Efforts to Assimilate the AFWA Snow Depth Product into NCEP Operational CFS/GFS System

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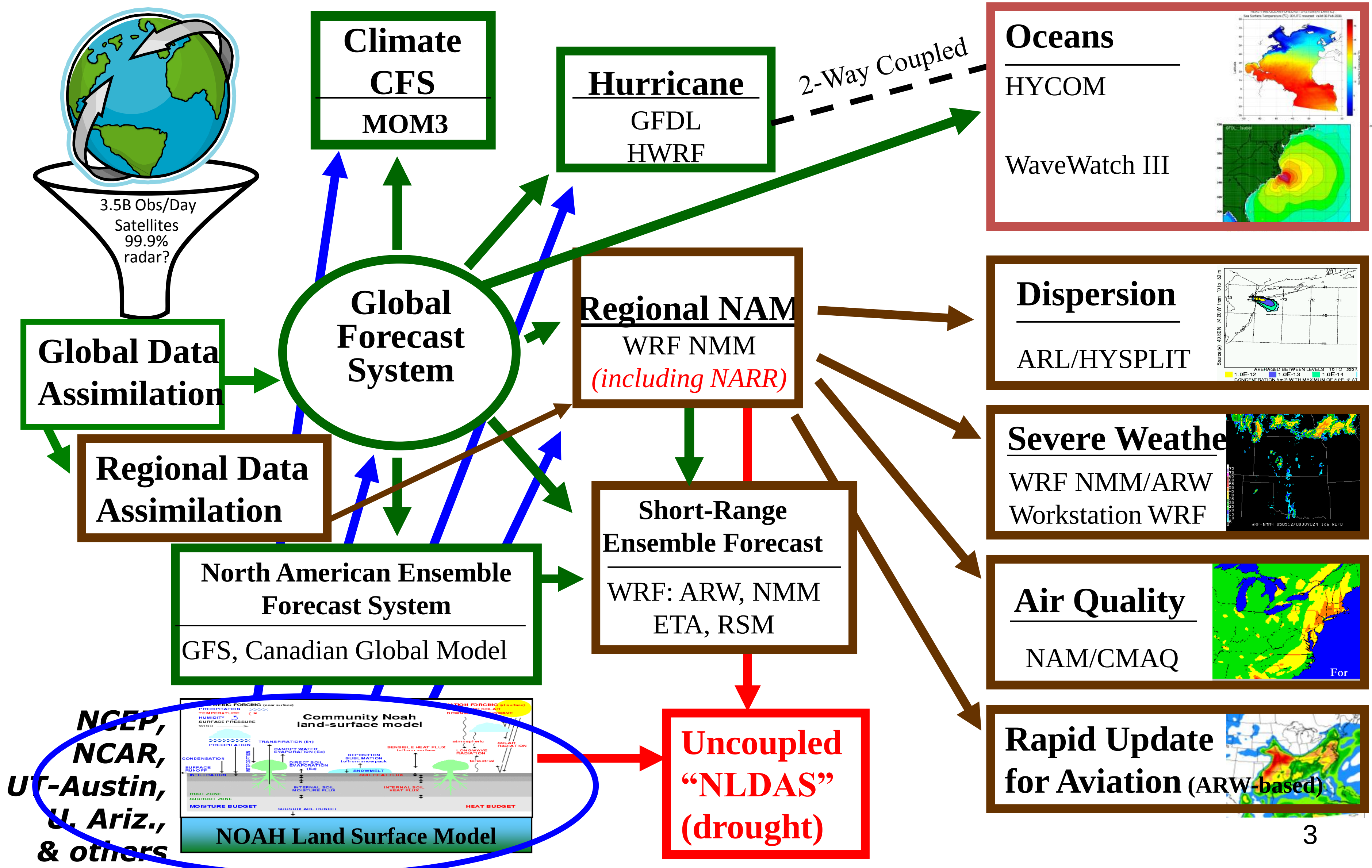
ISWG Workshop in Monterey, CA • 19-20 July 2017

Outline

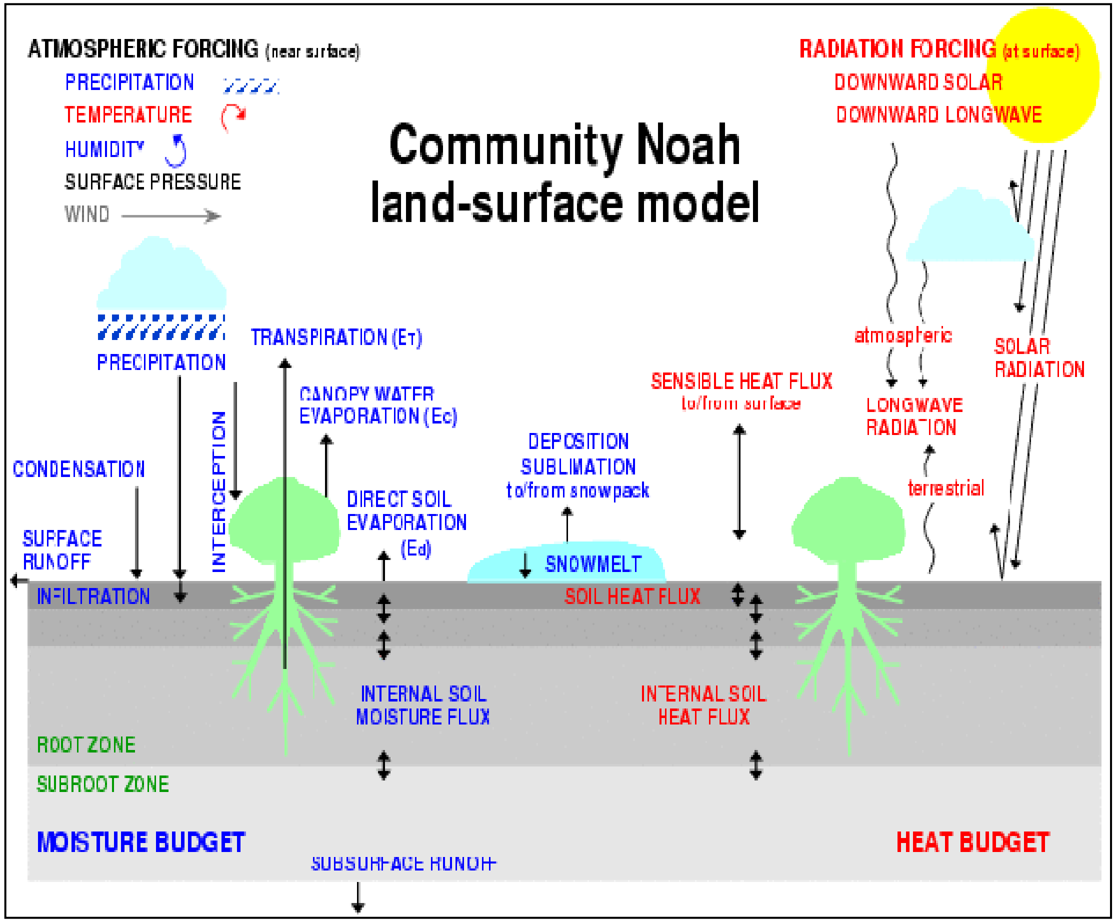
- NCEP Land Data Assimilation Systems
- NASA Land Information System Applications
- Land Data Assimilation Experiments
- Summary

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



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.

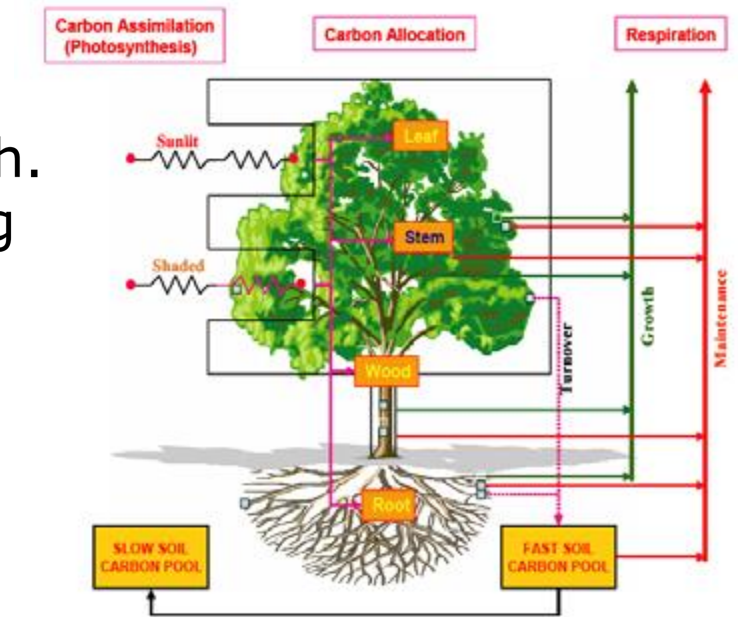


- Noah coupled with NCEP model systems: short-range NAM, medium-range GFS, seasonal CFS, HWRF, uncoupled NLDAS, GLDAS.

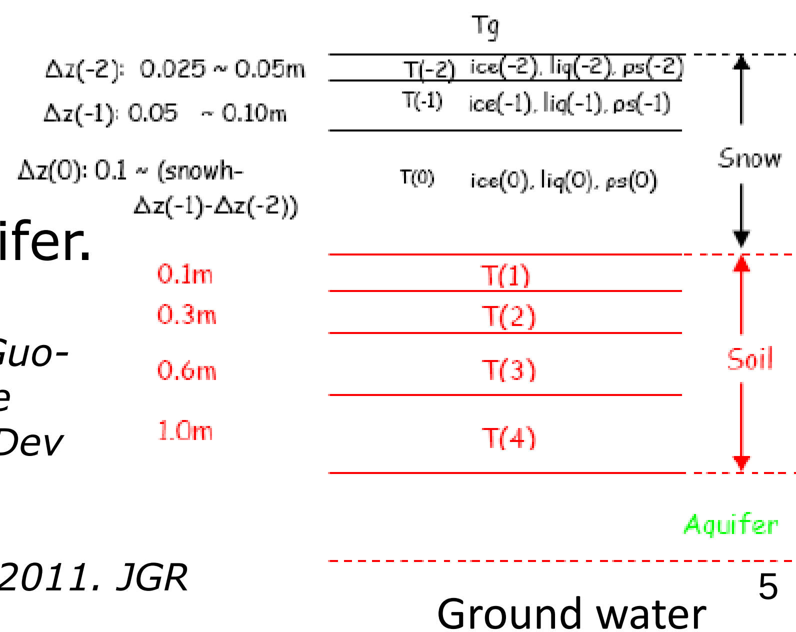
Noah Multi-Physics (Noah-MP)

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.



