Diagnosing Land-Atmosphere Coupling Strength from MPAS-NoahMP in S2S forecasts

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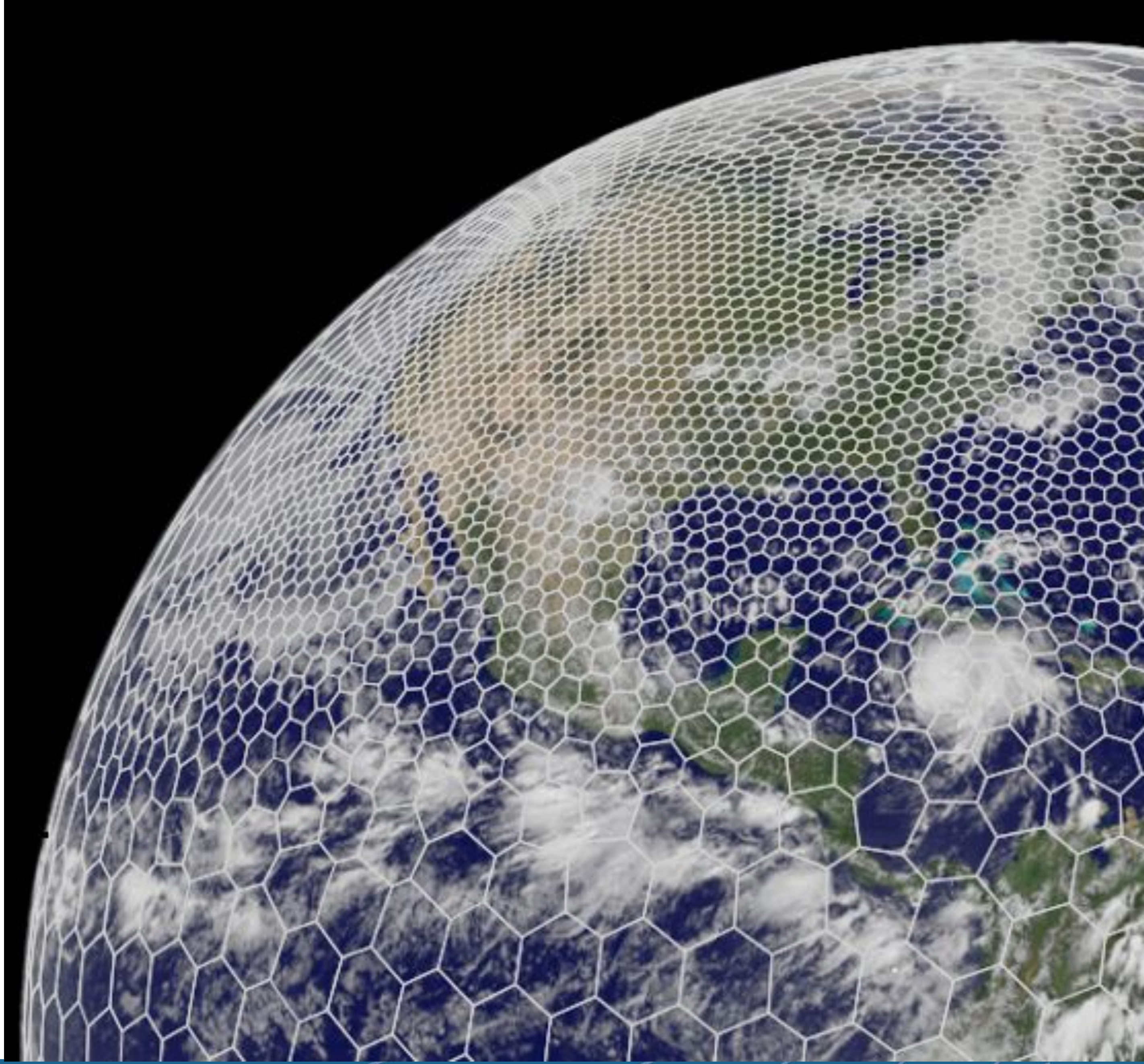
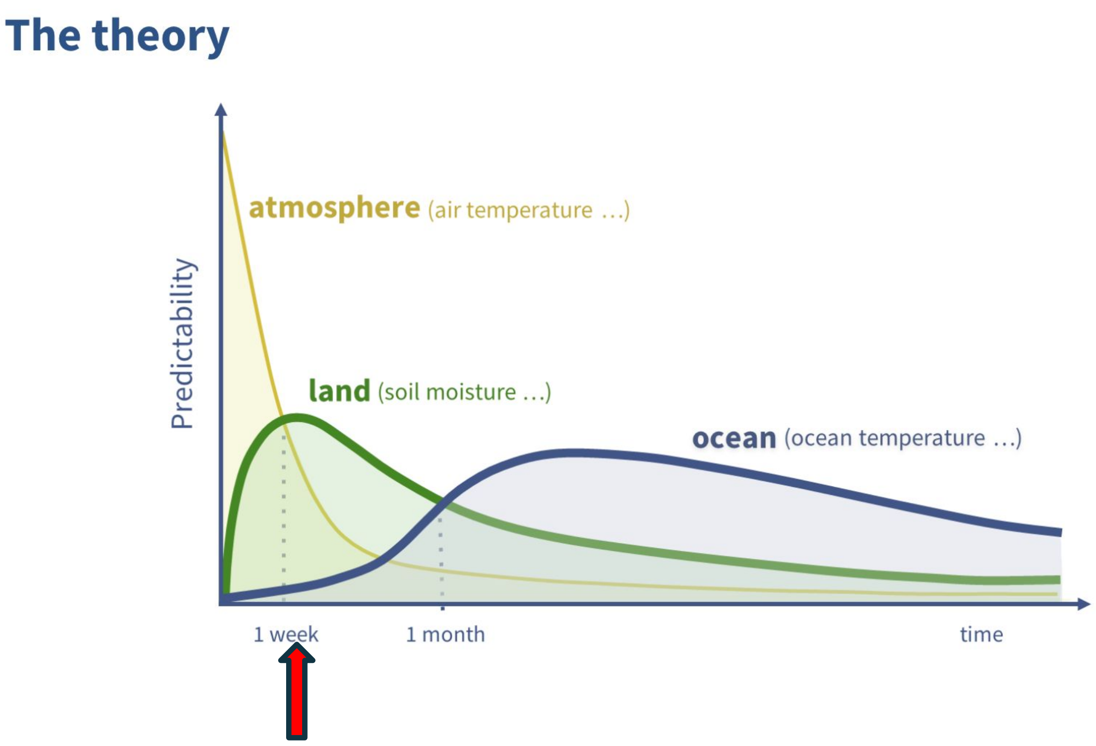


Motivation – Subseasonal Predictability and Prediction

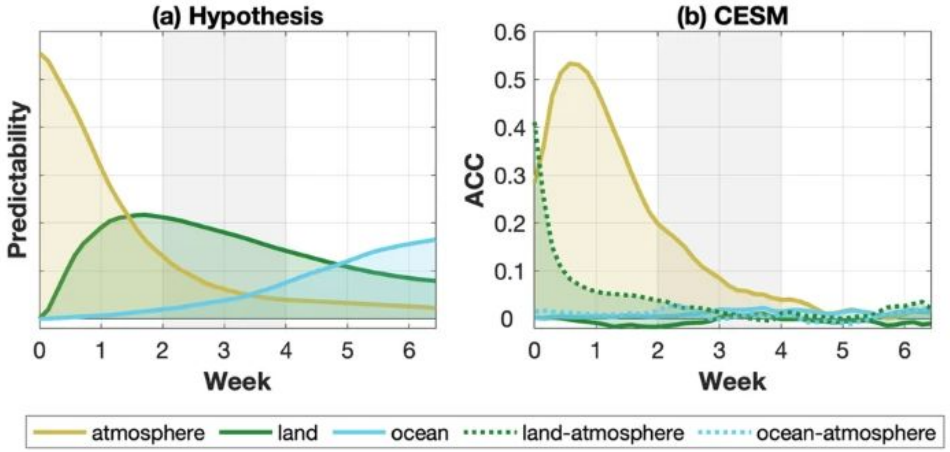
- Land states (soil moisture, snowpack, vegetation) can provide predictability within the window between weather (1 week) and climate (O-A) time scales.
- It is also the time scale where changes in land surface can actively provide sensitivity, variability, and memory
- The 2-4 week subseasonal range is a hot topic in operational forecast centers
- Provides longer time to react and prevent hazardous events, such as planning for agriculture/water resources/transportation, etc.



