MET O 19 BRANCH MEMORANDUM No. 101

THE EFFECT OF SPATIAL COLOCATION ERROR ON LASS MONITORING AND PERFORMANCE

by

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October 1989

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1. Introduction

The radiosonde colocation system operated as a part of LASS serves two distinct purposes. Firstly it monitors the accuracy of the retrieval and, importantly, compares that accuracy with that of the forecast background used to constrain the retrieval. Secondly, it is used to obtain error covariances, **E** , of the measured brightness temperatures and, **C** , of the forecast background. It is known (Watts and McNally, 1988) that correct specification of error covariances is important for the successful operation of LASS.

In order that colocations are obtained frequently enough for useful statistics (monitored approximately monthly) the allowable space and time windows are set fairly wide, at 150 Km and 3 hours respectively. That this window potentially allows significant contributions to the perceived measurement and background errors is demonstrated by Kitchen (1989). He finds that radiosondes separated by 52 Km give measured temperature profiles with a standard difference of order 0.5 – 1.0 K; at 220 Km the difference is order 2.0 K. Values around 1.0 K are typical for 4 hour time separation.

The background and retrieval 'errors' that LASS measures with the colocated radiosondes are typically between 1.5 and 3.0 K, the higher values being appropriate to near surface and tropopause levels. Similarly, measurement errors lie between 0.6 and 3 K, high values being associated with more transparent channels (weighting functions peaking near surface) and channels with large radiance contributions from the stratosphere or water vapour, neither of which are measured well with the sonde.

It is probable then, that colocation errors are responsible for a significant amount of the observed variance in radiosonde – measurement differences. This affects both functions of the colocation system.

Provided the colocation error, E_c, is independent of the true error in the profile, E_p, whose accuracy we are measuring (i.e. the background, retrieval or measurement vector), then the difference measured by the colocation system, $\hat{E}_p$, is given by;

$$\hat{E}_p^2 = E_p^2 + E_c^2$$

Thus for two profiles, $p1$ and $p2$,

$$\hat{E}_{p1}^2 = E_{p1}^2 + E_c^2\ , \quad \hat{E}_{p2}^2 = E_{p2}^2 + E_c^2$$

And therefore,

$$\hat{E}_{p1}^2 - \hat{E}_{p2}^2 = E_{p1}^2 - E_{p2}^2$$

Thus the true difference in error variance of two profiles is preserved if an independent colocation error (which is the same for each profile) is present. However, the traditional measures of success; difference of retrieval and background standard deviations, $\hat{E}_{ret}$ and $\hat{E}_{bck}$, and FUV, $\hat{E}^2_{ret}/\hat{E}^2_{bck}$, are both less sensitive with colocation error present. A further consideration is that E_c may well be different for retrievals and backgrounds if these have different horizontal variabilities.

More serious effects might be felt with the estimation of measurement and background error covariances since here the absolute values are required, not differences. In this case E_c^2 will be the error in our estimated background covariance.

2. Removal of spatial error

Why not use the results given by Kitchen to gauge the effect of colocation error and remove it from our measured statistics? There are several reasons why this would be unsatisfactory;

(a) Radiosonde/radiosonde colocations will have different error characteristics from radiosonde/satellite or radiosonde/forecast colocations because of the different sampling and horizontal and vertical resolutions of the three types of profile. E.g. a satellite radiance field will have less horizontal and vertical structure than a radiosonde 'field' and may consequently be expected to have lower colocation errors.

(b) The correlation of errors found important to the retrieval process are not discussed by Kitchen and, anyway, would be unrepresentative for the reasons given in (a).

(c) Kitchen's results are derived from U.K. sondes only and this sample may not be sufficient to describe the wider climatology appropriate to LASS.

This study uses archived colocation data sets from LASS over the periods Sept–Nov 1987 and Jan–May 1989. It attempts to estimate the effects of the spatial colocation error by analysing the retrieval (or background or measurement) field and interpolating (or extrapolating) this to the radiosonde location. No attempt has been made to remove the temporal colocation error, representativeness errors or errors intrinsic to the sonde measurement. The analysis is made using a recursive filter (Hayden and Purser, 1986) on the 3–10 retrievals colocated in the normal way with the sonde. Sondes with less than 3 retrievals are not considered since it is inappropriate to try to obtain a two dimensional field from one or two measurements. Equal weight is given to all soundings (except those with gross errors) since current colocation statistics take no account of the available confidence measures. Generally the radiosonde lies within the area defined by the soundings.

An example is given in figure 1 of the 850 mb retrieved temperature field. Figure 1a shows the observations about the radiosonde and the contoured analysis is hand drawn. Figure 1b is the field analysed by the recursive filter and contoured again by hand. That the two analyses are similar is indicative that the automatic analysis is working adequately. Further such subjective tests on different atmospheric levels were made but no objective measure of the filter's effectiveness was carried out. Doubtless filter parameters (principally smoothing radii) could be optimised for each level and particular care would be needed with humidity fields, but the above tests were deemed sufficient for this study.

'Analysed' colocation statistics were obtained by differencing the sonde temperatures with the values of the analysed field at the sonde location.

3. Results

3.1 Effect on monitoring statistics

The effect of the analysis procedure on background (forecast) – sonde differences is shown in figure 2. The dashed line shows the standard deviation as a function of pressure of the sonde background difference. The dot-dash line shows the results without analysis, i.e. the conventional colocation procedure. The solid line shows, for interest, the background error currently assumed in the retrieval process. The analysed errors are consistently 0.2 K less than the colocated errors up to about 250 mb. Above this there is little difference between the methods, perhaps because of less horizontal structure in the fields at this height. Figure 3 repeats these results and shows also the retrieval errors. A similar reduction in error to that of the background can be seen.

