Satellite Surface Data Products from NESDIS for Numerical Weather Prediction

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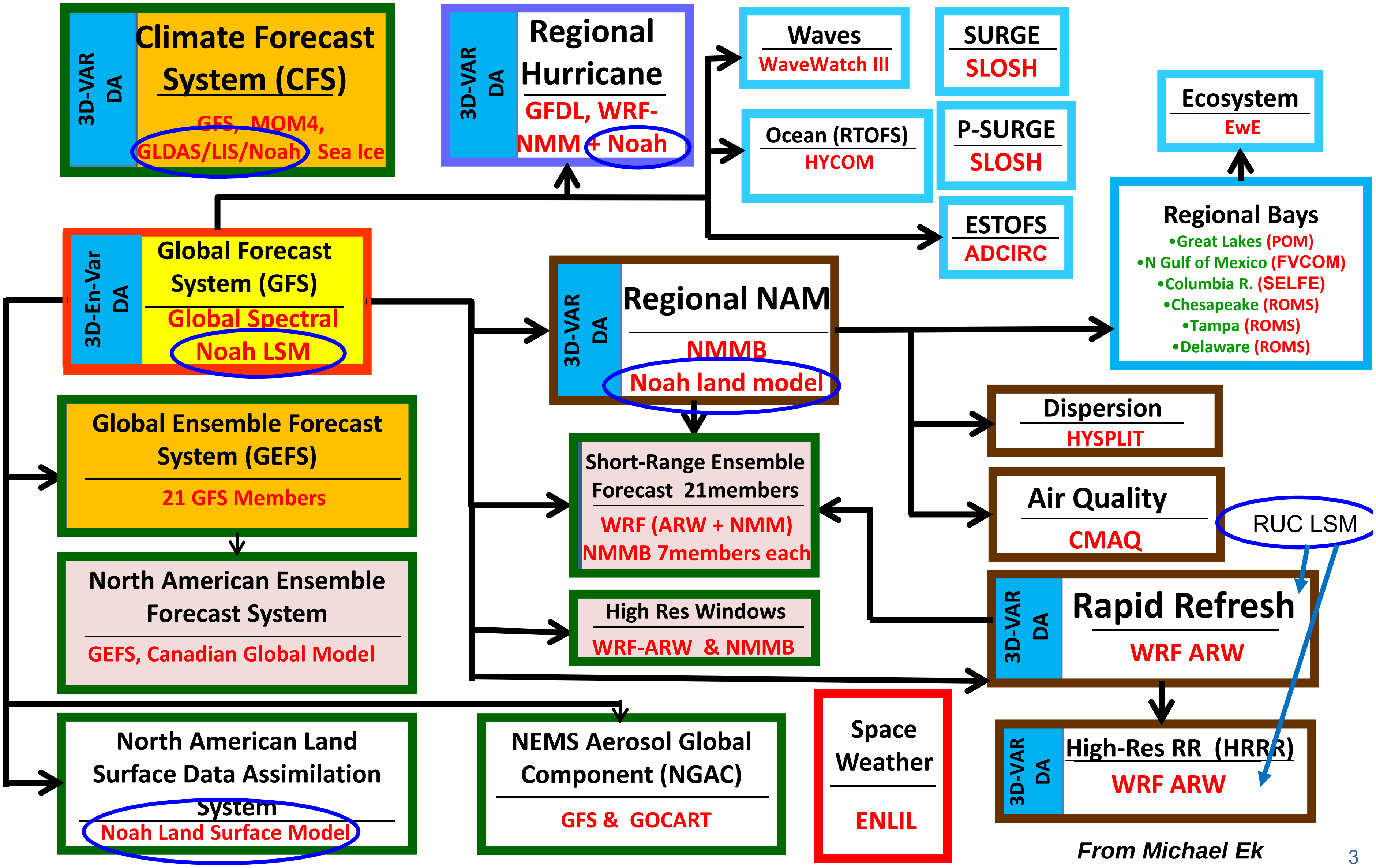
OUTLINE

- NCEP needs for land surface data products
- Satellite Surface Data Products from NOAA-NESDIS
  - SMOPS
  - GET-D
- Impact of Sat Surface Products on NWP Models
  - NCEP GFS
  - NASA NU-WRF
- Possible Causes of the Insignificant Impacts
- Summary

Land Prediction in Weather & Climate Models: NOAA's Operational Numerical Guidance Suite



From Michael Ek

NWP Needs for Land Surface Data Products

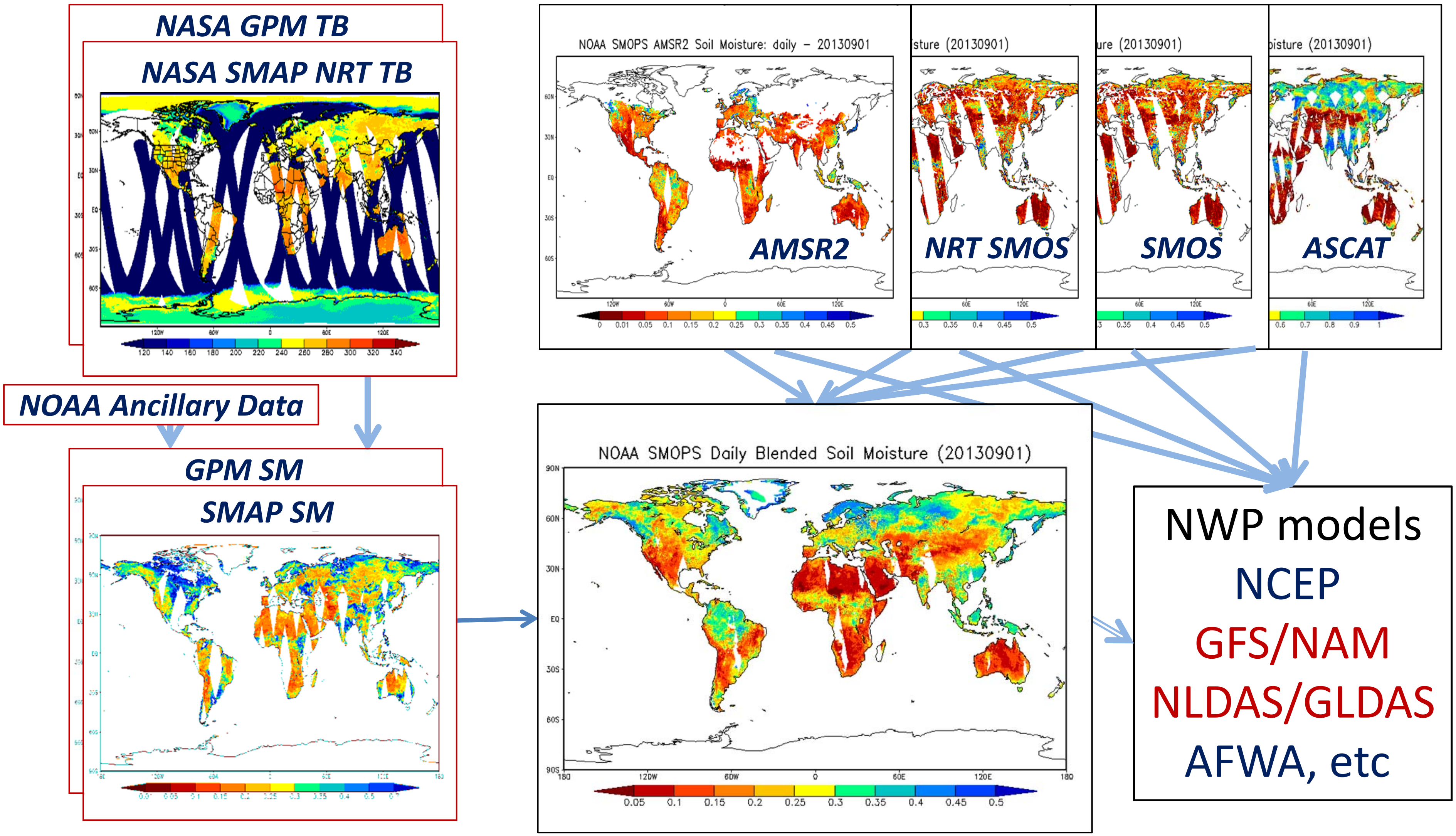
- Noah LSM requires initial values of static parameters and state variable initial values:
  - Green vegetation fraction (GVF), surface type (ST), snow cover (SC), *etc*
  - Land surface temperature (LST), soil moisture (SM), snow depth (SD), snow water equivalent (SWE), surface albedo (a), *etc*
- Satellite observational data are either directly assigned to parameters or assimilated into state variables via an assimilation algorithm (e.g. EnKF), or used to validate the LSM predictions

Current NRT Satellite Land Surface Data Products from NOAA-NESDIS

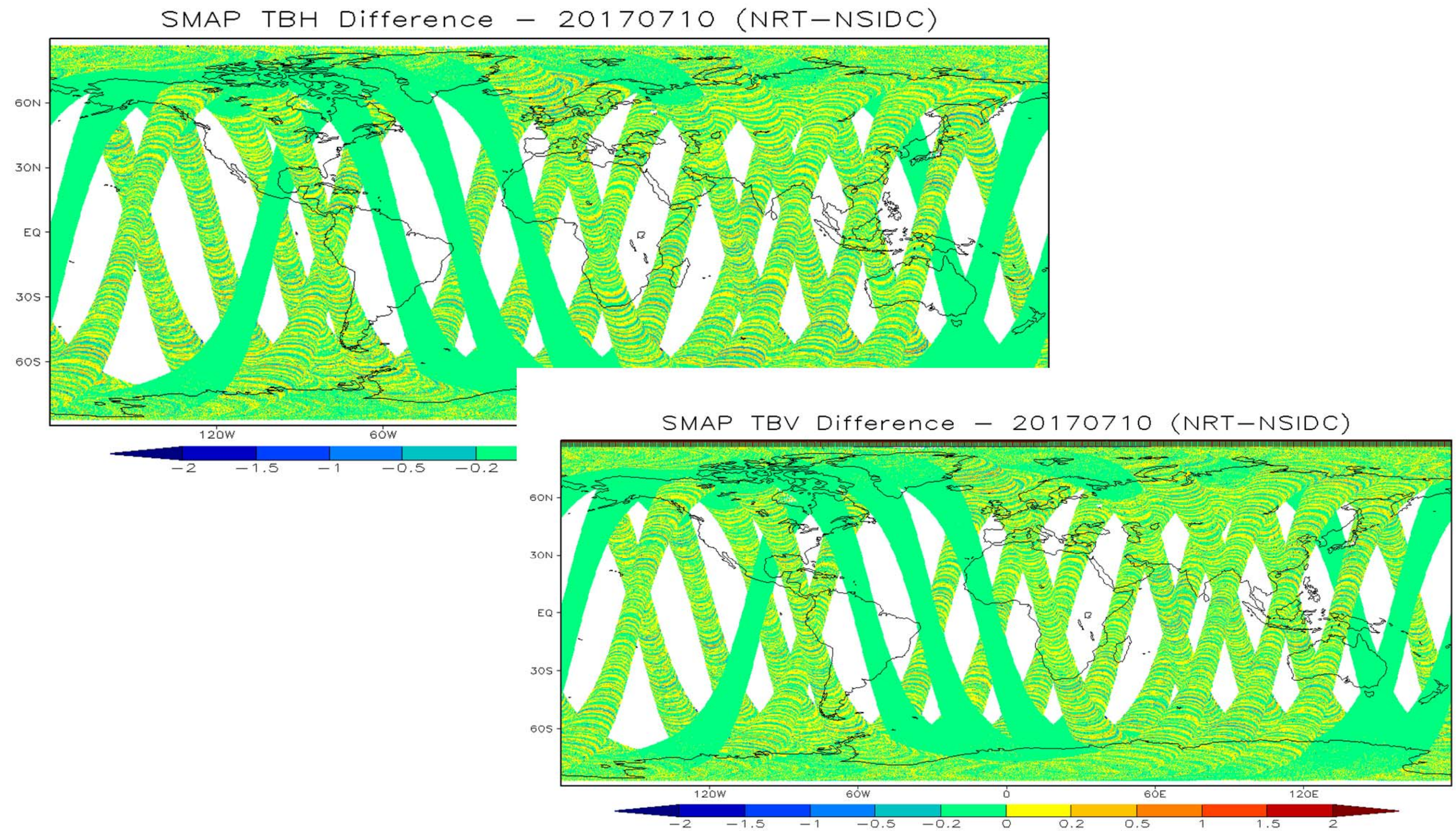
Name	Satellite/Sensor/System
Albedo	VIIRS, ABI
Fire	VIIRS, ABI
ST	VIIRS
LST	VIIRS, ABI
VI/GVF	VIIRS, ABI
SM	AMSR2, SMOPS, GET-D
SC /SD	AMSR2, VIIRS, AutoSnow, MiRS
SWE/SD	AutoSnow, MiRS
Sfc Emissivity	MiRS

