Near-Surface Parameterizations

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Collaborations with: R. Ferrari, G. Boccaletti, G. Danabasoglu, S. Peacock, W. Large, GFDL...
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, hr -> day) => crudely param.
- Turbulent mixing (10 cm - 100 m, s -> hr) => parameterized

Boundary Layer Models

Submesoscale variability

Climate models

Surface Wave Effects?

Coupling?
The Character of the Submesoscale

Capet et al., 2008

Fronts
Eddies
Ro=O(1)
Ri=O(1)

100 km

PROCESS

CLIMATE FORCING
BAROCLINIC & BAROTROPIC INSTABILITY
SUBMESOSCALE INSTABILITY
FRONTGENESIS
ISOTROPIZATION (Kelvin–Helmholtz)
DISSIPATION

LARGE-SCALE
MESOSCALE
SUBMESOSCALE
MICROSCALE

Capet et al. 2008
A Global Parameterization of Mixed Layer Eddy Re-stratification

\[
\Psi = \left[ \frac{\Delta x}{L_f} \right] \frac{C_e H^2 \mu(z)}{\sqrt{f^2 + \tau^{-2}}} \nabla \bar{b} \times \hat{z}
\]

\[
\mu(z) = \left[ 1 - \left( \frac{2z}{H} + 1 \right)^2 \right] \left[ 1 + \frac{5}{21} \left( \frac{2z}{H} + 1 \right)^2 \right]
\]

Which parameterizes eddy-induced velocity and buoyancy fluxes

\[
\mathbf{v}^\dagger = \nabla \times \Psi \quad \overline{\mathbf{v}'b'} \approx \Psi \times \nabla \bar{b}
\]
Better than the Competition:

Extends over Ri more mesoscale (9000) than submesoscale (1)
Better than the Competition:

And Agrees with Deep Convection Studies:
- Jones & Marshall (93,97), Haine & Marshall (98)

Mixed Layer Richardson Number

- Green, 72
- FFH, 08
- Canuto & Dubovikov, 09

Extends over Ri more mesoscale (9000) than submesoscale (1)

Green equals Visbeck (97)
Held & Larichev (95)

And Agrees with Deep Convection Studies:
- Jones & Marshall (93,97), Haine & Marshall (98)
Improves Restrtratification after Deep Convection
Note: param. reproduces Haine & Marshall (98) and Jones & Marshall (93,97)

& generally shallower boundary layers

GFDL CM2.1/GOLD
GFDL CM2.1/MOM
NCAR Normal Year/POP
NCAR CCSM/POP

MLE-Control: Climatologies at end of > 100yr simulation
Improves Restratiﬁcation after Deep Convection
Note: param. reproduces Haine&Marshall (98) and Jones&Marshall (93,97)

& generally shallower boundary layers

GFDL CM2.1/GOLD
CM2.1/GOLD $h_{bl}$ Control-Submeso (m) AUG

GFDL CM2.1/MOM
CM2.1/MOM $h_{bl}$ Control-Submeso (m) AUG

NCAR Normal Year/POP

NCAR CCSM/POP

MLE-Control:Climatologies at end of > 100yr simulation
Changes other variables we care about... CCSM

Avg. Ideal Age 4 yrs older at 500m with MLE (up to 30%)

MLE-Control: Climatologies at end of > 100yr simulation

MOC 10% greater with MLE

(as big as coarse vs 10km, Frank)
Coupled MOM Shows

Submeso increases MOC stability
Langmuir Parameterization

Figure 1: Images of Langmuir circulation windrows: (a) a photograph of Rodeo Lagoon in CA (from Szeri, 1996), (b) an infrared image of the surface of Tampa Bay (courtesy of G. Marmorino, NRL, D.C.), and (c) the evolution of surface tracers in a LES of Langmuir turbulence (McWilliams et al., 1997). Reproduced from Chini et al. (2008).
A Simple 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.
CCSM3.5 Impact: MLD

- With reasonable parameters, can produce deeper mixed layers
- This often reduces bias in some regions, e.g., ACC

August mixed layer depths.
With reasonable parameters, can affect CFCs
This reduces bias in some regions, e.g., ACC versus WOCE
Potentially Large impact, change as large as bias
Other Effects of Wind+Waves != Wind

Different Drag

Same Wind

March 1981

W. G. Large and S. Pond

10^3 CDN

0.0

2.0

UZ (m/s)

15.0

5.0

0 6 12 18 24 30 36

TIME (HOURS)
Conclusions

- Submeso generally accepted. Reduces bias, improves MOC stability, reduces spurious deep convection

- Langmuir turbulence important in mixed layer mixing and deepening, may reduce SO bias

- Langmuir scaling requires wind & waves: coupling prognostic wave model in planning phase, some discrepancies with satellite obs.

- Once we’ve got the wave model, it will be useful for other things!
Publications

Submeso

- Boccaletti, Ferrari, Fox-Kemper: 2007, JPO
- Fox-Kemper, Ferrari, Hallberg: 2008, JPO
- Fox-Kemper, Ferrari: 2008, JPO
- Fox-Kemper, Danabasoglu, Ferrari, Hallberg: 2008 CLIVAR Exchanges
- Fox-Kemper, Danabasoglu, Ferrari, Griffies, Hallberg, Samuels, Peacock: In prep for OMod

Langmuir

- Webb et al.: In prep for JGR
MLE Param. is now in testing in:

Models

- CCSM/POP
- CM/MOM
- CM/GOLD
- MITgcm
- NEMO
- Norway
- ECMWF?

Results

- Reduced ML Depth
- Reduced MLD Bias
- Modest CFC changes, some bias reduction
- Reasonable changes to circulation
- Stable, Minimal Cost
Nuance—CCSM3.5 and CCSM4.0

CCSM4.0 did not have the same initial improvement!

S & T particularly bad

Interactions with submeso?
Nuance--CCSM3.5 and CCSM4.0

Sensitive to detail