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RETRIEVAL OF STRATOSPHERIC DATA FROM THE SOUNDERS ON THE TIROS N SERIES OF OPERATIONAL SATELLITES DURING THE FIRST YEAR OF OPERATION

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Retrieval of Stratospheric Data from the sounders on the TIROS N series of Operational Satellites during the first year of operation.

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1. Introduction

Pick and Brownscombe (Ref 1) have presented a description of the performance of the Stratospheric Sounding Units (SSUs) on TIROS-N and NOAA-6, and reviewed the techniques used for deriving stratospheric thickness and geopotential height analysis. The objective of this report is to describe, in somewhat greater detail, the retrieval schemes which have been studied theoretically and used in practice. The method for nadir-correction of SSU radiances is also described.

2. Theoretical studies of Retrieval Techniques

In order to be able to monitor performance of the SSUs in orbit and to produce stratospheric analyses, arrangements were made for two types of data to be made available to Met O 19. The first type was raw telemetry data from the SSU. The second type comprised derived radiances for the SSU and selected channels from the other two component instruments of the TIROS Operational Vertical Sounder which also related to the stratosphere. Further details of these data streams are given in Section 3 below. The theoretical studies described in this Section were based on the assumed availability of these data streams.

2.1 The atmospheric sample

The investigations described in section 2 are based on simulated radiance data derived from a knowledge of the spectroscopic properties of the radiometers forming TOVS and a set of historical temperature profiles constructed from rocket measurements. The reasons and method for calculating simulated radiances have been described by Pick and Brownscombe (Ref 1).

The primary (historical) set of temperature profiles used was obtained from the Upper Air Branch of NOAA/NMC. It is a carefully quality controlled set and has been designed to include a wide range of previously measured temperature profiles. These profiles are grouped (zoned) into latitude bands and into seasons, and include profiles representative of winter warming conditions. The total sample contains 1200 profiles, based on some 600 rocket ascents made between 1965 and 1972. The disparity in numbers is due to using different radio-sonde tie-on ascents to correct for an initial tropospheric humidity bias. There is still an uncorrectable in-built hemispheric bias, because most rocket profiles are measured in the northern hemisphere; equivalent southern hemispheric data are assumed to be represented by a reflection across the equator with an accompaning date change.

A second set of tied-on rocket temperature profiles have been accumulated by Met O 19, in computer readable form, as a continuous and ongoing series from 4 February 1976. This set, besides providing an independent check on simulation retrieval performance, where regression coefficients have been derived from the primary historical sample, latterly provides some temperature profiles which can be collocated with satellite overpass radiance measurements. This collocated set provides the basic data for the comparisons described in section 3.

2.2 Regression methods

The required end-products from the TIROS-N series of satellite measured radiances are thickness values between constant pressure levels. A base of 100 mbar is used for the 'standard' retrieved thicknesses to 20, 10, 5, 2 and 1 mbar. All the retrival methods described here are based on the multiple linear regression techniques. The appropriate coefficients are calculated using the Biomedical programme suite (Ref 2) in conjunction with the historical temperature profile set, described in 2.1, and the equivalent simulated radiance data set (expressed as effective brightness temperatures).

Two regression methods have been investigated; these are stepwise regression (SWR) and principal component regression (PCR). Both methods attempt to minimize the undesirable effects of instrumental noise on the retrievals, and so random noise, with a gaussian distribution and standard deviation equal to the measured instrumental spectral channel noise, was added to the simulated brightness temperatures which were used to calculate the regression coefficients. The main indicator of performance of the regression technique is a parameter called the standard error of estimate (SEE). The SEE is the standard deviation of the differences between the actual thickness and the retrieved thickness. In general, the lower the SEE, the better the fit. This is discussed in more detail in section 2.4.

2.2.1 Stepwise regression

Stepwise regression involves an iterative sequence, which reduces the residual (the difference between the actual thickness and the retrieved thickness using the current estimate of the regression coefficients) by using the partial correlations between the channel brightness temperature and these residuals to select the next channel to be included in the regression equation. The sequence stops when the improvement is no longer statistically significant, as determined by a F-test on the standard error estimate. This prevents 'overfitting' to the historical data, which could lead to instabilities in the retrievals with real measurements, particularly where these measurements deviate from the norm of the reference data-set. A characteristic of a bad fit is that most of the coefficients are large and differ in sign.

2.2.2 Principal component regression

This method uses coefficients of an eigenvector representation of the channel brightness temperatures as the variables in a stepwise regression scheme. The stepwise scheme is identical to the one described in section 2.2.1 above. The basic eigenvectors are derived from the covariance matrix of the simulated brightness temperatures for the historic temperature profile set. For a particular ascent the set of channel brightness temperatures values are replaced by an equivalent set of coefficients of the predefined eigenvectors. These coefficients are then used as variables in the regression equation to derive the required products. The eigenvectors, when arranged in order of decreasing associated eigenvalue, contribute decreasing variance to the reference sample; the high order vectors, low eigenvalues, representing the noise component introduced to simulate the measurement noise as well as a variable term associated with the different weighting between the common temperature profile and the derived quantities of thickness and brightness temperature which are being regressed.

2.2.3 Descriptive comparison of these regression methods

The difference between these techniques is the way in which measurements are effectively used. For example, if two channels are highly correlated SWR will tend only to use the channel mostly highly correlated with the thickness; at the next iteration the other channel will have a low weight since most of the varianc it would have explained has been removed by the first channel. The PCR scheme tends to use both channels, with near equal weight. This is a better use of measurements which contain noise. Another practical advantage of PCR over SWR is found when retrievals are zoned (see section 2.3). The coefficients associated with the eigenvectors in the regression equation tend to vary relatively smoothly from zone to zone, reducing discontinuities in derived thickness fields near zone boundaries.

