Origins of Mesoscale Mixed Layer Depth Variability in the Southern Ocean

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Motivation

Mixed-layer depth (MLD) exhibits significant variability, which is important for atmosphere-ocean exchanges of heat and atmospheric gases. Origins of the mesoscale MLD variability at the oceanic mesoscale in the Southern Ocean are studied here in an idealized Regional Ocean-Atmosphere Model (ROAM). The main conclusion from the analysis of the upper-ocean buoyancy budget is that, while the atmospheric forcing and oceanic vertical mixing on average induce the mesoscale variability of MLD, the three-dimensional oceanic advection of buoyancy counteracts and partially balances these atmosphere-induced vertical processes. The relative importance of advection changes with both season and the average depth of the mixed layer.

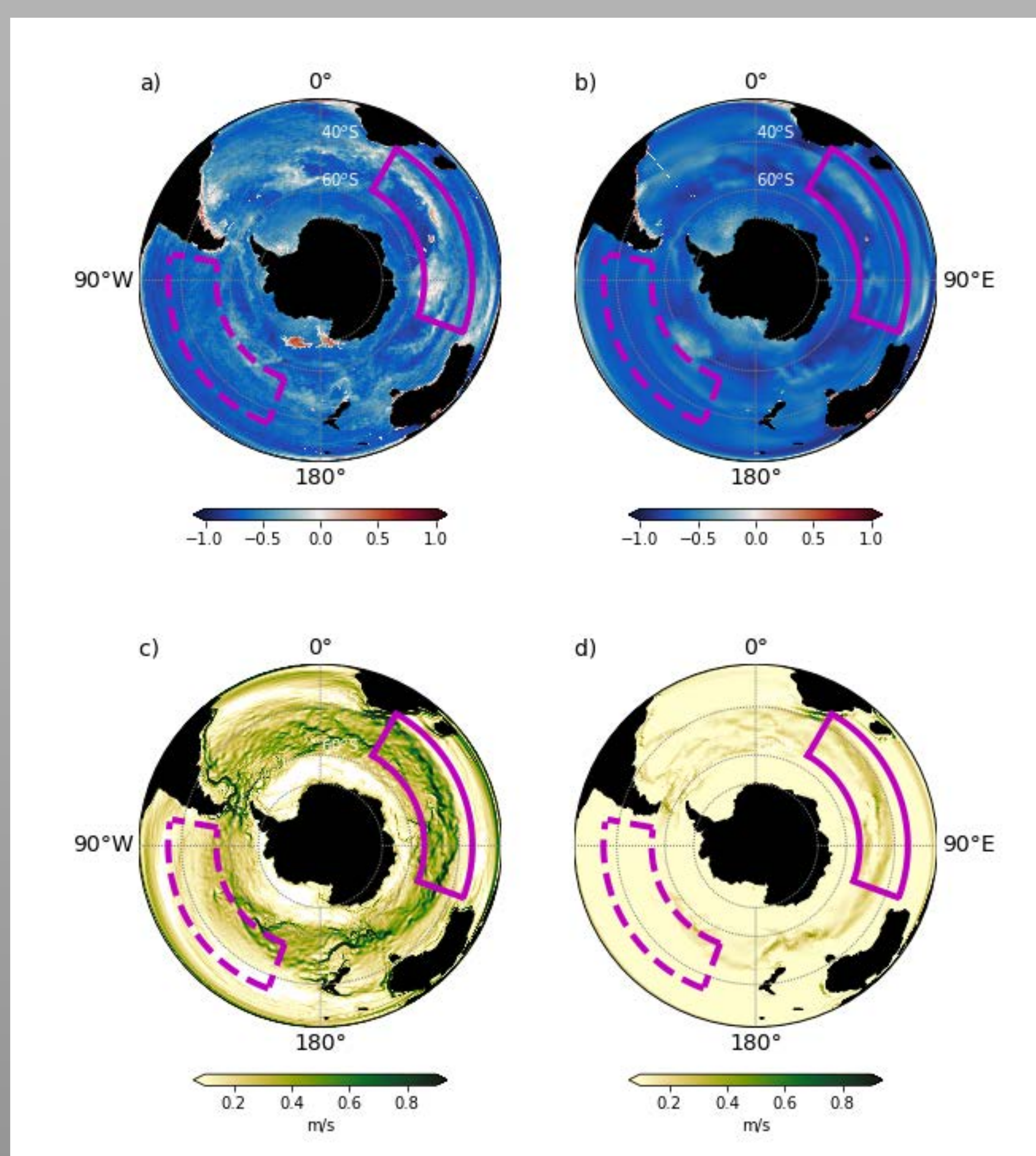


Figure 1: Global climate model CCSM4 results. Correlation between SSTA and MLD (**top**; negative means cooler SSTAs are associated with deeper OML) and time-mean surface currents (**bottom**) in two coupled-model simulations: with a high-resolution ocean (**left**), and with a low-resolution ocean (**right**).

