Wave Modeling and Langmuir Mixing

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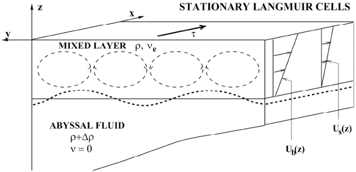
Inverse Turbulent Langmuir Mixing Number



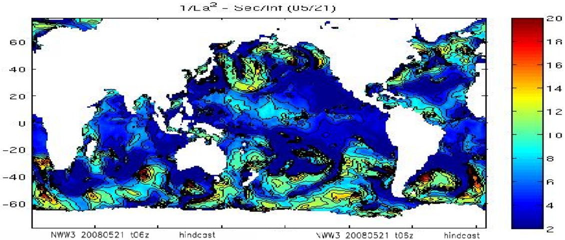
The inverse turbulent Langmuir mixing number accounts for nonaligned wind and wave fields.

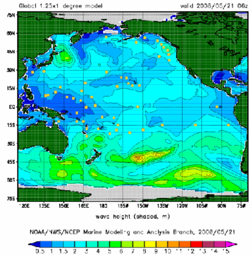
It is defined as

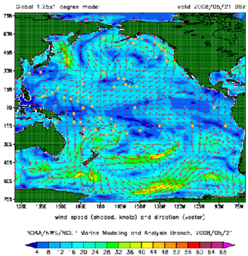
$$La_i = \begin{cases} \left(\dfrac{U_{stokes} \cdot u^*}{|u^*|^2} \right)^{1/2}, & |\theta| < \pi/2; \\ \\ 0, & |\theta| \geq \pi/2. \end{cases}$$

where θ is the difference in wind and wave directions

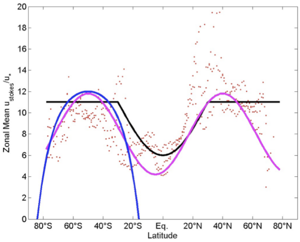
Previous Work: A Simple Climatology







- Used output from NWW3 to estimate areas of Langmuir mixing and derive a simple climatology



A Simple Scaling for Langmuir Depth/Entrainment:

(Li & Garrett, 1997)

CAM

related to CAM u* by WW3 Climatology

$$Fr = \frac{\omega}{NH} \approx 0.6 \qquad \omega \approx \frac{V}{1.5} \approx \frac{\sqrt{u^* u_s}}{1.5}$$

The Algorithm

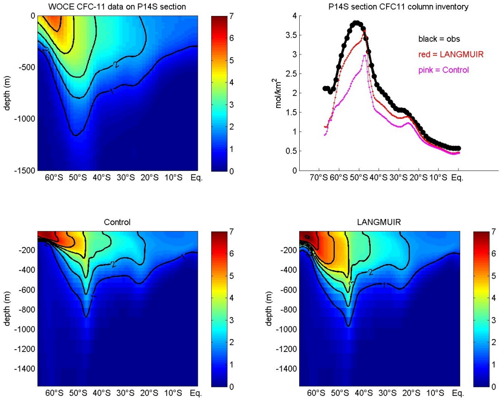
Use Fr to determine H

If H is deeper than KPP Boundary Layer depth, use H

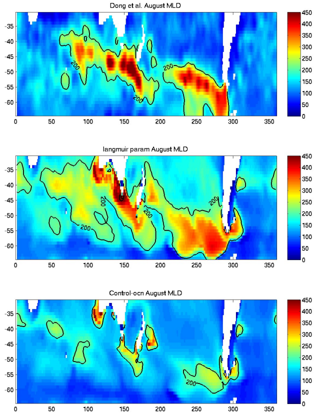
Large came up with clever choices for N, H that lead to a robust implementation in KPP

With these choices, H and BLD converge over time.

Previous Work: Shown Sensitivity to Inclusion



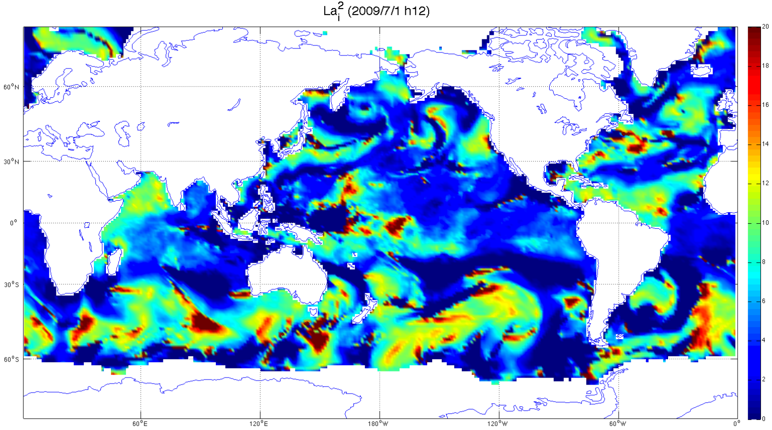
(a) CFC in CCSM 3.5 & P14S WOCE obs



(b) August mixed layer depths

Problem 1: Calculating the Surface Friction Velocity

- Installed WW3 on bluefire (details later)
- Obtained similar calculations of La_i using WW3's u^* with COREv2 forcings



Problem 2: Estimating Stokes Drift

For monochromatic waves, it can be shown that at the surface

$$U_{stokes} = \frac{\pi^3 Hs^2}{gTm^3}$$

where $Hs = 4\sqrt{m_0}$ and m_0 is the zeroth moment of the variance.

