Progress in NASA/GSFC's Land Information System (LIS)

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http://lis.gsfc.nasa.gov

Background: LIS Overview

Inputs

Topography, Soils

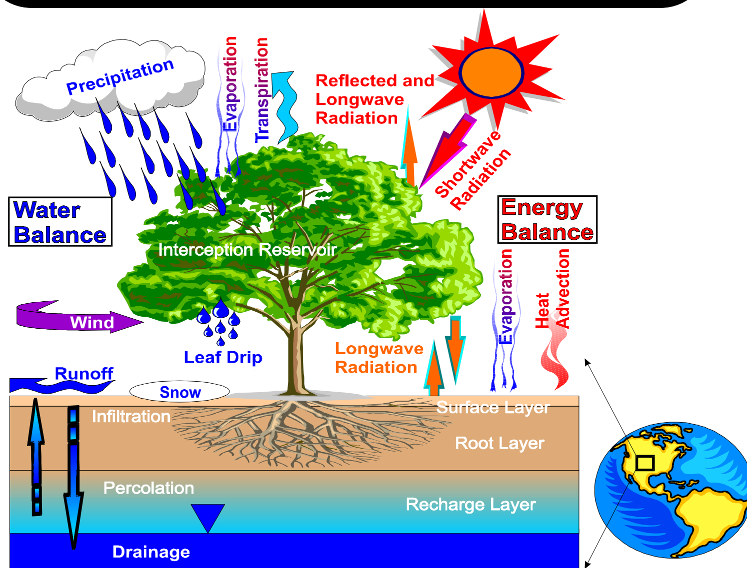
Land Cover, Vegetation Properties

Meteorology

Snow
Soil Moisture
Temperature

Physics

Land Surface Models



Data Assimilation Modules

Outputs

Soil Moisture & Temperature

Evaporation

Runoff

Snowpack Properties

Applications

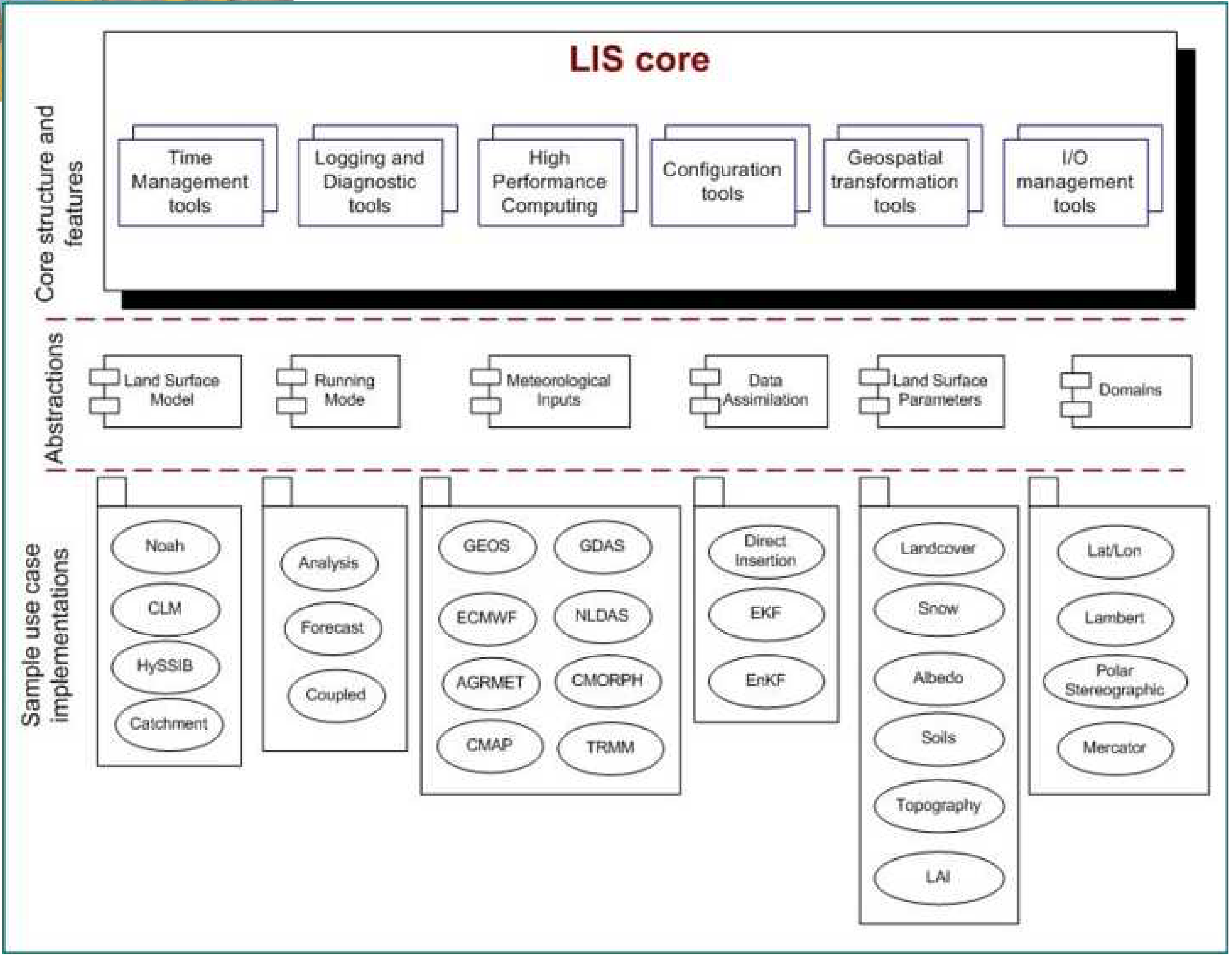
GFS/WRF Initialization

AFWA Tactical Decision Aids

USDA FAS

Other Users

Background: Structure of the LIS Framework



Kumar, S. V., C. D. Peters-Lidard, Y. Tian, P. R. Houser, J. Geiger, S. Olden, L. Lighty, J. L. Eastman, B. Doty, P. Dirmeyer, J. Adams, K. Mitchell, E. F. Wood and J. Sheffield, 2006. Land Information System - An Interoperable Framework for High Resolution Land Surface Modeling. *Environmental Modelling & Software,* Vol. **21**, 1402-1415.

Outline

1. Integrating NASA/GMAO’s EnKF in LIS
2. Coupling LIS to NOAA/NEMS
3. Coupling LIS to JCSDA/CRTM
4. Coupling LIS to WRF/ARW

A Unified Land Surface Modeling and Data Assimilation Framework for the JCSDA

S.V. Kumar, R.H. Reichle, C.D. Peters-Lidard, R.D. Koster, X. Zhan, W. Crow, J.B. Eylander, P.R. Houser

•NASA/GMAO-developed capabilities for sequential data assimilation have been implemented in the NASA/HSB Land Information System (LIS) framework.

•LIS is a comprehensive system that integrates the use of various land surface models, assimilation algorithms, observational sources for users at NASA, AFWA, NCEP and JCSDA investigators.

•Capabilities have been demonstrated for assimilating soil moisture, snow and skin temperature observations.

Kumar, S.V., R.H. Reichle, C.D. Peters-Lidard, R.D. Koster, X. Zhan, W.T. Crow, J.B. Eylander, and P.R. Houser, 2008. A Land Information System Data Assimilation Framework using the Land Information System, In Press, Advances in Water Resources.

Kumar, S. V., C. D. Peters-Lidard, Y. Tian, J. Geiger, P. R. Houser, S. Olden, L. Lighty, J. L. Eastman, P. Dirmeyer, B. Doty, J. Adams, E. Wood and J. Sheffield, 2006. LIS - An Interoperable Framework for High Resolution Land Surface Modeling. Environmental Modeling and Software, Vol. 21, pp 1402-1415.

