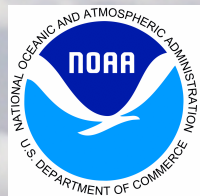


# Land Surface Model and Data Assimilation in NCEP FV3GFS

**Jesse Meng<sup>2</sup>, Helin Wei<sup>2</sup>, Youlong Xia<sup>2</sup>, Jiarui Dong<sup>2</sup>,  
Yihua Wu<sup>2</sup>, Rongqian Yang<sup>2</sup>, Weizhong Zheng<sup>2</sup>,  
Roshan Shresha<sup>2</sup>, Jack Kain<sup>1</sup>**

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Environmental Modelling Center (EMC)  
College Park, Maryland, USA

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College Park, Maryland, USA



# *Outline*

- **Role of Land Surface Model and Requirements**
- **Land Surface Physics – Noah Land Surface Model**
- **Land Data Sets**
- **Land Initialization**
- **Land Data Assimilation System**
- **Model Testing and Verification**
- **Current Development**
- **Summary**



# Role of Land Surface Model and Requirements

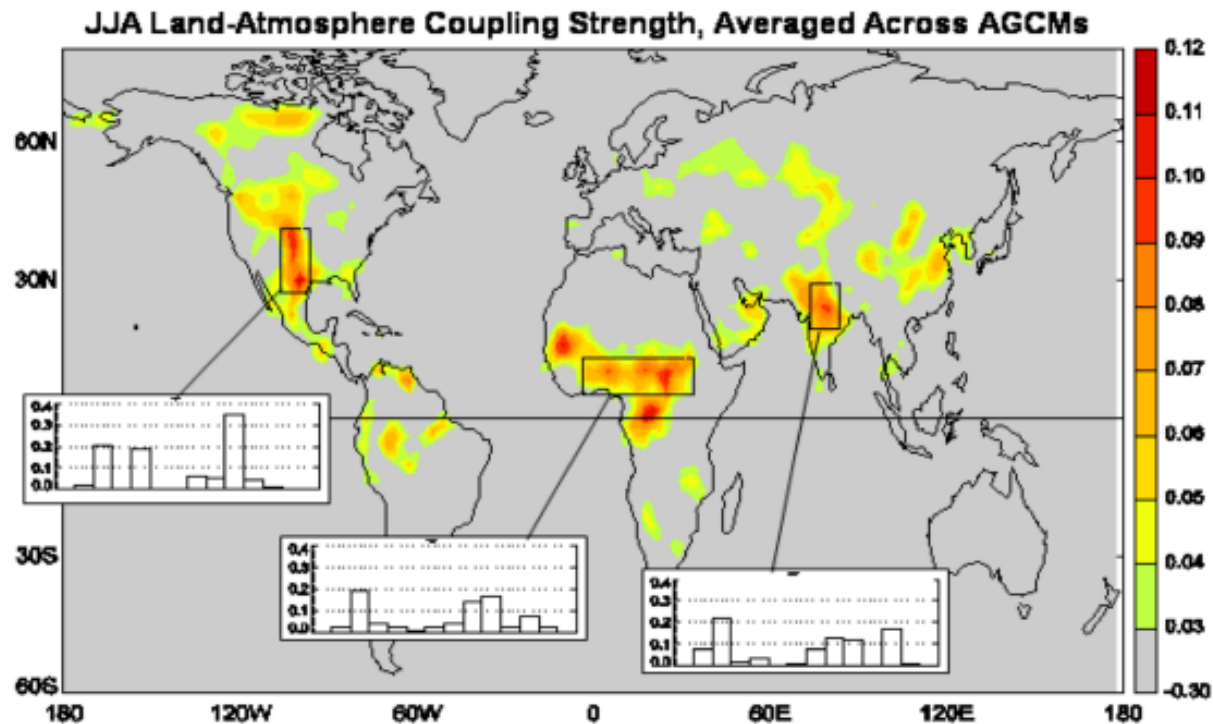
- **Land Surface Models (LSMs) provide surface flux boundary conditions for **heat**, **moisture**, and **momentum** to the atmosphere for NCEP weather and seasonal prediction systems.**
- **Land models close surface energy and water budgets.**
- **Land Model Requirements:**
  - ✓ **Physics:** appropriate to represent land surface processes (for relevant time/spatial scales) and associated LSM parameters.
  - ✓ **Atmospheric forcing:** drive LSM.
  - ✓ **Land data sets:** land use/land cover (vegetation type), soil type, surface albedo, surface roughness, etc.
  - ✓ **Land initial states:** compared to atmosphere, land states carry more memory (especially deep soil moisture), similar to the role of SSTs and ocean temperatures.
  - ✓ **Land Data Assimilation:** some of the state quantities may be assimilated, e.g. snow depth and cover, soil moisture.
  - ✓ **Land Data Assimilation System (LDAS): provide optimal land initial states for NCEP prediction systems.**

# Role of Land Surface Model

“Famous” figure from Koster et al. (2004, *Science*) which has become widely used to justify the role of land surface in weather and climate.

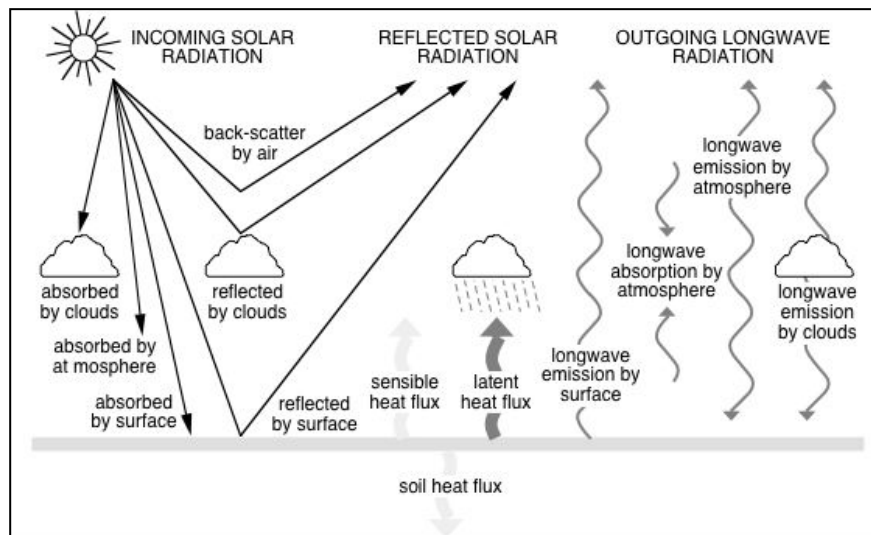
Land-Atmosphere coupling “hot spots” emerged in transition zones between arid and humid climate regions.

Land Surface Model is critical in weather and climate prediction.

