Using GRACE to validate Noah-MP water budget simulations in the Mississippi River Basin

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WHAT STARTS HERE CHANGES THE WORLD
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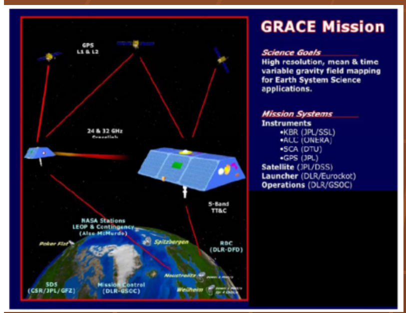
Amazing GRACE within the Center for Integrated Earth System Science



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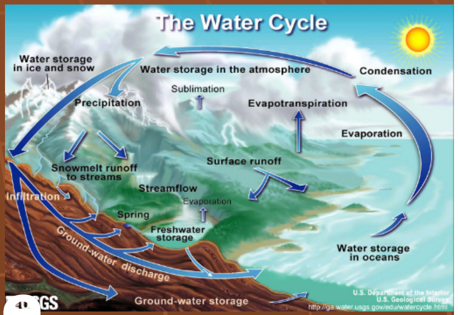

Improve, assess, and evaluate hydrological models on regional to global scales

- ✓ Using GRACE data to improve NCAR **CLM** and **CESM** (Niu and Yang, 2006a, b; Niu et al., 2007a, b; Oleson et al., 2008; Gent et al., 2011) and **Noah-MP** (Yang et al., 2011)
- ✓ Using GRACE data and **CLM** to retrieve water storage components (snow, groundwater) and fluxes (evapotranspiration, river discharge) (Niu et al., 2007a, b; Shi, Yang et al., 2013)
- ✓ Multi-sensor land data assimilation: snow (Su, Yang et al., 2008, 2010; Zhang et al., 2013), soil moisture, carbon, …
- ✓ Drought monitoring (Water Forum I, II, III, …)

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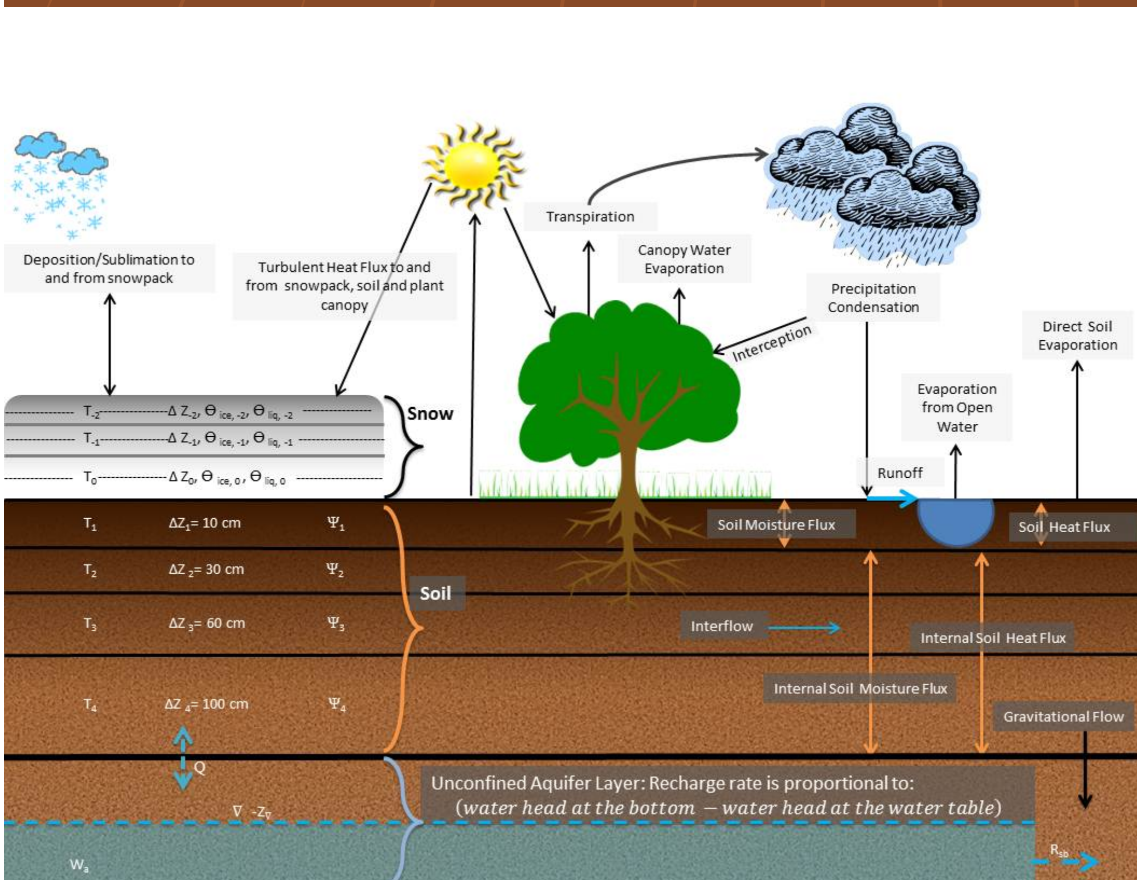
Noah-MP for Weather Research & Forecasting (WRF): Noah LSM with Multi-Parameterization options



