Some Modifications to the NESDIS Operational Clear Column Radiance Procedure

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1. INTRODUCTION AND REVIEW

It is difficult to know what to report on at this conference because there are so many interesting new results. For example, the classification approach is making substantial improvements in accuracy over the current operational procedure (see McMillin, 1985a), and a method of using satellite measurements to obtain biases between radiosonde types shows excellent agreement with conventional comparisons as well as providing some revealing facts about radiosondes (see McMillin, 1985b). While these results are being reported in other forums, there have been incremental changes in the operational clear radiance procedure which are not being reported elsewhere. In addition, the cloud clearing approach used by the National Environmental Data and Information Service (NESDIS) is unique in its emphasis on deleting multiple level clouds. Because of this uniqueness, a discussion of the approach is appropriate for this forum.

The present operational cloud clearing approach used by NESDIS evolved from ideas presented by W. L. Smith in several papers in the late 60's and early 70's (Smith 1967, Smith 1968, and Fritz et al. 1970). In 1967, Smith introduced the concept of $N^*$, defined as

$$N^* = \frac{I(v,1) - I(v,c)}{I(v,2) - I(v,c)} \quad (1)$$

where $I(v,c)$ is the clear radiance at wavenumber $v$, $I(v,1)$ was defined as the average of all the radiances in the total area of observation and $I(v,2)$ was defined as the average of all radiances less than the total average. In 1968, Smith modified the definitions of $I(v,1)$ and $I(v,2)$ to be two adjacent measurements within the total area. The change in definitions was made because the first definition required all spots within the area to have the same cloud height, an unlikely event for most situations. In (Fritz et al. 1970), Smith discussed the idea of using wavelength differences to
obtain a solution when no single channel could be regarded as clear.

An essential element of the solution is an assumption that $N^*$ is a constant that is independent of channel. Unfortunately, this has been frequently justified by assuming that emissivity is independent of wavelength and, as a result of this justification, it has often been assumed (incorrectly) that the method will not work if emissivity is wavelength dependent. While this assumption was not bad for some early instruments which had all the sounding channels in a single band, it is questionable for instrument systems such as the Tiros Operational Vertical Sounder (TOVS) which have channels at very different wavelengths. Fortunately, the clear column radiance procedure does not depend on this assumption because the assumption that cloud emissivities are equal for the two observations, rather than as a function of wavelength, leads to the same result. To see the alternative, note that $I(v,1)$ can be defined as

$$I(v,1) = (1-n(1)*\xi(v,1))*I(v,c) + n(1)*\xi(v,1)*I(v,o)$$

(2)

where $n(1)$ is the fraction of spot 1 covered by cloud, $\xi(v,1)$ is the cloud emissivity for spot 1, and $I(v,o)$ is the radiance from the overcast regions in spot 1. A similar equation can be written for spot 2 to yield

$$I(v,2) = (1-n(2)*\xi(v,2))*I(v,c) + n(2)*\xi(v,2)*I(v,o).$$

(3)

To obtain a solution with either assumption, it is necessary to require that $I(v,c)$ is the same for both spots. Effectively, this means that the cloud tops in both spots are equal. Given that the cloud heights are equal, if the cloud bases and densities are also equal then the cloud emissivities are also equal and $\xi(v,1)$ is equal to $\xi(v,2)$. Since cloud tops are more likely to vary than cloud bases, and because clouds with the same bases and tops in the same area are very likely to have the same densities, the assumption that cloud emissivities are equal is only slightly more restrictive than the assumption that the cloud tops are equal. Eq. (2) can be written as

$$I(v,1)-I(v,c) = n(1)*\xi(v,1)*[I(v,o)-I(v,c)].$$

(4)

