Assimilating SST with an atmospheric DA system

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ECMWF Workshop on Sea Surface Temperature and Sea Ice analysis and forecast
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"Where America's Climate, Weather, Ocean and Space Weather Services Begin"

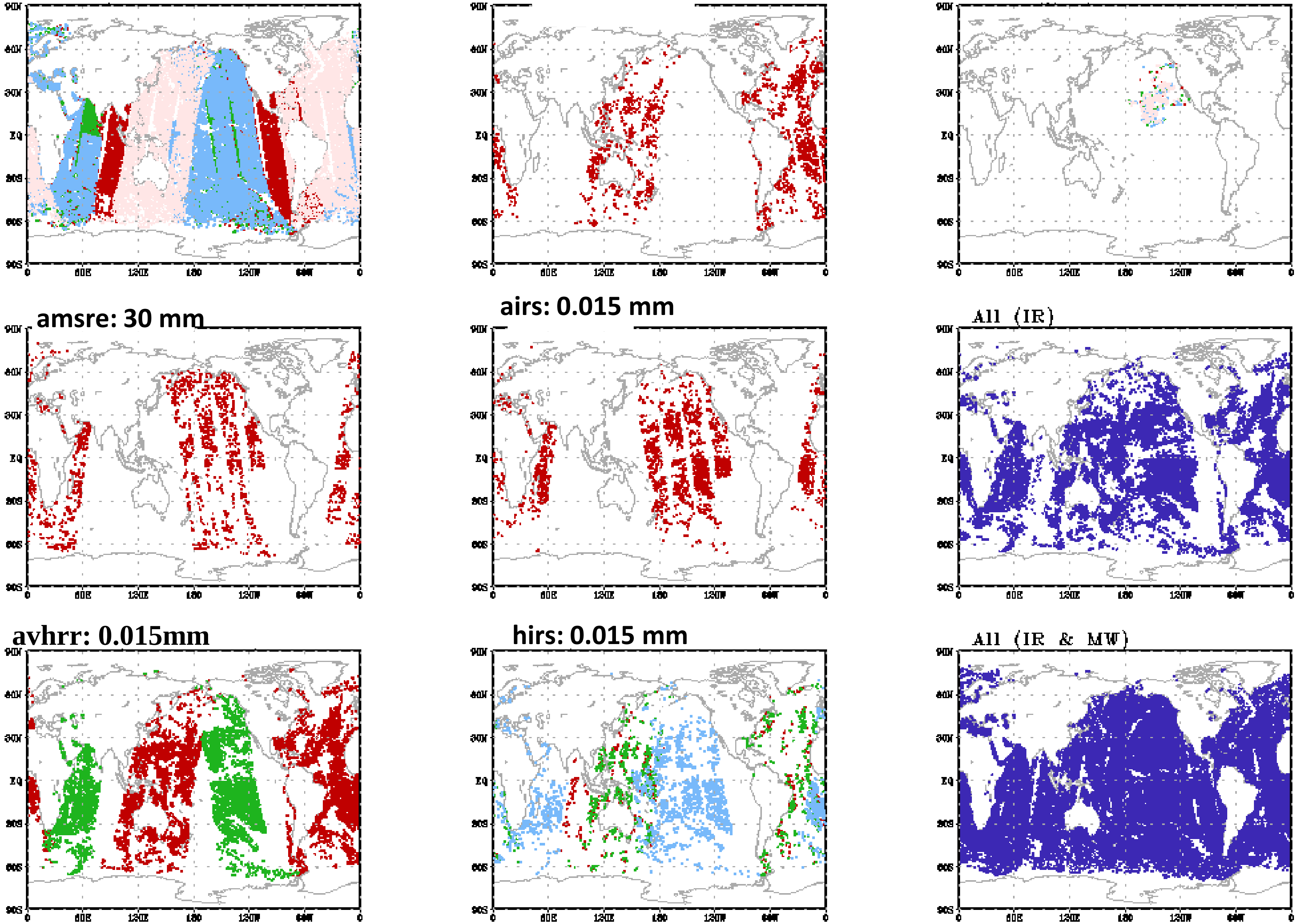
Motivation

- The SST has a significant impact on weather and climate forecasts.
  - Diurnal cycle of SST can be several degrees in low wind conditions. Impact on fluxes.
  - Use of daily mean SST analyses removes impact of diurnal cycle of SST on the forecast.
- Observations which have the significant diurnal cycle signal in them cannot be properly used. (e.g., Radiances, conventional obs.)
  - Without accounting for DC, signal can be aliased to atmospheric analysis.
  - Resolving the vertical structure in the mixed layer allows one to better use information in observations.

Observations – direct use

- Forward operator in variational problem
  - Can use Metadata when available (depth, etc.) to better describe the observation
  - Allow observations to be used directly without adjustment (retrievals) to make them more like the analysis variable.
  - Can account for non-ocean signals (e.g., atmosphere, aerosols, clouds, etc.).

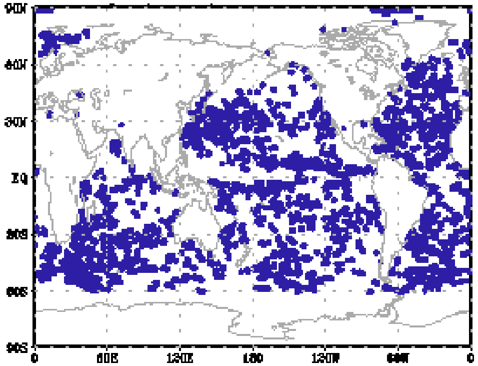
6-hour time window centered at 00Z, 5/22/2010



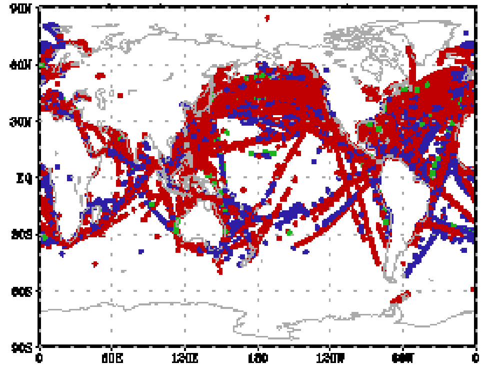
Satellite observations: coverage and skin-depth

