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To cite this version:

Valentin Resseguier, Etienne Mémin, Bertrand Chapron. Stochastic subgrid tensor for geophysical flow modeling. 8th European Postgraduate Fluid Dynamics Conference, Jul 2016, Varsovie, Poland. . hal-01377741

HAL Id: hal-01377741

https://inria.hal.science/hal-01377741v1

Submitted on 9 Nov 2016

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STOCHASTIC SUBGRID TENSOR FOR GEOPHYSICAL MODELING

Valentin Resseguier, Etienne Mémin, Bertrand Chapron

Motivations

- Rigorous identification of sudgrid dynamics effects
- Taking into account likely small-scale dynamics (stochastic backscatter)
- Forecast of likely distinct scenarios
- Quantification of the dynamics errors:
  - Diagnostic for numerical simulations (mesh refinements, …)
  - **Ensemble data assimilation and forecasts**

Transport under location uncertainty

Assumption:

Velocity decomposition: $v = w + \sigma\dot{B}$ with
- w: large-scale velocity
- $\sigma\dot{B}$: uncorrelated in time, divergence-free, correlated in space, Gaussian, inhomogeneous and anisotropic

From stochastic calculus theory, we proofed:

$$\frac{D\Theta}{Dt} = \partial_t\Theta + \boxed{w^\star\cdot\nabla\Theta + \sigma\dot{B}\cdot\nabla\Theta} - \boxed{\nabla\cdot\left(\frac{1}{2}a\nabla\Theta\right)} = 0$$

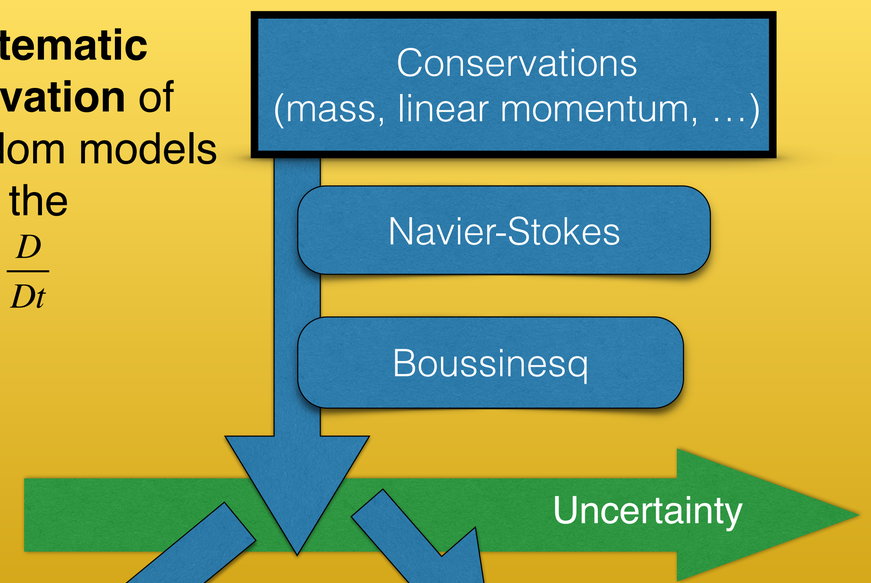
Advection — Inhomogeneous and anisotropic diffusion

Drift correction — Multiplicative random forcing — Balanced energy exchanges

$$w^* = w - \frac{1}{2}\nabla\cdot a$$

$$a = \sigma\sigma^T$$

Systematic derivation of random models with the new $\frac{D}{Dt}$



QG MU

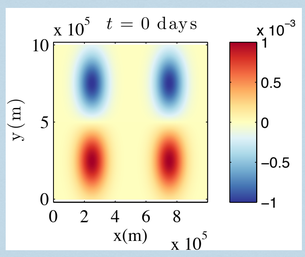
SQG under Moderate Uncertainty

Description

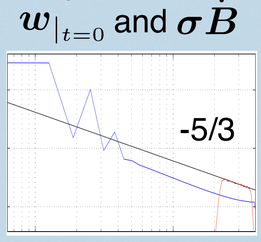
- Usual SQG relationship and transport under uncertainty of buoyancy
- Good illustration of our stochastic transport
- Simulations done with homogeneous small-scale velocity

