Resonant ocean current responses driven by coastal winds near the critical latitude

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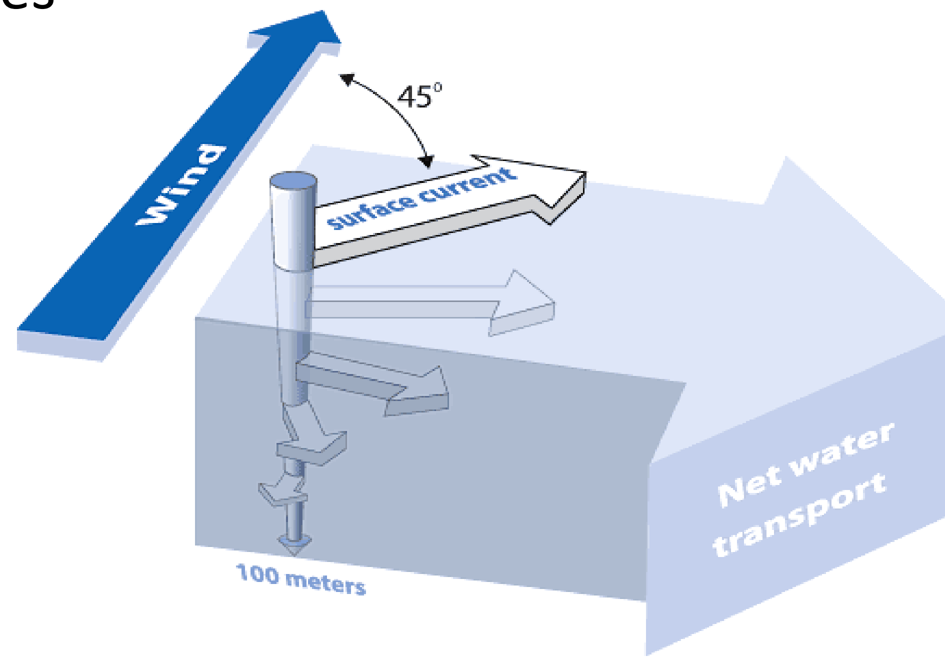
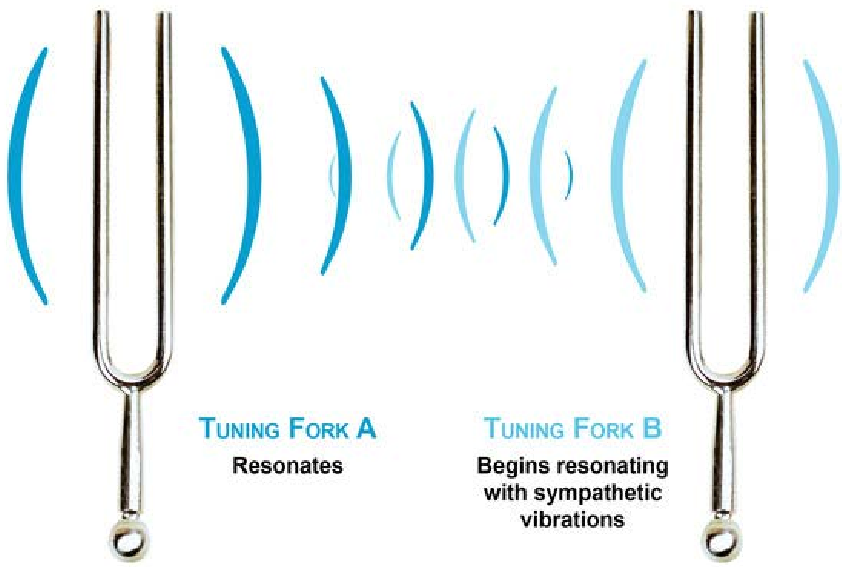
Resonant ocean current responses driven by coastal winds near the critical latitude

- Wind and current responses
  - Ekman theory..



Resonant ocean current responses driven by coastal winds near the critical latitude

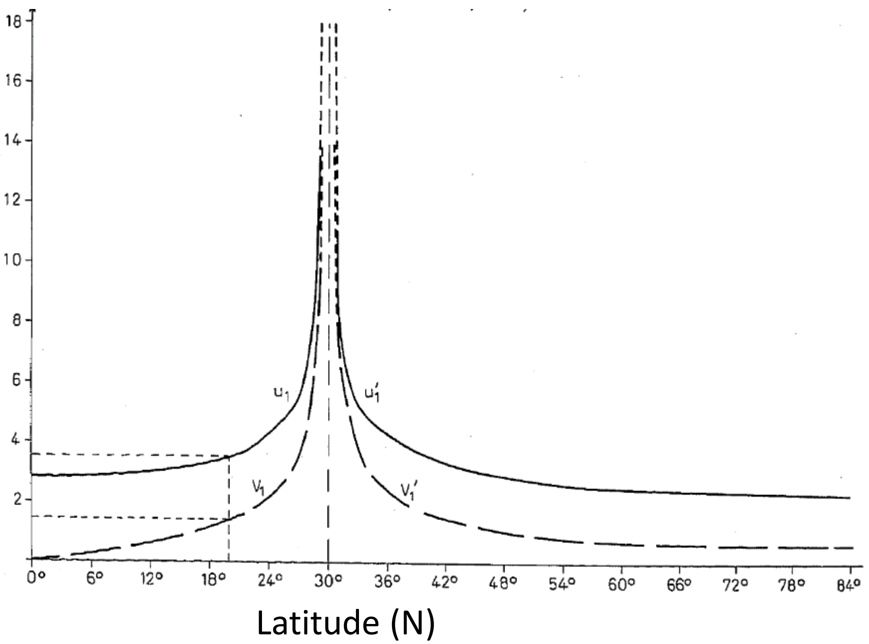
- Wind and current responses
  - Ekman theory..
- Resonance
  - Forcing-response in the frequency domain
  - Natural frequency – Coriolis frequency



f_c =2 sin (latitude) [cycles per day]

Resonant ocean current responses driven by coastal winds near the critical latitude

- Wind and current responses
  - Ekman theory..
- Resonance
  - Forcing-response in the frequency domain
  - Natural frequency – Coriolis frequency
- Critical latitude
  - Observations at different latitudes – wind and surface currents off the USWC



Shaffer, 1972; Ekman model

Resonant ocean current responses driven by coastal winds near the critical latitude

- At a given latitude, what would be the wind-current response in the frequency domain?
- At a given frequency, what would be the wind-current response as a function of latitude?

