NOAA

National Weather Service

UFS Land: The Development of a Community Effort to Expand NOAA Land Model Capabilities

UFS Webinar

March 11, 2021

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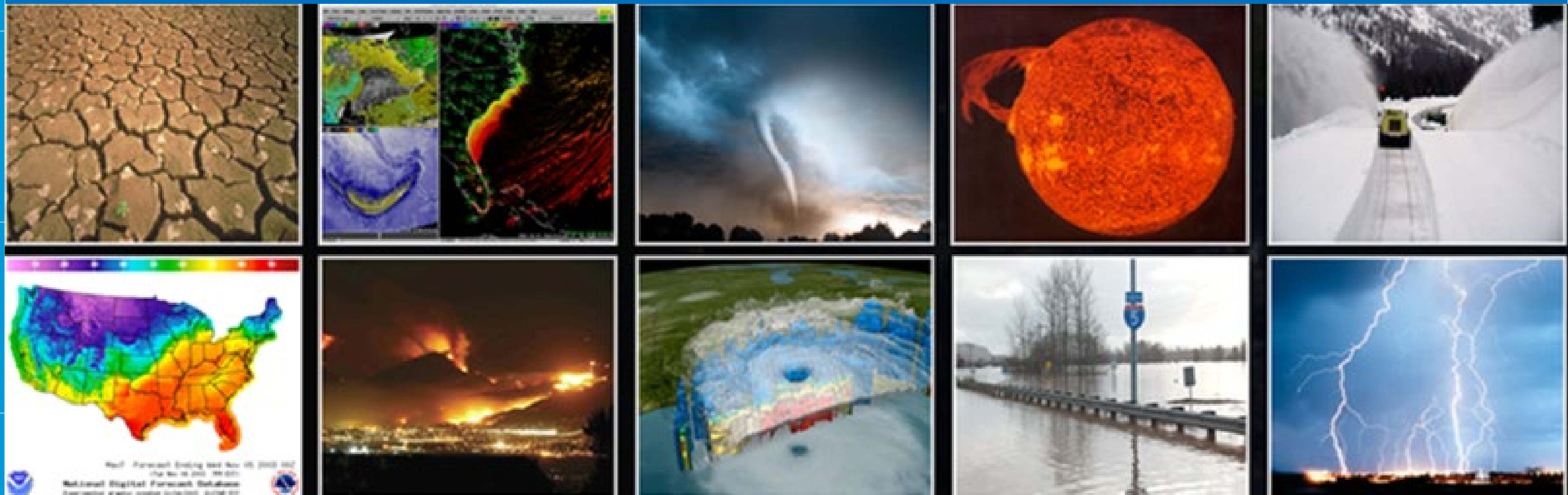
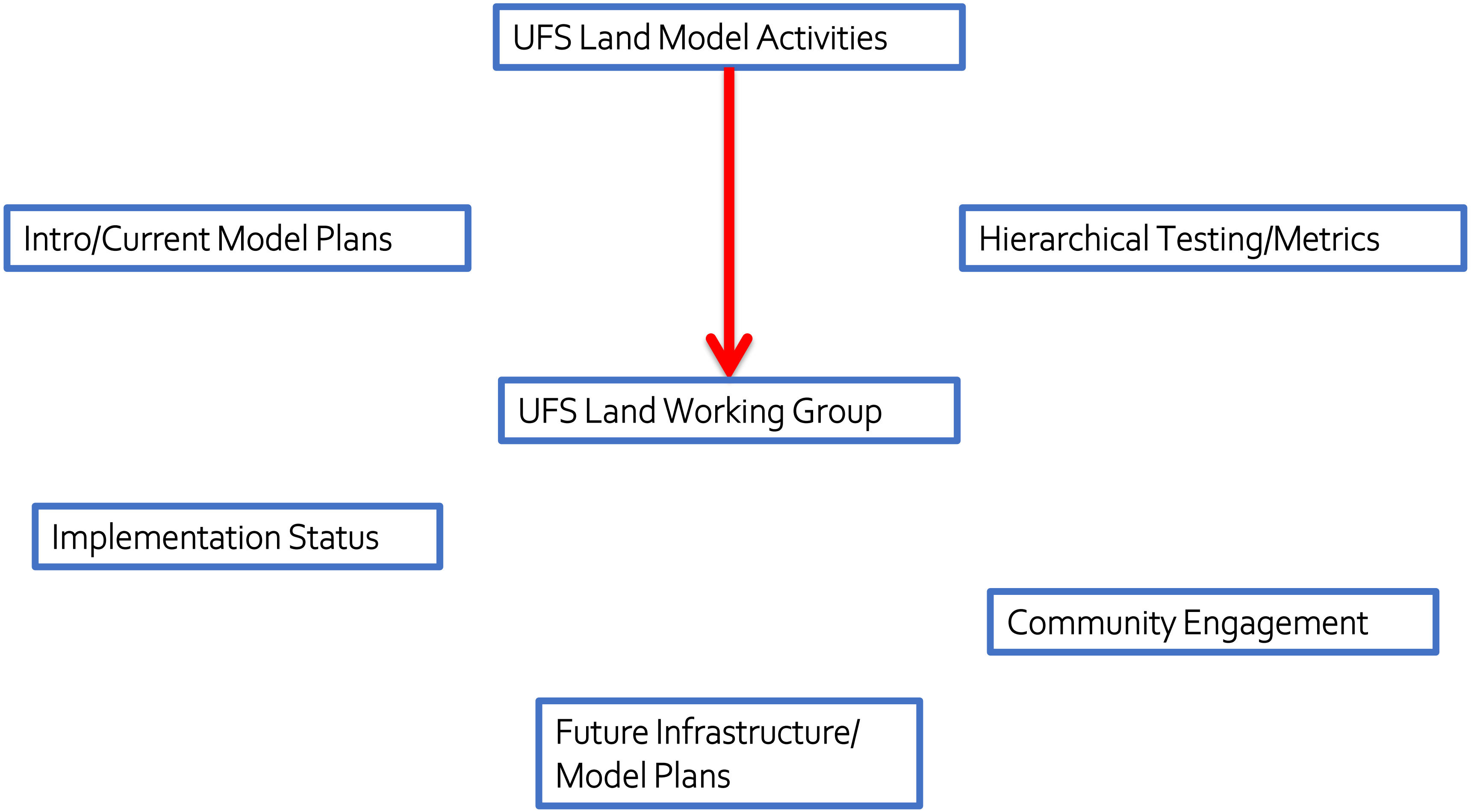
UFS Land Working Group Co-lead
Acknowledgements: EMC Land Team; UFS Land WG



Roadmap: Past, Current, Future



Unified Forecast System

- 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/Convection Allowing Model (SRW/CAM): Atmospheric behavior from less than an hour to several days
  - Medium-Range Weather (MRW): Atmospheric behavior out to about two weeks
  - Subseasonal-to-Seasonal (S2S): Atmospheric and ocean behavior from about two weeks to about one year
- Working Groups: Chemistry, DA, Dynamics, Ensembles, Marine, Physics, Post-Proc, LAND

Unified Forecast System – Working Groups

Working Group Charge (Org/Gov document):

- It is a key principle that component WGs will *work with existing communities* rather than replace them. Toward that end, component WGs will:
  - Develop and communicate UFS needs to the component model community.
  - Provide a forum for the component model communities to provide direct input to the UFS.
  - Assure that work done by the UFS on the community models finds its way into the official releases of such models.
  - Implement the components in the UFS, assuring that the models meet standards adopted by the UFS.
- Be responsive to *forecast skill priorities* and be *aligned with science goals*. WGs are expected to develop approaches that address both *short-term needs* and *strategic directions*.

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

Land Data Assimilation

Land-Atmo Interactions

Climate Development

NWP Development

Land Satellite Data

UFS Land Working Group and Workshop

- Currently WG meetings organized around two focus areas
  - short-term tiger team to address issues and short-term needs for upcoming operational releases (every few weeks)
  - long-term planning to enhance community participation (every few months)
- UFS Land Workshop (May 25-26, 2021)
  - ~40 participants
  - 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

Roadmap: Past, Current, Future

UFS Land Model Activities

Intro/Current Model Plans

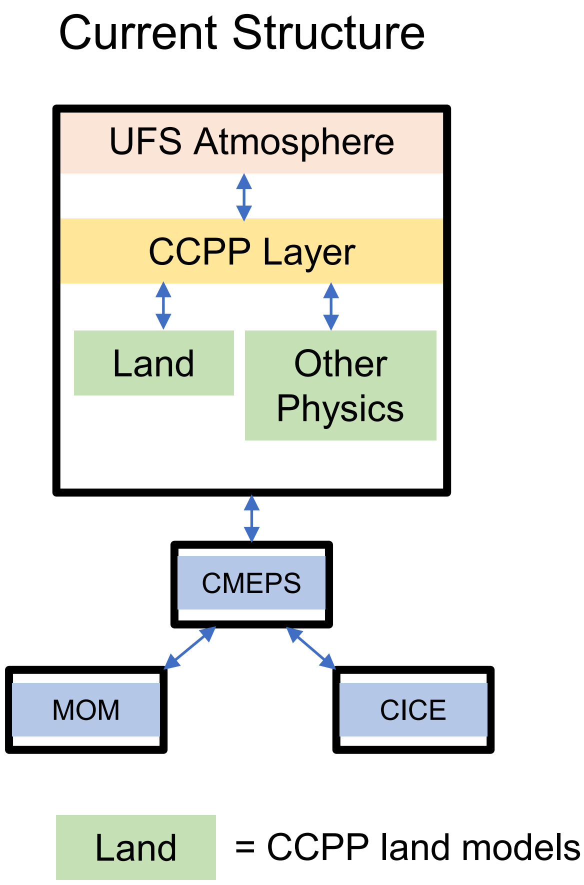
Hierarchical Testing/Metrics

Implementation Status

Community Engagement

Future Infrastructure/ Model Plans

UFS Land – Current Infrastructure



* inspired by Rocky Dunlap

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

Short History of Land Modeling at NCEP

- pre-1980s (LFM): land surface ignored
- Late 1980s (NGM): first simple land model introduced (Tuccillo)
- Early1990s (Global Model): OSU land model (Mahrt& Pan, 1984)
- Mid-90s (Meso Model): OSU/NOAH LSM replaces Force-Restore
- Mid 2000s (Global Model): NOAH replaces OSU (Ek et al. 2003)
- Mid 2000s (Meso Model: WRF): Unified Noah LSM with NCAR
- 2010s: Noah-MP coupled to CFS

Evolution of Land Surface Models

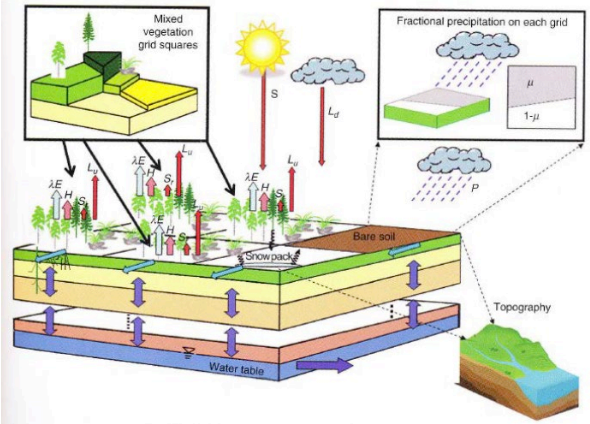


Plate 4 Schematic diagram of SVATS with improved representation of hydrologic processes

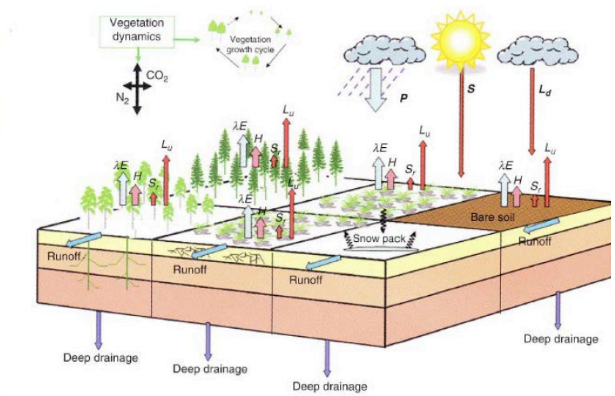


Plate 5 Schematic diagram of SVATS with improved representation of vegetation related processes, including CO_2 exchange and ecosystem evolution.

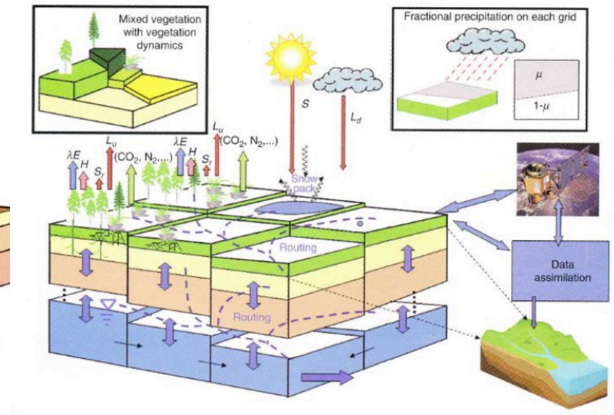


Plate 6 Schematic diagram of potential future developments in SVATS.

