NWP Cloud Initialization Using GOES Sounder Data and Improved Modeling of Nonprecipitating Clouds

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ABSTRACT

Cloud-top pressures and effective cloud amounts, derived from Geostationary Operational Environmental Satellite (GOES) sounders, are used to specify a three-dimensional mesoscale cloud field for numerical weather prediction. A bulk cloud parameterization scheme based on relative humidity is introduced into the forecast model to efficiently use the satellite sounder observations. The cloud initialization and bulk cloud parameterization are tested in the Cooperative Institute for Meteorological Satellite Studies Regional Assimilation System for summer and winter periods. Comparisons between cloud forecasts and GOES cloud observations for four model configurations are presented. It is shown that the use of the initialization improved the areal coverage of the nonprecipitating clouds early in the forecast period, which translated to an improvement of the precipitation equitable threat score for the 24-h forecast (when the model initial time was 1200 UTC) and the 36-h forecast (when the model initial time was 0000 UTC).

1. Introduction

Satellite observation of clouds began with the first visible images made from space in 1960. Today, instruments on weather satellites are used to estimate many meteorological variables, including cloud parameters. Two products derived from the infrared sounder on board the Geostationary Operational Environmental Satellites (GOES) (Menzel et al. 1998), when clouds are detected, are an estimate of cloud-top pressure (CTP) and the effective cloud amount (ECA). These products are determined by CO$_2$ absorption techniques and a “split window” technique (Menzel et al. 1992; Smith et al. 1974). An assessment of these data was done by Schreiner et al. (1993) where the authors state that the satellite-derived cloud parameters are most reliable above 400 hPa. Diak et al. (1998) showed that a simple adjustment to the surface thermal infrared radiation, using these data, improved the temperature prediction in a version of the Cooperative Institute for Meteorological Satellite Studies (CIMSS) Regional Assimilation System (CRAS).

Cloud modeling by operational numerical weather prediction (NWP) models is becoming more sophisticated. The Eta Model (Rogers et al. 1996) at the National Centers for Environmental Prediction (NCEP) incorporates a cloud prediction scheme that represents cloud water explicitly in the prognostic equations (Zhao et al. 1997). The Rapid Update Cycle includes explicit moisture microphysics adapted from the Pennsylvania State University—National Center for Atmospheric Research fifth-generation Mesoscale Model (Brown et al. 1998). To date however, neither model initializes clouds with cloud observations.

A number of researchers have used satellite data to refine an initial gridded cloud field. Wu and Smith (1992) presented an assimilation scheme of Earth Radiation Budget Experiment data that optimized the model-diagnosed fractional cloud cover at initialization time. Their scheme showed a positive impact on the surface temperature for a winter case. In Koch et al. (1997), the authors employed a statistical treatment of satellite infrared and visible moisture retrievals to create mesoscale detail of relative humidity and the surface moisture availability at the model initial time. They concluded that their method resulted in positive impact on forecasts of surface temperature, frontal dynamics, and precipitation. Zhang et al. (1998) reported on a cloud analysis procedure that incorporated cloud information from satellite infrared and visible imagery data, radar reflectively, surface reports, and aviation routine weather reports to specify three-dimensional cloud and precipitate fields. Lipton and Modica (1999) assimilated visible-
band satellite data and tuned their model solar radiation parameterization to obtain maximum agreement between the model-calculated surface insolation and that inferred from visible satellite data. Their adjusted scheme forecasts showed a positive impact on the surface temperature for at least a 6-h forecast. In addition, they mentioned that the assimilation of satellite cloud data can prove beneficial only if a mechanism exists to propagate information from the analysis to the forecast period.

In this paper, a two-tiered relative humidity scheme is introduced to efficiently use the satellite observations (section 2). This simple parameterization represents nonprecipitating clouds. Nonprecipitating implies that no measurable rainfall is calculated at the model surface from these clouds. Clouds are initialized using GOES sounder observations (which are available in real time) of CTP and ECA to improve the mesoscale cloud fields in a model cloud analysis scheme (section 3) in a version of the NWP mesoscale model, CRAS (section 4). Forecasts are evaluated against subsequent GOES cloud cover observations. Comparisons between CRAS cloud forecasts and GOES observations for four model configurations are presented in section 5 with a summary in section 6.

