Application of Satellite Land Measurements in Improving NCEP Numerical Weather Prediction

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The 1st International Surface Working Group, Montery CA, July 19-20, 2017

Motivation

- ***Objective:***

To improve satellite data utilization over land in NCEP forecast models and data assimilation system and then improve the numerical weather prediction (NWP).

- ***Land satellite data assimilation:***

– Utilization of satellite data sets in the models (e.g., *GVF, snow, burning area, albedo, emissivity, LST, radiation, vegetation and soil type, etc.*)

– Assimilation of satellite products (e.g*, Soil moisture (SMAP, SMOPS); snow*);

– Direct radiance assimilation (Tb)

Requiring a forward radiative transfer model (RTM) to calculate Tb with input of model atm profiles and sfc parameters. (sfc emissivity, sfc parameters). (Understand the interaction and feedback between land and atmosphere, and then improve NWP and DA)

Satellite Obs. in Monitoring and LDAS

- **Monitoring:** GOES / VIIRS LST (Yu), Sfc Rad. flux verification (Laszlo).

- **LDAS:** GLDAS (Jesse Meng), NLDAS (Youlong Xia)

- ***NLDAS*** *(Youlong Xia):*

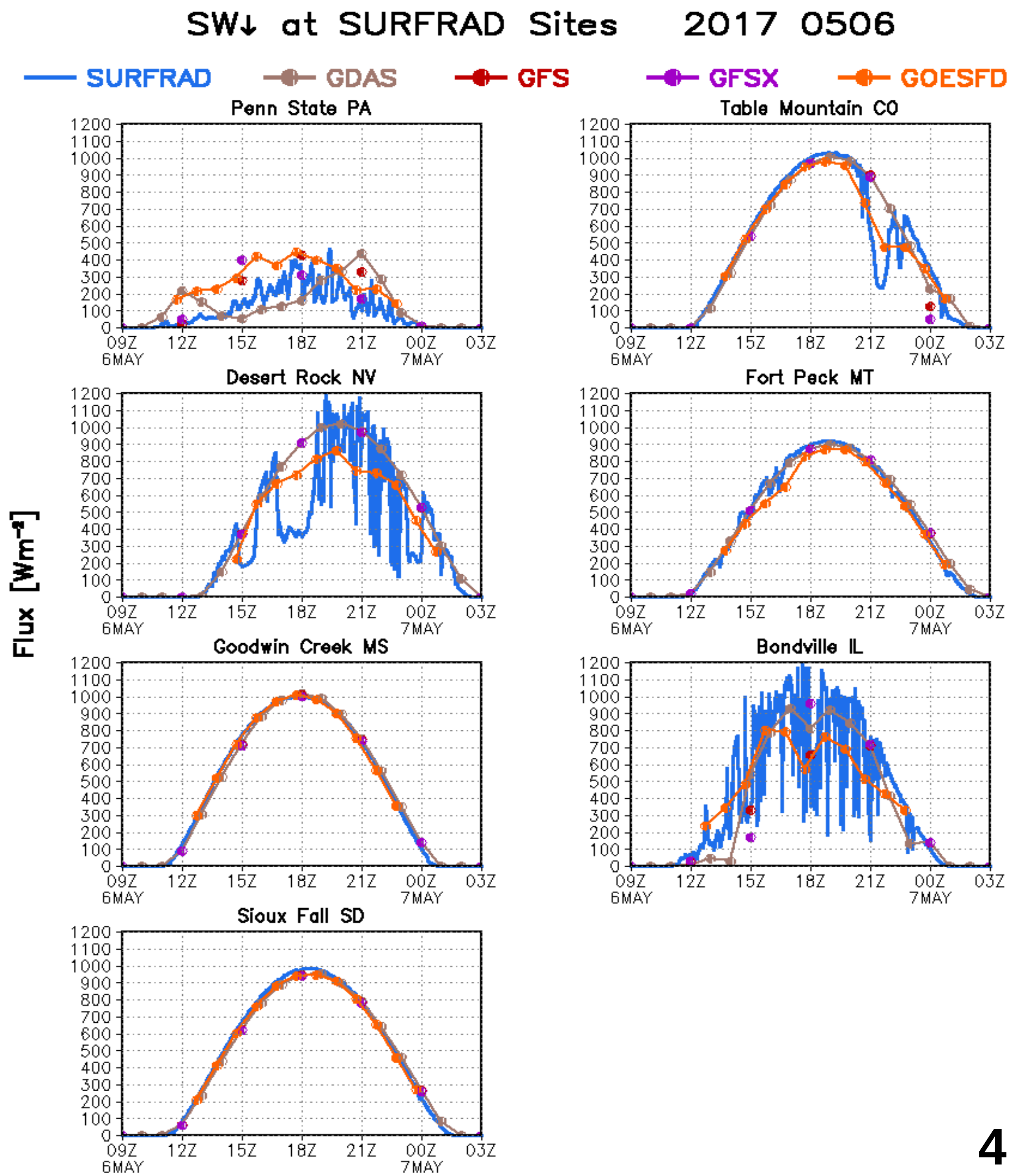
-- IMS snow cover data help NLDAS Noah model upgrade;
-- GOES skin temperature;
-- GOES downward shortwave radiation in next NLDAS upgrade;
-- Some snowpack, soil moisture, and terrestrial water storage assimilation is in CTB NLDAS resarch, which will be considered as NLDAS-3.0 implementation two years later.

NESDIS GSIP for GFS/NAM
Surface Shortwave Flux Verification

The NESDIS Geostationary Surface and Insolation Product (GSIP) of surface shortwave flux is used for the EMC model verification.

Model predicted diurnal cycles of surface shortwave fluxes at seven sites across US are compared with GSIP and surface observations on daily basis.

Istvan Laszlo (NESDIS)
Jesse Meng (EMC)



Courtesy Jesse Meng

Weekly Real-time VIIRS GVF

- **NCEP Operations: Monthly 0.14-deg (16-km) global climatology of GVF from AVHRR. (Gutman & Ignatov, 1998).**

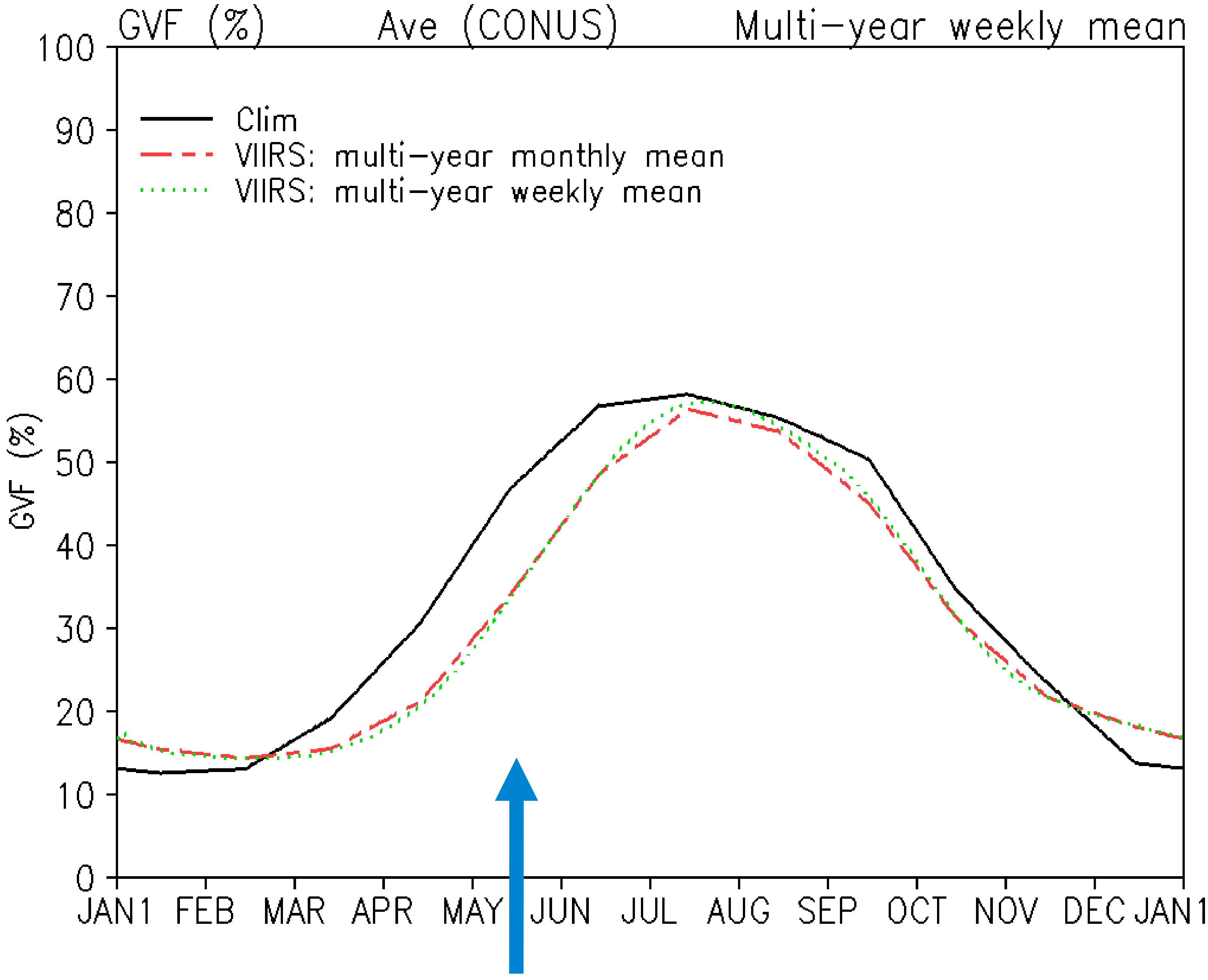
- **Weekly GVF: VIIRS near real-time weekly global 0.036-deg (4-km) GVF (Marco Vargas team@NESDIS). It starts from Sep. 2012 to current.**

- **Three data sets: (a) Weekly climatology GVF;**
  (b) Monthly climatology GVF;
  (c) Near real-time weekly GVF

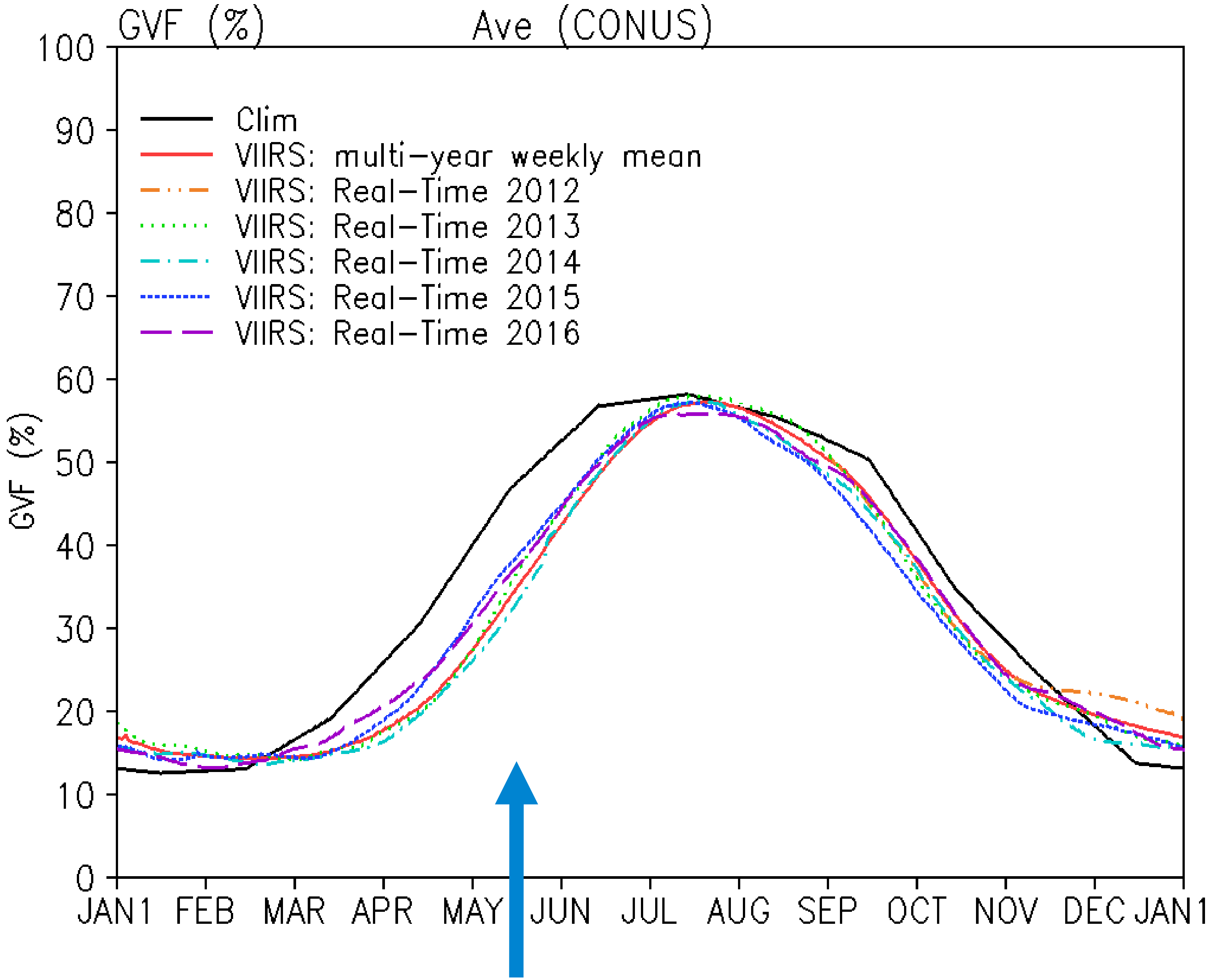
- **The other GVF data sets are also examined:**

(a) Near real-time weekly AVHRR (Le Jiang et al., NESDIS);
(b) Near real-time weekly MODIS (Xiaoyang Zhang, SD State U.).

