Evaluation of small-scale, nonlinear physical processes in climate simulations: the role of resolution and mixing parameterizations

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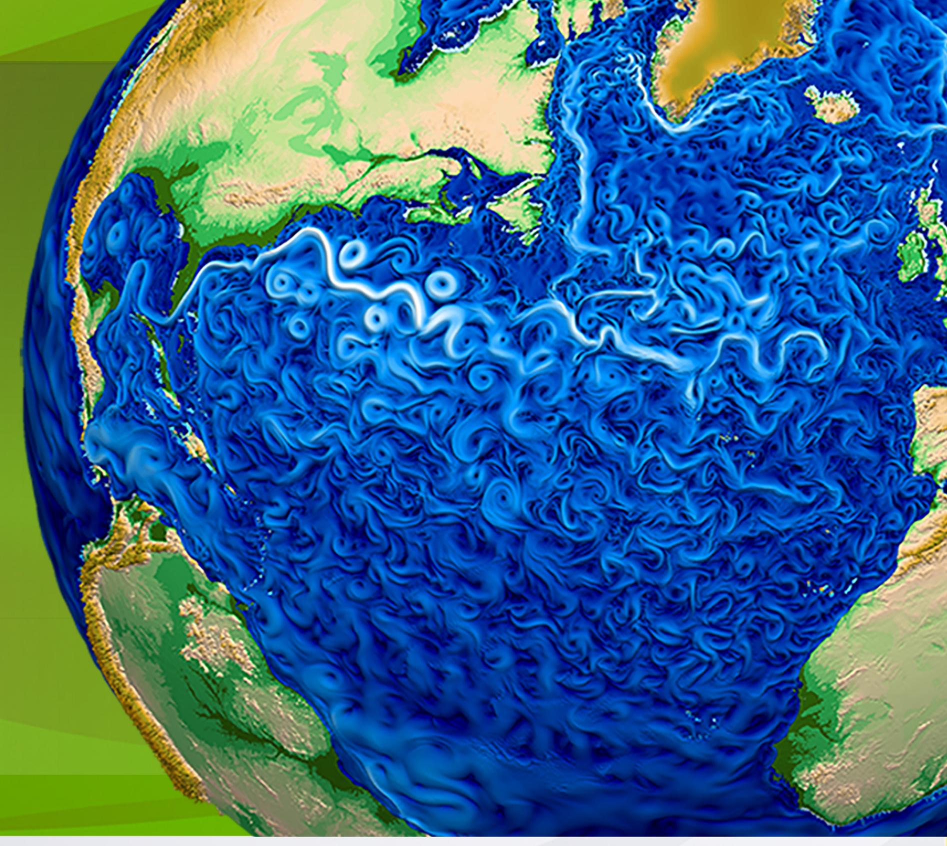

Quantifying ocean mixing

Summary:

Secular changes in the Earth's climate system are driven by sequestration of heat to the deep ocean by

1. Vertical mixing in the surface boundary layer.
2. Horizontal mixing along outcropping layers.

Given that vertical and horizontal mixing processes can not be simulated directly in Earth System Models we examine these processes in two novel ways:

- Use regional refined MPAS-O for important small scale processes
- Use Large Eddy Simulation (LES) for the smallest processes (< 100m).

