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TEMPERATURE RETRIEVALS - II

BY

SIGMUND FRITZ

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TECHNICAL REPORT

by

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Introduction

The 1976 Final Report (Fritz, 1976), hereafter designated FR-76, and a published report (Fritz, 1977) described a method for retrieving atmospheric temperatures, with the aid of satellite radiance measurements and also nearby radiosonde, (R/S), measurements. The method was applied to simulated satellite radiances at "stations" along a line between two radiosonde stations in a severe storm situation. For that purpose, the six CO_2 "radiances" for VTPR spectral frequencies were computed over each simulated R/S temperature sounding (VTPR = Vertical Temperature Profile Radiometer). The method developed in FR-76, derived a set of coefficients, which when multiplied by the measured radiances, yielded smaller temperature retrieval errors than the minimum-information retrieval method. At the two test R/S stations, the error was in fact forced to zero.

The purpose of this research program is to obtain accurate retrievals from the forthcoming VAS radiance measurements from the geostationary satellite (VAS = VISSR Atmospheric Sounder). Therefore similar computations were made with the seven VAS spectral frequencies. The results for the "stations" along the same line between the same two R/S stations used in FR-76 were essentially the same as for the VTPR frequencies.

But suppose that a severe storm situation arises in an area which does not lie exactly along a line between two radiosonde stations; instead suppose the storm area is surrounded by several radiosonde stations. Also suppose, as is often the case, that all measurements in the six or seven satellite radiance channels are not really independent; instead perhaps only three are independent. What would be the best method of treating such a situation? In that case, let's assume, for example, that four radiosonde stations surround the storm area and three independent satellite radiance channels are available. Let one radiosonde station serve as a "first guess" estimate of temperature. It would then be possible to derive the required coefficients by solving three equations in three unknowns. These coefficients would achieve zero temperature retrieval error at the three radiosonde stations. The coefficients could then be applied to points inside or near the area surrounded by the R/S stations. As will be shown later, when this was done with simulated data, the errors were relatively small.

It therefore seemed desirable to apply the method to real data. Data from VAS are not yet available. Therefore, to minimize the cloud contamination problem, microwave data from the NIMBUS 6 SCAMS instrument were used (SCAMS = Scanning Microwave Radiometer). As might be expected, the errors with real data were somewhat larger than the errors with simulated data, but still seem smaller than errors ordinarily obtained with the minimum-information method. However problems arose, related to the non-independence of the three SCAMS radiance channels; SCAMS often does not contain even three independent radiances. These problems are described later in this report.

Retrievals---VTPR vs VAS Spectral Frequencies

The results reported in FR-76 were based on VTPR spectral frequencies. To be more applicable to the forthcoming VAS, the method proposed in FR-76 should be applied to VAS radiance frequencies. This was done with transmittances kindly supplied by Mr. H. Fleming (NESS/NOAA). The frequencies used in the VTPR and VAS retrievals are as follows:

Table of Frequencies (cm^{-1})

VAS	-	680.0	692.0	703.0	715.0	745.0	760.0	775.0
VTPR	668.5	677.9	695.3	708.6	725.5	747.6	-	-

As might have been expected, the retrieval temperature errors with VAS frequencies were not much different from the VTPR errors reported in FR-76. This is indicated in Table 1. If anything, the VTPR results were slightly better than the VAS results; e.g., for the average temperature in the layer 1000-800 mb, $\bar{T}_{10-8}$, the errors were 0.3K vs 0.8K.

TABLE 1.

Retrieval Temperature Errors: VAS vs VTPR

Average Absolute Error (^{o}K)

Pressure (mb)	Adjustment Method		First-Guess	Min-info Method
	VAS	VTPR		
1000-800	0.8	0.3	3.0	2.9
800-600	1.0	1.2	7.4	2.3
600-400	1.4	1.0	7.1	1.6
400-200	1.3	1.2	4.0	3.8
200-5	0.3	0.2	4.6	0.1

For comparison, the average absolute difference between the First Guess and the true temperatures, and also the average absolute error from the minimum information method, are repeated from FR-76. As noted in FR-76, the errors in the proposed method are smaller than the errors in the minimum information method, especially in the lower layers of the atmosphere.

Retrievals--- N-Equations in N-unknowns.

As mentioned in the Introduction, a potential severe storm area will in general not lie along a line between two radiosonde stations, but might rather be surrounded by a few stations. Moreover, generally the radiances from the six VTPR or seven VAS CO_2 channels are not independent. We might therefore have as many radiosonde stations surrounding the storm area as there are independent satellite radiance channels. From these we need to derive a set of coefficients with which to multiply the radiances in order to retrieve the atmospheric temperatures. In that event, we can obtain the coefficients exactly by solving N-equations in N-unknowns; for this, N equals the number of radiance channels used.

Let us review briefly the linear retrieval method.

The linear problem is reduced to finding a set of coefficients which are to be multiplied by corresponding radiances. The problem is to find the "best" set of coefficients F(k,j) in the following relationship:

$$\Delta B_r(k) = \sum_j F(k,j) \cdot \Delta R(j) \quad (1)$$

$$B_r(k) = B_g(k) + \Delta B_r(k) \quad (2)$$

$$\Delta R(j) = R_m(j) - R_g(j) \quad (3)$$

In these equations

B(k) = Planck function at the pressure level, k, at a reference frequency, usually taken at 700 cm^{-1}, when the 15 μm CO_2 band is used in the satellite measurements.

R(j) is a radiance at the frequency, j.

The subscripts denote the following:

"g" = a guess (or initial estimate)

m = the measured value

r = the retrieved value.

Because B(k) depends only on the temperature, T(k), it is easy to compute T(k) from the inverse of the Planck function, once B(k) is known.

In FR-76 there were six radiances; therefore there were also six coefficients, F(k,j) in the minimum-information retrieval method. The method in FR-76 consisted of modifying two or more coefficients (at each pressure level, k) obtained from the minimum-information method. The new set of coefficients, G(k,j) yielded zero error at the radiosonde stations. When these new coefficients were used with simulated satellite data at "stations" between the R/S stations, the retrieved temperatures were more accurate than retrievals from the minimum-information method; this was already shown in Table 1, above.

If we use only N spectral intervals and N radiosonde stations, we can write Eq. (1) separately for each R/S station, substituting the true value of the Planck function, B_t, for the retrieval value, B_r.

Thus for R/S station 1 we would have

$$\Delta B_{t1}(k) = \sum_j F(k,j)\cdot\Delta R_1(j) = F(k,1)\cdot\Delta R_1(1)+\text{-----}+F(k,N)\cdot\Delta R_1(N)$$

for station 2

$$\Delta B_{t2}(k) = \sum_j F(k,j)\cdot\Delta R_2(j)$$

and so forth until the number of stations equals the number of frequencies used, N.

Since the F(k,j) remain the same at every station, we arrive at the N equations in the N unknown values of F(k,j), j = 1,N.

<u>Test for Two R/S Stations</u>. To test the selection of coefficients by solving N-equations in N-unknowns, we used the same two stations as in FR-76; namely, Omaha, Nebraska and Springfield, Ill. And we used two VAS spectral radiances; namely channels 2 and 5, or wave numbers 692 cm^{-1} and 745 cm^{-1} respectively. In this case, the simulated "station" at "Omaha + 150 km" was used as the First Guess station, and the coefficients were derived so

as to give zero error at Omaha and at Springfield. For the four remaining stations located at 50 km, 100 km, 200 km and 250 km from Omaha, the Average Absolute Errors of the temperature retrievals are shown in Table 2.

