Near Surface Sea Temperature (NSST) in NCEP FV3GFS

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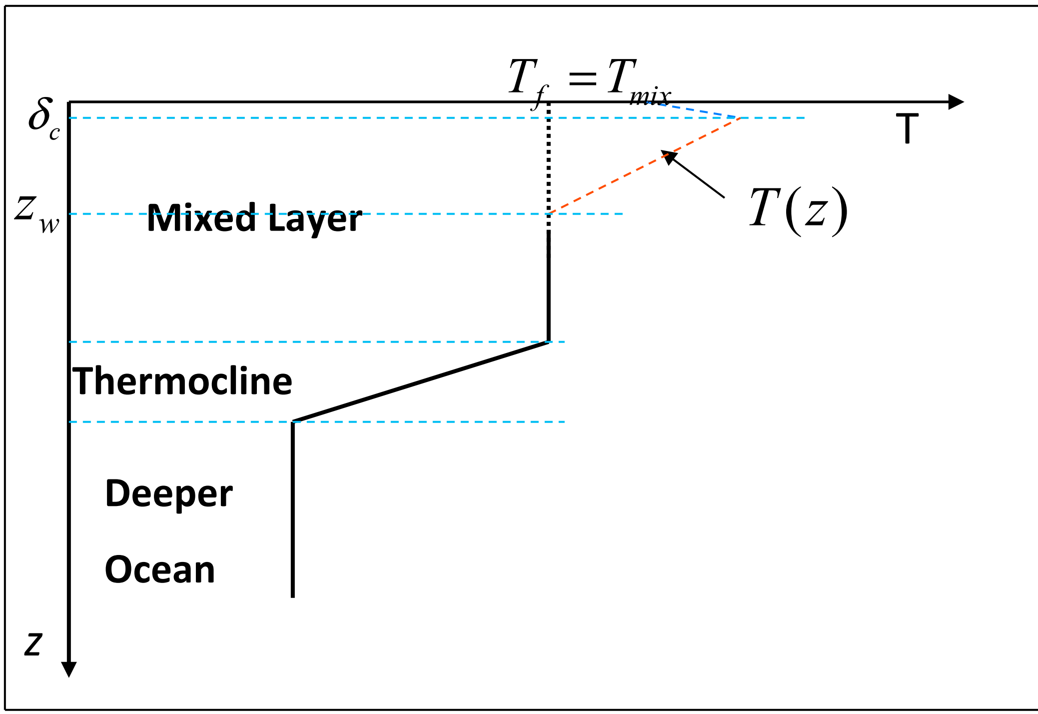
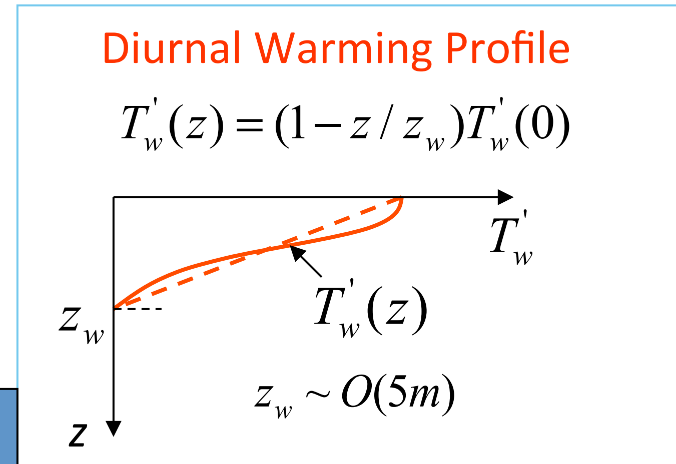
Outline

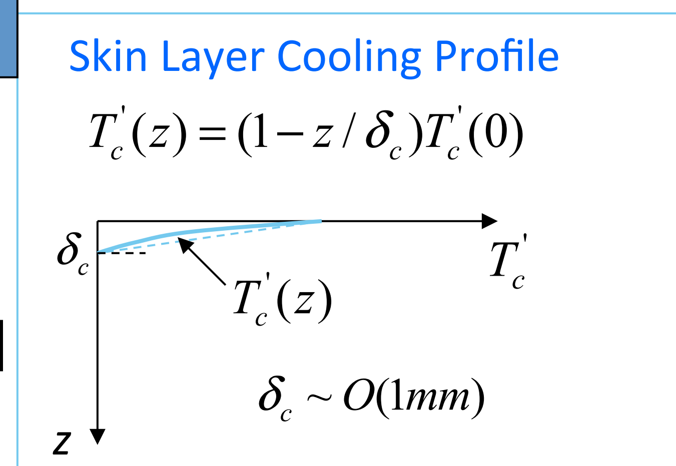
- The meaning of NSST
- Introduction
  - SST and NWP
- A brief review of SST analysis
- SST analysis within the NCEP GFS
  - Why & How?
- Verifications
- Summary

What is NSST: A T-Profile

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







$$T(z,t) = T_f(z_w, t) + T_w^{'}(z,t) - T_c^{'}(z,t) \quad z \in [0, z_w]$$

Linear T-Profile currently

NSST in NCEP FV3GFS

- NSST means two new features in the GFS
  - At the forecasting step, the high frequency variability, due to diurnal warming and sub-layer cooling, of SST is resolved
  - At the analysis step, SST is analyzed together with the atmospheric analysis variables with GSI (Grid Statistical Interpolation), the atmospheric data assimilation system of the NCEP GFS

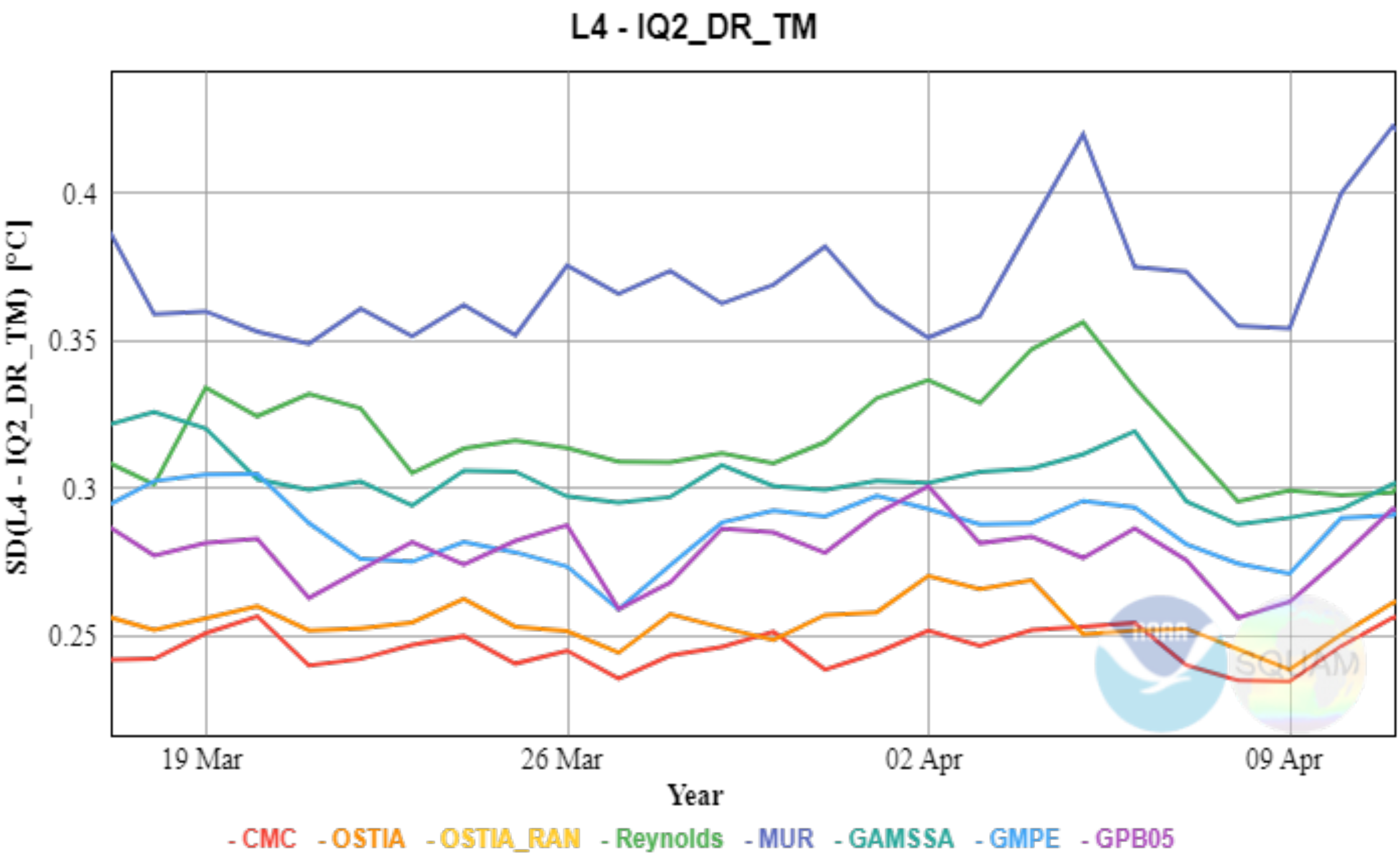
Introduction

- 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 (static part of 4DEnVar)
  - The analysis increment is generated at T574 (~50 km) , and then interpolated to T1534 (~13 km) horizontal resolution
- The same scheme is applied in NCEP FV3GFS

