Bidecadal North Atlantic ocean circulation variability controlled by timing of volcanic eruptions

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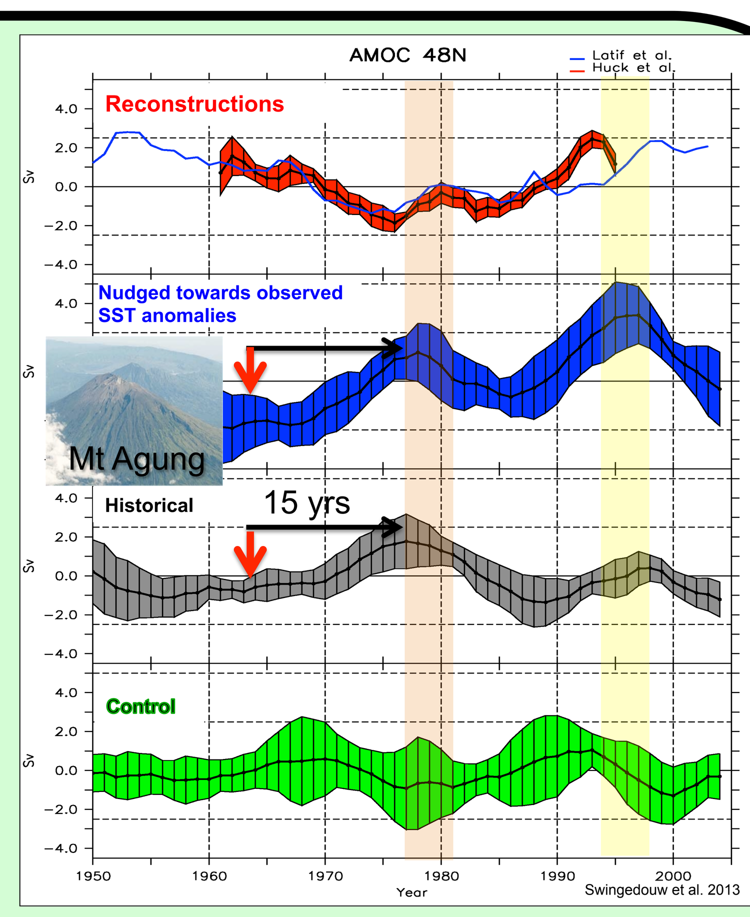
Background

- Clues for a 20-yr preferential variability in Greenland ice cores data (Chylek et al. 2011) in oceanic sediment data north of Iceland (Sicre et al. 2008) and in models (Frankcombe et al. 2010)
- Volcanoes can play the role of a pacemaker for the climatic variability (Otterå et al. 2011) and the Atlantic Meridional Overturning Circulation (AMOC)
- In the IPSL-CM5A-LR climate model: Mt Agung resets a 20-yr preferential variability in the North Atlantic (Swingedouw et al. 2013)



Aim of this work

1. Evaluate the timing of AMOC changes in CMIP5 simulations with respect to **Mt Agung eruption**
2. Evaluate the simulated processes using **North Atlantic *in situ* salinity data**
3. Evaluate the robustness of model response to volcanic events using **last millennium** simulations against **Greenland ice core and Iceland Sea bivalve data**
4. Investigate **interference patterns** due to the impacts of El Chichon and Pinatubo eruptions on ocean circulation

1) CMIP5 historical simulations perspective

Experimental Design:

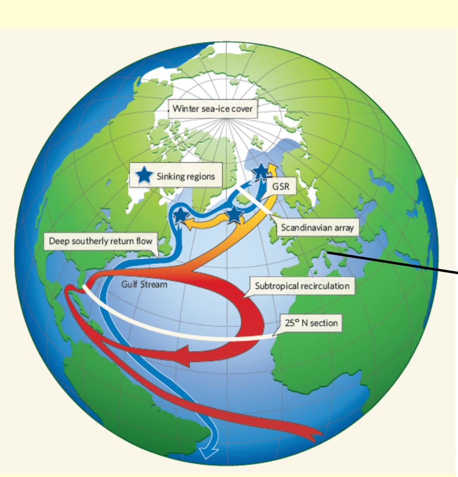
- Screening of 19 models for which the AMOC is available
- Selection of models for which the AMOC has a preferential variability at 12 to 30 yrs

