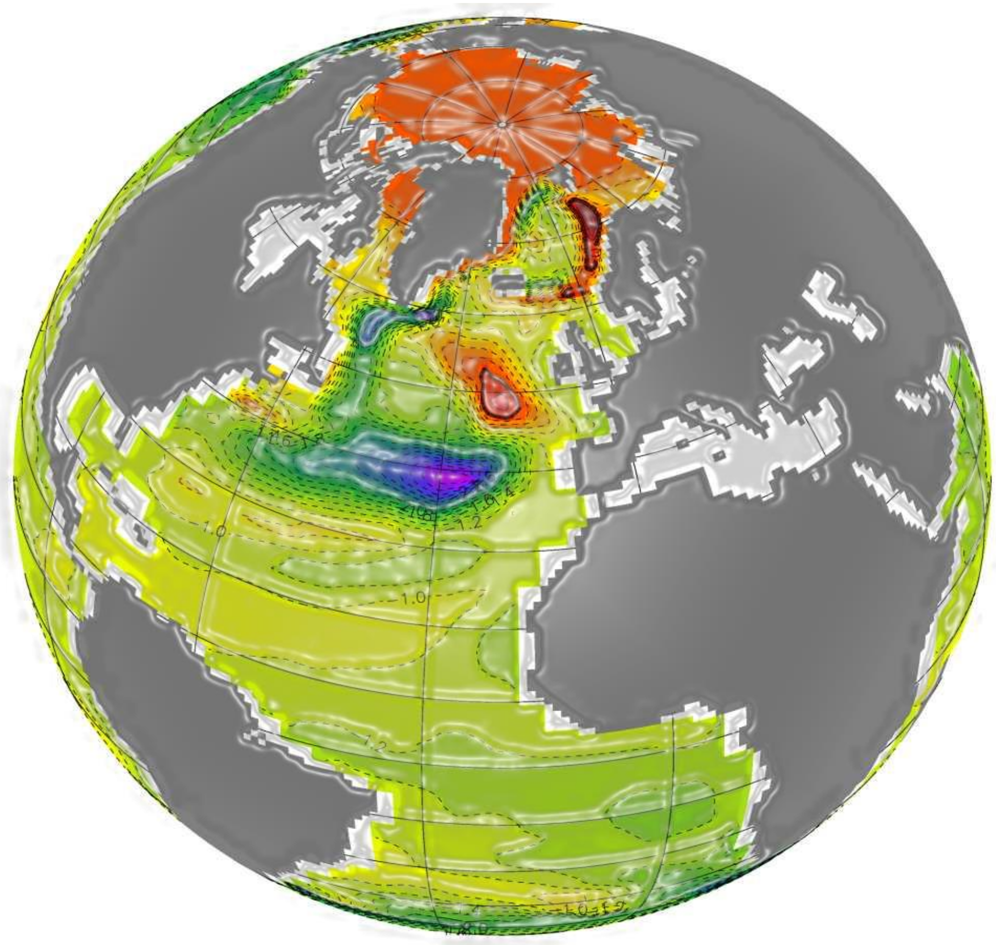
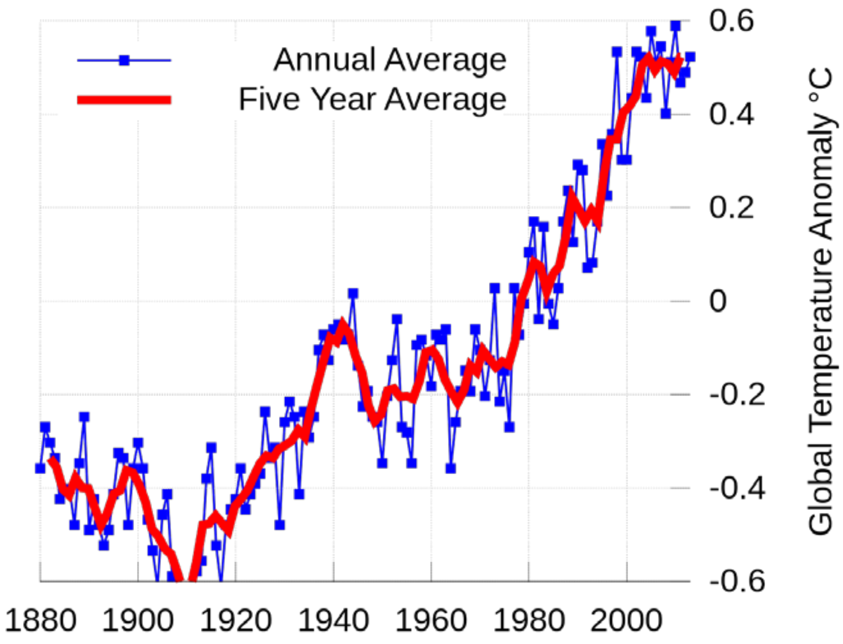
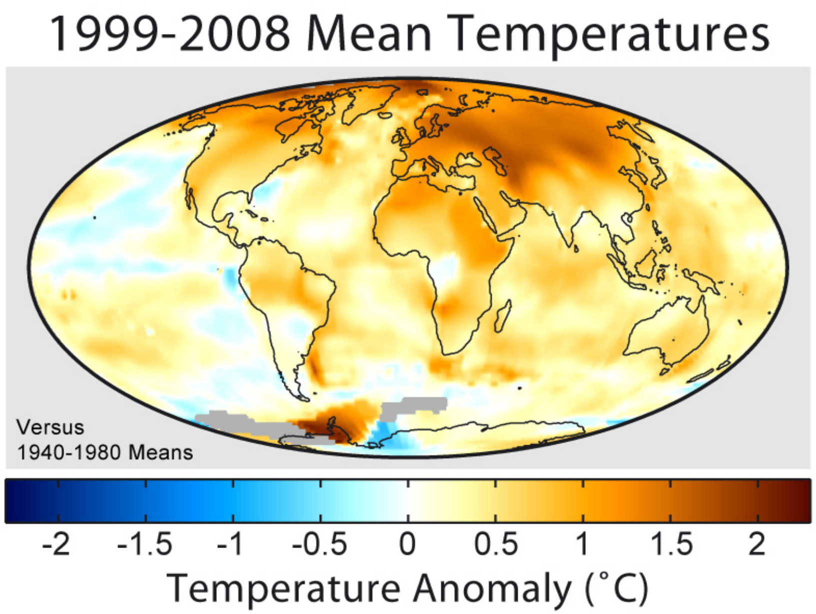
Zurich University
of Applied Sciences
IDP Institute of Data Analysis
and Process Design

Climate Modelling and BIG Data

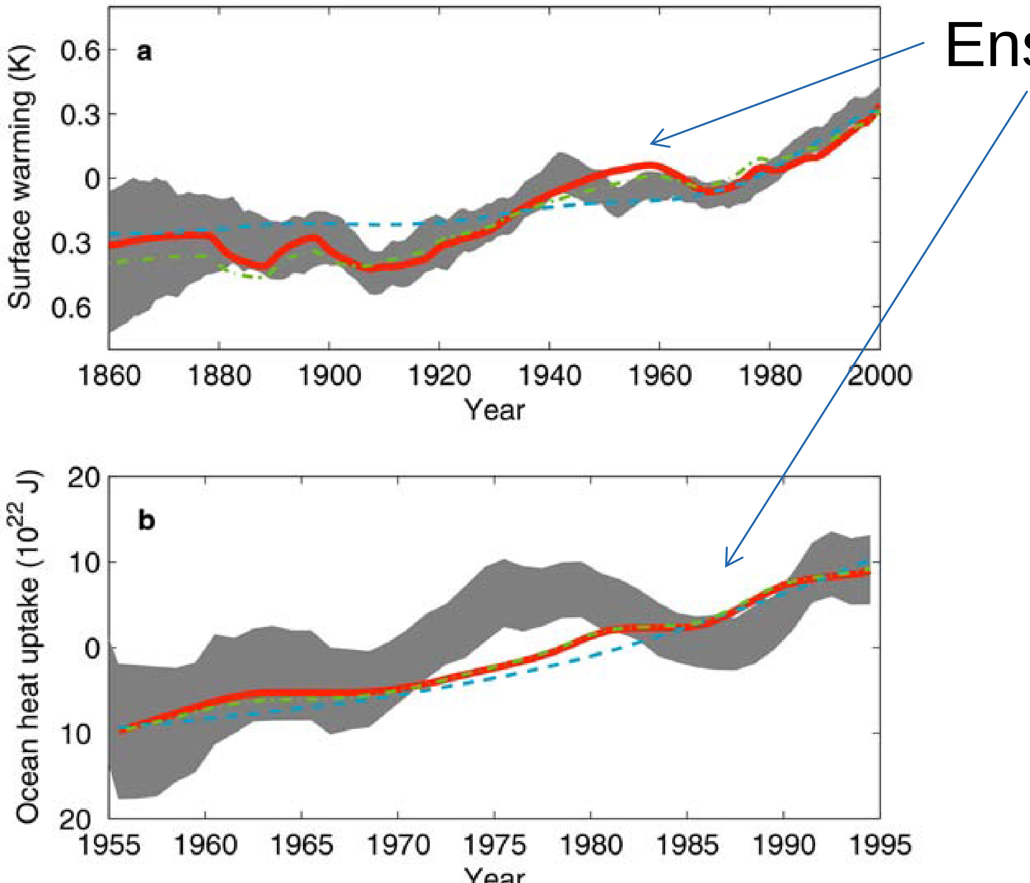


How to calculate the future global temperature?



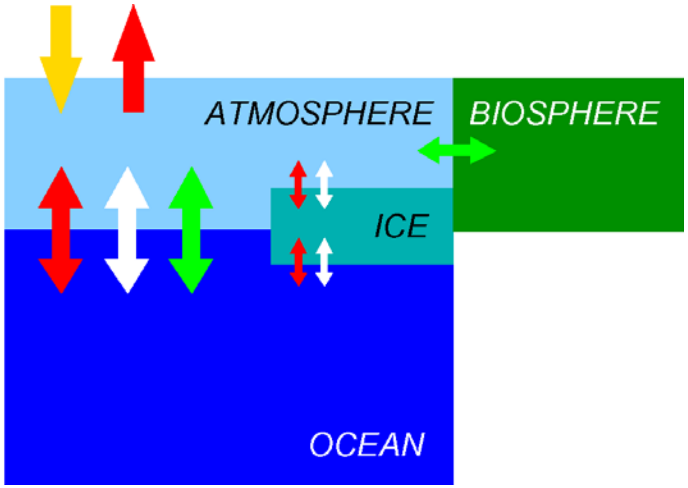


Climate Modeling



Stocker lecture notes 2012

Sub-models and fluxes

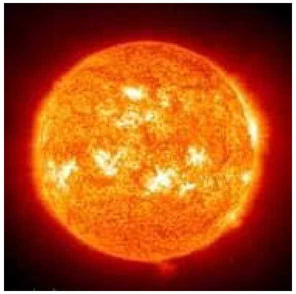


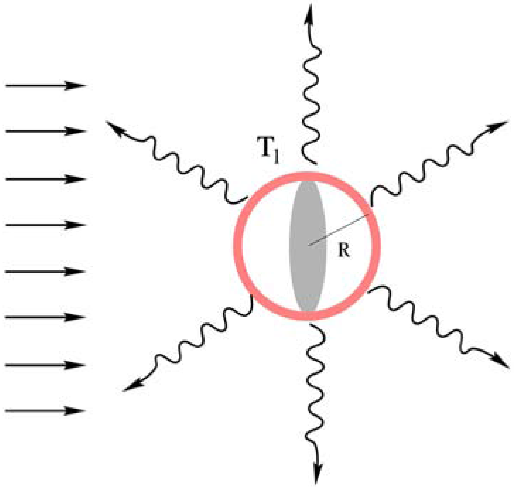
Bern 2D Model

Simplest Climate model: (need no sim!)

$$4 \cdot \pi \cdot R^2 \cdot h \cdot \rho \cdot C \cdot \frac{dT}{dt} = \pi \cdot R^2 \cdot (1-\alpha) \cdot S - 4 \cdot \pi \cdot R^2 \cdot \varepsilon \cdot \sigma \cdot T^4$$

• Radius Earth	$R = 6371 \text{ km}$
• Atmosphere	$h = 8.3 \text{ km}$
• Density	$\rho = 1.2 \text{ kg m}^{-3}$
• Heat Capacity	$C = 1000 \text{ J kg}^{-1}\text{K}^{-1}$
• Temperature	T
• Albedo	$\alpha = 0.3$
• Solar Constant	$S = 1367 \text{ W m}^{-2}$
• Emission	$\varepsilon = 0.6$
• Stefan-Bolzman	$\sigma = 5.67 \cdot 10^{-8} \text{ W m}^{-2}\text{K}^{-4}$

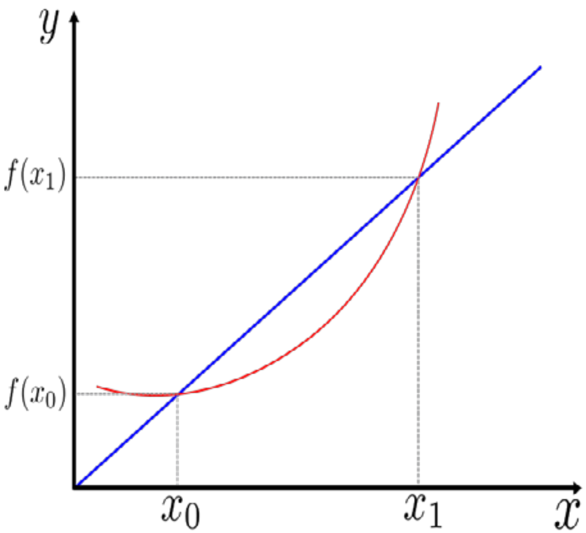

Sun



Earth

Simplest Climate Model:

$$4\cdot\pi\cdot R^2\cdot h\cdot\rho\cdot C\cdot\frac{dT}{dt} = \pi\cdot R^2\cdot(1-\alpha)\cdot S - 4\cdot\pi\cdot R^2\cdot\varepsilon\cdot\sigma\cdot T^4$$



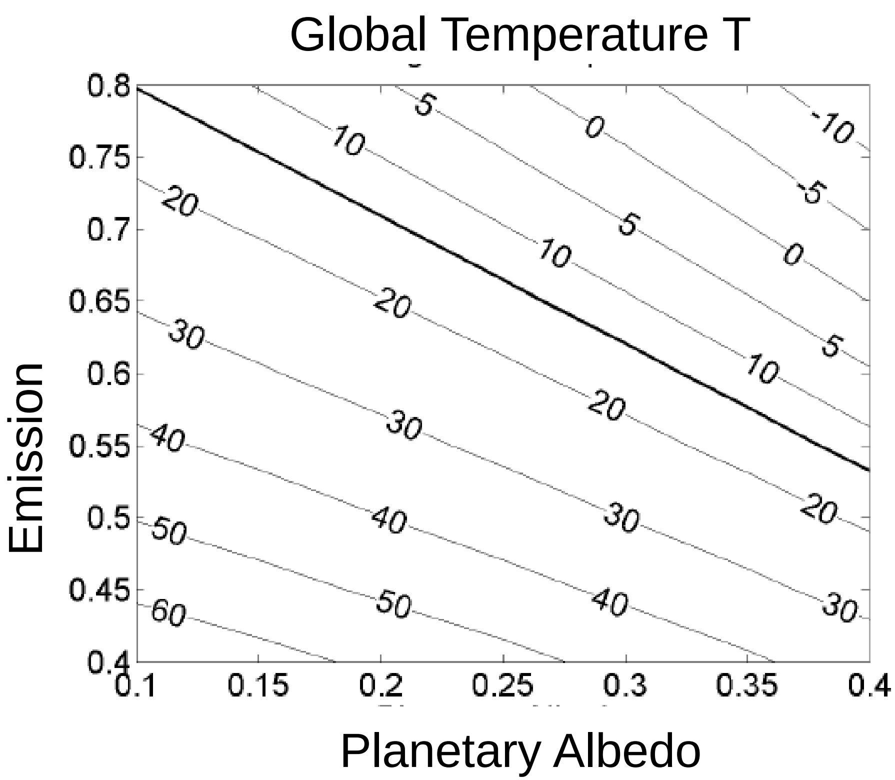
$\frac{dT}{dt} = -A\cdot T$	continuous	$T(t)$
$\frac{T_{n+1}-T_n}{\Delta t} = -A\cdot T_n$	discrete	$T_n \equiv T(n\cdot\Delta t)$

Simplest Climate Model:

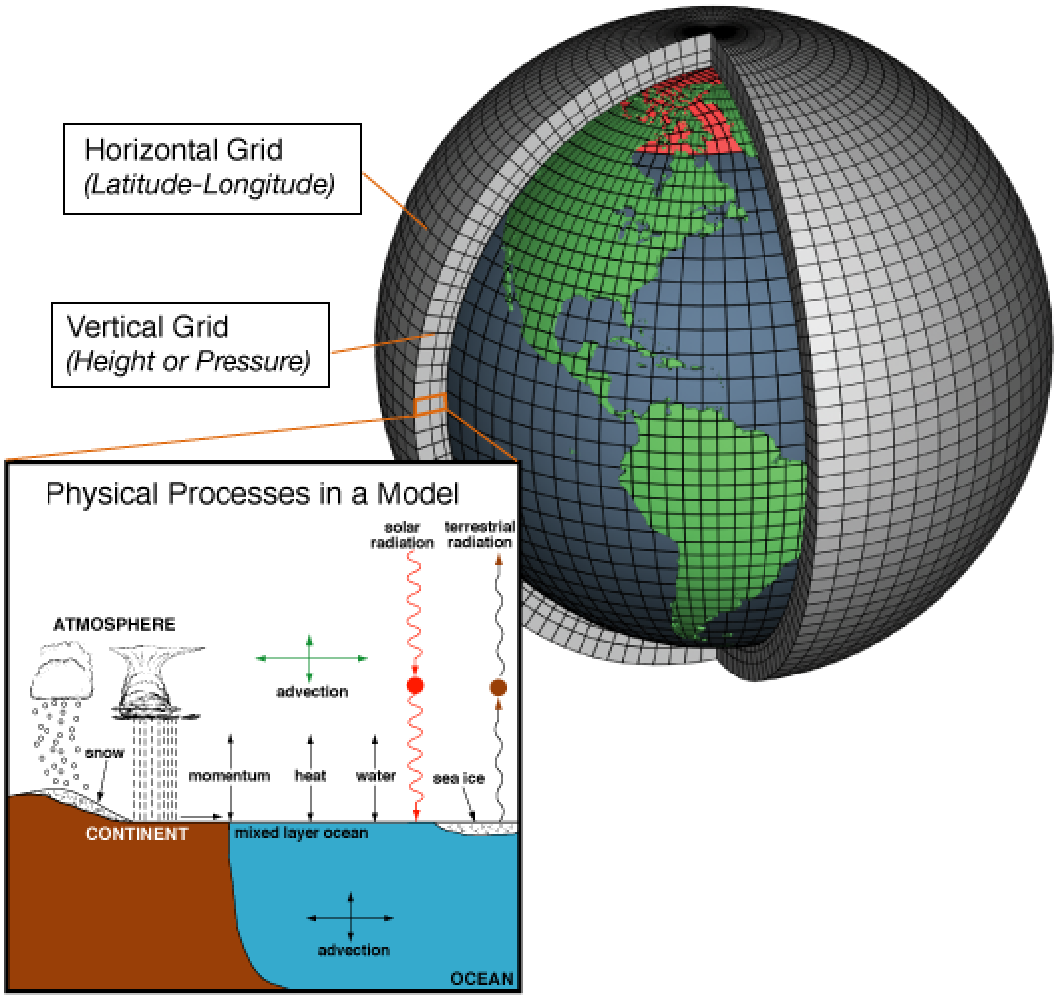
$$4 \cdot \pi \cdot R^2 \cdot h \cdot \rho \cdot C \cdot \frac{dT}{dt} = \pi \cdot R^2 \cdot (1-\alpha) \cdot S - 4 \cdot \pi \cdot R^2 \cdot \varepsilon \cdot \sigma \cdot T^4$$

Resulting Global Temperature:

$$T = \left(\frac{(1-\alpha) \cdot S}{4 \cdot \varepsilon \cdot \sigma} \right)^{0.25}$$



Coupled Models



Define:

- Physical Processes
- Grids (Space dimension)
- Time steps
- States and Variables

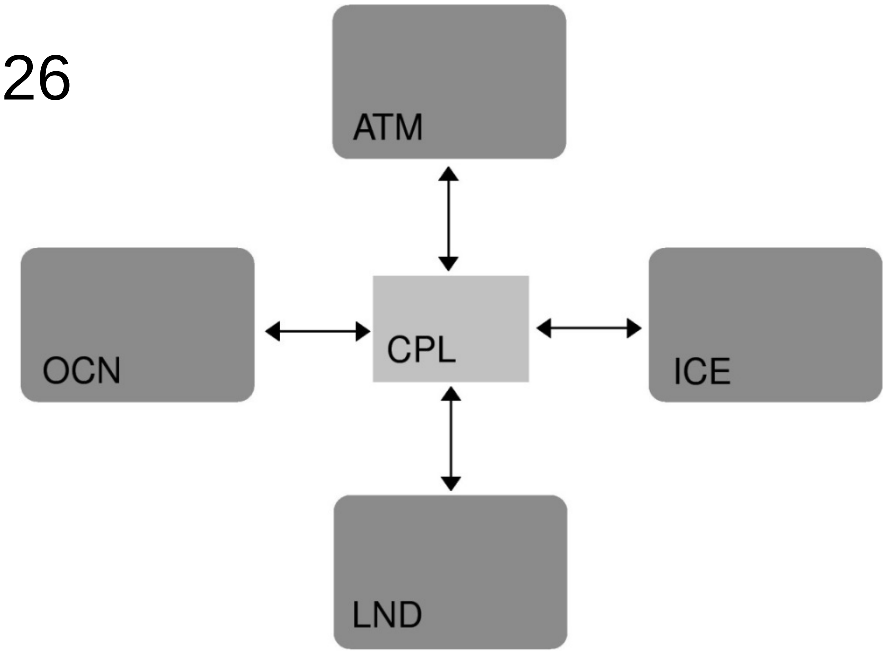
Define:

- Validation Methods
- Verification Methods

Climate Model

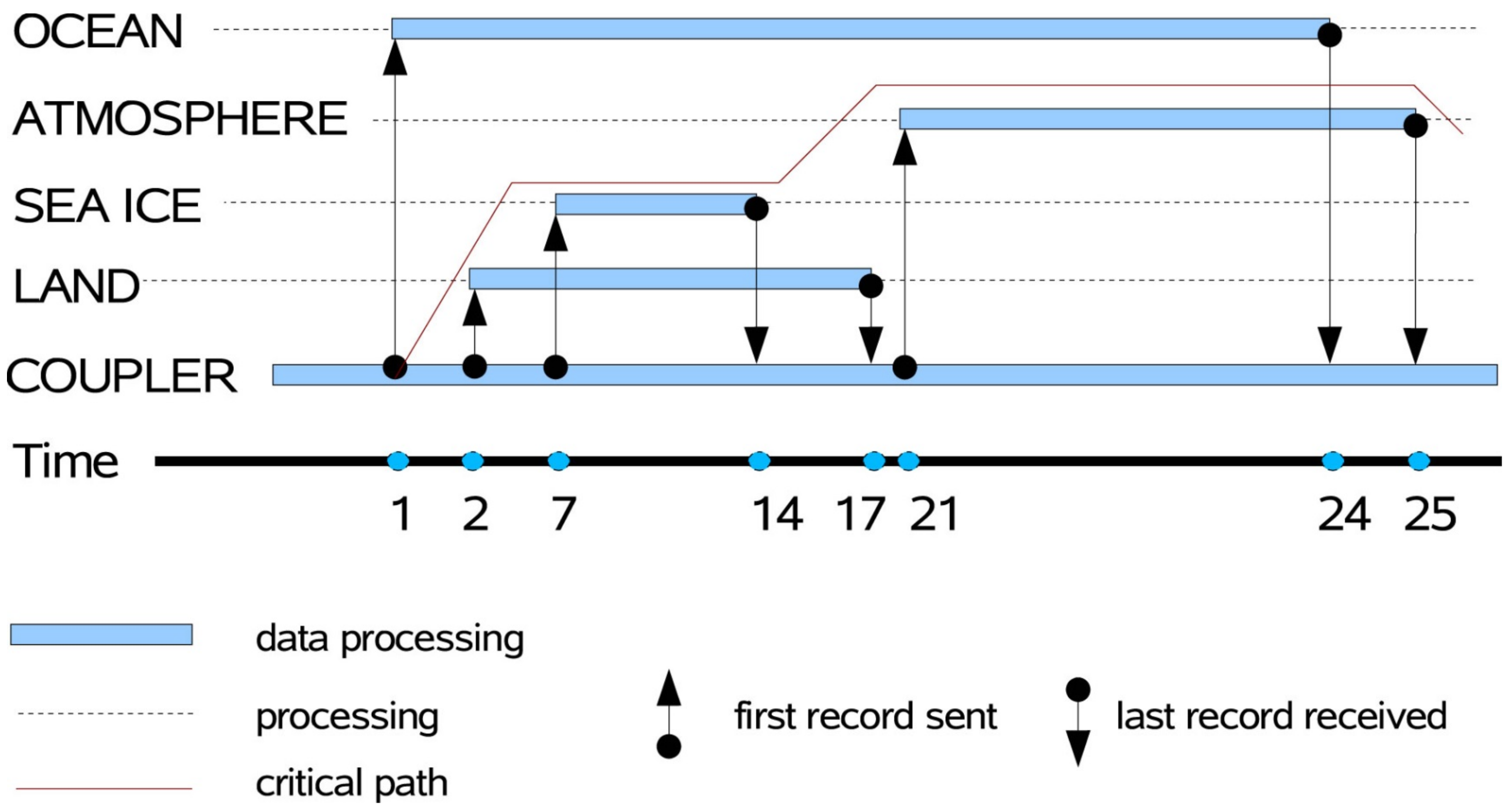
Community Climate System Model CCSM3: (AOGCM)

- ***Ocean***: POP, 3x3 degree resolution, 25 levels (Los Alamos National Lab)
- ***Atmosphere***: CAM3.0, T31, 26 levels
- **Sea Ice**: CSIM5.0, energy conserving thermodynamic, ice thickness distribution
- **Land model**: CLM3.0
- **Coupler**: CPL6



NCAR : National Climate and Atmosphere Research (USA)

“Critical path”



Outline

Zurich University of Applied Sciences
IDP Institute of Data Analysis and Process Design

A) Experimental Equipment:

B) Water hosing experiments:
A brief overview...