A brief review of SST analysis

- NMC SST analysis
  - Reynolds SST analysis
    - Used to be the most popular one
- GHRSST
  - An international activity (2000 to present)
    - Initially, The Global Ocean Data Assimilation Experiment (GODAE) High Resolution SST Pilot Project (GHRSST-PP)
    - Then, Group for High Resolution Sea Surface Temperature
  - All aspects of SST
    - L1 to L4 products
  - SST analysis
    - Uni-variate scheme
    - OSTIA, CMC, MUR and more
- Most of the NWP centers uses their own SST analysis
  - ECMWF uses OSTIA (by Met Office)

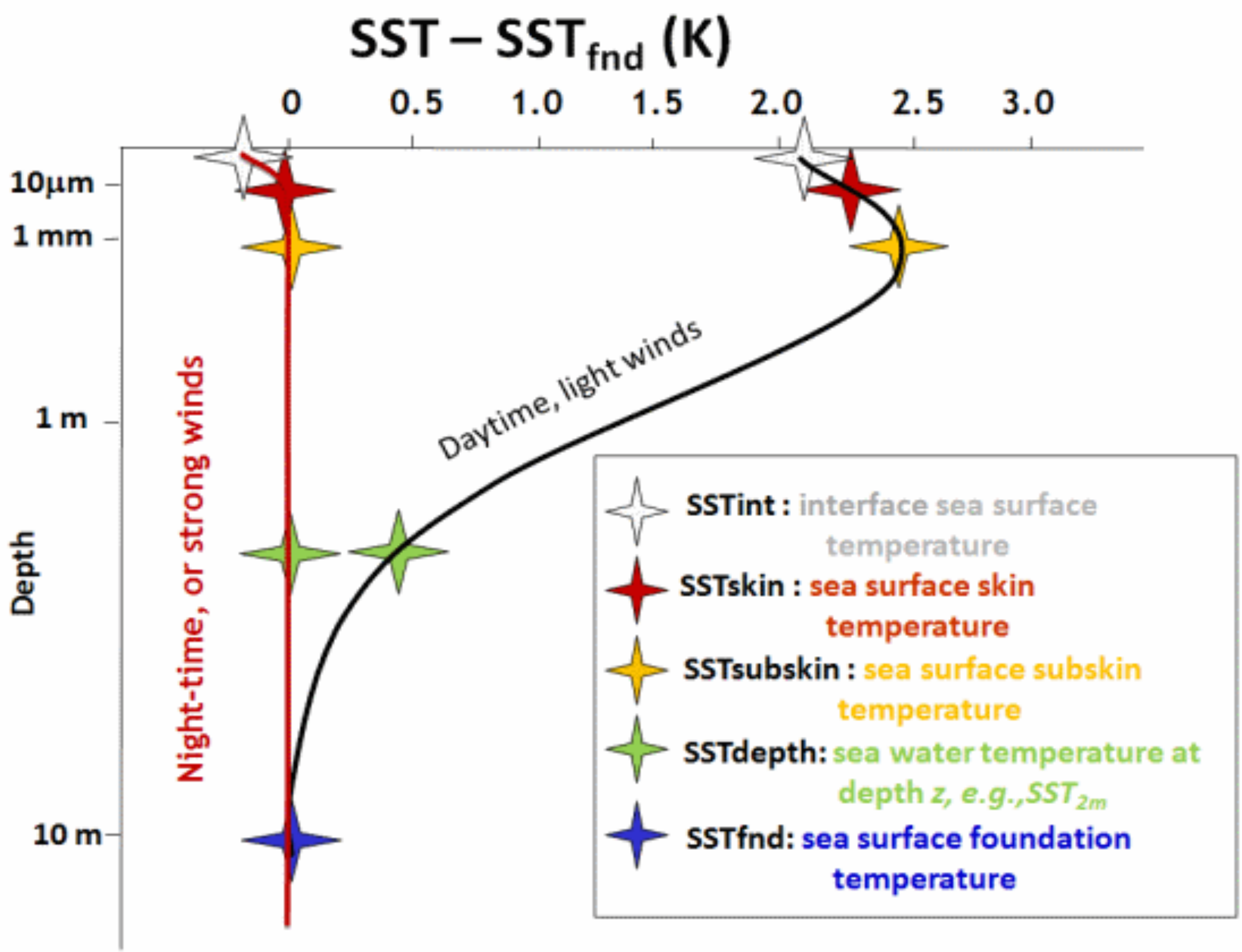
SST analysis evaluation, Standard Deviation against drifting and fixed buoys. 03/17/2017 - 04/11/2017. From NESDIS SST monitoring.



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: $15\ \mu m$

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 the advantages of an advanced atmospheric data assimilation system like GSI
  - Assimilation techniques
  - Direct assimilation
    - The capability to merge indirect observations
      - **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

Direct assimilation:
available, adopted and developed

- 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 is required**
    - The sensitivity of the temperature at depth z to, T_f, $\partial T_z / \partial T_f$, developed
    - The sensitivity of the radiance to the temperature at skin-depth z_{ch}, $\partial R / \partial T_{z_{ch}}$, available with CRTM
    - The sensitivity of the radiance to T_f, $\partial R / \partial T_f = \partial R / \partial T_{z_{ch}} \; \partial T_{z_{ch}} / \partial T_f$

NSST in NWP cycling: analysis and simulation

- 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

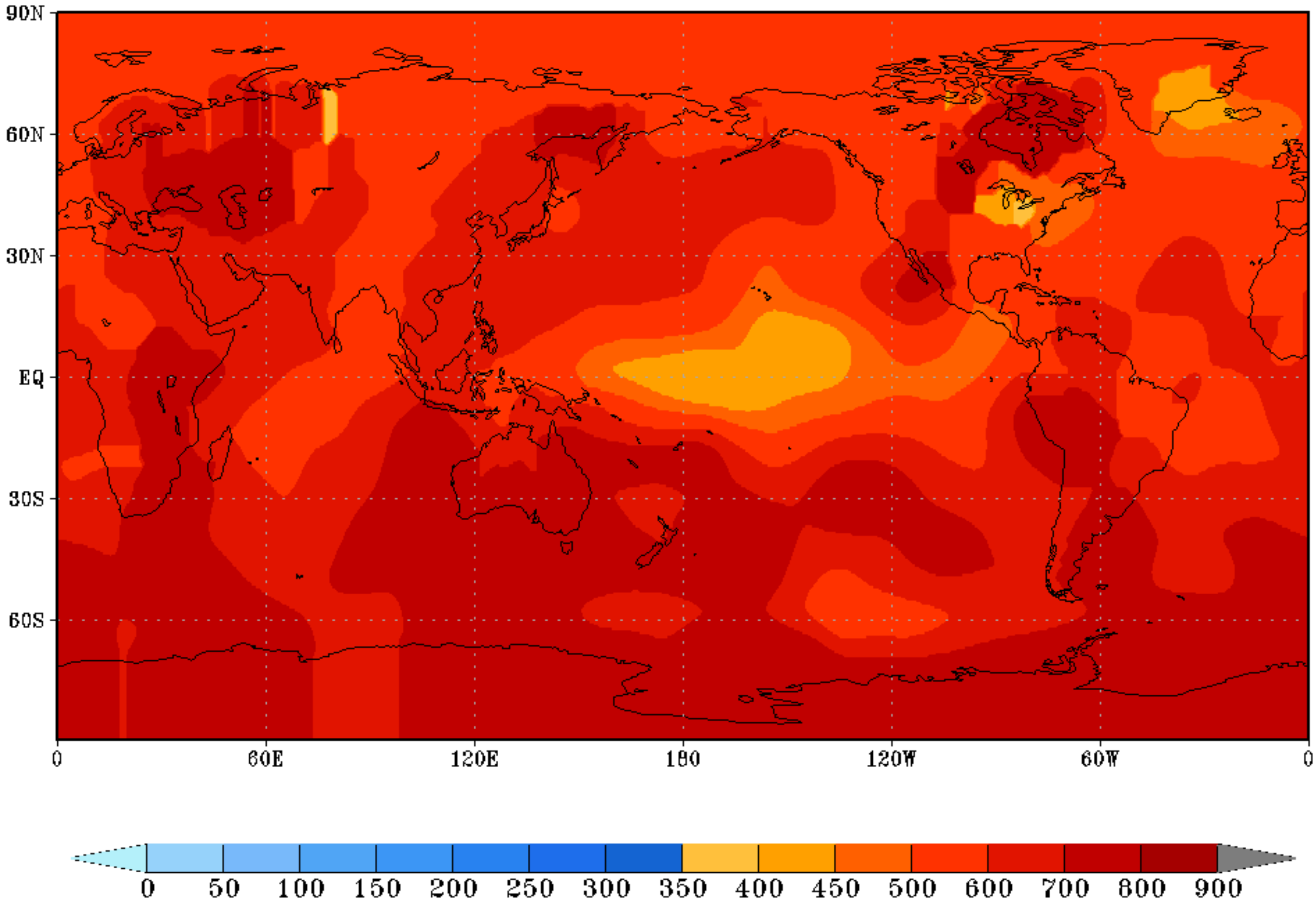
z_w : diurnal warming layer thickness

δ_c : sub-layer cooling layer thickness

NSST Model (NSSTM)

