Remote energy sources for mixing in the Indonesian Seas

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Background

The Indonesian Seas play an important role in climate and ocean circulation, which is attributed to the intense mixing observed throughout the region [1, 3]. Mixing cools the surface temperature and transforms water-mass properties [1, 4]. Mixing in the Indonesian Seas has long been identified to be driven locally by tides. Here we show that the observed mixing can also be powered by the remotely generated planetary waves and eddies (Fig. 1).

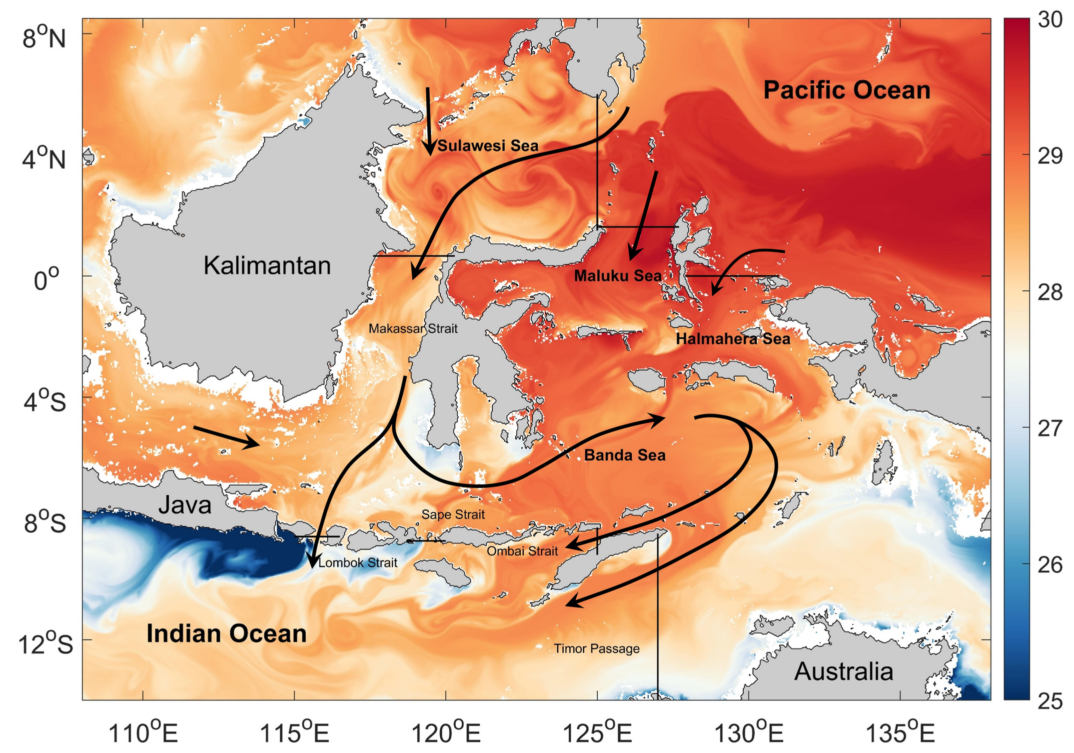

Figure1: A snapshot of the sea surface temperature in (°C) at 25 m depth.

Method

The total eddy kinetic energy budget can be written as

$$\frac{\partial \overline{E}}{\partial t} = -\nabla\cdot(\overline{\boldsymbol{u}E}) - \nabla\cdot(\rho_0\overline{\boldsymbol{u}'p'}) + \overline{b'w'} - \rho_0[\overline{u'\boldsymbol{u}'}\cdot\nabla\overline{u} + \overline{v'\boldsymbol{u}'}\cdot\nabla\overline{v}] + \overline{W} + \overline{\varepsilon} \qquad (1)$$

where $\boldsymbol{u} = (u, v, w)$ is the total velocity, $\overline{\boldsymbol{u}}$ is the time-mean (3-year mean in our study) velocity, $\boldsymbol{u}'$ is the eddy (i.e., time-varying) velocity; p' is the eddy pressure; b' is the eddy buoyancy; ρ_0 is a reference density; and

$$\overline{E} = \frac{1}{2}\rho_0\left(\overline{u'^2 + v'^2}\right) \qquad (2)$$

is the eddy kinetic energy (EKE). Terms on the right-hand-side of the energy budget from left to right are the advection of EKE by total flow; **the divergence of the radiative eddy energy flux**; the energy exchange with potential energy (i.e., EKE production from baroclinic instability); the eddy-mean flow interaction (i.e., EKE production from barotropic instability); $\overline{W}$ is the work done by wind stress; and $\overline{\varepsilon}$ is the eddy energy dissipation.