Both methods require a realistic estimate of the instrumental measurement noise in the brightness temperature. For the PCR method, this aspect determines the number of eigenvectors which can be used. In the SWR, an obviously relevant but rather noisy, channel may be rejected in favour of a channel which contributes information mainly through atmospheric correlations which exist between layers in the historic sample of temperature profiles.

2.3 Zoning of the sample

The regression retrieval technique exploits two different factors: measurements of sets of brightness temperatures and the height correlations which exists in temperature profiles. The basic atmospheric temperature profiles can be characterized according to season and location, and within this grouping the overall variances of thickness and simulated brightness temperatures are less than for the whole sample (with the exception of winter warming profiles in the polar regions). Hence retrievals optimized for each of these groups have a reduced SEE. This method of a priori zoning has the danger that retrievals will be degraded when an atmospheric profile departs from the expected boundary shapes appropriate to the ascribed zone. However until we can develop a better method, perhaps based on dynamically adjusted zones using crieteria derived from channel radiance measurements, the following scheme has been adapted.

Zone	Latitude	Season	Sample size
0	All	All	1200
1	$70^\circ - 90^\circ$ N or S	Winter	64
2	$50^\circ - 70^\circ$ N or S	"	213
3	$30^\circ - 50^\circ$ N or S	"	124
4	30°S – 30°N	All	400
5	$0^\circ - 50^\circ$ N or S	Summer	126
6	$50^\circ - 70^\circ$ N or S	"	202
7	$70^\circ - 90^\circ$ N or S	"	71

The seasons are defined as follows.

Winter: N – October to March; S – April to September.

Summer: N – April to September; S – October to March.

Size refers to the historical atmospheric sample.

The improvement of zoned over unzoned retrievals is apparent from Table 1 (discussed in detail in section 2.4). Besides the reduction in SEE, there is also a reduction in a bias which occurred in the tropics. This bias was readily apparent in our initial comparison between objective analysis, based on unzoned satellite retrievals, and subjective charts based on radiosonde measurements. The bias was substantially reduced when zoned retrievals were used.

2.4 Discussion of theoretical results

Table 1 shows the SEE obtained from different regression methods, with different combinations of channels and with zoned and with unzoned regression coefficients. These SEE contain two components:

- a noise component which comes from the simulated instrumental noise in the simulated brightness temperatures;
- a component arising from the inability of the regression equation to estimate the thickness from radiance measurements, due to the different functional weighting between these quantities and the common atmospheric temperature profile.

The second component exceeds the instrumental noise. The effect of instrumental noise is further reduced by the averaging and smoothing associated with the objective analysis. Because of the horizontal spatial correlation of atmospheric temperature structure (and associated thickness and brightness temperature fields), this second component manifests itself as extensive spatial or seasonal biases in the retrievals, through statistically it appears as a random error for the appropriate zonal temperature profile set. It is this latter component that is reduced by zoning.

It can be seen from Table 1 that zoning of retrievals brings a reduction in SEE for all but zone 1 (the polar winter zone). The reduction is especially marked in the summer hemisphere and in the tropics. The ratio of the standard deviation of the thickness in the sample to the SEE gives a good indication of the 'power' of a regression method. Not only is the SEE low in the summer hemisphere, but the power is high, whereas in the tropics although the SEE is comparitively low, the power is less impressive. The apparent deterioration of retrievals in zone 1, the polar winter zone, does not in fact mean that the retrievals will be worse in this region with zoned regression coefficients, but simply that the errors with unzoned retrievals are swamped by smaller errors in the rest of the sample to give an apparent improvement with unzoned retrievals. This result helps to illustrate the fact that the two high latitude winter zones contain a much wider range of shapes of temperature profile due to the combination of undisturbed and 'warming' profiles.

While zoning is obviously a useful technique, the zones cannot be subdivided indefinitely. The sample sizes in each zone will eventually become too small and there exists the possibility of constraining the regression equation to any anomolous profiles in the samples, increasing the chances of interzone discontinuities. There is also the practical difficulty of a priori defining the appropriate zone limits.

Table 1B shows that there is little difference in achieved SEE between the two regression methods, stepwise regression and principal component regression. However, PCR has been preferred due to its resultant smoother variation of coefficients from zone to zone and to its more intiuitively obvious method of reducing the effects of noise in actual measurements.

It is also apparent that retrievals for the 100 - 20 mbar layer with SSU channels only are (Table 1A) inferior to those which include the microwave sounder MSU (Table 1B). Figure 1, which shows the appropriate weighting functions, indicates that the improvement is related to the better height coverage of the weighting functions, particularly near 100 mbar, provided by the 'processed data' channels.

Another, somewhat surprising result is the apparent small contribution to retrievals when some channel 27 is added with NOAA to (this channel malfunctioned on TIROS N). Again this can be explained by examining the weighting functions (figure 1). Channel 27 contributes very little additional information below the topmost retrieval level of 1 mb.

During winter warming in the polar regions, the height of the stratopause decreases very substantially. This produces large retrieval errors because this type of temperature profile is so different from the undisturbed profiles which characterise a winter pole. The inclusion of channel 27 in the linear regression has only produced marginal improvement. It is conceivable that channel 27 may be of more use as an indicator of when and where radiances are being measured under warming conditions, and hence allow the regression coefficients to be switched to a more appropriate set.

