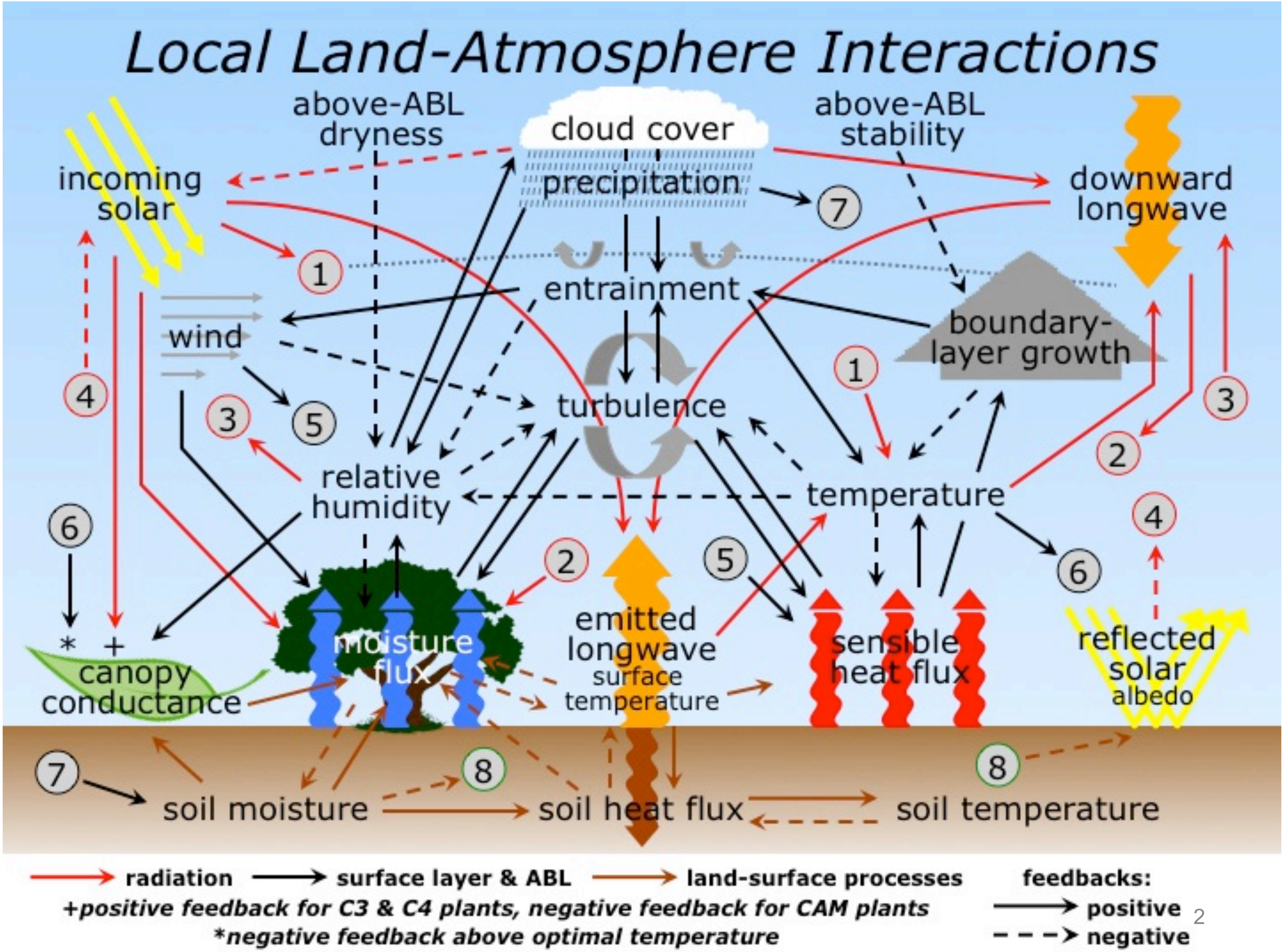
# *Earth System Surface Fluxes*

**Michael Ek**
**Environmental Modeling Center (EMC)**
**NOAA/NWS/NCEP**

**Fei Chen**
**NCAR/RAL**

**…and our partners/collaborators at NCEP, NCAR and elsewhere**

***NGGPS Atmospheric Physics Workshop***
***NCWCP, College Park, Maryland***
***8-9 November 2016***


Local Land-Atmosphere Interactions
above-ABL dryness
cloud cover
precipitation
above-ABL stability
incoming solar
downward longwave
entrainment
wind
boundary-layer growth
turbulence
relative humidity
temperature
canopy conductance
moisture flux
emitted longwave
surface temperature
sensible heat flux
reflected solar
albedo
soil moisture
soil heat flux
soil temperature
radiation
surface layer & ABL
land-surface processes
feedbacks:
positive
negative
+positive feedback for C3 & C4 plants, negative feedback for CAM plants
*negative feedback above optimal temperature

# *Land-related problems in the GFS*

## "Get the right answer with the right reason"

- **Better surface albedo results in warm biases:** *too much downward shortwave radiation bias offset by higher albedo bias.*
- **Better surface temperature and humidity degrades the precipitation forecast:** *convection scheme is tuned to the biased surface fields.*
- **Better snow forecast does not improve the surface temperature:** *GFS "gets used" to the early snowmelt bias.*

**Near surface fields over CONUS, Alaska**

- Summertime cold, wet bias in eastern US at 000 UTC (SPC reluctant to use GFS for severe weather and fire weather; problem reduced in T1534)
- Boundary layer problems (and land surface)
- Other 2 m temperature biases—too warm at 12Z southern plains
- Too weak surface inversions
- Afternoon boundary layer collapse; 10-m winds (too strong); representative diurnal cycle.

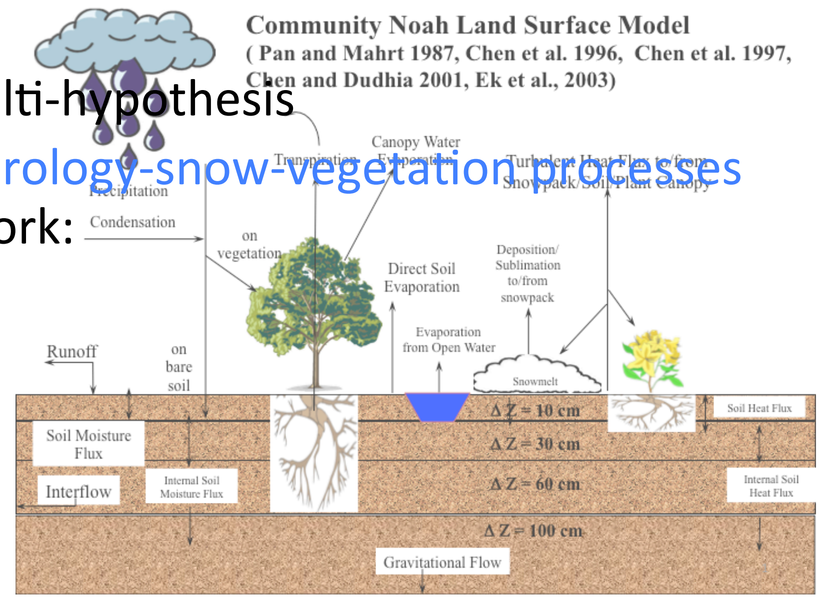
## *Land model evaluation and benchmarking*

- Current evaluations of NWP models are often based on a few variables, ad-hoc methods

- How does evaluation provide meaningful guidance to improving land modeling component?

# *New Generation Noah-MP (multi-parameterization)*

- Multi-parameterization=Multi-physics ≡ Multi-hypothesis
- Multiple parameterizations to treat key hydrology-snow-vegetation processes paradigm in a single land modeling framework:
  - Canopy turbulence (2 schemes)
  - Canopy radiation (3 schemes)
  - Canopy resistance (2 schemes)
  - Frozen ground physics (2 schemes)
  - Snow physics (2 schemes)
  - runoff/water table (4 schemes)




Limited Noah ability for seasonal prediction


JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, D12109, doi:10.1029/2010JD015139, 2011


**The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements**


Guo-Yue Niu, Zong-Liang Yang,[1] Kenneth E. Mitchell,[3] Fei Chen,[4] Michael B. Ek,[3] Michael Barlage,[4] Anil Kumar,[5] Kevin Manning,[4] Dev Niyogi,[6] Enrique Rosero,[1,7] Mukul Tewari,[4] and Youlong Xia[3]


Noah-MP a powerful tool for assessing land physics uncertainties and for physics ensemble prediction!


Received 4 October 2010; revised 3 February 2011; accepted 27 March 2011; published 24 June 2011.

