SST Analysis in NCEP GFS

Xu Li, John Derber

EMC/NCEP

General Picture

--- SST Improvement

Better SST Analysis Product

Extract SST information from satellite data more effectively

From Empirical retrieval
to Physical retrieval
to Direct assimilation of radiances

Resolve the vertical structure from surface to diurnal warming depth

Enable to use depth dependent observations consistently

Require to solve new, related issues

Assimilation scheme

- **SST is analyzed with the atmospheric data assimilation system (GSI) in NCEP GFS**
  - Add a new analysis variable (SST or equivalent) to GSI
    - Single cost function with more elements in the state vector
  - Add observation data related to SST
  - Error variance and correlation length for the new analysis variable
- **Problems**
  - SST prediction
  - Observation operators (**H**) for the new analysis variable (**x**) are not available, if the observations (**y**) are depth dependent.
  - Jacobi of the new observation operators need to be derived
  - Different lower temperature condition required for atmospheric model (Ts) and radiative transfer model (Tr).

Observations for SST analysis

Satellite: IR & MW
The radiances emitted from the sea water at skin depths (0.01mm – 1 mm)

In situ: Buoys, Ships
The sea water temperature at the depths (0.01 mm – 15+ m)

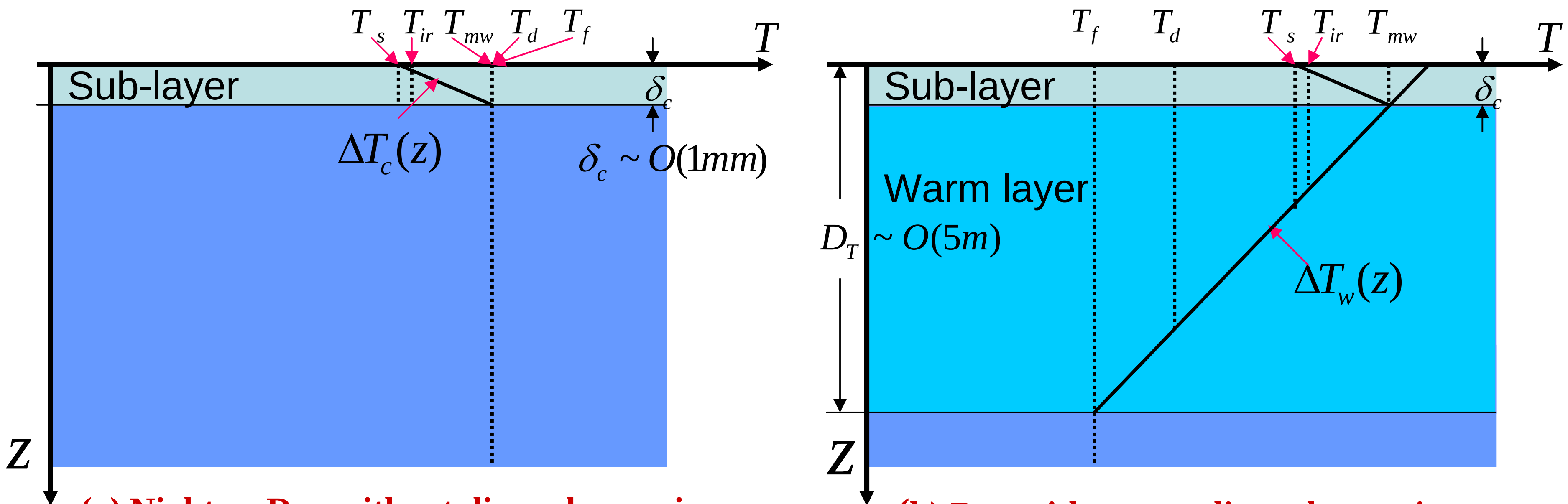
SST is not observed directly

(1) A various depths instead of surface (z = 0) only
(2) Radiance instead of temperature

Questions

Is it necessary to resolve the vertical structure near surface? How?
How to assimilate the indirectly observed data?

