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COURSE ON CLIMATE VARIABILITY STUDIES IN THE OCEAN
"Tracing & Modelling the Ocean Variability"
16 - 27 June 2003

301/1507-13

Oceanic Deep Convection and its role in Climate
Lecture II - Variability

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Lecture II − Variability

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Climate Variability Studies in the Ocean:
Tracing and Modeling the Ocean Variability
ICTP − June 2003

Role of Deep Convection in Climate

1. key component of poleward heat transport in the North Atlantic

2. associated with the sinking limb of the vertical overturning cell

3. exchange of heat between atmosphere and mid−depth/deep ocean

4. mixing of properties between surface and mid−depth/deep ocean

Outline Lecture II: Variability at Deep Convective Locations

Part III. Variability of Deep Convection Observations and Theories

- Interannual variability: observations
- Variability of Convection in Models
- Climate Variability associated with variability of Convection

Part IV. An idealized model as a tool to study variability

- a simplified description of convection
- response to a variable atmosphere

Why be interested in the Variability at Deep Convection Locations in the North Atlantic ?

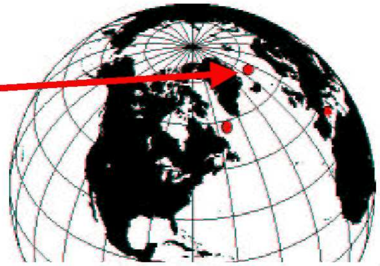
Poleward heat transport in the north Atlantic is associated with NADW formation and therefore with deep convection in the Labrador and Greenland Seas.

But convection in both these seas is far from a steady state process!

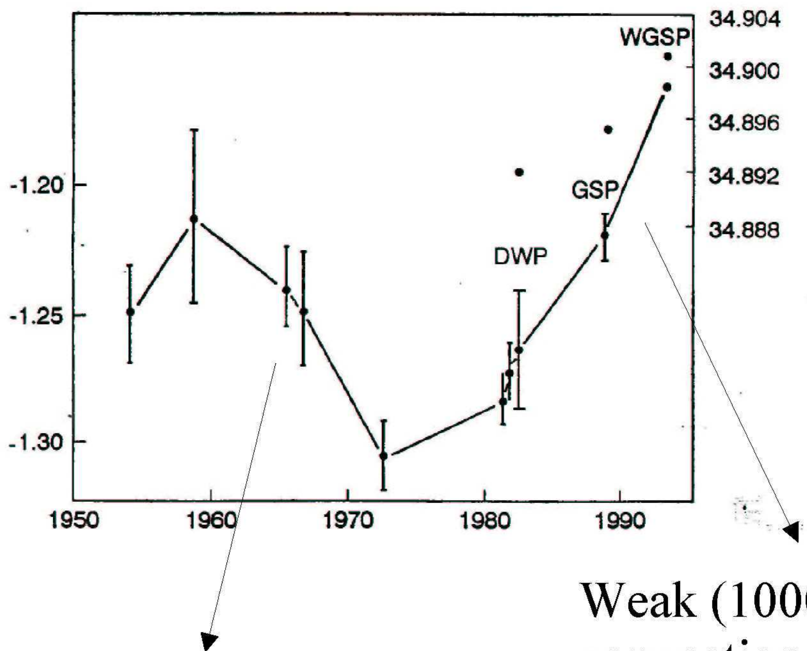
Infact, convection is particularly sensitive element of the climate system because it can shutdown completely.

Variability at Deep Convective Locations: Observations

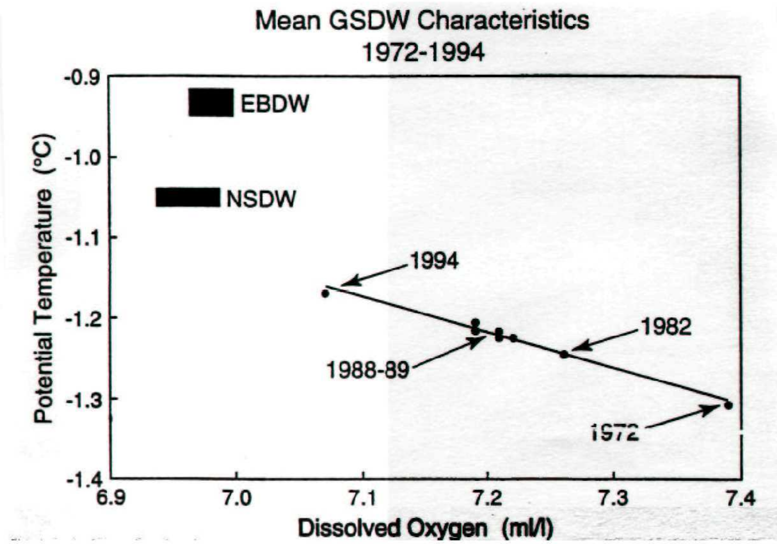
Greenland Sea Deep Water (GSDW), one of the constituents of NADW, is formed in the Greenland Sea.



Potential Temperature of GSDW



Oxygen/Pot. Temp. of GSDW



Strong convection reaching 3500m in 1970

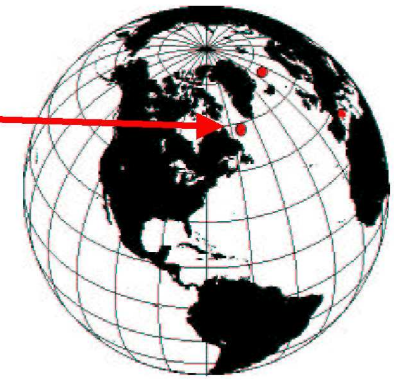
Weak (1000m) to no convection since 1970

