Time Dependent Wind-Driven Surface Currents

Kathleen Dohan
Earth and Space Research
Seattle, WA

collaboration with

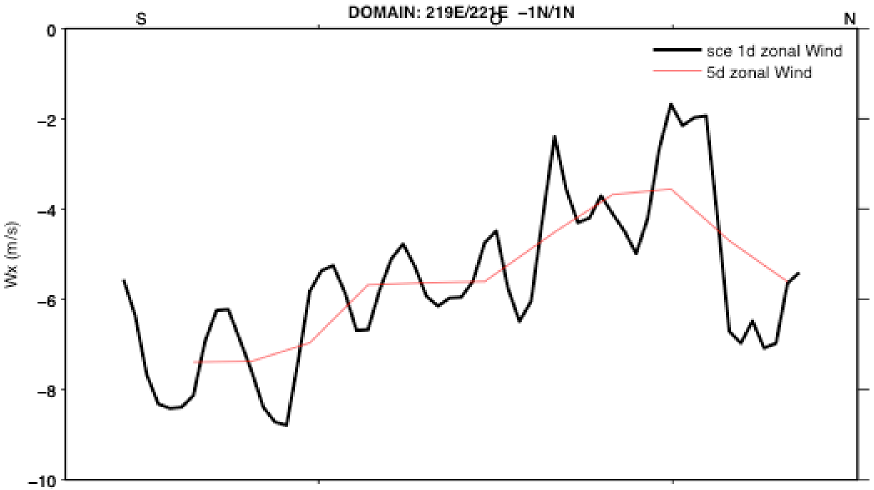
Jeffrey J. Early
NorthWest Research Associates
Seattle, WA

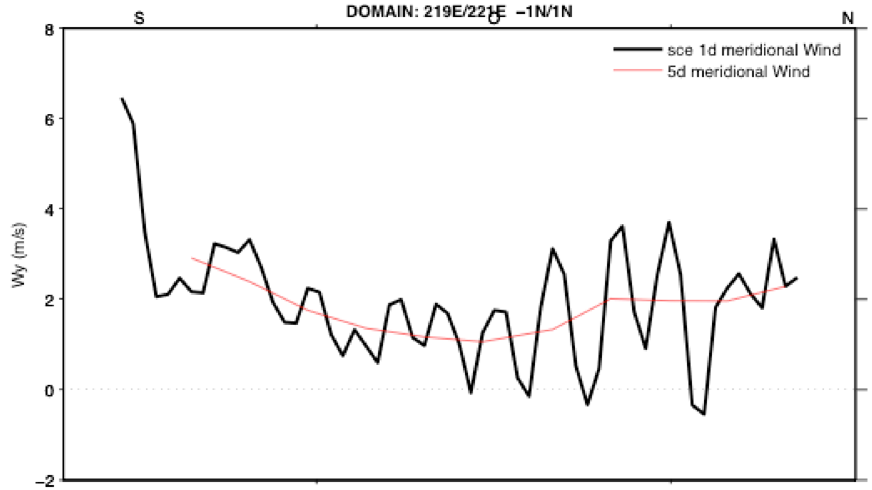
OSCAR Surface currents from satellite fields

- Ocean Surface Currents Analyses-Realtime processing system (OSCAR) is a satellite-derived global surface current product provided in near-real time based on geostrophy, Ekman dynamics, and thermal wind, assuming quasi-steady dynamics
- Hosted at the PO DAAC, http://podaac.jpl.nasa.gov/
- Surface currents are calculated from SSH, ocean vector winds, SST (note: all are gridded fields)
    - **SSH**: geostrophic term is computed from the gradient of ocean surface topography fields (merged gridded AVISO/CLS: Jason-1,-2, T/P, Envisat, GFO, ERS-1,-2)
    - **WIND**: wind-driven velocity is computed from an Ekman/Stommel formulation with variable eddy viscosity using QuikSCAT vector winds (FSU/COAPS) and NCEP winds, replaced by ERA-I winds (to be released very soon) – currently investigating CCMP winds
    - **SST**: thermal wind term using Reynolds OI SST data (looking at higher resolution products to capture fronts).

OSCAR wind component

- Wind-driven currents are consistently underestimated in OSCAR
- OSCAR uses 10-day temporally filtered fields, for all input fields
- Large-scale motions are captured (e.g. convergence to center of gyres, similar statistics to drifting buoys landing points)
- At a minimum, will use unfiltered winds





Time-dependent wind model

- OSCAR quasi-steady model: steady Ekman with constant in the vertical eddy viscosity

$$if\mathbf{u}(t,z) = -\frac{1}{\rho}\frac{\partial \tau(t,z)}{\partial z} \qquad \tau = -K\frac{\partial \mathbf{u}}{\partial z}$$

- Time-dependence: unsteady Ekman

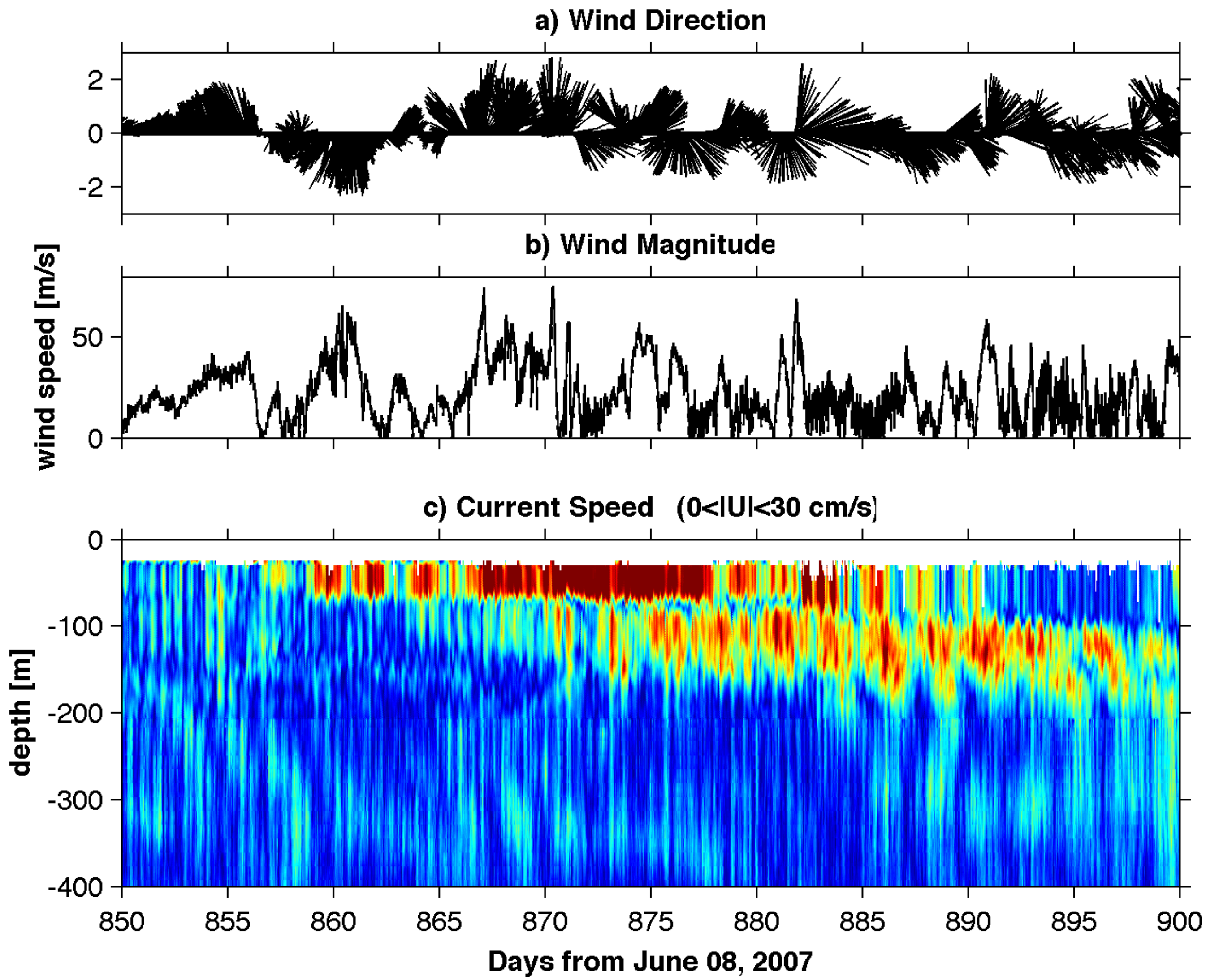
$$\frac{\partial \mathbf{u}(t,z)}{\partial t} + if\mathbf{u}(t,z) = -\frac{1}{\rho}\frac{\partial \tau(t,z)}{\partial z}$$

$$\frac{d\mathbf{U}(t)}{dt} + if\mathbf{U}(t) = \frac{\tau(t)}{\rho H} - r\mathbf{U}(t)$$

- Damped slab model: assume properties are vertically constant in the mixed layer, depth H. Surface stress is wind stress, turbulence is parameterized by Rayleigh damping. Integrate equation over z=0,-H. ODE for U(t).

