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Multiscale Interactions in Geophysical Fluids

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Abstract. The dynamics of the atmosphere and ocean involves a broad range of spatial and temporal scales, many of which emerge through complex nonlinear mechanisms from forcings at very different scales. This poses major challenges for the numerical prediction of the weather, ocean state and climate: many processes have scales that are too small to be resolved yet they play an essential role in determining large-scale features. This workshop examined how modern mathematical methods – ranging from multiscale asymptotics to adaptive numerical methods and stochastic modelling – can be applied to represent the large-scale impact of these small-scale processes and improve both deterministic and probabilistic predictions.

Mathematics Subject Classification (2010): 86A10, 37N10, 76U05.

Introduction by the Organisers

One of the most striking features of the dynamics of both the atmosphere and the ocean is the crucial role played by a range of small-scale, high-frequency phenomena in determining the large-scale flow. Examples of this abound, from the role of gravity waves on the middle-atmospheric circulation and the driving of jets by turbulent motion, to the impact of small-scale mixing on the deep ocean. This poses major challenges for atmospheric and oceanic predictions, of course, since these are based on numerical models that necessarily have limited spatial and temporal resolutions.
Advanced mathematical methods have an important part to play in addressing these challenges: a range of mathematical techniques, including multiscale asymptotics, adaptive numerics, dimensionality reduction, and stochastic and data-driven models, can be brought to bear on the problems. Their effective use depends on close interactions between mathematicians and atmosphere and ocean scientists. The workshop aimed at stimulating these interactions, by bringing together researchers from across applied mathematics and geophysical fluid dynamics to discuss key mathematical challenges arising from recent developments in atmosphere and ocean dynamics. It was well attended, with 45 participants from 10 countries representing weather centres as well as universities.

The workshop was structured around 7 thematic sessions, each consisting of 3 lectures that combined review material with descriptions of recent results. The first session highlighted the complexity of geophysical flows, with lectures by Nikurashin on the impact of small-scale topography on ocean flow, by Pauluis on the effect of moisture on the meridional circulation of the atmosphere, and by Muller on the self-organisation of atmospheric convection. Sessions 2 and 3 were dedicated to a range of multiscale methods applied to internal waves in the atmosphere (Achatz) and in the ocean (Young), to convection in planetary atmospheres (Julien), to the Julian–Madden oscillation (Stechmann), and to stochastic parameterisations (Gottwald, Grooms). Session 4 discussed rigorous results, with Doering on enstrophy dissipation, Bresch on the compressible Navier–Stokes equations, and Titi on data assimilation. Numerical methods are of course key to much of atmosphere and ocean modelling. They were represented at the workshop in session 5, with Korn and Smolakiewicz’s lectures on state-of-the-art numerical models based on unstructured grids, and Wingate’s lecture on methods that best exploit distributed computer architectures. Session 6 centred on data-driven modelling, with discussions of systematic approaches to the classification of multi-scale time series with inherent non-stationarity due to latent or unobserved scales and variables (Horenko), of stochastic parameterizations of sub-gridscale turbulence motivated by high-resolution simulations (Zanna), and of turbulent fluctuations in stably stratified boundary layers (Vercauteren). Probabilistic techniques are increasingly applied to geophysical fluids. This was reflected in the last lecture session with contributions by Bouchet on large-deviation techniques, by Kuksin on weak turbulence, and by Holm on variational stochastic models.

All the lectures involved a good degree of audience participation, with questions and clarifications making it possible to fully engage the multidisciplinary audience. They were complemented by a successful poster session, which gave the opportunity to ten researchers to present their recent results, and by many informal discussions. The workshop enabled participants to share ideas and work collaboratively on what emerged as the most promising avenues for the applications of modern mathematical methods to geophysical fluid dynamics.

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