State of the art numerical models used to determine
What drives variability in biological productivity?

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VARIABILITY IN PRODUCTION

Iron and **light** limit Southern Ocean phytoplankton growth (production). Seasonal modifications of wind and solar radiation strongly impact vertical ocean structure modulating light and iron availability. Yet, observations show high intra-seasonal and spatial variability unresolved by the seasonal cycle. Understanding the drivers of this variability is critical in our understanding of climate sensitivities in biological production and carbon export.

What mechanisms alleviate these limitations and explain observed variability?

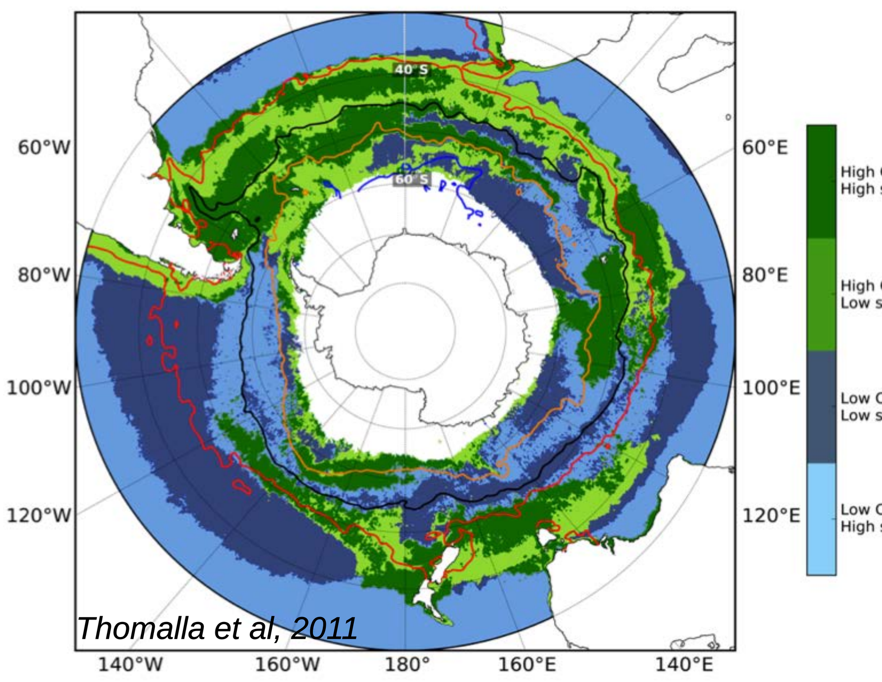

Fig. 1 The response of phytoplankton biomass to the underlying physics. Light green highlights regions with high chlorophyll-a (a proxy for phytoplankton biomass) that are unresolved by the seasonal cycle.

Mechanism 1: Energetic circulation [eddies]

Alleviate iron limitation: Eddies with large vertical transport supply iron to the upper-ocean at critical timescales that match phytoplankton growth rates (Mahadevan and Tandon, 2006)
Alleviate light limitation: Eddies stratify the upper-ocean by tipping light water over denser water (Mahadevan et al., 2012). Stratification allows phytoplankton to stay in the surface lit layers.

Mechanism 2: Atmospheric storms

Alleviate iron limitation: Storms supply biology with wind-induced iron injections through deepened mixing.
Increase light limitation: Storms mix biology out of the euphotic zone (abundant light layer).

