

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

Robert B. Scott

The University of Texas at Austin

and

National Oceanography Centre Southampton

Mechanical energy flux to surface geostrophic flow

Wind stress working on geostrophic flow builds gravitational potential energy:

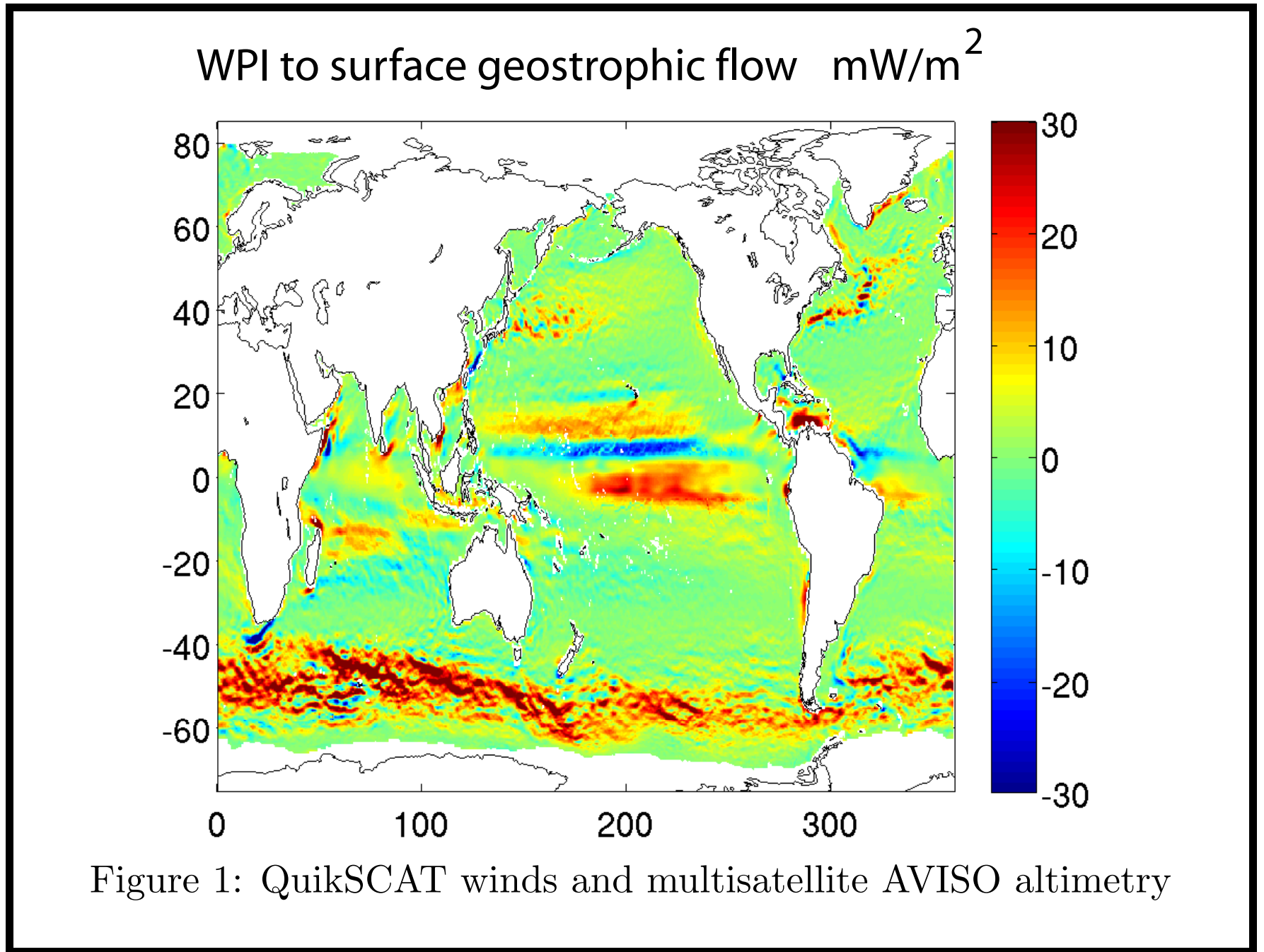
$$\text{WPI} = \int \vec{\tau}_s \cdot \vec{u}_g dA \quad (1)$$

$$= \int w_E b dA \quad (2)$$

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).



