The use of VIIRS radiances and products in NWP at NCEP

VIIRS User Meeting

June 29-30, 2022

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Outline

- How we do Data Assimilation
- Direct assimilation of VIIRS radiances to constrain SST
- Assimilation of polar AMVs derived from VIIRS radiances
- Summary

A reminder on how we do data assimilation

Data Assimilation

- We try to create the most probable state based on:
  - Current observations,
  - Information from prior observations brought to the current time,
  - Our knowledge of the atmosphere and
  - Our knowledge of the errors of the above.
    - Remember nothing is perfect and everything has errors.

Use of Observations

- Adjust model initial conditions so that they produce simulated observations that are closer to observations. E.g., model variables to satellite observations
  - Can be simple forward model or very complex (GPS-RO, Radiances, etc.)
- Try not to create model pseudo-observations from real observations. E.g., satellite observations to model variables
  - Often not well-posed problem

Atmospheric Analysis Problem

J = Fit to background + Fit to observations + constraints

$$\mathbf{J = J_b + J_o + J_c}$$

$$\mathbf{J = (x-x_b)^T B_x^{-1}(x-x_b) + (y-}\boldsymbol{H}\mathbf{(x))^T(E+F)^{-1}(y-}\boldsymbol{H}\mathbf{(x)) + J_C + J_B}$$

$\mathbf{x}$ = Analysis
$\mathbf{x_b}$ = Background
(usually a short-range forecast from the previous cycle)
$\mathbf{B_x}$ = Background error covariance
H = Forward model (nonlinear)
O = Observations
E+F = Instrument error + Representativeness error
$\mathbf{J_C}$ = Constraint term
$\mathbf{J_B}$ = Bias predictor term

Atmospheric Analysis Problem

$J = J_b + J_o + J_c$

$$J = (x-x_b)^T B_x^{-1} (x-x_b) + (y-H(x))^T (E+F)^{-1} (y-H(x)) + J_C$$

J = Fit to background + Fit to observations + constraints

The difference between the observations and the background transformed into model space, the first guess departure, is an important measure. It is often the basis of quality control procedures.

x = A

x_b = B

B_x = Background error covariance

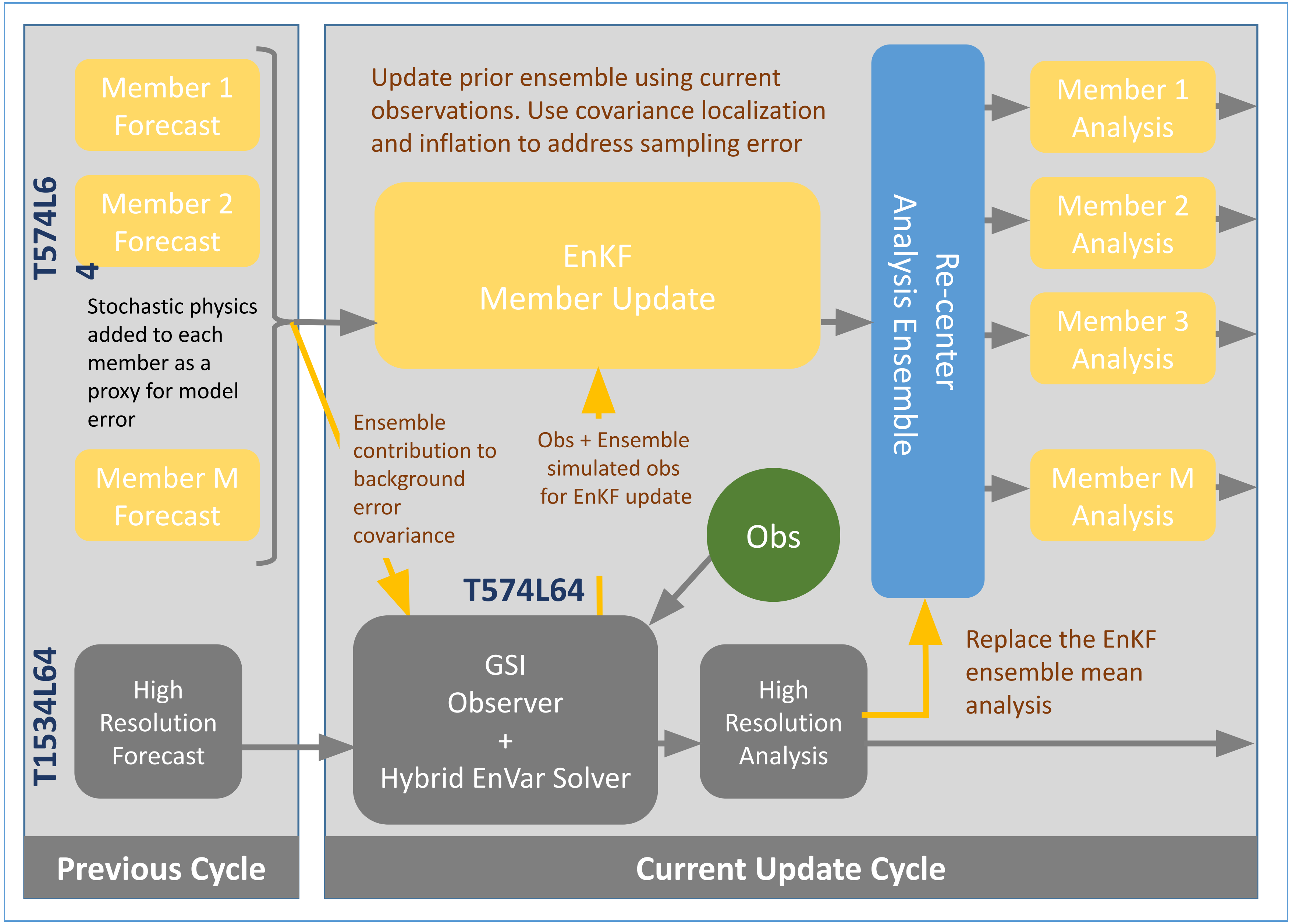
K = Forward model (nonlinear)

O = Observations

E+F = R = Instrument error + Representativeness error

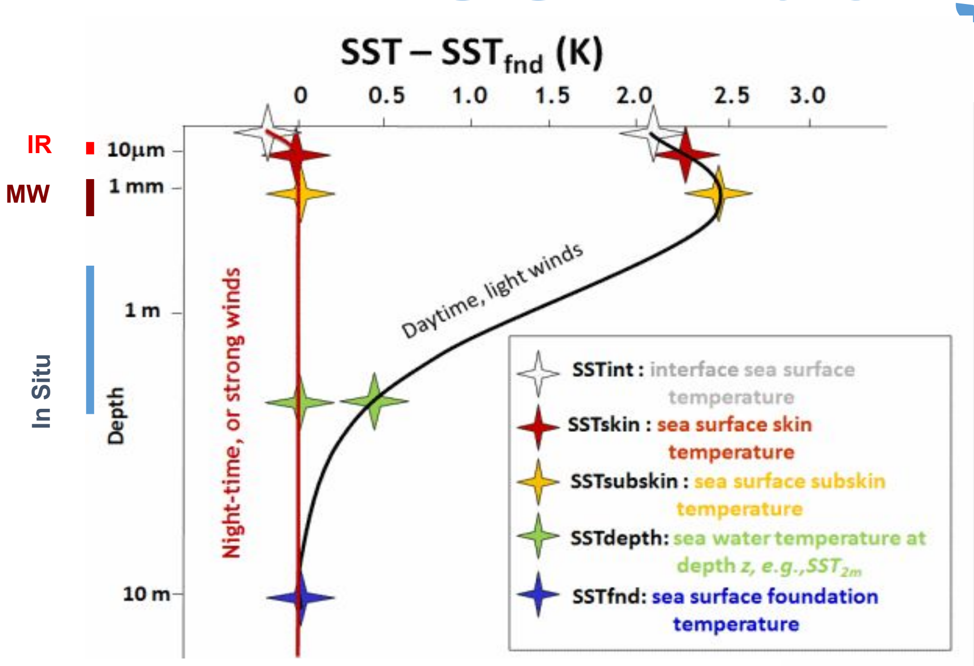
J_C = Constraint term

Hybrid Assimilation Workflow

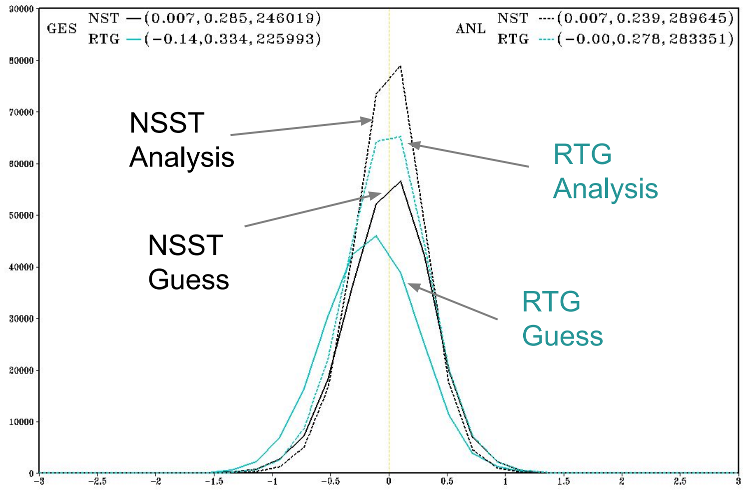


VIIRS Radiance Assimilation: Near Sea Surface Temperature

NSST Background and Updates



IASI Window Channel (data passed QC)