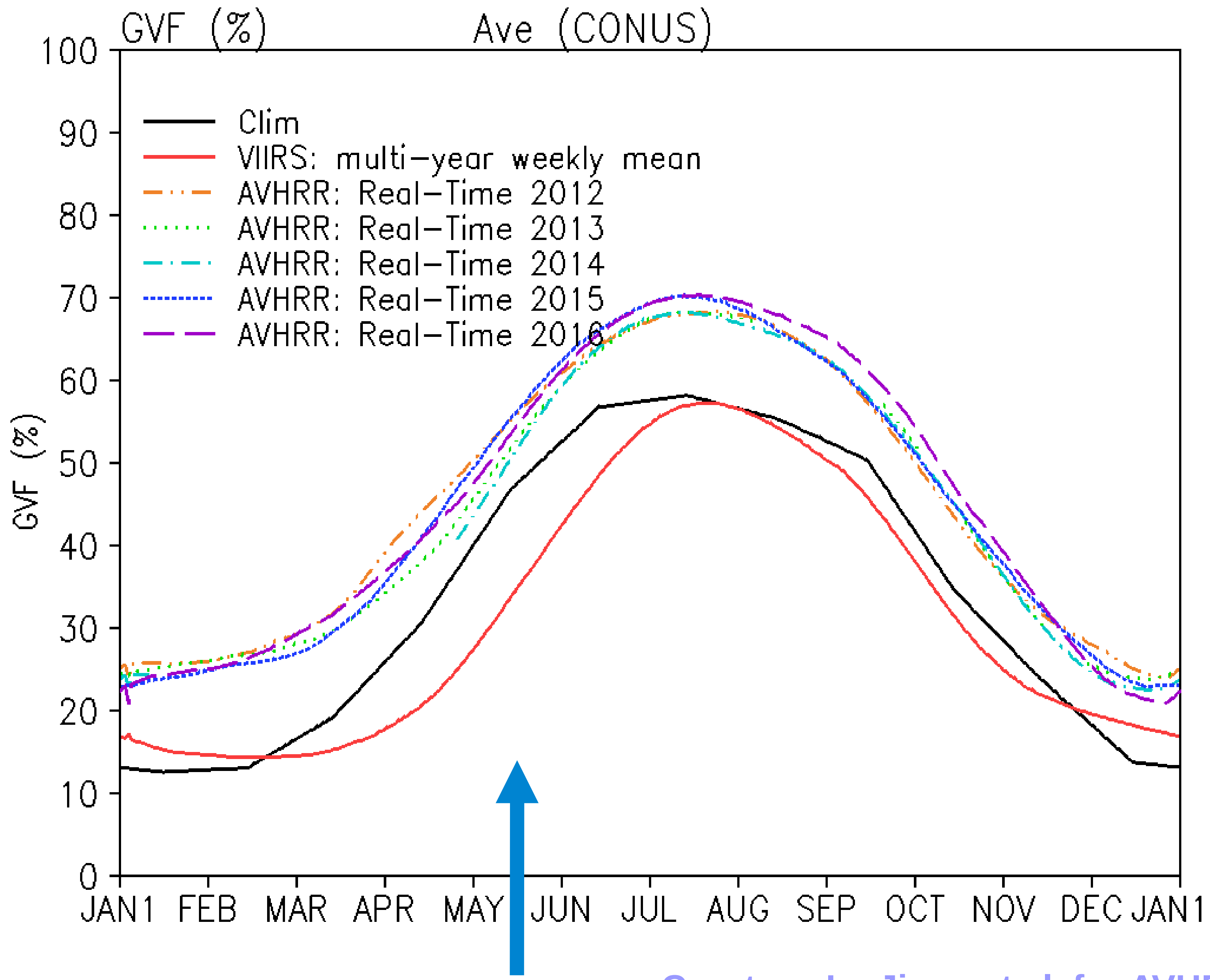
Multi-year mean VIIRS GVF over CONUS



Average VIIRS GVF over CONUS: Near Real-Time

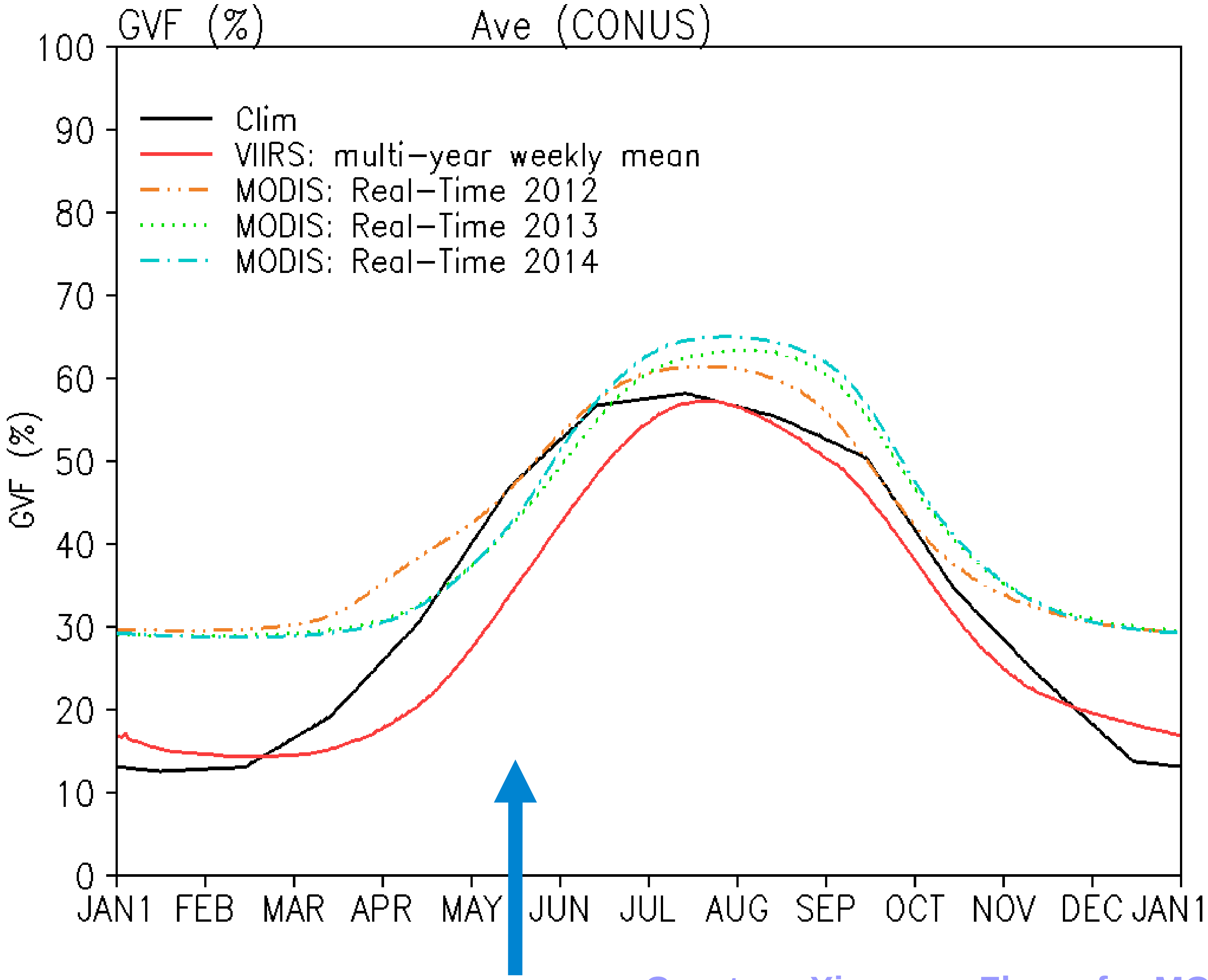


Average AVHRR GVF over CONUS: Near Real-Time



Courtesy Le Jiang et al. for AVHRR data

Average MODIS GVF over CONUS: Near Real-Time

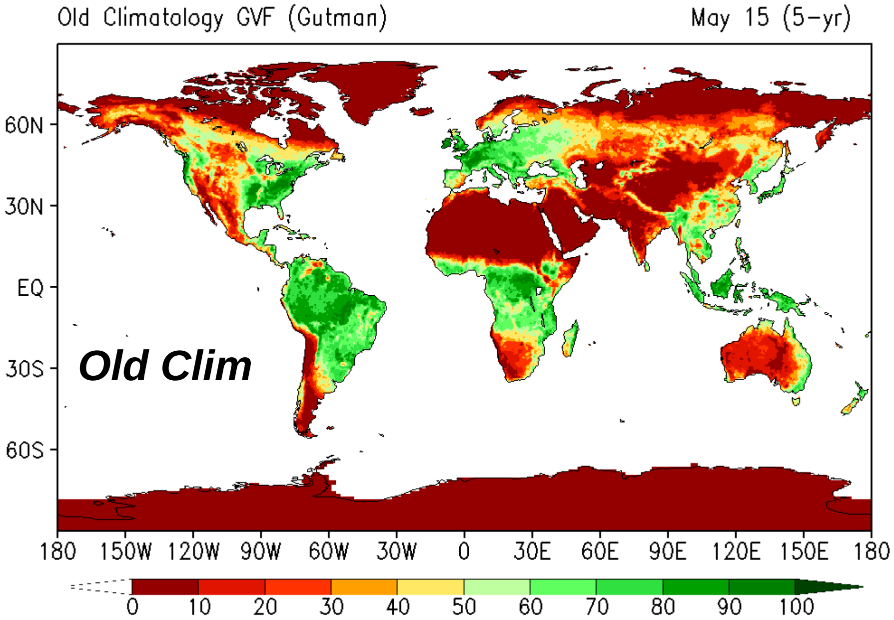


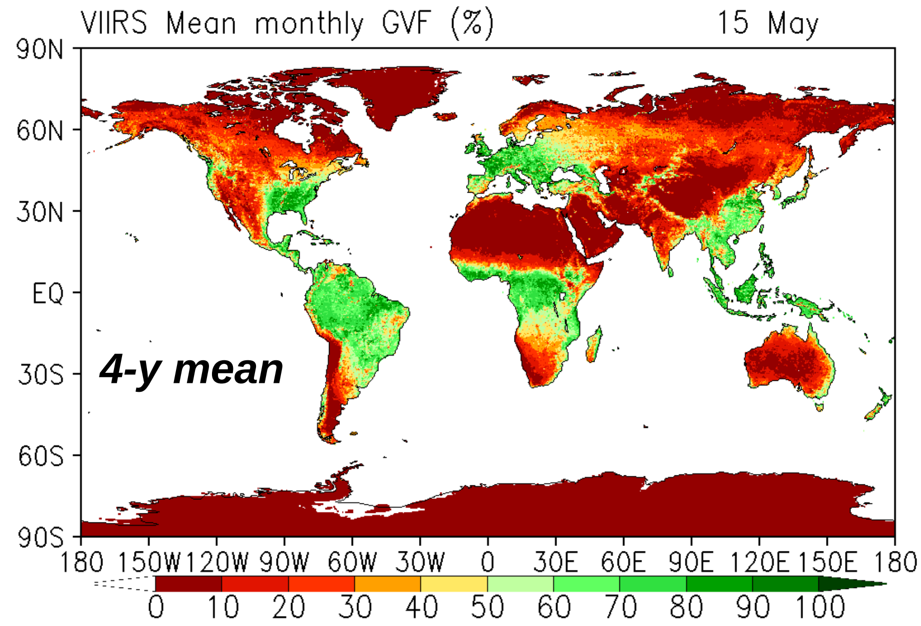
Courtesy Xiaoyang Zhang for MODIS data

VIIRS GVF (4-y monthly mean) test:

5/02 – 6/02, 2016

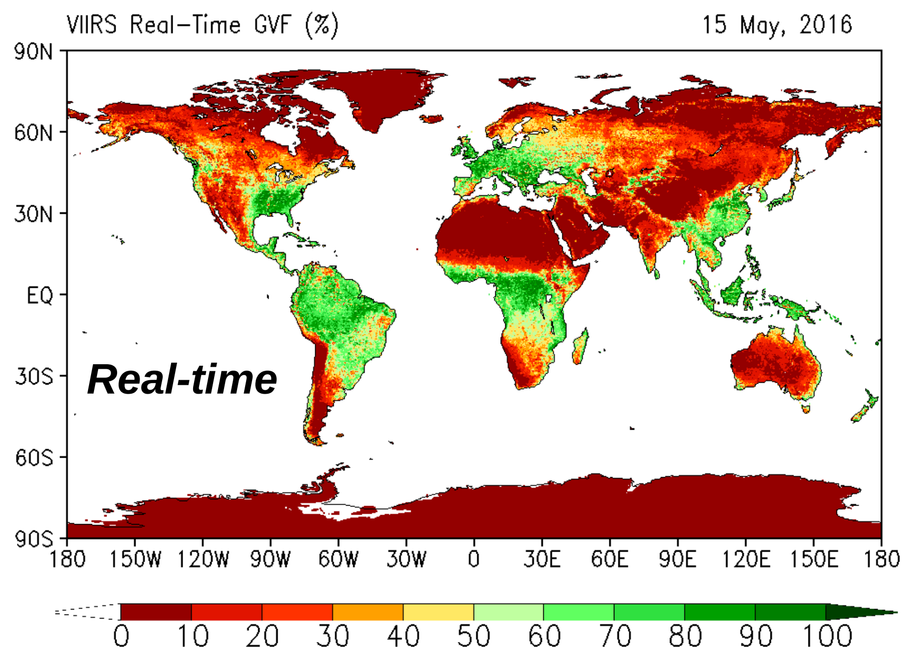
GVF: AVHRR monthly clim and VIIRS data: 15 May 2016



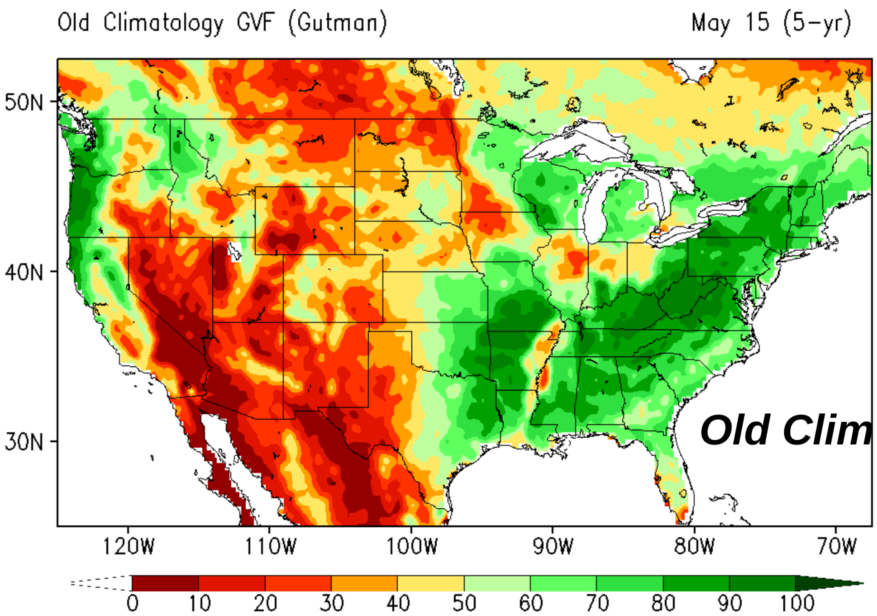


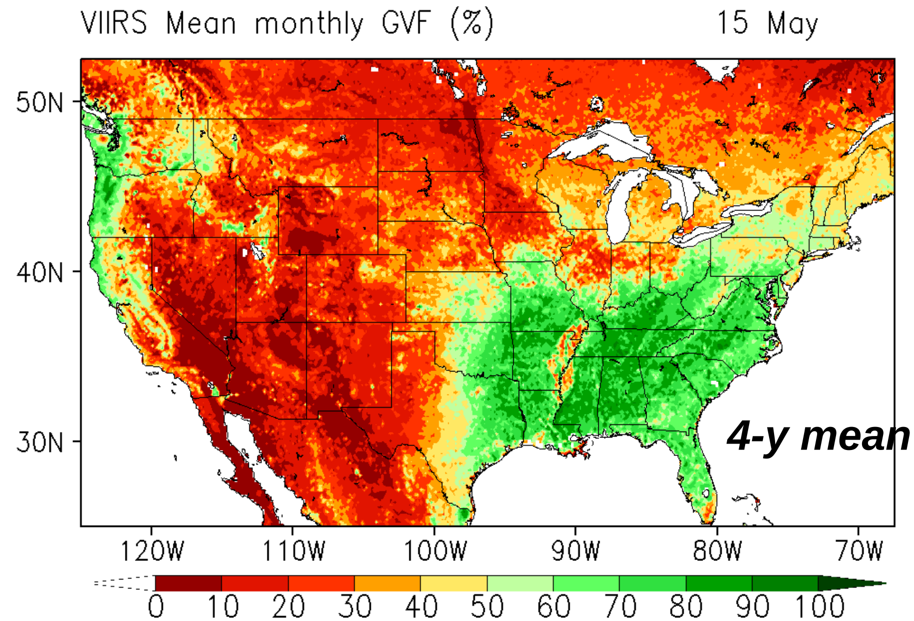
– ***Near real-time VIIRS GVF is similar to the 4-year VIIRS monthly mean;***

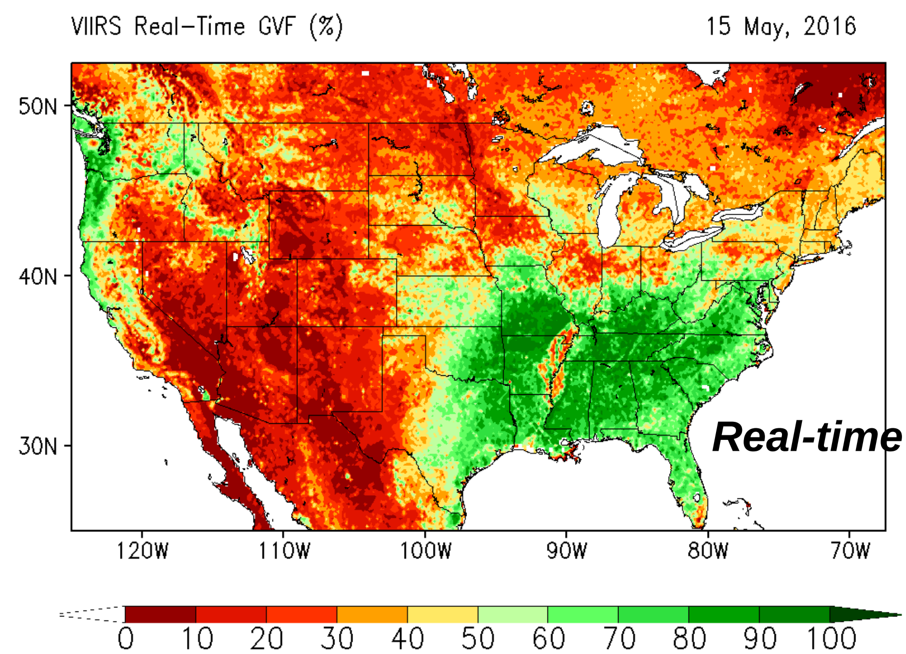
– ***Both are lower than the old AVHRR monthly climatology.***



GVF: AVHRR monthly clim and VIIRS data: 15 May 2016







– Near real-time VIIRS GVF is similar to the 4-year VIIRS monthly mean;

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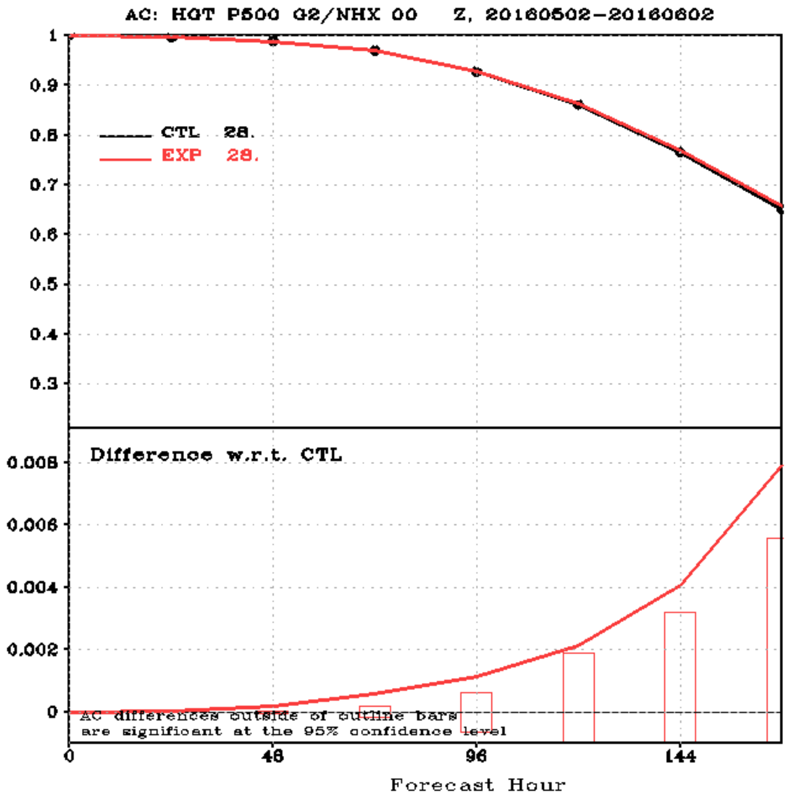
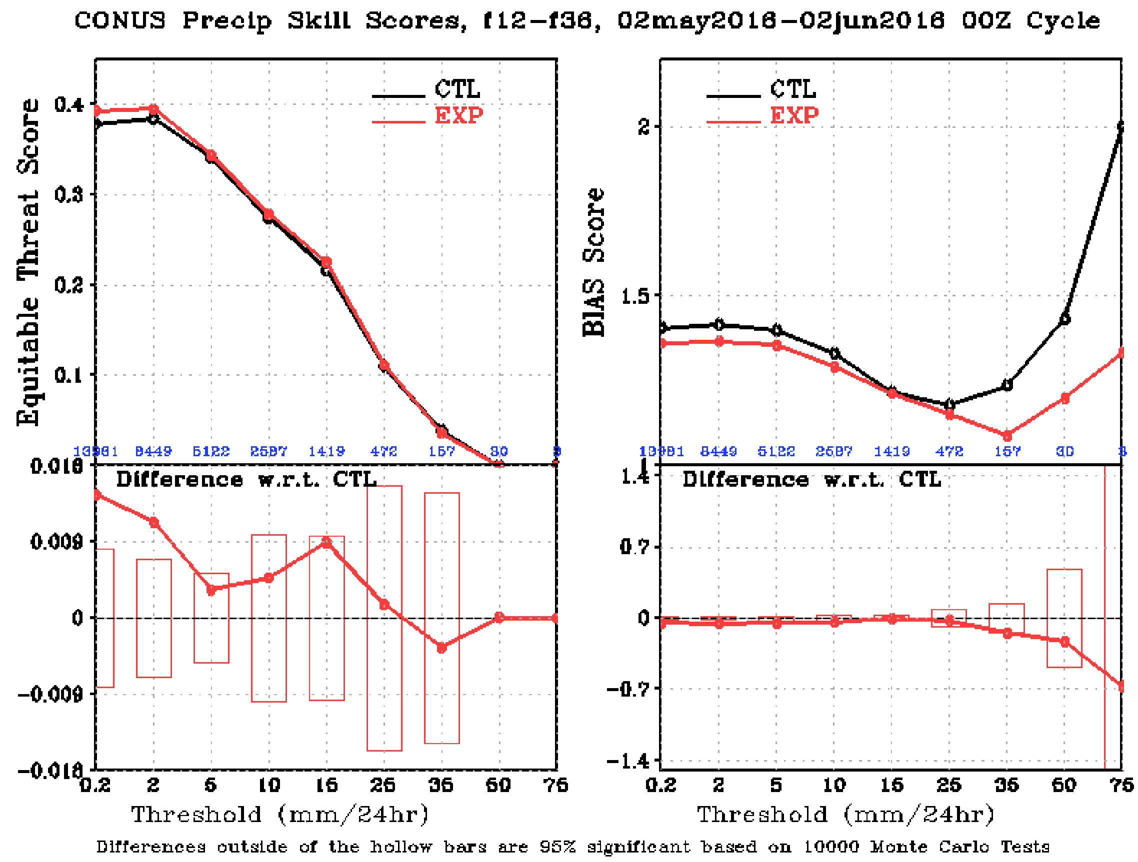
VIIRS GVF (4-y monthly mean) test: 5/02 – 6/02, 2016

AC: HGT 500 hPa G2/NHX



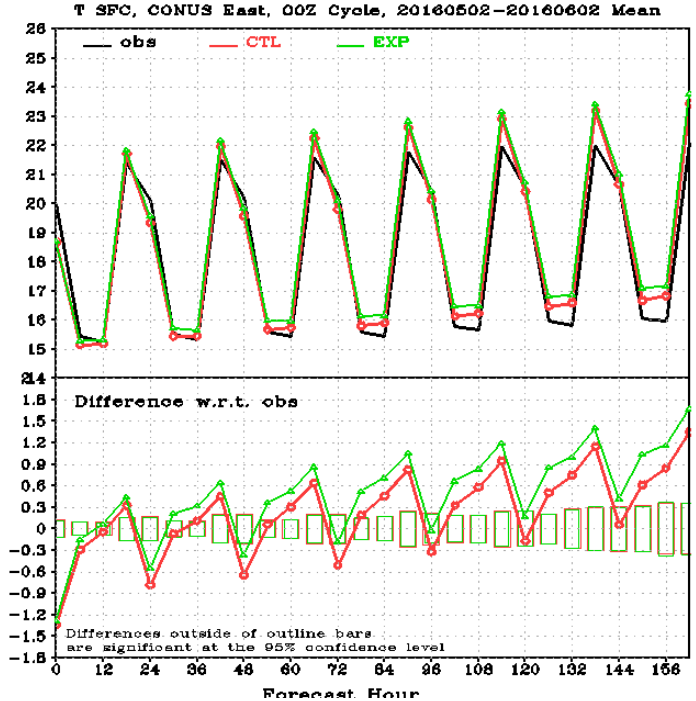
VIIRS test: Improve AC score @500 hPa.