Soil Moisture Operational Product System

SMOPS 2.0/3.0



SMAP L1B_TB: JPL NRT vs NSIDC



More than 99% of footprint TBs have difference smaller than 0.2 degree.

SMAP L1B_TB: Latency Improvements

April, 2017

Date	Total_In	Total_Orbits	Percent_In	Minimum	Medium	Average	Maximum
15	10	22	45	1:34	4:23	4:00	5:42
16	10	19	53	2:25	4:54	5:18	11:00
17	11	23	48	1:37	3:49	3:49	6:06
18	11	22	50	2:22	4:12	4:20	6:39
19	7	22	32	2:12	5:08	5:46	10:42
20	10	19	53	1:35	4:31	4:11	5:39
21	10	22	45	1:26	4:05	3:56	5:43
22	11	22	50	1:00	4:11	3:53	5:40
23	5	17	29	2:09	4:48	4:22	5:42
24	4	20	20	2:37	6:25	7:16	14:09
25	20	30	67	0:49	2:42	2:49	4:29
26	20	29	69	0:50	2:51	2:58	4:19
27	17	29	59	0:45	2:59	3:09	5:54
28	23	29	79	0:36	2:49	2:56	5:26
29	20	30	67	0:37	2:34	2:47	4:33
30	21	29	72	0:39	2:40	2:35	4:29

After transition (red), the percentage of number of orbits that can get in SMOPS operational run is significantly improved.

Soil Moisture Retrieval Algorithm

Single Channel Algorithm (SCA) : *(Jackson, 1993)*

$$T_{Bh} = T_s\,[1 - (1 - e_r)\,\exp(-2\tau/\cos\theta)]$$

$$\tau = b * VWC,\; VWC = f(NDVI)$$

$$e_h = f(e_v, h, Q)$$

$$e_s = f(\varepsilon) \qquad \text{-- Fresnel Equation}$$

$$\varepsilon = f(SM) \qquad \text{-- Mixing model}$$

$$T_s = T_s^{LSM}$$

NDVI = VIIRS near real time

T_s^{LSM} *= GFS Tskin*

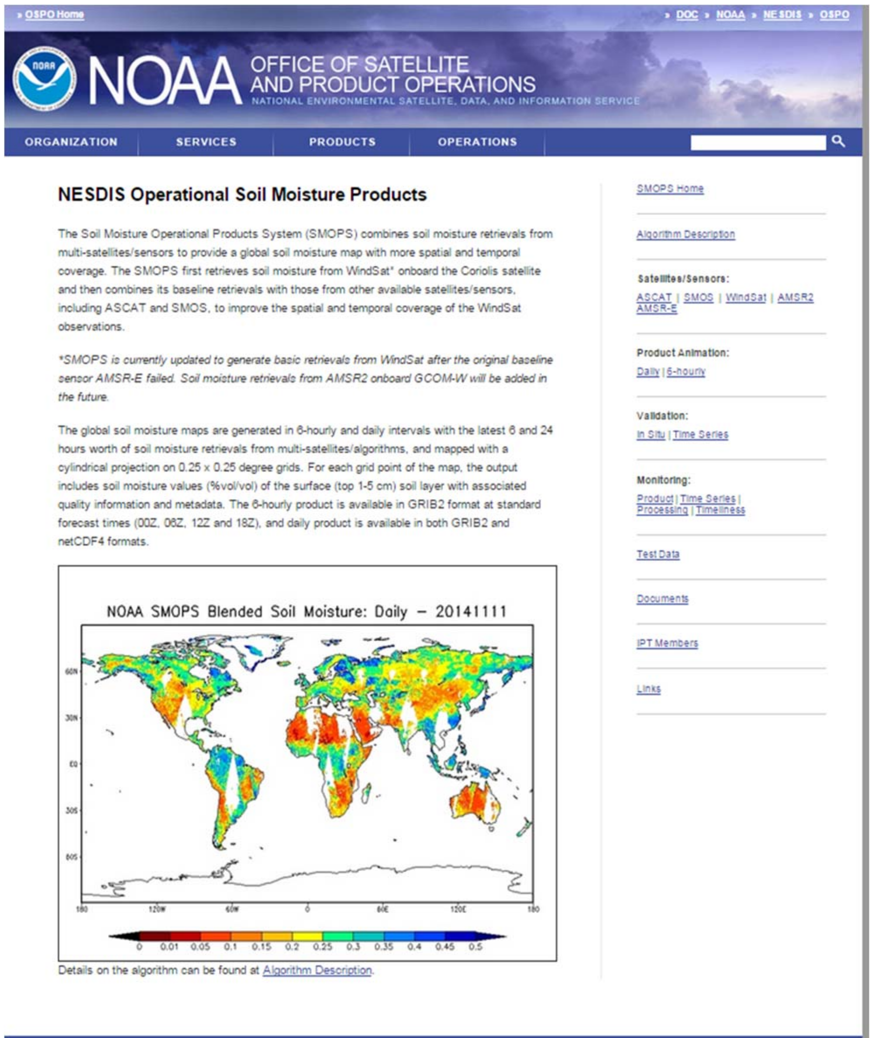
Validation of SMAP SM from SMOPS

Maqu	*ubRMSE*			*r*		
Site	NASA	NOAA	NFPR	NASA	NOAA	NFPR
CST_05	0.080	0.065	0.060	0.634	0.665	0.708
NST_01	0.070	0.065	0.067	0.660	0.624	0.652
NST_03	0.080	0.070	0.066	0.644	0.581	0.628
NST_06	0.067	0.059	0.062	0.705	0.596	0.608
NST_07	0.071	0.065	0.066	0.653	0.545	0.559
NST_08	0.073	0.059	0.056	0.572	0.717	0.750
NST_09	0.058	0.062	0.059	0.769	0.537	0.604
Ave	0.065	0.065	0.055	0.742	0.716	0.734

- *SMAP SM retrievals from gridded TBs in SMOPS is compatible with NASA baseline products*
- *SMAP SM retrievals from footprint TBs in SMOPS could be slightly better than those from gridded TBs*

NOAA-NESDIS Soil Moisture Product System (SMOPS)

http://www.ospo.noaa.gov/Products/land/smops/index.html



- **Developed by NOAA/NESDIS/STAR**
- **Operationally running at NOAA/NESDIS/OSPO**

