Climate Process Team: Ocean Mixing Processes Associated with High Spatial Heterogeneity in Sea-Ice and the Implications for Climate Models

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MOTIVATION

Earlier studies in single-column ice-ocean models showed that resolving high spatial variability in ice-ocean brine exchange has important effects on ocean mixing and resulting sea-ice mass budgets.

Existing climate models do not fully resolve these ice-ocean exchanges.

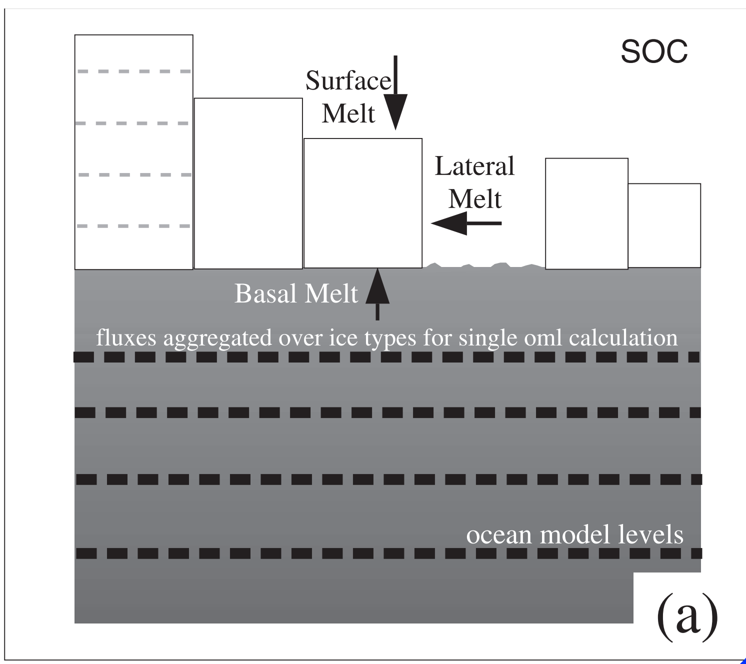
CPT focuses on improving the ocean model representation of processes associated with high spatial heterogeneity in sea-ice by implementing multi-column ocean grid (MCOG) in climate models. Goals include better climate model simulations via improved upper-ocean mixing and improved simulations of biogeochemical tracers involving ice-ocean fluxes. This will also set the stage for more realistic ecosystem models in regions affected by sea-ice.

Multi-Column Ocean Grid (MCOG)

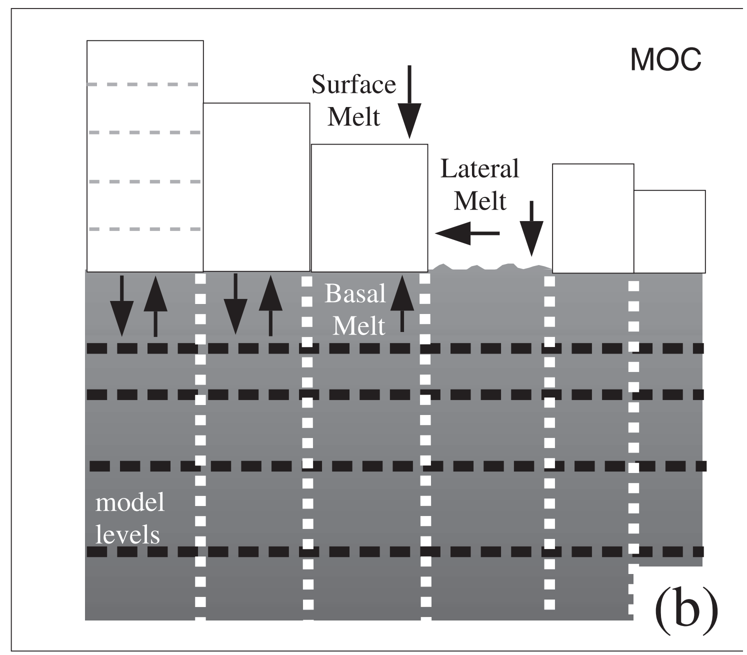
To allow high spatial heterogeneity in sea-ice to influence ocean mixing and under-ice biogeochemistry, a multi-column ocean grid has been implemented in the Community Earth System Model (CESM):