TABLE 2

Average Absolute Error (^{o}K)

	FG-True	Retrieval 2 channels	3 channels
1000-800	0.6	0.1	0.2
800-600	2.4	1.1	0.5
600-400	2.0	0.4	0.3
400-200	1.0	0.5	1.9
200-5	1.5	0.1	0.1

The results obtained when only two channels were used reduced the error when compared with the first guess errors. Still the average error in the layer 800-600 mbs was more than 1^{o}K. In an attempt to reduce that error, three channels were used namely, channels 2, 5, 7; channel 7 corresponds to wave number 775 cm^{-1}. And in addition to the same R/S stations as were used before, an additional condition was imposed; namely $\sum_j F(k,j) = 1$. The justification for such a condition was discussed in FR-76; its use will, however, improve the retrievals only when the coefficients are reduced in magnitude. In this case, it did reduce the average absolute error in the layer 800-600 mbs from 1.1K to 0.5K. But the error in the layer 400-200 mb was increased. Therefore, no conclusion about the efficacy of the added condition can be drawn. More experimence would be required before its merit can be evaluated.

Retrievals---Three Radiosonde Stations, Not in a Line.

As mentioned earlier, it is desirable to examine the retrievals based on R/S stations which do not lie along a line. The R/S stations could perhaps surround an area over which a storm might develop.

We therefore selected Monett, Mo., and Bismarck, N.D. as the test stations. Peoria, Ill. served as the "first-guess" station. The temperatures at standard pressure levels were the average monthly temperatures tabulated in the climatological data for April 1973 (NOAA, 1973). The simulated satellite "radiances" were computed for each station. With two test stations, we could utilize only two satellite radiance channels. In order to utilize a third channel, the condition $\sum_j F(k,j) = 1$ was also employed. The three VAS channels used were channels 2, 5, 7 which correspond to wave numbers 692, 745, 775 cm^{-1} respectively.

With that combination of R/S stations and satellite radiances, we had three equations from which we solved for three coefficients at each level. Then to test the coefficients, a set of additional stations arranged in a circular rings were used. Again the temperatures were obtained from NOAA, 1973. Those stations and the retrieval errors are indicated in Table 3. In Table 3, we note that although the First Guess error was 4.2K at St. Cloud, Minn., the retrieval error was only 0.7K for the layer 1000-800 mb. Similarly, the retrieval errors were everywhere 1K or less in Table 3. A trial with these stations for the minimum-information method, showed quite large errors. But even if the minimum-information error could be reduced to the 3K or so which is typical for that method in the lower atmospheric layers, the retrieval method described here would give better results.

Table 3

TEMPERATURE ERROR °K

FIRST GUESS-TRUE							
Δp (mb)	PEORIA	MONETT	BISMARCK	N. PLATTE	RAPID CITY	DODGE CITY	ST. CLOUD
1000-800	0	-2.0	+4.9	2.5	2.9	0.2	4.2
800-600	0	-2.5	3.5	0.3	1.3	-2.3	2.6
600-400	0	-1.7	3.6	1.0	2.5	-0.7	2.6
400-200	0	-1.4	2.1	1.1	2.2	-0.5	2.0
200-5	0	+0.6	-1.1	-0.4	-0.5	-0.1	-0.8

ADJUSTMENT METHOD							
1000-800	0	0	0	0.5	0.1	-0.4	0.7
800-600	0	0	0	0.1	0.0	-1.0	0.2
600-400	0	0	0	-0.3	0.4	-0.7	-0.1
400-200	0	0	0	0.7	0.9	+0.3	0.3
200-5	0	0	0	-0.5	-0.8	-0.1	-0.5

3 Frequencies (Channels 2, 5, 7)

PEORIA = First Guess Station

MONETT and BISMARCK = Adjustment Stations

$$\sum_j F(k,j) = 1$$

Retrievals---Four Frequencies

An attempt was also made to use four channels; the channels used were at wave-numbers 692, 703, 745, and 775. Here Peoria was again used as the "First-Guess" station, and, Monett, Bismarck, and North Platte, Neb., were used as the test stations. To use four frequencies with only these three test stations an additional condition was required. One possible condition is to make $\sum_j F(k,j) = 1$ at each level, k. This was done with the results shown in Table 4(b). We note that, unfortunately, several errors were larger than $1^{\circ}K$. In the layer 1000-800 mb, errors of 1.7 and -1.0 appear; in the layer 400-200 mbs one error reached $2.7^{\circ}K$.

These errors were associated with large values of F(k,j). In an attempt to reduce the values of F(k,j), another condition was substituted for $\sum_j F(k,j) = 1$. Instead we used $\sum_j F^2(k,j)$ = minimum real constant, at each level, k. The idea here is that if each F(k,j), is a vector component, then the composite vector would be $\sum_j (F)^2(k,j)$. By making $\sum_j (F)^2(k,j)$ small, we should reduce the values of F(k,j). This was indeed the case as shown in Table 4(d). For example in the lower levels, at p = 901 mb. F for ν = 703 was more than 6 times larger for the case when $\sum_j F = 1$; and for p = 299 mbs (k = 70), F was about 3 times larger. And we further note in Table 4(c) that the errors are in fact reduced when the values of F(k,j) are reduced; in Table 4(c) the errors are mainly smaller than in Table 4(b).

Real Data

All the results discussed above involved simulated data. And those results suggest that the "adjustment method" can produce temperature retrievals with relatively small errors. It therefore seemed desirable to proceed to real data. Unfortunately real sounding data from geostationary satellites are not yet available. Therefore data

TABLE 4. TEMPERATURE ERROR (^{o}K)

FOUR CHANNELS

THREE STATIONS PLUS (b) $\sum_j F(k,j) = 1$; (c) $\sum_j F^2(k,j)$ = min constant

Δp (mb)	PEORIA	MONETT	BISMARCK	N. PLATTE	RAPID CITY	DODGE CITY	ST. CLOUD
(a) FIRST GUESS-TRUE							
1000-800	0	-2.0	4.9	2.5	2.9	0.2	4.2
800-600	0	-2.5	3.5	0.3	1.4	-2.3	2.6
600-400	0	-1.7	3.6	1.0	2.5	-0.7	2.6
400-200	0	-1.4	2.1	1.1	2.2	-0.5	2.0
200-5	0	0.7	-1.1	-0.4	-0.5	-0.1	-0.8
(b) ADJUSTMENT METHOD							
1000-800	0	0	0	0	1.7	0.5	-1.0
800-600	0	0	0	0	0.3	-0.5	-0.1
600-400	0	0	0	0	-0.5	-0.8	0.9
400-200	0	0	0	0	2.7	1.1	-1.7
200-5	0	0	0	0	-2.7	-0.9	1.2
(c) ADJUSTMENT METHOD							
1000-800	0	0	0	0	-1.2	0.1	0.1
800-600	0	0	0	0	-0.7	-0.7	0.4
600-400	0	0	0	0	+0.6	-0.6	0.5
400-200	0	0	0	0	-0.5	0.5	-0.5
200-5	0	0	0	0	0.4	-0.4	0.1

(d) Values of F(k,j)

(a) $\sum_j F(k,j) = 1$; (b) $\sum_j F^2(k,j)$ = minimum

k	Δp (mb)	ν = Wave number (cm^{-1}) 692	703	745	775
97	901				
		(a) 17.1	-29.3	22.2	-9.1
		(b) 6.5	4.7	4.3	-1.8
70	299				
		(a) 2.1	-3.3	3.6	-1.4
		(b) 0.8	1.0	1.3	-0.5

from the polar-orbiting satellite, Nimbus 6, were used. Furthermore in order to minimize the complications introduced by clouds, the microwave data from the SCAMS (Scanning Microwave Spectrometer) were used.

