NCEP Land Data Assimilation Thrusts: including use of CRTM and Satellite Land Products

Ken Mitchell
NCEP/EMC (NOAA)

JCSDA Annual Science Workshop

10-11 June 2008

Span of JCSDA Land Arena

(Coordination via monthly telecons hosted by NCEP/EMC)

- Joint Center for Satellite Data Assimilation: Land PIs
  - **External** JCSDA-funded PIs

Presently

• U. Arizona:	Xubin Zeng
• NCAR / Purdue U.:	F. Chen and D. Niyogi
• U. Maryland:	S. Liang

Recent Past

• Boston U.:	M. Friedl
• Princeton.U / U.Washington:	E. Wood and D. Lettenmaier
• George Mason U.:	P. Houser
• NRL:	B. Ruston

  - **Internal** JCSDA Investigators:

• NCEP/EMC Land Team:	K. Mitchell, W. Zheng, J. Meng, V. Wong
• NESDIS:	X. Zhan, Ron Vogel, C.-Z. Zao
• NASA GSFC/HSB:	C. Peters-Lidard, S. Kumar, LIS Team
• NASA GSFC/GMAO:	R. Reichle
• Air Force Weather Agency	J. Eylander

Goals of Land-arena in JCSDA:

Improved Weather and Climate Forecast Skill Through Use and Assimilation of Satellite Land Data

- Derive and apply new satellite-based land surface characteristics
  - Boston U. (M. Friedl)
  - U. Arizona (X. Zeng)
  - NESDIS (L. Jiang)
- Improve land surface forward modeling of surface emission
  - Princeton U. / U. Washington (E. Wood/D. Lettenmaier)
  - U. Maryland (S. Liang)
  - NRL (B. Ruston)
  - NESDIS (R. Vogel)
- Improve Noah LSM physics to use satellite data (e.g.improve LST)
  - U. Arizona (X. Zeng)
  - NCAR / Purdue U. (F. Chen, D. Niyogi)
  - NCEP/EMC (K. Mitchell, W. Zheng, J. Meng
- Execute model impact studies for new land-sfc satellite products
  - NCEP/EMC (W. Zheng), NASA/HSB (Peters-Lidard), NASA/GMAO (R. Reichle)
  - NESDIS (C.-Z. Zao)
- Demonstrate Land 4DDA methods for land-state initial conditions
  - George Mason U. (P. Houser),
  - NASA/HSB (Peters-Lidard), NASA/GMAO (R. Reichle)
  - NESDIS/ORA (X. Zhan)
- Transition to operations
  - NCEP/EMC, AFWA, NESDIS

Changing focus of Land Arena of JCSDA:

- **Early work focused on deriving new satellite-based global land surface characteristics**
  - albedo, landuse class, vegetation phenology
- **More recent work has focused on:**
  - **1) Impact of above land datasets in models**
    - especially in NCEP global model, but also WRF
  - **2) Reducing large differences between simulated and observed satellite Tb for sfc-sensitive channels**
    - Improve physics of modeled land surface
      - Aerodynamic resistance, canopy resistance **and skin temperature**
      - Surface emissivity
  - **3) Actual land 4dda of satellite-based snow and soil moisture estimates**
    - Kalman filters in NASA LIS system
    - Rescaling satellite soil moisture to that of model

JCSDA Thrusts over past year in NCEP/EMC Land Team

- Develop & demonstrate stand-alone driver for CRTM
  - Next step now underway: add NASA LIS as land component
- Reduce bias in NCEP global forecast model (GFS) simulations of land surface skin temperature (LST)
  - Aerodynamic conductance
    - Thermal roughness length
- Test new NESDIS realtime weekly green vegetation fraction (GVF) product in GFS
- Refine MODIS IGBP 1-km landuse database
  - Add three tundra classes

Impact of new JCSDA global datasets of satellite-based land surface characteristics on NCEP global model

- **Order of testing in GFS at NCEP**
  - 1) Albedo datasets (focus of last year's presentation)
    - Snow-free (Boston U.)
    - Maximum albedo for deep snow (U. Arizona)
  - 2) Vegetation datasets (a focus of this presentation)
    - Weekly realtime Green vegetation fraction – GVF (NESDIS)
    - MODIS-based landuse (add tundra classes)
  - 3) Improve GFS LST simulations (a focus of this presentation)
    - Upgrade aerodynamic resistance treatment in Noah LSM
  - 4) Surface emissivity datasets (NRL, U. Maryland)
    - GFS: broadband in Noah LSM
    - CRTM: channel by channel

4DDA of Satellite Brightness Temperatures (Tb)

- GSI assimilates satellite observed Tb in various spectral channels (infrared & microwave)
  - Analysis increment is derived from the difference between forecast simulated Tb and satellite observed Tb
  - Simulated Tb is product of CRTM and GFS forecast of atmospheric states and earth surface states (land, ice, sea)

$$\mathrm{Tb}_p = T_{\mathrm{surf}} \varepsilon_p e^{-\tau(0,H)/} + T_{\mathrm{atm}}^{\downarrow} (1 - \varepsilon_p) e^{-\tau(0,H)/\mu} + T_{\mathrm{atm}}^{\uparrow},$$

with

$$T_{\mathrm{atm}}^{\downarrow} = \int_H^0 T(z)[\alpha(z)/\mu] e^{-\tau(z,0)/\mu} dz + T_{\mathrm{cosm}} e^{-\tau(0,H)/\mu}$$

$$T_{\mathrm{atm}}^{\uparrow} = \int_0^H T(z)[\alpha(z)/\mu] e^{-\tau(z,H)/\mu} dz.$$

$$\tau(z_0, z_1) = \int_{z_0}^{z_1} \alpha(z) dz$$

α = atmospheric absorption

For surface sensitive channels (so called “window channels”):

atmospheric absorption (α) is weak and Tskin & sfc emissivity (ξ) are key

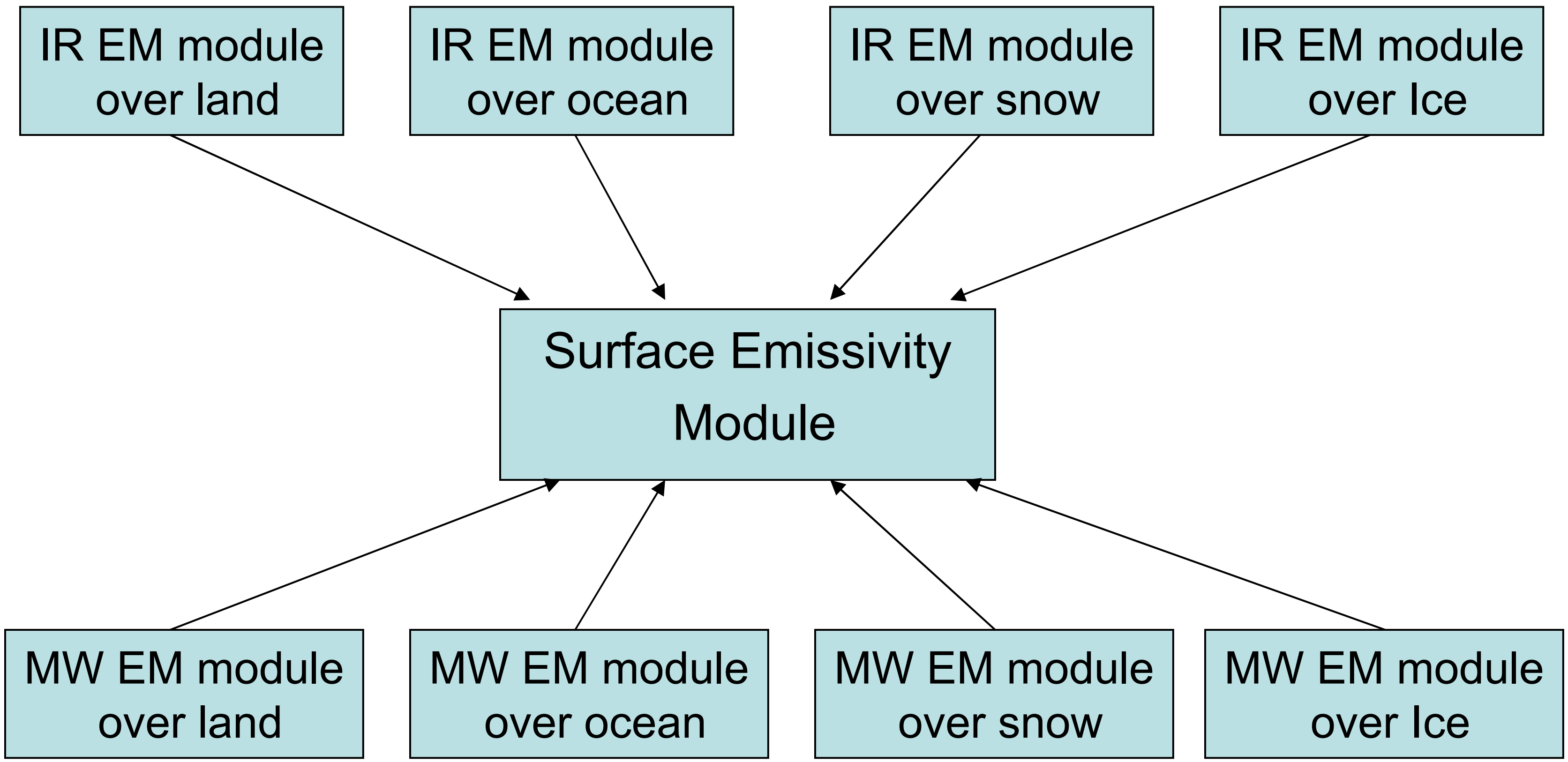
Sfc emissivity (ξ) is strong function of land surface states:

Snow cover/density, vegetation cover/density, soil moisture amount,

Soil moisture phase (frozen vs. liquid)

Surface Emissivity Module in JCSDA Community Radiative Transfer Model: CRTM

(Sfc Emissivity as function of satellite sensor channel & incidence angle)



Specified **surface emissivity** via
look-up tables OR **physical** OR **empirical models**,
depending on **spectral band** and
ocean / **land** / **snow** / **sea-ice** presence.

Fuzhong Weng et al., NOAA/NESDIS

Develop and Demonstrate a stand-alone driver for CRTM

Weizhong Zheng
NCEP/EMC

Assistance from Ron Vogel and Paul Van Delst

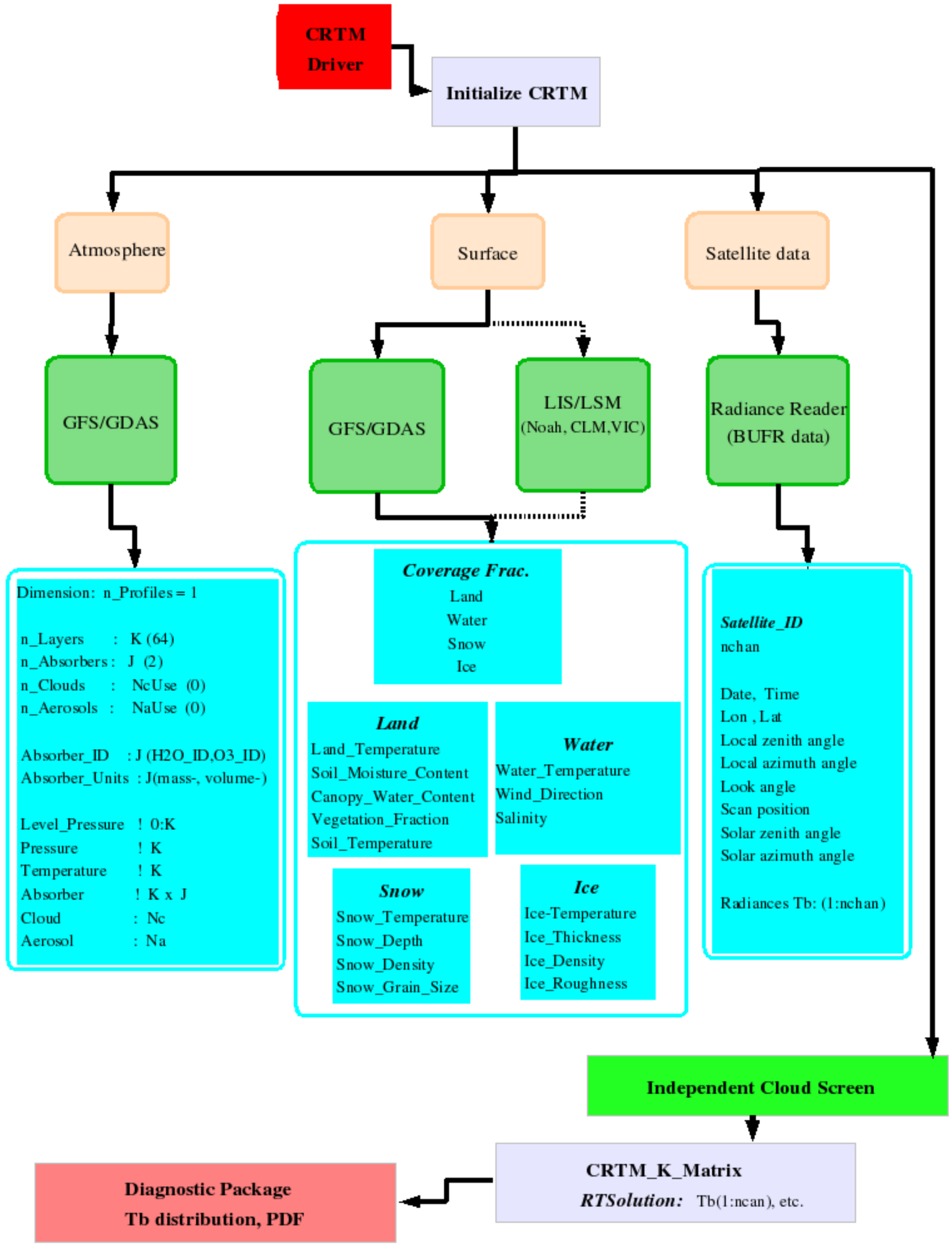
Develop and Demonstrate a stand-alone driver for CRTM:

