DC-8 MTP Calibration for SOLVE-2

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Abstract

The Jet Propulsion Laboratory (JPL) Microwave Temperature Profiler (MTP) was the only instrument making temperature measurements at and below flight level on the DC-8 during the SOLVE-2 campaign. Many years of careful comparison of MTP measurements with radiosondes near the DC-8 flight track have shown that the flight level temperature can be determined to an accuracy of 0.2 K relative to radiosondes. However, the noise on a single measurement is 0.5 K, so several MTP data cycles must be measured to achieve this 0.2 K potential accuracy. Since the DC-8 generally flew above, but near, the tropopause during SOLVE-2, the MTP observations will be a valuable source for accurate lower stratospheric temperature validation of satellite sounders. They can also be used to validate the tropopause height accurately. Because of the enormous temperature variability during the arctic winter, we have introduced a new analysis strategy, which has greatly improved the accuracy of the MTP retrievals. We have also developed an algorithm to avoid reporting tropopause solutions in cases where the WMO tropopause definition is not valid. The DC-8 MTP temperature calibration and new analysis techniques will be explained in this paper.

A New MTP Retrieval Algorithm

- Calculate retrieval coefficients (RCs) at all DC-8 flight levels flown during the campaign to minimize temperature profile interpolation errors

- Use radiosondes (RAOBs) launched near the DC-8 flight track as templates for selecting the several hundred additional soundings needed to calculate a set of RCs. This ensures that the actual atmospheric conditions are reflected in the RC sets, which totaled nearly 50 for the campaign. It also produces much better retrievals at larger distances from the DC-8 where the MTP does not receive many photons (see Figure 2).

- Modify the quality metric that compares MTP measurements to each RC set of archive average observables to put more emphasis on the variation of the shape of the measurements with elevation angle, and less emphasis on the bias.

- Correct the bias contribution, which has a second order effect on the oxygen absorption coefficient, by using a sensitivity matrix to get into the temperature regime of the RC set which best matched the shape of the MTP measurements with elevation angle.

- After performing the retrieval, bias the profile back to measurement space.

