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► To cite this version:

Long Li, Etienne Mémin, Bertrand Chapron, Noé Lahaye. Stochastic transport in an idealized oceanatmosphere coupled system. EGU General Assembly 2022, May 2022, Vienna, Austria. pp.1-24. hal-03676056

HAL Id: hal-03676056 https://inria.hal.science/hal-03676056

Submitted on 23 May 2022

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Stochastic transport in an idealized ocean-atmosphere coupled system

Long Li¹ May 23, 2022

Joint work with Etienne Mémin¹, Bertrand Chapron² and Noé Lahaye¹

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Stochastic Transport in Upper Ocean Dynamics (STUOD)



https://www.imperial.ac.uk/ocean-dynamics-synergy/



"Our approach accounts for transport on scales that are currently unresolvable in computer simulations, yet are observable by satellites, drifters and floats."

• Flow under location uncertainty (LU)



References: [Bauer et al., 2020a, Li, 2021]

• Flow under location uncertainty (LU)



• Stochastic transport of tracer

$$\mathbb{D}_t \Theta := \mathrm{d}_t \Theta + \left(\boldsymbol{u}^* \, \mathrm{d}t + \underbrace{\sum_{m} \boldsymbol{\xi}_m \, \mathrm{d}B_t^m}_{\mathrm{backscattering}} \right) \cdot \boldsymbol{\nabla} \Theta - \underbrace{\frac{1}{2} \, \boldsymbol{\nabla} \cdot \left(\sum_{m} \boldsymbol{\xi}_m \boldsymbol{\xi}_m^\top \boldsymbol{\nabla} \Theta \right) \, \mathrm{d}t}_{\mathrm{eddy \ diffusion}} = 0$$

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• Pathwise conservation of moments

$$\mathbb{D}_t \Theta^{\boldsymbol{p}} = 0, \quad \mathrm{d}_t \int_{\Omega} \Theta^{\boldsymbol{p}} \, \mathrm{d}\boldsymbol{x} = 0$$

References: [Bauer et al., 2020a, Li, 2021]

Application to Q-GCM [Hogg et al., 2003]



Figure 1: Model illustration from http://www.q-gcm.org

• Idealized midlatitude coupled model emphasizing ocean dynamics

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- Idealized midlatitude coupled model emphasizing ocean dynamics
- Classical Ekman model with wind-current-depended stresses

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- Idealized midlatitude coupled model emphasizing ocean dynamics
- Classical Ekman model with wind-current-depended stresses
- Our applications: stochastic transport of PV and SST for both ocean and atmosphere

• Our objectives: designing adequate unresolved flow structure (ξ_m) for coarse-resolution models to reproduce statistical properties of eddy-resolving simulation

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- Code available on:

https://github.com/matlong/qgcm_lu
https://github.com/louity/qgm_pytorch

Numerical results



Figure 2: Snapshots of ocean upper layer relative vorticity.



• Energy-budget-based parameterization [Bachman, 2019, Jansen et al., 2019]

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- More realistic configurations: surface buoyancy conditions [Lapeyre and Klein, 2006], North Atlantic circulation (from FFT to multigrid)
- Ensemble forecasting and data assimilation

Thank you very much! Questions?

References i

🔋 Bachman, S. D. (2019).

The GM+E closure: A framework for coupling backscatter with the Gent and McWilliams parameterization. *Ocean Modelling*, 136:85–106.

Bauer, W., Chandramouli, P., Chapron, B., Li, L., and Mémin, E. (2020a).

Deciphering the role of small-scale inhomogeneity on geophysical flow structuration: a stochastic approach. *Journal of Physical Oceanography*, 50(4):983–1003.



Bauer, W., Chandramouli, P., Li, L., and Mémin, E. (2020b). Stochastic representation of mesoscale eddy effects in coarse-resolution barotropic models. *Ocean Modelling*, 151:101646.

References ii

- Brecht, R., Li, L., Bauer, W., and Mémin, E. (2021).

Rotating shallow water flow under location uncertainty with a structure-preserving discretization.

Journal of Advances in Modeling Earth Systems, 13.



Gaube, P., Chelton, D. B., Samelson, R. M., Schlax, M., and O'Neill, L. W. (2015). Satellite observations of mesoscale eddy-induced Ekman pumping.

Journal of Physical Oceanography, 45:104–132.



Hogg, A. M., Dewar, W. K., Killworth, P. D., and Blundell, J. R. (2003).

A quasi-geostrophic coupled model (Q-GCM). Monthly Weather Review, 131(10):2261–2278.

References iii

Holm, D. D. (2015).

Variational principles for stochastic fluid dynamics. Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 471(2176):20140963.



Jansen, M. F., Adcroft, A., Khani, S., and Kong, H. (2019). Toward an energetically consistent, resolution aware parameterization of ocean mesoscale eddies. Journal of Advances in Modeling Earth Systems, 11(8):2844–2860.



Lapeyre, G. and Klein, P. (2006). Dynamics of the upper oceanic layers in terms of surface quasigeostrophy theory.

Journal of Physical Oceanography, 36:165–176.

References iv



Li, L. (2021).

Stochastic modeling and numerical simulation of ocean dynamics.

Theses, Université Rennes 1.



Stochastic parameterization with dynamic mode decomposition.

https://hal.archives-ouvertes.fr/hal-03597550.



Mémin, E. (2014).

Fluid flow dynamics under location uncertainty. Geophysical & Astrophysical Fluid Dynamics, 108(2):119–146.