The SCAMS data and radiosonde data for February 7, 1976 were kindly supplied by Dr. N. Grody of NOAA/NESS. Data over Europe were used in order to minimize the time difference between Nimbus data (noon-midnight orbit) and the 12 z radiosonde data. The data were examined in two areas, one over Eastern Europe and one over Western Europe.

Figure 1 shows an infrared cloud (and/or snow) picture, taken by satellite NOAA 4, over Europe on February 7, 1976. The two rectangular areas, enclosed by solid lines, are the Eastern and Western European areas for which retrievals were calculated in this paper. The area enclosed by the dashed line approximates the area of the synoptic analysis map of Figure 2. Figure 1 shows that some clouds were present over Western Europe; however near 50N, 10E the sky seemed clear. Over Eastern Europe, there also were some clouds, but these may have been lower than those over Western Europe.

Figure 2 shows the synoptic situation as represented by the heights and temperatures of the 850 mb surface. A high contour area was located near 58N, 20E. This was associated with cold air further east and a fairly steep E-W gradient of temperature there. Over Western Europe the air was warmer; and more importantly, a warm area was centered near 50N, 6E so that the temperature gradient there was small.

Figure 3 shows the weighting functions of the three SCAMS channels. The two lower channels "see" the ground; this is especially true for channel 3 (52.85 GHZ). We note also the substantial variation with nadir angle; this points up the possible error introduced by inexact correction of the observed radiance for nadir angle.

Figures 4 and 5 show the radiance distribution from SCAMS for Eastern Europe and Western Europe respectively. The patterns of temperature (Fig. 2) and radiance (Figs. 4 and 5) are fairly similar although the radiance patterns show more detail. This might be expected, if only because of the high spatial resolution of the radiance data. Over Eastern Europe, the north-south and east-west gradients are evident in both radiance and temperature data. Over Western Europe, the gradients are more irregular. It is however interesting to note that even relatively small features appear in both the temperature and radiance distributions. Thus the low radiances near 47N, 10E correspond to the tongue of cold air extending from Eastern Europe into Western Europe in Fig. 2. However in the radiance data this cold area seems to be cut off from the main cold area; in Fig. 2, the spatial resolution is inadequate to show such a detail.

TABLE 5

Average Absolute Temperature Error (^{o}K)

Eastern Europe

SCAMS (Nimbus 6)			SIMULATED IR		
Δp (mb)	F′-True	$T_r - T_t$	FG-True	Min-Info	Adjustment Method
1000-800	5.7	1.7	3.0	2.9	0.3
800-600	4.4	1.5	7.4	2.3	1.2
600-400	4.4	1.4	7.1	1.6	1.0
400-200	2.8	1.3	4.0	3.8	1.2

There are many radiosonde stations over Europe. And since the SCAMS makes measurements at three frequencies designed for temperature retrievals, (Staelin, et al., 1975), three radiosonde stations in the middle of the SCAMS data over Europe were selected. This was done separately for Eastern Europe and separately for Western Europe. In each region one additional station was selected as "first-guess" station. We therefore have three equations like Eq. (1). [For the microwave region it is appropriate to use ΔT instead of ΔB, since, to a close approximation, B is a linear function of T, at a given wavelength.]

From the three equations, three coefficients F(k,j) were computed at each level, k. To test the method, the SCAMS radiance measurements over a set of additional radiosonde stations were used. With these radiances, and using the coefficients, F(k,j) just derived, the temperatures were computed (or retrieved) at the additional radiosonde stations. The retrieved temperatures, T_r, were then compared with the corresponding radiosonde temperatures, to determine the errors in T_r.

Eastern Europe The results are shown in Table 5 for Eastern Europe (Fritz, 1977(b)). Table 5 shows the average absolute temperature error. In the layer 1000-800 mb, where large errors are often made in the minimum information method, the error was 1.7K; the average absolute difference between the "First-Guess" temperatures and the true temperature was 5.7K. For comparison, Table 5 shows also the errors from earlier reports (Fritz, 1976, 1977). We note here again that even with real data the errors seem smaller than are usually encountered with the minimum information method.

The errors for individual stations are shown in Fig. 7, alongside the line for channel 3. The errors were at most 2°K except for the two stations which were close to the satellite horizon. For those the error was 2.1 and 2.6°K. The reason for the somewhat larger error in the stations near the horizon may be in the corrections applied to the radiance. According to Dr. Grody (verbal communication) a correction is made to the radiances for nadir angle of the area viewed from the satellite. This correction is an a priori correction, based on a statistical sample from around the world obtained prior to the satellite launch. Obviously this correction can only be approximate and would be more inaccurate for large nadir angles than for small nadir angles.

However, the errors with real data were larger than the errors encountered with simulated data when the adjustment method was used. This is, of course, to be expected; with real data new sources of error appear. Not only are there errors in the radiance data, (which were, to some extent, also introduced in simulated data) but there are errors in the "truth"---the radiosonde temperatures contain errors.

Some error is introduced by inevitable time and space mismatch of the satellite radiance and radiosonde data. Clouds may influence the radiances somewhat, although in the microwave data, the cloud effect is minimized because the clouds are mainly transparent to microwave radiation. The ground emissivity may be different from unity and may vary from station to station. Therefore, with real data, "errors" [which are really <u>differences</u> from the <u>estimated</u> "true" values] should be larger than for simulated data.

Still the retrieved temperature errors in Table 5 are small even for the real data.

It should be pointed out that even for Eastern Europe, some trial and error was required in order to reduce the errors; that is, the selection of the first guess station as well as the test stations from which the coefficients F(k,j) are derived must be carefully selected.

This can best be explained if we recall that the solution for the three values of F(k,j) involve a fraction; thus for F(k,j) corresponding to channel 3,

$$F(k,3) = \frac{\begin{vmatrix} \Delta R_{11} & \Delta R_{12} & \Delta T_1 \\ \Delta R_{21} & \Delta R_{22} & \Delta T_2 \\ \Delta R_{31} & \Delta R_{32} & \Delta T_3 \end{vmatrix}}{\begin{vmatrix} \Delta R_{11} & \Delta R_{12} & \Delta R_{13} \\ \Delta R_{21} & \Delta R_{22} & \Delta R_{23} \\ \Delta R_{31} & \Delta R_{32} & \Delta R_{33} \end{vmatrix}} = \frac{\text{Num}}{\text{Den}} \qquad \text{Eq. (6)}$$

In order to arrive at small values of F(k,j),--a necessity if temperature errors are to be small--it is desirable to have the numerator small and the denominator large. If the ΔR's for each channel are highly correlated, the denominator will approach zero, and F(k,j) will tend to be large. It is therefore desirable to select a set of stations for which the ΔR's are independent and at the same time the ΔT's are relatively small.

