NCEP Land Data Assimilation Thrusts including use of CRTM and MODIS Land Products

Ken Mitchell

NCEP/EMC (NOAA)

JCSDA Science Workshop

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Acknowledgements

(Coordination via bi-monthly telecons hosted by NCEP/EMC)

- Joint Center for Satellite Data Assimilation: Land PIs
  - **External** JCSDA-funded PIs
    - U. Arizona: X. Zeng and M. Barlage,
    - Boston U.: M. Friedl,
    - Princeton.U / U.Washington: E. Wood and D. Lettenmaier,
    - George Mason U.: P. Houser,
    - NCAR / Purdue U.: F. Chen and D. Niyogi
    - U. Maryland: S. Liang
  - **Internal** JCSDA Investigators:
    - NCEP/EMC Land Team: K. Mitchell, G. Gayno, J. Meng, V. Wong
    - NESDIS/ORA Land Team: D. Tarpley, L. Jiang, X. Zhan, I. Laszlo
    - NASA GSFC/HSB: C. Peters-Lidard, S. Kumar, LIS Team
    - NASA GSFC/GMAO: R. Reichle, R. Koster
    - 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/ORA (D. Tarpley, 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/ORA (F. Weng)
- Improve Noah LSM physics to use satellite data (and improve Tsfc)
  - U.Arizona (X. Zeng)
  - NCAR / Purdue U. (F. Chen, D. Niyogi)
  - NCEP/EMC (K.Mitchell)
  - NASA/HSB (C. Peters-Lidard)
- Execute model impact studies for new land-sfc satellite products
  - U.Arizona (X. Zeng)
  - NCEP/EMC (H. Wei), NASA/HSB (Peters-Lidard), NASA/GMAO (R. Reichle)
- 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/ORA, NASA/HSB, NASA/GMAO

Uses of land-surface satellite products in NCEP modeling initiatives (operations or test beds: see last year's workshop talk for more details)

- **Derive and apply land surface characteristics**
  - **<u>Vegetation phenology</u>: annual cycle of green vegetation fraction (GVF)**
    - Operations: monthly 0.14-deg monthly global climatology of GVF from AVHRR
    - Test Bed:
      - External/U. Arizona & Boston U.: MODIS-based global climatology of GVF and LAI
      - Internal/NESDIS: AVHRR-based realtime weekly global 0.144-deg (16-km) GVF
  - **<u>Vegetation type</u> (land use class):**
    - Operations: AVHRR-based 12-class 1-deg (global model) or 24-class 1-km (regional model)
    - Test Bed:
      - External/Boston.U: MODIS-based 15-class 1-km global
  - **<u>Surface albedo</u>: snow-free and maximum for deep snow**
    - Operations: based on Briegleb (1992, 1986) and Matthews (1983,1984) seasonal, 1-deg global
    - Test Bed:
      - External/Boston.U: MODIS-based monthly 5-km global (snow-free)
      - :External/U.Arizona: MODIS-based global 0.05-deg maximum albedo over deep snow
- **Determine initial values of land prognostic states via data assimilation**
  - **<u>Snow cover and snowpack</u>:**
    - Operations: Daily multi-sensor 4-km global (Geo, AVHRR, DMSP, AMSU, MODIS)
    - Test Bed:
      - External/Princeton.U: 4DDA of microwave SWE estimates via forward modeling
      - Internal/HSB: MODIS snow cover assimilation
      - Internal/NESDIS: AMSU and GEO SWE estimates
  - **<u>Soil moisture</u>** -- Test Bed only (External: GMU, Internal: HSB, GMAO)
  - **<u>Land surface temperature</u>** – Test Bed only (External: GMU, Internal: HSB, GMAO)
- **Verification of land surface fields** (operations and test beds)
  - **<u>Land surface temperature</u>** (Internal:EMC)
  - **<u>Snow cover</u>** (External: Princeton.U, Internal: EMC and HSB)

Changing focus of Land Arena of JCSDA:

- **Early work focused on deriving new satellite-based global land surface characteristics**
  - albedo, landuse class, vegetation phenology
- **New work will focus on:**
  - **1) Impact of above land datasets in models**
    - especially in global models
  - **2) Reducing large differences between simulated and observed satellite Tb for sfc-sensitive channels**
    - Improve physics of modeled land surface skin temperature
      - Aerodynamic and canopy resistance
      - 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

4DDA of Satellite Brightness Temperatures (Tb)

- GSI or SSI 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)

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

with

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

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

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

α = atmospheric absorption

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

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

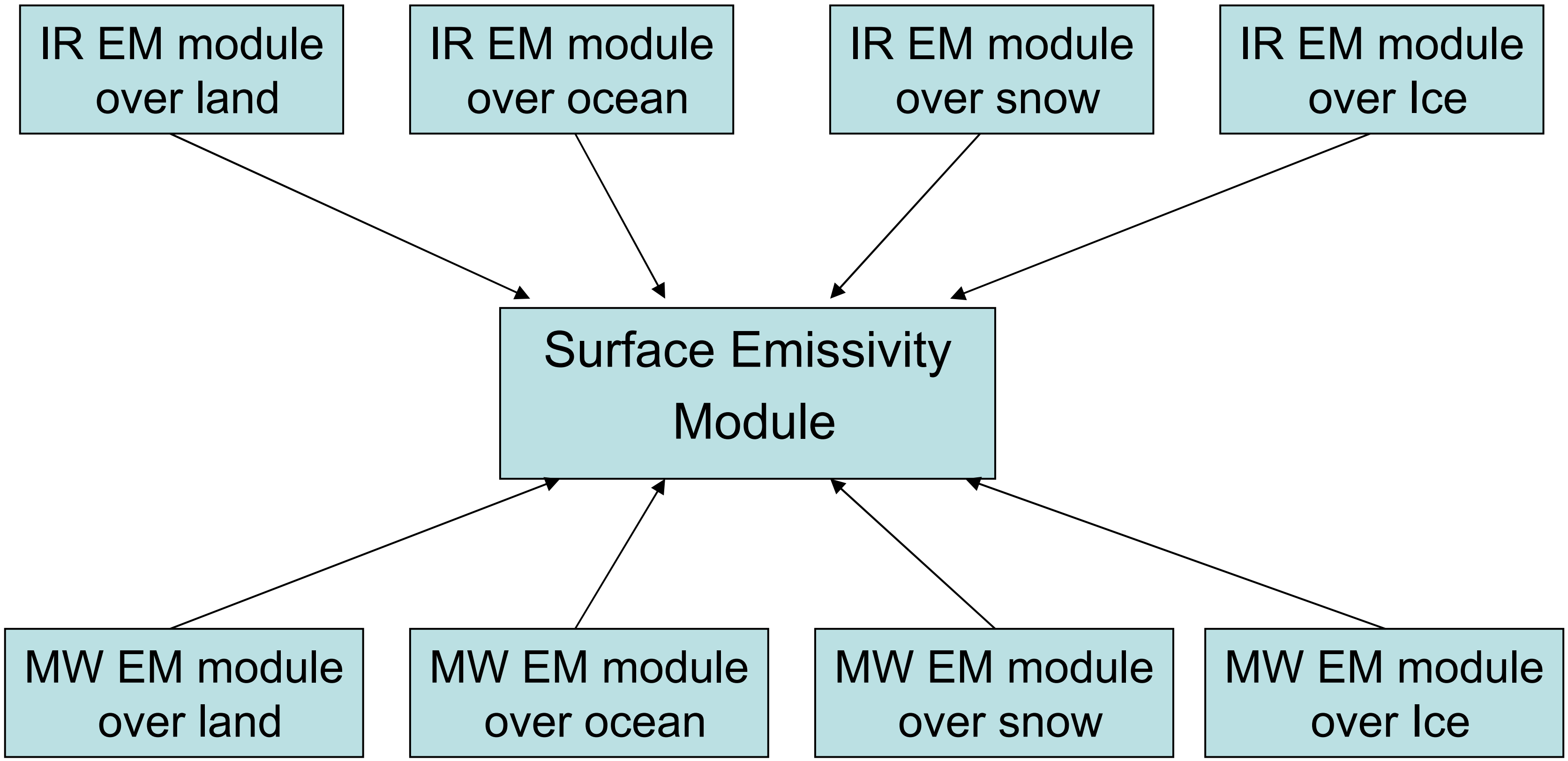
Sfc emissivity (ξ) is strong function of land surface states:

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)



