Diurnal and High-Frequency Variability in the Upper Ocean

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(with Donata Giglio, Stefan Llewellyn Smith, Aneesh Subramanian, and others)

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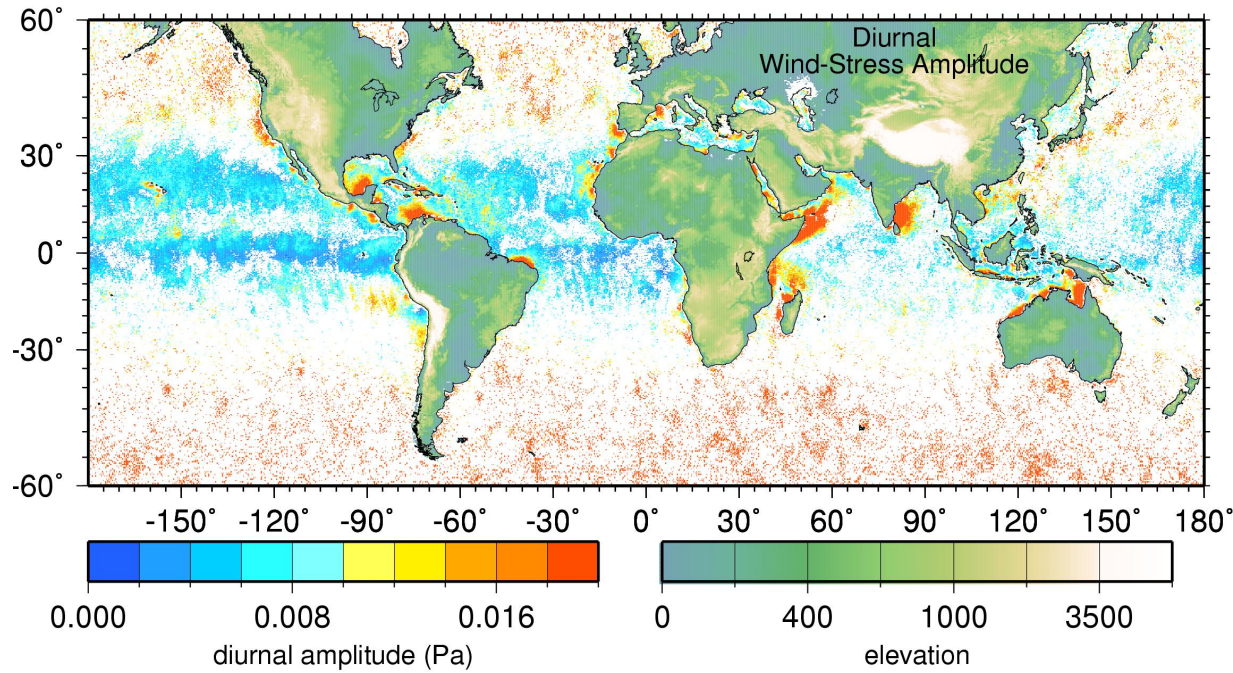


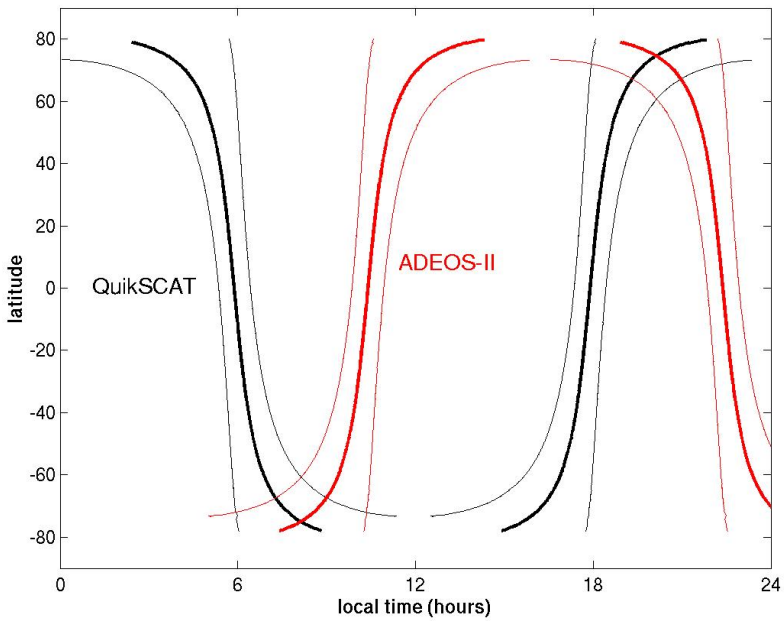
Diurnal cycle from QSCAT/ADEOS-2 scatterometry tandem mission, adapted from *Gille et al, 2005*

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



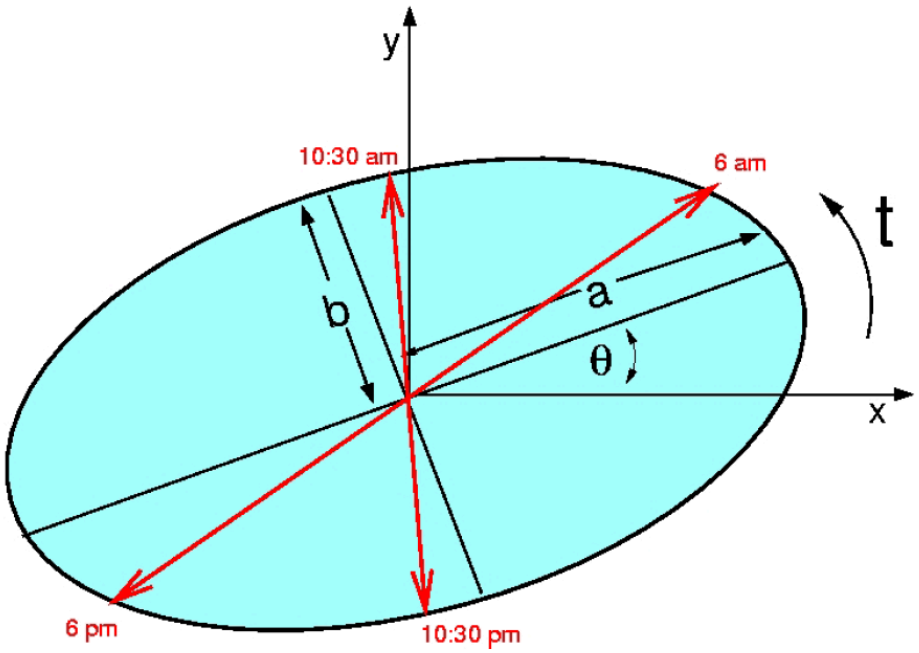
QuikSCAT/ADEOS-II tandem mission: Boreal summer 2003