Wind-current responses in the freq. domain

$$\frac{\partial \mathbf{u}}{\partial t} + if_c\mathbf{u} + r\mathbf{u} = \frac{1}{\rho}\frac{\partial \tau}{\partial z}$$

Ekman theory

Wind-current responses in the freq. domain

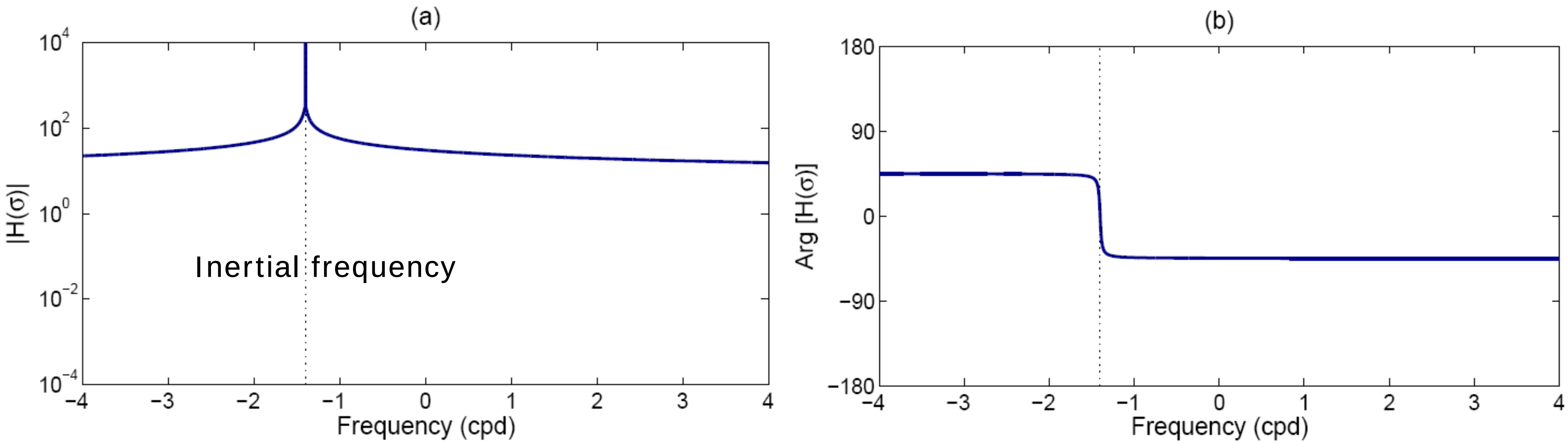
$$\frac{\partial \mathbf{u}}{\partial t} + if_c\mathbf{u} + r\mathbf{u} = \frac{1}{\rho}\frac{\partial \tau}{\partial z}$$

Ekman theory

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

as a function of frequency

$$\lambda = \sqrt{[i(\sigma + f_c) + r]/\nu}$$



At a given latitude, the relationship between wind stress and surface currents is given as a transfer function in the frequency domain.

Wind-current responses in latitude

$$\frac{\partial \mathbf{u}}{\partial t} + i f_c \mathbf{u} + r\mathbf{u} = \frac{1}{\rho}\frac{\partial \boldsymbol{\tau}}{\partial z}$$

Ekman theory

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

as a function of Coriolis freq. (latitude)

$$\lambda = \sqrt{[i(\sigma + f_c) + r]/\nu}$$

Wind-current responses in latitude

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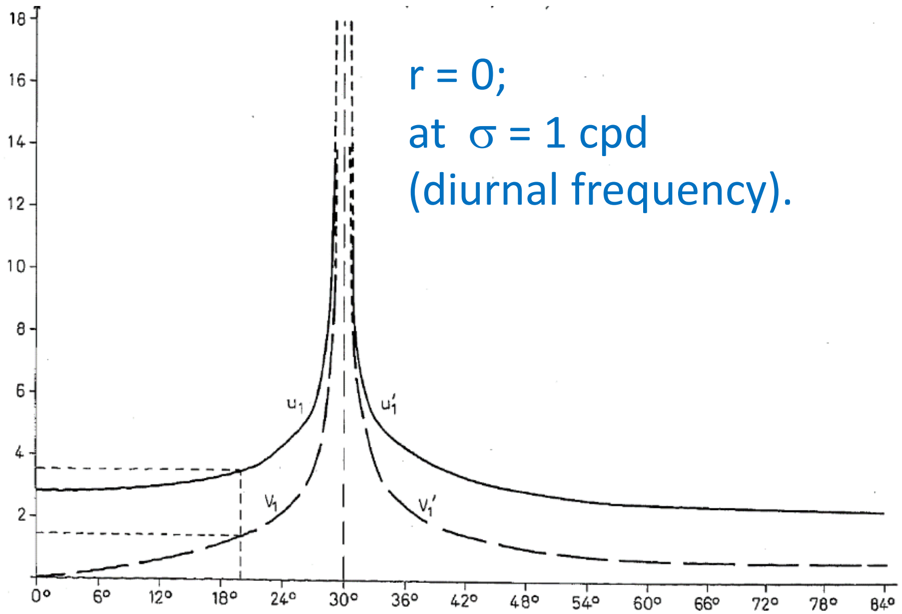
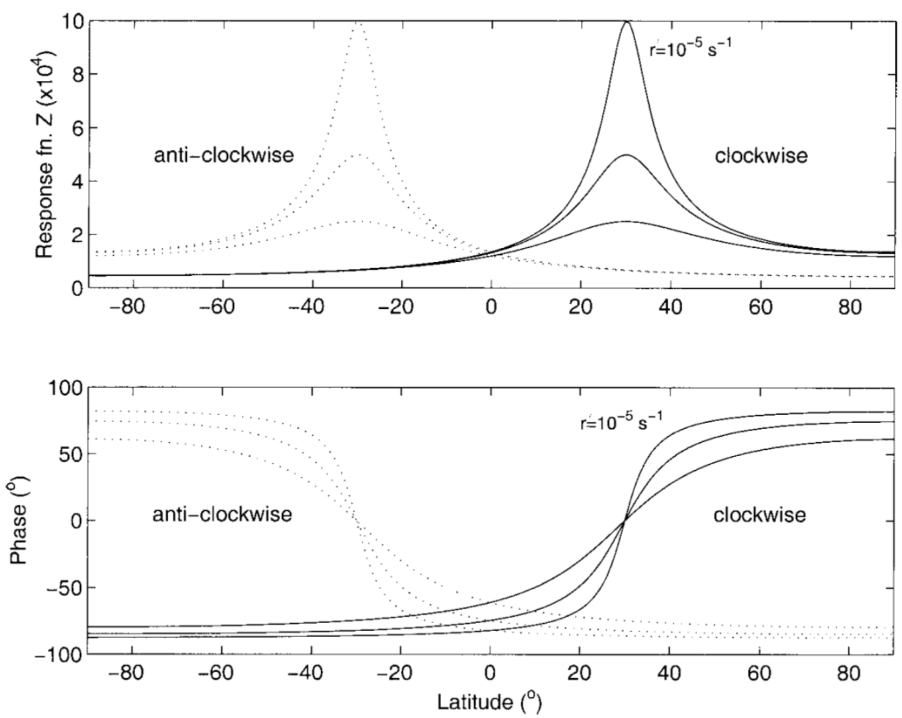


r = 0;
at σ = 1 cpd
(diurnal frequency).

