NOAA

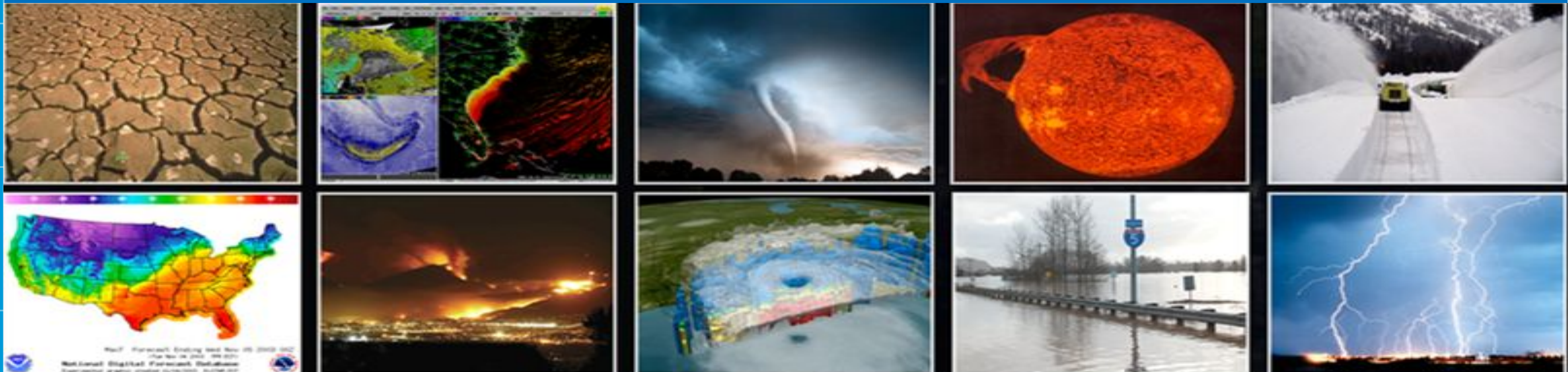
National Weather Service

UFS Land (for S2S): Progress and Evaluation

UFS S2S Application Team, August 18, 2023

Michael Barlage, NOAA Environmental Modeling Center

Acknowledgements: EMC Land Team (Weizhong Zheng, Helin Wei, Zhichang Guo, Rongqian Yang); Ufuk Turuncoglu (NCAR); Clara Draper (NOAA PSL); Paul Dirmeyer (GMU); Eunkyo Seo (GMU, Pukyong National University); UFS Land Working Group



Unified Forecast System - Land

- The Unified Forecast System (UFS) is a community-based, coupled, comprehensive Earth modeling system. It is designed to support the NOAA Weather Enterprise and to be the source system for NOAA's operational numerical weather prediction applications.
- The UFS is organized around applications. Each application has a forecast target. The UFS numerical applications span local to global domains and predictive time scales from sub-hourly analyses to seasonal.
- Application Teams (subset)

  Short-Range Weather (SRW): Atmospheric (and land) behavior from less than an hour to several days

  Medium-Range Weather (MRW): Atmospheric (and land) behavior out to about two weeks

  Subseasonal-to-Seasonal (S2S): Atmospheric and ocean (and land) behavior from about two weeks to about one year
- Working Groups: Chemistry, DA, Dynamics, Ensembles, Marine, Physics, Post-Proc, LAND

Inaugural UFS Land Working Group

- Brent Lofgren (NOAA/GLERL)
- Trey Flowers (NOAA/NWC)
- Clara Draper (NOAA/PSL/CIRES)
- Andy Fox (JCSDA)
- Sujay Kumar (NASA/HSL)
- Paul Dirmeyer (GMU)
- Joe Santanello (NASA/HSL)
- Elena Shevliakova (NOAA/GFDL)
- David Lawrence (NCAR/CGD)
- Tanya Smirnova (NOAA/GSL/CIRES)
- Guo-Yue Niu (U. Arizona)
- Fei Chen (NCAR/RAL)
- Zong-Liang Yang (UT-Austin)
- Xiwu Zhan (NOAA/NESDIS)
- Maoyi Huang (NWS/OSTI)
- Michael Ek (NCAR/DTC) – Co-Lead
- Michael Barlage (NOAA/EMC) – Co-Lead

Hydrology (Brent Lofgren, Trey Flowers)

Land Data Assimilation (Clara Draper, Andy Fox, Sujay Kumar)

Land-Atmo Interactions (Paul Dirmeyer, Joe Santanello)

Climate Development (Elena Shevliakova, David Lawrence)

NWP Development (Tanya Smirnova, Guo-Yue Niu, Fei Chen, Zong-Liang Yang)

Land Satellite Data (Xiwu Zhan)

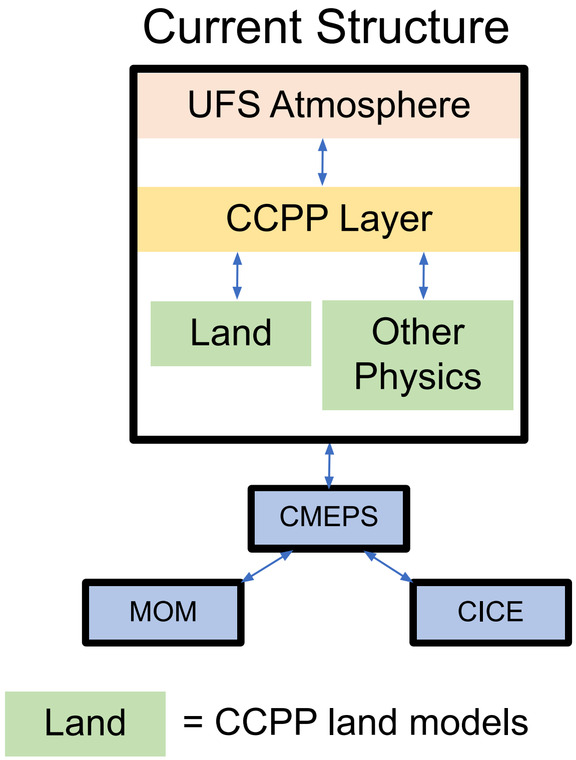
UFS Land Working Group and Workshop

- Currently WG meetings organized around centers of interest - quarterly
  - community open meetings where we discuss status of UFS Land Component(s) and issues relevant to the land model in general (EPIC, Infrastructure, Interactions (apps/physics), Coastal); invited speakers to enhance community usage of UFS (e.g., App Teams)
  - community-focused meeting designed to communicate modeling needs/performance and new advances from the community (lightning-style talks)
  - land "steering committee" meetings (long-term planning)
- UFS Land Workshop
  - developing design requirements for UFS land models
  - identifying priorities of land model development and metrics
  - better representations of key processes for capturing UFS land-atmosphere-ocean interactions
  - next 2 to 5 years timeframe

Workshop Report

General Capabilities Progress

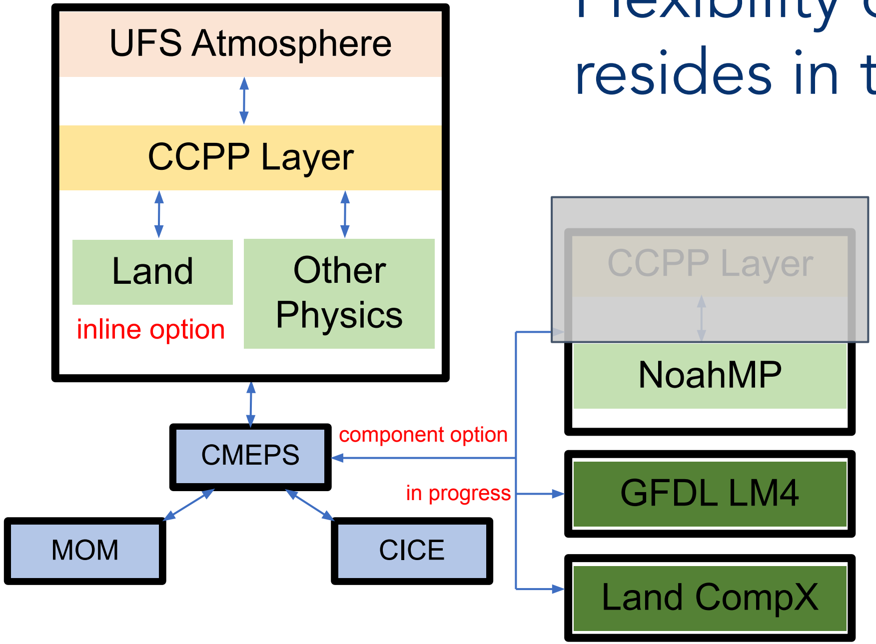
UFS Land – Current Infrastructure



- Current land models (Noah, Noah-MP, RUC) reside inside the atmospheric model (tightly coupled)
- These models are essentially modules/subroutines within the CCPP (Common Community Physics Package) repository
- Currently, CCPP modules are assumed to be 1D column models – no horizontal communication
- History and restarts are controlled by the atmosphere

