Title:
Learning from sparse observations:
the ocean parameter calibration and state estimation problem

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Abstract:
Because of the formidable challenge of observing the time-evolving full-depth global ocean circulation, numerical simulations play an essential role in quantifying the ocean's role in climate variability and long-term change. For the same reason, predictive capabilities are confounded by the high-dimensional space of uncertain variables (initial conditions, model parameters and external forcings), as well as model inadequacy. Inverse methods that optimally extract and merge information from diverse observations and models are powerful tools to enable rigorously calibrated and initialized predictive models to optimally learn from the sparse data. Parameter calibration and state estimation, in particular, provides the machinery for doing so systematically and quantitatively. Key enabling computational approaches are the use of adjoint methods for solving a nonlinear least-squares optimization problem. Emerging capabilities involving Hessians are the prior-to-posterior uncertainty propagation informed by the observations, and the application of optimal network design methods for developing observing systems. We will introduce these methods in the context of several science applications that are being pursued by members of the "Computational Research in Ice and Oceans" (CRIOS) group: (i) dynamical attribution of monthly to interannual South Atlantic meridional transport variability in the context of the "Estimating the Circulation and Climate of the Ocean" (ECCO) consortium, (ii) observing system design for subpolar North Atlantic heat content monitoring in the context of the Overturning in the Subpolar North Atlantic Program (OSNAP), and (iii) coupled Arctic ocean-sea ice modeling in the context of the Arctic-subpolar North Atlantic State Estimate (ASTE). We argue that the underlying computational methods remain under-utilized in ocean climate modeling. Realizing their full potential faces considerable practical hurdles, but is warranted for tackling pressing issues in climate science.