



Interaction of North American Land Data Assimilation System and National Soil Moisture Network: Soil Products and Beyond

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Christa Peters-Lidard³, David M. Mocko^{4,5}, and Sujay V. Kumar⁴**

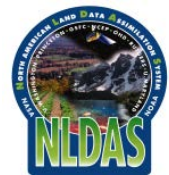
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Current Operational NLDAS Land Surface Models: NCEP/Noah, NASA/Mosaic, NWC/SAC, and Princeton/Washington/VIC

● NLDAS Products:

water fluxes – precipitation, runoff, routed streamflow, snowmelt, sublimation, ET;

energy fluxes – downward/upward shortwave and longwave radiation, net radiation, sensible heat flux, latent heat flux, ground heat flux;

state variables – soil temperature, soil moisture (liquid, frozen, total), skin temperature, SWE, snow cover and fraction, terrestrial water storage.

● Product evaluation/validation

Using in situ observations, remote sensing data, and reanalysis data to compressively evaluate almost all NLDAS products for different spatial and temporal scales. For more details, please see NASA NLDAS website:

<http://ldas.gsfc.nasa.gov/nldas/NLDAS2valid.php>

<http://ldas.gsfc.nasa.gov/nldas/NLDASpublications.php>

- NLDAS is a multi-model land modeling and data assimilation system...
- ...run in uncoupled mode driven by atmospheric forcing (using surface meteorology data sets)...
- ...with “long-term” retrospective and near real-time output of land-surface **water** and **energy** budgets.

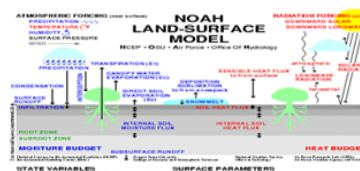
NLDAS Configuration: Land models

- Uncoupled (“offline”) simulations.

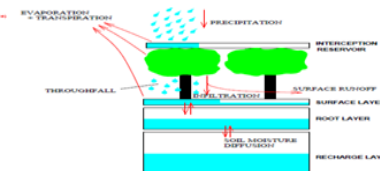
- Input: atmospheric forcing.

- Output: **water/energy** budgets (surface fluxes, land states)

Atmospheric Community

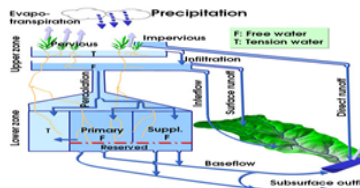


Noah
NCEP operational land model

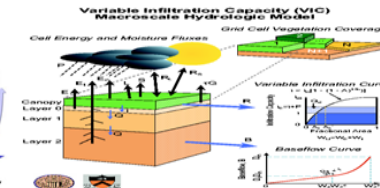


Mosaic
NASA GSFC

Hydrology Community



SAC
NWS operational hydrological model

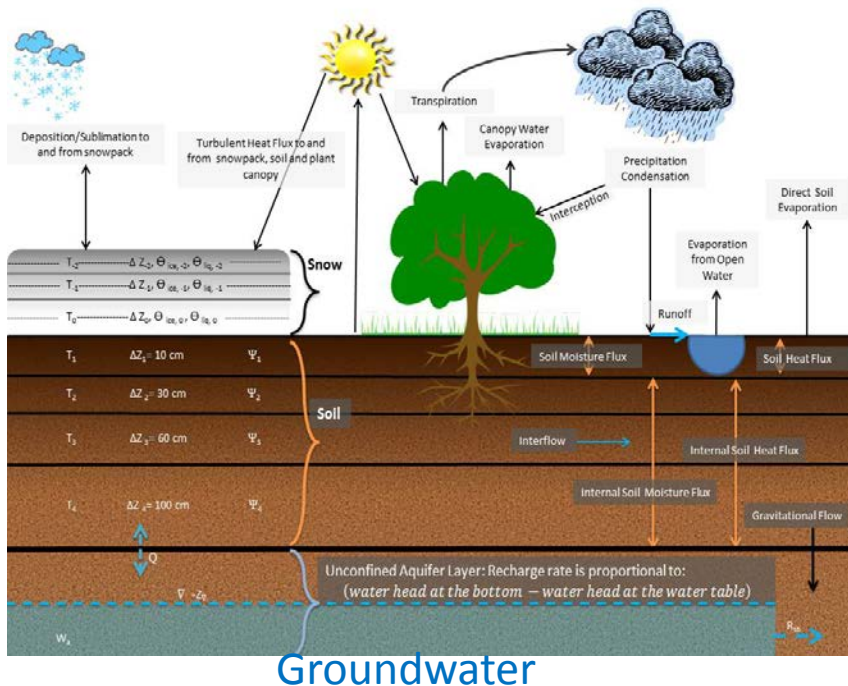


VIC
Princeton & U. Washington

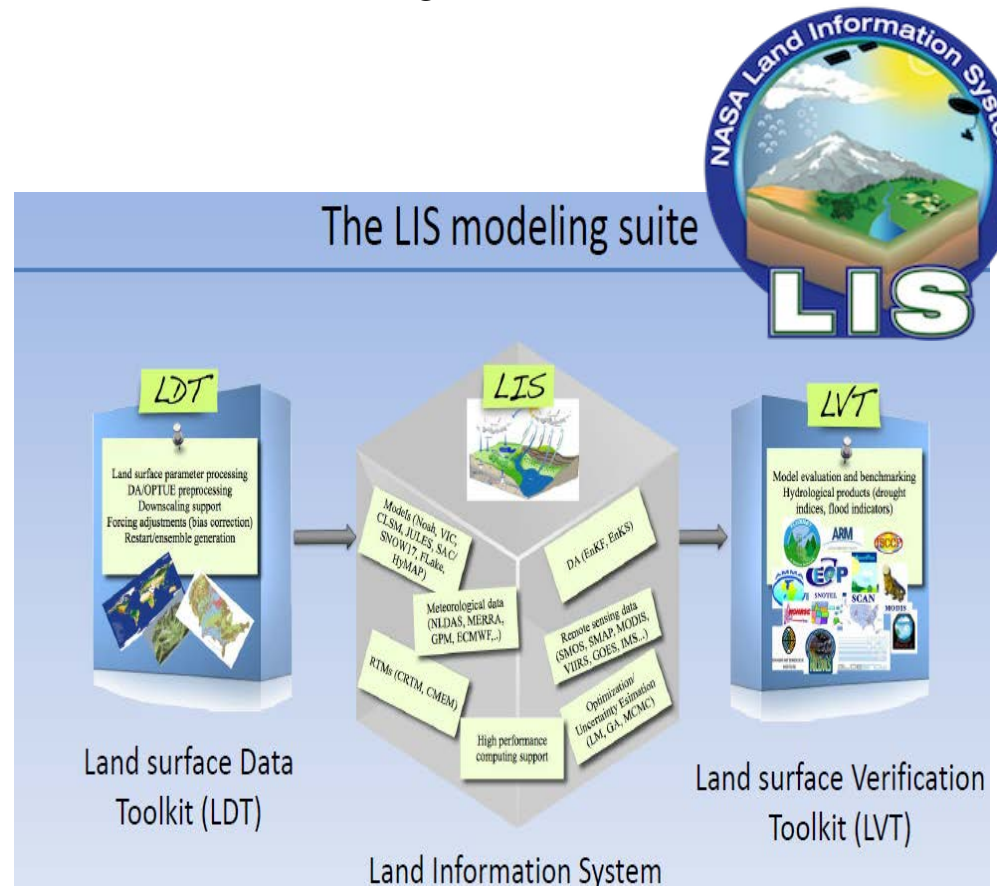
Next Phase NLDAS System – LIS-Based Framework

- NASA Land Information System (LIS) Framework
- Assimilation of soil moisture, snowpack, and GRACE terrestrial water storage
- Models: Catchment, Noah-MP, CLM4.5(?), **Noah3.6**, **VIC4.1.2**
- Addition of **groundwater and dynamic vegetation module**
- Output: groundwater storage, carbon flux, leaf area index and greenness fraction (simulated)

Noah-MP3.6



The LIS modeling suite



NLDAS Website

<http://www.emc.ncep.noaa.gov/mmb/nldas/>

More details can see NCEP and NASA NLDAS website

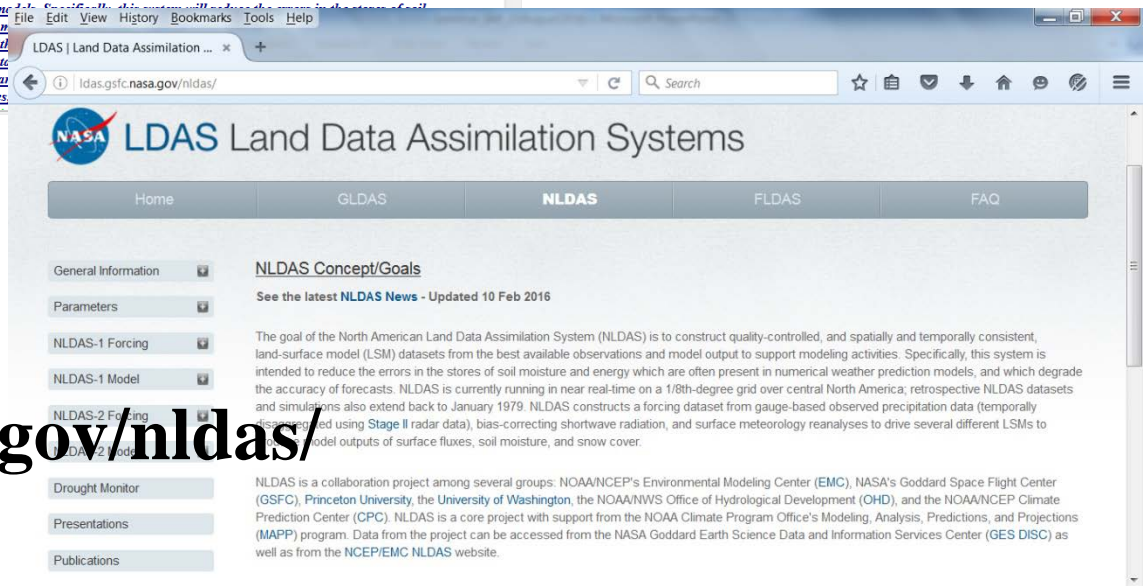


The screenshot shows the NLDAS Homepage in a web browser. The browser's address bar displays www.emc.ncep.noaa.gov/mmb/nldas/. The page features a navigation menu with links for NLDAS, Forcing Data, Model Output, NLDAS Monitor, NLDAS Forecast, and Quick Links. The main content area includes a red heading: "The NLDAS telecon presentations can be found at [NCEP Idas ftp site](#)". Below this, a paragraph states: "30-year retrospective (1979-2008) NLDAS forcing and outputs of four models and real-time updates (2009-present) are at the [NCEP Idas ftp site](#) NEW RELEASE: River routed hourly data from four NLDAS models can be downloaded from the link [Streamflow](#), and post-processed SAC soil moisture data can be downloaded from the link [Post-Processed SAC Soil Moisture](#). NLDAS became NCEP Operational on 5 August 2014 and the Operational Products can be downloaded from the link [Products](#); also, see the [NLDAS-2 transition Plan](#). "EMC NLDAS-2 realtime and retrospective products are back online through a newly rebuild sever. Contents of data and products included at NCEP Idas ftp site can see [this README file](#)."

Below the text is a heading: North American Land Data Assimilation System (NLDAS)

At the bottom left of the screenshot is a circular logo for NLDAS. The logo contains the text "NORTH AMERICAN LAND DATA ASSIMILATION SYSTEM" around the perimeter and "NLDAS" in large green letters at the bottom. The center of the logo features a satellite image of North America with various data overlays.

North American Land Data Assimilation (NLDAS) is being developed that will lead to more accurate reanalysis and forecast simulations by numerical weather prediction (NWP) moisture and energy which are often present in NWP running retrospectively and in near real-time on a 1/8th (NLDAS) precipitation data, space-based radiation data projects involve several LSMs, many sources of data, at NLDAS forcing pages, the NLDAS model output pages.