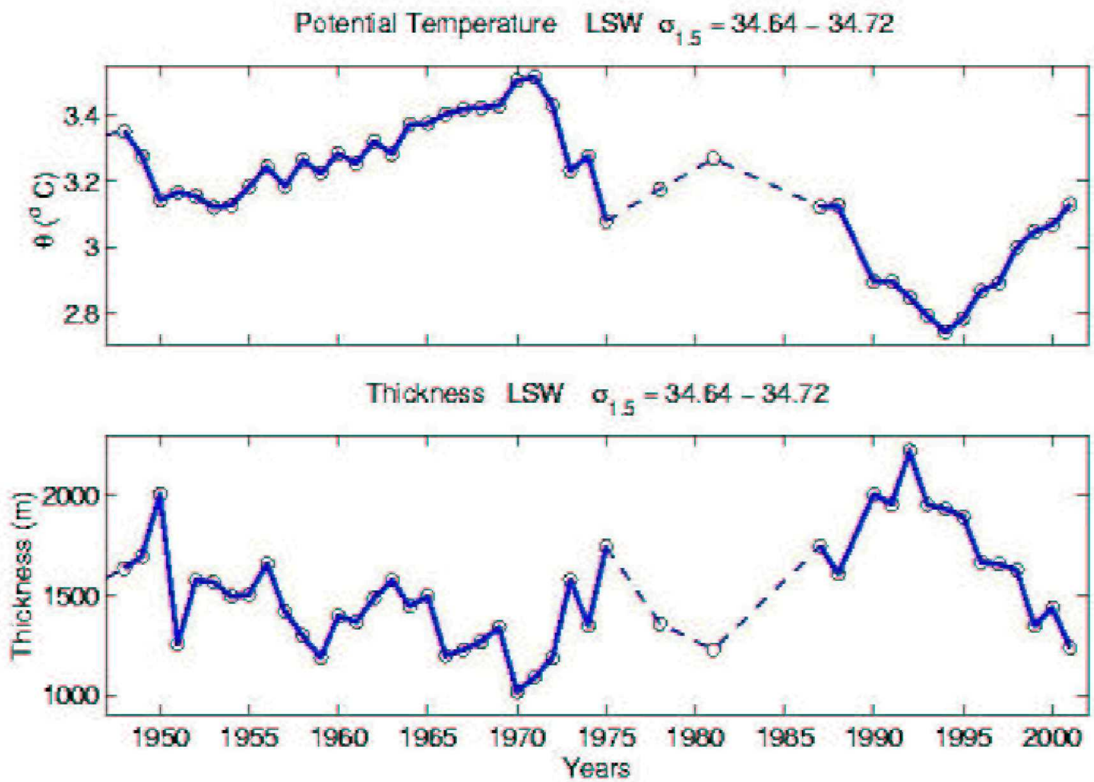
Reduction of convection associated with a reduction in oxygen concentration.

(Dickson et al., 1996)

Variability at Deep Convective Locations: Observations

Labrador Sea Water (LSW), one of the constituents of NADW, is formed in the Labrador Sea.



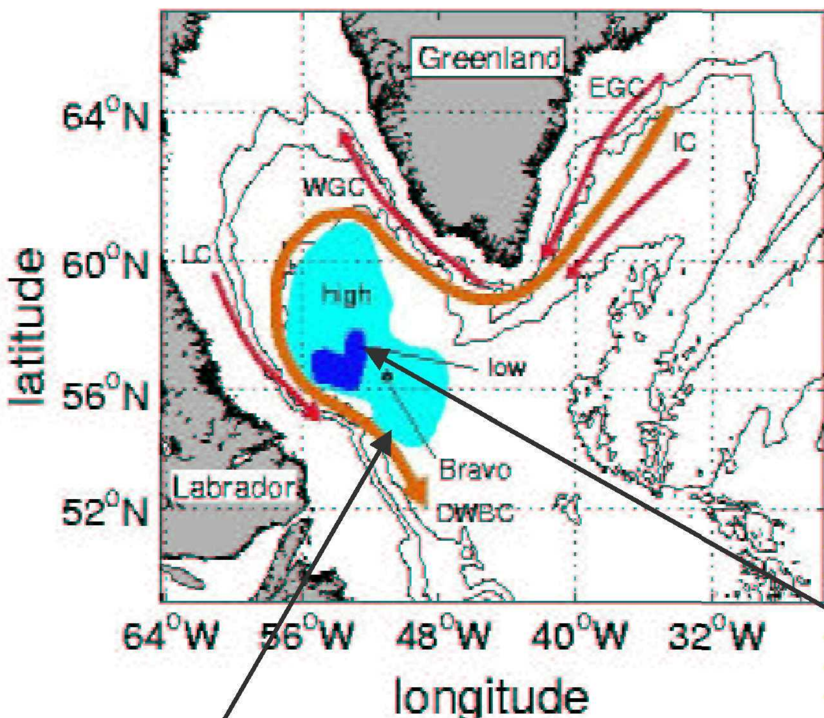


Strong convection in early 1990s reaching 2300m in 1992

Considerable interannual variability in LSW formation

(I. Yashayaev, BIO)

Variability at Deep Convective Locations: Observations



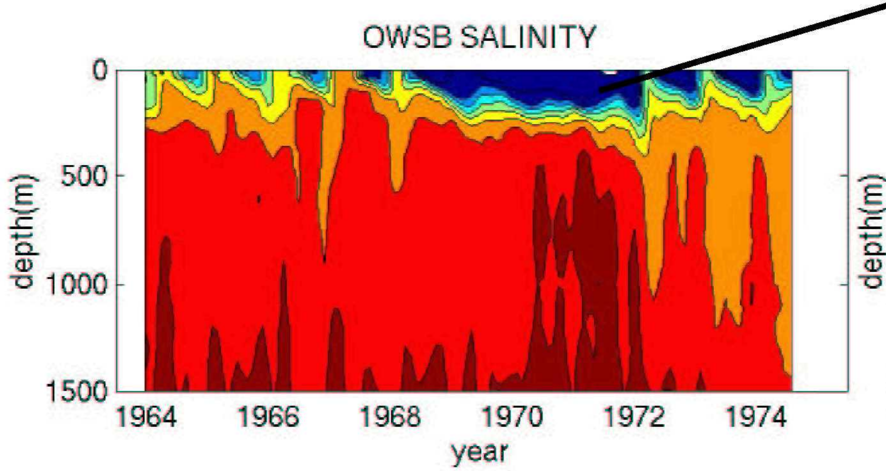
Variability in Deep Convection is also characterized by variability in the area over which deep convection occurs (not just depth).