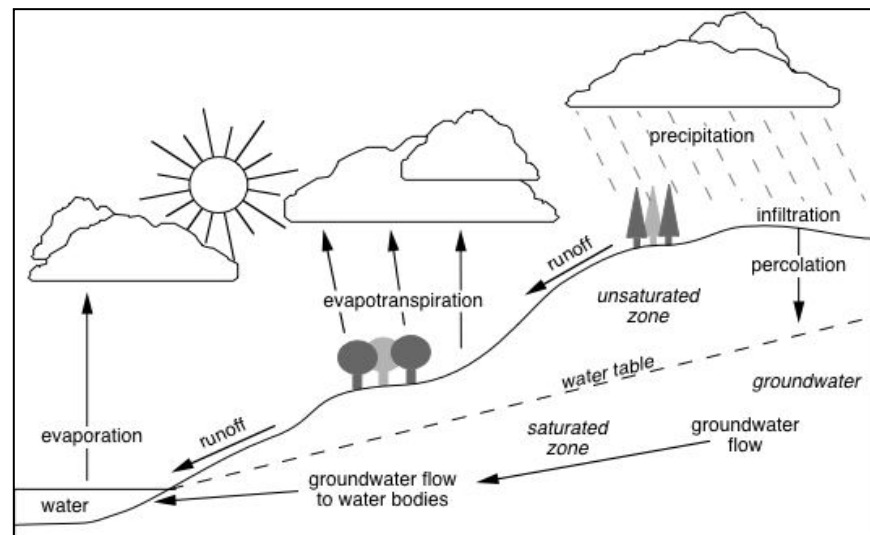


# Land Surface Energy and Water Budgets

## Energy

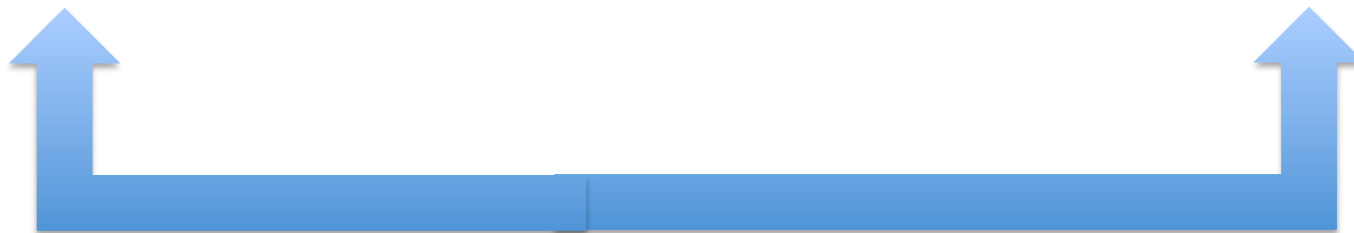


## Water



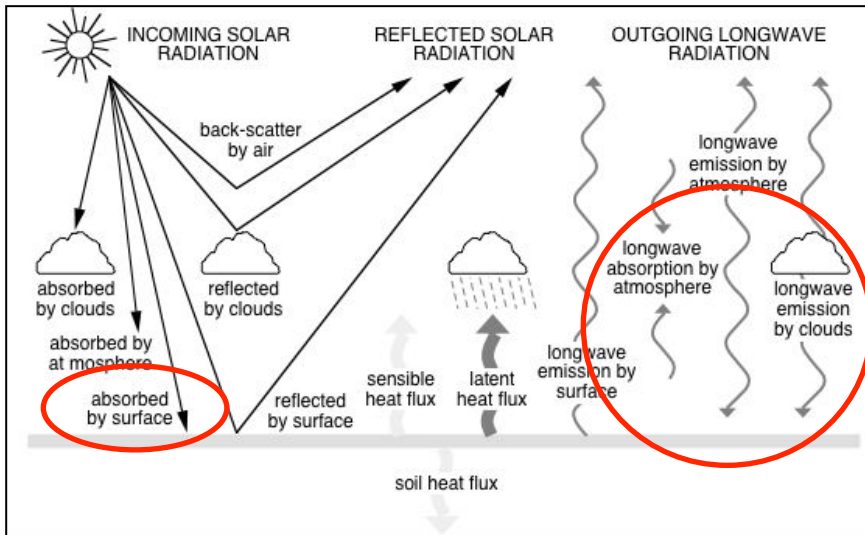
$$R_n = H + LE + G + SPC$$

$$\Delta S = P - R - E$$

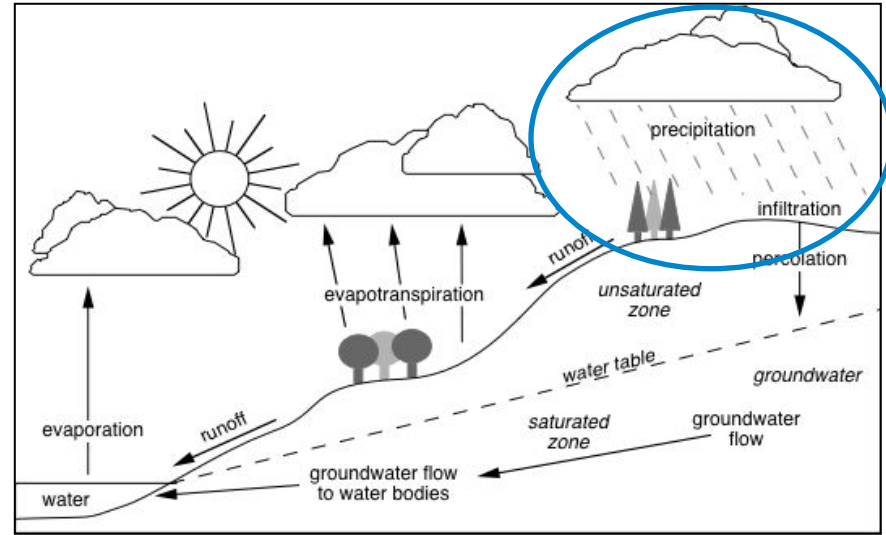


# Role of Land Surface Model in FV3GFS

## Energy



## Water

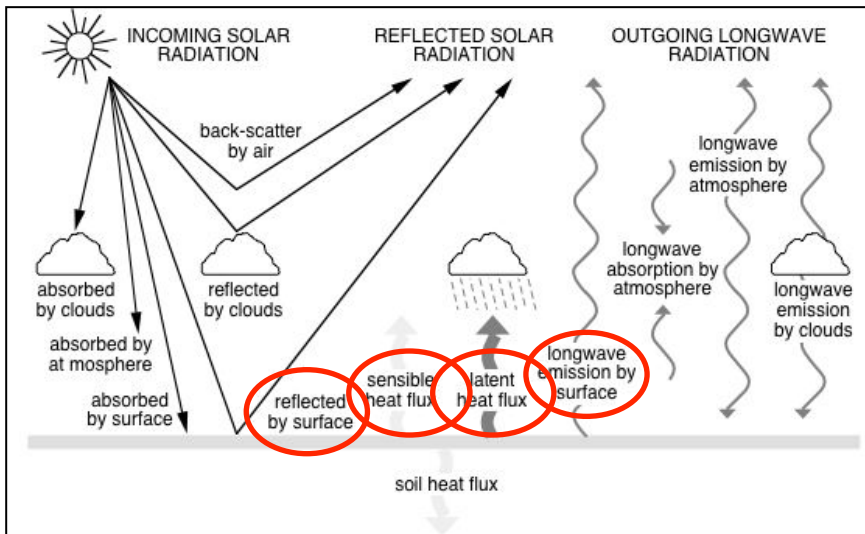


## Land Surface Model driven by the Atmospheric Model forcing

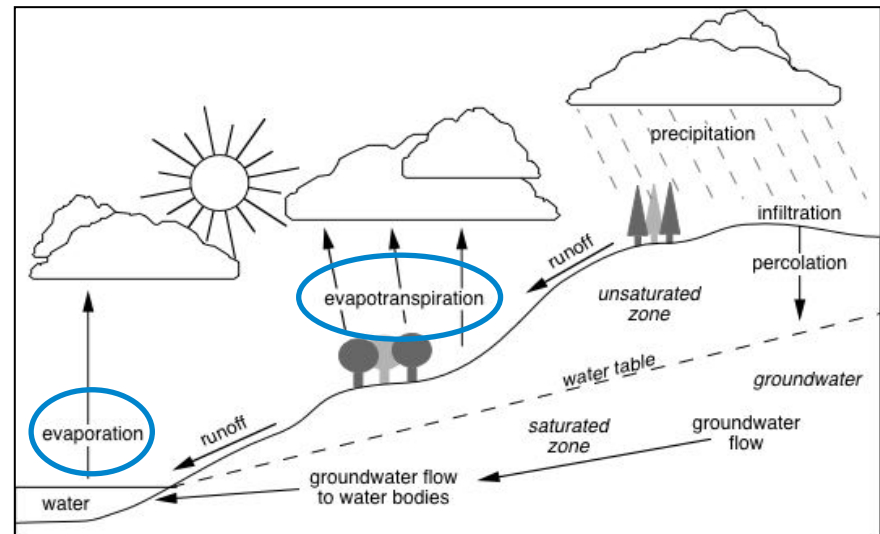
- Surface downward shortwave radiation
- Surface downward longwave radiation
- **Precipitation (rain and snow)**
- Surface pressure, air temperature, humidity, wind speed

# Role of Land Surface Model in FV3GFS

## Energy



## Water



## Land Surface Model provides the Atmospheric Model

- Surface upward (reflected) shortwave radiation (surface albedo, including snow effects)
- Surface latent heat flux and **Evapotranspiration**
- Surface sensible heat flux
- Surface upward longwave radiation (skin temperature and surface emissivity)
- Surface momentum flux

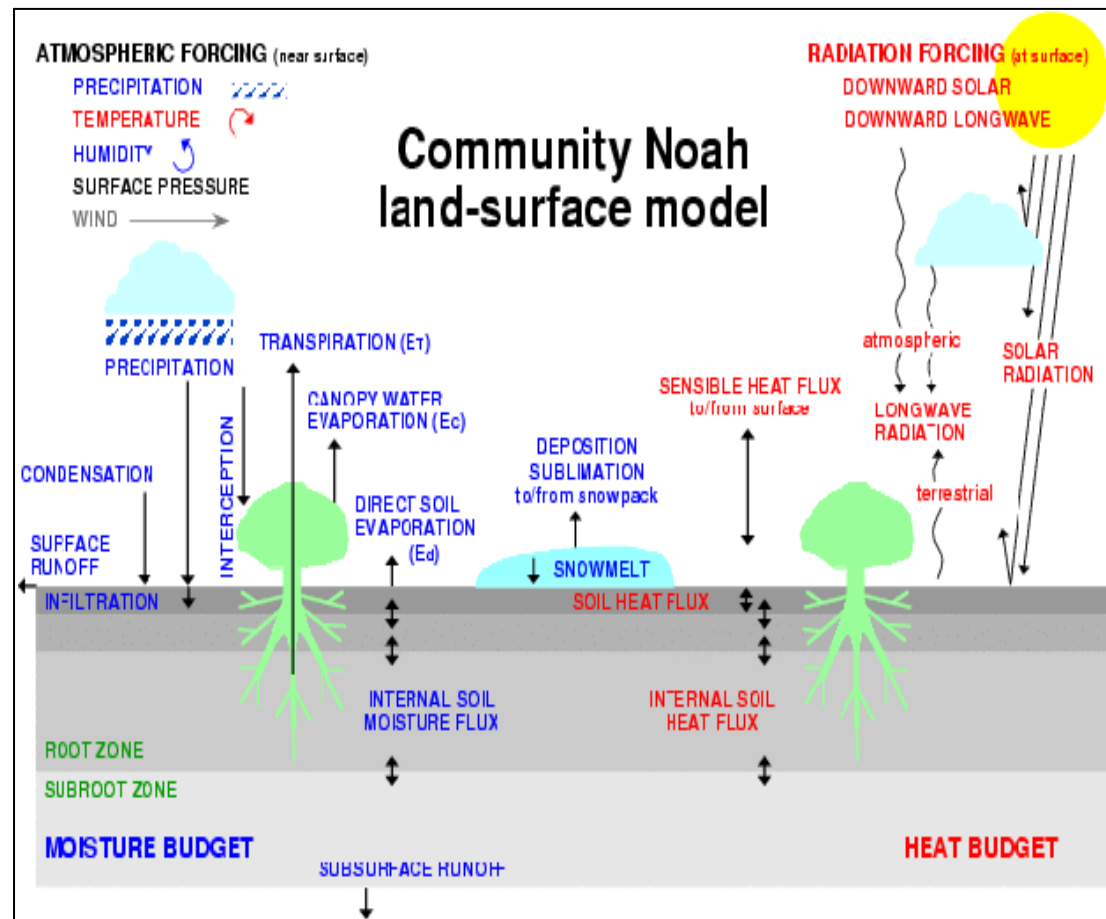


# Land Surface Model Physics

## Unified NCEP-NCAR Noah LSM

- Surface **energy** and **water** budget equations
- 2-meters 4 soil layers soil (10, 30, 60, 100 cm thick)
- Land data sets:
  - soil type
  - vegetation type
  - green vegetation fraction
  - snow-free albedo
  - maximum snow albedo
- Land states:
  - skin temperature,
  - soil temperature\*,
  - soil moisture\*,
  - soil liquid moisture\*,
  - snow water equivalent\*,
  - snow depth\*, canopy water\*