- Sub-gridscale ice category dependent fluxes are sent to ocean model
- Vertical mixing is performed separately for each sub-gridscale ocean column

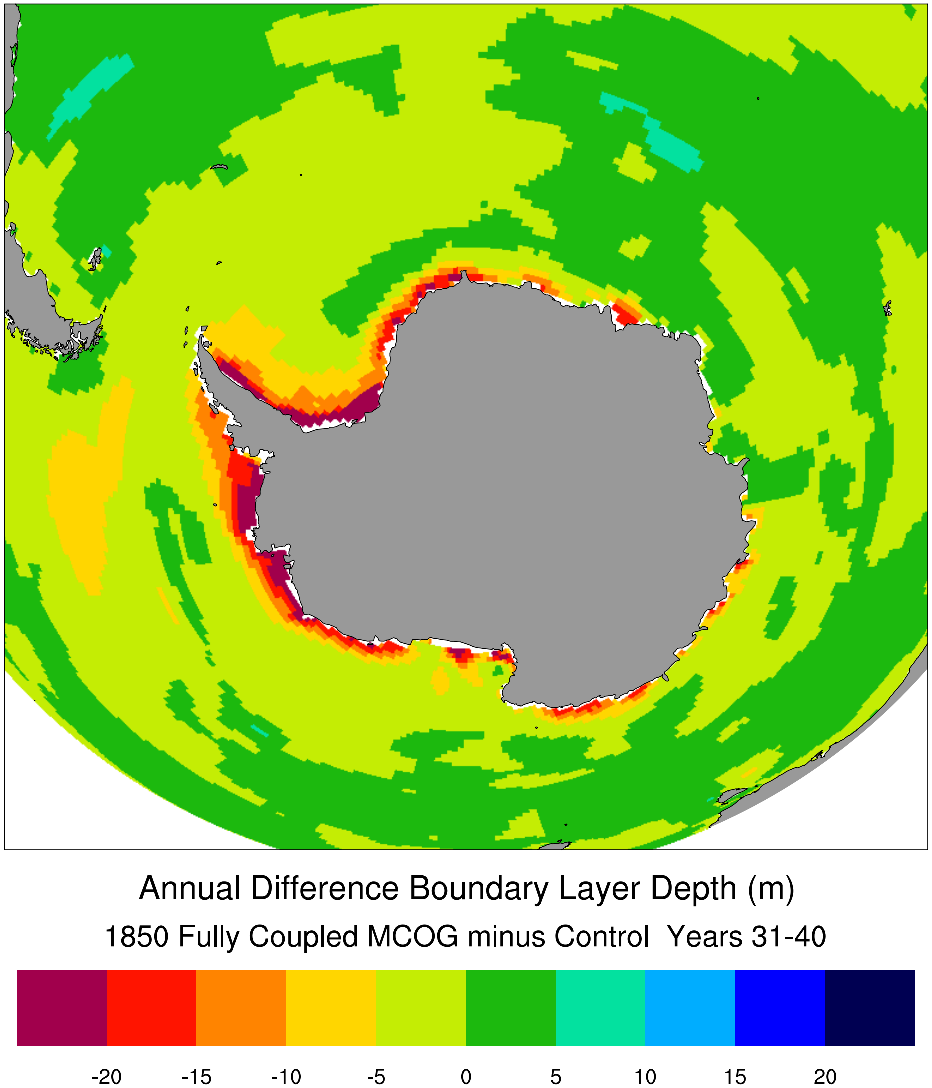
Standard Integrations



MCOG Integrations