UFS Land – Future Infrastructure

~~Possible Future~~ Structure



Land = CCPP land models

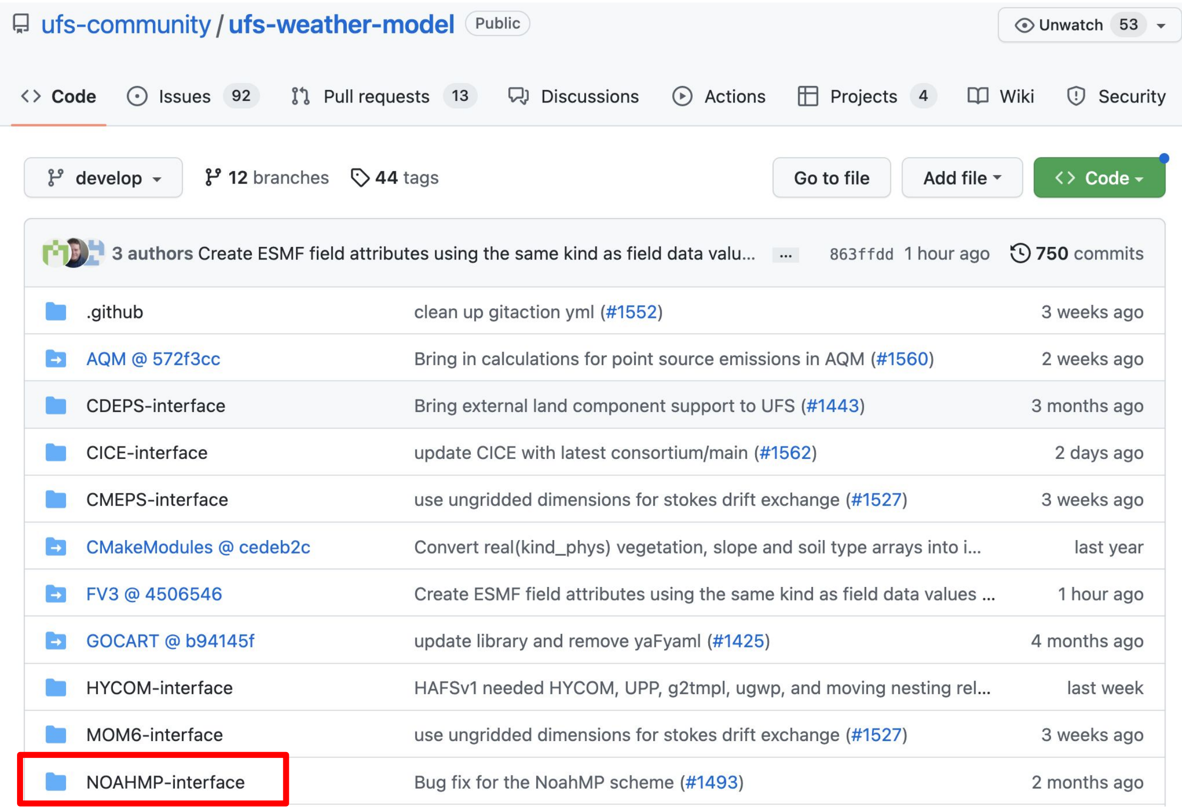
Land = component land models, including lakes, routing, etc.

Flexibility on where the land model resides in the system

- inline with the atmosphere
  - advantage: faster physics/coupling
  - single column model
- as a separate component
  - advantage: land model testing within a well-designed framework (i.e., with a data atmosphere)
  - advantage: evaluating fluxes across interface

NoahMP UFS Component Model

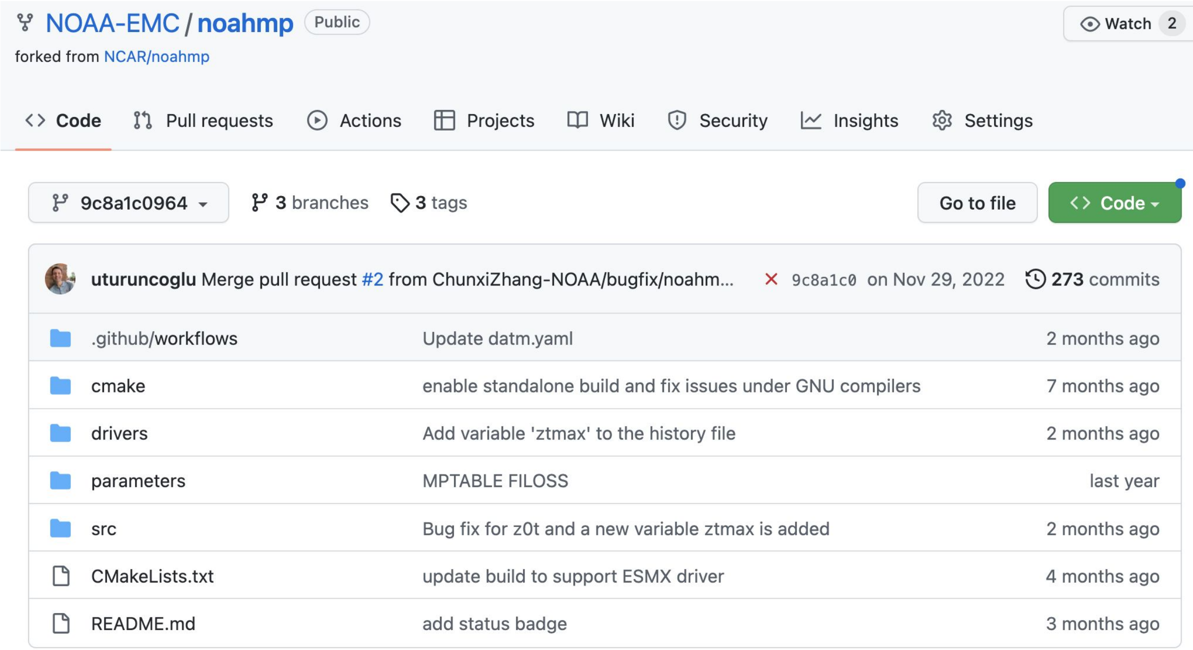
- NoahMP now exists as a component model in UFS
- Still in development
- Current capability to runs using CDEPS data atmosphere (land-only mode) and side-by-side (run land twice)
- Two-way coupling exists in a branch



github.com/ufs-community/ufs-weather-model

NoahMP UFS Component Model

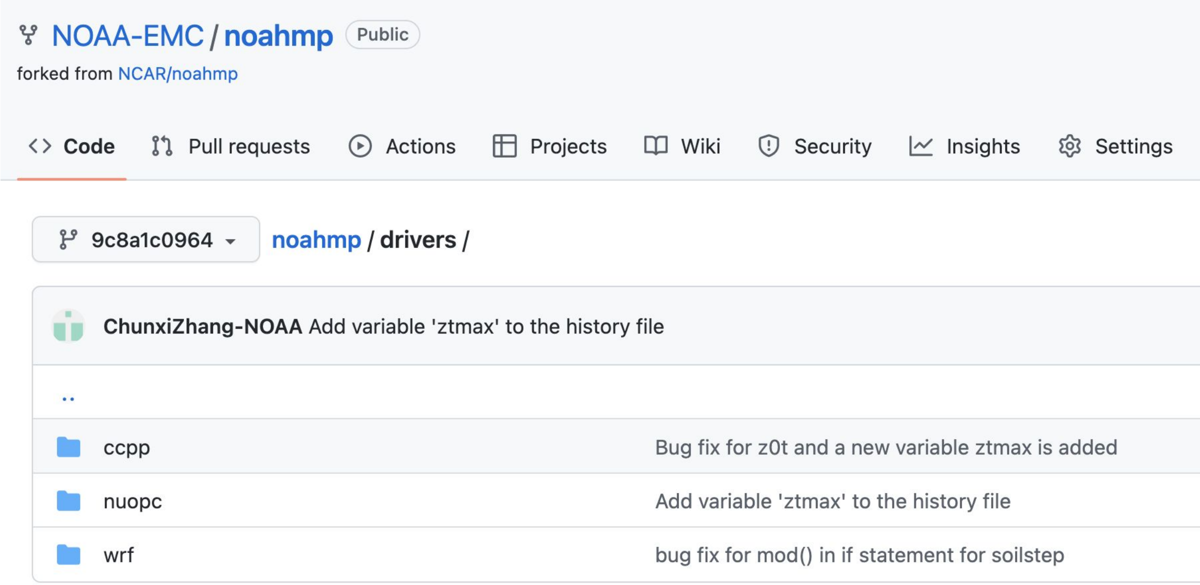
- EMC will use a fork of NCAR/noahmp to protect code versioning in operational model
- Several contributions here that can be moved to NCAR repo including automated testing through Github Actions and cmake



github.com/NOAA-EMC/noahmp

NoahMP UFS Component Model

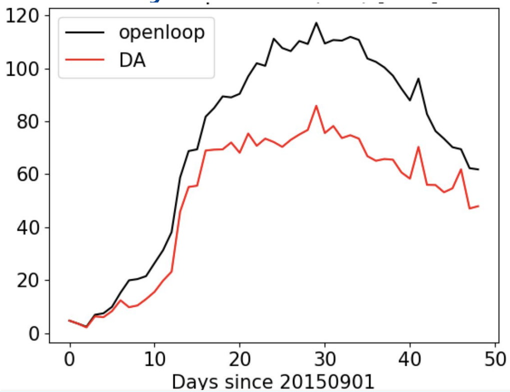
- NOAA-EMC fork adds connection to CCPP physics and a NUOPC cap
- noahmp will contain the necessary coupling code for both inline and component modes



github.com/NOAA-EMC/noahmp

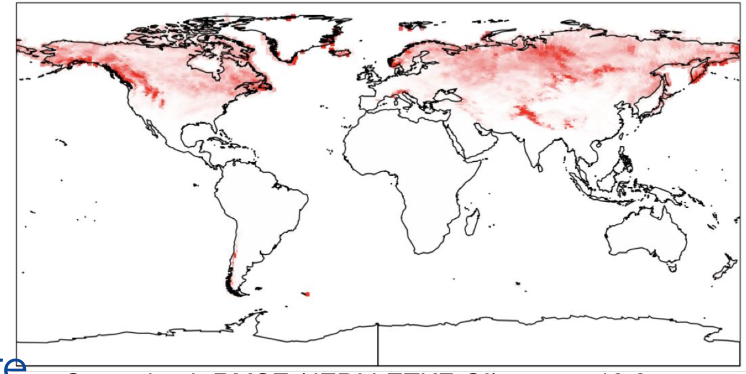
Land Data Assimilation

- Collaboration with OAR Labs (PSL) and across EMC Divisions to develop true land data assimilation system using JEDI
- First priorities (targeted for GFSv17):
  - Update the snow depth analysis
  - Introduce a soil temperature and soil moisture analysis

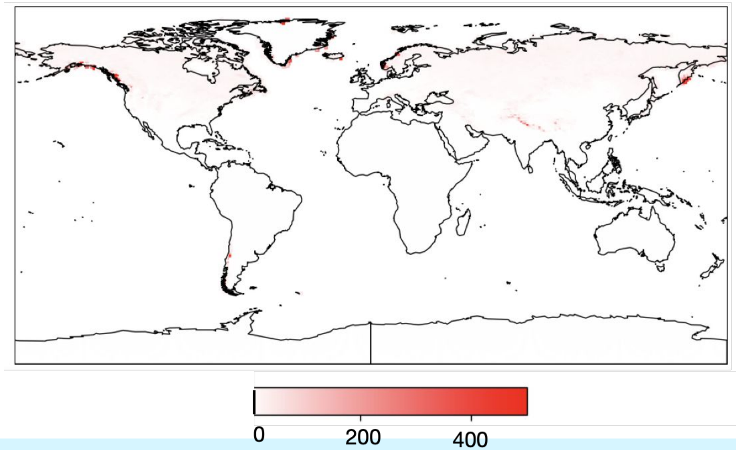


stdev(O-F) for the assimilation of GHCN snow depth observations [mm]

