Gyre variability and Tropical Modes in the Atlantic

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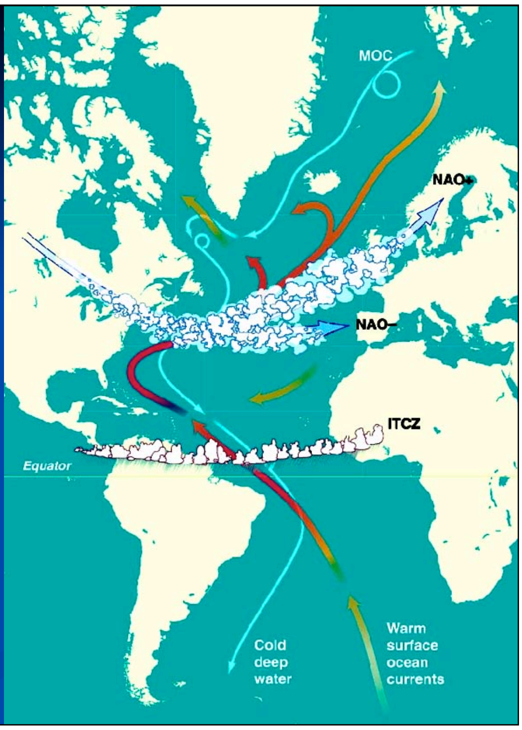
with input from:
Peter Brandt, Claus Böning, Markus Scheinert,
Laurent Terray and Yochanan Kushnir
and many others

Roadmap

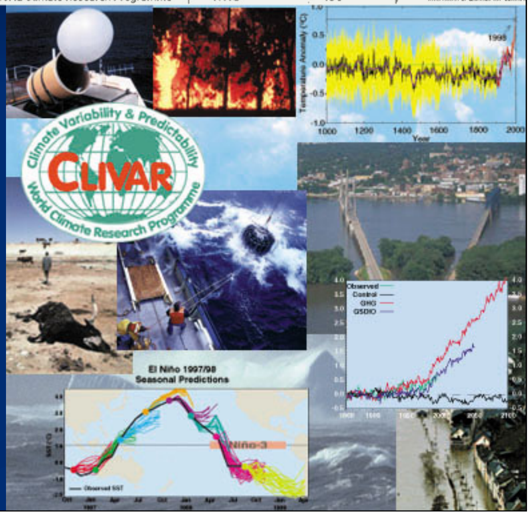
- CLIVAR
- Meridional Overturning
- Atlantic gyre variability
- Tropical Atlantic Variability

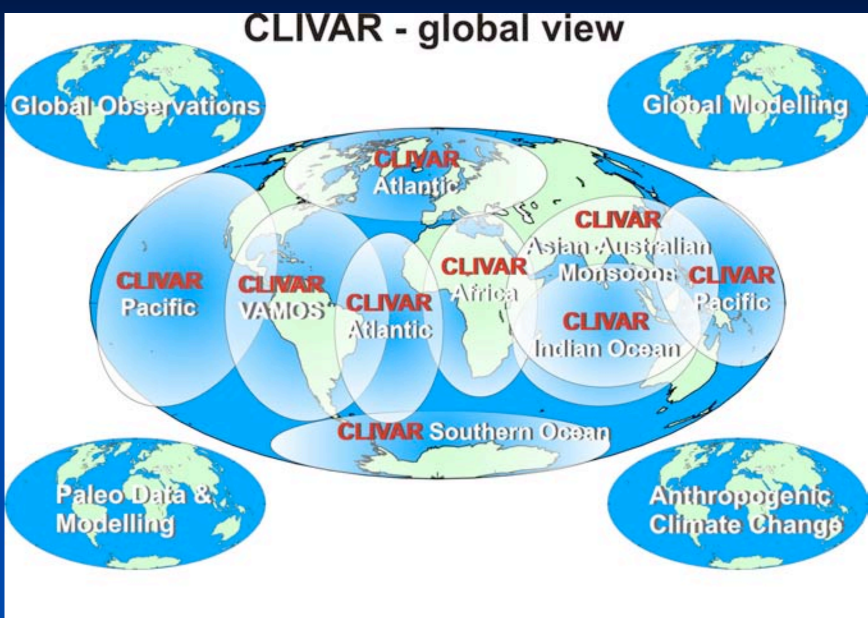


CLIVAR
(Climate Variability and Predictability)

Mission

To observe, simulate and predict Earth's climate system, with focus on ocean atmosphere interactions, enabling better understanding of climate variability, predictability and change, to the benefit of society and the environment in which we live.

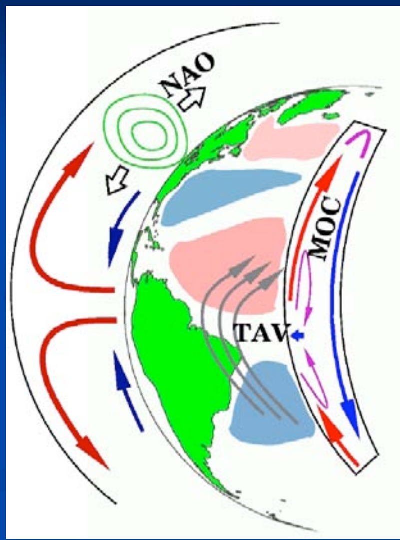




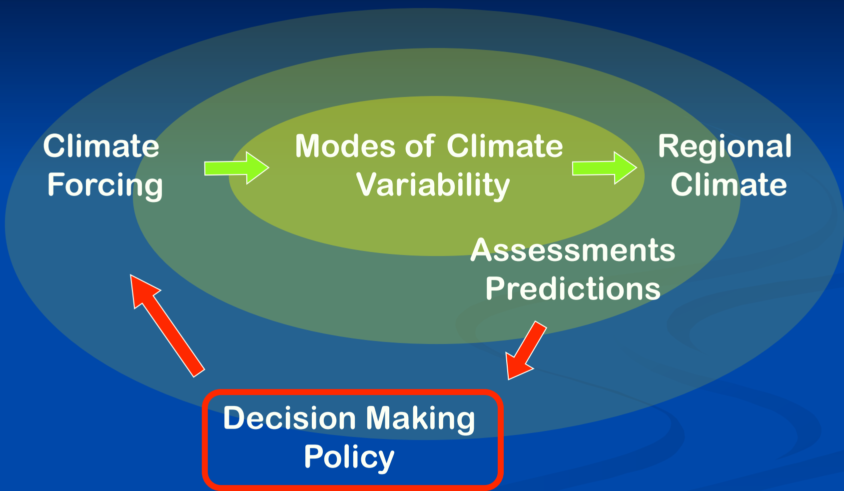
CLIVAR Atlantic Sector
Phenomena

- North Atlantic Oscillation
- Tropical Atlantic Variability
- Meridional Overturning in the Ocean

- With emphasis on interactions with each other and/or other climate forcings including ENSO and ACC



CLIVAR focus



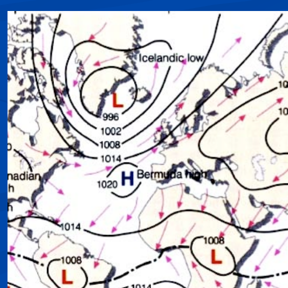
Point 1

- 'Linear' approach to understand and investigate Climate Variability and its Predictability
- The concept was implemented around 'phenomena of interest'
- It was helpful to make the problem tractable, but is it still a good model to follow? (see this seminar/talk)

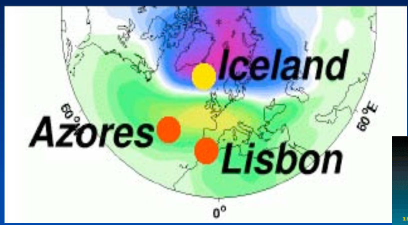
The North Atlantic Oscillation

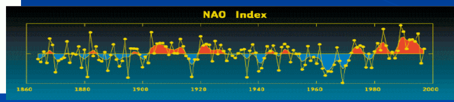
Changes in the Subpolar to Subtropical Atmospheric Pressure Difference lead to:

- Changes in strength and position of the westerly winds (storm track)
- Phase can be described by a see level pressure based index



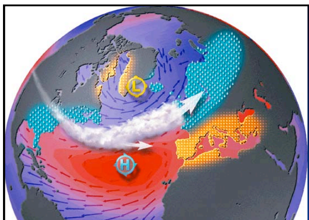
The North Atlantic Oscillation Index



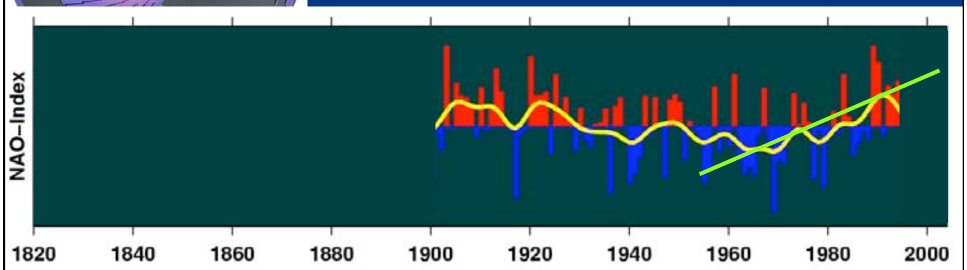


An Index can be constructed that represents the phase of the NAO. Most commonly the NAO index is based on the surface pressure (SLP) difference between the Subtropical (Azores) high and the Subpolar (Island) low.

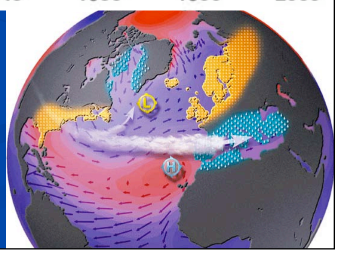
Very often the pressure readings from two stations one on Iceland and the other either the Azores, Lisbon or Gibraltar are used to construct the NAO index. The twice daily reading are averaged from November through March and the difference in then the winter NAO index.



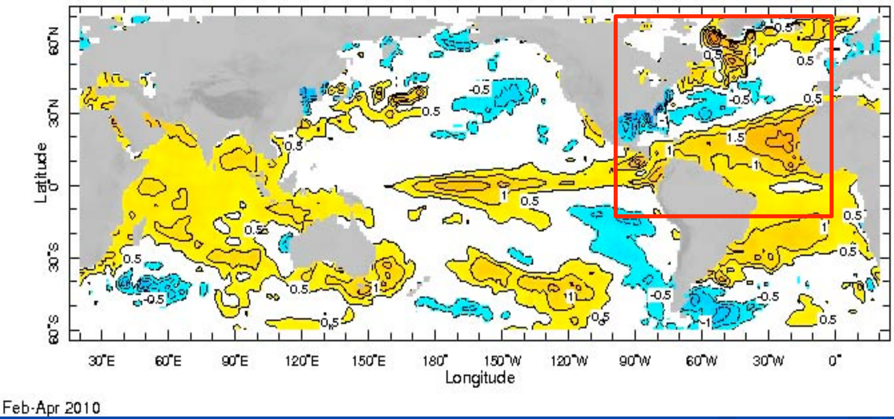
The North Atlantic Oscillation Index



Is the "apparent" trend of the last decades significant or explainable ?



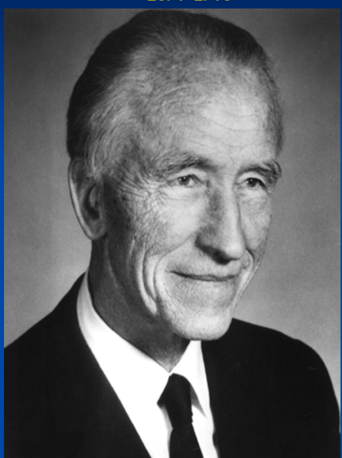
North Atlantic SSTA FMA 2010



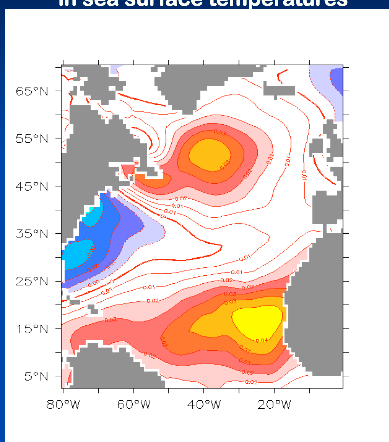
Spring 2010 shows the 'poster child' response to the negative NAO winter (record low index).

