Sea Surface Temperature analysis within the NCEP GFS

Xu Li[1], John Derber[2], Andrew Collard[1], Shrinivas Moorthi[2]

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

Acknowledgements:

Groups of DA, Model, Physics, Obsproc and others at EMC/NCEP

Wanqiu Wang at CPC/NCEP

19th GHRSST Science Team Meeting, Darmstadt, Germany, June 05, 2018

Outline

- Introduction
  - SST and NWP
- SST analysis within the NCEP GFS
  - Why and how?
- Verifications
- Conclusions and discussions

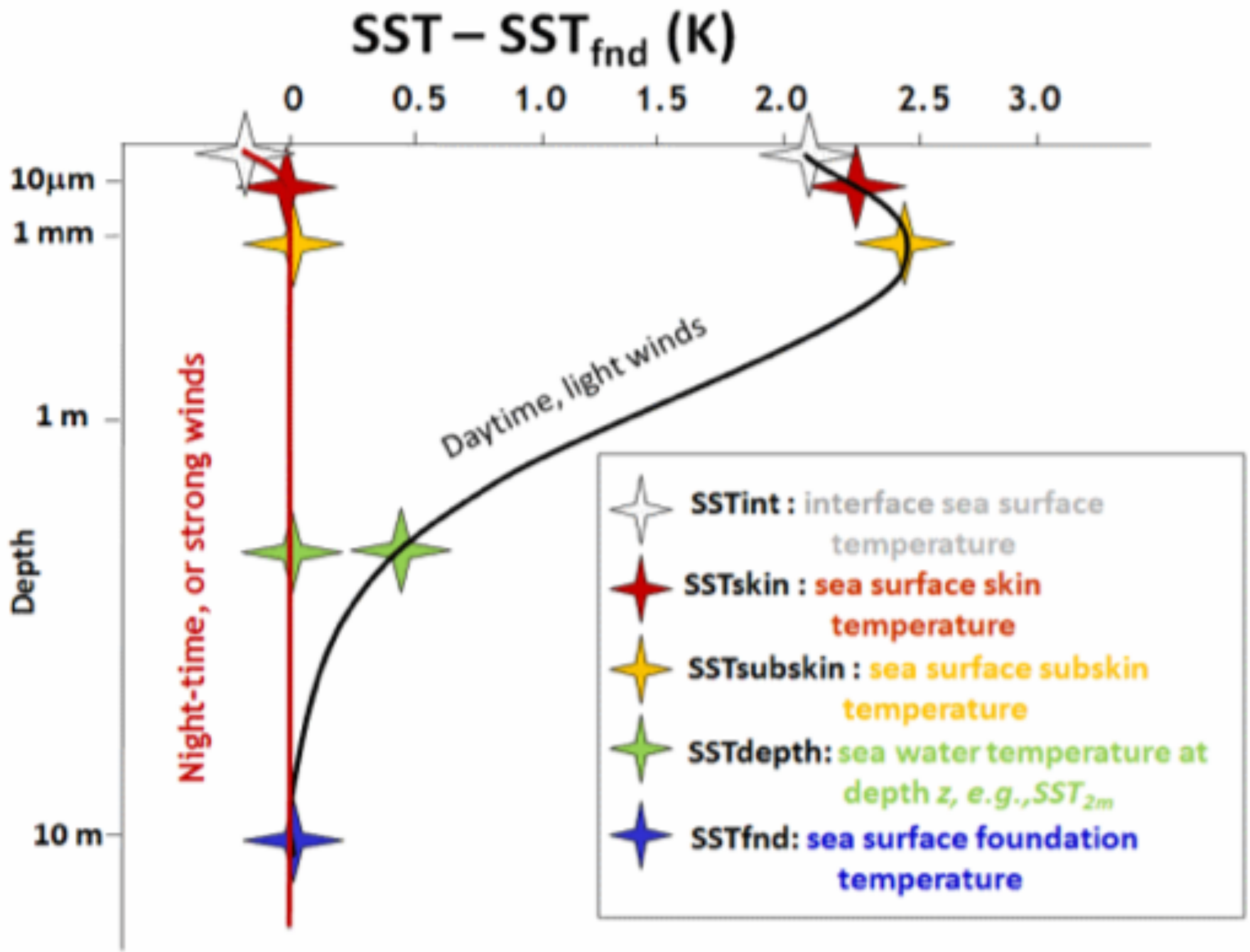
Introduction

- Sea Surface Temperature (SST) is required in a Numerical Weather Prediction (NWP) system as the lower thermal boundary condition of
  - A radiative transfer model (CRTM or RTTOV) at analysis step
  - Air-sea heat fluxes calculation at forecast step
- SST analysis has been produced independently and then provided to NWP system as an input
- In July 2017, **real-time 6-hourly** SST analysis became **operational** in the NCEP Global Forecasting System (GFS)
  - Analysis variable: foundation temperature
  - Analysis scheme: 3-DVAR
  - The analysis increment is generated at T574 (~50 km) , and then interpolated to T1534 (~13 km) horizontal resolution

How to improve SST for NWP
-- The original ideas then

- After the development a physical SST retrieval and application to the operational high resolution RTG SST analysis in 2005, how to further improve the SST analysis for NCEP GFS?
  - **SST is analyzed by assimilating the satellite radiances directly**
  - **The further work can not be done with the available RTG SST analysis scheme**
  - **How to incorporate the SST diurnal variability in GFS?**
  - **What is the analysis variable?**
    - Well-defined physically and mathematically
    - GHRSST SST definitions helped on this

SST definition (GHRSST)



Obs. Depth

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).

Two issues from GHRSST SST definitions

- How to merge the indirect observations from a various platforms?
  - Radiance instead of temperature
  - Different observation depths
- Which SST is provided to NWP?
  - At prediction step, **air-sea heat fluxes calculation**
    - $T(z=0)$ is used in heat fluxes calculation (currently)
    - But the following seems more reasonable (future)
      - Radiation (wavelength related skin depth): $T(z=z_{ch})$
      - Sensible heat : $T(z=0)$
      - Latent heat: $T(z=0)$?
  - At analysis step, **radiance simulation**
    - $SSTint, SSTskin, SSTsubskin\ or\ SSTdepth\ or\ all?$

Approach adopted to improve SST at NCEP

- **SST is analyzed within the NCEP GFS,** taking advantages of an advanced atmospheric data assimilation system like GSI
  - Assimilation techniques
  - Direct assimilation
    - The capability to merge indirect observations **(Issue 1 resolved automatically)**
      - **Extract the signal from the indirect observations more effectively**
  - Satellite data bias correction
  - Satellite data quality control
  - Easy to add a new satellite
- **SSTs are extended to a T-Profile, and which needs to be available**
  - Can the T-Profile be known?
    - Yes, but simplified
      - only the vertical thermal structure due to diurnal warming and sub-layer cooling
  - The sea temperature at any depth can be provided
    - Issue 2 resolved (which SST provided)

Direct assimilation

- All the observations can be used, with or without the diurnal warming signal.
  - **Question 1 resolved** (incorporate diurnal variability in NWP)
- In order to assimilate all the observations directly
  - A forward model is required to simulate the measurement accurately with the analysis variables
    - NSST T-Profile simulation
      - A sub-layer cooling model (Fairall, 1996, adopted)
      - A diurnal warming model (Xu Li, developed)
    - Radiance simulation with *atmospheric profiles* and *surface temperature* (available with CRTM)
  - The Jacobian of the forward model
    - The sensitivity of the temperature at depth z to, $\boldsymbol{T_f}$, $\frac{\partial T_z}{\partial T_f}$, derived
    - The sensitivity of the radiance to the temperature at skin-depth $\boldsymbol{z_{ch}}$, $\frac{\partial R}{\partial T_{z_{ch}}}$, available with CRTM
    - The sensitivity of the radiance to $\boldsymbol{T_f}$, $\frac{\partial R}{\partial T_f} = \frac{\partial R}{\partial T_{z_{ch}}} \frac{\partial T_{z_{ch}}}{\partial T_f}$

NSST definition and analysis variable

- Near-Surface Sea Temperature (**NSST**) is **a temperature profile** with the vertical thermal structure due to the diurnal warming and sub-layer cooling physics
  - T-Profile: $T(z) = T_f(z_w) + T_w'(z) - T_c'(z)$
  - Linear T-Profile: $T(z) = T_f(z_w) + (1 - z/z_w)T_w'(0) - (1 - z/\delta_c)T_c'(0)$

