Recent progress in quantifying the rate of mechanical energy forcing in the World Ocean

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Mechanical energy flux to surface geostrophic flow

Wind stress working on geostrophic flow builds gravitational potential energy:

$$\text{WPI} = \int \vec{\tau_s} \cdot \vec{u}_g \; dA \tag{1}$$

$$= \int w_E \, b \, dA \tag{2}$$

Available to drive mesoscale eddies via baroclinic instability.

Previously got right answer for wrong reasons

- Previous estimates *all* used NCEP wind stress (*Wunsch*, 1998; *Scott*, 1999; *Huang et al.*, 2006; *von Storch et al.*, 2007), and found 0.9 to 1.0 TW.
- Using latest available multi-satellite altimeter data, and QuikSCAT winds gives WPI $= 0.80 \pm 0.04$ TW (*Scott and Xu*, 2009).
- But NCEP winds are too weak!
- Error associated with currents are dominated by the geoid gradient errors, but these contribute only about 6% uncertainty (*Scott*, 1999).

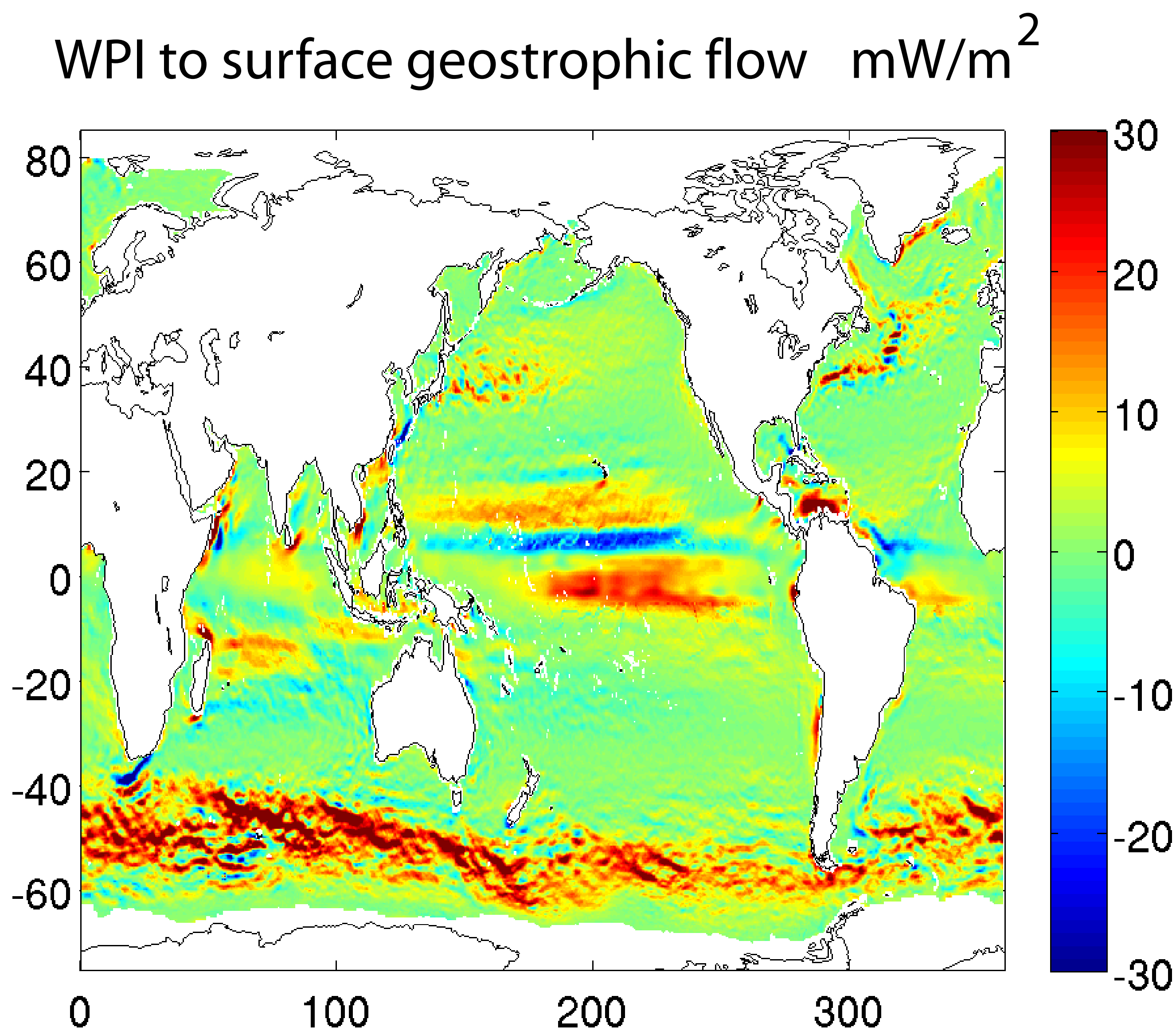


Figure 1: QuikSCAT winds and multisatellite AVISO altimetry

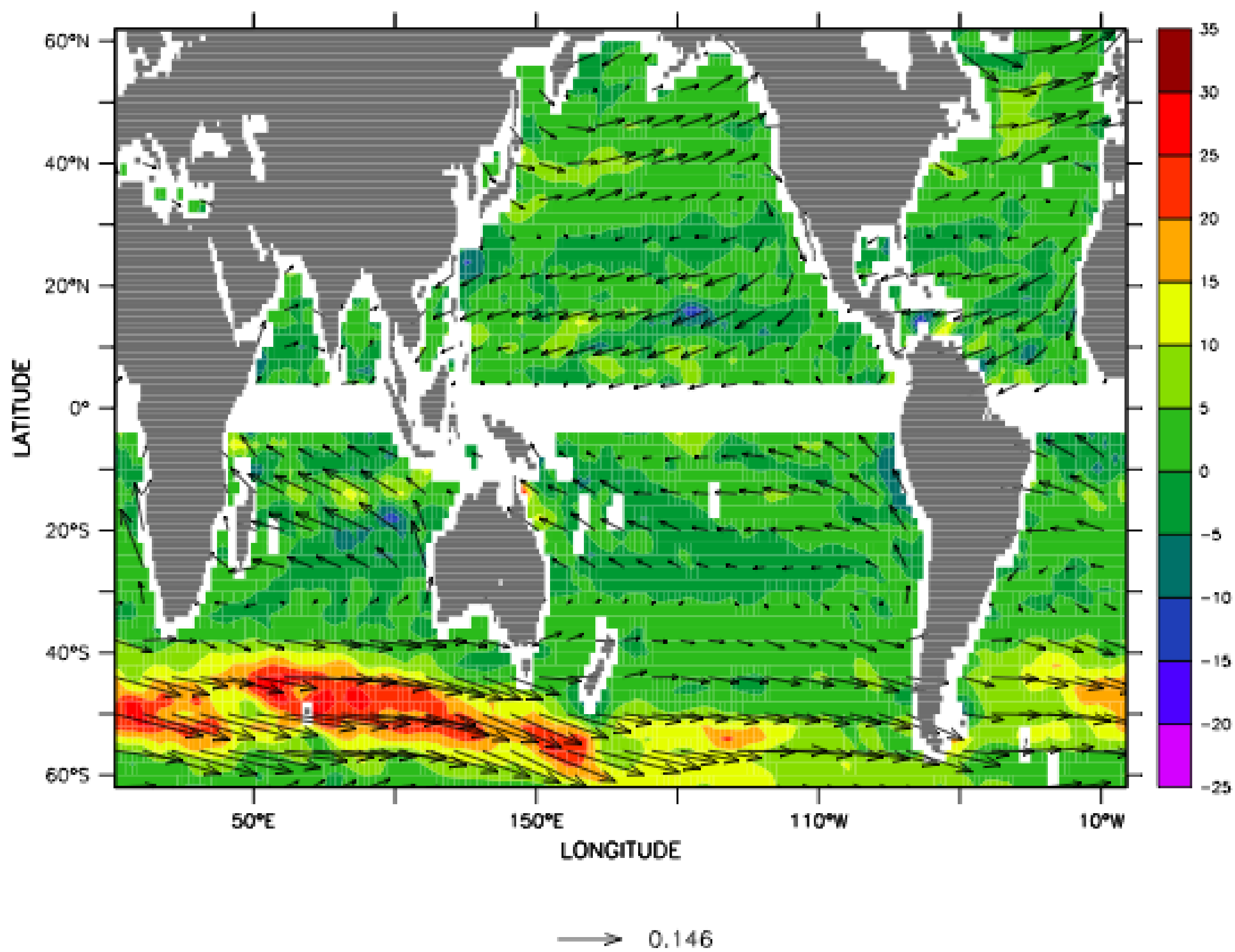


Figure 2: Time mean WPI in mW/m^2: NCEP winds and TP altimetry relative to JGM-3 Geoid (*Scott*, 1999)