2.5 Preliminary and independent assessment of methods.

As a preliminary check on the applicability of the regression technique, retrievals were performed on a set of simulated brightness temperatures derived from the Met O 19 rocket catalogue mentioned in section 2.1.

The simulation calculations used fixed weighting functions and only the unzoned system was checked. It was found that there was no significant bias in the mean estimated thickness for the sample from the Met O 19 catalogue as a whole, both for different combinations of channels and for SWR or PCR, although the mean thickness differed between the historic sample and the Met O 19 catalogue. The results are given in Table 2.

Table 2 also shows, in the last 2 columns, the 'power' of the retrieval. This indicates that the independent retrievals are worse than the reference (dependent) set, although the SEE is similar for the two data sets. This difference in power is mainly due to the smaller variance of thickness in the independent sample.

3. Performance of Methods in practice

3.1 Availability of data and impact on methods used.

Soon after the launch of TIROS N in October 1978, the Meteorological Office received almost complete coverage for the raw telemetry data from the SSU. Not until early 1979 did we receive processed data and then only erratically until July 1979, when more reliable coverage was provided. The channels available in the processed data stream are listed in table 3. Note that the excessive noise in channel 27 precludes its use in any retrieval scheme for TIROS N, and channel 17 has not been used because of an unresolved fluorescence problem for measurements made while the atmosphere is illuminated by sunlight.

Initially retrievals were done using a 2 channel SSU unzoned scheme. The more elaborate zoned 3 instrument scheme was used when the processed data reception became reliable. An iterim scheme, based on a double analysis stage using the simple 2 channel SSU retrievals as a background on to which the processed data was analysed, was successfully tried in order to improve on the simple 2 channel analysed field whilst processed data reception was erratic . For NOAA-6 the initial scheme is a 3-channel zoned SWR, which will be used until the processed data becomes reliable. Based on experience described in sections 2.2.2 and 2.2.3, a zoned PCR is used for the processed data for TIROS N with a more elaborate method of allowing for seasonal change. This involves using a weighted combination of the winter and summer regression equations, with the weights varing simusoidally over the year. This eliminates the seasonal change discontinuities, which would otherwise have occurred.

Lists of the regression coefficients actually used are available on request from Met O 19.

3.2 Some aspects of performance

The problems in assessing stratospheric products retrieved from satellites have been discussed by Pick and Brownscombe (Ref 1). The main problems are associated with:-

- accuracy of the comparison measurement derived either from a radiosonde or rocket sonde temperature profile:
- differing spatial resolution of the satellite and sonde;
- lack of spatial and temporal collocation between the two measurements and changes in the atmosphere on the scale of these differences;
- representativeness of the 'historic' rocket profiles to current atmospheric conditions;
- errors in position and shape of the weighting functions used to calculate simulated radiances.

However some general conclusions can be made. Objective and subjective comparisons between charts for the 10 and 20 mbar levels based on radiosonde measurements and the objective satellite charts, reveal a significant bias at low latitudes with unzoned retrievals.

While this bias is reduced by introducing zoning, there is still a tendency for the satellite charts to be biased high in the tropics.

These comparisons of satellite derived charts with hand-drawn charts further show that most features are fairly well represented by the satellite retrievals. However, there are some areas where large differences arise between the charts. On occasions these differences are as large as 1 kilometer. These areas of large differences tend to be small localised pools. Moreover, as they are mostly associated with regions showing very tight height or thickness gradients it is difficult to know whether they should be atributed to the retrieval or the analysis scheme. However, it seems probable that they are associated with retrievals under anomolous atmospheric conditions. For the higher level 100 - 1mb thickness direct comparisons with 'spot' rocket ascents are made. A histogram of such a comparison is given in figure 2, together with a histogram of differences between retrieved and actual thickness for the 'historic' sample used to derive the regression coefficients. It is encouraging, that, while the spread of differences is larger for the real data, the histograms are quite comparable.

4. Nadir Correction

The Nadir correction scheme is introduced to compensate for the upward vertical shift of the weighting functions as the radiometers scan away from a nadir view. Again the historic sample is used to calculate sets of simulated radiances, this time at nadir and at 10 and 30° off nadir. Regression coefficients are then calculated which enable the bias offset in radiance, for a particular angle from nadir due to a vertical shift of weighting function in a non isothermal atmosphere, to be estimated from the values of the off nadir radiances simultaneously measured in the available channels. Table 4 lists the nadir corrections required for the SSU channels. (A similar correction has already been applied to HIRS and MSU channels before receipt at Bracknell). It is apparent from table 4 that the top channel is least well corrected. This is what one would expect since the lower channels cannot give a good estimate of the mean lapse-rate across the higher weighting function. It is this mean lapse rate which determines the size and sign of the basis error with scan angle. The accuracy required for this correction is such that a unzoned and nonseasonally adjusted set of coefficients is adequate.

5. Suggested Further Work

The only method of independently monitoring the satellite retrievals is by comparison with conventional radiosonde and rocket sonde measurements. Differences have been found between the satellite retrievals and conventional measurements which are larger than would be expected from the attributed accuracy of the measurements, errors in weighting functions or from the variance within the historic sample. Until the source of this problem has been identified, comparison with conventional data maintains an important place. Indeed, if, as is currently suspected, the main cause of the large bias error pools described in section 3.2 above is associated with stratospheric warmings, then our historic sample is suspect, since none of its profiles produced such large bias errors.