North Atlantic SST connection

Jacob Aaal Bonnevie Bjerknes
1897-1975



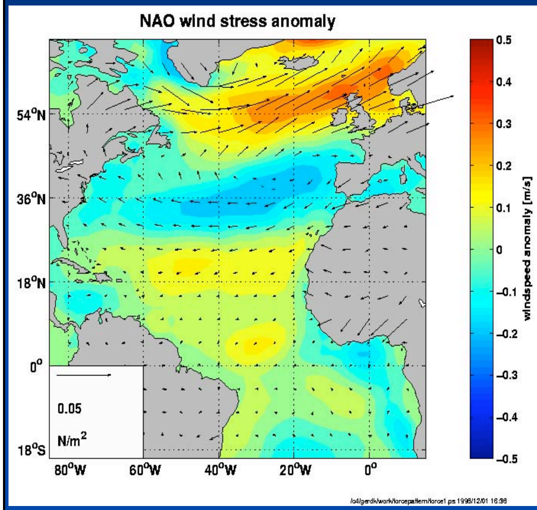
NAO related tripole in sea surface temperatures



Source: Rowan Sutton and D.B. Stephenson

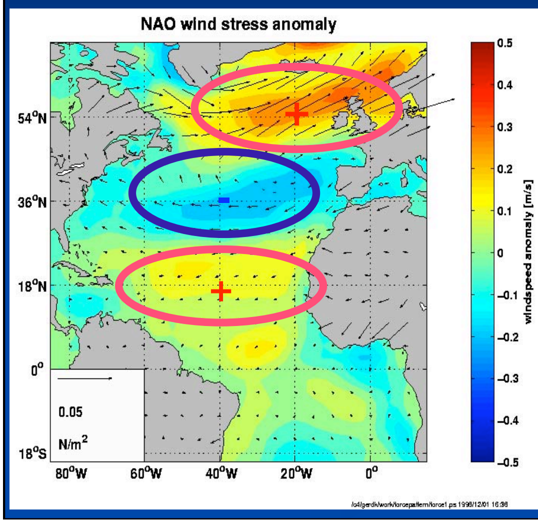
red shows cooler regions

Impacts of the North Atlantic Oscillation: Changes in wind stress and wind speed



Regression of the NCEP/NACR reanalyzed wind speed and wind stress on the NAO index averaged over the winter season (DJFM)

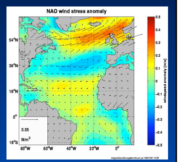
Impacts of the North Atlantic Oscillation: Changes in wind stress and wind speed



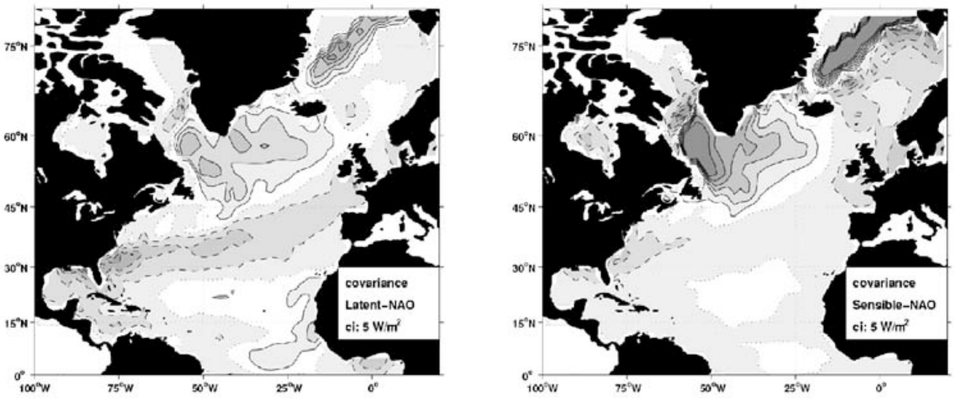
Regression of the NCEP/NACR reanalyzed wind speed and wind stress on the NAO index averaged over the winter season (DJFM)

Note the three lobes in wind speed anomalies.

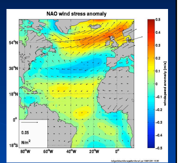
Impacts of the North Atlantic Oscillation: Changes in Surface Heat flux



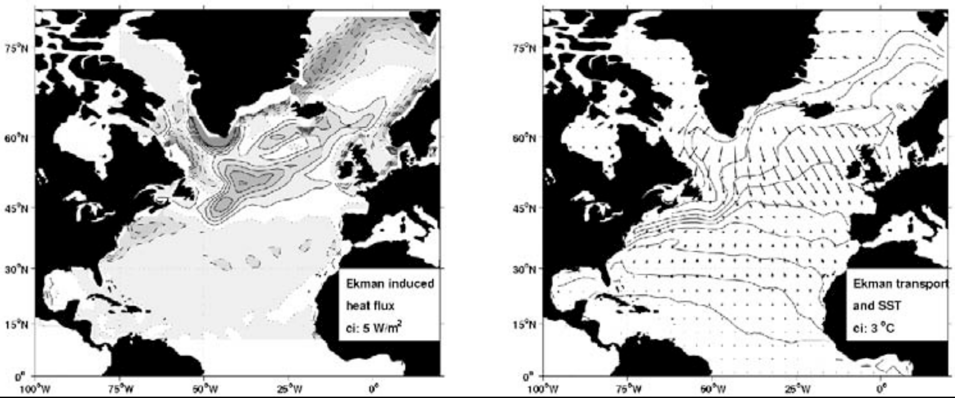
Latent and Sensible heat flux anomalies

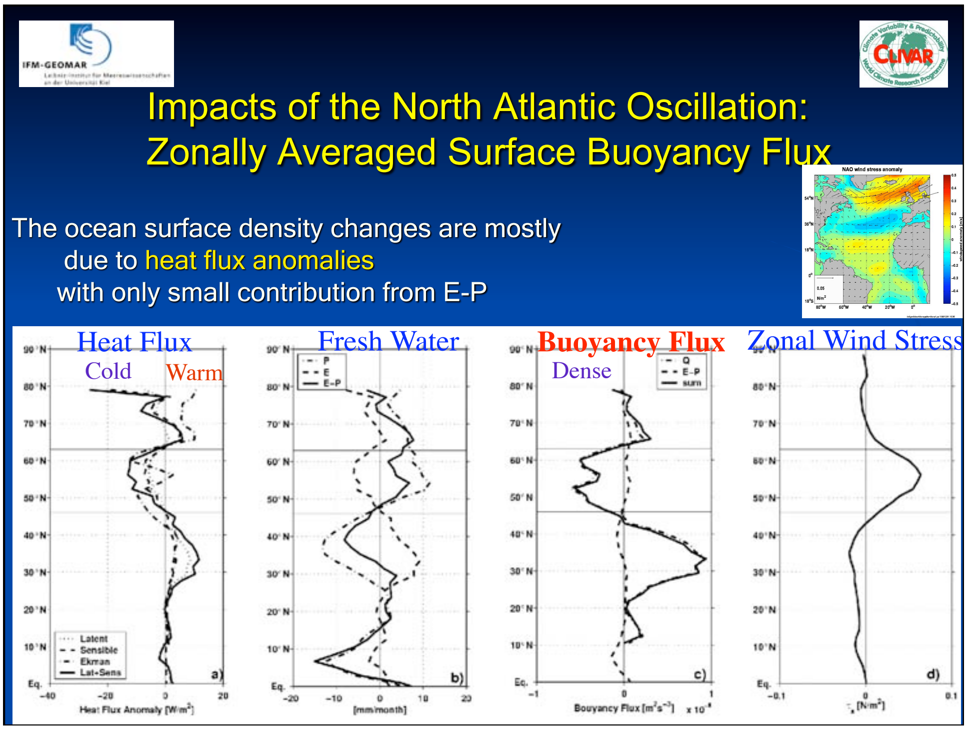


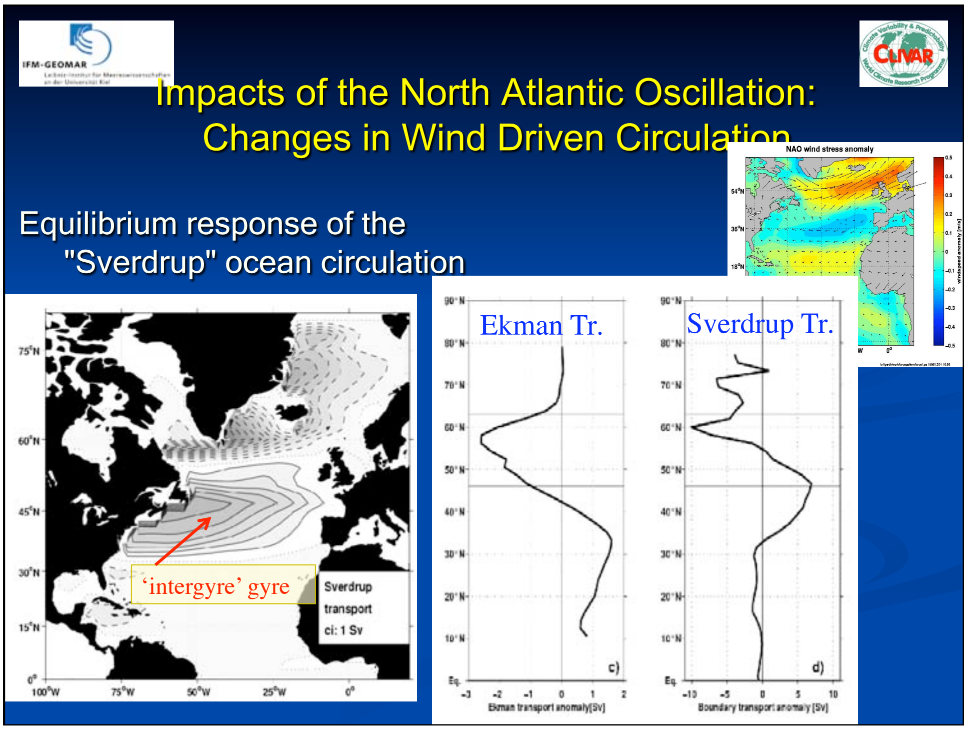
Impacts of the North Atlantic Oscillation: Changes in Surface Heat Flux



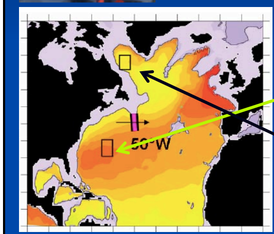
Ocean heat flux divergence due to changes in the surface Ekman transport acting on mean SST

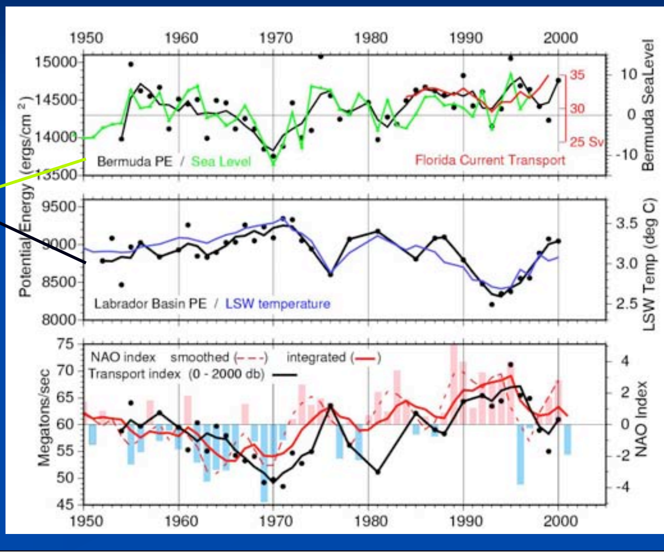



IFM-GEOMAR
CLIVAR
Impacts of the North Atlantic Oscillation:
Zonally Averaged Surface Buoyancy Flux
The ocean surface density changes are mostly
due to heat flux anomalies
with only small contribution from E-P
NAO wind stress anomaly
Heat Flux
Cold
Warm
Latent
Sensible
Ekman
Lat+Sens
Heat Flux Anomaly [W/m²]
Fresh Water
P
E
E-P
[mm/month]
Buoyancy Flux
Dense
Q
E-P
sum
Bouyancy Flux [m²s⁻³]
Zonal Wind Stress
a)
b)
c)
d)


IFM-GEOMAR
CLIVAR
Impacts of the North Atlantic Oscillation:
Changes in Wind Driven Circulation
Equilibrium response of the
"Sverdrup" ocean circulation
NAO wind stress anomaly
'intergyre' gyre
Sverdrup
transport
ci: 1 Sv
Ekman Tr.
Sverdrup Tr.
Ekman transport anomaly[Sv]
Boundary transport anomaly [Sv]
c)
d)

Impacts of the North Atlantic Oscillation: Changes in Wind Driven Circulation

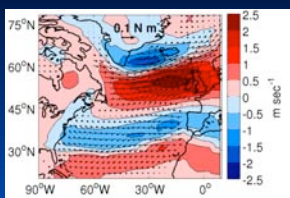


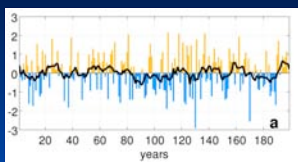


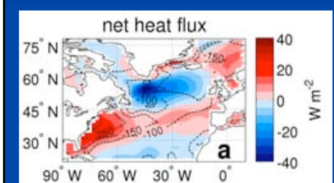
Gyre transport correlated with time integral of NAO

