Natural modes of climate variability associated with the oceanic thermohaline circulation

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ABSTRACT

Instabilities and modes of the large-scale ocean circulation contribute to climatic variability on interannual to millennial timescales. Ocean basin modes, standing or propagating waves resonating through boundary adjustment (just like the resonance of musical notes), fundamental and harmonic waves played by a string), can feed on the mean flow available potential energy and go spontaneously, as long as the mean circulation is sustained by differential surface heating or wind stress. Even weakly damped modes (most likely through interaction with bottom topography) may still be maintained by atmospheric stochastic forcing. We review here several modes of variability of the large-scale ocean circulation, on decadal to millennial time scales, often depending on surface boundary conditions for temperature and salinity. In order to understand their physical mechanism, we use basic tools from dynamical system theory, like linear stability analysis and weakly nonlinear multiple timescale expansion. We perform density variance budgets that enable to identify the source of the variability (internal hydrodynamical instability or surface forcing), and provide an objective criteria that allow to distinguish different oscillation types in the same frequency range. We finally discuss the mechanism of these oscillations before concluding on their relevance for the Earth climate system.

1. INTRODUCTION

Numerous analysis of historical and proxy climatological time series show significant climate variability on interannual to millennial timescales. Several paradigms apply to this low frequency variability, from external forcing variability (sole cycles, volcanic eruption, atmospheric composition), to integration of atmospheric white noise by the ocean into a red spectrum to intrinsic modes of variability of the atmospheric, oceanic, or coupled systems. For timescales longer than interannual, the ocean circulation is likely a major player, given its large heat capacity and long adjustment.

Typical time scales for the thermohaline circulation

- spin up time scale: \( \frac{3000}{u} \) yr, negligible for 5 yr
- advective time scale: \( \frac{10000}{u} \) yr, 250 yr
- diffusive time scale: \( \frac{4000}{D} \) m, \( \approx 1000 \) yr

Surface boundary conditions for ocean models

- restoring boundary conditions, appropriate for pace and ice;
- constant flux boundary conditions, appropriate for salinity;
- evaporation and precipitation independent of sea surface salinity (SSS);
- climatological precipitation, very poorly known, leads to large model drifts

Summary

To the extent that the oceanic instability modes play an important role, identifying their dynamical nature is crucial for climate prediction. As a first step, we study the time-dependent wind-driven quasi-geostrophic circulation as a prototype of decade-scale variability. Then we investigate three-dimensional thermally-driven and thermohaline circulation ocean models and analyse their interdecadal variability. Finally, we focus on centennial to millennial timescales with a simple two-dimensional (latitude-depth) ocean model.

2. OCEAN BASIN MODES: DECADAL TIMESCALE

Physical processes: [Cresswell/Peiman 2008; Ihns nell/Huck 2005; 2004] - basin-scale: wind-driven barotropic flow; - resonance through equatorial and boundary waves (mass conservation); - these modes may become unstable through large-scale baroclinic instability.

One-layer quasi-geostrophic dynamics

\[ \frac{\partial (\nabla \times \mathbf{v})}{\partial t} = - \nabla \times (\mathbf{v} \times \mathbf{b}) + \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x} \left( \frac{\partial \mathbf{v}}{\partial x} \right) = \text{Dissipation}. \]

Summary

At least two types of interdecadal variability may be distinguished (one-layer quasi-geostrophic circuit: [Huck et al. 2004; 2005]).

3. TWO TYPES OF INTERDECADAL VARIABILITY

At least two types of interdecadal thermohaline variability may be distinguished (one-layer quasi-geostrophic circuit: [Huck et al. 2004; 2005]).

4. CENTENNIAL TO MILLENNIAL TIMESCALE

In ocean-only models, decadal to millennial variability strongly depends on the surface boundary conditions used for temperature and/or salinity: Most oscillations are sustained by restoring surface temperature, even if they really reside in the ocean!). A single interdecadal mode is linked with a large-scale ocean heat anomaly.

REFERENCES