- 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

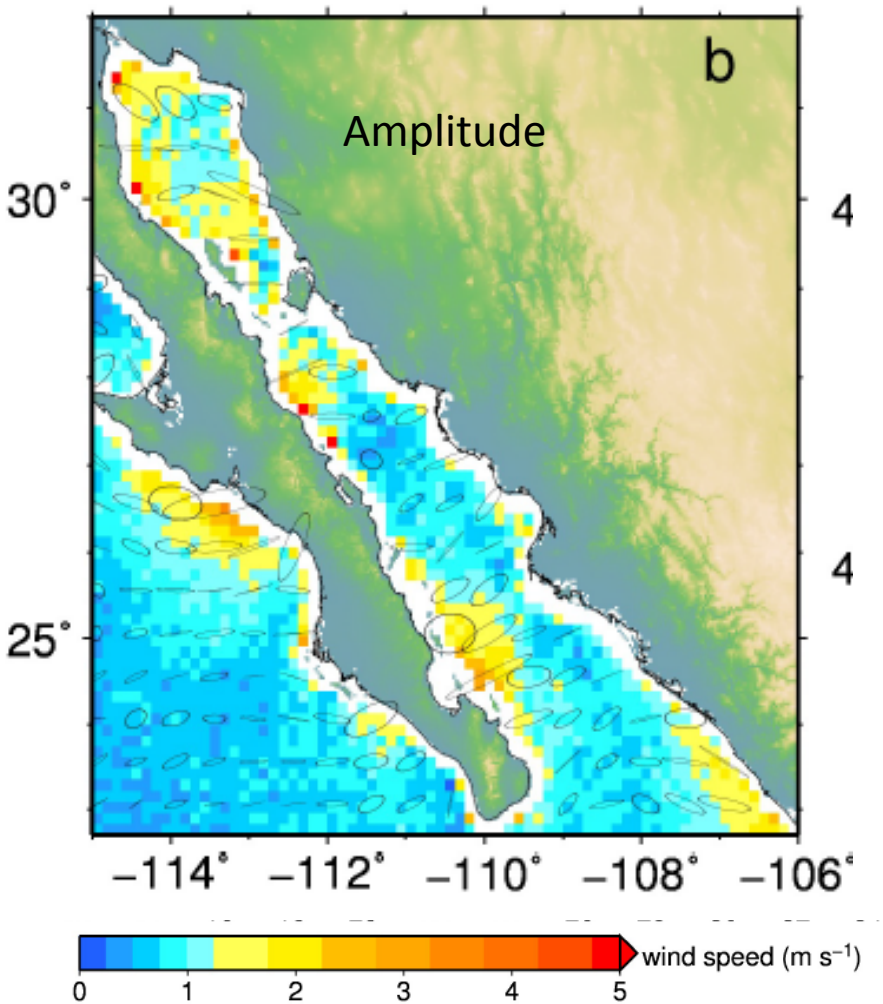
Projecting Winds Onto an Ellipse

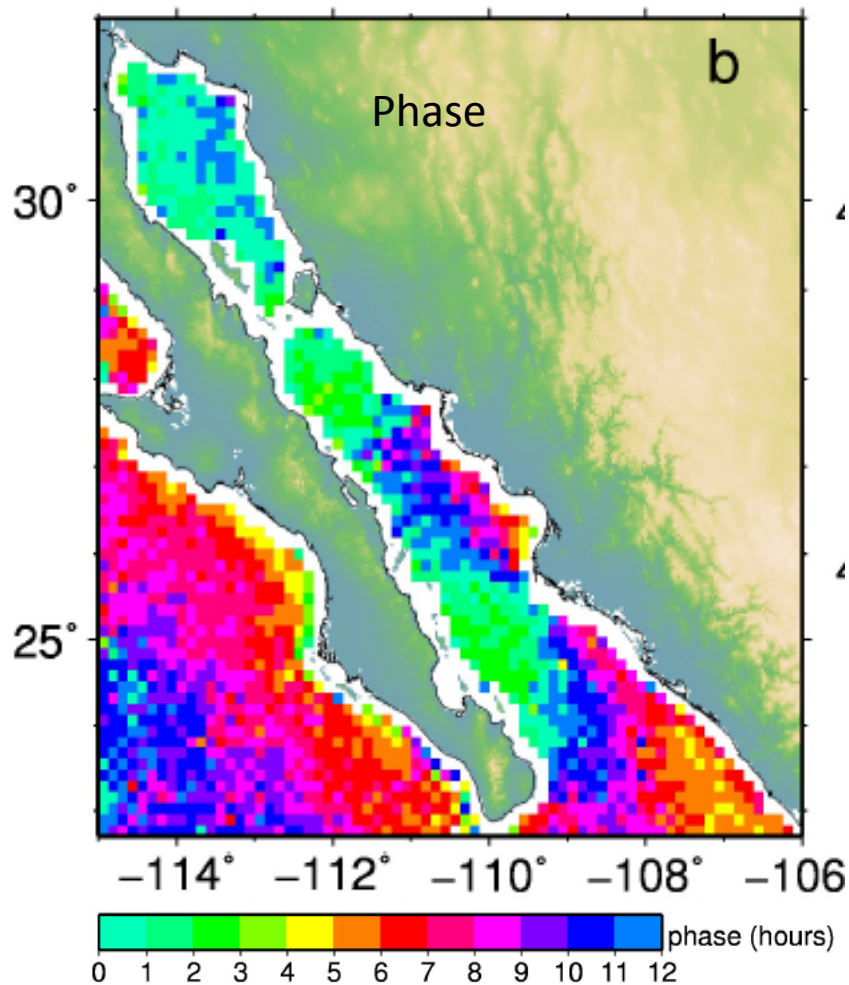
Least squares fit bin-averaged winds to sinusoid:

$$\begin{aligned}\tau^x &= \tau_0^x + \tau_1^x \cos\omega t + \tau_2^x \sin\omega t,\\ \tau^y &= \tau_0^y + \tau_1^y \cos\omega t + \tau_2^y \sin\omega t,\end{aligned}$$