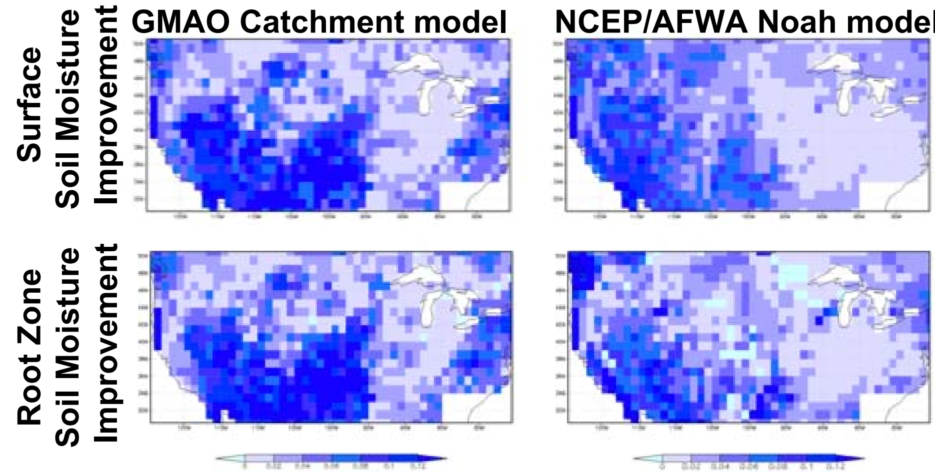


Figure 1: Soil Moisture Assimilation

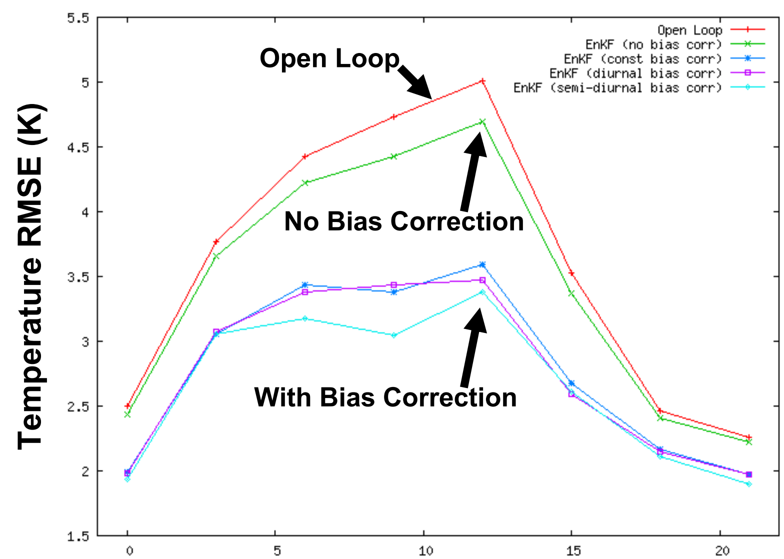
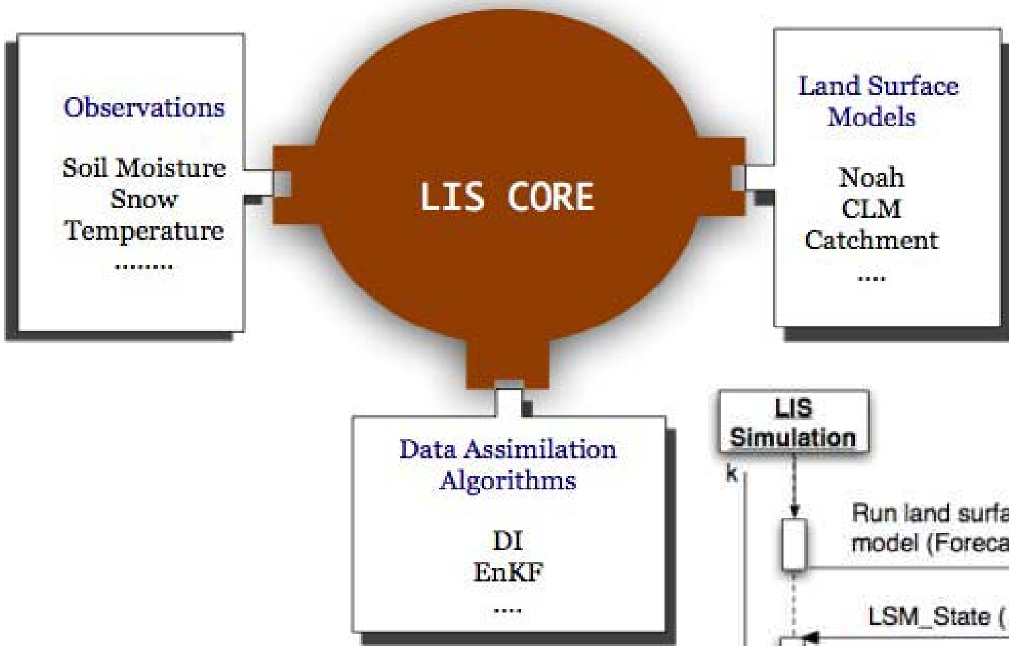
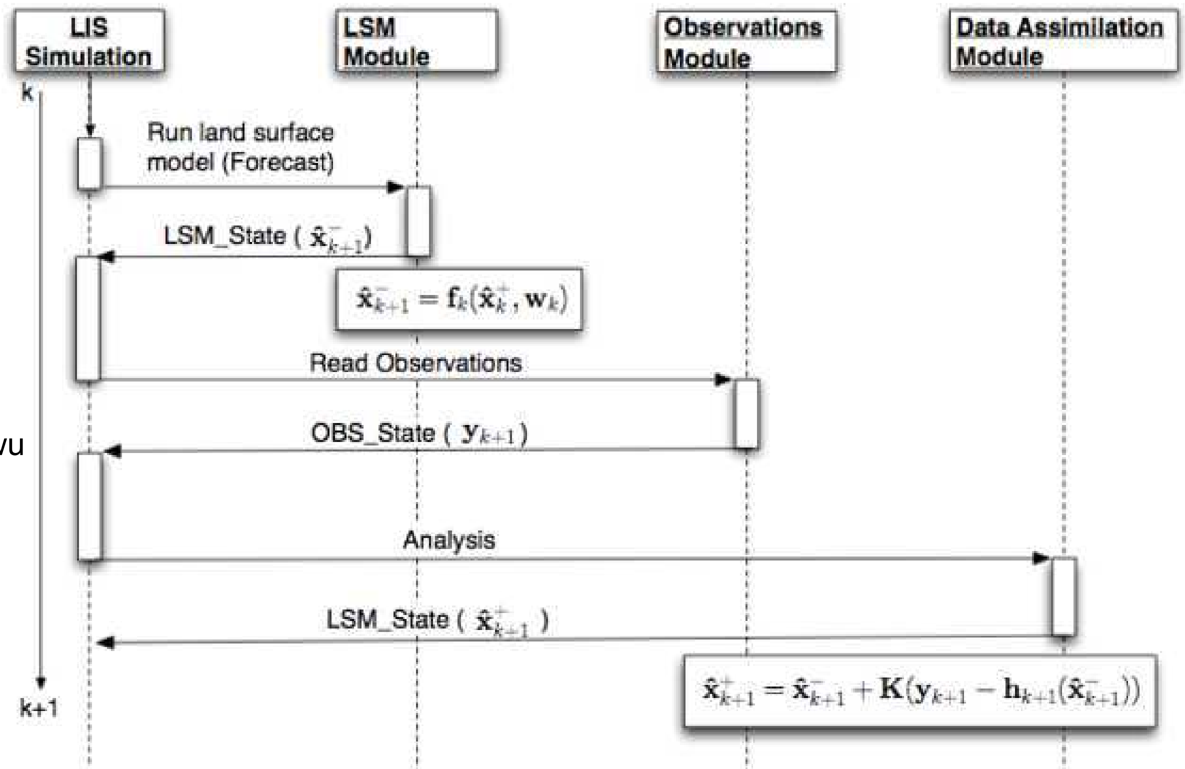


Figure 2: Skin Temperature Assimilation

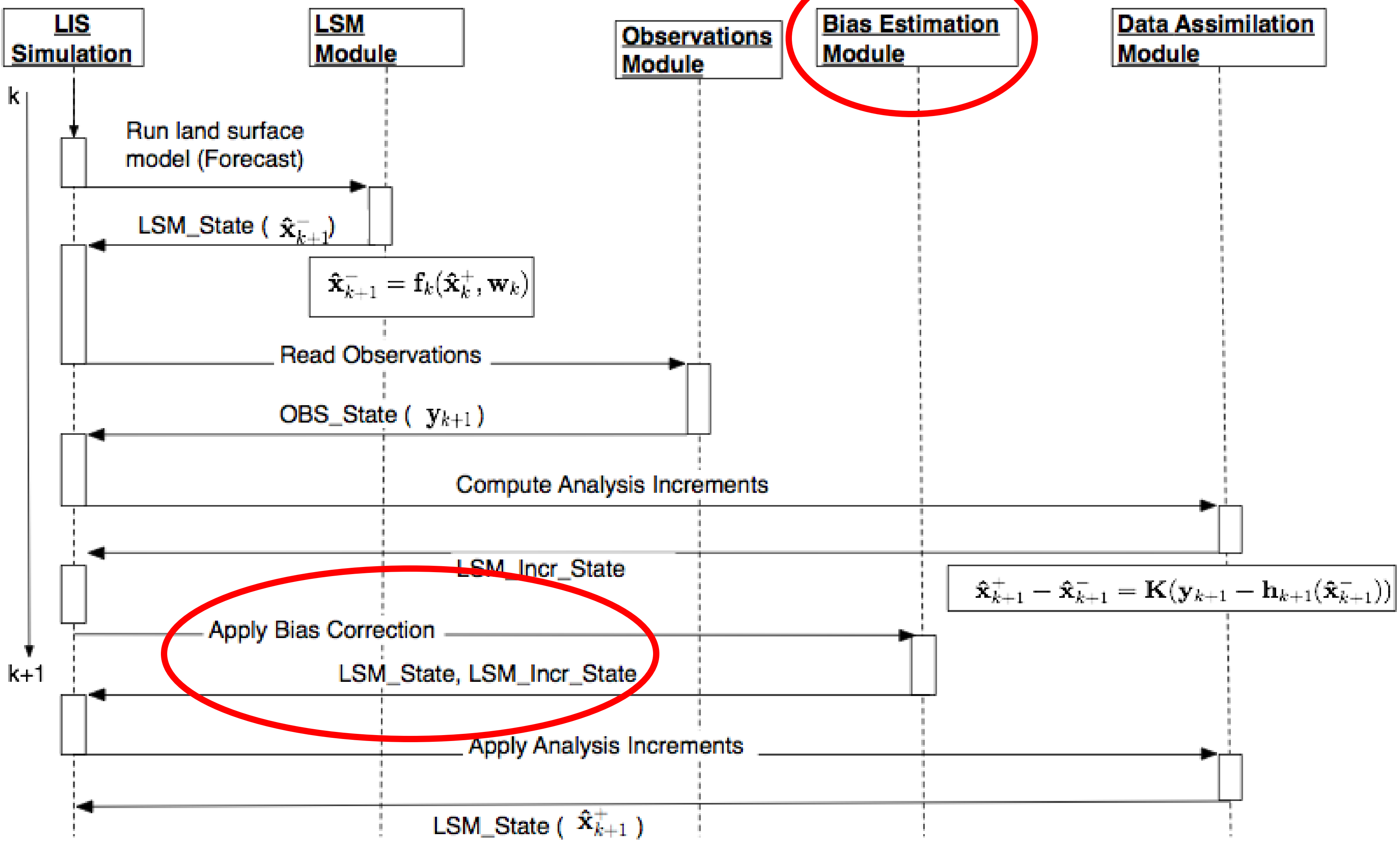
LIS data assimilation structure: New in LIS 5.0





Kumar, Sujay V., Rolf H. Reichle, Christa D. Peters-Lidard, Randal D. Koster, Xiwu Zhan, Wade T. Crow, John B. Eylander, and Paul R. Houser, 2008: A Land Surface Data Assimilation Framework using the Land Information System: Description and Applications, In press, Advances in Water Resources, Special Issue on Remote Sensing. doi:10.1016/j.advwatres.2008.01.013.

Bias estimation algorithm plug-ins



Bias estimation approaches in LIS

1. ***Off-line (a priori) scaling between climatology of obs. and land model:***
   \+ No assumption whether model or observations are biased.
   \+ Easy to implement in pre-processing.
   − Static (cannot adjust to changes in bias).

2. ***Dynamic model bias estimation:***
   − Assume obs. climatology is correct and the model is biased.
   \+ Dynamic (adjusts to changes in bias).