High convection scenario – large area

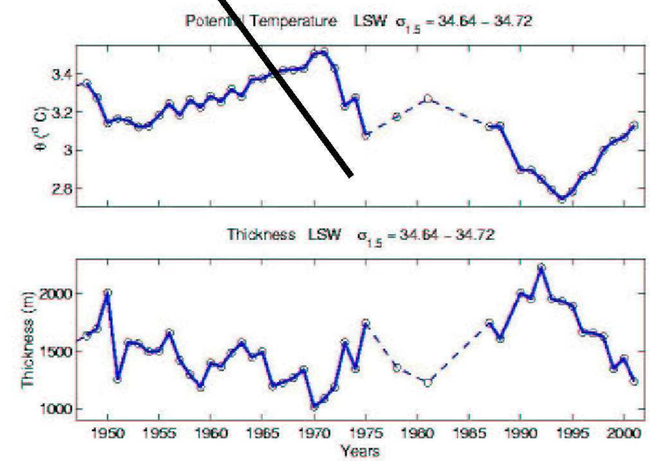
Low convection scenario – small area

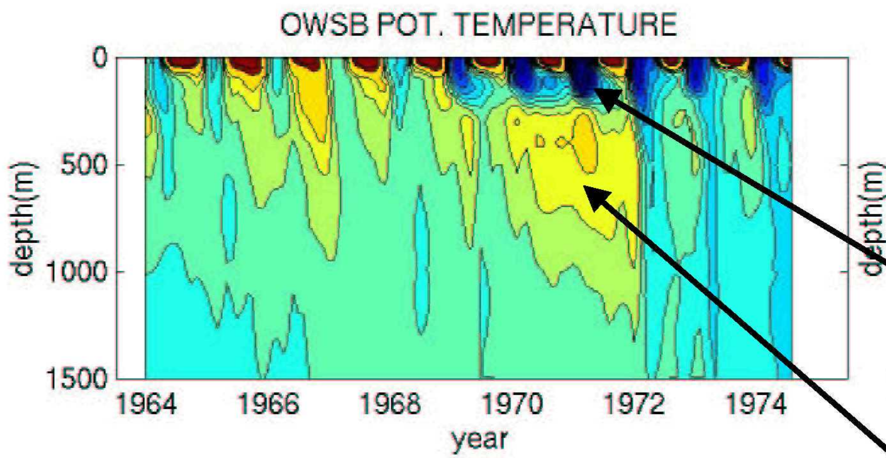
(Pickart et al., 2002; Straneo et al, 2003)

Observed Shutdown of Convection in the Labrador Sea 1969−1972



Great Salinity Anomaly (GSA) − freshwater anomaly





Very cold winter surface temperatures during GSA.

Accumulation of subsurface heat during GSA.

(Lazier, 1980)

Modeling Variability at Deep Convective Locations

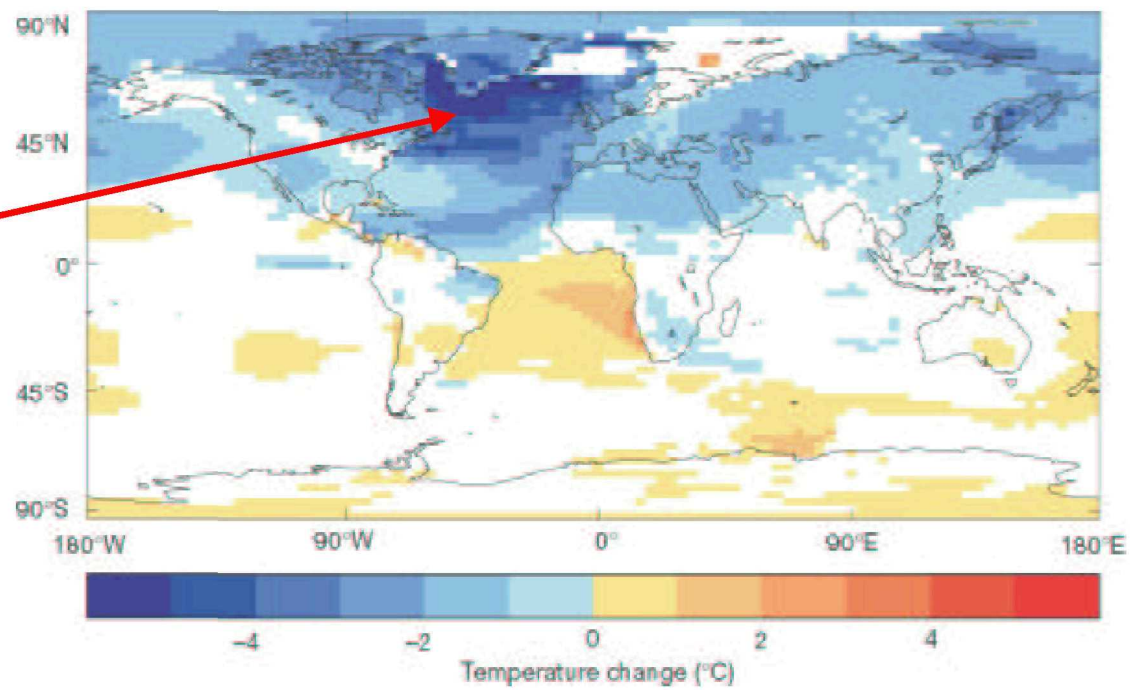
1. Variations in LSW and GSDW formation in models are associated with variations in the meridional overturning circulation and poleward heat transport (e.g. Velinga and Woods, 2002; Betsen et al., 2003)

2. Most past and future climate change scenarios involve either a complete or partial shutdown of NADW formation
(e.g. Rahmstorf, 2002)

Modeled Impact of the Shutdown of NADW Formation

Surface Air Temperature Change in a
Coupled Ocean−Atmosphere Model

Cooling
of 6°C



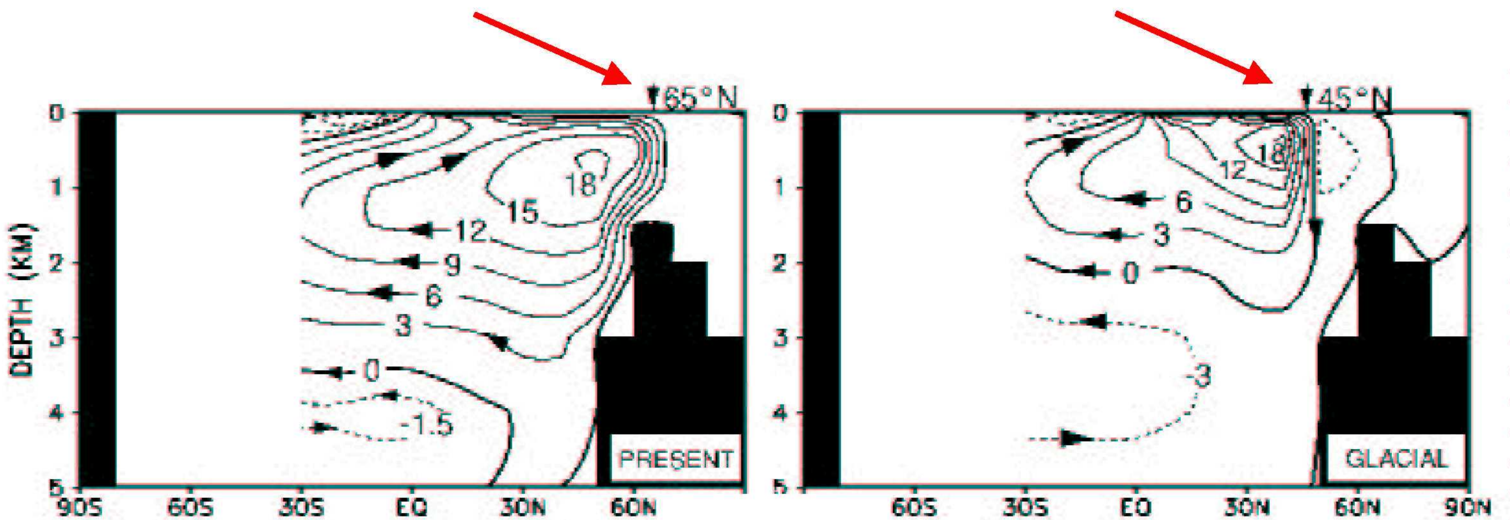
(HadCM3 − Velinga and Wood, 2002)

