Mapping coastal wind field using wind-current transfer function analysis

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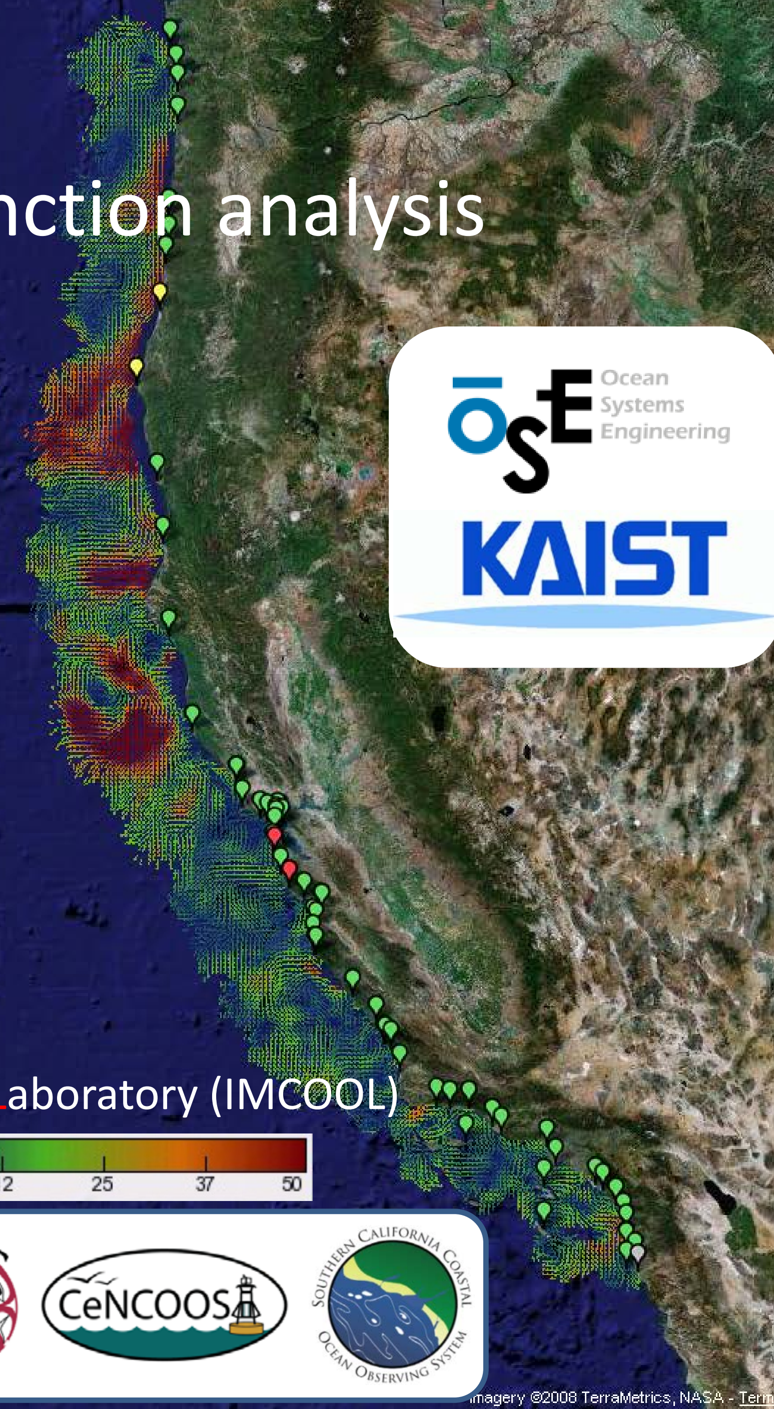
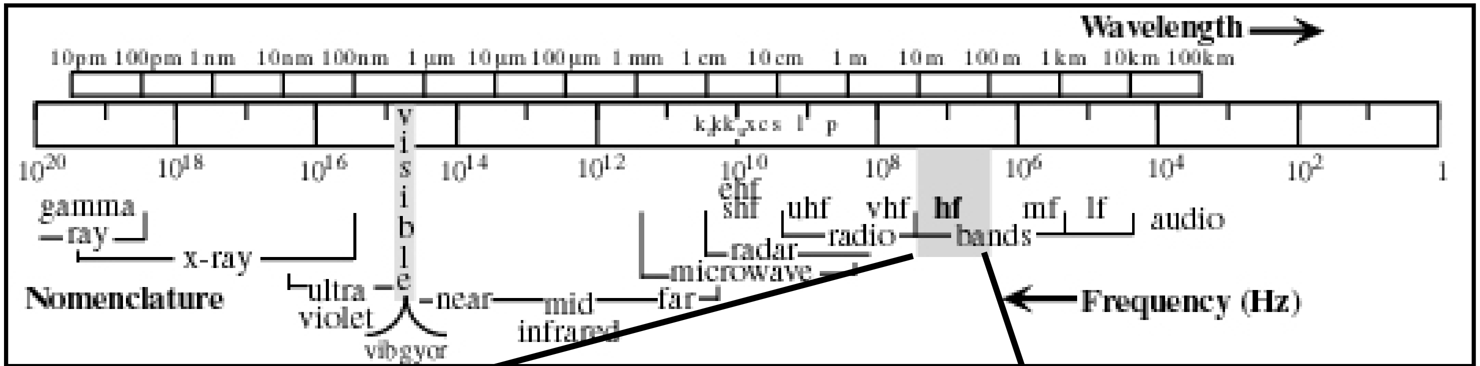
Integrated Marine Physical Coastal Ocean Observing Laboratory (IMCOOL)