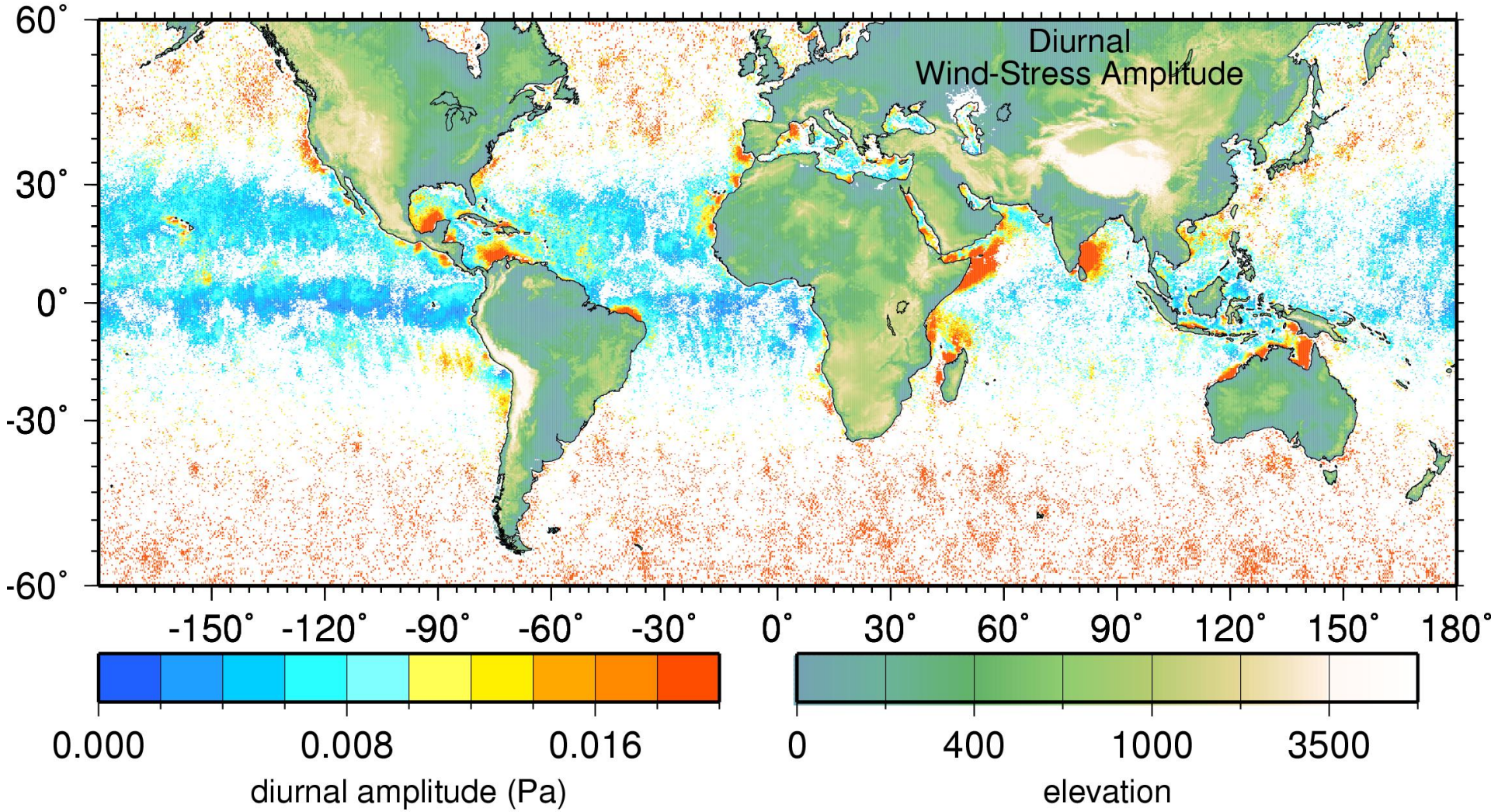
Baja California Diurnal Winds





Gille and Llewellyn Smith, 2014

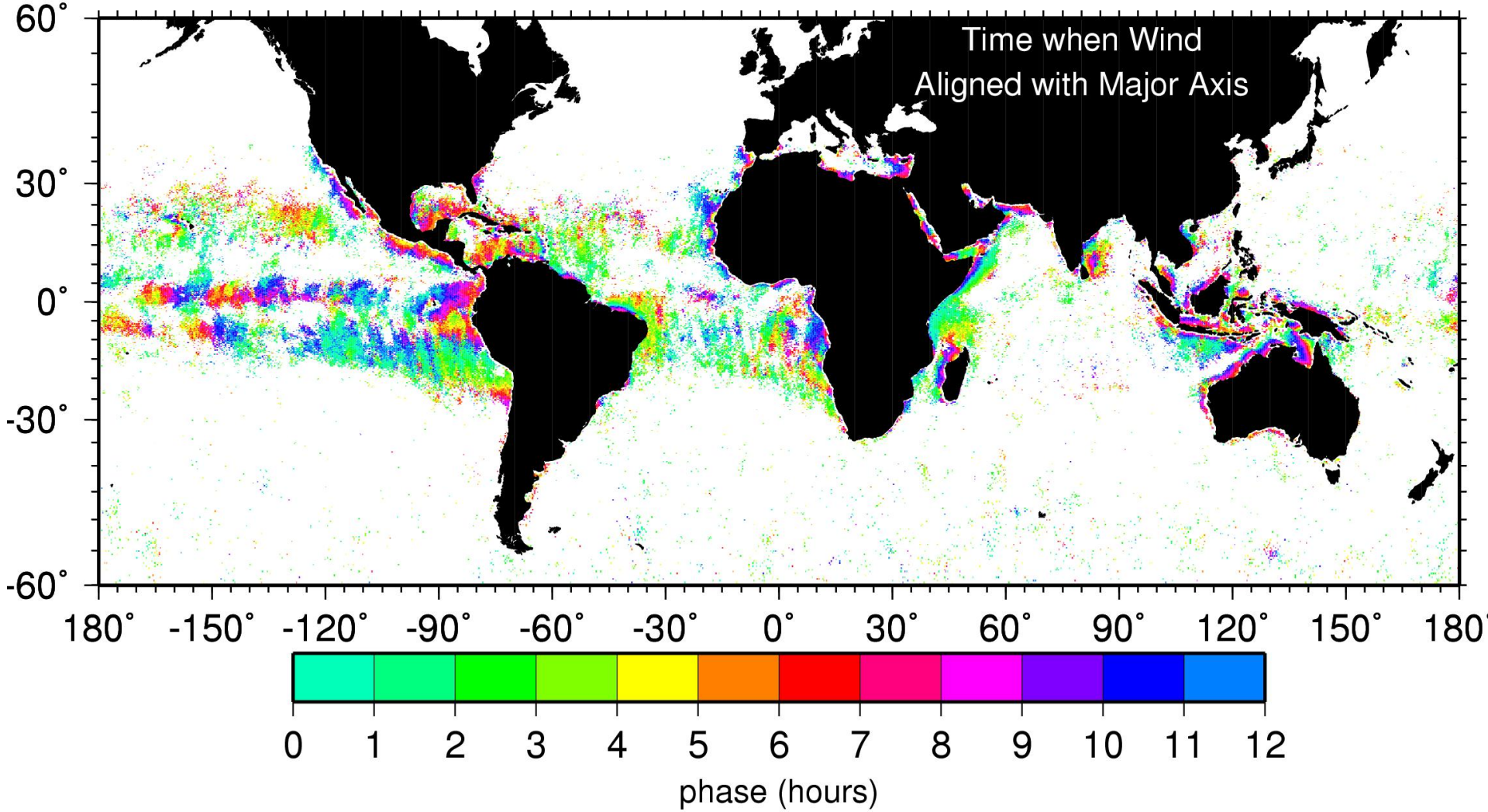
Diurnal amplitude



Take away: *Diurnal winds significant throughout the tropics*

Adapted from Gille et al, GRL 2005

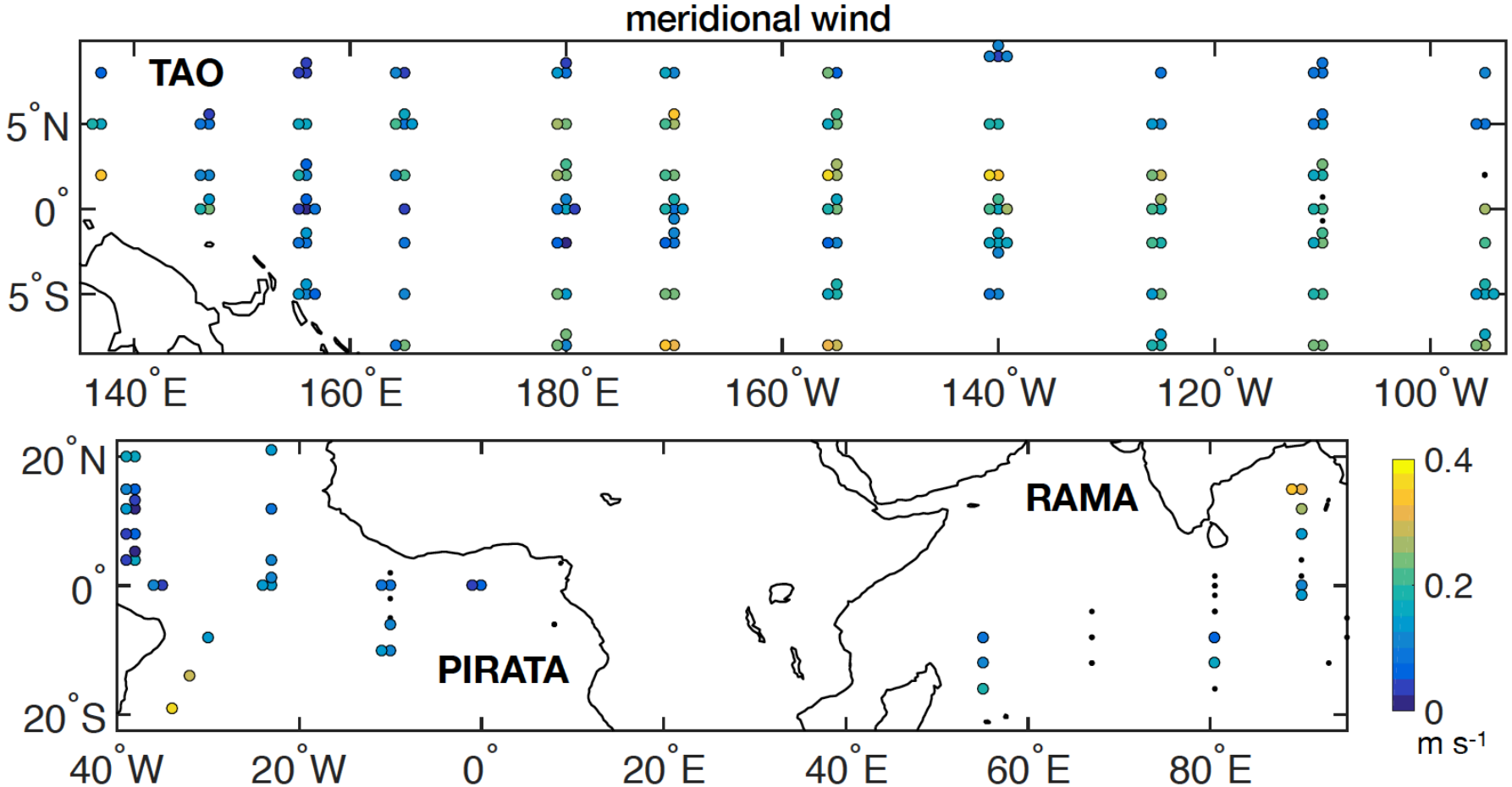
Diurnal phase



Take away: *Diurnal phase varies spatially*

