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Atmospheric Parameterization Schemes for Satellite Cloud Property Retrieval During FIRE IFO II

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1. Introduction

Satellite cloud retrieval algorithms generally require atmospheric temperature and humidity profiles to determine such cloud properties as pressure and height. For instance, the CO_2 slicing technique called the ratio method (e.g. McCleese and Wilson, 1976; Smith and Platt, 1978) requires the calculation of theoretical upwelling radiances both at the surface and a prescribed number (40) of atmospheric levels. This technique has been applied to data from, for example, the High Resolution Infrared Radiometer Sounder (HIRS/2, henceforth HIRS) flown aboard the NOAA series of polar orbiting satellites and the High Resolution Interferometer Sounder (HIS) (Smith and Frey, 1990). In this particular study, four NOAA-11 HIRS channels in the 15-μm region are used: 4 (14.22 μm), 5 (13.95 μm), 6 (13.66 μm), and 7 (13.34 μm). The ratio method may be applied to various channel combinations to estimate cloud top heights using channels in the 15–μm region. Presently, the multispectral, multiresolution (MSMR) scheme (Baum et al., 1992) uses 4 HIRS channel combination estimates, namely 4/5, 5/6, 5/7 and 6/7, for mid- to high-level cloud pressure retrieval and Advanced Very High Resolution Radiometer (AVHRR) data for low-level (>700 mb) cloud level retrieval. In order to determine theoretical upwelling radiances, atmospheric temperature and water vapor profiles must be provided as well as profiles of other radiatively important gas absorber constituents such as CO_2 , O_3, and CH_4. The assumed temperature and humidity profiles have a large effect on transmittance and radiance profiles, which in turn are used with HIRS data to calculate cloud pressure, and thus cloud height and temperature. For large spatial scale satellite data analysis, atmospheric parameterization schemes for cloud retrieval algorithms are usually based on a gridded product such as that provided by the European Center for Medium Range Weather Forecasting (ECMWF) or the National Meteorological Center (NMC). These global, gridded products prescribe temperature and humidity profiles for a limited number of pressure levels (up to 14) in a vertical atmospheric column. The FIRE IFO II experiment provides an opportunity to investigate current atmospheric profile parameterization schemes, compare satellite cloud height results using both gridded products (ECMWF) and high vertical resolution sonde data from the National Weather Service (NWS) and Cross Chain Loran Atmospheric Sounding System (CLASS), and suggest modifications in atmospheric parameterization schemes based on these results.

2. Clear Sky Temperature/Radiance

Atmospheric temperature and moisture profiles are used to determine transmittance and hence radiance profiles. Variations in atmospheric profiles and surface conditions can have a considerable effect on the radiance profiles (Menzel et al., 1992). Surface conditions, temperature in particular, have considerable importance since clear-sky radiance provides the benchmark for comparisons with measured radiance values in order to estimate cloud heights. The first atmospheric parameterization involves determining the surface temperature for use in determining the surface, or clear-sky, radiance. In order to diagnose the clear-sky radiance at a particular pixel location, some have simply employed the "closest" clear-sky radiance value from a nearby region and then interpolated to the pixel under analysis (Smith and Frey, 1990; Menzel et.al., 1992). This parameterization is most accurate when the clear-sky pixel is in close proximity to the one under analysis, but may be less accurate in cases of large-scale cloud coverage when the "closest" clear-sky pixel is a large distance from the analysis pixel. Also, one has to determine whether the closest "clear-sky" radiance is really "clear-sky".

