# Assimilation of Satellite Snow Products into NCEP Operational CFS/GFS System

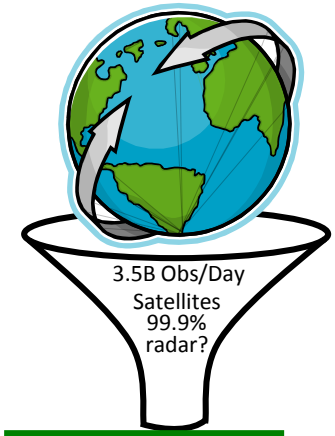
Michael B. Ek and Jiarui Dong
*NOAA/NCEP/EMC, College Park, Maryland, USA*

***STAR JPSS Science Team Meeting***
***August 17, 2017, NCWCP, College Park MD***

# Outline

- NCEP Land Data Assimilation Systems
- NASA Land Information System Applications
- Land Data Assimilation Experiments
- Summary

# Noah Land Model Connections in NOAA's NWS Model Production Suite



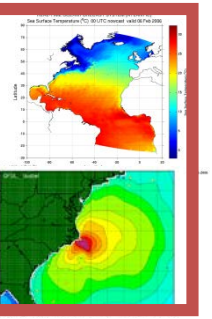

**Climate CFS**
MOM3

**Hurricane**
GFDL
HWRF

2-Way Coupled

**Oceans**
HYCOM

WaveWatch III



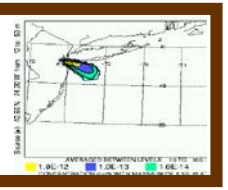
**Global Data Assimilation**

**Global Forecast System**

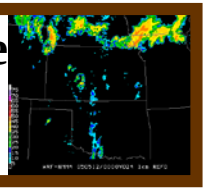
**Regional NAM**
WRF NMM
*(including NARR)*

**Regional Data Assimilation**

**Dispersion**
ARL/HYSPLIT



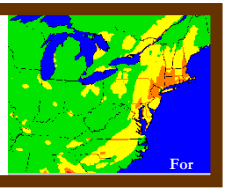
**Severe Weathe**
WRF NMM/ARW
Workstation WRF



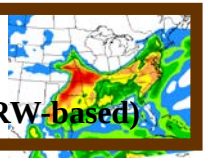
**North American Ensemble Forecast System**
GFS, Canadian Global Model

**Short-Range Ensemble Forecast**
WRF: ARW, NMM
ETA, RSM

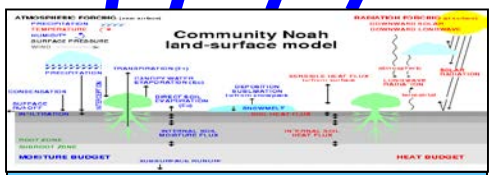
**Air Quality**
NAM/CMAQ



**Rapid Update for Aviation** (ARW-based)



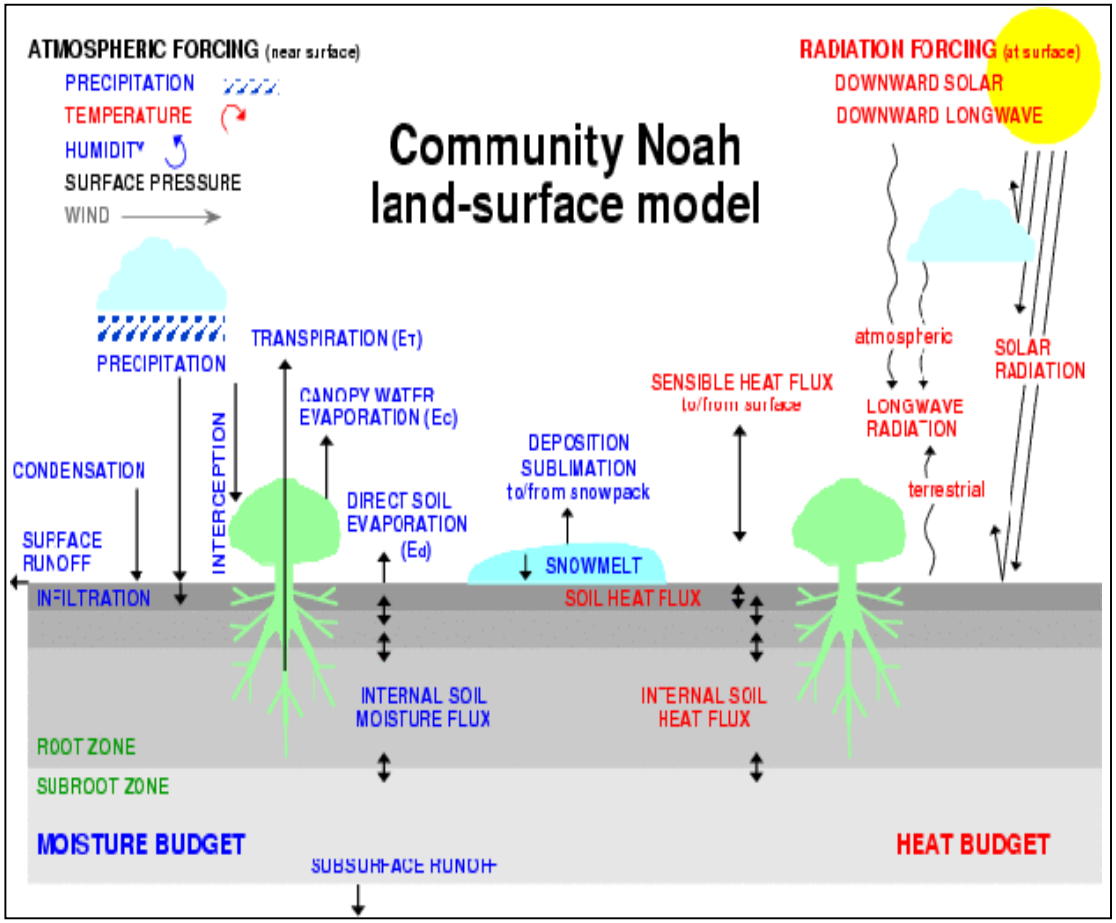
***NCEP, NCAR, UT-Austin, U. Ariz., & others***




**Uncoupled "NLDAS" (drought)**

# Unified NCEP-NCAR Noah Land Model

- Four soil layers (shallower near-surface).
- Numerically efficient surface energy budget.
- Jarvis-Stewart “big-leaf” canopy conductance with associated veg parameters.
- Canopy interception.
- Direct soil evaporation.
- Soil hydraulics and soil parameters.
- Vegetation-reduced soil thermal conductivity.
- Patchy/fractional snow cover effect on sfc fluxes.
- Snowpack density and snow water equivalent.
- Freeze/thaw soil physics.

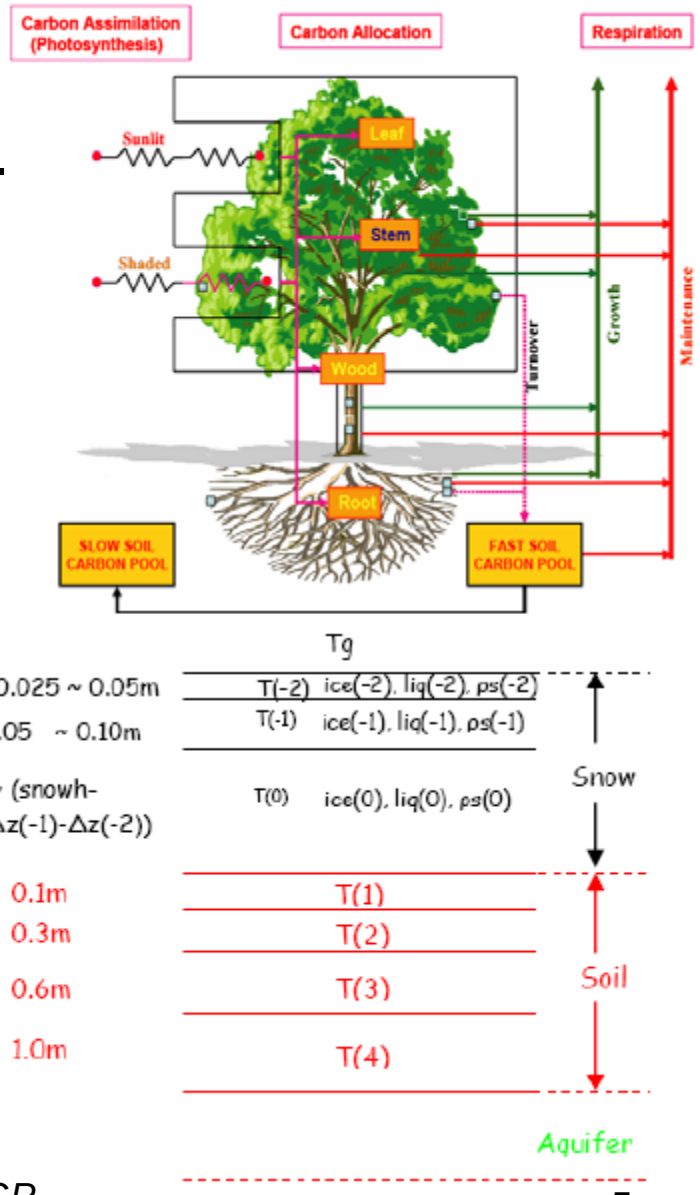



- Noah coupled with NCEP model systems: short-range NAM, medium-range GFS, seasonal CFS, HWRF, uncoupled NLDAS, GLDAS.