Next-generation LSM for NOAA/NCEP/EMC

- Well documented and highly **modular**
- **Improved biophysical realism**: separate vegetation canopy and ground temperatures; a multi-layer snowpack; an unconfined aquifer model for groundwater dynamics; **an interactive vegetation canopy layer**

Niu et al. (2011)
Yang et al. (2011)

http://www.geo.utexas.edu/noah_mp/default.htm

Noah-MP is unique among LSMs

- **A new paradigm** in land-surface, environmental, and hydrological modeling (Clark et al., 2007; 2011)
- In a broad sense,
  - o Multi-parameterization ≡ Multi-physics ≡ Multi-hypothesis
- **A modular & powerful framework for**
  - o Diagnosing differences
  - o Identifying structural errors
  - o Improving understanding
  - o Enhancing data/model fusion and data assimilation
  - o Facilitating ensemble forecasts and **uncertainty quantification**

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Noah-MP

1. Leaf area index (prescribed; predicted)
2. Turbulent transfer (Noah; NCAR LSM)
3. Soil moisture stress factor for transpiration (Noah; SSiB; CLM)
4. Canopy stomatal resistance (Jarvis; Ball-Berry)
5. Snow surface albedo (BATS; CLASS)
6. Frozen soil permeability (Noah; Niu and Yang, 2006)
7. Supercooled liquid water (Noah; Niu and Yang, 2006)
8. Radiation transfer:
   Modified two-stream: Gap = F (3D structure; solar zenith angle; ...) ≤ 1-GVF
   Two-stream applied to the entire grid cell: Gap = 0
   Two-stream applied to fractional vegetated area: Gap = 1-GVF
9. Partitioning of precipitation to snowfall and rainfall (CLM; Noah)
10. Runoff and groundwater:
    TOPMODEL with groundwater
    TOPMODEL with an equilibrium water table (Chen&Kumar,2001)
    Original Noah scheme
    BATS surface runoff and free drainage

More to be added

Niu et al. (2011)

Collaborators: Yang (UT), Chen (NCAR), Ek (NCEP/NOAA), and others

Maximum # of Combinations

1. Leaf area index (prescribed; predicted) 2
2. Turbulent transfer (Noah; NCAR LSM) 2
3. Soil moisture stress factor for transp. (Noah; SSiB; CLM) 3
4. Canopy stomatal resistance (Jarvis; Ball-Berry) 2
5. Snow surface albedo (BATS; CLASS) 2
6. Frozen soil permeability (Noah; Niu and Yang, 2006) 2
7. Supercooled liquid water (Noah; Niu and Yang, 2006) 2
8. Radiation transfer: 3
   - Modified two-stream: Gap = F (3D structure; solar zenith angle; ...) ≤ 1-GVF
   - Two-stream applied to the entire grid cell: Gap = 0
   - Two-stream applied to fractional vegetated area: Gap = 1-GVF
9. Partitioning of precipitation to snow- and rainfall (CLM; Noah) 2
10. Runoff and groundwater: 4
    - TOPMODEL with groundwater
    - TOPMODEL with an equilibrium water table (Chen&Kumar,2001)
    - Original Noah scheme
    - BATS surface runoff and free drainage

2x2x3x2x2x2x2x3x2x4 = 4608 combinations

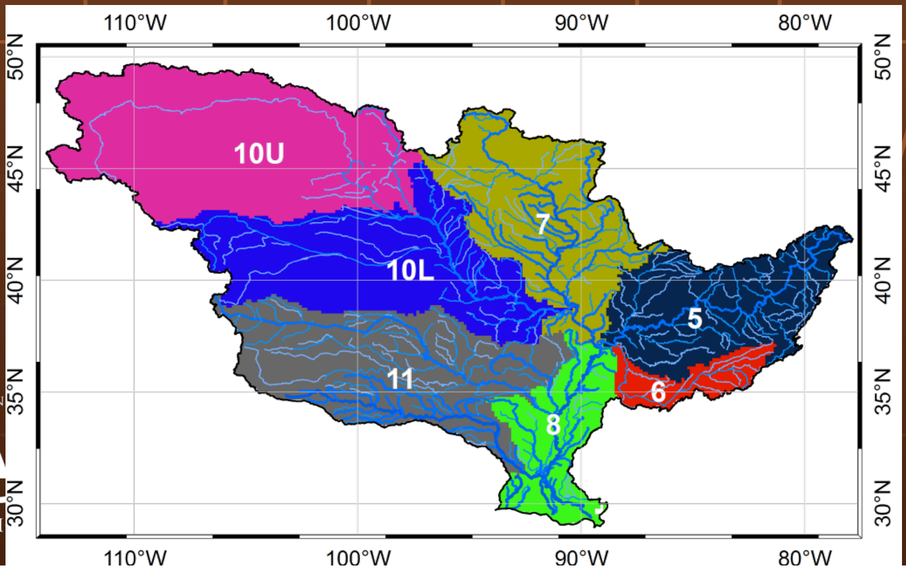
Process understanding, probabilistic forecasting, quantifying uncertainties