2. Representation of nonprecipitating clouds in explicit cloud calculations

For many years it has been recognized that it is difficult to reproduce the calculated cloud cover in forecasts from NWP and climate models (Smagorinsky 1960). Given the coarseness of NWP grid resolution, the models are really describing cloud systems, not individual cloud cells. Nevertheless, with advances in our knowledge of cloud physics, improved model resolution, and more realistic physical parameterizations, there have been improvements in cloud modeling, cloud feedback, and cloud cover estimates (Lopez 1977; Tiedtke 1993). While early studies may have crudely prescribed clouds from mean zonally averaged climatological values, today’s models include prognostic calculations of the cloud liquid water and/or ice content using parameterizations of cloud microphysical processes. Uncertainties in estimating these processes remain, as well as in the parameterization of other subgrid-scale features that influence cloud detrainment and growth factors (Tiedtke 1993). When numerical forecasts consistently do a reasonable job in estimating the precipitation amount and distribution, it must be assumed that the predicted mesoscale complex of precipitating clouds is adequately represented, at least with respect to areal coverage. However, it is our experience with the CRAS, described in Raymond and Aune (1998), Raymond et al. (1995), and Diak et al. (1992), that the forecast accuracy of nonprecipitating clouds varies dramatically with time of day, location, and synoptic condition. The production of nonprecipitating clouds in the CRAS appeared to be inadequate, especially early in the forecast period. There is an underproduction at some levels and overproduction at other levels of nonprecipitating clouds that seems to be common in NWP models.

Fractional (RH) cloud schemes (Zhang et al. 1998; Zhao and Carr 1997; Zhao et al. 1997; Koch et al. 1997) are commonly used today. Such schemes allow condensation of cloud water to occur for RH less than one since RH is calculated over a finite grid box. The regional model at NCEP, theEta, uses the same threshold for both condensation and evaporation though they vary for land (RH = 0.75) and ocean (RH = 0.80) (Q. Zhao 1999, personal communication). The difficulty in predicting nonprecipitating clouds is associated with a number of factors, including the coarse resolution of the model grid and topography, inadequacies in the model physics and subgrid-scale parameterizations, lack of surface detail in surface–air flux calculations, the effects of nonconservative horizontal smoothing and numerical approximations, and inadequate observational data.

Some nonprecipitating clouds owe their existence to boundary layer turbulence and other subgrid-scale processes, while others may be connected to advective processes, for example, tropical plumes. Improved techniques, such as nonlocal turbulence parameterizations (Raymond and Stull 1990; Raymond 1999) and conservative moisture advection schemes (Rasch and Williamson 1990) improve model estimates of clouds. However, many nonprecipitating clouds cannot be resolved since individual clouds occur on scales much smaller than mesoscale models can accurately depict. With the growing trend toward using prognostic cloud physics in NWP, there is a need to identify parameterization techniques that enhance the production of nonprecipitating clouds.

The production of clouds in the atmosphere commences when the cloud water mixing ratio $q_{\text{cloud}}$ is near or exceeds the saturation mixing ratio $q_s$. Mixing ratios slightly less than $q_s$ are often substituted for $q_s$ in numerical models in order to enhance model precipitation and cloud production (Smagorinsky 1960; Slingo 1980; Geleyn 1981; Morassutti 1989; Koch et al. 1997). This approach is used commonly in regional, global, and climate models because the cloud water must be distributed over a grid volume. However, several studies have identified that the relationship between RH and observed cloud cover is not well understood (Wu and Smith 1992; Soden 1993). Udiedhofen and Hartmann (1995) found in the Tropics that the upper-tropospheric humidity actually lags the diurnal cycle of upper-tropospheric clouds. Nonetheless, in the absence of a better estimation parameter, the CRAS uses a relative humidity of 100% to activate cloud formation, and a profile of RH values less than 100% to activate evaporation of cloud water or cloud ice.

The CRAS cloud parameterization scheme is based on two critical relative humidities (RH, saturation, and RH, evaporative) with two corresponding critical mixing ratio
limits, which can be tuned as desired. When using two RH limits, it enables the modeler to separate questions concerning cloud cover prediction from the topic of precipitation prediction. Thus, the two-tiered approach proposed here is fundamentally different from lowering the RH to estimate a critical saturation mixing ratio.