13 day period in May 2010

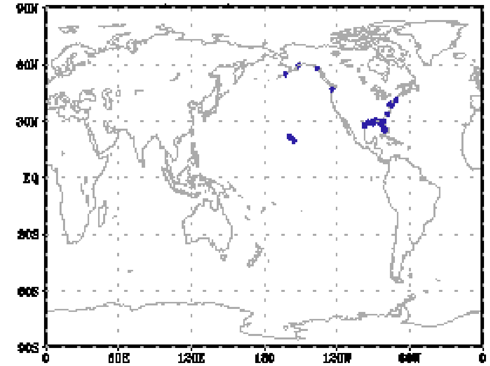
Drifting Buoy: 0.2 m



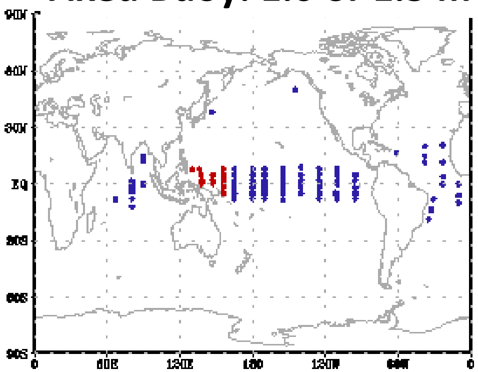
Ships: 1.0 – 3.0+ m



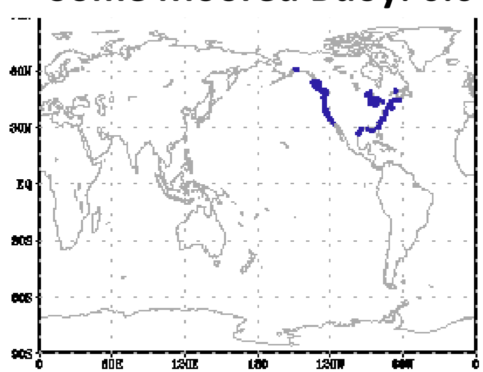
LCMAN: 1.0 m



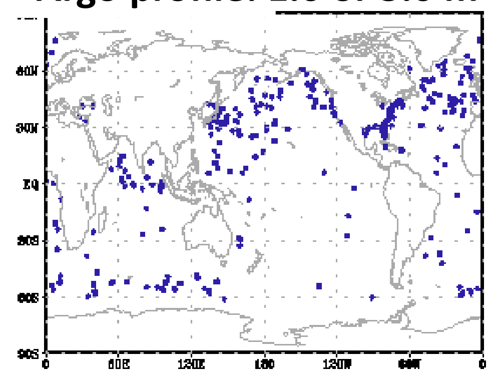
Fixed Buoy: 1.0 or 1.5 m



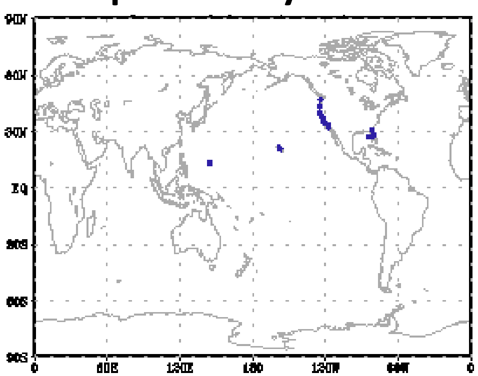
Some Moored Buoy: 0.6 m



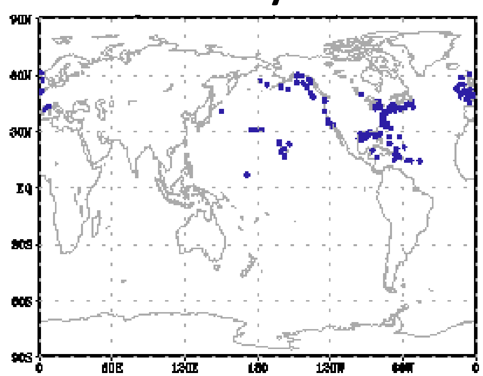
Argo profile: 1.0 or 5.0 m



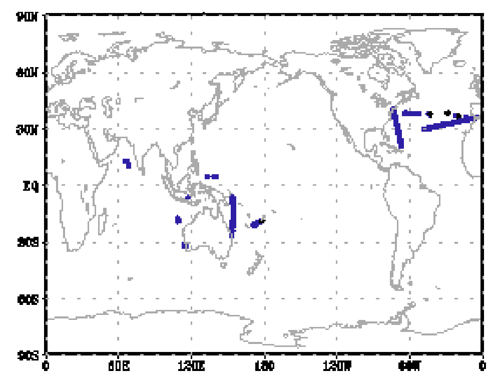
Scripts Mbuoy: 0.45m



Other Mbuoy: 1.0 m

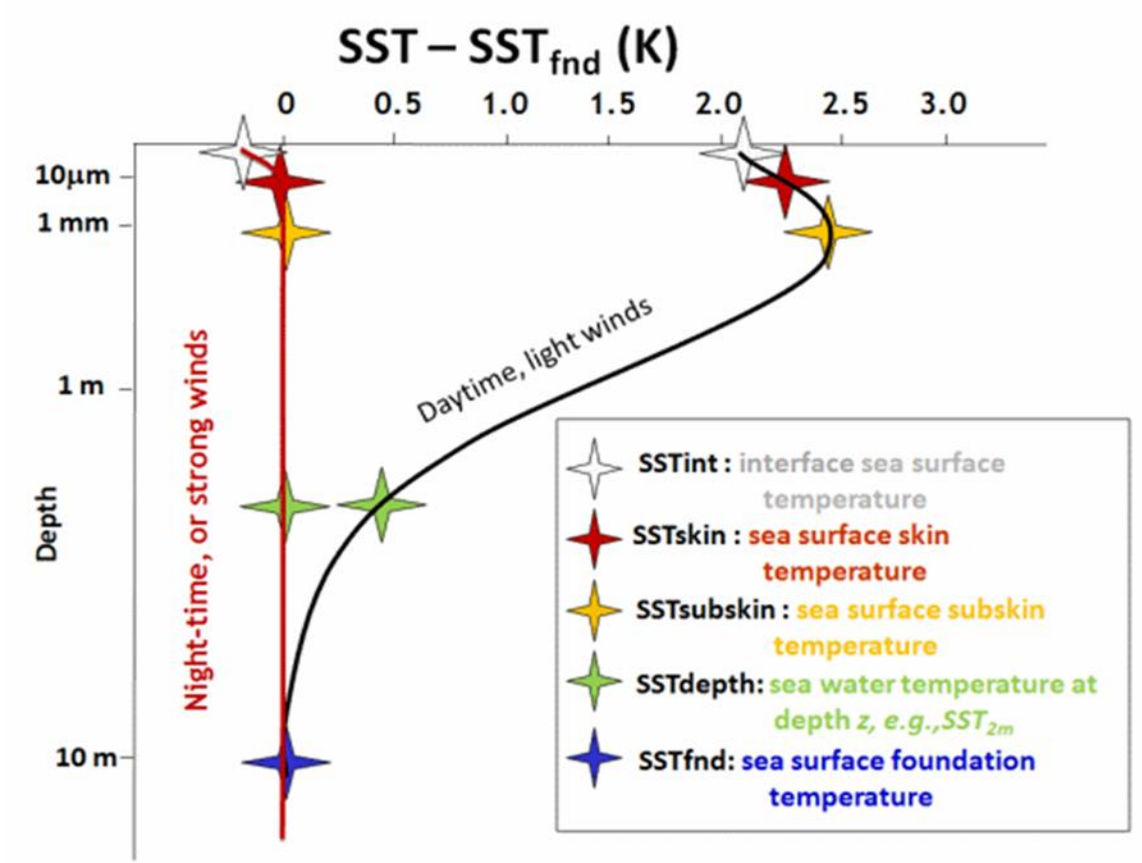


XBT: 1.5 – 5.0 m



In Situ sea temperature observations: coverage and depth

Near-surface SST model



Near-surface SST model