MCOG Influence in Coupled Simulations

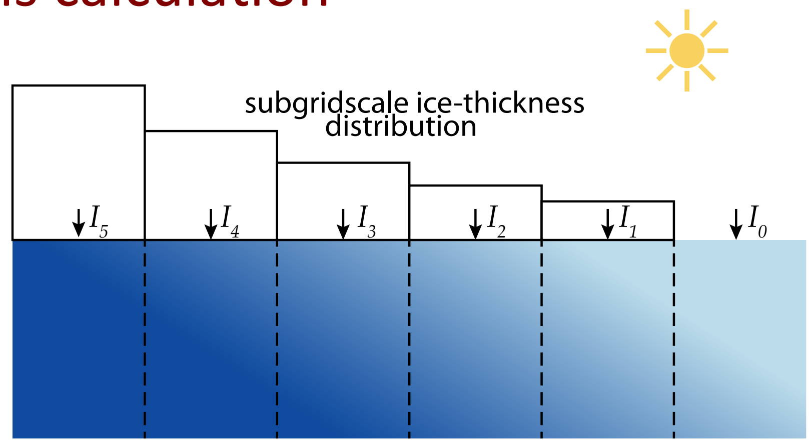


Physical Climate Conditions

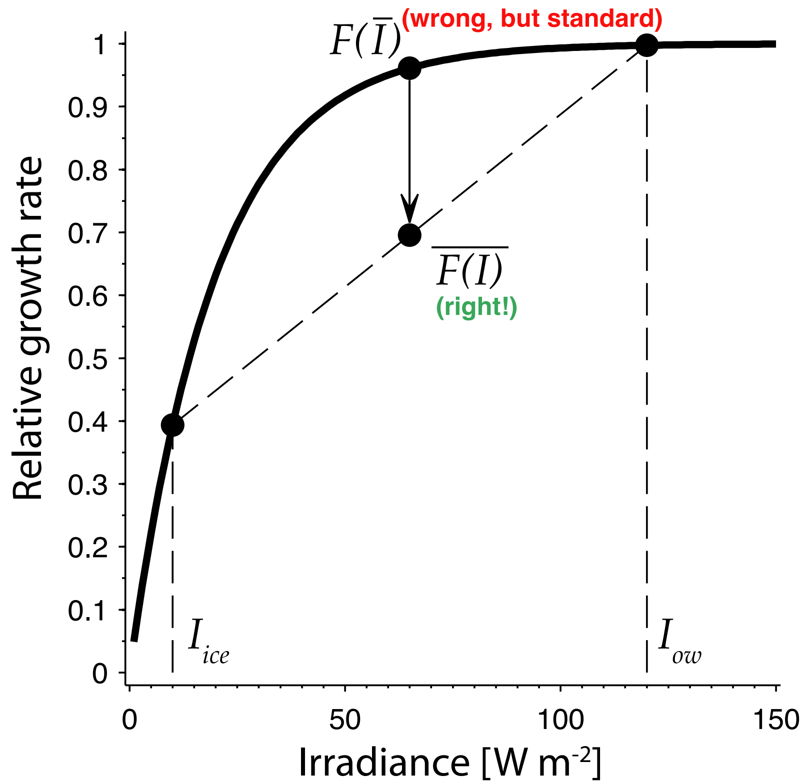
Modifies the ocean boundary layer depth primarily along the Antarctic coast