# *Using Noah-MP physics ensemble simulations to assess uncertainty in model parameterizations*

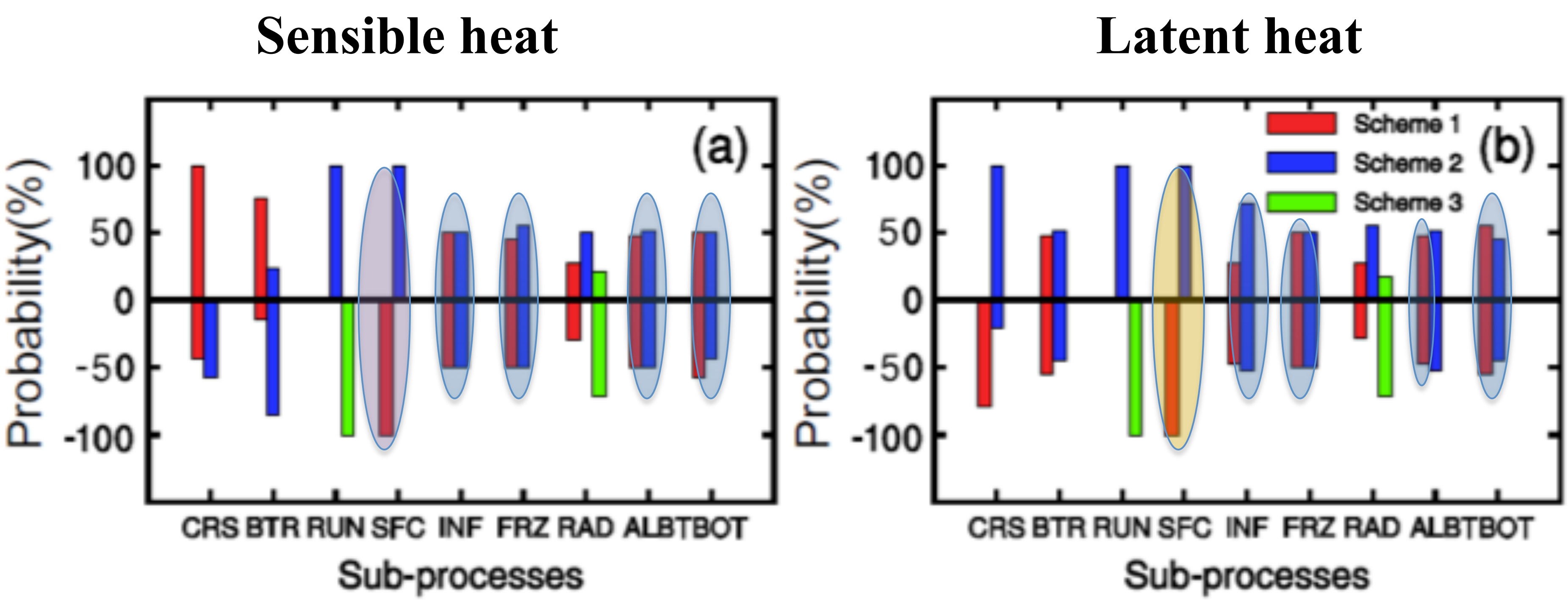
| Physical Processes | Options | References |
|---|---|---|
| Canopy resistance (CRS) | (1) Ball-Berry scheme<br>(2) Jarvis | Ball et al. 1987<br>Jarvis, 1976 |
| Soil moisture threshold for plant transpiration (BTR) | (1) Noah<br>(2) CLM | Chen et al. 1996<br>Oleson et al. 2004 |
| Runoff and groundwater (RUN) | (1) SIMGM<br>(2) SIMTOP<br>(3) Free-drainage scheme | Niu et al. 2007<br>Niu et al. 2005<br>Schaake et al. 1996 |
| Surface layer exchange coefficient (SFC) | (1) Monin-Obukhov scheme<br>(2) Noah | Brutsaert 1982<br>Chen et al. 1997 |
| Frozen soil permeability (INF) | (1) Function of soil moisture<br>(2) Function of soil liquid water | Niu and Yang 2006<br>Koren et al. 1999 |
| Supercooled liquid water in frozen soil (FRZ) | (1) Generalized freezing-point depression<br>(2) Variant freezing-point depression | Niu and Yang 2006<br>Koren et al. 1999 |
| Radiation transfer (RAD) | (1) Canopy gaps from 3-D structure and solar zenith angle<br>(2) No canopy gap<br>(3) Canopy gap from vegetation fraction | Niu and Yang 2004 |
| Snow surface albedo (ALB) | (1) BATS<br>(2) CLASS | Dickinson et al. 1986<br>Verseghy 1991 |
| Lower boundary of soil temperature (TBOT) | (1) Zero-flux scheme<br>(2) Noah | Chen et al. 1996 |

Noah-MP land model

MP = Multi-physics
= Multi-hypothesis

**2×2×3×2×2×2×3×2×2=1152 ensemble !!!**

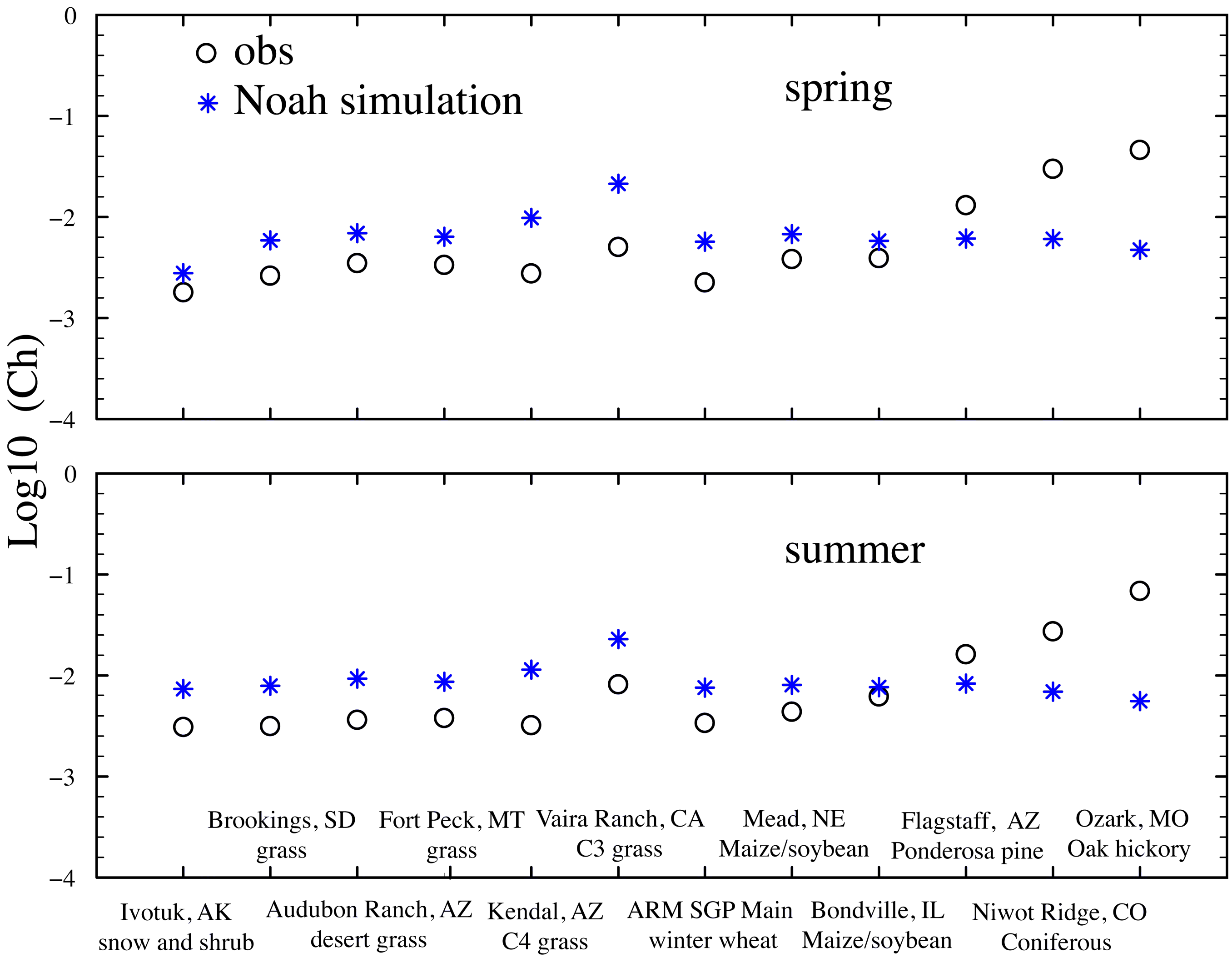
# *Natural selection method for identifying sensitive processes and better schemes*

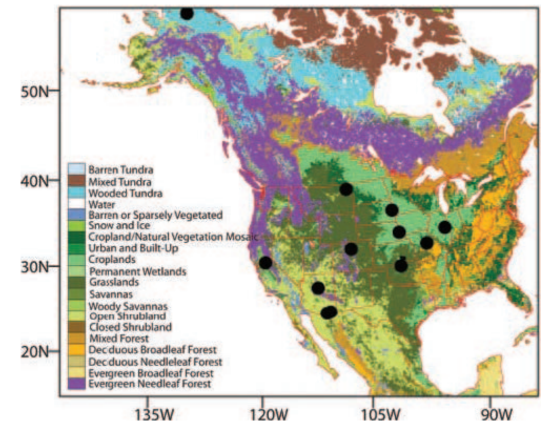



- INF (frozen soil permeability), FRZ (supercooled liquid water in frozen soil, RAD (radiation transfer), ALB (snow surface albedo), TBOT (lower boundary of soil temperature): schemes are not significantly different, and simulations are not sensitive to those physical processes;
- Surface layer turbulence (SFC): scheme-2 is better than scheme-1