Standard Kalman filter: $x^+ = x^- + K_x(y - Hx^-)$

$$K_x = P_x H^T (H P_x H^T + R)^{-1}$$

Bias estimation: $b^+ = b^- + K_b(y - Hb^-)$ (2nd Kalman filter)

Assume: $P_b \sim P_x$

$K_b = \text{function}(K_x)$

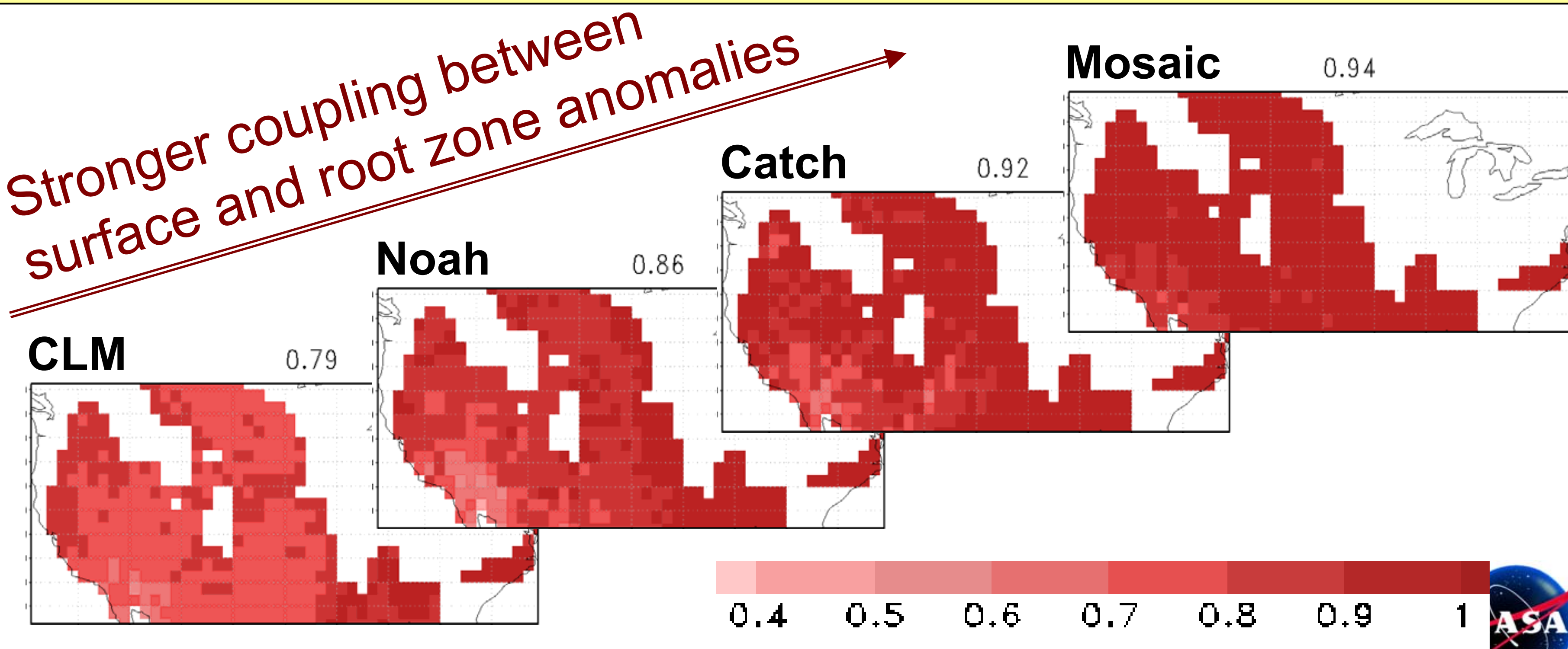
Use KF increments to update bias.

Bias estimate is effectively time average of increments.

Options for diurnal and semi-diurnal bias parameterization.

Example: Soil Moisture Assimilation

- Impact of different land surface physics in the assimilation of surface soil moisture
- Do model formulations impact the efficiency of soil moisture assimilation?
- How do land models perform in an assimilation system given different representations of possible true land surface processes?



Root zone soil moisture skill improvement from assimilation

NIC rzmc		Synthetic observations from				Avg
		Catch	Mos	Noa	CLM	
Model	Catch	0.67	0.61	0.22	0.26	**0.44**
	Mos	0.48	0.69	0.16	0.18	**0.38**
	Noa	0.48	0.55	0.46	0.29	**0.45**
	CLM	0.16	0.38	0.10	0.44	**0.27**
Avg		**0.45**	**0.56**	**0.24**	**0.29**	

1.) Average across rows (known truth physics):

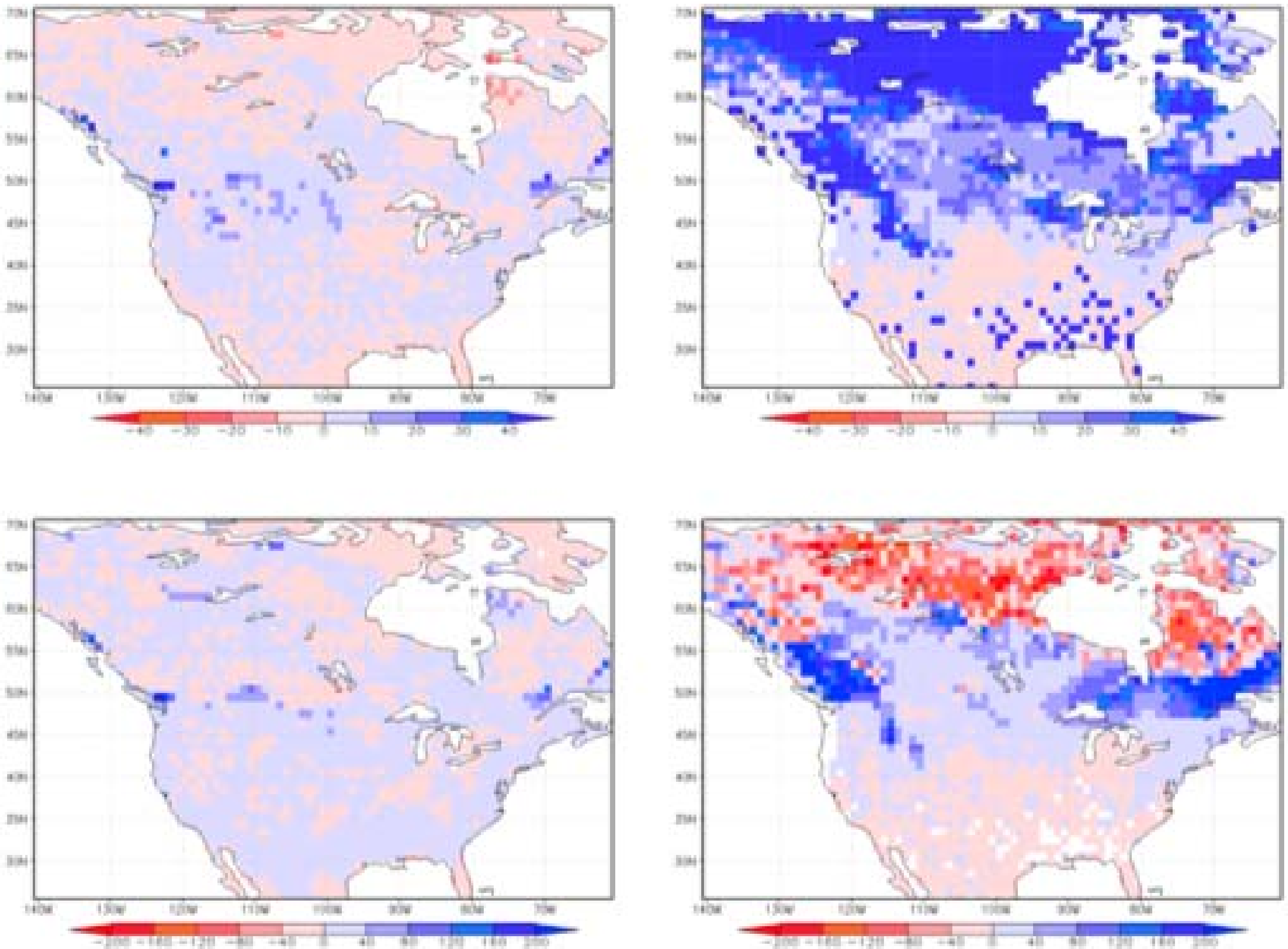
Mosaic or Catchment "truth" is "easier" to estimate in data assimilation than Noah or CLM "truth".

2.) Average across columns (unknown truth physics):

Use of Catchment, Mosaic, and Noah in assimilation system is better than use of CLM.

If coupling between surface and root zone is weak in truth, assimilation of surface observations is less efficient.

Example: Snow Assimilation



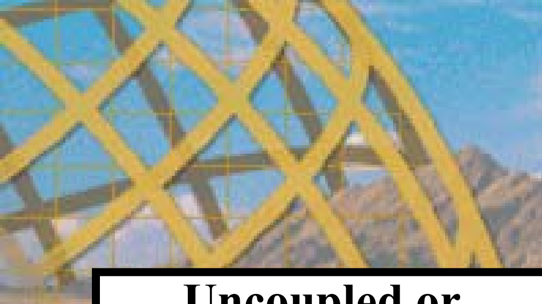
SWE

Snow depth

Rule-based DI

EnKF

Improvement metric (RMSE(open loop) – RMSE(assimilation))



LIS-NEMS Coupling

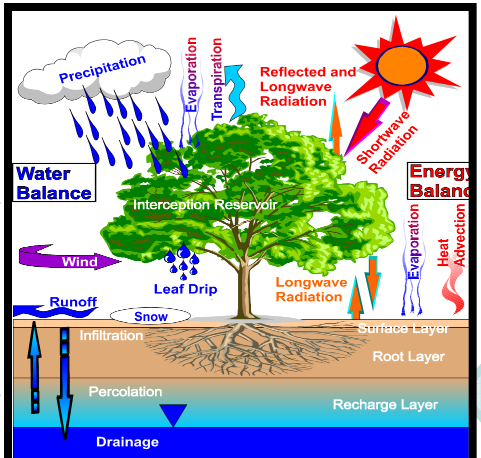
Uncoupled or Analysis Mode

Coupled or Forecast Mode

Station Data

Global, Regional Forecasts and (Re-)Analyses

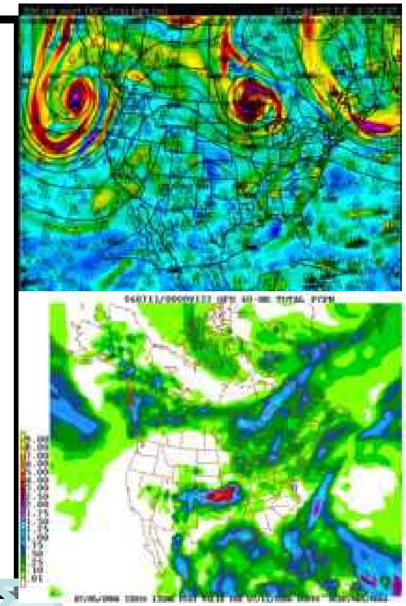
Satellite Products



LSM Physics (Noah, Catchment)