- **Accomplishments**
  1. **Developed a stand-alone CRTM driver**
  2. **Now adding LIS to CRTM**
  3. **Testing this CRTM driver to simulate brightness temperatures (Tb) that consistent with those of GSI/CRTM.**
  4. **Testing improvements to GFS LST and Tb simulations.**

Structure of CRTM Driver

CRTM REL-1.1

beta version



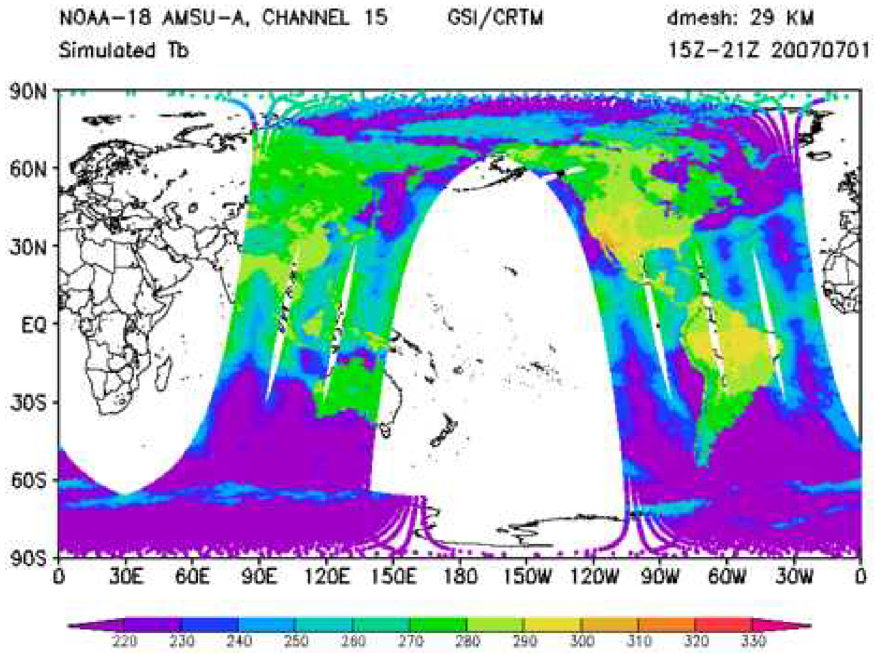
Comparison of CRTM Driver and GSI/CRTM: Tb Simulation

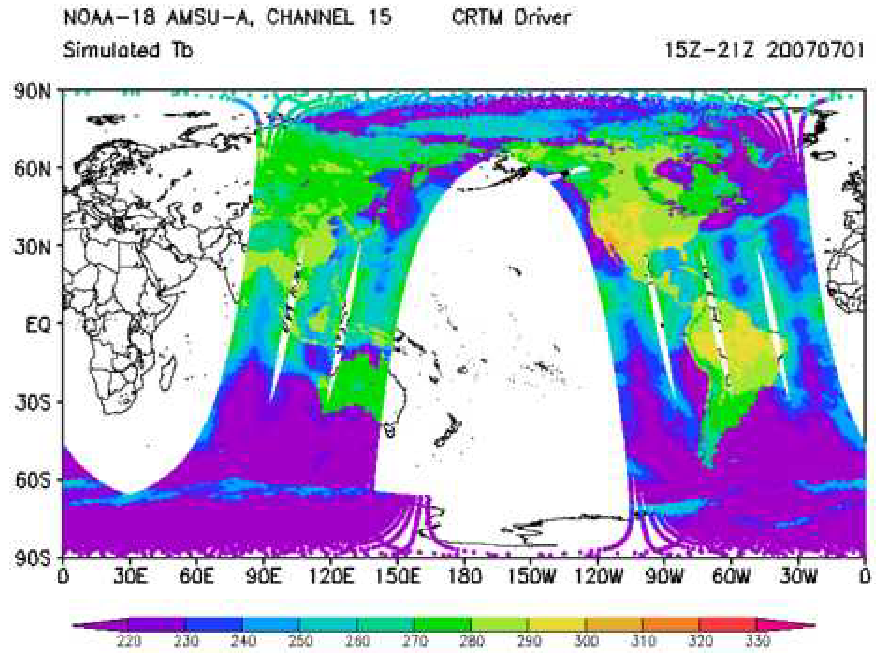
This is to check if the CRTM driver works properly, given the same input data as GSI, except that GSI performs QC and 'thin' to reduce satellite data pixels.

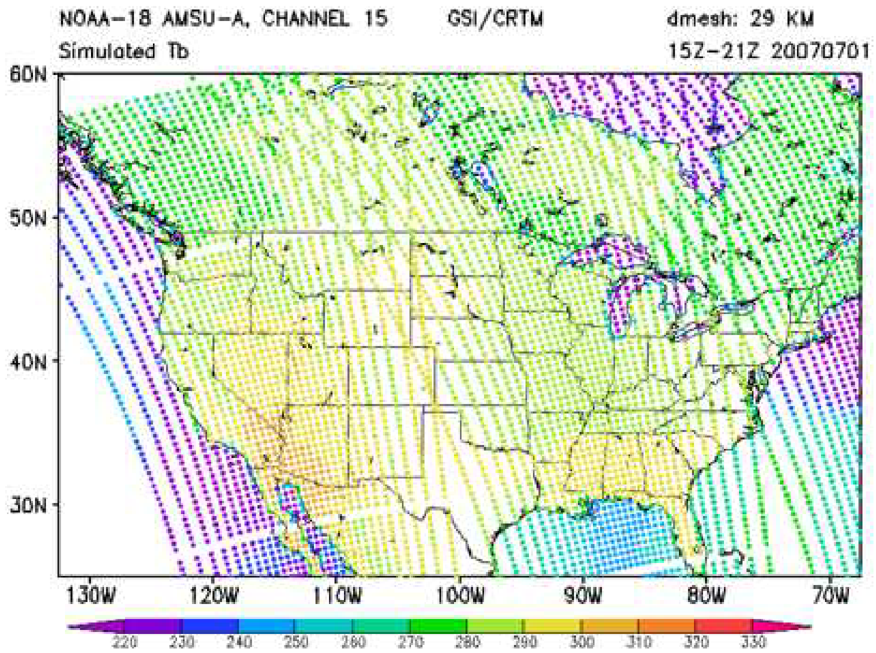
Sensor: NOAA-18 AMSU_A Ch15
Case : 1800 UTC, July 1, 2007

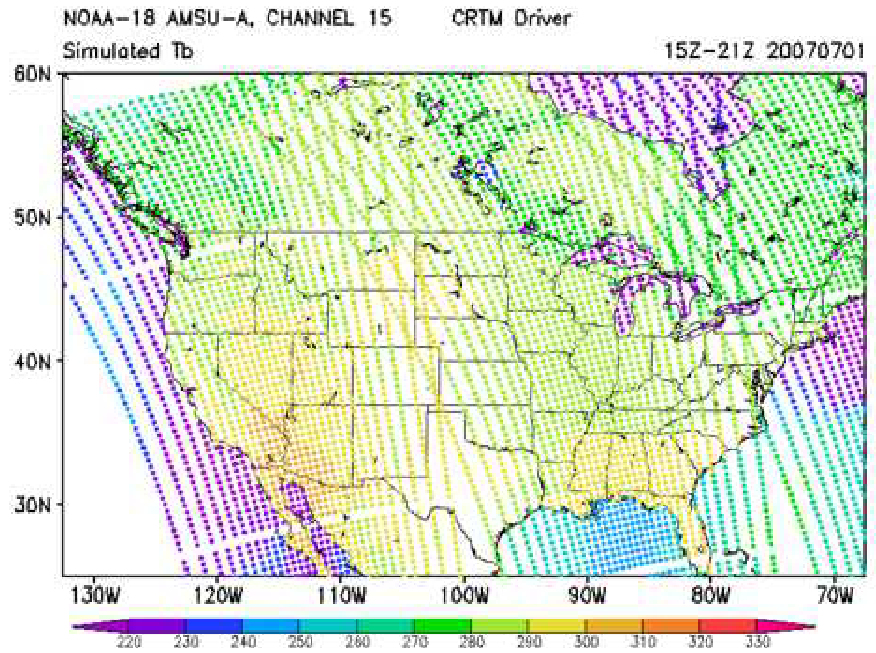
Comparison of GSI/CRTM and CRTM Driver: Tb Simulation

Case: 18Z, 20070701



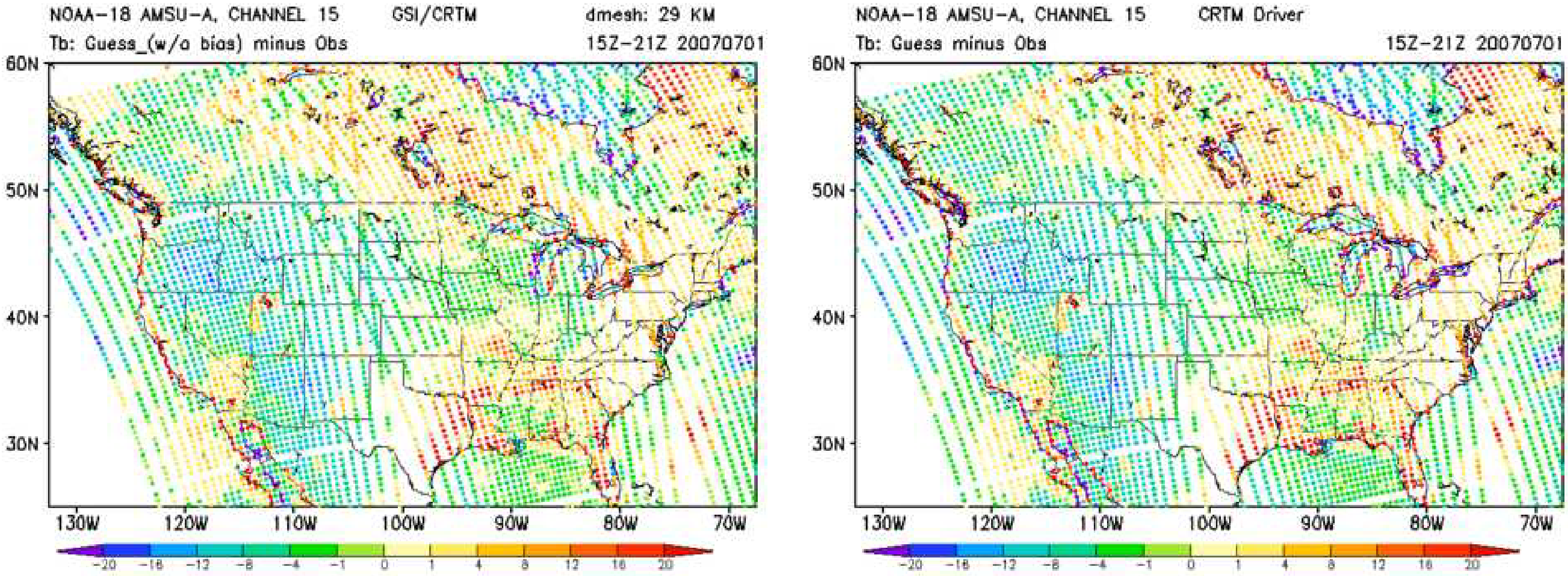






Comparison of GSI/CRTM and CRTM Driver: Tb: Guess-Obs

Case: 18Z, 20070701



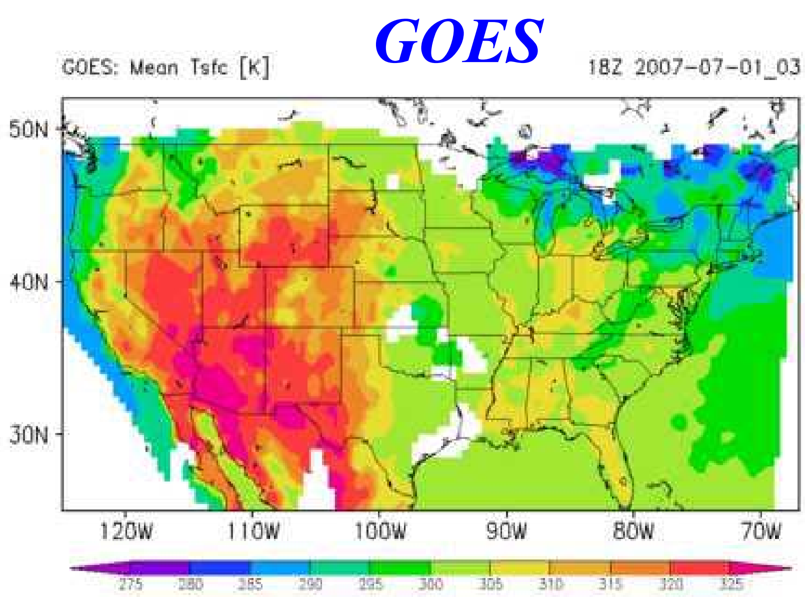
Note the large cool bias in simulated brightness temperature over arid western CONUS, which further study showed was a result of large cool bias in GFS simulated LST.