The Mississippi River Basin

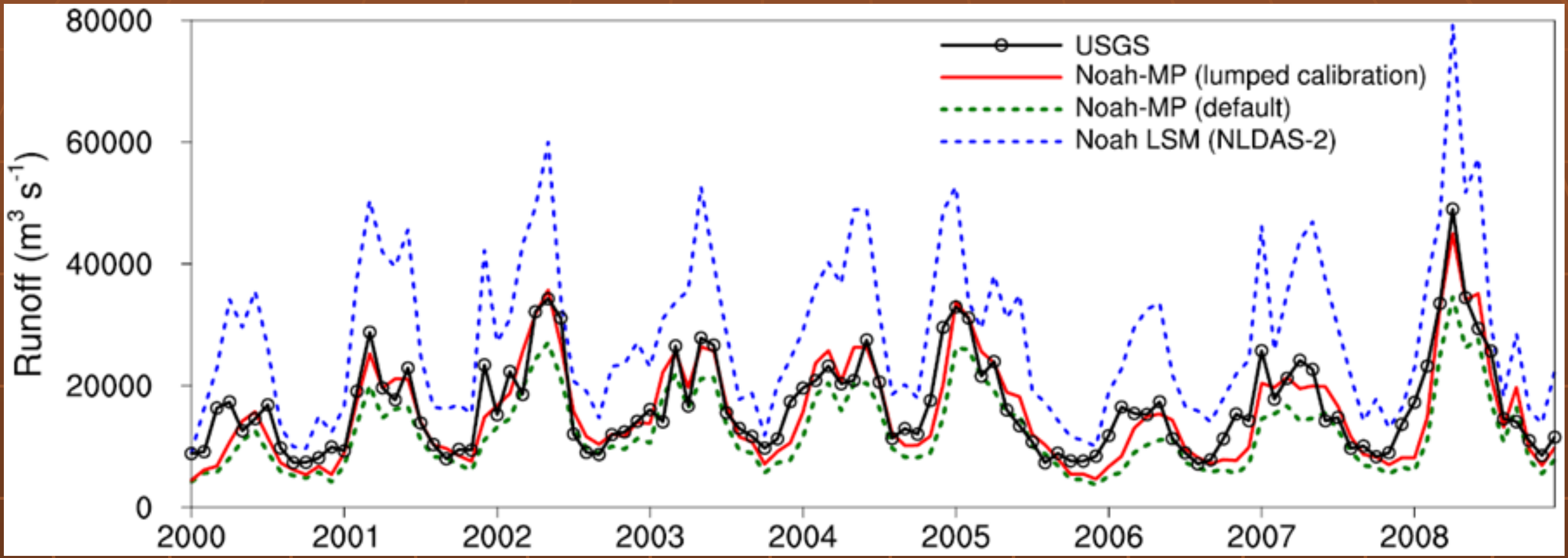
Static Data	**Lat-Lon mask, land mask, soil type, soil color, land use, greenness vegetation fraction (GVF)**
Forcing Data	**NLDAS2 forcing (hourly, 2000–2009): precipitation, temperature, specific humidity, air pressure, downward longwave and shortwave radiation, wind**
Validation Data	**USGS streamflow and groundwater, GRACE water storage change, CMC snow, MODIS LAI, ……**

Mississippi River Basin

- 6 HUC2 regions
- ~3.3 million km^2
- 0.125° × 0.125°
- ~22,378 grid cells



Runoff Calibration and Evaluation



- ✓ Noah-MP is calibrated against USGS observations.
- ✓ Default Noah-MP improves over default Noah.
- ✓ Calibrated Noah-MP improves marginally over default Noah-MP.