Outline

- Surface currents observations
  - High-frequency radar-derived surface currents
  - Geophysical signals
- Wind-current transfer function analysis
  - Definition
  - Statistical and dynamical descriptions
- Summary

Radio signals used in high-frequency radar



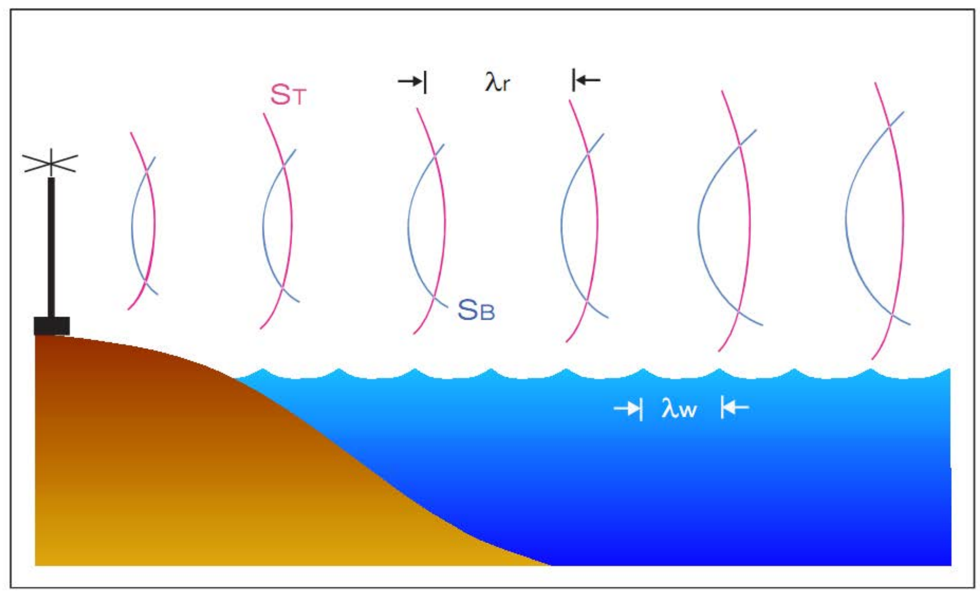
3-30 MHz (between AM radio and TV)

Wavelength (λ_r) : 10 ~ 100 (m)

Bragg backscattering

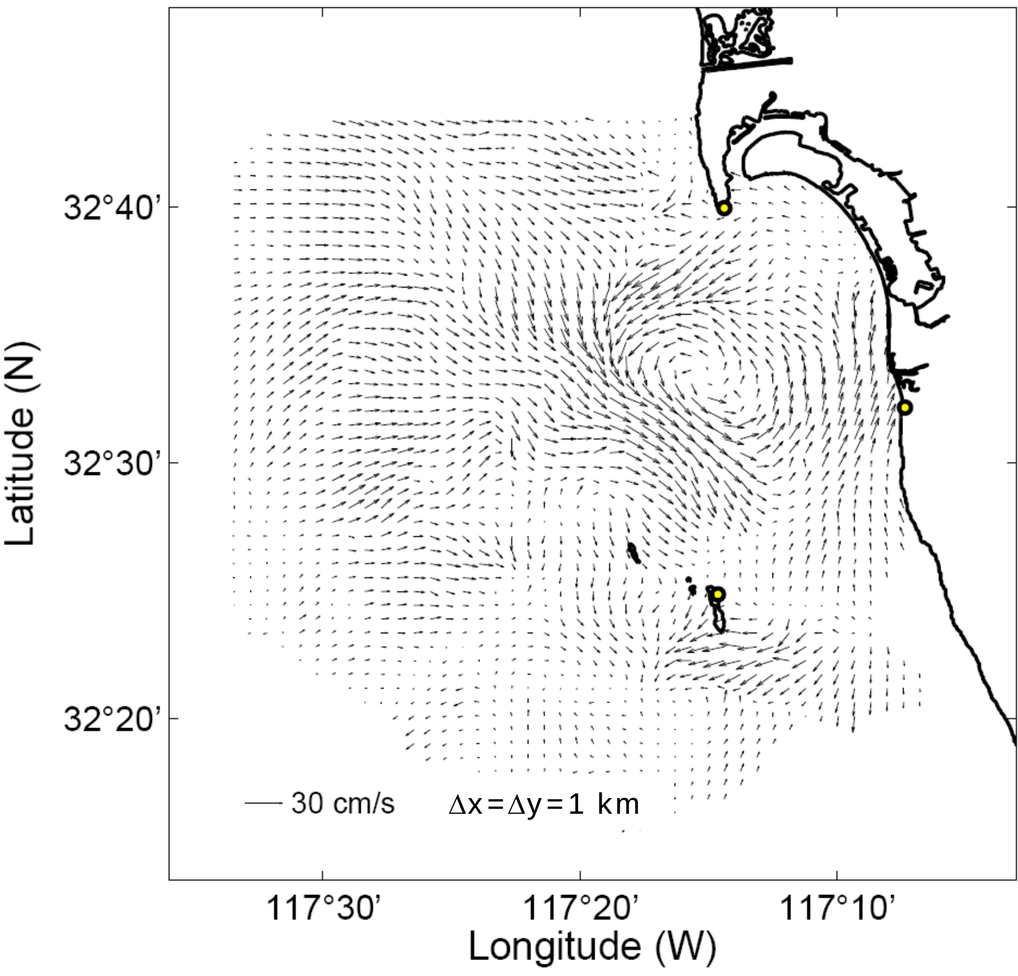
When the radar signals are backscattered in phase,

