



Subseasonal Prediction of U.S. Drought in NOAA GEFSv12 Reforecasts

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Motivation

- CPC performs research and development to improve its drought forecast capability and products, to meet evolving user needs and incorporate advances in climate science and technology.
 - Existing: Monthly Drought Outlook, Week-2 Rapid Drought Onset
 - New: Probabilistic Monthly Drought Outlook and Flash Drought Outlook
- The NOAA GEFSv12 subseasonal forecasts can serve as a key input.
- Before incorporating GEFSv12, it is essential to assess its performance in forecasting drought, develop ways to improve GEFSv12-based drought forecasts, and ensure the forecasts add value.

Objectives

- Evaluate GEFsv12 reforecasts for soil moisture
 - Forecast skill for soil moisture and its meteorological drivers
 - Accuracy of soil moisture initial conditions
 - Performance of Noah land surface model
- Improve GEFsv12-based subseasonal forecasts for soil moisture
- Produce real-time subseasonal drought forecasts to support CPC operational drought outlooks.

GEFSv12 Reforecasts

- **GEFSv12 Reforecasts (Guan et al. 2022)**
 - Phase II (2000-2019), initialized weekly on Wednesdays, 35-day forecasts
 - 11 ensemble members
- **GEFSv12 Reanalysis (Hamill et al. 2022)**
 - Designed for initializing GEFSv12 reforecasts
 - Produced using 5 parallel streams, 1-year spin-up per stream
 - Soil moisture
 - Produced by driving the reanalysis Noah land model with reanalysis atmospheric forcings
 - No direct assimilation of top-level soil moisture observations
 - Soil moisture below 10cm are relaxed to an externally specified GLDAS-based climatology with a time scale of 60 days

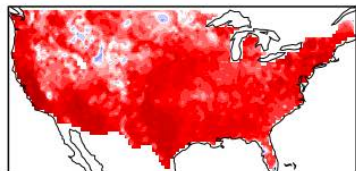
Observational References *for GEFsV12 Evaluation*

- Observational references
 - A Noah land analysis (Noah)
 - Produced by driving the Noah (ccpp) offline with NLDAS-2 hourly atmospheric forcings, with a sufficient (80-year) land surface spin-up (1979-present)
 - Used for evaluating GEFsV12 reforecasts and reanalysis
 - National Soil Moisture Network in-situ observations
 - PI: Steven Quiring (OSU); Supported by NIDIS
 - Historical daily data (1996/01/01-2021/09/21); 19 networks (1456 stations)
 - Used for evaluating a Noah (ccpp) land surface model

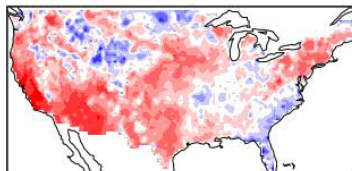
GEFSv12 Reforecasts: Soil Moisture

ACC (GEFSv12_Reforecasts, Noah)

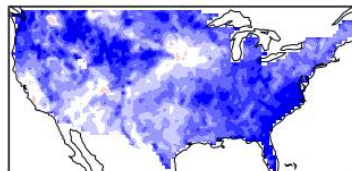
0-10cm Week1



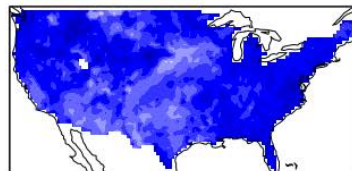
Week2



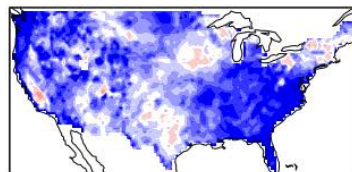
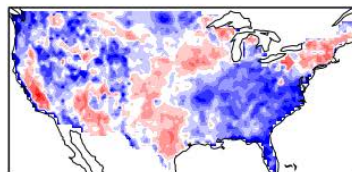
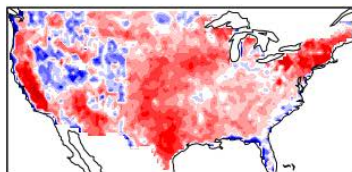
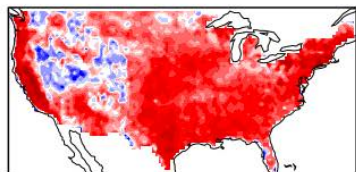
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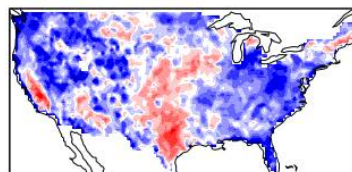
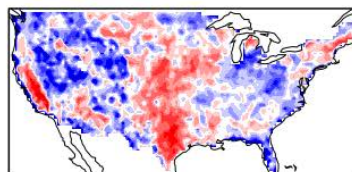
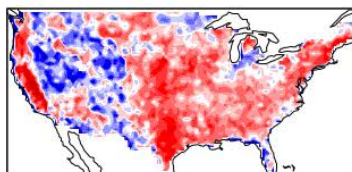
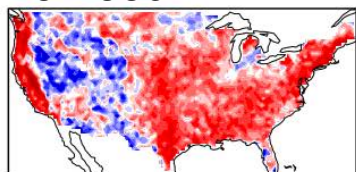
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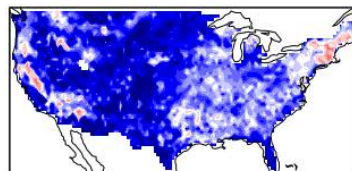
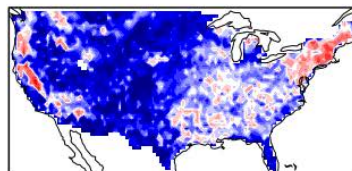
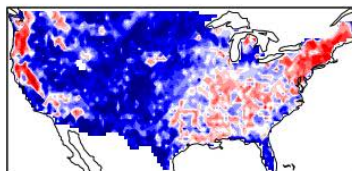
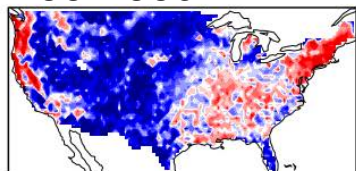
10-40cm



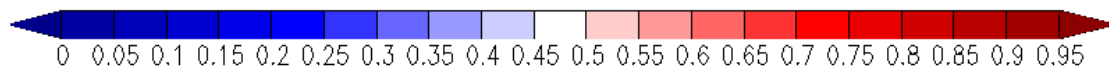
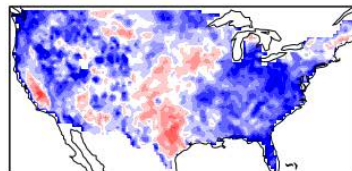
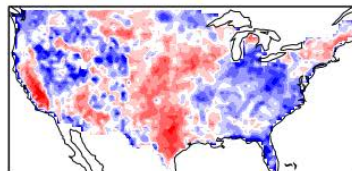
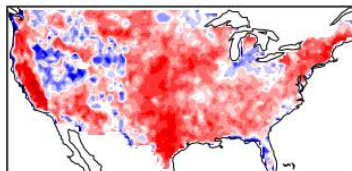
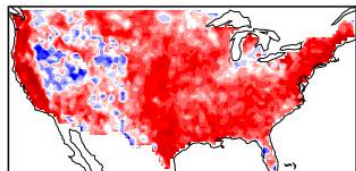
40-100cm



100-200cm



0-100cm

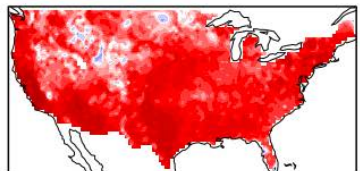


- Skill decreases with lead time, due to the skill decrease of atmospheric forcings (e.g., precipitation, temperature).
- Skill decreases faster at top-soil layers, where the effects of atmospheric forcings are more prominent
- Relatively low skills in western interior U.S. and deeper soil depths
 - Cause?