Representative temperatures near sea surface and analysis variable



(a) Night or Day without diurnal warming **(b) Day with strong diurnal warming**

T_s **: Surface Temperature, z=0**

T_{ir} **: Skin temperature, z ~ 0.01 mm. Detected by shortest IR (80000 GHz, CH-2 of AVHRR)**

T_{mw} **: Sub-skin temperature, z ~ 1.0 mm. Detected by longest MW (6.7 GHz, CH-1 of AMSRE)**

T_r **: Skin temperature, z ~ 0.01 mm - 1.0 mm. Between** T_{ir} **and** T_{mw}

T_d **: Depth Temperatures, z ~ 0.17m ~ 15m. Detected by buoys and ships**

T_f **: Foundation temperature,** $z = D_T$ **~ 0.5 m – 10 m**

Analysis variable: Foundation temperature T_f

$$T_s = f_s(T_f) = T_f + \Delta T_w(0) - \Delta T_c(0); T_r(\delta_r) = f_r(T_f) = T_f + \Delta T_w(\delta_r) - \Delta T_c(\delta_r)$$

$$T_{mw}(\delta_c) = f_{mw}(T_f) = T_f + \Delta T_w(\delta_c); T_d(d) = f_d(T_f) = T_f + \Delta T_w(d)$$

Sub-layer and diurnal warming layer

Sub-layer cooling model (Fairall et al , 1996):

$$-Q = R_{nl} - H_s - H_l$$

$$\delta_c = \frac{\lambda \nu}{(\rho_a/\rho)^{1/2} u_{*a}} = 6\{1 + [\frac{16 Q_b g \alpha \rho c_p \nu^3}{u_{*a}^4 (\rho_a/\rho)^2 \kappa^2}]^{3/4}\}^{-1/3} \frac{\nu}{(\rho_a/\rho)^{1/2} u_{*a}}$$

$$Q_b = Q + \left(\frac{S \beta c_p}{\alpha L_e}\right) H_l$$

$$\Delta T_c = \frac{H \delta_c}{\kappa} = \frac{6 \nu (\delta S_w - Q)}{\kappa (\rho_a/\rho)^{1/2} u_{*a}} \{1 + [\frac{16 g \alpha \rho c_p \nu^3 \left(Q + \frac{S \beta c_p}{\alpha L_e}\right) H_l}{u_{*a}^4 (\rho_a/\rho)^2 \kappa^2}]^{3/4}\}^{-1/3}$$

Diurnal warming model (Fairall et al, 1996):

The model assumes linear anomaly profiles of temperature and current in the diurnal warming layer. Once the solar heating exceeds the combined cooling of sensible, Latent and long wave radiation, integrate temperature equation and current equations (rotation effect omitted) along time ($t_0 \to t$) and depth ($0 \to D_T$)

$$\Delta T_w = \frac{I_h}{\rho c_p (D_T/2)}; \quad \Delta \rho = \alpha \Delta T_w; \quad \delta V = \frac{2 I_\tau}{D_T}; \qquad I_h = \int_{t_0}^{t} (\delta S_w - Q) dt; I_\tau = \int_{t_0}^{t} u_{*o}^2 dt$$

Assume the density and current anomalies, which mean the departures from the early morning oceanic state, and length scale satisfy Richardson number criterion:

$$\frac{g h \delta \rho}{\rho_o (\delta V)^2} \ge R_{ic} = 0.65 ==> \quad D_T(t) = \sqrt{2 R_{ic}} \frac{I_\tau}{\sqrt{(\alpha g / \rho c_p) I_h}}$$

Observation operators from T_f to T_d and T_r :

Conventional data:

$$T_d(d) = f_d(T_f) = T_f + \Delta T_w(d)$$

$$H_c(T_f) => T_f$$

$$H_c[f_d(T_f)] => T_d$$

Satellite data:

$$T_r(\delta_r) = f_r(T_f) = T_f + \Delta T_w(\delta_r) - \Delta T_c(\delta_r)$$

$$H_r(T_r) => T_r$$

$$H_r[f_r(T_f)] => T_r$$

Observation operator: To transform analysis variable to corresponding partner in observation space.

H_c : available, interpolation operator

H_r : available, radiative transfer model

Conversion between SST (T_s) and T_r :

$$T_s = f_s(T_f) = T_f + \Delta T_w(0) - \Delta T_c(0) \quad H_c(T_f) => T_f; H_c[f_s(T_f)] => T_s$$

Sensitivities of the representative temperatures to T_f :

Conventional data $\frac{\partial T_d}{\partial T_f}$:

$$T_d(d) = f_d(T_f) = T_f + \Delta T_w(d) ==> F_d\{T_d, T_f, \Delta T_w[D_T(I_h(D_T, T_s)]\} = 0$$

$$F_d[T_d, T_f, \Delta T_w(T_s)] = 0 ==> \frac{\partial T_d}{\partial T_f} = P_d(\frac{\partial \Delta T_w}{\partial T_s}, \frac{\partial T_s}{\partial T_{mw}}, \frac{\partial T_{mw}}{\partial T_d})$$