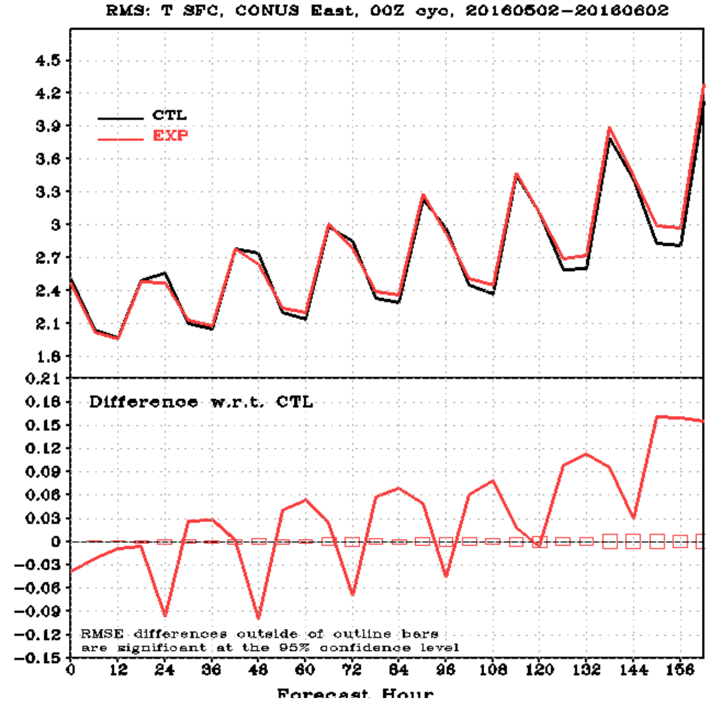
Precipitation Skill Scores over CONUS: f12-f36



VIIRS test: positive impact for light precipitation

T2m bias and rmse over E. &W. CONUS 5/02-6/02, 2016

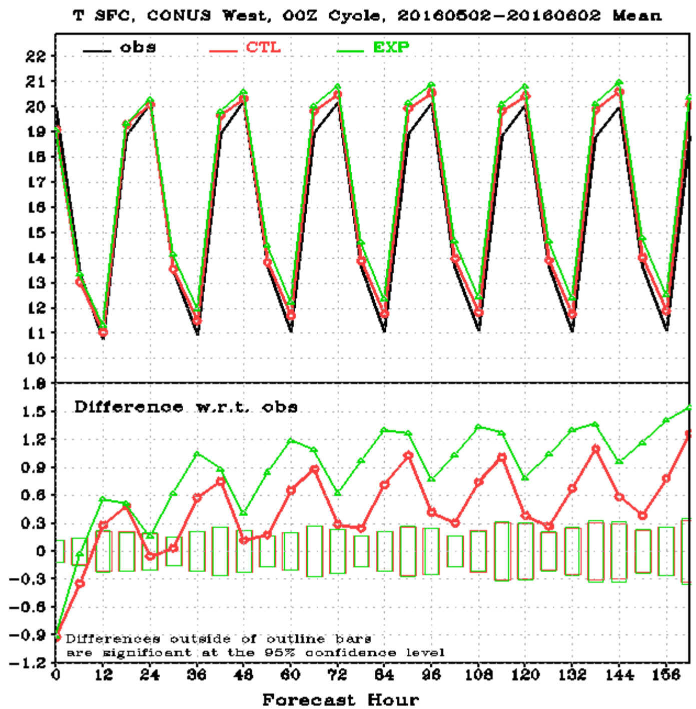


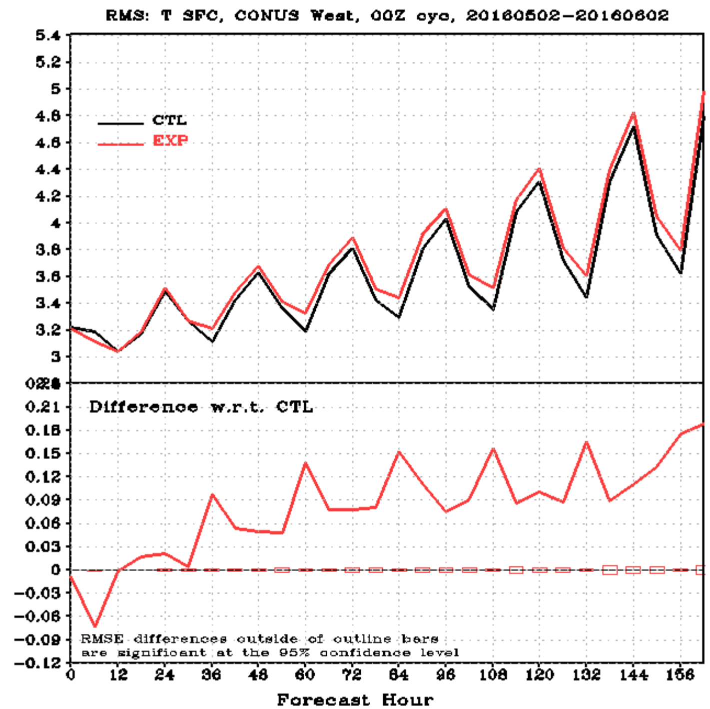


East CONUS

<u>VIIRS:</u>

Increase warm bias and RMSE!

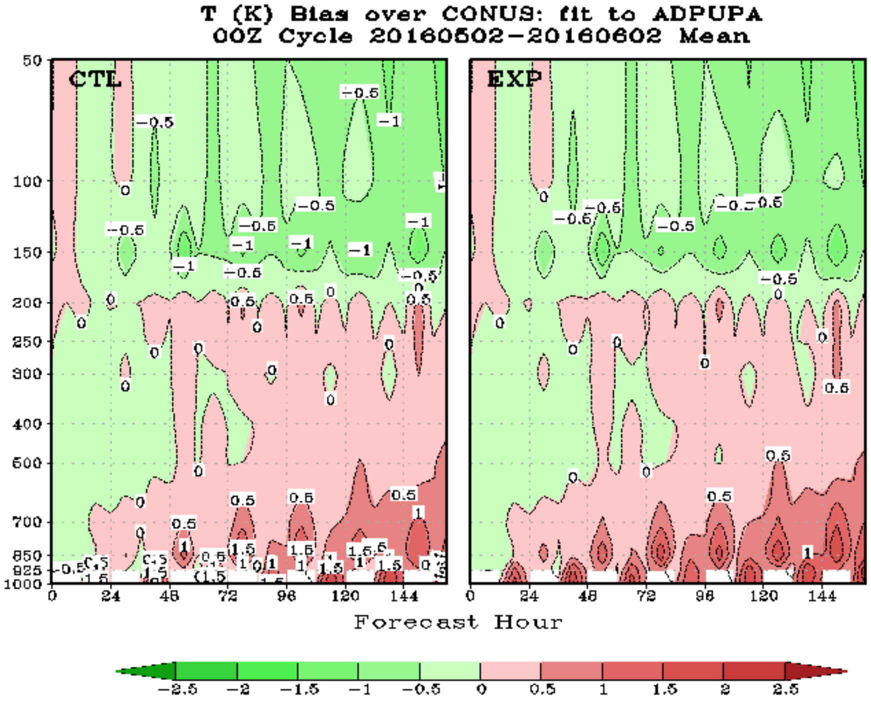




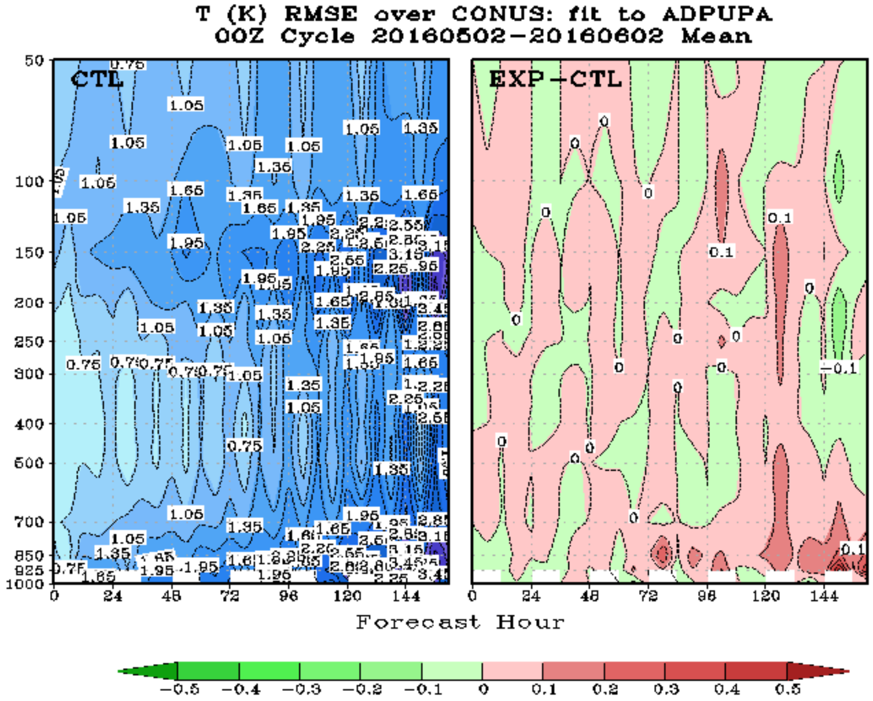
West CONUS

Temperature fits to Obs over CONUS 5/02-6/02, 2016

Temp Bias

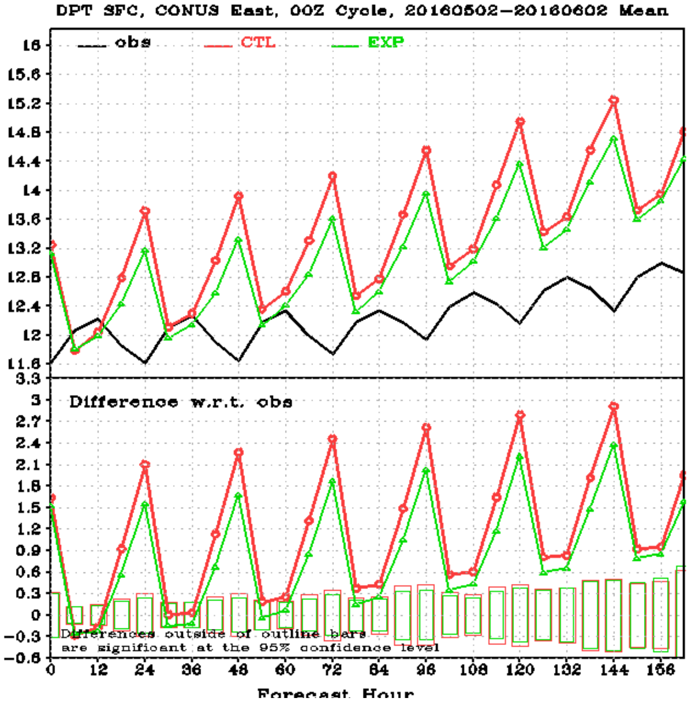


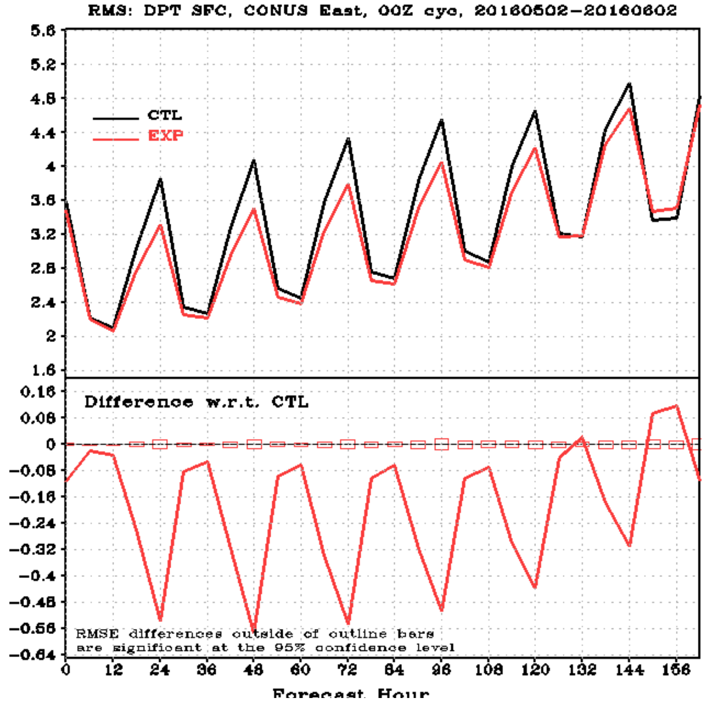
Temp RMSE



<u>VIIRS:</u> Increase warm bias and RMSE!

Td2m bias and rmse over E. &W. CONUS 5/02-6/02, 2016



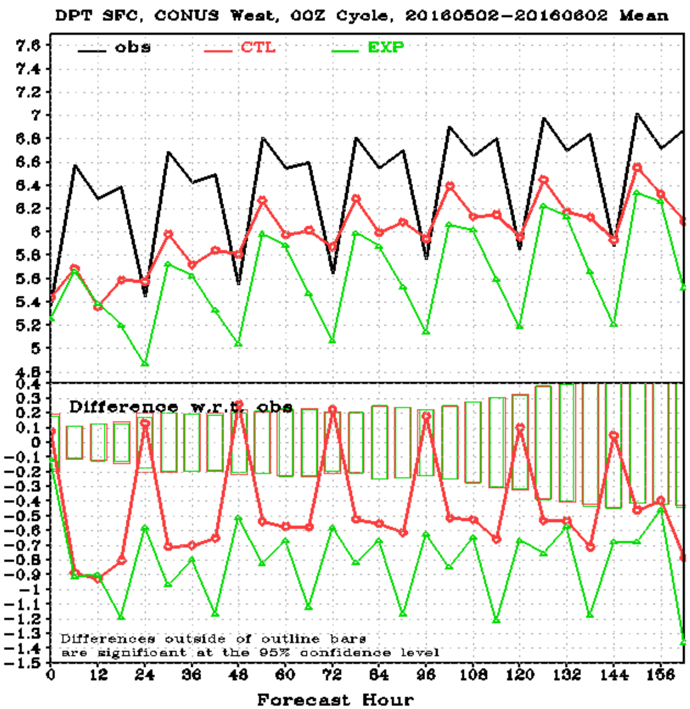


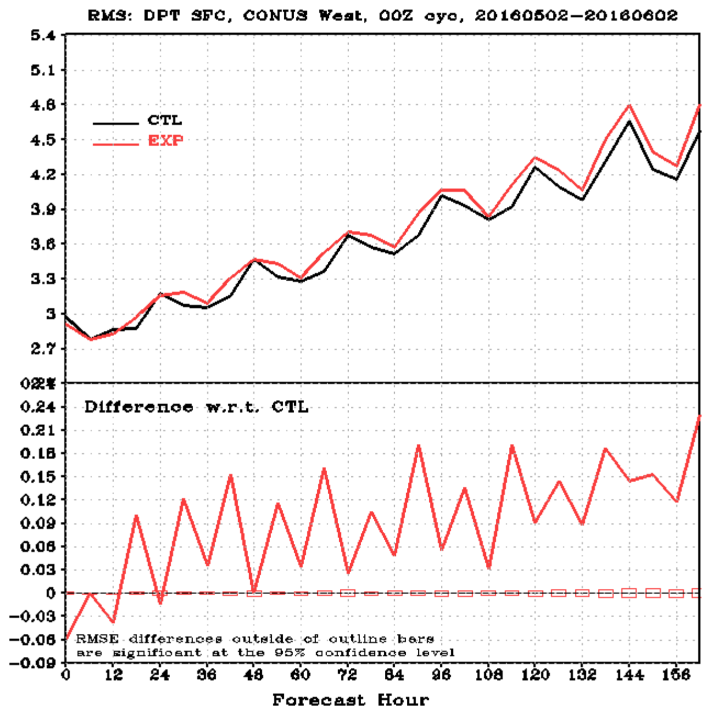
East CONUS

<u>*VIIRS:*</u>

East CONUS: *Reduce wet bias and RMSE.*

West CONUS: *Increase dry bias and RMSE.*



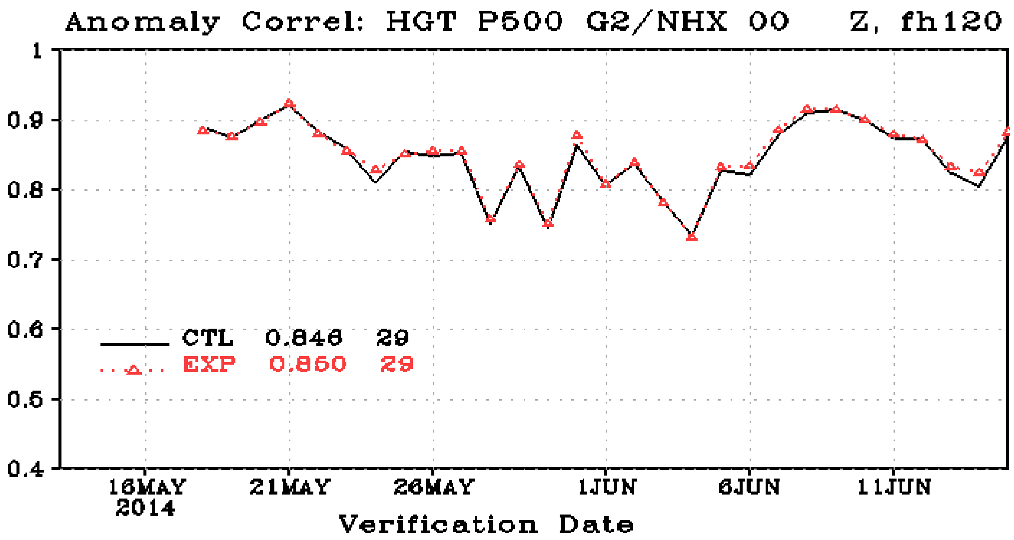


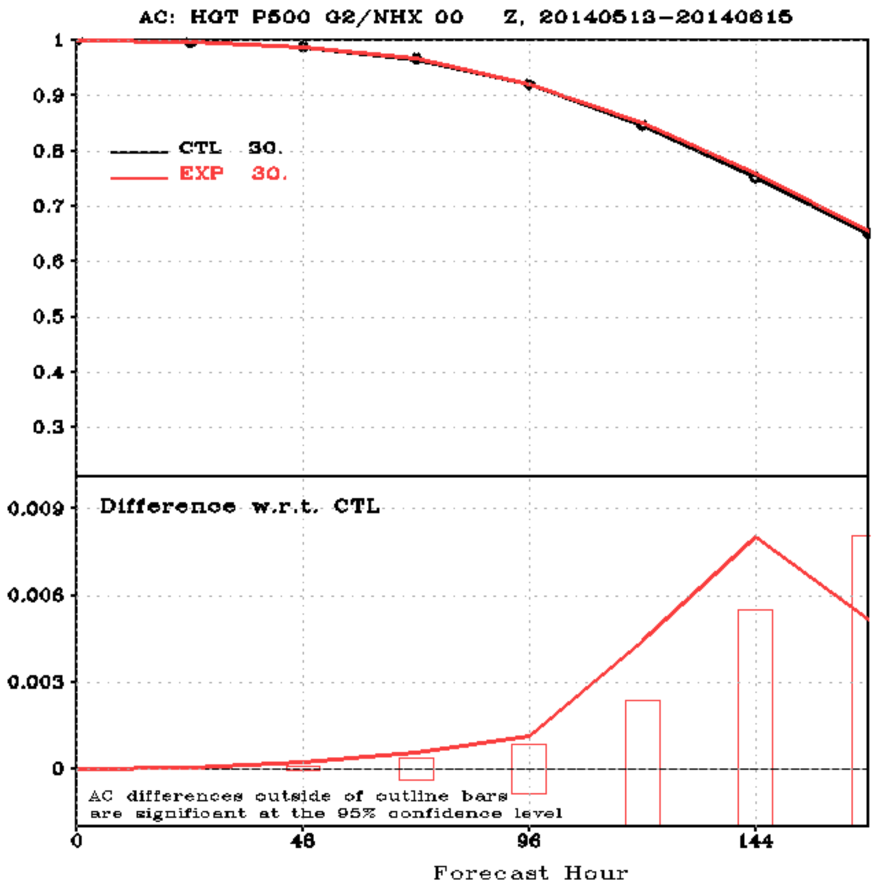
West CONUS

VIIRS GVF (4-y monthly mean) test:

5/13 – 6/15, 2014

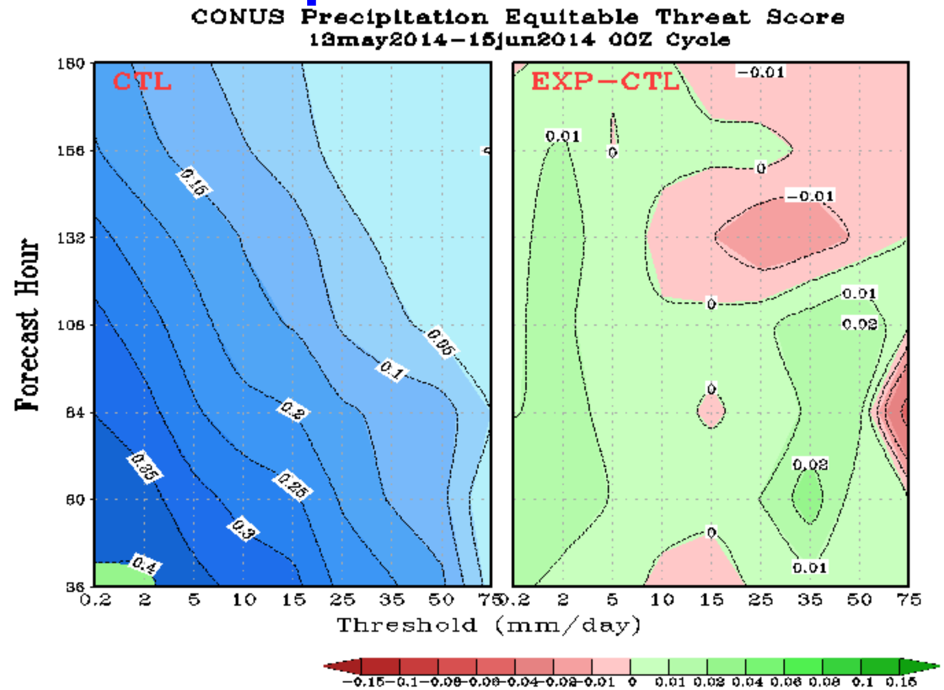
AC: HGT 500 hPa G2/NHX 5/13-6/15 2014

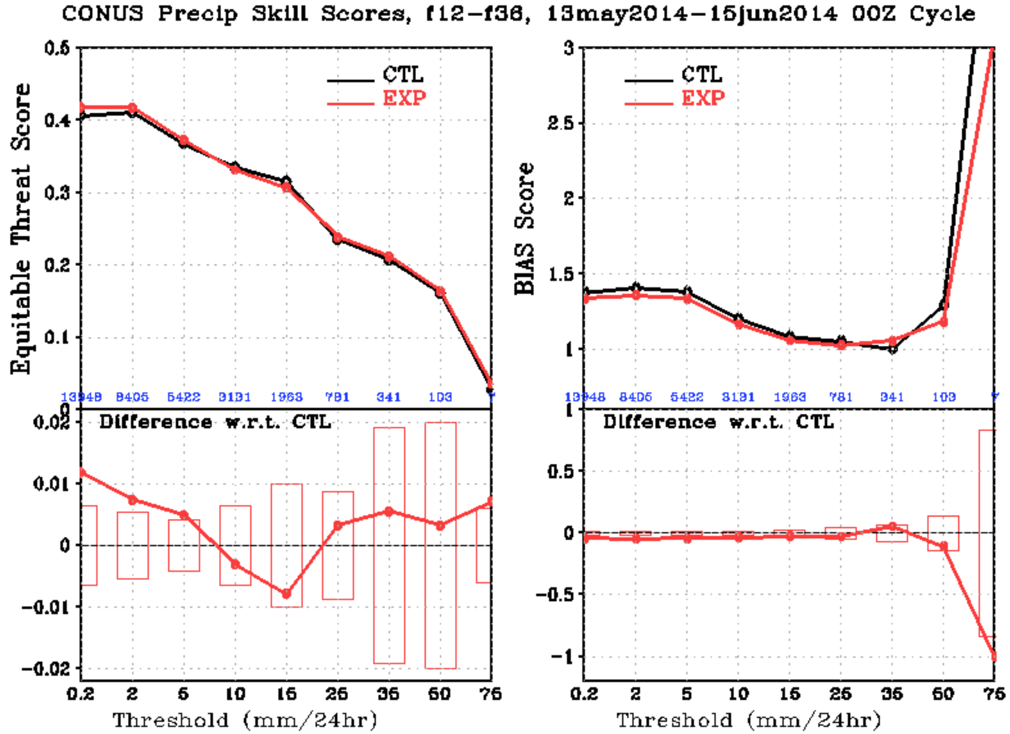


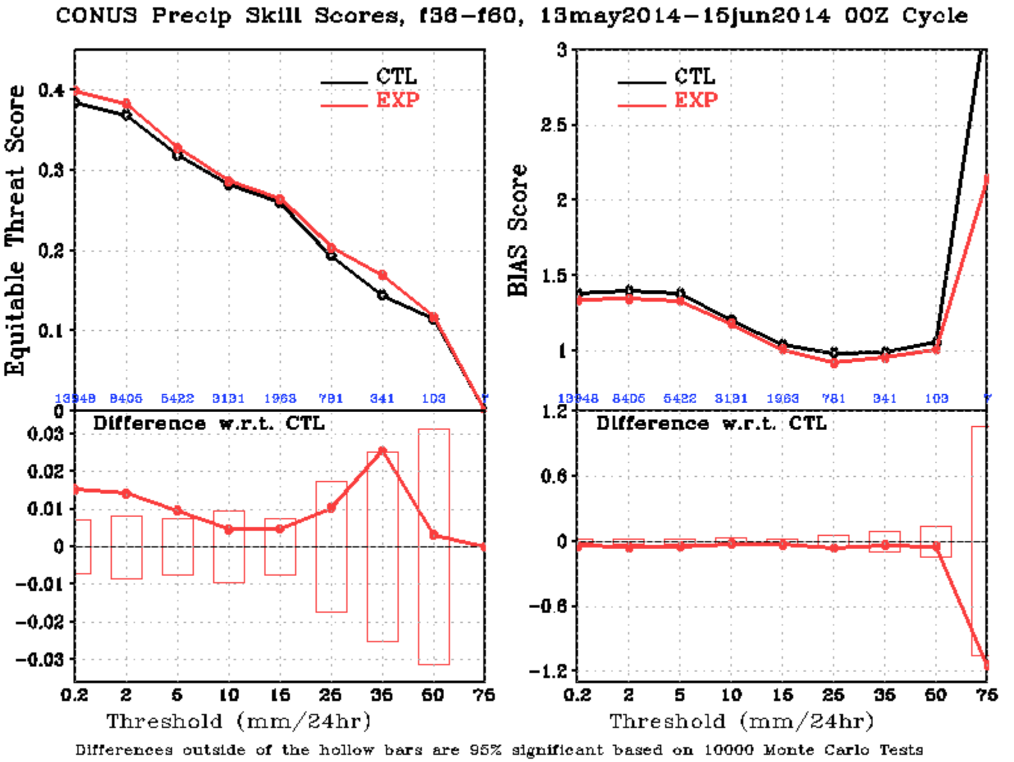


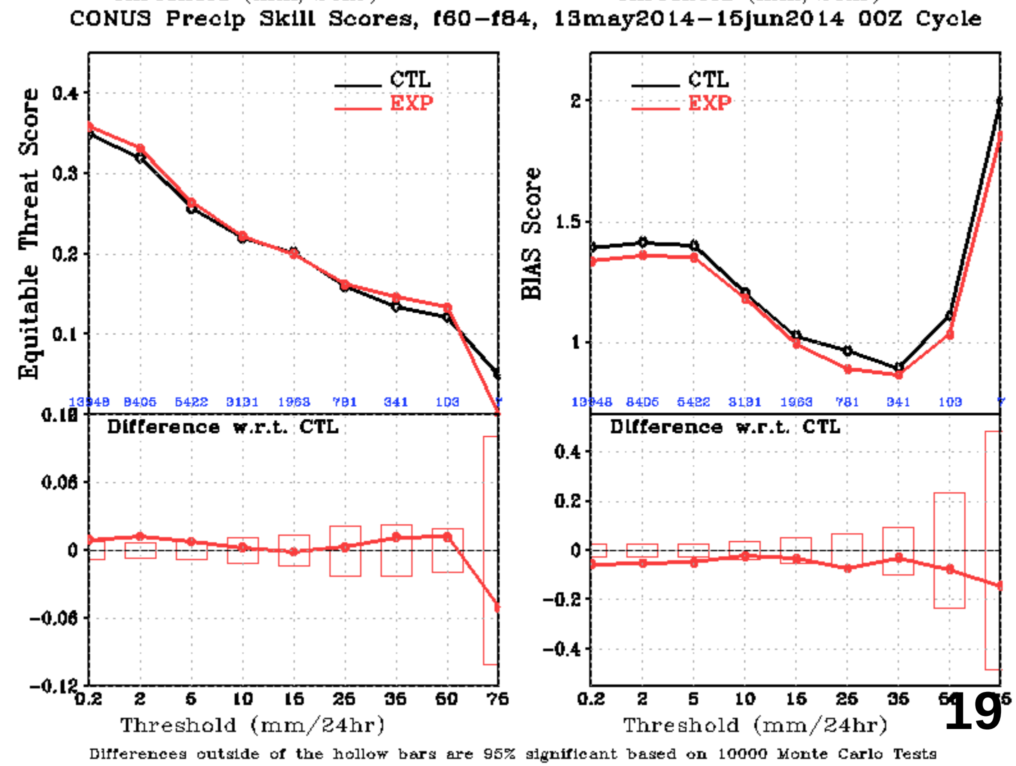
VIIRS test: Improve AC score @500 hPa.

Precipitation Skill Scores over CONUS: 5/13-6/15 2014

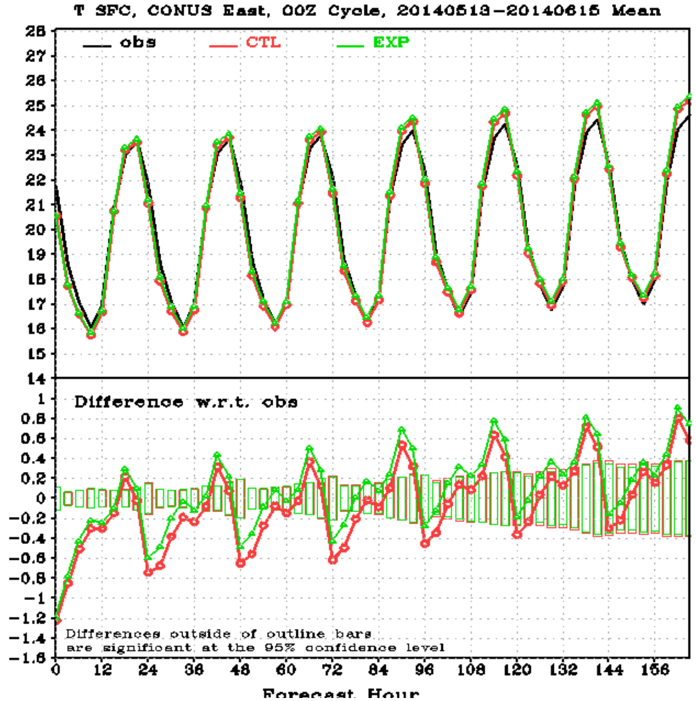


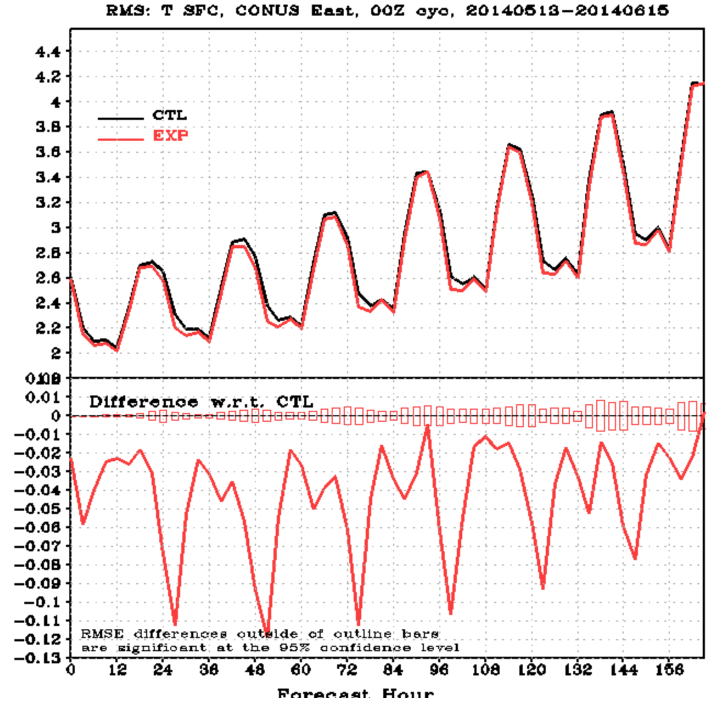






T2m bias and rmse over E. &W. CONUS 5/13-6/15, 2014

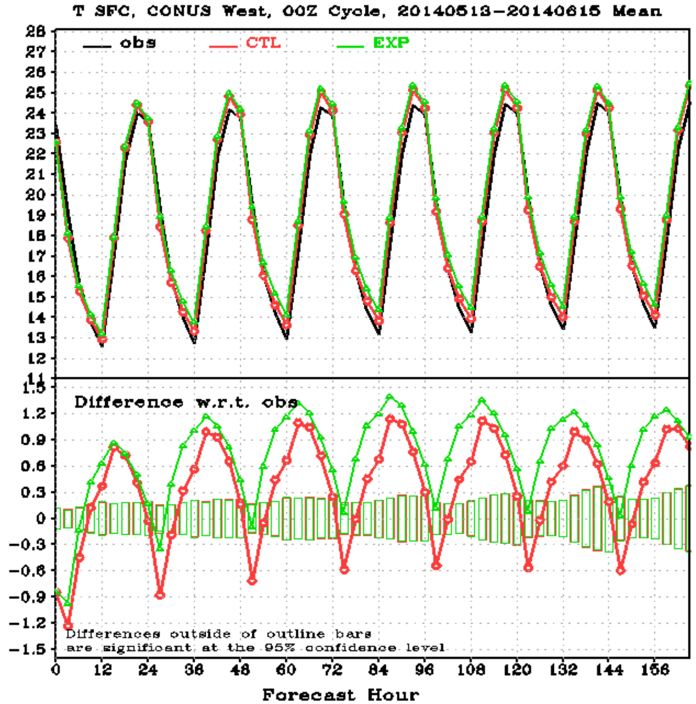


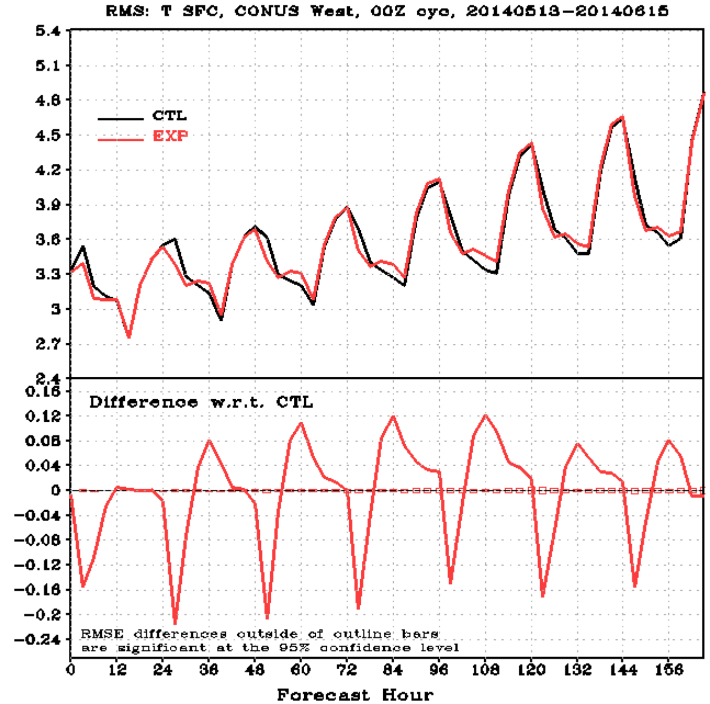


East CONUS

VIIRS:

East CONUS:
Reduce RMSE.

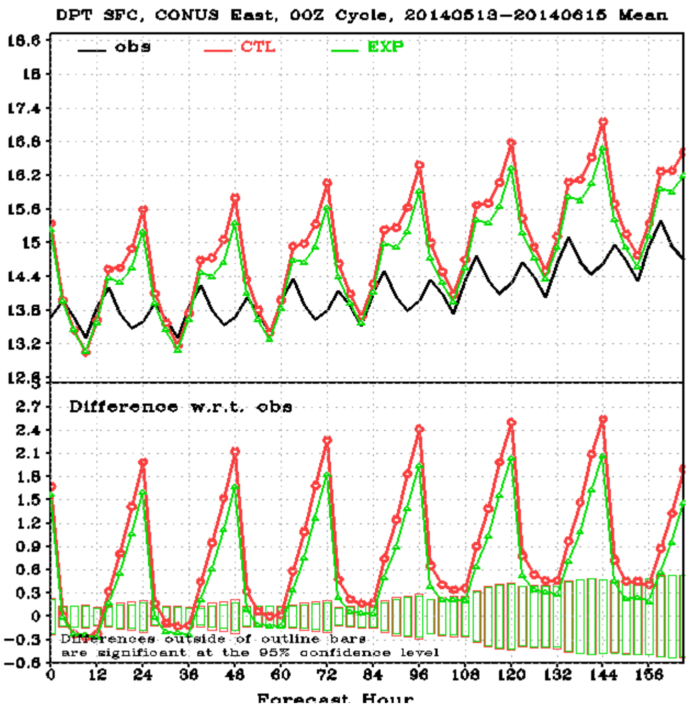


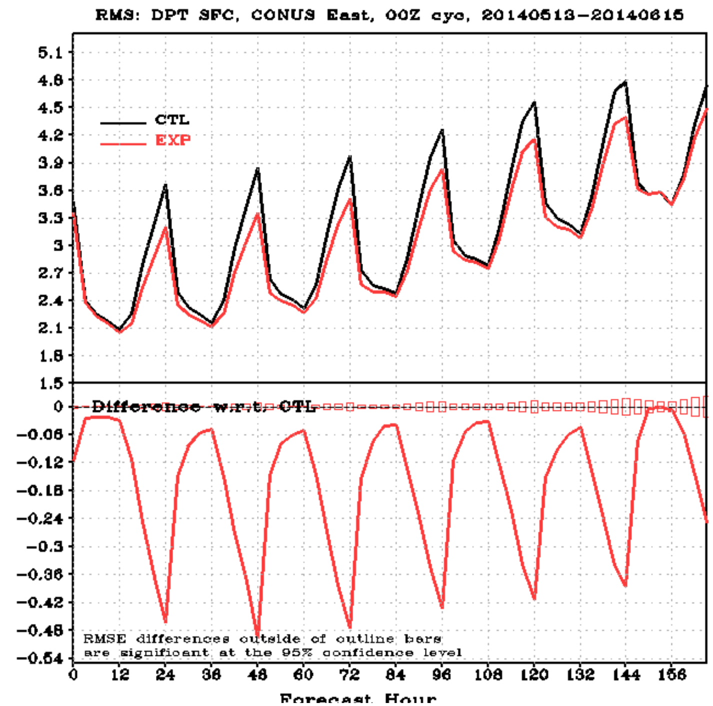


West CONUS:
Increase warm bias.

