Improving the Coupling of Land Surface Temperature Modeling and Remote Sensing

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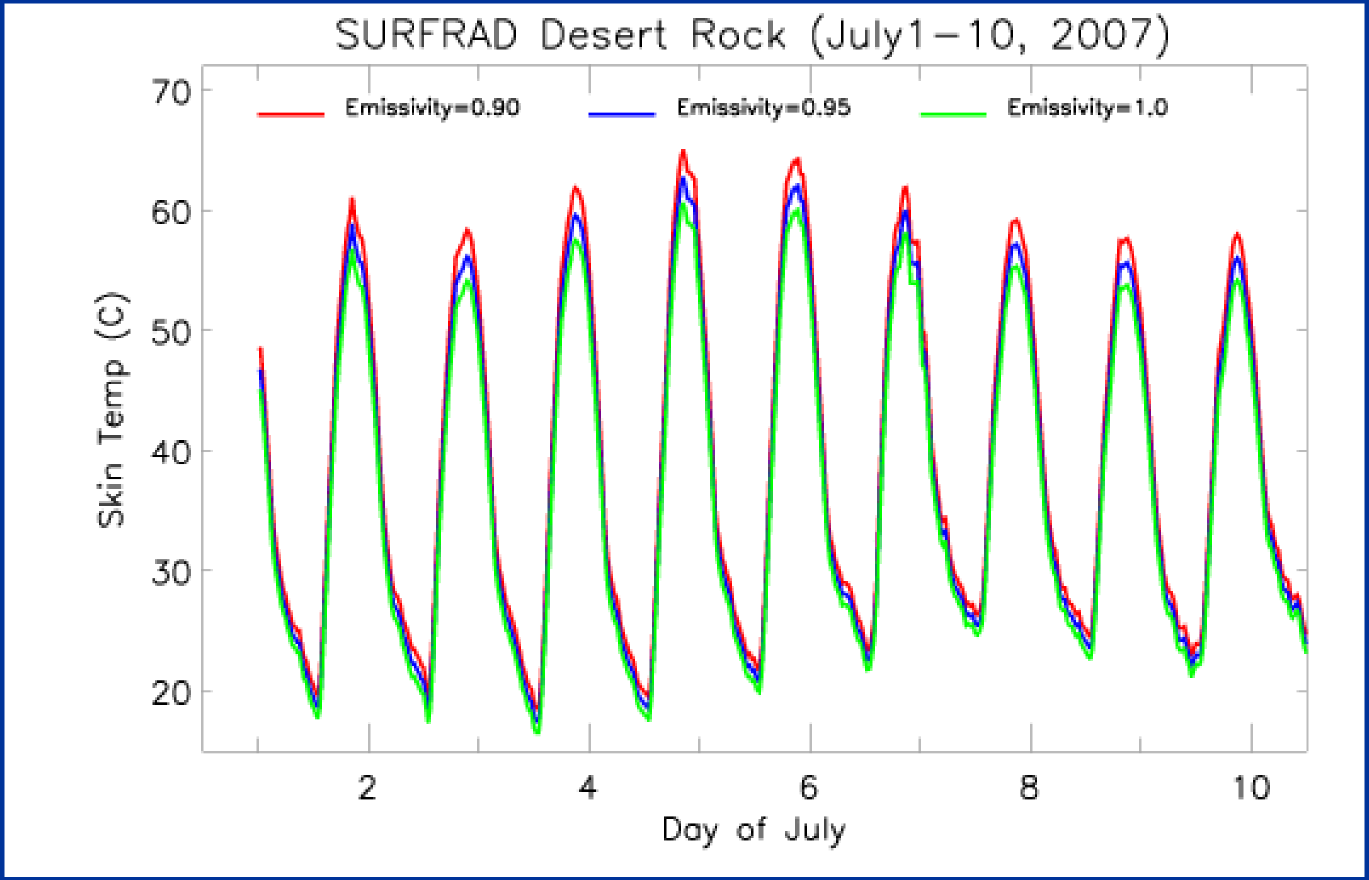
1. Emissivity and Ts

$LWu = \varepsilon\sigma Ts^4 + (1 - \varepsilon)\, LWd$



2. Bare soil: is the T_s problem solved?

$SH \sim (T_a - T_s)/(r_{ah} + r_{ss})$ (Zeng and Dickinson 1998)

$r_{ah} = f(Z_{om}, \text{stability})$

$r_{ss} = \ln(Z_{om}/Z_{ot})/(k u_*)$

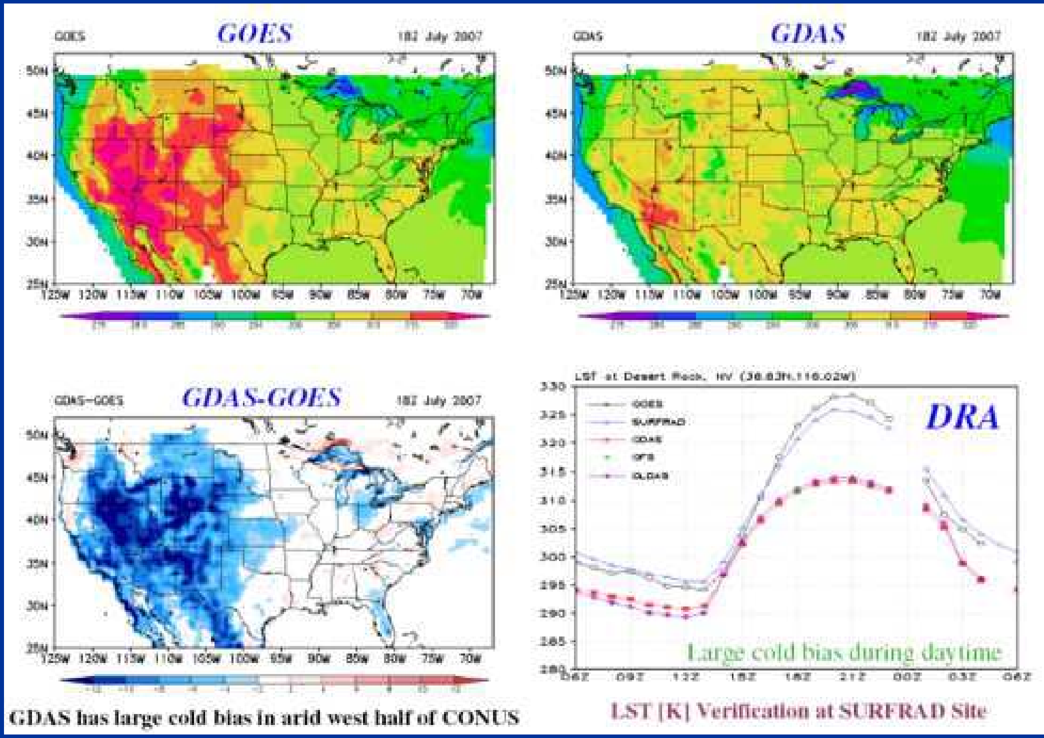
CLM:

$k B^{-1} = \ln(Z_{om}/Z_{ot}) = \alpha \, Re^{0.45}$

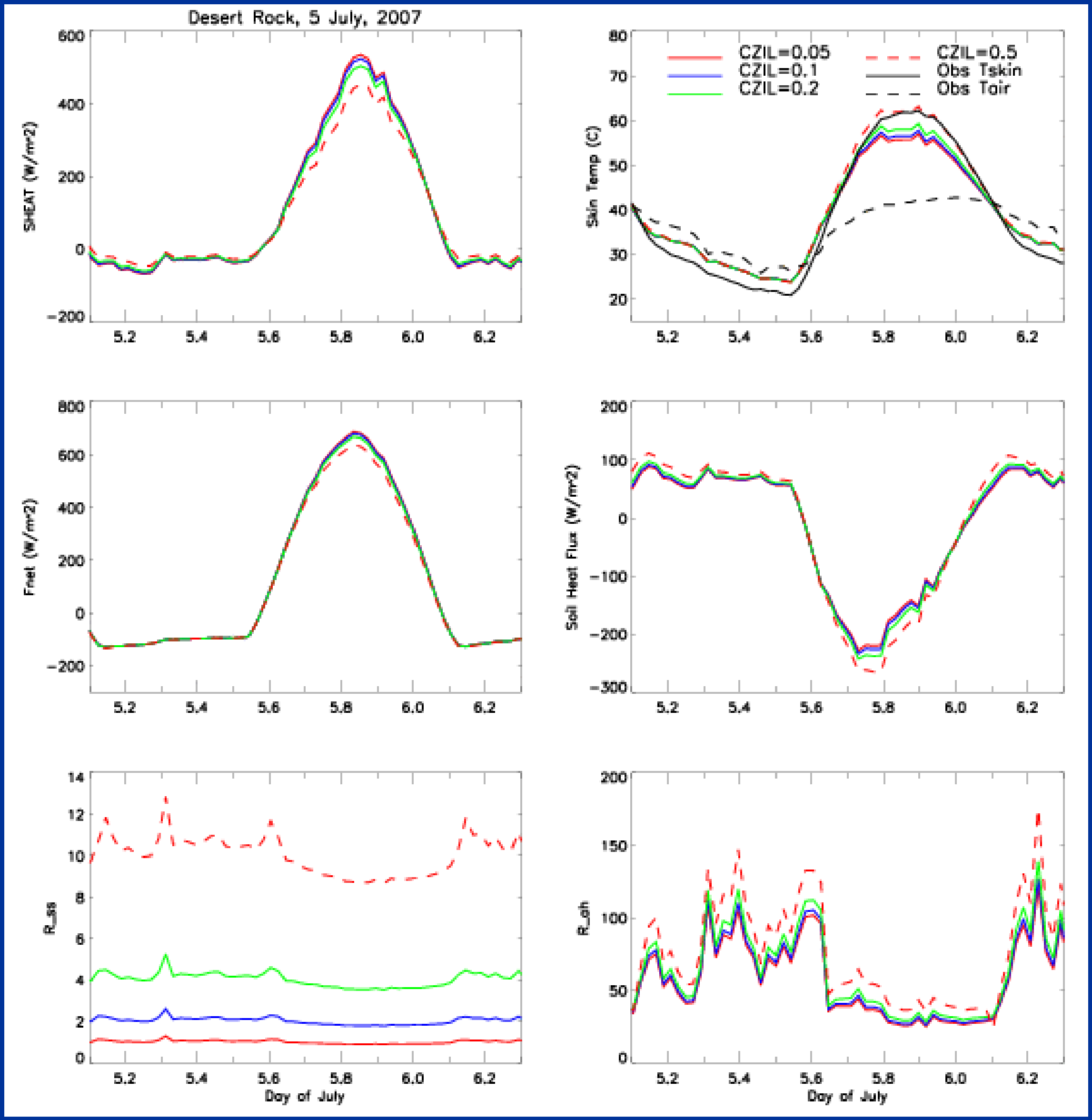
Noah:

$\ln(Z_{om}/Z_{ot}) = \underline{0.4 C_{zil}} \, Re^{0.5}$

$Re = u_* Z_{om}/\nu$

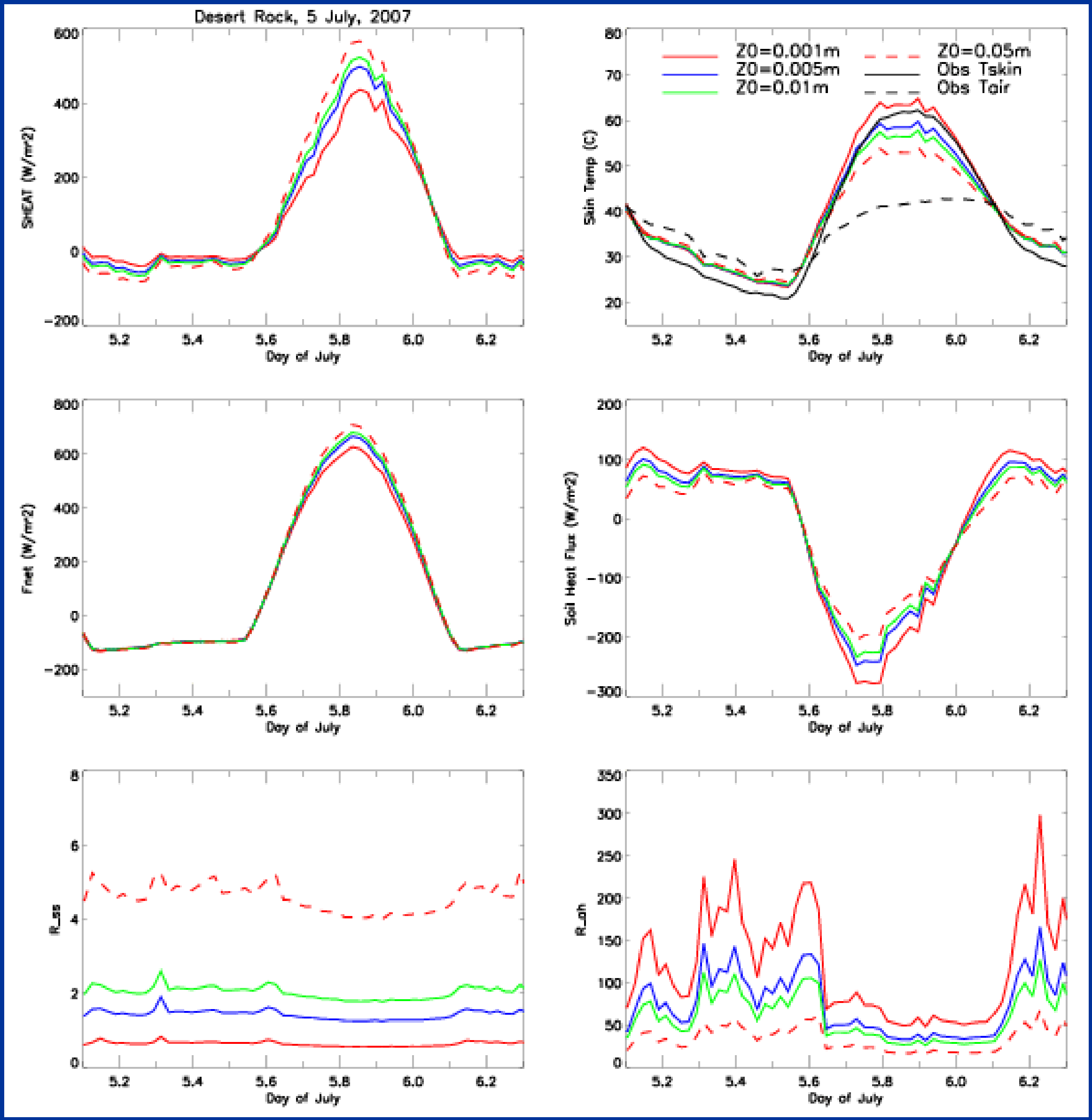


Zheng and Mitchell (2008): July 2007



Sensitivity to k B^{-1} formulation

C_{zil} = 0.5 (red dash)
0.2
0.1
0.05



Sensitivity to Zom

Zom = 0.001(red solid)
0.005
0.01
0.05 m

3. Full canopy: do we need to consider Zot ≠Zom?

In CLM (Zeng and Dickinson 1998)

Tva, Tv, Tg are considered separately, and SH balance at canopy is explicitly used: SH = SHc + SHg: Zot = Zom can be used.

In Noah

Tva, Tv, Tg are combined into a single Ts, and Zot ≠Zom may still be needed.

GFS: Zot = Zom

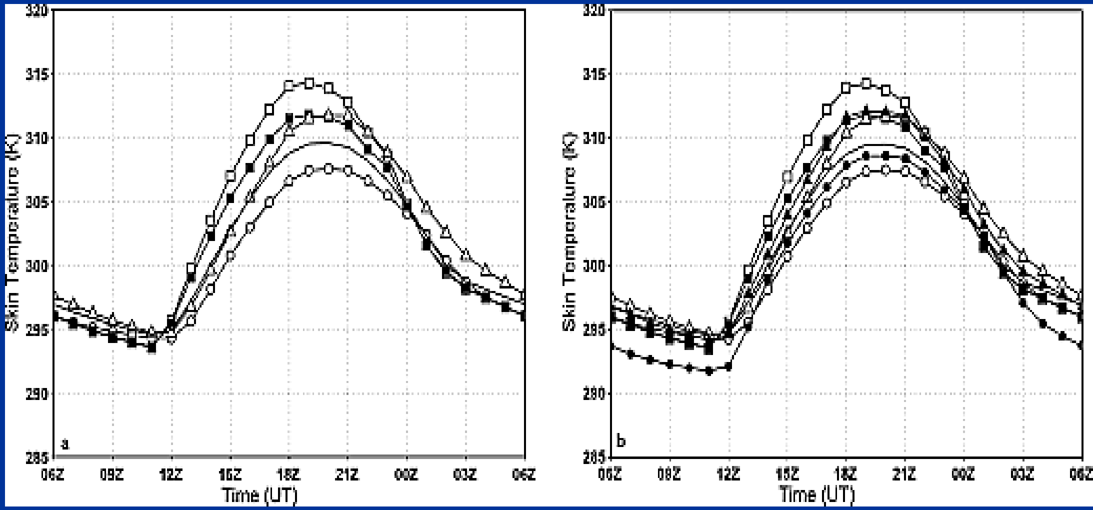
WRF: Zot ≠Zom (Czil = 0.1)

