Inclusion of Oceanic Temperature Diurnal Variability in NCEP CFS

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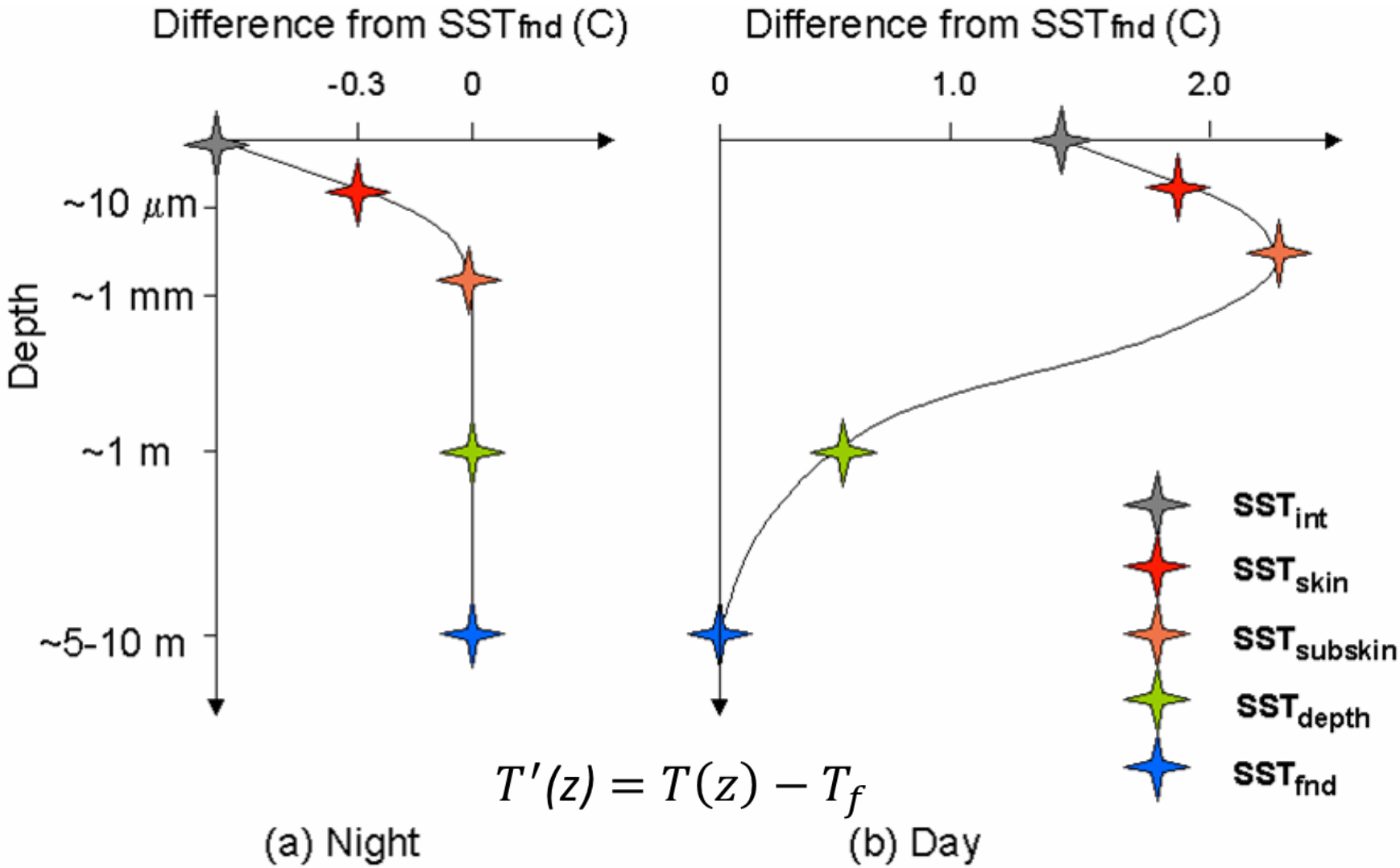
Outline

- **Inclusion of oceanic temperature diurnal variability in NCEP GFS**
  - Close to implementation
    - From SST to NSST (Near-Surface Sea Temperature)
    - Oceanic foundation temperature analysis within the NCEP GFS
    - Air-sea interaction
- **Inclusion of oceanic temperature diurnal variability in NCEP CFS**
  - Ideas and schemes for CFSv3
    - Oceanic diurnal variation is critical in coupling

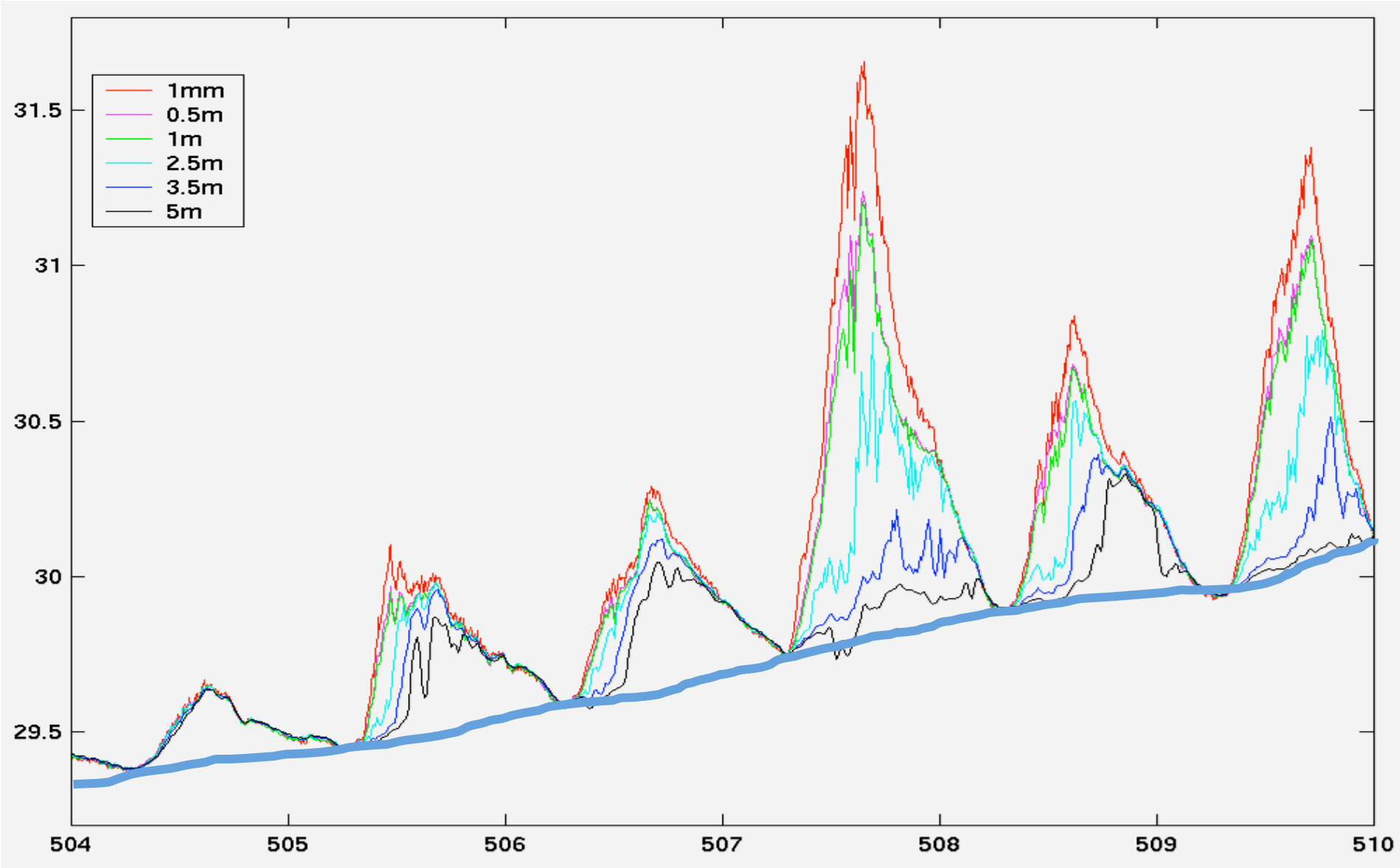
What exactly is the Surface Sea Temperature?

(The hypothetical vertical profile from GHRSST-PP)



$$T'(z) = T(z) - T_f$$

Observed NSST: Foundation temperature and diurnal variability

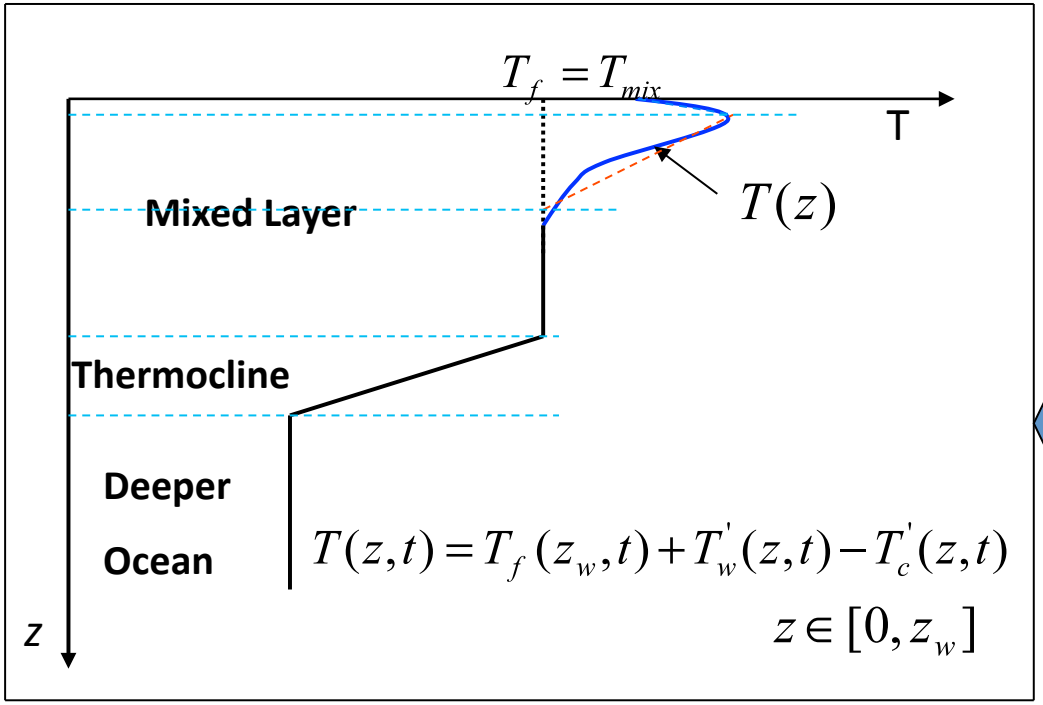


Foundation Temperature

- It is named to indicate that from which the growth of the diurnal thermocline develops each day
- It provides a connection with the historical "Bulk Temperature", considered as mixed layer temperature.
- It provides a more precise, well-defined quantity than previously loosely defined bulk SST and consequently, a better representation of the mixed layer temperature
- It is similar to a nighttime minimum or predawn value at the depths of ~1-5 m.

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

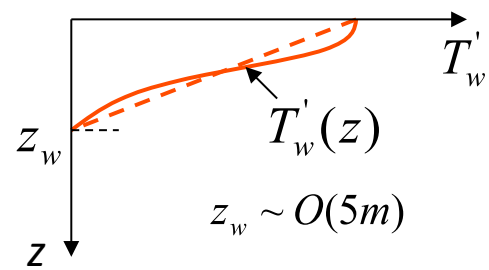


Assuming the linear profiles, then, 5 parameters are enough to represent **NSST:**

$$T(z) = F[T_f, T_w'(0), z_w, T_c'(0), \delta_c]$$

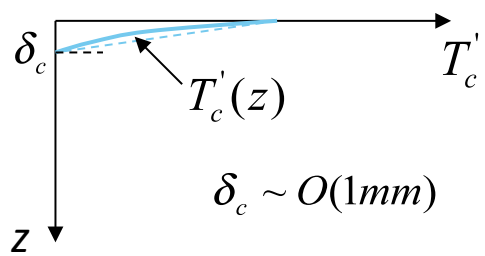
Diurnal Warming Profile

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



Skin Layer Cooling Profile

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



Oceanic T-Profile for NWP

Sea Surface Temperature:

$$T_s = T_f + T_w^{'}(0) - T_c^{'}(0)$$

The lower thermal boundary condition for atmospheric forecasting model

T-Profile in the skin layer:

$$T(z) = T_f(z_w) + T_w^{'}(z) - T_c^{'}(z) \quad (0 \le z \le \delta_c)$$

The lower thermal boundary condition for radiance simulation in atmospheric data assimilation