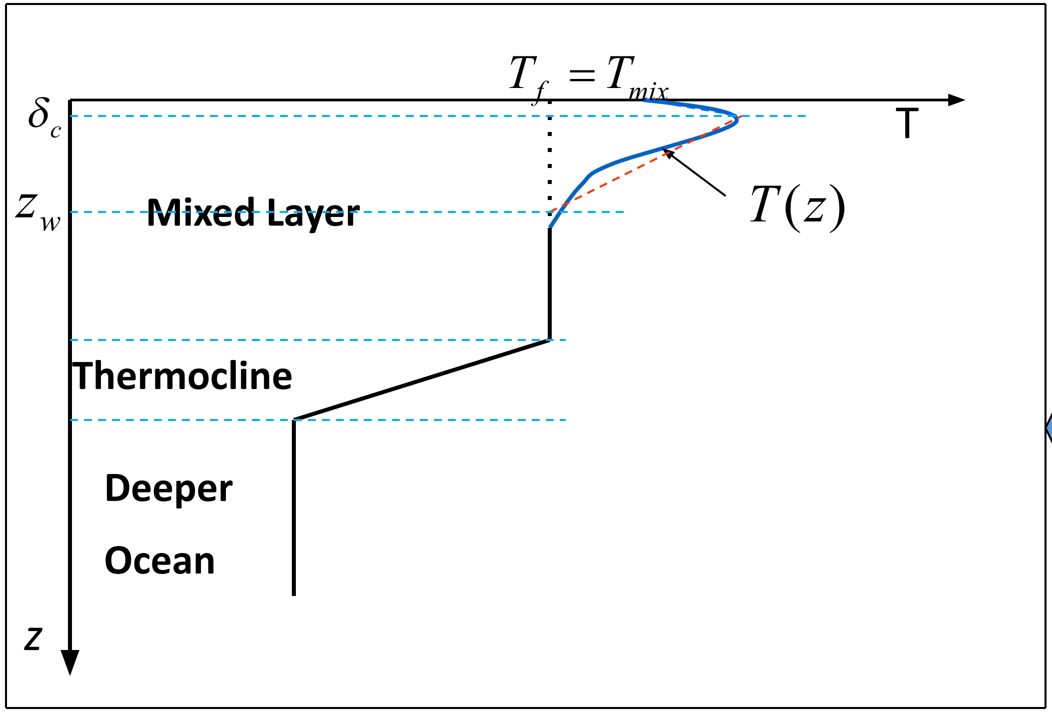


- Foundation Temperature is the analysis variable.
- Diurnal warming and sub-layer cooling T-Profile are simulated by NSST Model in the cycling of GFS.
- NSST T-Profile for atmospheric model and CRTM
- The input surface temperature to CRTM depends on instrument type
  - IR – temperature at 0.015 mm
  - MW – temperature at 1.0 mm
- Satellite radiances: AVHRR, AIRS, CrIS IASI, AMSU-A and ATMS are used in NSST along with in-situ observations to constrain the foundation temperature.
- The use of radiances in NSST analysis leads to better NSST profiles and this, in turn, improves the radiance assimilation.

Using the NSST at 0.015 mm for IASI in CRTM leads to more data passed quality control and better residual statistics.

What is NSST (Near-Surface Sea Temperature)?

NSST is a **T-Profile** just below the sea surface.
Here, only the vertical thermal structure due to **diurnal thermocline layer warming** and **thermal skin layer cooling** is resolved

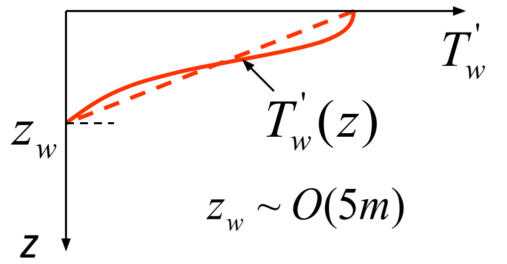


$$T(z,t) = T_f(z_w,t) + T_w'(z,t) - T_c'(z,t)$$

$$z \in [0, z_w]$$

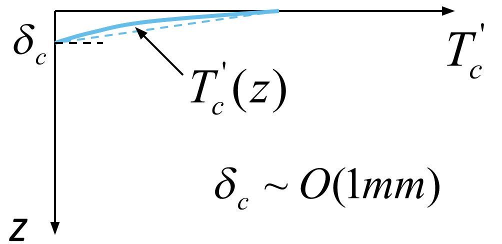
Diurnal Warming Profile

$$T_w'(z) = (1 - z/z_w) T_w'(0)$$



Skin Layer Cooling Profile

$$T_c'(z) = (1 - z/\delta_c) T_c'(0)$$



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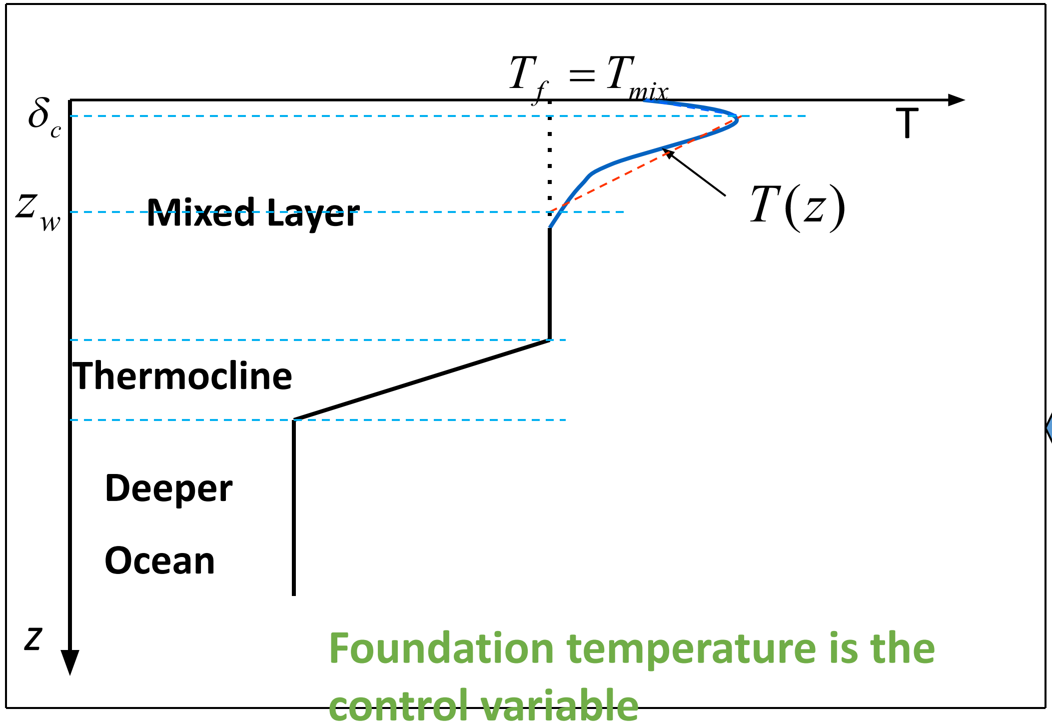