We can calculate the colocation error implied by these results;

$$E_c = \sqrt{E_{NA}^2 - E_{AN}^2}$$

where $_{NA}$ indicates no analysis or colocation method and $_{AN}$ indicates analysis method results. Figure 4 gives values derived using results from retrievals and backgrounds. The implied colocation error is approximately 1.5 K at the surface decreasing to around 0.5 K at high levels. There is some indication that it is higher for the retrieved profiles at and below 700 mb, implying there may be higher spatial variability in the retrieved fields at these levels.

Also plotted in figure 4 are the sonde–sonde colocation errors given by Kitchen for 52 Km separation. The values are consistent with our results up to 250 mb above which there is some discrepancy; the general agreement is reassuring. Kitchen's high value at 200 mb may be the large error incurred by having the wrong tropopause pressure, an effect that will be smaller with the lower vertical resolution soundings.

Kitchen also gives about 1 K colocation error for a 3 hour time separation (LASS mean separation is < 3 hours) and it is likely that such errors will also appear to some extent in our statistics. Spatial and temporal colocation errors are likely to be correlated and the total effect may be less than that of a simple addition. However, the total could be as large as 1.5 K which is comparable to the total error observed. While there is no 'daylight' between retrieval and background statistics this addition of colocation error is not important. However, the significant event of retrieval accuracy bettering background accuracy will be harder to detect if colocation error continues to contaminate the statistics.

As demonstrated the spatial colocation error is relatively easy to remove and it is recommended that this is done. The temporal error is less tractable and would need either a redesign of the colocation software with additional T+12 sondes saved, or possibly some tendency factors from the forecast model. The latter is not so difficult since the forecast is already time interpolated to the satellite overpass and so the gradient of the fields with time is known over the 3 hour period around the satellite pass. This could be used to correct the fields at satellite time to radiosonde time.

3.2 Effect on error covariances

The extension of the analysis method described above to calculate covariances is trivial and an estimated **C** matrix (background error covariance) was obtained. Similarly, measured brightness temperatures were analysed and interpolated to the sonde location and compared to brightness temperatures calculated from the sonde to give the **E** matrix.

3.2.1 Background error covariance

The difference between colocated and analysed versions of the background covariance are effectively shown in figure 2 which gives the square-roots of the diagonals of **C** . The question of whether the analysed **C** is significantly different to the colocated version in the retrieval context is addressed by a sensitivity analysis (see Watts and McNally, 1988). The sensitivity of the retrieval accuracy to incorrect specification of **C** is found and also the accuracy that would be obtained if the 'correct' **C** was to be used. Results are shown in figure 5. The solid line is the expected retrieval accuracy with the colocation **C** . The dashed line is the accuracy expected if the background errors are in reality described by the analysis **C** but the retrieval assumes the colocation version. Except in the stratosphere, retrievals with backgrounds described by the analysis **C** are better than expected with the colocation **C** . This is not surprising as the 'data' are more accurate than expected. The real question is whether there is a significant benefit in using the analysis **C** in the retrieval and this is shown by the dotted line. Clearly the effect is marginal and we may conclude that there is no urgency to obtain and use analysed matrices. Of course, removal of temporal and other colocation errors may increase the effect but it is likely to remain small (especially when it is noted that simulated effects are rarely found fully with real data).

3.2.2 Measurement error covariance

Analysed **E** matrices were derived separately for clear and MSU-regression type FOVs (Eyre and Watts, 1987) since we know the error characteristics are significantly different. N^* FOVs were too sparse and infrequent to allow good statistics in this limited study. At least three soundings of the appropriate cloud-clearing route in the vicinity of a sonde were required and only these FOVs were analysed and used in the statistics. The square-roots of the diagonals of the matrices obtained are shown in figures 6a and b, alongside the values for colocated measurements. The abscissa is ordered in channel with window channels to the left, rising through the atmosphere to stratospheric channels to the right (a prefix 'M' indicates an MSU rather than a HIRS channel). Water vapour channels 10,11 and 12 are shown extreme right. Figure 6a shows that analysed clear FOV data have significantly lower errors than colocations in low peaking channels (up to channel 7 or 6) and slightly higher errors in the stratospheric channels (cause unknown). The implied colocation error in low channels is around 1 K. With the MSU-regression FOVs, figure 6b, there is a slight reduction in error for low channels and little change for the higher.

The difference of the effect of analysis between clear FOVs and MSU-regression FOVs probably reflects the horizontal resolution of the different data. Clear FOVs have genuine HIRS data with resolution $\approx$ 40 Km, whereas the HIRS data in MSU-regression is obtained from the MSU with ground resolution $\approx$ 170 Km. Since the colocation maximum is 150 Km we may expect little effect of analysing MSU data.

Retrieval sensitivity studies were made using these covariances and results are shown in figures 7a and b. The significance of the lines is as in figure 5 with the difference between the dotted and dashed lines representing the gain possible if the analysed **E** matrices were used instead of the colocated version in the retrieval. The clear FOV cases show some improvement at mid and low levels (figure 7a) whereas the MSU cases are little affected. This is consistent with the changes to the matrices noted above.