Con: Czil=0.2 (open square)

New: Czil=0.05 (solid square)

Obs: solid line

(Mitchell et al. 2004)



4. Partial vegetation cover: consistency of Ts

Noah: LAI = constant; GVF = 0-1;

Challenge: at GVF=1, $T_s \sim T_v$, leading to errors in computing

ground heat flux (G) ~ K ($T_s - T_{soil}$)

under-canopy snow melt

Additional deficiency: Noah overestimates Ts over canopy but underestimates Ts over bare soil

Initial Solution:

$$\ln(Z_{om}/Z_{ot}) = 0.4\,(1-GVF)^2 C_{zil}\, Re^{0.5} \quad \text{and } Re = u_* Z_{om}/\nu$$

Czil=0.9 in GFS (tests done by Mitchell's team) give best results

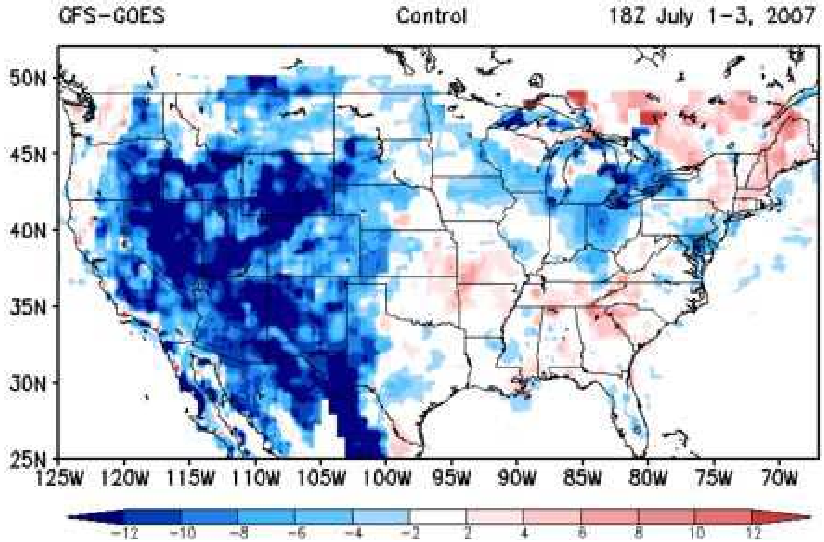
Our offline test: Czil=0.5 best

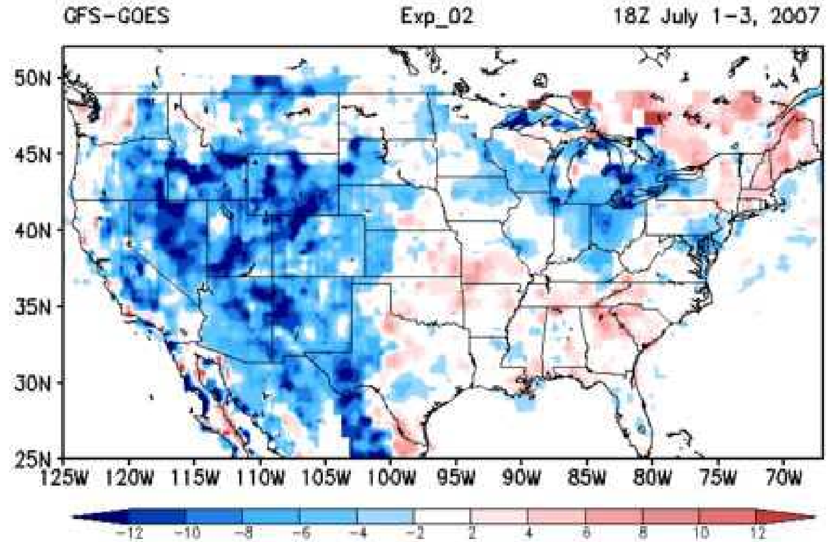
Why? (due to Z_{om} in Re)

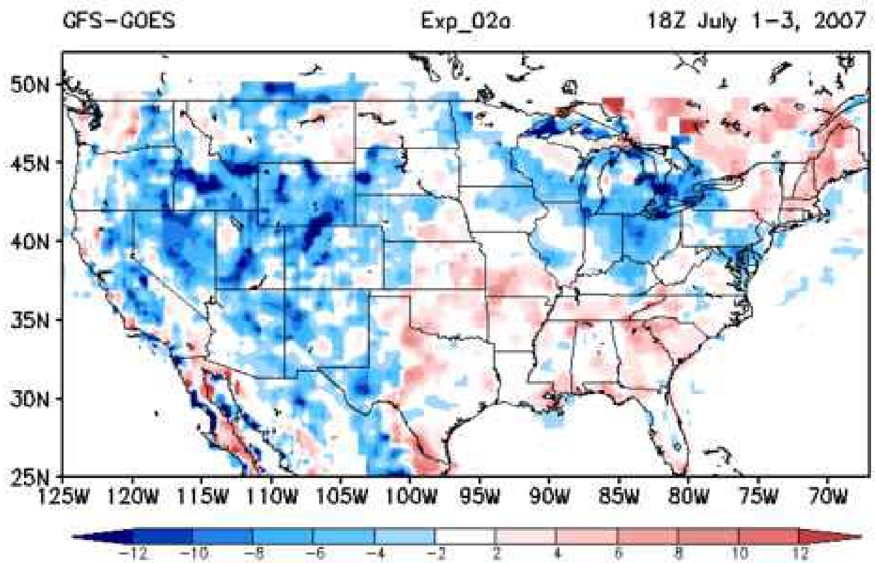
Difference of Mean 18Z LST [K] (GFS-GOES), July 1 - 3, 2007

