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

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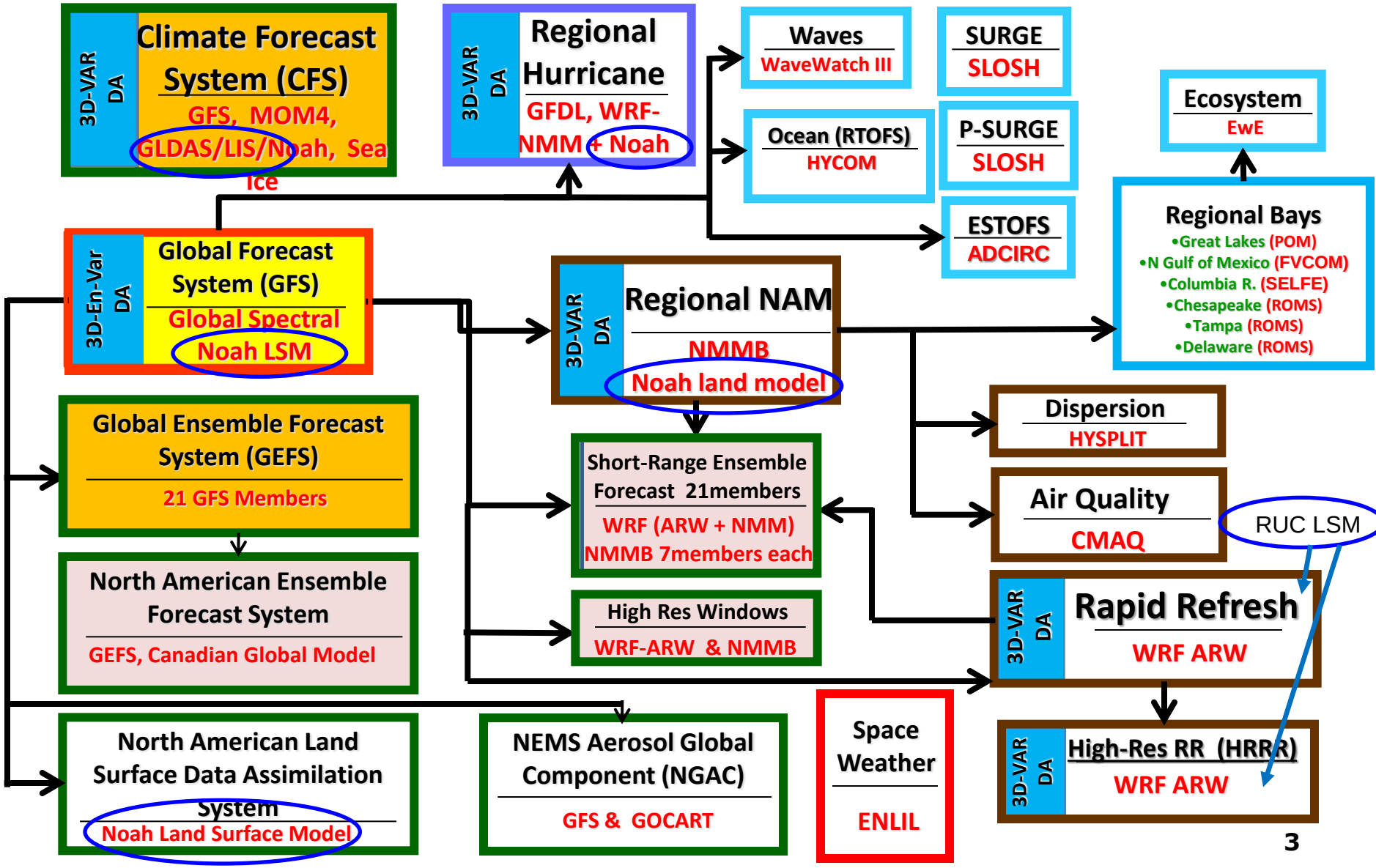
…and a large number of collaborators!

Outline

- **Role of Land-Surface Models, Requirements**
- **Remotely-Sensed Products and Land Data Assimilation Status and Upgrades (support from NGGPS)**
- **Land Data Assimilation Systems at NCEP:**
  - **Global Land Data Assimilation System (GLDAS)**
  - **North American LDAS (NLDAS)**
- **Model Improvement, Testing & Validation**
- **Summary/Future**

Land Prediction in Weather & Climate Models: NOAA's Operational Numerical Guidance Suite



Role of Land-Surface Models & Requirements

- Land Surface Models (LSMs) provide surface flux boundary conditions for heat, moisture and momentum to the atmosphere for **NCEP weather** and **seasonal climate models**.
- **Land models close surface energy and water budgets.**
- **Land Model Requirements:**

✓ **Physics**: appropriate to represent land-surface processes (for relevant time/spatial scales) and assoc. LSM model parameters.

✓ **Atmospheric forcing** to drive LSM.

✓ **Land data sets**, e.g. land use/land cover (vegetation type), soil type, surface albedo, snow cover, surface roughness, etc.

✓ **Initial land states**: Compared to atmosphere, land states carry more memory (especially deep soil moisture), similar to the role of SSTs and ocean temeratures.

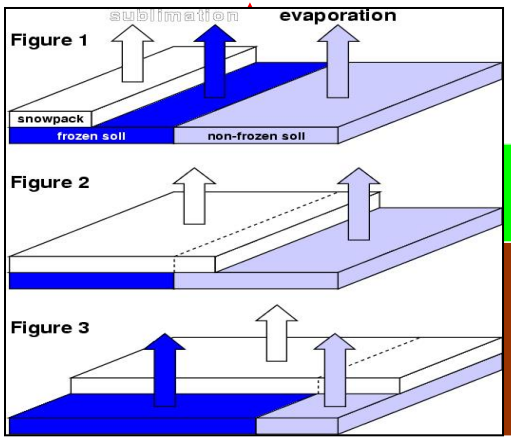
✓ **Land Data Assimilation**: some of these quantities may be assimilated, e.g. snow depth and cover, soil moisture.

✓ **Land Data Assimilation Systems (LDAS)**: provide initial land states for NCEP modeling systems.

Land Model Physics: Flux Boundary Conditions

$$H = \rho c_p C_h U (T_{sfc} - T_{air})$$

$$LE = LE_c + LE_t + LE_d$$



Sensible heat flux

from soil surface/canopy

Latent heat flux (Evapotranspiration)

Canopy Water Evaporation

Transpiration

Emitted longwave

canopy water

Direct Soil Evaporation

canopy

Snowpack & frozen soil physics

Soil heat flux to canopy/soil surface

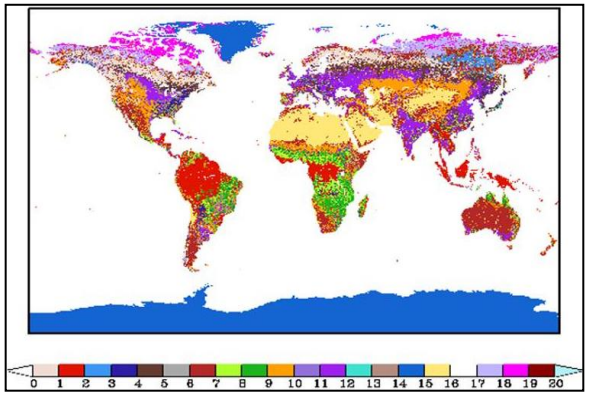
soil

- **Surface fluxes balanced by net radiation (Rn), = sum of incoming and outgoing solar and terrestrial radiation, with vegetation important for energy partition between H, LE, G, i.e. surface roughness & near-surface turbulence (H), plant & soil processes (LE), and heat transport thru soil/canopy (G), *affecting evolving boundary-layer, clouds/convection, and precipitation.***

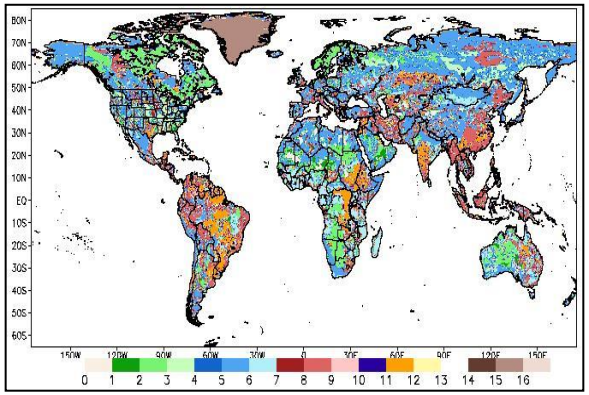
$$G = \left(\frac{K_T}{\Delta z}\right)(T_{sfc} - T_{soil})$$

$$R_n = H + LE + G$$

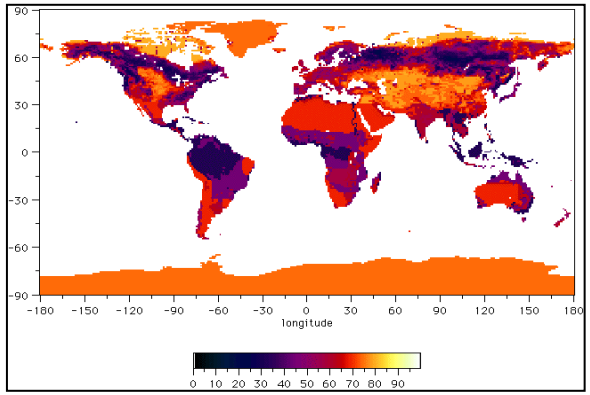
Land Data Sets Used in NCEP Modeling Systems



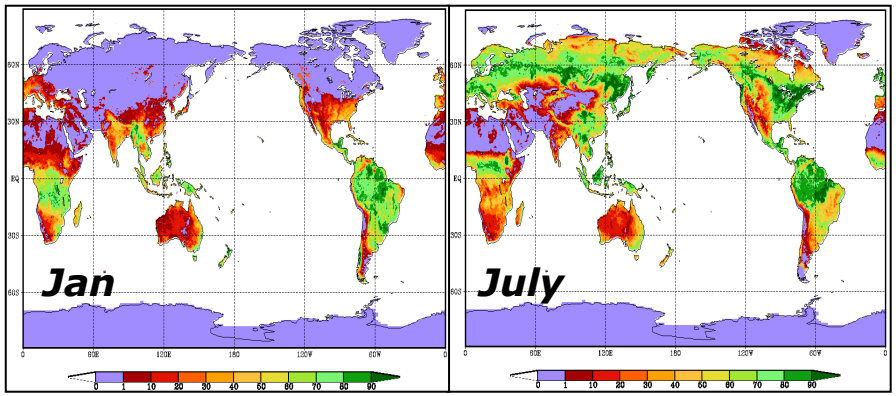
Vegetation Type
(1-km, IGBP-MODIS)