Again we may expect temporal colocation errors to be significant, in all types of FOV not just clear, and the effect on retrieval errors to be similar. The method of using model tendencies to interpolate fields to the sonde time could be extended to brightness temperatures, but at some computational expense.

4. Summary

An analysis method was used to reduce the error introduced in colocation statistics by the spatial separation of the radiosonde and the sounding. The error removed was of a size (order 1 K) that compared well with other work (Kitchen 1989) and this suggests the method is largely successful. The reduction in colocation error was very similar for both the forecast background and retrieved profiles but with some indication of a larger effect at low levels in the retrieval. Alone, the spatial colocation error appears to be sufficiently small not to cause seriously misleading statistics. However, if temporal or representativeness errors or both are of similar magnitude, the combined effect may be large enough for this not to be the case. The same conclusions appear to hold for the background covariance used in the retrieval, except that the simulated effect on retrievals is very small and even with all error sources may not become important.

Only in the case of measurement error in clear FOVs do we find a significant simulated effect on retrievals. On the lower resolution MSU FOVs there is no significant simulated retrieval improvement. Temporal colocation errors might be expected to affect all cloud-clearing routes equally and be of the same order as the spatial effects on clear FOVs. There therefore appears to be scope for small gains to be made in the specification of measurement covariances.

REFERENCES

Eyre J.R. and Watts P.D. 1987: A sequential estimation approach to cloud-clearing for satellite temperature sounding. *Q.J.R.Meteorol.Soc.*, **113**, *pp.1349-1376.*

Kitchen M. 1989: Representativeness errors for radiosonde observations. *Q.J.R. Meteorol.Soc.*, **115**, *pp.673-700.*

Hayden C.M. and Purser J.C. 1986: Applications of a recursive filter, objective analysis in the processing and presentation of VAS data. *Tech. Proc. Second Conference on Satellite Meteorology/ Remote sensing and Applications, May 13-16, 1986, Williamsburg, Va. Pub. American Met. Soc., Boston, Mass.*

Watts P.D. and A.P. McNally 1988: The sensitivity of a minimum variance scheme to the values of its principal parameters. *Tech. Proc. 4th Int. TOVS Study Conf.; Igls, Austria; 16-22 March 1988; Report of CIMSS, University of Wisconsin-Madison; Ed.: W.P. Menzel; pp. 399-412.*

FIGURE 1a.