Shuttleworth 2011

Focus on energy partitioning Soil moisture/temperature Broad heterogeneity	Explicit plant canopies Dynamic vegetation Groundwater Carbon cycle (crude)	Full nutrient cycles Land cover change Agriculture Lateral water transport Urban

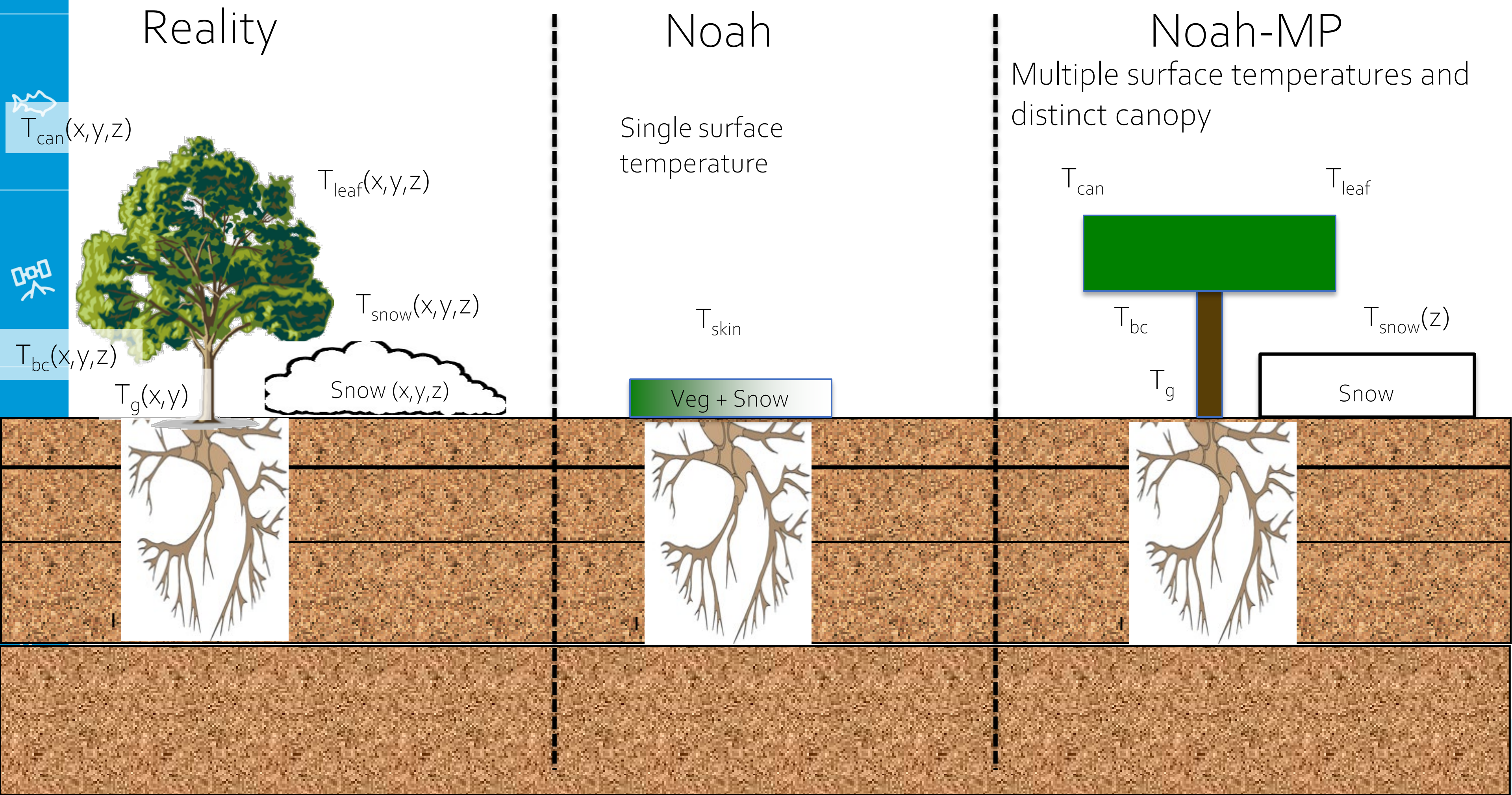
- Land surface models exist within a wide spectrum of complexity
- Processes necessary for application (complexity comes at a cost)
- Parameter proliferation
- Tightness/frequency of coupling with atmosphere

Evolution of Land Surface Models

- Consider two LSMs currently in use at NOAA:
  - Noah LSM – widely-used, bulk surface treatment
  - Noah-MP LSM – explicit canopy, process-based
- "Optimistic that US-based operational centers will transition from this bulk approach to an explicit-canopy process-based approach"
- This transition will contribute to
  - looking beyond the LSM as a boundary condition
  - improving surface forecasts especially when significant heterogeneities exist
  - providing land surface process-level information (e.g., multiple surface temperatures for agriculture or health forecasts)
  - increasing both atmospheric and land surface data assimilation

Model Structural Differences

Noah LSM in NCEP NAM/GFS/UFS, NCAR MM5/WRF Models
Also operational models worldwide
Noah-MP LSM in NWS CFS/GFS/NWM and NCAR WRF/WRF-Hydro



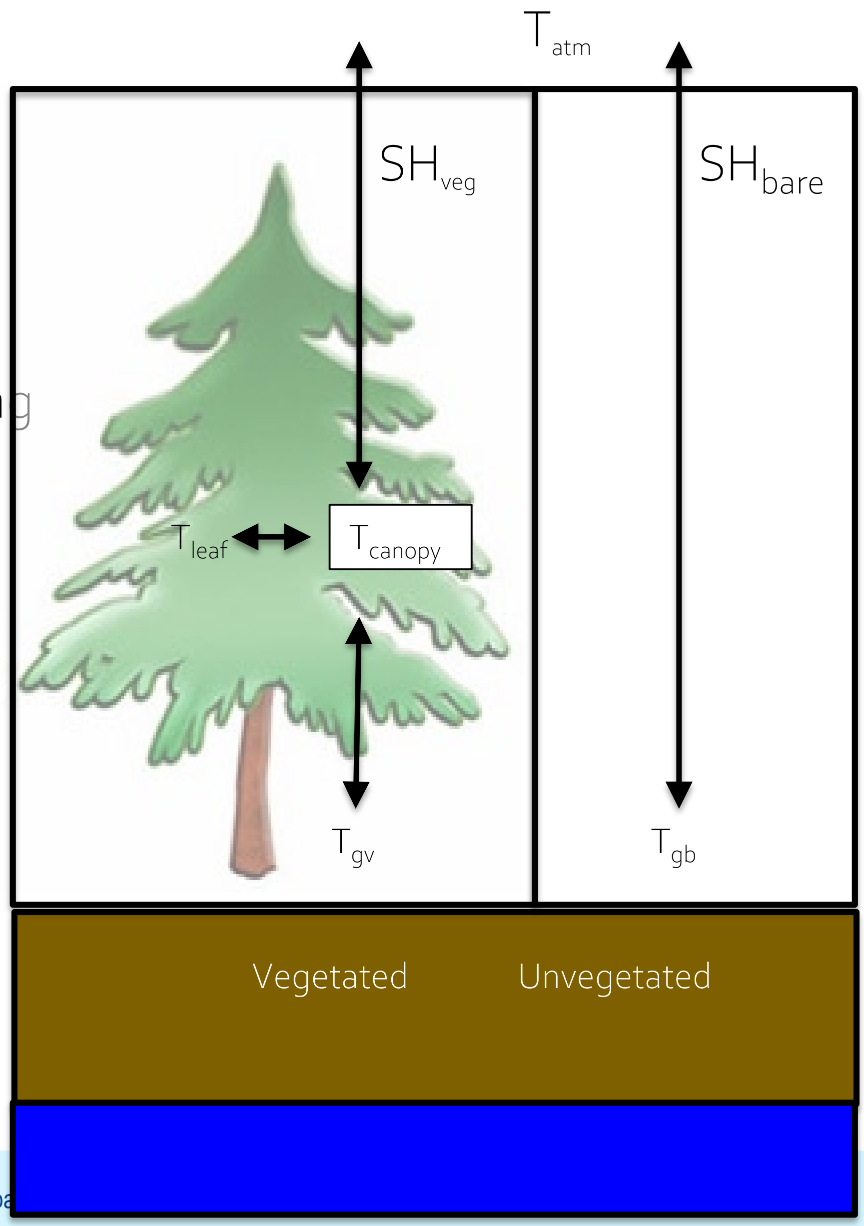
Noah-MP Land Surface Model

- Multiple parameterizations to treat key hydrology-snow-vegetation processes in a single land modeling framework
- Structural differences improve performance over heterogeneous surfaces
- A modular framework for
  - Diagnosing differences in process representation
  - Facilitating ensemble forecasts and uncertainty quantification
  - Choosing process representations appropriate for application
- Maintaining computational efficiency required in OP environments
- Original plan was to maintain Noah functionality
- Active community of users

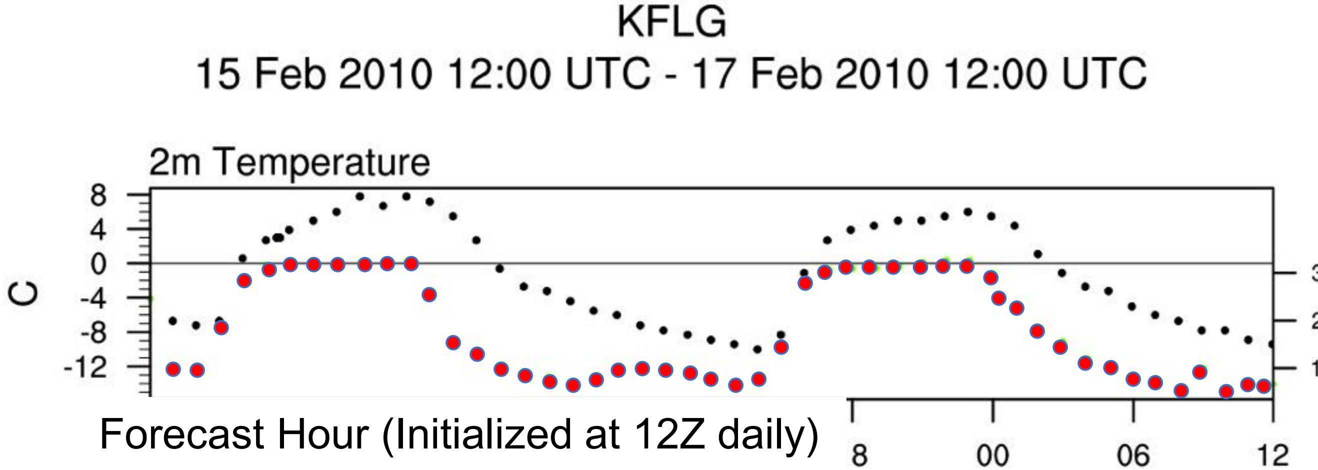
Noah-MP Land Surface Model

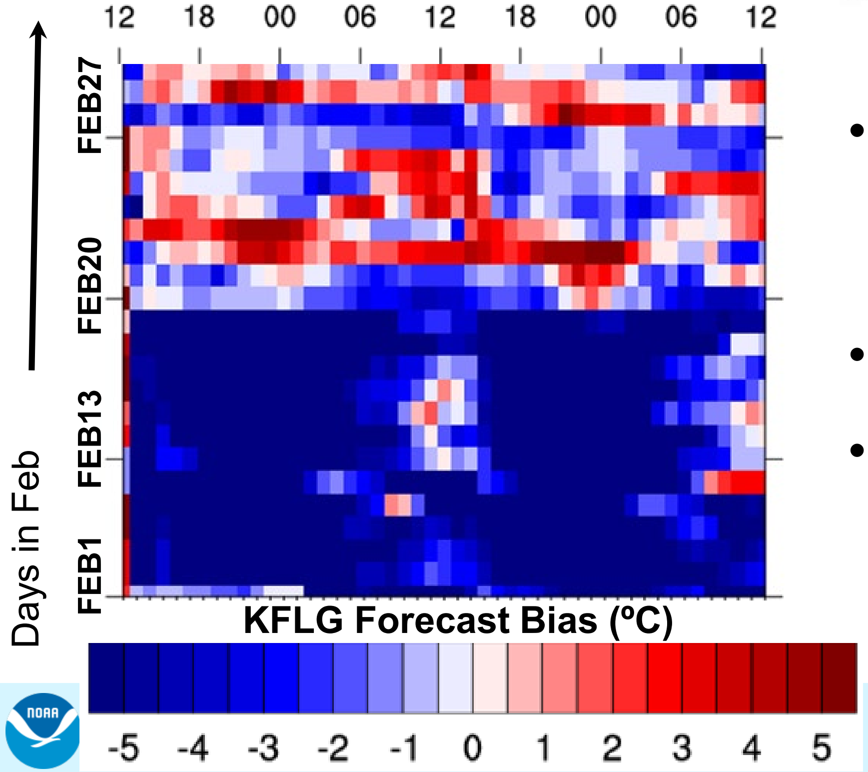
Noah-MP is a land surface model that allows a user to choose multiple options for several physical processes

- Canopy radiative transfer with shading geometry
- Dynamic vegetation
- Vegetation canopy resistance
- Multi-layer snowpack
- Snowpack liquid water retention
- Simple groundwater options
- Snow albedo treatment
- Frozen soil scheme
- Snow cover



Challenges with Noah LSM Structure

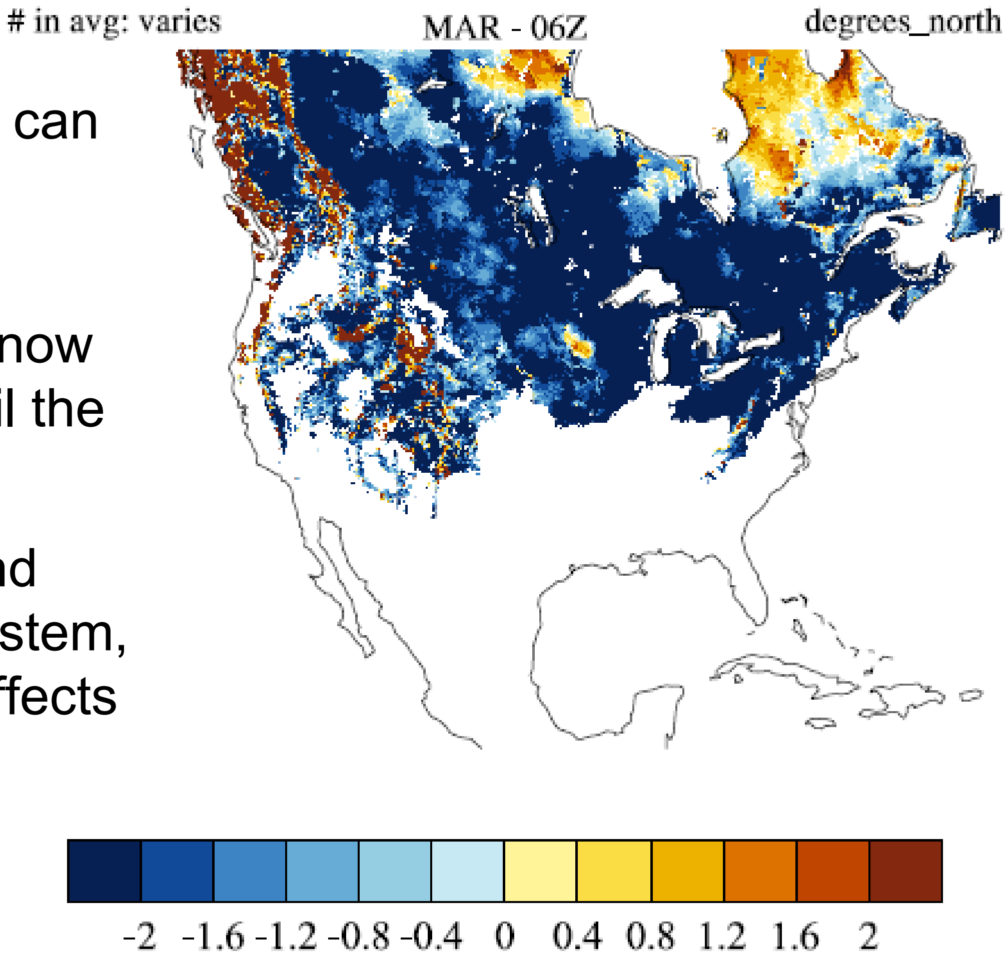




- Cold bias during the day results from capped surface temperature at freezing
- Bias recovers during the night
- When snow is gone, bias is low