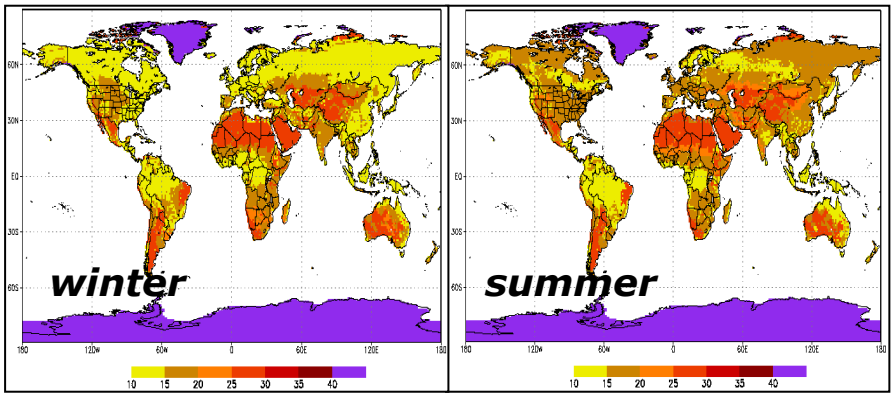
Soil Type
(1-km, STATSGO-FAO)



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



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

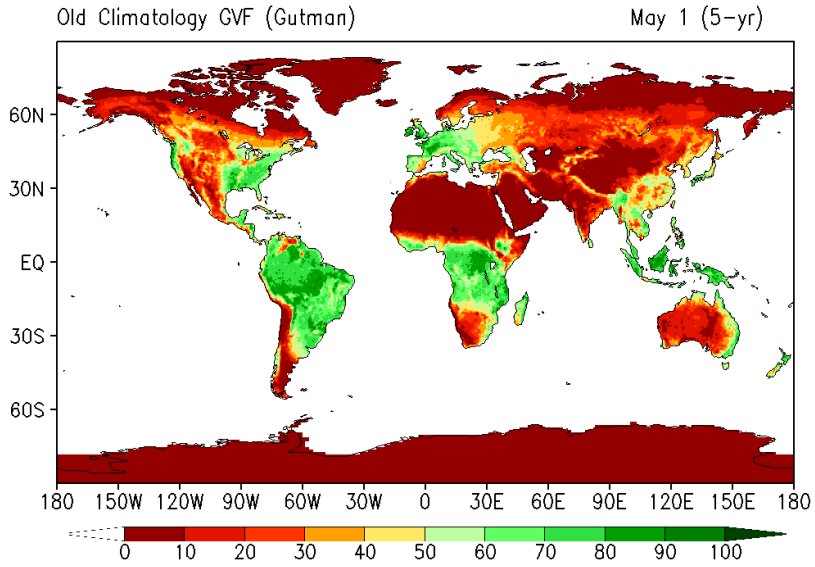


Snow-Free Albedo
(seasonal, 1-deg, Matthews)

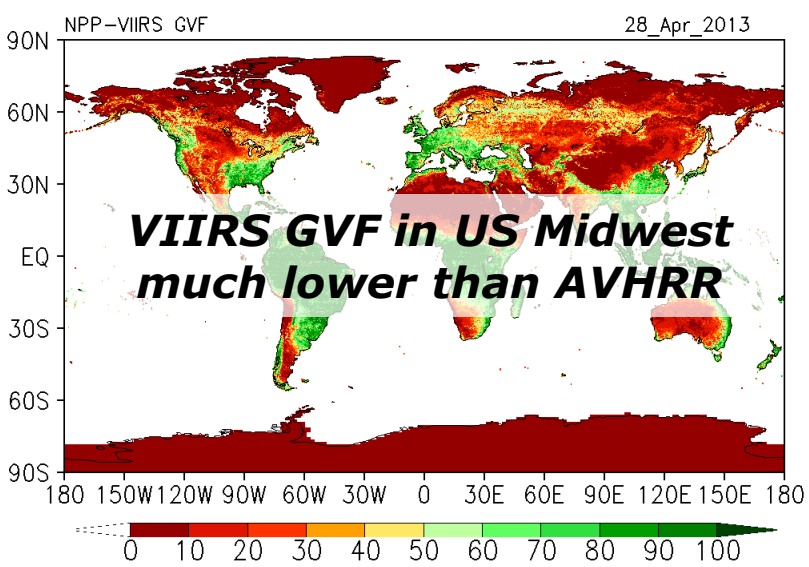
- Climatologies: fixed/annual, monthly, weekly.
- Near real-time observations, e.g. GVF "becoming" a land state.

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

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



AVHRR 5-year "Climatology"



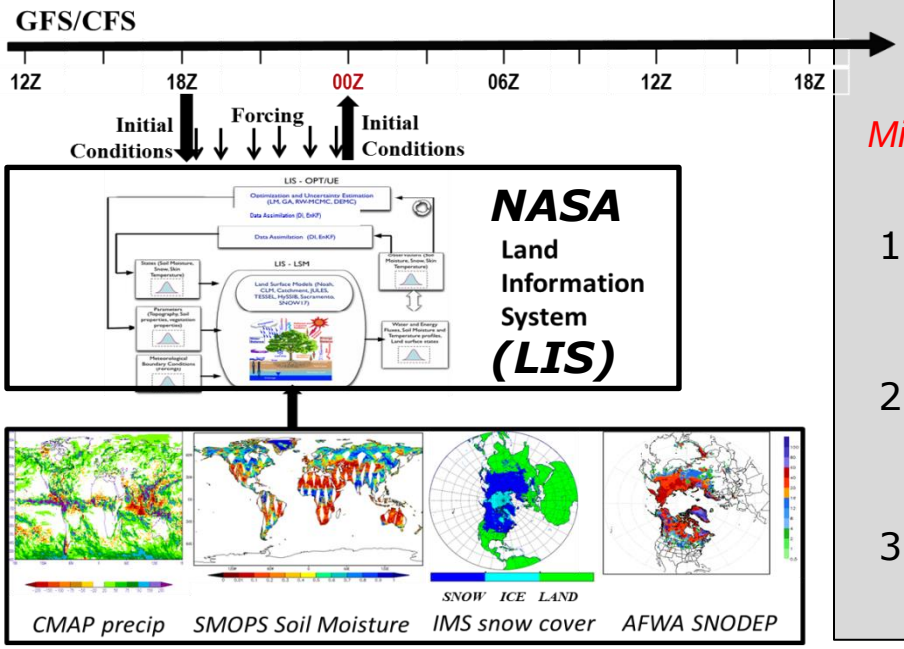
VIIRS

- **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.



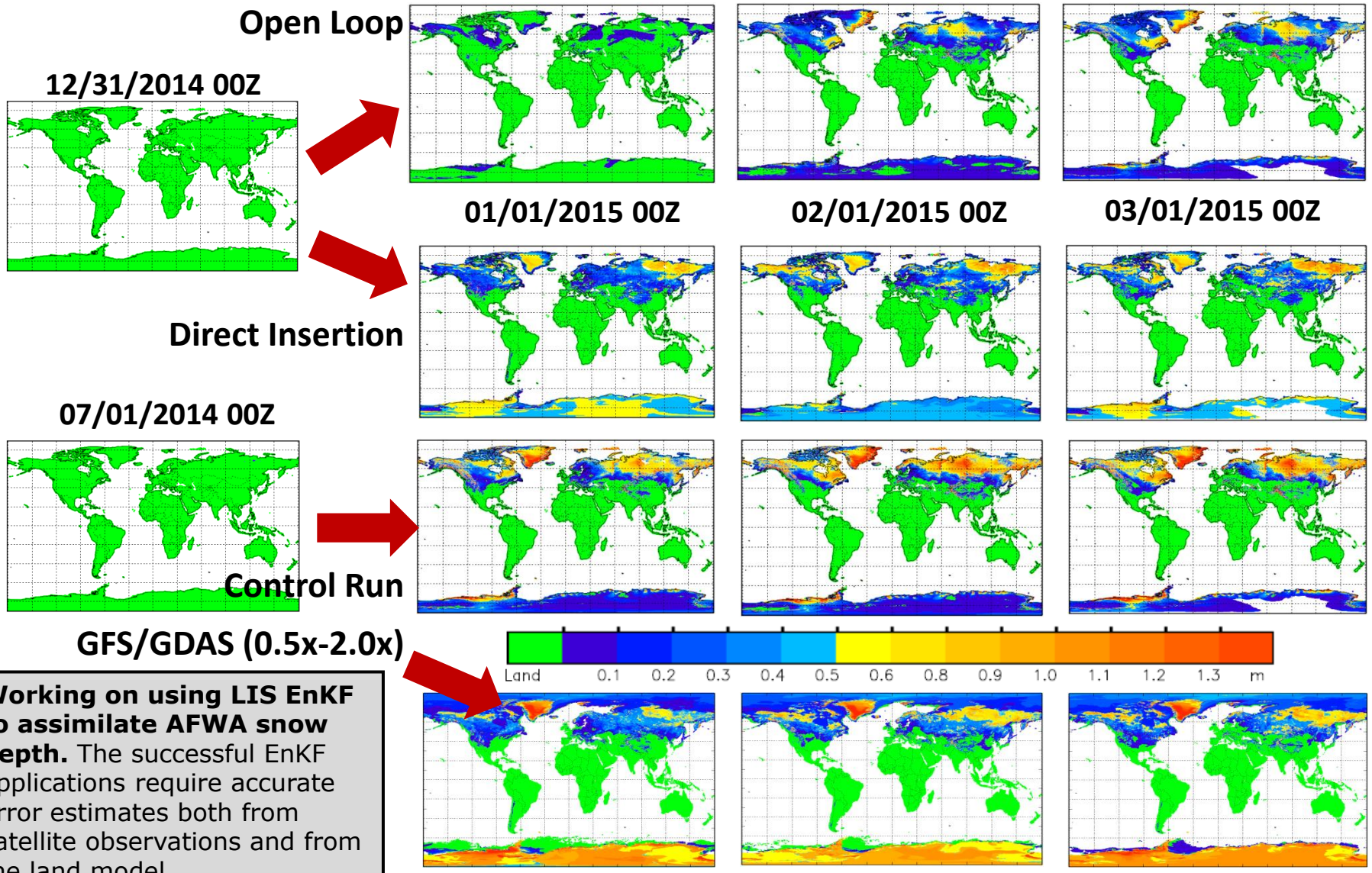
NGGPS Project: Land Data Assimilation

Michael Ek, Jiarui Dong, Weizhong Zheng (NCEP/EMC)
Christa Peters-Lidard, Grey Nearing (NASA/GSFC)

1. Build NCEP's GFS/CFS-LDAS by incorporating the NASA Land Information System (LIS) into NCEP's GFS/CFS (left figure)
2. Offline tests of the existing EnKF-based land data assimilation capabilities in LIS driven by the operational GFS/CFS.
3. Coupled land data assimilation tests and evaluation against the operational system.

