Role of Mesoscale Currents in Mixed Layer Heat Balance and Air-Sea Coupling

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Motivation

Ocean mixed layer (OML) modulates air-sea heat exchanges by changing the effective heat capacity of the surface water and responding to SST anomalies (SSTA). Cooler SSTs are generally associated with deeper OML, which is manifested by the negative correlation between the OML depth (MLD) and SSTAs. However, this simple relationship is broken in several parts of the Antarctic Circumpolar Current, where the large-scale currents and eddy activity are both strong. This property is observed in both comprehensive climate-model simulations and high-resolution regional simulations.

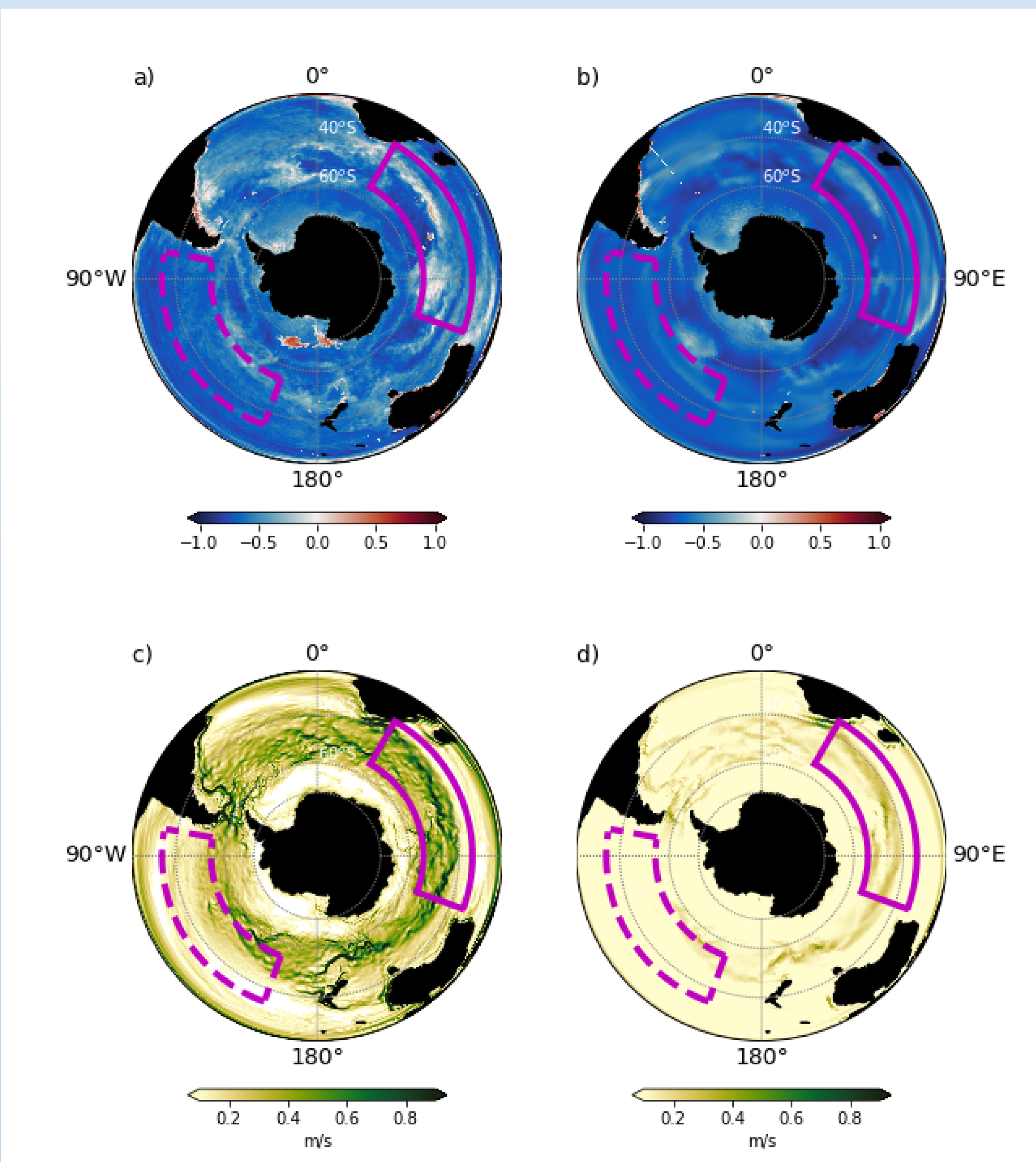


Figure 1: CCSM4 results. Correlation between SSTA and MLD (**top**; negative means cooler SSTAs are associated with deeper OML) and time-mean surface currents (**bottom**) in two coupled-model simulations: one with a high-resolution ocean (**left**), another – with a low-resolution ocean (**right**).

