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# Improvement of Land Surface Skin Temperature in NCEP Operational NWP Models and Its Impact on Satellite Data Assimilation

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## 1. Introduction

Satellite measurements in various spectral channels are assimilated through the JCSDA's Community Radiative Transfer Model (CRTM) on the NCEP Gridpoint Statistical Interpolation (GSI) (Wu et al. 2002). Currently, satellite measurements over ocean have been successfully utilized to improve numerical weather prediction (NWP). However, it is found that the amount of satellite data assimilated over land in the GSI/CRTM is far less than over ocean. One of the chief reasons is that there is a much larger cold bias in the current NCEP operational Global Forecast System (GFS) predicted land surface skin temperature (LST) over desert and arid regions during daytime in the warm season. LST predicted by the GFS is a critical factor to determine brightness temperature (Tb) simulation for satellite surface sensitive channels. After having compared LST in GFS/GDAS with that from GOES-derived or SURFRAD observations in summer, we found GFS/GDAS has a substantial cold bias of more than -12K over the arid western CONUS during daytime (Zheng et al., 2008). With such a large cold bias in LST, the CRTM simulates unreasonable brightness temperatures, thus most of satellite data are rejected in the GSI/CRTM analysis step, especially for surface sensitive satellite channels.

An investigation in GFS testing has revealed a major cause of the cold daytime LST bias is in the treatment for roughness lengths, particularly thermal roughness length ($z_{0t}$) in the physics of surface turbulent heat transfer. In this study, alternative formulations of momentum and thermal roughness lengths developed by Zeng et al. (personal communication) are tested to reduce the GFS warm season mid-day cold bias in LST. The impact of new roughness changes on the brightness temperature calculation in GSI is investigated to improve satellite data assimilation.

## 2. New treatment of momentum and thermal roughness lengths and improvement of land skin temperature in GFS

In current NCEP GFS, $z_{0t}$ uses the same value as momentum roughness length ($z_{0m}$). This is usually not true, especially over arid or semiarid regions, where the green vegetation fraction is low and $z_{0t}$ is typically much smaller than $z_{0m}$. Thus, the current large $z_{0t}$ in the GFS contributes to large aerodynamic conductance ($C_h$) and improper surface heat flux between the land and the atmosphere. Finally, it strongly influences the magnitude of the

LST for a given surface net radiation forcing. Zeng et al. propose a new formulation on $\ln(z_{0m} / z_{0t})$ as follows:

$$\ln(z_{0m} / z_{0t}) = (1 - GVF)^2 C_{zil}\, k\, (u_* z_{og}/\nu)^{0.5} \quad (1)$$

where $z_{0m}$ is the momentum roughness length specified for each grid, $z_{0t}$ is the roughness length for heat, $GVF$ is the green vegetation fraction, $C_{zil}$ is a coefficient to be determined (taken as 0.8 in this study), $k$ is the Von Karman constant (0.4), $\nu = 1.5\times10^{-5}\ m^2\ s^{-1}$ is the molecular viscosity, $u_*$ is the friction velocity, and $z_{og}$ is the bare soil roughness length for momentum (defined as 0.01 m).

In order to consider the convergence of $z_{0m}$ between fully vegetated and bare soil, the effective $z_{0m}$ is used as follows:

$$\ln(z_{0m}) = (1 - GVF)^2 \ln(z_{og}) + [1 - (1 - GVF)^2] \ln(z_{0m}) \quad (2)$$

To test the new roughness formulations, the NCEP operational GFS model at the resolution of T382L64 is used for these experiments. A total of 72-h forecasts are performed from the analysis at 0000 UTC, July 1, 2007. For control run, $z_{0t}$ uses the same value as $z_{0m}$, while in sensitivity run, both $z_{0t}$ and $z_{0m}$ use equations (1) and (2).