C) Climate reconstructions of the past 500 years :
Indian Ocean Zonal mode (IOZM) in a multi-century-integration

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How it began…

.**Nodes**

- -22 AMD-Athlon XP 2600+
  (2GHz/ 512MByte RAM)
- -18 AMD-Athlon 1400+
  (1GHz/512MByte RAM)
- -4 Dual AMD- Athlon 1400+
  (1GHz/512MByte RAM)

50 nodes (processors)

.**100 MBit/s Network**
- connected over 2 switches

.**1 GBit/s Network**
- connected over 1 switch

.**LINUX-OS**
- SuSe 8.0 with kernel 2.4.20 ff.
--> switch to Debian

Anno 2003

Infrastructure: CSCS

- IBM SP4
- A Parallel Constellation Cluster of 8 IBM Regatta p690 SMP nodes consisting of a total of 256 Power4 CPUs and 768 GBytes of main memory, giving a total theoretical peak performance of 1.3 TFlop/s. The Regatta frames are switched by a Double Colony interconnect in order to provide a parallel environment with a Global Parallel File System of 4 Terabytes. The overall system runs on AIX 5.2 with job management based on LoadLeveler.
- 1.3 Tflops
- 256 Skalar - Prozessoren (Power4)
- Typische Jobgroesse 4 – 32
- Top 500 Rank 26 (Dec. 2005)

IBM SP4

Swiss National Supercomputing Centre, Manno/TI

Performance

Time to calculate 1 model-month with T31_gx3

	LINUX	IBM P4	CrayXT3	Ratio
CSM1.4	(66 min)	15 min		4.4
CSM1.4	-	9 min*	-	-
CCSM2.0.1	29 min	17 min	1.7	
CCSM2.0.1 (x2)	53 min	-	-	-
CCSM3.0	25 min	10 min*		2.3

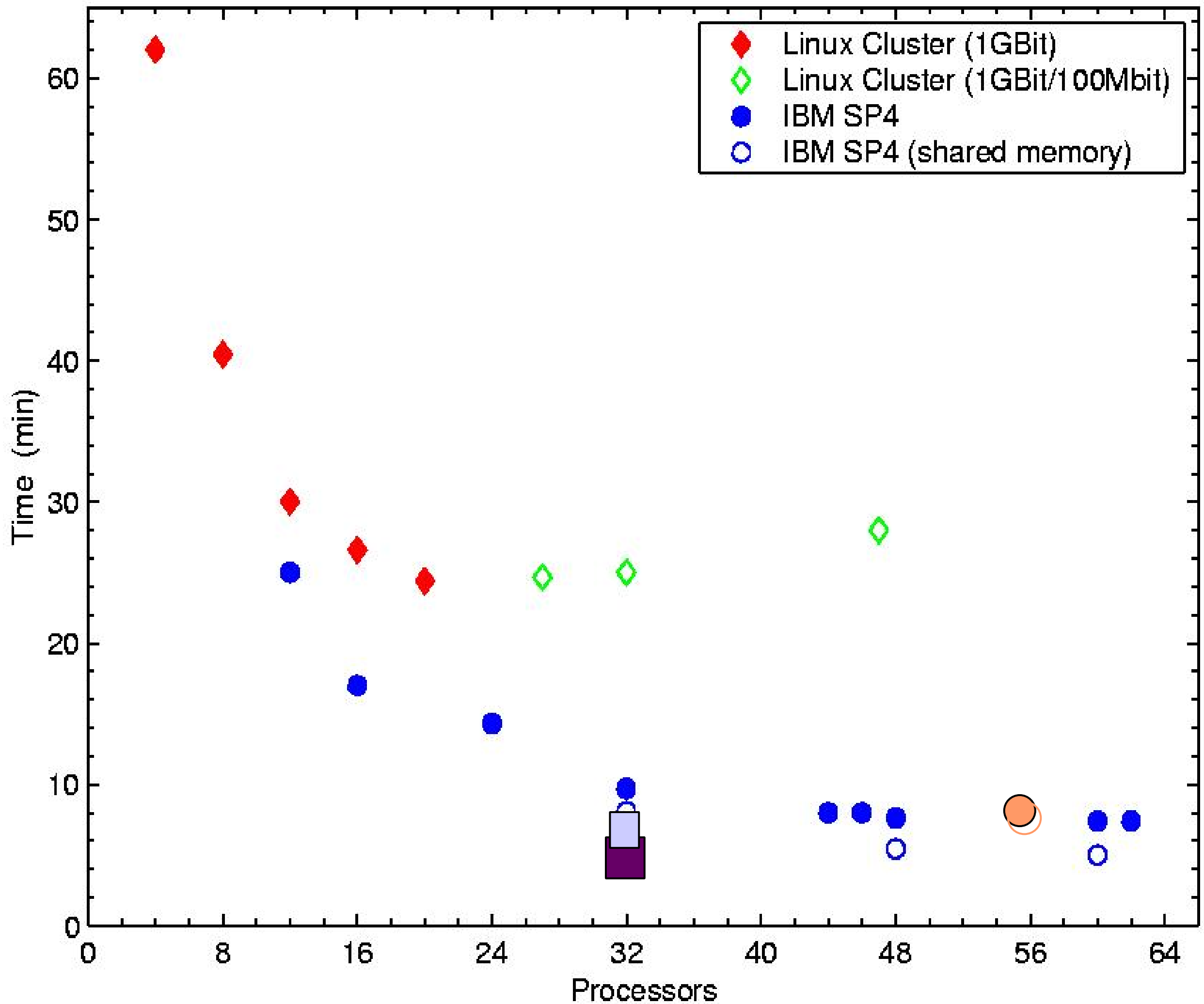
Time to calculate 1 model-month with T42_gx1v3

	LINUX	IBM P4	Ratio
CCSM2.0.1	180 min	70 min	2.5
CCSM3.0 -	41 min		

Scalability

Time to calculate one model month with different computers and different communication networks.

Cray XT3 >
IBM SP5 >
Myricluster >



(Renold et al. 2004)

Experiments

- CCSM3 5 x “water hosing” runs [running/re/3200yrs]
- CCSM3 flux004_co2 [running/re/~100yrs]
- CCSM3 2 x 1500-2000 reconstructions [re/1000yrs]
- CCSM3 CTRL (SP4) [re/178yrs]
- CCSM3 CTRL (Linux) [re/100yrs]

- CCSM2 30x Artificial volcanic ensemble runs [re/200yrs]
- CCSM2 Minimum reconstructions [yo/re/200yrs]
- CCSM2 CTRL [re/400yrs]
- CCSM2 3x GHG – runs [re/300yrs]

TOTAL of *5700* years

Development

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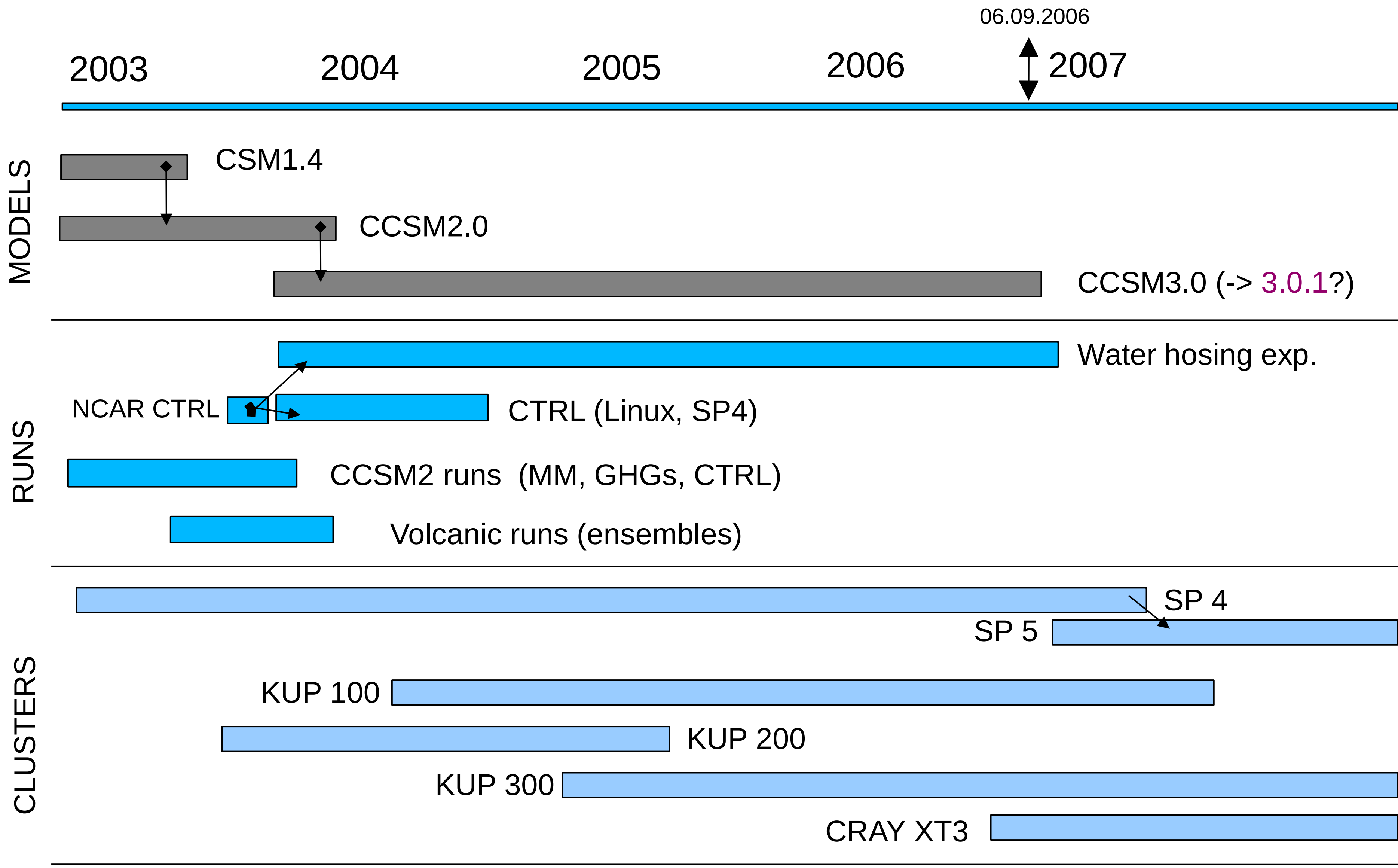

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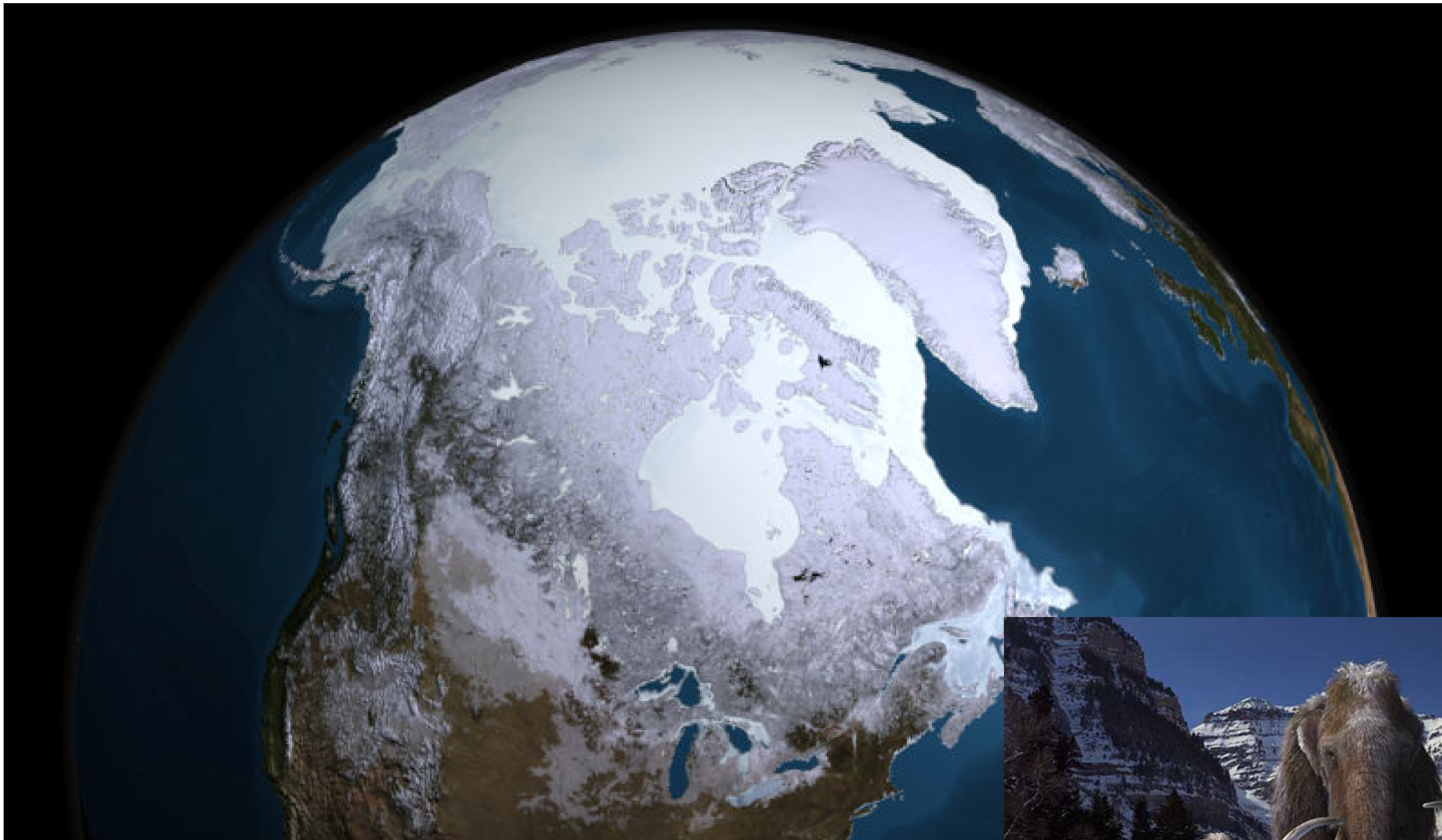
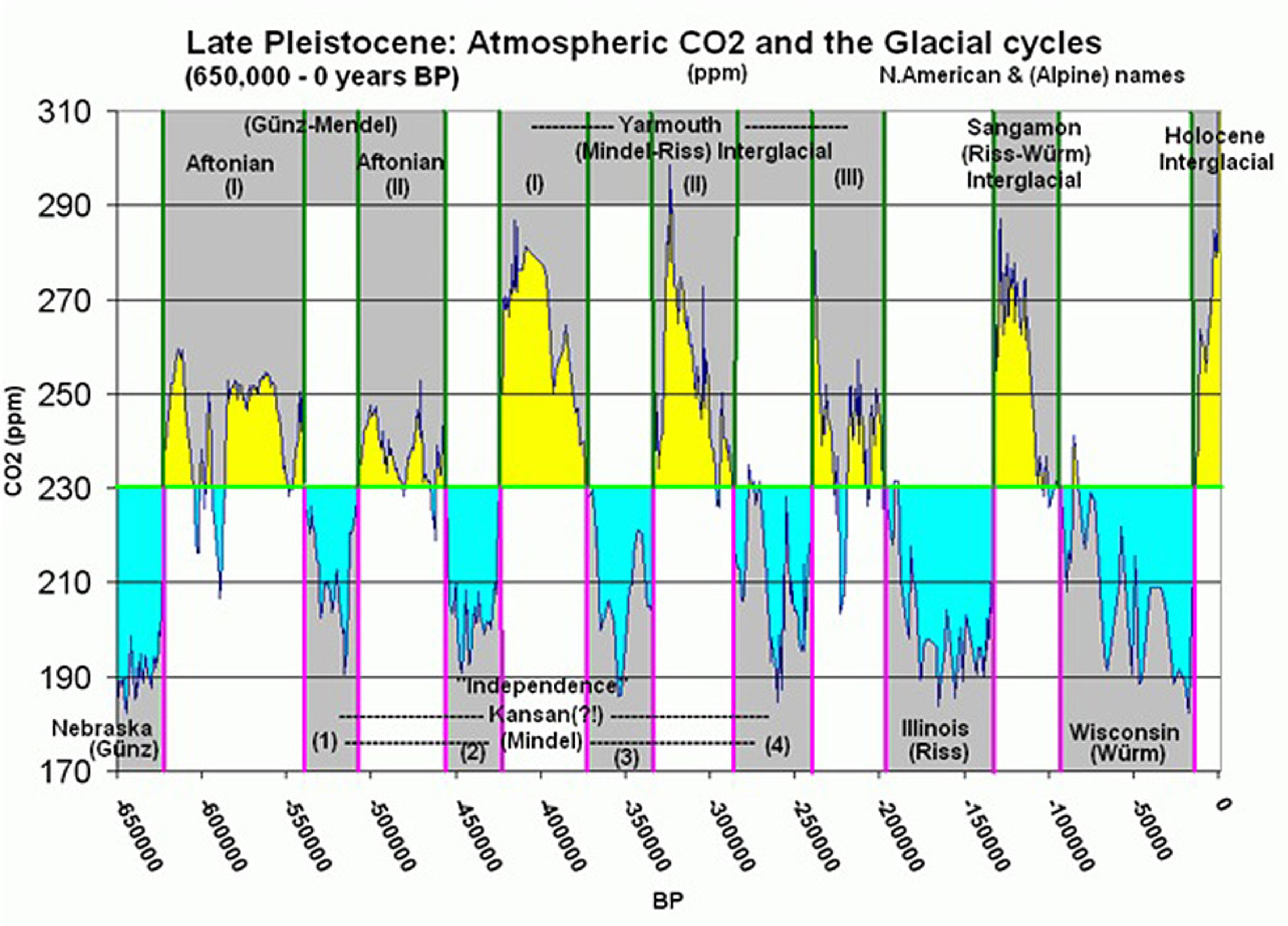
Interstadial periodes

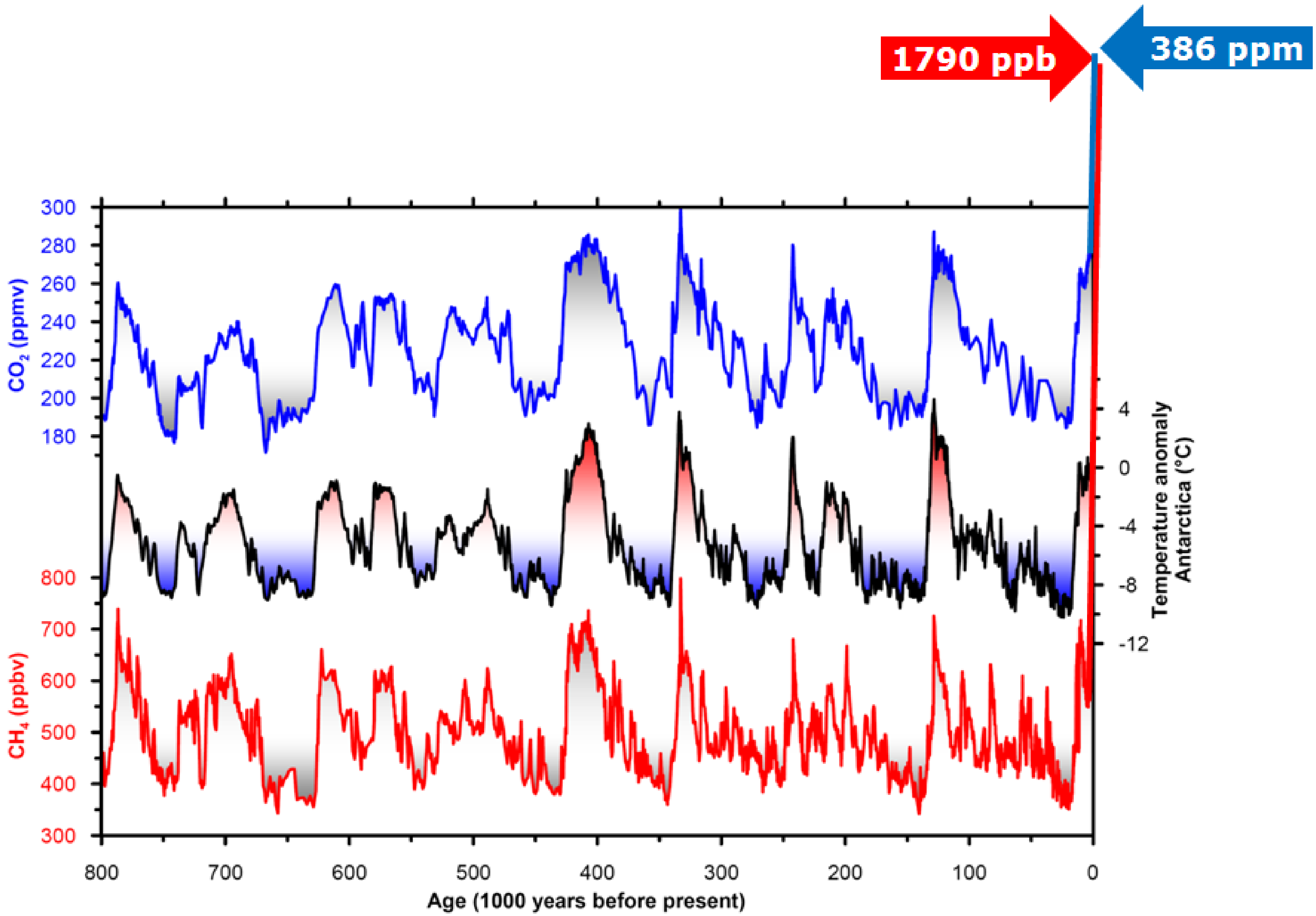


Ice ages

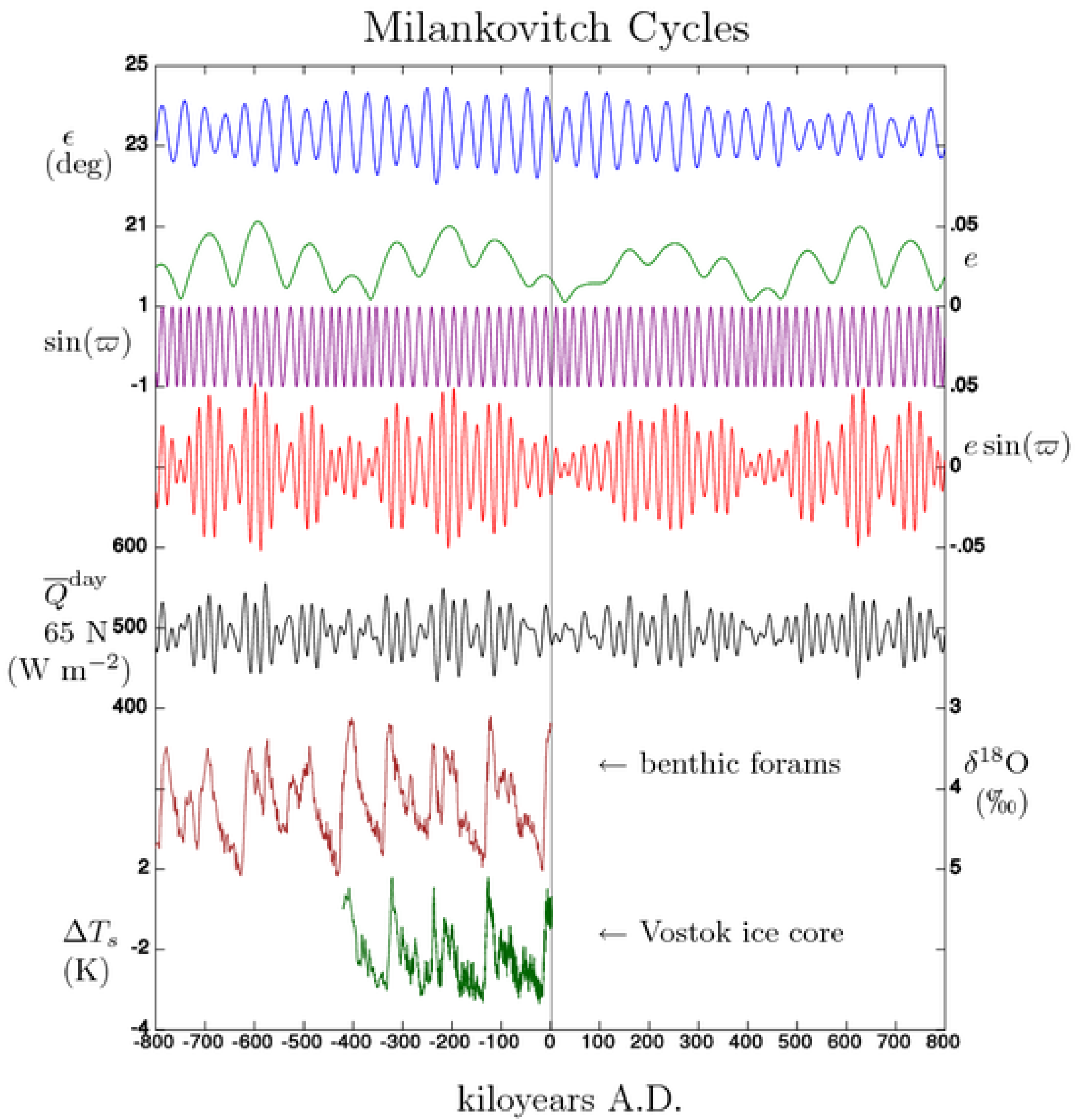


Late Pleistocene: Atmospheric CO2 and the Glacial cycles
(650,000 - 0 years BP)
(ppm)
N.American & (Alpine) names
CO2 (ppm)
310
290
270
250
230
210
190
170
(Günz-Mendel)
Aftonian (I)
Aftonian (II)
------------ Yarmouth ---------------
(Mindel-Riss) Interglacial
(I)
(II)
(III)
Sangamon (Riss-Würm) Interglacial
Holocene Interglacial
Nebraska (Günz)
"Independence"
------------------- Kansan(?!) ---------------------
(1) ------------------- (2) (Mindel) --------------------- (3) (4)
Illinois (Riss)
Wisconsin (Würm)
-650000
-600000
-550000
-500000
-450000
-400000
-350000
-300000
-250000
-200000
-150000
-100000
-50000
0
BP

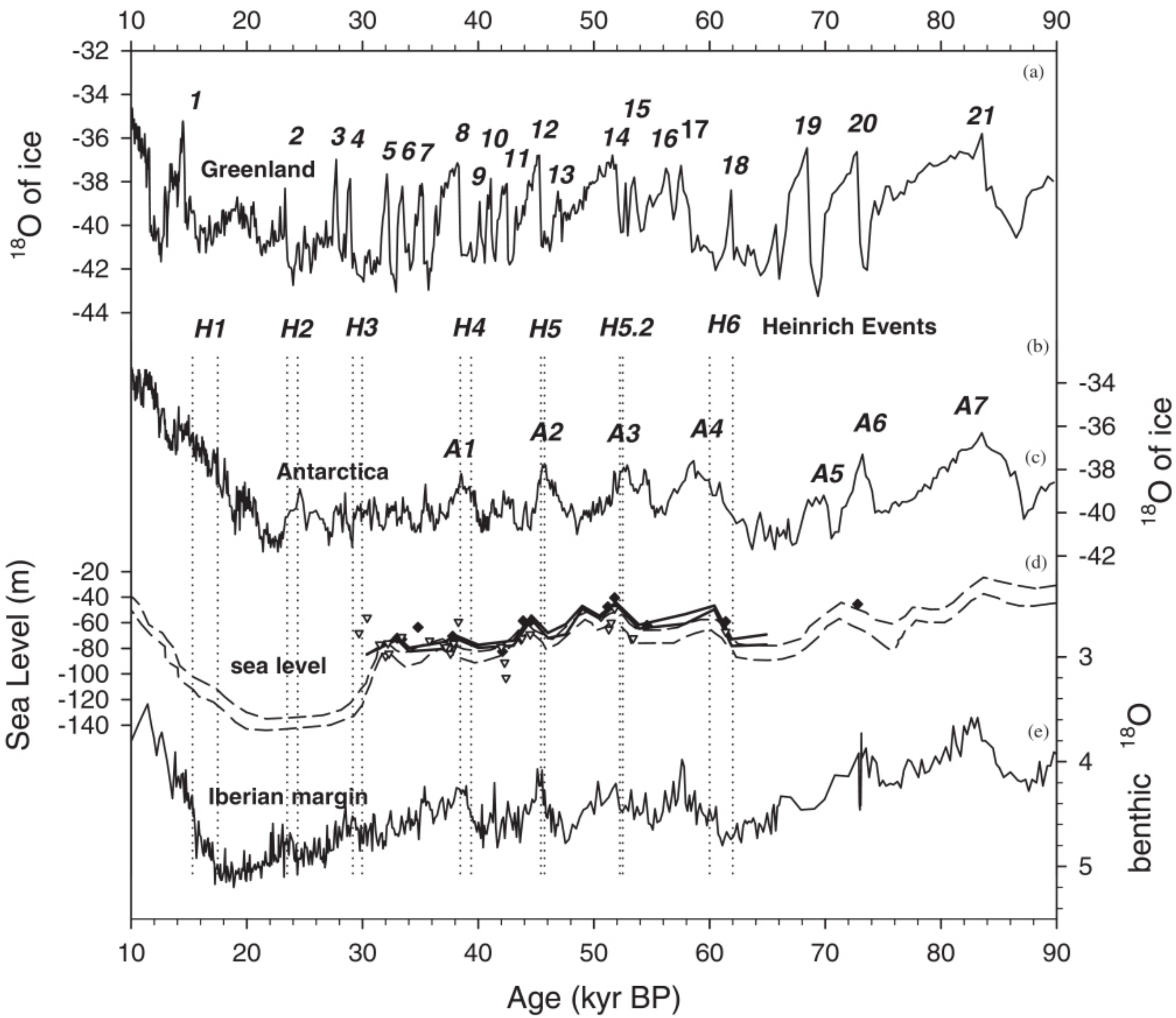
Climate Change !!



Antropogenic forcing??