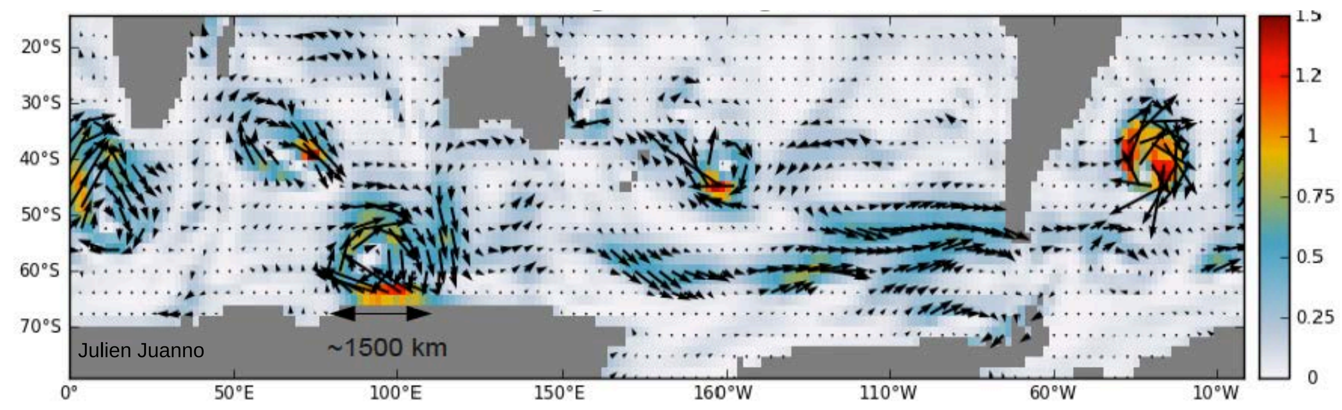

Fig 2. Wind stress generated from large winter storms in the Southern Ocean ($N.m^{-2}$) / CORE+ Large and Yeager (2004) / Date: 2007/06/01

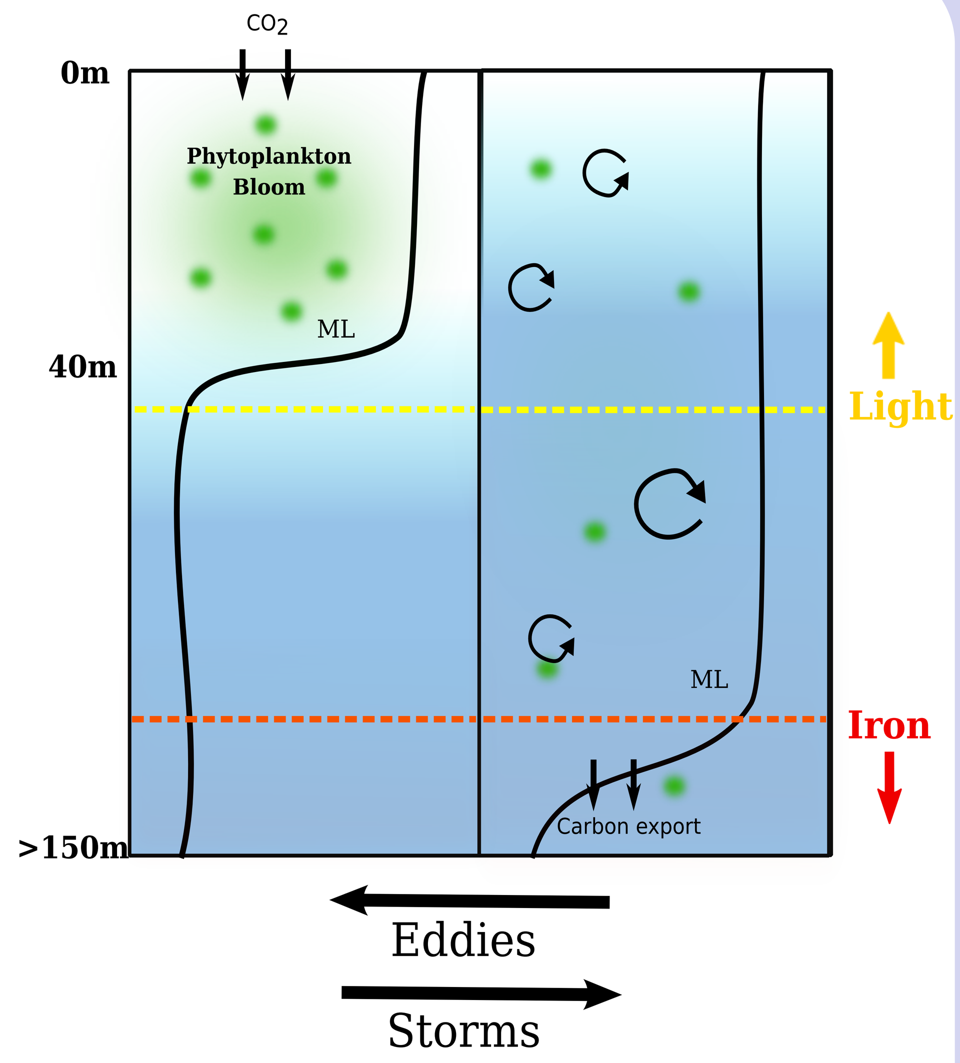

Fig 3. Schematic of upper ocean illustrating the impact of eddies and storms on phytoplankton. Phytoplankton photosynthetically fix atm. carbon (CO_2) which is exported via biological fallout from the ML. ML= mixed layer, Black line = temperature profile, green = phytoplankton. Yellow and red lines = light and iron limits.