# Noah Multi-Physics (Noah-MP)

Noah-MP is an extended version of the Noah LSM with enhanced multi-physics options to address shortcomings in Noah.

- Canopy radiative transfer with shading geometry.
- Separate vegetation canopy layer.
- Dynamic vegetation.
- Ball-Berry canopy resistance.
- Multi-layer snowpack.
- Snow albedo treatment.
- New snow cover.
- Snowpack liquid water retention.
- New frozen soil scheme.
- Interaction with groundwater/aquifer.

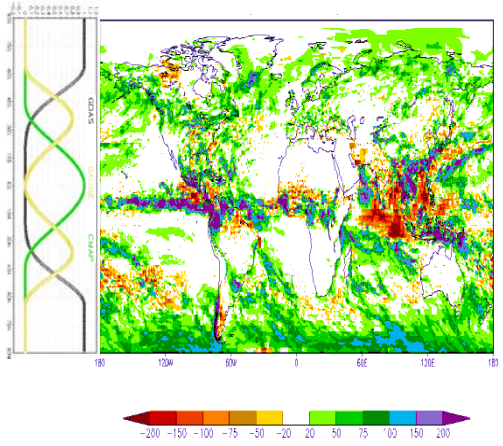



*Main contributors: Zong-Liang Yang (UT-Austin); Guo-Yue-Niu (U. Arizona); Fei Chen, Mukul Tewari, Mike Barlage, Kevin Manning (NCAR); Mike Ek (NCEP); Dev Niyogi (Purdue U.); Xubin Zeng (U. Arizona)*

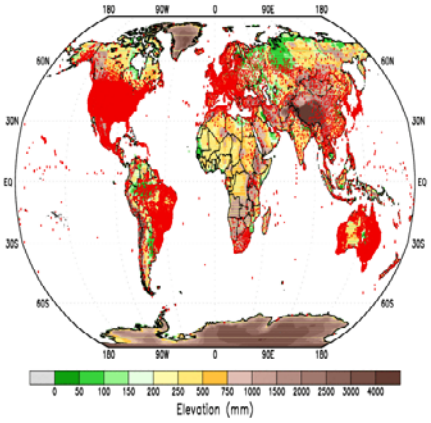
Noah-MP references: Niu et al., 2011, Yang et al., 2011. *JGR*

# *Global Land Data Assimilation System (GLDAS)*

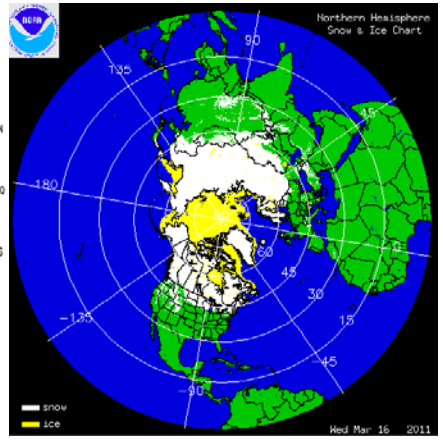
- Uses **Noah land model** running under NASA Land Information System forced with **Climate Forecast System** (CFS) atmos. data assimil. cycle output, & **"blended" precipitation** (gauge, satellite & model), "semi-coupled" –daily updated land states.
- **Snow** cycled if snow from Noah land model within a 0.5x/2.0x envelope of observed value (IMS snow cover, AFWA depth).
- GDIS: GLDAS soil moisture climatology from 30-year runs provides **anomalies** for **drought monitoring**.
- GLDAS land "re-runs", with updated forcing, physics, etc.