Climate sensitivity to the location of dense water formation

Coupled ocean−atmosphere simulations of present and glacial times showing a dramatic shift in the location of dense water formation and in the overturning circulation

high−latitude downward mass flux

mid−latitude downward mass flux



(Ganopolski et al., 1998)

How to Address Variability at Deep Convective Sites ?

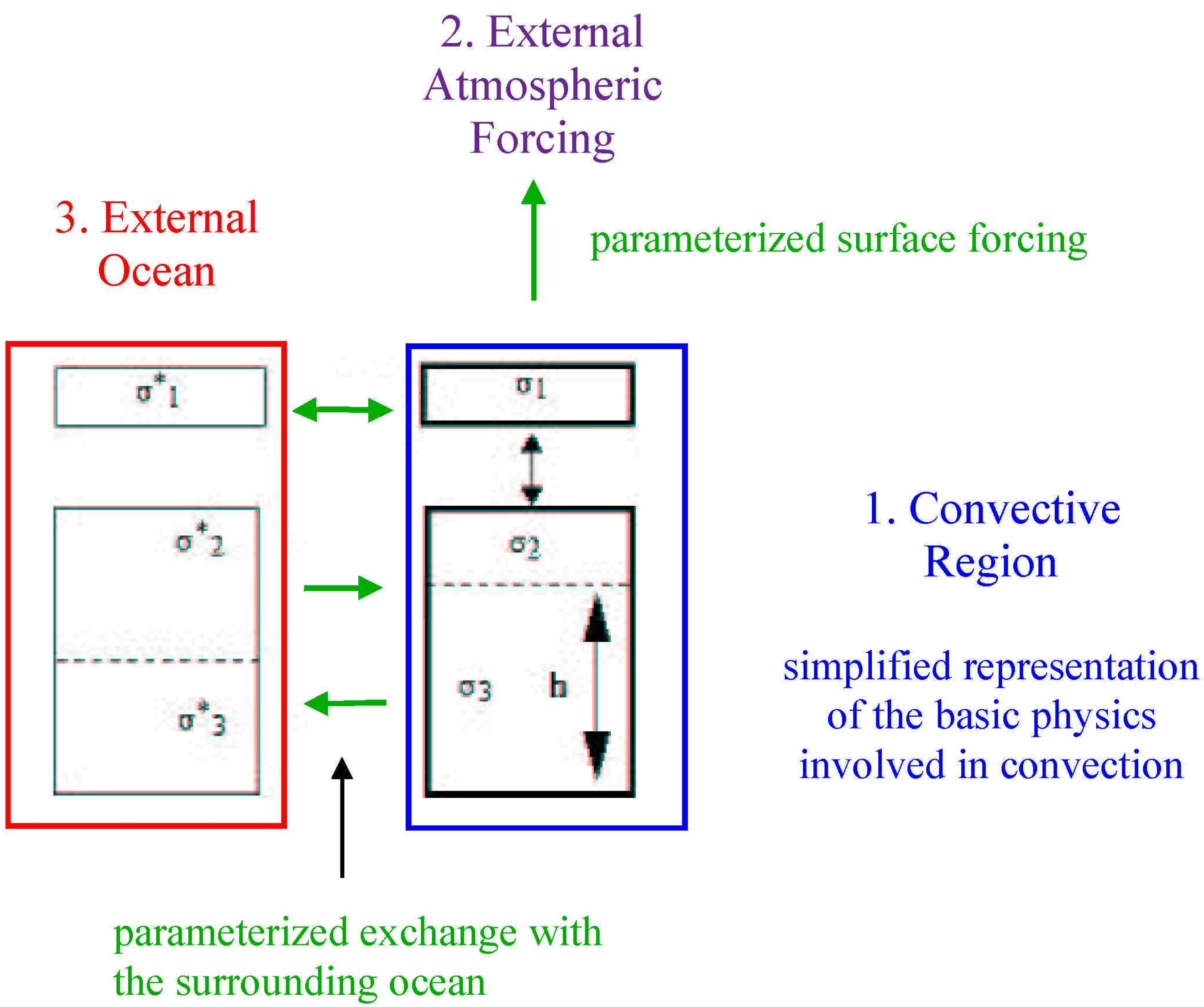
GCMs:

- Long–term simulations of coupled or uncoupled ocean GCMs are still unrealistic, and difficult to interpret.
- Convection is not well resolved by even the highest resolution GCMs.