The screenshot shows the LDAS Land Data Assimilation Systems website. The browser's address bar displays ldas.gsfc.nasa.gov/nldas/. The page features a navigation menu with links for Home, GLDAS, NLDAS, FLDAS, and FAQ. The main content area includes a heading: "LDAS Concept/Goals". Below this, a paragraph states: "The goal of the North American Land Data Assimilation System (NLDAS) is to construct quality-controlled, and spatially and temporally consistent, land-surface model (LSM) datasets from the best available observations and model output to support modeling activities. Specifically, this system is intended to reduce the errors in the stores of soil moisture and energy which are often present in numerical weather prediction models, and which degrade the accuracy of forecasts. NLDAS is currently running in near real-time on a 1/8th-degree grid over central North America; retrospective NLDAS datasets and simulations also extend back to January 1979. NLDAS constructs a forcing dataset from gauge-based observed precipitation data (temporarily disseminated using Stage II radar data), bias-correcting shortwave radiation, and surface meteorology reanalyses to drive several different LSMs to produce model outputs of surface fluxes, soil moisture, and snow cover."

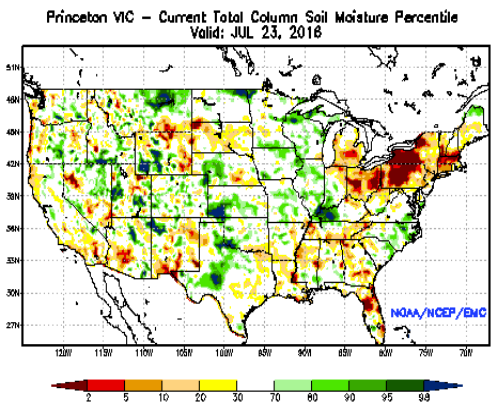
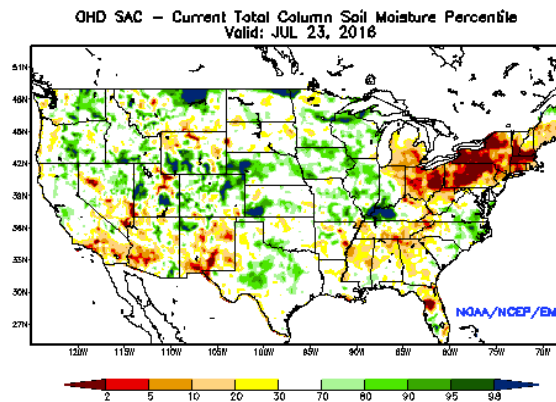
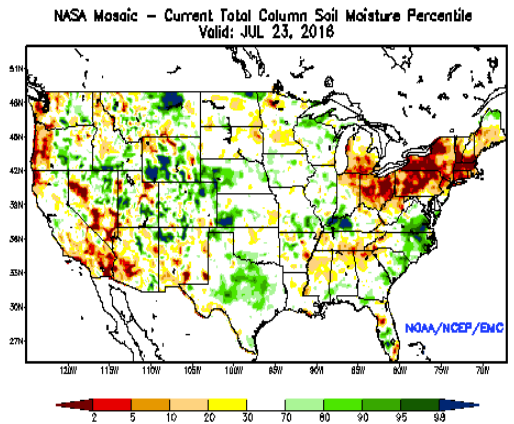
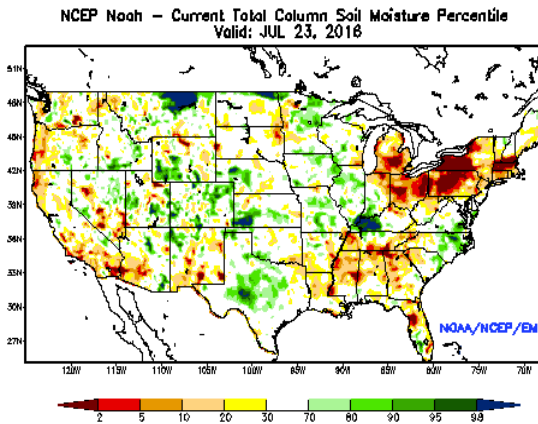
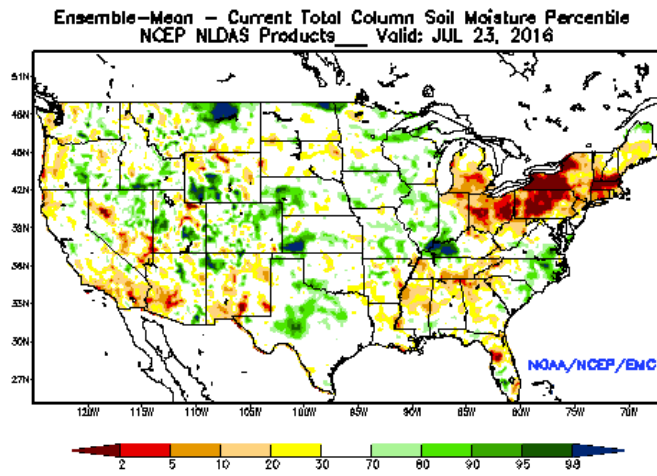
Below the text is a heading: "NLDAS is a collaboration project among several groups: NOAA/NCEP's Environmental Modeling Center (EMC), NASA's Goddard Space Flight Center (GSFC), Princeton University, the University of Washington, the NOAA/NWS Office of Hydrological Development (OHD), and the NOAA/NCEP Climate Prediction Center (CPC). NLDAS is a core project with support from the NOAA Climate Program Office's Modeling, Analysis, Predictions, and Projections (MAPP) program. Data from the project can be accessed from the NASA Goddard Earth Science Data and Information Services Center (GES DISC) as well as from the NCEP/EMC NLDAS website."

<http://ldas.gsfc.nasa.gov/nldas/>

Contributions of NLDAS Product to National Integrated Drought Information System (NIDIS, drought.gov)

NLDAS Drought Monitor

<http://www.emc.ncep.noaa.gov/mmb/nldas/drought/>



These products have been widely used by U.S. drought monitor author group, CPC, various regional climate centers and river forecast centers.

NLDAS Soil Moisture and Temperature

- **NLDAS Reliability:** NCEP operational product with a 4-day lag
Resolution: spatial – 0.125 degree (~12-14 km), temporal –hourly (daily, monthly, yearly)
- **Vertical Soil Depth:** 0-10 cm (5cm at mid-soil layer), 10-40 cm (25 cm), 40-100 cm (70 cm), 100-200 cm (150cm). SAC and VIC use their post-processes to convert simulated soil moisture to Noah soil layers. **Only Noah and VIC has four layers soil temperature.**
- **Covering Period:** 02 January 1979 - present

Next phase NLDAS Update –NLDAS2.5 and NLDAS3.0

Achieve Actual Real-time by Closing the 4-day lag (~ 1-2 years)

Upgrade Land Surface Models: Noah-2.8 → Noah-3.6; Mosaic → Catchment Model; VIC-4.0.3 → VIC-4.1.2; and Noah-MP . All models will include soil temperature output (~1-2 years)

Achieve Actual Data Assimilation by using remotely sensed soil moisture, snowpack and GRACE TWS data (~2 years)

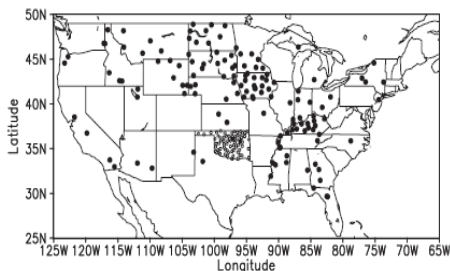
NLDAS white paper including design, plan and work schedule is nearly ready!

NLDAS Noah Soil Temperature Validation

J. Appl. Meteorol. Climatol., 52, 455-471, 2013

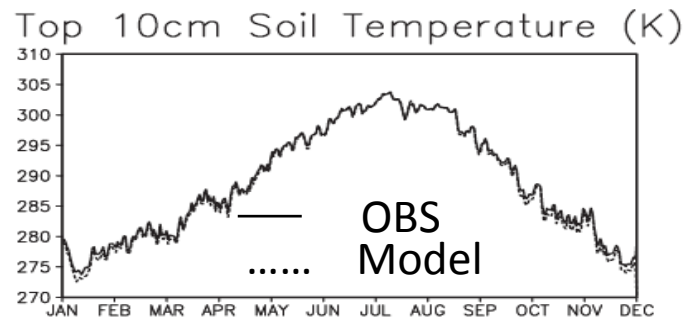
Validation of Noah-Simulated Soil Temperature in the North American Land Data Assimilation System Phase 2

YOULONG XIA,^{*,+} MICHAEL EK,⁺ JUSTIN SHEFFIELD,[#] BEN LIVNEH,[@] MAOYI HUANG,[&] HELIN WEI,^{*,+}
SONG FENG,^{**} LIFENG LUO,⁺⁺ JESSE MENG,^{*,+} AND ERIC WOOD[#]

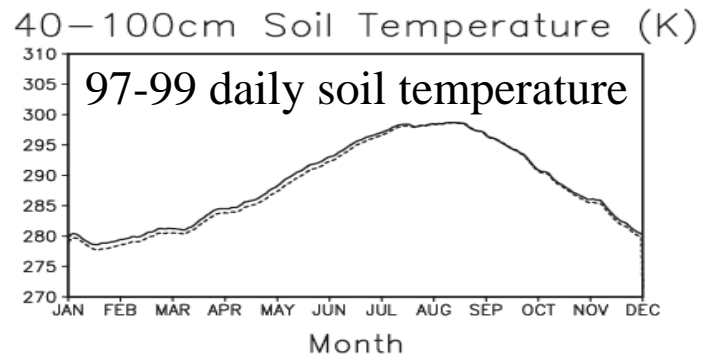
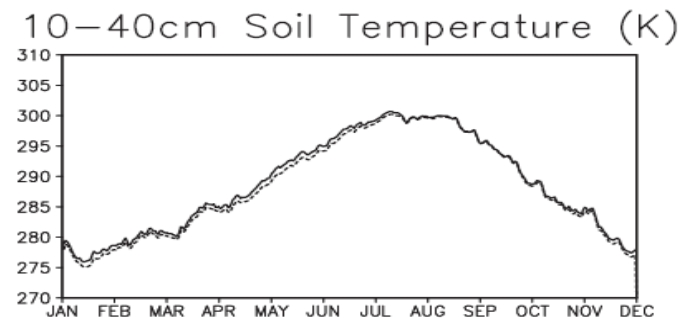
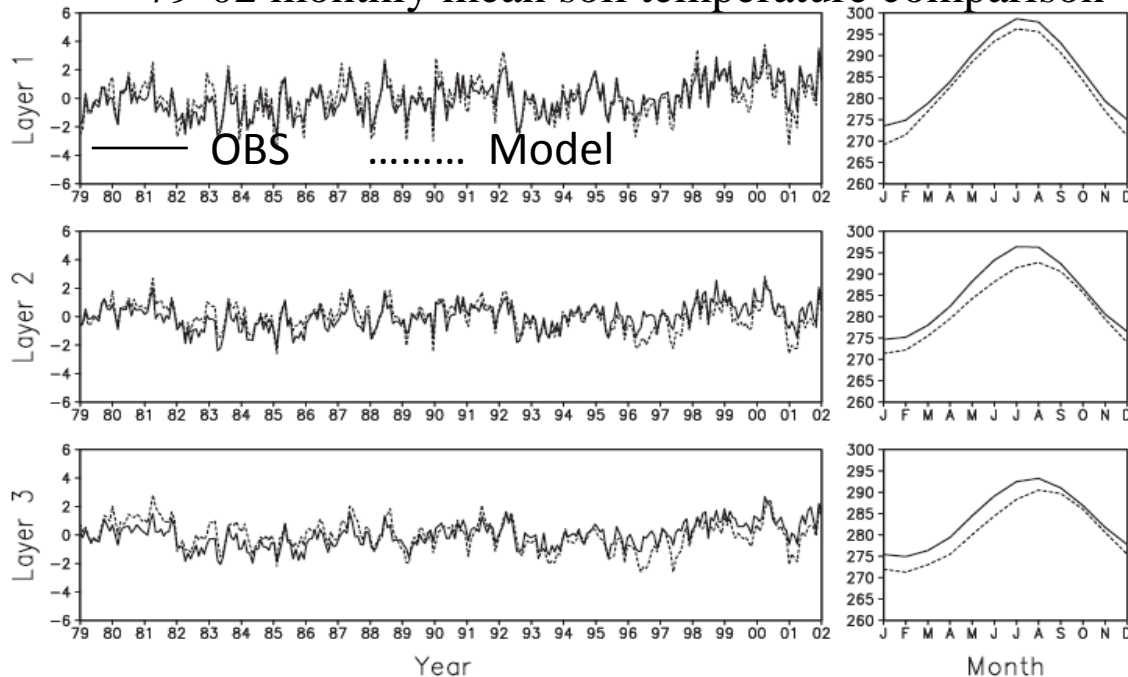