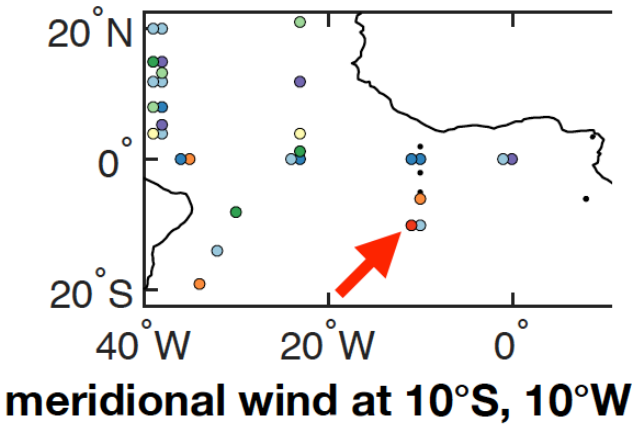
Adapted from Gille et al, GRL 2005

Annual mean diurnal amplitude, a_D

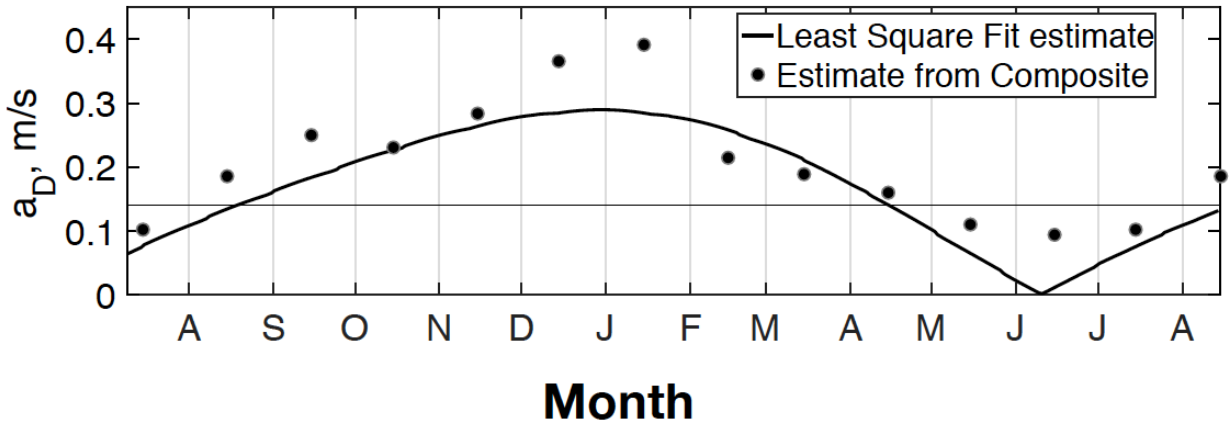


relevant for cross-calibration

Giglio et al, in prep



Diurnal amplitude in different months



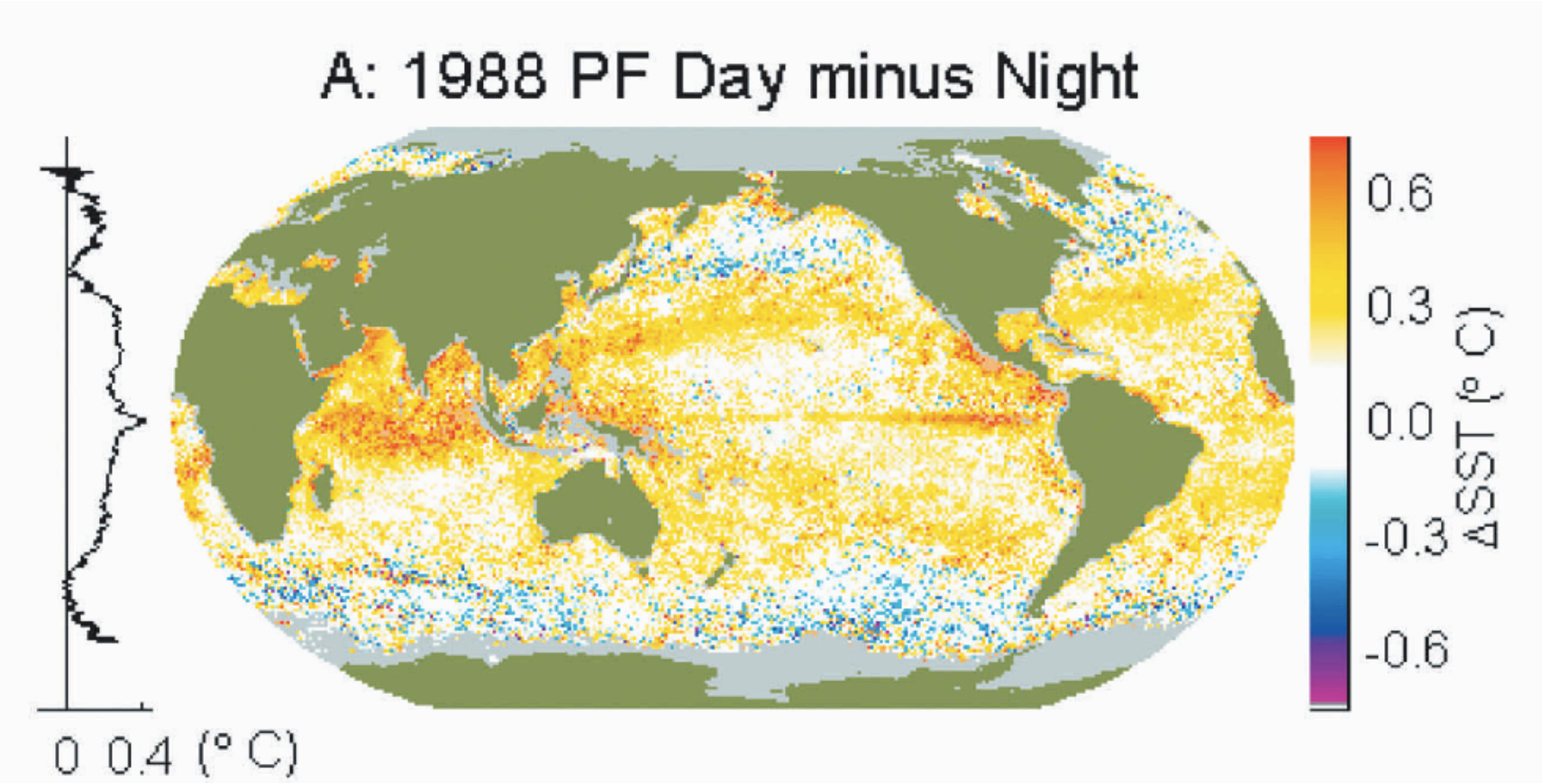
- January: Diurnal amplitude is double annual mean
- June: Diurnal amplitude is zero