Western Europe

Unfortunately, for Western Europe, the method of using three equations in three unknowns did not work well. This was caused by the fact that the three SCAMS radiances were not sufficiently independent over Western Europe.

When the radiances are not independent, the coefficients, F(k,j) become large, as was shown above. With large F(k,j) the errors become large.

The lack of independence of the SCAMS data over Western Europe is shown in Fig. 6. Figure 6 is a plot of ΔR, for channel 3, against ΔR for channel 2, and for channel 1. The figure shows that the radiances are too highly correlated (correlation coefficient ~ 0.9). This leads to large values of F(k,j) for all sets of test stations tried. As a consequence, we have essentially only one independent channel and the adjustment method requiring 2 or more channels will not work.

Regression Method.

With only one channel it may still be possible to obtain retrievals with small errors by regression methods. This would be possible if the temperatures were correlated with the radiances. And, indeed, the values of $\Delta\bar{T}_{10-8}[= \bar{T}_{10-8} - (\bar{T}_{10-8})_g]$ were well correlated with the corresponding values of ΔR for channel 3 and channel 2. Such a relationship is illustrated in Fig. 7 for Eastern Europe. The correlation between ΔT and ΔR are high for both channels 2 and 3. For channel 1, the correlation was poorer.

Similar curves are available for Western Europe. There the correlation is not as high largely because the variability of the temperatures was less than in Eastern Europe.

Because of the good correlation between ΔT and ΔR, we should expect reasonably accurate retrievals, even from one radiance channel. Therefore a regression method was applied to the radiances to obtain the temperatures.

This was done with a statistical package available in the University of Maryland computers, namely, Subroutine RLSEP, which selects a regression model using a forward stepwise algorithm, computes the coefficients in the regression equation and also various other statistics. In RLSEP it is possible to force all the radiances into the multiple regression; RLSEP can also be used so that only statistically "significant" radiances are used in the regression. Both methods were employed.

Western Europe

It turned out that only one radiance channel was significant for Western Europe. Usually, the results with one channel alone, were about as good as the result when all three channels were used. This is indicated in Table 6. From Table 6, we note that the percent variance explained in the dependent data is 84% when only one radiance channel was used. This was improved to only 88% when all three channels were used. More importantly when the regression equations shown in Table 6 were applied to independent data, the Average Absolute Error (AAE) was about 1.8K whether one radiance channel or three channels were used. In fact with the three channels, the error, if anything, was even slightly larger.

Table 6 also show that when all stations, the dependent together with those which had been used as independent stations, were used to obtain regression equations, the conclusion was the same; namely, the addition of two channels to channel 2 added almost nothing to the percent variance explained or to the standard deviation of the residuals.

Eastern Europe

Even though the method involving three equations was successful over Eastern Europe, the regression was employed there also. Table 6 shows the regression equations. The percent variance explained was very high, 97%; and the standard deviation of the residuals was small; namely, about 1.3K. The regression subroutine selected both channels 1 and 3

TABLE 6. Regression Equations, $\Delta T_{1000-800}$ vs SCAMS Radiance; % Var = Percent Variance Explained
S.D. = Standard Deviation of Residuals, AAE = Average Absolute Error

WESTERN EUROPE				EASTERN EUROPE		
Dependent Data Only (14 Stations)	% Var	S.D. ^oK	AAE ^oK		% Var	S.D. ^oK
$\Delta T = 2.978\ \Delta R(2) + 2.04$	84	1.9	1.8*	$\Delta T = -0.52\ \Delta R(1) + \text{----} + 1.44\ \Delta R(3) - 2.63$	97	1.2
$\Delta T = -1.11\ \Delta R(1) + 3.55\ \Delta R(2) + 0.45\ \Delta R(3) + 2.31$	88	1.8	1.9*	$\Delta T = 0.54\ \Delta R(1) + 0.10\ \Delta R(2) + 1.35\ \Delta R(3) - 2.56$	97	1.3
Dependent and Independent Data (14 + 10 Stations)						
$\Delta T = 2.54\ \Delta R(2) + 1.38$	80	1.8	–			
$\Delta T = -0.64\ \Delta R(1) + 3.86\ \Delta R(2) - 0.49\ \Delta R(3) + 1.84$	83	1.8	–			

AAE = Average Absolute Error

* when applied to independent data

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as significant for Eastern Europe. Apparently channel 2 did not add significantly to the explanation of variance. This might have been expected also from Fig. 7, which suggests that $\Delta R(3)$ and $\Delta R(2)$ are highly correlated, because both are highly correlated with ΔT. The fact that the regression equations over Western Europe are different from those over Eastern Europe was also observed by Grody and Pellegrino (1977).

Discussion.

The regression method when used with only one radiance channel depends on the good relationship between ΔT and ΔR. When one considers that $\bar{T}$ for the layer 1000-800 mbs contributes very little to the radiance in channel 3, the question arises as to why $\Delta\bar{T}_{10-8}$ is in fact highly correlated with $\Delta R(3)$, the Δ radiance in channel 3, and with $\Delta R(2)$. Such a correlation probably requires that the air temperature over a deep layer should also be correlated with $\bar{T}_{10-8}$.

To test this the average temperature for the layer 1000-800 mb, $\bar{T}_{10-8}$, was plotted against the average temperature in the layer 800-600 mbs. The result is shown in Fig. 8, for Eastern Europe. As expected, the relationship is quite good. Thus, when $\bar{T}_{10-8}$ is cold, $\bar{T}_{8-6}$ is cold also; this of course generally agrees with meteorological experience also. Major cold air outbreaks involve cold air over much of the troposphere. Also latitudinal temperature variation in winters has at least the same sign over most of the troposphere.

As a consequence, not only is $\Delta R(3)$ related to $\bar{T}_{10-8}$, but $\Delta R(3)$ is also highly correlated with $\Delta R(2)$.

Regression vs Adjustment Method. The regression method when applied over a limited geographical area can give as good results as any other method.

But the regression method requires a relatively large number of radiosonde stations in order to make the regression coefficients stable. Moreover using relationships from some other area or some other time leads to increased errors (Grody and Pellegrino, 1977). Therefore, for the times and place for which retrievals are desired it may be necessary to acquire R/S data over a relatively large area. This in turn may make the synoptic situation too variable to achieve good results over a small severe storm area. Therefore, where possible it may still be desirable to use the adjustment method, with three or four equations involving three of four radiosondes around the area under study. When this is not possible, the regression method can be used but at the expense of involving data from a larger area.