Snow depth RMSE (open loop), mean: 107.8 mm



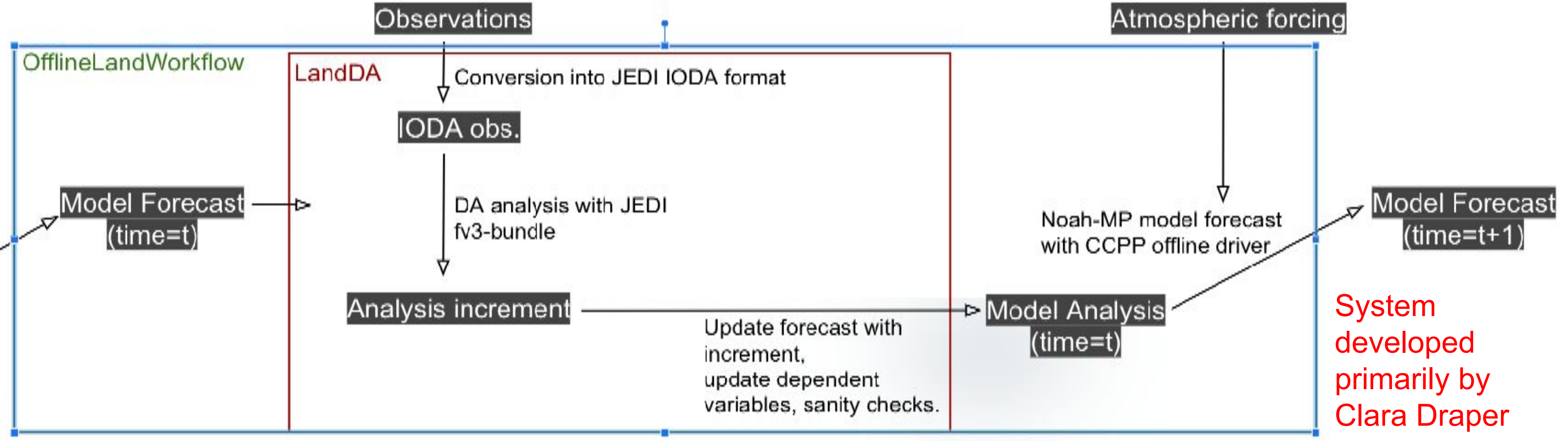
Snow depth RMSE (JEDI LETKF-OI), mean: 19.8 mm



UFS Land Data Assimilation System

- Developed an offline land DA workflow to perform cycling model forecasts and DA using the same DA and land model code as in coupled GFS (land/atmosphere) DA system

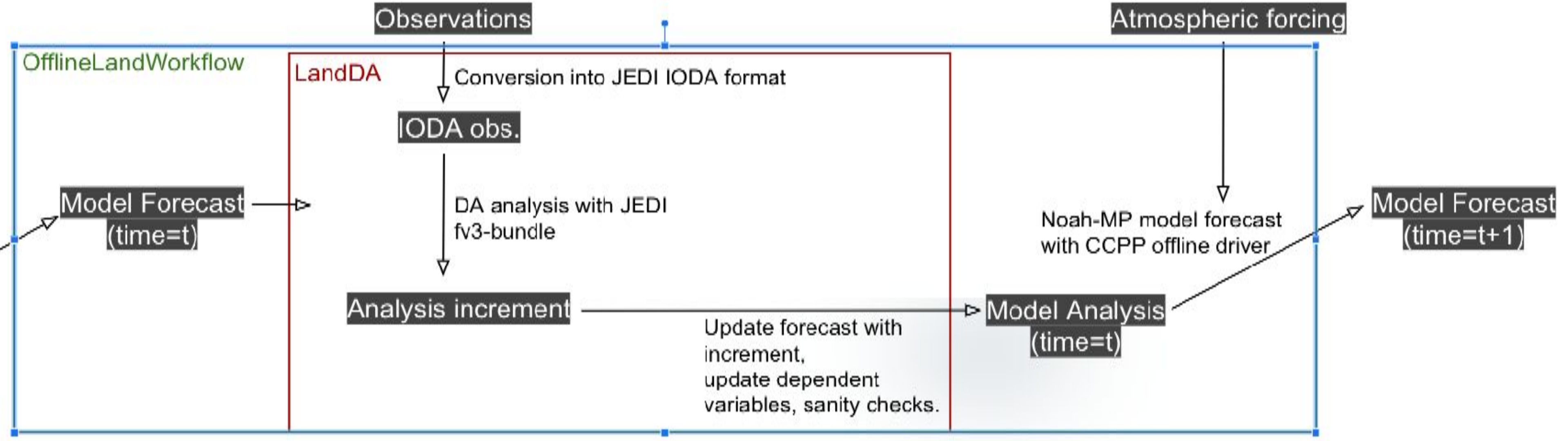
- Model: UFS code via Noah-MP CCPP code base
- DA: JEDI fv3-bundle for land update (future: GDASApp)



System developed primarily by Clara Draper

UFS Land Data Assimilation System

- Useful for development and testing of land model and DA for operational transition
- Coordination with EPIC will make this available to research community to facilitate land physics/DA research (April 2023 release: https://github.com/NOAA-EPIC/land-offline_workflow/tree/release/public-v1.0.0) – See EPIC website for training materials



UFS Capabilities Progress

Global Evaluation Prototypes

- Prototypes (PT 1-8, completed)

  Coupled Model: Atm (C384) - Ocean (¼ tripolar) - Ice (¼ tripolar) - Wave (⅙ tripolar)

  April 1, 2011 – March 15, 2018, cold start forecasts at 00Z cycle 1st and 15th of month, 35 day forecast (168 total forecasts)

- HR1 (completed)

  Coupled Model: Atm (C768) - Ocean (¼ tripolar) - Ice (¼ tripolar) - Wave (⅙ tripolar)

  Summer: June 1– Aug. 30, 2020, cold start forecasts at 00Z cycle every 3 days, 16 day forecast

  Winter: Dec. 03, 2019 – Feb. 26, 2020, cold start forecasts at 00Z cycle every 3 days, 16 day forecast

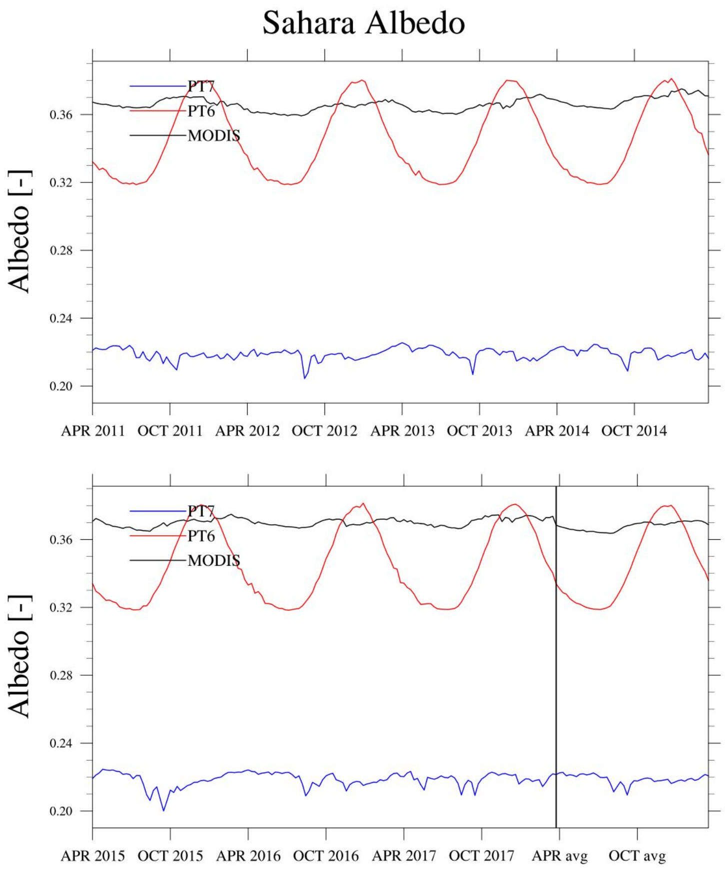
  Hurricane: July 20, 2020 – Nov 20th, 2020, cold start forecasts at 00Z cycle everyday, 7 day forecast

- Data stored at: /glade/scratch/barlage/prototype

Albedo Evaluation in Prototypes

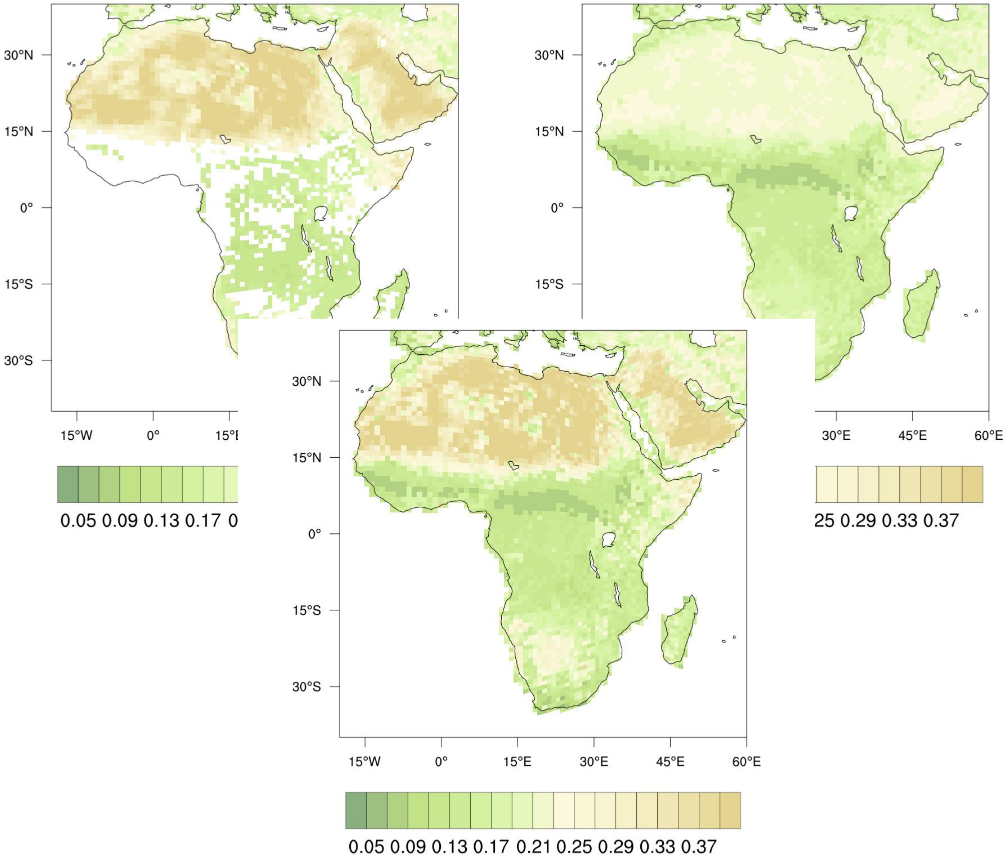
- Comparison of P6 (Noah) and P7 (NoahMP) albedo with MODIS observations
- P6 has prescribed albedo, hence the better performance compared to MODIS
- P7 albedo determine by soil color when no vegetation present