Figure 1 shows the 3-day average land surface skin temperature predicted by the GFS and comparison with the GOES-derived LST and the SURFRAD (Surface Radiation) network observation. At 1800 UTC (mid-day in local time over the central US) in the control run (Fig.1a), a substantial cold bias can be found over the west half of CONUS, where it is mostly covered by arid or semi-arid regions. The new roughness formulations significantly reduce the cold bias in western CONUS, while the LST in eastern CONUS, where the bias is small in the control run, is not much affected (Fig. 1b). Desert Rock station (36.63N, 116.02W), located in the Nevada (NV) desert, is one of observation stations within the SURFRAD network. The LST at Desert Rock during daytime is much high as Fig. 1c shows. One can also see that the GOES-derived LST is very similar to the SURFRAD observations. However, the GFS control run produces very low LST, compared to the observations, especially during daytime. During mid-day, the cold bias can reach up to -15C. The sensitivity run produces a reasonable LST diurnal change. The daytime LST increases substantially and is very close to the observations. In Fig.1d, the new roughness formulations result in a much more realistic and smaller aerodynamic conductance during daytime.

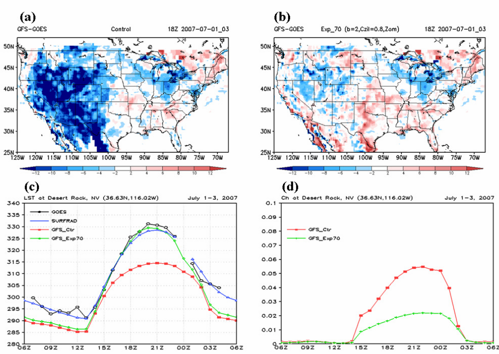


Fig.1. Comparison of land skin temperatures simulated in GFS and verification with the observations. (a) difference between GFS and GOES in the control run at 1800 UTC; (b) difference between GFS and GOES in the sensitivity run at 1800 UTC; (c) verification of diurnal change with GOES (black) and SURFRAD (blue) at Desert Rock, NV; red and green lines are for control run and sensitivity runs, separately;(d) diurnal change of aerodynamic conductance at Desert Rock.

## 3. New Impact of satellite data assimilation

The NCEP GFS forecast needs fields from the land surface such as albedo, upward long-wave flux and surface heat fluxes, which largely depend on LST predicted by the model. Moreover, the GFS also needs to provide atmospheric profiles and surface fields to the GSI data assimilation system. In order to examine the impact of LST improvements in the GFS on data assimilation, we choose two sensors, the NOAA-17 High Resolution Infrared Sounder-3 (HIRS3) and the NOAA-18 Advanced Microwave Sounding Unit-A (AMSU-A). With these two sensors, we will demonstrate how the LST improvement increases utilization of infrared (IR) and microwave (MW) satellite measurements in the GSI data assimilation system, separately.

(a) NOAA-17 HIRS3

NOAA-17 HIRS3 consists of 19 IR and 1 visible channel. Channel 8 is 11.11 microns and considered a window channel that is very sensitive to surface characteristics. Such window channels over arid or semiarid regions are found very difficult to be used in the current operational GSI data assimilation system because of large biases in calculated brightness temperature. Thus, in this study we focus particularly on HIRS3 channel 8. Two data assimilation experiments were conducted at 1800 UTC, July 1, 2007, which includes a control run using input of GFS control run data and a sensitivity run using input of GFS new roughness run data. All satellite measurements and other input data in GSI are the same in both experiments.

With the quality control in GSI, the satellite pixels with relatively large bias in calculated brightness temperatures are rejected. Figures 2a, b show the horizontal distribution of satellite pixels used in GSI. In the control run, most of the satellite data are tossed over the western CONUS according to the rejection criteria. With the improvement in LST, more satellite data are included in the data assimilation system in this region (Fig.2b).