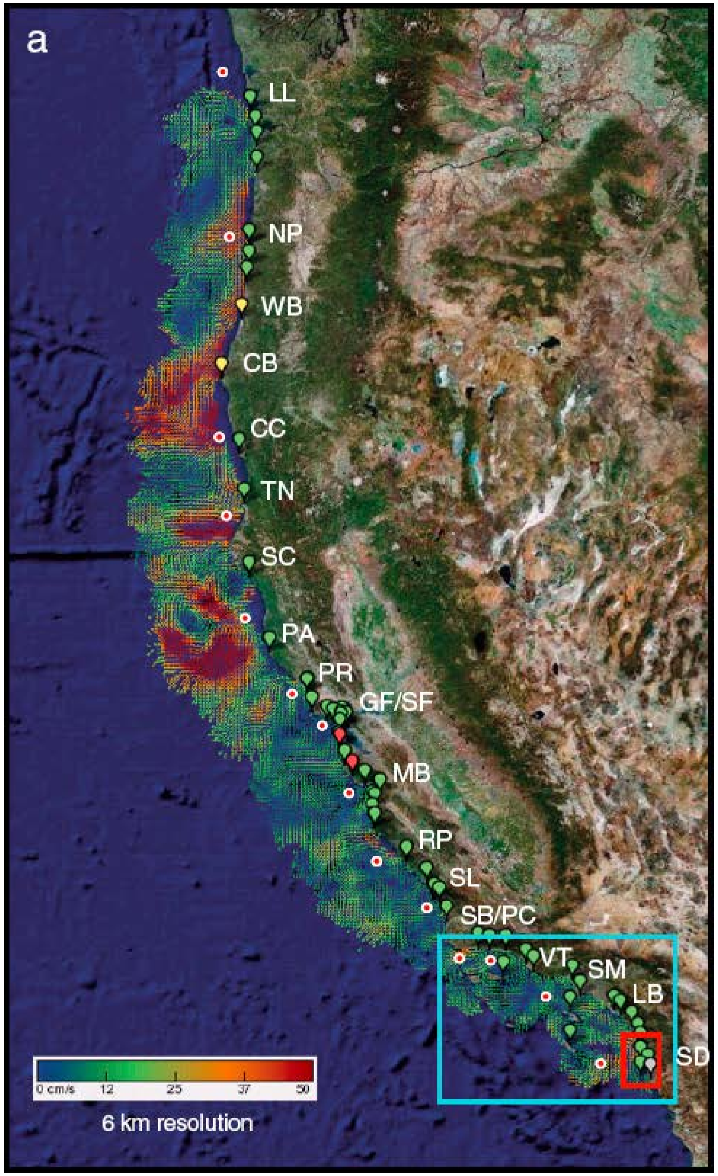
Shaffer, 1972; Ekman model



Simpson et al, JPO 2002 (Slab layer model)

Resonant latitude due to land/sea breeze: ±30°N

Latitudinal coastal observations



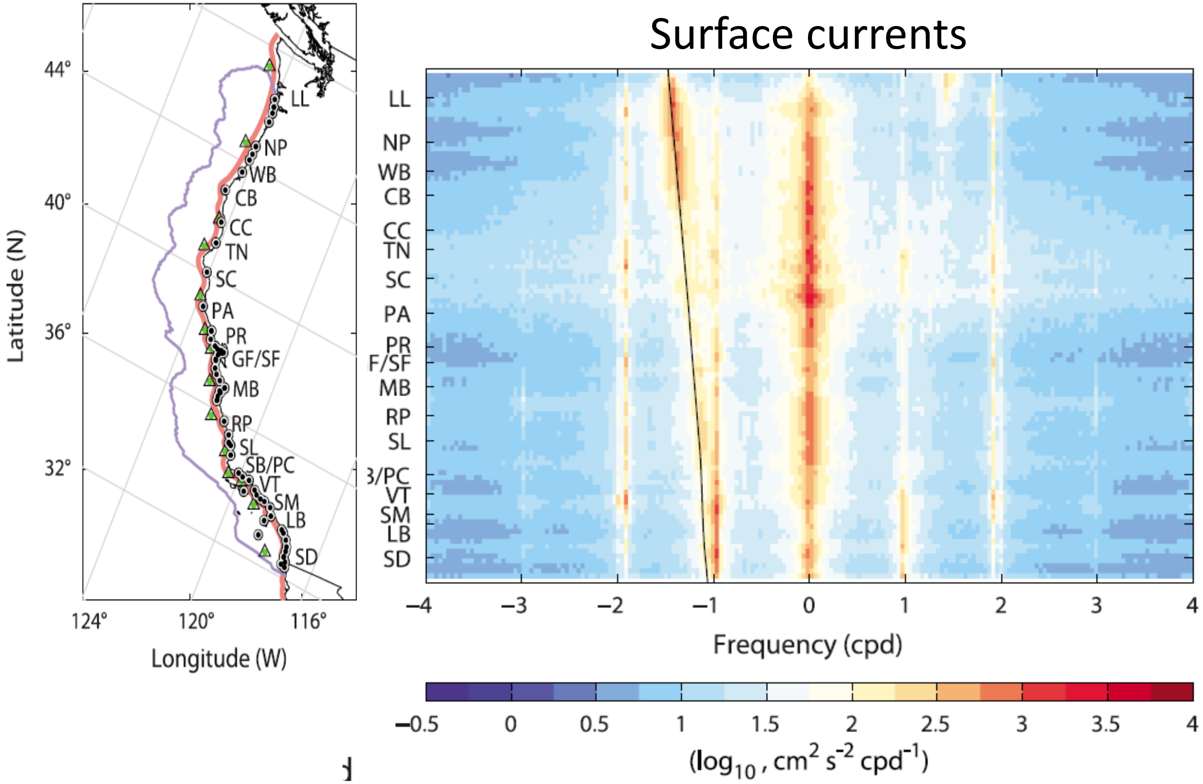
- US West Coast high-frequency radar network-derived surface currents and wind stress (red dots) at NDBC buoys.
- Latitudinal variation of 32^{o}N to 47^{o}N