T-Profile in the diurnal thermocline:

$$T(z) = T_f(z_w) + T_w^{'}(z) - T_c^{'}(z) \qquad (0 \le z \le z_w)$$

The combination of NSSTM and OGCM: the conversion between T_f and T_1

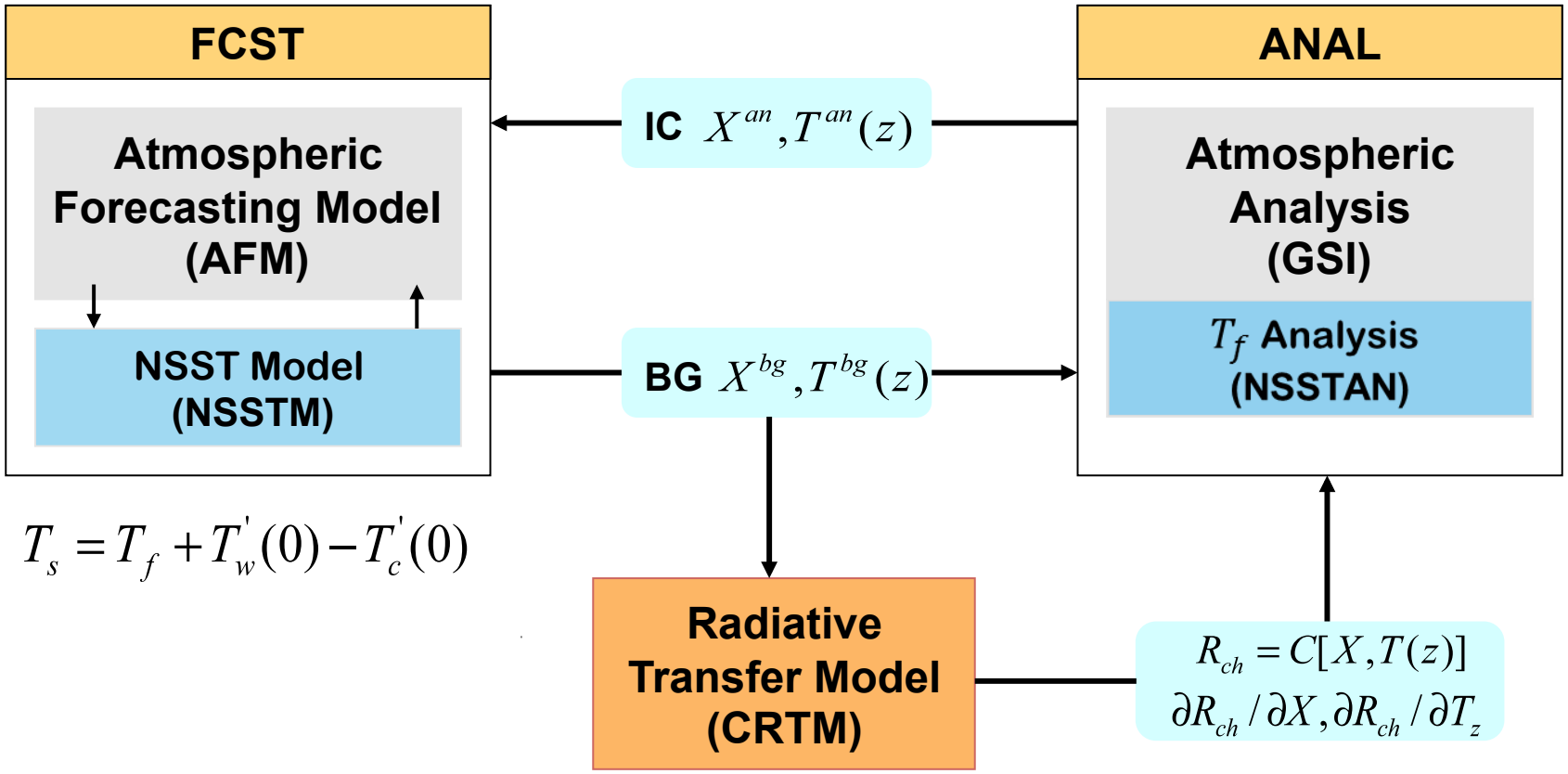
$Work\ done\ for\ T_f\ analysis\ at\ NCEP$

- NSST model
- Analysis variable selection/definition
- The observation operators
- Observation depths
- Skin depth determination for instrument dependent lower thermal boundary conditions in radiance simulation
- The use of more data sets
- A new quality control for radiances
- The coupling of NSST model and Atmospheric Forecasting Model (AFM) in GFS
- The cycling of analysis and forecasting
- A scheme has been developed to combine NSST into the air-sea coupled prediction system such as NCEP CFS

Characteristics in different SST analysis

Features	Operational SST analysis	GHRSST T_f analysis	NCEP T_f analysis
Well-defined Analysis variable	No	Yes	Yes
Analysis scheme	Uni-variate	Uni-variate	Multi-variate
Flexible Analysis resolution	Yes	Yes	No/Yes
Multi-Satellite	No	Yes	Yes
Direct Assimilation	No	No	Yes
Obs. with diurnal warming used	Yes	No	Yes
Diurnal variability resolved	No	Yes	Yes
T_f evolution in one day	N/A	No	Yes
NSST model used consistently	N/A	No	Yes
Coupled analysis	N/A	No	Yes

NSST $T(z)$ and NWP: GFS



$$T_s = T_f + T_w^{'}(0) - T_c^{'}(0)$$

$$T_{crtm}(z) = T_f + T_w^{'}(z) - T_c^{'}(z)$$

C : **Observation operator (relate T-Profile to the radiance)**

$\partial R_{ch} / \partial T_z$: **Jacobi (the sensitivity of the radiance to T-Profile)**

NSST Impact on GFS Forecasting

Exps	T_f	SST In FCST	$T^{'}(z)$ In ANAL
pre13c	SST^{op}	SST^{op}	SST^{op}
Pre13e	T_f^{an}	$T_f^{an}+T_w^{'}(0,t)-T_c^{'}(0,t)$	$T_f^{an}+T_w^{'}(z,t)-T_c^{'}(z,t)$

$$T(z)=T_f(z_w)+T_w^{'}(z)-T_c^{'}(z)$$

The **cycling run** in T576 resolution for the period of (1) May 12, 2010 to September 20, 2010. (2) November 12 to December 20, 2012.

Atmospheric Forecasting Model: Q3F10

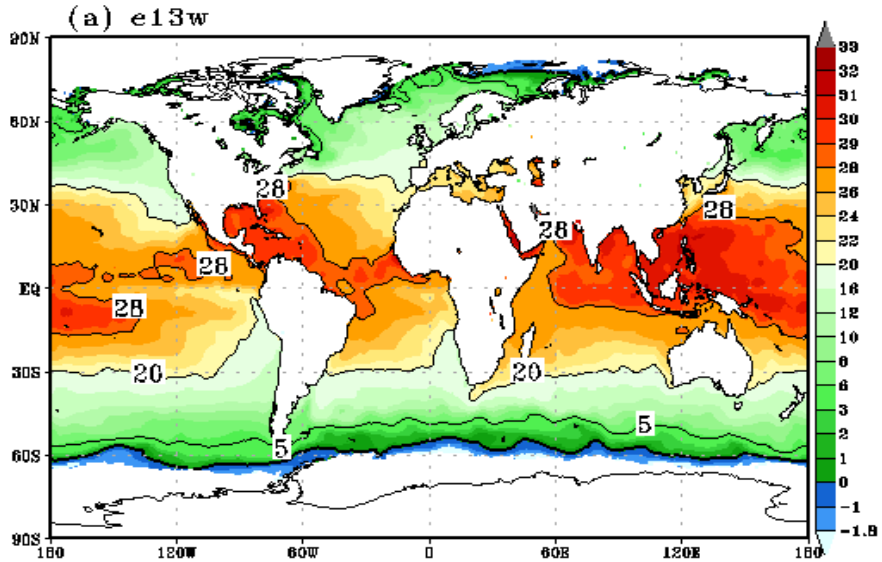
GSI: July 2011 trunk

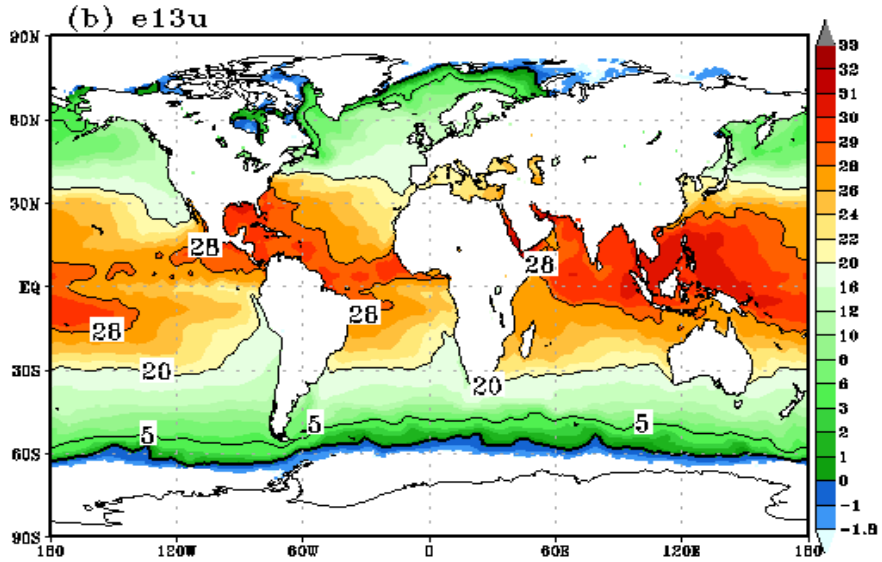
The forecasting results for JJA 2010 are shown here: 92 16-day forecasting initiated from 00Z analysis of GDAS run

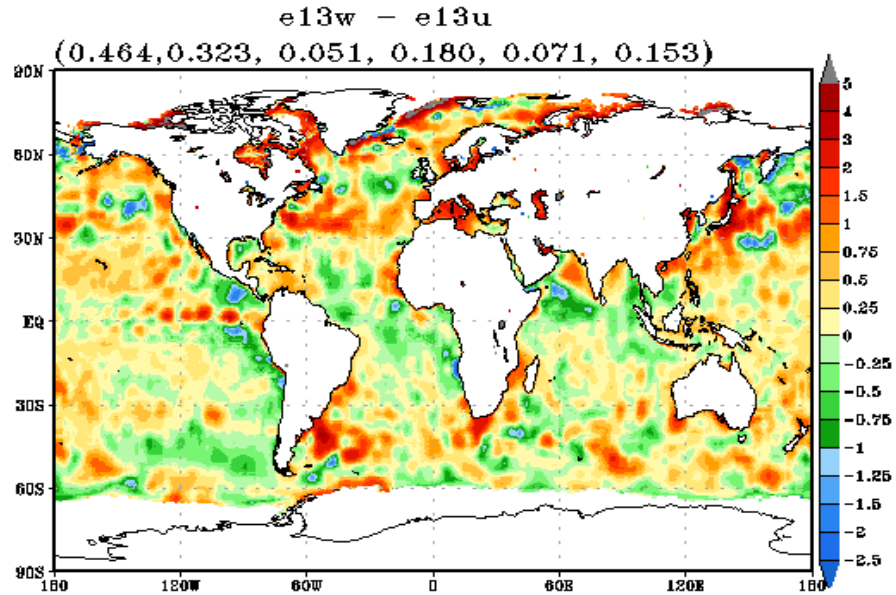
NSST impact evaluation

- **A complete evaluation necessary**
- **T_f analysis validation**
  - **Comparison: T_f, new SST and Operational SST**
  - **Statistics of O-B: $y - H(x^b)$**
  - Comparison with other global SST/T_f analysis
- Atmospheric analysis
- Land surface
- **Forecasting**
  - **Forecasting skill**
- **Weather or climate events**
  - Hurricane, MJO, Rainfall

Analysis in GFS NST file: (av_tref). 20100701_20100701.