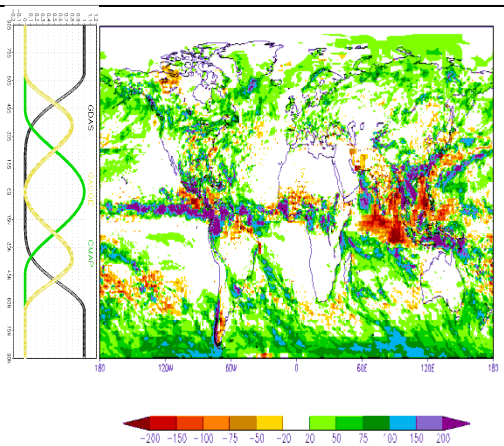
Main contributors: Zong-Liang Yang (UT-Austin); Guo-Yue-Niu (U. Arizona); Fei Chen, Mukul Tewari, Mike Barlage, Kevin Manning (NCAR); Mike Ek (NCEP); Dev Niyogi (Purdue U.); Xubin Zeng (U. Arizona)



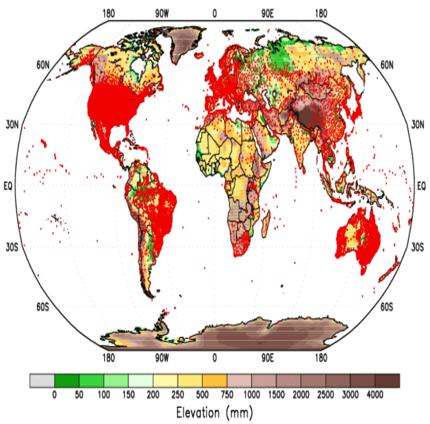
Noah-MP references: Niu et al., 2011, Yang et al., 2011. JGR

Global Land Data Assimilation System (GLDAS)

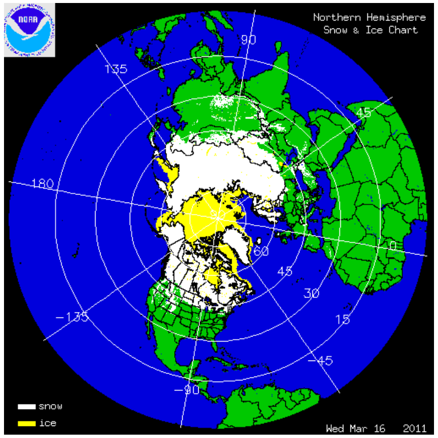
- Uses **Noah land model** running under NASA Land Information System forced with **Climate Forecast System** (CFS) atmos. data assimil. cycle output, & **"blended" precipitation** (gauge, satellite & model), "semi-coupled" –daily updated land states.
- **Snow** cycled if snow from Noah land model within 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.



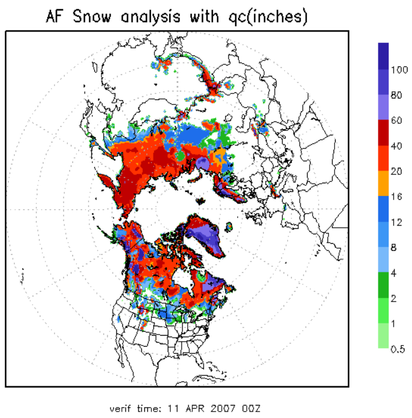
GDAS-CMAP precip



Gauge locations



IMS snow cover

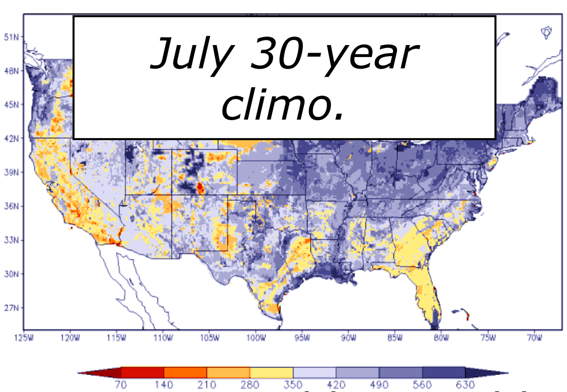


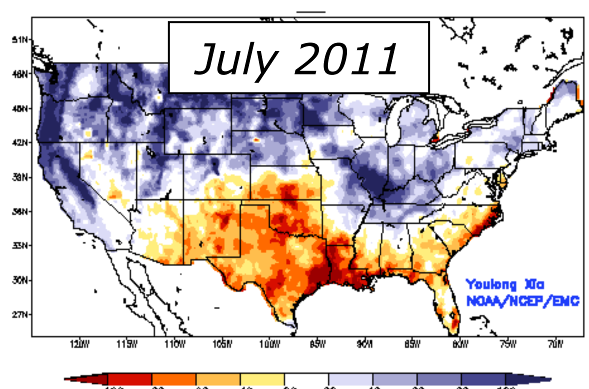
AFWA snow depth

North American Land Data Assimilation System (NLDAS)

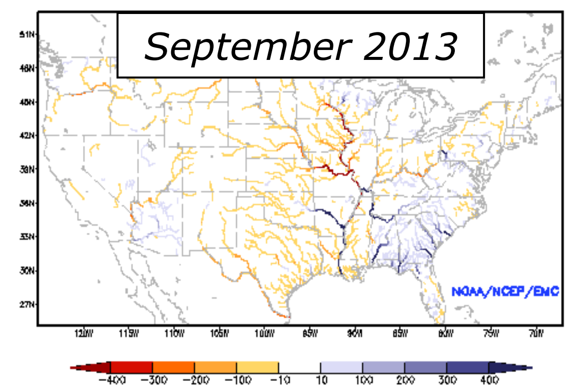
- 5 Aug 2014: North American LDAS (NLDAS) operational.
- NLDAS: 4 land models run uncoupled, driven by CPC observed precipitation & NCEP R-CDAS atmospheric forcing.
- Output: 1/8-deg. **land** & **soil states**, **surface fluxes**, **runoff** & **streamflow**; anomalies from 30-yr climatology for drought.
- Future: higher res. (~3-4km), extend to N.A./global domains, improved land data sets/data assimil. (soil moisture, snow), land model physics upgrades inc. hydro., initial land states for weather & seasonal climate models; global drought information.

www.emc.ncep.noaa.gov/mmb/nldas





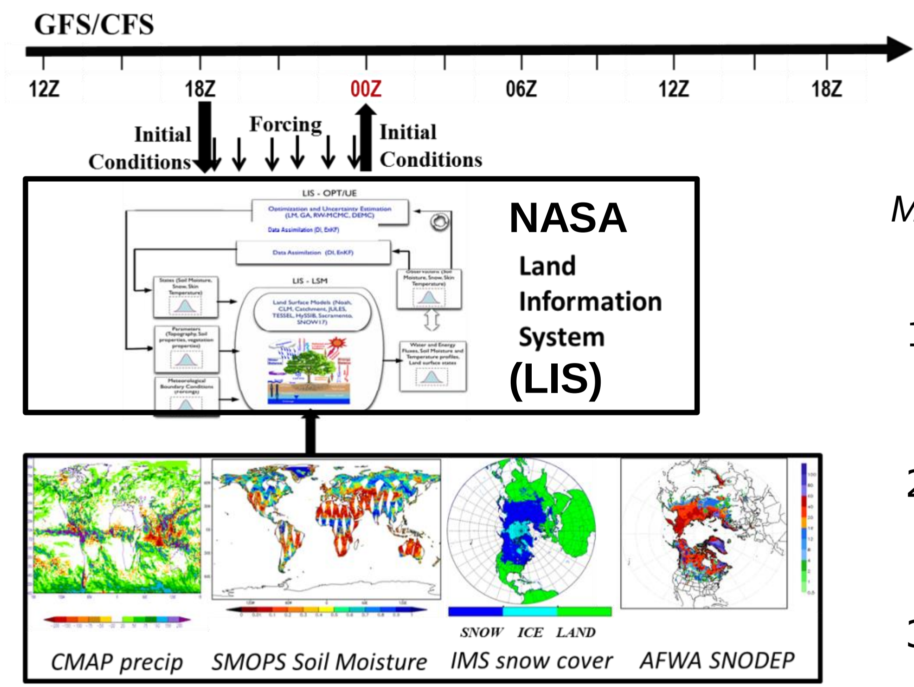
Ensemble monthly soil moisture anomaly



Daily streamflow anomaly

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

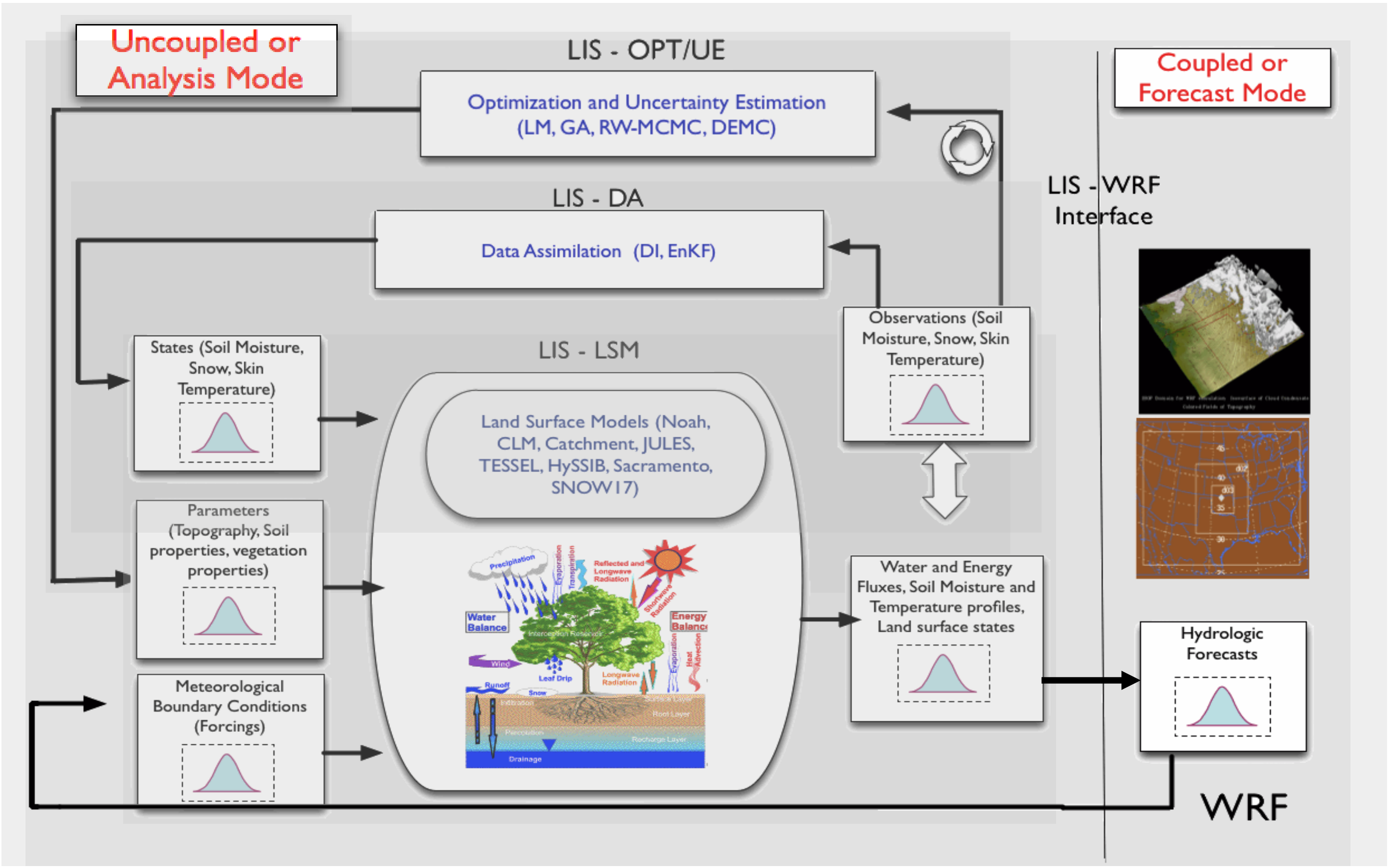
Michael Ek, Jiarui Dong, Weizhong Zheng (NCEP/EMC)
Christa Peters-Lidard, Grey Nearing (NASA/GSFC)

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.

