (UW/SSEC). INITIALLY BASED ON THE HARRIS 'SLASH-6' MINICOMPUTER, MCIDAS HAS RECENTLY BEEN IMPLEMENTED ON THE IBM 4341. THE SOFTWARE HEREIN SUPPLIED HAS BEEN CONFIGURED FOR AN IBM-OS SYSTEM TO PROVIDE THE MOST PORTABLE SYSTEM FEASIBLE, GIVEN THE RESOURCES AVAILABLE TO THOSE RESPONSIBLE FOR MAINTENANCE OF THE SYSTEM.

QUESTIONS AND/OR COMMENTS CONCERNING THE SYSTEM AND ITS IMPLEMENTATION, ESPECIALLY IN REGARD TO POSSIBLE ERRORS, SHOULD BE ADDRESSED TO

MR. HAROLD M. WOOLF
NOAA-NESDIS DEVELOPMENT LABORATORY
UW/SSEC, ROOM 219
1225 WEST DAYTON STREET
MADISON, WISCONSIN 53706
TELEPHONE ... (608) 264-5325
TWX/TELEX ... (910) 286-2771

CONTENTS OF THE REMAINING FILES ON THIS TAPE

FILE 2. IBM FORTRAN SOURCE FOR MAIN PROGRAMS
FILE 3. IBM FORTRAN SOURCE FOR SUBPROGRAMS
FILE 4. IBM ASSEMBLER SOURCE FOR I/O ROUTINE 'FFIO'
FILE 5. ORBITAL ELEMENTS FOR SATELLITE 1 (CURRENTLY NOAA-7)
FILE 6. ORBITAL ELEMENTS FOR SATELLITE 2 (CURRENTLY NOAA-8)
FILE 7. INGEST PARAMETERS FOR SATELLITE 1 (CURRENTLY NOAA-7)
FILE 8. INGEST PARAMETERS FOR SATELLITE 2 (CURRENTLY NOAA-8)
FILE 9. COEFFICIENTS FOR HIRS RADIATIVE-TRANSFER COMPUTATIONS
FILE 10. COEFFICIENTS FOR MSU RADIATIVE-TRANSFER COMPUTATIONS
FILE 11. COEFFICIENTS FOR HIRS LIMB-CORRECTION
FILE 12. COEFFICIENTS FOR MSU LIMB-CORRECTION
FILE 13. LOW-RESOLUTION (60 NAUT.MI.) EARTH TOPOGRAPHY & LAND-SEA FLAGS
FILE 14. REAL-DATA COEFFICIENTS FOR USE WITH PGMS 'TOVRET' & 'ENHRET'
FILE 15. COEFFICIENTS FOR MSU ANGLE-DEPENDENT RADIATIVE-TRANSFER
FILE 16. SYNTHETIC COEFFICIENTS FOR USE WITH PGM 'FXTIRO'
FILE 17. REAL-DATA COEFFICIENTS FOR USE WITH PGM 'FXTIRO'
FILE 18. HIGH-RESOLUTION (10 NAUT.MI.) GLOBAL TOPOGRAPHY

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NOTES ON FORTRAN SOURCE (FILES 2 AND 3)

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THE FIRST CARD OF EACH MAIN PROGRAM IN FILE 2 IS A FORTRAN COMMENT OF THE FORM

```
C     MAIN PROGRAM 'XXXXXX'
```

EACH MAIN PROGRAM, SUBPROGRAM, OR COLLECTION OF RELATED SUBPROGRAMS, CONTAINS A COMMENT CARD NEAR ITS BEGINNING OF THE FORM

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C  ***  VERSION OF DD MMM YY (DAY MONTH YEAR)
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USERS FOR WHOM THIS IS NOT THE FIRST PACKAGE SUPPLIED SHOULD FIND THESE 'VERSION-DATES' A CONVENIENT MEANS OF DETERMINING WHICH ROUTINES HAVE BEEN CHANGED SINCE THEIR INITIAL IMPLEMENTATION. ALTHOUGH IN THE PAST UPDATES TO THE PACKAGE HAVE BEEN PROVIDED IN THE FORM OF SELECTED SOFTWARE AND COEFFICIENTS, THE MOST RECENT CHANGES ARE TOO EXTENSIVE, AND THE NUMBER OF USERS WORLD-WIDE TOO GREAT, TO PERMIT SUCH 'LIMITED-EDITION' UPDATING. HEREAFTER, UPDATES - TO SOFWARE, COEFFICIENTS, OR BOTH - WILL BE IN THE FORM OF A NEW TOTAL-PACKAGE TAPE. IT WILL BE THE RESPONSIBILITY OF THE INDIVIDUAL USER TO DETERMINE WHICH 'NEW ITEMS' ARE RELEVANT TO HIS INSTALLATION.