Assess and reduce GFS LST cold bias in warm arid regions

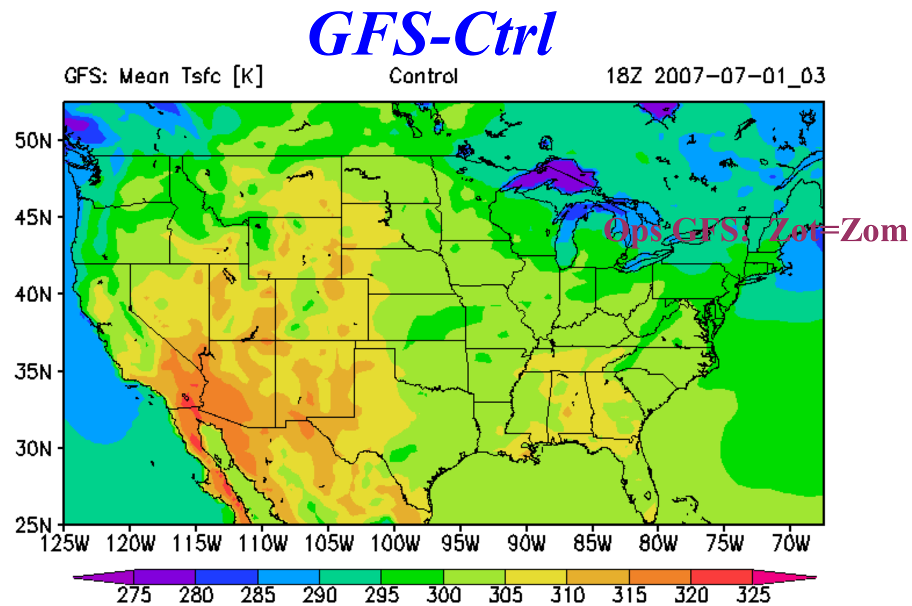
Weizhong Zeng, Helin Wei, Jesse Meng
NCEP/EMC

Xubin Zeng
U. Arizona

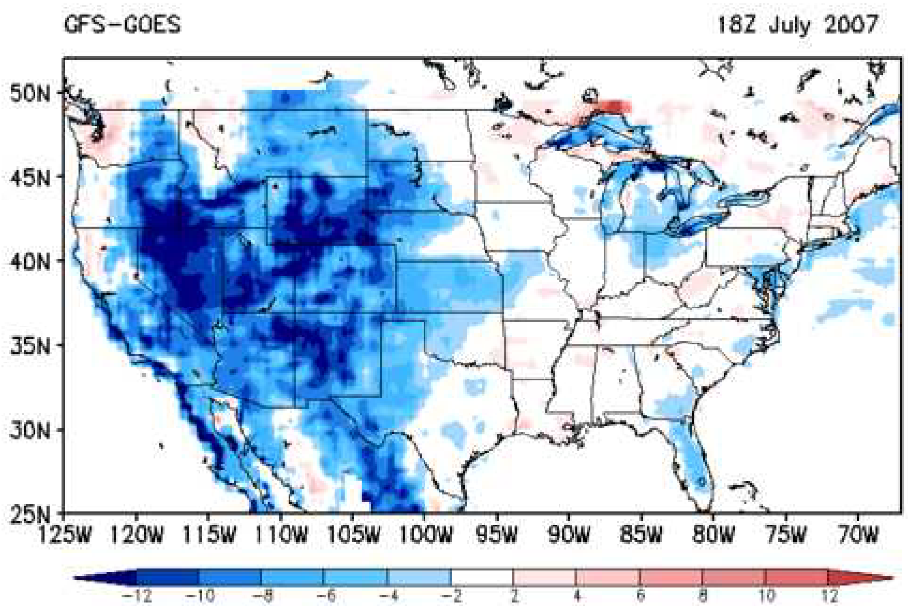
Mean 18Z LST [K] July 1 - 3, 2007 3-Day Mean



GOES Retrieval of LST

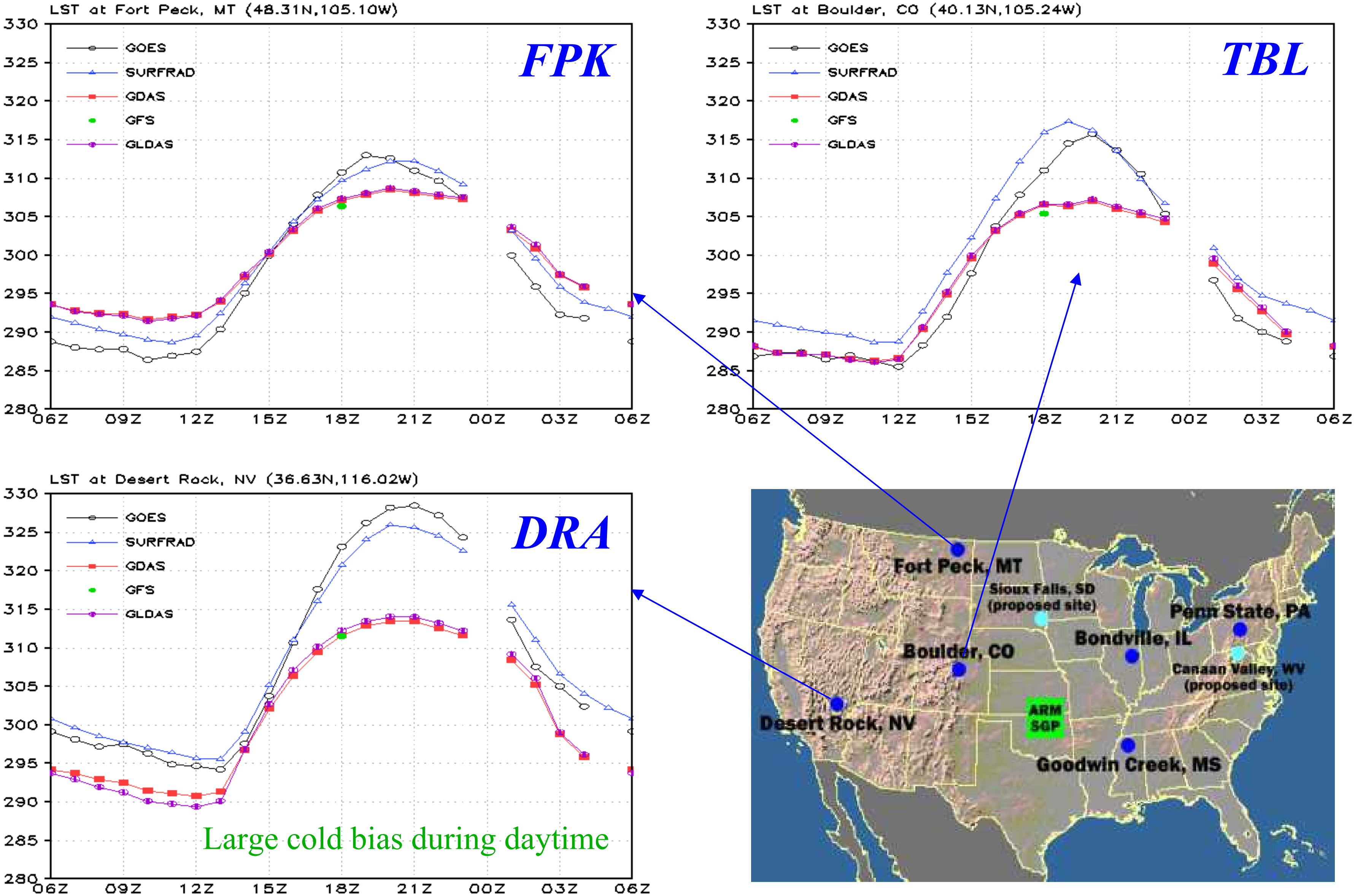


GFS Simulation of LST



Monthly Mean Difference:
GOES-minus-GFS 18Z LST
July 2007

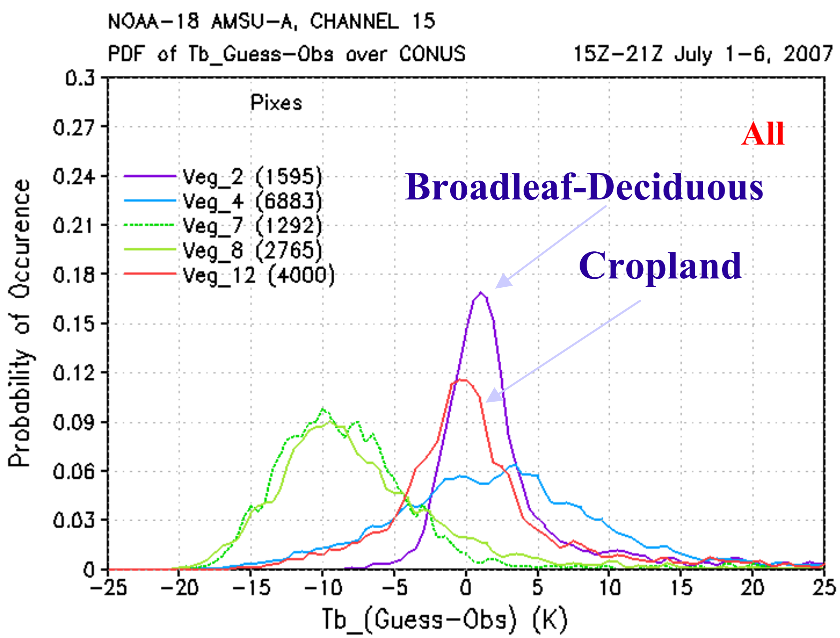
LST [K] Verification at SURFRAD Sites, July 2007

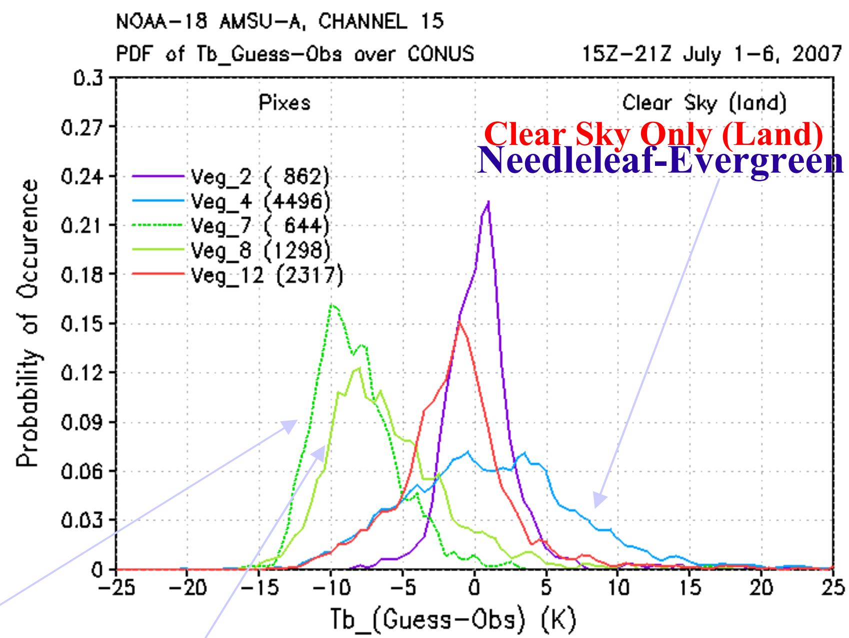


SURFRAD Network

Summer **PDF distribution: by Vegetation Type** ***15Z-21Z, July 1-6, 2007***

<u>Use Stand-Alone CRTM Driver</u> to simulate AMSU-A Channel 15 with GFS input and compare to observed AMSU-A Channel 15





Veg_7: Ground Cover Only; Veg_8: Broad leaf Shrubs w/ Ground Cover

LST (Tskin) and Surface Sensible Heat Flux

Sensible heat flux: $SH = \rho C_p C_h (T_{skin} - T_{air})$

Ch (m/sec) = (Ch*) x lVl = aerodynamic conductance

Ch* is non-dimensional surface exchange coefficient

lVl is the wind speed at same level as T_{air}

T_{skin} is land surface skin temperature (LST)

- **Errors in Ch and T_{skin} can offset each other to still yield reasonable sensible heat flux**
- **But CRTM surface emission module cannot tolerate large error in LST.**

From PI Xubin Zeng: The role of surface roughness length for heat (Zot)

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

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

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

CLM:

$\ln(Z_{om}/Z_{ot}) = \alpha\, Re^{0.45}$ $(Re = u_*\, Z_{om}/v)$

In GFS:

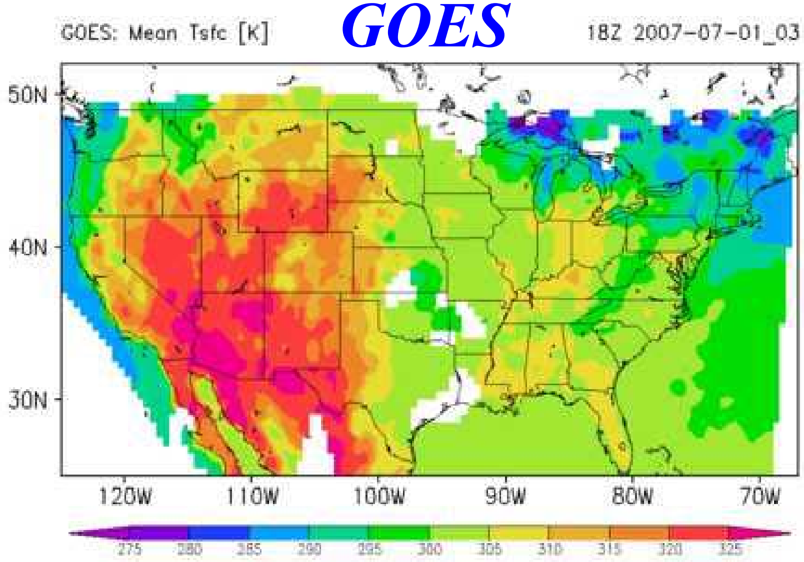
$\ln(Z_{om}/Z_{ot}) = 0$ (i.e. Zot = Zom)