Take away: *Diurnal winds vary seasonally; not trivially removed*

Strong semi-diurnal component in zonal wind (not shown)

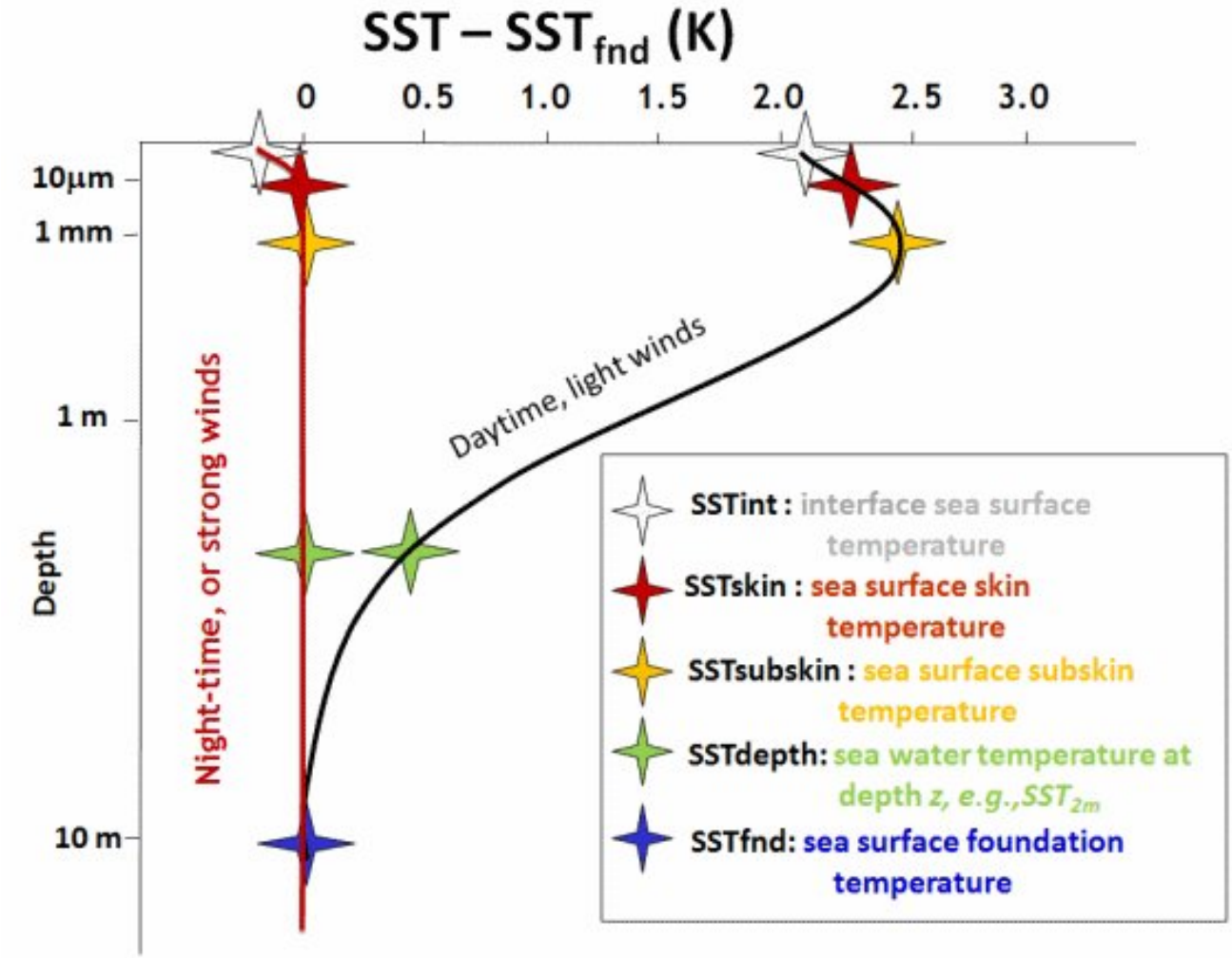
Giglio et al, in prep

Sea surface temperature also has diurnal cycle



Pathfinder SST differences, Gentemann et al (2003)

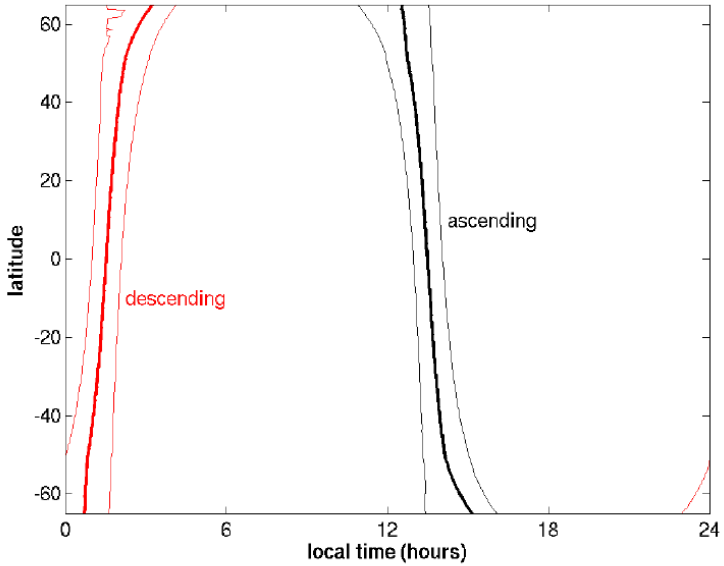
Temperature: No subsurface variability?

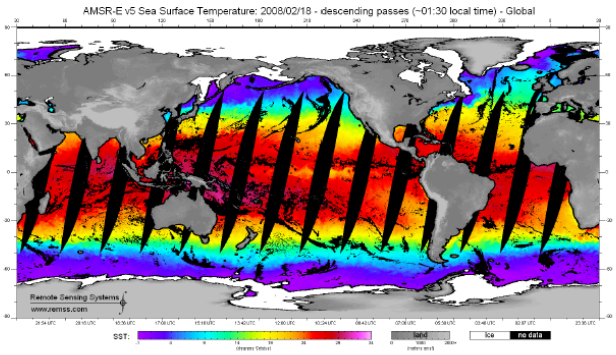


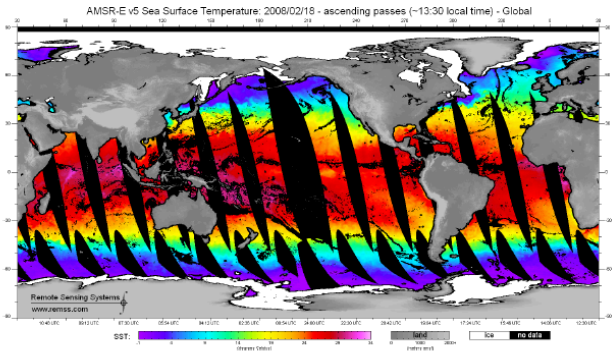
http://www.ghrsst.org/SST-Definitions.html