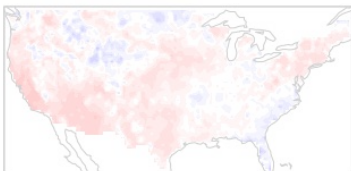
GEFSv12 Reforecasts: Soil Moisture

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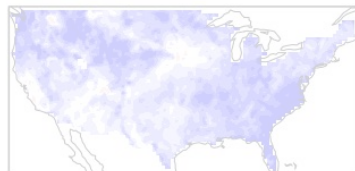
0-10cm Week1



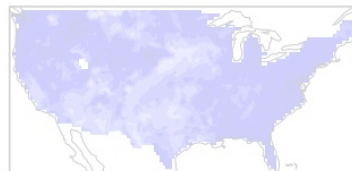
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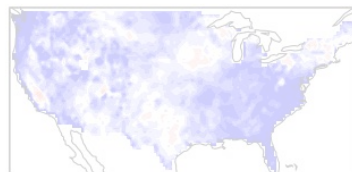
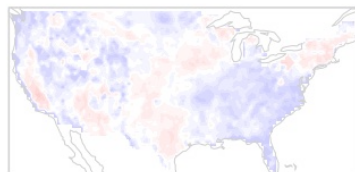
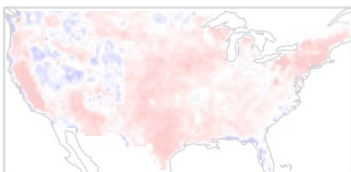
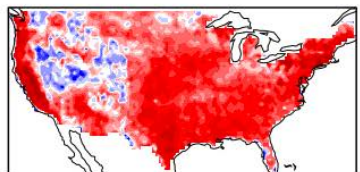
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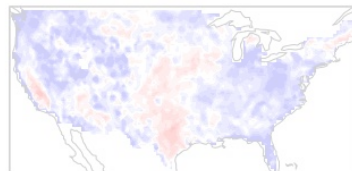
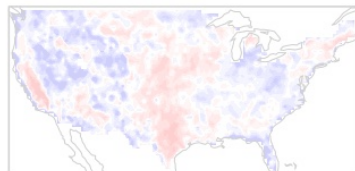
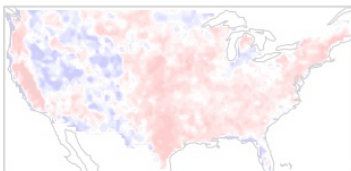
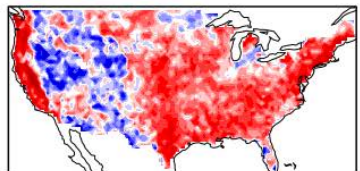
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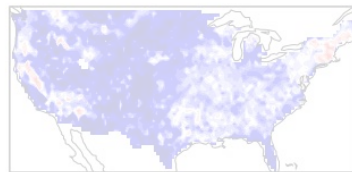
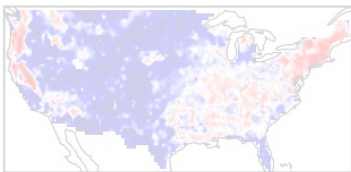
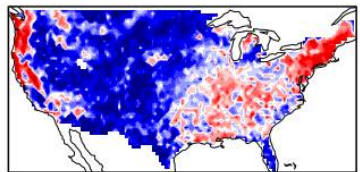
10-40cm



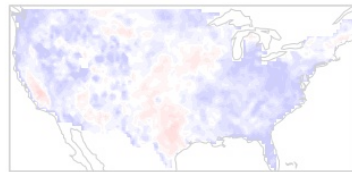
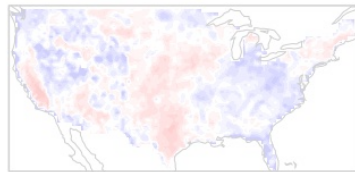
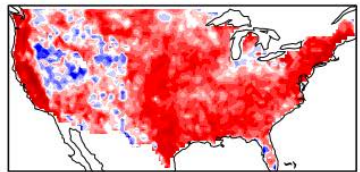
40-100cm



100-200cm

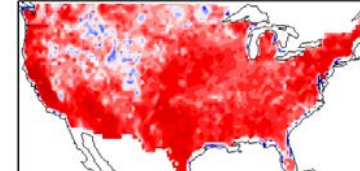


0-100cm

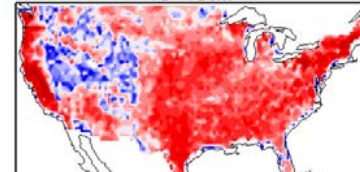


ACC (GEFSv12_Reanalysis, Noah]

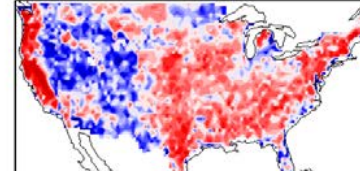
0-10cm



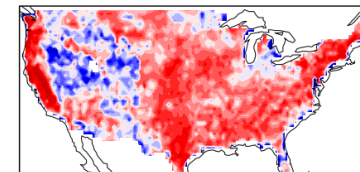
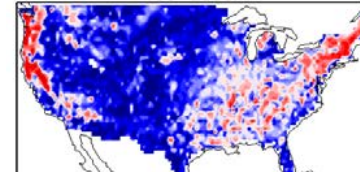
10-40cm



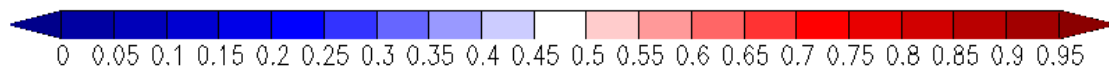
40-100cm



100-200cm



➤ Skill is strongly influenced by accuracy of soil moisture initial conditions.



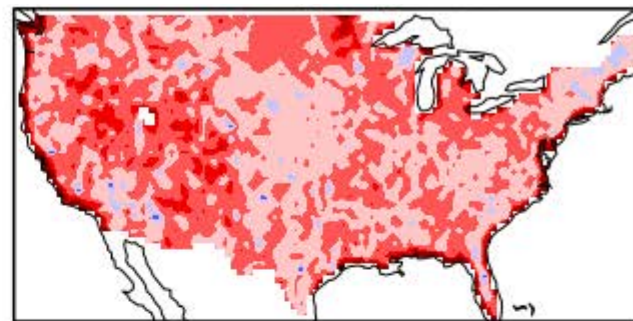
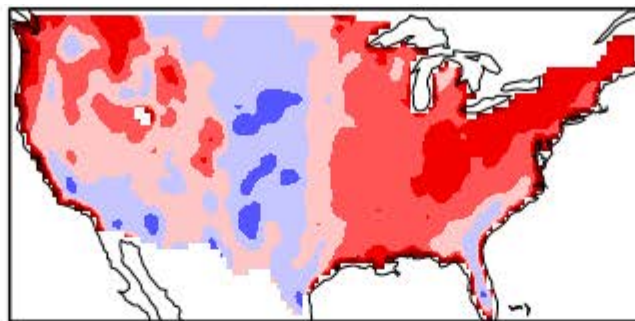
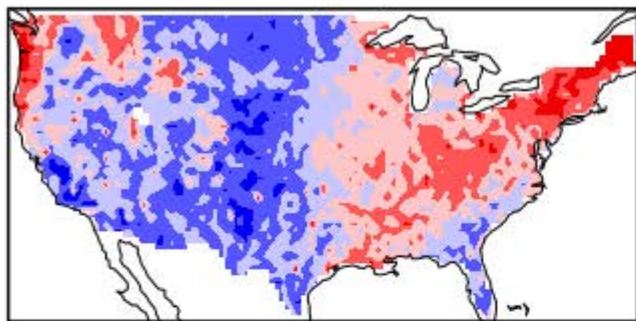
GEFSv12 Reforecasts: Soil Moisture Initial Conditions