Smaller impacts in the Arctic region

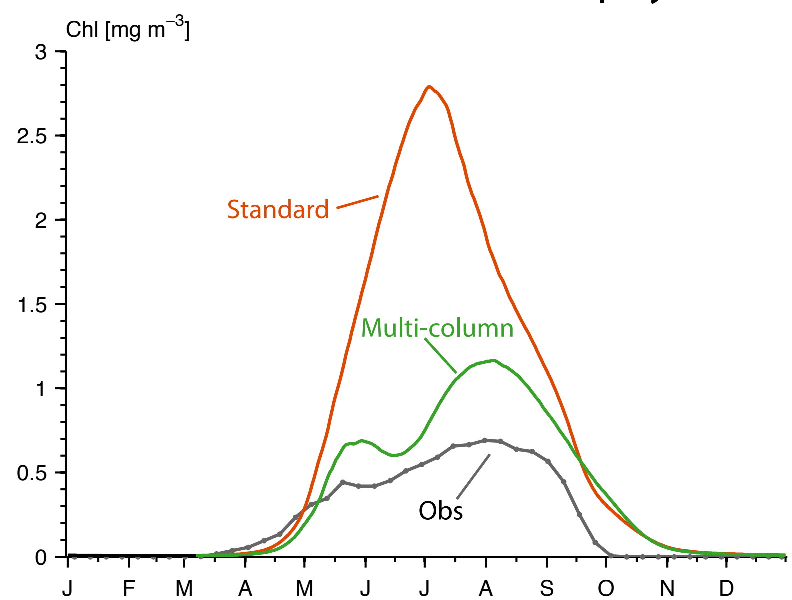
Multi-column treatment improves accuracy of photosynthesis calculation



Photosynthesis-irradiance relationship



Arctic Ocean surface chlorophyll



Long et al., in prep

Climate Process Team on Internal-Wave Driven Ocean Mixing

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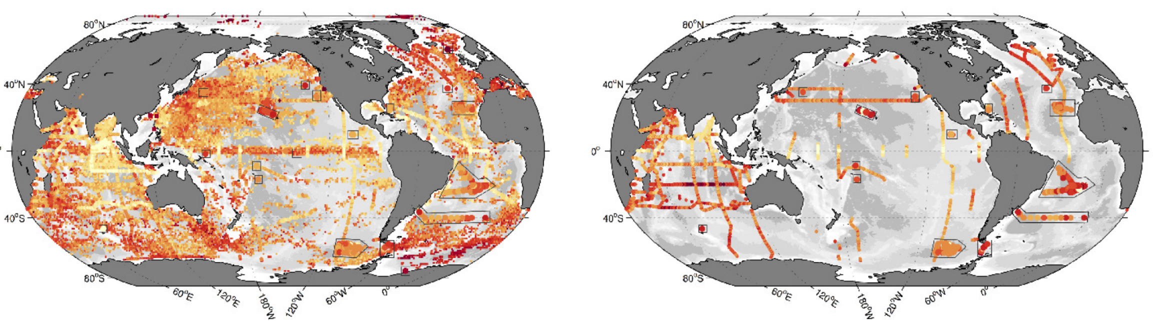
MOTIVATION

The overall goal of this CPT is to refine, develop, and implement dynamically appropriate parameterizations for diapycnal mixing due to internal-wave breaking for use in global climate models. In the ocean interior, the internal wave field is largely responsible for connecting the forcing scales of the circulation to the dissipative scale of turbulence. In particular, internal-wave-induced mixing drives the diabatic evolution of the ocean's stratification on the very time scales of central interest to the climate prediction problem.

Our task: Use what we collectively know about internal wave physics to develop dynamic parameterizations of diapycnal mixing that captures global patterns and can evolve in a changing climate.

Implementation of such parameterizations and assessing their climate impacts in GCMs are among the final goals – as in the other CPTs.

How much diapycnal mixing do we have?