Main Results

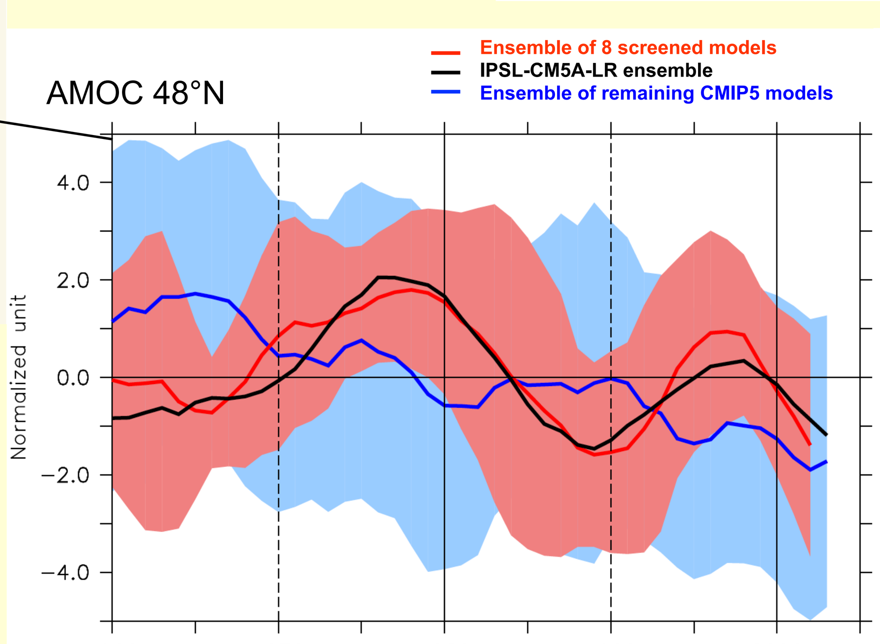
- 8 models + IPSL-CM5A-LR pass the selection test
- Robust timing: in these 8 models, AMOC is maximum around 1978 (15 years after Agung) and in the late 1990s (20 year after the former maximum)

Models	piControl		historical
ACCESS1-3	5-10 yrs	500 yrs	5-10 yrs
CanESM2	5-15 yrs	1000 yrs	15-25 yrs
CCSM4	15-25 yrs	500 yrs	Mainly red
CESM1-FASTCHEM	Mainly red	220 yrs	Mainly red
CESM1-CAM5	Mainly red	320 yrs	Mainly red
CESM1-WACCM	Mainly red	200 yrs	Mainly red
CESM1-BGC	3yrs and 20-30 yrs	500 yrs	Mainly red
CNRM-CM5	3 yrs and 100 yrs	850 yrs	Mainly red
FGOALS-g2	Mainly red	900 yrs	10 yrs
GFDL-CM3	10-20 yrs	800 yrs	10-20 yrs
GFDL-ESM2M	3-5 yrs and 10-20 yrs	500 yrs	10-20 yrs
inmcm4	Mainly red	500 yrs	Mainly red
IPSL-CM5A-LR	15-25 yrs	1000 yrs	15-25 yrs
IPSL-CM5B-LR	Mainly red	300 yrs	Mainly red
MPI-ESM-MR	Mainly red	1000 yrs	Mainly red
MPI-ESM-LR	5-10 yrs	1000 yrs	5-10 yrs
MRI-CGCM3	5-15 yrs	500 yrs	5-15 yrs
NorESM1-M	15-25 yrs	500 yrs	15-25 yrs
NorESM1-ME	Mainly red	250 yrs	15-25 yrs