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NOTES ON SUPPORTING-DATA FILES

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THE COEFFICIENTS IN FILES 7 THROUGH 12 ARE DETERMINED INITIALLY FOR EACH SATELLITE, AND CAN BE CONSIDERED FIXED FOR ITS OPERATIONAL LIFETIME UNLESS MAJOR CHANGES OCCUR IN THE PERFORMANCE OF ONE OR MORE SPECTRAL CHANNELS.* THIS IS ALSO TRUE FOR THE COEFFICIENTS IN FILES 15 AND 16. THE RETRIEVAL COEFFICIENTS IN FILES 14 AND 17 ARE UPDATED WEEKLY BY NESDIS OPERATIONS AND CAPTURED FOR INCLUSION IN THIS PACKAGE. ORBITAL ELEMENTS SUPPLIED IN FILES 5 AND 6 ARE ALSO UPDATED WEEKLY. THESE ARE NEEDED FOR NAVIGATION (EARTH-LOCATION) OF REAL-TIME DATA OBTAINED VIA DIRECT READOUT OF THE SPACECRAFT (BEACON). THE REAL-DATA COEFFICIENTS AND ORBITAL ELEMENTS ARE PROVIDED TO ASSIST IN THE INITIAL IMPLEMENTATION; THE USER MUST MAKE HIS OWN ARRANGEMENTS FOR CONTINUED ACQUISITION OF SUCH INFORMATION FOR REAL-TIME APPLICATIONS.

* OCCASIONALLY, SOME OF THE MSU CALIBRATION QUALITY-CONTROL LIMITS IN FILES 7 AND 8 MAY NEED TO BE ADJUSTED TO AVOID DISCARDING GOOD DATA AS A RESULT OF CHANGES IN GAIN OR OTHER INSTRUMENT CHARACTERISTICS.

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CONSTRUCTING THE TOVS DATA-PROCESSING SYSTEM

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THE SYSTEM MAKES EXTENSIVE USE OF DISK FILES, BOTH SEQUENTIAL AND DIRECT-ACCESS, FOR EFFICIENCY IN I/O OPERATIONS. TO ASSIST IN ESTABLISHING THE PERMANENT DATA FILES (ORBITAL ELEMENTS, COEFFICIENTS, AND TOPOGRAPHY), PROGRAMS HAVE BEEN PROVIDED (IN FILE 2) TO READ THE DATA FROM TAPE AND WRITE TO DISK.

PROGRAM	TAPE FILE(S)	DISK LUN	TYPE**
PUTELE	5,6	11,12	D,D

PUTPAR	7,8	15	S
HIRTCFTD	9	13	D
MSUTCFTD	10	14	S
HIRLCFTD	11	15	S
MSULCFTD	12	16	S
TOPOGFTD	13	17	D
RTVLCFTD **	14	25	D
MSZTCFTD	15	18	S
RTVCFOTD ***	16	25	D
RTVCFSTD	17	26	D
TOPOGHTD +	18	19	D

NOTES:

LUN = FORTRAN LOGICAL UNIT NUMBER

* S = SEQUENTIAL, D = DIRECT-ACCESS (IBM BDAM)

** PROGRAM 'RTVLCFTP' IS PROVIDED TO PERMIT EXTRACTION OF RETRIEVAL COEFFICIENTS FROM THE GENERAL COEFFICIENT-DATABASE TAPE THAT IS AVAILABLE FROM NESDIS OPERATIONS UPON SPECIAL REQUEST.

*** PROGRAM 'RTVLCXTP' IS ANALOGOUS TO 'RTVLCFTP', BUT PROVIDES THE RECORD STRUCTURE REQUIRED FOR INPUT TO PROGRAM 'FXTIRO'.

\+ PROGRAM 'SUBTOP' IS PROVIDED TO CREATE A SUBSET OF THE GLOBAL HIGH-RESOLUTION TOPOGRAPHY FOR USE IN PROGRAM 'FXTIRO'. IT IS ASSUMED THAT MOST USERS WOULD NOT BE ABLE TO MAINTAIN THE ENTIRE DATASET ON DISK, SINCE IT CONTAINS 16200 RECORDS, EACH 288 BYTES IN LENGTH.