Model

The regional model ($1/25^o$ horizontal resolution and 100 vertical levels) is based on MITgcm and drived by ACCESS-OM2-01 repeat-year forcing outputs.

At the boundaries, the model is forced by monthly-mean T, S, and **U** fields from ACCESS-OM2-01. At the surface, the model is forced by the ACCESS-OM2-01 wind stress.

Simulations are carried out with a K-profile parameterization (KPP) and Smagorinsky horizontal viscosity parameterization for sub-grid scale processes.

SRTM30_PLUS is used for the model bathymetry.

Eddy energy flux and convergence

We find that the total eddy energy flux into the region is 1.7 GW with 37% coming from the Pacific Ocean and 63% from the Indian Ocean (Table 1). Individual straits contribute between 0.1 to 0.4 GW to the energy flux into the region. The energy fluxes through all straits are directed towards the interior of the Indonesian Seas, and thus the Indonesian Seas are a net sink for eddy energy generated in the Indian and Pacific Oceans (Fig. 2). This previously unaccounted remote energy source contributes energy to power the elevated mixing observed in the region.

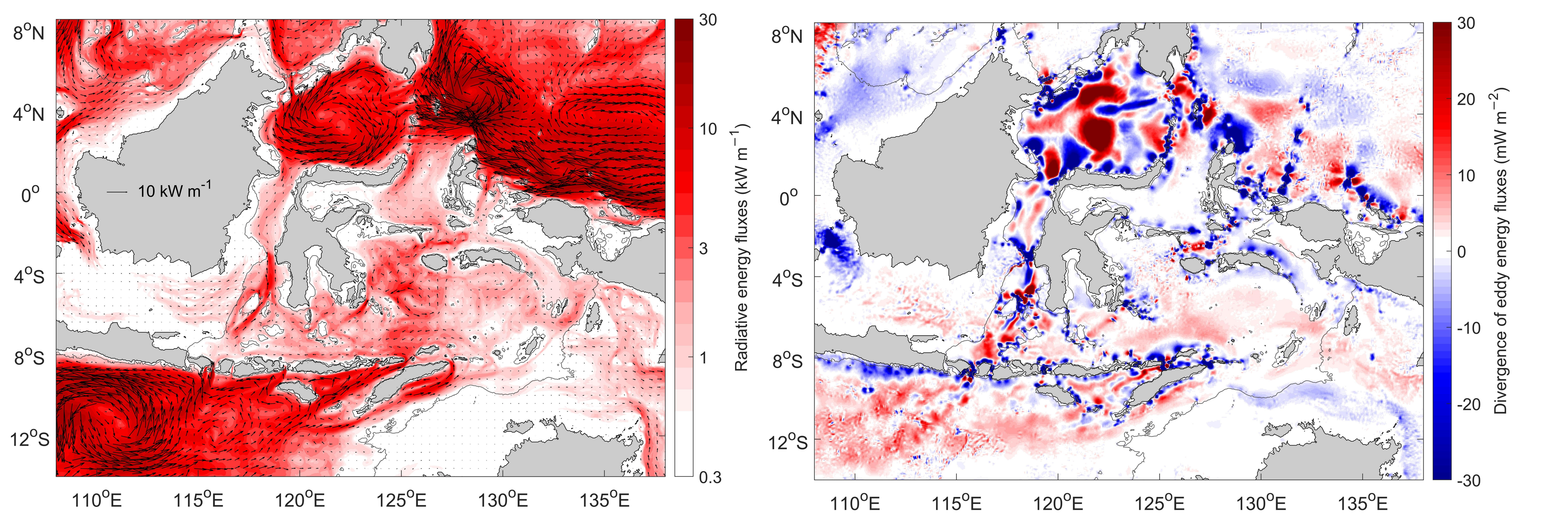

Figure 2: Time-averaged, vertically-integrated eddy energy fluxes in (kW m^{-1}) (left). Divergence of time-averaged, vertically-integrated eddy energy fluxes in (mW m^{-2}) (right).

