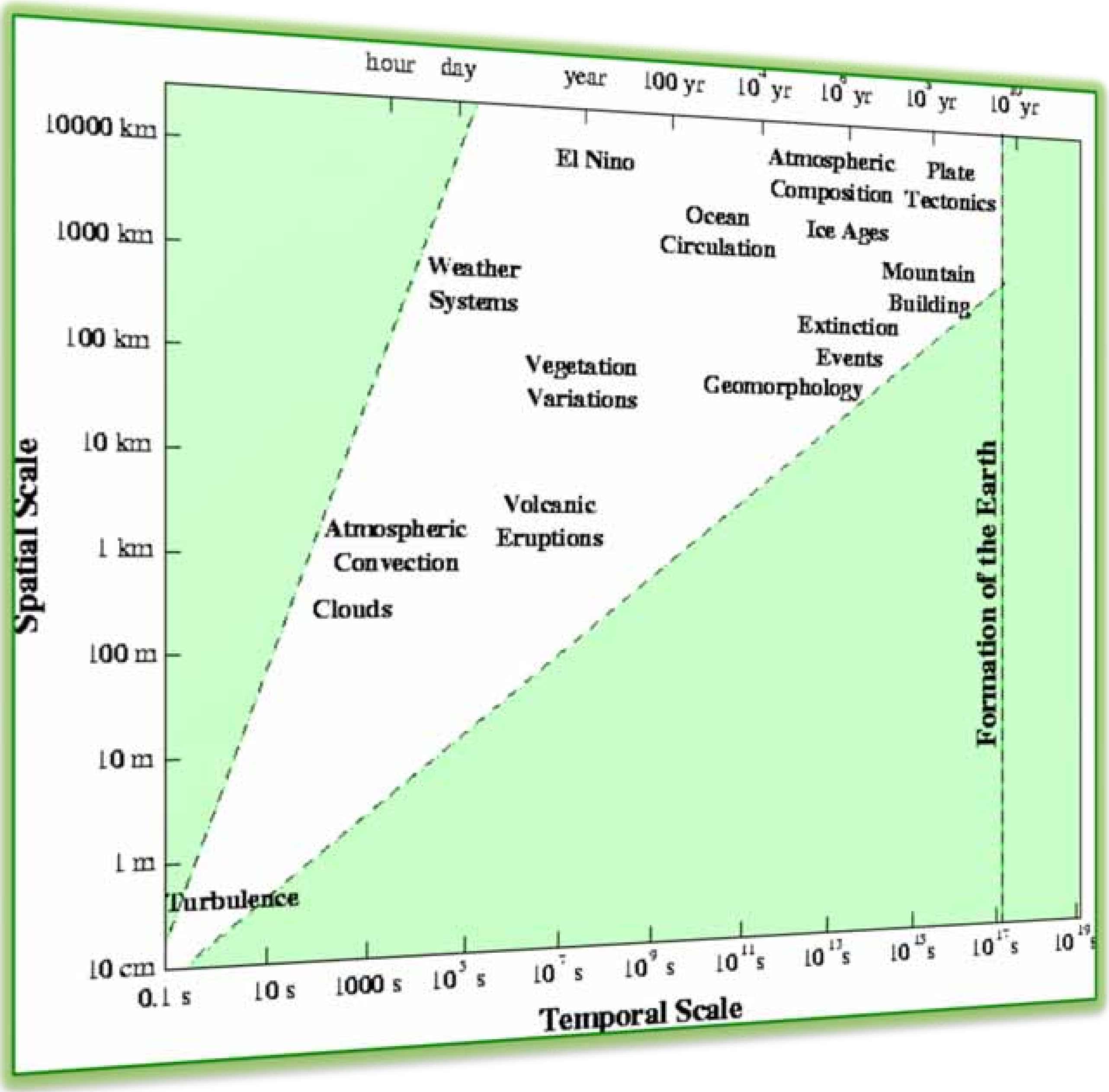
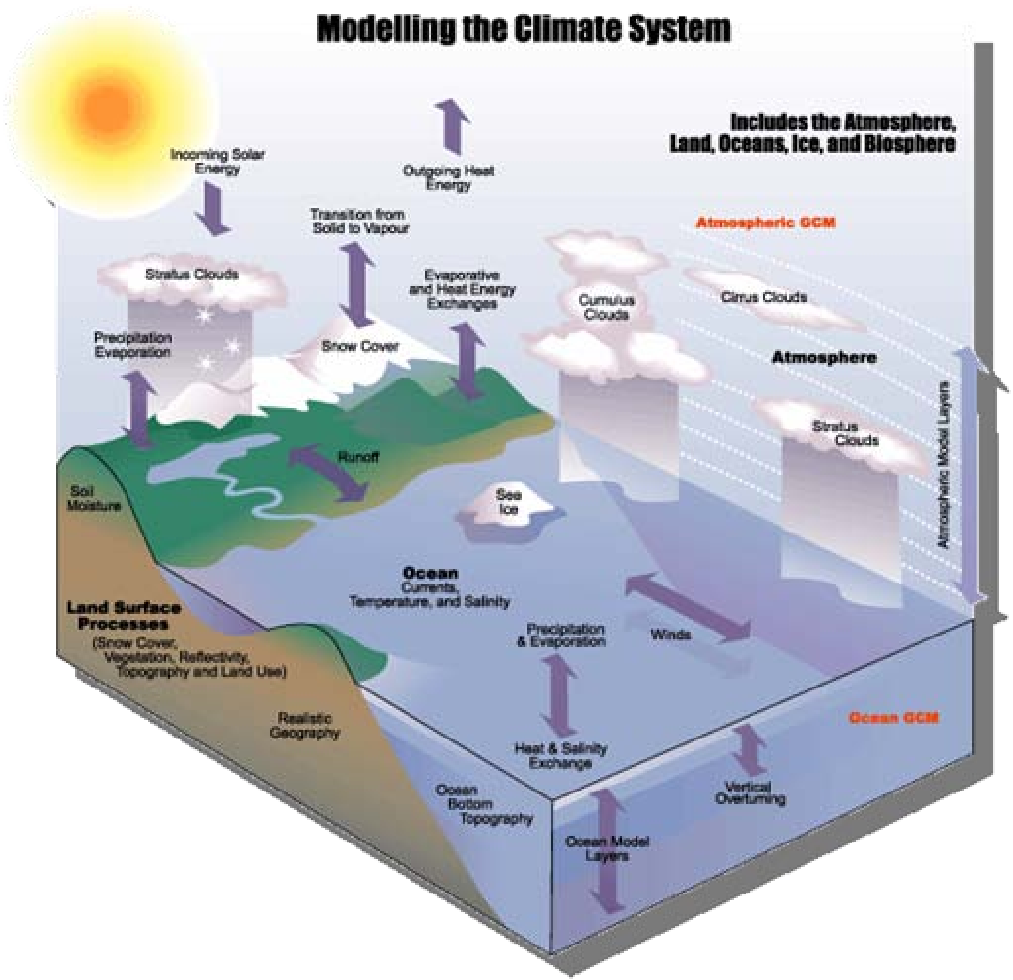
Introducción

