

Next Generation Global Prediction System: Land Prediction

**EMC Land-Hydrology Team and Partners
Environmental Modeling Center (EMC)
NOAA/NWS/NCEP**

***Next Generation Global Prediction System Annual Meeting
NCWCP, College Park, Maryland, USA
14-17 July 2015***

Outline

- Partners
- Role of land surface models and requirements
- Land model physics and parameters
- Land data sets
- Land data assimilation and data assimilation systems
- Current issues
- Testing and validation
- Future plans
- Summary

NCEP/EMC Land Team Partners

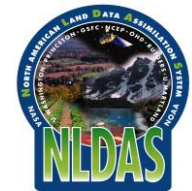
**NGGPS land team leader*

NCEP/EMC Land Team: **Michael Ek***, Jiarui Dong, Weizhong Zheng, Helin Wei, Jesse Meng, Youlong Xia, Rongqian Yang, Yihua Wu, Caterina Tassone, Roshan Shresth, working with:



Land Data Assimilation (LDA), LDA Systems (e.g. "NLDAS"):

- NASA/GSFC: **Christa Peters-Lidard***, David Mocko et al.
- NCEP/Climate Prediction Center: Kingtse Mo et al.
- Princeton University: Eric Wood, Justin Sheffield et al.
- Univ. Washington: Dennis Lettenmaier (now UCLA) et al.
- Lifeng Luo (Michigan State Univ./formerly Princeton).



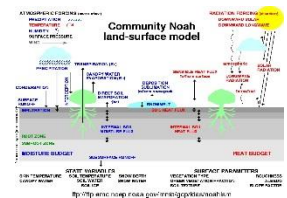
Remotely-sensed Land Data Sets:

- NESDIS/STAR land group: Ivan Csiszar, Xiwu Zhan (soil moisture), Bob Yu (Tskin), Marco Vargas (vegetation) et al.



Land Model (physics) Development:

- NCAR/RAL: **Fei Chen***, Mike Barlage, Mukul Tewari, et al.
- NWS National Water Center: Brian Cosgrove et al.
- Univ. Ariz.: Xubin Zeng et al.
- UT-Austin: Zong-Liang Yang et al.
- WRF land working group and NOAA/ESRL land model development:

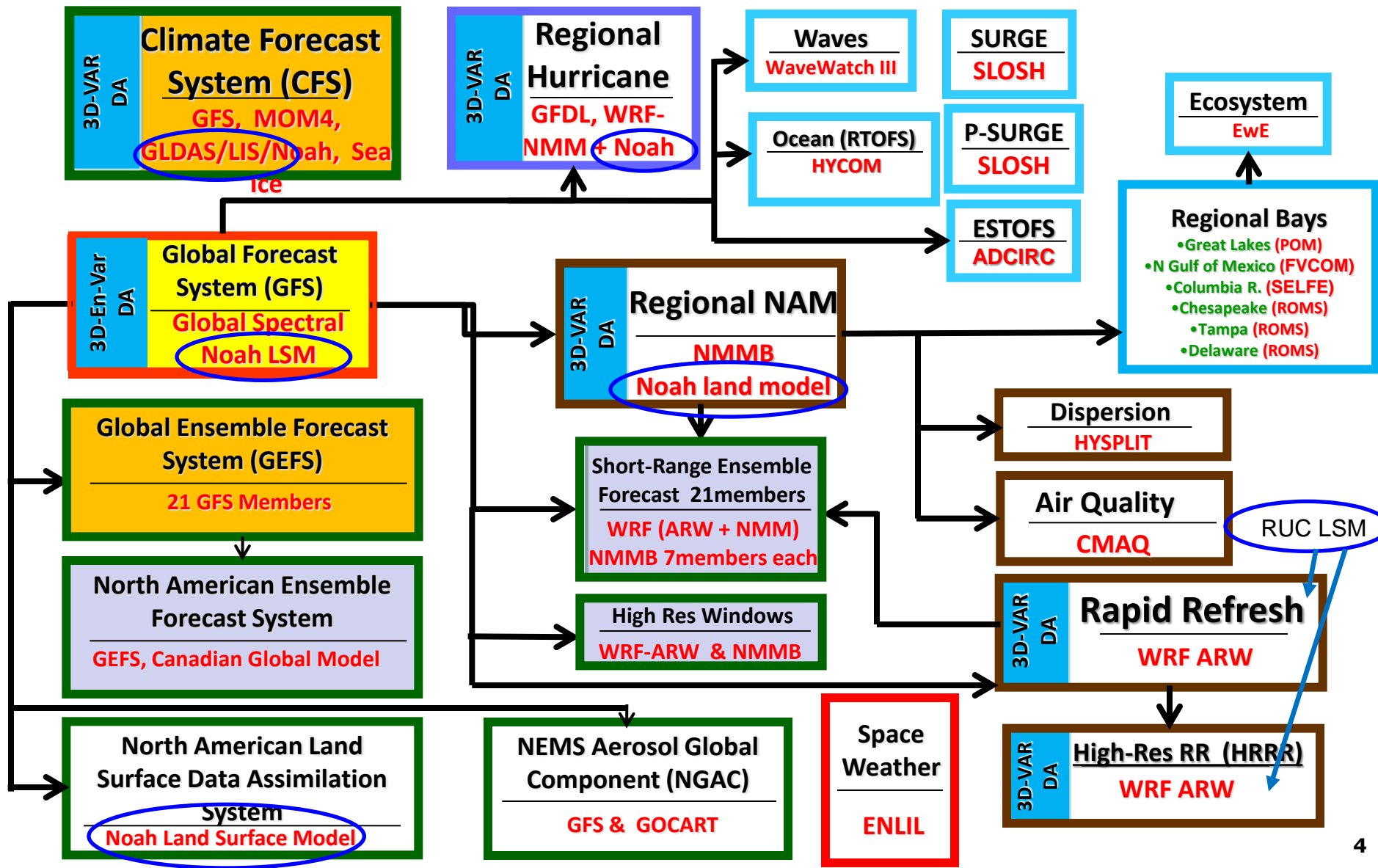


Tanya Smirnova*

- GEWEX/GLASS, GASS projects: Land model benchmarking,



NOAA's Operational Numerical Guidance Suite (Feb 2015)

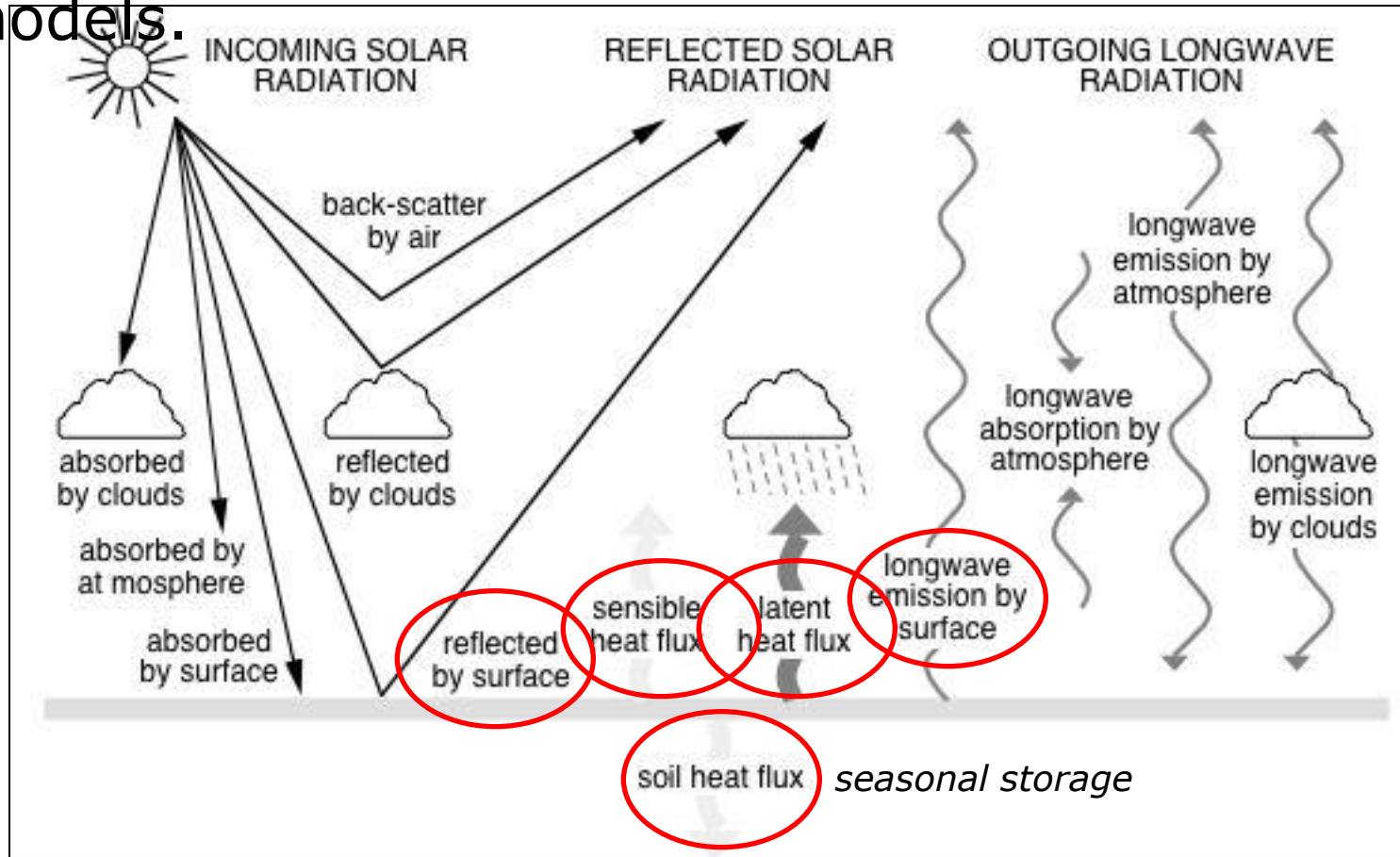


Role of Land Models

- Traditionally, from a *coupled (atmosphere-ocean-land-ice)* **Numerical Weather Prediction (NWP) and climate modeling perspective**, a land-surface model provides quantities as boundary conditions:
 - Surface **sensible heat flux**,
 - Surface **latent heat flux** (evapotranspiration)
 - Upward **longwave radiation** (or skin temperature and surface emissivity),
 - Upward (**reflected**) **shortwave radiation** (or surface albedo, including snow effects),
 - Surface **momentum exchange**.
- Part of the Energy, Water and Momentum budgets in NWP and earth system models.