RETRIEVED 1000 mb TEMPERATURE: SUBJECTIVE

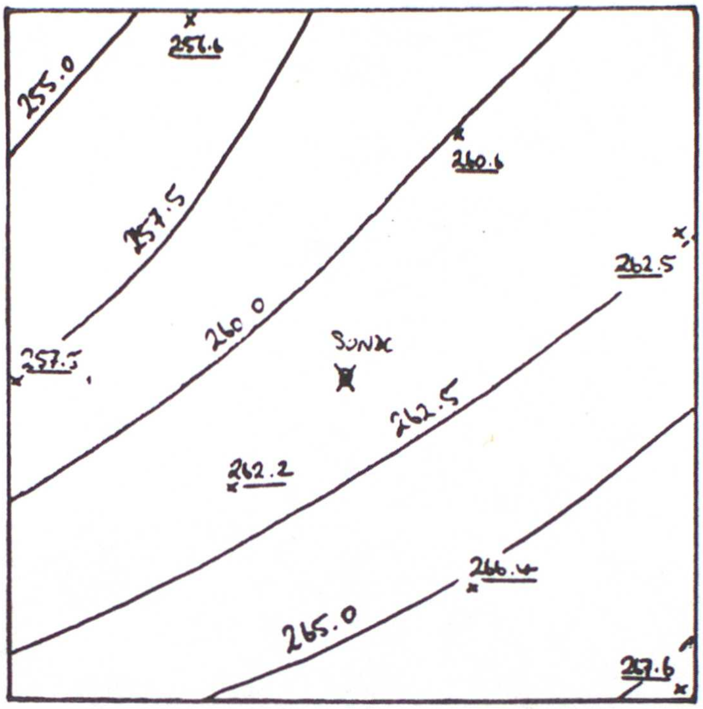


FIGURE 1b

RETRIEVED 1000 mb TEMPERATURE: OBJECTIVE

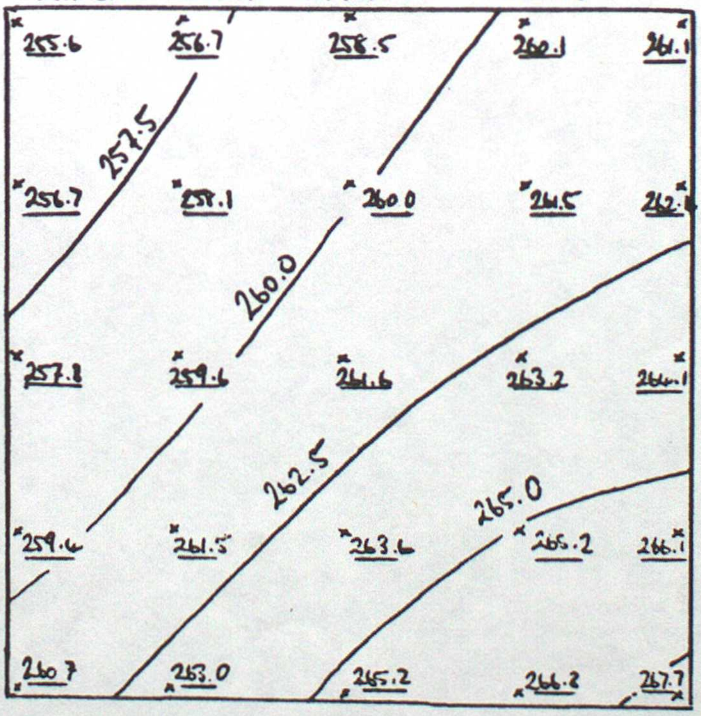


Figure 2

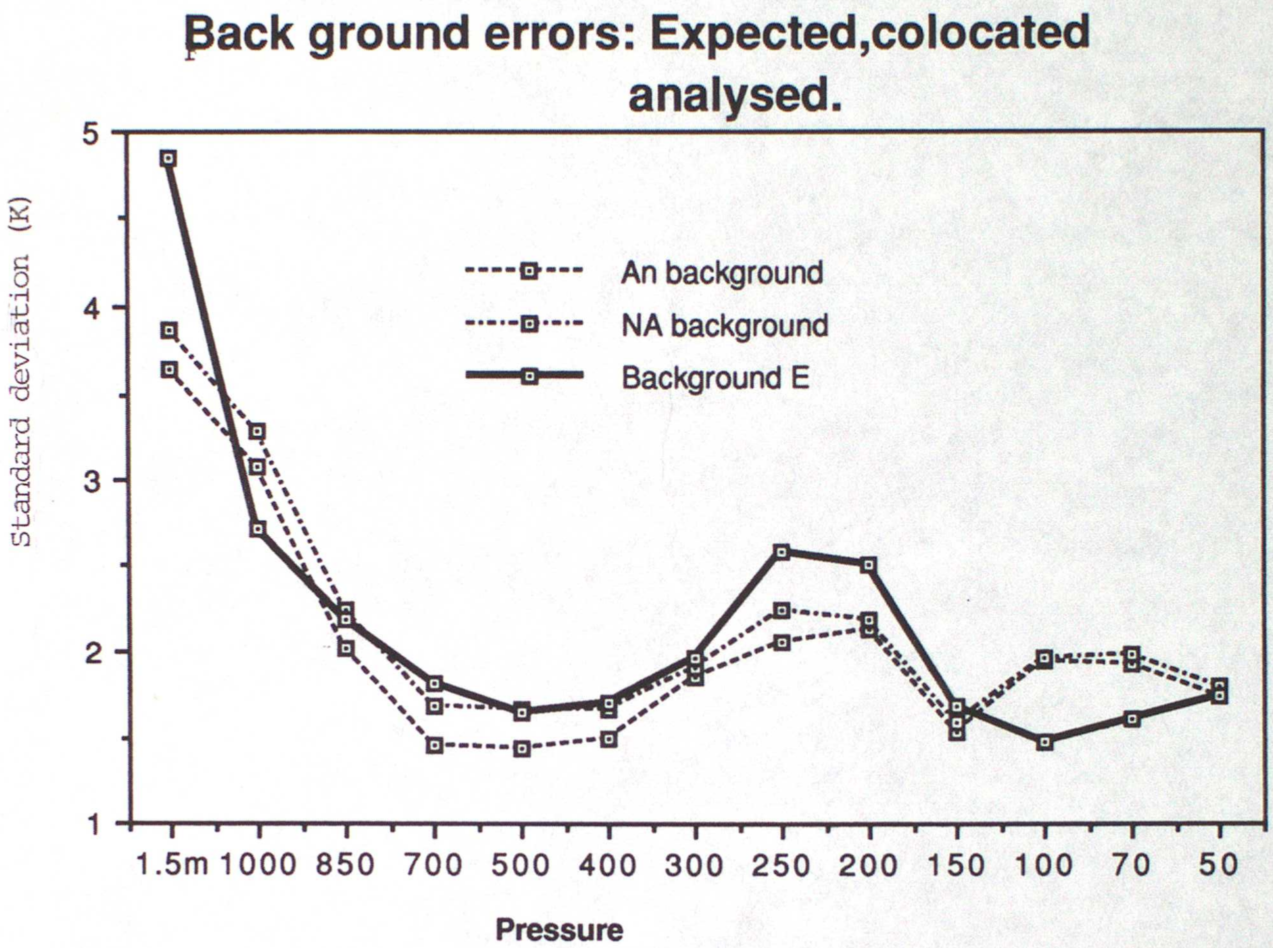

Back ground errors: Expected,colocated analysed.
Standard deviation (K)
5
4
3
2
1
An background
NA background
Background E
1.5m
1000
850
700
500
400
300
250
200
150
100
70
50
Pressure