GOES sounder observations are used to initialize non-precipitating cloud. The two-tiered cloud parameterization works by allowing predominately nonprecipitating clouds to exist above some “evaporation” relative humidity \( \text{RH}_s \), that is, when \( \text{RH} > \text{RH}_s \). Except during the cloud initialization at the beginning of the forecast, the condensation of cloud water or cloud ice can only occur when \( \text{RH} > \text{RH}_e \) (\( \text{RH}_e = 100\% \)). However, in our cloud parameterization, clouds can only evaporate when the lower relative humidity criterion has been reached, that is, \( \text{RH} < \text{RH}_s \). Thus clouds that are largely nonprecipitating can exist when the RH falls between the two limits satisfying \( \text{RH}_s < \text{RH} < \text{RH}_e \).

The evaporation humidity profile \( \text{RH}_e \) used in the forecast model is similar to those used by others (Koch et al. 1997) and is tuned so the forecasted cloud cover compares reasonably well against cloud observations measured from GOES. That is, model parameters were adjusted within reasonable values to produce realistic cloud forecast results. As shown in Fig. 1, the \( \text{RH}_e \) profile is 0.9 at the surface, decreases linearly to 0.65 at sigma = 0.65 (about 660 hPa), and increases linearly above that to 0.9 at 300 hPa. The minimum at about 660 hPa increased cloud retention at that level since the CRAS otherwise did not maintain enough midlevel clouds.

To place the above discussion into a more mathematical form let us define the increment of condensed grid-scale cloud mixing ratio \( \delta q_{\text{cloud}} \) (at a single time step) as

\[
\delta q_{\text{cloud}} = \begin{cases} 
(q - q_e)/(1 + L^2 q_e (c_p R_e T^2)^{-1}), & q > q_e \\
0, & q < q_e.
\end{cases}
\]

Here \( L \) is the latent heat of condensation, \( c_p \) is the specific heat at constant pressure, and \( R_e \) is the moist gas constant. In (1) the extra factor in the denominator represents the compensation for warming by latent heating (Asai 1965). The saturated mixing ratio \( q_s \) is defined by

\[
q_s = 0.622 e_s / (p - e_s),
\]

where \( e_s \) is the saturated vapor pressure and \( p \) is the pressure.

The evaporation process is described by

\[
\delta q_{\text{cloud}} = \begin{cases} 
f_s(q - q_e)/(1 + L^2 q_e (c_p R_e T^2)^{-1}), & \text{RH} < \text{RH}_e \\
0, & \text{RH} > \text{RH} > \text{RH}_s,
\end{cases}
\]

where

\[
f_s = (1 - \text{RH}/\text{RH}_s)^2
\]

and \( q_e \) is the mixing ratio for \( \text{RH} = \text{RH}_s \) (i.e., \( q_e = \text{RH}_s \)). Provided \( q_{\text{cloud}} > 0.0 \). The actual evaporation may be less than the \( \delta q_{\text{cloud}} \) predicted by (3) if \( q > q_s \) is reached. That is, once \( \text{RH}_s \) is exceeded, evaporation is turned off. The parameter \( f_s \) adjusts the evaporation since the smaller the difference between the observed RH and \( \text{RH}_s \), the less the evaporation is at that time step. The region where \( \text{RH}_s > \text{RH} > \text{RH}_e \) is where clouds are allowed to exist even though saturation is not maintained. Note that (1) and (3) describe a hysteresis (lag) since clouds condense when \( \text{RH} > \text{RH}_s \) but can only evaporate for \( \text{RH} < \text{RH}_s \).

It is our hypothesis that the hysteresis between condensation and evaporation of the cloud water (ice) is physically realistic. This lag is caused primarily by the uneven, irregular, and scale-dependent behavior found in the subgrid-scale cloud entrainment and detrainment processes, causing some fraction of the cloud or cloud system to be mixed away by the drier environmental air faster than others. Additionally, in this range of relative humidities between \( \text{RH}_e \) and \( \text{RH}_s \), there is a near balance between the formation of (fractional) clouds and the evaporation of clouds. The hysteresis provides a simple tunable parameterization that increases areal cloud cover in numerical model forecasts without significantly altering the precipitation.

The scheme for retaining clouds when \( \text{RH}_s < \text{RH} < \text{RH}_e \) should not be interpreted as meaning that there is a clear physical distinction in microphysical behavior between precipitating and nonprecipitating clouds. Even as the relative humidity decreases below \( \text{RH}_s \) there is some small potential to produce precipitation, especially if rain or ice droplets are falling from above through the cloud, but in most cases the precipitation fails to reach the earth’s surface. Thus the distinction between precipitating and nonprecipitating clouds does not allow...
a clean separation. The purpose of the proposed scheme is to increase the areal coverage of clouds, especially those that are nonprecipitating, in an attempt to compensate for model and scale deficiencies that fail to produce the correct cloud cover.