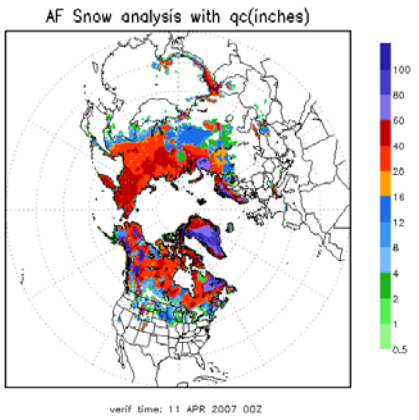

*GDAS-CMAP precip*




*Gauge locations*



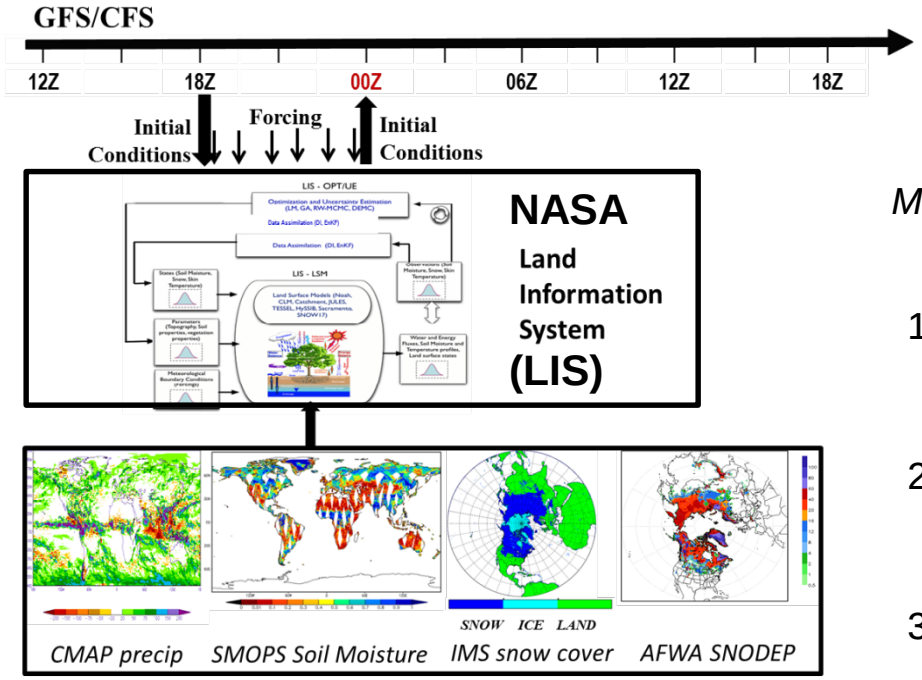

*IMS snow cover*




*AFWA snow depth*

# 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

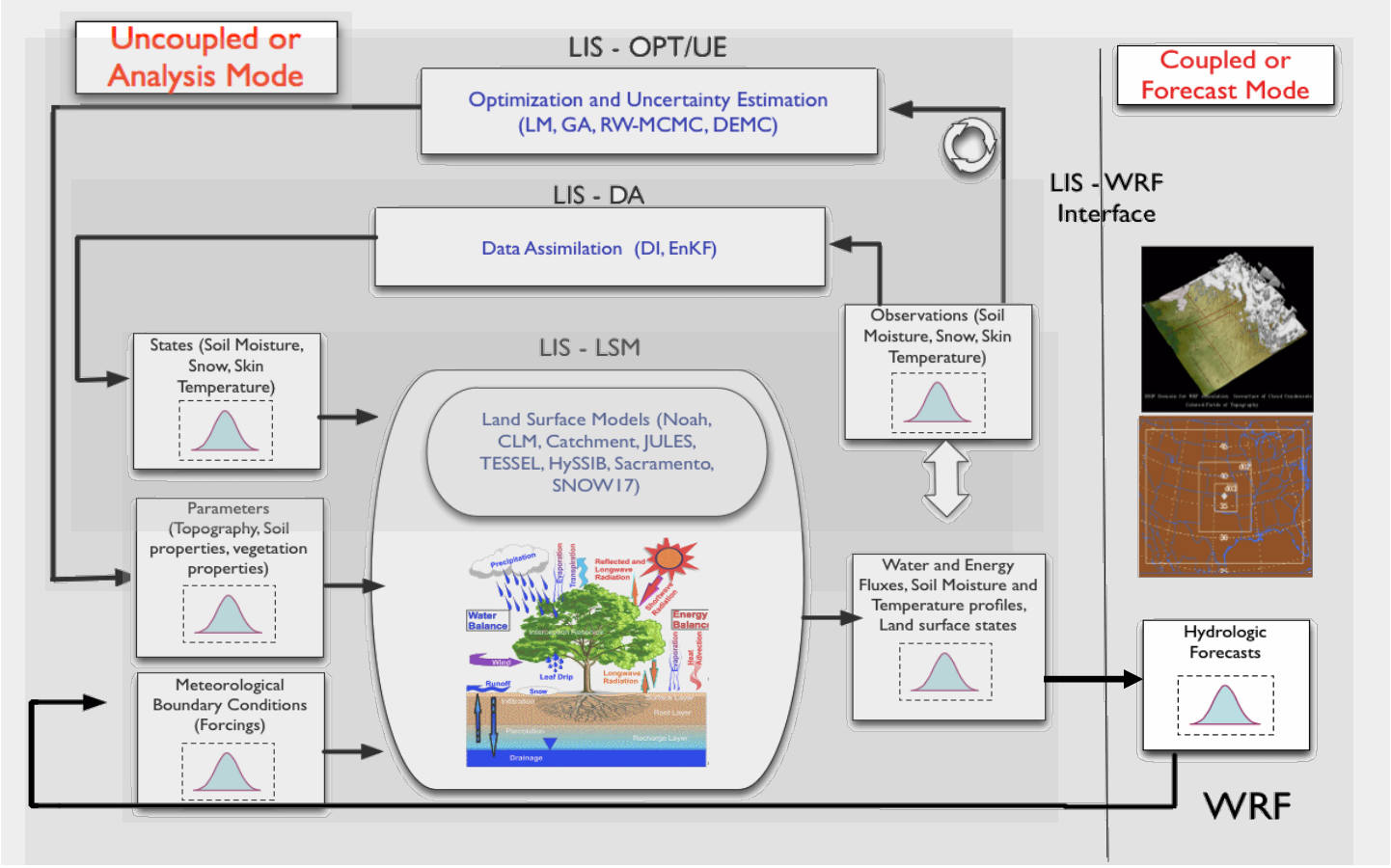
*Michael Ek, Jiarui Dong, Weizhong Zheng (NCEP/EMC)*
*Christa Peters-Lidard, Sujay Kumar (NASA/GSFC)*

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.

# NASA Land Information System (LIS)

- LIS is a flexible land-surface modeling and data assimilation framework developed with the goal of integrating satellite- and ground-based observed data products with land-surface models.

**Data Assimilation of: Soil Moisture, SWE, SCF, TWS**



# NCEP/EMC Land Team and DA Partners

NCEP/EMC Land Team: *Michael Ek*, Jiarui Dong, Weizhong Zheng, Helin Wei, Jesse Meng, Youlong Xia, Rongqian Yang, Yihua Wu, Anil Kumar, Roshan Shresth, working with:

Land Data Assimilation Algorithm:

- NASA/GSFC: *Christa Peters-Lidard*, Sujay Kumar et al. (LIS)
- NASA/GMAO: Rolf Rechelie et al. (EnKF)
- University of Maryland: Ning Zeng, Steve Penny (LETKF)
- NESDIS/STAR: Xiwu Zhan et al. (EnKF)
- Monash University, Australia: Jeffrey Walker (EKF)

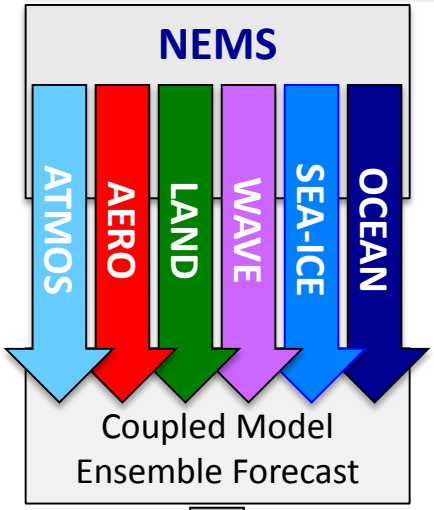
Remotely-sensed Land Data Sets:

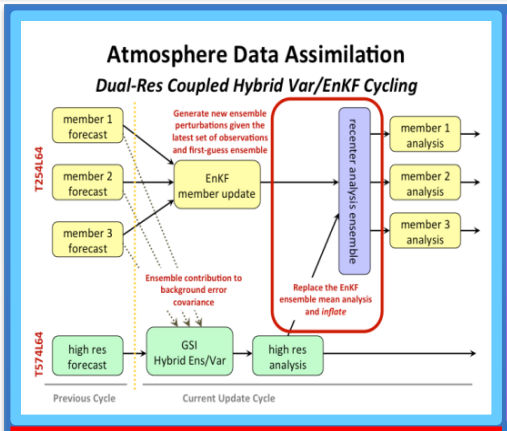
- NESDIS/STAR land group: Ivan Csiszar, Xiwu Zhan (soil moisture), Bob Yu (Tskin), Marco Vargas (vegetation) et al.
- NESDIS/OSPO: Sean Helfrich (IMS snow cover)
- 557th Weather Wing: Jeffrey Cetola (snow depth)
- NASA/GSFC: Dorothy Hall (MODIS snow cover), James Foster (SWE)

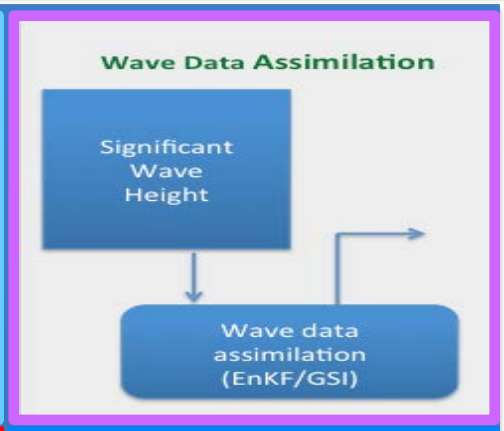
Verification:

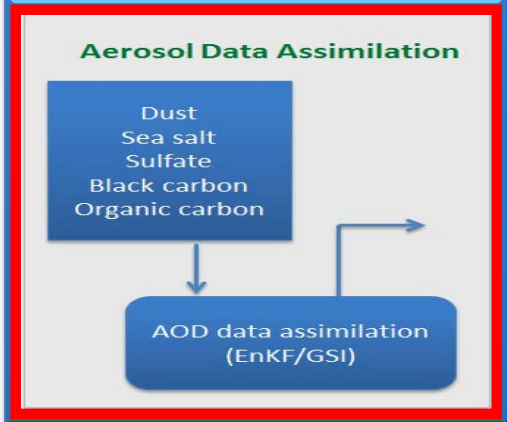
- GEWEX/GLASS, GASS projects: Land model benchmarking, land-atmosphere interaction exp. with international partners.