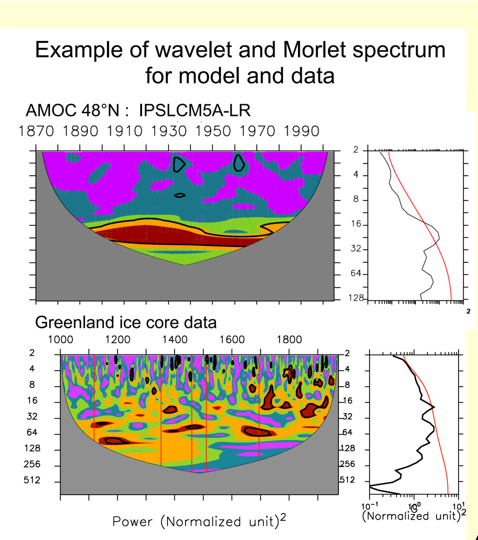
Table of CMIP5 models evaluated in terms of spectral characteristics of their 48°N AMOC index in historical and piControl simulations



Scheme of the Atlantic Meridional Overturning Circulation (AMOC) from Quadfasel (2005)



Example of wavelet and Morlet spectrum for model and data



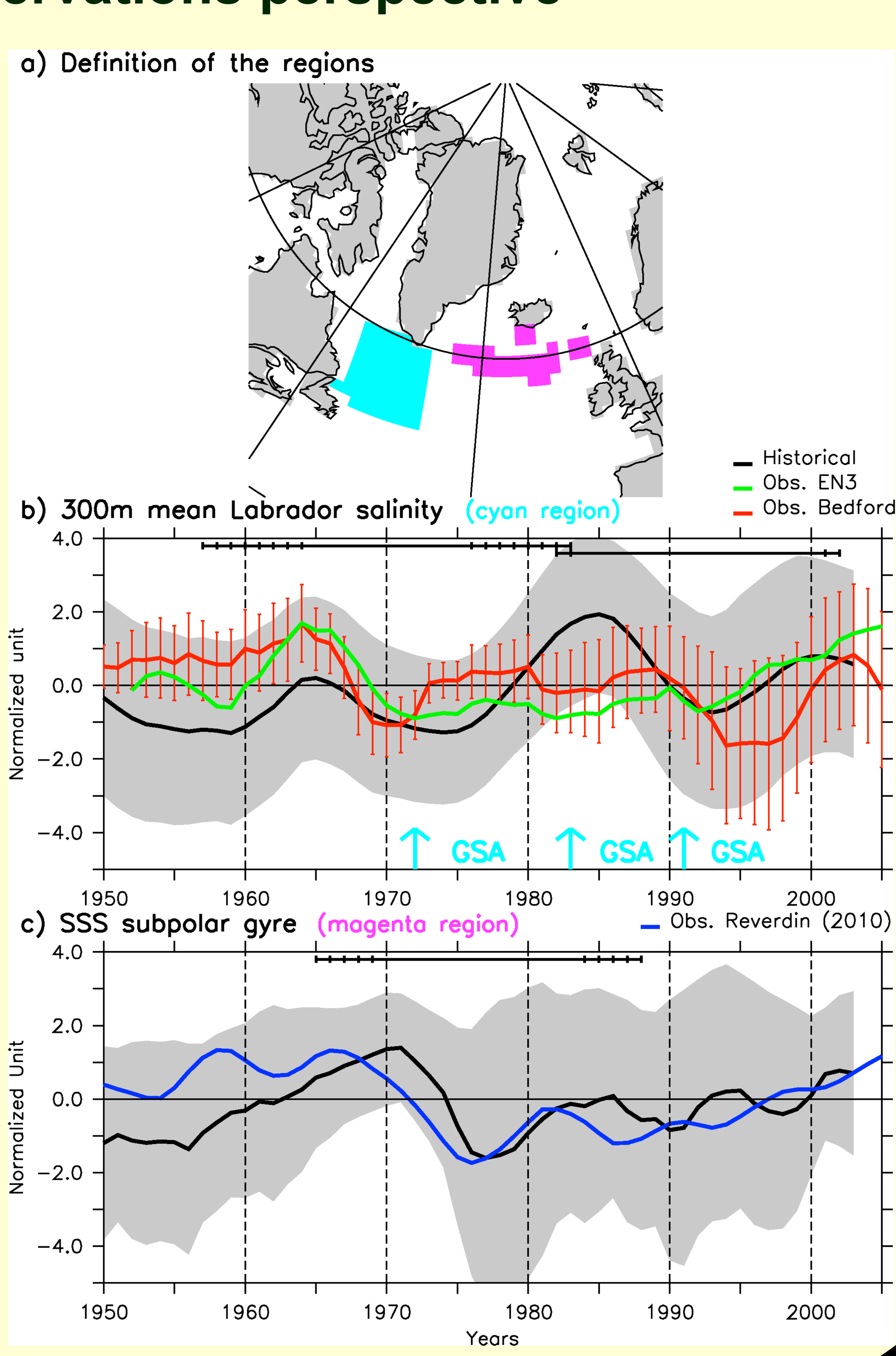
2) *In situ* salinity observations perspective

