Ocean Observations at global and regional scale (physical point of view)

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outlook of the presentation

- the “state of art” of the climate changes regarding the ocean (temperature, salinity and circulation);
- zooming on the marginal seas: the Mediterranean case and other relevant ocean basins;
- some conclusions.

Climate scientific problems involving ocean

Observations

Instrumental records of increasing duration and spatial coverage document substantial variability in the path and intensity of climate system characteristics on timescales of months to decades: ***oscillations or trends?;***

Heterogenity and nonlinearity

the ***climate system*** is heterogeneous, describable by many variables that vary significantly over space and time scale covering many order of magnitude, moreover the nonlinearity is also an intrinsic proprerty of the system, if only due to the dominance of local/regional fluxes exchange , but also to the many complex feedback between the domains;

Instability

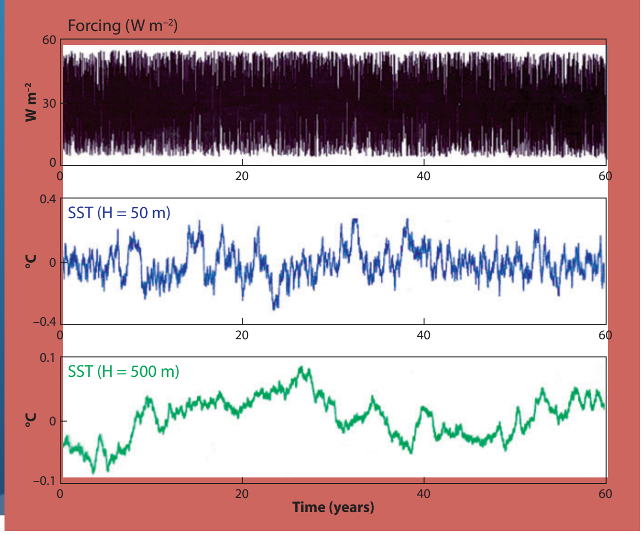
positive (negative) feedback can lead to instability that drives the system to new modes of ***behaviour that bear little resemblance to the external forcing***, if such destabilizing processes are not properly represented, the system may not able to display important modes of internal variability.

stochastic mixed layer model

Forcing (W m–2)

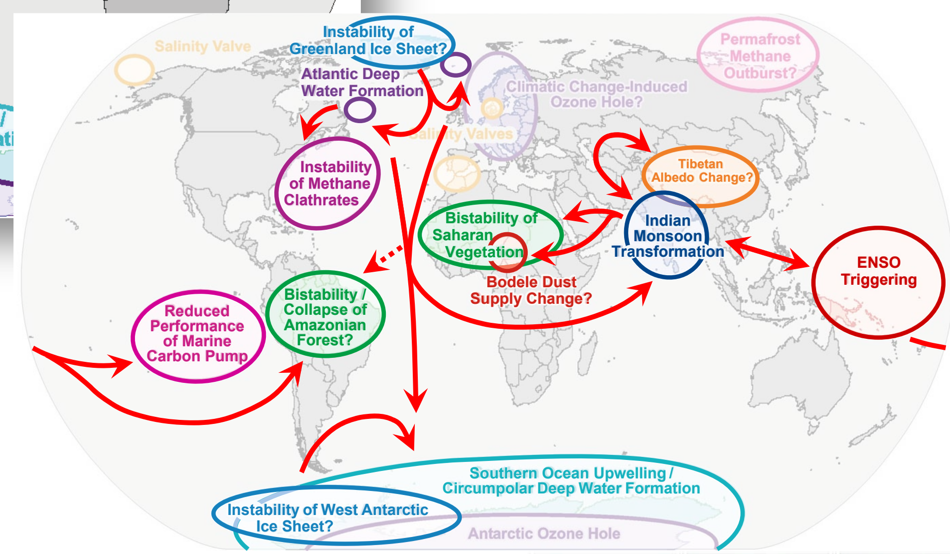
SST (H = 50 m)

SST (H = 500 m)



"tipping point" a critical threshold at which a tiny perturbation can alter the state of a system, below the large-scale components of the Earth system that may pass a tipping point.

...also through Teleconnections and Feedbacks

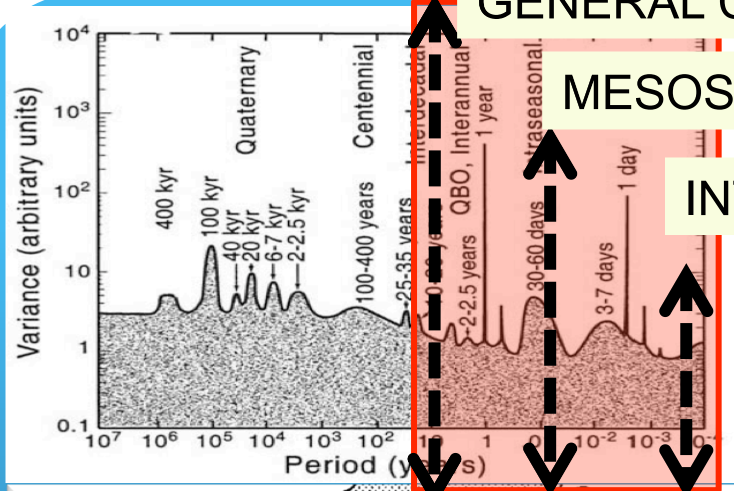


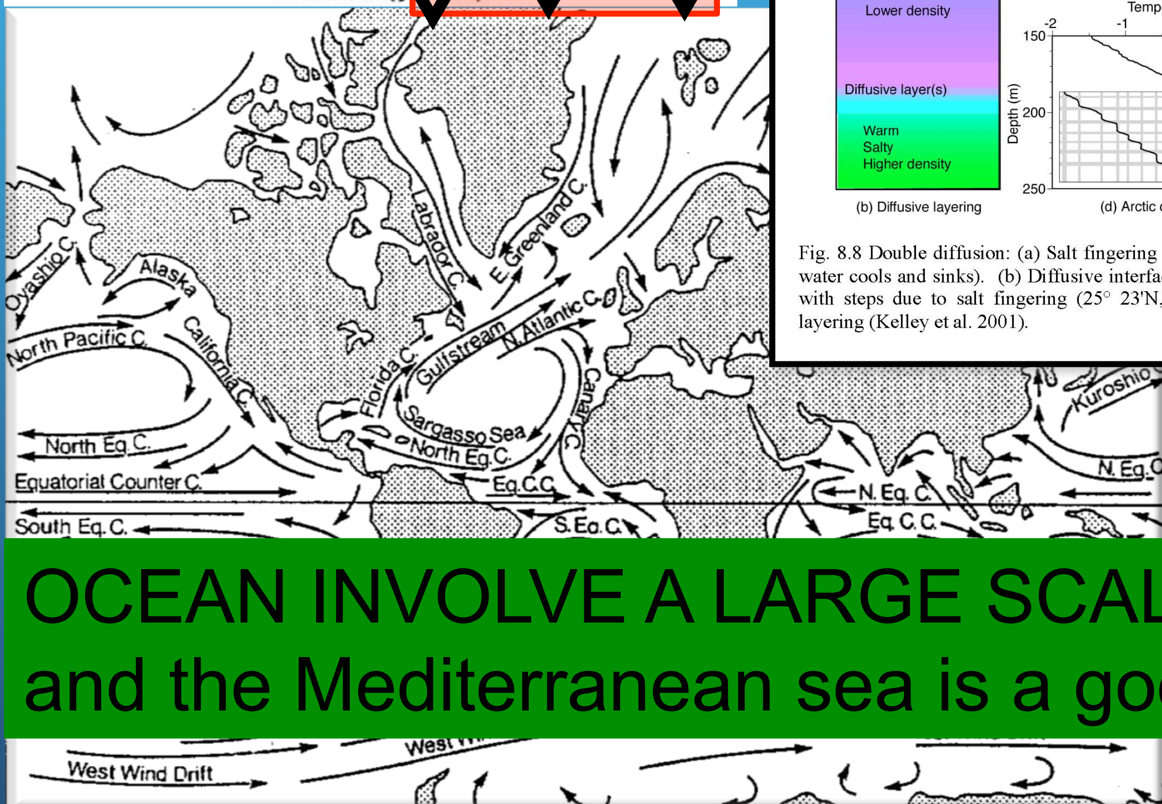
Schellnhuber et al., PNAS, 2008

GENERAL CIRCULATION

MESOSCALE

INTERNAL WAVES





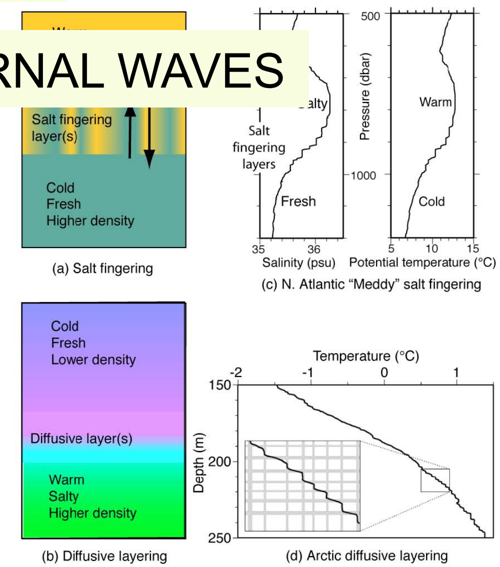


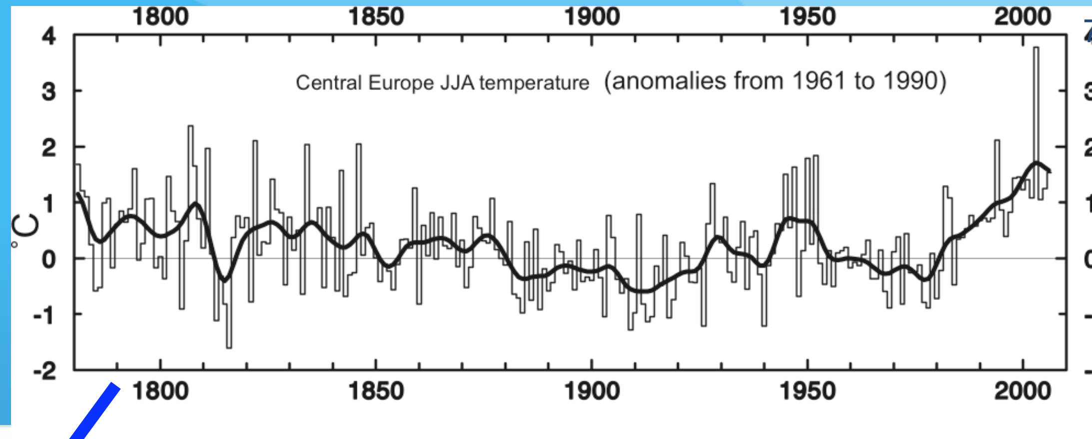
Fig. 8.8 Double diffusion: (a) Salt fingering interface (cold, fresh water warms and rises; warm, salty water cools and sinks). (b) Diffusive interface. (c) North Atlantic Mediterranean eddy salinity profile with steps due to salt fingering (25° 23'N, 26°W). (d) Arctic temperature profile with diffusive layering (Kelley et al. 2001).