- In the vertical temperature is defined as

$$T(z) = T_f + T_W\,(z) + T_C(z)$$

where

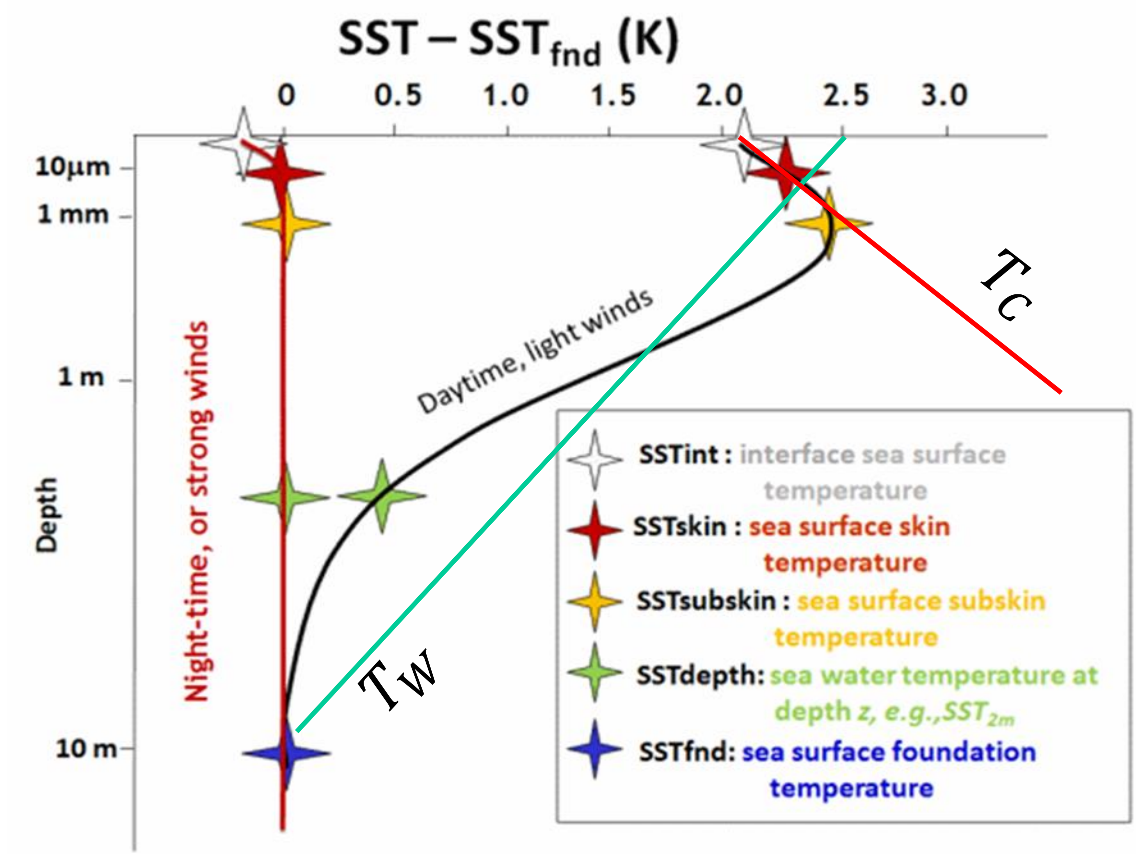
T_f - is the foundation temperature

T_W - is the Thermal Skin Layer (based on Fairall et al. 1996) – Warming

T_C - is the Diurnal Thermocline Layer (based on Price et al. 1986) - Cooling

- Both Layer models are assumed to be linear
- Cooling and warming forced by fluxes from atmospheric model
- Details in Li et al.(in preparation)

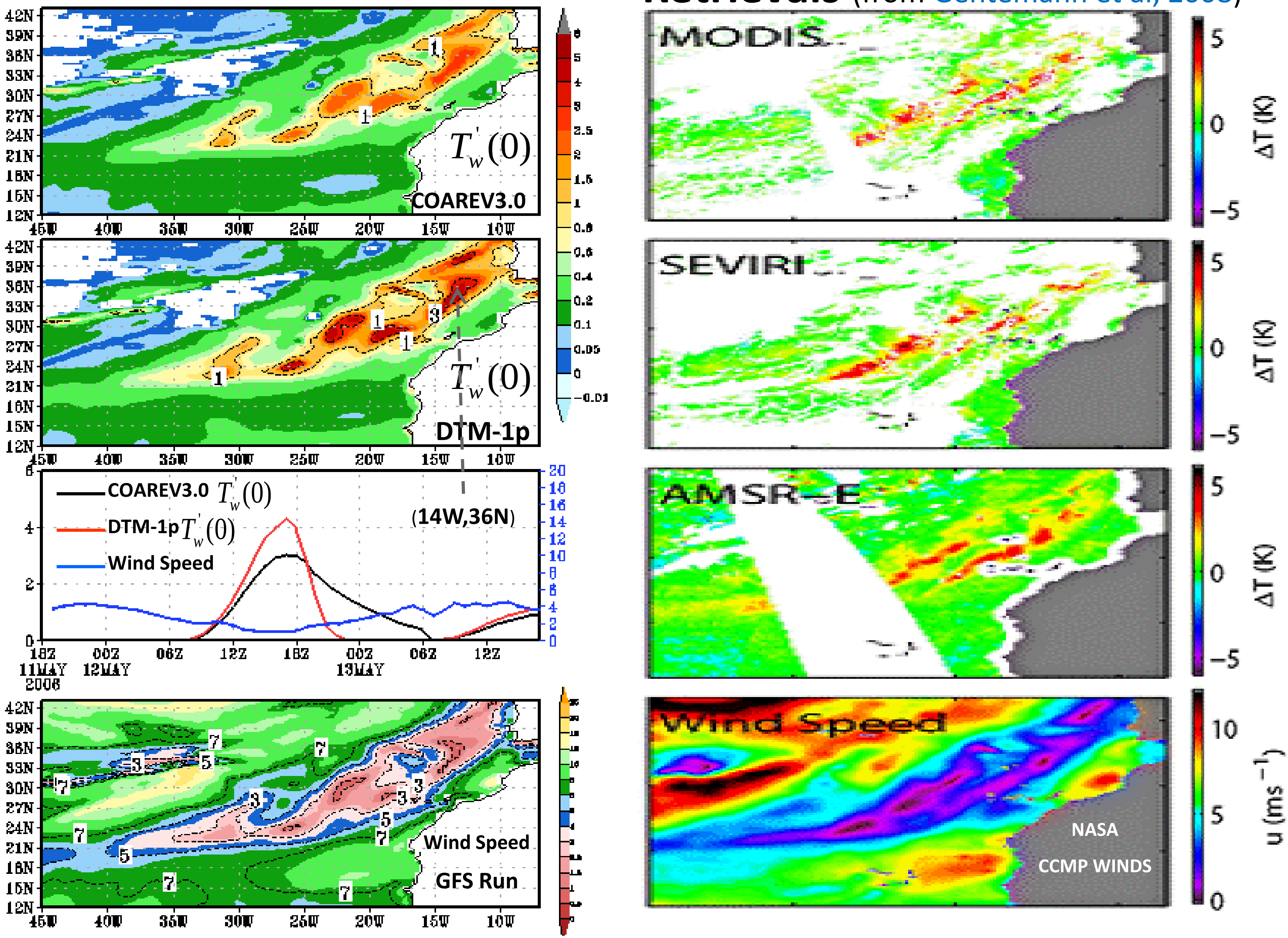
Near-surface SST model



SST diurnal warming: 14Z, May 12, 2006

Simulation

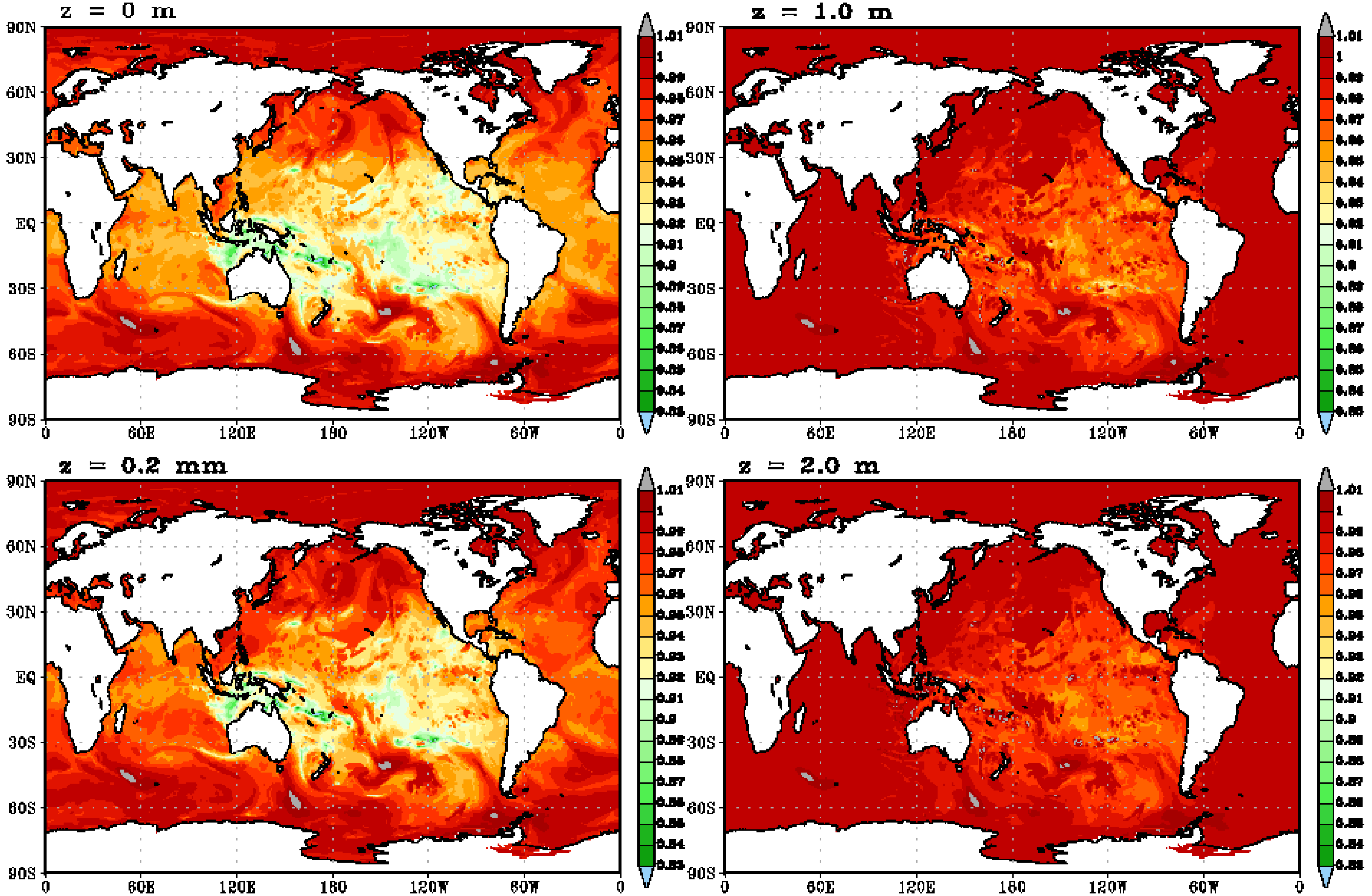
Retrievals (from Gentemann et al, 2008)