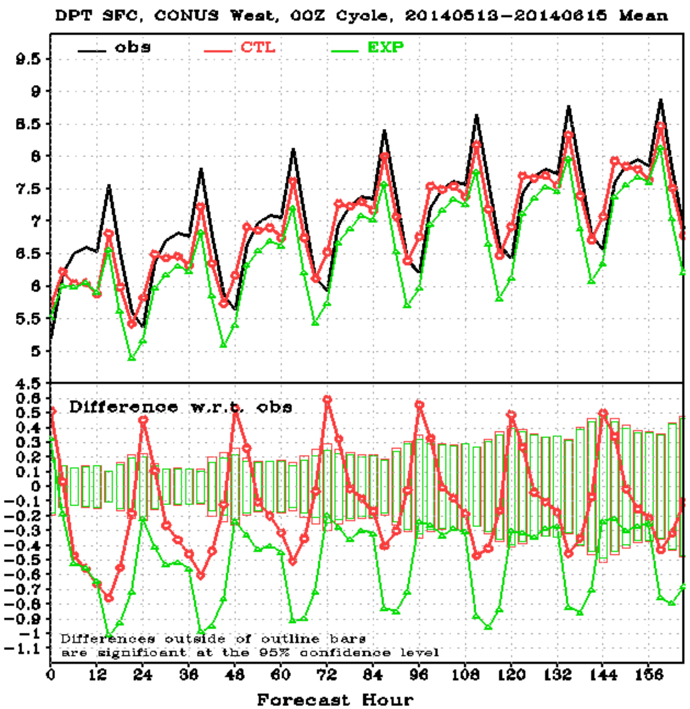
West CONUS

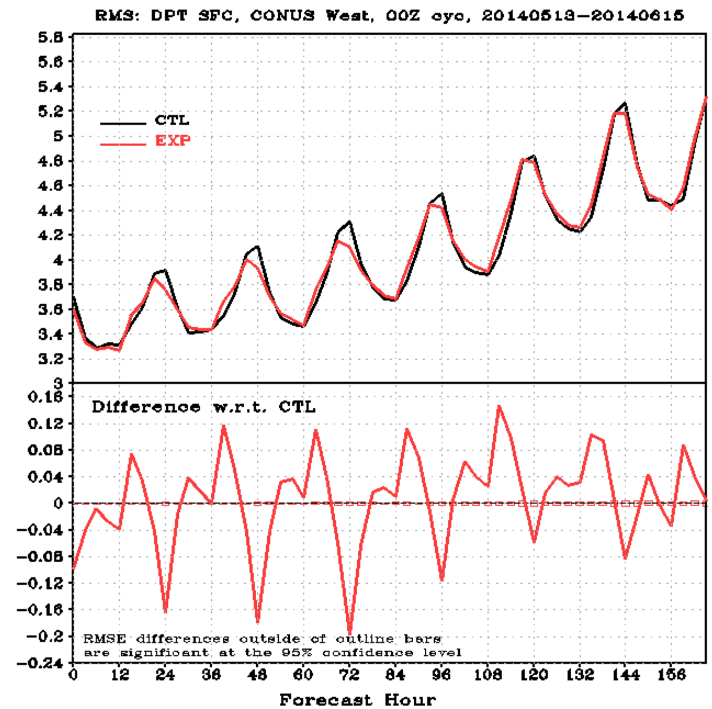
DPT bias and rmse over E. &W. CONUS   5/13-6/15, 2014





East CONUS





VIIRS:

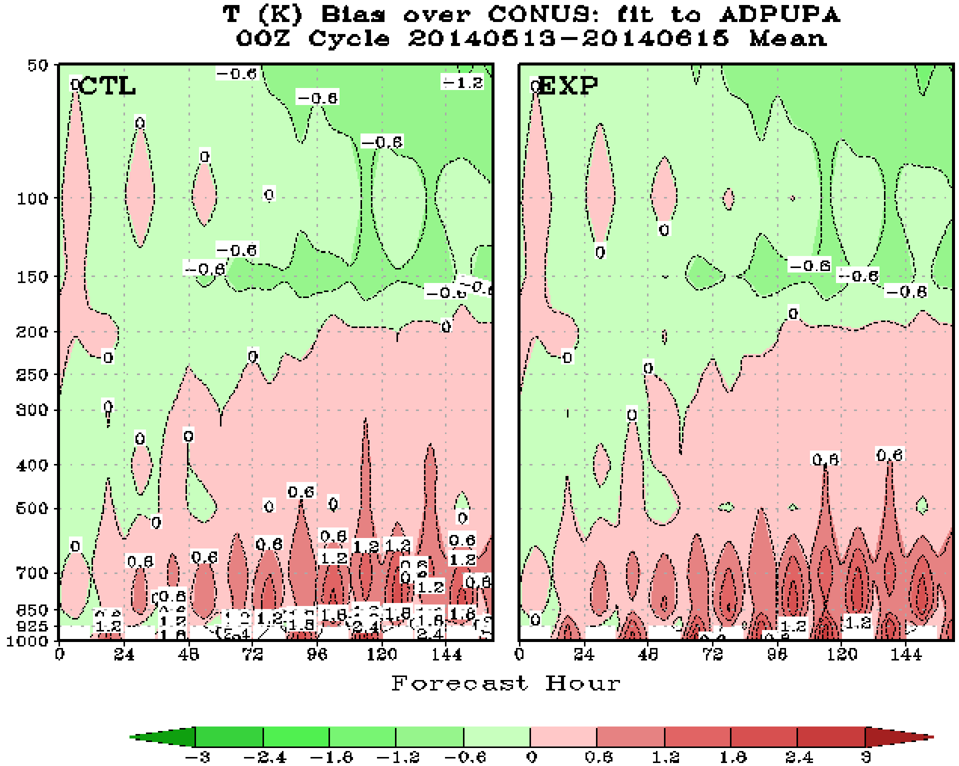
East CONUS: *Reduce wet bias and RMSE.*

West CONUS: *Increase dry bias.*

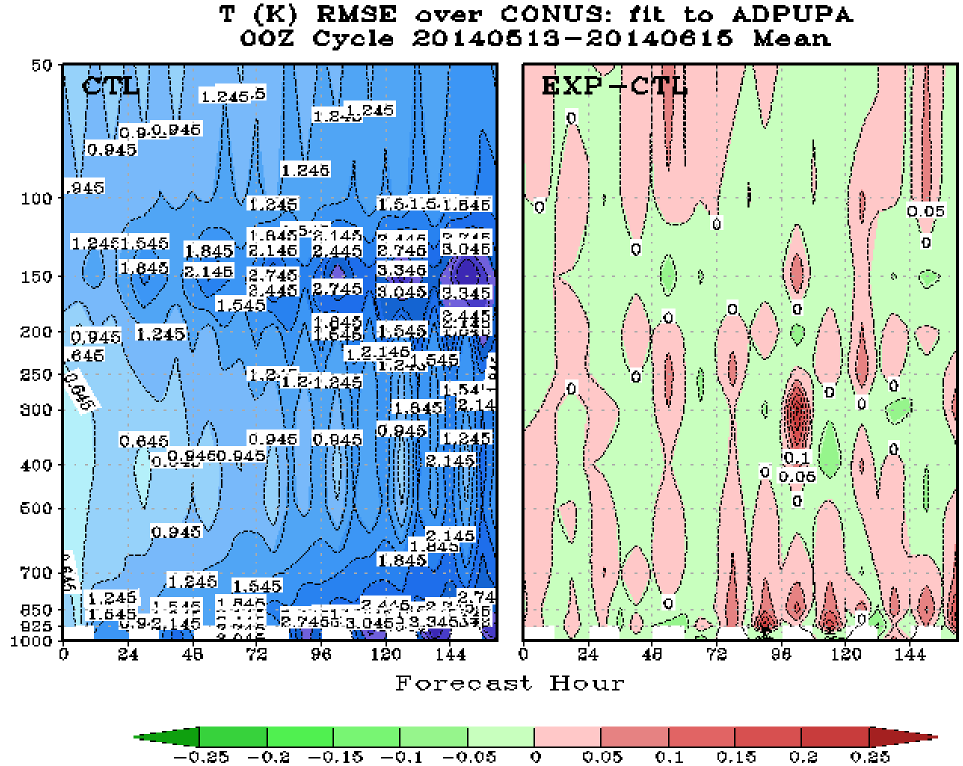
West CONUS

Temperature fits to Obs over CONUS 5/13-6/15, 2014

Temp Bias



Temp RMSE

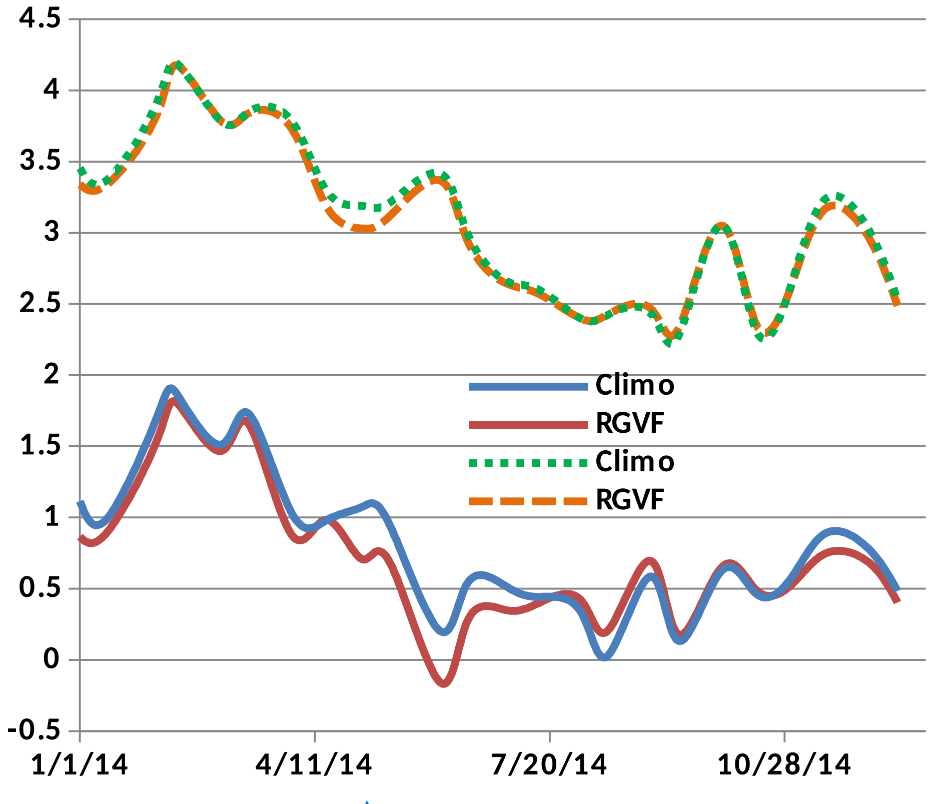


<u>VIIRS:</u> Increase warm bias and RMSE!

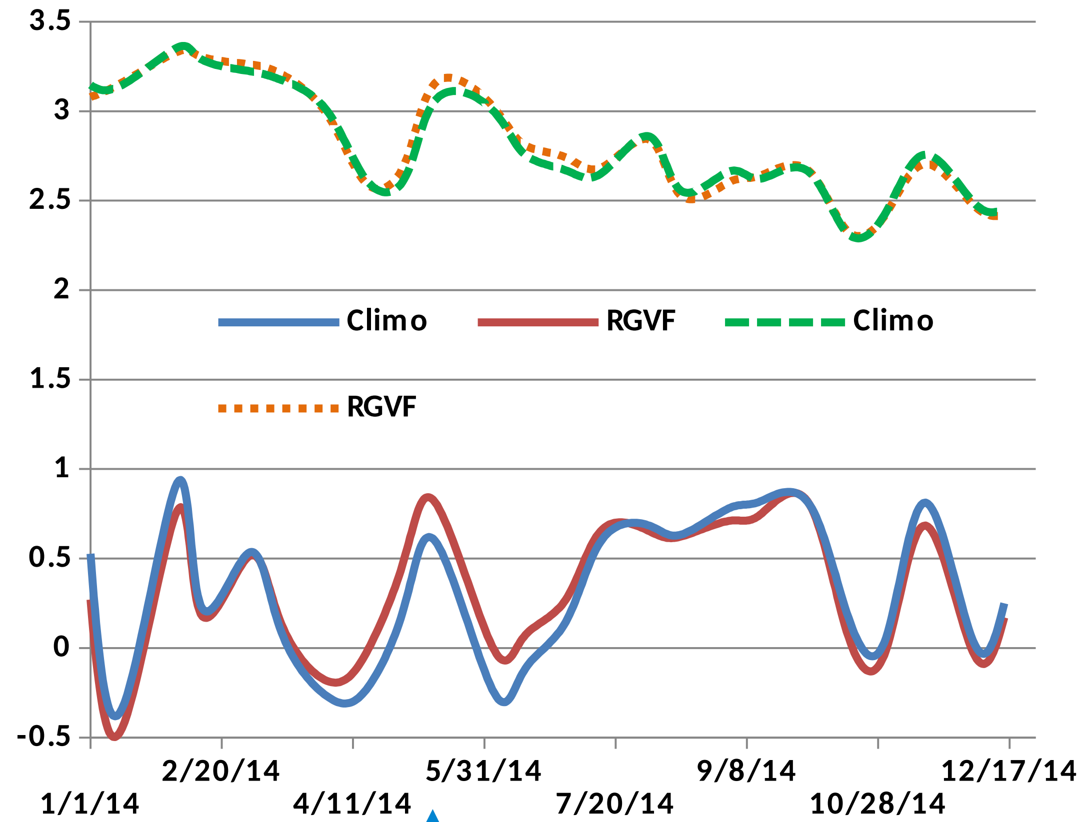
VIIRS GVF test in NAM (two 84h runs /Mon) : Jan -- Dec, 2014

Real time GVF can reduce Dew point temperature wet bias in NAM

DPT Bias & RMSE



Temp Bias & RMSE



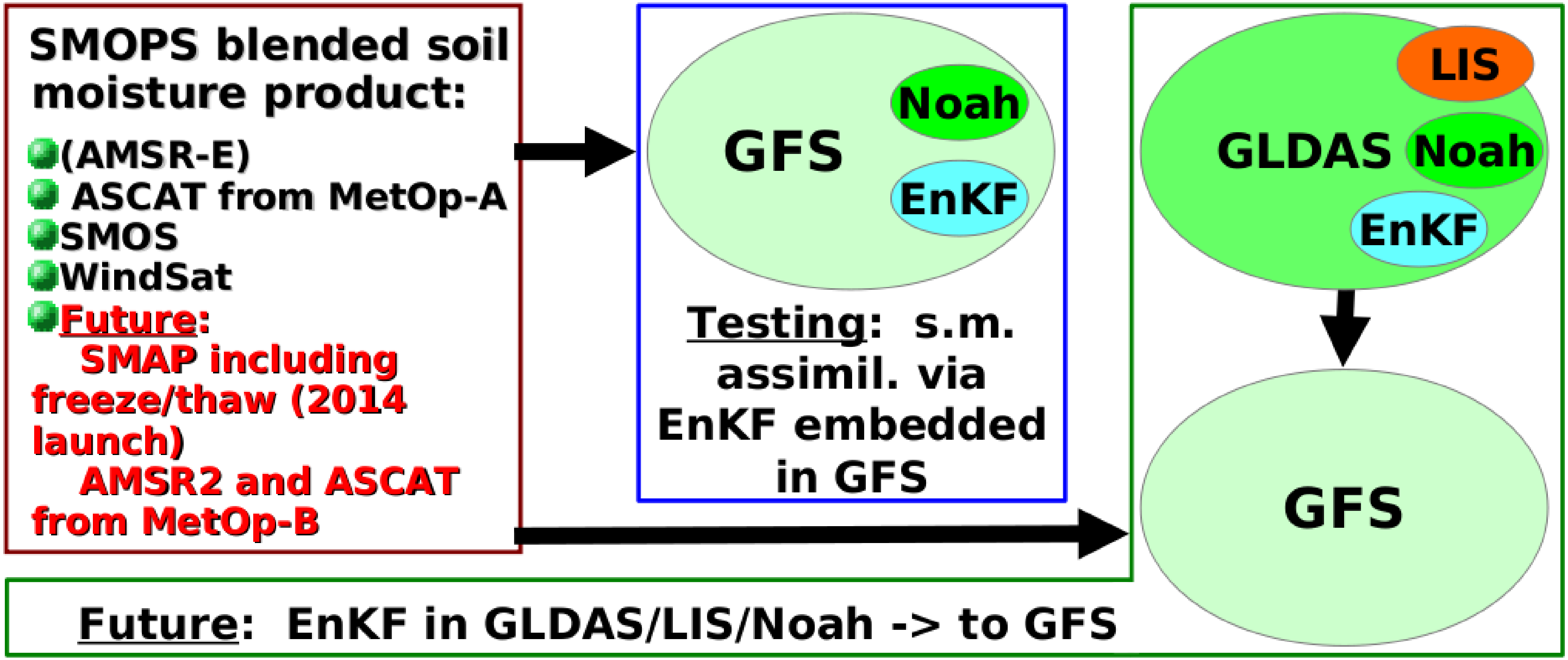
<u>VIIRS:</u> Reduce wet bias and RMSE.

<u>VIIRS:</u> Increase warm bias and RMSE. (some cold bias is reduced).

Courtesy Yihua Wu

Soil Moisture Data Assimilation

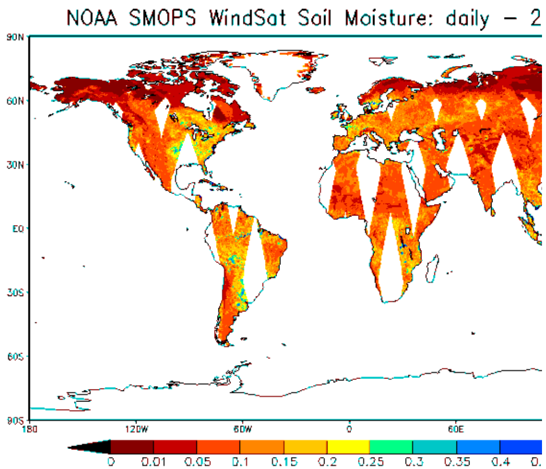
Schematic representation of assimilating satellite soil moisture products from NESDIS/SMPOS into NCEP Global Forecast System (GFS)



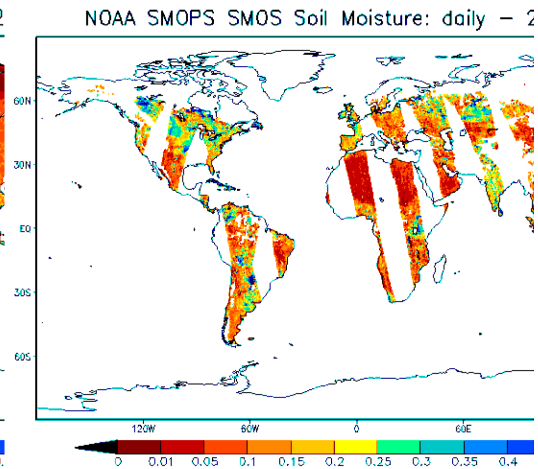
Global Land Data Assimilation System (GLDAS), NASA Land Information System (LIS), Noah land-surface model