Some preliminary work has been done to identify these error pools using channel radiance values, differences, ratios or products or even by retrieval of stratopause height. However, no definitive conclusion has yet been reached. This area, together with a careful re-appraisal of the accuracy of the weighting function shape and position, still require support.

An approach not yet tried is use of eigenvectors to attempt to characterise warming profiles. It is necessary to evaluate whether the amplitude of the vector representing readings from the satellite over-pass can be used to unambiguously identify the warming profiles and hence come up with a better retrieval scheme.

The only check on the zoning has been a subjective inspection of the charts, with the aim of identifying discontinuities; no obvious discontinuities have been found. However zonal means over several days (used by climatologists), particularly for periods near the solstices, ought to be examined for this effect, since during this period the zonal contrast between the regression equations is largest.

The retrieval scheme in use directly retrieves large layer thickness. However some of our users require values for shallow layers (eg for dynamical studies), which are derived by differencing the retrieved values for two deep layers. The errors in doing this as opposed to direct small layer retrievals have not been evaluated, though it is thought that from linear regression theory and from past experience (Ref 3) that the approaches are equivalent.

Finally the choice of a 100 mbar reference level is arbitary and a better level may be available. The 100 mbar level seems to be appropriate in winter, when a cyclonic vortex is often dominant throughout the 100 - 1 mbar layer. However, in summer this cyclonic vortex remains at 100 mb while the 20 mbar fields and above become anticyclonic. This means that in order to retrieve a height field whose contours are relatively smooth it is necessary to retrieve a thickness field which is exactly out of phase with the 100 mbar height field; this can present problems. Thus it might be appropriate to use a higher level field for tie-on during the summer months, although obviously this will depend on the data coverage at the new level.

<u>References</u>

(1) "The Stratospheric Sounding Unit: Performance and Products". DR Pick and J L Brownscombe. Met O 19. Branch Memo No 52, Oct 1979.

(2) BMDP Biomedical Computer Programs. Health Sciences Computing facility, Dept of Biomathematics, School of Medicine, University of California, L.A. (1975 and 1977 editions).

(3) A Stepwise Multiple Regression Computer Program for the Retrieval of Stratospheric Temperature Profiles from Satellite Radiances - A Slingo. Met O 19. Branch Memo 26, Jan 1976.

Table 1a. Retrieval statistics for simulated radiances for SSU channels (SSU 25, 26, on TIROS N & SSU 25, 26, 27 on NOAA 6) (Based on the historical rocket sample).

Zone	Sample size	Layer mbar	Mean Thickness dam	Mean Thickness °C	S.D of thickness dam	S.D of thickness °C	Standard error of estimate (dam) TIROS N (SWR)	Standard error of estimate (dam) NOAA 6	Power (SD/SEE) TIROS N	Power (SD/SEE) NOAA 6
0	1200	100–20	1024	−56.0	36.5	7.7	15.5	14.3	2.4	2.5
unzoned		100–10	1487	−52.8	50.2	7.4	11.3	11.0	4.4	4.6
		100–5	1968	−48.9	68.2	7.8	7.6	8.1	9.0	8.4
		100–2	2641	−42.7	97.9	8.5	8.7	8.0	11.2	11.0
		100–1	3174	−37.9	121.7	9.0	13.0	12.2	9.4	10.0
1	64	100–20	982	−65.0	30.0	6.4	14.5	12.1	2.1	2.3
70° – 90°		100–10	1414	−63.5	45.6	6.8	11.8	11.5	3.9	4.0
winter		100–5	1861	−61.1	67.2	7.7	7.6	8.2	8.9	8.2
		100–2	2478	−56.9	101.7	8.9	11.0	10.0	9.3	10.4
		100–1	2963	−53.6	130.7	9.7	19.0	19.0	6.9	6.9
2	213	100–20	1022	−56.5	38.1	8.1	11.0	9.5	3.5	4.0
50° – 70°		100–10	1465	−56.0	55.1	8.2	9.1	8.7	6.0	6.3
winter		100–5	1920	−54.4	70.2	8.0	6.9	7.3	10.2	9.5
		100–2	2549	−50.7	88.0	7.7	9.3	8.6	9.5	10.3
		100–1	3048	−47.2	102.0	7.6	13.4	13.2	7.3	7.7
3	124	100–20	1012	−58.5	14.9	3.2	10.5	10.6	1.4	1.4
30° – 50°		100–10	1467	−55.8	21.1	3.1	7.9	8.1	2.3	2.6
winter		100–5	1932	−52.4	29.9	3.4	6.2	5.9	4.8	5.1
		100–2	2599	−46.4	43.1	3.8	8.5	7.6	5.1	5.7
		100–1	3125	−41.5	55.9	4.1	9.1	8.7	6.2	6.4
4	400	100–20	1001	−60.8	13.5	2.9	8.0	8.1	1.3	1.7
30°S – 30°N		100–10	1469	−55.3	17.4	2.6	7.1	7.2	2.5	2.4
All seasons		100–5	1959	−49.9	23.1	2.6	6.4	6.1	3.6	3.8
		100–2	2646	−42.3	30.9	2.7	6.7	6.3	4.6	4.9
		100–1	3186	−37.0	34.9	2.6	7.0	7.0	5.0	5.0

Table 1a (cont'd)