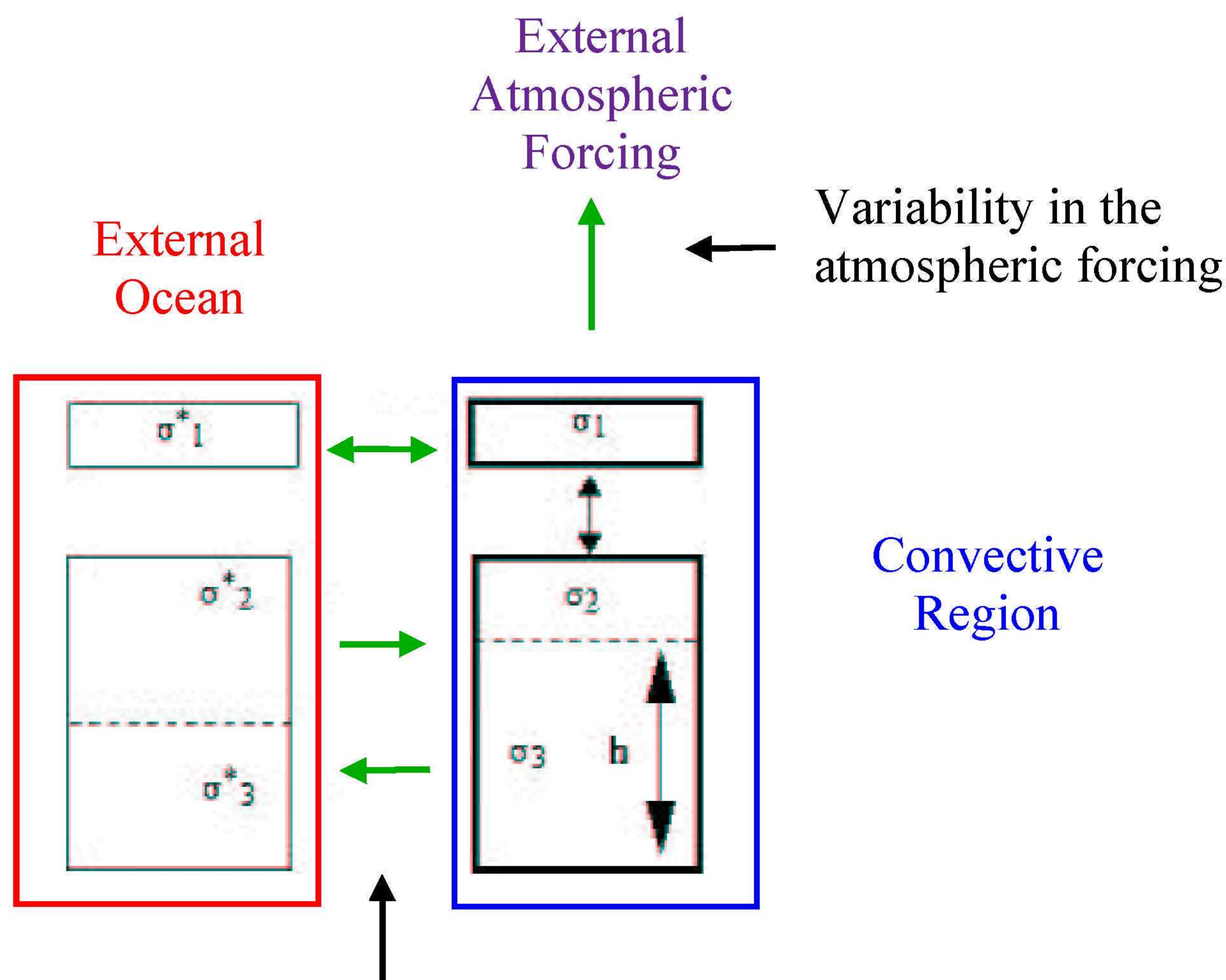
Idealized Models:

- Simplified representation of a convective system and of its exchange with the surroundings that can be solved analytically (or with simple numerics) and in which mechanisms can be understood.
- Must contain all the physical processes which play a role in the mechanisms under investigation.

A Simplified Model for the Interannual Variability of a Convective Location



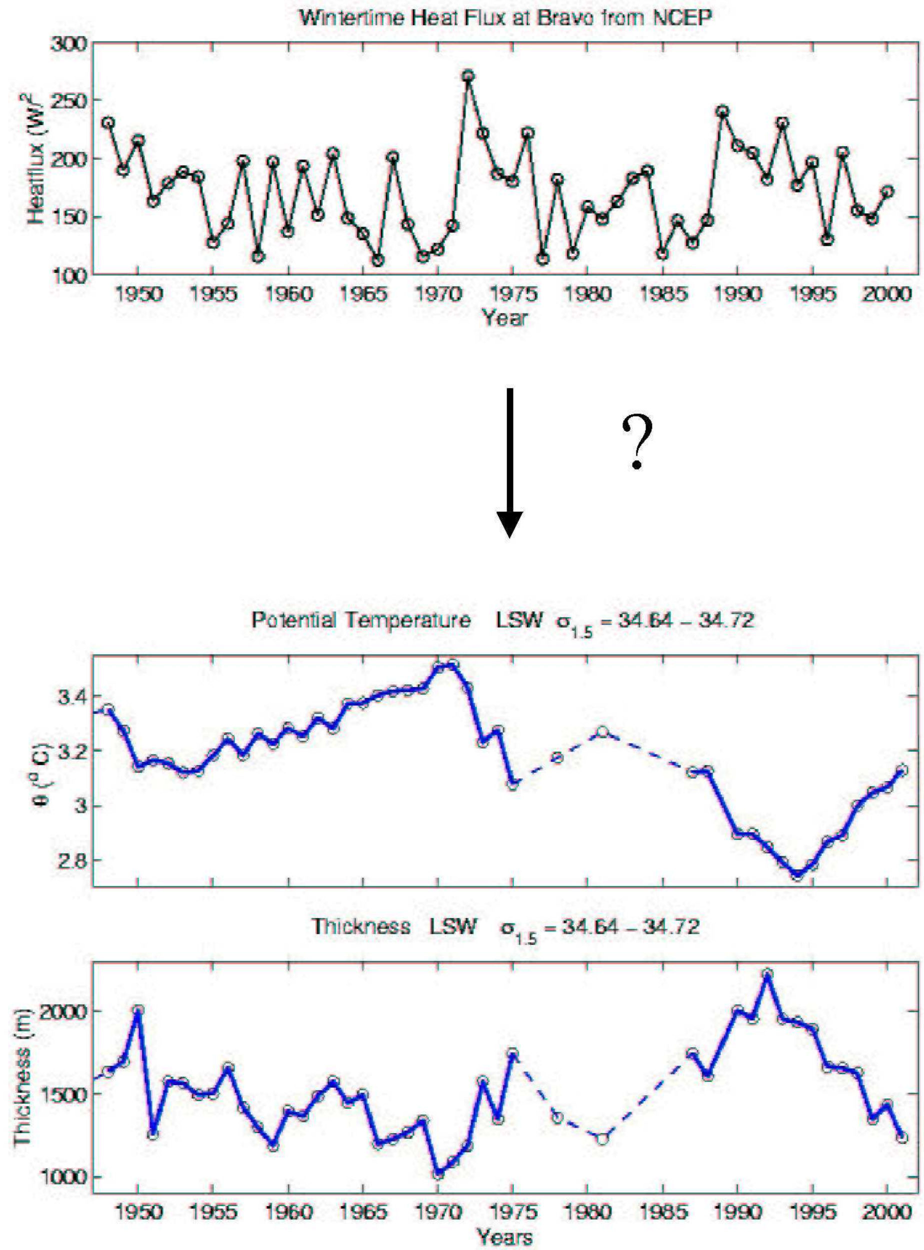
Starting from the Climatological Cycle: How to induce variability in the system ?