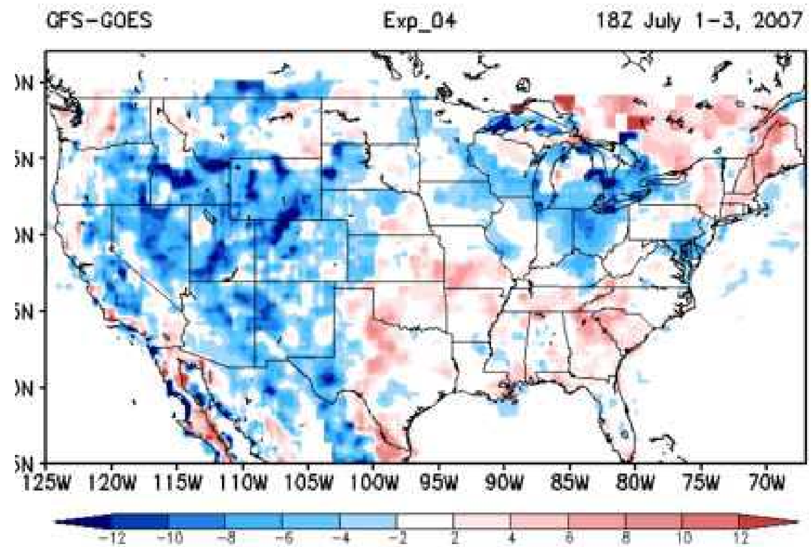
3-Day Mean

Ave_GOES







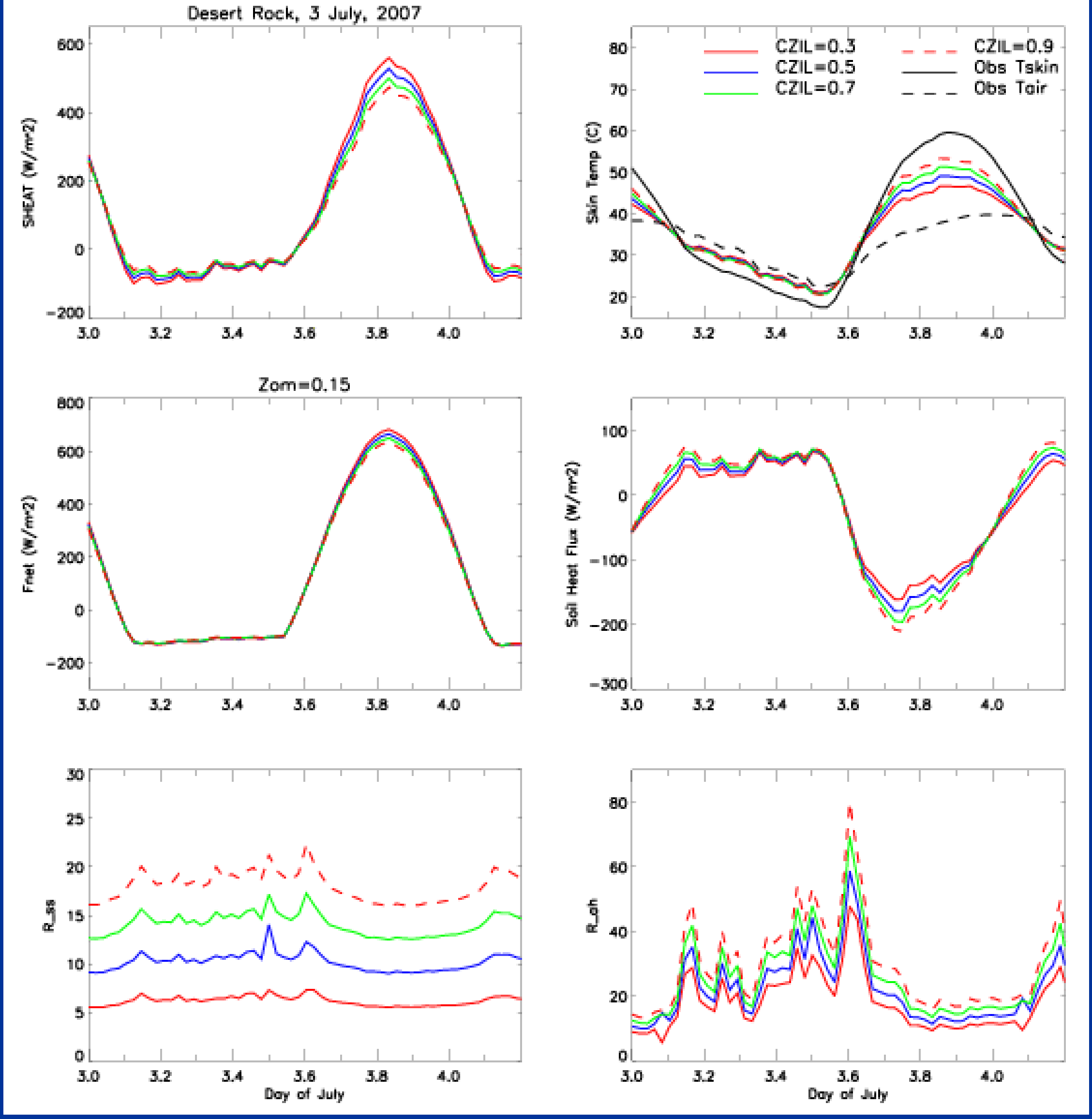


Interpolated value at Desert Rock in GFS:

Z_{om}=0.15m

Then even at Czil = 0.9

Still underestimates Ts



Final formulation

$$\ln(Z_{om,e}) = (1\text{-}GVF_{max})^2 \ln(Z_{om,g}) + [1 - (1\text{-}GVF_{max})^2] \ln(Z_{om})$$

where GVF_{max} is taken as the annual maximum GVF. In this way the effective roughness length $Z_{om,e}$ (x,y) is determined as a function of land cover type (default) and GVF_{max}

$$\ln(Z_{om,e}/Z_{ot}) = 0.4\,(1\text{-}GVF)^2\, C_{zil}\,(u_* Z_{om,g}/\nu)^{0.5}$$

and $C_{zil} = 0.5$, $Z_{om,g} = 0.01$ m

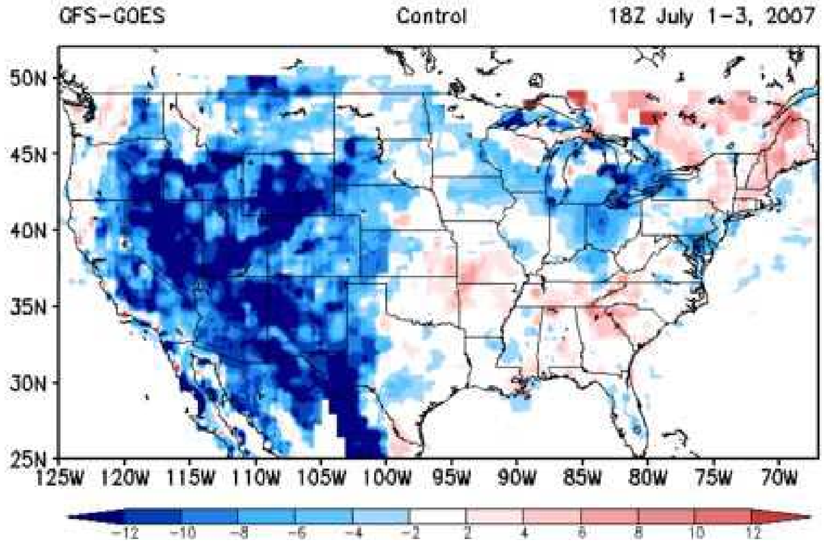
Test of Z0t Scheme (Zeng) with GFS for Summer Case

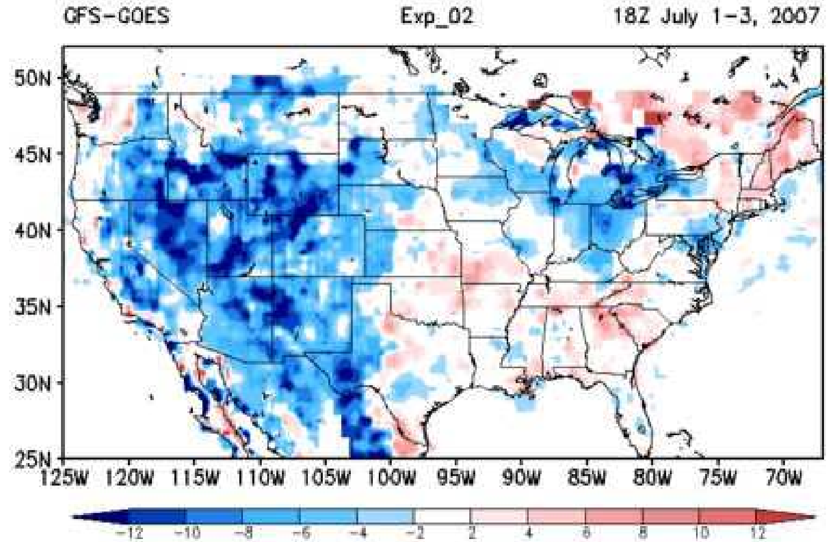
- Model: GFS prediction system.
- Z0t : ZTMAX(I) = Z0MAX(I)*exp(- ((1.-SIGMAF(I))**b) *C21*CA*sqrt(USTAR(I)*0.01/(1.5E-05)))
- Case : 00Z, July 1, 2007; 72-h integration.
- Exps: **Control run (Ctr)** : ZTMAX(I) = Z0MAX(I)
- **Sensitivity runs (Sen)** : Test different Z0t
- **Exp_01: b=4; C21=0.3**
  Exp_02: b=2; C21=0.5
  Exp_02a: same as 02 but the different effective z0
  Exp_04: b=2; C21=0.9
  Exp_05: b=2; C21=1.1
  Exp_06: b=2; C21=1.5
  Exp_07: b=4; C21=0.9
- Weizhong Zheng and Helin Wei