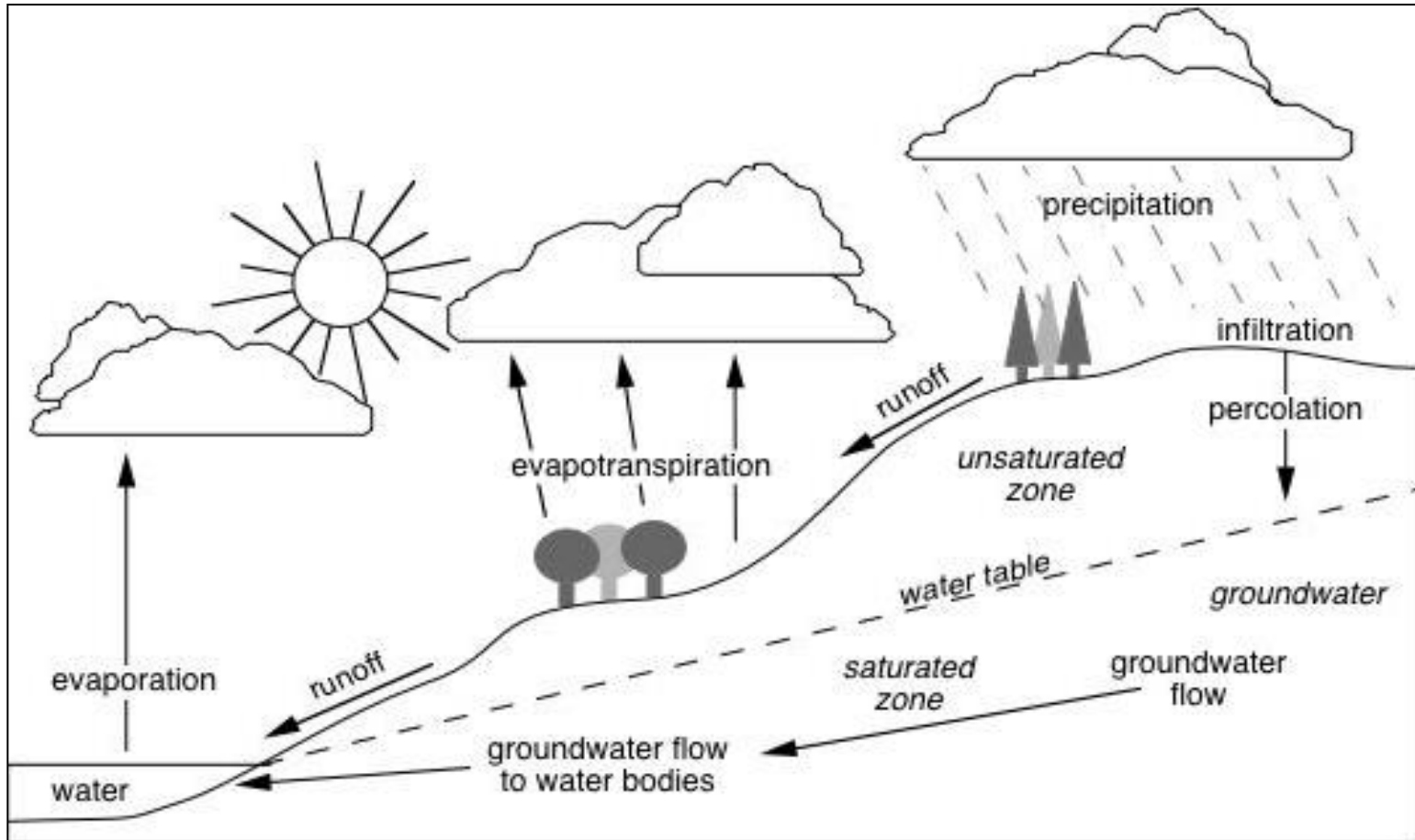
Atmospheric Energy Budget

- Close the surface energy budget, and provide surface boundary conditions to NWP and climate models.



Water Budget (Hydrological Cycle)

- Close the surface water budget, and provide surface boundary conditions to models.



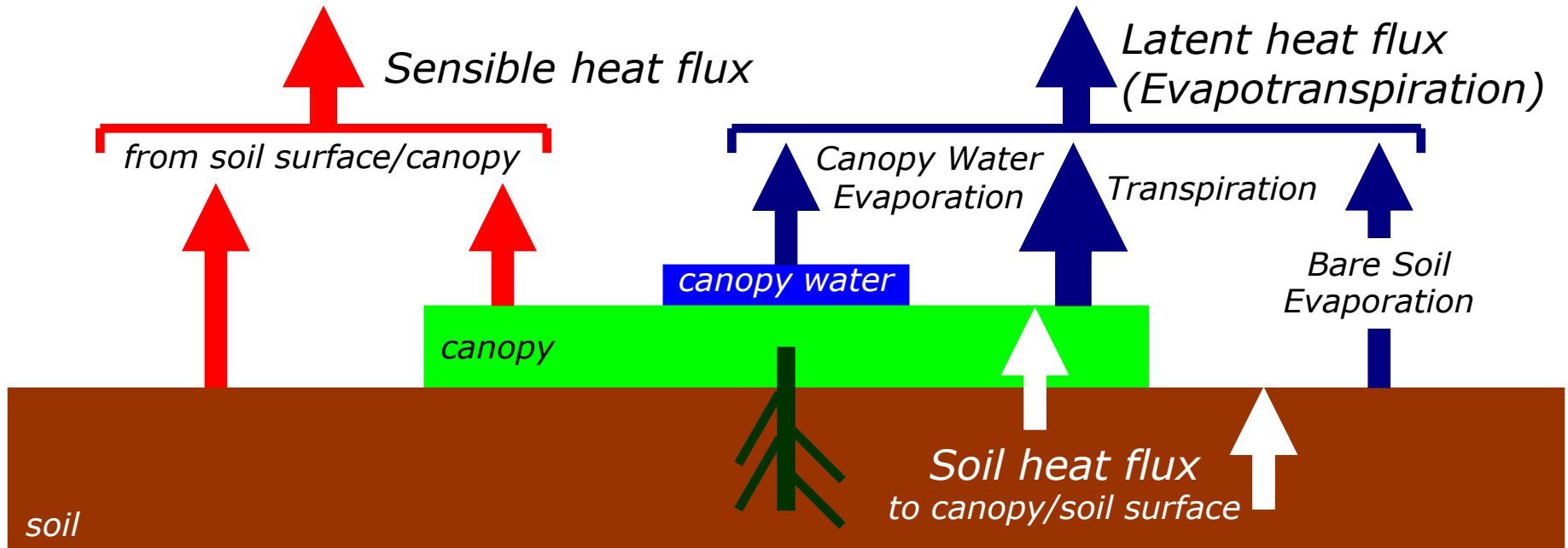
Land Model Requirements

- To provide proper boundary conditions, land model must have:
 - Appropriate **physics** to represent land-surface processes (for relevant time/spatial scales) and associated LSM model parameters.
 - Required **atmospheric forcing** to drive LSM.
 - Corresponding **land data sets**, e.g. land use/land cover (vegetation type), soil type, surface albedo, snow cover, surface roughness, etc.
 - Proper **initial land states**, analogous to initial atmospheric conditions, though land states may carry more “memory” (e.g. especially in deep soil moisture), similar to ocean SSTs.

Boundary Condition: Surface Fluxes

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

$$LE = LE_c + LE_t + LE_d$$



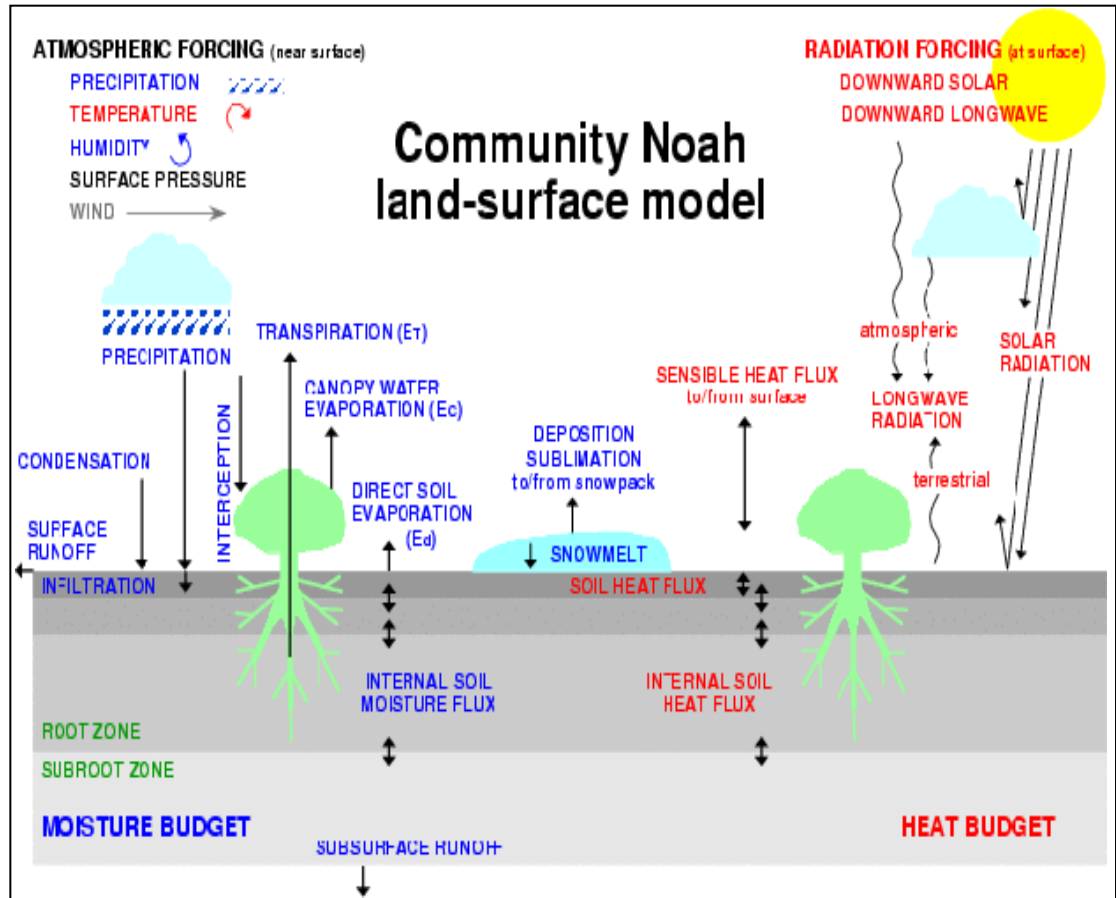
- **Surface fluxes balanced by net radiation (R_n), = sum of incoming and outgoing solar and terrestrial radiation, with vegetation important for energy partition between H , LE , G , i.e. surface roughness & near-surface turbulence (H), plant & soil processes (LE), and heat transport thru soil/canopy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

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

$$R_n = H + LE + G$$

Unified NCEP-NCAR Noah Land Model

- Four soil layers (shallower near-surface).
- Numerically efficient surface energy budget.
- Jarvis-Stewart "big-leaf" canopy conductance with associated veg parameters.
- Canopy interception.
- Direct soil evaporation.
- Soil hydraulics and soil parameters.
- Vegetation-reduced soil thermal conductivity.
- Patchy/fractional snow cover effect on sfc fluxes.
- Snowpack density and snow water equivalent.
- Freeze/thaw soil physics.

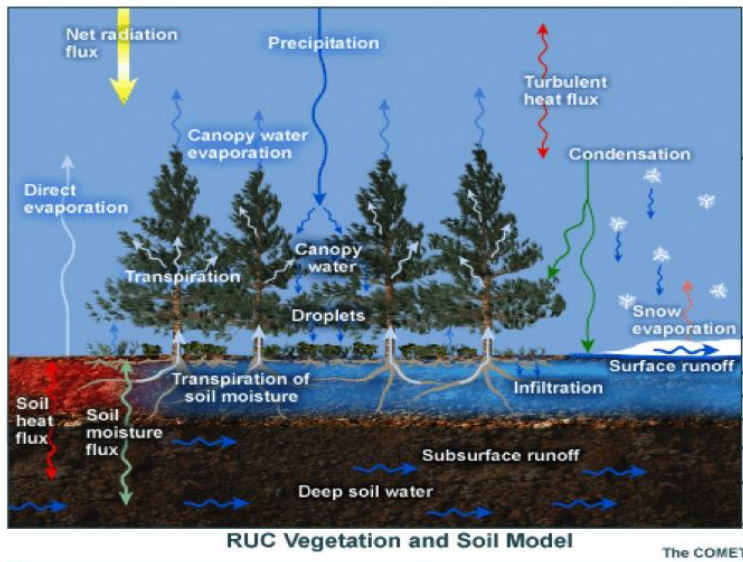


- Noah coupled with NCEP model systems: short-range NAM, medium-range GFS, seasonal CFS, HWRF, uncoupled NLDAS, GLDAS.

