Land Prediction in NCEP Modeling Systems: *Current Status and Future Plans (NGGPS Land Team)*

Michael Ek[1], Helin Wei[2], Jesse Meng[2],Rongqian Yang[2], Youlong Xia[2], Yihua Wu[2], Weizhong Zheng[2], Jiarui Dong[2], Caterina Tassone[2], Roshan Shresha[2]

[1]NOAA/NWS National Centers for Environmental Prediction (NCEP)
Environmental Modelling Center (EMC)
College Park, Maryland, USA

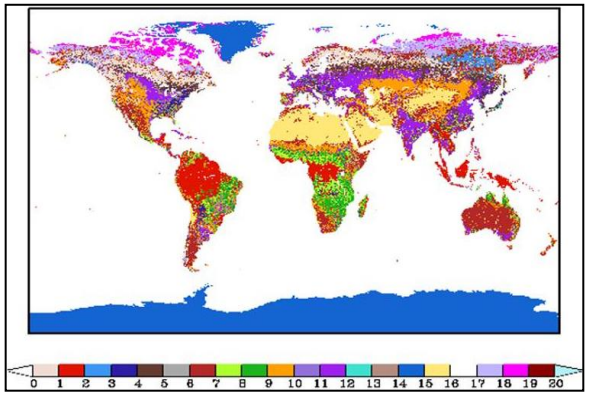
[2]NCEP/EMC and I.M. Systems Group (IMSG)
College Park, Maryland, USA

…and a large number of collaborators!

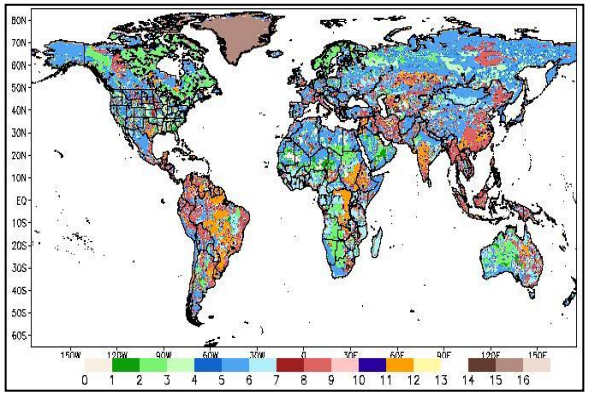
Outline

- **Update on Improvement of Land Surface Modeling in NGGPS:**
  - **Land data sets**, e.g. land use/land cover (vegetation type), soil type, surface albedo, snow cover, surface roughness, etc.
  - **Land Data Assimilation Systems (LDAS)**: provide initial land states for NCEP modeling systems.
    - GLDAS
    - NLDAS
  - **Physics**: appropriate to represent land-surface processes (for relevant time/spatial scales) and assoc. LSM model parameters.
    - Rapid temperature dropoff during sunset
    - Cold biases over cold region
- **Summary/Future**

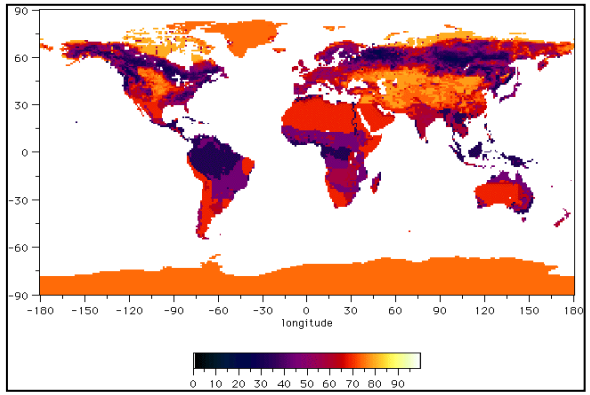
Land Data Sets Used in NCEP Modeling Systems



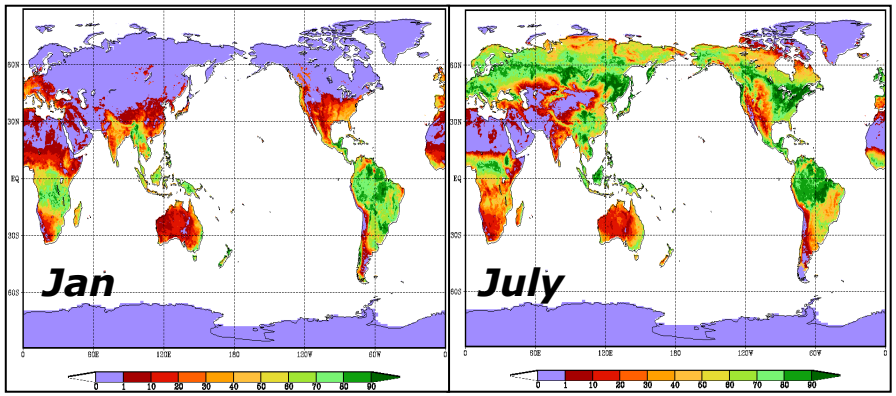
Vegetation Type
(1-km, IGBP-MODIS)



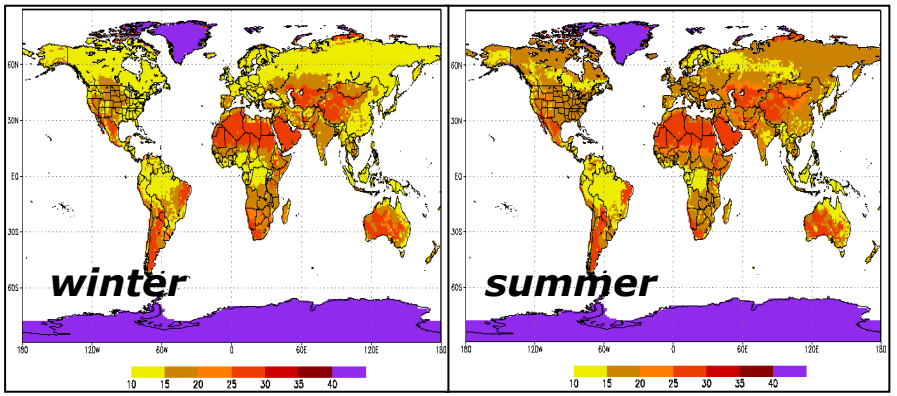
Soil Type
(1-km, STATSGO-FAO)



Max.-Snow Albedo
(1-deg, Robinson)



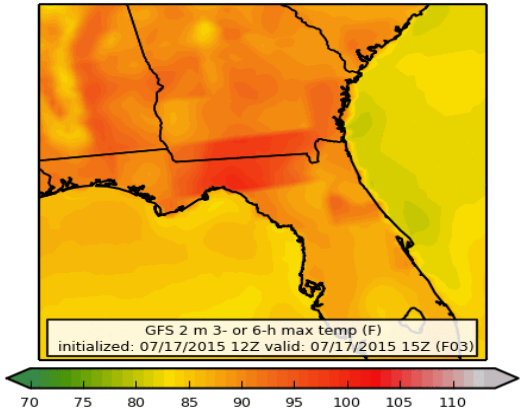
Green Vegetation Fraction (GVF)
(monthly, 1/8-deg, NESDIS/AVHRR)

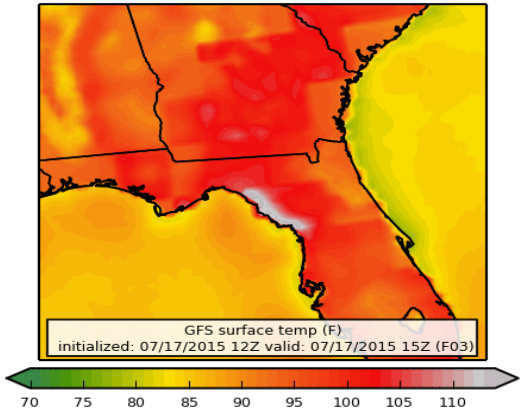


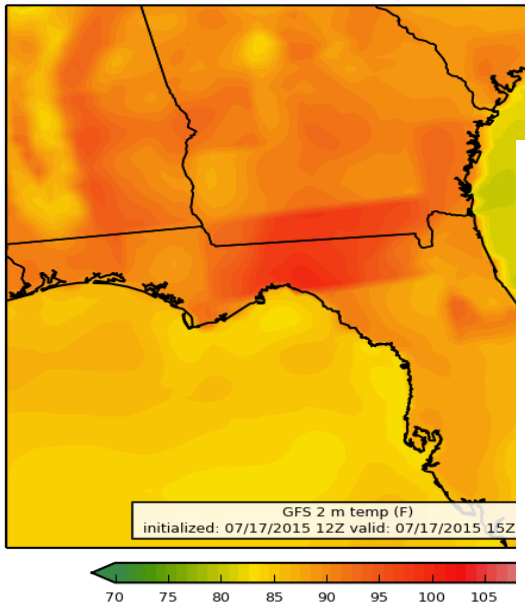
Snow-Free Albedo
(seasonal, 1-deg, Matthews)

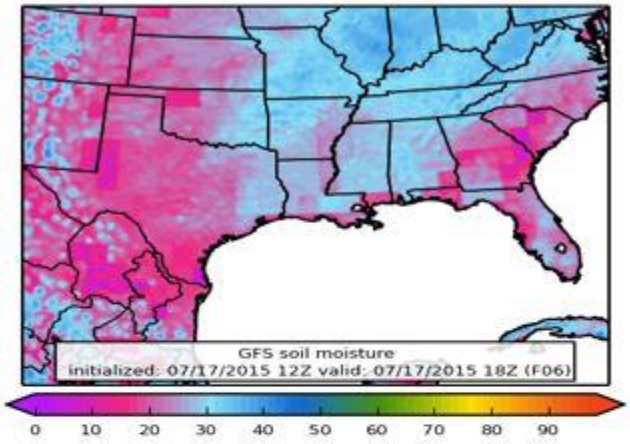
- Climatologies: fixed/annual, monthly, weekly.
- Near real-time observations, e.g. GVF "becoming" a land state.

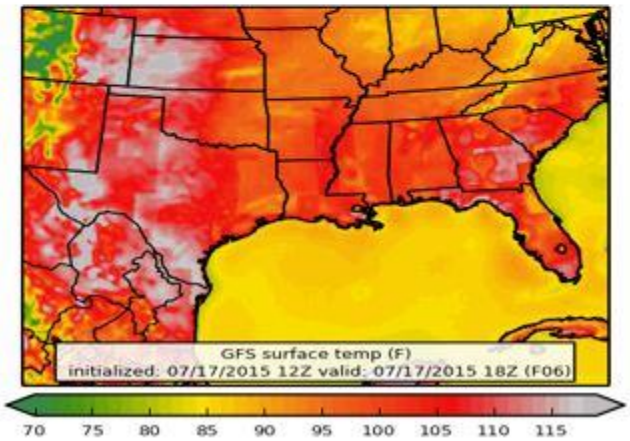
Land Data Sets Used in NCEP Modeling Systems









