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Geoscientific Model Development Discussions

Interactive comment on "'Climate Response Functions' for the Arctic Ocean: a proposed coordinated modeling experiment" *by* John Marshall et al.

G. Manucharyan (Referee)

gmanuch@caltech.edu

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Review of "'Climate Response Functions' for the Arctic Ocean: a proposed coordinated modeling experiment".

The authors propose to conduct a coordinated set of experiments to explore the response of the Arctic Ocean to key external forcing components. The study is motivated by a Green's function approach that allows restoring a linear response of a system to an arbitrary forcing if its response to an impulse forcing is known. The authors provide a comprehensive description of the model experiments that would result in a set of 'Climate Response Functions' (CRFs) for key observables of Arctic circulation and tracer distributions. Using a low-resolution climate model (MITGCM), they successfully demonstrate the usefulness of CRF approach and its potential in improving our understanding of the Arctic Ocean.

I find this study to be very timely, in particular, within a context of an increasing number of hypotheses attempting to explain the freshwater dynamics of the dramatically evolving Arctic Ocean. The manuscript expresses clearly the proposed ideas and methods used and I recommend it for publication after a suggested minor revision aimed at improving its clarity. Below I provide several discussion points, addressing which, would lead to a significant improvement of the manuscript.

1. CRFs can be constructed for any quantitative measure of a model state and as a result, the choice of 'observables' is unlimited. However, it is important to emphasize at least the two key types of 'observables' that can be of use in improving our dynamical understanding: a) 'observables' that are connected to existing hypotheses/theories about the Arctic Ocean dynamics; their CRF's can be directly used to test the existing theories and ii) 'observables' for which CRFs can be constructed from observations and provide a quantitative measure for model skill evaluation. The same logic applies to the choice of forcing.

2. Perhaps a discussion of the expected CRF being the exponential equilibration (Eq.4) will be helpful in the introduction or when Eq. (1) is discussed.

Concerning the discussion on Ln5 p.19: Exponential CRFs are obtained for classical dynamical systems linearized around equilibrium dY/dt = -\gamma*Y + F(t) where Y is observable and F is the forcing. The parameter \gamma can be interpreted as a stability of the observable and for a linear process \gamma should not depend on the amplitude of forcing perturbations. However, the CRF amplitude should be directly proportional to the amplitude of forcing perturbation as well as to \gamma^{-1}.

See a discussion of \gamma for the case of Beaufort Gyre freshwater content here: Manucharyan G.E., M.A. Spall, and A.F. Thompson (2016), A theory of the wind-driven Beaufort Gyre variability, J. Phys. Oceanogr., 46, 3263-3278.

2. CRFs are most useful when the system response is linear which is not guaranteed for a finite amplitude forcing perturbations. The manuscript can provide a more detailed discussion about an a priori choice of the amplitude of forcing perturbations; i.e. are there any scaling laws or perhaps observational constraints on when each of the proposed 'observables' responds in a nonlinear way to the 'forcing'?

3. What potential difficulties arise when comparing CRFs from models that have different resolutions and sub-grid-scale parameterizations? What are the key model parameters for a specific observable/forcing pair? In particular, a discussion of the role of mesoscale eddies might be beneficial since the eddy diffusion has been demonstrated to directly affect FWC in idealized Beaufort Gyre models.

4. L 20 p21: the sea ice dynamics responds to wind stress on inertial time scales while its thermodynamics has about 1-2 year time scale. Compared to the 6 year-long FWC equilibration time scale, the sea ice dynamics is sufficiently fast and thus might not directly affect \gamma. I would recommend adding a discussion of the availability of freshwater sources and time scales associated with its modification e.g. due to vertical mixing near continental shelves (note that in a closed Arctic Ocean domain FWC would be preserved unless strong vertical mixing is present).

5. I recommend adding a discussion of an organized data output of post processed CRFs e.g. output frequency, duration of runs etc. In addition to storage of CRF time series, a corresponding list of the key model parameters e.g. ice-ocean-atmosphere drag coefficients, eddy diffusivity scheme, vertical tracer mixing, momentum dissipation/bottom drag, etc.. would ease the subsequent analysis of results.

6. Finally, I recommend emphasizing that the analysis of various CRFs can help in the quantitative evaluation of existing hypotheses about the Arctic Ocean dynamics.

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