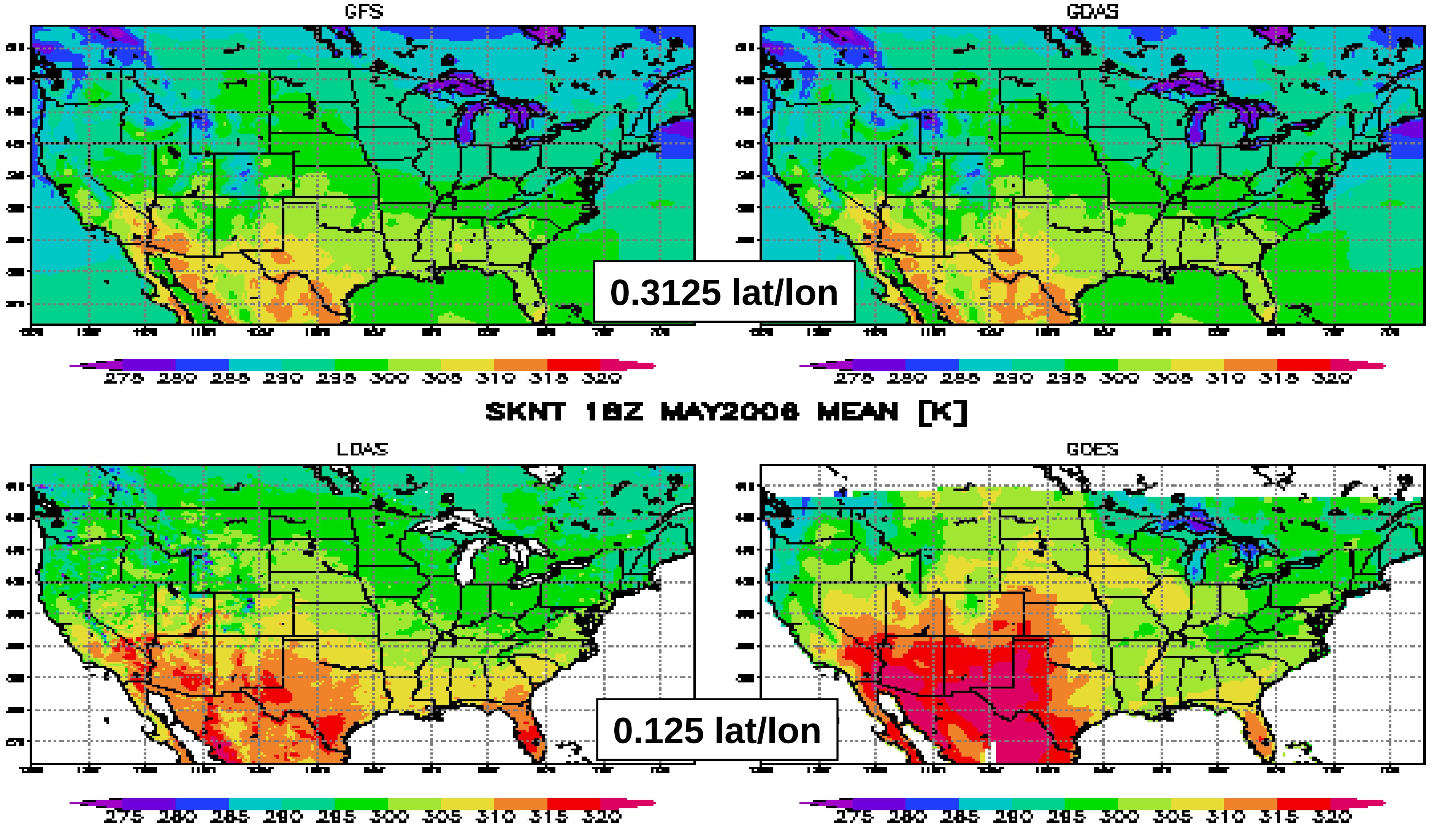
Specified **surface emissivity** via
look-up tables OR **physical** OR **empirical models**,
depending on **spectral band** and
ocean / **land** / **snow** / **sea-ice** presence.

Fuzhong Weng et al., NOAA/NESDIS

What CRTM surface emission module in GSI/SSI needs from land surface

- **Tskin: land surface skin temp (LST)**
- **Snowpack properties**
  - Snow cover fraction
  - Snowpack density profile
  - Snow crystal size distribution
- **Vegetation properties**
  - Vegetation type
  - Fractional cover
  - Surface moisture content (dew, frost, rain & snow interception)
  - Density
  - Height
- **Soil properties**
  - Soil type
  - Soil moisture
    - Amount
    - Phase: frozen versus liquid

Monthly Mean 18Z LST [K] May2006



GFS/GDAS has a substantial mid-day cold bias, which is worse in semi-arid regions

Global Vegetation Type Datasets

(aka Landuse Datasets)

- NCEP Operations: AVHRR-based
  - Global Model (1-deg global, SiB 12-classes, NASA/ISLSCP)
  - Regional Model (1-km global, USGS 24-classes, USGS/EDC)
  - CRTM (its own landuse classification, different from above two)
- GOAL: unify landuse map in above 3 suites
- NCEP Goal: MODIS-based (Boston U, M. Friedl)
  - **Global 1-km**
    - **21 classes**
      - **same as IGBP less 2 sparse classes, plus glacial ice, inland lakes, 3 tundra classes**
    - Fewer counts of mixed vegetation class
    - Less mixed forest,
    - less mixed cropland/grassland
    - Less tropical rain forest, more savanna

Land Surface Emissivity

- External initiative (funded by JCSDA)
  - Ben Ruston: NRL
  - Shunlin Liang (U. Maryland)

- Internal initiative
  - Chris Barnett: AIRS based (hyper-spectral)
  - Fuzhong Weng: IR sfc emission derived from MW

Integrated IR broadband realtime surface emissivity

Ben Ruston of NRL

ASTER reflectance library

- http://speclib.jpl.nasa.gov/

- Snow/ice classes:
  - fine snow, medium snow, coarse snow, frost, ice.

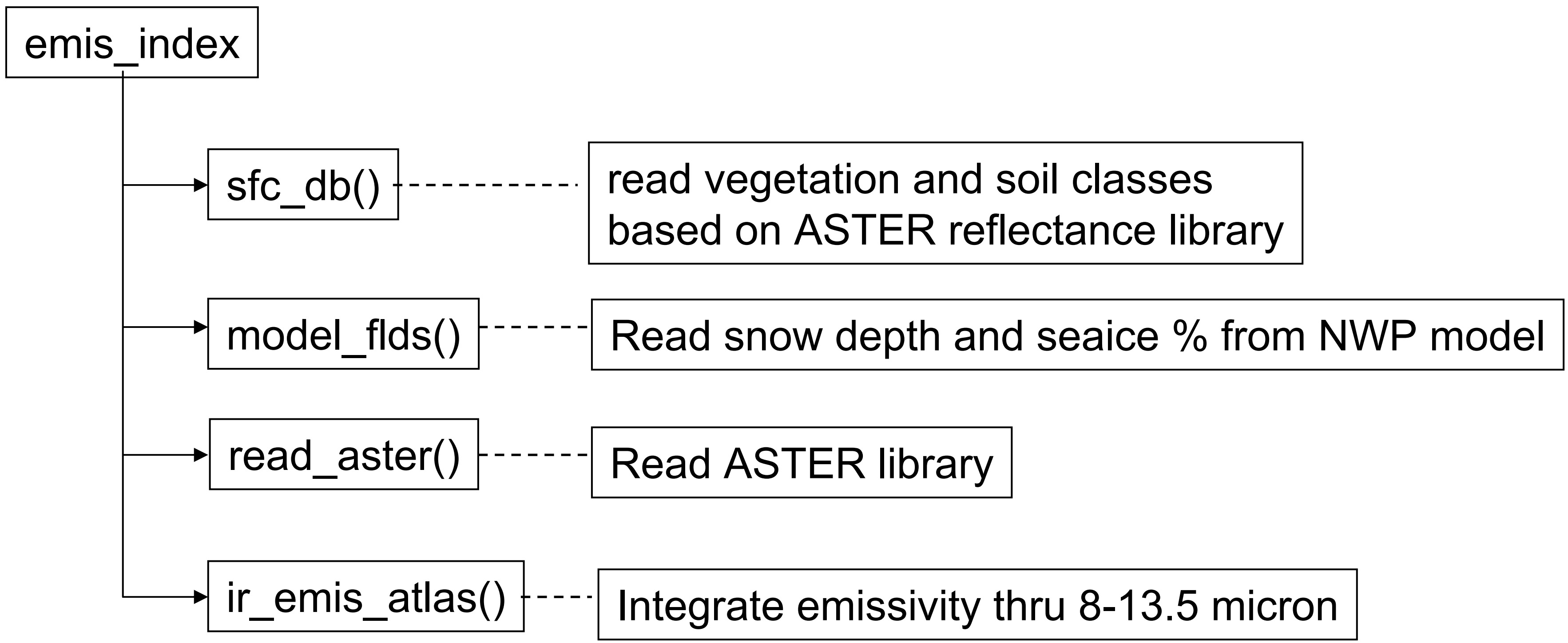
- Soil classes:
  - sand, loam, silt, clay.

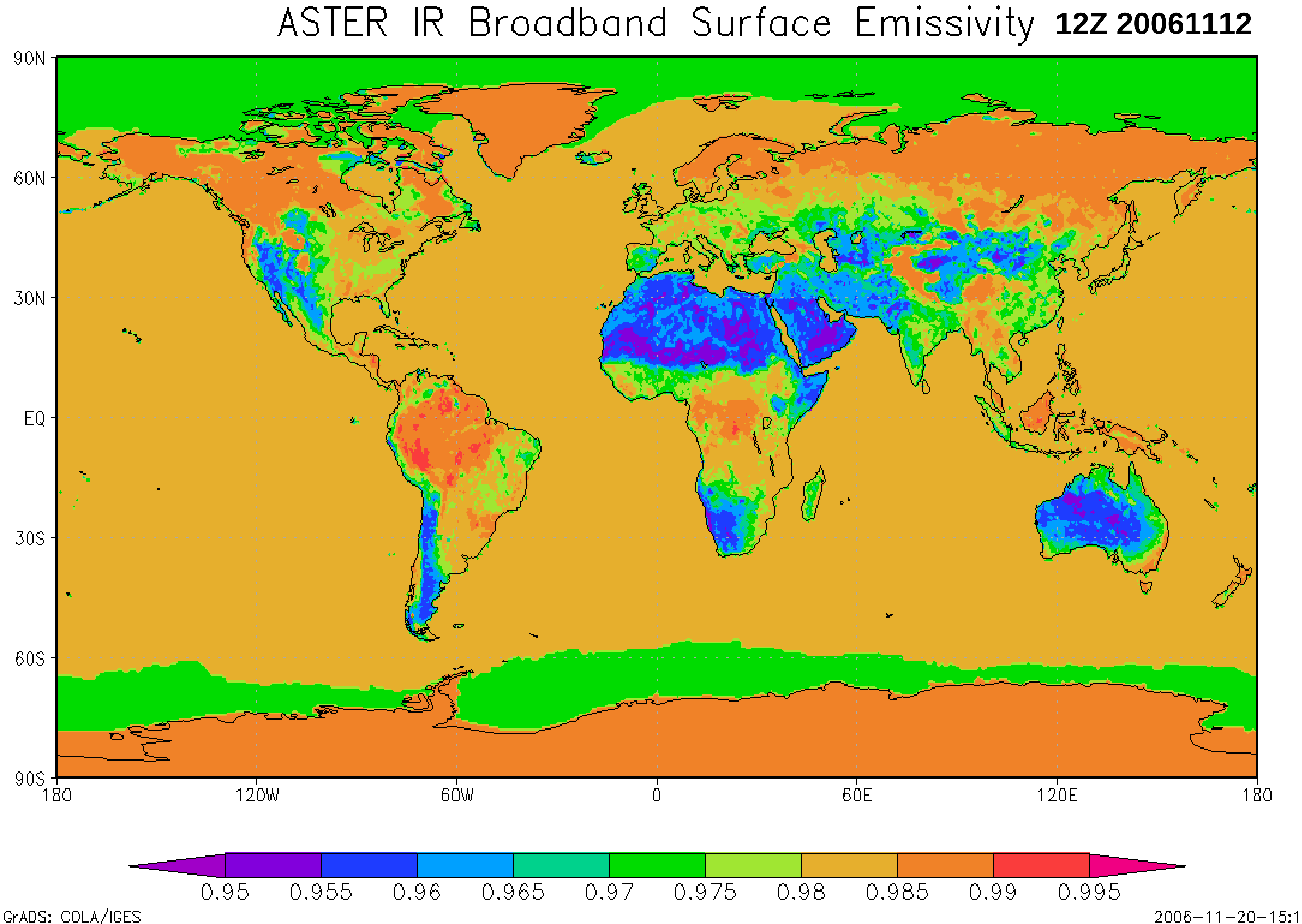
- Vegetation classes:
  - conifer (needleleaf), deciduous, dry grass, moist grass