NSST in Hybrid EnKF GSI

- Analysis performed as part of operational global atmospheric hybrid EnKF variational system.
- T_f is the control variable and T(z) is calculated using the NSST model
- T_f analysis is done using the static background 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
  - SST spread in the ensemble due to differences in forcing.
- The static covariance between the ocean (T_f) and atmospheric variable are set to zero, but atmosphere and ocean analysis are not independent due to forward model.

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

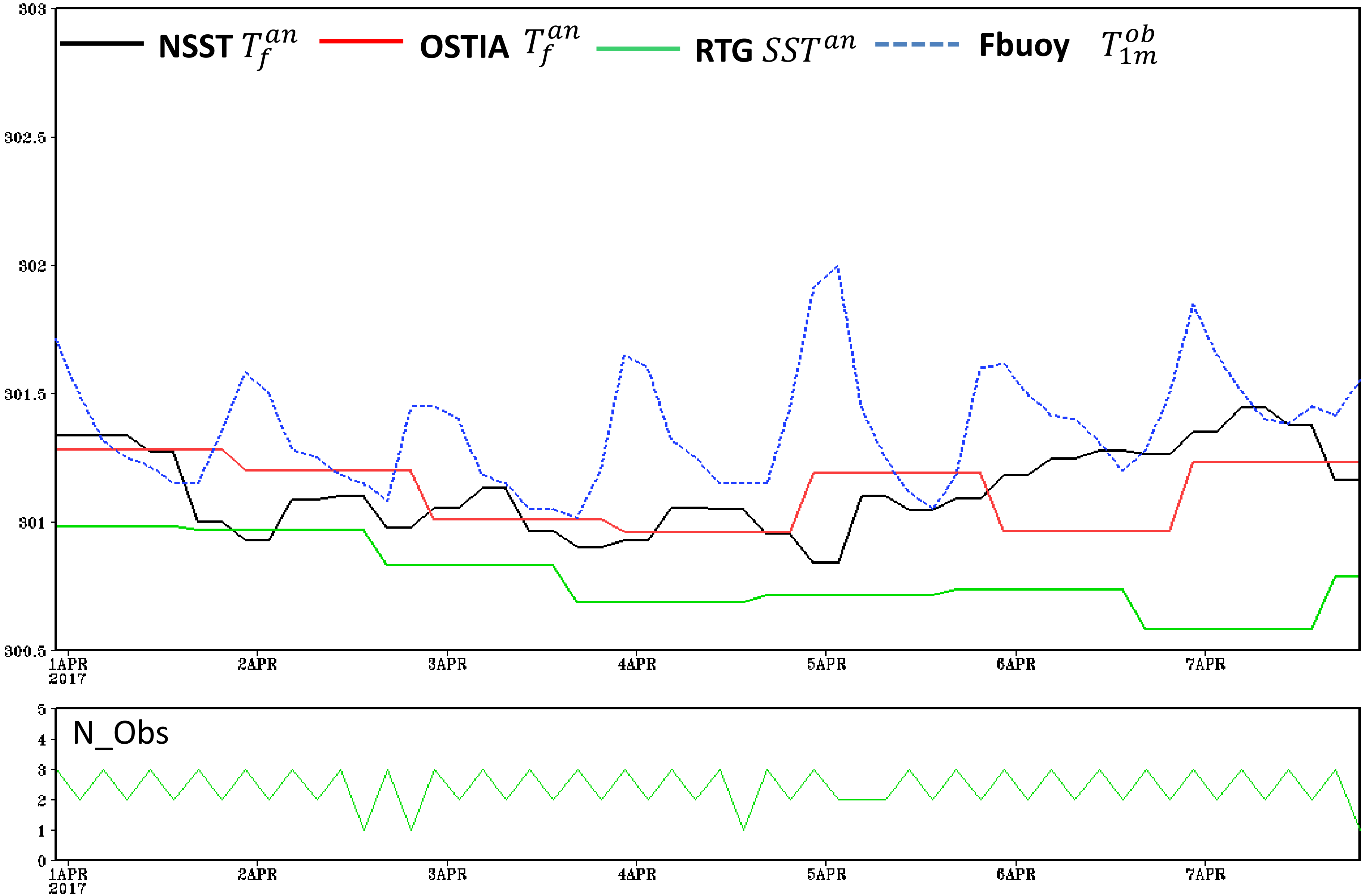


Verification

- **Difficult to verify – no truth**
- **Validating diurnal cycle**
- **Comparison of short forecasts to the observations**

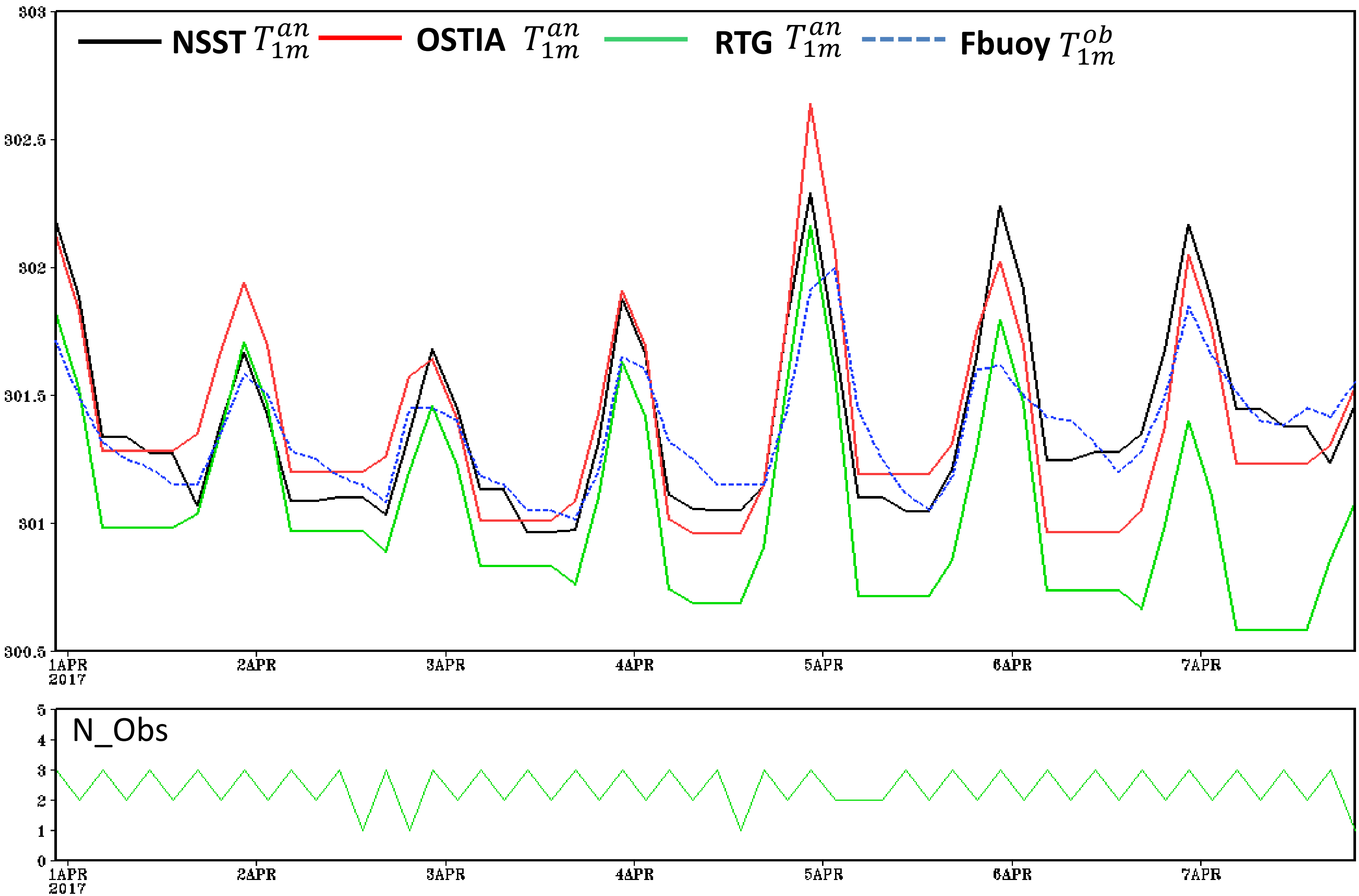
Time series of the analyzed T_f/SST and observed T (z=1m)