HYPOTHESIS

Energetic circulation and storms impact vertical mixing and stratification of the upper ocean, interacting with biological production on intra-seasonal scales. This in turn effects the seasonal cycle of biological production and carbon export.

Aim to show that the intra-seasonal modulation of upper-ocean physics:
1.) sustains summer production in the Sub-Antarctic Zone.
2.) accounts for observed spatial and temporal variability in production.

APPROACH: PHYSICAL BIOGEOCHEMICAL MODELLING

To explore the various scales of physical supply mechanisms we developed a hierarchy of configurations from large-scale to eddy resolving [mesoscale to sub-mesoscale]. Modelling system: NEMO3.4 coupled to biogeochemical model PISCES. The reference configuration is a re-entry zonal channel model of the Antarctic Circumpolar Current (ACC), 40-70°S.

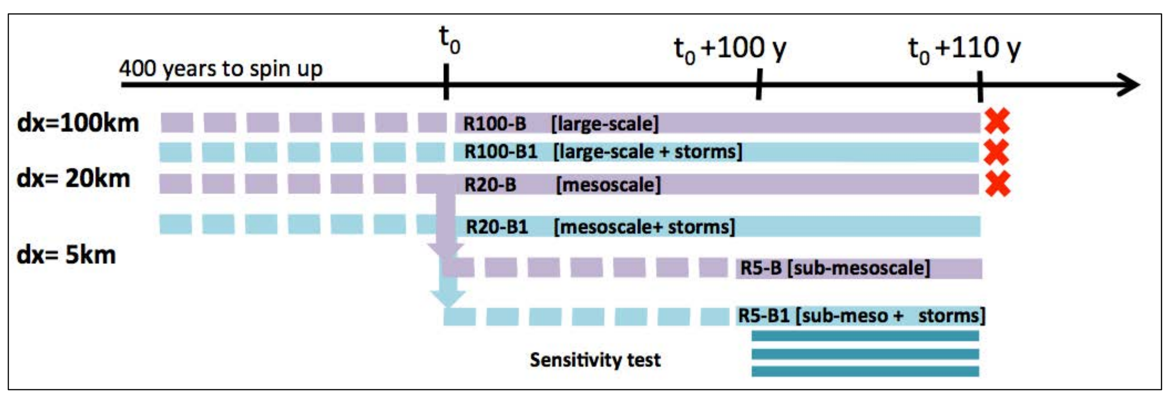

Fig. 4: Numerical strategy: hierarchy of increasing model resolution, red cross to show completed runs. Blue bars represents simulations that will incorporate storm forcing.