However, this is not true for anything other than monochromatic waves.

Problem 3: Different Definitions of Mean Wave Period

$$\begin{aligned} \text{WaveWatch:} \quad & Tm_0 = \overline{(f^{-1})} \\ \text{ERA40:} \quad & Tm_1 = 1 \big/ (\overline{f}) \\ \text{TOPEX:} \quad & Tm_2 = 1 \Big/ \sqrt{(\overline{f^2})} \end{aligned}$$

$$m_n = \int_0^{2\pi} \int_0^{\infty} f^n \, S(f, \theta) \, df \, d\theta$$

$$Tm_0 = \frac{m_{-1}}{m_0}, \quad Tm_1 = \frac{m_0}{m_1}, \quad Tm_2 = \left(\frac{m_0}{m_2} \right)^{1/2}$$

A Quick Example

Pierson-Moskowitz Spectrum

$$S(f,\theta) = S(f) = \frac{\alpha g^2}{(2\pi)^4}\, f^{-5} \;\; \mathrm{Exp}\left[-\frac{5}{4}\left(\frac{f_p}{f}\right)^4\right]$$

where α is the Phillips constant and f_p the peak frequency

$$(Tm_0/Tm_1)^3 = 1.37, \qquad (Tm_0/Tm_2)^3 = 1.76$$

$$(Tm_1/Tm_2)^3 = 1.28$$

Calculating Stokes Drift Using 2-D Spectrum

From previous work by Kenyon (1969) and McWilliams & Restrepo (1999), we can reformulate Stokes drift using the 2-D spectrum as

$$\begin{aligned} U_{stokes} &= \frac{16\pi^3}{g} \int_0^{2\pi} \int_0^{\infty} f^3 \, S(f, \theta) \, df \; d\theta \;\; \hat{\mathbf{e}}_d \\ &= \frac{16\pi^3}{g} m_3 \;\; \hat{\mathbf{e}}_d \end{aligned}$$

where $\hat{\mathbf{e}}_d$ is the dominant direction of wave propagation.

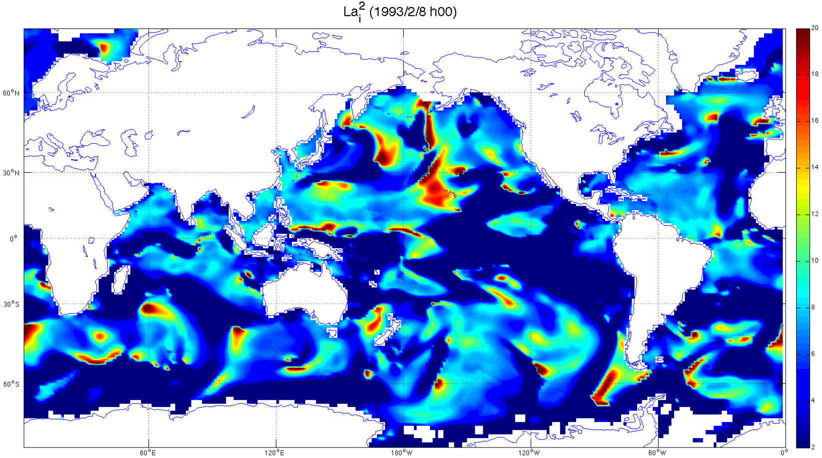
As a result, we no longer need the previous U_{stokes} approximation!

Refining our Stokes Drift Approximation

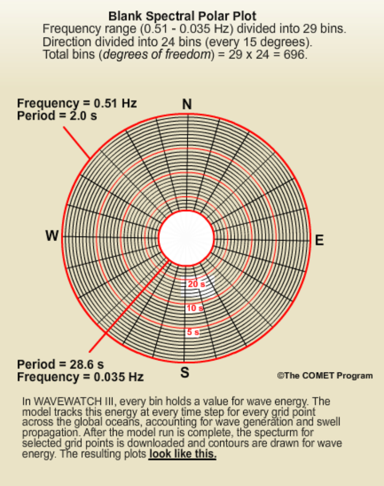
- Would still like to be able to estimate Stokes drift using satellite and buoy data for comparison
- Currently examining if there is an empirical or mathematical relationship that we can use such as

$$U_{stokes} \approx a(f) \frac{\pi^3 Hs^2}{gTm^3} \hat{\mathbf{e}}_d$$

Current Estimate of La_i^2



Problem 4: Numerical Cost



- 3^{rd} generation wave model
- Solves the spectral action density balance equation
- 15-20 sec per time step (1 hr) for one processor ($\approx$ 35-50 $\mathrm{hr/yr}$)
- Plan on scaling back the number of bins significantly and turning off some interactions
- Aternative 2^{nd} generation model developed by George Mellor (Princeton) worth exploring

Applications of Coupling a Wave Model

- Calculate Langmuir Mixing forcing prognostically
  - A coupled wave model will allow use of more sophisticated and validated parameterizations (e.g., Smyth et al, 04; Harcourt & D'Asaro, 08; Grant & Belcher, 09)
- Improve the air-sea momentum flux
- Improve the air-sea tracer flux
- Conduct climate change studies like erosion
- Others?

Some Properties of $a(f)$