\*prognostic



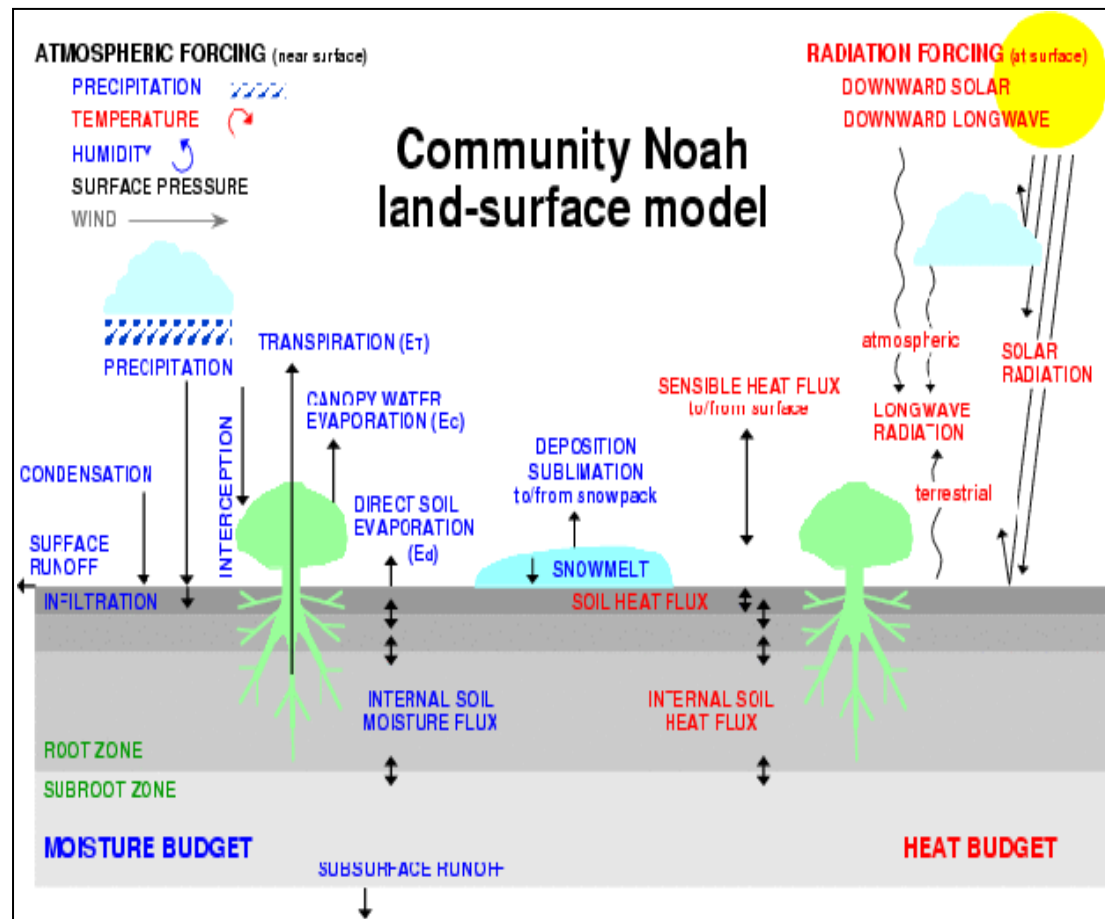
Land fluxes: SW $\square$ , LW $\square$ , LH, SH, G, ET, R



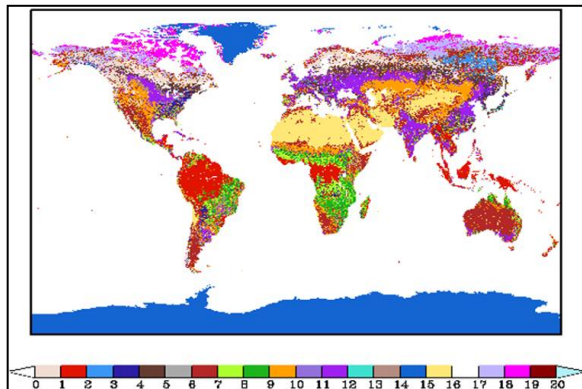
# Land Surface Model Physics

## Unified NCEP-NCAR Noah LSM

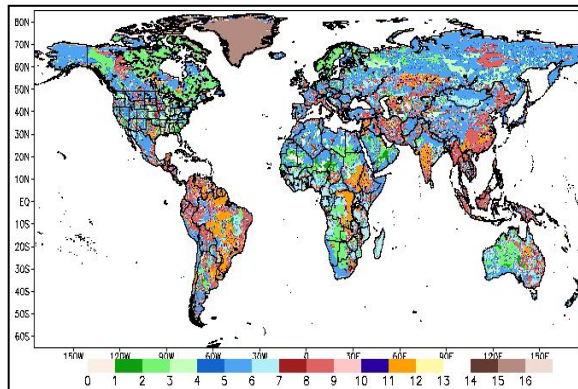
- Surface momentum roughness dependent on **vegetation/land-use type**.
- Surface thermal roughness dependent on **green vegetation fraction**.
- Stomatal control dependent on **vegetation type**, direct effect on transpiration.
- Depth of snow (snow water equivalent) for deep snow and assumption of maximum snow albedo is a function of **vegetation type**.
- Heat transfer through vegetation and the soil as function of **green vegetation fraction** (coverage) and **leaf area index** (density).
- Soil thermal and hydraulic processes dependent on **soil type**.



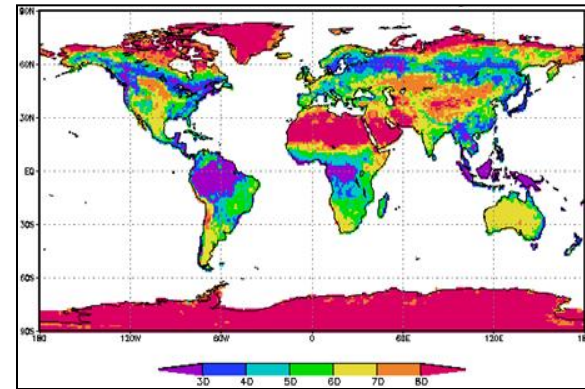
# Land Data Sets used in FV3GFS



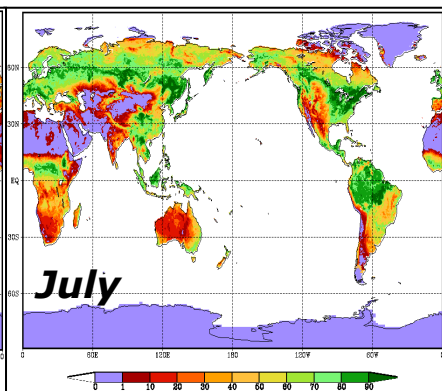
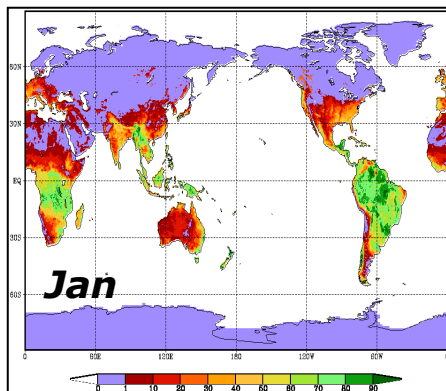
**Vegetation Type**  
(1-km, IGBP-MODIS)



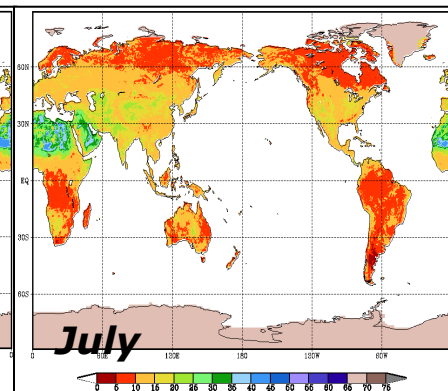
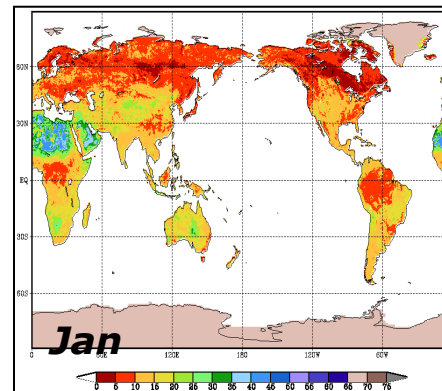
**Soil Type**  
(1-km, STATSGO-FAO)



**Max.-Snow Albedo**  
(1-km, UAZ-MODIS)



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



**Snow-Free Albedo**  
(monthly, 1-km, BU-MODIS)

- **Climatology: fixed/annual, monthly, weekly.**
- **Near real-time observations, e.g. GVF becoming a land state (DA).**

