10A.6 Impact of a New Thermal Roughness Length Treatment in the NCEP Global Forecast System (GFS)

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1, Introduction

Land surface schemes are largely responsible for the quality of model forecasts produced for near-surface weather parameters, such as 2-meter air temperature (T2m) and surface skin temperature (LST). LST is particularly important to remote sensing and data assimilation.
How precise these two parameters can be simulated by the model strongly depends on how accurate the surface heat fluxes are parameterized, particularly the surface sensible heat flux (SH). The surface thermal roughness length is a key parameter to determine SH. Some GCMs do not distinguish between the roughness length for heat and momentum. The aerodynamic roughness Zom is used for wind, while the thermal roughness Zot is used for heat and water vapor. In general, Zom is different from Zot, because the transfer of momentum is affected by pressure fluctuations in the turbulent waves behind the roughness elements, while for heat and water vapor transfer no such dynamical mechanism exists. Rather, heat and water vapor must ultimately be transferred by molecular diffusion across the interfacial sublayer. Braud et al. (1993) showed that the assumption Zom=Zot results in an inaccurate prediction of surface temperature over heated bare-soil in a semi-desert areas. Zeng and Dickinson (1998) found that the surface skin temperature can be at least 10 K higher when considering the surface sublayer (or the variable ratio of the Zom / Zot) than without in the desert summer afternoon.

The land-surface model component was substantially upgraded from the Oregon State University (OSU) land surface model to EMC's new Noah Land Surface Model (Noah LSM) during the major implementation in the NCEP Global Forecast System (GFS) on May 31, 2005. The Noah LSM upgrade greatly reduces the early depletion of snowpack and the warm-season high bias in both surface evaporation and precipitation in mid-latitudes. However, a warm bias vertically throughout the troposphere, as well as higher surface sensible heat flux emerged after this implementation, particularly, over the arid areas during the daytime. The biases may be caused by many factors such as radiation parameterization changes. But we cannot rule out that lack of a proper surface sublayer parameterization over land in the GFS may play a dominant role to causing this bias. Therefore we will test the surface sublayer scheme from Zeng and Dickinson (1998) in the GFS to investigate the GFS response to the more realistic surface process parameterization.

2 The Surface Sublayer Scheme (Zeng and Dickinson, 1998)

Zeng and Dickinson (1998) derived the ratio of Zom/Zot over bare soil as

$$\ln\frac{Zom}{Zot} = a\left(\frac{u_* Zom}{v}\right)^{0.45} \qquad (1)$$

Where a = 0.13, the quality $(u_* Zom / v)$ is the roughness Reynolds number (Re*) with the kinematic viscosity of air, v, being about 1.5 x 10^{-5} m^2 s^{-1}.

Over vegetated area, they introduced the effective roughness length Zoe for momentum.

$$[\ln(Z/Zoe)]^{-2} = (1-\sigma_v)[\ln(Z/Zog)]^{-2} + \sigma_v [\ln(Z/Zof)]^{-2} \qquad (2)$$

Where σ_v is the vegetation fraction, Z is the surface layer depth, Zog and Zof are roughness length for bare soil and vegetation respectively.

In this study, a slightly revised scheme has been used. Corresponding to equation (2) we define the effective roughness length Zoe as

$$\ln(Zoe) = (1-\sigma_v)^2 \ln(Zog) + [1-(1-\sigma_v)^2]\ln(Zof) \qquad (3)$$

Then Zoe/Zot is defined as

$$\ln\frac{Zoe}{Zot} = (1-\sigma_v)^2 C_{zil} k \left(\frac{u_* Zog}{v}\right)^{0.5} \qquad (4)$$

Czil is a coefficient (0.8 is used in this study); k is the Von Karman constant (0.4).

The purpose of using greenness fraction in both equation (3) and (4) is to consider the convergence between fully vegetated versus bare soil.

3. **Experiment Design**

The NOAA/NCEP Global Forecast System/Global Data Analysis System (GFS/GDAS) is used in this study. Two experiments are conducted for the period from July 15, 2008 to August 15, 2008. The first one, PRS50H, acting as the control run similar to the operational system, is running without modification to the surface sublayer over land. The second one, PRS50HA, is the sensitivity test where Equation (3) and (4) are applied. In both cases 7-day GFS forecasts are carried out at each 00Z initialized by GDAS.

4. Results

Figure 1 shows the difference of LST between PRS50H and PRS50HA averaged over 20080723 to 20080815 at 66h forecast for global, CONUS (Continental United States), Asia, and the Antarctic respectively. This is the mid-day over the west CONUS, where LST increases as large as 10^{o}C in the most area after inclusion of the surface sublayer modifications. The west CONUS is a semi-arid area where the large cool LST bias is found in the operational GFS. Meanwhile the impact is small over the east CONUS vegetated area and in Asia where the local time is evening to night. Over the Antarctic, LST decreases about 2^{o}C which is in the right direction to reduce the warm LST bias found in the operational GFS.