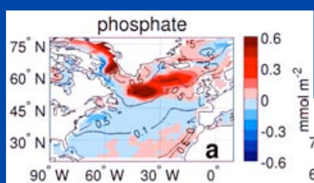
Curry&McCartney 2001

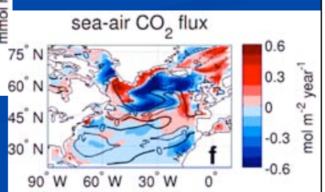
Oceans Model's response to NAO

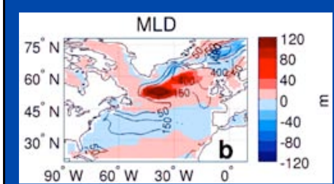


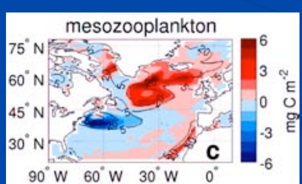












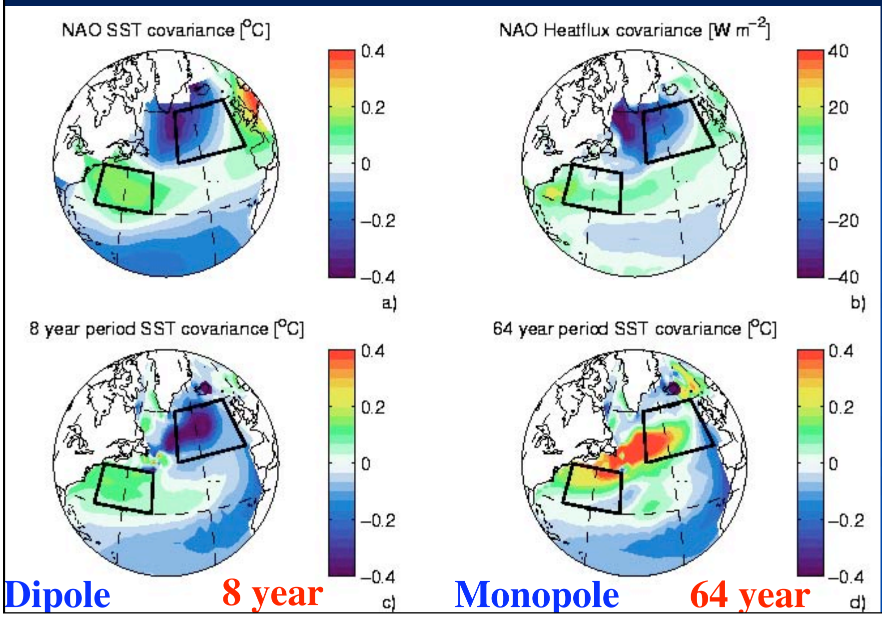
Marine biogeochemical responses to the North Atlantic Oscillation in a coupled climate model

L. Patara, M. Visbeck, S. Masina, G. Krahmann, M. Vichi

Comment

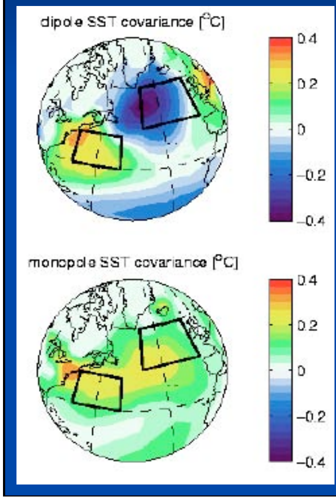
- SST tripole very well established SST response to interannually varying NAO forcing.
- How robust / stationary is the NAO SST response on longer time scales?

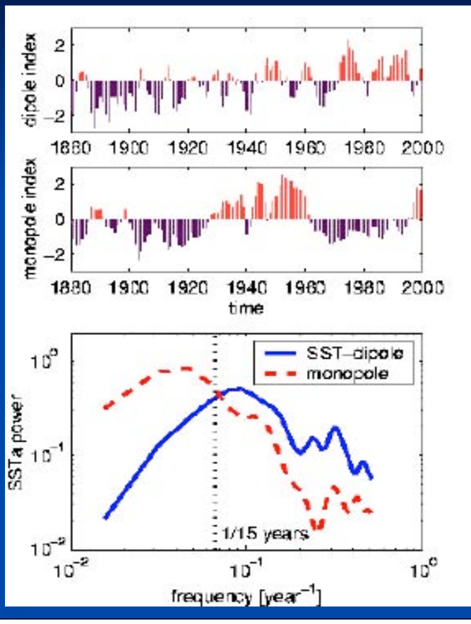
Oceans Model's response to NAO forcing: Dipole or Monopole ?



Observations: Dipole or Monopole ?

Kaplan SST reconstruction





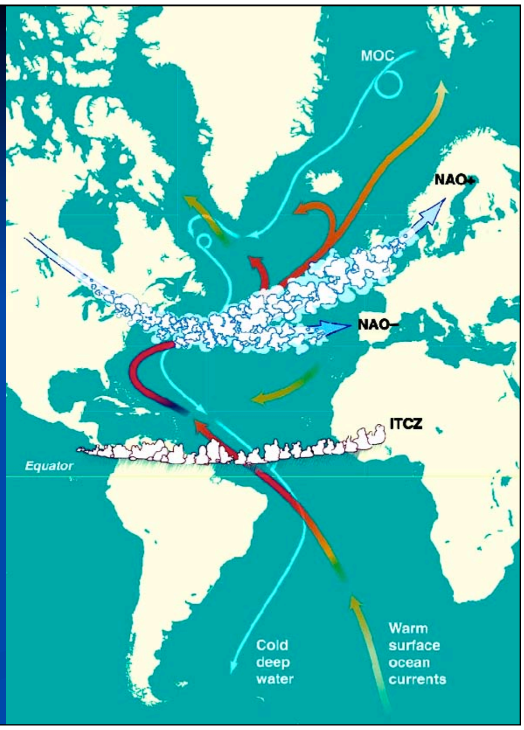
High frequency response

Low frequency response

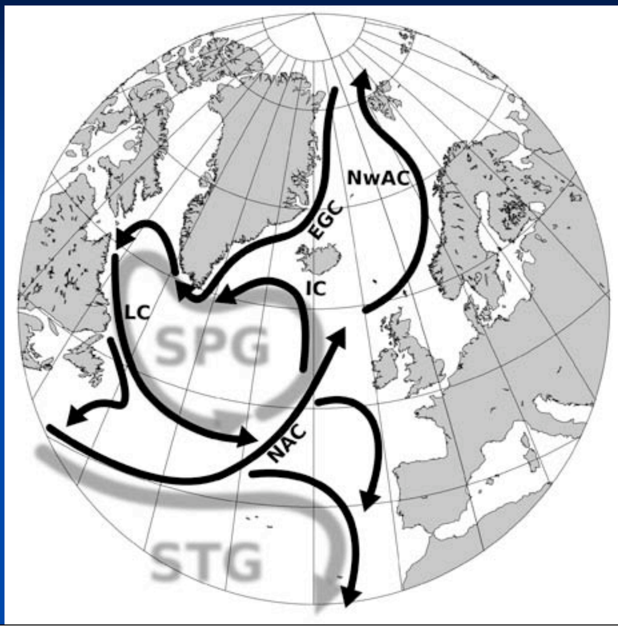
Switch occurs at about 15 year period

Roadmap

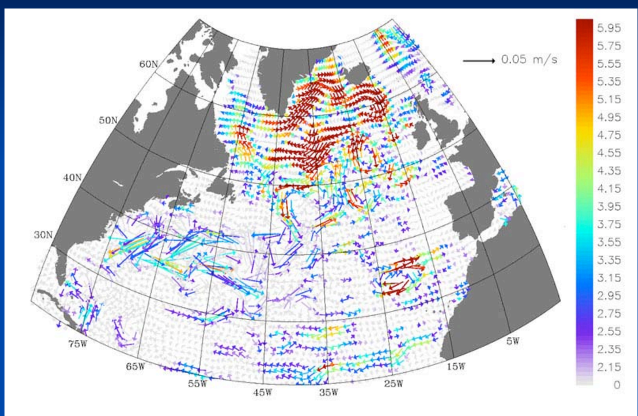
- CLIVAR
- Meridional Overturning
- Atlantic gyre variability
- Tropical Atlantic Variability



Atlantic Subpolar Gyre Change



Atlantic Subpolar Gyre Change

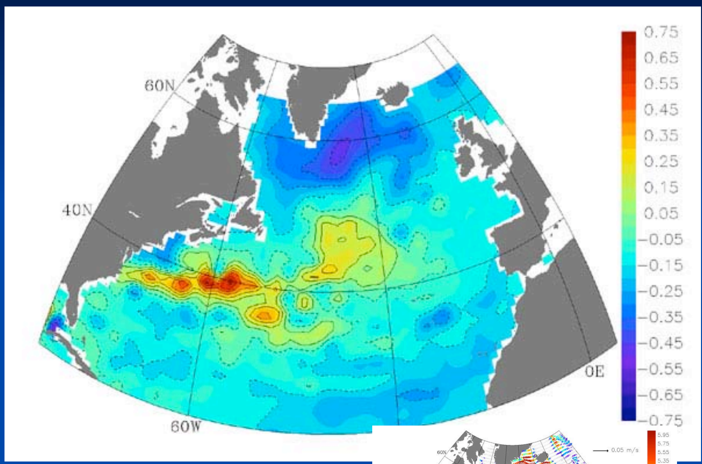


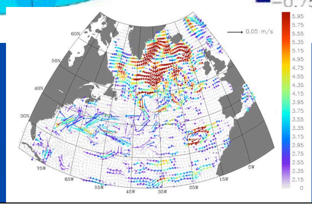
Hakkinen and Rhines

Decline in SPG circulation

Trend Velocities in North Atlantic. The trend of the velocities (meters per second per decade) derived from NASA Pathfinder altimeter data for the period May 1992 to June 2002. The colored vectors are statistically significant. Note how the vectors trace the following graphic of the subpolar circulation in reverse direction, which denotes a slowing gyre. The colors refer to t-test values (where anything above 2 is considered significant to 95%). Credit: Sirpa Hakkinen, NASA GSFC

Atlantic Subpolar Gyre Change



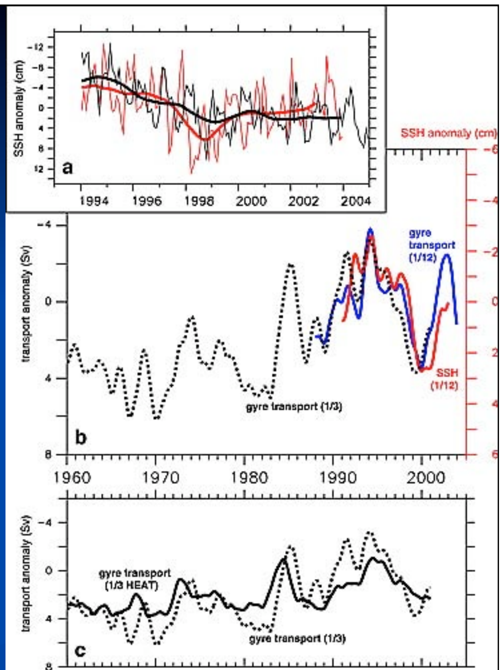


SSH Trends

Hakkinen and Rhines

Decline in SPG circulation

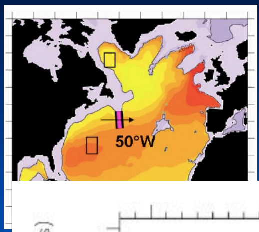
Decline in SPG circulation also found in 'forced' models



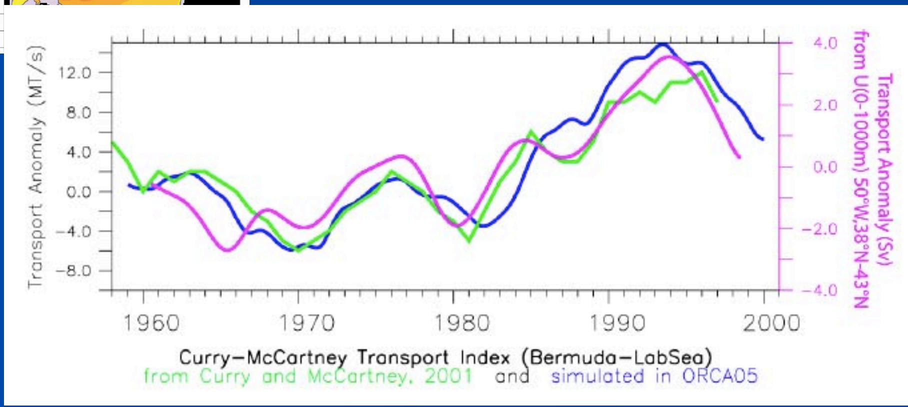
SSH anomaly in the central Labrador Sea (57°N, 52°W) in the 1/12°-model simulation (in red; thin curve: monthly values, heavy curve: 2-yr. low-pass filtered) and altimeter data (black), based on merged products from TOPEX/POSEIDON, ERS-2, Geosat Follow-on, Jason-1 and Envisat. (b) Comparison of the central gyre SSH-index (red) with the gyre transport in the 1/12°-model (blue), and the 1/3°-hindcast (black dotted); negative transport and SSH anomalies indicating a stronger cyclonic circulation. (c) Subpolar gyre transport in the 1/3°-model forced by interannually-varying heat fluxes and wind stresses