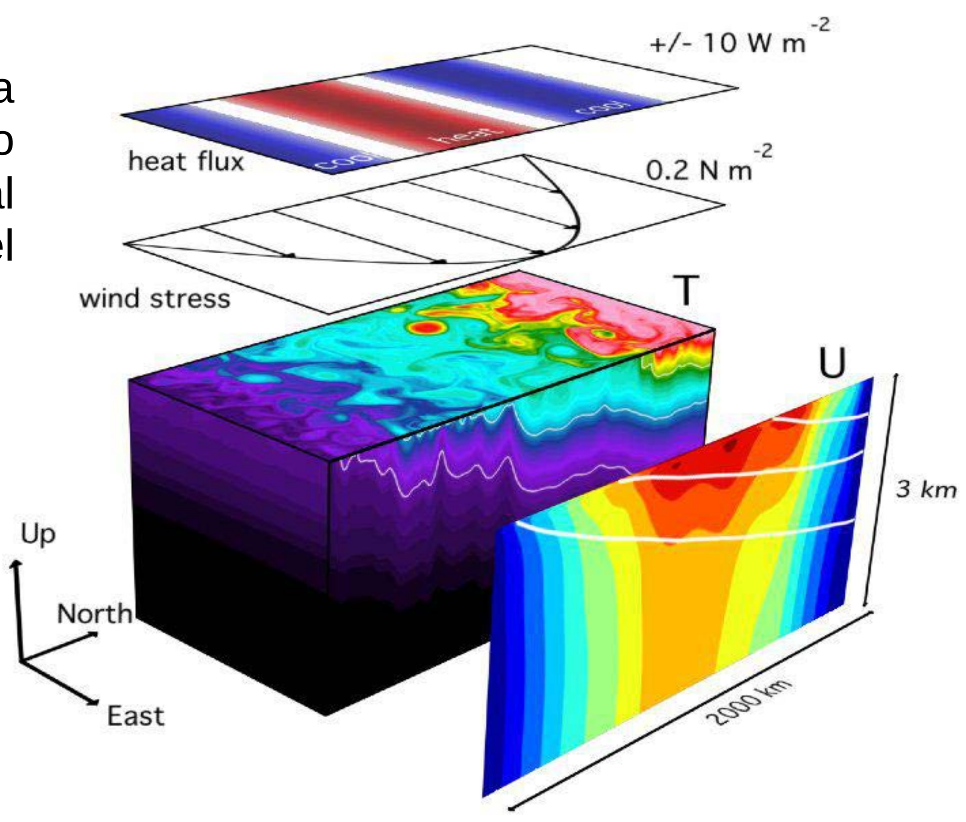

Fig 5: Reference configuration setup of Abernathey et al,2011

MODEL OUTPUT: FROM LARGE-SCALE FLOW TO EDDY RESOLVING

Here we provide some preliminary results from completed model runs. Fig 6 demonstrates the effect of increasing the model horizontal resolution from large-scale (dx=100km) to eddy resolving (mesoscale, dx=20km). Increased variability in flow.

Simulated deep mixed layers are typically associated with enhanced concentrations of dissolved iron in the surface waters, Fig 7. Deep winter mixing in the ocean accesses a reservoir of iron which has not been consumed by biology and is entrained into upper ocean.

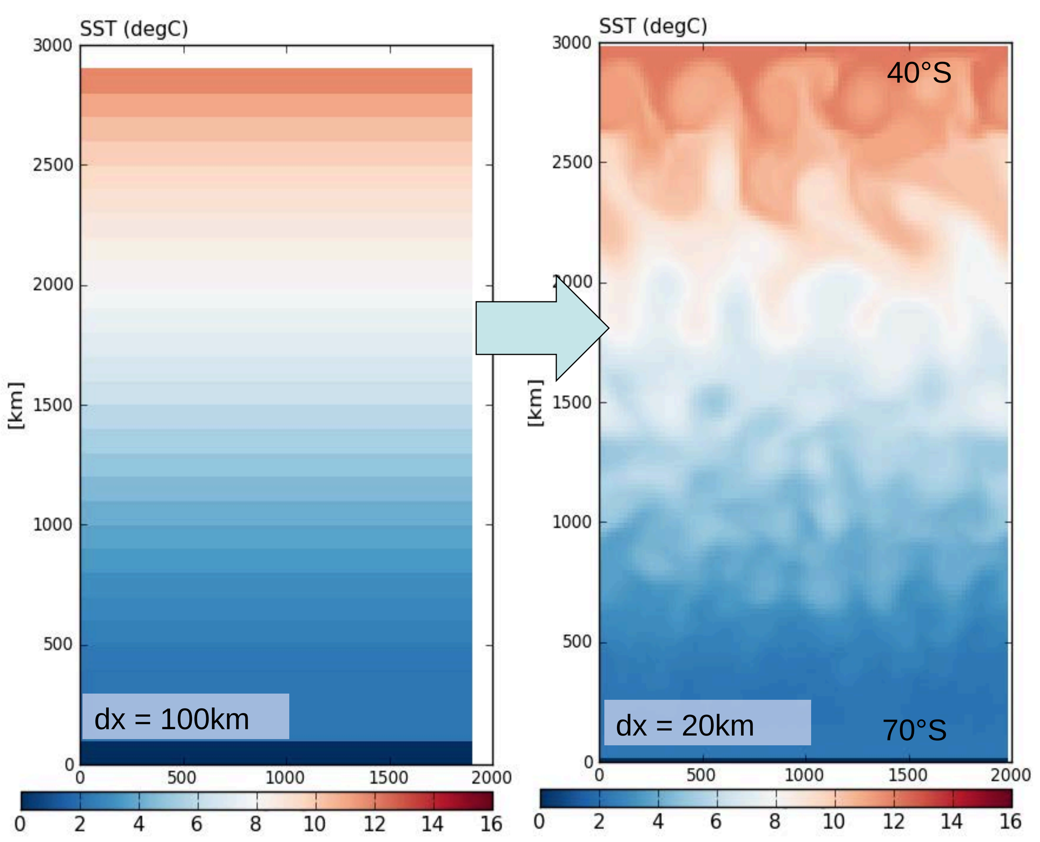

Fig 6: Comparison between the August monthly mean SST's for the 190th year of the dx=100km (left) and dx=20km (right) runs.