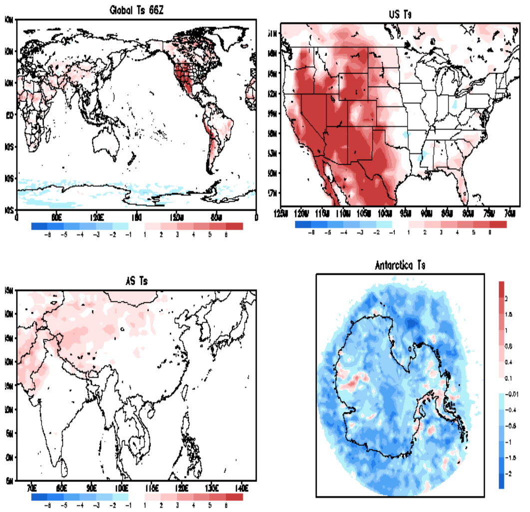

Figure 1. The difference of surface skin temperature between PRS50H and PRS50HA at 66h forecast (averaged over 20080723 to 20080815)

The thermal roughness length, Zot, is smaller than the momentum roughness length, Zom. As such, the surface exchange coefficient is usually proportional to the roughness length. Therefore the surface exchange coefficient is smaller for PRS50HA (not shown). Given the same temperature difference between the surface and the atmosphere, the smaller exchange coefficient will yield a lower surface sensible heat flux. Under unstable conditions likely during mid-day in west CONUS, the surface will lose less energy to the atmosphere (smaller upwards sensible heat flux). Therefore the surface will tend to be warmer while the atmosphere will become cooler. The opposite situation will occur under the stable conditions, especially the extreme conditions in the Antarctic where the sensible heat flux is downward (from atmosphere to surface). The air temperature will increase due to less energy lost to the surface. The contrasting performance of air temperature compared LST due to distinguishing Zot and Zom is illustrated in Figure 2. Figure 2 is the same as Figure 1 except for 2 meter air temperature. The cooling down (warming up) of 2 meter air temperature is always corresponding to the warming up (cooling down) of LST in Figure 1.

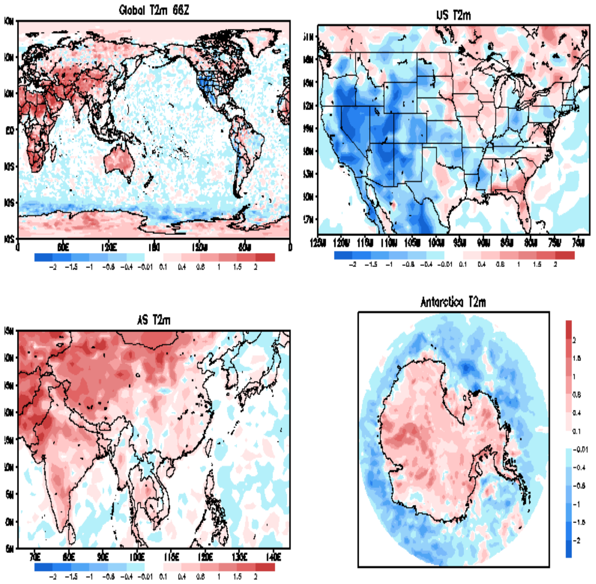

Figure 2. As in Figure 1, except the difference of 2 meter air temperature between PRS50H and PRS50HA at 66h forecast (averaged over 20080723 to 20080815)

The improvement in the temperature forecast is not just limited to the surface. Figure 3 shows the 48h forecast temperature bias at 700mb. The warm bias over the west CONUS in PRS50H (top panel) is about 2^{o}C. It is reduced to less than 1 ^{o}C in most areas in PRS50HR (bottom panel).

NCEP's Forecast Verification System (FVS) has been used to further diagnose the impact of these changes to the surface roughness on 2-meter temperature over semi-arid regions. Figure 4 shows the average diurnal 2-meter temperature over southwest CONUS for the period from July 23, 2008 to August 15, 2008. Compared to the observation (green curve), both experiments have daytime warm bias. But PRS50HA (pink curve) reduces the bias by about 0.5^{o}C with respect to PRS50H (blue curve). While during the nighttime, PRS50H has almost 2^{o}C cool bias and PRS50HA turns this cool bias to slightly warm bias. It is worth to point out that PRS50H has a big dropout during the late afternoon, but with modifications in the surface sublayer, PRS50HA has improved the dropout significantly.