3. Cloud analysis

a. Cloud-top pressure and effective cloud amount from the GOES sounder

The CO₂ absorption and split-window techniques are used to derive CTP and ECA. The first method is applied from 150 hPa to about 600 or 650 hPa, when this method fails to converge. Then the split-window method is applied until the surface is reached. An example of the GOES coverage on the CRAS grid is shown in Fig. 2 for 1200 UTC 4 December 1997. The northernmost extent of the data is approximately 50°N. This area is scanned every hour by the sounder. Cloud information from the sounder is used operationally by the National Weather Service to supplement the Automated Surface Observing System (ASOS) ground-based cloud measurements. Each sounder field of view (FOV) has a resolution of about 10 km at the subsatellite point. CTP is the height of the top of the cloud given in pressure (hPa) units. CTP is calculated for each FOV and then a composite average is calculated. The composite CTP average uses only the cloudy FOVs so that a clear FOV does not diminish the amount of cloud. The data then are averaged over an array of 5 × 5 FOV. Thus the horizontal resolution of the 25-FOV data is approximately 50 km. The algorithm produces values of CTP that range from 150 to 950 hPa. A value of 1013.0 hPa is assigned for clear FOVs. No indication of cloud depth is made. ECA is the ratio of the number of cloudy FOVs to the total number of FOVs (25 in this paper) and is also a function of the percentage of FOVs that is covered by cloud and the optical thickness of the cloud. The ECA is given as a percentage, where 0% is the ECA for clear skies. If 1 out of 25 FOVs is occupied by an optically thick cloud, an ECA of 4% is recorded. If all FOVs are occupied by clouds that have an optical thickness of 25%, then an ECA of 25% is made. The latitude and longitude of the observation is the centroid of the 5 × 5 box, where the centroid is weighted toward the locations of the clouds (see Schreiner et al. 1993). An example of part of an ASCII file containing these data is given in the appendix.

b. CRAS cloud analysis

The CRAS moisture variable is mixing ratio. Hence clouds are described by a three-dimensional mixing ratio array, \( q_{\text{cloud}} \), with units of g g⁻¹. This single array accounts for both frozen and liquid water states. The current CTP–ECA observations are objectively analyzed onto the model grid using a modified successive corrections algorithm based on Cressman (1959). The CRAS uses cloud data from 900 to 150 hPa. To compensate for inaccuracies over high terrain (less than 800 hPa) they are constrained to be at least 50 hPa above the model topography. Cloud presence is predicated on an ECA of 50% over a grid box. In the vertical, the model layer that contains the CTP value is filled with cloud. The model cloud analysis compares the observed cloud field to the previous 12-h CRAS forecast (background).
Case 1. If the background does not have cloud \( q_{\text{cloud}} = 0 \), but the GOES sounder indicates one is present, then the model \( q_{\text{cloud}} \) is adjusted at that location such that \( q_{\text{cloud}} \) is slightly smaller than the 0.5 g m\(^{-3}\) autoconversion limit. Since this cloud scheme has the limitation that it is for nonprecipitating clouds only, it is desirable to avoid activating precipitation in the cloud physics. The RH is adjusted to \( \text{RH} + 3\% \) to ensure cloud retention. When a new cloud is specified, it is limited to a thickness of two adjacent model sigma levels (the pressure layers are 0.034 sigma thick, approximately 34 hPa). This thickness limit is imposed since we are interested primarily in the radiative properties of the cloud so the exact thickness is of lesser importance. Multiple cloud layers are allowed if the observed CTP is at a smaller pressure and is separated by more than 100 hPa from the background CTP.

Case 2. If the background indicates a cloud lower in the atmosphere than the observed CTP, then two cloud layers are specified. For example, a background field cloud may exist at 700 hPa and a CTP retrieval at 500 hPa. Then, in the model column, the 700-hPa cloud is left in place and the 500-hPa cloud is added. These two separate cloud model layers are allowed since nothing is known about the lower clouds from GOES data and multiple layers of cloud are realistic.

Case 3. When the observed cloud is lower in the atmosphere than the background cloud, the background cloud is removed and the observed cloud is specified by modifying \( q_{\text{cloud}} \) to match the observed CTP.

