Analyze SST within the NCEP GFS

Xu Li[(1)], John Derber[(2)], Shrinivas Moorthi[2)]

(1) IMSG at EMC/NCEP/NOAA, USA

(2) EMC/NCEP/NOAA, USA

Acknowledgements:

Andrew Collard (DA), Jun Wang (Model, NEMSIO)

Diane Strokes, SST Group (SST)

Ilya Rivin & Carlos Lozano (NSST model initial stage)

Fanglin Yang, Russ Treadon, George Gayno (Parallel run, validation, chgres)

Xingren Wu, David Buheringer (Sea ice, Coupled),

Dennis Keyser & Jeff Whiting (Data)

18th GHRSST Science Team Meeting, Qingdao, China, June 05, 2017

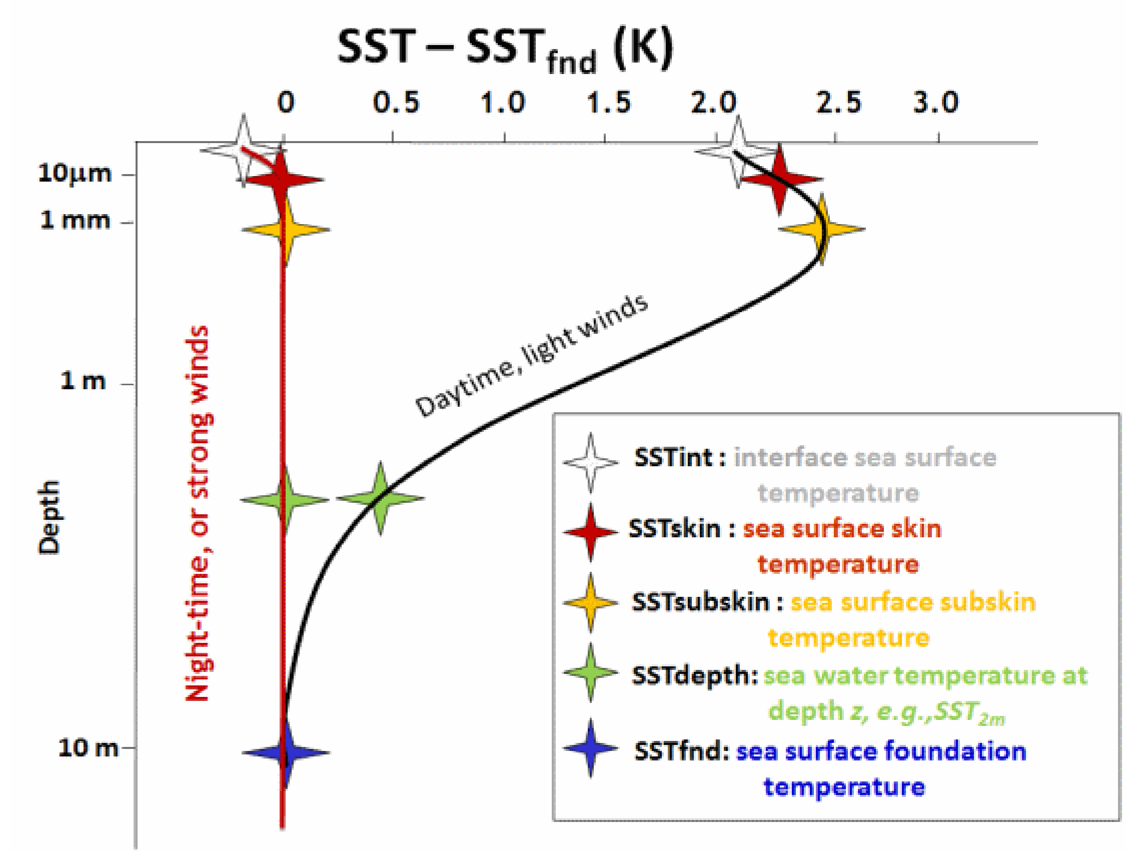
Outline

- Introduction
- SST analysis within the NCEP GFS
  - **A new analysis variable** definition and selection
  - **Observations** are indirect
  - **Direct assimilation** of the indirect observations
  - **The new capability** to analyze an oceanic variable within the NCEP GFS
- Verification
- Conclusion and discussion

Introduction

- So far, SST is analyzed independently and then provided to NWP system as an input
- Here, SST is analyzed together with the atmospheric analysis variables within the **NCEP GFS** (Global Forecasting System)

Foundation temperature and NSST definition



IR: 15 μm

MW: 1 $- 30\ mm$

In situ :
20 cm $-3 +$ m

Hypothetical vertical profiles of temperature for the upper 10m of the ocean surface
in high wind speed conditions or during the **night** (red) and for low wind speed during the **day** (black).