SMOPS Daily Product Sample

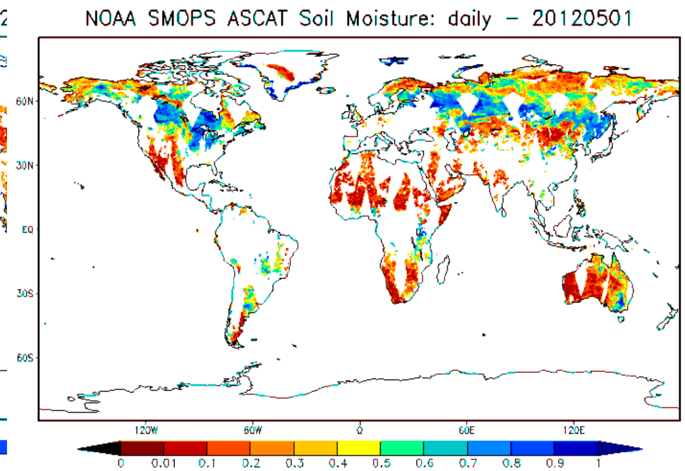
WindSat



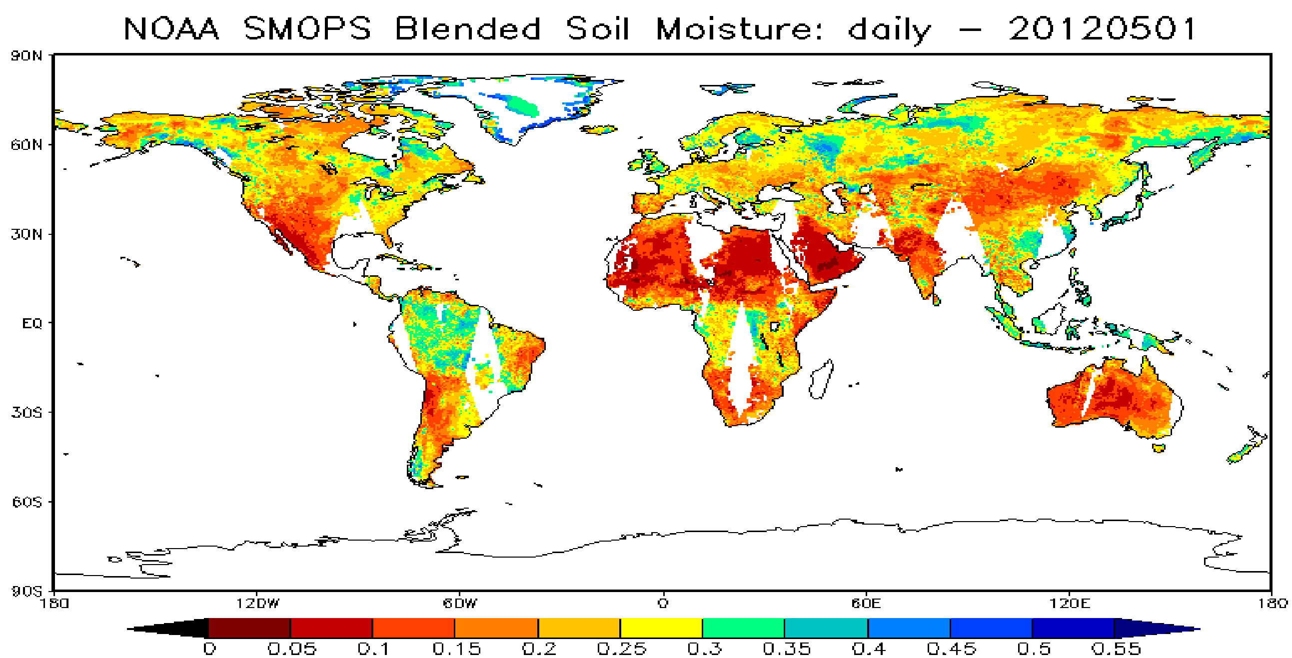
SMOS



ASCAT



Blended

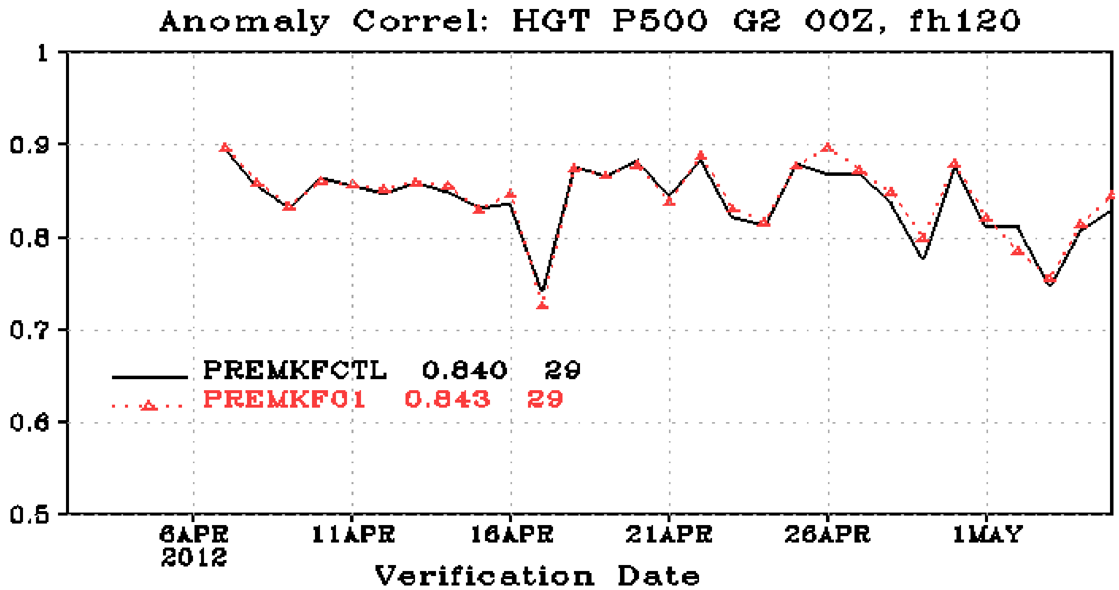


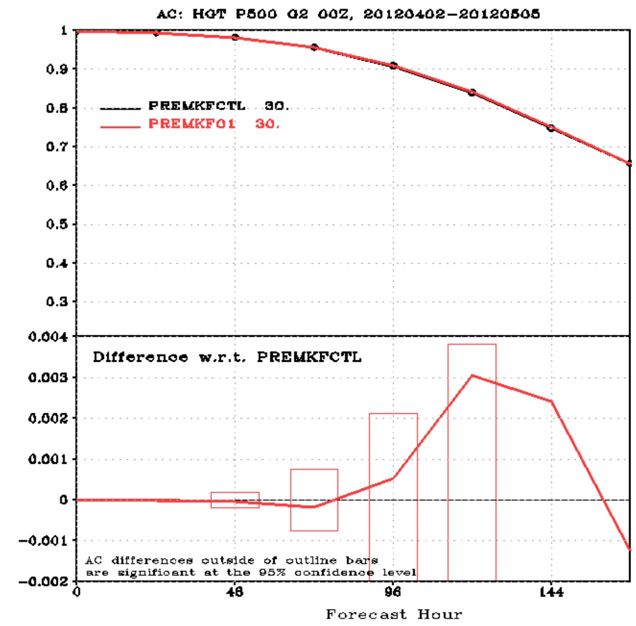
GFS Top Layer SM Validation

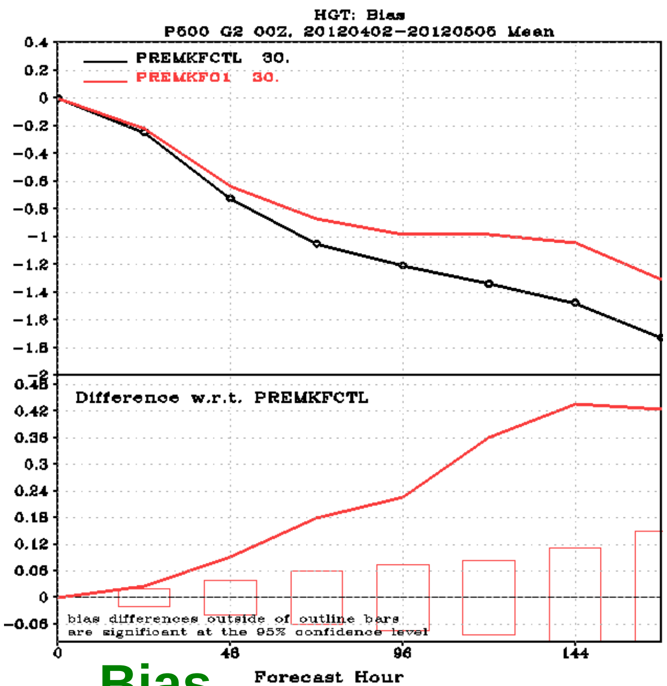
With USDA-SCAN Measurements
1-30 of April, 2012

	East CONUS (26 sites)			West CONUS (25 sites)			Whole CONUS		
	RMSE	*Bias*	*Corr-Coef*	*RMSE*	*Bias*	*Corr-Coef*	*RMSE*	*Bias*	*Corr-Coef*
CTL	0.135	0.046	0.565	0.124	0.033	0.448	0.129	0.040	0.508
EnKF	0.130	-0.031	0.613	0.114	-0.021	0.549	0.123	-0.031	0.587

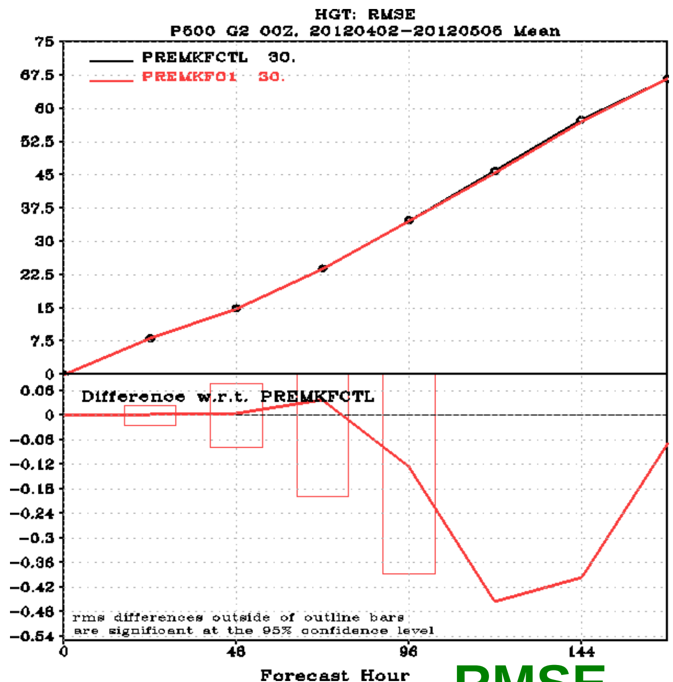
Analysis on Anomaly Correlation at 500 hPa: Day5







Bias



RMSE

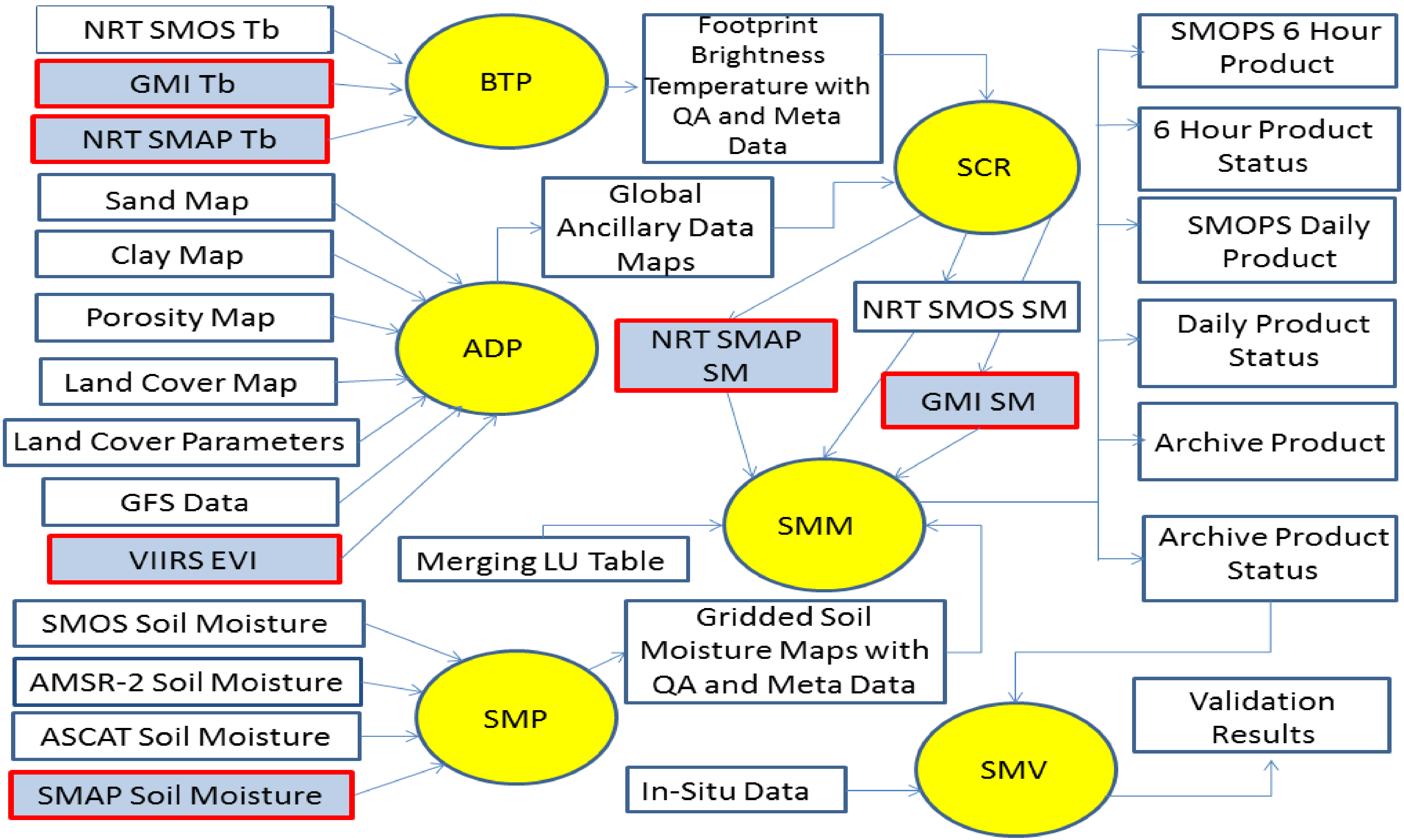
500 hPa HGT:

Reduced the bias; Reduced the rmse after day 4.

27

NESDIS SMOPS 3.0

System Layer Data Flow

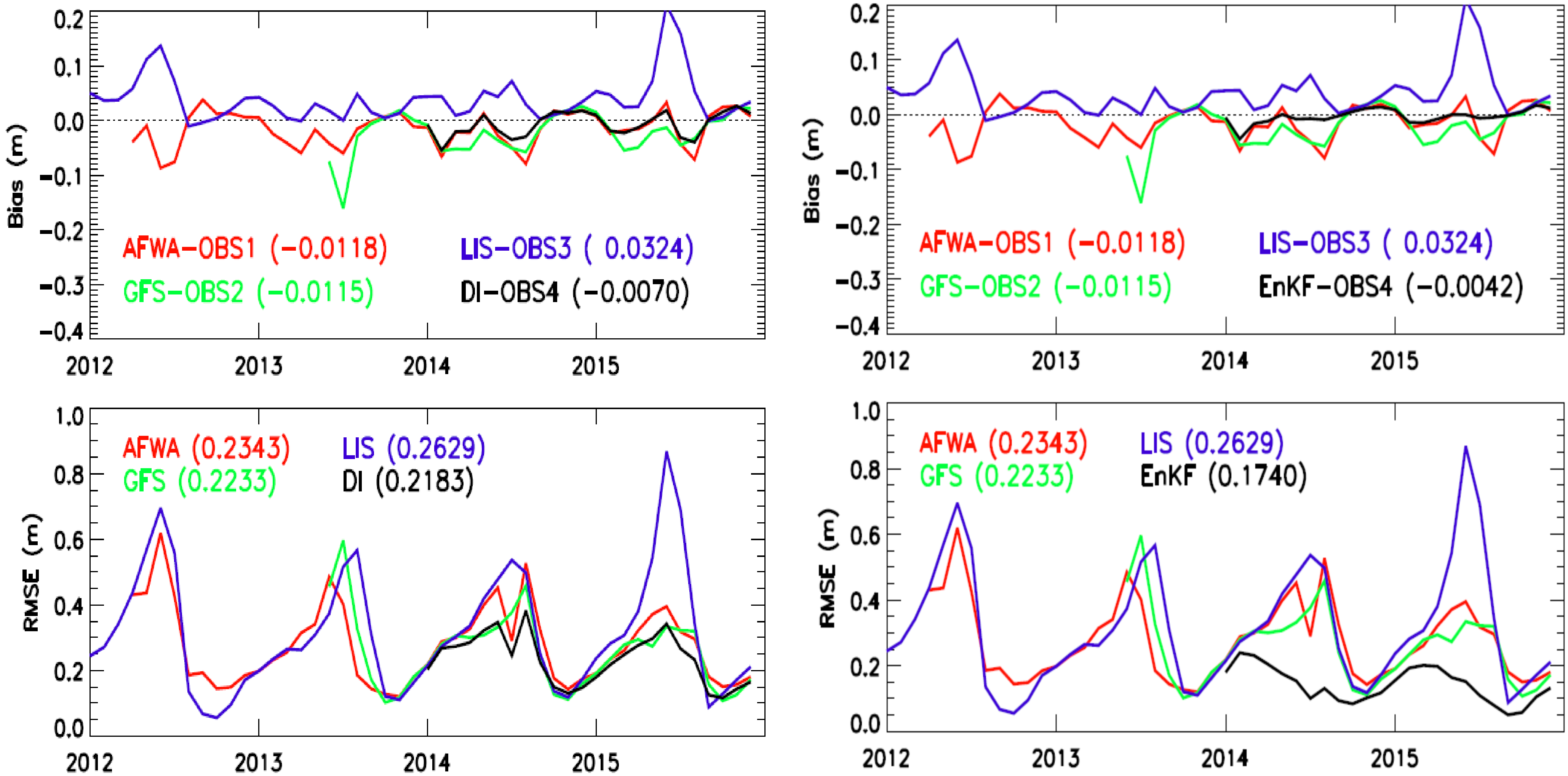


SMOPS: add GMI, SMAP NRT TB & NASA SMAP SM

Courtesy Jerry Zhan

Demonstration of LIS land DA of AFWA Snow Depth

AFWA/LIS/GFS vs DI & EnKF



Global

Direct Insertion **EnKF**

<u>EnKF method:</u> *Reduce bias and RMSE.*

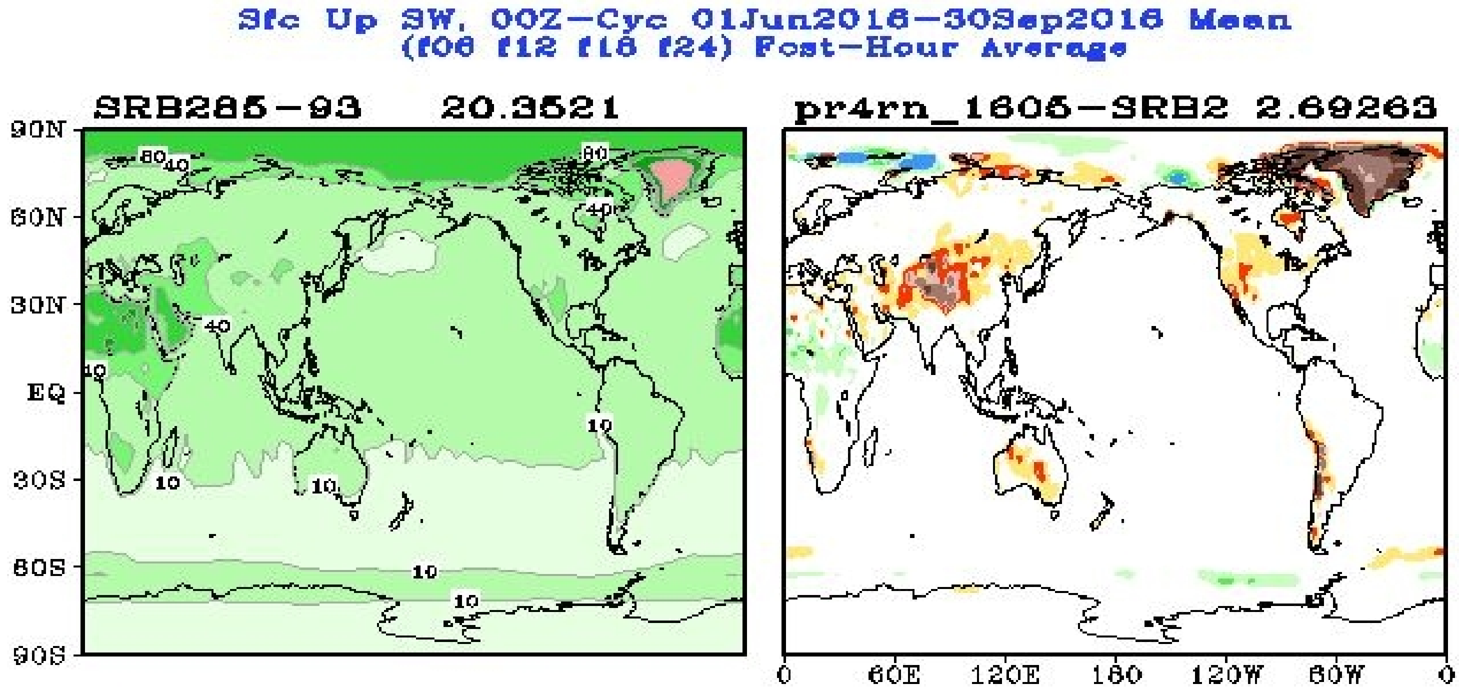
Courtesy Jiarui Dong

Land Surface Changes for Q3FY17 NEMS GFS

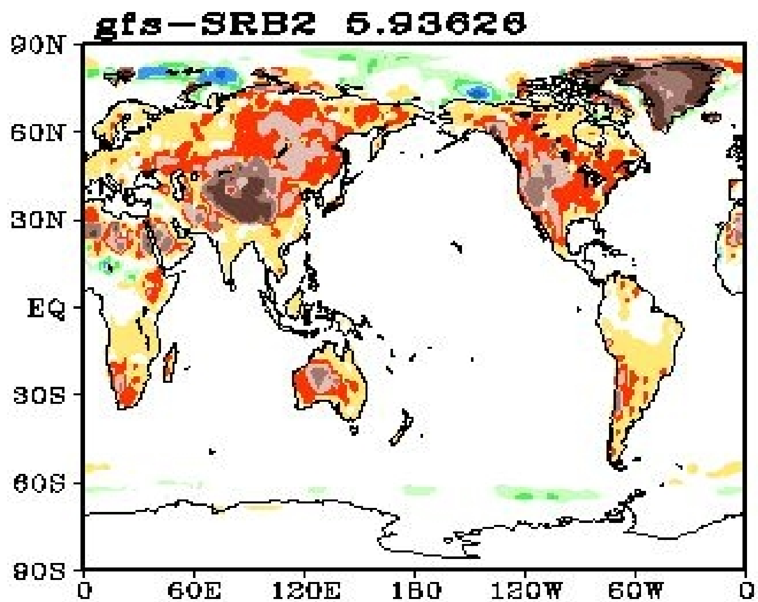
- **GBP 20-type land classifications and STASGO 19-type soil classifications**
- **The new MODIS-based snow free *albedo* from BostonU/Mark-Friedl (JCSDA funded)**
- **The new MODIS-based maximum snow *albedo* from UAZ/Xubin (JCSDA funded)**
- **Diurnal albedo treatment**
- **Unify two snow fields between radiation driver and Noah LSM**
  - **Snow cover**
  - **Snow albedo**
- **Fix excessive cooling of T2m during sunset**
- **Increase ground heat flux under the deep snow**

Courtesy Helin Wei

New Albedo: Surface Upward SW



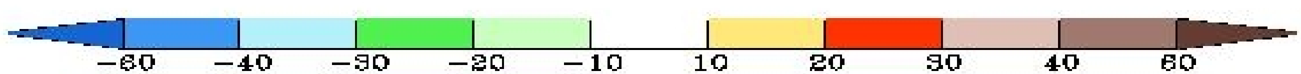
NEMS



GFS

New Albedo:
Reduce bias of surface upward SW.