Writing a similar equation for eq. (3) and dividing into Eq. (4) gives

$$\frac{I(v,1)-I(v,c)}{I(v,2)-I(v,c)} = \frac{n(1)}{n(2)} = N^*$$

(5)

since the emissivities are equal and the other terms cancel. As Smith showed, once $N^*$ is determined for one channel, it can be used to solve eq. (5) for $I(v,c)$, giving values of $I(v,c)$ for the other channels from the relationship

$$I(v,c) = \left[N^*I(v,2) - I(v,1)\right]/(N^*-1).$$

(6)
Although the N* approach provides clear radiances for all channels once a value is determined for any single one, it is necessary to obtain a value for at least one channel by some other method. One way is to use Eq. (5) with both clear and partly cloudy radiances for at least one channel. Appropriate values have been determined in several ways. Vertical Temperature Profile Radiometer (VTPR) data (see McMillin et al. 1973) were processed over oceans using the ocean surface temperature and a forecast to calculate a radiance for the window channel, since the atmospheric absorption for the window channel is minimal. If the forecast is in error, the solution can be iterated. McMillin (1971) suggested using a "split window" to remove the atmospheric effect and thus eliminate the dependence on an atmospheric forecast. Susskind et al. (1984) couple the cloud clearing process and the retrieval step. Approaches that depend on forecasts are followed by other countries, most notably Britain (Eyre et al. 1985), and to some extent, France (Chedin et al. 1985). Japan and New Zealand (Aoki et al. 1985, Taylor et al. 1985, and Hayden et al. 1985) have done work involving the use of higher resolution Advanced High Resolution Radiometer (AVHRR) to determine a clear value for the window channel which provides a clear estimate for the window channel on the TIROS Operational Vertical Sounder (TOVS).

There is an appeal to using a method that does not depend on a forecast. The AVHRR approach has this appeal, but presently AVHRR data are not available at NESDIS for real time processing. Iterative methods produce a retrieval for physical parameters and then calculate a radiance from the physical parameters. This is the actual method used by Susskind et al. (1984). However, an equivalent alternative is to use some channels to retrieve directly for another, thus bypassing the physical parameter retrieval and radianee calculation steps for the purpose of cloud clearing. This separates the cloud clearing and retrieval steps and greatly simplifies the maintenance of an operational system which must be periodically improved while minimizing the occurrence of catastrophic errors in the retrieval system. There are also potential advantages from an accuracy standpoint, since the retrieval for another channel radianee from channels with very similar weighting functions is inherently more accurate than a retrieval for a parameter with a very different weighting function such as temperature. In addition, errors caused by differences between calculated and observed quantities are avoided.

To be fair, these potential advantages are balanced, at least in the minds of people who prefer physical retrievals over regression methods, by the fact that a retrieval for another channel can only be done by regression. However, a correction for many regression errors can be made when a first guess is available by simulating radiances for both wavelength regions and applying the regression coefficients to the calculated values as well as the measured ones. For the calculated radiances, the simulated clear as well as the simulated cloudy radiances are known, so the error in the cloud clearing method for the local condition in question can be immediately determined. If the first guess is reasonable, then errors in the regression error due to errors in the first guess become second order errors in the final radiances. Application of this correction would allow

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separation of the cloud clearing and retrieval steps while providing results equivalent to those provided by the full iteration process since there is no doubt that radiance calculation errors far exceed the second order errors that would result from this approach. However, the results of this correction, as well as of the full iteration, are dependent on the accuracy of the radiance calculations. Any systematic difference in radiance calculation errors between channels could easily negate any potential advantage that this step could provide. Because of doubts that radiance calculations have reached the accuracy level required for this step to prove to be beneficial, this potential correction is not employed by NESDIS.

The approach used at NESDIS is based on regression relationships between channels which are described in detail in McMillin and Dean (1982). One relationship can be thought of as using microwave brightness temperatures to predict a clear brightness temperature for a 15 μm channel to be converted to a clear radiance, which is then combined with the observed cloudy radiances for the same channel to calculate N*. This is the way the solution would be done on an Advanced Microwave Sounding Unit (AMSU) with numerous microwave channels. However, TOVS has only three microwave channels and it is more accurate, but less straightforward, to calculate a cloudy microwave pseudo radiance, I(6,22), for channel 22, (MSU channel 2), scaled to a typical radiance in the 15 μm region (channel 6) from the relationship

\[ I(6,22) = C(0) + \sum_{c=5}^{8} C(c)*I(c) \]  