Soil Moisture: Top 1-meter

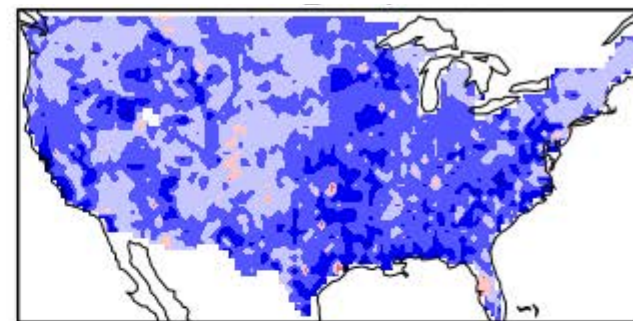
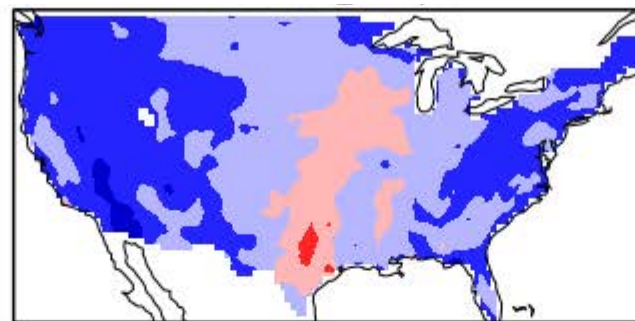
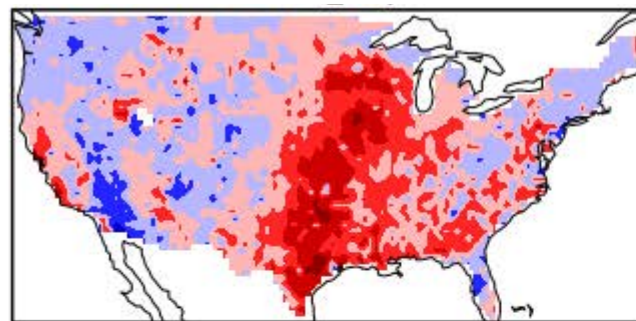
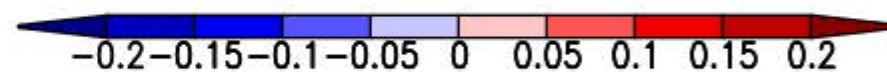
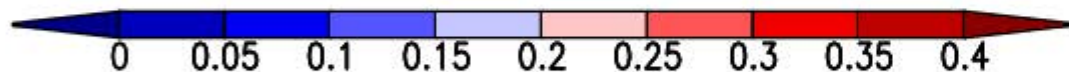
Noah

GEFSv12 reanalysis

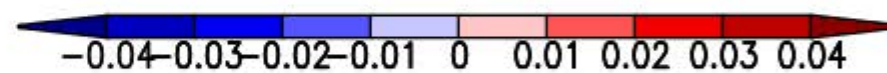
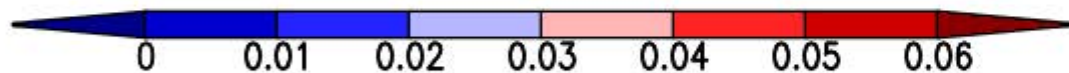
GEFSv12 reanalysis minus Noah



Climatology



Standard Deviation



- Relative to the Noah land analysis, the GEFSv12 reanalysis soil moisture is considerably wetter and exhibits weaker temporal variability.

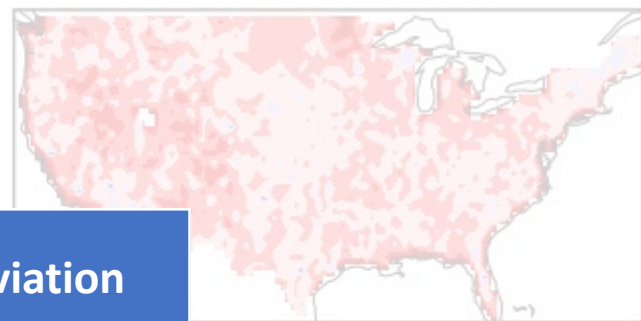
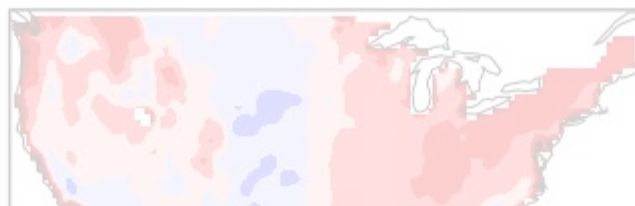
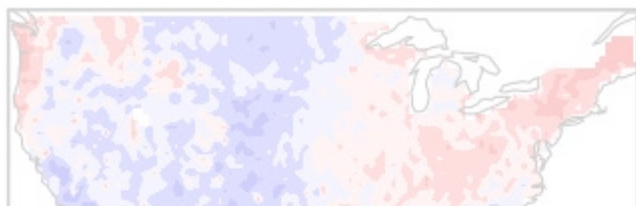
GEFSv12 Reforecasts: Soil Moisture Initial Conditions

Soil Moisture: Top 1-meter

Noah

GEFSv12 reanalysis

GEFSv12 reanalysis minus Noah



Climatology

GEFSv12_reanalysis/Noah
For CONUS Mean

Climatology

Standard Deviation

0-10cm

1.3

0.8

10-40cm

1.3

0.7

40-100cm

1.4

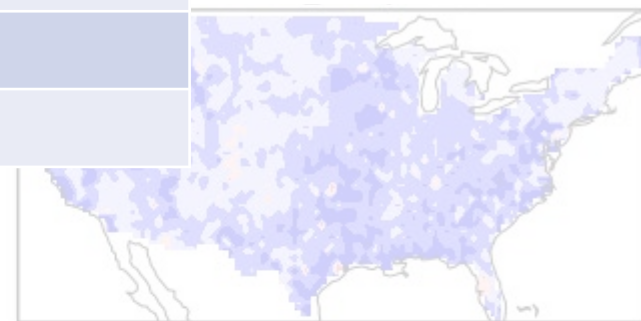
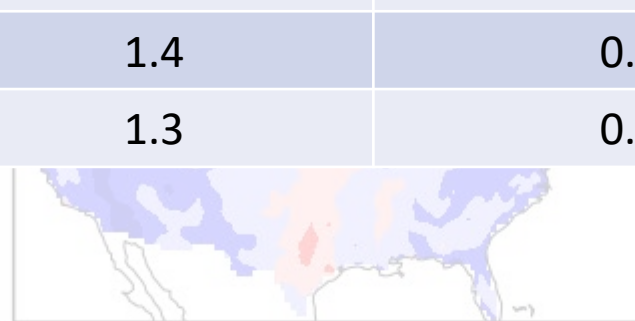
0.6

100-200cm

1.3

0.4

-0.05 0 0.05 0.1 0.15 0.2



Standard Deviation

0 0.01 0.02 0.03 0.04 0.05 0.06

-0.04 -0.03 -0.02 -0.01 0 0.01 0.02 0.03 0.04

- Relative to the Noah land analysis, the GEFSv12 reanalysis soil moisture is considerably wetter and exhibits weaker temporal variability.

GEFSv12 Reforecasts: Soil Moisture Initial Conditions

Offline Noah Land Surface Model Experiments

- Objective: investigate causes of regional low ACC consistency of soil moisture between GEFSv12 reanalysis and Noah land analysis

Offline Noah Experiment (2000-2019)	Atmospheric Forcings Taken From:		Sufficient Land Spin-up?
	GEFSv12 reanalysis	NLDAS-2	
Noah land analysis		All 7 Forcings	Yes
Experiment 1	P	T, wind10m, Q2m, Ps, SW, LW	Yes
Experiment 2	P, T	wind10m, Q2m, Ps, SW, LW	Yes
Experiment 3	P, T, SW	wind10m, Q2m, Ps, LW	Yes
Experiment 4	P, T, SW, LW	wind10m, Q2m, Ps	Yes
Experiment 5	P, T, SW, LW, Q2m	wind10m, Ps	Yes
Experiment 6	All 7 Forcings		Yes
GEFSv12 reanalysis	All 7 Forcings		1-year spin-up per stream

NLDAS-2 Atmospheric Forcings: P is based on CPC observations, whereas the rest forcings are from NARR.