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 Realtime Operational System

	GFS/CFS/ GLDAS	Meso. NAM	NLDAS	LIS
Noah Version	2.7.1	3.0	2.8	2.7.1 to 3.6 Noah-MP
Resolution	T1534	12km	1/8th degree	Multiple
Grid	Gaussian	B-grid	Lat/Lon	Multiple
Forcing	Coupled	Coupled	Offline	Offline
Atmos. DA	GSI/GSI/NA	GSI	NA	NA
Land DA	DI/DI/DI	DI	NA	DI, EnKF

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, Caterina Tassone, Roshan Shresth, working with:

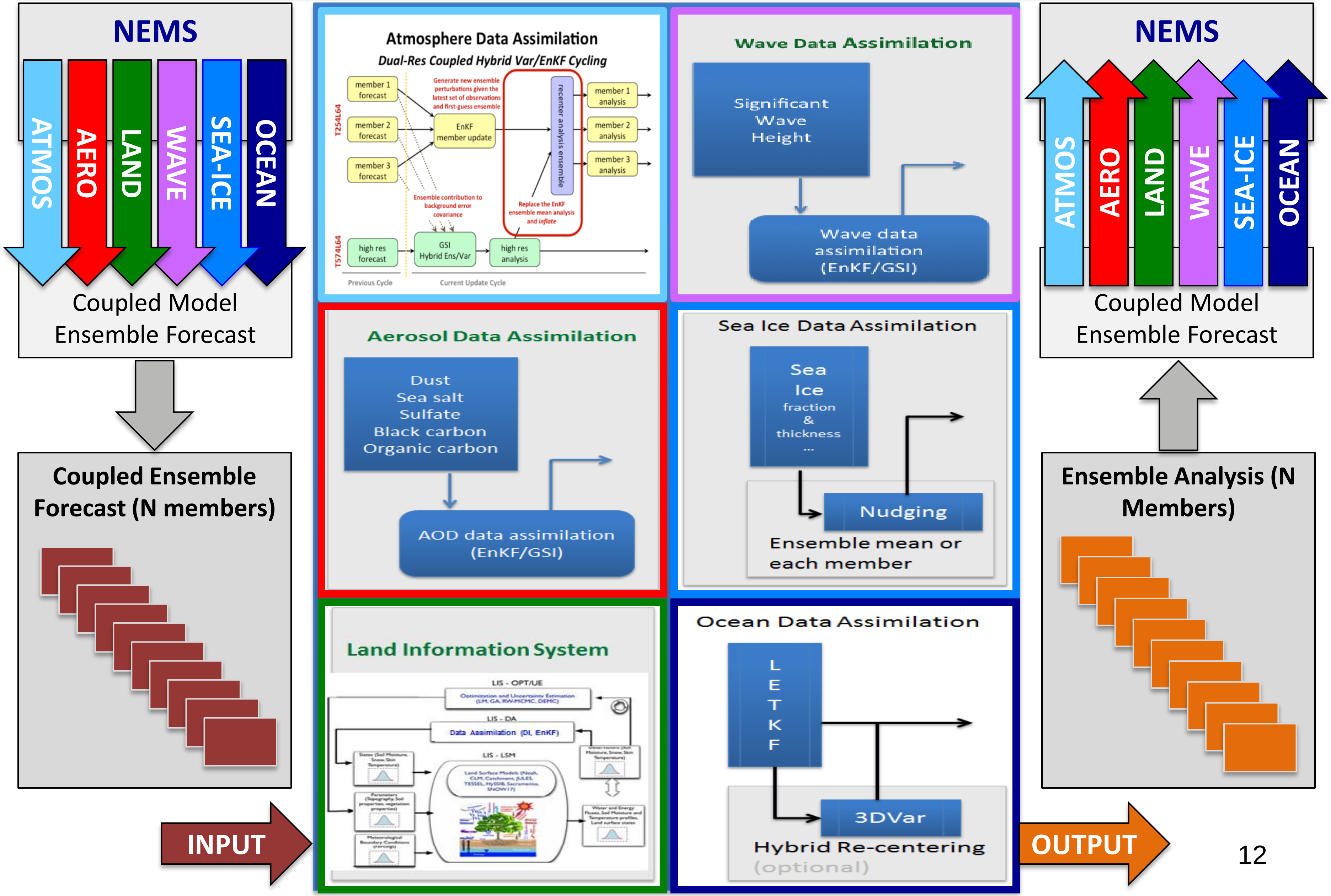
Land Data Assimilation Algorithm:
- NASA/GSFC: *Christa Peters-Lidard*, Sujay Kumar et al. (LIS)
- NASA/GMAO: Rolf Rechelie et al. (EnKF)
- University of Maryland: Ning Zeng, Steve Penny (LETKF)
- NESDIS/STAR: Xiwu Zhan et al. (EnKF)
- Monash University, Australia: Jeffrey Walker (EKF)

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)
- AFWA: 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



Operational Snow Products

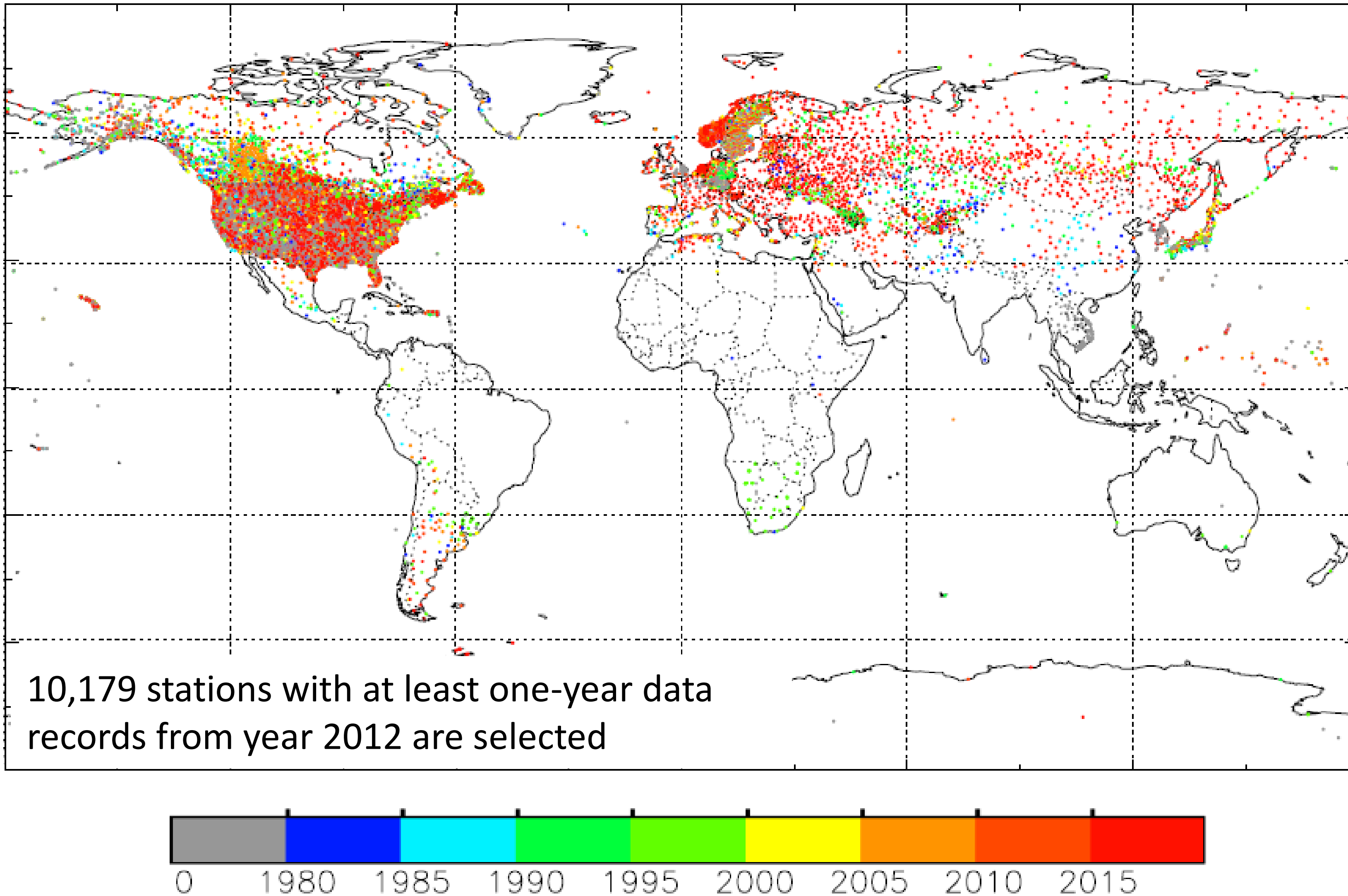
The **Air Force Weather Agency (AFWA)** snow depth is estimated daily by merging satellite-derived snow cover data with daily snow depth reports from ground stations.

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.