where \( C(c) \) are the regression coefficients for channel \( c \) and \( I(c) \) are the observed cloud contaminated radiances for channel \( c \). Values of \( C(c) \) are obtained from a sample that has been screened to contain only clear cases. The scaling to the channel 6 wavelength is similar to converting radiances to brightness temperatures when retrieving temperatures, and is done for the same reason, to minimize the nonlinear effects introduced by the Planck relationship. It differs from the brightness temperature approach in that instead of stopping with the brightness temperature, the brightness temperatures are used to calculate radiances at the desired wavelength which differs from the one at which the original measurement was obtained. At the same time, the scaling in eq.7 is done in a way that preserves the linear relationship between cloud amount and radiance that is present in the observed values, I(c), and creates the same relationship in the predicted value, I(6,22). Although the values of C(c) in eq.(7) are derived from clear values, when the values of I(c) are cloudy, eq.(7) provides the cloudy values required for the N* determination. Clear values are obtained by converting measured radiances observed the frequency of channel 22 in the microwave region to equivalent radiances at the wavelength of channel 6 in the infrared region. When these steps are completed, both clear and partly cloudy radiances for the pseudo channel I(6,22) are available and can be used to calculate a value of N*. Of course the method is dependent
on the assumption that the microwave measurements are not attenuated by clouds.

A second solution can be obtained from a regression relating radiances at 15 \(\mu\)m to a channel in the 4.3 \(\mu\)m region. This solution is an evolution of an idea presented by Smith in Fritz et al. (1972). Again, the regression coefficients are obtained from clear data. In this approach, neither observation is independent of clouds, but due to the highly nonlinear nature of the Planck function, they respond differently to clouds that differ in temperature from the surface. Because the method is dependent on sufficient contrast between the clouds and the surface, it works much better for high clouds in the tropics than for low clouds or clouds in polar atmospheres. The solution is both lengthy and iterative, and is given in the appendix of McMillin and Dean (1982). As explained by McMillin and Dean (1982), both methods are used in the operational processing and a consistency check is performed when both results are available.

2. MULTIPLE LEVEL CLOUD PROBLEMS AND SOME SOLUTIONS

The entire cloud clearing approach is dependent on the assumption that the clear and overcast radiances are uniform over the area covered by the spots used to obtain a solution. If the spots are close to each other and small, the assumption that the clear radiances are uniform is usually valid. However, cloud top heights vary rapidly over small areas and the overcast radiance is strongly related to the cloud top height. In addition, errors in cloud-cleared radiances due to mixed cloud heights are biased rather than random, an effect that is expected when cloud amount and cloud height are correlated rather than random. McMillin and Dean (1982) demonstrated that for a typical cloud shape, there is a significant correlation between cloud amount and cloud height. This correlation between height and amount in a field of view makes it even more difficult to find spots with different cloud amounts while still having similar cloud top heights. To avoid errors, some screening method is essential and much of NESDIS's effort has been devoted to assuring similar cloud heights in the measurements actually used in the cloud clearing process.

McMillin (1978) describes the major approach that has been used at NESDIS for screening observations for cloud heights. This approach has been supplemented by an additional test. When measurements for a partly cloudy area are plotted on a figure with radiances for one channel as one axis and radiances for a second channel as the other axis, the points fall into a roughly triangular area with one side determined by the points for the highest cloud in the area, another side determined by the points for the lowest cloud in the area, and a third side formed by a curve defined by the points completely overcast clouds at all heights. A typical case is shown in fig.1.
Fig. 1 Measured radiances for mixed clouds. Lines representing the high and low clouds are shown. Individual measurements are shown by points. Points between the lines are from mixed clouds.

Although the angle between the second and third sides is often small making the separation of the sides difficult to observe, the first side is usually clearly defined. An approximation to the first side can be obtained from a collection of observations by selecting only those points along the lower edge that form a monotonic progression from coldest to warmest. This is accomplished by ordering the observations according to the radiance values for one channel from lowest (coldest) to highest (warmest). Radiances for the second channel are then examined. If a given point is not ordered in the second channel, then one or more of the previous points is from a lower cloud and the previous point is discarded. The last point and the new previous point are then examined to see if they are monotonic. If they are not, the new previous point is discarded and the process is repeated until all the multiple cloud points have been eliminated. Figs. 2 and 3 illustrate the approach for a typical example. Fig. 2 contains all the points for a typical case and Fig. 3 shows the points that remain after screening. This procedure has demonstrated a capability to detect some cases of multiple level
clouds that were escaping detection by the tests described by McMillin and Dean (1982), and has been added to the string of tests.

