ANGEL ADJUSTMENTS FOR TOVS/AIRS - PAST, PRESENT AND FUTURE

L.M. McMillin, D.S Crosby, and Sisong Zhou

National Environmental Satellite Data and Information Service
Office of Research and Applications
Climate Research and Applications Division
4700 Silver Hill Road, Stop 9910
Washington, D.C. 20233-9910, USA.

1. INTRODUCTION

When radiances from a cross track instrument are used, there are angle effects that must be considered. There are several options for adjusting for angle effects. All have advantages and disadvantages. Three possible approaches are the following:

1. Do retrievals at the angle. But the data need to be processed before doing the retrieval. Cloud clearing requires a local adjustment, and clear area detection requires a sample of clear data for the training set. The problem then becomes the distribution of the clear areas. This distribution will be different for different angles. This may cause discontinuities in the retrieved fields. Doing retrievals at an angle may be a good idea, but it doesn’t remove the need for making angle adjustments. In fact, much of the work of this paper was done in response to the need to provide cloud-cleared data that could then be used to do retrievals at the measured angles.

2. Angle adjust using observations. This has the advantage of using real data, but has the disadvantage of producing biased results because of a severe sampling problem. This approach appears to work fairly well in the microwave region where cloud effects are small, but has significant problems in the infrared region. The main problem is a bias that is caused by the fact that parameters such as effective cloud amount change with angle. These factors include the effective cloud amount and local time with the effective cloud amount having the largest effect. The effective cloud amount increases with viewing angle for any cloud that has a vertical dimension. Experience has shown that this regression technique gives a warm bias at extreme angles.

3. Use calculated radiances to do the angle adjustment. This resolves the sampling questions. To a first approximation, it also resolves the effects that are angle dependent. The angle adjusted data will represent the physics of observed data. In terms of cloud amount, this means that the adjusted data will have the effective cloud amount of the observed data. The danger is that errors can be caused by systematic differences between channels. Channel to channel differences can be observed and used to make a bias adjustment using techniques such as those described by (Uddstrom and McMillin 1994a, 1994b).

2. HISTORY

The previous discussion presented cloud clearing techniques in a general setting. Each approach has variations. While not all variations are significant, it is important to understand the variations that have been employed in the operational retrievals. These retrievals have been archived and are frequently used for climate studies. In the TOVS processing, regression has been used to adjust cloud contaminated radiances to the nadir position (Smith et al. 1979). This technique was used until late 1997. A separate regression was done for a group of 5 scan positions and the secant of a local zenith angle was used to make changes
within each group. No adjustments were done for the center 6 spots (26-31). This approach produced 5 sets of coefficients, each of which covered 5 spots. In addition, the corrections were assumed to be symmetrical so the coefficients used for spots (1-5) were used for spots (51-56) etc. This was done because space to store coefficients was not readily available when the system was developed. There were several problems with this approach. One is that the regression adjustments were different for different groups and this gave discontinuities in the retrieved data. A second is that the regression was done on cloudy data and regression is not able to handle cloud effects and angle effects at the same time. This leads to large errors in the angle adjustments.

A second approach was to do only the small local angle adjustments necessary to do cloud clearing, then angle adjust the cloud-cleared or clear values. This is a much more satisfactory approach as the angle adjustment is done on clear radiances. This was planned for RTOVS, but has not been implemented.

A third approach (Wark 1993, 1998) is to use actual data to do the adjustments. This approach was implemented with the RTOVS processing in late 1997 and has been used for both RTOVS and ATOVS. It has the difficulty that it needs observations for the same locations under the same conditions at different angles. Since such observations don’t exist, observations are averaged in 2 degree latitude bands over 5 days and the assumption is made that the average values contain equal amounts of the different cloud and weather conditions. Several other steps, such as separating data into day and night and smoothing over angle were carried out (Wark 1993). The number of predictor channels was also limited. With this approach, there are several factors that change with angle, two of which are the local time of the area being viewed and the average cloud amount. Clouds have a vertical dimension and the clear area decreases as the angle changes. In addition, clouds are partly transparent, and the effective cloud transmittance decreases with viewing angle. These all have effects on the measured radiances, particularly in the infrared. This approach appears to give satisfactory results in the microwave region. However, in the infrared, angle dependent biases appear in comparisons between measured and calculated radiances. The angle dependence is explained by the fact that cloud amount increases with local zenith angle. The spots or the outer edge of the orbit are viewed as more cloudy and thus colder. This problem gives biases of up to 1.5 K.

3. APPROACH AND RESULTS

3.1 RTOVS

Each of the above procedures have advantages and disadvantages. In this paper, we will use simulation techniques to compare the accuracy of the various approaches. We have applied this approach to both HIRS and AIRS. The different instruments have different operational approaches, and the simulations will reflect these differences.

RTOVS angle adjusts all spots to nadir. The current cloud clearing is done with measured radiances. To study this effect we simulated cloudy radiances and used these data to generate angle corrections coefficients. To simulate the angle effect of clouds, we modeled the clouds as parallelograms with a given height to width ratio. For a parallelogram, the effective obscured fractional area $C_e$ as a function of angle is given by

$$C_e = C[1 + Atan(\theta)]$$

(1)
Angle Adjustment Bias for Clear areas
Coefficients from uniform 40% cloud cover

Fig. 1 Angle adjustment bias at nadir resulting from coefficients generated with a constant 40% cloud cover for channels 1 - 9.
Angle Adjustment Bias for Clear Areas
Coefficients from uniform 40% cloud cover

Fig. 2 Angle adjustment bias at nadir resulting from coefficients generated with a constant 40% cloud cover for channels 10 - 19.
Angle Adjustment Bias for Clear Areas
Coefficients from 40% Cloud at Nadir

![Graph showing bias vs field of view number for different channels.