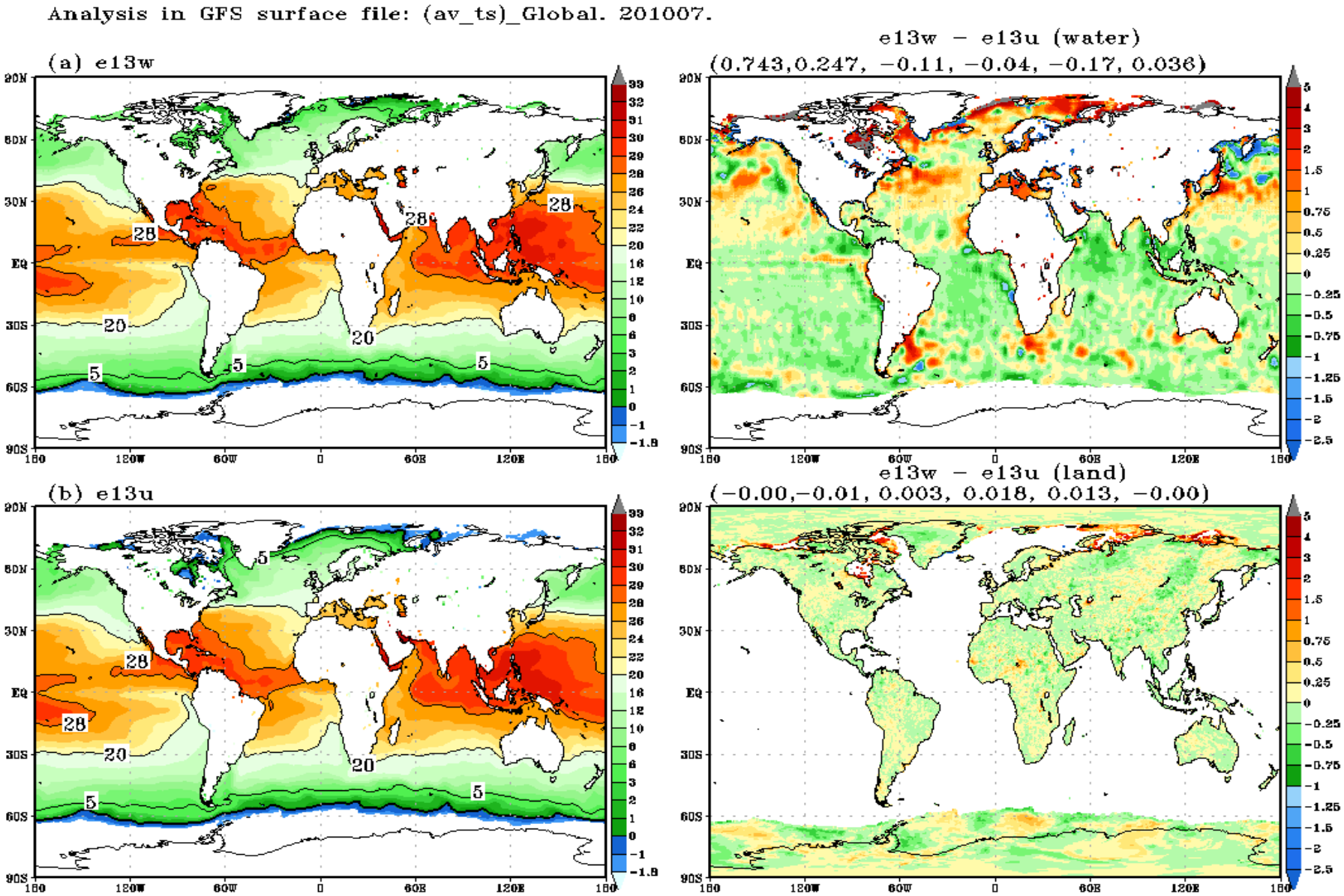






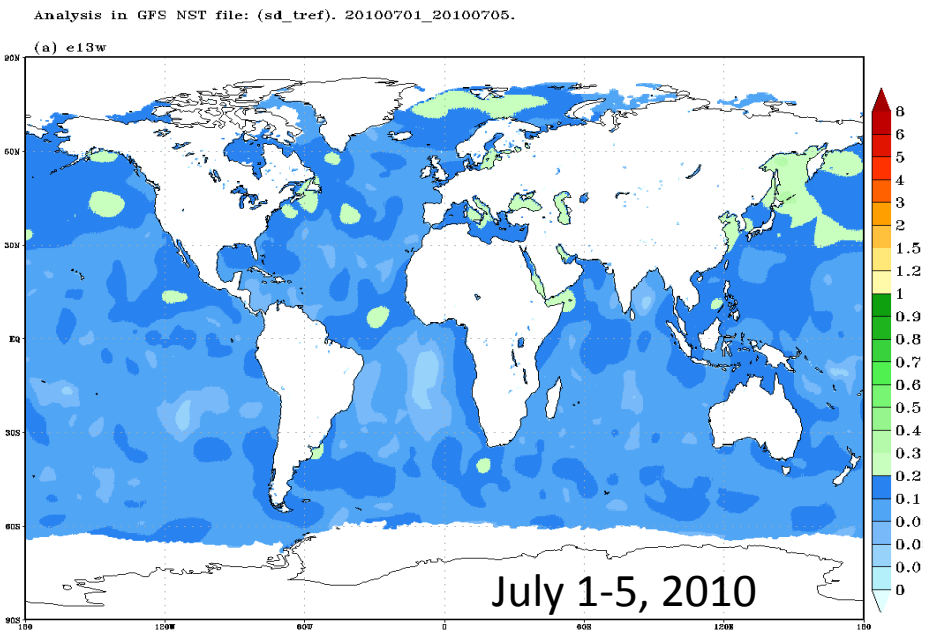
(N.Pole, N.Mid, Tropics, S.Mid, S.Pole, Global)

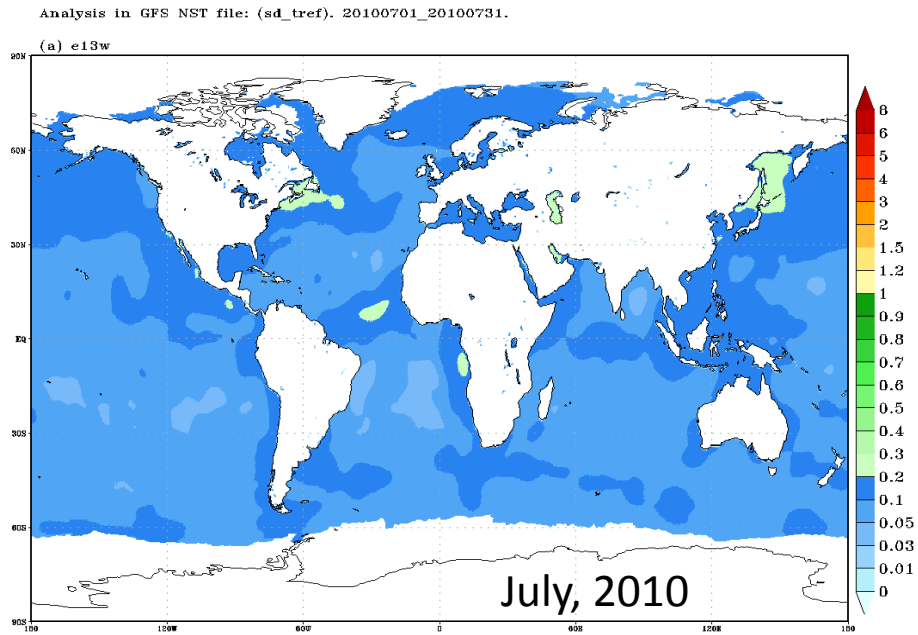
Comparison between T_f analysis in NSST and operational SST analysis used in pre13u.
July, 2010

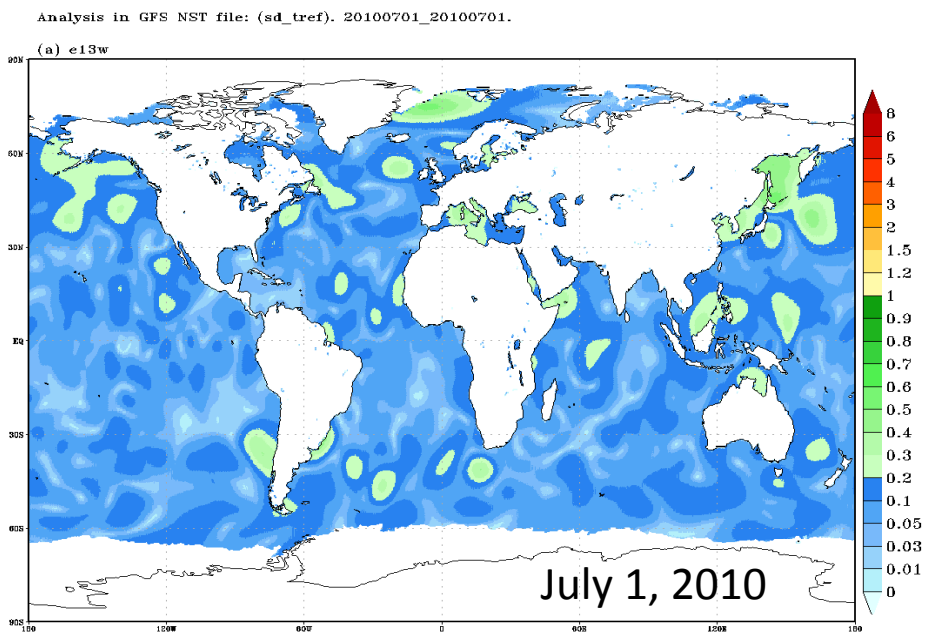


(N.Pole, N.Mid, Tropics, S.Mid, S.Pole, Global)

