Demonstrated Sensitivity to Langmuir Mixing in a Global Climate Model (CCSM)

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February 23, 2010

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Research funded by: NASA ROSES Physical Oceanography NNX09AF38G, NSF DMS, and OCE 0934737

"Essentially, all models are wrong, but some are useful" - George Box

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All *parametrizations* are wrong, but some are useful

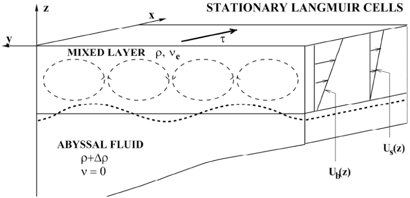
Talking Points

- Performed a climate modeling version of "back of the envelope" calculation for adding Langmuir mixing to the Community Climate System Model (CCSM)
- CCSM is sensitive to our "back of the envelope" parametrization"
- CCSM is sensitive to the details of the parametrization
- Essential to implement correctly and suggestions welcome

Langmuir Mixing and GCMs

Langmuir mixing is not directly included in any global climate model (2/2010)

- Mixing models (KPP) are trained against data which contains Langmuir mixing
- Is this sufficient? Why important for GCMs?
- Expect large areas of Langmuir mixing in the Southern Ocean



Inverse Turbulent Langmuir Mixing Number

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

- Mixing can be characterized by the turbulent Langmuir number:

$$La \equiv \sqrt{u^* / u_{stokes}}$$

- A new mixing number La_i is defined as

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

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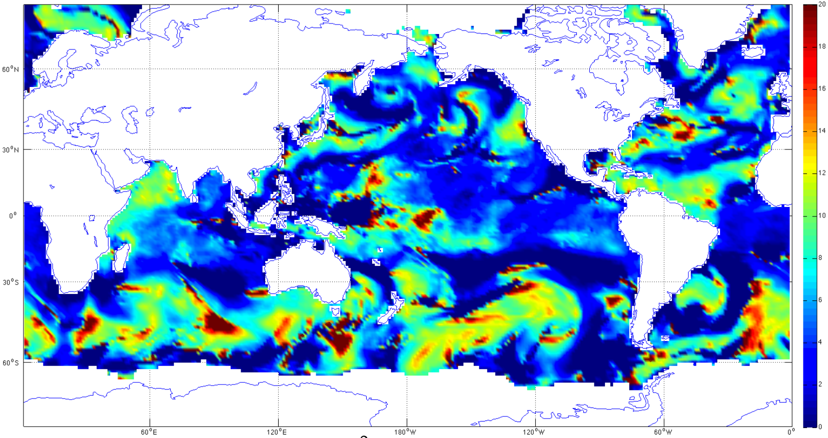
Snapshot of La_i^2

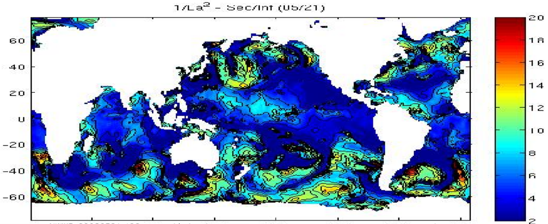


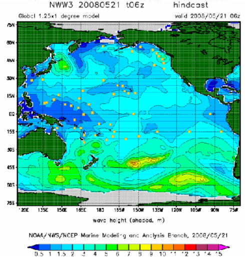
Map of La_i^2 on 1993/2/8 12:00

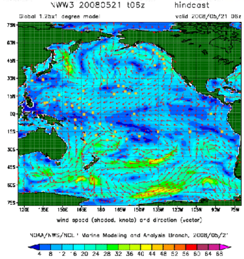
$$\mathbf{u}^* = \sqrt{|\tau|/\rho}\ \frac{\tau}{|\tau|}, \qquad |\mathbf{u}_{stokes}| = \frac{16\pi^3}{g} \int_0^{2\pi} \int_0^{\infty} f^3\, S(f,\theta)\, df\, d\theta, \qquad La_i^2 = \frac{\mathbf{u}_{stokes} \cdot \mathbf{u}^*}{|\mathbf{u}^*|^2}$$

A Simple Climatology

A preliminary La_i climatology was developed using NOAA WaveWatch III (NWW3) output.