137 US cooperative station
and 72 Oklahoma Mesonet
stations

Errors < 3°C for most cases



79-02 monthly mean soil temperature comparison

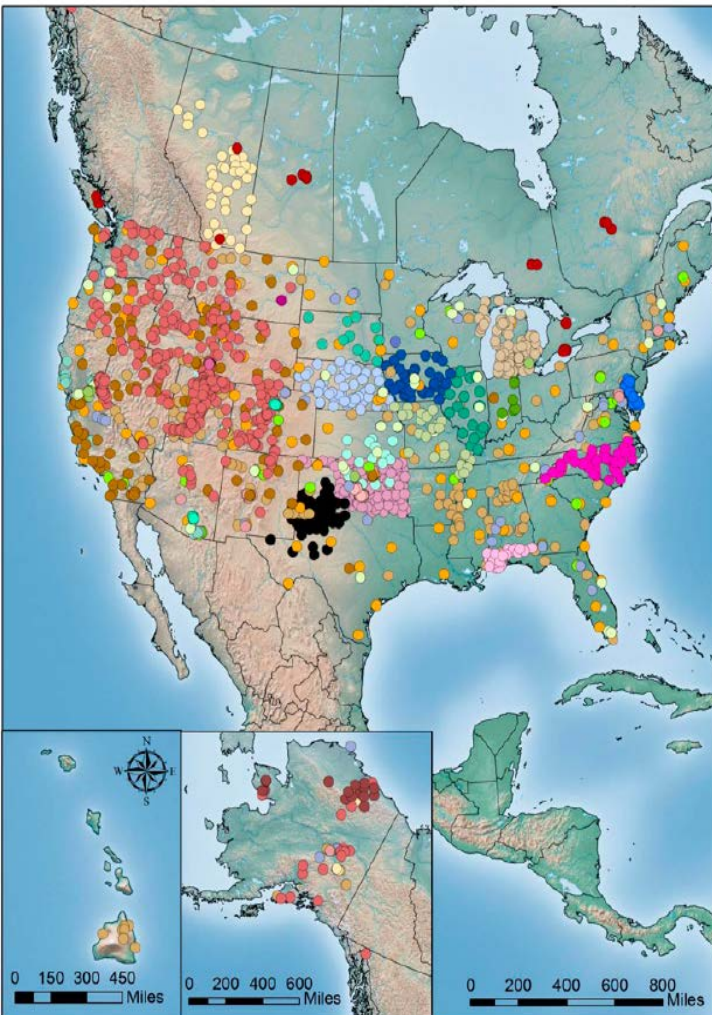


NLDAS soil temperature helps control NASMD data

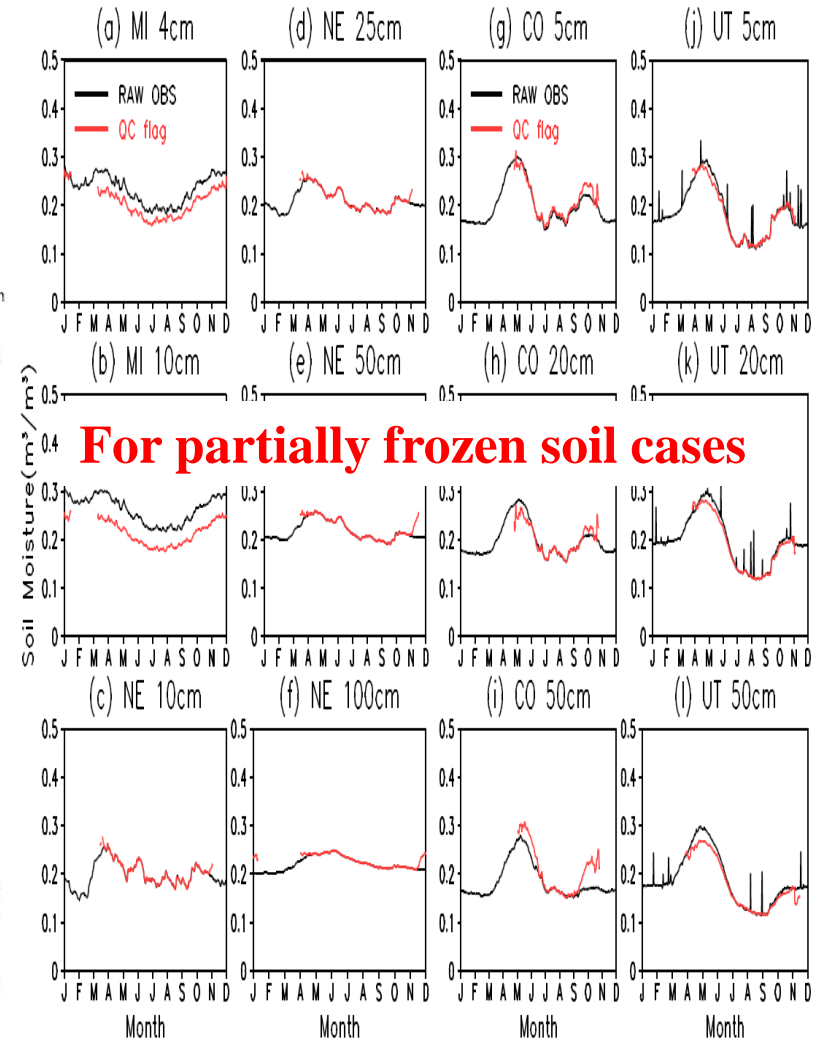
J. Appl. Meteorol. Climatol., 54, 1267-1282, 2015

Automated Quality Control of In Situ Soil Moisture from the North American Soil Moisture Database Using NLDAS-2 Products

YOULONG XIA, TRENT W. FORD, YIHUA WU, STEVEN M. QUIRING, AND MICHAEL B. EK



- Networks**
- Agricultural Research Service
 - Alberta Agriculture and Rural Development
 - AmeriFlux
 - Atmospheric Radiation Measurement
 - Automated Weather Data Network
 - CHILI
 - Central Plains Experimental Range
 - Climate Reference Network
 - Cosmic Ray Soil Moisture Observing Station
 - Critical Zone Observatory
 - Delaware Environmental Observing System
 - ECONET
 - Fluxnet Canada
 - GPS Soil Moisture
 - ISGMN
 - Illinois Climate Network
 - Iowa Historical Soil Moisture
 - Livestock and Range Research Laboratory
 - Long Term Ecological Research Network
 - Michigan Automated Weather Network
 - Missouri AgEBB
 - NOAA HMT
 - National Ecological Observatory Network
 - Oklahoma Mesonet
 - SNOTEL
 - Soil Climate Analysis Network
 - Soilscape
 - South Dakota Automated Weather Network
 - Southwest Research and Outreach Center
 - TW Daniels Experimental Forest
 - Water and Environmental Research Center
 - West Texas Mesonet

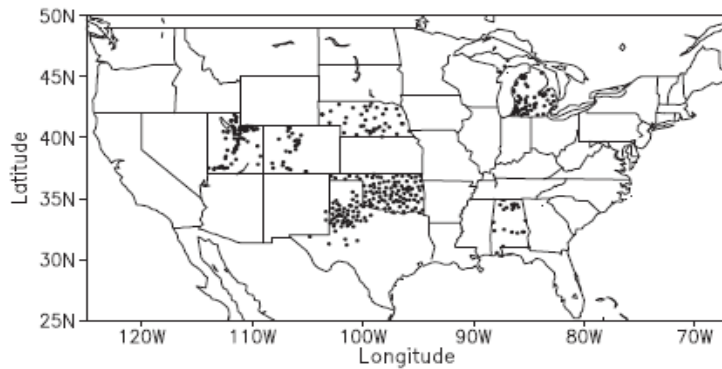


NLDAS soil moisture evaluation in North American Soil Moisture Database (NASMD)

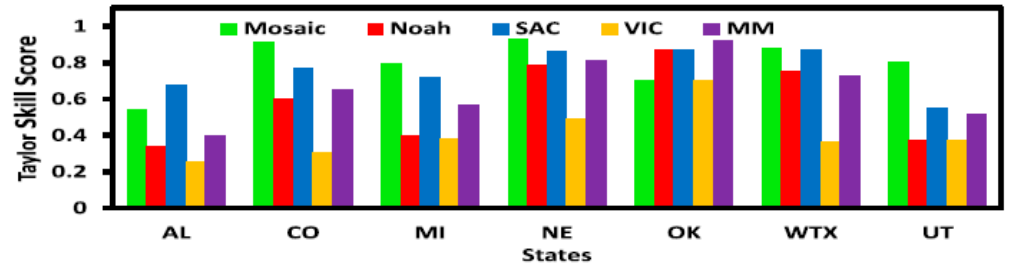
J. Hydrometeorol., 16, 1962-1980, 2015

Comparison of NLDAS-2 Simulated and NASMD Observed Daily Soil Moisture. Part I: Comparison and Analysis

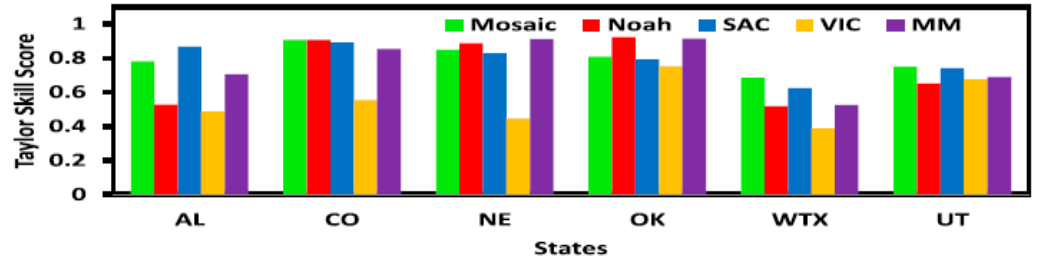
YOULONG XIA, MICHAEL B. EK, YIHUA WU, TRENT W. FORD, AND STEVEN M. QUIRING



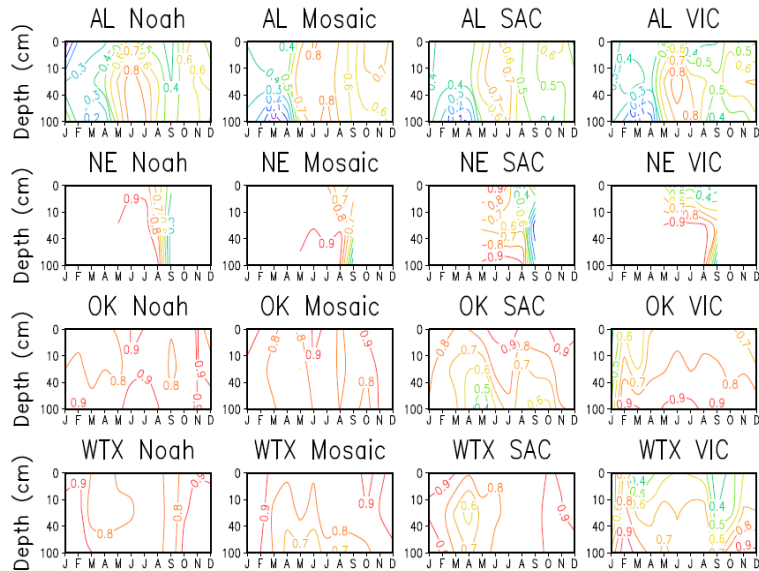
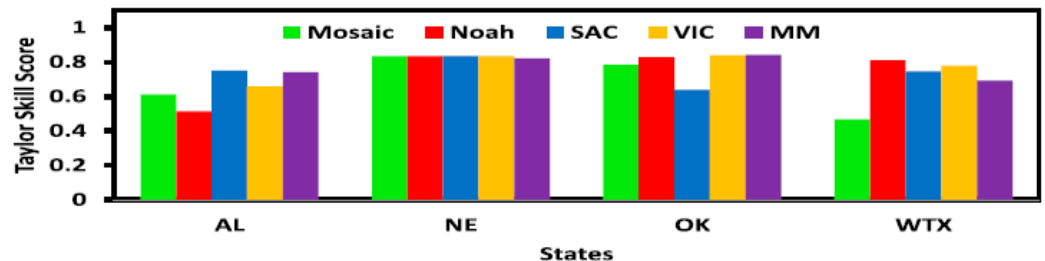
(a) 5 cm soil moisture