Input Data

- Seaice [%]
- Snow depth [cm]
- Soil classes
  - sand, silt, clay [%], Reynolds et al., 1999
- Vegetation classes
  - UMD vegetation types
  - vegetation fraction
  - monthly greenness fraction
- Soil and Vegetation classes are mapped to ASTER library classes

Software (Ben Ruston)




ASTER IR Broadband Surface Emissivity 12Z 20061112
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
0.95
0.955
0.96
0.965
0.97
0.975
0.98
0.985
0.99
0.995
GrADS: COLA/IGES
2006-11-20-15:19

Soil moisture assimilation

- External initiative
  - GMU / Paul Houser: separate presentation this session

- Internal initiatives
  - GMAO / Rolf Reichle:
  - NESDIS/ORA: Xiwu (Jerry) Zhan

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

- **Planned order of testing in GFS at NCEP**
  - 1) Albedo datasets
    - Snow-free (Boston U.)
    - Maximum albedo for deep snow (U. Arizona)
  - 2) Vegetation datasets
    - Land use (Boston U.)
    - Green vegetation fraction – GVF (NESDIS/ORA)
    - LAI (Boston U.)
  - 3) Surface emissivity datasets (NRL, U. Maryland)
    - GFS: broadband in Noah LSM
    - CRTM: channel by channel
    - Focus on GFS simulated land-sfc skin temp
      - Companion upgrades in aerodynamic and canopy resistance treatments in Noah LSM

Tests of a Bundle of Albedo-Related Changes in NCEP Global Forecast System

Helin Wei

George Gayno, Fanglin Yang, Ken Mitchell, Yu-tai Hou

NCEP/EMC

Features of the GFS Tests

- The new MODIS-based snow free albedo from BostonU/Mark-Friedl (JCSDA funded)
- The new MODIS-based maximum snow albedo from UAZ/Xubin (JCSDA funded)
- Fanglin Yang new diurnal albedo treatment
- Unify two aspects between radiation driver and Noah LSM
    - Snow cover
    - Snow albedo

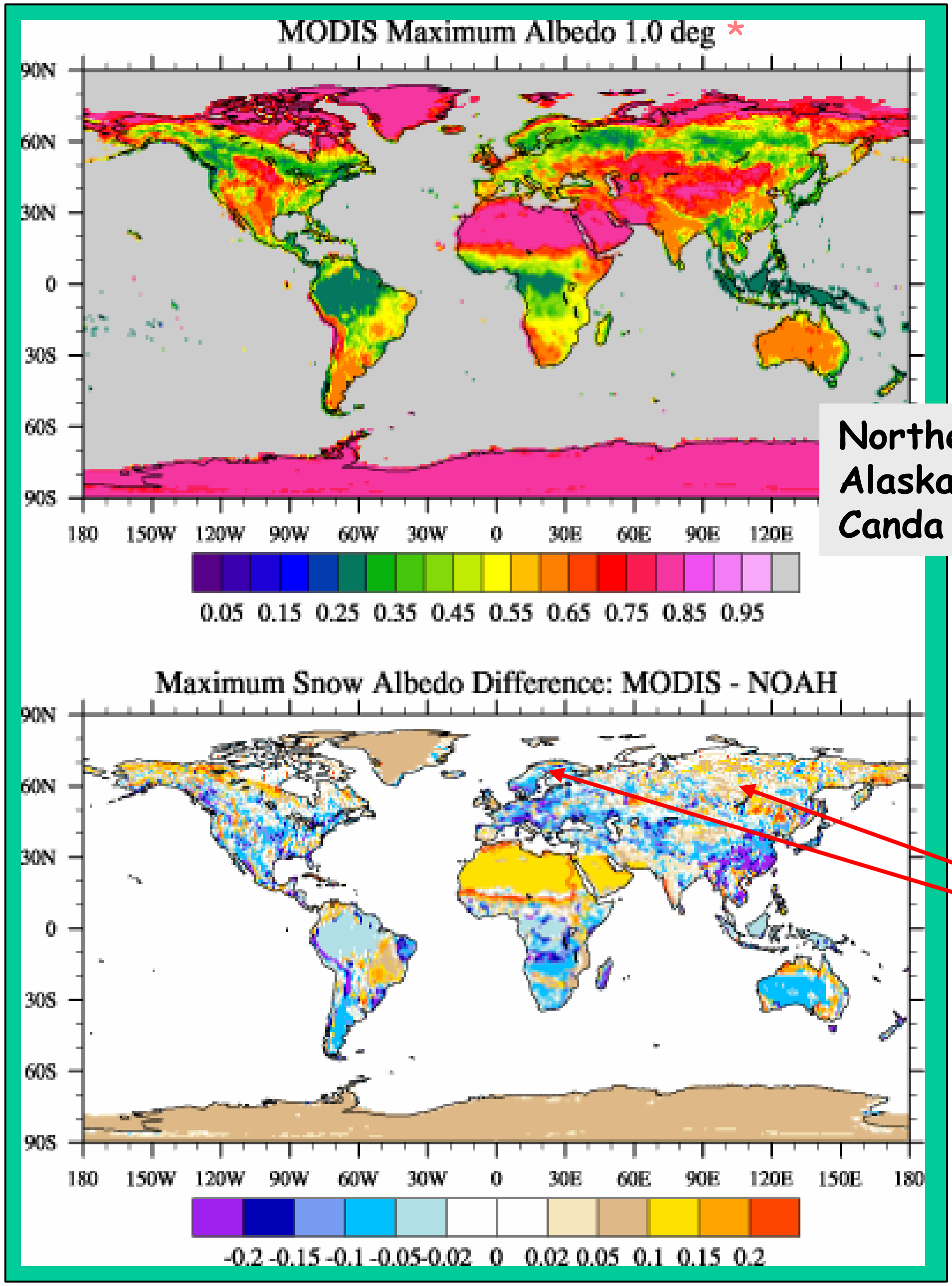
Snow Free Albedo

- Old data:
  - Contains 6 fields: vis/nir with strong/weak cosz dependency, fractional coverage with strong/weak cosz dependency
  - Quarterly, global 1-deg, Briegleb et al. (1992,1986), E. Matthews (1984).
- New data:
  - Contains 4 fields: vis/nir black/white sky (no need for two extra fields in the old data)
  - Monthly, global 5-km, based on 4-yr MODIS BRDF/albedo.

MAX Snow Albedo

Maximum Snow Albedo: New versus Old

(Barlage and Zeng, 2005 GRL)



Northern Alaska and Canda

- [Old database](#)
    - Global 1 degree, based on 1-yr of DMSP observation from 1979.
- [New database](#)
    - Global 0.05 degree, based on 4-yr MODIS BRDF/albedo.

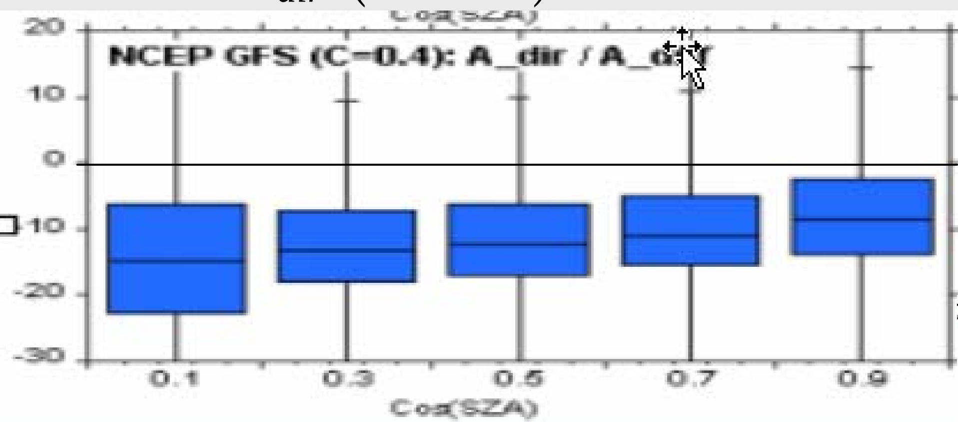
No consistent sign of the difference.

