Eddy-driven Low-Frequency Variability: Physics, and Observability through Altimetry

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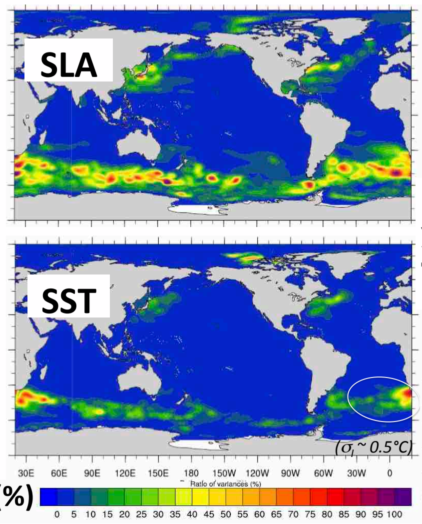
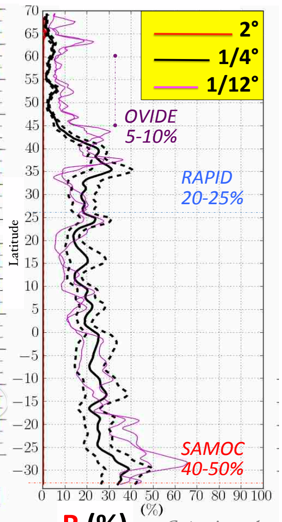
CONTEXT AND OBJECTIVES

Future climate simulators will include eddying rather than laminar oceans. **When eddies are present,** global ocean/sea-ice simulations forced by repeated annual cycles show that **an intermittent, intrinsic low-frequency (LF: interannual-to-multidecadal) oceanic variability emerges spontaneously**, with a **stochastic character, and a strong (large-scale) imprint on SLA, SST and MOC**. This intrinsic variability questions the determinism of ocean LF variability, and suggests that in coupled mode its SST signature might inject low-frequency eddy-driven « noise » into the atmosphere/climate. Here we use a gridded altimeter product, idealized quasi-geostrophic (QG) turbulent simulations, and realistic high-resolution global ocean simulations to study the **spontaneous tendency of mesoscale (high frequency/wavenumber) kinetic energy to non-linearly cascade towards larger time & space scales**.

SIGNAL: NEMO 1/4°: INTRINSIC PART (R in %) OF LARGE-SCALE INTERANNUAL VARIANCE (scales>1000km)



See Penduff et al 2011, Serazin et al (in revision)



Grégorio et al (in revision)

QG SIMULATIONS: INVERSE CASCADES OF MESOSCALE KINETIC ENERGY TOWARD LARGER SCALES & PERIODS

Doubly Periodic 2-layer QG model (Flierl, 1978). Constant forcing: $\overline{u_1} - \overline{u_2}$

$$\frac{\partial q_1}{\partial t} + \Gamma_1 + J(\psi_1, q_1) = ssd,$$

$$\frac{\partial q_2}{\partial t} + \Gamma_2 + J(\psi_2, q_2) = -R_2 \nabla^2 \psi_2 + ssd.$$

NL advection; Ekman Bott. Frict.; Small-scale spectral dissipation

Mean flow Forcing

$$\Gamma_1 = \overline{u_1}\frac{\partial q_1}{\partial x} + \frac{\partial \overline{q_1}}{\partial y}\frac{\partial \psi_1}{\partial x}$$

$$\Gamma_2 = \overline{u_2}\frac{\partial q_2}{\partial x} + \frac{\partial \overline{q_2}}{\partial y}\frac{\partial \psi_2}{\partial x}$$

PV anomalies

$$q_1 = \nabla^2\psi_1 + \frac{(\psi_2 - \psi_1)}{(1+\delta)L_d^2}$$

$$q_2 = \nabla^2\psi_2 + \frac{\delta(\psi_1 - \psi_2)}{(1+\delta)L_d^2}$$

Fourier transform (k,l,ω). Multiply by $-\delta\widehat{\psi_1}^*(k,l,\omega)/(1+\delta)$

Fourier transform (k,l,ω). Multiply by $-\widehat{\psi_2}^*(k,l,\omega)/(1+\delta)$,

add

Depth-averaged spectral energy transfer budget

integrate in either way

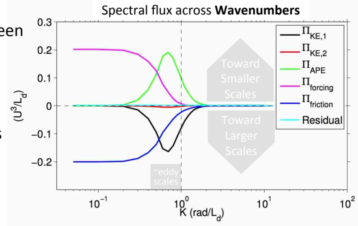
$$\Pi(K) = \int_{k^2+l^2 \geq K^2} \int\int d\omega\, dk\, dl$$

$$\Pi(\Omega) = \int\int\int_{\omega \geq \Omega} d\omega\, dk\, dl$$

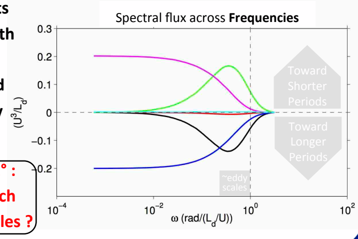
Spectral flux across **Wavenumbers** $\Pi_{KE,1}(K) + \Pi_{KE,2}(K) + \Pi_{APE}(K) + \Pi_{Forcing}(K) + \Pi_{Frict}(K) = 0$