$$\lambda_w = \lambda_r / 2$$

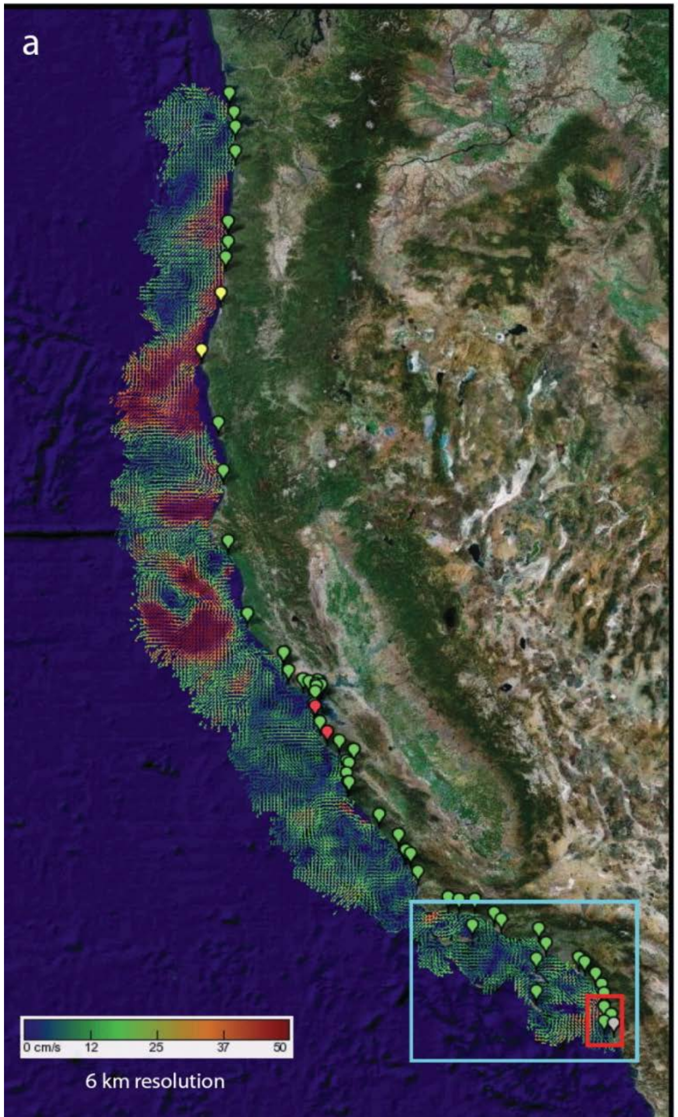


High-frequency (HF) radar

University of Hamburg, Germany

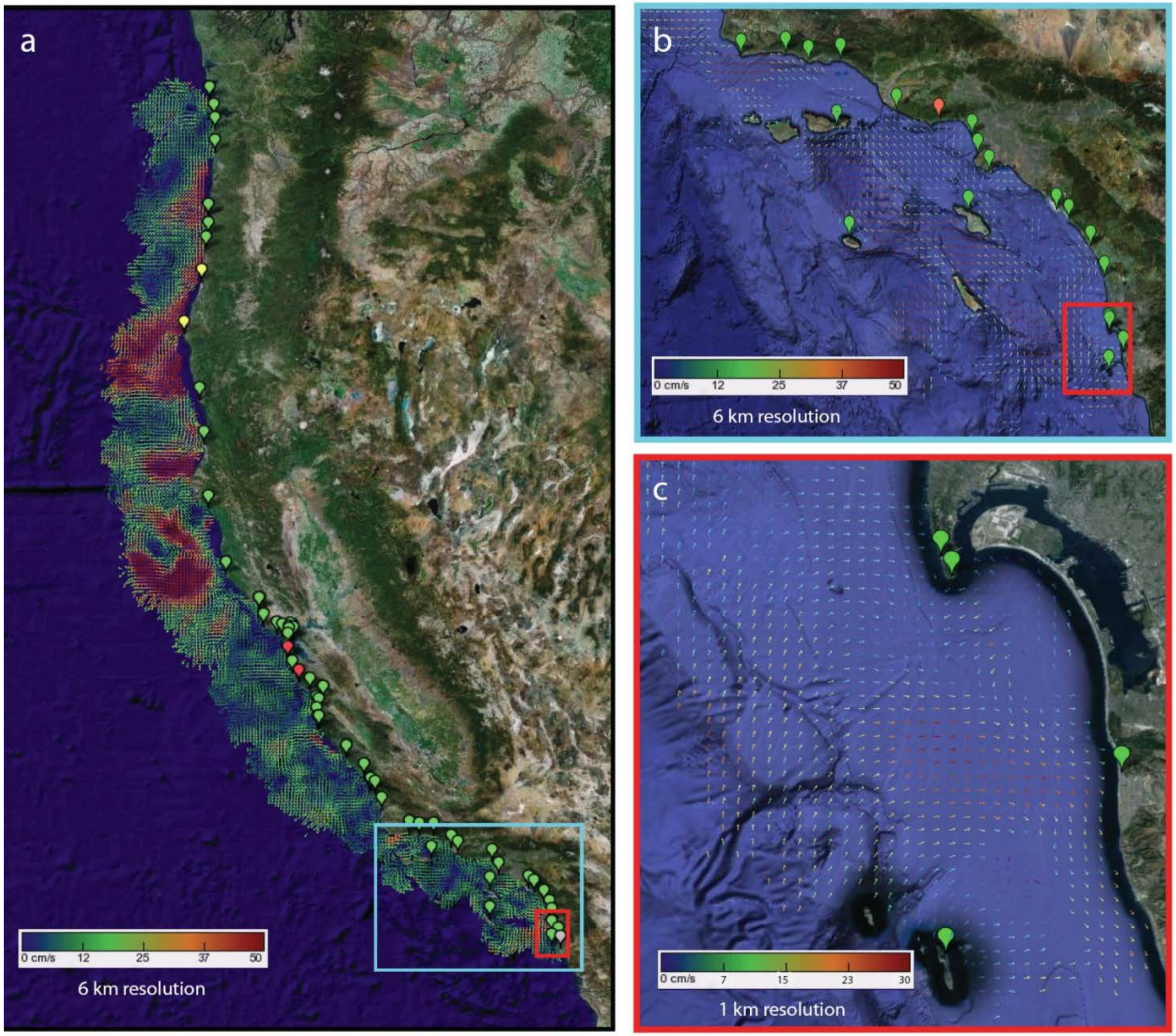


High-frequency coastal radar-derived surface currents off the U.S. West Coast



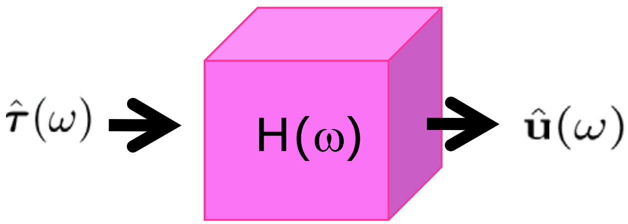
- A network of high-frequency radars (HFRs) along the coast over 2500 km of US West Coast provides km resolution and hourly surface current maps which cover about 150 km offshore from shoreline.
- Due to low signal-to-noise ratio of satellite remote sensing near coastal regions and high cost of transporting the wind energy to end users (e.g., cable), an approach to find hot spots of wind energy in coastal areas is proposed.

High-frequency coastal radar-derived surface currents off the U.S. West Coast (cascade maps)

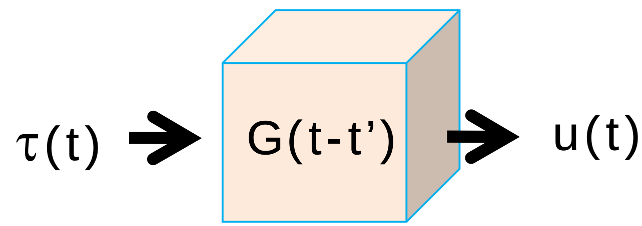


Wind transfer/response functions

- A statistical framework to represent the link between wind and currents in the frequency and time domains.
- Isotropic and anisotropic analyses/models.