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

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

$\mathbf{R_a}$: Regularization matrix

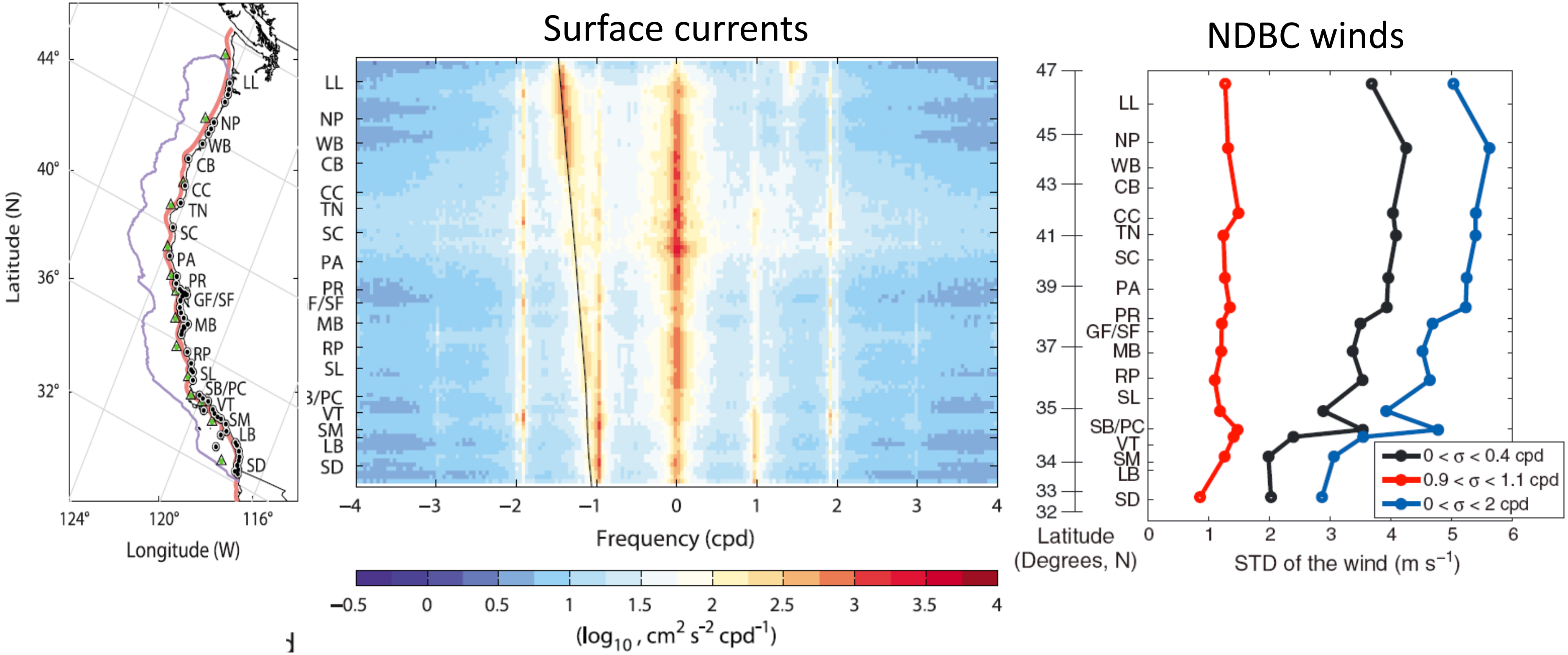
Variability of surface currents and wind



- Wind- and tide-coherent, low-frequency variance, and inertial variance

Kim *et al* (JGR, 2011)

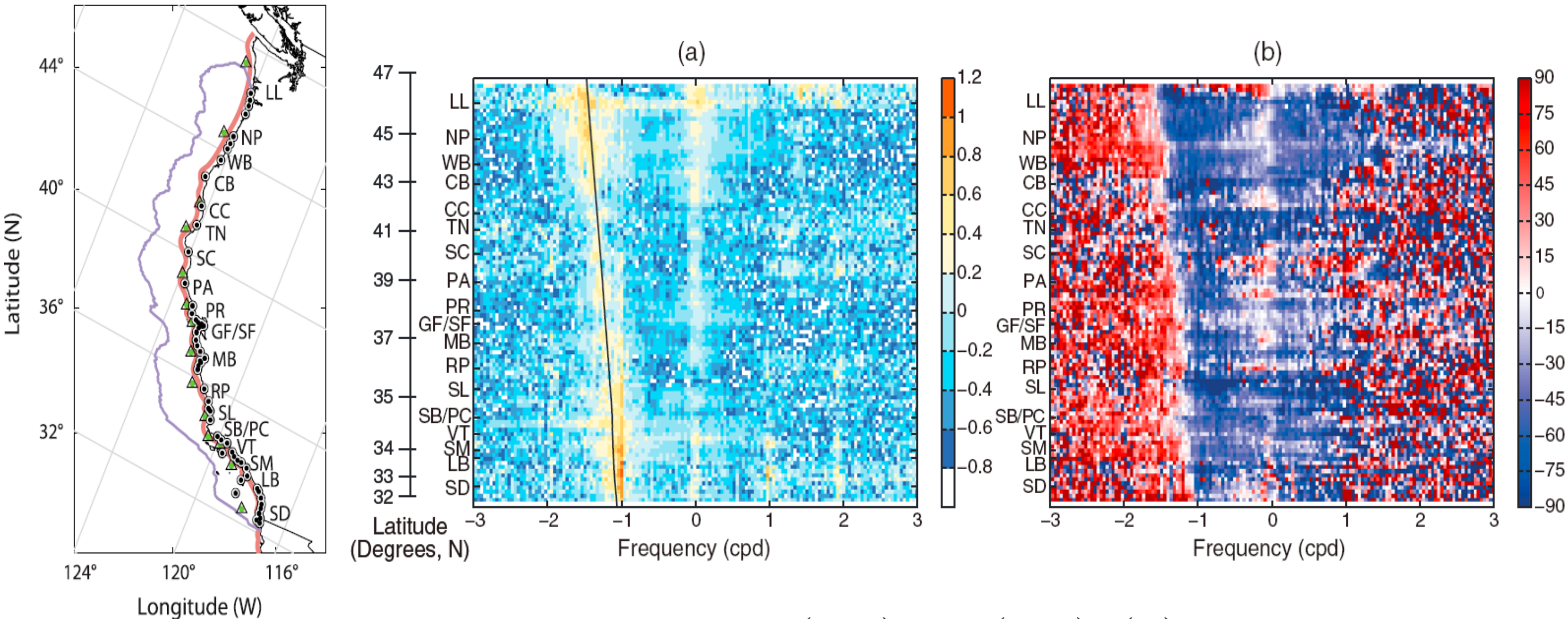
Variability of surface currents and wind



- Wind- and tide-coherent, low-frequency variance, and inertial variance
- Variance of the diurnal wind does not vary that much in the along-shore direction, but it is given as a function of distance from the shoreline (cross-shore direction).