22:30Z, 31Mar2017 to 19:30Z, 07Apr2017, 3-hourly.

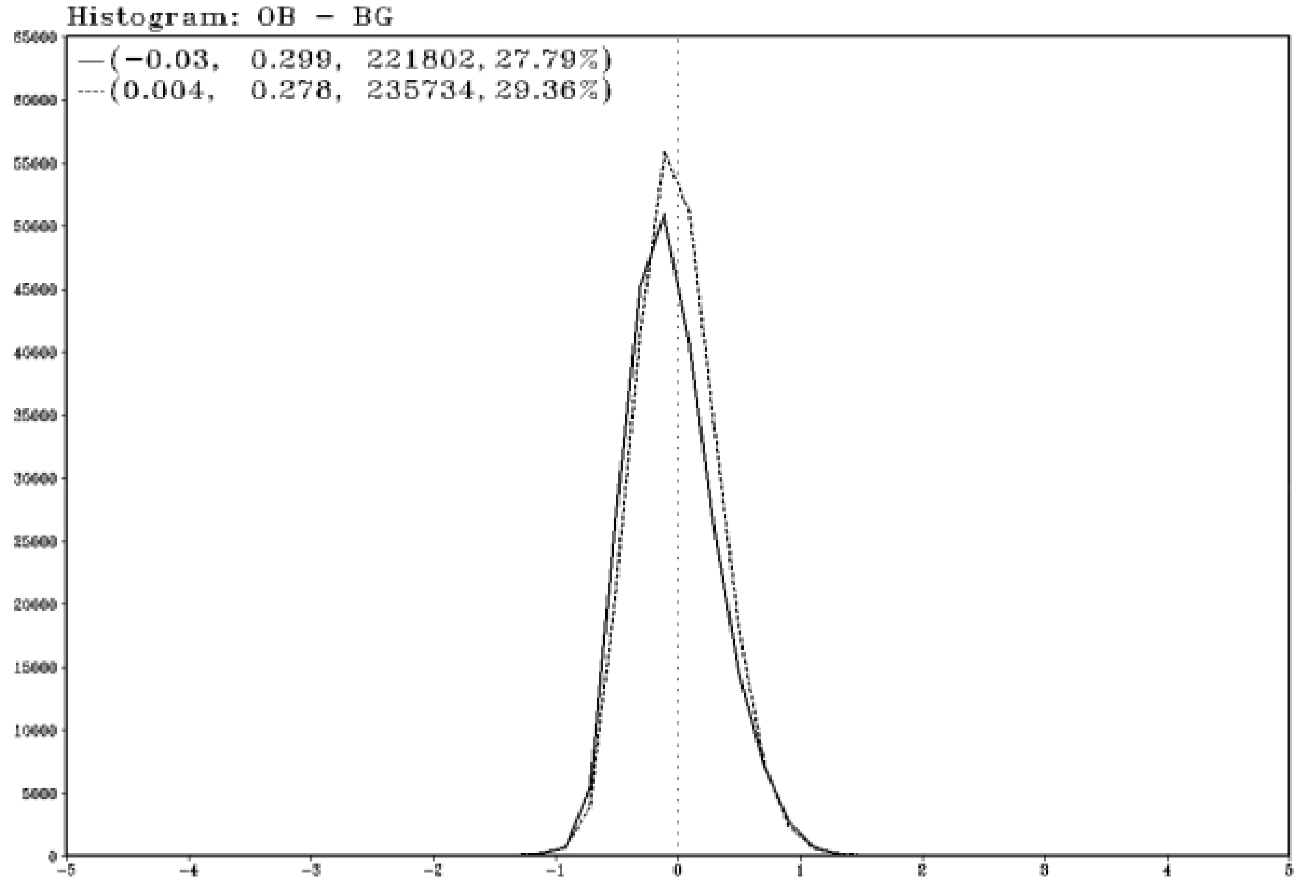


Time series of the analyzed and observed sea temperature at z=1m

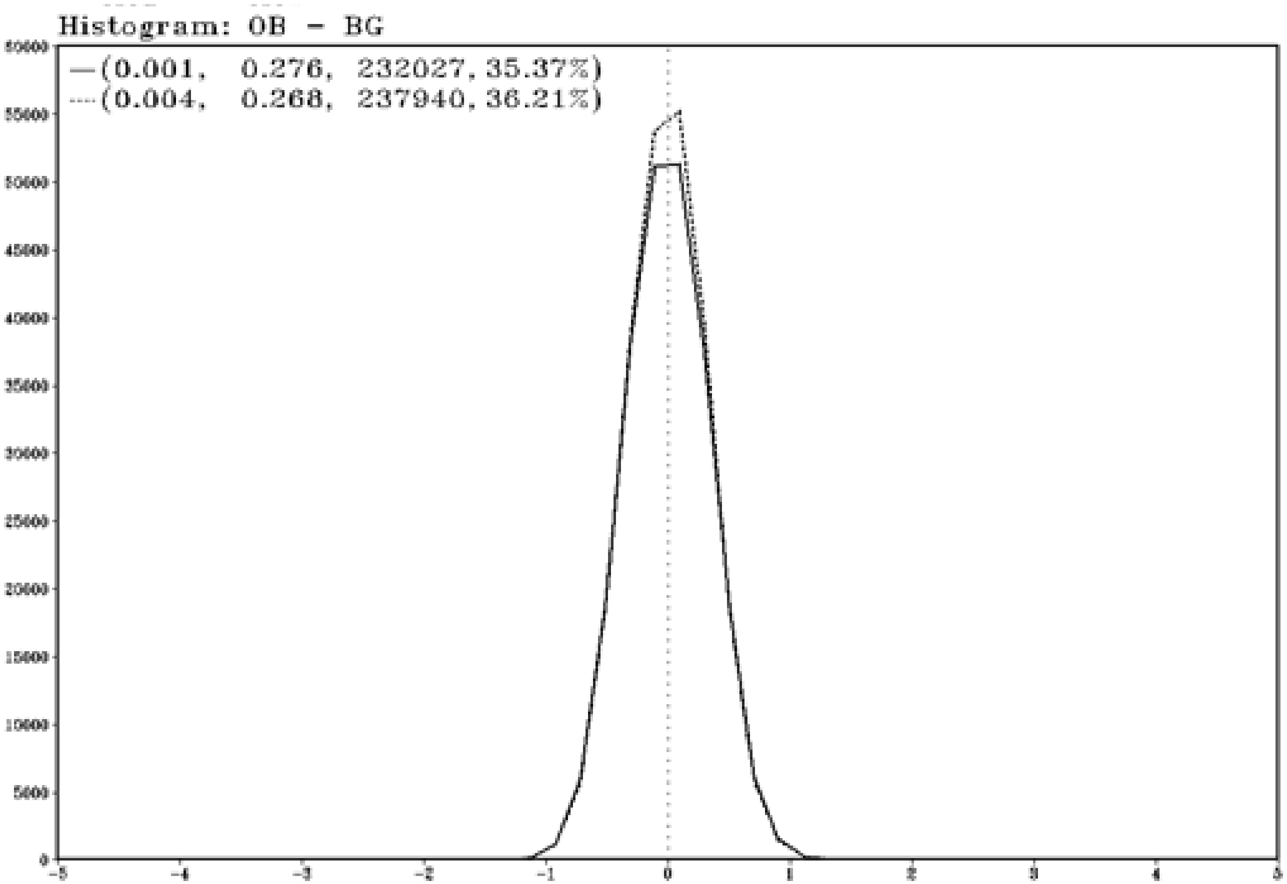
22:30Z, 31Mar2017 to 19:30Z, 07Apr2017, 3-hourly.