NOAA/ESRL Land-Surface Development

RUC LSM implemented in:

- Weather Research and Forecasting (WRF) modeling system in 2002, used frequently in WRF by non-ESRL WRF researchers
- NCEP/operational Rapid Refresh (RAP) system : RAPv1 - May 2012, RAPv2 - Feb 2014, RAPv3 in fall 2015 (<http://rapidrefresh.noaa.gov>)
- NCEP/operational HRRR – HRRRv1 - Sept 2014, HRRRv2 - fall 2015
- NASA Land Information System (LIS) - work in progress, nearly complete



Main characteristics of RUC LSM

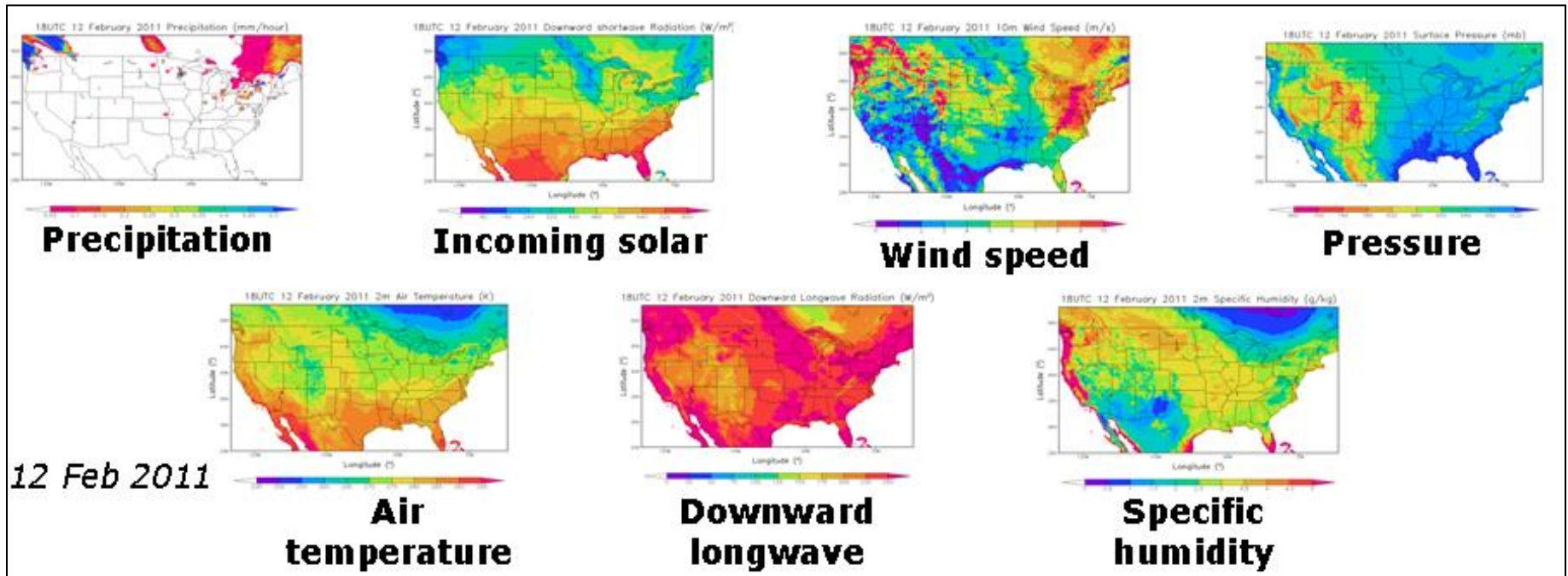
- Implicit solution of energy and moisture budgets
- Multiple soil levels with high vertical resolution near surface (9 levels)
- 2-layer snow model with iterative snow melting algorithm, patchy snow, also applied to snow cover on sea-ice
- Treatment of mixed phase precipitation
- Simple but effective frozen soil phys algorithm
- Smirnova et al. 2015 MWR, accepted w/ revs

Land Surface Model Parameters

- Surface **momentum roughness dependent on vegetation**/land-use type and 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 into the soil a **function of green vegetation fraction** (coverage) and **leaf area index** (density).
- **Soil thermal and hydraulic processes** highly **dependent on soil type** (vary by orders of magnitude).

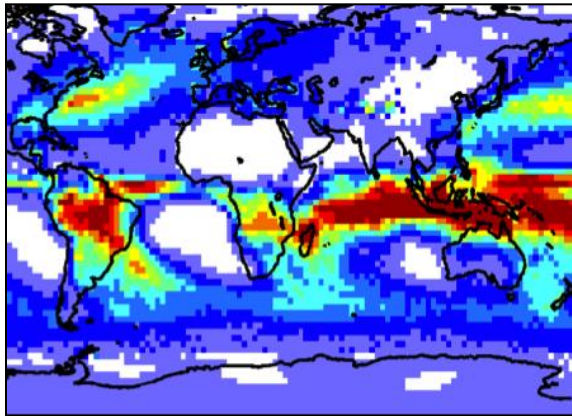
Atmospheric Forcing

- Atmospheric forcing from parent atmospheric model (e.g. GFS), or analysis/reanalysis (e.g. CFSR) or Regional Climate Data Assimilation System (real time extension of the North American Regional Reanalysis, NARR).
- Precipitation is quite important for land models with observed precip input to the land model in the assimilation cycle, e.g. CPC gauge-based observed precip., temporally disaggregated with radar data (stage IV), satellite data (CMORPH), bias-corrected with "PRISM".

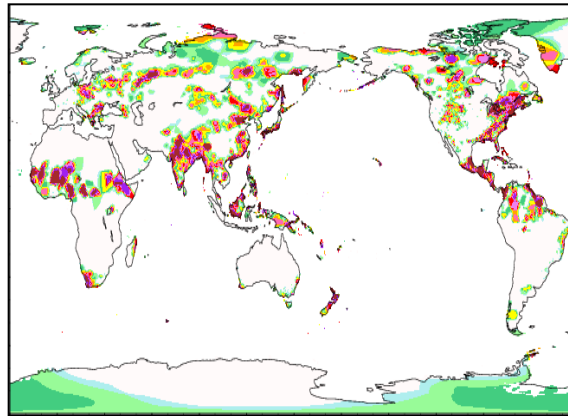


Atmospheric Forcing: Precipitation

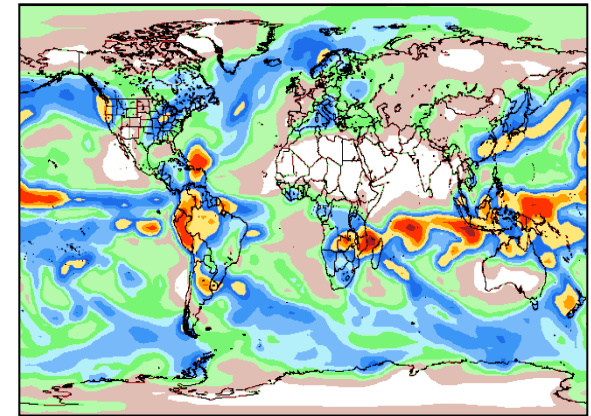
- Global Land Data Assimilation System (GLDAS) used in NCEP Climate Forecast System (CFS) relies on “blended” precipitation product, function of:
- **Satellite-estimated precipitation** (CMAP), heaviest weight in tropics where gauges sparse.
- Surface gauge network, heaviest in mid-latitudes.
- High-latitudes: Model-estimated precipitation based on Global Data Assimil. System (GDAS).



CMAP

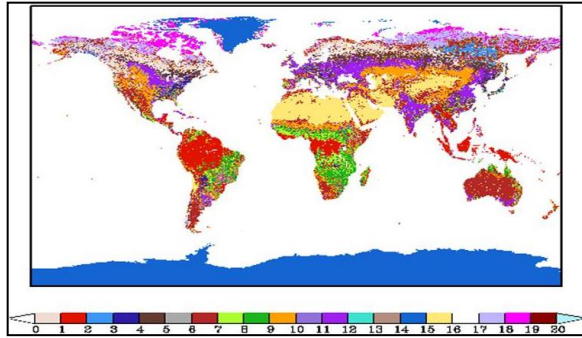


Surface gauge

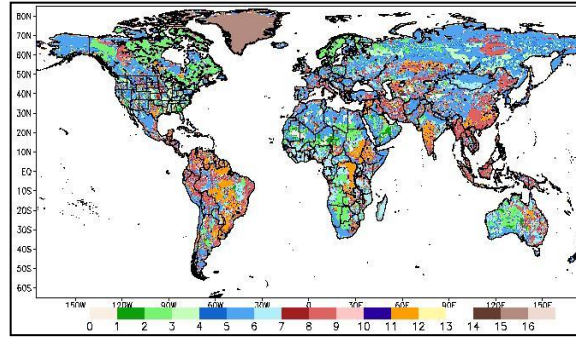


GDAS

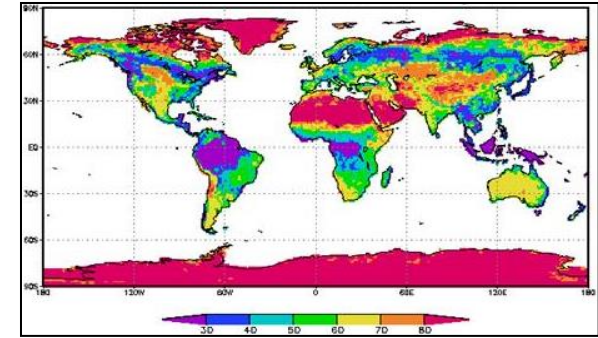
Land Data Sets



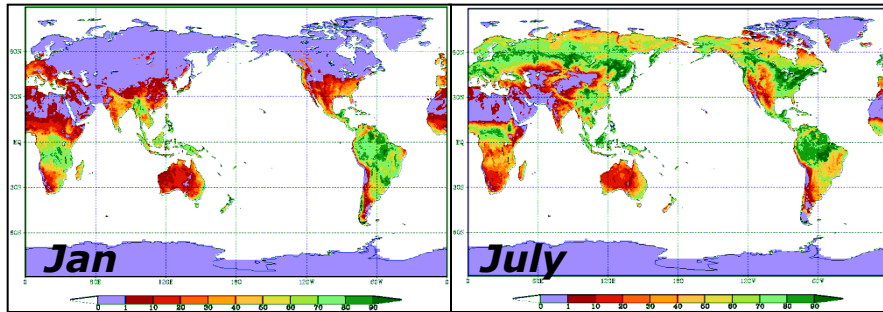
Vegetation Type
(1-km, IGBP-MODIS)



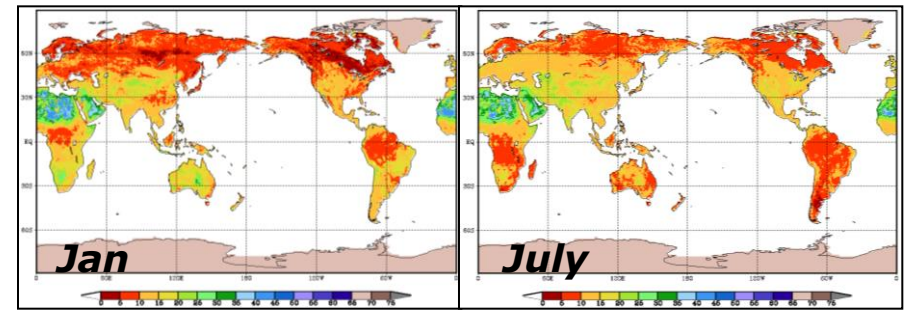
Soil Type
(1-km, STATSGO-FAO)



Max.-Snow Albedo
(1-km, UAz-MODIS)



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

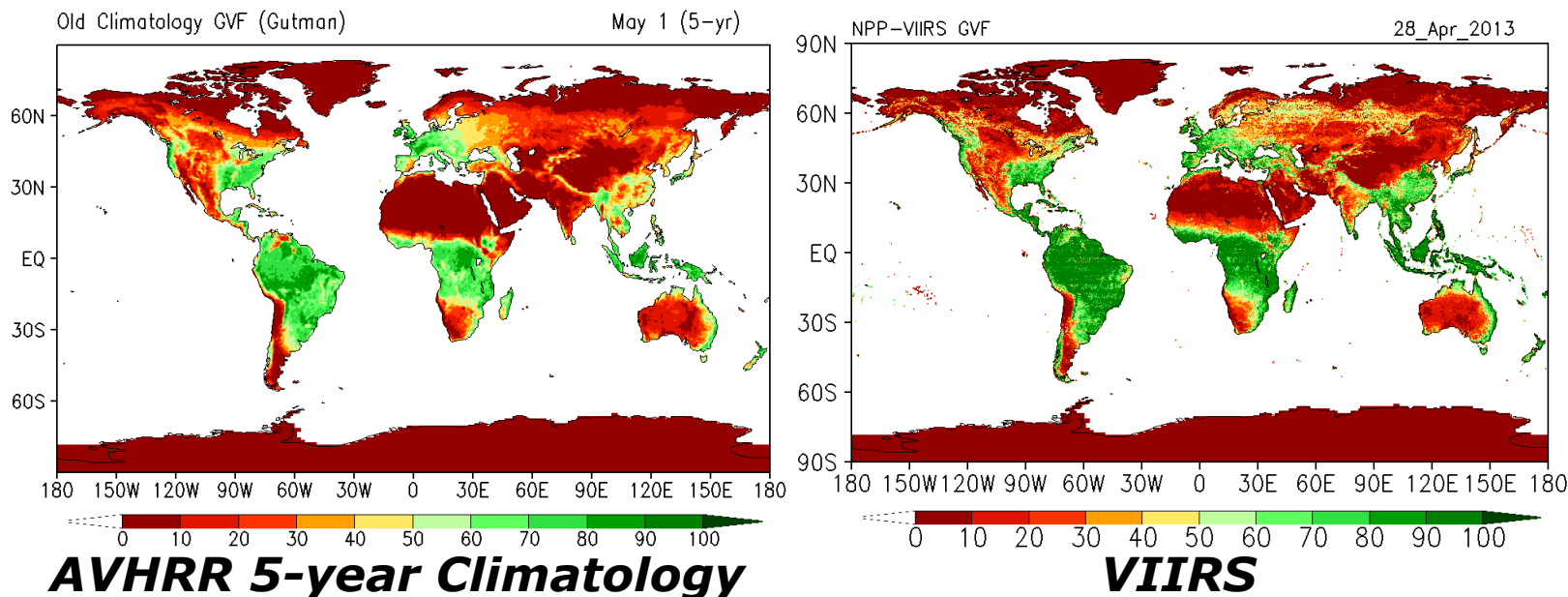


Snow-Free Albedo
(monthly, 1-km, Boston Univ.-MODIS)

- Fixed annual/monthly/weekly climatologies, or near real-time observations; some quantities may be assimilated into Noah, e.g. soil moisture, snow, greenness as initial land states.