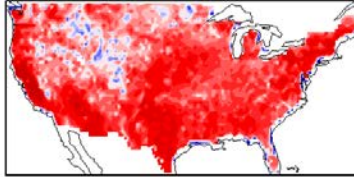
GEFSv12 Reforecasts: Soil Moisture Initial Conditions

Δ ACC (with Noah land analysis)

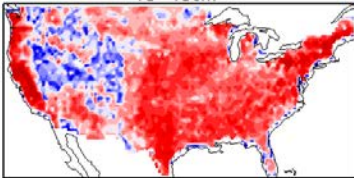
from using GEFSv12 reanalysis forcing or having insufficient land spin-up

ACC_GEFsv12reana

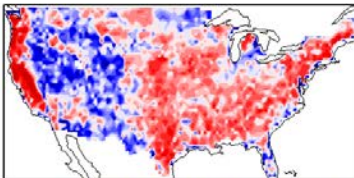
0-10cm



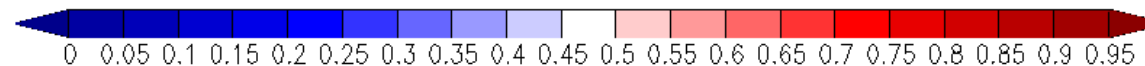
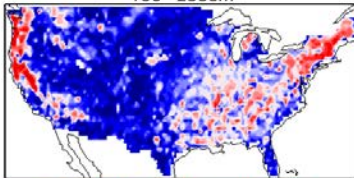
10-40cm



40-100cm



100-200cm



GEFSv12 Reforecasts: Soil Moisture Initial Conditions

Δ ACC (with Noah land analysis)

from using GEFSv12 reanalysis forcing or having insufficient land spin-up

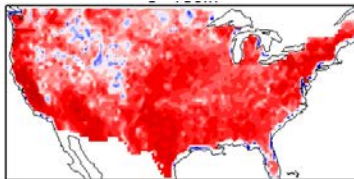
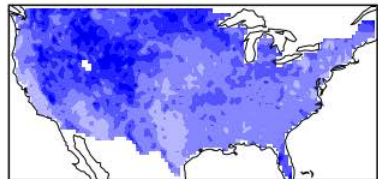
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[ACC_GFSv12reana-1.0]

ACC_GFSv12reana

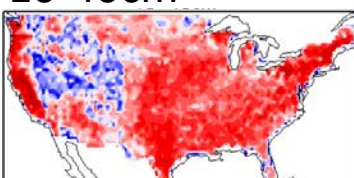
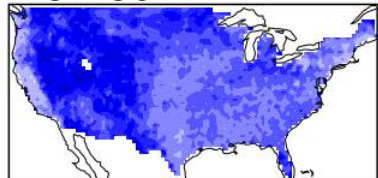
0-10cm

0-10cm



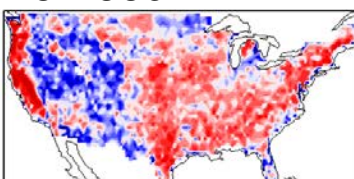
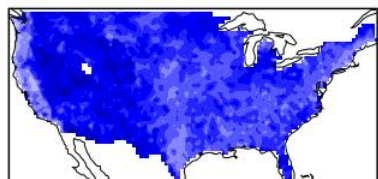
10-40cm

10-40cm



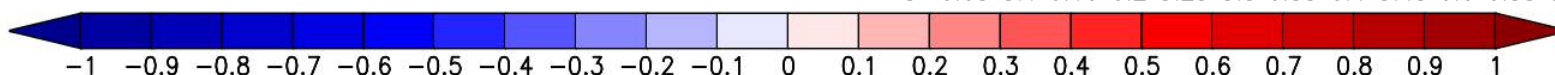
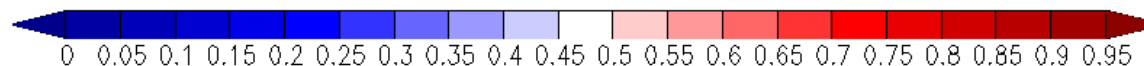
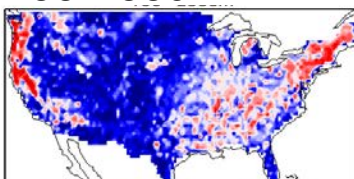
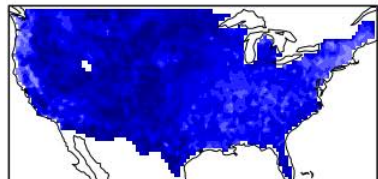
40-100cm

40-100cm



100-200cm

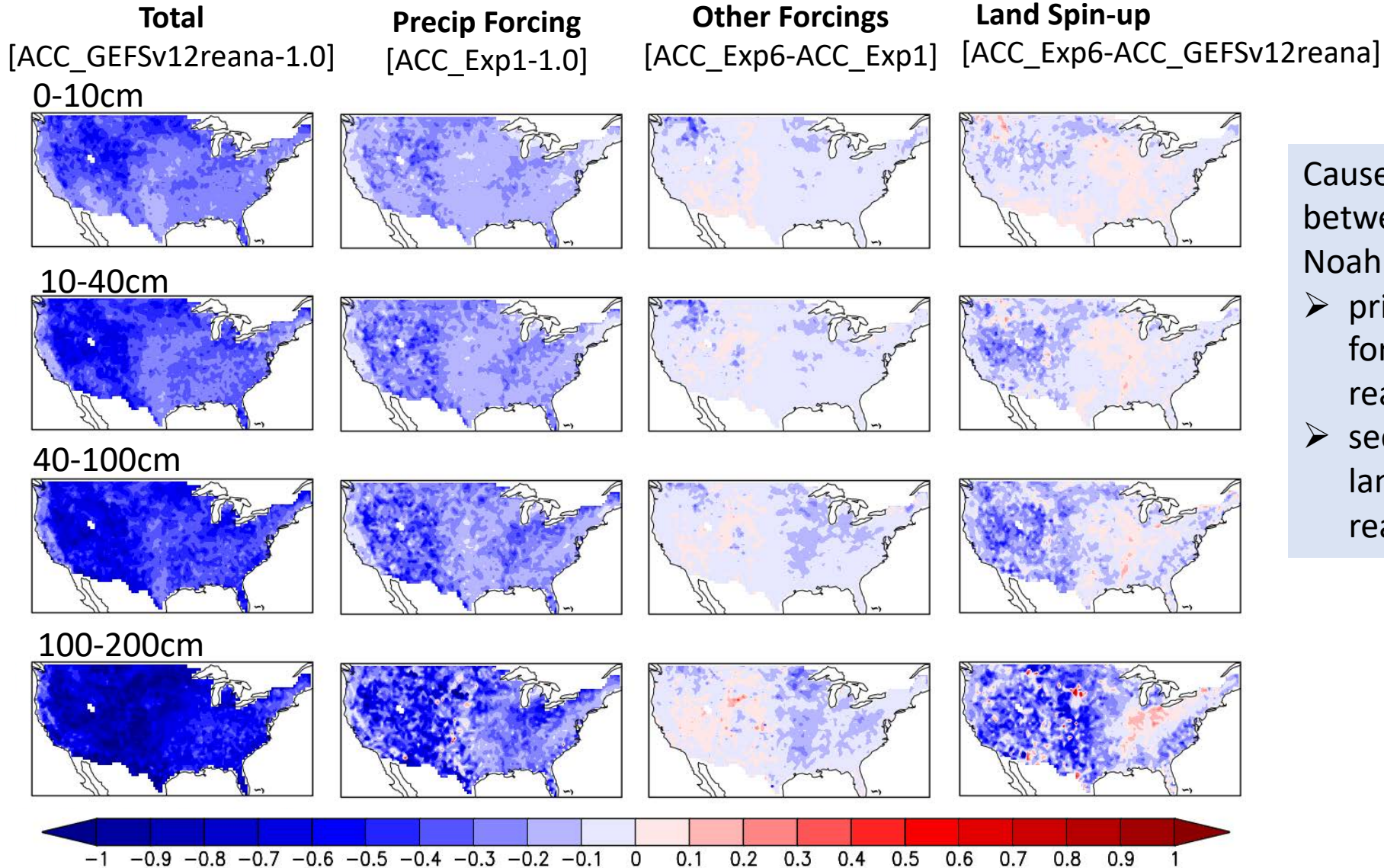
100-200cm



GEFSv12 Reforecasts: Soil Moisture Initial Conditions

Δ ACC (with Noah land analysis)