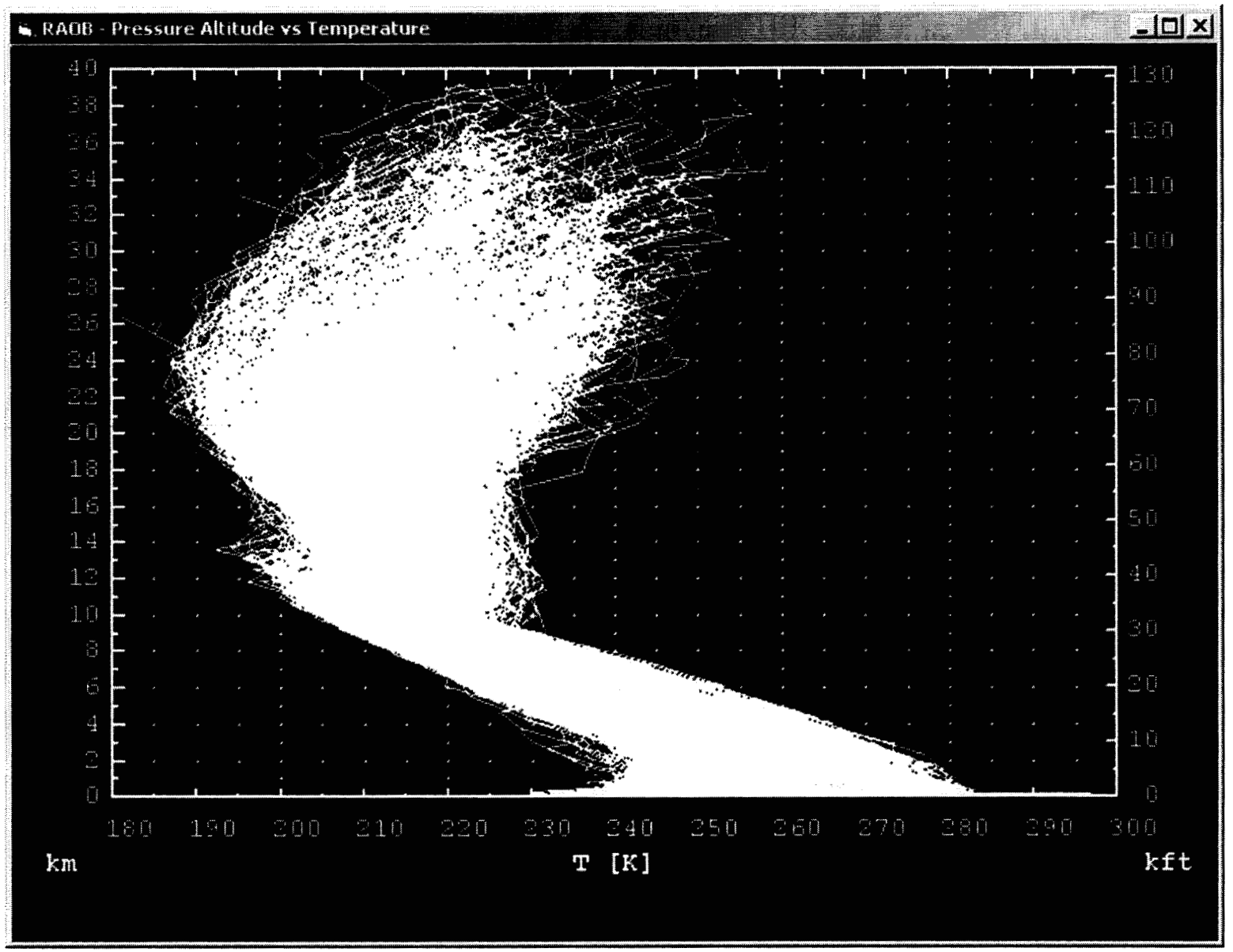


Figure 1. A composite of ~2000 radiosondes launched in the European Arctic during SOLVE-2. Notice the huge temperature variability over the course of just one month.

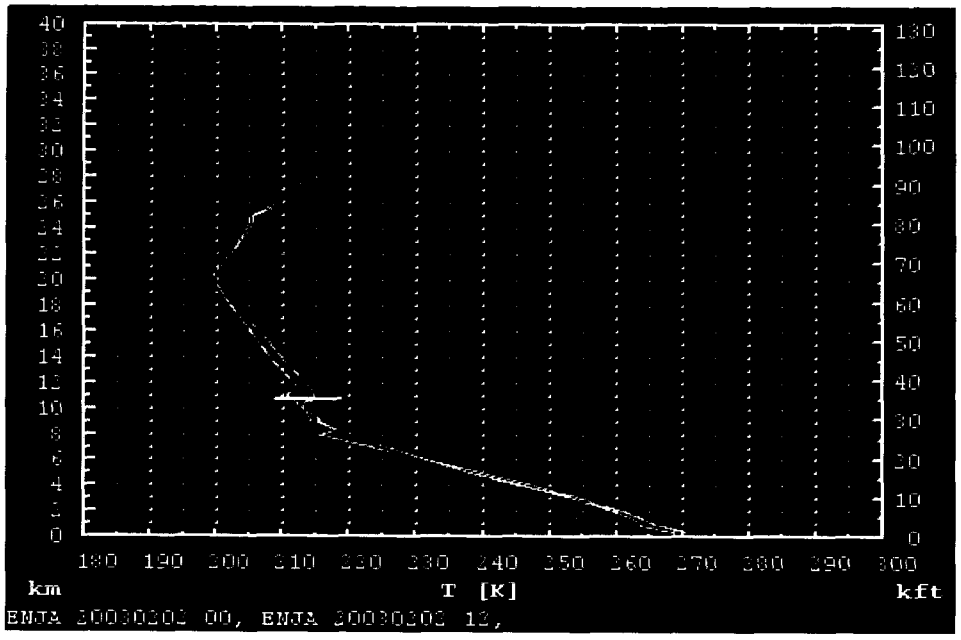
How Retrieval Coefficients Were Calculated