Variability in the exchange with the surrounding ocean:
e.g. freshwater or heat anomalies circulating around the subpolar gyre

An Example of an Idealized Model Applied to the Labrador Sea

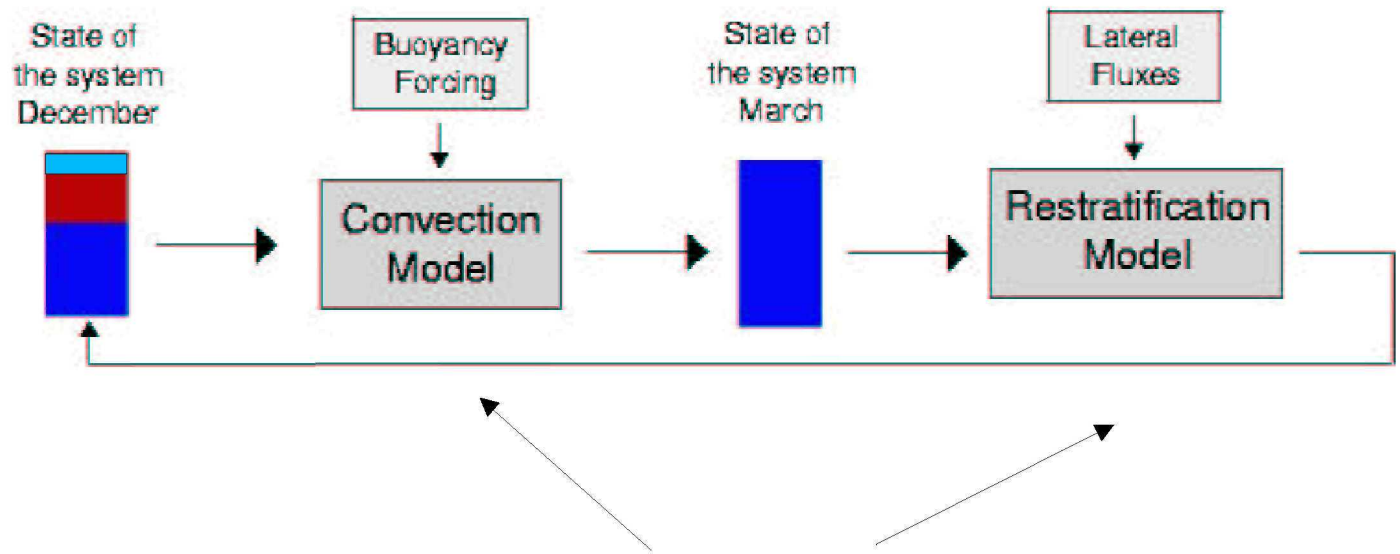
Given a variable atmospheric forcing − what is the response of a convective system ?



Building the Model:

the data analysis showed that the climatological cycle can be represented in terms of

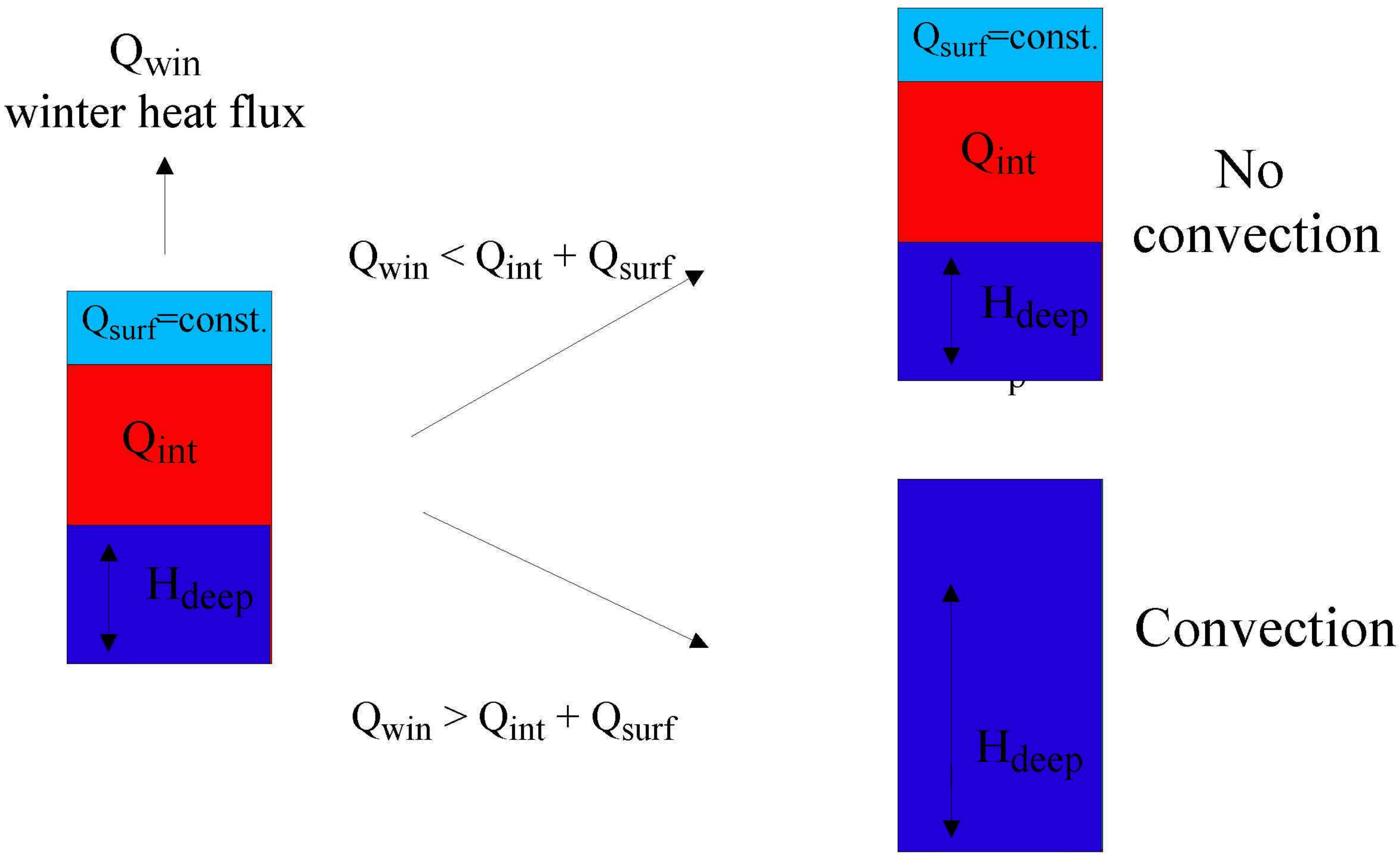
- two phases = convection and restratification
- three layers = surface, intermediate and deep



Different physics governing the two periods

Convection Model

Hypothesis: in order to form deep water the winter heat flux must be large enough to convert the entire surface and intermediate (warm) layers to the density of the deep layer.