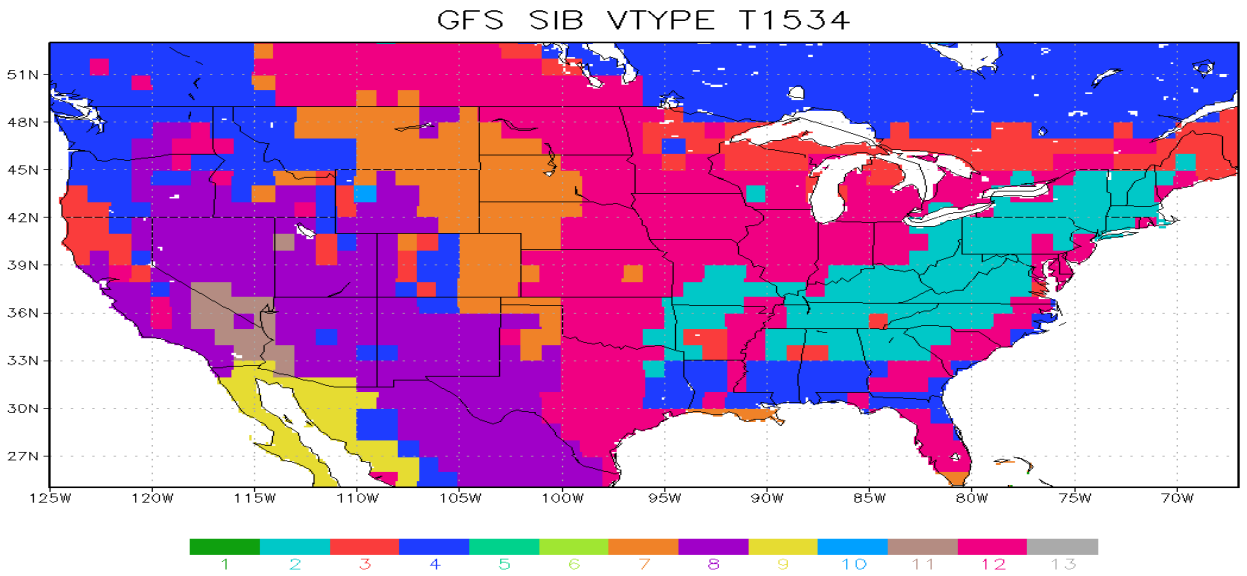


Tiling or blockiness readily apparent

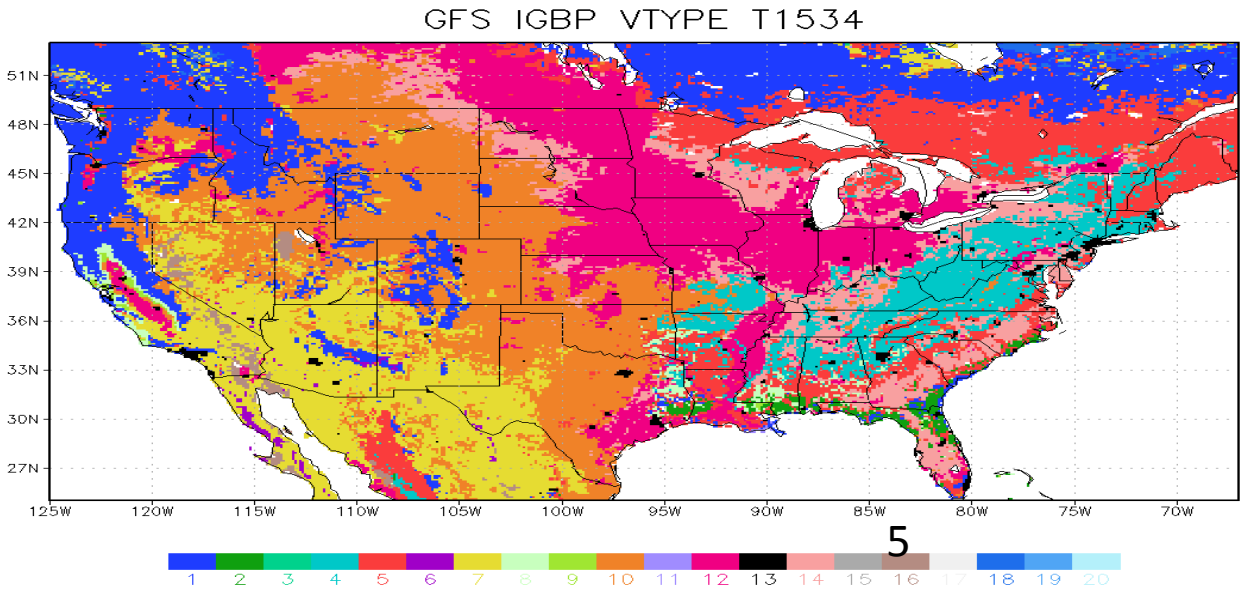
From Corey Guastini NCEP/EMC MEG Jul 23, 2015

Land Data Sets Used in NCEP Modeling Systems

1: broadleaf-evergreen trees
2: broadleaf-deciduous trees
3: broadleaf and needleleaf trees
4: needleleaf-evergreen trees
5: needleleaf-deciduous trees (larch)
6: broadleaf trees with groundcover
7: groundcover only (perennial)
8: broadleaf shrubs with perennial groundcover
9: broadleaf shrubs with bare soil
10: dwarf trees and shrubs with groundcover (tundra)
11: bare soil
12: cultivations (the same parameters as for type 7)
13: glacial ice

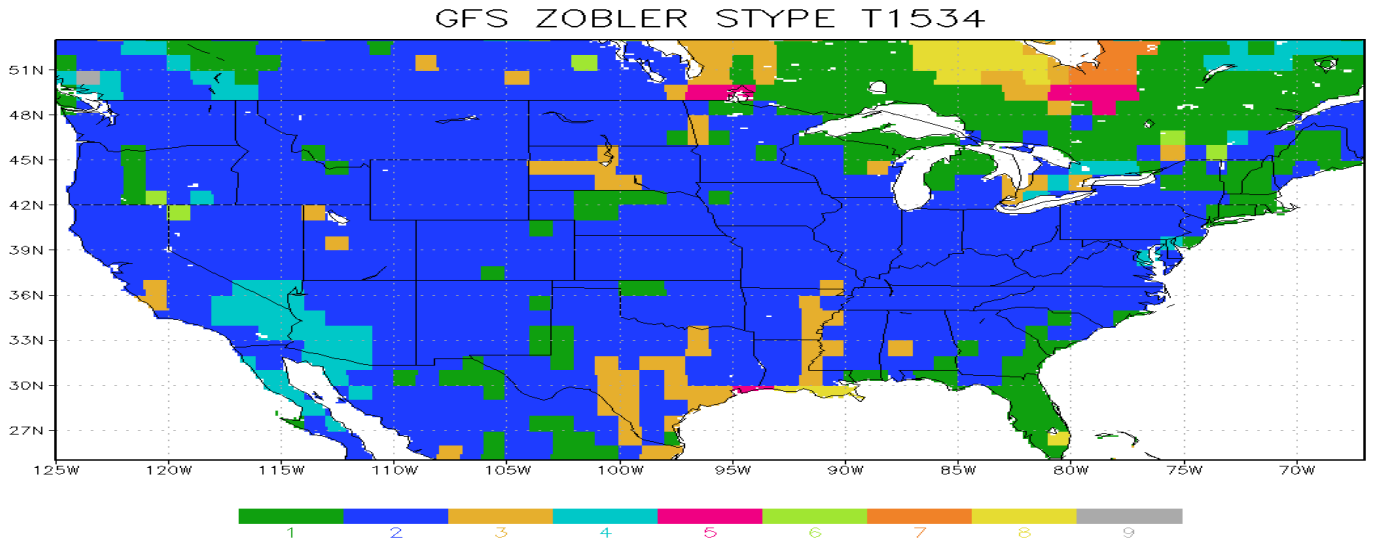


1: Evergreen Needleleaf Forest
2: Evergreen Broadleaf Forest
3: Deciduous Needleleaf Forest
4: Deciduous Broadleaf Forest
5: Mixed Forests
6: Closed Shrublands
7: Open Shrublands
8: Woody Savannas
9: Savannas
10: Grasslands
11: Permanent wetlands
12: Croplands
13: Urban and Built-Up
14: Cropland/natural vegetation mosaic
15: Snow and Ice
16: Barren or Sparsely Vegetated
17: Water
18: Wooded Tundra
19: Mixed Tundra
20: Bare Ground Tundra

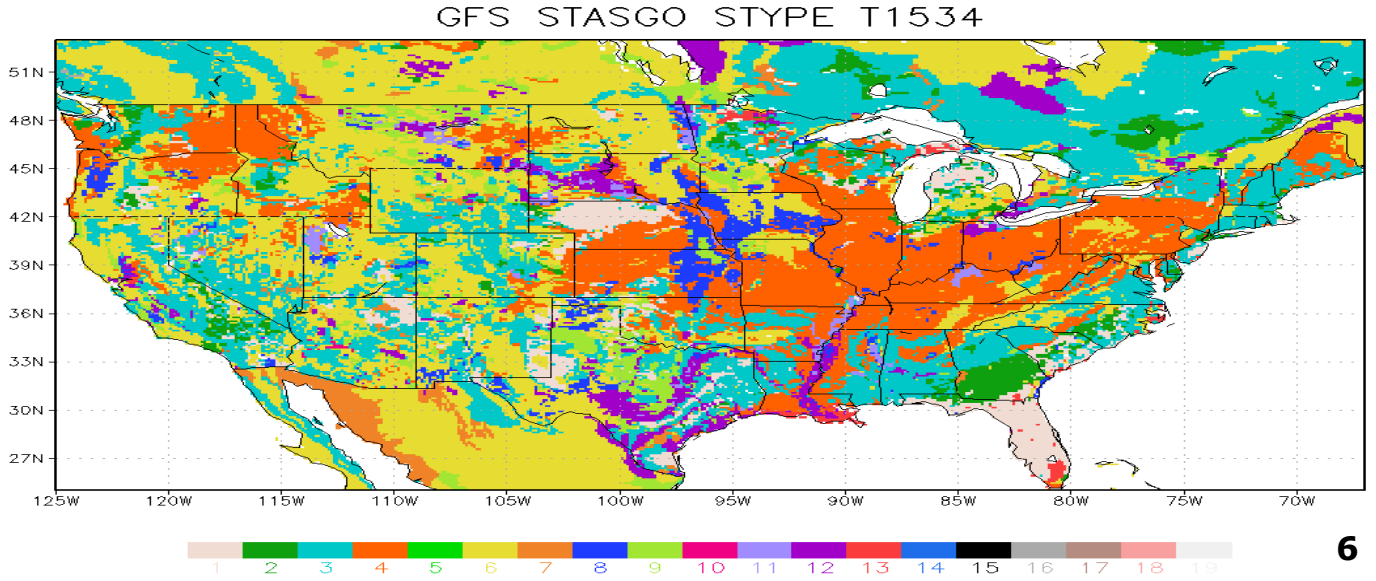


Land Data Sets Used in NCEP Modeling Systems

1: loamy sand
2: silty clay loam
3: light clay
4: sandy loam
5: sandy clay
6: clay loam
7: sandy clay loam
8: loam
9: glacial ice

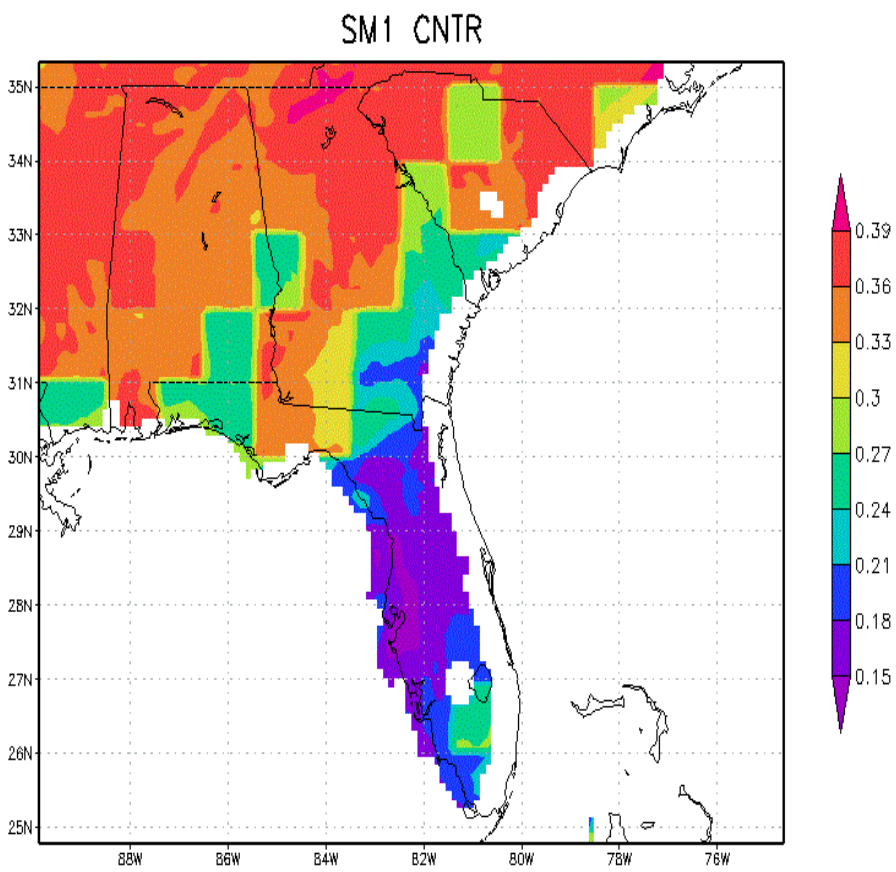


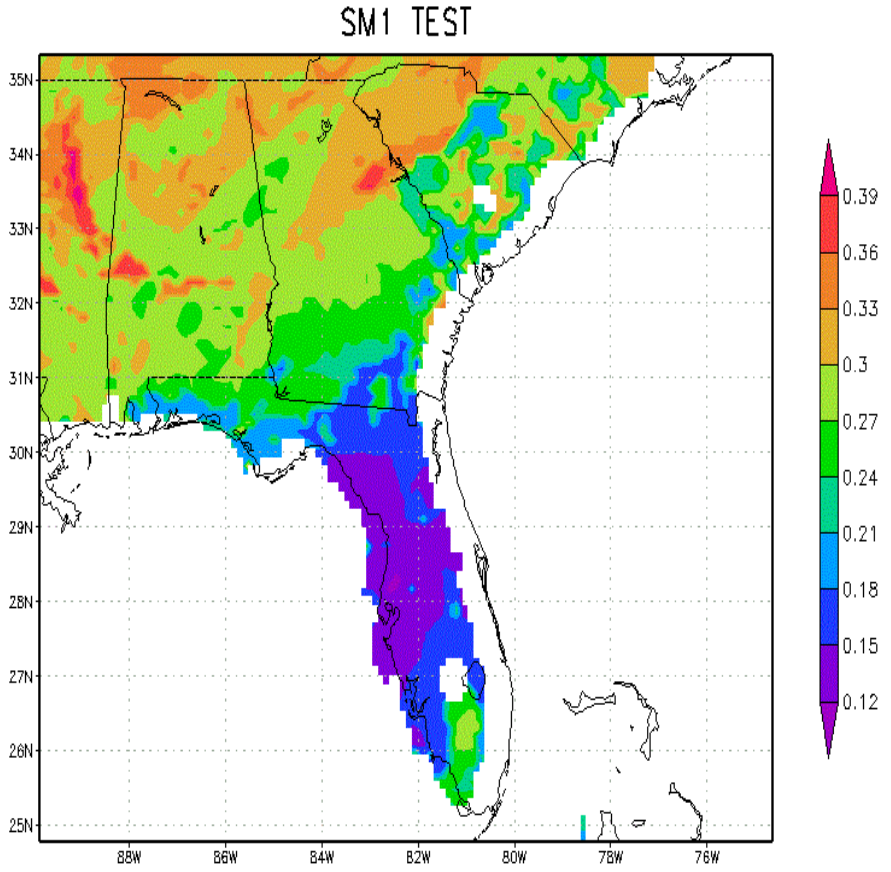
1: sand
2: loamy sand
3: sandy loam
4: silt loam
5: silt
6: loam
7: sandy clay loam
8: silty clay loam
9: clay loam
10: sandy clay
11: silty clay
12: clay
13: organic material
14: water
15: bedrock
16: other (land-ice)
17: playa
18: lava
19: white sand