Gao et al., 2016, *JGR*

# *Beyond traditional metrics: surface-layer physics*



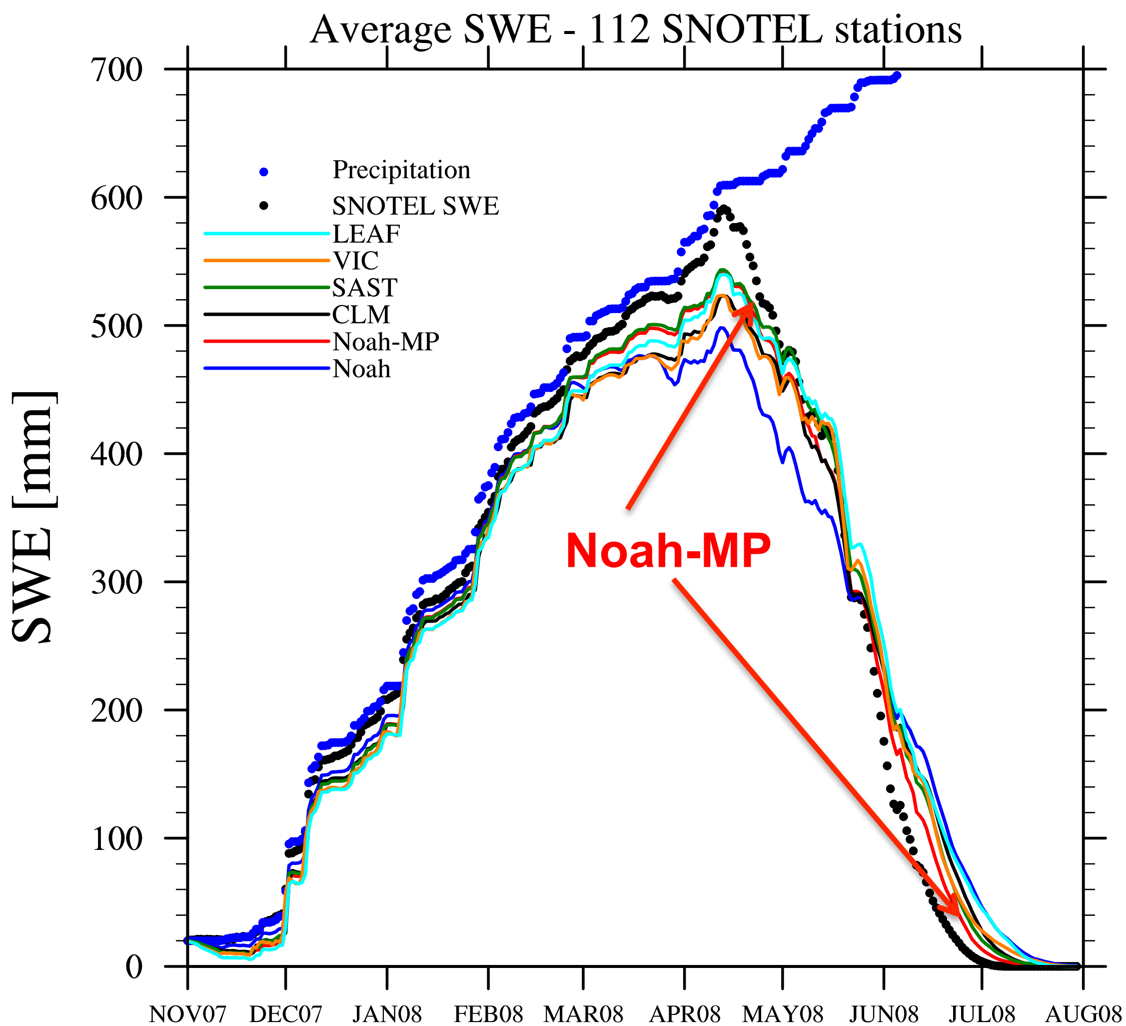




- modeled $C_h$ has less variability cross different land cover types
- Noah overestimate (underestimate) $C_h$ for short vegetation (tall vegetation)

*Chen and Zhang, 2009, GRL*

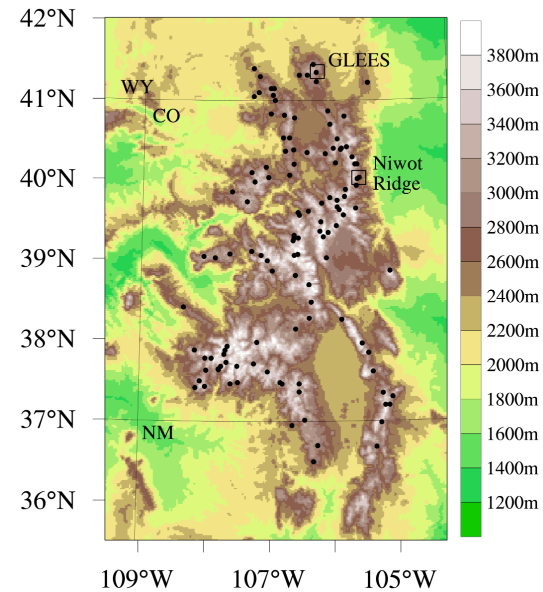
# *Snow Water Equivalent (SWE) simulated by six LSMs*

