Diurnal and High-Frequency Variability in the Upper Ocean

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Diurnal cycle from QSCAT/ADEOS-2 scatterometry tandem mission, adapted from Gille et al, 2005

Caltech, May 2018
William Dampier (1651-1715)

“There Sea-Breezes do commonly rise in the Morning about Nine a Clock, sometimes sooner, sometimes later ....”
Diurnal and high-frequency variability in the context of Earth System Modeling

- Diurnal winds: Lessons from scatterometry (and seasonal modulation of diurnal amplitude)
- Diurnal temperatures in the upper ocean
- Combined impact of wind and temperature
  - Diurnal
  - Other high-frequency

*QuikSCAT/ADEOS-II tandem mission: Boreal summer 2003*
Projecting Winds Onto an Ellipse

Least squares fit bin-averaged winds to sinusoid:

\[
\tau^x = \tau_0^x + \tau_1^x \cos \omega t + \tau_2^x \sin \omega t,
\]

\[
\tau^y = \tau_0^y + \tau_1^y \cos \omega t + \tau_2^y \sin \omega t,
\]
Baja California Diurnal Winds

Gille and Llewellyn Smith, 2014
Diurnal amplitude

Take away: Diurnal winds significant throughout the tropics

Adapted from Gille et al, GRL 2005
Diurnal phase

Take away: Diurnal phase varies spatially

Adapted from Gille et al, GRL 2005
• January: Diurnal amplitude is double annual mean
• June: Diurnal amplitude is zero

Take away: Diurnal winds vary seasonally; not trivially removed
Strong semi-diurnal component in zonal wind (not shown)

Giglio et al, in prep
Sea surface temperature also has diurnal cycle

A: 1988 PF Day minus Night

Temperature: No subsurface variability?

http://www.ghrsst.org/SST-Definitions.html
Diurnal Variability in Upper Ocean Temperature

- AMSR-E measure of “sub-skin” temperature.
- Sun-synchronous orbit: roughly 1:30 am/1:30 pm
- Use Remote Sensing Systems level 2 product, version 7
- Day/night inconsistencies expected, so compare with Argo floats
Argo sampling

- Benefits
  - Global coverage (3000 floats with 10-day sampling)
  - Quality controlled data
  - Provide measure of sub-surface variability

- Challenges
  - No skin temperature
  - Coarse vertical resolution
  - Incomplete time information for profile

Gille, 2012
Daytime Argo minus AMSR-E

- Diurnal cycle evident, even with large time separations between observations.

Gille, 2012
Diurnal cycle evident, even with large time separations between observations.

Comparable in amplitude for ascending and descending satellite passes.

AMSR-E and Argo differ by $O(0.1^\circ C)$: $\Delta T \neq 0$ at zero time lag.

Gille, 2012
How deep is the summer diurnal cycle detectable?

- Amplitude attenuates with depth above mean mixed layer. (Cross-hatching indicates one-sigma statistical significance.)
- Phasing later with depth, mostly.
- Below base of mixed-layer, amplitude is big, phasing shifts.

Take away: Diurnal temperature signal extends to base of mixed layer; phasing fairly uniform spatially and varies with depth

Gille, 2012
How much impact from diurnal variability?

- Price-Weller-Pinkel (PWP) model (JGR, 1986) implemented to look at mixed-layer depth $\langle \tau \rangle = 0.05 \text{ N m}^{-2}$.
- Constant winds lead to varying diurnal mixed layer depth.
How much impact from diurnal variability?

- Price-Weller-Pinkel (PWP) model (JGR, 1986) implemented to look at mixed-layer depth $<\tau> = 0.05$ N m$^{-2}$.
- Varying winds shift phasing of diurnal mixed layer depth.
Replicating the real upper ocean

• DYNAMO near-surface temperature, October 2011 (yellow circle with black edge)
• Use Generalized Ocean Turbulence Model (GOTM) to model difference between surface and “foundation” temperature

Giglio et al, 2017
Temperature differences

- Observed $\Delta T$
- Observed winds
- Daily-mean wind
- Diurnal wind
- Stochastic gusts
- Daily-mean wind and fluxes from smoothed wind
- Dashed: RAMA mooring
- Dotted: RAMA climatology

*Take away:* Diurnal winds are not enough to replicate observations; stochastic winds are effective.

Giglio et al, 2017
What does all of this mean for Earth System Models?

- Winds, heat fluxes, temperature all vary at high frequencies → Resolve air-sea exchanges at sub-daily time scales.
- These processes influence ocean mixed layer; expect turbulent exchange across base of mixed layer. → Slab mixed layer missing critical physics
- Diurnal signal is ubiquitous and easy to analyze, though not necessarily most energetic. At diurnal frequency winds and air-sea fluxes and produce rectified effects with impact on mixed-layer temperature and depth. → Phasing of wind relative to buoyancy forcing could matter
- High-frequency (stochastic) winds influence upper ocean temperature structure → Upper ocean temperature depends on wind-driven turbulence within mixed layer.
- Observations matter → Articulate Earth System Modeling observational requirements (e.g. for a Winds and Currents Mission [WaCM] or Tropical Pacific Observing System)