Dansgard/Oeschger Events



Keeling et al. 2005

Ocean Currents

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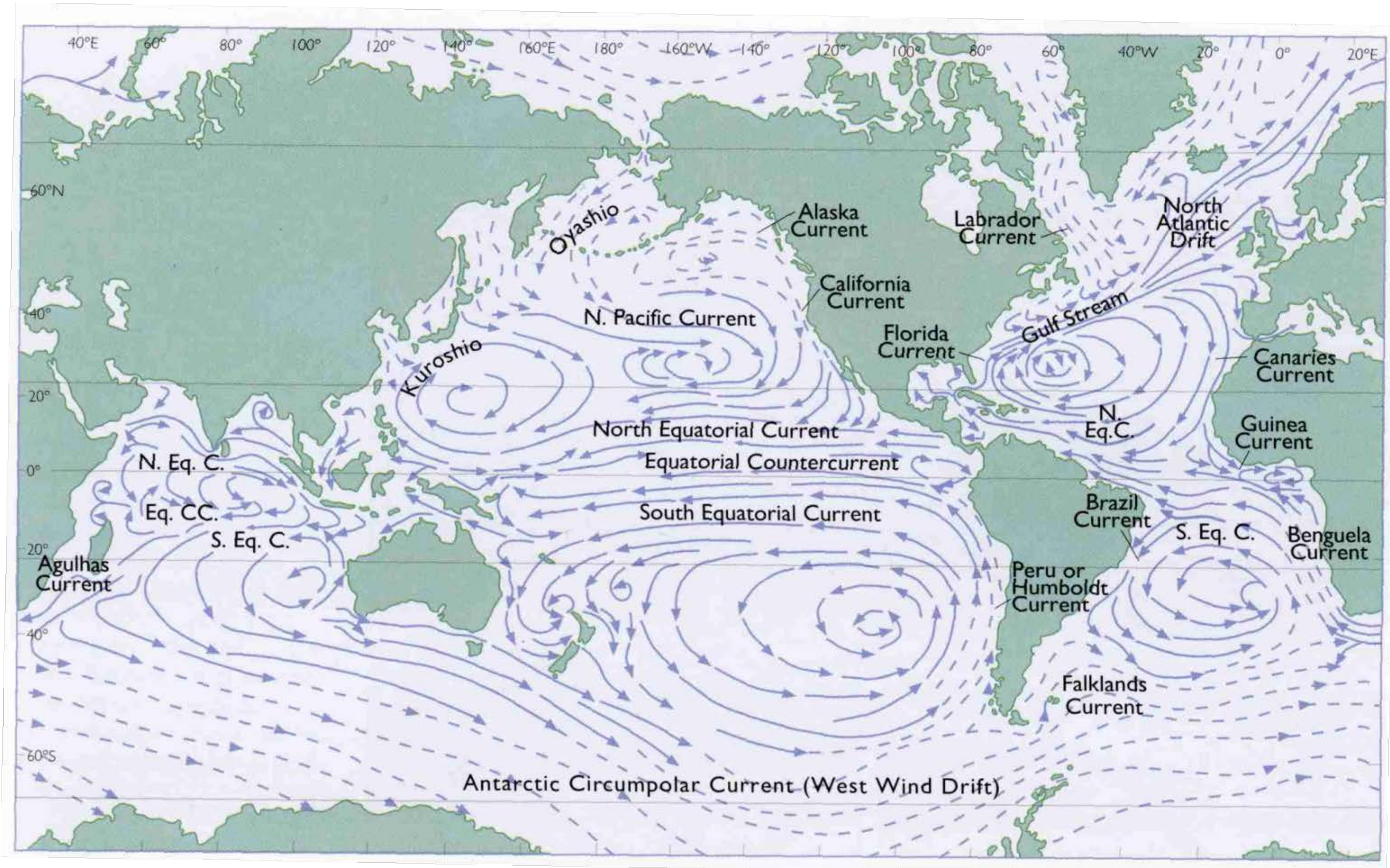
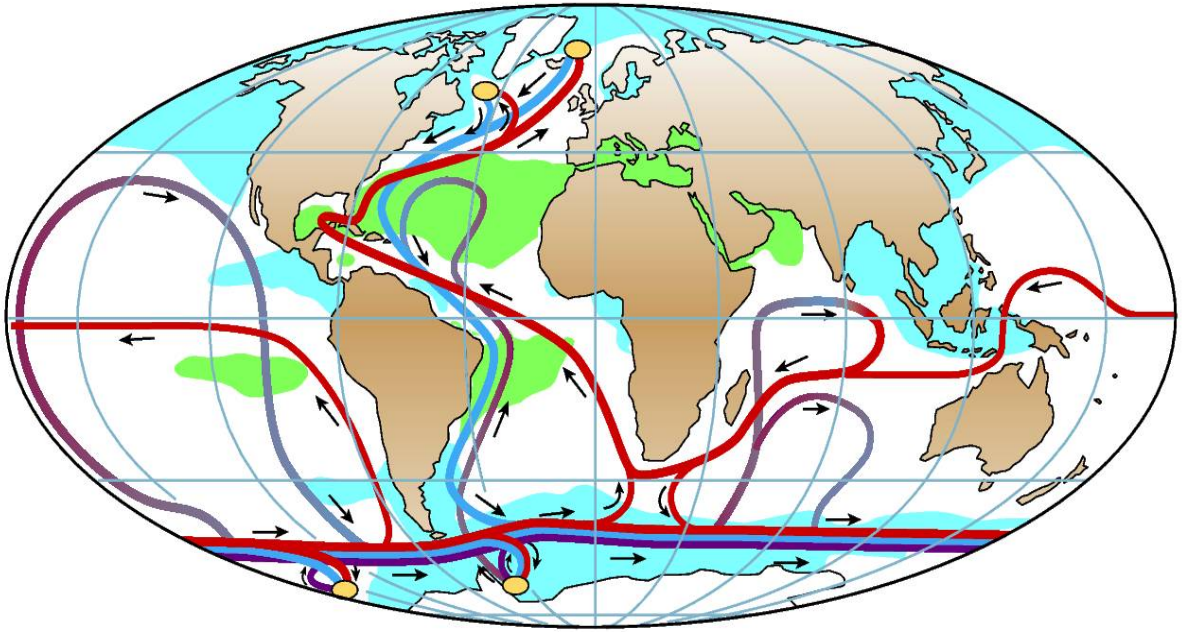
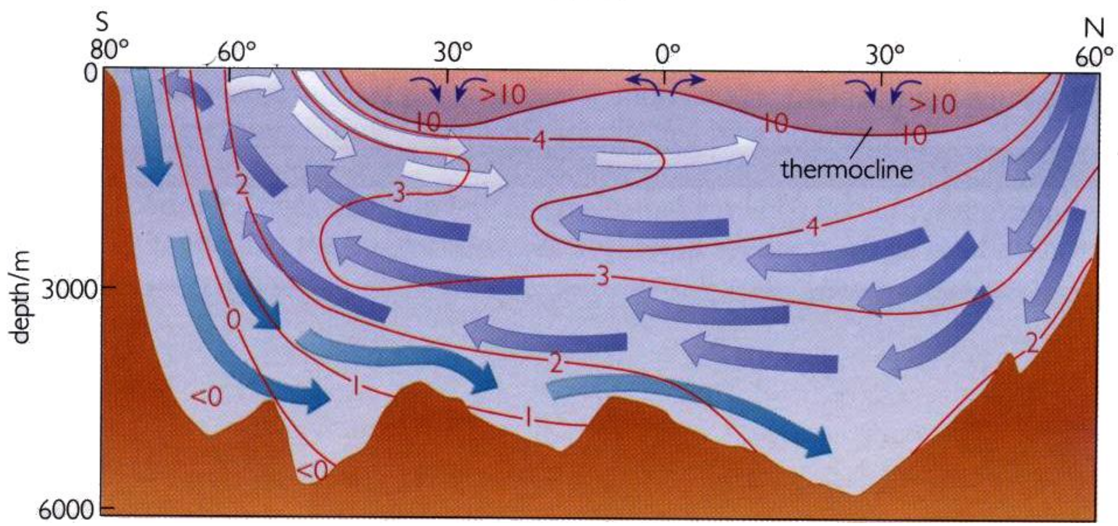
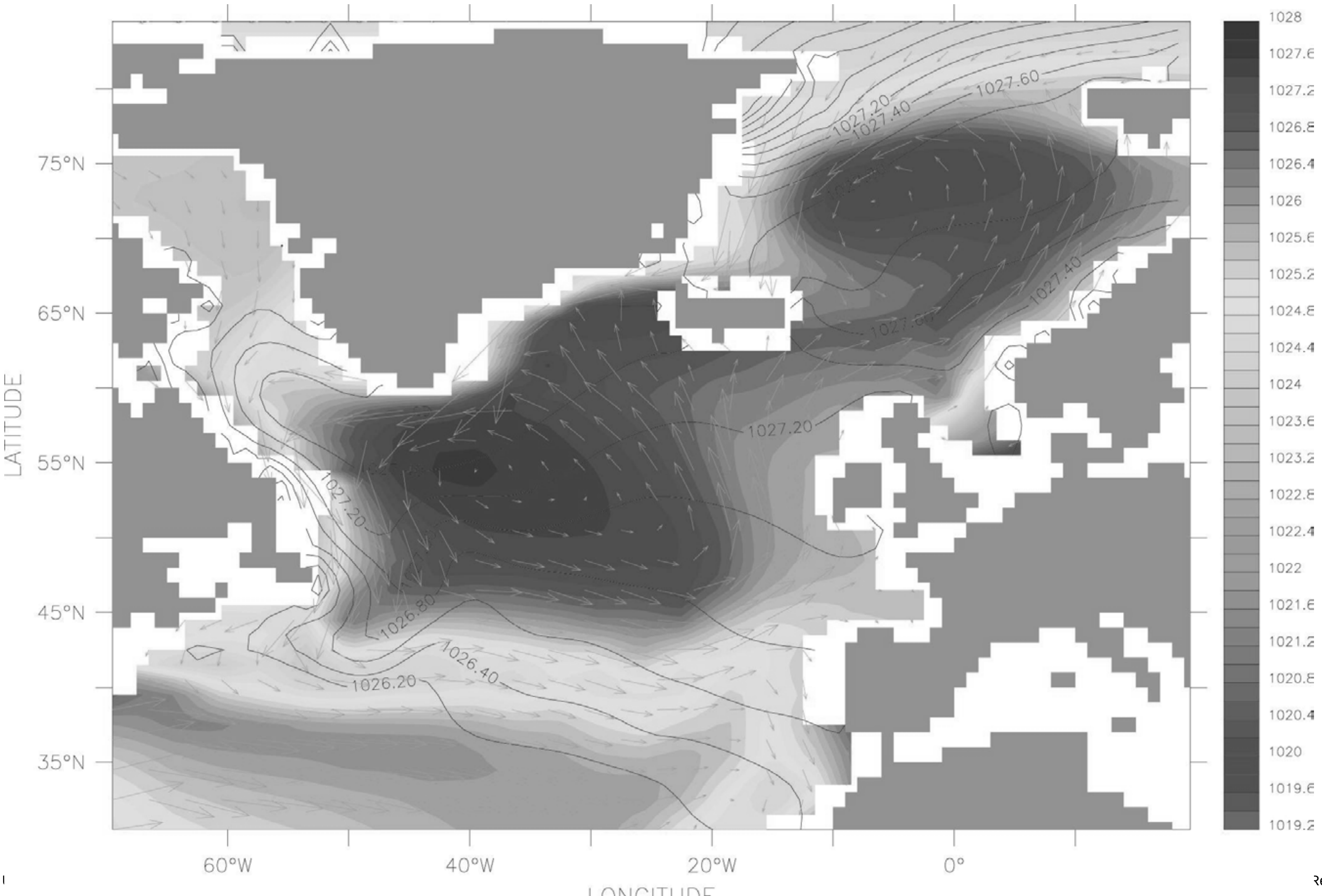


Conveyor Belt





Densitiy



75°N
65°N
55°N
45°N
35°N
60°W
40°W
20°W
0°
LATITUDE
1027.60
1027.20
1027.40
1027.20
1026.80
1026.40
1026.20
1028
1027.6
1027.2
1026.8
1026.4
1026
1025.6
1025.2
1024.8
1024.4
1024
1023.6
1023.2
1022.8
1022.4
1022
1021.6
1021.2
1020.8
1020.4
1020
1019.6
1019.2

Water hosing experiments

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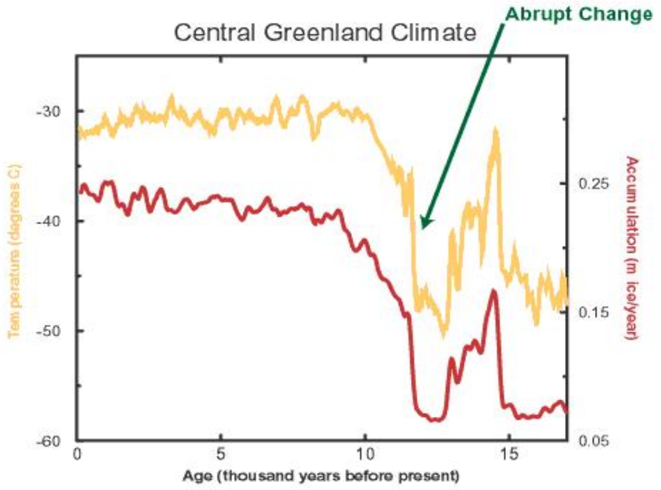
Abrupt Climate change: What can we learn from climate simulations? Links to proxies?

Rapid climate and environmental changes in the past, reported by proxies, suggest an important role of the so called Meridional Overturning Current (MOC) in the North Atlantic. (Keywords: Younger Dryas and Heinrich events)



What kind of climate effects do we see in the North Atlantic, by weakening the AMOC?
Is the influence of the AMOC global? (ENSO, Benguela, S.A.)
Do we have to care about the experimental setup?

Forcing areas

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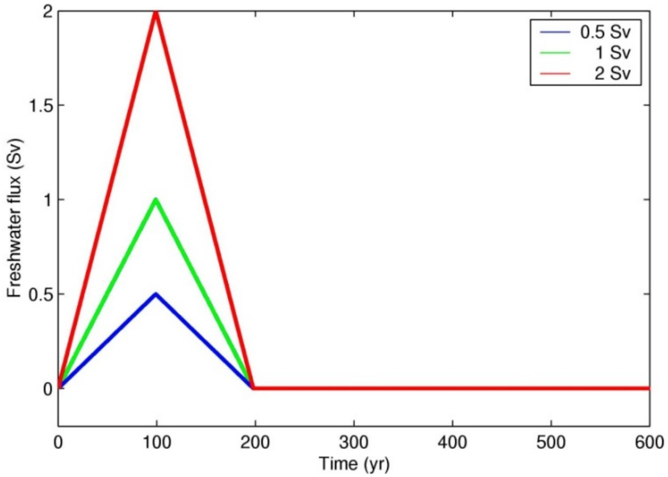
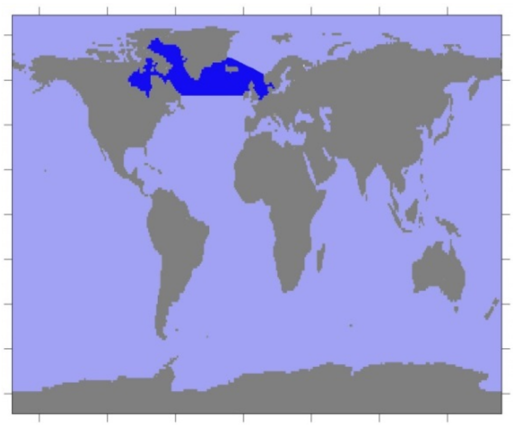
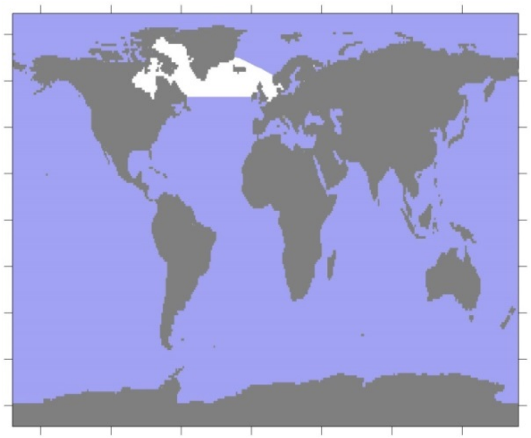


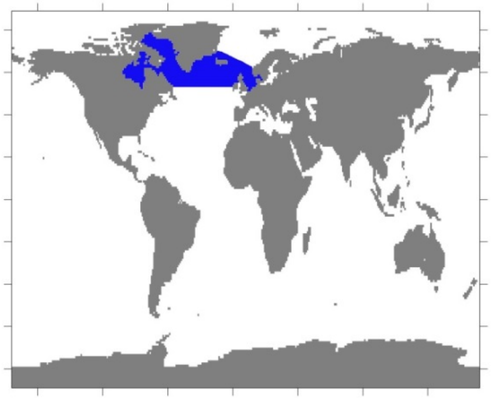


compensated



compensated only

- Freshwater pulse into the North-Atlantic basin
(50 to 70N)
- Period: 200 years with 0.5Sv/ 1Sv and 2Sv of freshwater.
- YD-event -> 0.1Sv
- 1 Sv -> 18m sea level (1Sv = 10^6m^3/sec)



not compensated

AMOC

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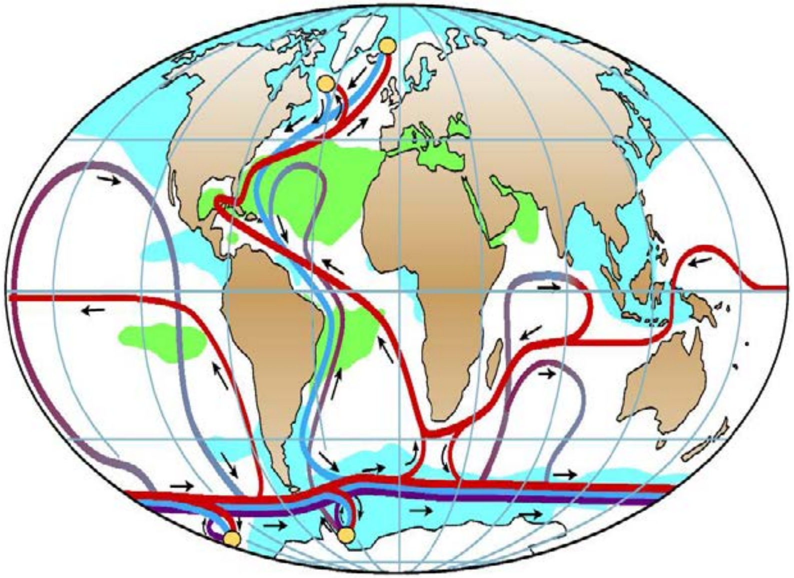
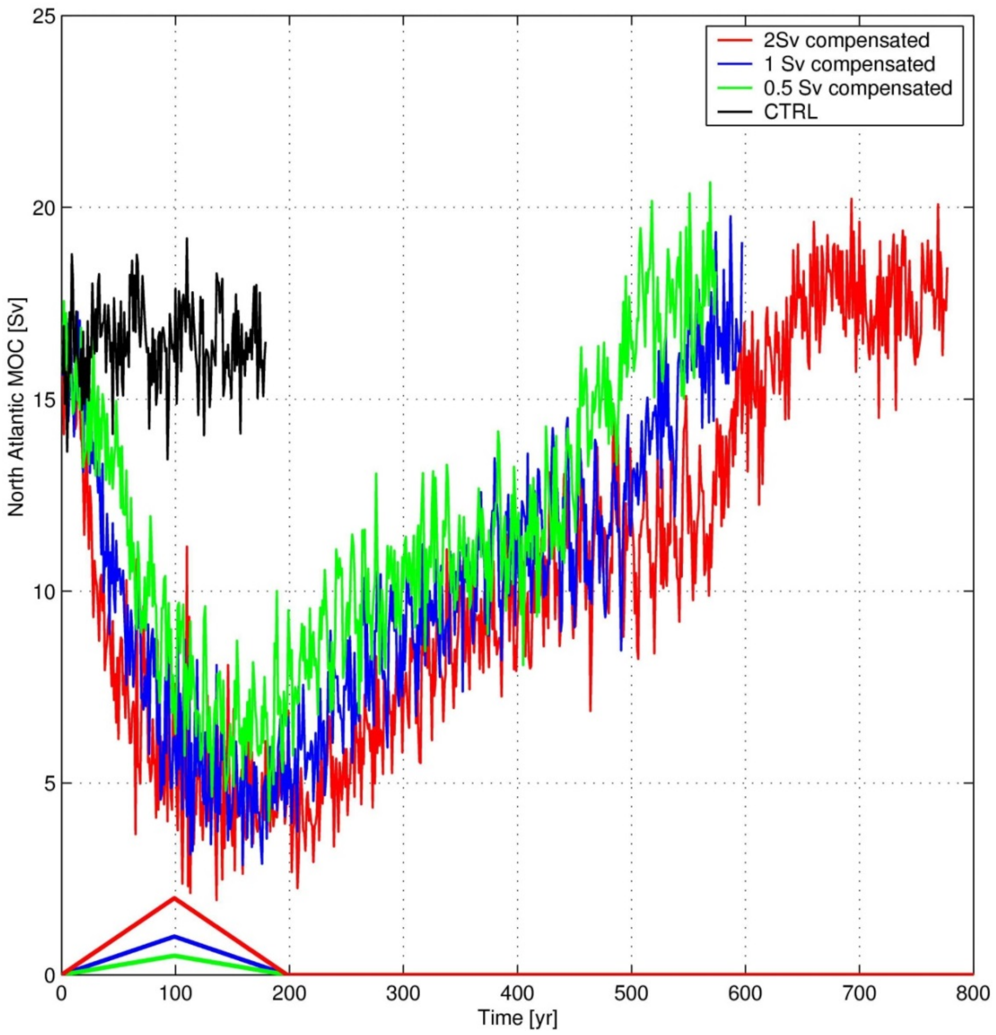
- Max. Meridional Overturning Circulation (AMOC) in the North Atlantic
  (below 500m, north of 28°)
- Plateau at 11Sv

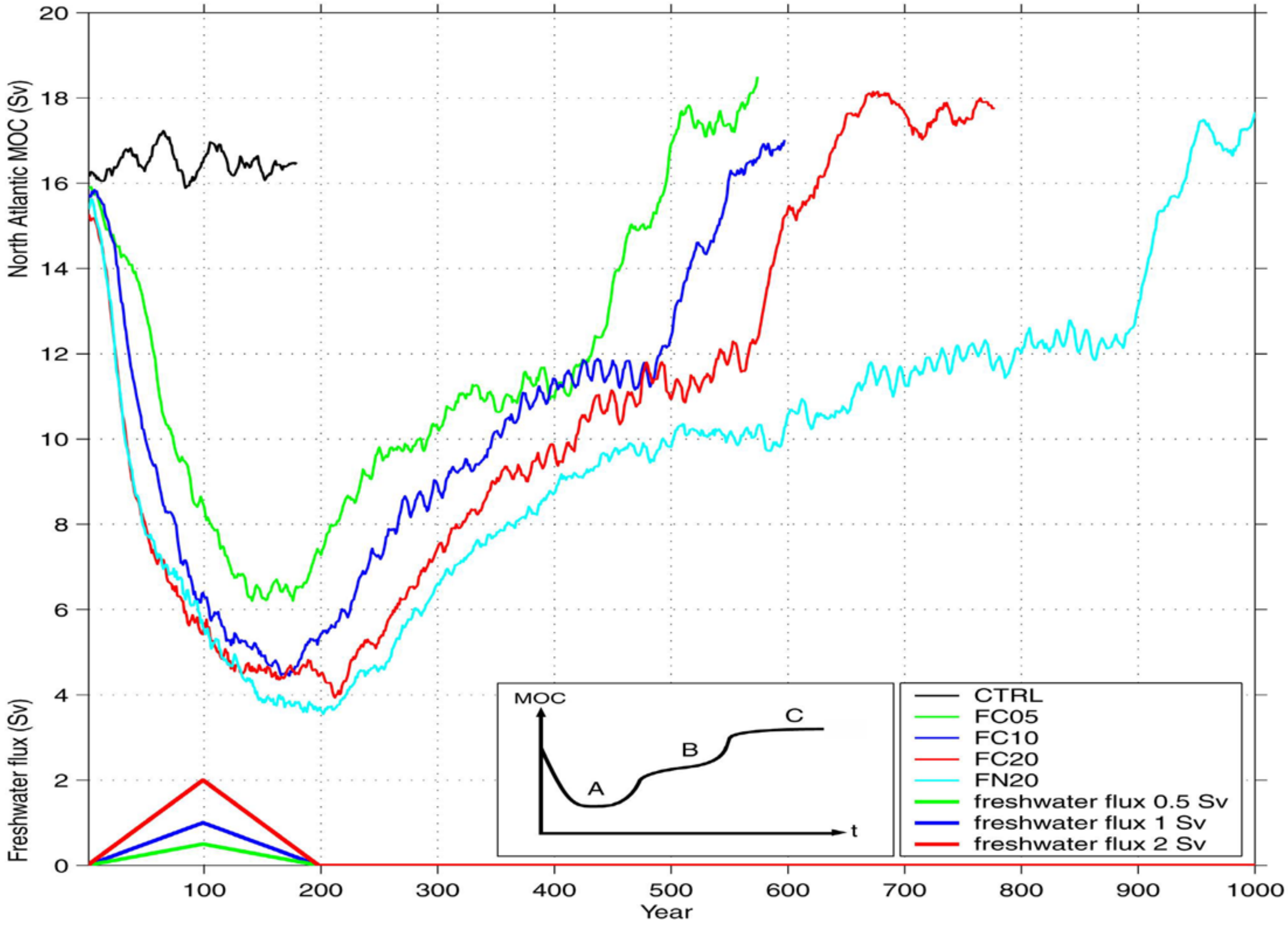


Broeckers Conveyor Belt



(1Sv = 10^6m^3/sec)

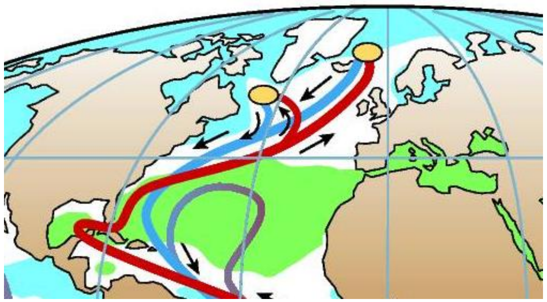
MOC – answer

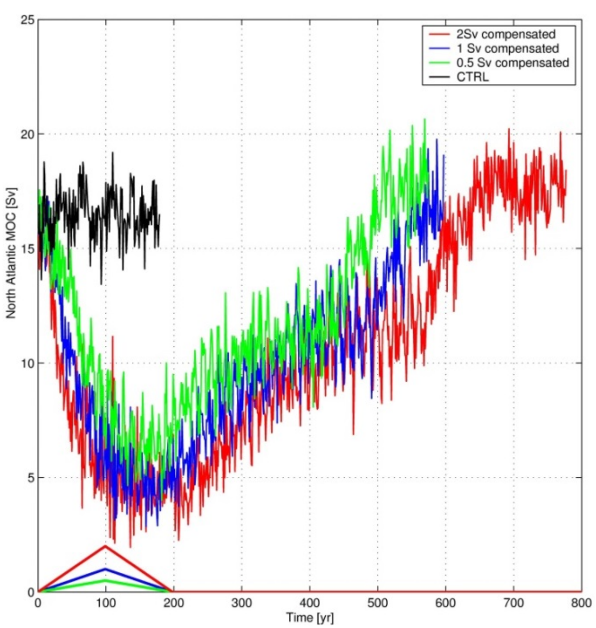


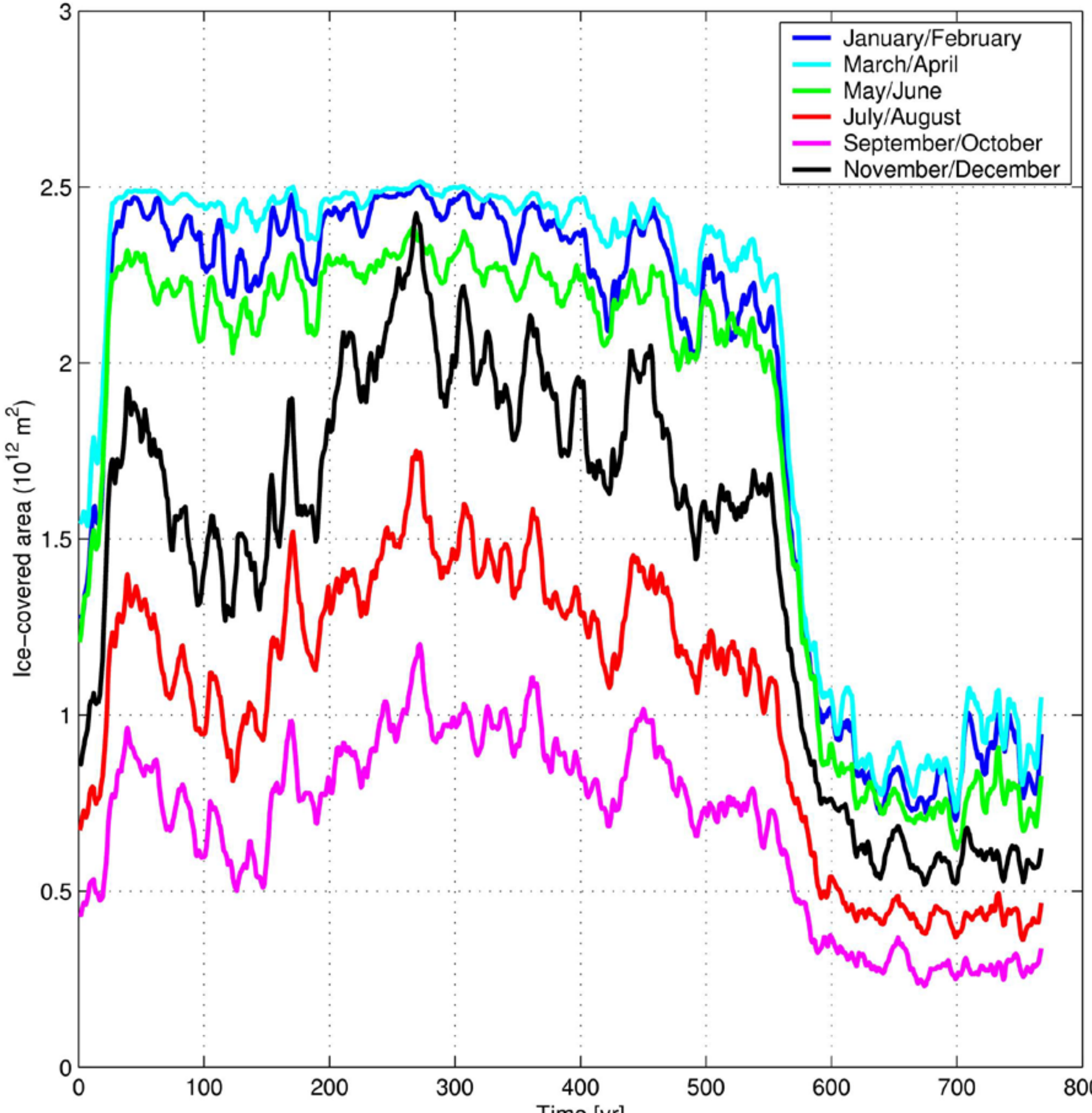
North Atlantic MOC (Sv)
Freshwater flux (Sv)
Year
MOC
A
B
C
t
CTRL
FC05
FC10
FC20
FN20
freshwater flux 0.5 Sv
freshwater flux 1 Sv
freshwater flux 2 Sv