Challenges with Noah LSM Structure

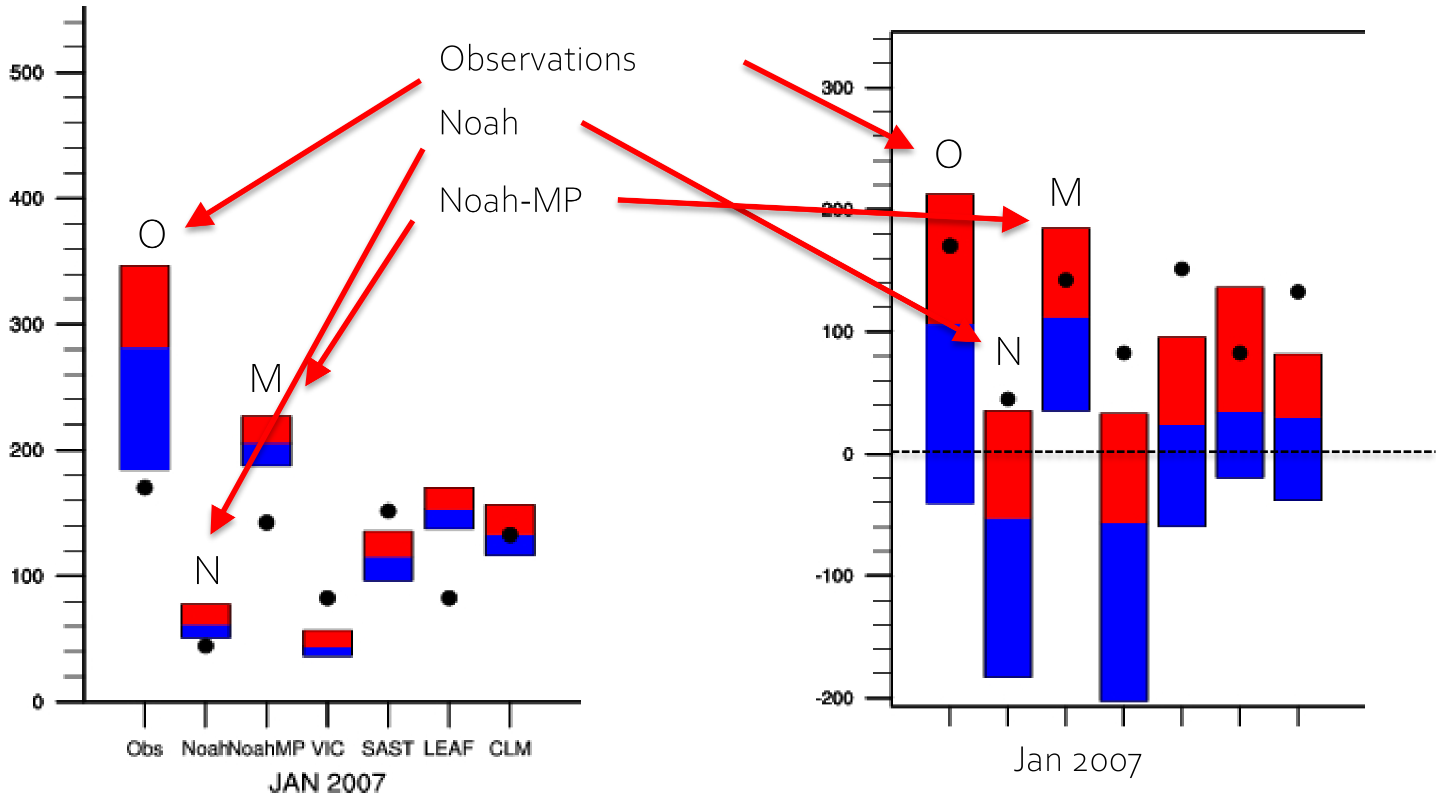
- Attempts to mitigate cold bias can result in snow continuously assimilated during spring
- Due to model structure, this snow melts during the 24 hours until the next assimilation cycle
- DA continues the cold bias and inserts more water into the system, potentially causing adverse effects to hydrology prediction



NCEP operational NAM model 24-hour forecasted snow minus analysis snow shows excessive melting during the entire month of March

Noah and Noah-MP LSM Structure Comparison

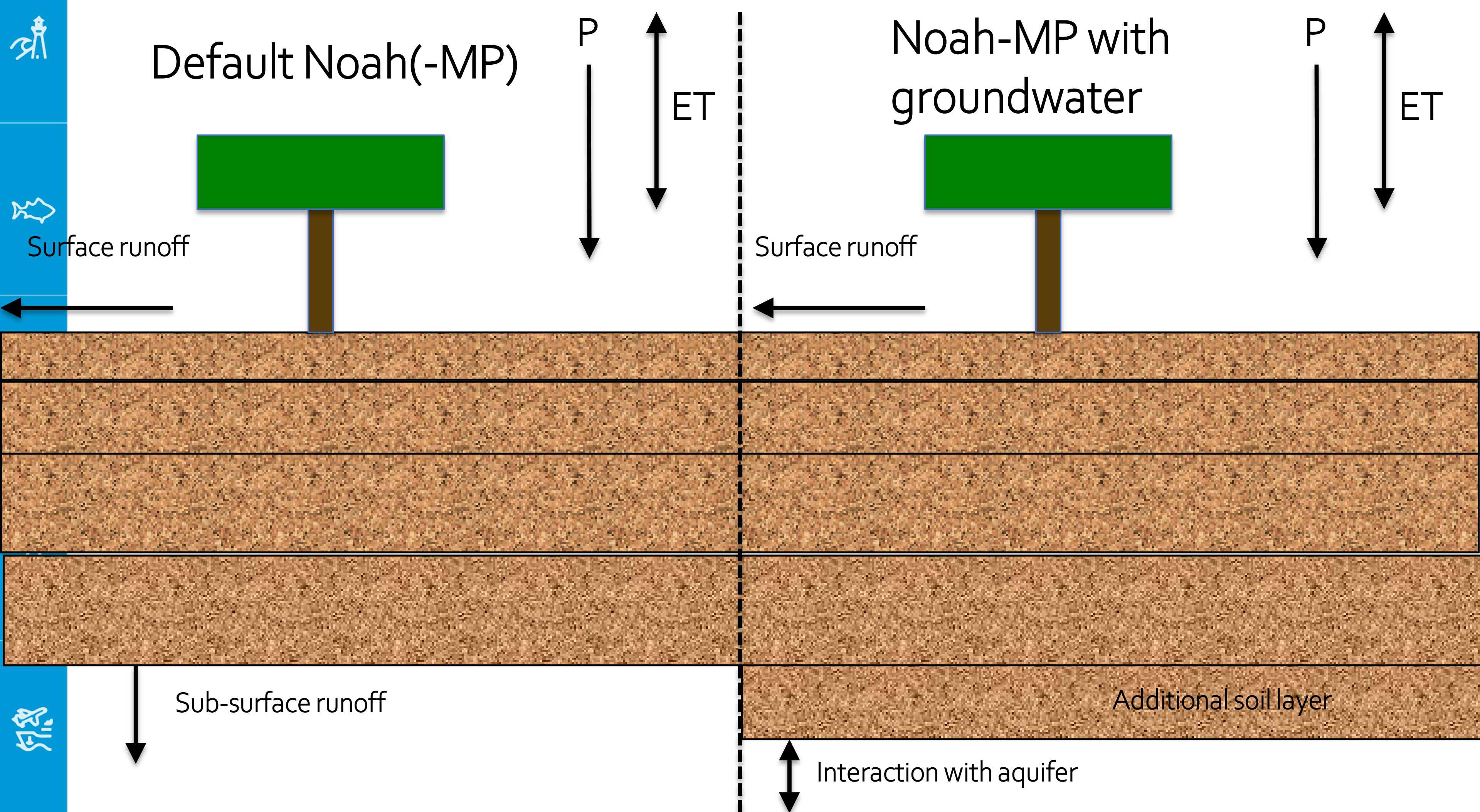
Absorbed SW ## Sensible Heat



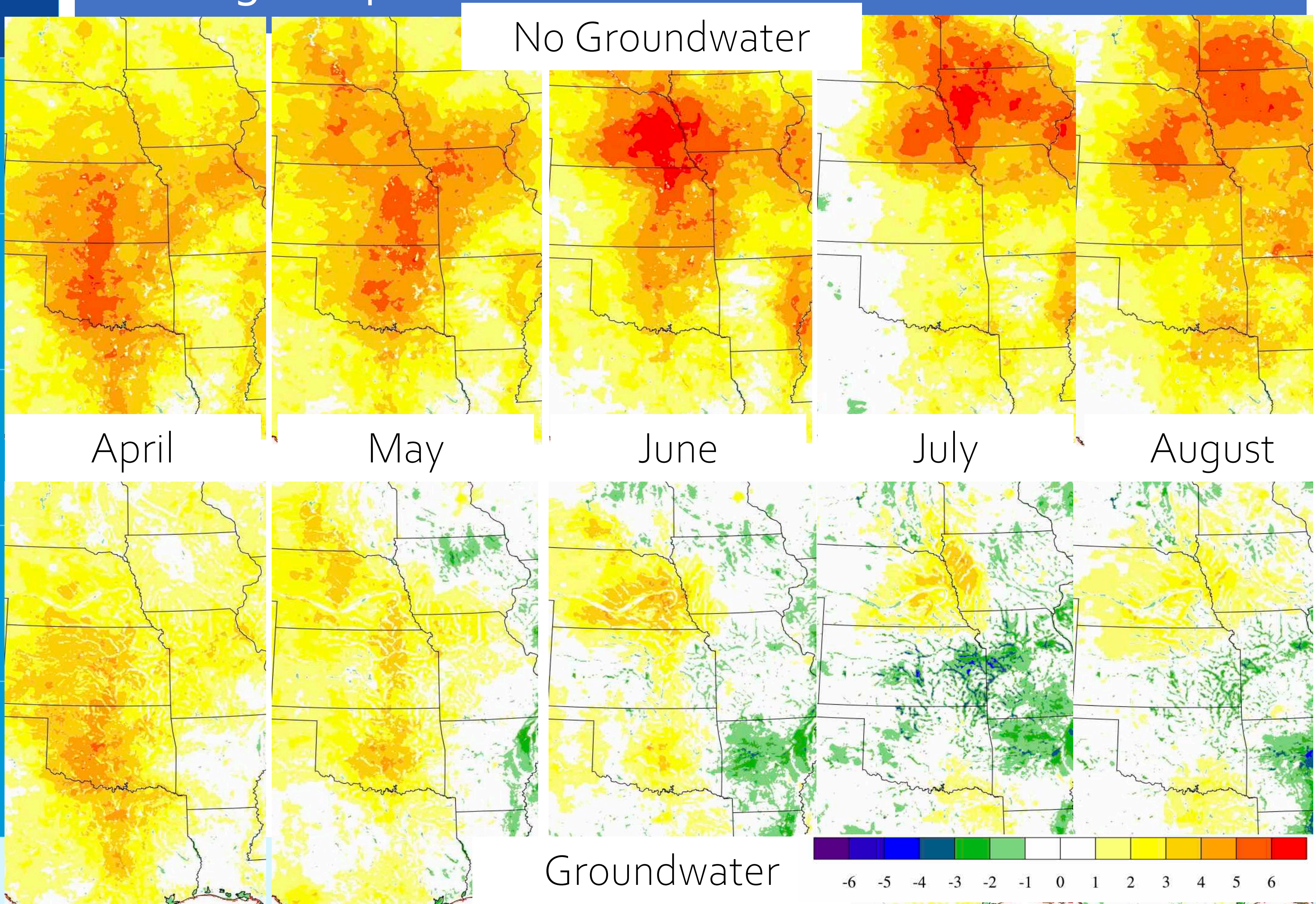
- Comparison of observed (O), Noah (N), and Noah-MP (M) at forested site
- Noah has less absorbed solar radiation resulting in colder surface and lower (or negative) sensible heat flux

Chen, Barlage, et al. 2014

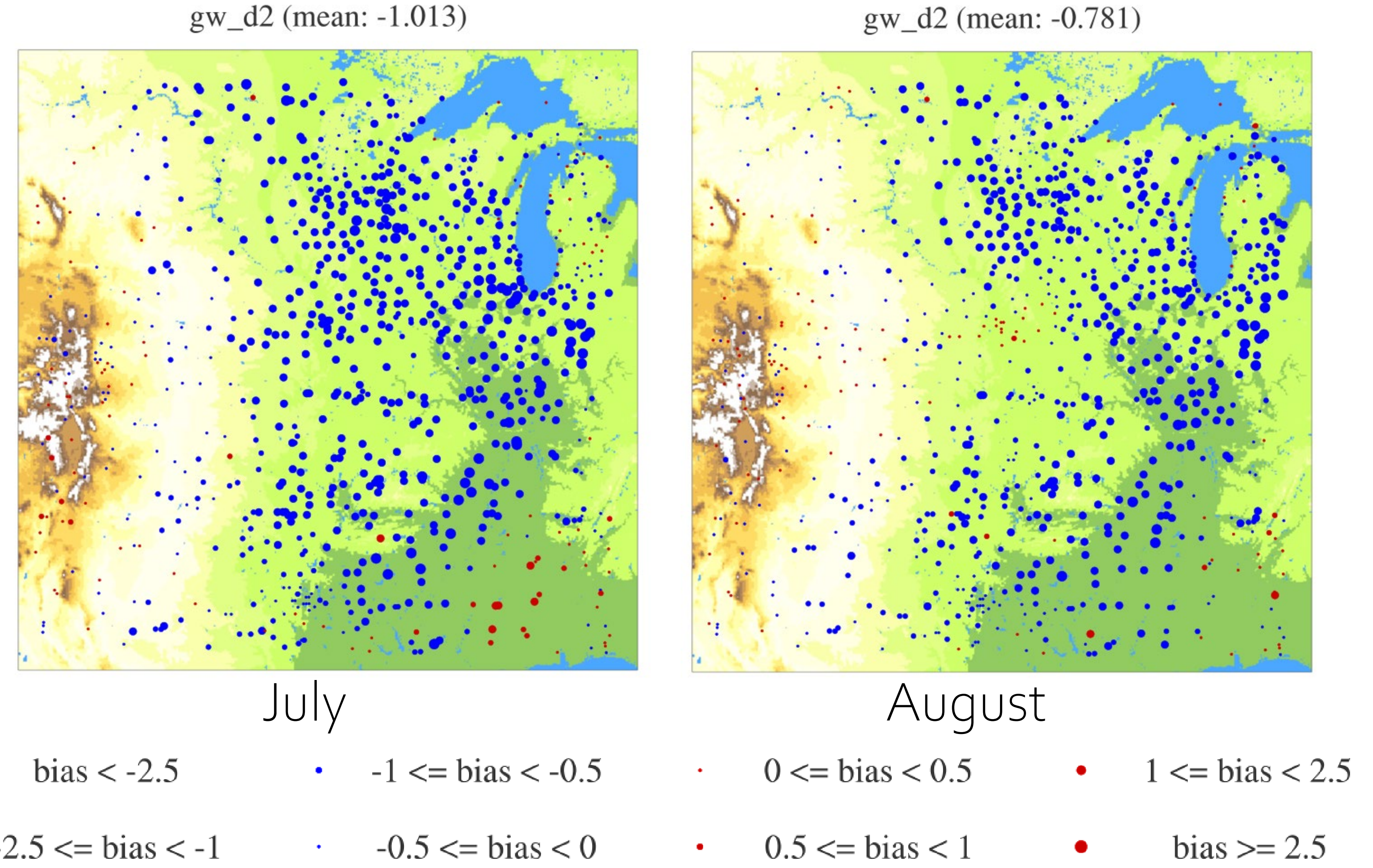
Noah-MP Process Benefits: Groundwater



Evolving Temperature Bias over Central U.S.

