The ocean mesoscale regime of the reduced-gravity quasi-geostrophic model*

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The ocean mesoscale regime

1. Altimeter SSH wavenumber-frequency power spectra show evidence of nondispersive propagation, but linear dispersive deviations would only be expected close to resolution limit of AVISO gridded product. Do these spectra show nonlinearity?

2. Eddy identification and tracking ("nonlinear, adaptive, lossy space-time wavelet transform") provides complementary quantitative description that retains phase information. What does this description imply when used to constrain a dynamical model?

3. The simplest quasigeostrophic models show a very wide range of quantitative regimes. Can a regime be identified that is a good representation of the mid-latitude mean mid-ocean mesoscale?

SSH wavenumber-frequency power spectrum

AVISO gridded altimeter data

(Early et al. 2011)

Linear theory (dispersive at short wavelengths)
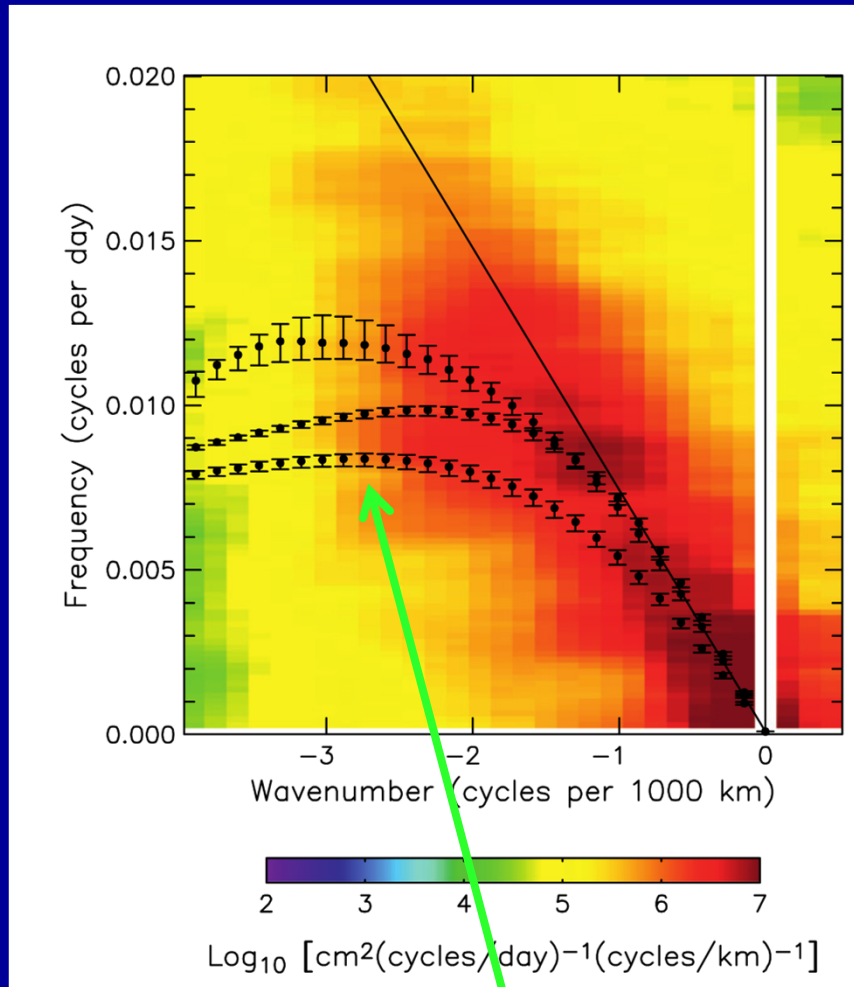
Non-dispersive propagation at long-wave speed (approximately), apparently indicating (weakly) nonlinear dynamical balance

Does the nondispersive line end because the resolution limit of the data is reached?

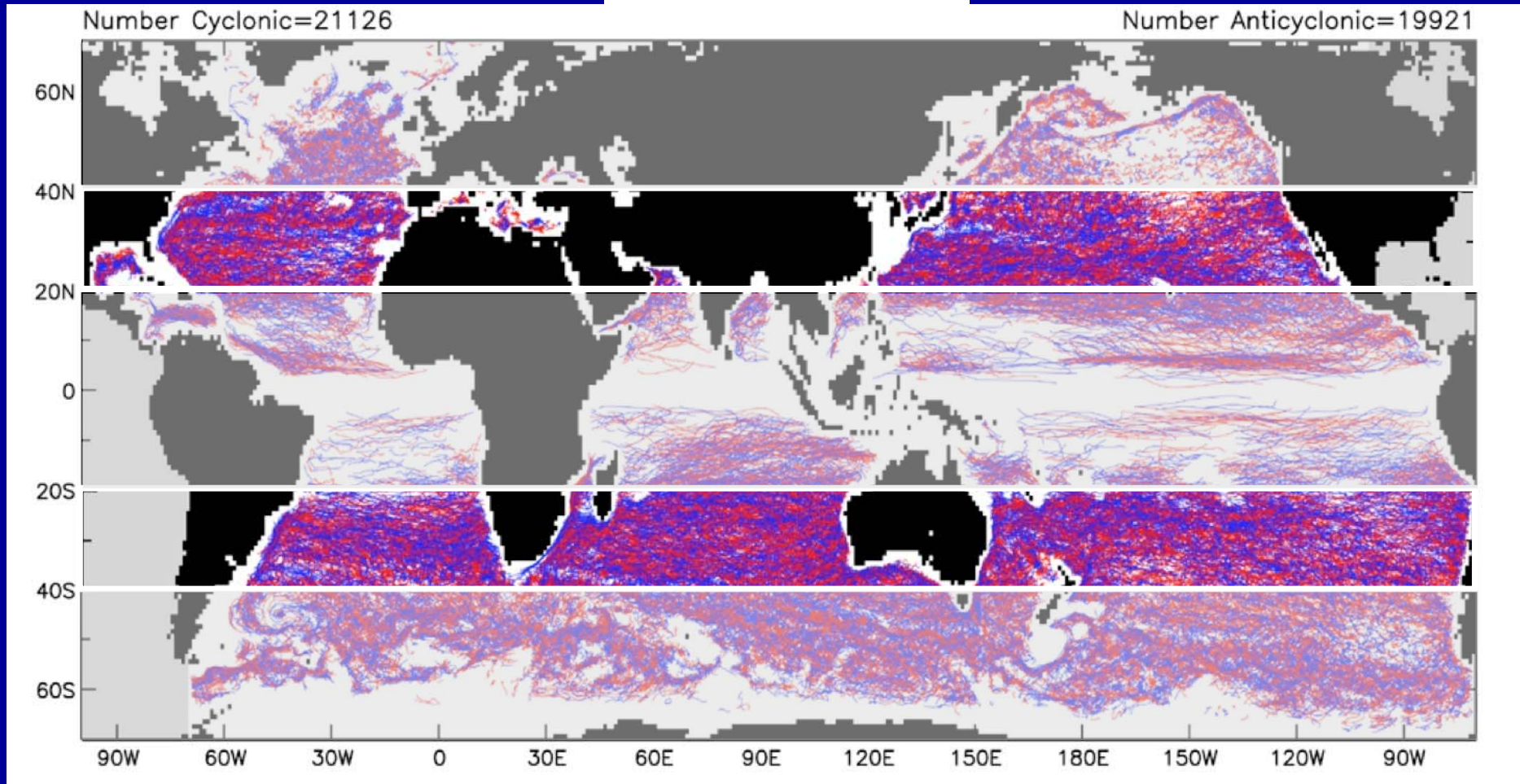Would we see linear dispersion at smaller scales?