One realization: better small-scale representation

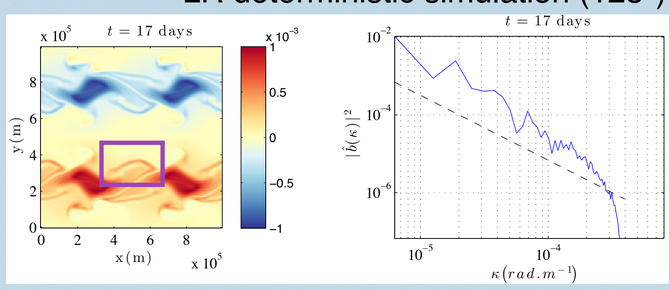
Initial condition



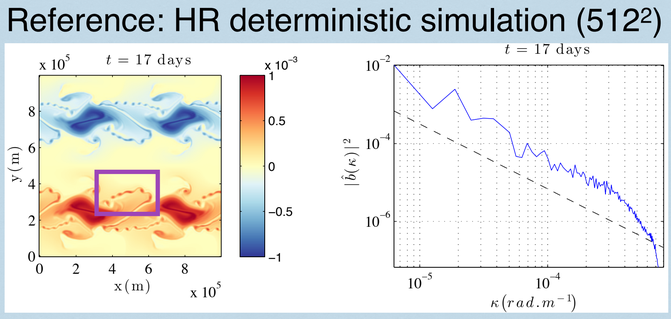
Spectrum of $w|_{t=0}$ and $\sigma\dot{B}$



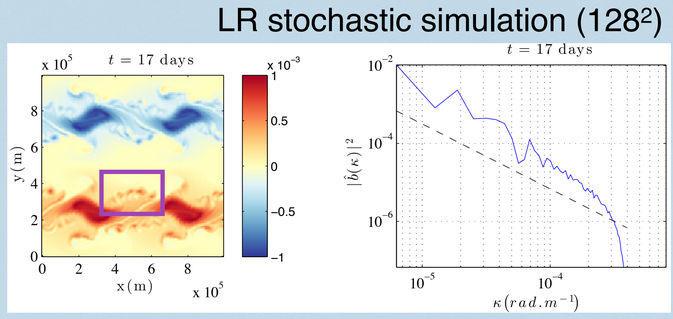
LR deterministic simulation (128²)



Reference: HR deterministic simulation (512²)

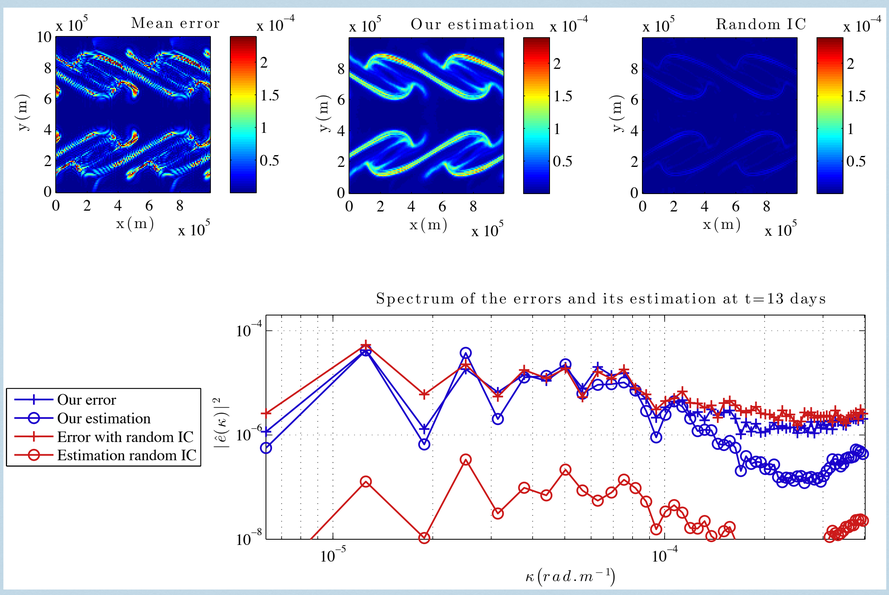


LR stochastic simulation (128²)