ESMF

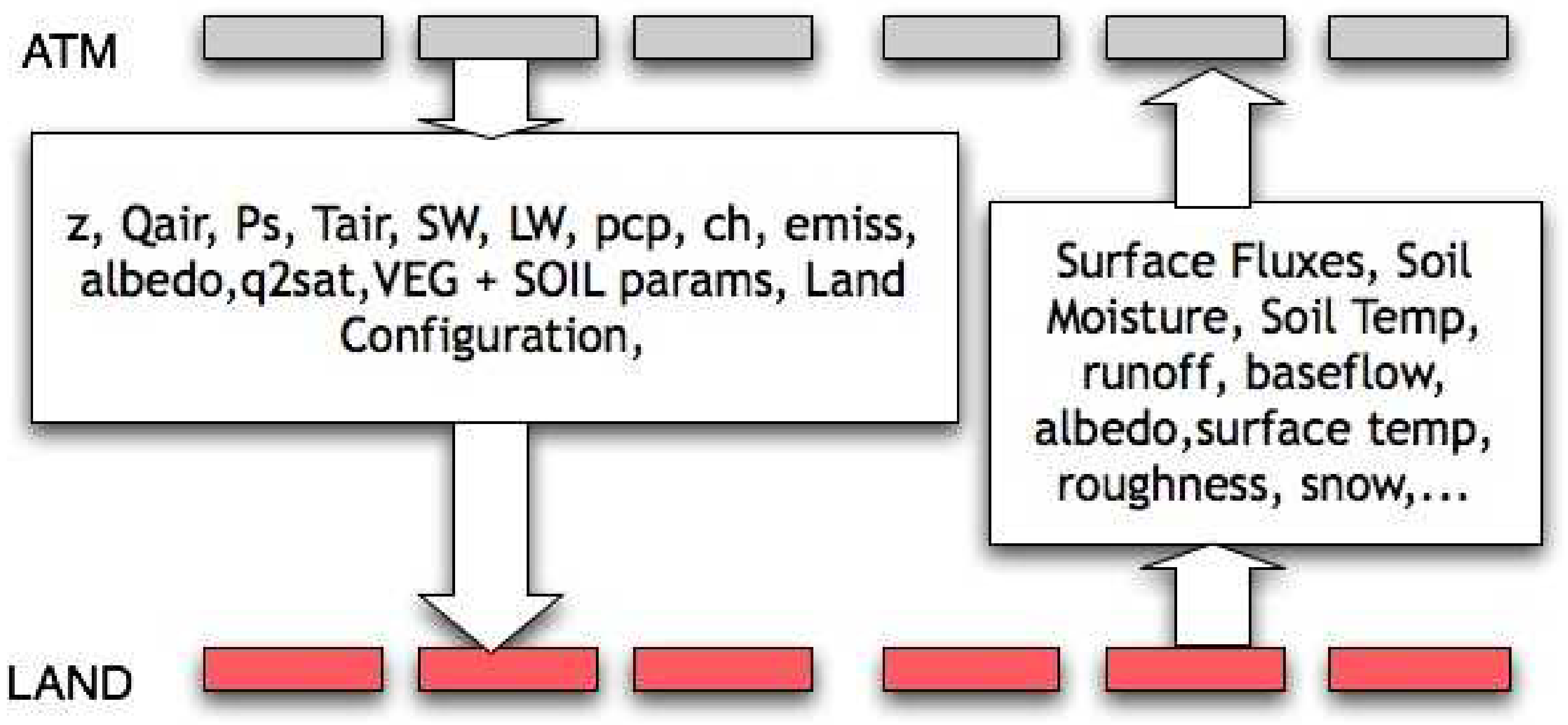
WRF GFS NEMS



LSM Initial Conditions

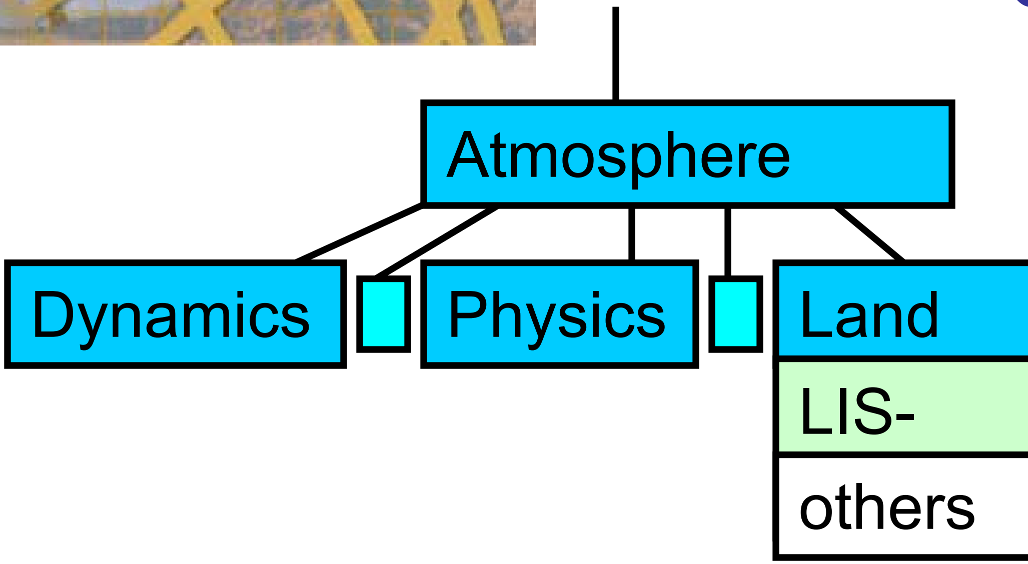
Kumar, S. V., C. D. Peters-Lidard, J. L. Eastman and W.-K. Tao, 2008. An integrated high-resolution hydrometeorological modeling testbed using LIS and WRF. *Environmental Modelling & Software,* Vol. **23**, 169-181.

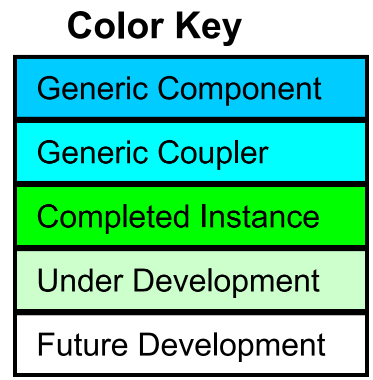
LIS-NEMS interface



- Land runs on the same grid as the atmosphere
- Static initializations and parameters in the input interface

LIS-NEMS coupling design

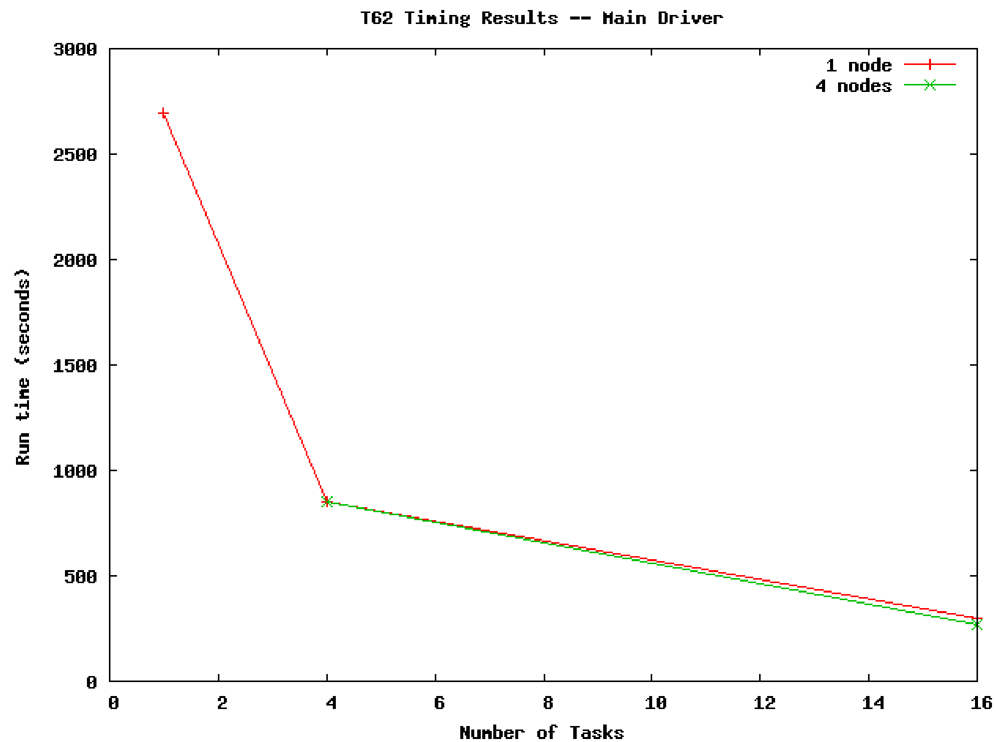




- **Land is responsible for computing surface fluxes.**
- **Land may need to be invoked inside physics, since it needs radiation and surface layer needs it.**
- **Implicit solving would require iteration between Land and PBL/Moist.**
- **Each component has the full flexibility of time space decomposition**

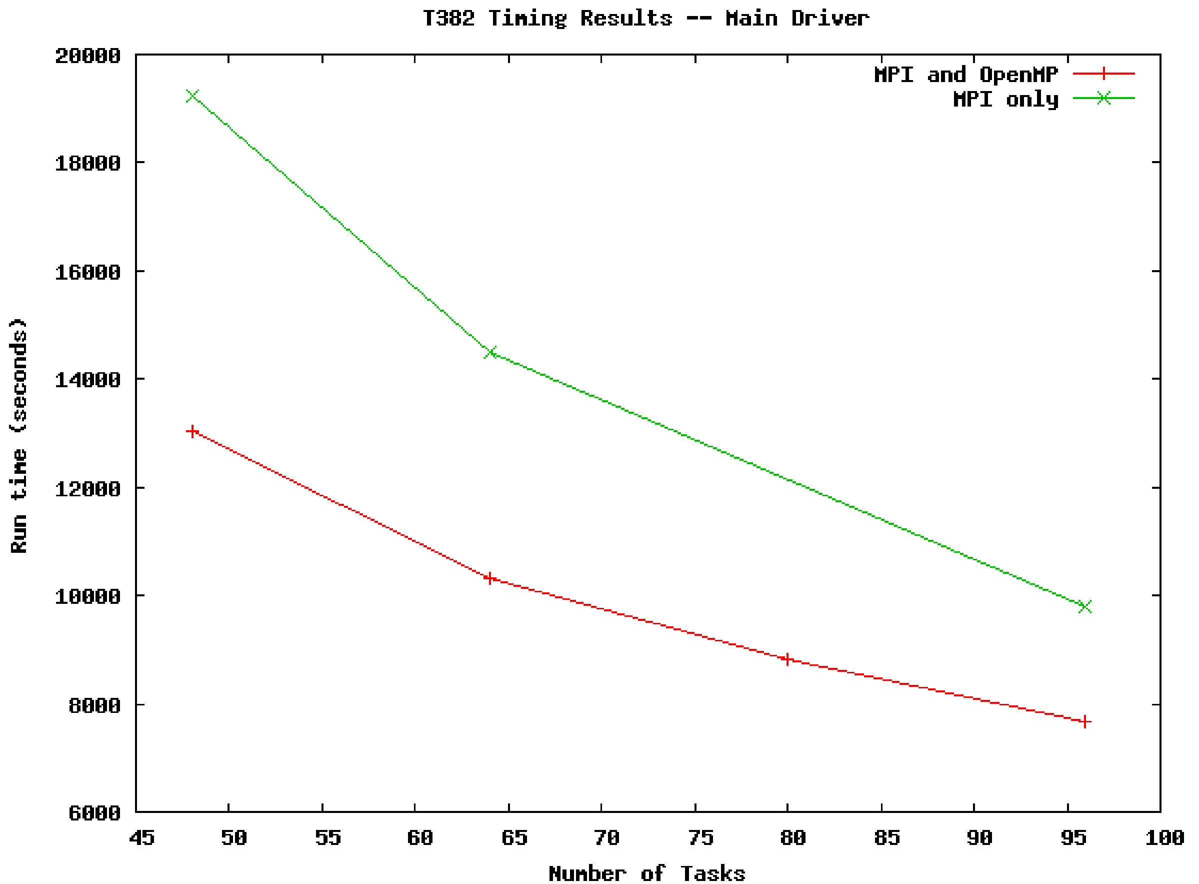
GFS Computational Scaling (T62)

- 6days starting 25 jul 2007, using a timestep of 600sec, 3 hourly output
- T62 test case was run for several different tasks/nodes combinations.
- These timing results will allow us to measure the impact of coupling GFS and LIS.