(b) 25 cm soil moisture

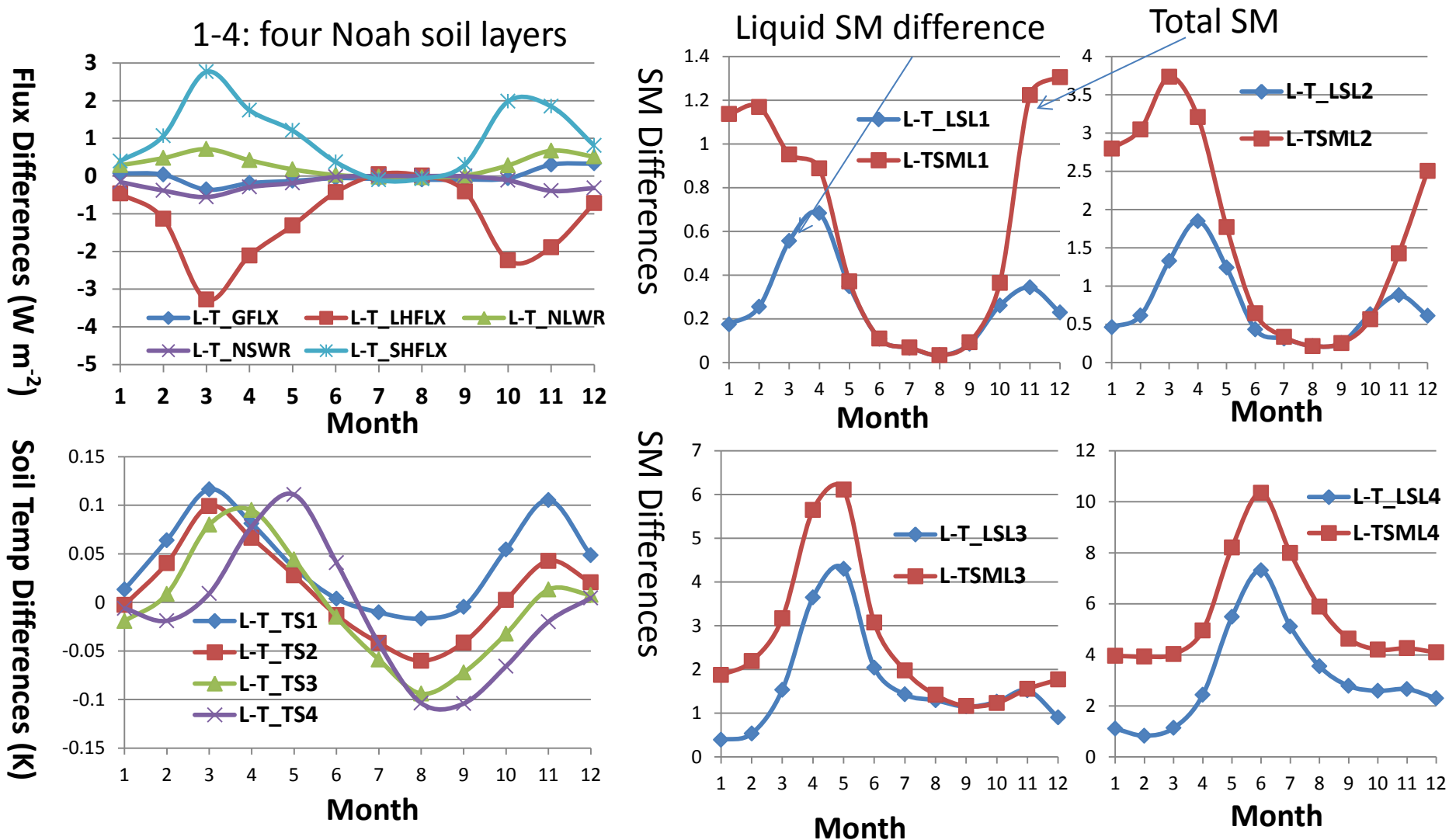


(c) 70 cm soil moisture



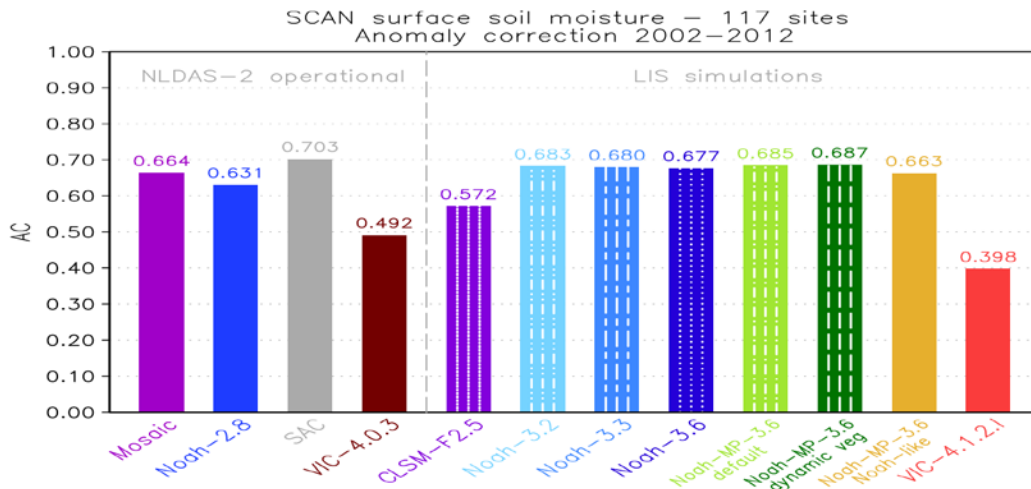
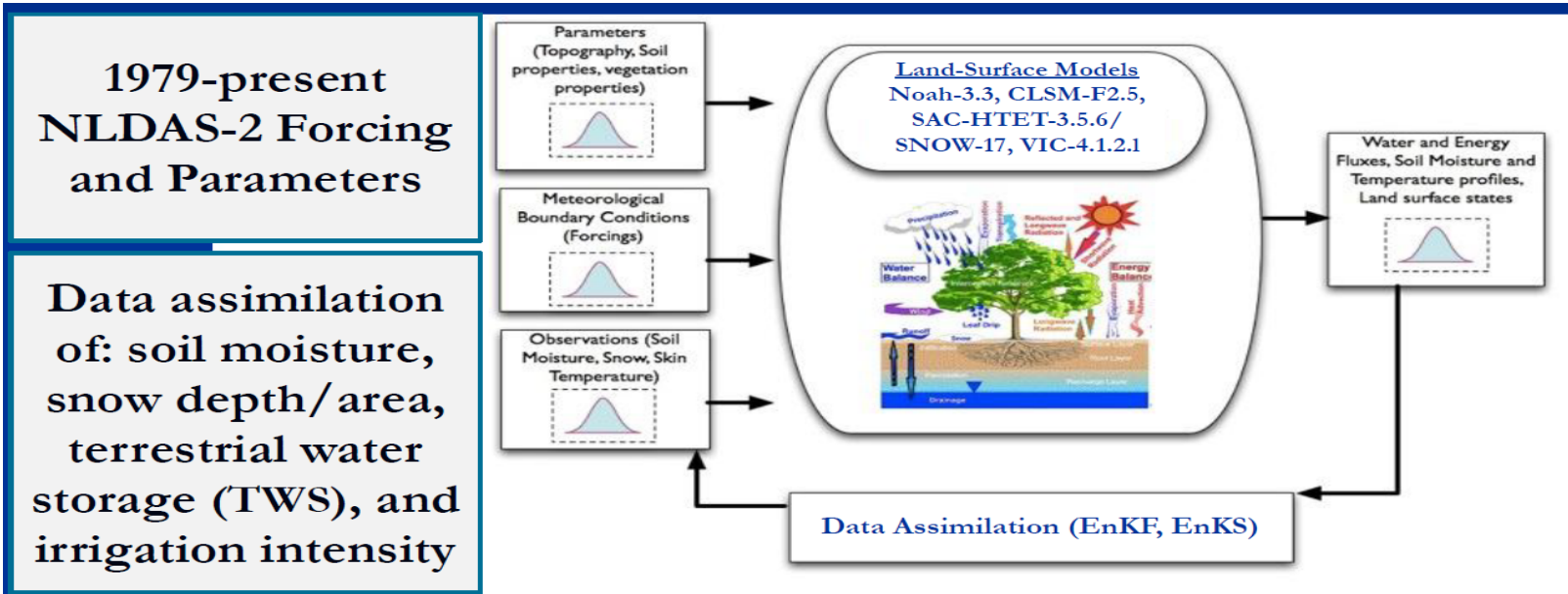
In model parameterization, the differences due to transpiration formula using liquid or total (liquid + ice) soil moisture. Soil physics plays an important role in particular spring time.

Outputs for Tenderfoot Creek (Lat: 46.95, Lon-110.89, Elevation 2255 m)



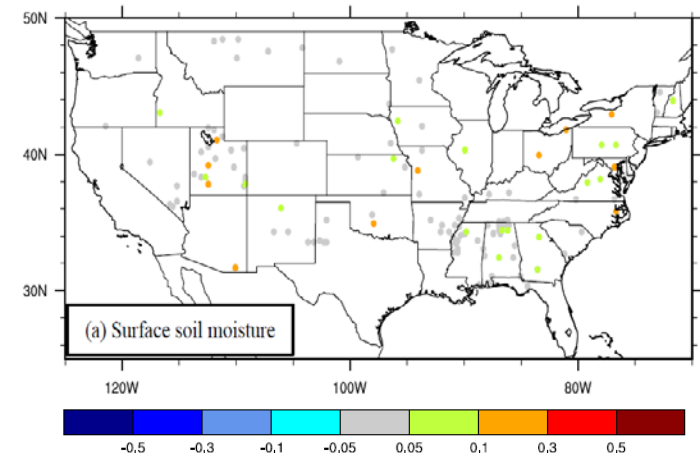
Improvement of NLDAS soil moisture via (1) upgrading model physics and (2) adding actual assimilation process

*Kumar et al., 2016,
J. Hydrometeorol., 17, 1951-1972*



5 cm soil moisture evaluation

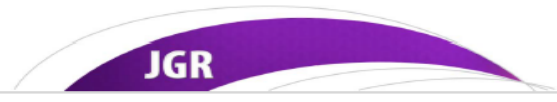
CLSM-F2.5 with GRACE DA



Warm color - significant improvement

Energy and Water Fluxes Evaluation in NLDAS

AGU PUBLICATIONS



Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE Basin-scale assessment of the land surface energy

10.1002/2015JD02

Key Points:

- To assess basin-scale components in NCEP research NLDAS-2
- To jointly use GEWEX/ and gridded FLUXNET fluxes
- To directly evaluate NLDAS products at 12 CONUS Centers

Supporting Information:

- Text S1

Correspondence to:

Y. Xia,



Journal of

RESEARCH ARTICLE

10.1002/2015JD02

Key Points:

- Evaluation of the water components in NCEP research NLDAS-2 system
- Focus on 12 National Weather Service River Forecast Centers
- Evaluation using GEWEX/ and gridded FLUXNET fluxes