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

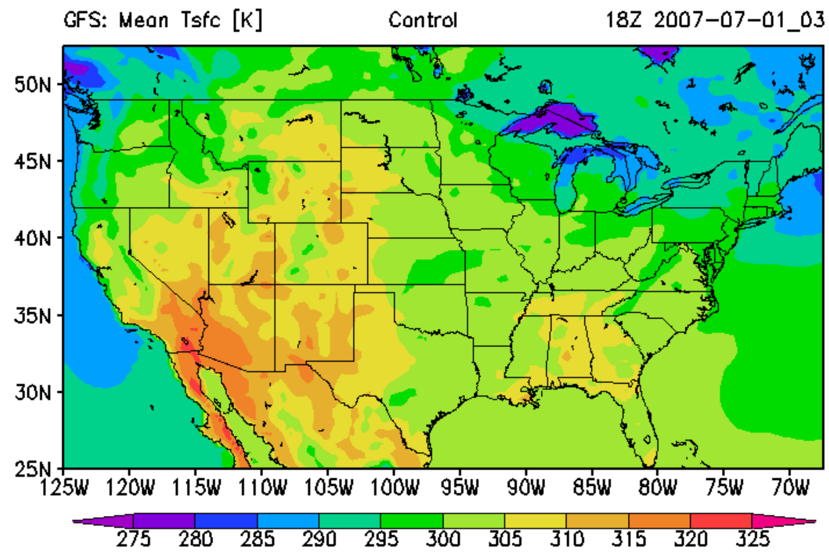
- Model: GFS prediction system.
- Z0t : Z0T(I) = Z0M(I)*exp(- ((1.-GVF(I))**b) *C21*CA*sqrt(USTAR(I)*0.01/(1.5E-05)))
- Case : 00Z, July 1, 2007; 72-h integration.
- Exps: **Control run (Ctr)** : Z0T(I) = Z0M(I)
- **Sensitivity runs (Sen)** : Test different Z0t
- **Exp_01: b=4; C21=0.3**
  Exp_02: b=2; C21=0.5
  Exp_03: b=2; C21=0.7
  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

Mean 18Z LST [K] July 1 - 3, 2007 3-Day Mean

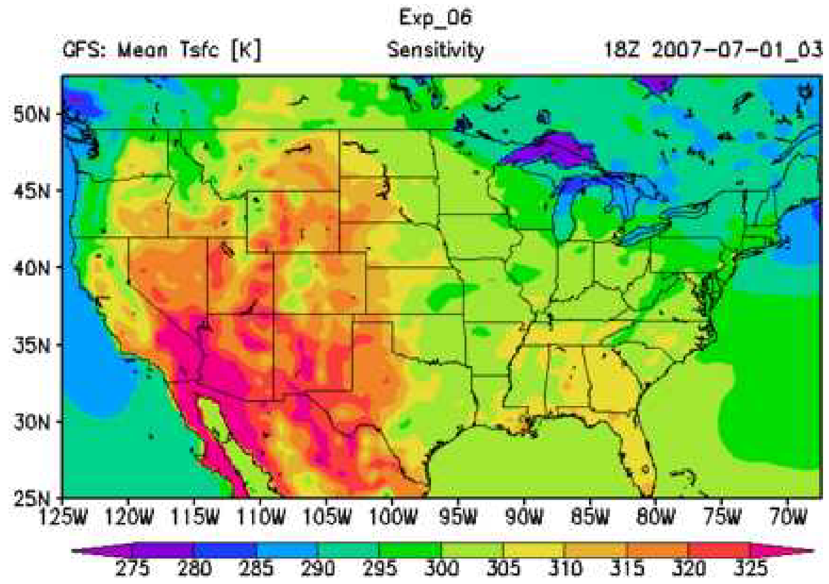
GOES



GFS-Ctr Ops GFS: Zot=Zom



GFS-E06



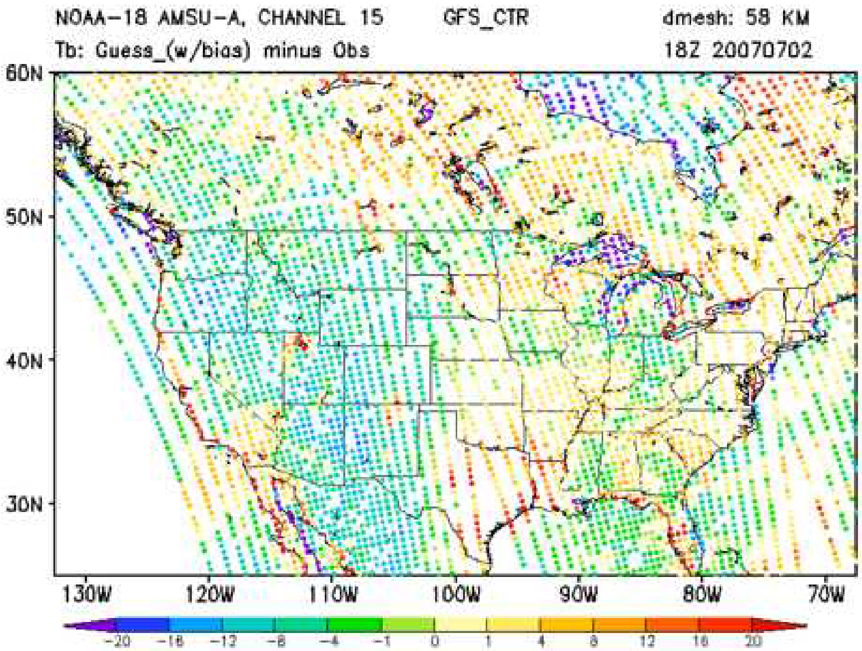
Next Two Frames:

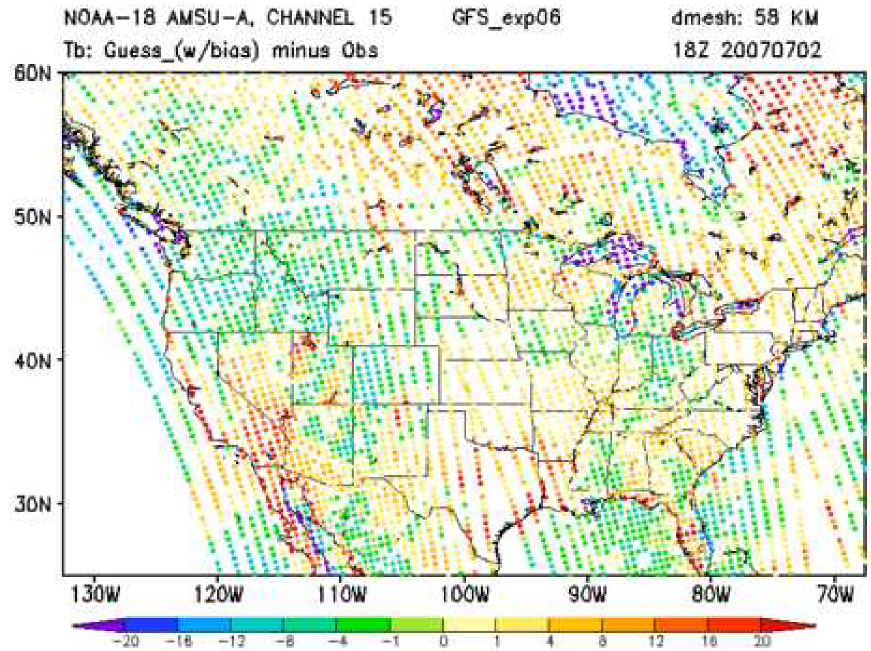
Comparison of Tb Simulation with GSI/CRTM: CTR and Exp06

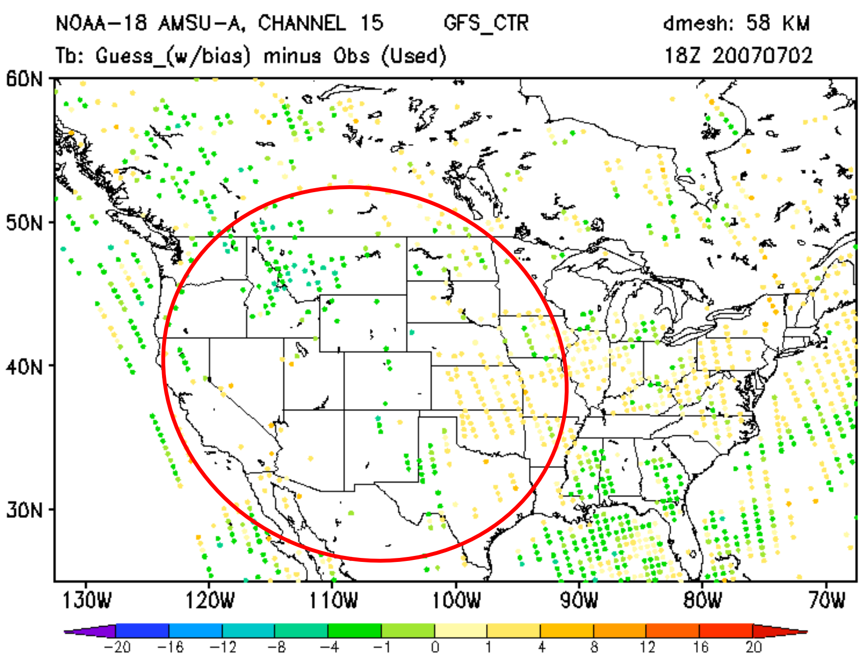
This is to study if the LST improvement in GFS (Zot, Exp06) can also improve Tb simulation with GSI/CRTM. The result shows that more radiance data are used in GSI/CRTM after GFS LST improvement over the western CONUS.
Sensor: NOAA-18 AMSU_A Ch15
Cases : July 1-3, 2007

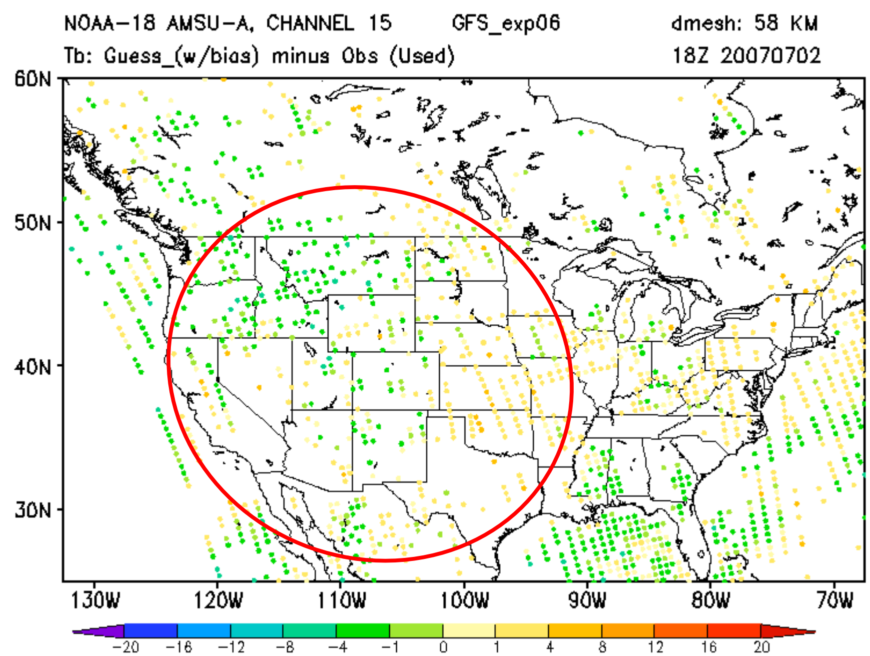
Comparison of Tb Simulation between CTR and Exp06 (Zot)

Case: 18Z, 20070702









Tests of New NESDIS realtime weekly global Green Vegetation Fraction (GVF):

GFS Impact Tests:
Weizhong Zheng, Helin Wei
NCEP/EMC

WRF Impact Tests:
Yuhong Tian, Cheng-Zhi Zao
NESDIS

New GVF Developed in NESDIS by
Le Jiang, Wei Guo, Felix Kogan and Dan Tarpley

Weekly Green Vegetation Fraction (GVF) Datasets

- **GVF in NCEP Operational GFS: Monthly 0.14-deg (16-km) global monthly climatology of GVF from AVHRR. (Gutman & Ignatov, 1998).**