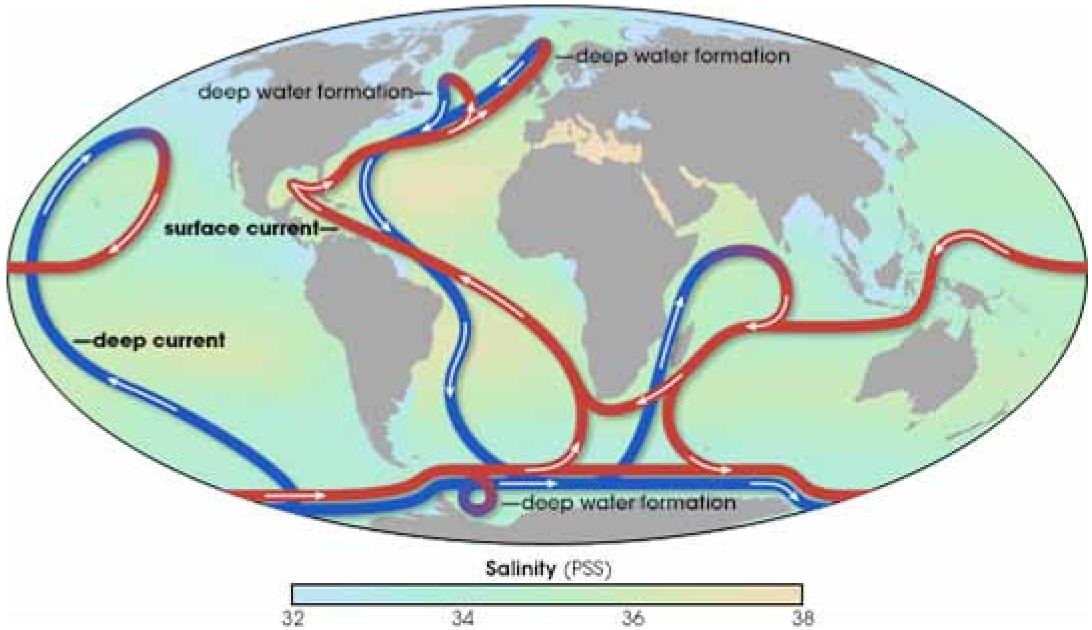


Variability in the climate system occurs over a broad range of scales in space and time, and this variability is coupled between scales.



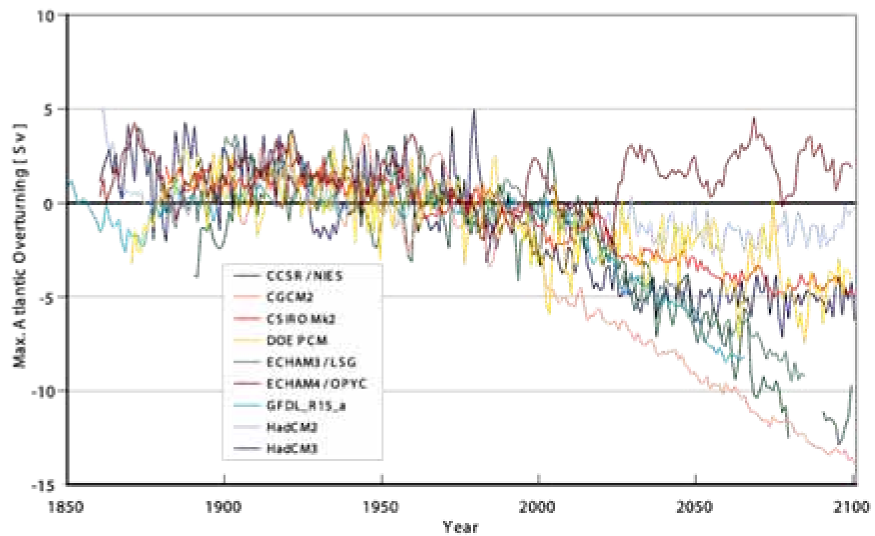
Hasselman and Epstein were pioneers on the use of stochastic models in climate physics the former with the treatment of high-frecuency fluctuations as stochastic processes and the later introducing stochasticity only through random selection of initial conditions in forecast models wholly deterministic.