Comparison between T_s (SST) in NSST and in Ctrl. July, 2010

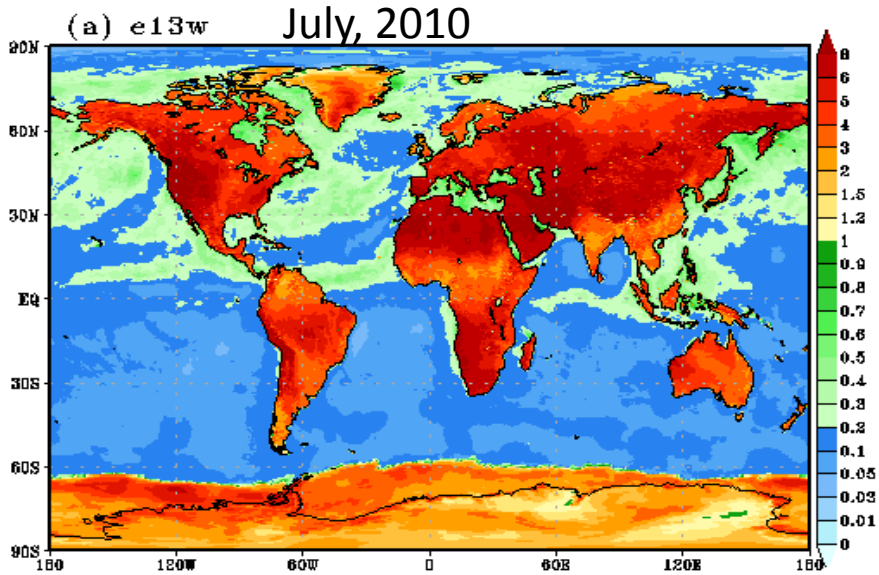


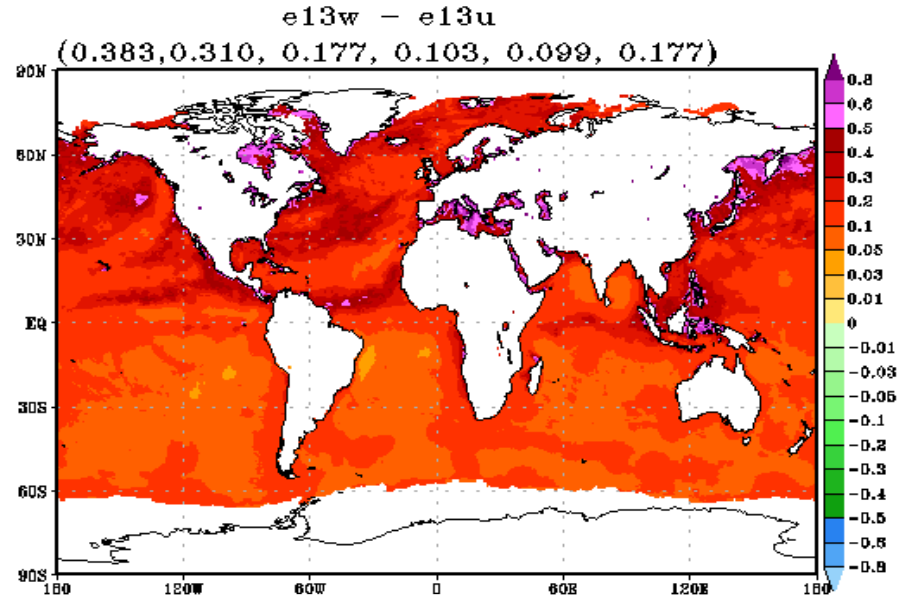




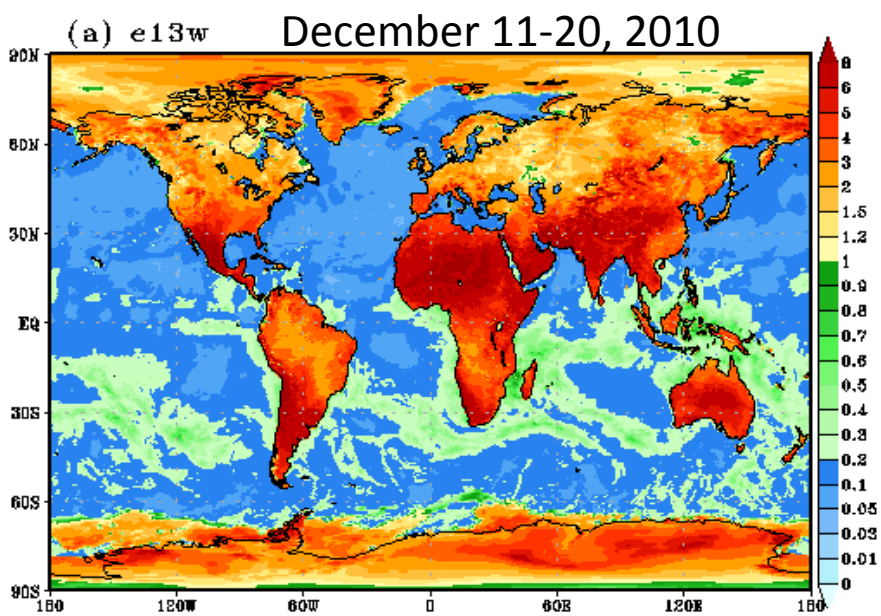
Diurnal Variability of T_f in NSST run

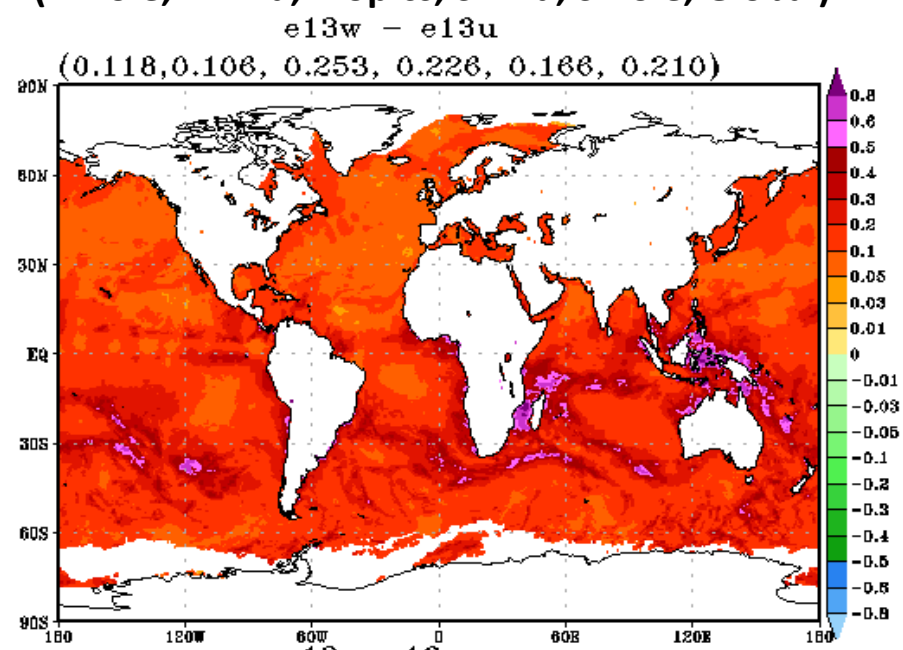
Diurnal Variability of SST in NSST

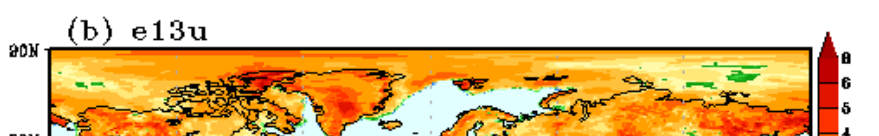


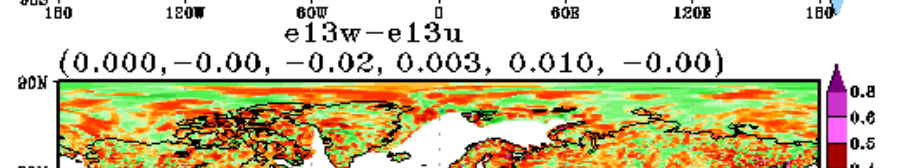


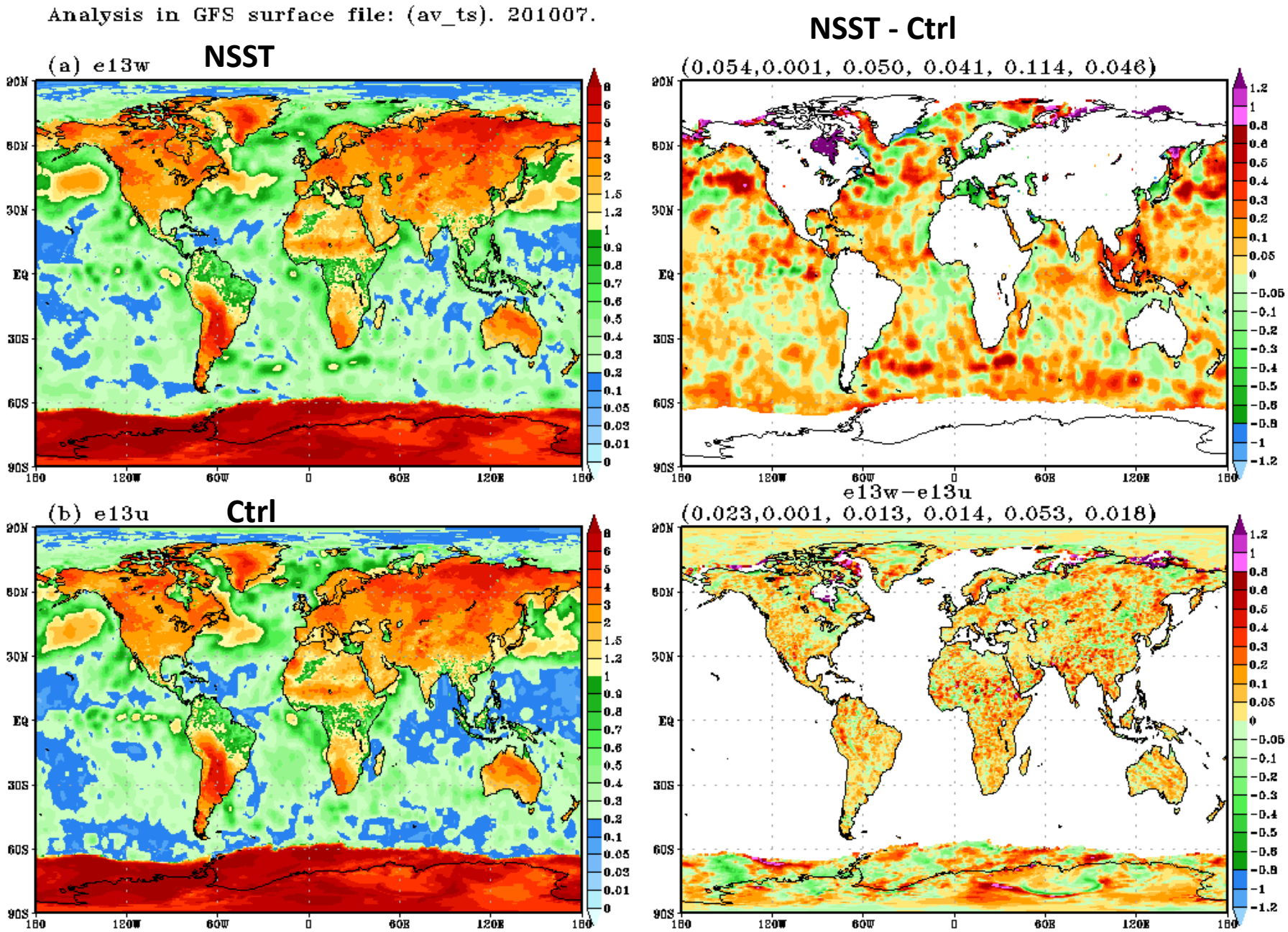
(N.Pole, N.Mid, Tropics, S.Mid, S.Pole, Global)





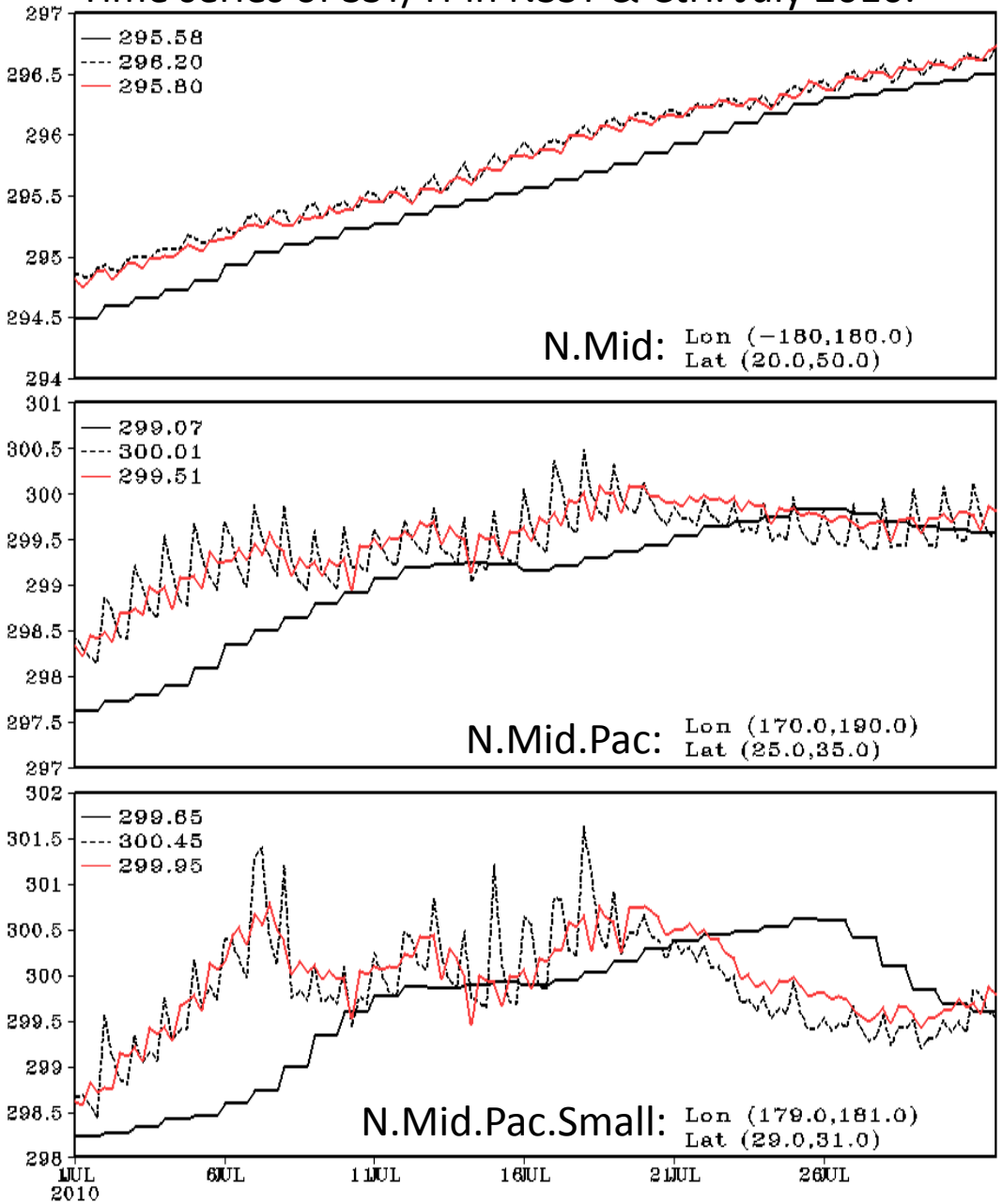




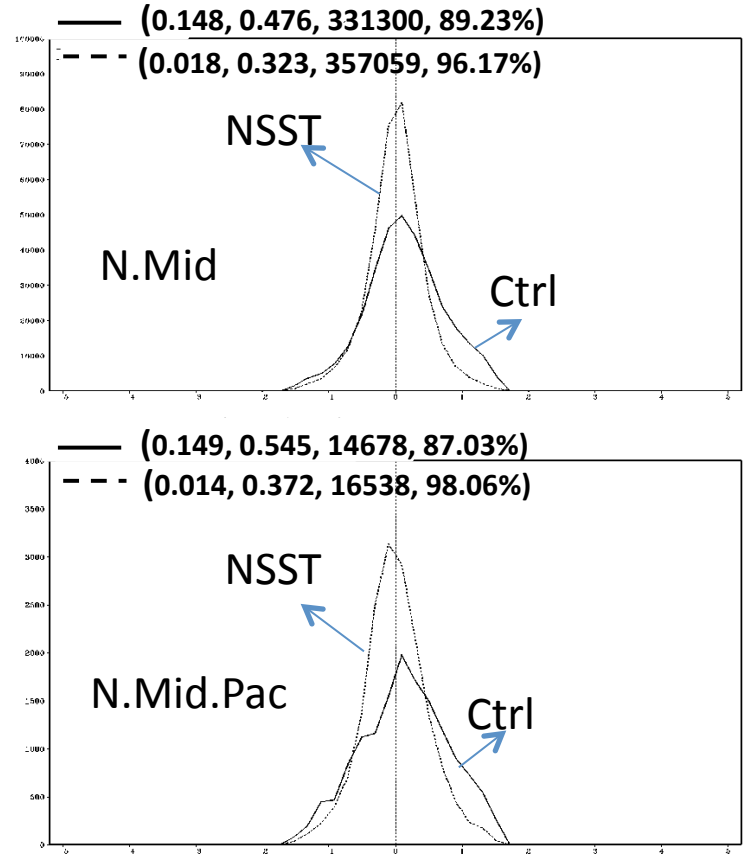


Day-to-Day Variability of SST in NSST & Ctrl (N.Pole, N.Mid, Tropics, S.Mid, S.Pole, Global)

Time series of SST/Tf in NSST & Ctrl. July 2010.

