What Needs Parameterization?
Assessing Climate Model Errors by Timescale

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Air-Sea Flux Errors vs. Data (Large & Yeager 09)

**Biases and Variance Errors**

- Mean Biases are familiar: WBC, Upwelling, Deep Convection, ITCZ

- Annual errors are *larger & more significant* than interannual

- Annual=Fast=Mixed Layer; Global extent!

- Continental vs. Maritime

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So, annual is worse than interannual, but...

- Annual variability errors are largely an OBL and ABL error problem.
- Fundamental ABL issues (e.g., clouds) remain.
- Fix what we can: many OBL processes are known to be important to this community, but not yet in climate models.
- Even small-scale phenomena can have important large-scale effects.
The Character of the Submesoscale

(Capet et al., 2008)

- Fronts
- Eddies
- $Ro = O(1)$
- $Ri = O(1)$
- near-surface
- 1-10km, days

Eddy processes often baroclinic instability (Boccaletti et al '07, Haine & Marshall '98).

Parameterizations of baroclinic instability?
Mixed Layer Eddy Restratification

Estimating eddy buoyancy/density fluxes:

$$\mathbf{u}'\mathbf{b}' \equiv \Psi \times \nabla \bar{\mathbf{b}}$$

A submeso eddy-induced overturning:

$$\Psi = \frac{C_e H^2 \mu(z)}{|f|} \nabla \bar{\mathbf{b}} \times \mathbf{\hat{z}}$$

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For a consistently restratiﬁng,

\[ \frac{w'}{b'} \propto \frac{H^2}{|f|} \left| \nabla_H \bar{b} \right|^2 \]

and horizontally downgradient ﬂux.

\[ \frac{u'}{H b'} \propto \frac{-H^2 \partial \bar{b}}{|f|} \nabla_H \bar{b} \]
Physical Sensitivity of Ocean Climate to Submesoscale Eddy Restratification:

MLE implemented in CCSM (NCAR), CM2M & CM2G (GFDL)

NO RETUNING NEEDED!!

Improves CFCs (water masses)

Deep ML Bias reduced


Physical Sensitivity of Ocean Climate to Submesoscale Eddy Restratification:

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Deep ML Bias reduced

Shallow ML Bias worse

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Bias w/o MLE

The Character of the Langmuir Scale

- Near-surface
- $\mathcal{R}_o >> 1$
- $\mathcal{R}_i < 1$: Nonhydro
- 10-100m
- 10s to mins
- $w, u = O(10 \text{cm/s})$
- Stokes drift
- Eqtns: Craik-Leibovich
- Params: McWilliams & Sullivan, 2000, etc.
Data + LES, Southern Ocean mixing energy: Langmuir (Stokes-drift-driven) and Convective

But, how well do we know Stokes drift?

\[
\frac{B_s}{u^2 s/h} = \frac{w^3_s/h}{w^3_s L/h} = \frac{h}{L_L}
\]

\[
\frac{u^2_s u_s / h}{u^2_s u_s / h} = \frac{u^3_s / h}{w^3_s L/h} = L a^2
\]

\[\varepsilon h / u_s^3\]

from LES Scaling

Within a factor of 2.
Assuming full-development (e.g., McWilliams & Restrepo, 1999) is worse

Generalized Turbulent Langmuir No., Projection of $u^*$, $u_s$ into Langmuir Direction

A scaling for LC strength & direction!

Wave Penetration Depth

- Harcourt and D’Asaro ’08 find an empirical way to consider mixed-layer-average mixing by Langmuir turbulence
- Long waves (swell) do more than short waves with similar surface Stokes drift
- We combine their scaling with misalignment


Traditional Misalignment

Jan00 median $\frac{w^2}{u'^2}(L_a)$

Wave Penetration

Jan00 median $\frac{w^2}{u'^2}(L_{\text{sl}})$

Both

Jan00 median $\frac{w^2}{u'^2}(L_{\text{sl,proj}})$

Jan, 2000
Traditional

Wave Penetration

Mar00 median $w^2/u^2(L_{a\text{t}})$

Mar00 median $w^2/u^2(L_{a\text{proj}})$

Mar00 median $w^2/u^2(L_{a\text{sl}})$

Mar00 median $w^2/u^2(L_{a\text{sl,proj}})$

Both

Mar, 2000
Traditional

Wave Penetration

May 00 median $w^2/u^2(La_{tr})$

May 00 median $w^2/u^2(La_{proj})$

May 00 median $w^2/u^2(La_{sl})$

May 00 median $w^2/u^2(La_{sl,proj})$

May, 2000
Traditional Misalignment

Wave Penetration

Both

July, 2000
Traditional

Wave Penetration

Dec00 median $w^2/u^2 (L_{a_t})$

Dec00 median $w^2/u^2 (L_{a_{proj}})$

Dec00 median $w^2/u^2 (L_{a_{sl}})$

Dec00 median $w^2/u^2 (L_{a_{sl,proj}})$

Both

Dec, 2000
Results

- Biases in climate model on annual to interannual timescales can be attributed (partly) to
  - Submesoscale mixed layer eddy restratification
  - Langmuir turbulence mixing

- We have been improving parameterizations

- But much work remains—we need more technology transfer from the OBL community!
All papers at:
fox-kemper.com/research


Many more wave-climate effects to come... stay tuned!

Coupling between Langmuir and Submeso?

2 runs:
Both spindown of submesoscale filament

Right -->
Stokes & Wind

<-- Left
Wind Only
Coupling between Langmuir and Submeso?

2 runs:
Both spindown of submesoscale filament

Right --> Stokes & Wind

<-- Left Wind Only
Vertical Velocity & Variance
Scale Decomposed Fields

Separate Langmuir turbulence and submesoscales by filtering at roughly 200m

Low-pass

High-pass

Ideal filtering would take into account wind-wave direction
Momentum $\langle uw \rangle$ and Heat $\langle wT \rangle$. 

Shear Flux is -10 to -25% 

Langmuir Flux is -100% to -140%
SI vs. LT--Different MLDs for $q, T$