Kim *et al* (JGR, 2011)

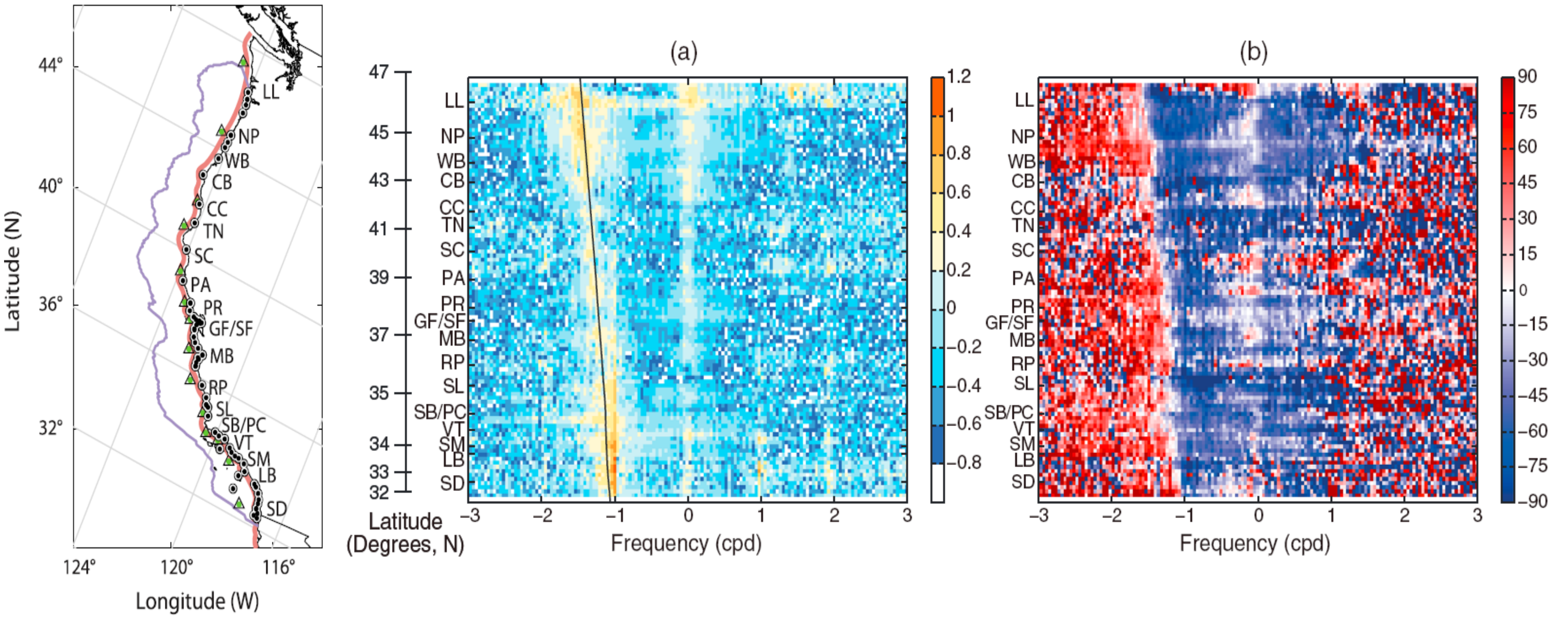
Coast-wide wind transfer functions



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

(Kim and Crawford, *GRL 2014*)

Coast-wide wind transfer functions



- At a given latitude, what would be the wind-current response in the frequency domain?
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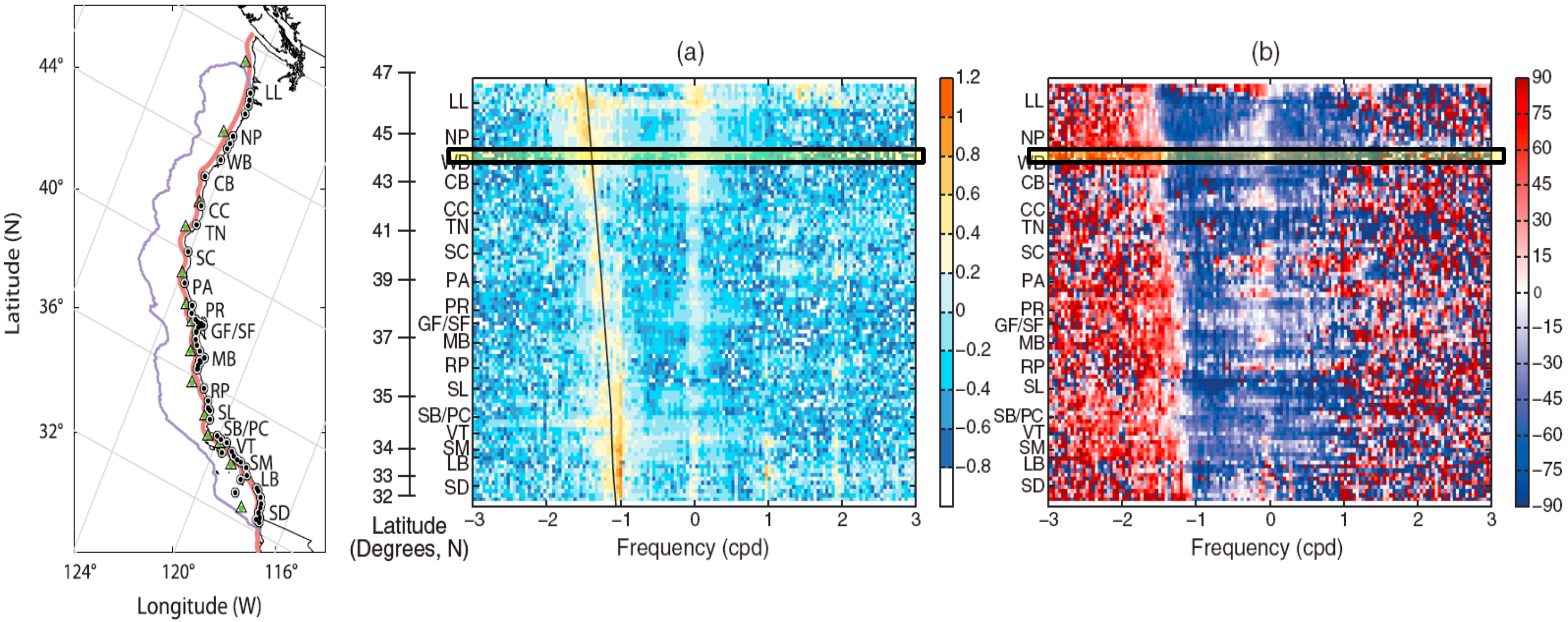
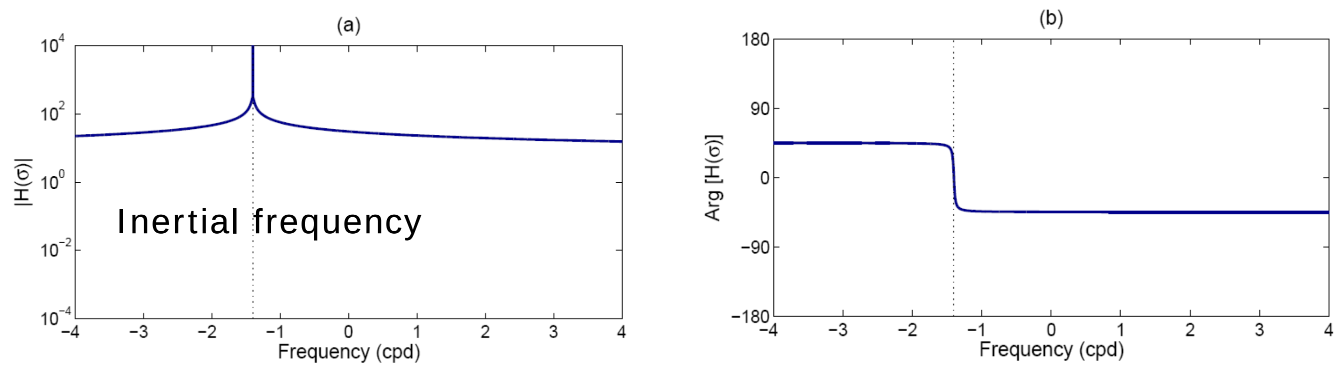
Coast-wide wind transfer functions