Land Data Sets Used in NCEP Modeling Systems

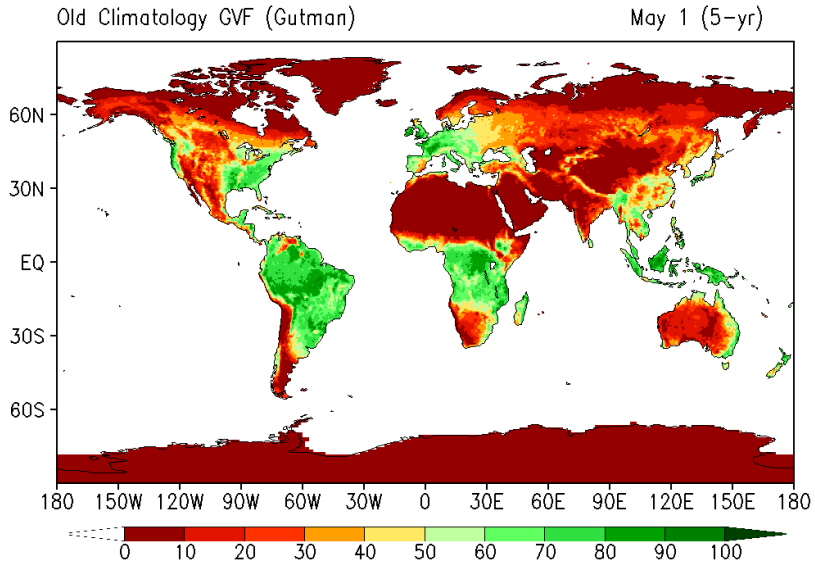
The issue of tiling or blockiness due to the coarse LSC data was solved first soil layer moisture 18h fcst 2015122200



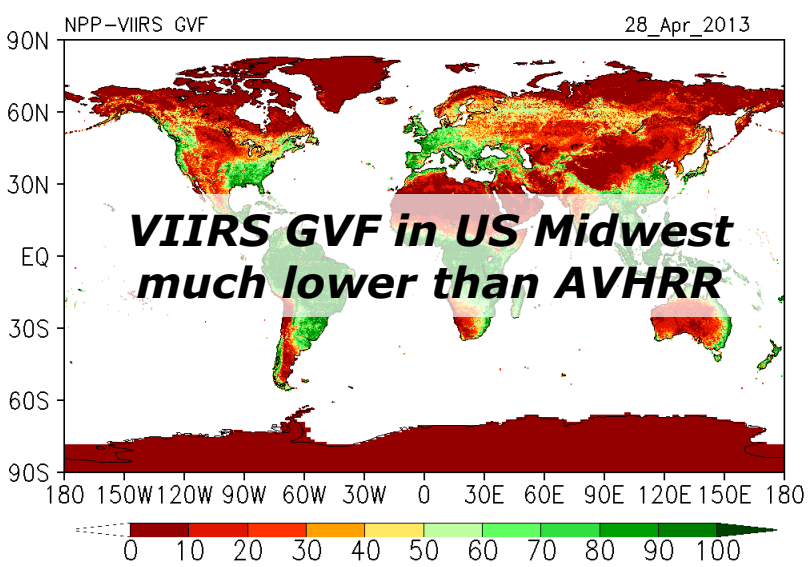


NGGPS Project: Incorporate near-realtime Green Vegetation Fraction (GVF), validation with LST

- **Climatology vs. near real-time GVF.**



AVHRR 5-year "Climatology"



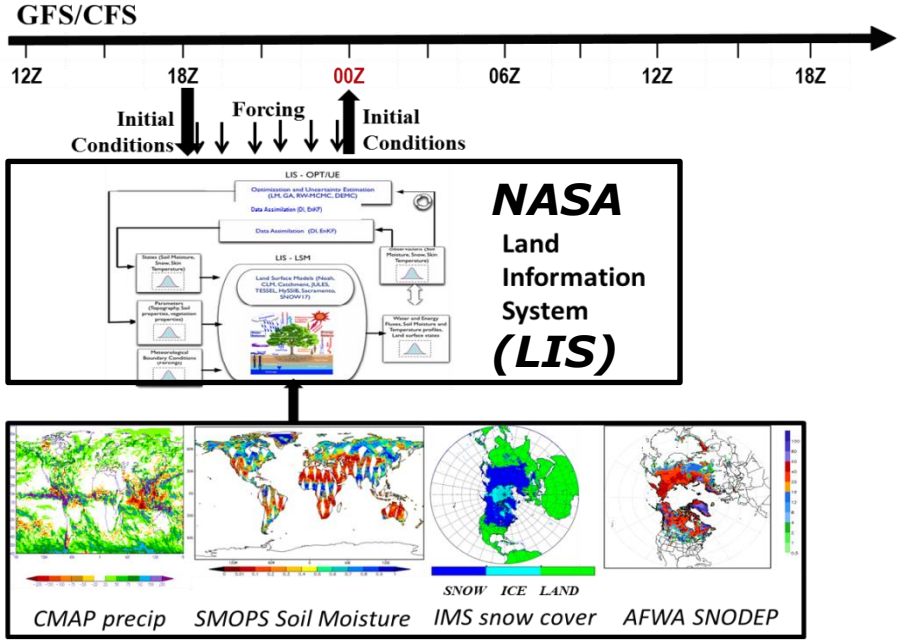
VIIRS

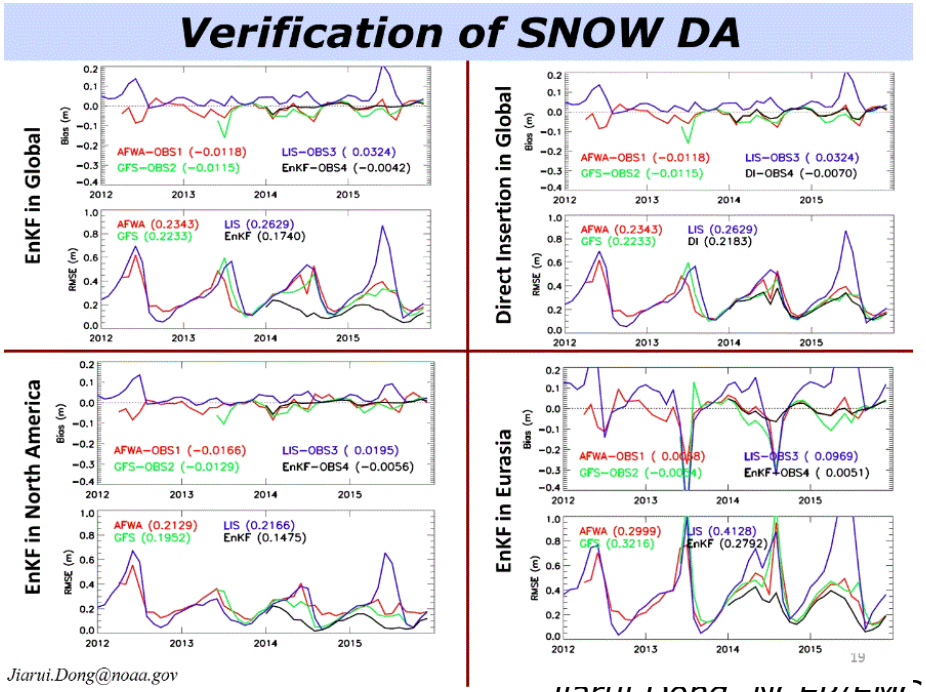
- **Ingest into NCEP models** where near real-time GVF leads to better partition between surface heating & evaporation --> impacts surface energy budget, PBL evolution, clouds & convection.
- Initial summertime GFS tests in 2013, 2014, 2015 show improvements in low-level temperature and dew point, land-surface temperature.
- Part of a broader effort for land product data set ingest with focus on internal consistency among various products (i.e. albedo, burned area, soil moisture, etc).

Weizhong Zheng, Yihua Wu (NCEP/EMC), Bob Yu, Ivan Csiszar, Marco Vargas et al (NESDIS/STAR)

NGGPS Project: Satellite-based Land Data Assimilation in NCEP Modeling Systems

- Use NASA Land Information System (LIS) to serve as a global Land Data Assimilation System (LDAS) for testing both GLDAS, NLDAS.
- LIS EnKF-based Land Data Assimilation tool used to assimilate:
- Soil moisture from the NESDIS global Soil Moisture Operational Product System (**SMOPS**).
- Snow cover area (**SCA**) from operational NESDIS Interactive Multisensor Snow and Ice Mapping System (**IMS**), and AFWA snow depth (**SNODEP**) products.



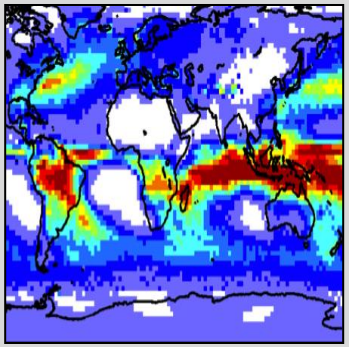


Jiarui Dong, NCEP/EMC

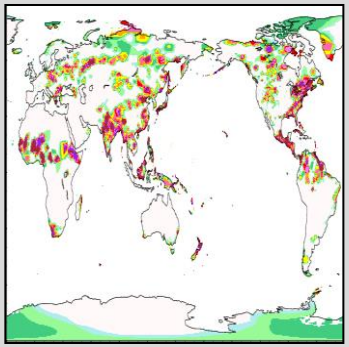
Current Global Land Data Assimilation System (GLDAS) at NCEP Operational in CFSv2 at NCEP 01 April 2011

- **Noah surface model** runs in semi-coupled mode with Climate Data Assimilation System version (CDASv2); daily update provides initial land states to operational Climate Forecast System version 2 (CFSv2).
- **Forcing**: CDASv2 atmospheric output, & "blended" precipitation, snow.
- **Blended Precipitation**: CPC **satellite** (heaviest weight in **tropics**); CPC **gauge** (heaviest **mid-latitudes**); **model** CDASv2 (**high latitude**).
- **Snow**: IMS cover & AFWA depth, *cycled if within 0.5-2.0x "envelope"*.
- **30+ year global land-surface climatology**.
- Research/partners supported by the NOAA Climate Program Office, Modeling, Analysis, Predictions, and Projections (MAPP) program.

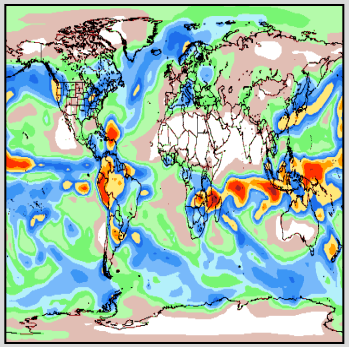
Precipitation



CMAP

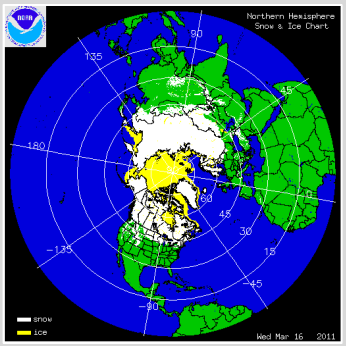


Surface gauge

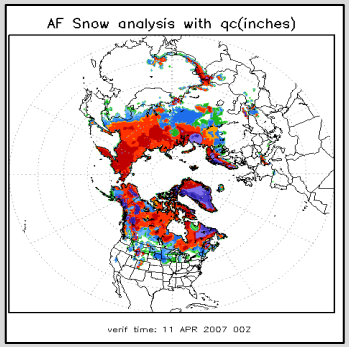


GDAS

Snow



IMS cover

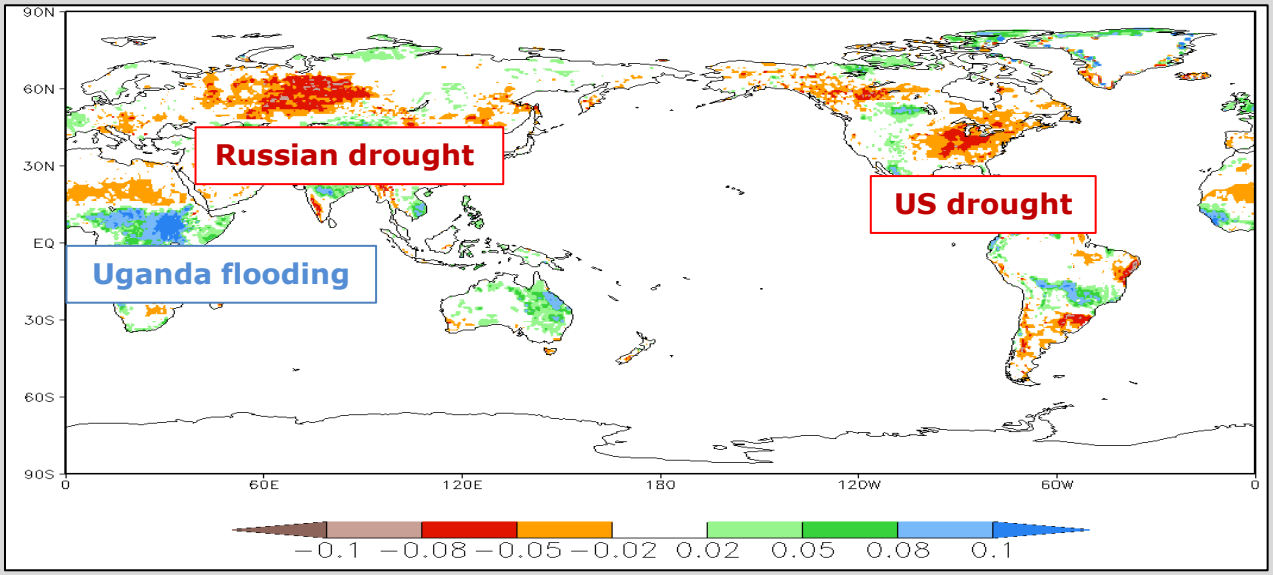


AFWA depth

Jesse Meng, NCEP/EMC

Global Land Data Assimilation System (GLDAS) version 2

- **Motivation:** NCEP CFS Reanalysis ran 6 simultaneous "streams"; soil moisture time series may have trends and discontinuity due to insufficient land surface spin up (~1 year, where ~10-years+ required).
- **Solution:** Retrospective single-stream GLDAS2 with 10-year spin-up procedure to resolve the issues of spin-up and stream discontinuity.
- Significantly **improved soil moisture time series** in the **semi-arid regions** and **cold regions** where longer spin-up period required.
- **Reasonable** soil moisture **climatology**, energy/water budget closure.