Ocean Station Papa test case, 50N 145W

- Test case: Ocean Station Papa mooring
- Slab behavior



Time-dependent wind model

- Unsteady Ekman

$$\frac{\partial \mathbf{u}(t,z)}{\partial t} + if\mathbf{u}(t,z) = -\frac{1}{\rho}\frac{\partial \tau(t,z)}{\partial z}$$

- Could numerically solve for U, given τ(t), or could view in frequency space. Consider the system as a casual linear system, input τ(t), output u(t,z), where the velocity is the convolution of the wind stress with the depth-dependent impulse response function for the system, h(t',z):

$$\mathbf{u}(t,z) = h(t',z) * \tau(t)$$

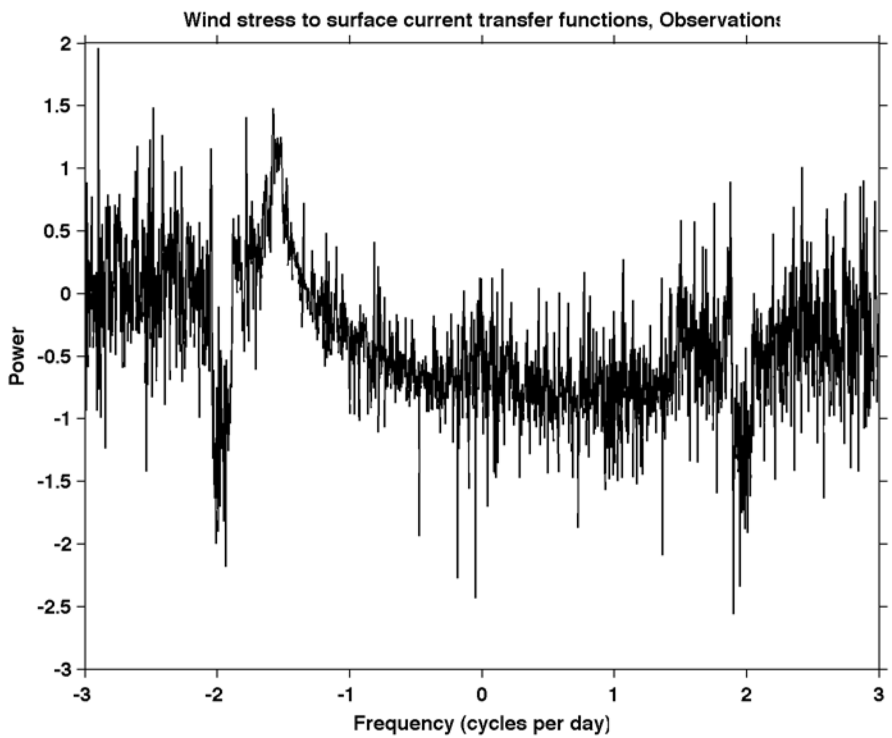
- Or, in Fourier space

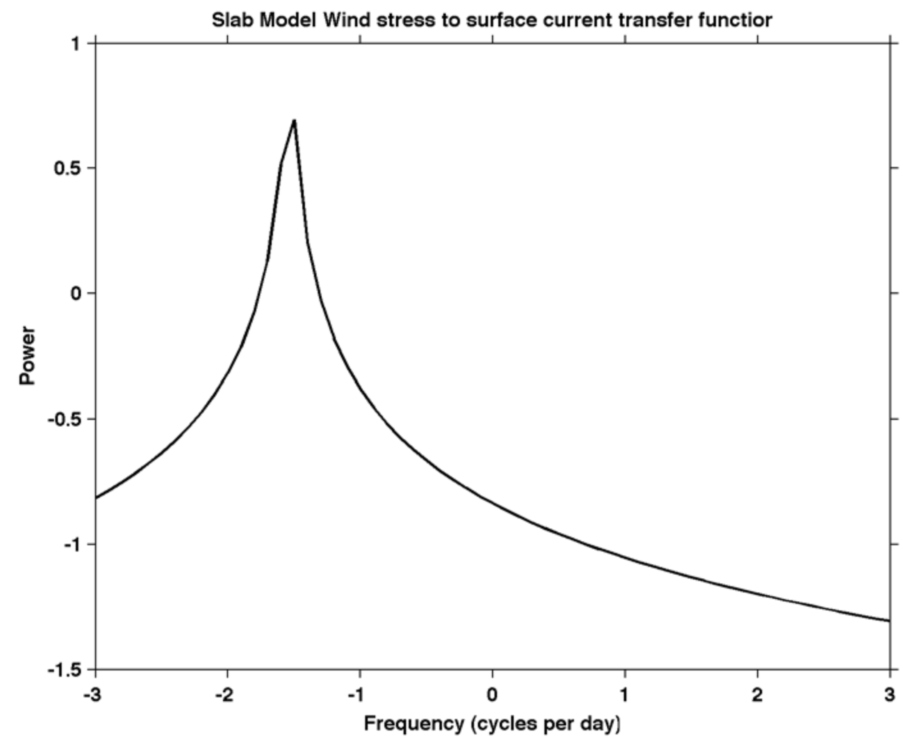
$$\hat{\mathbf{U}}(\nu,z) = \hat{\mathbf{H}}(\nu,z)\hat{\mathbf{T}}(\nu)$$

- Damped slab, simple solution for H(ν) since there is no z dependence. Fourier transform the ODE and solve for H.