Cyclonic and Anticyclonic Eddies with Lifetimes ≥ 16 weeks
(41,047 total)

Chelton, D. B., M. G. Schlax, and R. M. Samelson, 2011. *Progress in Oceanography*, 91, 167-216.
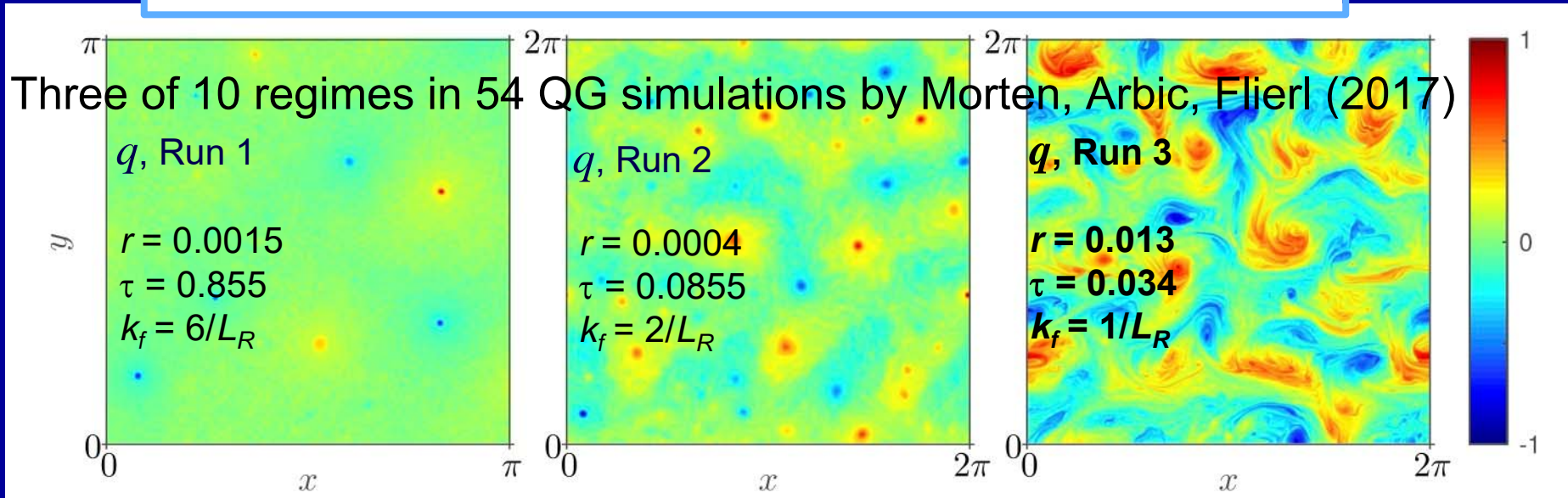
Now available through AVISO: https://www.aviso.altimetry.fr/en/data/products/value-added-products.html

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The reduced-gravity quasigeostrophic model with stochastic forcing

$$\frac{\partial}{\partial t}(\nabla^2\psi - \psi) + \beta\frac{\partial\psi}{\partial x} = -J(\psi, \nabla^2\psi) + \frac{\mathcal{F}_{0,\tau}}{\tau^{1/2}} - r_\psi\psi + \mathcal{D}_{ens}$$

Three of 10 regimes in 54 QG simulations by Morten, Arbic, Flierl (2017)

q, Run 1

$r = 0.0015$
$\tau = 0.855$
$k_f = 6/L_R$

q, Run 2

$r = 0.0004$
$\tau = 0.0855$
$k_f = 2/L_R$

q, Run 3

$r = 0.013$
$\tau = 0.034$
$k_f = 1/L_R$

$\mathcal{F}_{0,\tau}$ is a stochastic forcing function with unit time-mean spatial standard deviation and autocorrelation timescale τ

Three parameters:

$$\beta = \beta_* L_R^2/U_\mathcal{F} \qquad r_\psi = r_{QG*} L_R/U_\mathcal{F} \qquad \tau = \tau_{QG*} U_\mathcal{F}/L_R$$

…plus spatial (wavenumber) structure of $\mathcal{F}_{0,\tau}$

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The ocean mesoscale regime

1. Can a regime be identified that is a good representation of the mid-latitude mean mid-ocean mesoscale?
   Yes.

2. What does the eddy-based description imply when used to constrain a dynamical model?
   Tight constraints on model parameters:

   $$\beta \approx 0.6, \ r_\psi \approx 0.02, \ \tau \approx 1$$

   Stochastic forcing amplitude $1/4 \ \mathrm{cm}^2 \ \mathrm{day}^{-1}$
   SSH damping rate $1/62 \ \mathrm{week}^{-1}$
   Stochastic forcing timescale   1 week