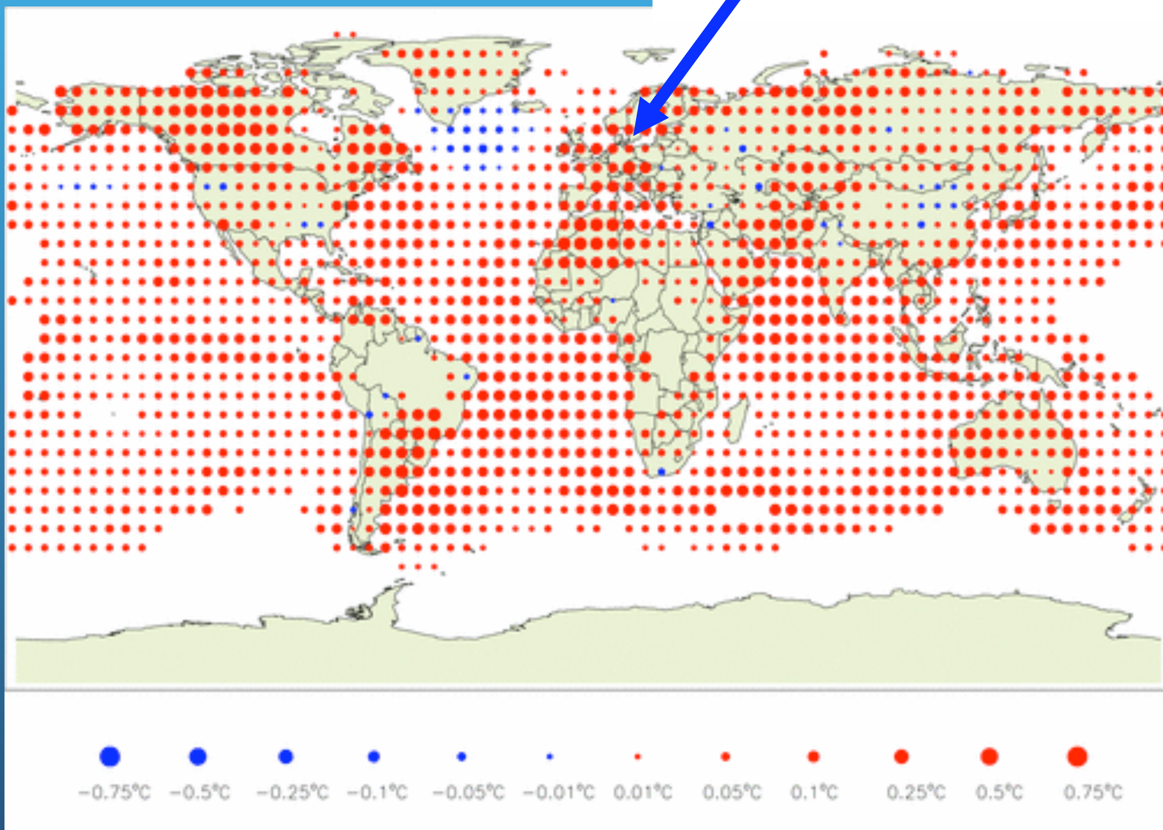
OCEAN INVOLVE A LARGE SCALE OF MOTION and the Mediterranean sea is a good example!!!

OBSERVATION: TEMPERATURE

Global distribution of temperature change for June/July/Aug since 1880

http://www.ncdc.noaa.gov/gcag/gcag.html

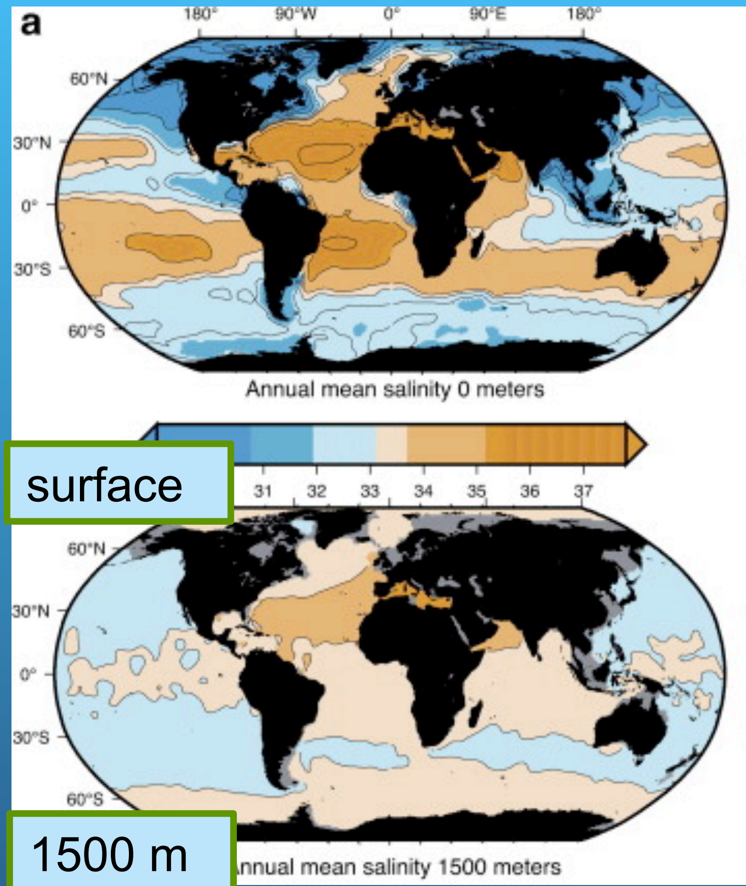


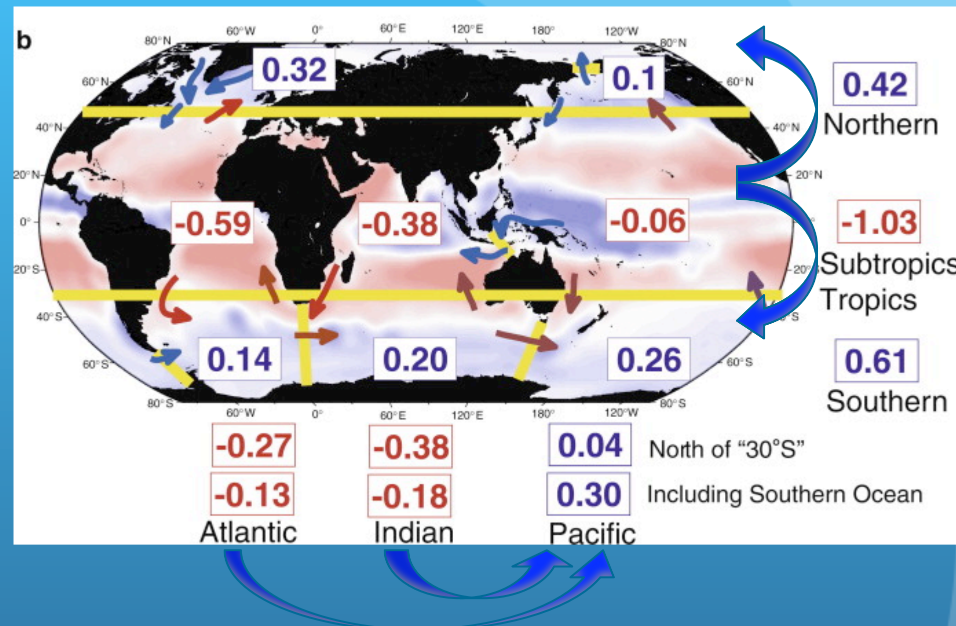


- **There are some exceptions to the general trends (land use?), and local ups and downs in individual years**
- **Global warming more likely than not contributed to the 2003 European heat wave. Future?**

SALINITY

Salinity balances and changes: example of importance of zonal redistribution pathways in addition to meridional (Talley, Proc. in Ocean. 2008)



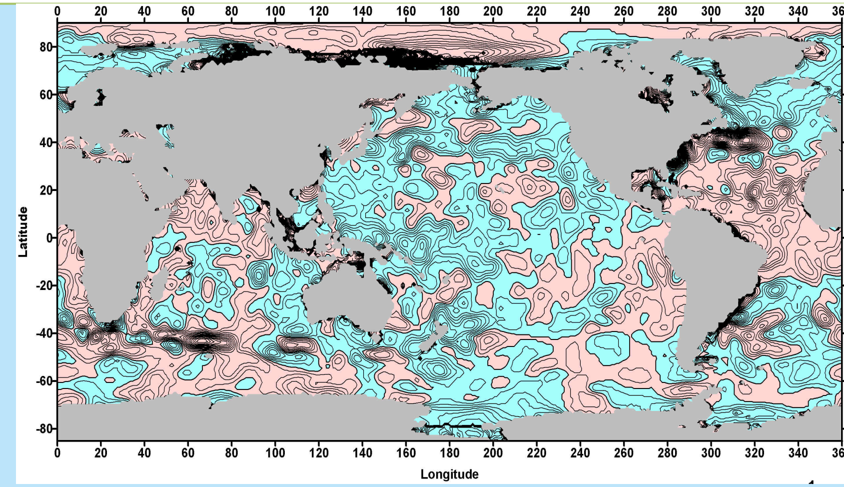


Saltier Atlantic and Indian
Fresher Pacific

1. Freshwater convergences required to maintain mean salinity distribution
2. Meridional FW transports from evaporative tropics/subtropics to high latitudes
3. Zonal FW transports from Atlantic/ Indian to Pacific