Experimental Design:

- *In situ* SSS data from Reverdin et al. (2010) for the eastern subpolar gyre
- *In situ* salinity data from Labrador obtained from the Canadian « Ocean Science Hydrographic Climate Database » from the Bedford Institute of Oceanography
- 5-member historical simulations from the IPSLCM5A-LR climate model.

Main Results

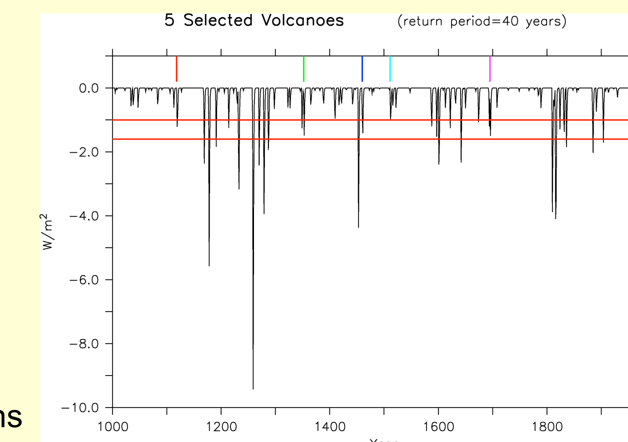
- Consistent pattern of changes in the ensemble of simulations and the salinity observations since the late 1960s
- Large salinity anomalies observed in the 1970s and 1990s well simulated (corresponding to the so-called Great Salinity Anomalies, **GSA**, Belkin et al. 1998)
- 1980s GSA not represented in the model and appears as very small in the data used as compared to the two other GSAs
- In the model, the 1990s GSA is due to excitation of the 20 year cycle in the North Atlantic by the Mt Agung eruption



3) Last millennium perspective

Experimental Design:

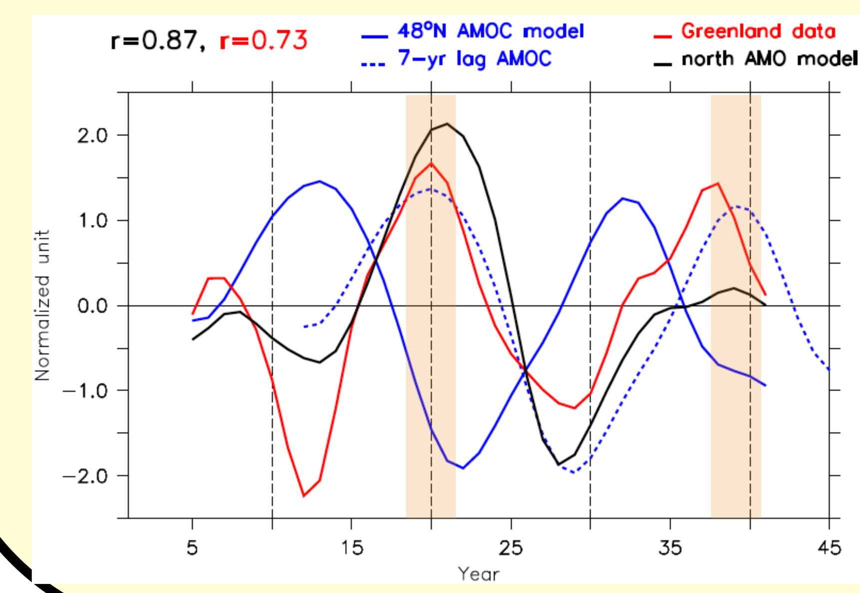
- Model: Last millennium simulation from IPSLCM5A-LR
- Paleodata:
  - 1[st] principal component of Greenland ice core δO^{18} data (accurate chronology and link with North Atlantic SST Ortega et al., 2015)
  - Bivalve data north of Iceland (Butler et al. 2013): annual resolution
- Focus on the 5 volcanic eruptions with amplitude similar to Mt Agung and not followed by major eruptions in the coming 40 years using the Ammann et al. (2008) volcanic forcing

