A regional coupled model for studies of mesoscale air-sea interaction in the Southern Ocean

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Introduction

The atmosphere and ocean interact on a wide range of spatial and temporal scales, and these interactions modulate weather and climate variability, as well as oceanic uptake of anomalous heat and carbon. The mechanisms of these interactions were found to be scale-dependent. We introduce a new coupling approach specifically designed for studies of the air-sea interactions at the oceanic mesoscales from 10 to several hundreds of kilometers. Our regional high-resolution atmosphere-ocean coupled model features a realistic atmospheric component and a semi-idealized oceanic model of a zonal flow.

Methods and models

Two regions in the Southern are chosen to represent different ocean regimes of the zonal flow. The oceanic isopycnals are steep and zonal ocean currents are strong in the SC region (“*StrongCurrent*”), and isopycnals are less steep with weaker currents in WC region (“*WeakCurrent*”). The coupled model consists of the atmospheric (COAMPS™) and ocean (ROMS) components that exchange surface 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 in 2-year coupled simulations.

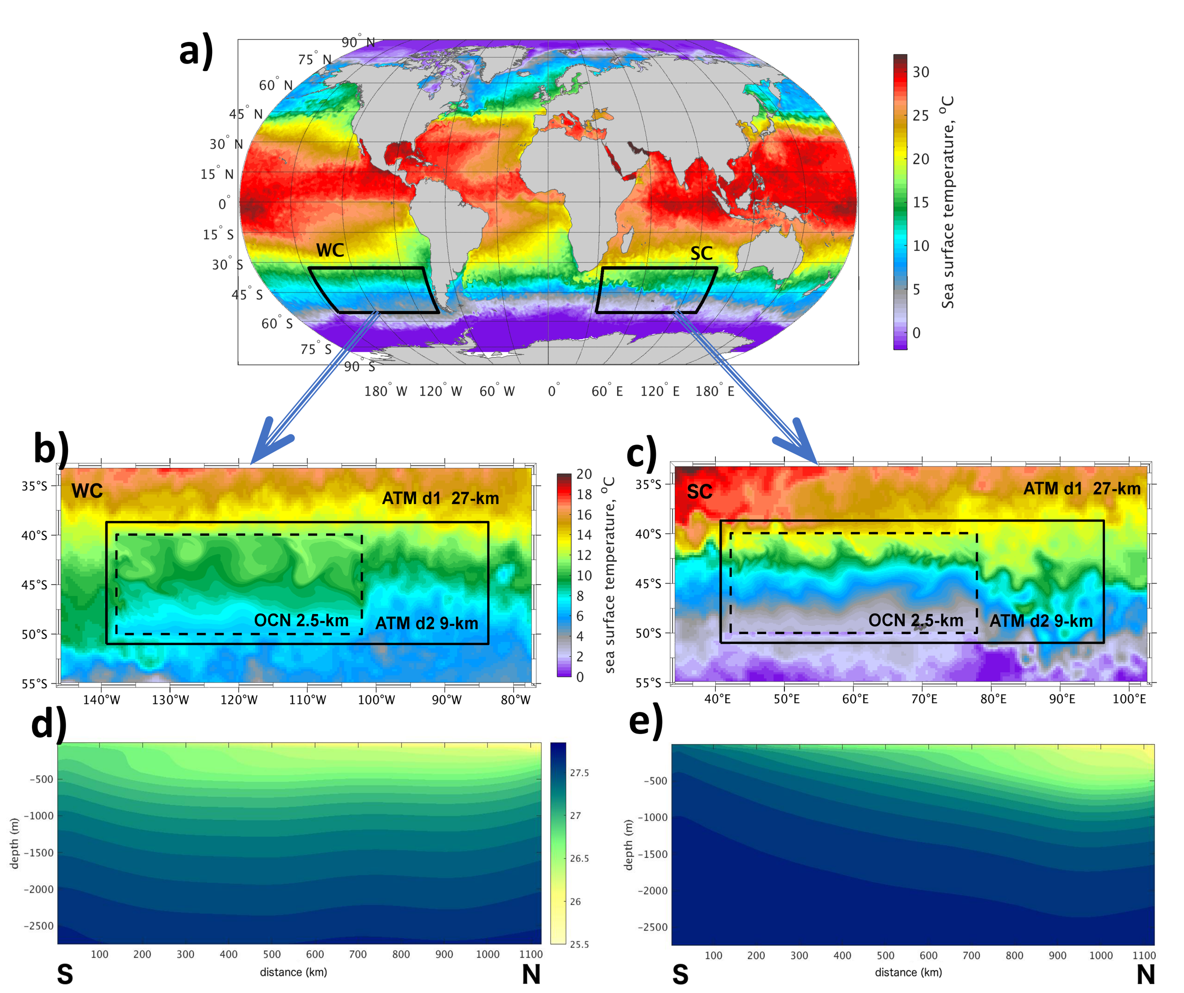
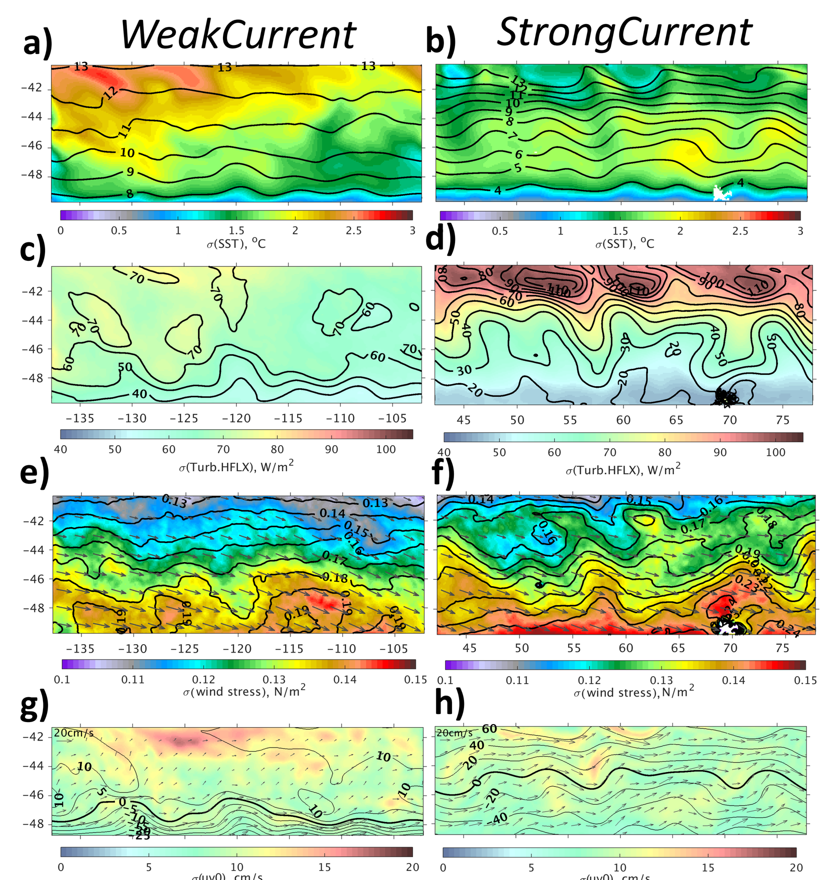


Figure 1. **a)** Sea surface temperature (SST) for 24 July 2015, from the NOAA OI SST 0.25° database. **(b-c)** SST over the WC and SC regions in the onset of 2-year runs for the three model grids. **(d-e)** Zonally-averaged time-mean ocean cross-sections of the potential density anomaly.

Time-mean surface statistics



Both stationary and transient mesoscale oceanic features have developed in the WC and SC study cases. These mesoscale anomalies are generated by a combination of oceanic processes, such as the instability of the mean flow or its interactions with topography, and atmospheric variability, such as wind and heat flux anomalies.