GIN Sea Ice

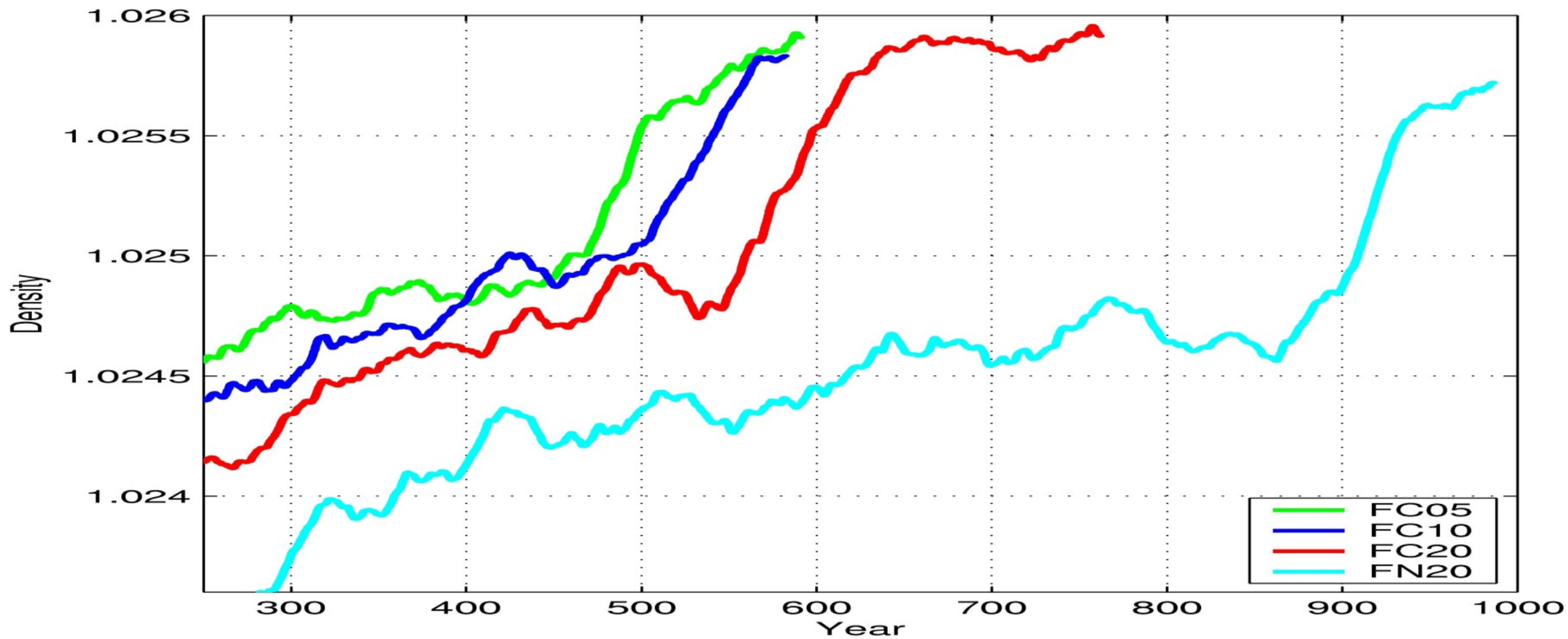
- GIN-Sea-Ice

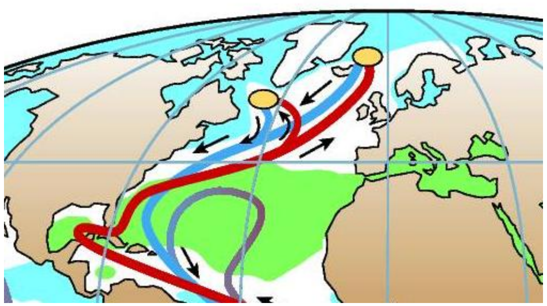




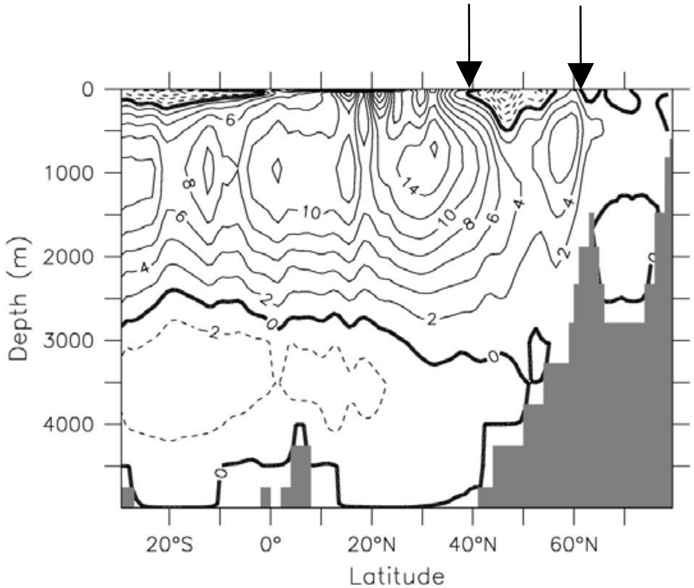


Ocean Surface Density

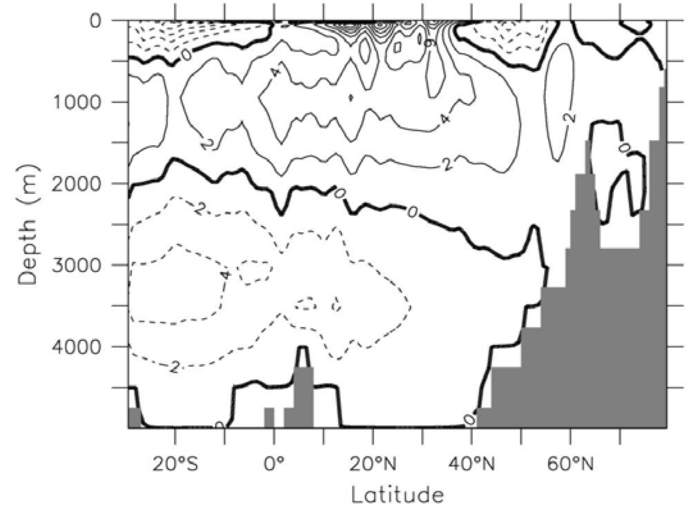




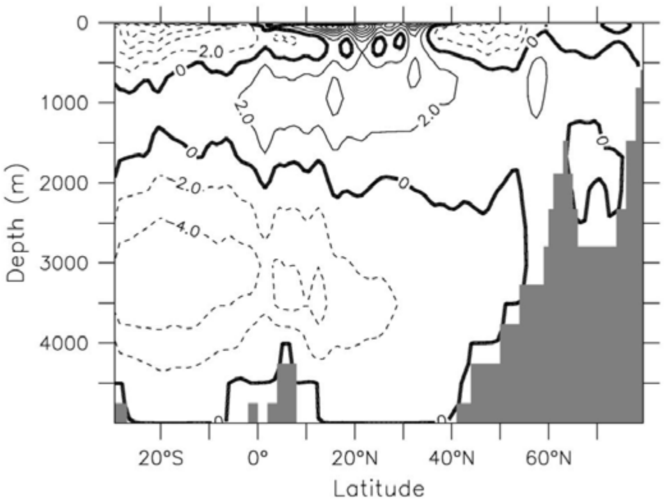
North Atlantic MOC



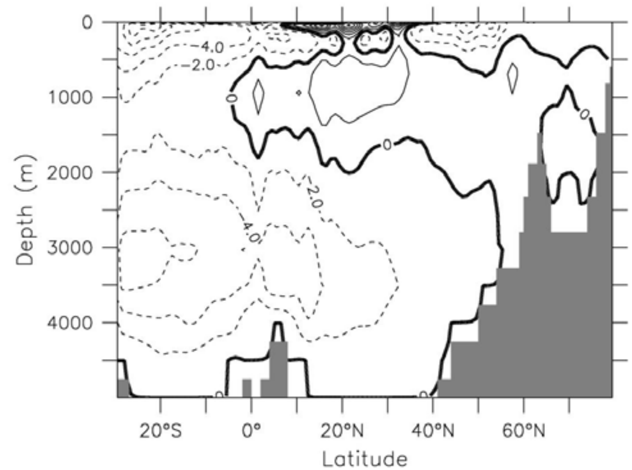
CTRL



0.5 Sv

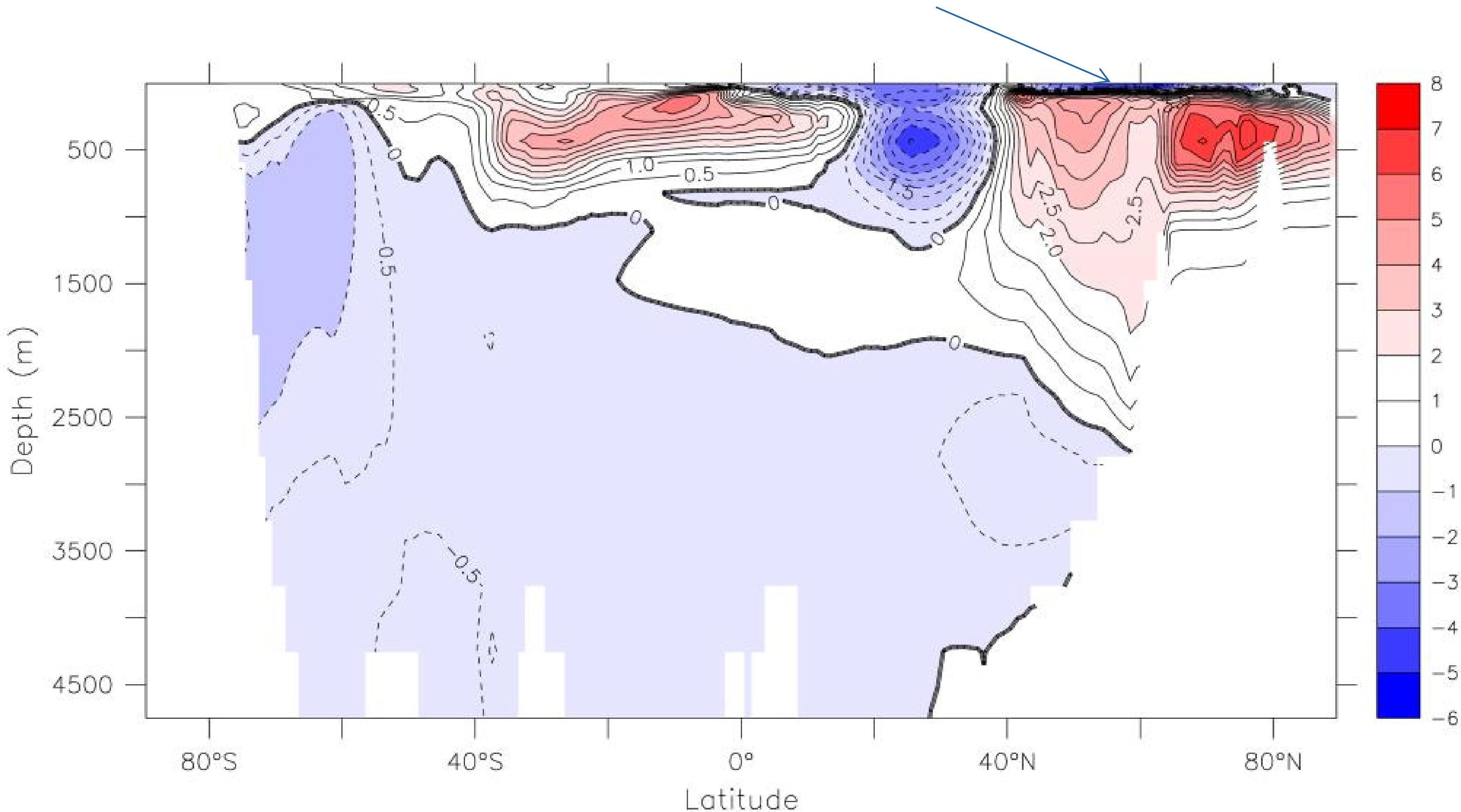


1Sv



2Sv

Potential Temperature Atlantic



Sea Surface Temperature

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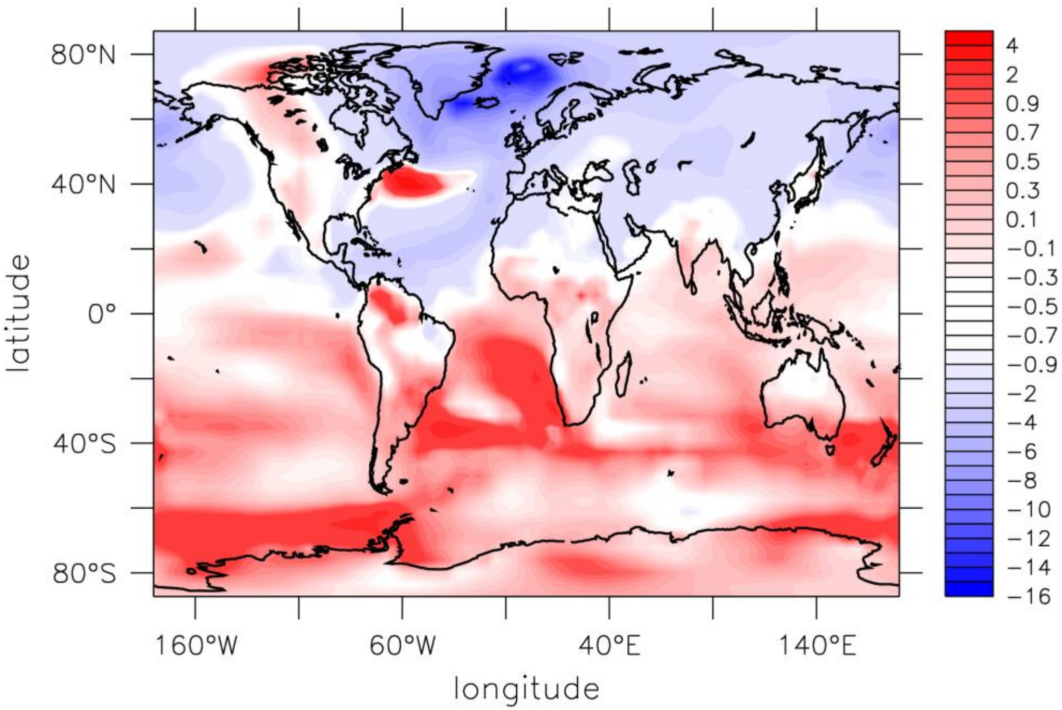
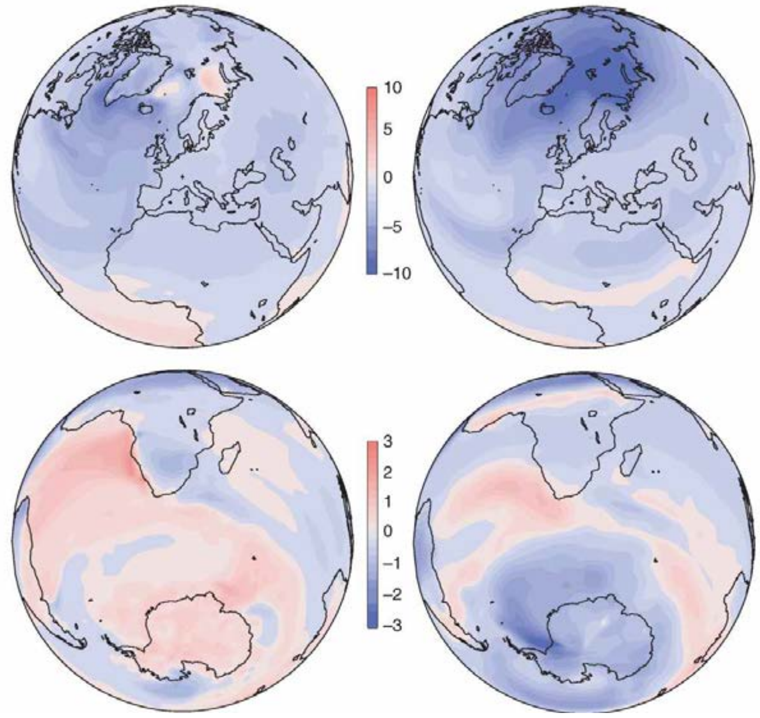
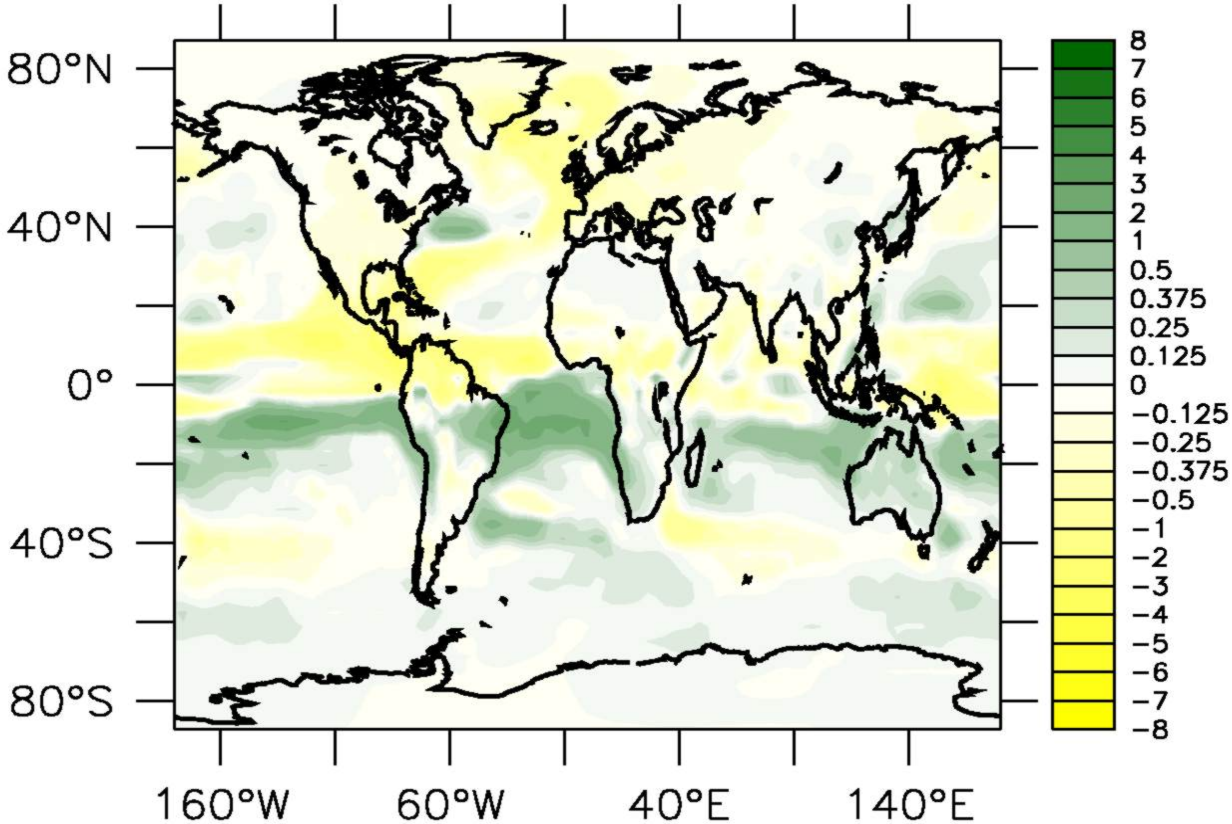




ITCZ shifts southward

- temperature dipole in low latitude Atlantic
- reorganization of the large scale tropical atmospheric circulation by increasing of the northeasterly trade winds.

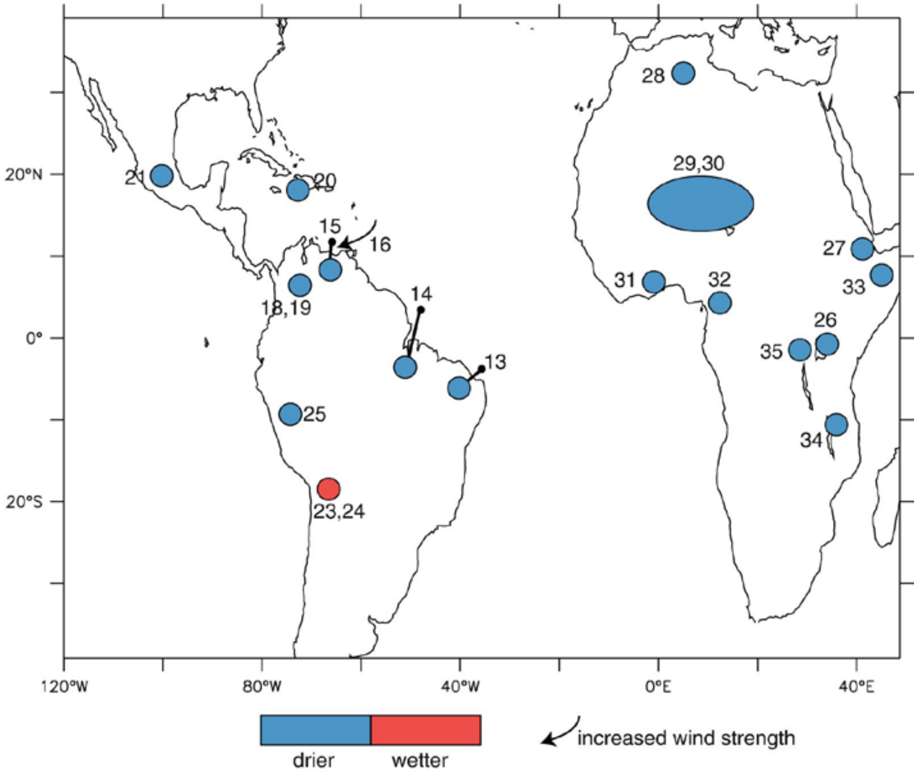
southward migration of the ITCZ

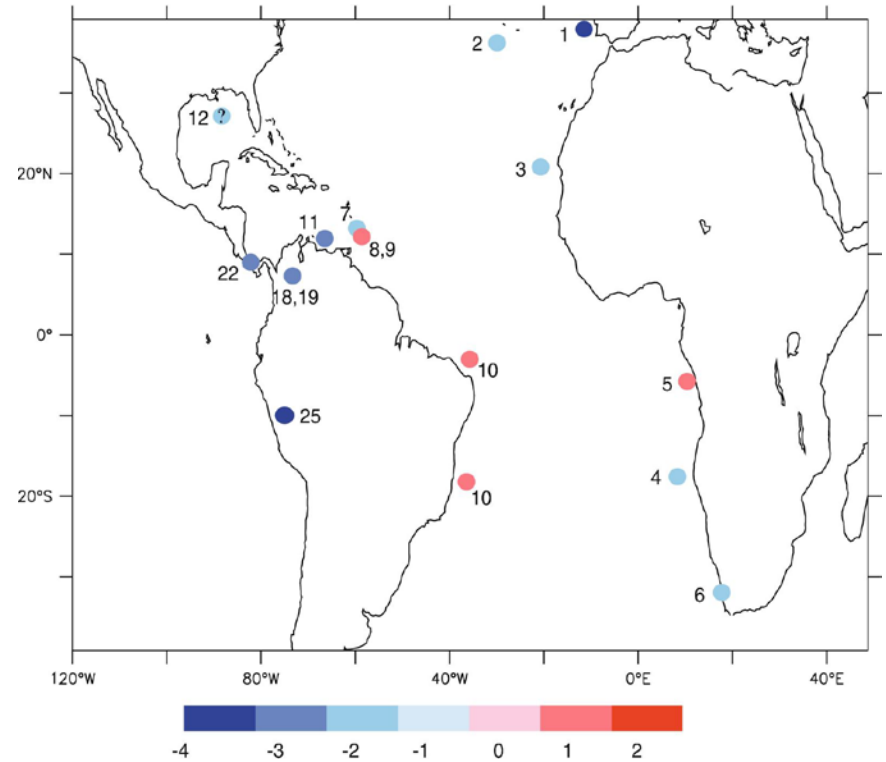


precipitation anomaly [mm] DJF 2Sv – CTRL

Tropical Proxies

Precipitation and Temperature proxies (Younger





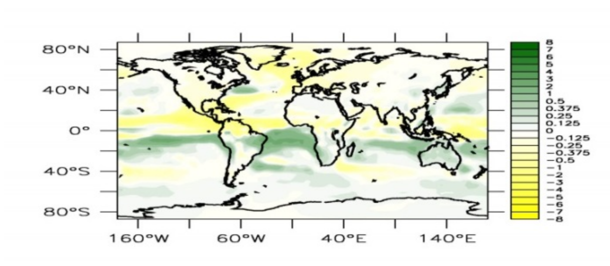
precipitation anomaly

temperature anomaly

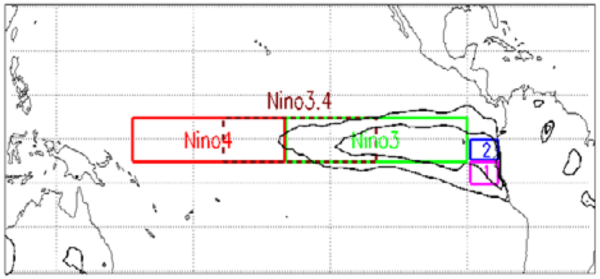
(Dahl et al. 2005)