- Soil color is a categorical parameter that determine wet/dry, vis/nir soil albedo
- Soil color is currently constant in model, lookup table has 8 categories
- CLM implemented 20 category table based on comparison to global MODIS albedo



Using Soil Color Dataset – Land-only Simulation

- MODIS albedo (July 1) shows a lot of variation across the Sahara
- Very little variation and much lower albedo in control
- Use of soil color brings the model more in line with observations



Using Soil Color Dataset – Atmo-Land Simulation

Model: HR1 (Atms-only)

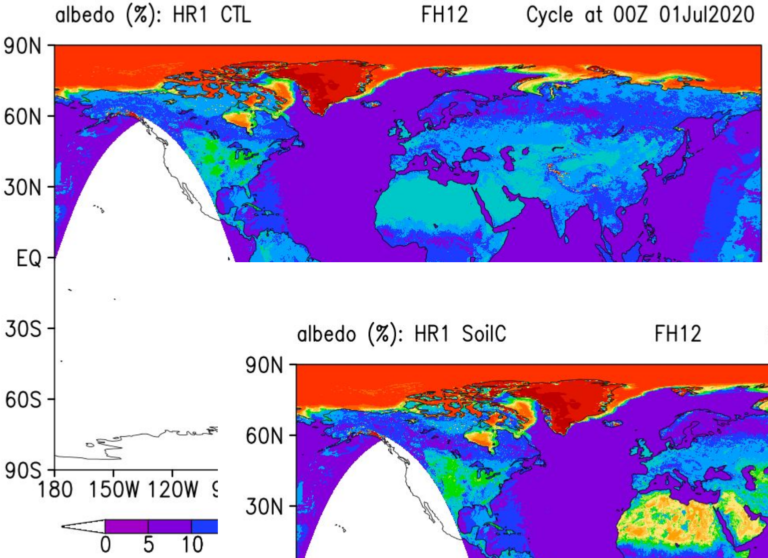
Case: Summer: 00Z 07/01/2020;

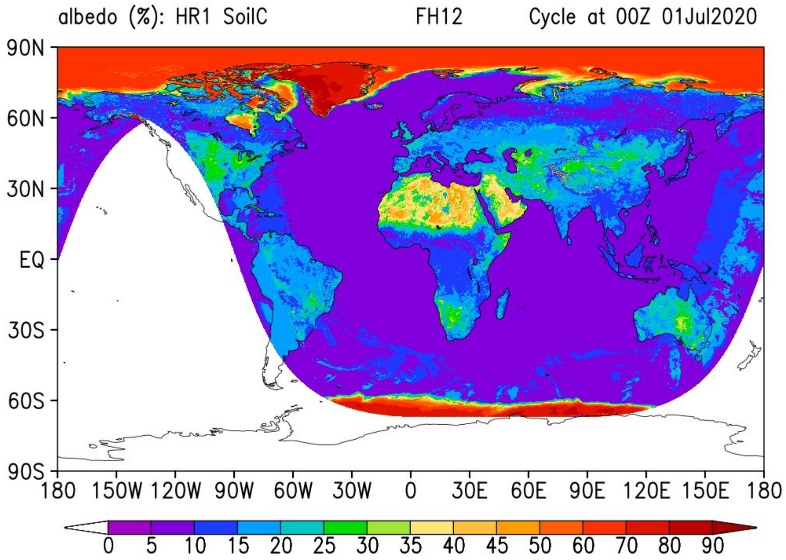
Initial: 00Z 07/01/2020;
Valid: 07/01 - 07/07/2020;

Two experiments

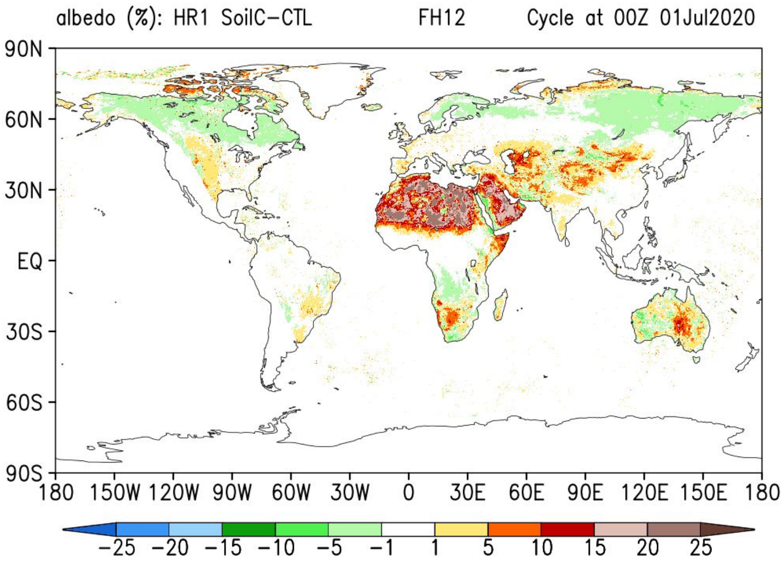
Control: NoahMP tile diagnostics w/ the bug fix for stability

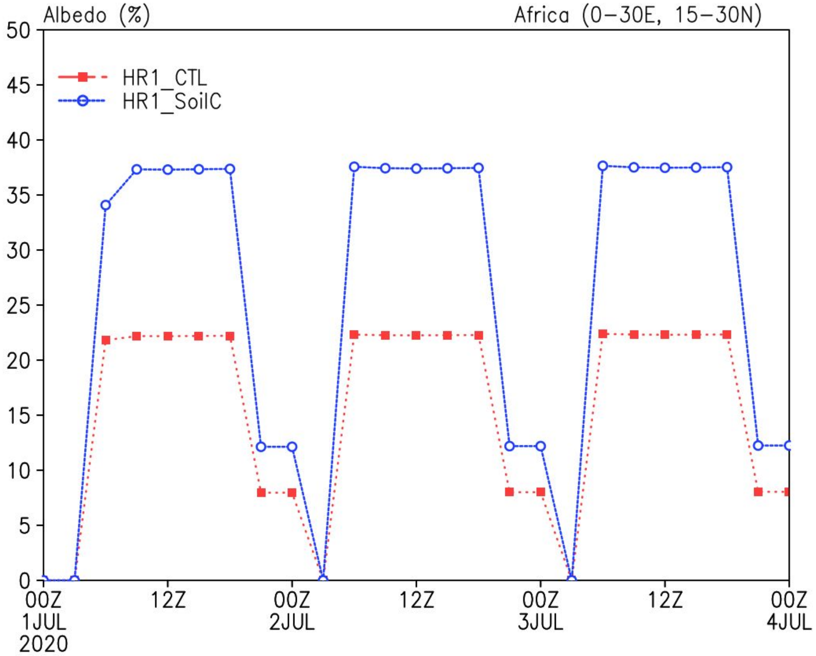
Sensitivity: New soil color data set





Using Soil Color Dataset – Atmo-Land Simulation





- Clear increased soil albedo over Sahara Desert
- Albedo effect consistent with land-only simulations

NoahMP 2m Temperature and Humidity Diagnostics

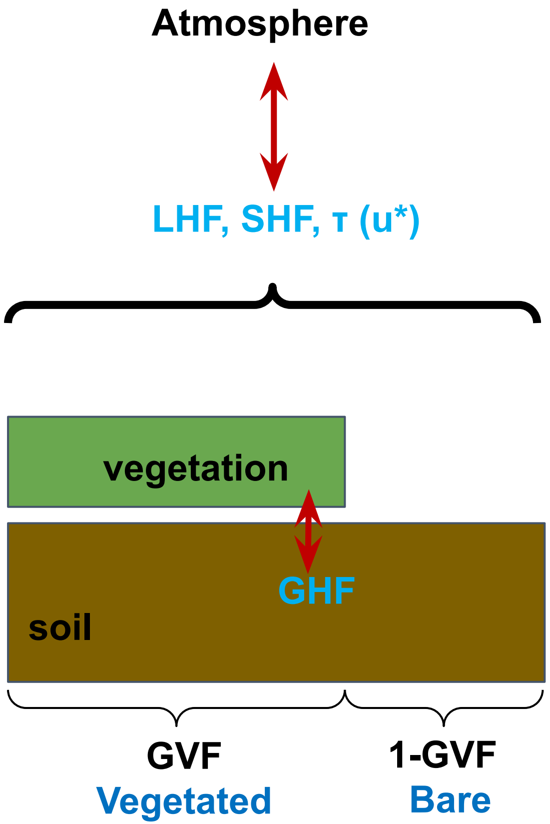
Two diagnostic algorithms of T2m and q2m:

External diagnostics: Use the whole grid box stability to derive T2m and q2m, like GFS diagnostics. This needs the composited surface fields to derive the composited stability (at the whole grid).