    T_f : foundation temperature

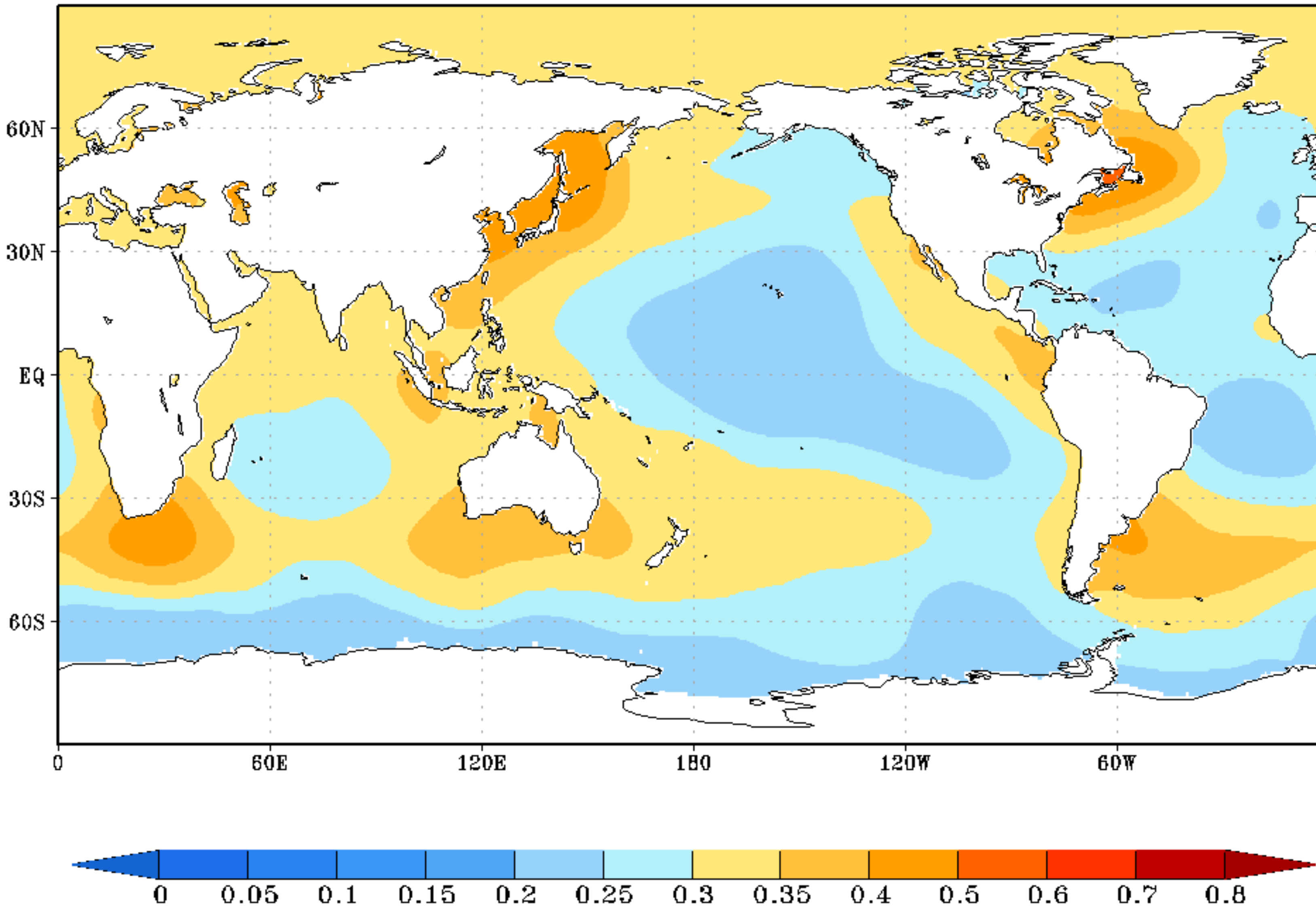
    T_w' : diurnal warming profile

    T_c' : sub-layer cooling profile

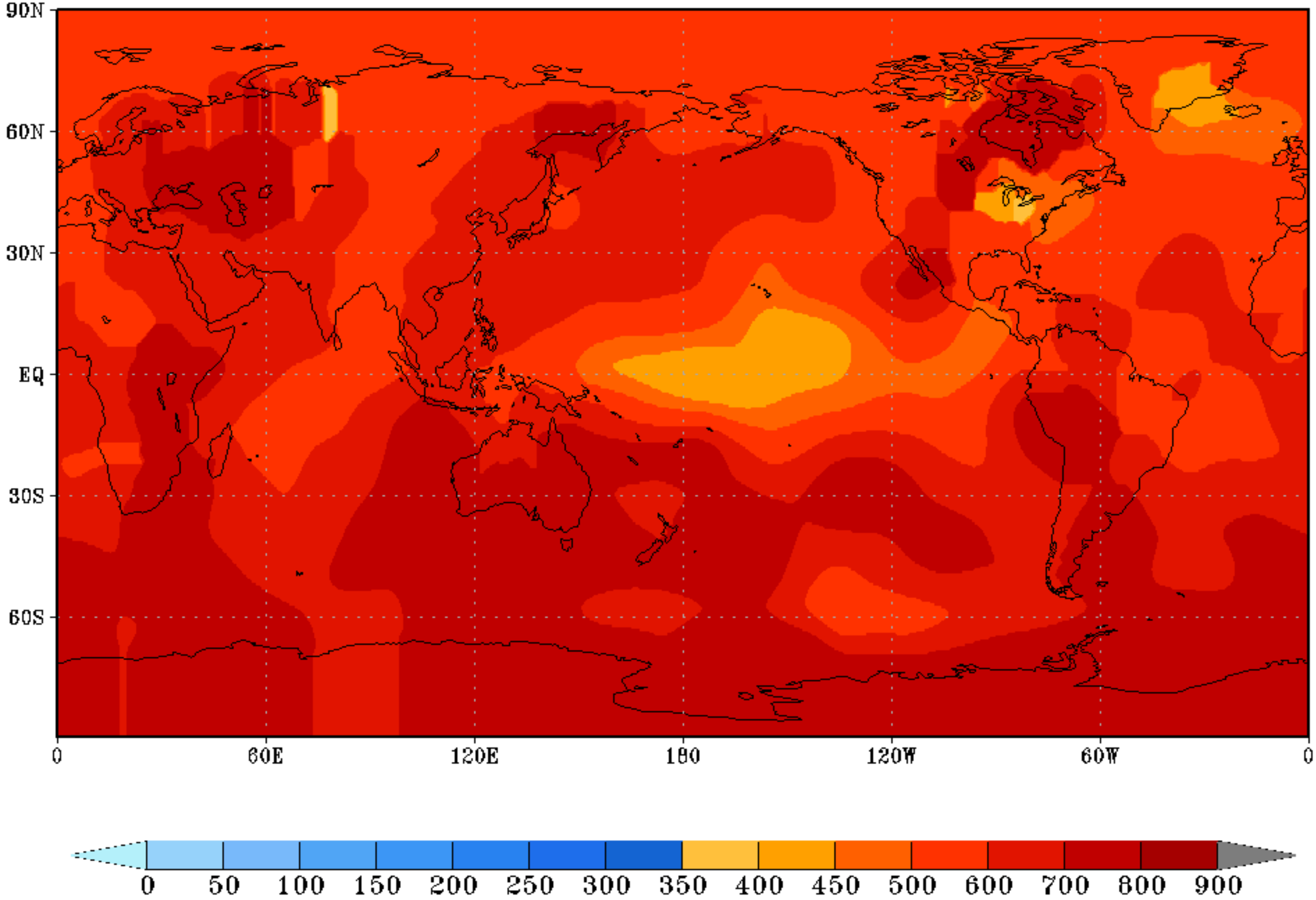
    z_w : diurnal warming layer thickness

    δ_c : sub-layer cooling layer thickness
- Foundation temperature (**T_f**) **is the analysis variable** (**question 2 resolved**)
- Diurnal warming and sub-layer cooling T-Profile are **simulated** by NSST Model in the cycling of GFS
- NSST T-Profile: $T(z) = T_f^{an}(z_w) + T_w'^{bg}(z) - T_c'^{bg}(z)$

Background error variance used in NSST (borrowed from RTG)



Background error correlation length used in NSST
(borrowed from RTG) **at first,** and then **changed to 50 km.**



Depth and observation errors used in NSST

Satellite radiances

Satellite instrument	Skin-depth	Obs. error
AVHRR	0.015 mm	0.65
CRIS	0.015 mm	0.80
AIRS	0.015 mm	0.80
IASI	0.015 mm	2.30
AMSUA	1.0 mm	2.20
ATMS	1.0 mm	5.0
AMSR2, GMI	30 mm	0.70