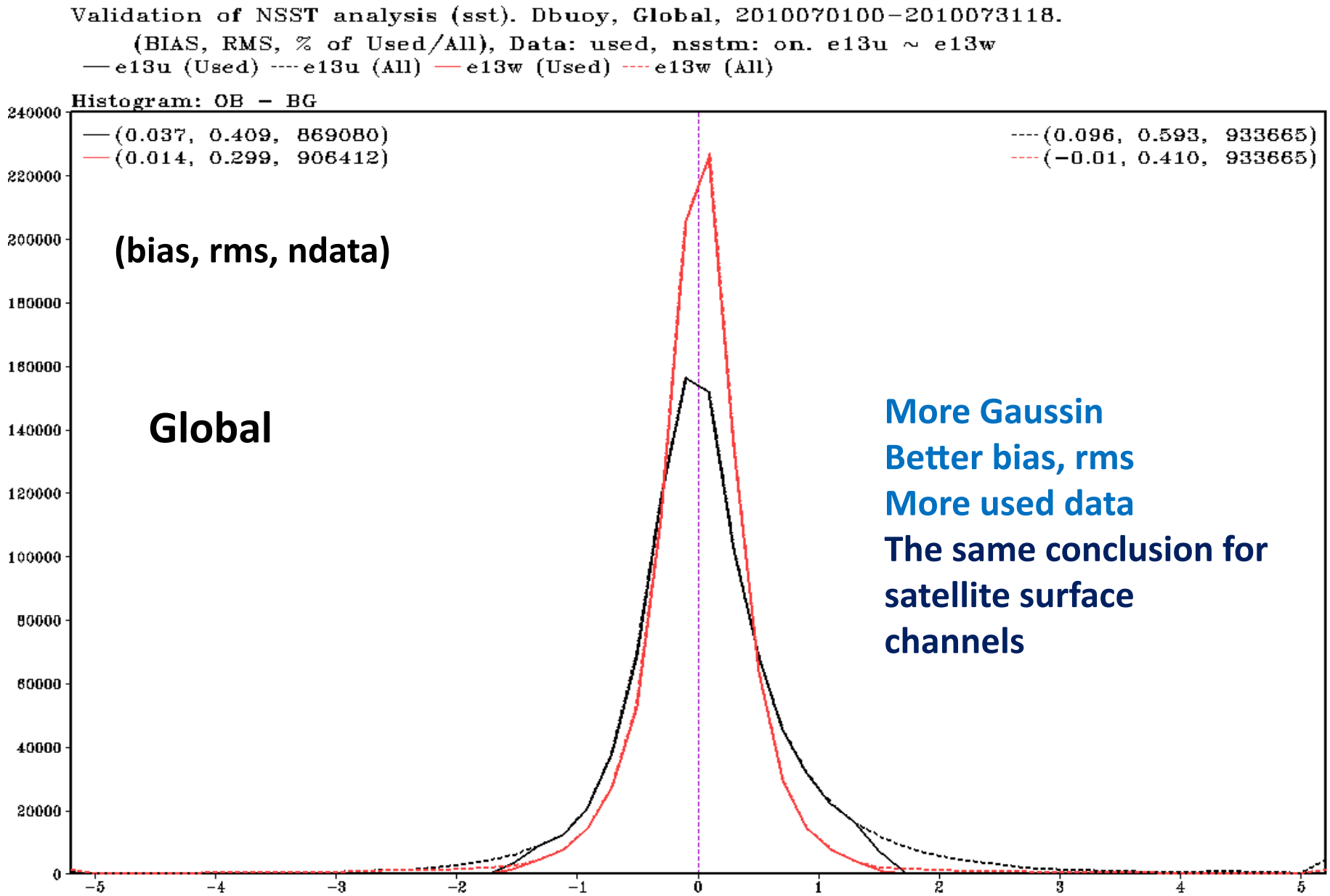


T_f/SST in Ctrl ---- SST in NSST T_f in NSST

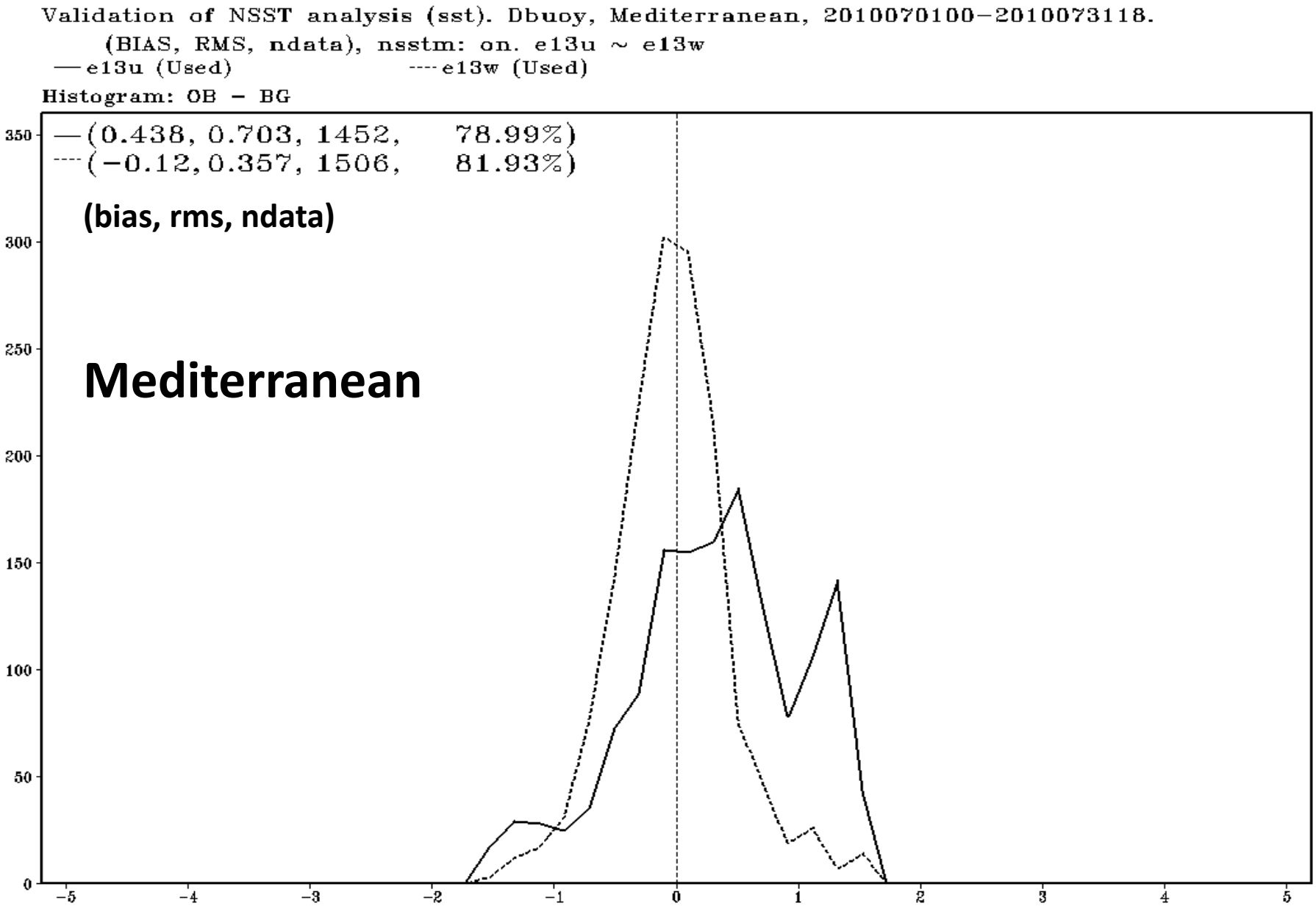


Histogram of O-B: $y - H(x)$.
Drifting buoy.

(bias, rms. nused, % of used)



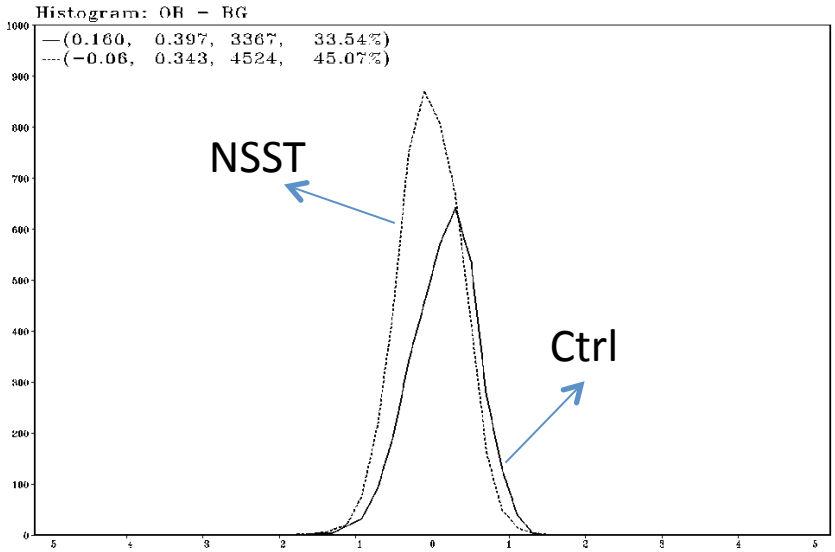
Validation of analysis: Histogram of O-B: $y - H(x^b)$. Drifting buoy, July 2010



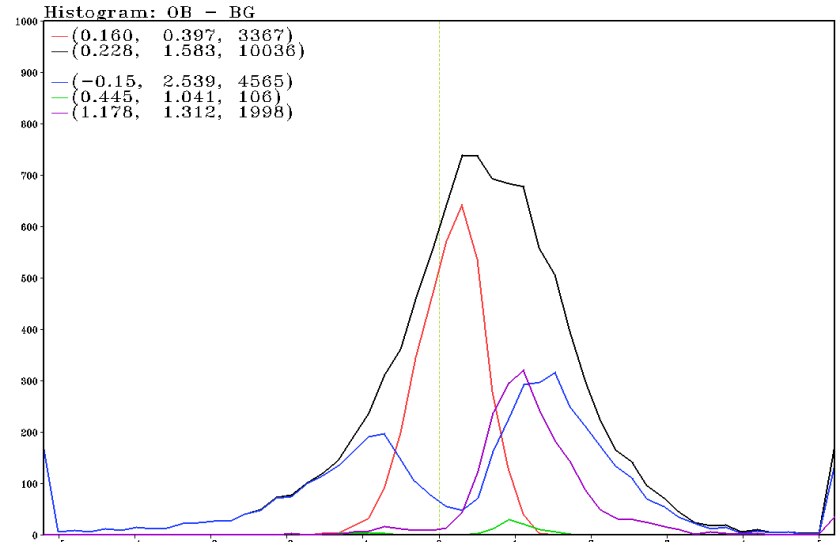
Validation of analysis: Histogram of O-B: $y - H(x^b)$. Drifting buoy, July 2010

Mediterranean

Control vs NSST



Quality Controls in NSST run



Validation of analysis: July 2010

Histogram of O-B: $y - H(x^b)$.

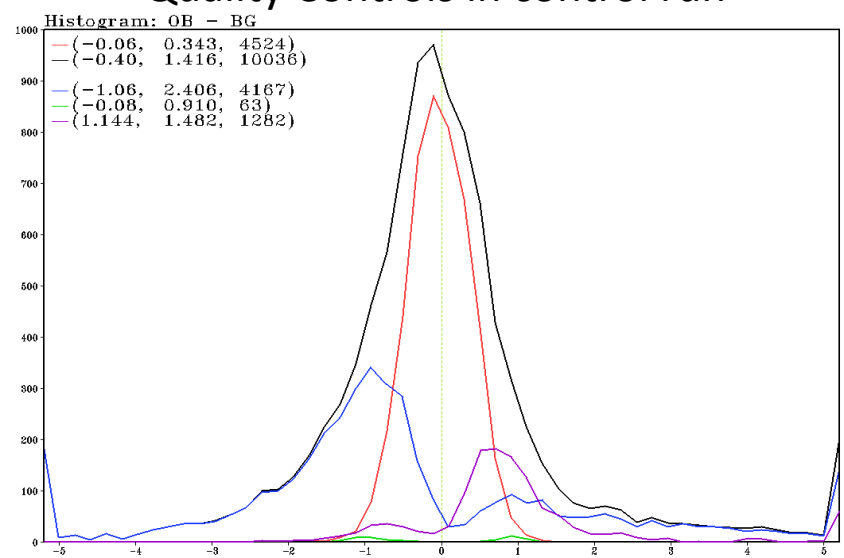
IASI (metop-a), Ch-211 (surface channel)

Quality Controls applied sequentially:

- **Cloud Detection Test**
- **Surface Temperature Test**
- **SST Physical Retrieval Test**