Zone	Sample size	Layer mbar	Mean Thickness dam	Mean Thickness °C	S.D of thickness dam	S.D of thickness °C	Standard error of estimate dam TIROS N (SWR)	Standard error of estimate dam NOAA 6	Power (SD/SEE) TIROS N	Power (SD/SEE) NOAA 6
5	126	100–20	1031	–54.5	15.8	3.4	7.4	7.5	2.1	2.1
30° – 50°		100–10	1502	–50.5	21.2	3.1	6.4	6.4	3.3	3.2
summer		100–5	1995	–45.9	27.2	3.1	5.2	5.2	5.2	5.3
		100–2	2685	–38.9	36.6	3.2	5.4	5.3	6.8	6.9
		100–1	3228	–33.9	42.5	3.2	6.9	6.7	6.2	6.3
6	202	100–20	1068	–44.6	17.3	3.7	5.4	5.5	3.2	3.2
50° – 70°		100–10	1543	–44.5	29.7	4.4	5.5	5.6	5.4	5.3
summer		100–5	2037	–41.0	44.7	5.1	5.0	4.6	9.0	9.7
		100–2	2734	–34.6	65.0	5.7	4.8	4.6	13.4	15.2
		100–1	3286	–29.6	76.1	5.6	5.1	5.1	15.0	15.0
7	71	100–20	1083	–43.5	28.9	6.1	5.9	6.0	4.9	4.8
70° – 90°		100–10	1565	–41.1	44.8	6.6	5.9	6.2	7.6	7.3
summer		100–5	2069	–37.4	62.2	7.1	5.2	4.9	12.0	12.7
		100–2	2777	–30.8	88.4	7.7	4.9	4.7	18.2	18.8
		100–1	3340	–25.6	105.1	7.8	6.4	6.4	16.4	16.4

Table 1b. Retrieval statistics for simulated radiances in the processed data channels (HIRS 1, 2, 3 MSU 23, 24, SSU 25, 26 for TIROS N and SSU 27 for NOAA6). (Based on the historical rocket sample).

Zone	Sample size	Layer mbar	Mean Thickness dam	°C	S.D of thickness dam	°C	Standard error of estimate dam PCR TIROS N	PCR NOAA 6	SWR TIROS N	Power (S D/SEE) PCR TIROS N	PCR NOAA 6	SWR TIROS N
0	1200	100–20	1024	−56.0	36.5	7.7	4.3	4.0	3.8	8.5	7.7	9.6
unzoned		100–10	1487	−52.8	50.2	7.4	4.9	6.2	4.6	10.2	8.1	10.9
		100–5	1968	−48.9	68.2	7.8	5.8	5.5	5.4	11.8	12.3	12.7
		100–2	2641	−42.7	97.9	8.5	7.4	7.0	6.2	13.3	14.0	15.8
		100–1	3174	−37.9	121.8	9.0	9.0	10.2	8.8	13.5	12.0	13.8
1	64	100–20	982	−65.0	30.0	6.4	4.2	4.6	3.7	7.2	6.5	8.2
70° – 90°		100–10	1414	−63.5	45.6	6.8	6.1	7.2	5.4	7.5	6.4	8.4
winter		100–5	1861	−61.1	67.8	7.7	6.9	6.0	6.9	9.8	11.3	9.9
		100–2	2478	−56.9	101.7	8.9	10.9	6.0	9.5	9.3	16.9	10.7
		100–1	2963	−53.6	130.7	9.7	14.0	11.8	12.7	9.3	11.0	10.3
2	213	100–20	1022	−56.5	38.1	8.1	4.6	5.1	3.6	8.3	7.5	10.4
50° – 70°		100–10	1465	−56.0	55.1	8.2	5.1	6.8	5.0	10.8	8.1	10.9
winter		100–5	1920	−54.4	70.2	8.0	6.2	6.8	6.4	11.3	10.4	10.9
		100–2	2549	−50.7	88.0	7.7	9.2	8.4	8.0	9.5	10.5	11.0
		100–1	3048	−47.2	102.0	7.6	11.7	12.9	11.0	8.7	7.9	9.3
3	124	100–20	1012	−58.5	14.9	3.2	3.7	3.4	3.4	4.0	4.4	4.4
30° – 50°		100–10	1467	−55.8	21.1	3.1	3.5	3.3	3.4	6.0	6.4	6.2
winter		100–5	1932	−52.4	29.9	3.4	4.5	3.6	4.6	6.6	8.3	6.5
		100–2	2599	−46.4	43.1	3.8	5.7	4.5	5.8	7.6	9.5	7.5
		100–1	3125	−41.5	55.9	4.1	5.8	5.3	5.8	9.6	10.5	9.6
4	400	100–20	1001	−60.8	13.5	2.9	3.0	2.9	3.0	4.6	4.8	4.5
30°S – 30°N		100–10	1469	−55.3	17.4	2.6	3.2	3.0	3.2	5.4	5.8	5.4
All seasons		100–5	1959	−49.9	23.1	2.6	3.8	3.8	3.9	6.0	7.1	6.0
		100–2	2645	−42.3	30.9	2.7	4.5	4.0	4.5	6.9	7.8	6.8
		100–1	3186	−37.0	34.9	2.6	4.8	4.5	4.8	7.3	7.7	7.2

Table 1b. (Cont'd)