Böning, C. W., M. Scheinert, J. Dengg, A. Biastoch, and A. Funk (2006), Decadal variability of subpolar gyre transport and its reverberation in the North Atlantic overturning, *Geophys. Res. Lett.*, *33*,

Subpolar Gyre Transport Index



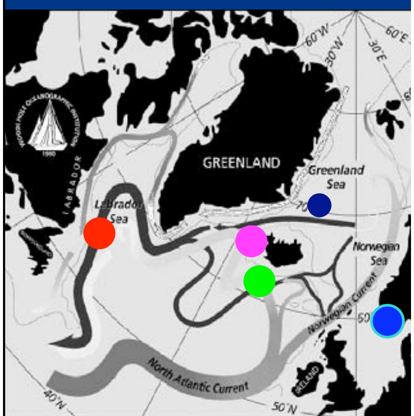
Proof of concept in numerical models …



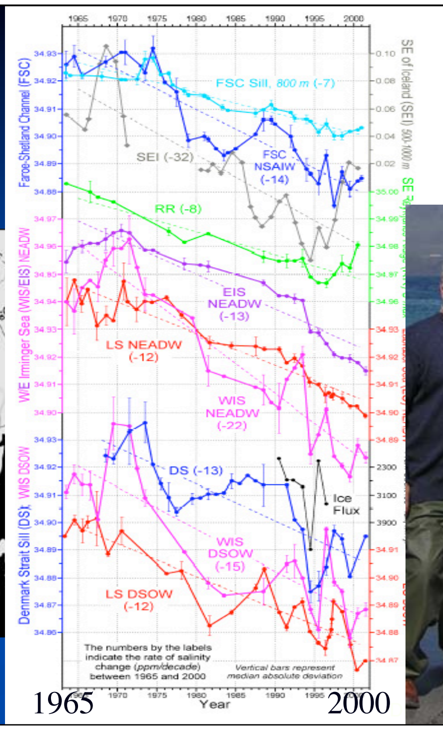
Scheinert PhD Thesis (Kiel)

Reduced sub-surface salinity

1963 to 2002



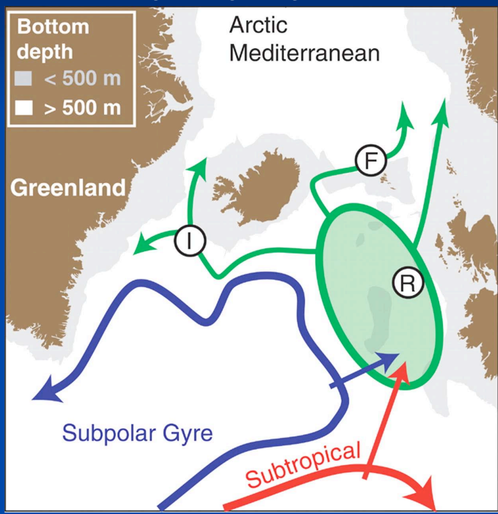
(Dickson et al 2002)



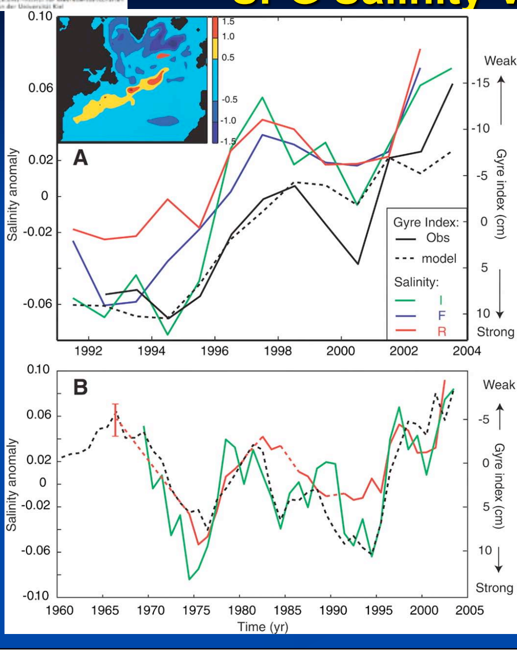
Fresh Water signal

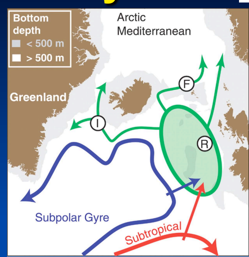
Influence of the Atlantic Subpolar Gyre on the Thermohaline Circulation

Hjálmar Hátún, Anne Britt Sandø, Helge Drange, Bogi Hansen,Heðinn Valdimarsson



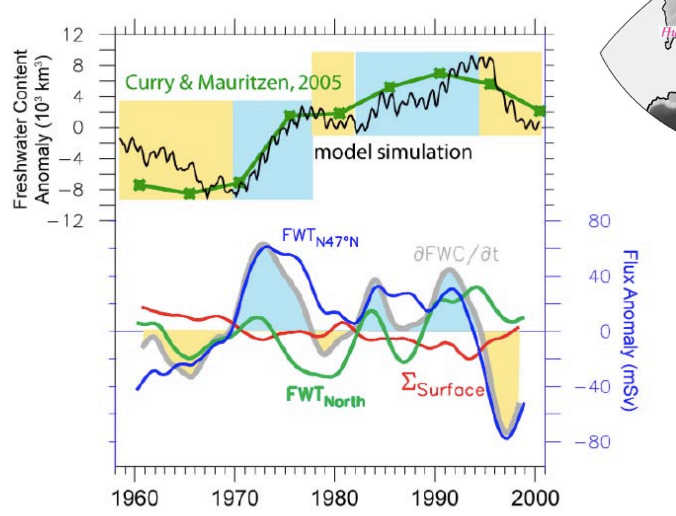
SPG Salinity Variability

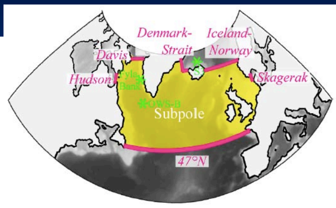




Temporal evolution of key parameters. (A) Colored lines show annual averages of the observed salinity anomalies (14) in inflow areas R, F, and I in Fig. 1. The time series R and F are shifted 1 year backward, and the time series I is shifted 2 years backward to account for advective delays. The solid black line shows the principal component, the gyre index (inverted), associated with the leading North Atlantic sea-surface height mode, as obtained from altimetry observations.

SPG Salinity Variability



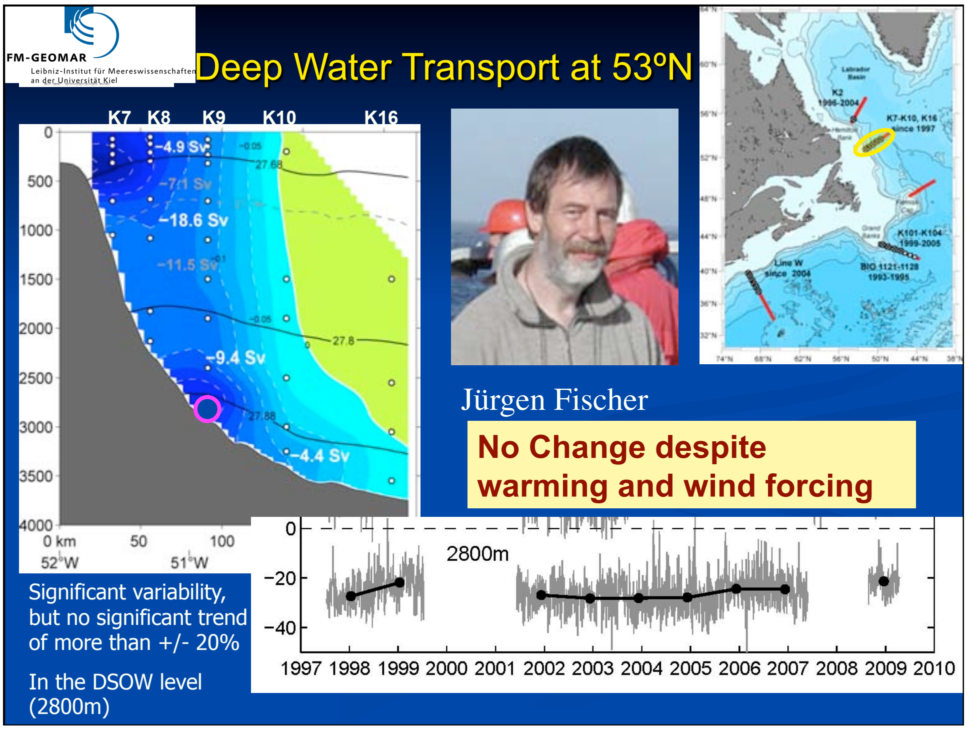


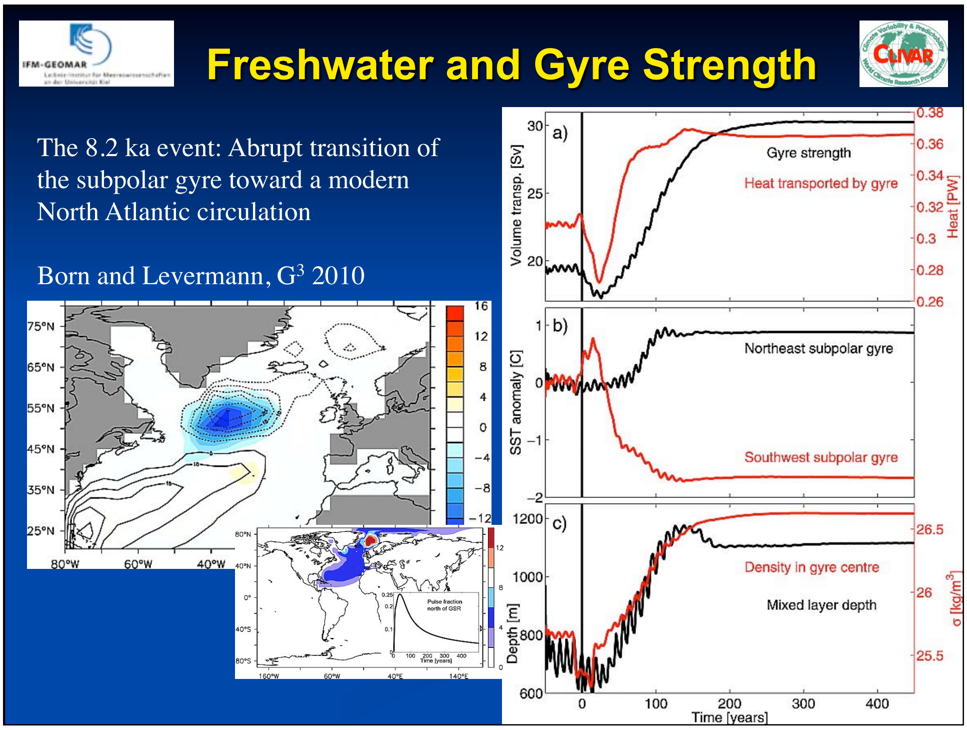
Observed freshening of the Subpolar Gyre can be 'explained' by wind driven changes of the Subtropical – Subpolar Gyre exchanges

Scheinert PhD Thesis (Kiel)

Comment

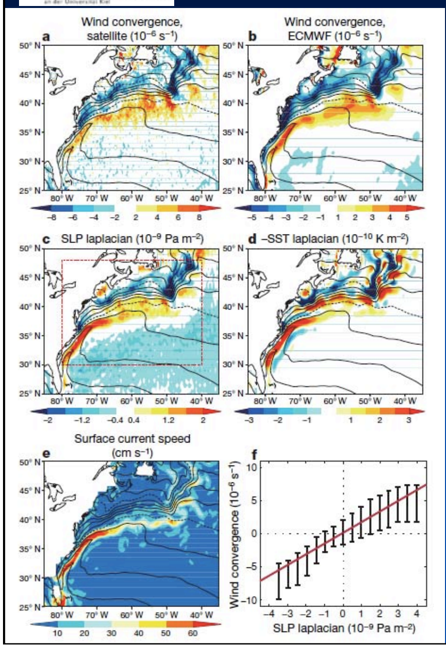
- Seems like 'observed' changes in the wind stress can 'explain' the observed changes in salinity and sea level over the subpolar gyre.
- How robust consistent is that signal in boundary currents transports?