New Diurnal Albedo Treatment

(Internal NCEP/EMC development: Fanglin Yang)

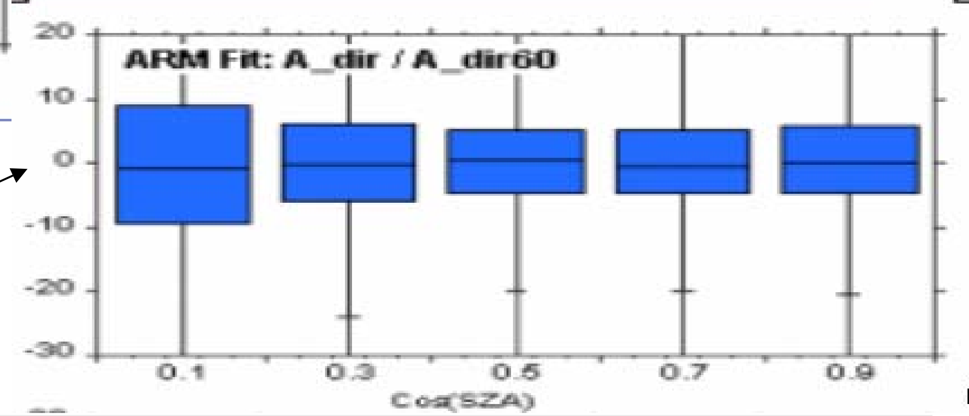
Fits using data at all ARM and SURFRAD stations

$$f_2(\theta) = \frac{\alpha_{dir}^{mn}(\theta, \lambda)}{\alpha_{dir}^{mn}(60^o, \lambda)} = 1.89 - 3.34\cos(\theta) + 4.13\cos^2(\theta) - 2.02\cos^3(\theta)$$



Old approach yields negative bias in reflected surface solar insolation.

New approach yields much less bias.



Median values and quartiles of the percent errors in the upward (direct and diffuse) SW fluxes for each SZA bin

MAX Snow Albedo
(upper bound over deep snow)

- Radiation driver

  Diffuse Albedo: 0.90(vis) 0.75(nir)

  Direct Albedo:

  -- low zenith angle same as diffuse

  -- high zenith angle: 0.98~1

  Usually substantially higher than that in satellite-derived max snow albedo.

GFS Albedo Test Runs

Two cases: Winter (January of 2007) and summer (August of 2006)

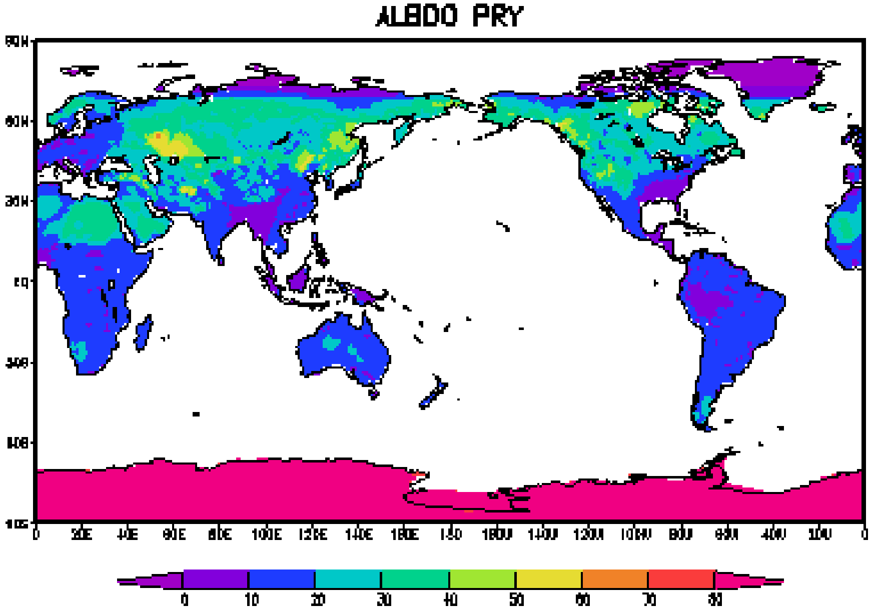
- One 6-day GFS forecast per day of month (31 forecasts)
- Without cycling
- T382 (full ops resolution)

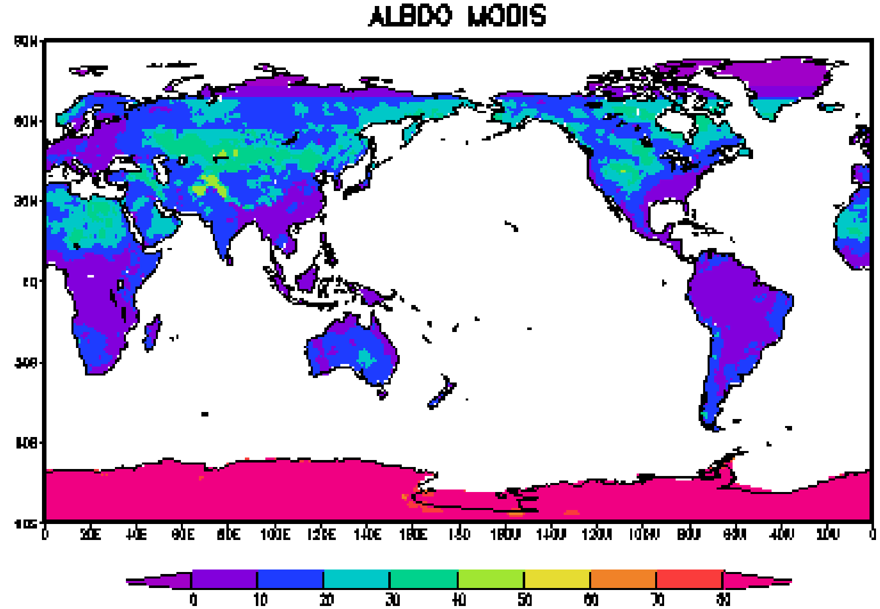
Comparison:

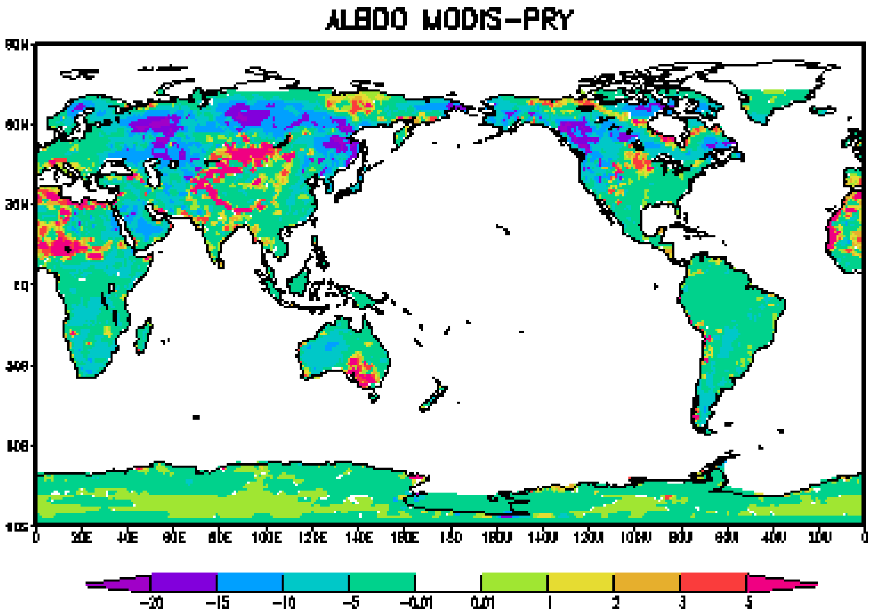
AVN: current operational GFS (before 01 May 2007)

NLLF: Russ Treadon PRY (new ops GFS as of 01 May 2007)

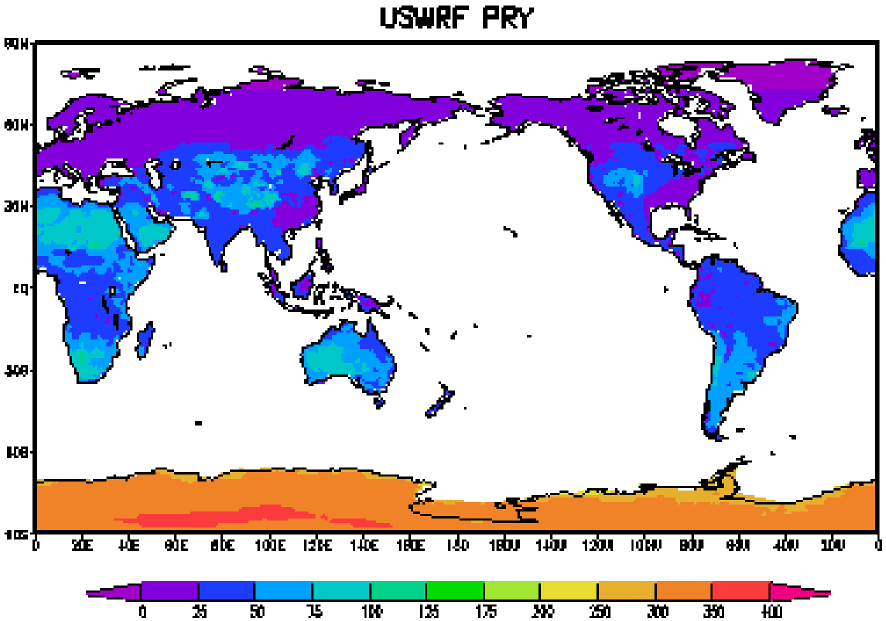
MODIS: test of albedo-related changes presented here