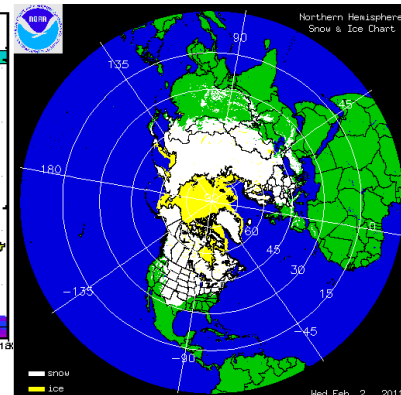
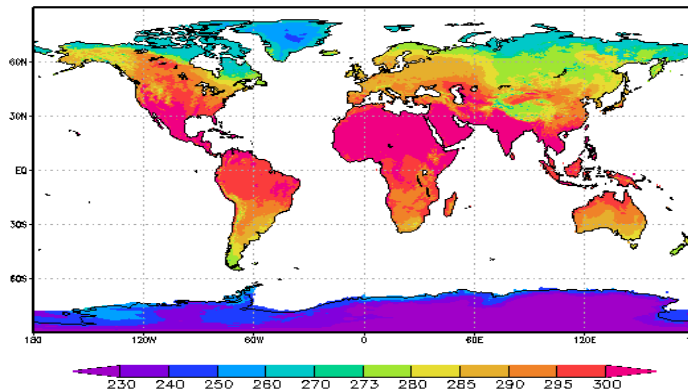
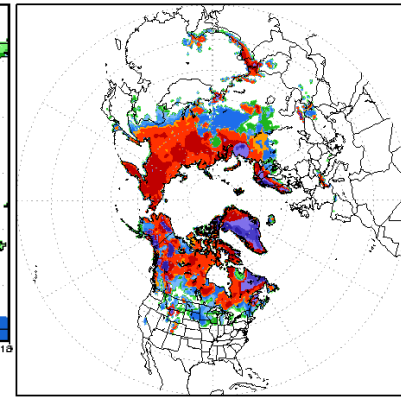
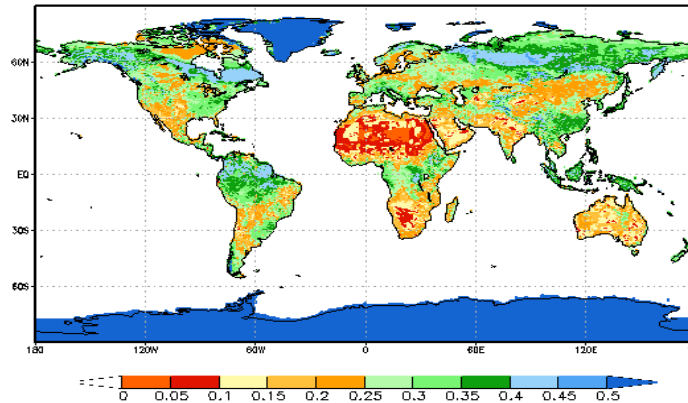
# Land Initial States

Valid **land states initial conditions** are **necessary** for NWP and climate models, and must be **consistent** with the **land surface model** used in a given NWP or climate model, i.e. from same **LSM cycling/spin-up** with same **land data sets**.

## Land Initial States for FV3GFS/Noah

*soil total moisture (4)*  
*soil liquid moisture (4)*  
*soil temperature (4)*  
*surface skin temperature*  
*snow water equivalent*  
*snow depth*  
*canopy water*

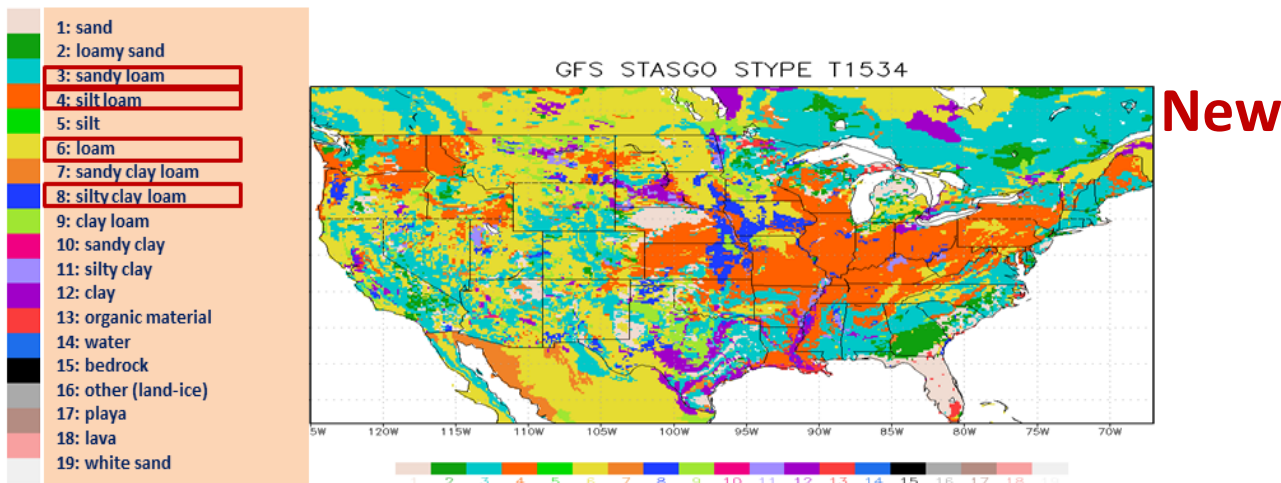
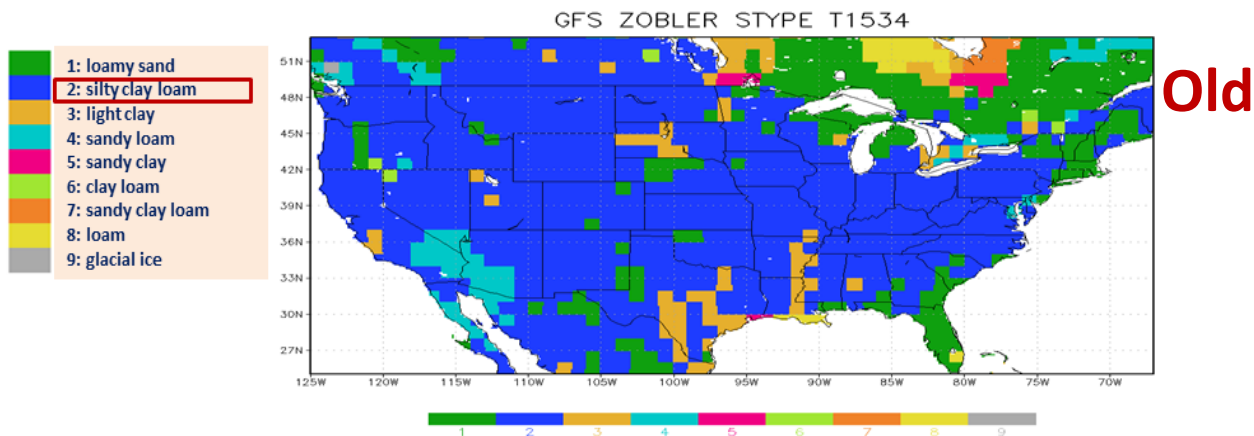
Land IC given in the FV3GFS sfc restart file.





# Soil Moisture Climatology

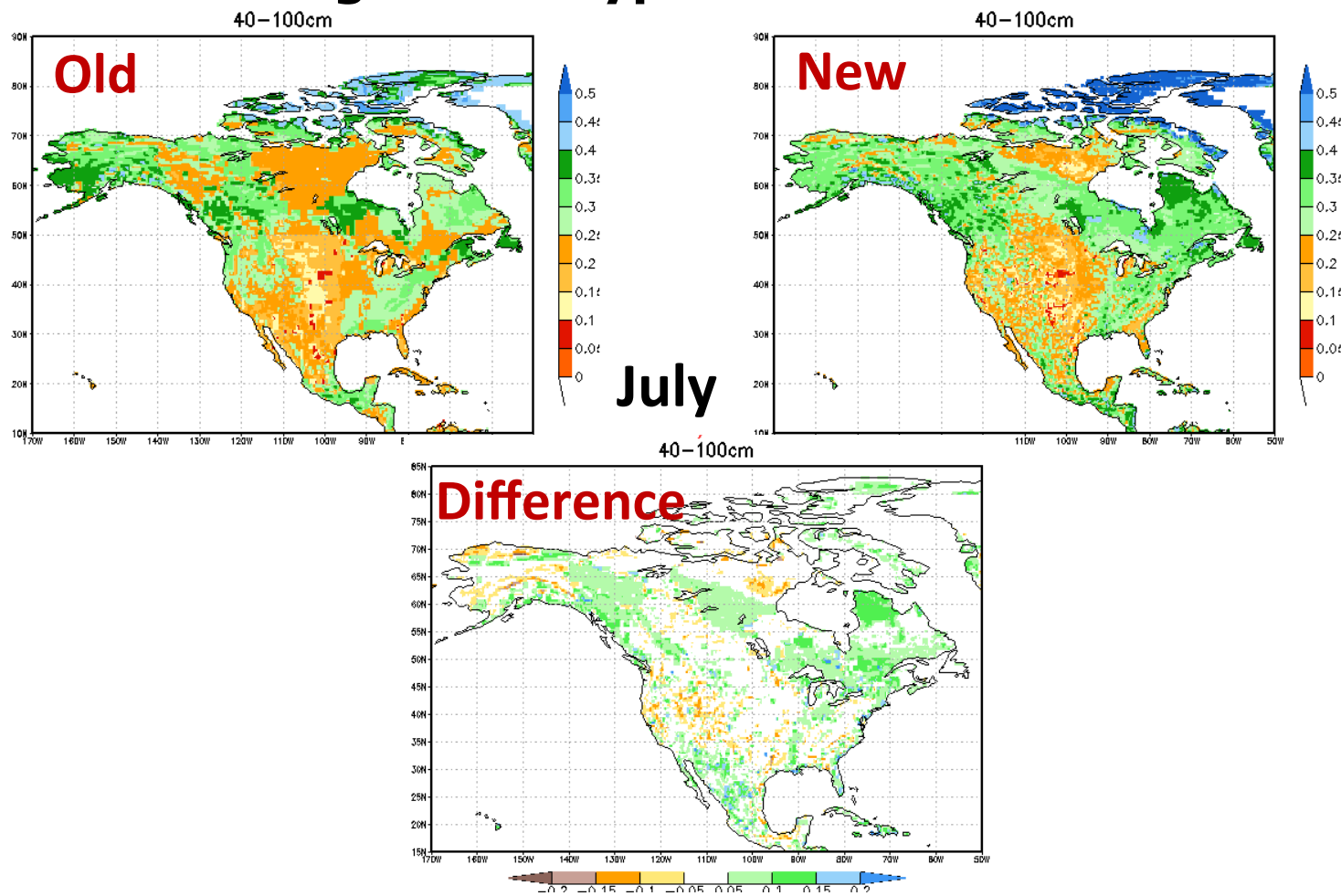
**Soil moisture** is highly dependent on **soil** and **vegetation types**.  
 Since soil and vegetation types are updated in **FV3GFS**,  
**soil moisture climatology** is also updated for consistency.