Deep Water Transport at 53ºN
K7 K8 K9 K10 K16
-4.9 Sv
-7.1 Sv
-18.6 Sv
-11.5 Sv
-9.4 Sv
-4.4 Sv
Jürgen Fischer
No Change despite warming and wind forcing
2800m
Significant variability, but no significant trend of more than +/- 20%
In the DSOW level (2800m)
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010


Freshwater and Gyre Strength
The 8.2 ka event: Abrupt transition of the subpolar gyre toward a modern North Atlantic circulation
Born and Levermann, G3 2010
Gyre strength
Heat transported by gyre
Volume transp. [Sv]
Heat [PW]
Northeast subpolar gyre
Southwest subpolar gyre
SST anomaly [C]
Density in gyre centre
Mixed layer depth
Depth [m]
Time [years]

Point 2

- Impact or ‘process’ understanding of the gyre dynamics and their impact on other aspects of the ocean system was advanced
- However, the ‘feedback’ to the climate system proved difficult because of the apparent ‘weak’ link back to the dynamical response of the atmosphere to SST-anomalies
- There are other feedback routes (CO_2)



Influence of the Gulf Stream on the troposphere
Shoshiro Minobe, Akira Kuwano-Yoshida, Nobumasa Komori, Shang-Ping Xie & Richard Justin Small

Here we consider the Gulf Stream’s influence on the troposphere, using a combination of operational weather analyses, satellite observations and an atmospheric general circulation model4. Our results reveal that the Gulf Stream affects the entire troposphere. In the marine boundary layer, atmospheric pressure adjustments to sharp sea surface temperature gradients lead to surface wind convergence, which anchors a narrow band of precipitation along the Gulf Stream. In this rain band, upward motion and cloud formation extend into the upper troposphere, as corroborated by the frequent occurrence of very low cloud-top temperatures. These mechanisms provide a pathway by which the Gulf Stream can affect the atmosphere locally, and possibly also in remote regions by forcing planetary waves5,6

Roadmap

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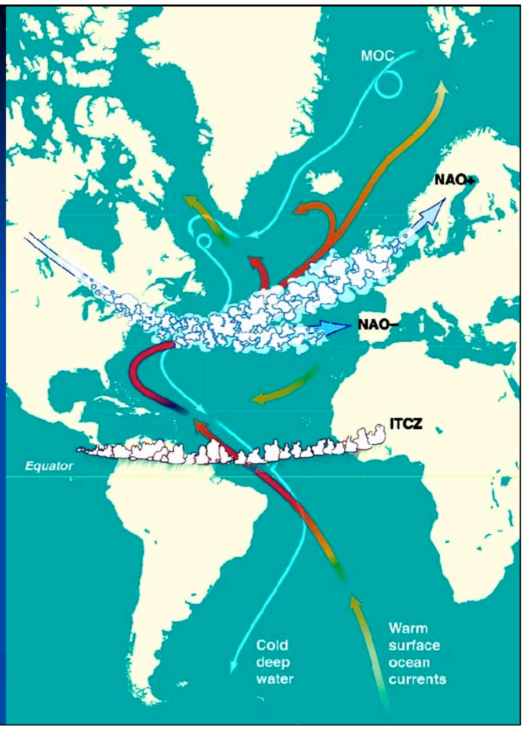
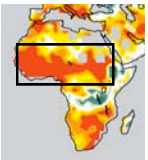
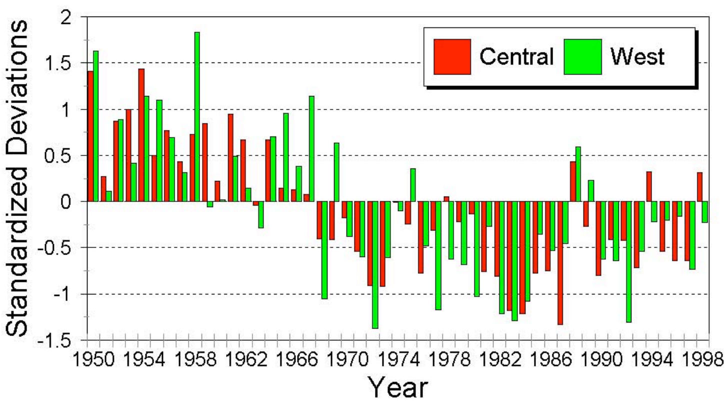
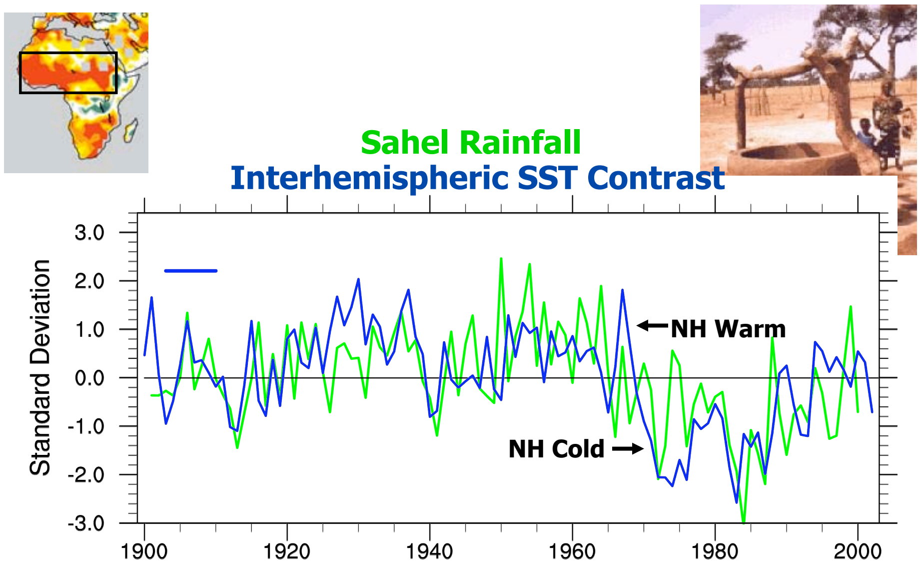
- Tropical Atlantic Variability



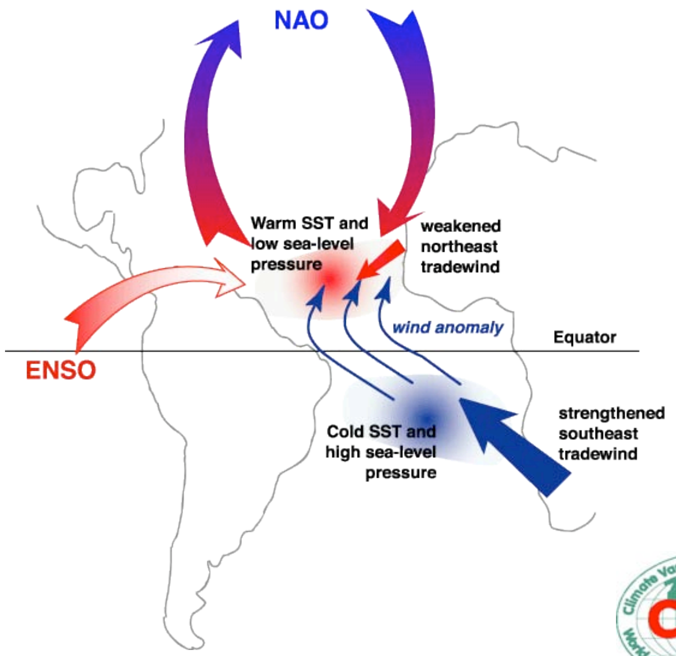


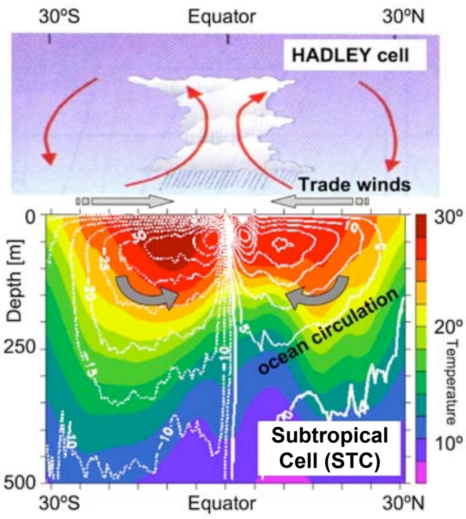
Central and West Sahel Rainfall
1950-1998





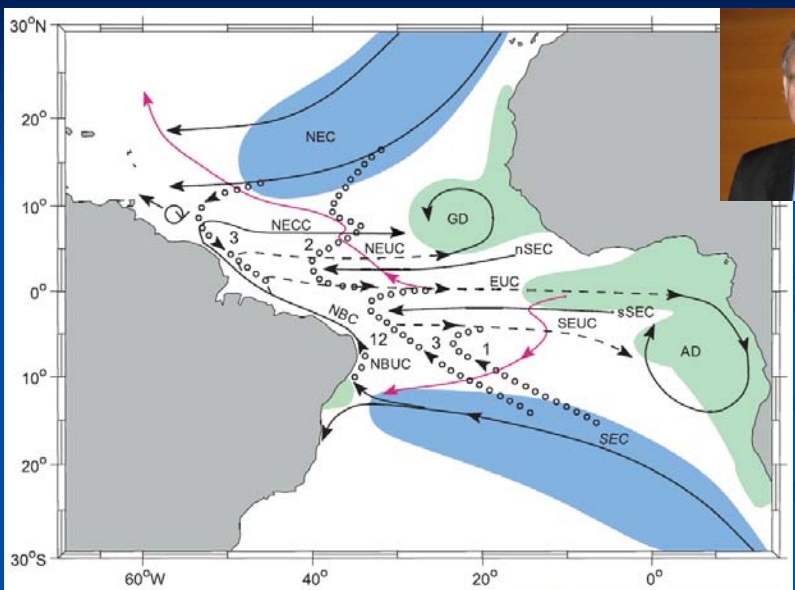
Strong relationship to SST changes





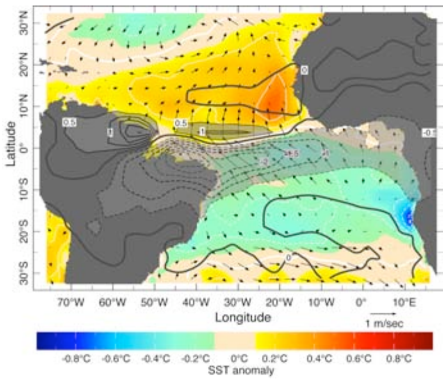
Zonal averaged circulation in the Tropical Ocean. Is it changing?

Shallow Overturning Circulations of the Tropical-Subtropical Oceans

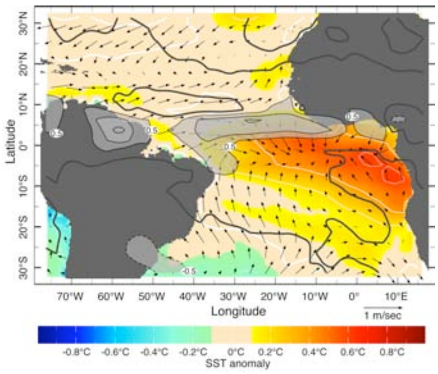


Schott , McCreary, Johnson 2004

Atlantic ITCZ Variability



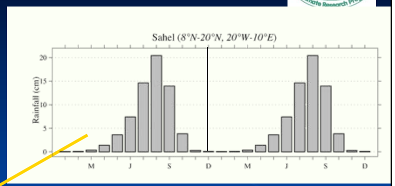
*First EOF (**33%**) of the March-April rainfall from GPCP 1979-2001 (contours in mm/day). March-April SST anomaly (colors, in °C & white contours, every 0.2°) and surface wind anomaly (vector, in m/sec) are determined by regression on the time series of the rainfall EOF.*

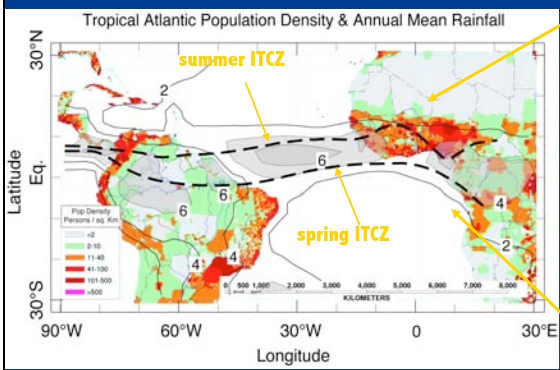


*First EOF (**23%**) of the June-August rainfall from GPCP 1979-2001 (contours in mm/day). June-August SST anomaly (colors, in °C & white contours, every 0.2°) and surface wind anomaly (vector, in m/sec) are determined by regression on the time series of the rainfall EOF.*

Atlantic Marine ITCZ

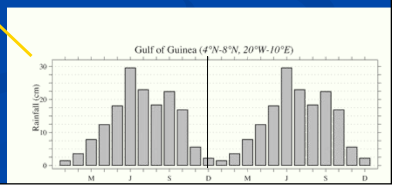
Sahel rainfall climatology



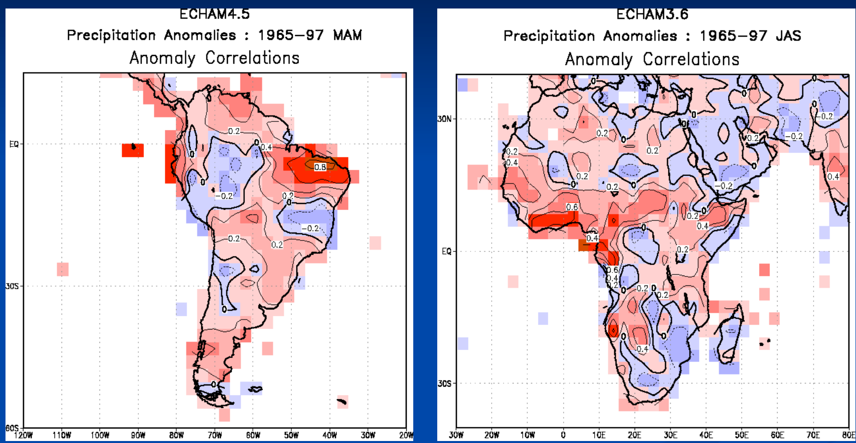


ITCZ position and rainfall intensity affect densely populated regions in West Africa

Guinea rainfall climatology



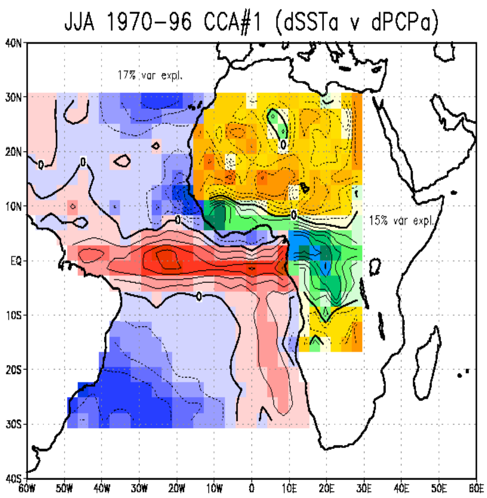
Tropical Atlantic rainfall variability is POTENTIALLY predictable



Results from perfect SST "AMIP" ensembles (*L. Goddard, IRI)*

… but current seasonal SST forecasts are without skill!