GFS Computational Scaling (T382)

- 6day simulation, starting 28 Aug 2006, with 600sec timestep, 3hourly output
- GFS code scales well with increased computational granularity



LIS-NEMS Coupling Progress

- LIS version 5.0 has been benchmarked on the JCSDA testbed (haze)
- A number of design prototypes for the LIS-NEMS coupling have been developed
- The domain decomposition strategies from NEMS have been abstracted
- A direct coupling strategy for combining LIS and NEMS is being explored.

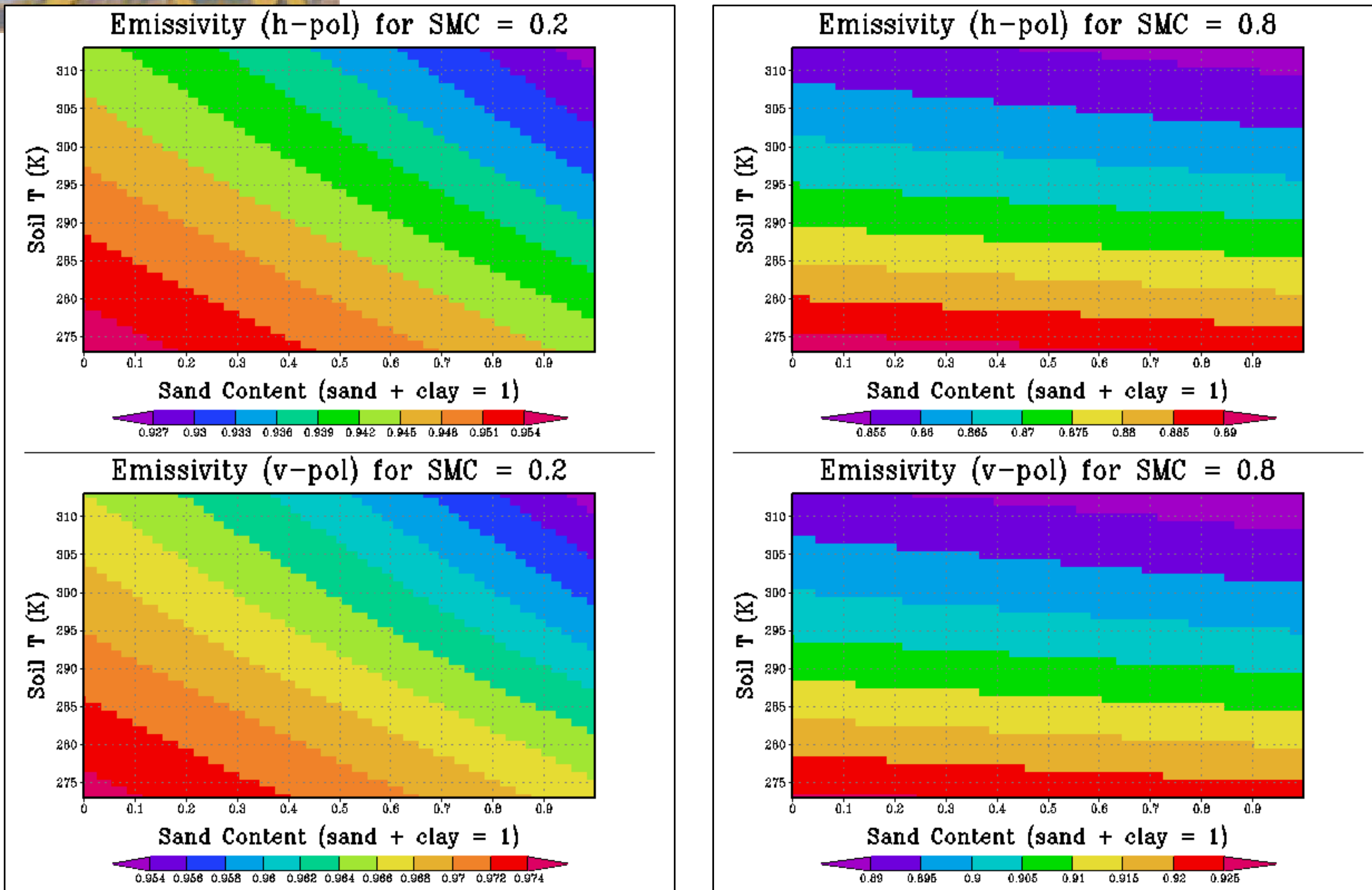
LIS-CRTM Coupling: Surface Emissivity

Initial Surface Emissivity Sensitivity Tests:
AMSR-E, 89.0 GHz, 55° incidence angle

- Soil temperature and moisture content
- Skin temperature
- Soil sand and clay content
- Snow depth
- Vegetation fraction

CRTM Bare Soil emissivity

Based on Wang and Schmugge [1980, *IEEE TGRS*]

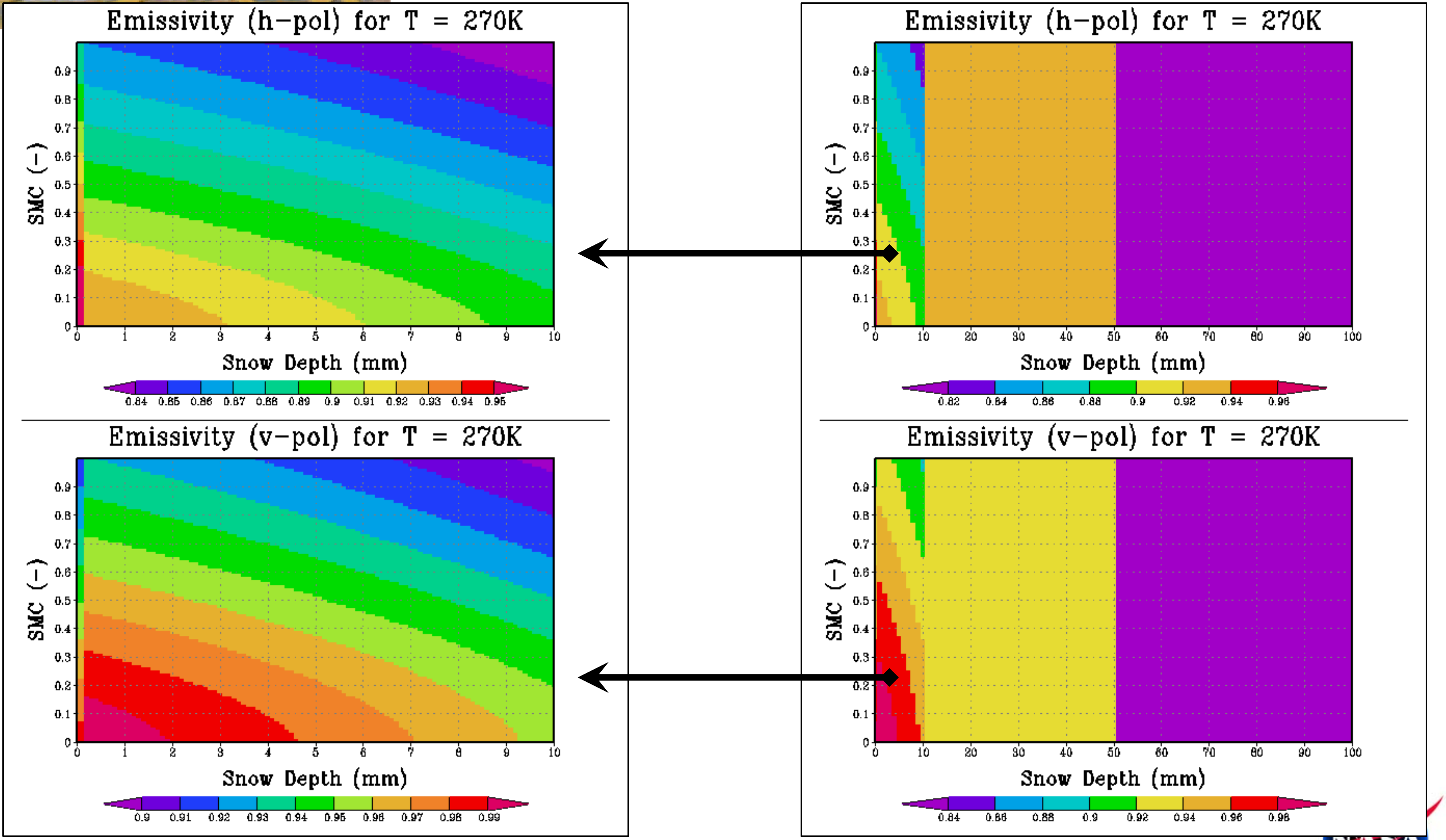


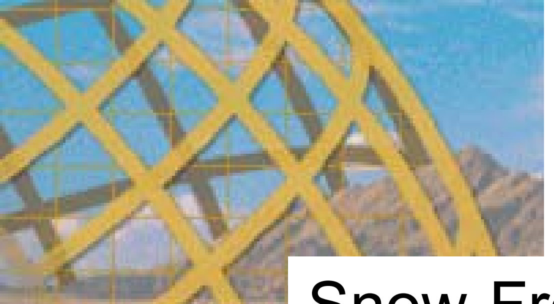
variation with T ~ variation with texture

variation with T > variation with texture

CRTM snow covered bare soil emissivity

Based on Weng and Yan [in-code © 2005 and under Gnu GPL]