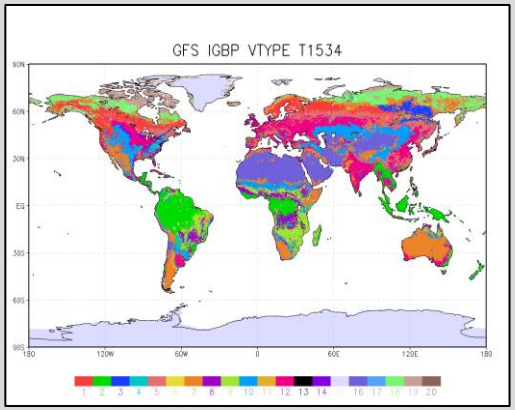


July 2012 Soil Moisture Anomaly *from NCEP GLDASv2*

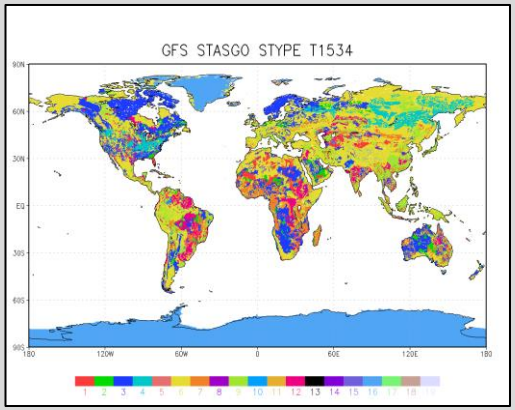
Jesse Meng, NCEP/EMC

LDAS Upgrade: Implementation of GLDAS in GFS

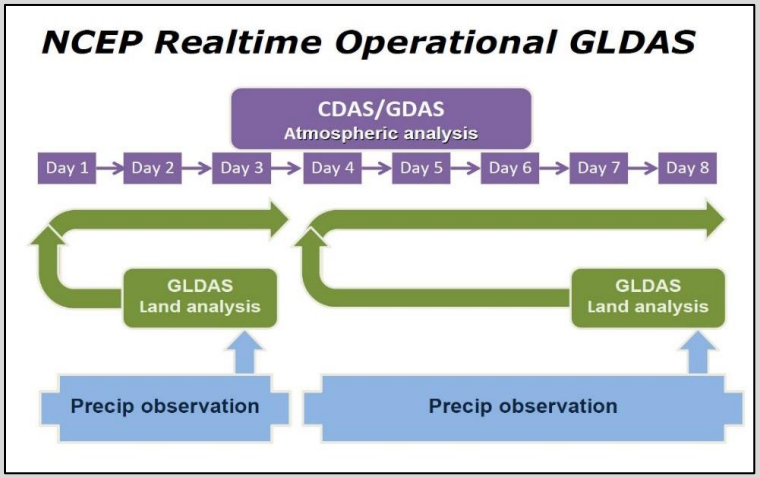
- CDASv2/GLDAS paradigm: adapt for Global Forecast System:
  - Noah land model physics upgrades; accommodate higher-res. GFS.
  - Land surface forcing/downscaling, e.g. precipitation.
  - Land data sets, e.g. land-use, soils, green vegetation fraction (GVF).
  - Land data assimilation, e.g. snow, soil moisture.
  - Replace soil moist. nudging which uses CDASv2/GLDAS climatology.
  - Hydrology/river routing for ocean coupling. (*National Water Center*)
  - Eventually one global high-resolution LDAS for all NCEP systems.
- Continue to work with partners: Noah LSM model development group; NWS NGGPS land/other teams; supported by NOAA/CPO/MAPP; part of CPO/MAPP Task forces on reanalyses, model development, drought.



Vegetation Type Data



Soil Type Data



Jesse Meng and Helin Wei, NCEP/EMC

LDAS Upgrade: GLDASv2.2 with New Precipitation Forcing

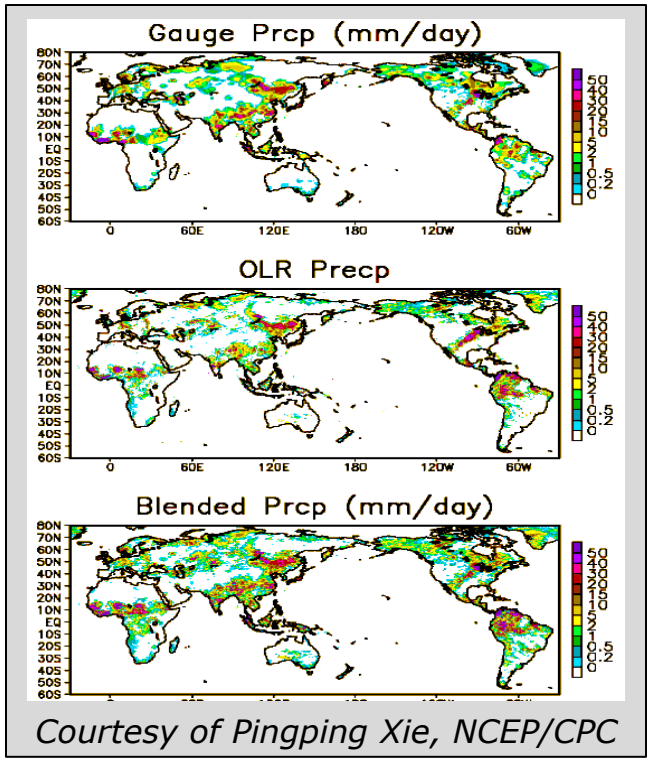
Precipitation Data:

- Gauge-satellite blended analysis of daily global precipitation.
- 0.25° lat/lon over the global land.
- Global daily anaiy., 0.25-deg, 1979-present.
- Blending information from different sources:
  - CPC daily gauge analysis.
  - GPCC monthly gauge data.
  - OLR-based precipitation estimates.
  - CMORPH-based precipitation estimates.

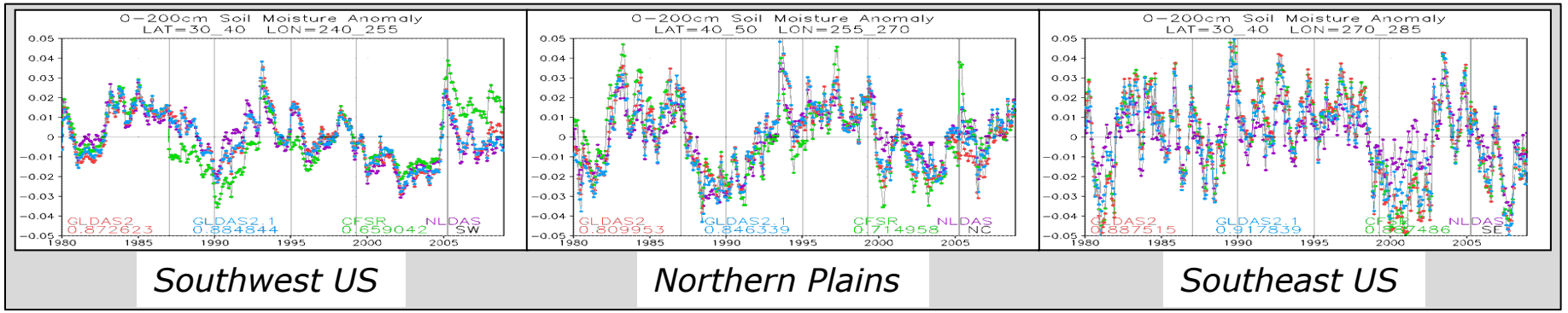
Preliminary Results:

- Improved soil moisture spin-up & anomalies.

Supported by NOAA/CPO/MAPP.



Courtesy of Pingping Xie, NCEP/CPC



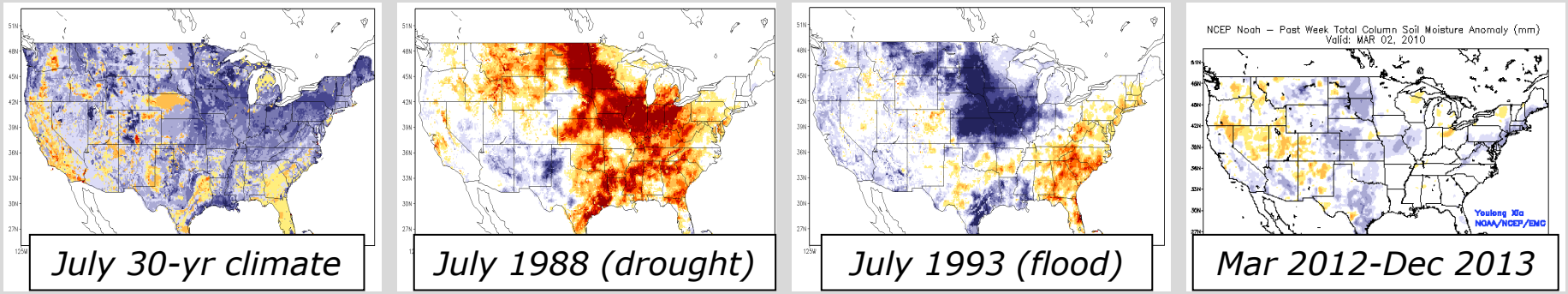
Southwest US | *Northern Plains* | *Southeast US*

Jesse Meng, NCEP/EMC

North American Land Data Assimilation System (NLDAS)
Operational at NCEP 05 August 2014

- **Land models**: Noah, SAC, VIC, Mosaic run in "uncoupled" mode.
- **Forcing**: NCEP Climate Prediction Center obs precip (gauge-based, radar/satellite disaggregatred), and atmospheric forcing from NCEP North American *Regional Climate Data Assimilation System.*
- **Output**: 1/8-deg. land & soil states, surface fluxes, runoff/streamflow.
- **Climatology** from land model assimilation runs for 30+ years provide **anomalies** used for **drought monitoring**; supports USDM, NIDIS etc.
- **Comprehensive evaluation** of **energy fluxes**, **water budget** and **state variables** using in situ and remotely-sensed data sets.
- **Evaluate** land-atmosphere **coupling metrics** for NLDAS climatology.
- NOAA/CPO/MAPP-supported partners: NCEP,NASA,***Princeton***,UW,NWC.

