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Super Channels for AIRS Retrievals

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1. INTRODUCTION

A new generation of operational infrared sounders for observing the earth and its atmosphere at high spectral resolution is being built and will become operational in the next few years. The number of channels (spectral "points") will vary from about 1400 for the Cross-track Infrared Sounder (CrIS) to about 8400 for Infrared Atmospheric Sounding Instrument (IASI). Observations from both instruments are expected to be assimilated operationally into numerical weather models by 2010. Such large numbers of channels can swamp numerical forecast models. In addition, many of the channels are highly correlated and provide redundant information except for the noise. Although many channels sense the same atmospheric regions, provide little new information once one has been used, and could just be eliminated, it is desirable to include the redundant channels in a retrieval to average out the noise. Several ways have been suggested such as the use of eigenvectors. One way that has been suggested is the use of "super channels" (McMillin and Goldberg, 1997), which are averages of highly correlated channels.

The super channel approach was selected after considering several alternatives. One, the selection of individual channels, was discussed in the previous paragraph. This approach can provide a set of channels that covers most of the relevant information, but adding redundant channels averages out the noise. Eigenvectors can also be used to reduce the random noise, but if a fast way to calculate radiances for an eigenvector exists, it has not been discovered. There are indirect ways to use statistics, but these can look good for routine cases and then produce large errors when a rare event occurs.

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This approach solves several difficulties associated with other approaches. With "super channels" both a reasonable transmittance function and a reasonable Plank function exist. It is obvious that this approach is useful only if the "super channels" have a corresponding Planck function. Otherwise the Planck calculations have to be done for each individual AIRS channel and averaged into a super channel resulting in little savings in computation time. With the Planck function, one calculates the transmittance for the "super channel" and multiplies it by its corresponding Planck value, just as for a normal channel. This paper presents an approach for accomplishing the use of "super channels" that includes a Planck calculation. Super channel accuracies are better than 0.015K when compared to the "exact" calculation.

2. APPROACH

2a. Selecting the channels

In an earlier paper (McMillin and Goldberg, 1997), we presented an approach in which the channel selection was based on correlations between brightness temperatures. One of the features of this approach stems from the fact that channels in the window regions are highly correlated. For example, all the channels that might be used for split window approaches tended to end up in one super channel. This had the undesirable effect of sometimes grouping channels with different weighting function weights together, especially channels that peaked near the surface. The split window is a good example, because it works since the channels are correlated with both temperature and water vapor; yet they need to be separated and differenced to calculate the atmospheric attenuation.

Because of this behavior, it was decided to match channels based on the shape of the weighting functions. This allows super channels peaking at different heights to be extracted, even though the temperatures for the channels may be highly correlated. It is important to note that approach makes the selection independent of the atmospheric profile and to clouds. When these are present, all the channels in a given super channel respond the same way because the weighting functions are the same. The channels were combined by looking at correlations of the weighting functions at each of the 100 levels used in the AIRS radiative transfer calculation. The selection was based on a set of profiles that covered the meteorological variability. This prevented channels that have profile dependent weighting functions due to absorption by multiple gases from being averaged together. Channels that were highly correlated were combined to form a super channel. With the first attempt, no limit was placed on the wave number interval. When combinations covering a wide wave number range appeared and were associated with large errors, a limit was placed on the maximum wave number range allowed. The errors were caused by the inability of the Planck approximation to work accurately when the wavenumber range is too large. Limiting the wavenumber range allowed for any given super channel solved the problem and gave the accuracies that were desired. Two hundred wavenumbers turned out to be a good value to use for a limit. This limit may be lowered in regions where there are strong emissivity features that have a spectral signature. These were not considered for this study, but adding them will only increase the accuracy. The major effect will be to increase the number of channels and thus the running time.

Fig. 1 shows the average wavenumber associated with each group. The groups have been ordered according to the wavenumber. The jumps in wavenumber are gaps between the detector arrays that result in gaps in the coverage of the AIRS instrument. These gaps were intentionally placed in spectral regions where the additional information content did not justify the additional cost.