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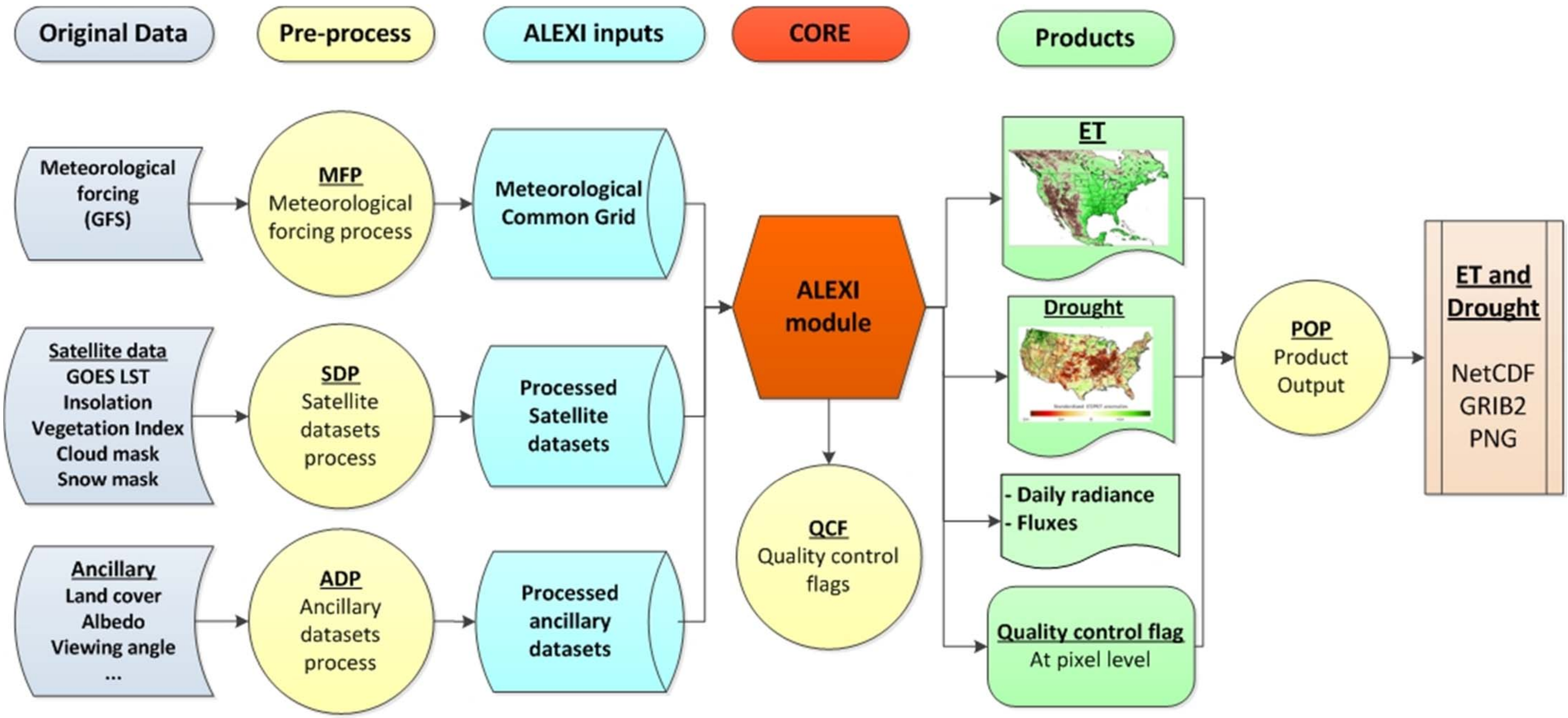
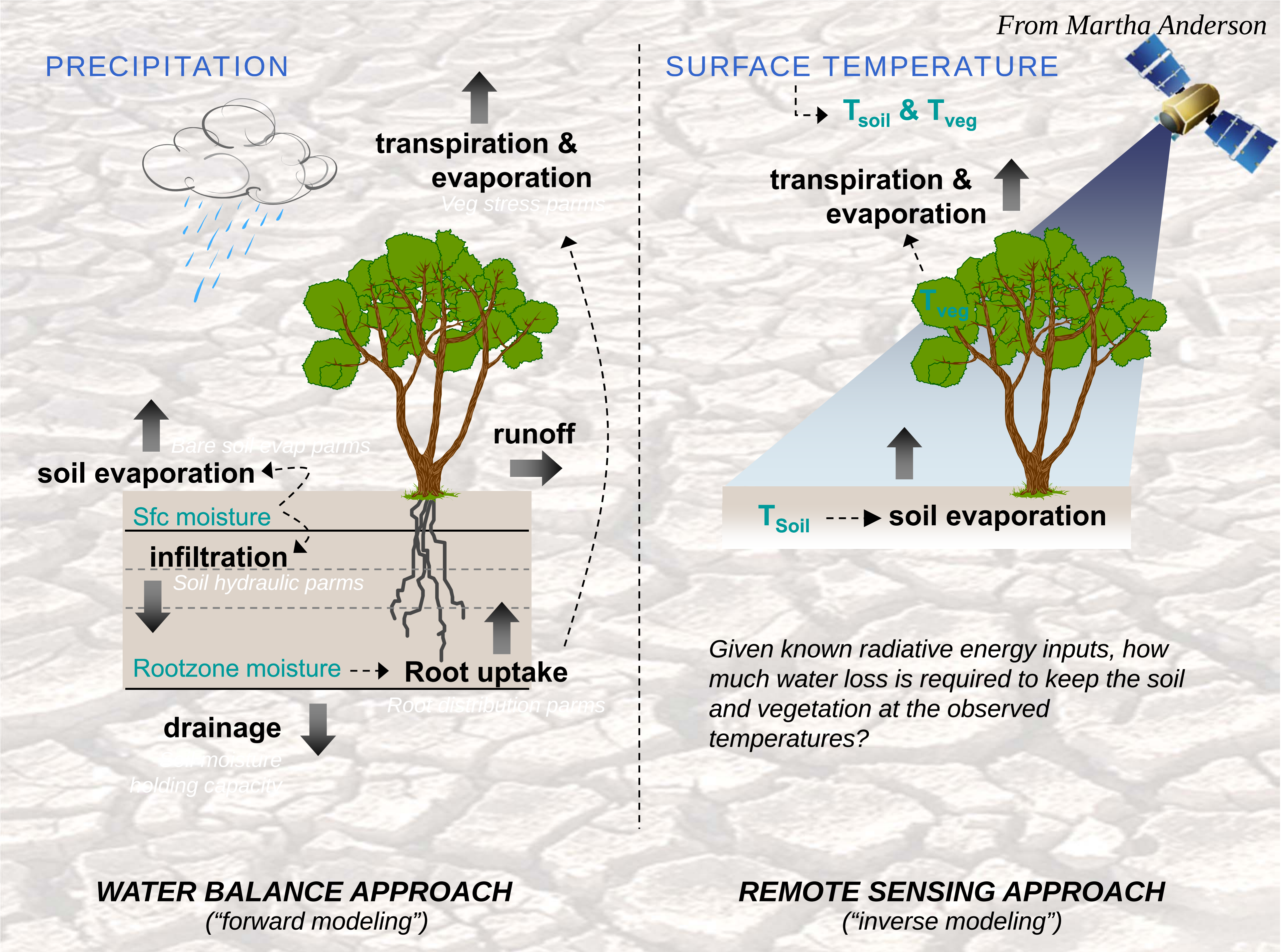
Jicheng.Liu@noaa.gov,

GOES ET and Drought Product System
(GET-D)

GET-D Data Flows




From Martha Anderson
PRECIPITATION
transpiration & evaporation
Veg stress parms
Bare soil evap parms
soil evaporation
runoff
Sfc moisture
infiltration
Soil hydraulic parms
Rootzone moisture
Root uptake
Root distribution parms
drainage
Soil moisture holding capacity
WATER BALANCE APPROACH
("forward modeling")
SURFACE TEMPERATURE
T_{soil} & T_{veg}
transpiration & evaporation
T_{veg}
T_{Soil}
soil evaporation
Given known radiative energy inputs, how much water loss is required to keep the soil and vegetation at the observed temperatures?
REMOTE SENSING APPROACH
("inverse modeling")

GET-D Input Data

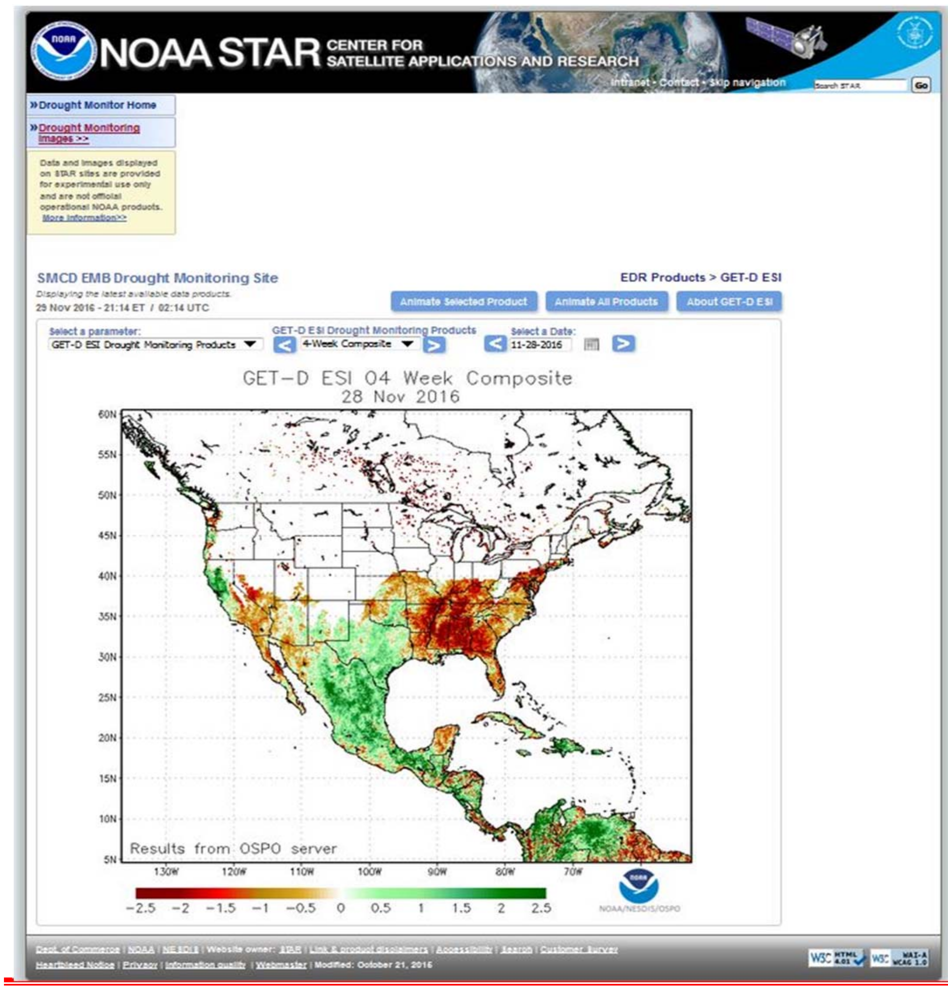
Name	Category	Source	Description
Brightness temperature	Satellite observation	GOES	GOES East/West Imagery; 11micron/3.9 micron brightness temperature
Insolation	Satellite observation	GSIP	GSIP real time insolation
Vegetation Index	Satellite observation	VIIRS	VIIRS EVI
Snow mask	Satellite observation	NOAA IMS	IMS Daily Northern Hemisphere Snow and Ice Analysis
Air temperature	Meteorological data	CFS	Surface and pressure level profiles
Specific humidity	Meteorological data	CFS	Surface and pressure level profiles
Geopotential height	Meteorological data	CFS	Surface and pressure level profiles
Wind speed	Meteorological data	CFS	Surface
Downwelling longwave radiation	Meteorological data	CFS	Surface
Land Cover	Ancillary data	University of Maryland	Land cover classes in 1km resolution (static)
Albedo	Ancillary data	MODIS	Surface Albedo from MODIS (static)
Clear day insolation	Ancillary data	GSIP	Clear day insolation (static)