Green Vegetation Fraction (GVF)

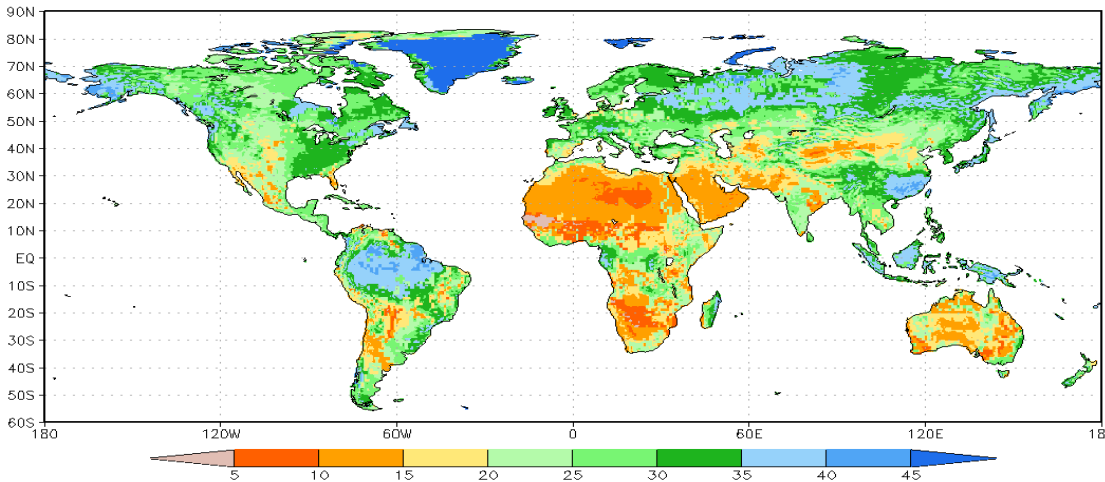
- **Climatology vs. near real-time GVF.**



- **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.
- Note: *VIIRS GVF in Midwestern US much lower than AVHRR GVF Climatology.*

Land States

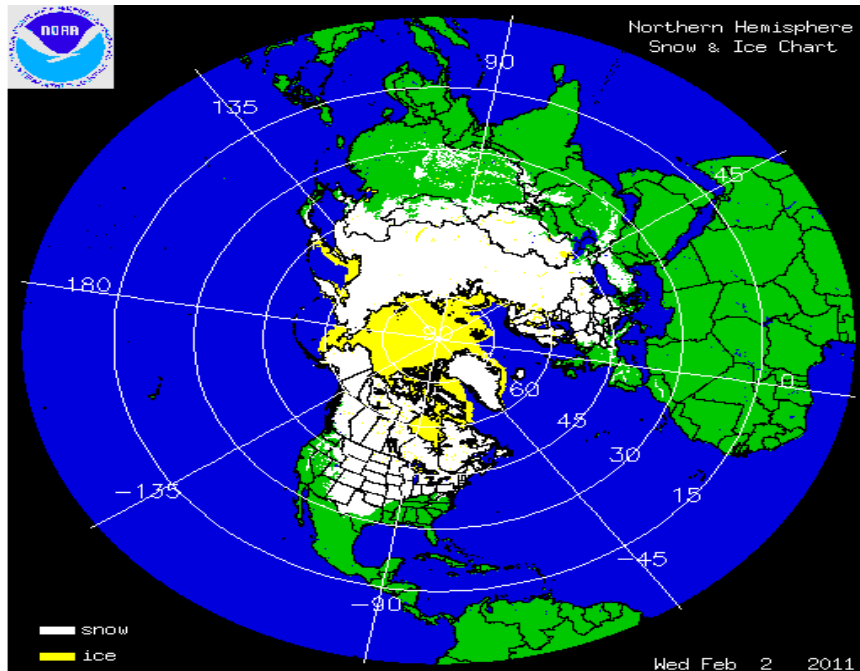
- Valid **land state initial conditions** are **necessary** for NWP and climate models, & must be consistent with the land model used in a given weather or climate model, i.e. from same **cycling** land model.
- Land states spun up in a given NWP or climate model **cannot** be used directly to **initialize** another model without a **rescaling** procedure because of differing land model soil moisture climatologies.



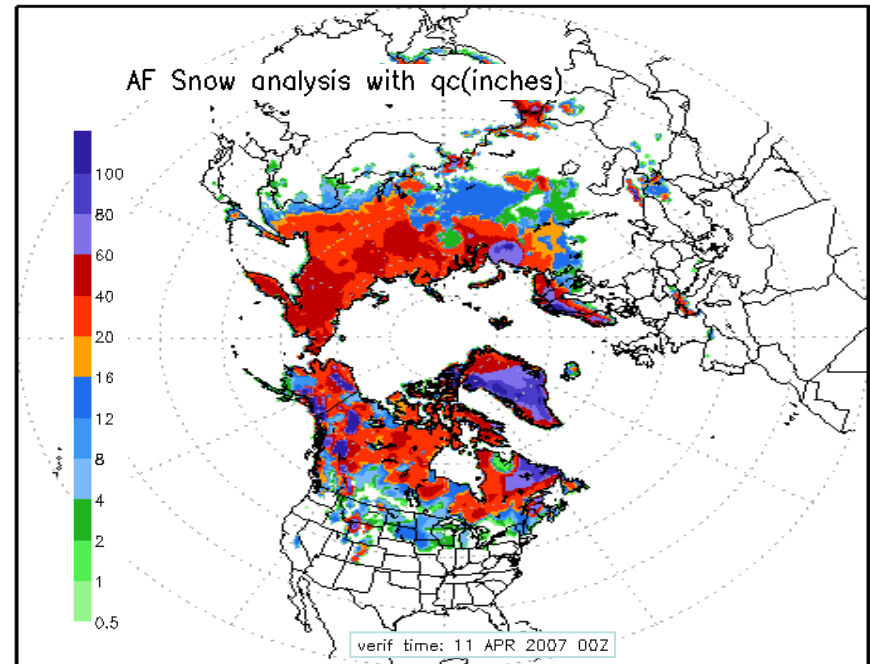
May Soil Moisture Climatology from 30-year NCEP Climate Forecast System Reanalysis (CFSR), spun up from Noah land model coupled with CFS.

Land States (cont.)

- In addition to *soil moisture*: the land model provides *surface skin temperature, soil temperature, soil ice, canopy water, and snow depth & snow water equivalent*.



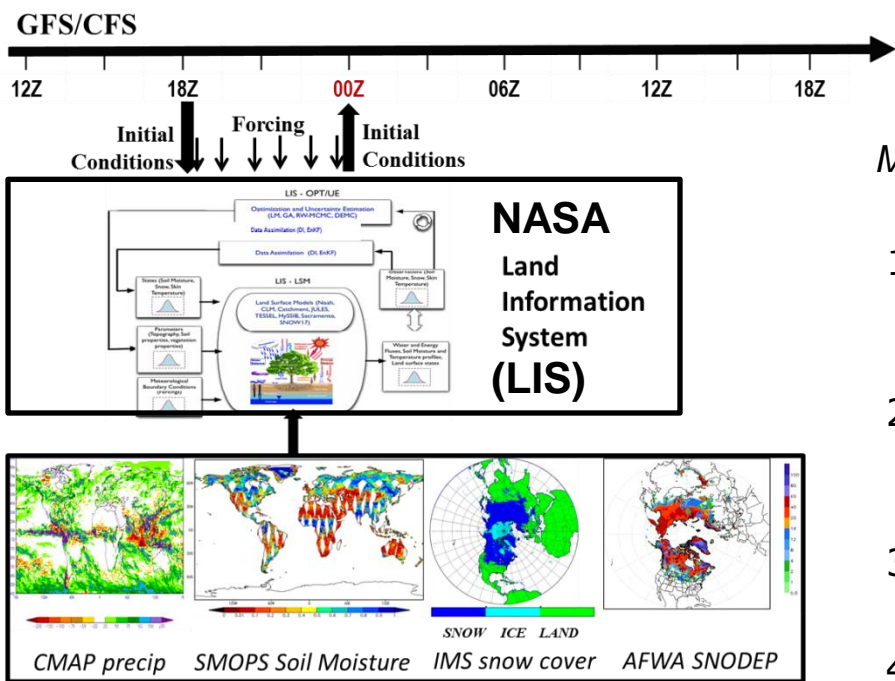
**National Ice
Center snow cover**



**Air Force Weather Agency
snow cover & depth**

Satellite-based Land Data Assimilation Tests in NWS GFS/CFS Operational Systems

- Use NASA Land Information System (LIS) to serve as a global Land Data Assimilation System (LDAS) for both GFS and CFS.
- 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.



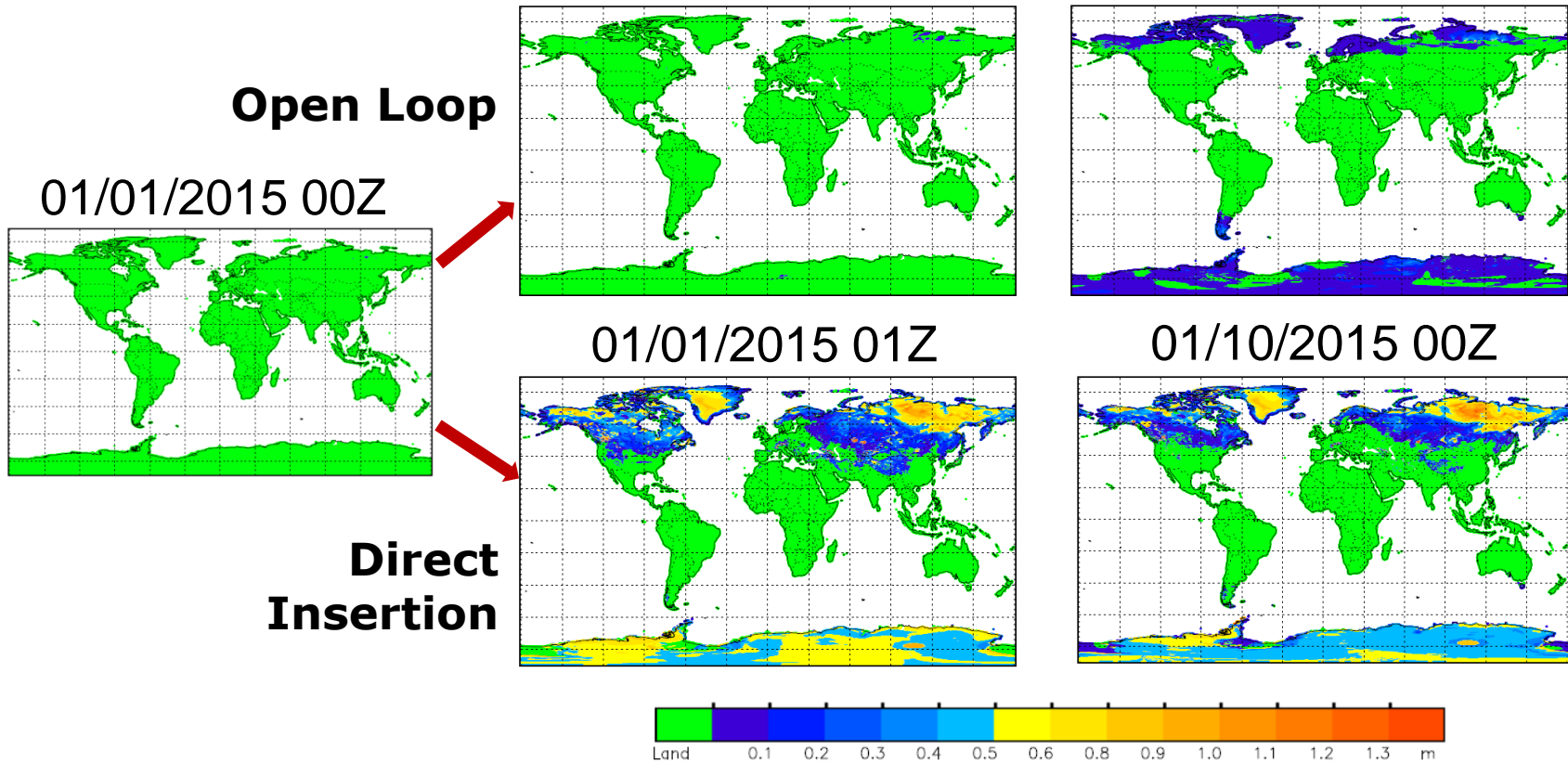
NGGPS Project: Land Data Assimilation

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.
4. End of 2 years: Pre-implementation testing for snow and soil moisture assimilation.