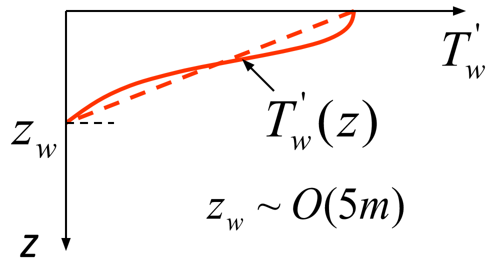
Foundation temperature is the control variable

$$T(z,t) = T_f(z_w,t) + T_w'(z,t) - T_c'(z,t)$$

$$z \in [0, z_w]$$

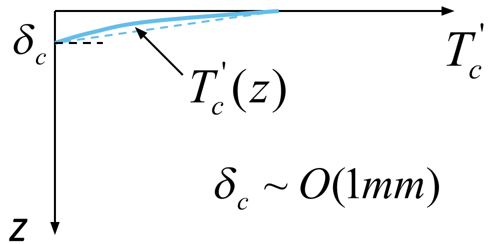
Diurnal Warming Profile

$$T_w'(z) = (1 - z/z_w)T_w'(0)$$

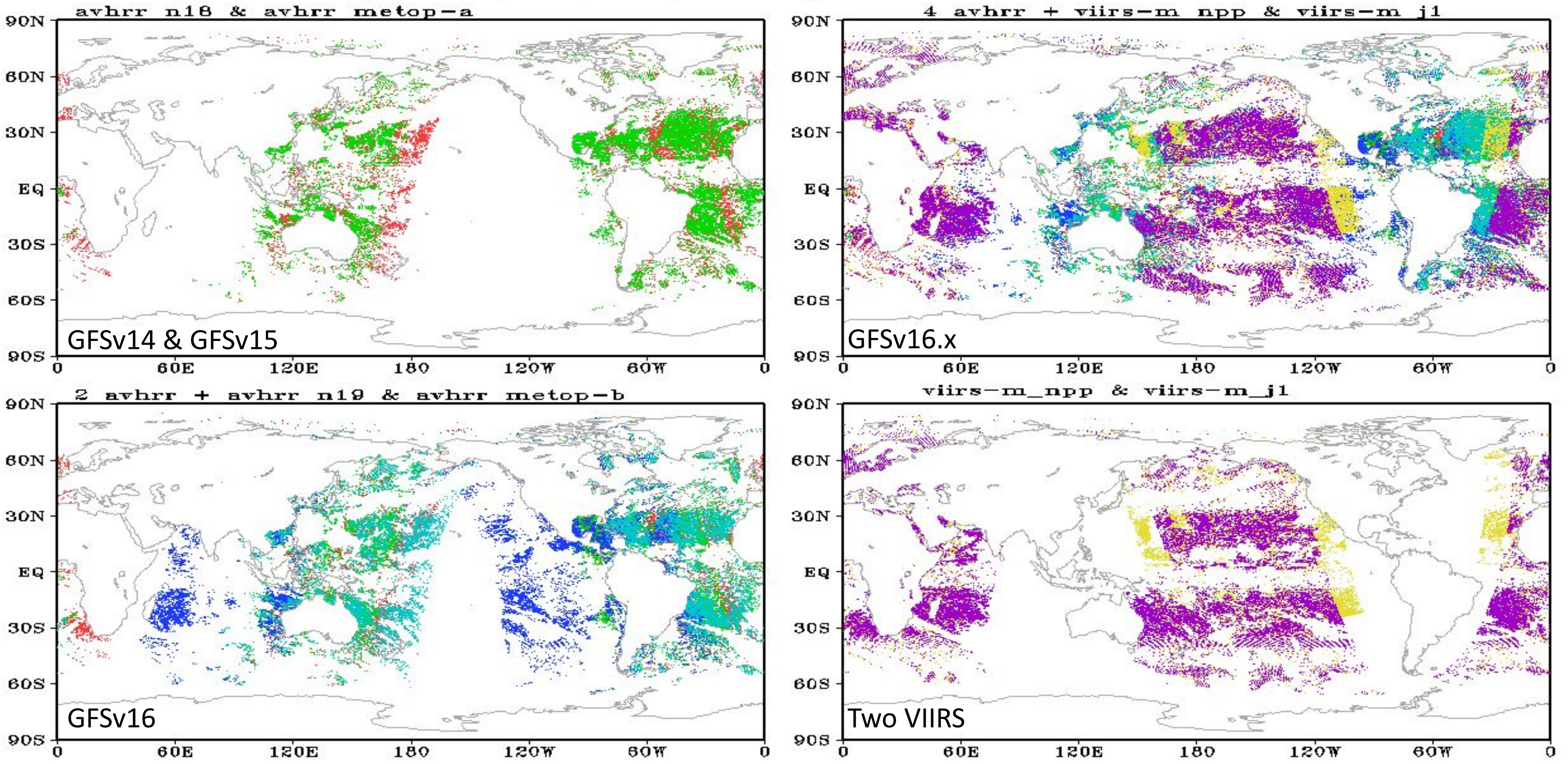


Skin Layer Cooling Profile

$$T_c'(z) = (1 - z/\delta_c)T_c'(0)$$



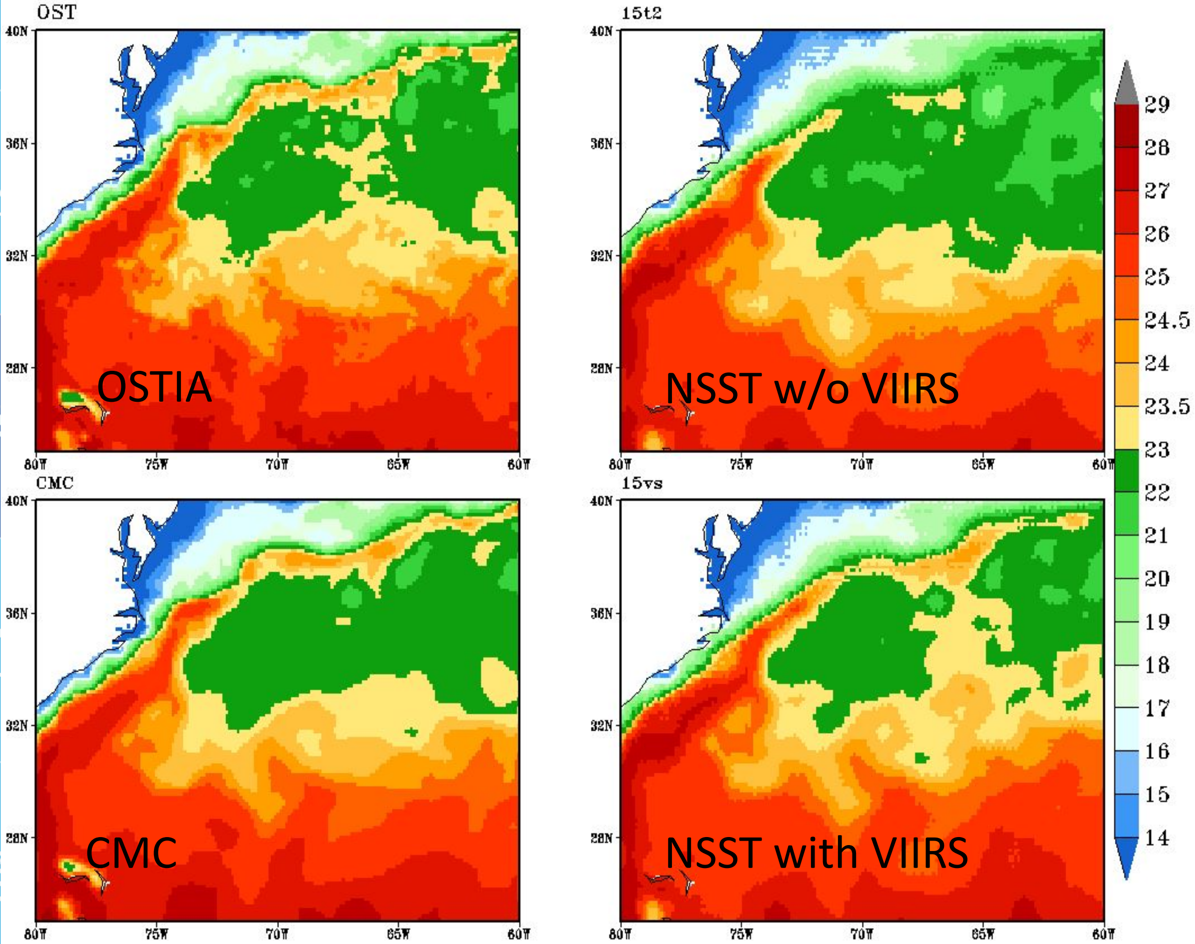
Coverage of the Infra-Red satellite radiance for GFS/GSI/NSST. 6-hourly window. 00Z01Sep2020



- **Satellite observation coverage is improved with operational GFS version updates.**

The use of VIIRS radiance in the NCEP GFS

The comparison of SST analyses over Gulf Stream area.
Nov. 29, 2019.