3. Do the altimeter wavenumber-frequency spectra show evidence of nonlinearity?
   Yes.

Fit QG model parameters

Deformation radius
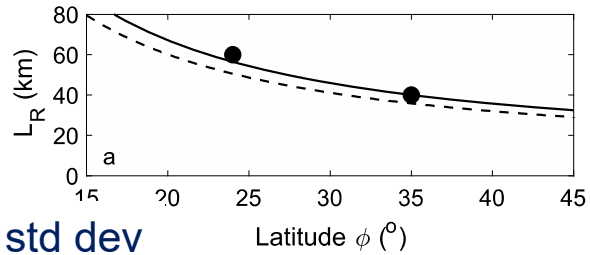
SSH std dev
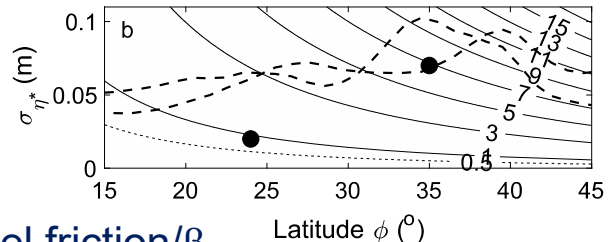
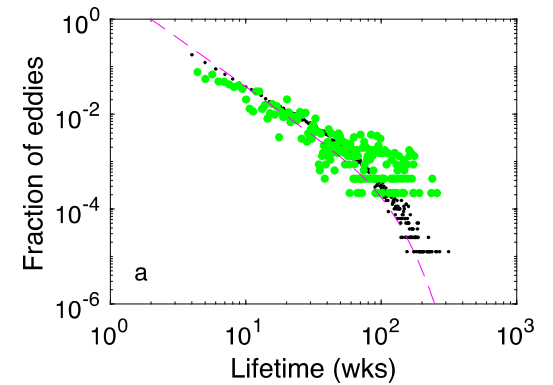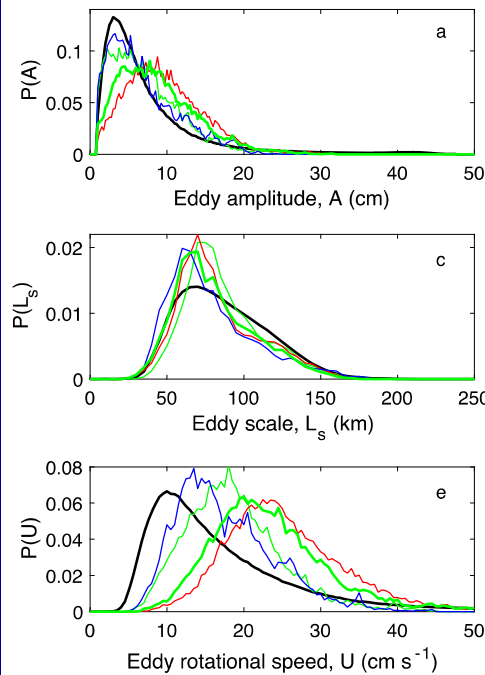### Model friction/β
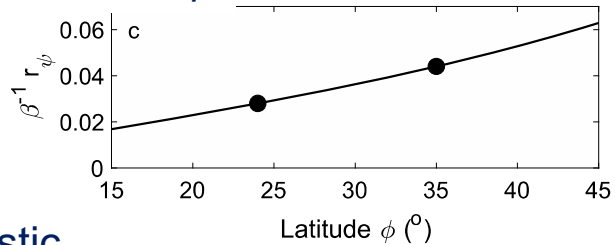
Stochastic amp. response
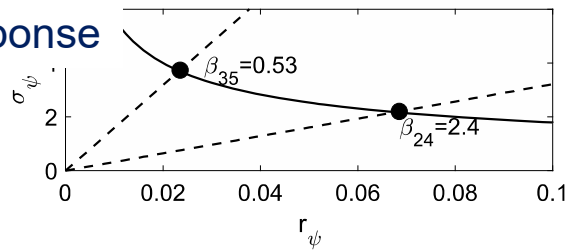
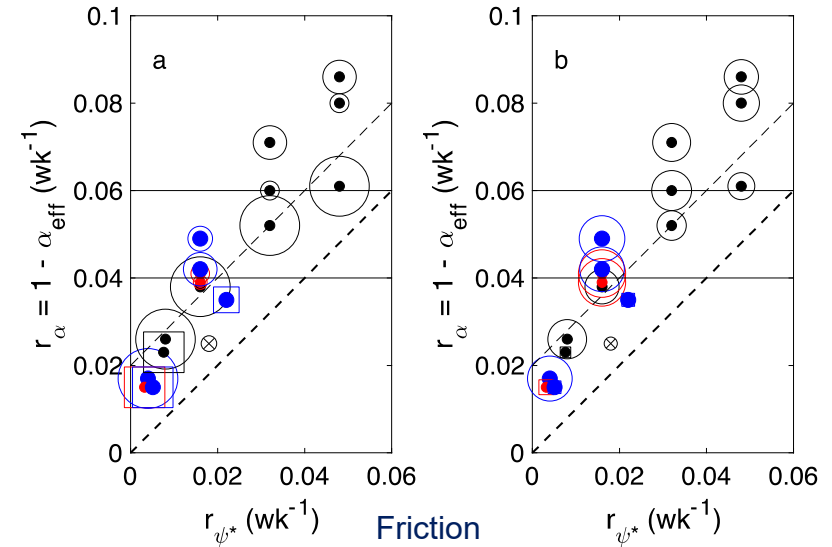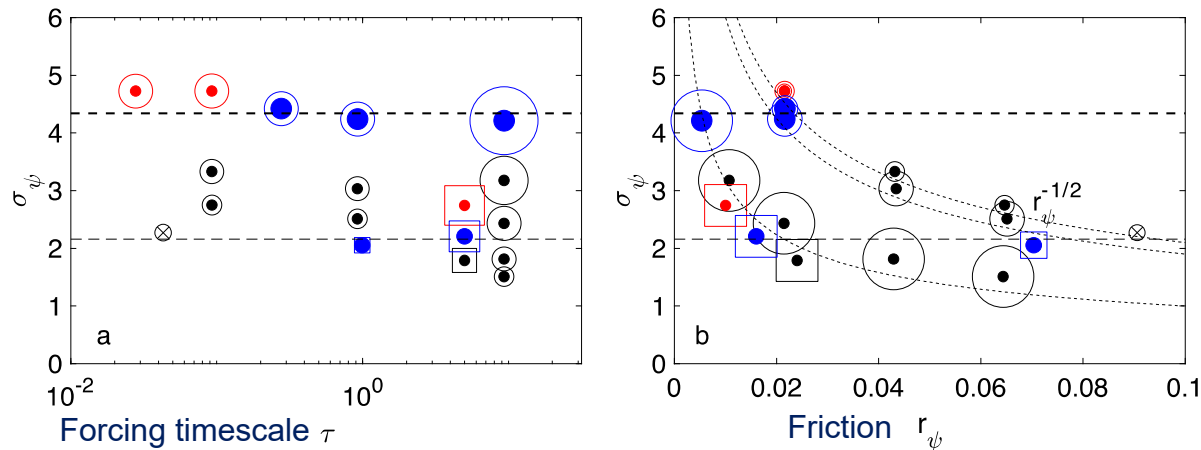## SSH autocorrelation along long-wave characteristics
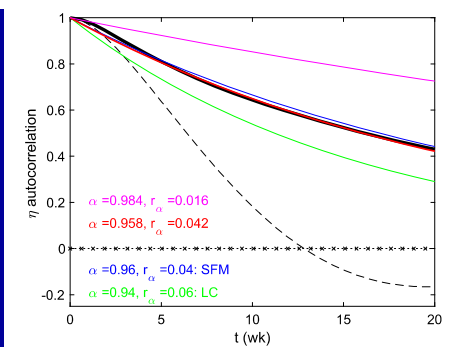
Eddy statistics

Fit QG model parameters

Morten et al. 2017
Run 3

Best fit

Friction r_ψ

Forcing timescale τ
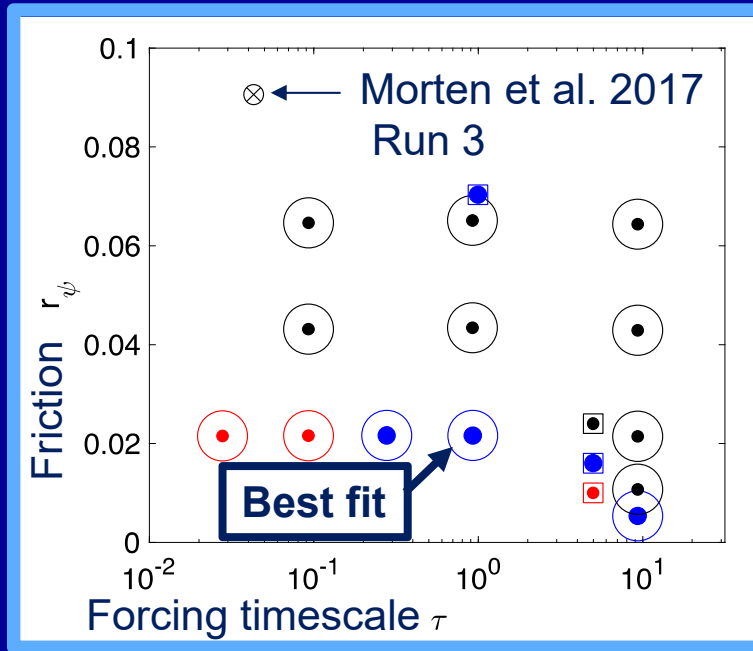
QG simulations: autocorrelation structure

a

$r_\alpha = 1 - \alpha_{eff}$ (wk^{-1})

$r_{\psi*}$ (wk^{-1})

Friction

b

$r_\alpha = 1 - \alpha_{eff}$ (wk^{-1})

$r_{\psi*}$ (wk^{-1})

QG simulations: amplitude response

σ_ψ

a

Forcing timescale τ

σ_ψ

b

$r_\psi^{-1/2}$

Friction r_ψ

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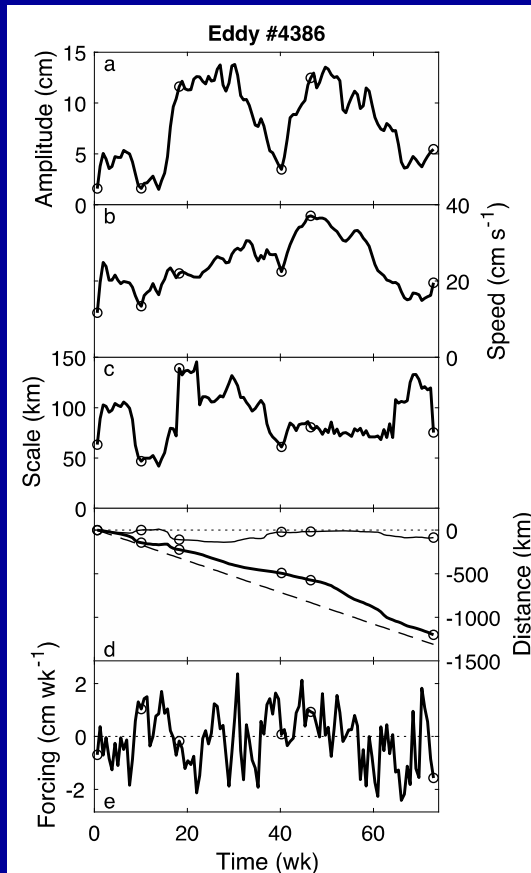Chicago, Illinois