## Averaged over 112 SNOTEL sites



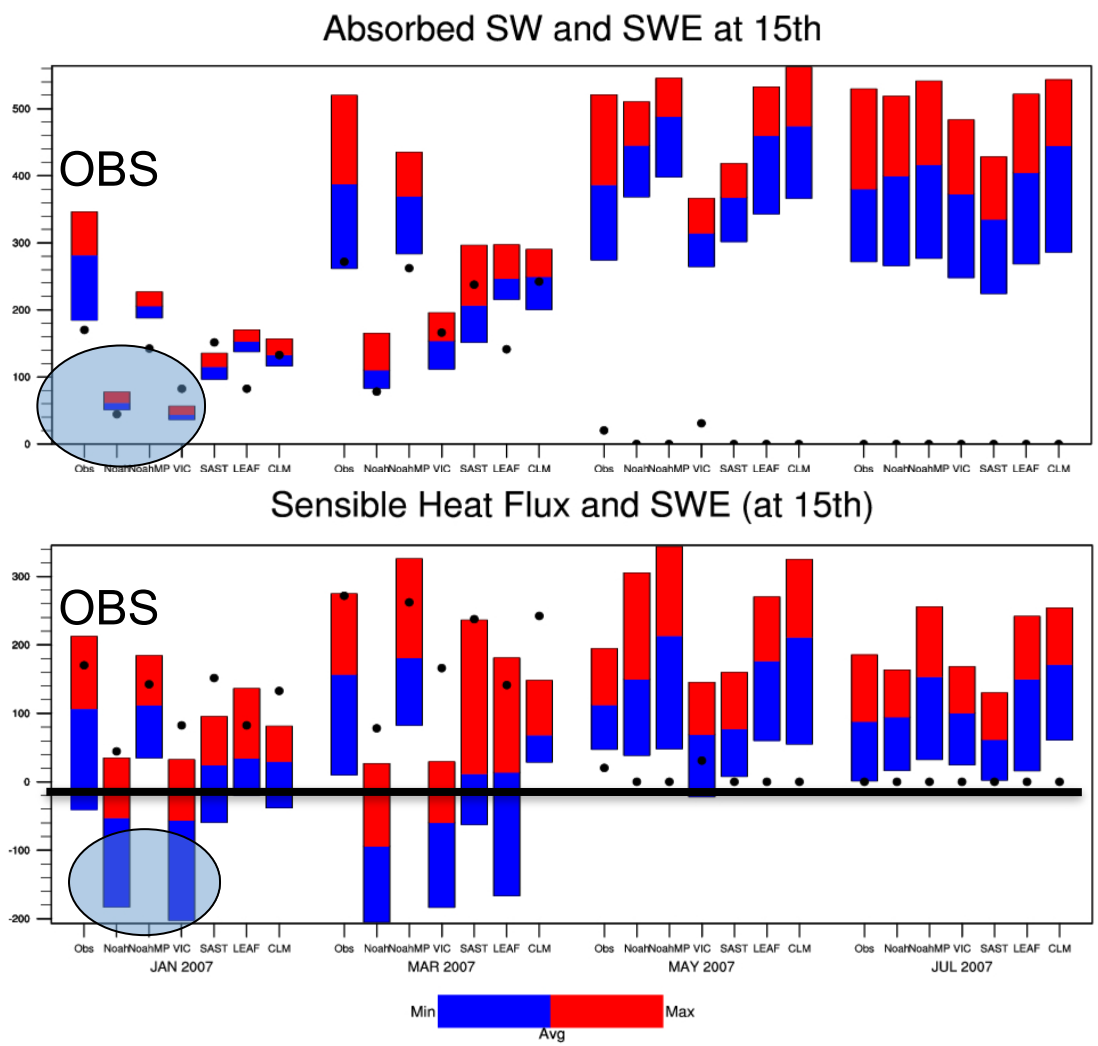

*Chen et al. 2014, JGR*

SNOTEL sites in
The Colorado Headwaters




SNOTEL site： Bison Lake, CO

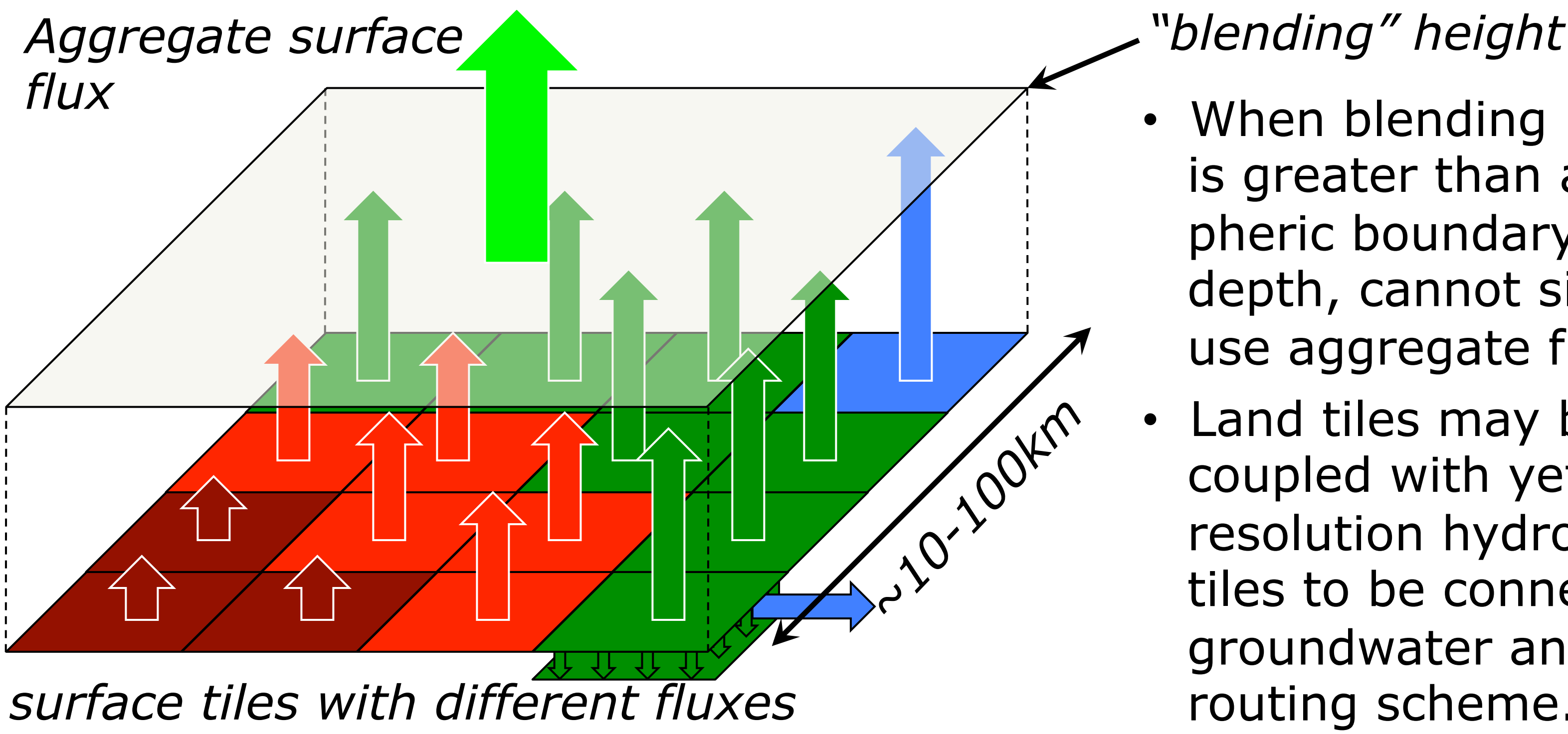
# *LSMs could produce right SWE by wrong reasons*




**Chen et al., 2014, *JGR***

# *Land Heterogeneity: Tiled Land Grids*

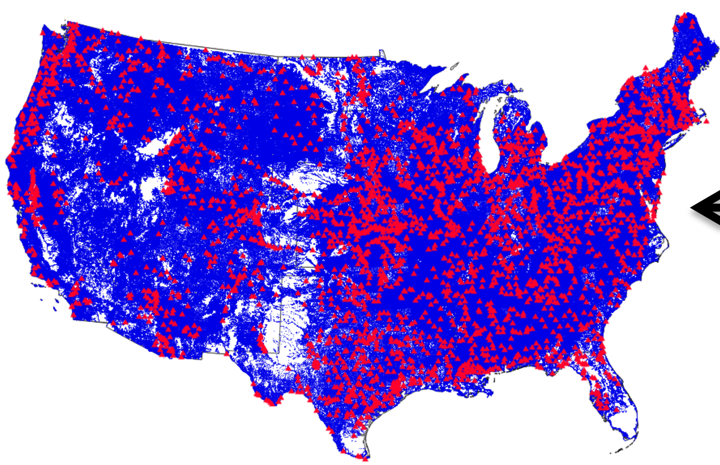
- Because of land surface heterogeneity, a model grid may comprise sub-atmospheric-grid-scale land "tiles", e.g. forest, grass, crop, water, etc, O(1-4km).
- Coarser-resolution atmospheric forcing to land.
- Aggregate flux input to "parent" atmospheric model.




- When blending height is greater than atmospheric boundary-layer depth, cannot simply use aggregate flux.
- Land tiles may be coupled with yet-higher resolution hydrology-tiles to be connected to groundwater and river-routing scheme.

# *Hydrology: National Water Model (NWM)*

- Version 1.0 of the National Water Model implemented into operations in August
  - A collaborative research-to-operations effort between OWP, NCAR and NCEP
  - Provides neighborhood-level forecast guidance for rivers/streams at 2.7 million locations, complementing the ~4000 NWS core river forecast locations now available
  - Output also includes key water budget components such as soil states, snow pack, and energy fluxes on 1km CONUS+ grid
  - Will help forecasters better predict droughts/floods, supports FEMA's flood response mission
  - Will support efforts to integrate additional hydrologic components into NCEP modeling efforts
- Uncoupled NWM system uses WRF-Hydro with NoahMP LSM as core, and atmospheric model data and observations as forcing
  - NWM analyses driven by hourly MRMS precipitation, assimilate streamflow from USGS gauges
  - Deterministic NWM forecasts driven by HRRR/GFS to 15 hours/10 days, ensemble CFS 30 days
- Dissemination via public OWP website, feed to RFC CHPS systems, and NOMADS

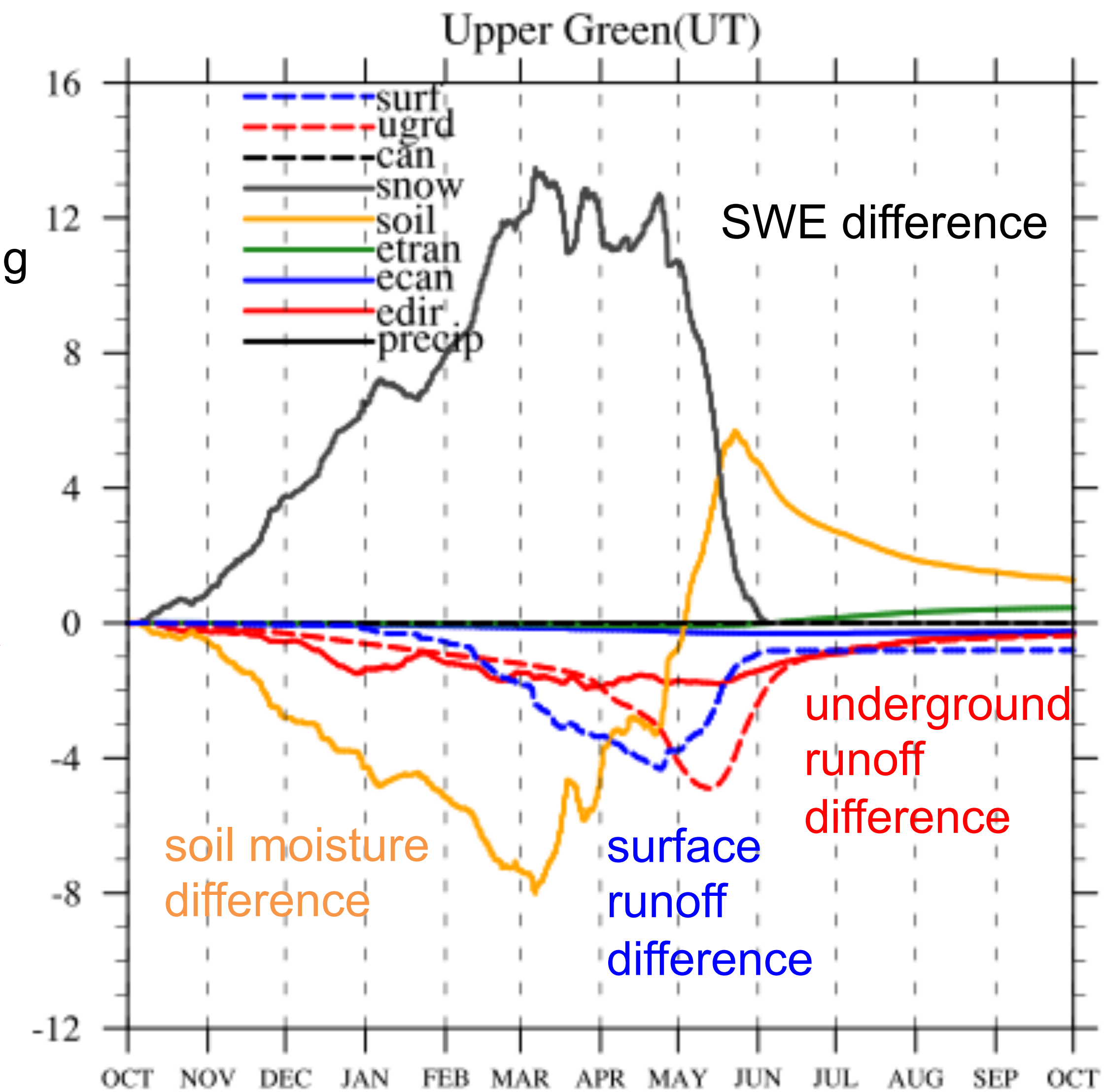


Current NWS river forecast points (red)
NWM forecast points (blue)