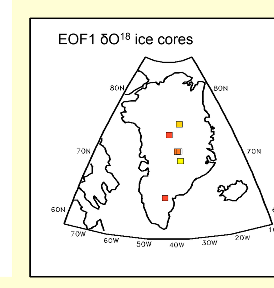


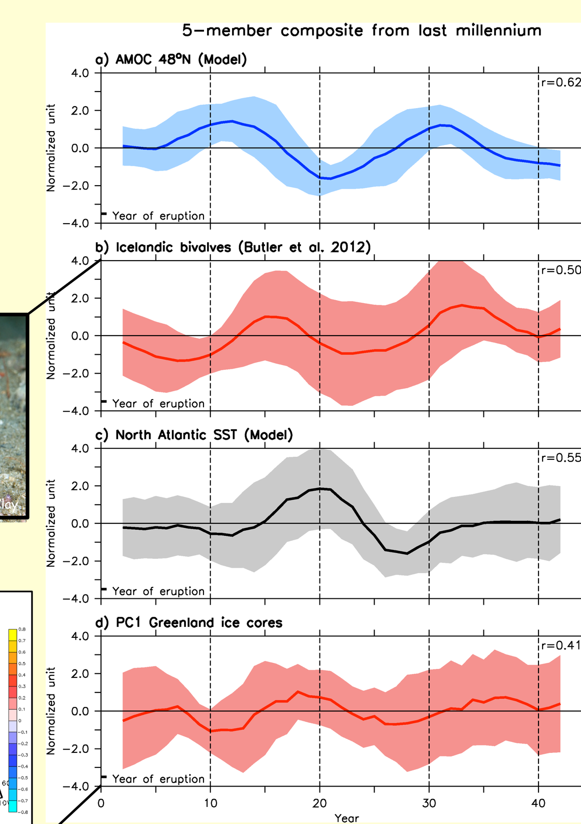
Main Results

- Bivalve data (AMOC proxy): max. 15 years after volcanoes and oscillations
- Ice core data (AMO proxy): max. 20 years after volcanoes and oscillations
- Simulations:
  1. Systematic AMOC maximum 15 years after the volcanic events
  2. AMO-like pattern with peak SST in the North Atlantic 20 years after the volcanic events
  3. Development of a second oscillation 20 years after the AMOC peak
  4. AMOC and Nutrient supply in Iceland related almost in phase.