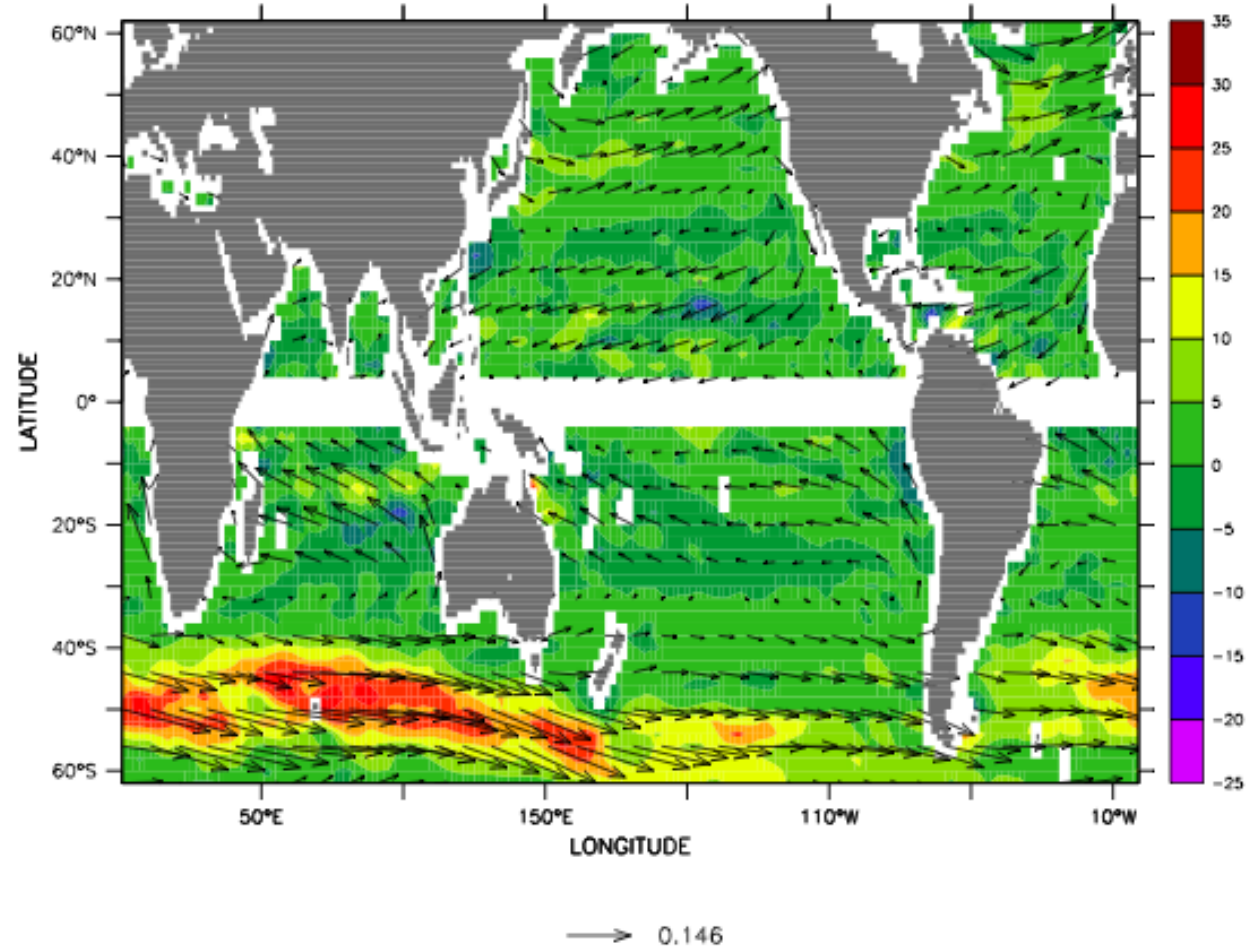


Figure 2: Time mean WPI in mW/m^2 : NCEP winds and TP altimetry relative to JGM-3 Geoid (*Scott, 1999*)

Surface boundary condition for momentum equations: Momentum flux

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

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

where $\rho_a \approx 1.2 \text{ kg m}^{-3}$ 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,

$$\vec{\tau} \approx \vec{\tau}_b = \rho_a c_d |\vec{U}_a| \vec{U}_a, \quad (4)$$

What's wrong with this!?

Energy flux is messed up!

Mechanical energy flux

The rate of working on geostrophic flow

$$\dot{W} = \vec{\tau} \cdot \vec{u}_g \quad (5)$$

$$= \rho_a c_d |\vec{U}_a - \vec{u}_s| (\vec{U}_a - \vec{u}_s) \cdot \vec{u}_g \quad (6)$$