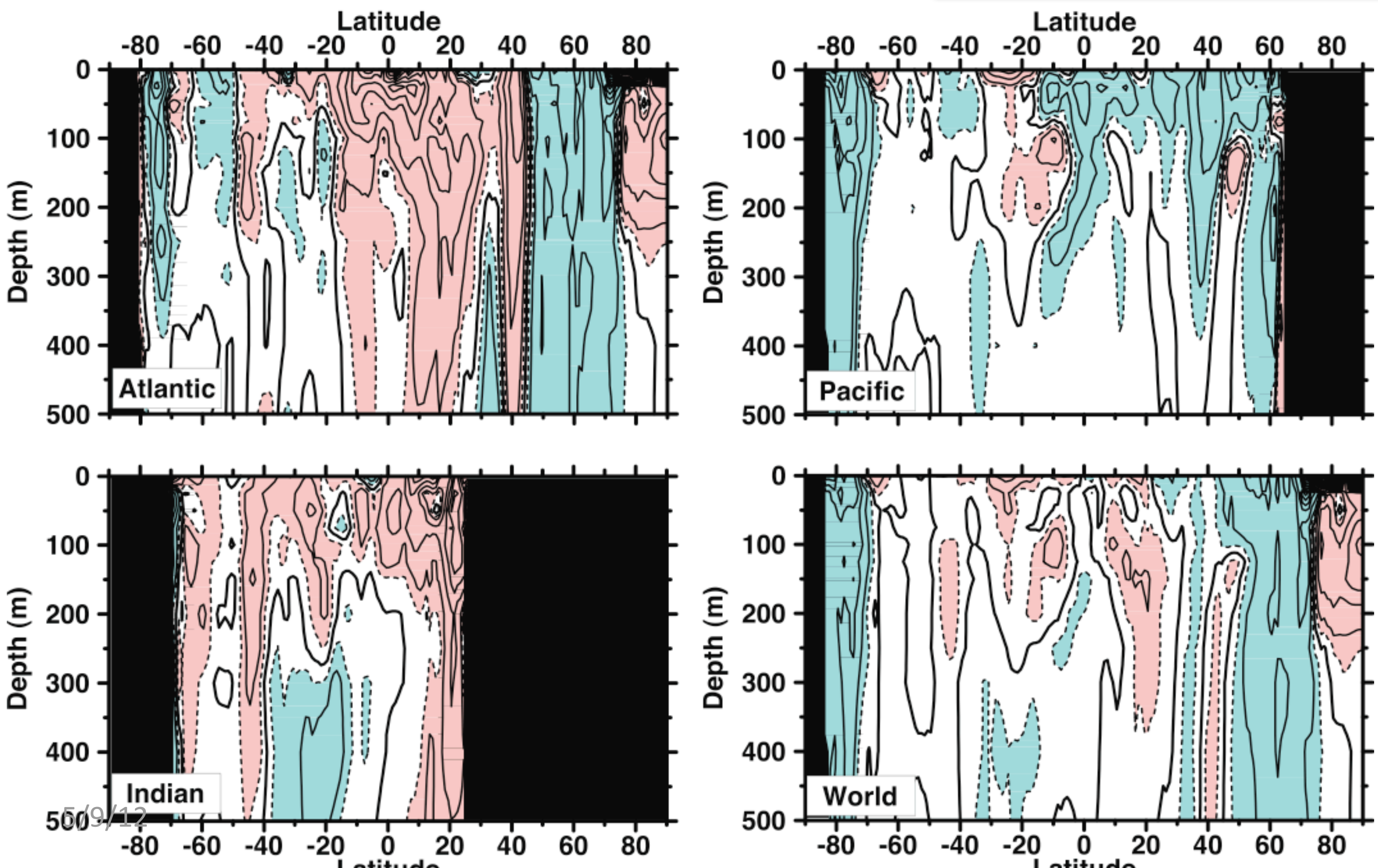
Salinity trends and relation to changes in freshwater forcing

Boyer et al. (2005)



Salty oceans becoming saltier
Fresher oceans becoming fresher

Linear trend 1955-1998, zonally-averaged salinity



Atlantic saltier

Pacific fresher

Indian saltier

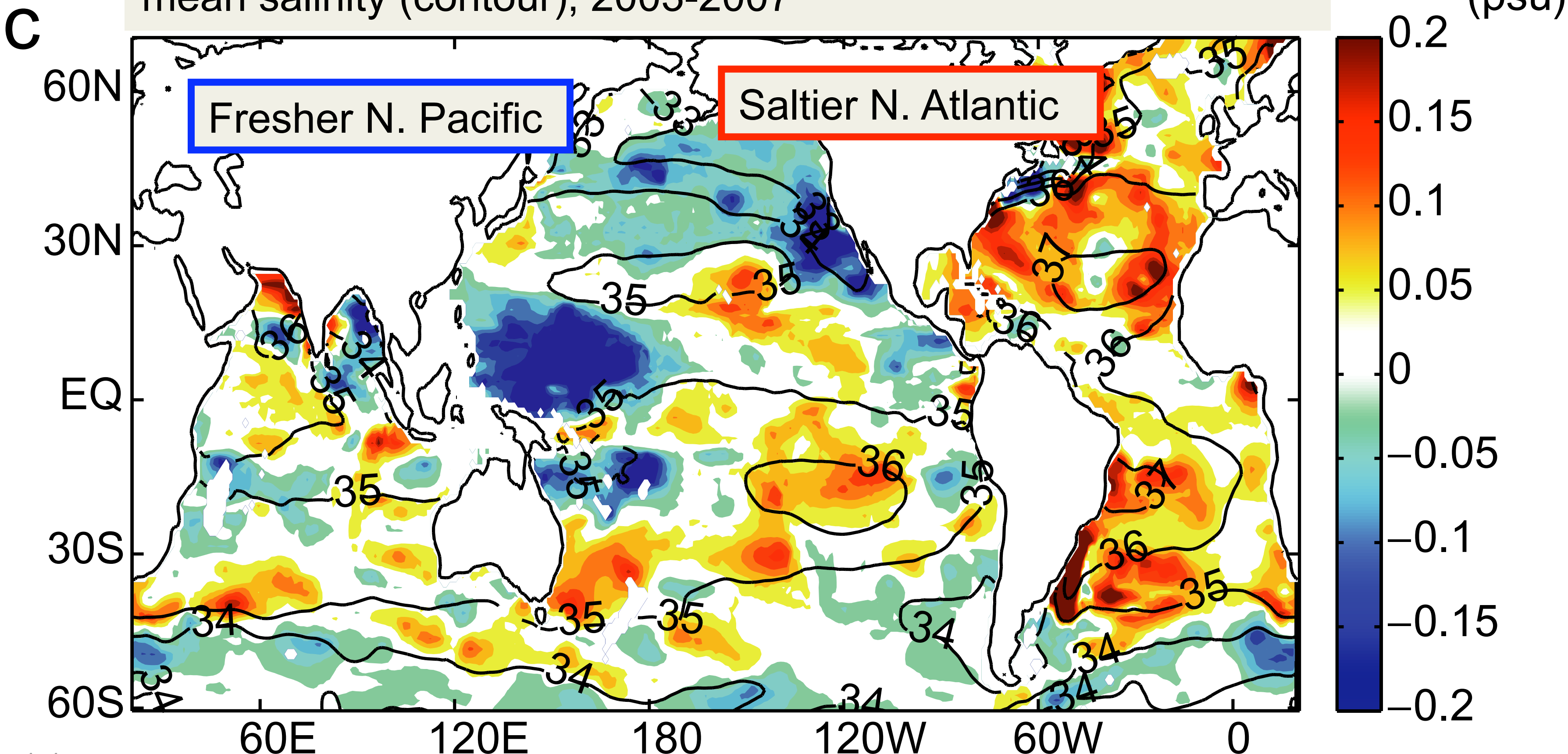
Global: neutral

Salinity variation: new data set to observe global pattern

Example of what will be possible with many years of Argo, the pattern much cleaner than historical trend because sampling is so much better.

Hosoda et al., 2008

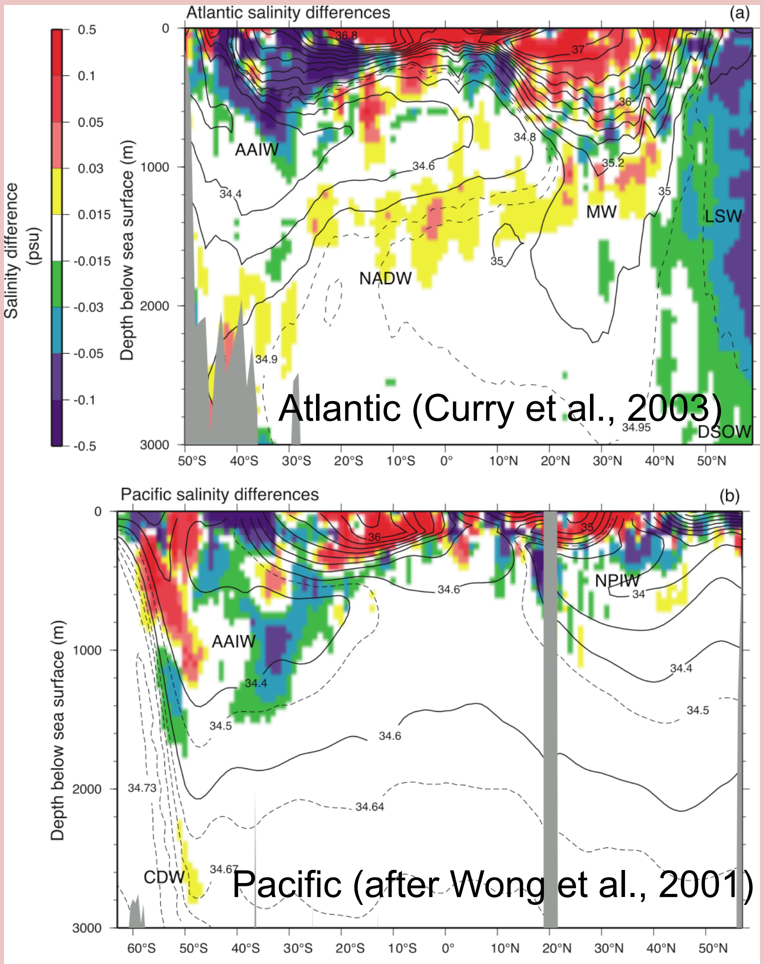
Surface-layer salinity anomaly (color) with the Argo annual mean salinity (contour), 2003-2007



open questions

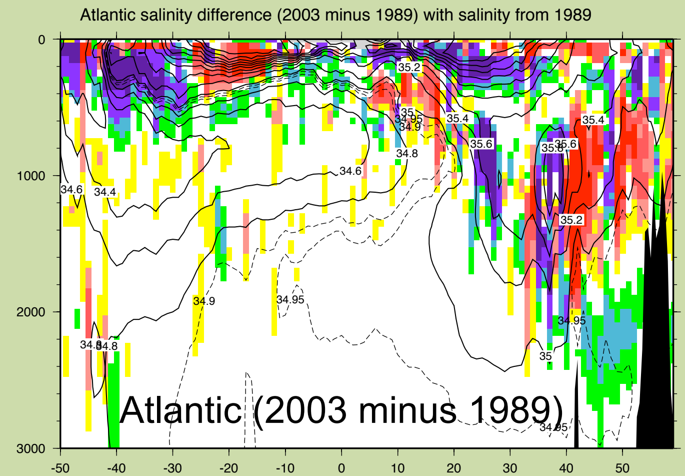
Salinity changes from quasi-synoptic data: trends or variability?