Transfer function



Response function

$$\hat{\mathbf{u}}(z,\omega) = \mathbf{H}(z,\omega)\hat{\boldsymbol{\tau}}(\omega)$$

$$\mathbf{u}(z,t) = \int_{t'} \mathbf{G}(z,t-t')\boldsymbol{\tau}(t')\,\mathrm{d}t',$$

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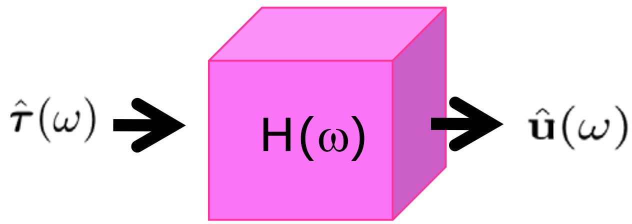
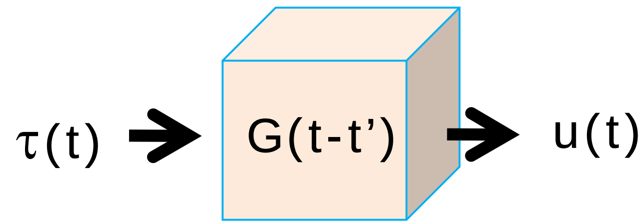


Transfer function

$$\hat{\mathbf{u}}(z,\omega) = \mathbf{H}(z,\omega)\hat{\boldsymbol{\tau}}(\omega)$$

$$\mathbf{H}(z,\omega) = \left(\langle \hat{\mathbf{u}}(z,\omega)\, \hat{\boldsymbol{\tau}}^{\dagger}(\omega)\rangle\right)\left(\langle \hat{\boldsymbol{\tau}}(\omega)\, \hat{\boldsymbol{\tau}}^{\dagger}(\omega)\rangle + \mathbf{R_a}\right)^{-1}$$

$\mathbf{R_a}$: Regularization matrix



Response function

$$\mathbf{u}(z,t) = \int_{t'} \mathbf{G}(z,t-t')\boldsymbol{\tau}(t')\,\mathrm{d}t',$$

$$\mathbf{G}(z,t) = \left(\langle \mathbf{u}(z,t)\, \boldsymbol{\tau}_N^{\dagger}(t)\rangle\right)\left(\langle \boldsymbol{\tau}_N(t)\, \boldsymbol{\tau}_N^{\dagger}(t)\rangle + \mathbf{R_b}\right)^{-1}$$

$\boldsymbol{\tau}_N$: *N*-hour advanced time lagged wind stress

$\mathbf{R_b}$: Regularization matrix

Isotropic model

$$\frac{\partial u}{\partial t} - f_c v = \frac{1}{\rho}\frac{1}{\partial z}\left(\mu\frac{\partial u}{\partial z}\right)$$

$$\frac{\partial v}{\partial t} + f_c u = \frac{1}{\rho}\frac{1}{\partial z}\left(\mu\frac{\partial v}{\partial z}\right)$$

$\mathbf{u} = u + iv$ $\boldsymbol{\tau} = \tau_x + i\tau_y$: isotropic assumption

Then, Fourier transform

$$\lambda^2\hat{\mathbf{u}}(z,\omega) = \frac{\partial^2\hat{\mathbf{u}}(z,\omega)}{\partial z^2},$$