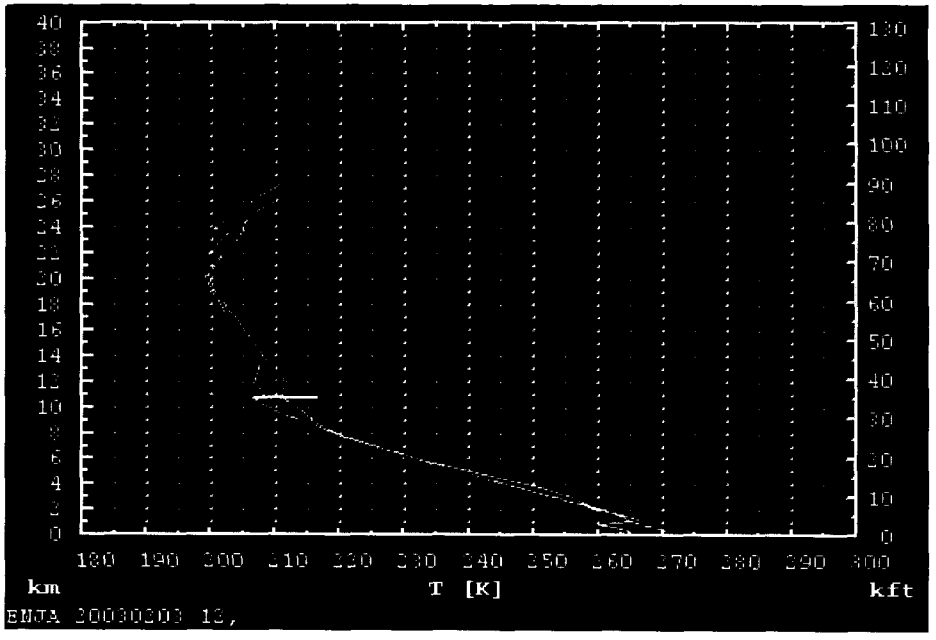
To convert the raw brightness temperatures measured by the MTP into temperature profiles, it is necessary to calculate retrieval coefficients (RCs). A decade ago, we would simply take hundreds of archived Arctic radiosondes (RAOBs) and calculate a single set of RCs for a campaign. The problem with this approach is that the formal retrieval errors are substantial at moderate distances from flight level because of the huge dispersion in the RAOB profiles (see Figure 1).

During the first SOLVE campaign, we attempted to minimize the formal retrieval errors by separating the RAOBs into temperature bins at a nominal flight altitude. This worked well for the ER-2, but was less successful for the DC-8 because there is much more temperature structure near the much lower DC-8 flight altitudes.

For SOLVE-2 RC calculations we used RAOBs launched near the DC-8 flight track as templates for selecting additional RAOBs to calculate RCs (Figure 3). This worked very well. Although the MTP doesn't measure many photons beyond ± 6 km, the range of accurate retrievals was much greater than in the past when within several hundred kilometers of a RAOB site.

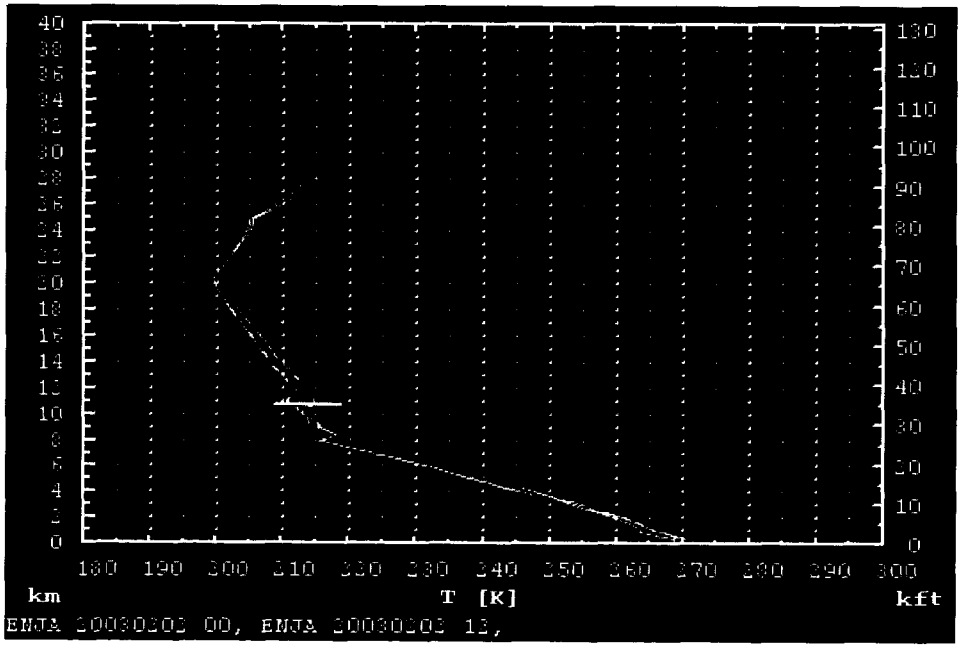
Nearly 50 sets of RCs were calculated to represent all the temperature profile shapes encountered during SOLVE-2. With so many RC sets to choose from, it was generally the case that the archive average observables of several sets might match the measurements quite well. However, by using an information content metric, it was always the case that, when near a radiosonde site, the RCs based on the template sonde were selected.