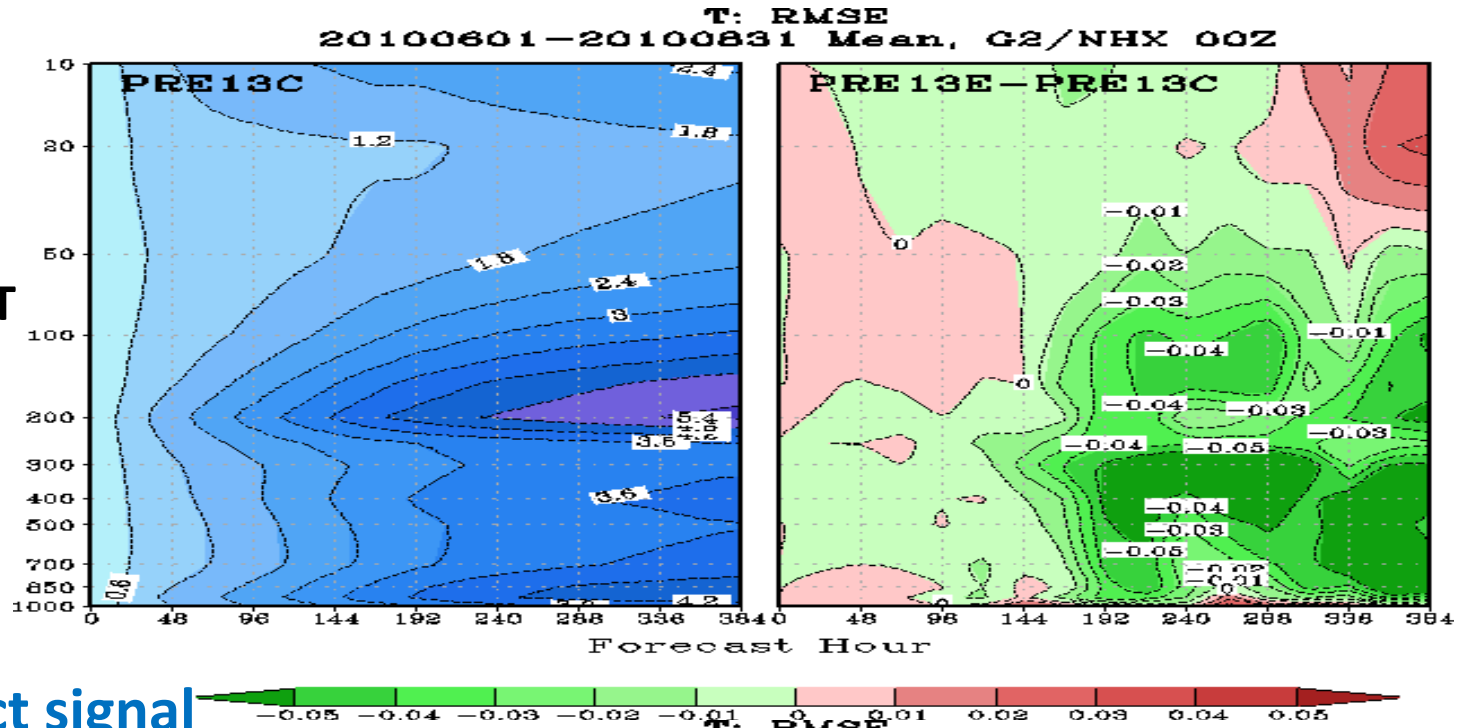
SST error leads to a bad QC performance

Quality Controls in control run



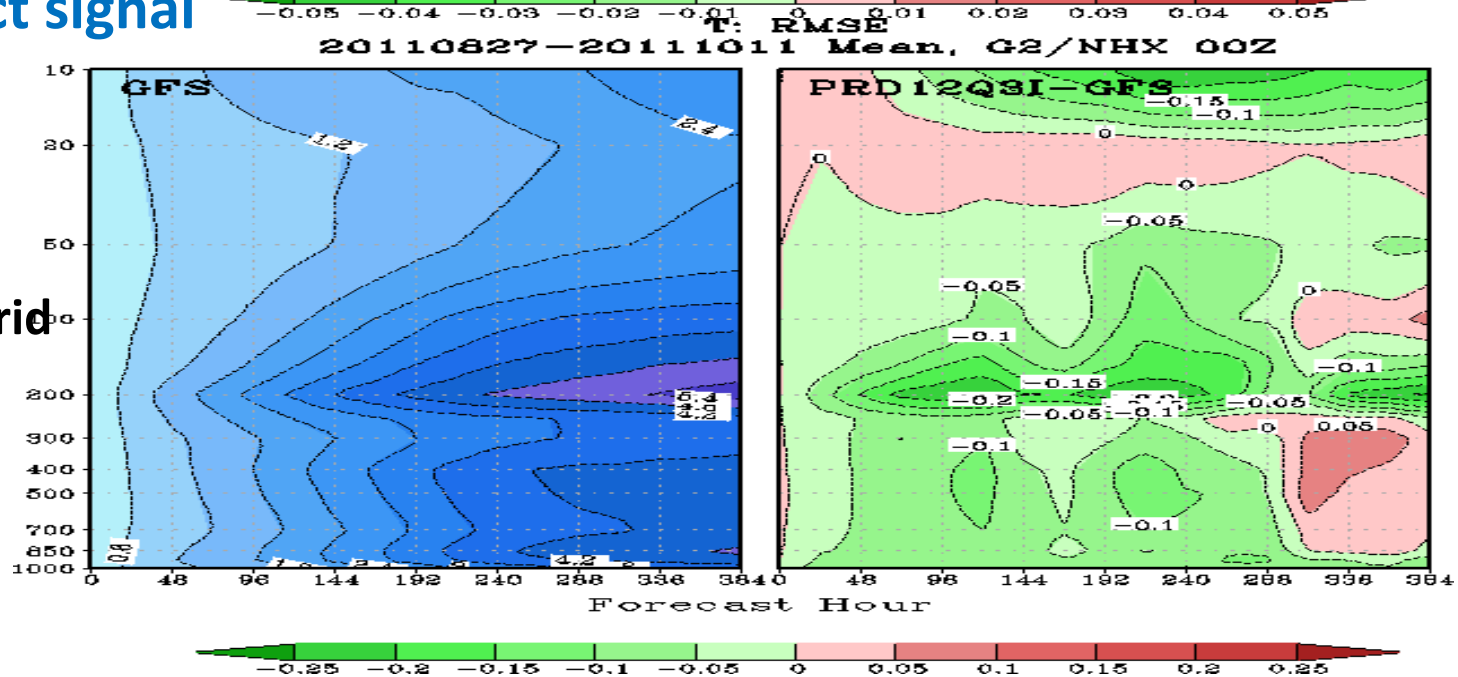
All Used

NSST

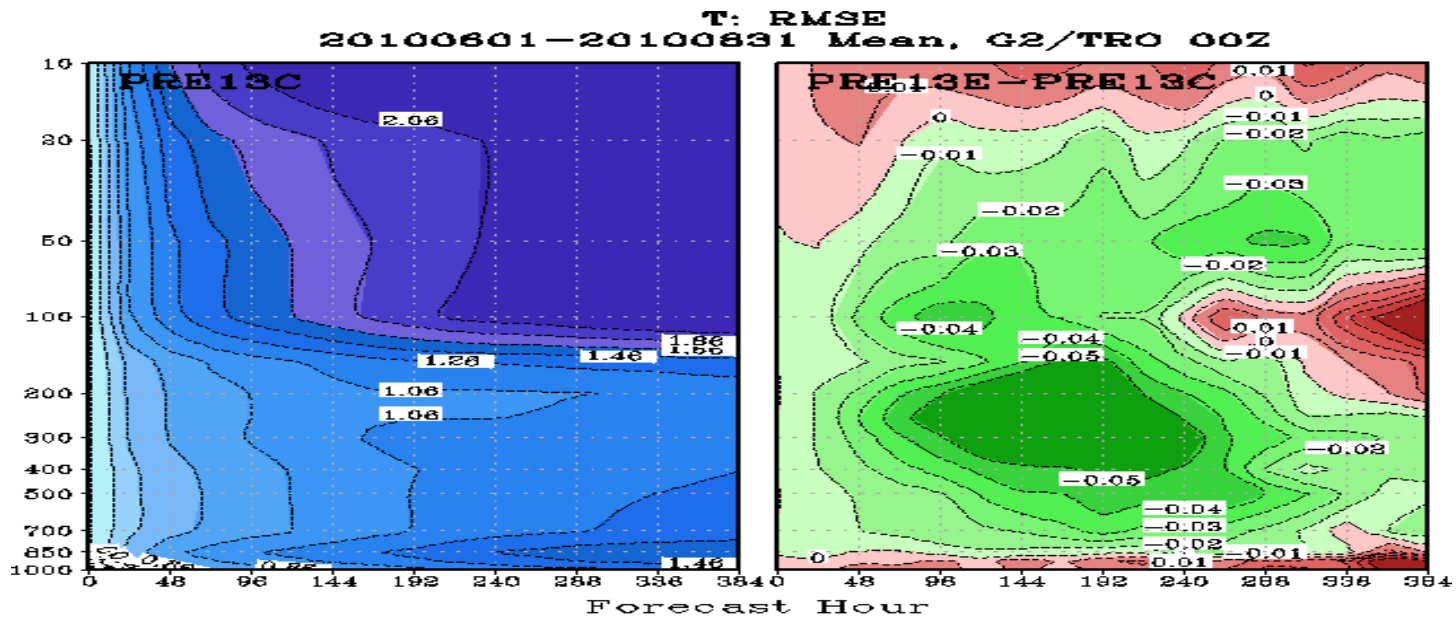


Impact signal

Hybrid

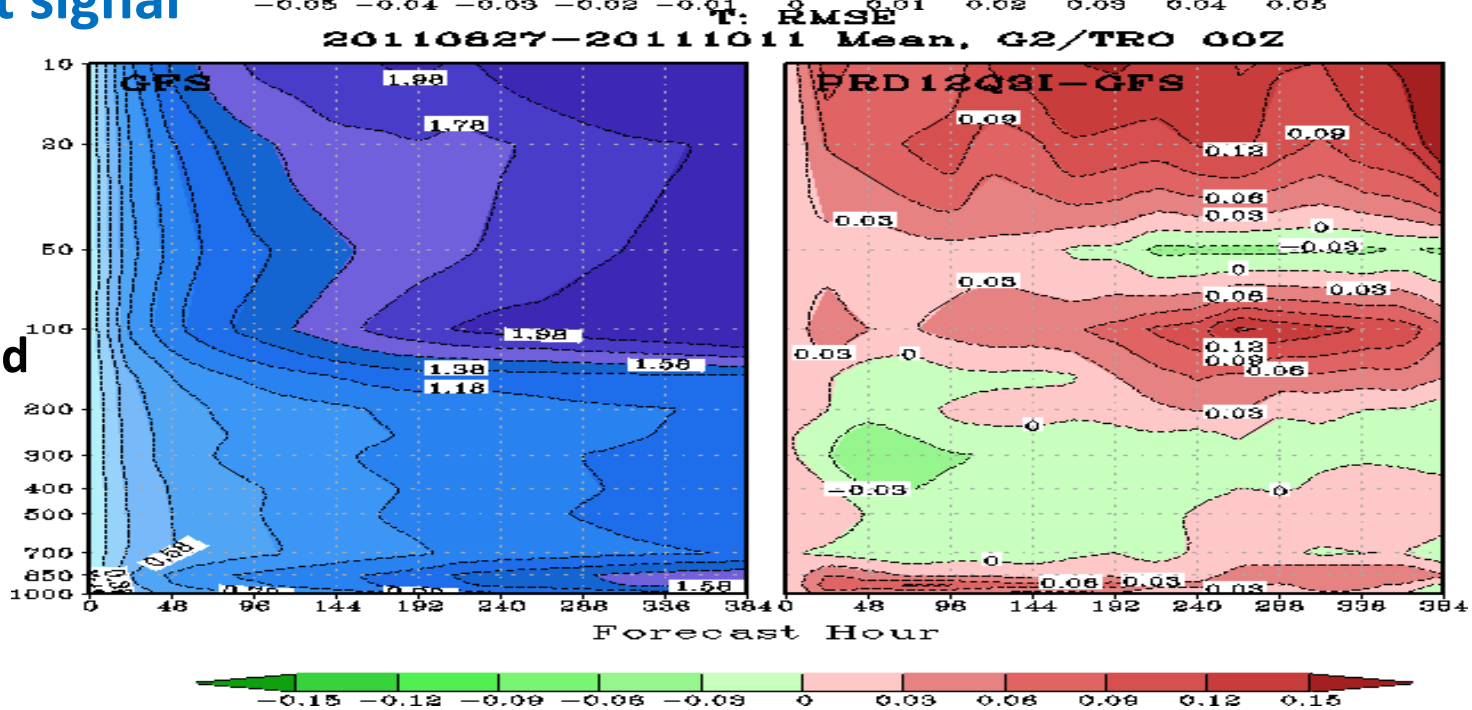


NSST

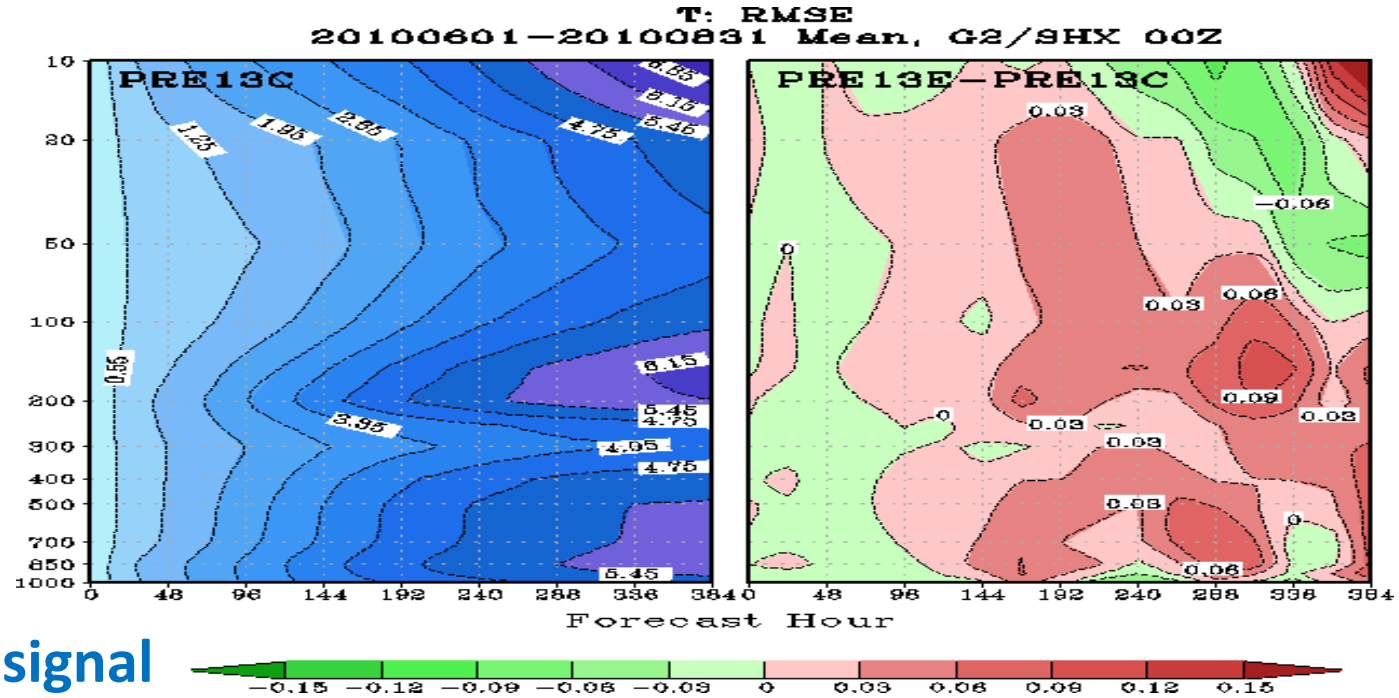


Impact signal

Hybrid

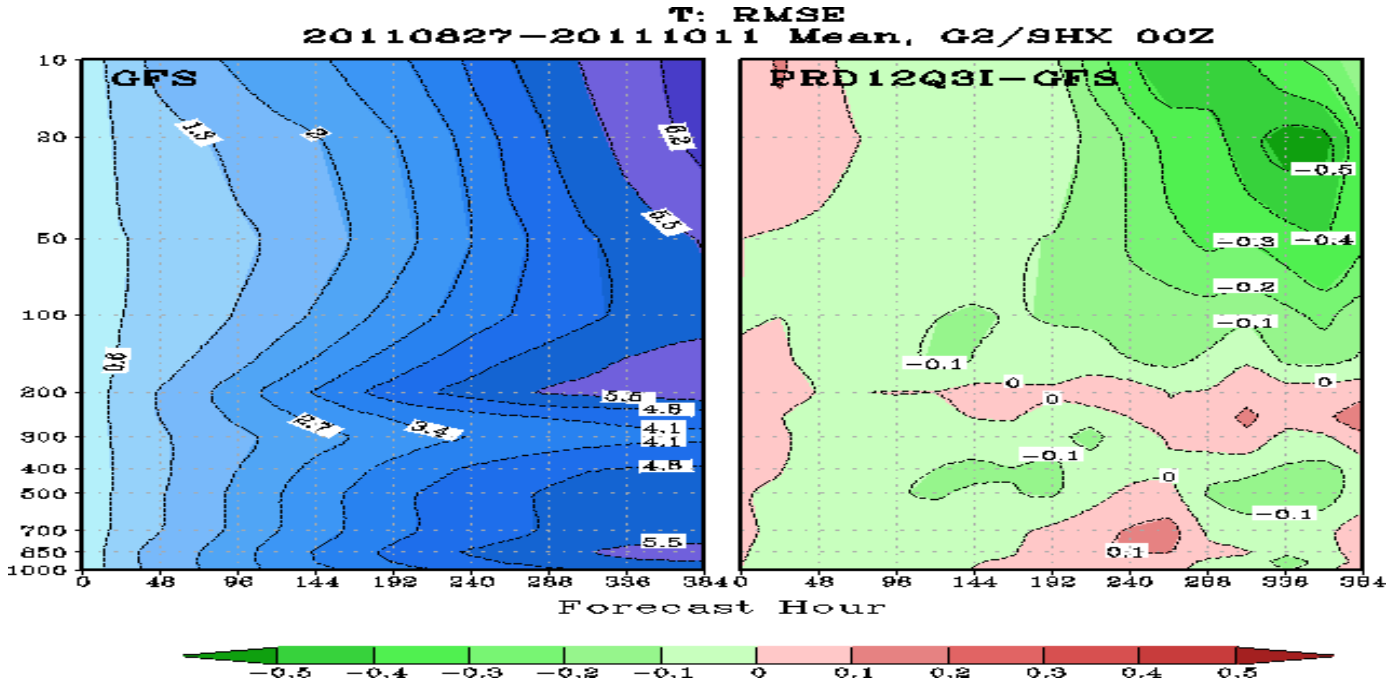


NSST



Impact signal

Hybrid



Conclusions of NSST impact on GFS

- Oceanic variables (T_f) analysis
  - Improved significantly based on statistics of O-B: $y - H(\boldsymbol{x^b})$, in terms of bias, rms and the number of the used data
- Atmospheric analysis
  - The use satellite data
    - surface channel improved based on statistics of O-B: $y - H(\boldsymbol{x^b})$
  - The impact is not limited near the surface
  - Further evaluation necessary
- Atmospheric forecasting (summer)
  - NH: positive but not significant in statistical test (95% confidence)
  - TRO: positive and significant in statistical test (95% confidence)
  - SH: the first two to three days positive and becomes negative afterwards but not significant in statistical test (95% confidence)
- Oceanic forecasting
  - Further evaluation necessary

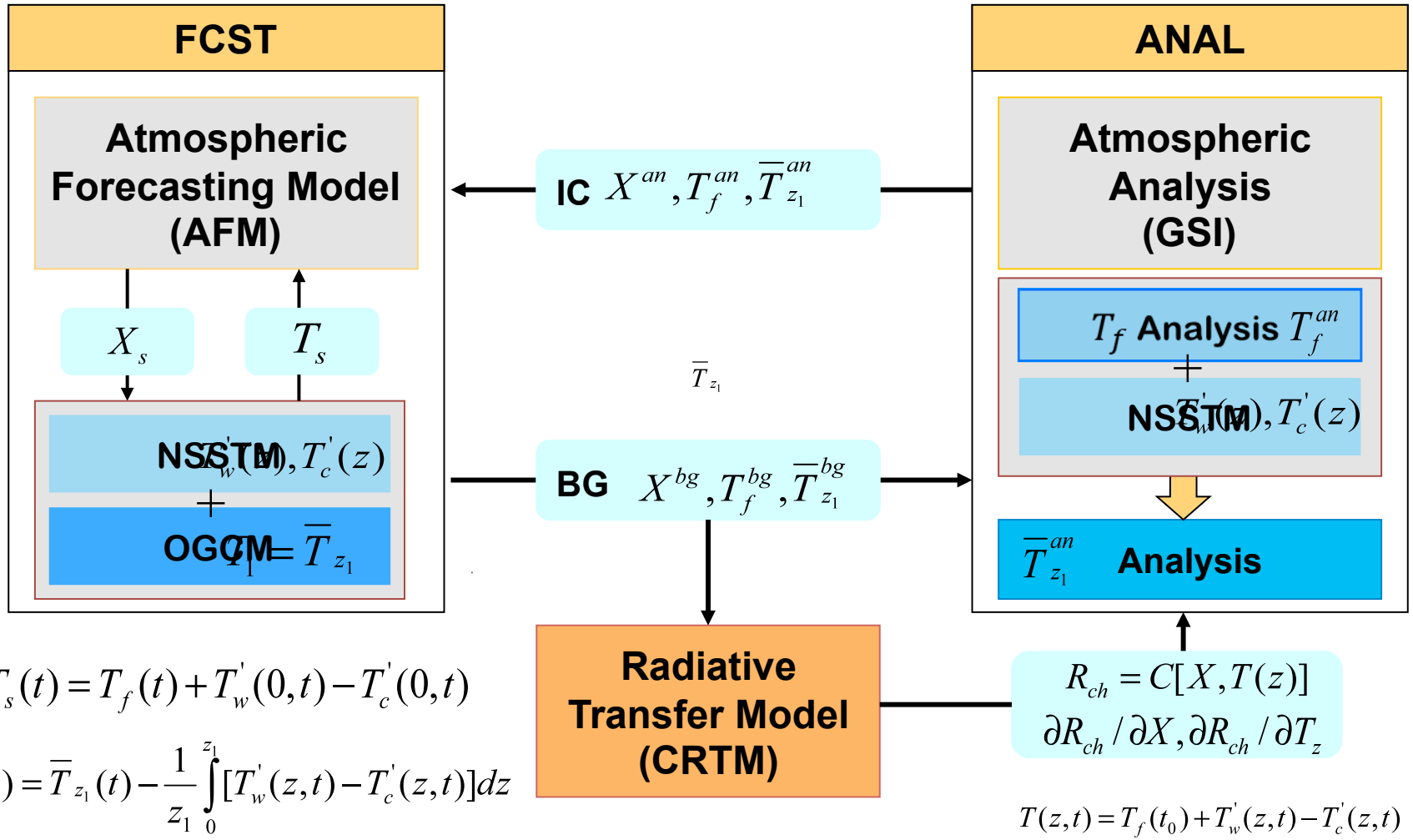
Coupled Data Assimilation

- **What does coupled data assimilation mean?**
  - Observations in one medium impacts the state of the other medium
  - Loosely coupled assimilation: assimilate in one medium and that state affects the other medium (CFS, NAVY)