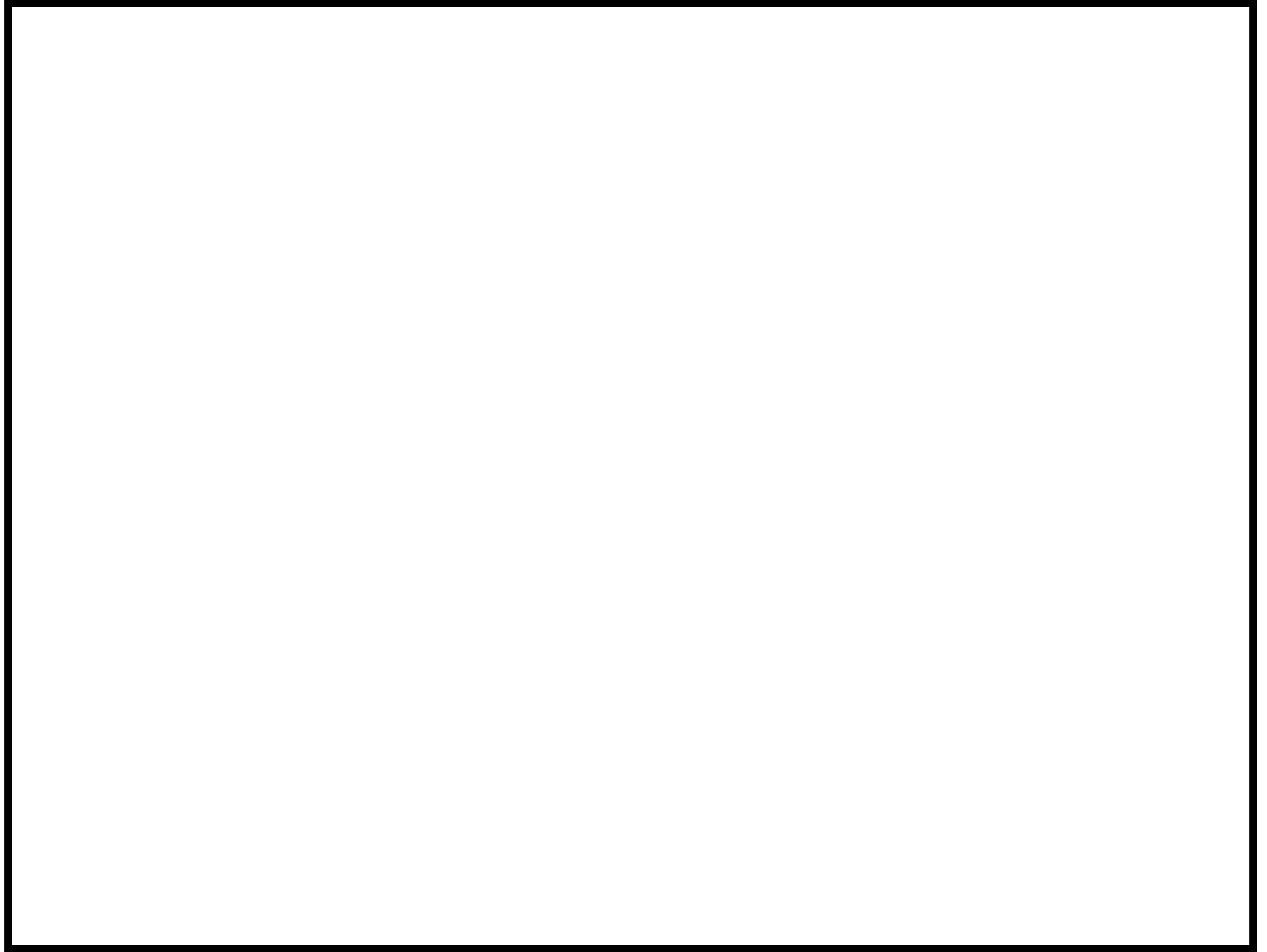
$$= \rho_a c_d |\vec{U}_a - \vec{u}_E - \vec{u}_g| (\vec{U}_a - \vec{u}_E - \vec{u}_g) \cdot \vec{u}_g \quad (7)$$

$$\dot{W}_b = \vec{\tau}_b \cdot \vec{u}_g \quad (8)$$

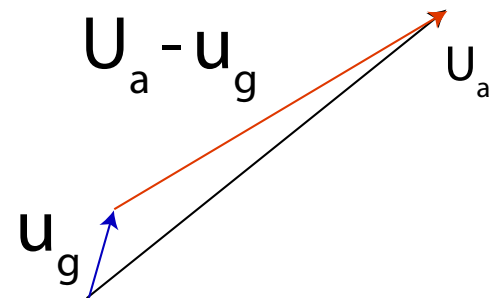
$$= \rho_a c_d |\vec{U}_a| \vec{U}_a \cdot \vec{u}_g \quad (9)$$

Systematic bias (“b” is for biased!)

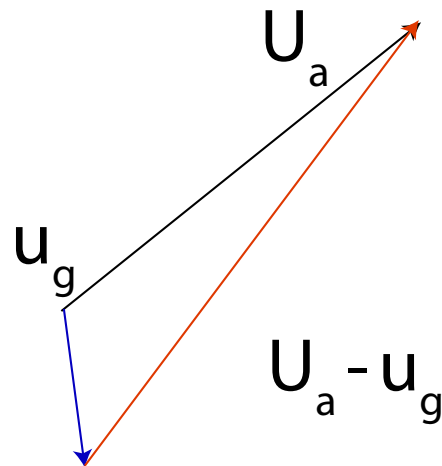
$$\dot{W}_b > \dot{W}$$



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,

$$\dot{W} = \vec{\tau} \cdot \vec{u}_s \quad (10)$$

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

Work on geostrophic flow:

$$WPI = \vec{\tau} \cdot \vec{u}_g \quad (12)$$