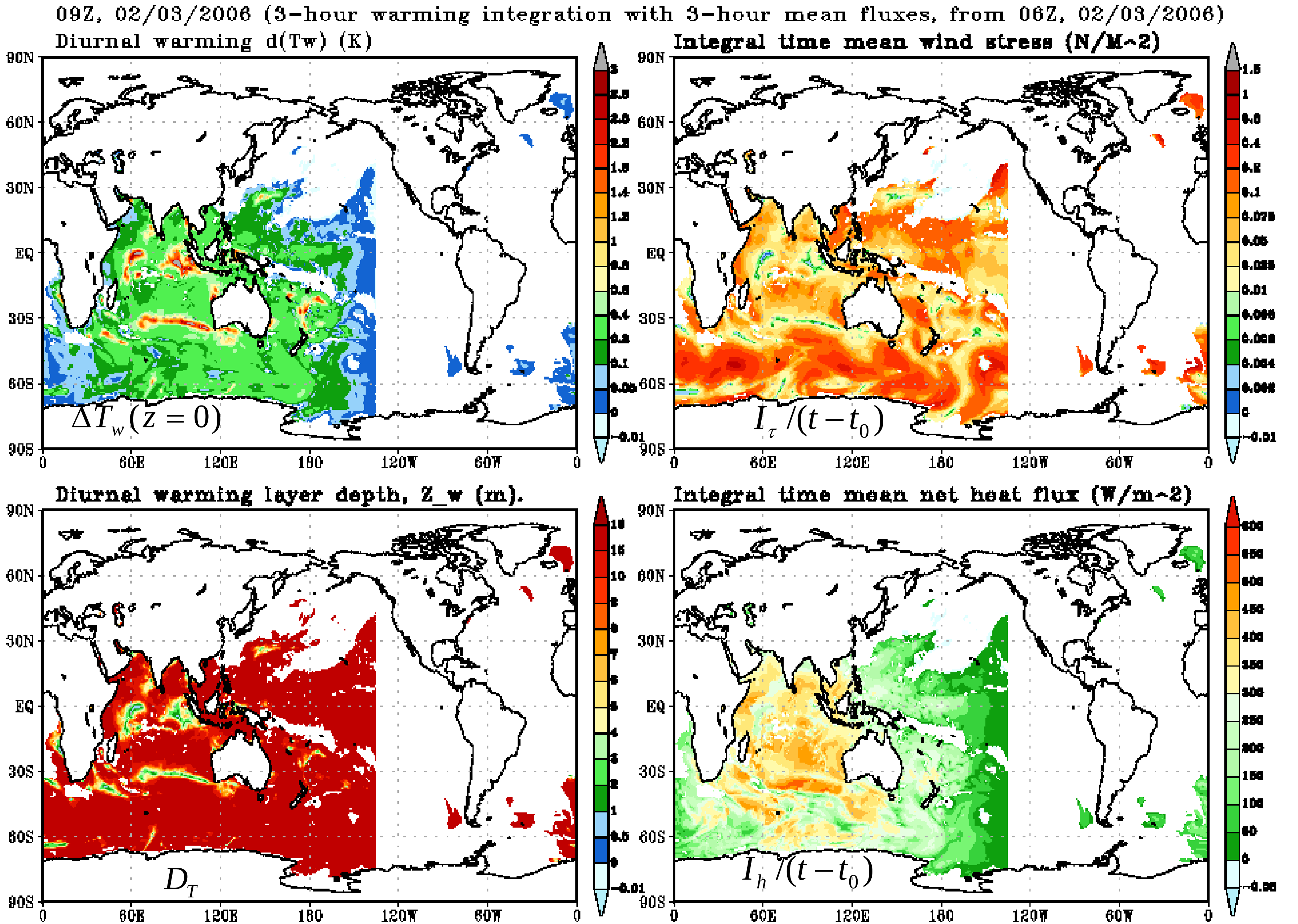
Satellite data $\frac{\partial T_r}{\partial T_f}$:

$$T_r(\delta_r) = f_r(T_f) = T_f + \Delta T_w(\delta_r) - \Delta T_c(\delta_r)$$

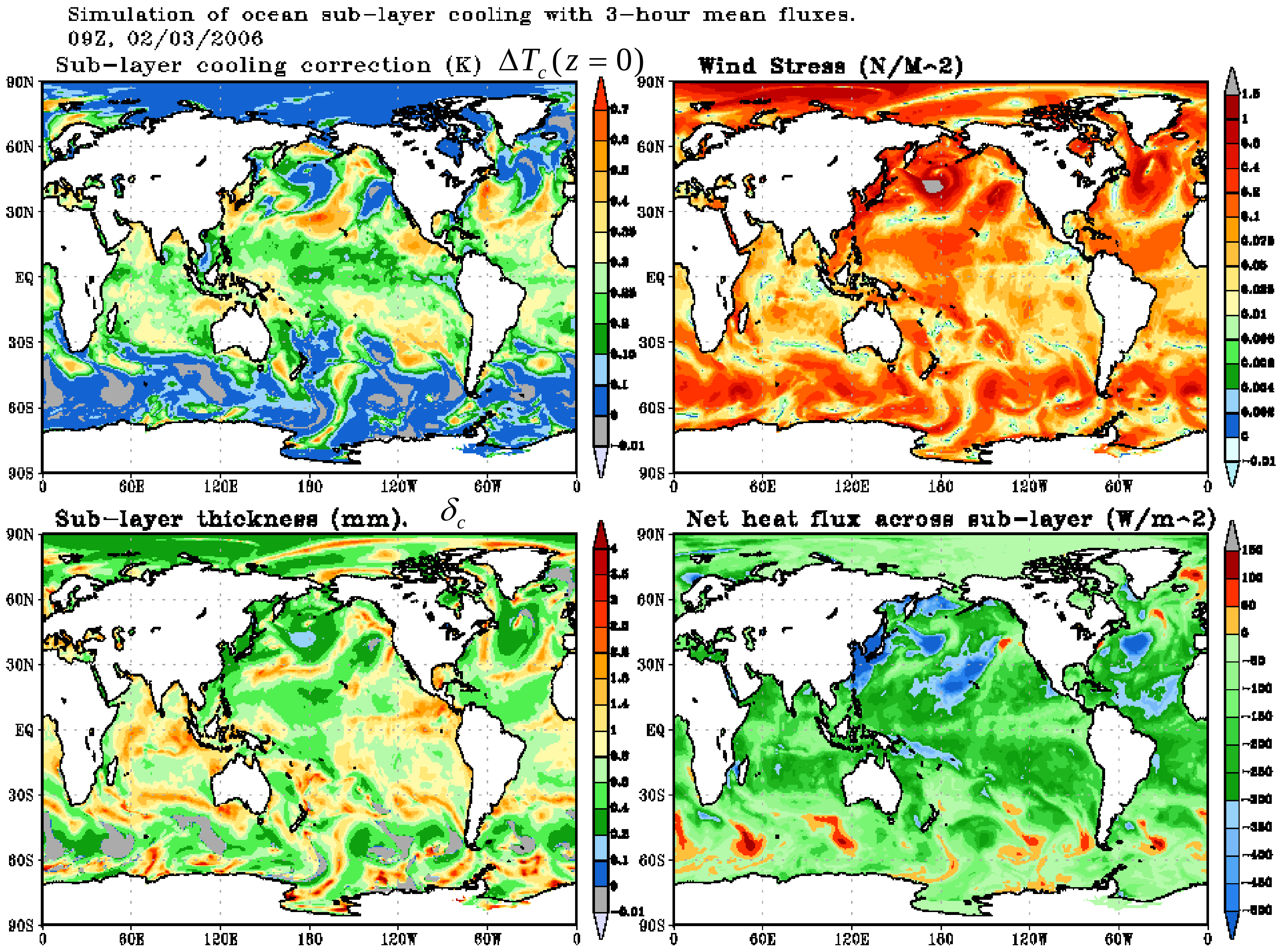
$$=> F_r[T_r, T_f, \Delta T_w(T_s) - \Delta T_c(T_s)] = 0$$

$$=> \frac{\partial T_r}{\partial T_f} = P_r(\frac{\partial \Delta T_w}{\partial T_s}, \frac{\partial T_s}{\partial T_r})$$