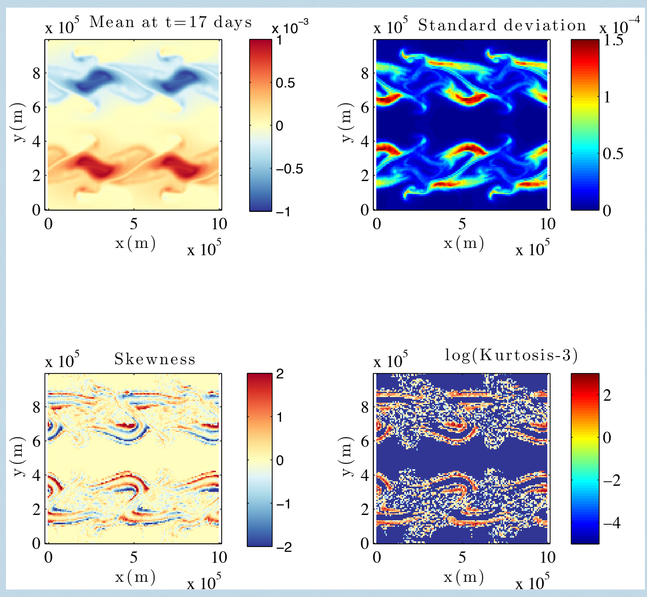


Ensemble of simulations

Errors estimation



Point-wise moments: variability, extreme events, …



Conclusion

- Random transport applicable to any dynamics
- Better representation of small scales
- Extreme events
- **Good errors estimation in location and amplitude**
- Likely scenarios

code available online: link from Fluminance website - V. Resseguier

SQG under Strong Uncertainty

Description

QG assumption under strong uncertainty:
- kills the interior dynamics
- creates horizontal velocity divergence
- provides a diagnostic relation

Modified geostrophic balance

Geostrophic balance	Horizontal Diffusion
$f \times u = -\frac{1}{\rho_b}\nabla p'$	$+\frac{a}{2}\Delta u$

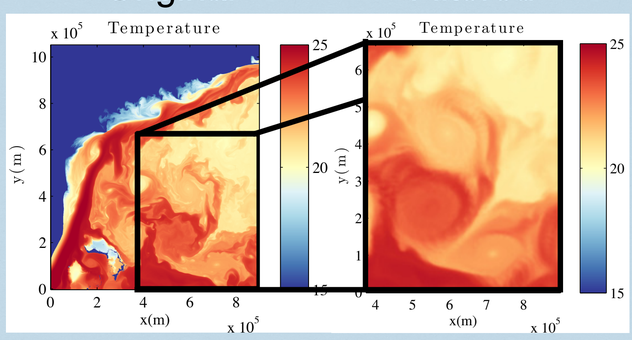
$$\nabla\cdot u \propto \Delta\nabla^\perp\cdot u$$

Testbed data:

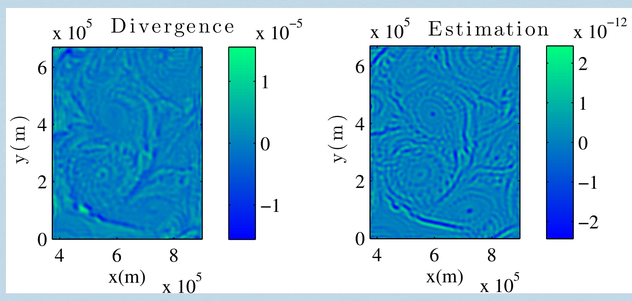
very high-resolution model outputs

Gula, J., Molemaker, J., and McWilliams J. "Gulf Stream dynamics along the southeastern US seaboard." *Journal of Physical Oceanography* 45.3 (2015): 690-715.

Original — Filtered



Results



Conclusion

- Frontolysis / frontogenesis on warm / cold side of fronts
- Estimation of horizontal divergence or diffusive coefficient and subgrid variance
- Strong uncertainty assumption verified *a posteriori* for the Gulf Stream during wintertime at mesoscales