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 GHRSSST-PP)

\[ T'(z) = T(z) - T_f \]

(a) Night

(b) Day
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**:

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

\[ T(z) = T_f(z_w) + T_w'(z) - T_c'(z) \quad (0 \leq z \leq \delta_c) \]

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

T-Profile in the diurnal thermocline:

\[ T(z) = T_f(z_w) + T_w'(z) - T_c'(z) \quad (0 \leq z \leq z_w) \]

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

<table>
<thead>
<tr>
<th>Features</th>
<th>Operational SST analysis</th>
<th>GHRSSST $T_f$ analysis</th>
<th>NCEP $T_f$ analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-defined Analysis variable</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Analysis scheme</td>
<td>Uni-variate</td>
<td>Uni-variate</td>
<td>Multi-variate</td>
</tr>
<tr>
<td>Flexible Analysis resolution</td>
<td>Yes</td>
<td>Yes</td>
<td>No/Yes</td>
</tr>
<tr>
<td>Multi-Satellite</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Direct Assimilation</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Obs. with diurnal warming used</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Diurnal variability resolved</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>$T_f$ evolution in one day</td>
<td>N/A</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>NSST model used consistently</td>
<td>N/A</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Coupled analysis</td>
<td>N/A</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Exps</th>
<th>$T_f$</th>
<th>SST In FCST</th>
<th>$T'(z)$ In ANAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>pre13c</td>
<td>$SST^{op}$</td>
<td>$SST^{op}$</td>
<td>$SST^{op}$</td>
</tr>
<tr>
<td>Pre13e</td>
<td>$T_f^{an}$</td>
<td>$T_f^{an} + T_w'(0,t) - T_c'(0,t)$</td>
<td>$T_f^{an} + T_w'(z,t) - T_c'(z,t)$</td>
</tr>
</tbody>
</table>

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

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.

Comparison between $T_f$ analysis in NSST and operational SST analysis used in pre13u. July, 2010
Comparison between $T_s$ (SST) in NSST and in Ctrl. July, 2010
Diurnal Variability of $T_f$ in NSST run

July 1-5, 2010

July, 2010

July 1, 2010
Diurnal Variability of SST in NSST

(a) e13w July, 2010

(b) e13u

(a) e13w December 11-20, 2010

(b) e13u

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

(0.383, 0.310, 0.177, 0.103, 0.099, 0.177)

(0.118, 0.106, 0.253, 0.226, 0.168, 0.210)

(0.000, -0.00, -0.02, 0.003, 0.010, -0.00)
Day-to-Day Variability of SST in NSST & Ctrl
(N.Pole, N.Mid, Tropics, S.Mid, S.Pole, Global)

N.Mid: Lon (-180,180.0) Lat (20.0,50.0)

N.Mid.Pac: Lon (170.0,180.0) Lat (25.0,55.0)

N.Mid.Pac.Small: Lon (170.0,181.0) Lat (29.0,51.0)

Histogram of O-B: $y - H(x)$. Drifting buoy.
(bias, rms. nused, % of used)
Validation of NSST analysis (sst). Dbuoy, Global, 2010070100-2010073118.

(BIAS, RMS, % of Used/All), Data: used, nsstn: on. e13u ~ e13w
--- e13u (Used) --- e13u (All) --- e13w (Used) --- e13w (All)

Histogram: OB ~ BG
--- (0.037, 0.409, 869080) --- (0.096, 0.593, 933665)
--- (0.014, 0.299, 906412) --- (-0.01, 0.410, 933665)

(bias, rms, ndata)

Global

More Gaussian
Better bias, rms
More used data
The same conclusion for satellite surface channels

Validation of analysis: Histogram of O-B: $y - H(x^b)$. Drifting buoy, July 2010
Validation of NSST analysis (sst). Dbuoy, Mediterranean, 2010070100–2010073118.

(BIAS, RMS, ndata), nsstn: on. e13u ~ e13w
— e13u (Used)   ---- e13w (Used)

Histogram: OB – BG

—(0.438, 0.703, 1452, 78.99%)  ----(−0.12, 0.35%, 1506, 81.93%)

(bias, rms, ndata)

Mediterranean

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

Impact signal

Hybrid
Conclusions of NSST impact on GFS

- Oceanic variables ($T_f$) analysis
  - Improved significantly based on statistics of O-B: $y - H(x^b)$, 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: $y - H(x^b)$
  - 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 (\( \overline{T}_{z_i} \)), which represent 10 meter mean temperature physically, is used at SST
  - An independent SST analysis is used as \( \overline{T}_{z_i} \)
- 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)
  - \( \overline{T}_{z_i} \) 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

**FCST**
- Atmospheric Forecasting Model (AFM)
  - $X_s$
  - $T_s$
- NSSTM $T'$
- OGCM $T_{z_1}$

**ANAL**
- Atmospheric Analysis (GSI)
  - $T_f$ Analysis $T_{an}^{f}$
  - $T_w'(z)$, $T_c'(z)$

**Radiative Transfer Model (CRTM)**
- IC $X^{an}, T_{an}^{f}, T_{an}^{zz}$
- $T_s(t) = T_f(t) + T_w'(0,t) - T_c'(0,t)$
- $T_f(t) = T_{z_1}(t) - \frac{1}{z_1} \int_0^{z_1} [T_w'(z,t) - T_c'(z,t)] dz$

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

$\frac{\partial R_{ch}}{\partial T_z}$ : Jacobi (the sensitivity of the radiance to T-Profile)
\[
\bar{T}_z - T_f = \frac{1}{z_1} \int_{0}^{z_1} [T_w(z) - T_c(z)] \, dz
\]
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.

(a) $e_{13w}$

(b) $e_{13u}$

$e_{13w} - e_{13u}$ (water)

(0.477, 0.129, -0.09, -0.03, -0.10, 0.013)

$e_{13w} - e_{13u}$ (land)

(-0.00, -0.01, 0.006, 0.019, 0.012, -0.00)
Analysis in GFS surface file: (av_q2m)_Global. 201007.
(N.Pole, N.Mid, TRO, S.Mid, S.Pole, Global). (g/kg)

(a) $e_{13w}$

(b) $e_{13u}$

$e_{13w} - e_{13u}$ (water)

(0.140, 0.022, -0.03, -0.00, -0.01, -0.00)

$e_{13w} - e_{13u}$ (land)

(-0.00, -0.00, 0.005, 0.007, 0.000, 0.000)
Diurnal Variability of air $T_{2m}$ in NSST & Ctrl
Day-to-Day Variability of air $T_{2m}$ in NSST & Ctrl