TWO PROGRAMS, 'RAOBHIRS' AND 'RAOBMSU' (AND ASSOCIATED SUBPROGRAMS) ARE SUPPLIED TO DEMONSTRATE THE PROCEDURES FOR CALCULATING, FROM RADIOSONDE TEMPERATURE AND HUMIDITY PROFILES, HIRS RADIANCES AND BRIGHTNESS (EQUIVALENT-BLACKBODY) TEMPERATURES, AND MSU ANTENNA OR BRIGHTNESS TEMPERATURES, RESPECTIVELY. THE REMAINDER OF THE SOFTWARE CONTAINED IN FILES 2, 3, AND 4 IS FOR PROCESSING HIRS AND MSU DATA TO OBTAIN PROFILES OF ATMOSPHERIC TEMPERATURE, HUMIDITY, GEOPOTENTIAL HEIGHT, AND GEOSTROPHIC WIND, AND FOR DISPLAYING AND MANIPULATING THOSE PROFILES IN VARIOUS WAYS. ESSENTIAL TASKS ARE 'INGEST', 'PREPROCESSING', AND 'RETRIEVAL'. THE TERM 'RTC' MEANS 'RADIATIVE-TRANSFER COEFFICIENTS', AND 'LCC' STANDS FOR 'LIMB-CORRECTION COEFFICIENTS'.

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INGEST
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FUNCTION: PRODUCE CALIBRATED, EARTH-LOCATED HIRS AND MSU RADIOMETRIC MEASUREMENTS FROM TOVS 'TIP' DATA. TWO VERSIONS ARE PROVIDED; THE ESSENTIAL DIFFERENCE IS IN THE TYPE OF INPUT DATA THEY ARE DESIGNED TO HANDLE - EITHER ARCHIVAL ('LEVEL 1-B') OR DIRECT-READOUT (REALTIME).

LEVEL 1-B: DATA THAT HAS BEEN THROUGH PRELIMINARY PROCESSING BY NESDIS OPERATIONS' TOVS GROUND SYSTEM, AND IS PROVIDED ON STANDARD COMPUTER TAPE TO USERS, UPON REQUEST, BY THE SATELLITE DATA SERVICES BRANCH OF NESDIS. SUCH TAPE CONTAINS, IN ADDITION TO VALUES (IN DIGITAL COUNTS) REPRESENTING RADIOMETRIC MEASUREMENTS, EARTH-LOCATION INFORMATION AND CALIBRATION PARAMETERS REQUIRED TO TRANSFORM THE RAW DATA VALUES INTO

RADIANCE OR BRIGHTNESS TEMPERATURE. THREE PROGRAMS ARE SUPPLIED FOR THIS TYPE OF OPERATION:

PROGRAM	INPUT(S)	OUTPUT(S) ( ) = LUN
*******	********	*********
INVTAP	1-B TAPE(10) DATA CARD	PRINTOUT OF DATA TYPE, TIMES, AND LOCATIONS FOR EACH FILE
TOVTAP	1-B TAPE(10) **DATA CARD	SELECTED HIRS(11) AND MSU(12) DATA ON DISK; PRINTOUT OF RELEVANT INFORMATION
TOVING	HIRS DISK(11) MSU DISK(12) HIRS RTC(13) ***DATA CARD	CALIBRATED, LOCATED DATA ON DISK(20); PRINTOUT

NOTES:

* NUMBER OF FILES TO READ; PROGRAM TERMINATES ON DOUBLE EOF IF ENCOUNTERED BEFORE COUNT IS SATISFIED.

** PHYSICAL FILE NUMBERS OF HIRS AND MSU DATA, PLUS BEGINNING AND ENDING TIMES.

*** SATELLITE NUMBER (1 FOR NOAA-7, 2 FOR NOAA-8); REQUIRED BECAUSE INFORMATION IN TAPE HEADER RECORDS MAY BE AMBIGUOUS.

DIRECT-READOUT: DATA OBTAINED ON-SITE BY DIRECT DOWNLINK FROM THE SPACECRAFT. THE SSEC SYSTEM USES DATA FROM THE VHF (137MHZ) BEACON. SUCH DATA CAN ALSO BE ACQUIRED BY EXTRACTING 'TIP' FROM AN HRPT DATASTREAM; CREATION OF THE NECESSARY SOFTWARE IS THE RESPONSIBILITY OF THE USER. PROCESSING OF DIRECT-READOUT DATA IS MUCH MORE COMPLEX THAN THAT OF LEVEL 1-B, SINCE THE USER MUST DO EVERYTHING - DECOMMUTATION OF RAW DATA, NAVIGATION OR EARTH-LOCATION, AND IN-FLIGHT CALIBRATION. TWO PROGRAMS ARE PROVIDED:

PROGRAM	INPUT(S)	OUTPUT(S)
*******	**********	**********
PREING	DATA TAPE(9) DATA CARD	DISK FILE(10) CONTAINING DECOMMUTATED HIRS AND MSU DATA PRINTOUT
INGTOV	DECOM DATA(10) **ORB-ELEM(11,12) HIRS RTC(13) ING-PARAM(15)	CALIBRATED, LOCATED DATA ON DISK(20) PRINTOUT

NOTES:

FILE TO PROCESS, IF MORE THAN ONE ON TAPE; FLAG FOR DETAILED (DIAGNOSTIC) MSU PRINT.

* UPDATED BY PROGRAM 'PUTELE' WITH DATA OBTAINED FROM DIRECT READOUT USER SERVICES.

THE DATA IN FILE 20 WILL HAVE THE SAME FORMAT, REGARDLESS OF THE SOURCE AND TYPE OF INGEST. THIS FILE SERVES AS INPUT TO THE NEXT STEP.

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PREPROCESSOR
************
   FUNCTION: TRANSFORM CALIBRATED, EARTH-LOCATED HIRS AND MSU MEASURE-
MENTS PRODUCED BY INGEST, INTO DATASETS FOR DISPLAY AND RETRIEVAL.

   PROGRAM          INPUT(S)               OUTPUT(S)
   *******          *********              *********
   TOVPRE           INGEST OUTPUT(20)      IMAGER FILE(22)
                    HIRS RTC(13)           SOUNDER FILE(23)
                    HIRS LCC(15)           PRINTOUT
                    MSU LCC(16)
                    LO-RES TOPOG(17)
                    DATA CARD

   TOVMAP           IMAGER FILE(22)        PRINTOUT OF DATA IN (LINE,ELEMENT)
                    DATA CARD -               COORDINATES
                    SPECIFY PARAM(S),
                    STARTING LINE

NOTE:
   SPECIFY WHETHER DATA ARE TO BE 'LIMB-CORRECTED' OR NOT (SEE BELOW)

THE PREPROCESSOR PERFORMS THE FOLLOWING FUNCTIONS:
   IF THE MSU 'LIMB-CORRECTION' FLAG IS ON, MSU DATA ARE CORRECTED FOR
      ANTENNA PATTERN (TRANSFORM ANTENNA TEMP. TO BRIGHTNESS TEMP.);
      LIMB EFFECTS (NORMALIZE TO THETA = 0);
      SURFACE REFLECTIVITY (NORMALIZE TO SFC.EMIS. = 1);
      LIQUID WATER (PRECIPITATING CLOUD) ATTENUATION.
   IF THE HIRS 'LIMB-CORRECTION' FLAG IS ON, HIRS DATA ARE CORRECTED FOR
      LIMB EFFECTS;
      WATER VAPOR ATTENUATION IN THE WINDOW CHANNELS.
   IN ADDITION, HIRS CHANNELS 17 AND 18 ARE CORRECTED, IN DAYLIGHT, FOR
      FLUORESCENCE AND REFLECTED SUNLIGHT, RESPECTIVELY, REGARDLESS OF
      THE STATE OF THE LIMB-CORRECTION FLAG.
   MSU AND HIRS ARE COLOCATED BY INTERPOLATING THE MSU OBSERVATIONS TO
      THE HIRS SCAN PATTERN.
   OUTPUT FILE 22 HAS ALL DATA FOR ONE PARAMETER CONTIGUOUS ON DISK,
      AND THUS IS OPTIMIZED FOR IMAGING;
   OUTPUT FILE 23 HAS ALL DATA FOR ONE SCAN SPOT CONTIGUOUS ON DISK,
      AND THUS IS OPTIMIZED FOR SOUNDING.
*****
******

RETRIEVAL
*********
   FUNCTION: DETERMINE, FROM PREPROCESSED HIRS AND MSU DATA, VERTICAL
PROFILES OF ATMOSPHERIC TEMPERATURE, HUMIDITY, AND GEOPOTENTIAL HEIGHT,
AS WELL AS TOTAL OZONE AND STABILITY PARAMETERS, AT HIGH SPATIAL RESOLU-
TION.  SEE NOTE ON 'SURFACE DATA' AT THE END OF THIS DOCUMENT.  THERE
```

```
ARE TWO VERY DIFFERENT RETRIEVAL PROGRAMS INCLUDED IN THIS PACKAGE:
STATISTICAL ('TOVRET') AND PHYSICAL ('FXTIRO').