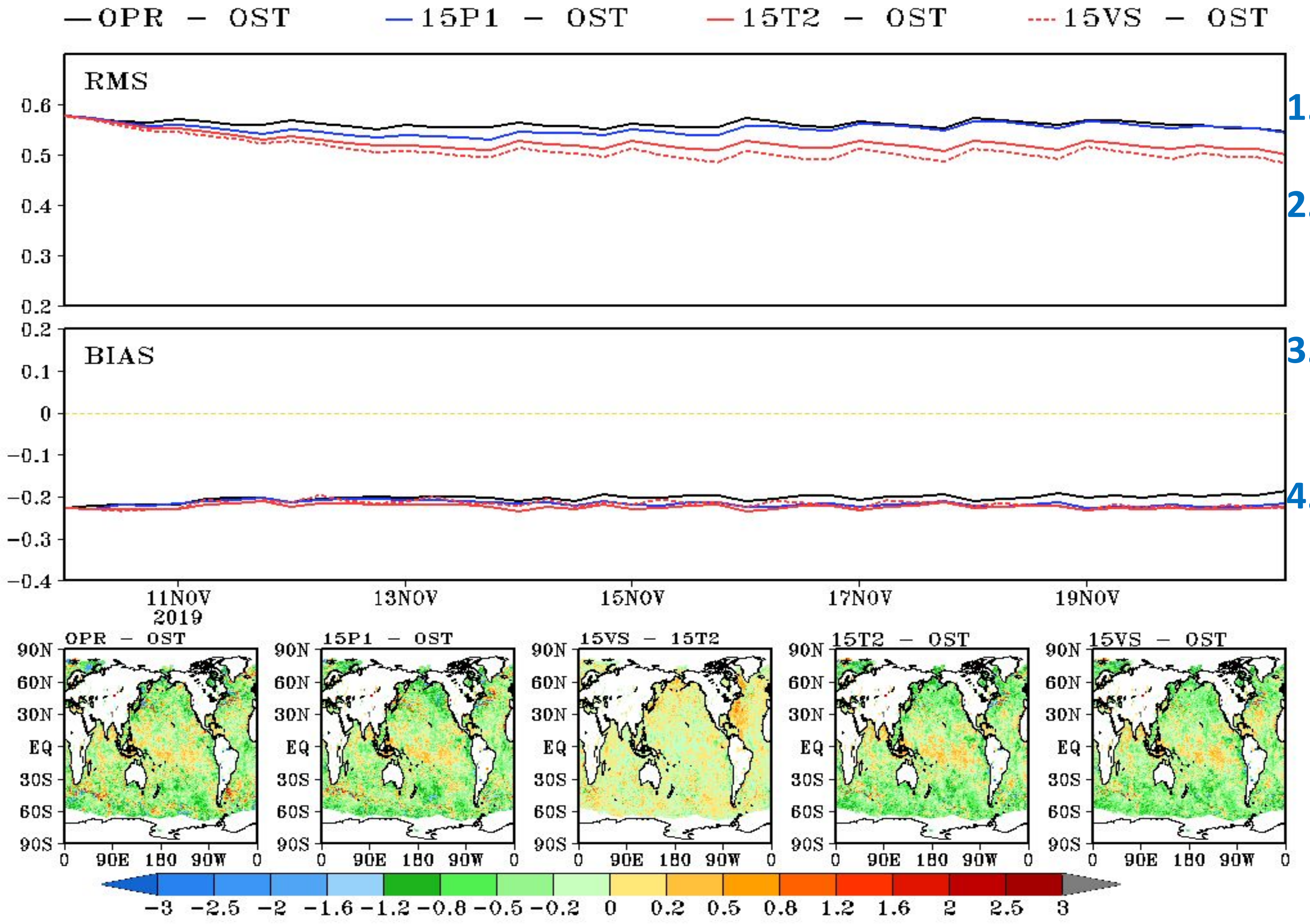


OSTIA: UKMO foundation temperature analysis
CMC: Canadian Meteorological Center foundation temperature analysis

- The VIIRS (NPP and J1) radiance observations, M12 (3.7μm), M15 (11μm), and M16 (12μm), in a ACSPO SST data files, have been tested in the NCEP GFS
- The results have shown positive impact of VIIRS radiance on the NCEP GFS NSST performance globally, particularly over the areas with small spatial scale features
- Specifically, the figure on the left shows the improved Gulf Stream in NEP GFS NSST foundation temperature analysis due to the better observation coverage by using VIIRS radiance additionally

Time series of NSST against OSTIA. 00Z, Nov. 10, 2019 to 18Z, Nov. 20, 2019.

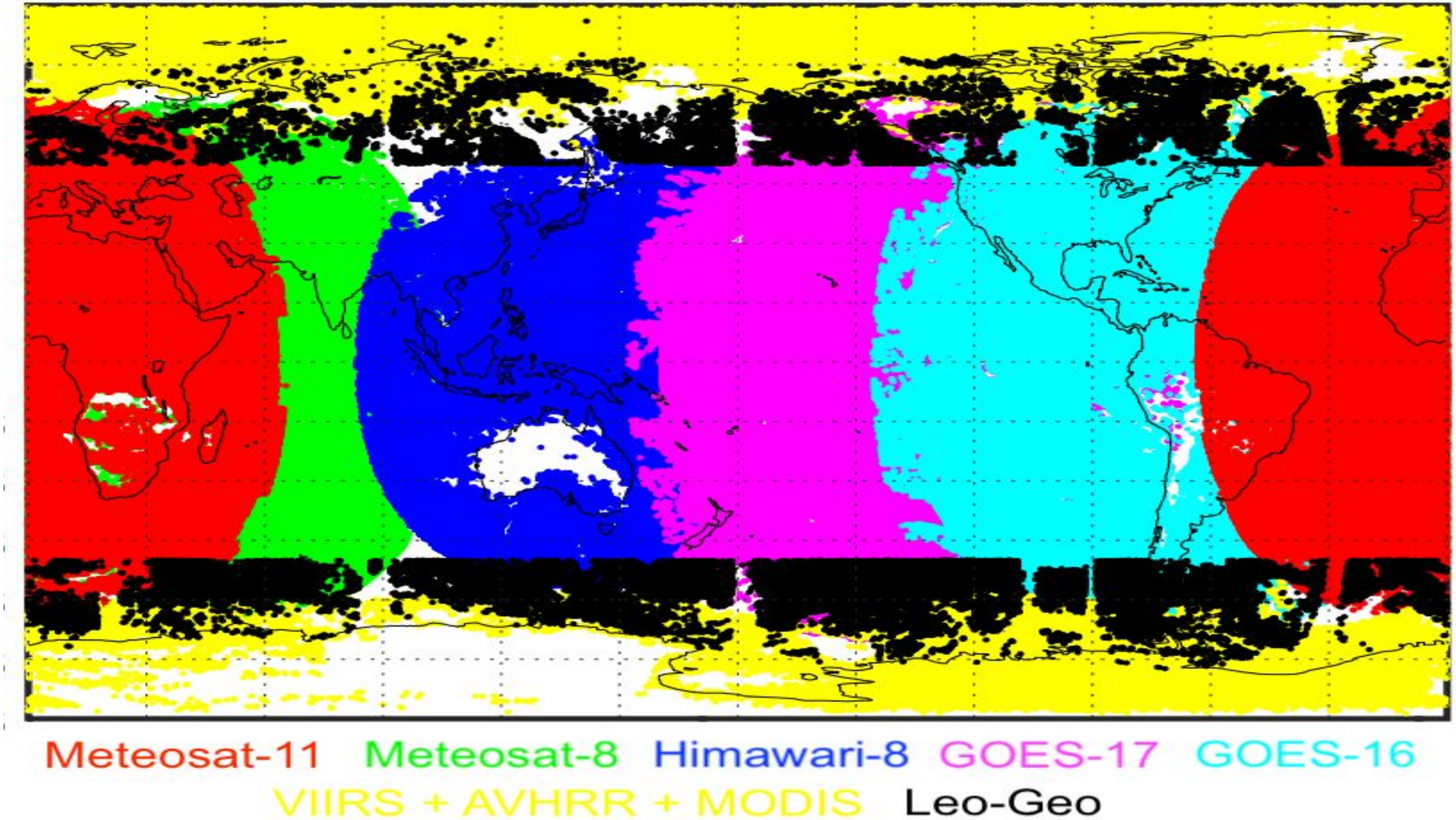
All NSST ICs: 00Z, Nov. 10, 2019.