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

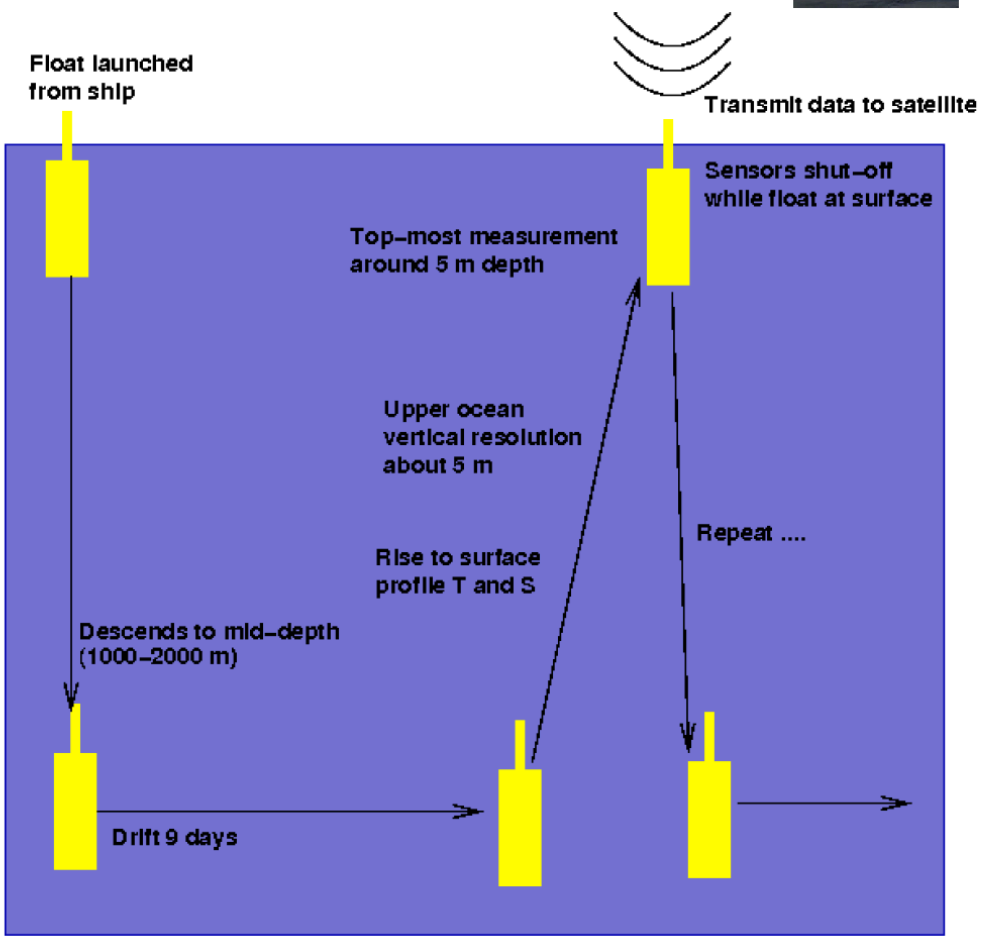






Gille, 2012

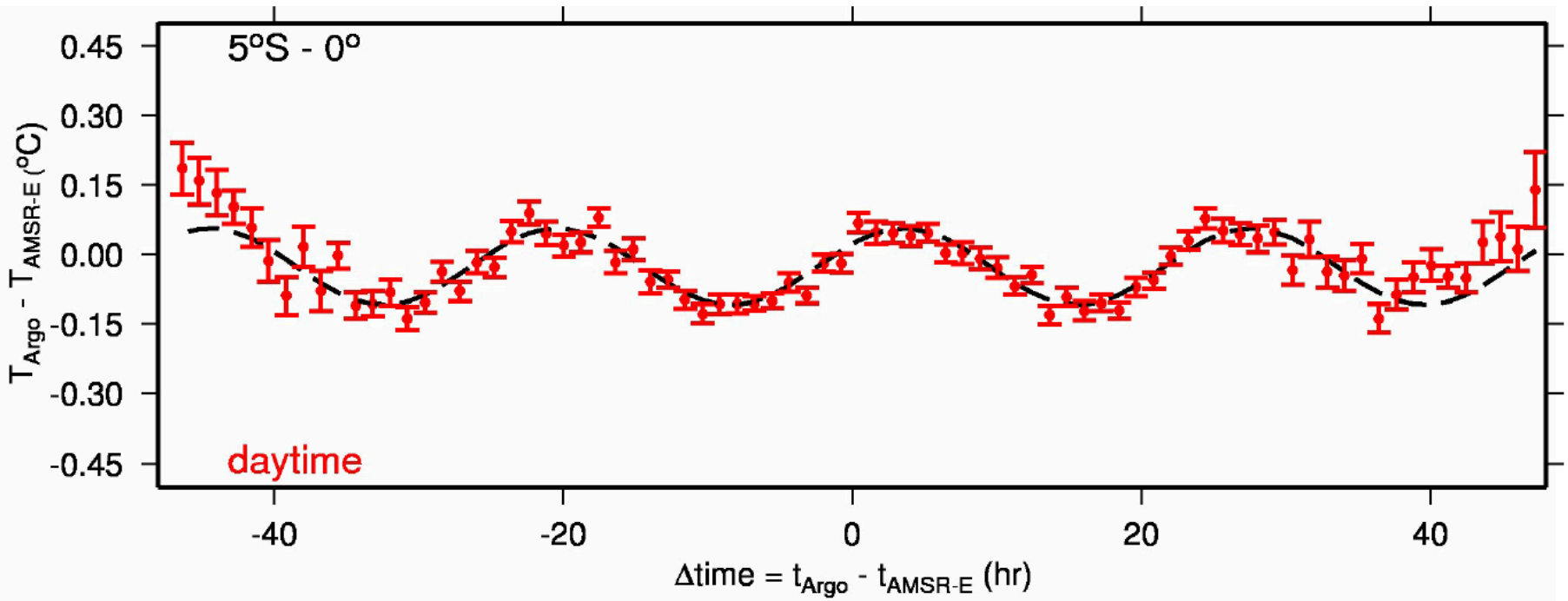
Argo sampling



- 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

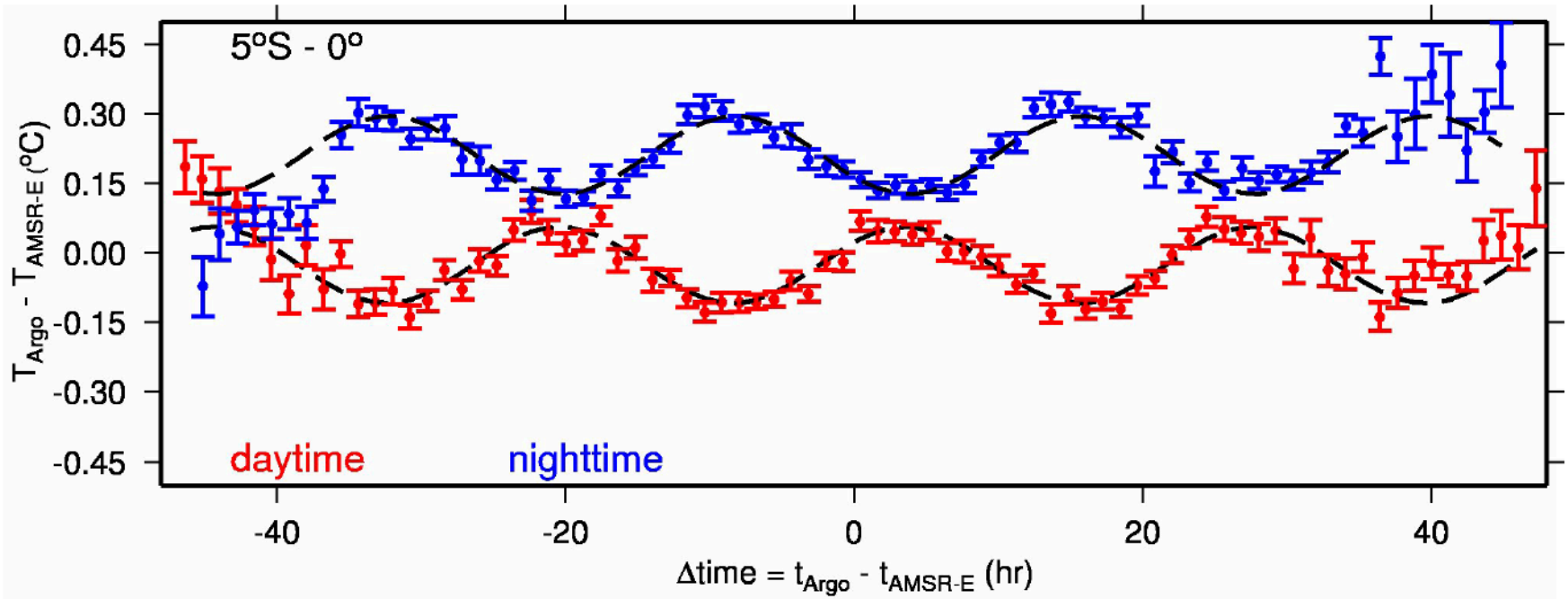
Daytime Argo minus AMSR-E



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

Gille, 2012

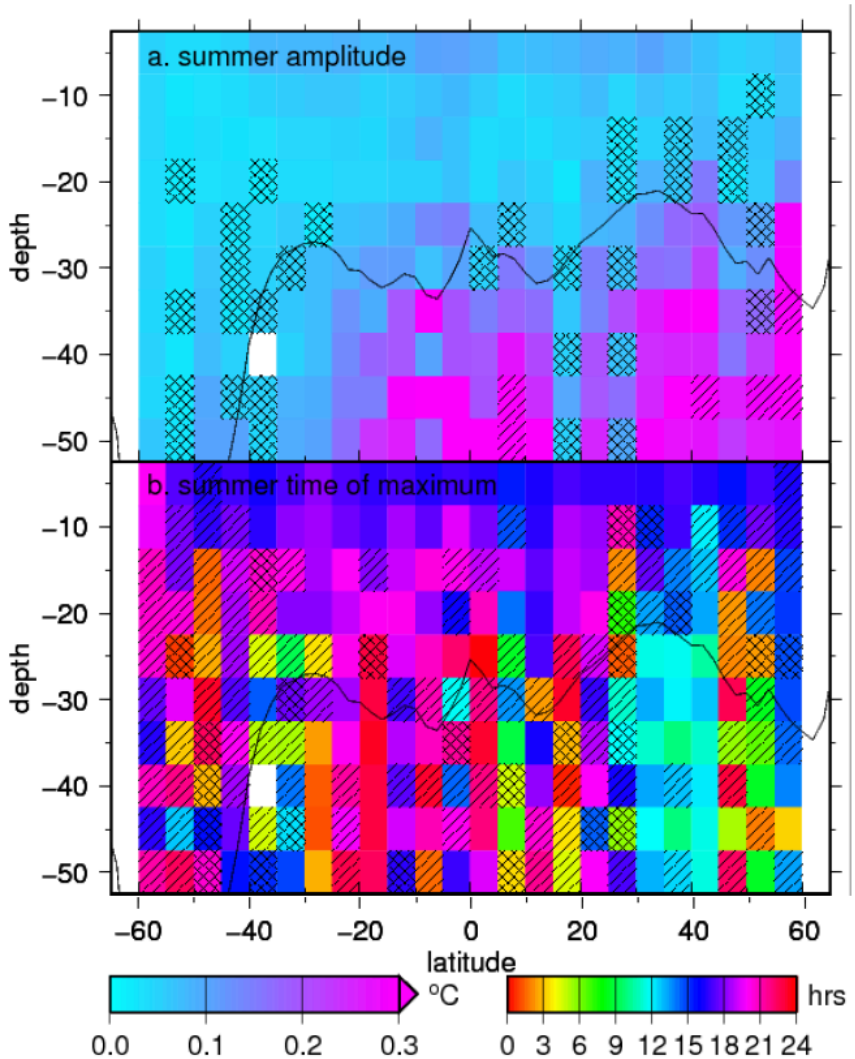
Daytime and Nighttime Argo minus AMSR-E