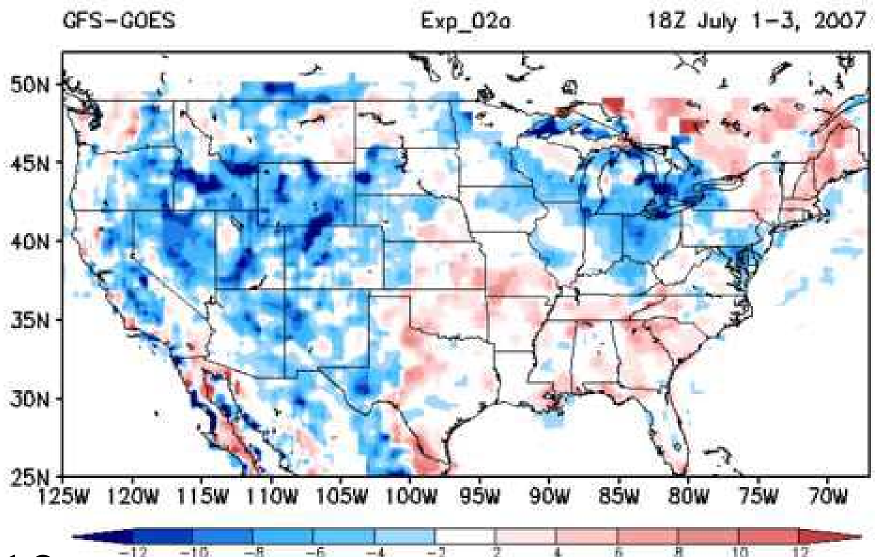
Difference of Mean 18Z LST [K] (GFS-GOES), July 1 - 3, 2007