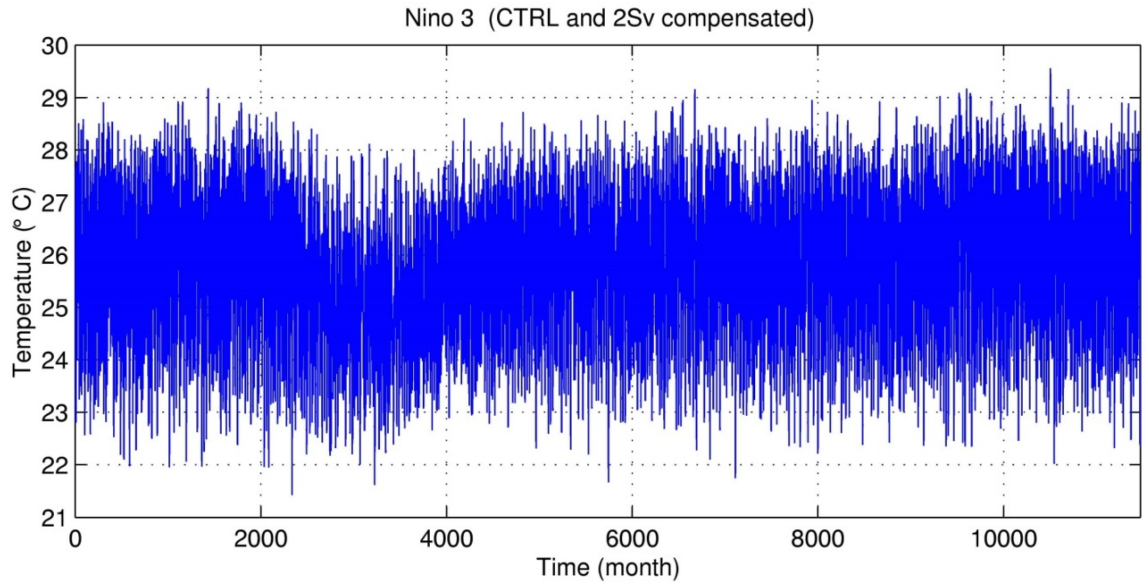
AMOC influence on ENSO

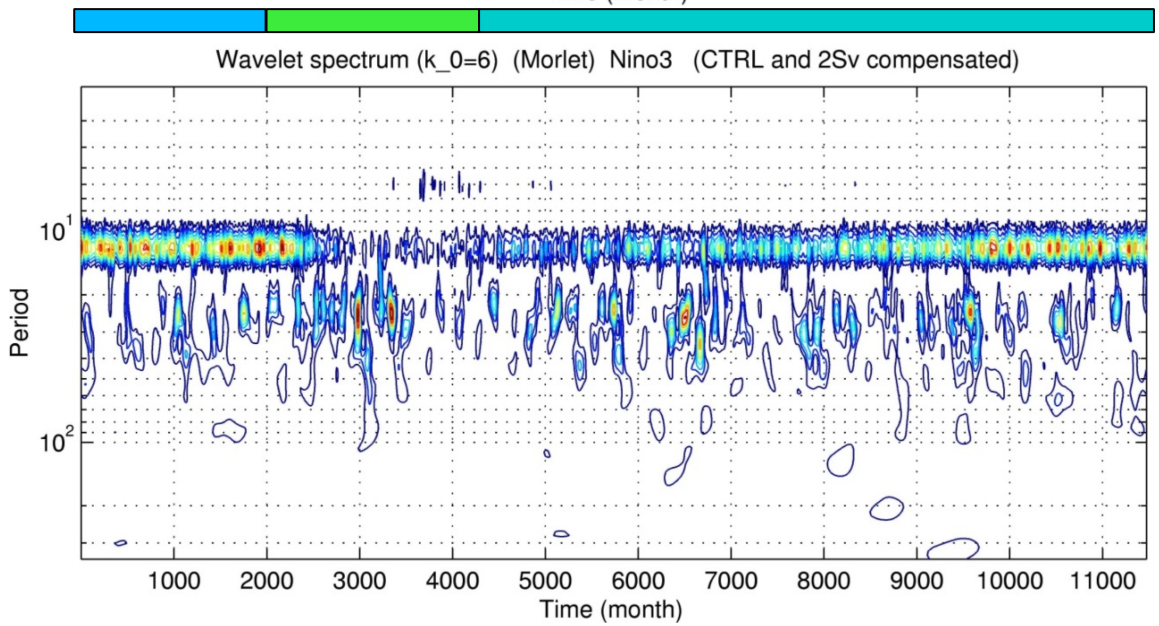
- Times series of Morlet wavelet



- CTRL
- forcing period
- not forced



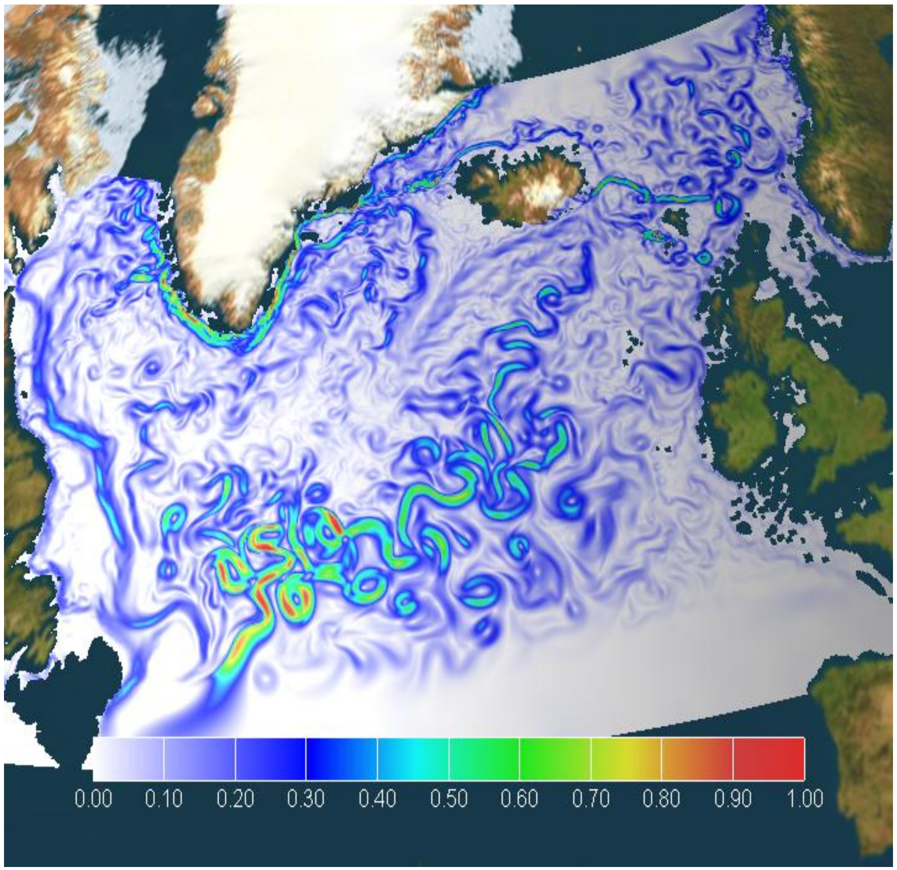




ENSO

movie

Nordatlantik



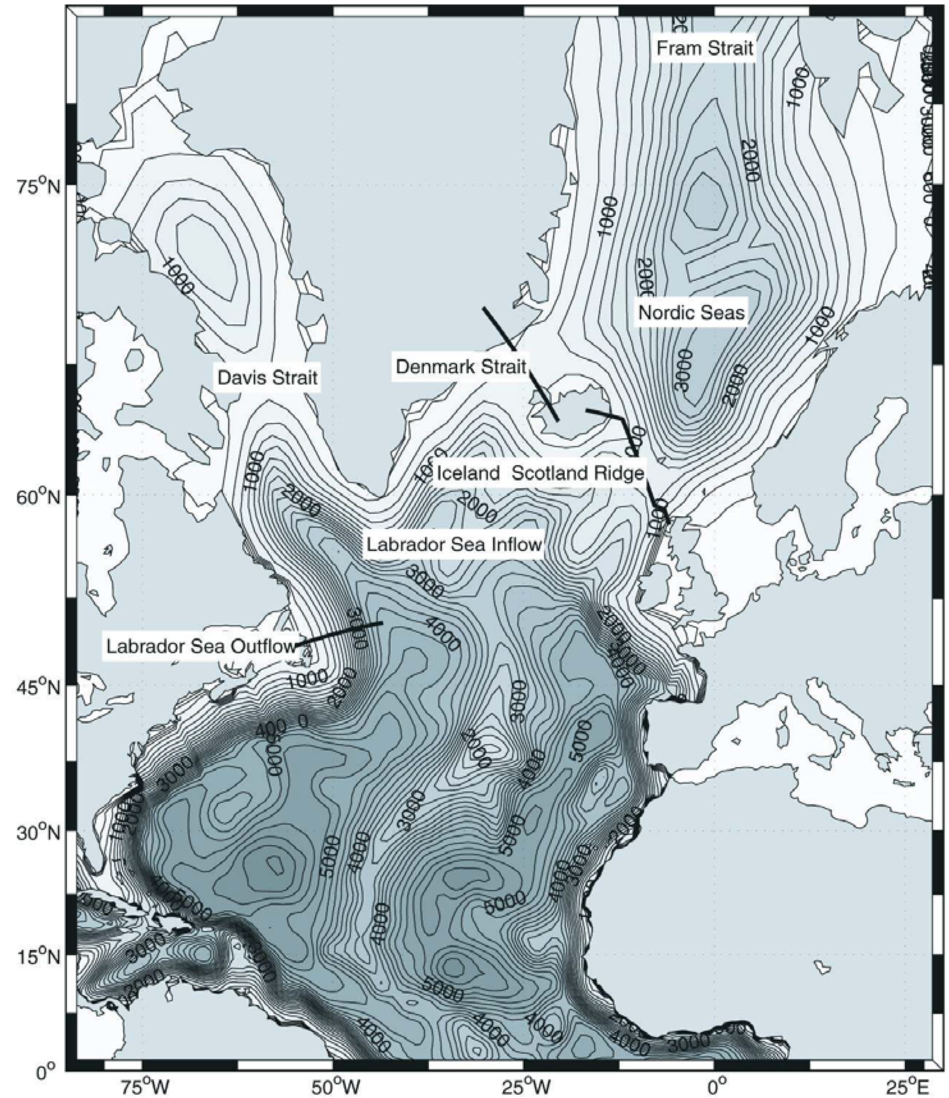
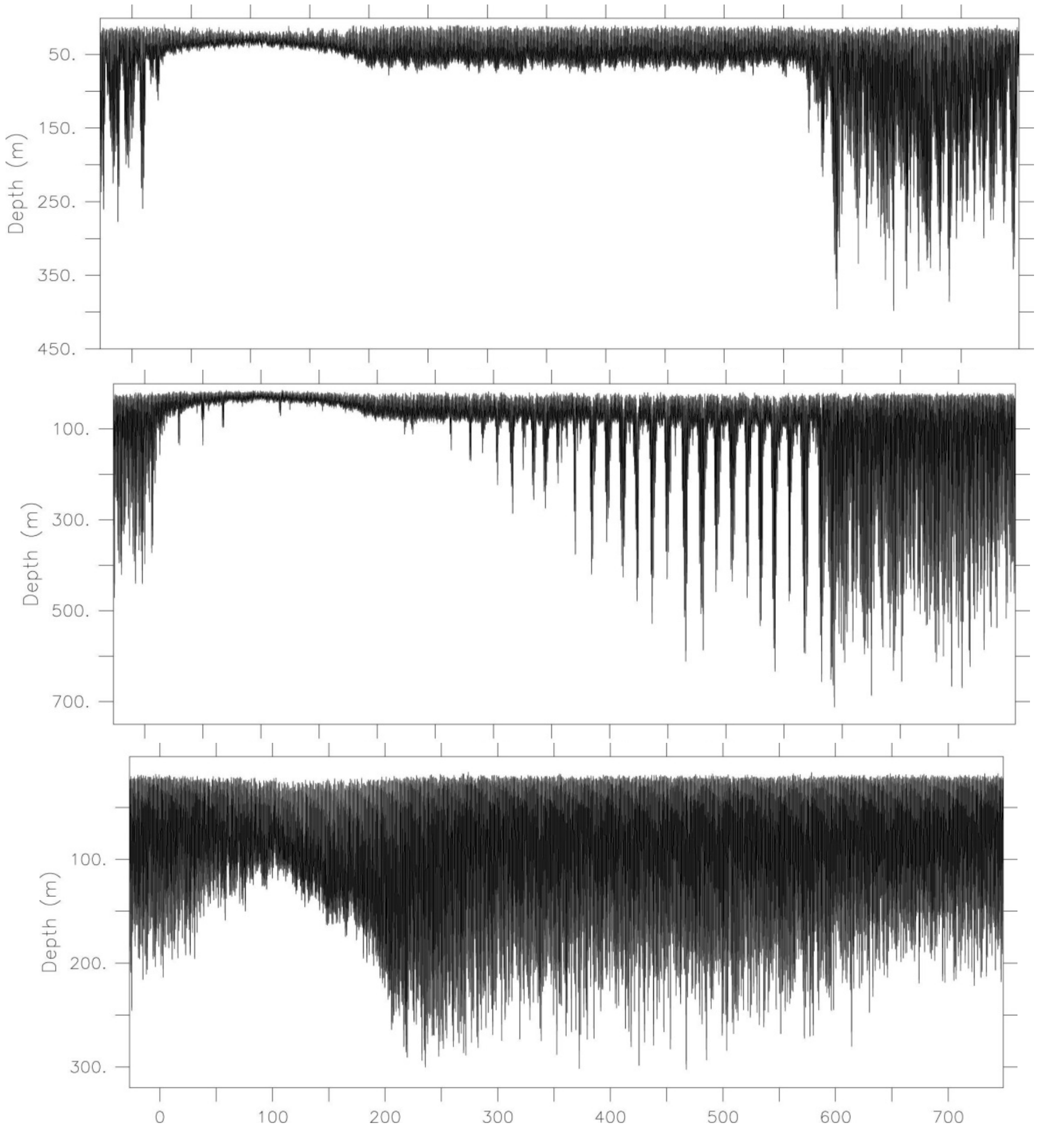


Bild NASA

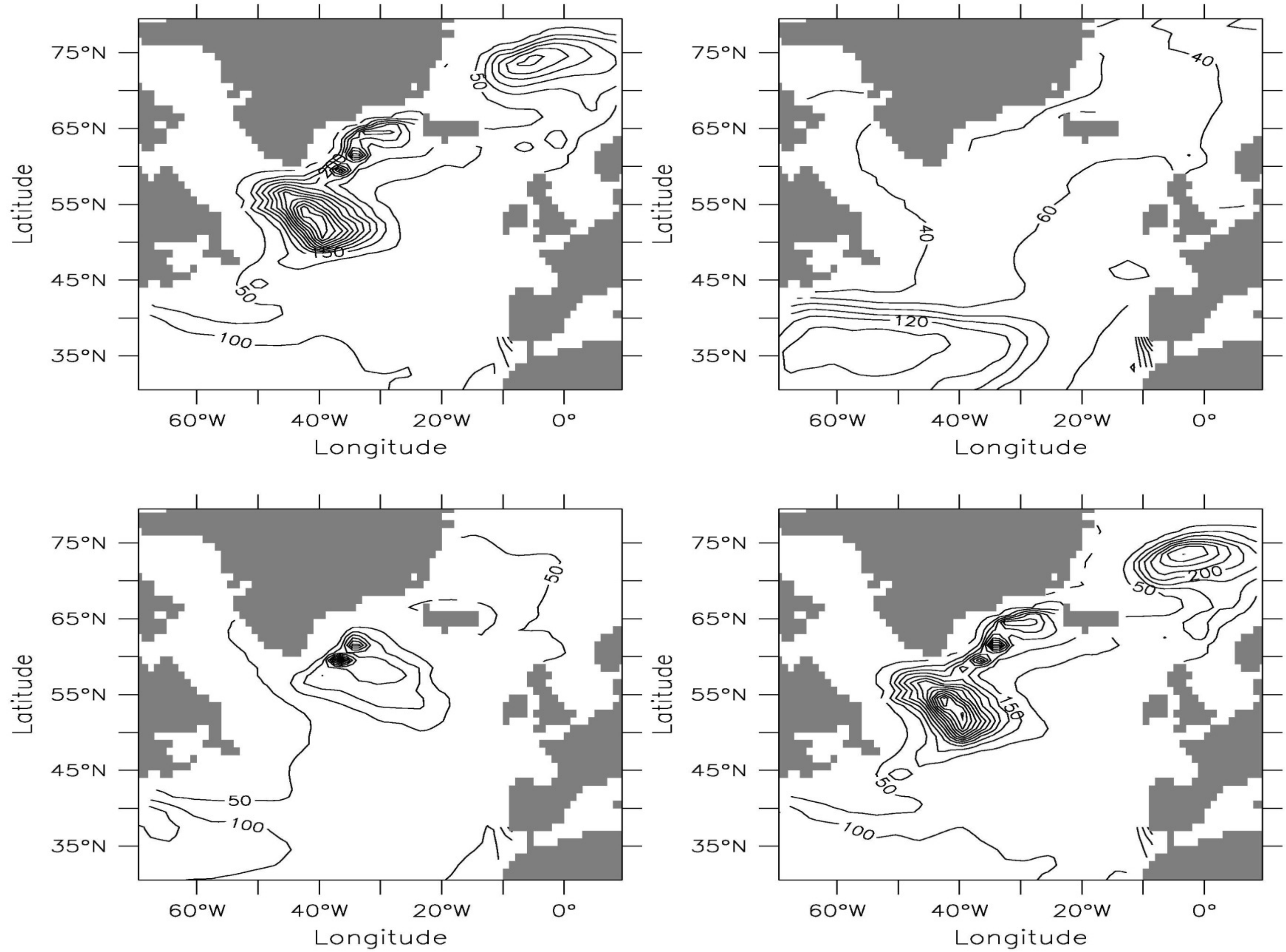
Bailey et al.

Mixed-Layer

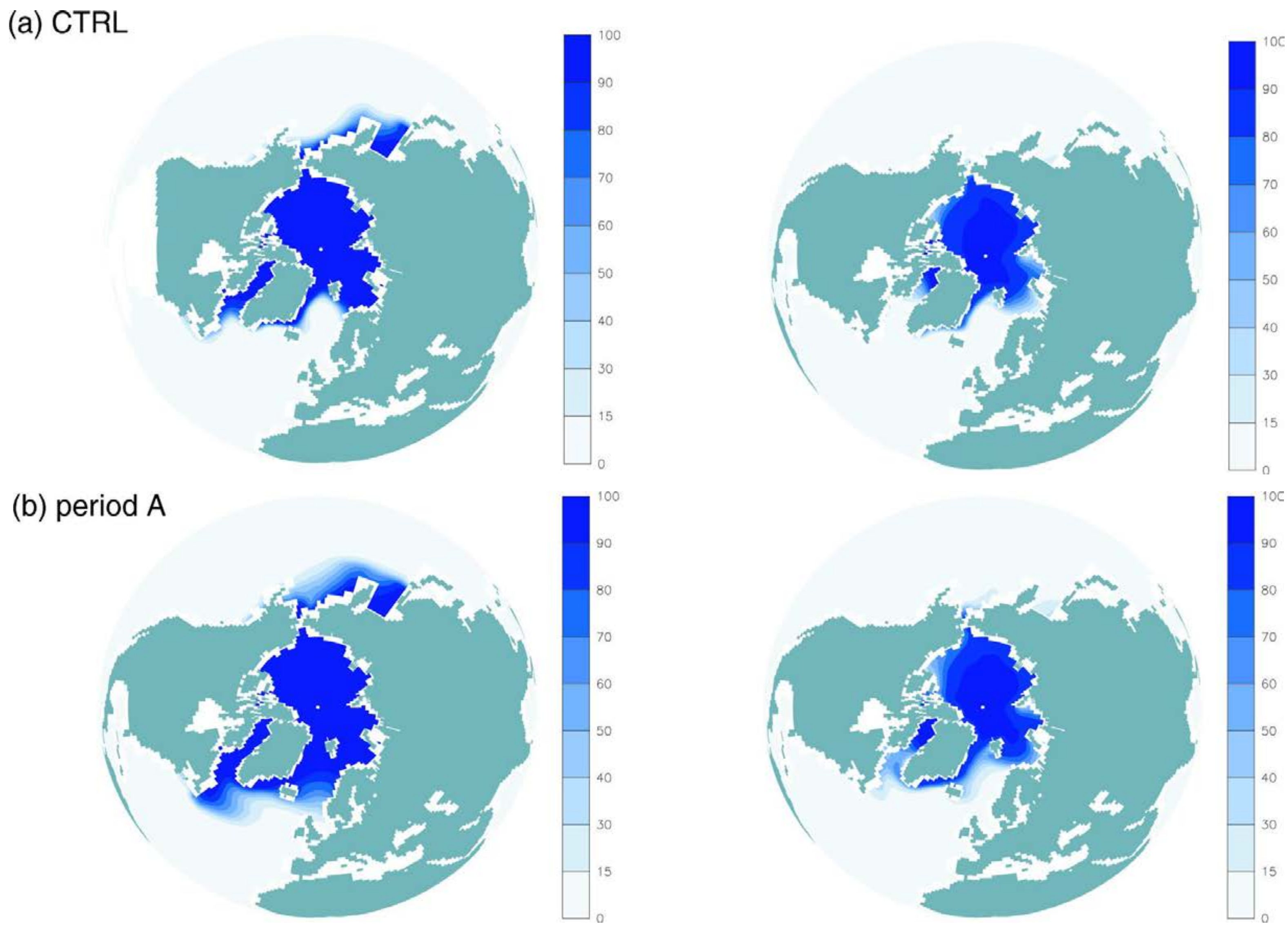


Depth (m)
50.
150.
250.
350.
450.
Depth (m)
100.
300.
500.
700.
Depth (m)
100.
200.
300.
0
100
200
300
400
500
600
700

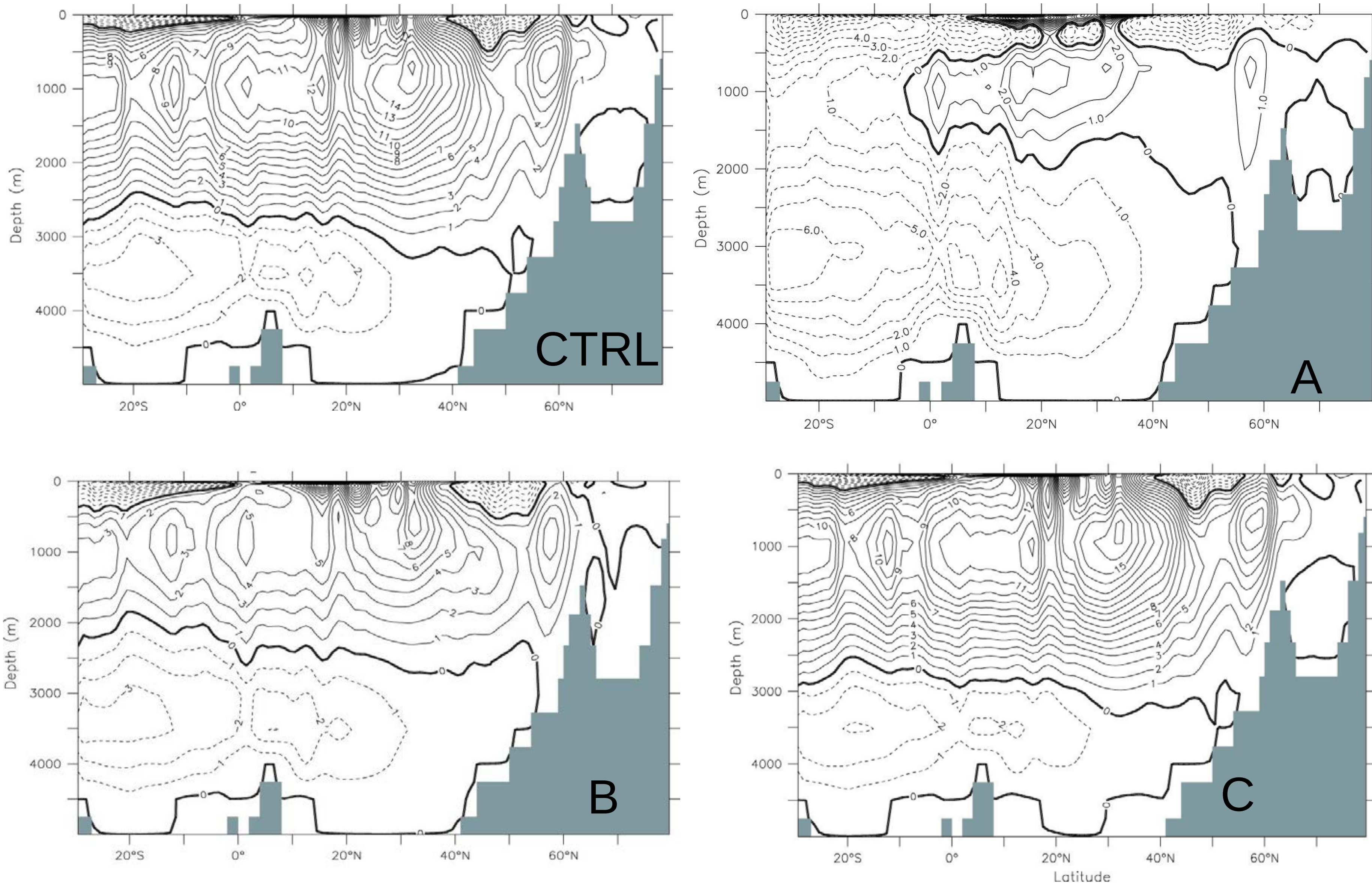
Mixed-Layer


75°N
65°N
55°N
45°N
35°N
Latitude
60°W
40°W
20°W
0°
Longitude
50
150
100
40
60
120
200

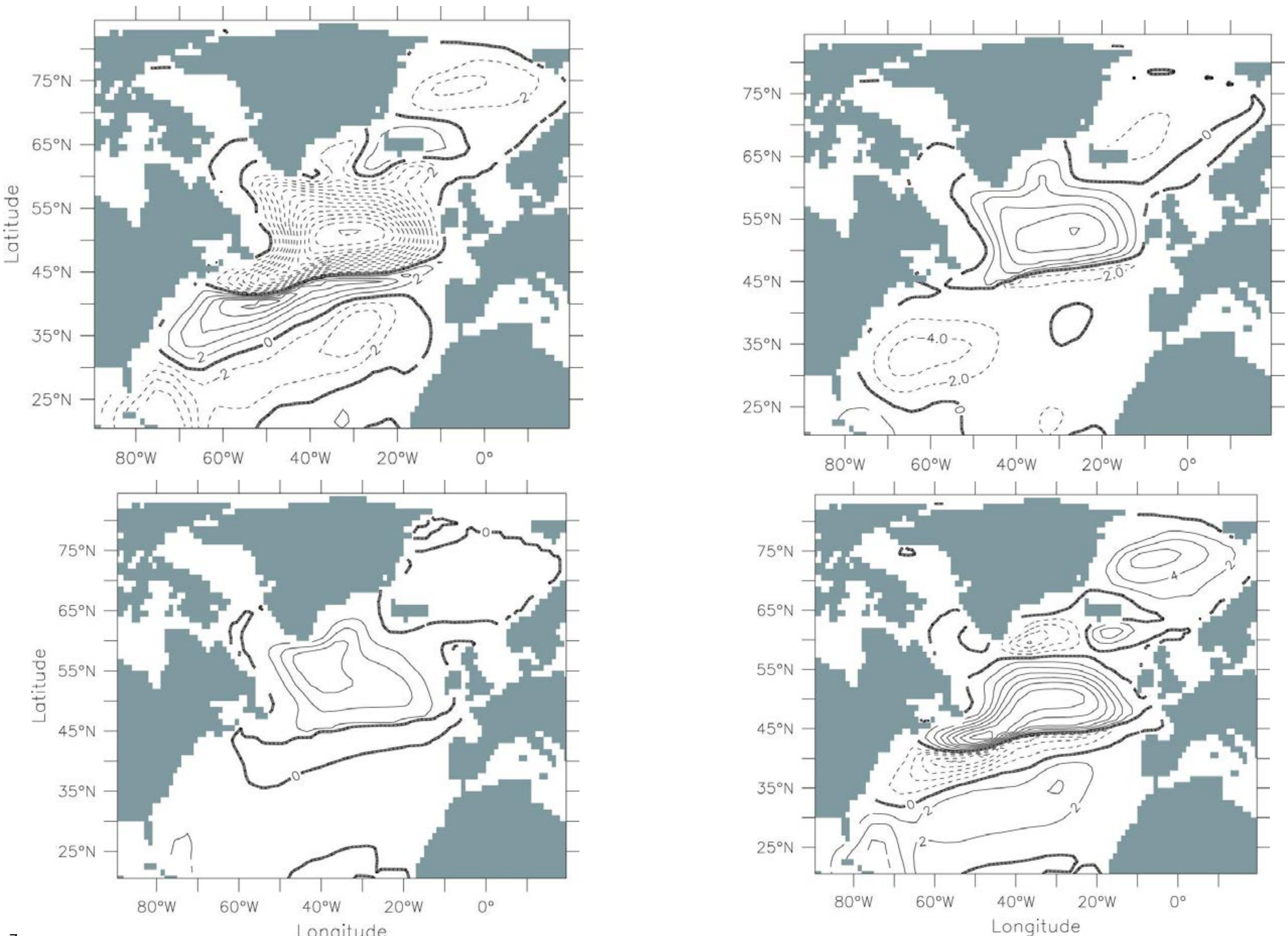
sea ice



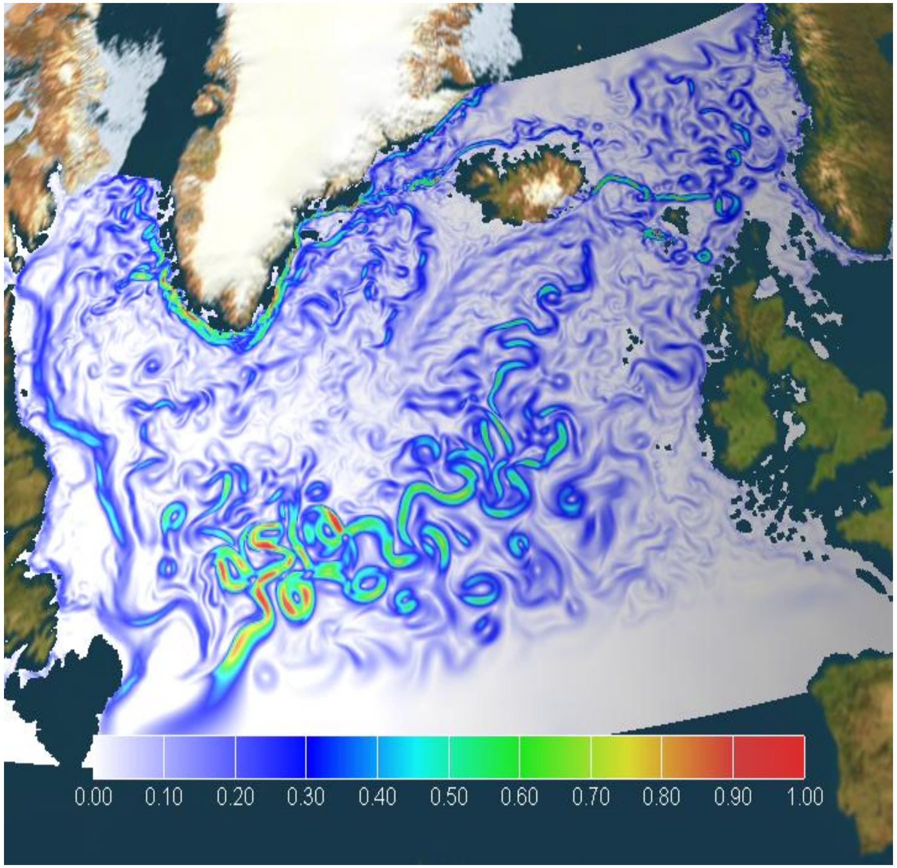
MOC-Periods



Gyres altering



Nord Atlantic



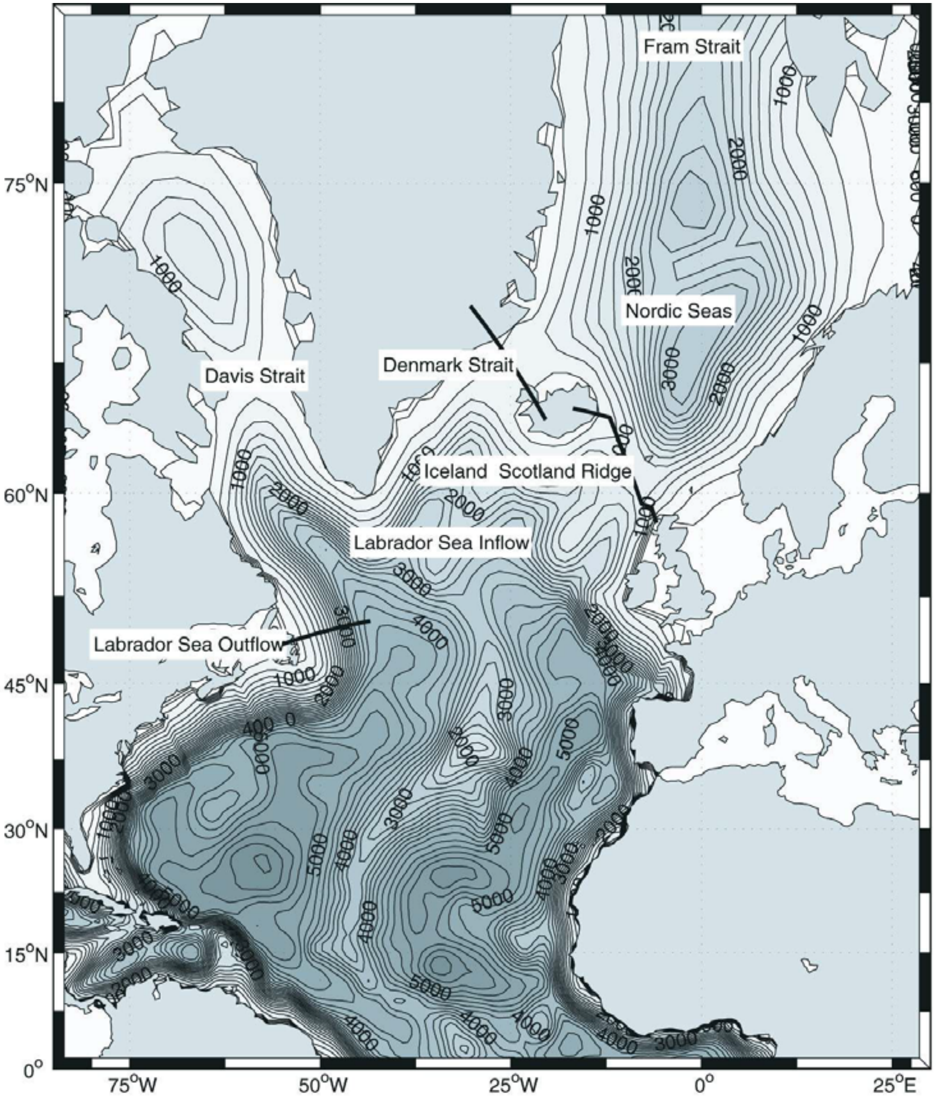


Bild NASA

Bailey et al.