Case 4. If the background shows cloud and the sounder indicates clear, the cloud mixing ratio profile is set to zero (any rain is also removed) and RH is reduced to a sub-RH\(_0\) level as given by (3).

Case 5. No action is taken in the final case where both the background and GOES observation indicate no cloud.

4. CIMSS Regional Assimilation System

a. Model overview

The CRAS is an improved version of the original Australian Bureau of Meteorology Research Centre’s operational analysis (Mills and Seaman 1990), vertical mode initialization (Bourke and McGregor 1983), and semi-implicit forecast model (McGregor et al. 1978; Leslie et al. 1985). Our calculations used a horizontal grid spacing of 80 km on an 113 × 83 lattice, with the vertical sigma coordinate divided into 30 levels. The horizontal extent is the entire plotting area in Fig. 2, which also shows the sounder coverage. During each time step, the horizontal wind components, and temperature and mixing ratio fields are smoothed using a sixth-order implicit low-pass tangent filter (Raymond 1988), with a filter parameter set sufficiently large to provide a limited amount of horizontal mixing. Cloud and rainwater are horizontally discontinuous quantities and are not filtered, nor is horizontal diffusion applied.

In our forecasts, cloud liquid water quantities appear to be of the proper magnitude (Raymond et al. 1995) and the lack of horizontal mixing has so far not presented any numerical stability problems. Horizontal diffusion is not used, but vertical turbulent exchange is modeled using a \( K \)-theory scheme. The magnitude of the \( K \)-theory coefficients is computed each time step using a modified turbulent kinetic energy expression evaluated using nonlocal techniques (Raymond 1999).

The forecast model contains explicit conservation equations for cloud water and rainwater (Diak et al. 1992; Raymond et al. 1995). Ice clouds are diagnosed following Dudhia (1989) except supercooled water droplets are allowed for temperatures 258–273 K. The cloud physics parameterization uses a modified Kessler-type scheme (Kessler 1974), while the condensation and fall velocity calculations are similar to those described in Asai (1965) and Liu and Orville (1969). Cloud and rainwater quantities are used in all calculations involving the virtual temperature; that is, water loading is included. The parameterization of deep cumulus convection is accomplished using a modified Kuo scheme (Sundqvist et al. 1989). Clouds that cap the boundary layer are estimated by a shallow cumulus parameterization that depends on the turbulence scheme and is based on a nonlocal evaluation of total kinetic energy. This is a commonly used parameterization where specific humidity is conserved. A parcel is assumed to rise adiabatically from the surface to the top of the boundary layer defined by the turbulence scheme. If condensation is reached, then all turbulent layers satisfying this criterion are assigned clouds with water concentrations below the precipitation (autoconversion) threshold.

As suggested in the hybrid scheme described in Molinaro and Dudek (1992), a fraction of the convective cloud and rainwater is detrained to the grid-scale cloud variables. In the hybrid scheme, convective rainwater is not instantaneously converted into surface precipitation. To increase the opportunity for (additional) evaporation, the hybrid approach explicit cloud calculations contain both time-dependent liquid water advection and rainwater fallout calculations. A grid-scale rain drag is included as a Rayleigh damping term to help control the production of excessive precipitation (Raymond and Aune 1998).

The CRAS is configured to use GOES data in real time on a routine forecast schedule. The daily forecasts can be accessed on the CIMSS Web site.\(^\dagger\)

The routine CRAS runs started ingesting GOES cloud data in 1996. Conventional rawinsonde and surface data are acquired from NCEP. Boundary and initial con-

\(^\dagger\) The CIMSS Web site URL is http://cimss.ssec.wisc.edu/model/daily/daily.html.
ditions are specified using NCEP’s regional ETA model (Rogers et al. 1996).

b. Configuration of the four experiments

CRAS runs were made for four model configurations as summarized in Table 1. Forecasts of 36 h were made for each period of this study; one period covered summer conditions and the other winter. No GOES sounder cloud information was used in experiments 1 and 2. Experiment 1 (the control), allowed condensation of cloud water only at a relative humidity greater than 1.0. Nothing was done to enhance nonprecipitating clouds. Experiment 2 parameterized nonprecipitating clouds as described in section 2. Experiments 3 and 4 used the two-tiered approach of section 2 and added GOES sounder cloud data in the initial fields for experiment 3 and every 3 h in a 12-h preforecast for experiment 4. The preforecast started at the forecast initial time minus 12 h ($t - 12$) so that the data were assimilated 3-hourly for 12 h prior to the forecast initial time. Thus, the data were inserted a total of five times. $t = 0$, $t = 12$, $t = 24$, $t = 36$, and $t = 48$, with an assimilation of conventional data at time $t$. The CRAS preforecast mixing ratio field was used as the $t = 0$ first guess whereas the temperature and winds came from the ETA. In this manner, the moisture gradient information provided by the cloud data was maintained.