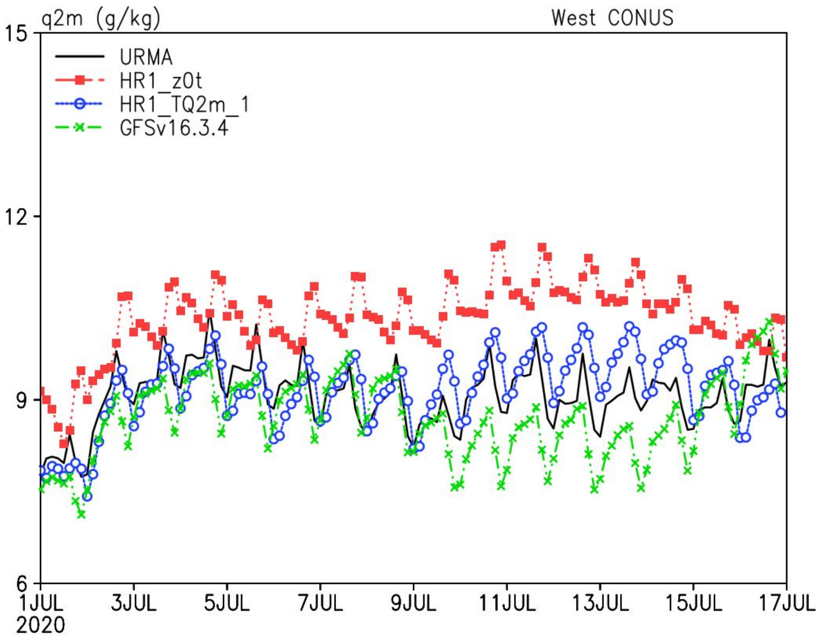
Composited Sfc fields → stability → Composited T2m/q2m

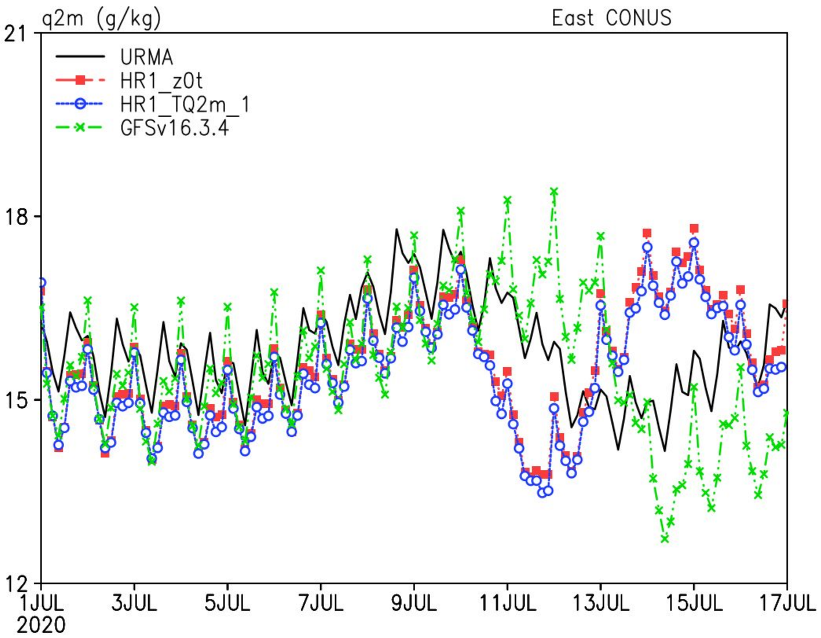
NoahMP tile diagnostics: the surface fluxes at each tile, vegetated or bare, are used to interpolate each tile T2m and q2m, and then obtain the composited T2m and q2m.

Tile Sfc fluxes → tile T2m/q2m → Composited T2m/q2m



NoahMP 2m Temperature and Humidity Diagnostics

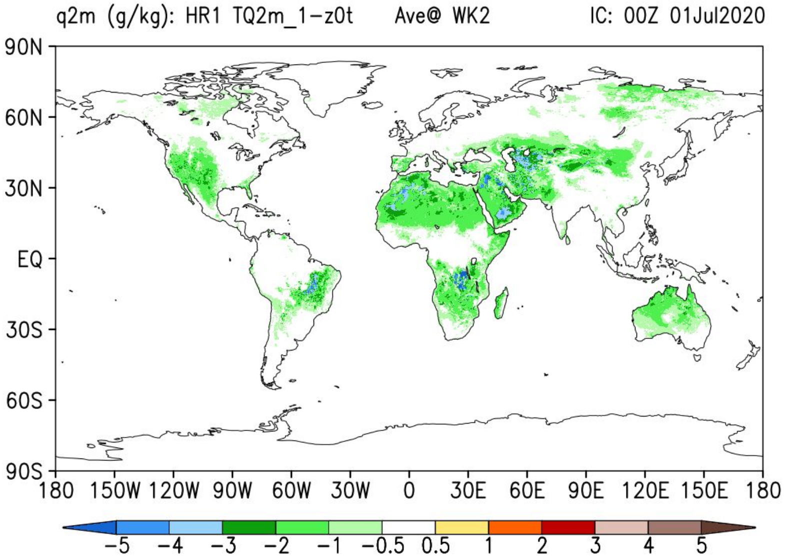




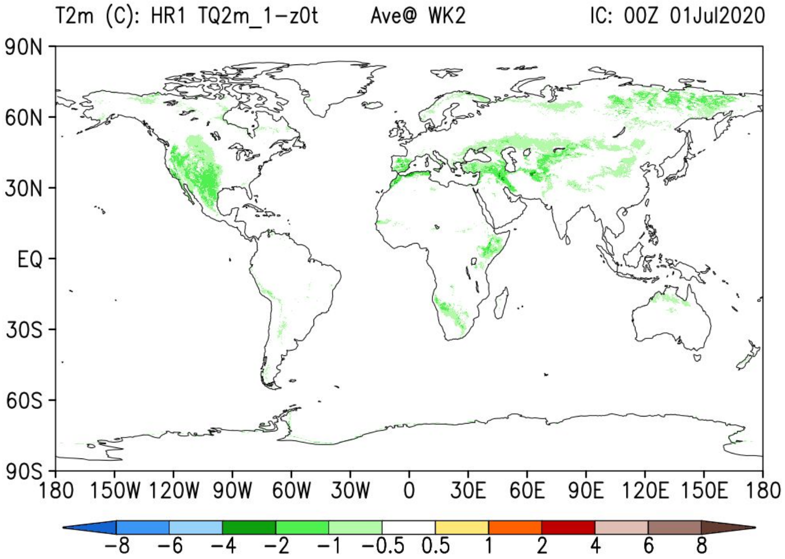
- West CONUS q2m using external diagnostics is too high
- West CONUS q2m using internal tile diagnostics good

NoahMP 2m Temperature and Humidity Diagnostics

q2m: external – internal



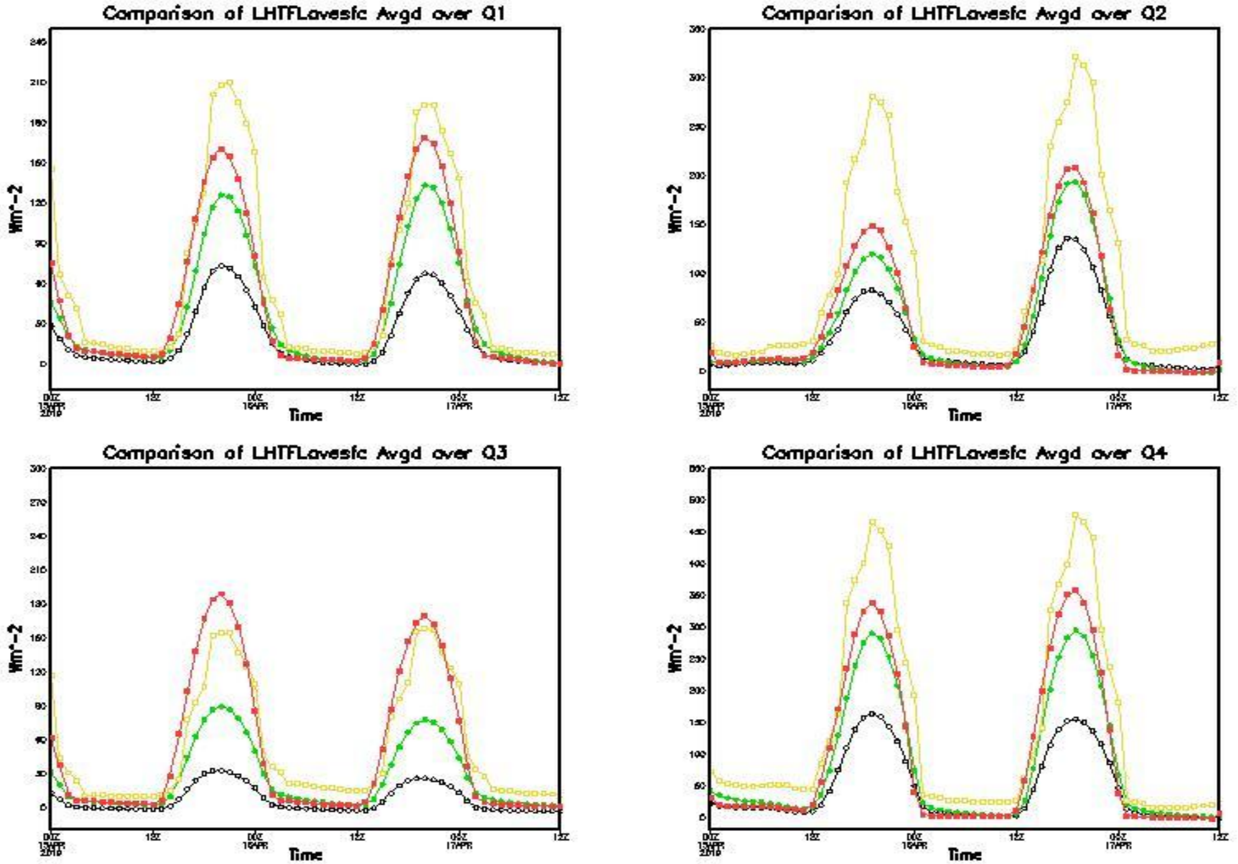
T2m: external – internal



Increasing soil layers in NoahMP

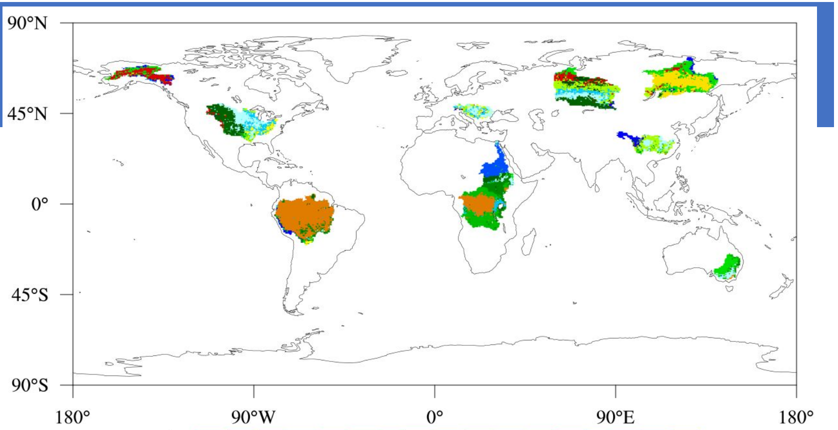
- Implemented 9 soil layer version of NoahMP
- Evaluating results
- Current soil model: 4layer/2meter
- Need more/deeper layers for S2S