GET-D Output Products

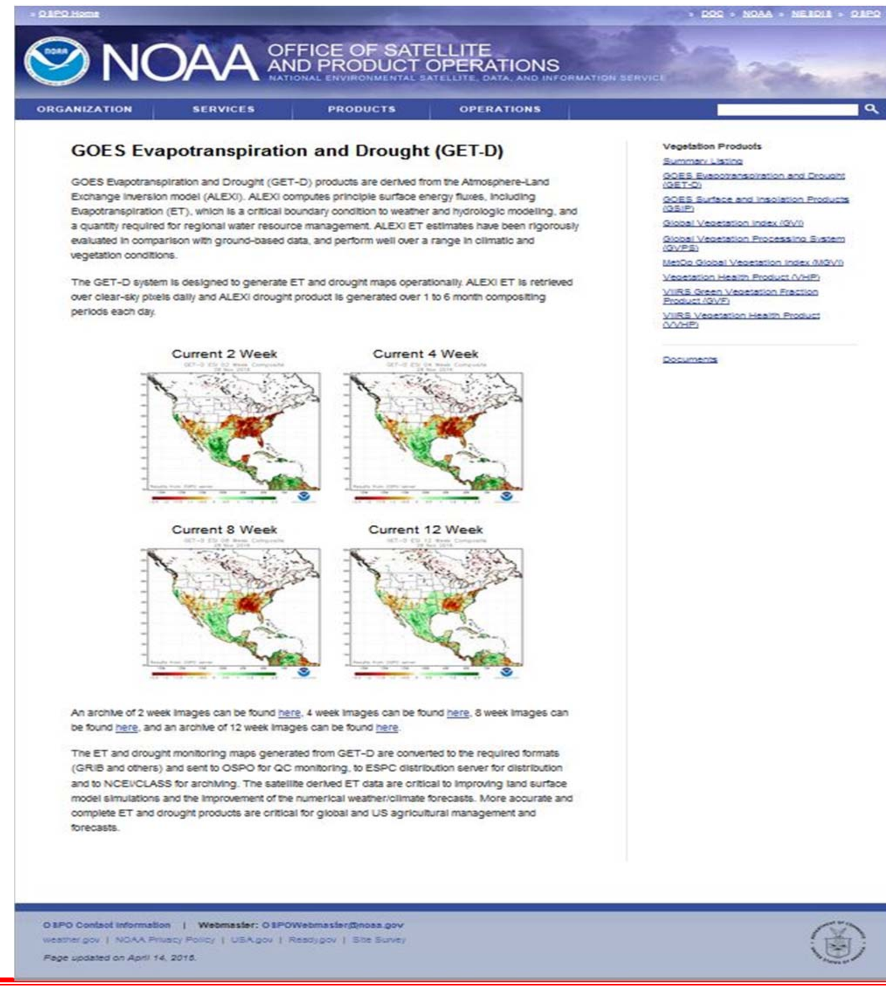
Variables	Description
ET product with QC	Daily ET map
ESI products with QC	2,4,8, 12-week composite drought map
Flux products with QC	Daily sensible heat, soil heat, downward short wave radiation, long wave down/up ward radiation and net radiation
Coverage	North America
Spatial Resolution	8km

GET-D Websites

NESDIS-STAR:
https://www.star.nesdis.noaa.gov/smcd/emb/droughtMon/products_droughtMon.php

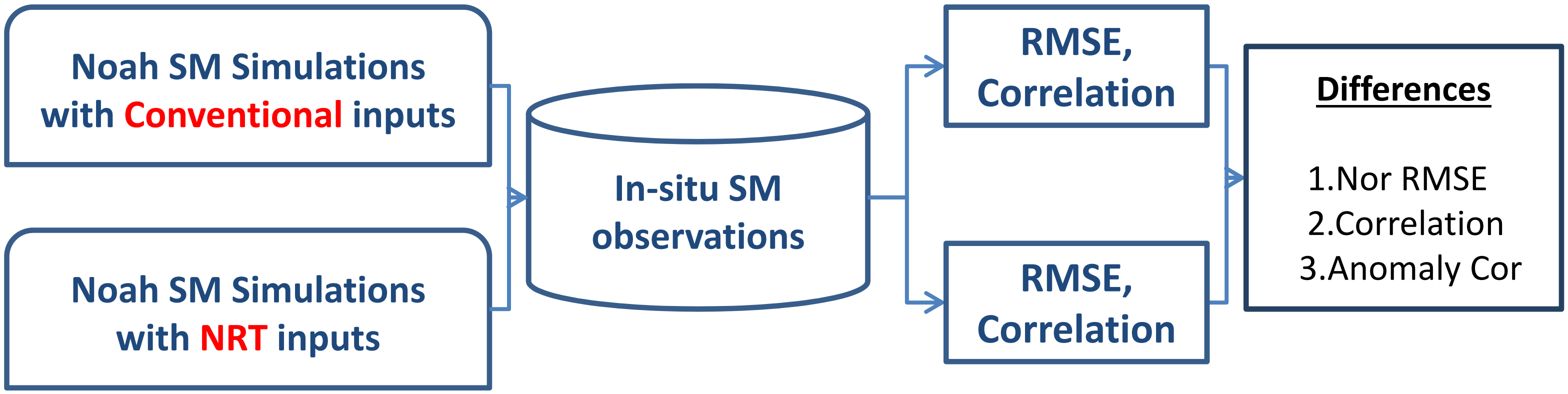


NESDIS-OSPO:
http://www.ospo.noaa.gov/Products/land/getd/



Impacts of Sat Surface Products on NWP models

Impact of NRT GVF & albedo on Noah SM



Positive (negative) values represent added (degraded) skill by assimilating NRT observations

ID	Parameters	Description of parameters (resolution and data source)			Simulation period
		Temporal	Spatial	Data source	
S01	GVF Climatology	5-year average	0.144°	AVHRR	2000 – 2012
	Albedo Climatology	5-year average	0.144°	AVHRR	2000 – 2012
	NARR Insolation	Hourly	0.125°	NLDAS-2 NARR	2000 – 2012
S02	NRT GVF	8-day composite	1 km	MODIS	2000 – 2012
S03	NRT Albedo	8-day composite	1 km	MODIS	2000 – 2012

* S01: Noah simulation with climatological parameters of GVF and albedo
* S02 – 03: Noah simulations with single replacement of one of the NRT three parameters as model inputs

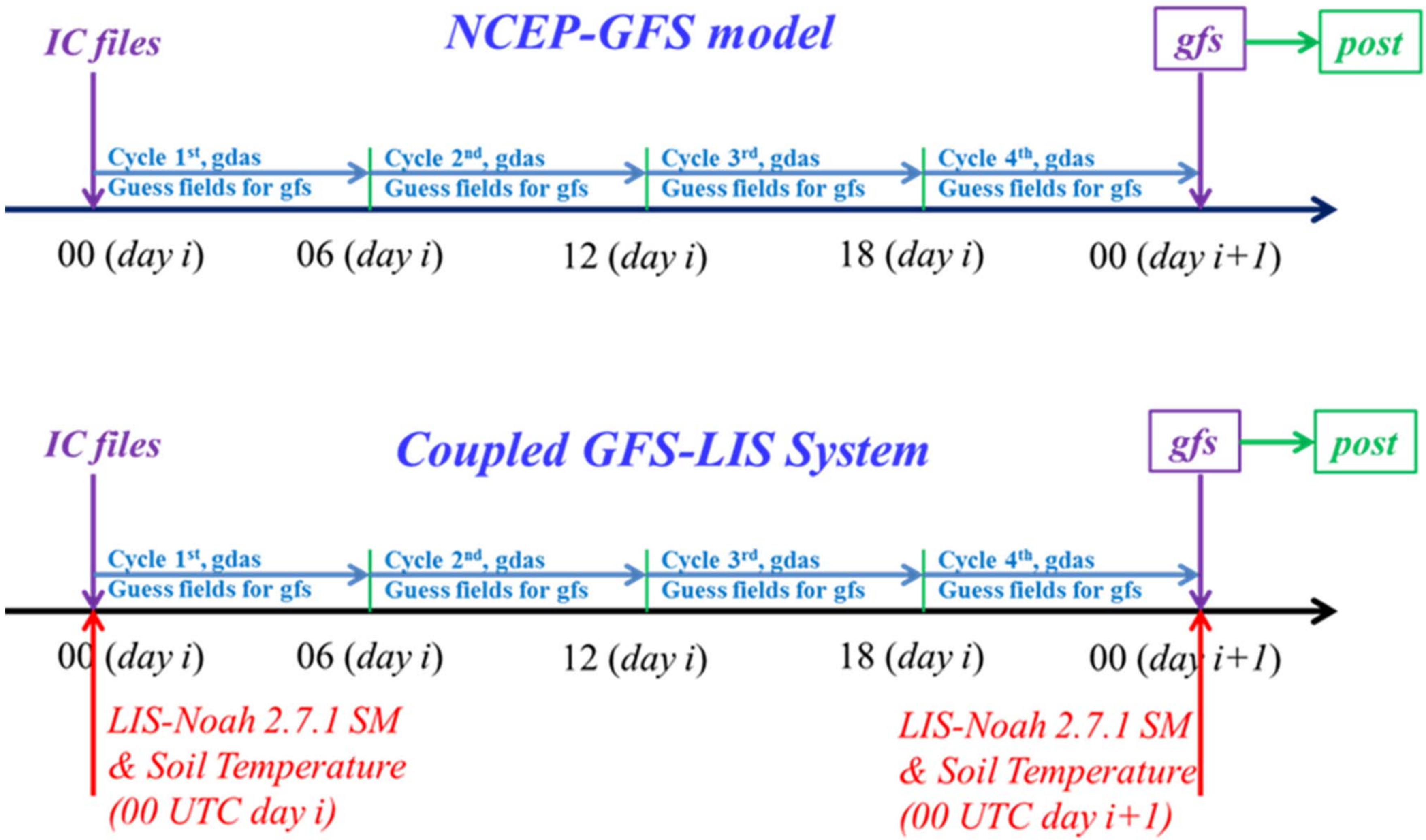
Impact of NRT GVF & albedo on Noah SM

Variables	Average Normalized RMSE improvement (%)		Maximum impact period (MIP) DOY (beg. – end.)		Maximum Normalized RMSE improvement (%)		Number (%) of improved sites	
	Surface	Rootzone	Surface	Rootzone	Surface	Rootzone	Surface	Rootzone
GVF	0.63	1.50	230-280	230-280	11.8	12.38	51.01	57.03
Albedo	0.23	0.56	221-256	249-283	1.67	3.97	66.04	64.42
Insolation	1.67	0.93	94-111	128-184	3.98	10.00	69.79	52.61
Combined	0.62	10.7	222-281	222-277	2.49	12.65	62.10	55.13