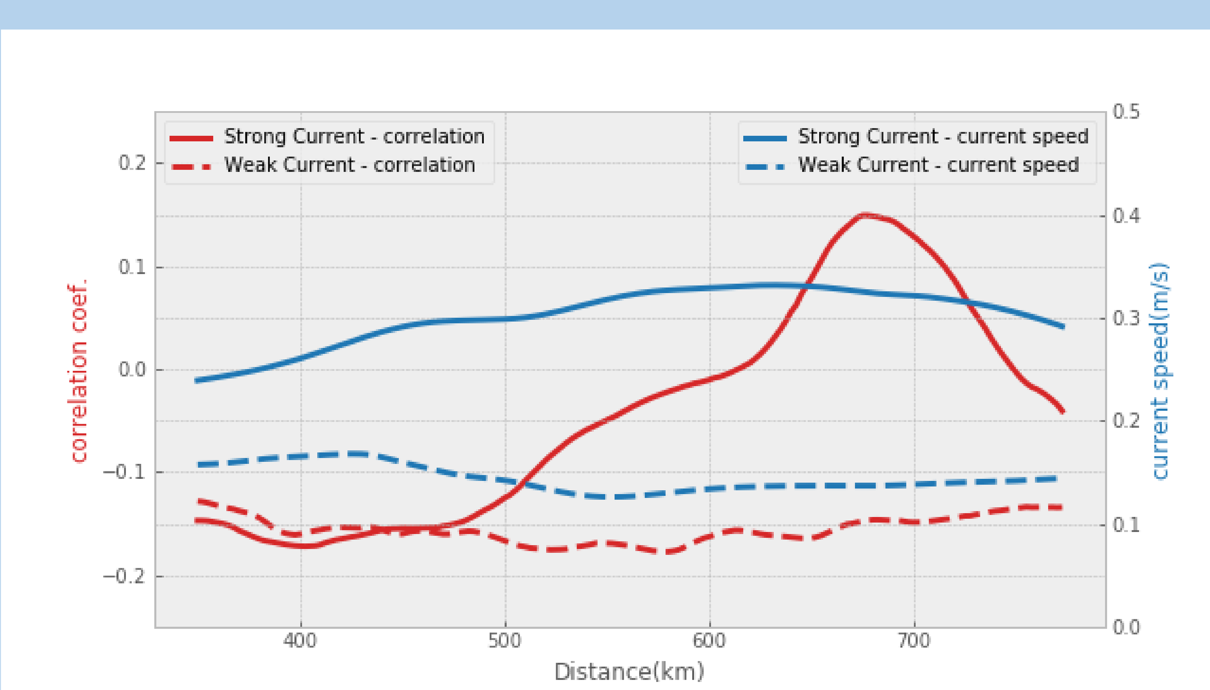


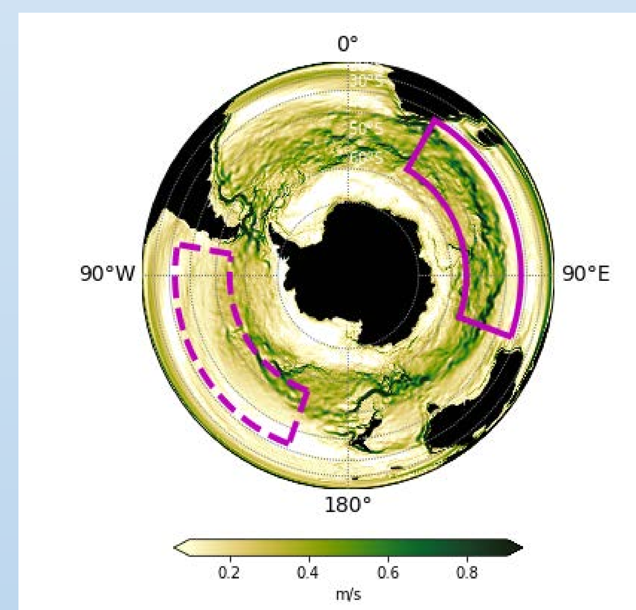
Figure 2: **ROAM results.** Zonal average of the correlation between SSTA and MLD and time-mean zonal current speed in the Strong Current simulations (solid lines); and the Weak Current simulations (dashed lines).

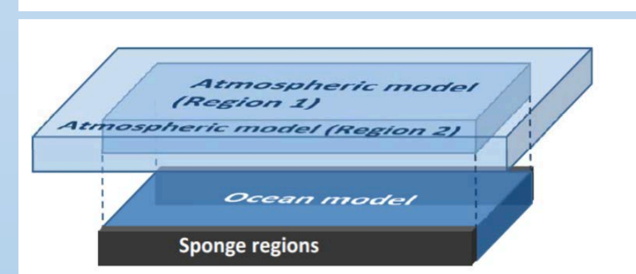
Regional Ocean-Atmosphere Model (ROAM)

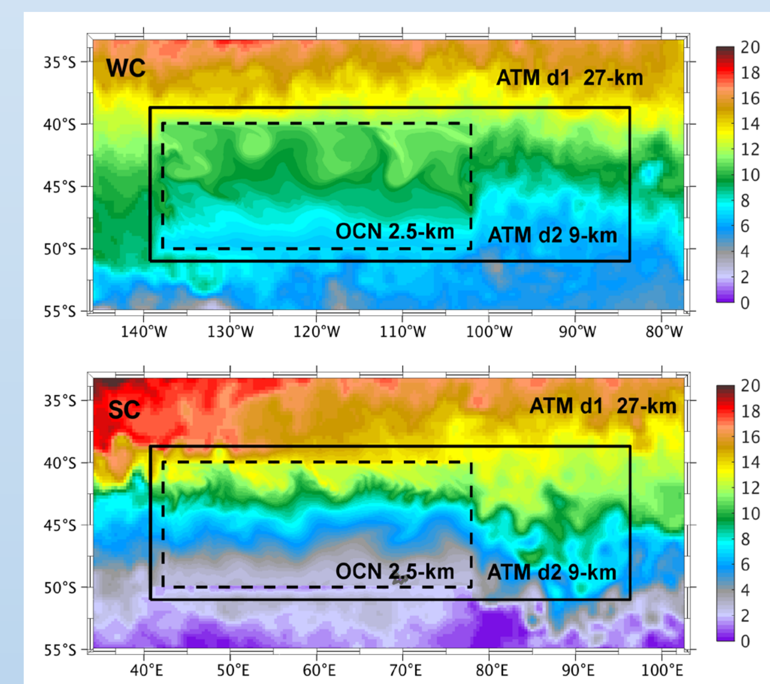
Two regional simulations in the Southern Ocean represent different ocean regimes:

- "*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.