Jiarui Dong, NCEP/EMC

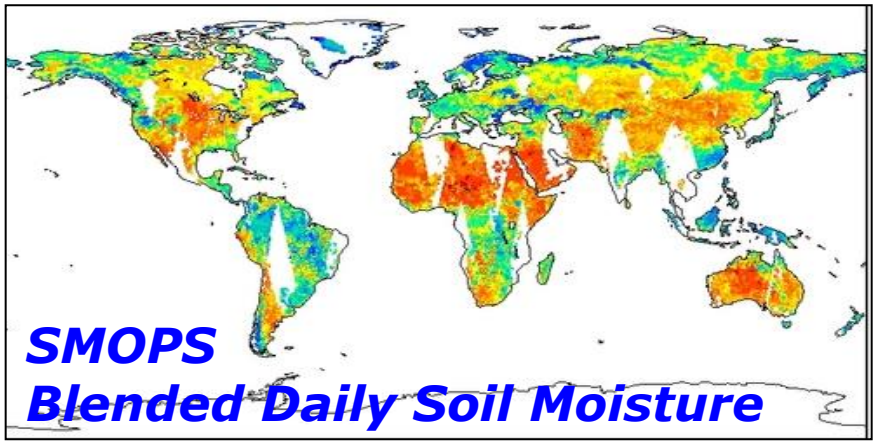
NGGPS: Demonstration of land data assimilation of AFWA Snow Depth (initially under LIS)

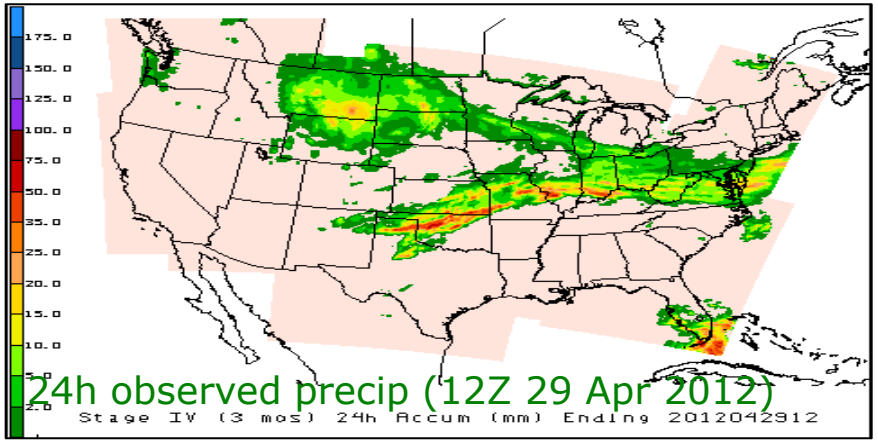


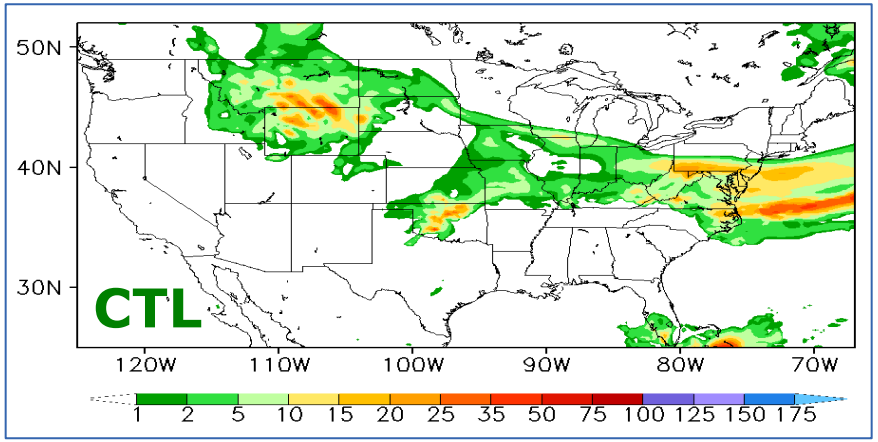
Working on using LIS EnKF to assimilate AFWA snow depth. The successful EnKF applications require accurate error estimates both from satellite observations and from the land model.

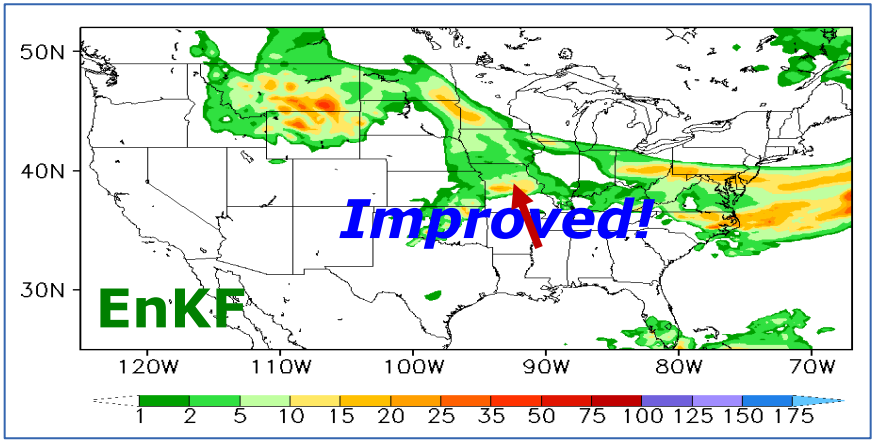
Jiarui Dong, NCEP/EMC

Demonstration of land data assimilation of SMOPS Soil Moisture









Forecast hour 60-84, precipitation forecast 24h accum (mm) ending at 12Z 29 Apr 2012

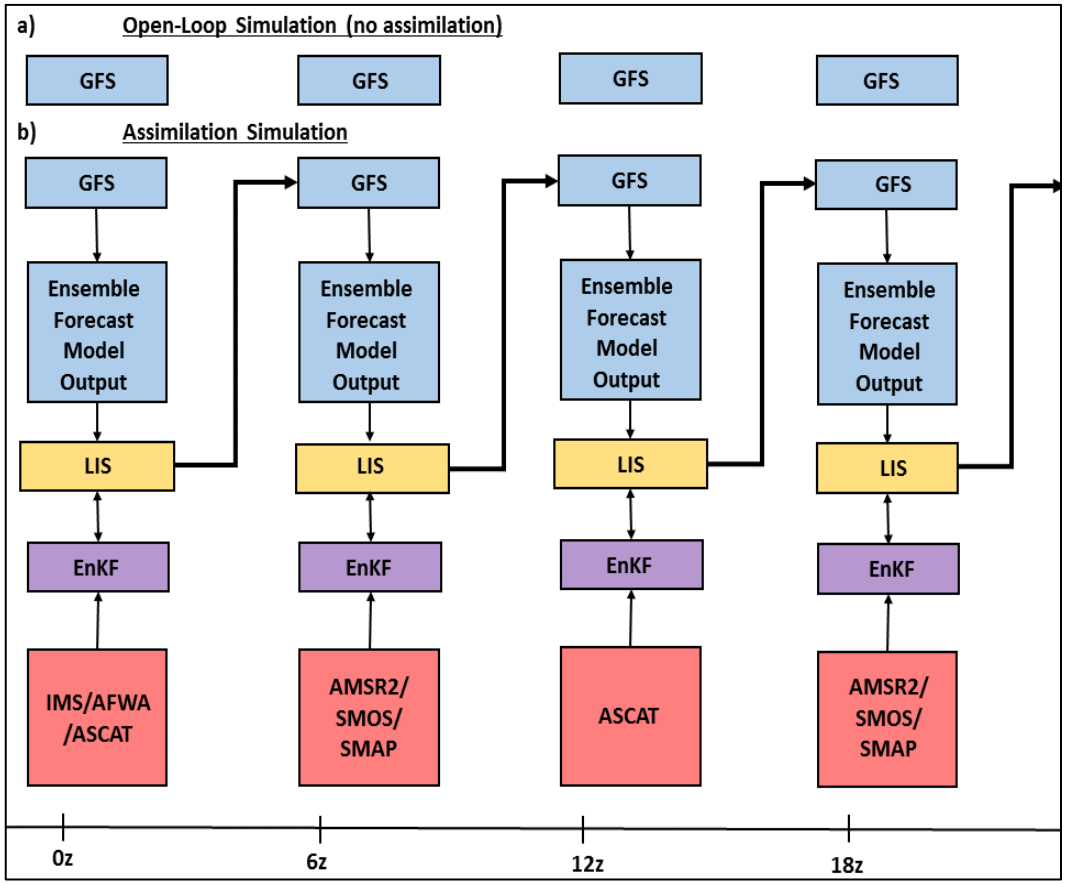
- Noah land model multiple-year grid-wise means & std devs used to scale surface layer soil moisture retrievals before assimilation.
- Testing assimilation of SMOPS in GFS; positive impact on precipitation.

Weizhong Zheng, NCEP/EMC and Xiwu Zhan, NESDIS/STAR

NGGPS Project: Enhancing NCEP GFS Forecasts via Assimilating Satellite Soil Moisture and Snow Observations

Project Team: C. Hain (UMD), X. Zhan (STAR), M. Ek (EMC), J. Liu (UMD), W. Zheng (EMC/IMSG); J. Dong (EMC/IMSG), L. Fang (UMD); J. Meng (EMC/IMSG)

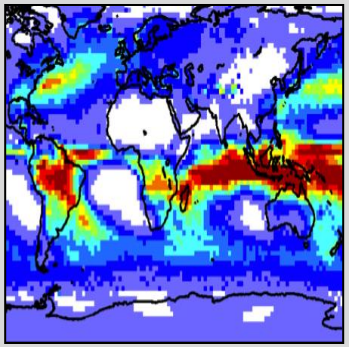
- Recent research has shown the unique value of satellite-based SM and snow retrievals and the feasibility of assimilating these retrieval products into the land surface models (LSMs) to improve the land-atmosphere water and energy exchange simulations.
- The assimilation approach will run a series of assimilation experiments with the semi-coupled LIS/GFS system over an three-month warm-season period: (1) an open-loop simulation [no DA] and (2) simulations that assimilates all available MW observations and IMS/AFWA snow cover/depth products.
- Each simulation will use a MODIS/VIIRS near-real-time GVF product, replacing the climatological fields currently used in the GFS.