where $\lambda = \sqrt{i(\omega + f_c)/\nu},$

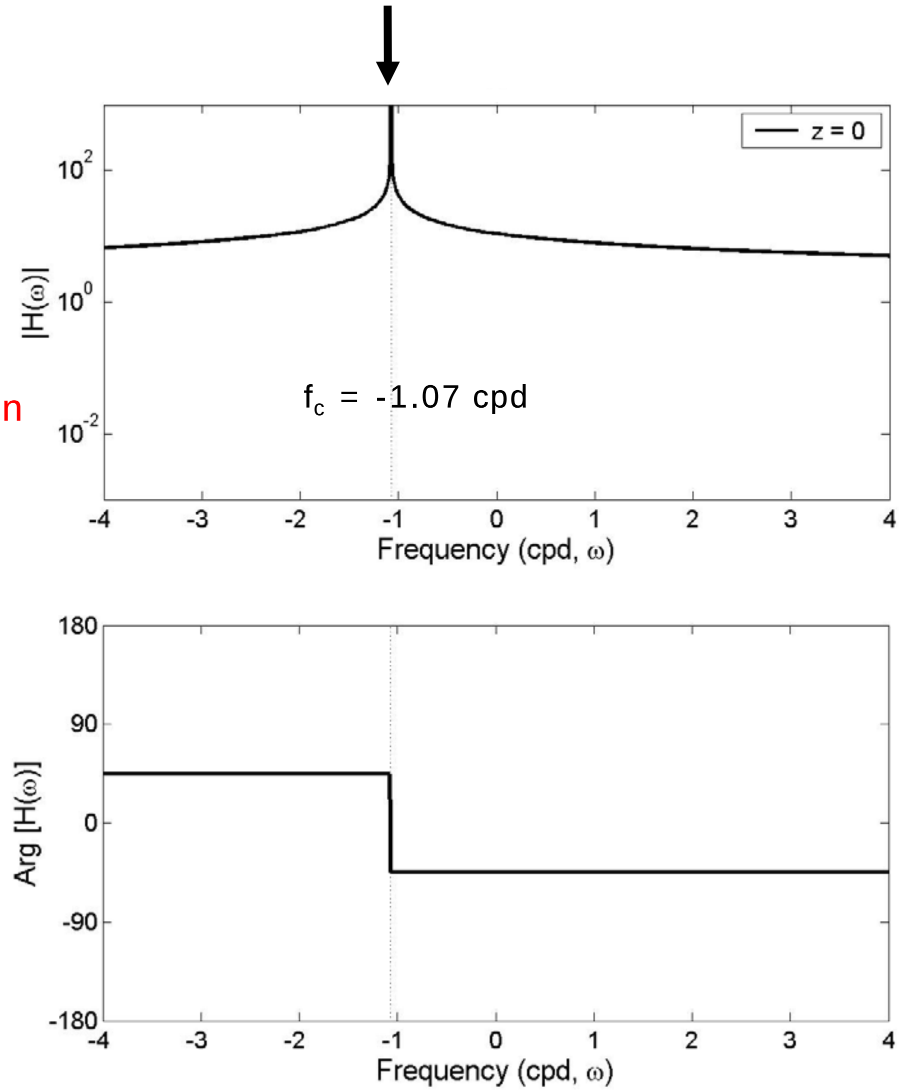
ν = Depth independent eddy viscosity

With BCs (finite or infinite depth)

$$\left.\frac{\partial\hat{\mathbf{u}}(z,\omega)}{\partial z}\right|_{z=0} = \frac{\hat{\boldsymbol{\tau}}(\omega)}{\rho\nu}. \qquad \hat{\mathbf{u}}(z,\omega)|_{z=-\infty} = 0,$$

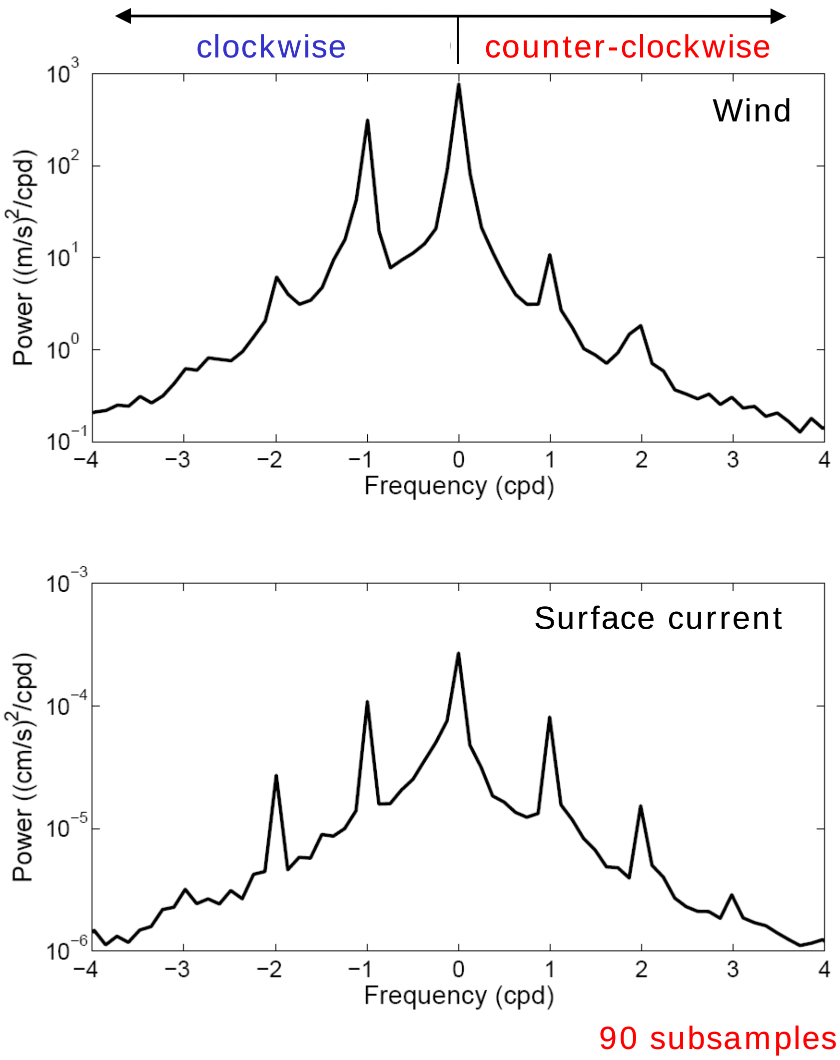
$$\mathbf{H}(z,\omega) = \frac{\hat{\mathbf{u}}(z,\omega)}{\hat{\boldsymbol{\tau}}(\omega)} = \frac{e^{-\lambda z}}{\lambda\rho\nu},$$