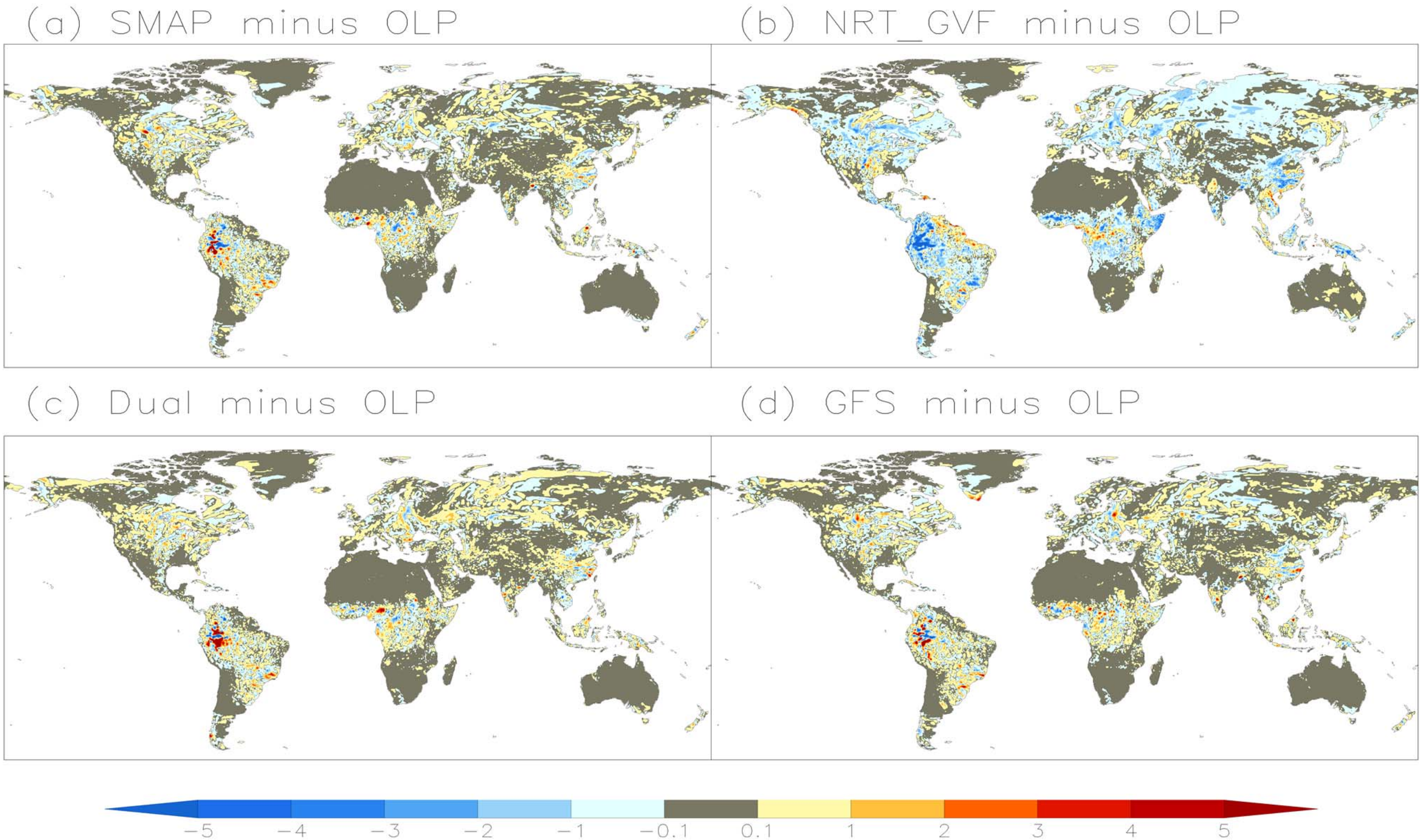
Assimilate SMAP SM with NCEP LIS-GFS

- *Use LIS-EnKF to assimilate NASA SMAP L3 SM daily with GDAS forcing*
- *Initialize GFS T670-254 with LIS output of ST and SM (see next flow chart)*
- *DA experiments:*
  - *OLP –> LIS run without SM DA and NRT GVF for GFS IC*
  - *SMAP –> assimilate SMAP SM only*
  - *NRT_GVF –> replace multi-year GVF with NRT GVF of VIIRS*
  - *Dual –> assimilate SMAP SM and use NRT GVF*
  - *GFS –> no LIS coupling for GFS initial conditions*
- *Evaluation:*
  - *All GFS 3-hour rainfall forecasts are compared with the best available rainfall observations used to drive GLDAS*

Assimilate SMAP SM with NCEP LIS-GFS

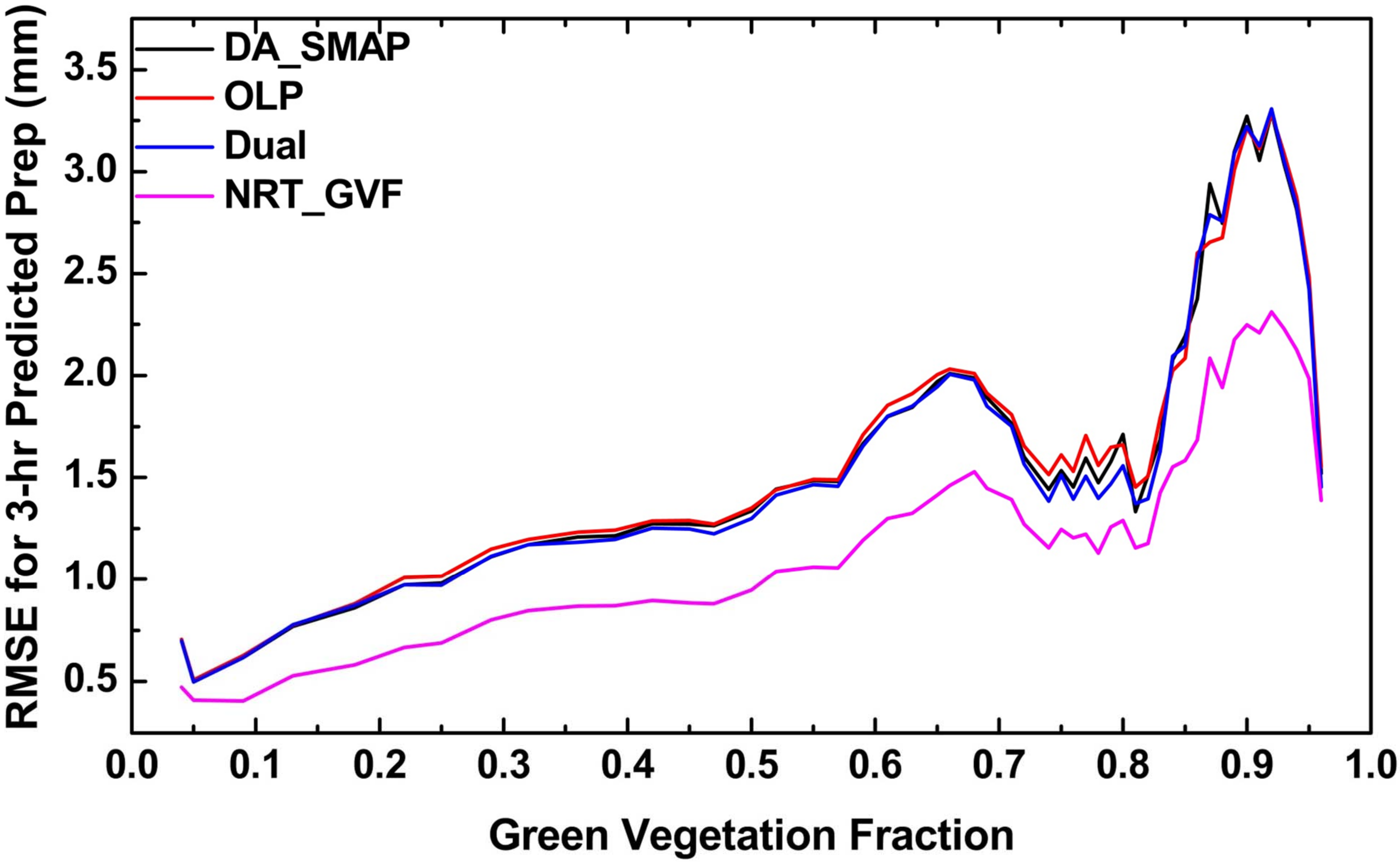


Assimilate SMAP SM with NCEP LIS-GFS



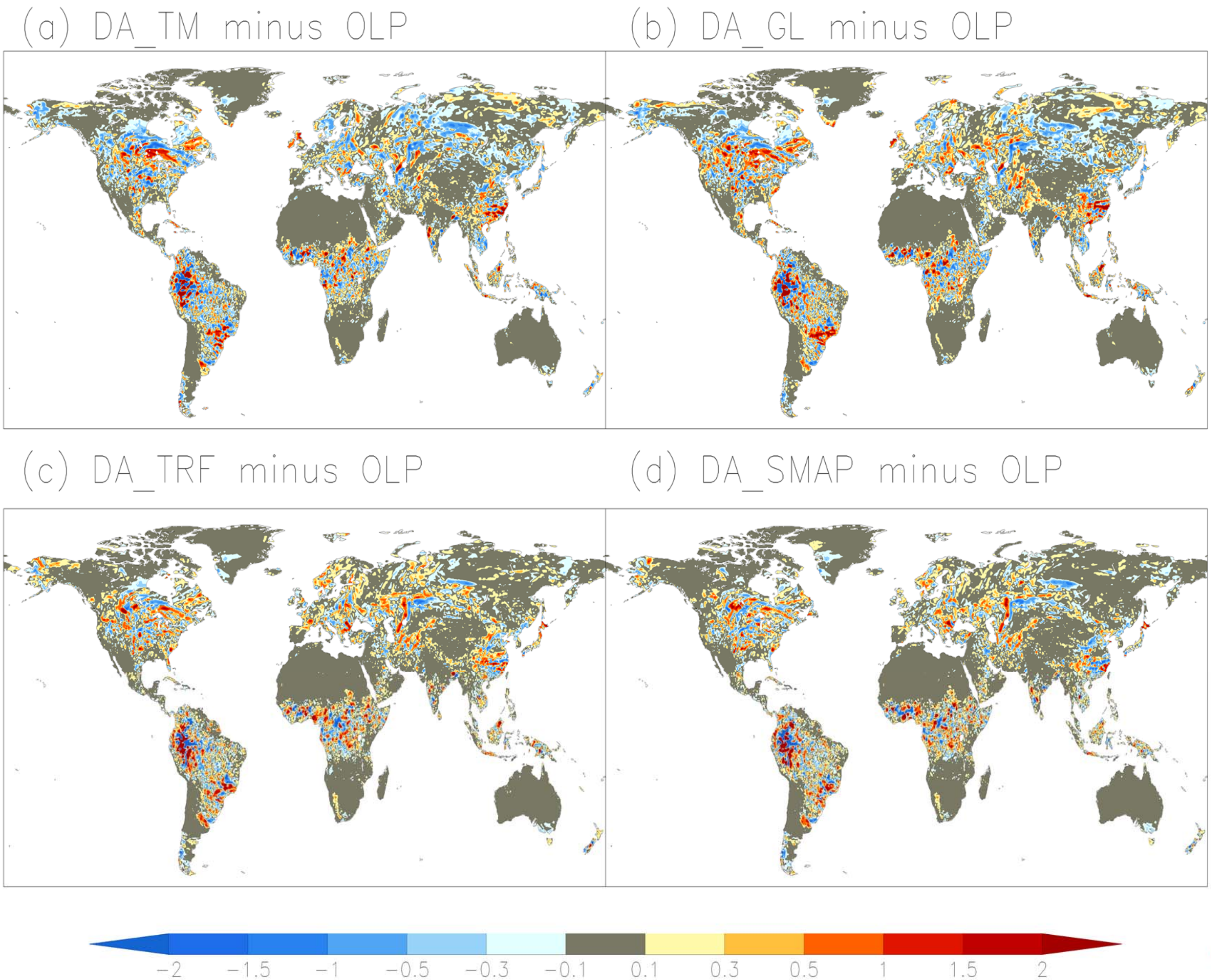
RMSEs of all GFS (3 hour interval for 7 days) rainfall forecasts from May 2-3, 2015 (112 samples)
(yellow and red indicate degradation and blue means improvement)

