The recent updates of the SST analysis in the NCEP GFS and a few related fundamental issues

Xu Li, Andrew Collard

IMSG at Environment Modeling Center, National Center for Environmental Prediction, NOAA, USA

Introduction

The Sea Surface Temperature (SST) analysis within the NCEP GFS, referred as NSST, has been updated a few times since its initial operational in July 2017.

The developments and updates are basically on four aspects, the science, the use of more observations, the use of SST climatology and the handling of some unexpected issues for the operation.

The most recent updates in the operational GFS, **developments** for the further improvement are reported here.

The definition of the foundation temperature is revisited. Very often, it is defined as the temperature at a depth/time when the diurnal warming is zero. It is proposed that the temperature at the base of the diurnal warm layer defines the variable more physically. Its diurnal variability (supposed to be zero with the first definition) is demonstrated with the NSST 6-hourly analysis.

The impact of the convective adjustment (free convection), which is usually missing in most of the diurnal warming model, is demonstrated based on the experiments with the current NCEP GFS.

Recent updates in the operational GFS

- **The use of more observations** (two more AVHRR radiances)
- **The stricter constraints of the SST climatology**
- **The modified background handling for just melted sea ice situation**

Recent developments for further improvement

- **A new background error correlation length,** based on Rossby radius of deformation, is adopted. The **correlation length is reduced** from 100 km constant. A minimum (resolution dependent) and a maximum (75 km) are applied to the new correlation length.
- **A new correlation length dependent thinning scheme** for AVHRR and VIIRS is developed. **The thinning box sizes are reduced** from a constant 145 km to 25 ~ 100 km
- **The VIIRS** radiances (NPP and J1/N20) is added
- **The partly cloudy AVHRR radiances is tossed**, considering the limited validity of GSI cloud detection for AVHRR due to its image property

Future

- The SST analysis in the future coupled GFS
  - Develop **the observation operators** to relate the analysis variable (T_1, the temperature of first layer oceanic model) to all the observations, and their **Jacobi**
  - Produce the **water temperature, which is not T_1, for the fluxes calculation and radiance simulation**