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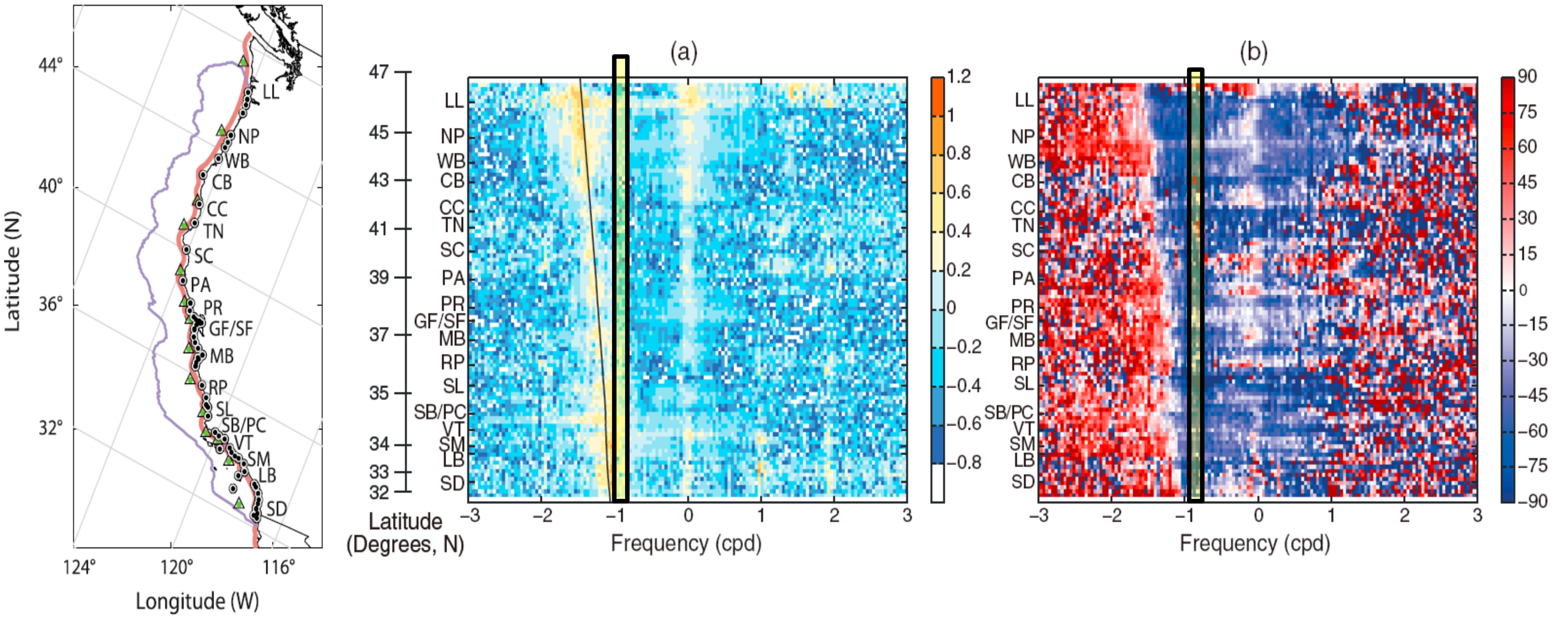
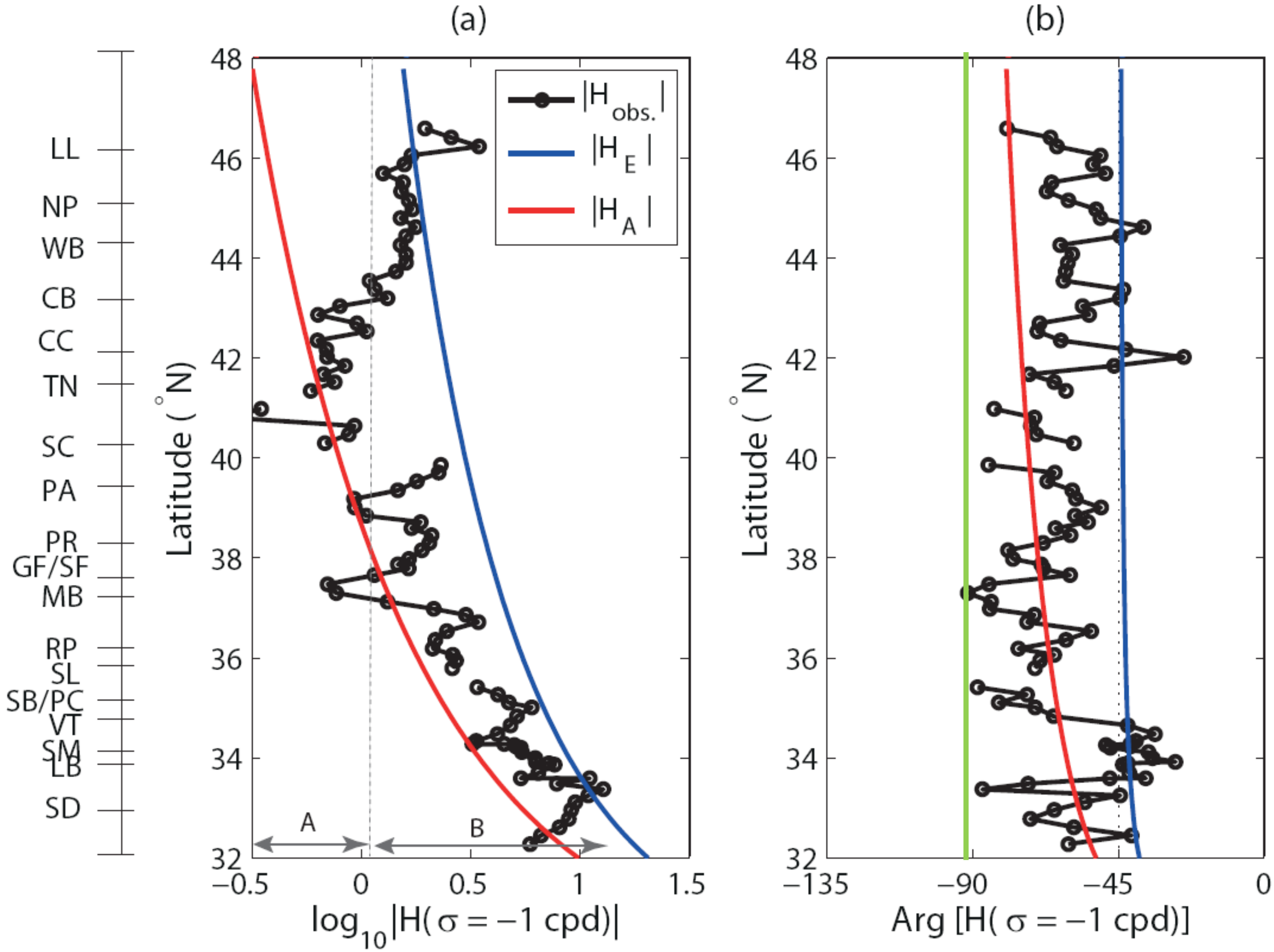
Coast-wide wind transfer functions