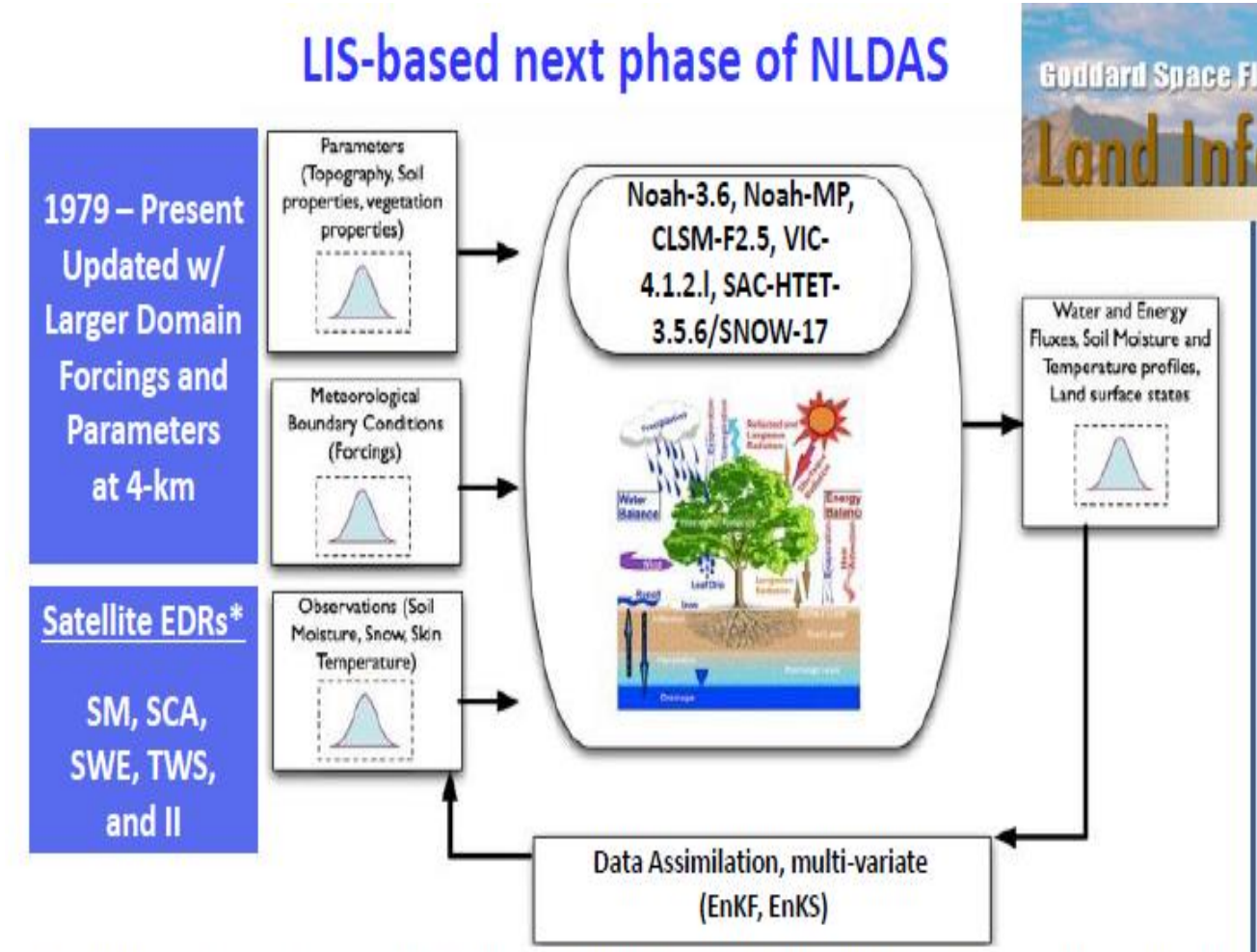
www.emc.ncep.noaa.gov/mmb/nldas ldas.gsfc.nasa.gov/nldas/NLDAS2valid.php



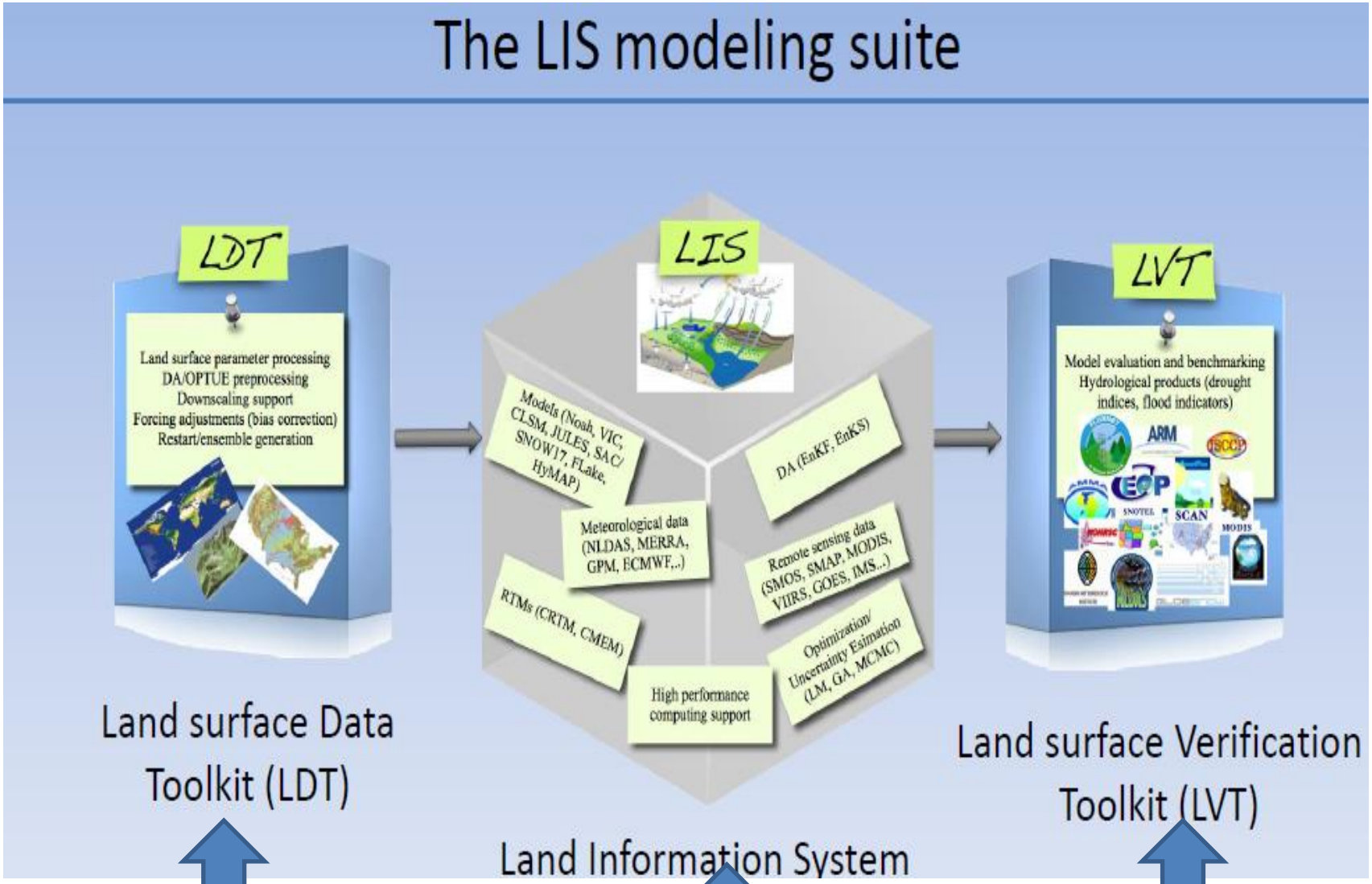
July 30-yr climate | *July 1988 (drought)* | *July 1993 (flood)* | *Mar 2012-Dec 2013*

NLDAS four-model ensemble monthly soil moisture anomaly

Next Generation NLDAS within Land Information System (LIS) and Actual Data Assimilation (Snowpack, Soil Moisture, GRACE)



The Land Information System (LIS) is a flexible land-surface modeling and data assimilation framework developed with the goal of integrating satellite- and ground-based observed data products with land-surface models.

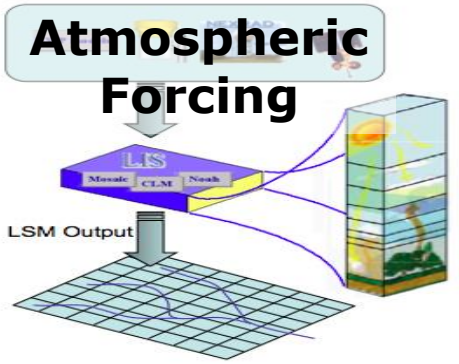


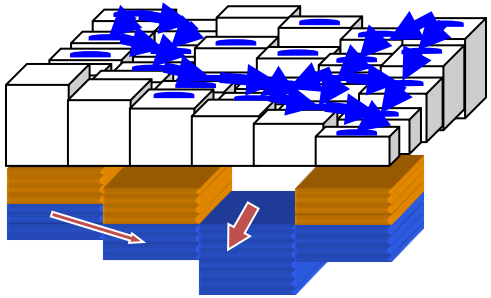
Data Preprocessor

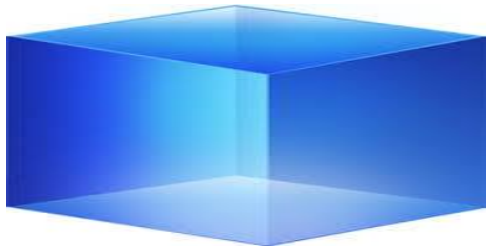
Modeling and Assimilation

Evaluation and Validation

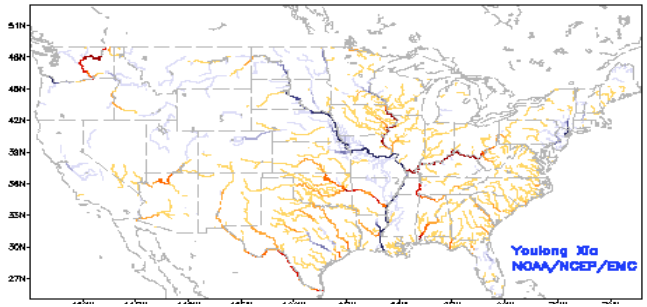
NLDAS Connection: Hydrology, River-Routing



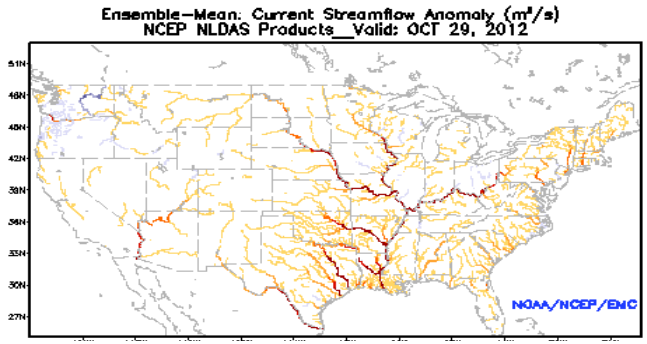




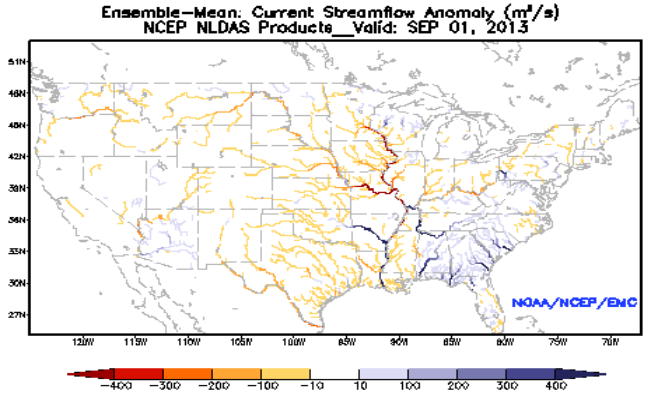
Ensemble mean daily streamflow anomaly (NLDAS)



Hurricane Irene and Tropical Storm Lee, 20 August – 17 September 2011



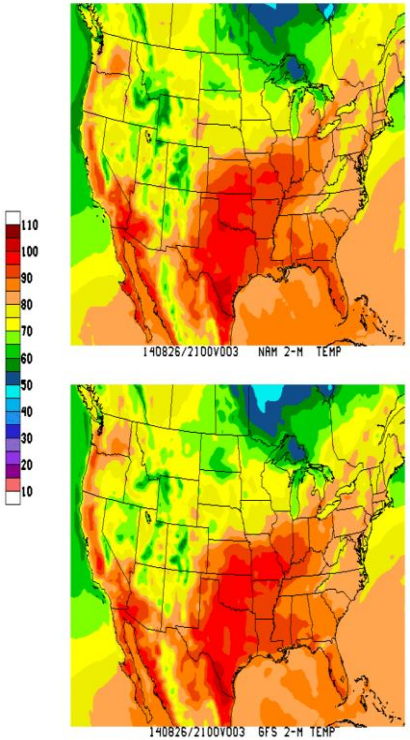
Superstorm Sandy, 29 October – 04 November 2012

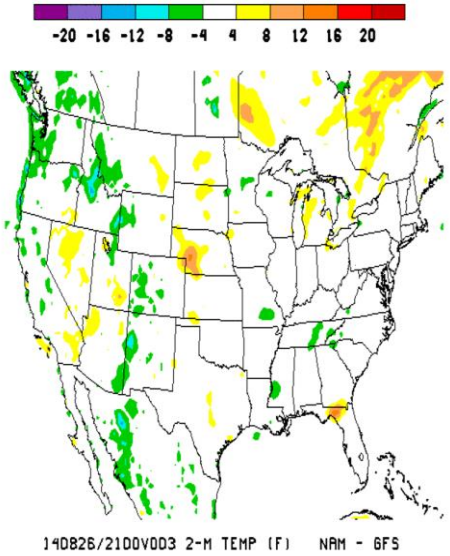


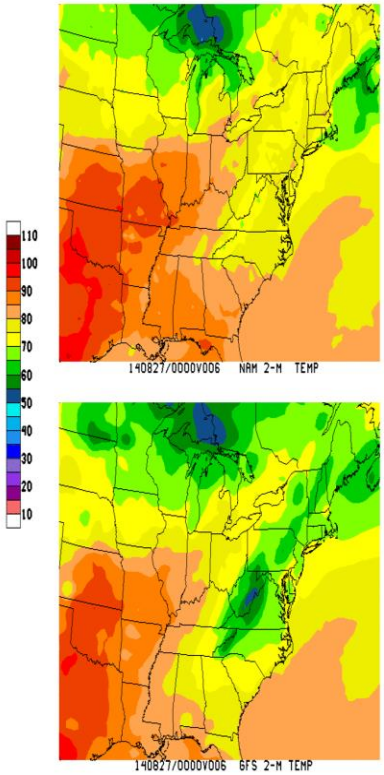
Colorado Front Range Flooding, September 2013