The improvement of the Gulf Stream due to recent developments

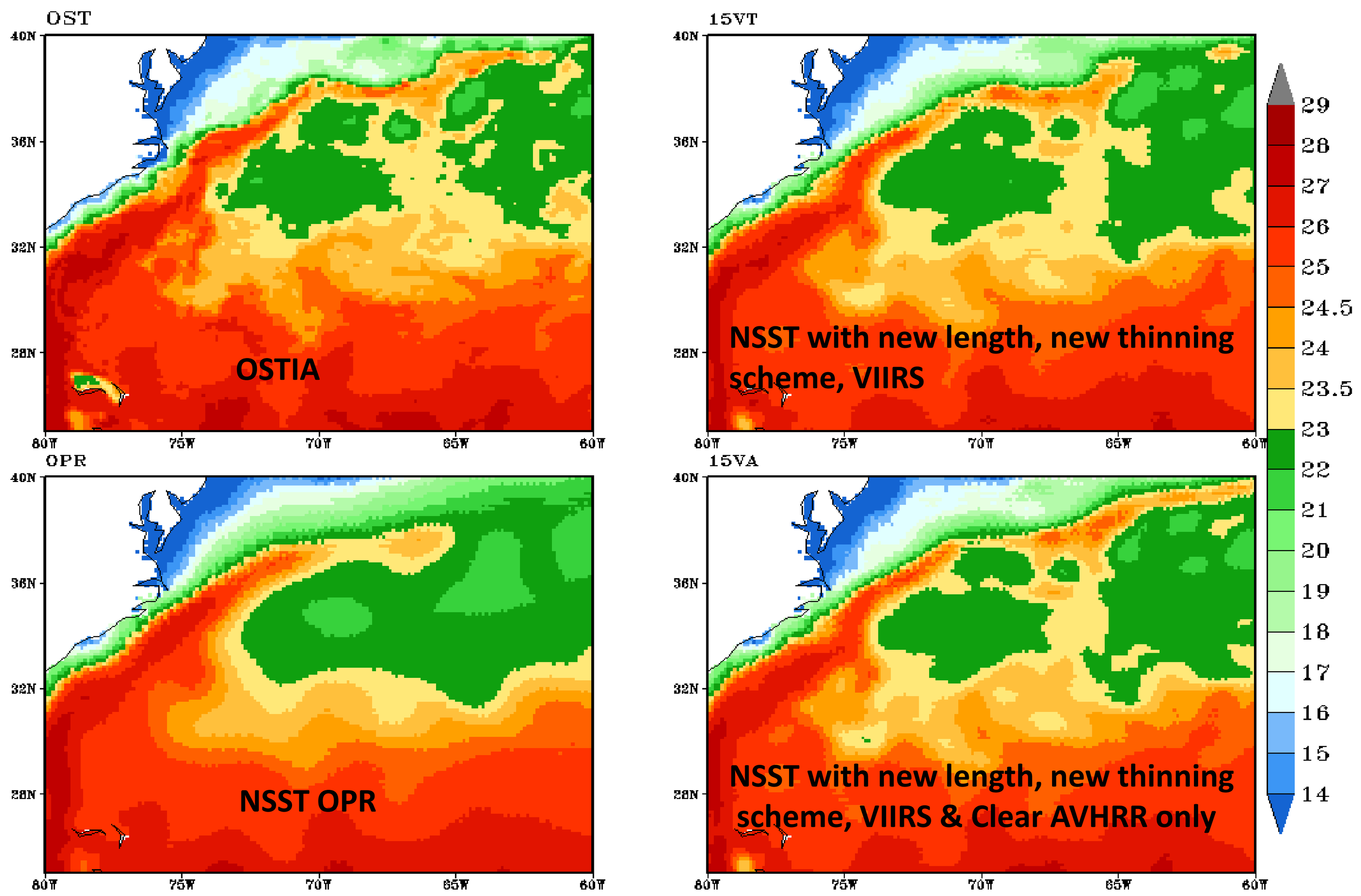

Figure 1. The Gulf Stream in the foundation temperature analyses. 18Z, Nov. 20, 2019. 19 days after starting from the operational initial conditions (at 00Z, Nov. 10, 2019) for the NSST ones.

Gulf stream is too weak in the operational NSST, due to the broader correlation length and large thinning box size, is improved with 3 updates (**new length, new thinning and addition of VIIRS**) and is improved even more with 4 updates (3 above updates plus the 4th one, **the toss of the partly cloudy AVHRR** radiances).