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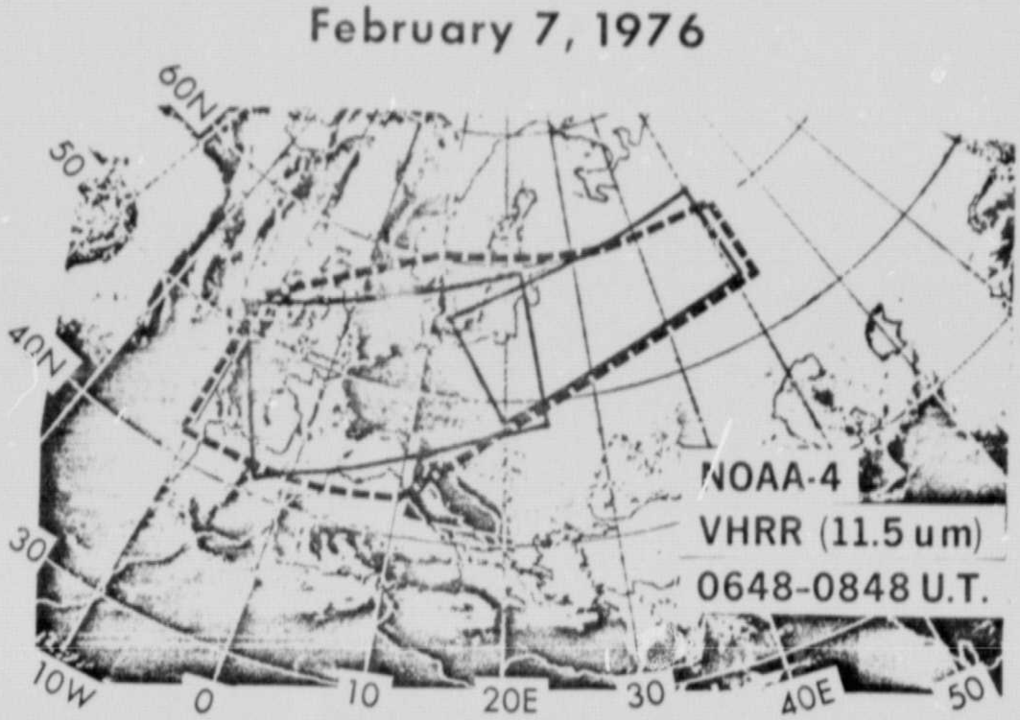

Fig. 1. Infrared picture from satellite NOAA-4. Rectangles with solid lines are areas over Eastern Europe and Western Europe for which temperature retrievals were made with SCAMS data. Irregular dashed line bounds area of synoptic chart in Fig. 2. (Courtesy Grody and Pellegrino).

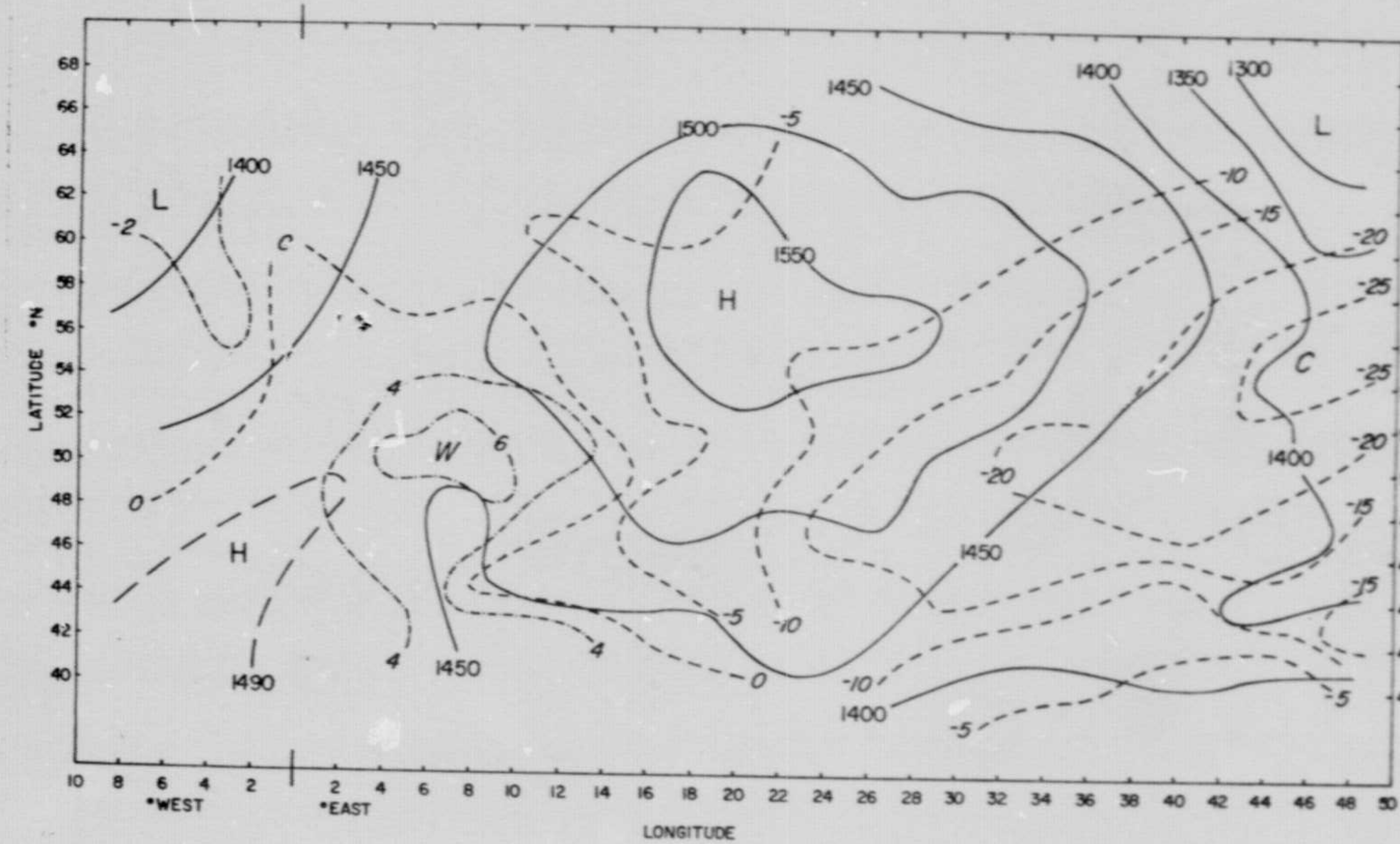

Fig. 2. Synoptic 850 mb chart over Europe. Solid lines are contours, dashed lines are isotherms. Feb. 7, 1976, 12Z.