Zone	Sample size	Layer mbar	Mean Thickness dam	Mean Thickness °C	S.D of thickness dam	S.D of thickness °C	Standard error of estimate PCR TIROS N	Standard error of estimate PCR NOAA 6	Standard error of estimate SWR TIROS N	Power ($^{SD}/_{SEE}$) PCR TIROS N	Power ($^{SD}/_{SEE}$) PCR NOAA 6	Power ($^{SD}/_{SEE}$) SWR TIROS N
5	126	100–20	1031	−54.5	15.8	3.4	3.7	3.8	3.5	4.3	4.2	4.5
30° – 50°		100–10	1502	−50.5	21.2	3.1	3.7	3.6	3.5	5.8	5.9	6.0
summer		100–5	1995	−45.9	27.2	3.1	4.0	3.6	4.0	6.8	7.5	6.9
		100–2	2685	−38.9	36.6	3.2	4.2	4.0	4.3	8.7	9.0	8.6
		100–1	3228	−33.9	42.5	3.2	5.6	5.6	5.6	7.5	7.7	7.6
6	202	100–20	1068	−46.6	17.3	3.7	2.9	2.8	2.7	5.9	6.1	6.3
50° – 70°		100–10	1543	−44.5	29.6	4.4	3.7	3.5	3.5	8.1	8.5	8.4
summer		100–5	2037	−41.0	44.6	5.1	4.0	3.4	3.9	11.3	13.2	11.5
		100–2	2734	−34.6	65.0	5.7	4.6	3.9	4.4	14.1	16.7	14.6
		100–1	3286	−29.6	76.1	5.6	4.8	4.8	4.8	16.0	16.0	16.0
7	71	100–20	1083	−43.5	28.9	6.1	3.6	3.3	2.7	8.0	8.8	10.8
70° – 90°		100–10	1565	−41.1	44.8	6.6	5.5	4.1	5.1	8.1	10.9	8.7
summer		100–5	2069	−37.4	62.2	7.1	6.3	3.9	5.6	9.9	15.8	11.1
		100–2	2777	−30.8	88.4	7.7	4.2	3.3	4.9	21.3	26.7	18.2
		100–1	3340	−25.6	105.1	7.8	5.3	4.9	6.4	20.0	21.3	16.4

Table 2.

Comparisons of retrievals[1] made from coefficients applied to both the dependent sample (D) and an independent sample (I).

a) 3 SSU channels (unzoned retrievals)

Layer mbar	Mean Actual dam		S.D Actual dam		Bias dam		Error S.D dam		Power	
	D	I	D	I	D	I	D	I	D	I
100-20	1024.	1016.	38.0	34.4	0.0	-1.0	12.7	11.7	3.0	2.9
100-10	1487.	1477.	55.2	43.6	0.0	-0.1	8.4	7.7	6.6	5.7
100-5	1968.	1957.	74.7	55.7	0.0	-0.7	5.3	5.4	14.1	10.3
100-2	2641.	2629.	101.8	78.4	0.0	-1.2	7.4	7.0	13.8	11.2
100-1	3173.	3162.	125.8	93.7	0.0	1.5	9.9	9.2	12.7	10.2

b) 9 Processed channels (unzoned retrievals)

	D	I	D	I	D	I	D	I	D	I
100-20	1024.	1016.	38.0	34.4	0.0	0.1	4.4	4.5	8.6	7.6
100-10	1487.	1477.	55.2	43.6	0.1	0.0	4.7	4.5	11.7	9.7
100-5	1968.	1957.	74.7	55.7	0.1	-0.4	3.3	3.2	22.6	17.4
100-2	2641.	2629.	101.8	78.4	0.0	0.3	5.4	5.2	18.9	15.1
100-1	3173.	3163.	125.8	93.7	0.0	3.1	7.6	7.2	16.6	13.0

Note 1. Both the dependent and independent samples are based on simulated retrievals. The dependent set refers to the historical sample used to calculate the regression coefficients, while the independent set refers to the 'Met O 19 rocket catalogue'.

Table 3. List of channels from TIROS N and NOAA 6 which are received over the data link.

Channel	Instrument	Purpose[1]	Peak of Weighting function (mbar)	Wavenumber	Noise (K) Tiros N	NOAA 6	Data stream [2]
1	HIRS	Temperature	35	668.3	1.2	3.6	P
2	HIRS	Temperature	70	679.1	0.2	0.2	P
3	HIRS	Temperature	110	690.7	0.2	0.2	P
8	HIRS	Window	surface	899.6	-	-	P
9	HIRS	Ozone	-	1027.2	-	-	P
17	HIRS	Temperature	20	2359.1	0.9	0.9	P
23	MSU	Temperature	300	1.83	0.3	0.3	P
24	MSU	Temperature	90	1.93	0.3	0.3	P
25	SSU	Temperature	15	670.0	0.3	0.3	S & P
26	SSU	Temperature	5	669.6	0.4	0.4	S & P
27	SSU	Temperature	1.5	669.3	40. [3]	0.7	S & P

Notes

1. All temperature sounding channels have been used for retrievals. However HIRS 17 is no longer used due to a fluorescence problem.
2. P - Processed data stream; S - SSU data stream.
3. Now reduced to ~ 8 K.

Table 4

SSU Nadir corrections for TIROS N and NOAA 6 from 1) SSU data and 2) Processed data and 3) associated regression coefficients.