Jiarui Dong, NCEP/EMC

Land data assimilation: Snow Depth



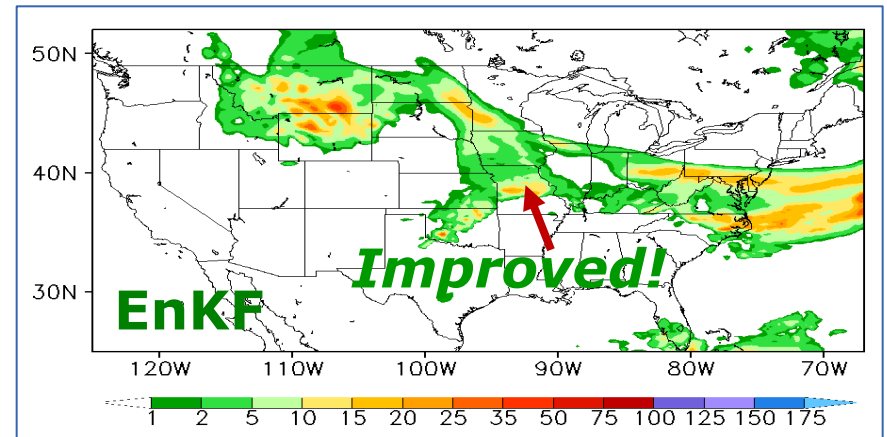
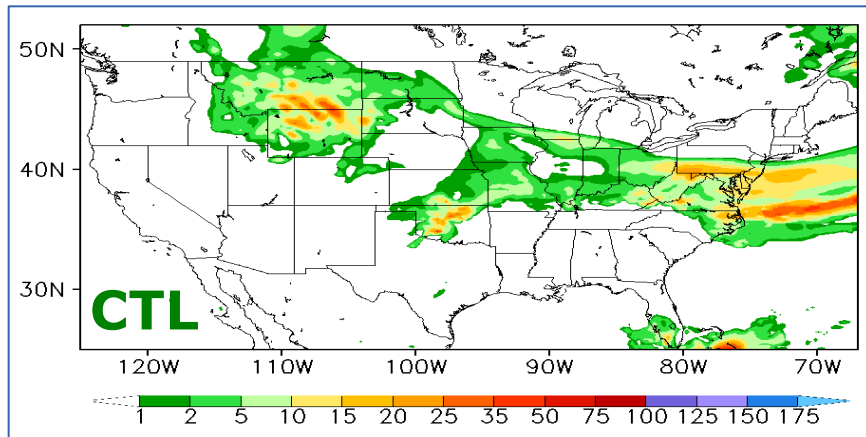
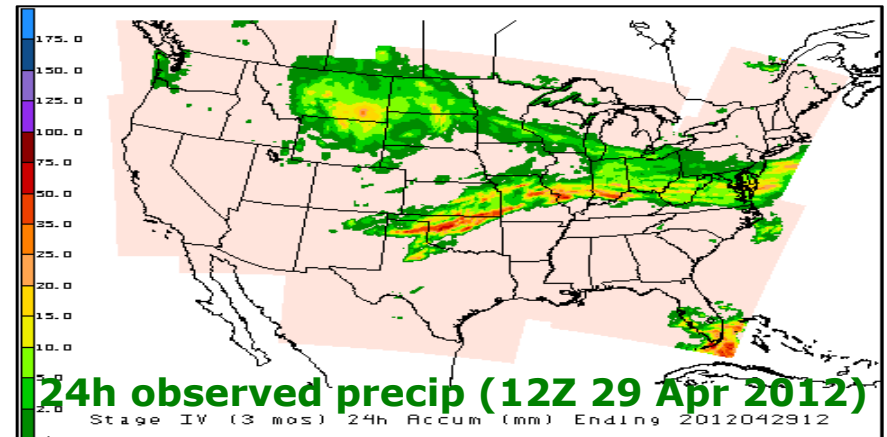
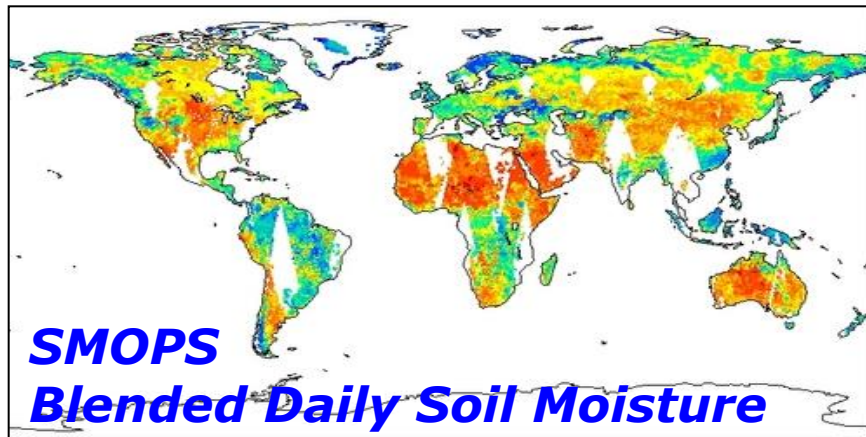
EnKF

We are 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

Land data assimilation: 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 precip.

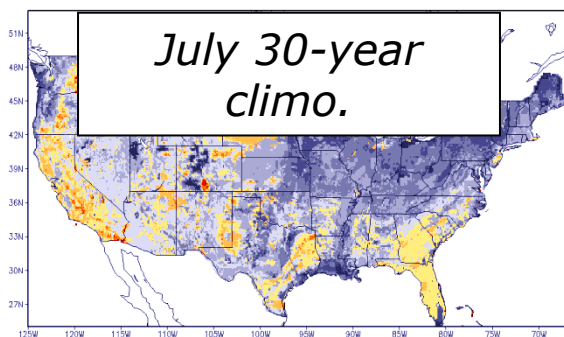
Weizhong Zheng, NCEP/EMC and Xiwu Zhan, NESDIS/STAR

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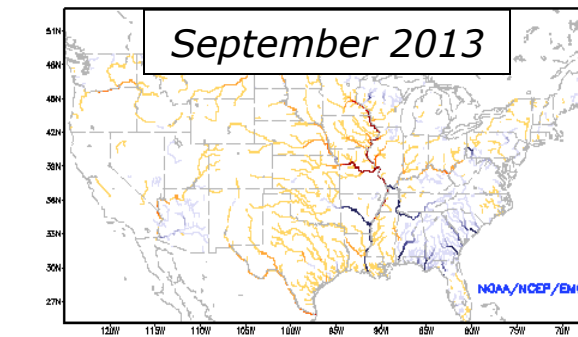
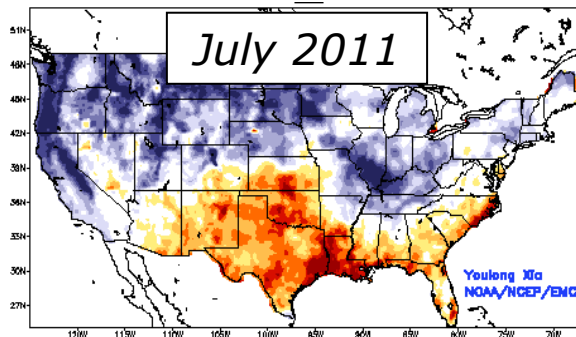
North American Land Data Assimilation System (NLDAS)

- 5 Aug 2014: North American LDAS (NLDAS) operational.
- NLDAS: 4 land models run uncoupled, driven by CPC observed precipitation & NCEP R-CDAS atmospheric forcing.
- Output: 1/8-deg. **land & soil states**, **surface fluxes**, **runoff** & **streamflow**; anomalies from 30-yr climatology for drought.
- Future: higher res. (~3-4km), extend to N.A./global domains, improved land data sets/data assimil. (soil moisture, snow), land model physics upgrades inc. hydro., initial land states for weather & seasonal climate models; global drought information.

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



Ensemble monthly soil moisture anomaly

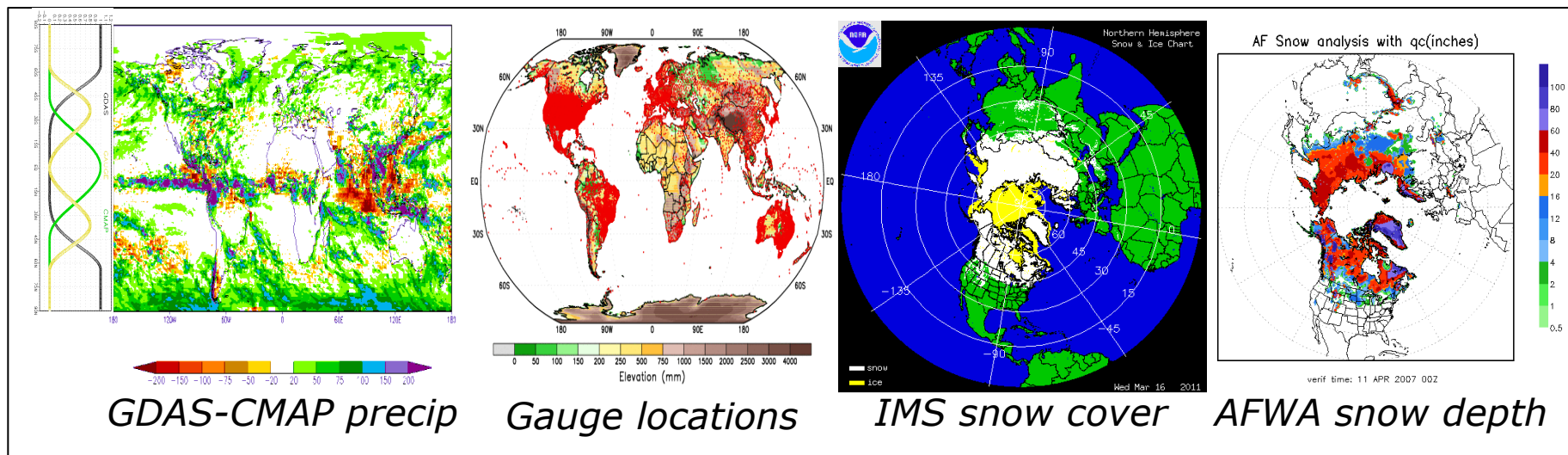


Daily streamflow anomaly

Youlong Xia, NCEP/EMC

Global Land Data Assimilation System (GLDAS)

- Uses **Noah land model** running under NASA Land Information System forced with **Climate Forecast System (CFS)** atmos. data assimil. cycle output, & **"blended" precipitation** (gauge, satellite & model), "semi-coupled" –daily updated land states.
- **Snow** cycled if snow from Noah land model within a 0.5x/2.0x envelope of observed value (IMS snow cover, AFWA depth).
- GDIS: GLDAS soil moisture climatology from 30-year runs provides **anomalies** for **drought monitoring**.
- GLDAS land "re-runs", with updated forcing, physics, etc.