Assimilate SMAP SM with NCEP LIS-GFS



NRT GVF appears to improve GFS rainfall forecasts more significant than satellite soil moisture

Impact of SM Bias Correction Method in DA on GFS Rainfall Forecasts



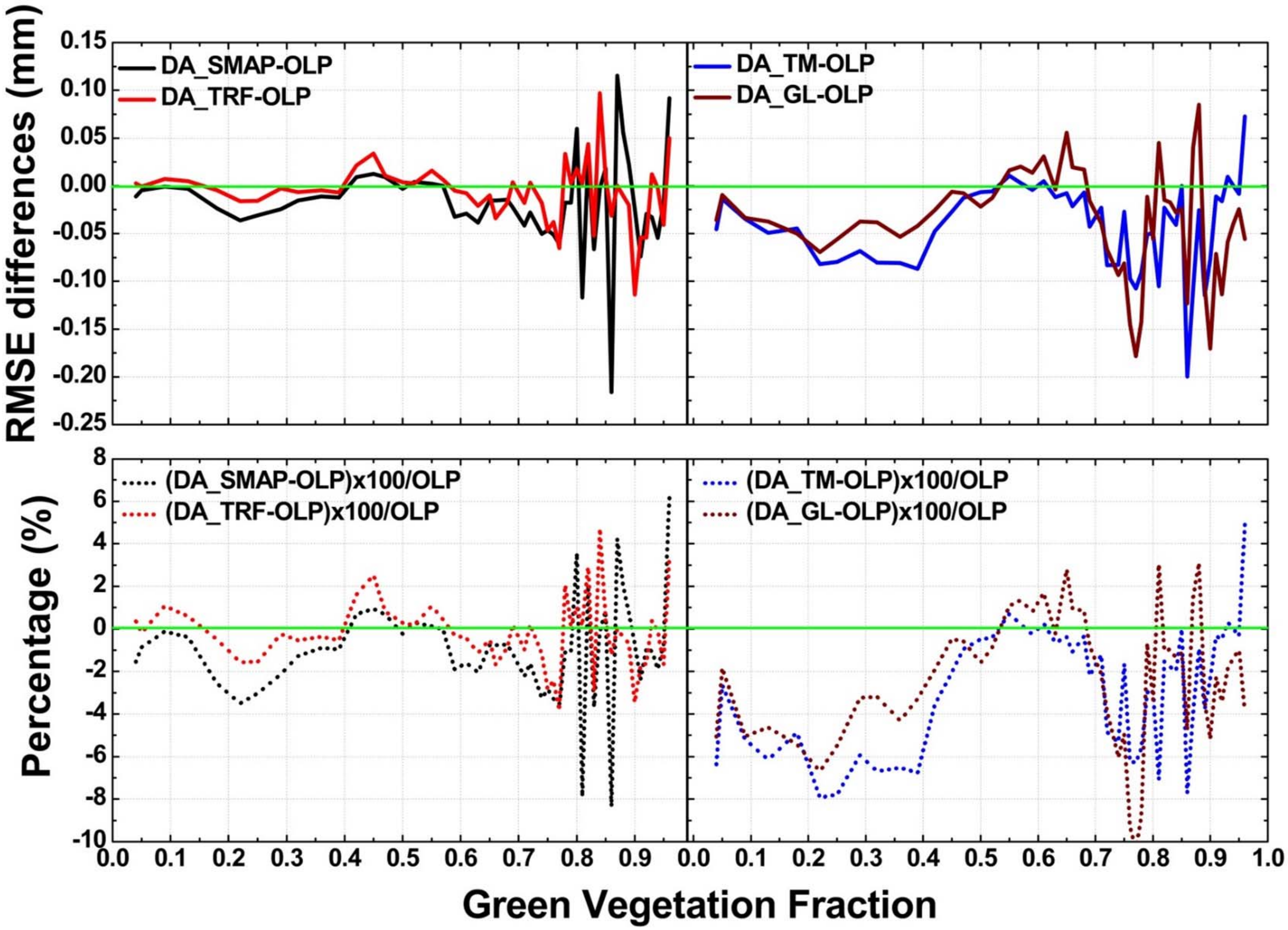
RMSE (mm) Difference Maps:

TM – pixel monthly CDF
GL – global CDF
TRF – monthly av & sd matching
SMAP – original SMAP
OLP – no assimilation

SMAP data:
4/2015 – 3/2017

(yellow and red indicate degradation and blue means improvement)

Impact of SM Bias Correction Method in DA on GFS Rainfall Forecasts



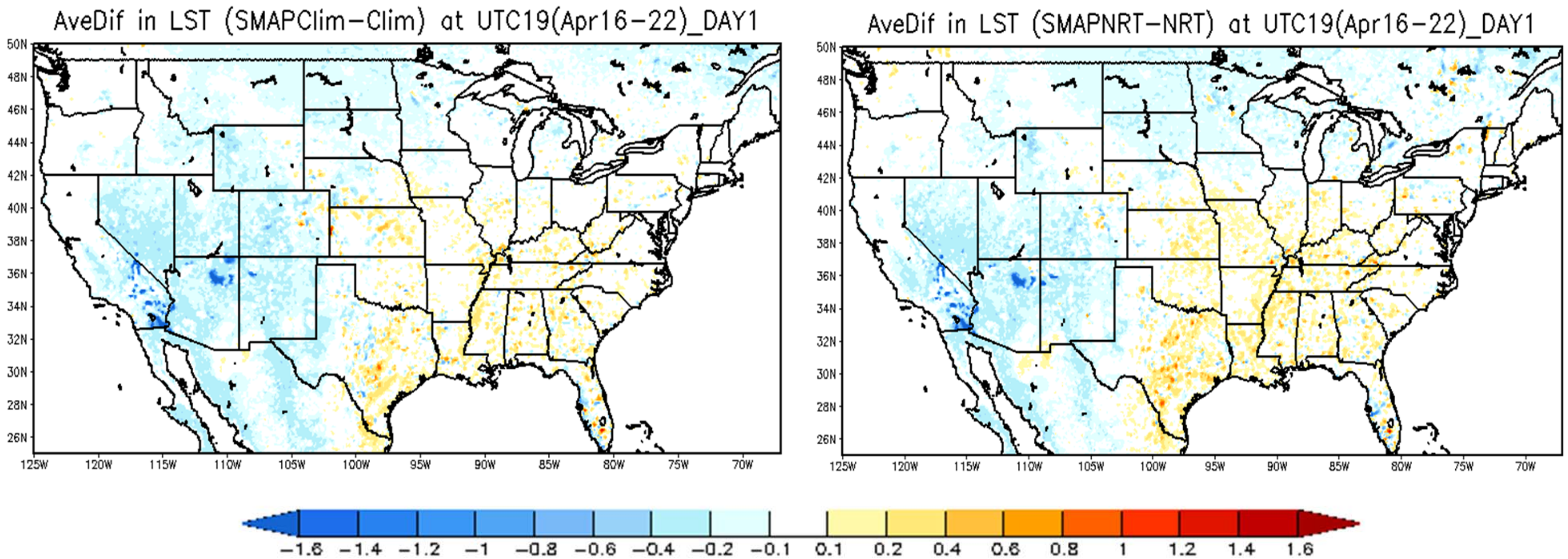
SMDA with pixel-wise monthly CDF matching for bias correction produced larger impacts on GFS rainfall forecasts depending on vegetation density

Assimilate SMAP SM with NASA NU-WRF

- *Use LIS-WRF (NASA NU-WRF) to assimilate NASA SMAP L3 SM daily*
- *SMDA is done with the EnKF in LIS using the standard set ups*
- *DA experiments:*
  - *CLIM –> LIS run with multiyear averages of AVHRR GVF*
  - *LAI –> LIS run with NRT GVF from MODIS LAI*
  - *EVI –> LIS run with NRT GVF from VIIRS EVI*
  - *SMAPCLIM –> SMAP SMDA using averaged AVHRR GVF*
  - *SMAPLAI –> SMAP SMDA using NRT GVF from MODIS LAI*
- *Evaluation:*
  - *All LIS-WRF Day 1 and Day 2 forecasts (6 hour interval) of T2m, RH and rainfall against ground observations of 1074 sites over CONUS*
  - *Forecasts are carried out from April 16 to 22, 2015 using SMAP SM data from April 1 to the forecast time for the SMDA cases*

Assimilate SMAP SM with NASA NU-WRF

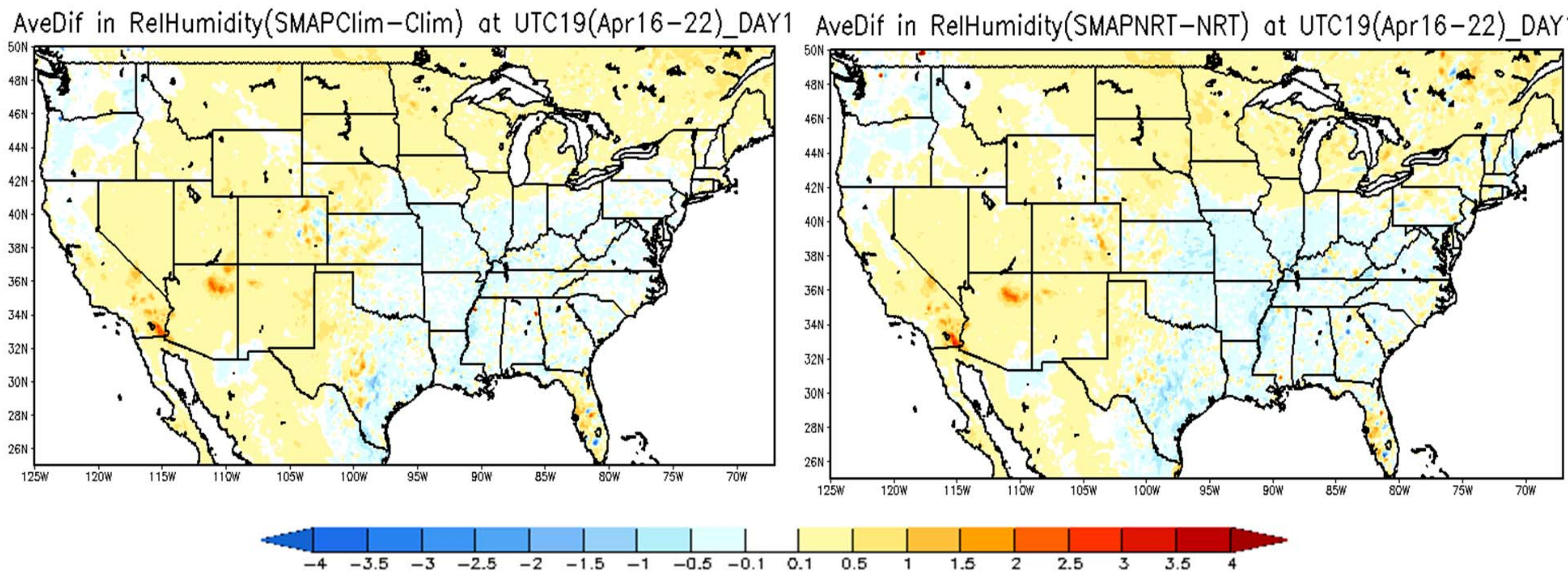
Average Differences of T2m forecasts between with and without SMAP SM DA