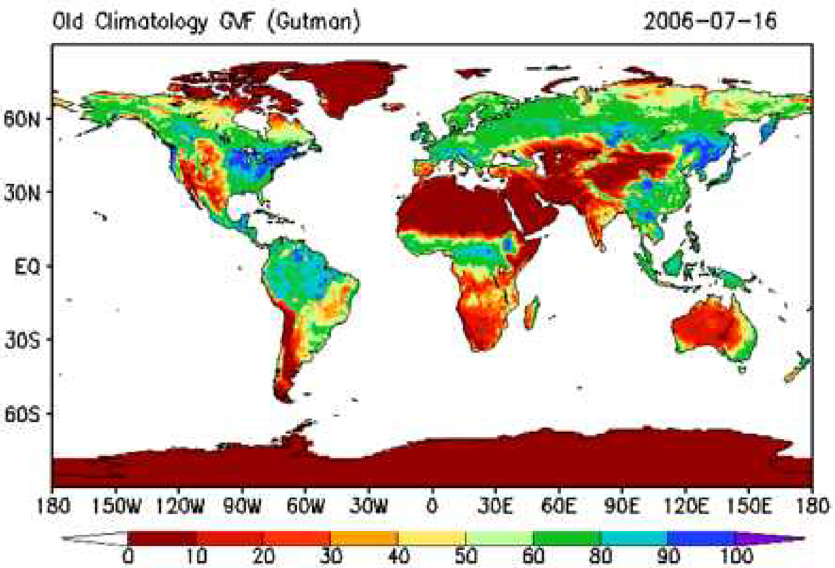
- **New Weekly Realtime GVF: AVHRR-based weekly global 0.144-deg (16-km) GVF (Jiang et al., 2007).**
- **The weekly GVF data set starts from 1981 to include AVHRR observations from NOAA 7, 9, 11, 14, 16, 17, and 18 satellites.**

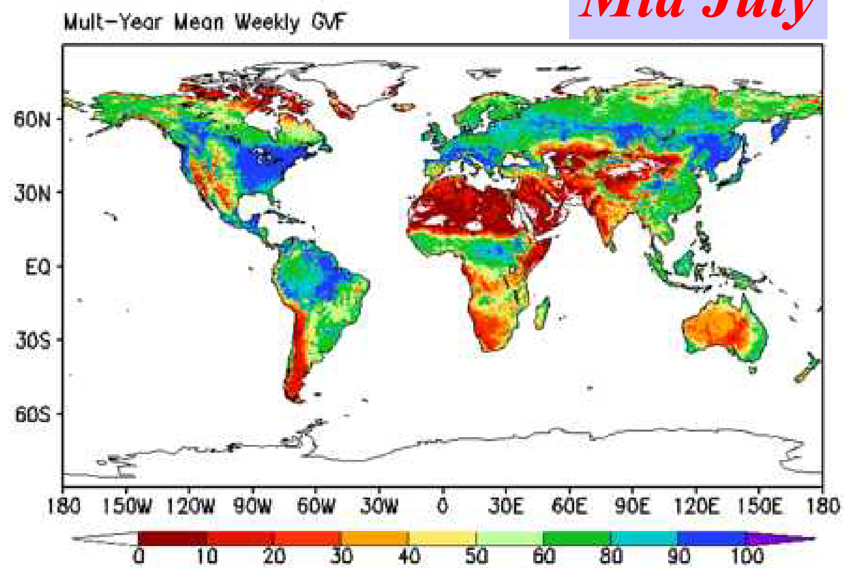
- **Two new datasets: Weekly climatology GVF (1982-2005); Near real-time weekly GVF**

- **The new GVF datasets can potentially improve the NWP skills, especially during the spring growing season when vegetation has large variations.**