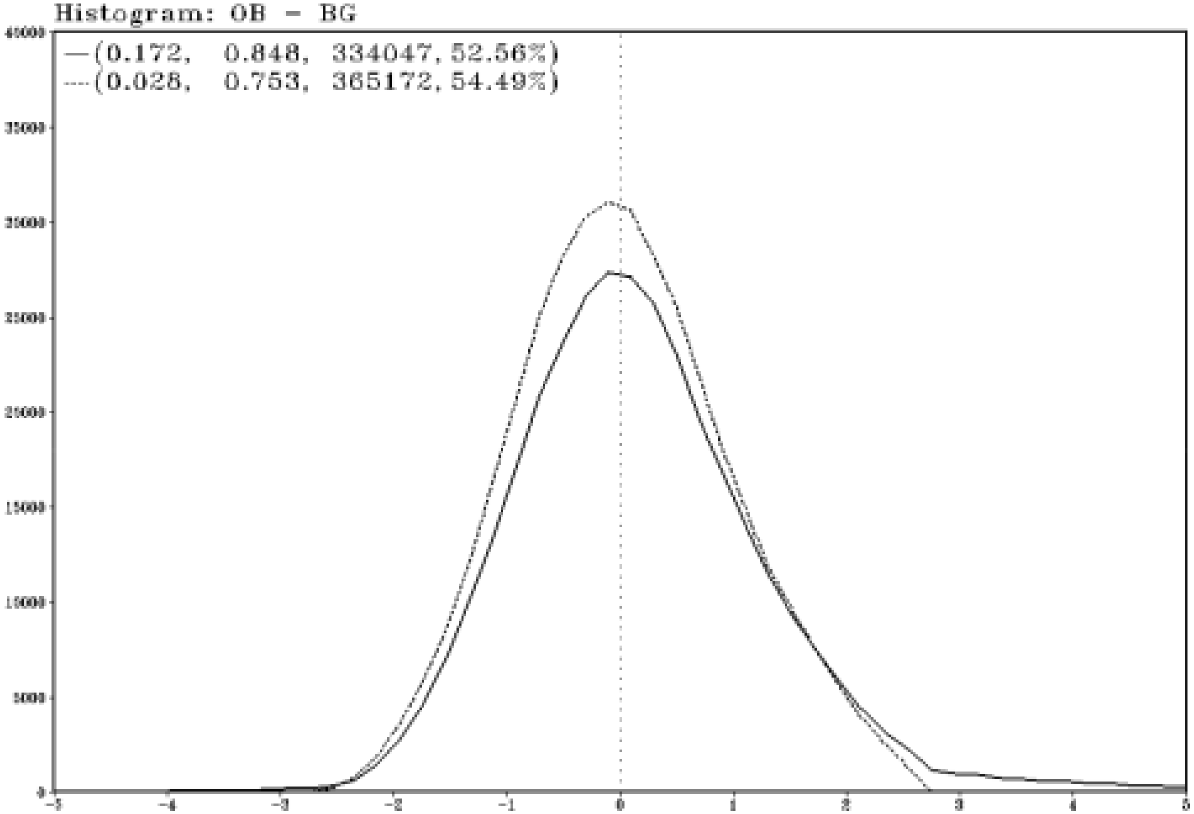
N-18 AVHRR Ch. 3



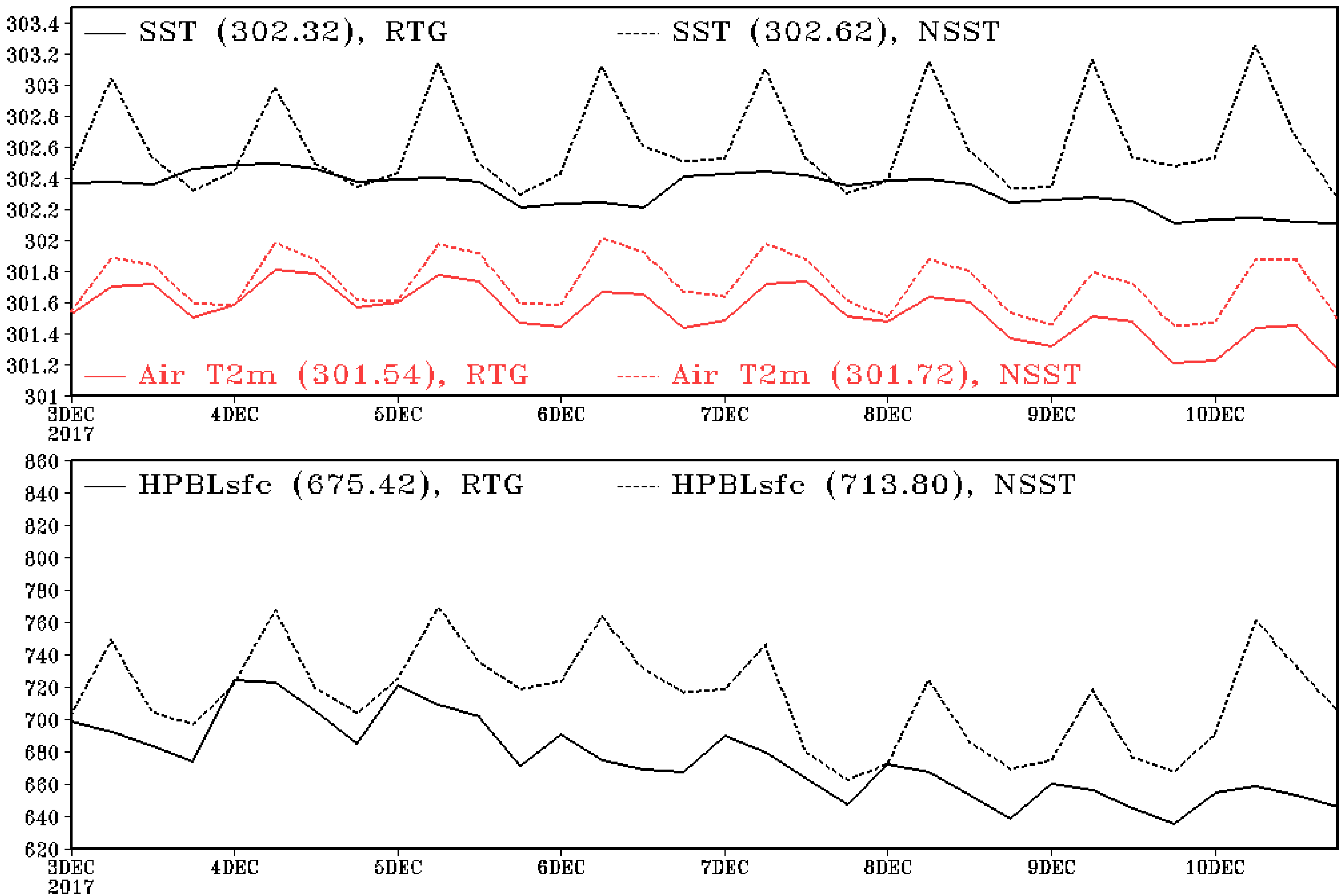
Metop-a IASI ch. 208



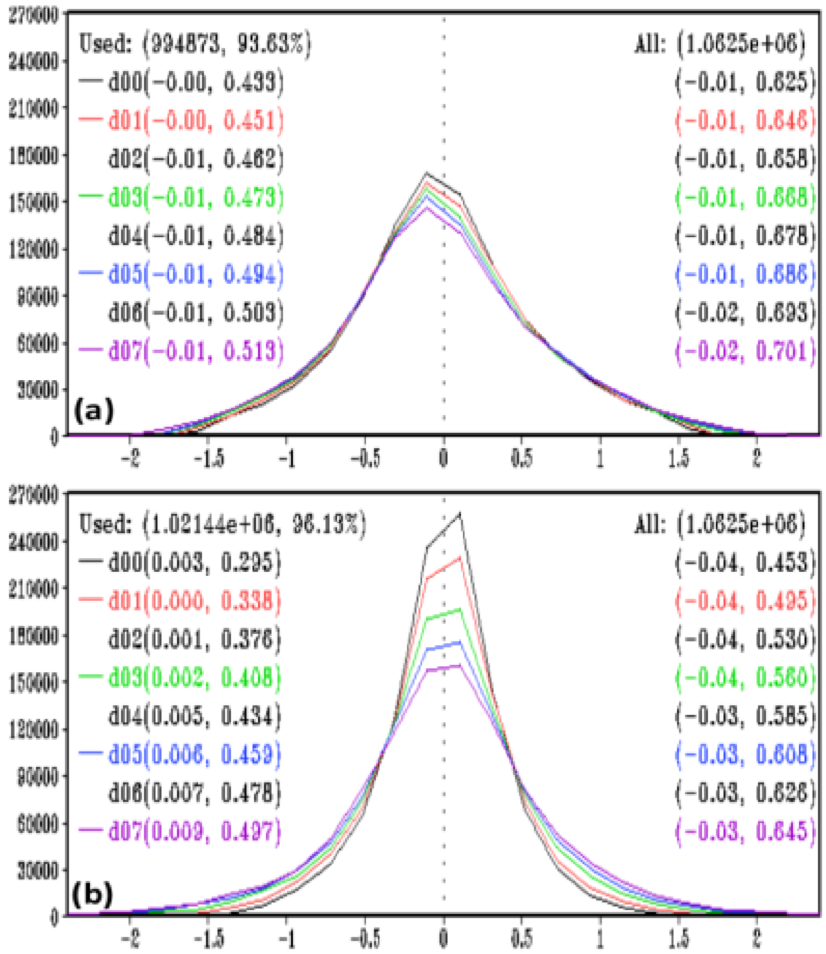
AMSR-E Ch. 1



Time series of SST, Air T2m & planetary boundary layer height. Water.
Phillipine: Lon (90.0,150.0), Lat (-15,15.0). 00Z03Dec2017 to 18Z10Dec2017. 6-Hourly.



Verification of model forecasts vs. Buoys
Retention of information by model



RTG

NSST

Verification

- **Oceanic analysis and prediction**
  - Positive – improved fit to observations
- **The use of satellite data (O-B)**
  - Slightly Positive – more observations used with smaller RMS
- **Weather Prediction**
  - Neutral for NH and SH, positive for tropics (esp. surface pressure)
  - Slightly positive when verified against conventional observations

Final Comments and issues

- Included in the operational global model on July 19, 2017.
- Some positive impact noted in the tropics. Mid-latitudes neutral.
- Extension to Hybrid (currently only static background term)
- Placement of observations (shallow buoys in coastal regions)
- Coupled ocean/atmosphere system – should it be integrated into ocean model.

Backup Slides

Derivation of Diurnal Thermocline Model (DTM)

$$\frac{\partial T}{\partial t} = -\frac{1}{\rho_o c_p}\frac{\partial F}{\partial z} - \frac{1}{\rho_o c_p}\frac{\partial I}{\partial z}$$