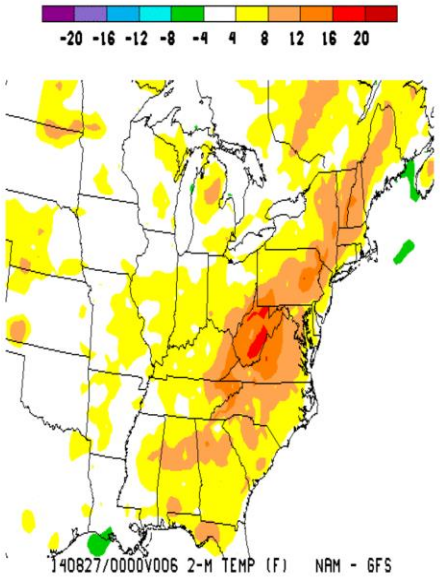
Close Coordination with Office of Water Prediction (OWP) on National Water Model(NWM)

Model Physics Improvement: Decoupling









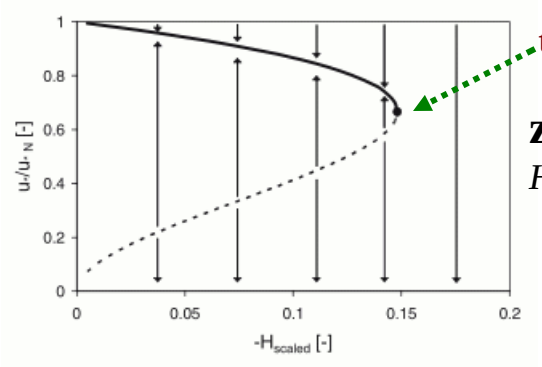
GFS T2m Rapid drop after sunset (from Manikin, NCEP/EMC MEG)

Model Physics Improvement: Decoupling

Approach to fix excessive cooling of T2m in GFS

"Excessive cooling and decoupling": surface roughness, soil thermal diffusivity, vegetation layer, turbulence, etc.

- **Limit the system not beyond the turning point (MO stability parameter):**



turning point

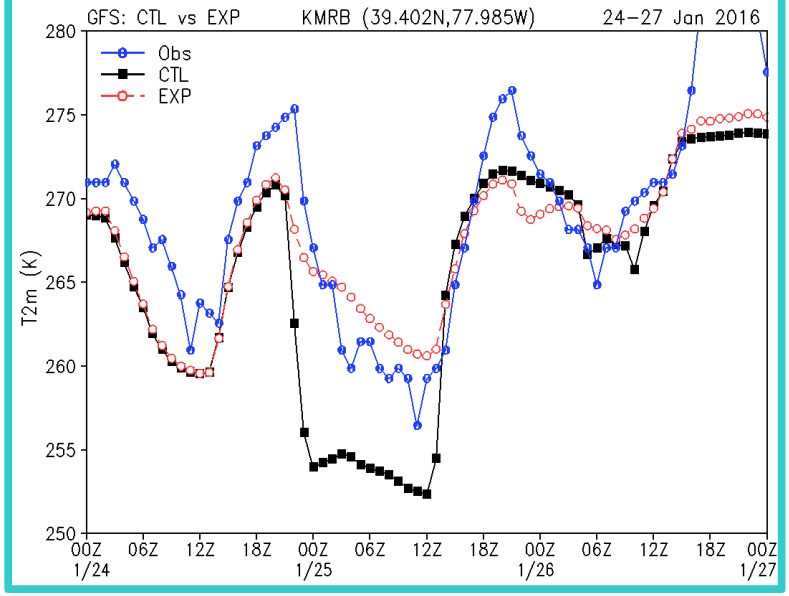
$$z/L < z/L|_M = \ln(z/z_0)/[2*\alpha*(1-z_0/z)]$$

Here z0 is the momentum roughness length, and α=5.

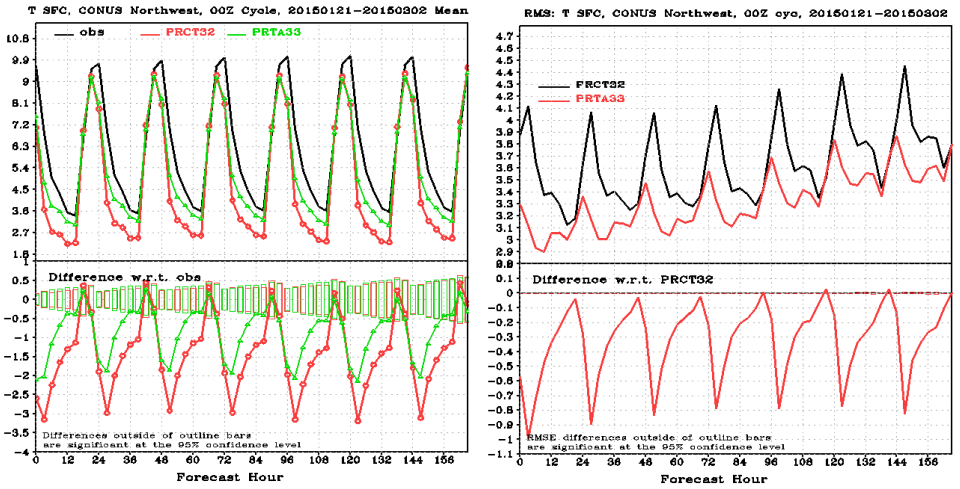
Van de Wiel et al.

Model Physics Improvement: Decoupling

T2m @ MRB Matinsburg RGNL, WV



T2m @ Northwest: 1/21-3/2, 2015

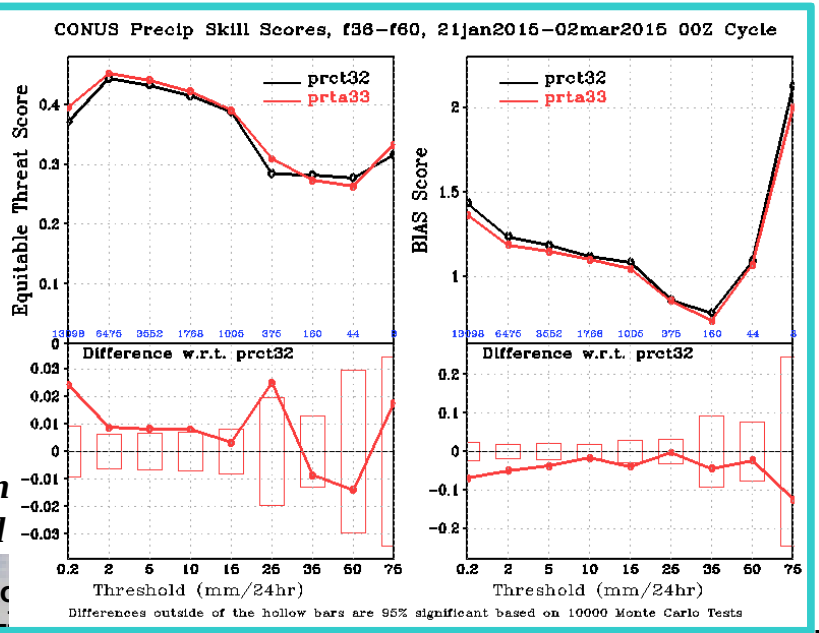


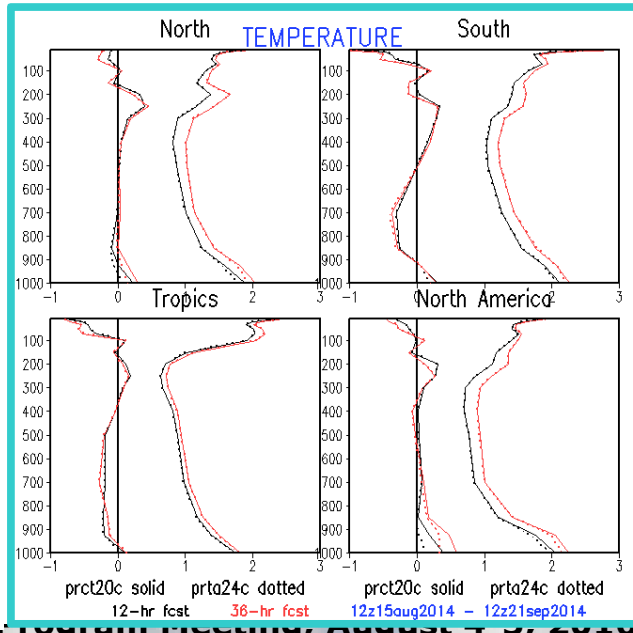
Reduced cold bias afternoon and nighttime (~ 1.2 °C);
Reduced RMSE afternoon and nighttime up to 1.0 °C (~ 25% RMSE).

Pr skills (CONUS) f36-f60

1/21-3/2, 2015

Improved scores for light and medium precipitation and reduced their bias.





T fits Obs:

8/15-9/22, 2014

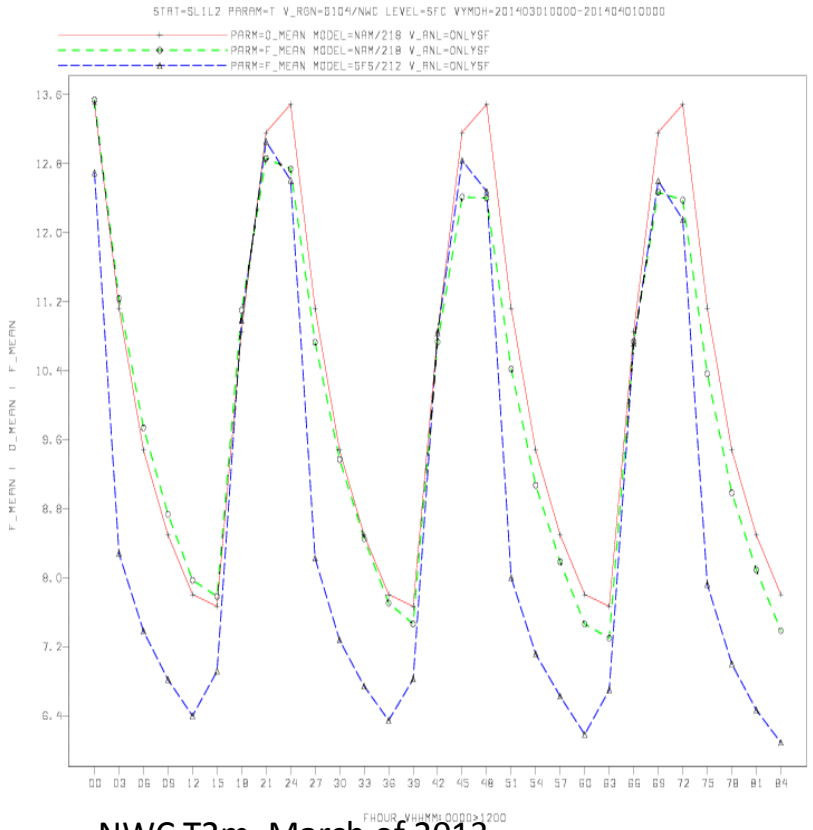
Reduced temperature bias and RMSE near the surface.