Courtesy Helin Wei



Radiance DA: Satellite Brightness Temperatures (Tb)

- GSI analysis assimilates satellite obs Tb in various IR and MW channels
  - Analysis increment: derived from difference of observed and simulated Tb
  - Simulated Tb is product of CRTM radiative transfer applied to GFS forecast of atmospheric states **and** earth surface states (land, ice, sea)

Example expression for simulated Tb for a microwave channel:

$$\mathrm{Tb}_p = \boxed{T_{\mathrm{surf}} \varepsilon_p e^{-\tau(0,H)/}} + T_{\mathrm{atm}}^{\downarrow}(1-\varepsilon_p)e^{-\tau(0,H)/\mu} + T_{\mathrm{atm}}^{\uparrow},$$

$$T_{\mathrm{atm}}^{\downarrow} = \int_H^0 T(z)[\alpha(z)/\mu]e^{-\tau(z,0)/\mu}dz + T_{\mathrm{cosm}} e^{-\tau(0,H)/\mu}$$

$$T_{\mathrm{atm}}^{\uparrow} = \int_0^H T(z)[\alpha(z)/\mu]e^{-\tau(z,H)/\mu}dz.$$

$$\tau(z_0, z_1) = \int_{z_0}^{z_1} \alpha(z)dz$$

α = atmospheric absorption

For surface sensitive channels (aka "window channels"):
atmospheric absorption (α) is weak, so Tsurf & sfc emissivity (ξ) are key factors
Surface emissivity (ξ) is strong function of land surface states:
snow cover/density, vegetation cover/density, soil moisture amount,
soil moisture phase (frozen vs. liquid)
If LST has a large error, Tb would have a large error too.

Kenneth Mitchell

▶ Problems in surface sensitive channels data assimilation:

Much less satellite data (IR/MW) is assimilated over land than over ocean. e.g. in GFS/GSI, the large Tb bias can be seen over the CONUS from the GDAS radiance assimilation monitoring .

▻ **West CONUS:**

(a) Substantial cold bias of land surface skin temperature (LST) in GFS, resulting in the large simulated Tb bias (IR/MW) in the GSI;

(b) In desert area, errors of emissivity calculation for MW;

▻ **East CONUS:** **errors of surface emissivity calculation for MW.**

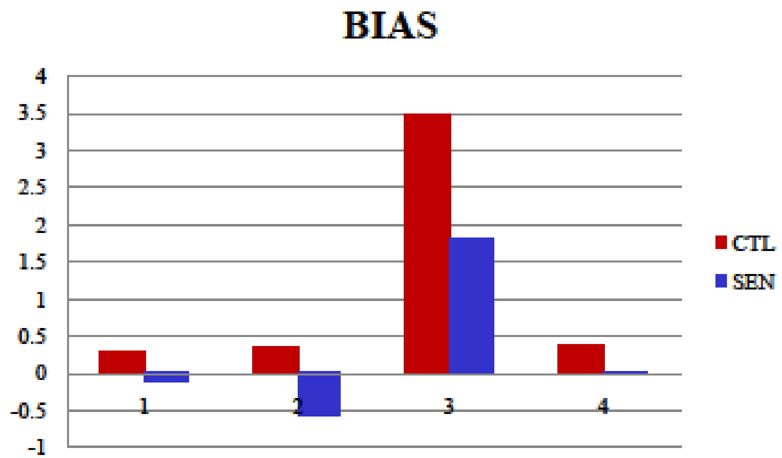
▶ Approaches of improvement:

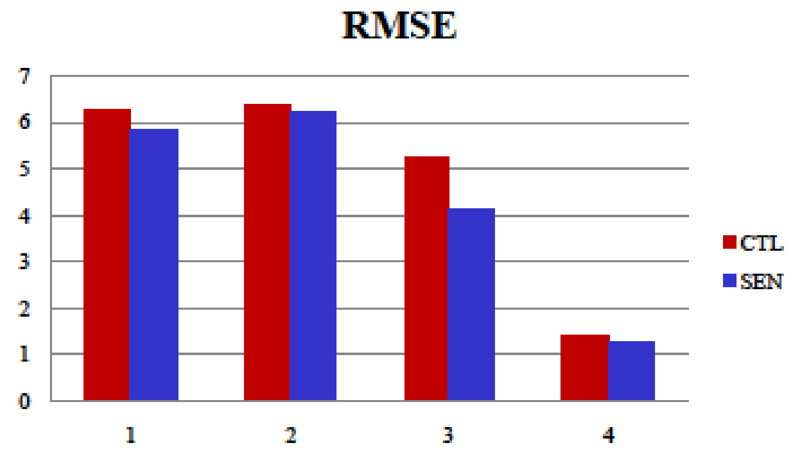
(a) Reduction of GFS LST bias with new formulations (Zom and Zot) (Zeng et al., U. of Arizona; Zeng et al. 2012; Zheng et al. 2012). (*Operational GFS in May, 2011*)

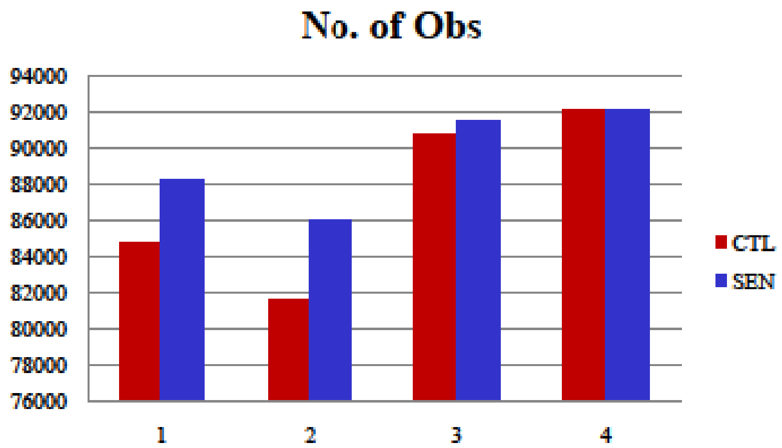
(b) Improvement of MW emissivity calculation in the MW land emissivity model (Weng et al., 2001). (*Implemented in the release CRTM v2.1*).

Comparisons of Tb Bias and RMSE and Number of Obs Assimilated in GSI

T_b BIAS, RMSE and No. of Obs assimilated in GSI: 12Z (Ave: 01-31 July 2010)





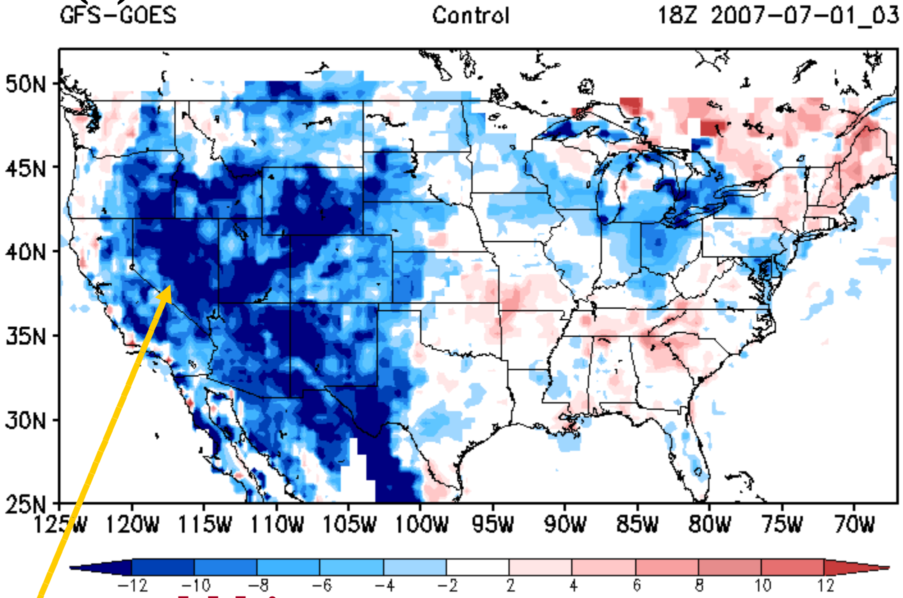


Red: CTL
Blue: SEN

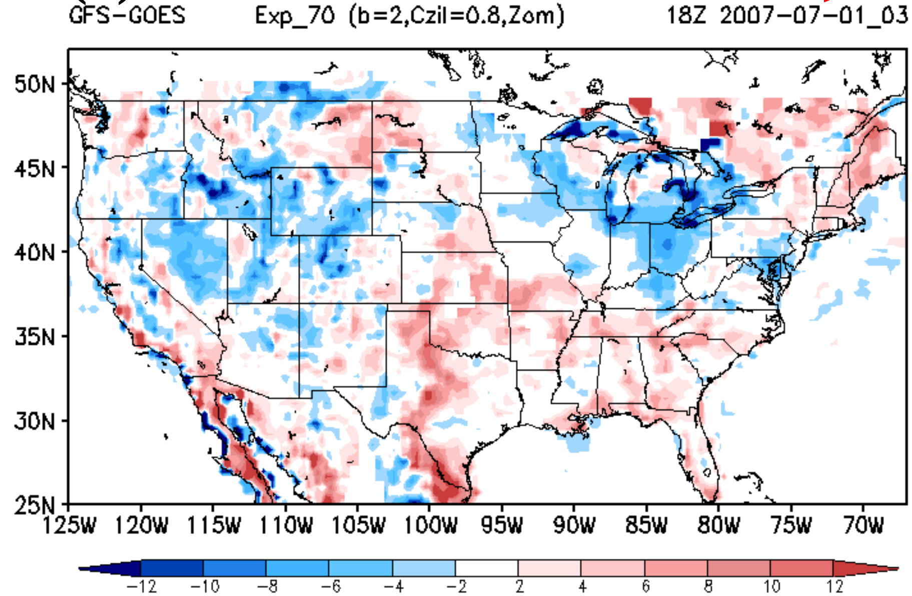
LST [K] Verification with GOES and SURFRAD

3-Day Mean: July 1-3, 2007

(a) ***GFS-GOES: CTR***

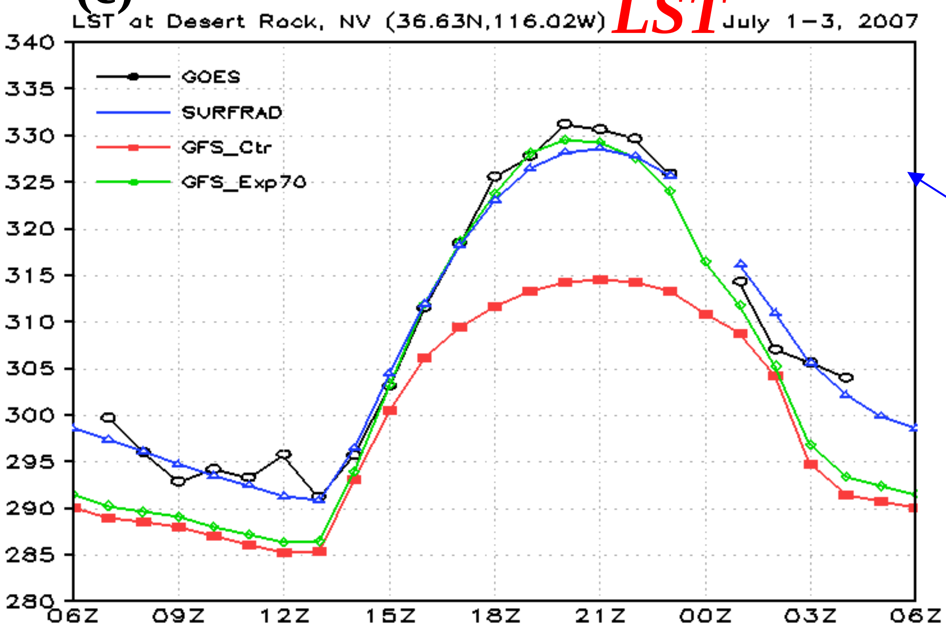


(b) ***GFS-GOES: New Zom,t***

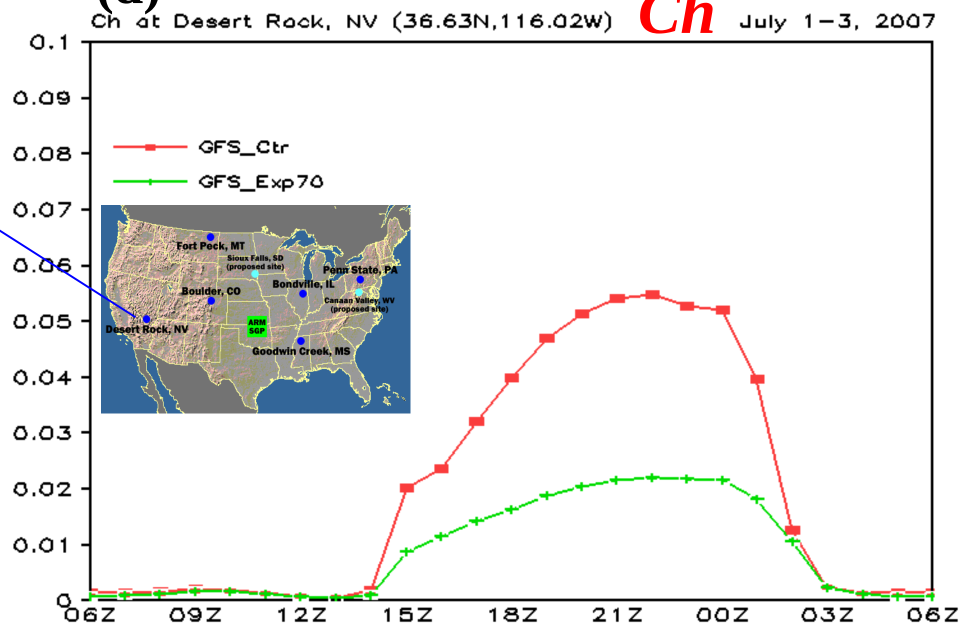


Large cold bias

(c) ***LST***



(d) ***Ch***



Improved significantly during daytime!

Aerodynamic conductance: CTR vs Zom,t

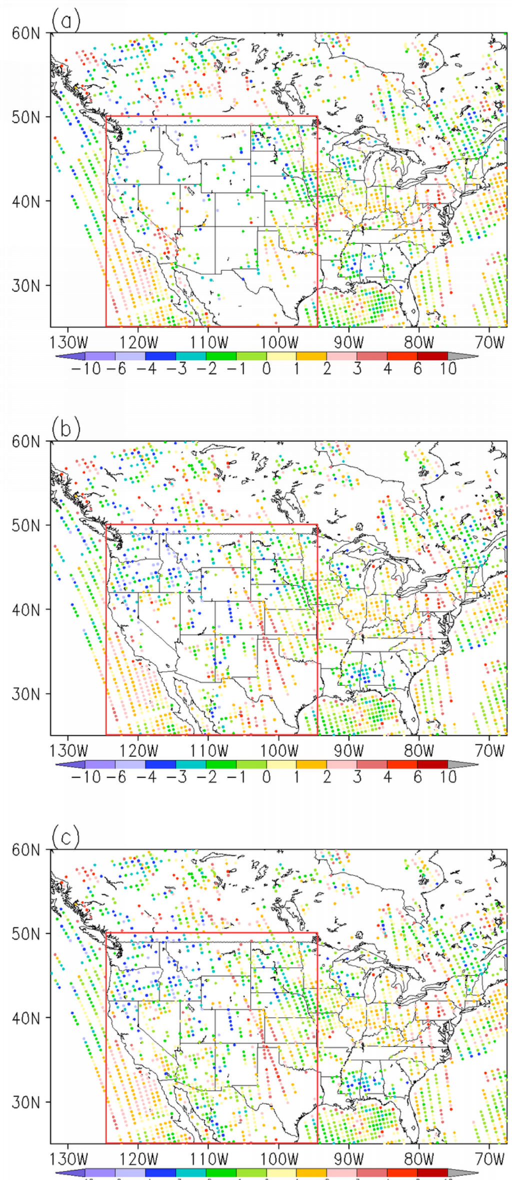
LST Impact on Data Assimilation: Tb simulation