Retrievals 144 km from ENJA w/o (above) & with (below) ENJA-based retrieval coefficients

Retrievals 15 km from ENJA w/o (above) & with (below) ENJA-based retrieval coefficients



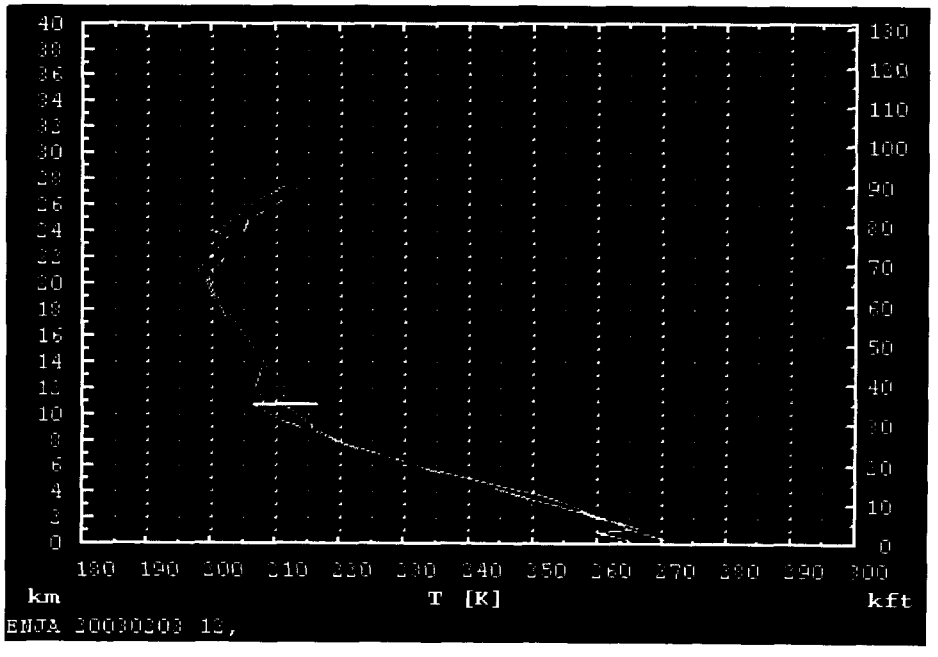


Figure 2 shows how the new method of selecting RCs to perform retrievals can improve the accuracy of the retrieval at large distances from flight level (white horizontal line at ~10 km) when near a radiosonde launch site. The pink profiles are the MTP retrievals, and the yellow traces are the radiosondes launched before and after the DC-8 flew near the island of Jan Mayen (ENJA) on 2003.02.02.

The left two panels show retrievals performed 144 km from the island. For the upper panel retrieval, a RC set was used that was not based on the ENJA soundings for this day. It does a poor job of matching the soundings above 20 km. The lower panel, on the other hand, did use an RC set based on the ENJA sounding. We believe that the warm bias above 18 km is real.

The two right panels show retrievals performed 15 km from the island. Even though the upper panel does not use a RC set based on the ENJA soundings, it does an excellent job. The lower panel is almost identical to the upper panel, but careful examination shows that it does a little bit better at ~26 km. Since both retrievals near the island did so well, it supports the suggestion that the ~ 2 K warmer temperature at ~20 km in the left, lower panel is real. Such a change is consistent with expected temperature gradients over 144 km.