In Situ sea water temperature

Platform	depth	Obs. error
Fixed buoy (TAO ...)	1.0 m	0.5 K
Triton	1.5 m	0.4 K
Drifting buoy	0.2 m	0.6 K
COMPS moored buoy	1.2 m	0.5 K
SCRIPPS moored buoy	0.45 m	1.5 K
Moored buoy with 3-m discus	0.6 m	1.5 K
Coast moored buoys	1.0 m	2.0 K
Other moored buoy	1.0 m	1.0 K
BATHY (XBT)	1.0 to 5.0 m	0.5 K
TESAC (ARGO)	1.0 to 5.0 m	2.5 K
Ships (Bucket)	1.0 m	2.0 K
Ships (known types)	1.0 to 30.0 m	2.5 K
Ships (unknown types)	2.0 to 3.0 m	3.0 K

Verifications (data preparation)

- 4 T_f/SST analysis for the verifications here
  - **NSST $\boldsymbol{T_f}$**, T1534 (3072 x 1536) Gaussian grids, 6-hourly
  - **OSTIA $\boldsymbol{T_f}$** 1/20 degree (7200 x 3600), daily
  - **RTG *SST***, 1/12 degree (4320, 2160), daily
  - **NCDC *SST***, 1/4 degree (1440,720), daily
- OSTIA T_f, RTG and NCDC SST are prepared to the NSST T_f resolution 6-hourly
- T_f/SST are interpolated to the location (x, y, z) and time (t) of the observations
- The same quality control is applied to **OSTIA $\boldsymbol{T_f}$, RTG and NCDC SST**
  - QC here is done based on $(O - B)$ and is observation error dependent

SST verifications

- Difference map (preliminary)
- Against in situ observations
  - Time series of analysis and observation for a fixed buoy station
  - $(O - B)$ & $(O - A)$ **statistics**
    - RMS, BIAS, Counts of the used data in analysis
- Against satellite observations
  - $(O - B)$ & $(O - A)$ **statistics**
    - RMS, BIAS, Counts of the used data in analysis
- Known features
  - Gulf stream
  - Tropical Instability Wave (TIW)

$\boldsymbol{O-B}$ & $\boldsymbol{O-A}$ statistics

- In situ observations:
  - $\boldsymbol{O-B}$: $T^{ob}(z_{ob}) - \{T_f^{bg}(z_w) + [T_w'^{bg}(z_{ob}) - T_c'^{bg}(z_{ob})]\}$
  - $\boldsymbol{O-A}$: $T^{ob}(z_{ob}) - \{T_f^{an}(z_w) + [T_w'^{bg}(z_{ob}) - T_c'^{bg}(z_{ob})]\}$
- Satellite observations
  - $\boldsymbol{O-B}$: $R^{ob}(z_{ch}) - R^{bg}\{T_f^{bg}(z_w) + [T_w'^{bg}(z_{ch}) - T_c'^{bg}(z_{ch})]\}$
  - $\boldsymbol{O-A}$: $R^{ob}(z_{ch}) - R^{an}\{T_f^{an}(z_w) + [T_w'^{bg}(z_{ch}) - T_c'^{bg}(z_{ch})]\}$