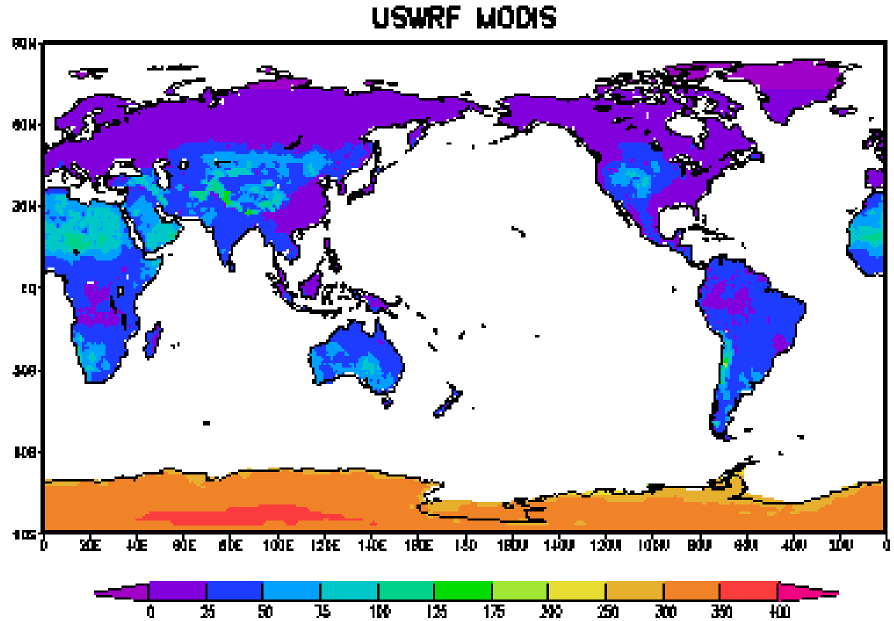


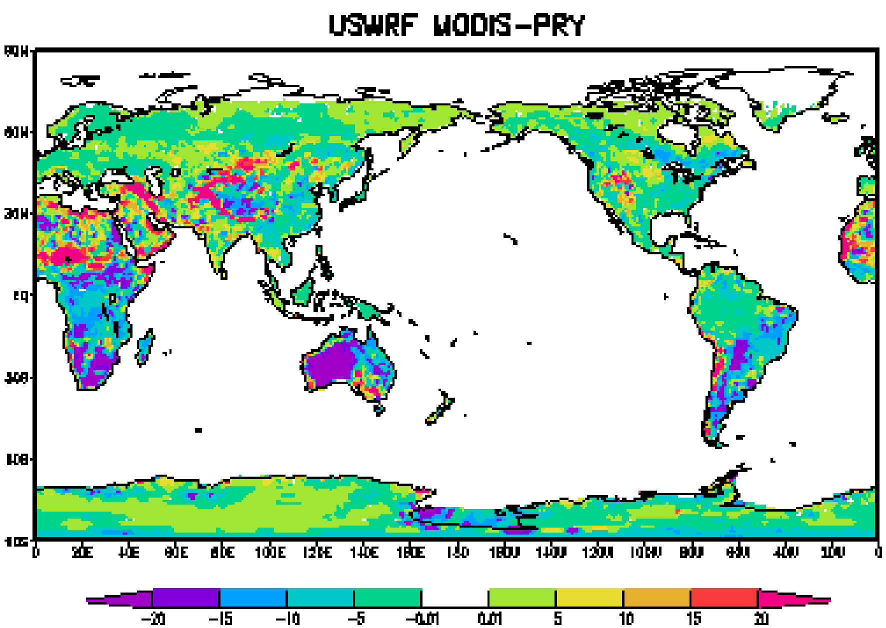




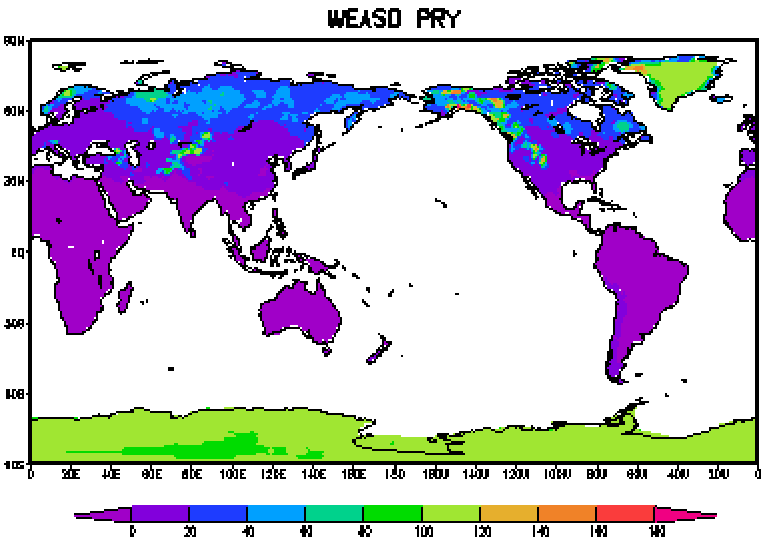
31-day mean of 12-36h surface albedo (January 1-31, 2007)

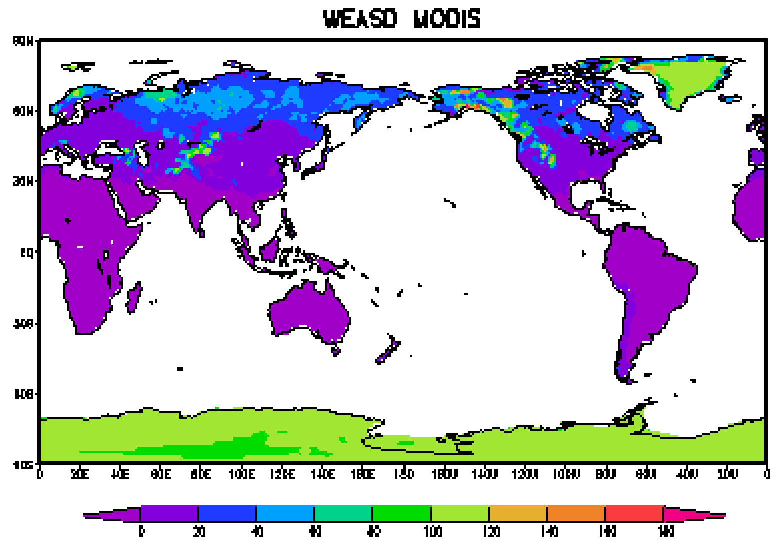


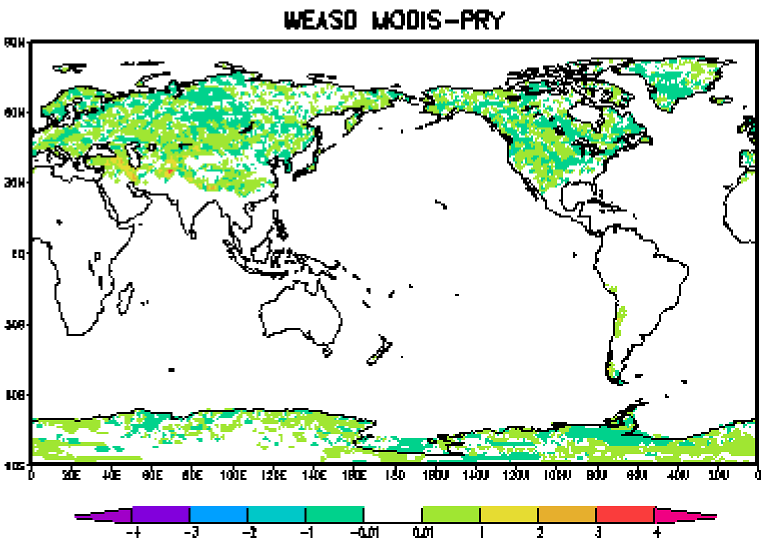




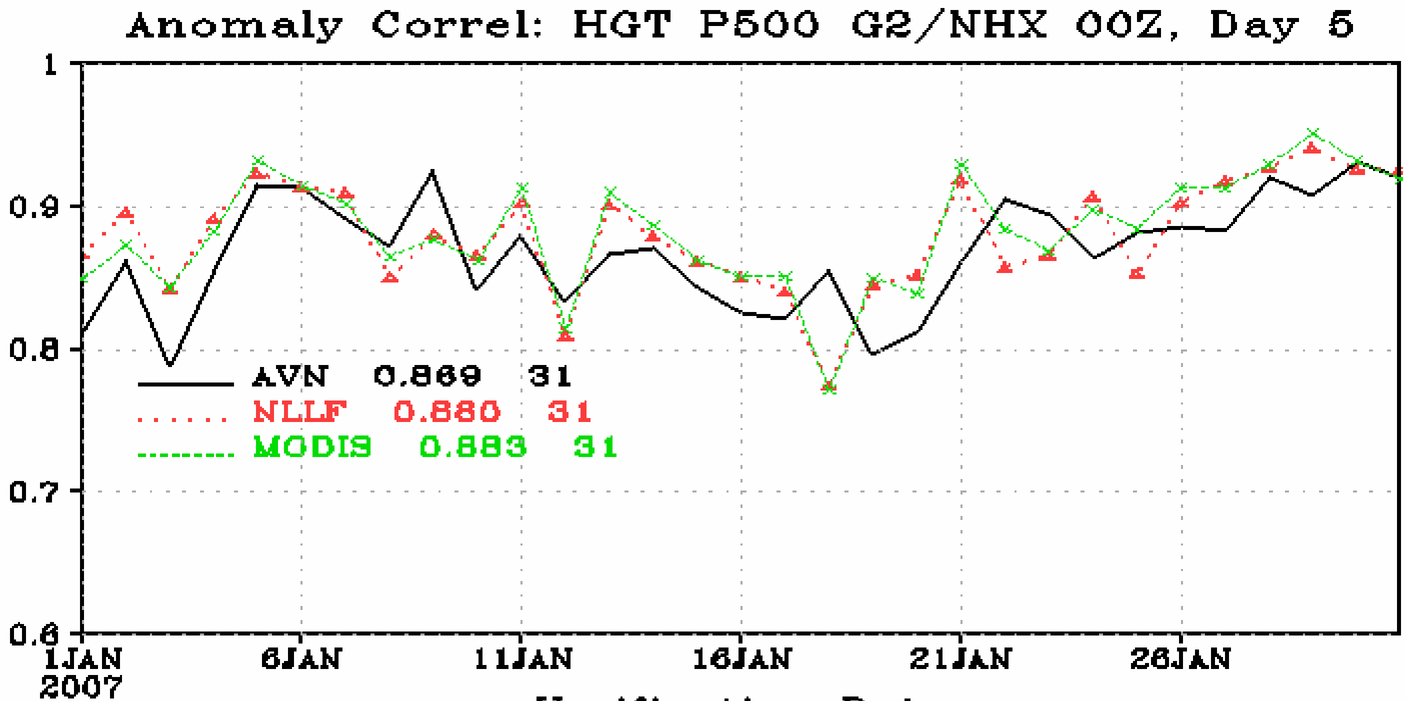
31-day mean of 12-36h upward shortwave (January 1-31, 2007)