(Kim and Crawford, *GRL 2014*)

Resonant responses near the critical latitude



Slab layer model

Z = 0 (Ekman)

$Z = 0.35\delta_E$(Near-surface avg. Ekman)

Resonant latitude due to land/sea breeze: ±30°N

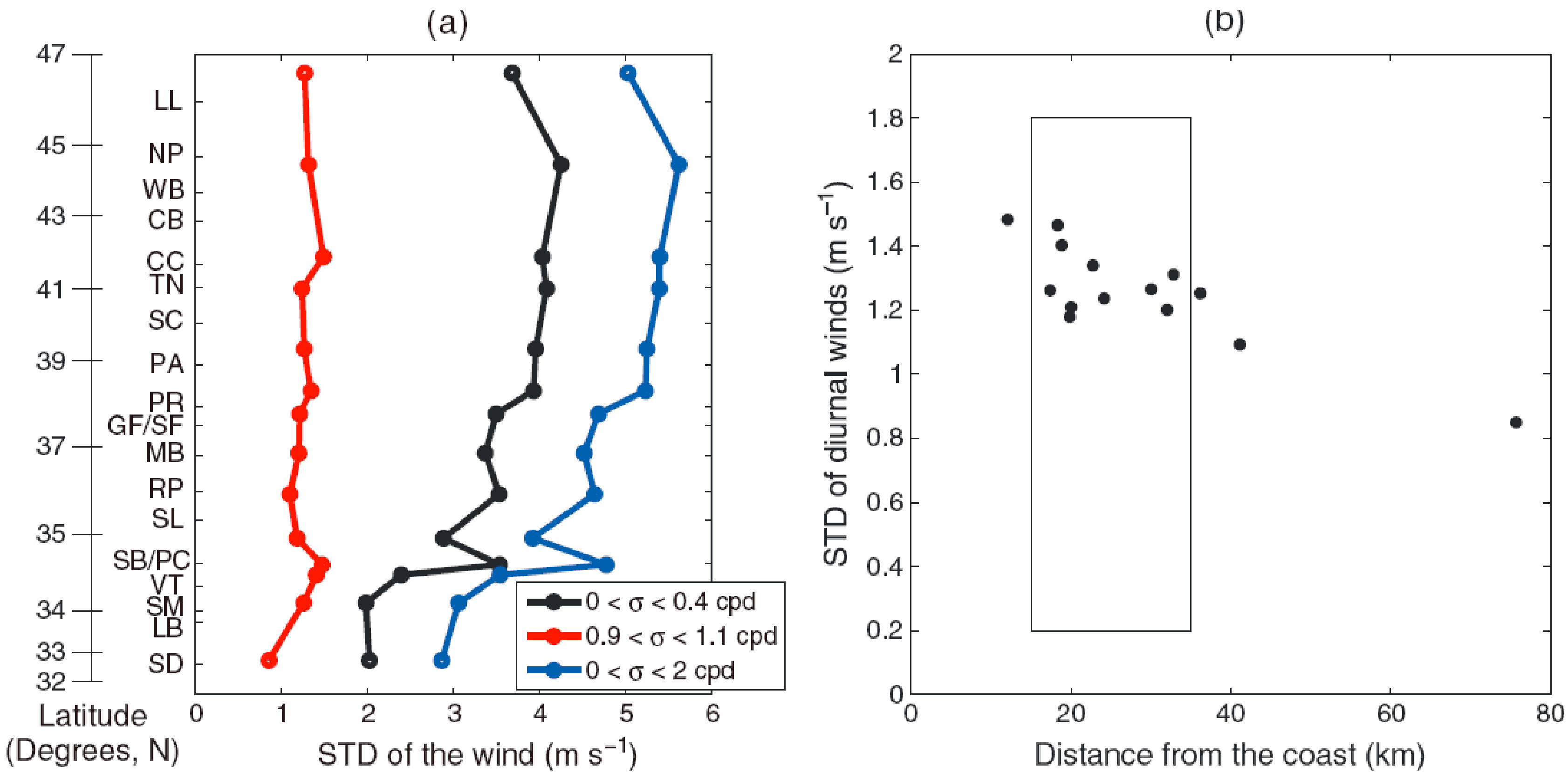
Summary

- Wind-current responses are examined in the frequency domain and latitude using analytic solutions of Ekman model (and slab layer and surface-averaged Ekman models) and observations off the US West Coast.
- The current responses are enhanced at the local inertial frequency.
- Resonant responses can be expected at the +/-30^o latitude in the diurnal land-sea breeze environment.
- Energetic mixing and potential internal motions near the critical latitude are expected.

BACKUP SLIDES

Wind variability

- Variance of the diurnal wind does not vary that much in the along-shore direction, but it is given as a function of distance from the shoreline (cross-shore direction).