5. Experiment results

Figure 3 displays an example of the growth with time of the three-dimensional total area precipitable water (PW, mm) for 4 December 1997 in the four CRAS experiments. It shows the progression of the differences between the four experiments. Since the forecast initial time was 1200 UTC 4 December 1997, experiment 4 began with a 12-h preforecast at 0000 UTC 4 December 1997. Experiment 1 exhibited the lowest PW since the nonprecipitating cloud scheme was not implemented. The PW in experiment 2 exceeded that in experiment 1 after the initial few hours. This is an indication of two things: the time required to preforecast the model clouds was about 2–3 h, and parameterization of nonprecipitating clouds did indeed result in more clouds. Assimilation of cloud data at the initial time in experiment 3 resulted in about 100 mm more PW at the initial time but after that the growth was similar to that of experiment 2. For experiment 4, a notable decrease in PW occurred at the $t = 0$ insertion because an analysis of conventional data was performed after this assimilation. Experiment 4 was able to support more cloud earlier in the forecast because it already had the PW well established due to the preforecast. The fact that the PW for experiments 2–4 merge at the end of the 48-h forecast period showed that the GOES cloud data lost its impact on the CRAS by that time.

For verification of the forecast clouds, we calculated the equitable threat score (ETS) on the CTP, which we call CTP ETS. A perfect ETS is 1 and a no-skill ETS is 0. The ETS was computed over the atmospheric layer from the upper extent of the data, 150 hPa, to 650 hPa since it was in this layer that the CO$_2$ slicing technique was applied (and thus there is the greatest degree of confidence in the data). The verification area excluded the five outermost rows and columns of the computational grid. If the model field showed a cloud anywhere in the defined layer and the GOES cloud observations confirmed the cloud, a hit was tallied. Figure 4 illustrates the average CTP ETS for the July and December 1997 periods. At the zero hour, the CTP ETS for experiments 1 and 2 was low (about 0.05–0.1) since no cloud information was used. One insert of CTP data (expt 3) raised the CTP ETS to 0.2–0.35 and five inserts (expt 4) raised the CTP ETS to 0.35–0.4. Experiments 3 and 4 show that the model maintained information provided by the GOES cloud data to about 6 h but that its largest impact was at the initial time. The higher values of CTP ETS at the 12-h forecast in Fig. 4b may result from an updated guess (from the ETA model) to the cloud retrievals. To confirm that it was not the preforecast alone that improved the cloud forecast, a run was done for a preforecast without any GOES sounder cloud data. The 3-hourly CTP ETS for this run was always lower than that of experiments 3 and 4.

A July 1997 example of runs from experiment 2 (no

### Table 1. Configuration of the four CRAS experiments.

<table>
<thead>
<tr>
<th></th>
<th>Expt 1</th>
<th>Expt 2</th>
<th>Expt 3</th>
<th>Expt 4</th>
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<td>GOES sounder cloud data</td>
<td>No</td>
<td>No</td>
<td>Yes, at initial time</td>
<td>Yes, 3-hourly in preforecast</td>
</tr>
<tr>
<td>New modeling of nonprecipitating clouds</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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Fig. 3. Total area precipitable water (mm) vs forecast hour for four CRAS experimental model runs. The initial time for expts 1–3 was 1200 UTC for 4 Dec 1997. Expt 1 was the control, expt 2 included a nonprecipitating cloud parameterization, expt 3 added GOES CTP data at the initial time, and expt 4 added 3-hourly GOES CTP data for a 12-h preforecast.
GOES CTP data) and experiment 4 (3-hourly GOES CTP data) and the verifying GOES CTP data is shown in Figure 5. The 3-h forecasts for experiment 2 and experiment 4 are in Figs. 5a and 5b, respectively. Figure 5c depicts the 50-km resolution data objectively analyzed on the 80-km CRAS grid. The model depiction of clouds over the western half of the United States was more complete and the model began to fill in the eastward line of convection. The cell over Georgia was also better represented. A gap existed in the coverage between GOES-8 and GOES-9 over the north-central portion of Mexico so the north–south line of cloud there was missing in Fig. 5c. A corresponding set of fields valid at 1500 UTC 7 December 1997 is shown in Fig. 6. The spatial extent of the clouds over the western half of the United States was more accurate as was the cloud mass across Mexico and along the Gulf coast. Again the coverage gap was apparent in Fig. 6c.