Figure 3

Retrieval and Background errors: Analysed to sonde, colocated to sonde FFG

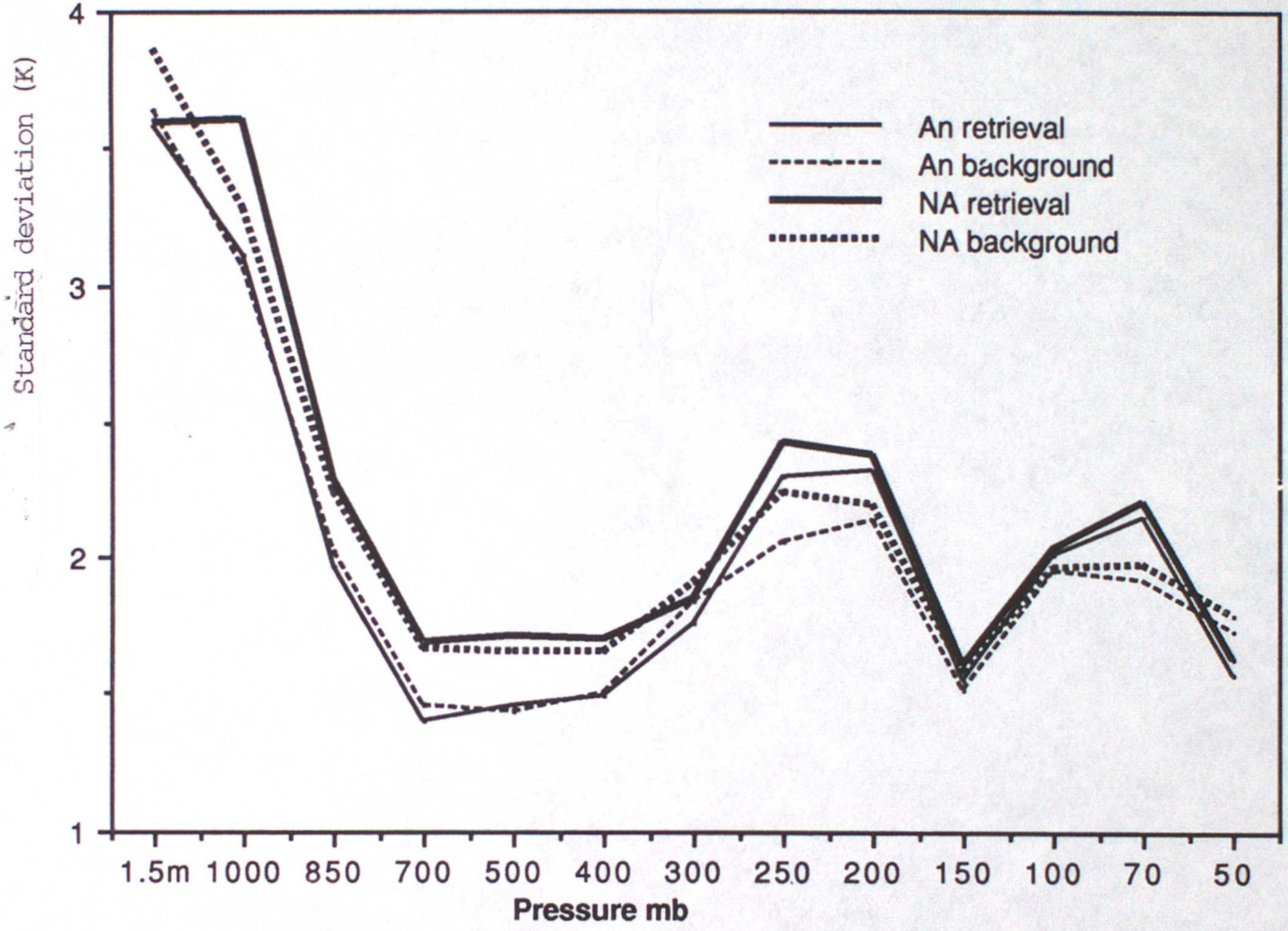


Figure 4. Spatial colocation errors from Kitchen (@52Km) and implied by background and retrieval errors

