A Comparison of Model-Simulated Relative Humidity with Satellite-Derived Cloudiness

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Introduction

One of the unresolved problems in climate and numerical weather prediction is the treatment of cloudiness. In the real atmosphere, clouds are interactively linked to dynamical, hydrological, turbulent, and radiative processes over scales ranging from the microphysics of cloud particles to the synoptic and planetary scales of extensive multi-layered clouds. In current general circulation models (GCMs), clouds are not related to the hydrological cycle; they exist only for their direct impact on the radiation fields, and their characteristics (horizontal cover, height, optical properties) are either held constant or diagnosed from a limited set of parameters (Rutledge and Schlesinger 1985). Following Smagorinsky (1960), many modelers have relied on resolvable-scale relative humidity for diagnosing non-convective cloudiness; some investigators have incorporated a dependence on the vertical wind or the potential temperature (Hense and Heise 1984; Slingo 1980). Methods for linking clouds to the hydrological cycle or to the turbulent processes in GCMs are still in their infancy, although it is possible that liquid water will be explicitly predicted in the next generation of GCMs.

Few comparisons of observed clouds and related relative humidity fields have actually been performed so far because of the lack of adequate cloud climatologies and atmospheric data sets allowing one to make verifications. The recent availability of the International Satellite Cloud Climatology Project (ISCCP) data sets, a consistent and global cloud climatology, is of great interest for climate research; however, the resulting cloud climatology (consisting of 30-day means of cloud characteristics averaged over approximately [250 km^2]) may not be sufficient for validating cloud generation schemes. The comparison of model-generated parameters associated with observed cloudiness requires a more detailed approach: for example, model-generated relative humidity must be compared with observed cloudiness for a variety of meteorological situations, and the results must be examined in terms of physically significant and predictable parameters.

In an attempt to perform a preliminary study of the large-scale parameters associated with the formation, maintenance and dissipation of clouds at different altitudes in the atmosphere, we construct a data set including satellite-derived cloud heights and effective cloud amounts, as well as resolvable-scale relative humidity derived from daily 24-hour forecasts performed with the National Meteorological Center's (NMC) regional ETA step-coordinate model. The data set corresponds to a limited geographical area (western Atlantic Ocean over the Gulf Stream) and to a 1-month time period (January 1994). During this month, several extreme cold air outbreaks occurred in the study area, providing an abundance of low-level cloudiness. In addition, cyclogenesis was also quite common during this month, affording an excellent opportunity to study mid- and high-level cloudiness.

Satellite-derived cloud information is derived using the CO_2 slicing technique, which calculates both cloud top height, in terms of pressure, and effective cloud amount from radiative transfer principles. Applications of the CO_2 slicing technique have been described in the literature by Menzel et al. (1992). The satellite cloud heights are available at 0000 UTC and 1200 UTC throughout January 1994. The cloud top pressures are interpolated to 50-mb intervals. Twenty-four-hour forecasts of relative humidity, available at 50-mb resolution from 1000 mb to 100 mb, valid at the satellite analysis times are obtained.

Since the satellite estimates yield a cloud 'top' pressure, the relative humidity at the next lowest level (50 mb) in the atmosphere is collocated with the cloud top pressure, assuming the relative humidity is greater below the cloud than above. This assumption was valid nearly 100% of the time during the comparisons. Comparisons were segregated according to their height in the atmosphere, with cloud top pressures < 400 mb defined as high clouds, those between 400 mb and 600 mb as mid-level clouds, and those greater than 600 mb as low clouds. Since the horizontal resolution of the satellite information is finer than the 90-km resolution of the ETA model, there were occasions when more than one cloud top pressure per model grid point existed. In these situations, the lowest cloud top pressure (highest cloud) was chosen for the cross correlation since the CO_2 slicing technique performs best for high clouds.

Results

Figure 1(a-c) represents the histograms of the frequency of high, middle and low clouds, respectively, as a function of model-simulated relative humidities. Most high clouds corresponded to relative humidities greater than 80%, with the median of observations associated with humidities greater than 95%. The mean relative humidity was 90% with a standard deviation of 14%. Ten percent of the observations were, however, found with relative humidities as low as 26%. Overall, observations of high cloudiness correlated well with humidities, which are thought to be associated with the cloud formation.