Representative of a mid-latitude mid-continental location
Credit to: Prof. Paul Dirmeyer

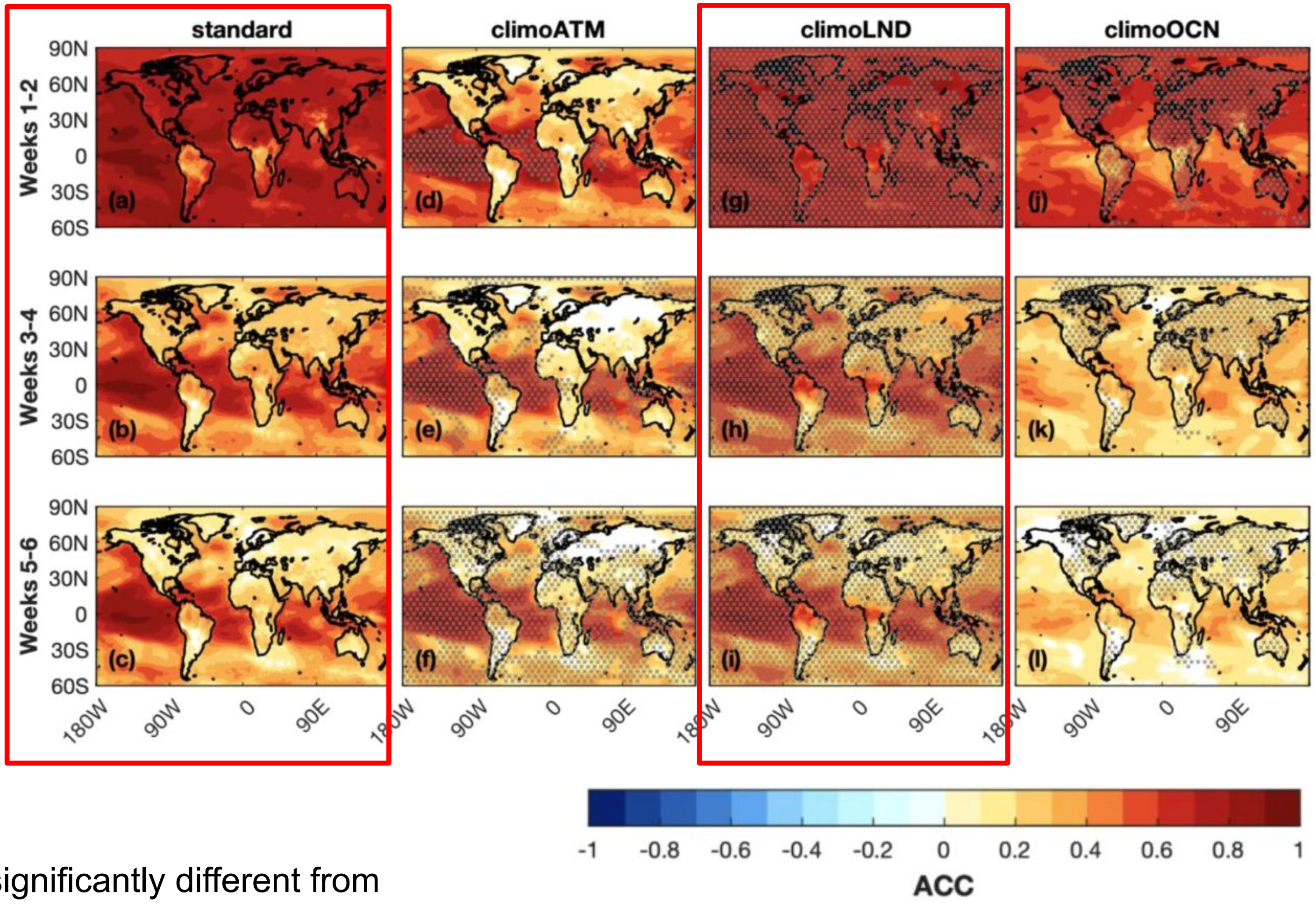
Land surface contribution to S2S predictability in CESM2

Fig. 1: Sources of subseasonalpredictability of temperature.



Predictability coming from the atmosphere (yellow), land (green), and ocean (blue) as a function of forecast time for annual mean 2 m temperature from 30ºN to 60ºN over land regions only: **a**) Hypothesis, adapted from a graphic by Paul Dirmeyer[7], (**b**) derived from CESM simulations Panel (b) includes additional two coupling terms: land-atmosphere (green dashed) and ocean-atmosphere (blue dashed). The derivation of (**b**) is described throughout the paper and further investigated in Fig. 4.

Richter et al. 2024

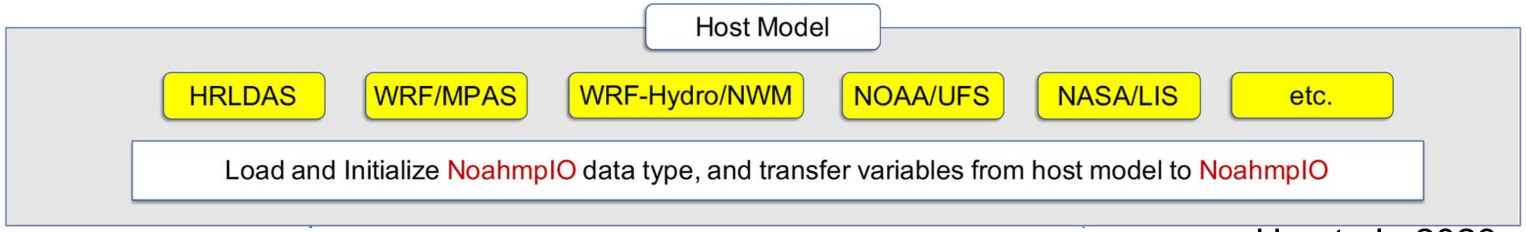


Standard reforecasts with realistic model initial conditions are not significantly different from using climatology land state – Climatological land initial conditions provide better predictability in some regions

MPAS-NoahMP: Goal

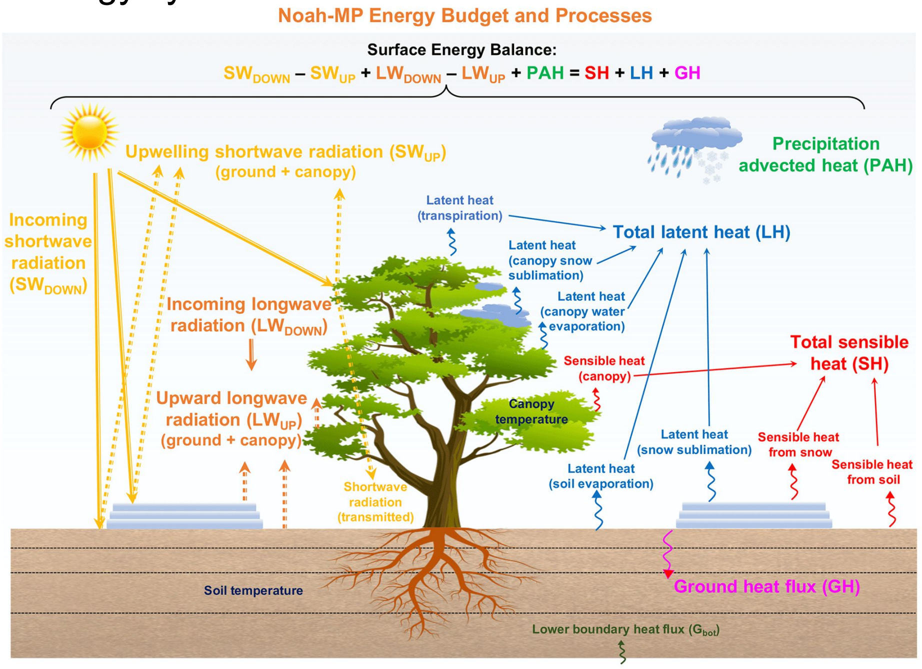
- Understand existing model biases in Land-Atmosphere Interactions in MPAS-NoahMP (multi-parameterization)
- Evaluate the performance of MPAS-NoahMP in S2S predictions