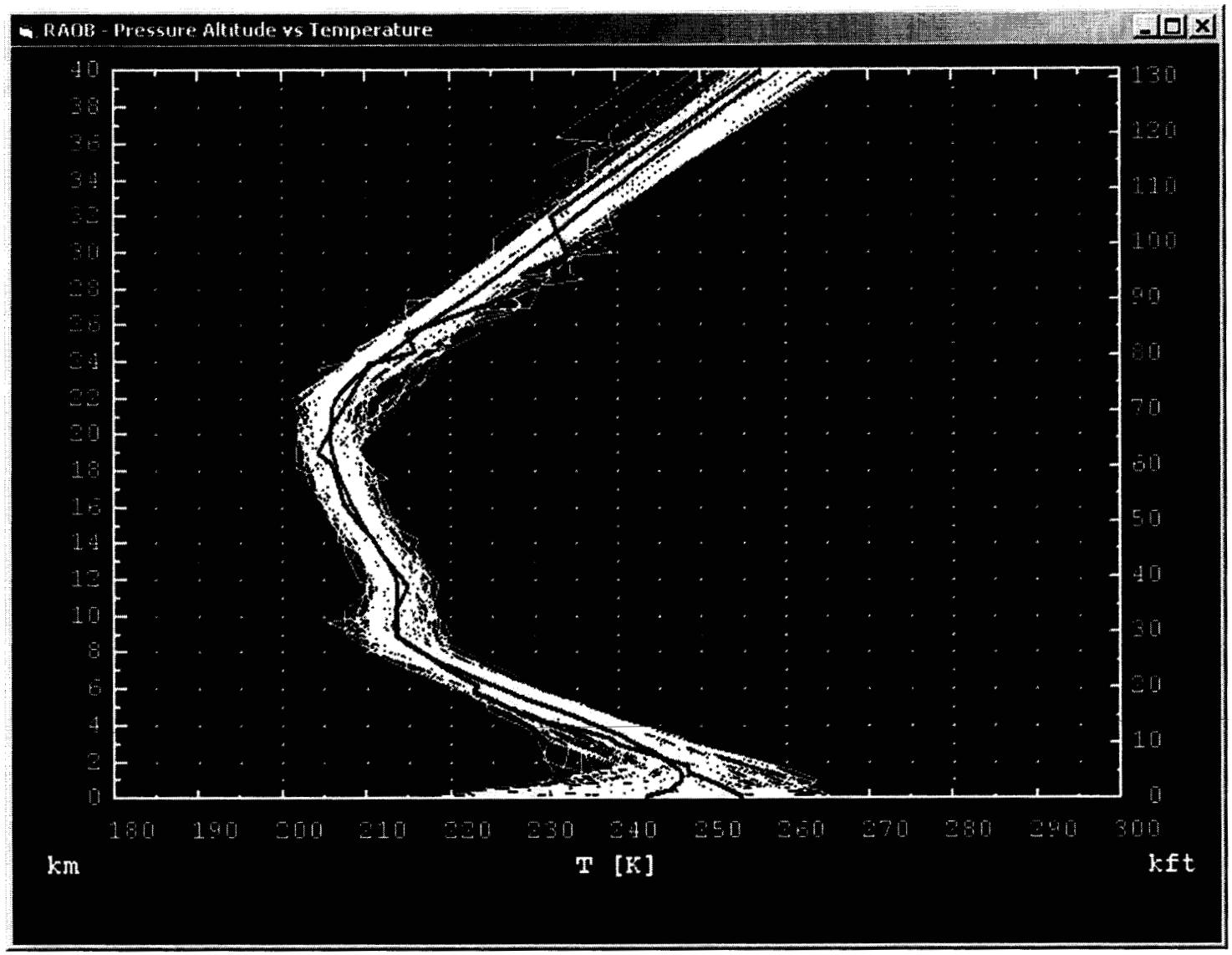


Figure 3. An example of a 2003.01.19 1200 UT radiosonde from Spitzbergen (blue) being used as a template to find other similar looking sondes -- within a specified bias and standard deviation -- to calculate retrieval coefficients for that days DC-8 flight. The yellow traces are the ~100 similar sondes and the red trace is their average.

Selecting Radiosondes to Calculate Retrieval Coefficients (RCs)

When calculating the retrieval coefficients necessary to convert raw brightness temperature measurements into temperature profiles, it is necessary to find several hundred radiosondes that match a "template" radiosonde launched near the DC-8 flight track (see Figure 3). In addition, the sondes must reach some minimum altitude to be useful since the radiative transfer calculation of observables is performed to 50 km.

Despite having a data base of >25,000 Arctic radiosondes to choose from, there were many times when a template sonde was so unique that only a handful of sondes would match it within some specified bias and standard deviation.

In this situation, soundings would be synthesized by extending sondes that matched until they burst. Generally, this could be done by extending to a temperature inflection using one lapse rate and then above the inflection using a second lapse rate. To get good statistical behaviour, 0.2 K/km of noise was added to the lapse rates, and 0.2 km of noise was added to the inflection altitude.