Fig. 2 shows the group size as a function of the group number. Sizes range from 1 to 17. There are over 60 groups that have 17 sub channels. There are also over 60 channels that are unique and can't be combined with any other channel. If these are not needed for a particular application, eliminating them can reduce the number of groups. Many of these are unique because they are channels with roughly equal absorption by two different gases such as carbon dioxide and water vapor. Finding another channel with the same effects is rare so they don't get combined. At the same time, using such channels is difficult and may not justify the cost of doing the forward calculation. Fig. 3 shows the wavenumber range for the groups. The maximum range is under 130 wavenumbers.

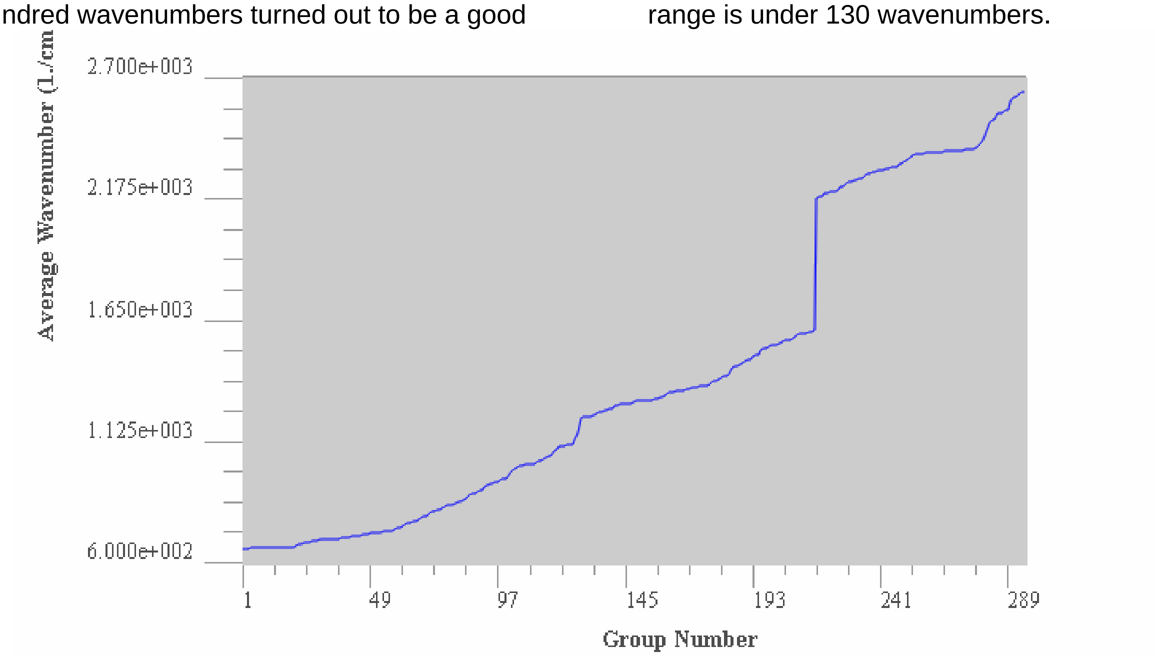


Fig 1. the average wavenumber for the super channel group numbers

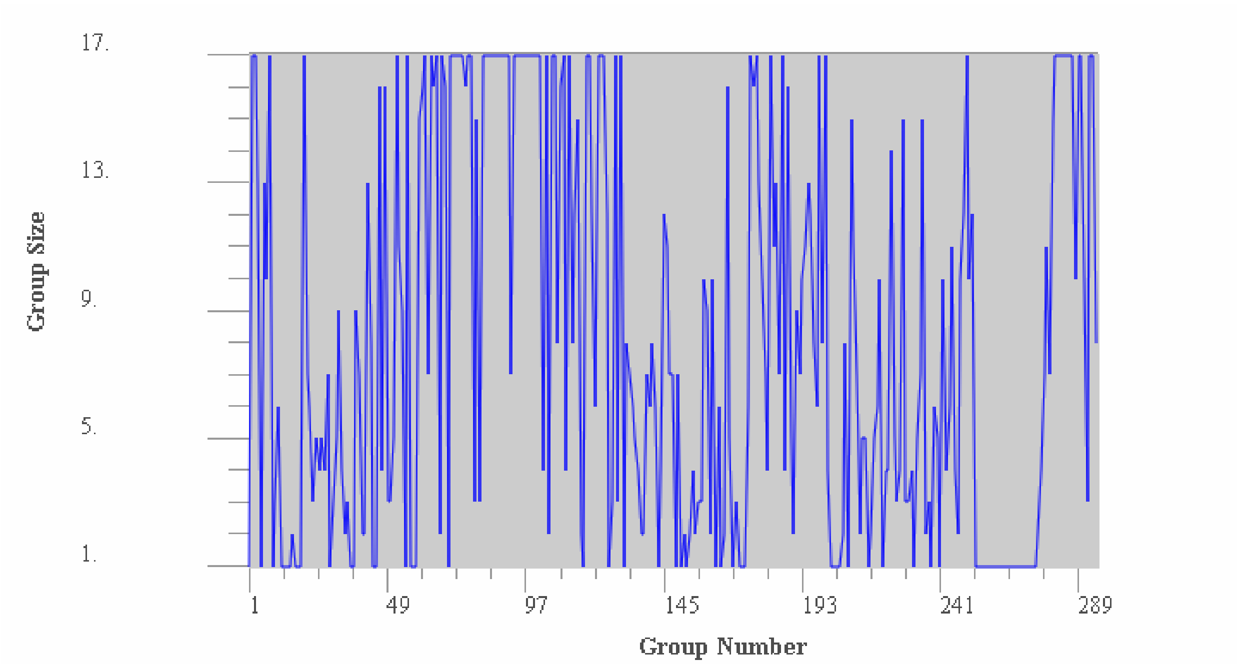


Fig. 2 The group sizes listed as a function of the group number

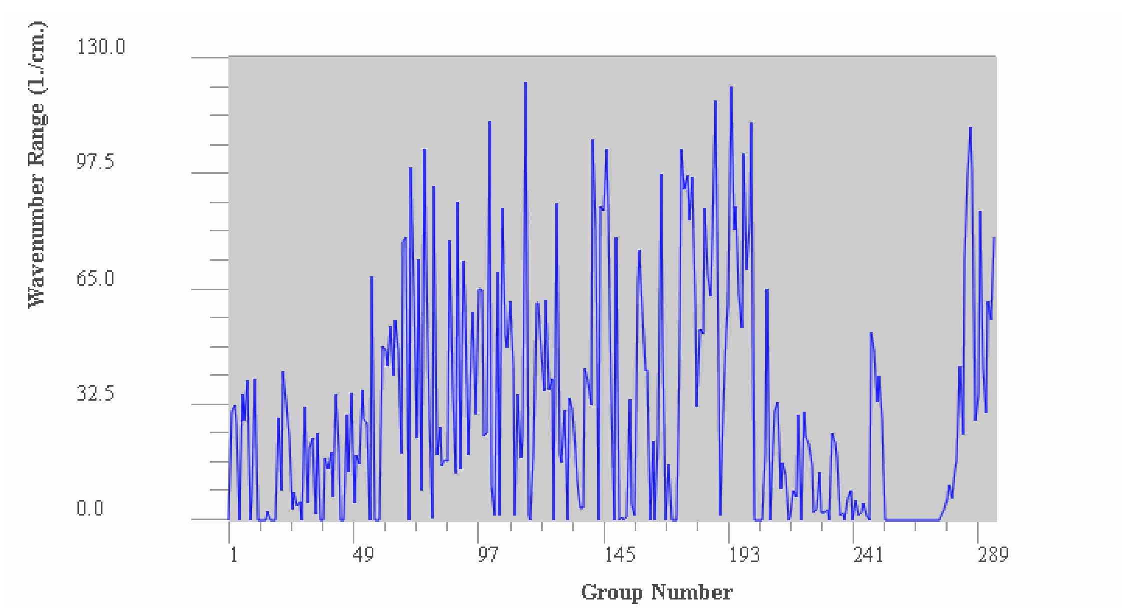
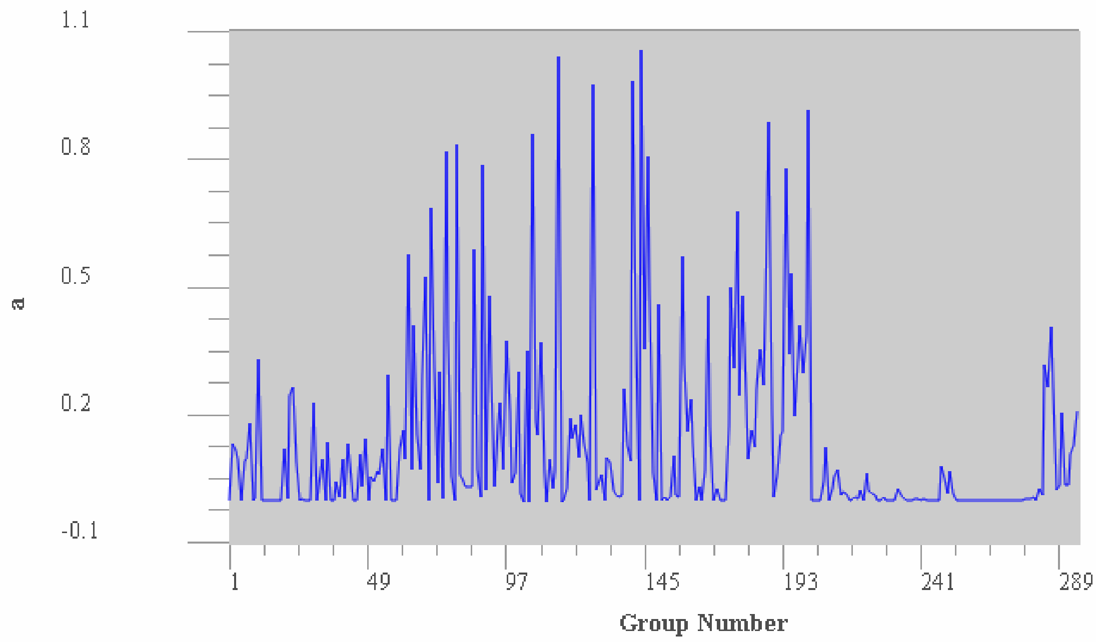