1) SSU data ie regression equation can use channels 25, 26 (and 27 NOAA 6)

Angle	Channel	Mean Difference	SD of Nadir Differences (R.V)	SEE for correction equ (RU) a) TIROS N	b) NOAA 6	Power:- SD/SEE a) TIROS N	b) NOAA
10^o	SSU25	0.10	0.04	0.01	0.01	3.4	5.1
	SSU26	0.13	0.04	0.01	0.01	3.6	18.1
	SSU27	0.10	0.04	-	0.01	-	3.5
30^o	SSU25	0.35	0.35	0.11	0.07	3.3	4.9
	SSU26	0.29	0.29	0.07	0.02	4.3	15.6
	SSU27	0.27	0.27	-	0.07	-	4.0

30^o

2) Processed data ie regression equation can use channels 1,2,3,23,24,25,26 (and 27 NOAA 6)

Angle	Channel	Mean Difference	SD of Nadir Differences (RU)	SEE for correction equ (RU) a) TIROS N	b) NOAA 6	Power:- SD/SEE a) TIROS N	b) NOAA 6
10^o	SSU25	0.10	0.04	0.01	0.01	12.4	13.2
	SSU26	0.13	0.04	0.01	0.01	8.4	17.2
	SSU29	0.10	0.04	-	0.01	-	3.1
30^o	SSU25	0.35	0.35	0.03	0.02	13.1	14.6
	SSU26	0.29	0.29	0.03	0.02	9.6	15.6
	SSU27	0.27	0.27	-	0.08	-	3.2

RU is a radiometric unit = $mW/(cm^{-1}\ sr\ m^2)$

3) Regression coefficients for NADIR corrections corresponding to tables 4.1 and 4.2
Both correction and channel variable are in $mW/cm^{-1} m^{2} sr$ (note 23&24 coefficients have been rescaled by 10^{-4})

Channel	Angle	Const	1	2	3	23	24	25	26	27	
Tiros N											
25	10	-.065	-	-	-	-	-	-.0079	0.0090	-	SSU data stream
26	10	0.049	-	-	-	-	-	-.0098	0.0092	-	
25	30	-0.534	-	-	-	-	-	-0.0596	0.0687	-	
26	30	0.319	-	-	-	-	-	-0.076	0.072	-	
25	10	.008	0.0	0.0	-0.0062	-0.0003	0.0	0.0003	0.0053	-	Processed data stream
26	10	-0.147	0.0	0.0	0.0	.0025	0.0	-0.0152	.0066	-	
25	30	0.310	0.0	0.0	-0.0455	-0.0053	0.0	0.0025	.0403	-	
26	30	-1.029	0.0509	0.0	0.0	0.0181	0.0	-0.1099	0.0576	-	
NOAA 6											
25	10	-.012	-	-	-	-	-	-0.0119	0.0171	-0.0048	SSU data stream
26	10	-.007	-	-	-	-	-	-0.0056	0.0006	0.0050	
27	10	0.017	-	-	-	-	-	0.0081	-0.0235	0.0153	
25	30	-0.106	-	-	-	-	-	-0.0901	0.1308	-0.0368	
26	30	-0.043	-	-	-	-	-	-0.0501	0.0195	0.0311	
27	30	0.112	-	-	-	-	-	0.0563	-0.1706	0.1137	
25	10	0.014	0.0	0.0	-0.0062	-0.0002	0.0	0.0	0.0061	-0.0005	Processed Data Stream
26	10	-0.015	0.0	0.0	0.0	0.0	0.0	-0.0054	0.0005	0.0052	
27	10	0.479	0.0334	0.0	0.0	0.0	0.0085	-0.0192	-0.0118	0.0	
25	30	0.258	0.0	0.0	-0.0457	-0.0035	0.0	0.0	0.0467	-0.0044	
26	30	-0.077	0.0	0.0	0.0	0.0	0.0	-0.0494	0.0192	0.0316	
27	30	3.107	0.2416	0.0	0.0	0.0	-0.0554	-0.1465	-0.0784	0.0	