  - Fully coupled assimilation: simultaneous minimization of a single cost function for atmosphere and ocean
- **NSST**
  - Add one oceanic analysis variable T_f to atmospheric analysis vector in GSI ➔ Simultaneous minimization of a single cost function for atmosphere and ocean but the correlation between T_f and atmospheric analysis variables

Combination of NSST and OGCM in CFS

- A primary problem in current air-ocean coupled model such as CFS
  - The first layer's temperature of the oceanic model ($\overline{T}_{z_1}$), which represent 10 meter mean temperature physically, is used at SST
  - An independent SST analysis is used as $\overline{T}_{z_1}$
- A primary problem in the current GFS with NSST
  - Although the GFS with NSST is a coupled system (partially) already, but T_f doesn't evolve with time since no prediction model
- Solution
  - The combination of NSST and OGCM
- Fully coupled data assimilation and forecasting (future)
    - $\overline{T}_{z_1}$ instead of T_f will be the analysis variable and is done in the ocean
    - NSST model still necessary
    - Covariance between oceanic and atmospheric variables in the coupled analysis

NSST $T(z)$ and CFS



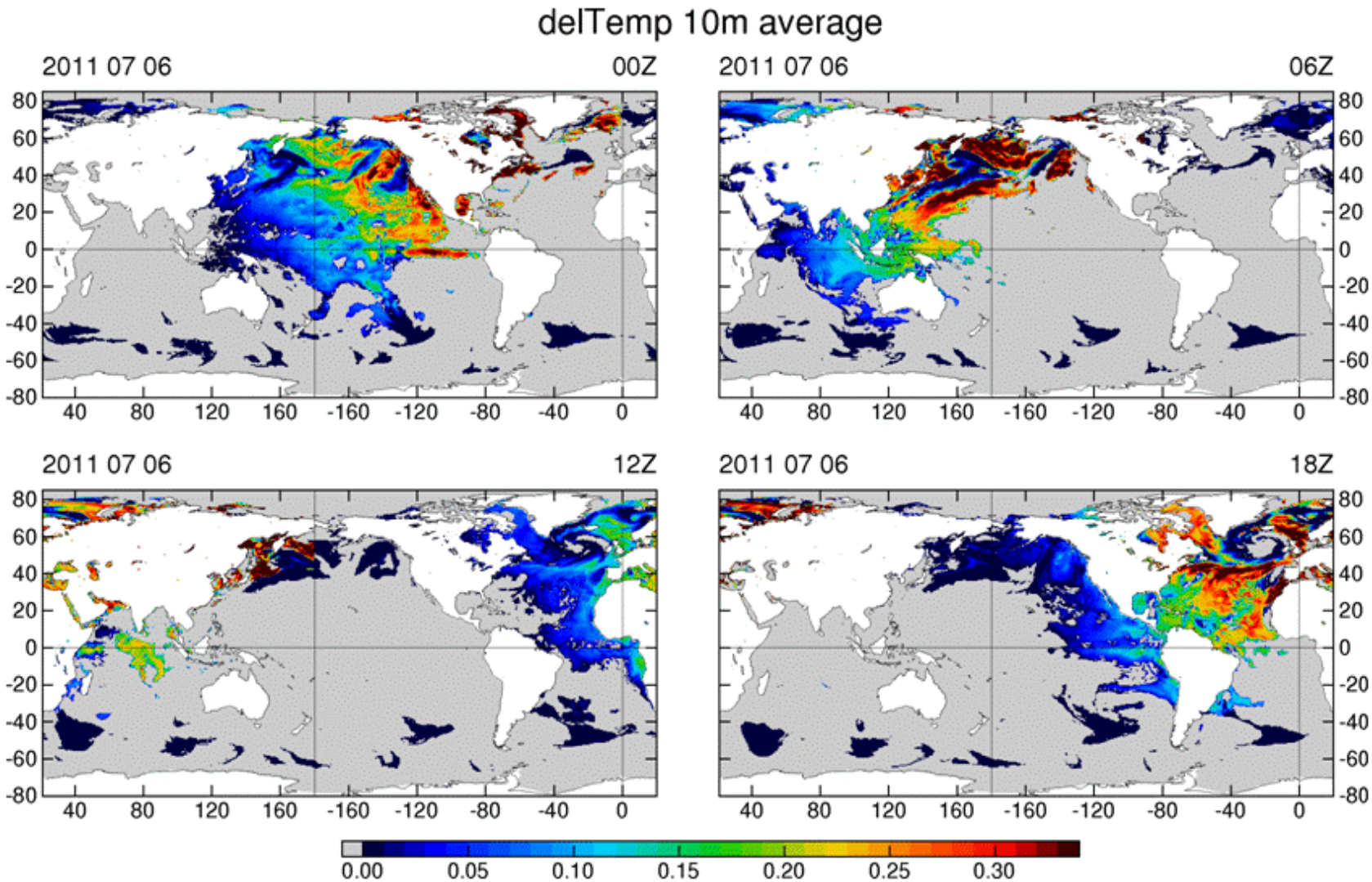
$$T_s(t) = T_f(t) + T_w'(0,t) - T_c'(0,t)$$

$$T_f(t) = \overline{T}_{z_1}(t) - \frac{1}{z_1}\int_0^{z_1}[T_w'(z,t) - T_c'(z,t)]dz$$

$$T(z,t) = T_f(t_0) + T_w'(z,t) - T_c'(z,t)$$

C : Observation operator (relate T-Profile to the radiance)

$\partial R_{ch} / \partial T_z$: Jacobi (the sensitivity of the radiance to T-Profile)