Here,

T : sea water temperature

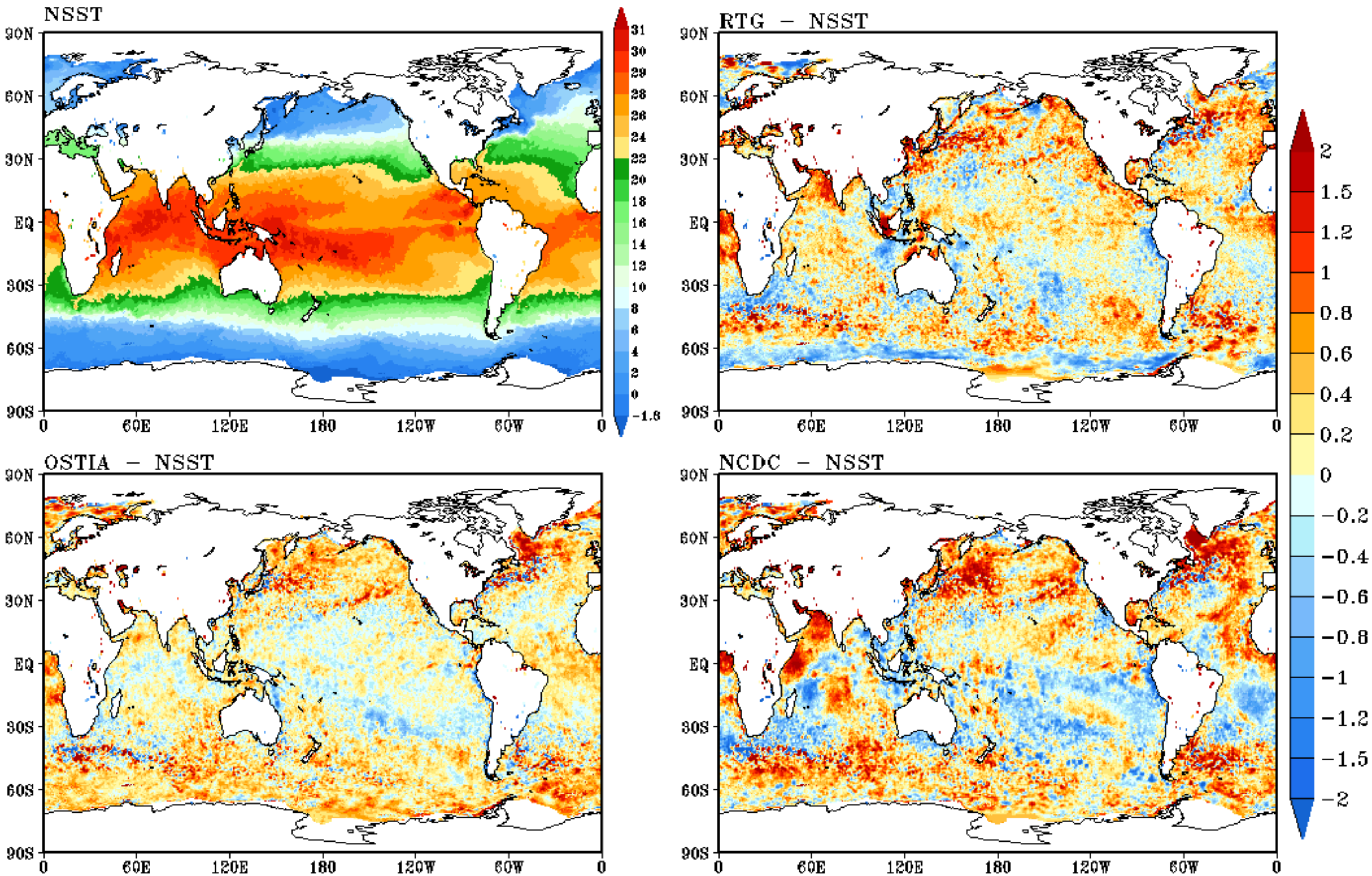
R: Radiance

z_{ob}: observation depth

z_{ch}: skin-depth for channel *ch*

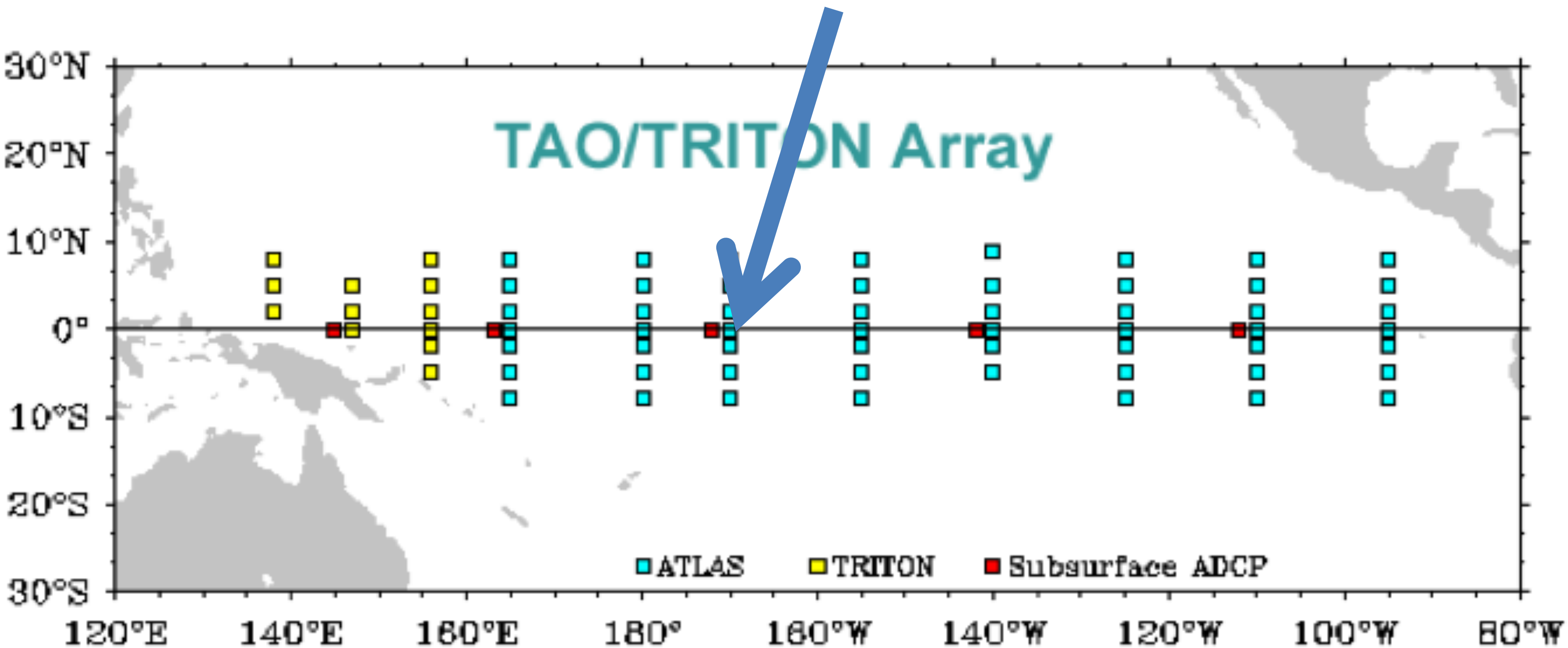
z_w: diurnal warming layer thickness

Comparison of 4 T_f/SST analysis. 00Z, April 1, 2017.



Verification of the analyzed T_f/SST, T_{1m} at a fixed buoy location

A fixed buoy (z=1m) at (EQ, 170W)

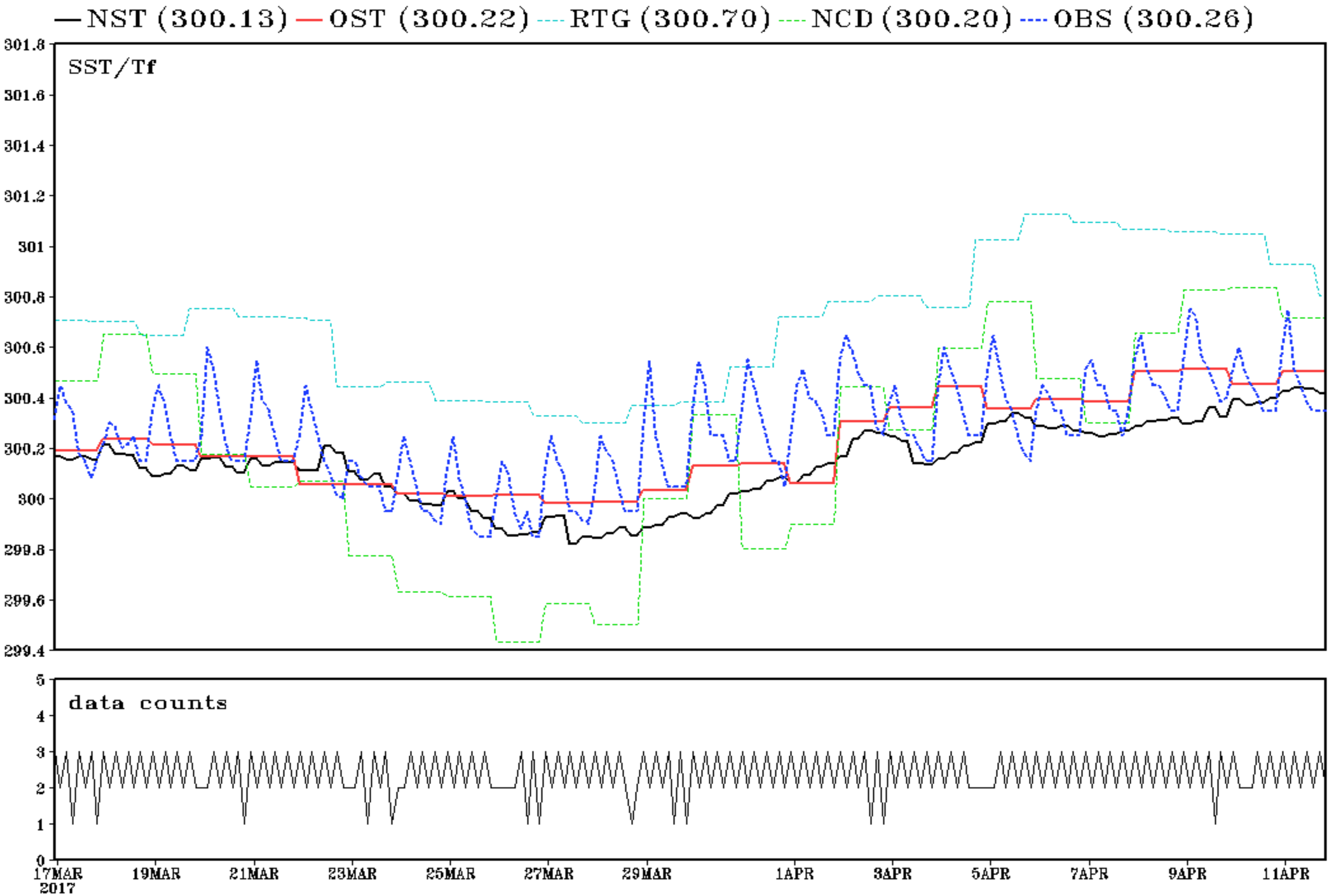


$$T'_c(z = 1m) = 0$$

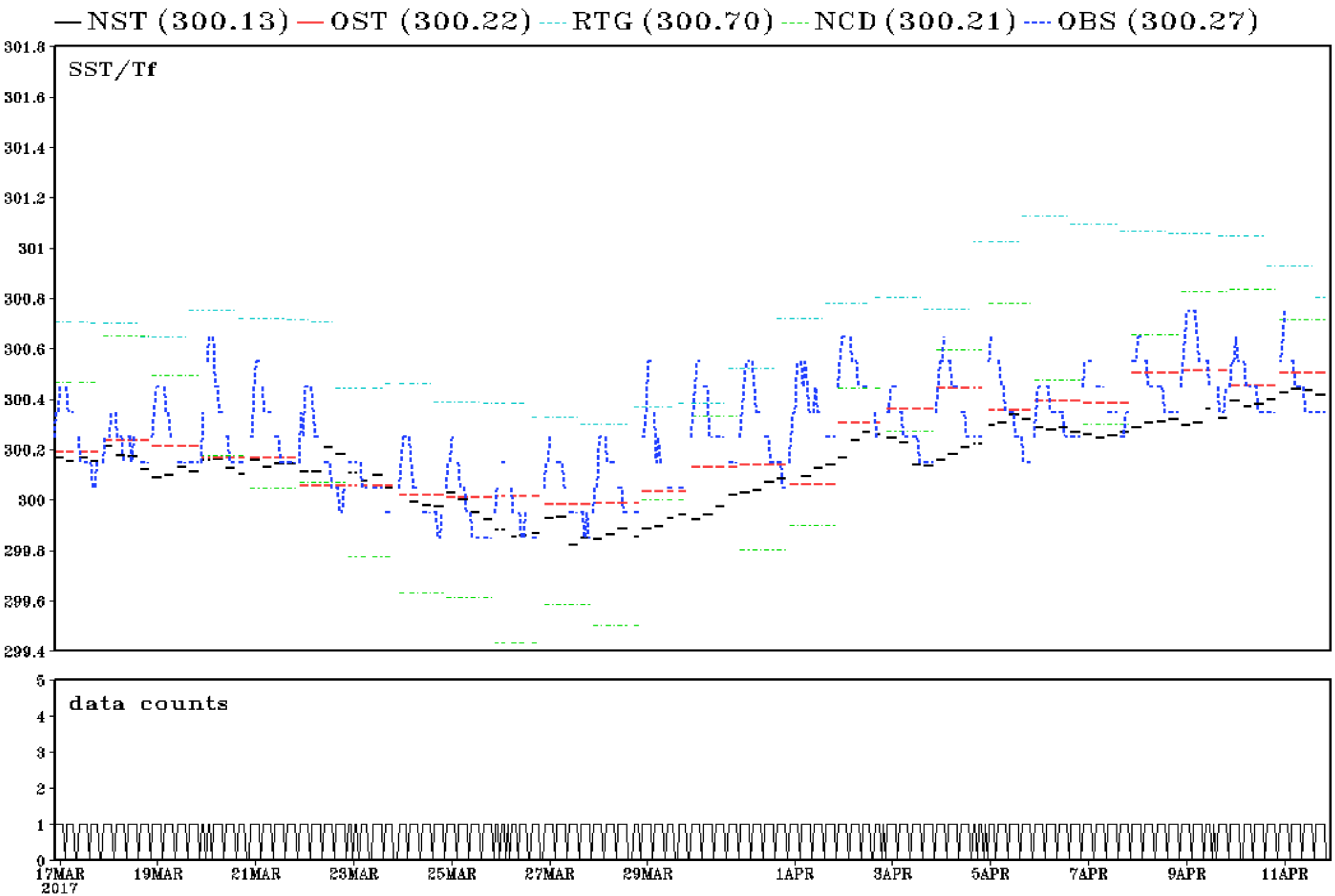
$$T_{1m}^{an} = T_f^{an} + T_w^{\prime bg}(z = 1m)$$ For NSST and OSTIA

$$T_{1m}^{an} = SST^{an} + T_w^{\prime bg}(z = 1m)$$ For RTG and NCDC (the warming is counted twice)

Time series of 4 T_f^{an} or SST^{an} and T_{1m}^{ob} at a fixed buoy station. 20170317 – 20170411, 3-hourly.