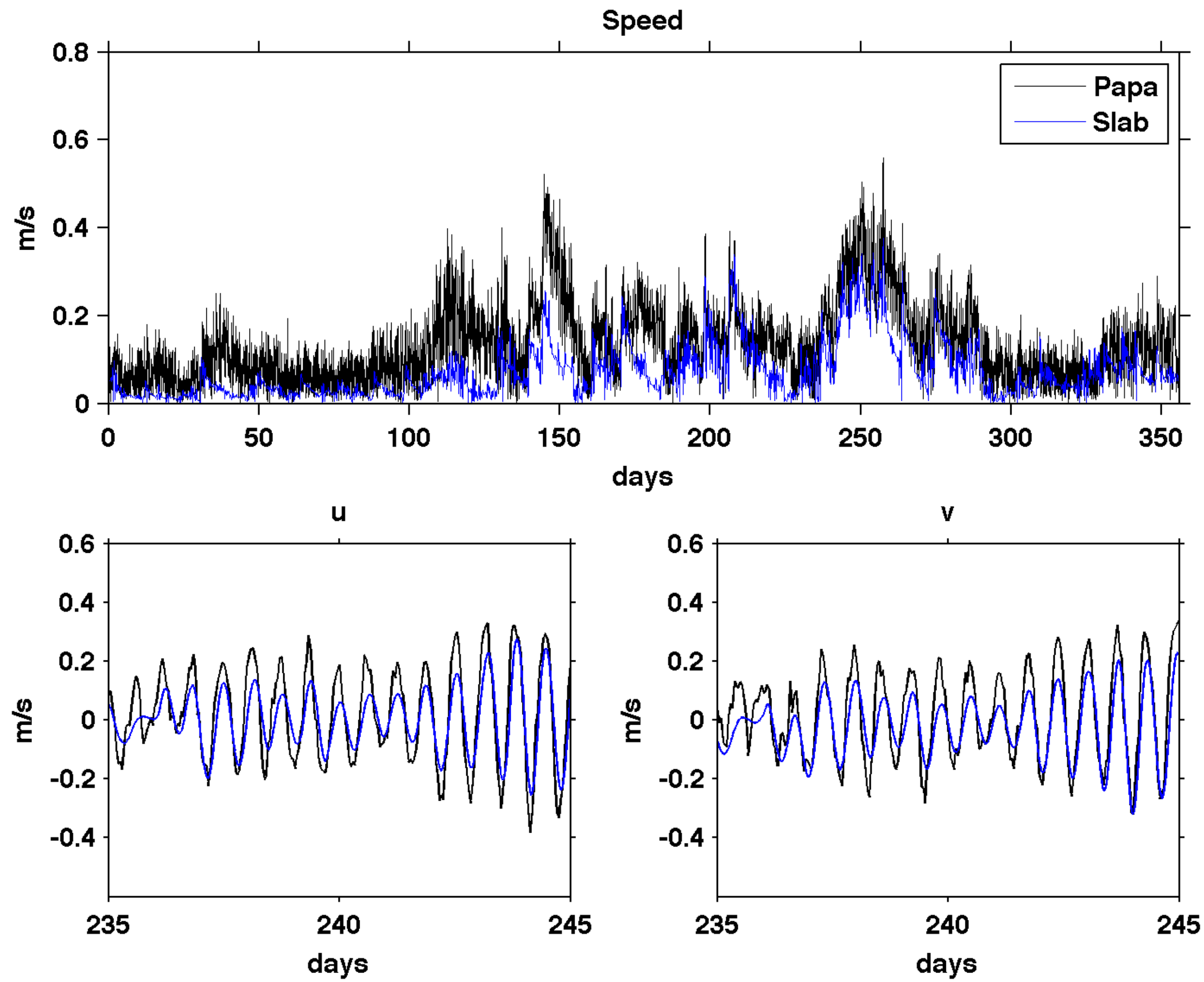
Transfer Functions

- H numerically solved from observations vs slab model H.
- Very simple notch filter to remove tides.
- Damped slab: Fourier transform the ODE and solve for H.

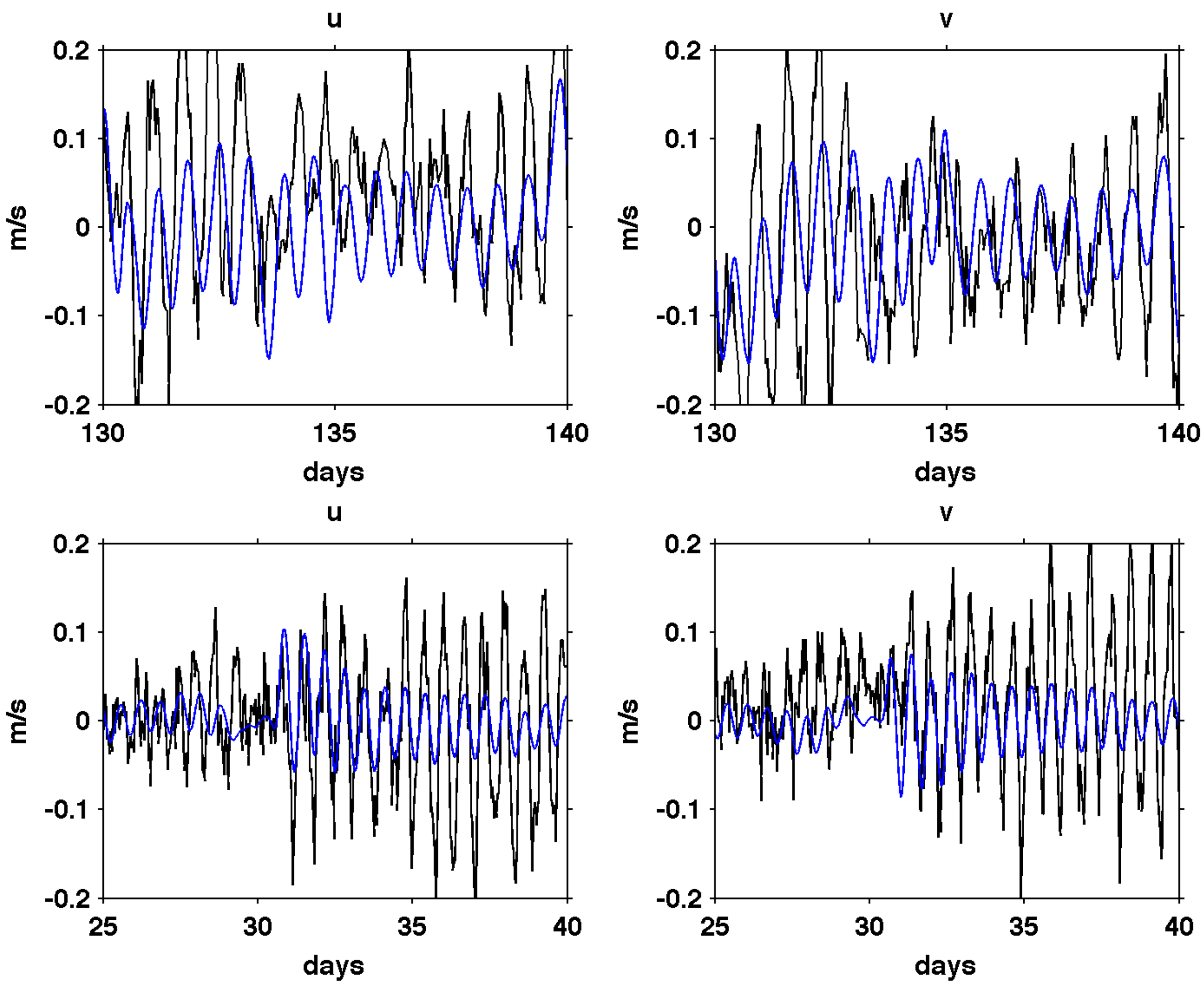




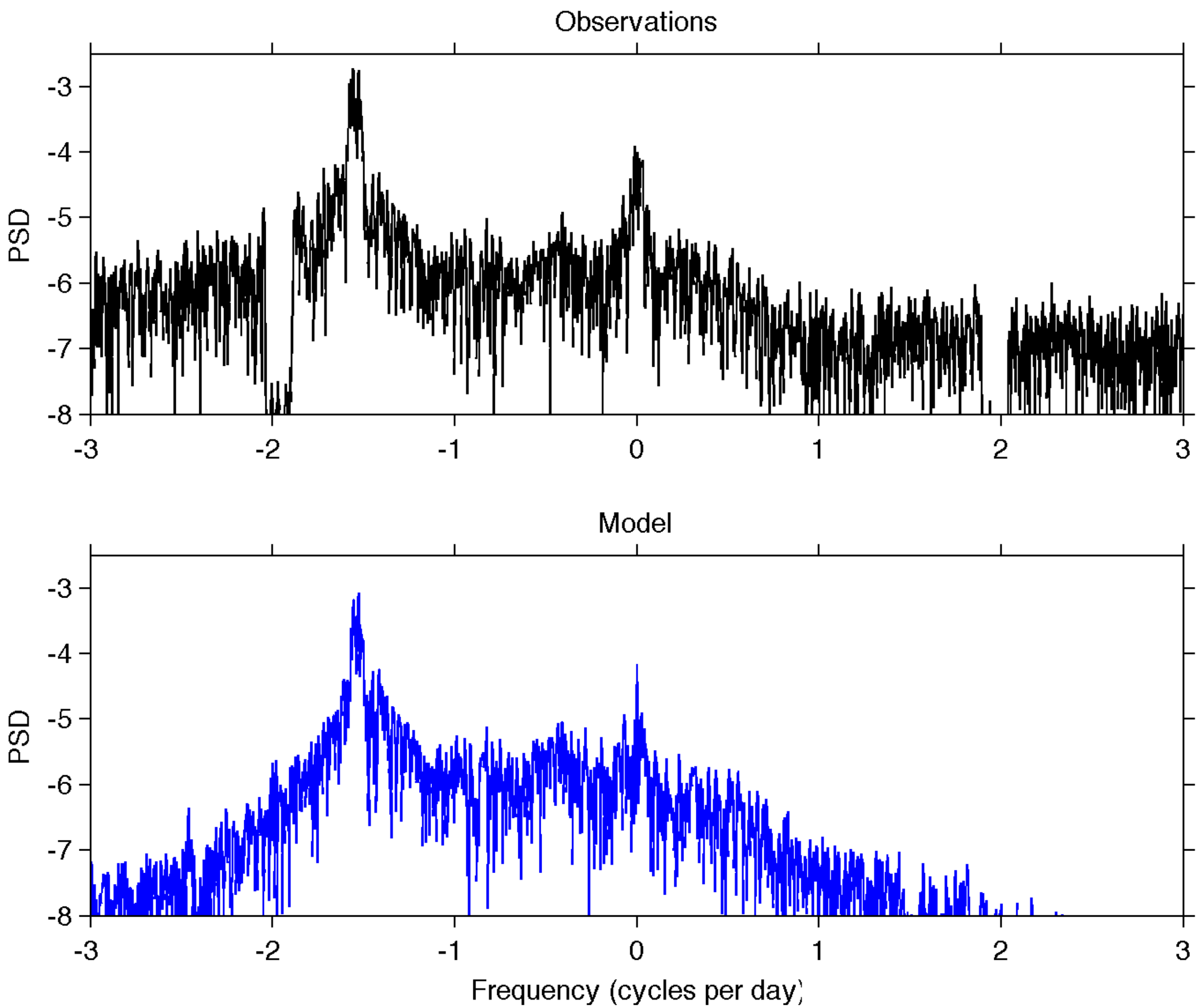
Slab Model Results with 10 minute Papa Winds