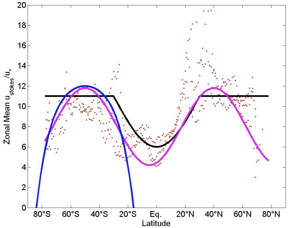




Left bottom: NWW3 0hr forecast significant wave heights and wind speeds (2008/5/21 00:00)

Left top: Estimated regions of Langmuir mixing (La_i^2)

Below: Zonal mean inverse Langmuir (La_i) climatologies



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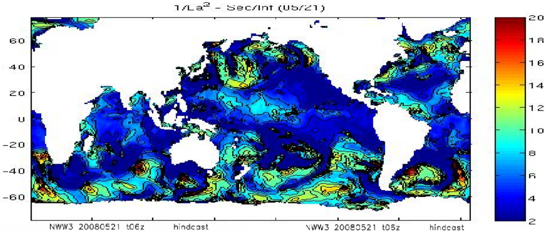

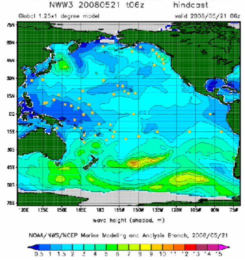

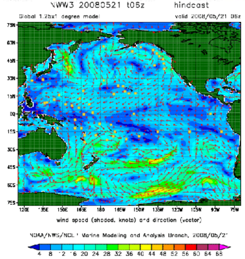

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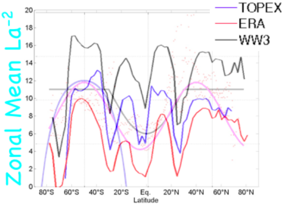


Poster PO35F-01

A Simple Scaling for Langmuir Depth/Entrainment

related to CAM u* by WW3 Climatology

CAM

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

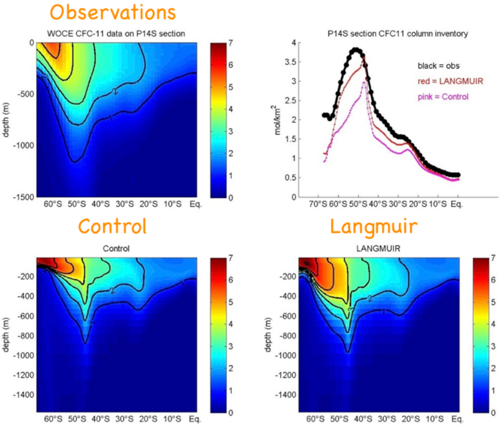
(Li & Garrett, 1997)

- The Algorithm uses *Fr* to determine *H*. If *H* is deeper than the KPP boundary layer depth (BLD), *H* is used.
- 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.

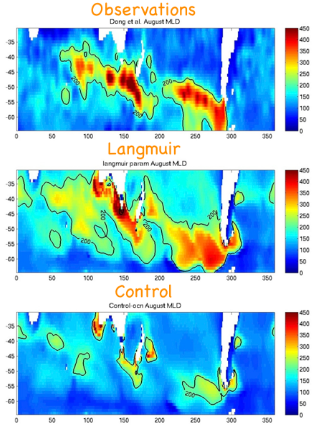
Sensitivity to Inclusion

There is a persistent shallow mixed-layer bias in the Southern Ocean in all GCMs.

- Addition of Langmuir parametrization helps correct this bias



(a) CFC in CCSM 3.5 & P14S WOCE observations



(b) August mixed layer depths

Motivation and Applications of Coupling a Wave Model

- Calculate Langmuir Mixing forcing prognostically
    - A coupled wave model will allow use of more sophisticated and validated parametrizations (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 coastal erosion
- Others suggestions?

Conclusion

- Added a simple parametrization for Langmuir mixing to NCAR's CCSM
- CCSM is sensitive to our parametrization and has potential to correct long-standing biases
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Please check out poster PO35F-01 by Erik Baldwin-Stevens for more details about a newer Langmuir climatology

Calculating Stokes drift at the surface

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

$$|\mathbf{u}_{stokes}| = \frac{16\pi^3}{g} \int_0^{2\pi} \int_0^{\infty} f^3\, S(f,\theta)\, df\, d\theta$$

For monochromatic waves, this simplifies to

$$|\mathbf{u}_{stokes}| = \frac{\pi^3 Hs^2}{gTm^3}$$

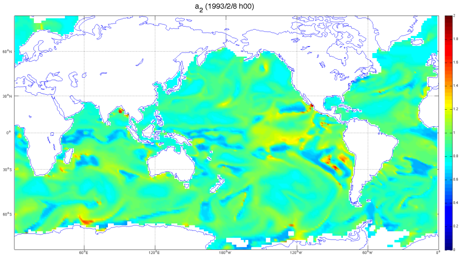
where $Hs = 4\sqrt{m_0}$ and m_0 is the zeroth moment of variance.