Comments:

1. The 5 defined SSTs are just characteristic temperatures of the Near-Surface Sea Temperature (**NSST**) T-Profile : $T(z)$
2. **SST** $= T(z=0)$: SST_{int}
3. SST is **never observed directly**

NSST & SST can split into three components

- Nera-Surface Sea Temperature (**NSST**) T-Profile:

$$T(x, y, z, t) = T_f(x, y, z_w, t) + T'_w(x, y, z, t) - T'_c(x, y, z, t)$$

T_f : foundation temperature

$z_w = z_w(x, y, t)$: diurnal warming layer thickness

T'_w : diurnal warming profile

T'_c : sub-layer cooling profile

- **SST** is the foundation temperature plus surface diurnal warming amount minus surface sub-layer cooling amount at $z = 0$:

$$SST(x, y, t) = T_f(x, y, z_w, t) + T'_w(x, y, 0, t) - T'_c(x, y, 0, t)$$

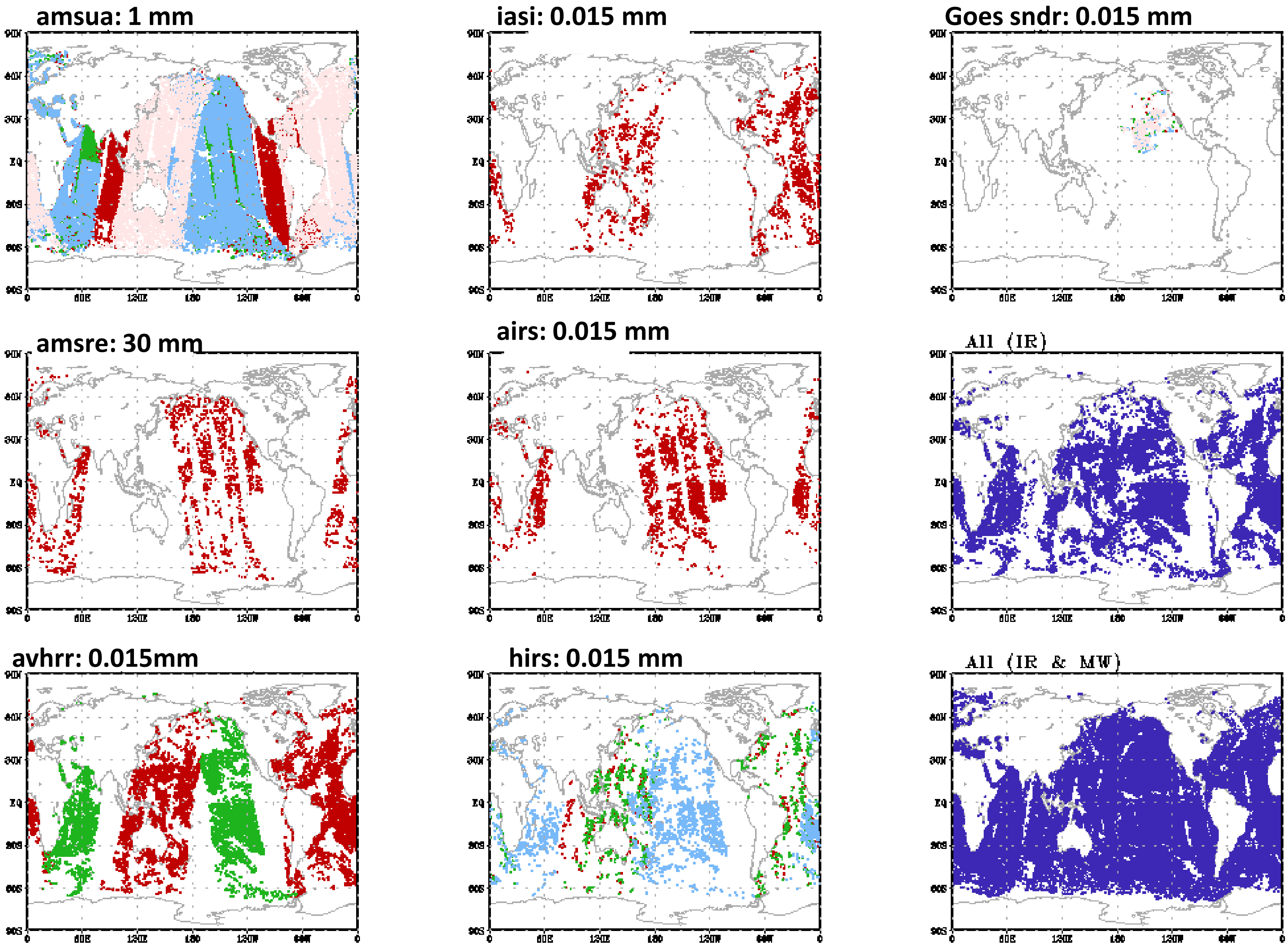
T_f is selected as the analysis variable

- Which analysis variable is more appropriate?
  - Foundation temperature (T_f)
  - Skin temperature (T_s)
  - Others
- The reasons to **analyze T_f**
  - Slower varying ➔ smaller analysis increment
  - More convenient background covariance determination
  - Consistent with GHRSST
- The other two components, diurnal warming and sub-layer cooling T-Profile are **simulated** by NSST Model in the cycling of GFS

Depth dependent Observations

- The observation depth determination
  - A preliminary way for the radiance
  - No good way for some in situ sea temperature
    - A table generated based on inventory
- The observation coverage to do 6-hourly analysis

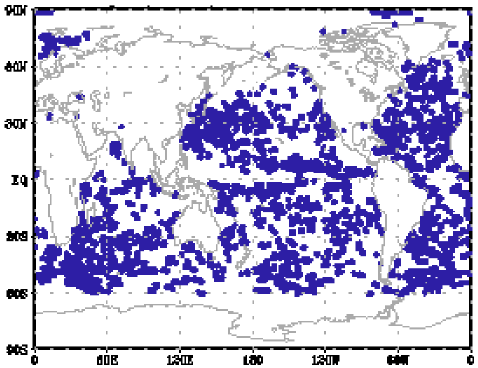
6-hour time window centered at 00Z, 05/22/2010



