ROMS Turbulence Parameter Comparisons with Field Data

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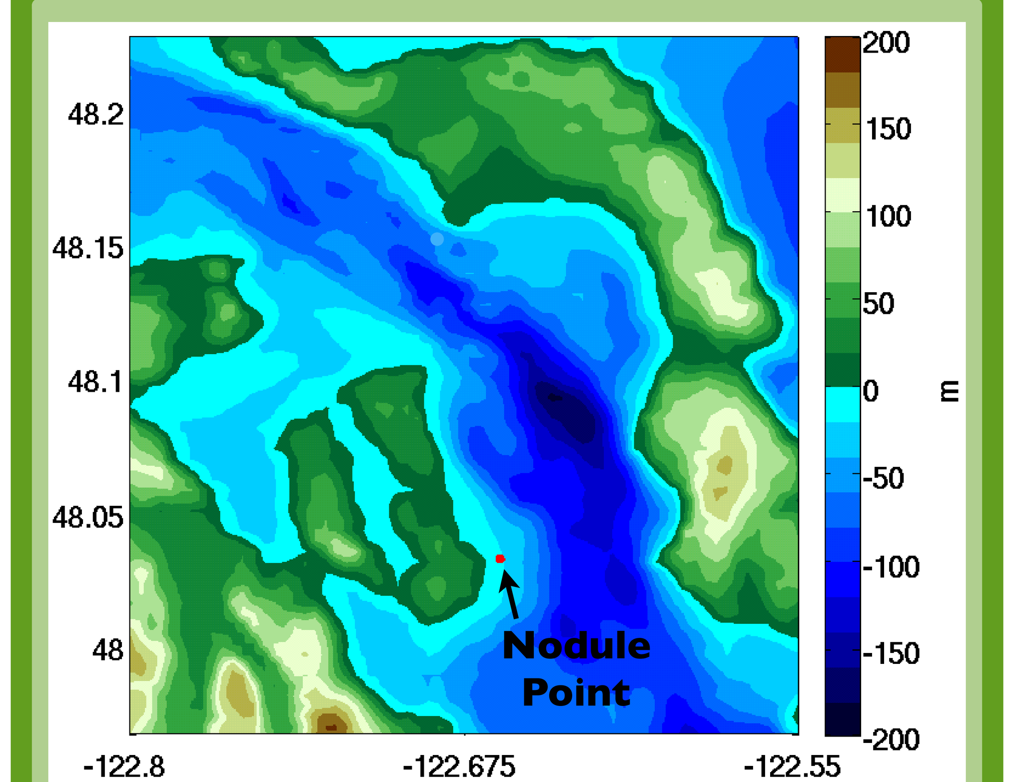
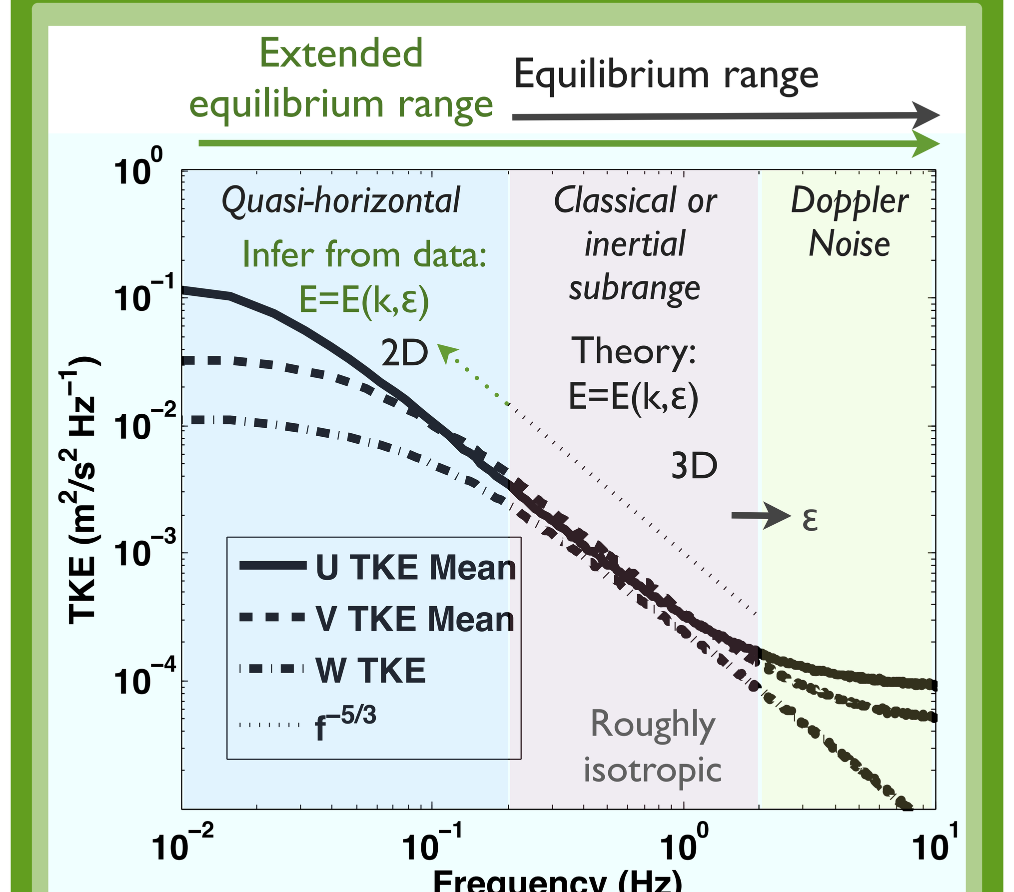
Motivation