Jesse Meng NCEP/EMC

Land model and land-related issues

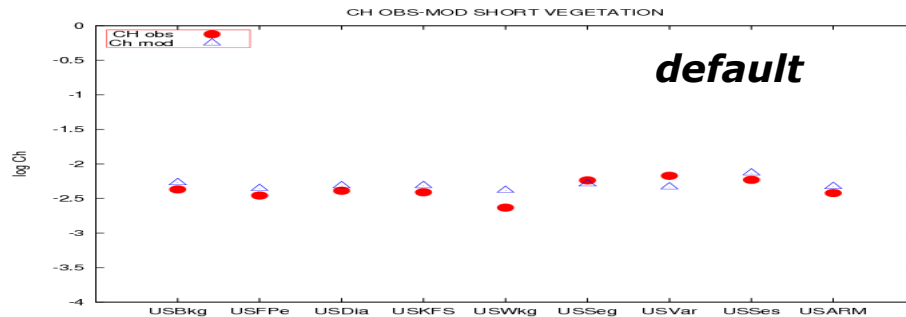
Low-level biases in winds, temperature, and humidity are influenced in part by the land surface via biases in surface fluxes exchanged with the atmospheric model.

Improving the proper partition of surface energy budget between sensible, latent, soil heat flux and outgoing longwave radiation currently requires:

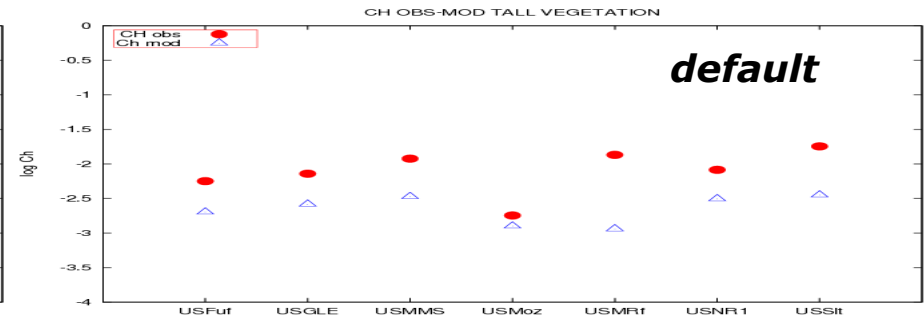
- Improved vegetation parameters to calculate transpiration.
- Near-realtime vegetation greenness to improve bowen ratio.
- Better specification of surface and soil properties to address heterogeneity.
- Improved snow physics (melt/freeze, densification).
- Data assimilation of near-realtime snow, soil moisture, GVF.
- Improved forcing for the land model, especially precipitation and downward radiation; requires enhanced downscaling techniques.
- Surface-layer physics, especially nighttime/stable conditions.

Testing and Validation: Surface-layer Simulator

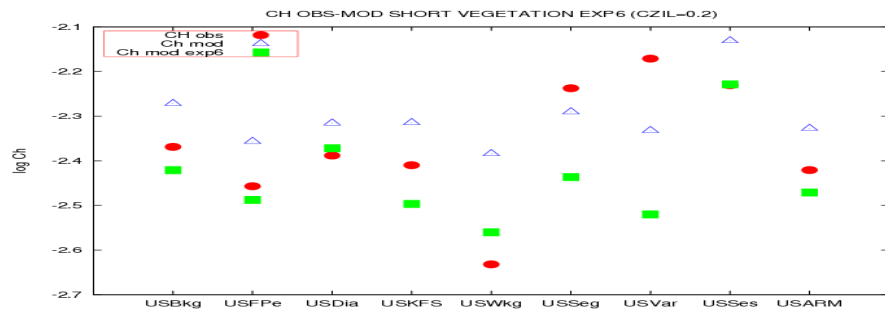
- GOAL: Improve surface turbulence exchange coefficients.
- Surface-layer simulation ("SLS") code simulates surface-layer and schemes from meso-NAM and medium-range GFS.
- Use observations to drive SLS (U,T,q and Tsfc) and compare with inferred Ch, Cd from independent "fluxnet" obs (H, LE, τ).
- Bias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



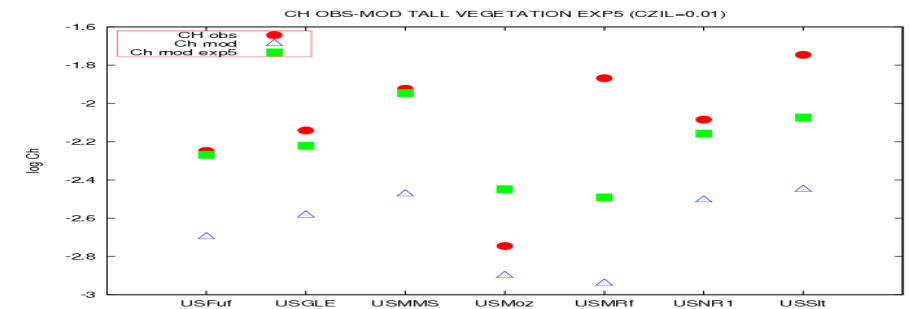
short vegetation, czil=0.1



tall vegetation, czil=0.1



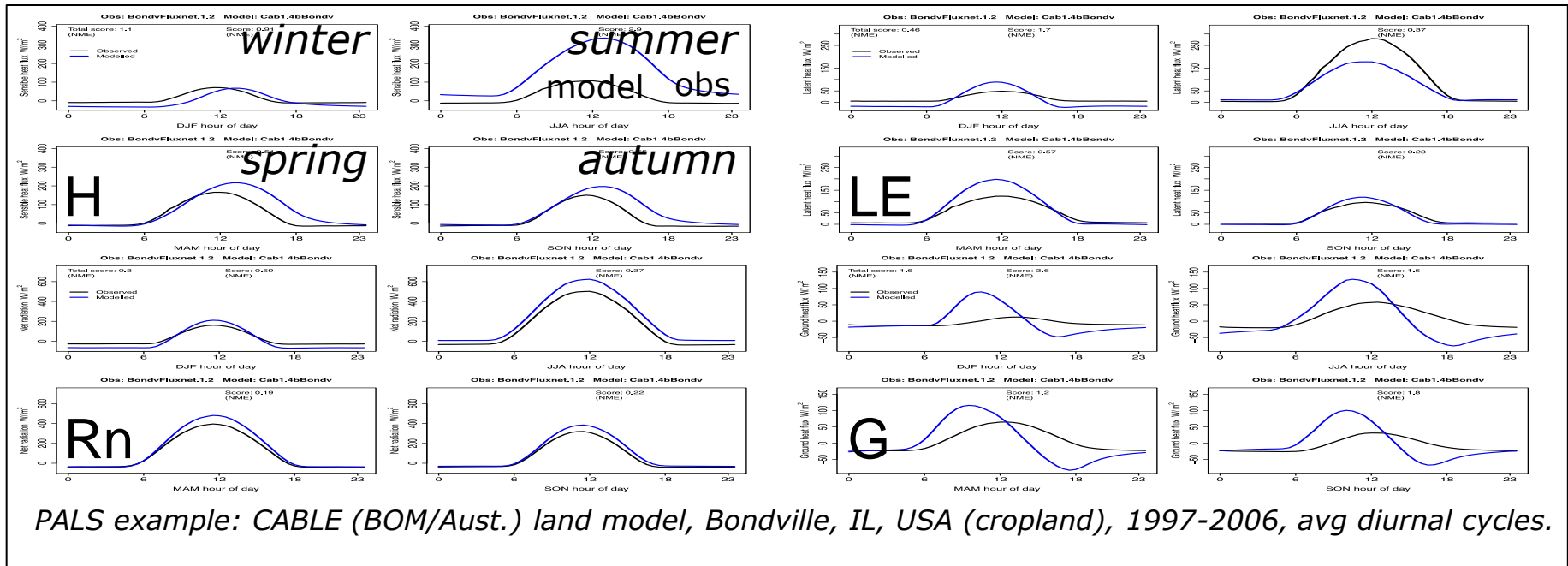
short vegetation, czil=0.2



tall vegetation, czil=0.01

Testing & Validation: Land Model Benchmarking

- Benchmarking: Decide how good model needs to be, then run model and ask: *Does model reach the level required?*
- **Protocol for the Analysis of Land Surface 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: Column Model Testing

Diurnal land-atmosphere coupling experiment (DICE)

Objective: Assess impact of land-atmosphere feedbacks.

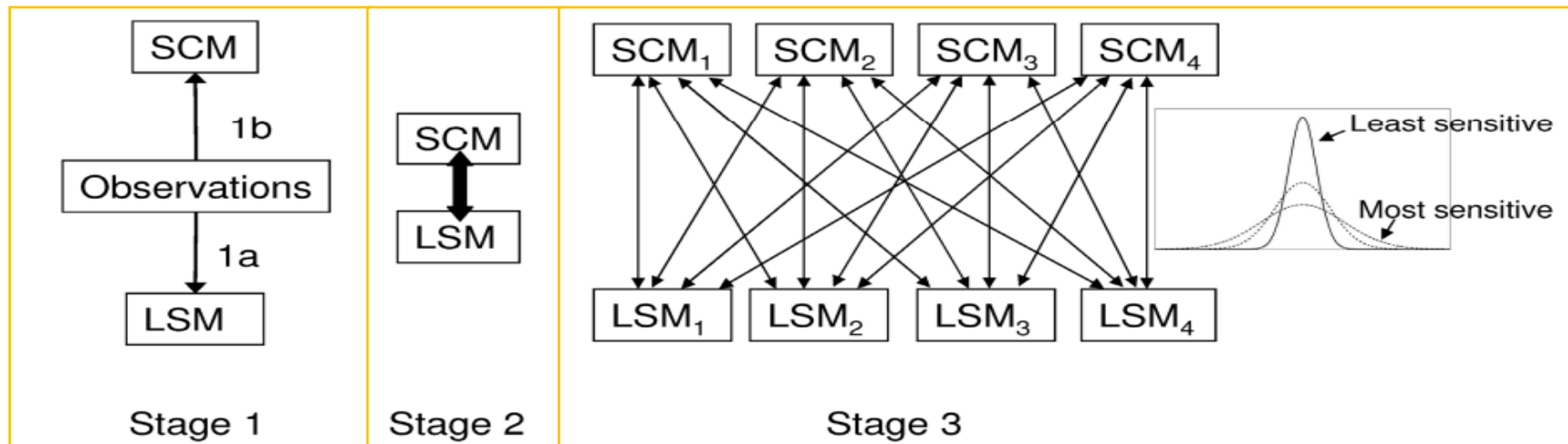
Stage 1: stand alone land, and single column model (SCM) alone.

Stage 2: Coupled land-SCM.

Stage 3: Sensitivity of LSMs & SCMs to variations in forcing.