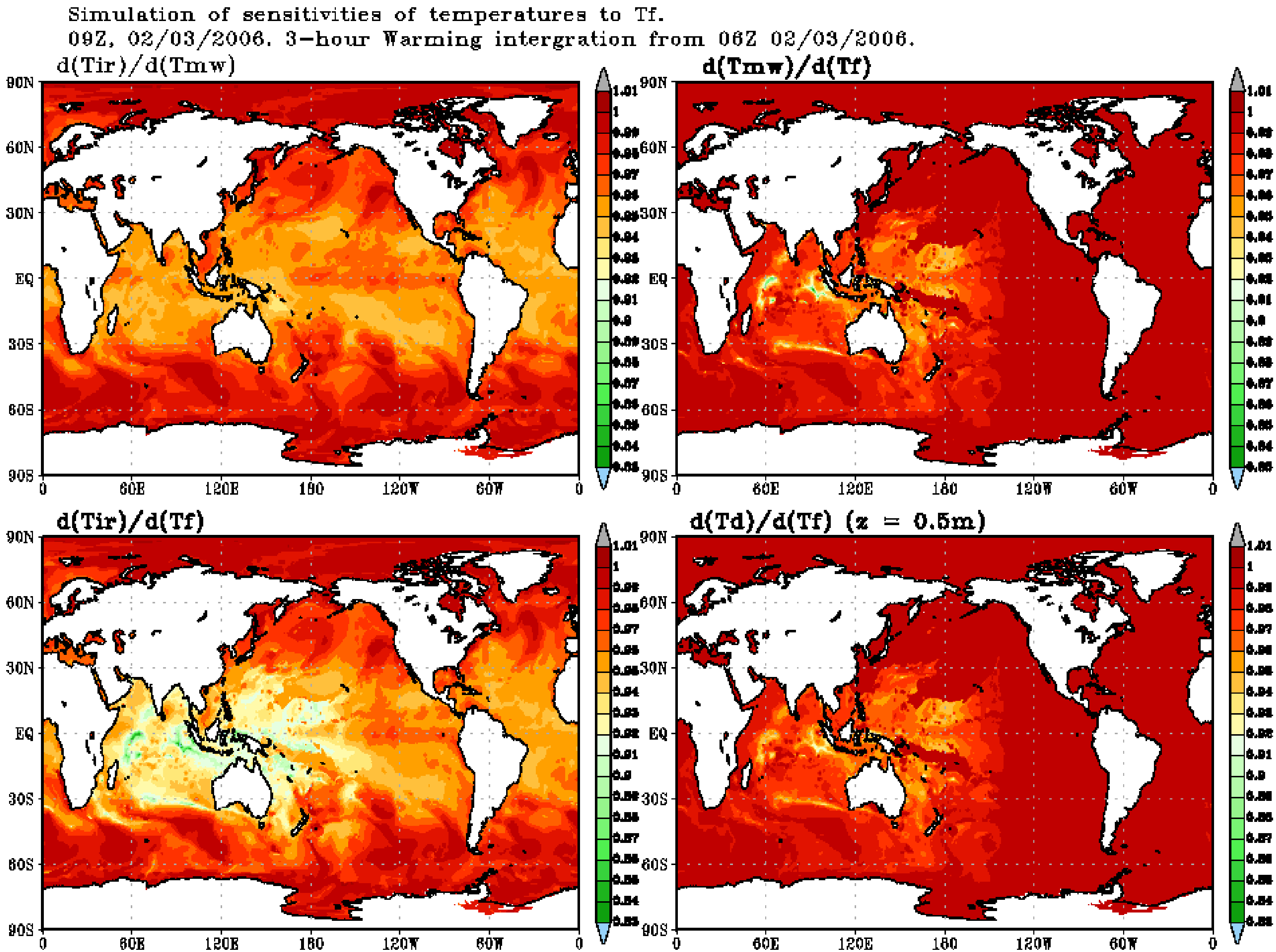
F_d : Implicit compound function to relate $T_d(z=d)$ and T_f through Heat fluxes and therefore T_s