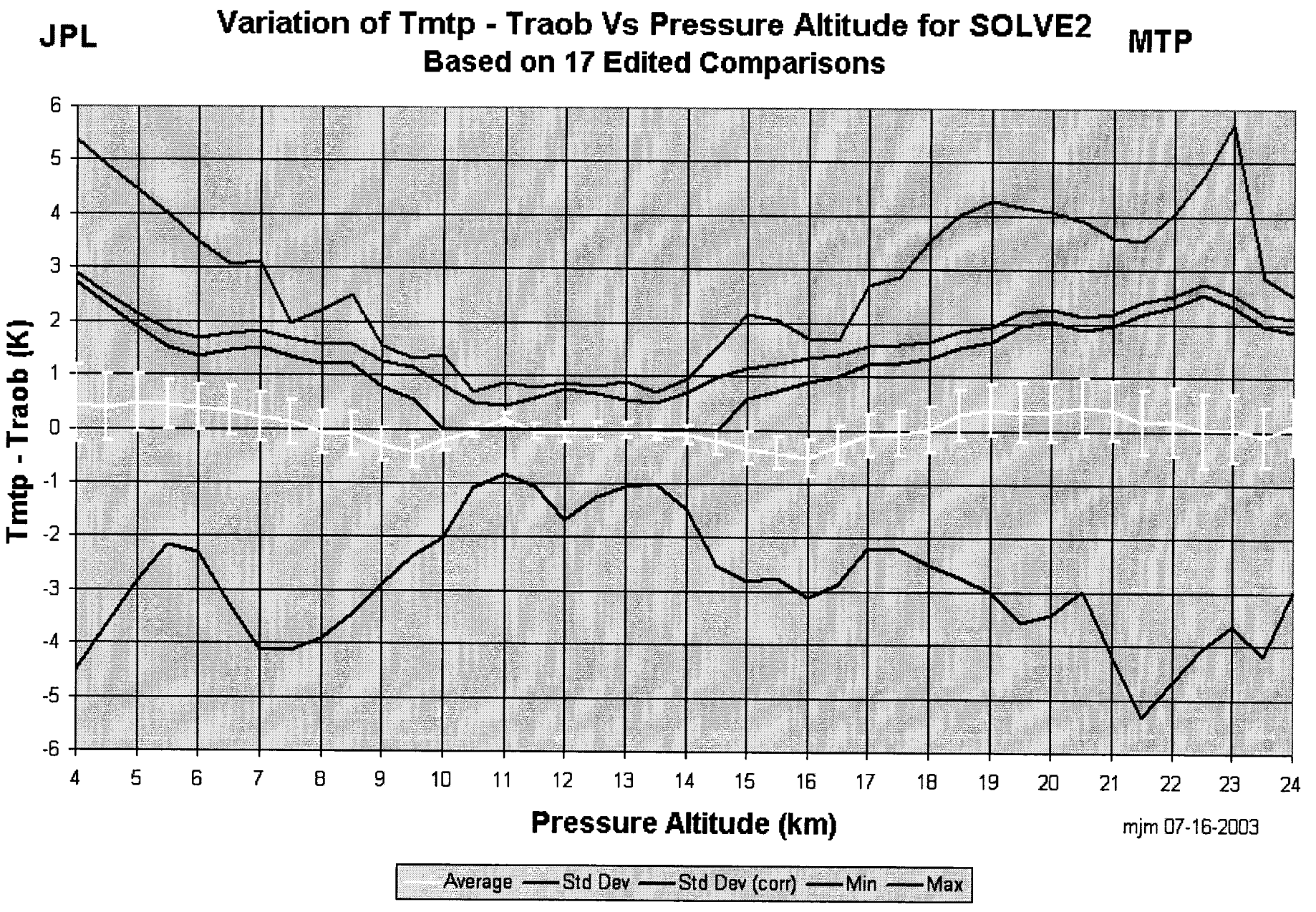


Figure 4. MTP performance compared to radiosondes

Figure 4 summarizes the result of comparing MTP temperature profiles to the temperature profiles of 17 radiosonde launch sites that the DC-8 flew close to during the SOLVE-2 campaign. The average flight altitude for these comparisons was 11.6 km, and the average distance to the radiosonde launch sites was 84 km. The white trace is the average bias of the MTP temperatures compared to radiosondes, and the error bars represent the standard error on the average bias. The green and brown traces show the maximum and minimum temperature differences between the MTP and RAOBs for the 17 comparisons. The pink trace is the population standard deviation for the 17 temperature comparisons, and the blue trace is an estimate of the retrieval error, which is calculated by removing 1 K in quadrature from the pink trace to correct for the fact the the MTP and radiosondes are not co-located. For level flight, the expected standard deviation in flight level temperatures separated by 84 km is ~1 K; this is due to real temperature gradients in the atmosphere.