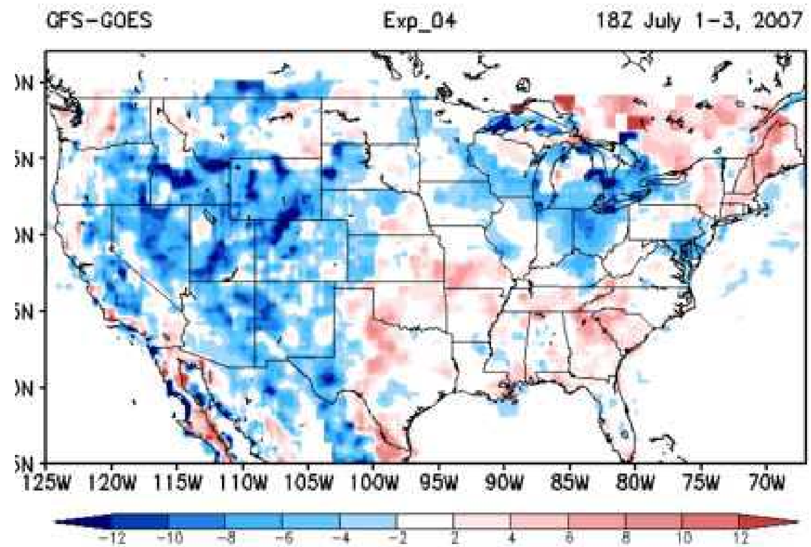
3-Day Mean

Ave_GOES









Mean LST Difference [K], July 1 - 3, 2007

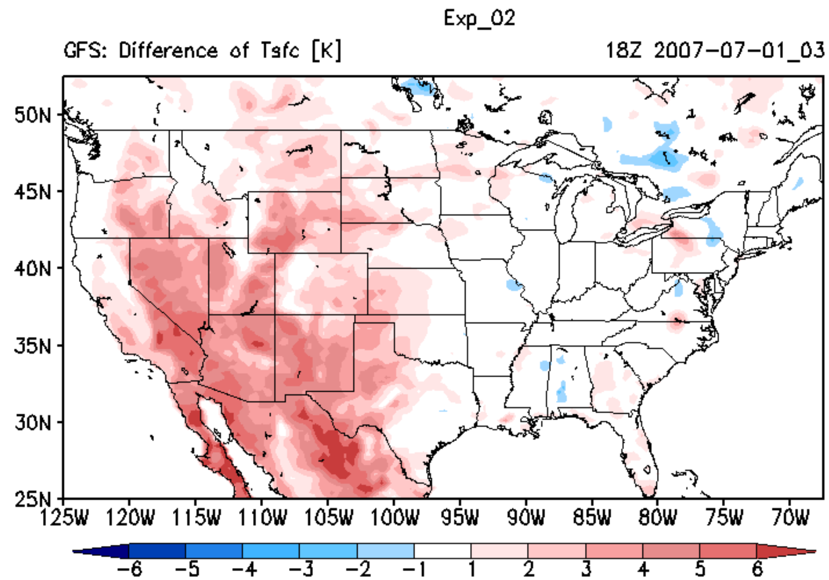
3-Day Mean

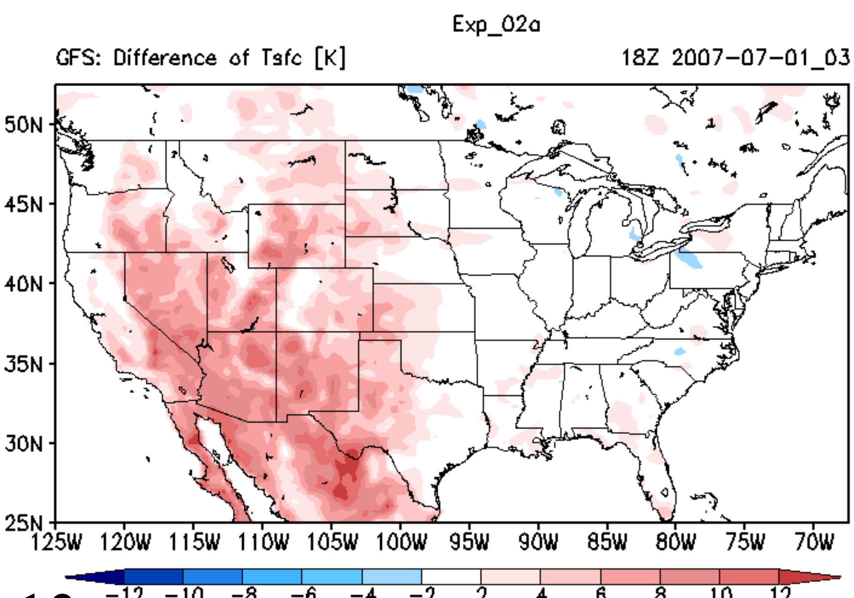
GFS: Sen-Ctr

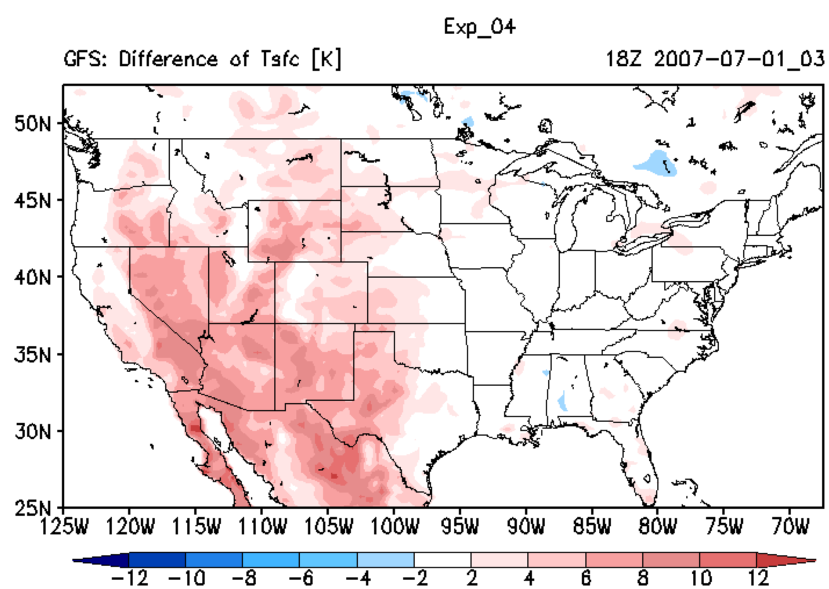
Exp_02: b=2; C21=0.5

Exp_02a: same as 02 but the different z0

Exp_04: b=2; C21=0.9

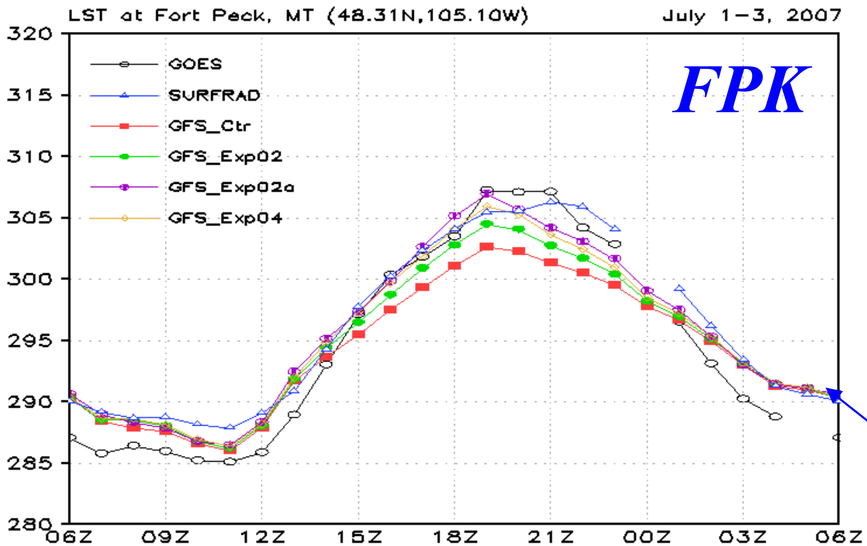


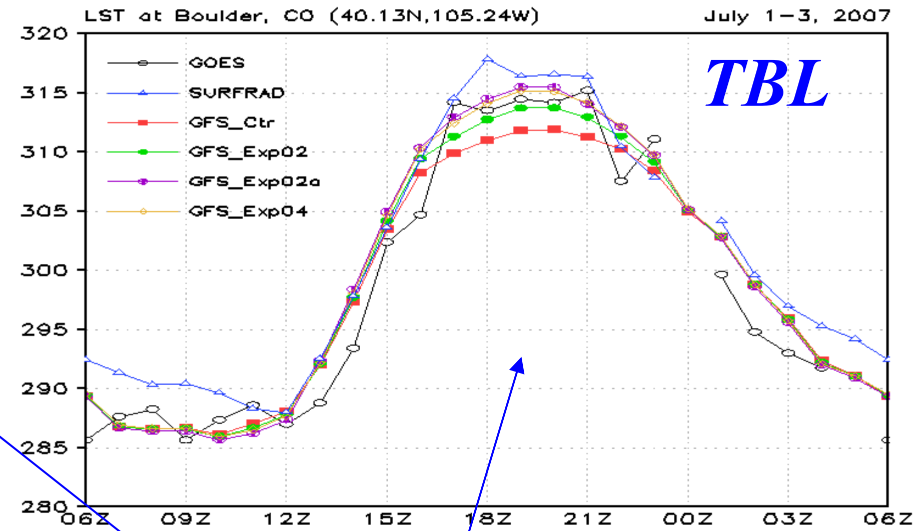


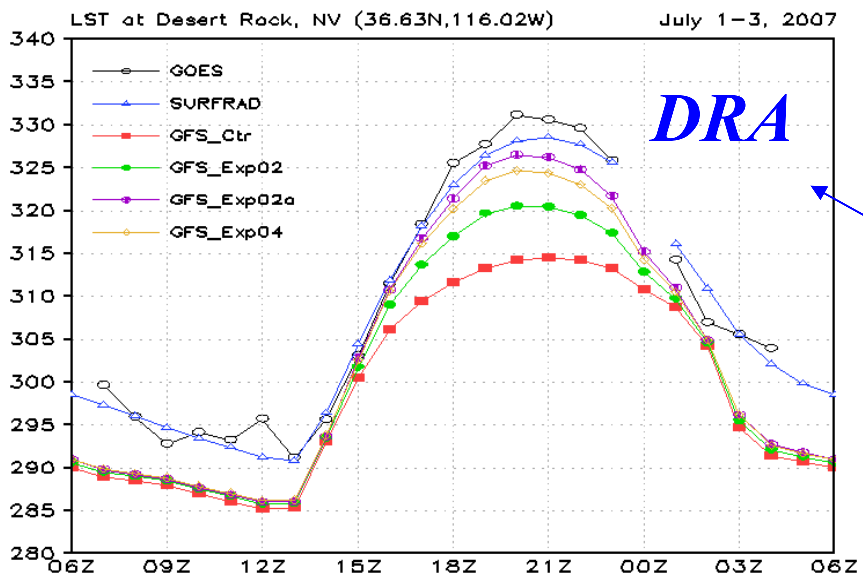


LST [K] Verification at SURFRAD Sites

3-Day Mean





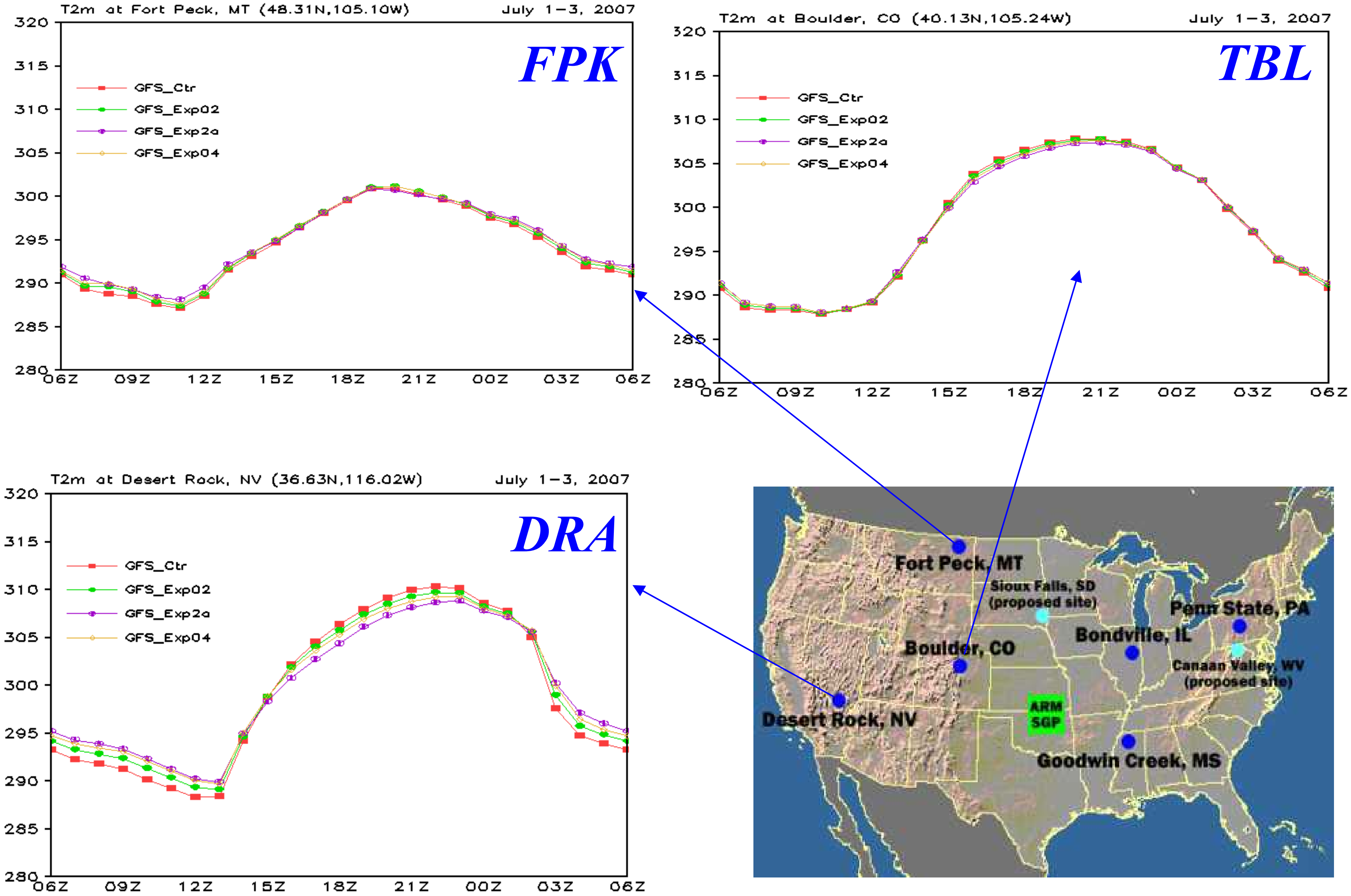


SURFRAD

Network

T2m [K] Comparison at SURFRAD Sites

3-Day Mean



5. Snow/vegetation/soil mixture

- Snow fraction is needed primarily for albedo (not Ts).
- Both emissivity and Ts are important for CRTM

Assume:

evergreen needleleaf trees: GVF = 0.6, and LAI = 4.0;
snow depth D_{sn} = 50, 100, and 200 mm
snow density = 100 kg/m^3
no snow remaining on the leaves

Advanced Microwave Sounding Unit-A (AMSU-A):