   PROGRAM        INPUT(S)            OUTPUT(S)
   *******        *********           *********
   TOVRET         HIRS RTC(13)        RETRIEVAL FILE(24)
                  LO-RES TOPOG(17)    PRINTOUT
                  SOUNDER FILE(23)
                  RTVL COEF(25)

  *THIS PROGRAM REQUIRES BOTH HIRS AND MSU TO HAVE BEEN LIMB-CORRECTED.
NOTE:
   COEFFICIENTS STAGED TO DISK BY 'RTVLCFTD' OR 'RTVLCFTP'.

   PROGRAM        INPUT(S)            OUTPUT(S)
   *******        *********           *********
   FXTIRO         HIRS RTC(13)        RETRIEVAL FILE(24)
                  MSU RTC(14)         PRINTOUT
                 +HIRS LCC(15)
                 +MSU LCC(16)
                  LO-RES TOPOG(17)
                 *MSU RTC(18)
                **HI-RES TOPOG(19)
                  IMAGER FILE(22)
                  SOUNDER FILE(23)
               ***RTVL COEF(25)
               ***RTVL COEF(26)
               ***DATA CARD

  *THIS PROGRAM CAN OPERATE ON HIRS AND MSU DATA THAT HAVE BEEN LIMB-
   CORRECTED OR NOT ... THE LATTER SEEMS TO GIVE BETTER RESULTS.
NOTES:
     THE RTC IN FILE 14 ARE FOR LIMB-CORRECTED MSU DATA; THOSE IN FILE
   18, FOR NON-LIMB-CORRECTED DATA.
+  NEEDED FOR REGRESSION ESTIMATION OF FIRST-GUESS TEMPERATURE AND
   OZONE PROFILES.
   * PRESUMED TO BE A REGIONAL DATASET CREATED BY 'SUBTOP'.  IF THE
   GLOBAL DATASET IS TO BE USED, REPLACE SUBROUTINE 'HRTOPX' (IN 'NTOPO')
   WITH 'HRTOPO'.
   ** FILE 25 CONTAINS 'REAL-DATA' COEFFICIENTS OBTAINED FROM NESDIS/
   OPERATIONS; FILE 26, 'SYNTHETIC' COEFFICIENTS - SEE NOTES UNDER
   DESCRIPTION OF INITIAL-DATA-STAGING PROGRAMS.
   *** SPECIFY VARIOUS OPTIONS TO CONTROL EXECUTION OF PROGRAM - SEE
   SOURCE CODE FOR PARAMETERS AND THEIR MEANINGS.
  *****
  *****
FILTERING
*********
   FUNCTION: ELIMINATE SOUNDINGS OF QUESTIONABLE RELIABILITY BY OBJECT-
IVE ANALYSIS OF DIFFERENCES BETWEEN INFRARED AND MICROWAVE RETRIEVALS
FOR THE SAME LOCATION, AND OF VARIABILITY IN 1000-500MB THICKNESS AND
LONGWAVE-WINDOW VS. SURFACE TEMPERATURE.
```

```
    PROGRAM       INPUT(S)        OUTPUT(S)
    *******       ********        *********
    FILRET        RTVL FILE(24)   RTVL FILE(24), WITH 'FAILED'
                  DATA CARD          SOUNDINGS FLAGGED
                                  PRINTOUT
```

NOTE:
TO CONTROL FILTERING PARAMETERS ... SEE SOURCE CODE FOR DETAILS

*****
*****
ENHANCEMENT
****

FUNCTION: ADD MICROWAVE-ONLY SOUNDINGS IN AREAS WHERE INFRARED RETRIEVALS WERE NOT MADE, OWING TO HEAVY CLOUDINESS, OR WERE FLAGGED 'FAILED' BY THE FILTER PROGRAM. THIS PROGRAM WAS ORIGINALLY DEVELOPED WHEN ONLY STATISTICAL RETRIEVALS COULD BE MADE (BY 'TOVRET'); IF THE PHYSICAL RETRIEVAL ('FXTIRO') IS USED, ENHANCEMENT SHOULD NOT BE NEEDED.