Denmark Strait

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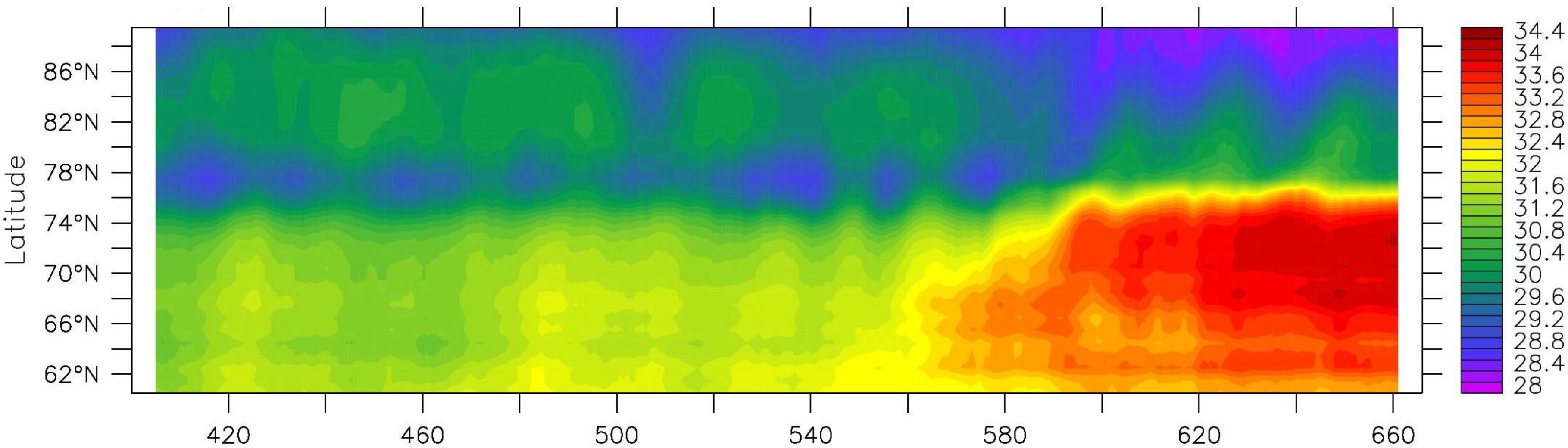
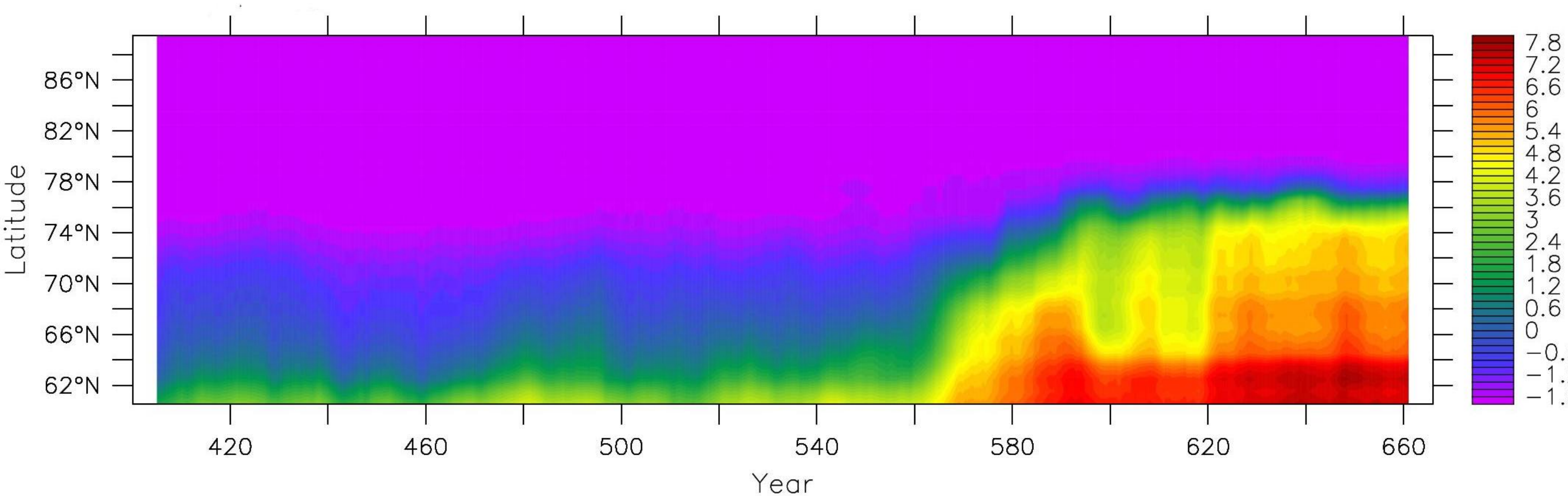
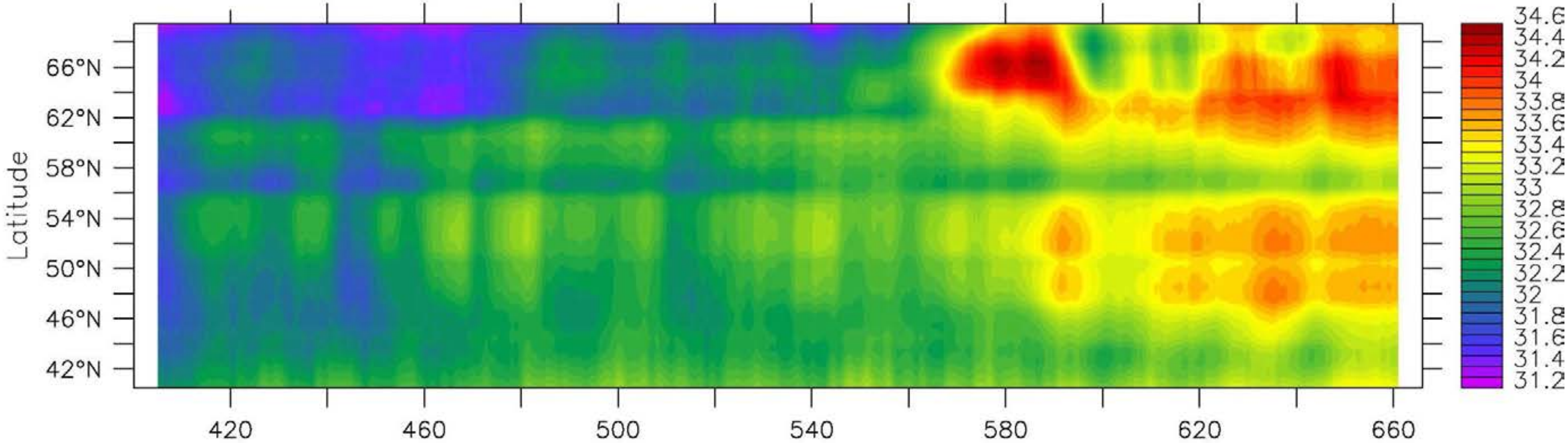
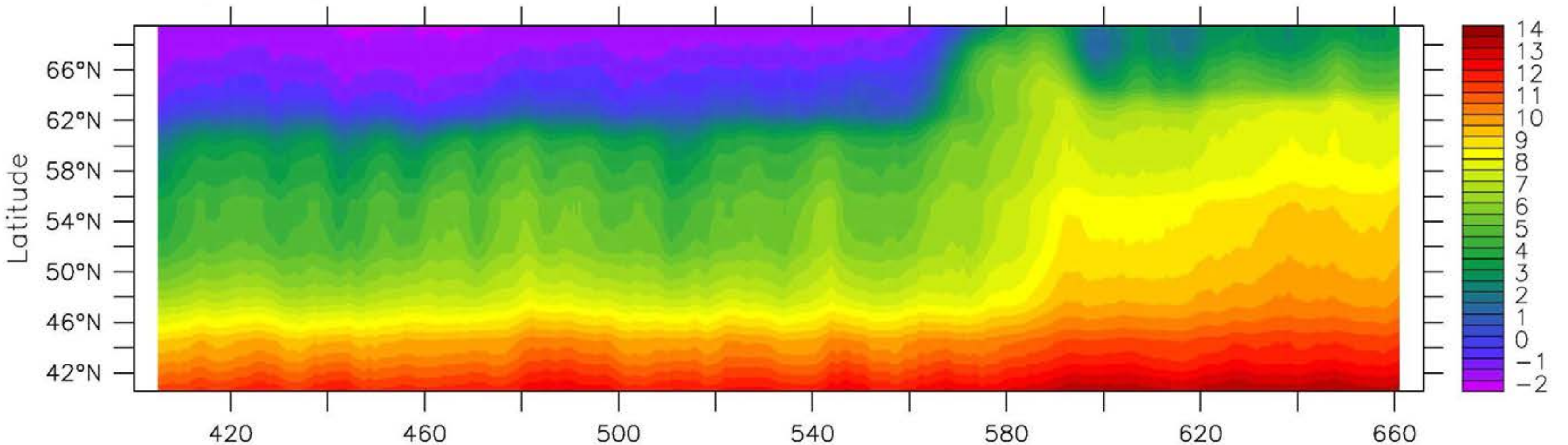




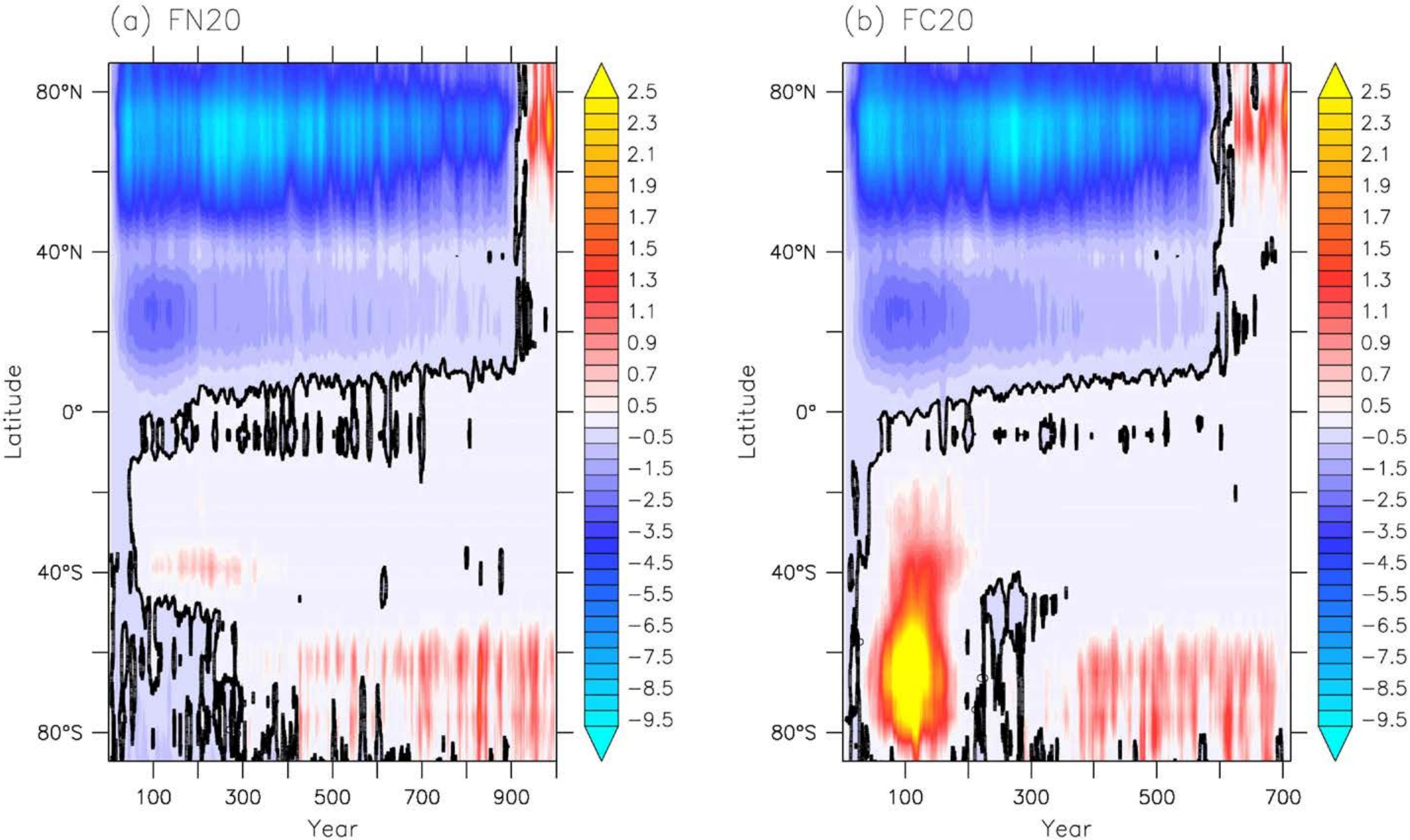
d

GIN sea strait





Sea surface temperature



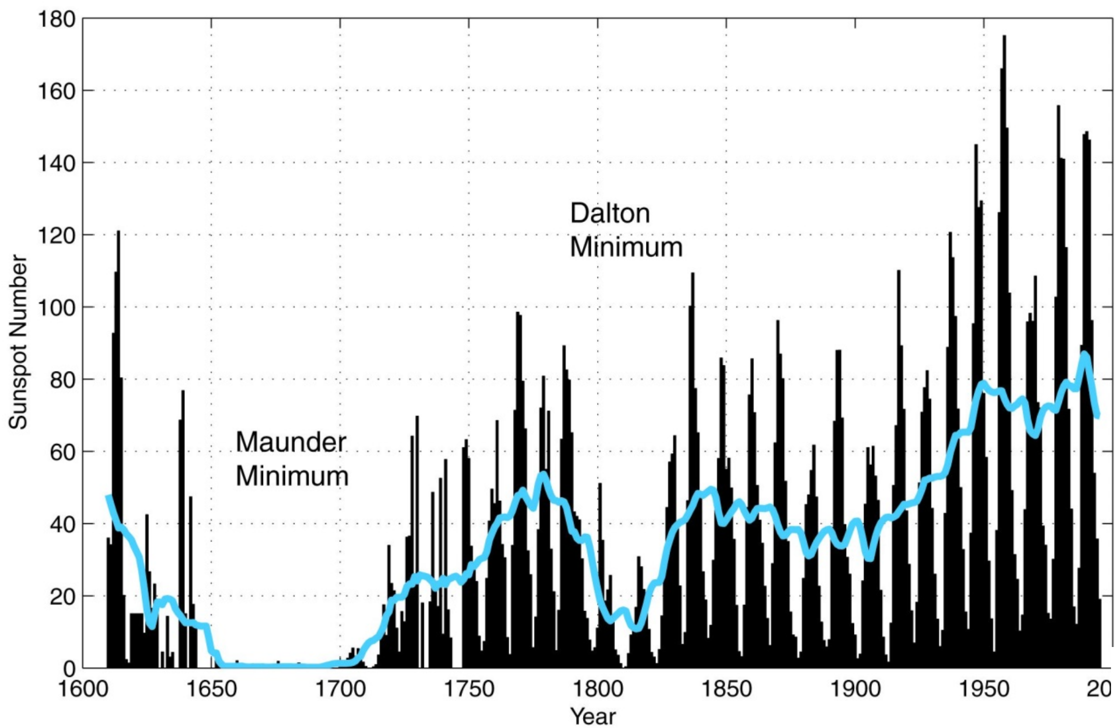
Outline

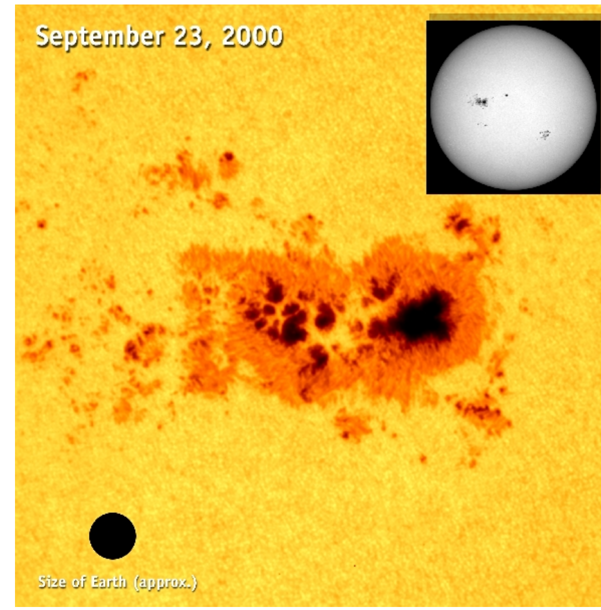
A) Experimental Equipment:

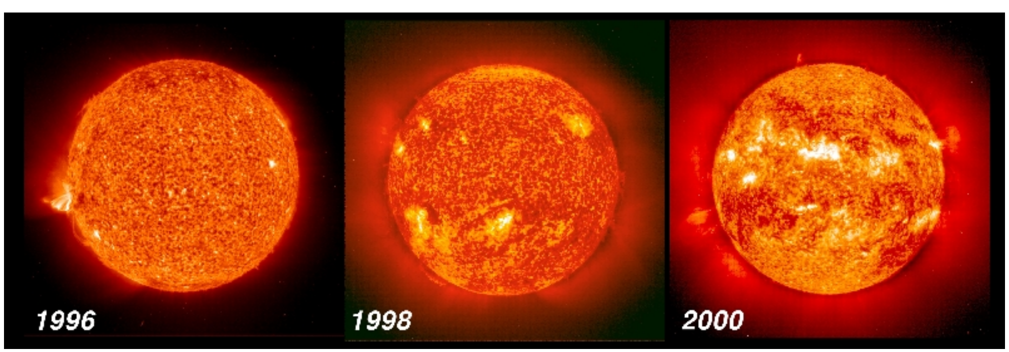
B) Water hosing experiments:
A brief overview...

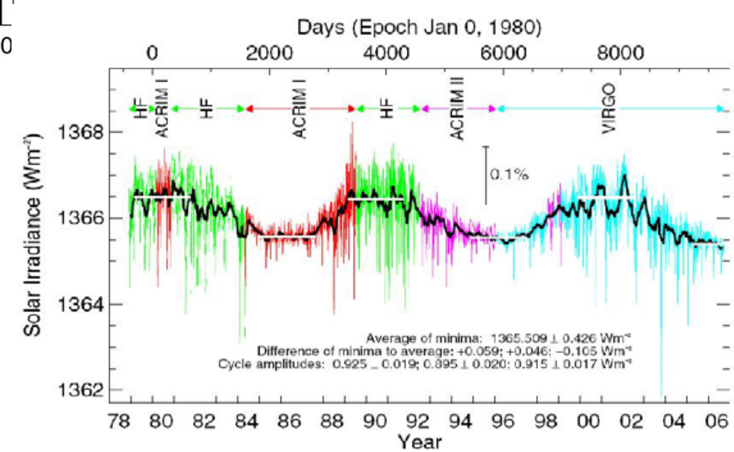
C) Climate reconstructions of the past 500 years :
Indian Ocean Zonal mode (IOZM) in a multi-century-integration

Sonnenflecken



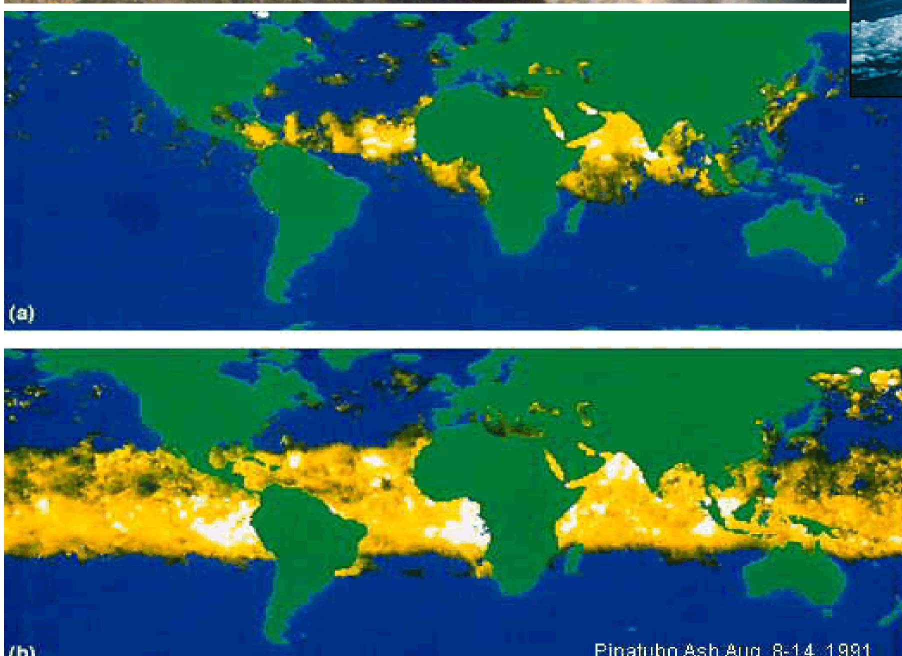


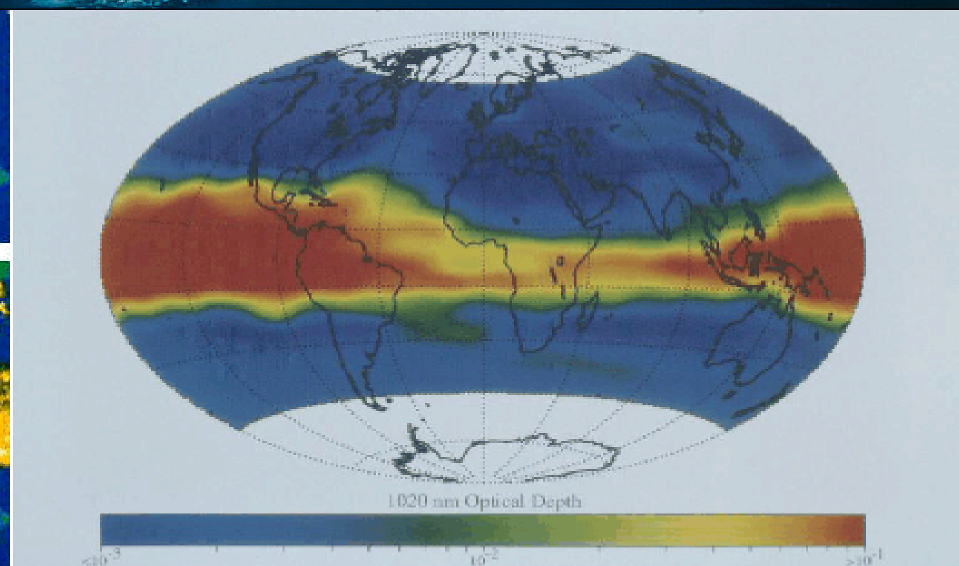




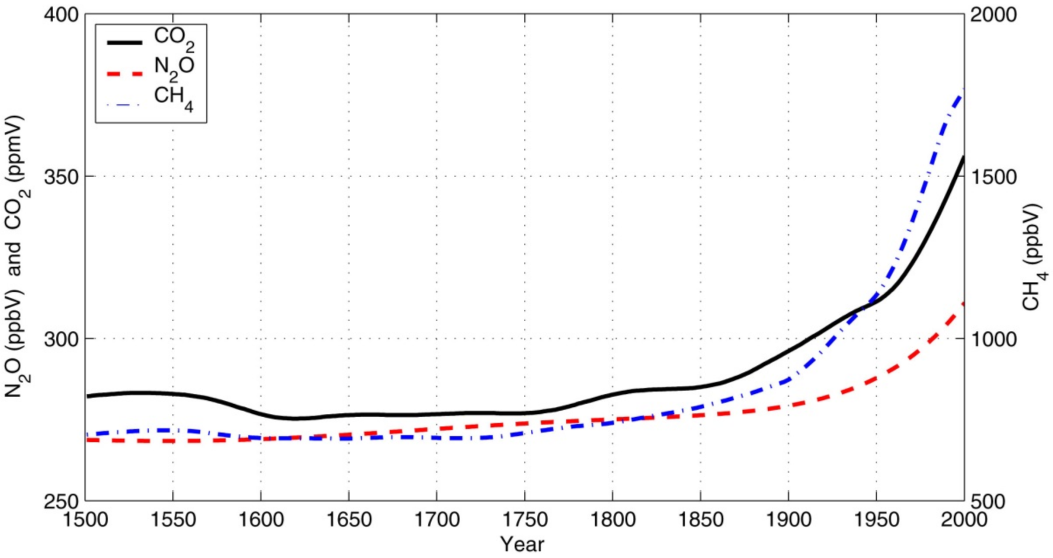
SOHO Mission/ & World Radiation Center Davos, CH