Diurnal warming model run with 3-hourly GFS fluxes



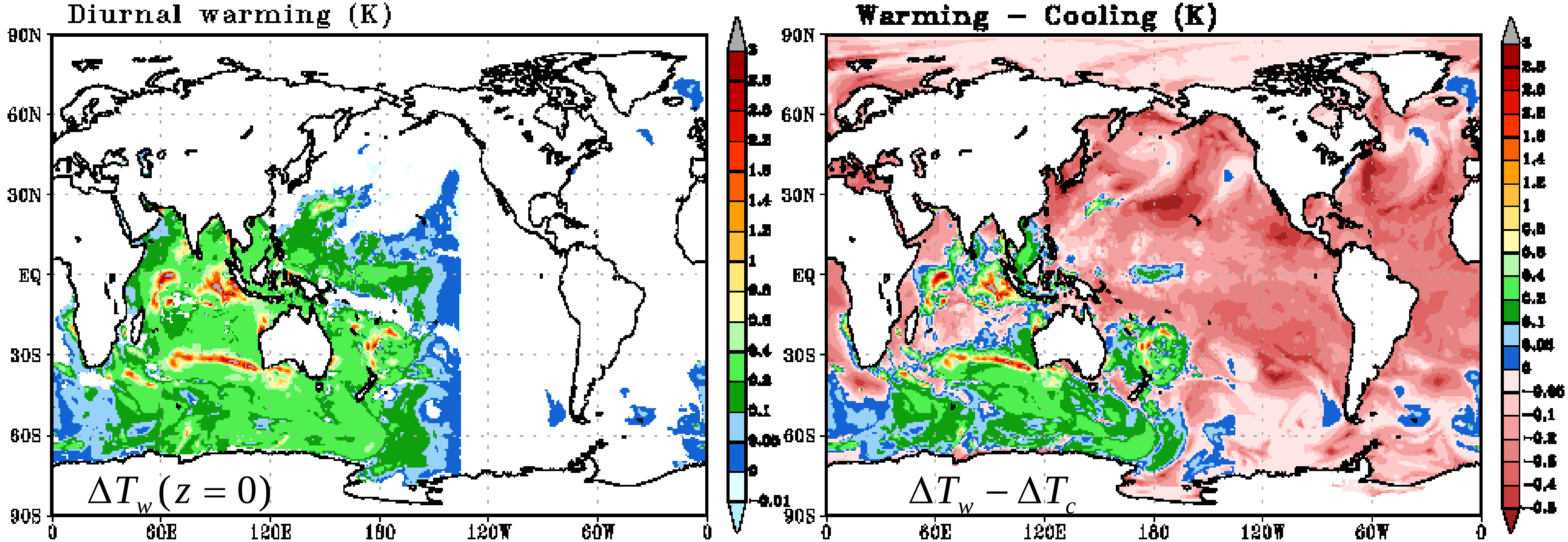
Sub-layer model run with 3-hourly GFS fluxes

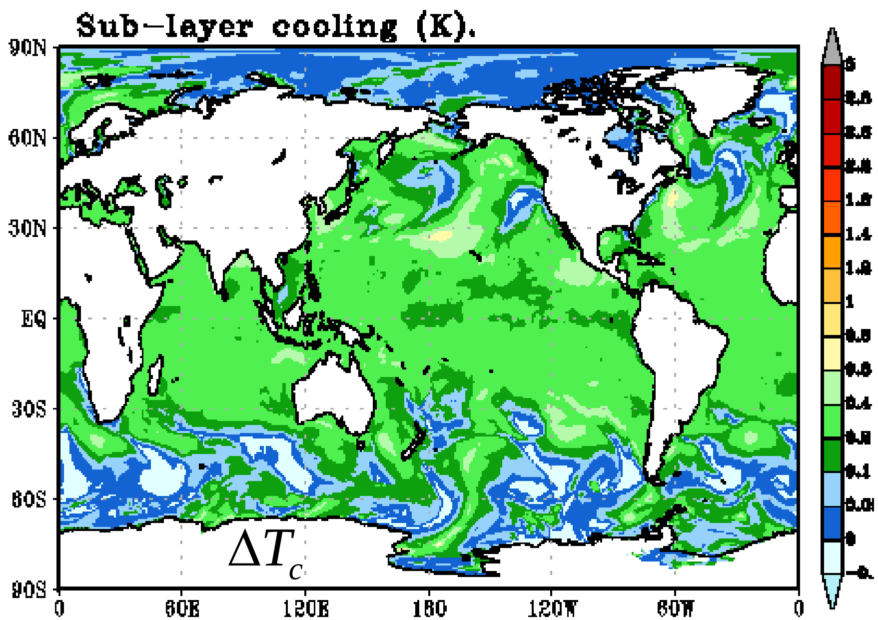


Sensitivities of representative temperatures to foundation temperature

Simulation of ocean diurnal warming and sub-layer cooling.