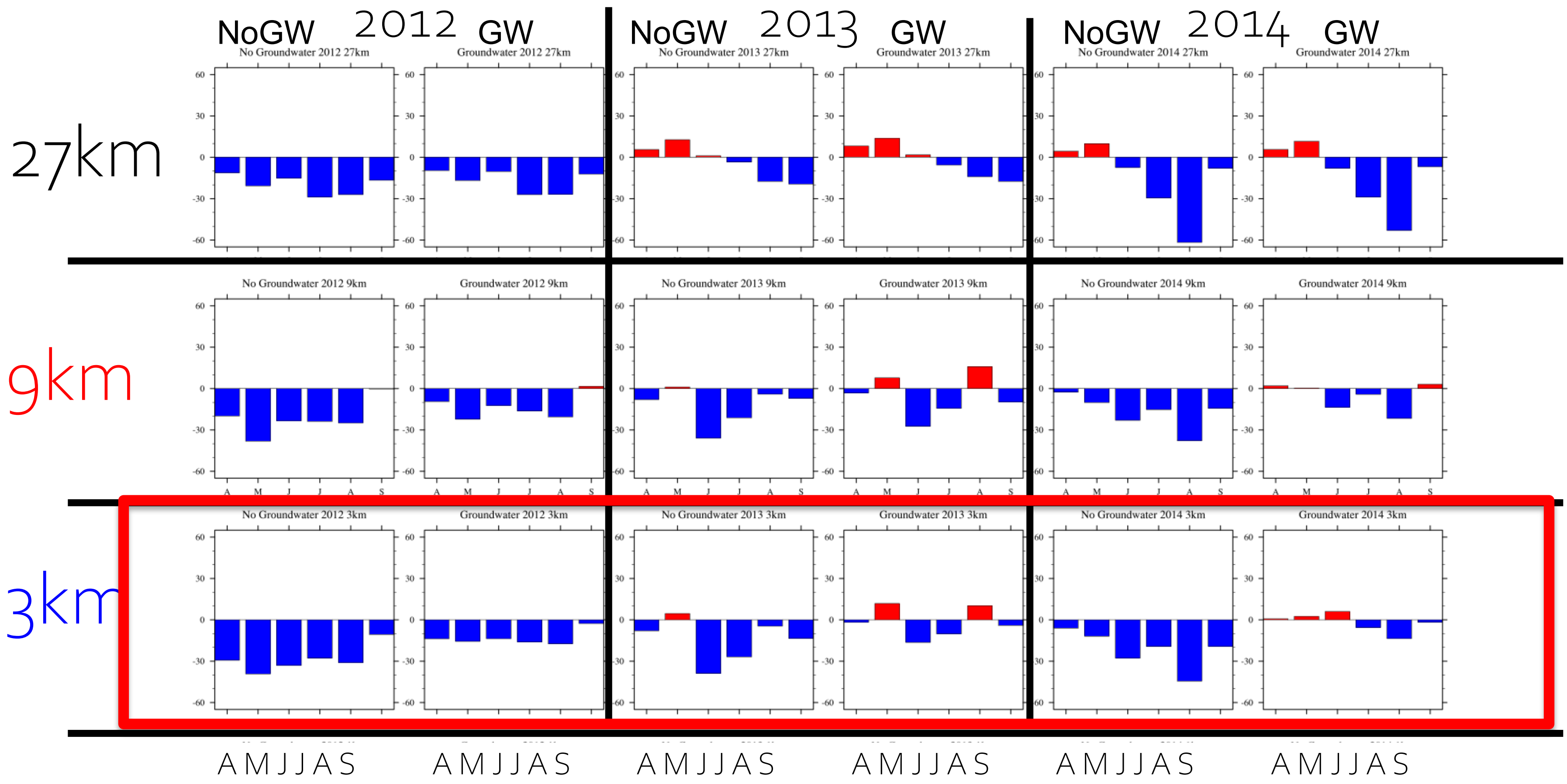


Groundwater Impact on 2-m Temperature



Groundwater Scale Dependencies – Precipitation

- Monthly precipitation bias in the Central U.S.



Results from Barlage et al. 2021

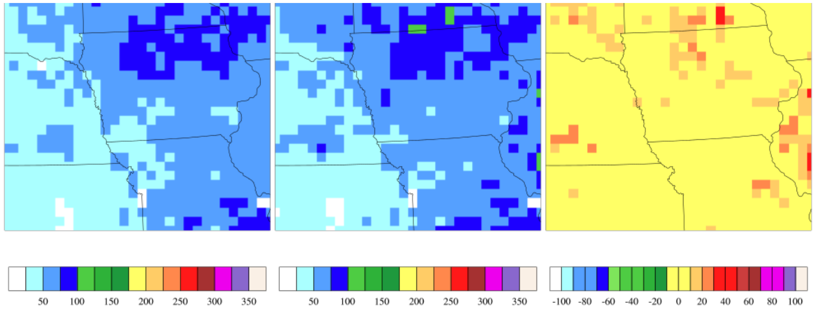
Groundwater Scale Dependencies – Latent Heat Flux

- Higher resolution simulations show the largest latent heat flux impact

No Groundwater Groundwater Groundwater Effect

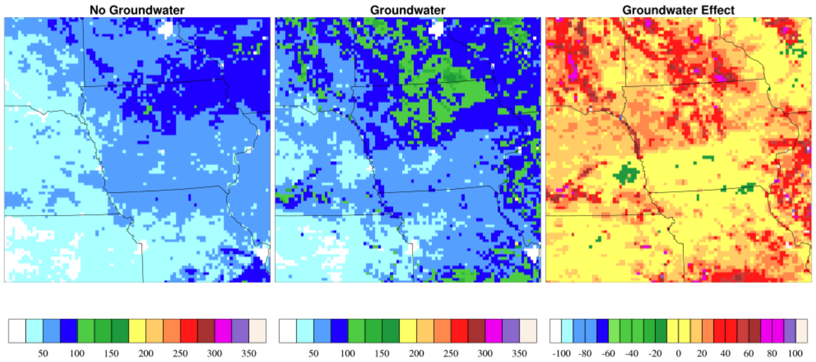
July latent heat flux

27km



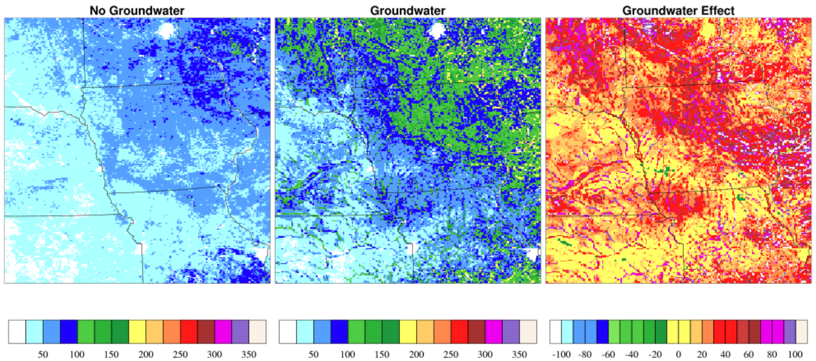
Mean: 5.2 mm

9km



Mean: 16.8 mm

3km



Mean: 33.5 mm

Groundwater Scale Dependencies – Downward Solar Flux

- Higher resolution simulations show the largest SW reduction/cloud cover

No Groundwater Groundwater Groundwater Effect

August Downward Solar at 20Z

27km

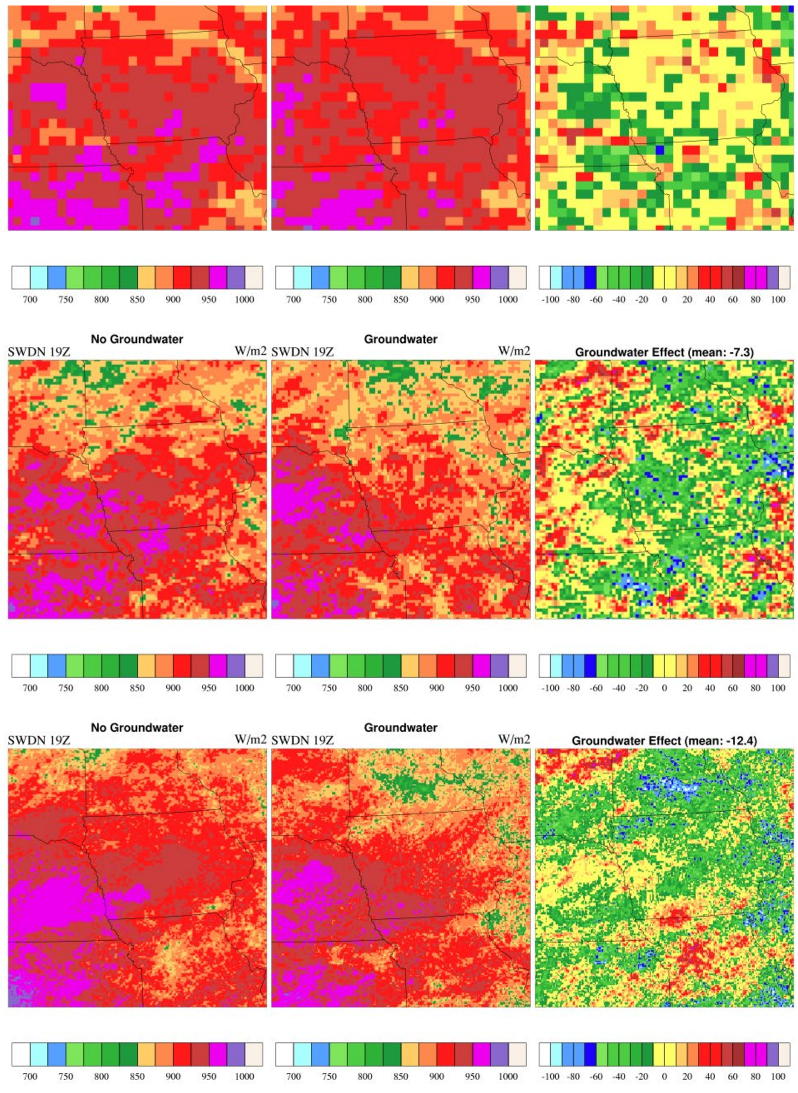
Mean: -2.3 W/m²

9km

Mean: -7.3 W/m²

3km

Mean: -12.4 W/m²

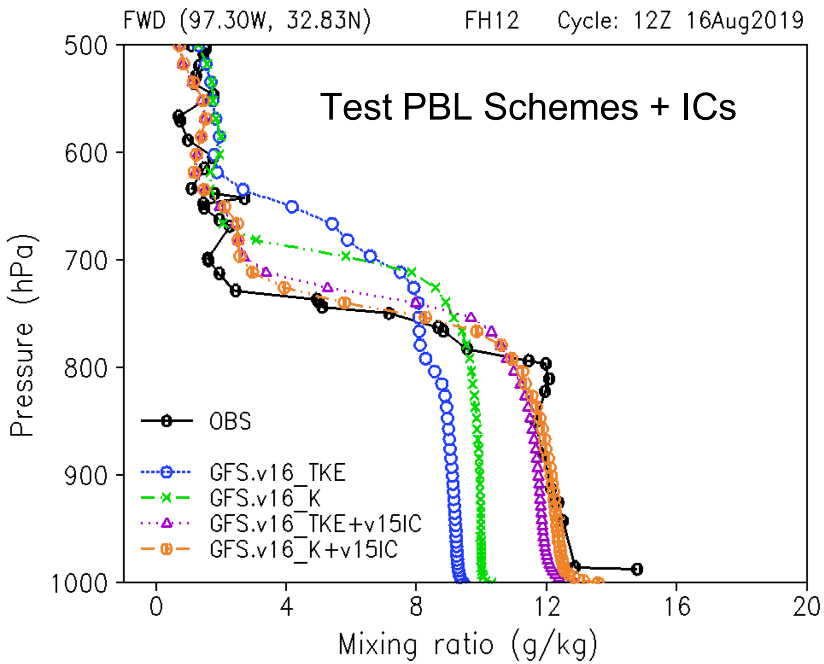


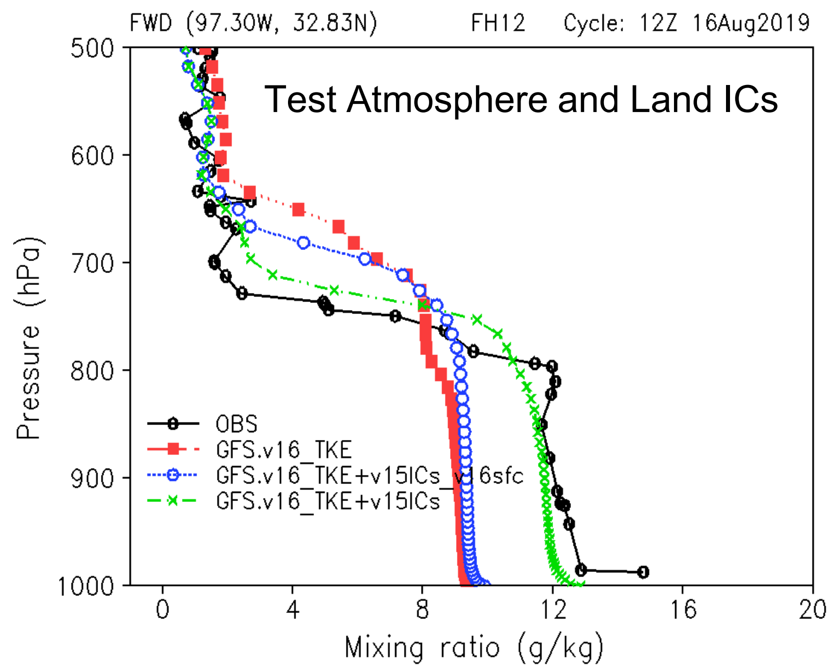
Communication of Land Model Deficiencies

Concerns for GFSv16 (EMC MEG overview)

- Increased right-of-track bias at longer lead times for North Atlantic TCs
- Larger TC False Alarm Rate (FAR) in the western North Atlantic (70°W–50°W)
- Tendency to strengthen all TCs in the long range (pre-formation, not in stats)
- Degradation of HMON performance
- Some regional degradation of waves forecasts
- Exacerbation of low instability (i.e., CAPE) bias that already existed in GFSv15, driven largely by low soil moisture
- Colder low-level temperature analyses, especially in the cool season
- Lack of considerable improvement in forecasting radiation inversions