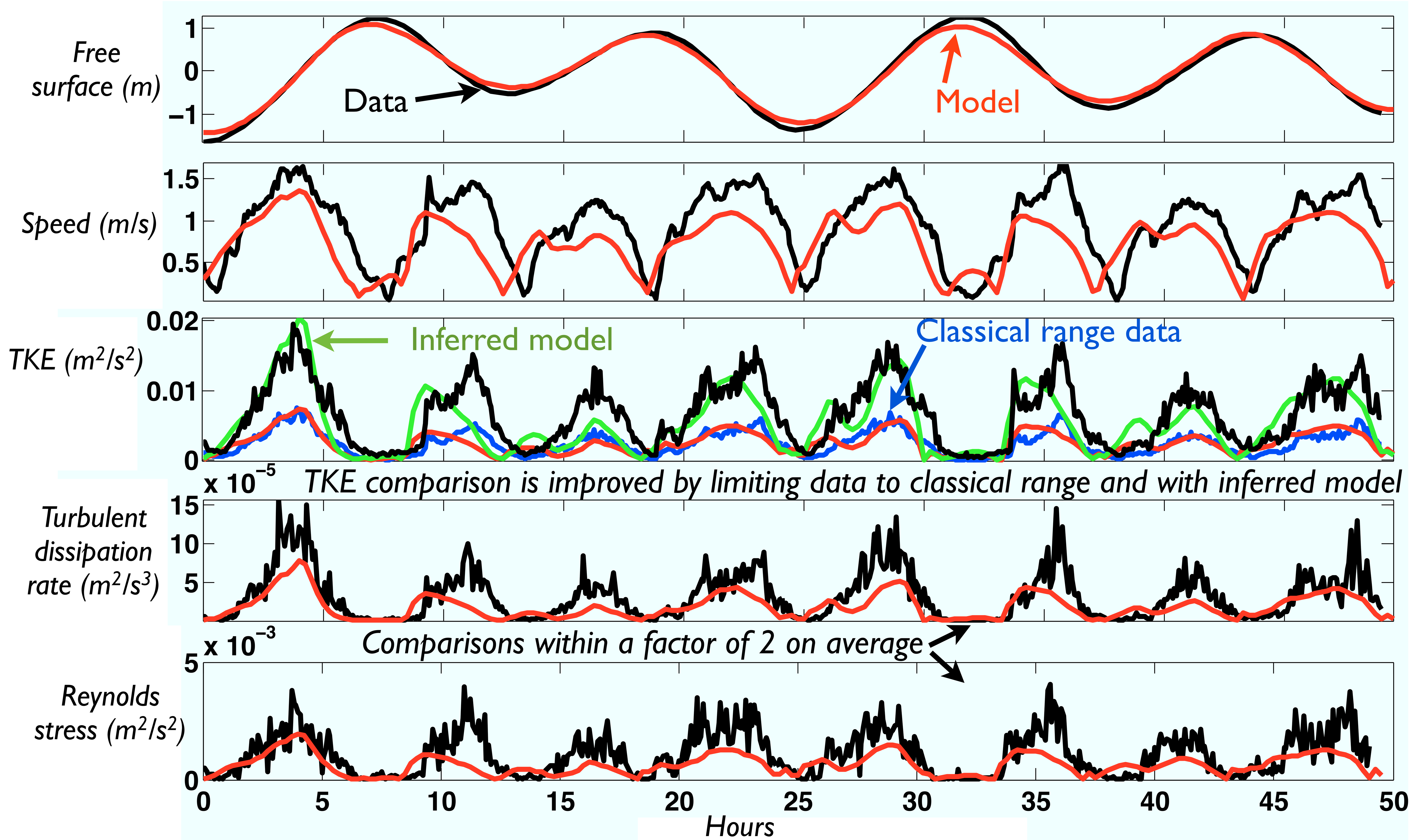
Turbulence closure schemes are commonly used in oceanographic circulation models to represent processes at scales smaller than the grid resolution, but output parameters have not been extensively compared with field data to see how well they perform.

