Investigation and modelling of decadal-scale climate variability over the North Atlantic, the Arctic and Europe.

Laboratoire de Physique des Océans, Université de Bretagne Occidentale, Brest
Nansen Environmental and Remote Sensing Center, Bergen

Rationale

The North Atlantic climate system undergoes large interannual fluctuations, known as the North Atlantic Oscillation (NAO), that are predominately modulated on the decadal and interdecadal time scale. Through the variation in intensity of the westerly winds, the amount of heat and moisture exchanged between the atmosphere and ocean varies greatly and influences primarily the climate over Europe (especially winter temperatures and precipitations). Understanding its underlying mechanisms will – among other things – facilitate prediction of short-term climate fluctuations, with socio-economic implications. Anticipated anthropogenic climate signals can also more easily be discerned from backround variability once its characteristics are better known.

Although the scientific comunity has provided many convincing results using coupled atmosphere-ocean models of immense complexity, many key-questions remain considering the controlling mechanisms of decadal-scale variability.

The co-operative institutions of the proposed project have initiated several modelling projects with the common philosophy to investigate the behaviour of simplified systems, in order to sort out dominant mechanisms and critical model parameters and forcing functions. More complex processes will be added in the future, by a step-wise approach, founded on a firm base of knowledge.

Objectives

The objectives of the project is to

> **initiate co-operation and exchange experience and expertise in the investigation of the governing mechanisms of decadal-scale variability in coupled atmosphere-ocean-sea ice models of various levels of complexity.**

Co-operative institutions

The two institutions (project leaders in parenthesis)

- *Laboratoire de Physique des Océans, Université de Bretagne Occidentale*, Brest (Prof. A. Colin de Verdière)
- *Nansen Environmental and Remote Sensing Center*, Bergen (Dr. K. Lygre)

share a common approach to the modelling of climate processes by exploring simplified systems. The French group (LPO) has performed a multitude of numerically efficient ocean-only and coupled integrations of models with simplified geometry that support a mechanism for decadal variability based on the instability of the ocean circulation. The Norwegian group (NERSC) has long experience in the modelling of Arctic processes, including sea-ice, mainly on the basin scale.

Thus, the diversity of focus of the two institutions make the approaches complementary with optimal conditions for fruitful exchange of ideas and experience.

Follow-up funding

At NERSC the current research will be carried out under EC FWP5 PREDICATE and SINTEX (FWP 4) or a dedicated project proposed for the Norwegian Research Council. The LPO is working in accord with the CLIVAR goals and the french national research program in climate dynamics (PNEDC), that provided some funding in 1999.

The objectives of the current project fits nicely into the FWP 5 *Environment and sustainable development*. The aim of the current co-operation is to contribute to future proposals, either as joint initiatives or contributions to larger consortiums. In addition the co-operation should mutually strengthen ones position versus national funding agents.

State of the art

A current challenge is the prediction of short-term climatic variations (1–10 years; Sutton and Allen, 1997). An important part of this issue concerns decadal-scale phenomena related to the North Atlantic Oscillation (NAO) (Hurrell, 1995). A manifestation of the NAO is the near-decadal temperature variability in the northwestern Atlantic (Deser and Blackmon, 1993) and the propagation of salinity anomalies around the subpolar gyre (Reverdin *et al.*, 1997; Belkin *et al.*, 1998). Salinity anomalies are generated in the Arctic or in the Labrador Sea/ Baffin Bay area from excess freezing of ice due to anomalous cold, off-shore winds with a subsequent melting in warmer water. The slope currents of the Labrador Sea have been identified as a generation area with subsequent propagation of anomalies northeastward along the southern rim of the subpolar gyre. Wohlleben and Weaver (1995) invoked ocean atmosphere interactions associated with the subpolar gyre and ther Greenland high to explain the variability.

The several explanations for decadal-scale variability – revolving around the extent of ocean-atmosphere coupling – has been reviewed by Rahmstorf (1999). One of the recent ones – and intriguingly simple – are due to Colin De Verdiere and Huck (1999), who argue that the baroclinic instability of the part of the western boundary current region where the heat loss is largest, triggers interdecadal oscillations. The simplicity relies in that the ocean is the origin of the variability, with the atmosphere playing a passive role. Huck *et al.* (1999) found that the amplitude of oscillation increased with forcing strength (heat flux) and also that vertical diffusion had a driving role on the oscillation. There may also exist regional modulations of the variability, as many studies (e.g. Delworth *et al.*, 1997) find a 40 years (or longer) periodicity in the Greenland Sea. Lygre (1996) proposed a coupling between Arctic circulation and Greenland Sea convection that may be an underlying mechanism in these oscillations.

In close relation to the interdecadal variability stands the stability properties of the thermohaline circulation (THC) of the Atlantic and the World Ocean (Rahmstorf, 1999). The role of a sea-ice cover in the stability mechanism has been shown by Lohmann and Gerdes (1998), employing an ocean-sea ice model coupled to an interactive energy balance model of the atmosphere. Subject to convective shut-down by a salinity perturbation, convection is supressed and the ice is insulating the ocean from being further cooled. Thus, considerable ice-edge excursions are allowed.