Aerosols

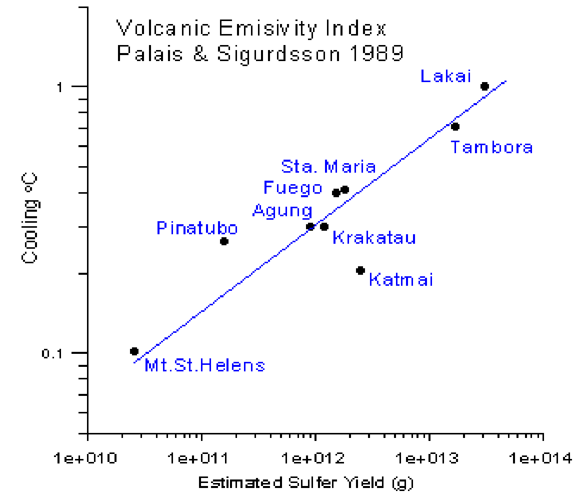




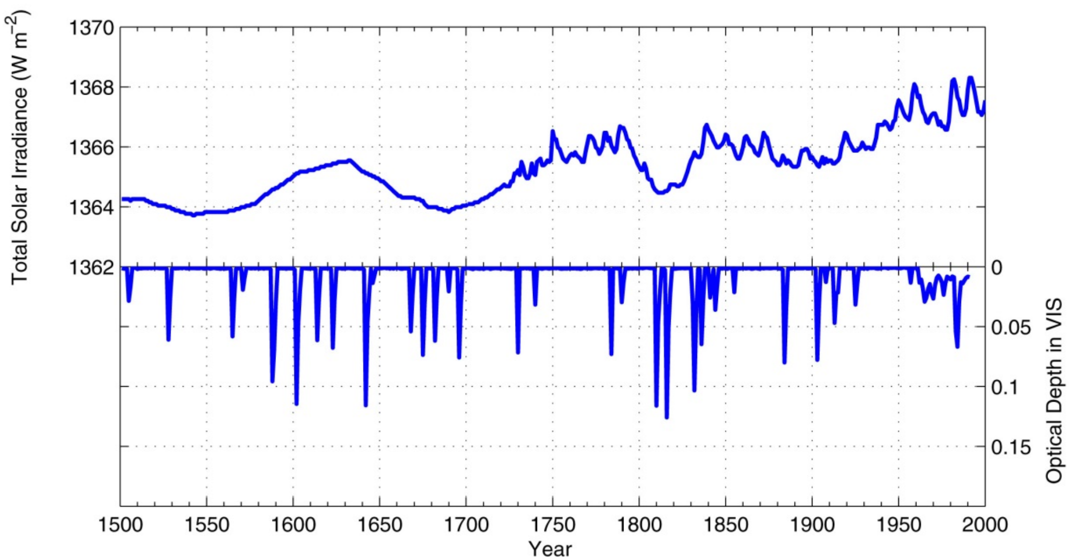
Forcings



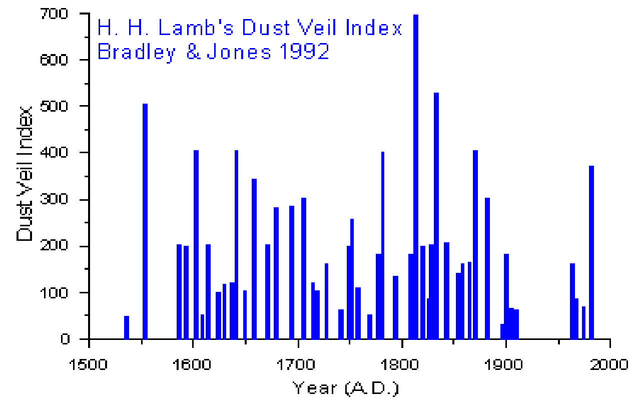
CO2
N2O
CH4
N2O (ppbV) and CO2 (ppmV)
CH4 (ppbV)
Year



Volcanic Emisivity Index
Palais & Sigurdsson 1989
Lakai
Tambora
Sta. Maria
Fuego
Agung
Pinatubo
Krakatau
Katmai
Mt.St.Helens
Cooling °C
Estimated Sulfer Yield (g)



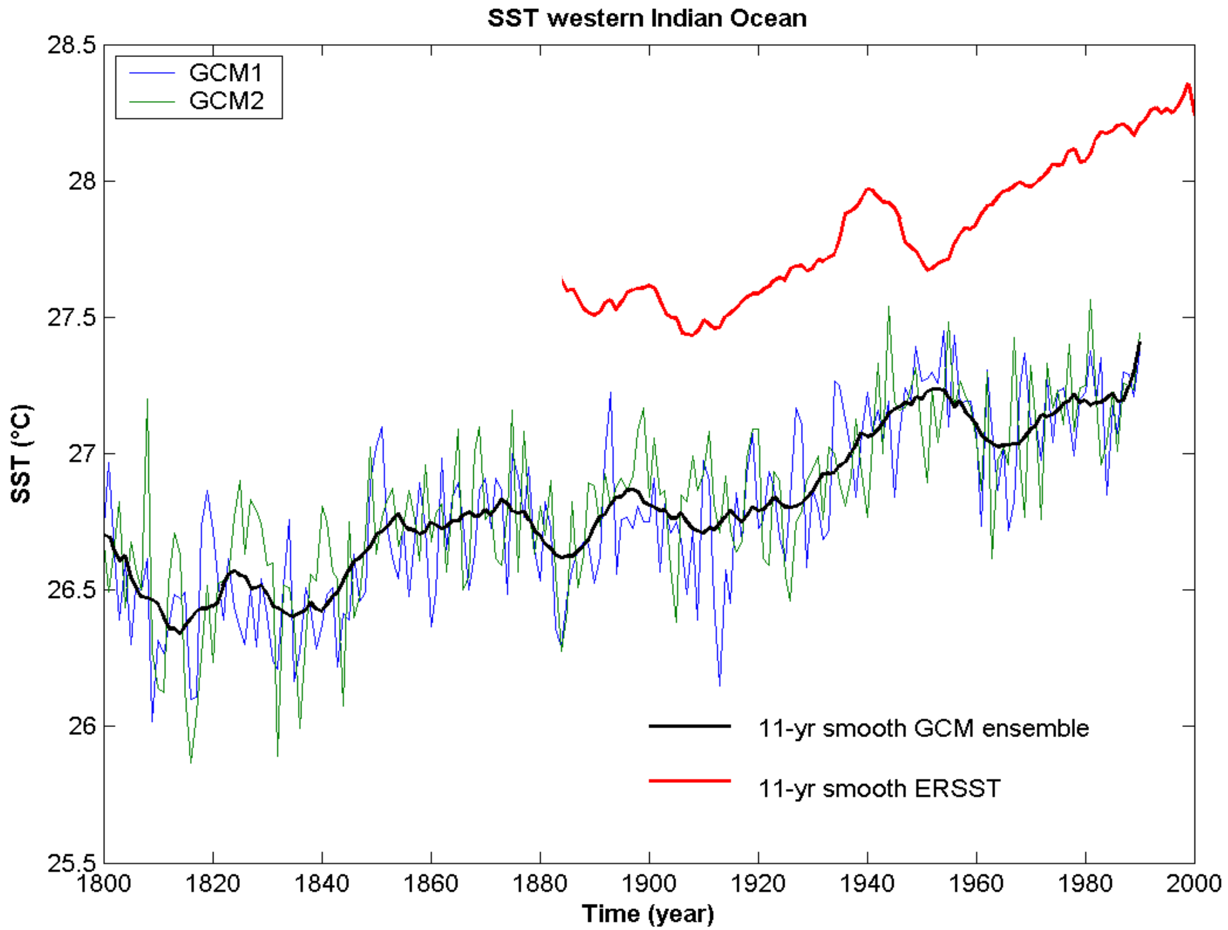
Total Solar Irradiance (W m-2)
Optical Depth in VIS
Year



H. H. Lamb's Dust Veil Index
Bradley & Jones 1992
Dust Veil Index
Year (A.D.)

SST Indian Ocean

- SST-Indian Ocean vs. ERSST observational data
- Model has a cold bias of 2^oC due



SST Western Indian Ocean

ERSST: Extended Reconstruction Data (Smith & Reynolds, 2004)

“Victoria project”

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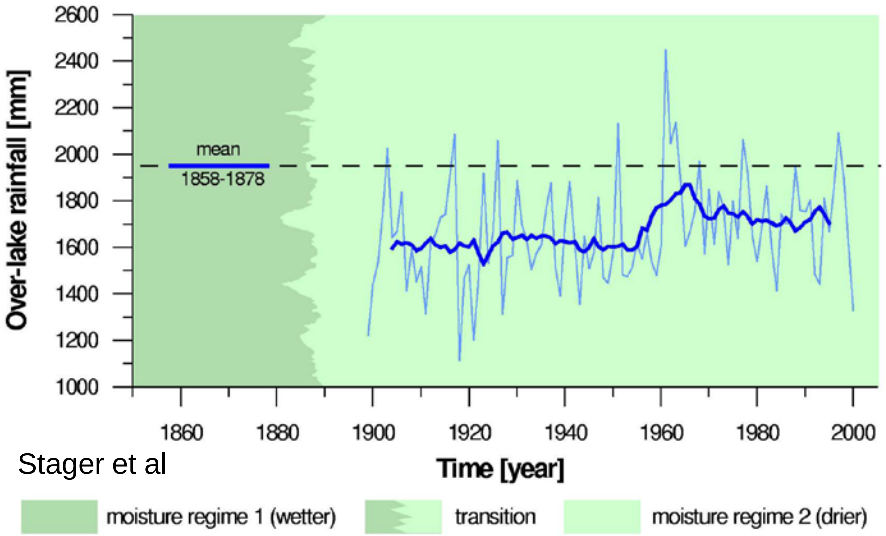
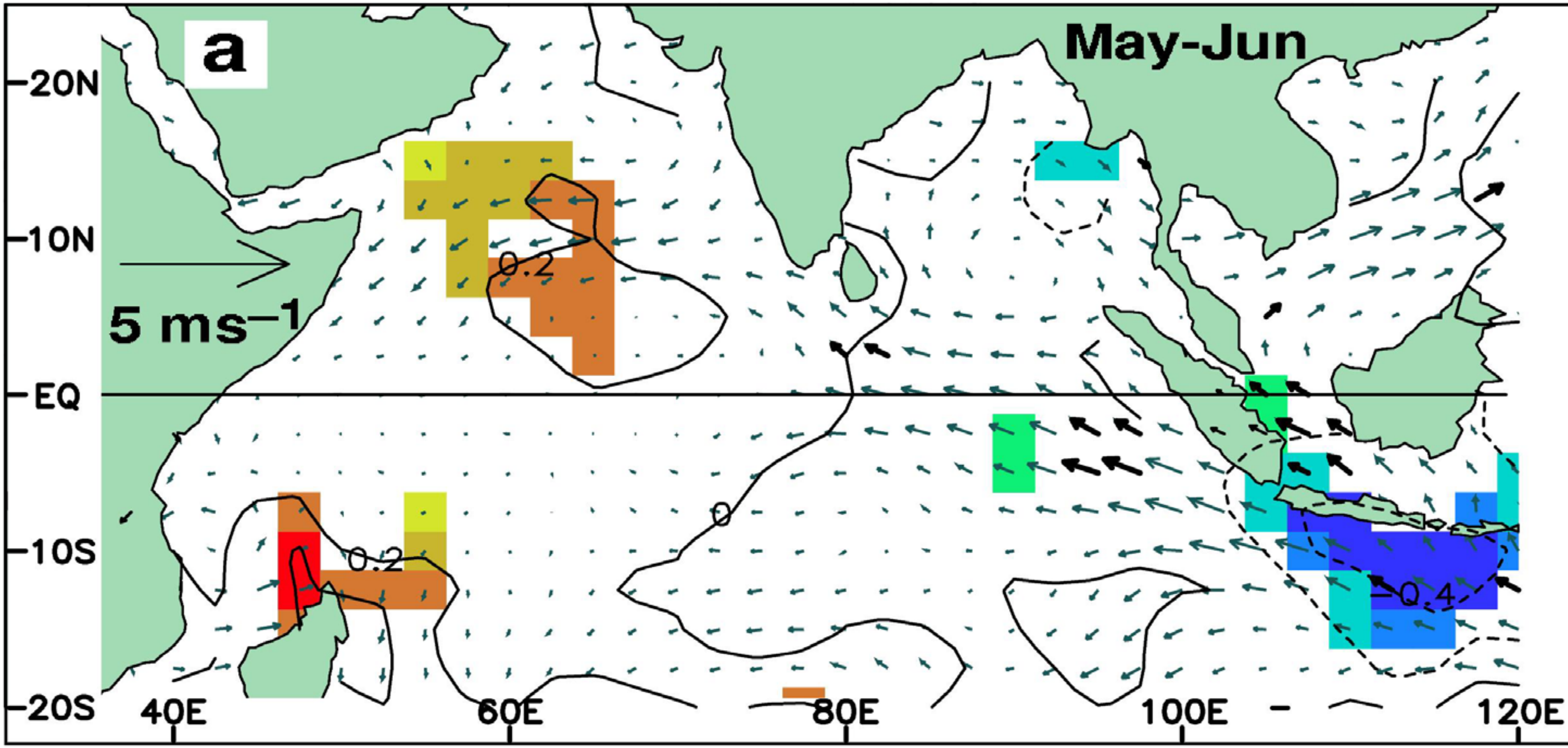
Indian Ocean Zonal mode(IOZM)



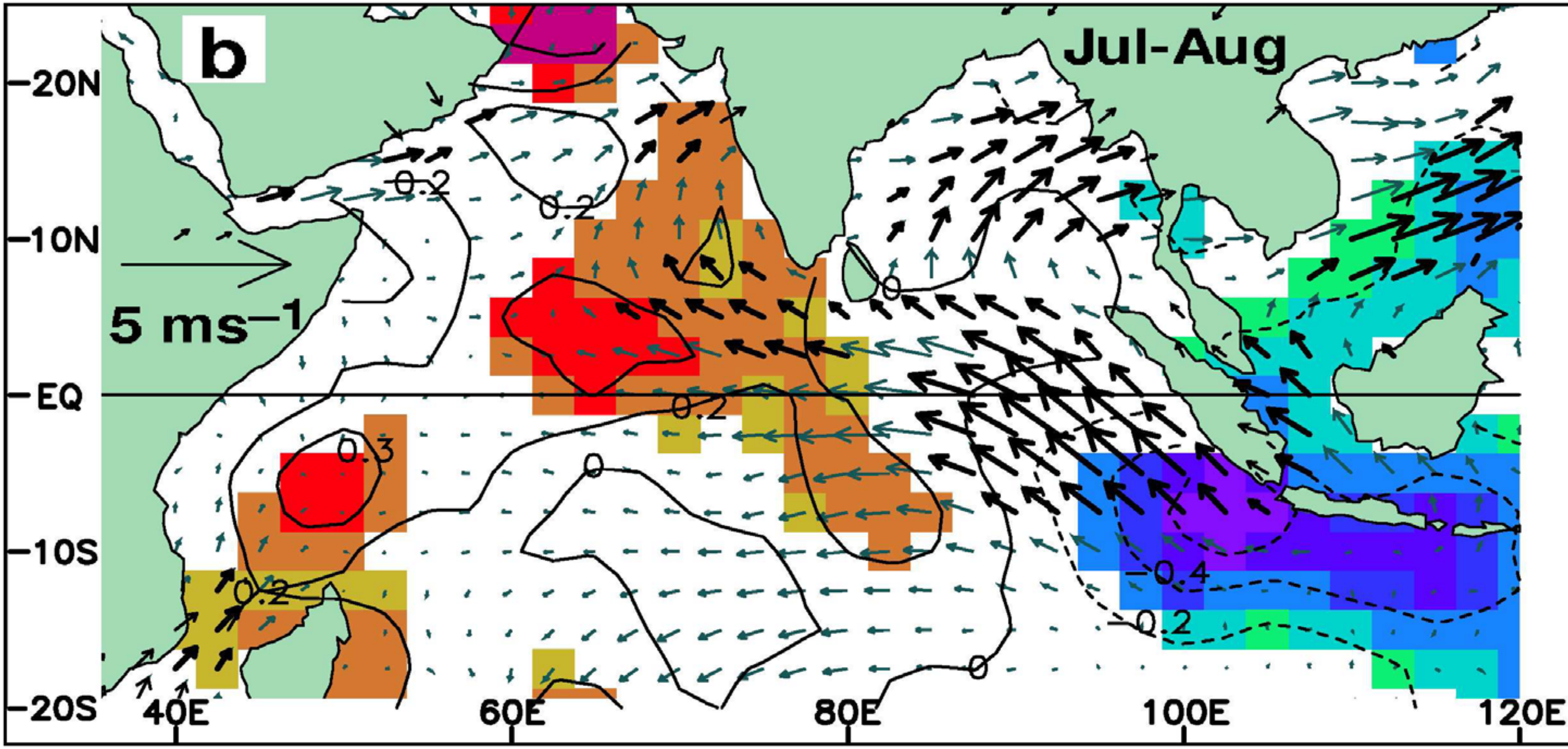
Stager et al

IOZM



Indian Ocean Zonal Mode (IOZM)

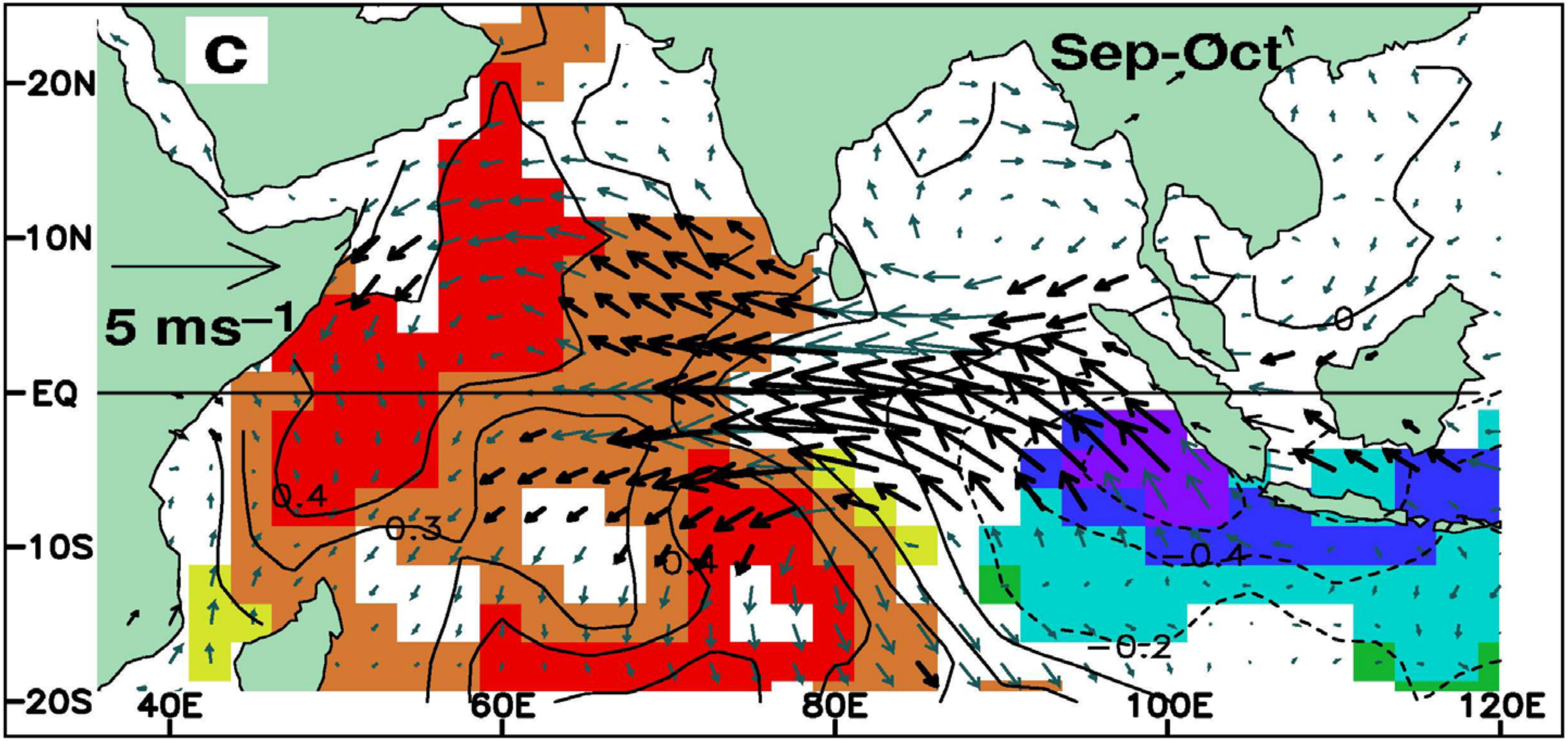
IOZM



Indian Ocean Zonal Mode (IOZM)

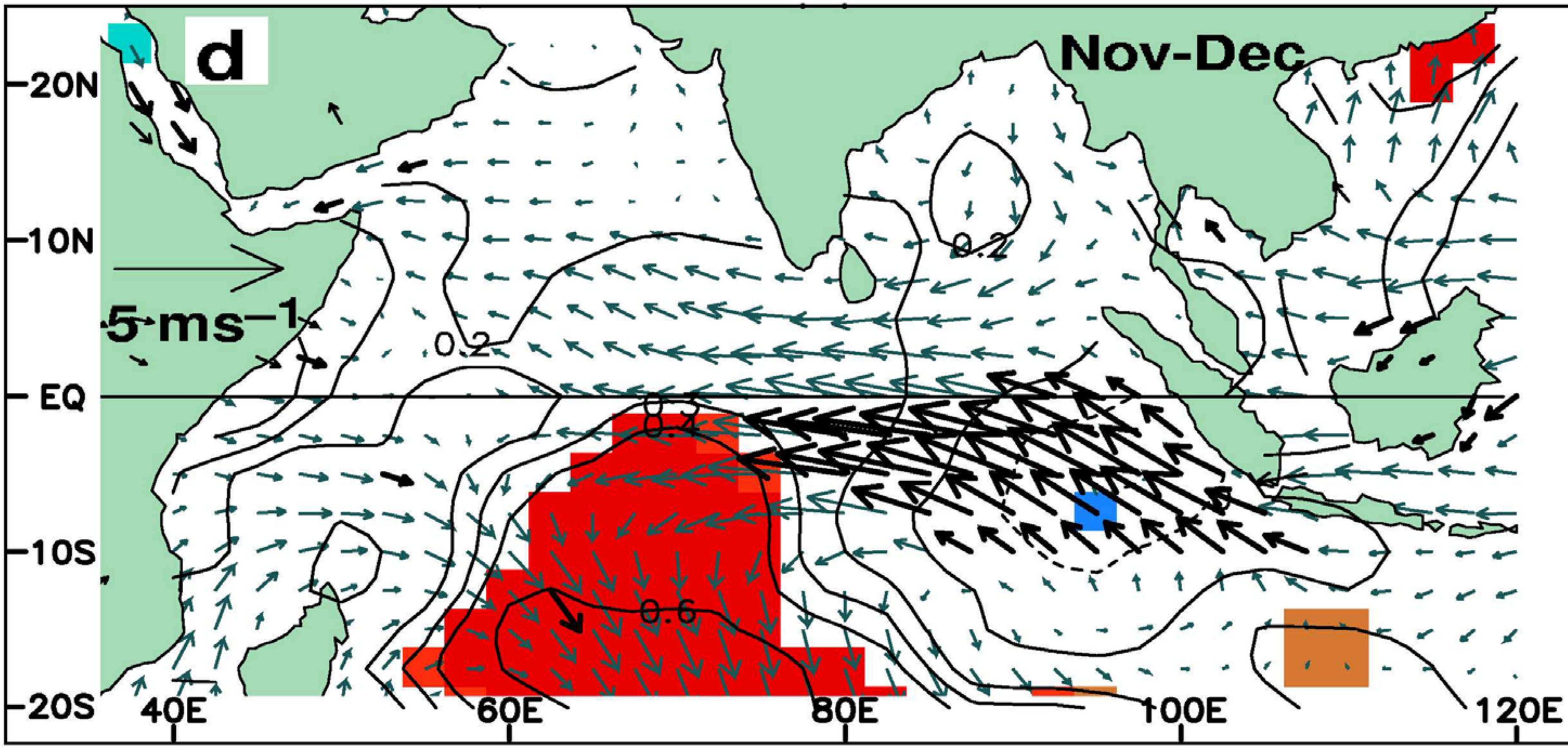
Saji et al. 1999

IOZM



Indian Ocean Zonal Mode (IOZM)

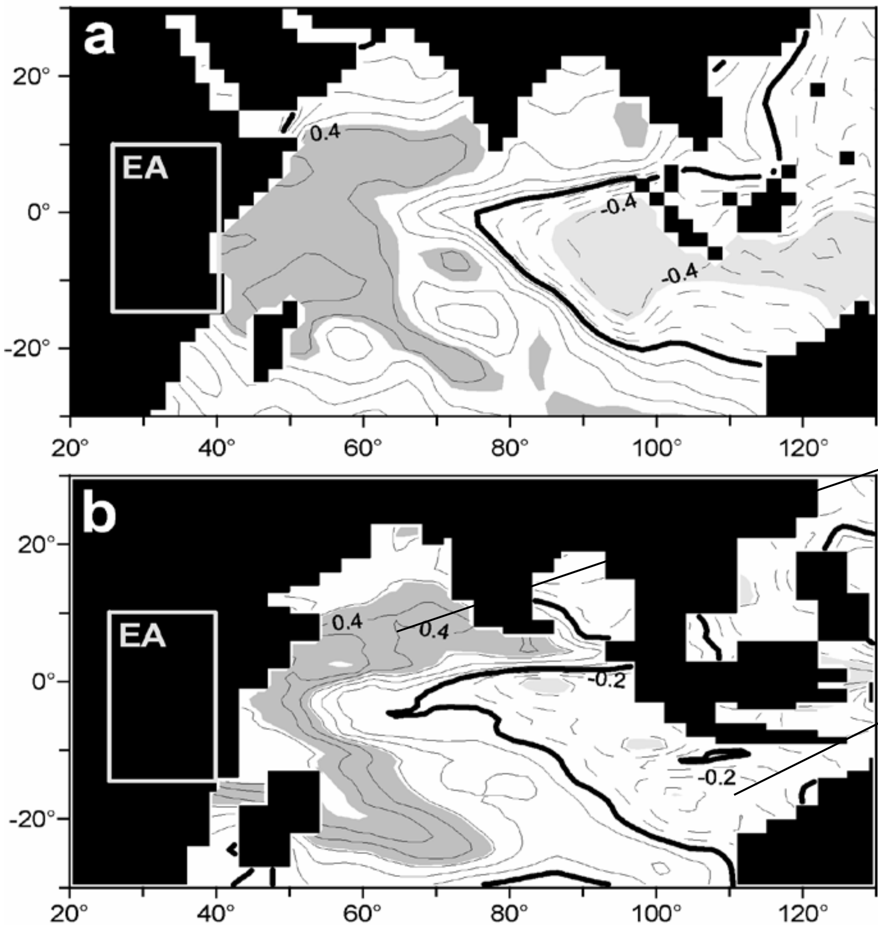
IOZM



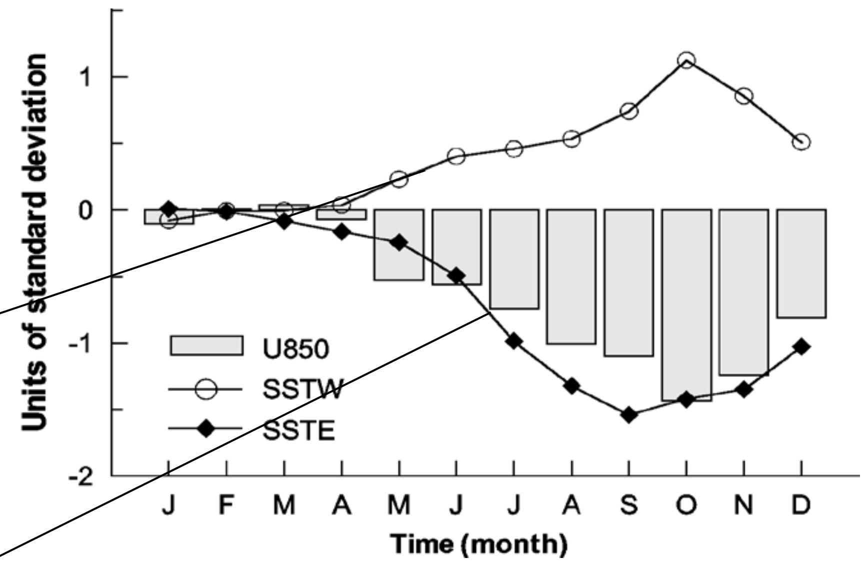
Indian Ocean Zonal Mode (IOZM)