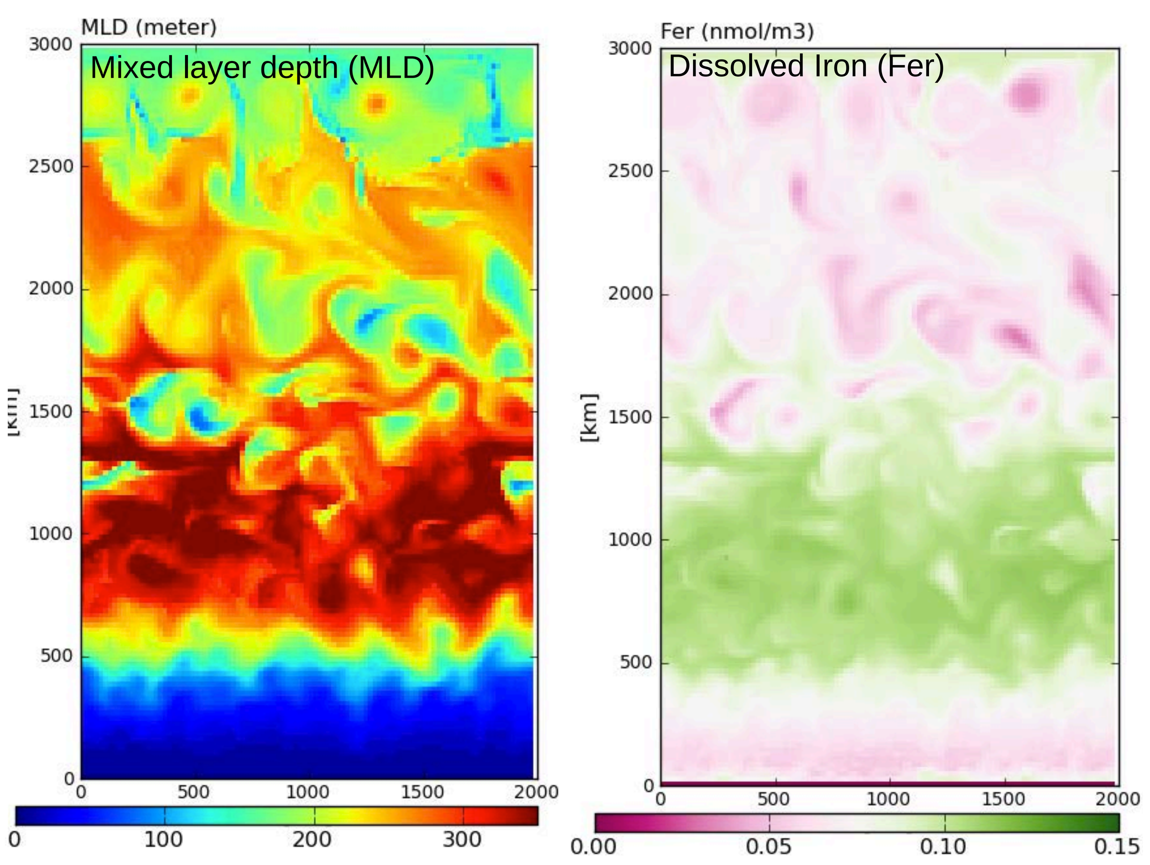

Fig 7: August monthly mean for dx=20km run, yr =190, MLD (right), surface dissolved iron (left).

FUTURE WORK

The addition of storms: to simulate a passing storm we will make use of the Rankin radial flow vortex model.