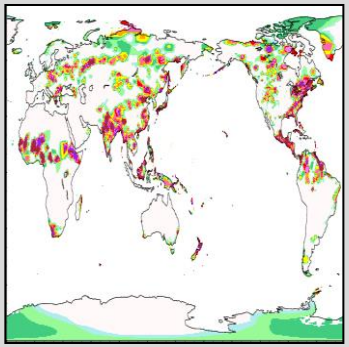
Current Global Land Data Assimilation System (GLDAS) at NCEP Operational in CFSv2 at NCEP 01 April 2011

- **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 NOAA Climate Program Office.

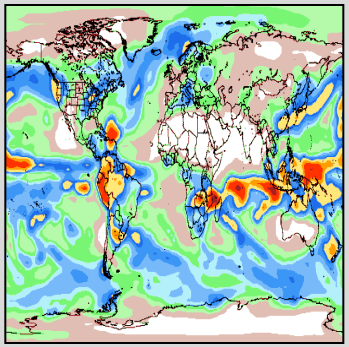
Precipitation



CMAP

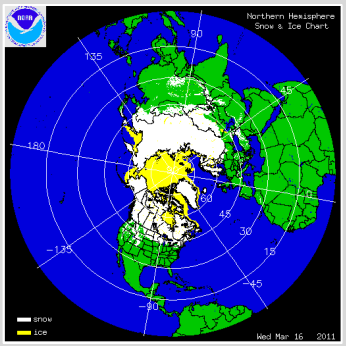


Surface gauge

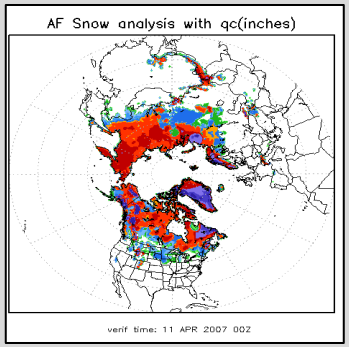


GDAS

Snow



IMS cover

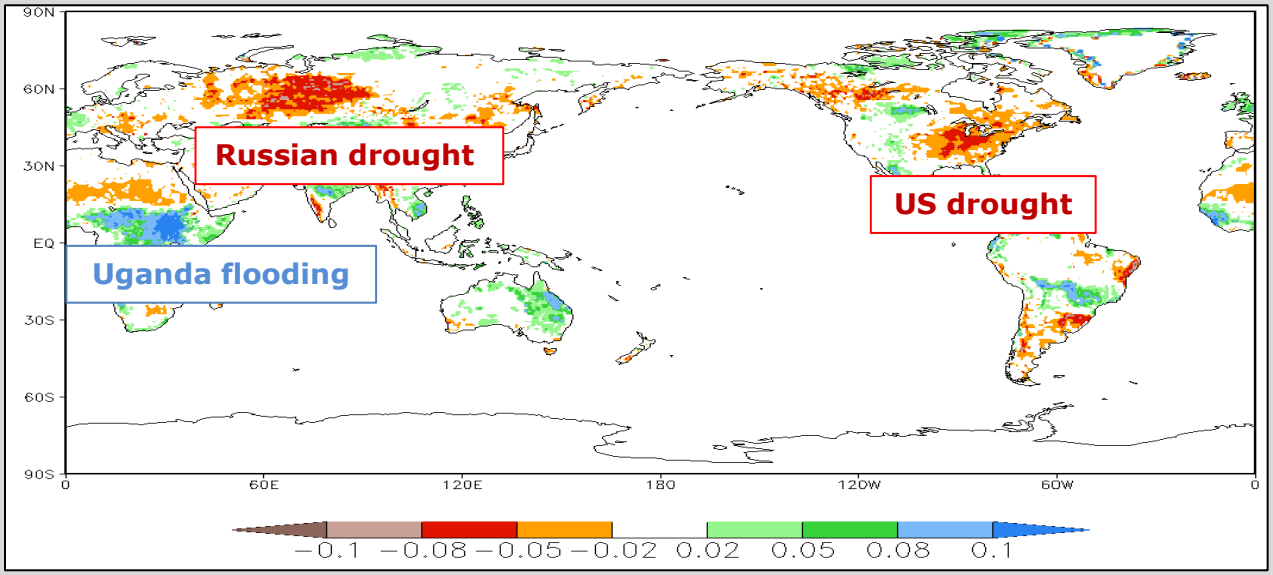


AFWA depth

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**, and energy & water budgets

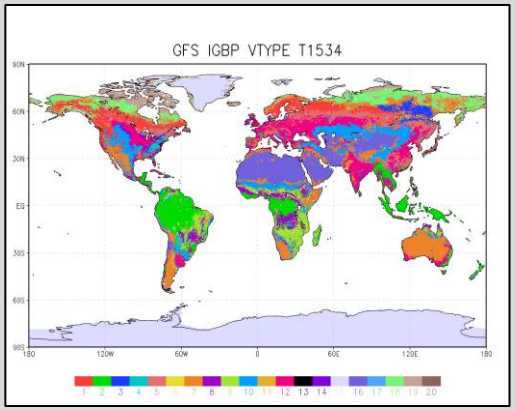


July 2012 Soil Moisture Anomaly *from NCEP GLDASv2*

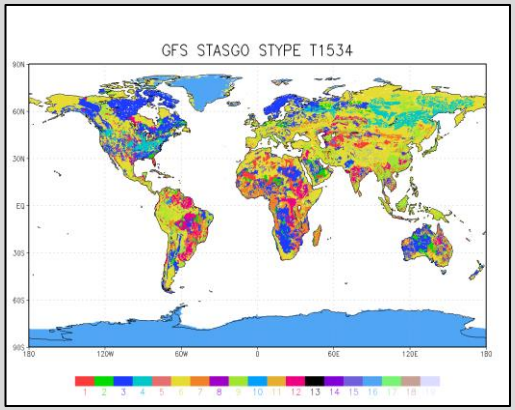
Jesse Meng, NCEP/EMC

LDAS Upgrade: Implementation of GLDAS in GFS

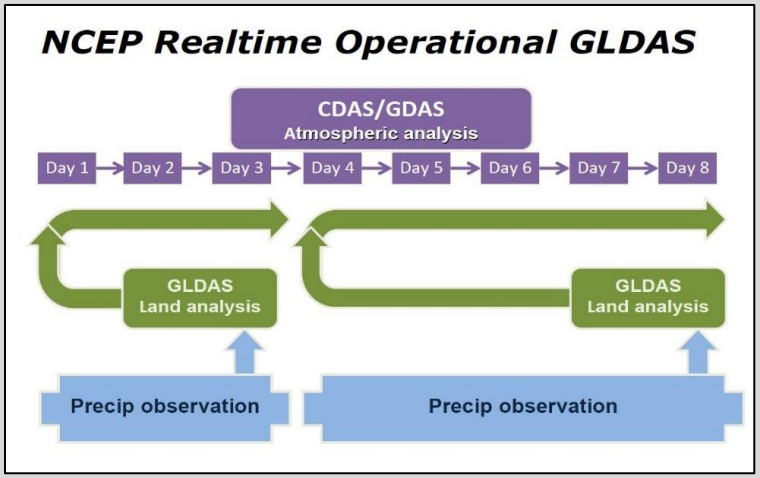
- CDASv2/GLDAS paradigm: adapt for Global Forecast System:
  - Noah land model physics upgrades; accommodate higher-res. GFS.
  - Land surface forcing/downscaling, e.g. precipitation.
  - Land data sets, e.g. land-use, soils, green vegetation fraction (GVF).
  - Land data assimilation, e.g. snow, soil 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; NOAA CPO MAPP Task forces on reanalyses, model development, drought.



Vegetation Type Data



Soil Type Data



Jesse Meng and Helin Wei, NCEP/EMC

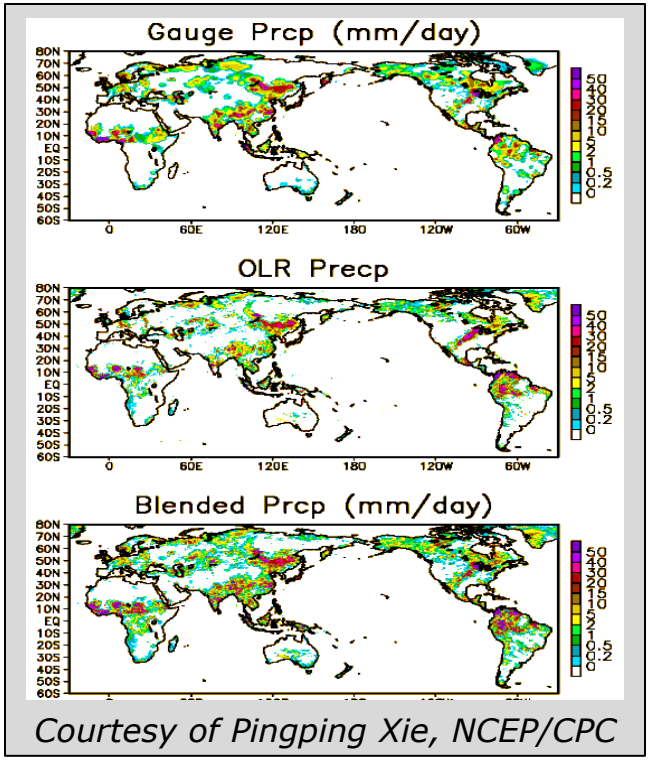
LDAS Upgrade: GLDASv2.2 with New Precipitation Forcing

Precipitation Data:

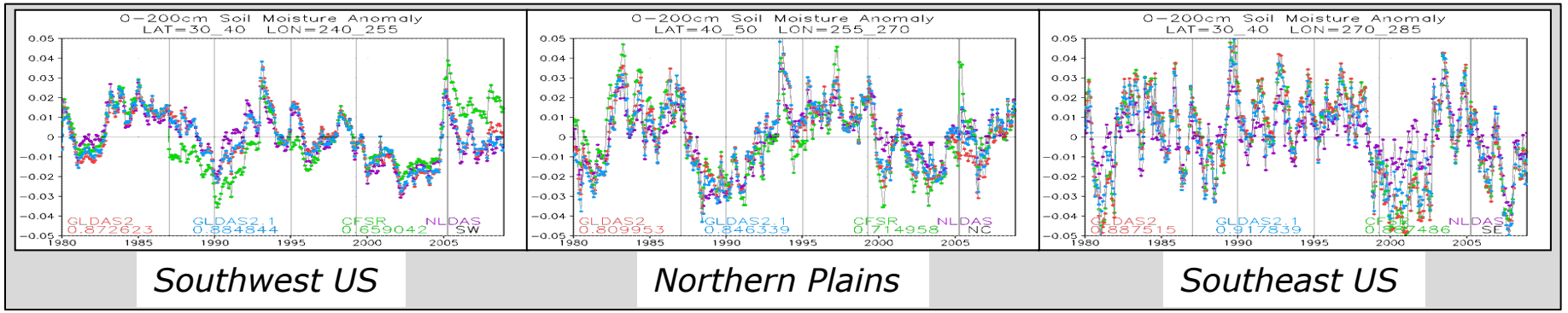
- Gauge-satellite blended analysis of daily global precipitation.
- 0.25° lat/lon over the global land.
- Global daily anaiy., 0.25-deg, 1979-present.
- Blending information from different sources:
  - CPC daily gauge analysis.
  - GPCC monthly gauge data.
  - OLR-based precipitation estimates.
  - CMORPH-based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

Preliminary Results:

- Improved soil moisture spin-up & anomalies.