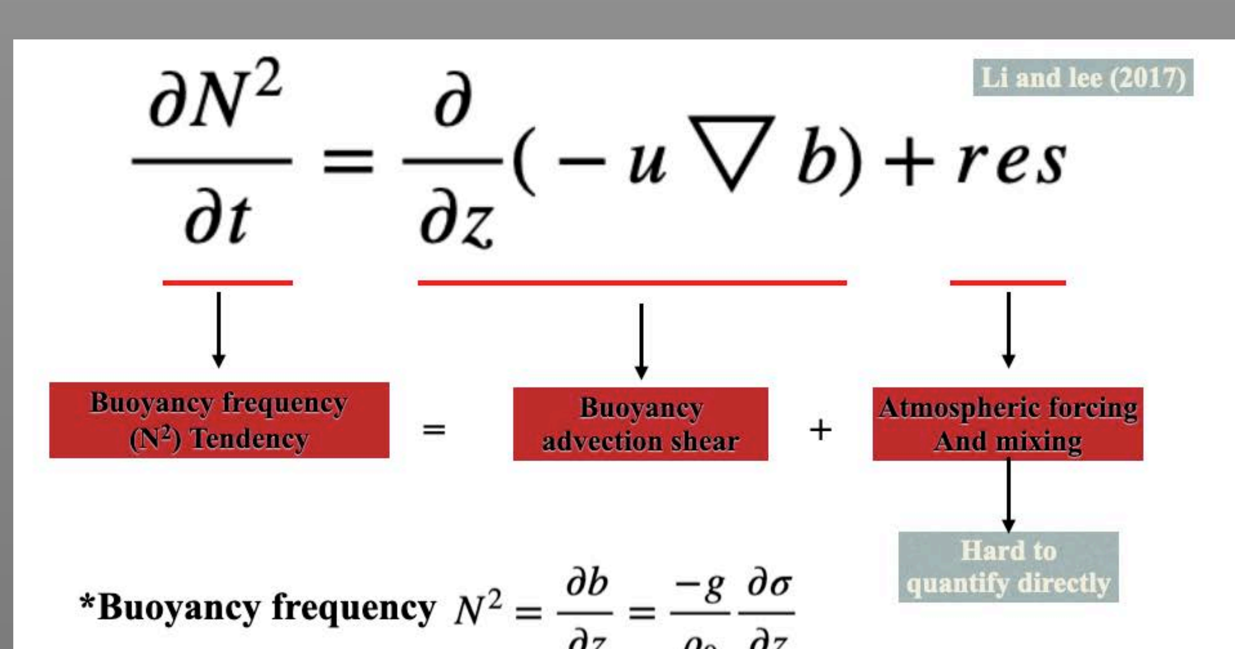


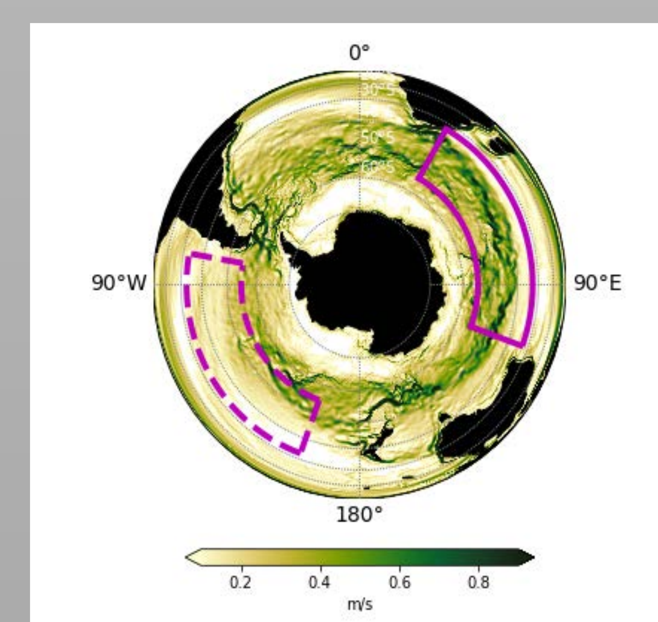
Figure 2: **Depth-dependent buoyancy budget.** Positive tendency means stratifying and mixed layer gets shallower. Negative tendency means de-stratifying and mixed layer gets deeper.