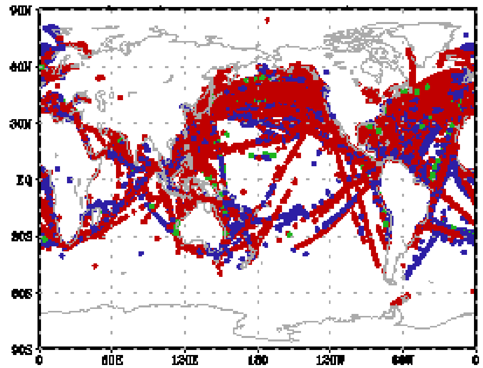
Satellite observations: coverage and skin-depth

13 days period in May 2010

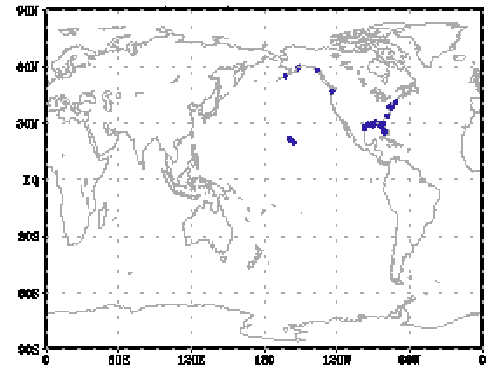
Drifting Buoy: 0.2 m



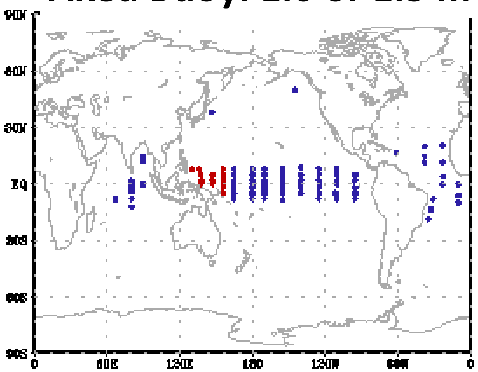
Ships: 1.0 – 3.0+ m



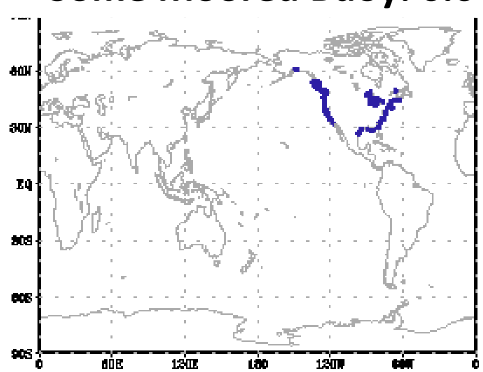
LCMAN: 1.0 m



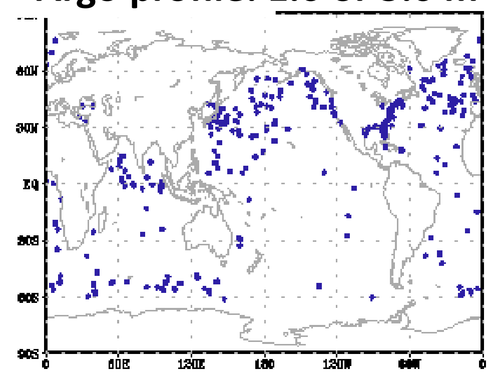
Fixed Buoy: 1.0 or 1.5 m



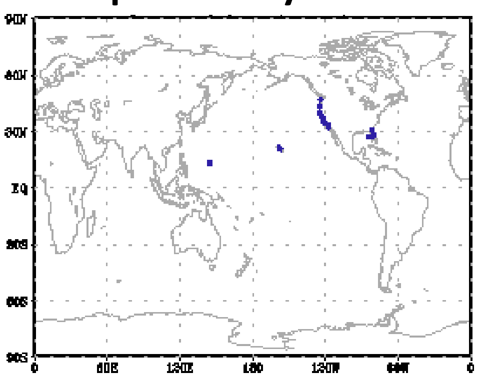
Some Moored Buoy: 0.6 m



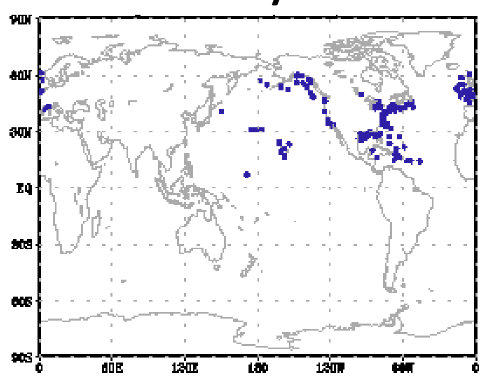
Argo profile: 1.0 or 5.0 m



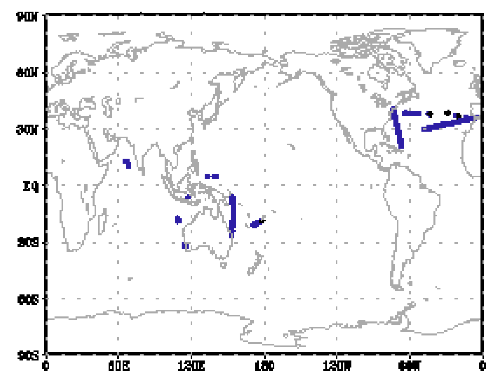
Scripts Mbuoy: 0.45m



Other Mbuoy: 1.0 m



XBT: 1.5 – 5.0 m



In Situ sea temperature observations: coverage and depth

How to use the indirect observations to analyze T_f?