Thermohaline Circulation



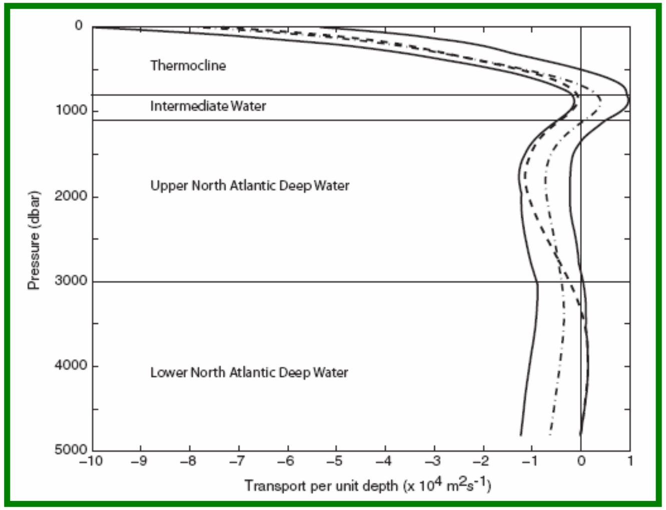
(Map by Robert Simmon, adapted from the IPCC 2001 and Rahmstorf Nature 2002.)

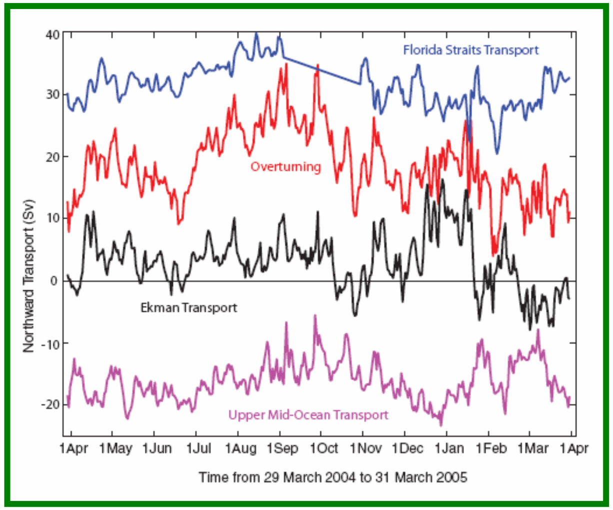
The most ocean-atmosphere coupled models forecast show a weaken of the thermohaline circulation for a scenario of global warming. However the deterministic models show a great variability of behaviors.

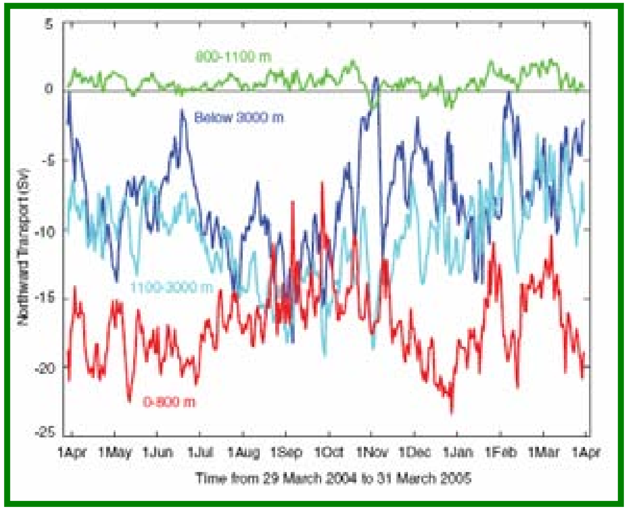


Introducción

Measures taken by current meter in situ show how this circulation is influenced by stochastic forcing which are not consider in the models with deterministic parameterizations.







To study the contribution of the variations of this parameter we can introduce a stochastic forcing through Gaussian noise.

Science ***317, 935 (2007);*** Stuart A. Cunningham, *et al.* **Overturning Circulation at 26.5°N Temporal Variability of the Atlantic Meridional.** DOI:10.1126/science.1141304

Model

The coupled model has been taken from Roebber (1995). In this article, the atmosphere model has been taken from Lorenz and the ocean model is a 3-box model.