Model Physics Improvement: Cold Biases

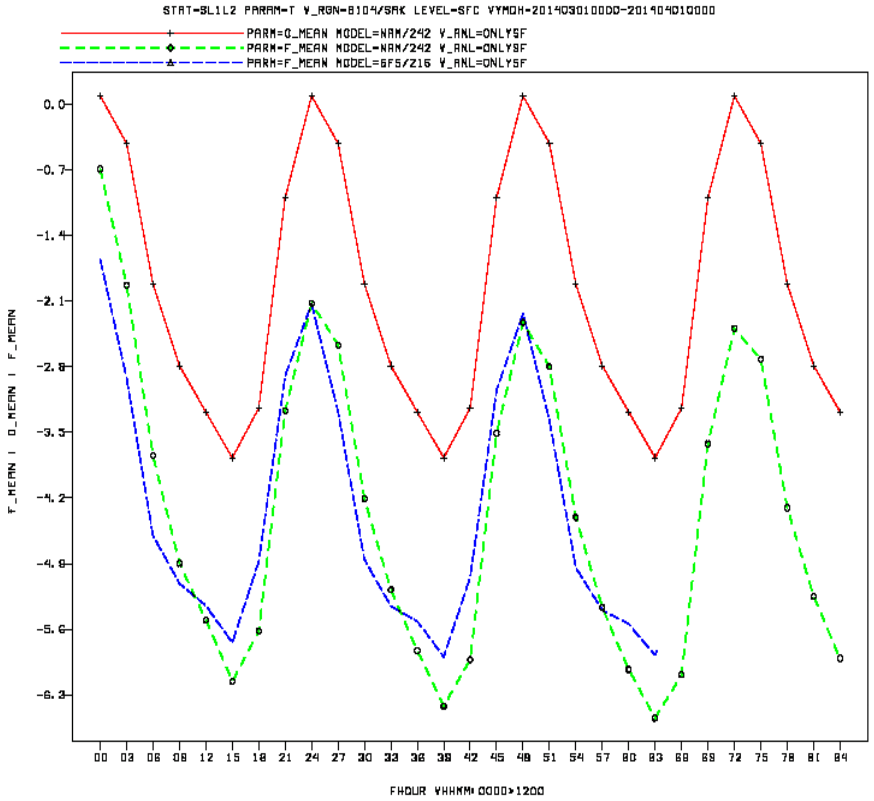
- Cold temperate bias over snow

Alaska, NW, NE

- Stable boundary
- Decoupling
- Surface exchange coefficient (Ch)
- Snow albedo being too large



NWC T2m, March of 2013



Southern Alaska, T2m, March of 2014

Revised ground heat flux under deep snow

[32] The ground heat flux under snow condition i puted in Noah as

$$G = \left(T_1 - T_{soil(1)}\right) \cdot \frac{DF_1}{DTOT},$$

$$DTOT = \Delta Z_s + \Delta Z_{s1},$$

$$DF_1 = F_{sn} \frac{\Delta Z_s K_s + \Delta Z_{s1} K_{s1}}{\Delta Z_s + \Delta Z_{s1}} + (1 - F_{sn}) \cdot K_{s1},$$

[34] To remove the Noah deficiency in computing G under deep snow condition (which is primarily caused by using a single bulk snow layer in Noah), we revise the ground heat flux by limiting the minimum value of $DF_1/DTOT$ used in equation (7a) by

$$G = \left(T_1 - T_{soil(1)}\right) \cdot \mathrm{Max}(DD_{min},\ DF_1/DTOT), \qquad (8)$$

where $DD_{min} = 7\ \mathrm{W\ m^{-2}\ K^{-1}}$, as motivated by the European Centre for Medium-Range Weather Forecasts (ECMWF) land model (see http://www.ecmwf.int/research/ifsdocs/CY28r1). Figure 2 shows that equation (8) (Exp. 4) improves the Noah simulation of SWE and snow depth.

Citation: Wang, Z., X. Zeng, and M. Decker (2010), Improving snow processes in the Noah land model, J. Geophys. Res., 115, D20108, doi:10.1029/2009JD013761

Model Physics Improvement: Cold Biases

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 Noah LSM (below)

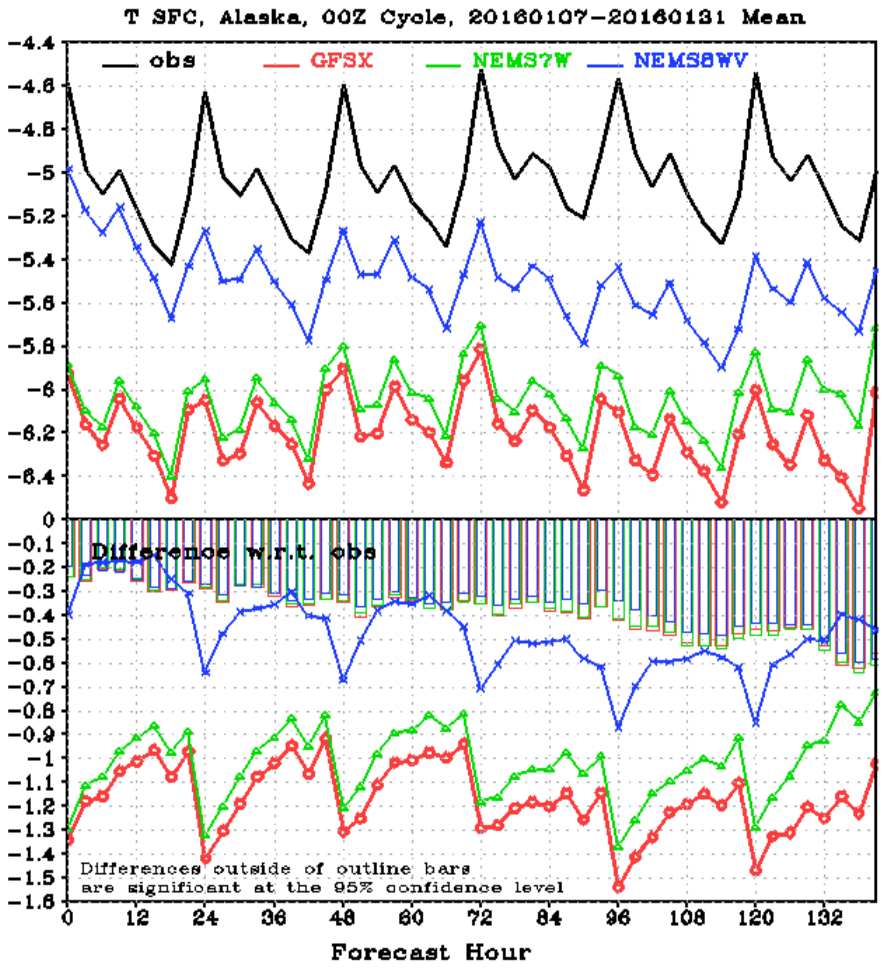
- Noah LSM

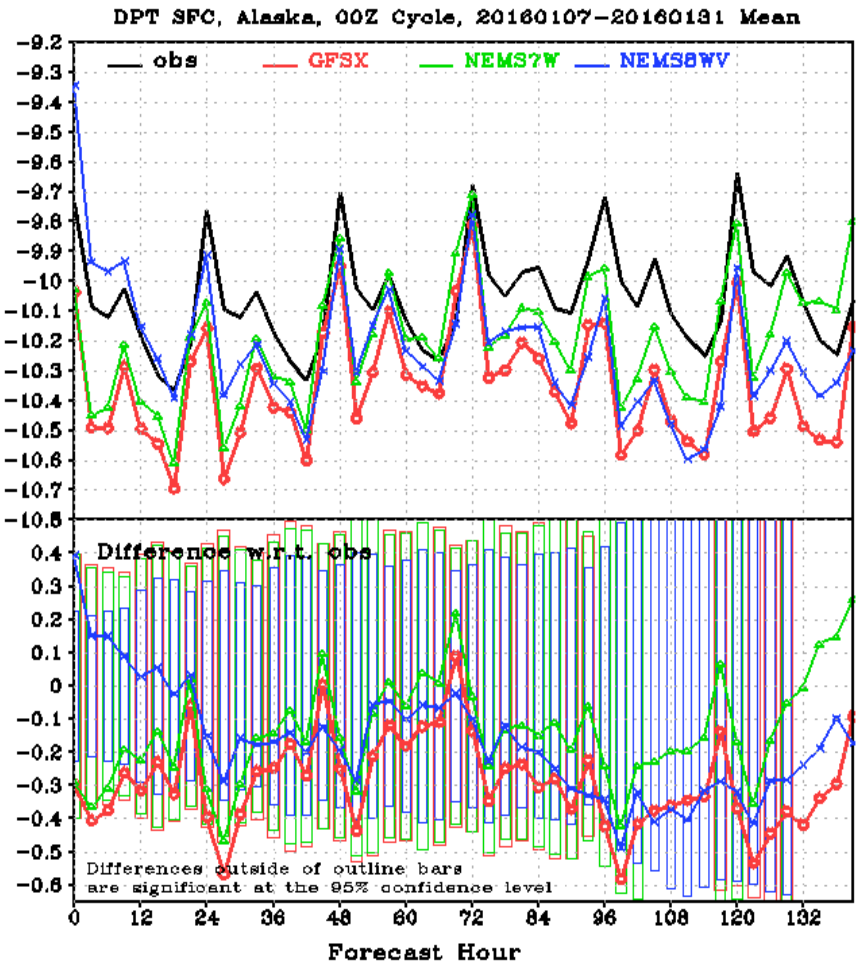
  Based on global field of Maximum Snow albedo

Model Physics Improvement: Cold Biases

reduced cold bias

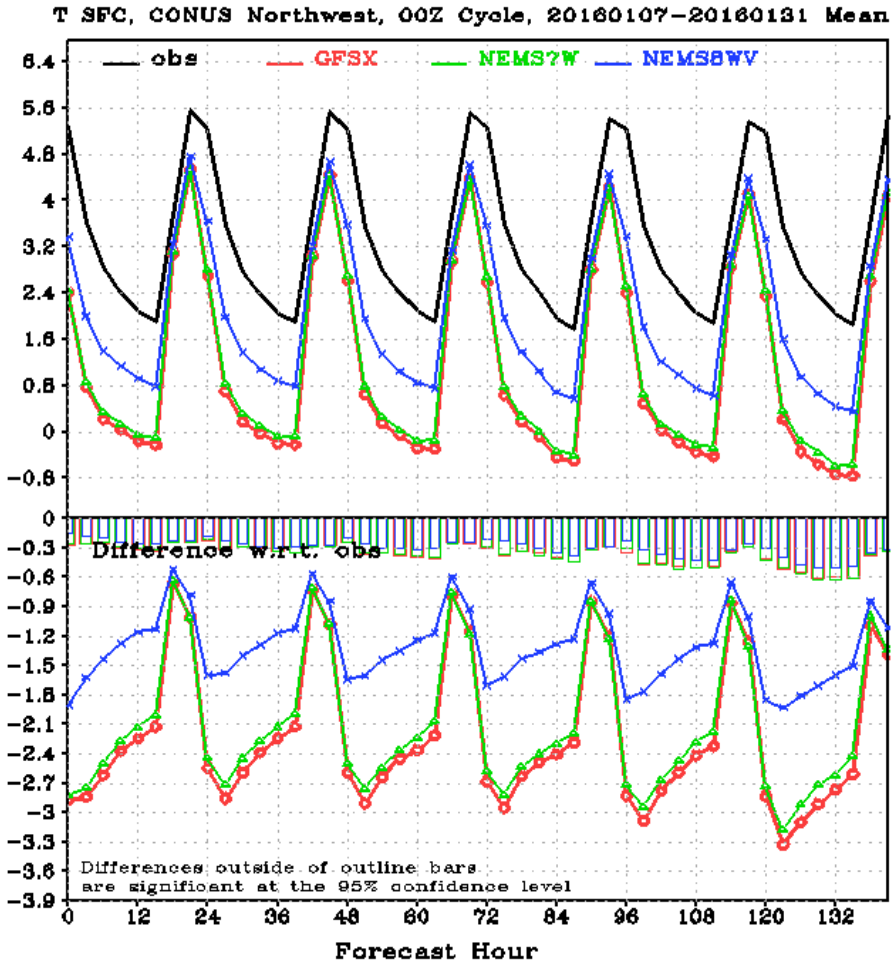
2m-T and Td over Alaska, January of 2016