OML Heat Budget

We analyze the OML-integrated heat budget. The advection is split into the large-scale and mesoscale components. Large-scale and mesoscale fields are separated using a 300 km x 300 km running-average box filter (low-pass filtered fields are marked by the overbars)

$$\int_{-h(t)}^{0}\frac{\partial}{\partial t}T\,dz = -\int_{-h(t)}^{0}\nabla\bullet\vec{u}T\,dz + \int_{-h(t)}^{0}A_h\nabla_h^2 T\,dz + \int_{-h(t)}^{0}A_z T_{zz}\,dz + \frac{Q_{net}-q}{\rho C_p H_{mix}}$$

Time tendency | Advection | Mixing | Surface heating

$$\int_{h(t)}\bar{u}\frac{\partial\bar{T}}{\partial x}dz$$

Large-scale advection

$$\int_{h(t)}u\frac{\partial T}{\partial x}dz - \int_{h(t)}\bar{u}\frac{\partial\bar{T}}{\partial x}dz$$

Mesoscale advection

Conclusions

The results show that the OML heat budget is dominated by the large-scale and mesoscale heat advection, as well as by the heat exchanges at the base of OML. On average, the OML-integrated mesoscale heat advection is shown to induce SSTAs, while the large-scale heat advection acts to weaken them. The negative correlation between SSTAs and surface heat flux into the ocean further demonstrates that these mesoscale current-induced SSTAs drive the anomalous air-sea heat exchange, with the warmer SSTAs releasing heat to the atmosphere, and vice versa. Therefore, neglecting the mesoscale currents in low-resolution climate model may lead to errors in the simulated SST variability and air-sea heat exchange.

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Relationship between OML heat advection and SST