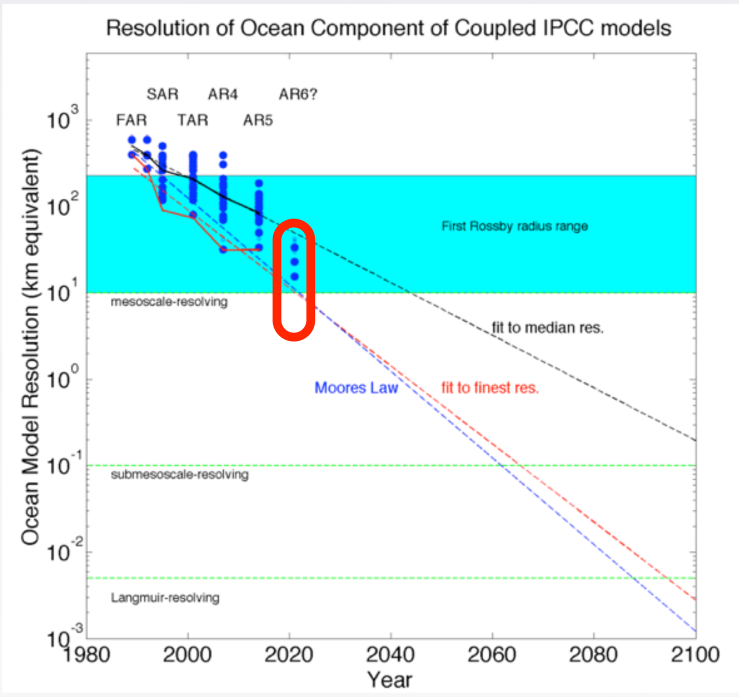

Fig 1. Predicted model resolution with time. Horizontal lines signify scales of important processes.

MPAS Analysis Online diagnostics

- Novel MPAS-O in-situ analysis [1, 5, 6] for fine resolution.
- High data-need analysis is possible.
- Quantify impact of small scale eddies on the large scale flow at exascale.

MPAS Analysis Members provide unparalleled diagnostic opportunities.

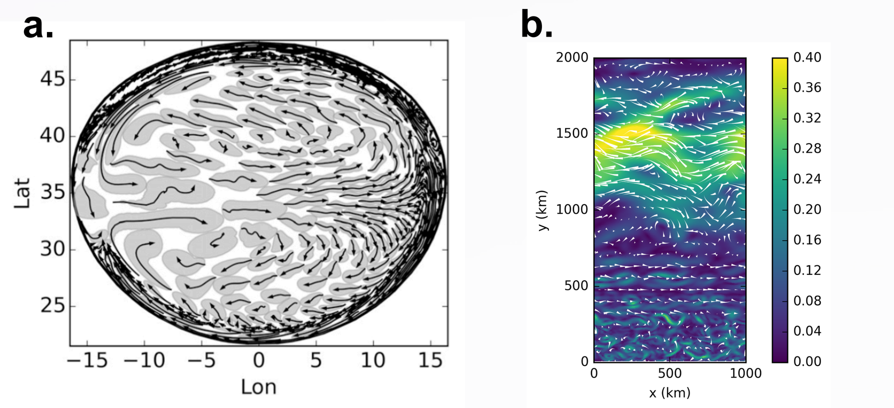

Fig 2. Lagrangian particle a) statistics for mid-latitude basin [5] and b) pathlines for idealized Southern Ocean [4] using Lagrangian In-situ Global High-performance particle Tracking (LIGHT).

Nonlinear eddy-mean flow interactions

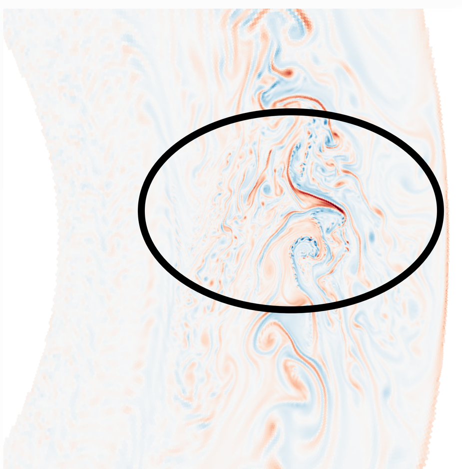

Fig 3. MPAS-O faithfully reproduces small scale variability of relative vorticity in the high resolution region.