- 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°C): $\Delta T \neq 0$ at zero time lag.

Gille, 2012

How deep is the summer diurnal cycle detectable?



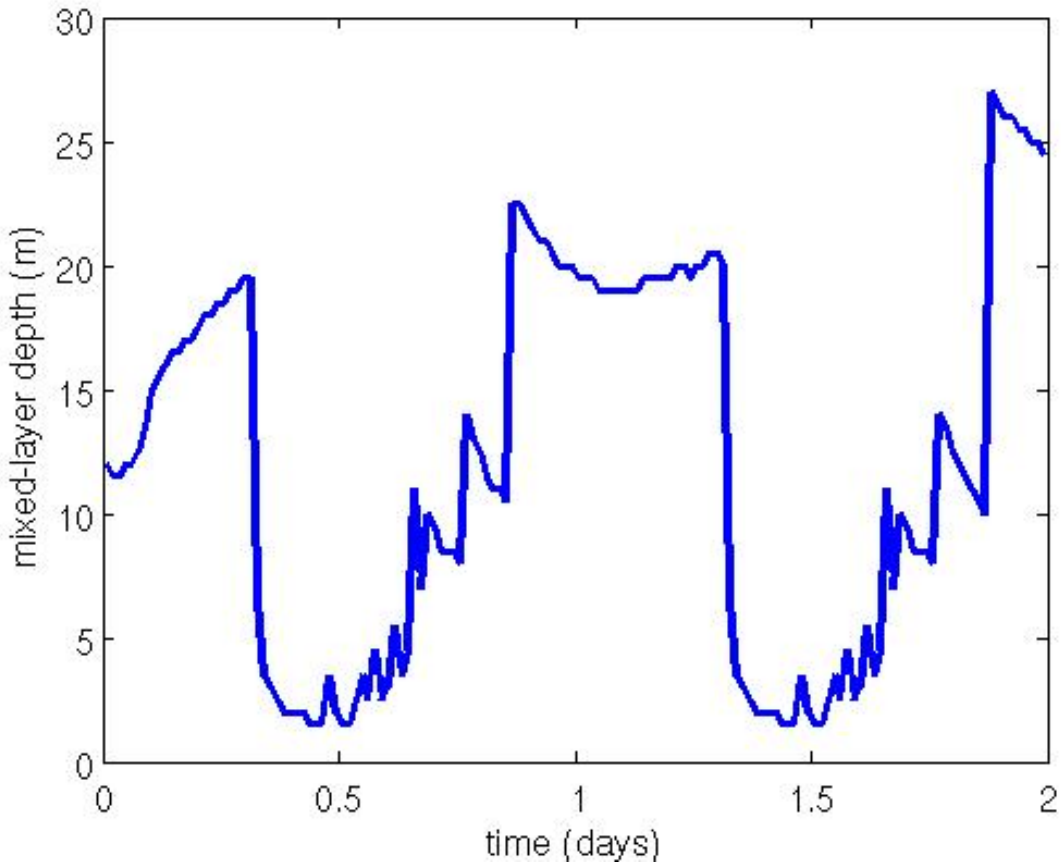
- Amplitude attenuates with depth above mean mixed layer. (Cross-hatching indicates one-sigma statistical significance.)
- Phasing later with depth, mostly.
- Below base of mixed-layer, amplitude is big, phasing shifts.