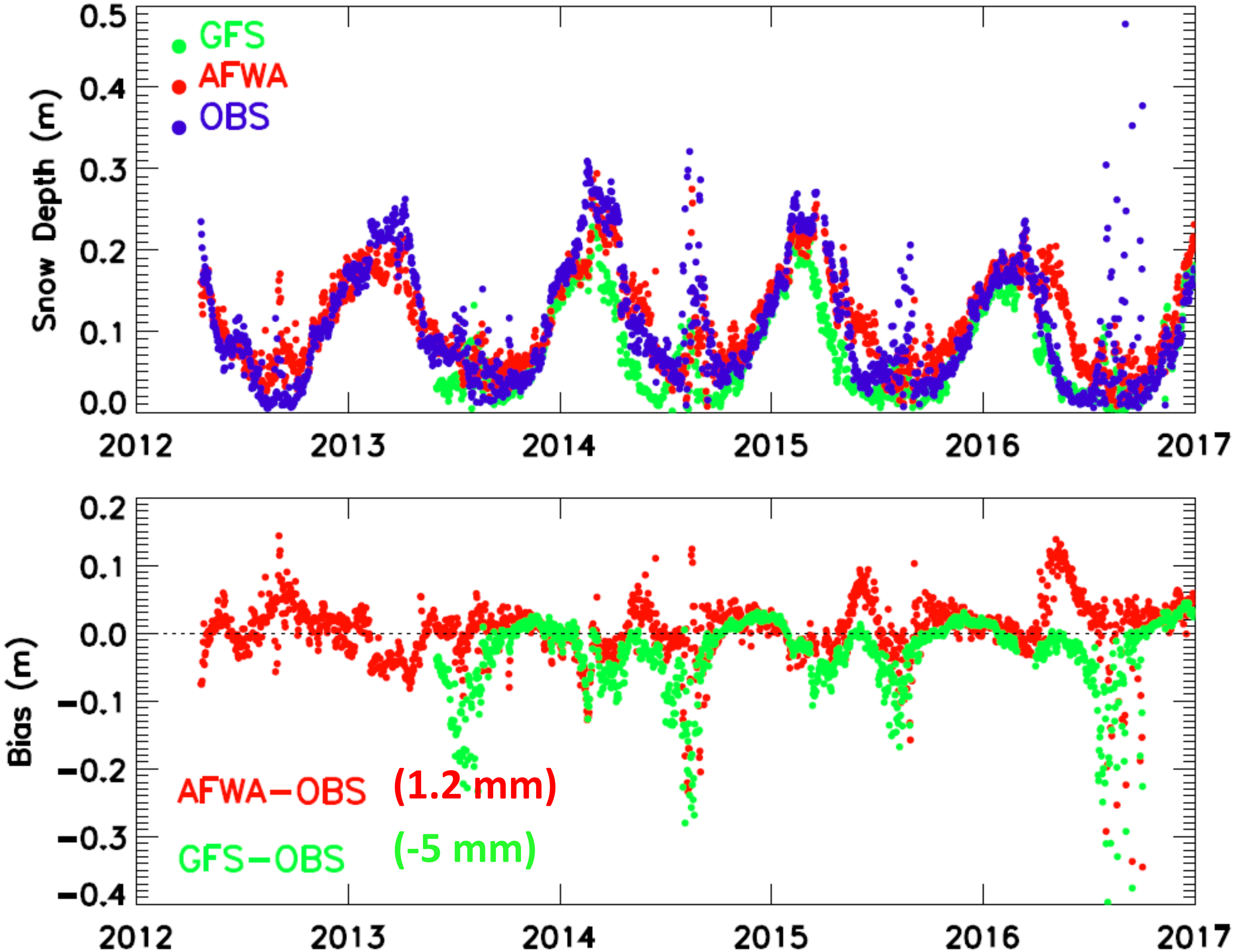
In-situ Data



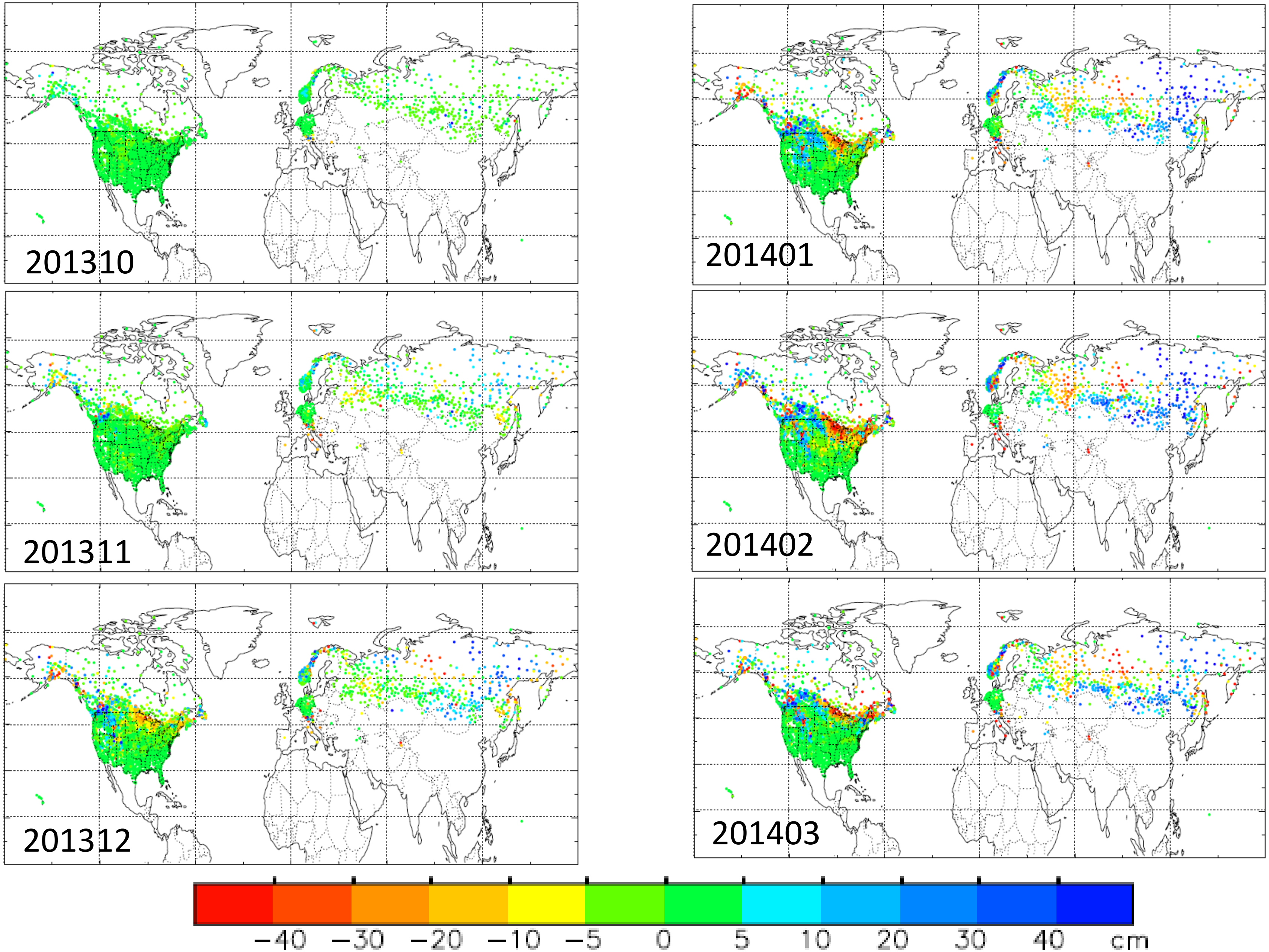
Global Historical Climate Network

Total Station Number: 50,020

Comparison of daily snow depth



AFWA SNODEP and GFS snow depth versus OBS



Monthly Mean Bias of AFWA Snow Depth versus GHCN OBS

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

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

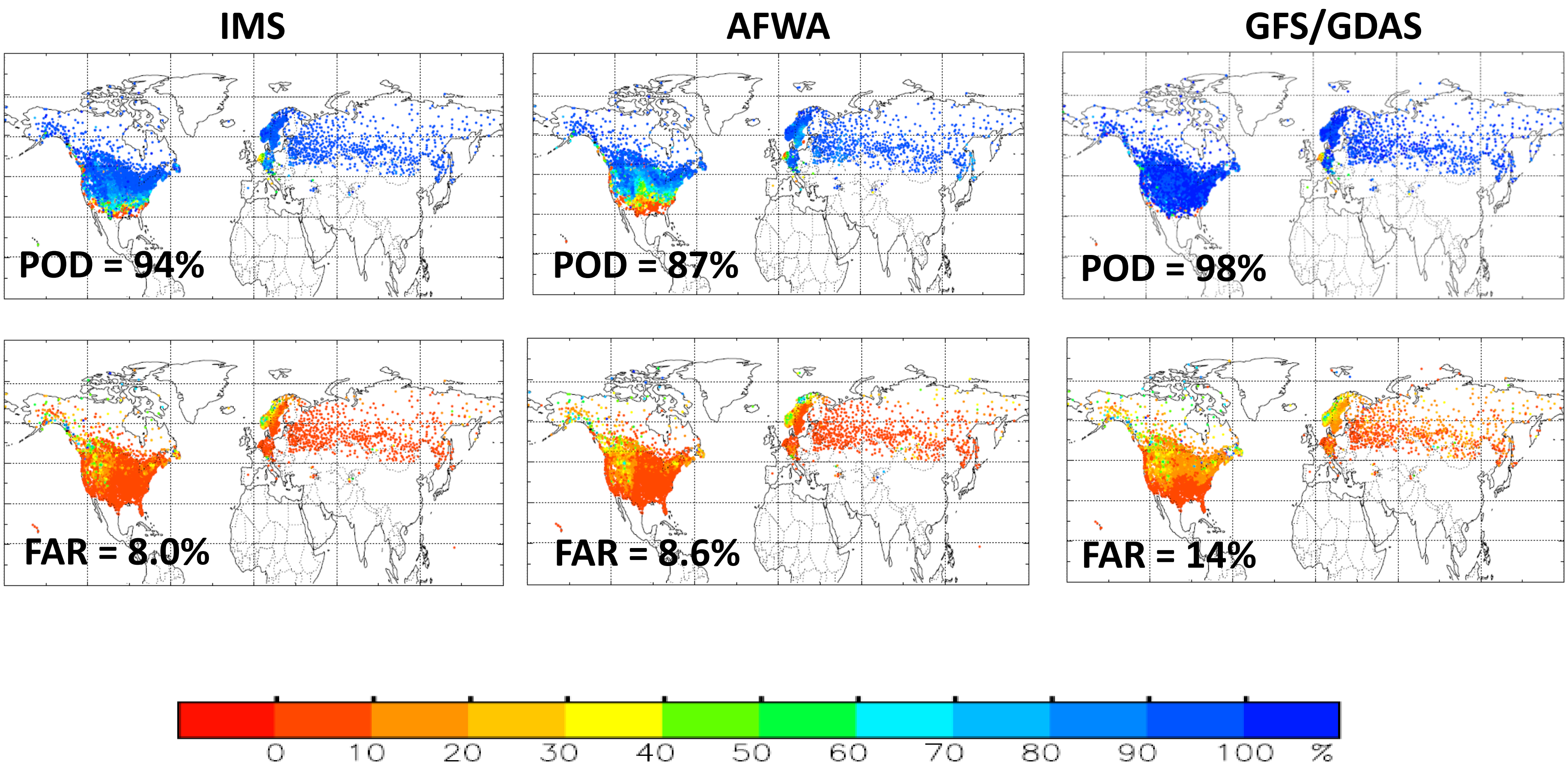
$$POD_N = \frac{NN}{NN + NS}$$

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

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

POD: Probability of Detection
FAR: False Alarm Ratio

Statistics

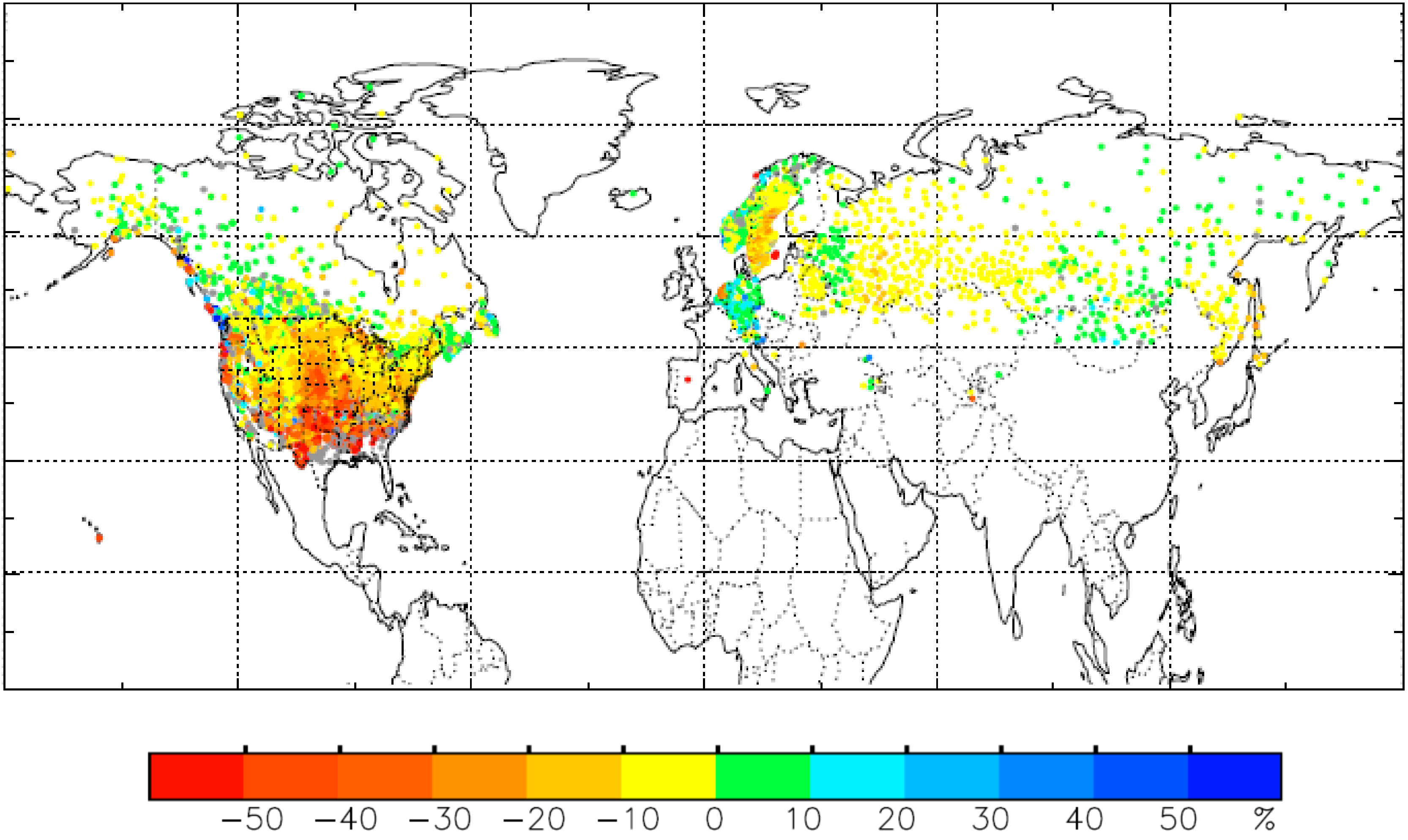


POD and FAR statistics of IMS SCA, AFWA snow depth and GFS snow depth

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

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

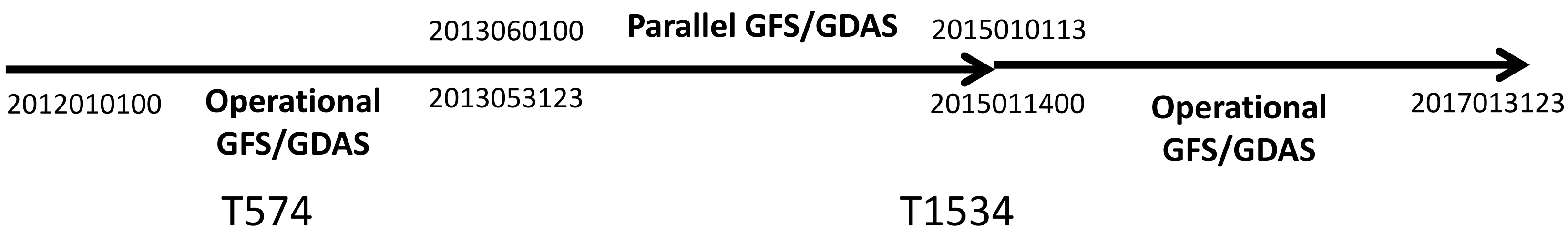