```
    PROGRAM       INPUT(S)           OUTPUT(S)
    *******       ********           *********
    ENHRET        LO-RES TOPOG(17)   RTVL FILE(24)
                  SOUNDER FILE(23)
                  RTVL FILE(24)
                  RTVL COEF(25)
```

NOTE:
SAME COEFFICIENTS AS USED WITH 'TOVRET'

*****
*****
GEOSTROPHIC WINDS
****

FUNCTION: DETERMINE GEOSTROPHIC WINDS FOR 'GOOD' SOUNDINGS IN RETRIEVAL FILE, BY LEAST-SQUARES OBJECTIVE ANALYSIS OF HEIGHT FIELDS.

```
    PROGRAM       INPUT(S)        OUTPUT(S)
    *******       ********        *********
    WINRET        RTVL FILE(24)   RTVL FILE(24)
                  DATA CARD
```

NOTE:
TO CONTROL QUANTITY OF PRINTOUT

*****
*****
REDUNDANCY ELIMINATION
****

FUNCTION: ELIMINATE REDUNDANT INFRARED RETRIEVALS, BASED ON VARIABILITY IN SELECTED HIRS CHANNELS.

```
   PROGRAM        INPUT(S)         OUTPUT(S)
    ******        ********         ********
   REDRET         RTVL FILE(24)    RTVL FILE(24)
                  DATA CARD

NOTE:
   TO SPECIFY OTHER THAN DEFAULT (BUILT-IN) CONTROL PARAMETERS

 *****
 *****
RETRIEVAL PLOTTERS
 ******************
   FUNCTION: TO PLOT VARIOUS QUANTITIES FROM THE RETRIEVAL FILE.  INPUT
CONSISTS OF THE RETRIEVAL FILE(24) AND DATA CARDS TO CONTROL THE LOCA-
TION AND PARAMETERS PLOTTED ... SEE SOURCE CODE FOR DETAILS.
   PROGRAM          PRODUCT
    ******          *******
   TOVPLFIL         IR-MW SOUNDING DIFFERENCES, WITH CHARACTERS APPENDED
                       TO DENOTE RESULTS OF 'FILRET' AND 'REDRET'
   TOVPLDIF         IR-MW DIFFERENCES
   TOVPLTEM         IR-RETRIEVAL TEMPERATURES
   TOVPLDEW         IR-RETRIEVAL DEWPOINTS
   TOVPLTBB         SOUNDING TBB'S FOR SPECIFIED CHANNELS

'TOVPLFIL'  SHOULD BE RUN BEFORE THE NEXT PROGRAM TO BE DESCRIBED
  ('COMRET'); THE OTHER PLOTTERS SHOULD BE RUN AFTER FILE-COMPRESSION.

 *****
 *****
FILE COMPRESSION
 ****************
   FUNCTION: COMPRESS THE RETRIEVAL FILE BY DELETING SOUNDINGS THAT
HAVE BEEN FLAGGED BY 'FILRET' AND/OR 'REDRET', AND MOVING THE REMAINING
SOUNDINGS TO REPLACE THE 'EMPTY' RECORDS.

   PROGRAM        INPUT(S)         OUTPUT(S)
    ******        ********         ********
   COMRET         RTVL FILE(24)    RTVL FILE(24)

  *****
 *****
NOTE ON 'SURFACE DATA'

   PROGRAMS 'TOVRET' AND 'ENHRET' INVOKE SUBROUTINE 'RTV', WHICH IN
TURN CALLS SUBROUTINE 'GETSFC'.  IN LIKE MANNER, THE ROUTINE 'GETSFX'
IS CALLED FROM WITHIN 'FXTIRO'.  IT IS OBVIOUS FROM INSPECTION OF THE
SOURCE CODE THAT THESE ARE DUMMY ROUTINES.  THE USER SHOULD PROVIDE AN
INTERFACE TO ACTUAL SURFACE DATA (1000MB HEIGHT, TEMPERATURE, AND DEW-
POINT) IF SUCH INFORMATION IS AVAILABLE AT HIS INSTALLATION.
 *****
 *****
END OF DOCUMENT
```

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