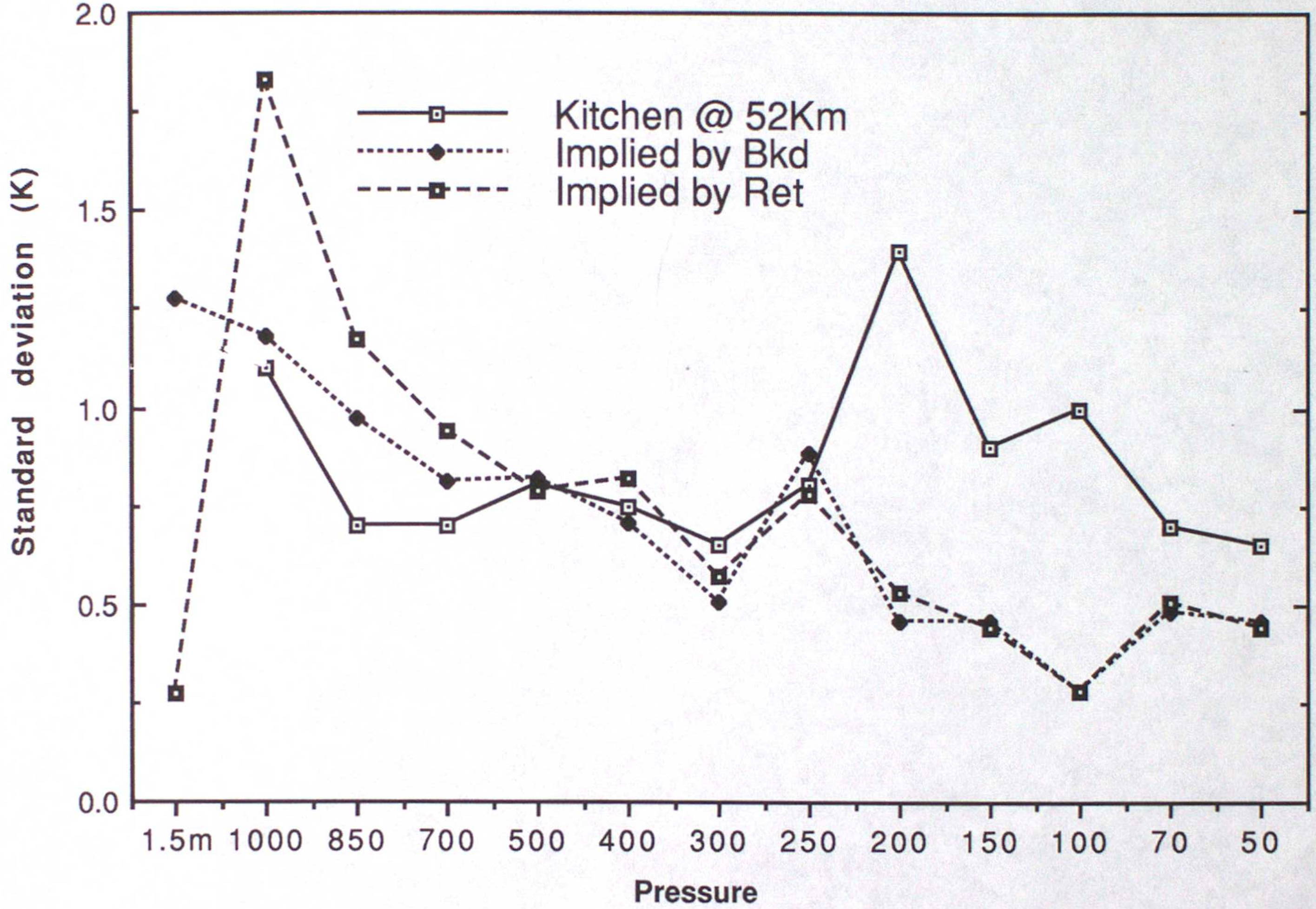


Figure 5

TOVS RETRIEVAL ERROR STATISTICS: SIMULATION

SIMULATED RETRIEVAL STATISTICS:

(SEE TEXT FOR KEY)