Fig. 3 The wavenumber range as a function of the group number

Once the "super" channels are selected, it is necessary to calculate transmittances for the "super" channels. The rapid transmittance techniques, Optical Path TRANsmittance (OPTRAN) routines that we use at the National Environmental Satellite Data and Information Service (NESDIS) provide the means of calculating transmittances. These algorithms have been



applied to broadband instruments and are suitable for the rapid transmittance calculations (McMillin et al. 1985). Applying OPTRAN to "super" channels is similar to applying to a broadband instrument such as HIRS. Coefficients can be generated for the transmittances corresponding to the super channels using the existing algorithms.

2b. Calculating the Planck function

$$T^* = a + bT \qquad (1)$$

A super channel is useful only if a corresponding radiance can be determined. As mentioned earlier, if the individual channels have to be summed up for each profile, no time is saved and the point of making the super channels is lost. We solve this problem by using the band corrections that have been used for TOVS soundings (McMillin et al. 1981), but with an improvement. In the old approach, the Planck function was used to calculate radiances at the wavenumber that represents the centroid of the filter function. We will use $\bar{\nu}$ to denote this wavelength. The temperature used for the calculation was then modified by the expression

where T^* denotes the temperature used for radiance calculation, T denotes the true temperature, and a and b are constants. These were derived by the following procedure:

Using a set of profiles, radiances at a spectral resolution that can be considered to be monochromatic were calculated at the frequencies that cover spectral range for a given channel. These were then convoluted with the filter function for that channel to produce the "true radiance." At the same time, the radiance for temperature, T^*, at wavenumber, $\bar{\nu}$, was calculated. This was repeated for temperatures spanning the range covered by the particular channel, typically 200 K - 320 K, and the values of a and b that minimized the maximum brightness temperature error over the range of atmospheric temperatures observed by that particular channel were found using an iterative procedure that changed the values of a and b to increase the accuracy until a specified accuracy was obtained.

In our approach, we treat the wavenumber as an additional variable to be optimized in the minimization. It is usually close to the centroid, but does not match it exactly. Adding another degree of freedom to the optimization increases the wavelength range over which the approximation is valid. We found negligible errors over a range as

Fig. 4 The value of the a coefficient as a function of the group number.

