From the Langmuir Scale to Submesoscale and Climate Scale

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Opening Remarks for the combined meeting (2/21/10) of scientists in
NSF OCE0934737:
Multiscale Modeling of the Coupling between Langmuir Turbulence and
Submesoscale Variability in the Oceanic Mixed Layer
&
NASANNX09AF38G:
Langmuir Circulations: Observing and Modeling on a Global Scale
Upper Ocean in Climate Models

- Large-scale ocean circulation (100 - 10,000 km, yrs->centuries) => resolved
- Mesoscale variability (10 - 100 km, mo -> yrs) => resolved or parameterized
- Submesoscale variability (100 m - 10 km, d -> mo) => ignored until recently
- Internal waves & Langmuir circulations (10-100m, min -> hr) => crudely param.
- Turbulent mixing (10 cm - 100 s -> min) => parameterized
The Character of Langmuir Scale

- Near-surface
- $Ro >> 1$
- $Ri < 1$: Nonhydro
- 10-100m mins, hours
- $w, u = O(20 \text{cm/s})$
- Stokes drift
- Eqtns: Craik-Leibovich
- unused params exist (M&S,01 etc)

image: Leibovich, 83

image: Sullivan & McWilliams, 10
Near-surface Fronts, ageo. wind Eddies $\text{Ro}=O(1)$ $\text{Ri}=O(1)$: mostly Hydrostatic near-surface 10km, days $u=O(20\text{cm/s})$ $w=O(100\text{m/day})$ Param. eddies (FFH) Eqtns: QG/SQG/SG
The Character of Climate Scale

Gyres, MOC, ENSO

Ro=O(0.01): geostropic

Ri=O(1000): hydrostatic

near-surface flux control

full-depth transport

10,000km, decades

Eqtns: PG, GCMs, Box Models

Ocean Energy Flux

Ocean Carbon Uptake

Figure 2.19: Estimate of the Earth’s annual and global mean energy balance for the March 2000 to May 2004 period in W m⁻². Figure from Trenberth et al. (2009). Copyright 2009 American Meteorological Society (AMS).
Note: we skipped over:

- Mesoscale (10–100km)
- Finescale (Kolmogorov→Kelvin-Helmholtz--0.01–10m)
- Wave-breaking, gas transfer by bubbles, air-sea momentum according to sea state, etc. This will be revisited in discussion.
Our scales are connected in 2 ways:

- **Langmuir** ←neighbors→ **Submesoscale**
- ‘background’ of Langmuir=Submeso (Chini, NR)
- ‘subgrid’ of Submeso=Langmuir

**Climate Scale** ←sources→ **Langmuir & Submesoscale**

- In ocean—all sources are surface sources
- *Atmosphere, Cryosphere, & Ocean ‘Talk’ through the upper-ocean processes*
- Large-scale climate system sets up the mixed layer, wind, cooling, etc.
Submeso Principles and Terms

- **Mixed Layer or Fossil OBL**—low stratification due to past mixing, region of submesoscale activity, strong fronts, submesoscale eddies, front–wind interaction

- **Mixed Layer Base**—Jump in stratification below mixed layer, upper pycnocline

- **Mixing Layer or Oceanic Bndy Layer**—region of active diabatic mixing—mesoscale fluxes essentially horizontal & diabatic

- **Transition Layer**—occasionally diabatic—mesoscale fluxes partly diabatic

- **Ocean Interior**—adiabatic, geostrophic, & internal waves—mesoscale & mean flow fluxes are largely adiabatic (if steady eddy statistics)

- **Subduction/Obduction**—advective transport out/in to the mixed layer

- **Entrainment**—turbulent deepening of the mixed layer

- **Restratification**—dynamical or forced (e.g. solar) restoration of stratification to a mixed region.
Langmuir Principles and Terms

- **Langmuir Cell**—Coherent vortex structure that forms in the presence of waves & wind. Rotation axis is horizontal and aligned with waves & wind.

- **Langmuir Turbulence**—Disorganized near-surface turbulence sometimes with Langmuir cellular structures, always with

- **Stokes Drift**—time-averaged transport by waves

- **Stokes Shear**—d/dz of drift, can be a source of energy for Langmuir

- **Stokes Production**—turbulent energy extraction from Stokes drift shear

- **Langmuir mixing efficiency**—increased mixing for given turbulent kinetic energy due to Langmuir structures (i.e., Langmuir effects beyond Stokes shear production)

- **Wave Age**: wave phase velocity over $u^*_a$. Asymptotes to 1.2 for fully-dev. waves.

\[
\sqrt{\frac{u^*}{u_s Re^3}} = \sqrt{\frac{v_e^3 \rho}{u_s \cdot \tau h^3}}
\]

- **Turbulent Langmuir #**: \[\sqrt{\frac{u^*}{u_s}} \sim \sqrt{\frac{u^*^2}{u^* \cdot u_s}}\]

- **Kantha #**: \[\left[\frac{u_s \cdot \tau}{\rho u^*_3}\right]^{1/3}\]

Friday, March 26, 2010
Biogeochemical Principles and Terms

- **Dissolved Inorganic Carbon (DIC)** -- primary sink of anthropogenic CO₂, DIC concentration in mixed layer vs. atmospheric concentration limits flux