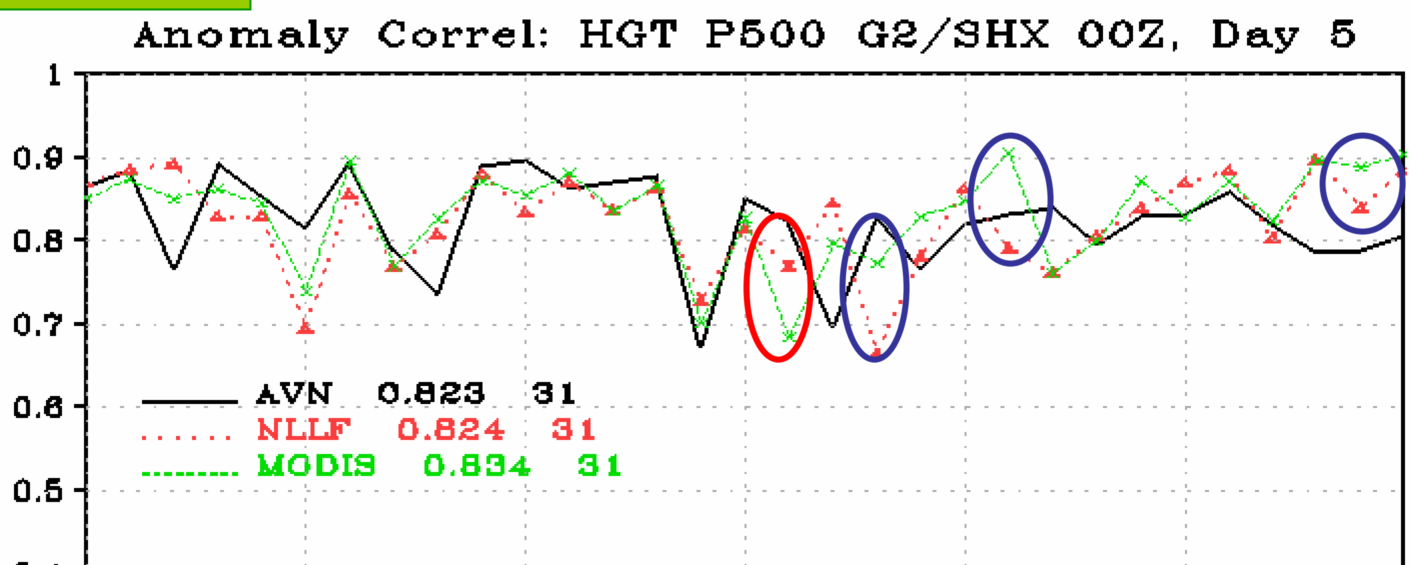


31-day mean of 12-36h SWE (January 1-31, 2007)

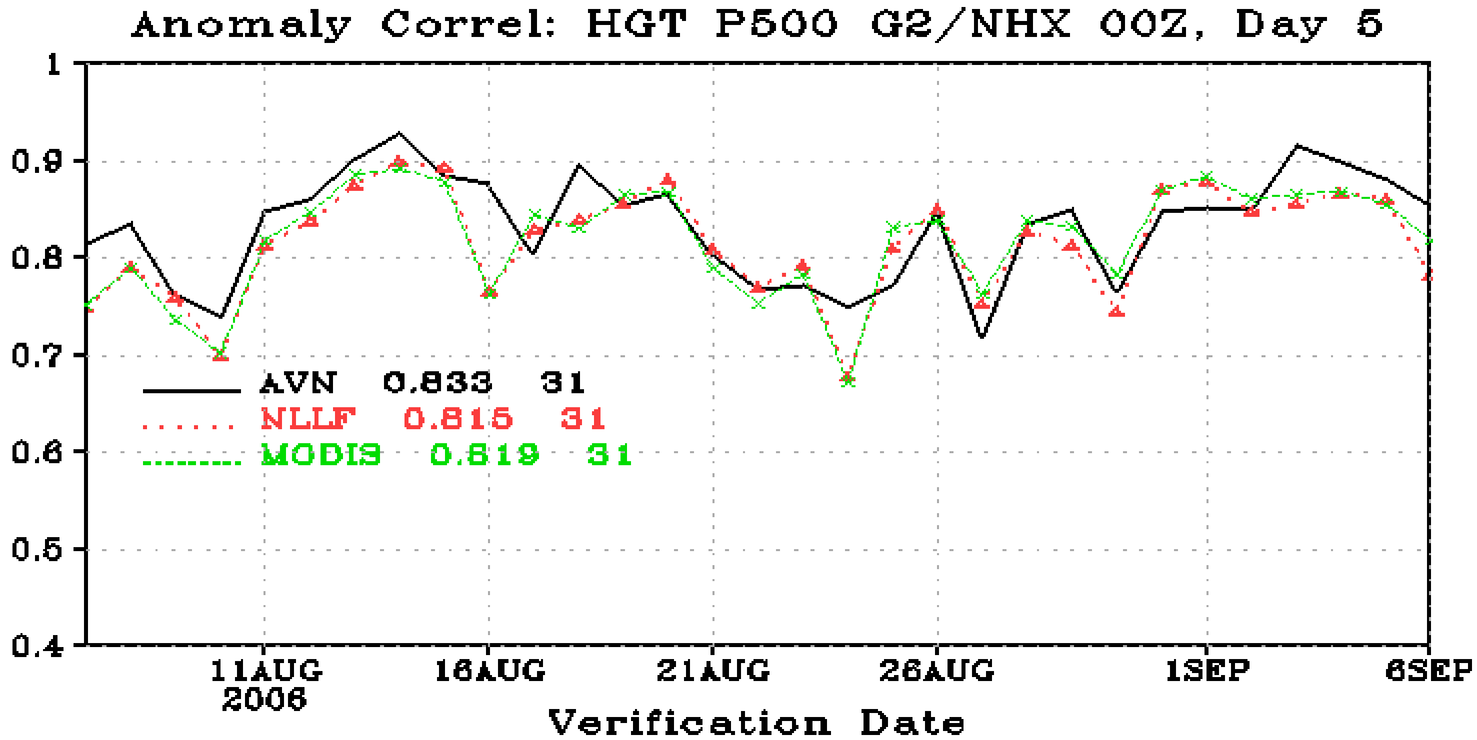


Anomaly Correl: HGT P500 G2/NHX 00Z, Day 5
1
0.9
0.8
0.7
0.6
AVN 0.869 31
NLLF 0.880 31
MODIS 0.883 31
1JAN
2007
6JAN
11JAN
16JAN
21JAN
26JAN
Verification Date