Tendency to Overmix the Boundary Layer





Experiments run by Weizhong Zheng (IMSG/EMC)

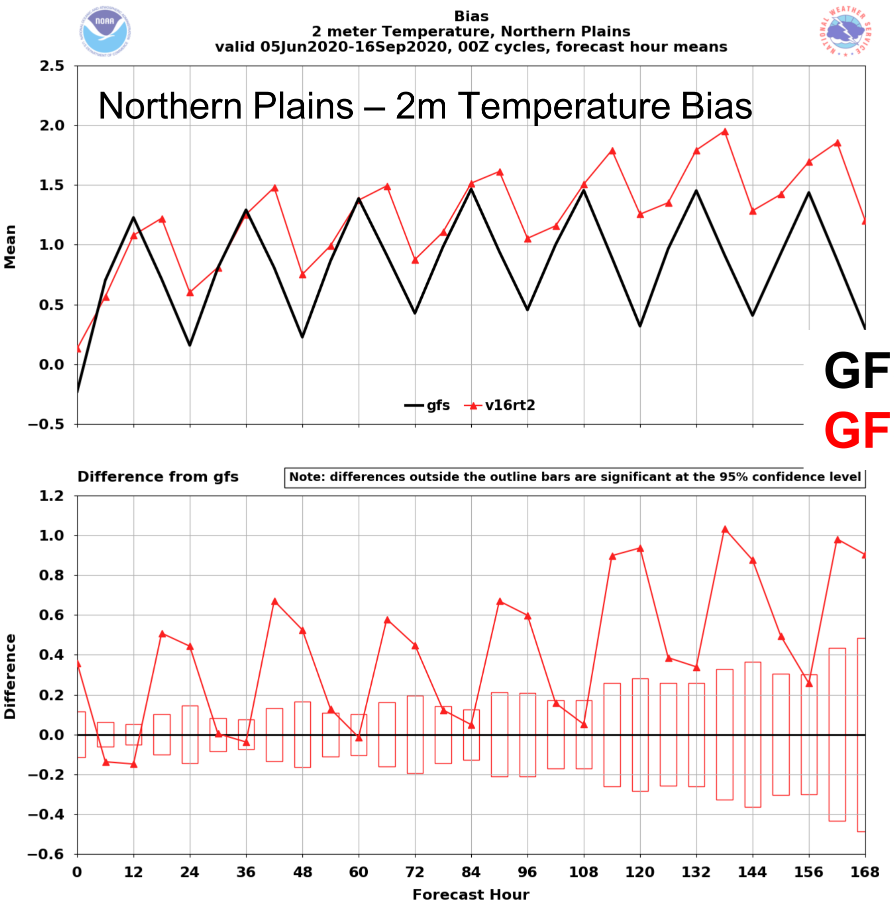
Minor sensitivity to PBL scheme; major sensitivity to initial conditions

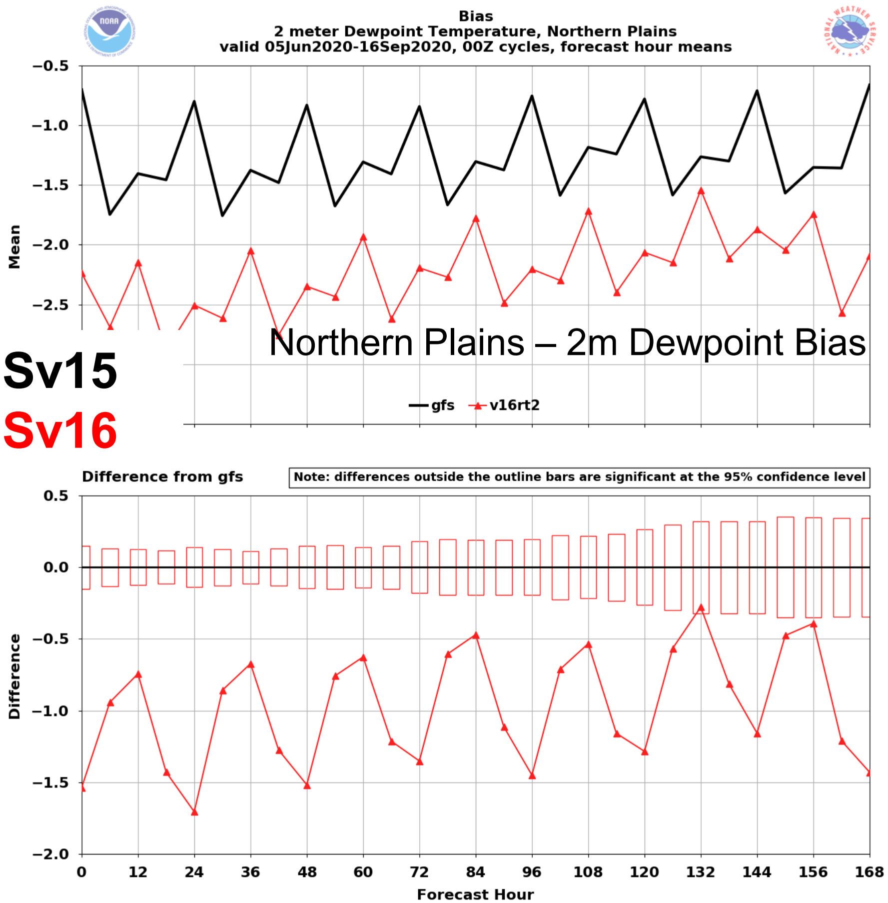
Most of the initial condition sensitivity is to the surface states and not the atmospheric states

IC issues are a result of both IC procedure and model deficiencies

Warm/Dry Bias Exacerbated Across the Great Plains

Northern Plains 2-m T (left) and 2-m Td (right) Bias as a Function of Forecast Lead

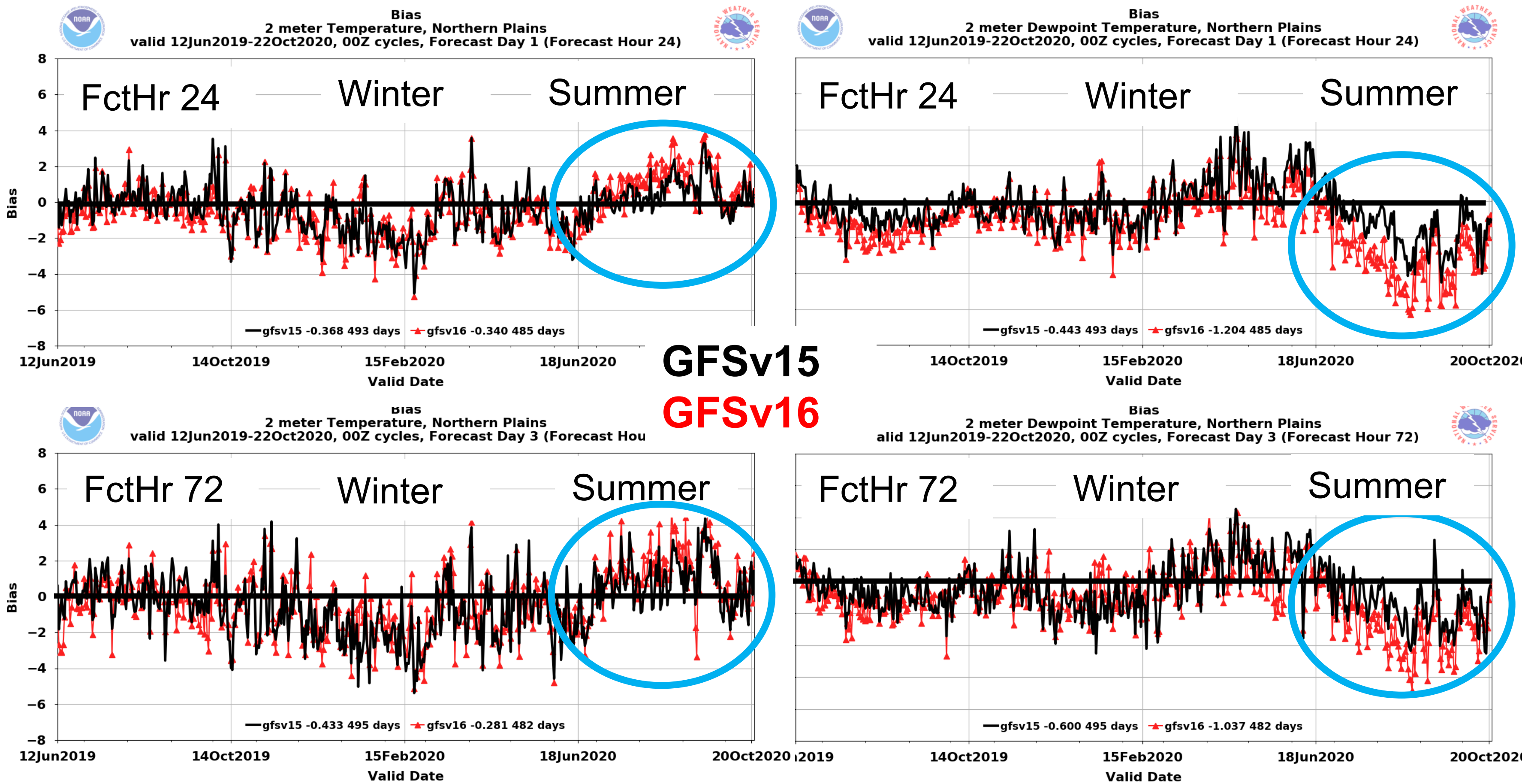




GFSv15

GFSv16

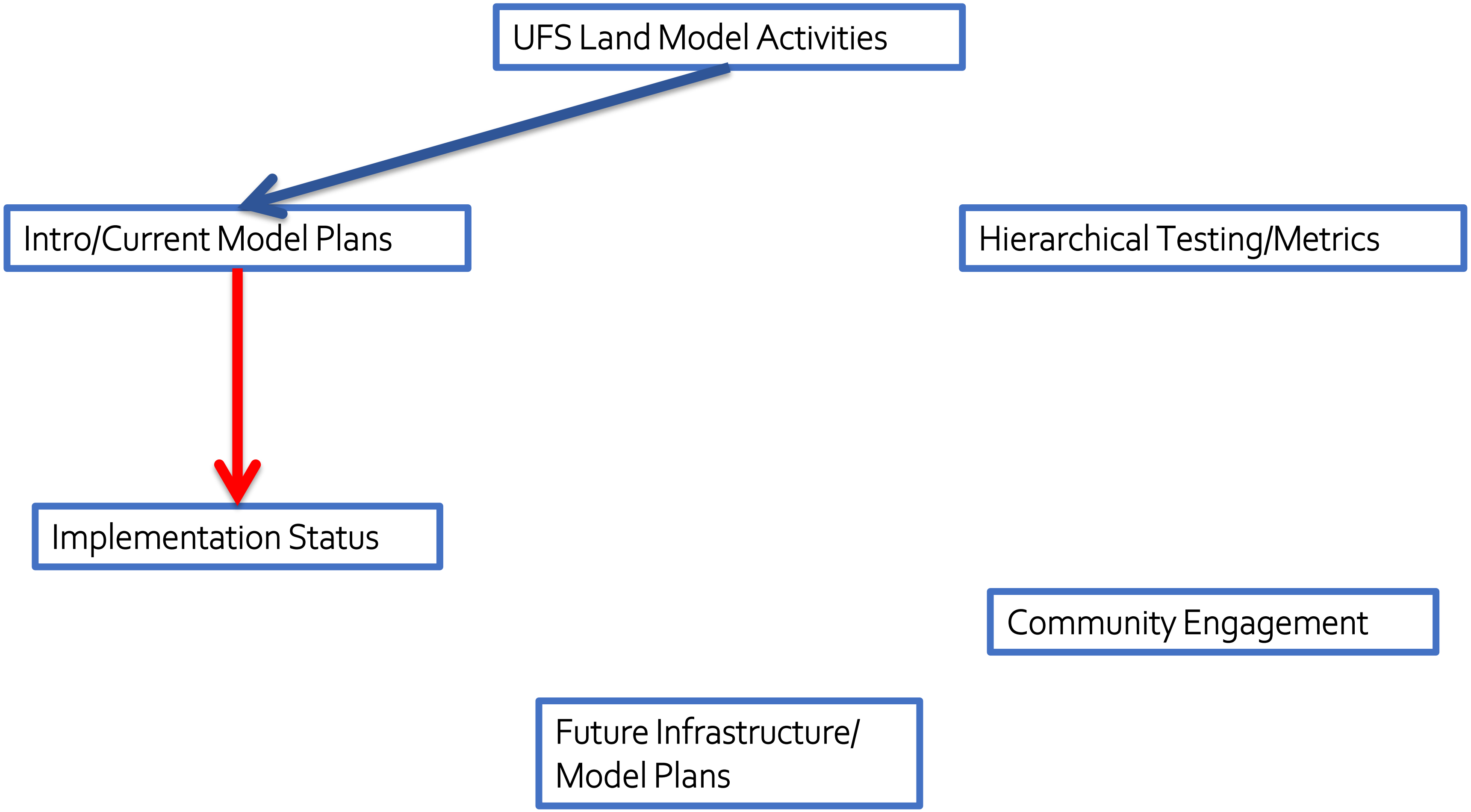
Warm/Dry Bias Exacerbated Across the Great Plains



Northern Plains Temperature Bias
Fcst Hr 24 (top); Fcst Hr 72 (bottom)

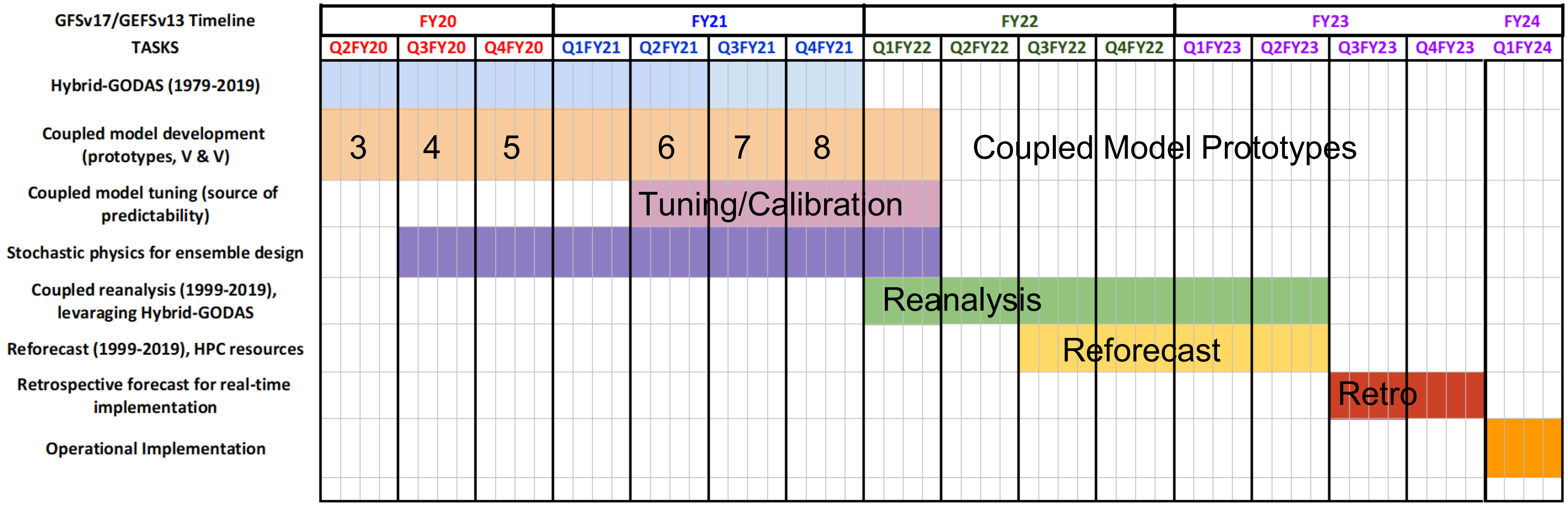
Northern Plains Dewpoint Bias
Fcst Hr 24 (top); Fcst Hr 72 (bottom)