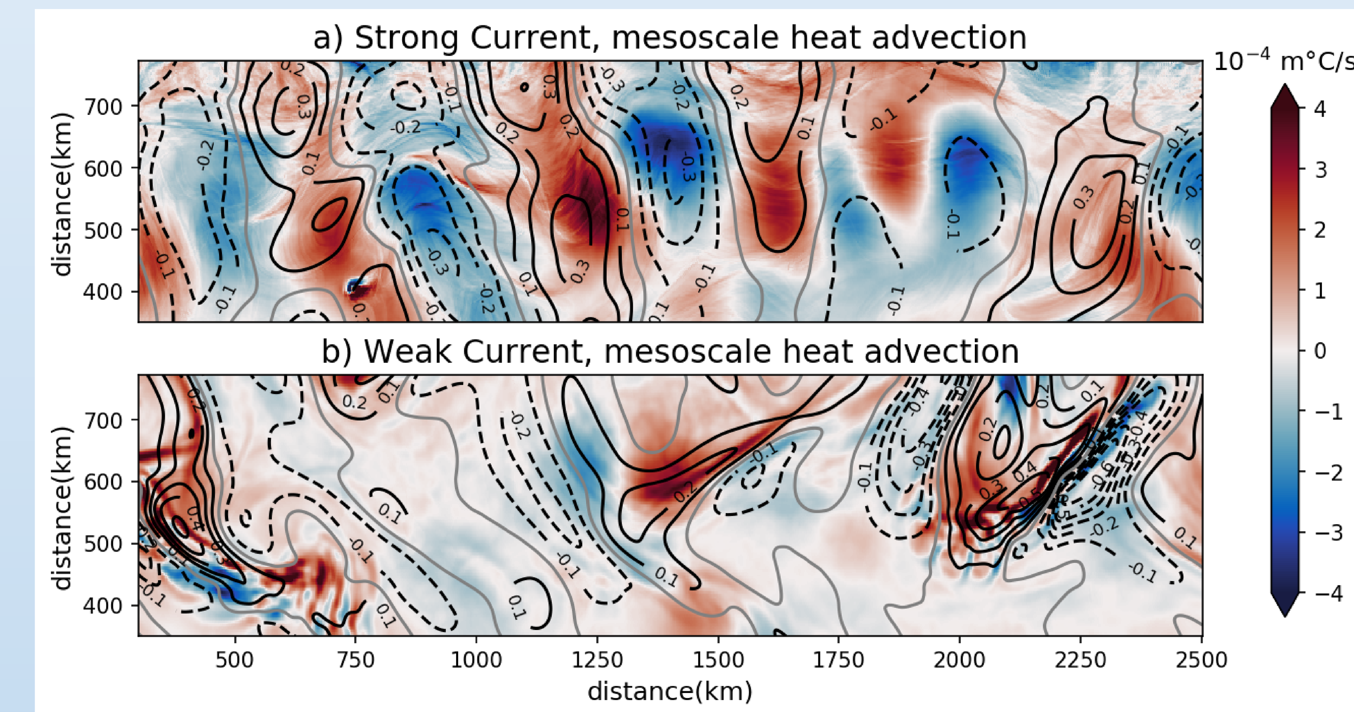

Figure 4: OML-integrated heat advection (shading, positive values indicate warming) and SSTAs (contours) in the Strong Current (**top**) and Weak Current (**bottom**) simulations. Mesoscale advection generates SSTAs in the Strong Current case.