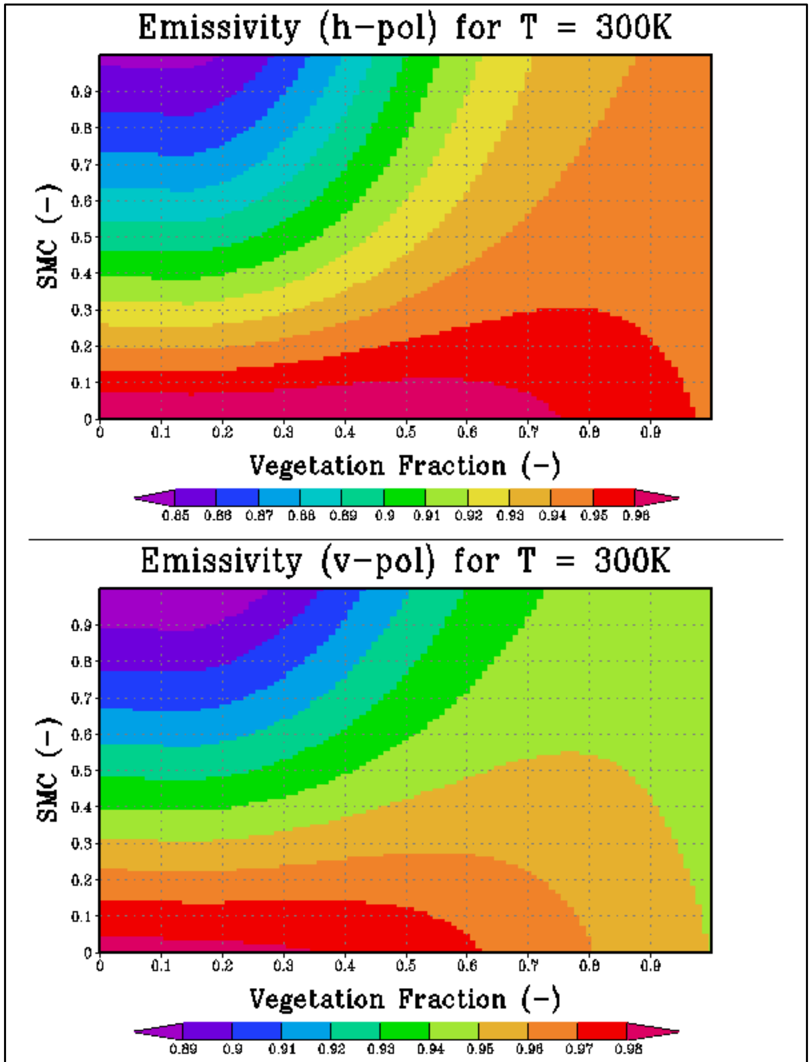




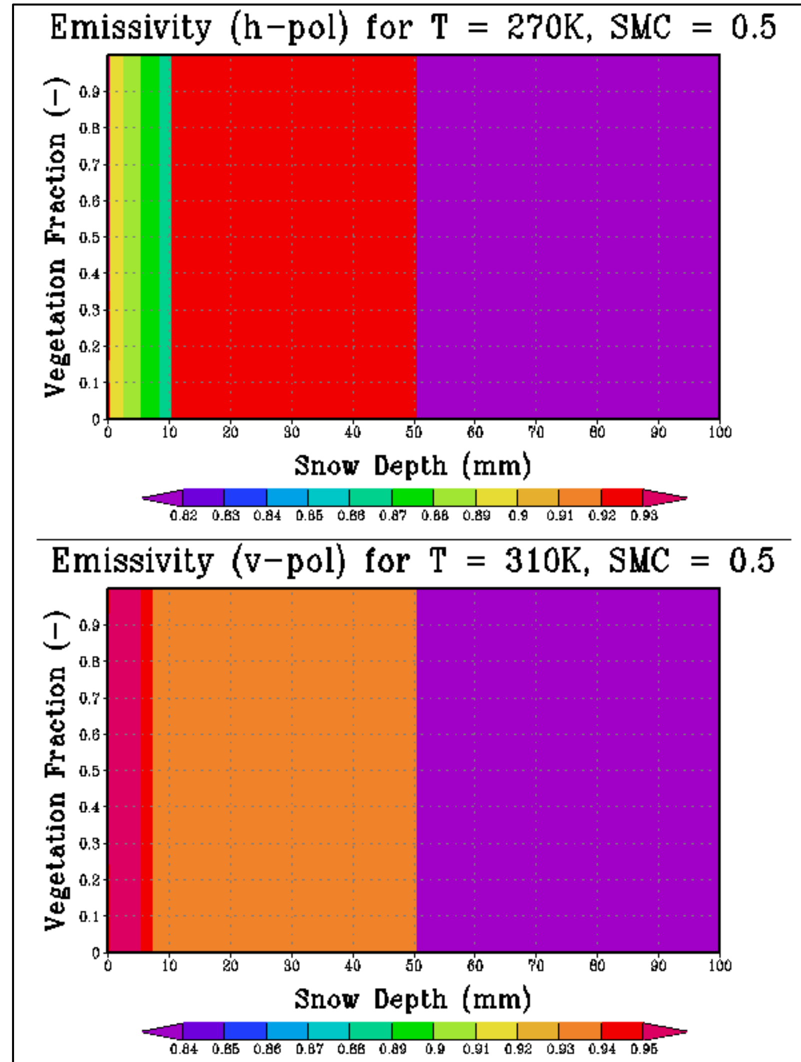
CRTM vegetated land emissivity

Based in part on Ulaby and el-Rayer [1987, *IEEE TGRS*]

Snow-Free



Snow-Covered

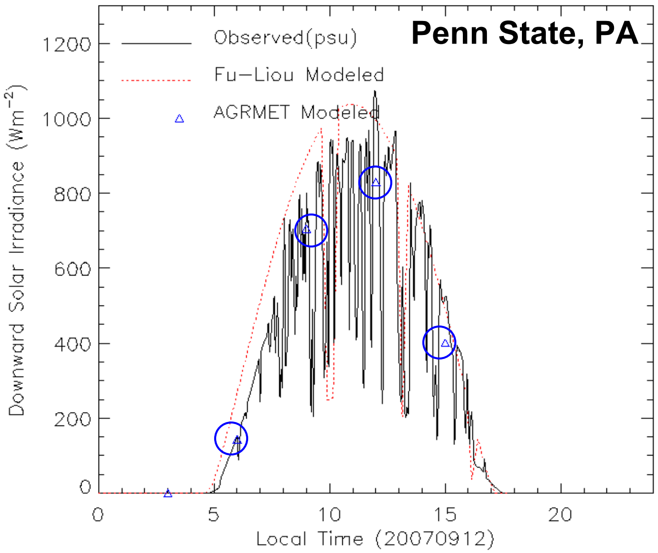


LIS-CRTM Coupling
Atmospheric RT

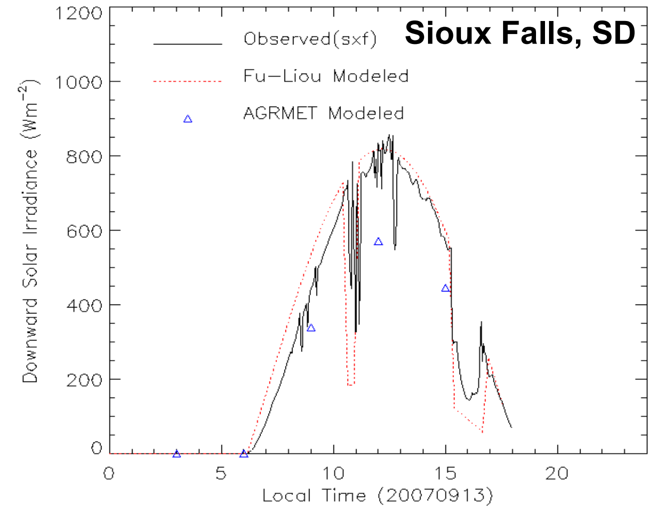
- CRTM Four stream RTM input data:
  – CDFSII (new version): GOES retrieved cloud optical thickness, cloud effective radius, cloud temperature, cloud height
- Test case: September, 2007
  – Control: AGRMET
  – CRTM Four-stream Fu-Liou