Slab Model Results with 10 minute Papa Winds

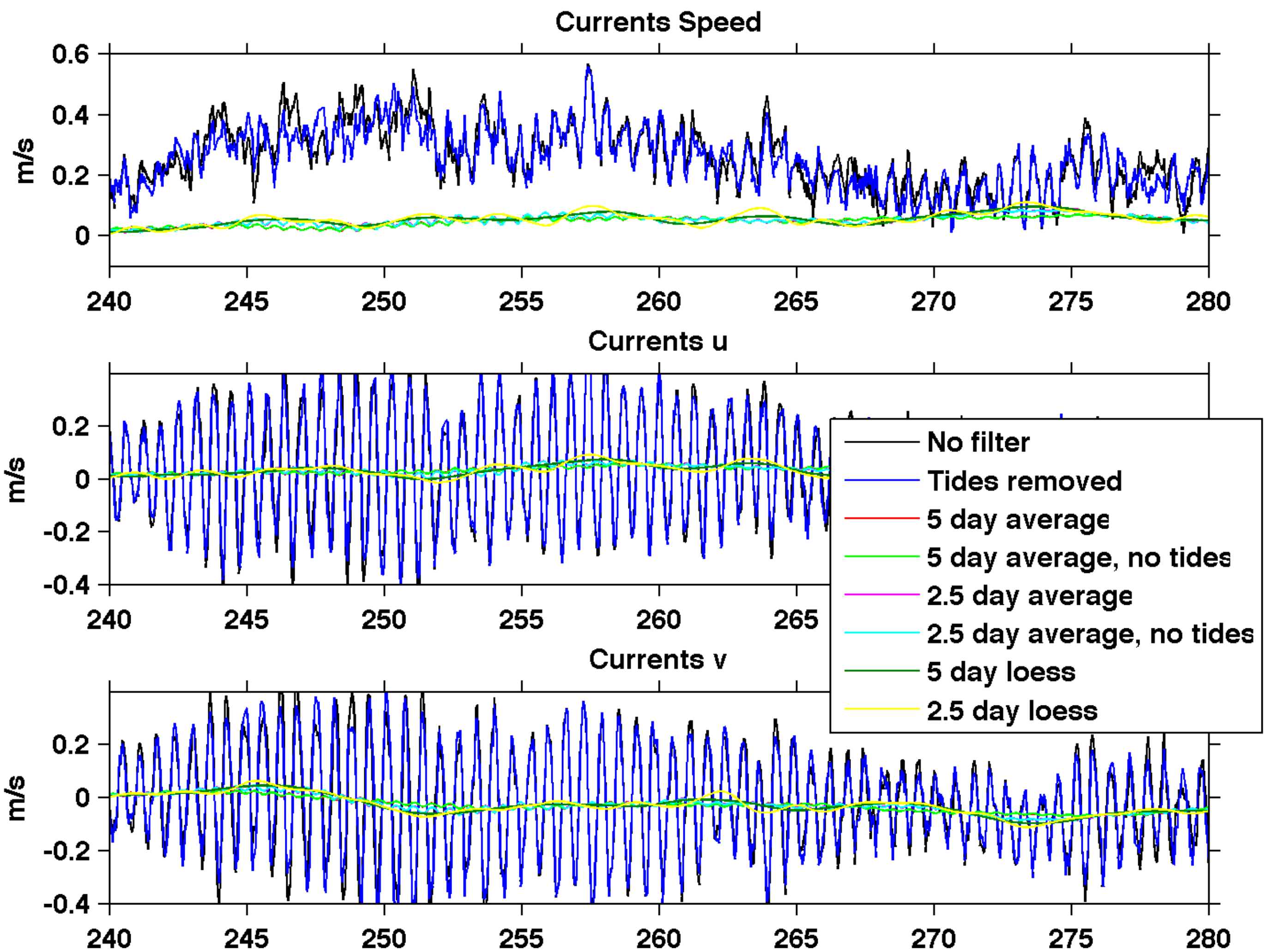


FFT Observed Currents vs Slab Model with Observed WInds



Do we want NIO or slower wind response?

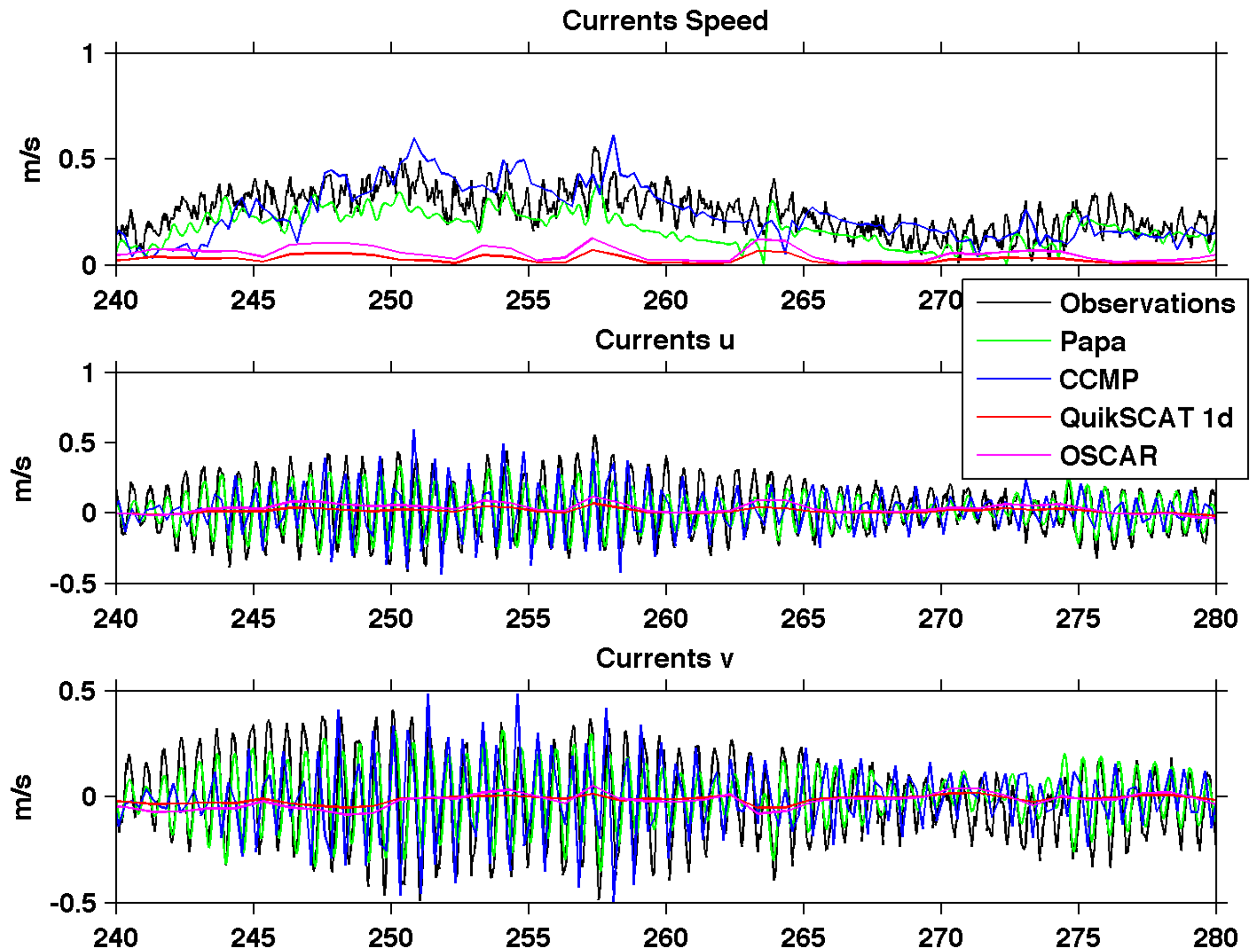
- Capture inertial currents or temporally averaged wind-driven currents? Realistically, what can/should we be doing?