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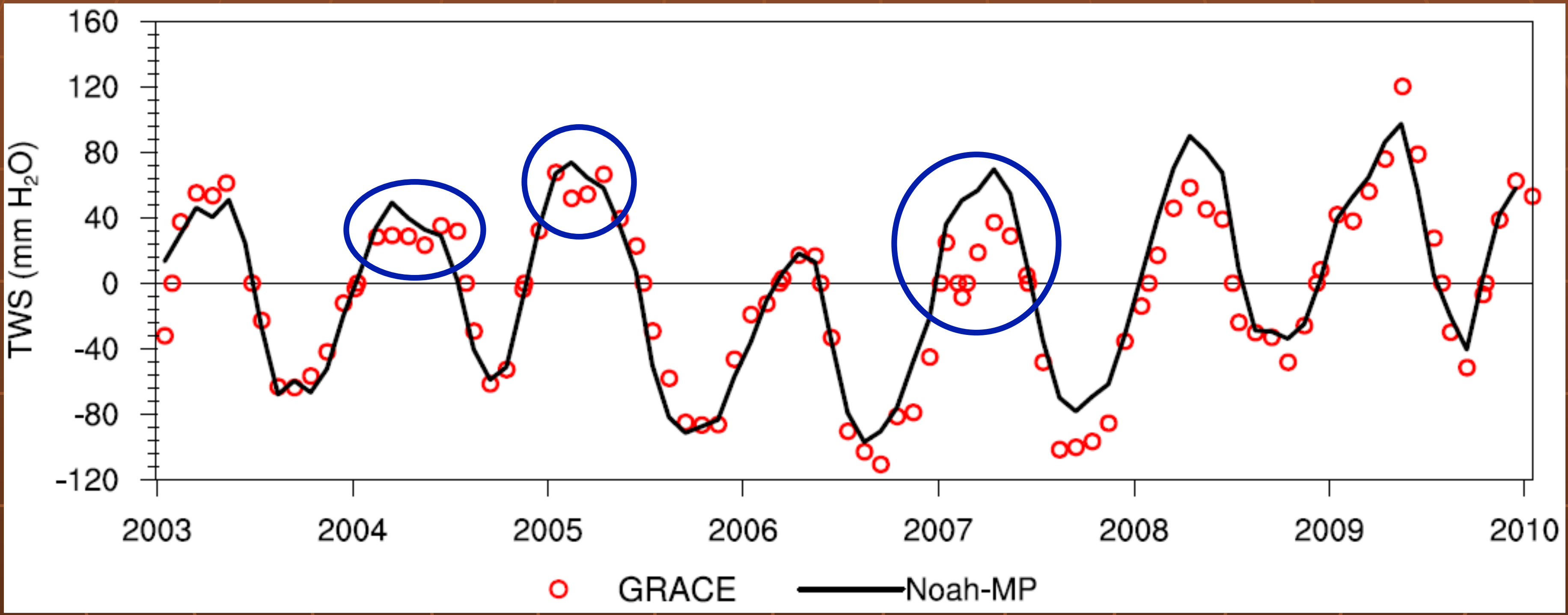
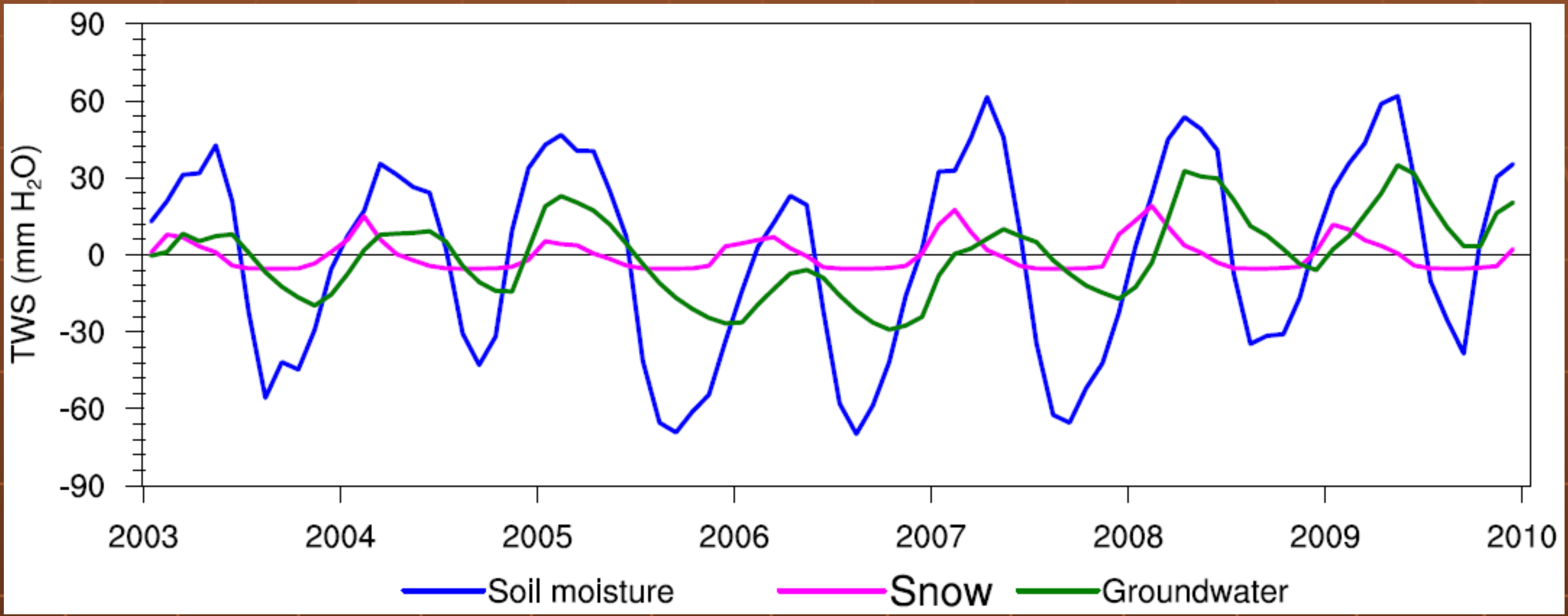
Terrestrial Water Storage

TWS anomaly (GRACE vs. Noah-MP) for the Mississippi River Basin



✓ Noah-MP captures GRACE TWS variations.