Indian Straits		Pacific Straits	
Lombok Strait	0.36	Makassar Strait	-0.13
Sape Strait	0.15	Sulawesi Sea	-0.34
Ombai Strait	0.31	Maluku Sea	-0.19
Timor Passage	0.22	Halmanhera Sea	-0.12
Indian Ocean total	1.09	Pacific Ocean total	-0.65

Table 1: Eddy energy fluxes integrated across major straits and passages. Positive (negative) fluxes correspond to eastward/northward (westward/southward) flux direction.

The spatial distribution of divergence (convergence) of the eddy energy flux indicates local sources (sinks) of the eddy energy (Fig. 2). The eddy energy flux convergence (negative) is concentrated in narrow regions along topography and within the straits, **suggesting that the eddy energy is likely dissipated through eddy (wave)-topography interaction.**

The magnitude of the eddy energy flux convergence is 10-30 mW m^{-2} along topography and reaches 100 mW m^{-2} within the straits. The distribution and magnitude of the eddy energy flux convergence, implying local energy dissipation, is in agreement with the turbulent energy dissipation observations [5, 6]. Similar energy dissipation magnitudes and distribution were found for tidal energy dissipation[6]

Vertical distribution of eddy energy fluxes

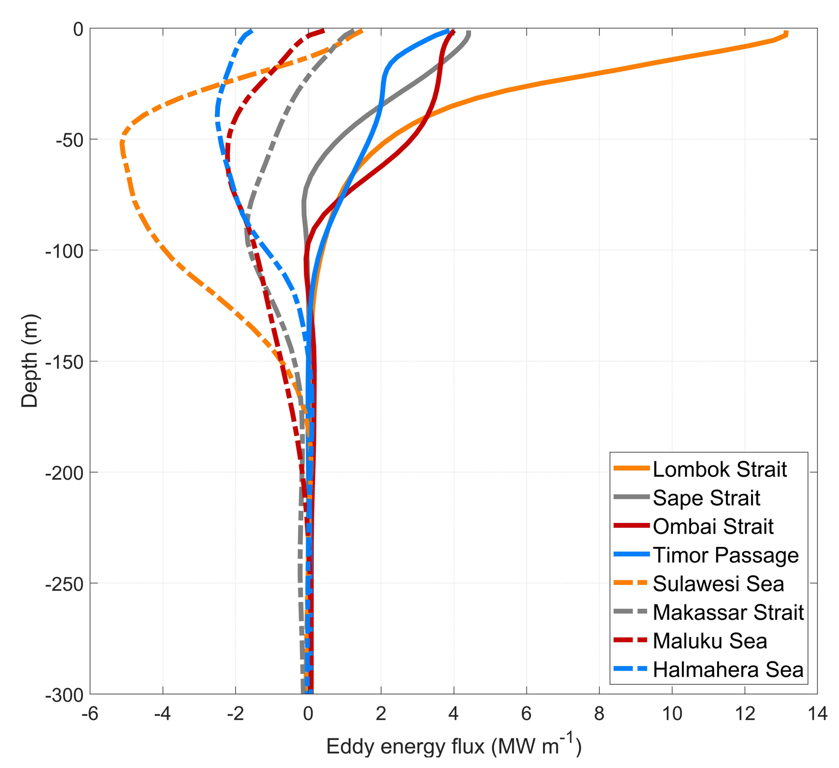

Figure 3: Vertical profiles of time-averaged, horizontally-integrated eddy energy fluxes in (MW m^{-1}) across major straits. Fluxes on the Indian Ocean and the Pacific Ocean side are shown by solid lines and dashed lines, respectively.

The propagating planetary (Rossby and Kelvin) waves and ocean eddies are generated by winds or instabilities of ocean currents and hence are surface intensified. Consistently, **the vertical distribution of the energy fluxes integrated across major straits (Fig. 3) shows an enhancement in the upper 100-200 m of the ocean in all of the straits.**

Reference

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