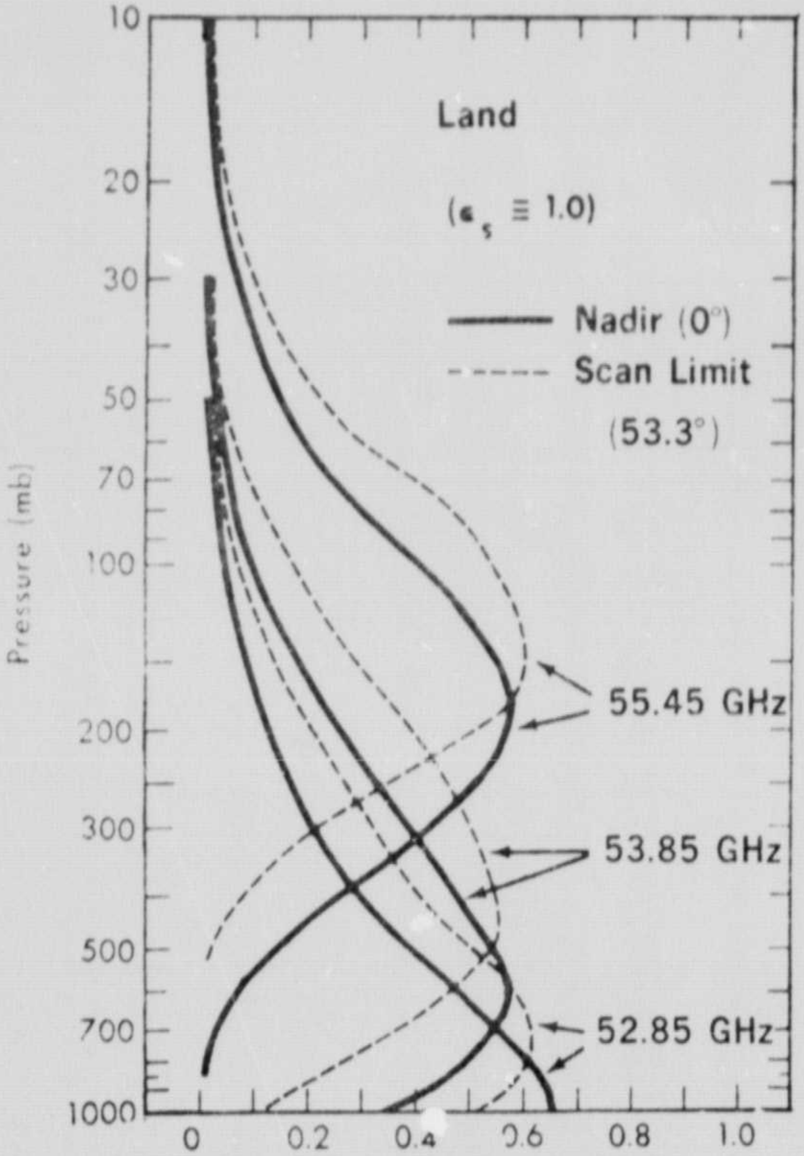

Fig. 3. Weighting functions for SCAMS channels in the oxygen band. The three channels were designated 1, 2, 3; channel 1 corresponding to the uppermost channel, 55.45 GHZ, and channel 3 to the lowermost, channel 52.85 GHZ. (Courtesy Grody and Pellegrino)

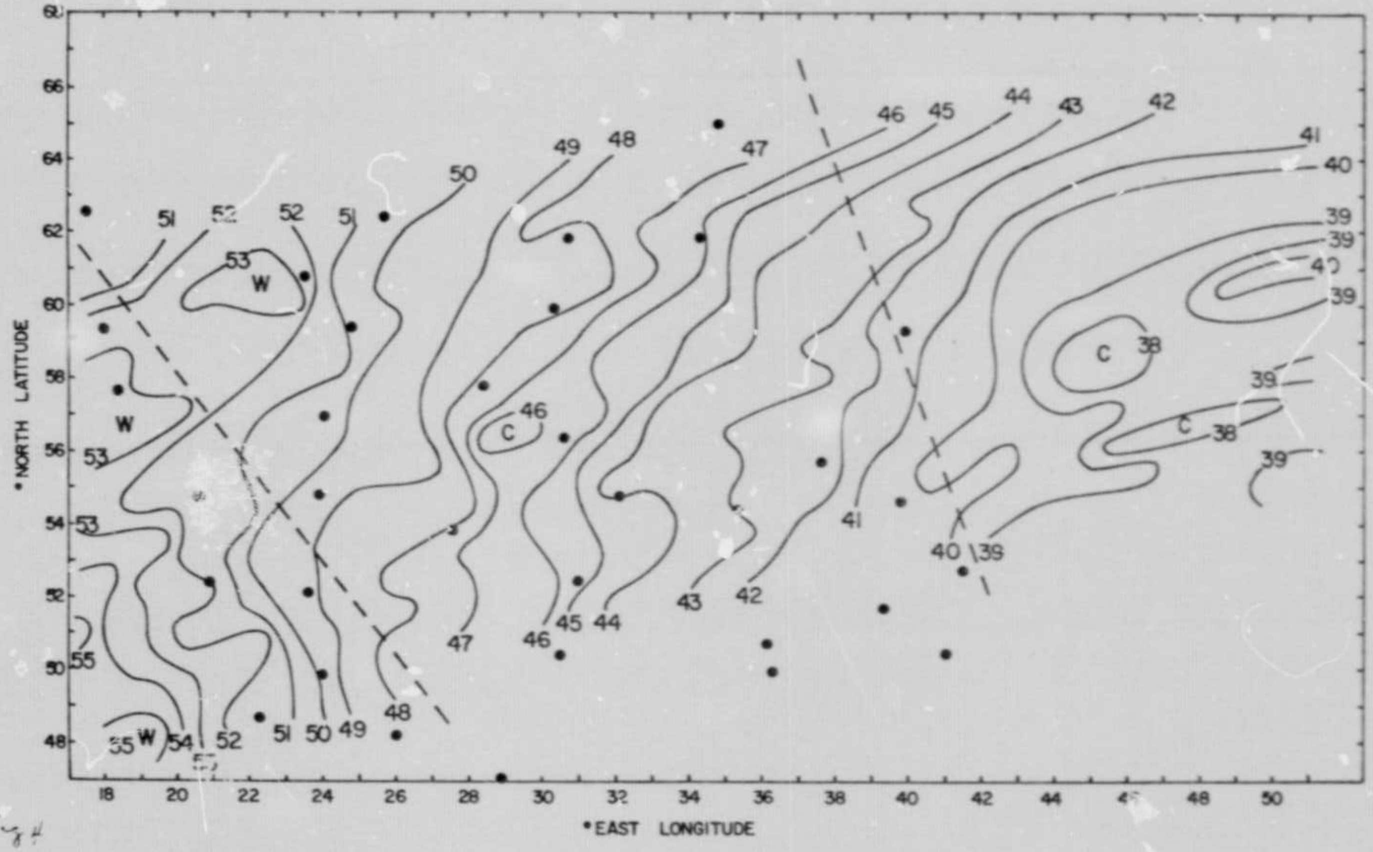

Fig. 4. Isolines of radiance for SCAMS channel 3 (52.85 GHZ) for Eastern Europe. Isoline numbers are antenna temperatures (^{o}K) minus 200. Number "50" corresponds to 250K. Dashed lines bound the area with relatively small satellite nadir angle. The black dots are the locations of radiosonde stations.

