Diurnal variability in the upper ocean

Chelle L. Gentemann
Peter J. Minnett

Satellite measurement
Radiometric measurements
Models
Global distribution
Air-sea interactions
Conclusions
What is a daily SST?

Diurnal warming aliased onto SST time series (CLIMATE)
Upper Ocean Thermal Structure

(A) night or daytime well mixed

(B) daytime stratified

Foundation SST
Summary of empirical models

- Bulk – no vertical structure, fast
- Turb. Models – vertical structure, slow
Measurements at the ocean surface

• Few measurements of diurnal warming at the air-sea interface exist
• Most research / model development use in situ observations at depth or extrapolated from 0.5m or 1.0 m to the ocean surface
• Extrapolation done using bulk (PWP, Fairall, Kraus-Turner, or turbulence closure models (Mellor,Yamada / Kantha/Clayson)
AVHRR diurnal warming

A: 1988 PF Day minus Night

B: 1988 SSM/I Wind Speed

C: 1988 Diurnal Warming

D: 1988 PF Day minus Diurnal minus Night
\[ \Delta SST_{tmi}(t, Q, u) = f_1(t)[(Q - Q_o^t) - 9.632 \times 10^{-4}(Q - Q_o^t)^2] e^{-0.44u} \]

- \( Q \) = insolation
- \( t \) = local time
- \( u \) = wind speed

\( f(t) \) = truncated Fourier Series as wind increases, equation approaches 0

\( Q < Q_0 \), equation = 0

TMI/PF Model and Data

- SST Buoy (K)
- SST MW (K)
- SST IR (K)

- Wind speed (m/s)
- Insolation (W/m^2)
- Local Time (hrs)
Low winds

SSM/I wind speeds 1995-1999 highlight regions where indirect validation should be targeted. Average wind speed is 8.3 m/s and 30% of winds are < 6 m/s. 3% of winds are less than 2 m/s.
4 research cruises + Explorer
72 days with diurnal warming
All DW > 4 K from Melville cruise in Gulf of California
Peak warming not at peak insolation
Compare data & models

Graph A:
- ΔSST (K) vs. LMT (hrs)
- Different models shown as lines:
  - F96
  - POSH
  - CG04
  - ASM bulk
  - ASM sub-skin
  - MAERI Data

Graph B:
- ΔSST (K) vs. Wind Speed (ms⁻¹)
Static stability and mixed layer stability are enforced, but not shear layer instability.

Once incoming (solar and LW) heat flux exceeds the outgoing heat flux (sensible, latent, LW radiation, the diurnal warm layer forms a separate layer within the mixed layer.

Surface inputs of heat and momentum are confined within this layer.

Using the 1D heat & equation of state you can determine the diurnal heating at the surface.

Require the bulk Ri to be 0.65, to determine the depth of the warm layer.
• Profiles of Surface Heating (POSH)
  – F96
  – Absorption
  – Dissipation of heat/momentum
  – **Structured profiles** of temperature within the warm layer (CG empirical or Kantha/Clayson (WICK) profiles)
Dimensionless DW profile

NonDim Heat Content

NonDim Depth (z)

Wind Speed (ms$^{-2}$)
Comparison throughout the day

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Mean Bias (K)</th>
<th>STD (K)</th>
<th>Number Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>F96-MAERI</td>
<td>-0.00</td>
<td>0.42</td>
<td>9680</td>
</tr>
<tr>
<td>POSH-MAERI</td>
<td>-0.07</td>
<td>0.36</td>
<td>9680</td>
</tr>
<tr>
<td>CG04-MAERI</td>
<td>-0.04</td>
<td>0.37</td>
<td>9680</td>
</tr>
<tr>
<td>ASM bulk – MAERI</td>
<td>0.05</td>
<td>0.47</td>
<td>9680</td>
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<td>ASM sub-skin – MAERI</td>
<td>0.13</td>
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A

\[
\Delta \text{SST} (K)
\]

\[
0 \quad 5 \quad 10 \quad 15 \quad 20 \quad \text{LMT (hrs)}
\]
Peak at solar noon
Conclusions

- The variability in warming and total daily heat available from the surface are not well represented by a single point such as the KK02 or K96 models.
Conclusions

- CG04 model has largest errors in the late afternoon or evening when there is a sudden drop in wind speed. Diurnal warming is then over estimated by CG04 model.
Conclusions

- F96 model is too small and tends to overestimate warming in afternoon (due to the accumulation of heat)
- POSH model responds rapidly to the onset of warming and decreases realistically in afternoon. Additionally model returns information on warming profile within the warm layer
Conclusions

Comparisons at solar noon: models do not model variability well

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<td>PWP-MAERI</td>
<td>-0.47</td>
<td>0.66</td>
<td>72</td>
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<tr>
<td>PWP3-MAERI</td>
<td>-0.32</td>
<td>0.55</td>
<td>72</td>
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<tr>
<td>CG03-MAERI</td>
<td>-0.34</td>
<td>0.61</td>
<td>72</td>
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<tr>
<td>ASM_bulk – MAERI</td>
<td>-0.51</td>
<td>0.77</td>
<td>72</td>
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<tr>
<td>ASM_skin – MAERI</td>
<td>-0.27</td>
<td>0.63</td>
<td>72</td>
</tr>
<tr>
<td>W96 – MAERI</td>
<td>-0.13</td>
<td>0.76</td>
<td>72</td>
</tr>
<tr>
<td>KK02 – MAERI</td>
<td>0.18</td>
<td>0.78</td>
<td>72</td>
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Conclusions

- Accuracy of CG04 model indicates that it is useful, especially for polar orbiters with 2AM/PM LECT while POSH more useful for geo-stationary satellites, understanding intra-day variability, and vertical structure.

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Global distribution

SSMI Winds: Diurnal Mean

Model Winds: Diurnal Mean
Diurnal Time series

- El Nino warm pool / stronger equatorial winds
- La Nina cold tongue / weaker equatorial winds
Diurnal Time series

- El Nino warm pool / stronger equatorial winds
- La Nina cold tongue / weaker equatorial winds
Change

• Change in wind patterns lead to changes in the vertical structure of surface heating
• Heat available to atmosphere
• Clouds/convection/feedbacks
Conclusions

• Look at wind fields to understand diurnal variability

• There are air-sea feedbacks: cold SSTs stabilize the MBL, lower wind speeds at surface, which result in more surface warming, destabilizing MBL, increasing winds.....
conclusions

• In the tropics it is highly likely that in situ observations are affected by diurnal warming.

• We see in ALL buoy arrays clear warming