Admiralty Inlet



Data TKE spectra follows $f^{-5/3}$ in subinertial range and beyond





Turbulence theory

Kolmogorov's theory describes spectral energy transfer in 3D turbulent flows, wherein energy is input into a flow at large scales and transferred to smaller scales. At and above some critical wavenumber, the spectral energy density in the system is approximately a function of only the wavenumber, κ, the turbulent dissipation rate, and the viscosity. This region is called the equilibrium range and can be subdivided into two regions: the inertial subrange and the viscous subrange. In the inertial subrange, the energy can be interpreted as eddies which degenerate into eddies of smaller scale (or larger wavenumber), cascading the energy to smaller and smaller scales at the turbulent dissipation rate, ε, without the influences of viscosity. The spectral form of the inertial subrange is

$$E(\kappa) = \alpha\varepsilon^{2/3}\kappa^{-5/3}$$

Using Taylor's frozen field approximation, $L = u/f$, which assumes that the turbulence is advected without distortion over L at the mean speed of the horizontal motion, u, in the major principal axis direction, and $\kappa = 2\pi/L$, we have:

$$E = \frac{\alpha}{(2\pi)^{5/3}}\varepsilon^{2/3}u^{5/3}f^{-5/3}. \quad (1)$$

Classical TKE matches well

When the field data TKE is limited in frequency range to the classical turbulence range, the data-model match is much improved, as shown in blue in Figure 1.

Analysis

The TKE data spectra indicate that $f^{-5/3}$ is a good approximation to the horizontal TKE to frequencies that are lower than the inertial subrange (Figure 1), suggesting an extension of the relationship to lower frequencies. Integrating over the full range of data frequencies as are included in the Nodule Point spectral data in order to find an expression for this inferred TKE, k_{it} gives

$$k_{it} = \int_{\kappa_1}^{\infty} \alpha\varepsilon^{2/3}\kappa^{-5/3}d\kappa = \int_{f_1}^{\infty} \alpha\varepsilon^{2/3}\left(\frac{2\pi f}{u}\right)^{-5/3}\frac{2\pi}{u}df = \frac{3}{2}\frac{\alpha}{(2\pi)^{2/3}}(\varepsilon u)^{2/3}f_1^{-2/3},$$

where $f_1 = 1/T_1 = 1/128$ s is the lowest frequency included in the data analysis averaging time period.

k_{it} gives an alternative expression for the TKE, calculated as a function of turbulent dissipation rate and mean local horizontal speed (both of which compare reasonably between the model and data).

This calculation is shown in Figure 1 in green.

Conclusions

- Model turbulent dissipation rate and Reynolds stress compare reasonably well with field data
- Model TKE compares well with data TKE from the classical frequency range
- Full range TKE data is matched well using an extrapolation of the inertial sub-range, relying on the reasonable comparisons of ε and the mean local speed
- This realistic behavior and analysis implies that ROMS simulations can be used to understand spatial and temporal variations in turbulence

Field Data

- Described in Thomson et al. (2012)
- ADV at 4.7 meters above seabed
- Sampling rate of 32 Hz, then split into five minute turbulent averaging windows
- Horizontal currents rotated onto principal axes for each window
- Turbulent kinetic energy is considered from both horizontal components

Pertinent Variables

- k turbulent kinetic energy (TKE)
- ε turbulent dissipation rate
- E TKE spectral density
- κ horizontal wave number
- $\alpha = 0.5$ experimental constant
- L length
- f frequency, T period

Simulation

- ROMS (Shchepetkin and McWilliams, 2005)
- Described in Thyng (2012)
- 65 meter horizontal resolution and 20 evenly-spaced vertical layers
- k-ε turbulence closure scheme (Warner et al., 2005)
- Nested inside a larger regional model (Sutherland et al., 2011)
- Model performs well in many metrics but M_2 tide is about 25% low on average

References

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