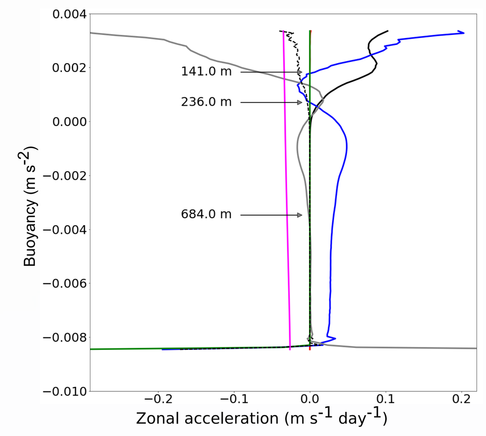

Fig 4. MPAS analysis member tools can be used to nearly close zonal eddy-mean flow momentum balance. Can be used to assess balance regionally [1].

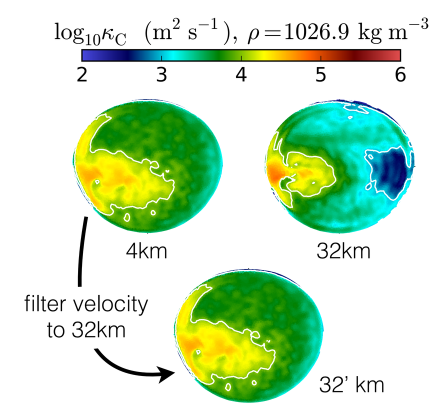

Fig 5. κ (eddy diffusivity) requires high resolution to compute large eddies and correct mixing: 5km with small scales removed and unfiltered 4km similar relative to 32km case [5].

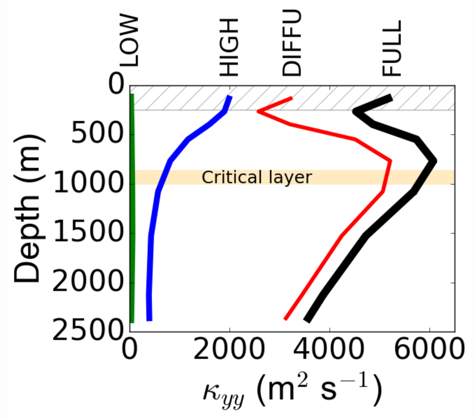

Fig 6. Eddy and mean κ decomposition via HIGH- and LOW-pass temporal filtering gives residual diffusivity (DIFFU) from FULL flow resulting from nonlinearity [4].

Impact of ocean vertical mixing on climate

The influence of small-scale three-dimensional eddies:

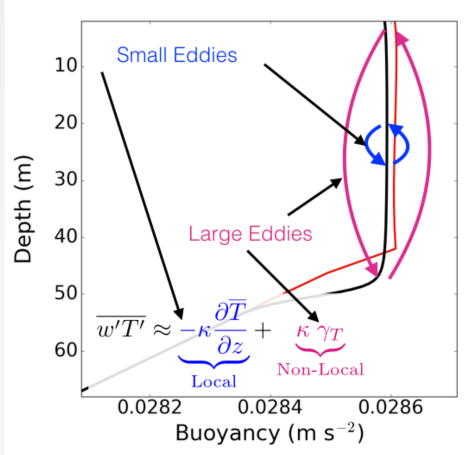

Fig 7. KPP Schematic. KPP seeks to capture influence of small, three-dimensional eddies on the climate [3].

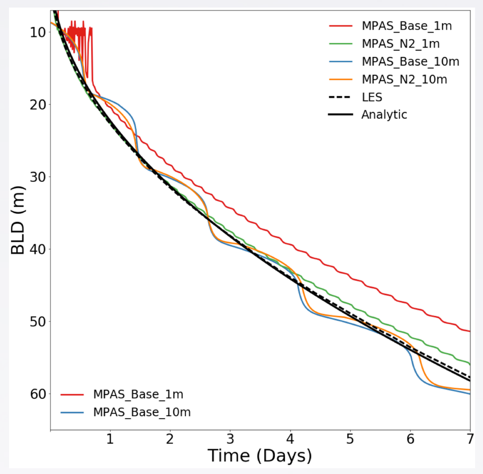

Fig 8. Free convection test results. Increased bias relative to LES at high resolution in KPP [3].