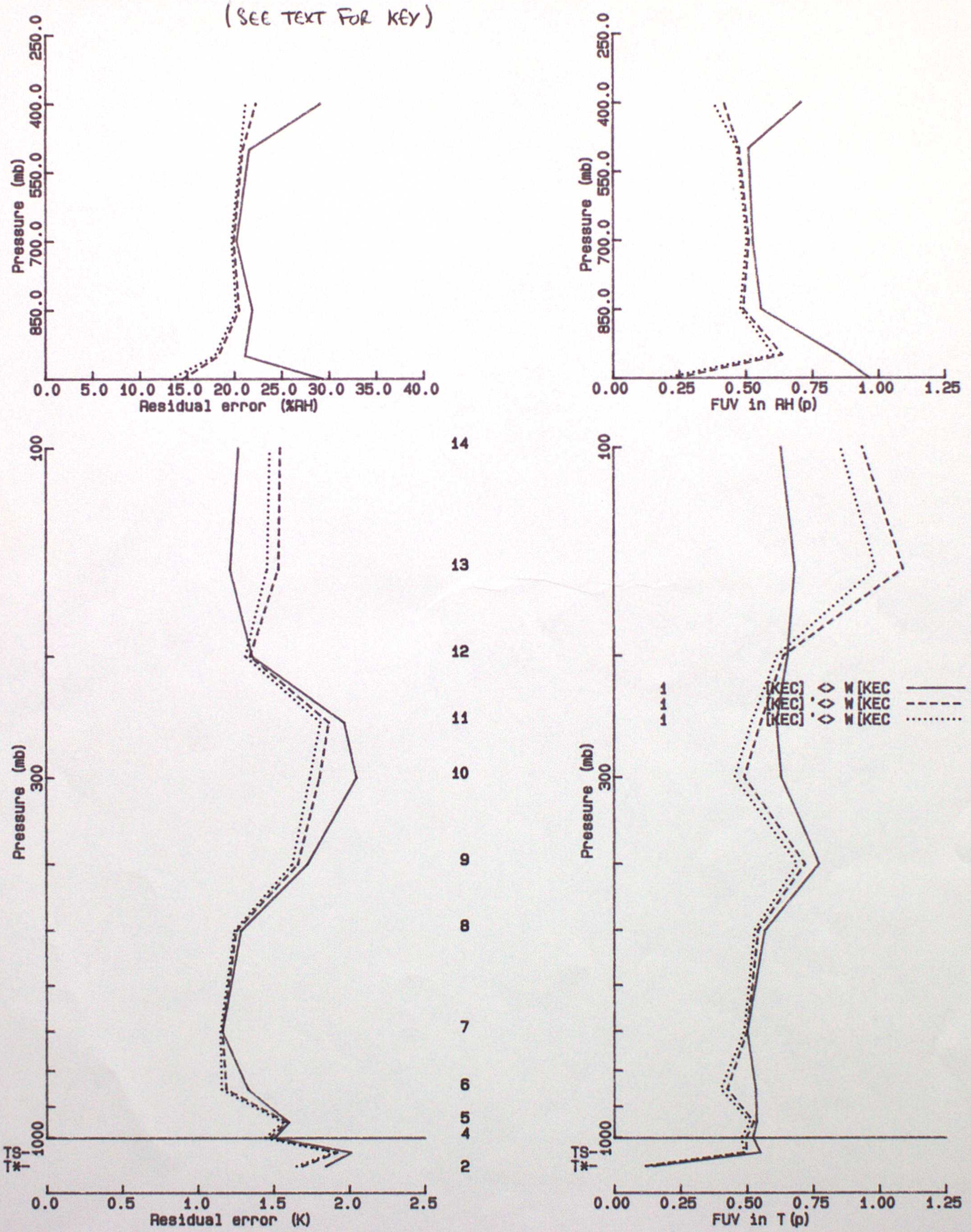


Figure 6a

MEASUREMENT ERRORS: ANALYSED AND COLOCATED: CLEAR

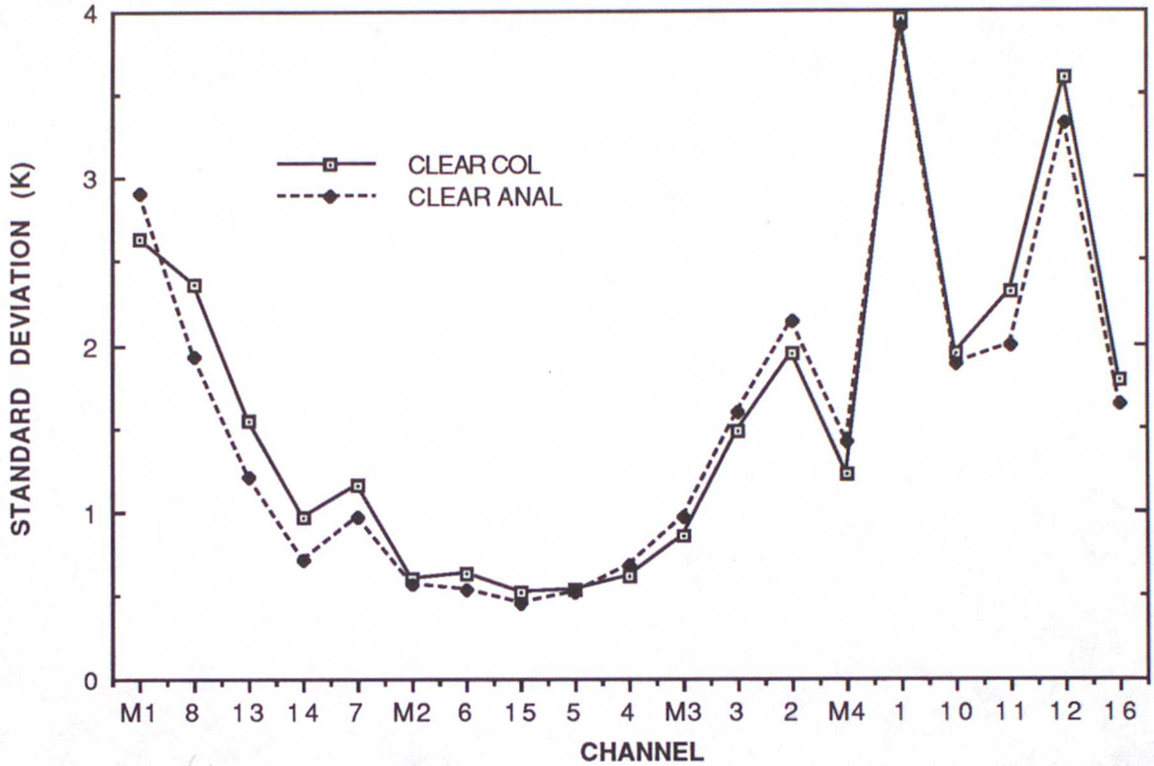
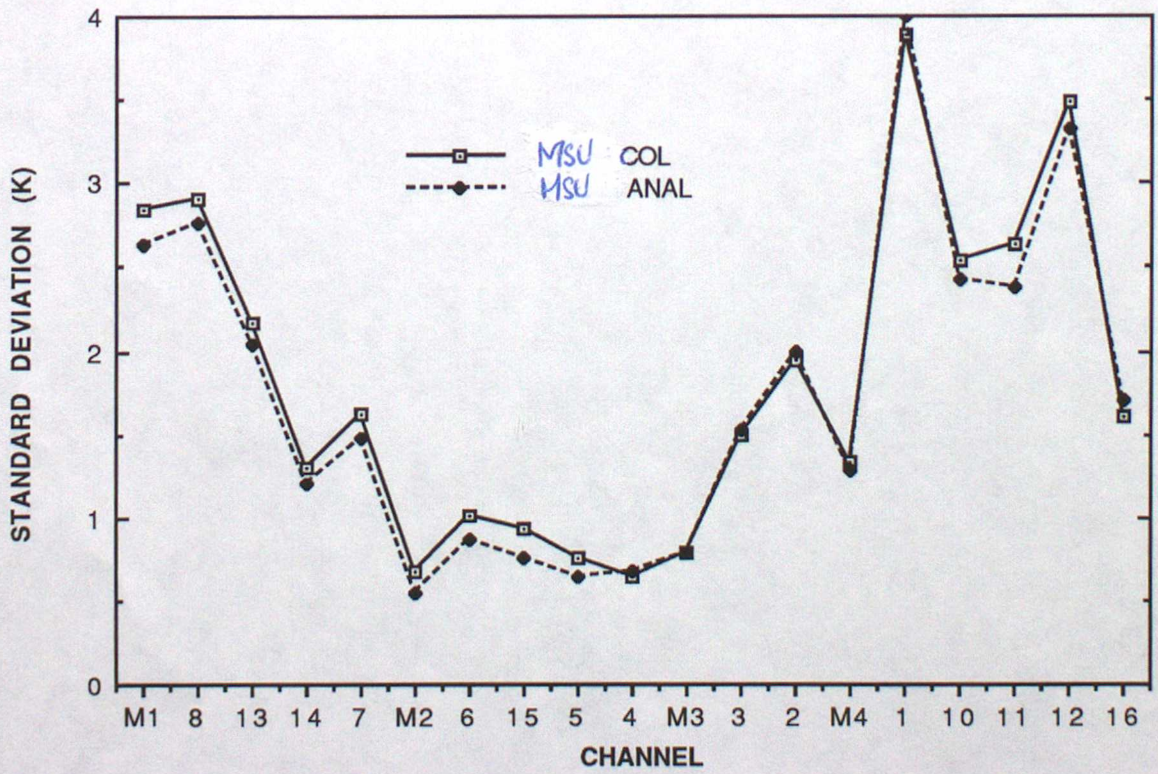