RUC
Noah (4)
NoahMP (4)
NoahMP (9)



UFS Land-focused Evaluation

Global Water Cycle



Dataset: Multiple Obs Datasets, P6, P7, P8

Long-term Average Water Cycle

Precipitation = Evapotranspiration + Runoff

= [Transpiration + Evaporation] + [Surface Runoff + Baseflow]

Additional interests:

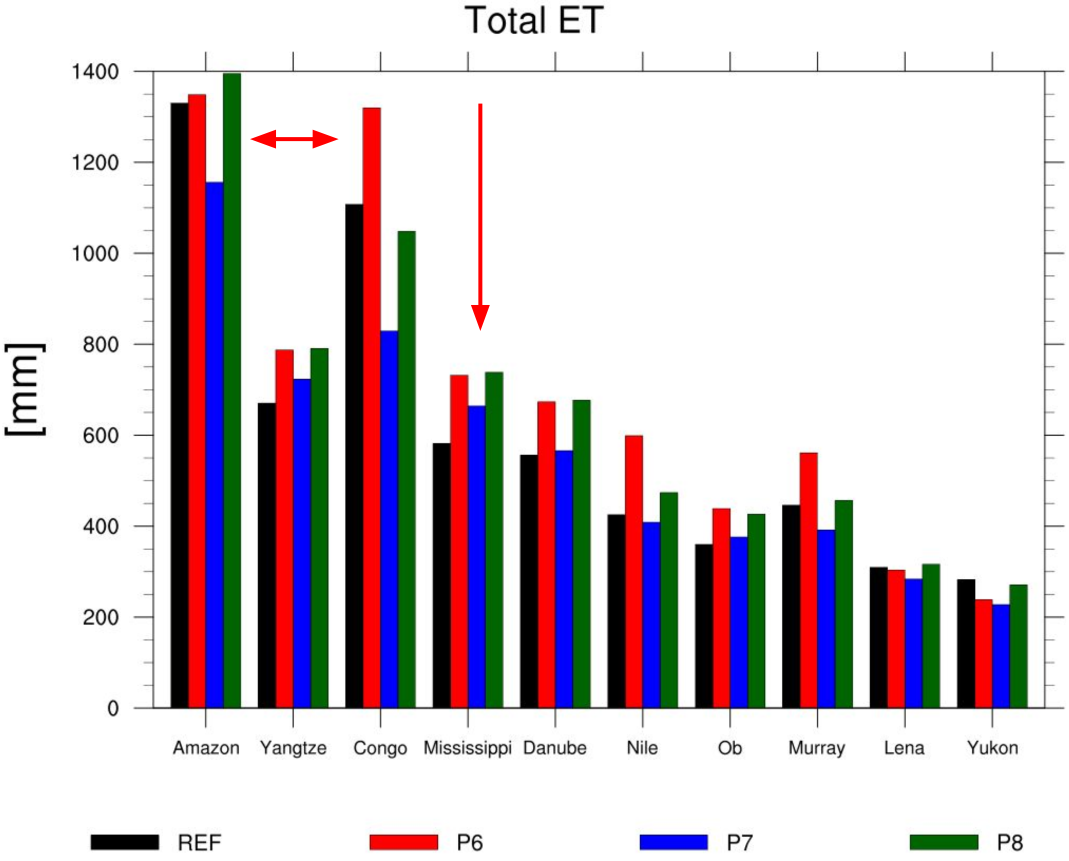
Baseflow Index = Baseflow / Runoff

T/ET = Transpiration / Evapotranspiration

ET/P = Evapotranspiration / Precipitation

Global Water Cycle Climatology

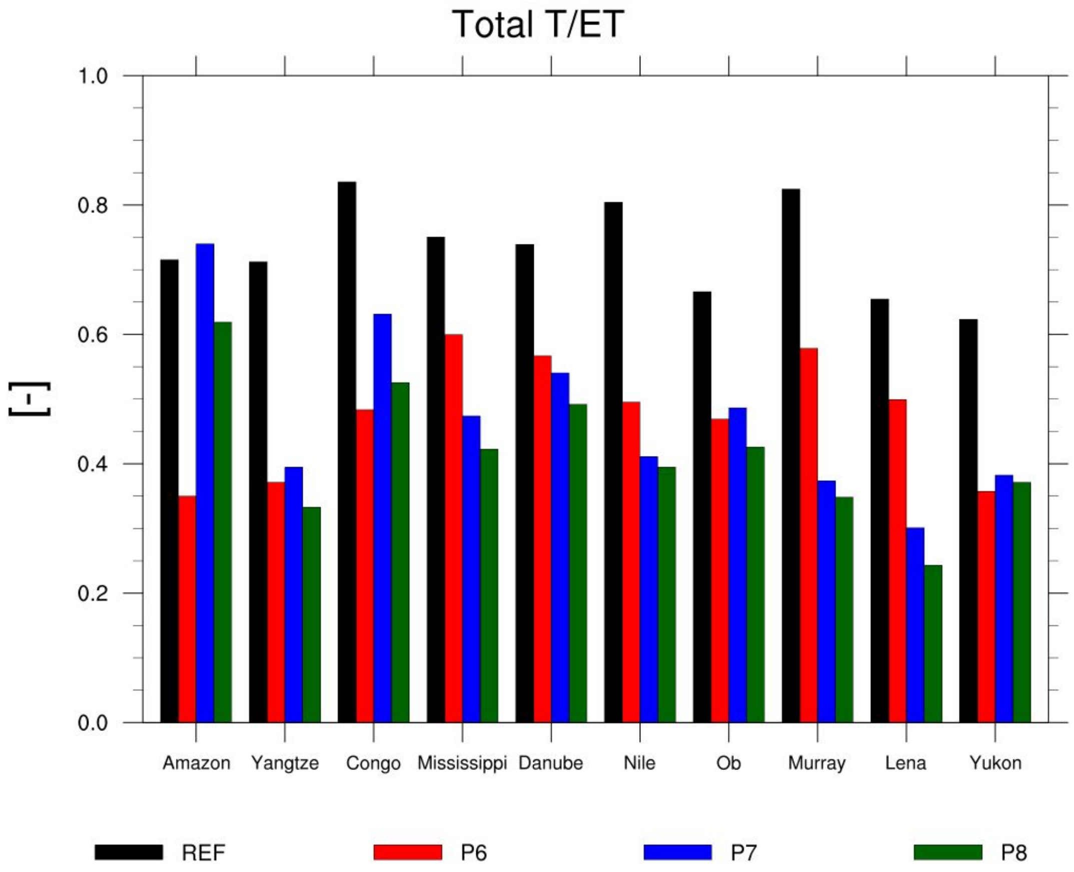
- P6 ET higher than P7 in almost all basins and mostly too high relative to observations
- P7 ET too low in tropics - consistent with high temperatures in these basins
- In other basins, P7 ET is more inline with obs
- P8 increase ET significantly over P7



Global Water Cycle Climatology

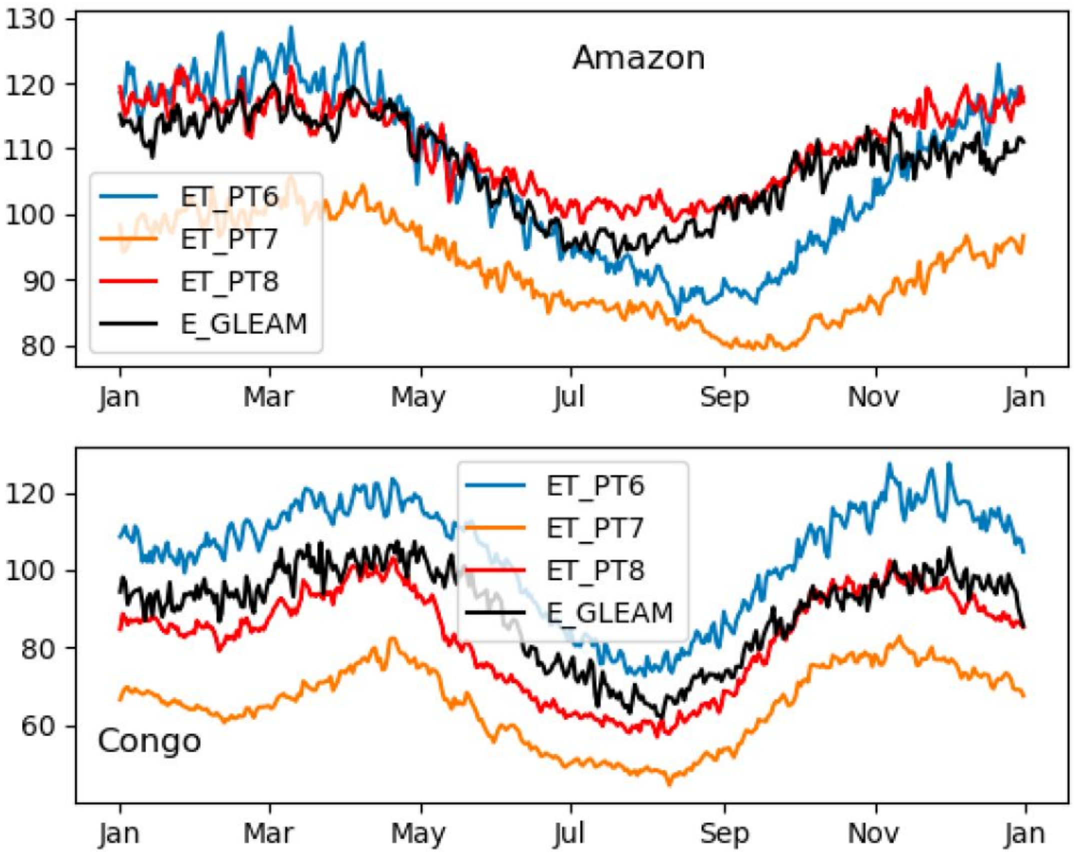
- Transpiration fraction is too low in all prototypes
- Too efficient evaporation leads to faster recycling of soil moisture and less transpiration further in the forecast
- Global average: 61% (+/-15%)*
- Dependence on vegetation (50% - 70%)*