To further illustrate the improvement in Tb simulation, we concentrate in the western CONUS area labeled with the red box. We calculate Tb biases, root-mean-square errors (rmse) and Probability Density Function (PDF) for all clear sky pixels within the red box. Figures 2c, d give these statistic analyses for land and various land surface categories like compacted soil (bare soil in GFS), scrub-soil (broadleaf shrubs with bare soil in GFS), and scrub (groundcover or broadleaf shrubs with perennial groundcover in GFS). There is no significant difference for compacted soil. However, the PDFs of other categories in the control run have a widespread distribution in the left, particularly in scrub-soil and scrub which contribute large errors to the whole land because these two categories dominate over the western CONUS. Such large error is improved in the sensitivity experiment (Fig. 2d) for all categories. Consistently, their bias and rmse become smaller, too. The bias over the land reduces to -1.841 from -6.015 and the rmse reduces to 3.925 from 7.716 in the control run.

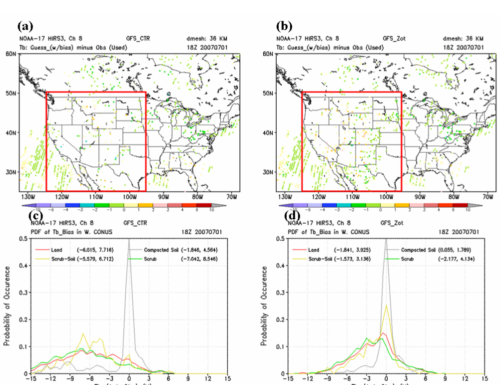

Fig.2. Horizontal distribution of satellite pixels used in GSI: brightness temperature bias of Channel 8, NOAA-17 HIRS3 from control run (a) and sensitivity run (b). PDF of Tb bias for all clear sky pixels within the western CONUS (red box) from the control run (c) and the sensitivity run (d). Tb biases (first values in parentheses) and rmse (second values in parentheses) for various land surface categories are also given.

(b) NOAA-18 AMSU-A

AMSU-A is a passive microwave sensor and has 12 sounding channels and 3 window channels at 23.8, 31.4 and 89 GHz. Such microwave observations in the window or near the window channels are strongly affected by surface emissivity and are very difficult to be used in NWP models because of the variability of surface emissivity and for a given wavelength, which is largely unknown over different surfaces (Weng et al., 2001). Although a new land emissivity model (Weng et al., 2001) improved the emissivity calculation over various surface conditions with more satellite measurements utilized in the models, there still remain outstanding problems in using satellite measurements over arid or bare soil regions such as western CONUS. In addition to the surface emissivity, LST is a big problem that causes large errors in Tb simulation over arid regions.

Similar to experiments of HIRS3, the impacts of the new roughness formulations in the GFS on utilization of AMSU-A data in GSI can be seen from the control run and the sensitivity run in Figures 3a, b. Over the western CONUS, much more satellite pixels are used for data assimilation system with a corresponding LST improvement. However, in some regions such as southeast California and southern Nevada, as well as the western part of Mexico where it is mostly covered by compacted soil (bare soil in GFS) or scrub-soil (broadleaf shrubs with bare soil in GFS), the new roughness scheme results in worse brightness temperature simulation, thus many satellite data are rejected in GSI. Further investigation of the surface emissivity calculation indicates that the land emissivity model in the CRTM produces the unreasonable high emissivity in those regions, particular in window channels like channel 15. The microwave land emissivity model was recently improved over bare soil or desert regions by Yan et al. (personal communication). Its deficiency was much corrected as shown in Fig. 3c.

The statistical analyses indicate a substantial improvement in brightness temperature simulation with the new roughness (Fig.4). The PDF for scrub category has wide-spread and departs considerably from the center to the left, showing large cold bias (-3.811) and large rmse (6.030). In the new roughness experiment, its bias and rmse are properly corrected (2.419, 5.564, separately), and significantly corrected with the new land emissivity model (1.574, 4.727, separately) as shown in Fig. 4c. Another category, scrub-soil, shows a similar result as scrub (not shown).