⇒ **Agreement between model and data in general**



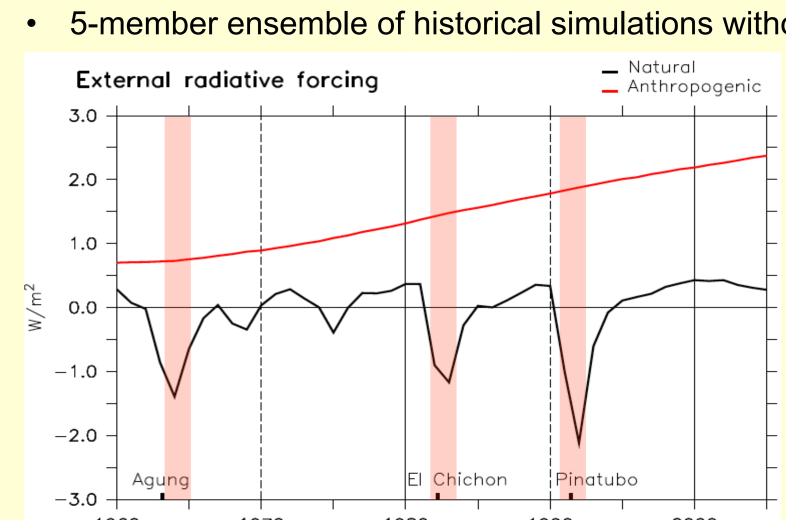




4) Interference pattern over the recent period

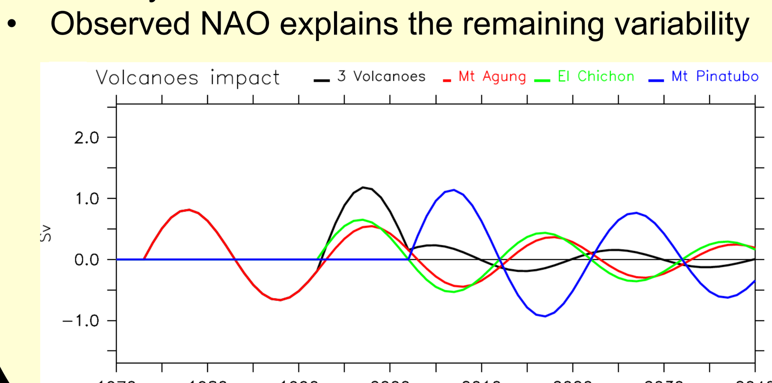
Experimental Design

- 5-member ensemble of historical simulations from IPSLCM5A-LR climate model
- 5-member ensemble of historical simulations without Pinatubo eruption