09Z, 02/03/2006 (3-hour warming integration with 3-hour mean fluxes, from 06Z, 02/03/2006)





Experiment:

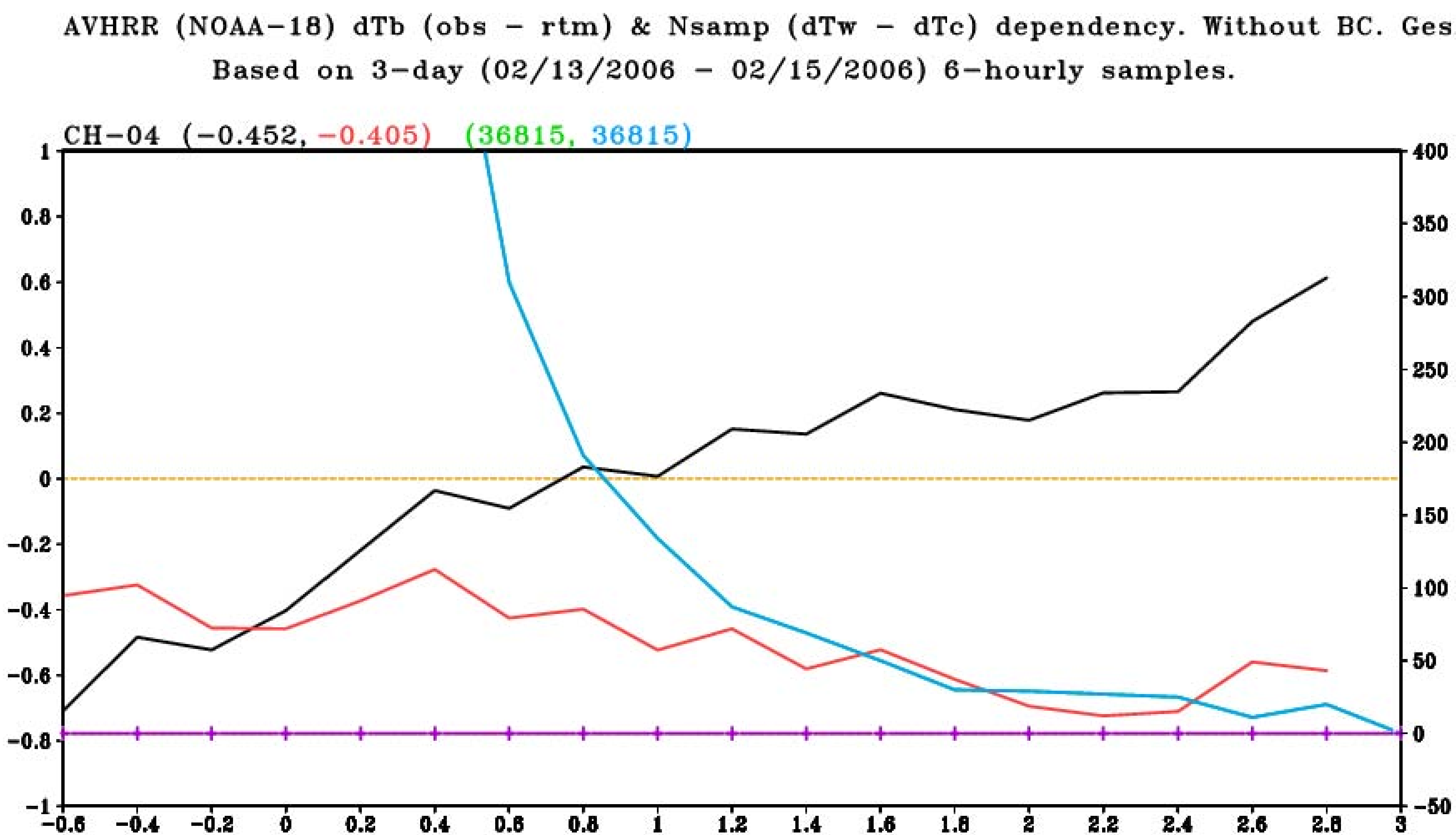
Use the SST currently used by GFS, T_{ctl} as the foundation temperature. Satellite instruments are divided into IR and MW:

For IR: $T_{ir} = T_{ctl} + \Delta T_w(z=0) - \Delta T_c(z=0)$

For MW: $T_{mw} = T_{ctl} + \Delta T_w(z=0)$

Then, 7-day analysis is done with GSI, GFS forecast (03, 06, 09) used as the first guess; GFS fluxes used to get ΔT_w and ΔT_c