Comparison of GVF Climatology Datasets: Old vs New

Mid July



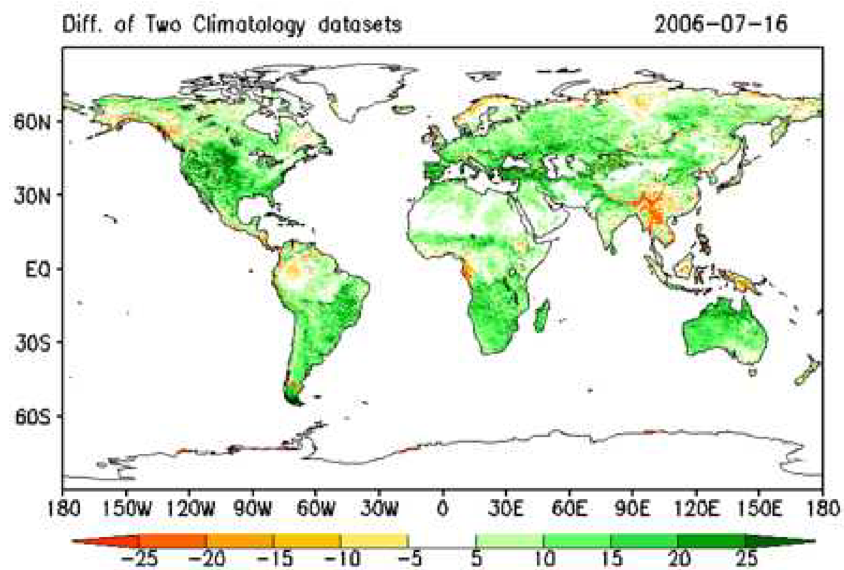


Old_Clim

Ops at NCEP

New_Clim

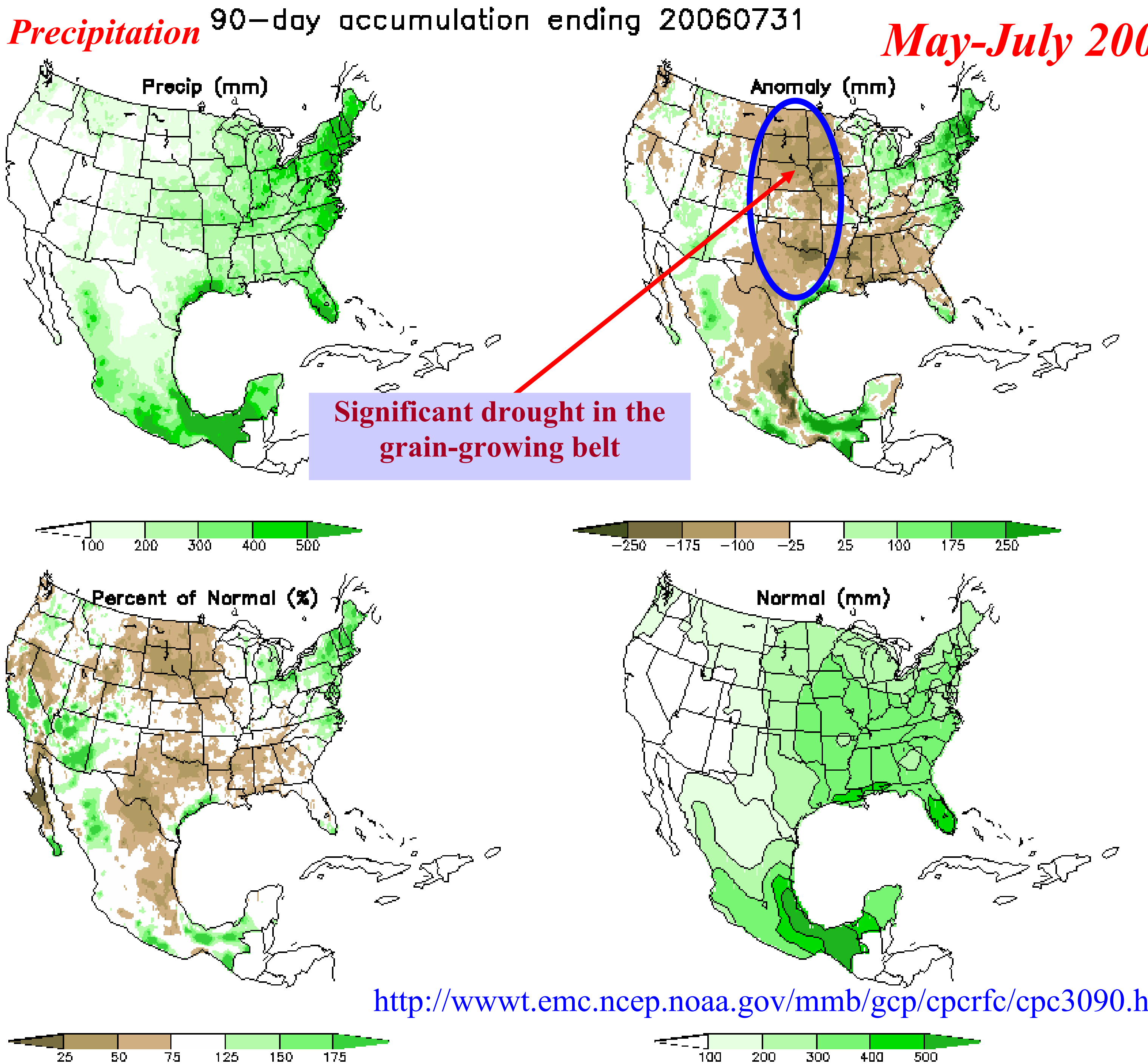
1982-2005



Diff_Clim

Accumulated Precipitation

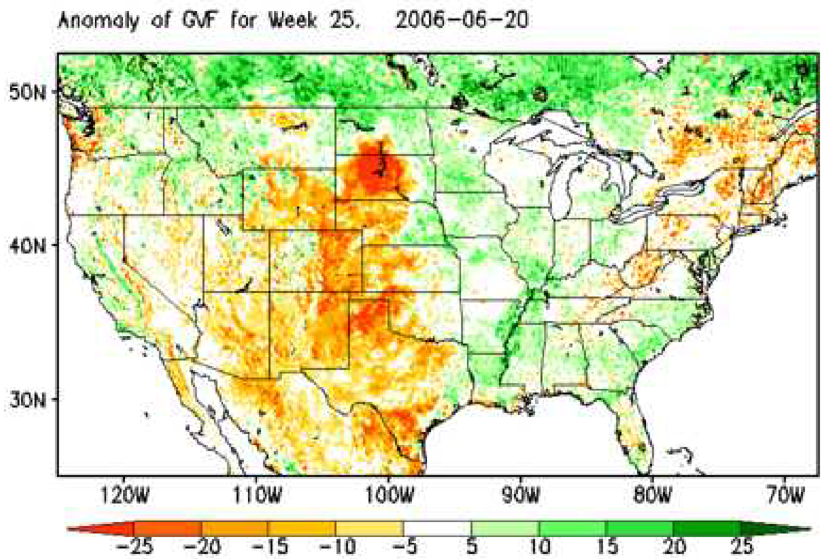
May-July 2006

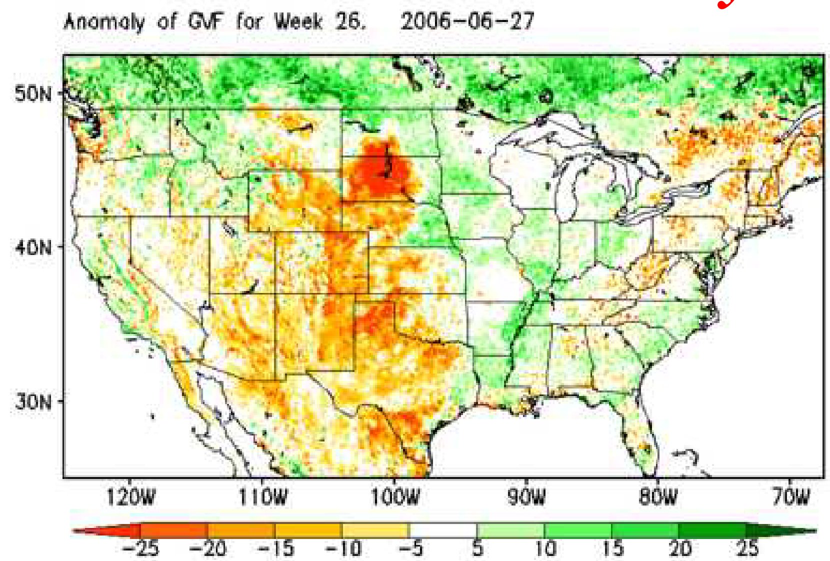


http://wwwt.emc.ncep.noaa.gov/mmb/gcp/cpcrfc/cpc3090.html

Real-time Weekly GVF Anomaly (real-time - Clim.) in CONUS

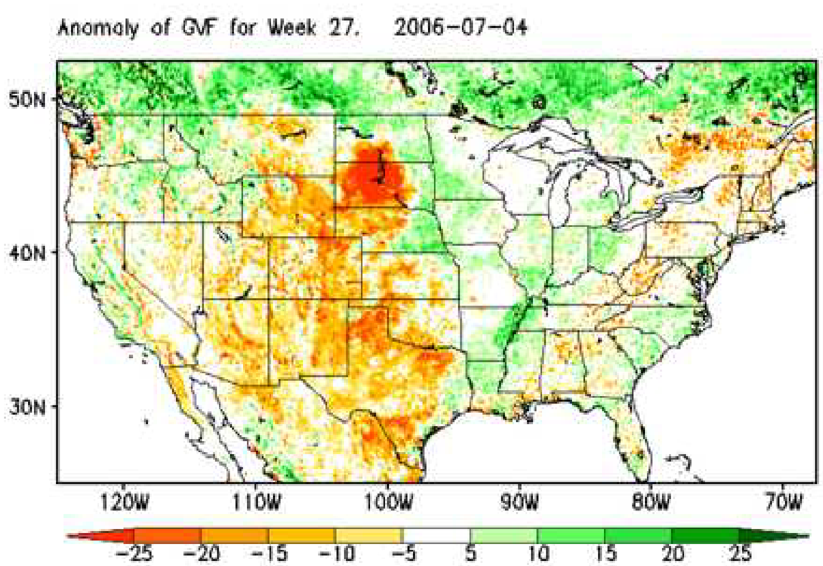
June-July 2006

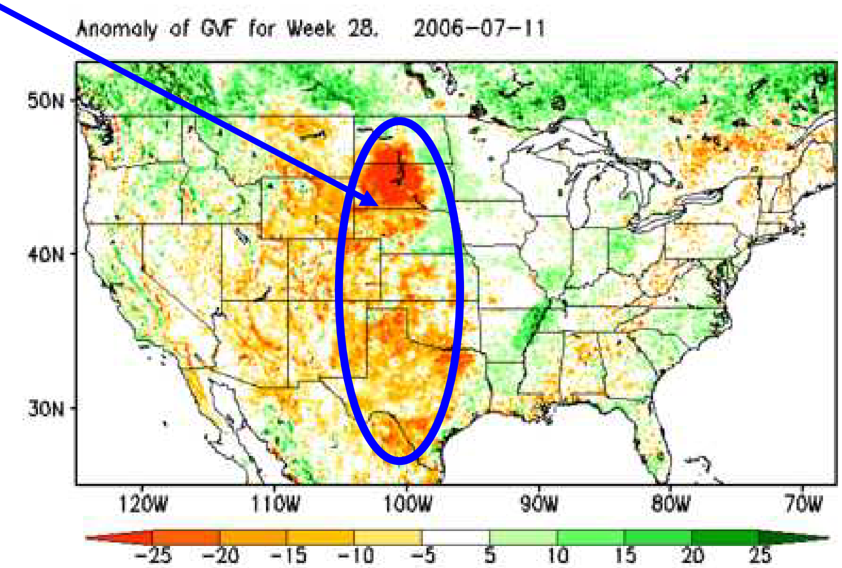




Lower GVF in the grain-growing belt

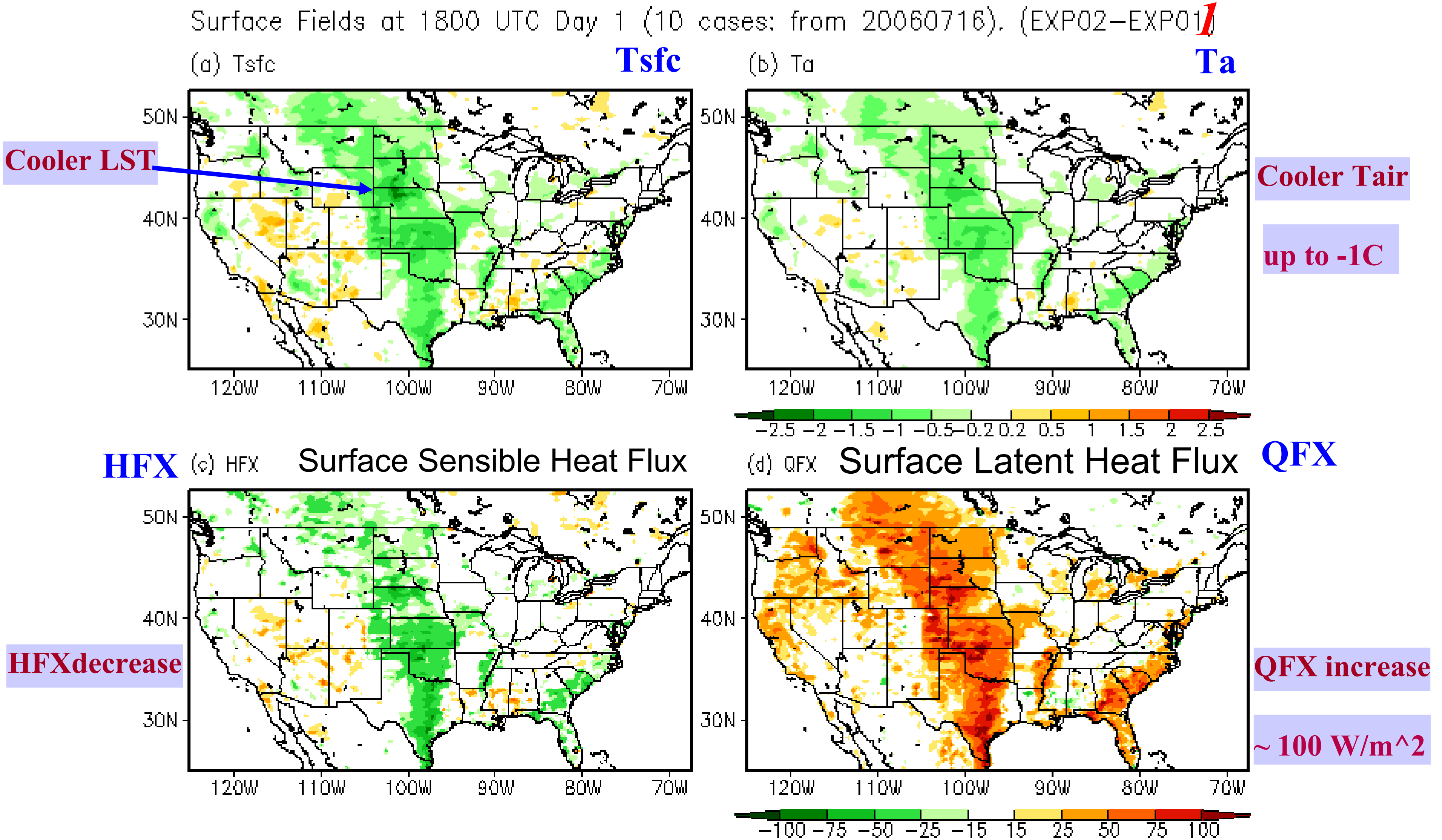
up to 25% reduction





GFS_T382L64 model results: 10 Cases from 20060716; 7days free forecast

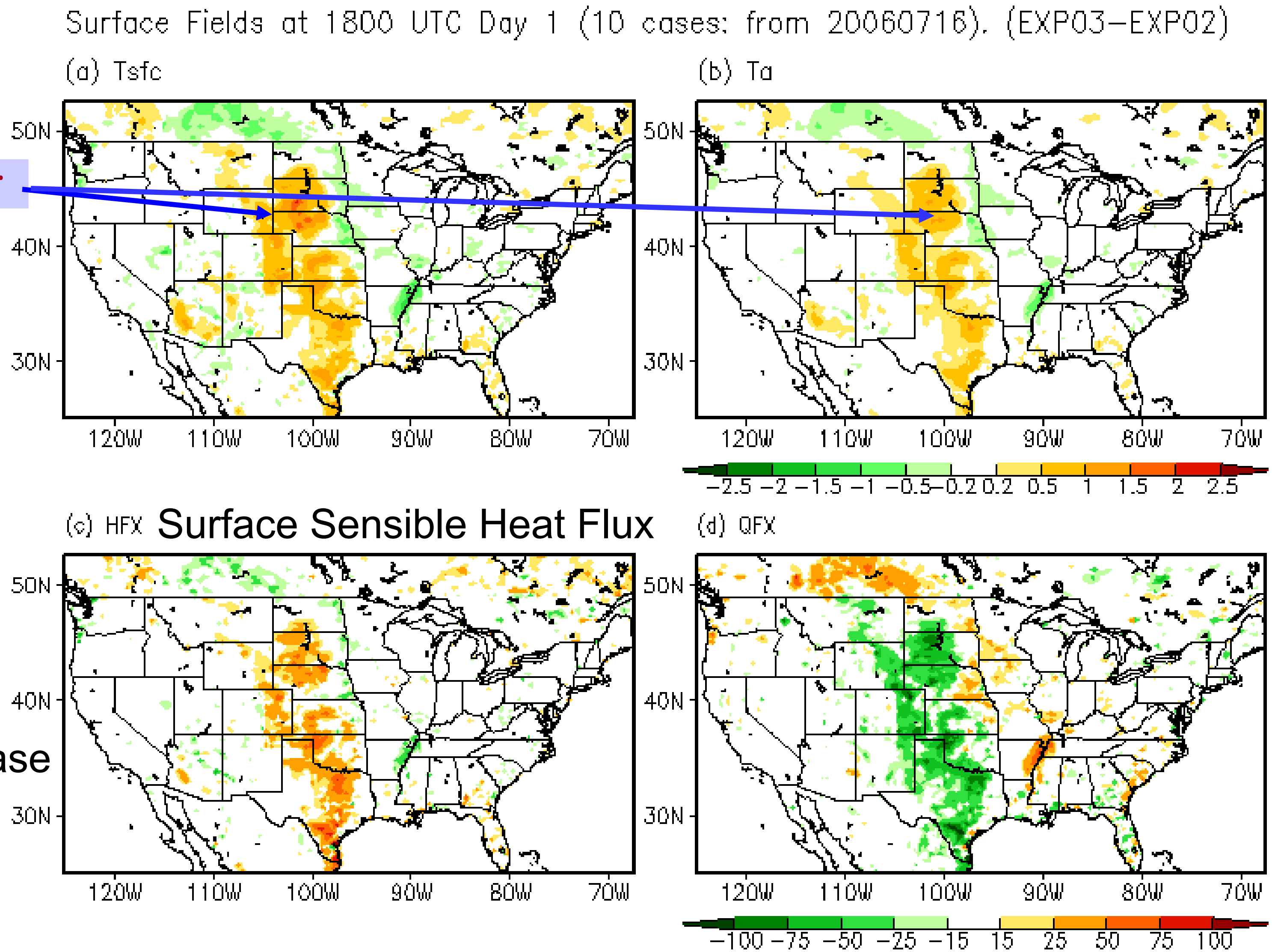
Sensitivity Test: New_Clim minus Old_Clim ***1800 UTC: Day 1***



GFS Impact Test: New GVF Climo minus Old GVF Climo

Sensitivity Test: Anomaly of Realtime Weekly GVF data ***1800 UTC: Day 1***

Warmer



HFX Increase

QFX decrease

GFS Impact Test: Realtime GVF minus Realtime GVF Climo

WRF-ARW Model Simulation Experiments

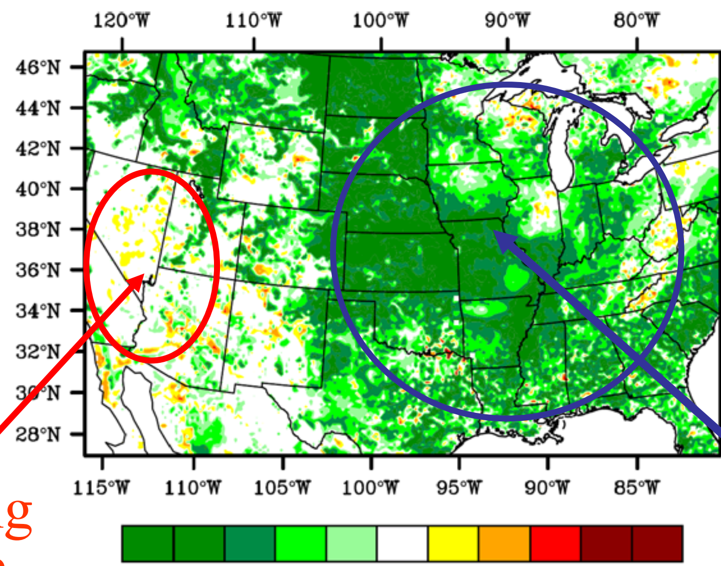
- **10 Cases selected: 2006-07-16 to 2006-07-25 (10 days)**
- **For each day, 3-day free forecast with WRF-ARW**
  - **EXP1: Control run with old monthly climatology GVF**
  - **EXP2: Experiment run with new weekly climatology GVF**
  - **EXP3: Experiment run with near real-time weekly GVF**

- **Results**
  - **Study 1: New_Clim minus Old_Clim** (EXP2 – EXP1)
  - **Study 2: New_real-time minus New_Clim** (EXP3 – EXP2)

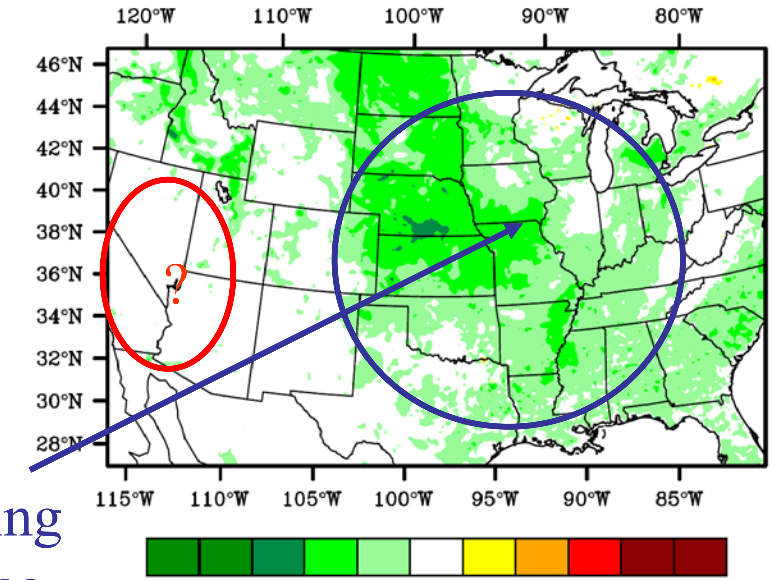
WRF-ARW results: 10 Cases average from 20060716 to 0725 (3-day free forecast)

Study 1: New_Clim minus Old_Clim, 1800 UTC, Day 1 forecast

Surface Skin Temp. (TSK)