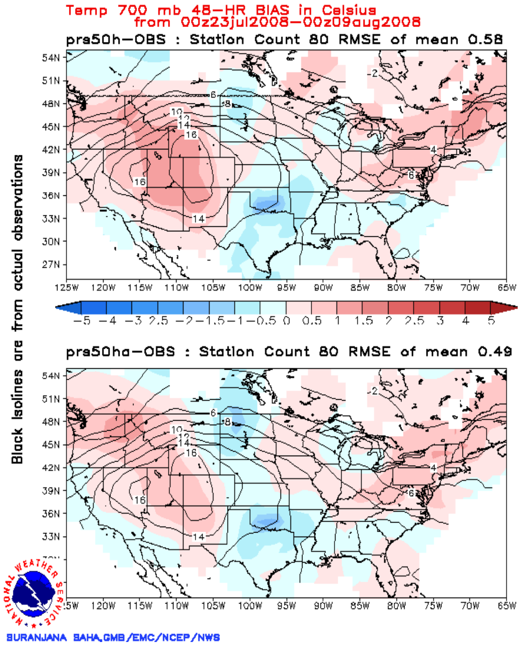

Figure 3 the bias of 48-h forecast temperature at 700mb: PRS50H (Top) and PRS50HA (Bottom)

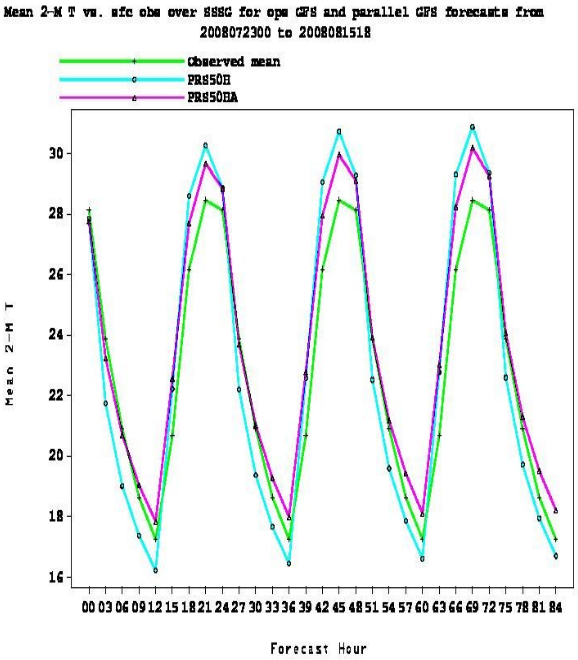

Figure 4. Average diurnal 2-meter temperature over southwest CONUS

Other verifications have also been carried out in these two experiments, such as the Anomaly Correlation (AC) score, BIAS, RMSE, and precipitation score. It is found that the new thermal roughness length scheme improves not only the temperature, but also the atmospheric circulation and precipitation.

The large error in GFS simulated LST is one of the major factors to cause the data assimilation system (GDAS) to reject large amount of satellite data over land. With improved LST after inclusion of surface sublayer modifications, more satellite data should be expected to be accepted by GDAS. Therefore GDAS can provide more accurate initial conditions to GFS for forecasting.

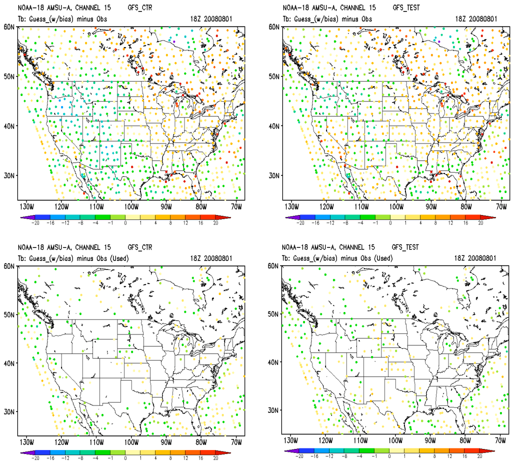

Figure 5. The difference of brightness temperature between simulation and observation. (PRS50H: left panel; PRS50HA: right panel)

Figure 5 shows the brightness temperature bias for AMSU-A channel. The cool bias over southwest CONUS in PRS50H (top left) has been reduced significantly in PRS50HA (top right), which results in more satellite data are used in PRS50HA (bottom right) than PRS50H (bottom left). The more detail impact can be found in Zheng et al. (2009).

5. Conclusions

This study presents summer tests to study of the impact of surface sublayer modifications (in the form of adding a new thermal roughness, and weighting both thermal and momentum roughnesses by vegetation fraction), on NCEP GFS/GDAS. Distinguishing Zot and Zom has reduced the cold bias in GFS daytime warm-season LST and the warm bias in GFS near-surface air temperature significantly, especially over semi-arid regions. It also improves the atmospheric circulation and precipitation simulation. More satellite data have been accepted in the data assimilation system due to the better simulated LST.

Further tests for the other seasons and longer simulation periods (for climate forecast purpose) are necessary before this scheme can be put into the current NCEP operational GFS.

Reference

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