$$\frac{\partial S}{\partial t} = -\frac{\partial M}{\partial z}$$

$$\frac{\partial u}{\partial t} - fv = -\frac{1}{\rho_o}\frac{\partial \tau_x}{\partial z}$$

$$\frac{\partial v}{\partial t} + fu = -\frac{1}{\rho_o}\frac{\partial \tau_y}{\partial z}$$

Linear Profile, $\int_0^{z_w}$

$$\frac{\partial C_T}{\partial t} = \frac{1}{\rho_o c_p}\left[f_w(z_w)I_0 - Q\right]$$

$$\frac{\partial C_s}{\partial t} = S_r(E-P)$$

$$\frac{\partial C_u}{\partial t} = \frac{\tau_x}{\rho_o} + fC_v$$

$$\frac{\partial C_v}{\partial t} = \frac{\tau_y}{\rho_o} - fC_u$$

$$C_x(z_w,t) = \int_0^{z_w} x\ (z,t)dz = \frac{1}{2}x\ (0,t)z_w,$$

x* can be *T, S, u, v

The mixed layer stability criterion requires:

$$\alpha C_h + \beta C_s = \frac{2R_{ic}(C_u^2 + C_v^2)}{g z_w^2}$$

The 5th control equation for z_w is derived:

$$\frac{\partial z_w}{\partial t} = \left(\frac{\tau_x C_u + \tau_y C_v}{\rho_o} + \frac{g}{4R_{ic}} z_w^2 \Delta\rho'\right)\frac{z_w}{C_u^2 + C_v^2}$$

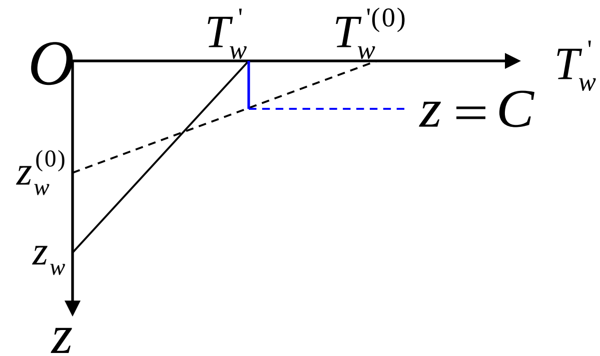
where $\Delta\rho' = -\frac{\alpha[f_w(z_w)I_0 - Q]}{c_p\rho_0} + \beta S_r(E-P)$

Thickness of free convection: *C*

$$C = \sqrt{\frac{2 z_w \Delta t}{\alpha \rho_o T_s^{'} - \beta \rho_o S_s^{'}} \{ \frac{\alpha}{c_p} Q - \frac{\alpha}{c_p} [f_w(C) - sum \cdot C] I_0 + \beta \rho_o S_r (E-P) \}}$$