Contributions of TWSA from Storage Terms



Contribution to TWSA: 72.8% 14.4% 23.8%

✓ The Noah-MP improvement in TWS simulations may be due to the inclusion of the second largest component—the groundwater dynamics.

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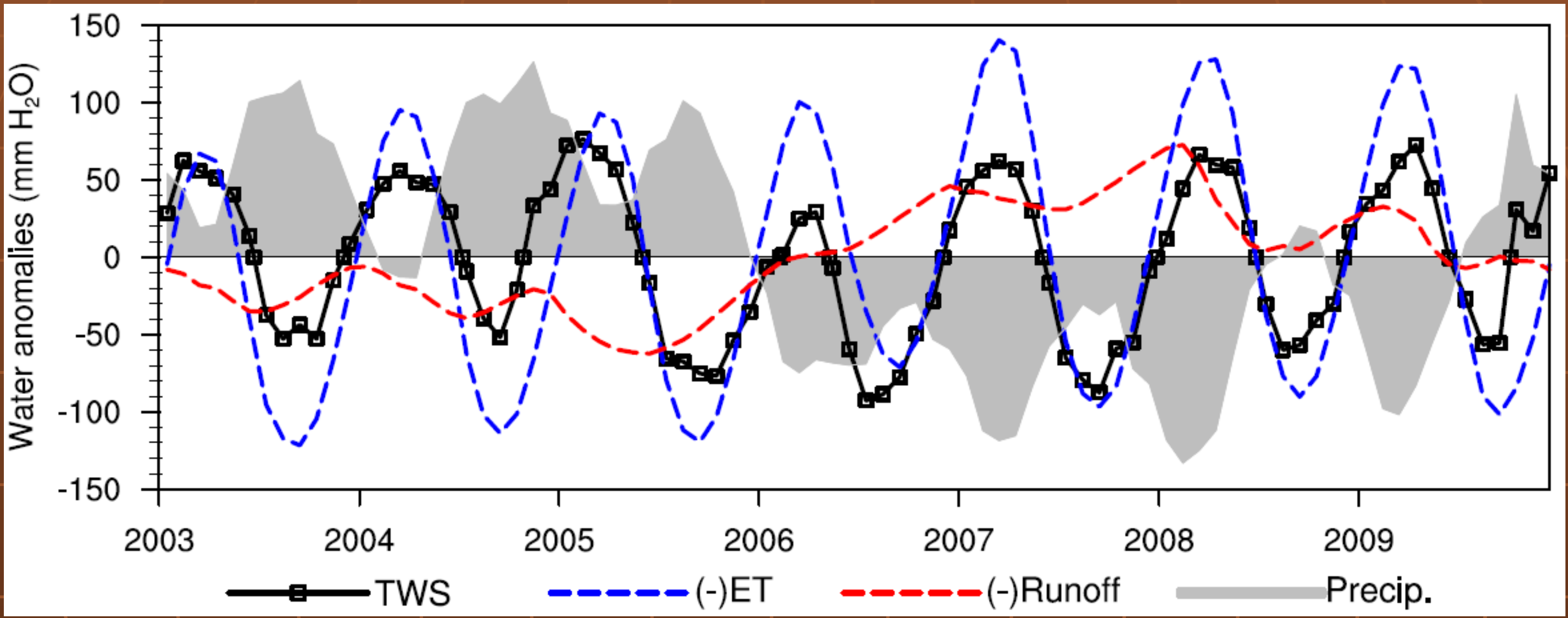
TWSA from Each Flux Term