Refining our Stokes Drift Approximation

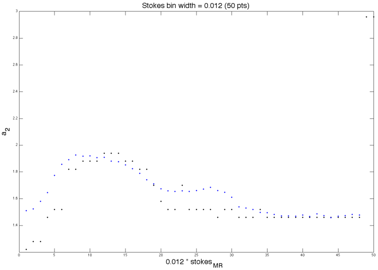
We would like to approximate Stokes drift for different products without using the wave spectrum.

- Currently examining if there is an empirical or mathematical relationship similar to the monochromatic form

$$\mathbf{u}_{stokes} \approx a(f)\, \frac{\pi^3 Hs^2}{g Tm^3}\, \hat{\mathbf{e}}_d$$



Map of $a(f)$ on 1993/2/8 12:00



$a(f)$ vs $|\mathbf{u}_{stokes}|$ with mean

Different Definitions of Mean Wave Period

WaveWatch: $Tm_0 = \overline{(f^{-1})}$

ERA40: $Tm_1 = 1 \Big/ (\overline{f})$

TOPEX: $Tm_2 = 1 \Big/ \sqrt{(\overline{f^2})}$

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

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

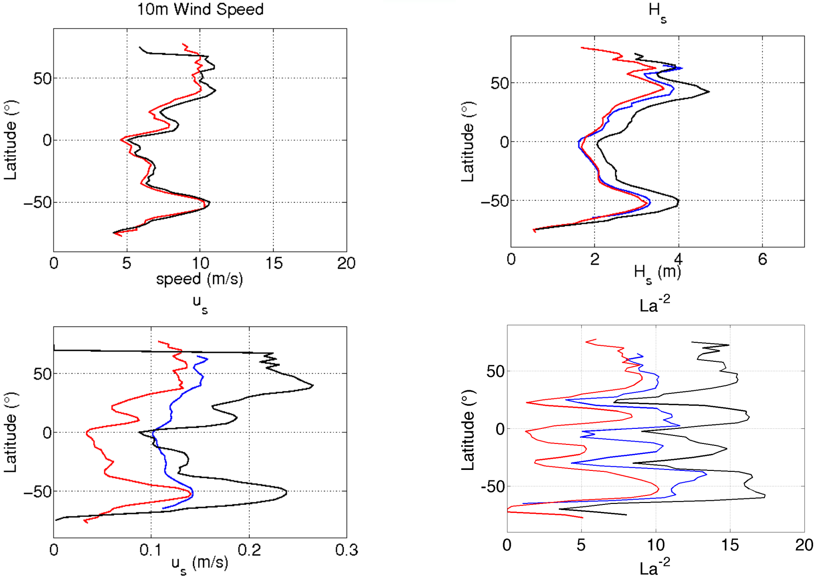
Using Assumed Forms of the Spectrum

Pierson-Moskowitz Spectrum

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

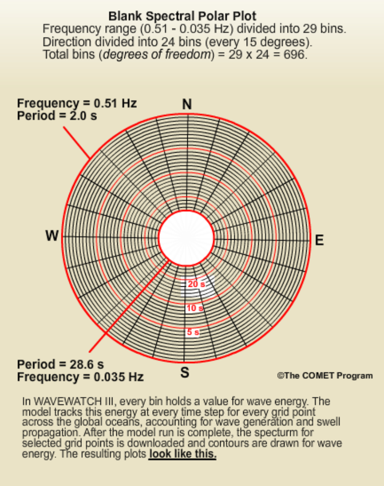
where α is the Phillips constant and f_p the peak frequency

Preliminary Comparisons of Different Products



1994-7 January zonal mean data for WW3 (black), ERA40 (red), and TOPEX (blue)

WaveWatch Details



- 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 (George Mellor, Princeton) worth exploring