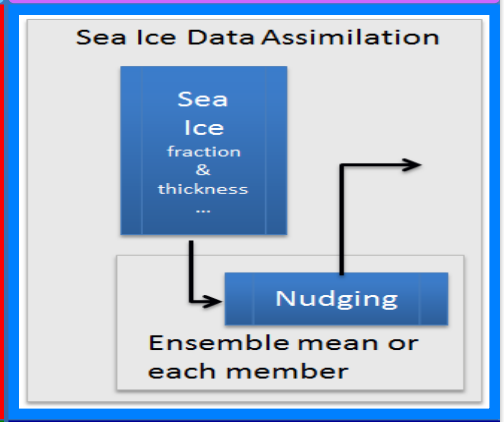
# NCEP Coupled Hybrid-EnKF Data Assimilation System

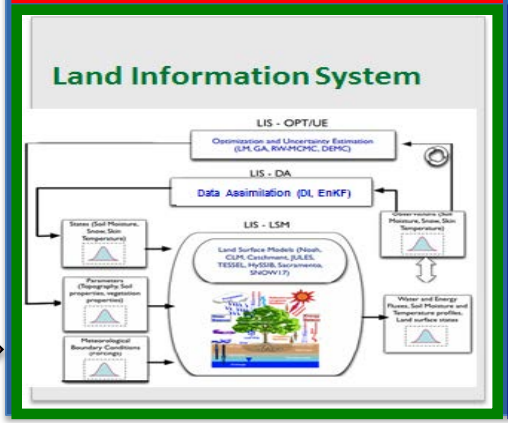


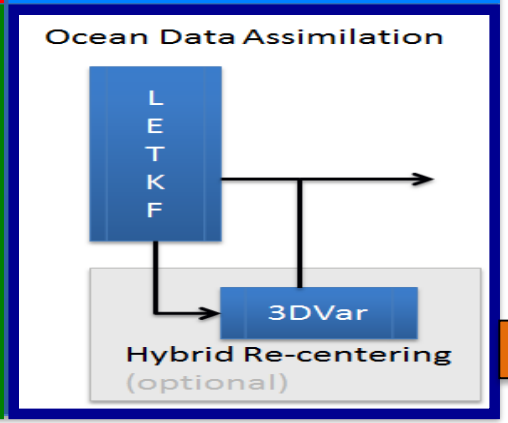



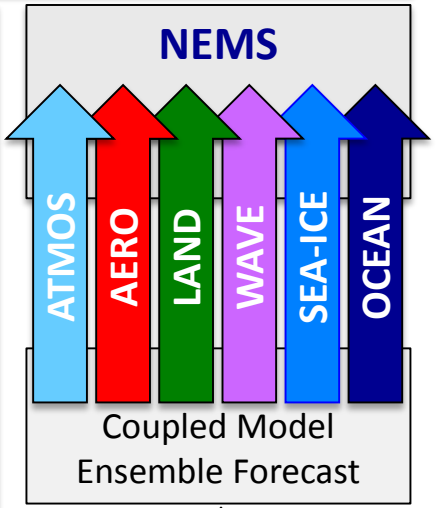




**Coupled Ensemble Forecast (N members)**

**Ensemble Analysis (N Members)**

**INPUT**

**OUTPUT**

# *Snow Products Received at NCEP*

The **Air Force 557th Weather Wing (557WW)** snow depth is estimated daily by merging satellite-derived snow cover data with daily snow depth reports from ground stations.

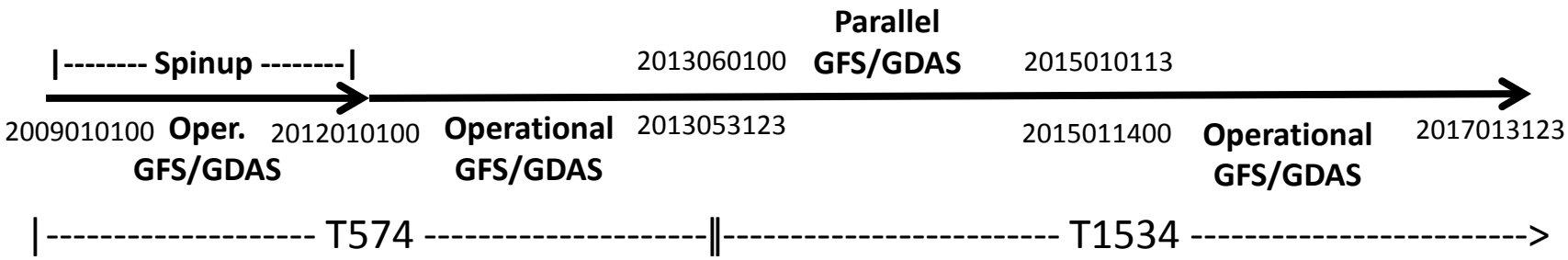
Snow depth reports are updated by additional snowfall data or decreased by calculated snowmelt.

The **Interactive Multisensor Snow and Ice Mapping System (IMS)** snow cover product is a snow cover analysis at 4-km resolution manually created by looking at all available satellite imagery, several automated snow mapping algorithms, and other ancillary data.

Regions covered by cloud during the 24-hour analysis period take lower resolution passive microwave data and surface observations into account where possible. There are no missing values over the mapped region.

# Experiment Design

**1. Forcing:**




**2. Initial conditions:**

**Spinup run** three times over GFS forcing from 01/01/2009 to 12/31/2011

**Control Run**: Starting at 00Z 01/01/2012 with initial condition from spinup run

**Direct Replacement**: Starting at 01/01/2014 with the initial condition from the Control Run.

**EnKF**: With 20 ensemble members starting at 01/01/2014 with the initial condition from the Control Run.

**3. Model configuration:**

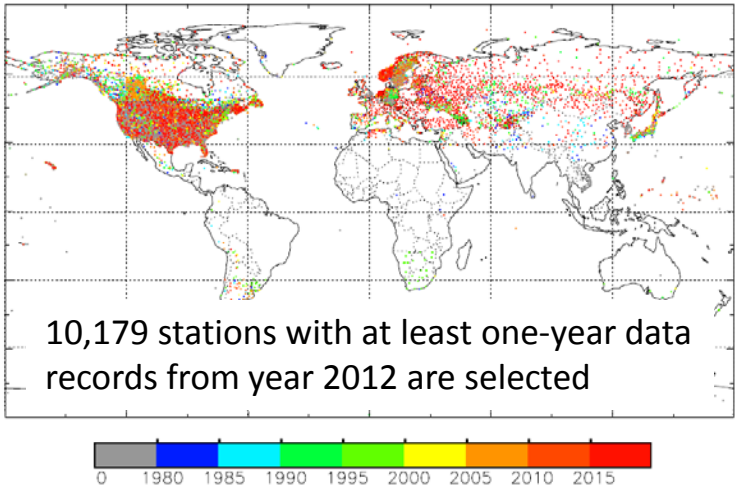
Model is configured at T1534 (3072 by 1536) globally