The atmospheric model

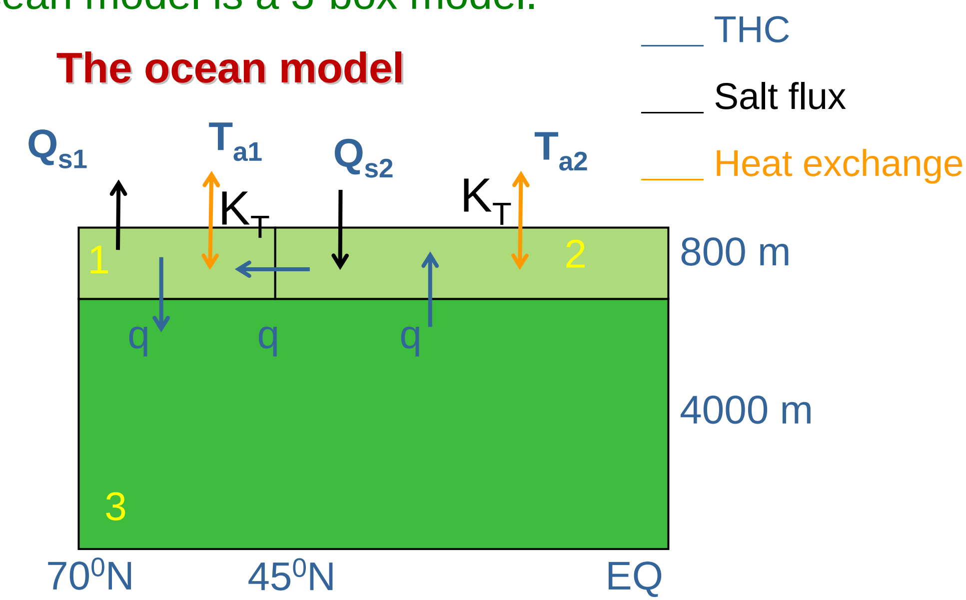
$$\frac{dX}{dt} = -Y^2 - Z^2 - aX + aF$$

$$\frac{dY}{dt} = XY - bXZ - Y + G$$

$$\frac{dZ}{dt} = bXY + XZ - Z$$

X, Y and Z represent the meridional temperature gradient and the amplitudes of the cosine and sine phases of a chain of superposed large scale eddies, a=0.25 and b=4.

The ocean model



q is the magnitude of the thermohaline circulation. The sense of the circulation indicated denotes q positive.

The coupled model

1.- *Atmospheric coupling*

$$F(t) = F_0 + F_1 \cos \omega t + F_2 (T_2 - T_1)$$

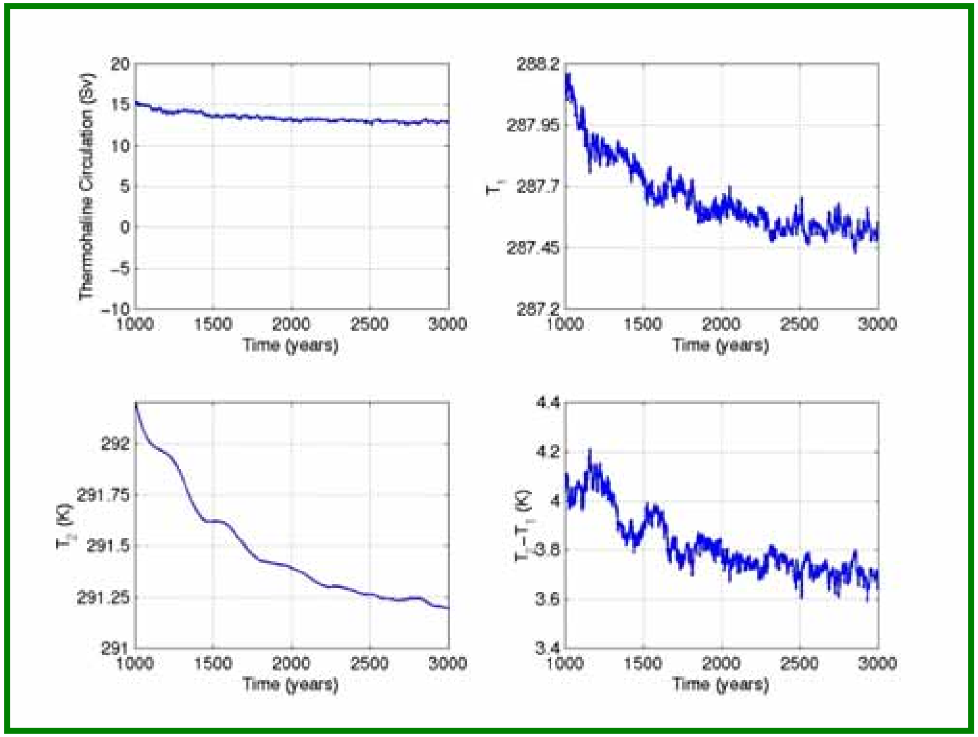
$$G(t) = G_0 + G_1 \cos \omega t + G_2 T_1$$

2.- *Ocean coupling*

$$T_{a1}(t) = T_{a2} - \gamma X(t); \ \gamma = 0.06364$$

$$Q_s(t) = 0.00166 + 0.00022(Y^2 + Z^2)$$

Model



Present-day steady state of the ocean-atmosphere system with active THC.

Thermohaline Atlantic circulation estimations have been obtained from hydrographical data gathered in the World Ocean Circulation Experiment (WOCE), with a value of 15+/-2 Sv (Ganachaud and Wunsch, 2000). In this way the model was calibrated to give this value for THC in present-day conditions.

Results

1.- *Forcing in the atmospheric coupling*

To introduce the synoptic variability inside this model, i.e., the main stochastic component of climate system, we added random fluctuations in an additive way in parameters *F* and *G*.

$$F(t) = F_0 + F_1 \cos\omega t + F_2(T_2 - T_1)$$
$$G(t) = G_0 + G_1 \cos\omega t + G_2 T_1$$

These fluctuations are given by white Gaussian noise with zero mean and whose correlation function is

$$<\xi_w(t), \ \xi_w(t')>=2A\delta(t-t')$$

where *A* represents the noise intensity and 2*A* its variance.
We have chosen this kind of noise parameterization because we are looking for the possibility that processes of a frequency higher than the considered in the model could provoke a collapse in thermohaline circulation. Moreover, the effect of atmospheric processes on the ocean has been taken into account in previous work as white noise (Frankignoul and Hasselmann, 1977).