12 sounding channels (within 50-60 GHz)
3 window channels at 23.8, 31.4, and 89 GHz

New Snow fraction formulation

Snow-free fraction in CRTM

Snow fraction in CRTM

Snow-free soil
$(1-F_v) * (1-F_{g,sn})$

Snow-covered soil
$(1-F_v) * F_{g,sn}$

Canopy without or shading snow
$F_v * (1-F_{g,sn})*(1-F_{v,sn})$

Vegetation covered by snow due to interception and burial
$F_v * F_{v,sn}$

Snow under vegetation that cannot be "seen" by satellites

$(1-\beta) F_{v,b}$

$\beta F_{v,b}$

Snow on the ground that can be "seen" by satellites

If LAI is large

Vegetation with snow below
$F_{v,b} = F_v * F_{g,sn} * (1-F_{v,sn})$

If LAI goes to zero

$\beta = \exp(-LAI)$

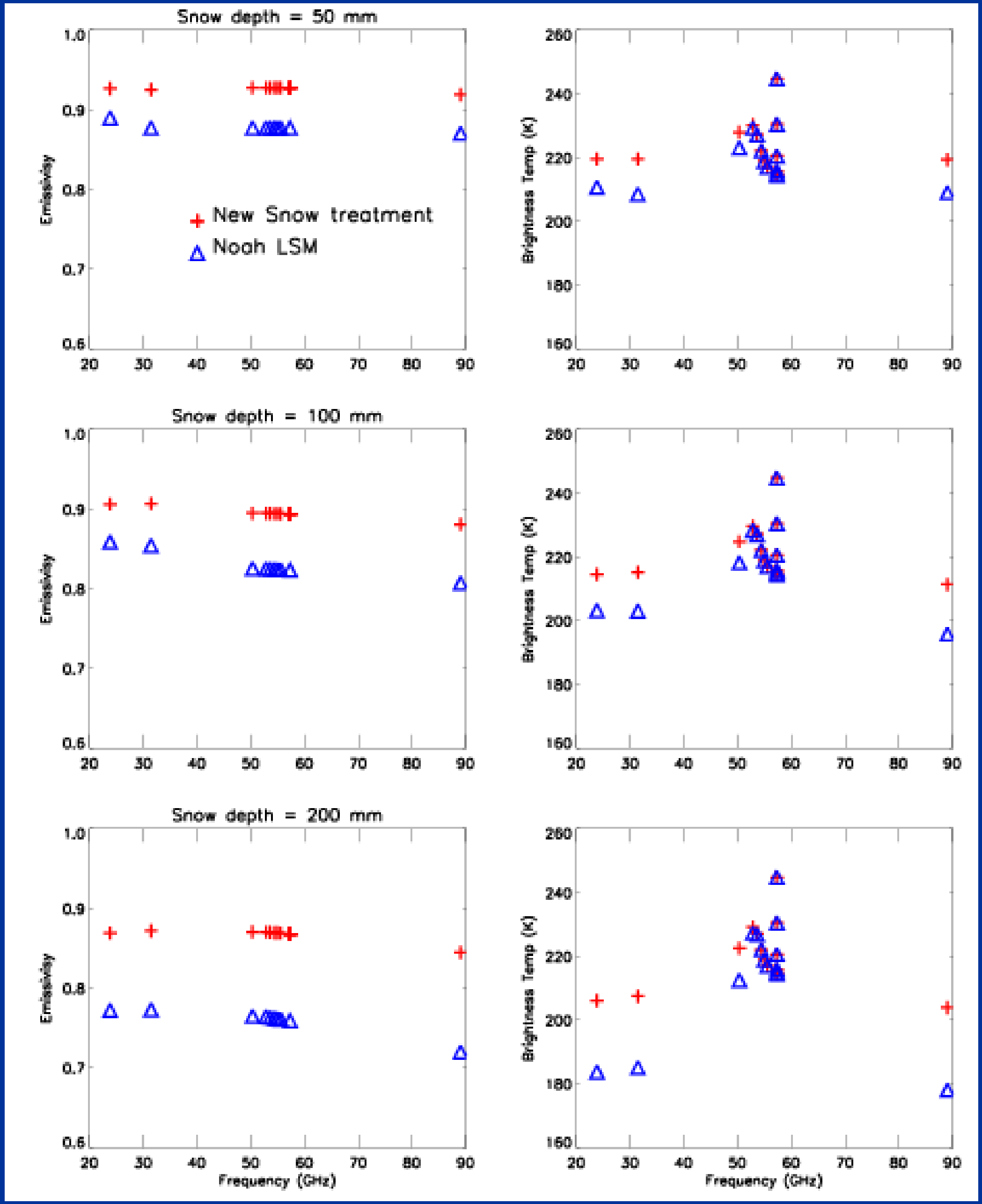
$F_{v,sn} = \min(F_{int}+F_{bur}, 1)$

Snow Fraction
Con: 0.4
New: 0.2

0.65
0.3

Emissivity

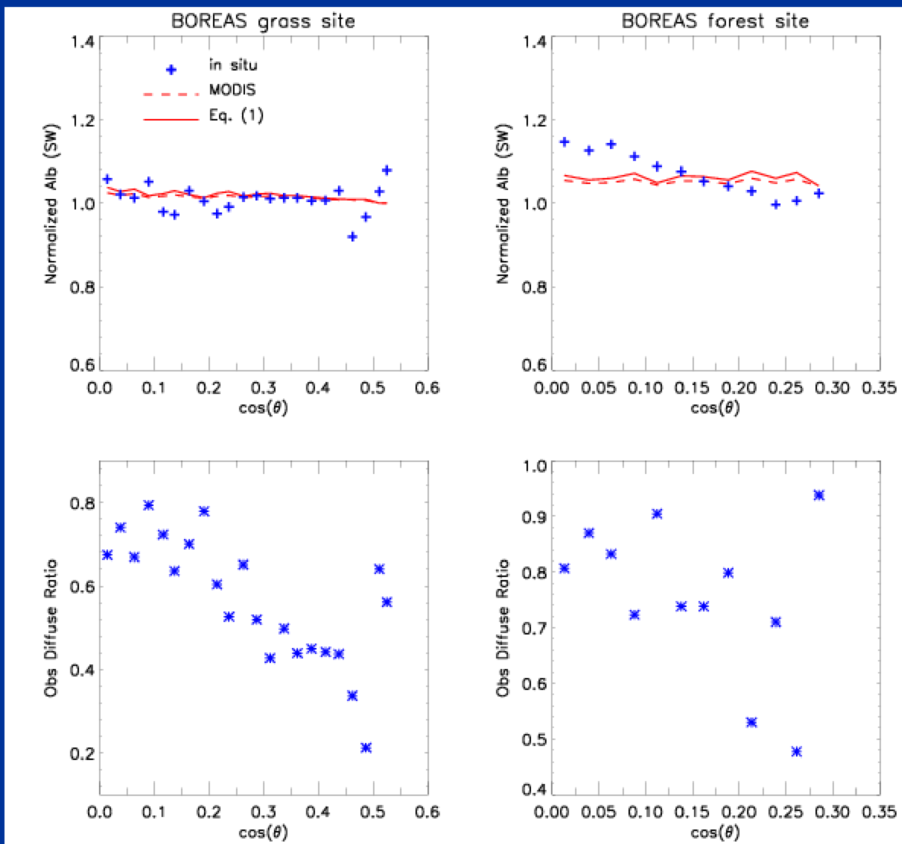
0.85
0.4

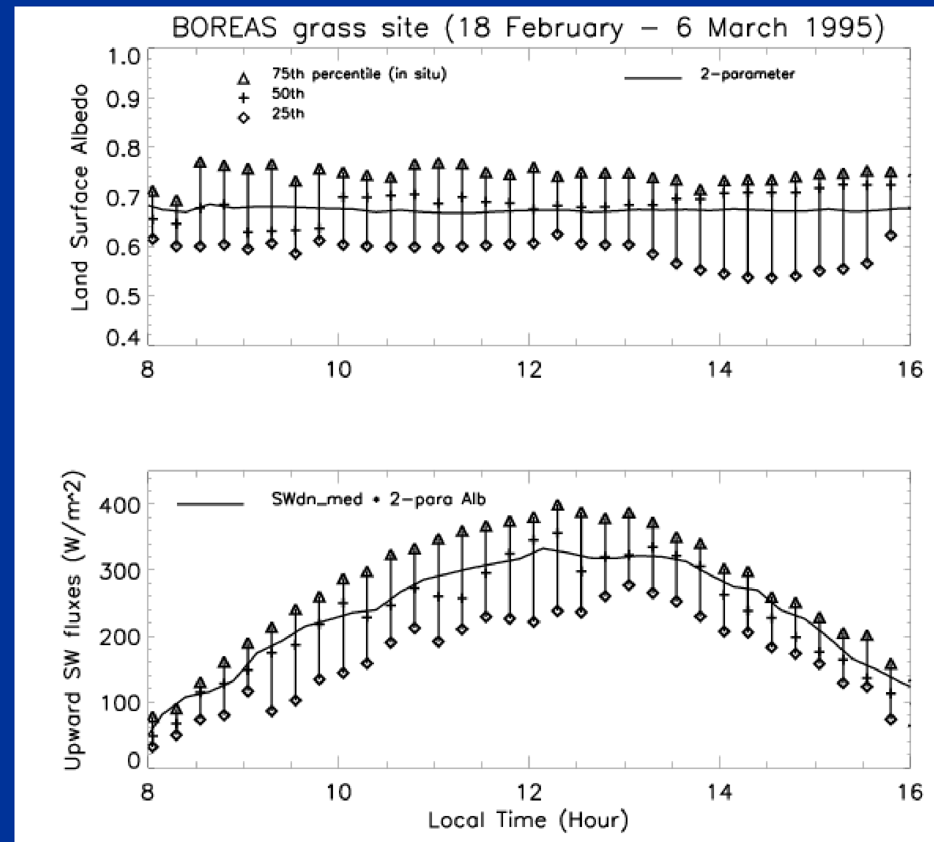


same Tg in sensitivity tests

TB

Snow albedo's dependence on SZA from in situ and MODIS data

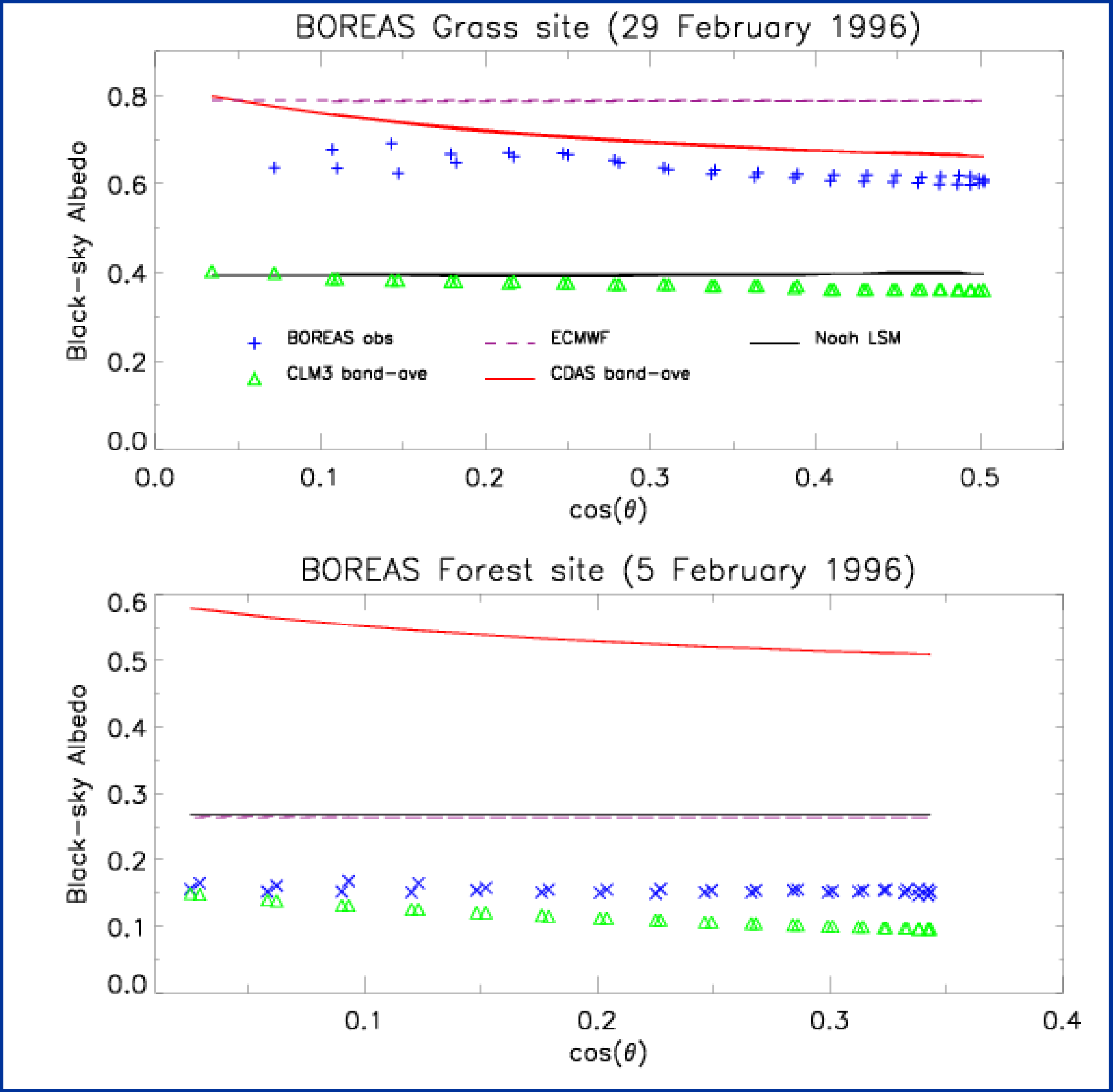




6. Intercomparison of snow albedo parameterization in climate models

Hsn = 72mm
Fsn = 40%
Max_alb
= 0.71 (MODIS)
0.64 (WRF)

Hsn = 440mm
Fsn = 81%
Max_alb
= 0.31 (MODIS)
0.52 (WRF)