Resonant responses at the critical latitude

$$\frac{\partial \mathbf{u}}{\partial t} + if_c\mathbf{u} + r\mathbf{u} = \frac{1}{\rho}\frac{\partial \tau}{\partial z}$$

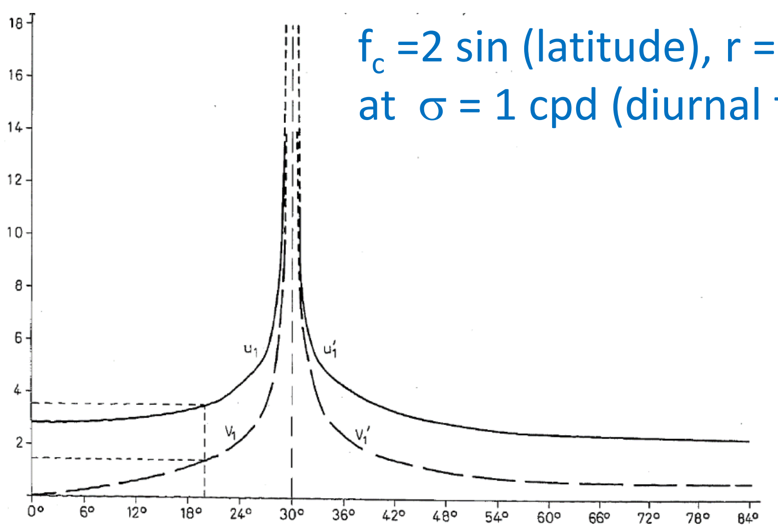
$$\mathbf{H_E}(z,\sigma) = \frac{\hat{\mathbf{u}}(z,\sigma)}{\hat{\tau}(\sigma)} = \frac{e^{\lambda z}}{\lambda \rho \nu}$$

$$\lambda = \sqrt{[i(\sigma + f_c) + r]/\nu}$$

$$\frac{\partial \mathbf{u}}{\partial t} + if_c\mathbf{u} + r\mathbf{u} = \frac{\tau^W}{\rho h}$$

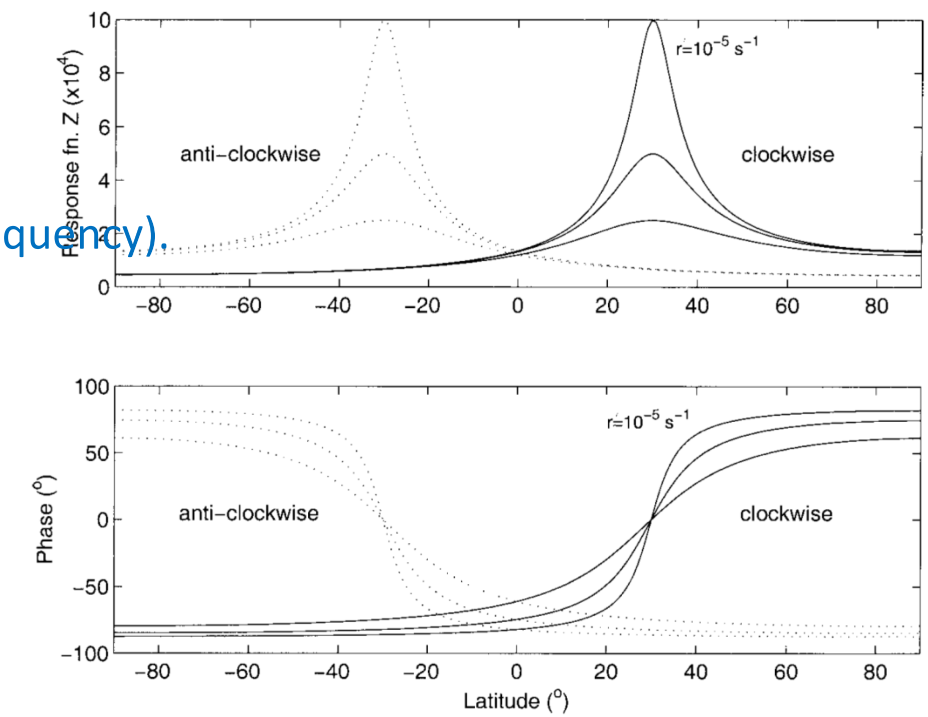
$$\mathbf{H_S}(\sigma) = \frac{\hat{\mathbf{u}}(\sigma)}{\hat{\tau}(\sigma)} = \frac{1}{\rho h[i(\sigma + f_c) + r]}$$

f_c =2 sin (latitude), r = 0;
at σ = 1 cpd (diurnal frequency).



Latitude (N)

Shaffer, 1972; Ekman model



Simpson et al, JPO 2002 (Slab layer model)

Resonant latitude due to land/sea breeze: ±30°N

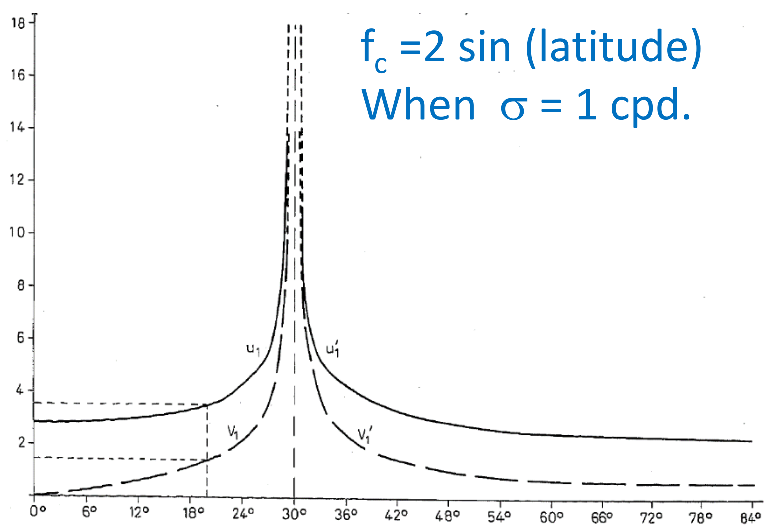
Resonant responses at the critical latitude

$$\frac{\partial \mathbf{u}}{\partial t} + i f_c \mathbf{u} + r\mathbf{u} = \frac{1}{\rho}\frac{\partial \tau}{\partial z}$$

$$\mathbf{H_E}(z,\sigma) = \frac{\hat{\mathbf{u}}(z,\sigma)}{\hat{\tau}(\sigma)} = \frac{e^{\lambda z}}{\lambda \rho \nu}$$

$$\lambda = \sqrt{[i(\sigma + f_c) + r]/\nu}$$

$$\mathbf{H}_A(\sigma) = \frac{1}{z^*}\int_0^{z^*} \mathbf{H}_E(z,\sigma)\,dz, = \frac{1}{z^*}\frac{1}{\lambda^2 \rho \nu}\left(e^{\lambda z^*} - 1\right),$$



f_c =2 sin (latitude)
When σ = 1 cpd.

Latitude (N)

Shaffer, 1972; Ekman model

Near-surface averaged Ekman model can be appropriate to explain the HFR-derived surface currents.

Resonant latitude due to land/sea breeze: ±30°N