Even in the absence of frontal situations where temperature gradients may be quite large, clear-sky radiances can vary quite significantly over a short distance. For example, cloud top heights are computed using the ratio method for all HIRS fields of view (FOV) in the 2.5 degree square ISCCP box containing Coffeyville for the NOAA-11 overpass at 0932 UTC on Dec 5th. Of the 56 feet, two are classified as "clear-sky". That is, all four combinations in the 15-μm window yielded cloud-free estimates. The 11-μm brightness temperatures (HIRS and AVHRR) for the northernmost clear FOV were approximately 270 K, while the southernmost FOV had temperatures some six degrees warmer at 276 K. The two feet are denoted as solid ovals on figure 1. The difference may have been attributed to some frozen ground in the northern region of the ISCCP box. Nonetheless, if either of these two feet were to be used as a "box-average" clear-sky radiance value (in the absence of the other), it would be quite unrepresentative of the entire region. ECMWF surface temperature values are 275.8, 274.5, and 276.9 for the grid points on the northern edge of the box, and 277.3, 275.3, and 274.7 on the southern edge of the box. These too cannot totally account for the frozen ground, but they do provide a more coherent spatial pattern for the calculation of clear-sky radiances. Therefore, in situations when the closest clear-sky pixel is too far from the analysis pixel, surface air temperatures are employed for calculating clear-sky radiances.

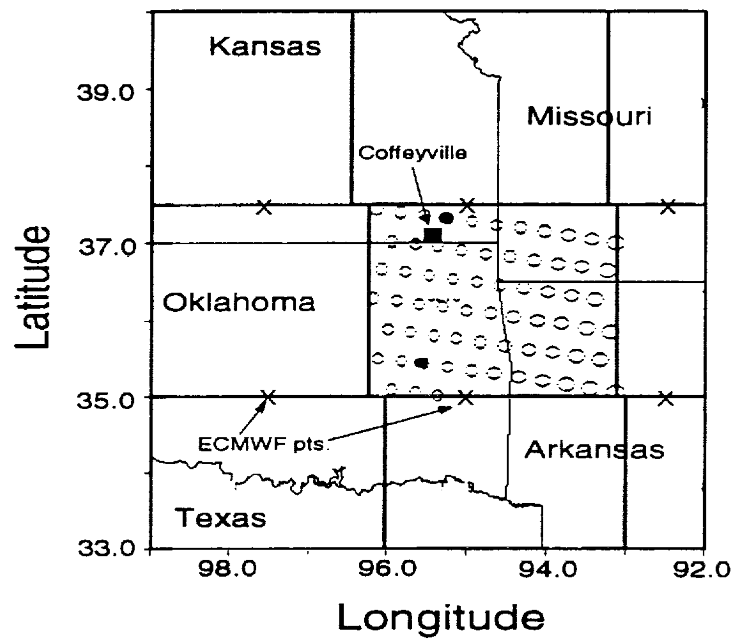

Figure 1. NOAA-11 HIRS/2 footprints within ISCCP box for Coffeyville, Kansas for Dec 5th 09UTC overpass. ECMWF dataset grid points also shown on figure. Solid pixels denote "clear-sky" conditions.

In addition, since ECMWF gridded data sets contain surface temperature and a 2-meter air temperature, adjustments are made when situations (i.e. fog, shallow nocturnal inversions, etc.) create markedly different values between the surface and 2 meter temperature value. The same adjustment is made when using high-vertical resolution rawinsonde data with data levels immediately above the surface. The exact adjustment to surface temperature is a function of the surface and above-surface air temperatures plus surface moisture conditions.

3. Tropopause

While atmospheric temperature and moisture profiles are required to compute upwelling radiances, these profiles may be used for additional purposes in cloud retrieval schemes. The ratio method allows diagnosis of cloud heights by comparing ratios of remotely-sensed radiances to clear-sky radiances of two closely spaced spectral bandsin the CO_2 band. Computationally, the technique is bounded by the surface and the portion of the free atmosphere that is assumed to be void of temperature inversions. With the definition of the tropopause based partially on temperature inversion, the logical upper bound is placed here. Physically, the tropopause often marks the upward vertical ascent of cirrus and convective clouds. Therefore, an accurate diagnosis of the tropopause is often crucial in determining cirrus cloud heights.