OWP OFFICE OF WATER PREDICTION

# *Evaluation of water partitioning at NWC*

- Evaluating the new National Water Model (NWM V1.0, using Noah-MP)
- Modifying soil roughness length (1cm to 2mm) can significantly alter timing of annual water budget over a large watershed
- Total runoff not affected much



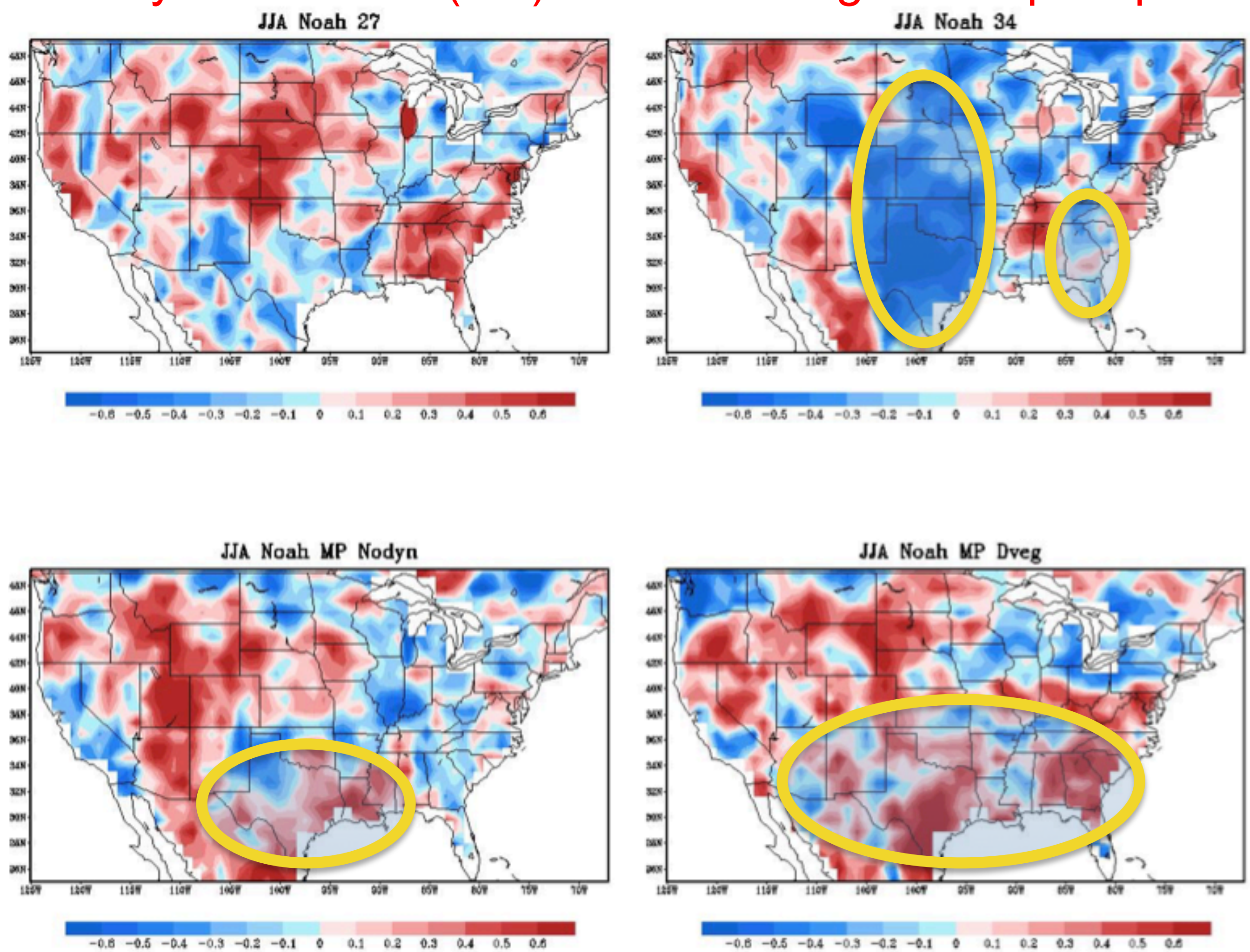
## *Finally, everything integrated in fully-coupled model runs:*
## ***Noah-MP with dynamic vegetation (bottom right) improves CFS summer precipitation correlations***

T126 CFS reforecasts using different land models: eleven years (1982, 1987, 1996, 1988, 2000, 2007, 1986, 1991,1999, 2011, 2012) with four ensemble members

Anomaly Correlation (AC) skill of averaged JJA precipitation

Noah 2.7

Noah 3.4




Noah-MP

Noah-MP dyn veg.

# *Land model evaluation and benchmarking*

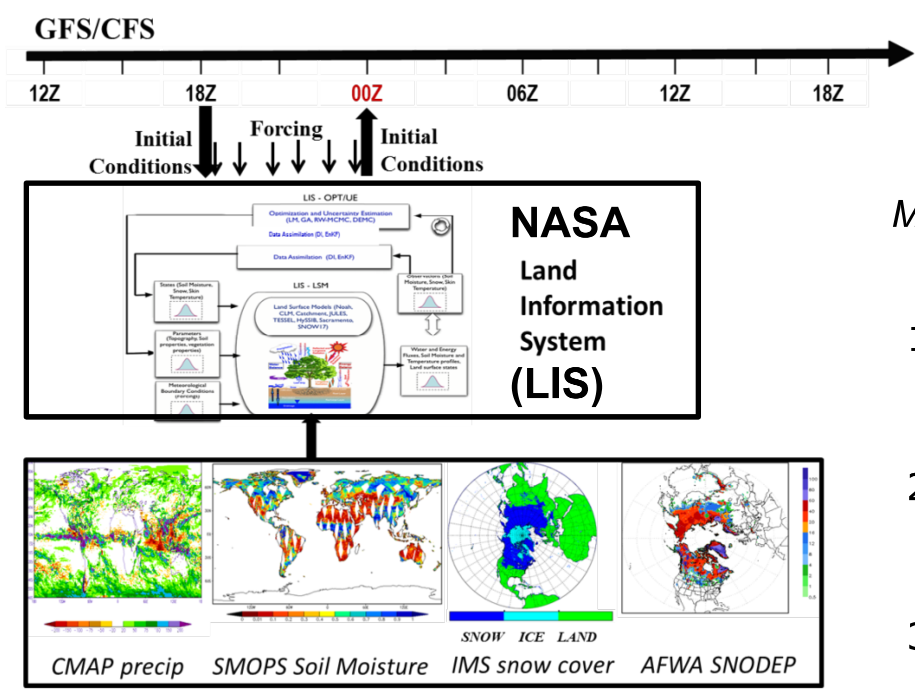
- Systematic evaluation of LSM uncertainty.
- Energy and water partition across various time and space scales; diurnal cycle.
- Coupling strategies (numerical efficiencies, consistency, data and parameter input).
- Integrated metrics evaluation. Unify current operational evaluation metrics.
- Provide meaningful guidance to improving land modeling component.

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NOAA

# *Satellite-based Land Data Assimilation in NWS GFS/CFS Operational Systems*

- Use NASA Land Information System (LIS) to serve as a global Land Data Assimilation System (LDAS) for both GFS and CFS.
- LIS EnKF-based Land Data Assimilation tool used to assimilate soil moisture from the NESDIS global Soil Moisture Operational Product System (**SMOPS**), snow cover area (**SCA**) from operational NESDIS Interactive Multisensor Snow and Ice Mapping System (**IMS**) and AFWA snow depth (**SNODEP**) products.