1. New correlation length (15P1) : Improved slightly (not consistent)
2. New thinning (4t75): Mixed impact and weak signal (not shown here)
3. Combination of the new length and new thinning scheme (15T2): Improved significantly
4. VIIRS added (15VS): Positive impact (consistent and significant)

VIIRS Wind Assimilation

Atmospheric Motion Vectors Observations



VIIRS winds Data Assimilation investigation

VIIRS is an imaging radiometer, a cross between MODIS and AVHRR. It has resolution of 750m for most bands and 375m for some. VIIRS has a wider swath (3000 km) than MODIS (2320 km) and AVHRR (2600 km), and a constrained pixel growth (better resolution at edge of swath)

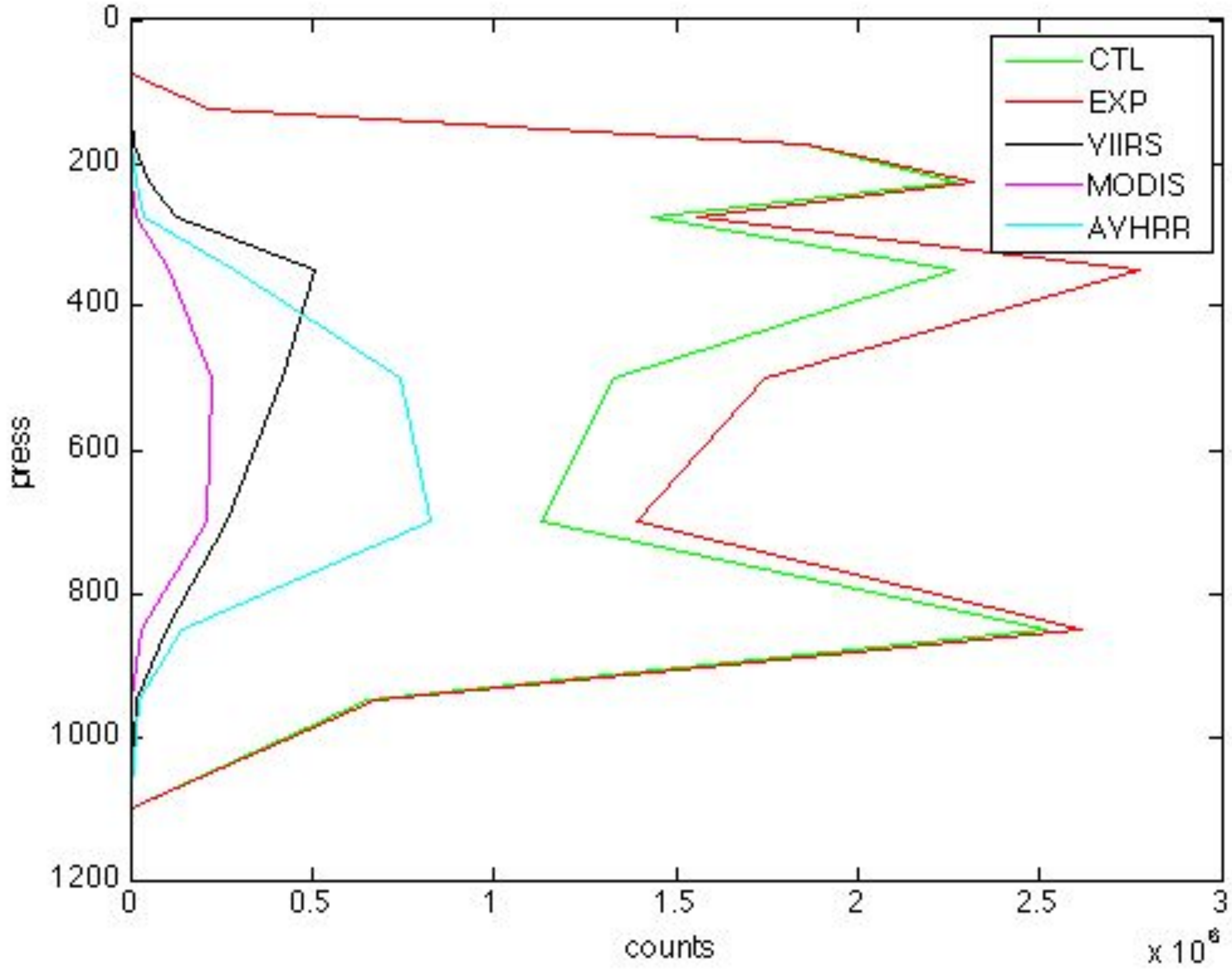
VIIRS winds (IR) are extracted with the GOES-R-like (so called 'nested tracking') algorithm, but reported in the current BUFR format.

VIIRS AMVs use MODIS AMVs' observation error profile, no thinning and they undergo a LNVD check (first introduced by D.Santek for AVHRR winds DA, operational since May 2017)

