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Estimates of the subinertial air-sea flux of mechanical energy from concurrent drifter and satellite observations

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1. Introduction:

- The air-sea flux of mechanical energy can be computed via the dot product between the wind stress and surface current velocity vectors, $P = \mathbf{u} \cdot \boldsymbol{\tau}$.
- Assuming that $\mathbf{u}$ can be decomposed into geostrophic and Ekman components, P can be expanded as $P = P_g + P_a$. Here, P_g is the main energy source for the general ocean circulation, while P_a powers vertical mixing within the Ekman layer.
- Recent numerical studies showed that mesoscale air-sea coupling mechanisms, arising from the τ dependence on $\mathbf{u}$ and on SST-driven anomalies in wind speed (w_c) can influence the time-dependent components of P_g, with strong feedbacks to the evolution and decay of mesoscale ocean variability [e.g. 1, 2].
- While there is a building consensus that current-driven coupling both reduces P_g and exert a net damping effect on the oceanic eddy field, model-based results diverge on the role of the SST-driven coupling;
- Observational evidence for both effects is scarce, potentially due to deficiencies of altimeter-derived geostrophic velocity products (e.g. AVISO) for resolving the ocean mesoscales.
- To circumvent this limitation, this study uses $\mathbf{u}$ observations from ocean drifters, combined with a suite of satellite products, to estimate P, P_g, and P_e, and to assess the relative importance of the current and SST-driven coupling to the energy fluxes.

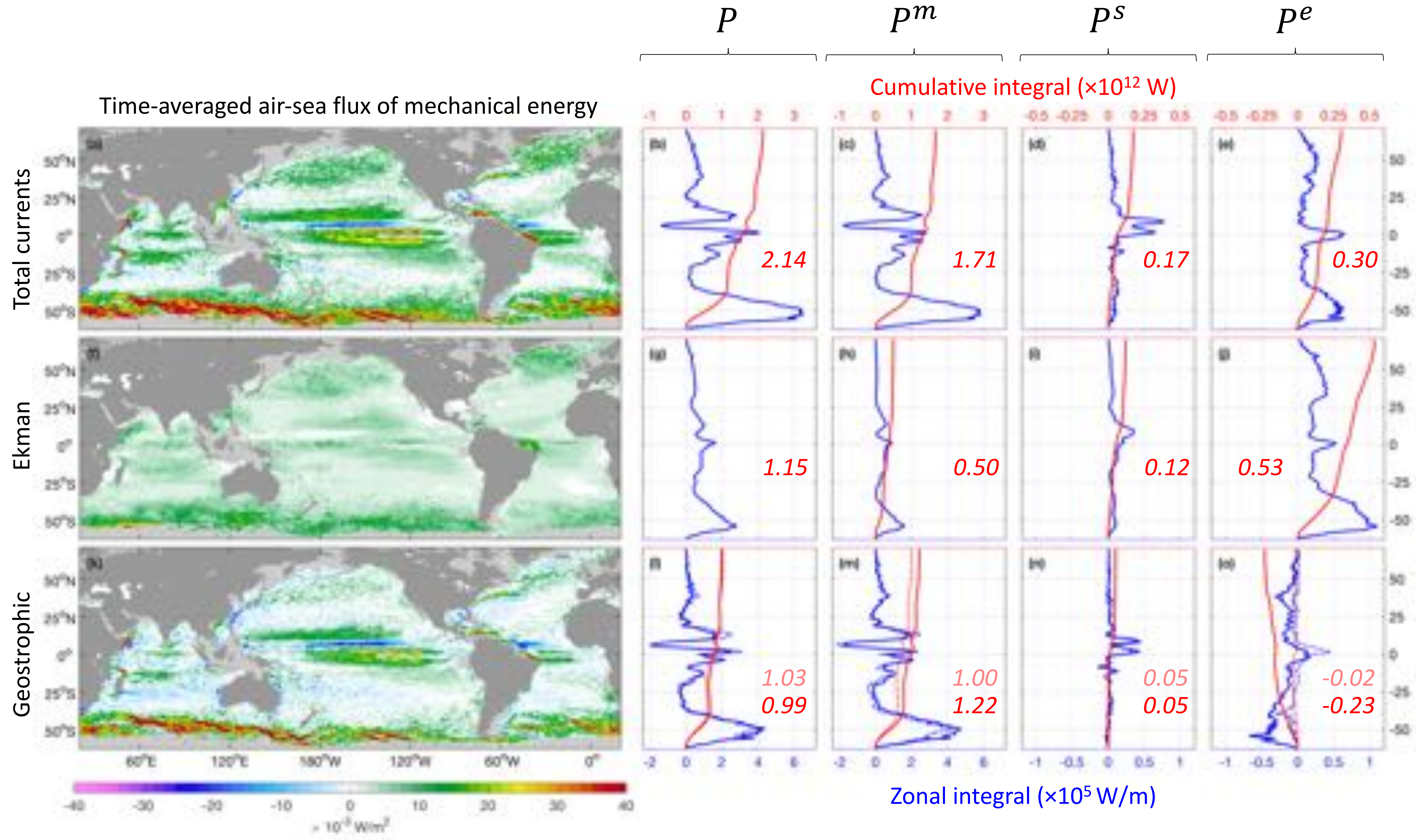
2. Methods:

- Velocity measurements ($\mathbf{u}$) are from NOAA's Global Drifter Program (GDP) drifters.
- Equivalent-neutral wind velocities at 10-m height ($\mathbf{w}$) are from orbital scatterometers, used to compute $\boldsymbol{\tau}$ via bulk formulations. SST is from the NOAA OISST. Both satellite products obtained at a 0.25°×0.25°×1-day resolution, and from Aug. 1999 to Dec. 2016.
- Drifter-based estimates of $\mathbf{u}_g$ are obtained by subtracting an empirical Ekman model ($\mathbf{u}_e$) from $\mathbf{u}$.
- Satellite estimates of tau are interpolated to drifter locations. The collocated $\mathbf{u}$ and $\boldsymbol{\tau}$ estimates are then decomposed into mean, seasonal and eddy components over a 0.25°×0.25° global grid [c.f. 3]. This allows expanding P as:

$$P = P^m + P^s + P^e + P^{ct}$$

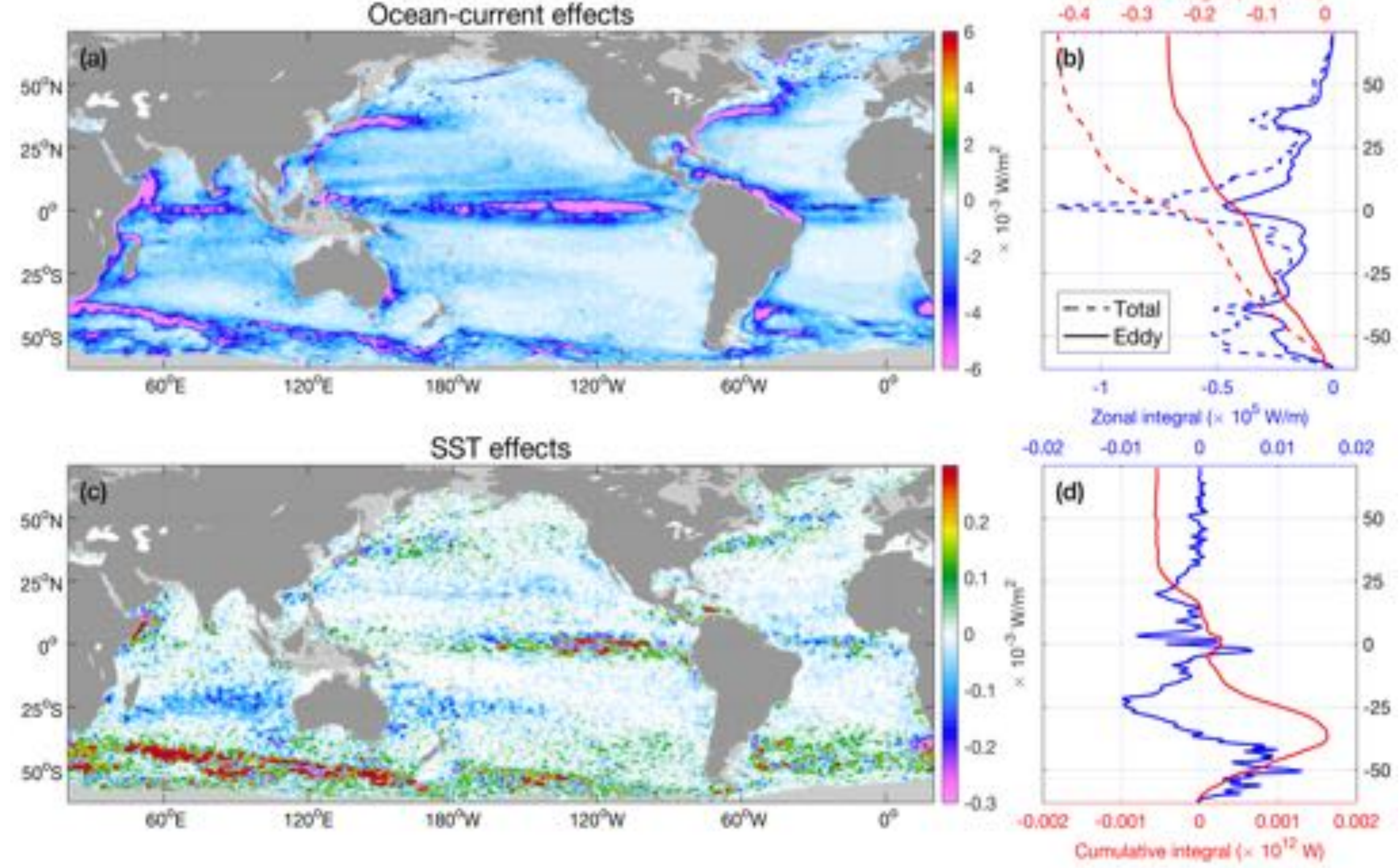
- where P^m holds the contribution of the time-mean components of $\mathbf{u}$ and $\boldsymbol{\tau}$, P^s (P^e) is the covariance between between their seasonal (eddy) fluctuations, and P^{ct} holds the sum of the resulting cross-covariance terms.
- The influence of air-sea coupling mechanisms is estimated by by recomputing the energy fluxes using wind stress data with either the SST and ocean-current dependencies removed.
  - *The current effect is removed by first adding the drifter-based* $\mathbf{u}$ *from the scatterometer* $\mathbf{w}$ *when computing* $\boldsymbol{\tau}$.
  - *The SST-driven wind response* ($\mathbf{w}_c$) *is computed using transfer functions for the spectral linear SST/w relationship [c.f. 4]. The SST effect is removed by first subtracting* $\mathbf{w}_c$ *from* $\mathbf{w}$ *prior to computing* $\boldsymbol{\tau}$.