QG eddy phenomenology
Example: eddy #4386
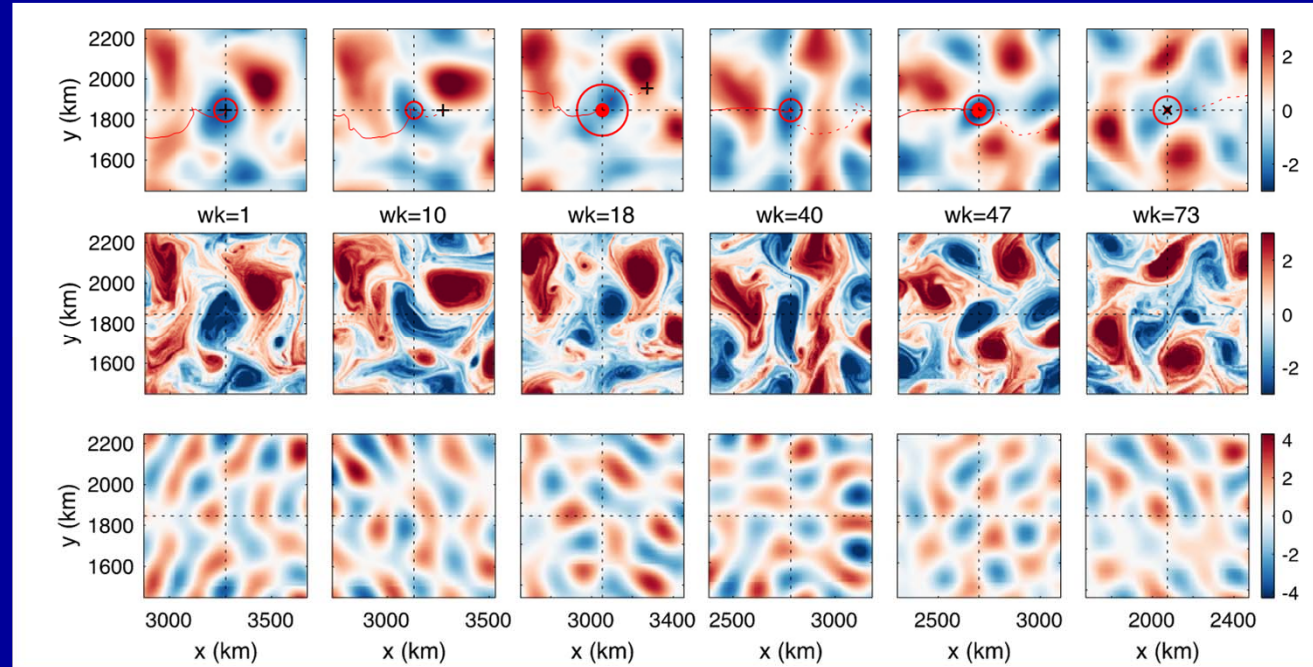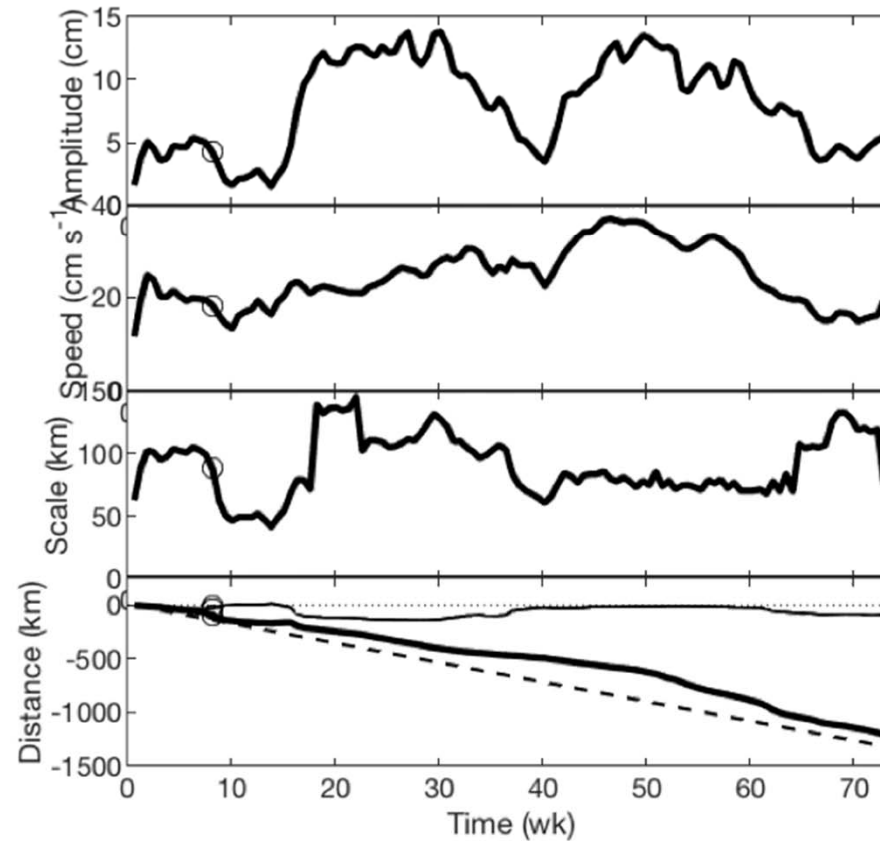

Not a classical baroclinic wave growth and decay lifecycle.
Instead, random nonlinear interactions dominate.