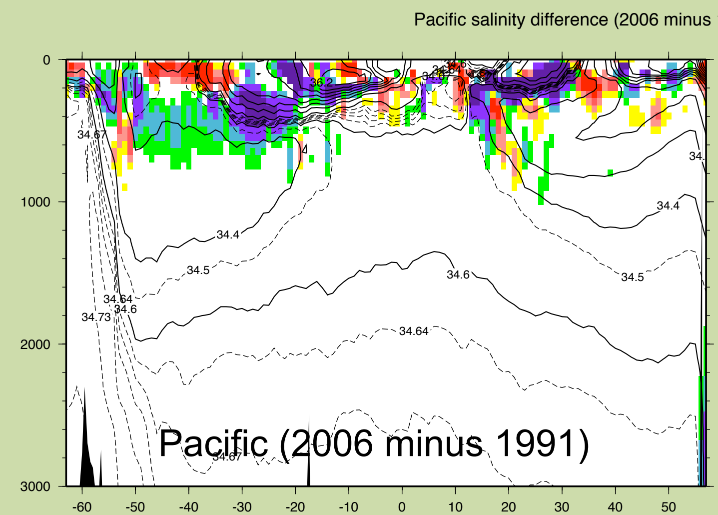
1990s minus 1950s-1960s



Freshening of AAIW, LSW, NADW,NPIW
Salinification of subtropics

2000s minus 1990s





Freshening of SAMW
(SubAntarticModeWater)
Saltier northern N. Atlantic
Mixed results in subtropics

Moving towards to the next IPCC report

Equal attention should be given to global-reaching changes originating in the Antarctic/Southern Ocean (e.g. bottom water has warmed by about 0.005 to 0.01°C in recent decades– Johnson et al., Kawano et al.);

Analysis in terms of global redistributions, not just meridional changes;

Apparent trends based on decadal differences must be treated with caution;
changes in integrating properties such as salinity, temperature, oxygen can be better interpreted in terms of trends than can synoptic changes in circulation;

Can ocean heat, chemistry and circulation changes be partially understood in terms of the natural modes of variability?

Mediterranean ocean variability over recent centuries inferred from observation and climate modeling

Mediterranean climate

(it's relevant for climate studies?)

The Mediterranean is located in a transitional zone where mid-latitude and tropical variability are both important and compete

The northern part of the Mediterranean region presents a Maritime west coastal climate while the southern part is characterized by a Subtropical desert climate

in summer is exposed to South Asian Monsoon and the Siberian high pressure system in winter

The southern part is mostly under the influence of the descending branch of the Hadley cell, while the northern is more linked to NAO and other mid-latitude teleconnections patterns

The hydrological Mediterranean cycle
(The closure depends on the Gibraltar Strait !!)

In the Mediterranean P has an annual mean ranging from 331 to 477 mm yr-1, with a seasonal cycle amplitude of 700 mm yr-1.
Evaporation is estimated in the range of 934–1176 mm yr-1 with a seasonal cycle amplitude of 1000 mm yr-1.
The E-P gives an annual mean Mediterranean Sea water loss from 500 to 700 mm yr-1.
The annual mean river discharge is 100 mm yr-1.

The estimated Mediterranean freshwater deficit of about 500 mm yr-1, consistent with the water flux at the Gibraltar Strait of about 1 Sv (from Mariotti et al., 2002)

Closure of the Mediterranean hydrological cycle
(from Mariotti et al., 2002)

The main components of the Mediterranean Sea hydrological cycle are shown in the schematic two-box diagram of Fig. 1. The time-varying equation for the vertically integrated atmospheric water budget is

$$\frac{dW}{dt} = E - P - D, \qquad (1)$$

where W is the total water vapor content, P is precipitation, E evaporation, and D is the vertically integrated moisture divergence:

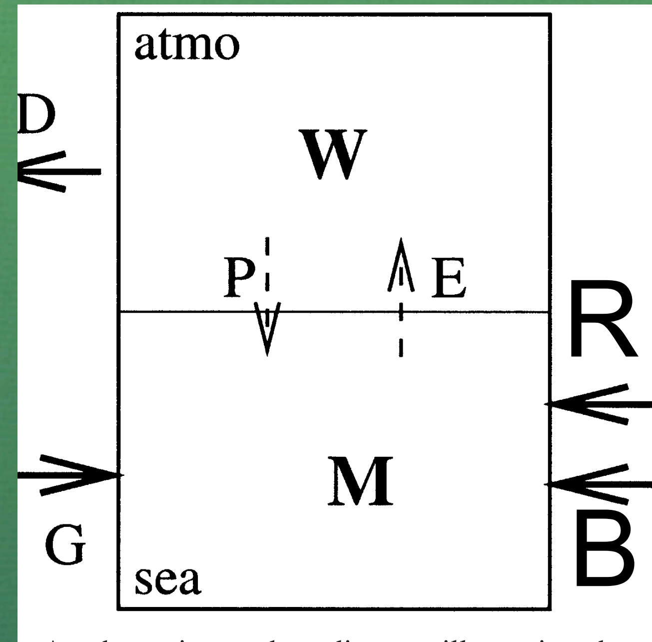
$$D = \nabla \cdot \mathbf{Q}, \qquad \mathbf{Q} \equiv \int_0^H \mathbf{V} q \, dz.$$

Here $\mathbf{Q}$ is the vertically integrated atmospheric moisture flux ($\mathbf{V}$ is the wind, q is atmospheric specific humidity, and H is the height in meters). On an annual mean basis the 1hs of Eq. (1) can be neglected and the atmospheric water budget equation is approximately

$$E - P \simeq D. \qquad (2)$$

Here we have also neglected the analysis error (Schubert et al. 1993) that for NCEP reanalyses is at most about 25% of the annual mean D. The time-varying equation for the total Mediterranean Sea water content M is

$$\frac{dM}{dt} = G + B + R - D, \qquad (3)$$



A schematic two-box diagram illustrating the m

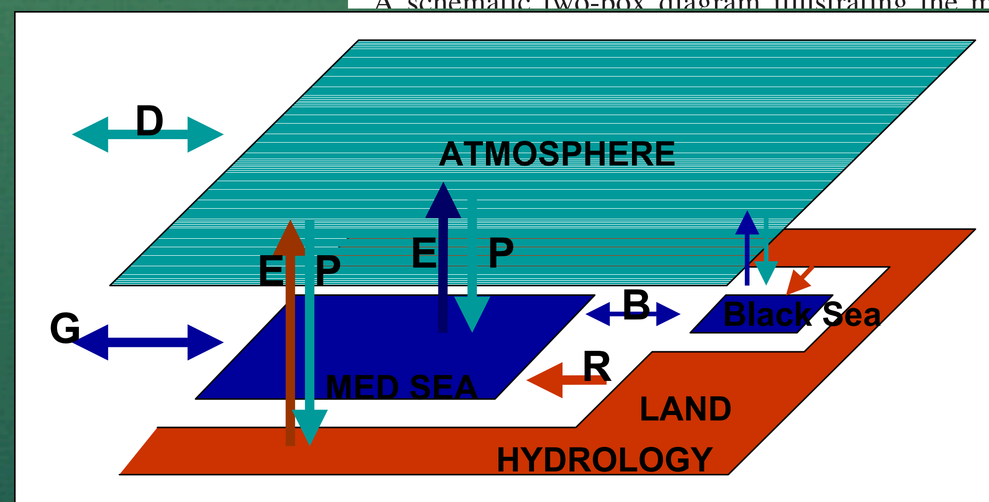


Figure 3.1. A schematic 3D box diagram illustrating the main components of the Mediterranean basin. P stands for precipitation, E for evaporation, R for river runoff, D for atmospheric water divergence, G for Gibraltar transport, B for Black Sea transport.

Role of the Mediterranean at global scale

- as heat resorvoir and source of moisture for surrounding land areas

- as source of energy and latent heat for cyclone development and its possible effect on remote areas, such as Sahel region