3. Time-averaged air-sea exchange of mechanical energy:

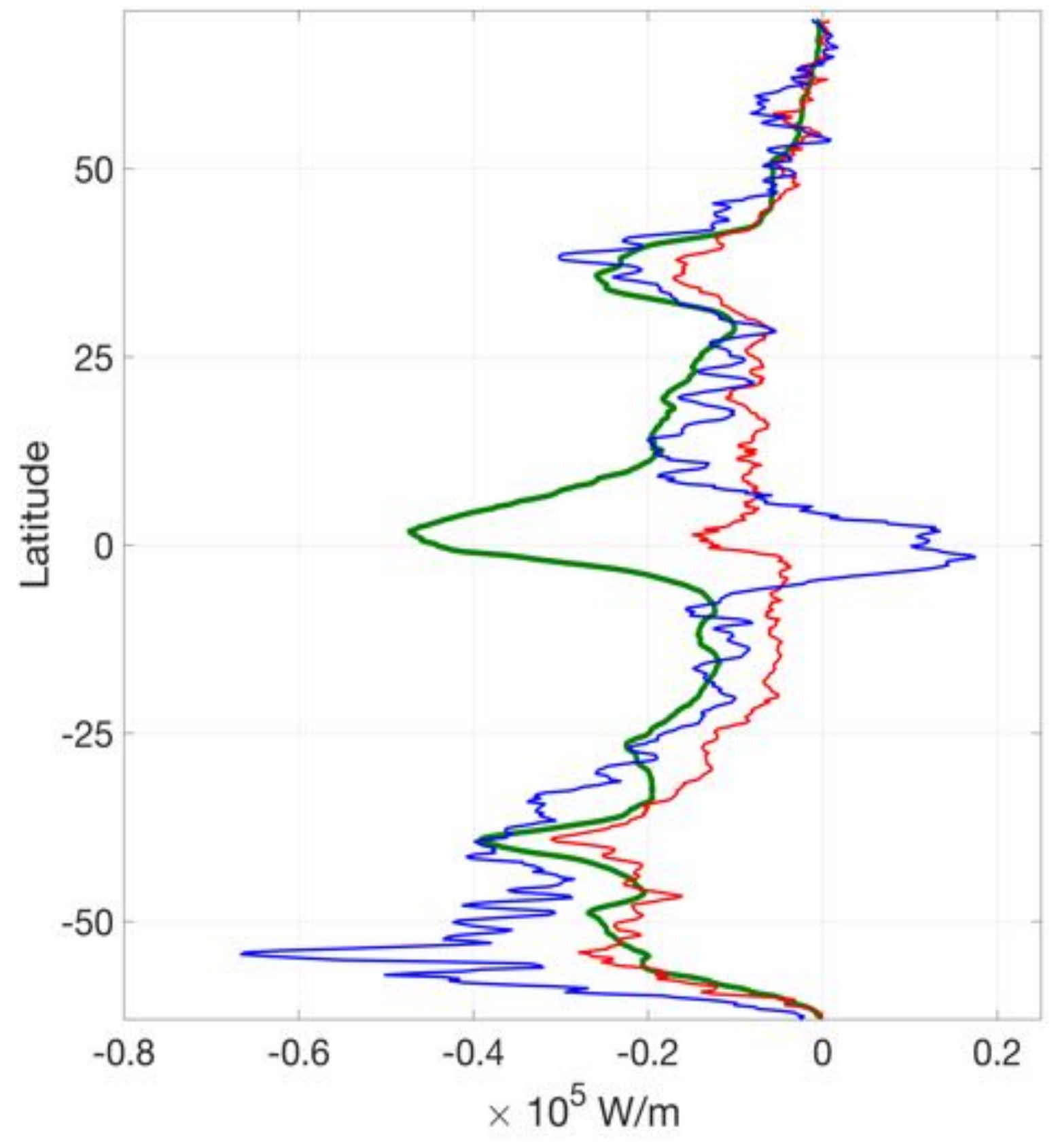


- **Figure 1:** Time-averaged air-sea fluxes of mechanical energy computed using drifter and satellite observations, associated with the full circulation field and its Ekman and geostrophic components. Positive (negative) values refer to air-sea fluxes of mechanical energy into (out) of the ocean.
- **Blue lines** are zonal integrals of the power exchange. **Red lines** are cumulative integrals starting at 60°S, with the overlaid numbers highlighting the globally-integrated power, in terawatts (1 TW = 10^{12} W).
- **Geostrophic component:** dashed lines and pink numbers are results computed using altimeter-derived geostrophic velocities (AVISO).
  - *Both altimeter and drifter-based estimates result in a globally-integrated P of ~1 TW*
  - *However, drifter results show an excess of 0.22 TW in* P^m*, that is fully compensated by negative energy fluxes in* P^e.

4. Influence of the current and SST-driven air-sea coupling:



- **Figure 2:** Impact of the wind stress (τ) dependency on ocean currents (a, b) and on SST (c, d) to the air-sea exchange of mechanical energy, computed using drifter and satellite data.
- **Current effects:** definite-negative variation to P, that integrates to −0.43 TW globally. Virtually all this variation takes place at the geostrophic component (P_g), with about 58% (−0.25 TW) via its eddy covariance term (P_g^e).
- **SST effects:** well-defined patterns of negative and positive values, attributed to the interaction between the dipolar SST anomaly associated with coherent eddies with winds blowing across the background SST fronts [c.f. 5]. However, their magnitudes are about 30 times smaller than of those induced by the effect of ocean currents.



- **Figure 3:** Zonal integrals of the predicted variation in P induced by the influence of oceanic eddy fluctuations (**green line**), and of drifter-based estimates of P_g^e computed using the original $\boldsymbol{\tau}$ measurements (**blue**) and $\boldsymbol{\tau}$ estimates preliminarily low-pass filtered at a 7° × 7° half-power cutoff scale to isolate the ocean mesoscales (**red**).