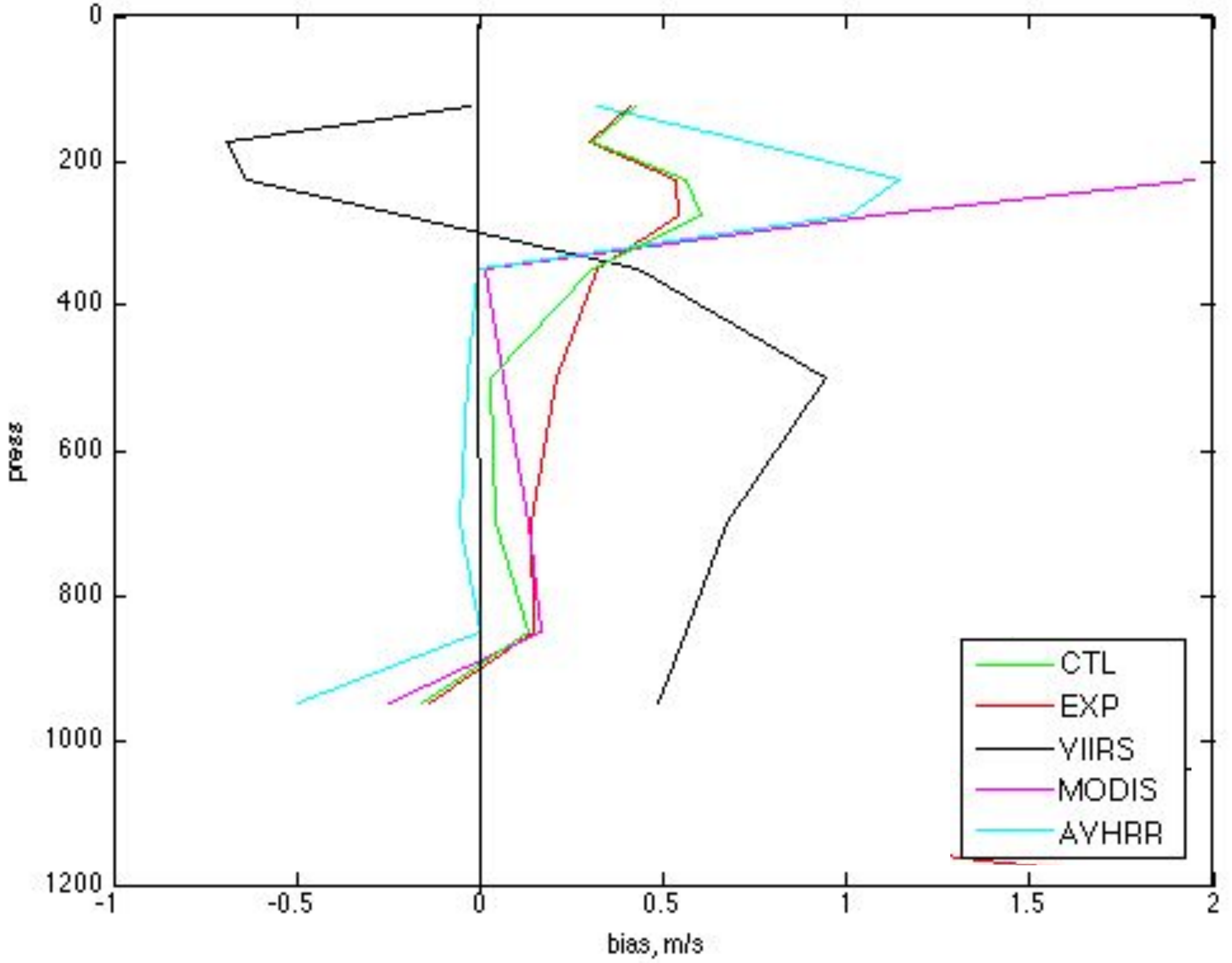
Log Normal Vector Departure Check

SQRT[(UAMV – UGFS)^2 + (VAMV – VGFS)^2] / LOG(SpeedAMV) < 3

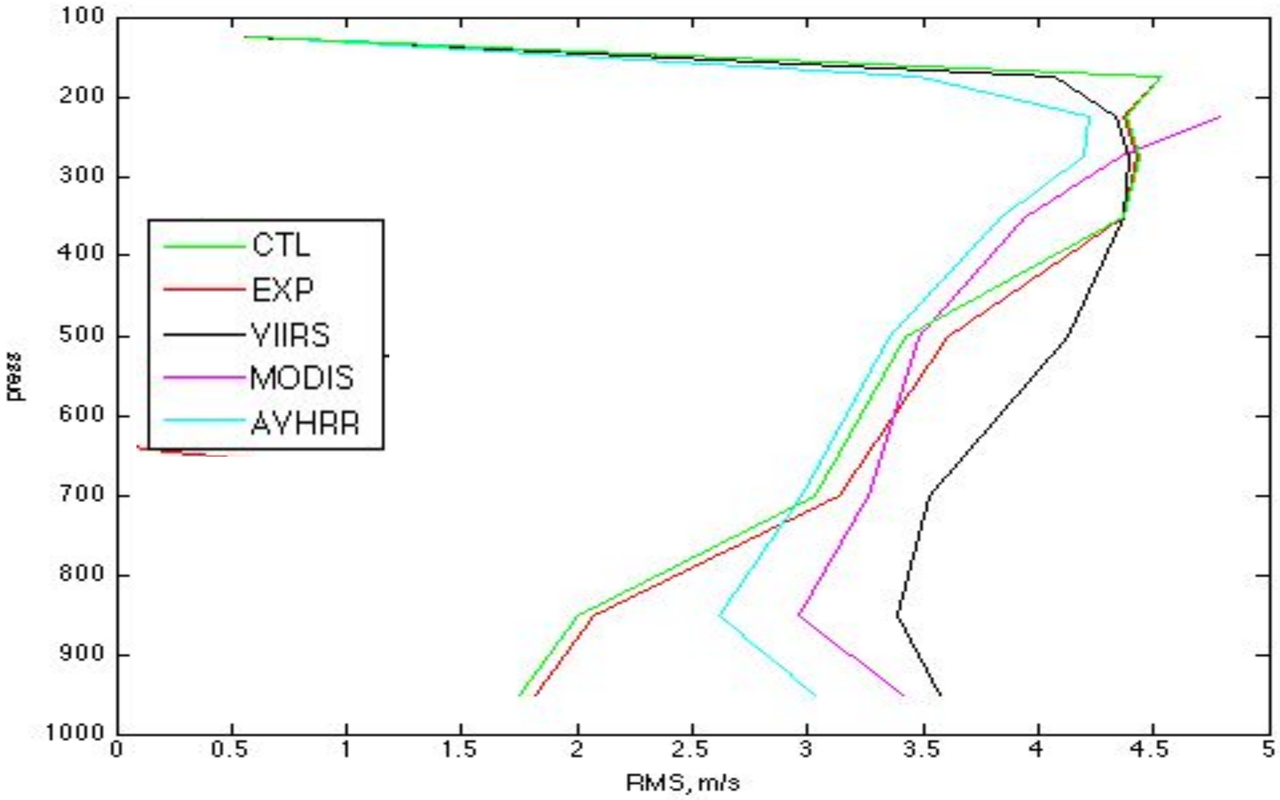
Counts of **USED** AMVs in the control and experiment runs (2014-09-14 till 2014-10-07)



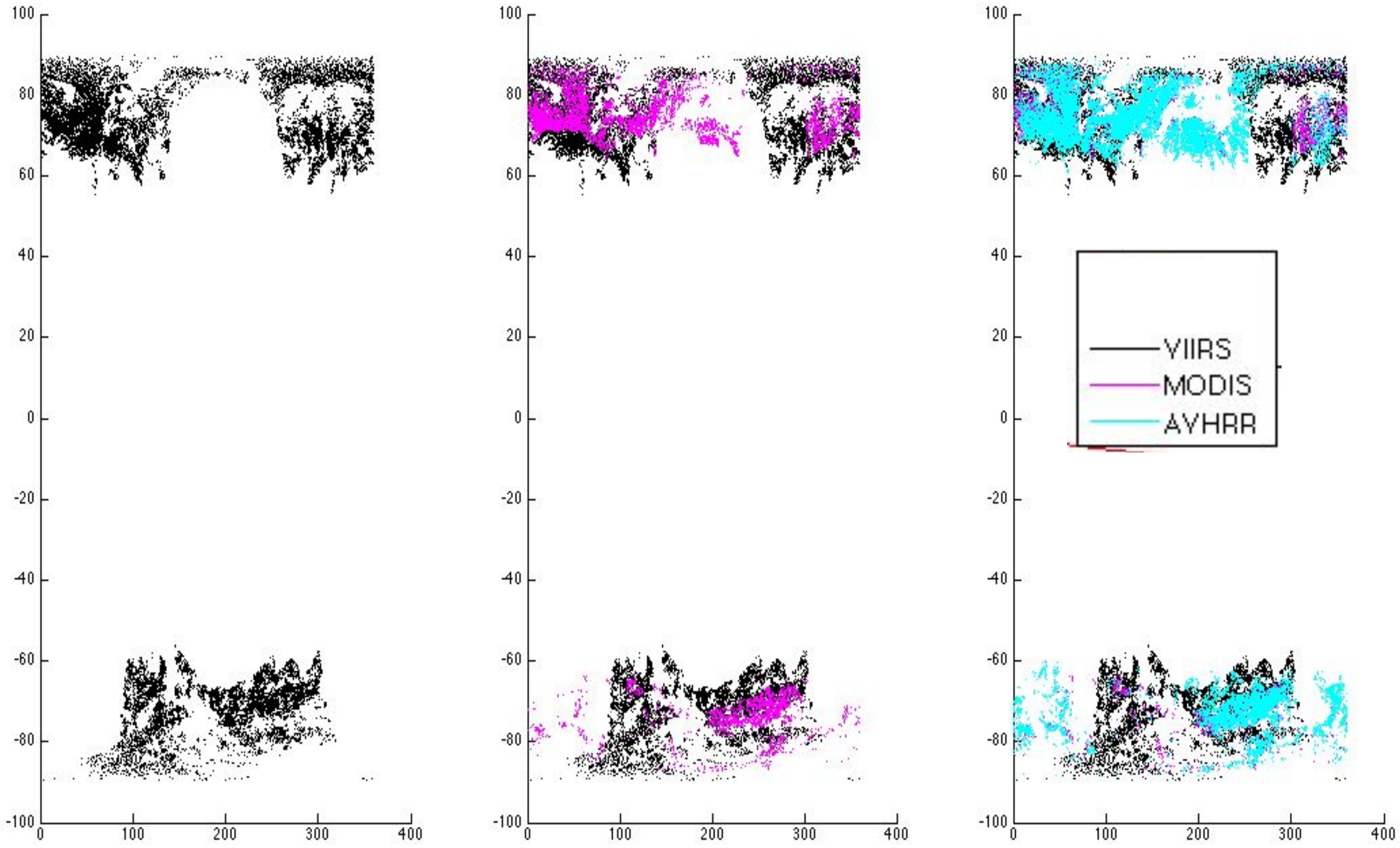
O-B Bias of **USED** AMVs in the control and experiment, and polar winds in experiment