Courtesy of Pingping Xie, NCEP/CPC



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

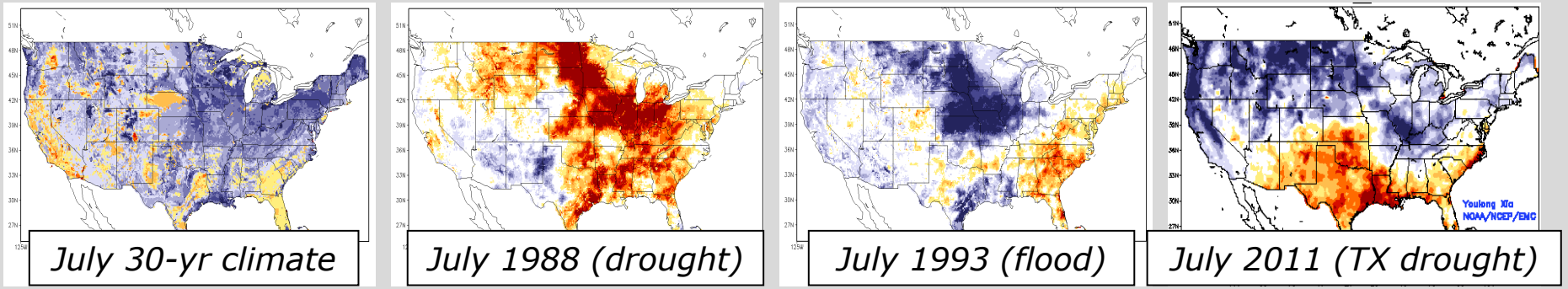
Jesse Meng, NCEP/EMC

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.

(ldas.gsfc.nasa.gov/nldas/NLDAS2valid.php)

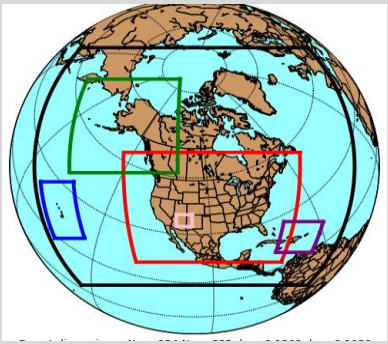
www.emc.ncep.noaa.gov/mmb/nldas



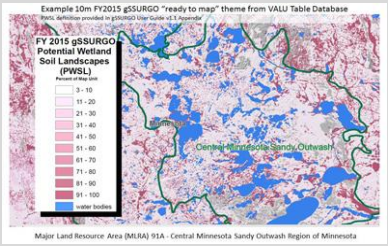
NLDAS four-model ensemble monthly soil moisture anomaly *Youlong Xia, NCEP/EMC*

LDAS Upgrade: NLDAS Future

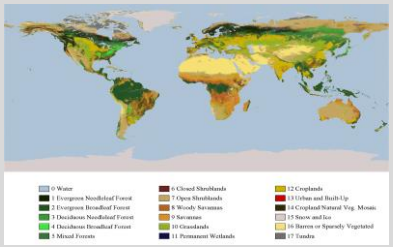
- **Bring NLDAS up to real-time**: close 3.5-day lag in current operational NLDAS, using NARR, NDAS, & NAM analysis & forecast data, replace NDAS/NAM downward shortwave radiation with GOES retrievals to overcome shortcomings, and for precipitation: 0.125-deg CPC operational global gauge-based daily global analysis & NAM 48-hour forecast precipitation.
- Forcing at **~3-4km resolution**; downscaling issues.
- **LSM physics upgrades** for Noah, SAC, Catchment (move from Mosaic), VIC; add additional LSMs.
- **New high-res land-use (veg.) & soils data sets**.
- **LIS-based land data assimil.** snow/soil moisture.
- **Extend domain to North America** to provide initial land states to NAM & support N. A. Drought Monitor.
- Continue to work with our key NLDAS partners, including NASA & National Water Center, academic community on forcing data set generation (e.g. Precip) & Noah LSM/hydrology model development.
- NOAA Climate Program Office Drought Task Force.



N.A. domain



USDA Soil Survey Geographic database

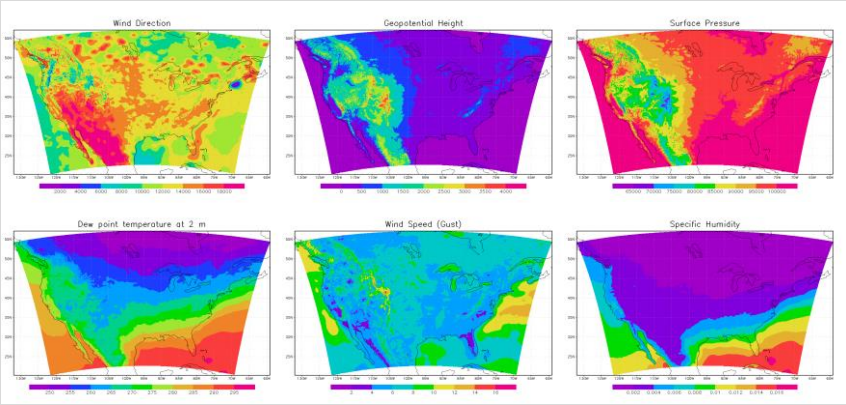


MODIS land-use

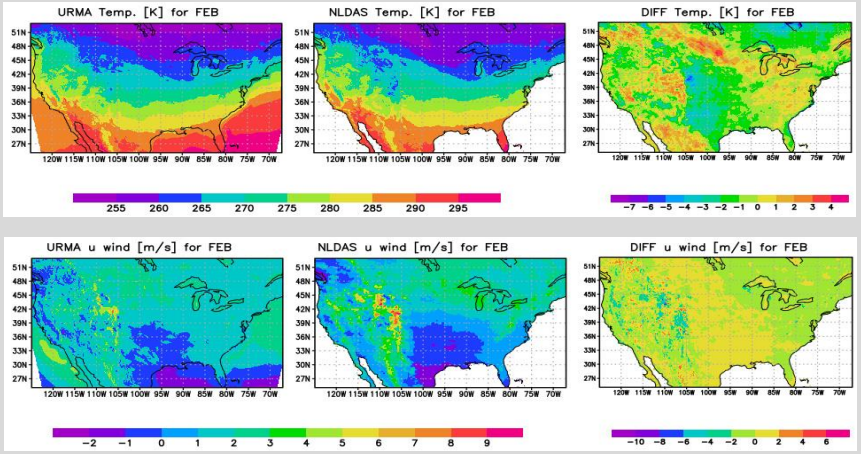
Youlong Xia, NCEP/EMC

LDAS Upgrade: Finer-Resolution Forcing Input for NLDAS

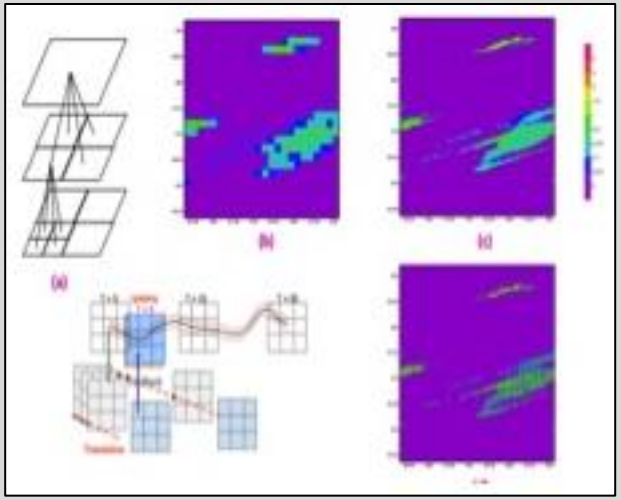
Re-run of URMA retrospective analysis producing 2.5-km 30 years historical mesoscale reanalysis for CONUS and Alaska.



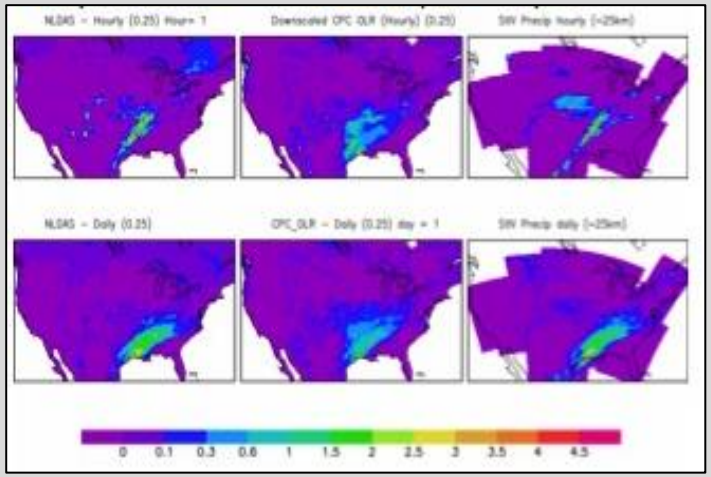
Comparison of UnRestricted Mesoscale Analysis (URMA) and NLDAS forcing



Downscaling and merging of precipitation (CPC OLR-based latest product)



Snapshots of precipitation events in 2013. Stage IV and NLDAS precipitation are compared against OLR precipitation.