AGRMET vs. LIS-CRTM Downward SW

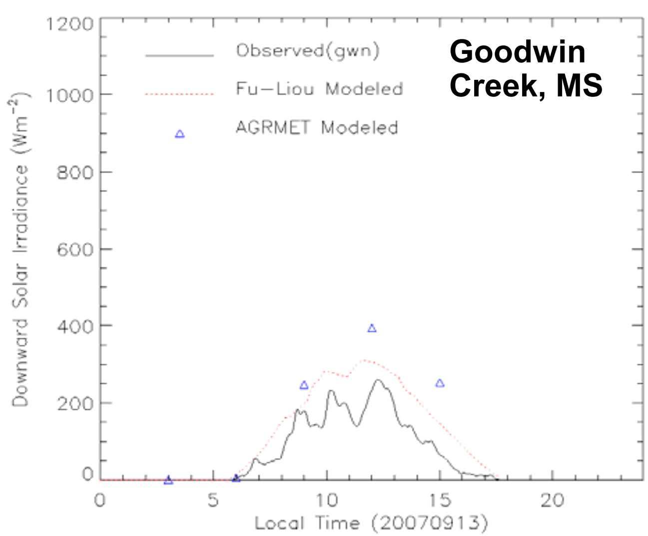
Partly cloudy



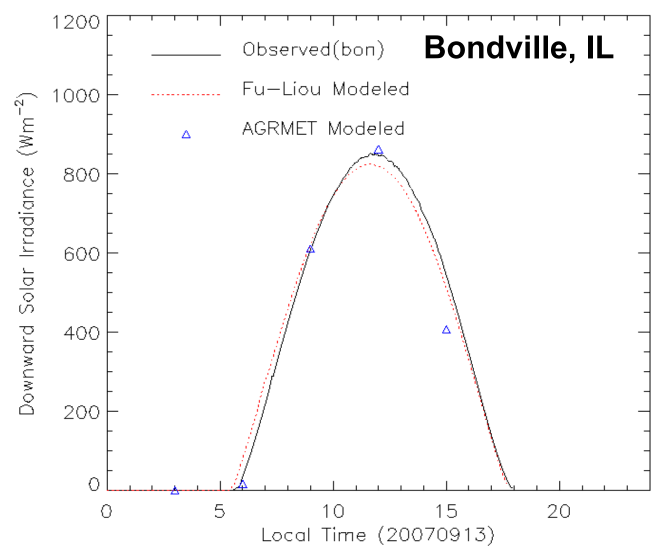
Partly cloudy



Cloudy

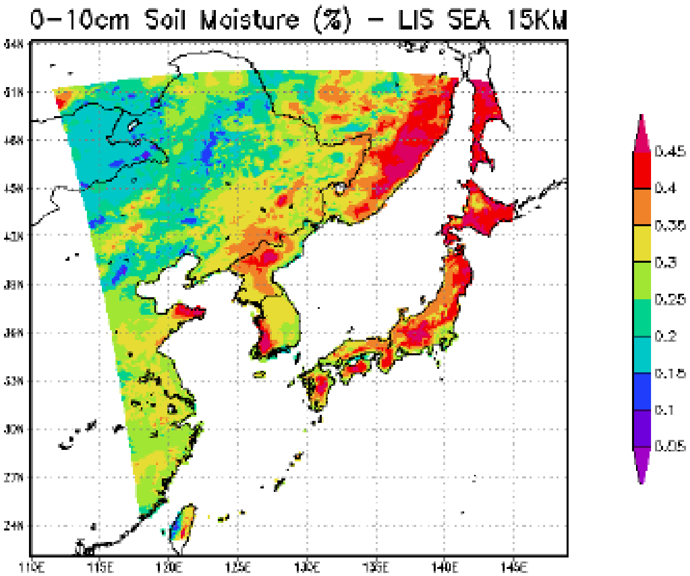


Clear sky

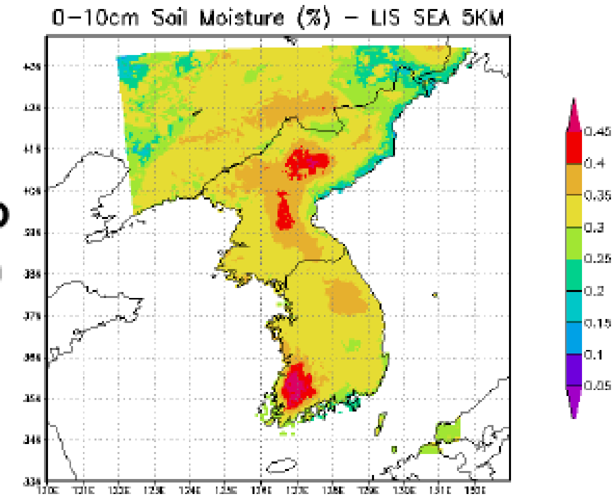


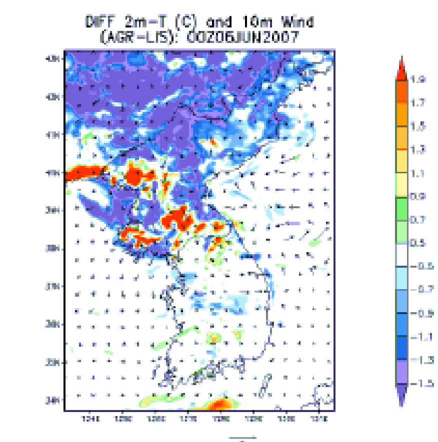
AFWA simulation in the clear sky condition is close to truth, but in cloudy or partly cloudy conditions the AFWA simulation overestimated or underestimated the flux.

LIS-WRF Coupling
AFWA, NASA and NCAR Joint Study



- Demonstrate and evaluate using LIS to initialize WRF (ARW) SE Asia domain
- 4 seasonal test case periods



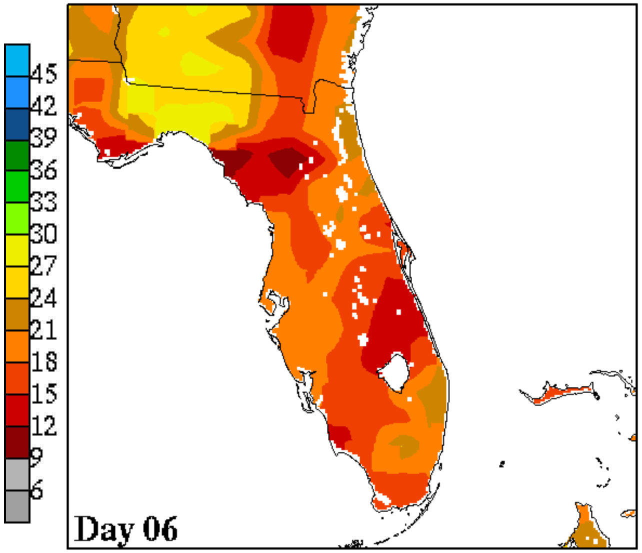


<u>STUDY RESULTS:</u>

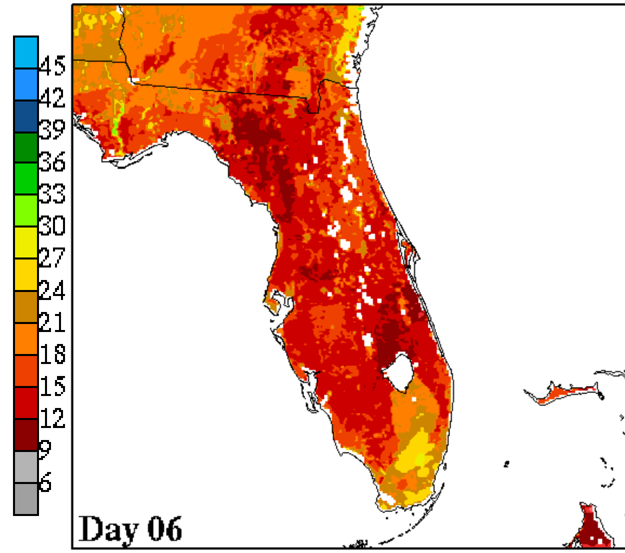
- LIS initialized runs were able to reduce WRF warm bias
- LIS affected 0-48 hour fcst variables of surface weather, boundary layer, cloud, and precipitation
- LIS soil and snow fields capture fine scale surface features, reflecting important role in high resolution NWP

LIS-WRF Example:
0-10 cm initial soil moisture (%)
(1200 UTC 6 May 2004)

Eta soil moisture

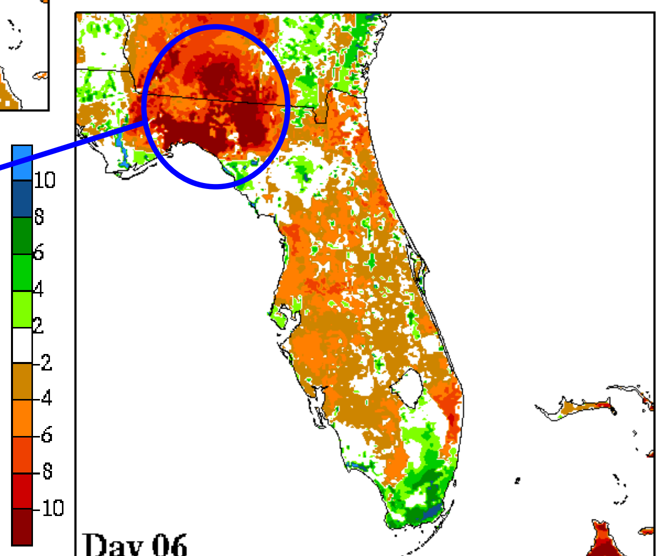


LIS soil moisture



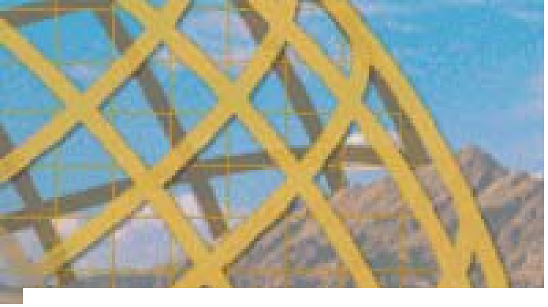
- Much more detail in LIS (as expected)
- LIS drier, especially over N. FL & S. GA
- LIS slightly more moist over Everglades

Difference (LIS – Eta)



LIS Substantially Drier

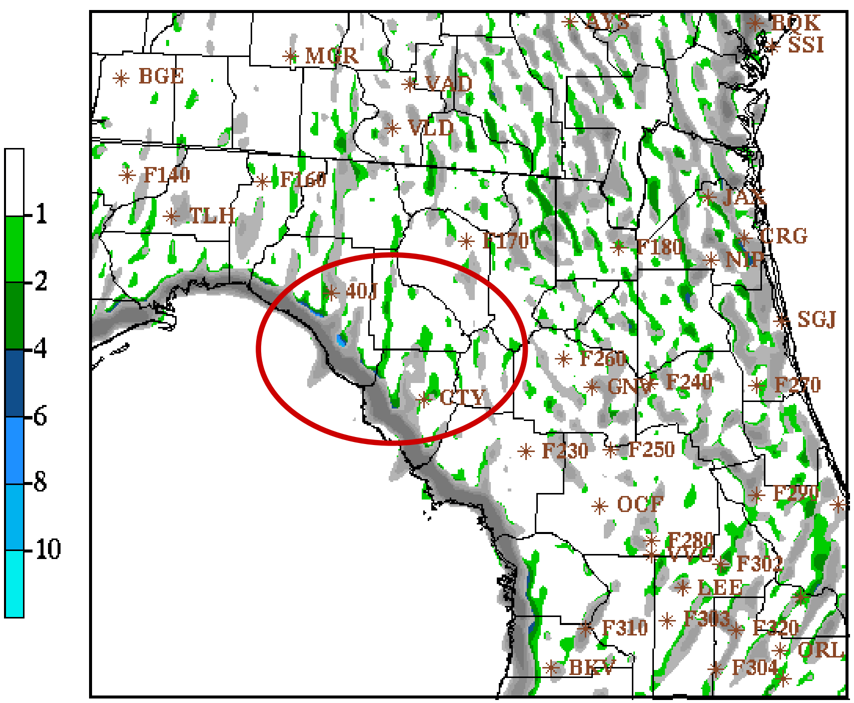
Case et al., 2008, JHM, in press



LIS-WRF Example: Sea Breeze Evolution Difference

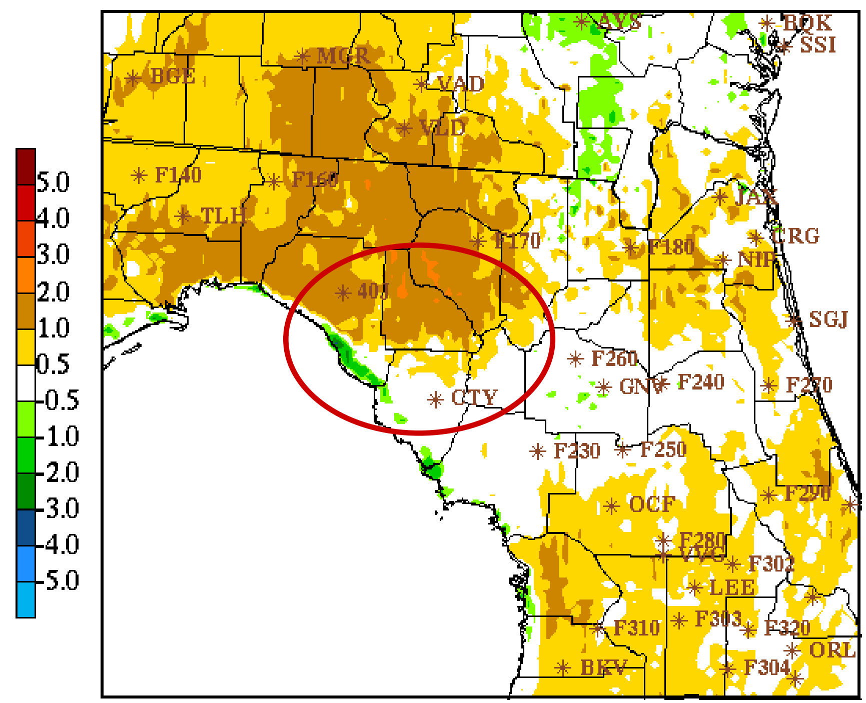
(1800 UTC 6 May to 0300 UTC 7 May)