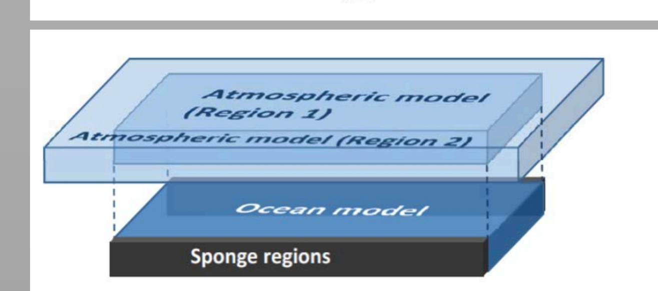
Regional Ocean-Atmosphere Model (ROAM)

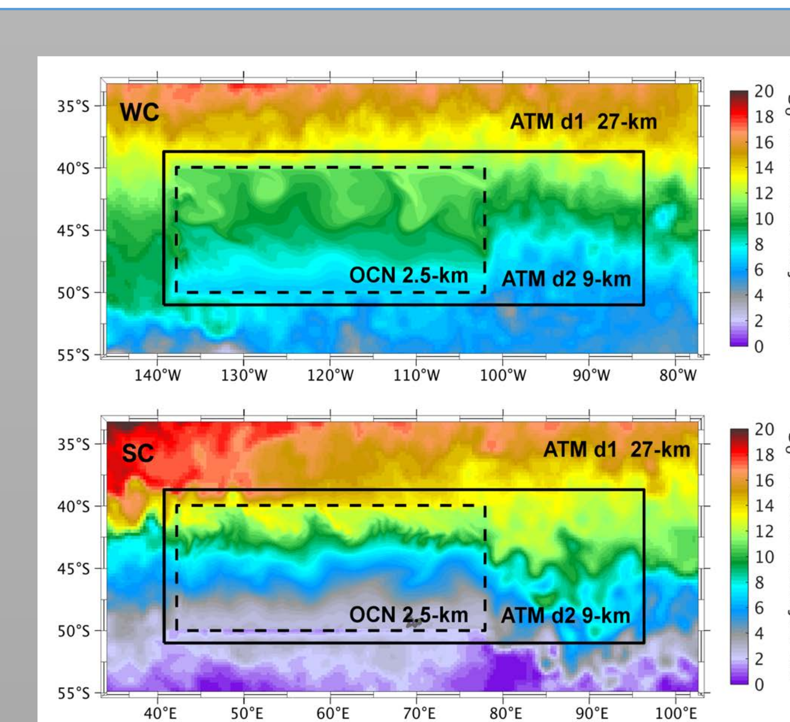
Two regional simulations in the Southern Ocean represent different ocean regimes:

- "*Strong Current*" simulation: Steep isopycnals and strong currents
- "*Weak Current*" simulation: Less steep isopycnals and weaker currents

ROAM consists of an atmospheric (COAMPS™) and ocean (ROMS) components that exchange heat and momentum fluxes. The atmospheric model has two nested domains: the inner domain fully coupled with the ocean model, and the outer domain one-way coupled with the observed SST. Forcing of the lateral boundary conditions comes from the global analysis, and ensures realistic synoptic-scale conditions. Resolution is 2.5 km in the ocean and 9-27 km in the atmosphere.







SST over the areas of *WeakCurrent* (WC; **top**) and *StrongCurrent* (SC, **bottom**) regions after the spin-up period and in the beginning of the control run. Areas show outer atmospheric grid domain (d1), nested grid domain (d2), and the ocean grid domain (dashed). The domain d2 receives the SST from the ocean model in a two-way coupled run, while the outer grid d1 uses global observation-based SST data updates.