- **Thermal Skin Model/Parameterization** (adopted)
  - $T_c'(z,t), z \in \delta_c \sim O(1mm)$
  - 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)
  - $T_w'(z,t), z \in z_w \sim O(5m)$
  - Formation mechanism
    - The net heat flux in a near surface layer is positive (heating)
    - Vertical mixing is weak

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

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)

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

- In situ observations:
  - $\boldsymbol{O}-\boldsymbol{B}$: $T^{ob}(z_{ob})-\{T_f^{bg}(z_w)+[T_w^{\prime bg}(z_{ob})-T_c^{\prime bg}(z_{ob})]\}$
  - $\boldsymbol{O}-\boldsymbol{A}$: $T^{ob}(z_{ob})-\{T_f^{an}(z_w)+[T_w^{\prime bg}(z_{ob})-T_c^{\prime bg}(z_{ob})]\}$
- Satellite observations
  - $\boldsymbol{O}-\boldsymbol{B}$: $R^{ob}(z_{ch})-R^{bg}\{T_f^{bg}(z_w)+[T_w^{\prime bg}(z_{ch})-T_c^{\prime bg}(z_{ch})]\}$
  - $\boldsymbol{O}-\boldsymbol{A}$: $R^{ob}(z_{ch})-R^{an}\{T_f^{an}(z_w)+[T_w^{\prime bg}(z_{ch})-T_c^{\prime bg}(z_{ch})]\}$

Here,

T : sea water temperature

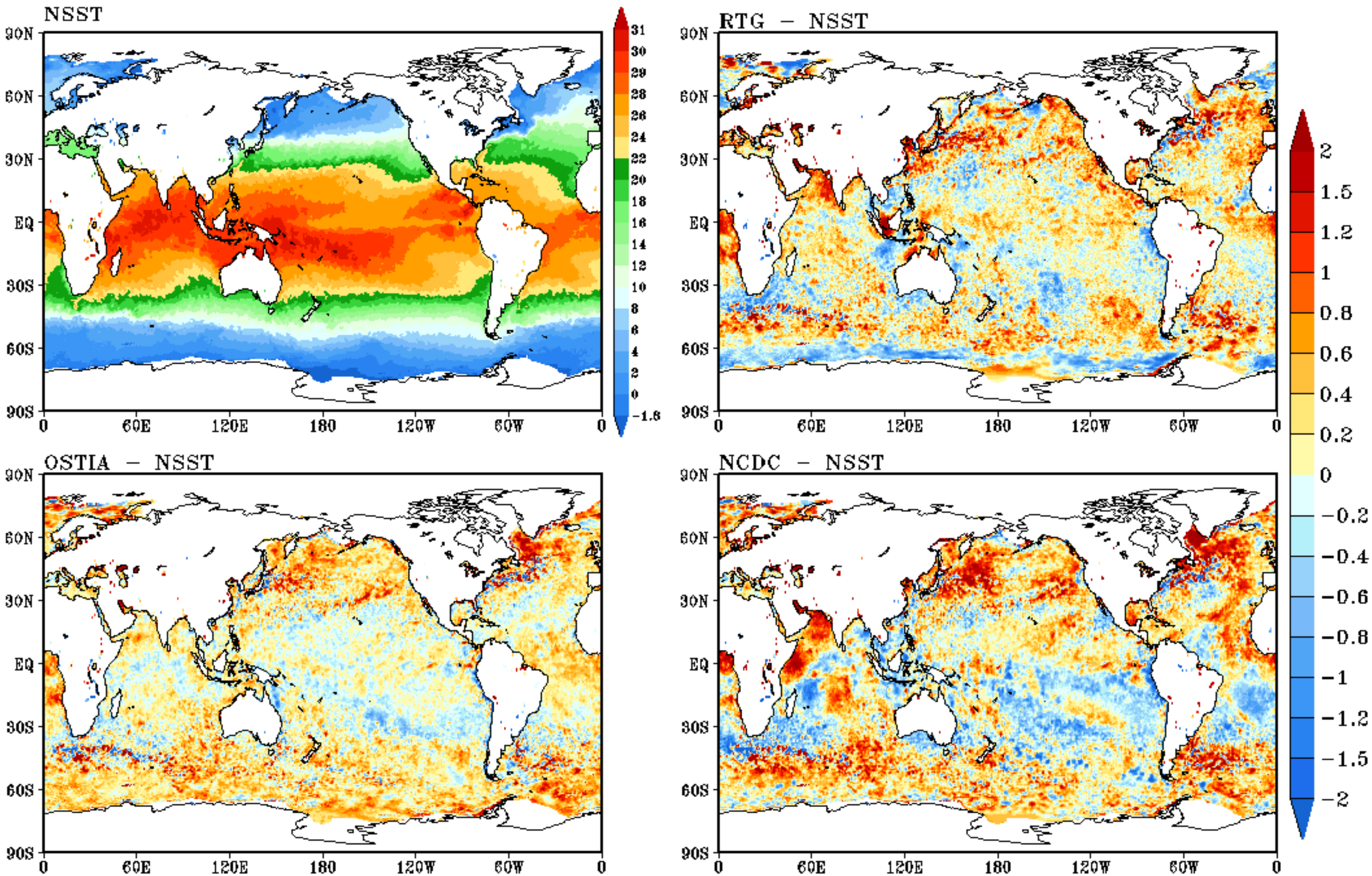
R: Radiance

z_{ob}: observation depth

z_{ch}: skin-depth for channel ch

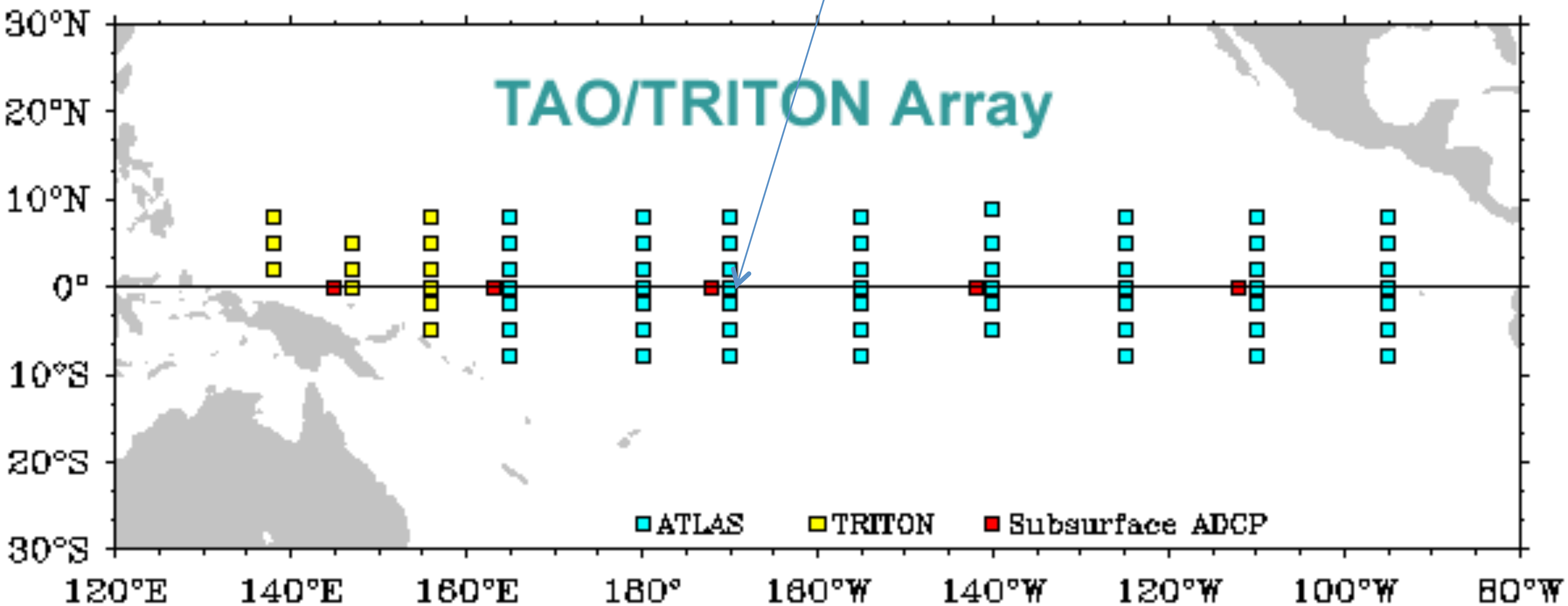
z_w: diurnal warming layer thickness

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)