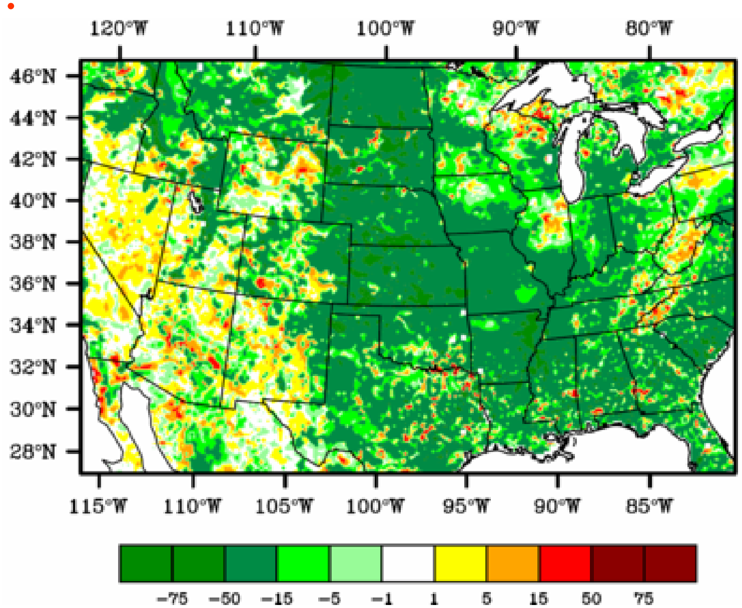
2 m Temp. (T2)



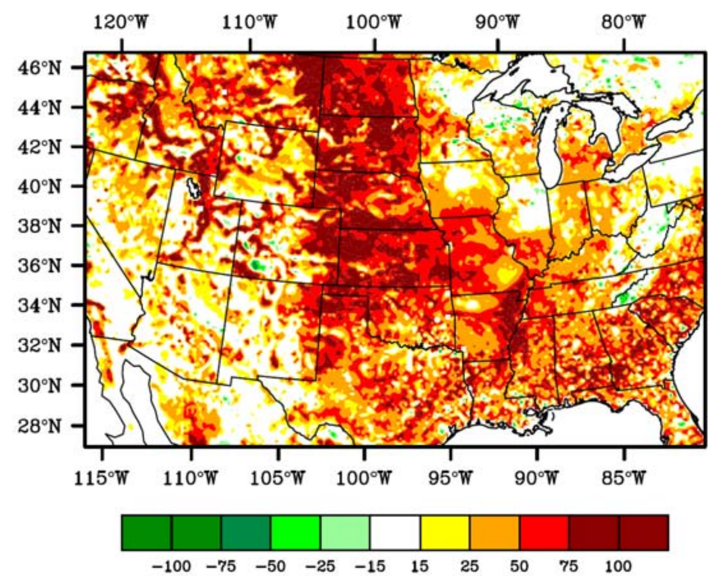
Warming surface?

Cooling surface

Sensible heat flux (HFX)



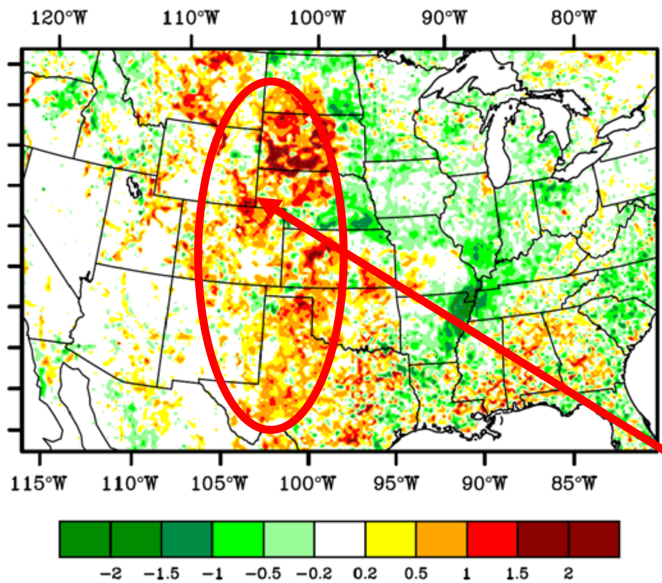
Latent heat flux (LH)



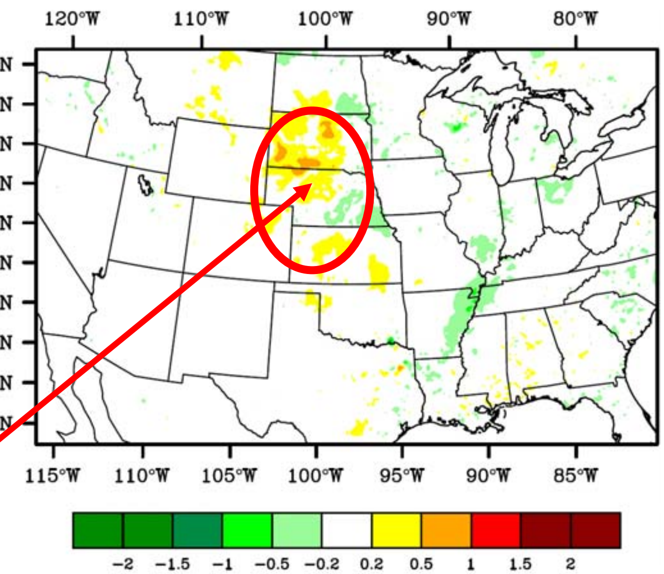
WRF-ARW results: 10 Cases average from 20060716 to 0725 (3-day free forecast)

Study 2: New_Real-time minus new_Clim, 1800 UTC, Day 1 forecast

TSK

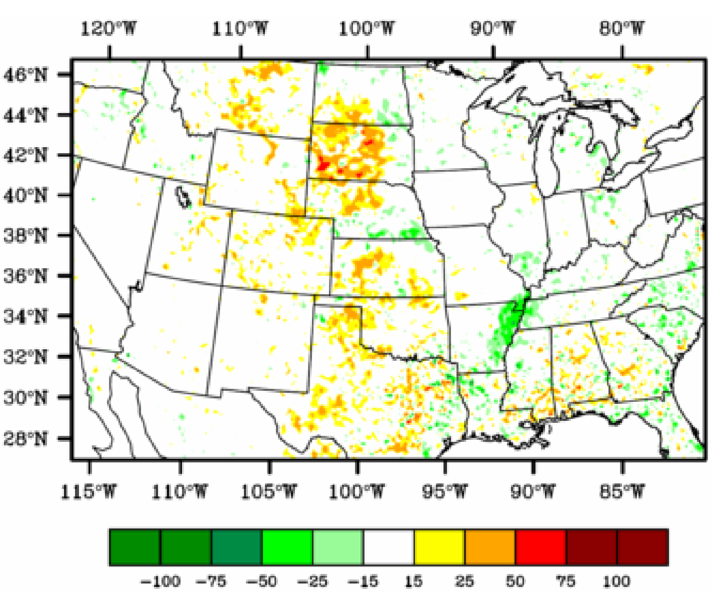


T2

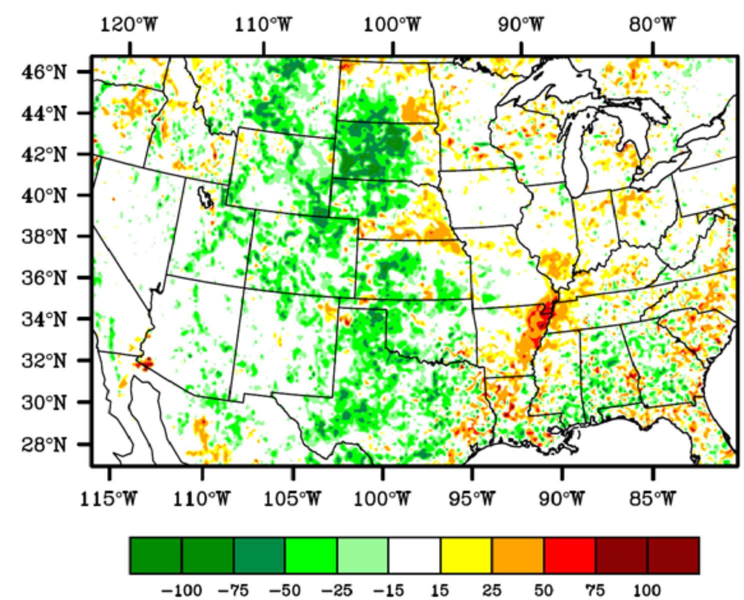


Warmer surface

HFX

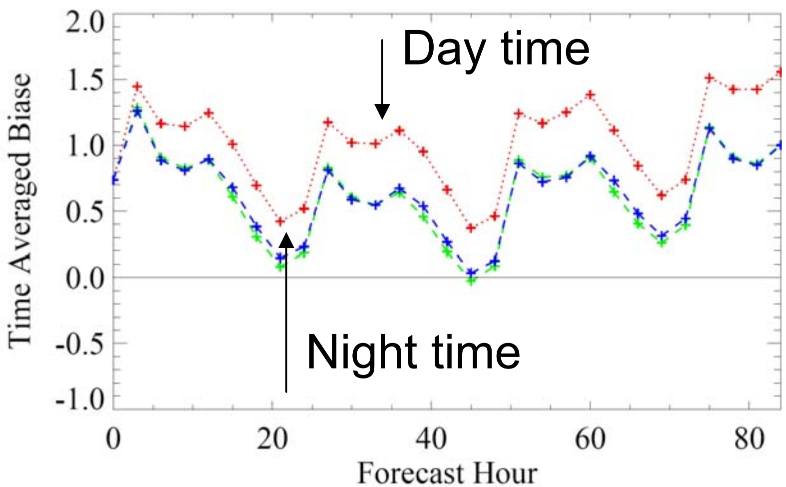


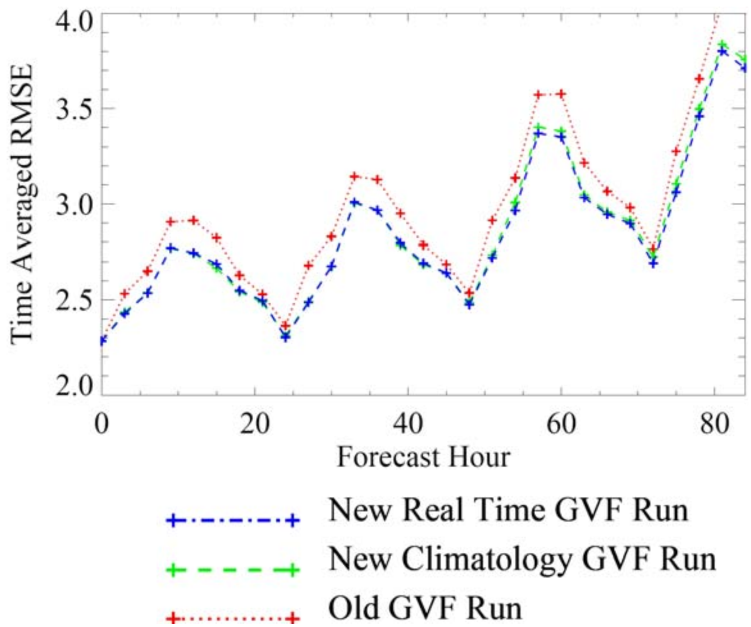
LH



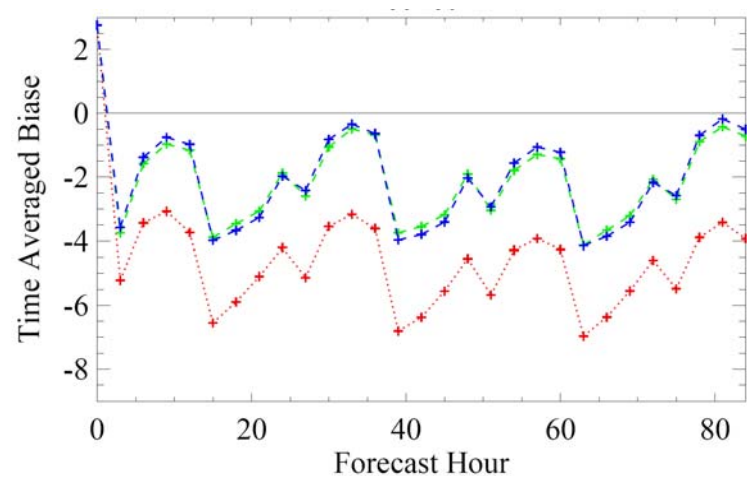
Improved WRF-launcher 2-m temperature and RH forecasts using NESDIS new GVF data

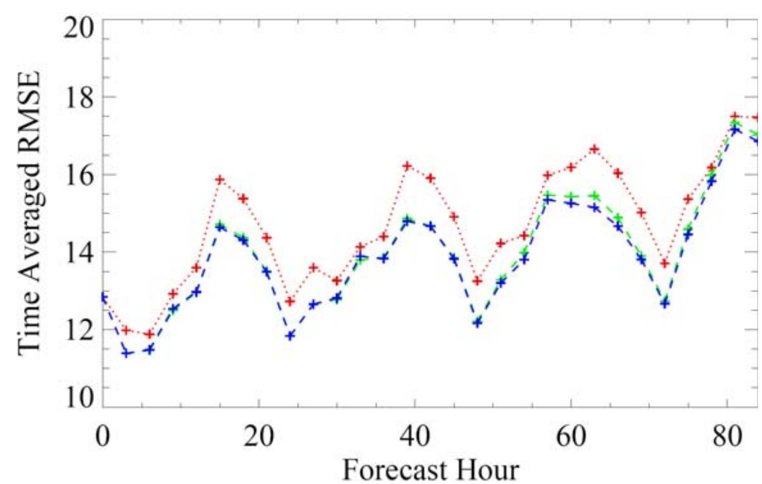
2-m air temperature (°C)