$q(t=3400.0d)/q_0, q_0=2\pi\beta$
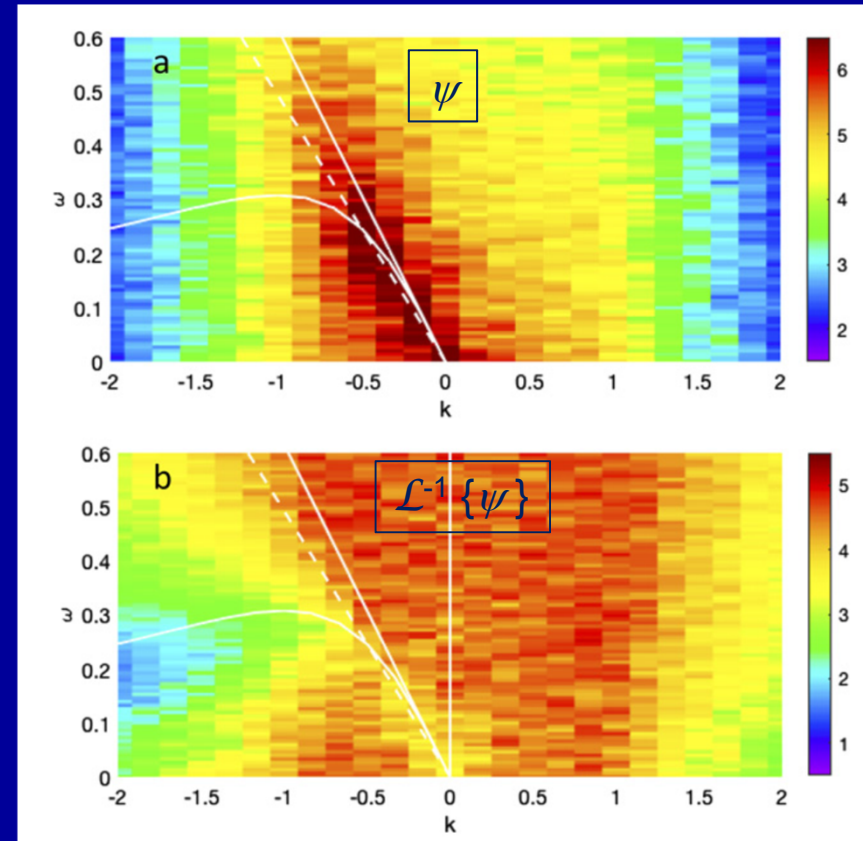
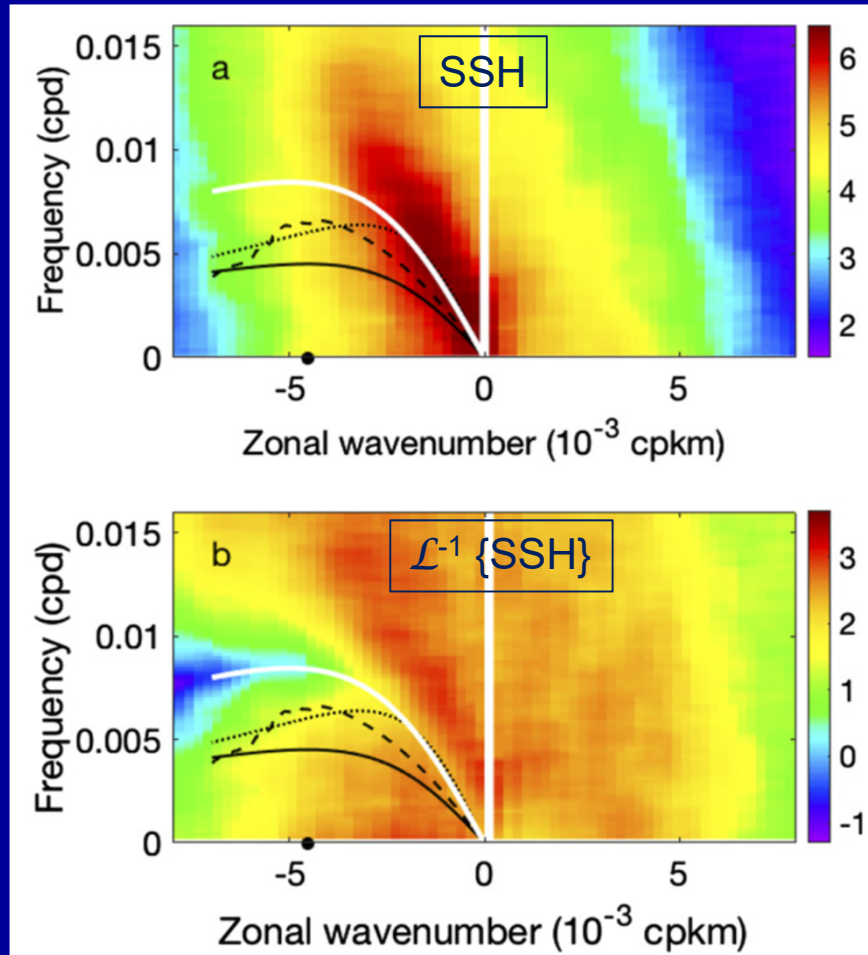$q_{thick}(t=3400.0d)/q_0, q_0=2\pi\beta$
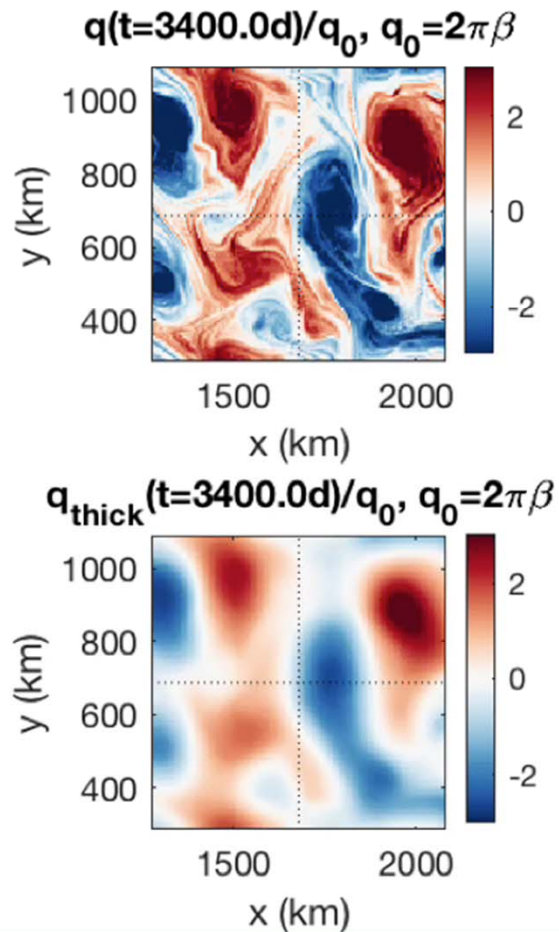
Wavenumber-frequency spectra

