Improved Treatment of Surface Evapotranspiration in a Mesoscale Numerical Model

C-R Chen and P. J. Lamb
Cooperative Institute for Mesoscale Meteorological Studies and
School of Meteorology
The University of Oklahoma
Norman, Oklahoma

Surface evapotranspiration can affect the formation processes of low-level clouds and even precipitation. Accordingly, in daily short- and medium-range forecast applications, an inappropriate representation of evapotranspiration leads to errors in cloud predictions and precipitation forecasts. A much better precipitation forecast can be anticipated due to a more realistic thermodynamic structure resulting from the improved estimation of evapotranspiration. In addition, a more accurate estimation of surface evapotranspiration would be very beneficial to the understanding of atmosphere-land exchange processes and the formation mechanisms of low-level clouds and precipitation. To that end, a confident prediction of surface evapotranspiration will help to further identify the complicated radiative transfer processes exerted by clouds, which is one of the main objectives of the Atmospheric Radiation Measurement (ARM) project.

A series of Pennsylvania State University/National Center for Atmospheric Research MM4 model runs showed that the simplified Manabe bucket method to parameterize surface evapotranspiration tends to overestimate that process during both nighttime and daytime, due to 1) the inappropriate assignment of a parameter called the moisture availability (M) in the method, and 2) the use of the saturation mixing ratio at the skin temperature as the surface mixing ratio. It was also noted that the degree to which the latent heat flux is overestimated decreases with the forecast time—the so-called spinup problem that is common in many numerical models owing to an inadequate assignment of the initial skin temperature and the associated saturation surface mixing ratio.

A Penman-Monteith method, which 1) excludes the use of the hypothetical saturation mixing ratio at ground surface to estimate the moisture gradient between the ground and lowest model level, 2) includes the effect of stomatal resistance, and 3) uses the surface energy balance as a bound to estimate potential evapotranspiration in each model grid, was implemented into the modeling system and shown to lead to a more reasonable estimation (less overestimation) of evapotranspiration. The degree to which the latent heat flux is overestimated or underestimated by the PM method is mainly controlled by the setting of stomatal resistance. Less surface evapotranspirative cooling, as implied by the PM method, led to a warmer skin temperature and, thus, a stronger estimation of the daytime sensible heat flux by the model. Relative to the bucket method, the PM method led to less moisture supply from the model's ground surface and, thus, a reduced probability of low-level cloud formation. A more reasonable estimation of net radiation at the ground surface was then proven to be associated with the use of the PM method. The PM method restricts the moisture supply from the ground surface; thus, the model was able to predict the amount and tendency of the mixing ratio at the lowest model level (about 40 meters above ground level), which is more agreement with the corresponding observations.

The Gal-Chen Four-Dimensional Data Assimilation (FDDA) technique for assimilating satellite measurements was also implemented into the model in hope of further improving its estimation of surface evapotranspiration. This FDDA technique seeks to adjust the model's temperature and geo-potential height at all vertical levels in the atmosphere and the ground surface based on the information from satellite measurements.

Observing system simulation experiments (OSSEs) and real satellite (Geostationary Operational Environmental Satellite) temperature data assimilation experiments have shown that, when the bucket method is in use during the data assimilation period, the assimilation of satellite temperature measurements helps the model better estimate the surface evapotranspiration during the ensuing forecast period. This results from a significant decrease of potential evapotranspiration due to 1) a pronounced decrease of skin (ground surface) temperature, 2) a decrease of saturation mixing ratio at the ground surface, and 3) a decrease of moisture gradient between the ground surface and lowest model level. When the PM method was in use, the assimilation of GOES data tended to 1) decrease the temperature and associated saturation mixing ratio at the lowest model level, and 2) increase the mixing ratio at the lowest model level during the data assimilation period. The potential evapotranspiration was then decreased during the data assimilation period. Therefore, the model was better able to correctly estimate the latent heat flux after the data assimilation period.

This shows that Gal-Chen's FDDA algorithm for assimilating GOES data gives the model using the PM method a greater possibility of yielding the most accurate estimation of evapotranspiration. Also, with the insertion of GOES data, the model with the bucket method has a higher probability of more accurately estimating the latent heat flux, than does the model using the PM method without the GOES data insertion.

Furthermore, a nudging technique was shown to enhance the advantages of the proposed FDDA algorithm, by making the model generate a more realistic assimilation period estimation of surface evapotranspiration resulting from a further decrease of the skin temperature, the temperature at the lowest model level, and the accompanying ground surface moisture content.

A higher frequency of GOES data insertion did not necessarily lead to a more accurate estimation of latent heat flux by the model (using either the bucket or PM method). A higher frequency of data insertion may cause too much noise in the model during the data assimilation period and result in a worse latent heat flux estimation during the forecast period. In addition, as long as the degree of the reduction of skin temperature, temperature at the lowest model level, saturation surface mixing ratio, and saturation mixing ratio at the lowest model level, or the degree of the increase of mixing ratio at the lowest model level were not sufficient enough during the data assimilation period, the positive impact of GOES data on the model's latent heat flux estimation was less pronounced during the simulation or forecast period.