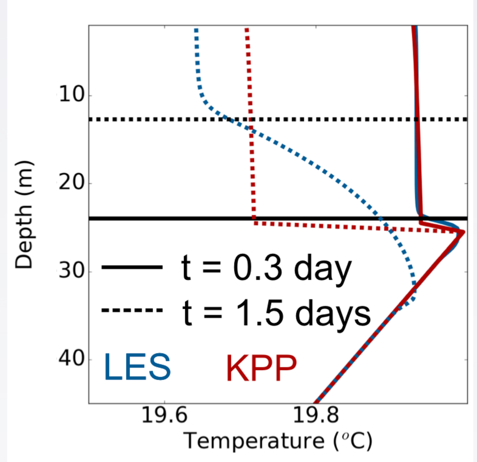

Fig 9. River outflow test results KPP temperature rapidly diverges from LES. Cooling is too uniform in vertical [3].

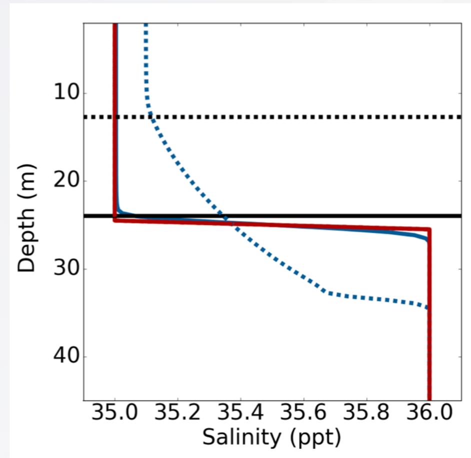

Fig 10. River outflow test results. KPP cannot mix salinity Transport by large eddies is not proportional to surface flux [3].

Feedbacks of unresolved eddies on the simulated climate:

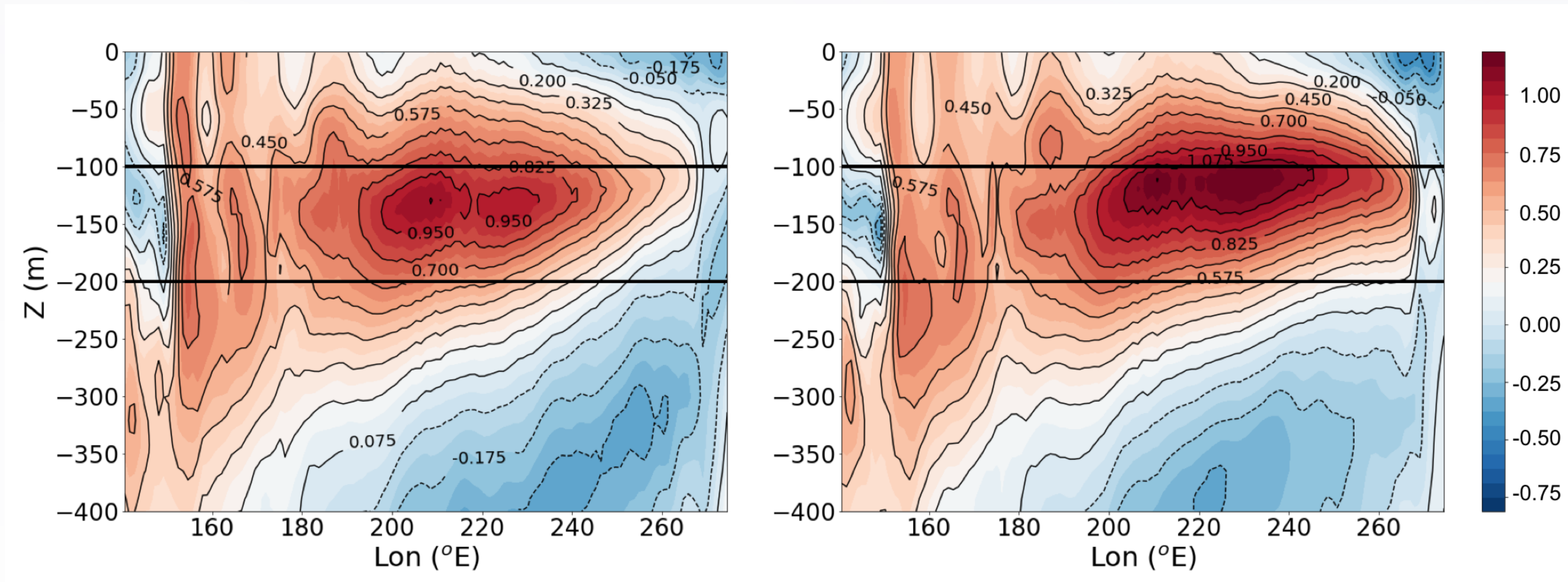

Fig 11. Equatorial Pacific cross sections of zonal velocity. Left - no smoothing, Right - Smoothing. Smoothing of mixing parameters has profound impact on ocean currents. Appropriate degree of smoothing is unknown and likely regionally dependent.

Future directions

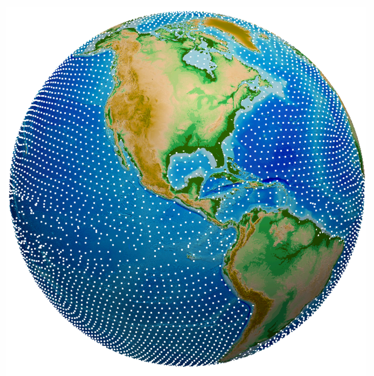

Fig 12. LIGHT yields Lagrangian ocean flow within ACME for fate and transport diagnostics.

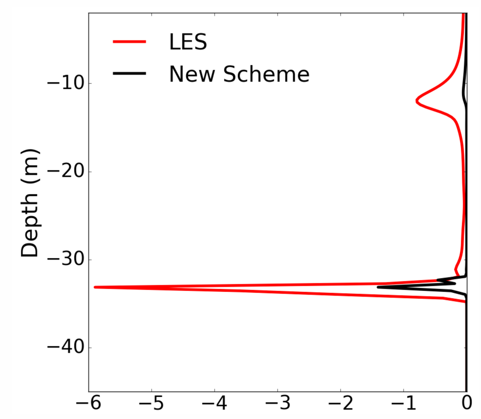

Fig 13. A new vertical mixing scheme produces a salinity flux where KPP has none.

Ultimately, fidelity of climate simulation depends on ocean mixing parameterizations.

[1] Todd Ringler, Juan A. Saenz, Phillip J. Wolfram, and Luke Van Roekel. A thickness-weighted average perspective of force balance in an idealized circumpolar current. Journal of Physical Oceanography, 47(2):285–302, 2017.
[2] Luke Van Roekel. The influence of variations in penetrating solar radiation on the diurnal and intraseasonal structure of the oceanic boundary layer. PhD thesis, Colorado State University, 8 2010.
[3] Luke Van Roekel, Alistair Adcroft, Gokhan Danabasoglu, Stephen Griffies, Brian Kauffman, William Large, Michael Levy, Brandon Reichl, Todd Ringler, and Martin Schmidt. The KPP boundary layer scheme: revisiting its formulation and benchmarking one-dimensional ocean simulations relative to LES. Ocean Modelling, in prep, 2017.
[4] Phillip Wolfram and Todd Ringler. Quantifying residual, eddy, and mean flow effects on mixing in an idealized circumpolar current. J. Phys. Oceanogr., in press, 2017.
[5] Phillip J Wolfram, Todd D Ringler, Mathew E Maltrud, Douglas W Jacobsen, and Mark R Petersen. Diagnosing isopycnal diffusivity in an eddying, idealized midlatitude ocean basin via Lagrangian, In-situ, Global, High-Performance Particle Tracking (LIGHT). J. Phys. Oceanogr., 45(8):2114–2133, 2015.
[6] Jonathan Woodring, Mark Petersen, Andre Schmeißer, John Patchett, James Ahrens, and Hans Hagen. In situ eddy analysis in a high-resolution ocean climate model. IEEE transactions on visualization and computer graphics, 22(1): 857–866, 2016.

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