Research proposal

Approximate computing in climate simulations

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Deriving the Navier-Stokes equations relies on the assumption of a fluid being a continuum, i.e. assuming that any property is well-defined for a given infinitesimal volume. The resulting equations of motions are deterministic, which leads to the following paradox: once the state of all relevant variables is known for a given time the future can theoretically be forecasted without uncertainty (Laplace's demon[1]), conflicting the predictability horizon in chaotical systems[2]. Grid cells in numerical simulations of the atmosphere or the ocean are many orders of magnitude larger than an infinitesimal volume, limited towards a finer resolution by computational power. Dividing the reality into such grid cells, their associated value claims to represent some average but ignoring all sub-grid scale variations. The question about the role of this sub-grid scale variability is still unanswered, but observational spectral power-law behaviour of atmospheric or oceangraphic variables propose an inseperability of scales, making the sub-grid scale variability non-negligible. Mimicing its effect in terms of stochastic parametrizations was therefore proposed[3], supporting the idea that the underlying equations of motions are non-deterministic and should be regarded from a stochastic perspective.

However, the finite precision of a numerical floating-point number might overestimate the real information content, that the single value associated with a grid cell is able to represent regarding the spatial variability within. The actual significant figures of such a number could be less than its numerical precision, meaning that computational capacities are used inefficiently. What is the necessary precision to represent the real information and retain the dynamics of the underlying equations? For the dynamical system representing geostrophic turbulence in the North Atlantic computed with a precision of 64bit the first 32bits presumably contain real information, whereas the last 32bits do not (see Figure), but rather represent one possible realization of the processes at sub-grid scale.

Furthermore, as stochastic approaches in weather and climate simulations are successful[3], is there a way to mimic the effect of stochastic parametrizations with bit-flips that could occur spontaneously on the first non-significant figure?

Finding answers to these questions is relevant for climate simulations: we need to understand the dynamical system describing the Earth's climate in order to predict its changes under current greenhouse gas emissions. It is especially necessary to understand its numerical representation in climate models for the interpretation of all climate projections, aiming to inform decision-makers how to mitigate or adapt to climate change. What is the real uncertainty of the future evolution of Earth's climate and what is the additional uncertainty provided by current climate models?

With these questions driving my curiosity, I seek the supervision, scientific environment and time at the University of Oxford in order to successfully complete a DPhil degree within the Atmospheric, Oceanic and Planetary Physics department.

References

[1] PS Laplace, 1902. *A philosophical essay on probabilities*, Wiley and Sons.

[2] EN Lorenz, 1993. *The essence of chaos*, University of Washington Press.

[3] TN Palmer, 2012. Towards the probabilistic Earth-system simulator: a vision for the future of climate and weather prediction. *Q. J. R. Meteorol. Soc.*, 138, 841-861.

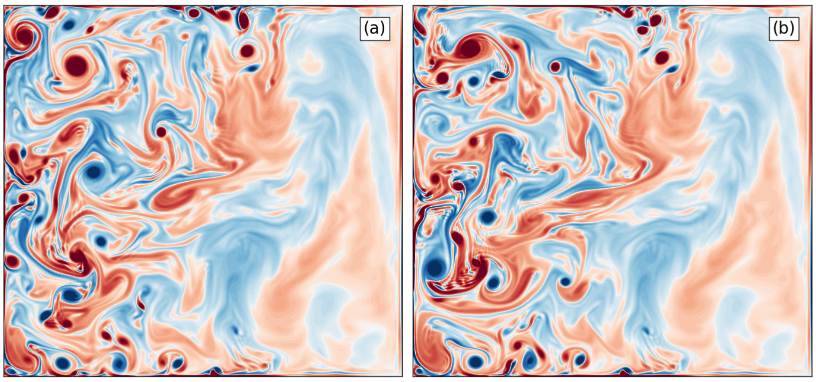

Figure: Relative vorticity from an idealized shallow water simulation, representing geostrophic turbulence in the North Atlantic. Computations performed at (a) 64bit floating-point precision and (b) 32bit. Both simulations started from the same initial conditions 200 days before the timestep shown.