Roadmap: Past, Current, Future



EMC Operational Global Model Timeline

- EMC Global Model (GFSv17) scheduled for implementation Q1FY24
- Land model (Noah-MP) enters coupled development in Prototype 7
- Three quarters for tuning and interaction with other physics
- Code freeze in Q1FY22 for beginning of reanalysis and reforecast



Short-term Noah-MP Implementation Plan

Land Model Prototypes

L-PT1
- Updated Noah-MP code consistent with NOAA NWM (+code precision)
- New vegetation cover dataset from MODIS
- New land cover classification dataset from NESDIS/VIIRS
- Use monthly LAI dataset from MODIS/update table

L-PT2
- Update canopy wind parameters
- Surface exchange coefficient options
- Soil evaporation (opt_rsf in new code)
- Groundwater initialization

L-PT3
- Update table albedo parameters
- Unify/coordinate with PBL/surface layer

	S	O	N	D	J	F	M	Q3	Q4	Q1
Establish Noah-MP Baseline										
	L-PT1: update code and land datasets (land class; veg datasets; equil GW)									
			L-PT2: surface exchange option; evaporation resistance; groundwater init; canopy wind							
					L-PT3: parameter updates; canopy properties (albedo); consistency with PBL					
Coupled Model Dev	Prototype 5				Prototype 6			PT7	PT8	

Current implementation/evaluation status

- Summer testing of CCPP/Noah-MP (June-August 2019)
- Winter testing of CCPP/Noah-MP (January 2020)
- Testing new NESDIS/VIIRS land cover
  - updating ~2000 MODIS land cover with recent years update
  - increased urban area
- Recently completed global Noah-MP spin-up
- Coupled model prototype structure:
  - 2011-2018; 35-day forecast; 1st/15th each month (8*12*2 sims)

Outstanding Issues – Coupling!

- Differences between how Noah and Noah-MP use/calculate albedo and emissivity
  - Removing historical assumptions of land model's role
- Consistency between land model coupling to the PBL scheme
  - Flexibility with PBL scheme (K/TKE-EDMF, MYNN, etc.)
- Heterogeneous surface coupling

Short-term Land DA Plan

Existing system
- Direct insertion of AFWA snow depth merged with IMS snow cover
- GLDAS w/obs precip -> update states (GFSv16 warm/dry bias)

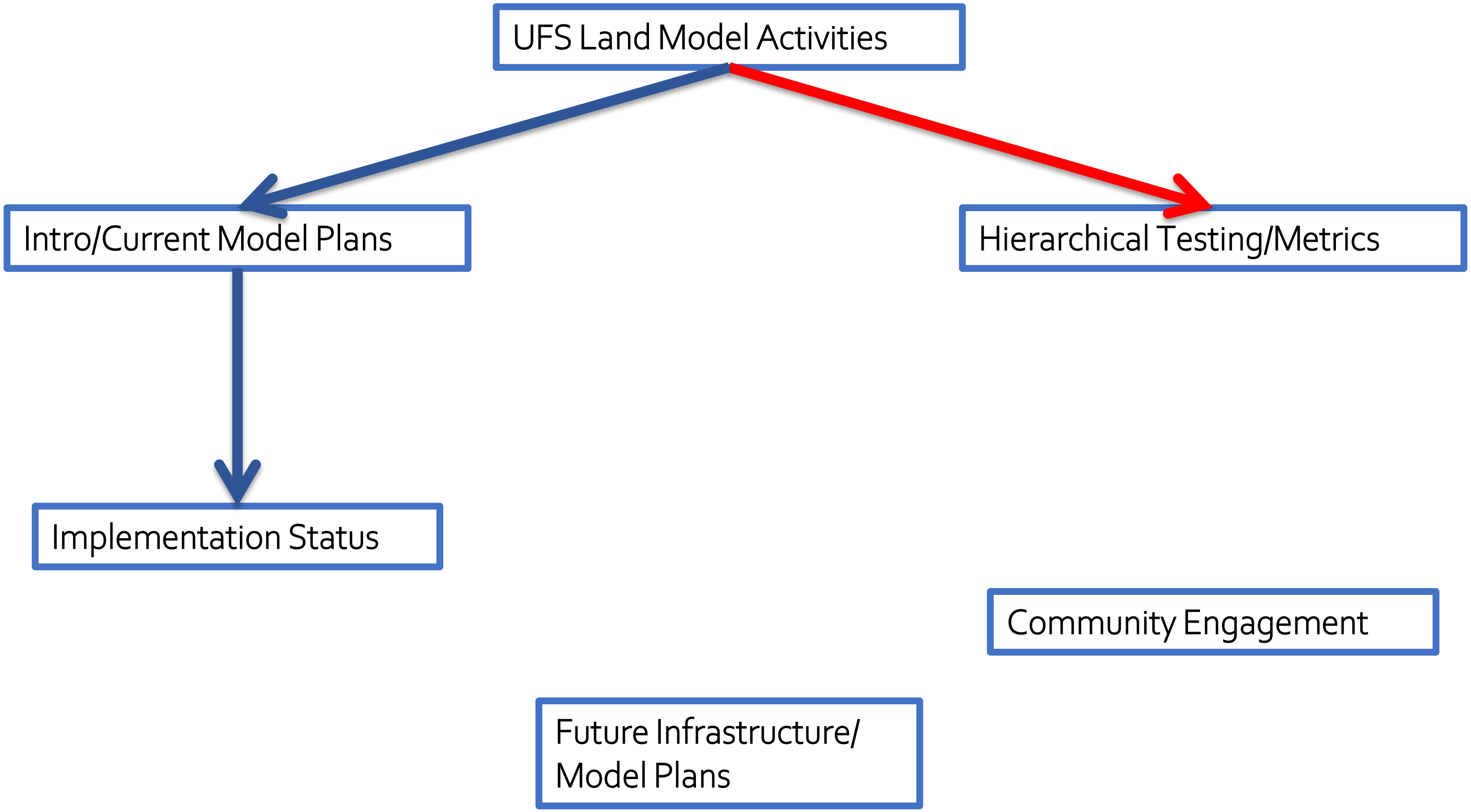
JEDI – atmosphere DA-based
- snow DA
- screen height T/q assimilation
- soil moisture DA

Benefit for strongly-coupled DA

JEDI – land DA-based (weakly-coupled)
- snow and soil moisture DA
- screen height T/q assimilation
- using land driver for CCPP models

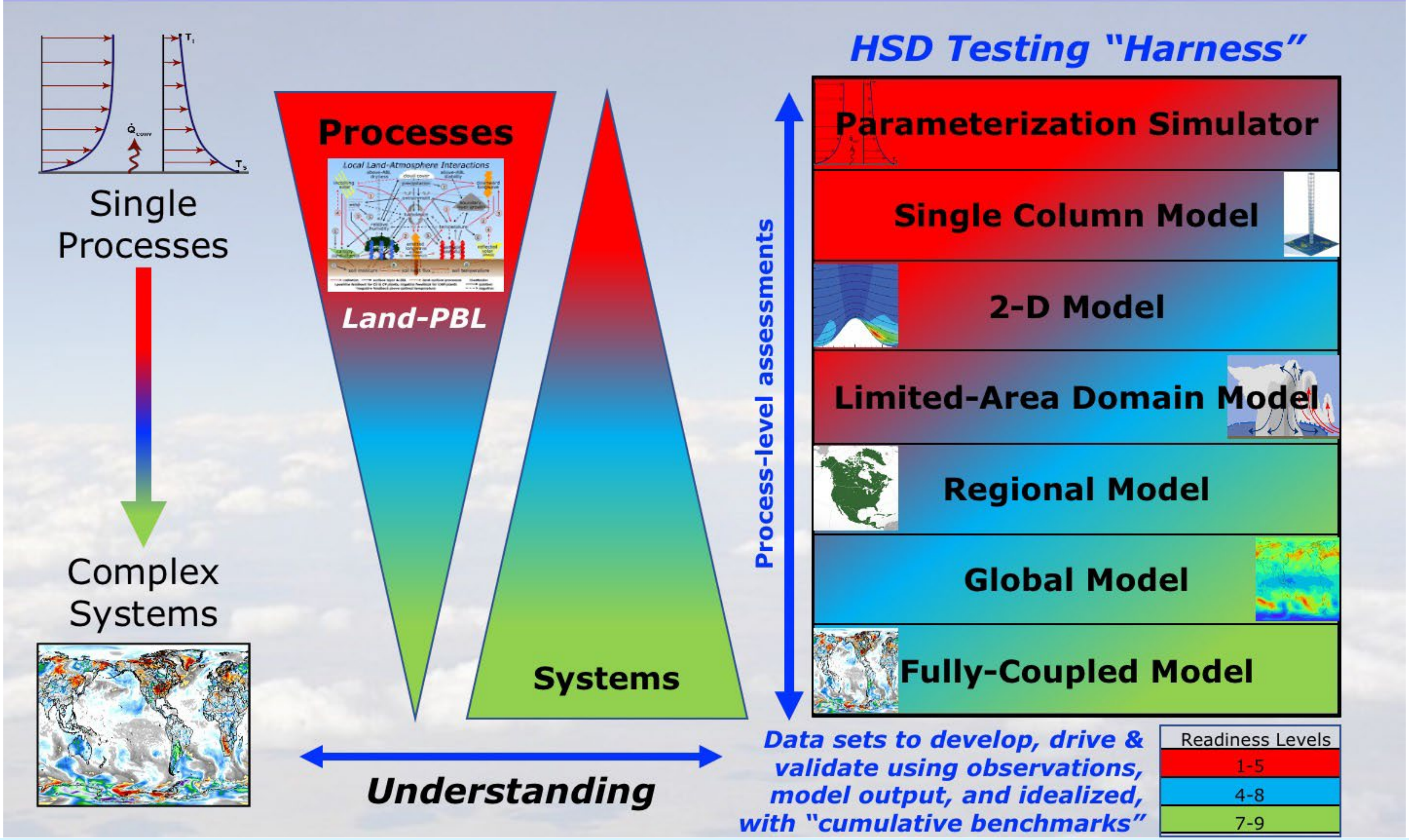
Optimally a combination of these

Roadmap: Past, Current, Future



Hierarchical Testing/Evaluation Framework

Hierarchical System Development (HSD): ***A simple-to-more-complex comprehensive approach to identify systematic biases and improve models***



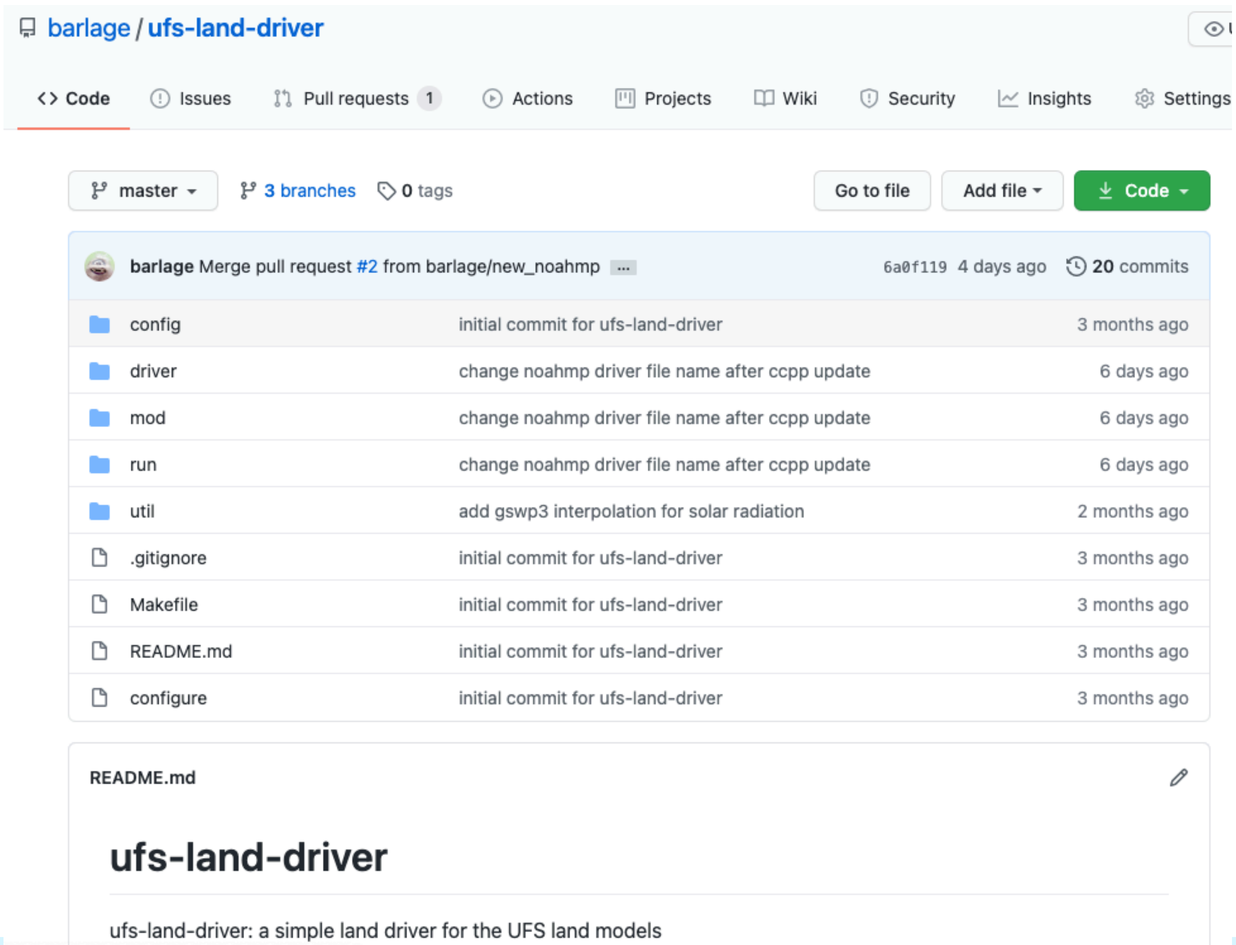
Source: Ek

Hierarchical Testing/Evaluation Framework

- Land model process testing and evaluation
  - Essentially non-existent in Noah and Noah-MP (and most other land models)
  - Noah-MP refactor work at NCAR potentially allowing for this
- Land model testing and evaluation
  - Essentially land model drivers: GLDAS, NLDAS, HRLDAS, LIS
  - These have more usefulness if connected directly to code used in ops repositories