- Convert the observations to be T_f
  - Retrieval
  - Conversion from T_z to T_f
- Toss the observations with diurnal warming signal (like in OSTIA and other univariate analysis scheme)
- **Direct assimilation**
  - Assimilate the indirect observations directly to analyze T_f
    - Development of observation operator and its Jacobian to relate T_f to the observations

Direct assimilation

- Successful experiences in atmospheric radiance assimilation (no retrieval needed)
  - Extract the oceanic thermal information from the radiances more effectively
  - Not yet in oceanic data assimilation
- GSI is capable of assimilating satellite radiance directly
  - NSST T-Profile simulation, which will relate T_f , the new analysis variable, to sea temperature at a specific depth, ie required

Why analyze T_f, an oceanic variable, within an integrated atmospheric prediction system?

- **More consistent NWP initial conditions**
  - A single cost function for two media
- **More effective use of the observations**
  - Direct assimilation: extract the signal from the satellite radiance more optimally
- **More advanced data assimilation algorithm**
  - The atmospheric data assimilation system, such as GSI, is advanced and updated frequently
- **A direction towards the coupled data assimilation**
  - Surface sensitive channel radiances depend on both atmosphere and ocean ➔ both media need to be adjust to fit the observation in their analysis

NSST Model (NSSTM)

- Thermal Skin Model/Parameterization (adopted)
  - $T_c'(x, y, z, t), z \in \delta_c \sim O(1mm)$
  - Formation mechanism
    - $I(0) - I(\delta_c)$-Q_r-Q_l-Q_s< 0 in the skin layer
    - Weak mixing in the skin layer
  - COARE V3.0 (Fairall, 1996)
- **NCEP Diurnal Warming Model** (developed)
  - $T_w'(x, y, z, t), z \in z_w \sim O(5m)$
  - Formation mechanism
    - The competing result of solar radiation (stratification) and mixing (mixed layer)

Brief review on diurnal warming models

- Fairall et al diurnal warming model
  - Based on a simplified scale version of PWP 1-D model
  - Applied in TOGA COARE
    - For an average over 70 days sampled during COARE, **the cool skin increase the average atmospheric heat input to the ocean** by about **11 w/m^2**, **the warm layer decrease it** by about **4 w/m^2** (but the effect can be **50 w/m^2** at midday).
- X. Zeng et al diurnal warming model
  - Derived from T equation only, fixed 2 m layer thickness
- **NCEP diurnal warming model (Xu Li)**

NCEP diurnal warming model

- Based on PWP 1-D model instead of its scale version.
- The evolution of the diurnal warming is controlled by a system with 5 ordinary differential equations for *T, S, u, v* and z_w
- Observation operator (NSSTM): relate T_f to $T(z)$