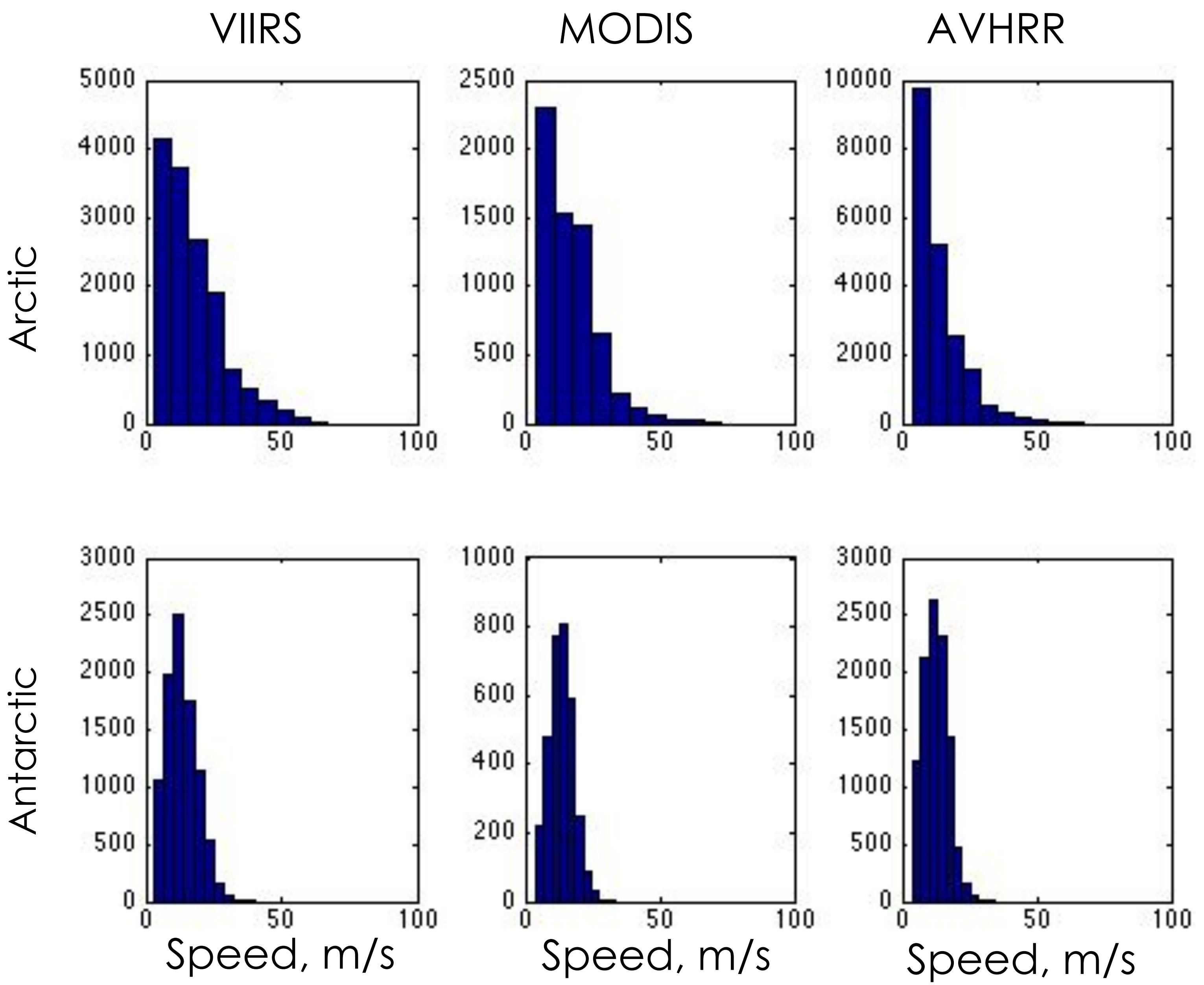


O-B RMS of **USED** AMVs in the control and experiment, and polar winds in experiment

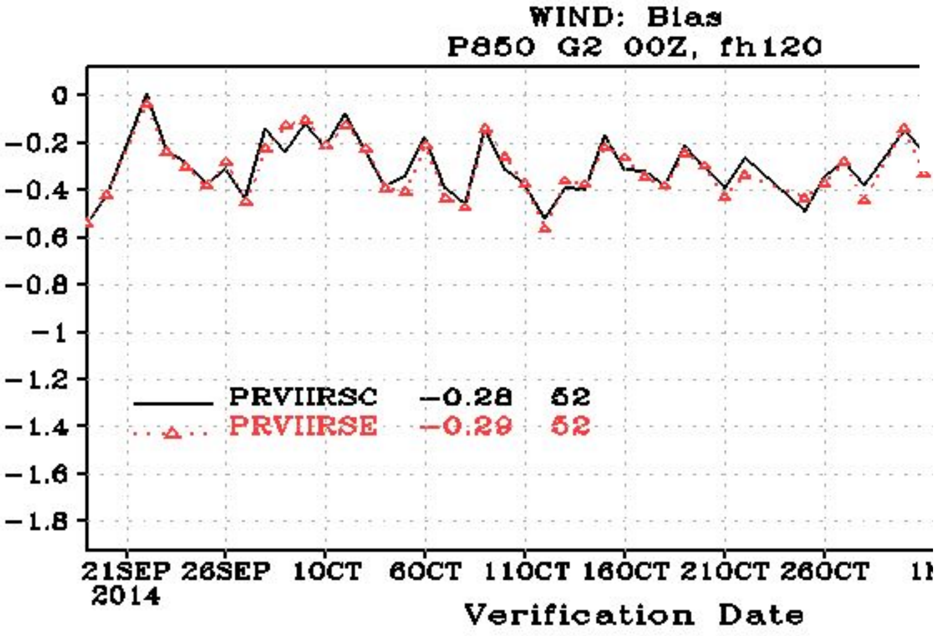


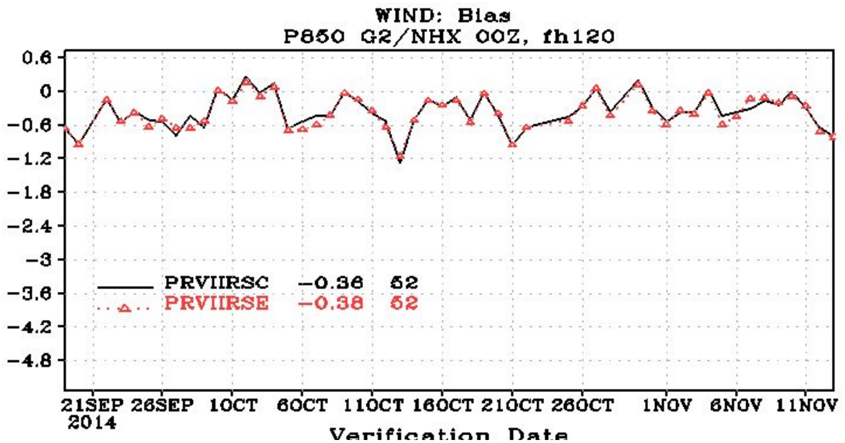
Spatial distribution of USED polar winds in the experiment with VIIRS winds

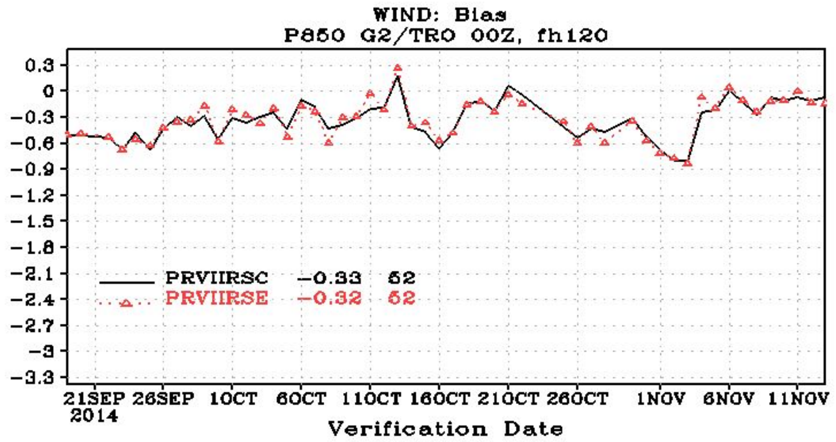




VIIRS
MODIS
AVHRR
Arctic
Antarctic
Speed, m/s
Speed, m/s
Speed, m/s


WIND: Bias
P850 G2 00Z, fh120
PRVIIRSC −0.28 52
PRVIIRSE −0.29 52
21SEP 2014 26SEP 1OCT 6OCT 11OCT 16OCT 21OCT 26OCT
Verification Date


WIND: Bias
P850 G2/NHX 00Z, fh120
PRVIIRSC −0.36 52
PRVIIRSE −0.38 52
21SEP 2014 26SEP 1OCT 6OCT 11OCT 16OCT 21OCT 26OCT 1NOV 6NOV 11NOV
Verification Date