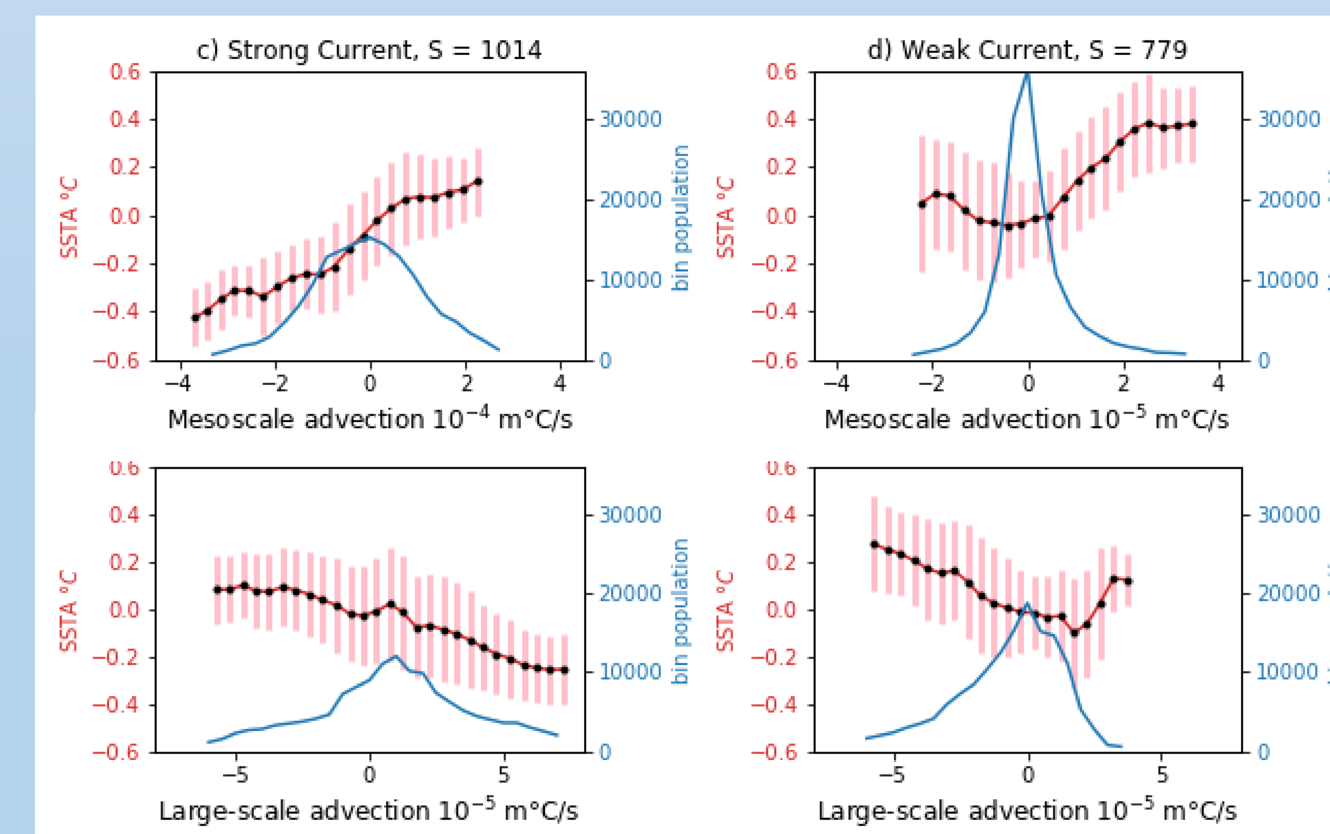

Figure 5: Binned values of SSTA vs. mesoscale advection (**top**) and large-scale advection (**bottom**). Red bars show standard deviations and blues lines – bin population.