# Verification Data and Method

***POD*$_S$ measures the fraction of observed snow cover presence that were correctly detected in AFWA/IMS/GFS**

***POD*$_N$ measures the fraction of observed snow-free land that were correctly detected in AFWA/IMS/GFS**

***FAR* measures the fraction of observed snow-free land that were incorrectly detected as snow cover in AFWA/IMS/GFS**




$$POD_S = \frac{SS}{NS + SS}$$

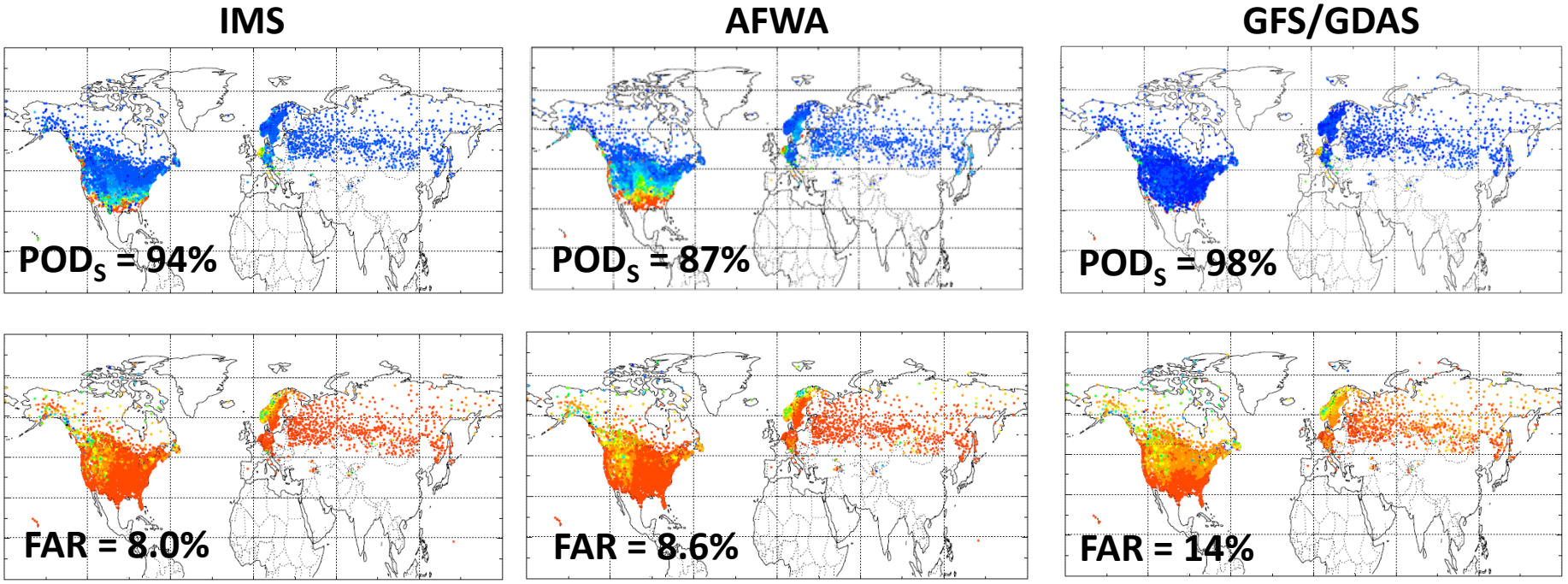
$$POD_N = \frac{NN}{NN + NS}$$

$$FAR = \frac{SN}{SN + NN}$$

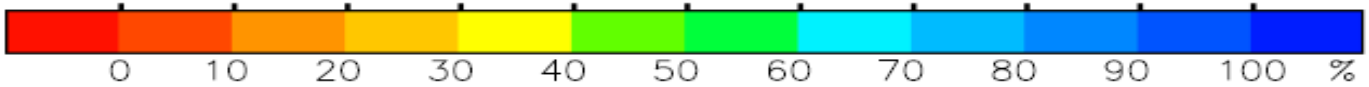
| | | OBS | |
|---|---|---|---|
| | | SNOW | NO SNOW |
| AFWA IMS GFS LIS | SNOW | SS | SN |
| | NO SNOW | NS | NN |

***POD*: Probability of Detection**
***FAR*: False Alarm Ratio**

# Statistics of Snow Cover Mapping




**POD and FAR statistics of IMS SCA, AFWA snow depth and GFS snow depth**

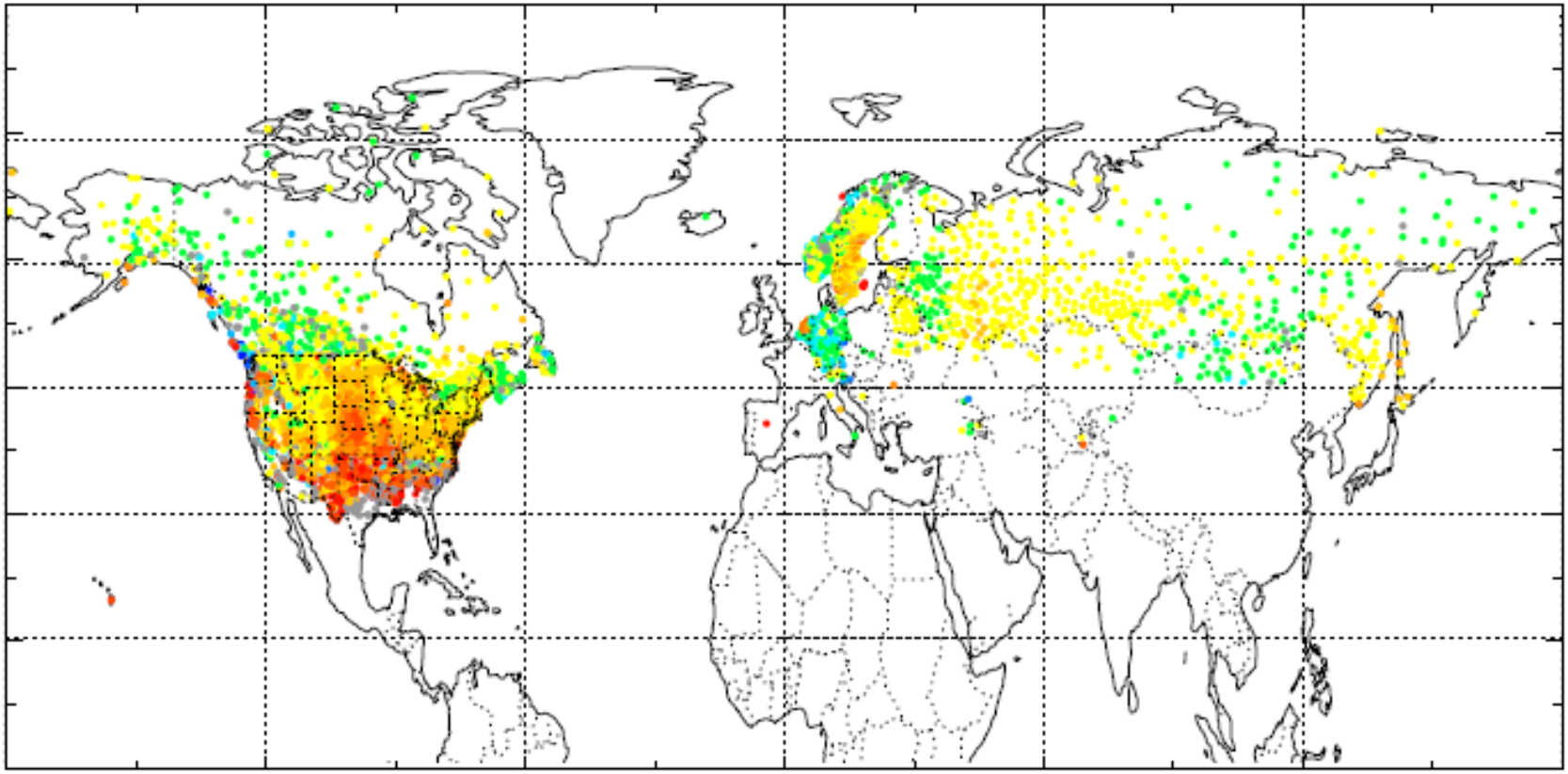



$$POD_S = \frac{SS}{NS + SS}$$

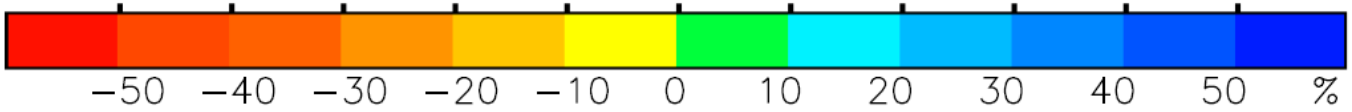
$$FAR = \frac{SN}{SN + NN}$$

**GFS/GDAS Product:** Higher *POD* (98%) everywhere, but larger *FAR* (14%) in Canada, Mountains in the US and Europe.
**Satellite Products:** Lower *POD* in the southern U. S. and larger *FAR* in mountains of the US and in Norway