Depth-dependent buoyancy budget

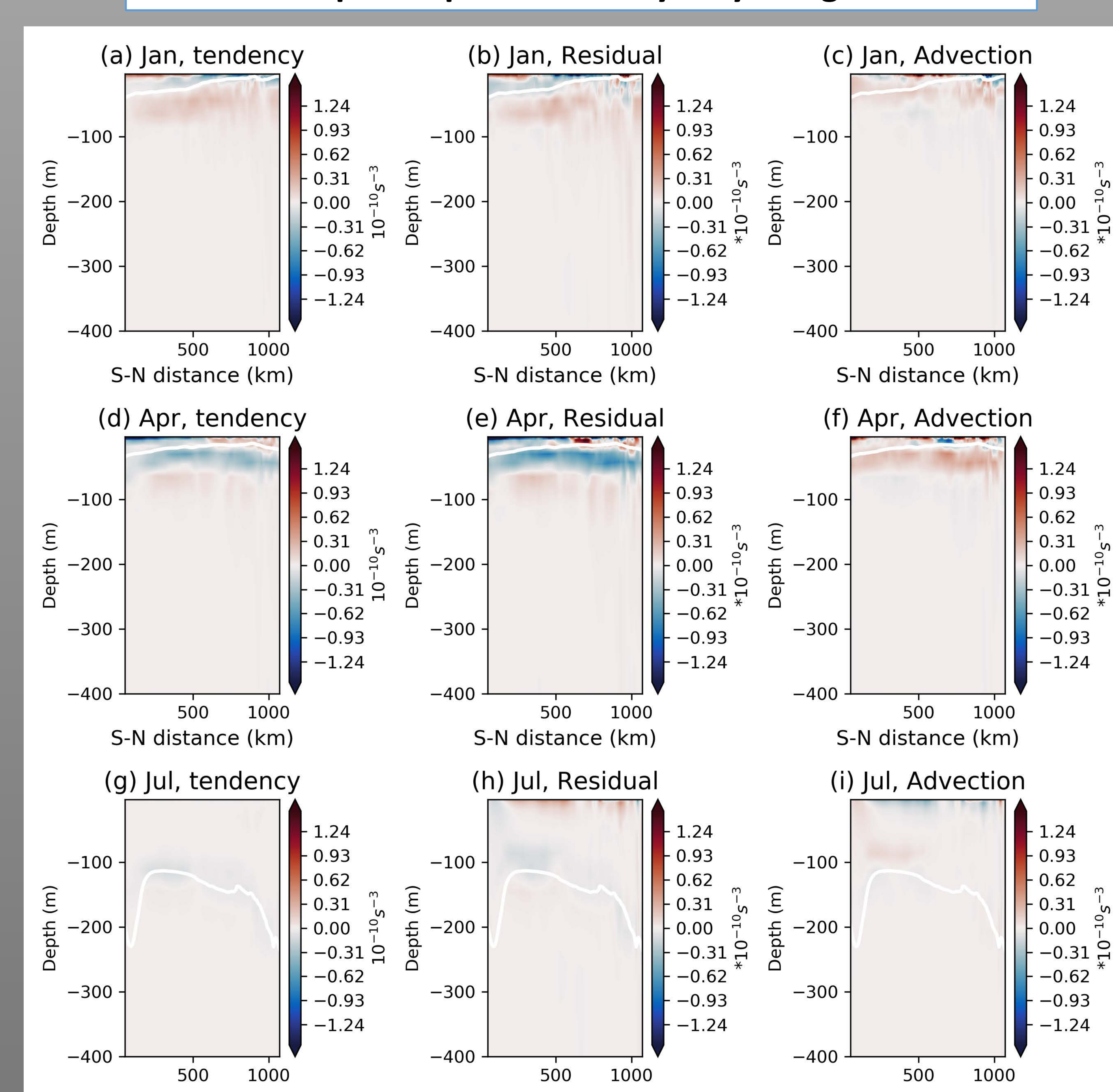


Figure 4: Monthly-mean depth-dependent buoyancy budget in the Control case at the vertical cross section X = 2000 km in January, April and July, respectively.