2-m Relative Humidity (%)





July 08 ~ July 18 2006, continental USA

IGBP_MODIS + 3 TUNDRA 1 KM LAND COVER

PIs and Co-PIs: Vince Wong (NCEP/EMC)

NWP Center Collaborators: Ken Mitchell

Accomplishments

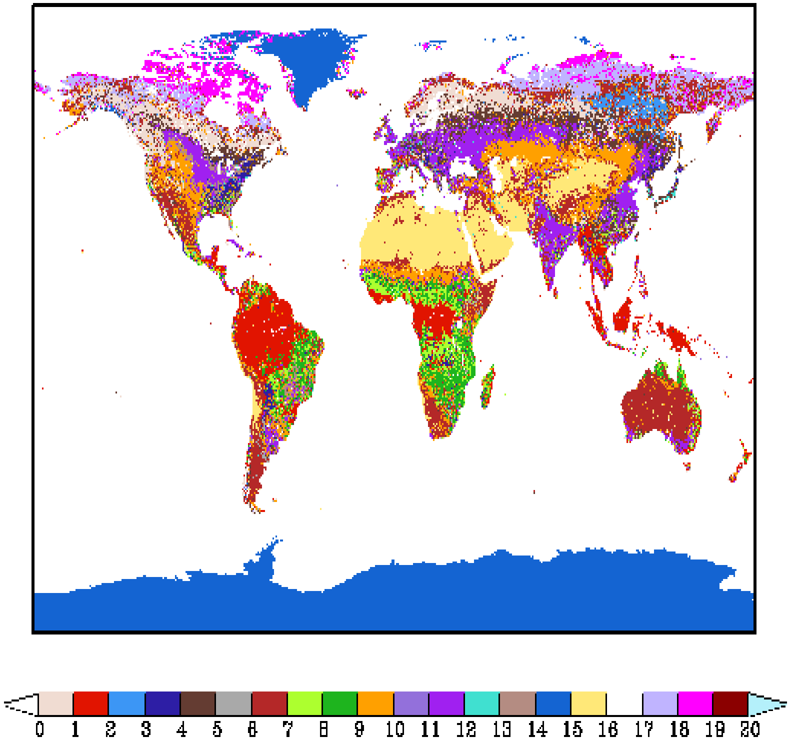
3 tundra classes have been added to the MODIS 1km land cover data base under IGBP classification.

Corrections were made to some erroneous pixels of the savannah, woody savannah, deciduous needle-leaf forest, and glacial ice classes.

Future Plan

This global landuse map is now ready for testing in GFS and CRTM.

IGBP_MODIS+Tundra 1km Land Cover



Natural Vegetation (11)
1. Evergreen Needleleaf Forests
2. Evergreen Broadleaf Forests
3. Deciduous Needleleaf Forests
4. Deciduous Broadleaf Forests
5. Mixed Forests
6. Closed Shrublands
7. Open Shrublands
8. Woody Savannas
9. Savannas
10. Grasslands
11. Permanent Wetlands

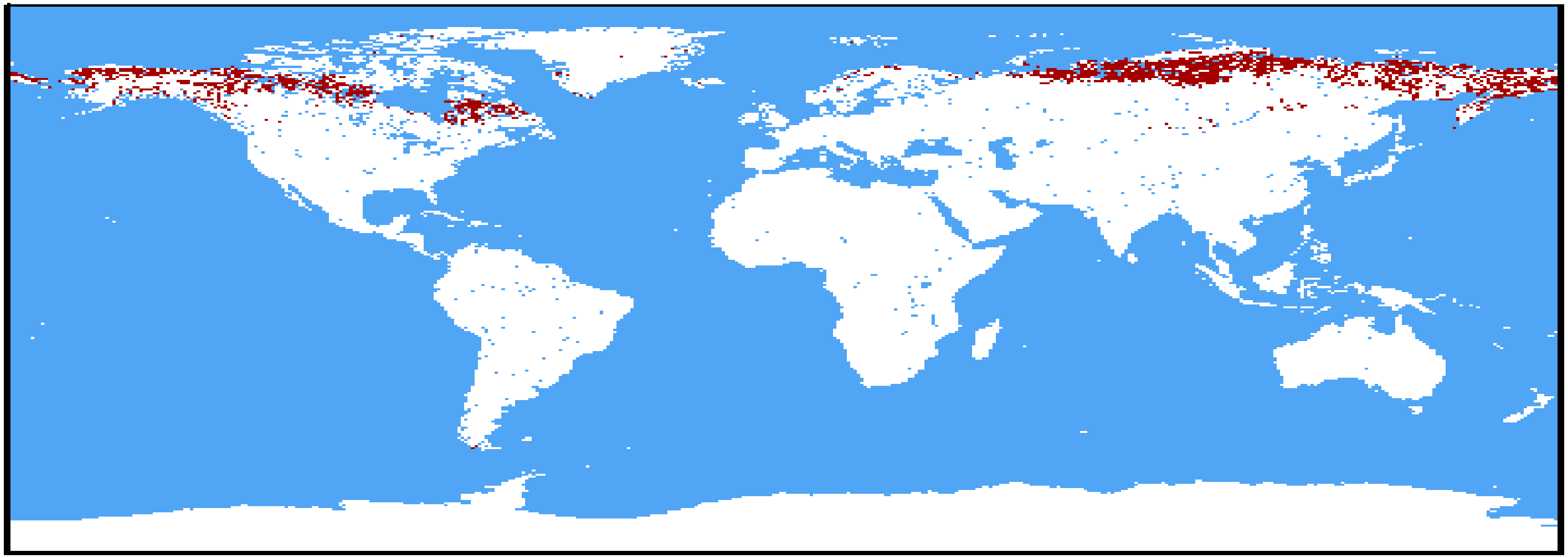
Developed and Mosaic Lands (3)
12. Croplands
13. Urban and Built-Up Lands
14. Cropland/Natural Vegetation Mosaics

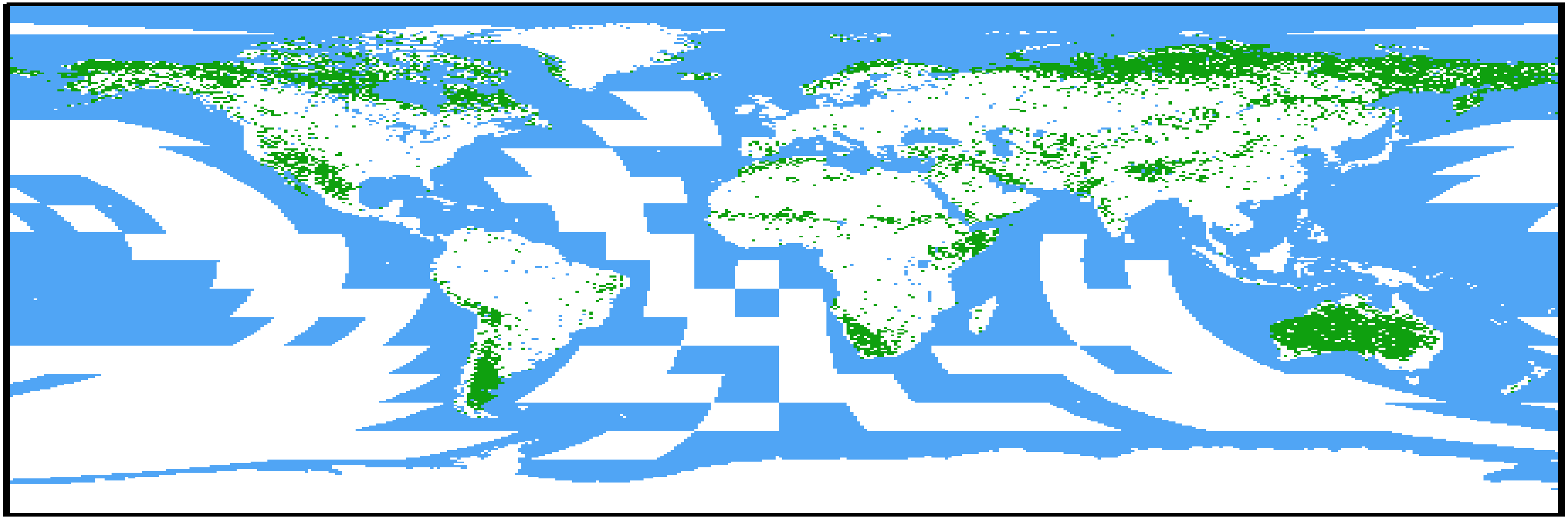
Nonvegetated Lands (3)
15. Snow and Ice
16. Barren
17. Water Bodies

Tundra Lands (3)
18. Wooded Tundra
19. Mixed Tundra
20. Bare Ground Tundra

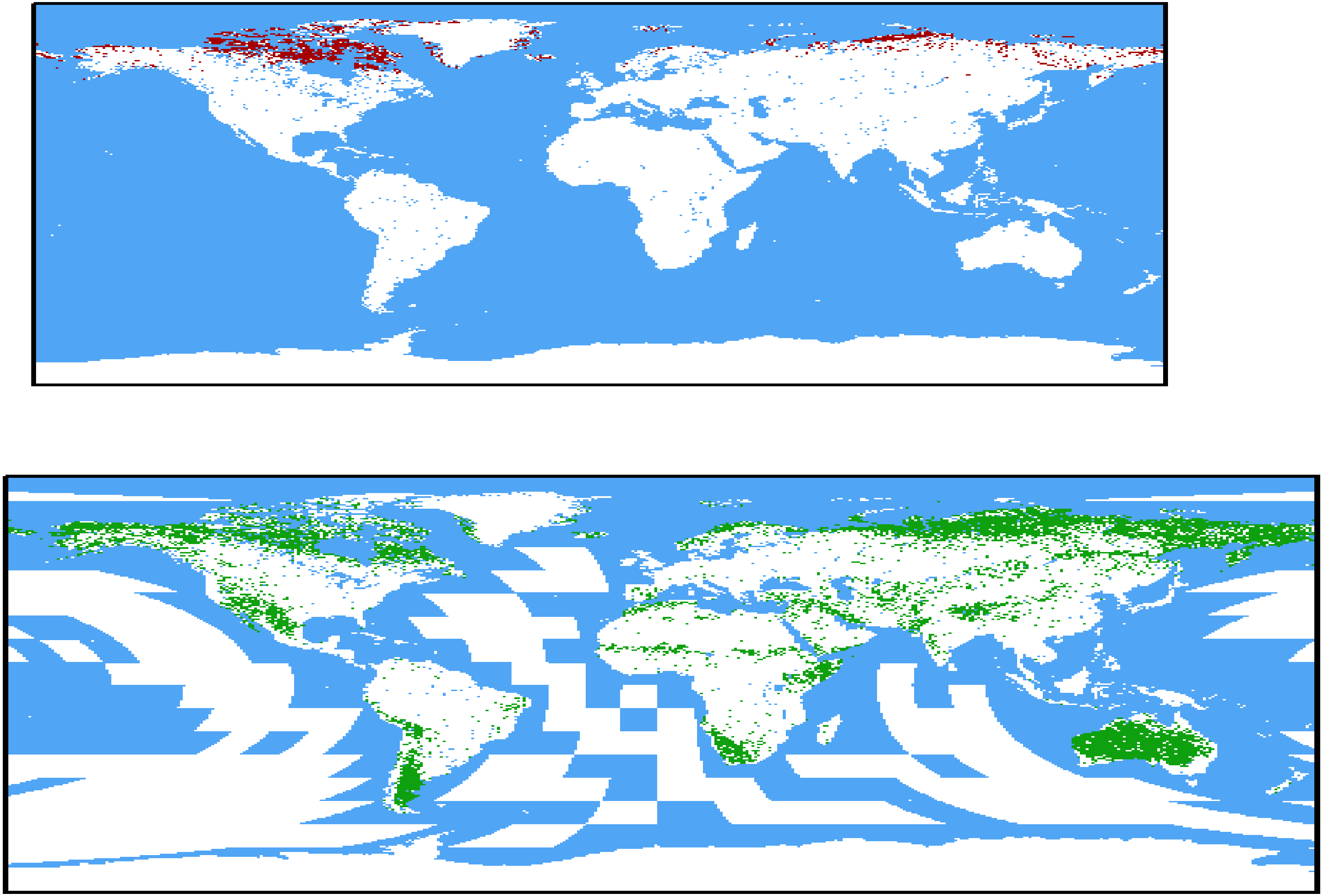
IGBP_MODIS(Red):Wooded Tundra(18)

IGBP_MODIS_Ori(Green):Open Shrubland(7)





IGBP_MODIS(Red):Mixed Tundra(19)
IGBP_AVHRR(Green):Open Shrubland(7)



Changing focus of Land Arena of JCSDA:

- **Early work focused on deriving new satellite-based global land surface characteristics**
  - albedo, landuse class, vegetation phenology
- **More recent work has focused on:**
  - **1) Impact of above land datasets in models**
    - especially in NCEP global model, but also WRF
  - **2) Reducing large differences between simulated and observed satellite Tb for surface-sensitive channels**
    - Improve physics of modeled land surface
      - Aerodynamic resistance, canopy resistance **and skin temperature**
      - Surface emissivity
  - **3) Actual land 4dda of satellite-based snow and soil moisture estimates**
    - Kalman filters in NASA LIS system
    - Rescaling satellite soil moisture to that of model