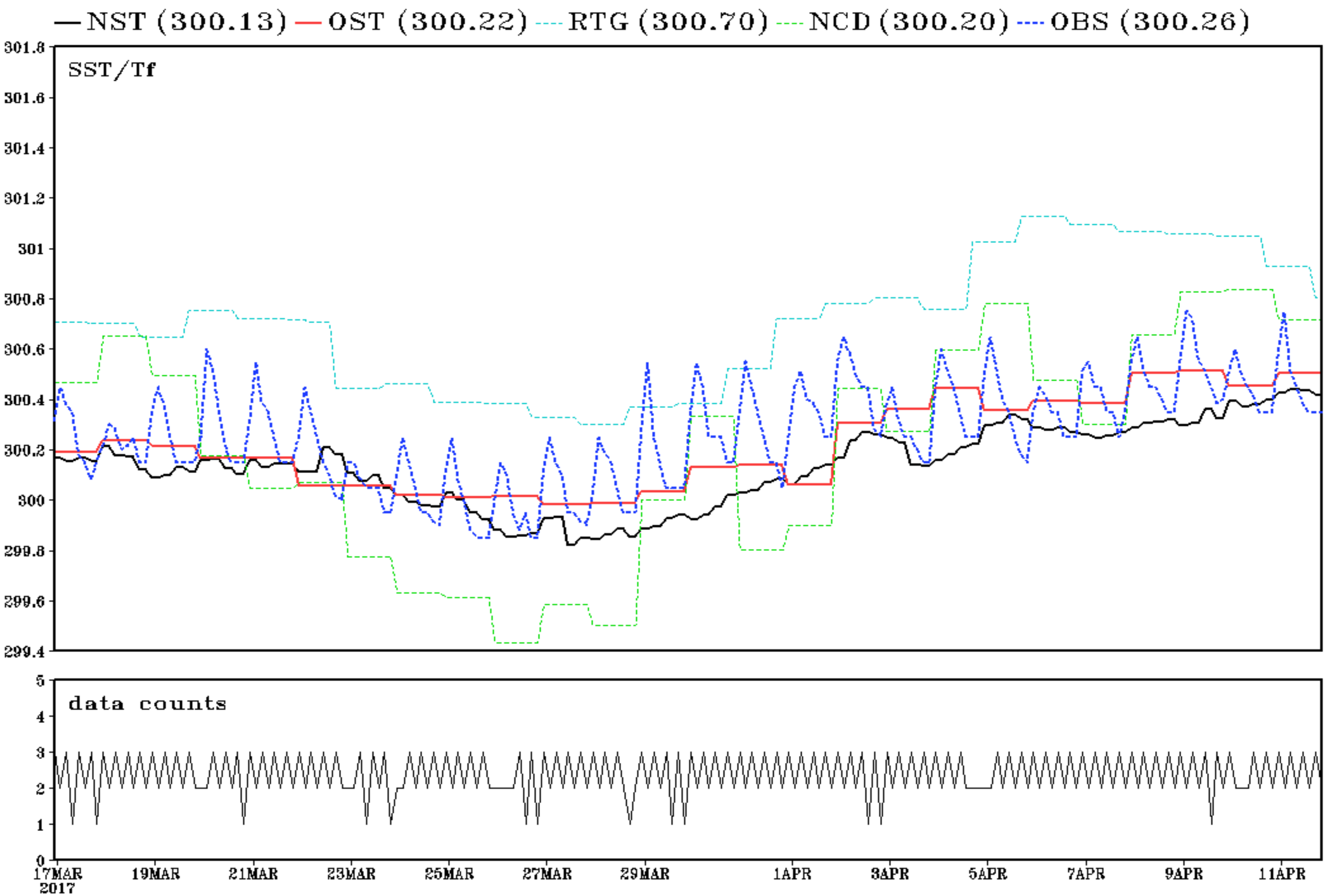


$T_c'(z=1m)=0$

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

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

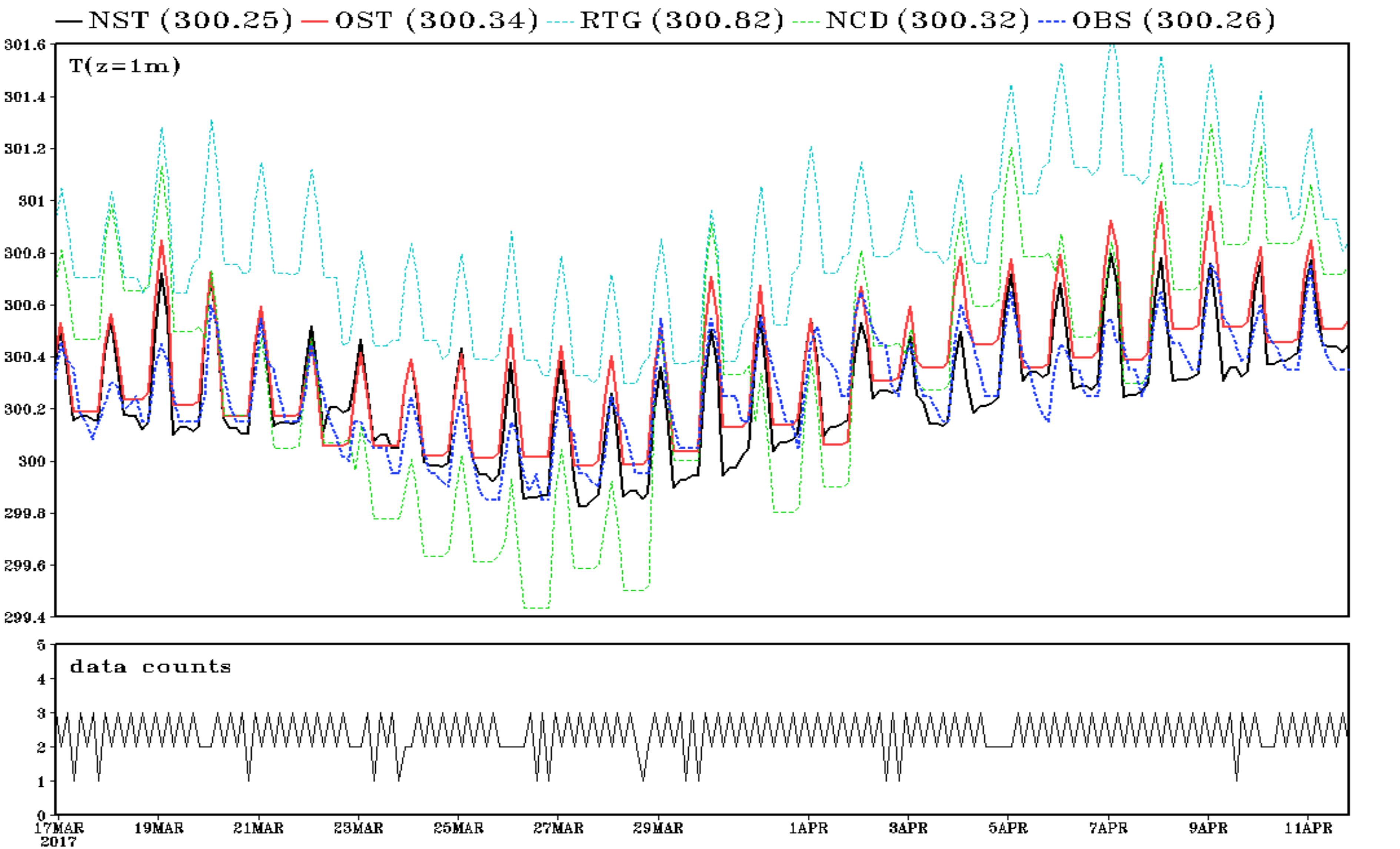
Time series of 4 T_f^{an} or SST^{an} and T_{1m}^{ob} at a fixed buoy station. 20170317 – 20170411, 3-hourly.