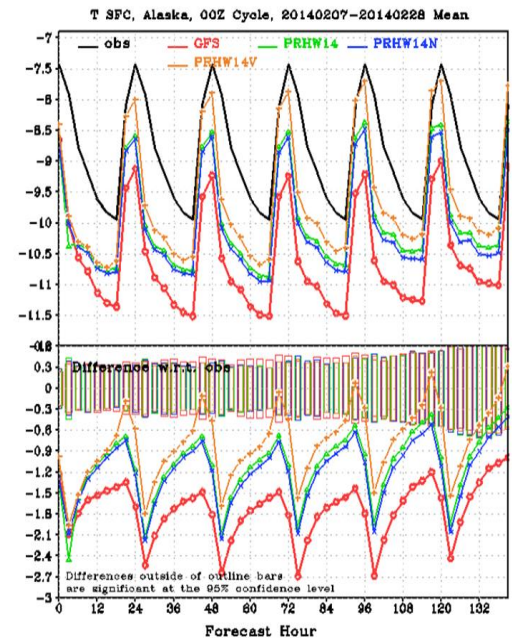
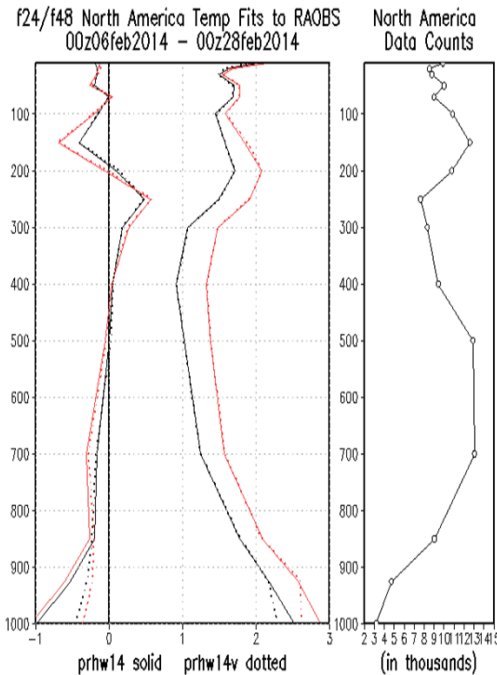
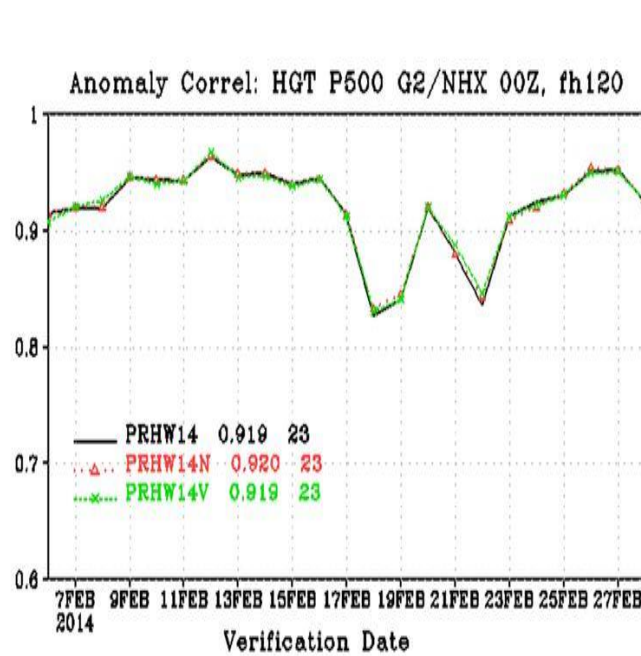
Data Set: CASES-99 field experiment in Kansas, using 3 days: 23-26 Oct 1999, 19UTC-19UTC.

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

Future

- Improve/include:
 - Forcing, e.g. precipitation (CONUS and global data sets).
 - Land data sets, e.g. vegetation greenness (near-realtime).
 - Land data assimilation, i.e. snow, soil moisture.
 - Land model physics, e.g. vegetation dynamics, carbon, irrigation, etc., via latest Noah or **Noah-MP** land model.
 - Influence of freshwater lakes ("**FLake**").
 - Higher resolution/downscaling (forcing, model output).
 - Enhanced land model spin-up procedures.
 - Extend the current North American Land Data Assimilation System (CONUS-domain) to entire North America (NAM-domain), then "merge" with GFS/CFS/Global LDAS (GLDAS).
- Provide improved initial land conditions for NAM, GFS, CFS.
- Earth System modeling: Include hydrological prediction (e.g. groundwater, **streamflow**) via cooperative interaction/direct connection in model development with the new NWS National Water Center whose focus is on hydrology.

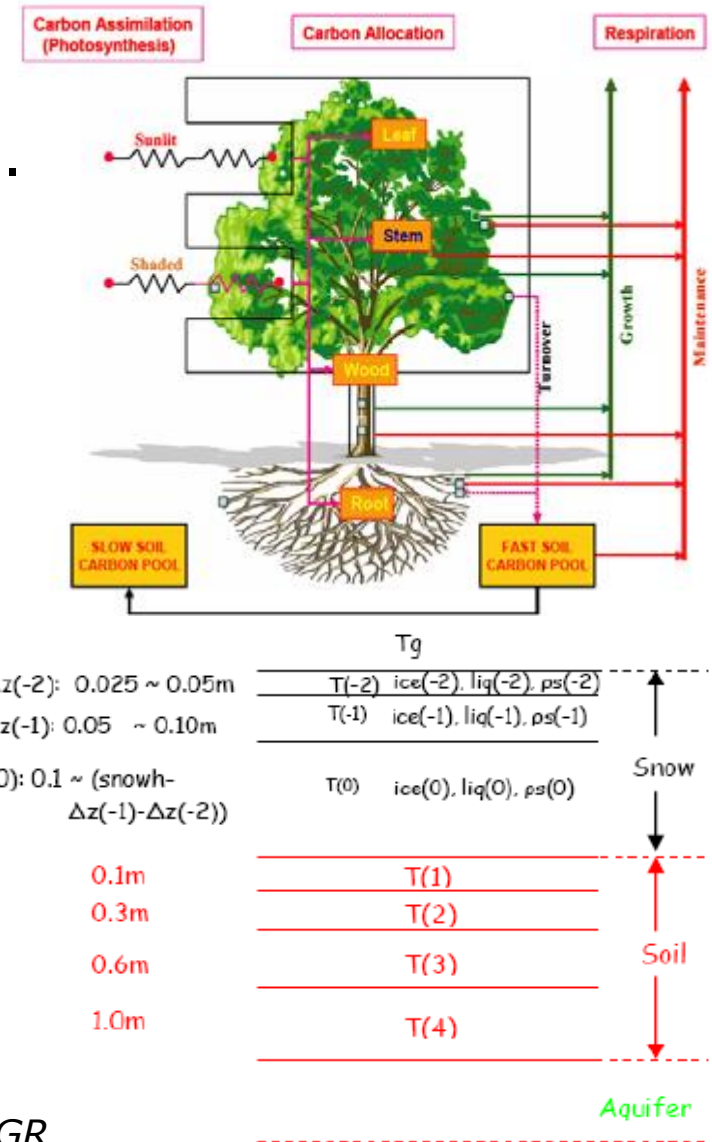
Noah Multi-Physics (Noah-MP)

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.
- Snowpack liquid water retention.
- New frozen soil scheme.
- Interaction with groundwater/aquifer.

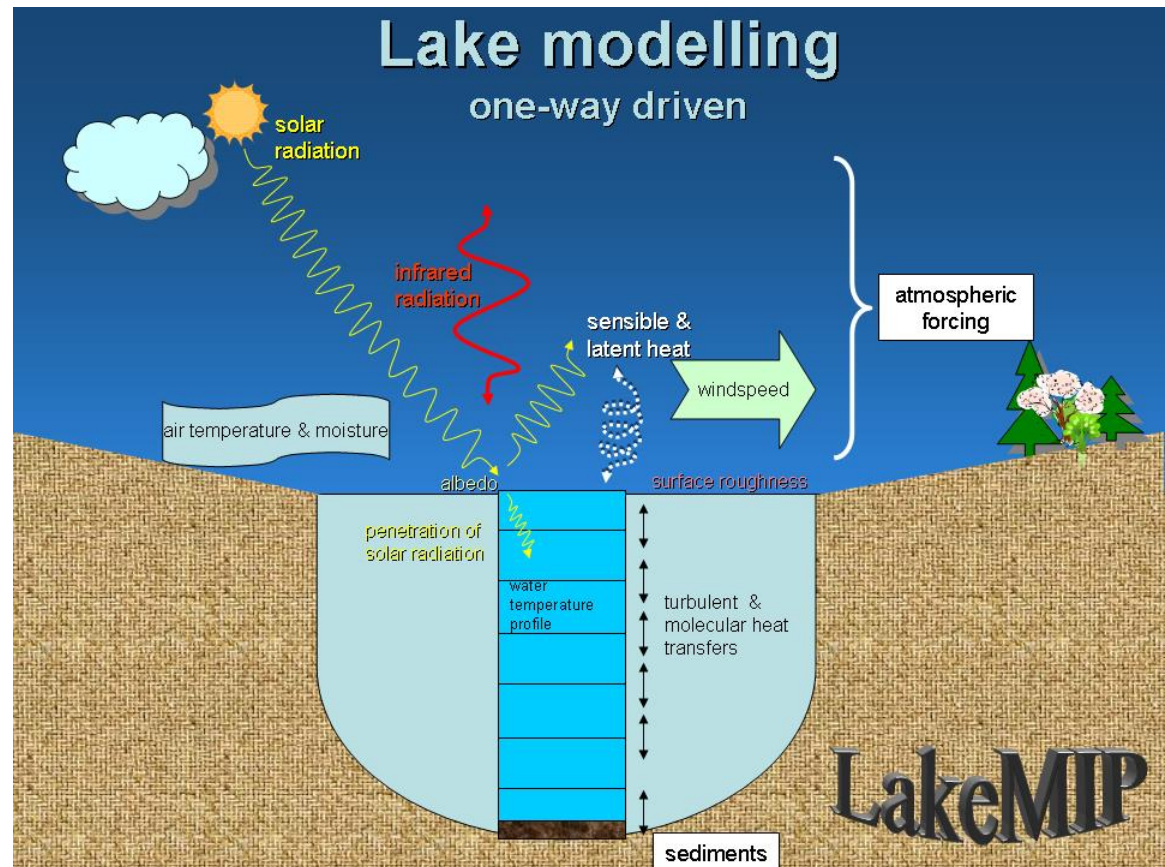
Main contributors: Zong-Liang Yang (UT-Austin); Guo-Yue-Niu (U. Arizona); Fei Chen, Mukul Tewari, Mike Barlage, Kevin Manning (NCAR); Mike Ek (NCEP); Dev Niyogi (Purdue U.); Xubin Zeng (U. Arizona)

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



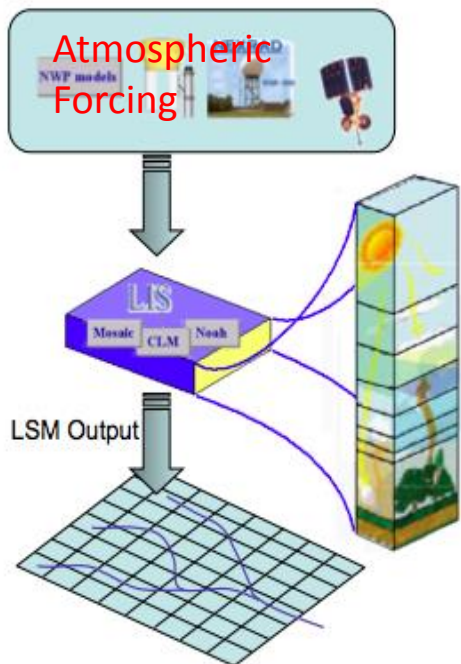
Lake modeling

- Freshwater lake “**FLake**” model (*Dmitrii Mironov, DWD*).
- In use in regional COSMO, HIRLAM (European meso-scale models), CMC, UKMO and ECMWF (global).
 - two-layer.
 - temperature and energy budget.
 - mixed-layer and thermocline.
 - snow-ice module.
 - atmospheric forcing inputs.
 - specified depth and turbidity.