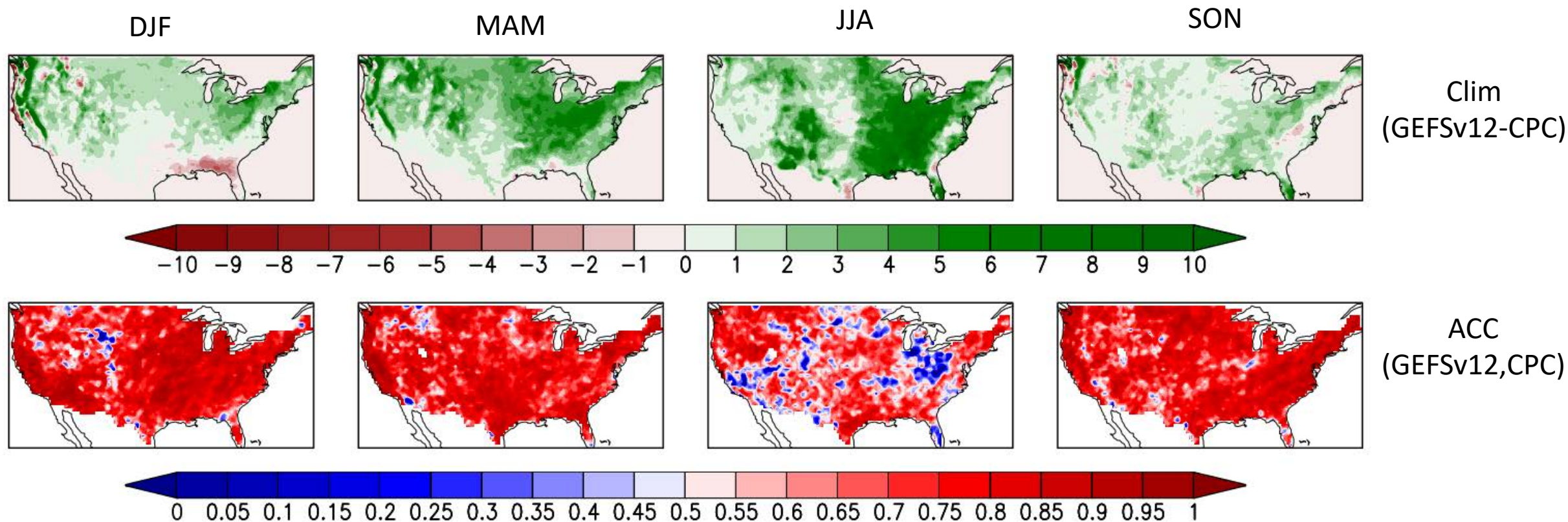
from using GEFSv12 reanalysis forcing or having insufficient land spin-up



Causes of the low consistency between the GEFSv12 reanalysis and Noah land analysis for soil moisture:

- primarily due to the precipitation forcing bias in the GEFSv12 reanalysis,
- secondarily due to the insufficient land spin-up in the GEFSv12 reanalysis streams.

GEFSv12 Reanalysis: *Precipitation Evaluation*



- **Observational Reference:** CPC unified precipitation (2000-2019)
- Relative to the CPC observations, the GEFSv12 reanalysis precipitation is considerably wetter, particularly during warm seasons. Temporally, GEFSv12 reanalysis reasonably agrees with the CPC observations except in summer when it exhibits considerable biases.

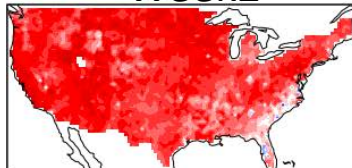
Offline Noah Reforecasts: Soil Moisture

ACC (offline_Noah_Reforecasts, Noah]

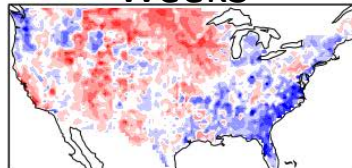
0-10cm Week1



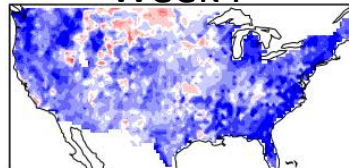
Week2



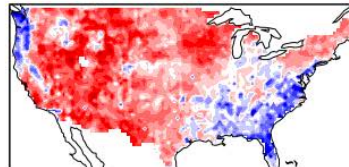
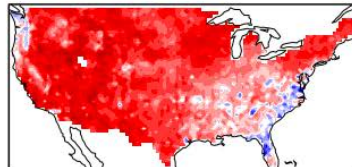
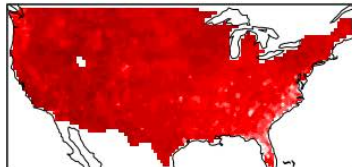
Week3



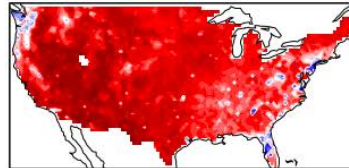
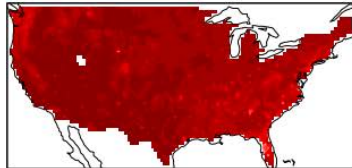
Week4



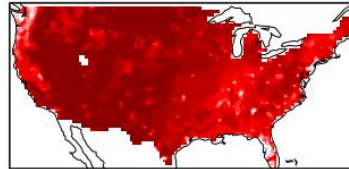
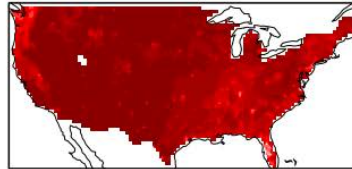
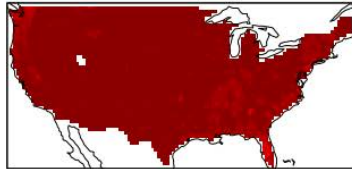
10-40cm



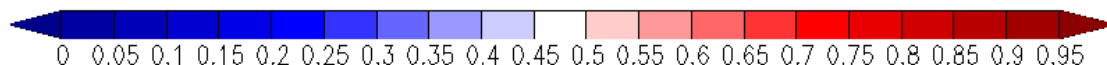
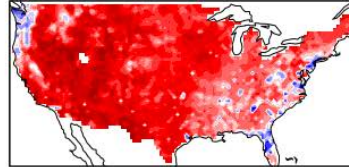
40-100cm



100-200cm



0-100cm



Offline Noah reforecasts

Produced by driving Noah offline with i) GFSv12 meteorological forecasts and ii) land initial conditions from the Noah land analysis

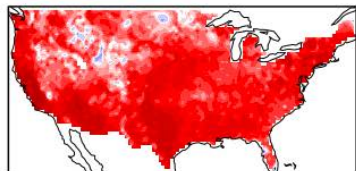
Evaluation

- Skill is substantially improved with the improved land restarts
 - Soil moisture memory is better leveraged as a source of S2S drought predictability
- Skill decreases faster in the southeastern US and coastal Pacific Northwest in the topsoil layers, where soil moisture shows less persistence.