Noah-MP LSM released in MPAS Version 8.2.0 (2024 Jun)

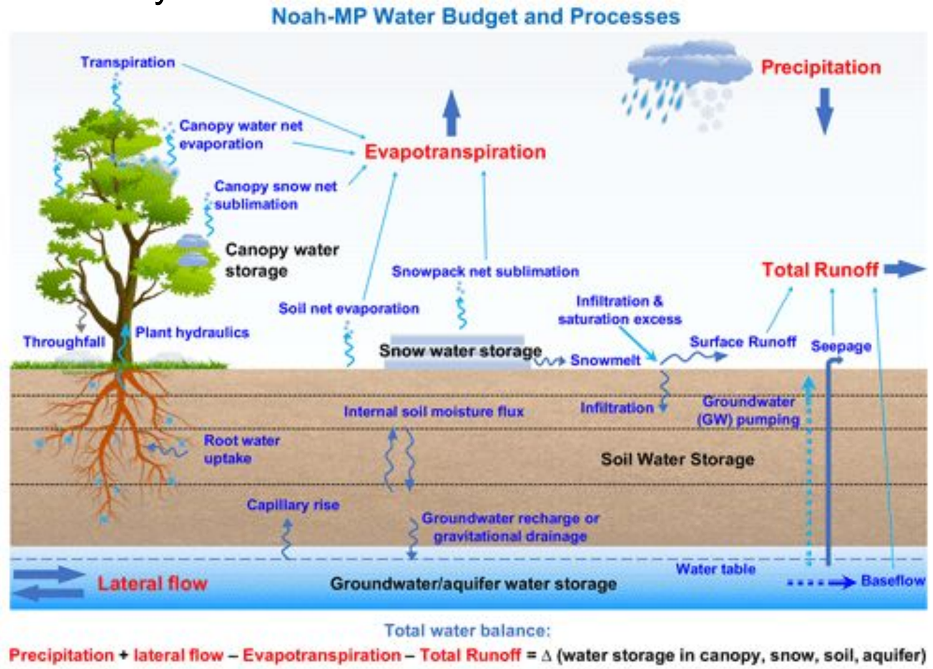


He et al., 2023

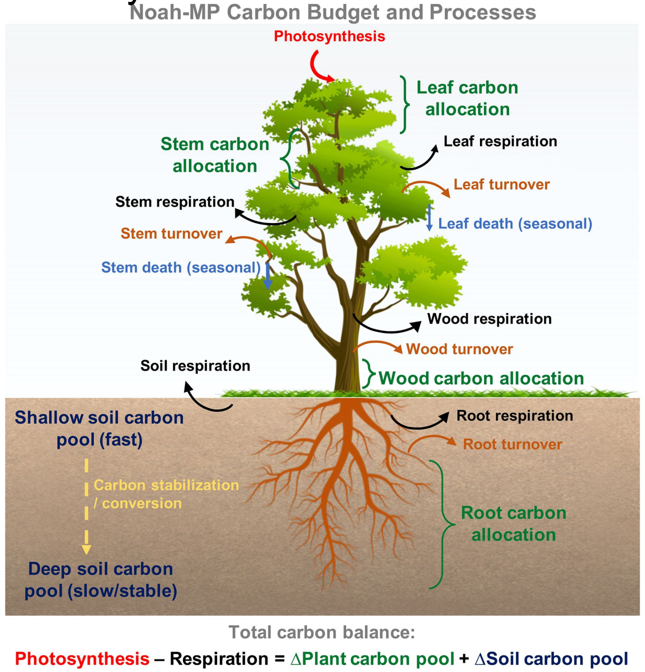
Energy cycle



Water cycle



Carbon cycle



Assessing Land-Atmosphere Coupling strength: LoCo metric

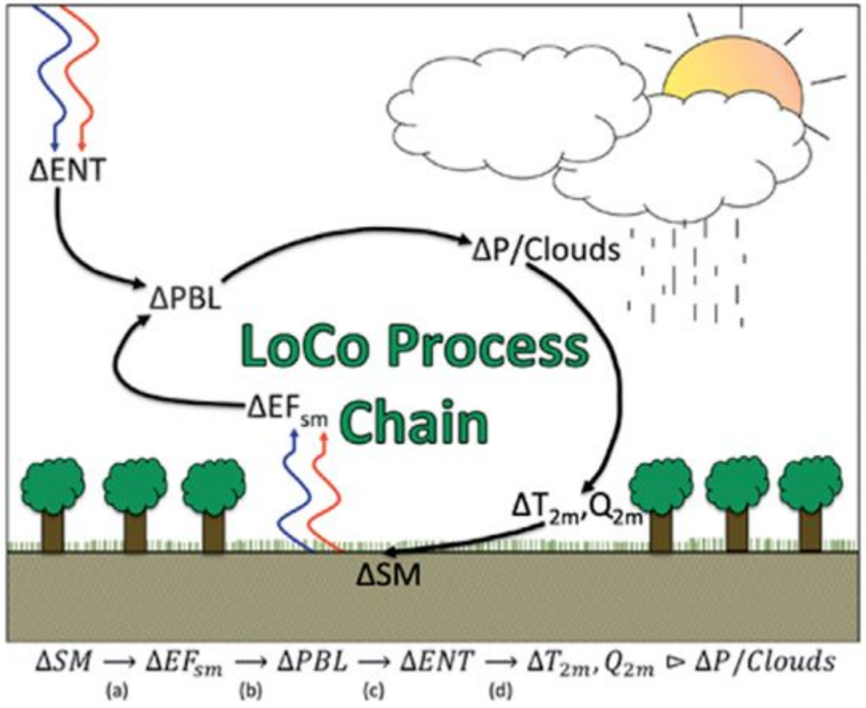


Fig. 2. Schematic of the LoCo process chain describing the components of L-A interactions linking soil moisture to precipitation and ambient weather (T_{2m}, Q_{2m}), where SM represents soil moisture; EF_{sm} is the evaporative fraction sensitivity to soil moisture; PBL is the PBL characteristics (including PBL height); ENT is the entrainment flux at the top of the PBL; T_{2m} and Q_{2m} are the 2-m temperature and humidity, respectively; and P is precipitation.