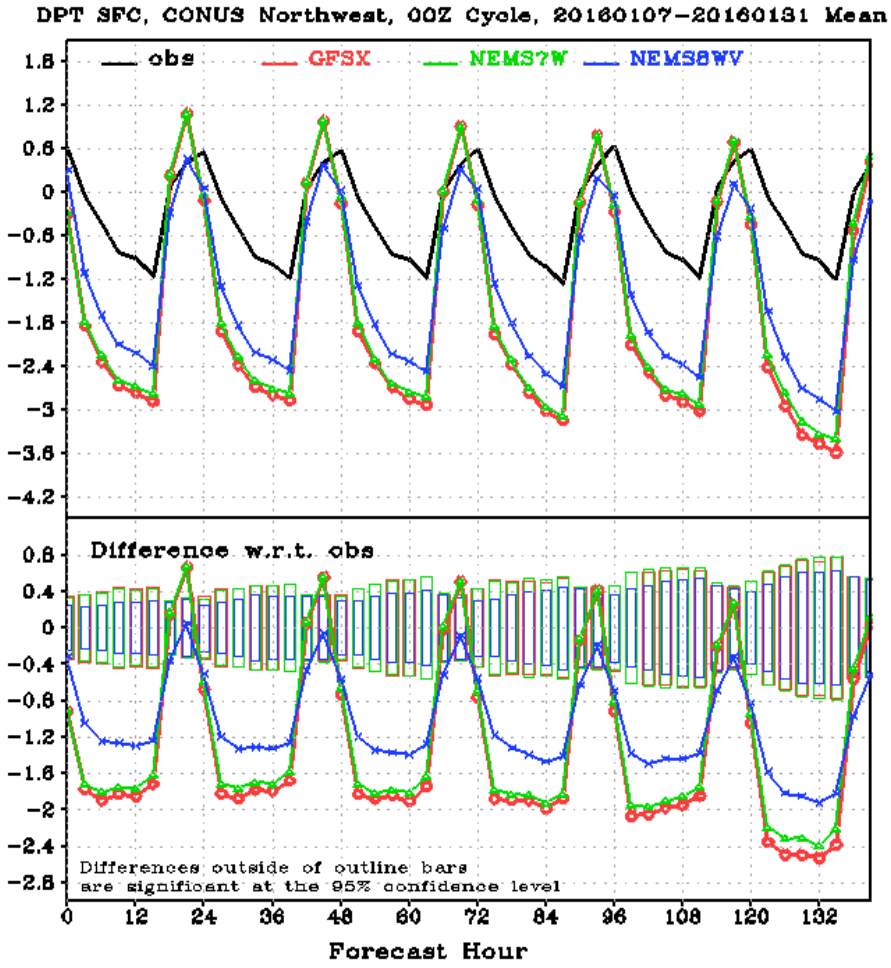




Model Physics Improvement: Cold Biases

2m-T and Td over NW CONUS, January of 2016

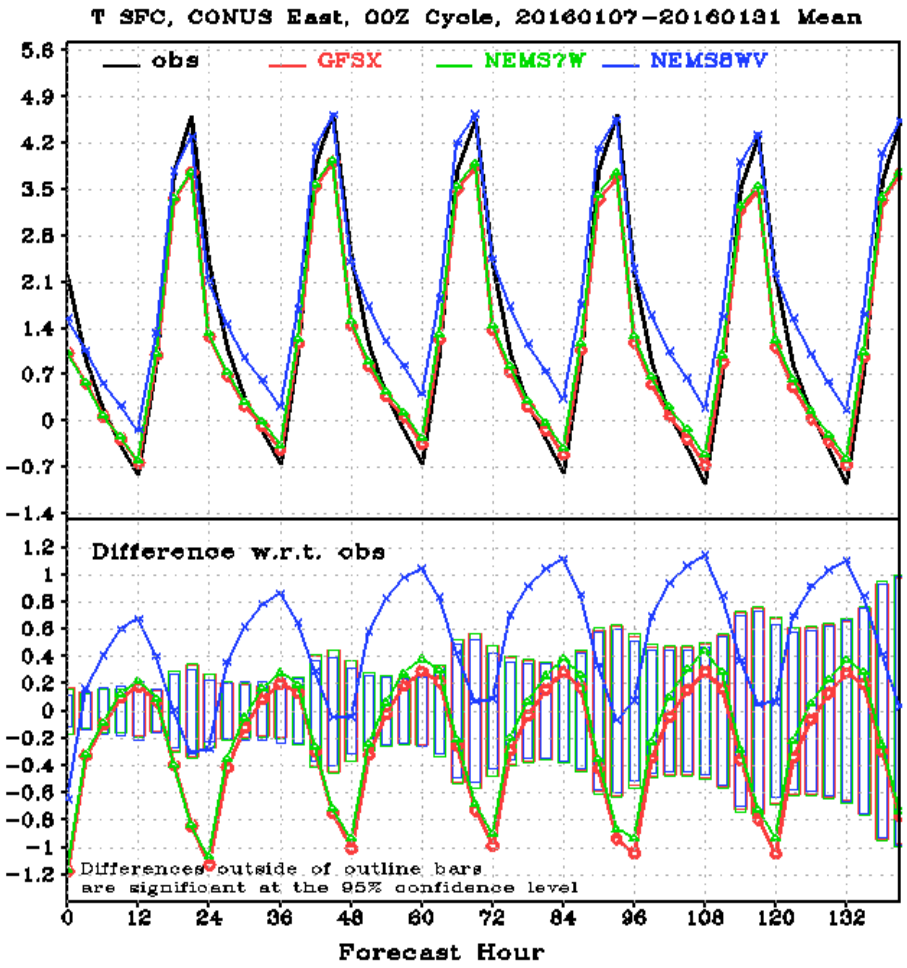


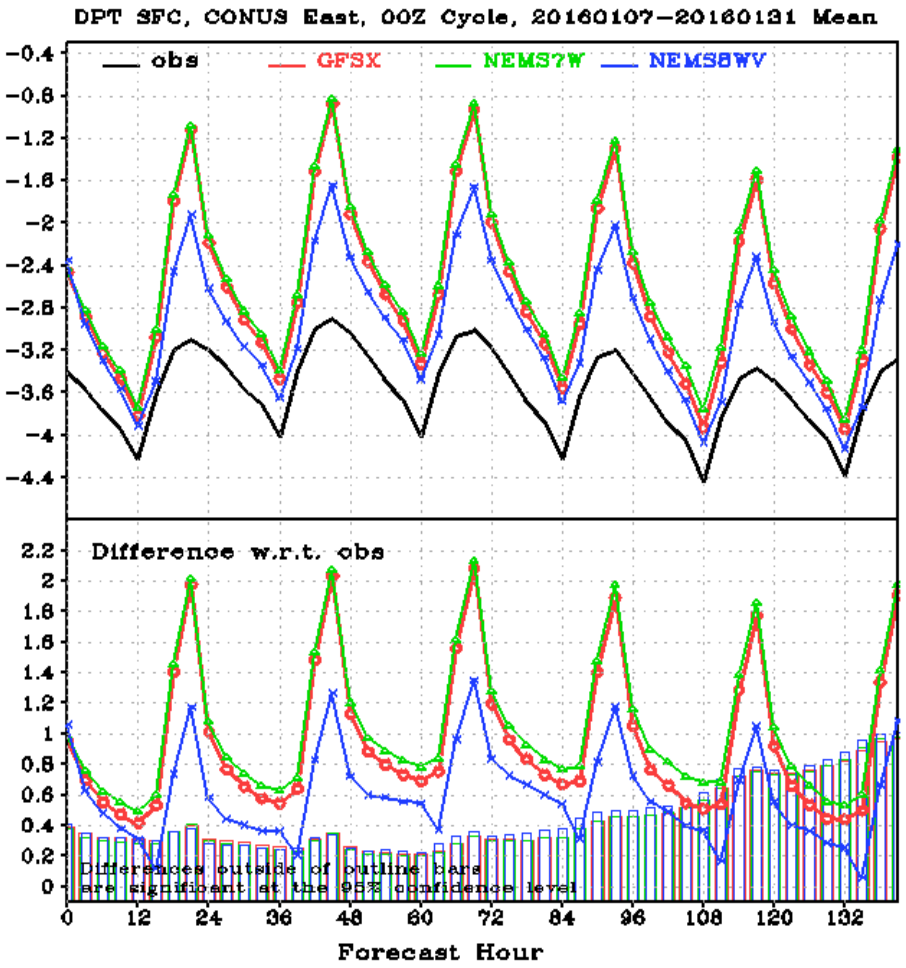


reduced nighttime cold bias, but still have significant day/nighttime cold bias

Model Physics Improvement: Cold Biases

2m-T and Td over East CONUS, January of 2016

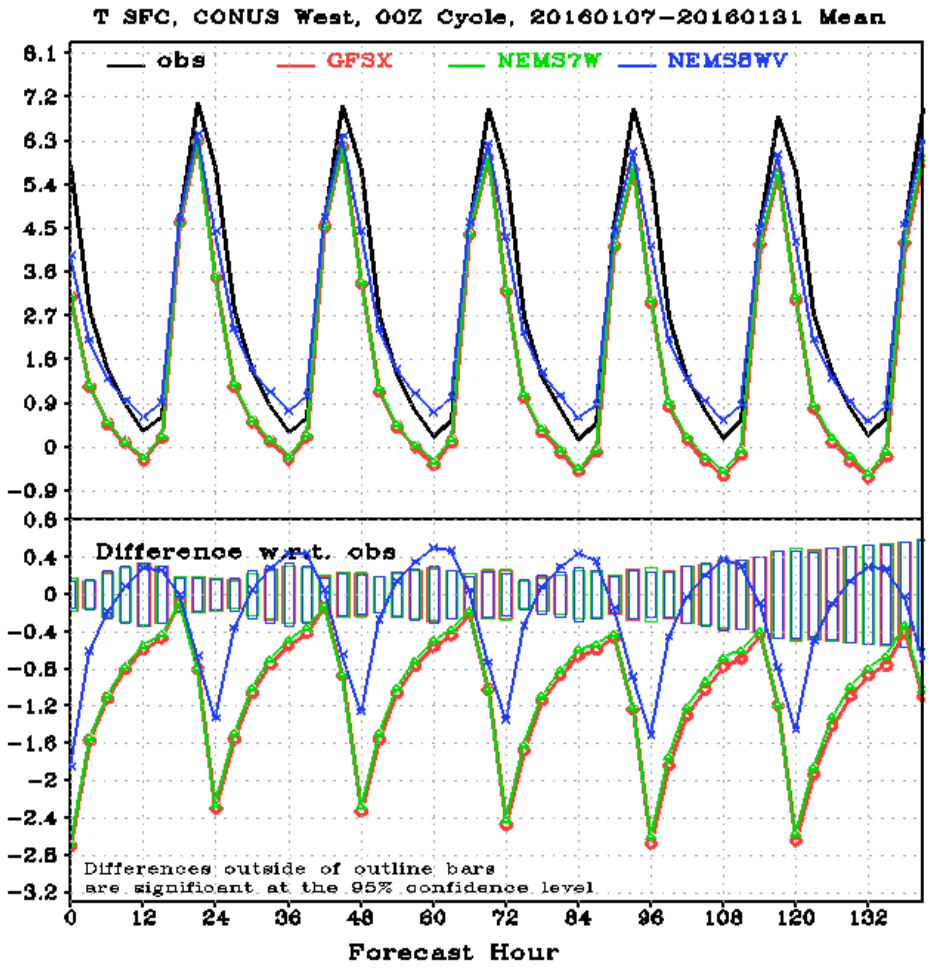


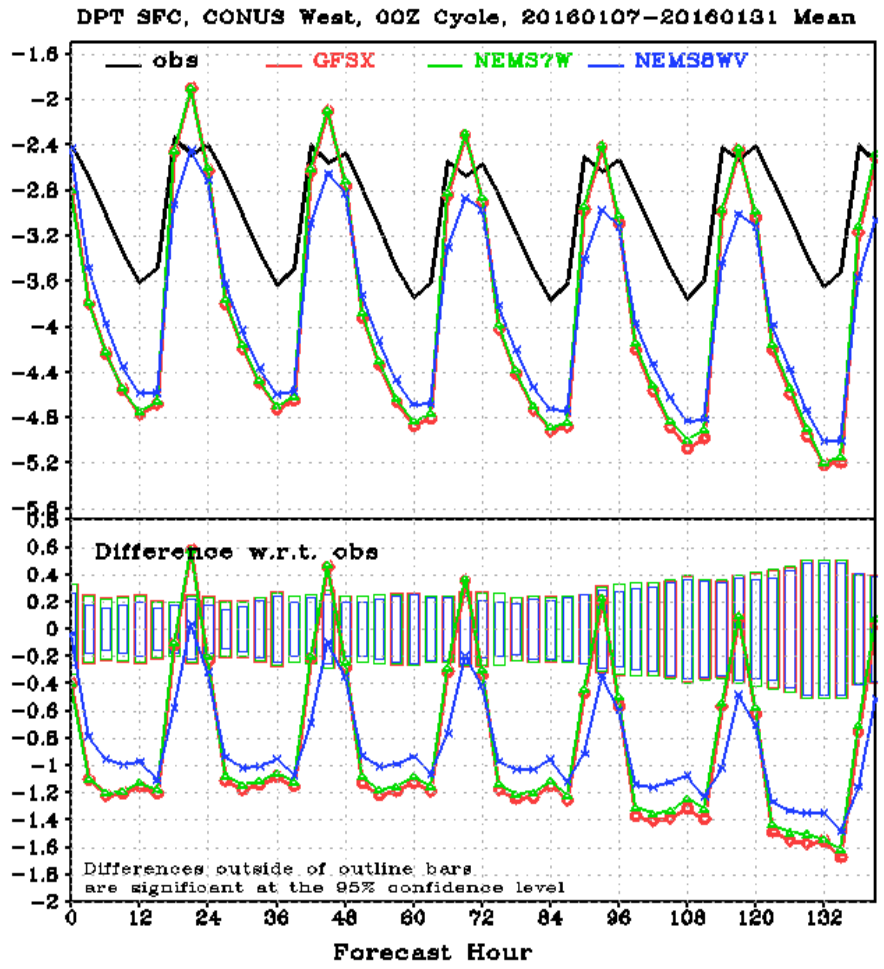


reduced daytime cold bias, nighttime warm bias likely
due to more ground heat flux from new soil texture

Model Physics Improvement: Cold Biases

2m-T and Td over West CONUS, January of 2016





reduced cold bias

Proposed Changes for the Next NEMS Implementation

- IGBP 20-type land classifications and STASGO 19-type soil classifications
- 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's diurnal albedo treatment
- Unify two aspects between radiation driver and Noah LSM
  - Snow cover
  - Snow albedo
- Fix excessive cooling of T2m
- Increase ground heat flux under the deep snow

Land Prediction at NCEP: Summary/Future

- **Improve & unify Noah land model and GLDAS/NLDAS at NCEP**:
  - Forcing, e.g. precipitation, & land data sets, e.g. near-realtime GVF.
  - Run GLDAS, NLDAS under NASA Land Information System (LIS): parallel run environment, latest land model versions, land data sets, data assimilation/validation tools for e.g. snow, soil moisture.
  - Land model physics improvements, including next-generation "Noah-MP" with dynamic vegetation, etc; account for agriculture, irrigation, etc; lakes; hydrology/groundwater/river-routing.
  - Higher resolution and downscaled forcing and model output.
  - Enhance land model spin-up procedures.
  - Extend domain/resolution of NLDAS to North America, to then "merge" with GLDAS for global models (GFS, CFS), providing **unified initial land conditions** for all NCEP regional, global and climate models.
  - Comprehensive hierarchy of model development and evaluation.
- *Land models role expanding for weather & climate in increasingly more fully-coupled Earth-System Models (atmosphere-ocean-land-ice-waves-aerosols) with **connections** between **Weather & Climate** and **Hydrology**, **Ecosystems & Biogeochemical** cycles (e.g. **carbon**), and **Air Quality**, models and communities, i.e. under community model development, e.g. NOAA Environ. Modeling System (NEMS).*