The new roughness scheme not only increases utilization of satellite data and reduces errors in brightness simulation at window channels, but also improves those at sounding channels. Figure 5 gives AMSU-A channel 4 (52.8 GHz) as an example. In GFS, the new roughness reduces the substantial cold bias in LST over arid regions during daytime. At the same time, due to the correction in land-atmosphere turbulent heat exchange with the new roughness, it also reduces biases in atmospheric profiles, particularly in the lower troposphere. Thus, this is a reasonable result that satellite data for sounding channels are improved in the data assimilation system as well.

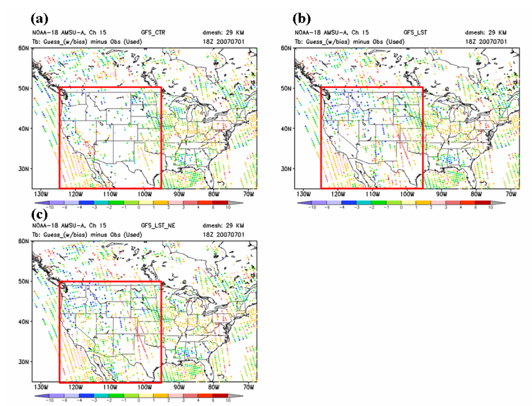

Fig.3. Horizontal distribution of satellite pixels used in GSI: brightness temperature bias of Channel 15, NOAA-18 AMSU-A from control run (a), new roughness sensitivity run (b), and new emissivity with new roughness run (c).

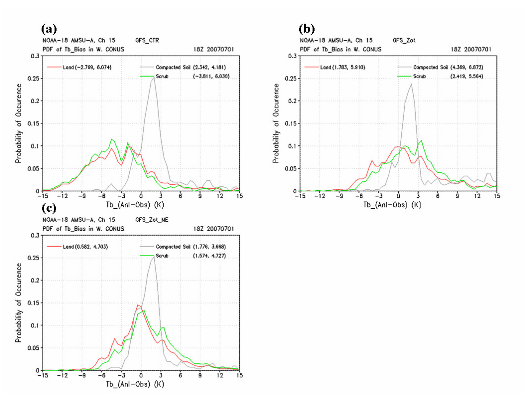

Fig.4. PDF of Tb bias for all clear sky pixels within the western CONUS (red box in Fig. 3) from the control run (a), new roughness sensitivity run (b), and new emissivity with new roughness run (c). Tb biases (first in parentheses) and rmse (second in parentheses) for various land surface category are also given.

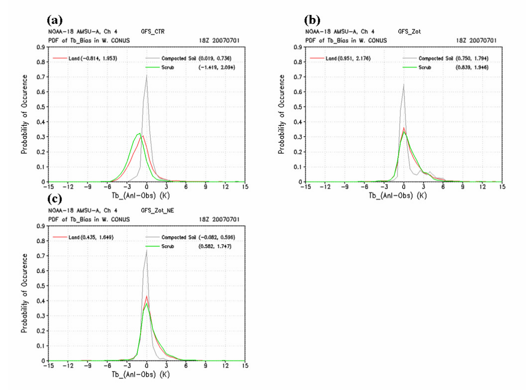

Fig.5. As in Fig.4, but for channel 4 (52.8 GHz).

## 4. Conclusions

In this study, new formulations for surface roughness were tested in the NCEP GFS model to reduce a substantial cold bias in land surface skin temperature (LST) over arid or semi-arid regions during daytime in the warm seasons. With an increased LST over west CONUS, there is an obvious reduction in the large cold biases of calculated brightness temperatures found for infrared and microwave satellite sensors in window or near window channels, so that many more satellite measurements can be used in the GSI data assimilation system. In desert or bare soil regions, unreasonable surface emissivity for microwave sensors in CRTM was corrected, and the new emissivity model together with increased LST via changes in surface roughness gave smaller biases and rmse in the calculated brightness temperature.

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