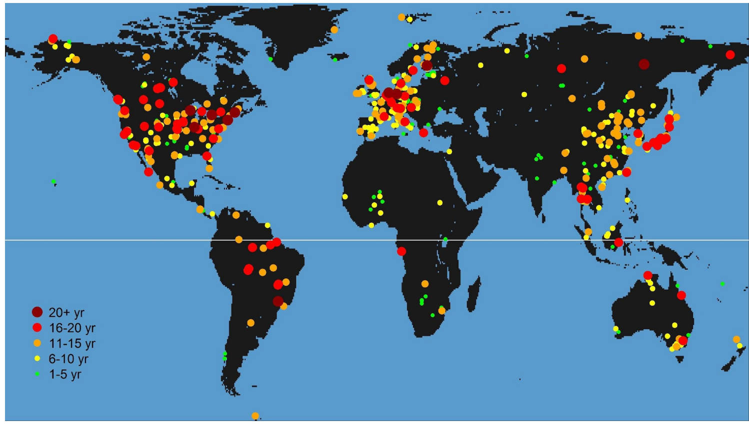
Santanello Jr, et al. 2018

Evaporative Fraction = E/Rn

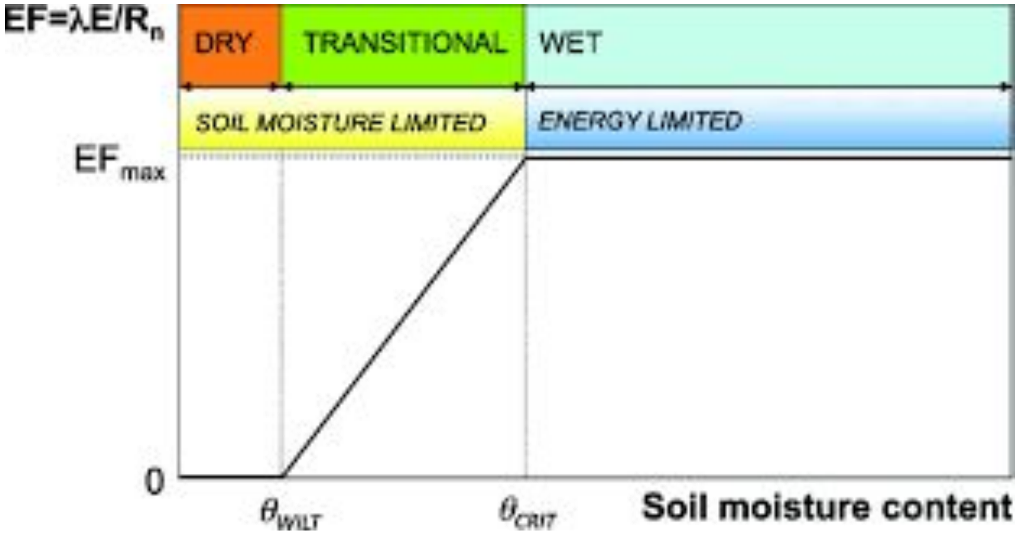
Local Land-Atmosphere Coupling

Terrestrial leg (R):
Soil water content vs Latent heat flux

Atmospheric leg (R):
Sensible heat flux vs LCL



FLUXNET 2015 dataset



Seneviratne et al. (2010)

Simulation Setup

60-km uniform mesh

Test two land surface models:

- Noah (original in MPAS-A)
- NoahMP (new since 2024-06)

Test two SM conditions:

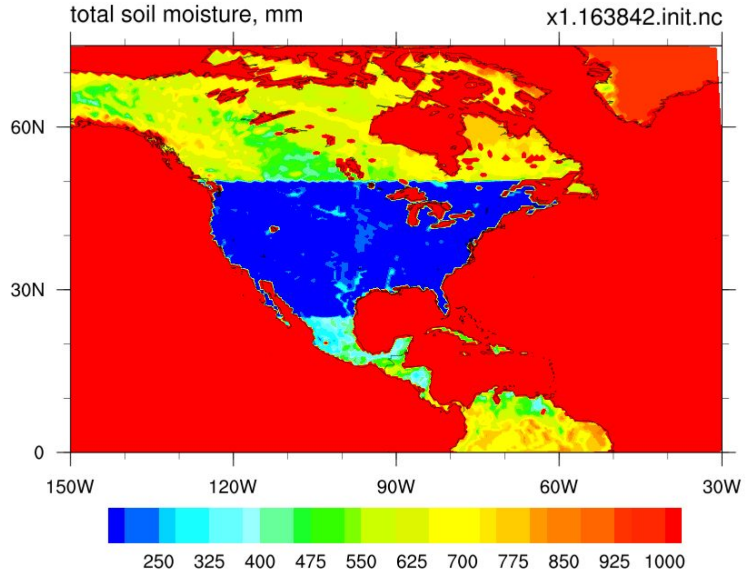
- dry (25 percentile) & wet (75 percentile) in North America
- in the wilting point to saturated point range

- Simulation time: 2021-06~2021-07
- Initial conditions: GFS (discussion on change to ERA5)
- SST: ERA5 3h

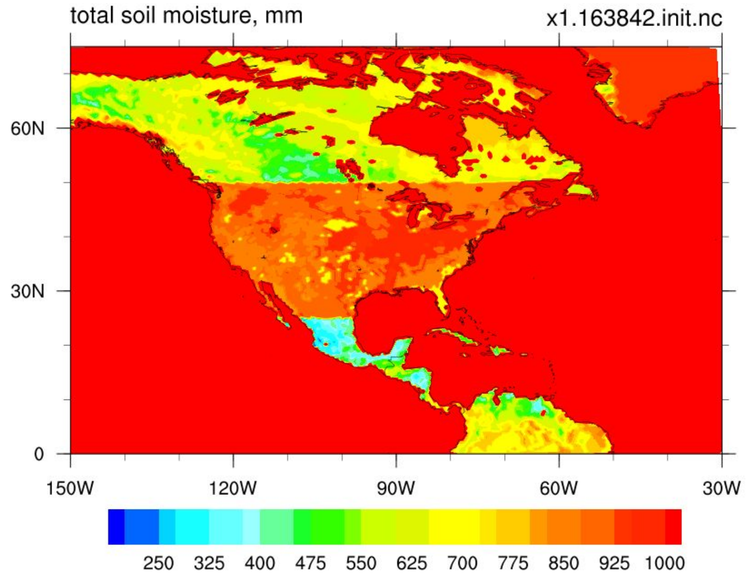
- Analysis:
- 1 Model 2m temp (week1~6)
- 2 Land-atmosphere coupling strength (LoCo metrics)

Set a very dry soil moisture init condition

25 percentile for dry

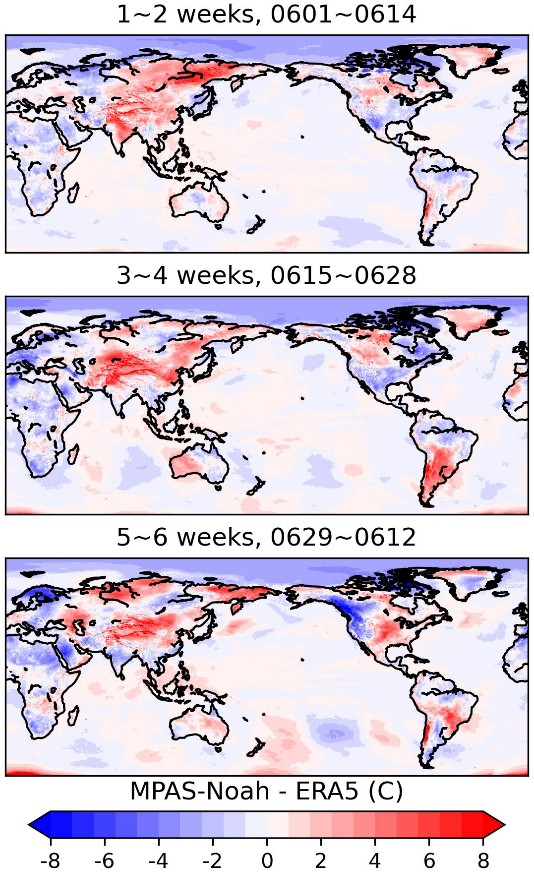


75 percentile for wet



Model simulated temperature:

MPAS-Noah – ERA5:

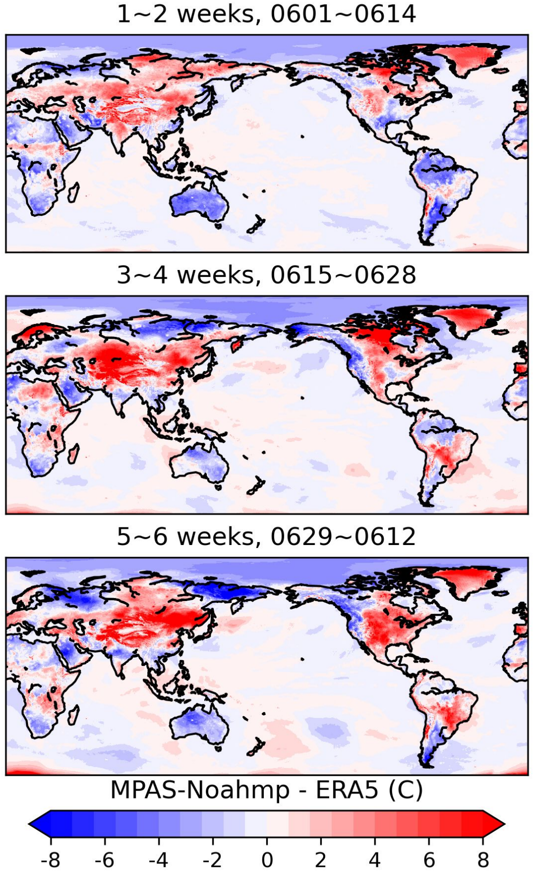


BIAS:
-0.33

-0.42

-0.43

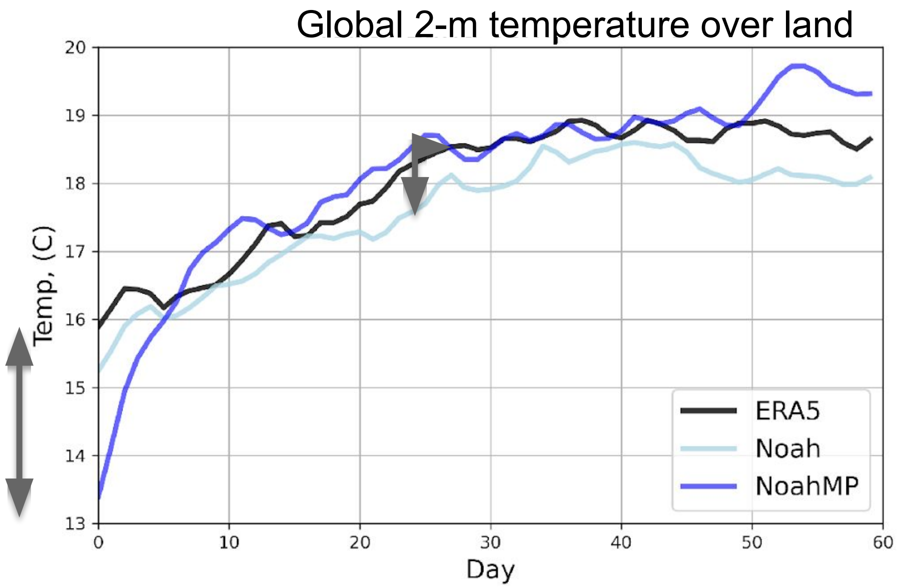
MPAS-NoahMP – ERA5:



BIAS:
-0.35

0.22

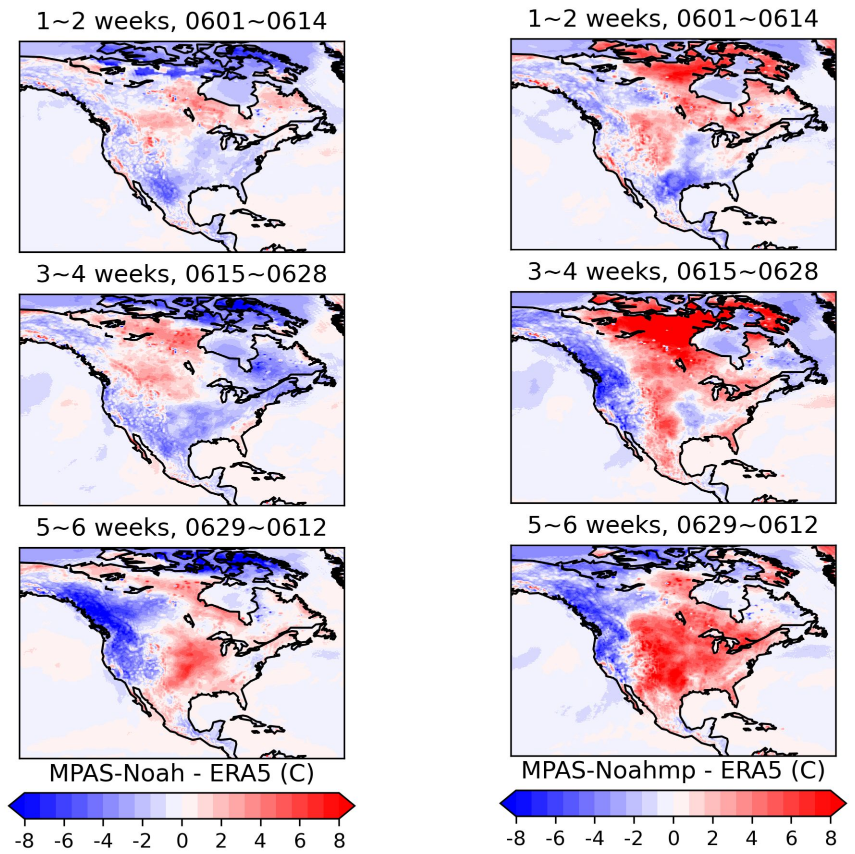
-0.02

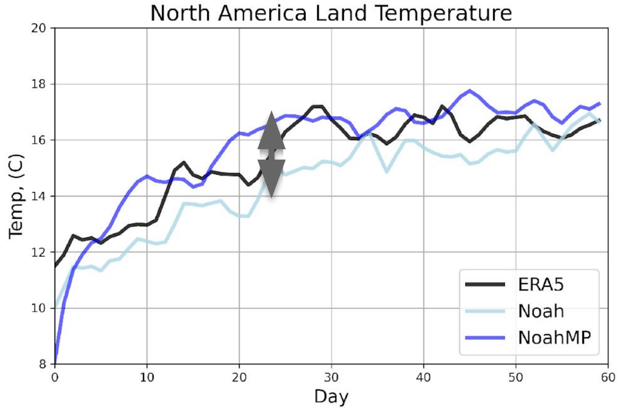


- Noah shows cooler temperature
- NoahMP with warmer temperature
- NoahMP takes longer time to spin-up (GFS uses Noah as land model)
- After 2 weeks, NoahMP shows better agreement with ERA5

Model simulated temperature in North America:

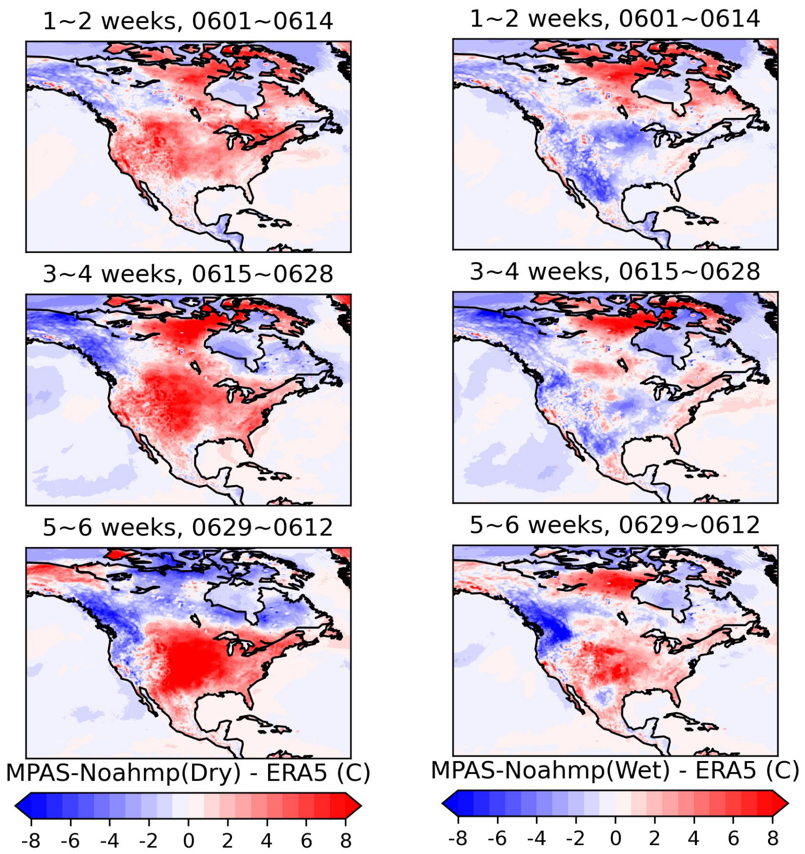
Noah NoahMP

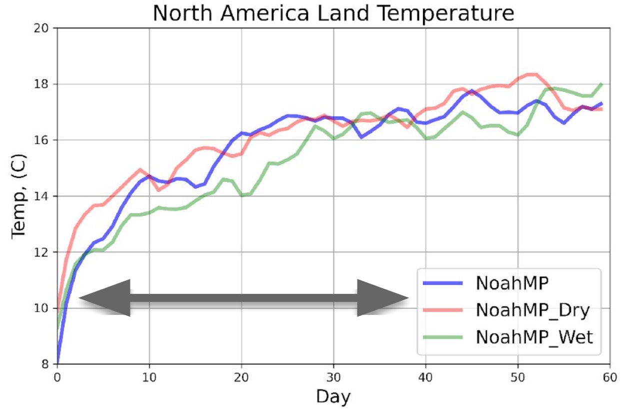




Temp difference between Noah & NoahMP
is bigger in North America

NoahMP (dry) NoahMP (wet)

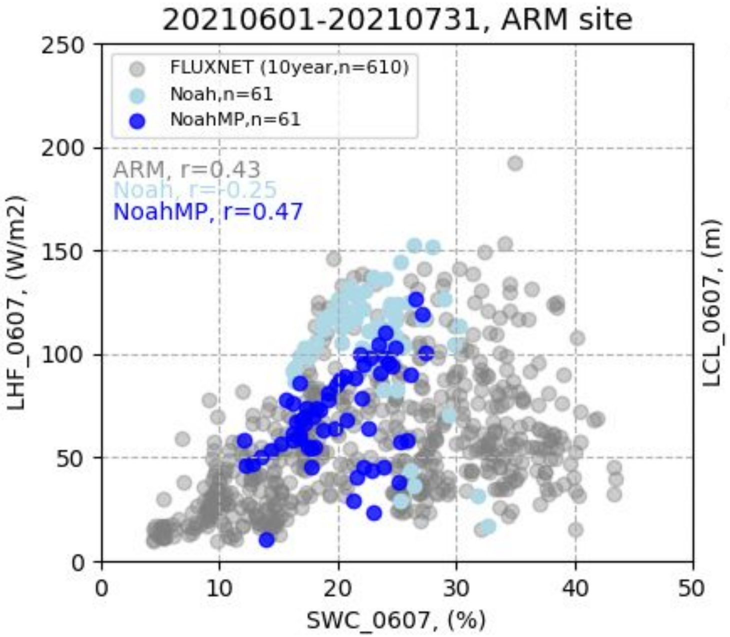




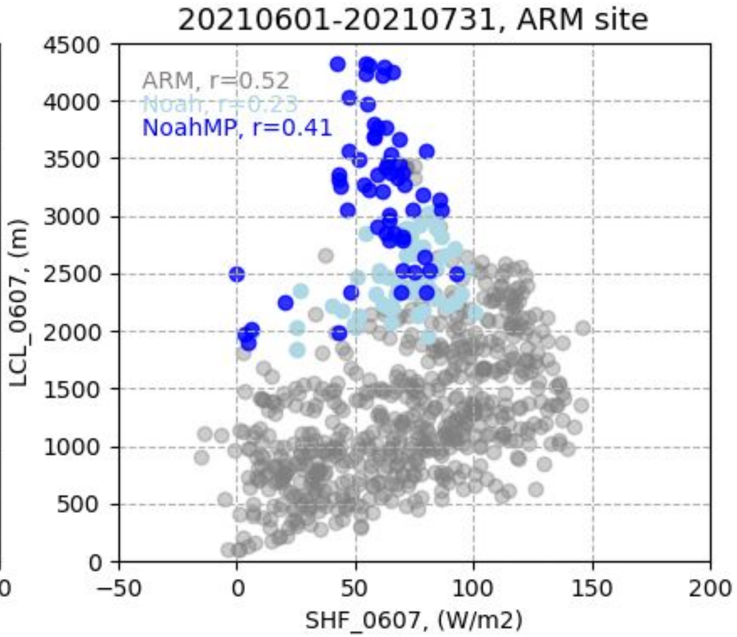
Init soil moisture impacts on North America temperature can last between week1~week5

L-A LoCo Metric

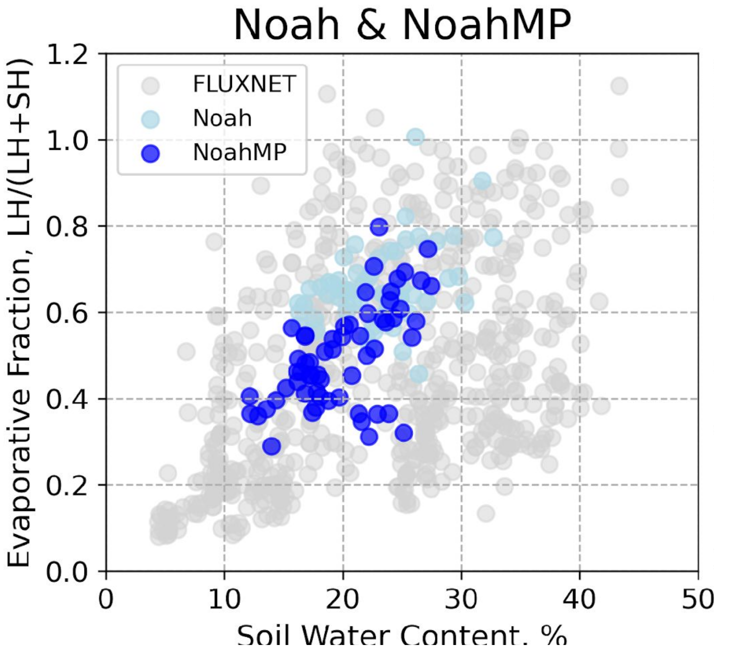
Terrestrial leg
Soil water content vs Latent heat flux