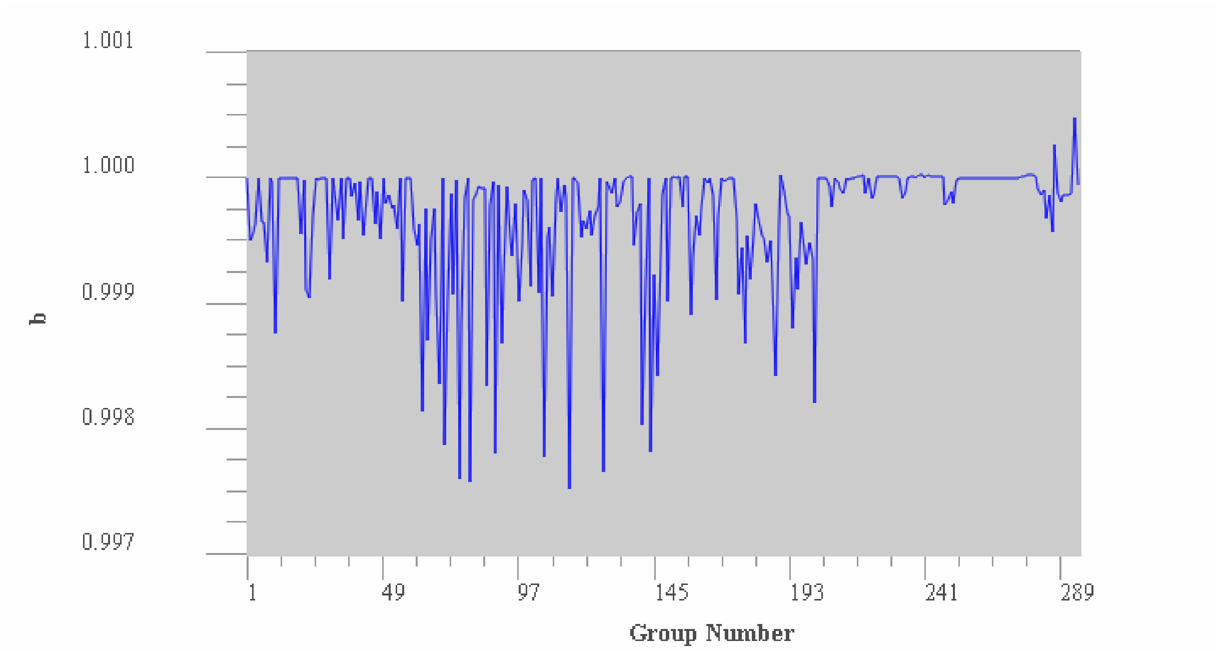


Fig. 5 Value of the b coefficient as a function of the group number.

wide a 500 cm^{-1}. However, for this application the range was reduced to 200 cm^{-1}. This allows us to average over super channels of this width or less and is adequate for super channels for two reasons. Averaging channels from widely spaced spectral regions produces other problems (such as large ranges in surface emissivity) which we wish to avoid, and channels which should be averaged should have similar spectral characteristics. Figures 4 and 5 show the values of a and b that were obtained. For a single AIRS channel, the value of a should be 0 and the value of b should be 1.0. For the larger groups, the value of a gets as large as 1.0 and the value of b gets as small as .9975. It should be noted that the "super" channels used for this study were derived from simulations because the transmittances are required, but the information content was determined using AIRS data.

3. RESULTS

A global set of profiles was used to define the groups. The set was obtained from a set of global operational TIROS operational Vertical Sounder (TOVS) measurements matched with radiosondes. Since these are simulations, the TOVS measurements are not that important, but they did provide a means for supplementing the radiosondes to provide the more complete specification of the atmospheric state that is required for radiative transfer calculations. For example, a surface skin temperature, an ozone profile, and an upper atmospheric temperature were obtained from the retrieval and used to supplement the radiosonde information to obtain complete profiles. Two hundred profiles were used to generate the retrieval coefficients.

The channels that were added together to define the "super channels" were selected by summing the level transmittances over both levels and atmosphere to calculate a channel-by-channel correlation matrix. Then a channel was selected and the remaining channels were scanned to find a channel that matched its characteristics. The limits used were .999 and +/-100 wavenumbers for the lower frequency channels (< 1357.5 $cm.^{-1}$), and .9995 and +/-100 wavenumbers for the higher frequency channels.