- ✓ The fluctuation of (-)ET is in phase with TWSA but with a larger amplitude

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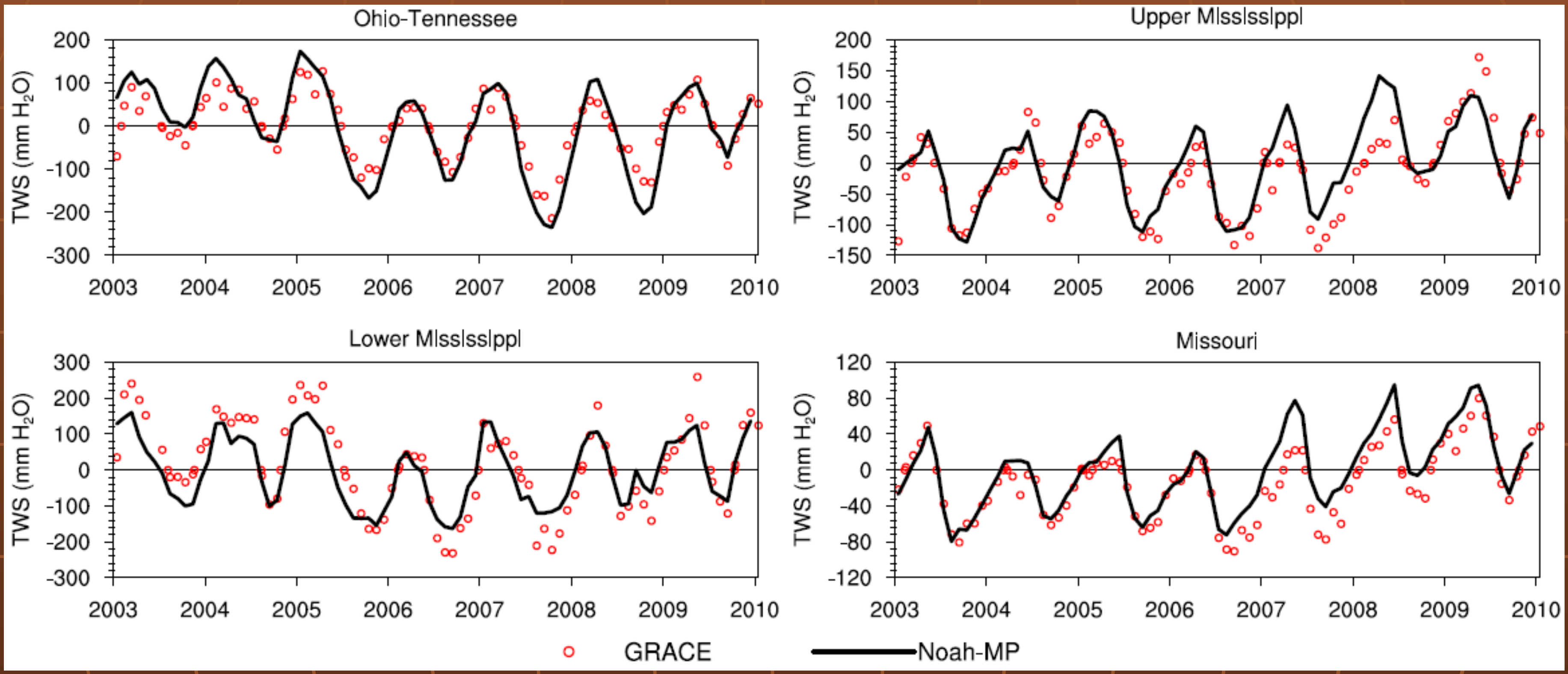
TWSA on Subbasins



✓ Noah-MP reproduces sub-basin variability of GRACE TWS anomalies.

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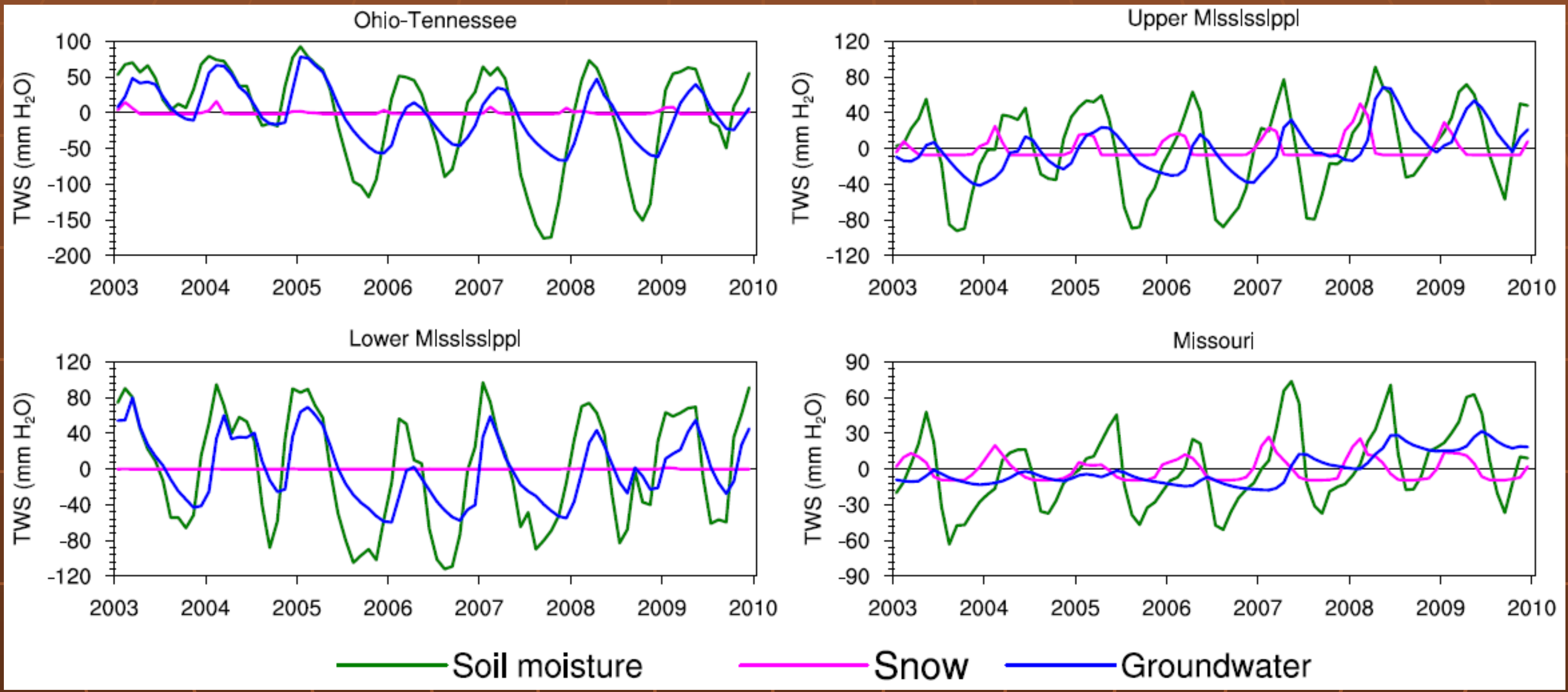
Contributions of TWSA on Subbasins