Tasks

Several numerical experiments will be initiated at the two institutions in year 2000. Mutual visits and exchanges will ensure optimal model lay-outs and parameters. During the year results will be mutually evaluated and further experiments recommended.

1 NERSC: Analysis of equilibrium and variability in an Atlantic-Arctic model. The system consists of a layered oean model, a dynamic-thermodynamic ice model and an atmospheric EBM, i.e. energy balance model (Bleck *et al.*, 1992; Drange, 1996; Chierici *et al.*, 1999). The ocean/ice model is spun up with state-of-the-art climatology before the atmosphere is matched to the implied heat and moisture fluxes. A key issue is to assume mass conservation in the treatment of the surface freshwater flux.

2 LPO: Stability and variability of the ocean circulation in the North Atlantic. The results from a global realistic ocean model (z-coordinate) wil be analyzed. It is forced by prescribed fluxes of heat and freshwater (from climatologies and from coupled simulations), and also coupled to an atmospheric EBM (with and without interactive winds). First, the natural variability of the ocean model is investigated when traditionally-used surface restoring boundary conditions are relaxed — Random noise in the forcing might be necessary to trigger variability. Second, the underlying physical mechanisms for decadal-scale variability will be determined, especially its oscillation period and patterns.

We will adapt and use the methods and stability analysis tools that have been developped to point out the long-wave baroclinic instability of the ocean circulation (in the western boundary region and along the North Atlantic drift) as a wavemaker for the interdecadal variability in idealized geometry ocean models (Huck et al. 1999; Colin de Verdière and Huck 1999). Finally the cooperation with NERSC should permit to incorporate the influence of sea ice in the variability and stability analysis.

3 Advantages of a dual approach. The approaches followed by NERSC and LPO will be beneficial for each group for understanding the physics of the decadal-scale variability, but also the limitations and specific behaviours of the different models. Different levels of complexity and realism in the models will determine which physical processes are necessary for reproducing decadal-scale variability. Differences may also emerge due to layer vs. level formulation of ocean models, as well as model resolution and domain. This should allow us to distinguish idiosyncratic features from more general and reproducible results. Finally the emphasize will be put on the role of the ice (eventually through its interaction with wind) and salinity anomalies on the variability, as pointed out by several authors (cf. introduction).

References

Belkin, I. M., Levitus, S., Antonov, J., and Malmberg, S. (1998), “Great salinity anomalies” in the North Atlantic, *Prog. Oceanog.*, **41**:1–68.

Bleck, R., Rooth, C., Hu, D., and Smith, L. T. (1992), Salinity-driven thermocline transients in a wind- and thermohaline-forced isopycnic coordinate model of the North Atlantic, *J. Phys. Oceanogr.*, **22**:1482–1505.

Chierici, M., Drange, H., Andersson, L. G., and Johannessen, T. (1999), Inorganic carbon fluxes through the boundaries of the Greenland Sea Basin based on in situ observations and water transport estimates, *J. Mar. Syst.*, in press.

Colin De Verdiere, A. and Huck, T. (1999), Baroclinic instability: an oceanic wavemaker for interdecadal variability, *J. Phys. Oceanogr.*, **29**:893–910.

Delworth, T. L., Manabe, S., and Stouffer, R. J. (1997), Multidecadal climate varianility in the Greenland Sea and surrounding regions: A coupled model simulation, *Geophys. Res. Lett.*, **24**:257–260.

Deser, C. and Blackmon, M. L. (1993), Surface climate variations over the North Atlantic Ocean during winter 1900–1989, *J. Climate*, **6**:1743–1753.

Drange, H. (1996), A 3-dimensional isopycnic coordinate model of the seasonal cycling of carbon and nitrogen in the Atlantic Ocean, *Phys. and Chem. of the Earth*, **21**:503–509.

Huck, T., Colin De Verdiére, A., and Weaver, A. J. (1999), Interdecadal variability of the thermohaline circulation in ocean models, *J. Phys. Oceanogr.*, **29**:865–892.

Hurrell, J. W. (1995), Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation, *Science*, **269**:676–679.

Lohmann, G. and Gerdes, R. (1998), Sea ice effects on the sensitivity of the thermohaline circulation, *J. Climate*, **11**:2789–2803.

Lygre, K. (1996), *A numerical modelling study of the circulation of the North Atlantic and Arctic oceans*, PhD thesis, Geophysical Institute, University of Bergen/ Nansen Environmental and Remote Sensing Center, NERSC techn. rep. 118.

Rahmstorf, S. (1999), Decadal variability of the thermohaline oceancirculation, in *Beyond El Niño: decadal an interecadal climate variability*, edited by Navarra, A., pp. 329–351, Springer.

Reverdin, G., Cayan, D., and Kushnir, Y. (1997), Decadal variability of hydrography in the upper northern North Atlantic in 1948–1990, *J. Geophys. Res.*, **102**(C4):8505–8531.

Sutton, R. T. and Allen, M. R. (1997), Decadal predictability of North Atlantic sea surface temperature and climate, *Nature*, **388**:563–567.

Wohlleben, T. M. H. and Weaver, A. J. (1995), Interdecadal climate variability in the subpolar North Atlantic, *Clim. Dyn.*, **11**:459–467.