$$T(x,y,z,t) = T_f(x,y,z_w,t) + T'_w(x,y,z,t) - T'_c(x,y,z,t)$$

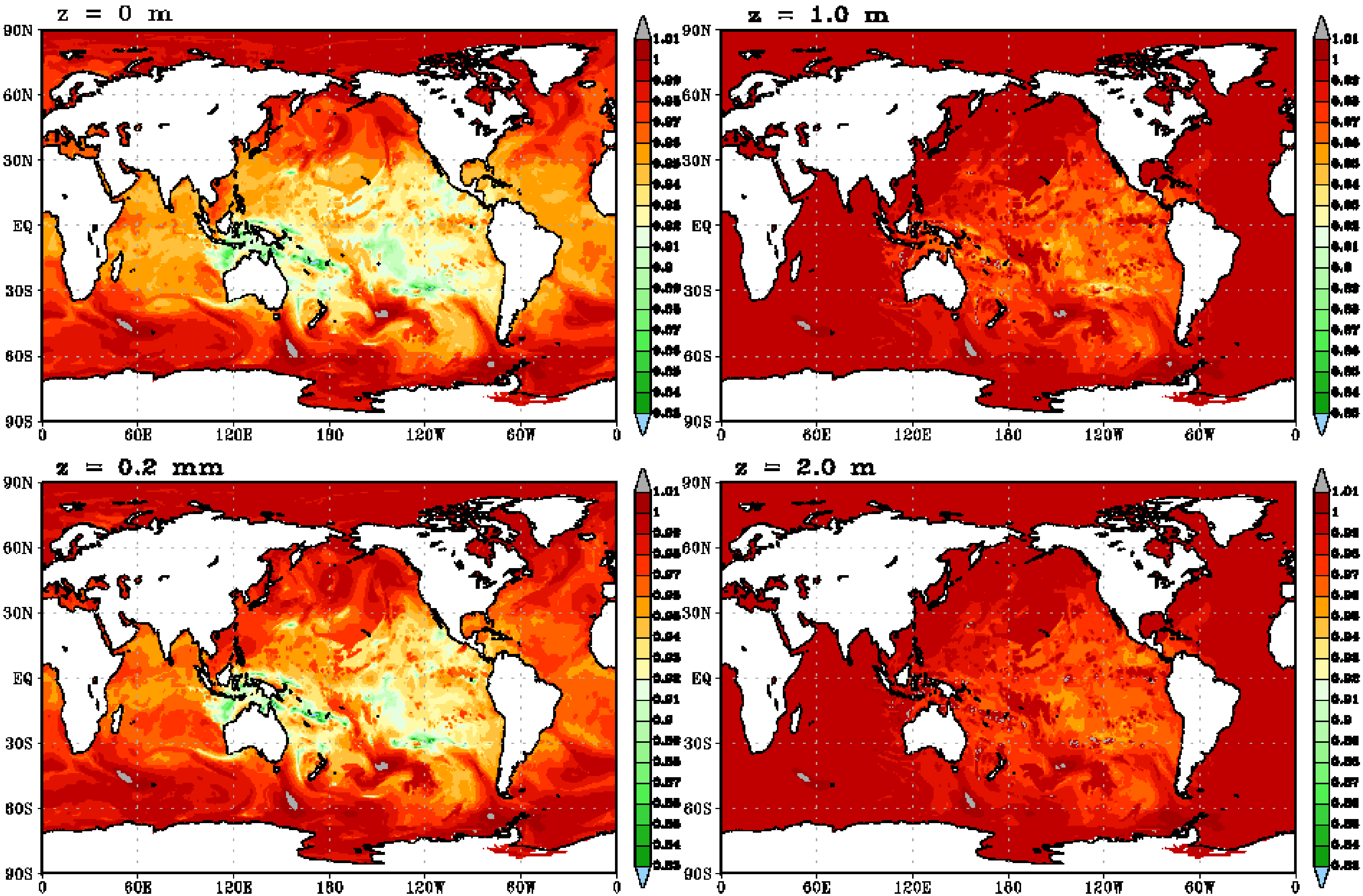
- Jacobian of observation operator

$\frac{\partial T_z}{\partial T_f}$, required in the minimization of a variational assimilation scheme to assimilate observations directly

Note, the sensitivity of radiance (T_b) to T_f:

$\frac{\partial T_b}{\partial T_f} = \frac{\partial T_b}{\partial T_z}\frac{\partial T_z}{\partial T_f}$, ($\frac{\partial T_b}{\partial T_z}$ provided by CRTM)

Jacobian of observation operator: $\partial T_z / \partial T_f$. 06Z, 02/06/2006



Analyze T_f within the NCEP GFS

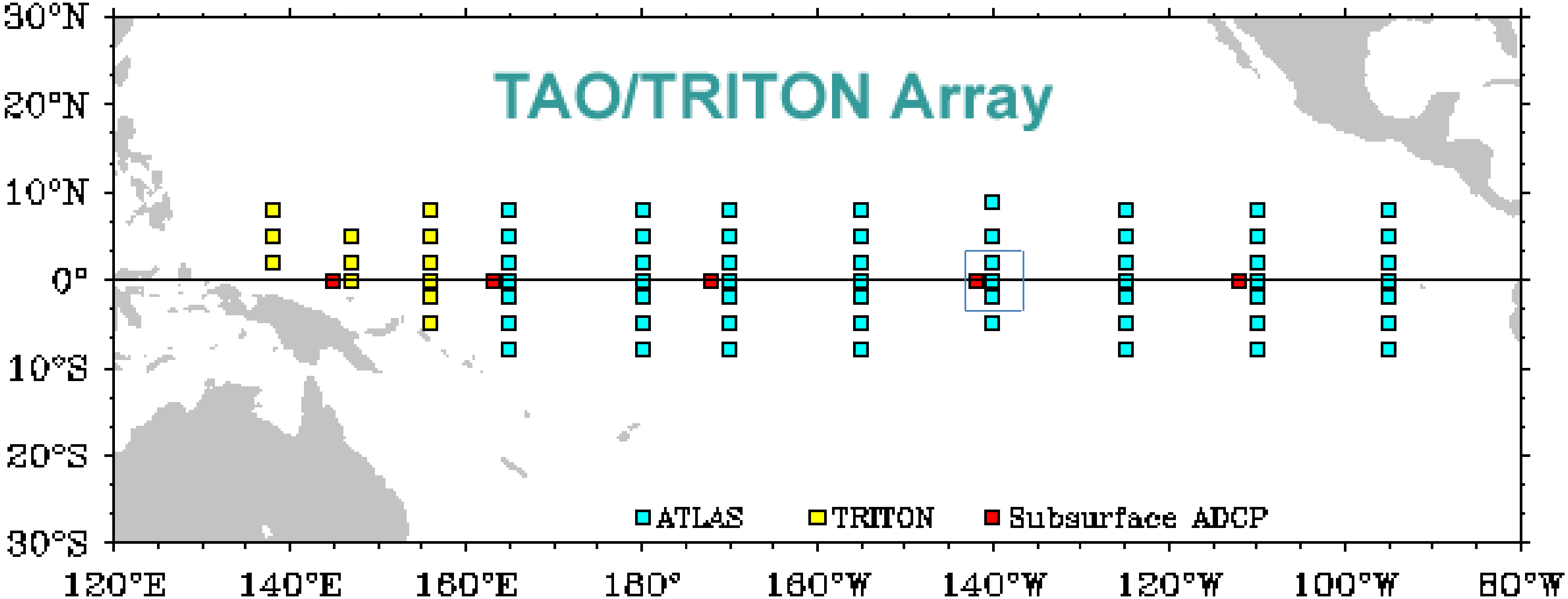
- Develop the NSST Model, including the Jacobian of the observation operator
  - NSSTM is built in the GFS atmospheric prediction model with the same time step as the atmosphere
- Add a new analysis variable(T_f) to GSI
- The background error variance and correlation scale are from RTG
- Add new observations
  - AVHRR GAC
  - In Situ sea temperature
- Other necessary components follow GSI
  - Quality Control
  - Satellite data bias correction
  - Satellite data thinning
  - Other details