- Discrepancies between the **green** and **blue** lines are observed (a) near the equator, thought to reflect the oceanic response to atmospheric forcing at temporal scales varying from semiannual to interannual; and (b) in the Southern Ocean (SO), potentially reflecting self-covariances introduced artificially due to the subtraction of empirical models for the drifter slip and Ekman velocities from $\mathbf{u}$.
- Since the mechanisms giving rise to these discrepancies should scale as a function of the large scale winds, the **red line** was computed to isolate the ocean mesoscales. Indeed, it reduces the differences relative to the theoretical predictions (**green**) both near the equator and in the SO.

5. Conclusions:

- The time-averaged P inferred from drifter and satellite observations is of 2.14 TW, partitioned as 1.15 TW in P_a, and 0.99 TW in P_g.
- Wind power input to the Ekman circulation (P_a).
  - *Time-mean and time-dependent components contribute about equally to the global integral.*
  - *Due to the vertical shear of Ekman currents, and since GDP drifters measure the flow at 15-m depth rather than at the surface, results are interpreted as lower-bound estimates.*
- Wind power input to the geostrophic ocean circulation (P_g).
  - *Globally-integrated power of about 1 TW is similar to altimeter-based estimates.*
  - *In contrast with the altimeter estimates, drifter-based results indicates that, while the wind supplies 1.22 TW to the ocean circulation via the time-mean and seasonal components of* P_g (P_g^m *and* P_g^s*, respectively), about 0.23 TW is lost back to the atmosphere via the eddy component* (P_g^e).
- Negative energy fluxes in P_g^e can be largely explained by the influence of the current-driven air-sea coupling mechanism.
- The influence of SST-driven coupling mechanism is detectable and produces well-defined large-scale patterns in the energy fluxes, however with magnitudes about 30 times smaller than those driven by the ocean-current effect.
- These results provide observational evidence that the current-driven coupling gives rise to an non-negligible sink of kinetic energy for the oceanic mesoscale variability, and may serve as a basis to evaluate the competing conclusions of recent numerical experiments on the impact of the SST-driven coupling mechanism to ocean energetics.

6. References:

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