Why are the rain fall predictions over Africa so bad?



Dominant pattern of precipitation *error* associated with dominant pattern of SST prediction *error* based on persistent SST anomalies *(**Goddard & Mason** ,Climate Dynamics, 2002)*

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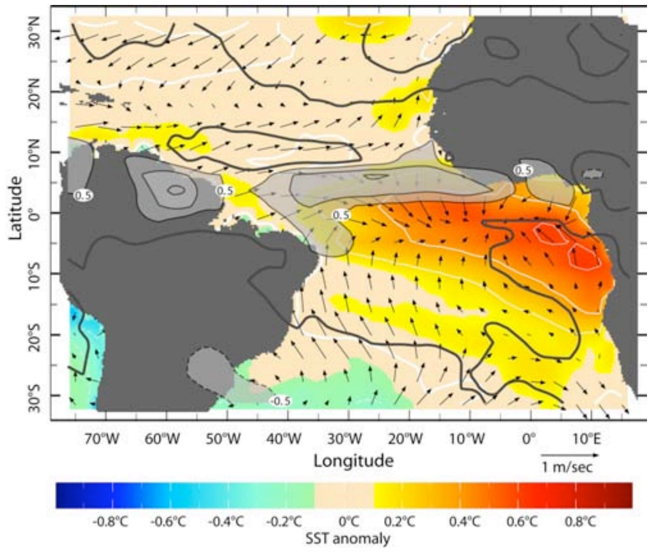


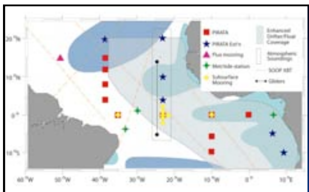
Zonal Mode - „Atlantic Nino"

Dominant mode during boreal summer

Increased precipitation (grey shaded, mm/day) during warm events

⇒ SST in the equatorial cold tongue important for regional climate prediction

Kushnir et al. (2006)

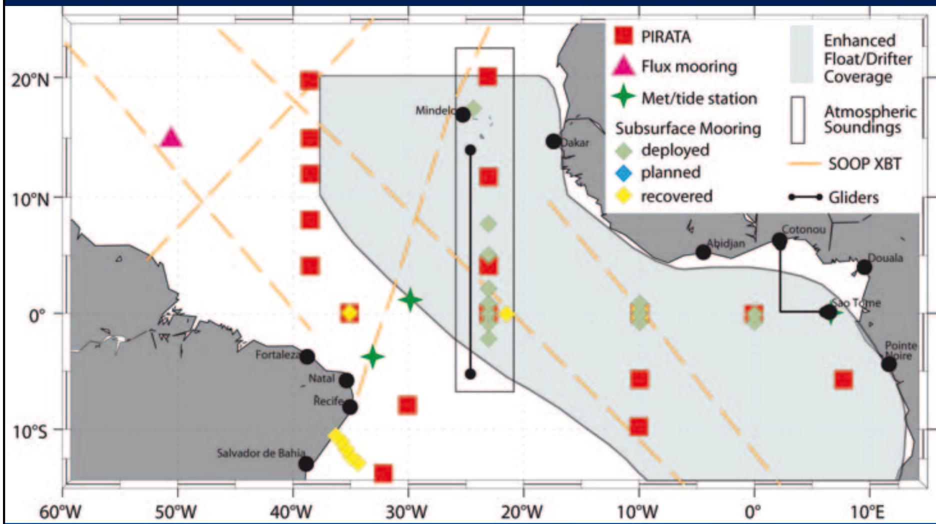


Tropical Atlantic Climate Experiment
TACE
(B. Johns W. Hazeleger)

To advance understanding of coupled ocean-atmosphere processes and improve climate prediction for the Tropical Atlantic region

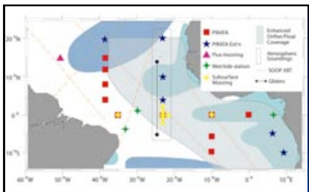
Specific goals are:
a) To advance understanding of the key processes that control SST, interactions with the AMI (Atl. Marine ITCZ), and related climate predictability in the eastern tropical Atlantic.
b) To contribute to the design of an enhanced sustained observing system for the tropical Atlantic region.

Tropical Atlantic Observations



TACE: Tropical Atlantic Climate Experiment

TACE core period six years: 2006/7 - 2011/12



TACE
Modeling Strategy

(B. Johns W. Hazeleger)

1) Determine oceanic processes important in regulating SST in the tropical Atlantic and associated atmospheric responses

2) Improve SST forecasts on seasonal to interannual time scales in the tropical Atlantic

3) Provide parameterizations and model improvements to global and regional prediction centers

4) Investigate response of tropical Atlantic region to global warming, including teleconnection patterns

Tropical Atlantic Climate Experiment

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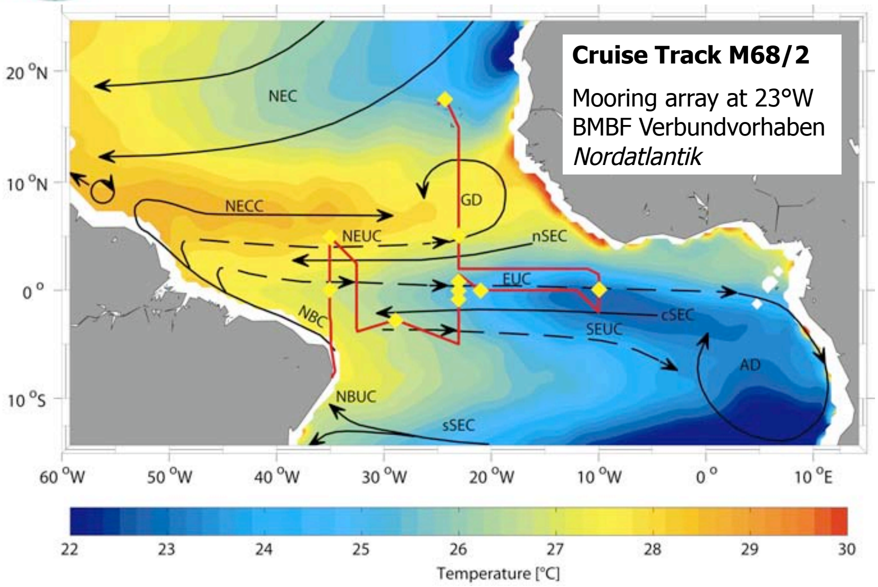
Cruise Track M68/2

Mooring array at 23°W
BMBF Verbundvorhaben
Nordatlantik



Tropical Atlantic Climate Experiment

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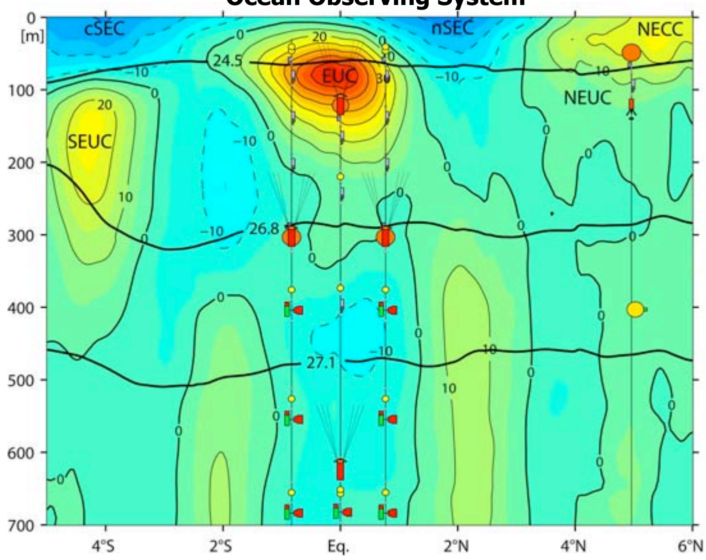
Ocean Observing System



3 Moorings at 23°W
0.75°N, 0°N, 0.75°S
(including the PIRATA ADCP in the central mooring) and
one at 21.5°W, 0°N

CTD-profiler
at 23°W, 0°N
1000m - 3500m
(John Toole, WHOI)

CTD/O_2-profiler
At 23°W, 5°N
120m – 1000m
(new SFB)

Interannual Variability

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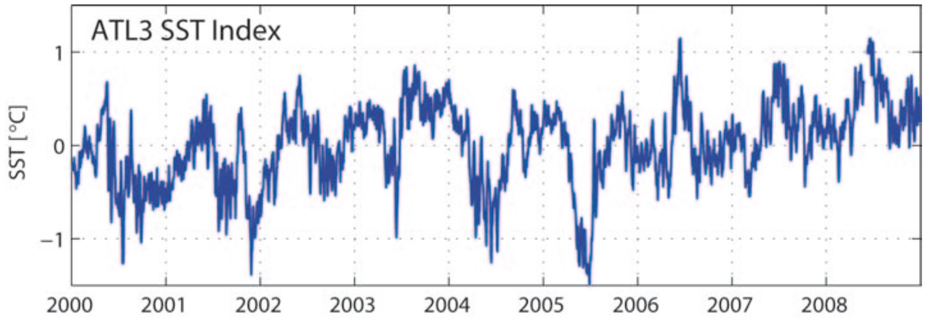
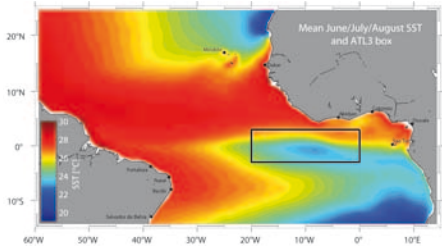


Seasonal dependence of interannual variability:
Strongest during boreal summer (June/July)



Interannual Variability

IFM-GEOMAR
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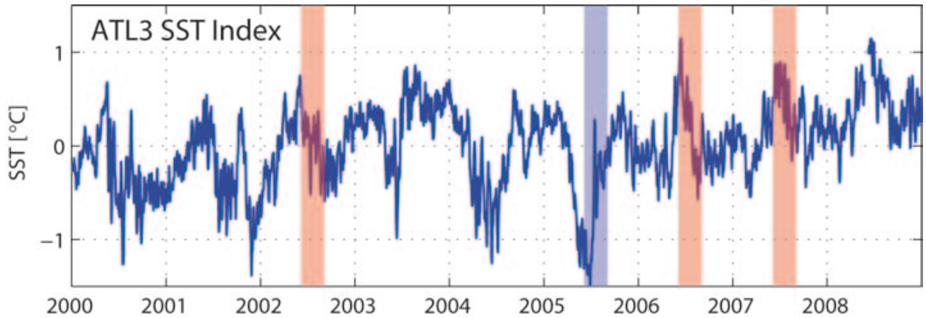
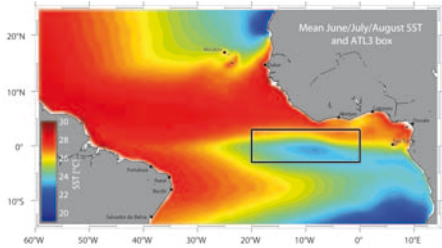