# $POD_{afwa}$ - $POD_{ims}$

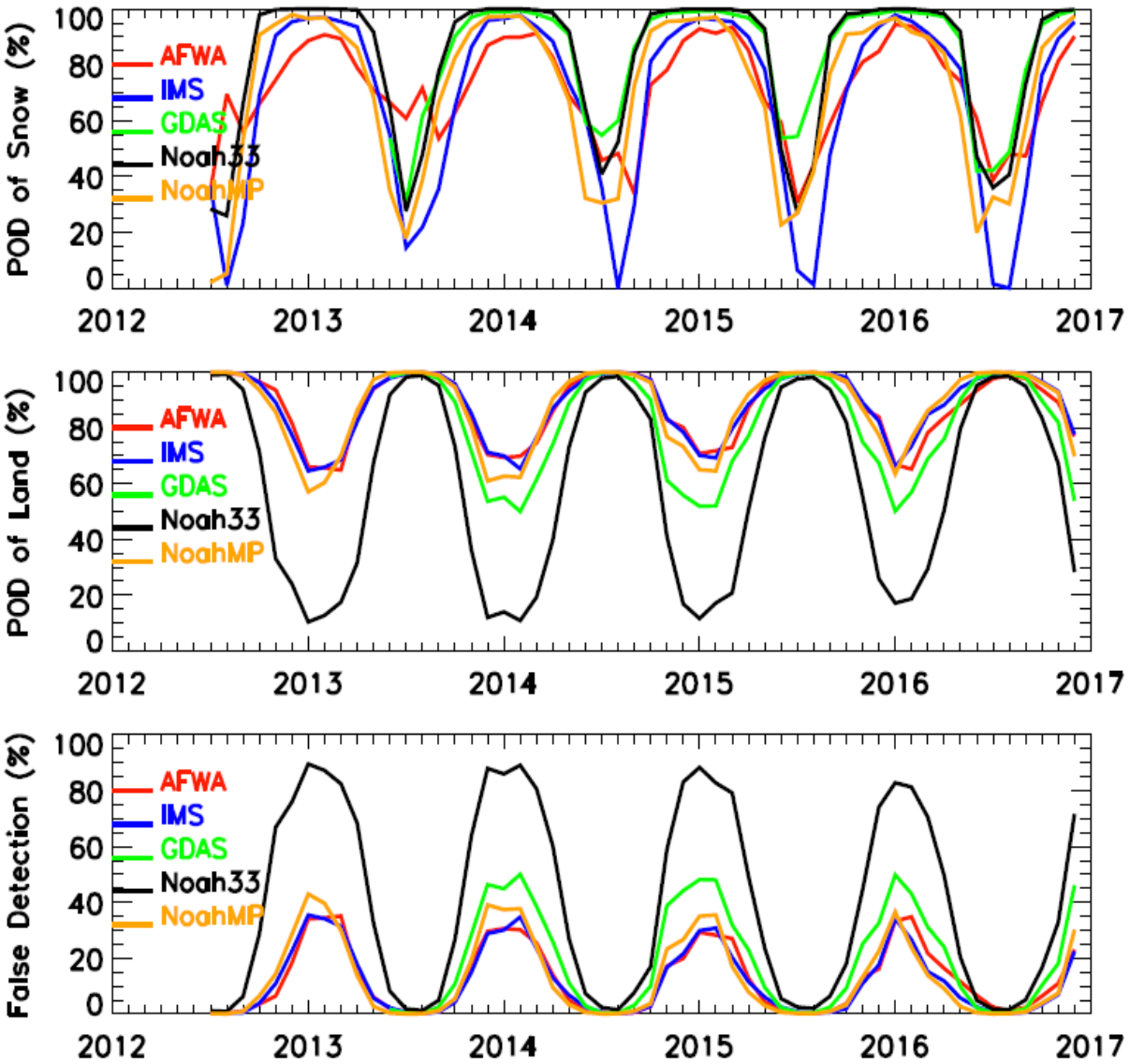


**Comparison of POD between AFWA SNODEP and IMS Snow Cover**




IMS snow cover product shows higher accuracy in snow cover detection than AFWA/SNODEP, especially over CONUS. Assimilation of IMS snow cover will be helpful in the regions with fast snow phase changes.

# Snow Cover Mapping




GFS demonstrates a strong ability to simulate the presence of snow cover (98%) comparing to IMS (94%) and AFWA SNODEP (87%).

However, GFS shows larger false snow cover detection (>40%) in winter months than IMS and AFWA (<30%).

LIS/Noah Cycle with GFS forcing shows even higher *POD* in snow detection (99%), but false alarm ratio is as higher as 80% during winter months.

$$POD_S = \frac{SS}{NS + SS}$$

$$POD_N = \frac{NN}{NN + NS}$$

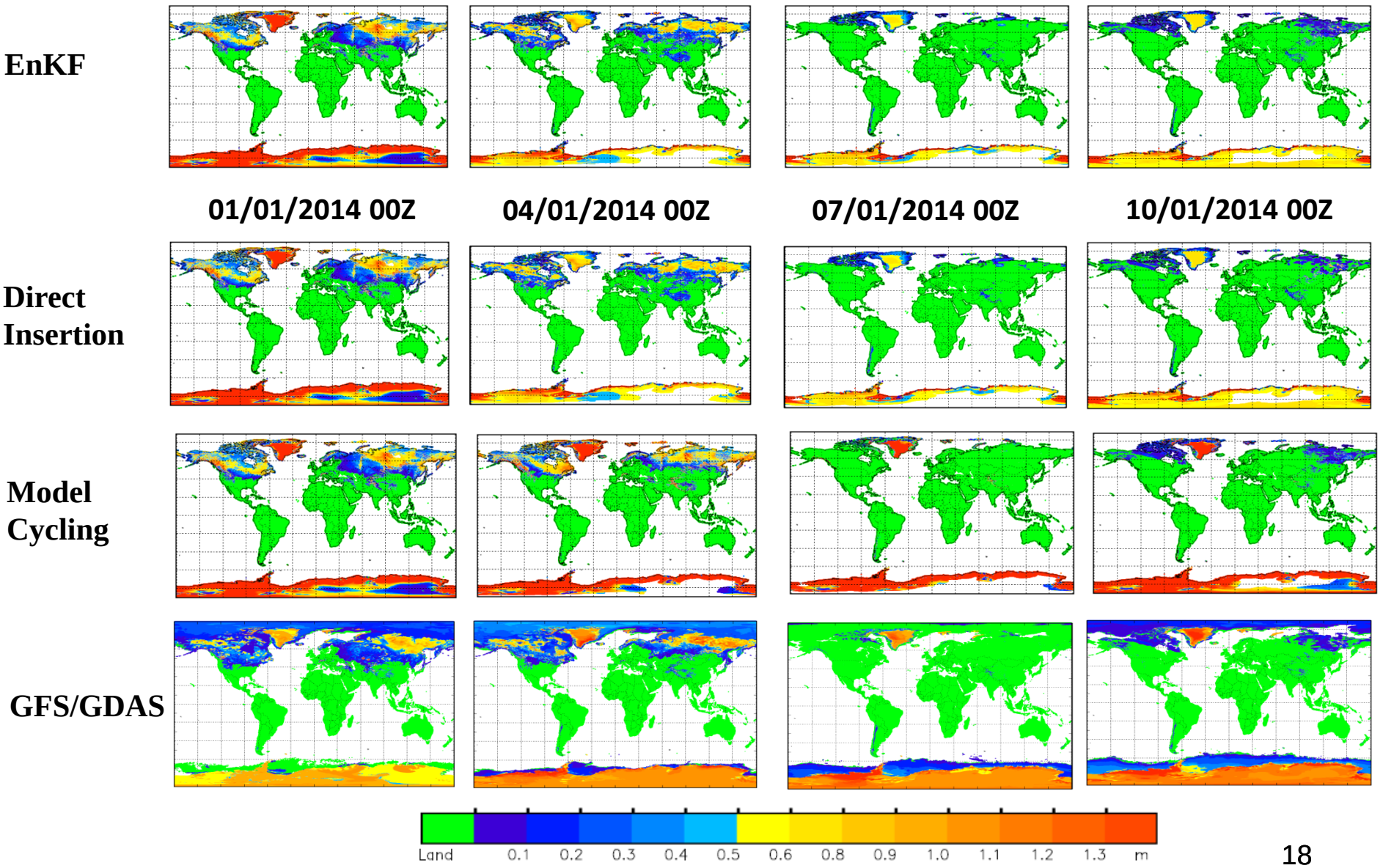
# Snow Cover Mapping

| | $POD_S$ | FAR | Accuracy $POD_{S+N}$ |
|---|---|---|---|
| IMS | 93.85 | 8.29 | 91.91 |
| AFWA | 87.46 | 8.80 | 90.85 |
| GFS/GDAS | 98.35 | 14.47 | 86.69 |
| Noah.3.3 | 99.50 | 32.10 | 71.01 |
| Noah-MP3.6 | 93.71 | 9.03 | 91.24 |