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

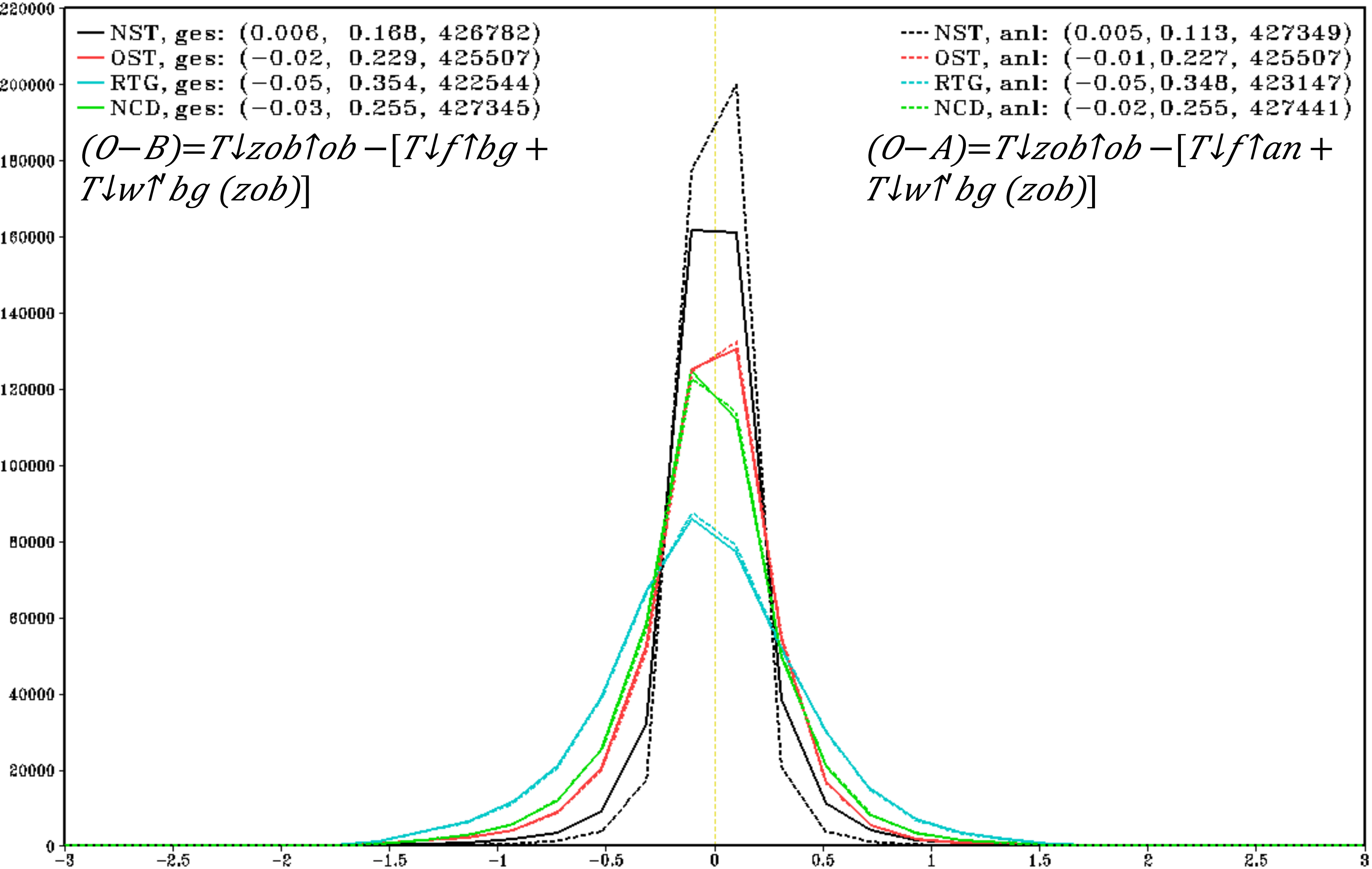
$T_{1m}^{an} = T_{f}^{an} + T_{w}'^{bg}\,(z=1m)$ for NSST and OSTIA

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



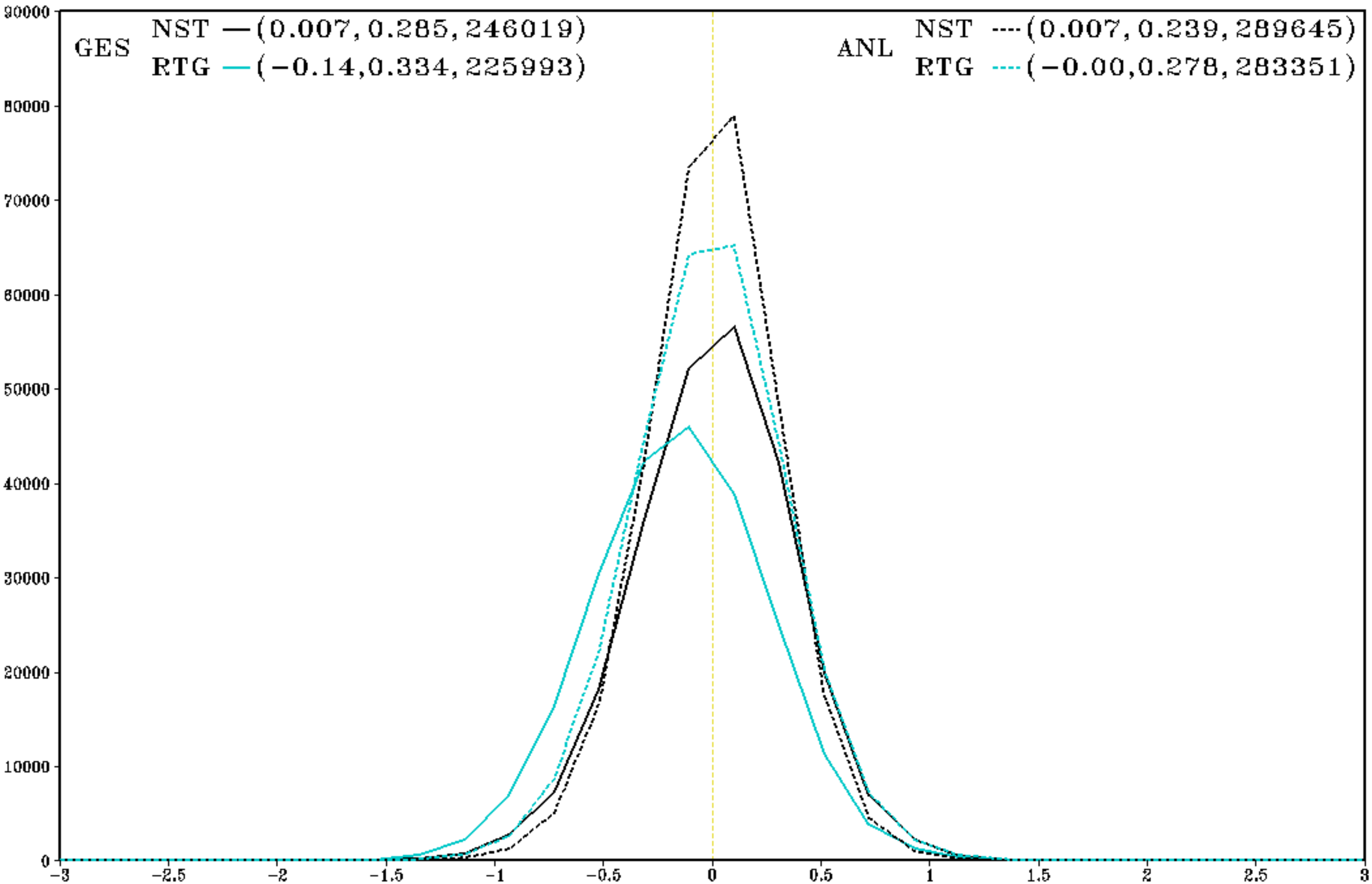
(O-B) & (O-A) histogram against the drifting buoys (Used)

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.



