On the predictability of the North Atl ocean state

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Ocean Scale Interactions
A Tribute to Bach-Lien Hua
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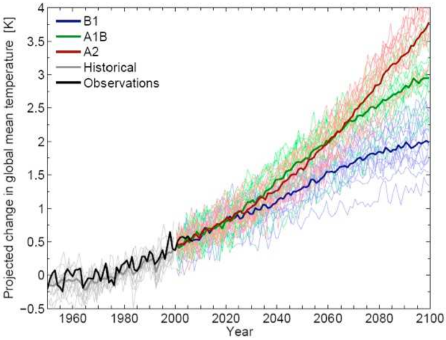
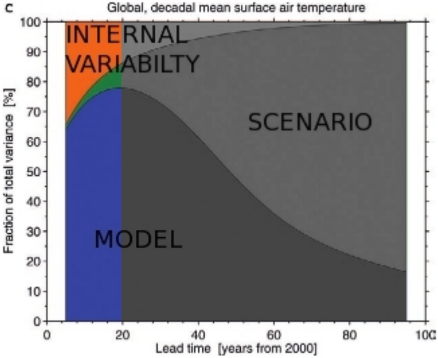
Which climate for the next decades?



IPCC (AR3, 2007)

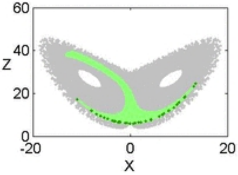


Hawkins and Sutton (2009)

⇒ Study of the models sensitivity (error bar due to initial condition)

Societal demand for "near-term" climate prediction

- Response:
  - Decadal projections are included in CMIP5 (IPCC, AR5)
- Difficulty:
  - Sensitivity to initial conditions or error growth due to the chaotic behavior of the climate (T. Palmer: `www2.physics.ox.ac.uk`)



- Current issues:
  - ~~The state of the climate in 2035?~~
  - Is it possible to make predictions? ⇒ predictability study

⇒ **Can we quantify uncertainties?**

- Current "shortcoming":
  - Role of the Ocean (*vs* Atmosphere)?

⇒ **Impact Oceanic initial error on the North Atl. Climate?**

Ensemble runs and General Stability Analysis

To test the importance of initial condition two methods exist:

- Pragmatic: Ensemble runs with **randomly** chosen set of initial conditions.
  - \+ Straigthforward to apply (largely used in CMIP5).
  - – Could underestimate the uncertainty due to i.c.
- Exact: **Generalized Stability Analysis** (GSA identifies the most sensitive i.c.).
  - \+ Identify the bound of the uncertainty due to i.c. and so the predictability.
  - – Less straigthforward to apply, only few groups in the world use this method (especially in oceanography).
  - – Linear framework.

GSA ref: Farrell and Ioannou (1996I,II), Tziperman and Ioannou (2002)

Ocean General Circulation Model: NEMO-OPA

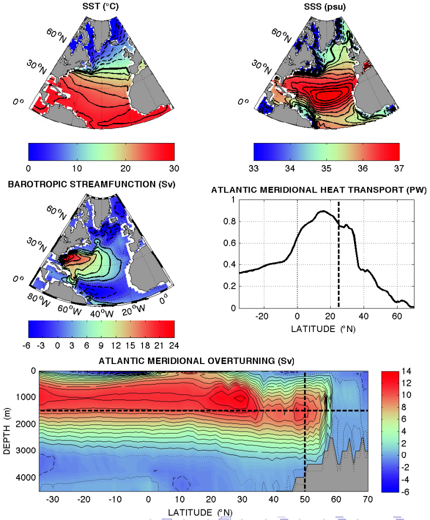
- OPA 8.2: primitive equation model (Madec et al., 1997; ESOPA team)
- ORCA2: global configuration (Madec and Imbard, 1996)
- Resolution: 2° with 31 vertical levels
- OPATAM: linear and adjoint model (Weaver et al., 2003)