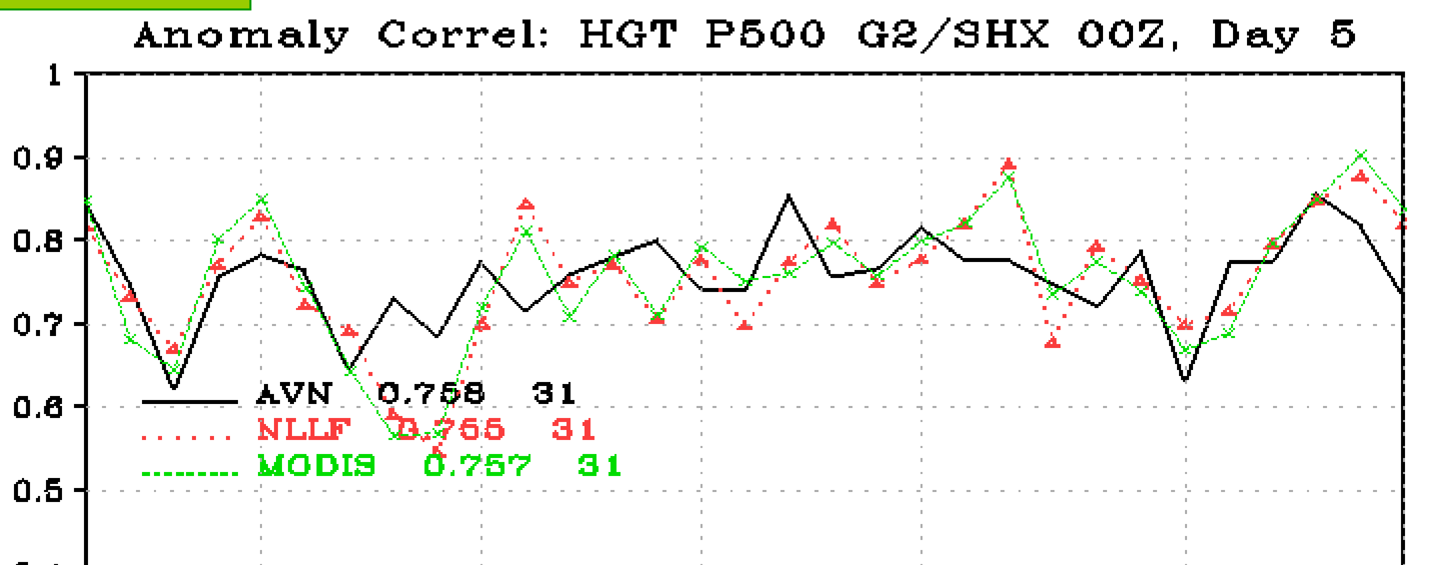
Winter case

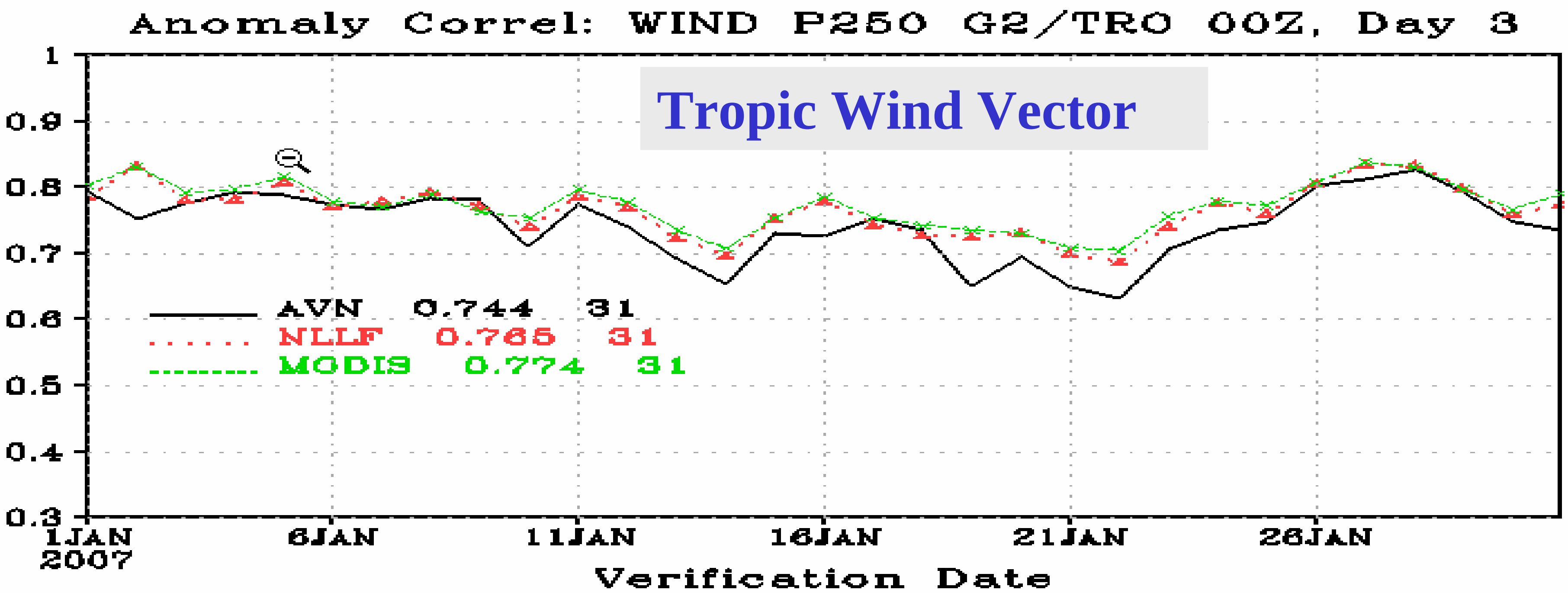


Anomaly Correl: HGT P500 G2/SHX 00Z, Day 5
1
0.9
0.8
0.7
0.6
0.5
AVN 0.823 31
NLLF 0.824 31
MODIS 0.834 31

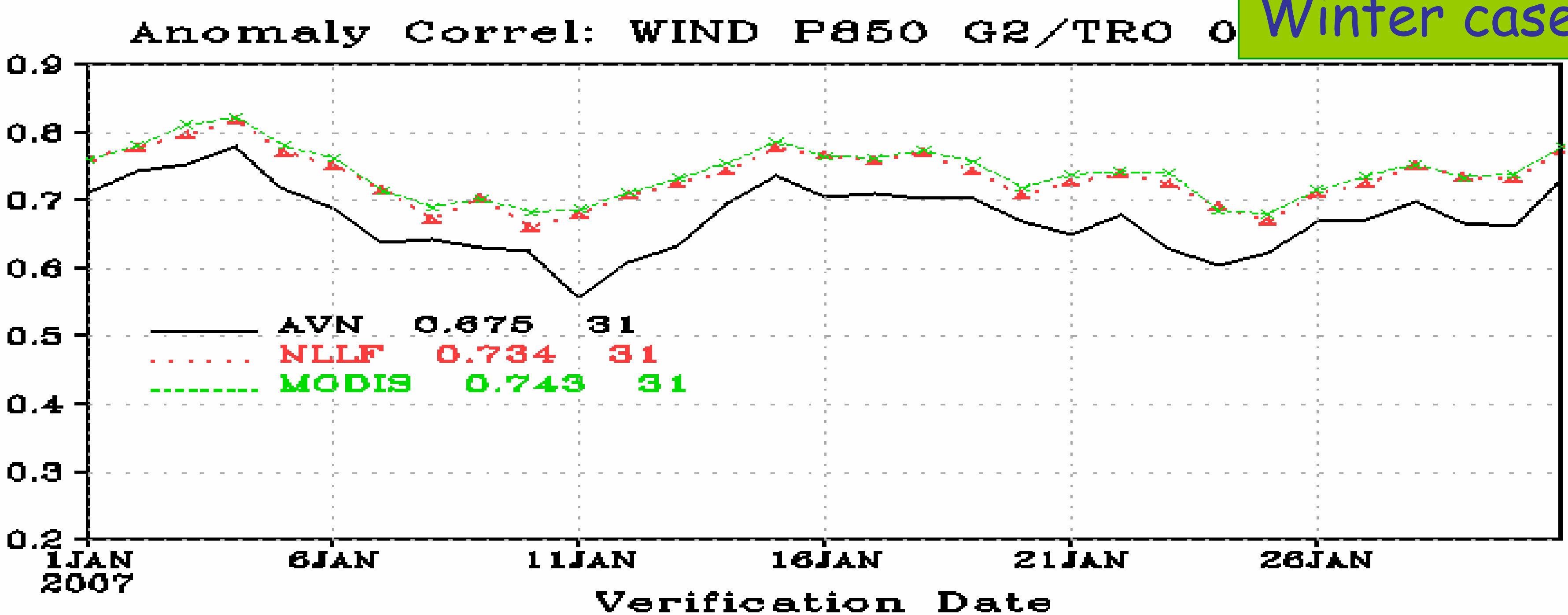

Anomaly Correl: HGT P500 G2/NHX 00Z, Day 5
1
0.9
0.8
0.7
0.6
0.5
0.4
AVN 0.833 31
NLLF 0.815 31
MODIS 0.819 31
11AUG
2006
16AUG
21AUG
26AUG
1SEP
6SEP
Verification Date

Summer case


Anomaly Correl: HGT P500 G2/SHX 00Z, Day 5
1
0.9
0.8
0.7
0.6
0.5
AVN 0.758 31
NLLF 0.765 31
MODIS 0.757 31


Anomaly Correl: WIND P250 G2/TRO 00Z, Day 3
Tropic Wind Vector
AVN 0.744 31
NLLF 0.765 31
MODIS 0.774 31
1JAN 2007
6JAN
11JAN
16JAN
21JAN
26JAN
Verification Date