(a) Upper 1000 m $\log_{10} K$ (b) Full depth $\log_{10} K$

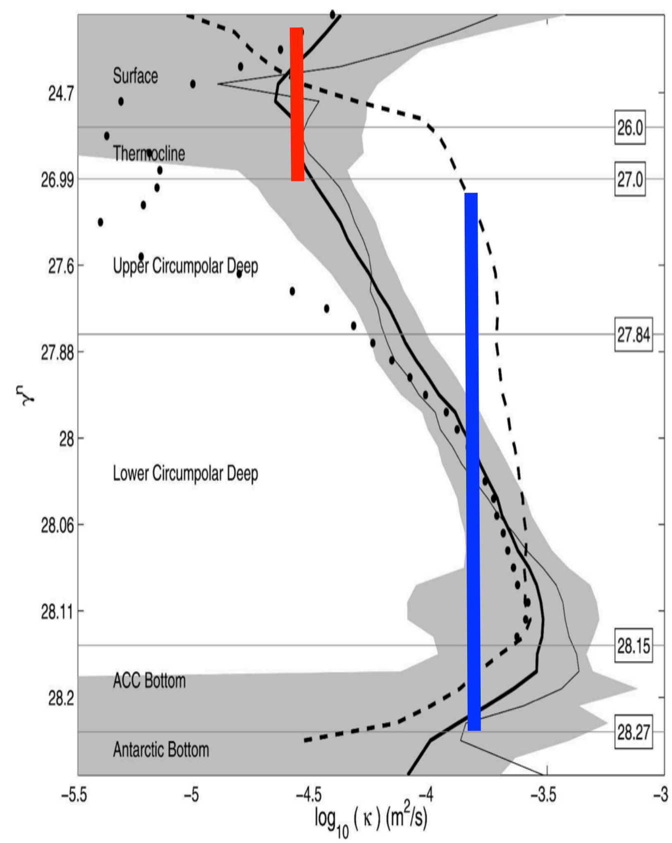
Waterhouse et al. (2014, JPO, in press)

One of the first CPT goals was to compile all available microstructure measurements of mixing from the last three decades. Though the number of full-depth profiles is limited, they do not appear to be unduly biased towards particularly quiet or energetic seasons.

The observationally-based estimates of diffusivity values are OF THE SAME order as that required to power the MOC and drive observed water mass transformation rates.

Average diffusivity, upper 1 km:
0.3×10^{-4} m^2/s [0.1-0.4]

Average diffusivity, 1 km-bottom:
2.3×10^{-4} m^2/s [0.4-3.8]

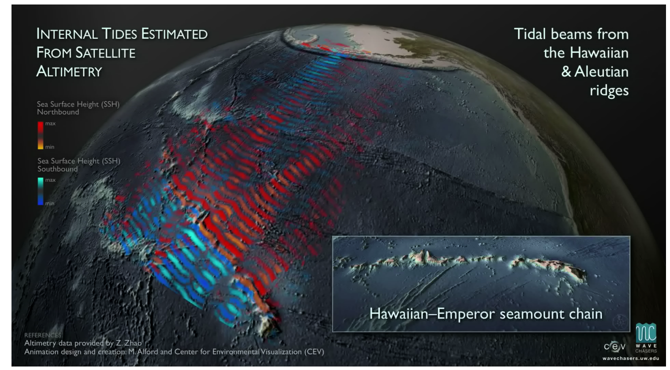


(Lumpkin and Speer 07)

Internal-tide driven mixing

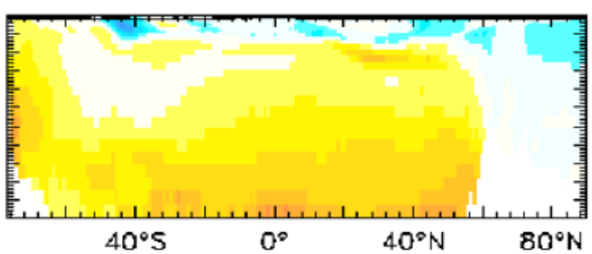
Turbulence is elevated above rough topography, where internal tides are generated (and where some of them break). A parameterization of the "nearfield" (= local) part of this turbulence has been implemented and tested at GFDL – also implemented at NCAR (Polzin 09, Melet et al. 13). Produces modest changes in deep and abyssal circulation.

A key unknown parameter is the percentage ("q") of internal tide energy which is dissipated locally. It is thought to vary from close to 100% over deep rough topography down to 10-20% over steep tall topography (e.g., Hawaii). The energy that does not dissipate locally (e.g., the remaining 80-90%) propagates long distances across ocean basins in the form of low-mode waves (Zhao and Alford). Ongoing work (Sun et al.) is producing a global map of this parameter.