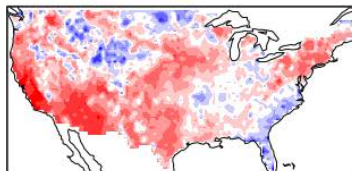
GEFSv12 Reforecasts: Soil Moisture

ACC (GEFSv12_Reforecasts, Noah)

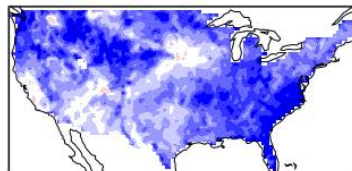
0-10cm Week1



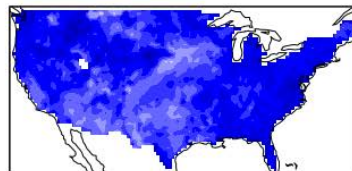
Week2



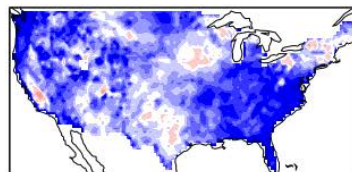
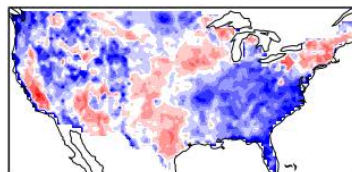
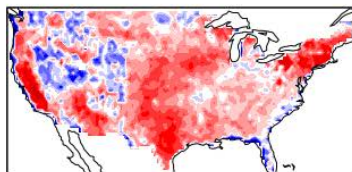
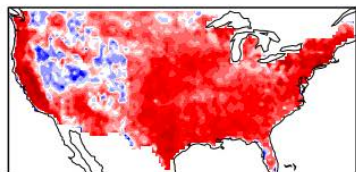
Week3



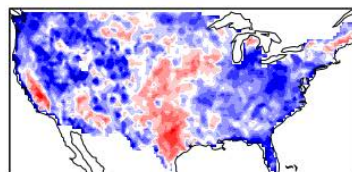
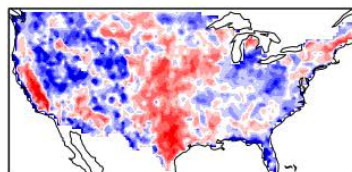
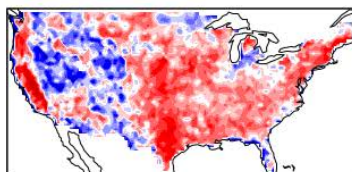
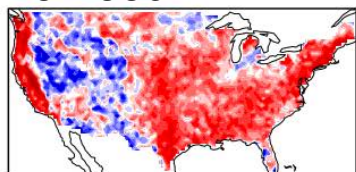
Week4



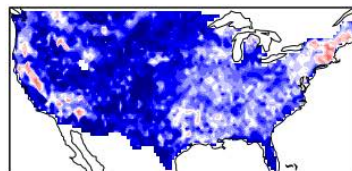
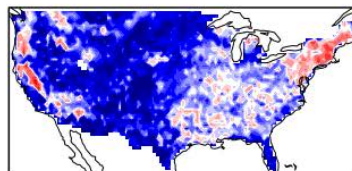
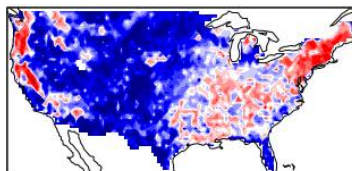
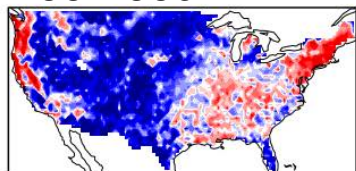
10-40cm



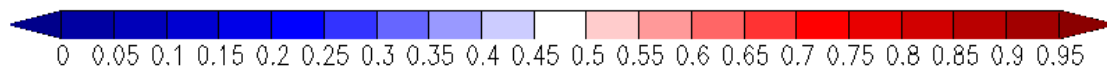
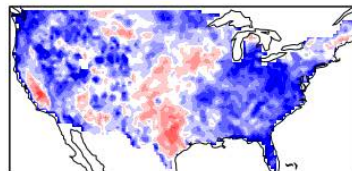
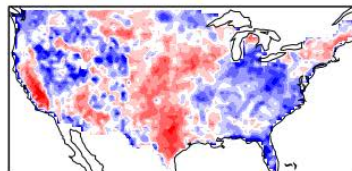
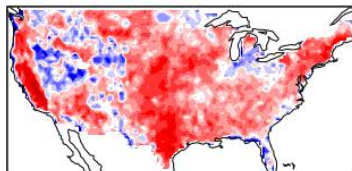
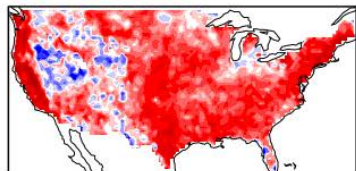
40-100cm



100-200cm



0-100cm



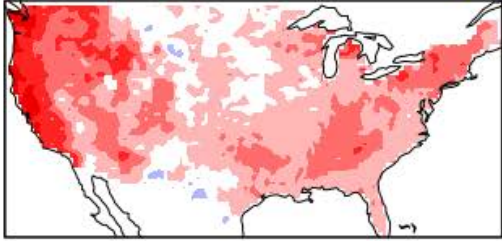
- Skill decreases with lead time, due to the skill decrease of atmospheric forcings (e.g., precipitation, temperature).
- Skill decreases faster at top-soil layers, where the effects of atmospheric forcings are more prominent
- Relatively low skills in western interior U.S. and deeper soil depths
 - Cause?

Soil Moisture Tendency: GFSv12 Reforecasts vs. Offline Noah Reforecasts

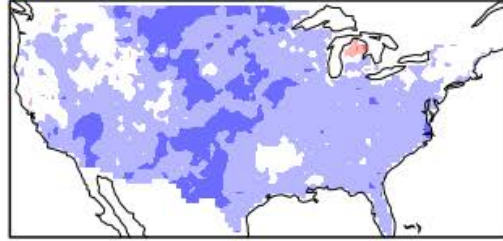
Top 1-meter Soil Moisture: Weekly Tendency

Offline Noah Reforecasts

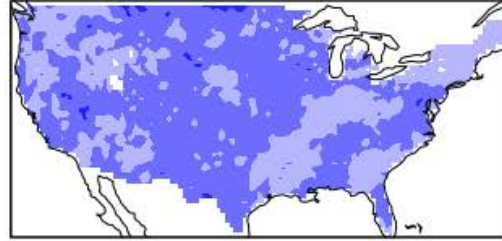
WK2-WK1



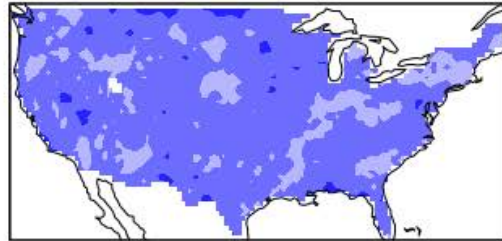
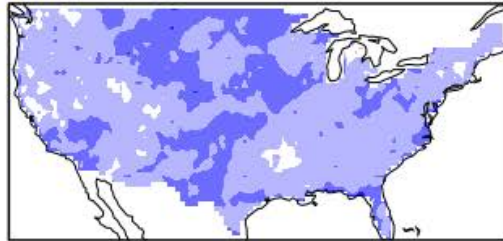
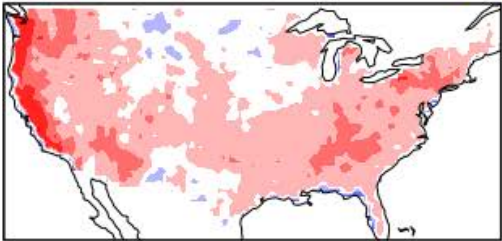
WK3-WK2



WK4-WK3

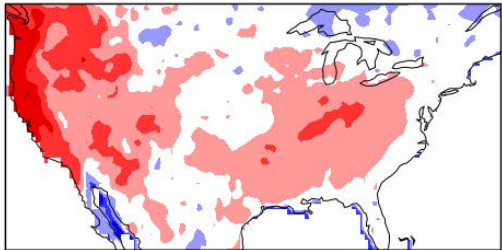


GFSv12 Reforecasts

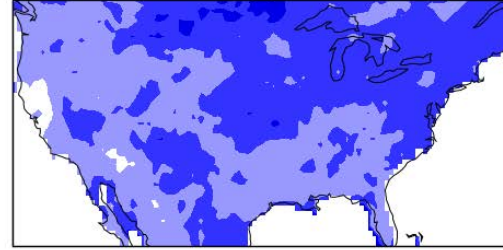


Precip

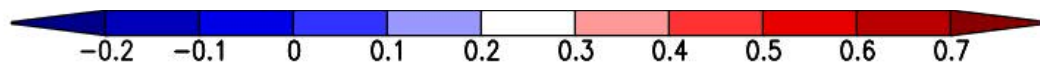
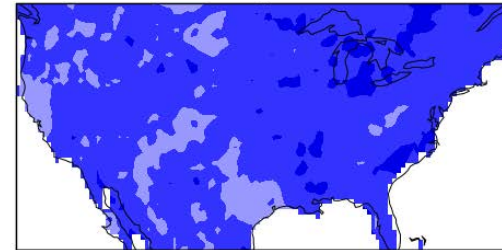
WK2