$POD_{afwa} - POD_{ims}$



Comparison of POD between AFWA SNODEP and IMS Snow Cover

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

Data Assimilation Formulation

Forecast

$$\mathbf{X}_{i,k}^{f} = M_{k-1}[\mathbf{X}_{i,k-1}^{a}] + \boldsymbol{\varepsilon}_{i,k-1}$$

Update

$$\mathbf{X}_{i,k}^{a} = \mathbf{X}_{i,k}^{f} + \mathbf{K}_{k}(\mathbf{y}_{k} - H_{k}\mathbf{X}_{i,k}^{f} + \mathbf{r}_{i,k})$$

Kalman Gain:

$$K_{\mathrm{k}} = \frac{P_{\mathrm{k}}^{\mathrm{f}} H_{\mathrm{k}}^{\mathrm{T}}}{H_{\mathrm{k}} P_{\mathrm{k}}^{\mathrm{f}} H_{\mathrm{k}}^{\mathrm{T}} + R_{\mathrm{k}}}$$

$$\mathbf{P}_{k}^{f} = \mathbf{M}_{k-1}\mathbf{P}_{k-1}^{a}\mathbf{M}_{k-1}^{T} + \mathbf{Q}_{k-1}$$

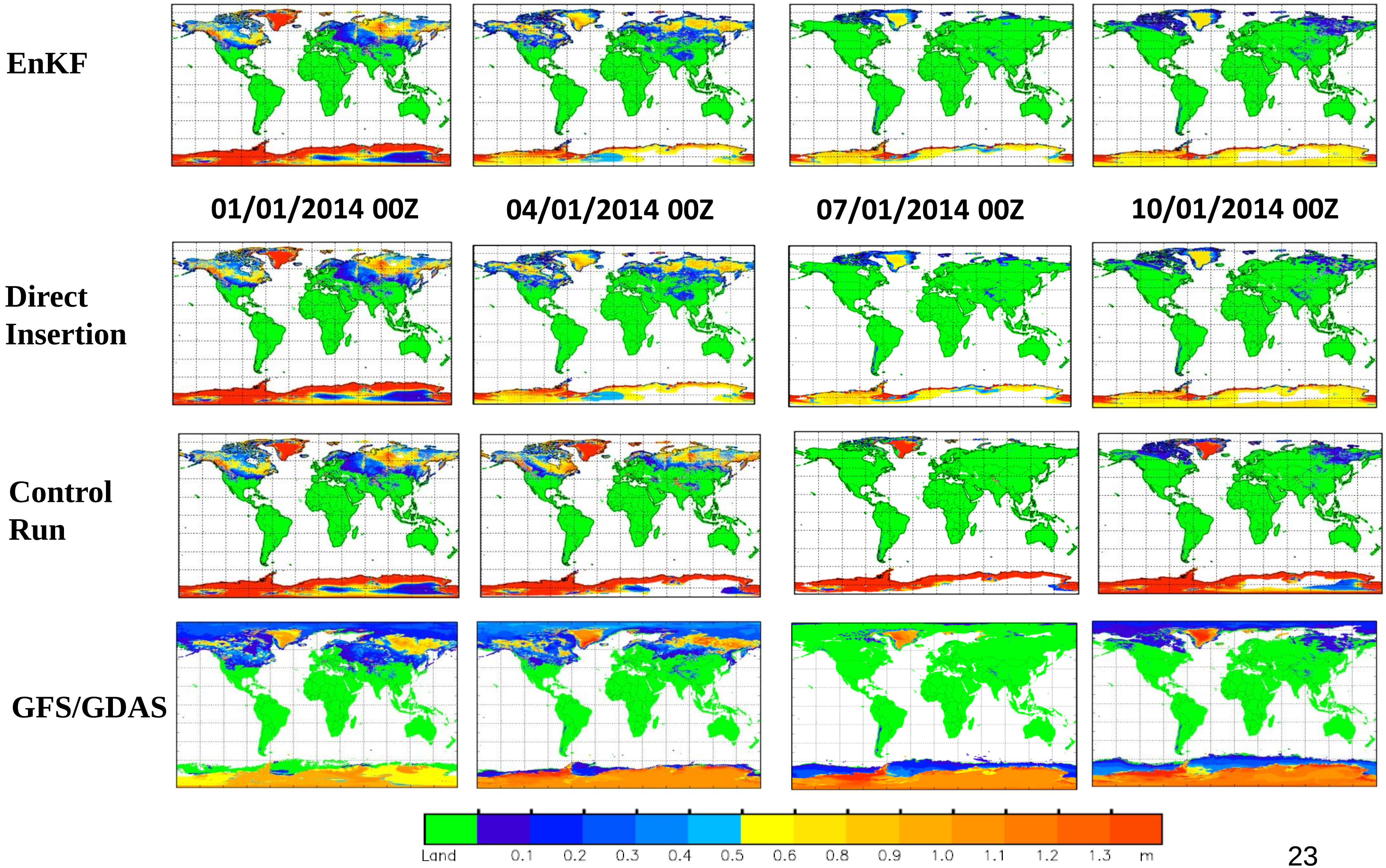
$$\mathbf{P}_{k}^{a} = (\mathbf{I} - \mathbf{K}_{k}\mathbf{H}_{k})\mathbf{P}_{k}^{f}(\mathbf{I} - \mathbf{K}_{k}\mathbf{H}_{k})^{T} + \mathbf{K}_{k}\mathbf{R}_{k}\mathbf{K}_{k}^{T}$$