- **on the Atlantic overturning circulation (MOC)**

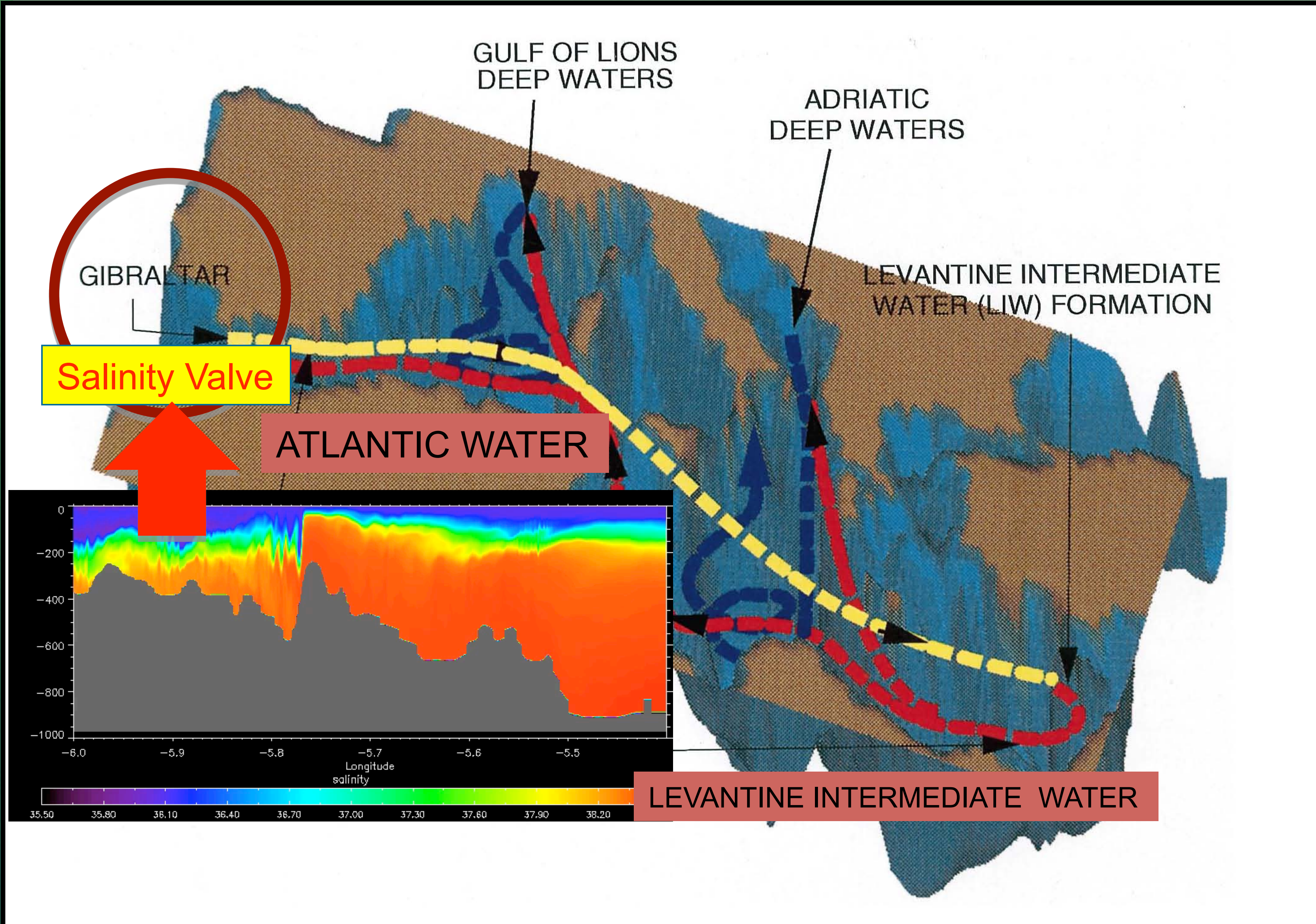
Mediterranean thermohaline circulation

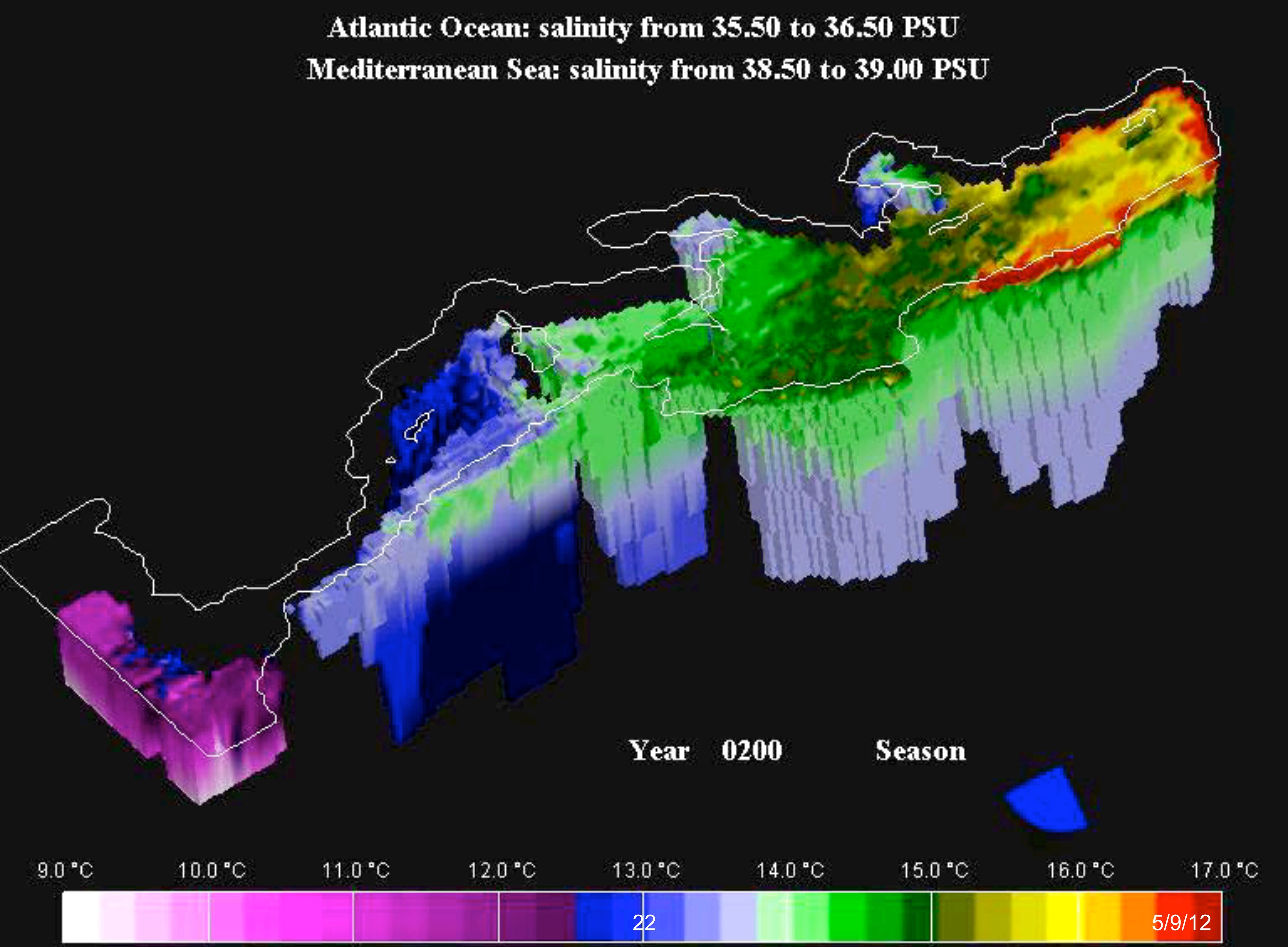
the basin-scale circulation is composed by three major thermohaline circulation : the first is “open” zonal circulation that connects the western to the eastern part of the basin; the others two are meridional cells confined to the western and eastern basin

the driving force is derived by air-sea interaction that determines localized convection processes

the western and eastern sub-basins are disconnected at deep levels and their thermohaline circulation are driven by the respective sources. The eastern is a closed cell endowed with multiple equilibria (EMT), in the western sub-basin observational and modelling studies are lacking

Mediterranean Thermohaline Circulation




Atlantic Ocean: salinity from 35.50 to 36.50 PSU
Mediterranean Sea: salinity from 38.50 to 39.00 PSU
Year 0200
Season
9.0 °C
10.0 °C
11.0 °C
12.0 °C
13.0 °C
14.0 °C
15.0 °C
16.0 °C
17.0 °C

Hydrological characteristic of the Mediterranean sea at multidecadal scale

(Marullo, Artale and Santoleri, published in J. of Climate, 2011)

1- SST (from 1854-today)

SST variability

Patterns of sea surface temperature (SST) variability on interannual and longer timescales result from a combination of atmospheric and oceanic processes.

These SST anomaly patterns may be due to intrinsic modes of atmospheric circulation variability that imprint themselves upon the SST field mainly via surface energy fluxes.

Examples include SST fluctuations in the Southern Ocean associated with the Southern Annular Mode, a tripolar pattern of SST anomalies in the North Atlantic associated with the North Atlantic Oscillation, and a pan-Pacific mode known as the Pacific Decadal Oscillation.

They may also result from coupled ocean-atmosphere interactions, such as the El Nino-Southern Oscillation phenomenon in the tropical Indo-Pacific, the tropical Atlantic Nino, and the cross-equatorial meridional modes in the tropical Pacific and Atlantic.

Finally, patterns of SST variability may arise from intrinsic oceanic modes, notably the Atlantic Multidecadal Oscillation (AMO).

Goals

- To evaluate long term variations of the Sea Surface Temperature (as climatic index) in the North Atlantic Ocean and Mediterranean Sea
- To understand relations between Atlantic and Mediterranean variations
- To measure the contribution of harmonic components to long terms variations (multidecadal variability)
- To understand how much the observed multi-decadal variability is internal versus forced climate change

Available Data

The Sea Surface Temperature is the longest instrumental information available for the global world ocean.

- Interpolated: Reconstructed SST produced by NCDC (ERSST.v3 1854-present) and Hadley Centre (HadISST 1870-present) including pre-1942 adjustment.
- Non interpolated: ICOADS (International Comprehensive Ocean-Atmosphere Data Set) SST (gridded, non interpolated 1x1 , 2x2) up to may 2007.

Barnett (1984) gave strong evidence that historical marine data are heterogeneous. He found a sudden jump around 1941 in the difference between SST and all-hours air temperatures reported largely by the same ships. Folland *et al. (1984) explained this as* being mainly a result of a sudden but undocumented change in the methods used to collect sea water to make measurements of SST. The methods were thought to have changed from the predominant use of canvas and other uninsulated buckets to the use of engine intakes (From Folland and Parker 1995).