SMAP SM DA makes T2m forecasts cooler in the western CONUS, and warmer in the eastern CONUS under either averaged or NRT GVF conditions

Assimilate SMAP SM with NASA NU-WRF

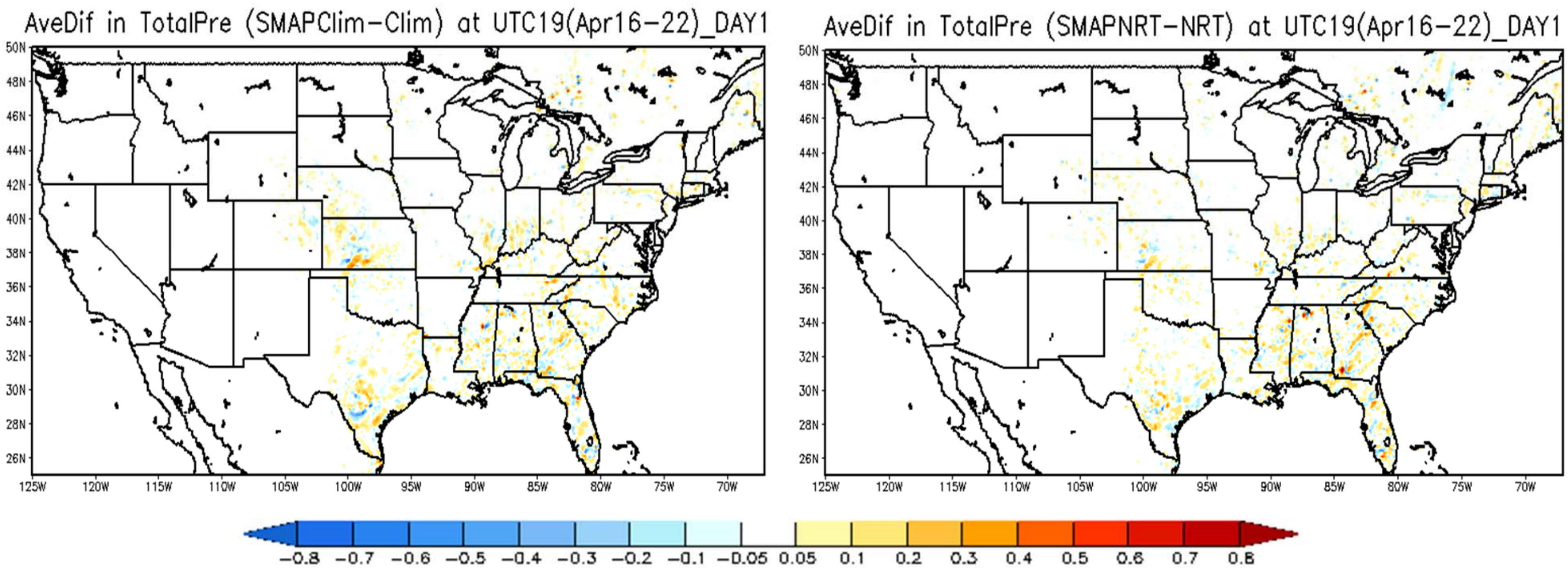
Average Differences of RH forecasts between with and without SMAP SM DA



SMAP SM DA makes RH forecasts wetter in the western CONUS, and slightly drier in the eastern CONUS under either averaged or NRT GVF conditions

Assimilate SMAP SM with NASA NU-WRF

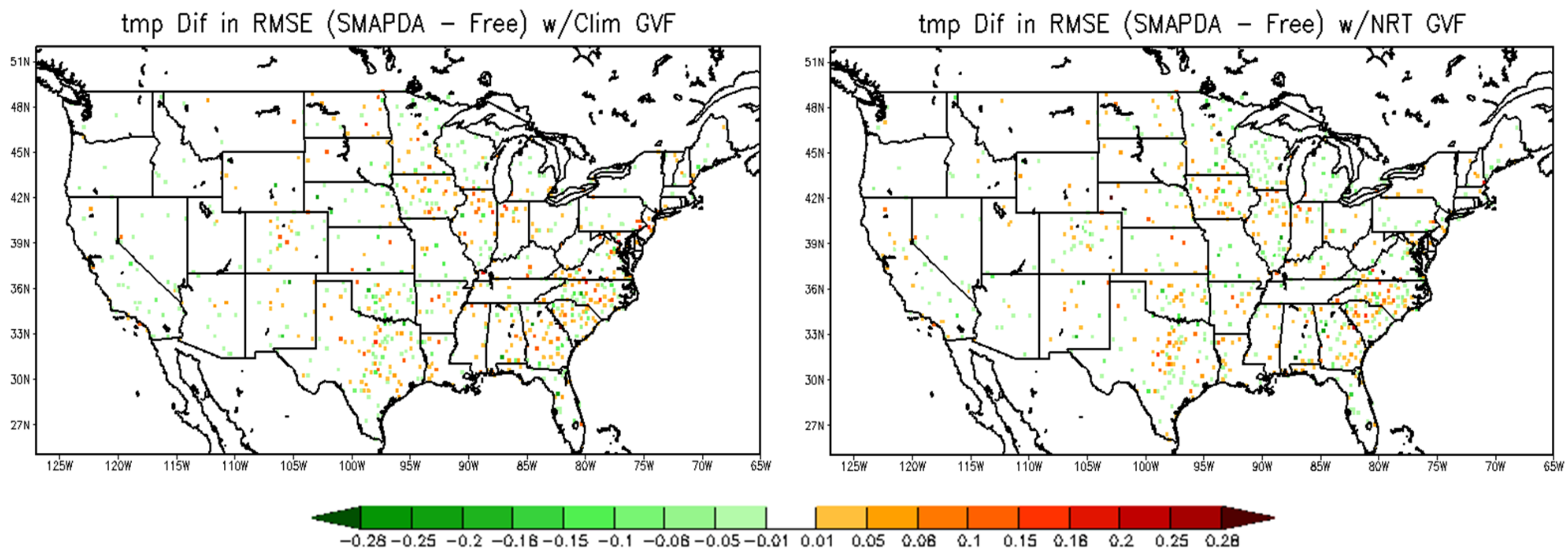
Average Differences of total precip forecasts between with and without SMAP SM DA



SMAP SM DA makes some differences in total precip in the eastern CONUS under either averaged or NRT GVF conditions

Assimilate SMAP SM with NASA NU-WRF

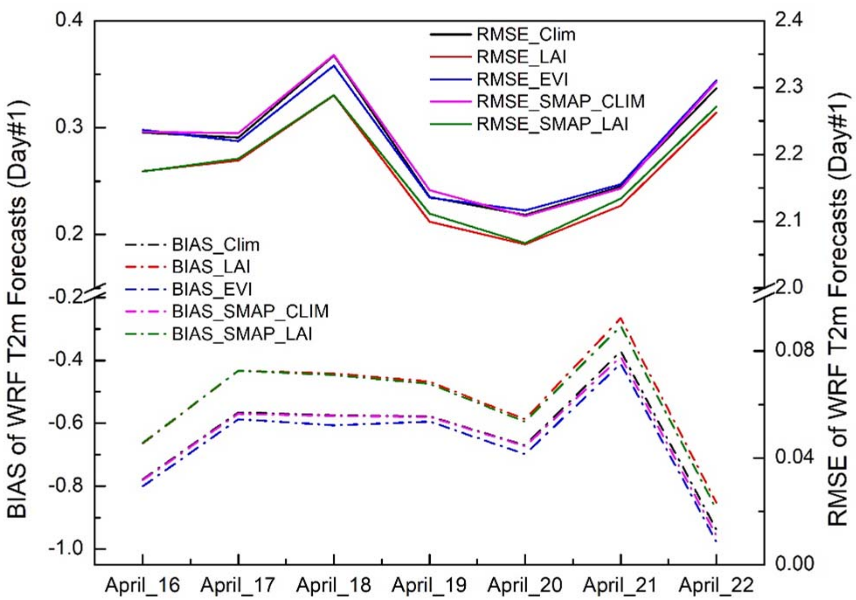
RMSE Differences of T2m forecasts between with and without SMAP SM DA against ground observations of 1074 sites

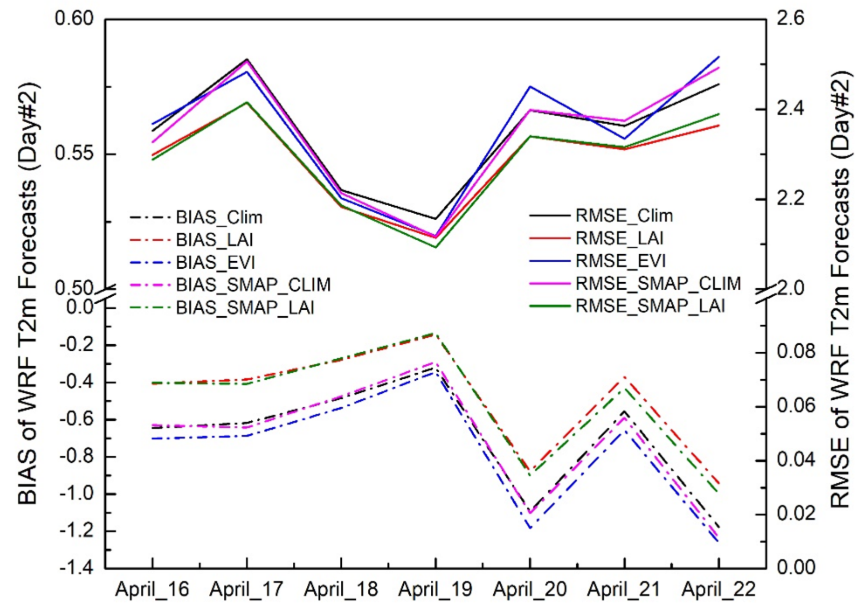


SMAP SM DA may make T2m forecasts better for some and worse for the other locations under either climatological or NRT GVF conditions

Assimilate SMAP SM with NASA NU-WRF

Biases and RMSEs of LIS-WRF T2m forecasts of Day1 and Day2 with different GVF and SM Setups