AVISO
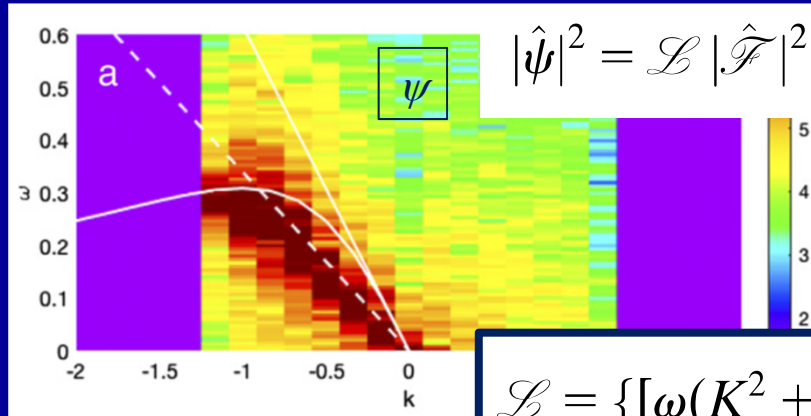
QG simulation

Wavenumber-frequency spectra

Linear QG simulation **QG simulation**

$$|\hat{\psi}|^2 = \mathscr{L} |\hat{\mathscr{F}}|^2$$

$$\mathscr{L} = \{[\omega(K^2 + 1) + \beta k]^2 + r^2\}^{-1}$$

$$|\hat{\mathscr{F}}|^2 = \mathscr{L}^{-1} |\hat{\psi}|^2$$
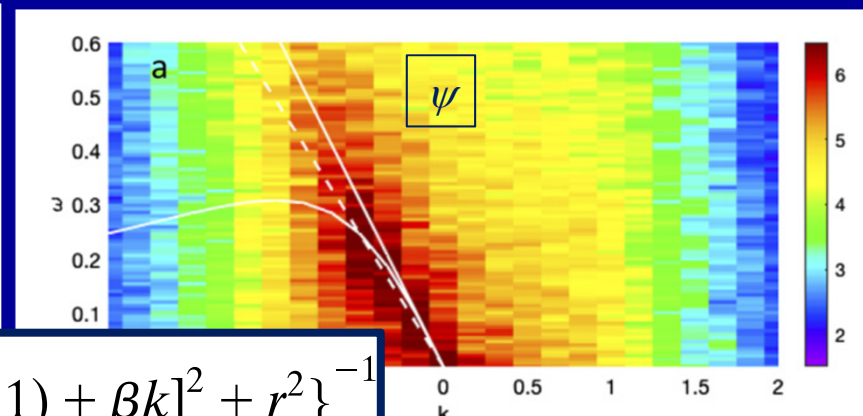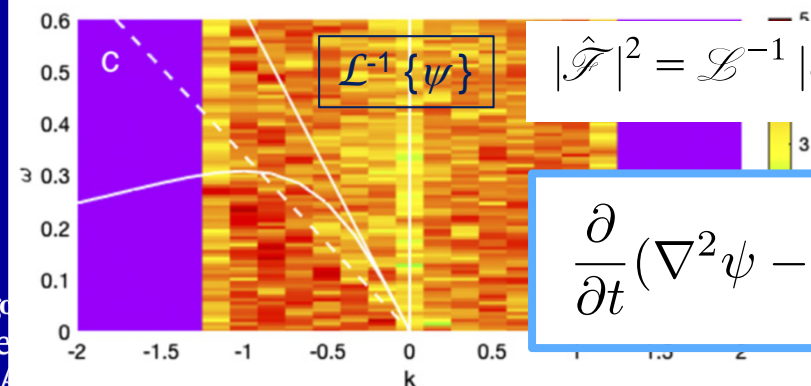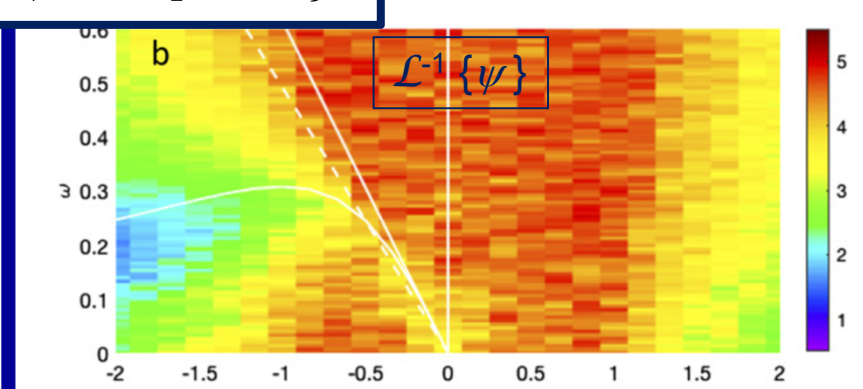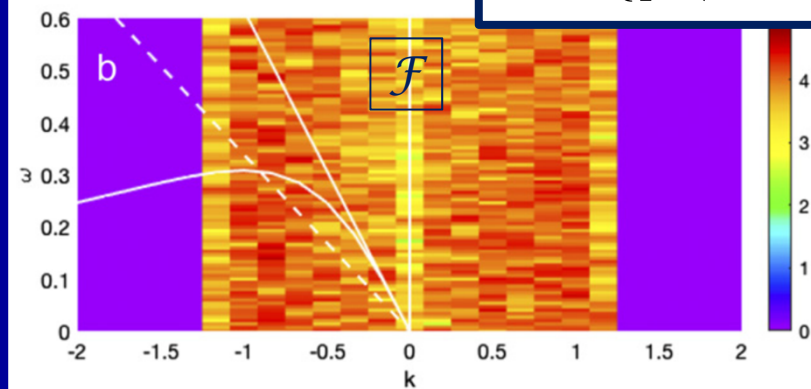
$$\mathscr{L}^{-1} |\hat{\psi}|^2 = |\hat{\mathscr{F}} - \hat{J}|^2$$

$$\frac{\partial}{\partial t}(\nabla^2 \psi - \psi) + \beta \frac{\partial \psi}{\partial x} = -J(\psi, \nabla^2 \psi) + \frac{\mathscr{F}_{0,\tau}}{\tau^{1/2}} - r_\psi \psi$$

Oregon
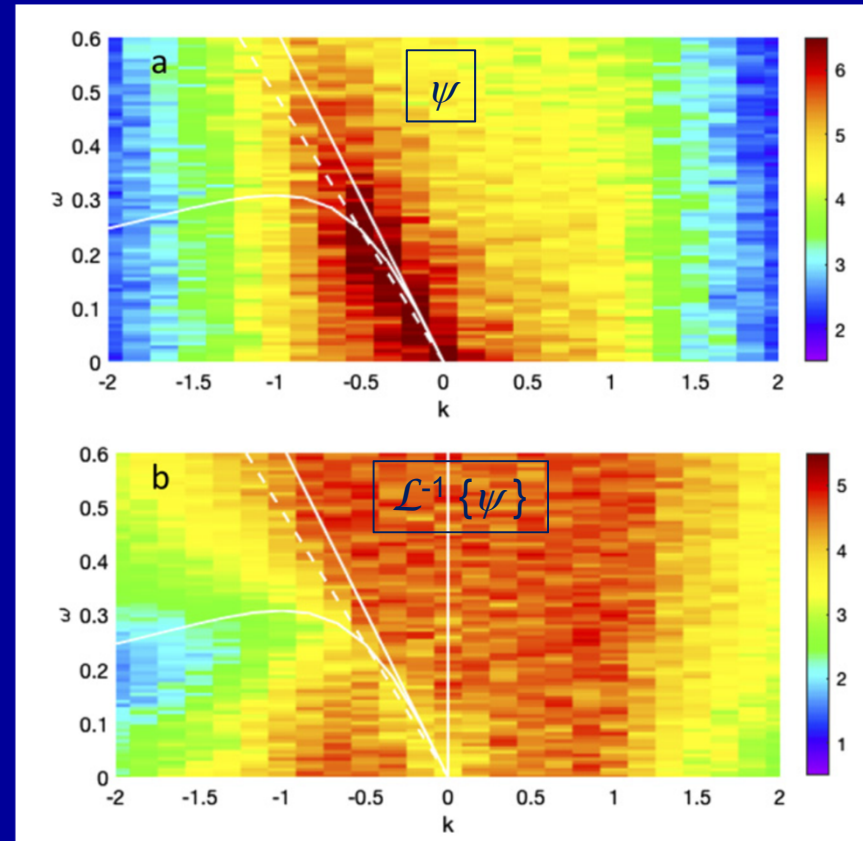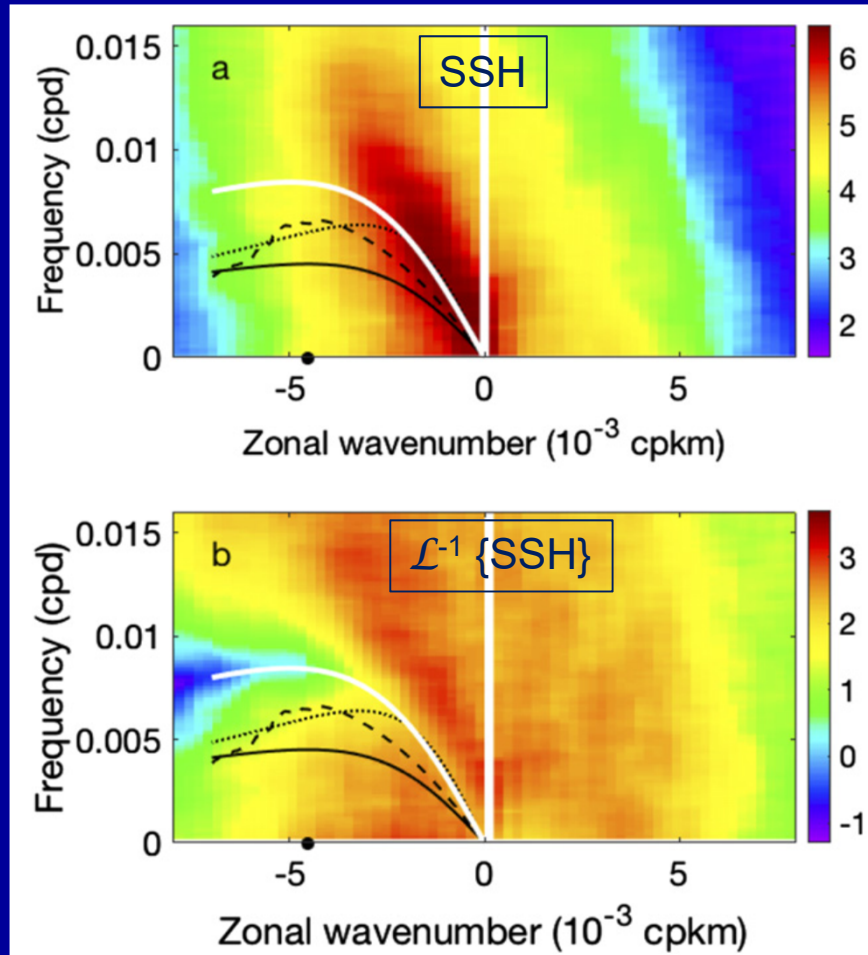Colle
and A

Wavenumber-frequency spectra

AVISO

QG simulation

Nonlinearity removes energy along the linear dispersion relation and deposits it elsewhere.