Hierarchical Testing/Evaluation Framework

- UFS land driver that plugs directly into CCPP Physics repository
- Designed for ease-of-use – Graduate/Undergraduate student laptop capability
- Lapenta NOAA Student Internship project to assist development



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  - Essentially land model drivers: GLDAS, NLDAS, HRLDAS, LIS
  - These have more usefulness if connected directly to code used in ops repositories
- Single column model (SCM)
  - Very useful for efficient testing of land-atmosphere coupling
  - Rapid L-A sensitivity tests of land model parameters and physics
- SRW App test cases
  - Add to existing collection of test cases to share with community
- Global land-atmosphere – MRW App cases
  - This is where most of the EMC land testing occurs now
- Global coupled cases

Land and Land-Atmosphere Focused Metrics

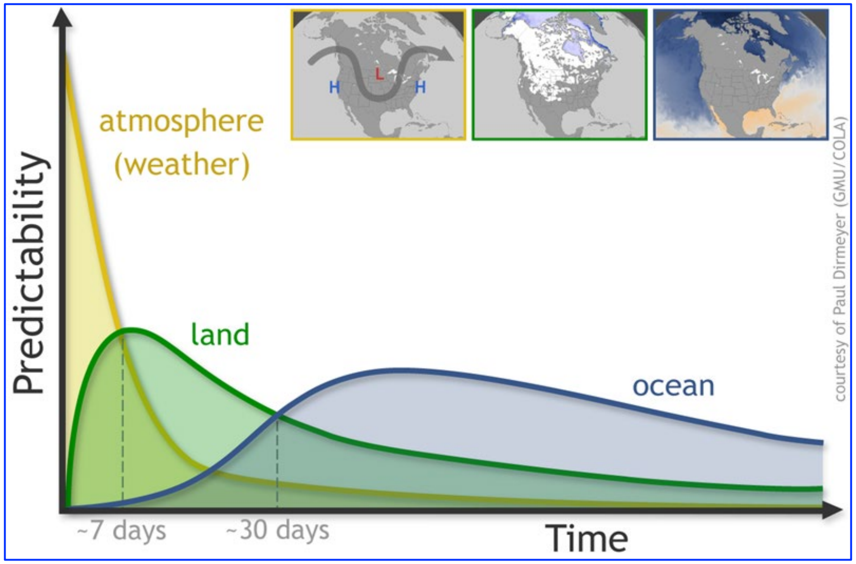
Metrics connecting earth system processes to useful predictions

Land processes and Land-Atmosphere Interaction

Paul Dirmeyer (George Mason Univ.) & Mike Ek (NCAR)

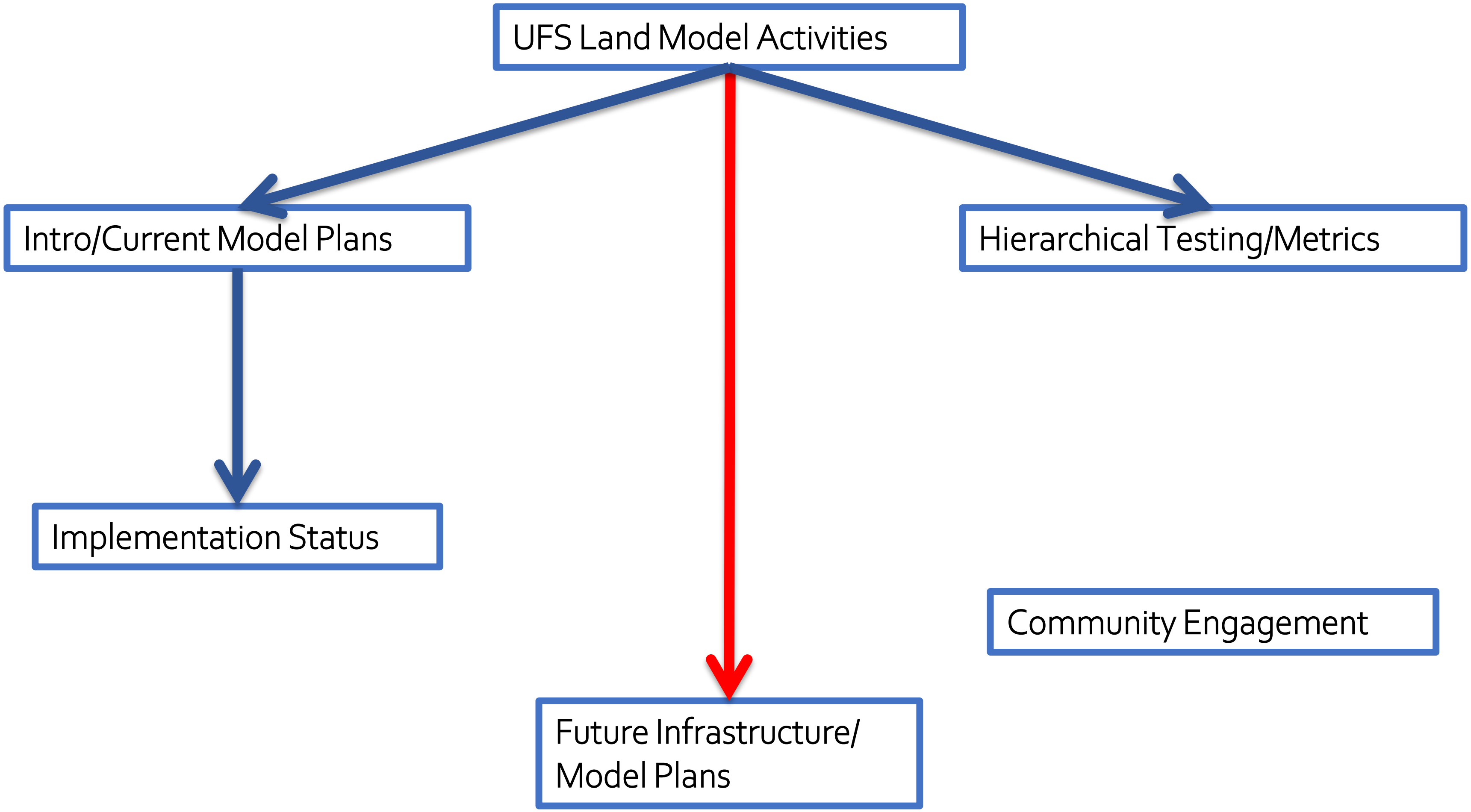
- Land states, i.e. Soil Moisture, Snow and Soil Temperature, can provide predictability from deterministic Weather (from day "zero" using Numerical Weather Prediction models) to Climate (Ocean-Atmosphere), peaking at subseasonal-to-seasonal ("S2S") time scales.

- Vegetation states, related to soil moisture anomalies, also give predictability at and beyond S2S time scales.
- Land-Atmosphere Coupling is active where there is *sensitivity*, *variability* and *memory*.
- *Good models* & *analyses* (of atmosphere and land states) are needed to exploit this source of skill.

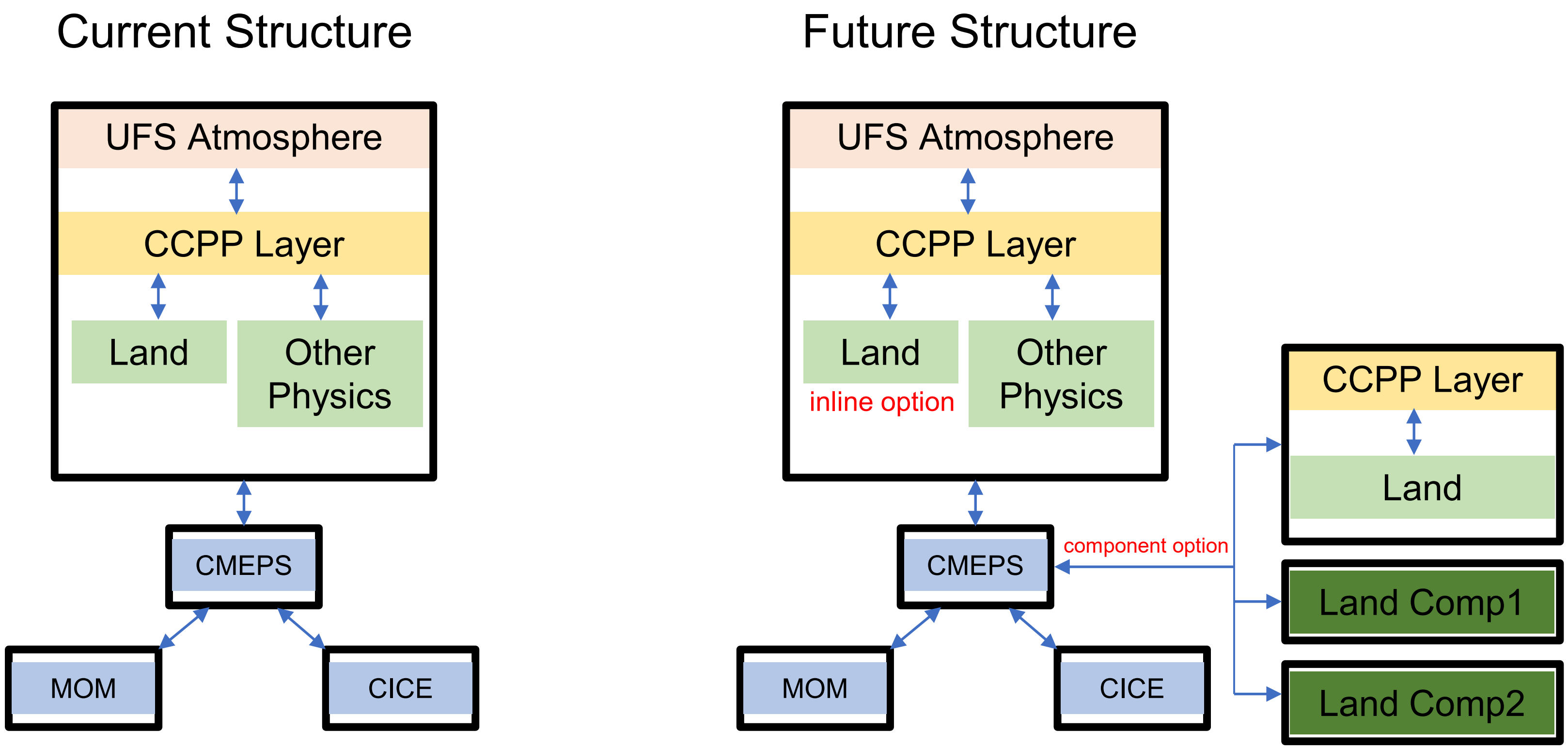


Courtesy of Ek and Dirmeyer

Roadmap: Past, Current, Future



UFS Land – Current/Future Infrastructure



Land = CCPP land models

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

* inspired by Rocky Dunlap

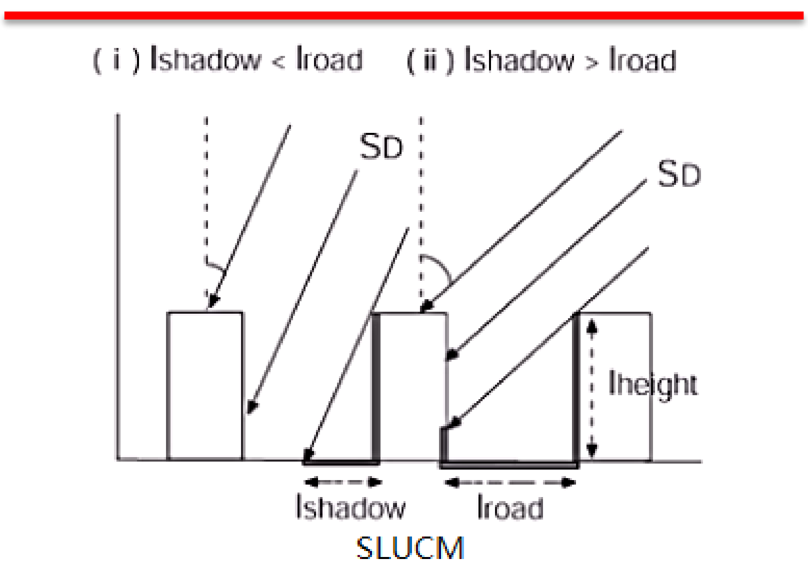
Outstanding Land Infrastructure Issues

- A challenge with multiple physics options: need well defined requirements between physics schemes
- Consistency between land model coupling (or fractional grid components) to the PBL scheme
  - Flexibility with PBL scheme (K/TKE-EDMF, MYNN, etc.)
- Current land models within CCPP are not modeling “systems”; they have no self-contained history and restart capabilities

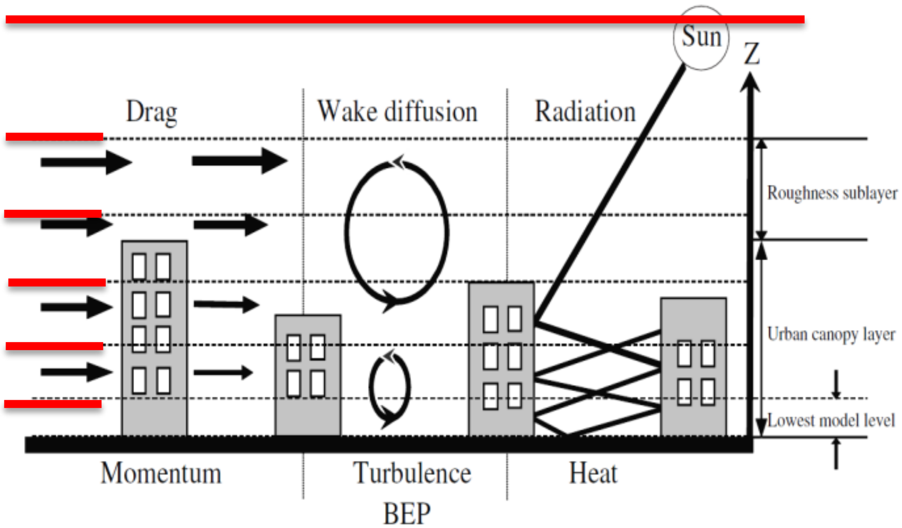
UFS Land – Gaps: Urban Modules

- All current UFS land models have very crude representation of urban areas
- As horizontal and vertical resolutions increase, more sophisticated representation of urban processes become necessary