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

Gille, 2012

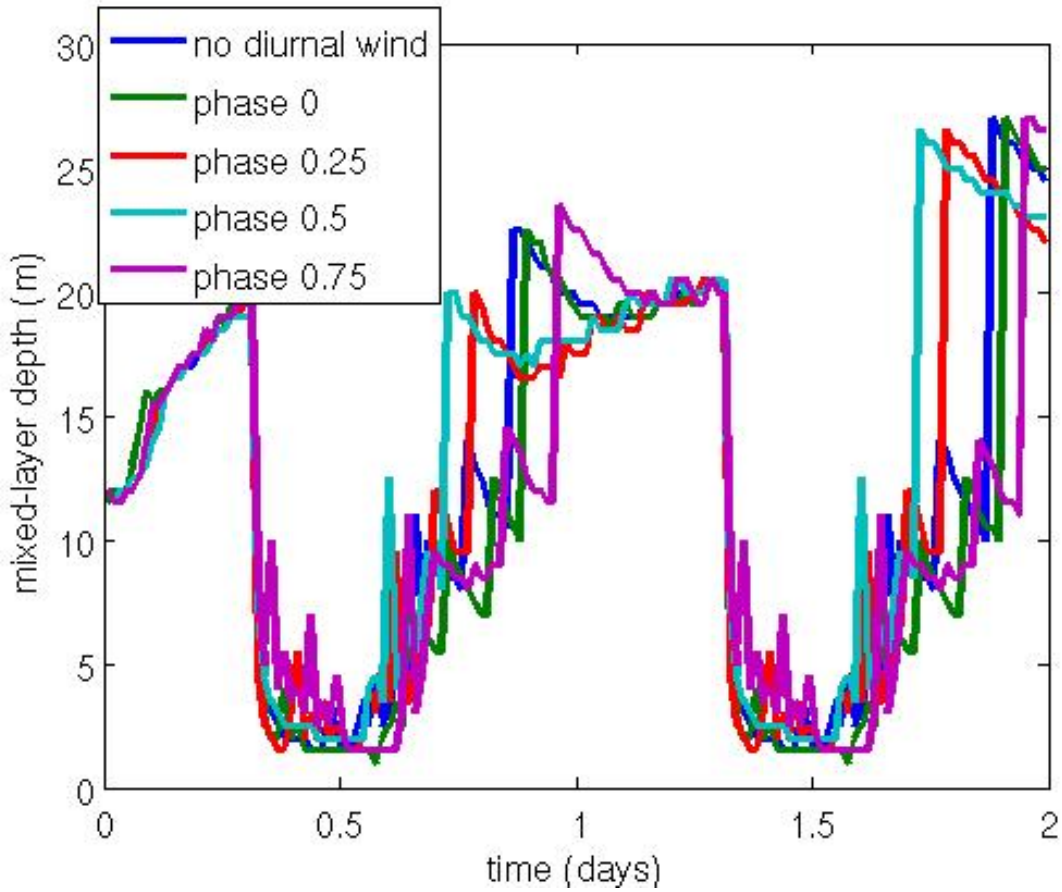
How much impact from diurnal variability?

- Price-Weller-Pinkel (PWP) model (JGR, 1986) implemented to look at mixed-layer depth <τ>= 0.05 N m^{-2}.
- Constant winds lead to varying diurnal mixed layer depth.



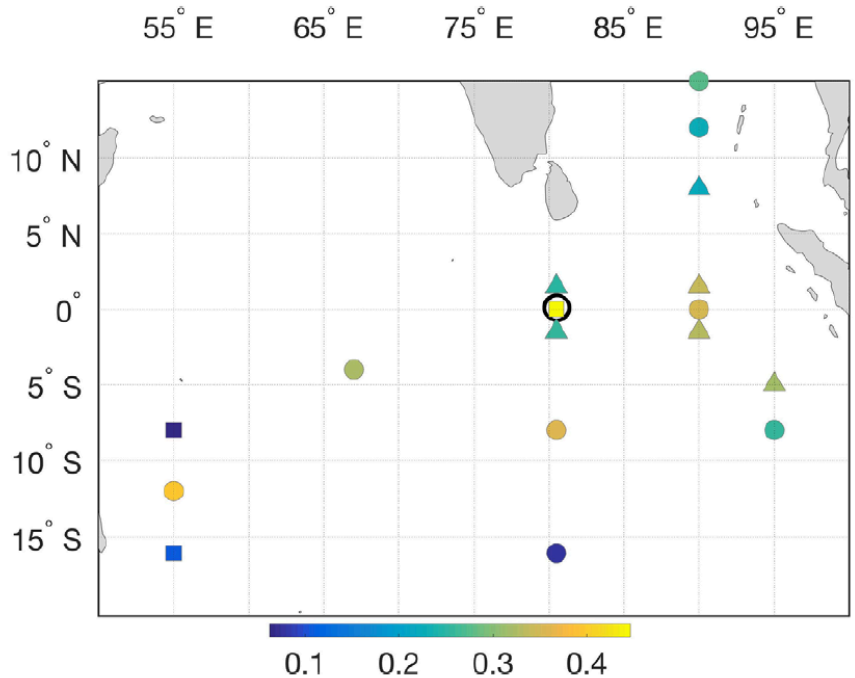
How much impact from diurnal variability?

- Price-Weller-Pinkel (PWP) model (JGR, 1986) implemented to look at mixed-layer depth <τ>= 0.05 N m^{-2}.
- Varying winds shift phasing of diurnal mixed layer depth.



Replicating the real upper ocean

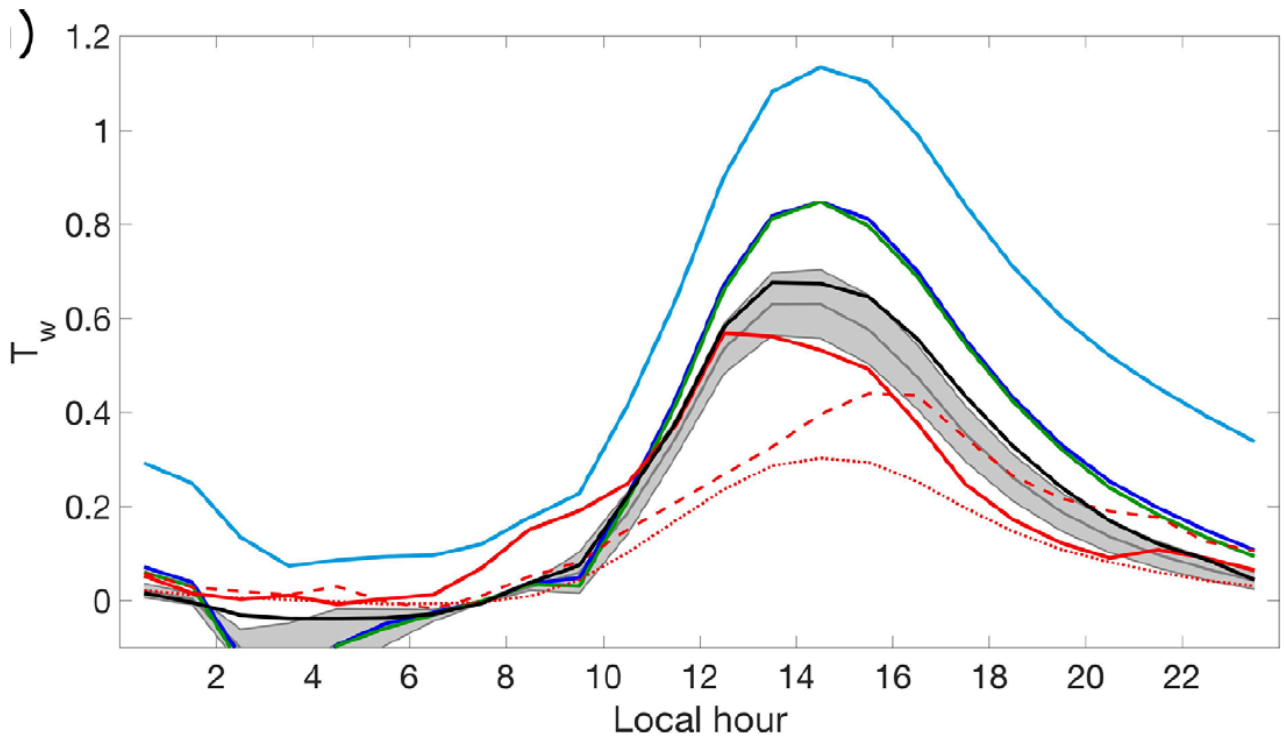
- DYNAMO near-surface temperature, October 2011 (yellow circle with black edge)
- Use Generalized Ocean Turbulence Model (GOTM) to model difference between surface and "foundation" temperature



Giglio et al, 2017

Temperature differences

- Observed ΔT
- 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)