# Soil Moisture Climatology

**Monthly 4-layer soil moisture climatology of FV3GFS is generated from a 30-year offline spin-up run of Noah LSM with updated soil and vegetation types.**



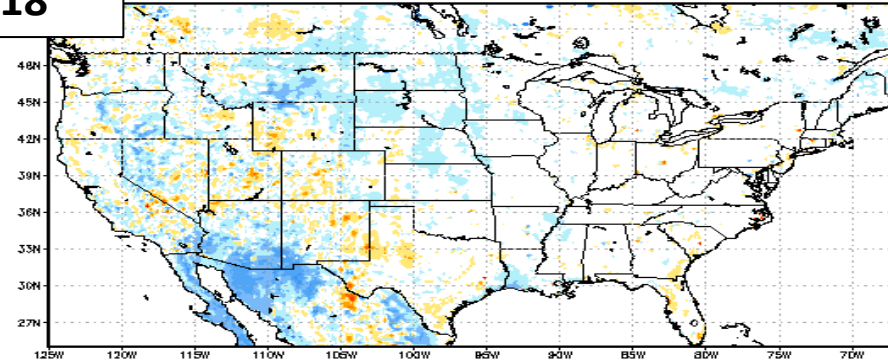
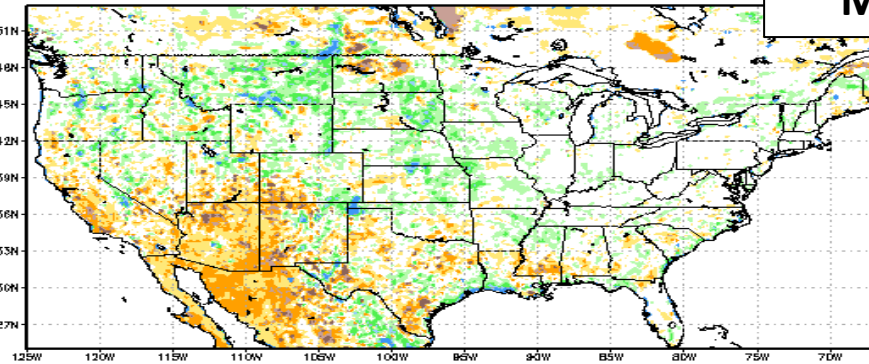
# Soil Parameters Refinement

Reduce **bare soil** resistance of **top soil layer** (0-10cm) to allow more evaporation from the **top layer**, potentially dryer and cooler top layer in the dry season, less impact on deep soil.

**Soil Moisture differences**  
0-10cm

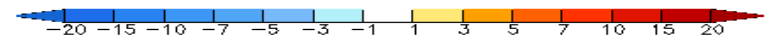
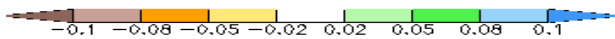
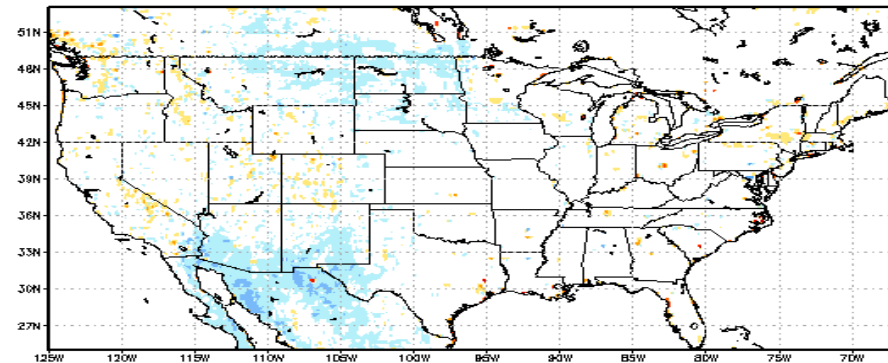
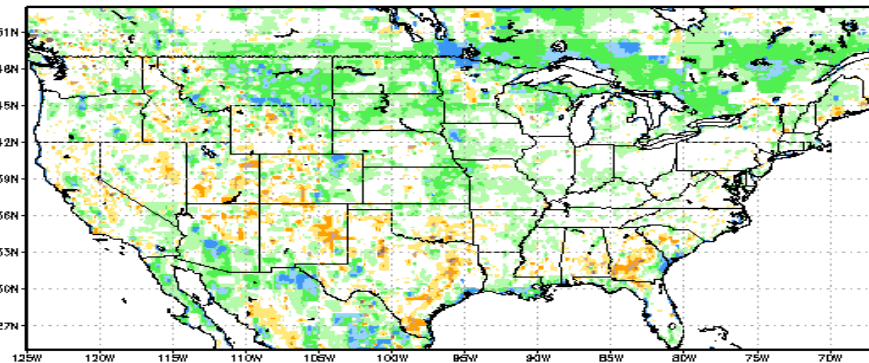
FV3 minus GFS  
May 2018

**Soil Temperature differences**  
0-10cm



40-100cm

40-100cm

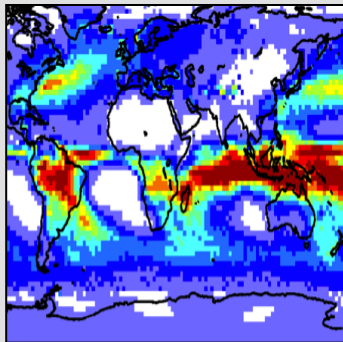


# NCEP Global Land Data Assimilation System (GLDAS)

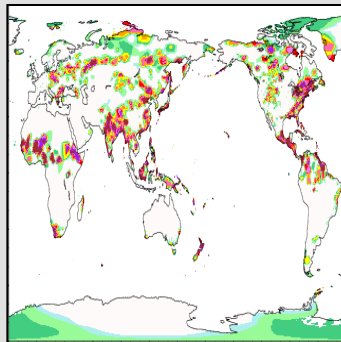
**Operational since 01 April 2011**

- **Noah LSM** 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.