(Gonella, DSR 1972)

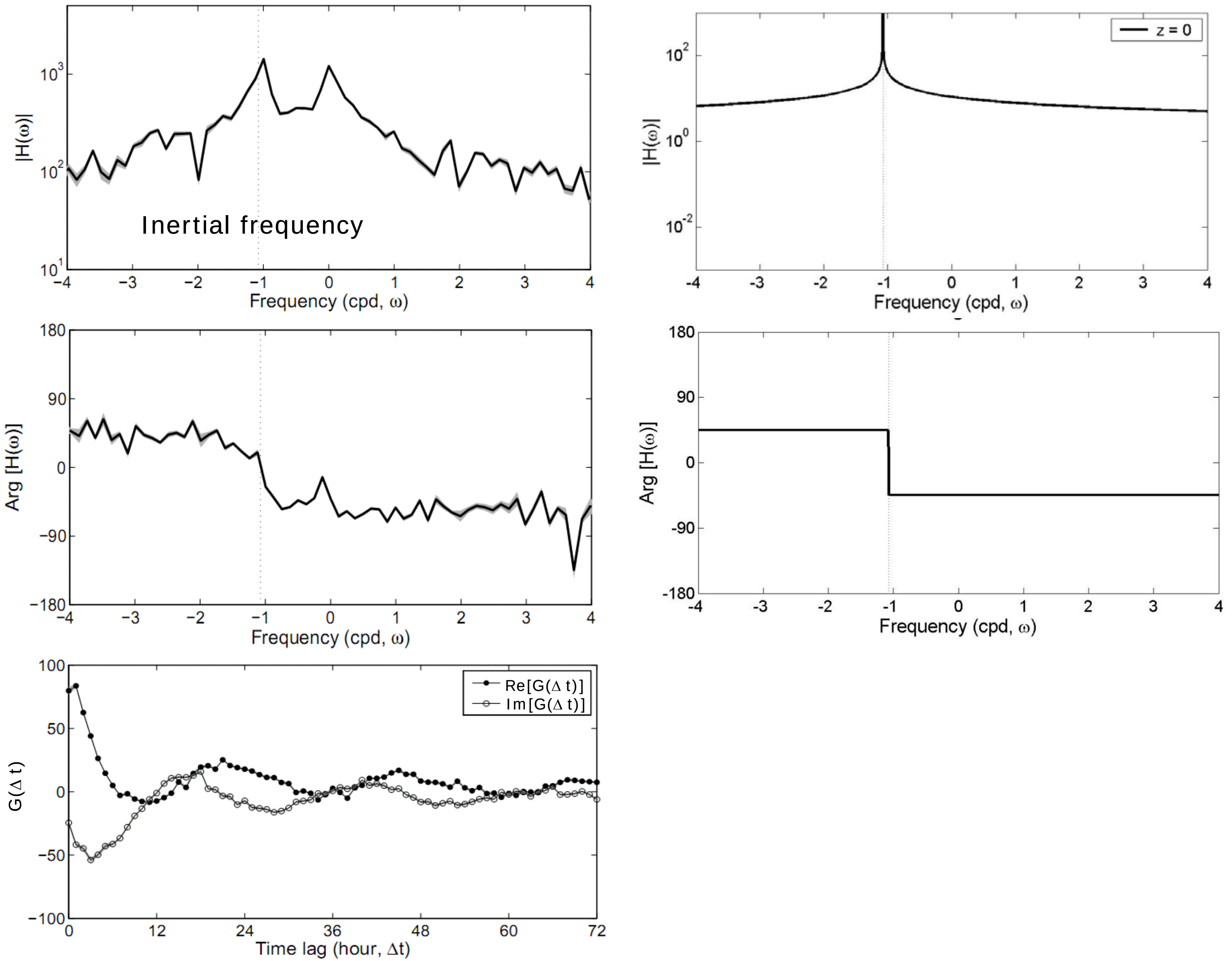


Data analysis

- Two-year records of hourly spatially averaged surface current and hourly wind observations near Tijuana River are used.
- Diurnal wind and its harmonics.
- Clockwise dominance.
- Major tides (K1, P1, O1, M2, and S2) in the surface current are removed for the WIRF estimate.