Based on these comparisons and assuming an average flight level of 11.6 km, the retrieved MTP temperature profiles have an accuracy of <1 K from 8.5 to 16.5 km, <2 K from 5 to 21 km, and <3 K from 4 to 26 km.

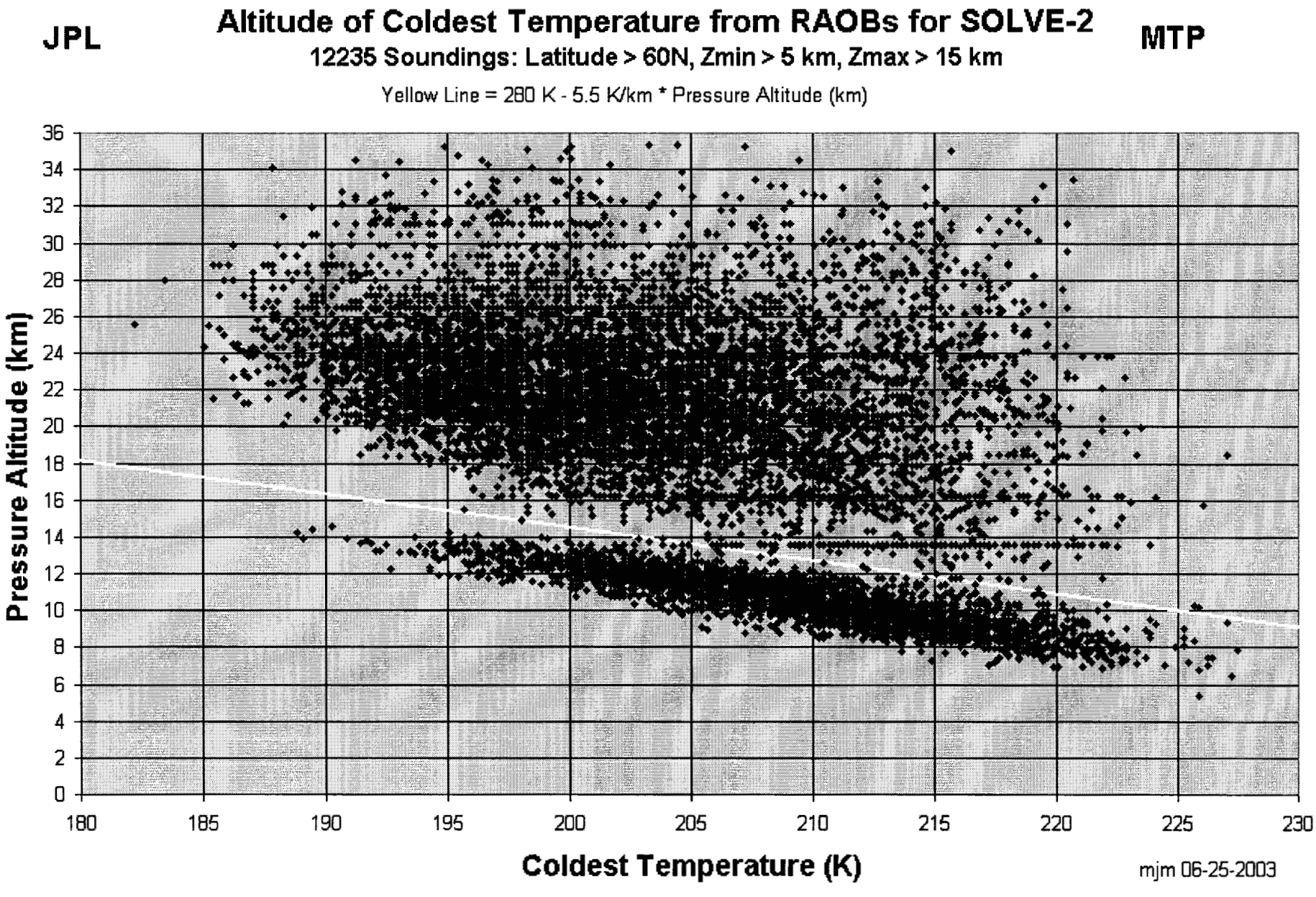


Figure 5. A plot of coldest temperature for 12,235 radiosondes north of 60 ° N.

Figure 5 illustrates a technique developed to avoid reporting high tropopauses in the MTP retrievals. Tropopauses below the yellow line were found to be valid, and those above, invalid. The WMO definition for tropopause based on the temperature profile was not intended for use in the winter polar vortex, where diabatic cooling and descent create quite unusual departures from all other "normal" profiles, as the figure illustrates.