,

Where, $sum = \sum_{i=1}^{N} \left[(F_i / \gamma_i) e^{-C/\gamma_i}) \right]$



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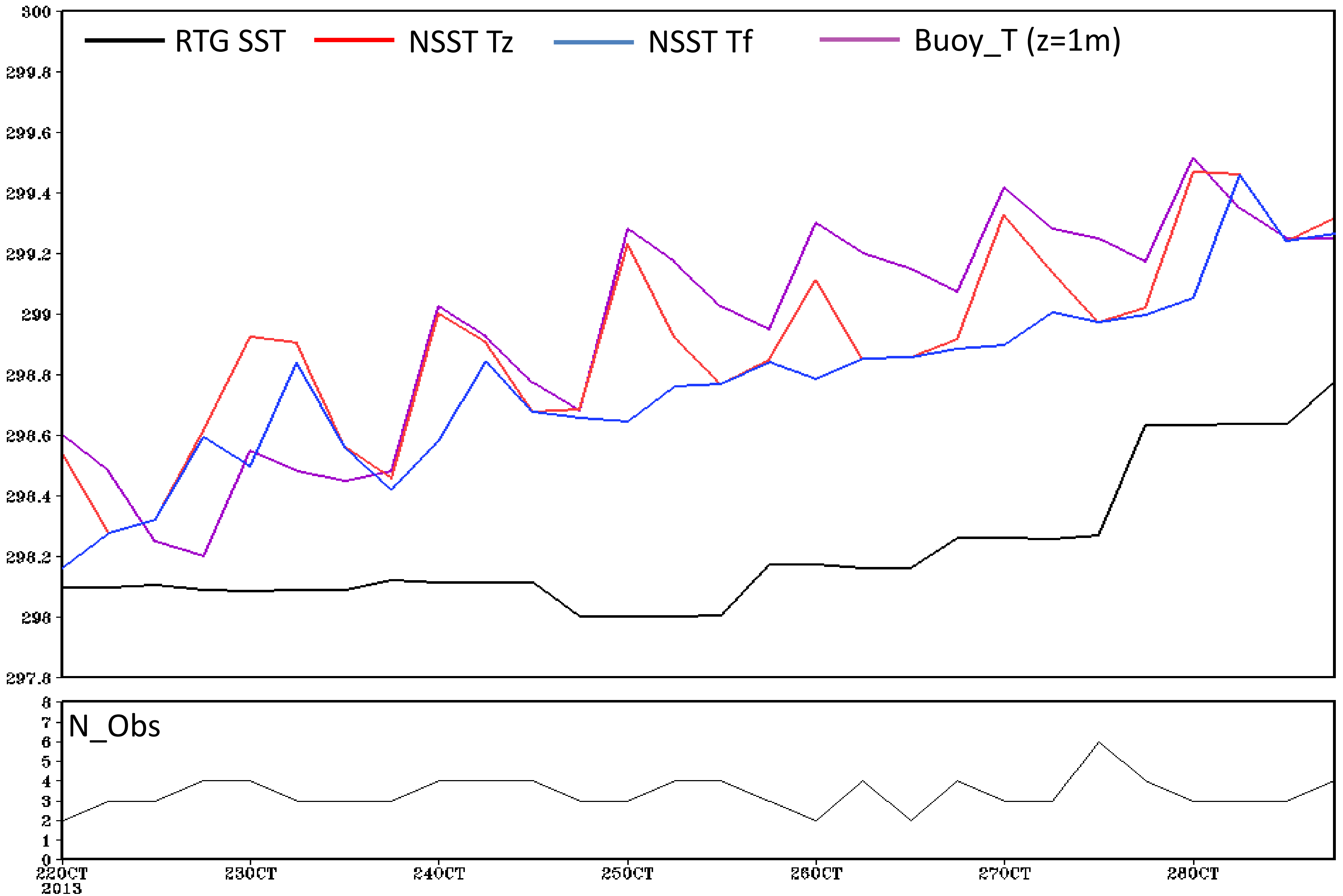
Jacobi of observation operator: $\partial T(z) / \partial T_f$

$$\frac{\partial T_z}{\partial T_f} = \frac{1}{1 - W_0 + C_0} + \frac{W_d - C_d}{1 - W_0 + C_0} z$$

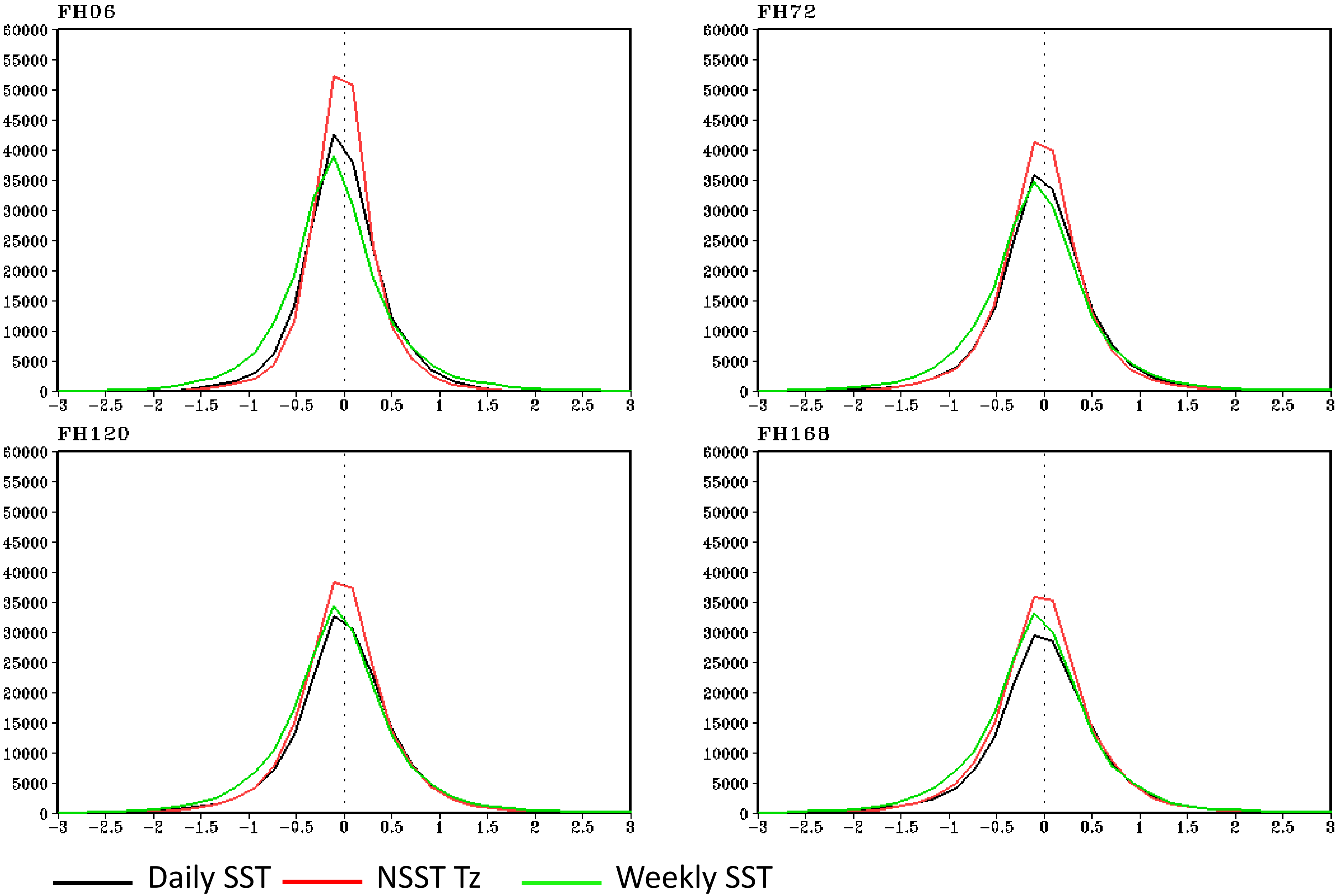
$$W_0 = \frac{\partial T_w^{'}(0)}{\partial T_s} = \frac{2}{z_w} \frac{\partial C_T}{\partial T_s} - \frac{2 C_T}{z_w^2} \frac{\partial z_w}{\partial T_s}, \qquad W_d = \frac{T_w^{'}(0)}{z_w^2} \frac{\partial z_w}{\partial T_s} - \frac{1}{z_w} \frac{\partial T_w^{'}(0)}{\partial T_s}$$

$$C_0 = \frac{1}{\kappa} \left[\delta_c \frac{\partial Q}{\partial T_s} + (Q - S_c - I_0 A_c \delta_c) \frac{\partial \delta_c}{\partial T_s} \right], \; C_d = \frac{1}{\kappa} \left(I_0 A_c \frac{\partial \delta_c}{\partial T_s} - \frac{\partial Q}{\partial T_s} \right)$$

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



Histogram of (F-O), against Buoy. Based on 30 predictions in November, 2013. Global



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