✓ Soil moisture is always the largest contributor in all four regions.
✓ In Missouri, snow contributes as much as groundwater.

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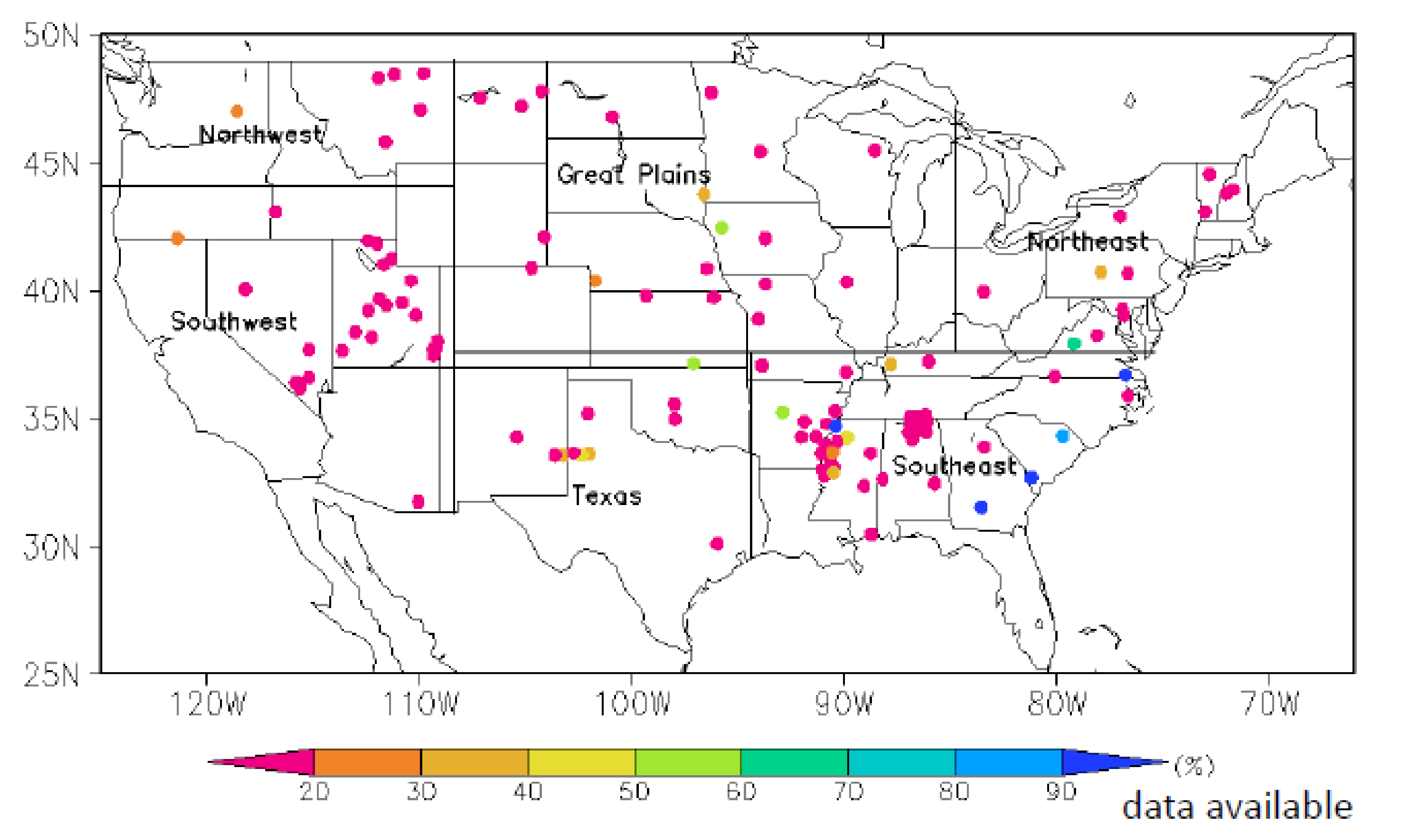
Soil Climate Analysis Network (SCAN)