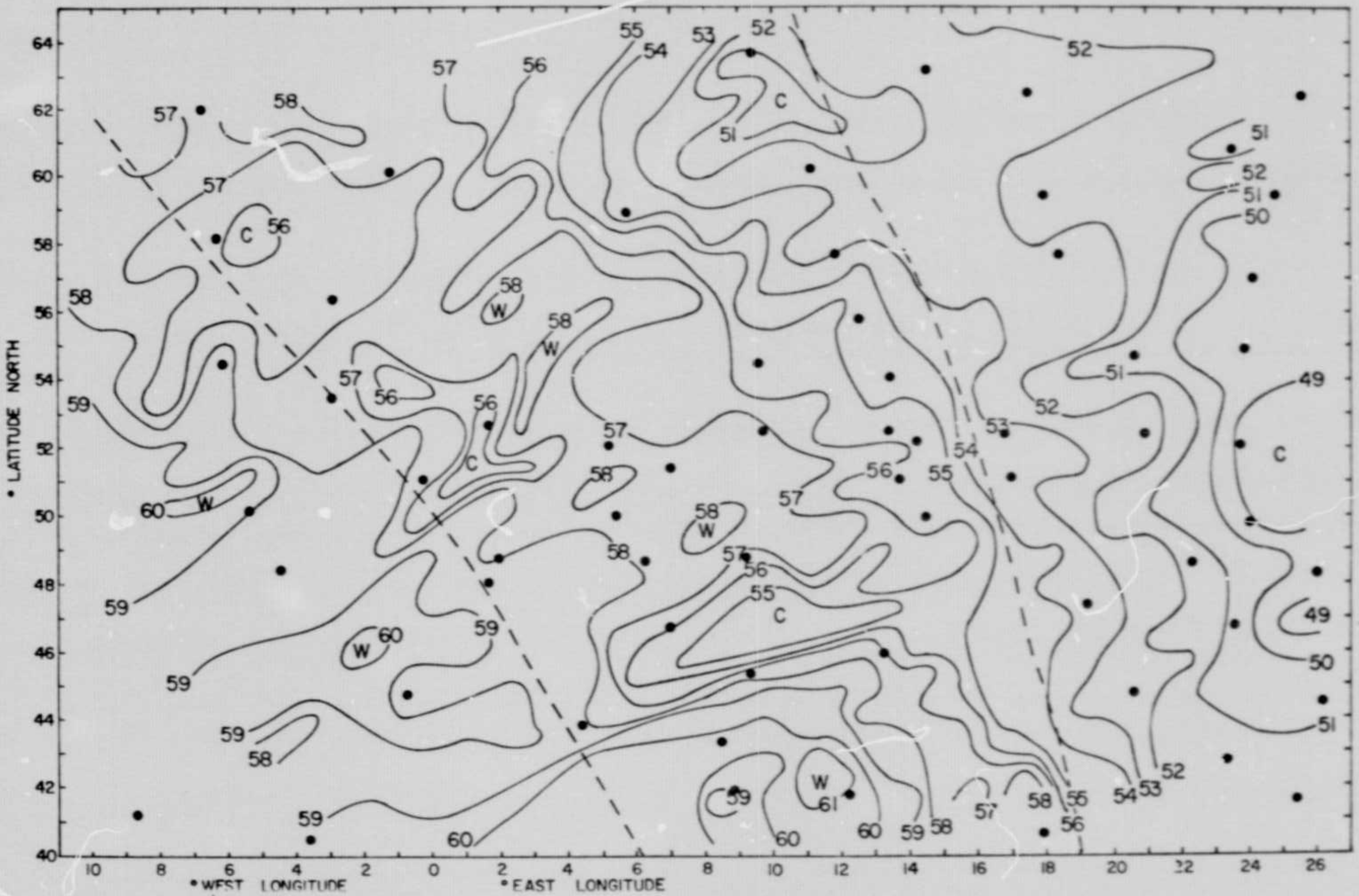

Fig. 5. Isolines of radiance for SCAMS channel 3 (52.85 GHZ) for Western Europe. Isoline numbers are antenna temperatures (^{o}K) minus 200. Number "50" corresponds to 250K. Dashed lines bound the area with relatively small satellite nadir angle. The black dots are the locations of radiosonde stations.

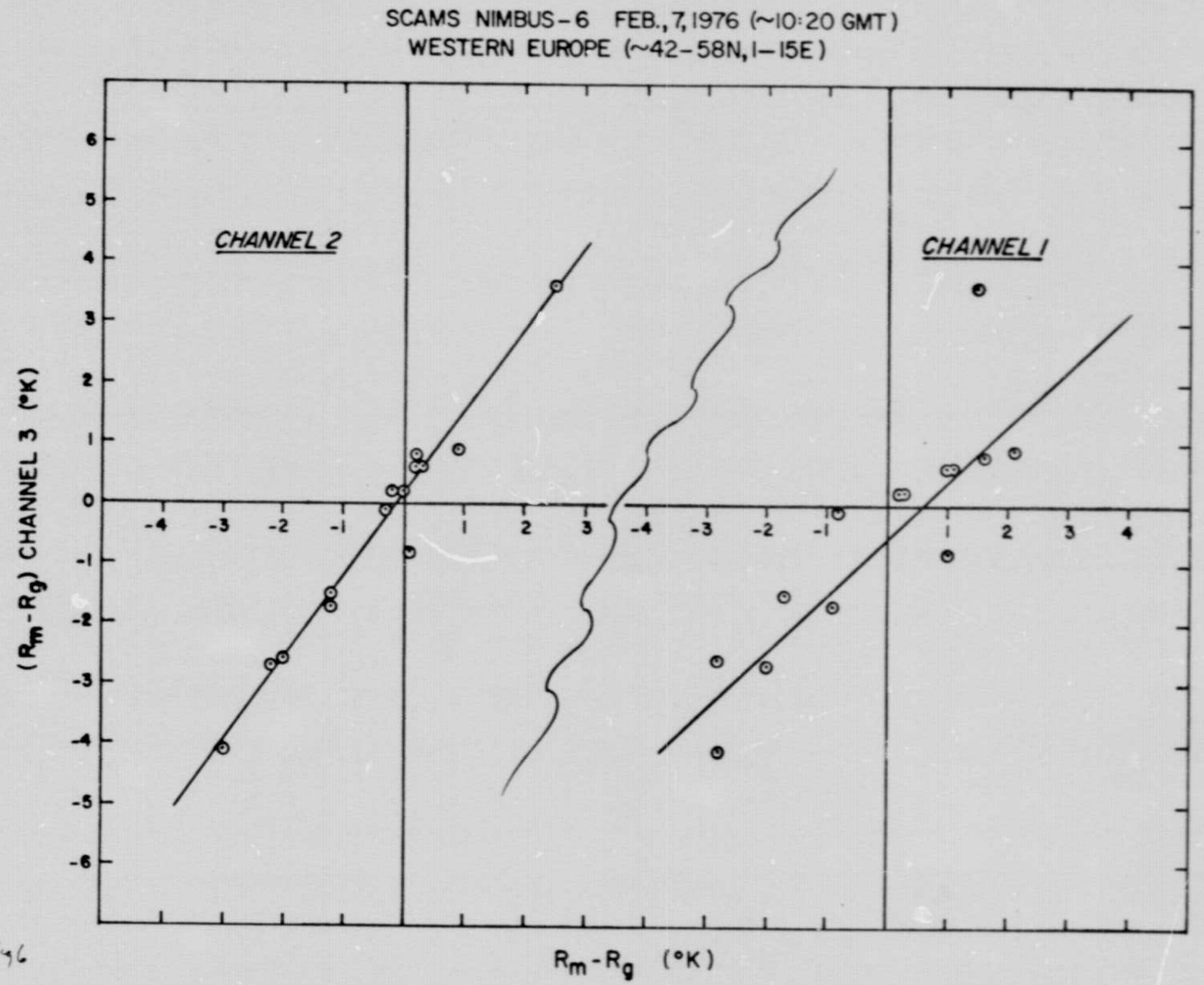

Fig. 6. Relation of radiances in channel 3 with radiances in channel 2 and in channel 1.