<u>Linear Model BC:</u>

- **MBC**, Flux Boundary Condition (Heat flux & Freshwater flux)
- **FBC**, Mixed Boundary Condition (Restoring SST & Freshwater flux)

- Max AMOC = 13 Sv (50°N, 1000 m)
- Max MHT = 0.75 PW (25°N)

⇒ **One of the models used in IPCC (AR5) Climate projection**



Measuring the North Atl. Climate

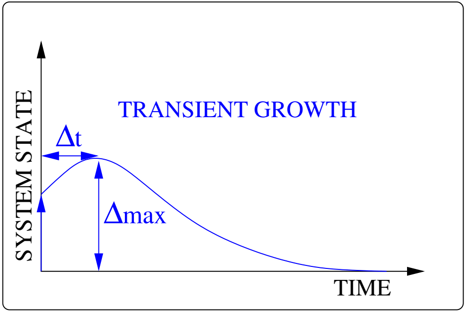
We choose two typical metrics:

1. The intensity of the Meridional Volume Transport (MVT):
$\langle \mathbf{F} | \mathbf{U} \rangle = \int_{z_{\max(\overline{\mathrm{MVT}})}}^{0} \int_{x_W}^{x_E} v|_{y_{\max(\overline{\mathrm{MVT}})}} \, dxdz$,
2. The Oceanic Heat Content (OHC):
$\langle \mathbf{F} | \mathbf{U} \rangle = \frac{1}{V_{\mathrm{NA}}} \iiint_{\mathrm{NA}} T \, dv$.

Comments: These two Climate metrics depend of time, to simplify the problem, we study only: t=December 31$^{\mathrm{st}}$.

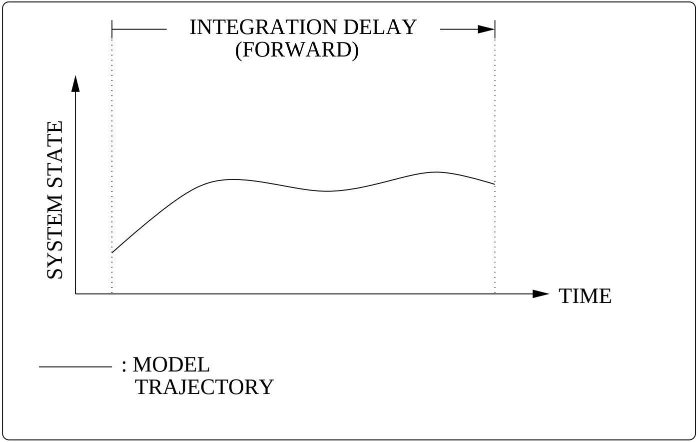
Optimal initial perturbation of the North Atl. Climate

"What perturbation to the initial condition (temporal Dirac) leads to the maximum change of the AMOC?"



What is the most efficient structure (↑) and delay (Δt), which lead to the maximum change (Δ max)?

Step of the study



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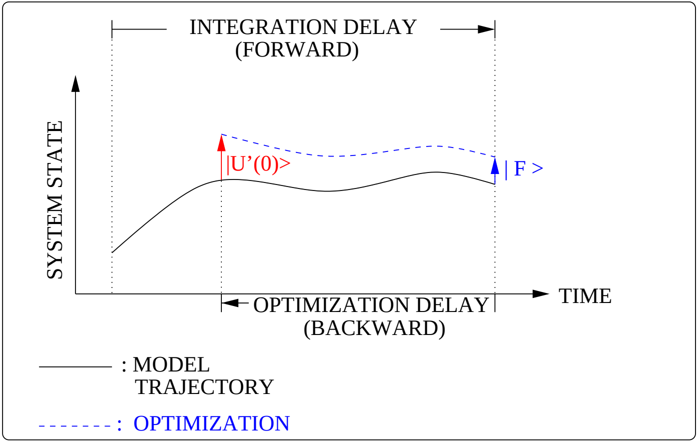