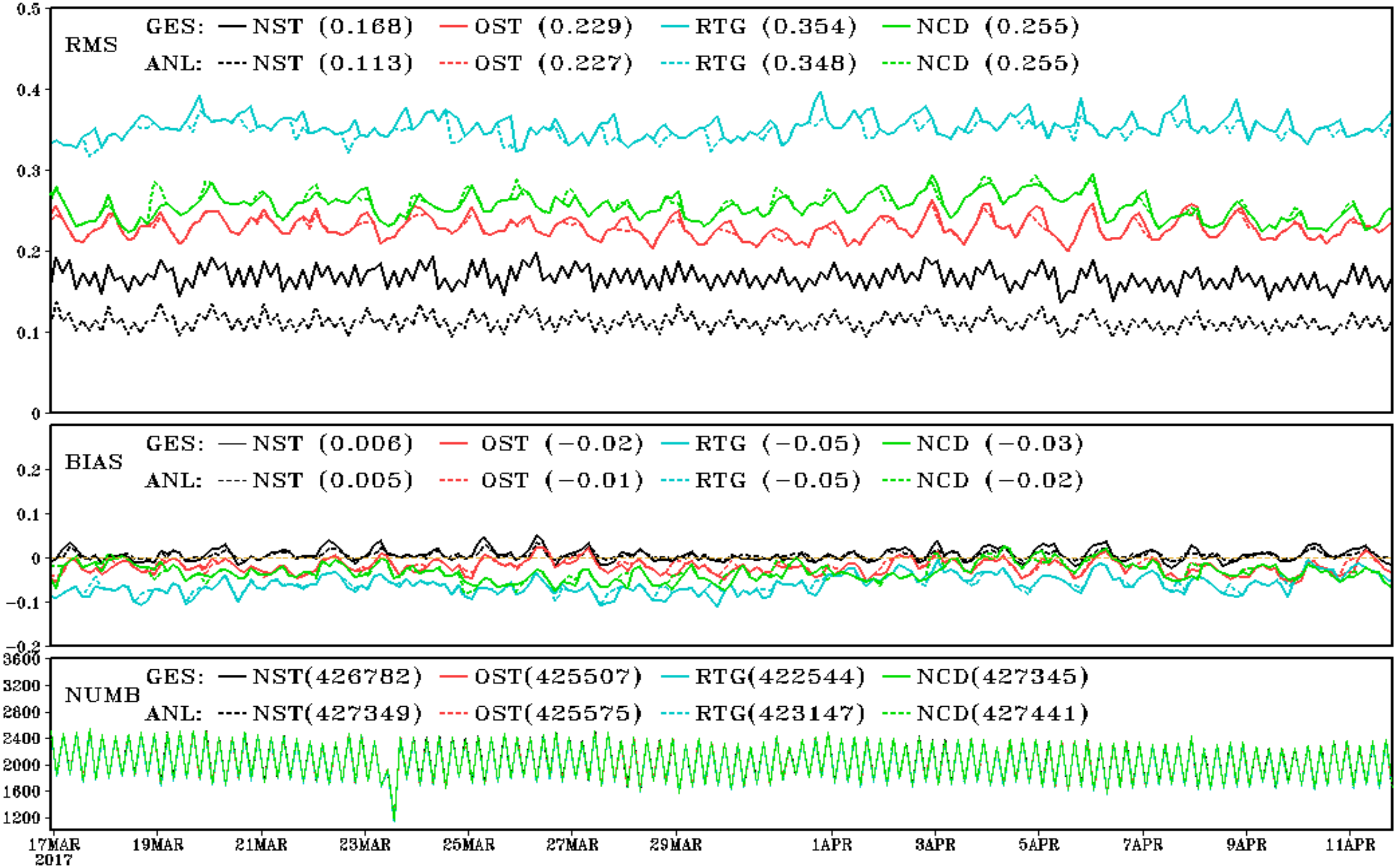
Summary

- 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

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

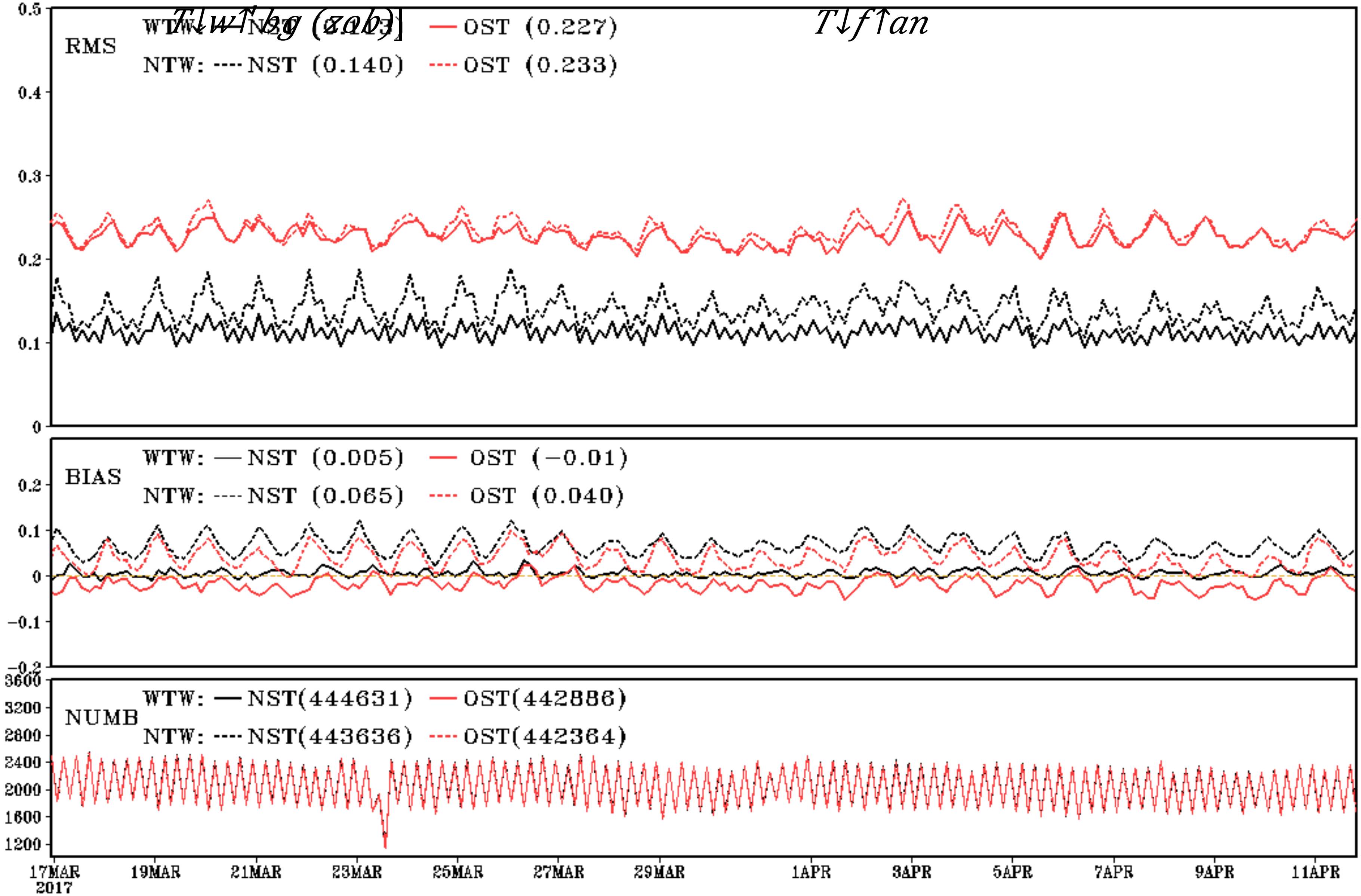


$(O-B) = T_{zob}^{ob} - [T_f^{bg} + T_{w'}^{bg}(zob)]$

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

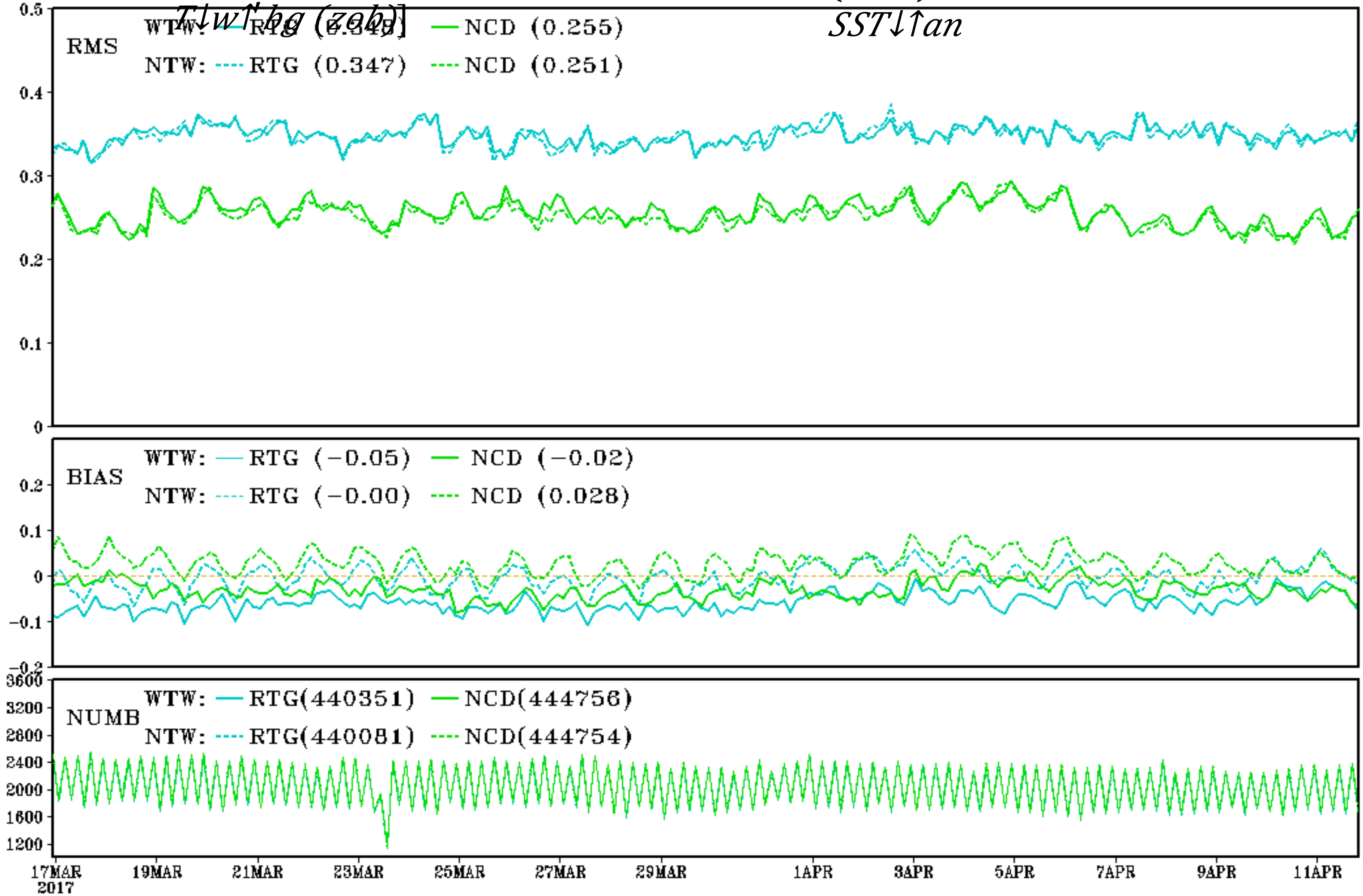
Time series of RMS, BIAS and NUMB for **NSST** and **OSTIA** T_f analysis against the drifting buoys. Global, 20170317 ~ 20170411, 3-hourly.