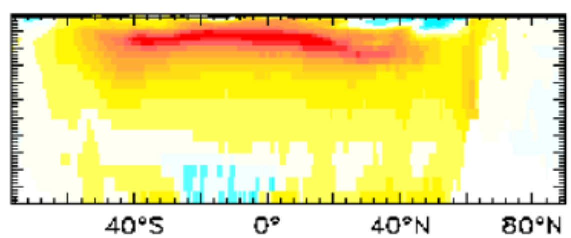


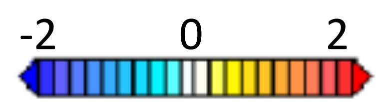
Some of this propagating low-mode energy is dissipated by i) scattering off further rough topography along it's path, or ii) nonlinear processes like PSI (Ansong et al 14). However up to 30% of that energy may reach continental margins and dissipate there. Idealized GCM runs (ESM2G, 1000 yrs, pre-industrial) show large changes to <u>zonal averaged ocean temperature</u> depending on whether the available power in low-mode propagating internal tides is dissipated either:

over rough topography (deep)



over continental slopes (main thermocline)





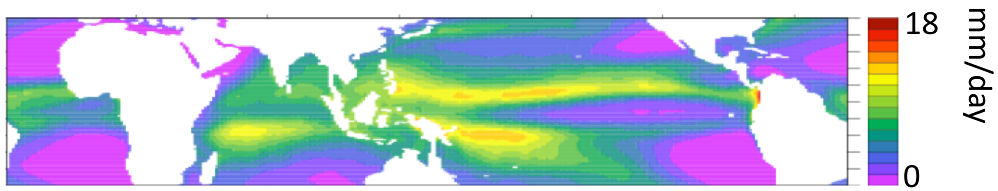
(Melet et al.)

Wind-driven inertial motions

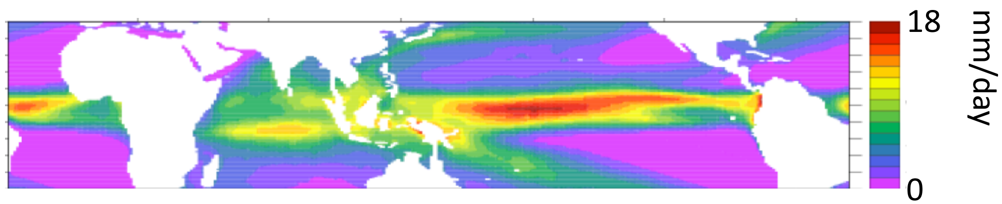
Sensitivity experiments with CESM1: Near-inertial power input vs. tropical precipitation

Annual Mean Precipitation

with 0.34 TW available



with 0.68 TW available



Jochum

Summary

- Roughly the *right* amount of mixing to power MOC, (~2 TW), in an average sense, primarily through wind and tide generated internal waves, but patterns important.

- Interesting emerging conclusion is that there may be significant dissipation at the boundaries; unclear what the effect on circulation is.

- We're developing GCM parameterizations for some of these patterns, mostly related to mixing near internal wave generation sites (rough topography, storm tracks).

- New parameterizations will be put into generalized format for broad multi-model distribution: Community Ocean Vertical Mixing (CVMix) framework (NCAR, GFDL, LANL).

- Developing database of historical and new turbulent microstructure data through CCHDO (CLIVAR & Carbon Hydrographic Data Office) data repository.

SOME THOUGHTS

- Ocean-related CPTs have been successful: better physics; improved model simulations (bias reductions; ecosystem); significant climate impacts
- Success is primarily due to tackling a problem that can be addressed within 3-5 years with existing observational data and existing process modeling frameworks; free exchange of information / data is essential
- CPTs represent great value: The whole is greater than the sum of its individual components
- CPTs should involve multiple modeling centers, but the science should be initiated by the community in consultation with modeling centers
- CPTs, if possible, should avoid conflicts with similar ongoing developments both at the modeling centers or in the community