Surface boundary condition for momentum equations: Momentum flux

Wind shear stress, $\vec{\tau}$ commonly parameterized with quadratic drag law or *bulk aerodynamic formula*,

$$\vec{\tau} = \rho_a \, c_d \, |\vec{U}_a - \vec{u}_s|(\vec{U}_a - \vec{u}_s), \tag{3}$$

where $\rho_a \approx 1.2$ kg m^{-3} is the air density, $\vec{U}_a$ is the surface wind velocity at some reference height (typically 10 m above sea level), $\vec{u}_s$ is the surface current, and $c_d = O(10^{-3})$ is the dimensionless drag coefficient. c_d itself is a weak function of the surface wind speed and static stability of the boundary layer.

Can we ignore the surface current?

Ocean moves much more slowly than atmosphere, $\vec{U}_a \gg \vec{u}_s$.

To a very good approximation,

$$\vec{\tau} \approx \vec{\tau_b} = \rho_a \; c_d \; |\vec{U}_a| \vec{U}_a, \tag{4}$$

What's wrong with this!?

Energy flux is messed up!

Mechanical energy flux

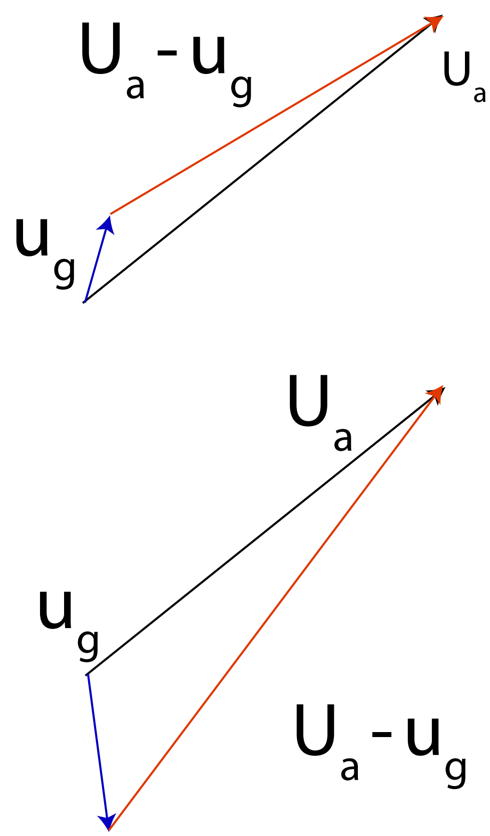
The rate of working on geostrophic flow

$$
\begin{aligned}
\dot{W} &= \vec{\tau} \cdot \vec{u}_g & (5)\\
&= \rho_a \; c_d \; |\vec{U}_a - \vec{u}_s|(\vec{U}_a - \vec{u}_s) \cdot \vec{u}_g & (6)\\
&= \rho_a \; c_d \; |\vec{U}_a - \vec{u}_E - \vec{u}_g|(\vec{U}_a - \vec{u}_E - \vec{u}_g) \cdot \vec{u}_g & (7)\\
\dot{W}_b &= \vec{\tau}_b \cdot \vec{u}_g & (8)\\
&= \rho_a \; c_d \; |\vec{U}_a|\vec{U}_a \cdot \vec{u}_g & (9)
\end{aligned}
$$

Systematic bias ("b" is for biased!)

$$\dot{W}_b > \dot{W}$$

Ignoring surface geostrophic current $\vec{u}_g$: Systematic bias in energy flux



Positive wind power input is *increased*

Negative wind power input is *reduced*

Is it significant in the real world?

- Using observational data, we estimate about a 32% effect (*Xu and Scott*, 2008; *Scott and Xu*, 2009).
- Consistent with models and theory (*Duhaut and Straub*, 2006; *Dawe and Thompson*, 2006; *Zhai and Greatbatch*, 2007).
- Implications for how to best force an (free running, not data assimilation) ocean model (*Xu and Scott*, 2008).
- Not just important for energetics, also affects Southern Ocean transport (*Hutchinson et al.*, 2009).

References

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In case you asked: Mechanical energy flux – decomposition into parts

The rate of working on the ocean at the air-sea interface is derived from Newton's laws of motion,

$$\dot{W} = \vec{\tau} \cdot \vec{u}_s \tag{10}$$

$$= \vec{\tau} \cdot (\vec{u}_g + \vec{u}_e + \vec{u}_a) \tag{11}$$

Work on geostrophic flow:

$$WPI = \vec{\tau} \cdot \vec{u}_g \tag{12}$$