NSST in Hybrid EnKF GSI

- GSI consist of a static (full resolution) step and a EnKF step
- T_f analysis is done at the static step only and not included in EnKF yet
- T_f analysis increment by the static GSI is applied to ensemble members
  - No T_f spread in the ensemble
  - But there is SST spread in the ensemble due to $T_w'(x, y, 0, t)$ and $T_c'(x, y, 0, t)$
- The covariance between the ocean (T_f) and atmosphere is not addressed yet

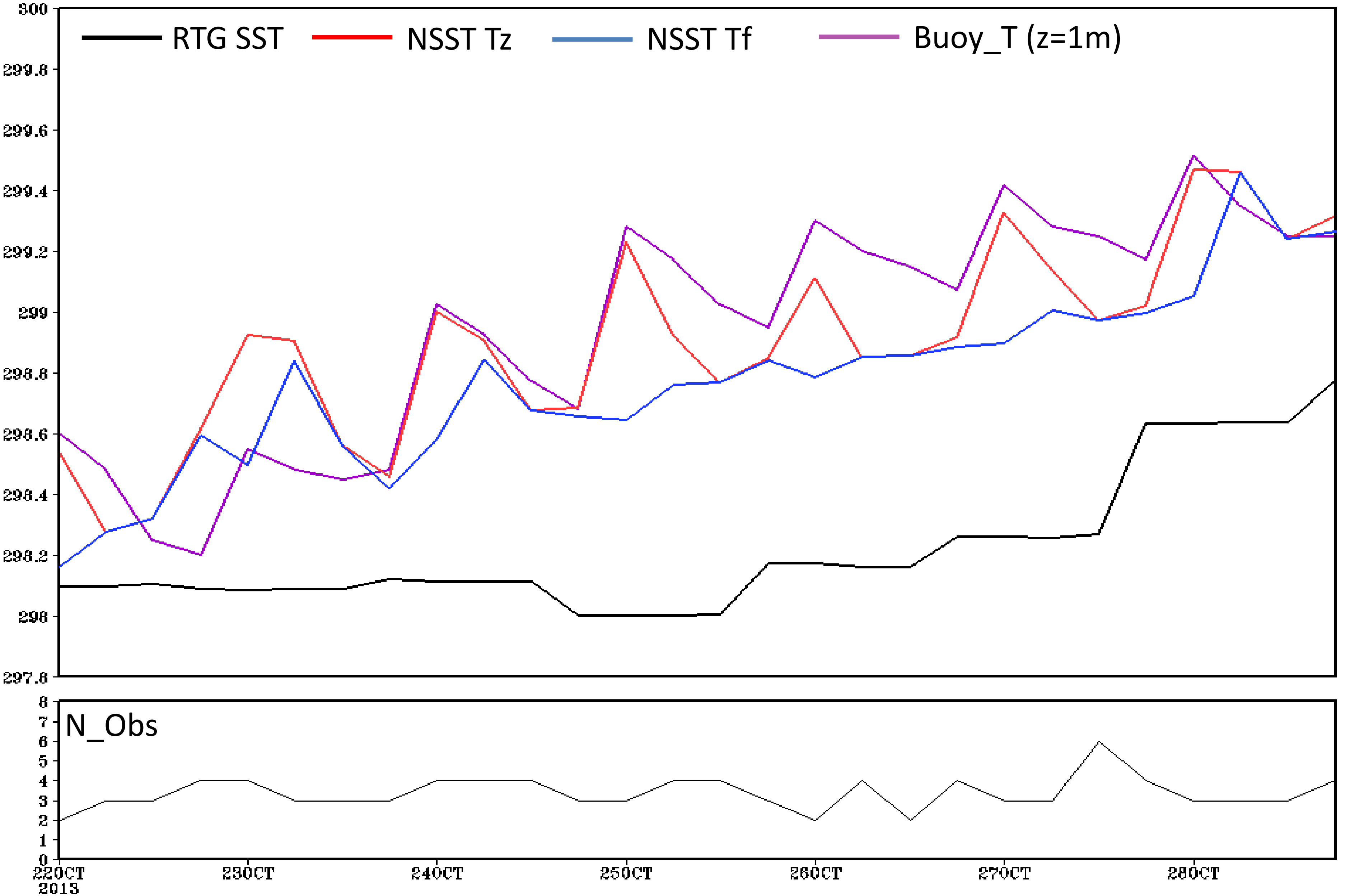
Verifications

- **Oceanic analysis and prediction**
  - Positive
- **The use of satellite data (O-B)**
  - Positive
- **Weather Prediction**
  - Neutral for NH and SH, positive for tropics, when verified against to the own analysis
  - Slightly positive when verified against the conventional observations