This produced a set of 295 "super channels". The group sizes ranged from 1 to 17. As mentioned earlier Fig. (1) shows the frequencies for the groups, Figs. 2 shows the group sizes, Fig. 3 shows the wavenumber range, Figs. 4 & 5 show the Plank calculation coefficients, and Fig. 6 shows the errors. The actual maximum error observed was 0.0115K, but we will round this to 0.015 K or less. This is certainly good enough for most uses. Making the selection criteria tighter could reduce the errors.

Conversely, relaxing the selection criteria could reduce the number of super channels. In other words, there is a trade between accuracy and number of channels. The selection we made is a reasonable compromise, but not the only one.

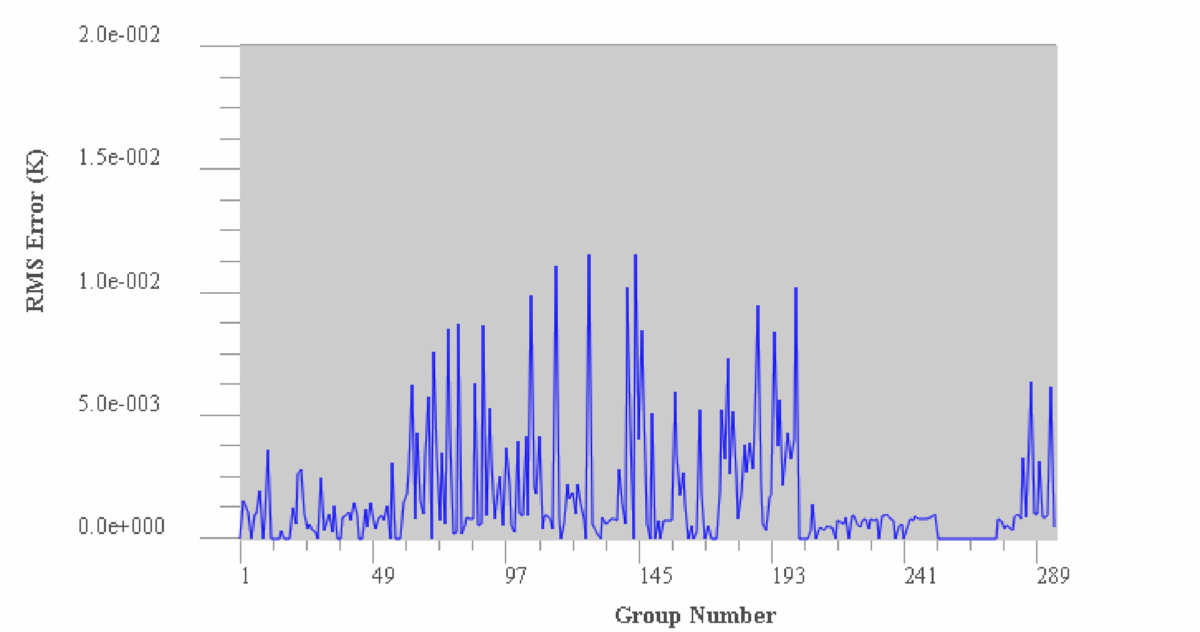


Fig. 6 RMS error for the groups as denoted by group number

4. FORWARD CALCULATION ERROR

As mentioned, a forward transmittance model is required for super channel calculations. Fig. 7 shows the errors in the forward calculation. Dark blue shows the error for dry, green is for water vapor, red is for ozone, and cyan is the total amount. For most channels the error is less than 0.01K. It is larger for selected channels where the error is dominated by ozone, both near the 9.6 ozone absorption band and at isolated lines where the ozone absorption is significant. It should be noted that similar errors have been noted for individual AIRS channels, so this is a transmittance issue, not a super channel one. The number of super channels shown in Fig. 7 is less than the number shown in Fig. 6. This is because Fig. 7 includes only those AIRS channels which do not show a history of noise and are therefore considered to be reliable. This reduced the number of channels in some of the groups and some groups were totally eliminated.