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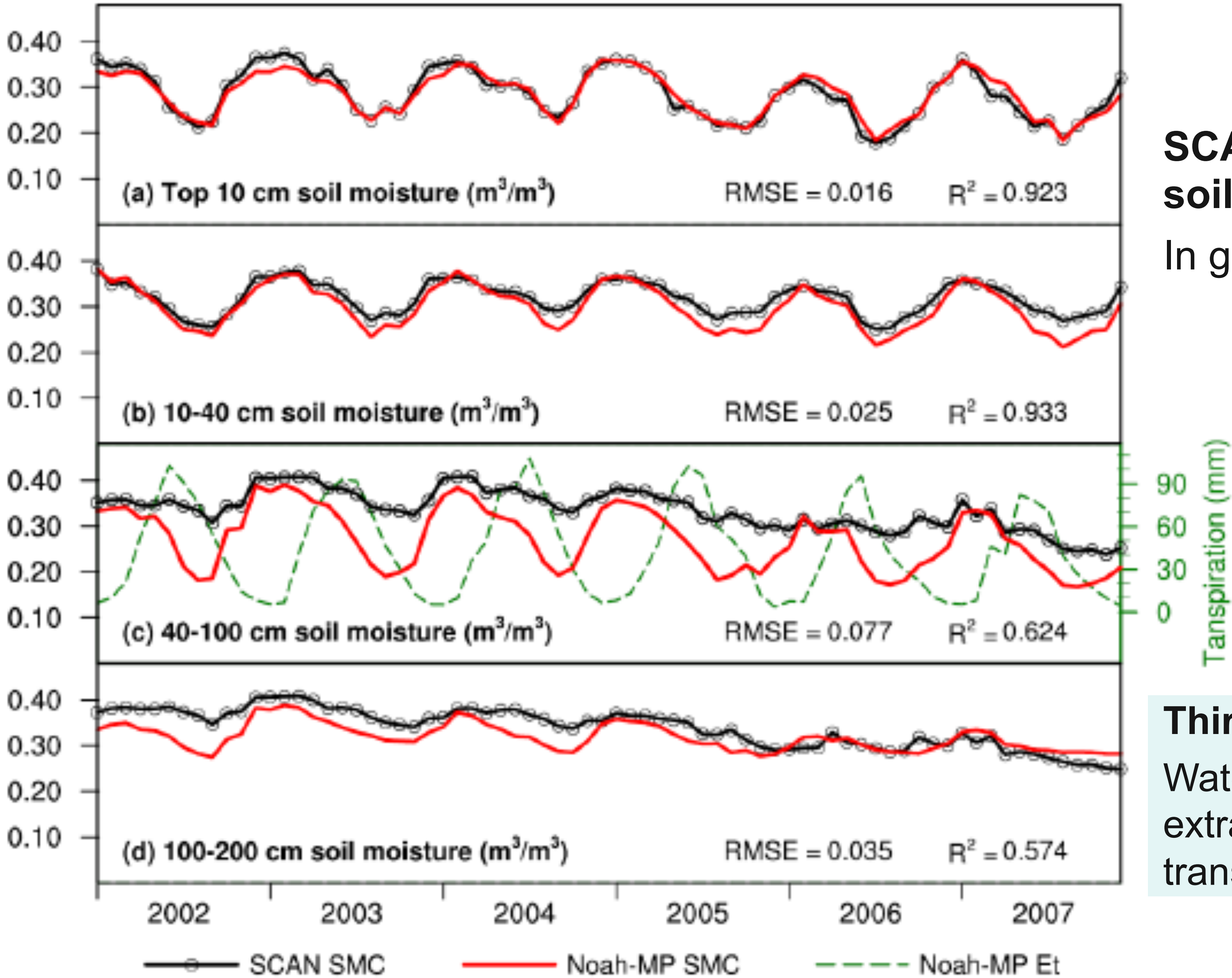

SCAN vs. modeled soil moisture:

In good agreement.

Third soil layer:

Water is over extracted for transpiration.

Conclusions

GRACE data have been used to evaluate the newly developed Noah-MP, the next-generation land surface model WRF and NOAA/NCEP climate forecasting systems.

- Noah-MP captures the timing and magnitude of TWS anomaly for the Mississippi River Basin.
- For the entire MRB, the ranked contribution to TWS anomaly is as follows:
    - 1st: Soil moisture
    - 2nd: Groundwater
    - 3rd: Snow
- Among the flux terms (precipitation, ET, and runoff), the cumulative anomaly of ET is the dominant water flux in driving the TWS anomaly.

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Path Forward: Terrestrial Hydrological Model Intercomparison Testbed: Multi-Everything

- Data
- Cal/Val
- Bench-marking
- Scaling
- Data Assimila-tion
- Cloud Computing
- Parallel Applications

LSMs ↕ Coupler ↔ RTMs

Coupler ↕ SSMs

CLM	JULES	Noah-MP
SiB	VIC	…

CATHY	ParFlow	OGS
PAWS	PIHM	…

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Questions?

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