Atmospheric leg
Sensible heat flux vs LCL



Soil Water Content vs Evaporative Fraction



ARM Site in US
South Great Plains

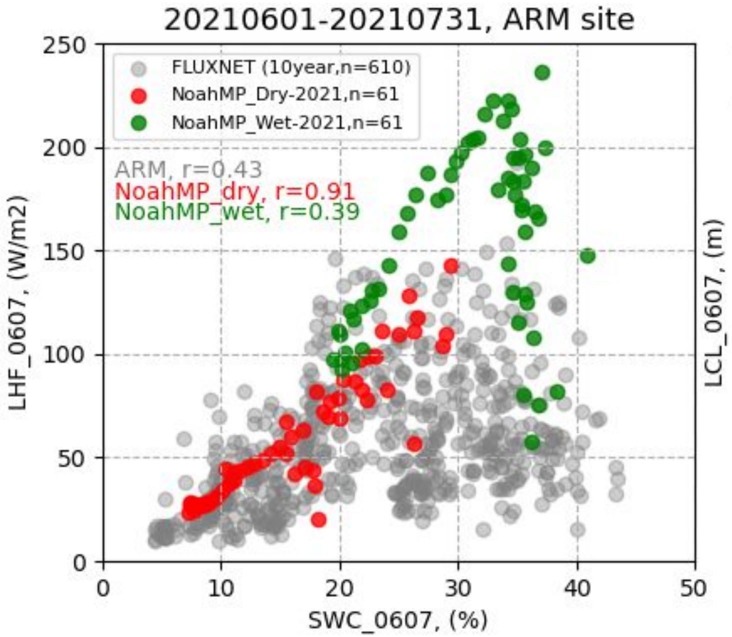
NoahMP shows higher correlation coefficient than Noah
stronger coupling strength than Noah

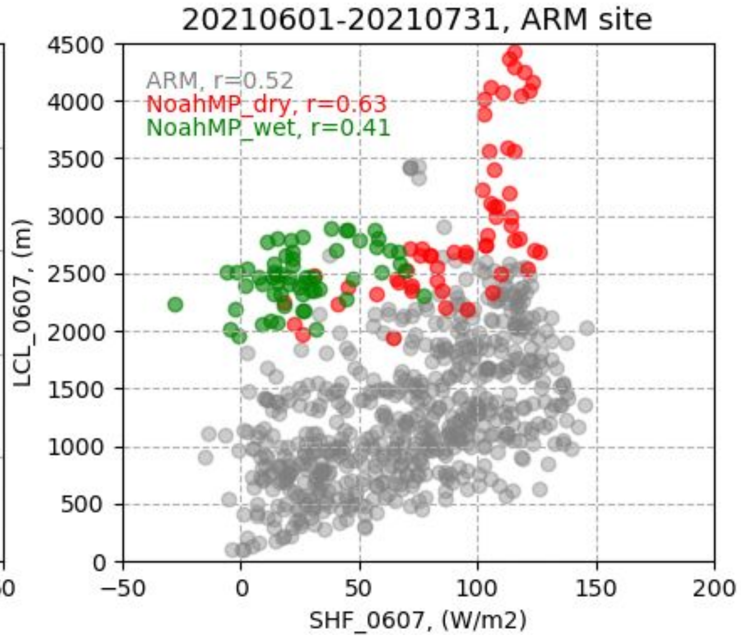
L-A LoCo Metric

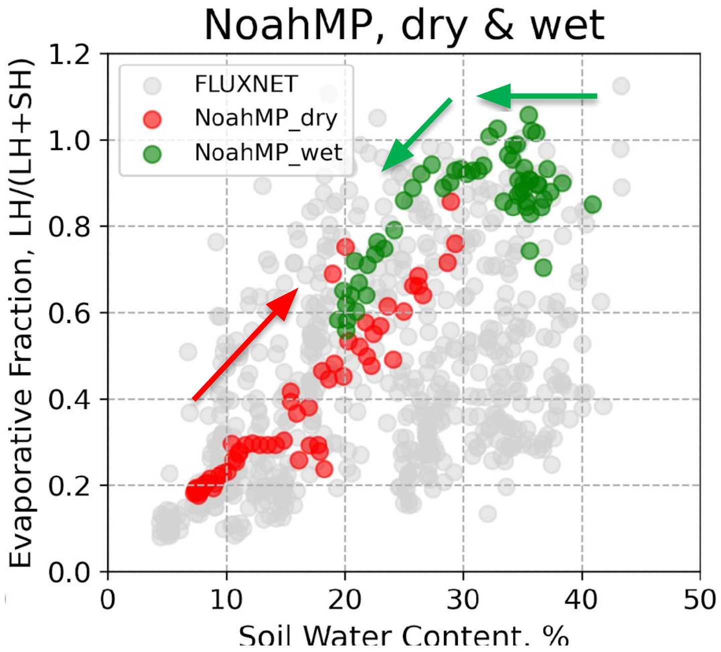
Terrestrial leg
Soil water content vs Latent heat flux

Atmospheric leg
Sensible heat flux vs LCL

Soil Water Content vs Evaporative Fraction







Water limited Energy limited

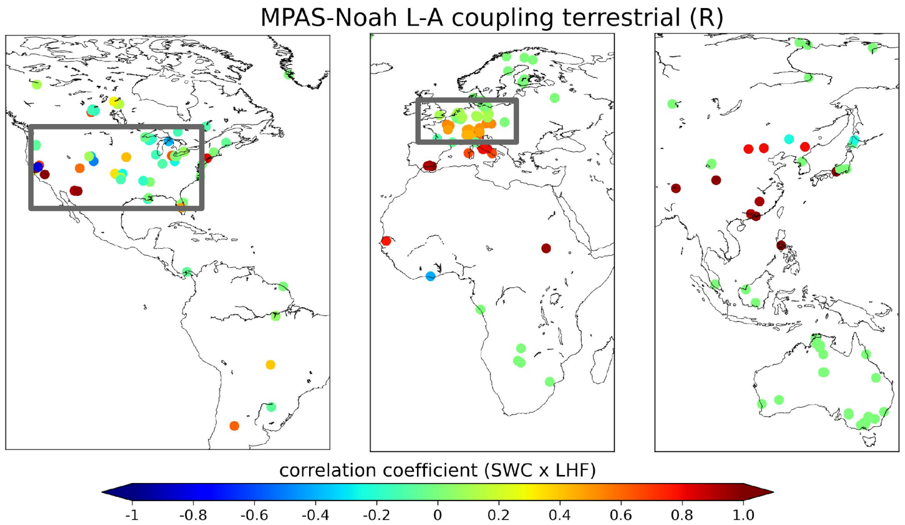
ARM Site in US
South Great Plains

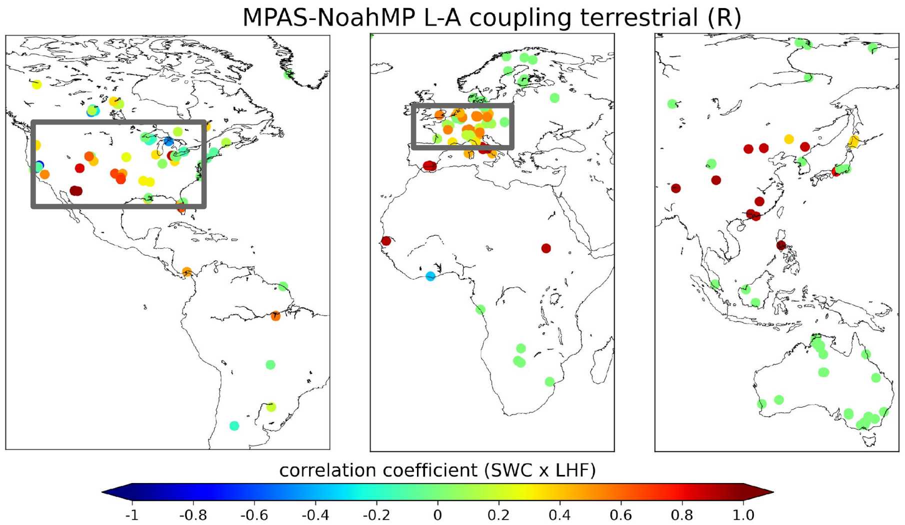
NoahMP_Dry shows stronger L-A coupling than NoahMP_Wet