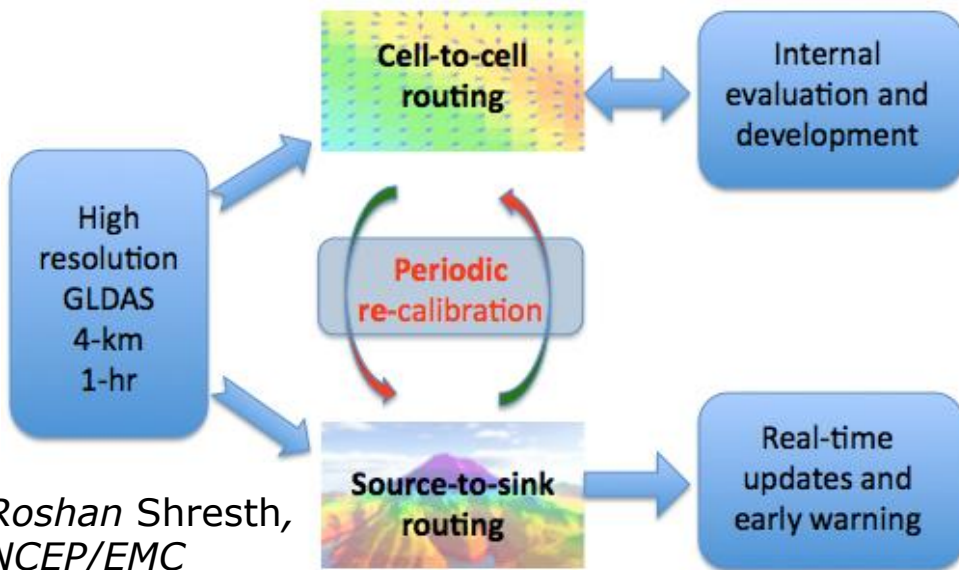
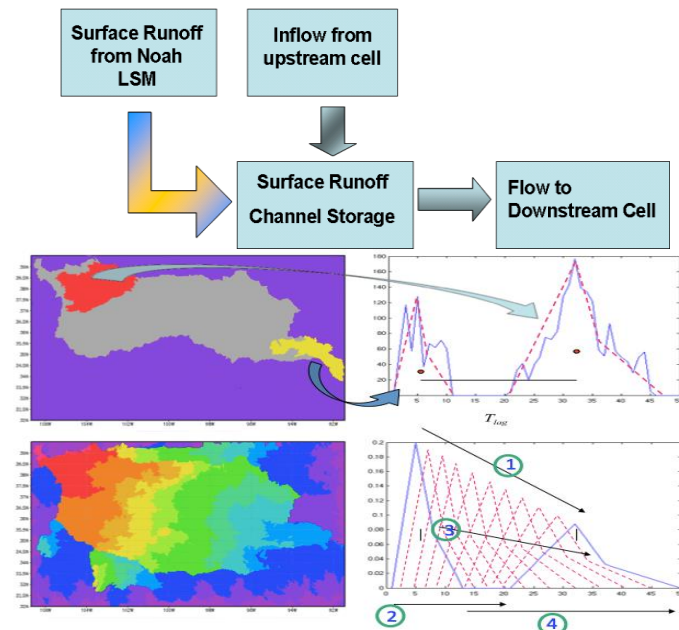
Yihua Wu, NCEP/EMC

Streamflow: River-routing scheme

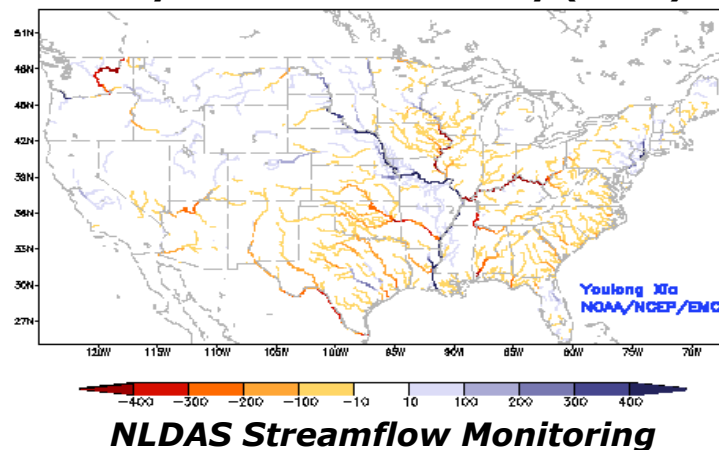


Cell-to-cell routing
 computationally intensive
 parameter calibration is challenging
 Hard to implement for ensemble simulation and real-time operation

Source-to-sink routing
 Computationally efficient
 Accuracy is close to Cell-to-cell routing
 Useful for providing real-time updates and ensemble simulation



**Hurricane Irene and Tropical Storm Lee
 20 Aug–17 Sep 2011
 Daily streamflow anomaly (m^3/s)**



RUC LSM Upgrades

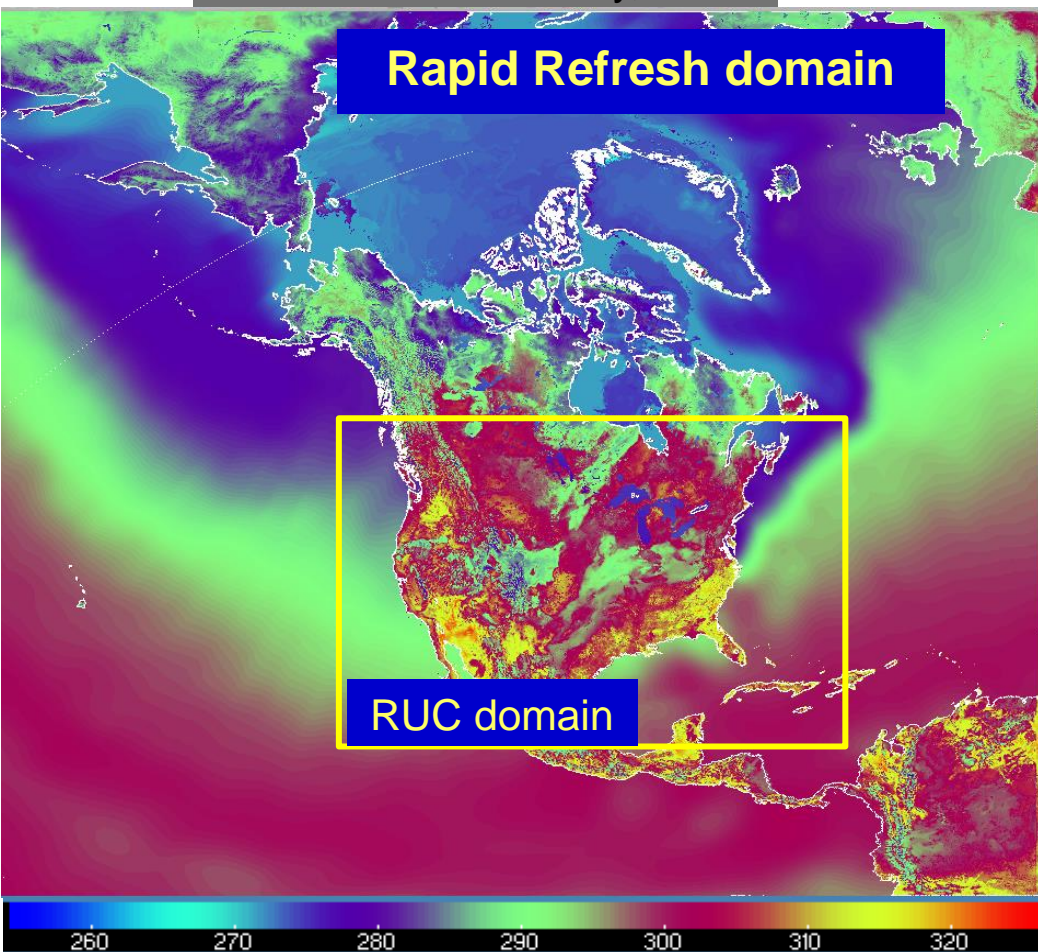
-motivated by WRF-based Rapid Refresh (RAP)

RAP Skin Temperature
Valid at 18 UTC 8 July, 2015

➤ RAP polar application in Canada and Alaska

- new treatment for sea ice in RUC LSM
- modifications to snow model and snow/ice albedo
- Increased vertical resolution
- Use of MODIS greenness fraction climatology; seasonal variations of z_0
- Use of MODIS Leaf Area Index (LAI) climatology
- Subgrid-scale heterogeneity
- Exponential formulation for grid cell effective z_0
- “Mosaic” approach for patchy snow
- Simple treatment of cropland irrigation

NGGPS future: Ensemble LDAS (different numerical treatment), ensemble LIS, intercomparisons with Noah LSM, code contributions to Noah



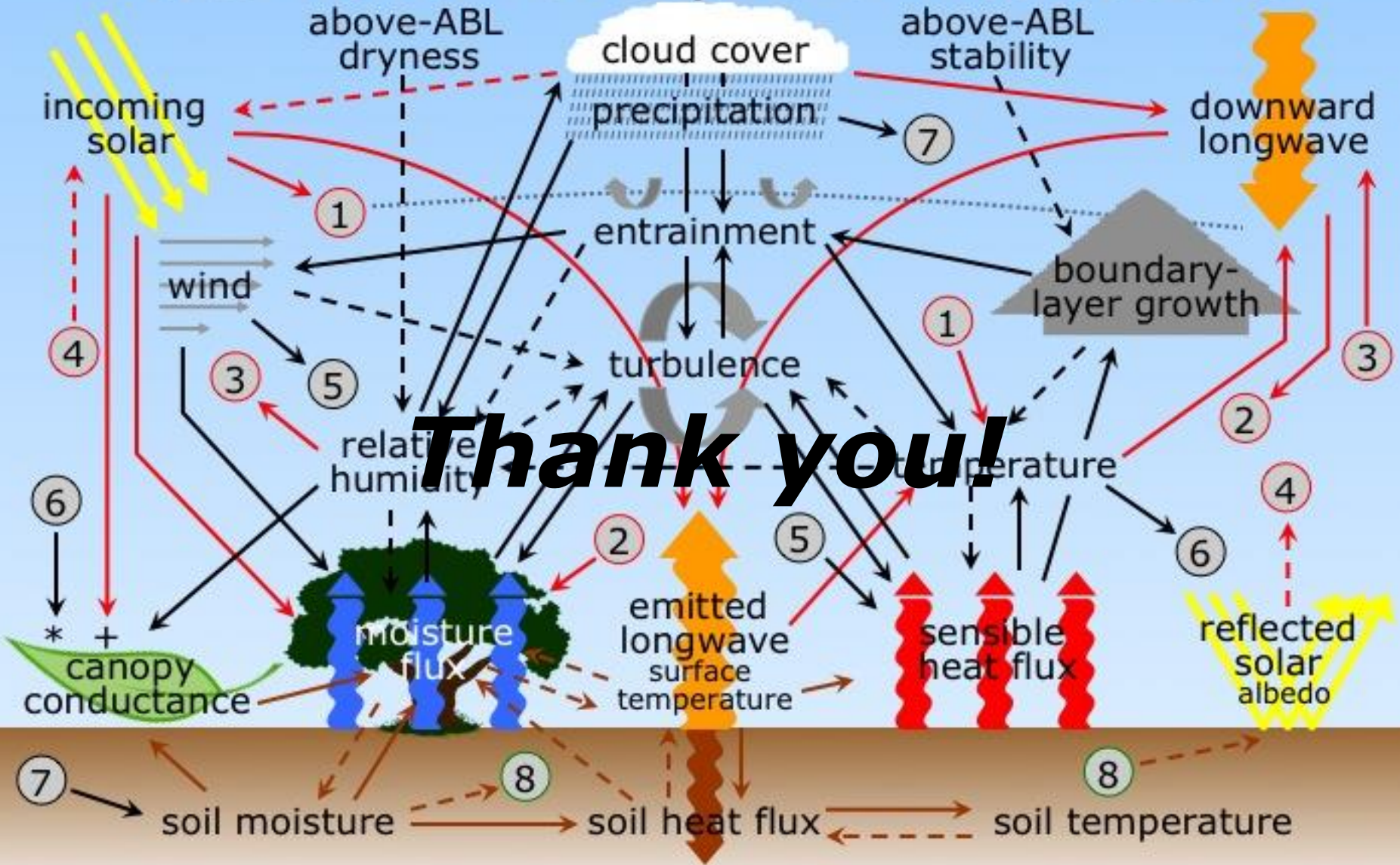
Tanya Smirnova and Stan Benjamin NOAA/ESRL

NGGPS Annual Meeting, NCWCP, College Park, Maryland, USA, 14-17 July 2015

Land Surface Prediction: Summary

- Land models provide surface **boundary conditions** for weather and climate models (e.g. NCEP GFS), and then **proper representation of interactions** with atmosphere.
- For NWP and seasonal forecasting, land models must have **valid physics** and associated parameters, representative **land data sets** and in some cases **near-realtime**, proper **atmospheric forcing**, and **initial and cycled land states**.
- Land model **validation** using (near-) **surface observations**, e.g. air temperature, relative humidity, wind, soil moisture, surface fluxes, etc ...suggests model **physics improvements**.
- The role of land models is expanding for weather and climate in increasingly more fully-coupled Earth-System Models (atmosphere-ocean-land-sea ice-waves-aerosols) with **connections** between **Weather & Climate** and **Hydrology**, Ecosystem, **Biogeochemical** cycles (e.g. carbon), and **Air Quality** communities and models on local as well as large scales.

Local Land-Atmosphere Interactions



Thank you!

→ radiation → surface layer & ABL → land-surface processes → feedbacks:
 + positive feedback for C3 & C4 plants, negative feedback for CAM plants → positive
 *negative feedback above optimal temperature - - - → negative