WK3



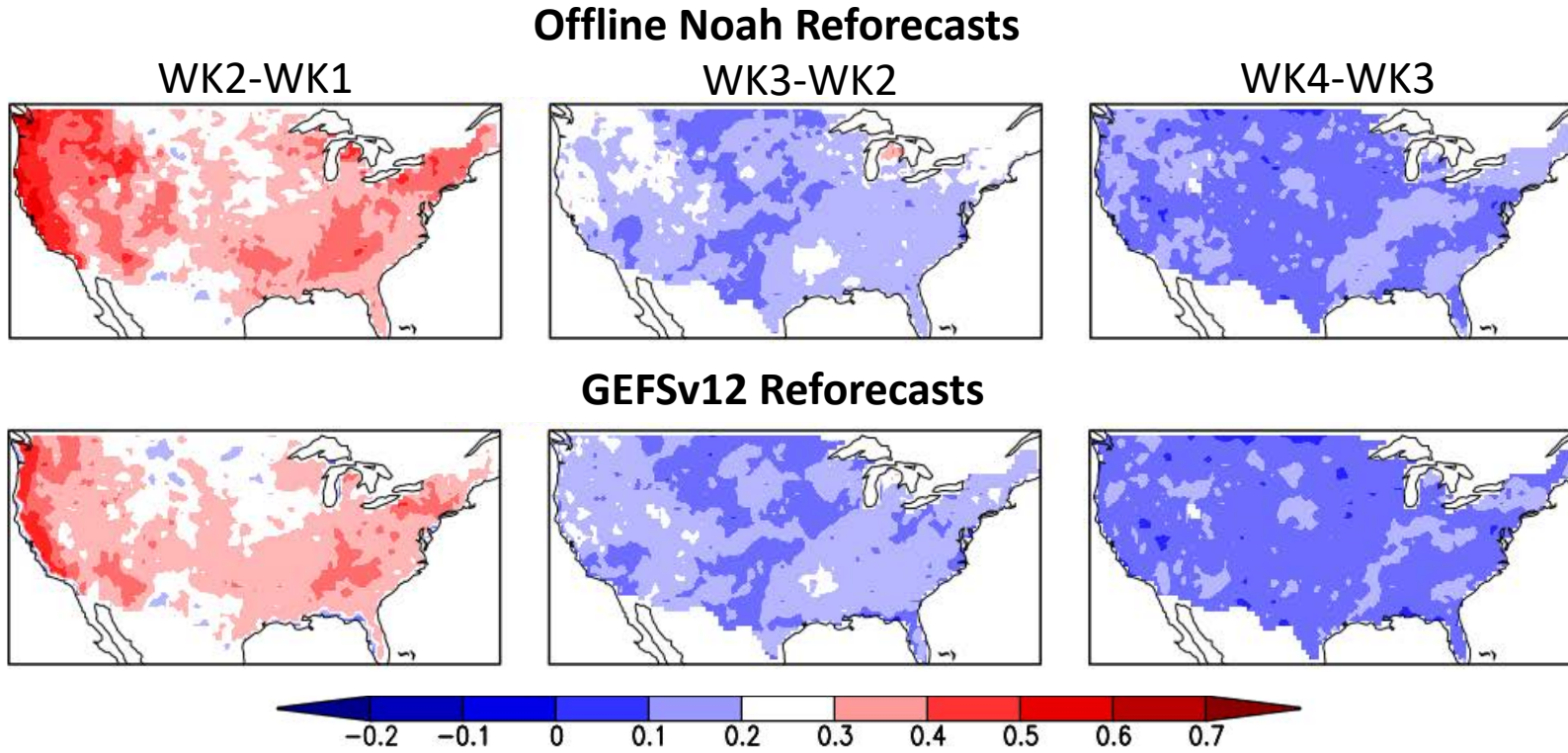
WK4



The forecast skill for soil moisture tendency is largely determined by those for the atmospheric drivers.

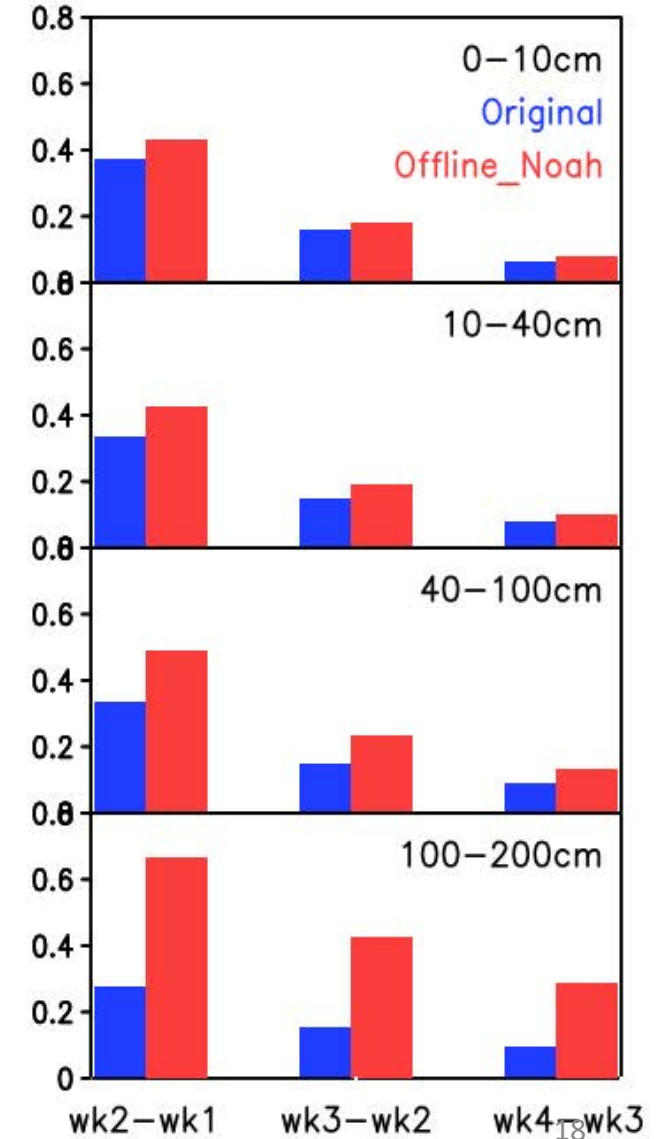
Soil Moisture Tendency: GFSv12 Reforecasts vs. Offline Noah Reforecasts

Top 1-meter Soil Moisture: Weekly Tendency



The accuracy of Initial soil moisture matters as well.