- **Ocean Acidification** -- Excess DIC reduces pH of ocean

- **Subduction of DIC** -- important player in dilution of ocean acidification

**Organic Carbon**

- **Euphotic zone** -- region where phytoplankton production exceeds respiration

- **Nutricline** -- gradient of nutrients below MLB

- **Nutrient supply** -- limiting factor for phytoplankton growth in oligotrophic regions depends on *entrainment*, *obduction* & upwelling

- **Grazing** -- zooplankton eat phytoplankton

- **Biological Pump** -- vertical export of organic carbon from the surface ocean to deeper layers
Physical Sensitivity of Ocean Climate to Submesoscale Eddy Restratification

Stabilizes AMOC

ML Bias reduced

Figure 7: Time series for the annual mean Atlantic meridional overturning (AMOC) index from three coupled climate models, computed from taking the maximum overturning streamfunction at 45°N. The blue line is from CM2.1, which uses no submesoscale parameterization and the implementation of GM90 according to Treguier et al. (1997) (see Appendix A). The red line is from CM2Mα⁺, which employs the submesoscale parameterization, and the Ferrari et al. (2008) implementation of GM90. The green line is from CM2Mα⁻, in which the submesoscale scheme is removed.
Sensitivity of Climate to Submeso: Biogeochemical & Cryospheric Affects sea ice

Figure 10: Wintertime sea ice sensitivity to introduction of MLE parameterization (CCSM\(^+\) minus CCSM\(^-\)): January to March Northern Hemisphere a) ice area and b) thickness and July to September Southern Hemisphere c) ice area and d) thickness.

Figure 9: CFC-11 concentration bias (pmol/kg, observed range about 0 to 2 pmol/kg) in CCSM\(^\pm\) at the correct simulation year after CFC introduction to simulate WOCE sections

Improves CFCs

Thursday, March 25, 2010
Observations are mixed as to the importance of Langmuir mixing on stratification:

- Li, Garrett & co: Langmuir mixing scaling -> rapid deepening (mooring)
- Sullivan & co find differing wave & wind states, but often prime for Lang. development.
- D’Asaro & co find overwhelming evidence for VKE exceeding wave-free predictions, but wind & waves scale together
- Smith & co. see rapid deeping by Langmuir sometimes--scaling law unclear
- Kukulka et al. see agreement of LES vs OBS only with Langmuir
- Weller & Price (88) saw Langmuir cells in only upper 1/3 of mixed layer--no Langmuir entrainment!
- Kantha et al (08)--Stokes production extracts 2.5-3.7TW from waves!

Sensitivity of Climate to Langmuir?
Results from Scaling, LES, OBS

- Li et al (05) -> Langmuir turb for $La_t < 0.3$

- McWilliams & Sullivan (01) gave added diffusivity as a fct. of $La_t$

- Harcourt & D’Asaro (07) emphasized $La$ based not on surface $u^*$, but upper mixed layer $u^*$. Wave age plays a role, too. Also, LES showed different scaling for diffusivity on $La$ than M&S

- So, a single param. $La_t$ is a crude tool, but...
NASA Goals

- We set out to see if Langmuir mixing might be important globally—not in any given location
  - Requires a scaling for Langmuir mixing
  - Requires a climatology or knowledge of wave field
  - Requires global data validation (satellite)
- We’ll hear from Greg, Adrean & Erik later
A Crude Scaling for Langmuir Depth/Entrainment: (Li & Garrett, 1997)

\[ Fr = \frac{\omega}{NH} \approx 0.6 \quad \omega \approx \frac{V}{1.5} \approx \frac{\sqrt{u^* u_s}}{1.5} \]

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.
Sensitivity of Climate to Langmuir (NASA prelim. Adreian will discuss more)

**CCSM3.5 Impact:**

MLD

- With reasonable parameters, Langmuir produces deeper mixed layers
- Often reduces bias in some regions, e.g., ACC

August mixed layer depths.
With reasonable parameters, Langmuir affects CFCs.

Langmuir reduces bias in some regions, e.g., ACC versus WOCE.

Potentially large impact, change as large as bias.

CFC in CCSM & P14S WOCE observations.
Erik will discuss these estimates -->
What else do we need for pure Langmuir?

LES: What happens in non-fully developed or swell? When waves & winds misaligned? Can we get the Weller & Price situation (do we need submeso restrat)?

OBS: What scenarios & scalings should Langmuir params & LES reproduce?

GCM: Need coupled wave model to feed info to params--reason for the Crude Param Above.

THEORY: What are the controlling parameters for efficiency of Langmuir mixing? Stokes production is a start, but...
Submeso<-->Langmuir

- What are the coupling mechanisms?
- What are the equations?
- What are the effects on scalings?
- What physical scenarios exemplify coupling?
- Do we need to include in parameterizations?
Where do we each come in?

- Langmuir→Climate sensitive to param. details, get it right!
- Better scalings
- Better forcing (prognostic waves)
- Better validation (satellite, obs)
- Synthesis

- Langmuir & Submeso neighbors--coupling?
  - Pure competition (restrat vs. destrat) or more subtle couplings?

- Basic principles questions
  - What is the degree & kind of coupling Lang→SM (Keith & Edgar)
  - Quasi-balanced connect to nonhydro? (Keith & Edgar)
What do we need to get it done?
Collaborations
Promised Goals
Priorities
Goals for Session?
Future Meetings