Optimization using Lagrange multipliers:

$\Rightarrow$ Explicit Solution $=$ fct($\mathbf{M}^{\dagger}$,τ_{opt})

Optimal T-S initial perts

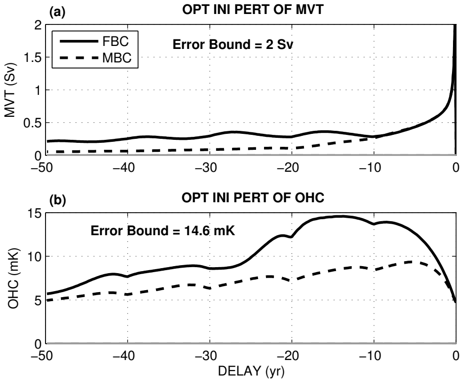
- MVT is most sensitive to "present" anomalies ($\tau_{\rm opt}$=0 yr)
- OHC is most sensitive to "delayed" anomalies ($\tau_{\rm opt}\simeq$14 yr)

Error of 1 mK on initial condition leads to

- 118% of relative error on MVT
- 31% of relative error on OHC

(= Error Bound / std(MVT) from IPSL model)

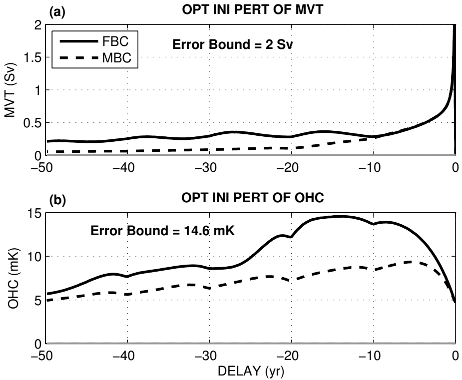
Relatively insensitive to BC (MBC$\simeq$FBC)



$\Rightarrow$ **Predictability depends on the way one measures the system**

Optimal T-S initial perts

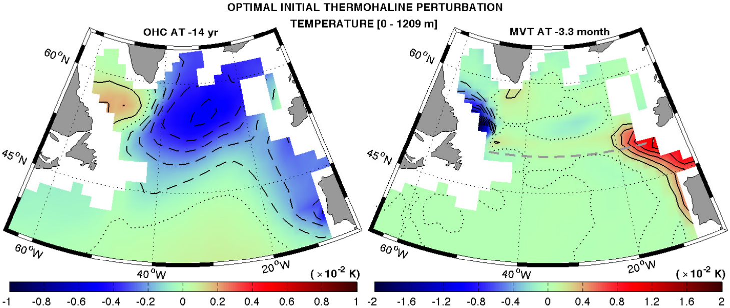
1. Why does some Climate metrics are the most sensitive to past disturbances?
2. Whereas others are the most sensitive to present disturbances?



⇒ **What is the spatial shape of the Linear Optimal Perturbations?**

Optimal T-S initial perts

The spatial scale of the most efficient disturbance seems crucial...



MVT instantaneous sensitivity is associated to small scale

OHC delayed sensitivity is associated to large scale

Optimal T-S initial perts

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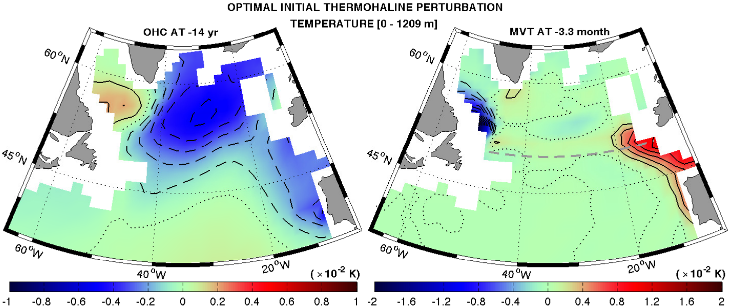