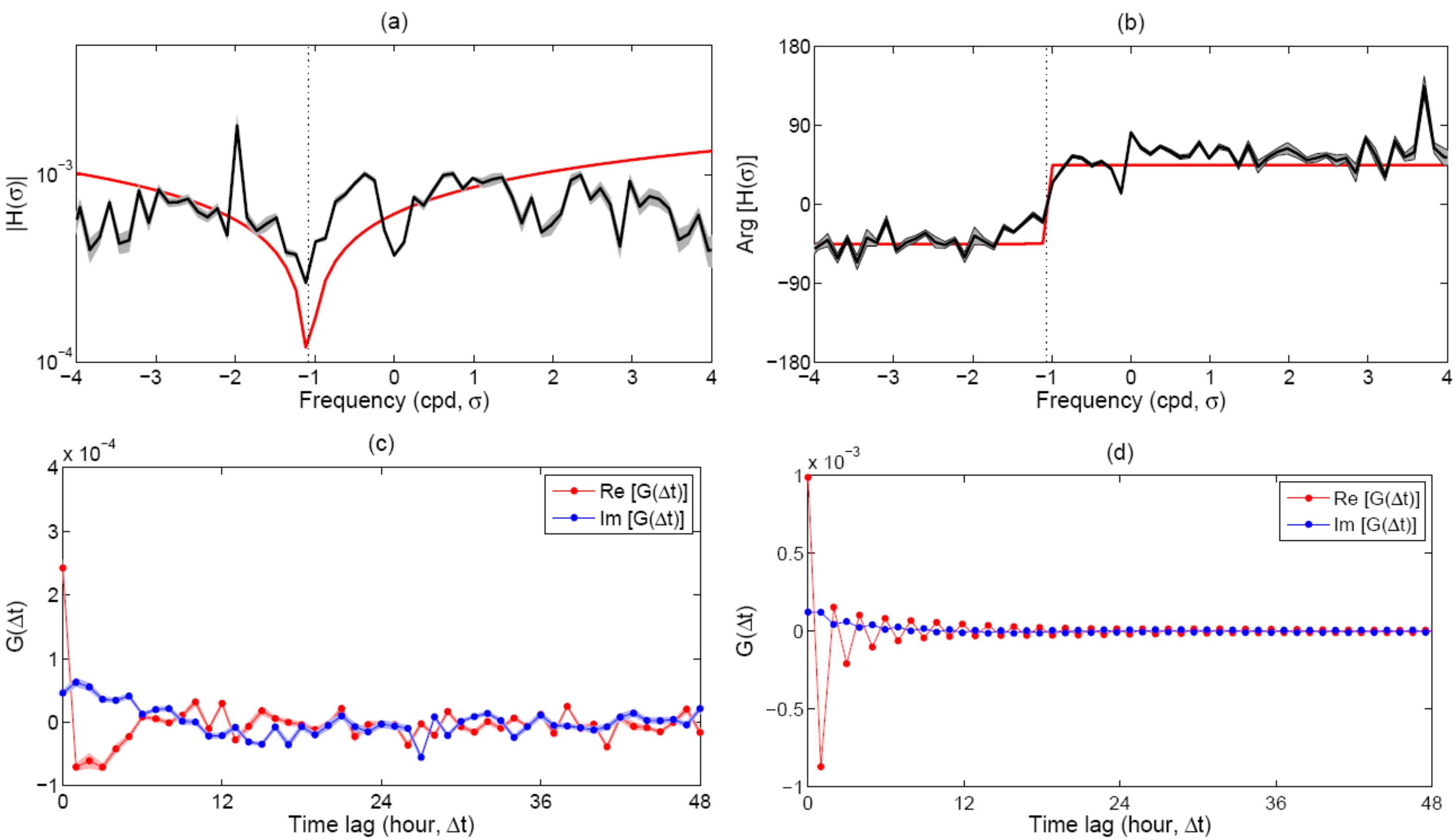
Wind transfer function and response function



Wind mapping transfer function

$$\hat{\tau}(\mathbf{x},\sigma) = \mathbf{H}(\mathbf{x},\sigma)\hat{\mathbf{u}}(\mathbf{x},\sigma)$$

$$\tau(\mathbf{x},t) = \int_{t'} \mathbf{G}(\mathbf{x},t-t')\mathbf{u}(\mathbf{x},t')\mathrm{d}t'.$$



Summary and discussion

- Environmental parameterization using wind-current transfer function provides statistical framework, consistent with analytic solutions derived from linearized momentum equations.
- Isotropic and anisotropic responses near the coast can be applicable to wind-driven surface transport model in the coastal regions.
- Limited wind observations at the similar temporal and spatial resolutions with surface currents
- Wind profile etsimates?