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



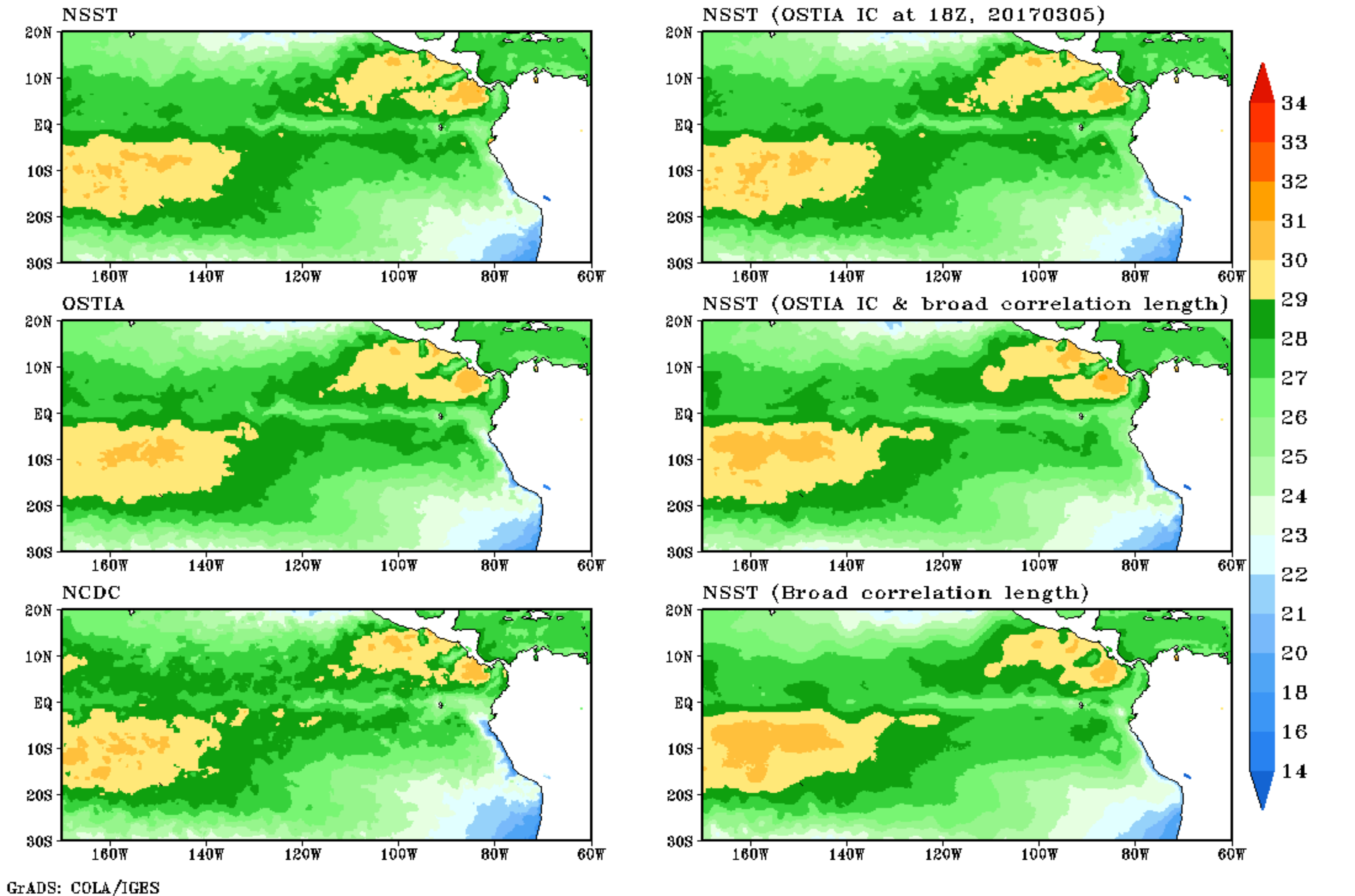
Time series of RMS, BIAS and NUMB for RTG and NCDC ***SST*** analysis against the drifting buoys. Global, 20170317 ~ 20170411, 3-hourly.

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



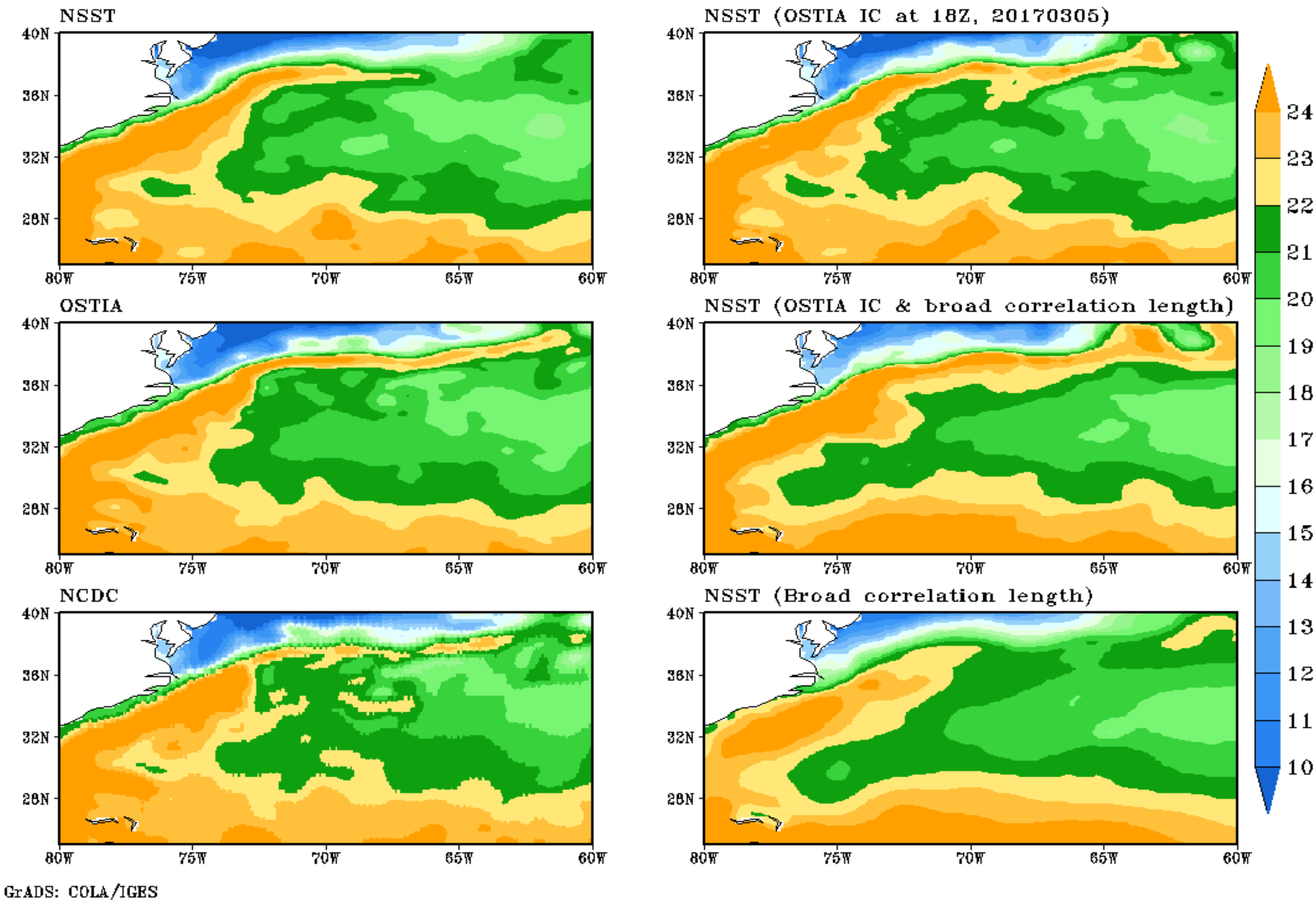
Comparison of 3 T_f /SST (NSST, OSTIA and NCDC) analysis, 18Z, 04/17/2017. TIW.