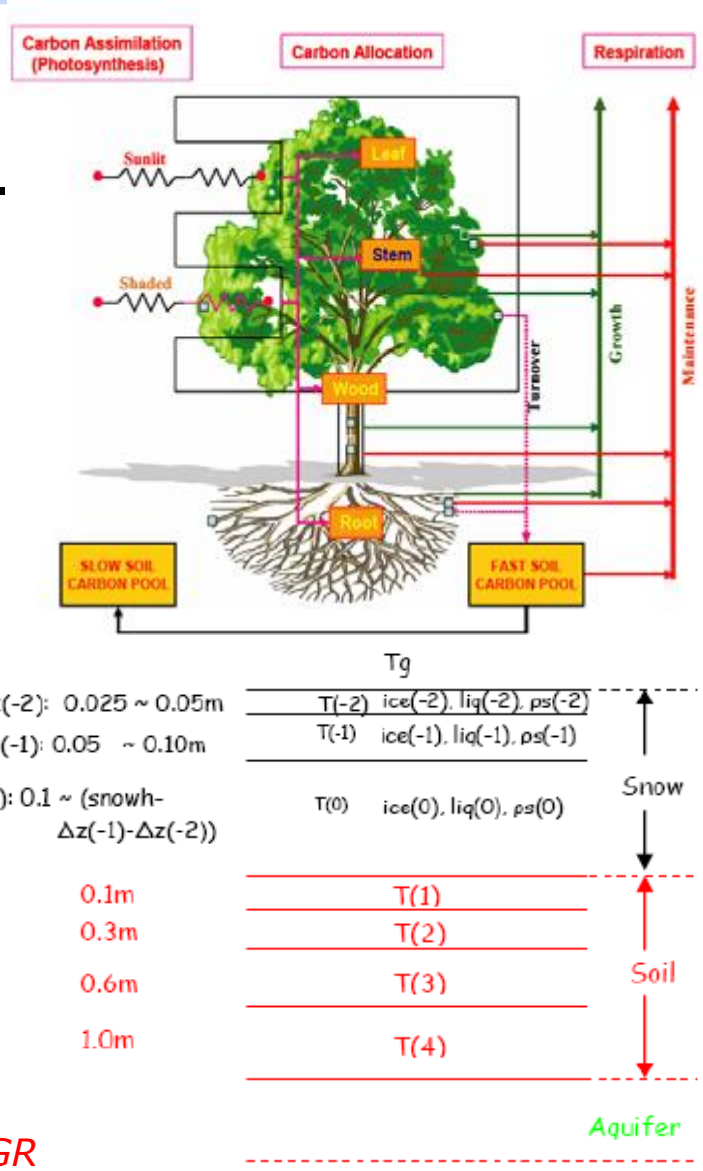


Roshan Shretha, NCEP/EMC

Model Physics Improvement: Noah-MP

Noah-MP is an extended version of the Noah LSM with enhanced multi-physics options to address shortcomings in Noah.

- Canopy radiative transfer with shading geometry.
- Separate vegetation canopy.
- Dynamic vegetation.
- Ball-Berry canopy resistance.
- Multi-layer snowpack.
- Snow albedo treatment.
- New snow cover algorithm.
- Snowpack liquid water retention.
- New frozen soil scheme.
- Interaction with groundwater/aquifer.



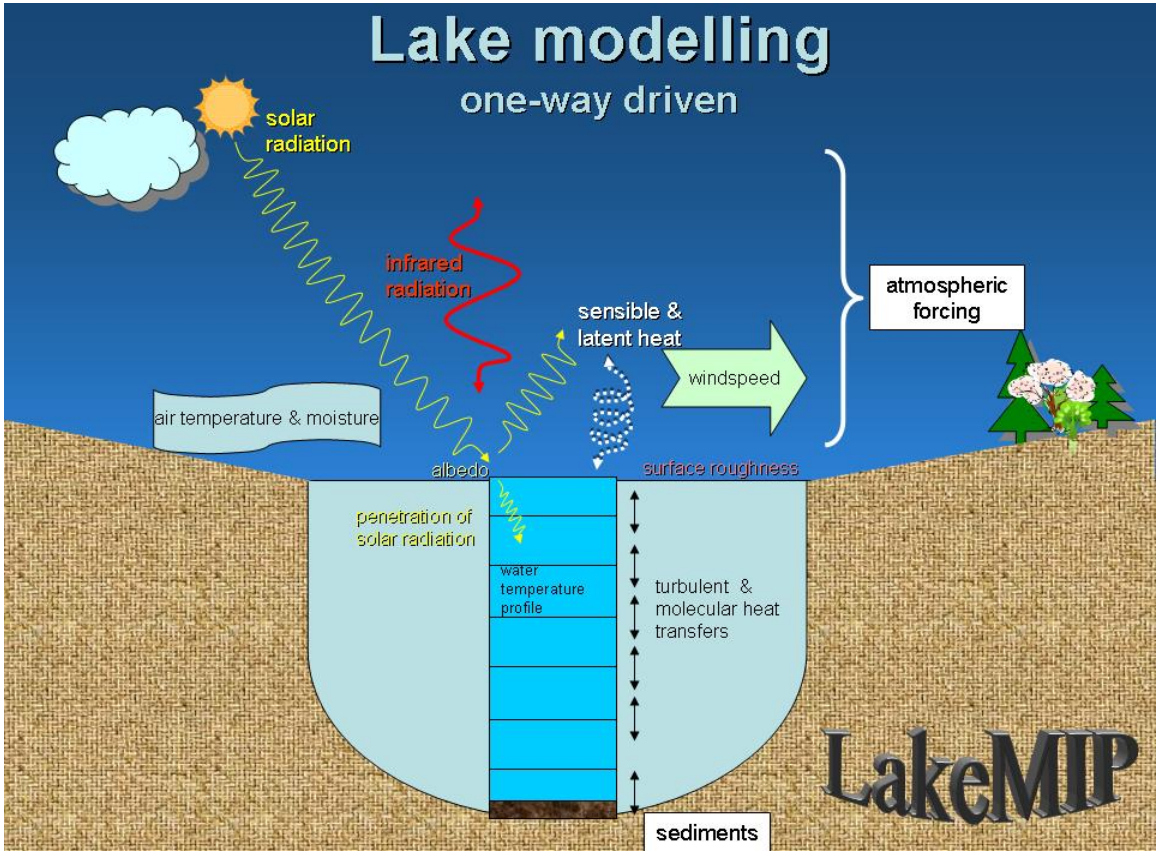
Main contributors: Zong-Liang Yang (UT-Austin); Guo-Yue-Niu (U. Arizona); Fei Chen, Mukul Tewari, Mike Barlage, Kevin Manning (NCAR); Mike Ek (NCEP); Dev Niyogi (Purdue U.); Xubin Zeng (U. Arizona)

Noah-MP references: Niu et al., 2011, Yang et al., 2011. *JGR*

Model Improvement: Freshwater Lakes

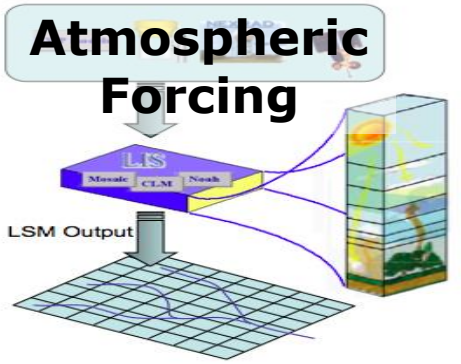
- ***Thousands*** of lakes on scale of 1-4km not resolved by SST analysis -> greatly influence surface fluxes; explicit vs subgrid.
- Freshwater lake "***FLake***" model *(Dmitrii Mironov, DWD).*

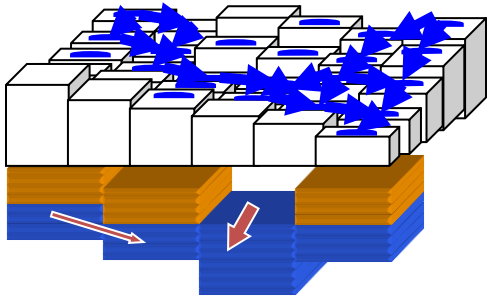
- Two-layer.
- Atmospheric forcing inputs.
- Temperature & energy budget.
- Mixed-layer and thermocline.
- Snow-ice module
- Specified depth/turbidity.
- Used in COSMO, HIRLAM, NAM (regional), and global ECMWF, CMC, UKMO.

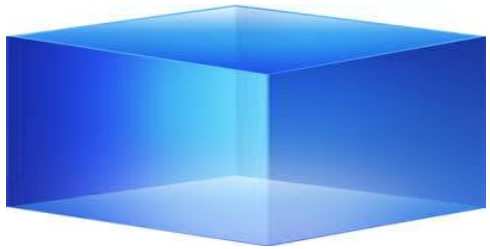


Yihua Wu, NCEP/EMC

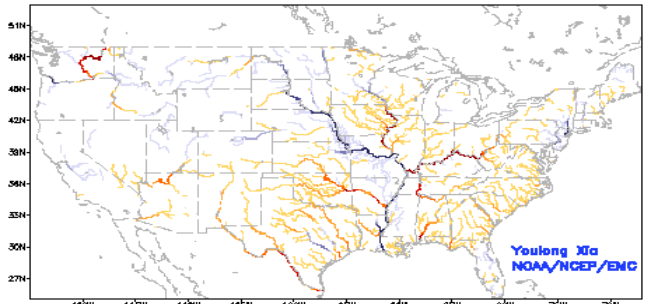
Model Improvement: Hydrology, River-Routing



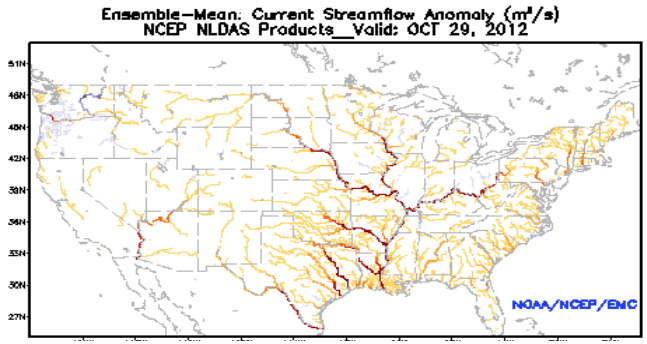




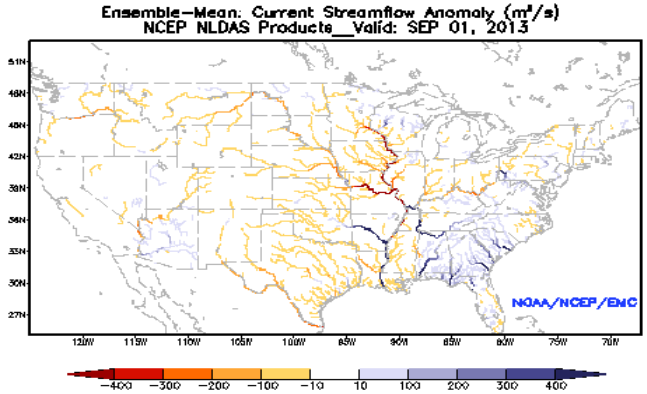
Ensemble mean daily streamflow anomaly (NLDAS)