5. INFORMATION CONTENT

There are several possible ways to reduce the volume of data and retain information content. Eigenvectors are one way, but a fast radiative transfer calculation is difficult if not impossible. In any case, it is desirable to know the information content that is lost when reducing the data volume. At this point, it should also be mentioned that the AIRS instrument has some channels that are

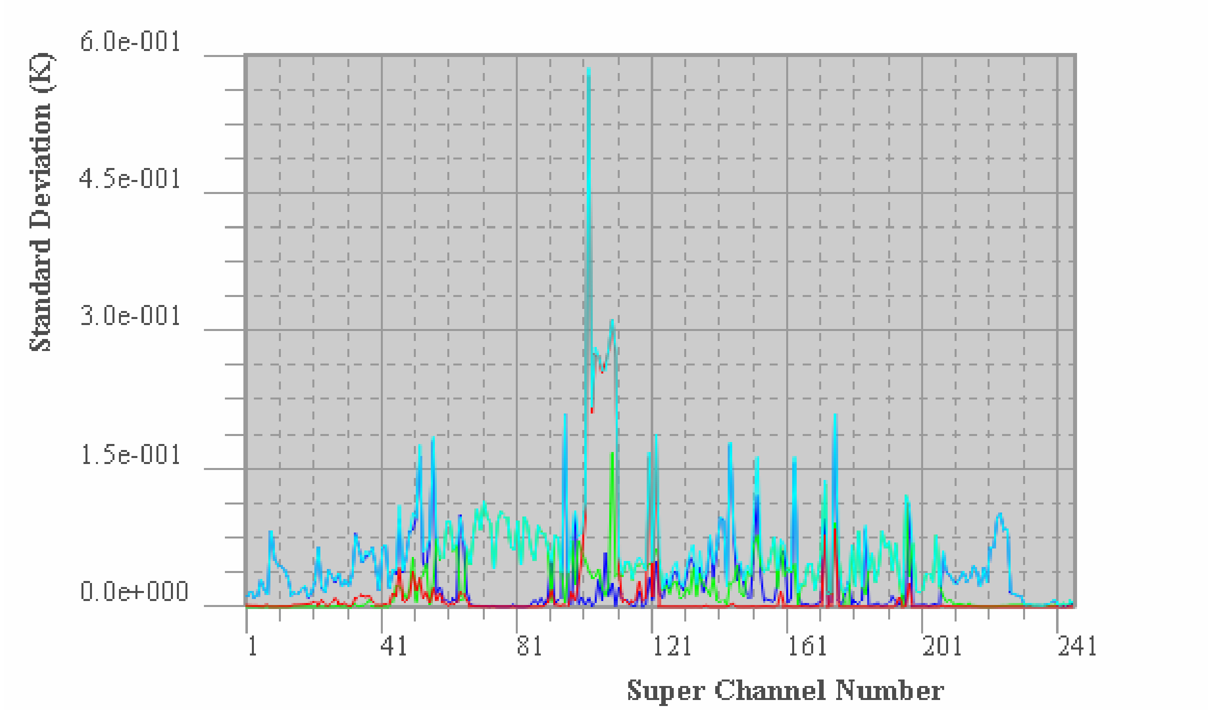


Fig. 7 Radiance errors as a function of the super channel number. Blue shows the dry gas values, red shows the ozone values, green shows the water vapor values, and cyan shows the total.

noisy. With the large number of redundant channels, this is not a major issue, but it needs to be stated that only the “good” channels were used for this analysis. The total variance was calculated as the sum of the diagonal elements of the covariance matrix. This calculation is obvious for the actual case. For the super channels, the variance was calculated by taking the super channels and using these to predict all the AIRS channels. An alternative is to take the variance for a particular super channel and multiply it by the number of channels averaged together, but this is not as accurate. The ratio of the variances was then calculated by dividing the value for the super channels by the value for the individual channels. The ratio was 0.9999, which means that the super channel approach captures over 99.99% of the total variance.

6. EXAMPLES OF SUPER CHANNELS

Figures 8 and 9 show some examples of super channels. Figure 8 shows an example of super channel 1 for an AIRS granule, an area of 135 scan lines by 90 scan positions. This super channel is an average of 13 individual channels. Figure 9 shows the corresponding values for super channel number 9 which contains a single AIRS channel. The reduction in error due to the averaging is obvious from the two pictures.