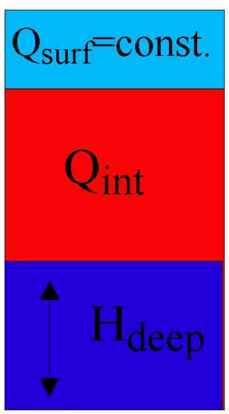


Convection Model

Preconditioning:

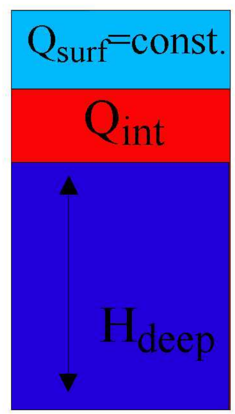
data analysis has shown that the thickness of the intermediate (warm) layer is inversely proportional to that of the deep layer − hence the amount of heat loss needed to form deep water is inversely proportional to the thickness of the intermediate layer.

Weakly preconditioned



Need significant heat loss to convect

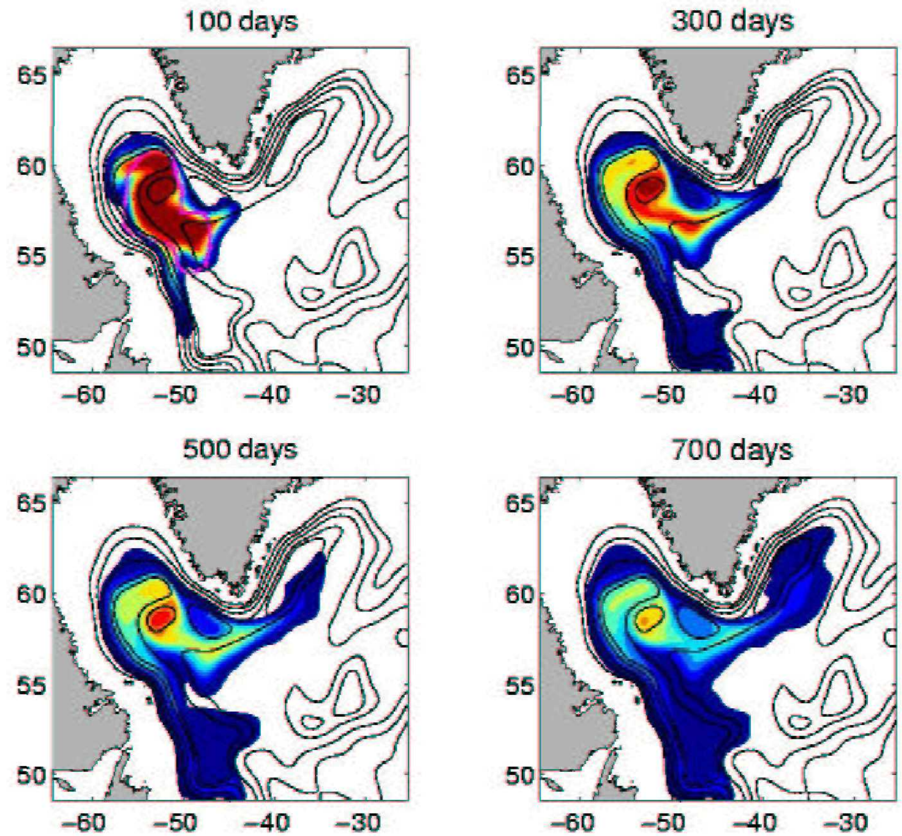
Strongly preconditioned



Need small heat loss to convect

Restratification Model

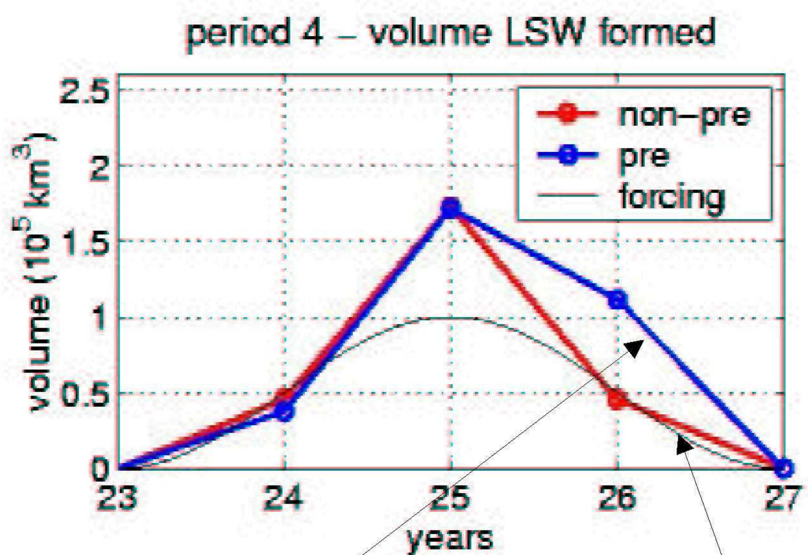
Restratification is simulated using an advection−diffusion model for the spreading of the deep water based on observed velocities and eddy kinetic energy. It takes approx. 4 years for the dense water to leave the basin.



(Straneo et al., 2003)

Investigating the Model Response to Idealized Variability

1. Atmospheric Forcing: 4 year periodicity



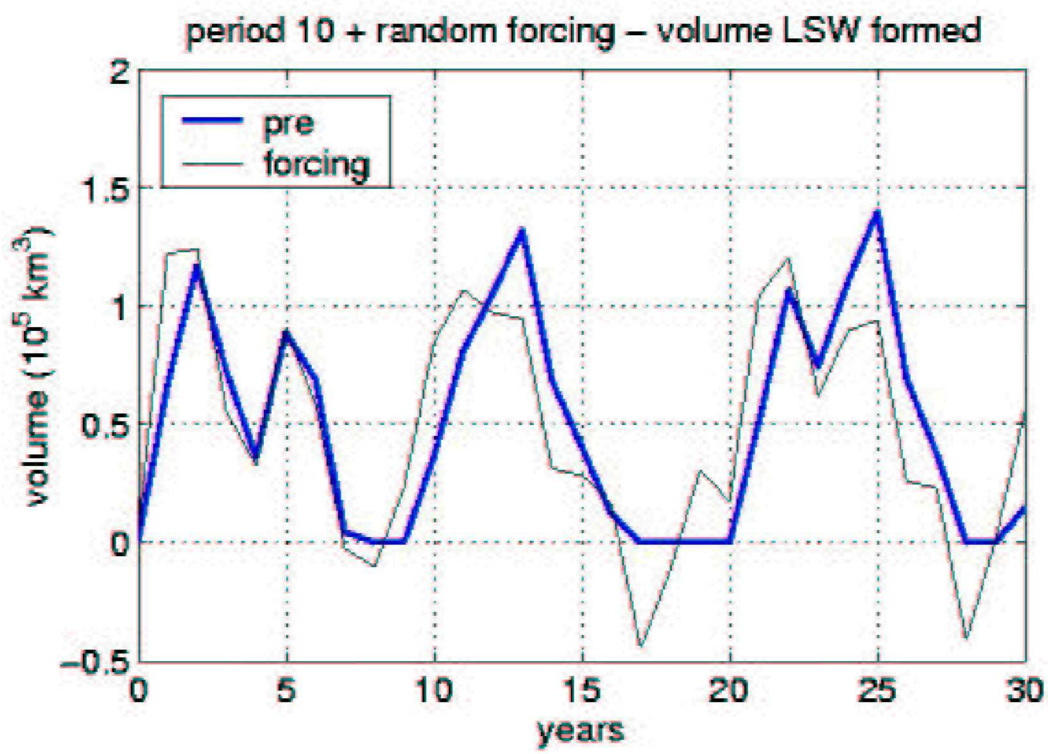
A year of strong convection is followed by moderate convection even if the forcing is weak.