Specifying Perturbations

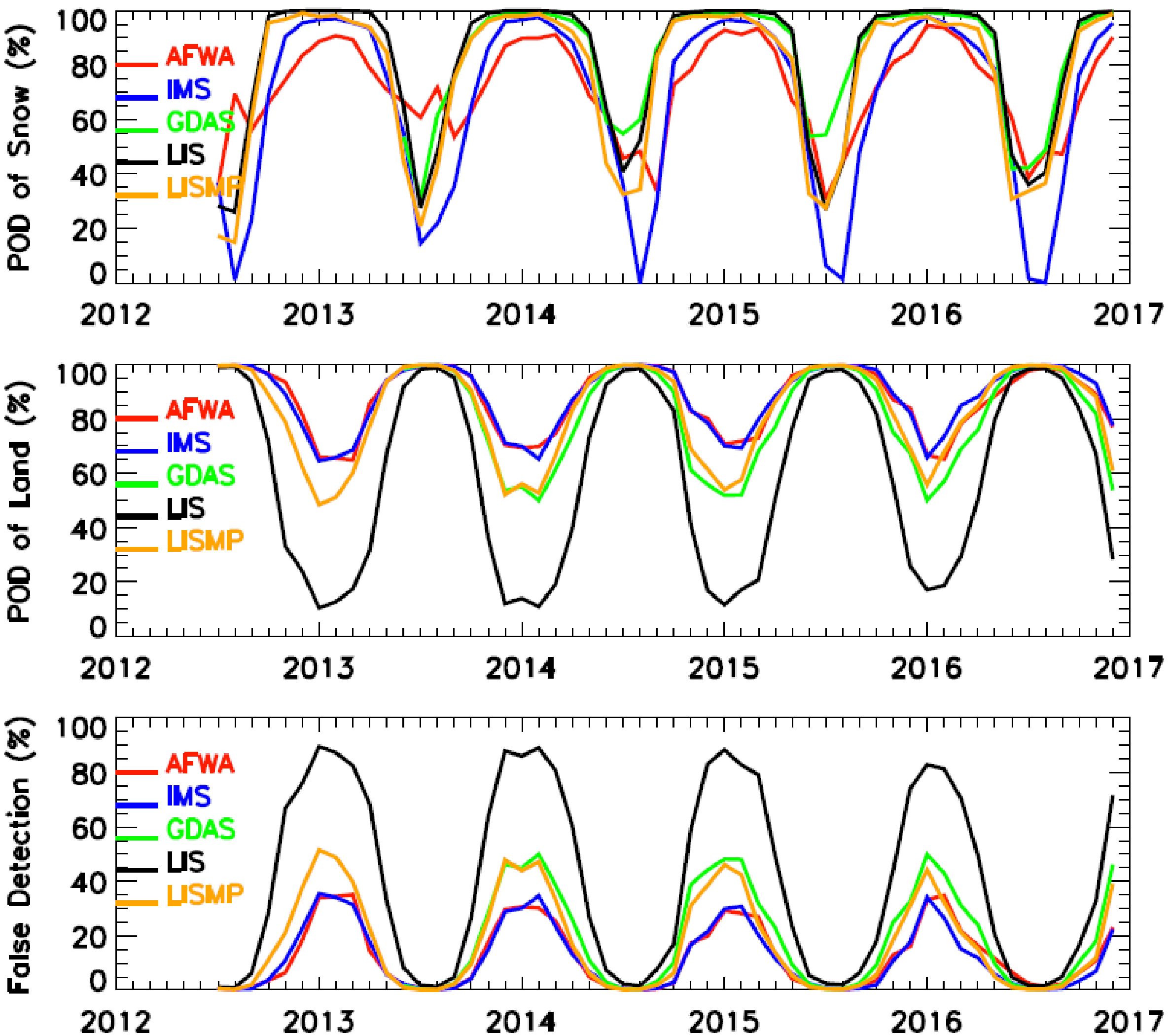
#ptype	std	std_max	zeromean	tcorr	xcorr	ycorr	ccorr
Incident Shortwave Radiation							
1	0.20	2.5	1	86400	0	0	1.0 -0.3 -0.5 0.3
Incident Longwave Radiation							
0	30.0	2.5	1	86400	0	0	-0.3 1.0 0.5 0.6
Rainfall Rate							
1	0.50	2.5	1	86400	0	0	-0.5 0.5 1.0 -0.1
Near Surface Air Temperature							
0	0.5	2.5	1	86400	0	0	0.3 0.6 -0.1 1.0
SNODEP obs							
1	0.01	2.5	1	10800	0	0	1

Perturbation type: additive (0) or multiplicative (1)
Std: standard deviation of perturbations
Zero mean: enforce zero mean across the ensemble
Std_max: maximum allowed normalized perturbation (relative to N (0 , 1))
Tcorr: temporal correlation scale (in seconds) used in the AR(1) model
Xcorr, Y-corr: Spatial correlation scale (deg)
Ccorr: cross correlations between variables

Demonstration of LIS land data assimilation of AFWA Snow Depth



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 show larger false snow cover detection (14%) than IMS (8%) and AFWA (9%).

LIS/Noah offline run with GFS forcing shows even higher POD in snow detection (99%), but false alarm ratio is as higher as 32%.

LIS/Noah-MP offline run with GFS forcing shows higher POD in snow detection (97%), and false alarm ratio is 12%.

$$POD_S = \frac{SS}{NS + SS} \qquad POD_N = \frac{NN}{NN + NS} \qquad FAR = \frac{SN}{SN + NN}$$

Statistics of the offline LIS/Noah, LIS/Noah-MP, operational GFS/GDAS, IMS snow cover, and AFWA snowdepth with the in-situ observations

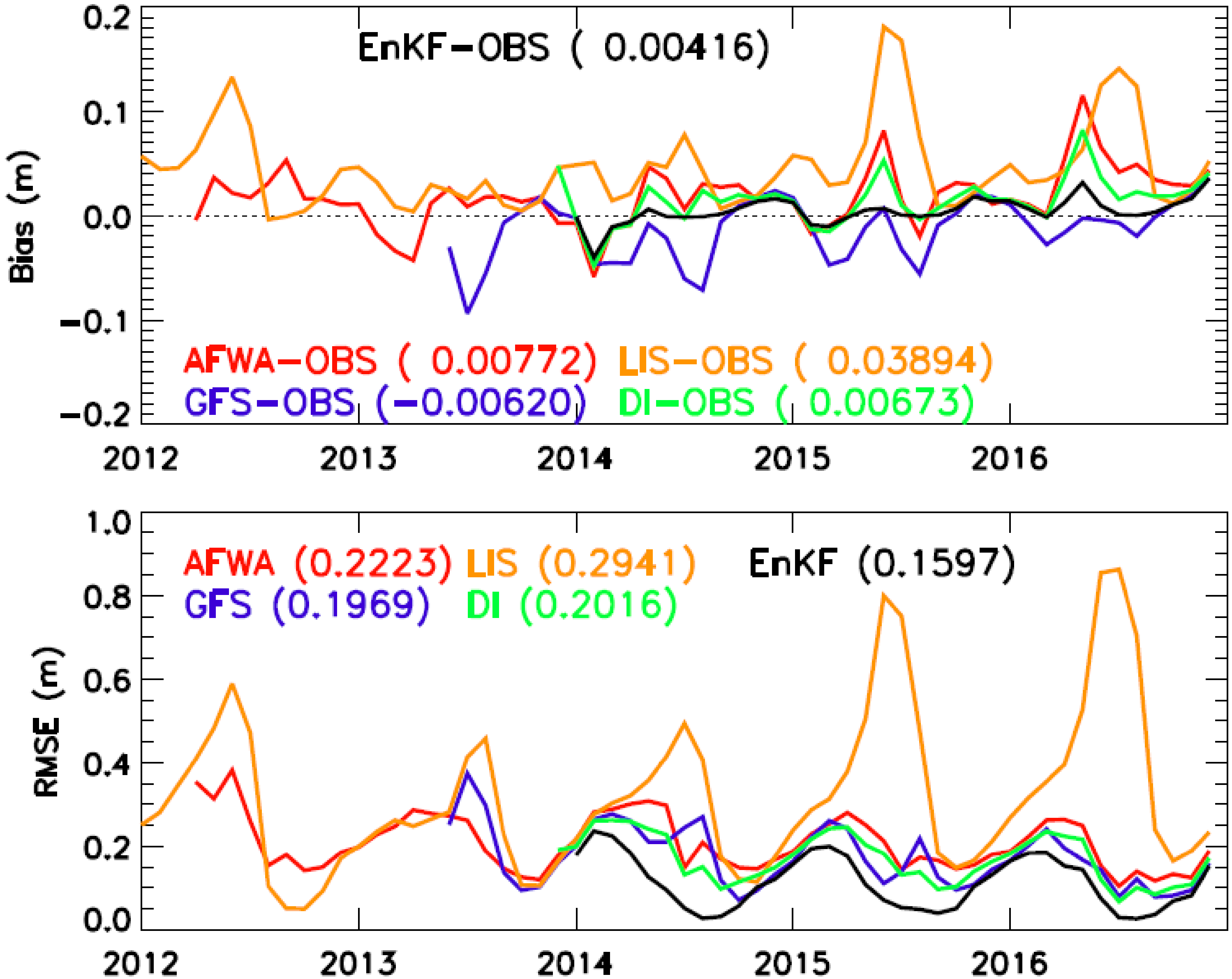
	POD_S	FAR	Accuracy POD_{S+N}
IMS	93.85	8.29	91.91
AFWA	87.46	8.80	90.85
GFS/GDAS	98.35	14.47	86.69
LIS/Noah.3.3	99.50	32.10	71.01
LIS/Noah-MP3.6	96.57	12.73	88.19