Diurnal Variability of the foundation temperature

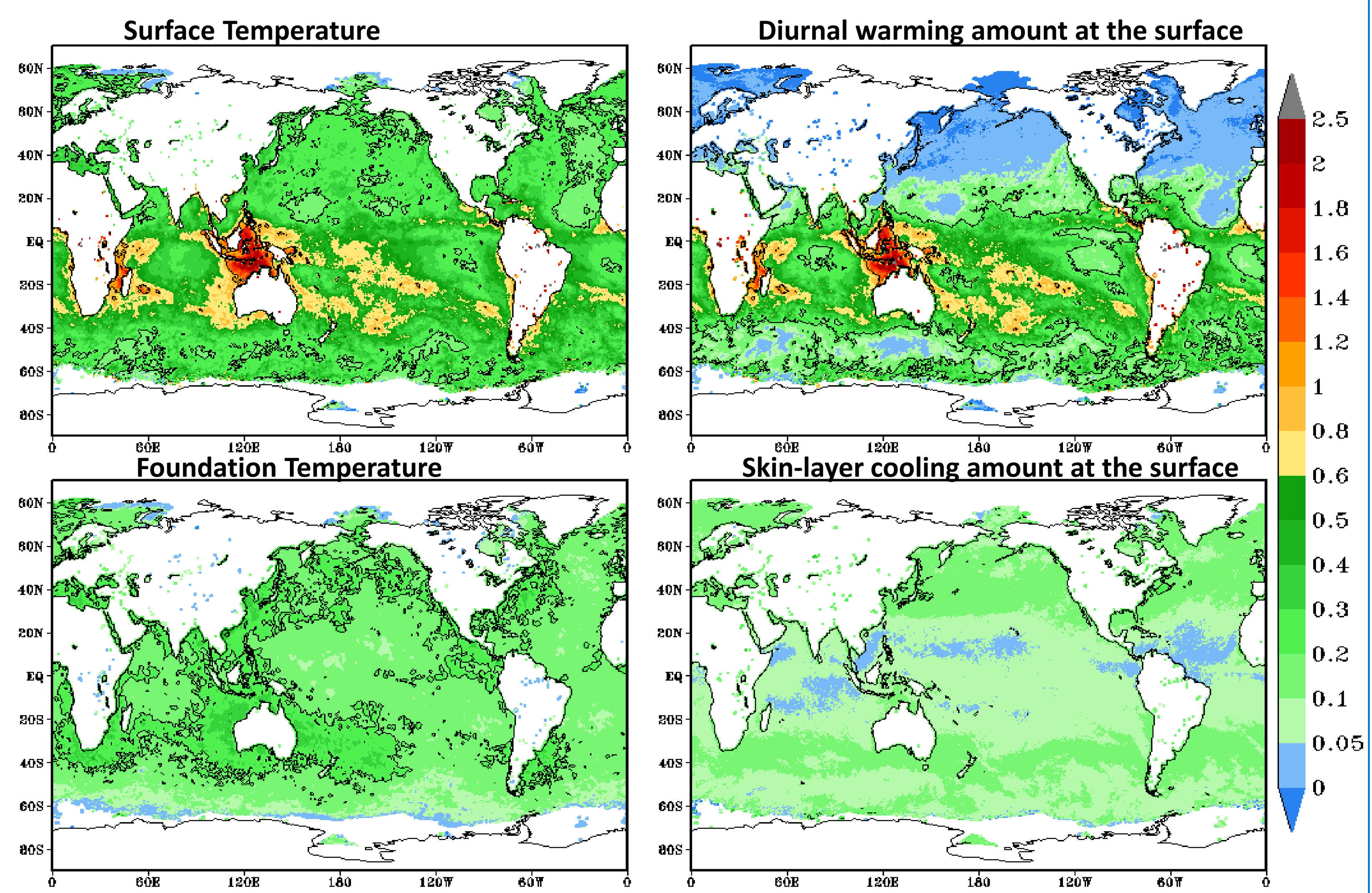

Figure 2. **The diurnal variability, measured as the difference of the maximum and minimum in a day** with 6-hourly analyses/simulations. The contours of 0.2 and 1.0 are plotted. Nov 11, 2019 to Dec 9, 2019, 29-day average.

- **The foundation temperature does vary with time in hours time scale.** The diurnal variability is smaller than 0.2 K for most of the areas in the 29-day average, but it can reach 0.5+ K for an individual day
- The diurnal variability of the skin-layer cooling amount is hardly to reach 0.2 K

The diurnal warming model in the NSST

Derivation of Diurnal Thermocline Model (DTM-1p)

$$\frac{\partial T'}{\partial t} = -\frac{1}{\rho_0 c_p}\frac{\partial F}{\partial z} - \frac{1}{\rho_0 c_p}\frac{\partial I}{\partial z}$$

$$\frac{\partial S'}{\partial t} = -\frac{\partial M}{\partial z}$$

$$\frac{\partial u'}{\partial t} - f v' = -\frac{1}{\rho_0}\frac{\partial \tau_x}{\partial z}$$

$$\frac{\partial v'}{\partial t} + f u' = -\frac{1}{\rho_0}\frac{\partial \tau_y}{\partial z}$$

Linear Profile, $\int_0^{z_w}$ →

$$\frac{\partial C_t}{\partial t} = \frac{1}{\rho_0 c_p}[f_w(z_w)I_0 - Q]$$

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

$$\frac{\partial C_u}{\partial t} = f C_v + \frac{\tau_x}{\rho_0}$$

$$\frac{\partial C_v}{\partial t} = -f C_u + \frac{\tau_y}{\rho_0}$$

$C_x = \int_0^{z_w} x'(z,t)dz = \frac{1}{2}x'(0,t)z_w$, where x can be t, s, u or v.

The mixed layer stability criterion requires: $\frac{g(\alpha C_t - \beta C_s)z_w^2}{2(C_u^2+C_v^2)} = R_{ic} = 0.65$

The 5th control equation for z_w is derived:

$$\frac{\partial z_w}{\partial t} = \left(\frac{\tau_x C_u + \tau_y C_v}{\rho_0} + \frac{g}{4R_{ic}} z_w^2 \Delta\rho\right)\frac{z_w}{C_u^2 + C_v^2}$$

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

The convective adjustment in the NSST diurnal warming model

Equation to solve thickness of free convection: C

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

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

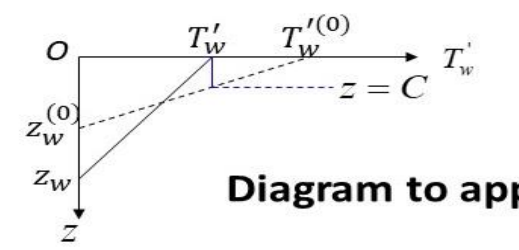

Diagram to apply the free convection adjustment.