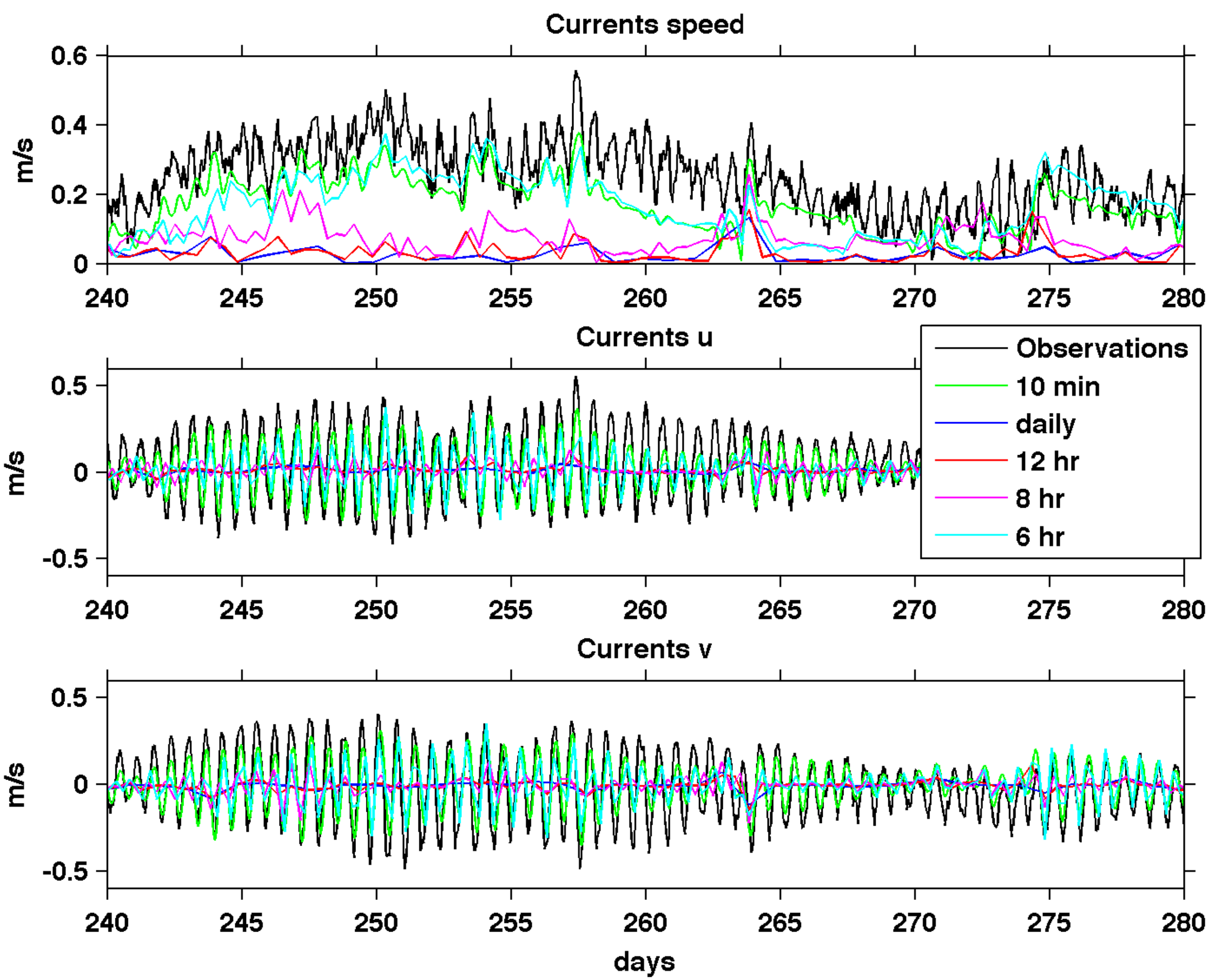
2012

Slab Model, Different Wind Input

- CCMP: over-estimate, observed Papa 10 minute winds, underestimate. Highly dependent on parameter choices.
- Daily winds (obviously) not resolving NIO, 15.6 hr inertial period.

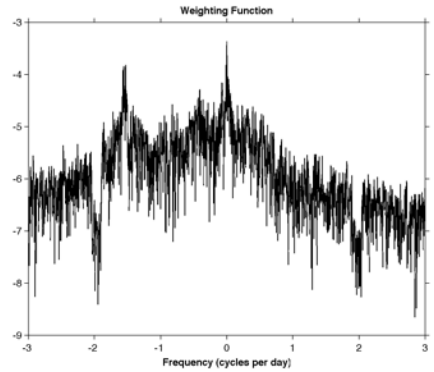


Temporal Resolution of Winds



Eddy viscosity model, Optimization of parameters

- Following Elipot and Gille (Ocean Science, 2009)
- They investigated models with 3 forms of eddy viscosity K(z):
  - K(z)=K0, K1 z, K0+K1 z
- And 3 types of boundary conditions
  - U->0 as z->-infinity, u=0 at z=-H, du/dz=0 at z=-H.
- Analytical solutions for H(v,z).
- Optimized choice of K0,K1,H, by minimizing cost function

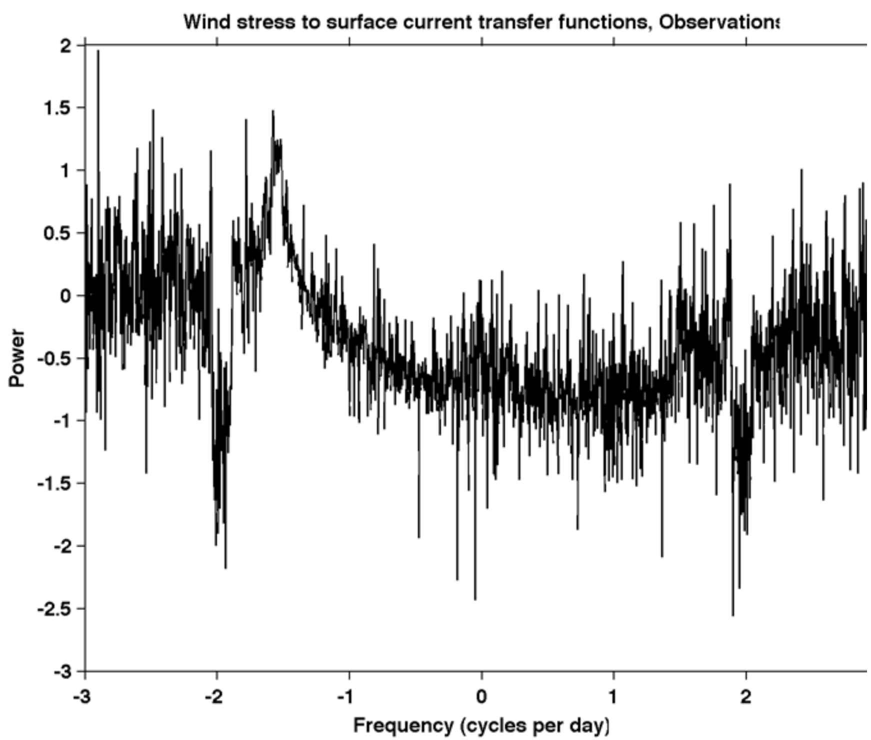


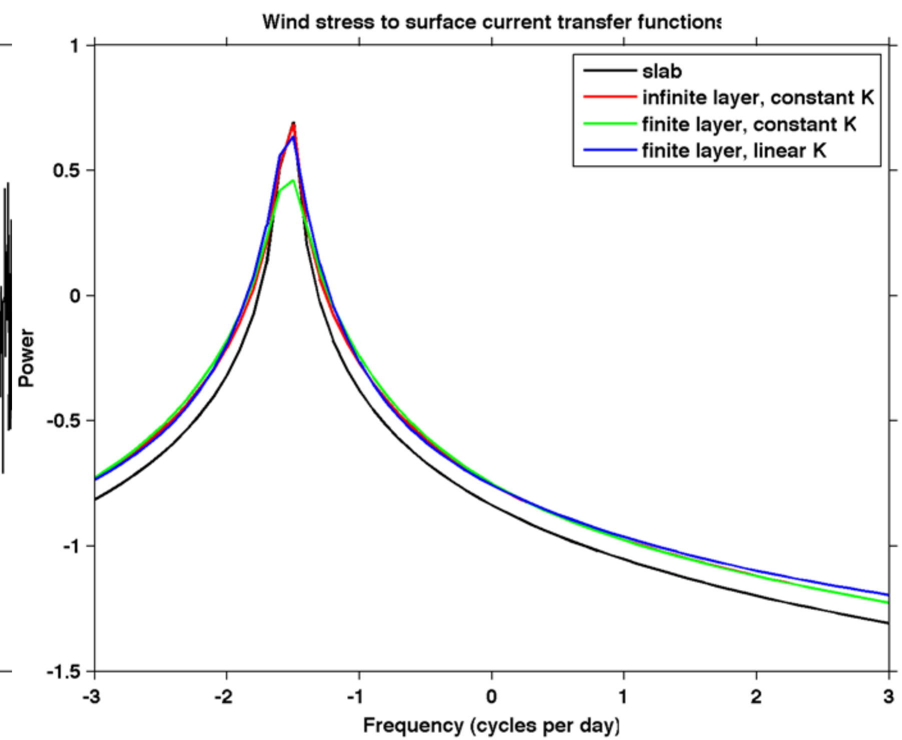
$$L = \sum_{\nu_k} |\mathbf{H}_{model}(\nu_k, z) - \mathbf{H}_{obs}(\nu_k)| \times w(\nu_k)$$