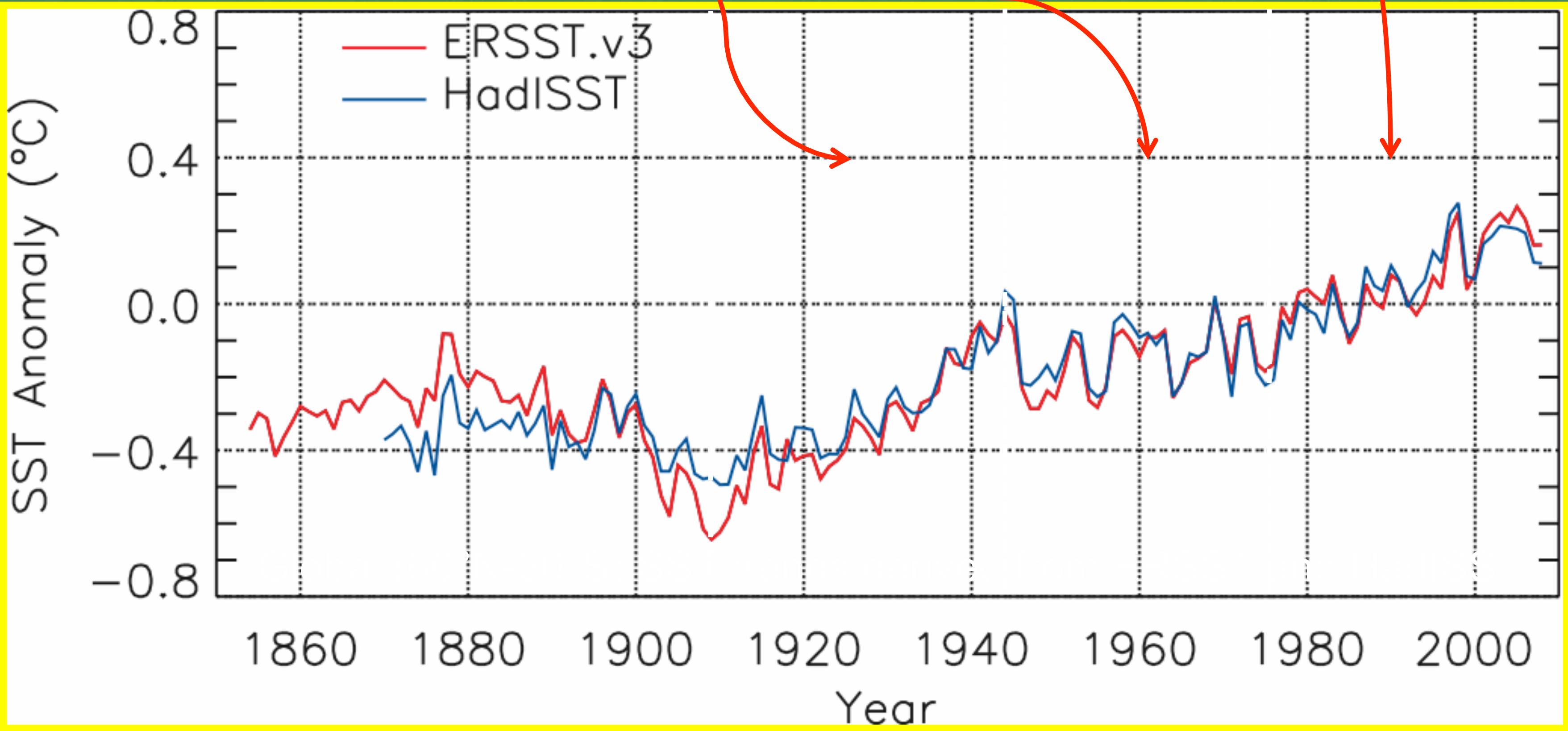
ERSST.v3 pre-1942 SST corrections are based on Smith and Reynolds (2002) while HadISST corrections are based on Folland and Parker (1995)

Figure 9. (a) The UK Meteorological Office REF 1800 black insulated bucket, German metal and leather bucket and the UK Meteorological Office Mk II canvas sea temperature bucket and (b) ship's wooden bucket. 1891 (courtesy of Scottish Maritime Museum).

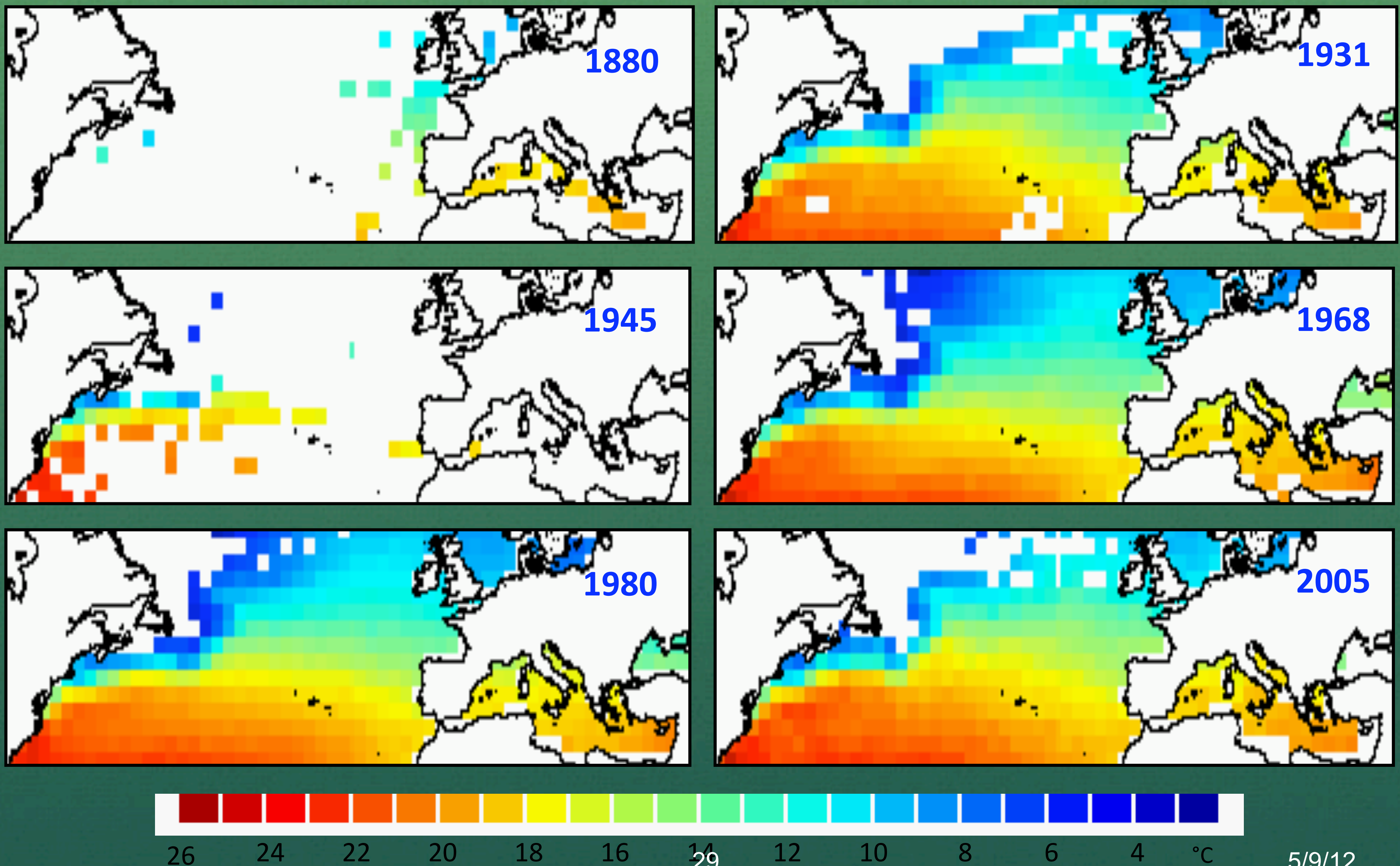
SST Increase: 0.4-0.5 °C
in 35 years

SST constant

SST Increase: 0.4-0.5 °C
in 35 years

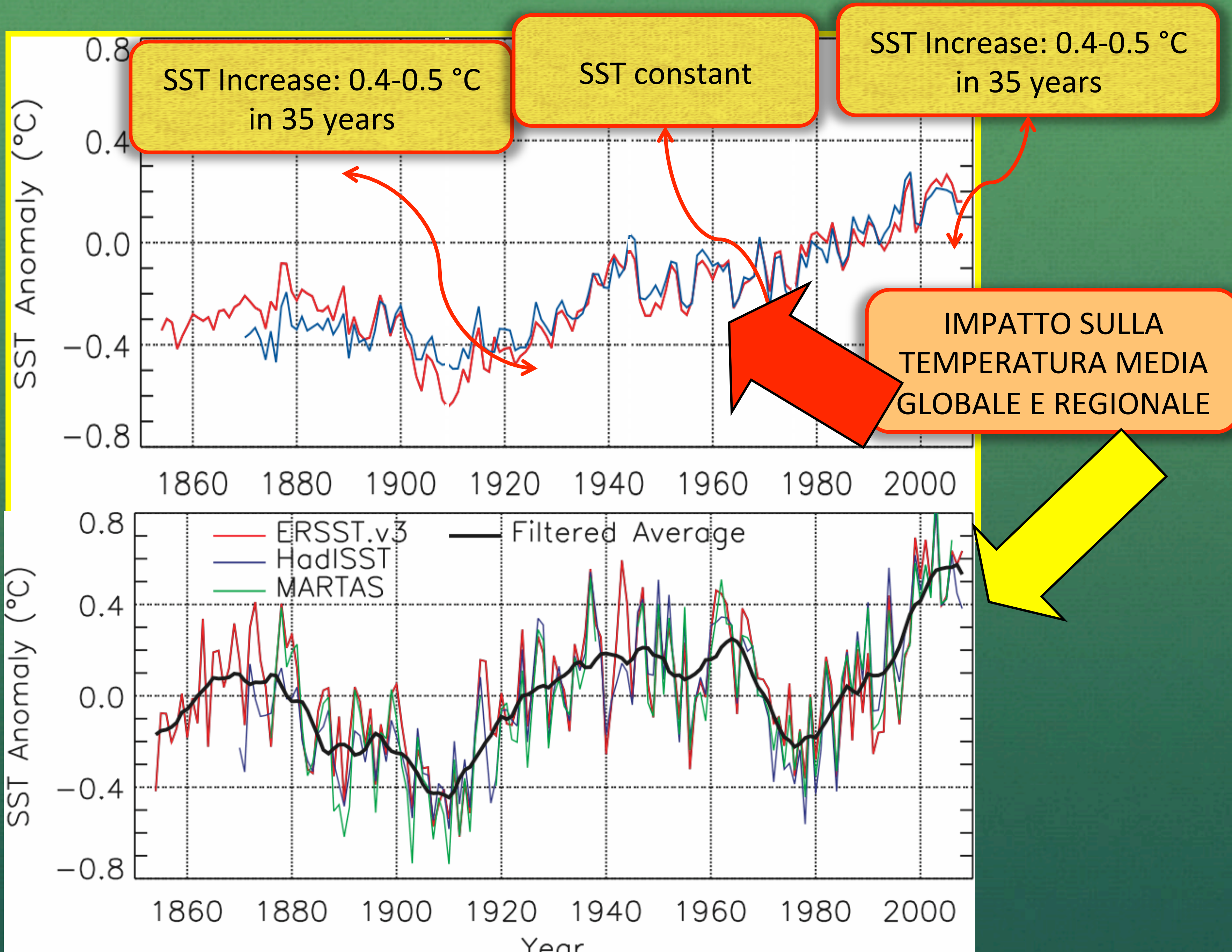


Spatial distribution of available yearly ICOADS SST average for some selected year at the Mediterranean latitude