WIND: Bias
P850 G2/TRO 00Z, fh120
PRVIIRSC −0.33 52
PRVIIRSE −0.32 52
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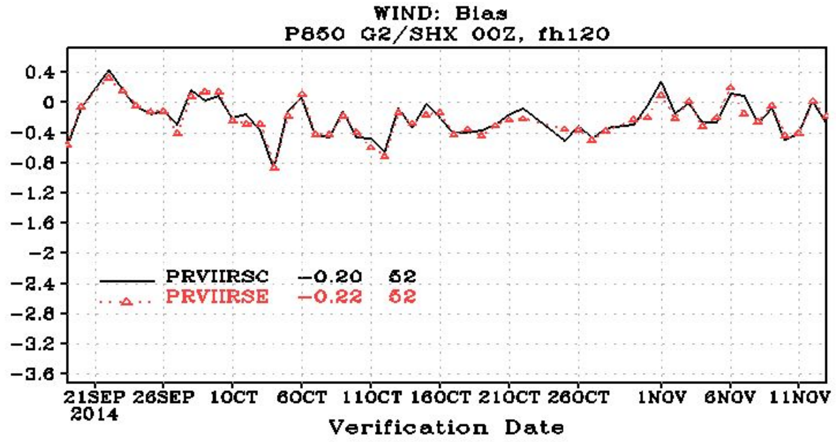
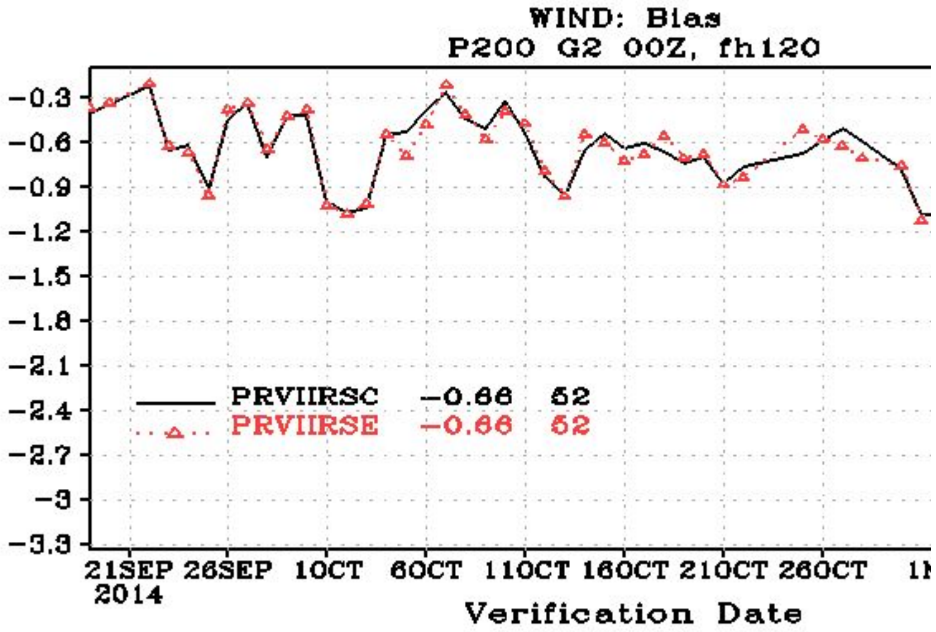
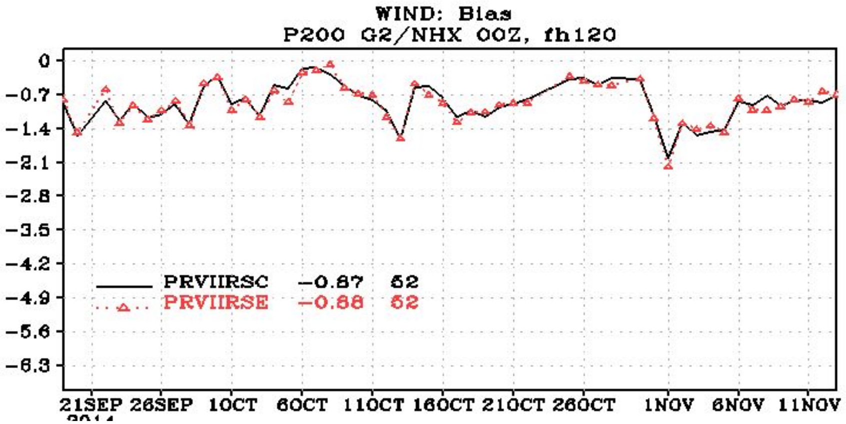
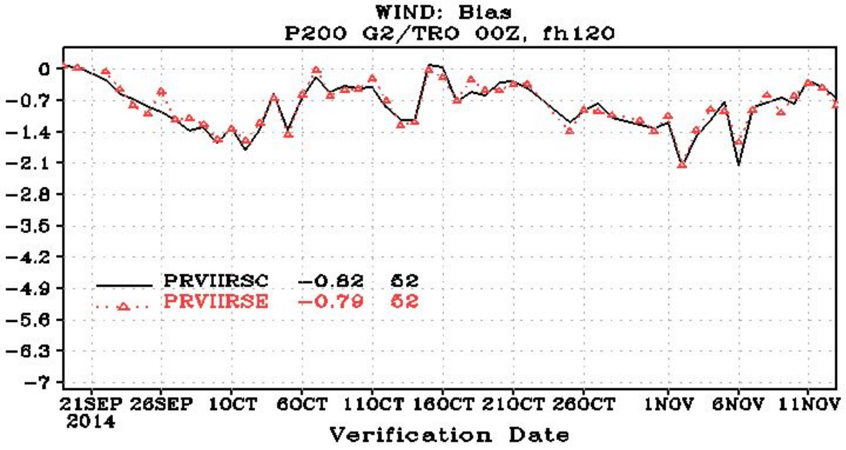
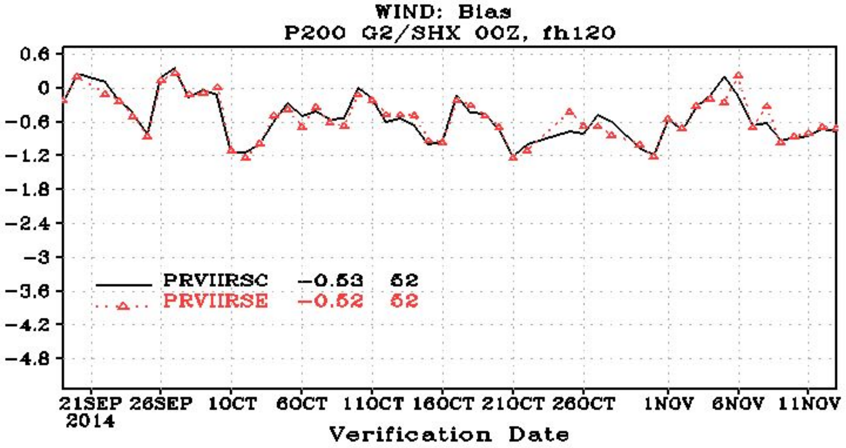
Verification Date


WIND: Bias
P850 G2/SHX 00Z, fh120
PRVIIRSC −0.20 52
PRVIIRSE −0.22 52
21SEP 2014 26SEP 1OCT 6OCT 11OCT 16OCT 21OCT 26OCT 1NOV 6NOV 11NOV
Verification Date


WIND: Bias
P200 G2 00Z, fh120
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
-2.1
-2.4
-2.7
-3
-3.3
PRVIIRSC -0.66 52
PRVIIRSE -0.66 52
21SEP 26SEP 1OCT 6OCT 11OCT 16OCT 21OCT 26OCT
2014
Verification Date


WIND: Bias
P200 G2/NHX 00Z, fh120
0
-0.7
-1.4
-2.1
-2.8
-3.5
-4.2
-4.9
-5.6
-6.3
PRVIIRSC -0.87 52
PRVIIRSE -0.88 52
21SEP 26SEP 1OCT 6OCT 11OCT 16OCT 21OCT 26OCT 1NOV 6NOV 11NOV


WIND: Bias
P200 G2/TRO 00Z, fh120
0
-0.7
-1.4
-2.1
-2.8
-3.5
-4.2
-4.9
-5.6
-6.3
-7
PRVIIRSC -0.82 52
PRVIIRSE -0.79 52
21SEP 26SEP 1OCT 6OCT 11OCT 16OCT 21OCT 26OCT 1NOV 6NOV 11NOV
2014
Verification Date


WIND: Bias
P200 G2/SHX 00Z, fh120
0.6
0
-0.6
-1.2
-1.8
-2.4
-3
-3.6
-4.2
-4.8
PRVIIRSC -0.53 52
PRVIIRSE -0.52 52
21SEP 26SEP 1OCT 6OCT 11OCT 16OCT 21OCT 26OCT 1NOV 6NOV 11NOV
2014
Verification Date

Summary

Summary

- VIIRS is used in the NCEP Global Forecasting System in two different ways.
- VIIRS radiances are used as an important constraint on the sea surface temperature analysis
- VIIRS polar AMVs are also assimilated.   The impact from these observations is mostly neutral, but are an additional source of robustness.

Thank You!