Figure 2. Time-means and their standard deviations (colors) derived from daily average fields in 2-year coupled simulations, over the ocean grid area. **(a-b)** SST; **(c-d)** Turbulent (latent+sensible) heat fluxes; **(e-f)** Wind stress magnitude and vectors; **(g-h)** Surface current vectors, standard deviation of the surface currents (color), and free surface height (contours, cm)

Transient mesoscale features

Simulated transient mesoscale variability occurred on a wide range of scales. To distinguish large-mesoscale (< 100s of km) and small-mesoscale (<10s of km) anomalies, we applied differential spatial high pass filtering.

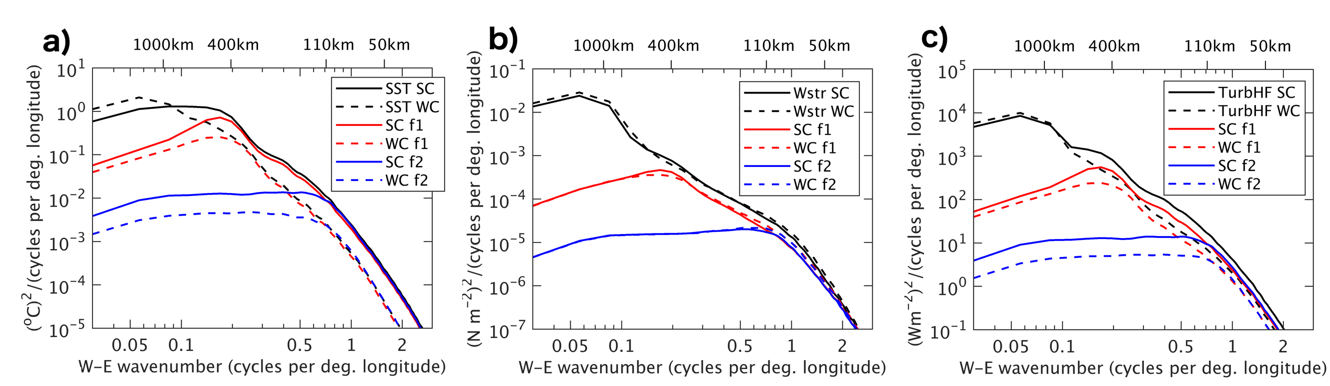


Figure 3. Average power spectral density of the full fields (black lines) and high-pass filtered fields in the zonal wavenumber space, for the *SC* and *WC* cases, for **a)** SST, **b)** wind stress magnitude, Wstr, and **c)** turbulent heat flux, TurbHF. **f1** denotes high-pass filtered fields using quadratic loess filter with 10° x 5° half-span window; **f2** denotes high-pass filtered fields using loess filter with 150km x 150km half-span window. The spectral density was computed for the individual latitudinal grid lines for the fields smoothed with 5-day running average, and then meridionally- and time-averaged.