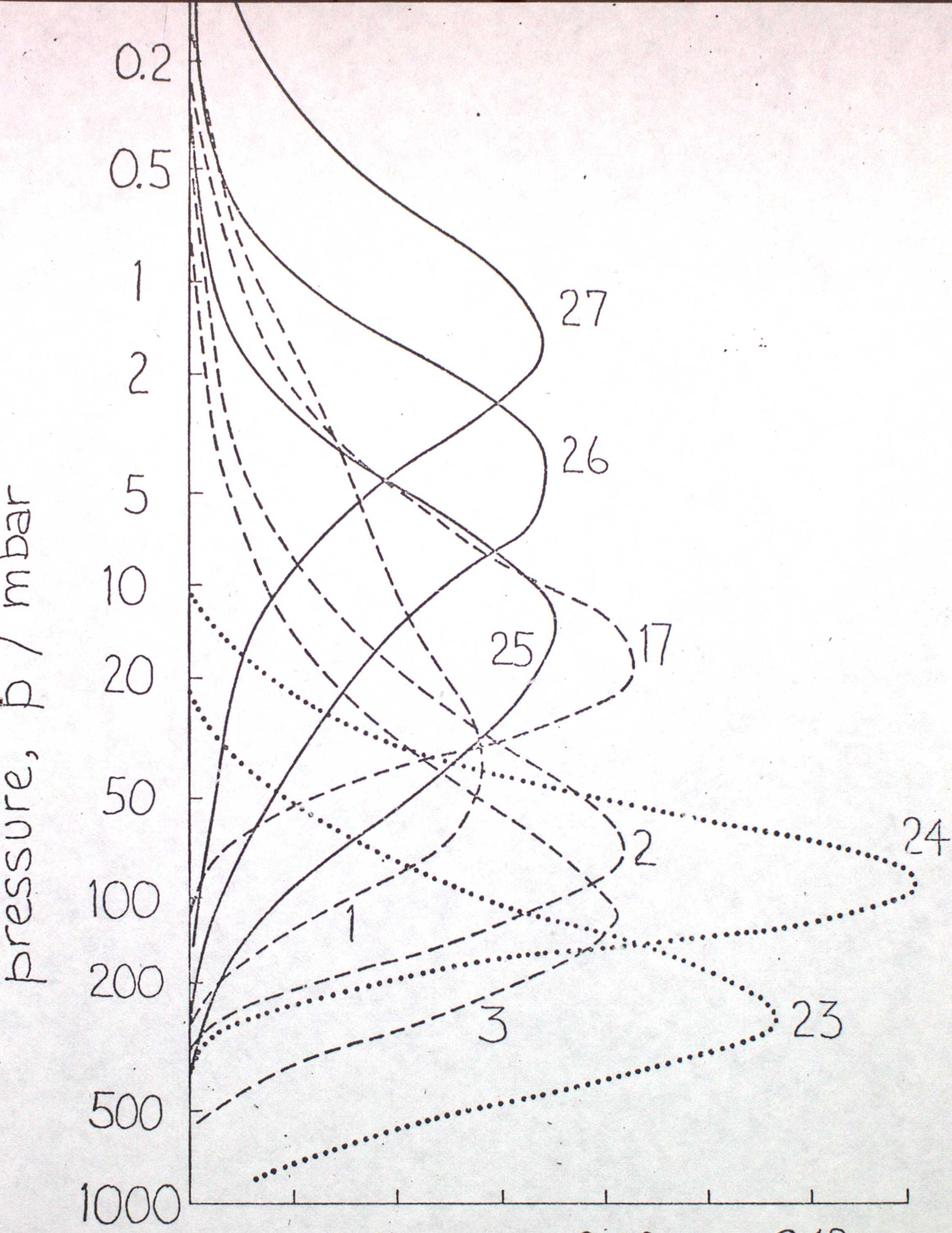
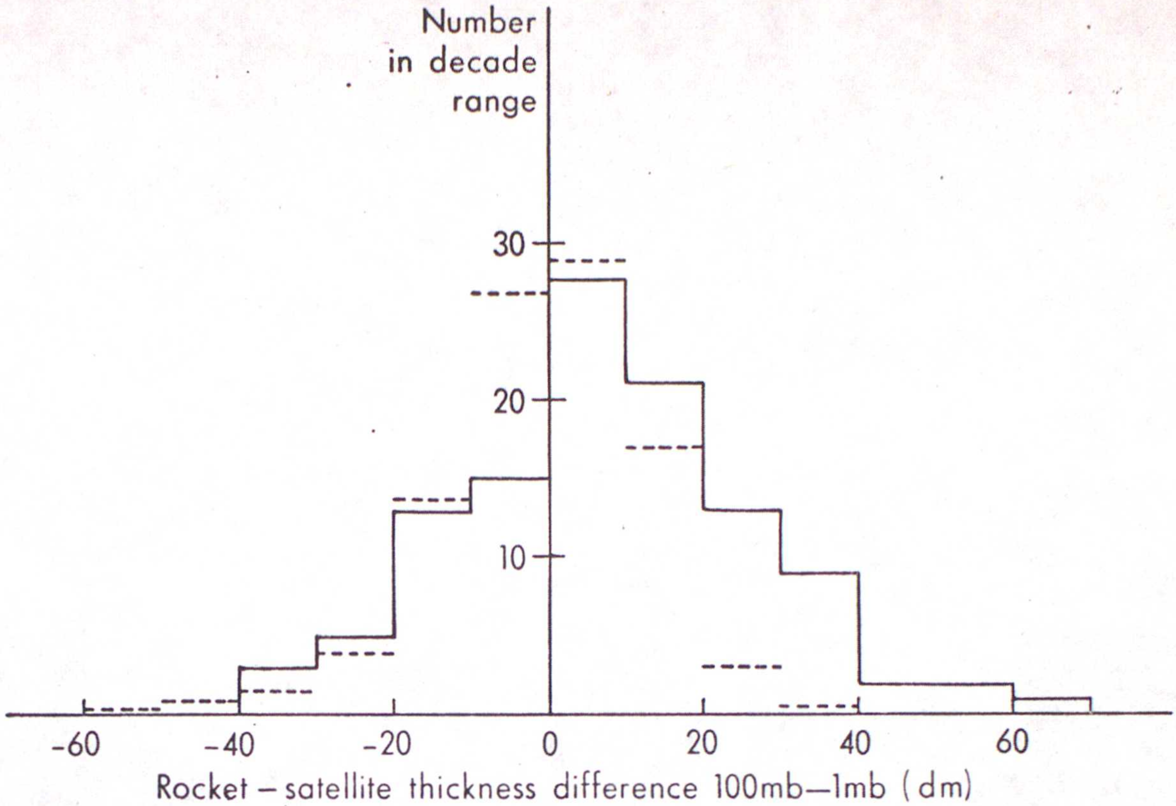


Figure 1. TIROS-N. Weighting functions appropriate to stratospheric retrievals



—— Tiros N collocated set

----- Basic atmosphere statistics set and simulated retrievals (scaled)

	Mean	s.d.
——	8.	19.
----	0·3	14.

Figure 2 Histogram of 100mb—1mb rocket/satellite derived thickness

Data has been screened to collocations within 125km and ± 12hr; dynamic situations, tight gradients and Russian profiles have been removed

Retrievals used zoned coefficients for 2 SSU channels