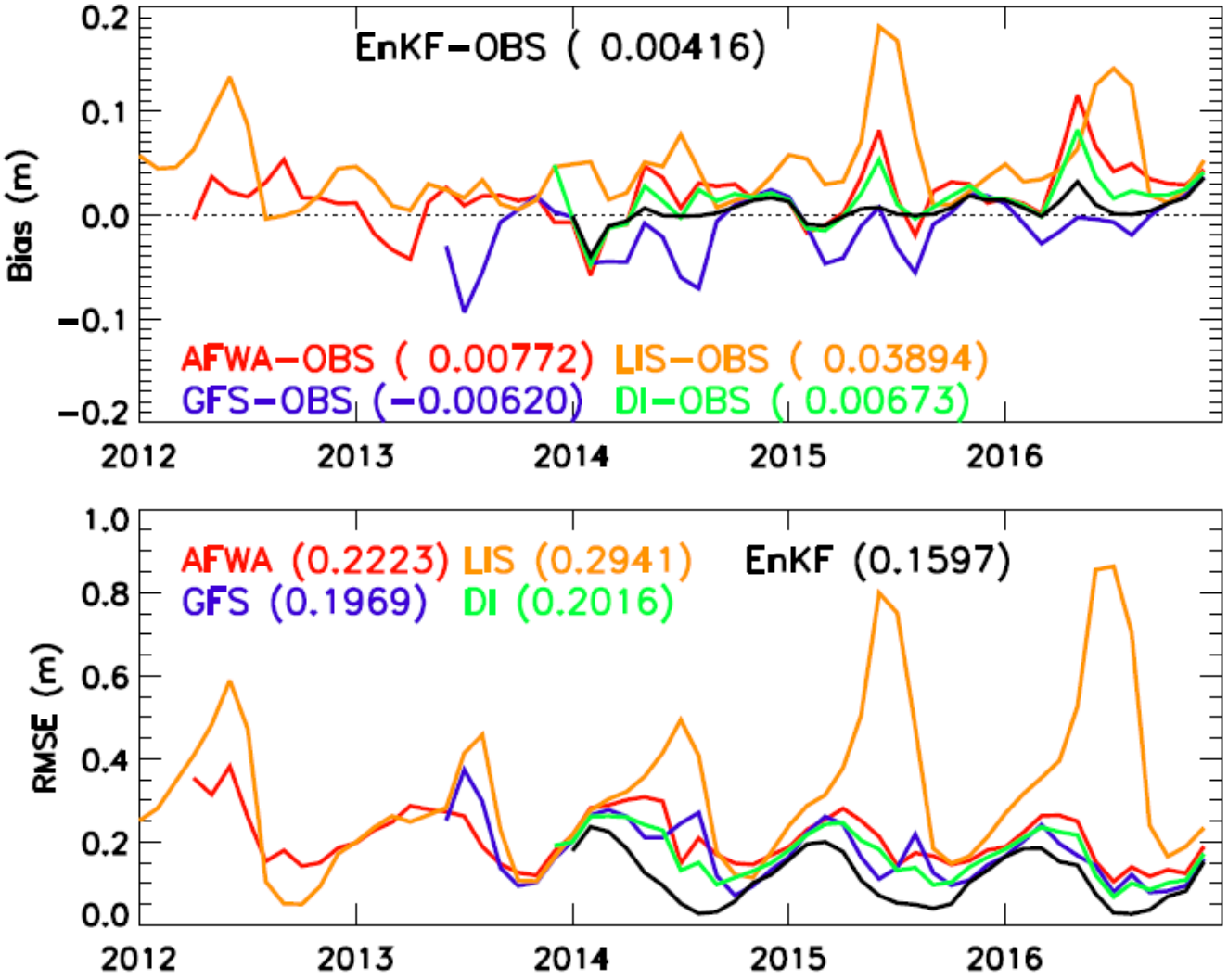
$$POD_S = \frac{SS}{NS + SS} \qquad FAR = \frac{SN}{SN + NN} \qquad POD_{S+N} = \frac{SS + NN}{NS + SS + SN + NN}$$

Noah.3.3 cycled with GFS forcing shows higher *POD* of snow (99.5%), but with large FAR (32%).
The general accuracy of *POD* of snow and land ($POD_{S+N}$) is higher from IMS, AFWA and Noah-MP cycle.

# Demonstration of LIS land data assimilation of AFWA Snow Depth

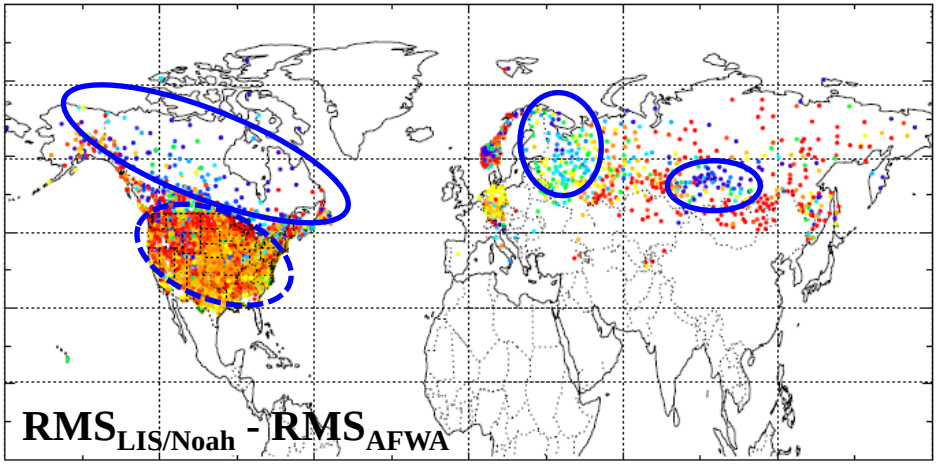


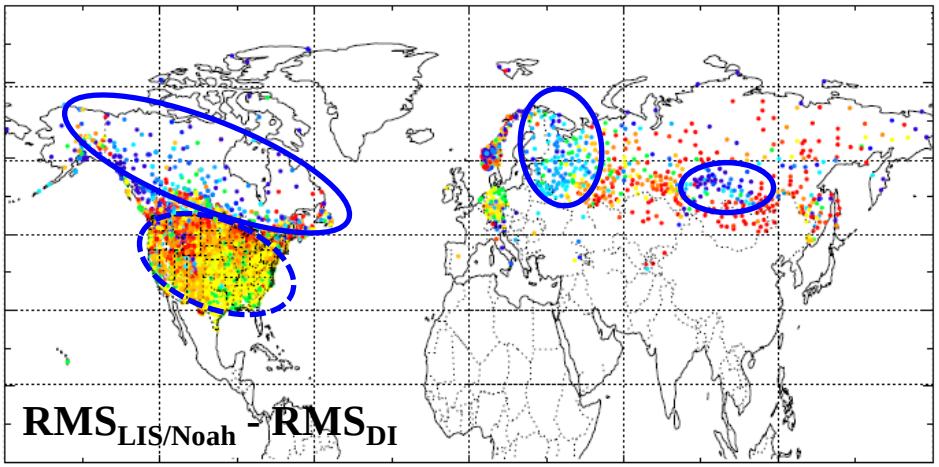
# AFWA / Noah33 / GFS / DI / EnKF

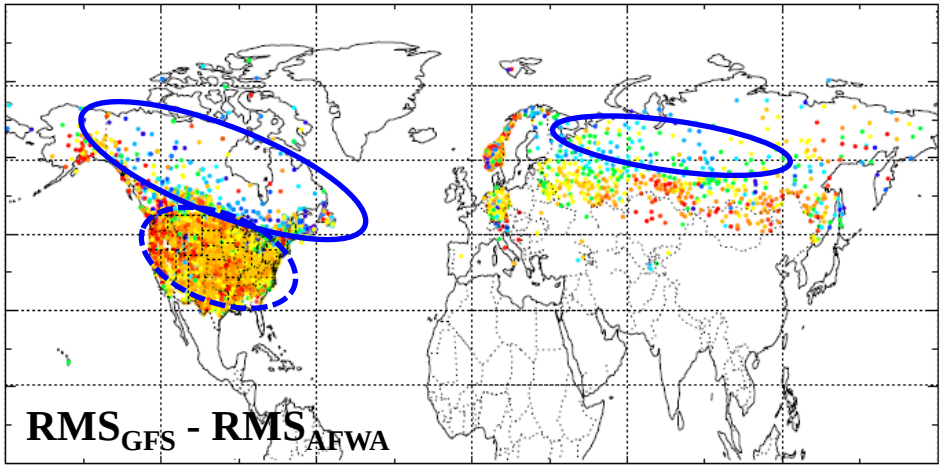


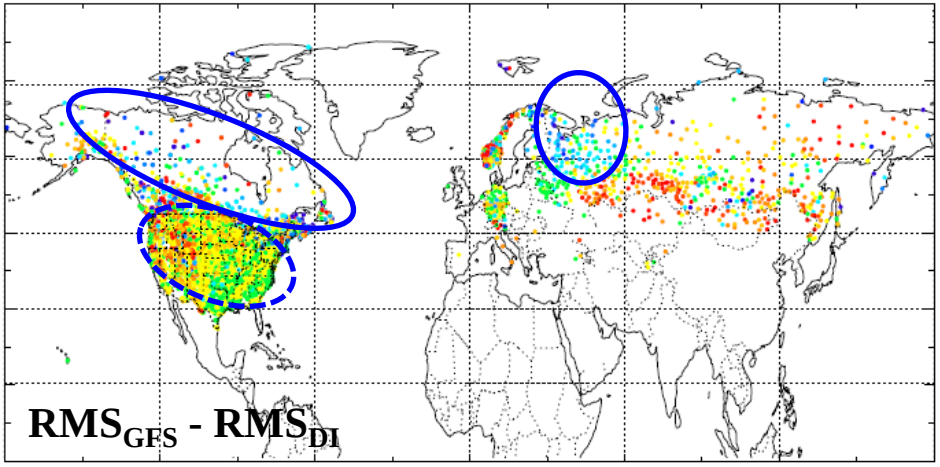

Temporally, **AFWA/SNODEP** shows positive bias, and **GFS/GDAS** shows negative bias.
**DI** (ingest AFWA/SNODEP into Noah) shows improved estimates in snowdepth with less bias and RMS errors.
**EnKF** DA results are much better than all the other products with bias and RMS significantly reduced.