Winter case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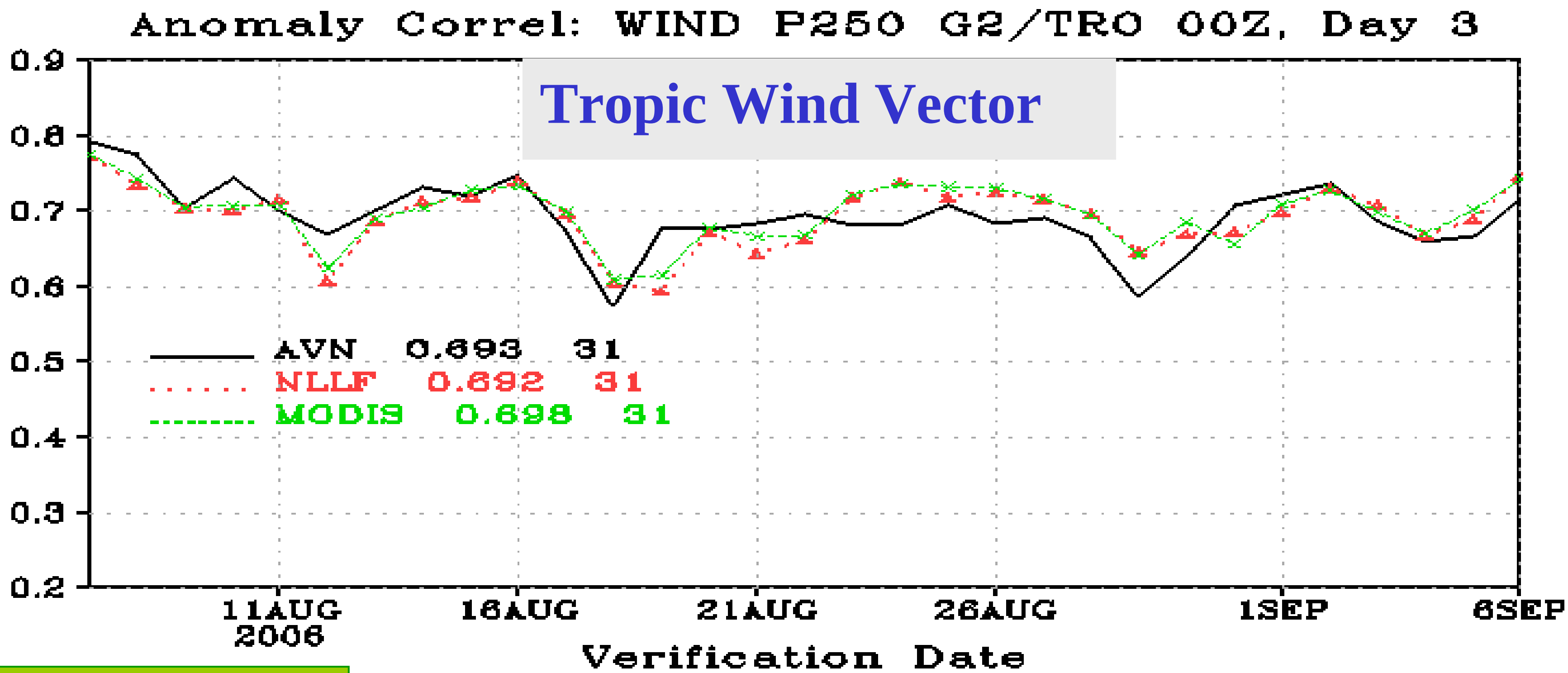
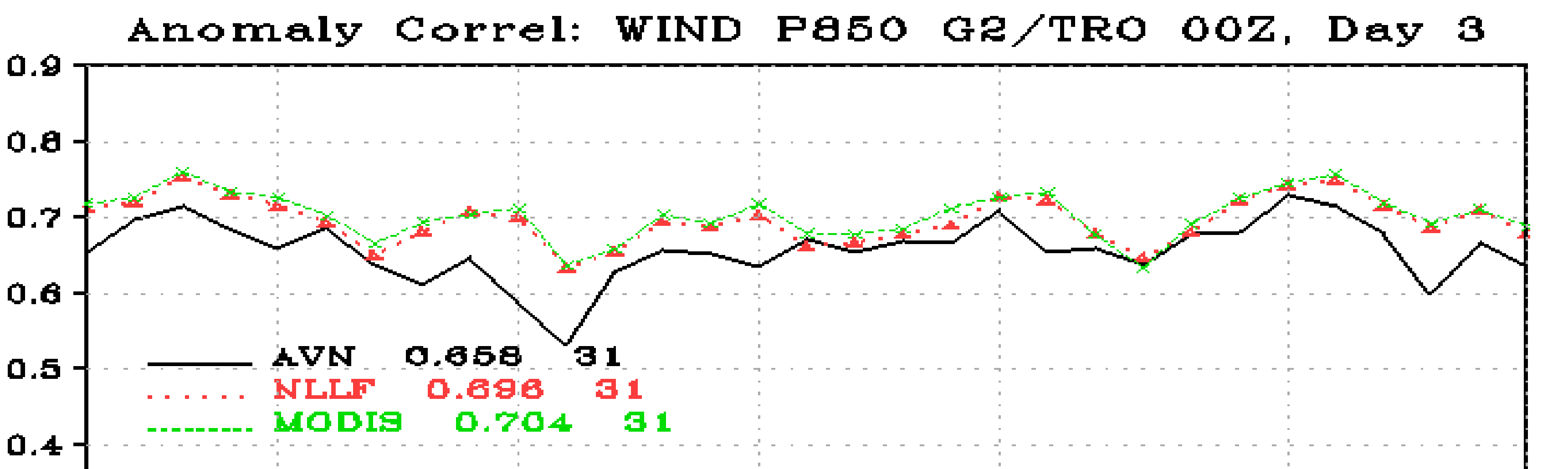
AVN 0.675 31
NLLF 0.734 31
MODIS 0.743 31
1JAN 2007
6JAN
11JAN
16JAN
21JAN
26JAN
Verification Date

Tropic Wind Vector

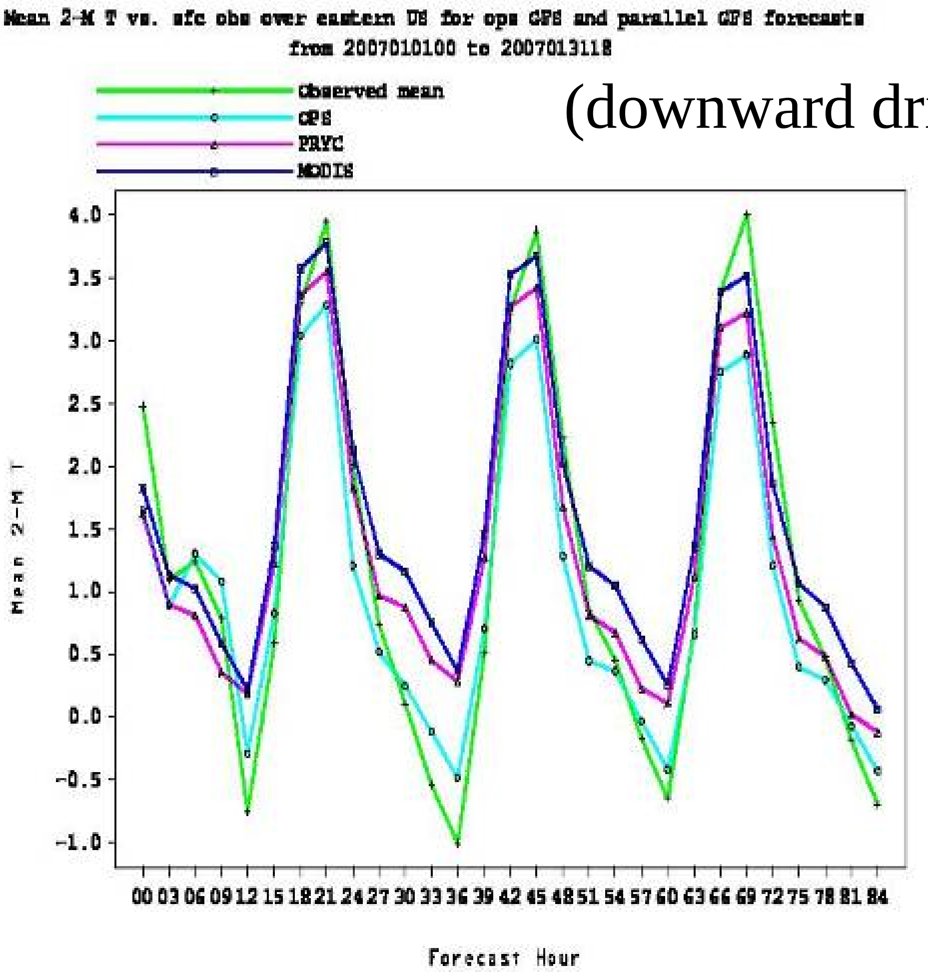


Summer case



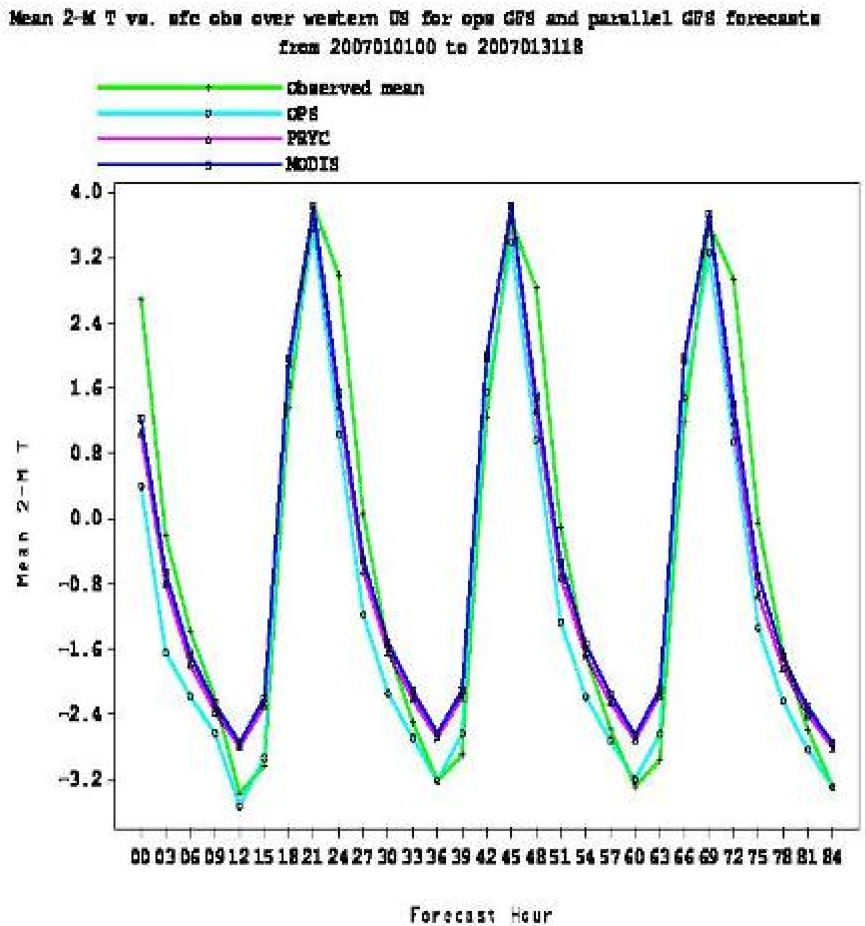
2-m T

(downward drift)



East CONUS

West CONUS



Winter case

Conclusions from Albedo Tests in GFS

- The Changes have shown all positive impact on the atmospheric circulations (AC, bias, RMSE). More improvement has been obtained in the SH than NH and winter (NH) than summer (NH).
- Over CONUS the changes have little impact on the precipitation. The surface temperature tends to warm a little bit due to the changes.
- Need to test in decadal runs of NCEP Climate Model

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- **New work will focus on:**
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    - Kalman filters in NASA LIS system
    - Rescaling satellite soil moisture to that of model

Research to Operations Strategy

for Land Data Assimilation:

Ongoing thrusts

- **Couple NASA/HSB Land Information System (LIS) to the NCEP GFS/GDAS via the Earth System Modeling Framework (ESMF)**
  - NASA funded
- **Substantially expand CRTM testing and focus in LIS**
  - NCEP/EMC funded
  - MODIS, AIRS and MW-based surface emissivity
- **Substantially expand Ensemble Kalman Filter component and testing in LIS**
  - Joint NASA and NCEP and USAF
- **Continue the expanding collaboration between NCEP/EMC, NASA/HSB, and NASA/GMAO in land data assimilation algorithms, methods, approaches**