Control Run: $T_{ir} = T_{mw} = T_{ctl}$



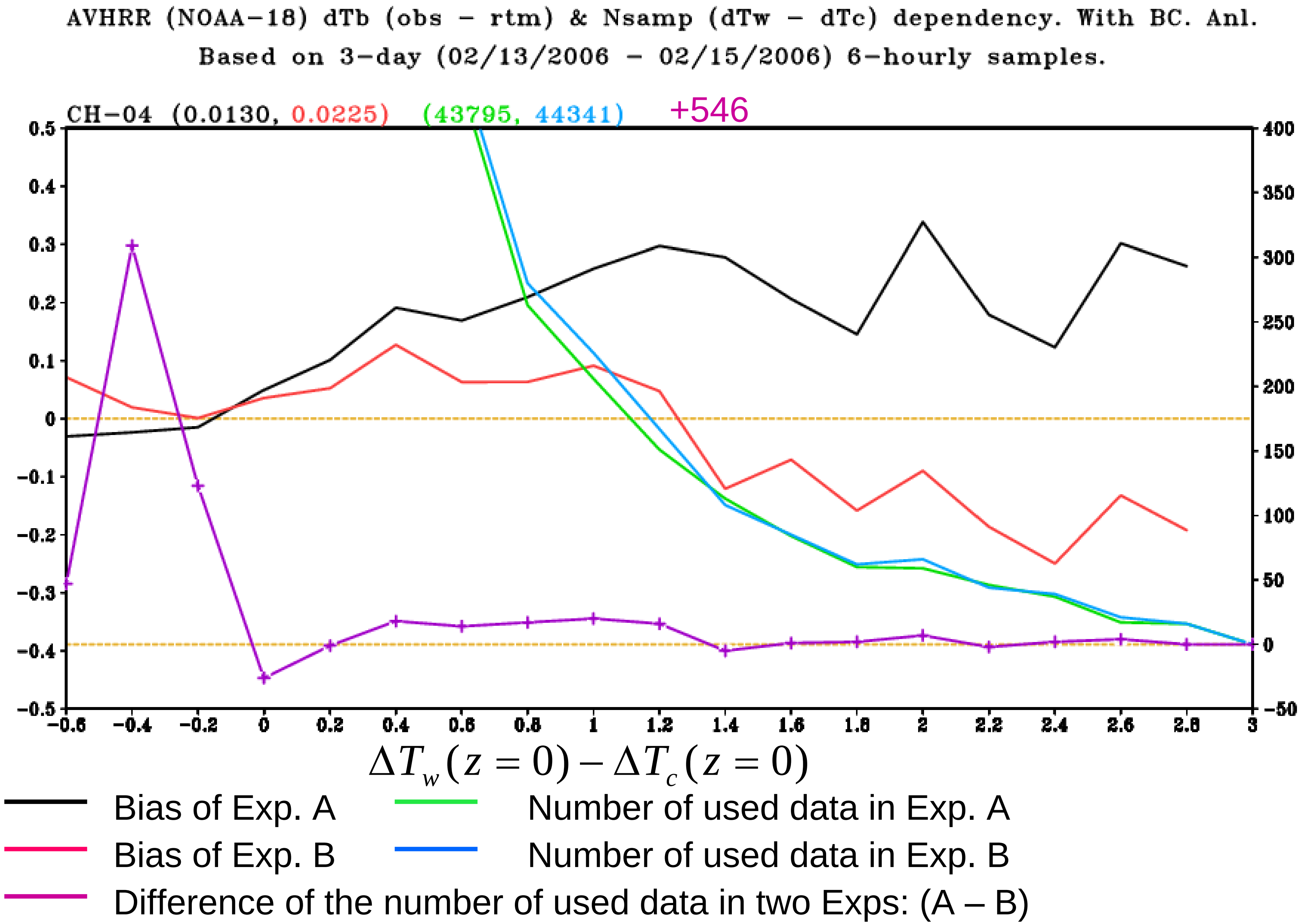
$$\Delta T_w(z=0) - \Delta T_c(z=0)$$

Bias of Ctl Run — Number of used data in Ctl Run

Bias of Exp. — Number of used data in Exp.

Difference of the number of used data in two runs: (Exp – Ctl)

Impacts of sea water diurnal warming and sub-layer cooling on AVHRR radiance simulation (Bias), based on the data used in both experiments



Impacts of sea water diurnal warming and sub-layer cooling on the analysis of AVHRR data

Plan

- **Foundation temperature analysis in GSI**
  - T_f error statistics based on a period of analysis sample
  - How often the fluxes and therefore the diurnal warming amount updated?
  - Parallel run
    - Consistency among SST, fluxes and atmosphere
- **Diurnal warming model improvement**
  - Theoretical analysis done: rotation effect, vanish wind handle, E-P effect, linear to exponent profile
  - Solar radiation penetration
- **One-dimensional oceanic model**
  - T_f forecasting