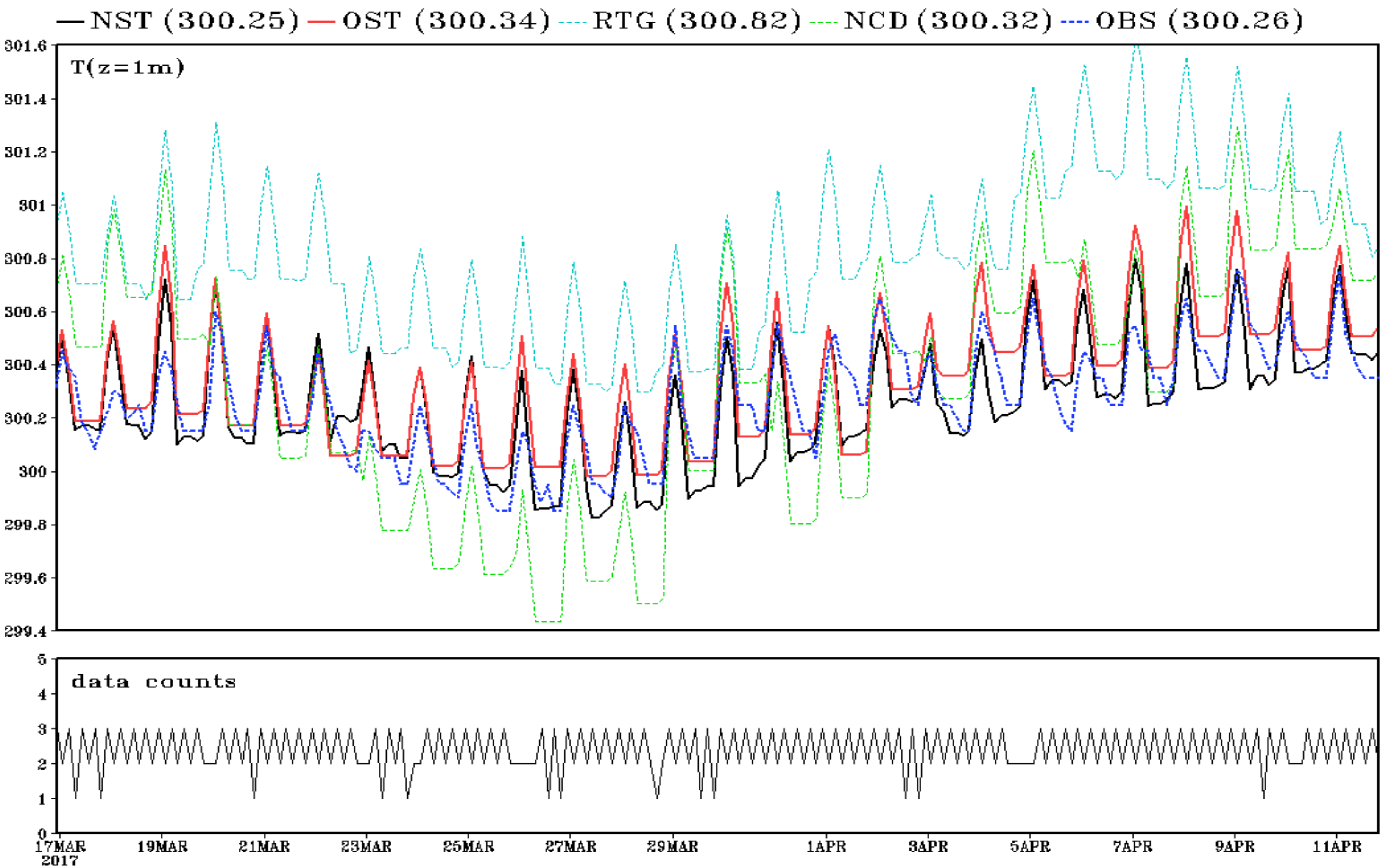
Time series of 4 T_f^{an} or SST^{an} and T_{1m}^{ob} at a fixed buoy station. 20170317 – 20170411, 1-hourly.



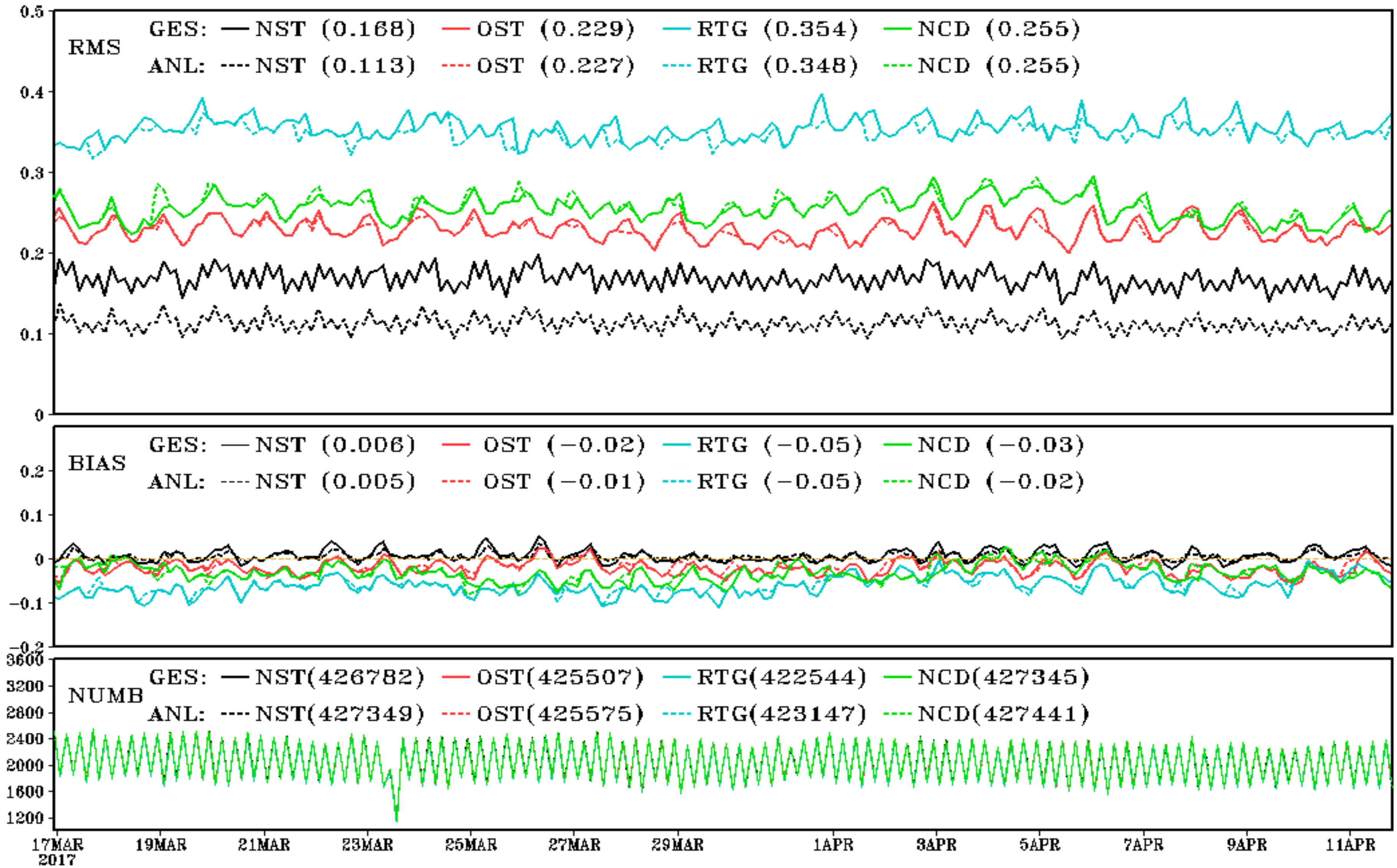
Time series of 4 T_{1m}^{an} and the T_{1m}^{ob} at a fbuoy station. 20170317 – 20170411, 3-hourly.