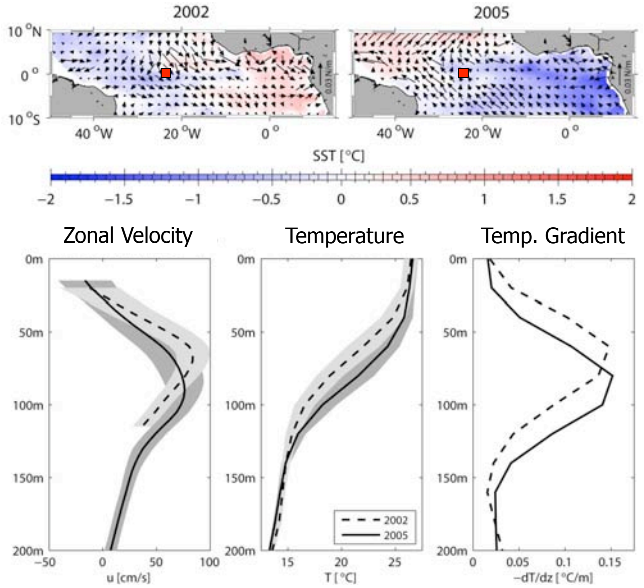
Boreal summer cold tongue:

Warm events in 2002, 2006, 2007

Cold event in 2005



Interannual Variability



EUC and cold tongue variability

warm (cold) event in JJA 2002 (2005), with relaxed (intensified) winds in the west during boreal spring (MAM)

EUC embedded in shallower (deeper) thermocline at 23°W during boreal summer 2002 (2005)

Hormann and Brandt (2009)

Point 3

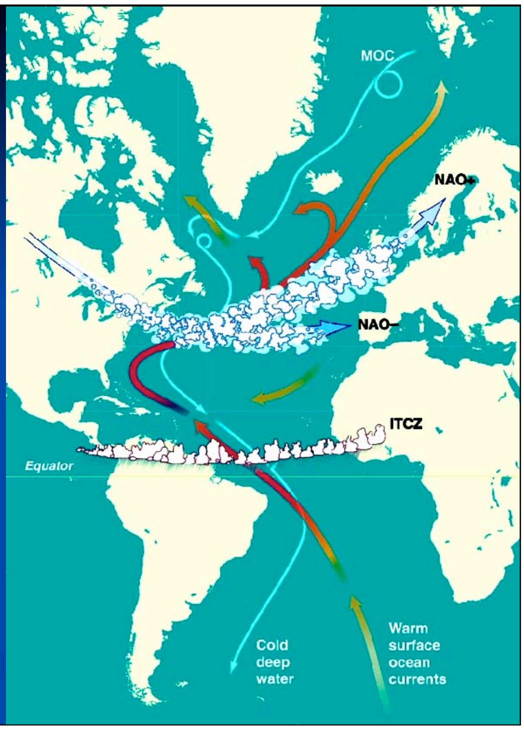
- Tropical Atlantic Variability fundamentally involves the interaction between the ocean surface and the ITCZ

- Its patterns are highly seasonal

- In the summer fall the role of the EUC seems to be relevant. The predictability of changes has yet to be fully explored (TACE)

Roadmap

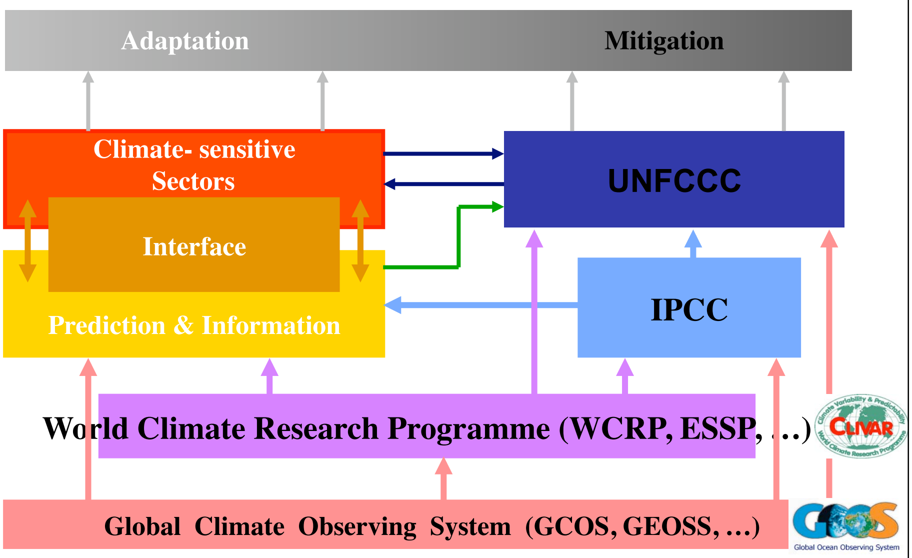
- CLIVAR
- Meridional Overturning
- Atlantic gyre variability
- Tropical Atlantic Variability
- Recomendations



Observation

- ‘Linear’ approach to understand and investigate Climate Variability and its Predictability has shown to be of limited value to realize the full predictability (in my opinion). But can help to highlight issues …
- There is a need to take a more ‘integrated’ approach (coupled, high resolution, non-linear feedbacks allowed systems)
- What is then on the ‘agenda’?

World Climate Conference 3 (WCC3)
Global Framework for Climate Services



Elements of Climate Services

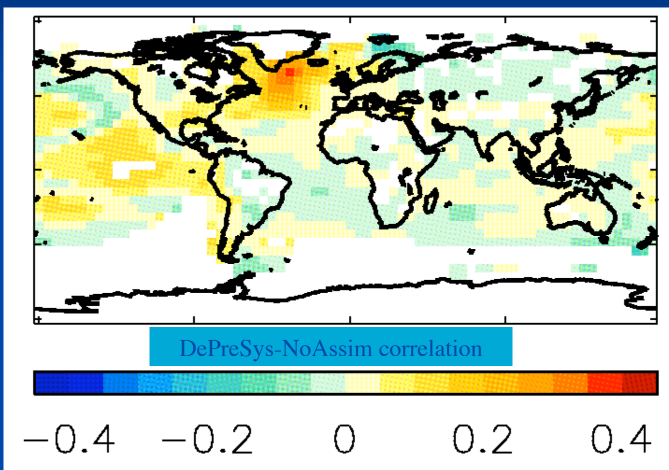
- The **Global Climate Observing System** and all its components and associated activities; and provision of free and unrestricted exchange and access to climate data;
- The **World Climate Research Programme**, underpinned by adequate computing resources and increased interaction with other global climate relevant research initiatives.
- **Climate services information systems** taking advantage of enhanced existing national and international climate service arrangements in the delivery of products, including sector-oriented information to support adaptation activities;
- **Climate user interface mechanisms** focussed on building linkages and integrating information, at all levels, between the providers and users of climate services; and
- Efficient and enduring **capacity building** through education, training, and strengthened outreach and communication.

CLIVAR Imperatives

- Anthropogenic Climate Change
- Decadal Variability, Predictability and Prediction
- Intraseasonal and Seasonal Predictability and Prediction
- Improved Atmosphere and Ocean Components of Earth System Models
- Data Synthesis and Analysis and Uncertainty
- Ocean Observing System
- Capacity Building

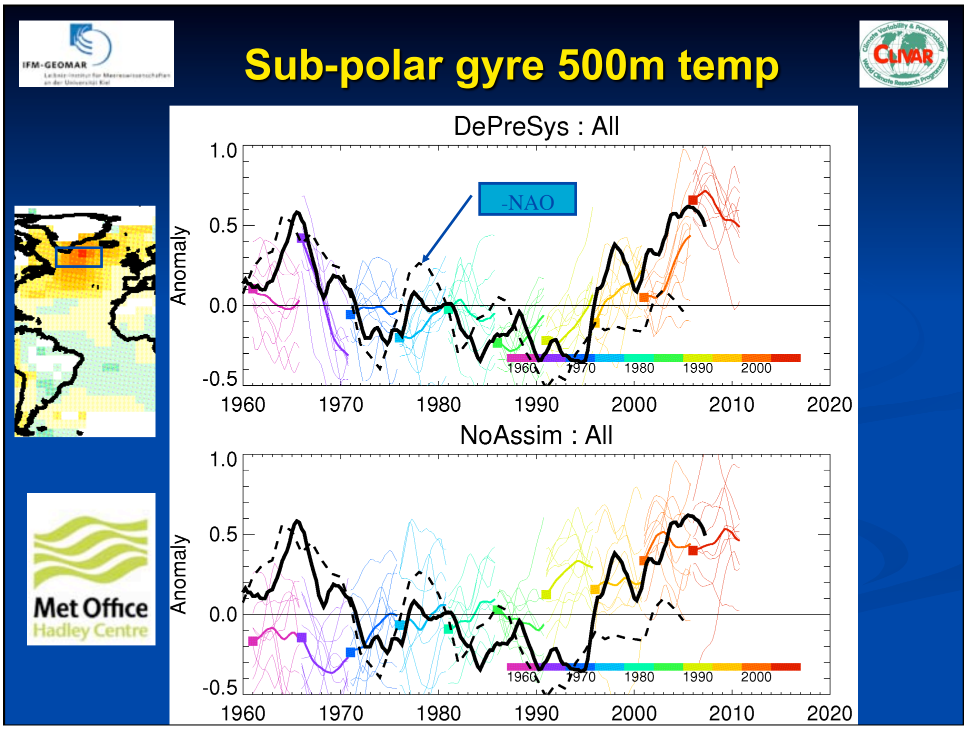
Impact of initialisation on hindcast skill

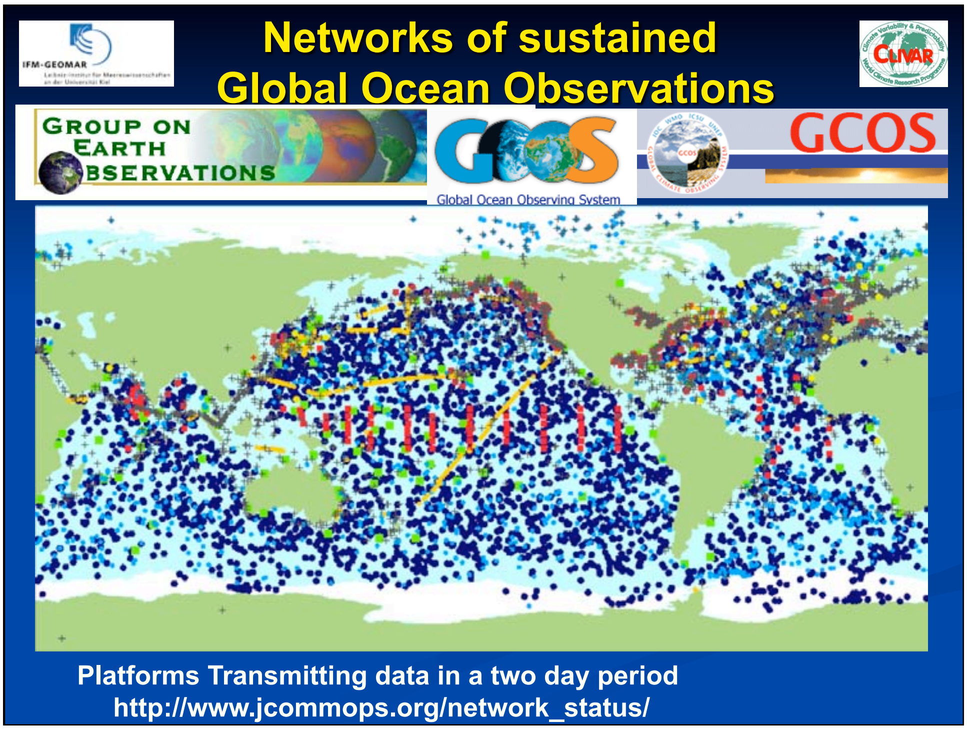
9 year mean surface temp : 15x15 degrees : start dates each Nov from 1960 to 2005