In the MSMR algorithm, the diagnosis of the tropopause is a 2-step process. Initially, the tropopause is set climatologically as a function of the Julian day and the latitude of the pixel under analysis. Nine default climatological profiles are set to choose from. Once an initial level is set, a looping procedure is employed starting at 2 levels below the initial tropopause level and extending to 2 levels above the initial tropopause. The lapse rate is computed for each level: if it is less than 5.0 C per kilometer, the tropopause level is re-set to that level. This allows for the tropopause to be re-set below OR above the level initially set. For example, during the NOAA-11 2108 UTC overpass over Coffeyville on Dec 5th, the tropopause is diagnosed at 200 mb over the northern region of the ISCCP box containing Coffeyville, but changes to 150 mb over the southern portion of the box. On this day, cloud top heights were measured at high altitudes approaching the tropopause. All surface-based instruments and aircraft yield cloud-top heights ranging from 12 to 12.3 km which is in accordance with the MSMR results. ECMWF relative humidity profiles reveal the peak moisture layer at the two grid points at 35 degrees north at 200 mb, whereas the peak moisture layer is lower at 250 mb along the 37 degree north parallel. This parameterization allows higher cloud height retrievals over the southern portion of the region which coincides with the higher peaks in the relative humidity profiles.

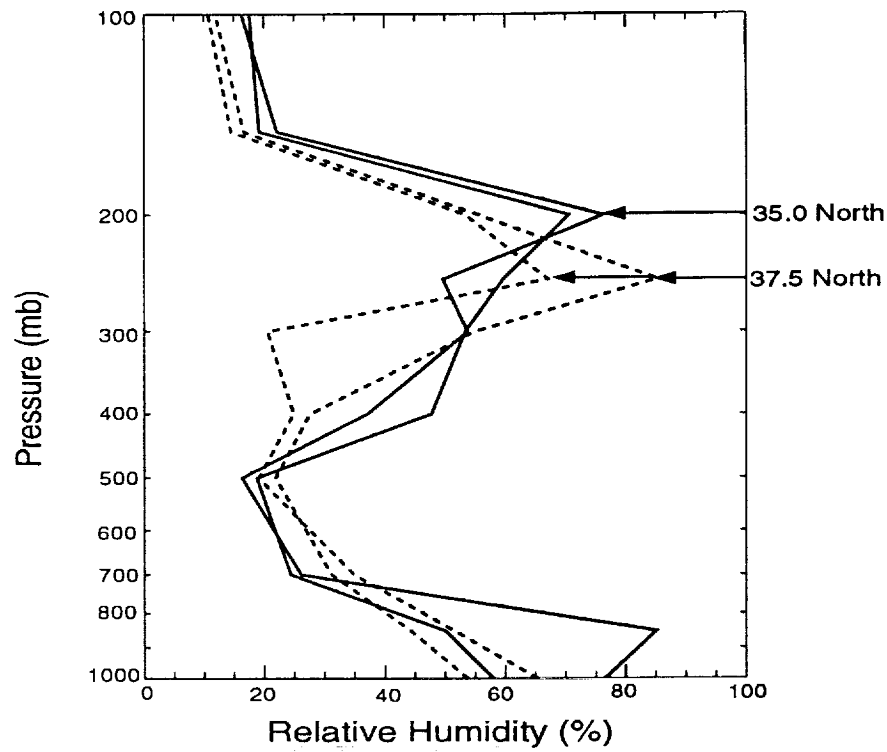

Figure 2. Dec 6th 00 UTC 1991 ECMWF relative humidity profiles for 4 grid points along 2 latitude bands: 35.0 and 37.5 degrees north. The longitude points are 95.0 and 97.5 degrees west.

4. Cloud Top Relative Humidity

Another atmospheric parameterization further reveals cloud features on this day. The four HIRS channel ratio combinations may yield markedly different cloud pressure estimates when cloud elements are thin and/or patchy in nature due to low cloud signal (the difference in upwelling radiance due to the presence of cloud). A priori knowledge of the region of the atmosphere where clouds exist may reveal the best channel combination to use. Unfortunately this knowledge rarely exists, so large differences in cloud-top pressure estimates may result. Therefore, there is a need for additional information to help choose the "correct" cloud-top estimate. Since cloud elements are often regions of increased moisture, cirrus uncinus a possible exception, a useful parameterization involves employing the input moisture profile to create a profile of relative humidity in the region of the cloud-top height estimations. A relative humidity value can then be diagnosed for each of the different cloud top heights. Heights that correspond areas with high relative humidity are treated with a greater degree of confidence than those with lower values. The relative humidity profile is created as a function of temperature and mixing ratio using the procedure outlined in Starr and Wylie,1990.