At each time step, C is solved iteratively, then the convection adjustment is applied (see the diagram)by modifying the surface warming amount ($T_w'^{(0)} \Rightarrow T_w'$) and warm layer thickness ($z_w^{(0)} \Rightarrow z_w$), by keeping the areas of the two triangles, $\Delta O z_w T_w'$ and $\Delta O z_w^{(0)} T_w'^{(0)}$, are equal to each other. T_w' is the vertical average value from 0 to C of the warming profile prior to the adjustment.

The impact of the free convection in the NSST diurnal warming model

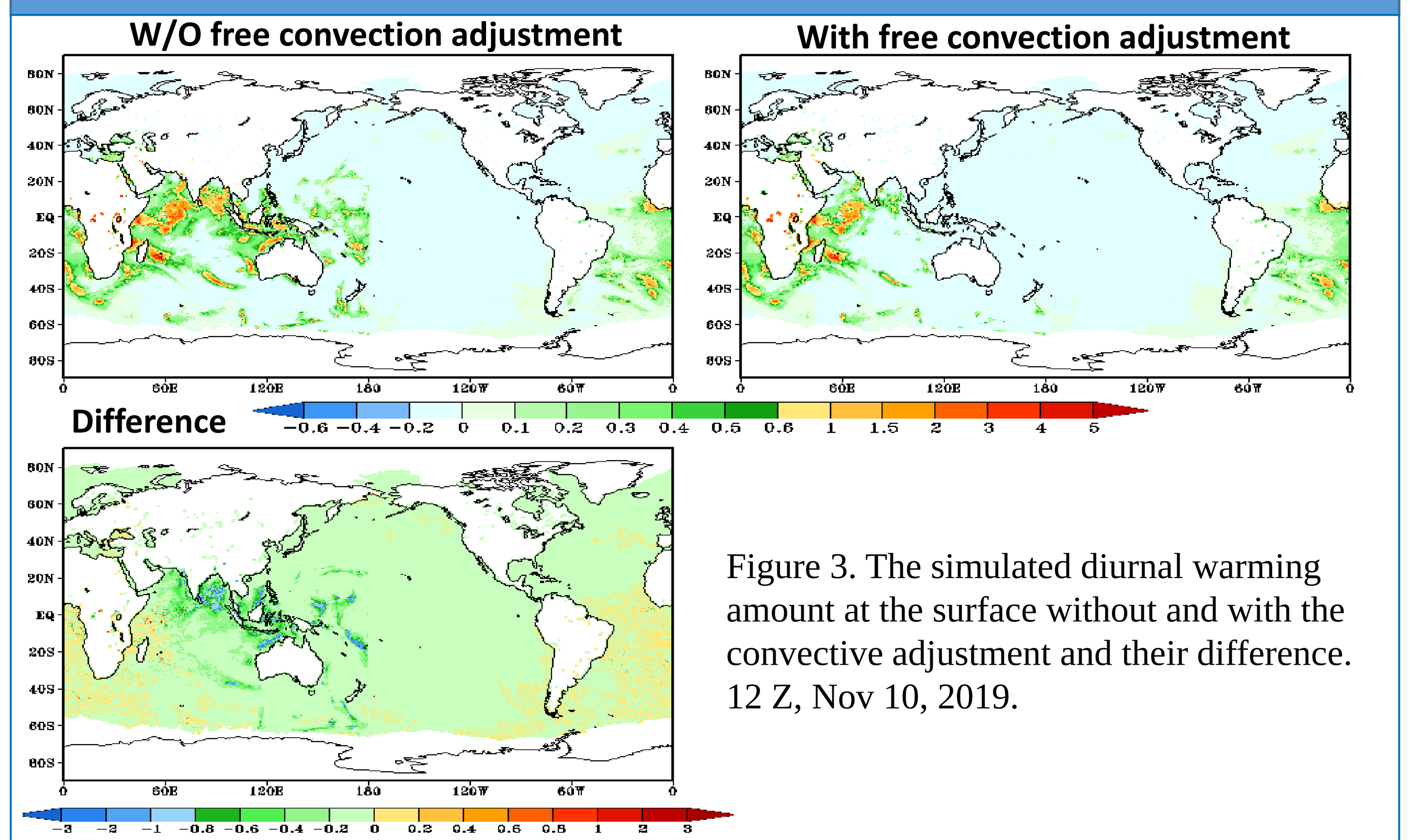

Figure 3. The simulated diurnal warming amount at the surface without and with the convective adjustment and their difference. 12 Z, Nov 10, 2019.

- **The convective adjustment**, which is missing in most of the diurnal warming models, **weakens the diurnal warming event** in the NSST diurnal warming model.
- **The warming event can end naturally** (without a reset at midnight) with the convective adjustment