Geophysical Research Abstracts
Vol. 20, EGU2018-5534, 2018
EGU General Assembly 2018

Stochastic Variational Principles for GFD: Modelling the unknown unknowns

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For the purpose of estimating model error in predictions of climate and weather variability, we propose an approach which includes stochastic processes. The idea is to represent unknown errors, as "cylindrical noise" appearing in systems of stochastic evolutionary PDEs that derive from variational principles which are invariant under a Lie group action. The main objective of the presentation is the inclusion of stochastic processes in ideal fluid dynamics, via a variational principle which is invariant under "particle relabelling" by spatially smooth invertible maps. Examples include Euler's fluid equations for incompressible flows and also approximate GFD (Geophysical Fluid Dynamics) equations for ocean and atmosphere circulation.

The approach is via a stochastic extension of the Hamilton's principle for fluid which imposes a constraint of stochastic transport of advected quantities, whose spatial correlations are obtained from observed data for tracer transport. The equations we derive via this approach keep their deterministic form and geometric meaning, which both derive from the variational principle. However, their transport vector field becomes stochastic, corresponding to stochastic Lagrangian particle paths. This means, for example, that Kelvin's circulation theorem for the stochastically modified Euler equations for incompressible flow has the same integrand as in the deterministic case, but its circulation loop moves with the fluid flow along stochastic Lagrangian paths.

Details and examples for GFD may be found in: Darryl D. Holm, Variational principles for stochastic fluid dynamics, [2015] Proc Roy Soc A, 471: 20140963.