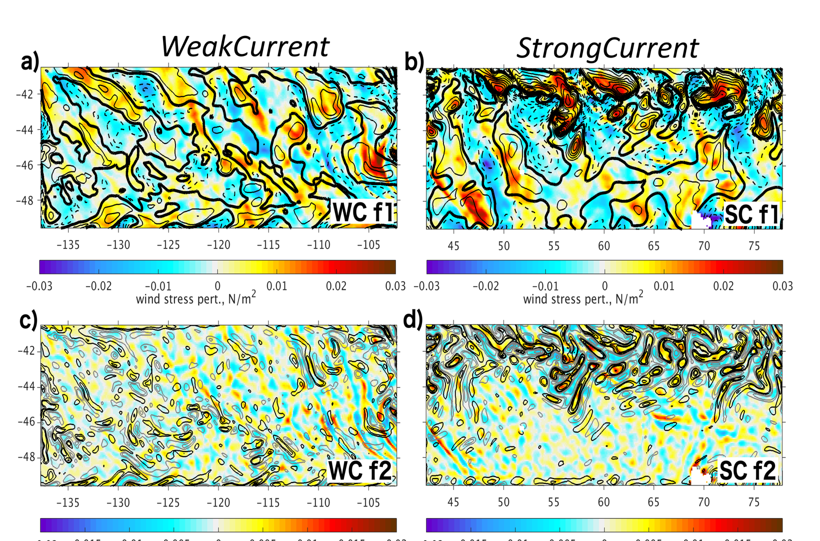


Figure 4. Snapshots of the high-pass filtered SSTA (isolines) and wind stress perturbations (colors) for 15 January 2017: **(left column)** *WeakCurrent* case and **(right column)** *StrongCurrent* case. **(a-b)** Filter f1; **(c-d)** filter f2. The SSTA contours are 0.2°C in (a-b), with the “0” contour in bold, and negative contours dashed; the contours in (c-d) are black for positives, gray for negative anomalies, with no “0” contour.

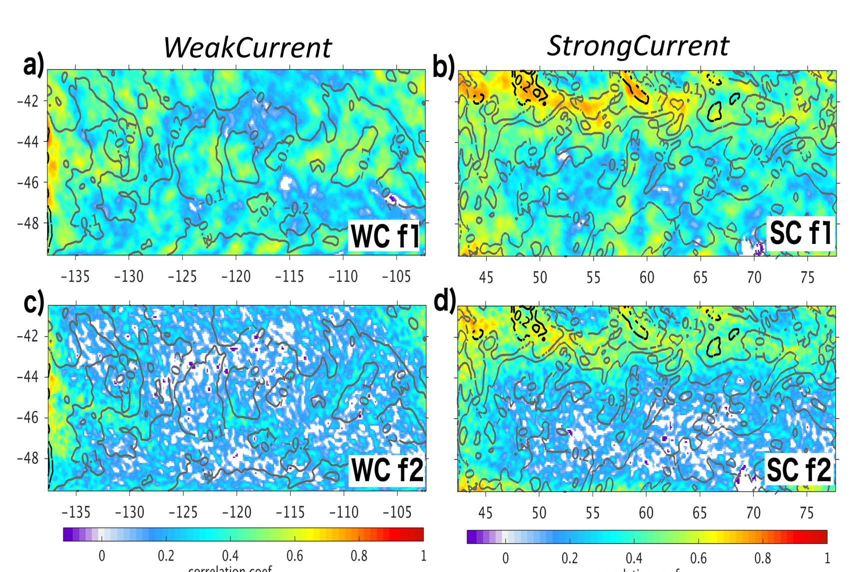


Figure 5. Temporal correlations between SSTA and wind stress perturbations (color), and between full fields (contours) for **(a-b)** filter f1, **(c-d)** filter f2. Annual cycle was removed from the full SST and wind stress time series. The temporal correlations are smaller for the small-mesoscale anomalies (f2); they are higher for the SC region.

Reference: Perlin, N., I. Kamenkovich, Y. Gao, and B.P. Kirtman (2020): A study of mesoscale air-sea interaction in the Southern Ocean with a regional coupled model (*in revision following a submission to Ocean Modelling*)

Vertical Mixing Mechanism

Coupling coefficients are used as a measure of the sensitivity of mesoscale atmospheric adjustment to the SSTA, explained by the vertical mixing mechanism (VMM): stronger (weaker) winds over warm (cold) SSTA.

		f1: 10 deg. x 5 deg.		f2: 150 km x 150 km	
		s	ρ	s	ρ
s_U	WC	0.53	0.37	0.49	0.25
	SC	0.43	0.44	0.40	0.36
s_{str}	WC	0.020	0.36	0.016	0.22
	SC	0.017	0.42	0.015	0.31
s_{Dstr}	WC	1.65	0.21	1.39	0.15
	SC	1.53	0.27	1.23	0.20
s_{Cstr}	WC	1.86	0.20	1.61	0.16
	SC	1.49	0.25	1.41	0.21

Table 1. Binned linear regression estimates of wind- and SST-derivatives coupling coefficients: s_U is between the ENS 10-m wind speed and SST, s_{str} is between the wind stress and SST, s_{Dstr} is between wind stress divergence and downwind SST gradient, s_{Cstr} is between wind stress curl and cross-wind SST gradient.