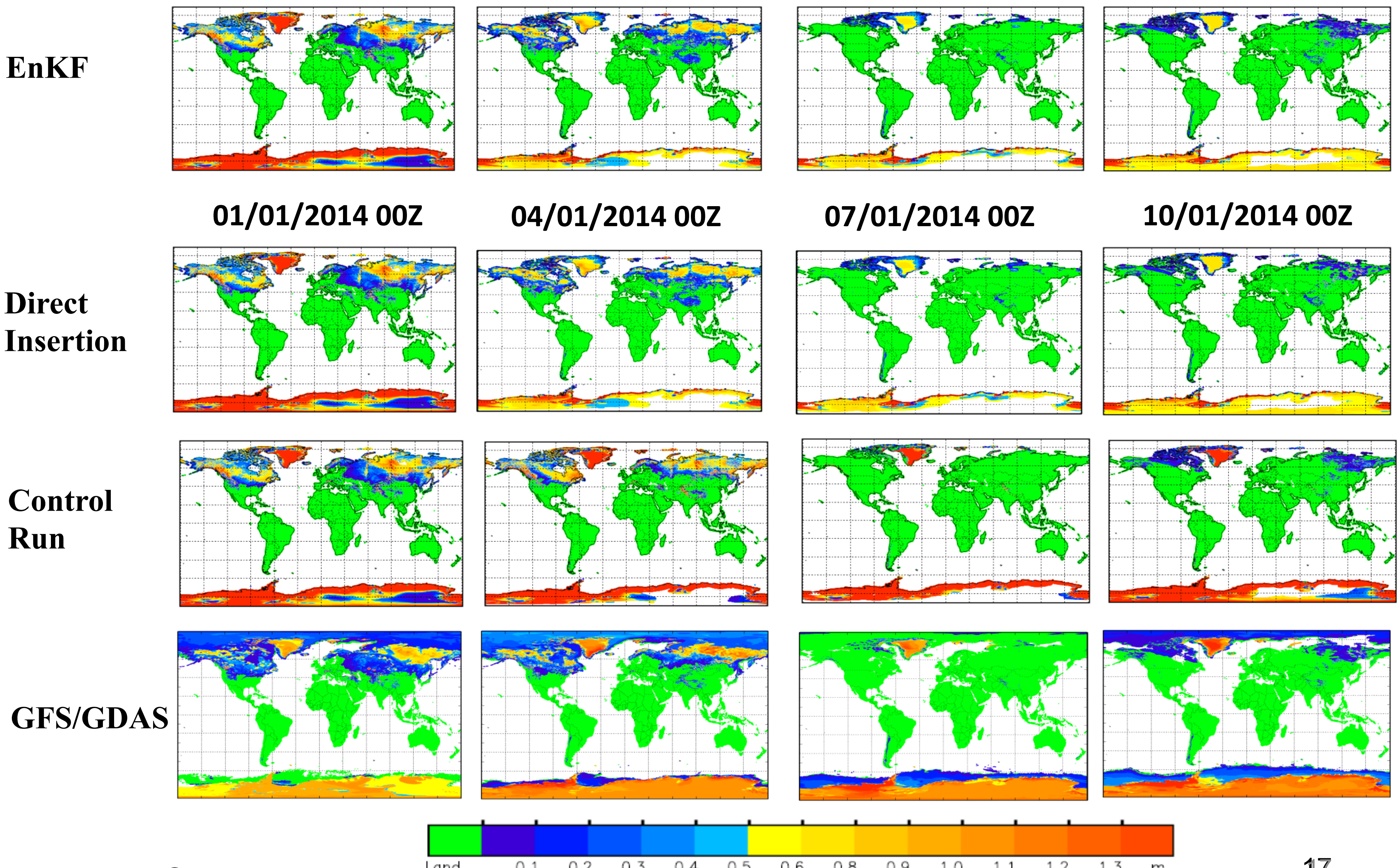



## NGGPS Project: Land Data Assimilation


*Michael Ek, Jiarui Dong, Weizhong Zheng (NCEP/EMC)*
*Christa Peters-Lidard, Grey Nearing (NASA/GSFC)*

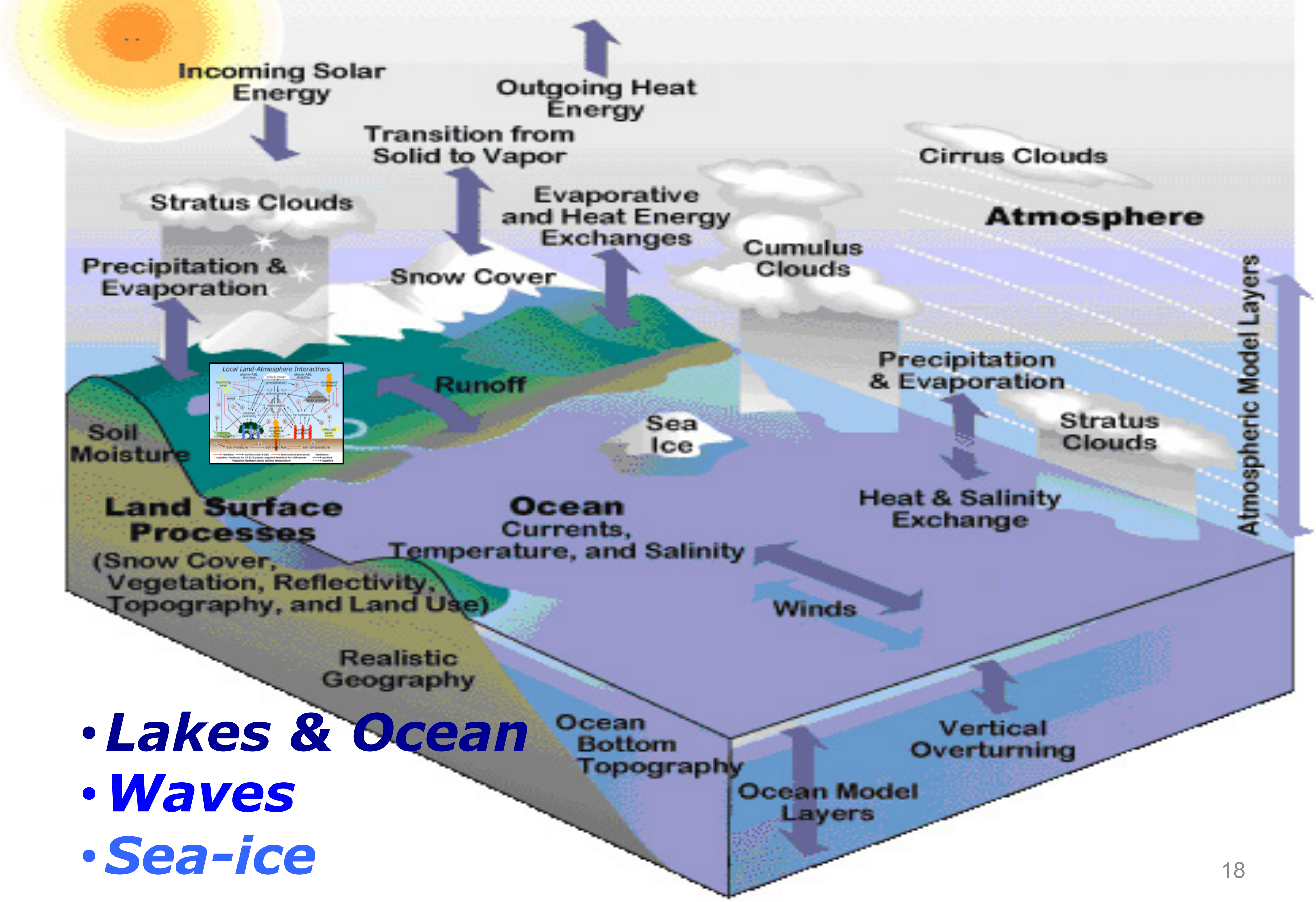

1. Build NCEP's GFS/CFS-LDAS by incorporating the NASA Land Information System (LIS) into NCEP's GFS/CFS (left figure)
2. Offline tests of the existing EnKF-based land data assimilation capabilities in LIS driven by the operational GFS/CFS.
3. Coupled land data assimilation tests and evaluation against the operational system.