Curve that takes into account preconditioning

No preconditioning accounted for

Investigating the Model Response to Idealized Variability

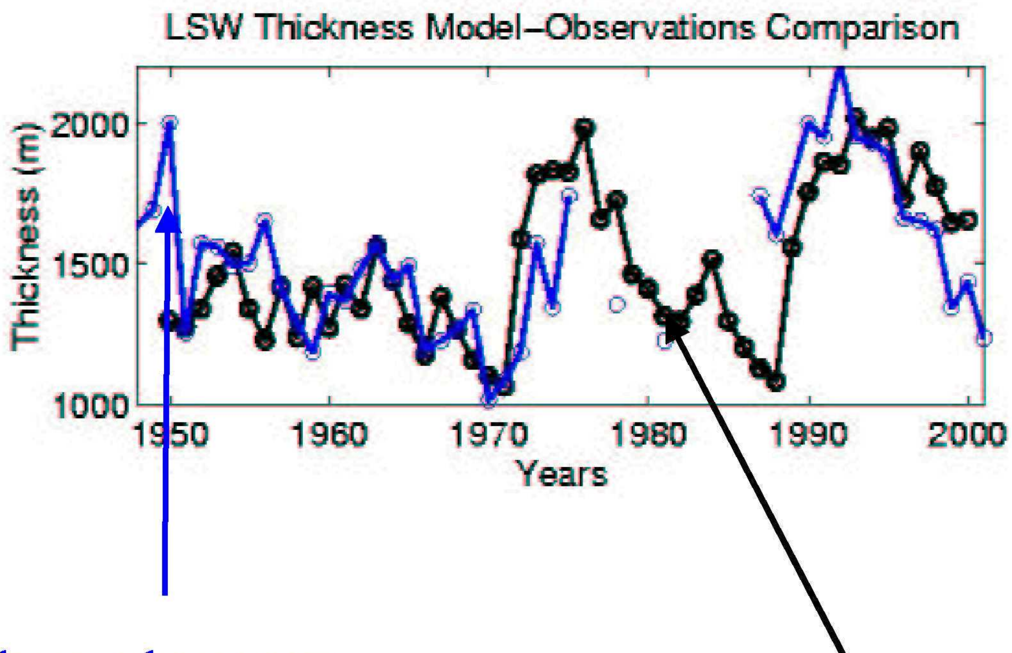
2. Atmospheric Forcing: 10 year periodicity plus random noise



The decadal signal is preserved, but there is no direct correlation between the forcing and the response on an interannual basis.

Investigating the Model Response to Realistic Variability

2. Atmospheric Forcing: Observed Forcing from 1948−2000



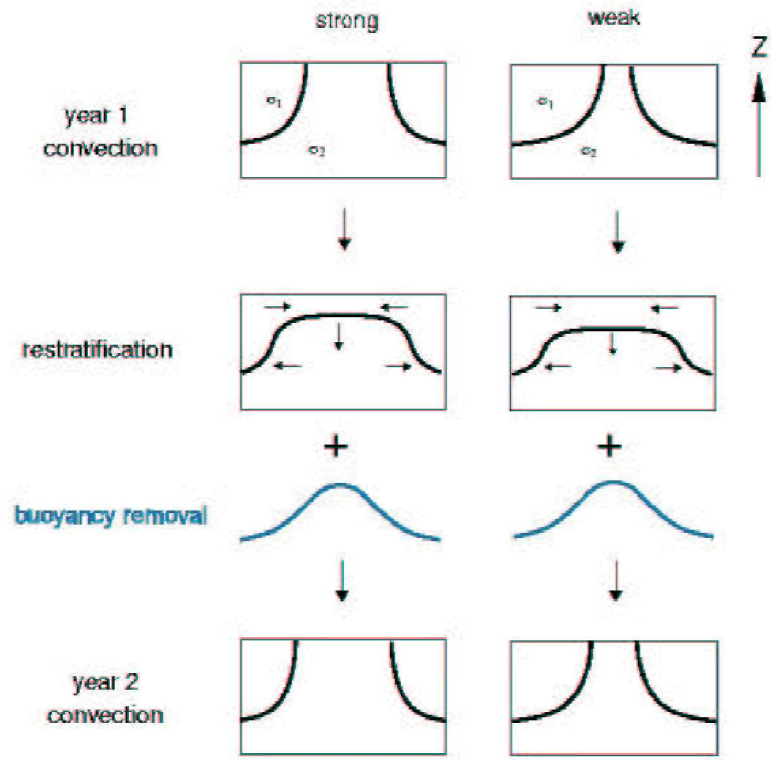
Observed response

Simulated response

Results from the idealized study:

i. the amount of dense water formed one year strongly affects the amount formed the following year.

ii. the basin has a 4−5 year memory, therefore it can be expected that on longer timescales the response closely follows that of the forcing.



Summary − General Role of Convection in Climate

i. Deep convection is a key component of the climate system because of its role in the overturning circulation and poleward heat transport.

ii. It is a highly variable process, which can exhibit strongly non−linear behaviour, including a complete shutdown of convection.

iii. Climate models are extremely sensitive to the extent and location of convection.

Summary − An Idealized Model to Study the Variability of Convection

i. Using data to determine a climatological seasonal cycle of convection one can identify the significant physical variables and the basic physical mechanisms involved in convection.

ii. Once the variables and physical mechanisms are identified, they can be summarized in an idealized model containing the basic physics of convection and the exchange between the convection region and the surrounding atmosphere and ocean.

iii. One can use this idealized model to test and understand the response of the system to idealized perturbations of the basic state and to realistic forcing.