The ETA model has 38 vertical layers. The best resolution is found in the boundary layer, with a secondary maximum in resolution placed around 250 mb in order to capture details in the vertical structure of the jet stream. This resolution may explain the good comparison at altitudes less than 400 mb.

In the middle troposphere (400-600 mb), cloudiness is associated with humidities between 20% and 98%, with the mean relative humidity being equal to 71% (Figure 1b). In addition, the standard deviation was 22.3%. Unlike high clouds, 50% of the mid-level clouds were found at humidities of at least 75%. Also 10% of the mid-level cloud observations had relative humidities as low as 21%.

In Figure 1c, results from the comparison of low-level clouds and relative humidities are shown. Here, the average relative humidity associated with low clouds was 58% with a standard deviation of 26%. The median relative humidity

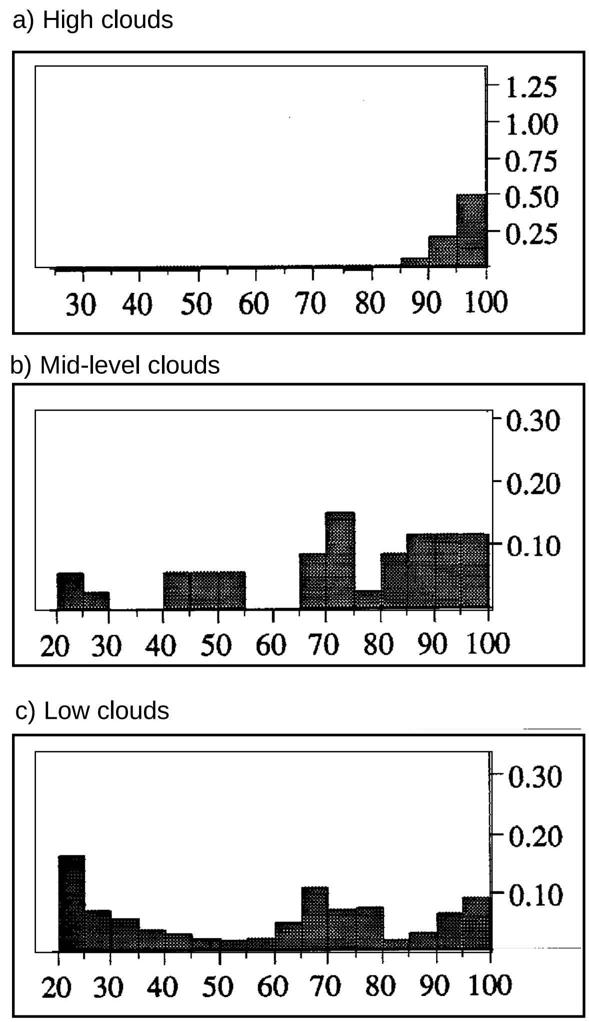

Figure 1. Histogram of the frequency of high, mid, and low clouds, as a function of relative humidity.

was 65%, that is, 50% of the observations had relative humidities above and below that value. Although more than half of the observations were correlated with humidities of at least 50%, slightly more than 20% of the time low clouds were found when humidities did not exceed 30%.

As alluded to earlier, low-level clouds cannot be estimated using the CO_2 slicing technique because of instrument noise problems. Therefore, a cloud top pressure is calculated directly by comparing the 11.2 mm infrared window channel brightness temperature with an in situ temperature profile. In these situations, the cloud is assumed to be opaque. Since not all low clouds are opaque, this assumption is not always valid; thus, errors in cloud top height arise. The degree of transparency of the cloud is the important consideration in determining the error. The more transparent the actual cloud, the more radiation below the cloud appears in the window channel radiance, thus increasing the error in cloud height. In these situations, the cloud top height will be underestimated.

Discussion

Regional scale numerical models, such as the one used in this study, and their associated relative humidities appear to be coincident with observed high- and mid-level cloudiness. This is true since large-scale dynamics of the atmosphere produce most high- and mid-level cloudiness. However, according to the model predictions, high/mid clouds may be found at humidities much below 100%. Furthermore, in this preliminary study, the model was unable to resolve the relative humidity fields associated with sub-grid-scale dynamics which produce low clouds (i.e., cumulus). This is obviously a function of the cumulus parameterization scheme used. Further work is ongoing to better correlate observed cloudiness with model-generated dynamical and thermodynamical fields.

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