# *Demonstration of NASA Land Information System (LIS) land data assimilation of AFWA Snow Depth*




*Jiarui.Dong@noaa.gov*

# *“Other” Surface Fluxes*

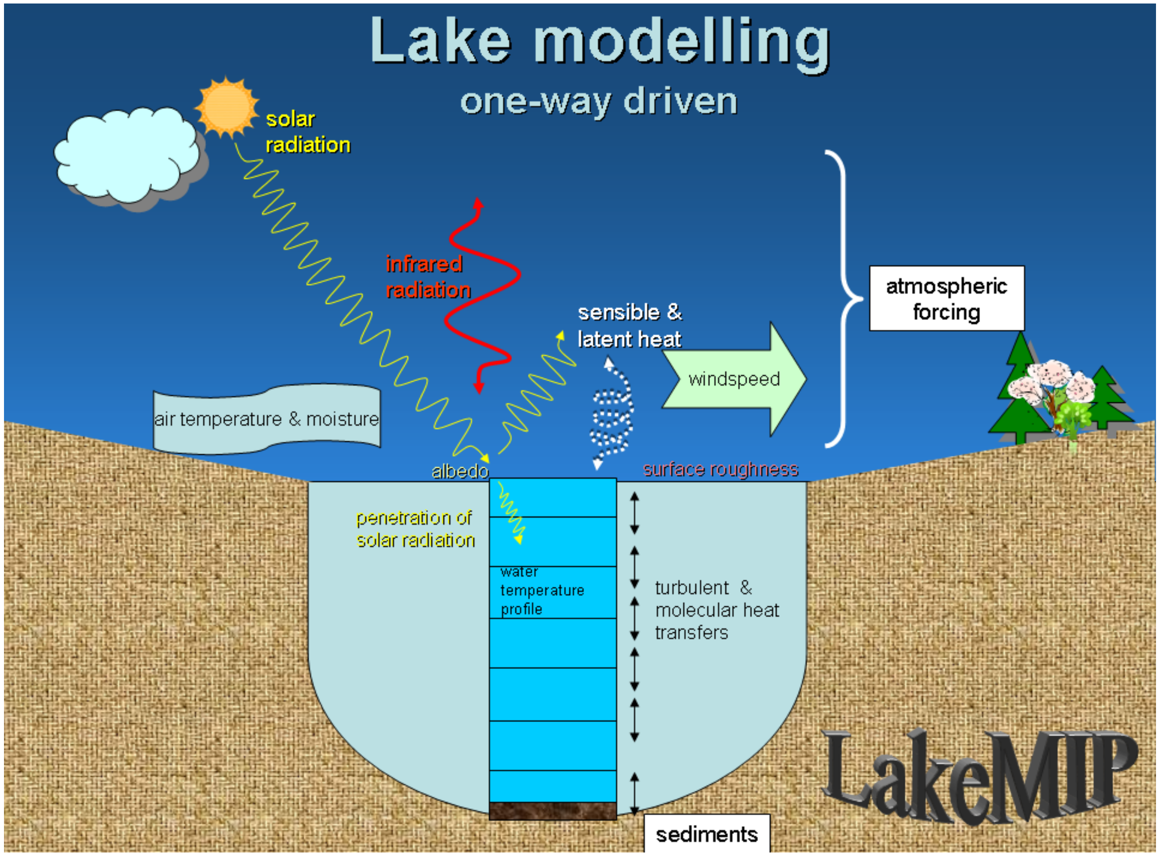



- ***Lakes & Ocean***
- ***Waves***
- ***Sea-ice***

# *Lakes* *"Not ocean, so let the land team deal with it!"*

- ***Thousands*** of lakes on scale of 1-4km not resolved by SST analysis -> greatly influence surface fluxes; explicit vs subgrid.
- Freshwater lake "***FLake***" model *(Dmitrii Mironov,DWD).*

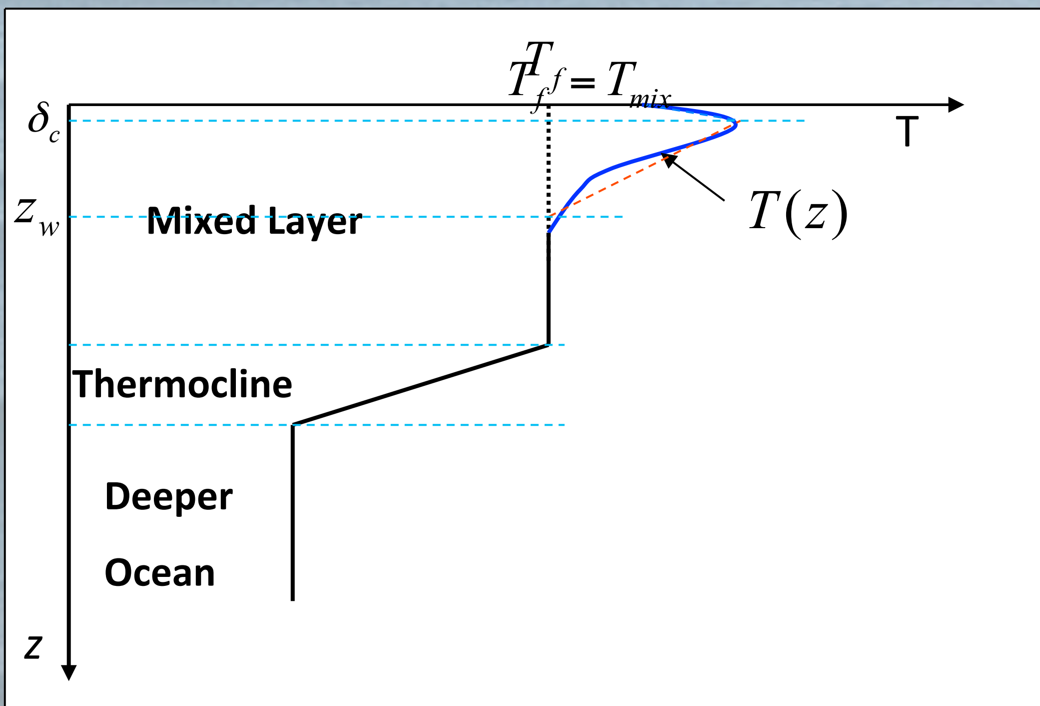
- Two-layer.
- Atmospheric forcing inputs.
- Temperature & energy budget.
- Mixed-layer and thermocline.
- Snow-ice module
- Specified depth/ turbidity.
- Used in COSMO, HIRLAM, NAM (regional), and global ECMWF, CMC, UKMO.




*Yihua Wu (NCEP/EMC)*

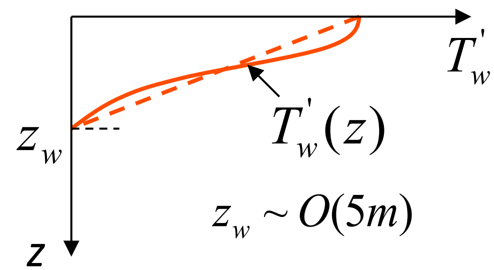
# Near-Surface Sea Temperature (NSST )

The ocean model does not produce an actual SST. The **NSST** determines a **T-Profile** just below the sea surface, where the vertical thermal structure is due to **diurnal thermocline layer warming** and **thermal skin layer cooling**.



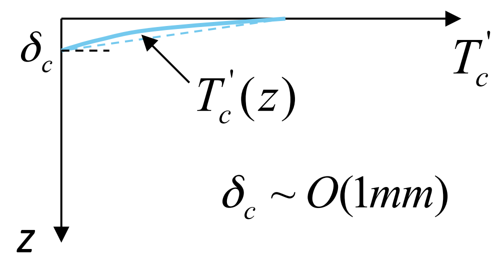

Diurnal Warming Profile

$$T_w'(z) = (1 - z / z_w) T_w'(0)$$




Skin Layer Cooling Profile

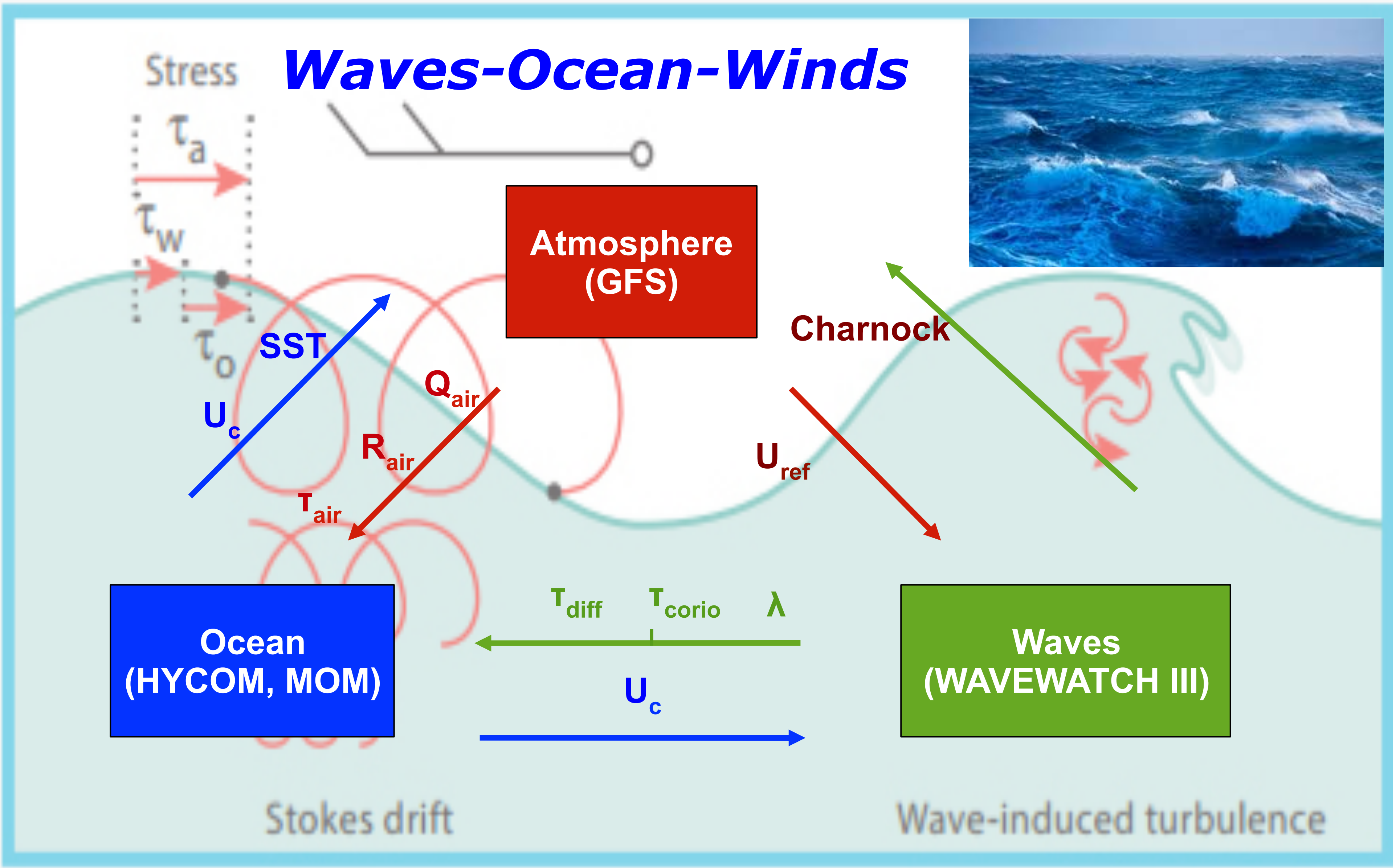
$$T_c'(z) = (1 - z / \delta_c) T_c'(0)$$