Verifying precipitation observations were rain gauge data from National Weather Service River Forecast Centers, taken over 24-h periods that operationally start at 1200 UTC. Thus, for 0000 UTC runs, the 12–36-h forecast was verified, and for 1200 UTC runs the 0–24-h forecast was verified. ETS for 24-h integrated amounts of precipitation greater than a trace were calculated. These ETSs indicated improvement with the use of the GOES cloud data in experiments 3 and 4. The average equitable threat score for the July period improved 3.9% for experiment 3 and 5.3% for experiment 4 in comparison to the control, experiment 1. For the December 1997 period, the ETS improvement for experiment 3 was 0.36% and for experiment 4 was 4.8%.

The root-mean-square (rms) difference of the sounder-derived CTP versus the model-produced CTP was decreased by the cloud data most notably at the initial time. Figure 7 illustrates the rms difference of the CTP every 3 h out to 12 h, and also at 24 h, for the July experiments (Fig. 7a) and the December experiments (Fig. 7b). The differences between the four experiments were very small everywhere except at the initial time.
Inclusion of the GOES cloud data slightly cooled the model atmosphere. This is reasonable since additional cloud would reduce total insolation. The rms errors and biases of dewpoint temperature and surface temperature, following the model preforecast period, of the four experimental runs, were so small that they are not presented here.

6. Conclusions

The cloud scheme used for this study was purposely simple and thus easily implemented. The two-tiered RH scheme is highly tunable as seen by Fig. 1. Other NWP models would require specific tuning. GOES sounder cloud data, averaged over a 50-km grid, were used to indicate the presence of cloud. We did not intend to define specific types of clouds or precipitation since distinction of cloud or ice particle types is not easily accomplished using an infrared sensor. These NWP runs generally indicated that GOES cloud data were valuable in defining the cloud field at the model initial time. The total PW generated by experiments with a 12-h preforecast assimilation of GOES cloud data was much greater than that of experiments without it, especially during the first 12 h of the forecast. The rms differences of the cloud-top pressure indicate general improvement in the initial cloud field, but by 3 h, the differences between the experiments were very small. An equitable threat score calculation on the cloud field shows significant improvement out to a 6-h forecast with the use of GOES cloud data. The 24-h precipitation ETS indicates improvement for the 0–24-h forecast (for initial time at 1200 UTC) and the 12–36-h forecast (for initial time at 0000 UTC). Since the clouds improved within the first 6 h of the forecast period, the precipitation was most likely improved for about the same period. Still, this translated as a positive impact on the 24-h ETS.

Plans for future testing include hourly ingestion of these data in short-term (1–3 h) forecasts. This may also be done with the work station version of the Eta Model that runs at CIMSS. Additionally, testing of single field of view (10-km horizontal resolution) data, which will eliminate spatial averaging, is planned.

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APPENDIX

Sample Sounder Cloud Data File

The listing in Table A1 is an example of part of an ASCII file of GOES sounder cloud data. The filename is 26Feb99.12z.g10.ecldc. The current version of these data is 3 x 3 FOVs whereas previously 5 x 5 FOVs were made. The last five digits of the LDAY block give Julian date. The LTIM block gives the scan line time as HHMMSS. Next are latitude and longitude (Western Hemisphere is positive) in degrees. Column CA is effective cloud amount. PCT is the pressure of the cloud top (elsewhere denoted as CTP). Clear is reported as 1013.0. Column TC is the brightness temperature in degrees kelvin. NUM is the number of cloudy FOVs. XPCT is the maximum CTP; NPCT is the minimum CTP and VPCT is the variance. Missing data are denoted by 9999.9. These hourly data are available by anonymous ftp to suomi.ssec.wisc.edu on directory pub/rtascii.

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REFERENCES

Raymond, W. H., 1988: High-order low-pass implicit tangent filters...