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# Original and linear-inverted AVISO spectra

model

Xt-smoothed $\tau = 10$, $r = 0.005$ Xt-smoothed
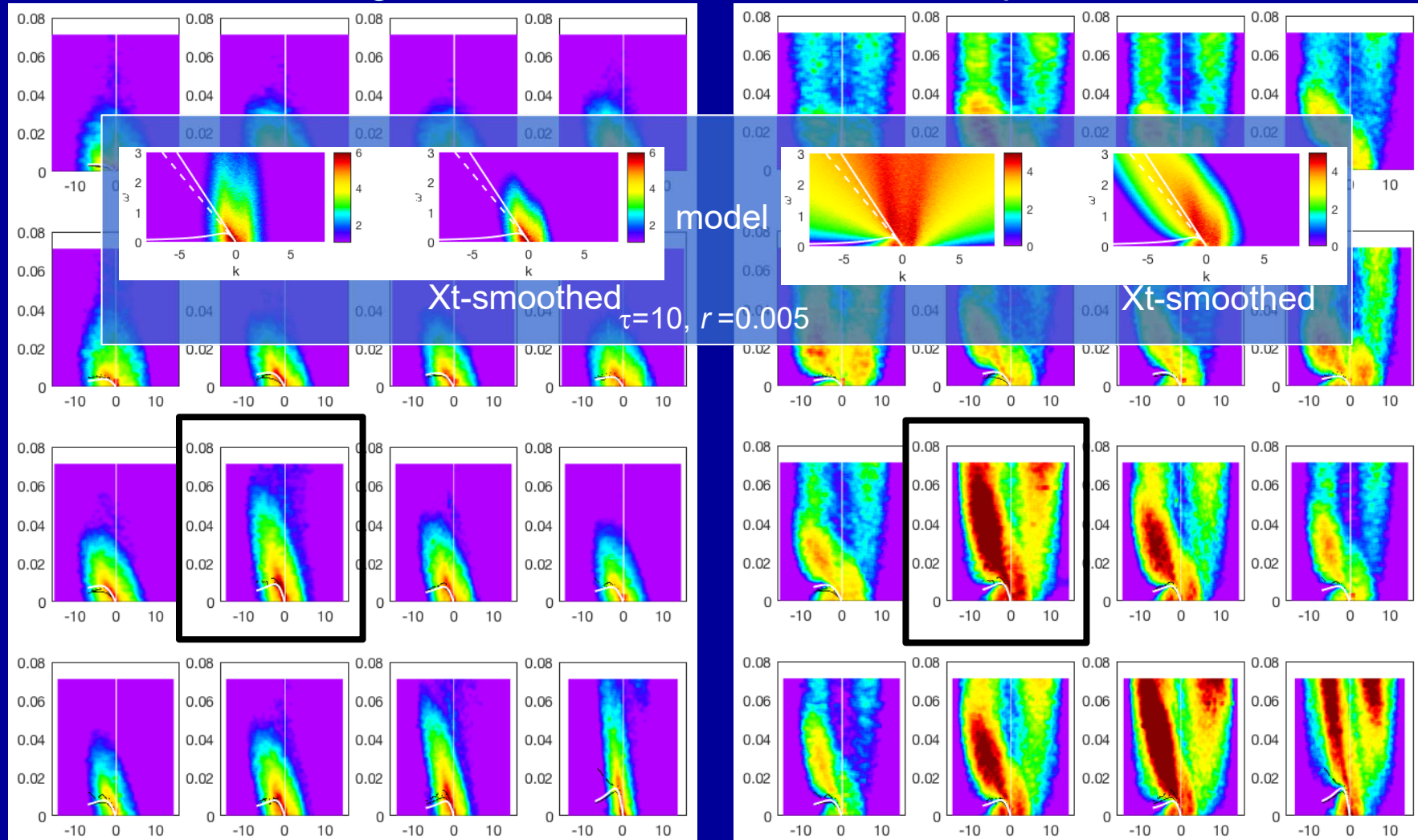
SSH   **Linear-inverted SSH**

Signature of propagating covariance in AVISO objective analysis?

Gridded altimeter SSH from 21-day window objective analysis (2DVAR: variational interpolation in two spatial dimensions) Preliminary results from M. Archer, Z. Li, L.-L. Fu (JPL)[*]

(Fu 2004)

(Samelson et al. 2019)
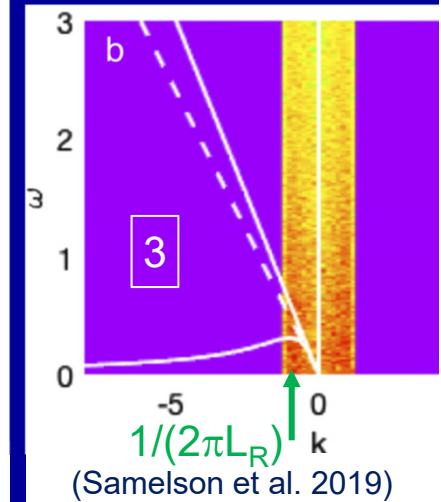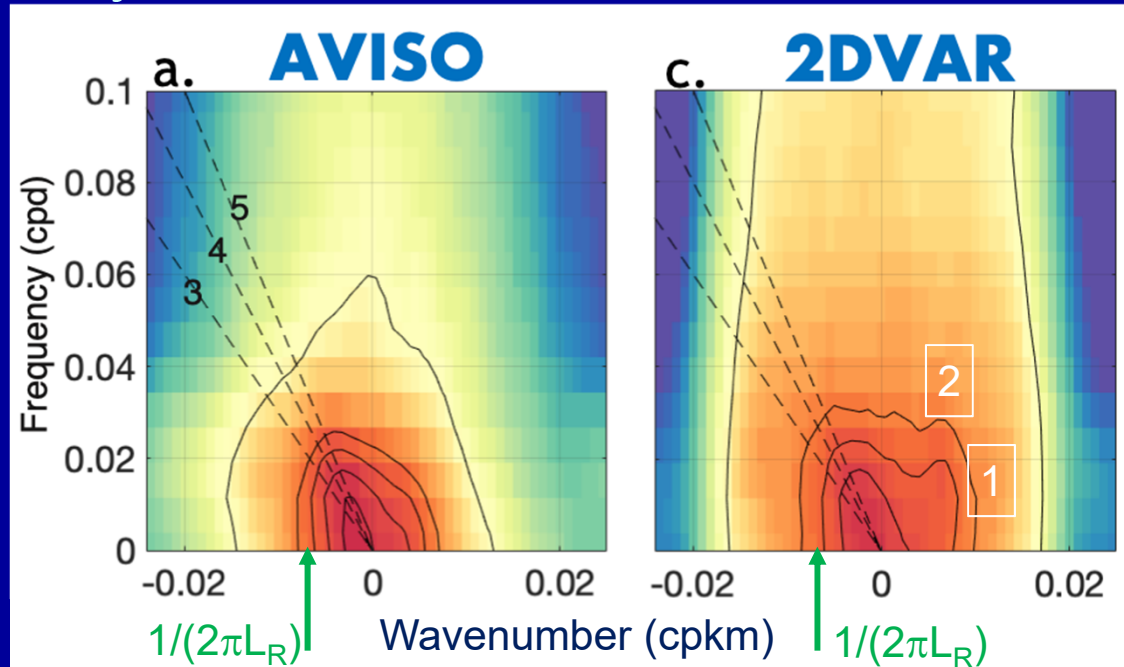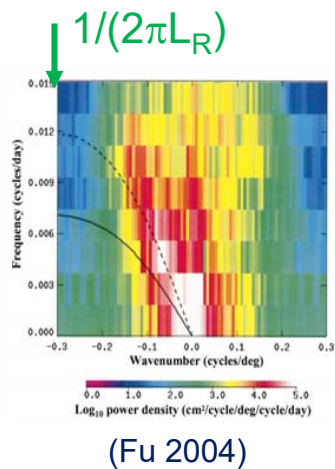
1. Spectral contours away from nondispersive line show little indication of propagation (i.e., are not parallel to ridge).
2. Higher levels away from ridge, and more symmetric across zero wavenumber.
3. Similar to QG model spectra, but with even more high frequency energy.