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

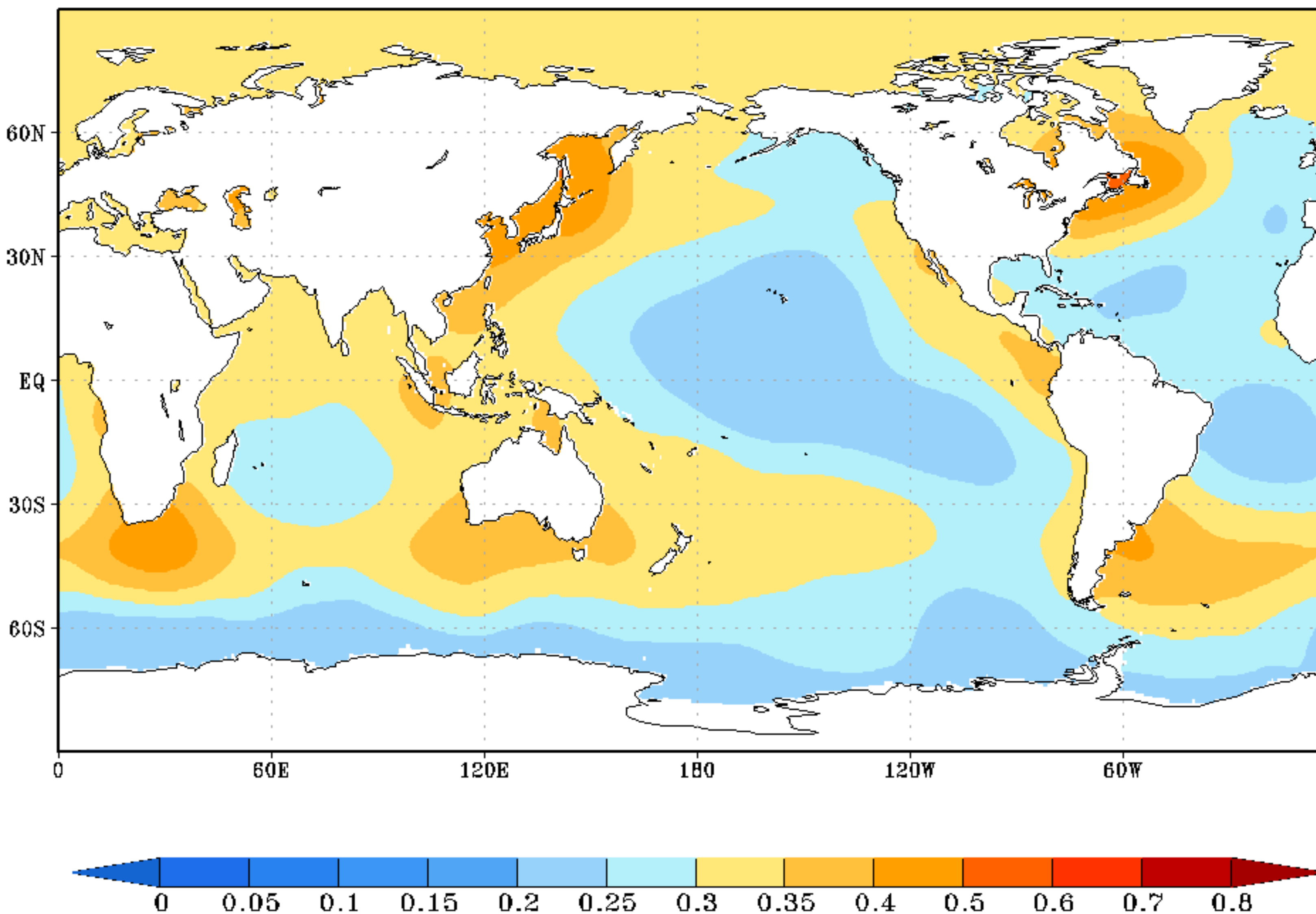


Comparison of 3 T_f/SST (NSST, OSTIA and NCDC) analysis, 18Z, 04/17/2017. Gulf stream.

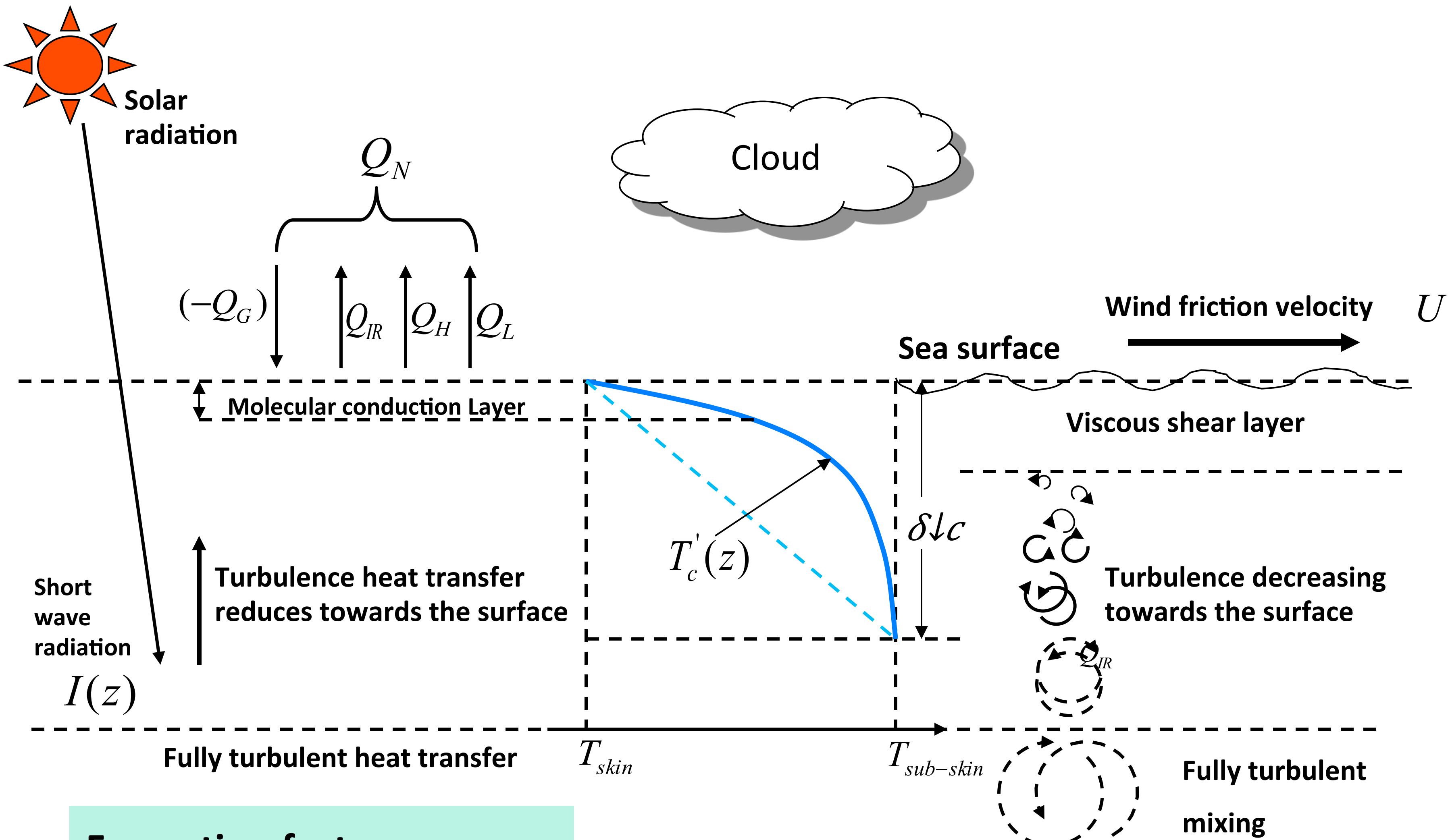
Three NSST experiments on the initial condition and Correlation length are shown as well



Background error variance used in NSST (borrowed from RTG)



Physical factors to form the thermal skin layer in the ocean



Formation factors:

1. $I(0) - I(z_c) + Q_N < 0$
2. **Weaker turbulence**

$$T_c'(z=0): 0.0 \sim 1.0K$$

$$z_c \sim O(1mm)$$