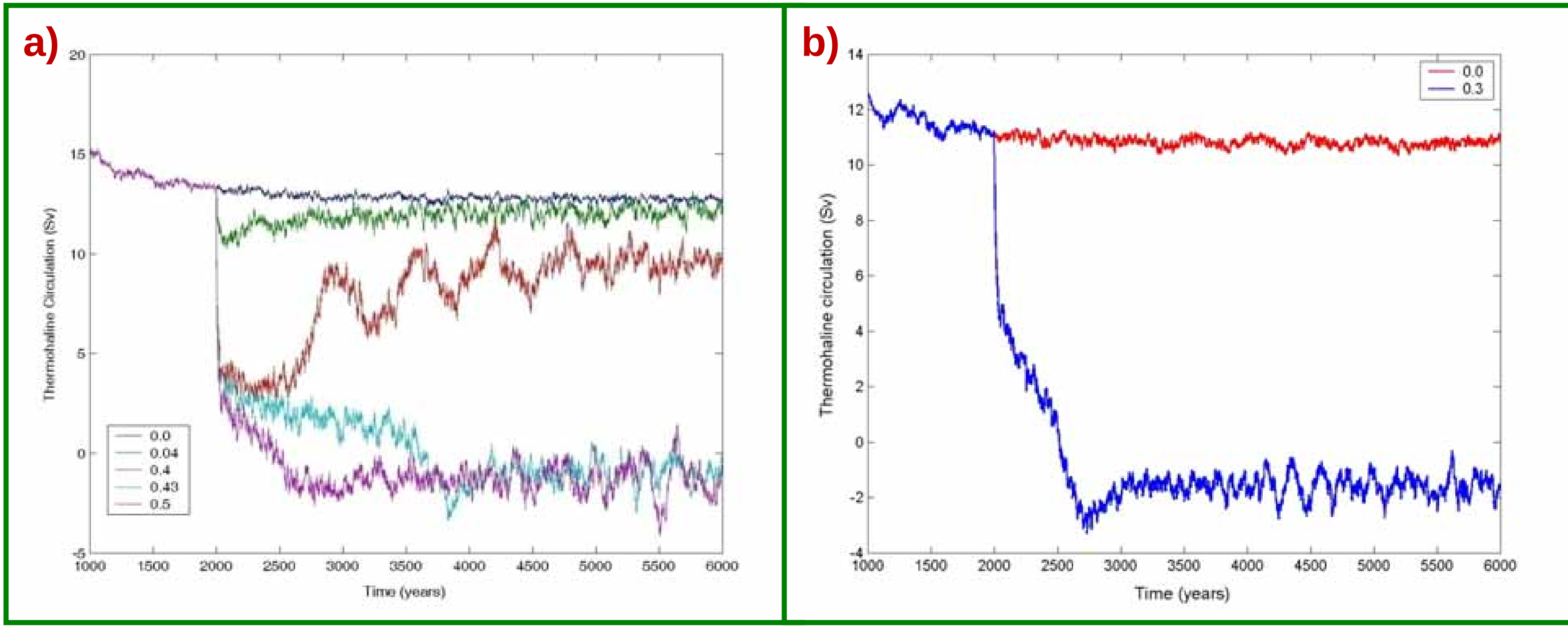
***** J.J. Taboada and M.N. Lorenzo "Effects of the synoptic scale variability on the thermohaline Circulation". Nonlinear Processes in Geophysics **12** , 435 – 439 (2005).

Results

1.- *Forcing in the atmospheric coupling*

$$F(t) = F_0 + F_1 \cos \omega t + F_2 (T_2 - T_1)$$

$$G(t) = G_0 + G_1 \cos \omega t + G_2 T_1 + \textbf{White noise}$$



a) Effects of a stochastic forcing on the zonal gradient in diabatic heating G for different values of the intensity of the applied noise A.

b) Effects of a stochastic perturbation on the zonal gradient in diabatic heating G after a weakening of the THC due to a increasing of the CO_2 concentration for two values of the intensity of the applied noise A shown in the legend.

Results

2.- *Forcing in the oceanic coupling*

To introduce the synoptic variability inside this model, i.e., the main stochastic component of climate system, we added random fluctuations in an additive way.

$$T_{a1}(t) = T_{a2} - \gamma\, X(t);\ \gamma = 0.06364$$
$$Q_s(t) = 0.00166 + 0.00022(Y^2 + Z^2)$$

These fluctuations are given by colored Gaussian noise of zero mean whose dynamics is given by

$$\dot{\xi}(t) = -\tau^{-1}\xi(t) + \tau^{-1}\xi_w(t)$$
$$\langle \xi(t), \xi(t') \rangle = \frac{A}{\tau} e^{\frac{|t-t'|}{\tau}}$$

The Ornstein-Uhlenbeck stochastic process is driven by the white Gaussian noise. where τ is the correlation time, A is the noise amplitude, and $\sigma=(A/\tau)^{1/2}$ is the noise dispersion.

***** M.N. Lorenzo, J.J. Taboada, I. Iglesias and I. Alvarez “The role of stochastic forcing on the behaviour of the thermohaline Circulation”. Annals of the New York Academy of Sciences. Trends and Directions in climate Research (in press 2008).