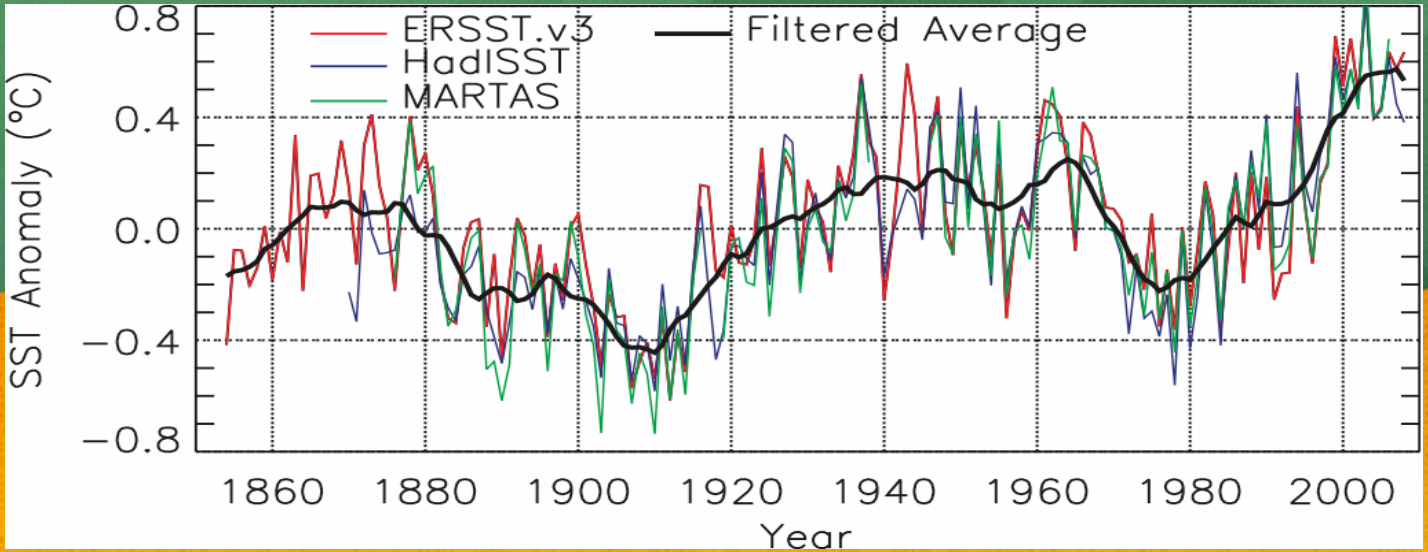


Having no independent sea truth data to validate the reconstructed SST products for most of the analysis period (1854 - today), a strategy could be either to investigate the consistency between the two time series evaluating differences in long term trends or oscillations and seasonal components or to produce a third SST time series over some region where more original ICOADS data are available using a simple but robust space average that consider the number of valid ICOADS SST for each month in the whole region.

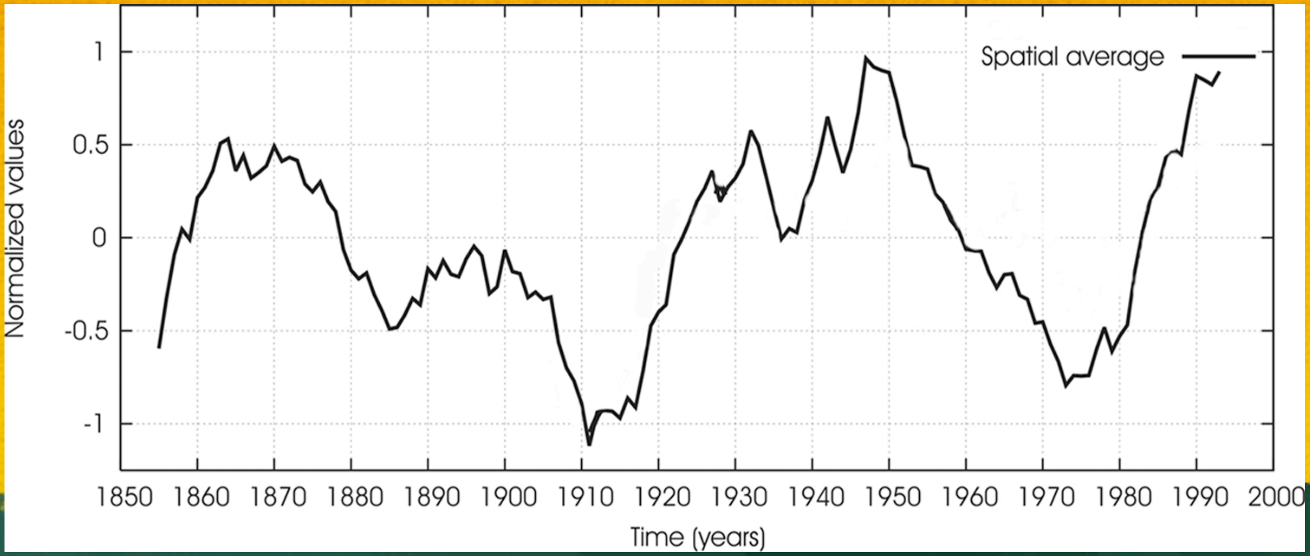
The Mediterranean Sea is one of these data rich region.


SST Increase: 0.4-0.5 °C in 35 years
SST constant
SST Increase: 0.4-0.5 °C in 35 years
IMPATTO SULLA TEMPERATURA MEDIA GLOBALE E REGIONALE
SST Anomaly (°C)
0.8
0.4
0.0
−0.4
−0.8
1860
1880
1900
1920
1940
1960
1980
2000
ERSST.v3
HadISST
MARTAS
Filtered Average
Year

Hydrological characteristic of the Mediterranean sea at multidecadal scale: 1- SST (from 1854-today)



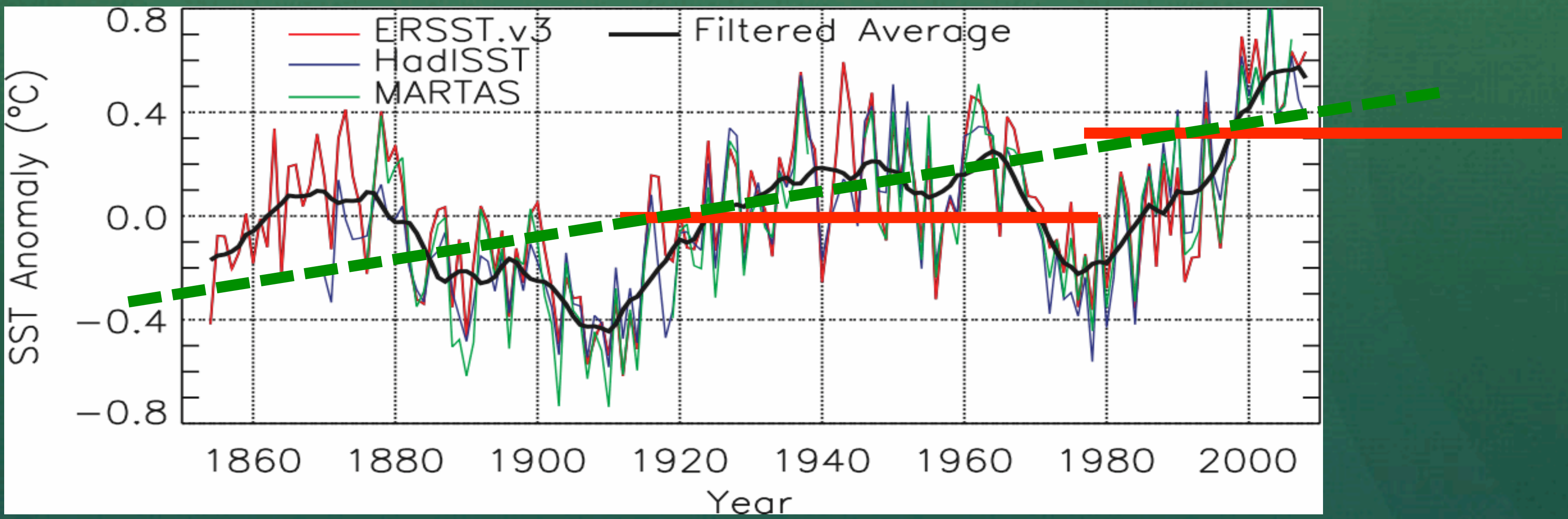
Mediterranean annual SST anomaly (respect to the 1971-2000 average) from 1854 to 2008



The curve corresponds to standardized values of the spatial average of Mediterranean summer temperatures for the period 1850–1999 (Adapted from Xoplaki et al., 2003b).

Role of the Mediterranean at global scale

- as heat resorvoir and source of moisture for surrounding land areas
- as source of energy and latent heat for cyclone development and its possible effect on remote areas, such as Sahel region
- impact on the Atlantic overturning circulation (MOC)
- Mediterranean SST (from 1854-today) shows multidecadal
- variability similar to the Atlantic Multidecadal Oscillation (AMO)