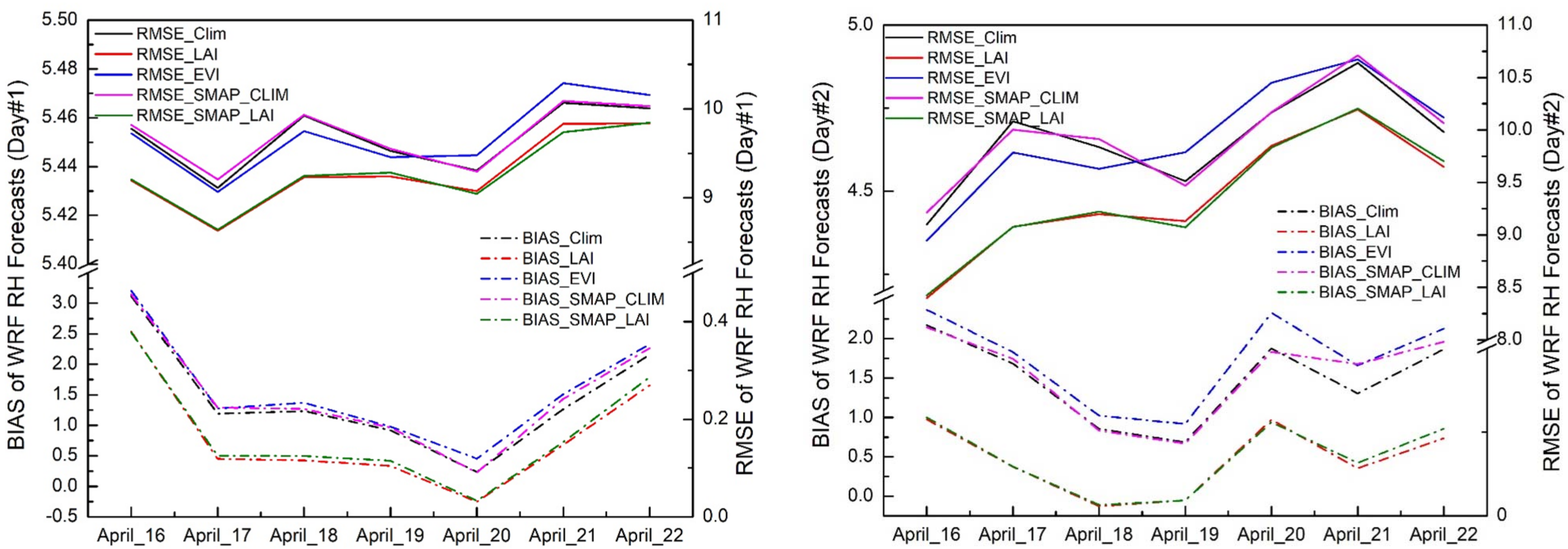




Generally using NRT GVF may improve LIS-WRF T2m forecasts more significant than SMAP SM DA

Assimilate SMAP SM with NASA NU-WRF

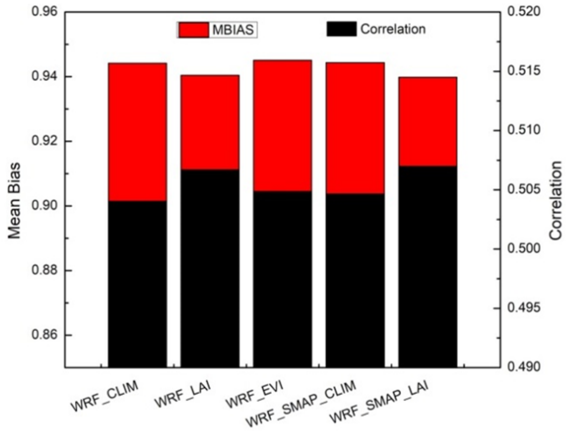
Biases and RMSEs of LIS-WRF RH forecasts of Day1 and Day2 with different GVF and SM Setups

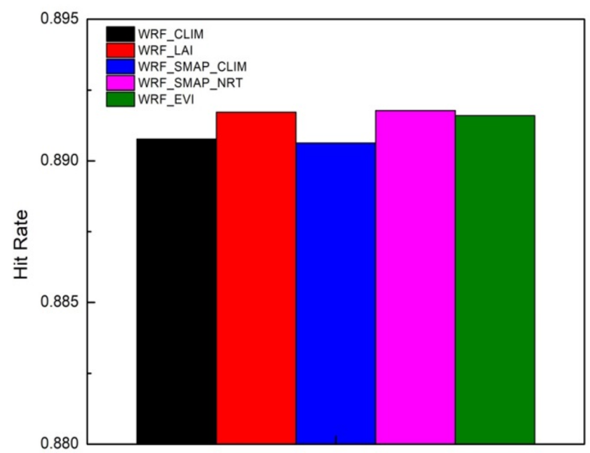


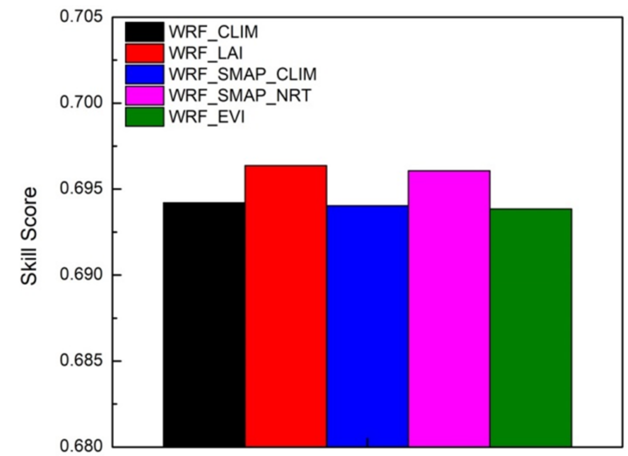
Generally using NRT GVF may improve LIS-WRF RH forecasts more significant than SMAP SM DA

Assimilate SMAP SM with NASA NU-WRF

Statistics of LIS-WRF Precipitation Forecasts under various GVF and SMDA setups against Stage IV Data



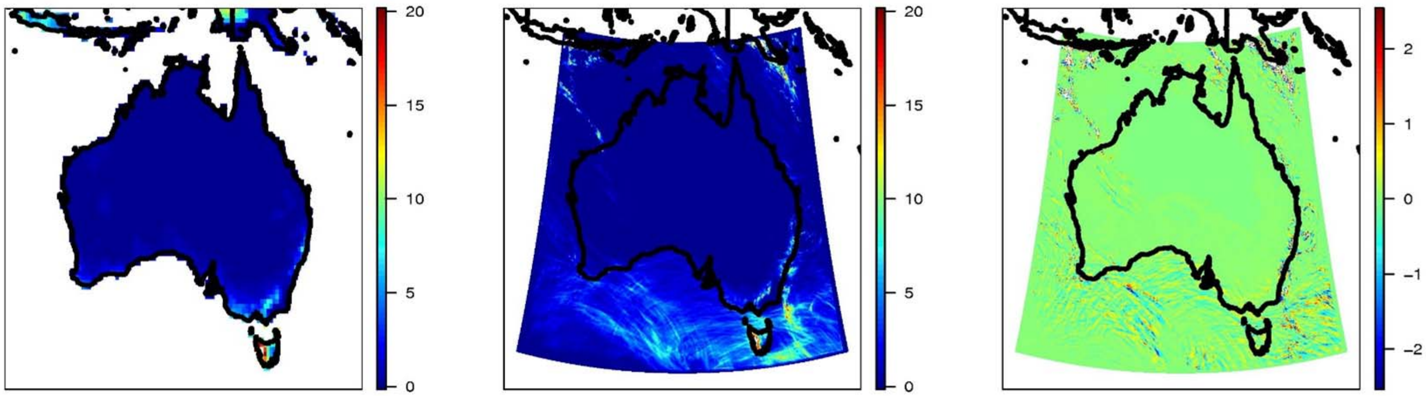




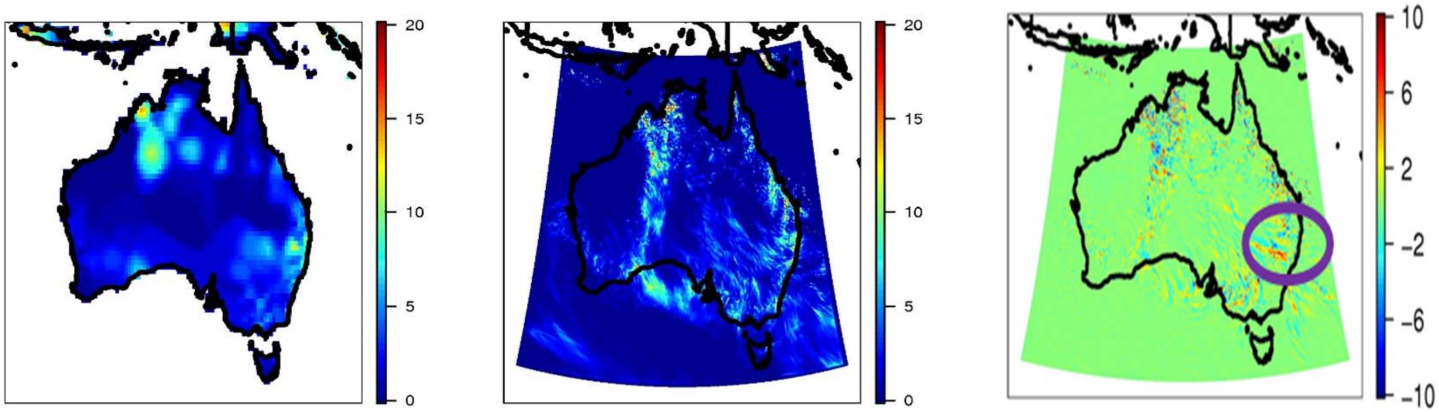
SMAP SM DA did not significantly improve LIS-WRF precipitation forecasts as using NRT GVF

Assimilate SMAP SM with NASA NU-WRF

May 2-10, 2015



Gauge obs, ¼ degree (mm)   Free run, 12km (mm)   Assim-Free (mm)



Nov 2-10, 2015

After SMAP SM data assimilation, the 9 day daily averaged rainfall forecasts of NUWRF looked closer to the gauge observations than the free run without the DA

Causes of the Insignificant Impacts

- ***GVF:***
  - *Inconsistent impact assessment might be caused by the GVF product algorithm itself (LAI-based/LAI?)*
- ***Albedo:***
  - *Insignificant inter-annual variations so that seasonal average might have represented the reality well at least for the time period studied (dual-pass DA?)*
- ***Soil Moisture:***
  - *CDF matching for bias correction (dual-pass DA?)*
  - *Observation error variance set up (pixel-wise?)*
  - *Observation accuracy itself (heterogeneity?)*
  - *Model physics (SM-fluxes-weather coupling?)*

SUMMARY

- *Many surface data products have been generated from NOAA-NESDIS operationally*
- *But almost none of them has been used in NOAA NWP operations because of inconsistent impact assessment results*
- *In addition to the product accuracy and consistency issues, data assimilation algorithm may have to be investigated further*