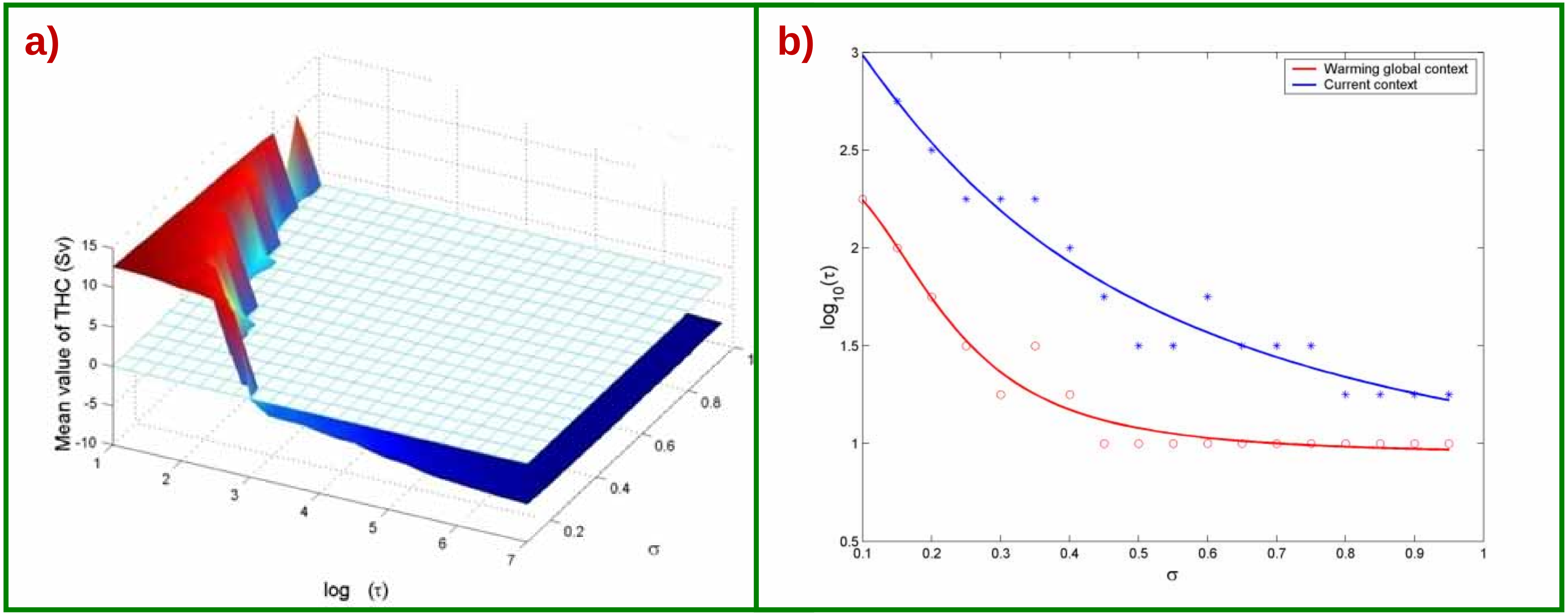
Results

2.- Forcing in the oceanic coupling

$$T_{a1}(t) = T_{a2} - \gamma X(t)$$

$$Q_{s2}(t) = 0.00166 + 0.00022\left(Y^2 + Z^2\right)$$

$$Q_{s1}(t) = Q_{s2}(t) + \textbf{Colored noise}$$



a) Effects on the mean value of the THC of a stochastic perturbation on equivalent flux sal of the box 1 (Qs1) for different values of the dispersion (σ) and correlation time (τ).

b) Location of the bifurcation point in the behaviour of THC versus the dispersion (σ) and correlation time (τ).

Conclusions

- We observe that the behavior of the THC is seriously modified when a stochastic forcing is added in key parameters such as zonal temperature variation (G) or equivalent salt flux (Q).

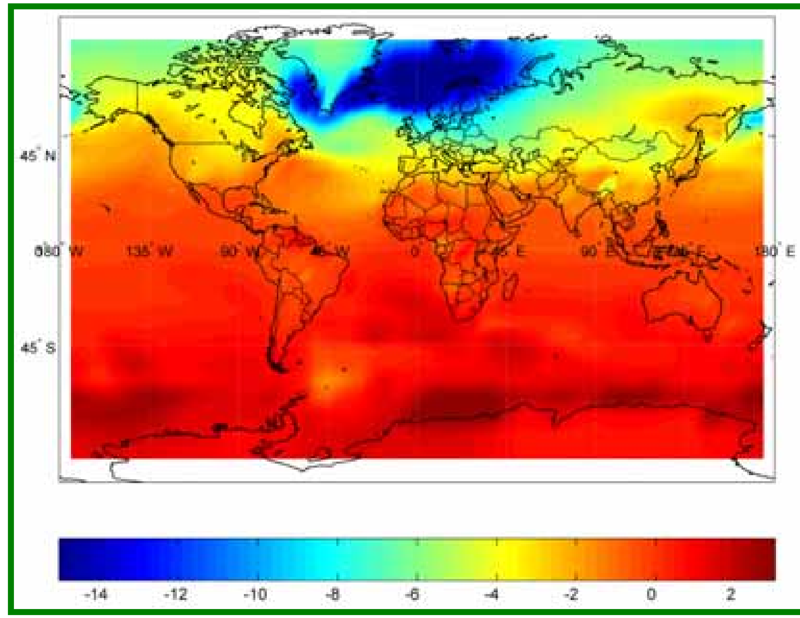
- Depending on the forcing we observe different states of the THC, reaching a shutdown above a critical value of the forcing and even a flow reversal of the circulation. This critical value depends both on the dispersion and the time correlation. The increase in the time correlation is more effective that the increase in the dispersion in the oceanic forcing. This means that it is more significant the duration of the entry of additional flow than the intensity of this flow to provoke a collapse of the THC.