$T_{1m}^{an} = T_f^{an} + T_w'^{bg}(z = 1m)$ for NSST and OSTIA

$T_{1m}^{an} = SST^{an} + T_w'^{bg}(z = 1m)$ for RTG & NCDC



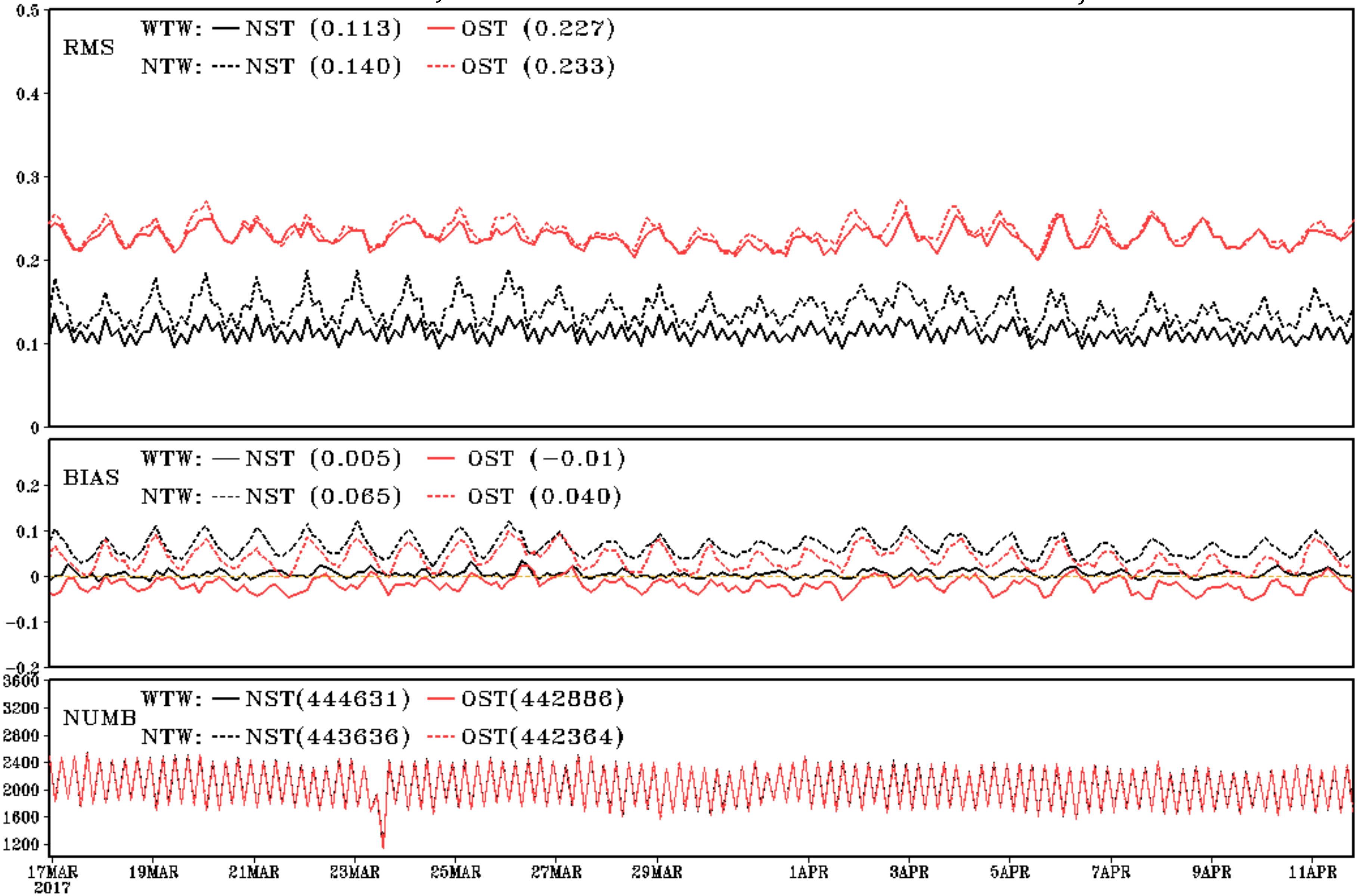
Time series of **RMS, BIAS and NUMB** (used data counts) for **4** $\boldsymbol{SST/T_f}$ background (GES, solid) & analysis (ANL, dashed) against **drifting buoys**. Global, 20170317 ~ 20170411, 3-hourly.



$(O-B) = T_{zob}^{ob} - [T_f^{bg} + T_w'^{bg}(zob)]$ $\quad$ $(O-A) = T_{zob}^{ob} - [T_f^{an} + T_w'^{bg}(zob)]$

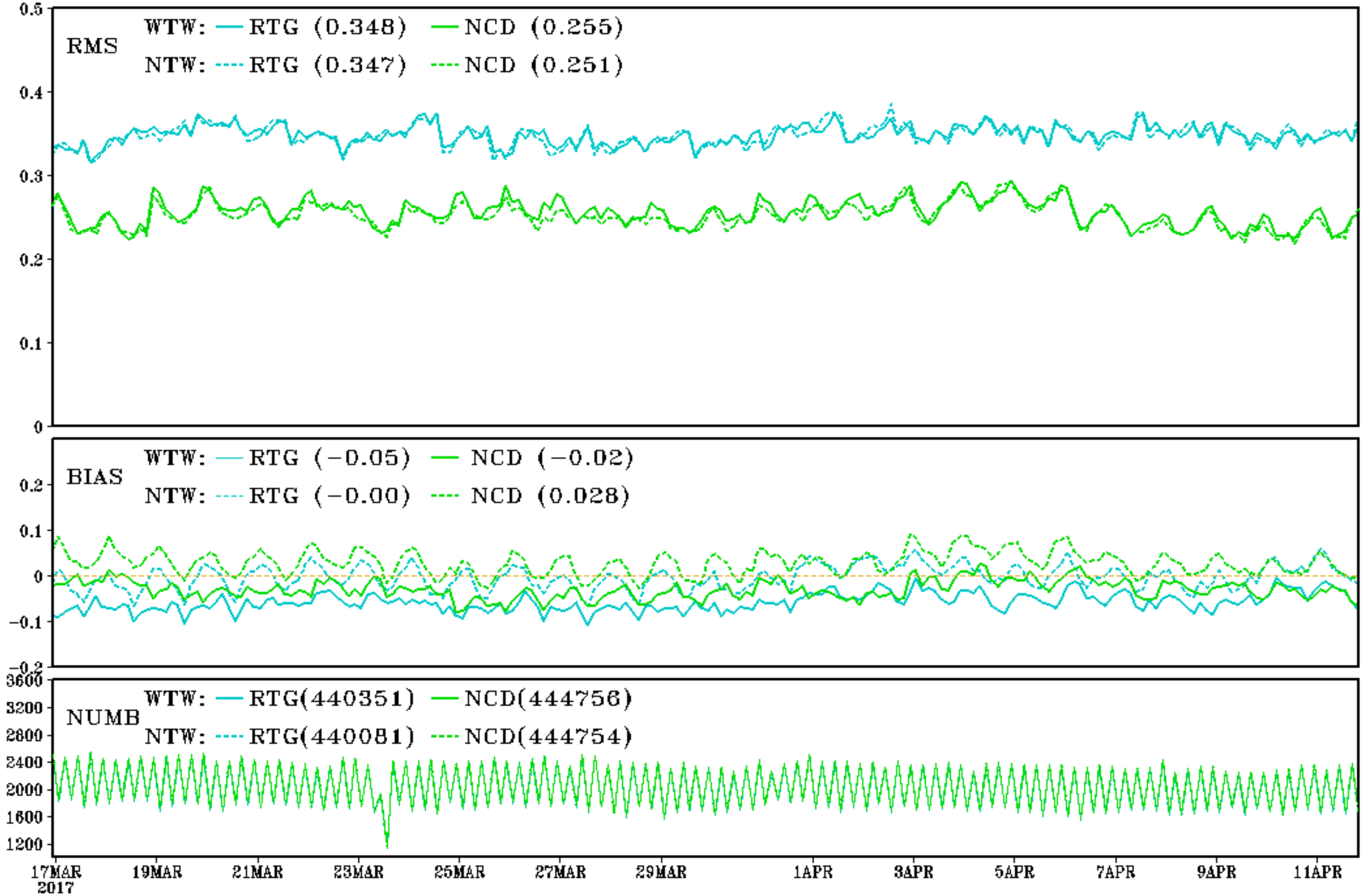
Time series of RMS, BIAS and NUMB for **NSST** and **OSTIA** $\boldsymbol{T_f}$ analysis against the drifting buoys. Global, 20170317 ~ 20170411, 3-hourly.