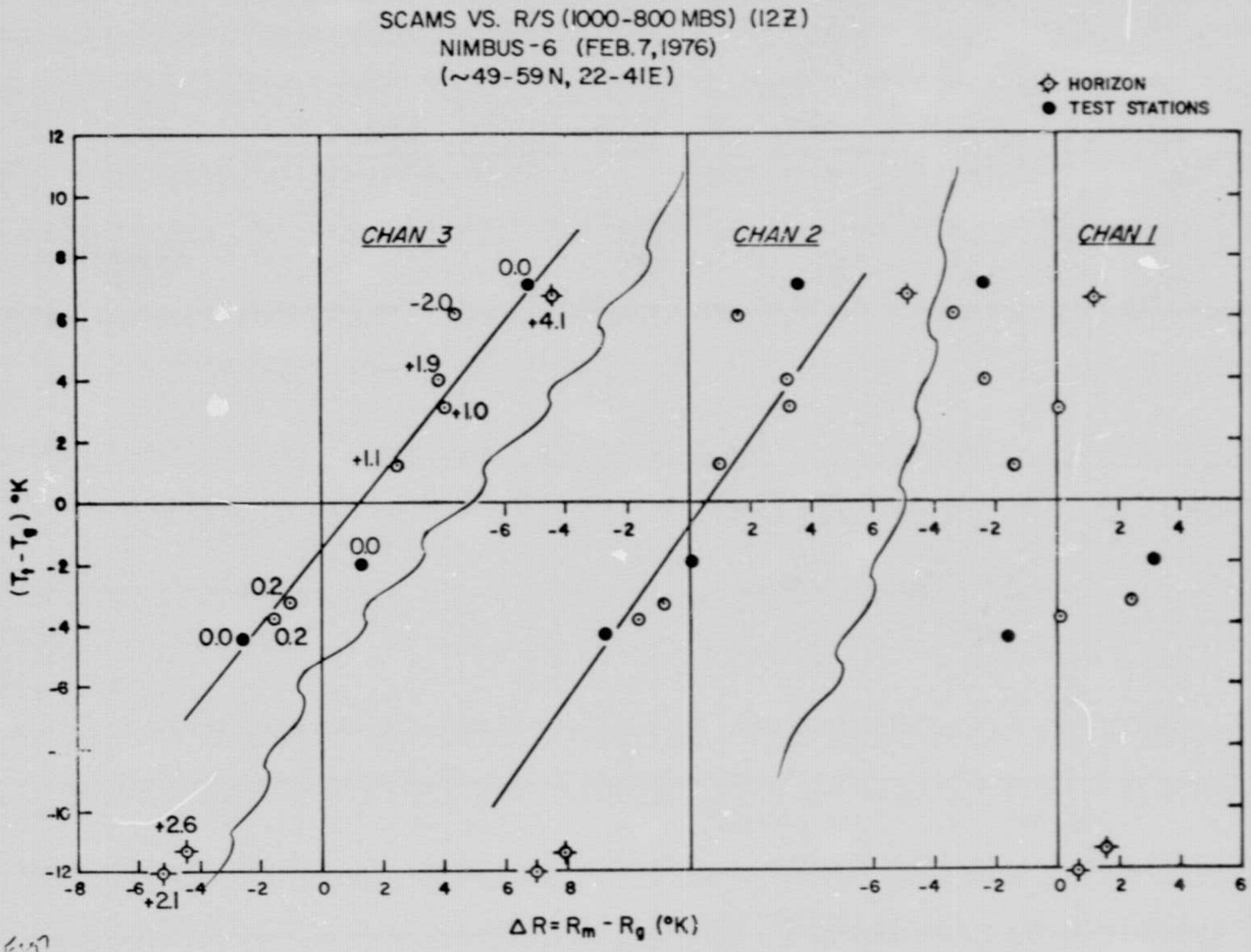

Fig. 7. Relation between $(T_t - T_g)_{1000-800}$ vs $(R_m - R_g)$. The black dots represent the stations used to derive the coefficients F(k,j). The circles with the radial lines represent R/S stations near the horizon, outside the dashed lines in Fig. 4. The numbers near the circles are the temperature retrieval errors.

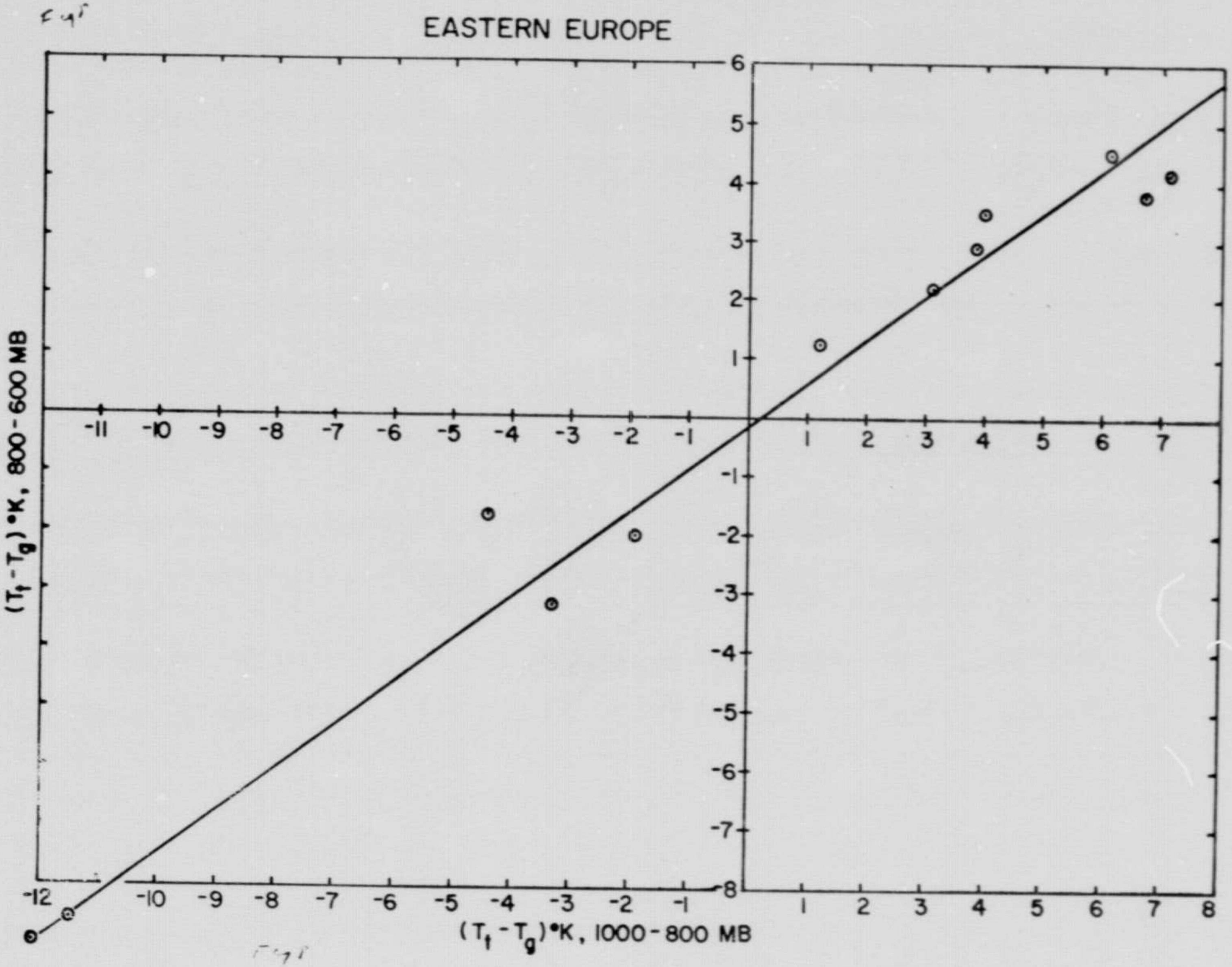

Fig. 8. Relation between average temperature in layer 1000-800 mb with average temperature in layer 800-600 mbs. Line drawn by eye.