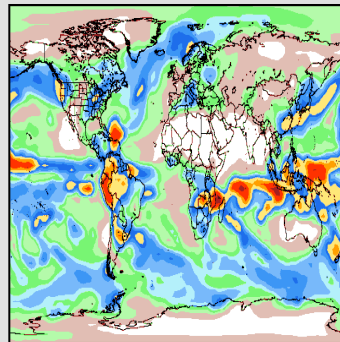
## Precipitation



**CMAP**

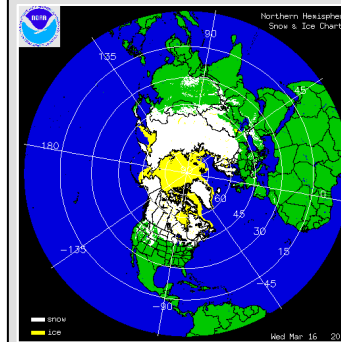


**Surface gauge**

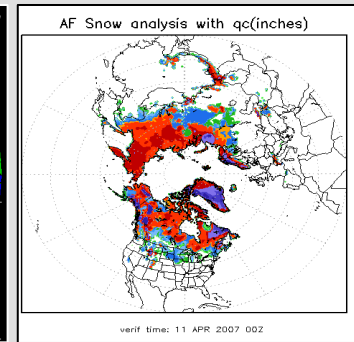


**GDAS**

## Snow



**IMS cover**



**AFWA depth**

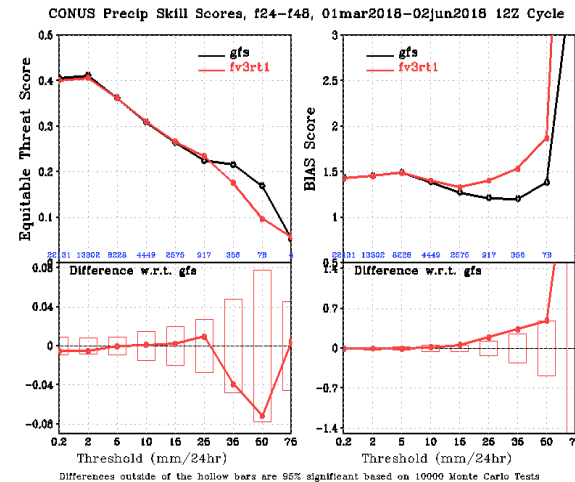
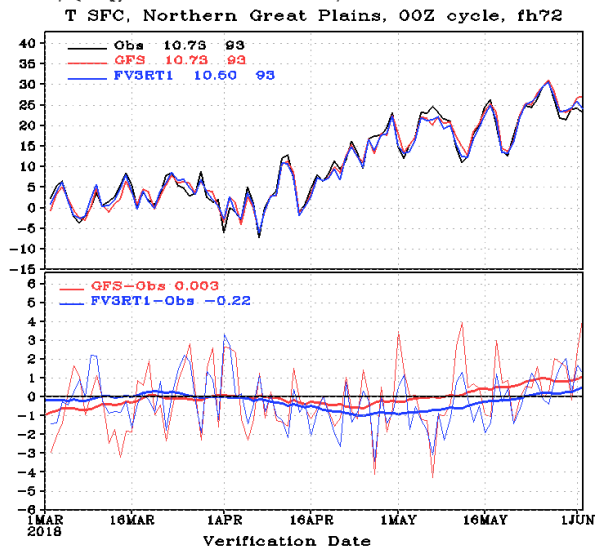
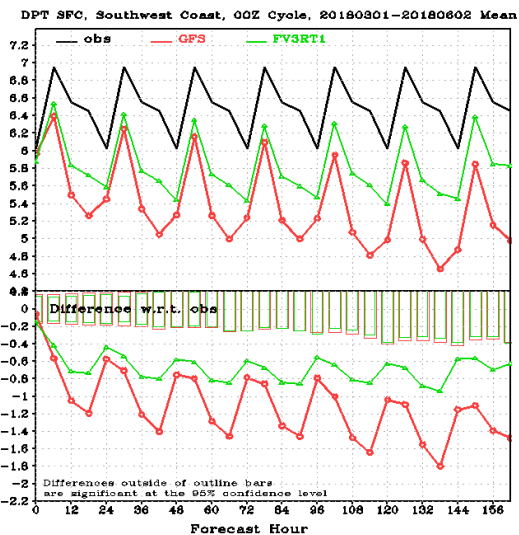
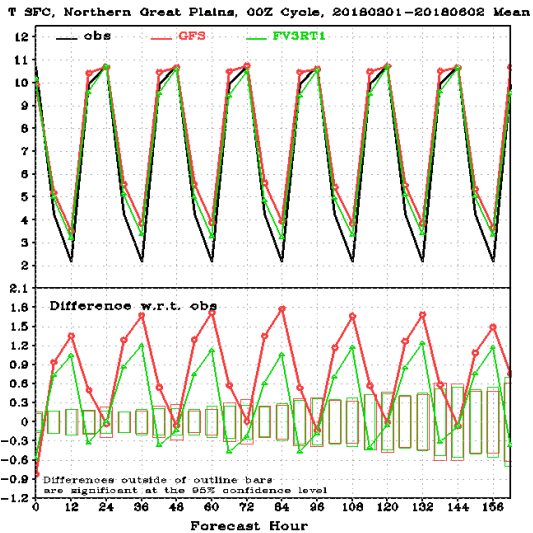
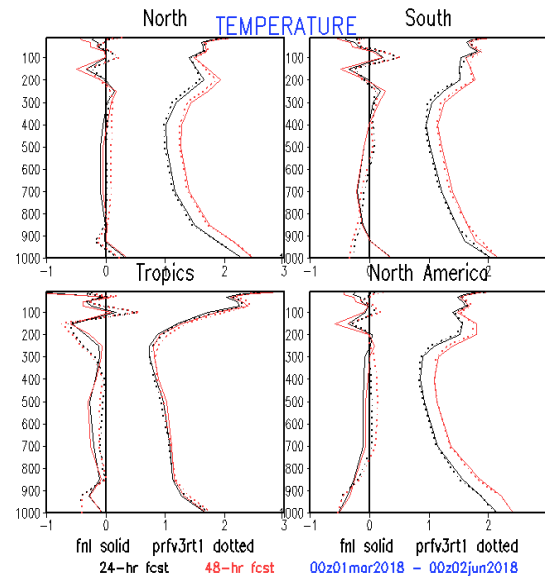
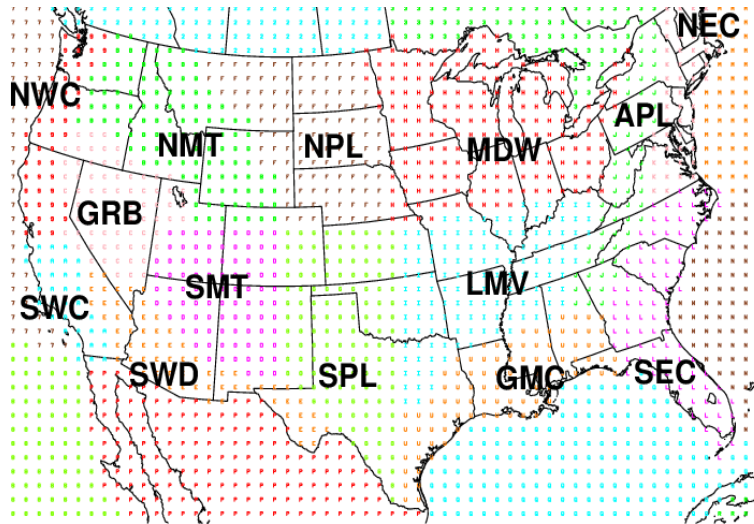
Jesse Meng, NCEP/EMC



# Model Testing and Verification

## FV3 vs GFS

20180301-20180602





# *Land Surface Model and land-related issues*

Low-level biases in **winds, temperature, and humidity** are influenced in part by the **land surface** via biases in surface fluxes exchanged with the **atmospheric model (radiation, precipitation, etc)**.

Improving the proper partition of surface energy budget between **sensible, latent, soil heat fluxes** and **outgoing longwave radiation** in FV3GFS/Noah requires:

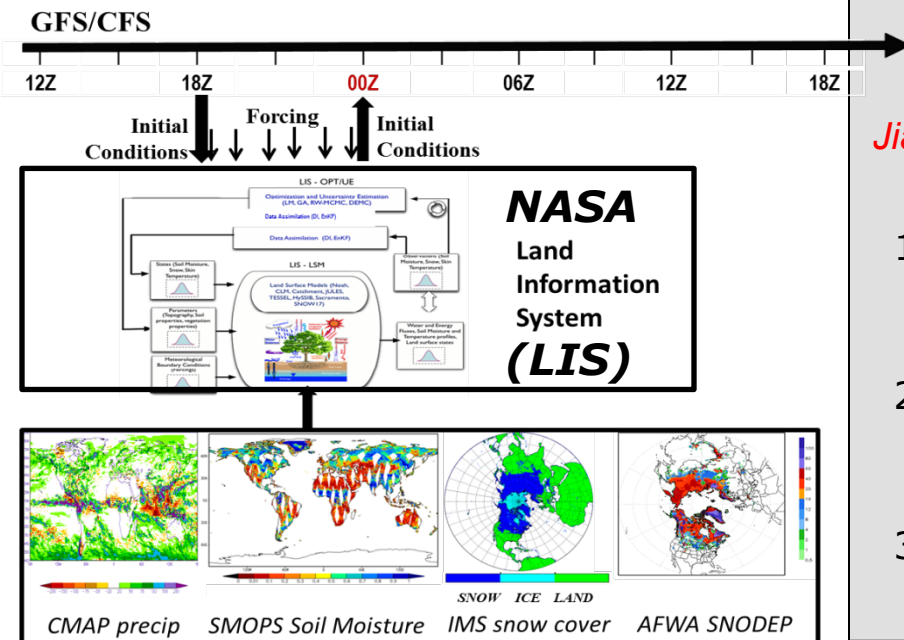
- Improve **atmospheric forcing** for the land model, especially **precipitation** and downward **radiation**; enhanced downscaling techniques.
- **Data assimilation** of near-realtime snow, soil moisture, GVF.
- Improve **snow** physics (multi-layers, melt/freeze, densification).
- Improve **vegetation parameters** to calculate **transpiration**.
- **Near-realtime vegetation greenness** to improve **Bowen ratio**.
- Improve specification and representation of **surface heterogeneity**.

# Summary

- **Noah Land Surface Model** and **land data sets** are updated and coupled to **FV3GFS** to enhance the representation of land processes and land-atmosphere coupling, toward improving NCEP operational predictions.
- Further developments for **NCEP Land Surface Model** and **Land Data Assimilation Systems** in fully-coupled Earth System Model and Data Assimilation (atmosphere-ocean-land-ice-waves-aerosols) with connections between **Weather and Climate**, **Hydrology**, **Ecosystems and Biogeochemical cycles** (carbon), and **Air Quality**, models and communities, e.g., community model development of **FV3GFS**.

# Land Data Assimilation development

- 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:
- **Snow depth (SNODEP)** from AFWA and **Snow cover area (SCA)** from operational NESDIS Interactive Multi-sensor Snow and Ice Mapping System (**IMS**).
- **Soil moisture** from the NESDIS global Soil Moisture Operational Product System (**SMOPS**).



## Land Data Assimilation Development

Jiarui Dong, Weizhong Zheng, Jesse Meng (NCEP/EMC)  
Christa Peters-Lidard, Sujay Kumar (NASA/GSFC)