$$T(z,t) = T_f(z_w,t) + T'(z,t),$$

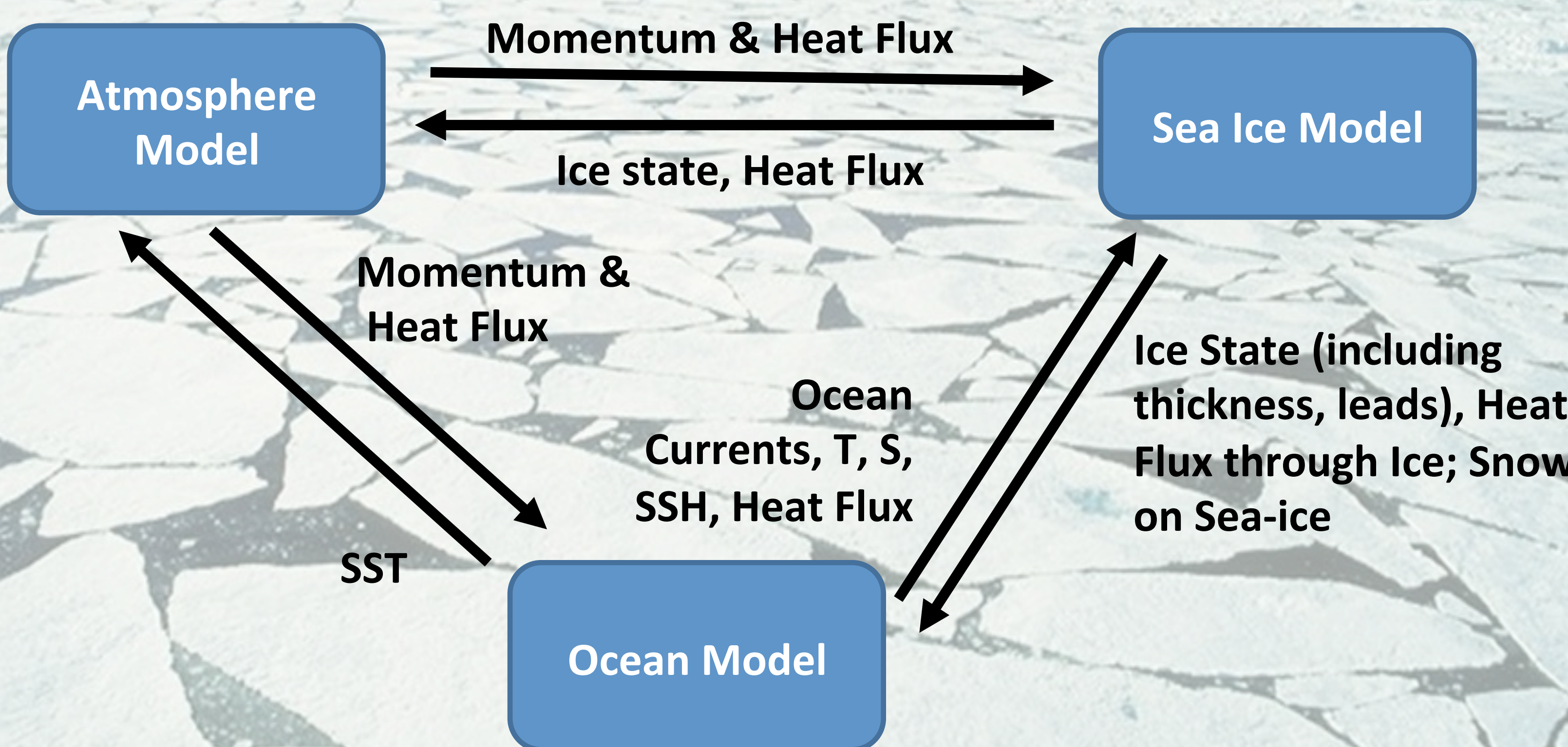
$$T'(z,t) = T_w'(z,t) - T_c'(z,t)$$

$$z \in [0, z_w]$$




GFS model air-sea fluxes depend on **sea state** (roughness -> Charnock).
WAVEWATCH III model forced by **wind** from GFS and currents from Ocean**.**
Ocean model forced by **heat flux**, sea state dependent **wind stress** modified by **growing or decaying wave fields and Coriolis-Stokes effect.**

# *Sea-Ice*


Atmosphere Model
Momentum & Heat Flux
Ice state, Heat Flux
Sea Ice Model
Momentum & Heat Flux
Ocean Currents, T, S, SSH, Heat Flux
Ice State (including thickness, leads), Heat Flux through Ice; Snow on Sea-ice
SST
Ocean Model

## *Surface Fluxes: Summary*

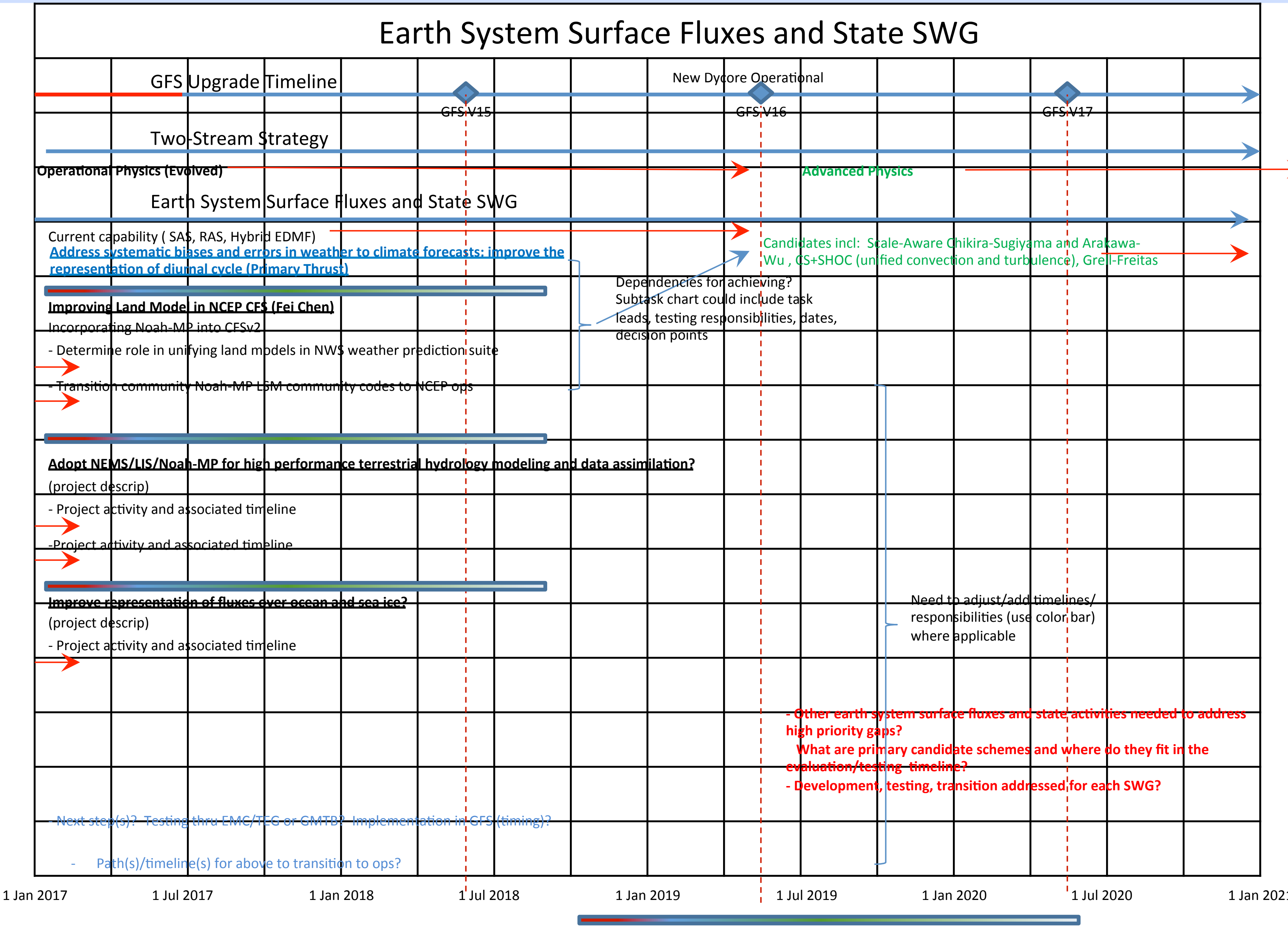
- Process-level understanding.
- Systematic metric-based evaluation and hierarchical testing (single parameterizations up to fully-coupled models).
- Scale-aware surface processes.
- Efficient physics (appropriate for operations).
- Community codes for effective R2O2R.

THE UNIVERSITY OF TEXAS AT AUSTIN JACKSON SCHOOL OF GEOSCIENCES

NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NOAA

# NGGPS Physics Team Plan




**Legend:** **Red text** = unfunded; (add colors to indicate funding source?)

**Red** = Phys Dev; **Blue** = DTC; **Green** = EMC