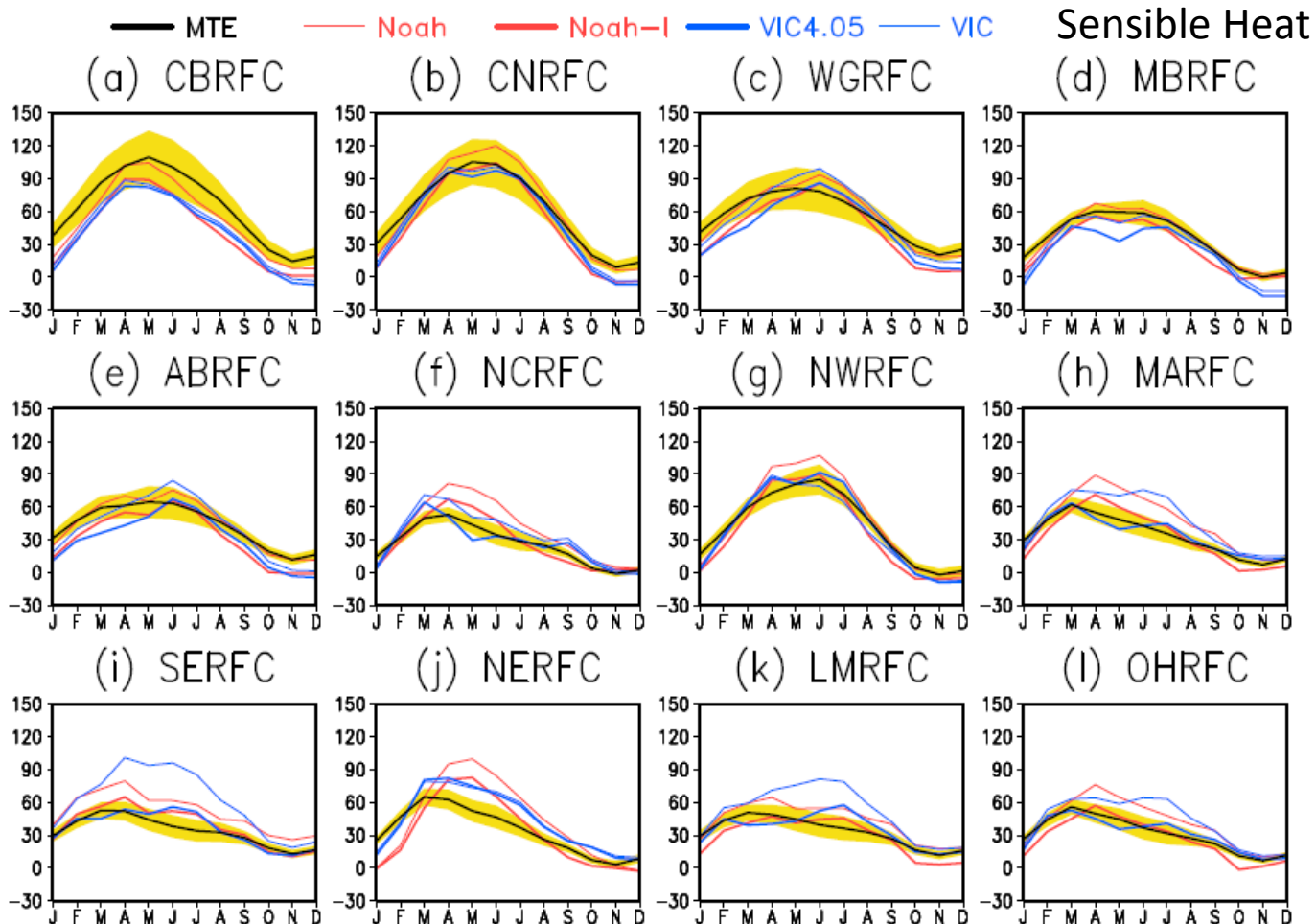
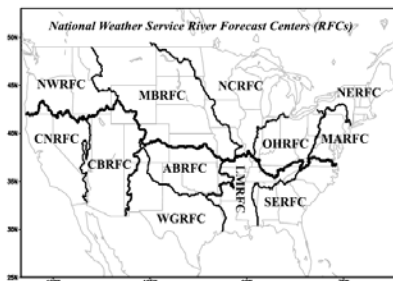


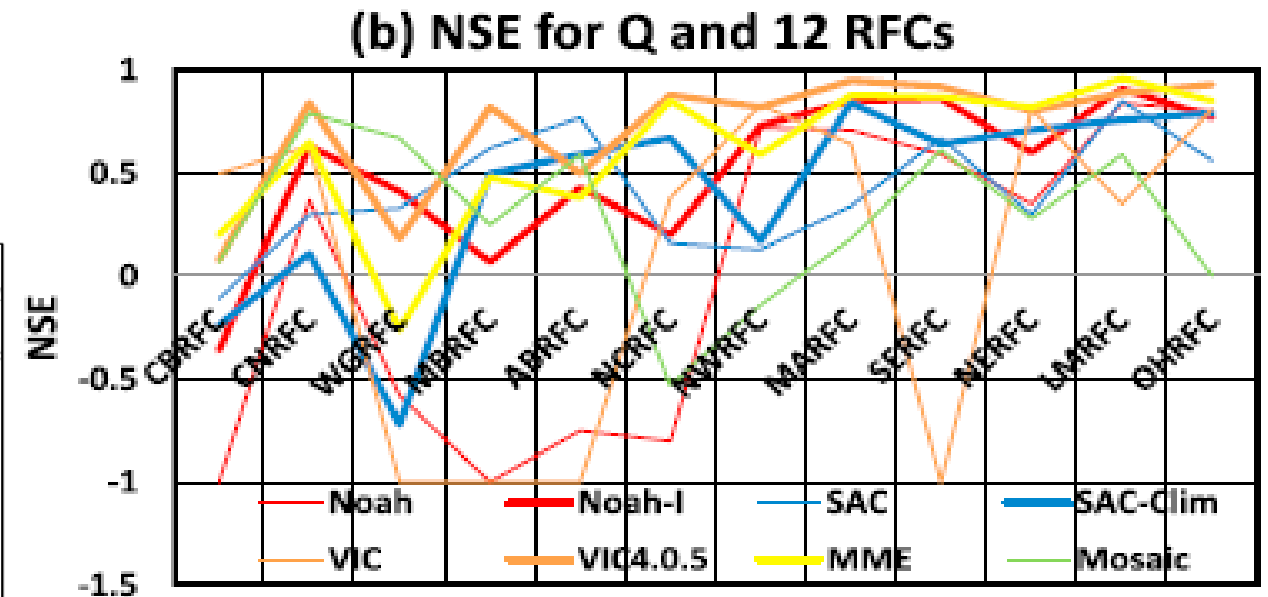
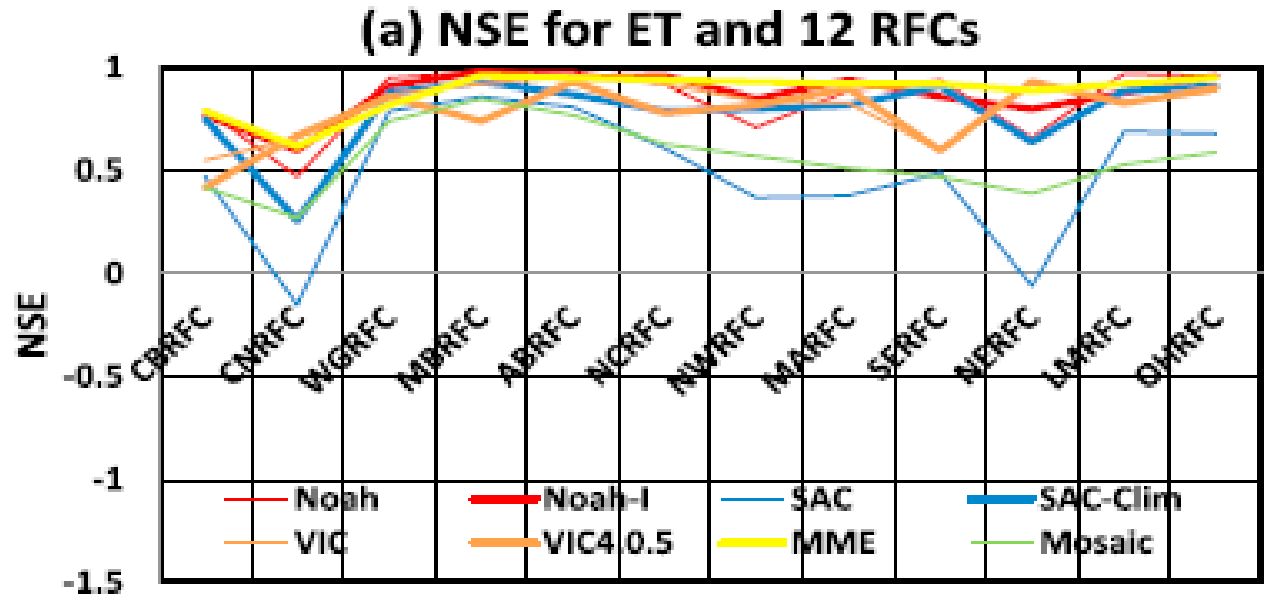
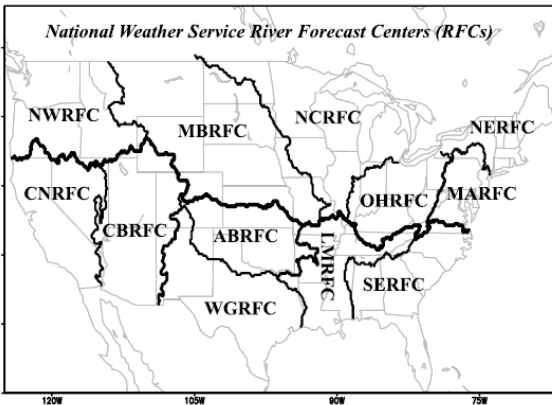
Figure 1. Monthly Sensible Heat Flux (W m⁻²) for 12 National Weather Service River Forecast Centers (RFCs) using four land surface models (Noah, SAC-Sacramento Soil Moisture Accounting Model, VIC-Variable Infiltration Capacity Model, and Mosaic) applied in the newly implemented National Centers for Environmental Prediction

NSE – Nash-Sutcliffe Efficiency

**Q- USGS
ET- Gridded FUXNET**

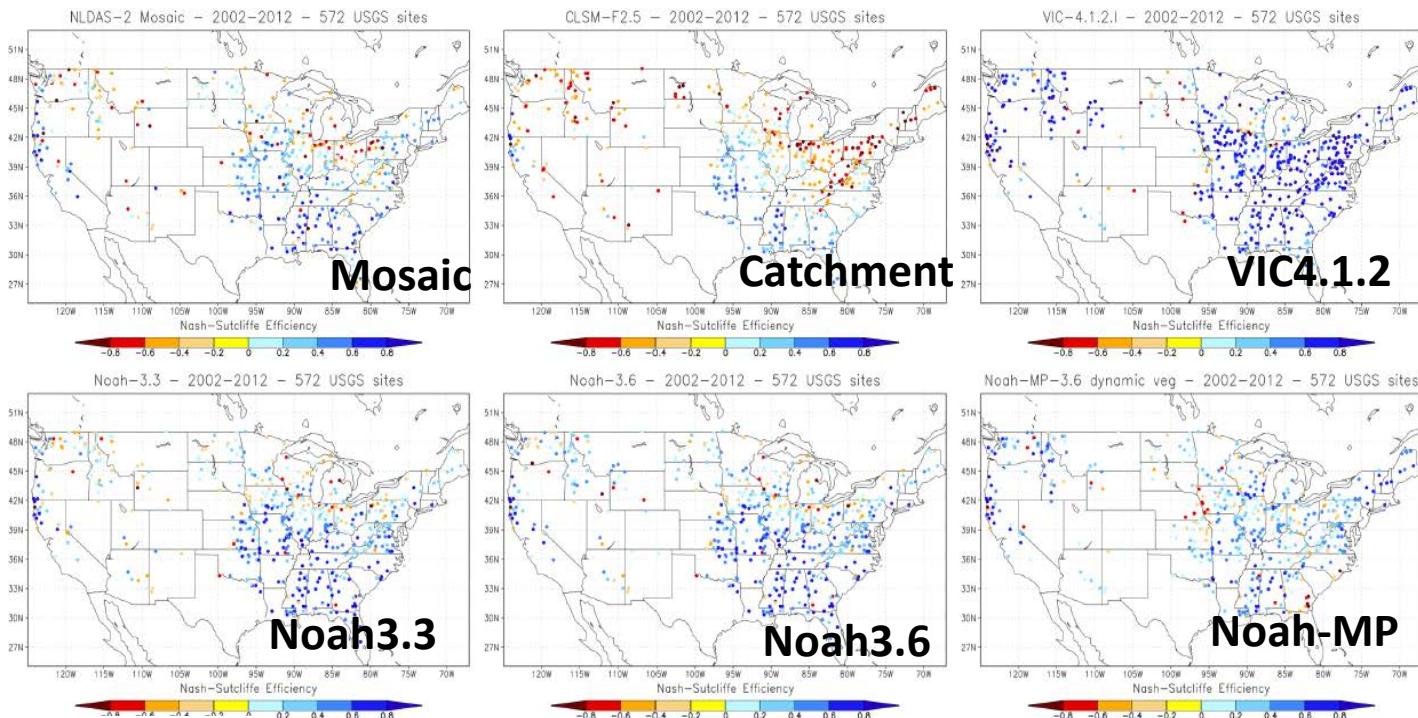
**Research version
improved Q and ET
simulations for most
RFCs**