Coupling Strength: Noah

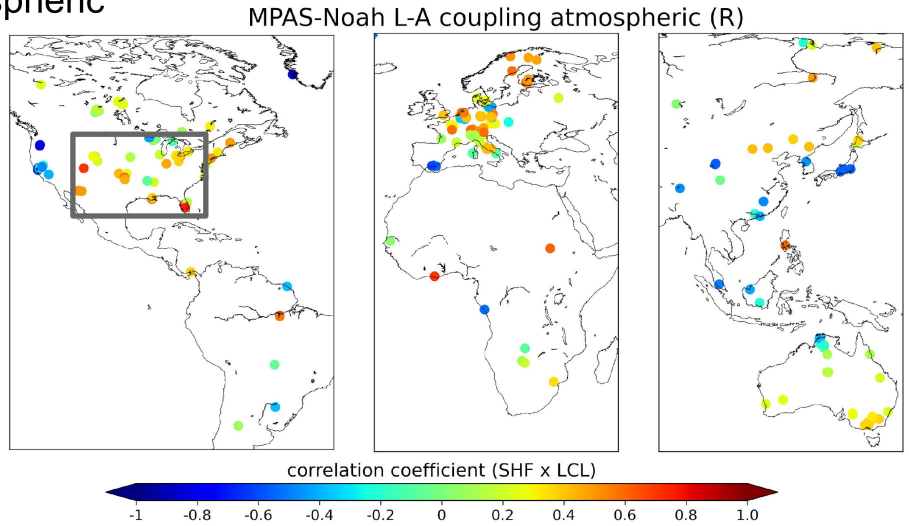
NoahMP

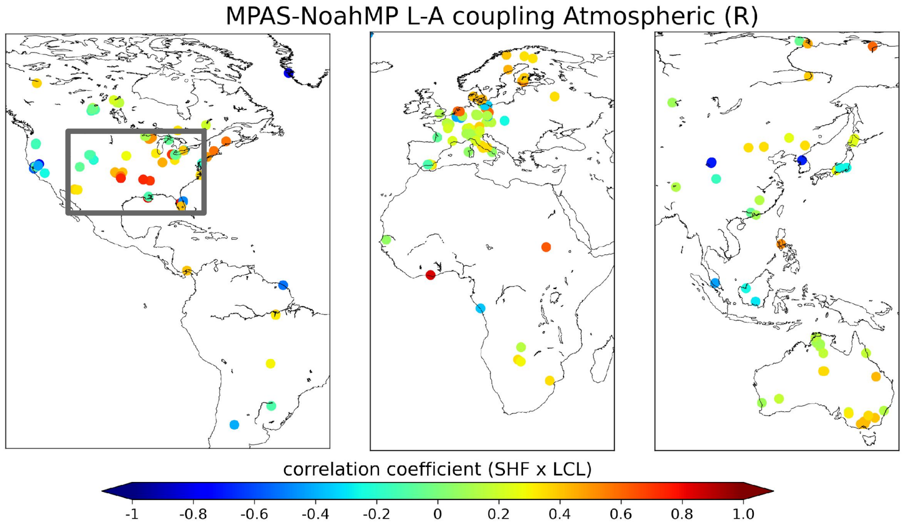
Terrestrial Leg





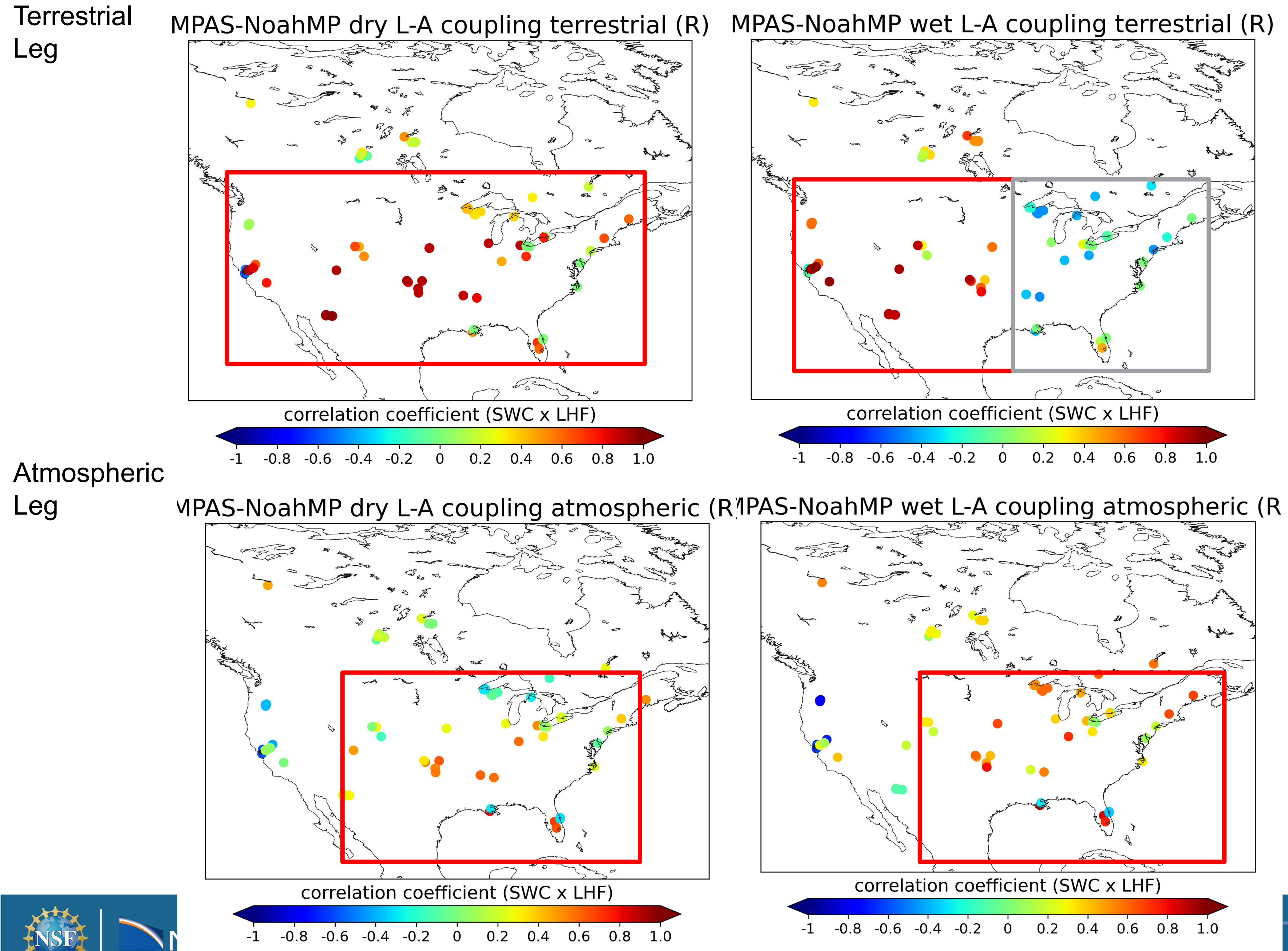
Atmospheric Leg





NoahMP shows stronger L-A coupling strength in many NH mid-latitude regions
Stronger in terrestrial leg than in atmospheric leg

Coupling Strength: NoahMP dry NoahMP wet



On Terrestrial leg:
Dry soil:
Strengthening L-A terrestrial leg

Wet soil:
Reduce L-A coupling strength
Eastern US shows negative correlation
Could be related to changing rainfall

On Atmospheric leg:
Wet soil moisture strengthens atmospheric coupling in Eastern US

Summary

- **NoahMP has stronger L-A coupling strength and warmer T2m than Noah**
- **T2m, Turbulent fluxes (SH, LH) and L-A coupling strength are sensitive to soil moisture conditions**
- **SM effects on T2m can last about 1~5 weeks**

Future Steps

- **Provide a bulk evaluation of MPAS-NoahMP for different configuration (snow compaction, lateral groundwater flow, etc.)**

- **Provide the optimal setup for MPAS-NoahMP for S2S reforecast**

- **Generate initial condition ensembles from ERA5 (EC-flow) (Abby and Judith)**

- **Different resolution refinement: 60-12 km, 60-3km, etc.**