![RADIANCE FILTER PLOT](image)

**Fig. 2** Measured radiances for channel 6 vs. measured radiances for channel 8 for a case of mixed cloud heights. All points are shown.

Recent evaluations have shown that the best cloud clearing algorithm is level dependent in that more averaging is better at higher levels where multiple level cloud effects are minimal, while more screening is better at lower levels where multiple level cloud effects are present. The reason for this can be seen from eq. 8. When it is written as

\[ I(v,c) = I(v,2) + \frac{(I(v,2) - I(v,1))}{(N^*-1)}. \]  

it becomes obvious that any noise in the quantity \((I(v,2) - I(v,1))\) is multiplied by the ratio \(N^*/(N^*-1)\). Since \(N^*\) is usually close to 1.0, any noise is amplified. Near the ground, radiances are affected by both high and low level clouds, and cloud effects are larger than any noise. However, at higher levels, radiances are affected only by the highest clouds and effectively only one cloud level is present. And at still higher levels, cloud effects go to zero and noise.
amplification becomes the dominant error source. At these levels, it would be better to follow the original approach (Smith 1967) of using differences of averages rather than the later approach (Smith 1968) of averages of differences of adjacent pairs because the method based on averages is correct for single level clouds, and produces errors where multiple cloud levels are present, while the method based on adjacent pairs minimizes errors at these levels. These effects are clearly evident in the results of the Second International TOVS Study Conference (ITSC-11) where the comparisons presented by LeMarshall (1985) show that model using the averaging approach (Susskind et al. 1984) produced some of the most accurate results of all the methods in the upper troposphere while an approach based on the adjacent pair approach (McMillin 1982) produced some of the most accurate results of all the methods in the lower troposphere.

It is desirable to devise a method that has both advantages. In an attempt to do so, all the spots which are monotonic are used to produce a least squares line for two channels. The differences between the points and the line are screened for outliers which are
rejected. Points that remain are used to derive least squares lines for all channels relative to the channel for which a clear radiances is known. This slope is used for all spots within the area from which the sample was collected. Typically, the area required to produce a sample large enough for the slope procedure to work is larger than is desirable for a single sounding. If the intercept were also fixed, all the soundings in the larger area would be identical. To avoid this, a separate intercept is derived for each sounding based on the subset of screened points that lie within that particular sounding area. In this new approach, it is anticipated that the least squares procedure will provide some of the noise reduction of the averaging at high levels while allowing for the screening of multiple level clouds to minimize cloud clearing errors at lower levels.

3. CLOUD RETRIEVALS

On July 2 1984 the TOVS adopted a new method for retrieving cloud parameters. It is based on the radiance slope method described by McCleese and Wilson (1976) and evaluated by Wielicki and Coakley (1981). That approach is based on the relationship between the slope of a line connecting two or more spots with different cloud amounts on a plot with radiances for two channels as the axis. However our new approach has a significant difference in the way the overcast radiance is obtained. In the old version, cloudy radiances were obtained by calculating radiances from the retrieved profile. In the new version, it is noted that a curve exists on a plot of radiance of one channel versus radiance for a second channel that is the locus of all the points for which both radiances have the same brightness temperature. The intersection of a line connecting radiances for two spots with this curve is taken as the first estimate of the cloudy radiance. Because the atmosphere above the clouds has some attenuation, the curve defined by the locus of points is shifted to account for the attenuation at the point of intersection and the new point of intersection is found. For programming ease, use is made of the fact that a shift of the line formed by the two measurements is equivalent to a shift of the curve formed by the locus of points since the point of intersection is determined by the relative positions of the two curves. After an evaluation of possible corrections for the attenuation, a correction of the form

\[ T_{bn}(i) = T_{bm}(i) + C(i,0,k) + \Delta[C(j,k,i)T_{bo}(j) + C(j,k,i)T_{bc}(j)] \]  