- Although in actual conditions is not able to collapse THC if this circulation is progressively weakening by global warming, the threshold necessary to provoke the collapse diminishes and the climate variability could help THC to collapse.

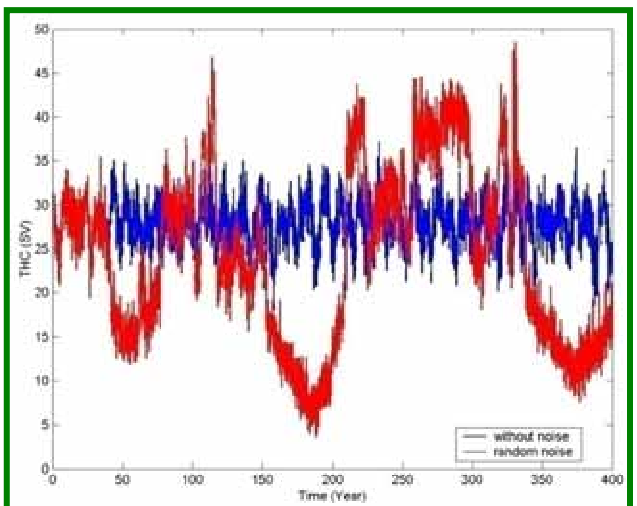
Outlooks

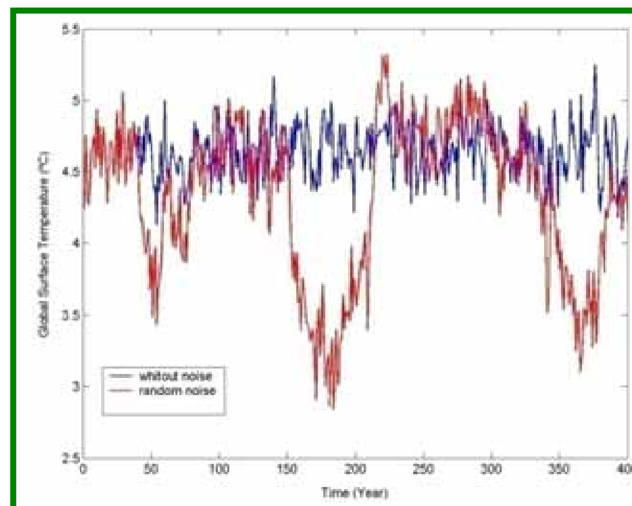
Earth Models of the Intermediate Complexity (EMICs). The model ECBilt-Clio

A continuum discharge of 0.8 Sv in GIN seas. The result was a strong cooling in the North Atlantic region spreading over the NH and a slight warming in the SH. This result is consistent with paleo-proxy reconstructions. The strength of forcing freshwater flux is between 0.1 Sv, which is the magnitude predicted for a large CO_2 induced climate change (4 x CO_2), and 1 Sv, which is within the range envisaged for events driven by meltwater release during the last glacial era and the deglaciation.



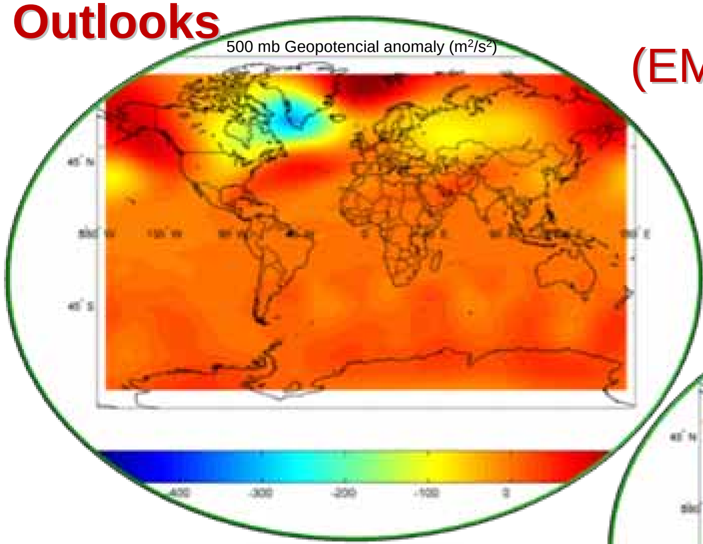
we introduced forcing where the value of the fluctuation change in a random way each year, each 10 years, 20 years, etc.