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



Superstorm Sandy, 29 October – 04 November 2012

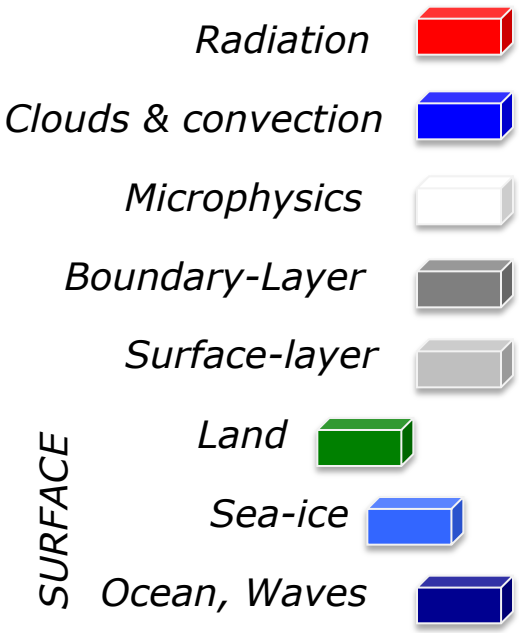


Colorado Front Range Flooding, September 2013

Close Coordination with National Water Center

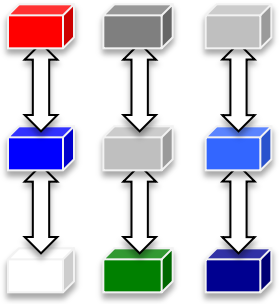
Testing & Validation: Simple-to-More Complex Hierarchy of Model Parameterization Development

Simulators

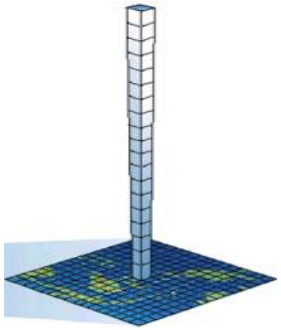


- Simulators: test submodel parameterizations at process level, e.g. radiation-only, land-only, etc.
- Testbed data sets to develop, drive & validate submodels: observations, models, idealized, *with "benchmarks" before adopting changes*.
- Submodel interactions, *with benchmarks*.
- Full columns, *with benchmarks*.
- Limited-area/3-D (convection) *with benchmarks*.
- Regional & global NWP & seasonal climate, *with benchmarks.*
- **More efficient** model development, community engagement, R2O/O2R & computer usage.

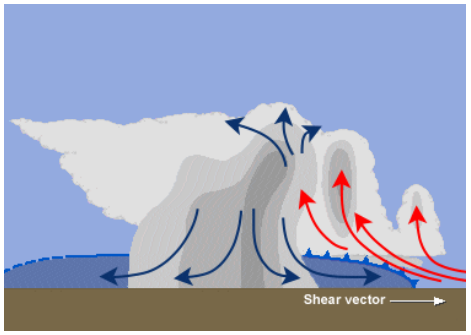
Interaction tests



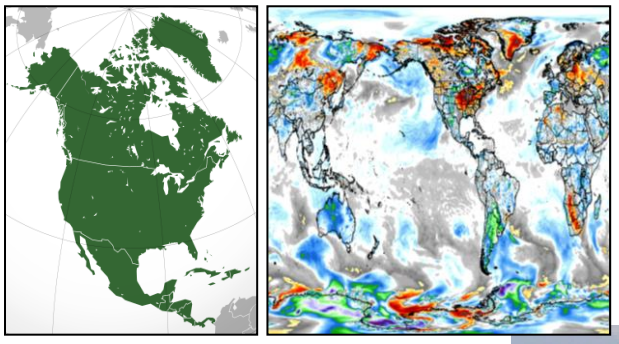
Column tests



Limited-area



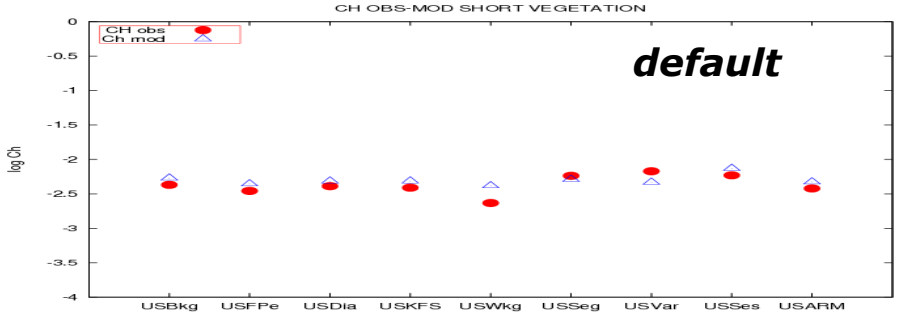
Regional & Global



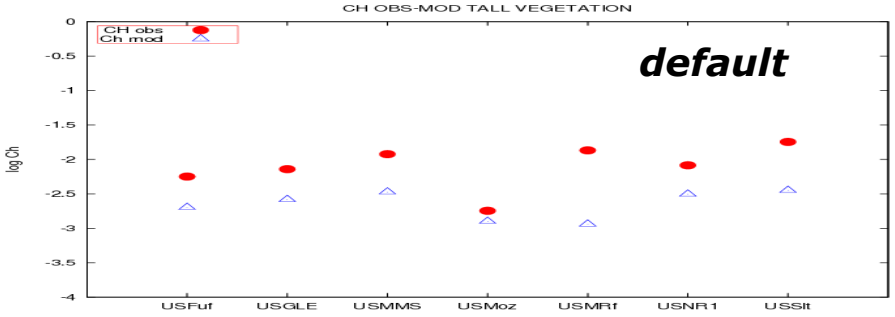
- ***Close Interaction with NOAA Testbeds***

Testing and Validation: Surface-layer Simulator

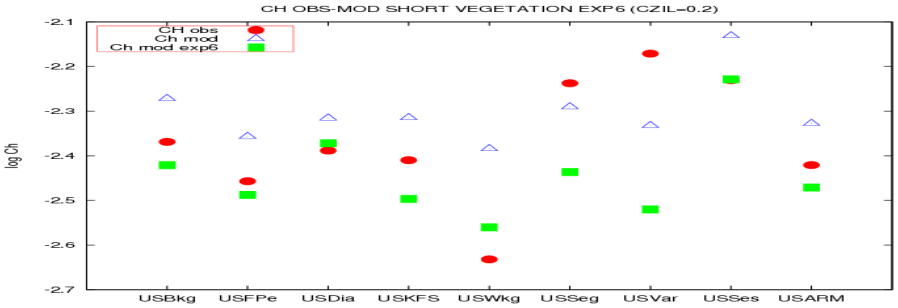
- GOAL: Improve surface turbulence exchange coefficients.
- Surface-layer simulation ("SLS") code simulates surface-layer and schemes from meso-NAM and medium-range GFS.
- Use observations to drive SLS (U,T,q and Tsfc) and compare with inferred Ch, Cd from independent "fluxnet" obs (H, LE, τ).
- Bias in surface exchange coefficient for heat dependent on vegetation height. Action: adjust thermal roughness parameter.



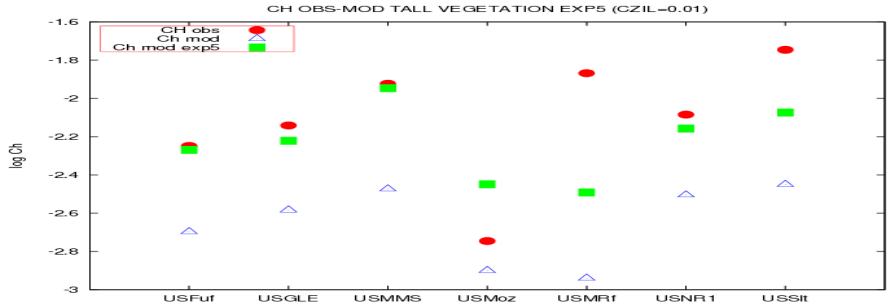
short vegetation, czil=0.1



tall vegetation, czil=0.1



short vegetation, czil=0.2



tall vegetation, czil=0.01

Testing and Validation: Land Model & Sfc-Layer

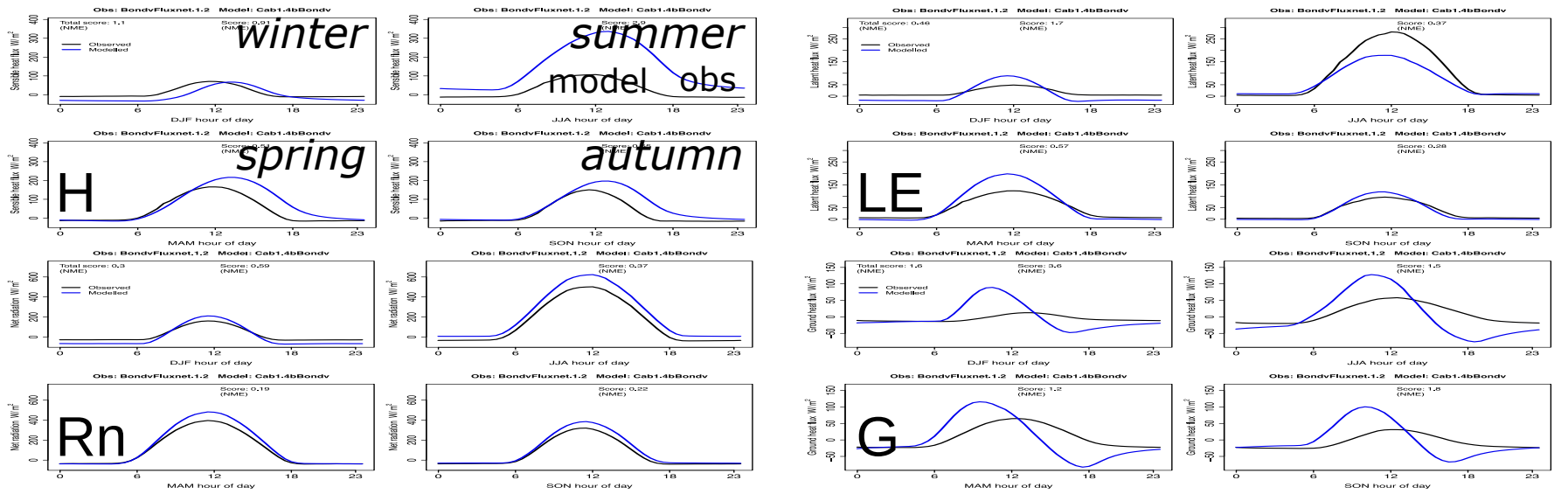
- **Validation** uses near-**surface** observations, e.g. routine weather observations of air temperature, dew point and relative humidity, 10-meter wind, along with upper-air validation, precipitation scores, etc.

- To more fully validate land models at the ***process level***, **surface fluxes** and soil states (soil moisture, etc) are also used.

- Monthly diurnal composites to **assess systematic model biases** (averaging out transient atmospheric conditions), and suggest land physics upgrades.