Model Forcing Level



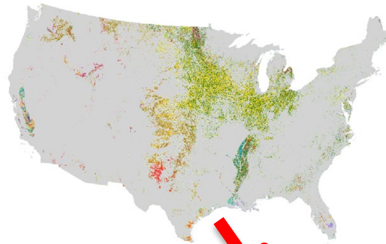
Model Forcing Levels

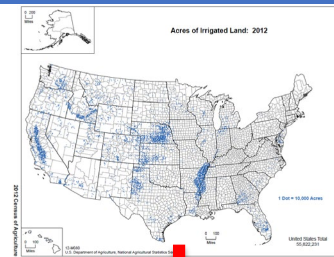


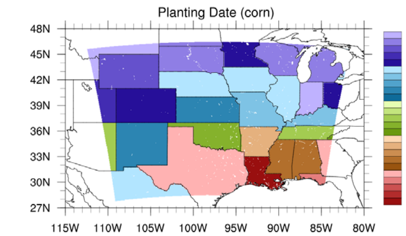
Chen et al. 2011

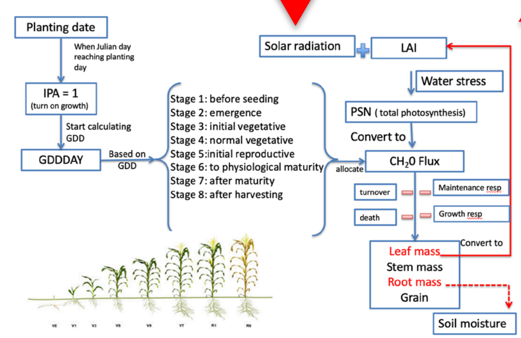
UFS Land – Gaps: Agriculture Modules

- High resolution information of crop types, irrigation and management
- Potential for providing county-level information to agriculture industry

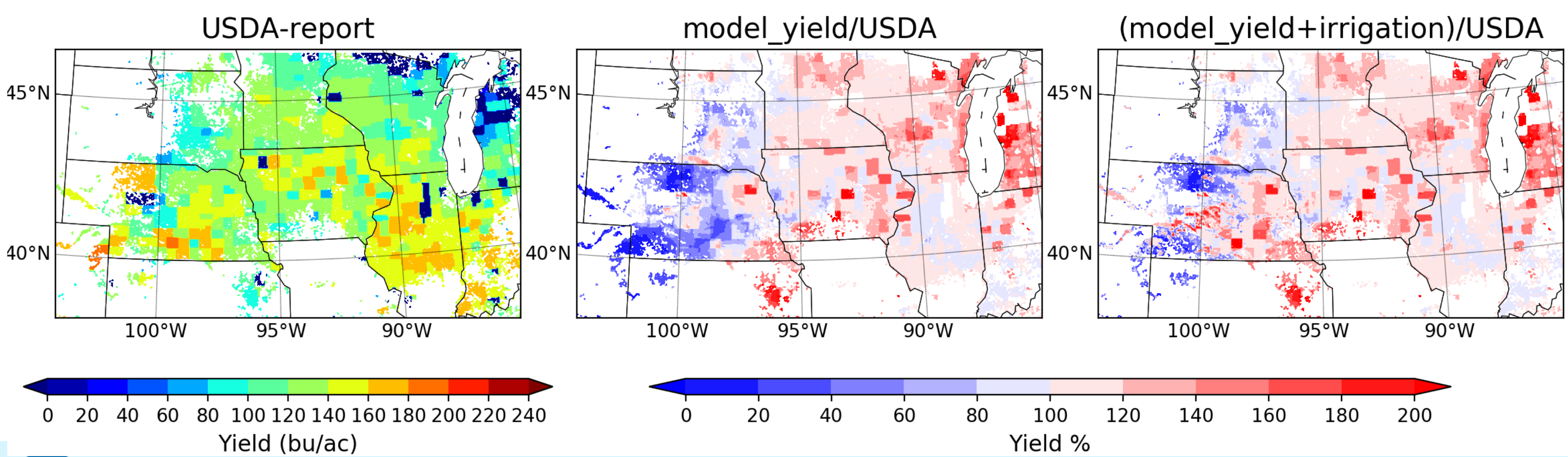






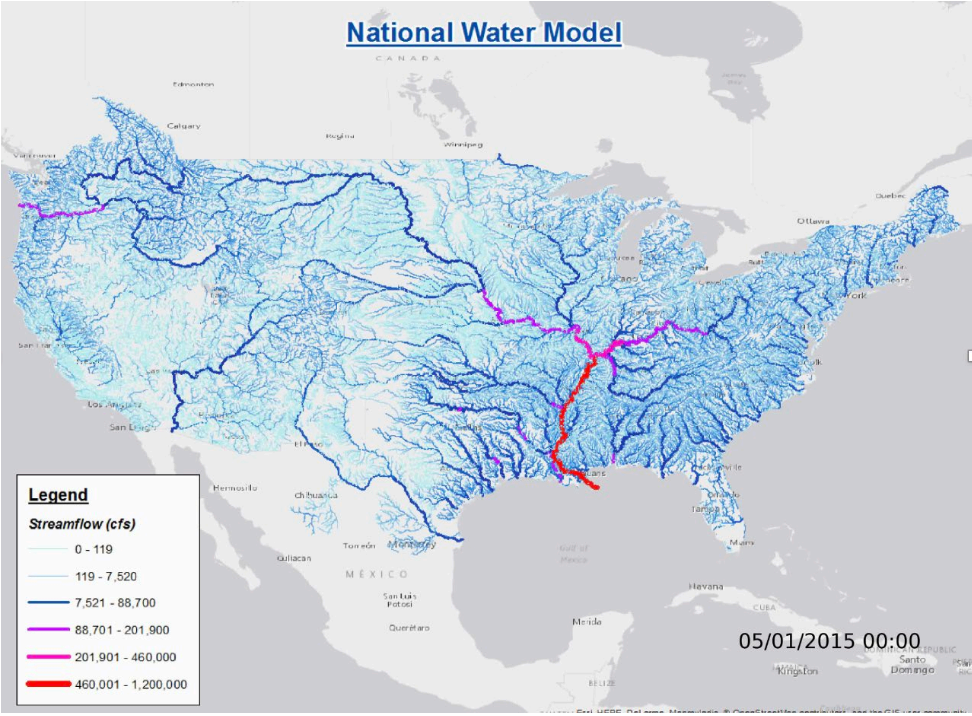


Zhang et al. 2020

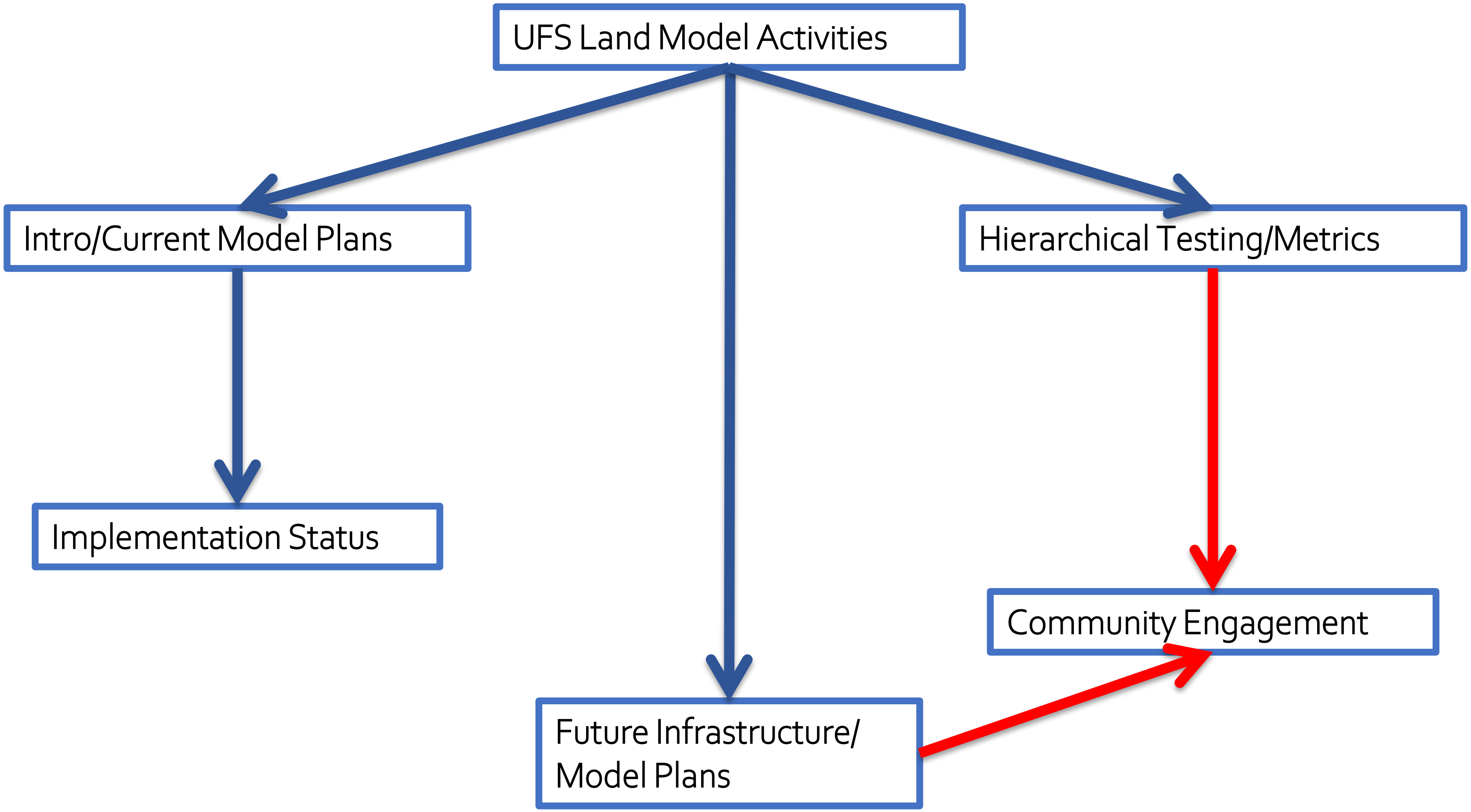


UFS Land – Gaps: Hydrology and Lakes

- No lake model running in regional or global models
- Options being developed
  - FLake – in CCPP
  - CLM lake model – being added
  - FVCOM for Great Lakes
- No reservoirs or management
- No routing module means link between column land surface model and ocean model does not exist
  - Current JTTI project to connect UFS SRW configuration (RRFS) to National Water Model
- Crude treatment of groundwater



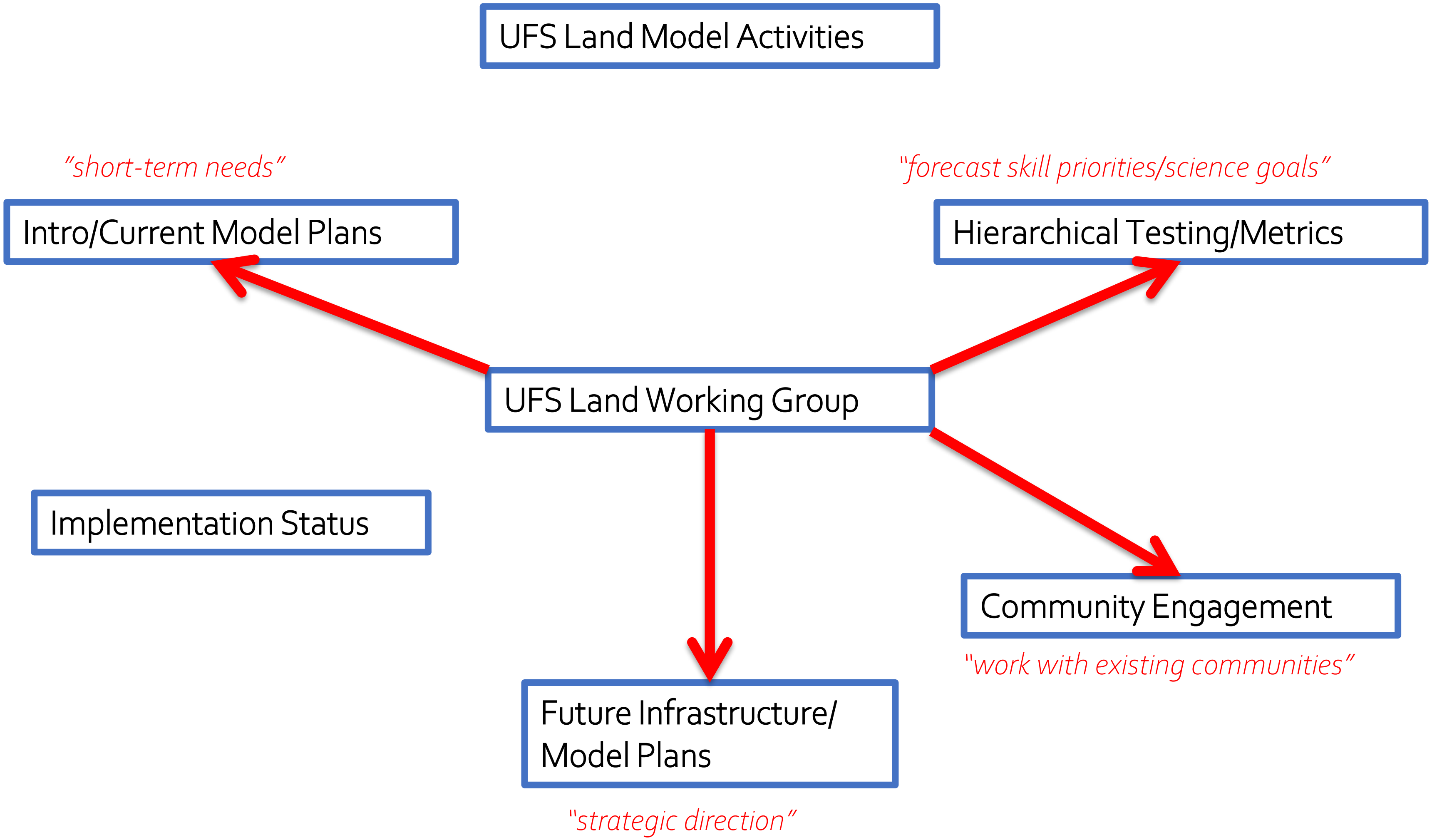
Roadmap: Past, Current, Future



Community Engagement and Collaboration

- Metrics Workshop was an important step toward elevating land-specific metrics, moving beyond those driven by operational priorities
  - soil moisture/temperature, turbulent fluxes, coupling metrics, snow/streamflow
- Need clear, defined hierarchical path from research to operations
  - Involve both operational-priority "super" metrics ***and*** land process metrics
- Flexibility on where the land model resides in the system
  - inline with the atmosphere
    - advantageous for faster physics/coupling
  - as a separate component
    - advantageous for land model testing within a well-designed framework (i.e., with a data atmosphere)
    - advantageous for evaluating fluxes across interface
- Increasing collaboration with the community
  - I feel this grows organically with a well-designed Hierarchical Testing and Evaluation Framework
  - We have to give the community a core set of tools and cases to facilitate onboarding

Roadmap: Past, Current, Future



The End – Any Questions?