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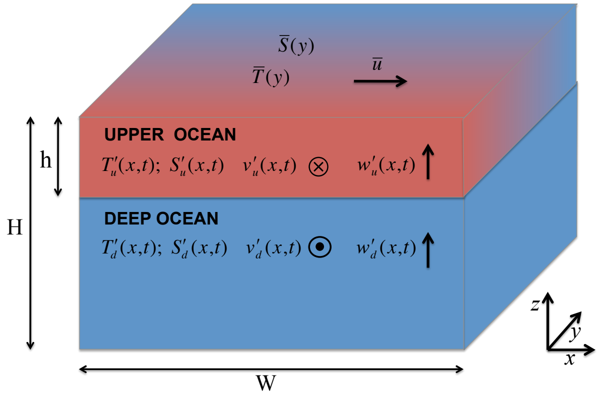
⇒ **Let's investigate further with a spectral idealized model!**

A spectral idealized model: setting

- Advection-diffusion of T & S + Geostrophic balance
- Decomposition on zonal mode (Fourier series)

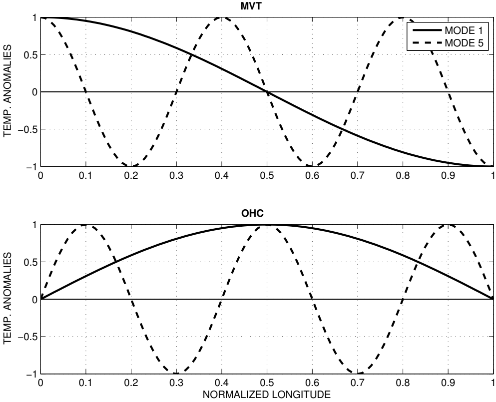
(Sévellec and Fedorov, *J. Clim.* 2013)



A spectral idealized model: metric sensitivities

MVT has similar sensitivity to Mode 1 and Mode 5:

The sensitivity of MVT **does not change** with the scale of the anomalies



OHC is more sensitive to Mode 1 than Mode 5:

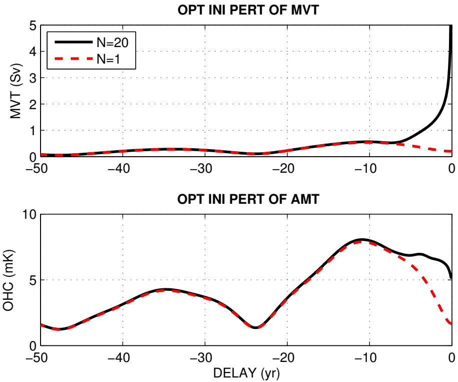
The sensitivity of OHC **change proportionaly** with the scale of the anomalies

A spectral idealized model: results

Roughly speaking:

- MVT $\propto \partial_x T$
- OHC $\propto \int T\,dx$

So that MVT is a lot more sensitive to smaller scale than OHC, and transient growth are proportional to the scale.



$\Rightarrow$ **MVT optimal transient growth $\rightarrow$ 0 (when $N \rightarrow \infty$).**

Conclusion

- <u>Results:</u>
  - Predictability depends on the metric: MVT $\neq$ OHC.
    $\Rightarrow$ Initial error of 1 mK leads $\sim \mathrm{std}$(IPSL).
    - MVT seems unpredictable
    - OHC has a predictability barrier at $\sim$ 14 yr
  - Climatically relevant metrics have higher predictability.
  - We need accurate measurement in deep ocean to increase predictability!

- <u>Future work:</u>
  - Role of the mean state (Alexey V. Fedorov & Les Muir)
  - Role of the turbulence (Simon Müller *et al*, Meso-Clip)
  - Role of the nonlinearity (Victor Estella Perez)
  - Role of the coupling (Agathe Germe *et al*)

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Thank you for your attention!