Testing & Validation: Land Model Benchmarking

- Benchmarking: Decide how good model needs to be, then run model and ask: *Does model reach the level required?*
- ***P**rotocol for the **A**nalysis of **L**and **S**urface models (**PALS**)*: www.pals.unsw.edu.au. ***GEWEX/GLASS project.***
- Compare models with empirical/statistical approaches, previous model versions, other land models. Different plots/tables of model validation and benchmarking metrics.
- Identify systematic biases for model development/validation.



PALS example: CABLE (BOM/Aust.) land model, Bondville, IL, USA (cropland), 1997-2006, avg diurnal cycles.

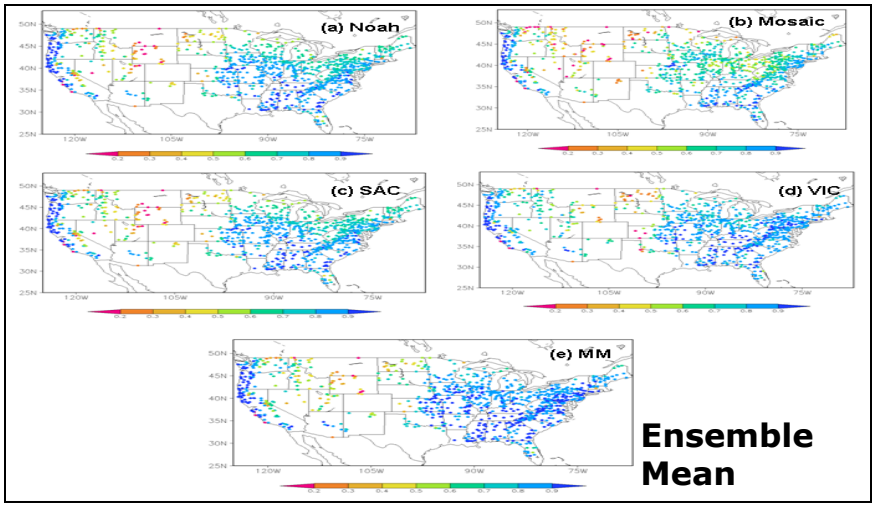
Testing & Validation: (uncoupled) NLDAS

Comprehensive evaluation against *in situ* observations and/or remotely sensed data sets.

Energy flux validation from tower: net radiation, sensible, latent & ground heat fluxes.

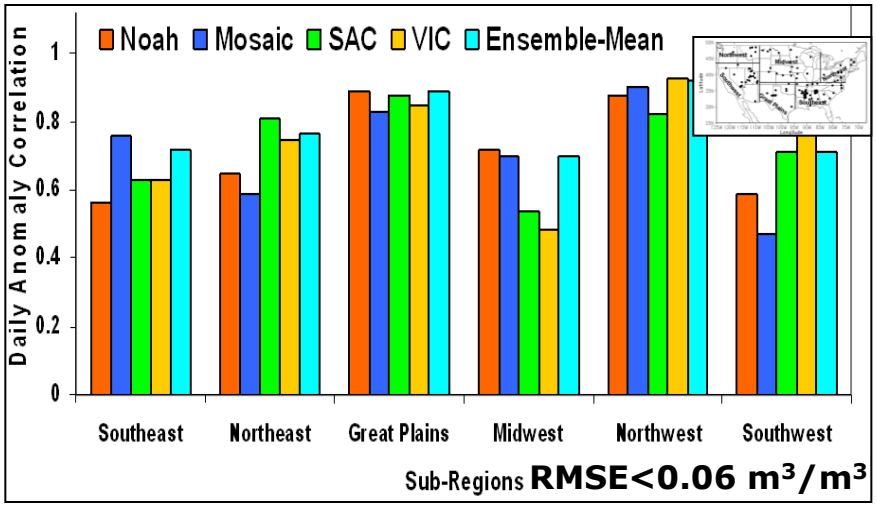
Water budget: evaporation, total runoff/streamflow.

State variables: soil moist., soil/skin temp., snow depth/cover.



Xia et al., JGR-atmosphere (2012)

Monthly streamflow anomaly correlation (1979-2007 USGS measured streamflow)



Xia et al., J. Hydrol. (2014)

Daily top 1m soil moisture anomaly corr. (2002-2009 US SCAN Network)

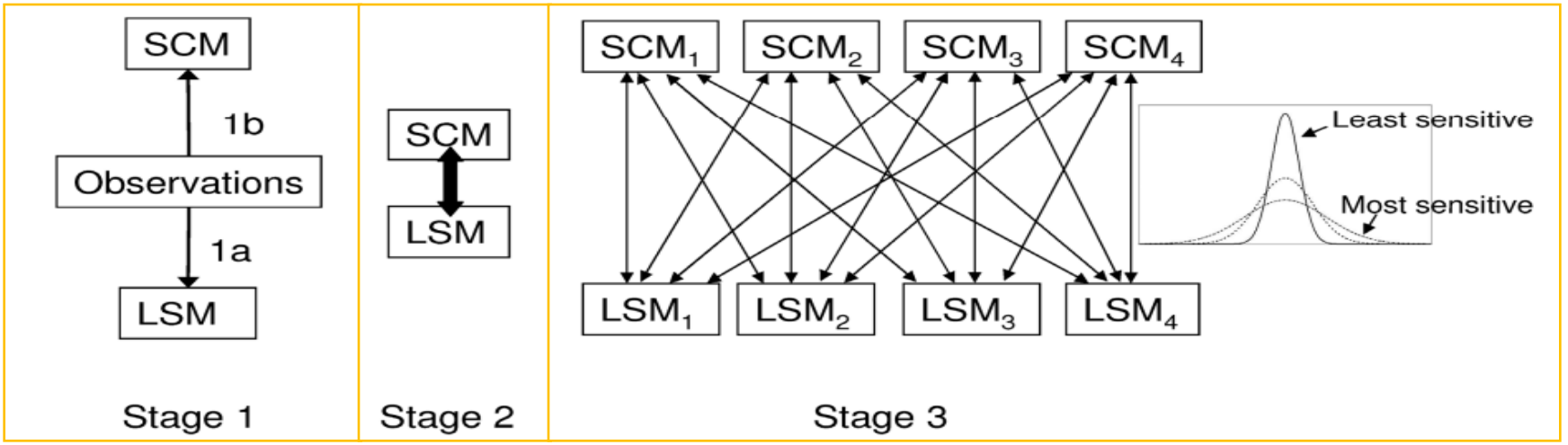
Testing & Validation: Column Model Testing

Diurnal land-atmosphere coupling experiment (DICE)

Objective: Assess impact of land-atmosphere feedbacks.
Stage 1: stand alone land, and single column model (SCM) alone.
Stage 2: Coupled land-SCM.
Stage 3: Sensitivity of LSMs & SCMs to variations in forcing.

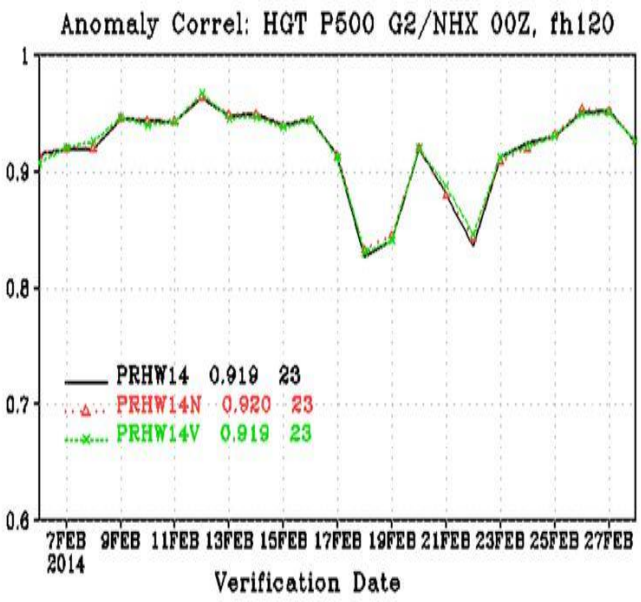
Data Set: CASES-99 field experiment in Kansas, using 3 days: 23-26 Oct 1999, 19UTC-19UTC.

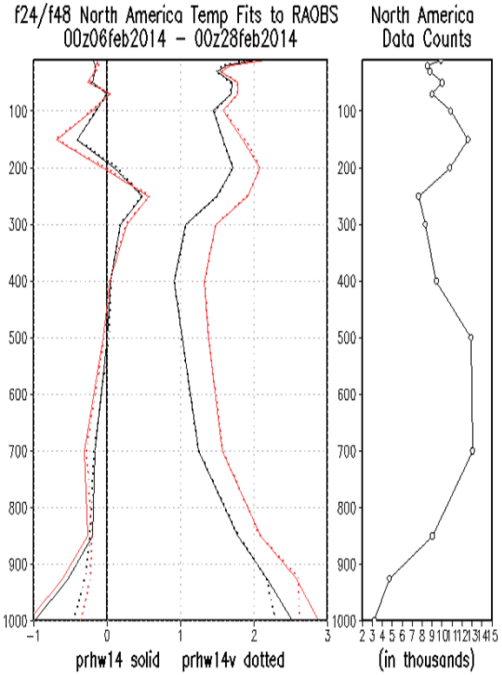
Joint GEWEX GLASS-GASS project –outgrowth of GABLS2 (boundary-layer project) where *land-atmosphere coupling was identified as a important mechanism*. ~10 models participating.

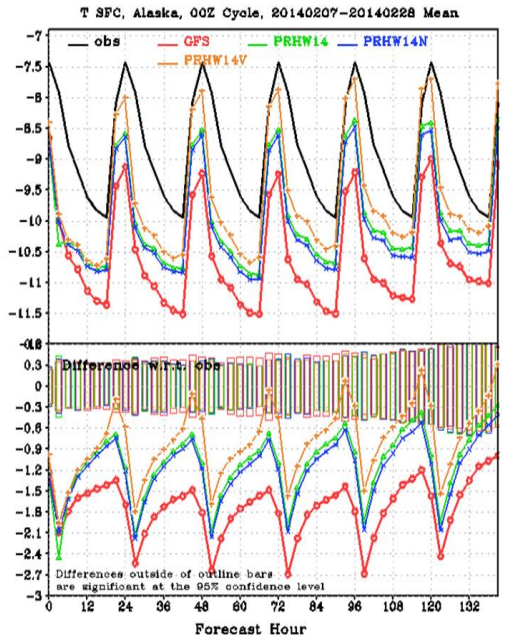


Testing and Validation: Fully Coupled GFS

- Forecast only
- Cycled
- Full parallel
- Metrics: precip, 500mb AC, upper air, surface temp/wind, etc
- Examples







Results from the new LSC dataset tests on the GFS

Helin Wei, NCEP/EMC

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).*