SST vs. OND precipitation

Correlation field SON



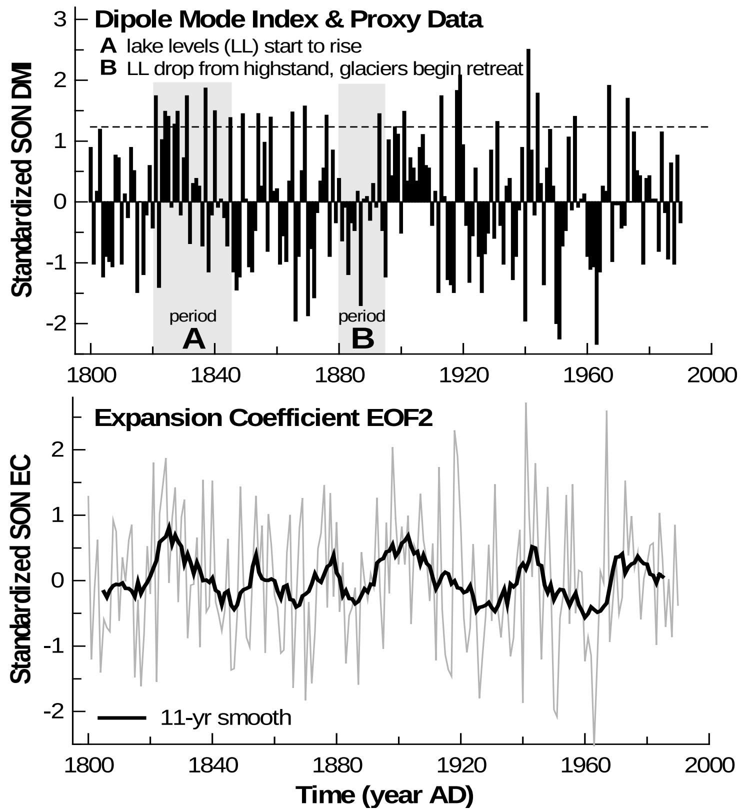
Reconstruction

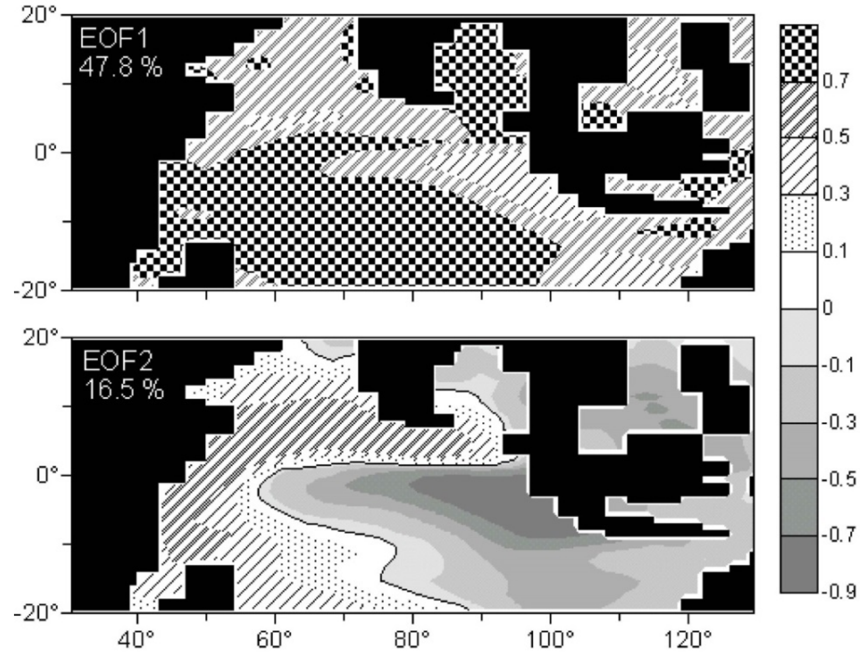


Phase
looking

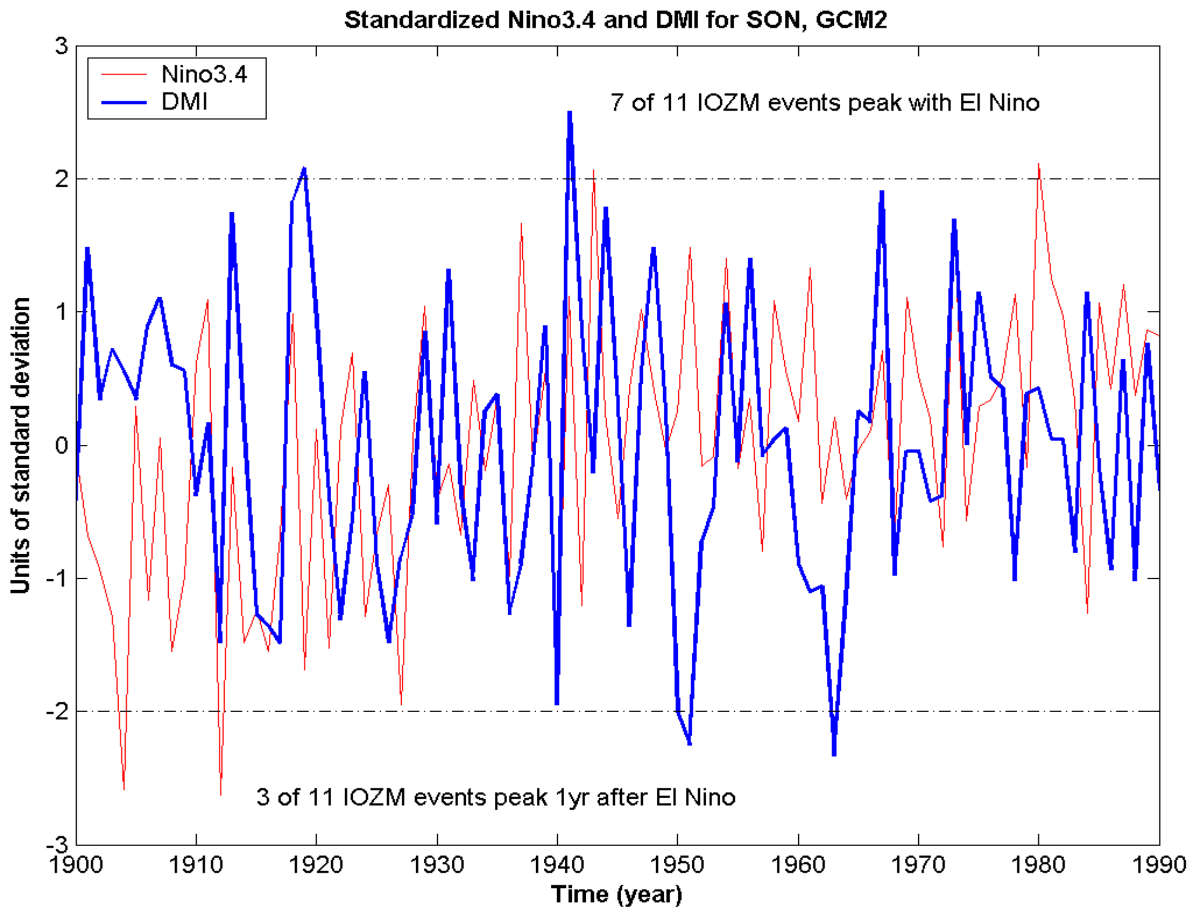
EOF & DMIs

High frequency of strong IOZM events is found in 1820-1880 (n=15), but only 9 IOZM in the 20th century



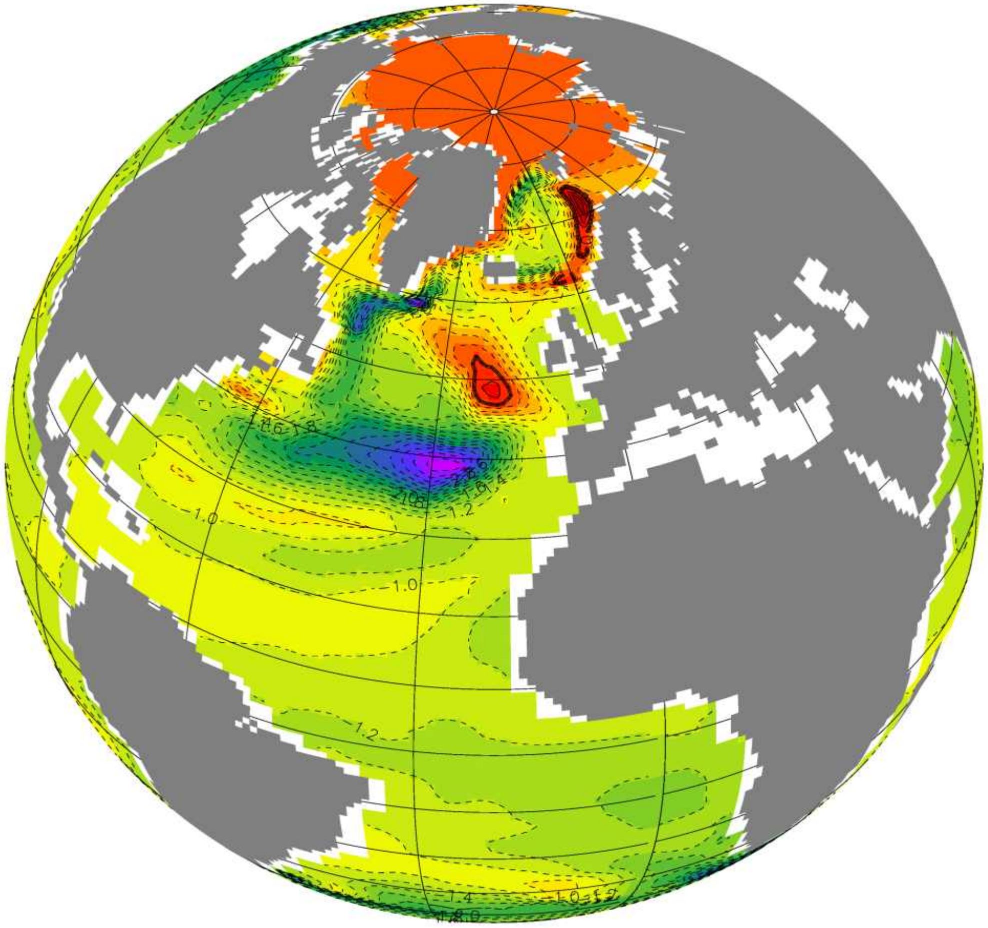


ENSO versus IOZM

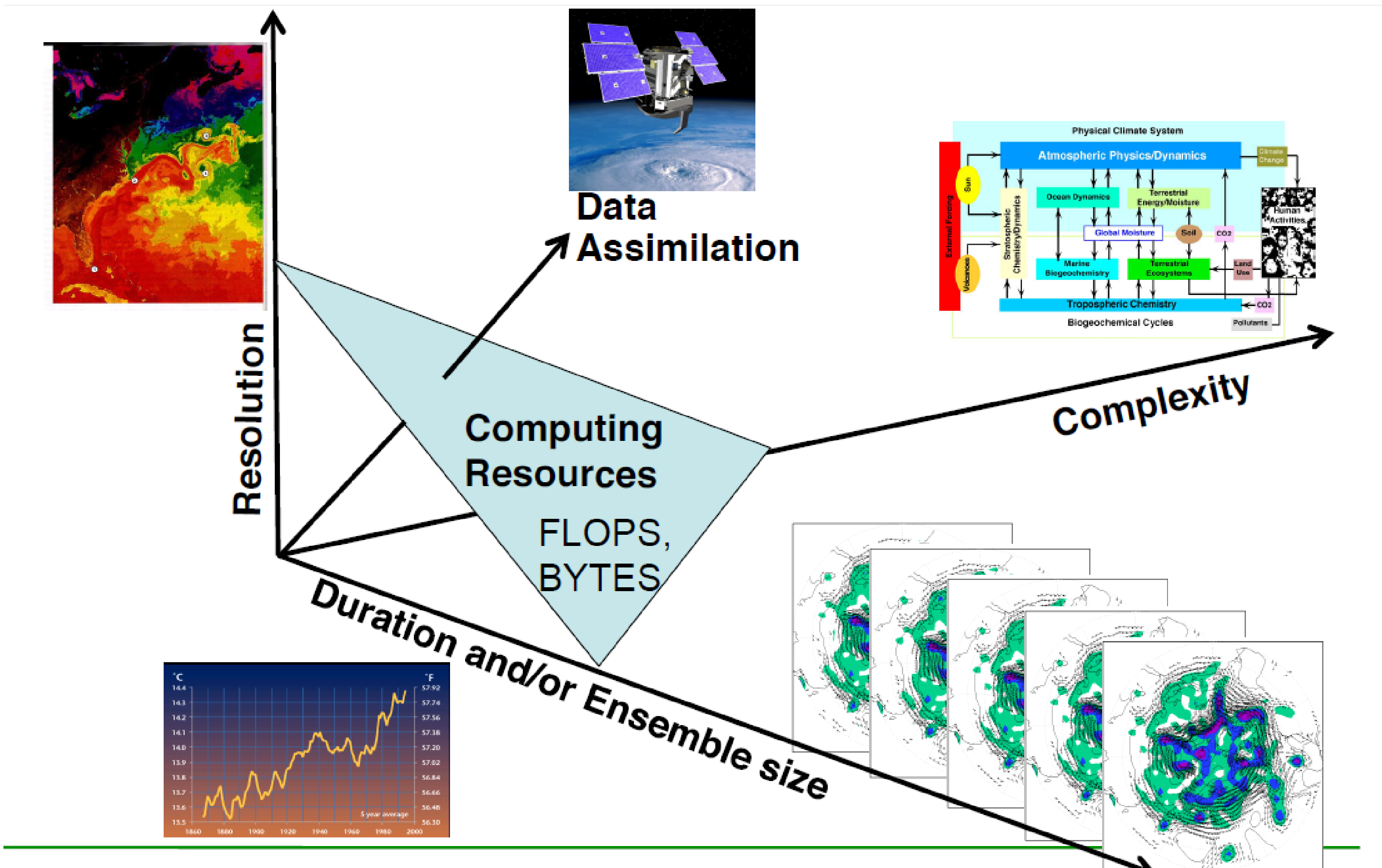


- 7 of 11 IOZM events peak 1 yr after El Nino

Climate Modelling and BIG Data



Resource demands



Resource demands

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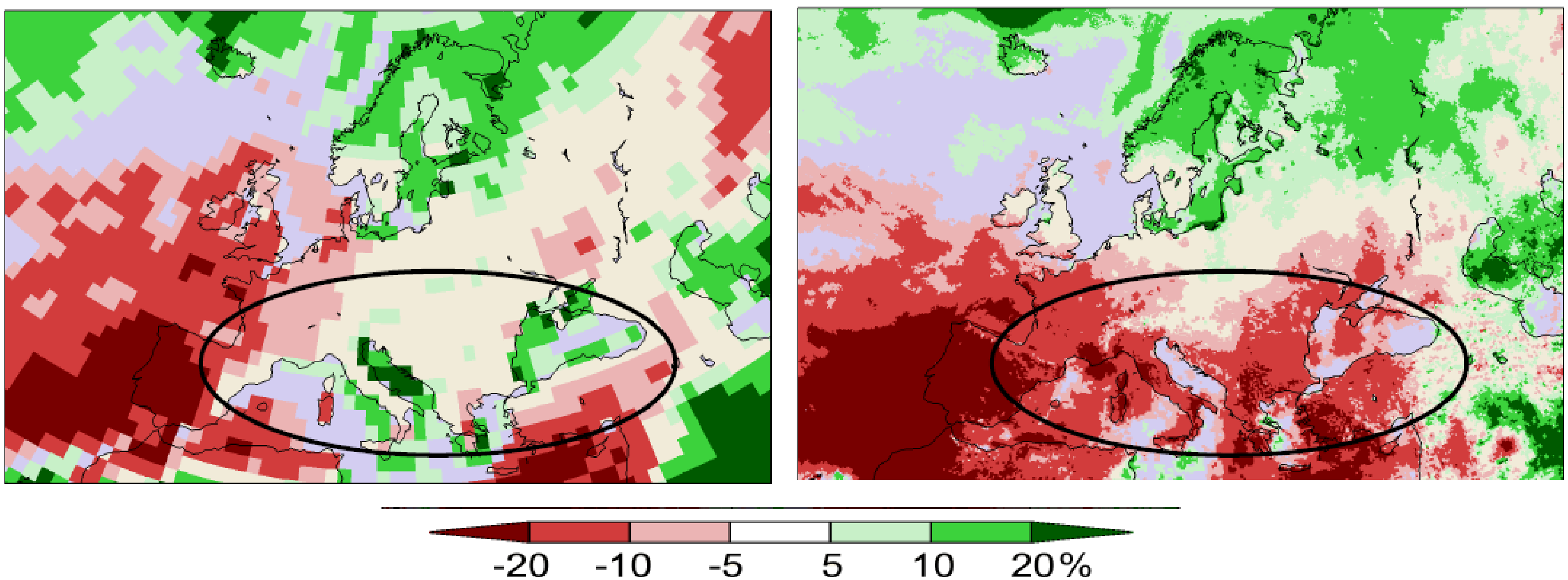
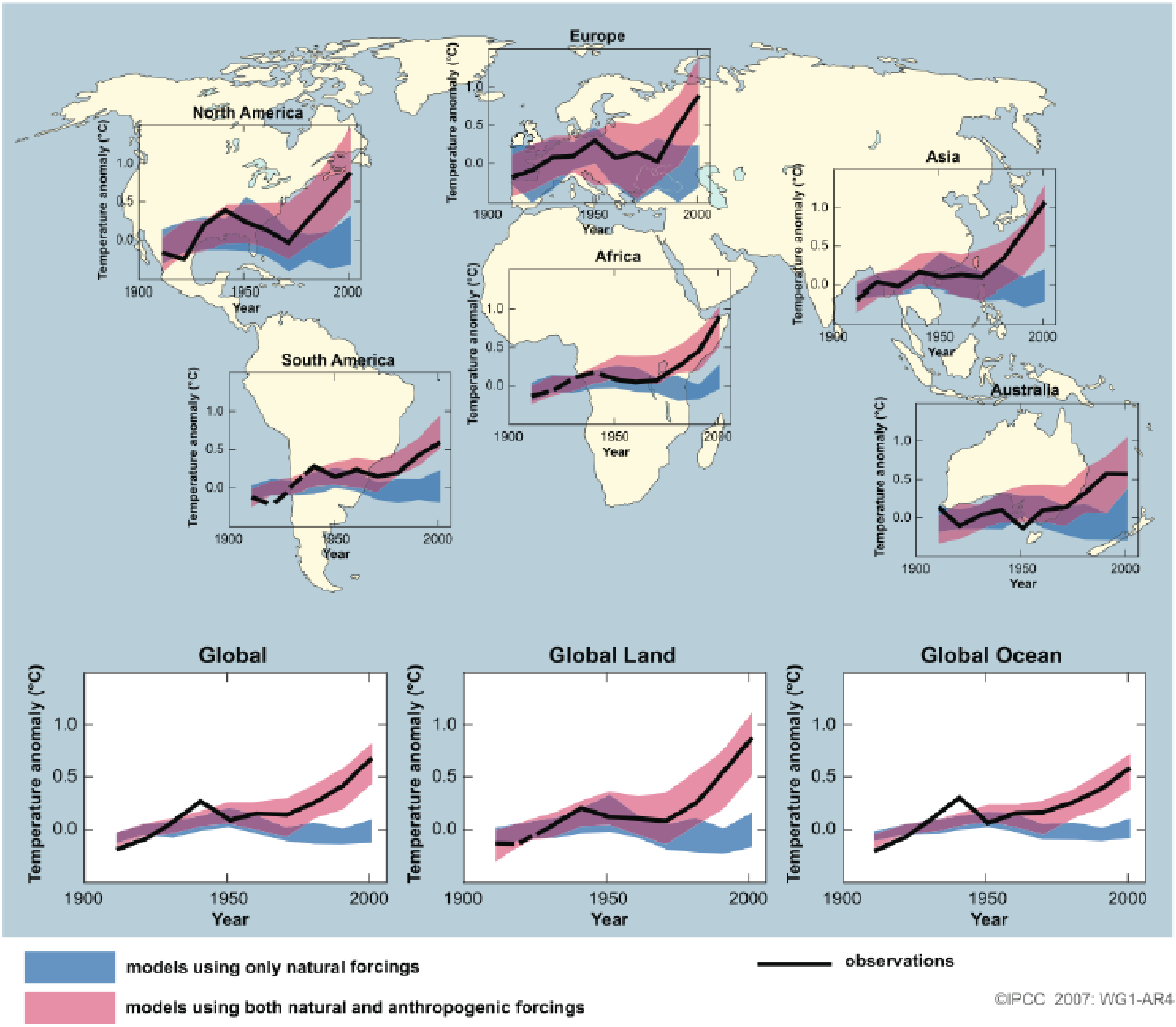
Europe Growing Season (Apr-Oct) Precipitation Change: 20th C to 21st C

T159 (125-km) | T1279 (16-km)

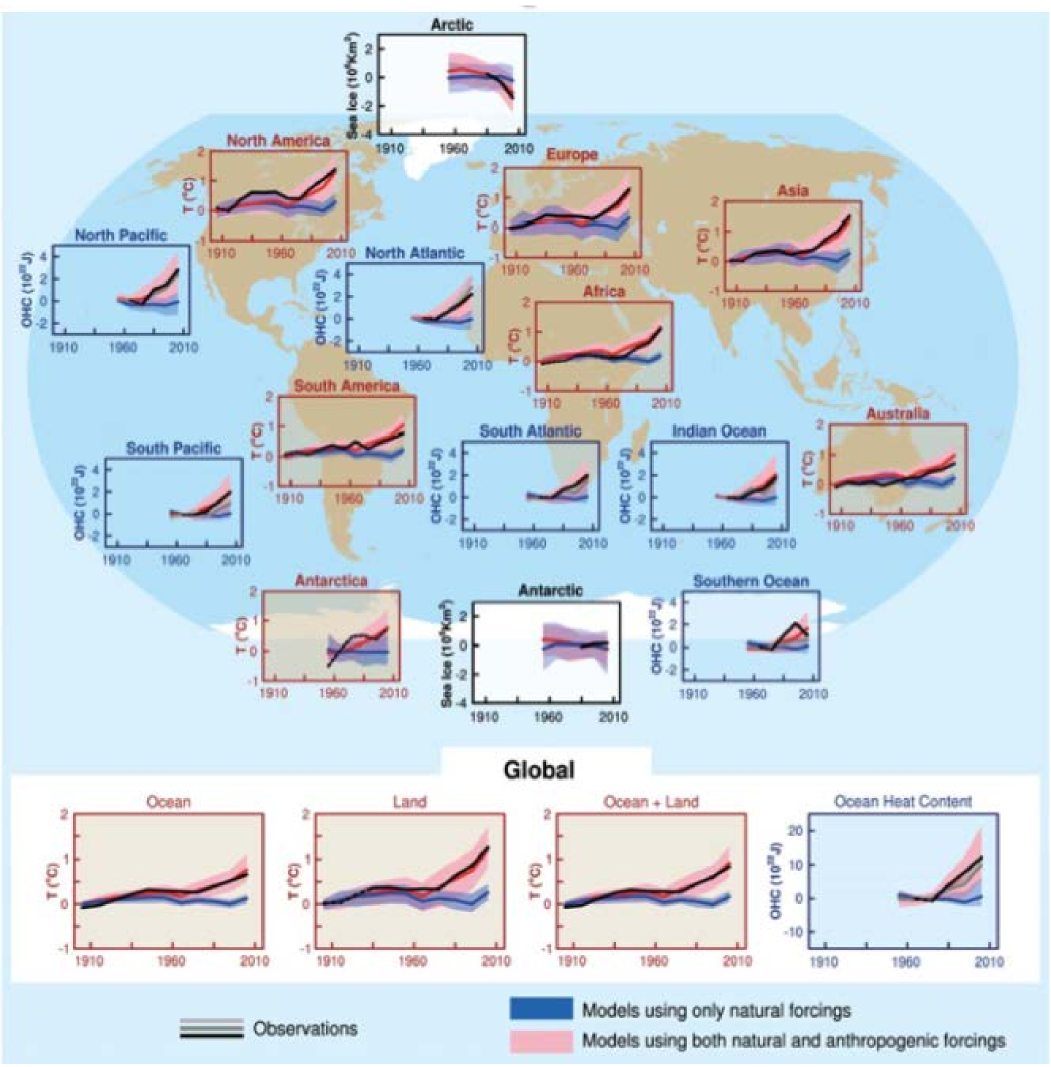


"Time-slice" runs of the ECMWF IFS global atmospheric model with observed SST for the 20th century and CMIP3 projections of SST for the 21st century at two different model resolutions

IPCC 2007 Surface Temperature Change



IPCC 2014 Surface Temperature Change



Why Big Data ?

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Why Makes Climate Research a Big Data Field?

People wants information about weather
impacts in our changing climate
→ this requires high spatial and temporal resolution models

Uncertainty in these impacts is addressed through multi-model ensembles and Earth system prediction
→ requires added data and system complexity

Storage Demand

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IDP Institute of Data Analysis
and Process Design

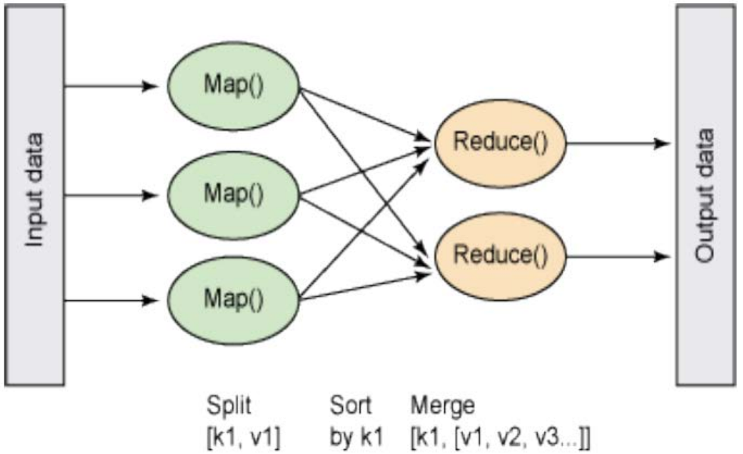
- 2005-2006 CMIP3 (in support of IPCC AR4) **36 TB**
- 2009-2010 Project Athena 1.2 PB
- 2010-2011 CMIP5 (in support of IPCC AR5) **3 PB**
- 2012-2014 Project Minerva **3+ PB**
- 2011- NMME 1 PB
- COLA storage resources for 2015- **47 PB**

This much data breaks everything: H/W, systems management policies, networks, apps S/W, tools, and shared archive space

Hadoop/HDFS (example)

The NASA Center for Climate Simulation (NCCS) is using Apache Hadoop for high-performance analytics because it optimizes computer clusters and combines distributed storage of large data sets with parallel computation.

Hadoop is well known for text-based problems. Their scenario involves binary data. So, they created custom Java applications to read/write data during the Map Reduce process.



Hadoop/HDFS

Software framework to store large amounts of data in parallel across a cluster of nodes:

• Provides fault tolerance, load balancing, and parallelization by replicating data across nodes

• Co-locates the stored data with computational capability to act on the data (storage nodes and compute nodes are the same – typically)

• A MapReduce job takes the requested operation and maps it to the appropriate nodes for computation using specified keys

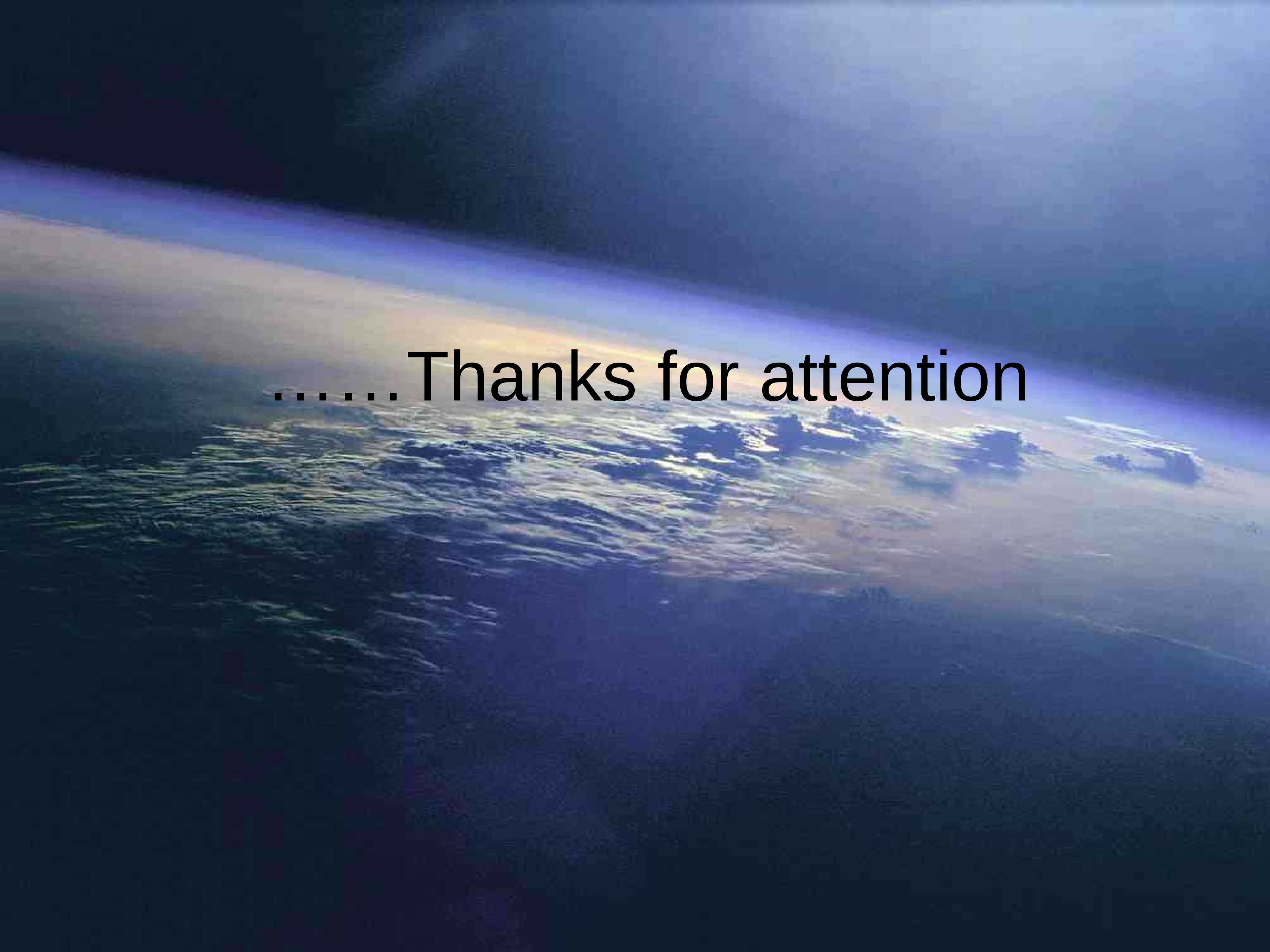
Where Data Science comes in….

Climate Informatics

2011	First International Workshop on Climate Informatics
	New York Academy of Sciences
	Climate Informatics Wiki launched
2013	"Climate Informatics" book chapter [M et al. 2013]
2015	Please join us in September as Climate Informatics turns 5!

www.climateinformatics.org

Figure courtesy C. Monteleoni


......Thanks for attention