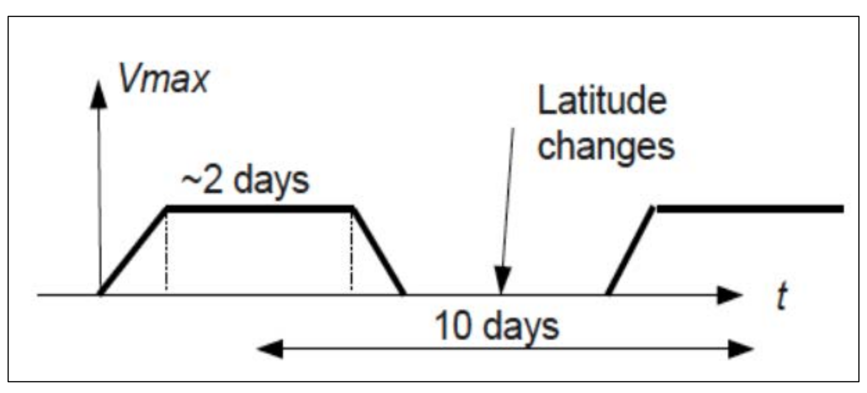

Fig 8: Description of simulated storm, period of 10 days and life time of ~ 2 days

Further increase model resolution to 5km: to simulate sub-mesoscale circulation (highly energetic eddies)

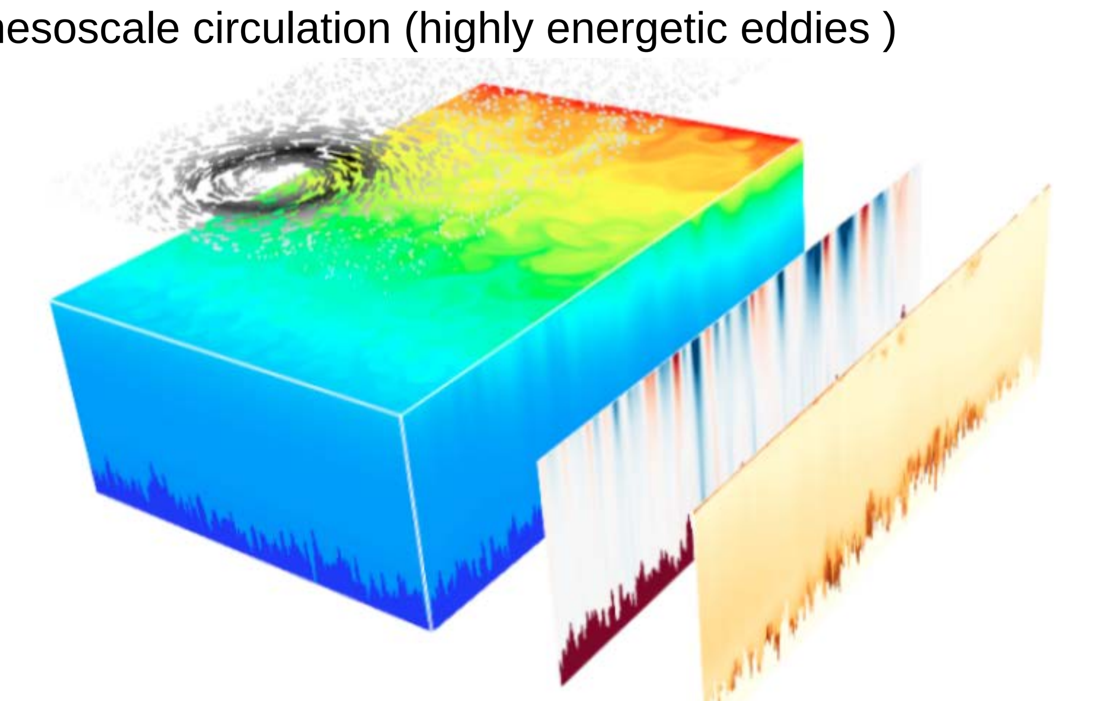

Fig 9: 3D representation of final model configuration. Instantaneous buoyancy (box), sections of zonal velocity and vertical mixing intensity and wind stress vectors in grey.

References: Abernathey, R., J. Marshall, and D. Ferreira (2011), The Dependence of Southern Ocean Meridional Overturning on Wind Stress. Journal of Physical Oceanography, 41, DOI: 10.1175/. Mahadevan, A, Eric D'Asaro, Craig Lee, Mary Jane Perry (2012), Eddy-Driven Stratification Initiates North Atlantic Spring Phytoplankton Blooms. Science. Vol. 337 no. 6090 pp. 54-58. DOI: 10.1126/science. Mahadevan, A. and A. Tandon (2006), An analysis of mechanisms for submesoscale vertical motion at ocean fronts, Ocean Modelling, 14 (3-4), 241–256.

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