12 River Forecast Centers

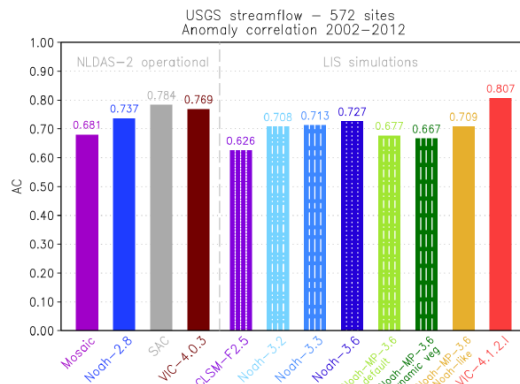
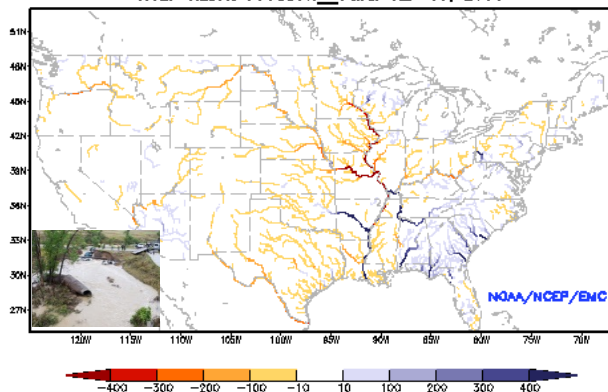


Daily streamflow evaluation in NLDAS Nash-Sutcliffe Efficiency (NSE)

**Operational
NLDAS Router
(*Xia et al.,
2021, JGR-
Atmos.*) –
Colorado Front
Ridge Flooding
in September
2013**



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

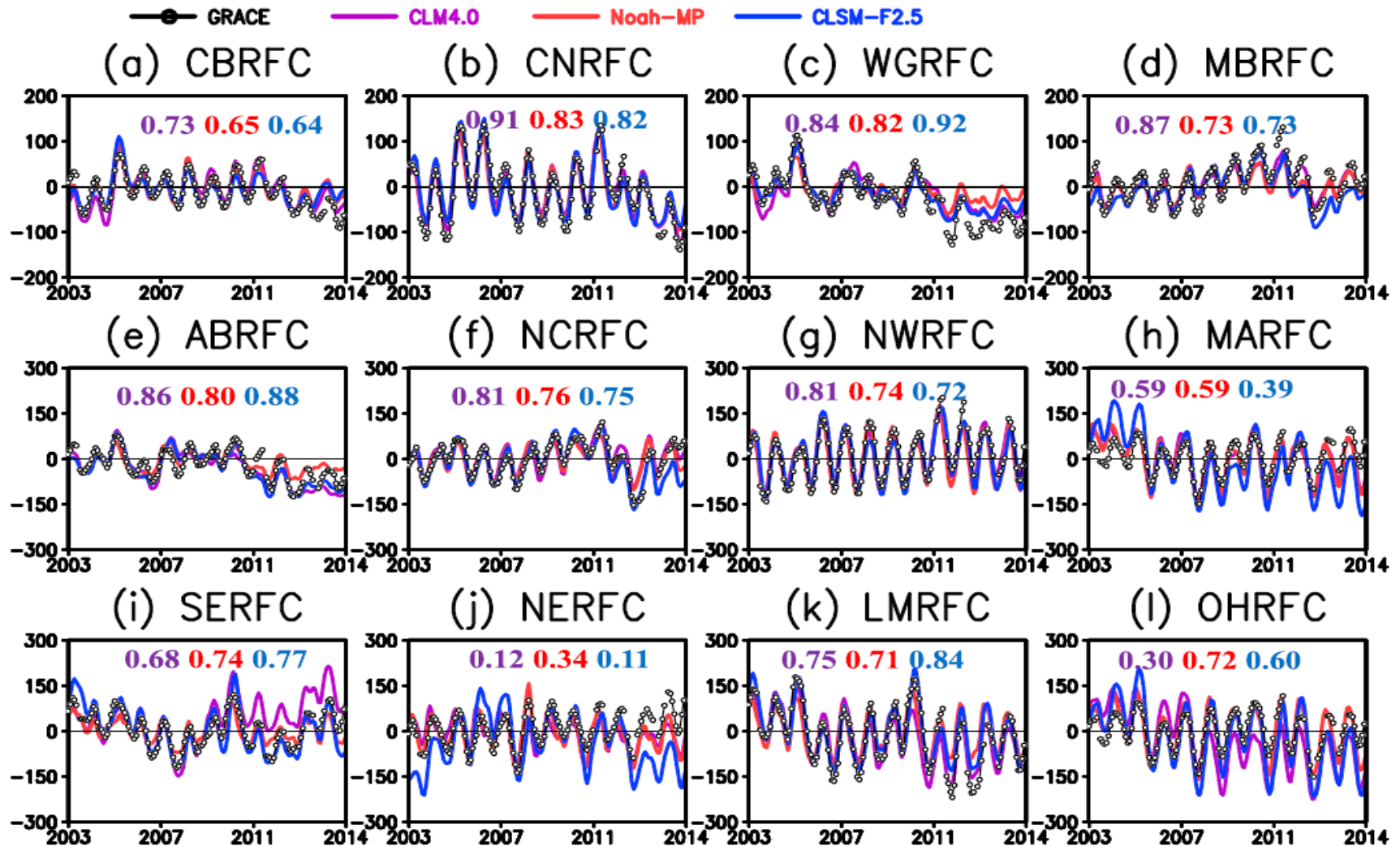


**VIC4.1.2 performs best and
CLSM-F2.5 performs worst.**

**Larger NSE appears in southeast
and west coast where there are
large precipitation. Small NSE
appears in interior US region
as there is less precipitation.**

Terrestrial Water Storage (TWS) Anomaly Evaluation

(TWS=SMC+SWE+GWS), SMC-soil moisture content,
SWE – snow water equivalent, GWS-ground water storage



SWE Evaluation in LIS-Based NLDAS

CLSM-F2.5 has too little SWE when compared with SNODAS SWE. The reason is large sublimation. Further investigation (leading to large sublimation) is ongoing.

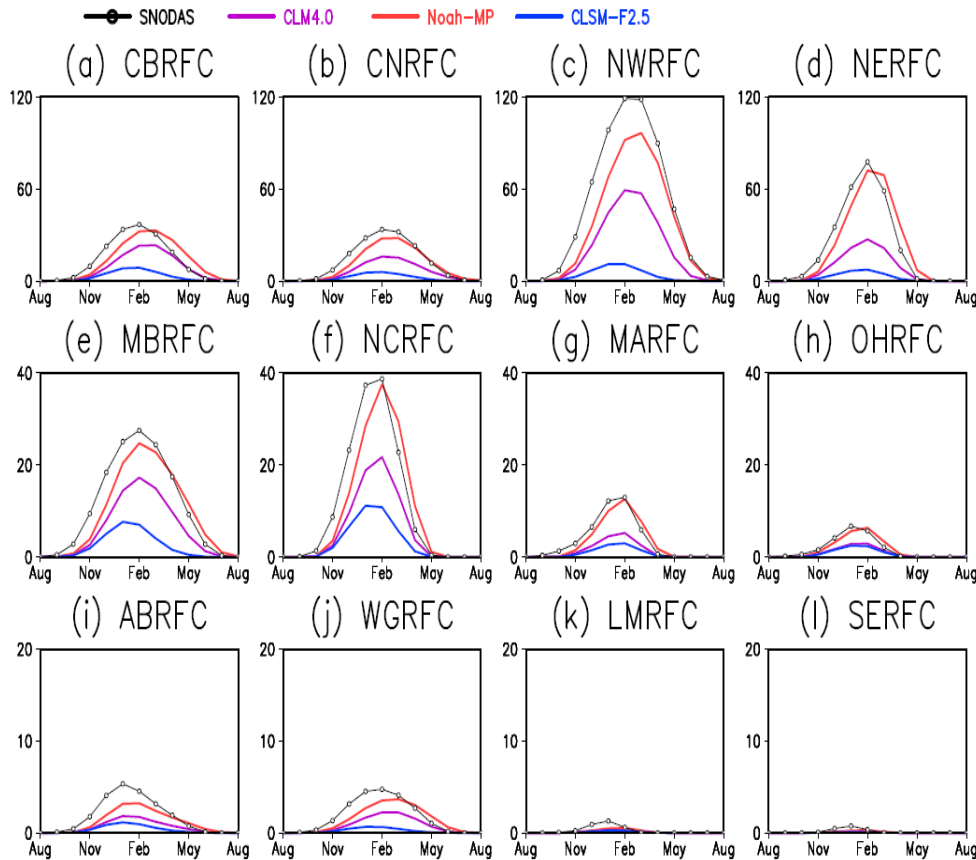


FIG. 8. Mean annual cycle of monthly mean SWE (mm) for each of 12 RFCs for the three models and SNODAS reanalysis calculated for the 11-yr period of 2004–14 (thin black line with open circles, SNODAS; purple line, CLM4.0; red line, Noah-MP; blue line, CLSM-F2.5). Note that the y-axis ranges from 0 to 120 in (a)–(d), from 0 to 40 in (e)–(h), and from 0 to 20 in (i)–(l).

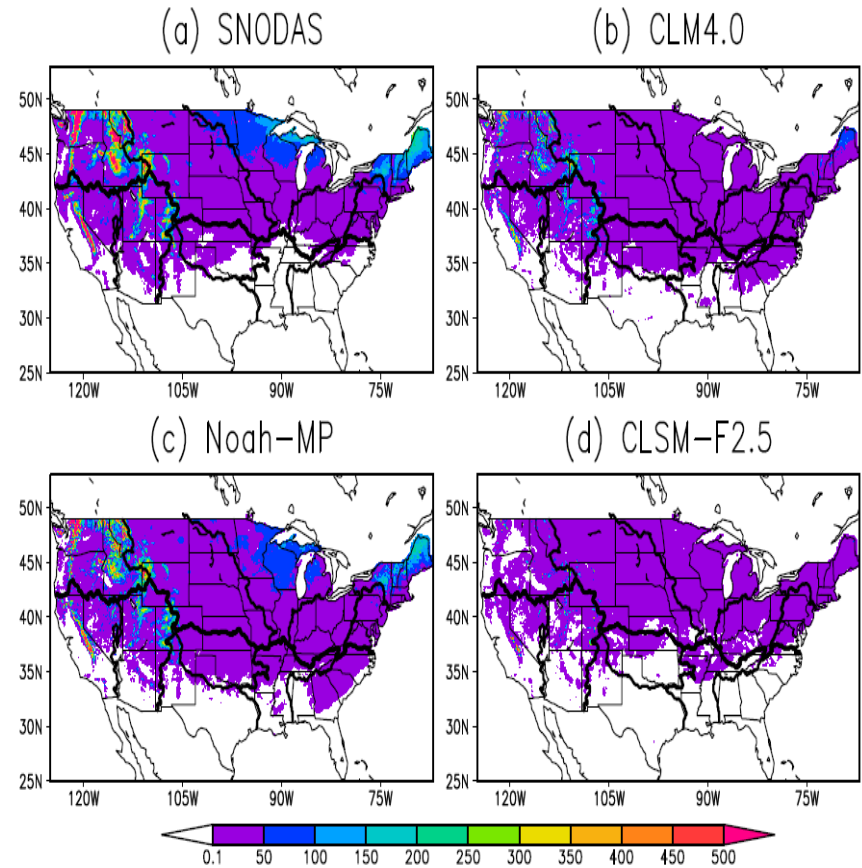
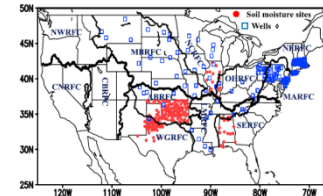


FIG. 9. Spatial distribution of 11-yr (2004–14) averaged February SWE (mm) derived from (a) SNODAS, (b) CLM4.0, (c) Noah-MP, and (d) CLSM-F2.5.