Figure 6b

MEASUREMENT ERRORS: ANALYSED AND COLOCATED: MSU REGRESSION



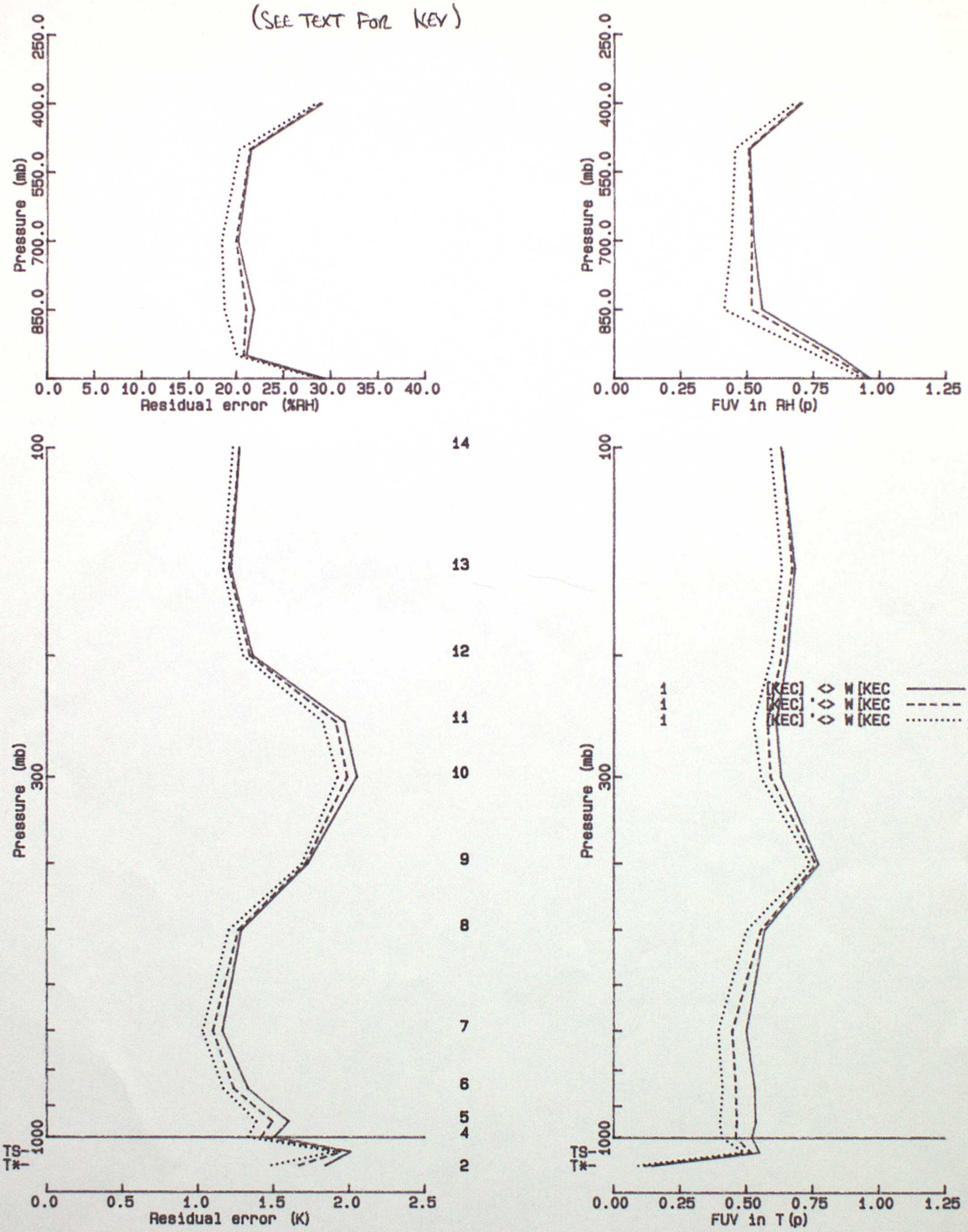
7a

Figure 7a

TOVS RETRIEVAL ERROR STATISTICS: SIMULATION

SIMULATED RETRIEVAL STATISTICS: CLEAR FOV

(SEE TEXT FOR KEY)



7b

Figure 7b

TOVS RETRIEVAL ERROR STATISTICS: SIMULATION

SIMULATED RETRIEVAL STATISTICS: MSU FOVs

(SEE TEXT FOR KEY)