# AFWA SNODEP and DI

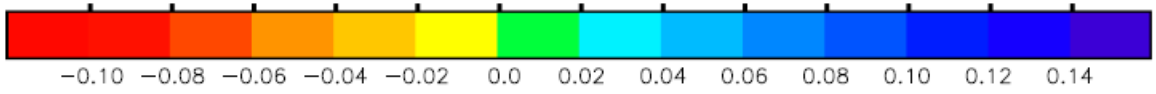



**Statistics over January 2014 to December 2016**

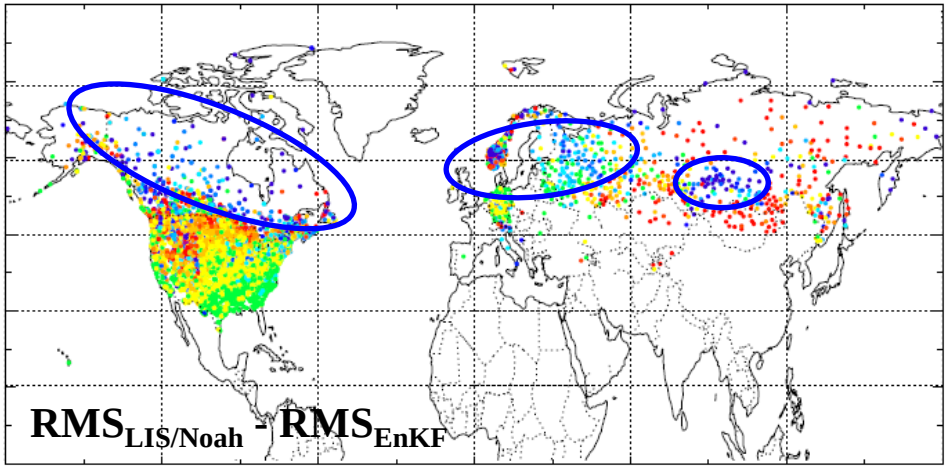


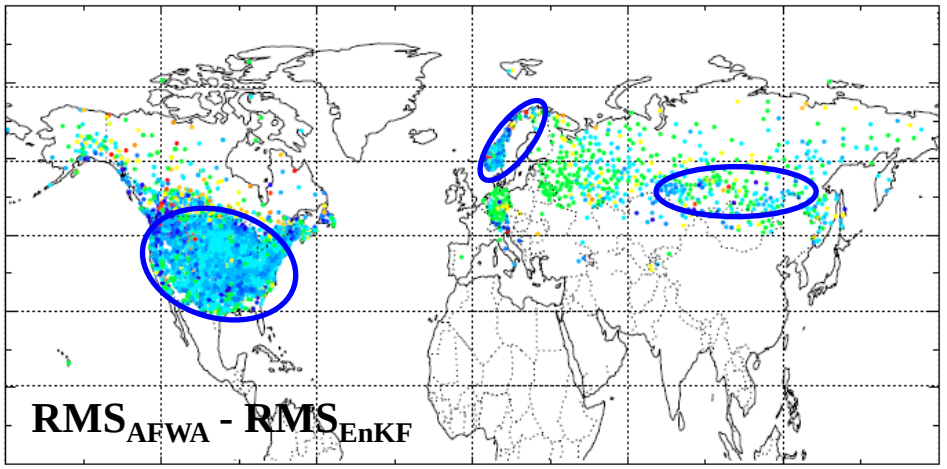

**AFWA SNODEP** is better in Canada and Europe, and **DI Assimilation** shows improvements in these regions.

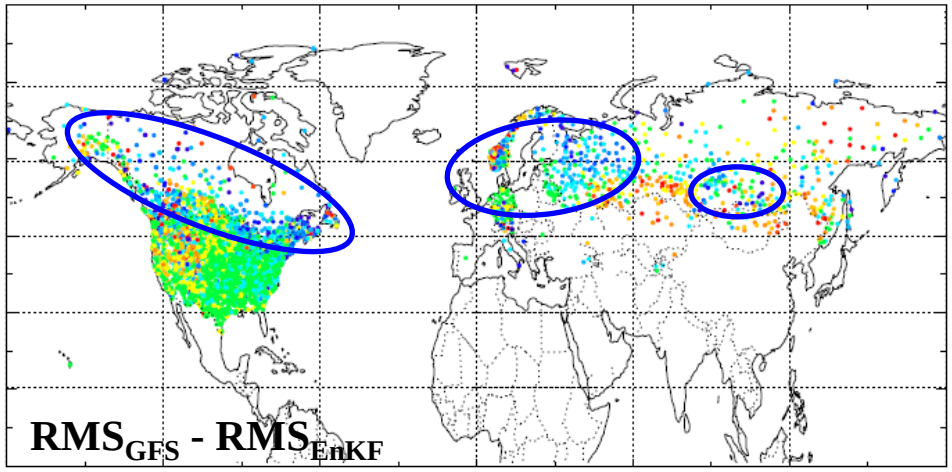
**AFWA SNODEP** is worse over CONUS, while **DI Assimilation** of AFWA SNODEP shows improvements over CONUS.

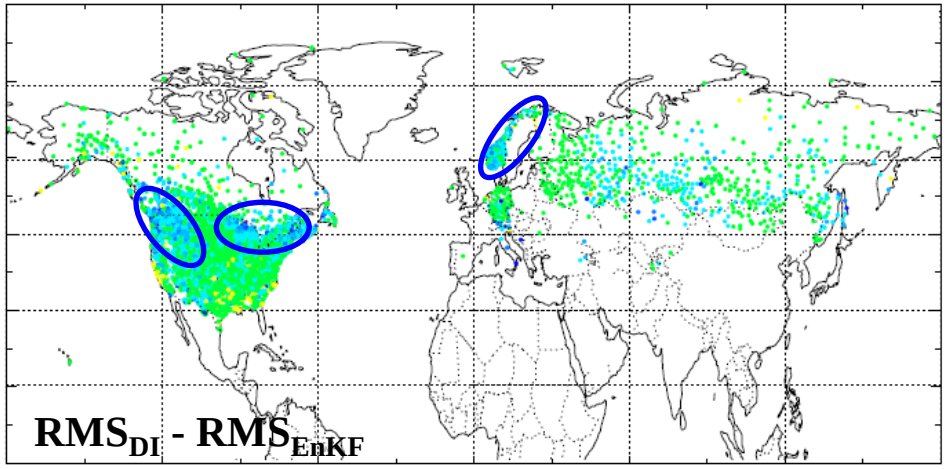
High quality satellite data will be required to improve surface snow depth estimates.

# EnKF vs Others

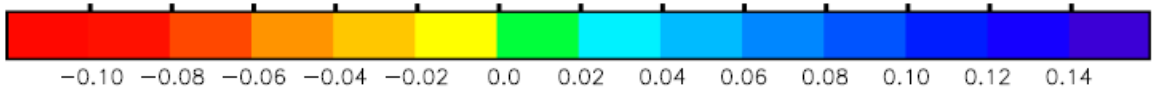



**Statistics over January 2014 to December 2016**




**LIS EnKF DA** results are better than all the other products including **model cycling**, **AFWA/SNODEP**, **GFS/GDAS**, and **DI**. Again, high quality satellite data result in big improvement in snow depth estimates.

# *Summary*

- For NWP and seasonal forecasting, assimilation of AFWA SNODEP snowdepth demonstrated the improved estimates of surface states.

- Noah-MP is improved with explicit canopy, $CO_2$-based photosynthesis, dynamic vegetation, groundwater, multi-layer snowpack, and refined soil processes. Noah-MP is good at mapping snow.

- Large errors of snow depth modeling result from forcing including cold bias and overestimates of snowfall. EnKF is working relatively well with considering the errors from forcing fields.


THANK YOU!