GWS Evaluation in LIS-Based NLDAS

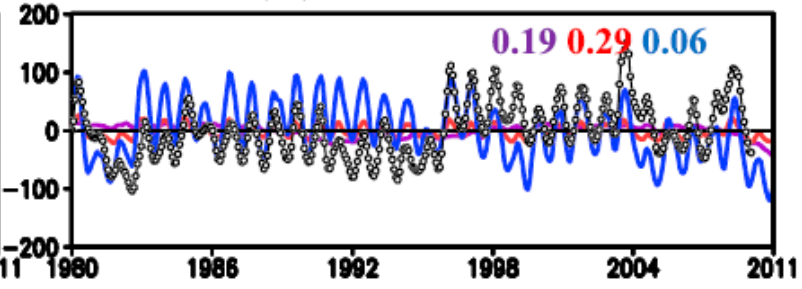
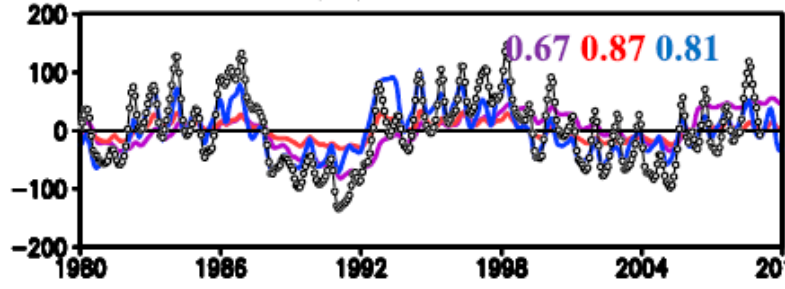
Xia et al., JHM, 2017



—●— USGS — CLM4.0 — Noah-MP — CLSM-F2.5

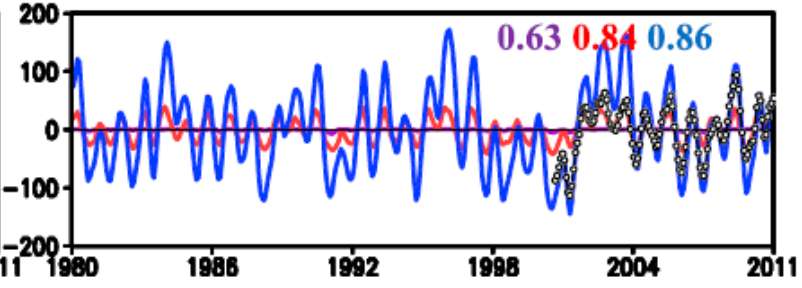
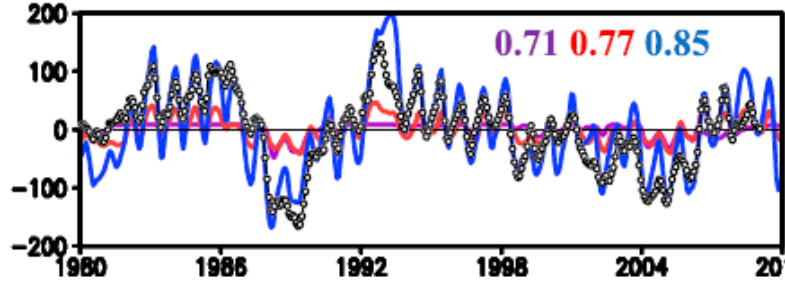
(a) MBRFC

(b) AB-LMRFC



(c) NCRFC

(d) MARFC



(e) NERFC

(f) OHRFC

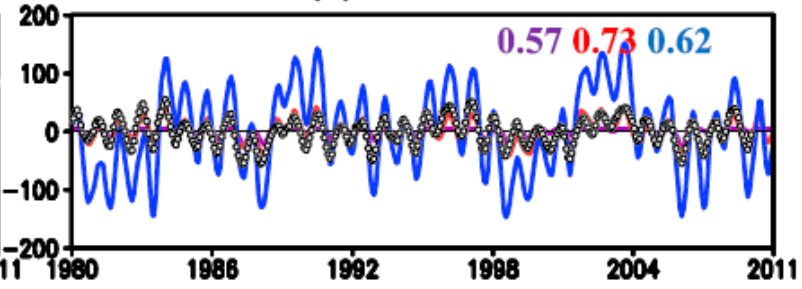
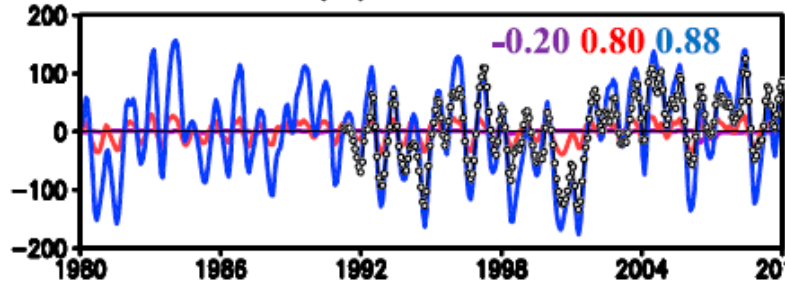
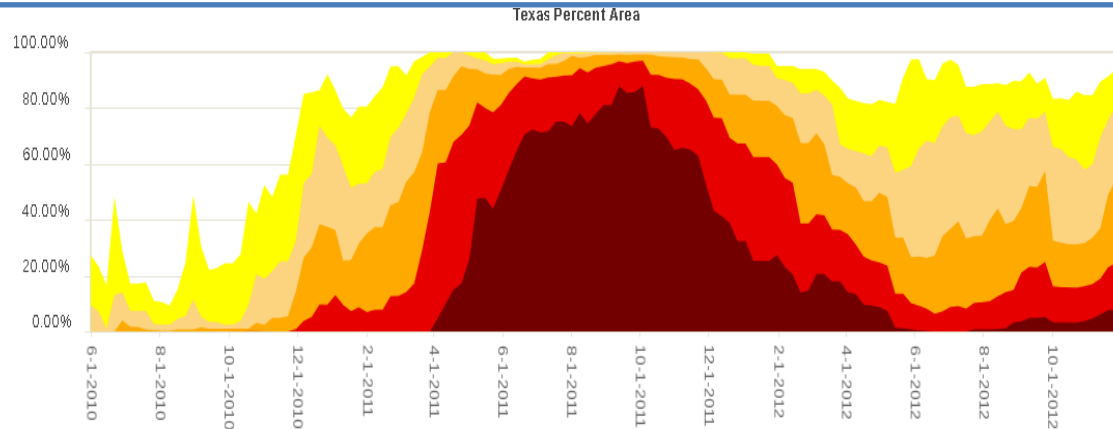
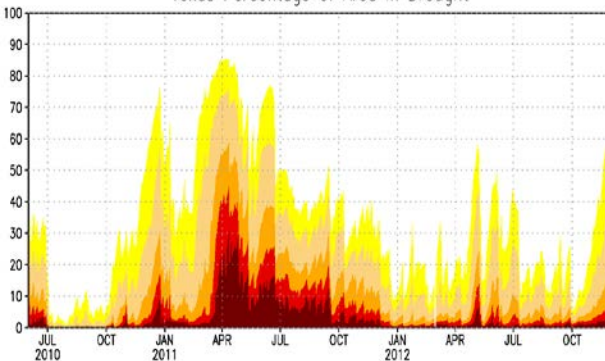


FIG. 7. Comparison of 32-yr time series of GWSA (mm) between USGS wells (thin black line with open circles) and the three models for six basins (purple line, CLM4.0; red line, Noah-MP; blue line, CLSM-F2.5). The model AC values given at the top of each frame correspond to model line color. The USGS values are unavailable before year 2002 (year 1992) for MARFC (NERFC).

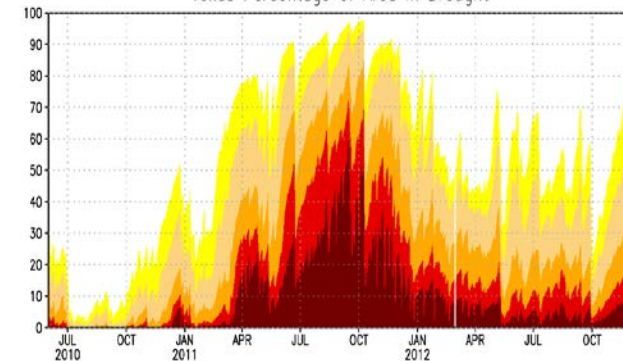
2011 Texas Drought (different options for Noah-MP)



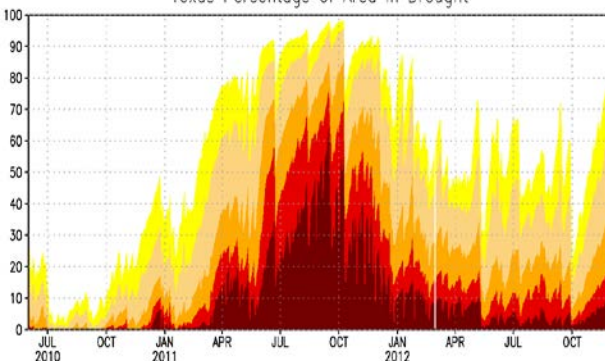
Noah-MP-3.6 RootMoist
Texas Percentage of Area in Drought



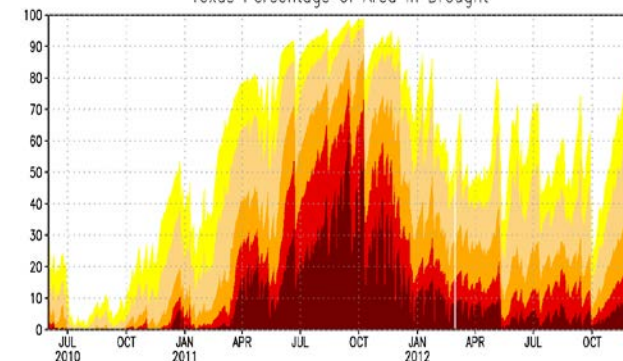
Noah-MP-3.6.WRF RootMoist
Texas Percentage of Area in Drought



Noah-MP-3.6.SIMTOP RootMoist
Texas Percentage of Area in Drought



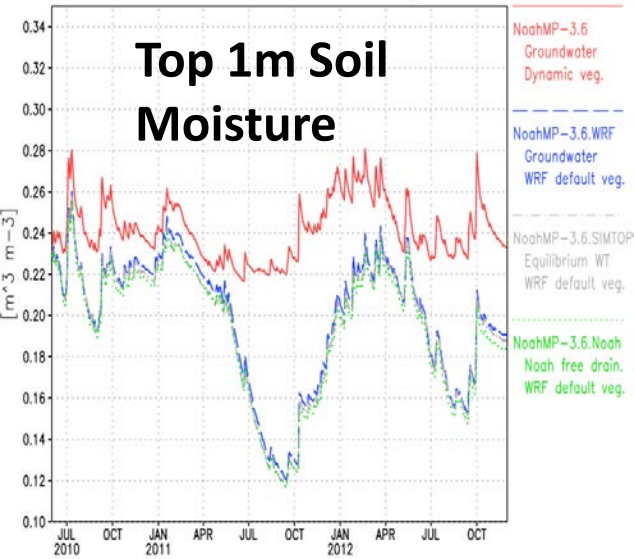
Noah-MP-3.6.Noah RootMoist
Texas Percentage of Area in Drought



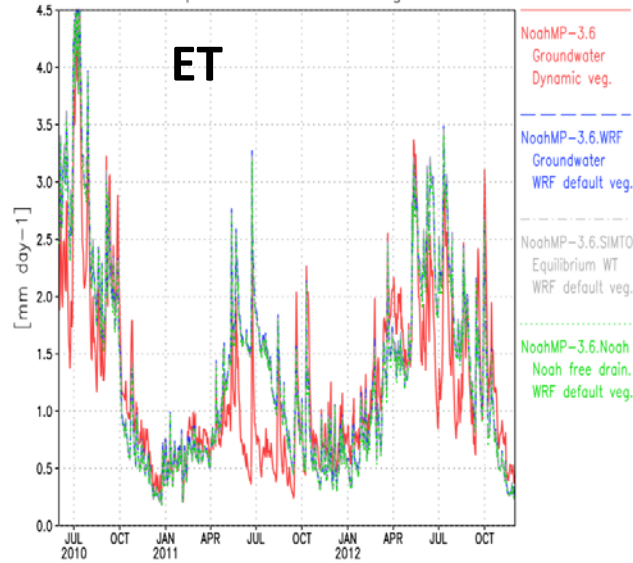
The **dynamic vegetation** run (upper left) completely misses the 2011 TX drought in the top 1-m soil moisture. **The other runs that use WRF default vegetation** do a better job, and are similar to each other, despite using groundwater, equilibrium water table, or free drainage.