Acknowledgements

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We also thank Bruce Gary for important contributions to the calibration of the DC-8 MTP measurements.

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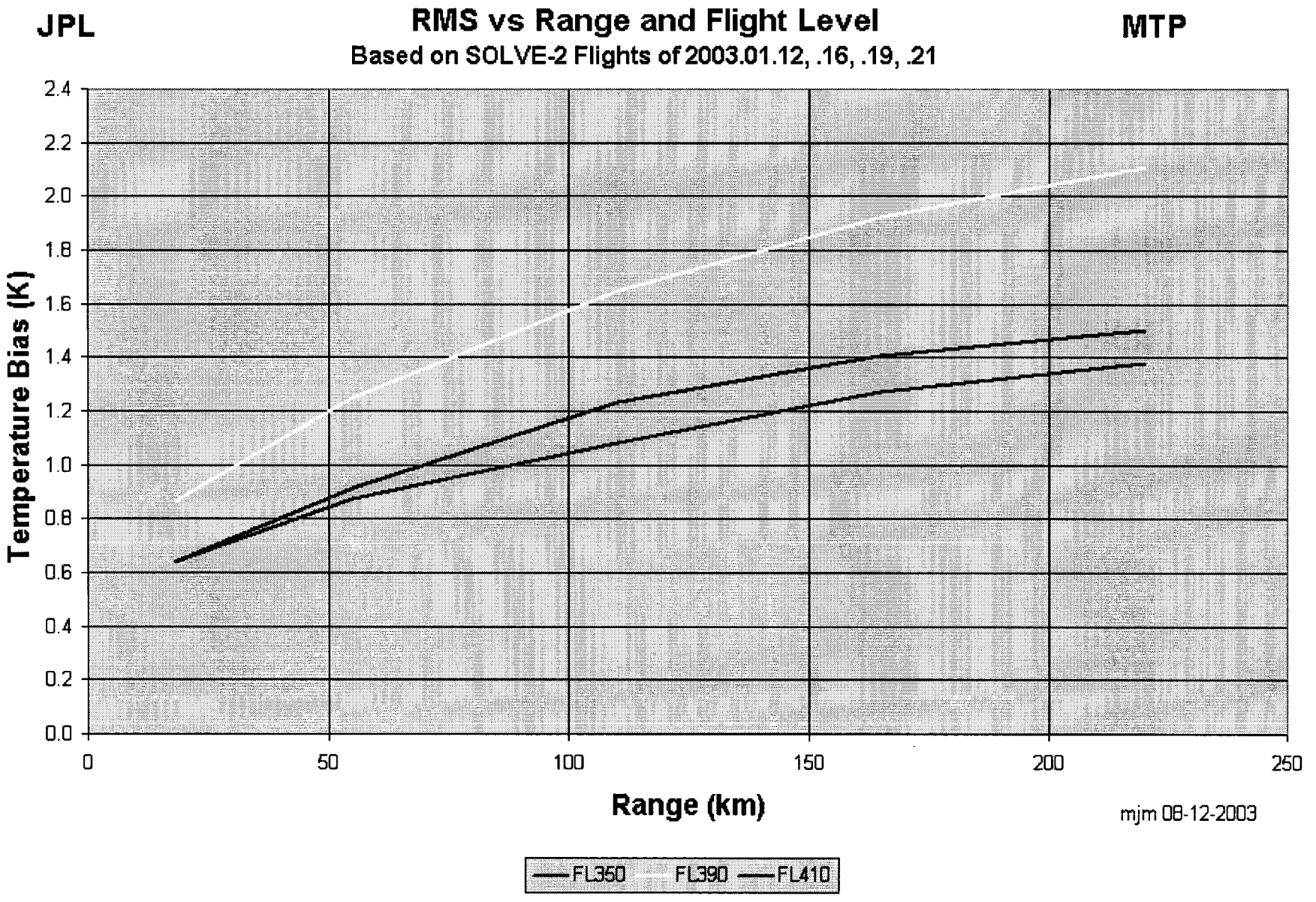
BACKUP SLIDES


JPL
RMS vs Range and Flight Level
Based on SOLVE-2 Flights of 2003.01.12, .16, .19, .21
MTP
Temperature Bias (K)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
Range (km)
mjm 08-12-2003
FL350
FL390
FL410