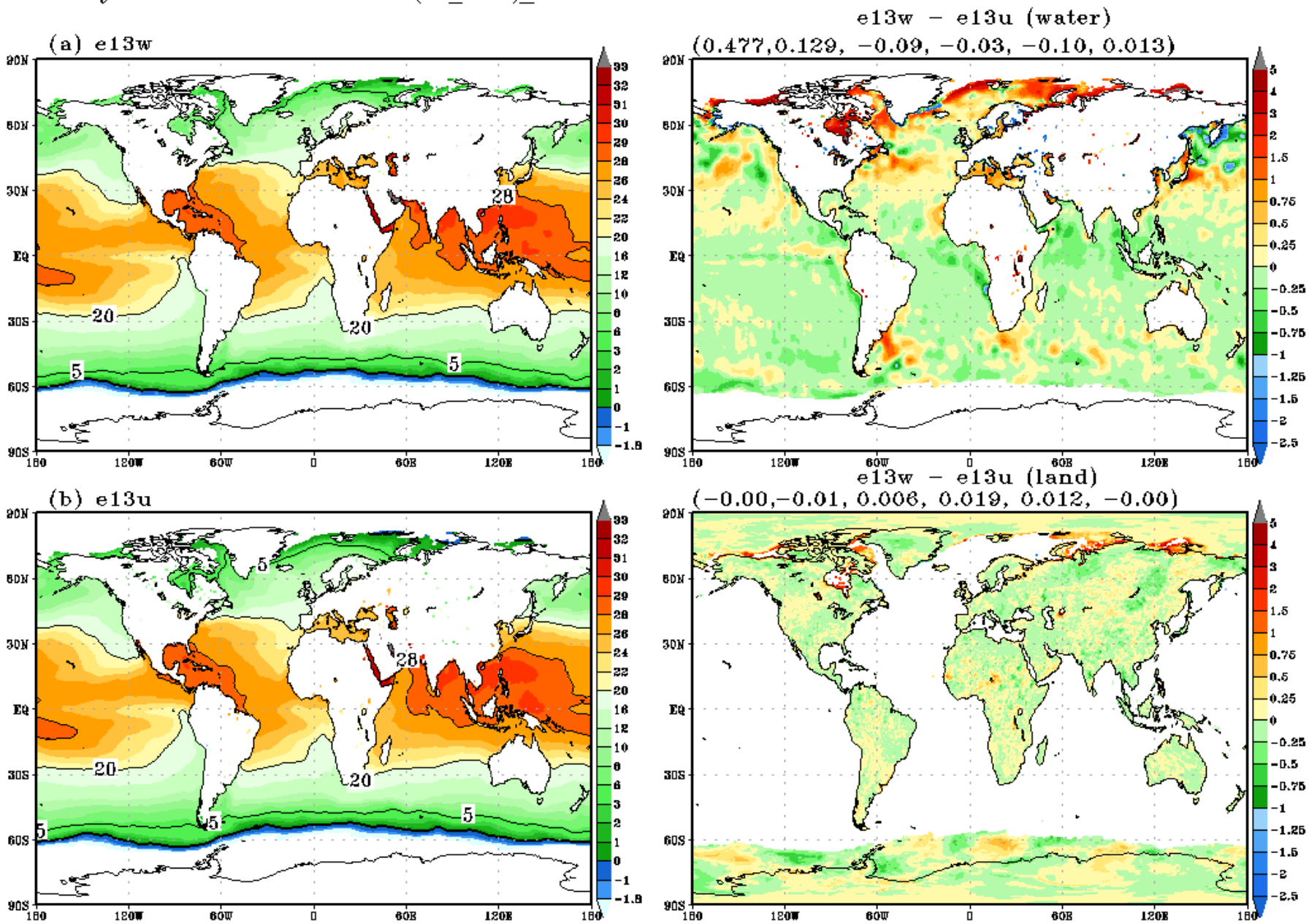


$$\overline{T}_{z_1} - T_f = \frac{1}{z_1}\int_0^{z_1}[T_w'(z) - T_c'(z)]dz$$

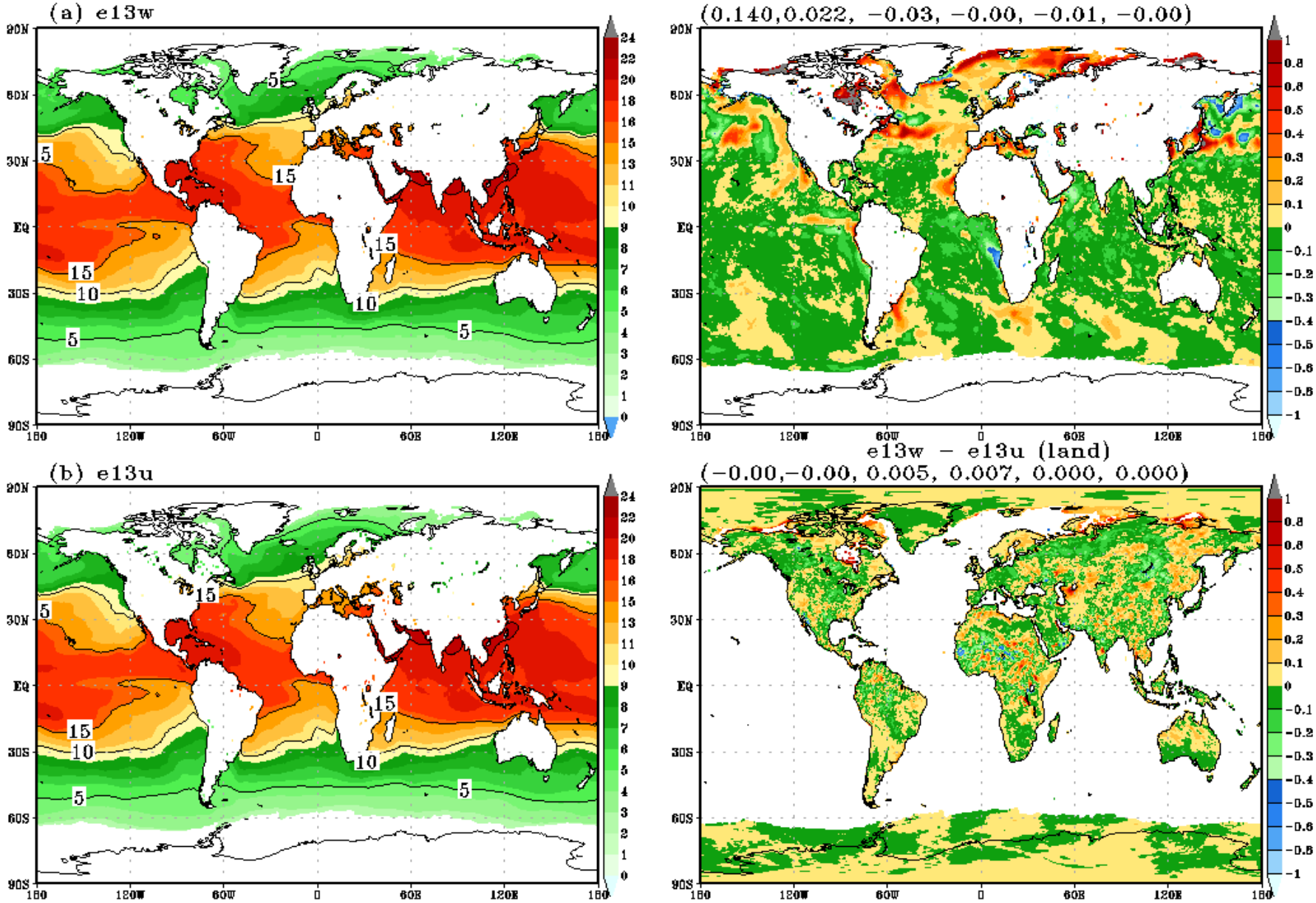
Future & Potential Applications

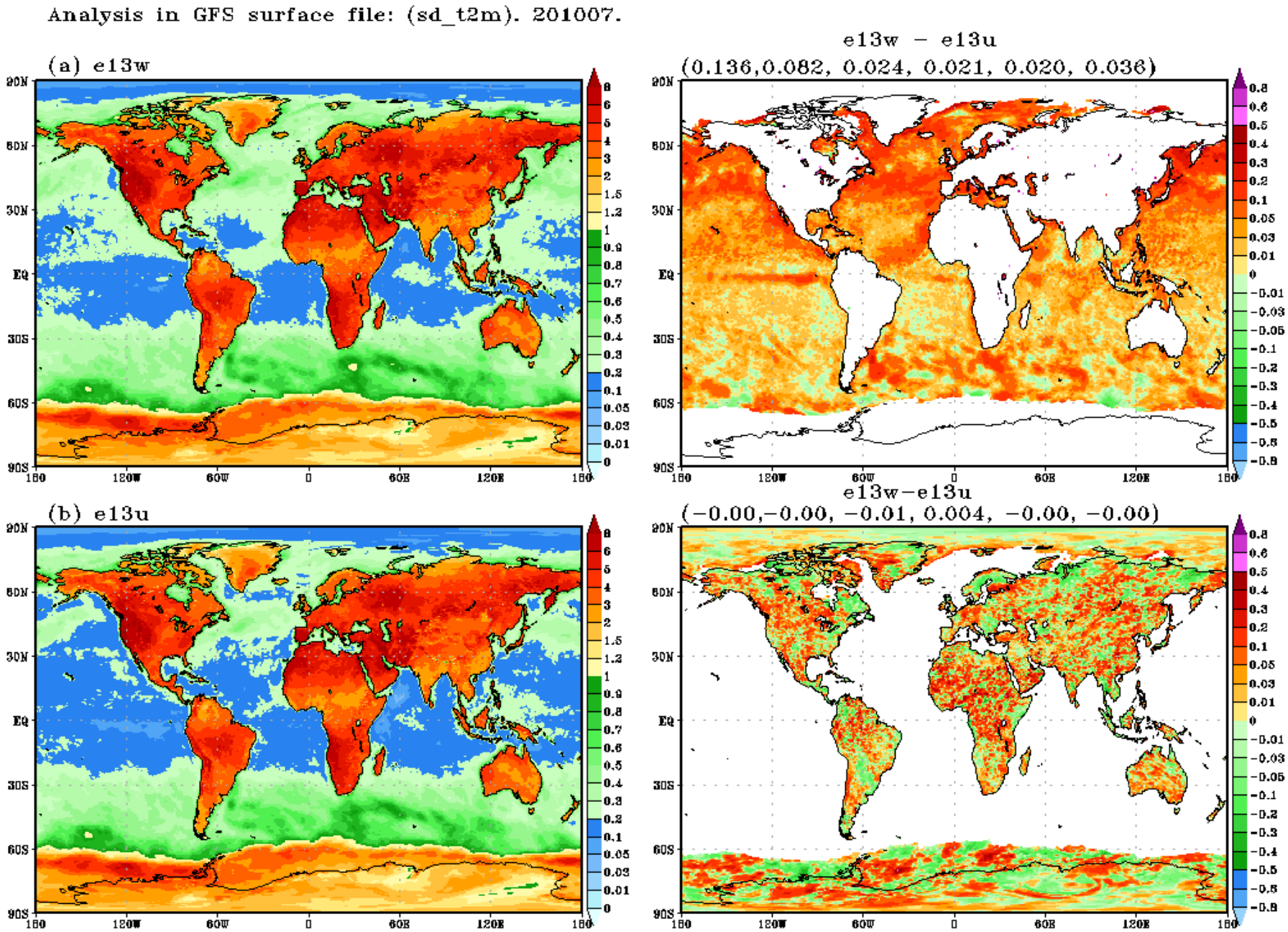
- More evaluation of NSST impact on NWP
- NSST Model improvement: Nonlinear T-Profile
- T-Profile analysis: more analysis variables (z_w)
- Coupled data assimilation
- Lake temperature analysis
- Extend Hybrid EnKF to include oceanic variable
- Climate simulation & prediction
- Applied to regional analysis and forecasting
- Hurricane forecasting
- Reanalysis

Analysis in GFS surface file: (av_t2m)_Global. 201007.

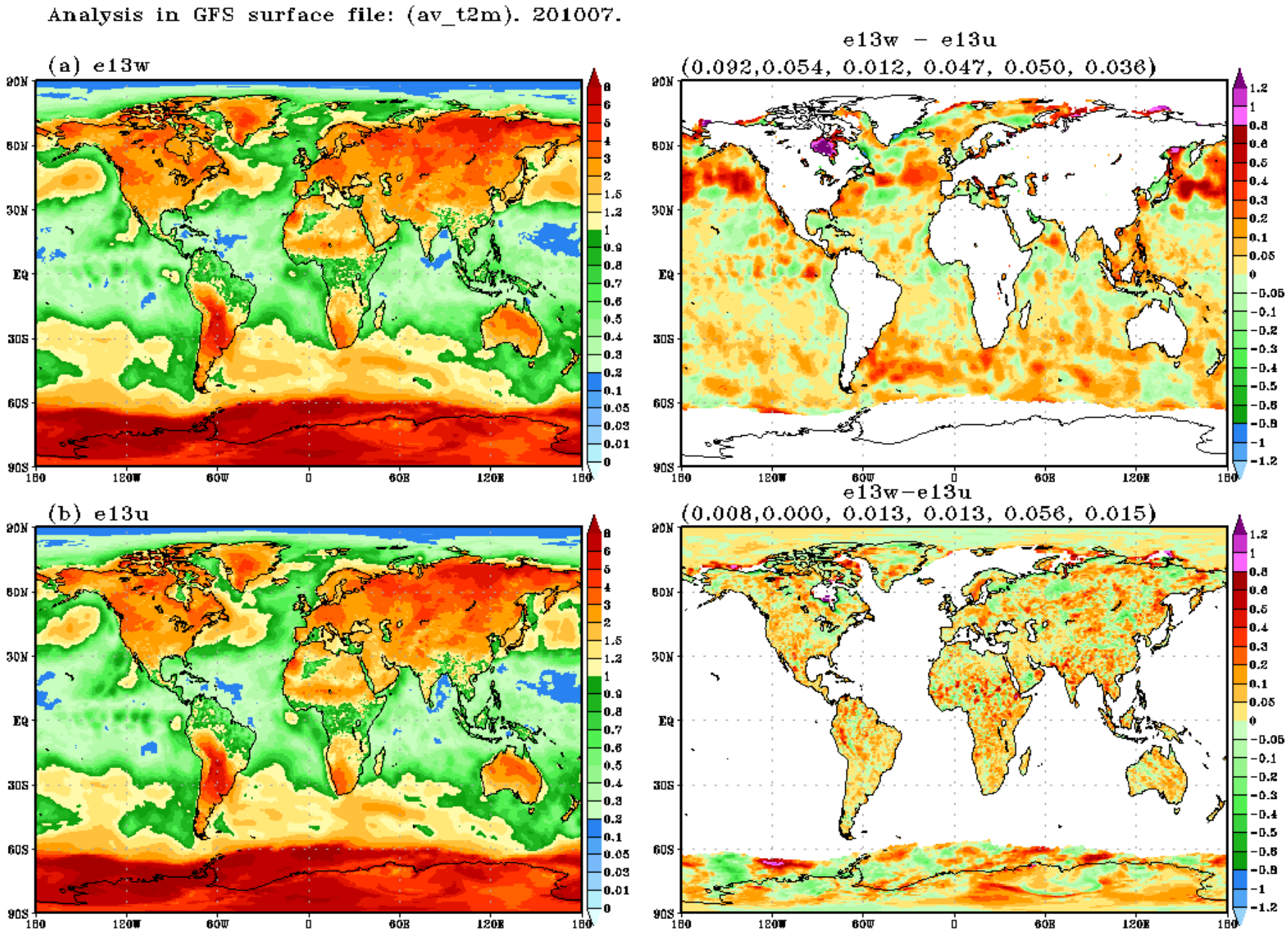


Analysis in GFS surface file: (av_q2m)_Global. 201007.
(N.Pole, N.Mid, TRO, S.Mid, S.Pole, Global). (g/kg)





Diurnal Variability of air T_{2m} in NSST & Ctrl



Day-to-Day Variability of air T_{2m} in NSST & Ctrl