[*] See also OSTST poster APOP_005, Z. Li, J. Wang, M. Archer, L.-L. Fu

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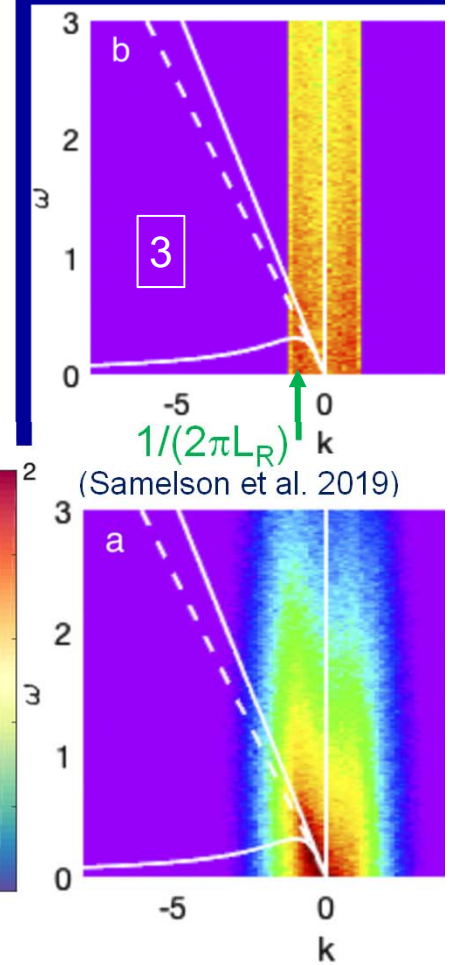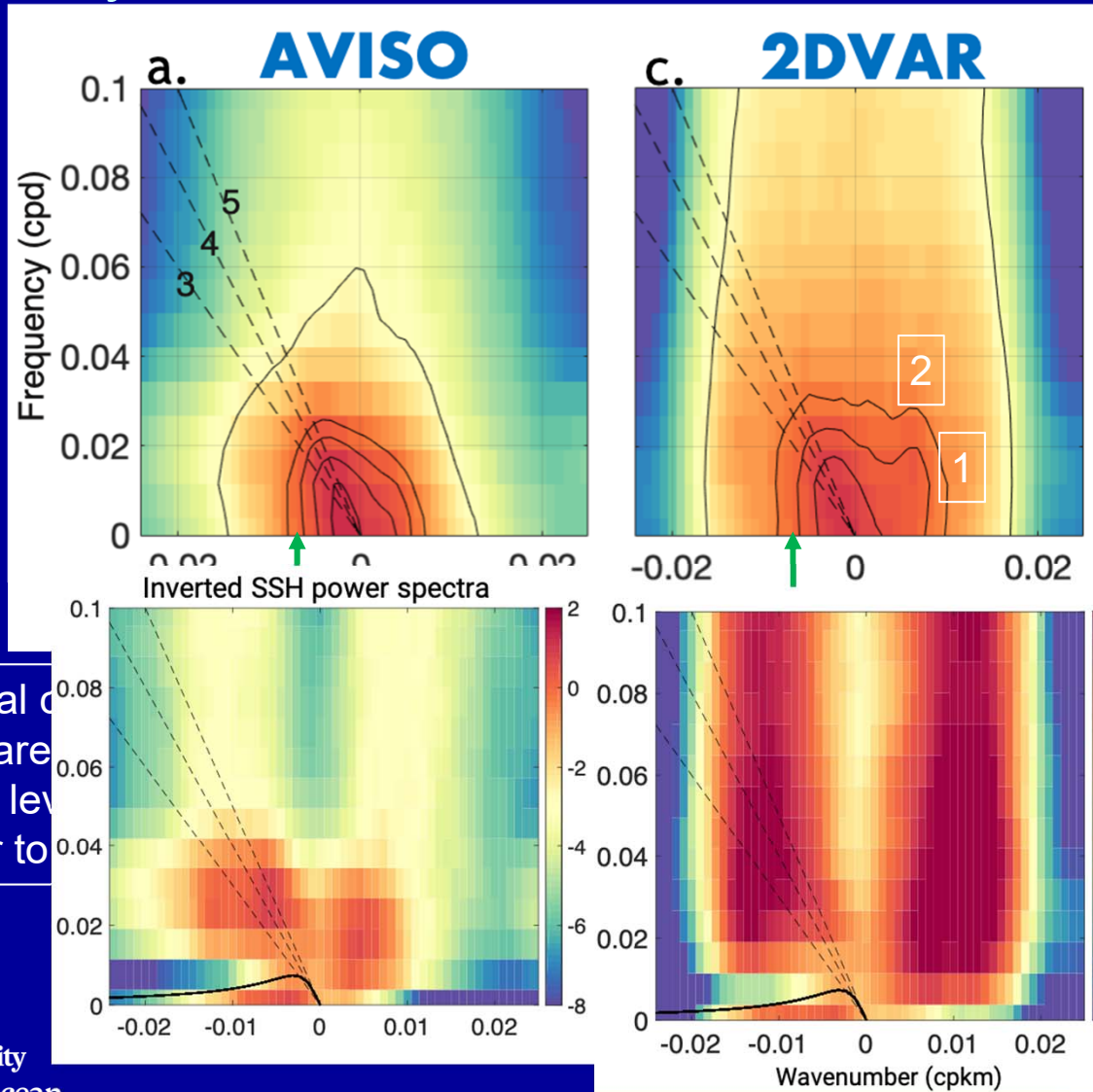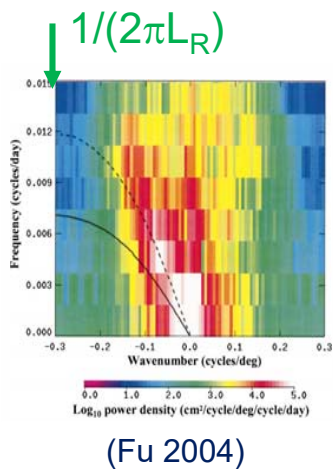cnes NOAA NASA EUMETSAT esa

Gridded altimeter SSH from 21-day window objective analysis (2DVAR: variational interpolation in two spatial dimensions) Preliminary results from M. Archer, Z. Li, L.-L. Fu (JPL)[*]

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3. Do the altimeter wavenumber-frequency spectra show evidence of nonlinearity?

   Yes: nonlinearity removes energy along the linear dispersion relation and deposits it elsewhere.

4. The altimeter SSH record likely contains largely unexplored wavenumber-frequency information at high frequencies and wavenumbers, which is affected by the propagating space-time covariance structure in the AVISO objective analysis: re-examine in context of high-resolution next-generation altimetry (SWOT).