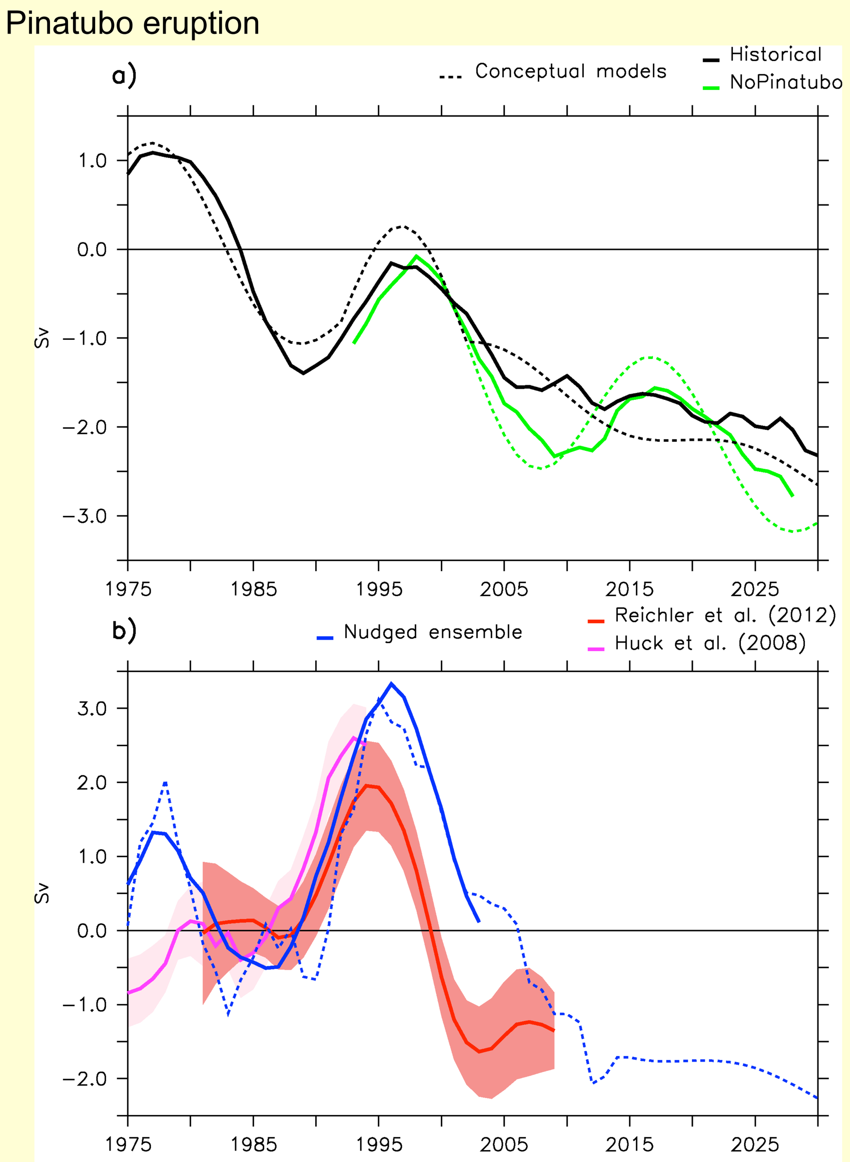


Main Results

- Without Pinatubo eruption, AMOC peak in the 2015s
- With Pinatubo eruption, destructive interference and flat AMOC in 2005-2025: due to the timing of El Chichon (19 yrs after) and Pinatubo (28 yrs after)
- Consistent with result from a simple conceptual model of delayed interferences
- Observed NAO explains the remaining variability



$$f(t) = \alpha \sum_{i=1}^{3} \lambda_i H(t-\tau_i)\sin\left(\frac{2\pi}{20}t\right)e^{\frac{t-\tau_i}{\Delta}}$$