WTW: $(O-A) = T_{zob}^{ob} - [T_f^{an} + T_w'^{bg}(zob)]$ **NTW**: $(O-A) = T_{zob}^{ob} - T_f^{an}$



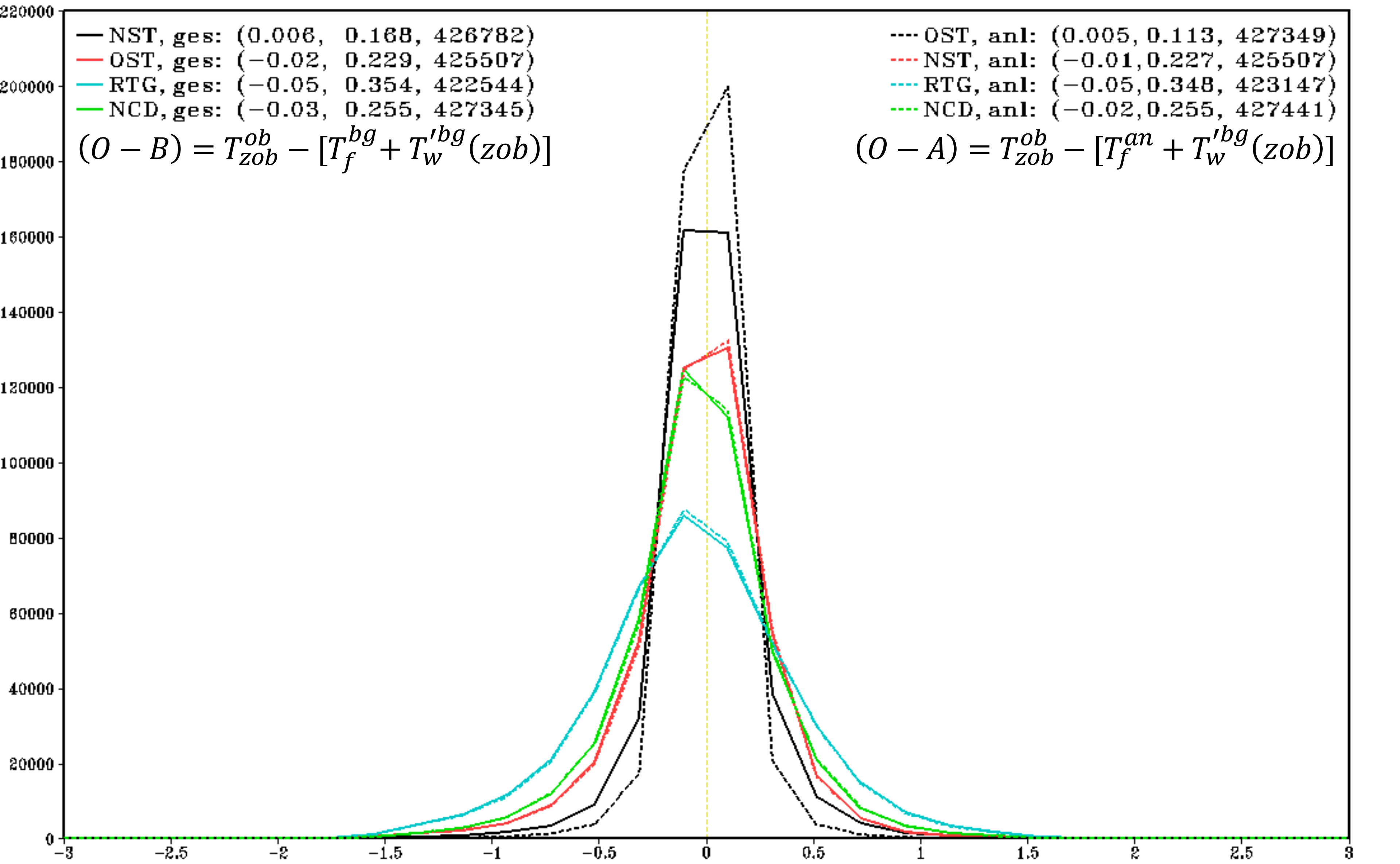
Time series of RMS, BIAS and NUMB for RTG and NCDC ***SST*** analysis against the drifting buoys. Global, 20170317 ~ 20170411, 3-hourly.

WTW: $(O - A) = T_{zob}^{ob} - [SST^{an} + T_w^{\prime bg}(zob)]$ **NTW**: $(O - A) = T_{zob}^{ob} - SST^{an}$



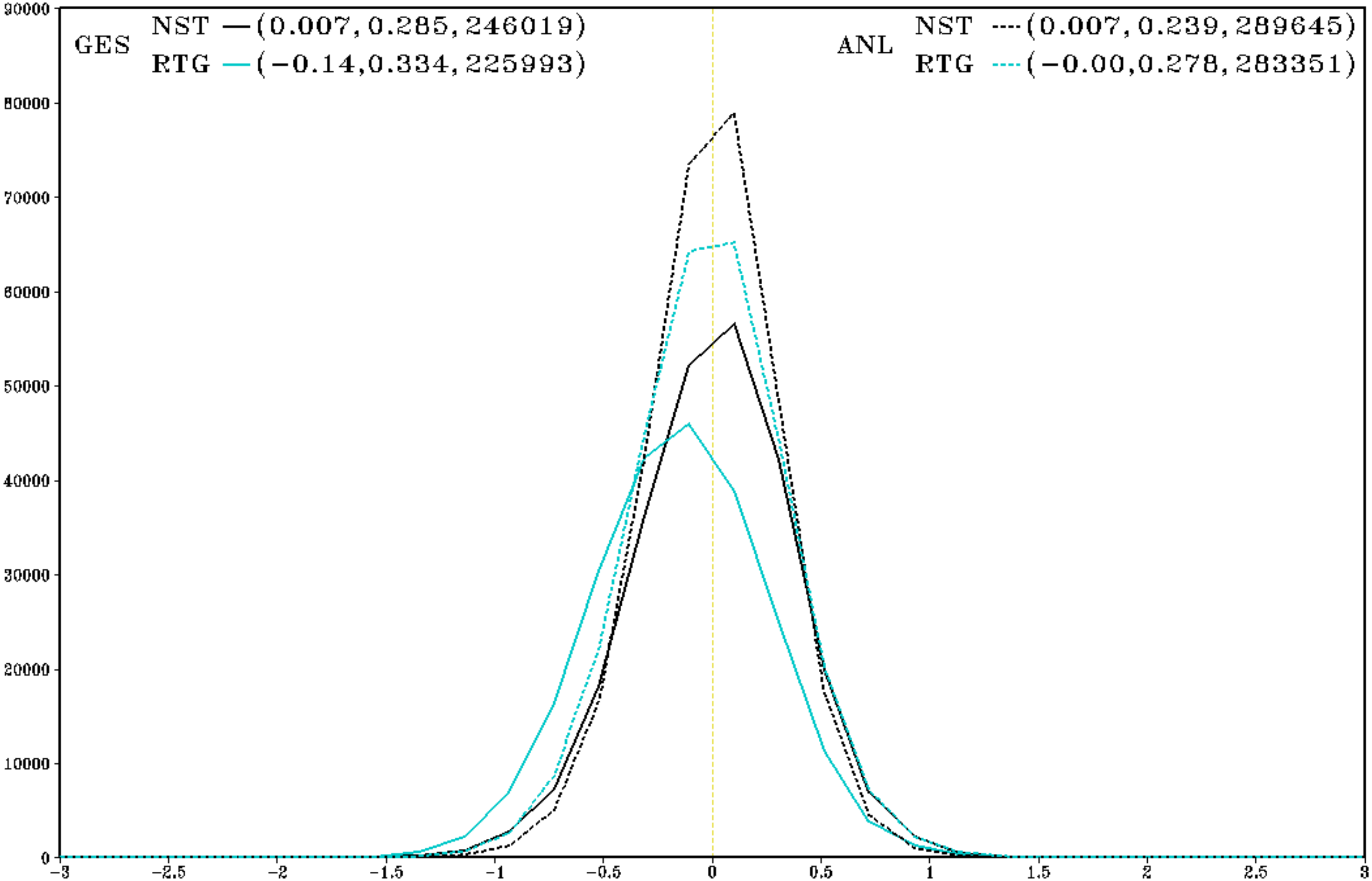
(O-B) & (O-A) histogram against the drifting buoys (Used)

NSST vs OSTIA vs RTG vs NCDC. 20170317 – 20170411. (BIAS, RMS, NUMB)