Depth-integrated mixed layer buoyancy budget

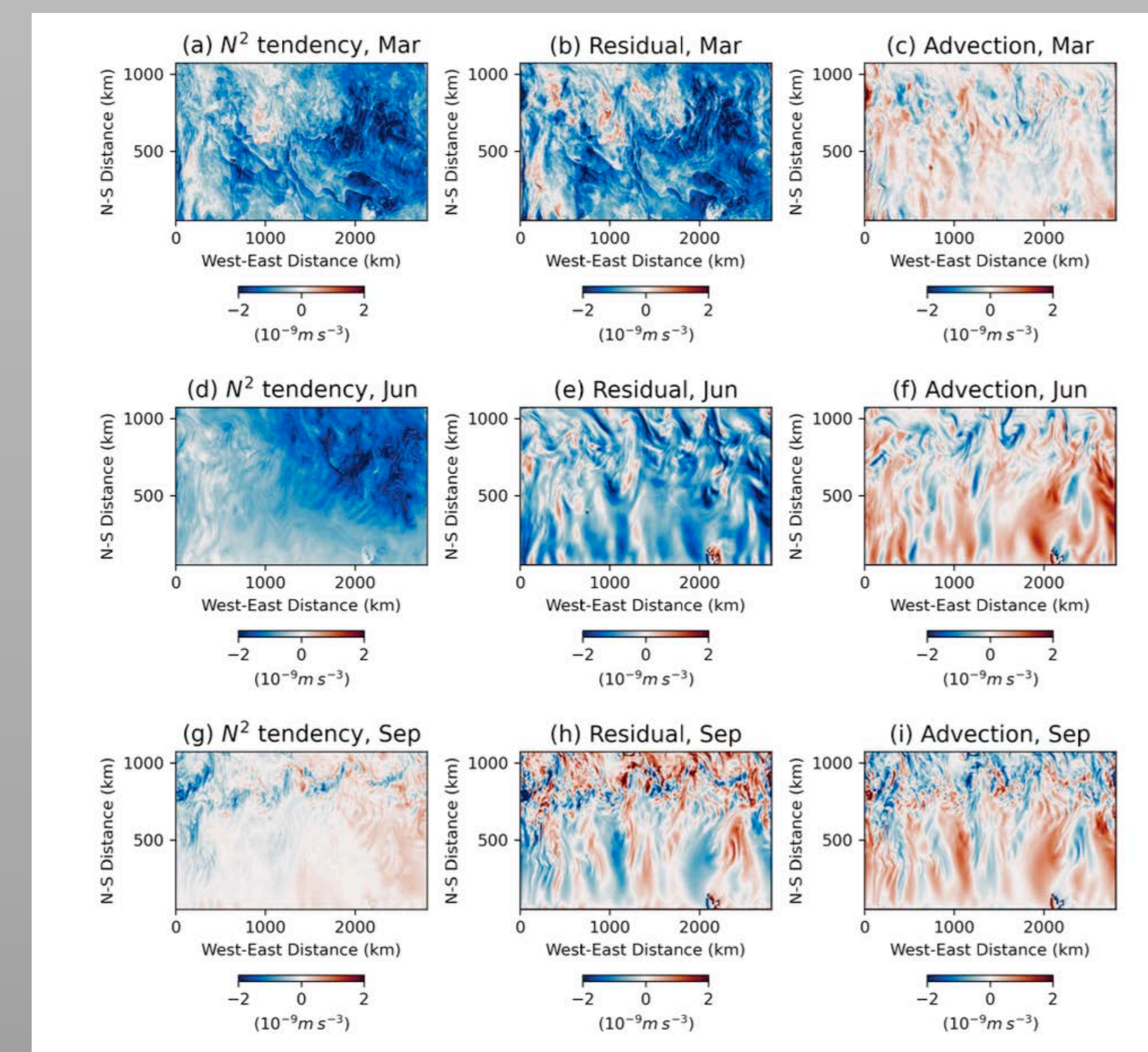


Figure 5: Surface heat flux into the ocean (shading) and SSTA (contours) in the Strong Currents (**top**) and Weak Current (**bottom**) simulations.

Conclusions

In the budget analysis, the time evolution of the buoyancy frequency N^2 represents the re- or destratifying tendency in the water column. This tendency is driven by the two main processes: the three-dimensional advection of buoyancy and the atmospheric forcing and upper-ocean mixing (the "residual term"). The mixing and surface fluxes of heat and momentum in the residual term are closely intertwined and represent the one-dimensional vertical forcing. The budget also exhibits strong seasonal variations due to the changes in mixed-layer heat inertia. In summer and autumn, when the mixed layer is shallow, atmospheric forcing and ocean mixing dominate the budget while the buoyancy advection is of minor importance and its significance is mainly restricted to the jet region. In winter and spring, when the mixed layer is deep and its inertia is large, the buoyancy advection becomes more important and balances the mixing and atmospheric forcing. Another important result is that the advection can have both re-stratifying (mixed-layer shoaling) and destratifying (mixed-layer deepening) effects. In fact, the destratifying advective effects are widespread at mesoscale, which challenges a common view that mesoscale eddies always restratify the upper ocean.

Acknowledgement

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