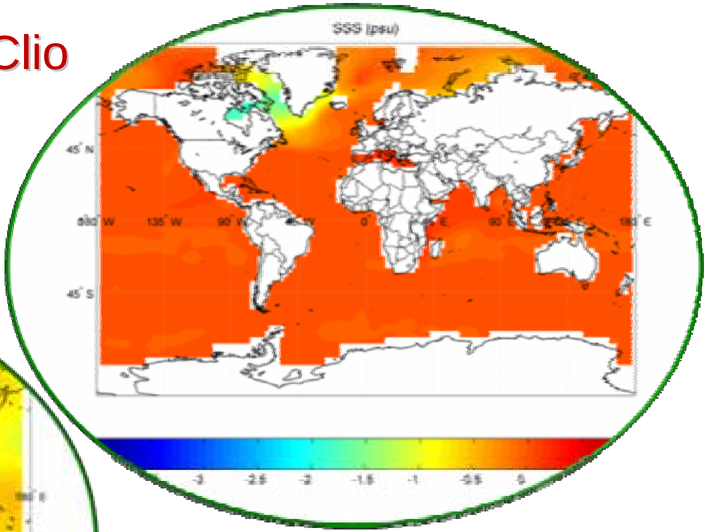


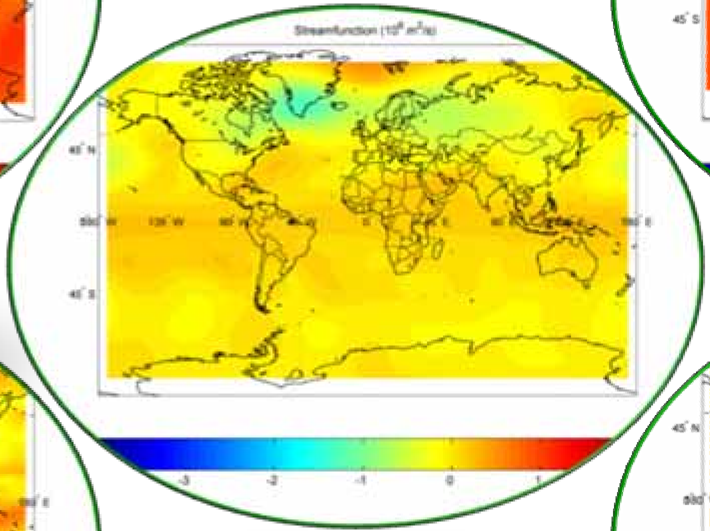


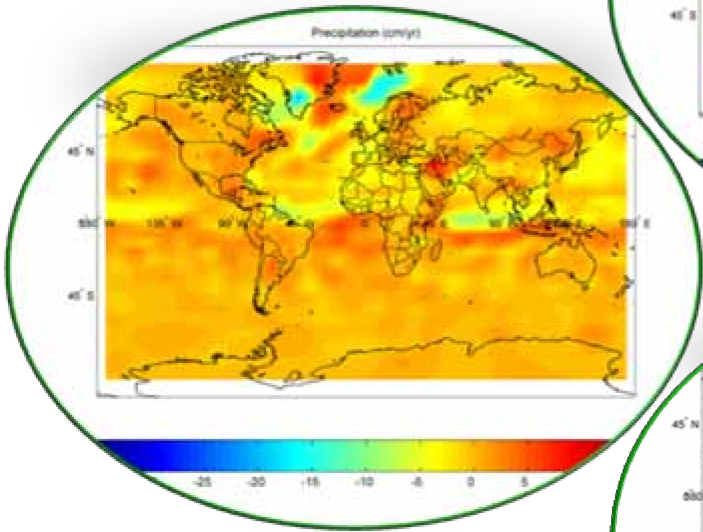
Outlooks

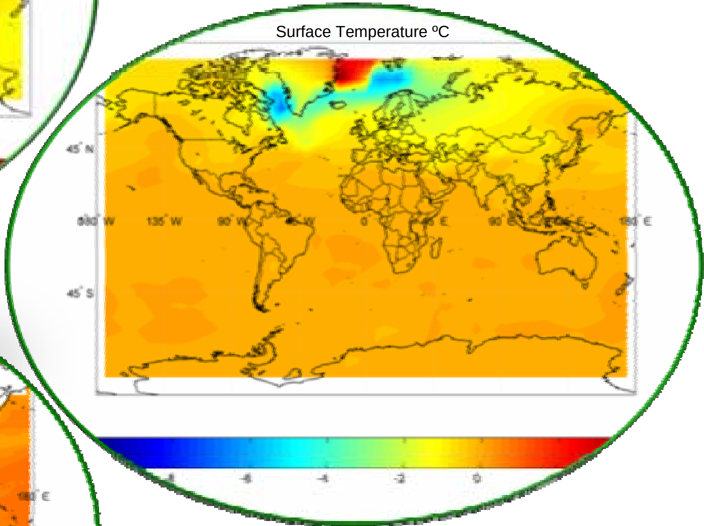
(EMICs) the model ECBilt-Clio

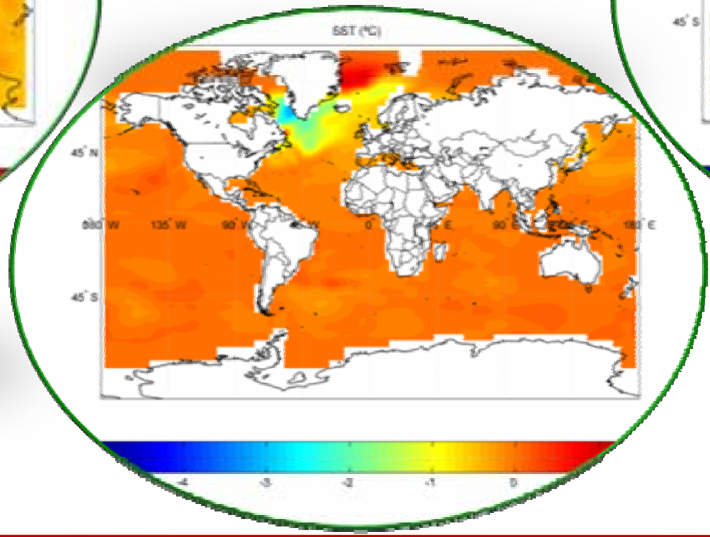












THANKS FOR YOUR ATTENTION