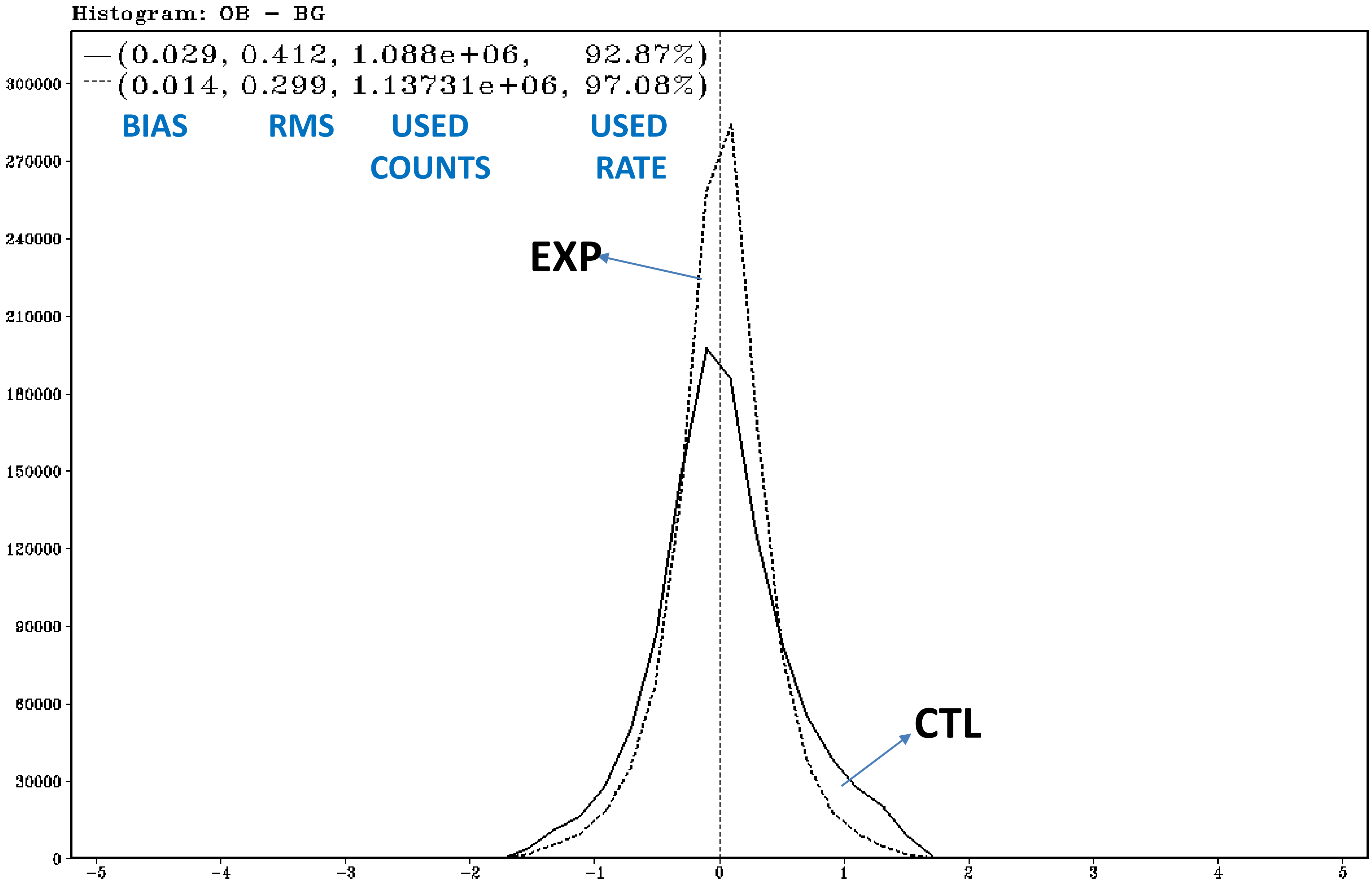


TAO/TRITON Array
30°N
20°N
10°N
0°
10°S
20°S
30°S
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
80°W
ATLAS
TRITON
Subsurface ADCP

Time series of SST/Tz/Tf **BG** and buoy observation. Area: (141 W – 139 W, 4S – 4N)



Verification of operational SST ($x^o - x^b$) and NSST SST [$x^o - N(x^b)$]
Against drifting buoy, Global. 20100701 - 20100731