7. Soil moisture (SM) Richards equation

Solution: revised form of the Richards equation

In the atmosphere: Vertical velocity equation:

$$\frac{dw}{dt} = \frac{1}{\rho}\frac{\partial p}{\partial z} - g$$

hydrostatic approximation:

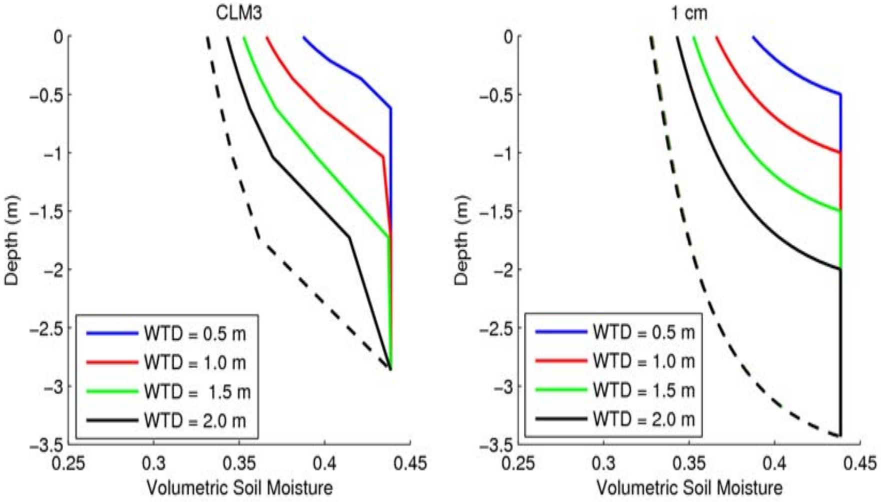
$$\frac{1}{\rho}\frac{\partial P}{\partial z} - g = 0$$

In the soil: soil moisture-based Richards equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K\frac{\partial(\psi + z)}{\partial z}\right] - S$$

with a steady-state solution:

$$\psi(\theta) + z = \psi_{sat} + z_w$$



Deficiency: Numerical solution in CLM3.5 and other land models cannot maintain this steady state solution of the differential equation even for zero flux (top and bottom) boundary conditions

Summary

- From desert to full vegetation cover: New formulations for effective Zom and Zot are proposed for Noah that significantly improves the GFS Ts forecasts in summer
- Over snow/vegetation/soil mixture: A new formulation for effective snow fraction is proposed for testing in CRTM/Noah coupling; it significantly affects emissivity and Ts
- Snow albedo formulations in Noah, CLM, ECMWF, CDAS are evaluated
- Revised Richards equation is developed for all land models with a shallow or deep water table