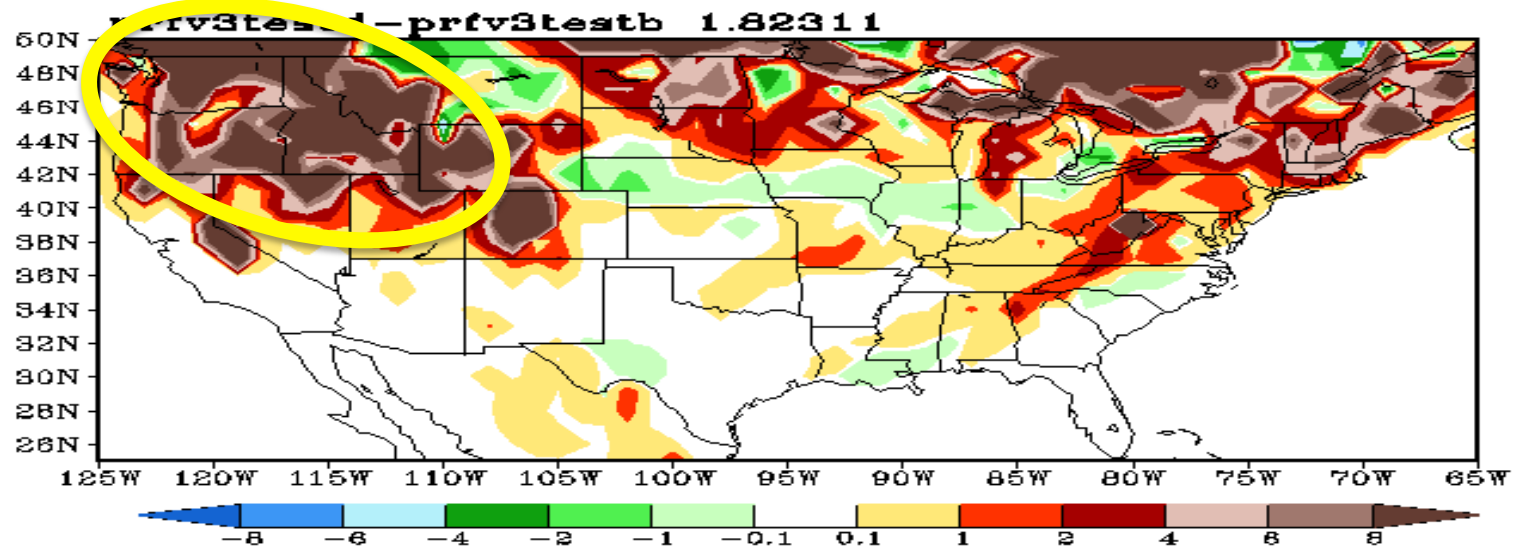
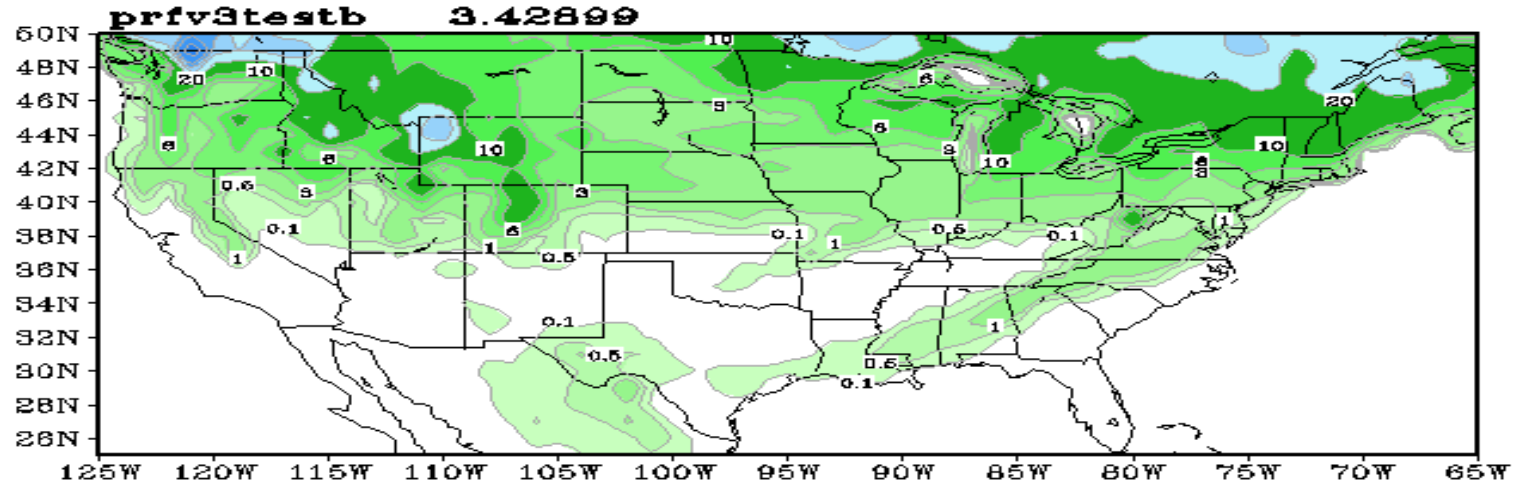
1. Build NCEP's FV3GFS/LDAS by incorporating the NASA Land Information System (LIS) into NCEP's FV3GFS.
2. Offline tests of the existing EnKF-based land data assimilation capabilities in LIS driven by the operational GFS.
3. Coupled land data assimilation tests and evaluation against the operational system.



# FV3GFS/GLDAS Initial States Testing and Verification

20181207-20171231

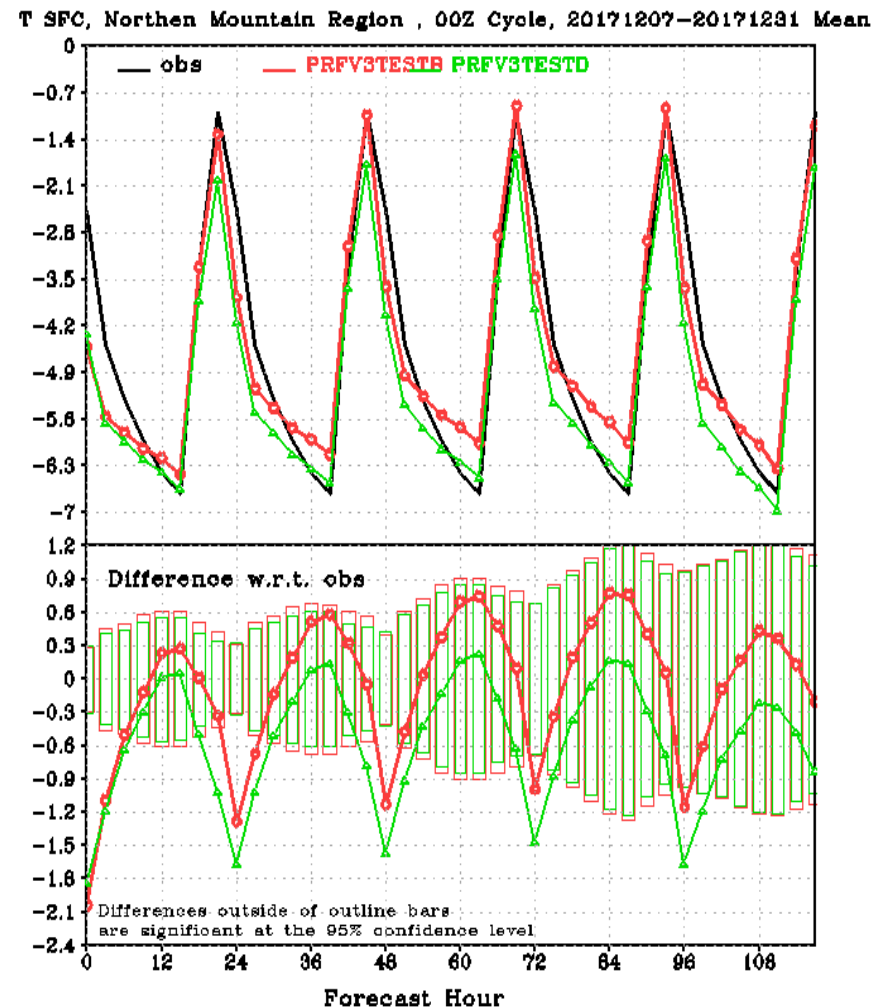
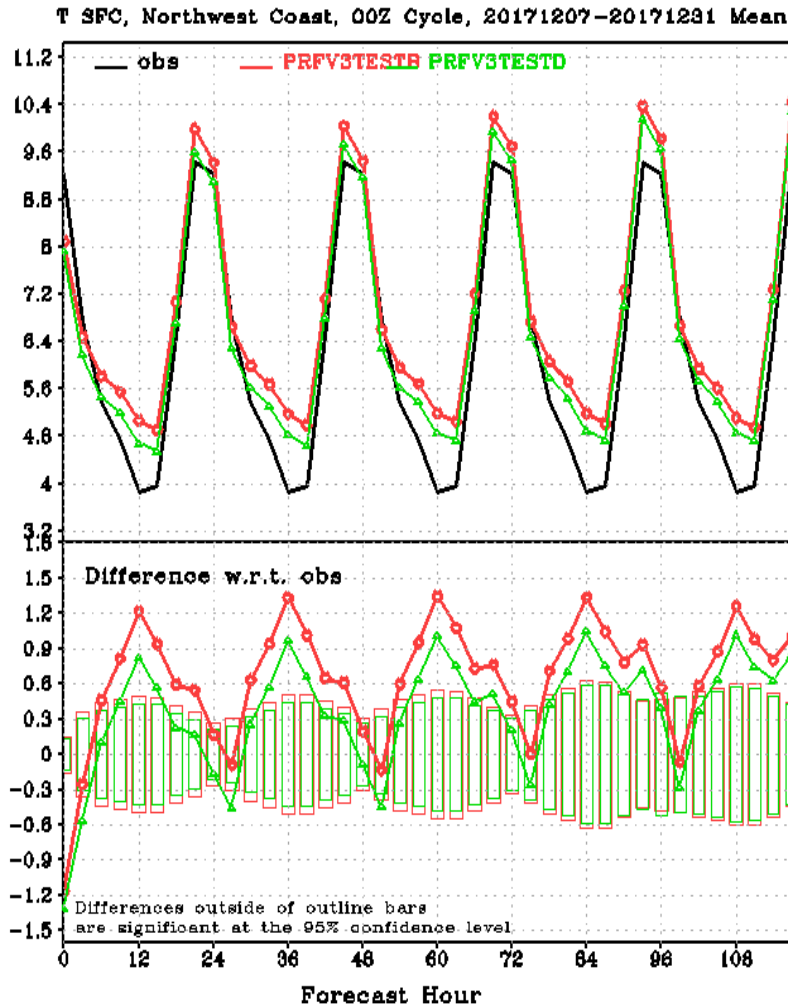
Surface Accum Snow [kg/m<sup>2</sup>]  
00Z-Cyc 07Dec2017-31Dec2017 Mean  
(f12 f12 f12 f12) Post-Hour Average