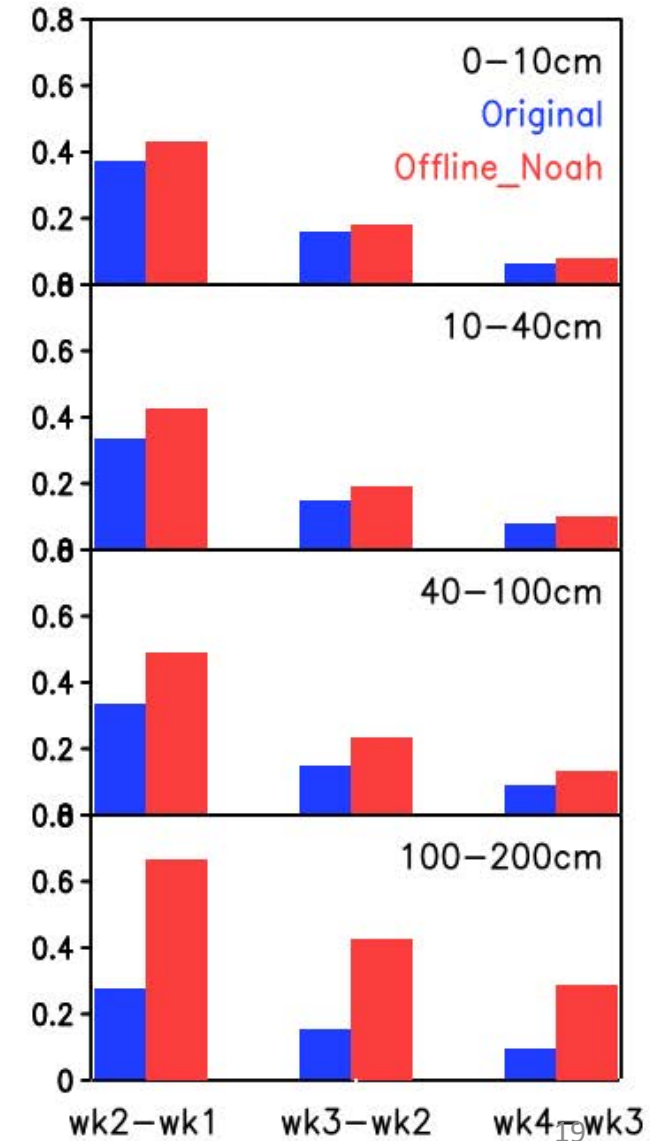
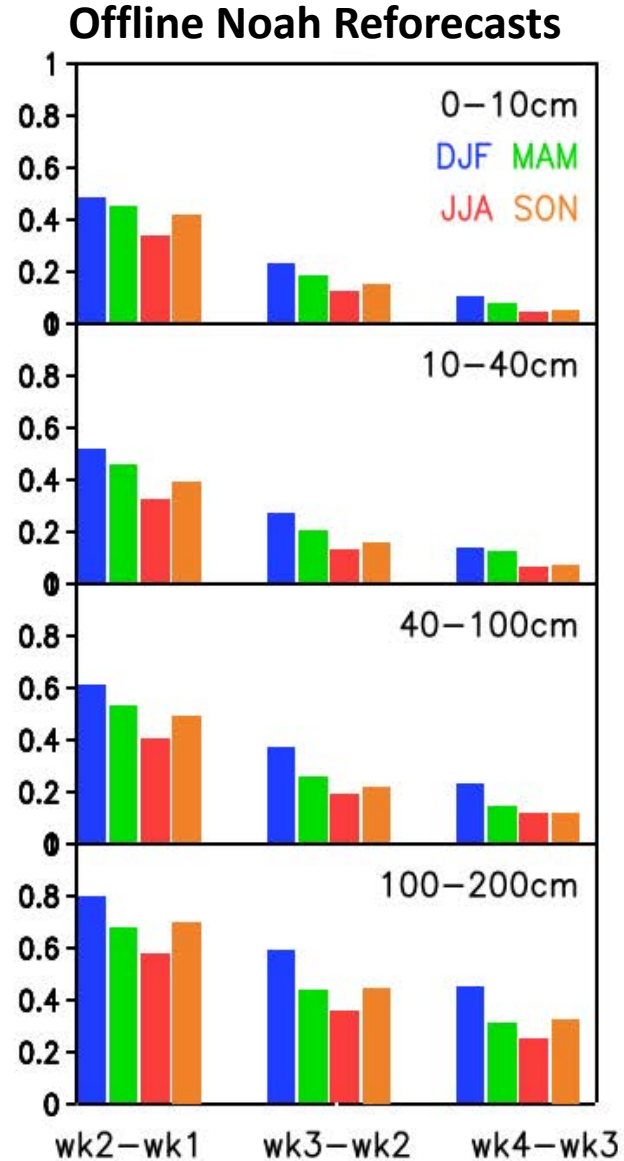
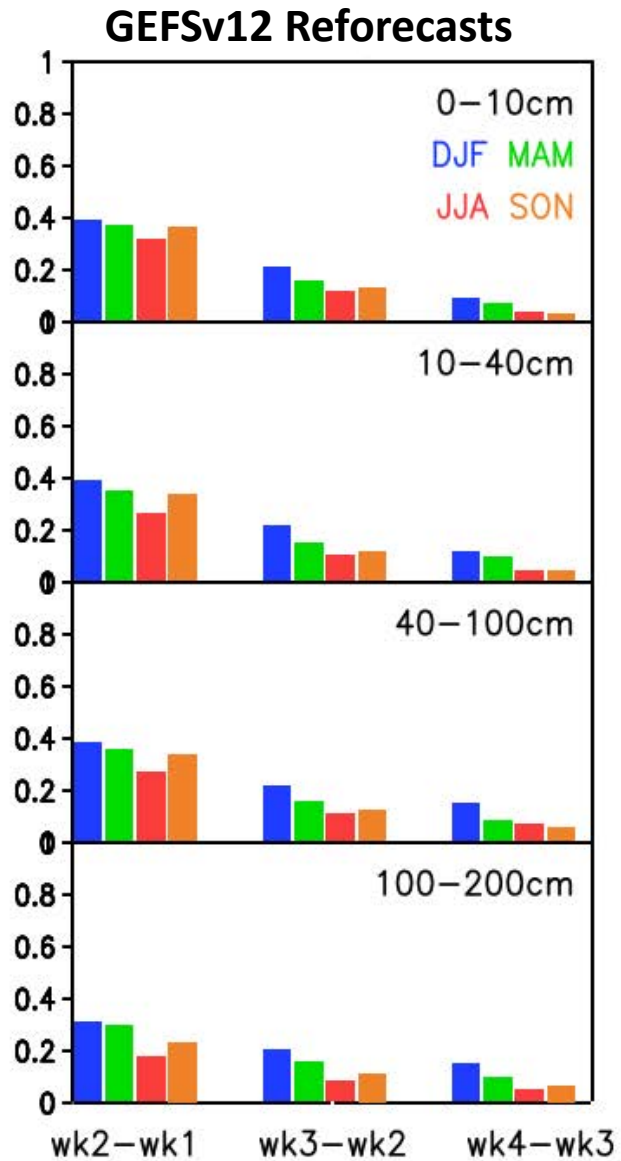
ACC: CONUS Mean



Soil Moisture Tendency: GFSv12 Reforecasts vs. Offline Noah Reforecasts

ACC: CONUS Mean by Season

ACC: CONUS Mean



Next Steps

- Further improve soil moisture forecasts
 - Incorporate post-processing to improve skill and reliability of atmospheric forcings (e.g., precipitation) and subsequently those of soil moisture
 - Include a more advanced land surface model (EMC Noah-MP)
- Produce real-time forecasts, and develop subseasonal drought forecast tools and products
 - Produce real-time atmospheric forcings and land initial conditions

Hourly Atmospheric Forcings over the U.S.	1Jan1950-present (with 1-day latency)	Last 24 hours
P	Gauge-based daily observations temporally disaggregated to hourly using hourly station reports and CORE	Integration of available observations (e.g., CMORPH2, stage IV precipitation) and GFS forecasts
T2m	CFSR T2m adjusted by observational daily Tmax / Tmin analyses	GDAS adjusted by observations
Wind10m, Q2m, Ps, SW, LW	CORE	GDAS adjusted by CORE

Note: The LSM output for the last 7 days will be overwritten in subsequent cycles as the quality-controlled P and T2m observations (as well as CORE) become available.

Summary

- GEFSv12 reforecasts demonstrate that **initial soil moisture anomalies contribute substantially to the soil moisture forecast skill**, owing to their intrinsic memory on subseasonal timescales.
- When an offline Noah land analysis is used as an observational reference, **the GEFSv12 soil moisture initialization shows low accuracy in much of the western interior U.S., which adversely impacts soil moisture forecasts for these regions.**
 - The low accuracy results primarily from **precipitation forcing bias in the GEFSv12 reanalysis**, and secondarily from the **insufficient land surface spin-ups** in the GEFSv12 reanalysis streams.
 - The GEFSv12 reanalysis soil moisture could be improved by
 - using observational precipitation or corrected reanalysis precipitation to drive its LSM to produce land surface states,
 - having sufficient land surface spin-ups
 - soil moisture assimilation

Summary

- Efforts are ongoing at CPC to improve soil moisture forecasts by
 - incorporating post-processing to improve forecasts for meteorological drivers (e.g., precipitation)
 - including a more advanced land surface model (Noah-MP).

Extra slides

GEFSv12 Reforecasts: 2012 Great Plains Drought