Fig. 3 Angle adjustment bias at nadir resulting from coefficients generated with 40% cloud cover at nadir and increasing with angle (channels 1 - 9).
Fig. 4 Angle adjustment bias at nadir resulting from coefficients generated with 40% cloud cover at nadir and increasing with angle (channels 10 - 19).
where $C$ is the area obscured by the parallelogram at nadir, $\theta$ is the viewing angle, and $A$ is the ratio of the height to width. We used a value of 0.3 for $A$. Cloud amounts were varied randomly, but forced to average 0.4, a typical global average. The profiles were selected from a globally representative sample. The microwave channels were assumed to be cloud free. The data were evaluated on a sample that was assumed to be cloud free. This is because retrievals are currently performed on clear radiances. We generated angle adjustment coefficients from data which satisfy the following three sets of conditions:

1. The data are clear.
2. The data are cloudy but the cloud amount does not change with angle.
3. The data are cloudy and the amount changes with angle.

The coefficients were generated using a modified ridge regression procedure. This was done to suppress the effects of channels with a small or negative correlation with the channel being adjusted as an alternative to limiting the channels used for the adjustment. One or the other approach is required to prevent predictor channels combinations that make no physical sense. An example is a channel whose weighting function peaks near the ground having the largest prediction coefficient for angle adjusting a channel whose weighting function peaks near the tropopause. Such combinations occur because there is a large negative correlation between the surface and tropospheric channels over a global sample, but one does not want to depend on this correlation for angle adjustments. Also, this correlation weakens in meteorologically active conditions, and one wants to use satellite measurements to monitor these conditions.

For case 1, when the data used to generate coefficients are clear, the bias is essentially zero (between -0.0001 and +0.0001) as it should be. For case 2, when clouds are present but don’t change with angle, the biases for the infrared channels are shown in Fig. 1 (channels 1-9) and Fig. 2 (channels 10-19). These figures show significant biases with viewing angle for the channels which view the surface. It exceeds -1.0 for channel 9. It is also apparent that the procedure for applying the ridge regression technique needs to be adjusted for most of the shortwave channels. This is apparent from the changes in bias near field of view number 1 which is at the largest angle. At these angles, the channel with the highest correlation is frequently not the channel itself, but a channel that peaks lower in the atmosphere. For case 3, where the cloud amount changes with angle, the angle effects for the surface channels are much larger (Figs. 3&4). The biases reach 20 K. The shape of this curve matches the patterns that were observed in the actual TOVS data but the size of this bias indicates that the cloud aspect ratio we used, 0.3, is larger than is typical. We have demonstrated that it is important to keep the cloud amount uniform when generating angle adjustment coefficients. This effect explains a large portion, if not most, of the bias that was observed with the initial RTOVS angle adjustment approach.

3.2 AIRS

The angle adjustment for the AIRS is done only for adjacent spots. The plan is to perform retrievals at the angle. This is particularly suited to a physical retrieval approach or a regression based on simulated radiances. The large number of channels on the AIRS instrument also helps the angle adjustment. When generating data to use for angle adjustment coefficients, it is important to simulate the problem correctly. When an instrument is measuring a spot, some event happens that affects the detector and becomes noise. If the mirror had been pointing in a different direction, the same event would have happened and the detector would have had the same noise. Thus it is important to simulate data with noise that varies with profile and with channel, but is the same for all angles. Using this procedure we simulated radiances for a representative set of profiles and calculated angle adjustment coefficients for the outer two scan angles. We then applied these coefficients to an independent set. Solar effects were included in the simulation. This was done because one does not want to mix channels that differ in their response to solar radiation in

371
Fig. 5 RMS temperature difference between adjacent spots before correction for nighttime data.
Fig. 6 RMS temperature difference between adjacent spots and after correction for nighttime data.
View Angle Affect Before Adj. (Mix 7/13/98)

Fig. 7 RMS temperature difference between adjacent spots and before correction for daytime data.
the angle adjustment. Results are shown in Figs. 5-8. Fig. 5 shows the error for nighttime data before any adjustment is performed. Maximum errors exceed 0.4 K, well above the instrument error level. Fig. 6 shows the errors after adjustment. The largest values are 0.015 K, well below the instrument error level, and typical errors are 0.005 K. Fig. 7 shows the errors in daylight before the adjustment is made. As at nighttime, maximum errors exceed 0.4 K and the patterns are quite similar. Fig. 8 shows the errors after the adjustment is made. Again, the errors are small, but they approach 0.05 K at short wavelengths, and the effect of solar radiation is evident. Part of the reason is that the solar angle and the viewing angle both change with spot, but the changes are independent. Thus one can adjust for one or the other but not both. Even at the maximum value of 0.05 K, the error is below the instrument noise, but it is large compared to the error in the nighttime case.

4.0 SUMMARY AND CONCLUSIONS

This study was performed to diagnose problems that were observed in the operational angle adjustments. It was suspected that the problem was caused by the change in cloud amount with angle, but the effect had to be demonstrated. This study demonstrates that effect and shows that, to get unbiased clear radiances, angle adjustments have to be derived with clear data. There are also other effects, such as diurnal temperature changes that are embedded in angle adjustments made with observed data. At the same time, some additional changes need to be made in the simulated approach. The instability at the large angles needs to be resolved using a constrained regression approach such as is discussed in Crone et al. (1996).

4.1 References