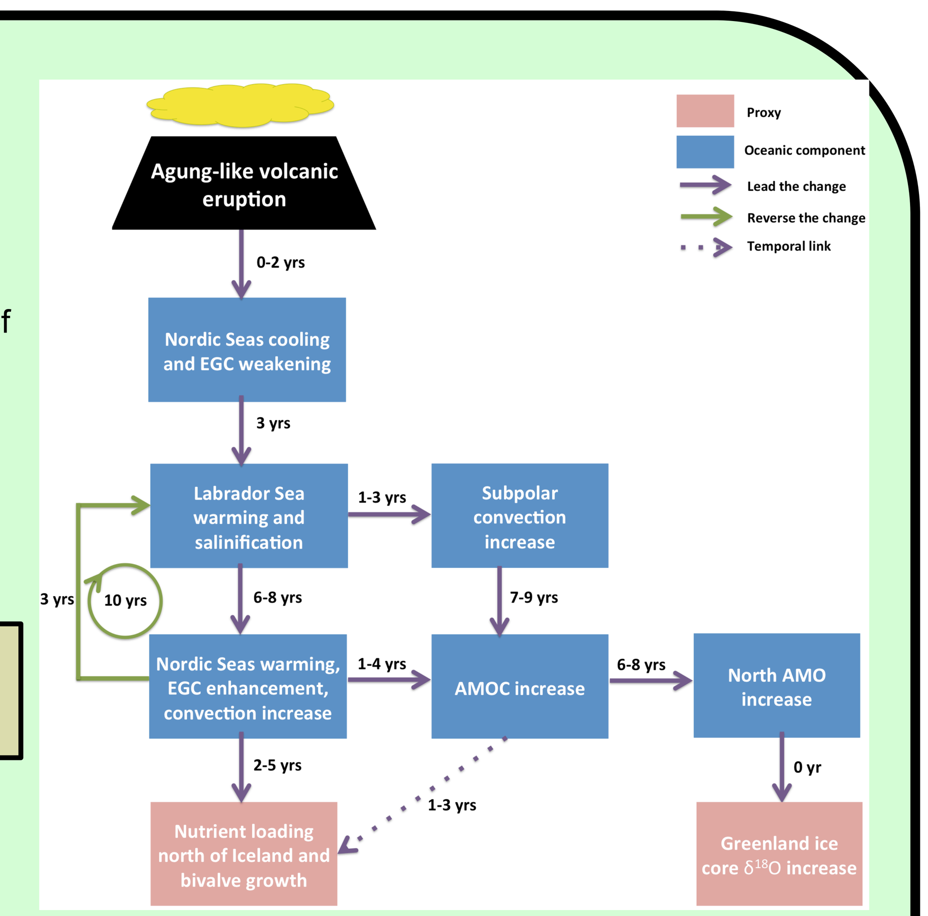


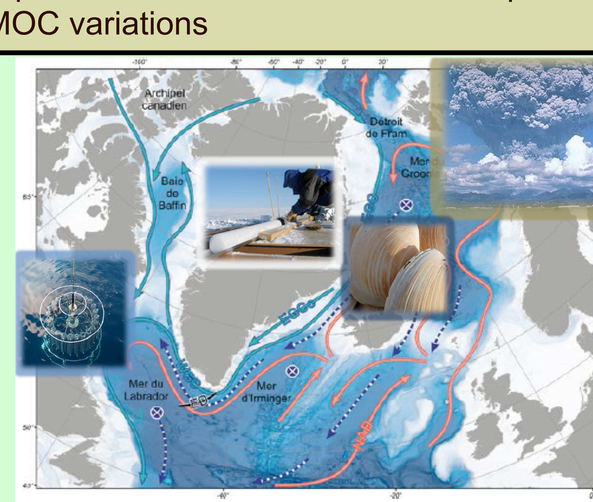
$$f(t) = \alpha \sum_{i=1}^{3} \lambda_i H(t-\tau_i)\sin\left(\frac{2\pi}{20}t\right)e^{\frac{t-\tau_i}{\Delta}} - \beta\times \mathrm{GW}(t) + \gamma\times \mathrm{NAO}(t-5)$$

Discussions and conclusions

- Agung or Pinatubo-like eruptions precede an AMOC maximum by ~15 years
- Consistent with ***in situ* salinity data** from the subpolar gyre for the last 60 years
- Shown by IPSL historical simulations and selected periods of a last millennium simulation, and in a **subset of CMIP5 simulations**
- Consistent with **Greenland** temperature changes inferred from **ice core data** over the last millennium
- Importance of the pacing between medium size volcanic eruptions: **destructive interference** due to the Pinatubo eruption

⇒ **A large body of evidence** supports long lasting impacts of volcanic eruptions on ocean circulation and explains recent decadal AMOC variations





References:

- Belkin IM, Levitus S, Antonov J, Malmberg S-A (1998) Great salinity anomalies in the North Atlantic. *Prog. Oceanogr*. 41:1–68
- Chylek P, et al. (2011) Ice core data evidence for a prominent near 20 year time-scale of the Atlantic multidecadal oscillation. *GRL*38:L13704
- Frankcombe et al. (2010) North Atlantic multidecadal climate variability: an investigation of dominant time scales and processes. *J Clim.* 23:3626–3638
- Ortega et al. (2015) Characterizing atmospheric circulation signals in Greenland ice cores: insights from the weather regime approach. *Clim. Dynamics*, 43, 2585-2605
- Otterå et al. (2010) External forcing as a metronome for Atlantic multidecadal variability. *Nat Geosci* 3:688–694.
- Persechino et al. . (2013) Decadal Predictability of the Atlantic Meridional Overturning Circulation and Climate in the IPSL-CM5A model. *Clim. Dyn.* 40, 2359-2380.
- Reverdin (2010) North Atlantic Subpolar Gyre Surface Variability (1895-2009). J. *Clim.* (23) 17, pp 4571-4584
- Sicre et al. (2008) Decadal variability of sea surface temperatures off North Iceland over the last 2000 years. Earth Planet Sci Lett 268:137–142
- Swingedouw et al.(2013) Initialisation and predictability of the AMOC over the last 50 years in a climate model. *Clim Dyn*. 40, 2381-2399
- **Swingedouw et al. (2015) Bidecadal North Atlantic ocean circulation variability controlled by timing of volcanic eruptions. *Nature Communications* 6, pages: 6545**