# FV3GFS/GLDAS Initial States Testing and Verification

20181207-20171231



# Model Physics Improvement: Noah-MP

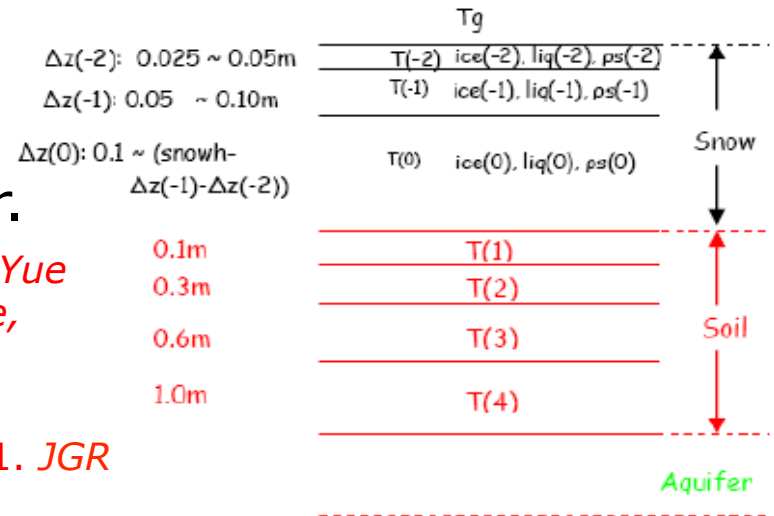
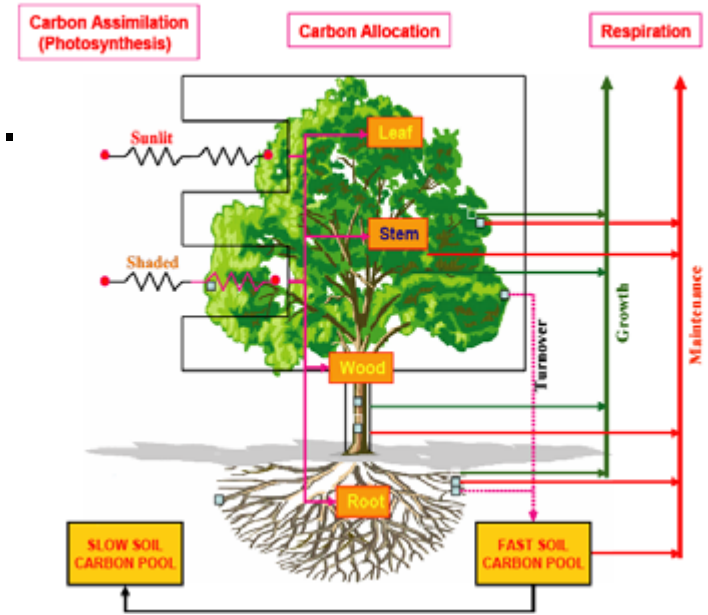
Noah-MP is an extended version of the Noah LSM with enhanced multi-physics options to address shortcomings in Noah.

- 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 (UCAR); Dev Niyogi (Purdue U.); Xubin Zeng (U. Arizona), EMC Land Team*

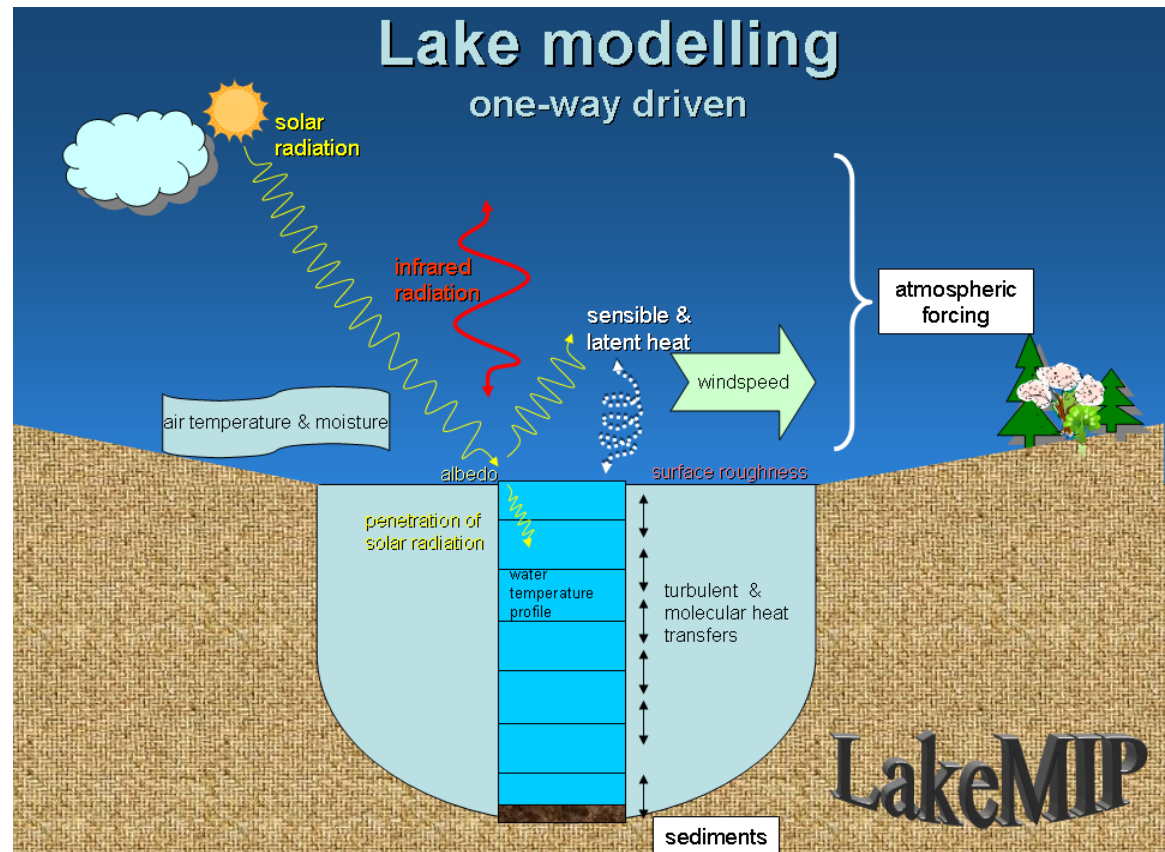
Noah-MP references: Niu et al., 2011, Yang et al., 2011. JGR

Noah-MP development via CPO/MAPP

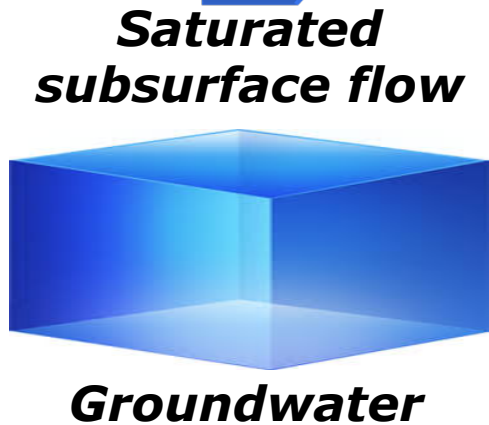
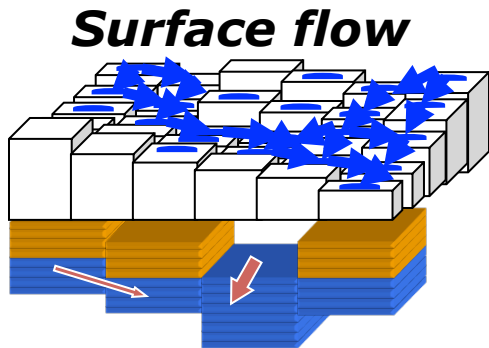
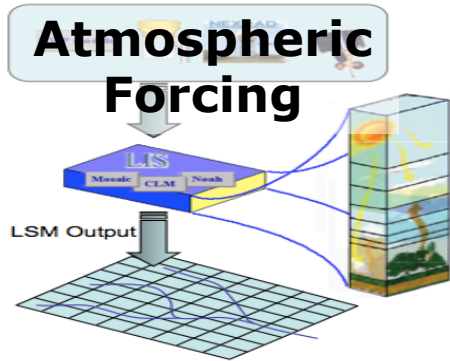


# Model Improvement: Freshwater Lakes

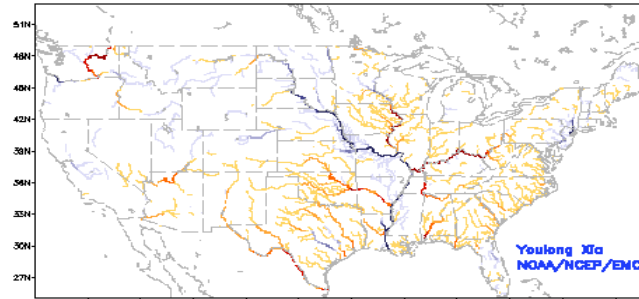
- **Thousands** of lakes on scale of 1-4km not resolved by SST analysis -> greatly influence surface fluxes; explicit vs subgrid.
- Freshwater lake “**FLake**” model (Dmitrii Mironov, DWD).
  - Two-layer.
  - Atmospheric forcing inputs.
  - Temperature & energy budget.
  - Mixed-layer and thermocline.
  - Snow-ice module
  - Specified depth/turbidity.
  - Used in COSMO, HIRLAM, NAM (regional), and global ECMWF, CMC, UKMO.



# Model Improvement: River Routing

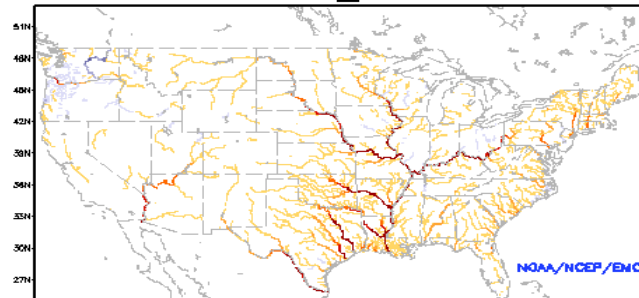


## Ensemble mean daily streamflow anomaly (NLDAS)



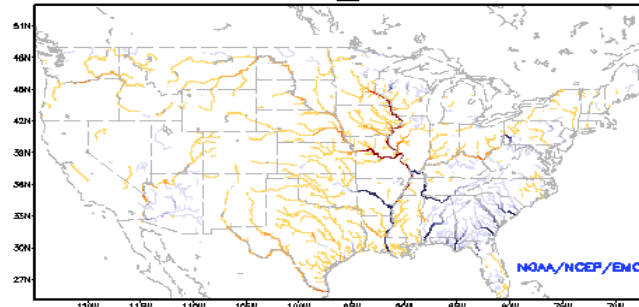
Hurricane Irene and Tropical Storm Lee, 20 August - 17 September 2011

Ensemble-Mean: Current Streamflow Anomaly (m<sup>3</sup>/s)  
NCEP NLDAS Products Valid: OCT 29, 2012

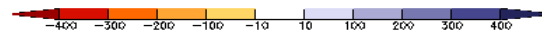


Superstorm Sandy, 29 October - 04 November 2012

Ensemble-Mean: Current Streamflow Anomaly (m<sup>3</sup>/s)  
NCEP NLDAS Products Valid: SEP 01, 2013



Colorado Front Range Flooding, September 2013



**Collaboration with National Water Center**