*Schlesinger and Jasechko (2013)



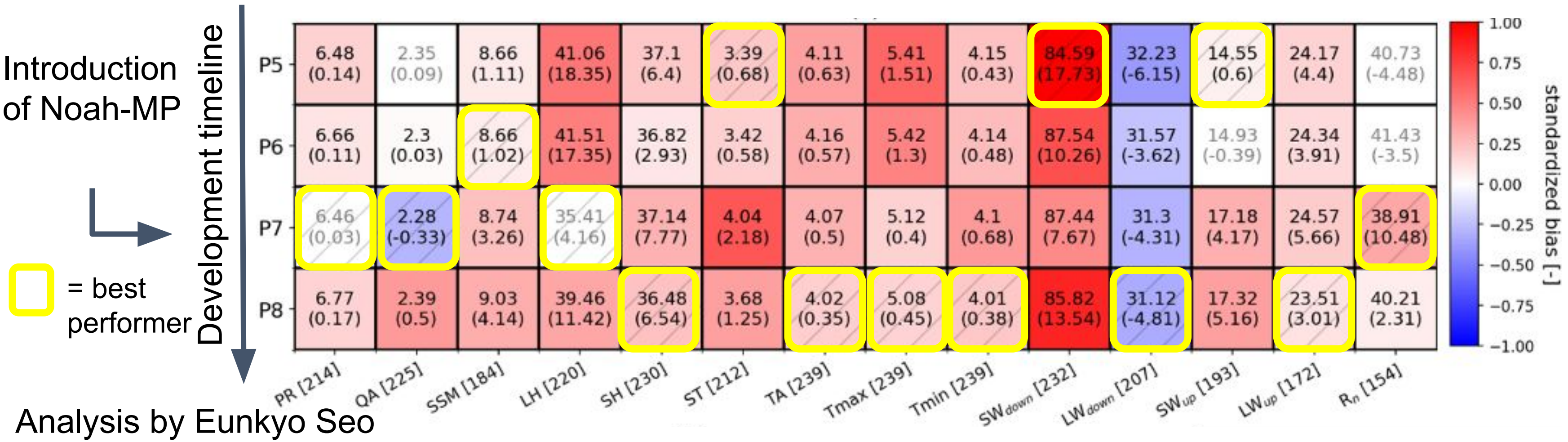
Tropical Water Cycle

- Tropical ET seems to be much better simulated in P8, especially compared to P7
- Direct relationship with increased precipitation



Transition from Noah to Noah-MP

- Noah-MP introduced in Global Prototype 7
- Fundamentally different land model structure; coupling interface
- Surface metrics scorecard shows 10 of 14 improved with Noah-MP



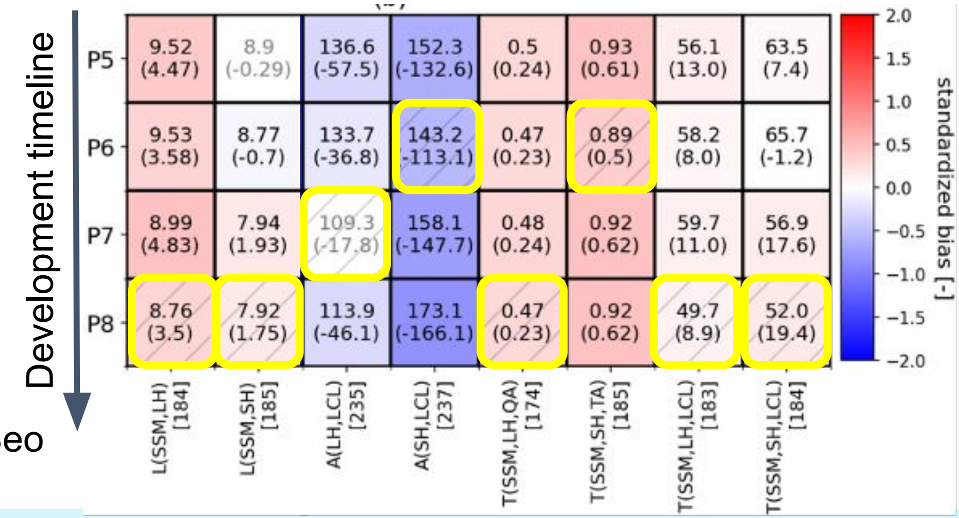
Analysis by Eunkyo Seo and Paul Dirmeyer

Improving Land-Atmosphere Coupling and Memory

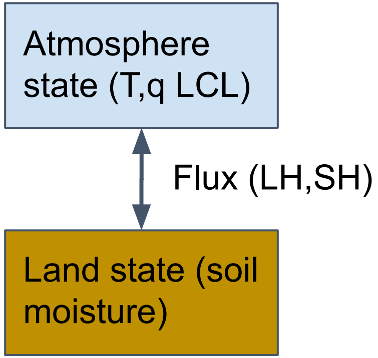
- Land models are a significant source of earth system memory
- Communicating that memory to the atmosphere requires intricate chain of processes