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

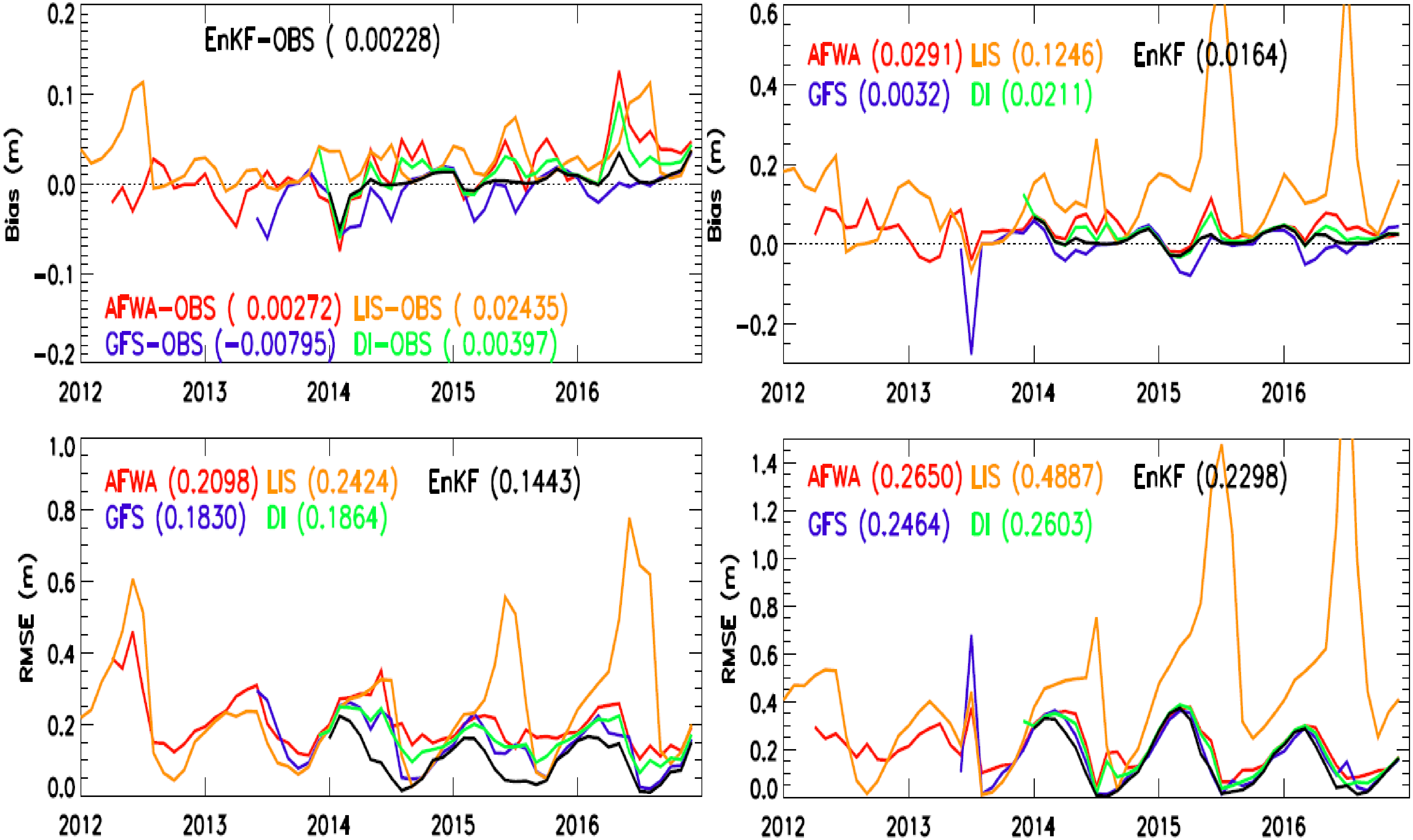
$$FAR = \frac{SN}{SN + NN}$$

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

AFWA/LIS/GFS/DI/EnKF

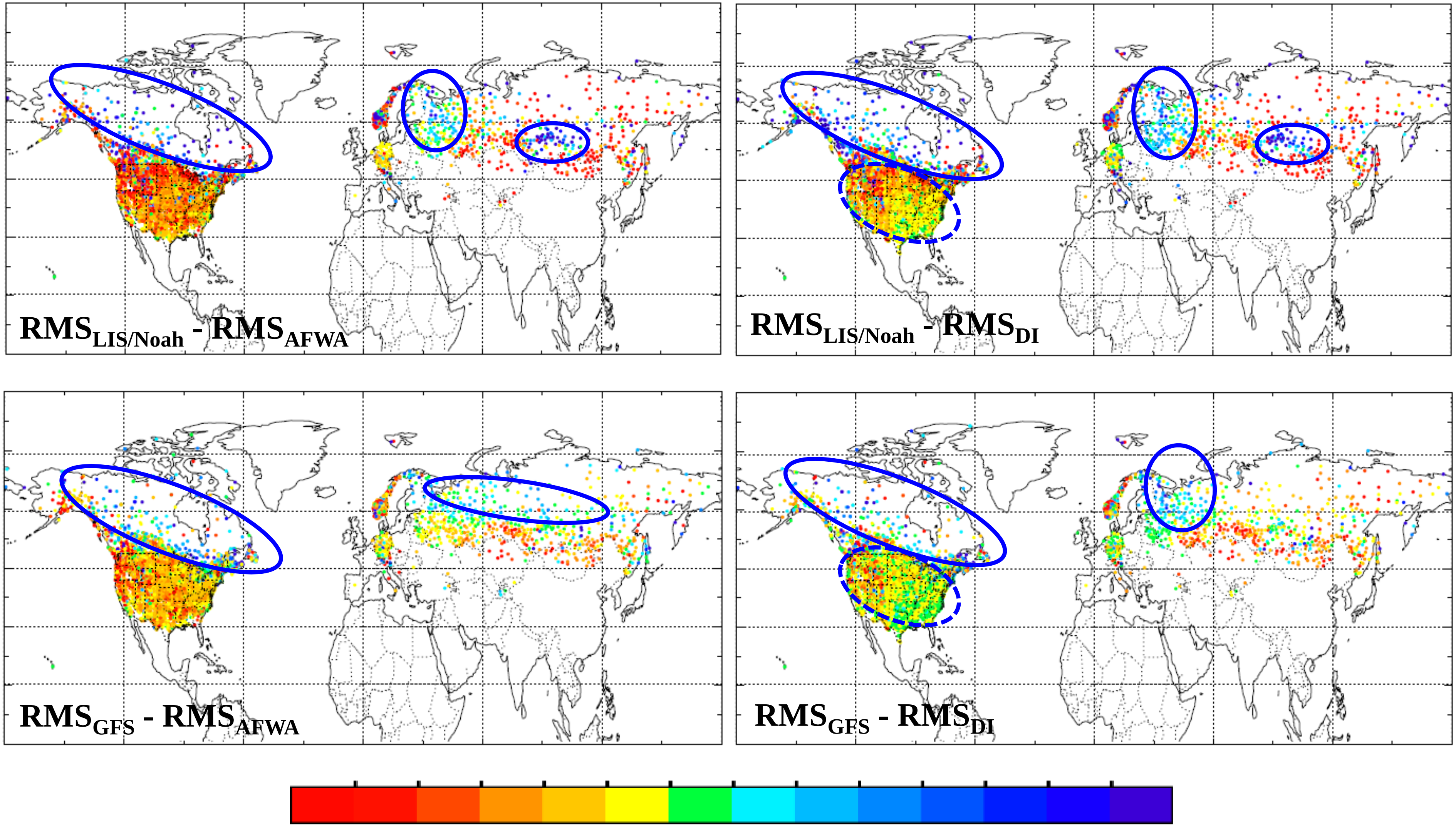


NA VS EA



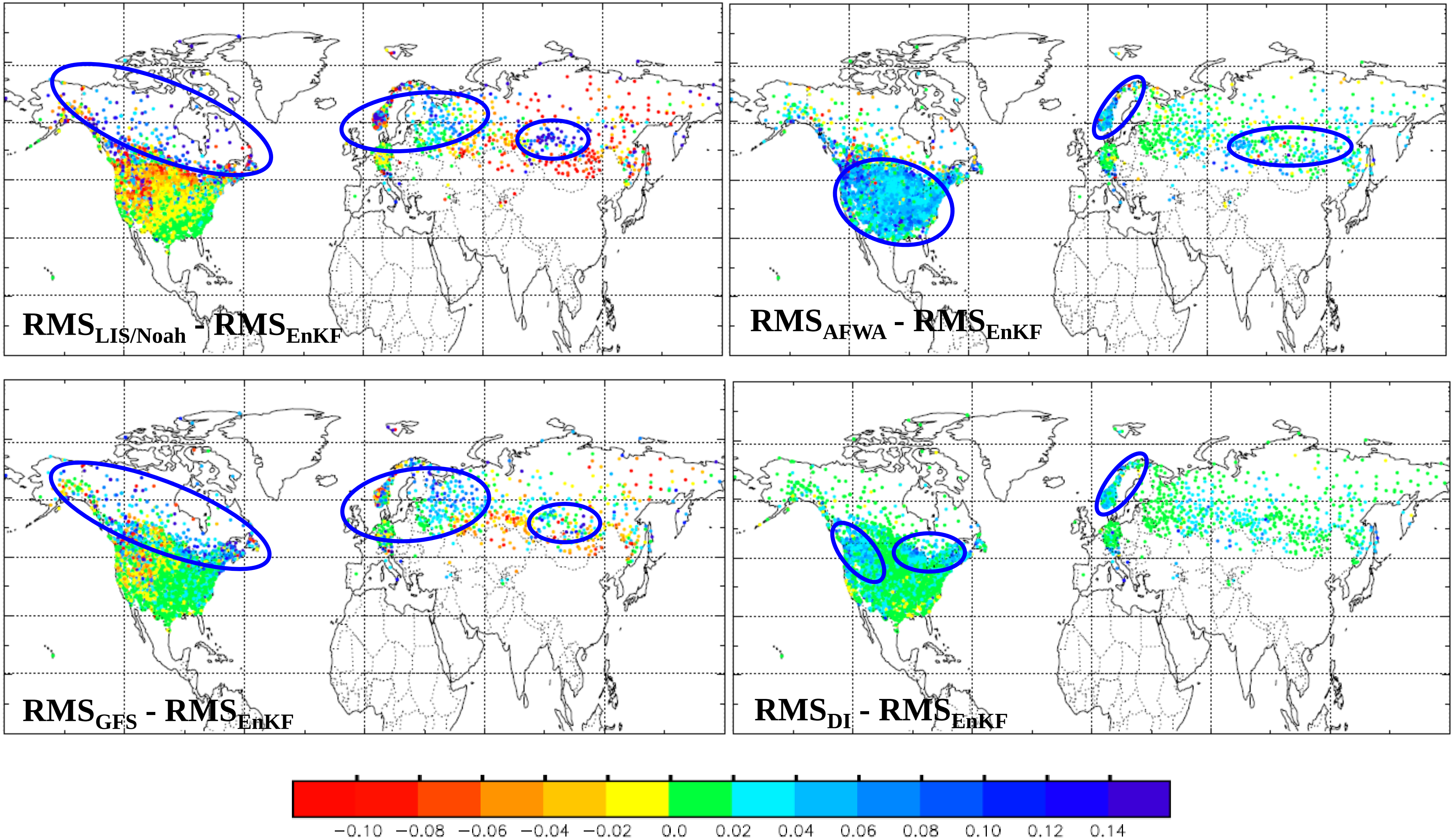
North America **Eurasia**

AFWA SNODEP and DI



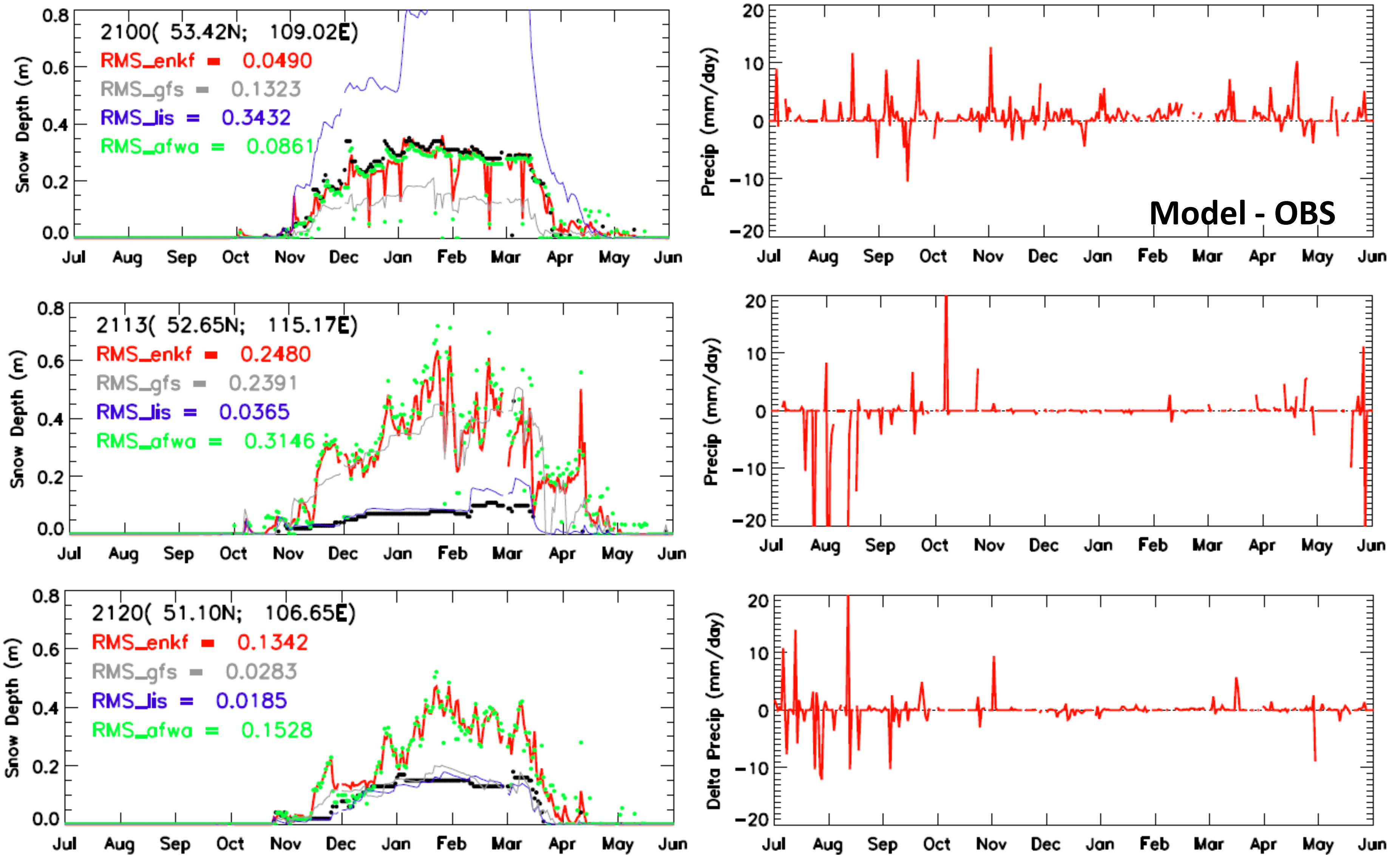
Statistics over January 2014 to December 2016