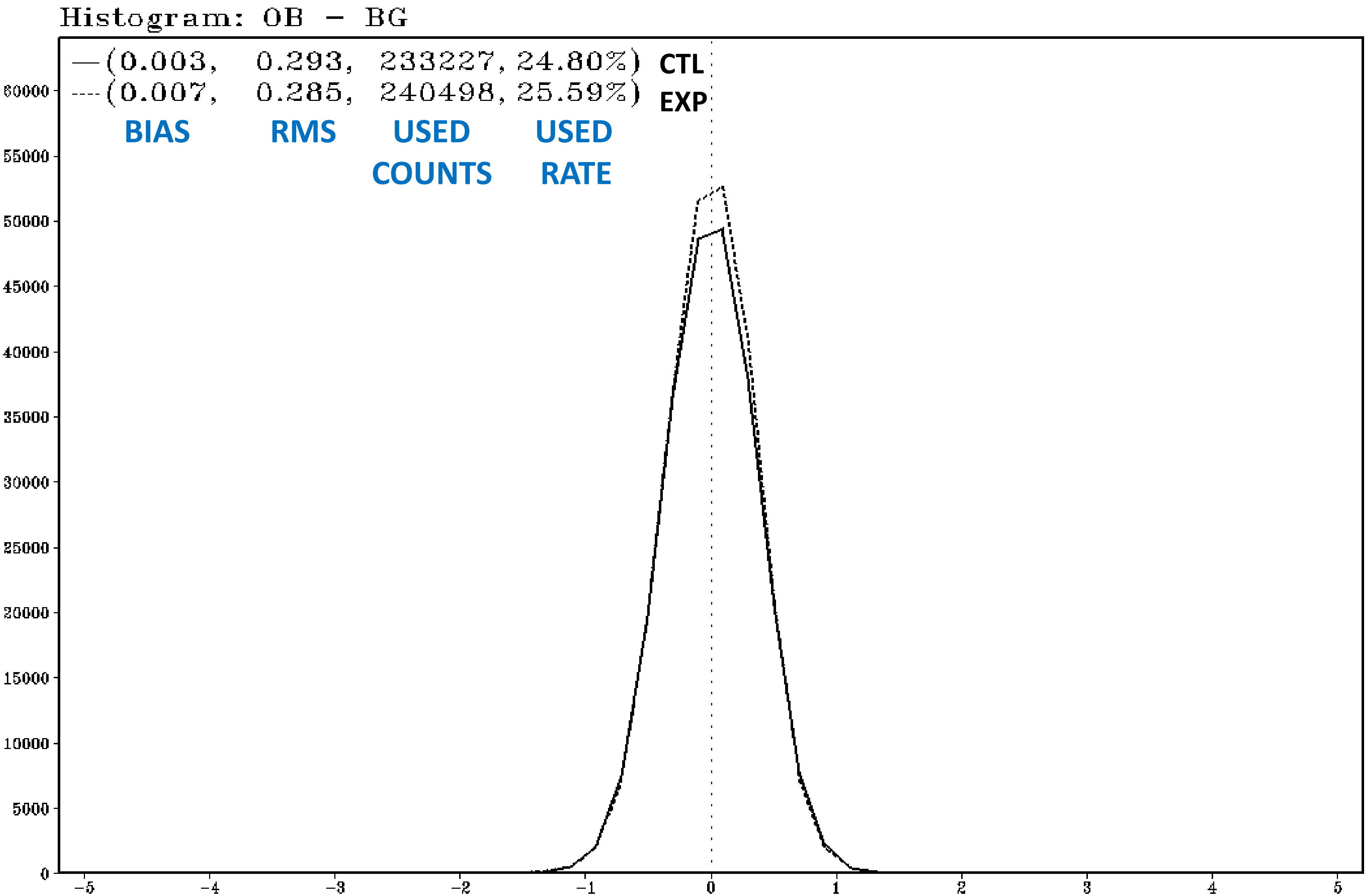


Verification of operational SST $(x^o - x^b)$ and NSST SST $[x^o - N(x^b)]$ Against drifting buoy. 20100701 - 20100731

area	e13u				e13w			
	BIAS	RMS	USED COUNTS	USED RATE	BIAS	RMS	USED COUNTS	USED RATE
Global	(0.029,	0.412,	1.088e+,	92.87%)	(0.014,	0.299,	1.13731,	4.531%)
N.Pole	(0.288,	0.583,	89783,	81.51%)	(0.026,	0.365,	106354,	18.45%)
N.Mid	(0.148,	0.476,	331300,	89.23%)	(0.018,	0.323,	357059,	7.775%)
Tropics	(−0.04,	0.295,	309696,	98.17%)	(0.016,	0.223,	311457,	0.568%)
S.Mid	(−0.09,	0.416,	289228,	94.91%)	(−0.00,	0.324,	293797,	1.579%)
S.Pole	(−0.00,	0.387,	68049,	97.37%)	(0.048,	0.318,	68693,	0.946%)
GreatLake	(−999,	−999,	0,	−999%)	(−999,	−999,	0,	−999%)
Mediterr	(0.438,	0.703,	1452,	78.99%)	(−0.12,	0.357,	1506,	3.719%)
TAO	(−0.10,	0.306,	78735,	98.43%)	(0.001,	0.230,	79000,	0.336%)
Triton	(0.111,	0.402,	3276,	82.70%)	(0.152,	0.358,	3666,	11.90%)
Pirata	(−0.00,	0.322,	74225,	98.85%)	(0.061,	0.250,	74554,	0.443%)
IndiaFbuoy	(−0.09,	0.338,	18454,	93.35%)	(−0.01,	0.195,	18648,	1.051%)
N.Mid.Atl	(0.042,	0.434,	22260,	97.61%)	(0.001,	0.243,	22720,	2.066%)
N.Mid.Pac	(0.223,	0.575,	18014,	84.46%)	(0.007,	0.375,	20897,	16.00%)
S.Mid.Ind	(−0.22,	0.435,	6559,	98.72%)	(−0.04,	0.331,	6644,	1.295%)
S.Mid.Pac	(−0.02,	0.283,	4845,	99.97%)	(0.052,	0.168,	4845,	0%)
SmlTAO	(−0.34,	0.504,	176,	97.23%)	(−0.21,	0.372,	181,	2.840%)
SmlTriton	(−0.10,	0.222,	428,	100%)	(0.103,	0.224,	428,	0%)
Sml.N.Mid.Atl	(−999,	−999,	0,	−999%)	(−999,	−999,	0,	−999%)
Sml.N.Mid.Pac	(−0.24,	0.312,	315,	100%)	(−0.03,	0.127,	315,	0%)

CTL EXP

O-B histogram for an IASI window channel, Global.
20100701 - 20100731



Conclusions

- The SST has been improved and is generated 6-hourly with the NCEP GFS
  - Well-defined analysis variable
  - Direction assimilation
- Satellite data assimilation (for surface sensitive channels) in GSI has been improved
- Weather prediction impact
  - Positive in tropics, neutral to positive for NH and SH

Discussions

- Extend the EnKF analysis variable to include T_f
  - Will start without a T_f forward model
- Fully coupled data assimilation and prediction
  - Schedule of the coupled system?
  - Gradually (weak to strong couple)
- Other applications
  - Reanalysis, Lake, Hurricane
- Better observation depth determination
  - Skin-depth
  - In situ
- Disadvantages to analysis SST in an integrated NWP system
  - Every element has to work well
  - Atmospheric analysis in priority
    - Resolution, thinning
    - The use Micro-wave instruments with good signal-noise ratio for SST analysis
- Comparison with more SST analysis products
  - Feedback and further improvement