Tb: NOAA-18 AMSU_A Ch15

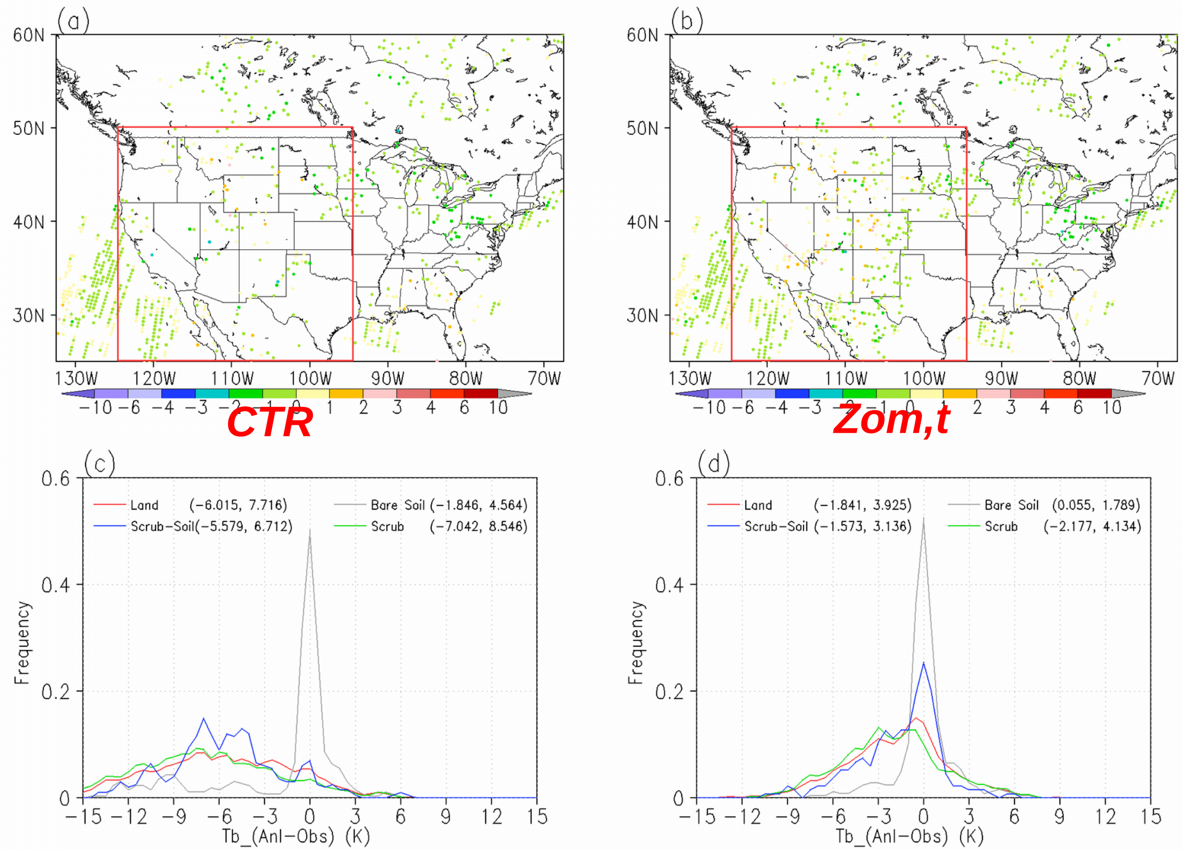
CTR

Zom,t

Zom,t + ε



Tb: NOAA-17 HIRS3 Ch8



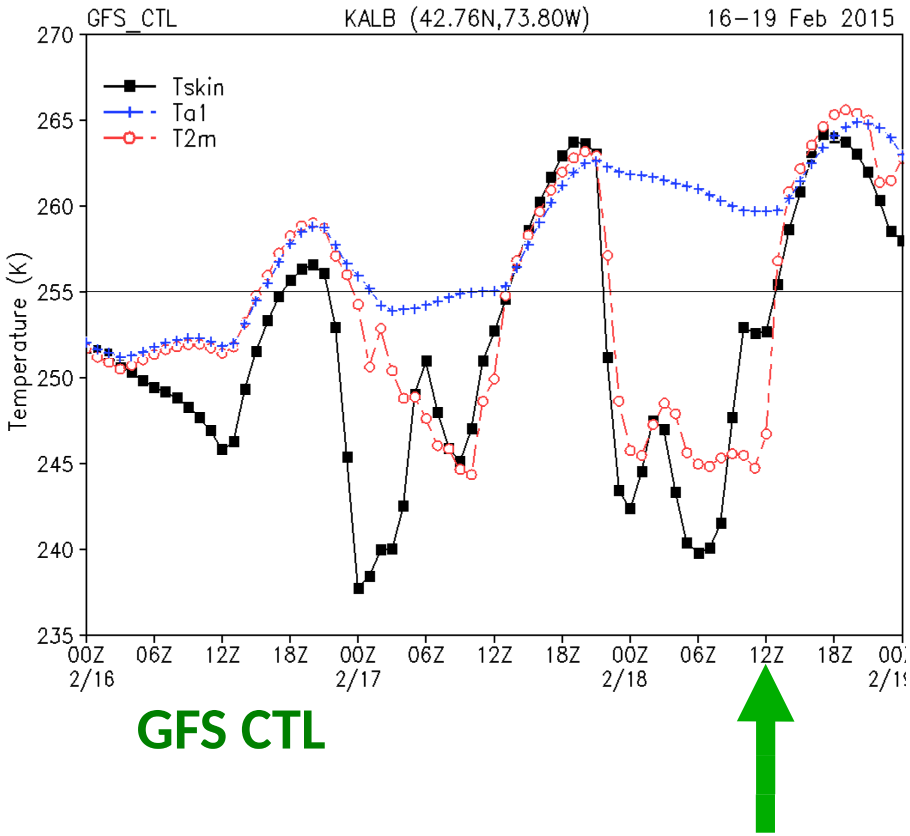
CTR: Less data used in GSI

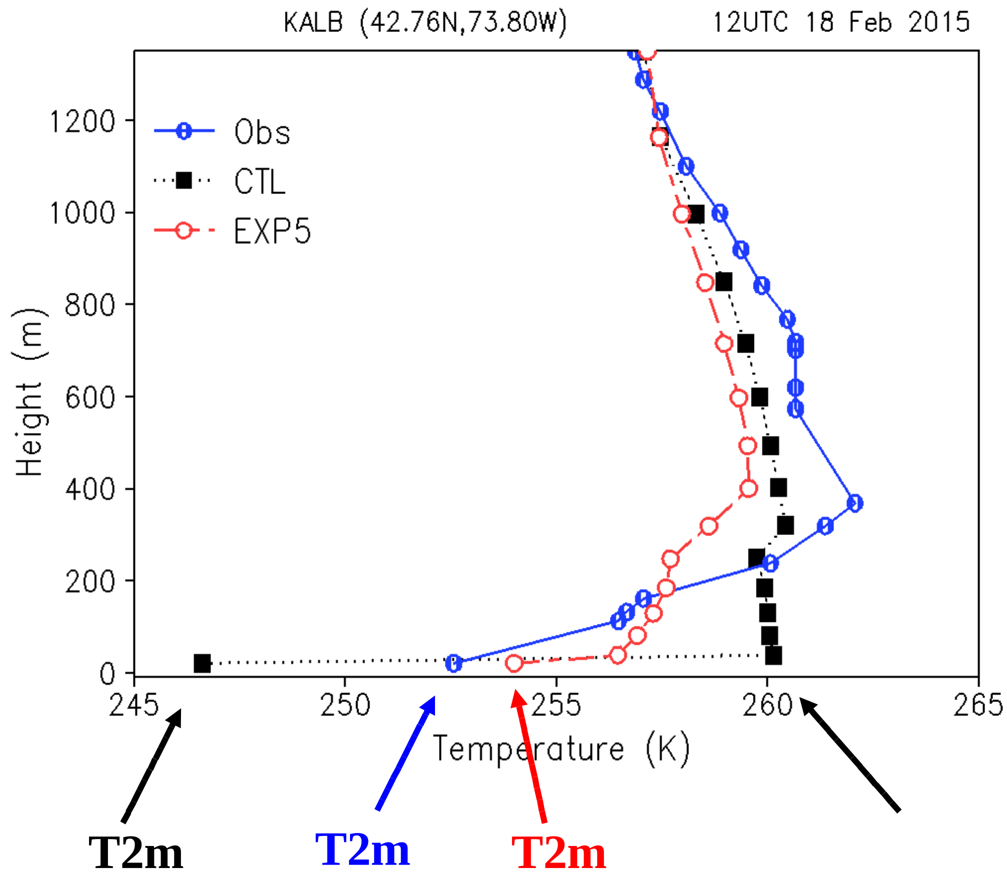
EXP: Improved

Zheng et al. 2012

GFS Excessive Cold Bias of Tskin and T2m (late pm & night)

GFS Test: Tskin, T2m and T profiles @ KALB



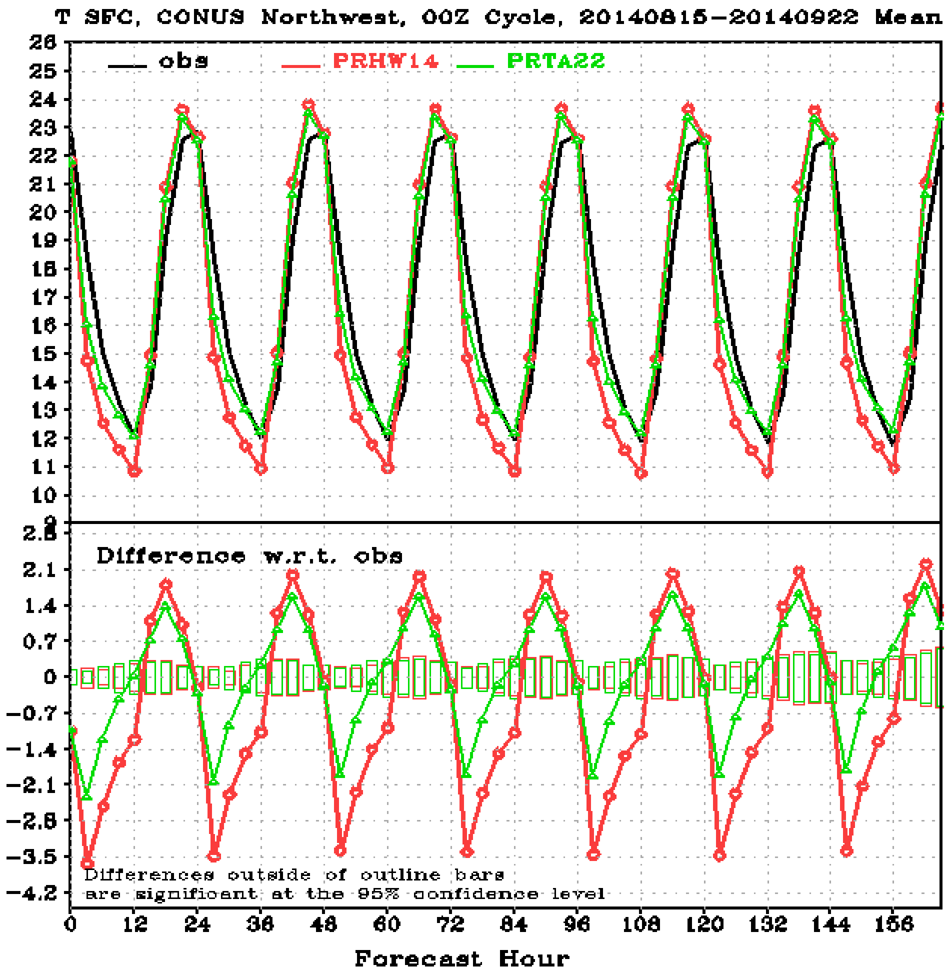


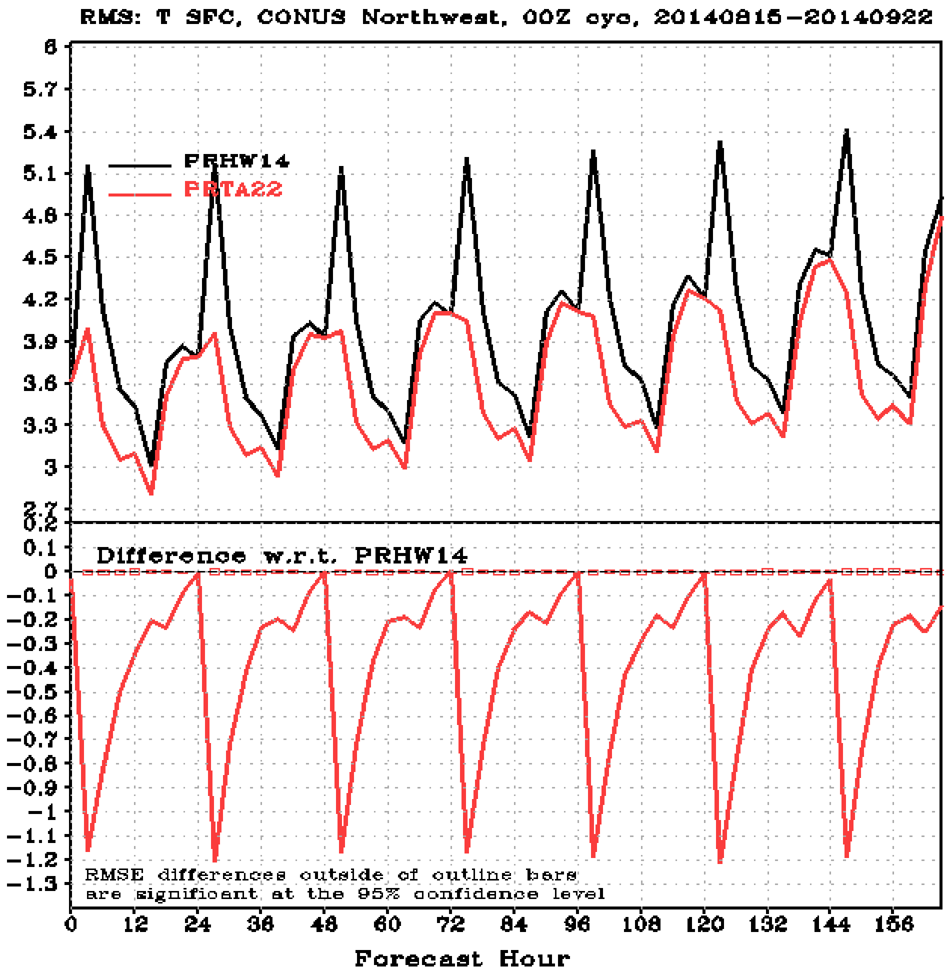
***<u>CTL:</u>* Large difference between T1 and T2m (or Tskin) during a period of nighttime on 2/18.**

***<u>CTL:</u>* Little downward heat transport (atmos-->land) during the night decoupling period results in accumulation of exess heat and as a result, the warm bias exists above the first model level.**

Zheng et al. 2017

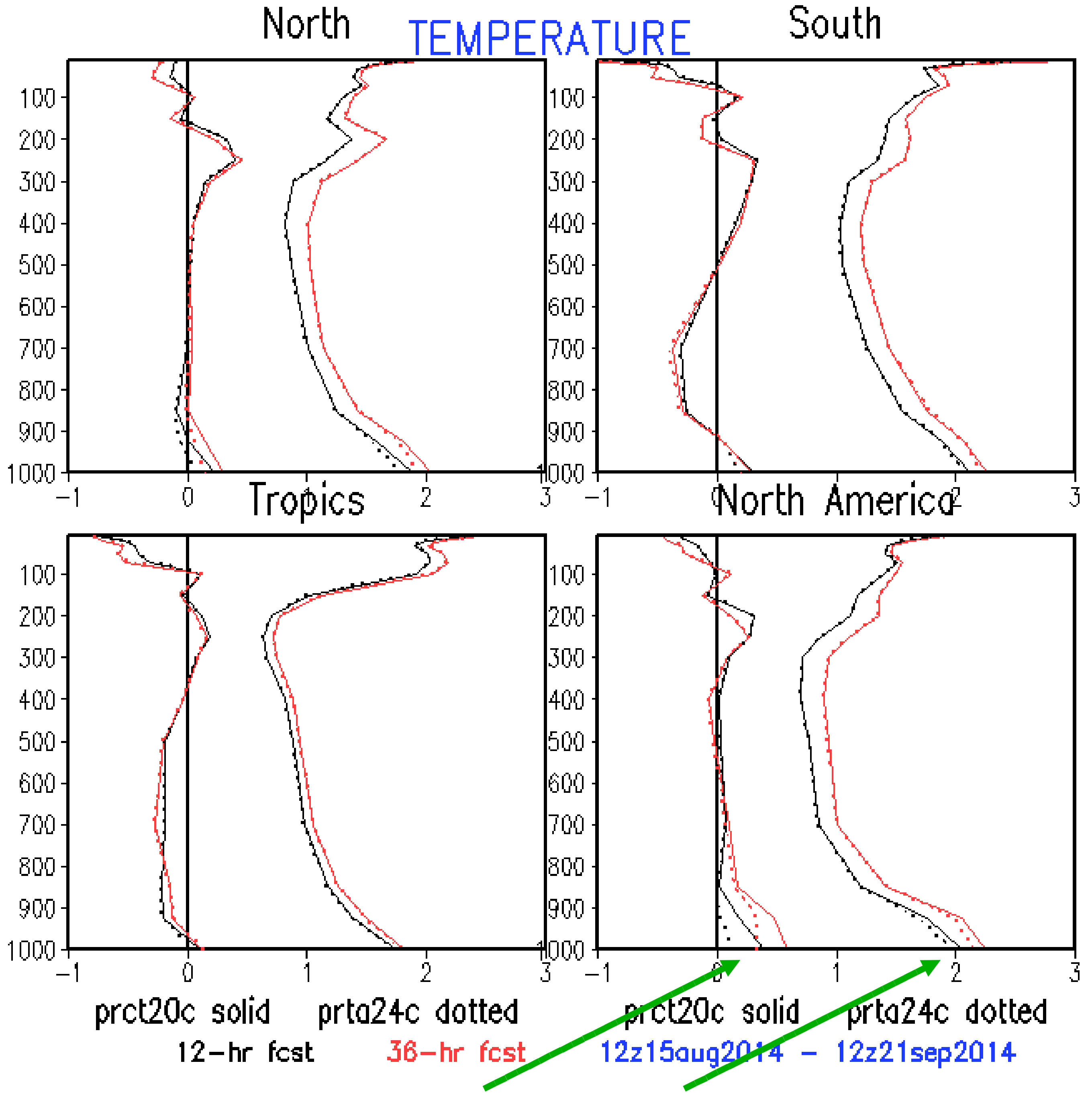
T2m and its RMSE Northwest 8/15-9 /21 2014





Reduced warm bias in the morning and cold bias in the afternoon (1.5 °C);
Reduced RMSE afternoon and nighttime up to 1.2 °C (~ 25% RMSE).

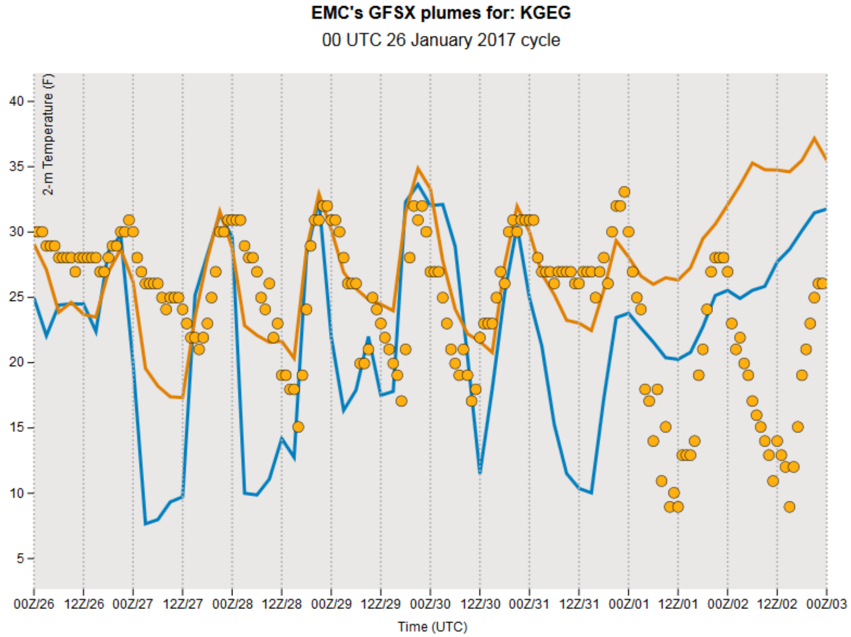
Temperature fits to Obs: Bias and RMSE   8/15-9/21 2014



Reduced temperature bias and RMSE near the surface.

NEMS Case: GFS/NEMS T2m @ GEG Spokane Airport, WA

00Z 01/26/2017 Cycle: 1/26 – 2/1



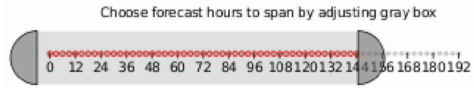
y min y max Set y axis Reset y axis

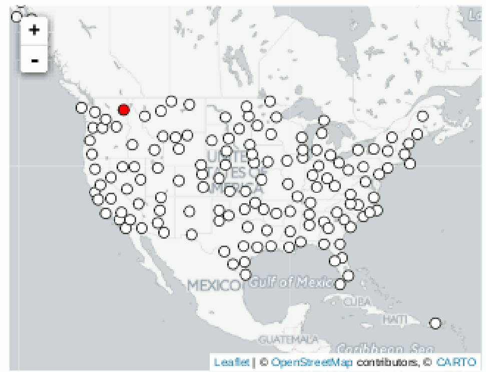
T2m: GFS vs NEMS

About the plumes: Data for each station is interpolated from a 0.5-degree grid for both the GFS (blue) and GFSX (orange). All observed data are derived from hourly station reports. Zoom for more CONUS stations.

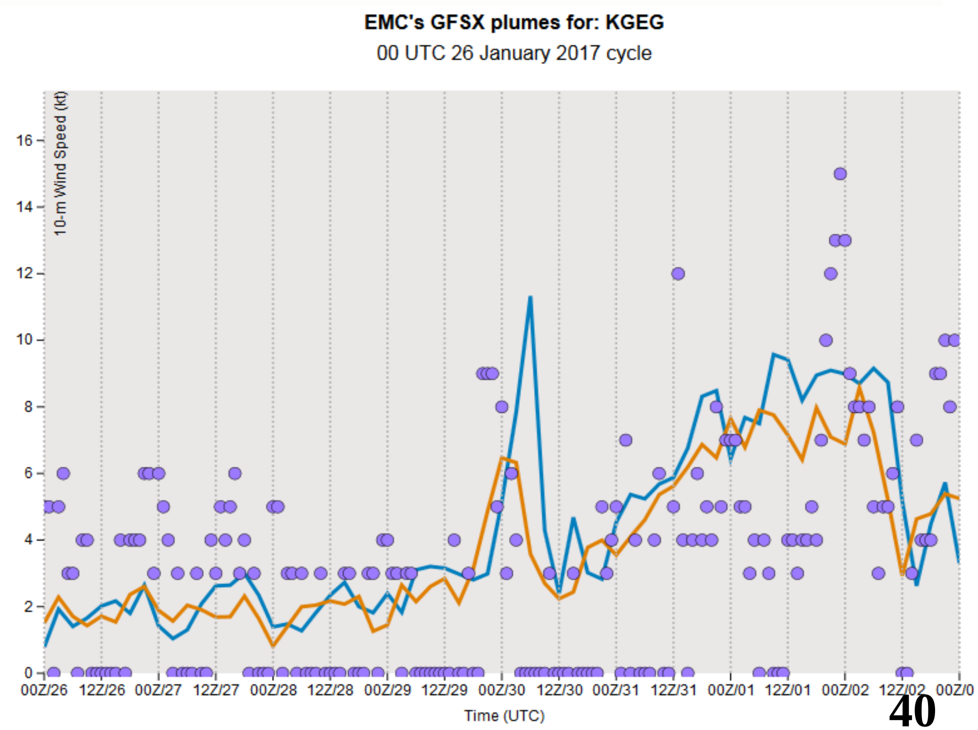
This site is not operational; therefore, data will be missing occasionally. The contact for this site is corey.guastini@noaa.gov

Courtesy Corey Guastini &Tracey Dorian for the plume diagrams





Courtesy Glenn white for the obs.



wspd@10m: GFS vs NEMS

Weak wind: 1/26 – 1/29

Summary and Future Plan

- **Several satellite data sets developed recently (e.g., GVF, snow, burning area, albedo, radiation, soil and vegetation type) have been tested in the NCEP models. The results show good improvements, compared with the current data sets; However, some data sets need further validation with ground measurements, and consistence of all these data sets is required.**

- **The SMOPS soil moisture data assimilation in GFS have been continuously examined; More tests will be done after NESDIS further validate the blended SMOPS products.**

- **Large cold bias of surface temperatures in GFS was identified and substantially reduced by the proposed solution, which resulted in improvement of Tb in GSI/CRTM;**

- **We will continue our efforts and working together with several research teams to improve satellite data utilization and data assimilation and then improve NCEP NWP.**

Thank You !

Any questions/comments?