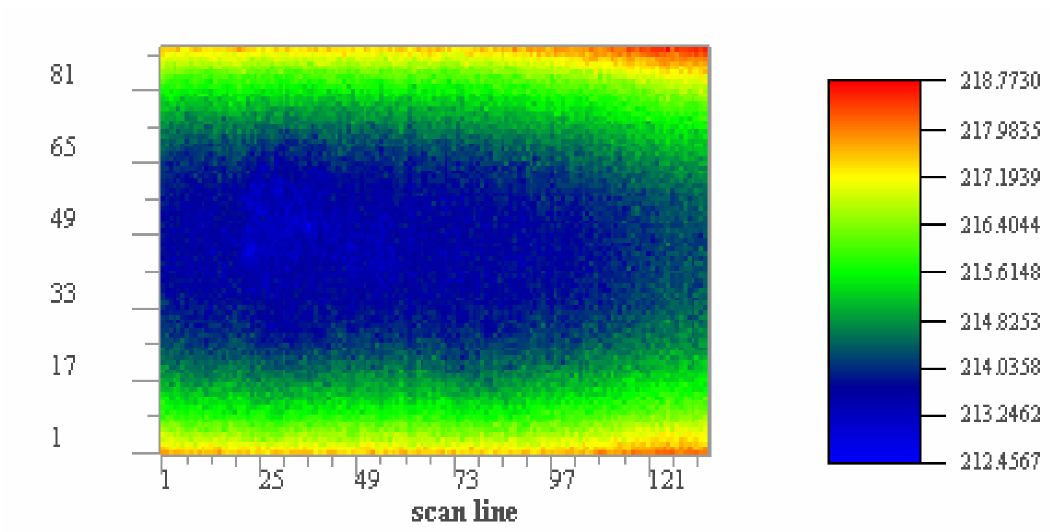


Fig. 8 Temperatures for AIRS super channel 1 which is an average of 13 channels.

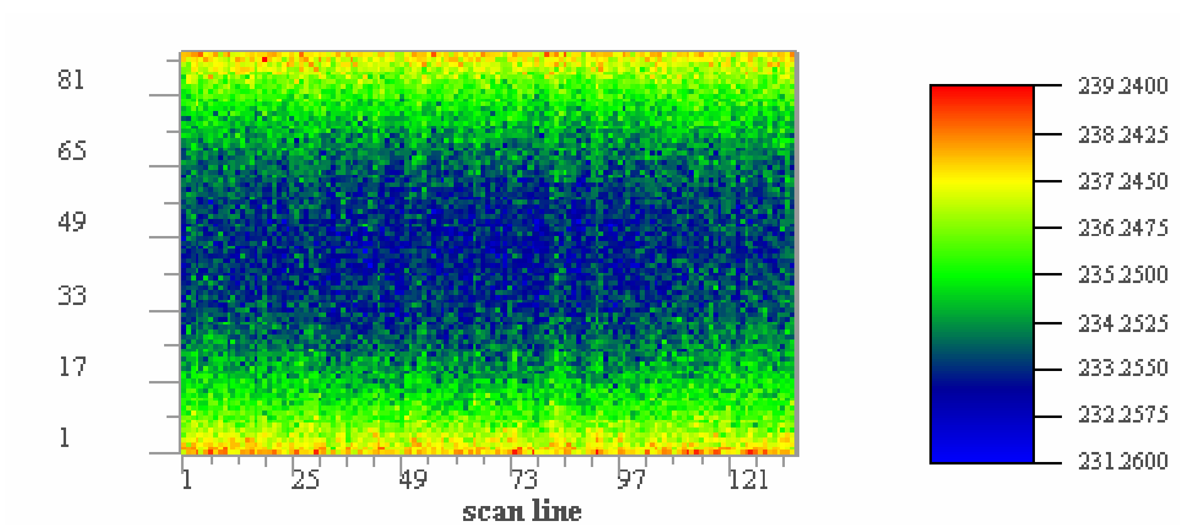


Fig. 9 Temperatures for AIRS super channel 9 which is a single channel.

7. SUMMARY AND CONCLUSIONS

The steps required to do retrievals with super channels have been demonstrated. First a set of super channels have been defined, next a rapid transmittance approach has been demonstrated, and finally a Planck function approximation has been demonstrated. These are the components required to perform a physical retrieval based on the super channels. Together, these provide the speed and accuracy required for use of high resolution sounder information in numerical models. The number of channel calculations is reduced by a factor of 10 while the error is kept under to 0.015K.

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