EnKF VS Others

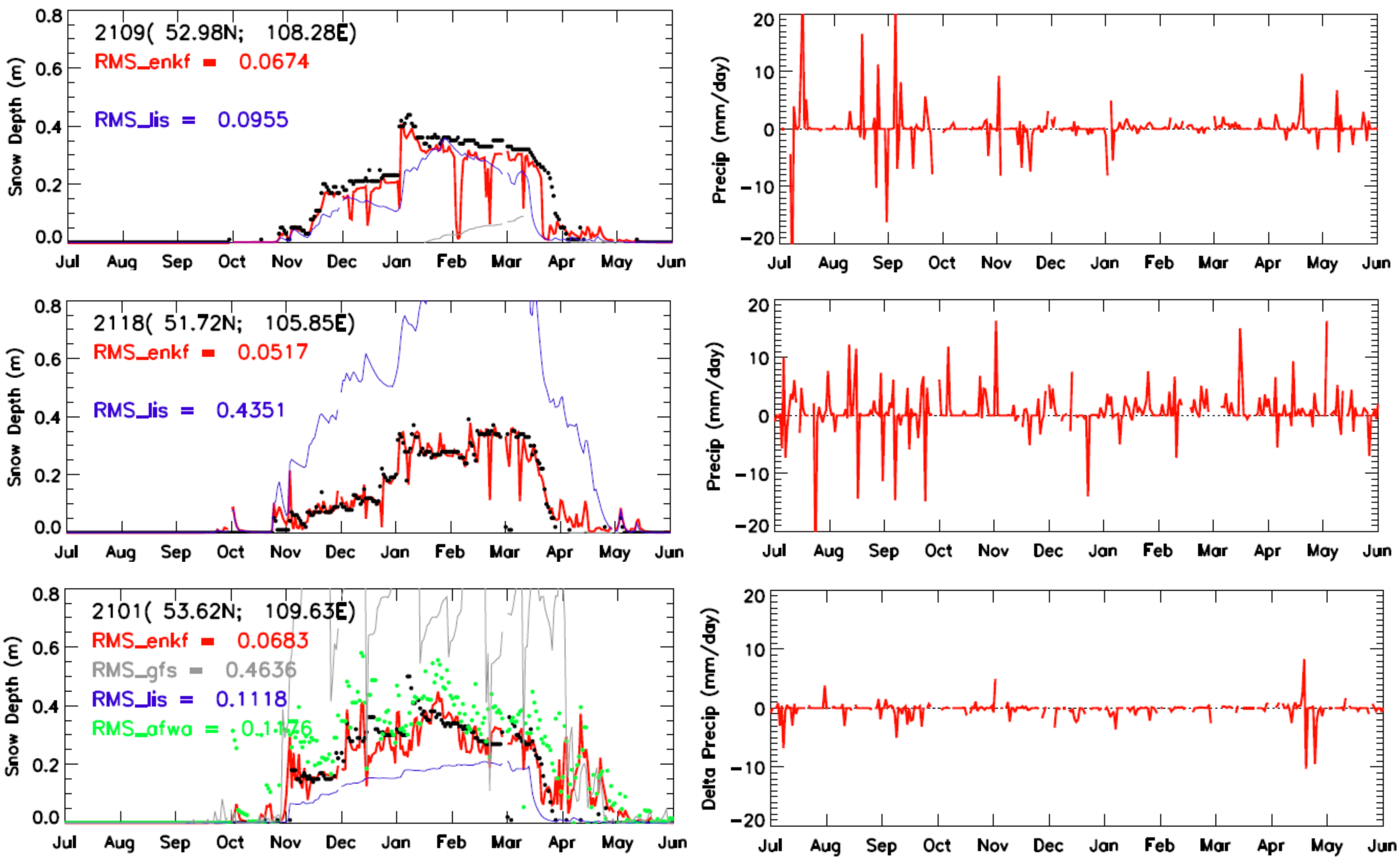


Statistics over January 2014 to December 2016

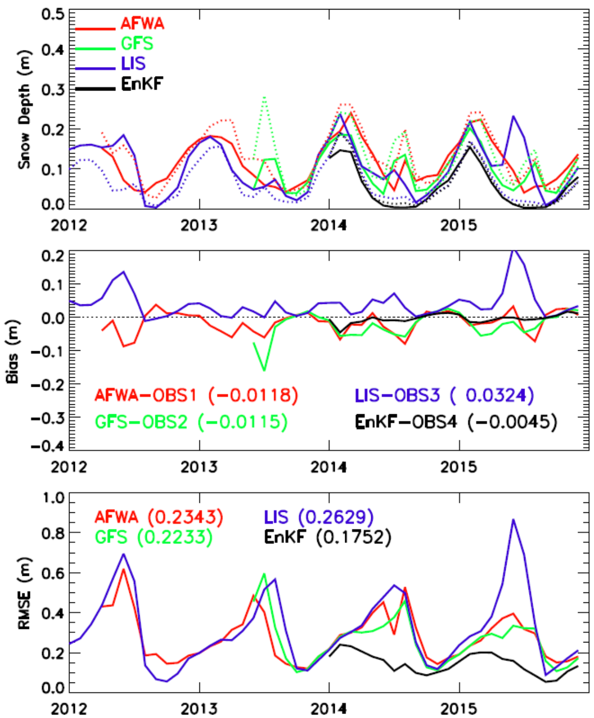
Challenges in land data assimilation

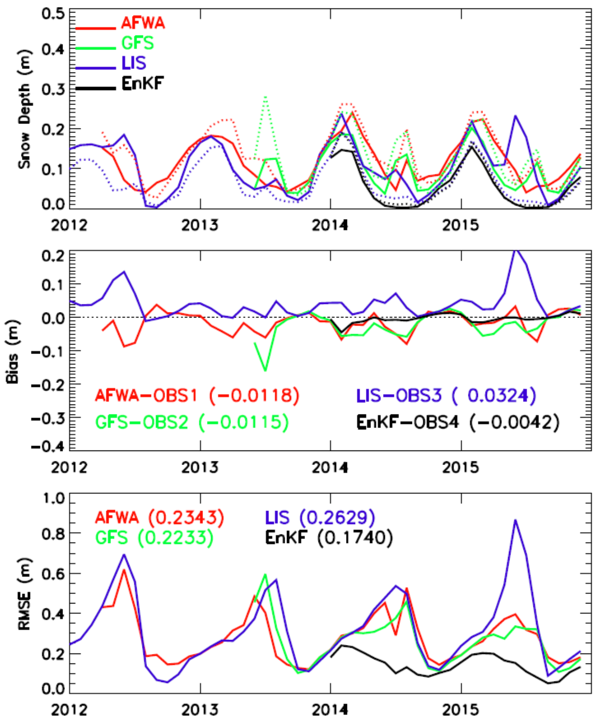


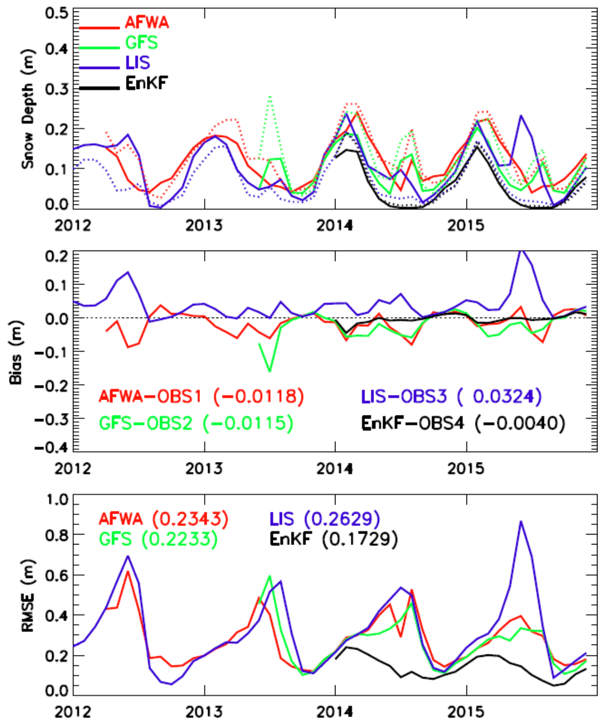
Challenges in land data assimilation



EnKF (12, 20 VS 40 members)







12 members | **20 members** | **40 members**

40 CPU hours/year | **62 CPU hours/year** | **70 CPU hours/year**

Challenges in land data assimilation

1) Differences between ***satellite retrievals*** and ***model simulations*** are due to errors in, and inconsistencies between:
   -- satellite retrieval algorithm,
   -- model physics and parameterization,
   -- representation of spatial heterogeneity,
   -- vertical resolution, …
2) ***Validation*** is hampered by lack of ground truth data. In any case, station data are point observations, satellite data are area averages.
3) ***Assimilation of satellite retrievals must consider differences between satellite and model climatologies.*** *Otherwise*, *excessive and unrealistic sensible and latent heat fluxes are generated*, which matter in coupled assimilation.
4) ***Strategies to avoid such negative effects include:***
   -- Scaling of satellite retrievals into the model climatology prior to assimilation
   -- Dynamic bias estimation
   -- Dynamic tuning of model parameters

Summary

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

- Improve land data assimilation systems (LDAS) and land-surface model physics will require further verified in the fully coupled NWP systems (e.g., GFS/CFS, and future in NEMS).

- Future assimilation will include IMS snow cover, soil moisture, GVF, LAI, Carbon, etc.


THANK YOU!