Spectral flux across **Frequencies** $\Pi_{KE,1}(\Omega) + \Pi_{KE,2}(\Omega) + \Pi_{APE}(\Omega) + \Pi_{Forcing}(\Omega) + \Pi_{Frict}(\Omega) = 0$

Classical spatial inverse cascade (Fjortoft 1953), seen in gridded altimeter data by Scott & Wang (2005)
- Large-scale shear feeds APE & baroclinic KE
- APE forward cascade → smaller scales.
- Baroc.KE & KE1 inverse cascades → larger scales
- Friction removes large-scale KE
- Spatial inverse cascade efficient over 1 decade



A temporal inverse cascade (Arbic et al 2012) acts in parallel. Arbic et al (2014) examine it along with its spatial counterpart in QG.
- Eddies can flux chaotic mesocale energy toward longer timescales → Intrinsic low-freq variability
Efficient over ~2 decades in these experiments :

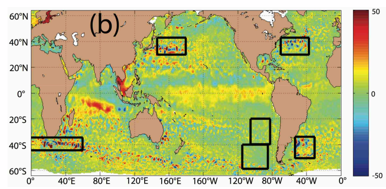


HYCOM 1/12°: regions? AVISO : observed?

NEMO 1/4°, 1/12° : Can this effect reach (multi)decadal scales ?

HYCOM 1/12° : TEMPORAL INVERSE CASCADE

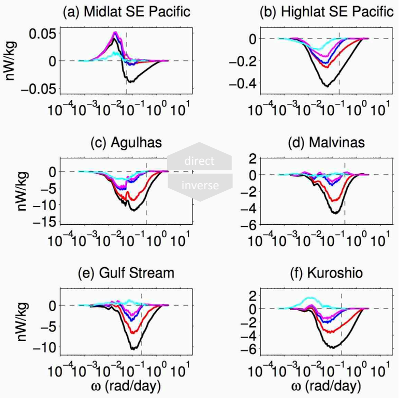
Arbic et al 2014



(left : regions of investigation overlaid on AVISO SLA snapshot)

The spectral flux of surface KE across frequencies is diagnosed within six regions. ψ_1(x,y,t) = SLA(x,y,t) . g/f

$\Pi_{KE,1}(\Omega)$: negative for inverse cascades.



5-yr 1/12° HYCOM run (black lines)
- Negative $\Pi(\Omega)$ prevail in most regions in HYCOM (besides region *(a)*)
- This matches QG predictions in most regions in HYCOM :

(Chaotic) high-frequency KE associated with mesoscale spontaneously feeds the (*apriori* chaotic) low-freq variability. Could this explain the *signals plotted* in the frame above?

GRIDDED SLA : TEMPORAL INVERSE CASCADE?

NO : CYAN lines above show **no robust evidence of temporal inverse cascade in gridded product**

WHY : diagnostics above from filtered HYCOM outputs strongly suggest that the **mapping/ smoothing procedure yielding gridded AVISO products strongly distorts the $\Pi(\Omega)$ diagnostic.**

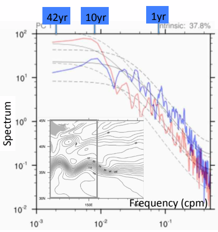
GRIDDED ALTIMETRIC PRODUCTS (including e.g. *SWOT*) WITH HIGH *SPATIO-TEMPORAL* RESOLUTION ARE REQUESTED

NEMO ¼° & 1/12° : LONG PERIODS? INVERSE CASCADE?

Sérazin et al (in revision)

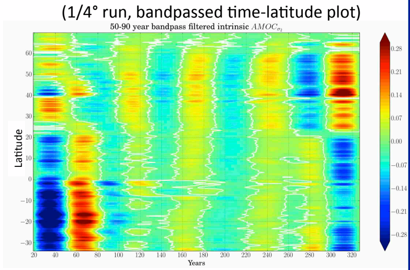
85-year 1/12° run: Intrinsic Variability Reaches Multi-Decadal Time Scales

Kuroshio's latitude (SLA PC1), 1/12° run intrinsic and total



Grégorio et al (in revision)

intrinsic AMOC anomalies (30°S-70°N) (1/4° run, bandpassed time-latitude plot)



85-yr 1/12° NEMO run

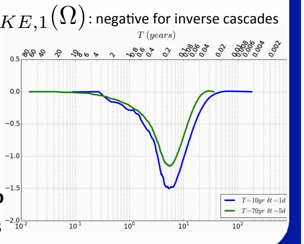
Sérazin et al (in preparation)

$\Pi_{KE,1}(\Omega)$: negative for inverse cascades

Baroclinic instability → Mesoscale eddies
Eddy-eddy interaction → 2-3 year intrinsic (stochastic) variability
What drives it toward decadal+ timescales?
(horizontal & overturning eigenmodes)

Ongoing CHAOCEAN OST/ST project

Temporal Inverse Cascade Seems at work up to ~2-3 years



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