- Where w(v) = a weighting function = the squared coherence between wind stress and velocity of the observations.
- *Should we weight differently for slower timescales?*

Transfer Functions, model with eddy viscosity K(z)

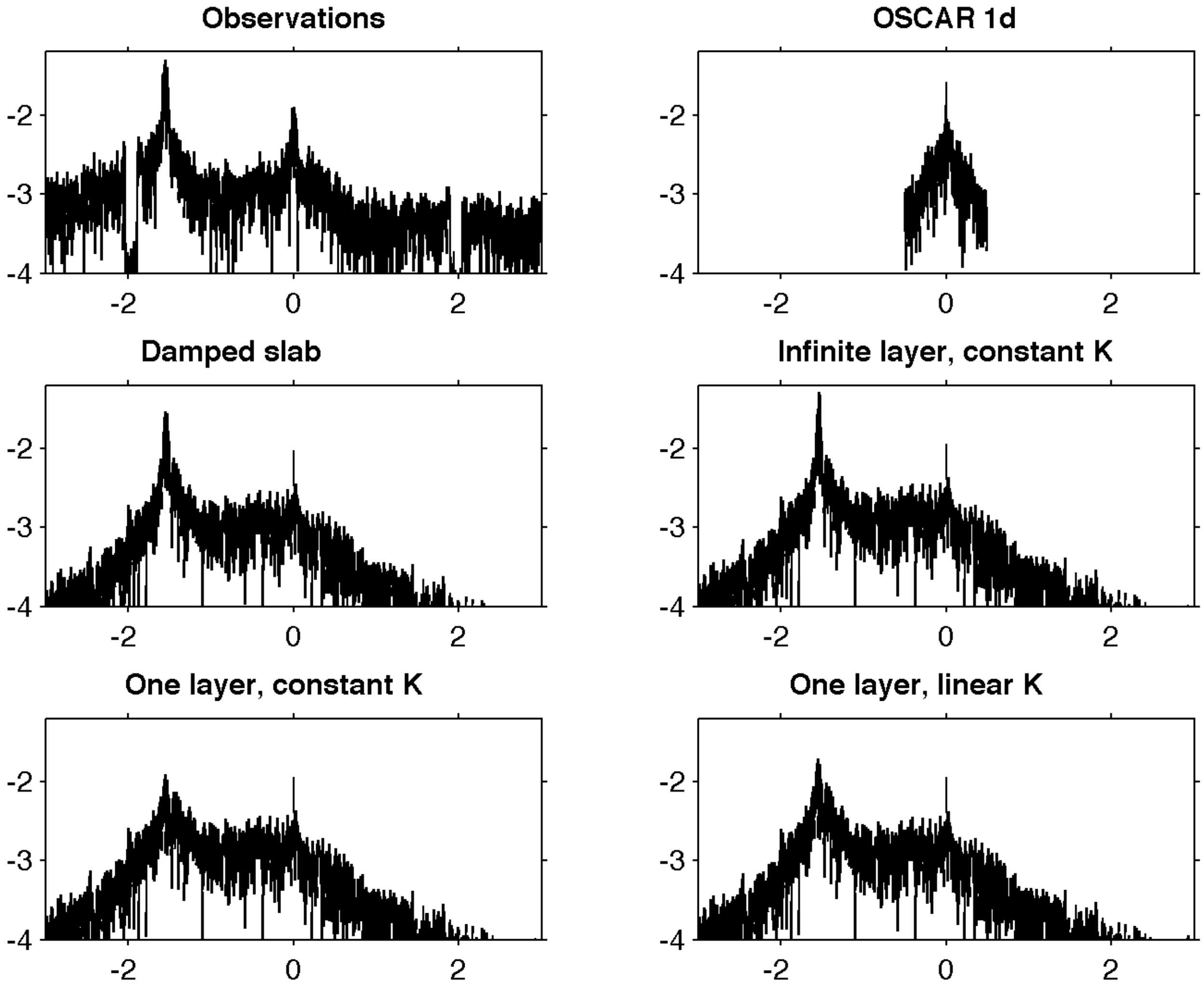
- Transfer functions for 3 cases, eddy viscosity models vs slab.
- Chose parameters to provide similar H.
- Note: integrated over the mixed layer.





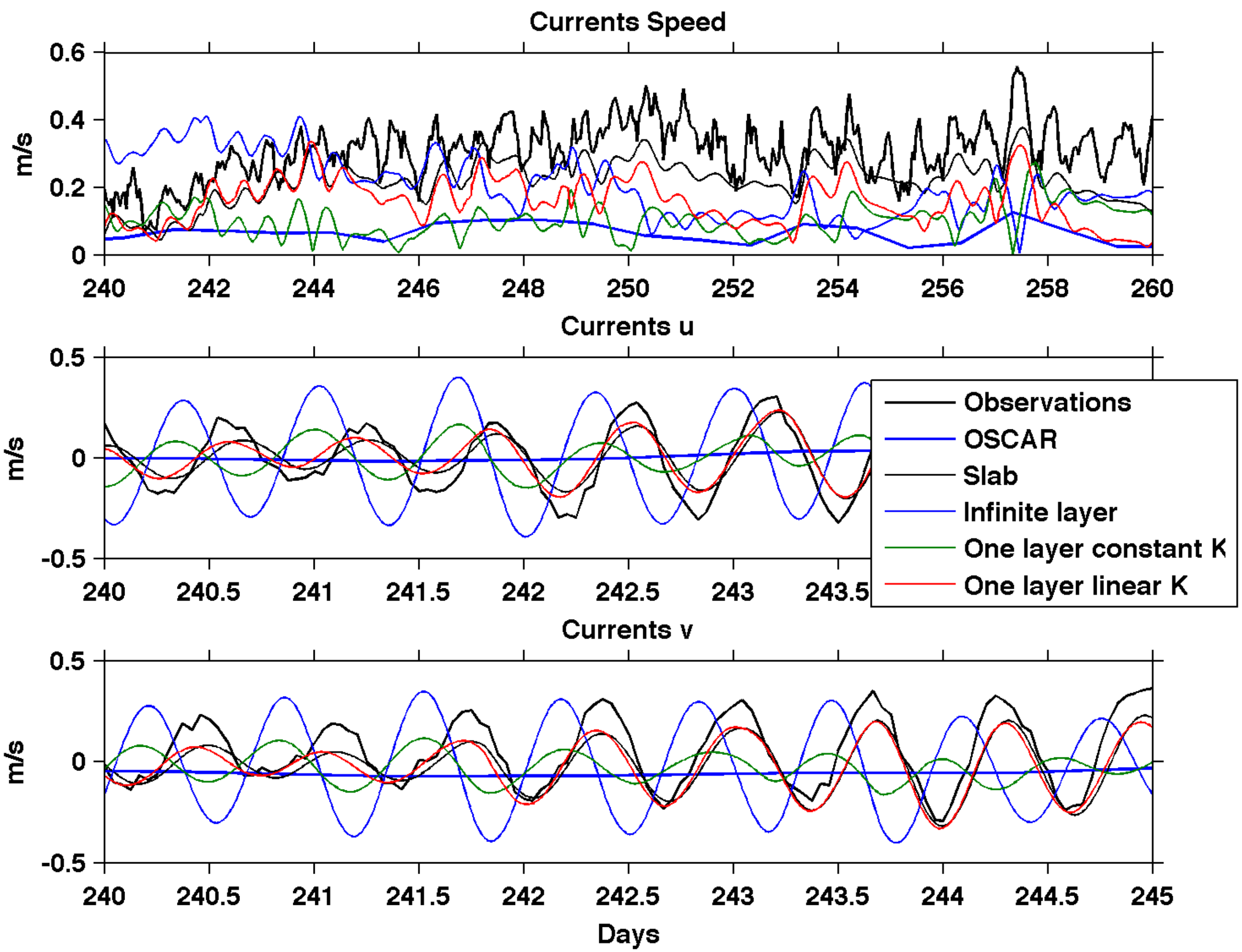
Model Results, Frequency Domain

- Very similar results in frequency domain



Eddy viscosity K(z) performance

- Quite different results, phasing and speed.
- Note: averaged over the top 30m – K models vary with depth.