The Dec 5th 1991 NOAA-11 2108 UTC overpass provides some excellent examples of how the addition of the relative humidity data provide the necessary information to choose the proper channel combination cloud-top estimate. In the southern portion of the "Coffeyville ISCCP box", there appear to be broken cirrus at very high altitudes. The tropopause parameterization scheme increases the possible "cloud-top placement" region to 13.85 km (150 millibars). For the HIRS foot over Fort Smith, Arkansas (on the Oklahoma/Arkansas border), the five channel combination estimates are: 8.2, 7.4, 8.0, 10.3, and 13.84 km. The relative humidity values for the same combinations are 57, 40, 52, 90, and 40%, respectively. The 90% relative humidity value corresponds to the 10.3 km cloud top height. This value is consistent with the values estimated by aircraft to the northwest of Fort Smith, and the Monett Missouri Rawinsonde humidity trace. The relative humidity profile is only a good as the input moisture profile. While all input atmosphere profiles are converted to 40 levels for use in theoretical radiance calculations, the ECMWF profiles are input at 14 levels while rawinsondes are input at about 400 levels. One can see that the resolution of the sondes will yield more representative values for the 40-level relative humidity profile. Comparisons of the ECMWF and rawinsonde derived profiles yeilded similar results over the Coffeyville region. Dense spatial coverage of rawinsondes, input in ECMWF product, are responsible for the agreement. One would expect that over oceans and in the southern hemisphere, the ECMWF relative humidity profiles will be more suspect.

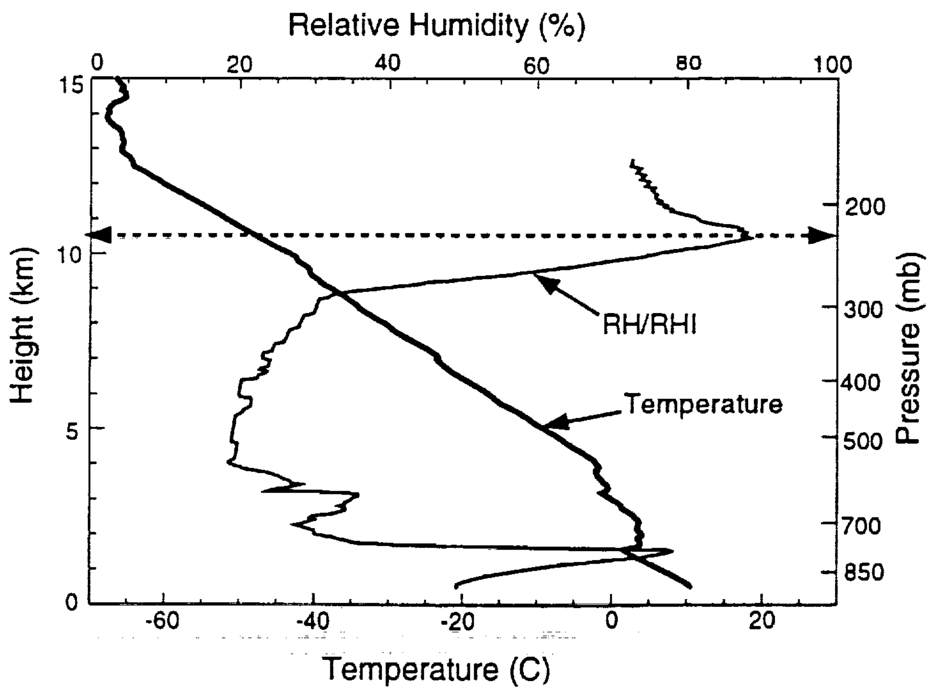

Figure 3. Rawinsonde temperature and relative humidity(liq/ice) trace for NWS Monett, Missouri Dec 6th 00UTC launch.

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