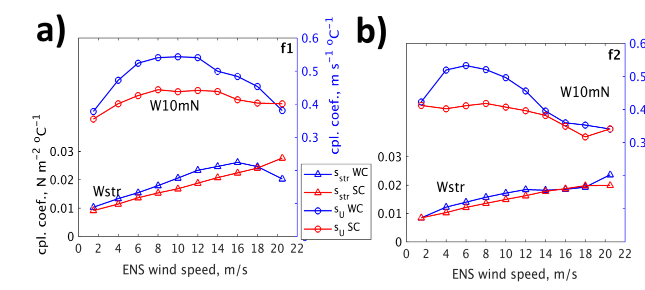


Figure 6. a) Coupling coefficients s_U and s_{str} for the wind stresses (left axis) and the 10-m ENS winds (right axis), respectively, as functions of the binned ENS 10-m wind speeds, from f1-filtered perturbations and for the inner domain. **b)** As in a) except for the f2-filtered.

Pressure Adjustment Mechanism

This atm. response mechanism (PAM) suggests a correspondence between the wind convergence and the Laplacian of the sea level pressure. Hydrostatic pressure response is expected to result in surface winds convergence, with sufficient time and spatial scales to reach the equilibrium.

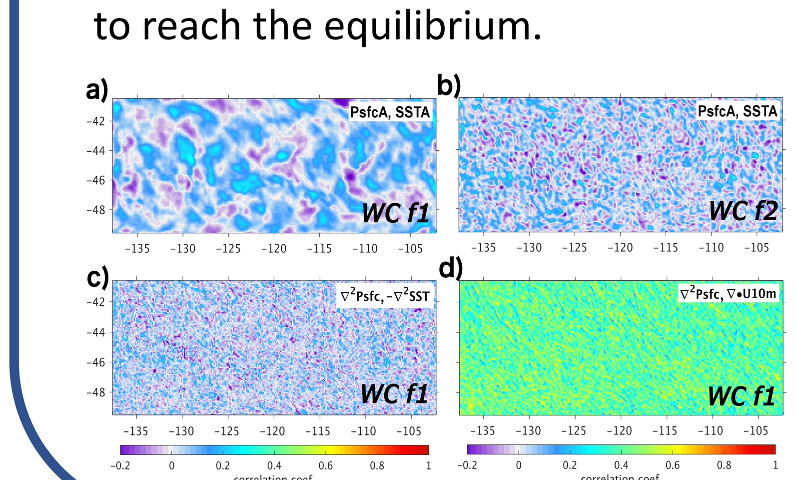


Figure 7. Temporal correlations between **(a-b)** surface pressure anomalies and SSTA with the negative sign, for the f1- and f2-filtered anomalies, as marked in the panels; **c)** Laplacian of the surface pressure anomalies and the SSTA Laplacian with a negative sign, f1-filtered; **d)** Laplacian of the surface pressure anomalies and 10-m wind convergence anomalies, f1-filtered.

Summary

- Two regions in the Southern Ocean represent different ocean eddy and current regimes: *WeakCurrent* and *StrongCurrent*
- Vertical Mixing Mechanism (VMM) of the atmospheric response is well defined on both small-mesoscales and large-mesoscales
- Consistently stronger coupling coefficients resulted for the *WeakCurrent* domain for all pairs of variables, despite yielding lower temporal correlations between the same pairs
- Wind speed coupling coefficients are found to be the most stable quantitative parameter of the atmospheric response
- The pressure adjustment mechanism (PAM) could not be confirmed to be active on the spatial and time scales analyzed

Acknowledgements

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