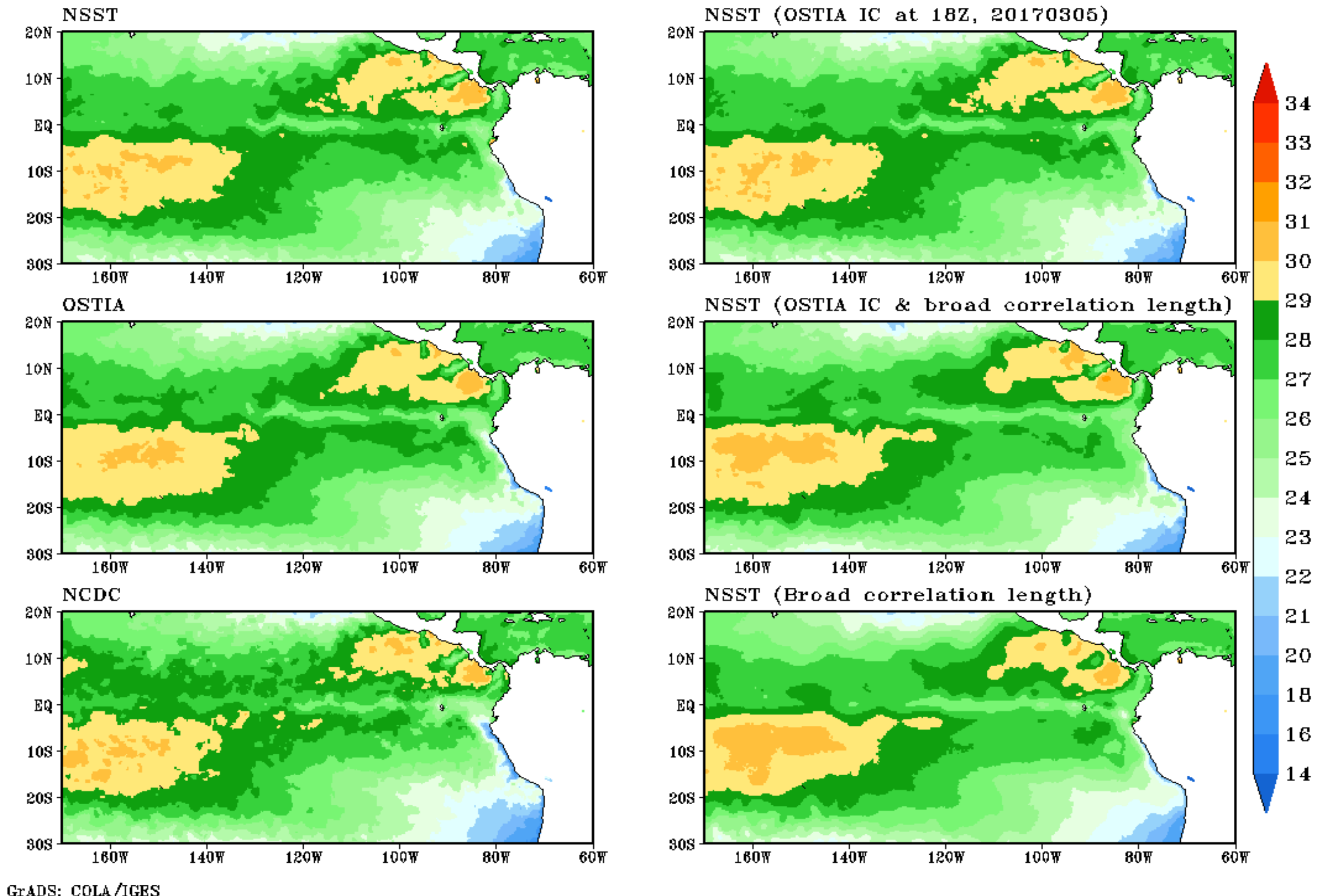
(O-B) & (O-A) histogram for satellite radiance assimilation: An iasi IR window channel

NSST vs RTG. 20170317 – 20170411. (BIAS, RMS, NUMB) for used data.



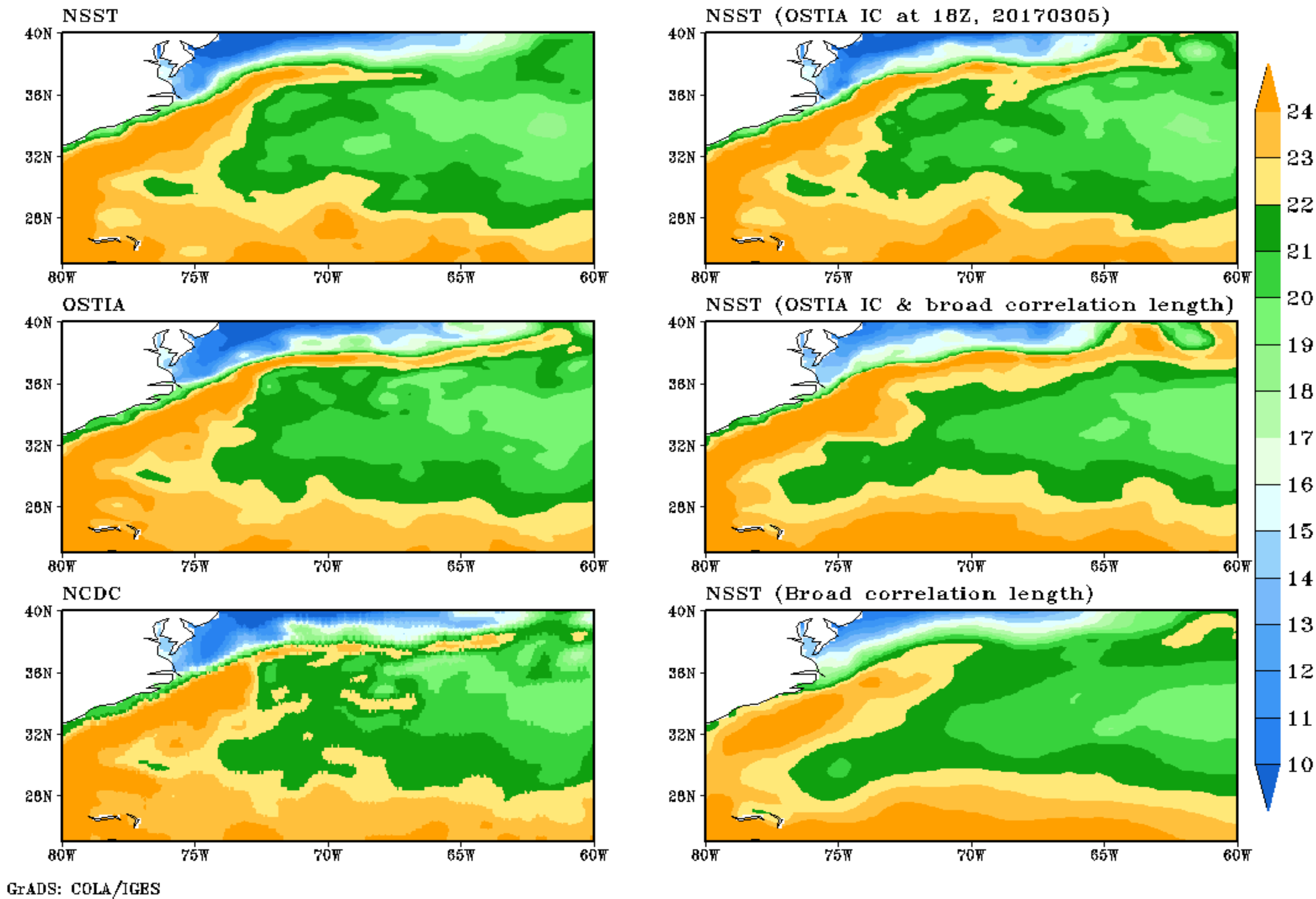
Comparison of 3 T_f/SST (NSST, OSTIA and NCDC) analysis, 18Z, 04/17/2017. TIW.

Three NSST experiments on the initial condition and Correlation length are shown as well



Comparison of 3 T_f/SST (NSST, OSTIA and NCDC) analysis, 18Z, 04/17/2017. Gulf stream.

Three NSST experiments on the initial condition and Correlation length are shown as well



Conclusions

- Background error correlation length is critical
- 6-hourly SST has been analyzed in real-time within the NCEP GFS and the verification has shown it is superior to other SST analysis products.
- A T-Profile is available to support the applications in NWP
- The satellite data assimilation has been improved for the surface sensitive channels over water area due to the improved SST
- The impact on weather prediction is positive in tropics, neutral in higher latitude areas.
  - With too broad background error correlation length
- The impact on weather prediction with 50 km length?

Discussions

- More comparisons with other SST analysis
- Background error variance and correlation length
- Observation depth determination
- Use of more observations
- NSST model improvement
- Diurnal warming analysis
- Coupled data assimilation