Introduction of Noah-MP

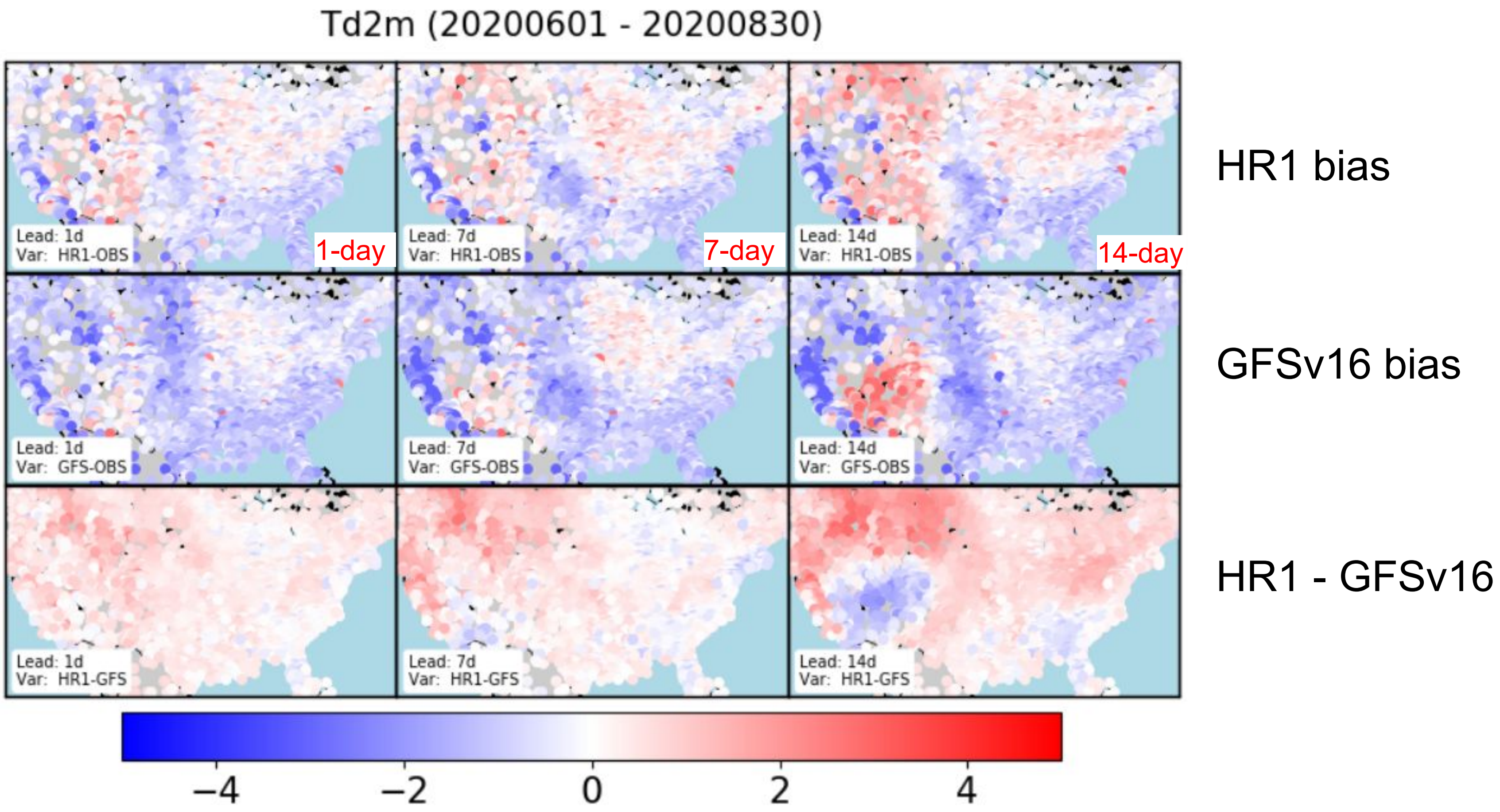
= best performer

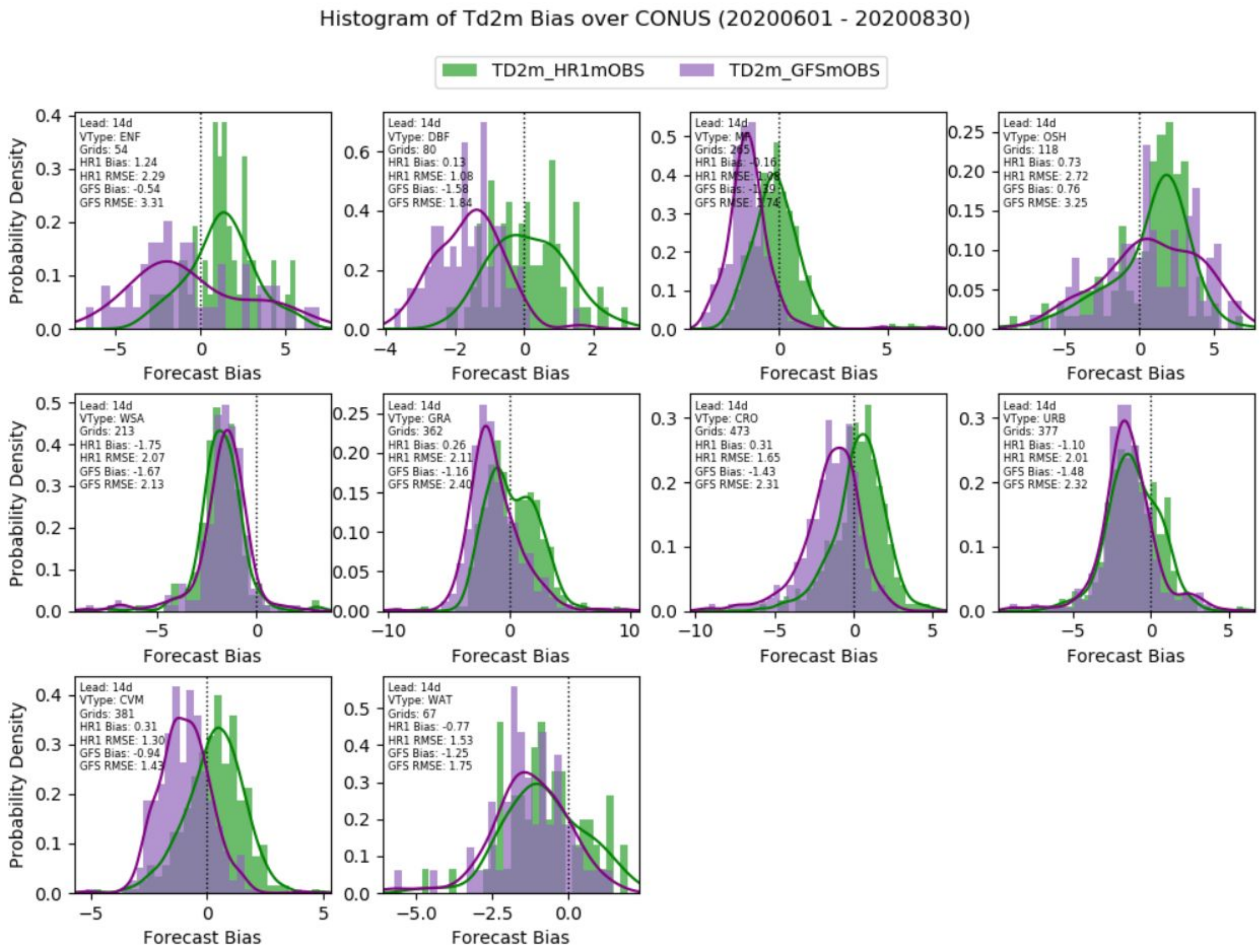


Analysis by Eunkyo Seo and Paul Dirmeyer



METAR Td_{2m} : Summer Simulations

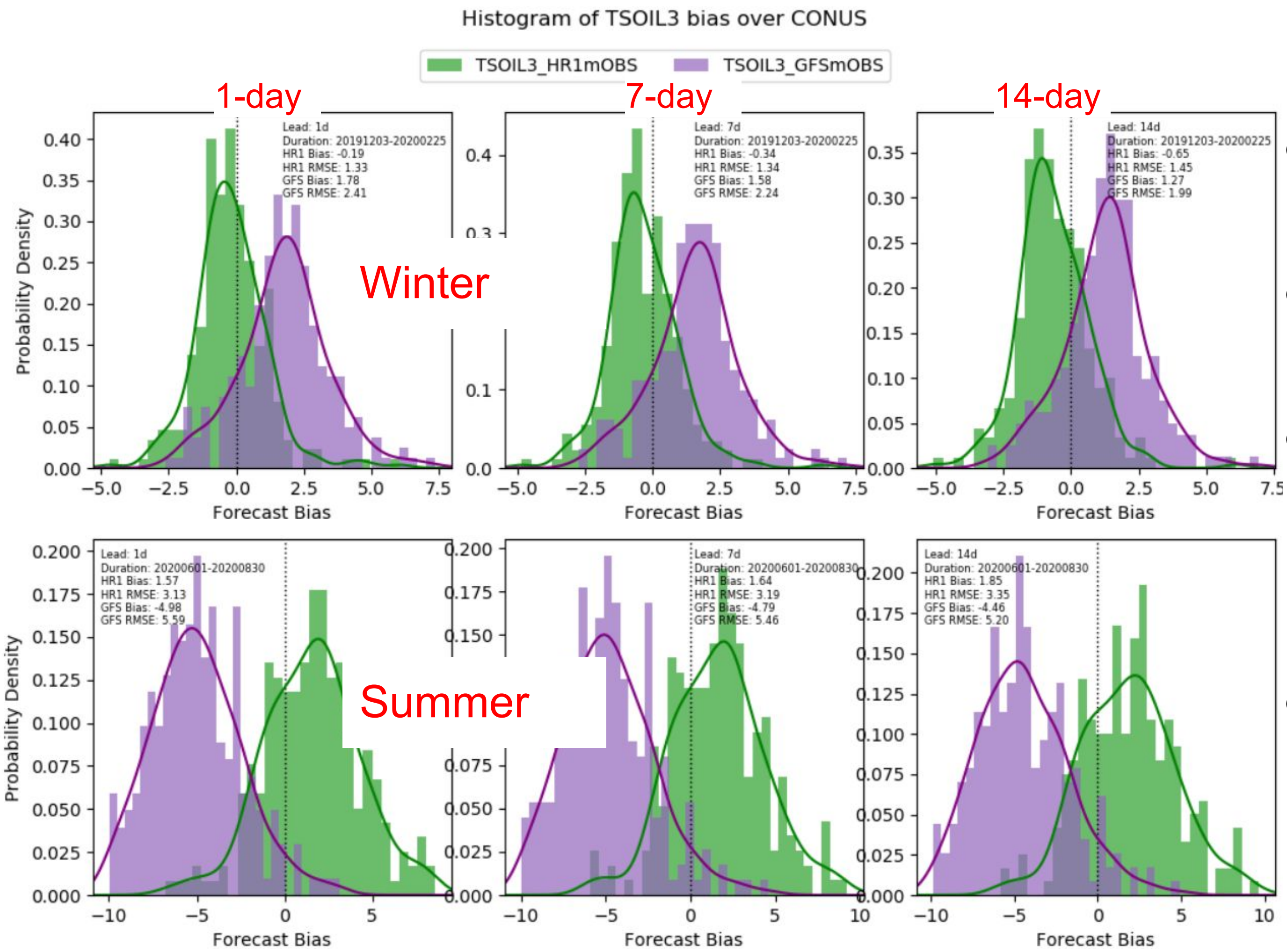




Summer 14-day

- HR1 significantly better over high vegetation (DBF, MF)
- HR1 significantly better over cropland (CRO, CVM)
- HR1 slightly better over grass (GRA)

Soil T 70cm



- HR1 better in winter
- HR1 better in summer
- Exploring some numerical solution issues with soil thermal diffusion
- Obs: SCAN/USCRN

Future Priorities

S2S Model Development Priorities

- Existing land physics optimizations
  - Vegetation phenology model local performance at the global scale
  - Activate agriculture modules (crop specific phenology, planting/harvest, irrigation/tile drainage)
  - Integration of existing S2S funded project on season snow prediction
  - Deeper soil configuration and explicit use of soil composition including organic matter
- New land physics
  - More tightly couple to community noahmp repository (vegetation hydraulics)
  - Incorporate medium-complexity urban canopy model
  - Better representation of hydrologic cycle: groundwater, ocean inflows, runoff fraction
  - Test if more complex land model is necessary
- Interaction with other components
  - Unify surface input data (collaboration with composition team)
  - Ocean inflows
  - Coupling with PBL at seasonal scale (e.g., phenology dependence)
- Initialization
  - Assimilation of vegetation and albedo (co-dependent)
  - Improved use of human influenced surface characteristics (e.g.,burned area, land cover change)

Recently Funded Land Projects

- **Enhancing NOAA UFS subseasonal to seasonal predictions of precipitation and drought via improved representation of snowpack processes** (WPO S2S FY22) - Cenlin He (PI), Fei Chen, Ronnie Abolafia-Rosenzweig
- **Assessing the impact of dynamic vegetation on drought forecasts** (WPO S2S FY22) - Jason Otkin (PI), Michael Ek, Tara Jensen
- **Beyond the "Big-Leaf" Model at NOAA: Use of Novel Satellite Data and In-Canopy Processes to Improve U.S. Air Quality Predictions** (WPO AQ FY22) - Patrick C. Campbell
- **Advanced Coupling Evaluation Metrics in METplus for UFS Land Surface Models** (WPO JTTI FY22) - Scott Miller (PI), Sarah Lu, Andrew Newman
- **Integrated surface physics for coupled hydrometeorology in the UFS for S2S prediction** (WPO S2S FY22) - David Gochis (PI), Paul Dirmeyer, Michael Ek
- **Improving land-surface flux partitioning in operational short range forecasts through integration of NOAA weather and water models** (WPO JTTI FY20) - David Gochis, Jason English
- **Advancing Land Modeling Infrastructure in the UFS for Hierarchical Model Development** (WPO JTTI FY21) - Ufuk Turuncoglu
- **An Optimized Lake-Treatment Strategy for Improved Land-Surface Modeling and Weather Prediction in the Unified Forecast System** (UFS) (WPO JTTI FY21) - Andrew Gronewold, David Yates, Tatiana Smirnova
- **A New Global 4-km Multi-Decadal Snow Cover Extent/Snow Water Equivalent/Snow Depth Dataset from Blended In-situ and Satellite Observations** (WPO Obs FY21) - Peter Romanov, Cezar Kongoli
- **Analysis of coupled land-atmosphere behavior in P8, GFSv17 GEFSv13/Implement basic land-atmosphere metrics in METplus** (UFS-R2O) - Paul Dirmeyer, Mike Ek, Eunkyo Seo

The End