(9)

was applied to the two channels forming the straight line, where \( T_{bn}(i) \) is the corrected (new) radiance for channel 1, \( T_{bm}(i) \) is the measured radiance, \( C(j,k,i) \) are the regression coefficients to predict the correction for channel 1 from measurements from channel \( j \) for overcast condition \( k \) (clear or overcast), \( T_{bo}(j) \) are the overcast estimates of brightness temperature for channel \( j \) from the first iteration, and \( T_{bc}(j) \) are the clear radiances for channel \( j \). In practice, it was found that the correction could be produced from a single channel, (channel 8) and that addition of other channels increases the size of the regression coefficients while producing a minimal improvement in accuracy. This approach has the advantage of
making the retrieval for cloud amount and cloud top temperature a single step that can be incorporated as part of the cloud clearing process, separate from the retrieval step. Cloud top height can be obtained at a later step by finding the level in the profile with the same temperature as the cloud top temperature.

As usual, the implementation of the cloud retrieval is more complex than indicated by the description in the previous paragraph. Cloud retrievals are processed by one of four selections of channels, given here in order of decreasing accuracy, depending on the situation. The most accurate results are obtained by using HIRS channels 8 and 18. However, channel 18 is subject to contamination by solar radiation and can be used only at night. In daylight, channel 18 is replaced by channel 6. Another problem occurs in completely overcast areas where the required estimate of the clear column radiances is not available. In these areas, the solution must be obtained from microwave channels. Over oceans, an estimate of the surface skin temperature is available for channel 8 and can be used with eq. 7 and measurements of MSU 2 and HIRS channel 8. Estimates for cloudy cases over land are derived by using MSU channels 2, 3, and 4 to predict HIRS channels 6 and 7 using normal regression procedures. Of course the last method can be applied everywhere that microwave measurements are available, but is the least accurate.

For a single point, an initial estimate of the cloud top radiances is obtained by solving for the intersection of the straight line and the line defined by the locus of all points with the same brightness temperature. Figure 4 illustrates the method. It shows the locus of points of equal temperature as a curve, and several pairs of clear and observed points as straight lines connecting the two points. These lines can be extended to find the intersection with the curve. Since the line defining the locus of points with the same brightness temperature is a curve, in practice, the Newton-Raphson method is used to find the intersection.

4. SUMMARY

Several incremental improvements to the cloud clearing algorithm have been presented, as well a modified method to obtain cloud amounts and heights. The improvements stem from the recognition that many cloud fields consist of clouds for which cloud amount and cloud height are correlated. This lack of independence causes a bias rather than a random error in derived clear column radiances, and methods that rely only on statistical approaches such as averaging to remove the errors will be affected by the bias. To remove the bias, some means of filtering is needed, and the NESDIS procedure is designed to filter out cases of mixed cloud heights. After filtering, many of the statistical procedures are useful as additional steps.

The new cloud algorithm has been implemented into the operation. In doing so, the definition of the TOVS cloud height and amounts have been changed. When the present processing system was designed, there was interest in a dynamic indicator of retrieval accuracy for retrievals derived from clear column radiances. Cloud amount and
Fig. 4  Channel 8 radiance vs. channel 18 radiance showing the curve formed by the locus of points with the same brightness temperature. Extrapolation of the lines to the left to intersect the curve provides the overcast radiances. Straight lines on the figure connect clear and observed radiances for several examples. Lines nearly tangent to the curve and short lines lead to larger uncertainties in the derived cloud top temperature.

height for the spots going into the retrieval provide some limited information about the reliability of the resulting retrievals. Since that time, we know of no user who has used these quantities as accuracy indicators, and there has been considerable interest in cloud amounts and heights. For these reasons, these parameters have been modified to represent the average of all the spots in a retrieval box, rather than just the spots used in deriving clear column radiances. As a result, the current cloud amounts and heights being produced by NESDIS provide useful meteorological information and are better agreement with conventional measurements of these quantities.
5. REFERENCES


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