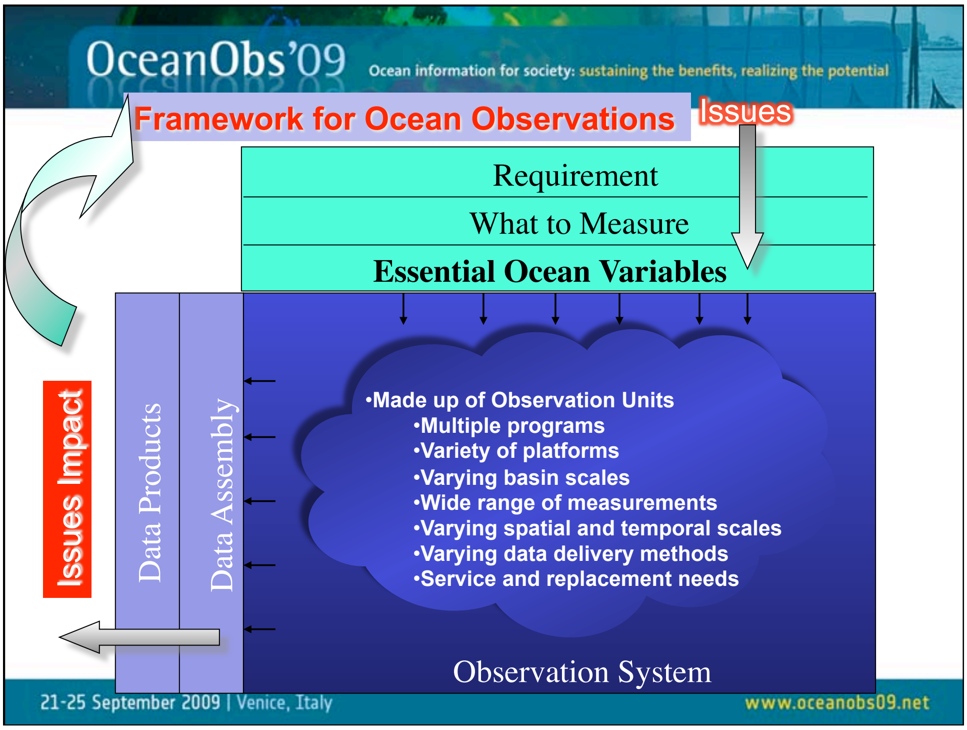


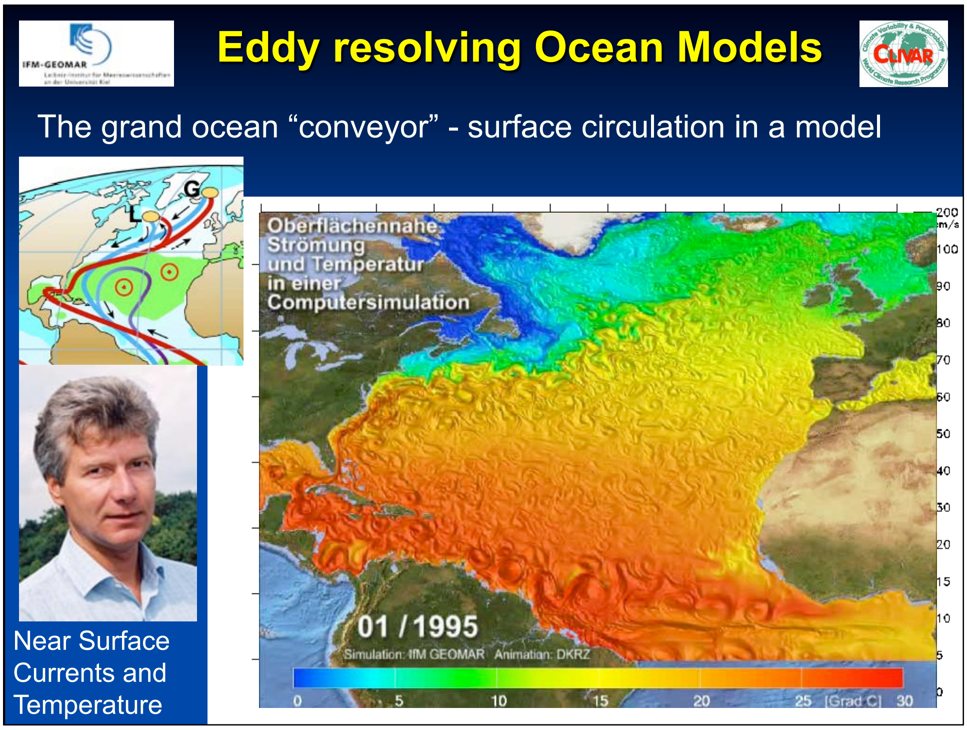
- HadCM3
- 9 member perturbed physics ensemble
- Starting every Nov from 1960 to 2005

Met Office Hadley Centre

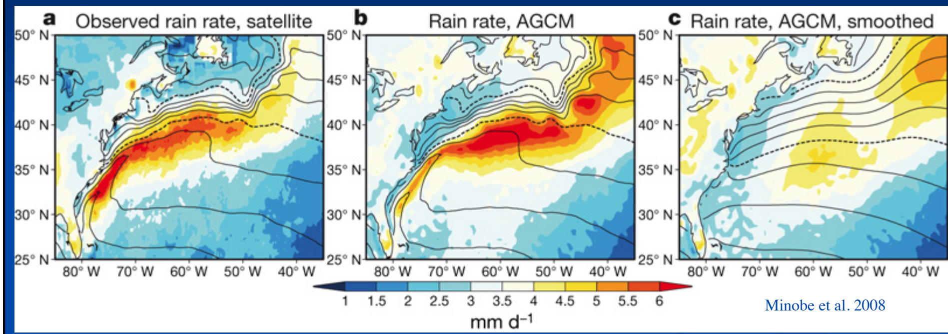

Sub-polar gyre 500m temp
IFM-GEOMAR
CLIVAR
DePreSys : All
-NAO
Anomaly
1.0
0.5
0.0
-0.5
1960 1970 1980 1990 2000 2010 2020
NoAssim : All
Met Office
Hadley Centre


Networks of sustained
Global Ocean Observations
IFM-GEOMAR
CLIVAR
Group on Earth Observations
GOOS
Global Ocean Observing System
GCOS
Platforms Transmitting data in a two day period
http://www.jcommops.org/network_status/


OceanObs'09
Ocean information for society: sustaining the benefits, realizing the potential
Framework for Ocean Observations
Issues
Requirement
What to Measure
Essential Ocean Variables
•Made up of Observation Units
•Multiple programs
•Variety of platforms
•Varying basin scales
•Wide range of measurements
•Varying spatial and temporal scales
•Varying data delivery methods
•Service and replacement needs
Issues Impact
Data Products
Data Assembly
Observation System
21-25 September 2009 | Venice, Italy
www.oceanobs09.net


IFM-GEOMAR
CLIVAR
Eddy resolving Ocean Models
The grand ocean "conveyor" - surface circulation in a model
Oberflächennahe Strömung und Temperatur in einer Computersimulation
01 / 1995
Simulation: IfM GEOMAR Animation: DKRZ
0 5 10 15 20 25 [Grad C] 30
Near Surface Currents and Temperature

‘responsive’ Atmospheres



Minobe et al. 2008

- Much stronger atmospheric response to SST at high resolution

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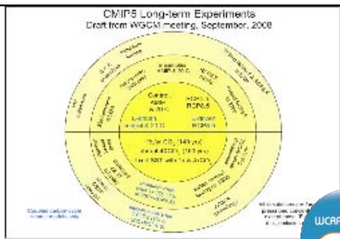
WCRP Climate-system Historical Forecast Project (CHFP)

As part of CMIP5



Seasonal and CMIP5 Near Term hindcast simulations

CLIVAR Regional Panels to Lead Application Interface for Seasonal Prediction Skill Assessment

Sea-Ice Predictability Experiments:
To explore seasonal predictability associated with snow and sea ice.

Stratosphere-resolving HFP experiment (StratHFP):
High and low top models will be used to quantify improvements in *actual* predictability by initializing and resolving the stratosphere in seasonal forecast systems.

Global Land-Atmosphere Coupling Experiment (GLACE-2):
To determine prediction skill associated with accurate initialization of land surface states.

Reduced (Atlantic) SST bias

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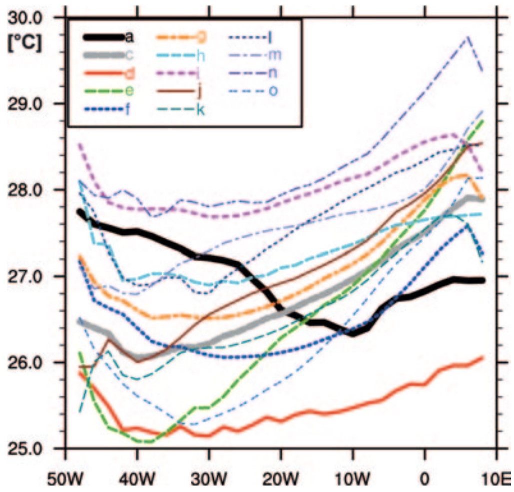


SST along the equator

- as observed (thick black)
- in coupled ocean–atmosphere general circulation models (GCMs)

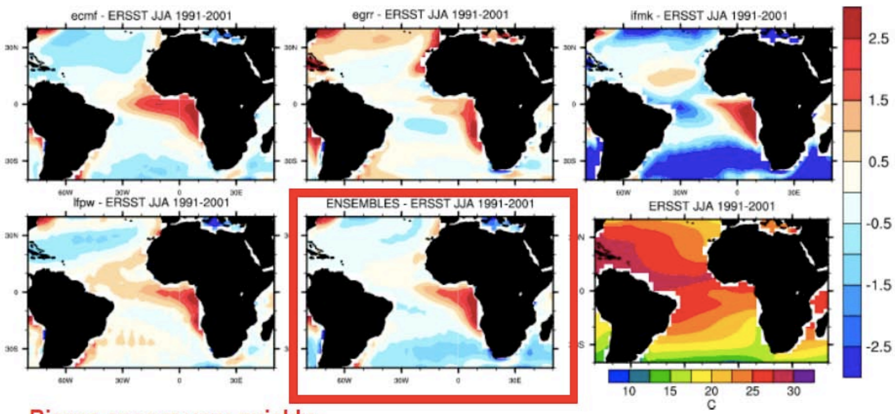
⇒ Strong biases in GCMs including a failure of reproducing cold tongue

Errors in AGCMs during spring

Possibility of improving coupled simulations

Richter and Xie (2008)

Stream 1 ENSEMBLES Seasonal Hindcasts: SST bias - ref. ERSST JJA 1991-2001



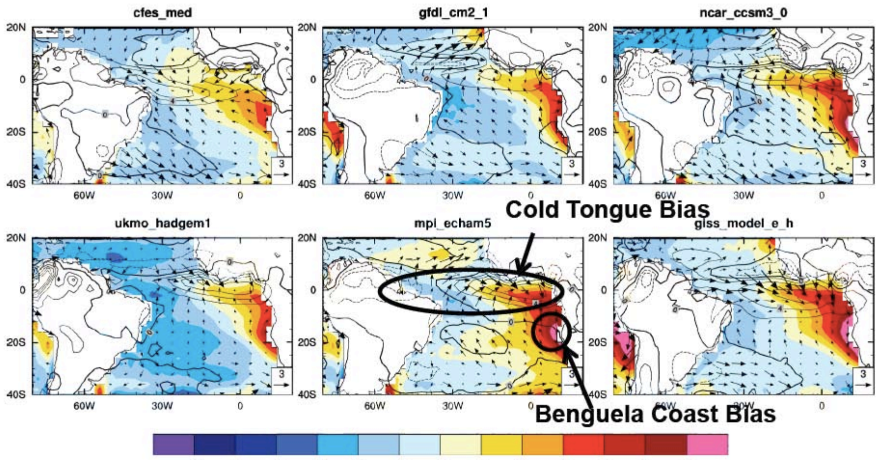
Biases appear very quickly in all forecast models!

Caminade et al. (2009)

Forecast start: May 1st,
Forecast period: month [2-4] JJA

JJA biases

SST (shading), sfc winds (vectors), precip (contours)
reference: ICOADS (SST, winds), CMAP (precip)



From Richter

Workshop on Coupled Ocean-Atmosphere-Land Processes in the Tropical Atlantic

Wednesday 23 (noon) – Friday 25 (noon) March 2011, Miami
(appended to the VOCALS meeting March 21-23)

- **Wednesday: Large-Scale Overview (pm)**
  - Tropical Pacific and Atlantic climates: The problems with CGCMs
  - Ocean-atmosphere-land interactions in the tropical Atlantic
- **Thursday: Southeastern Atlantic Regional Climate (am)/ Process Studies (pm)**
  - The southeastern Atlantic: Subsidence, aerosol and cloud systems
  - The southeastern Atlantic: Upwelling system and ocean eddy field
  - Ocean-atmosphere-land interactions in the Pacific: The lessons from VOCALS
  - Field experiments/observational work
- **Friday: Climate Change and and Planning (am)**
  - Climate Change projections in the (sub) tropical Atlantic
  - Discussions in break-out and plenary modes

CLIVAR Imperatives

- Anthropogenic Climate Change
- Decadal Variability, Predictability and Prediction
- Intraseasonal and Seasonal Predictability and Prediction
- Improved Atmosphere and Ocean Components of Earth System Models
- Data Synthesis and Analysis and Uncertainty
- Ocean Observing System
- Capacity Building

CLIVAR Imperatives

- Anthropogenic Climate Change
  - Long term change
  - Natural versus forced variability
  - Regional phenomena and impacts
  - Extremes
- Decadal Variability, Predictability and Prediction
  - Determination of predictability
  - Mechanisms of variability
  - Role of oceans
  - Adequacy of observing system
  - Initialization
  - Monsoons
  - Extremes - drought
- Intraseasonal and Seasonal Predictability and Prediction
  - Role of land/ocean (GOALS)
  - Initialization
  - Monsoons, ISV/MJO

CLIVAR Imperatives

- Anthropogenic Climate Change
- Decadal Variability, Predictability and Prediction
- Intraseasonal and Seasonal Predictability and Prediction

- Improved Atmosphere and Ocean Components of ESMs
  - Ocean model development
  - Analysis and Evaluation
  - Process studies/"Climate Process Teams"
- Data Synthesis and Analysis and Uncertainty
  - Ocean
  - Coupled Data Assimilation Systems (with WOAP)
- Ocean Observing System
  - Development and System Design
  - (Build LINKS WITH IGBP for Carbon, Biogeochemistry, Ecosystems)
- Capacity Building