Relationship between SST and air-sea heat exchange

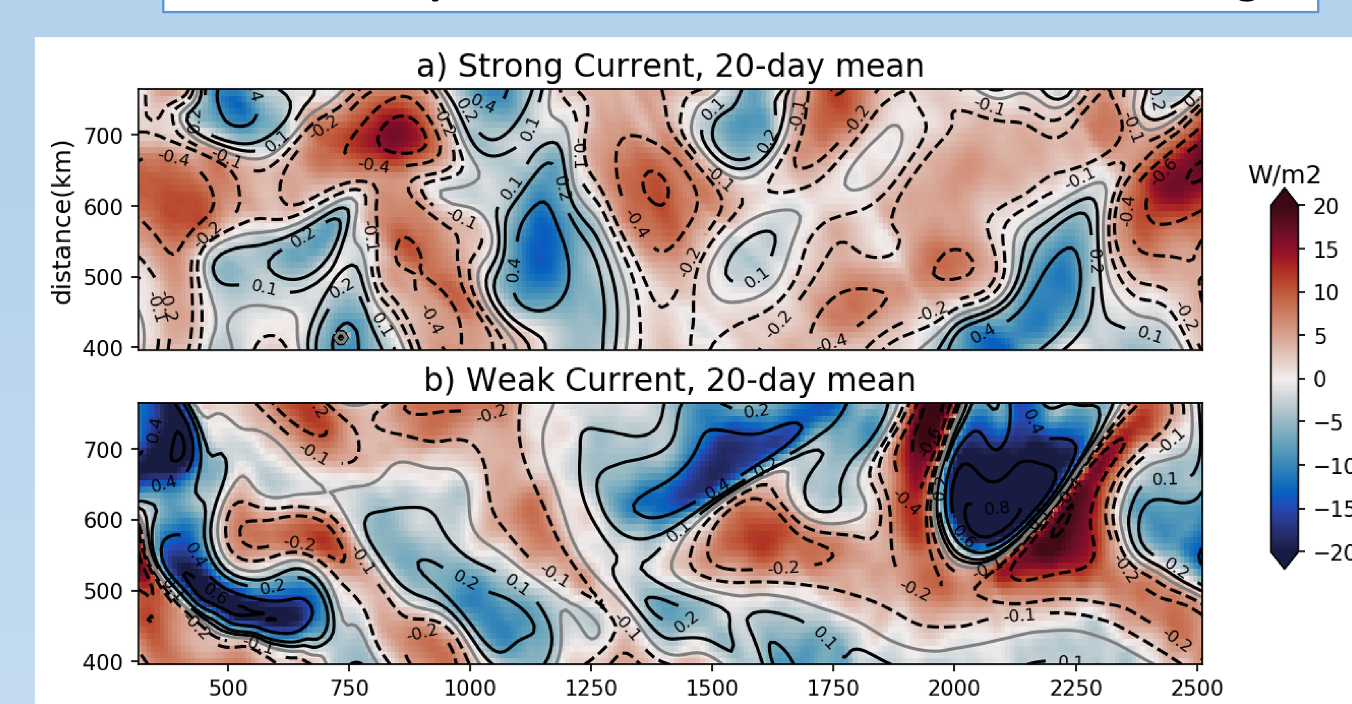

Figure 6: Surface heat flux into the ocean (shading) and SSTA (contours) in the Strong Currents (**top**) and Weak Current (**bottom**) simulations.