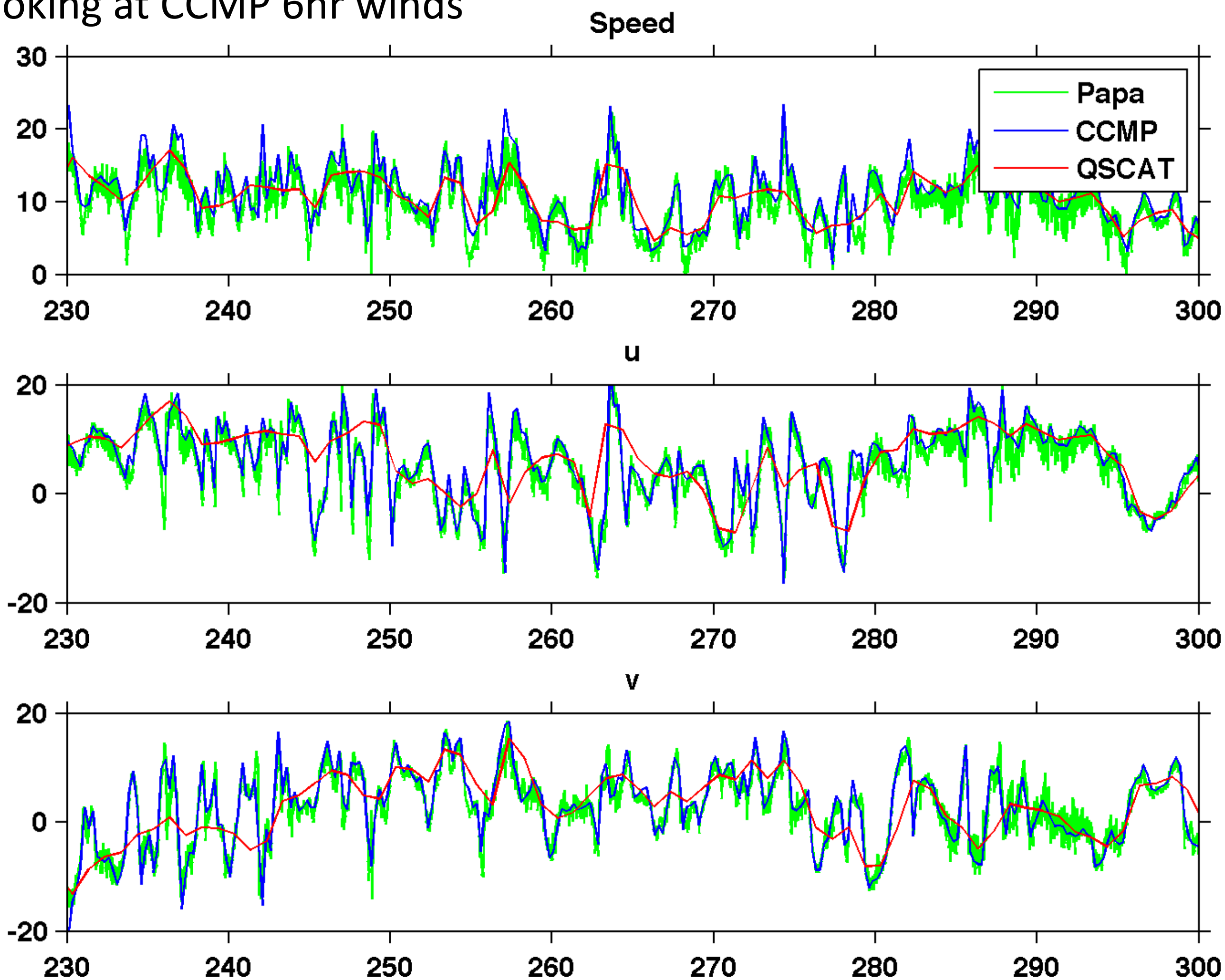


Time-dependent OSCAR

- Slab model is promising for either 1d or 6hr winds, depending on what is desired
  - Global, test against drifters (need metrics for evaluations)
  - Time-dependent MLD - how robust are the results
  - Study the decay timescales
- Vertically varying eddy viscosities need more tuning, more parameters
  - Vertical variation results in large differences for averaged currents
  - Time dependent K, as in OSCAR
- Can we get away with simple models versus KPP, PWP
  - Density profiles, surface inputs, transition layer mixing
- Different goals:
  - Improve OSCAR 5-day wind-driven very simple model
  - Study NIO generation, decay, using satellite-sensed fields
  - Isolate momentum transfer to test parameterization performance

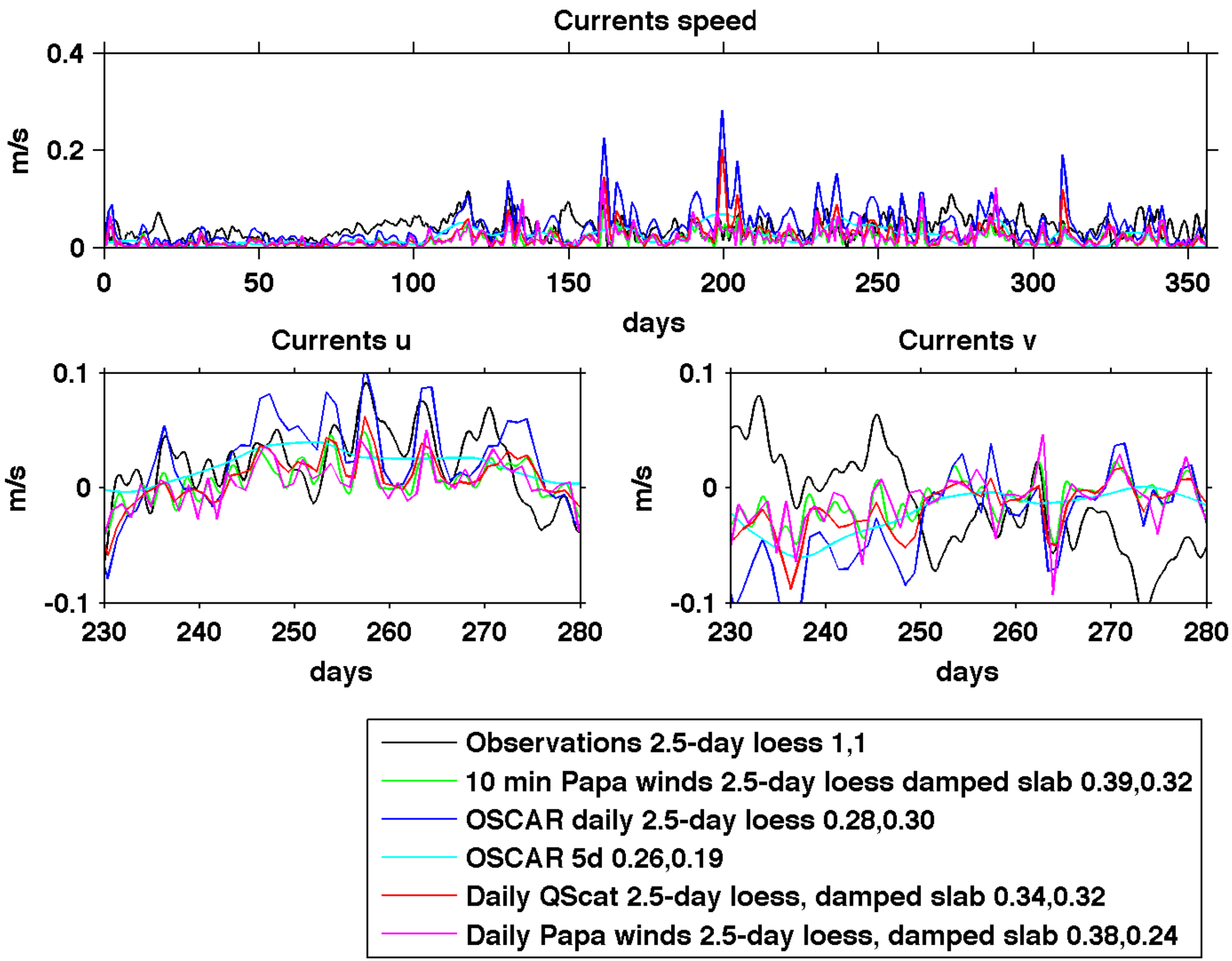
Input Winds for Model

- I've been using the FSU QuikSCAT winds, on daily timebase
- Looking at CCMP 6hr winds