2011 Texas Drought

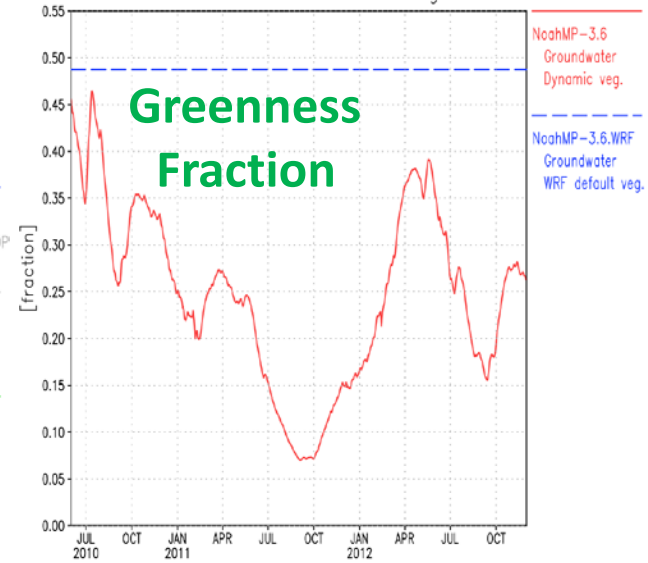
RootMoist – Texas 2011 Drought



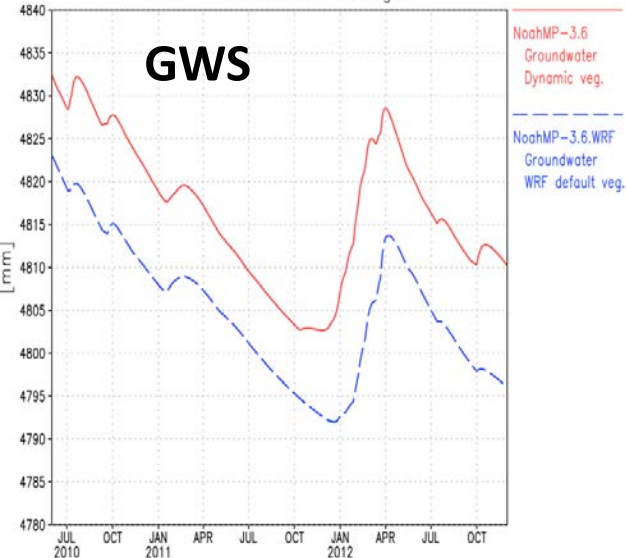
Evap – Texas 2011 Drought



Greenness – Texas 2011 Drought

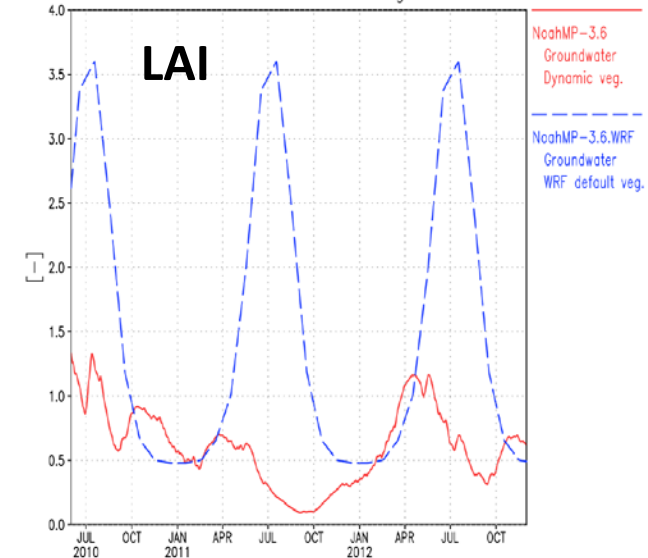


GWS – Texas 2011 Drought

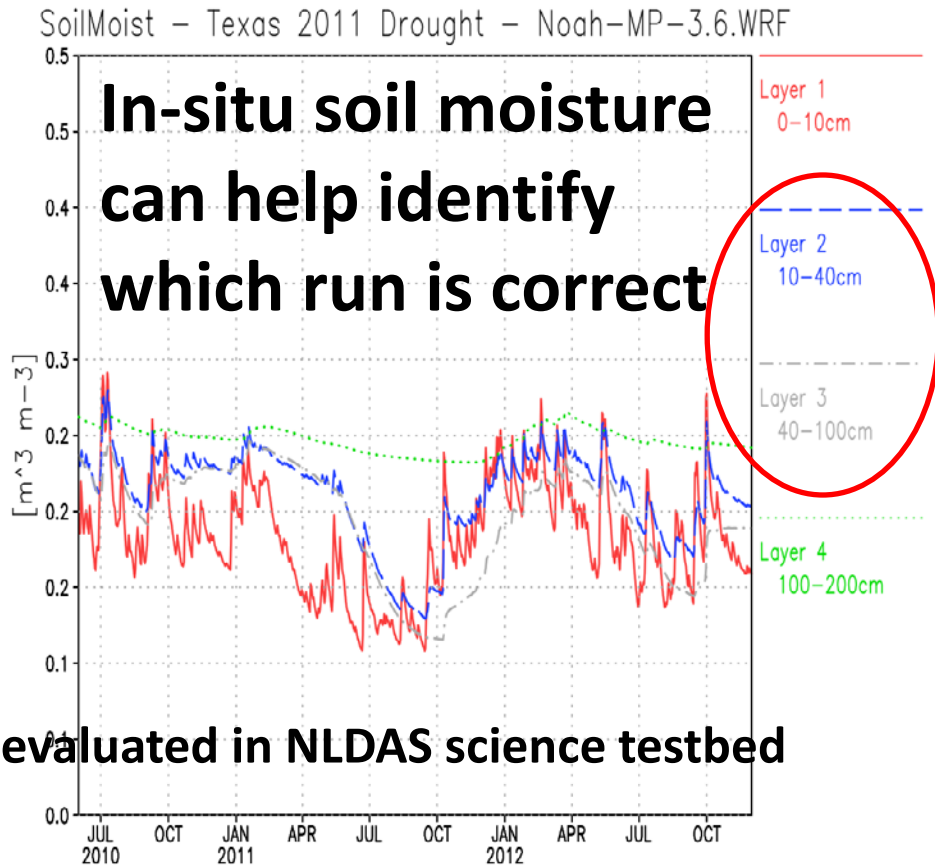
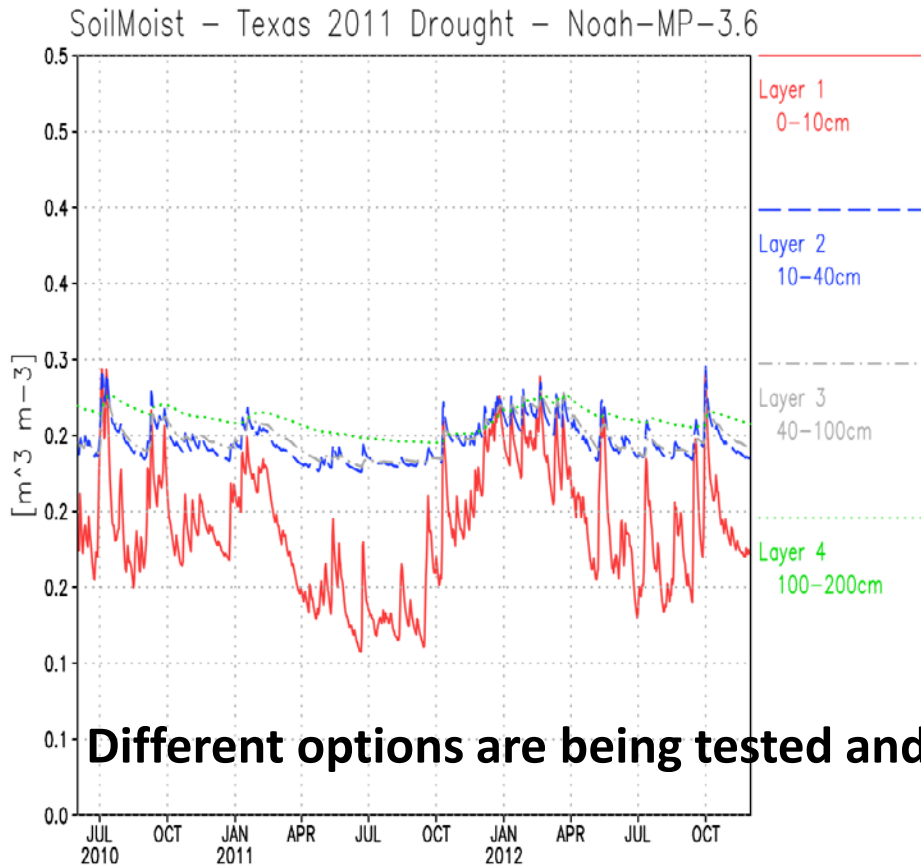


The top 1-m soil moisture does not decrease in TX during 2011 drought, compared to the other runs. GWS behaves similarly between dynamic vegetation and WRF default, although with slightly different mean values. Evaporation is much lower during the summer due to lower GVF and LAI from the dynamic vegetation run.

LAI – Texas 2011 Drought



2011 Texas Drought



Different options are being tested and evaluated in NLDAS science testbed

These figures now show the 4 soil moisture layers for (LEFT) dynamic vegetation and (RIGHT) WRF default vegetation. The **top layer SM is generally similar, but the 2nd and 3rd layers differ significantly between the runs.** In the dynamic vegetation, there is little drying of the SM, while in the WRF default runs, the soil moisture drops significantly in the late summer.

Future work plan

- To enhance the collaboration with NSMN scientists to use observed soil data to improve NLDAS product quality and model physical processes understanding
- To efficiently use NASA/NCEP joint NLDAS science and evaluation testbed to help R2O task via O2R experiments
- To achieve real-time (zero day lag) NLDAS system to meet the public requirements – NLDAS2.5
- To transition LIS-based NLDAS system developed at NASA to NCEP to move toward operational implementation (R2O) –NLDAS3.0
- To extend NLDAS to North America and 1/8th degree to 1~3 km (NLDAS 3.5 and beyond)
- To unify NLDAS with GLDAS to form a unified LDAS system at NCEP
- To improve surface forcing, to upgrade soil and vegetation parameter datasets, to add irrigation, vegetation dynamics, groundwater dynamics, lake model , ecosystem processes, biochemistry, carbon and nitrogen dynamics, etc.

Useful Datasets from NSMN for NCEP/NASA NLDAS team

1. Several example datasets have liquid and frozen soil moisture measurement separately. This will help our model team to check if model physical processes are correct for frozen soil simulation.
2. More soil moisture measurements in middle to east Texas will help us to check if our models can correctly capture soil moisture variation, such as 2011 Texas drought.
3. Harmonized and QC soil moisture and temperature measurement is helpful for NLDAS product evaluation/validation in future.
4. Human management impacts. There should be focused effort to capture the impact and seasonality from human management processes as part of NSMN (from Sujay Kumar)
5. Biases: Right now, the global soil moisture climatology is unknown. The NSMN should consider as part of its core mission to close this gap by bringing the in-situ, model, remote sensing communities together (from Sujay Kumar).

Potential contributions to NSMN from NLDAS Project

1. NLDAS is going to provide spatially and temporally continuous soil moisture estimates from latest models and remote sensing datasets
2. 12 km and high-resolution NLDAS (1-3 km) soil product, snow water equivalent, terrestrial water storage, groundwater, simulated/predicted LAI, greenness fraction, and ET
3. NLDAS soil products with reasonable soil physics explanations
4. Gridded data in national, North America, and global domain

Comments/Suggestions to:

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