Divergence (x10**4 s**-1) valid 040506/1800V006



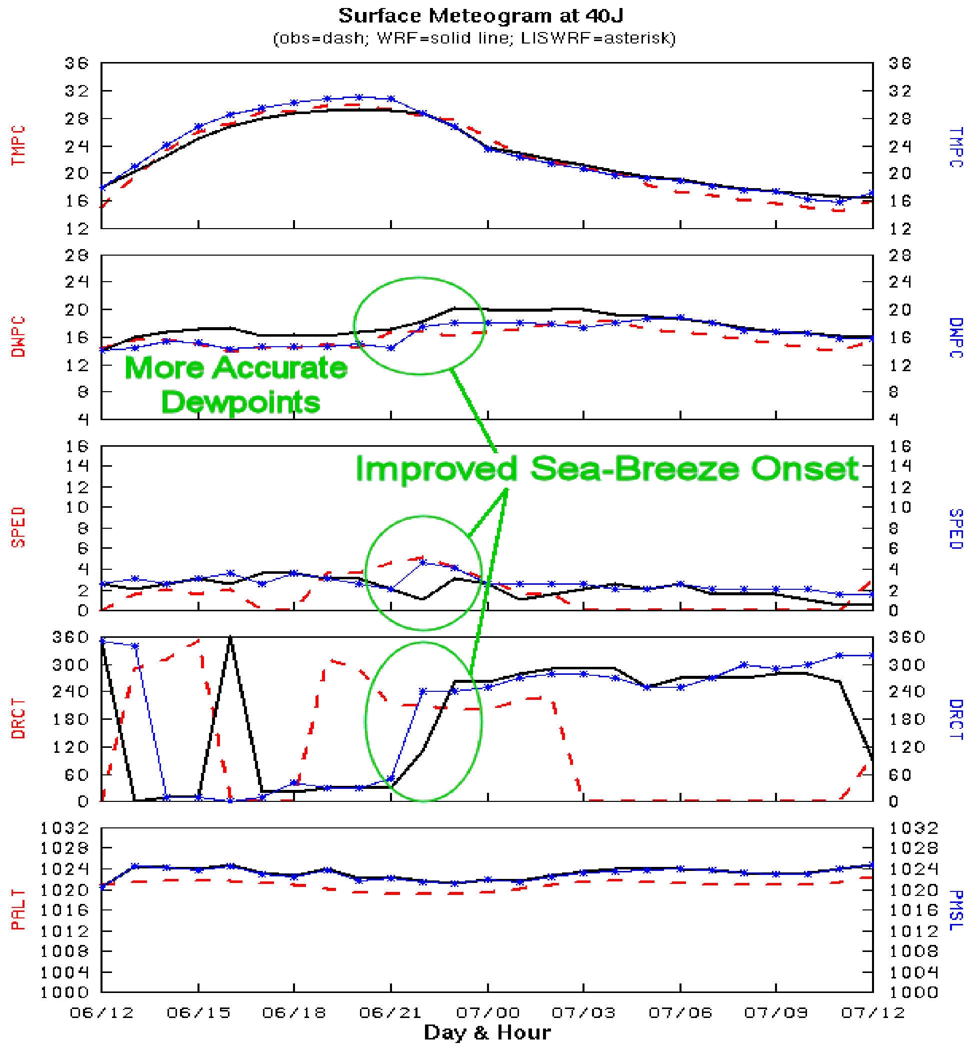
(color=LISWRF ; gray=WRF)

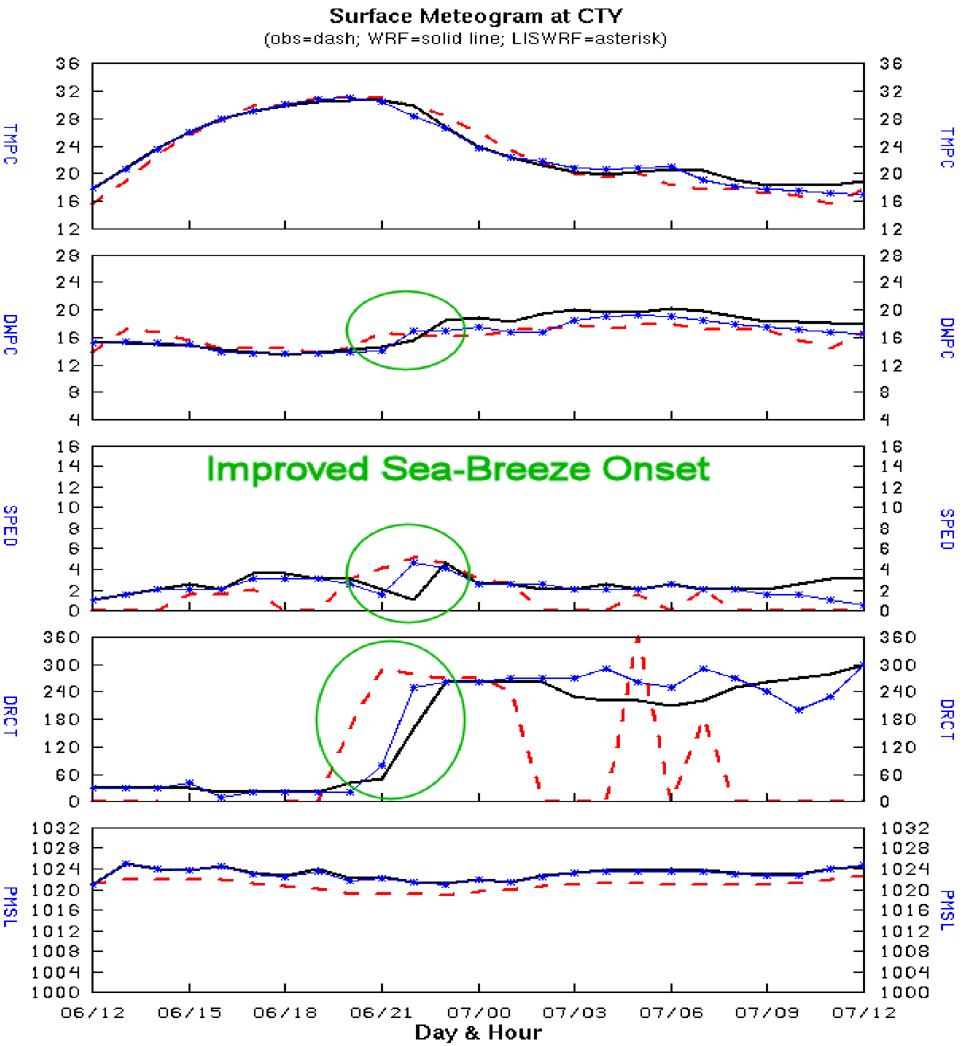
2-m Temp Diff (LISWRF - WRF) valid 040506/1800V006



LIS-WRF Example: Sea Breeze Evolution Difference

(Meteogram plots at 40J and CTY)



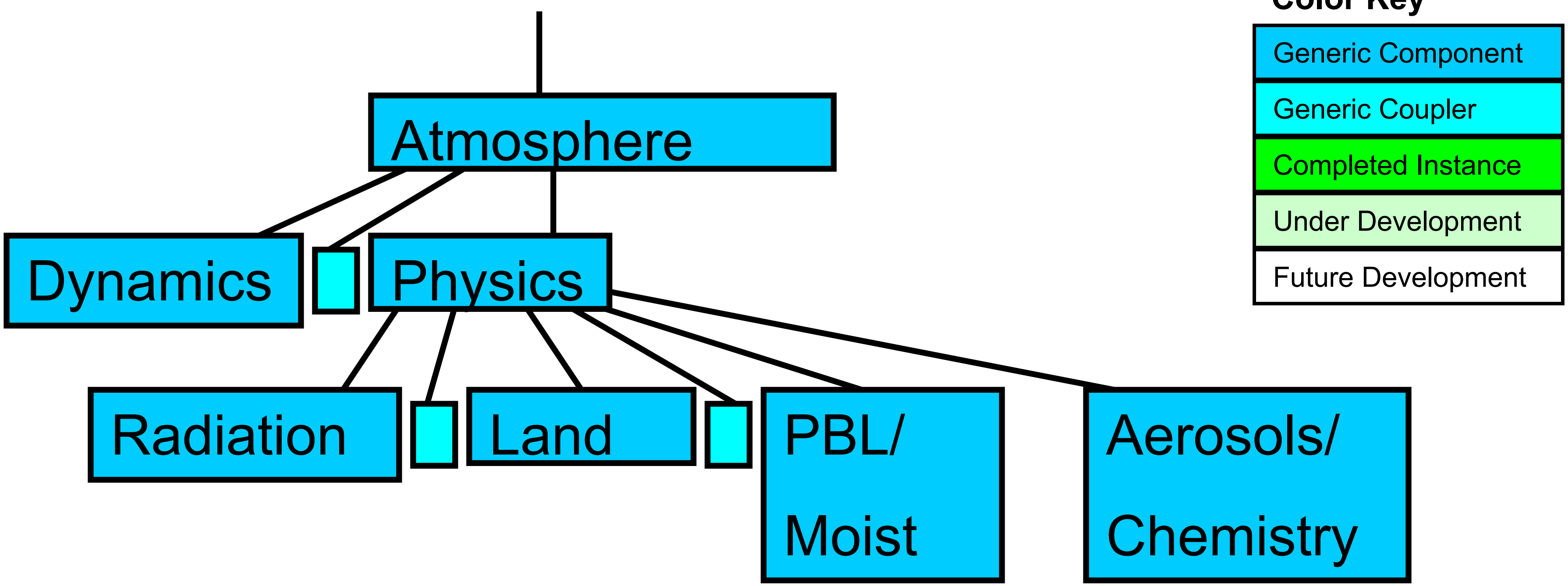


Summary

1. We have successfully integrated NASA/GMAO's EnKF in LIS for use by JCSDA investigators
2. With NCEP/UMIG, we have designed the interface for coupling LIS to NOAA/NEMS and completed uncoupled benchmarks
3. With NCEP, AFWA and NESDIS, we are working towards coupling LIS to JCSDA/CRTM, with a focus on MW, VIS, IR.
4. With NCAR and AFWA, we have coupled LIS to WRF/ARW, and we will streamline this coupling to be ESMF compliant and ready "out of the box".

Backup

LIS-NEMS Design 2



- **Land physics is temporally in sync with the physics**
- **Will require considerable ESMF implementations in the code hierarchy**
- **Time decomposition is imposed in the land component**