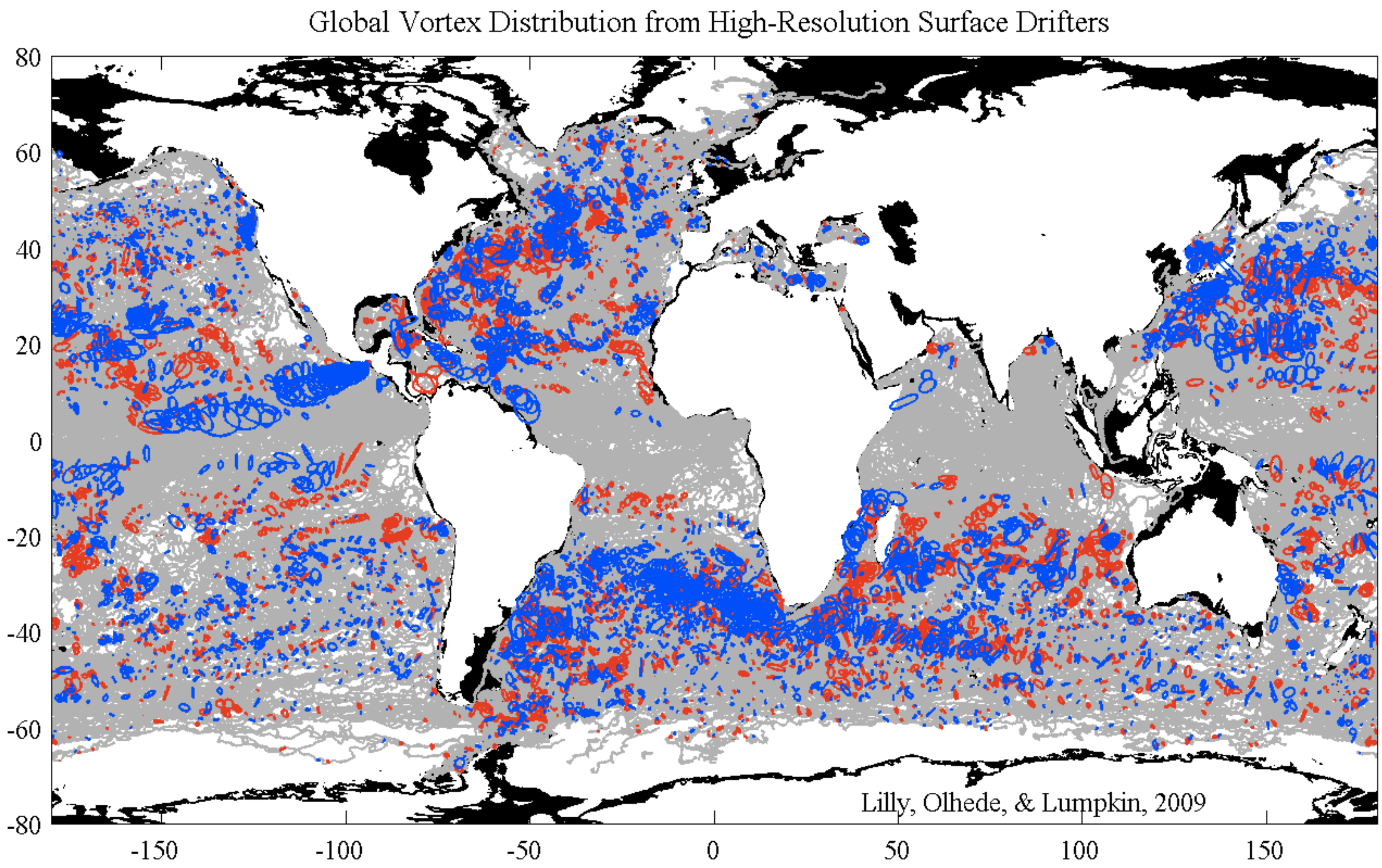


Slab performance, slow times

- Results after smoothing
- Optimized for NIO, not 2.5-day filtered

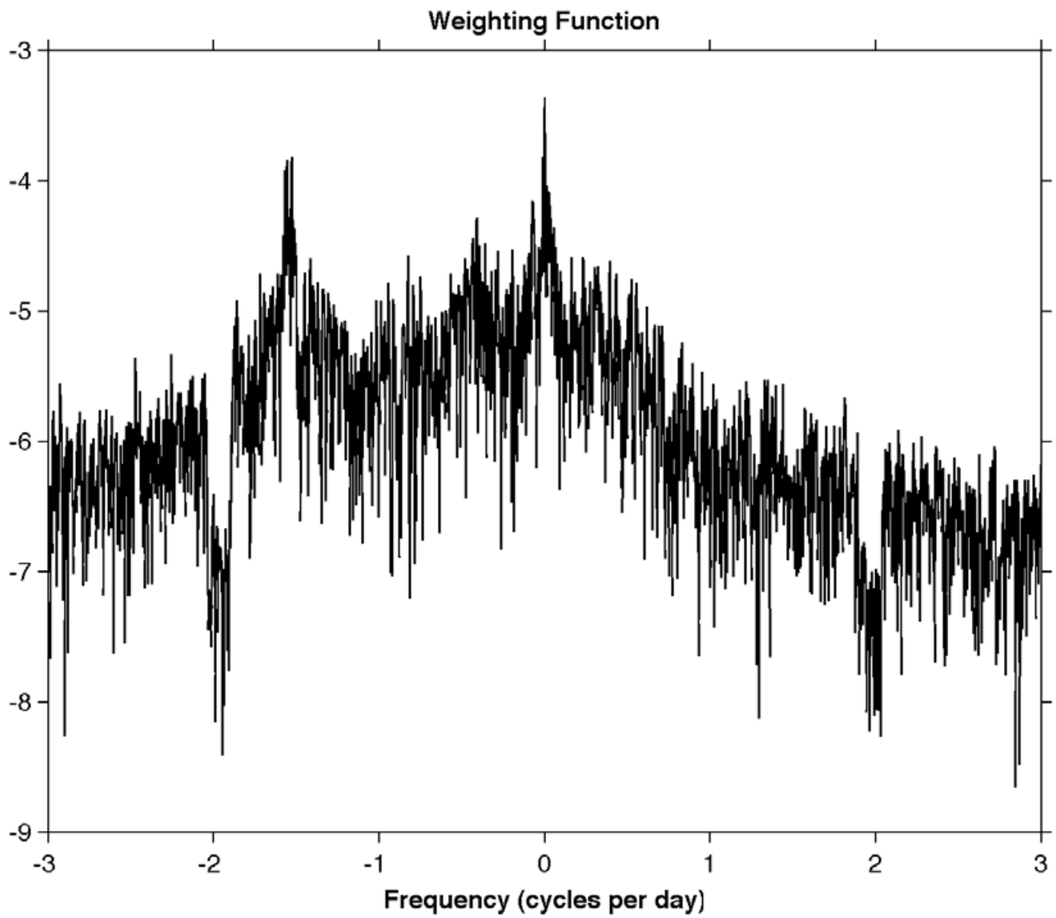


NIO statistics from drifters (collaboration with J. Lilly)



Weighting Function from Observations

- *Should we weight differently for slower timescales?*



OSCAR Surface currents from satellite fields

- Quasi-steady linear flow with turbulent mixing parameterized by a constant vertical eddy viscosity. Frontal model: buoyancy force is a function of horizontal gradients of SST only. Surface layer velocity U is the average over the top 30m.

$$if\bar{\mathbf{U}} = -g\nabla\zeta + \frac{h}{2}\nabla\theta + \frac{\tau_0 - \tau(-h)}{h}$$

$$\tau = \nu\frac{\partial \mathbf{U}}{\partial z}$$

where: $\mathbf{U} = u + \mathbf{i}v$, τ_0 is surface wind stress, $h = 30m$, ζ is SSH, θ is buoyancy, based on SST ($\theta = g\chi_T SST$), and ν is a vertical eddy viscosity, calculated as a function of wind

- OSCAR quasi-steady model: steady Ekman with constant in the vertical eddy viscosity

$$\nu = a\left(\frac{|\mathbf{W}|}{W_0}\right)^b$$