WARMING OF THE MEDITERRANEAN SURFACE LAYER: SST ARE INCREASING SINCE 1860 BY 0.4°C

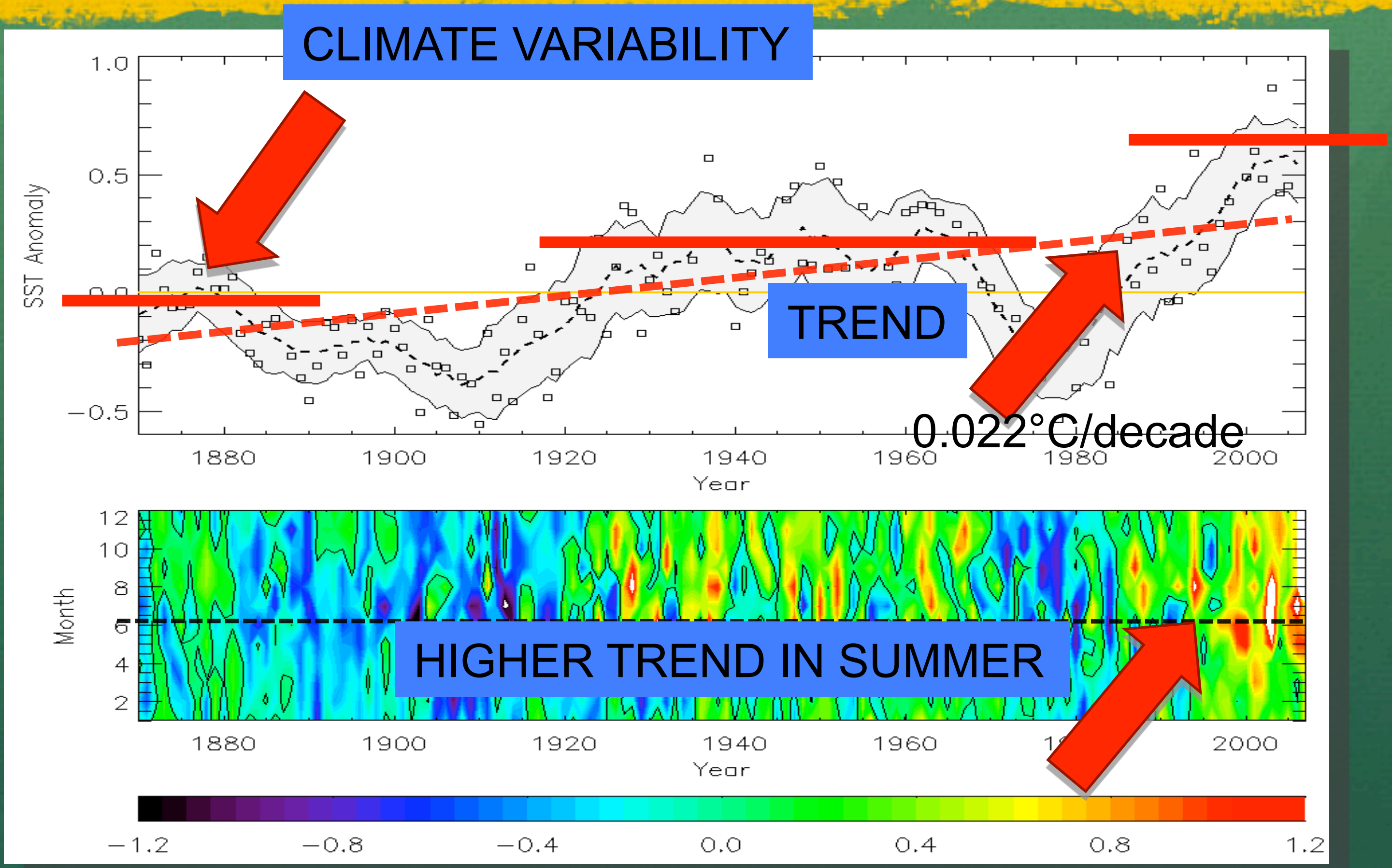
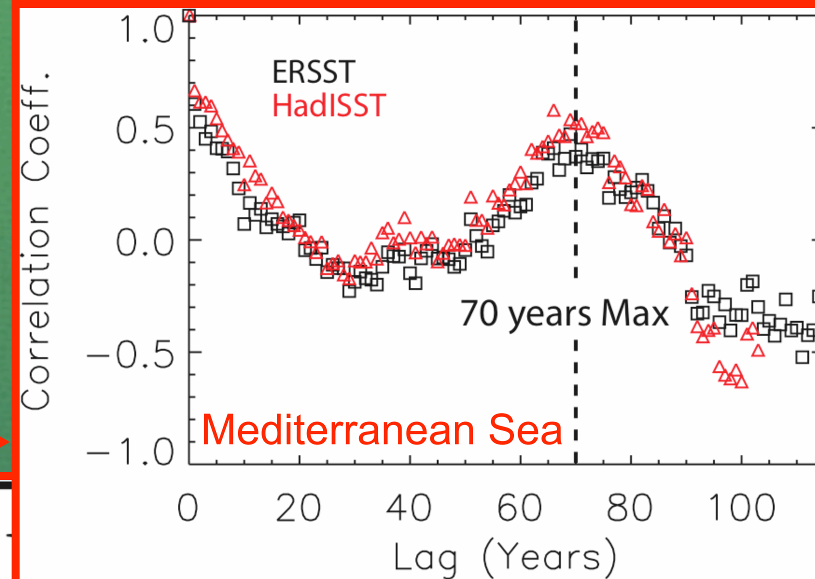
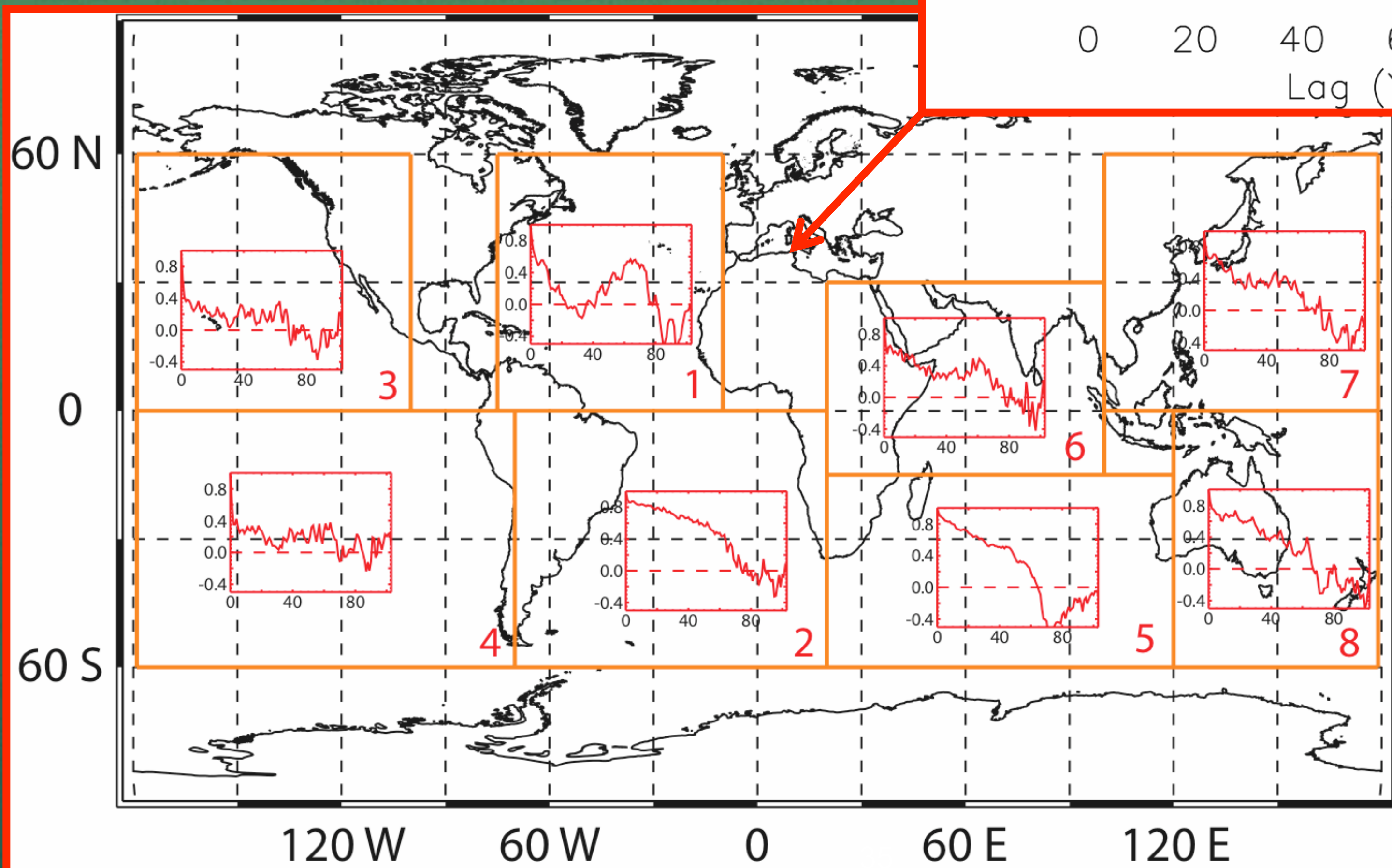


Figure 1. Upper panel SST yearly anomaly. Lower panel SST Monthly anomalies. The black contour line is the zero level

Is this frequency observed in other areas of the world oceans?

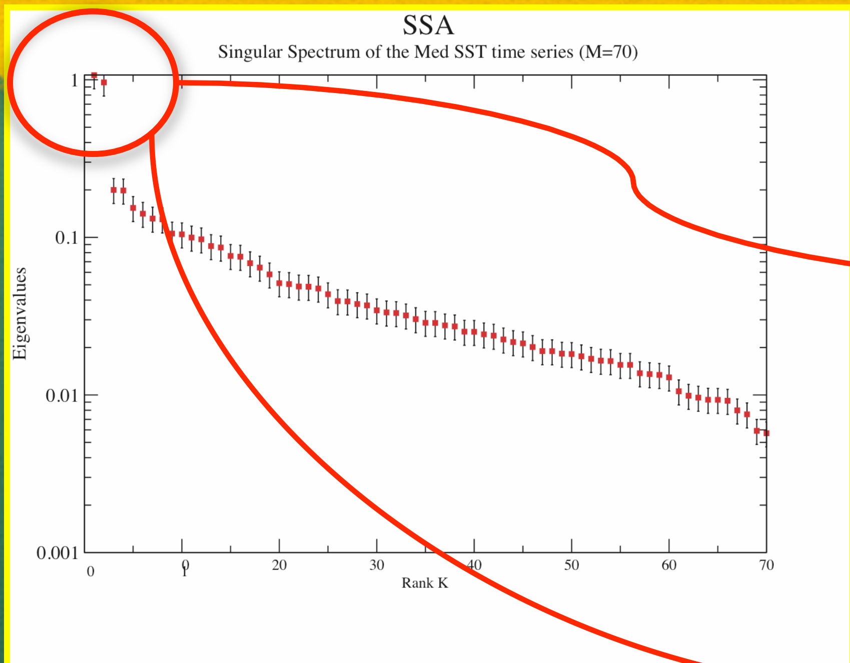
Autocorrelation coefficients for different time lags over the Mediterranean using HadISST (red triangles) and ERSST (black squares).



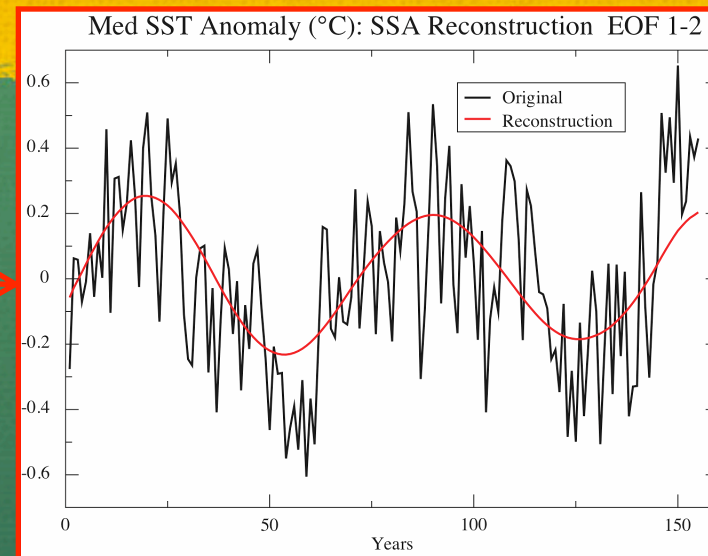


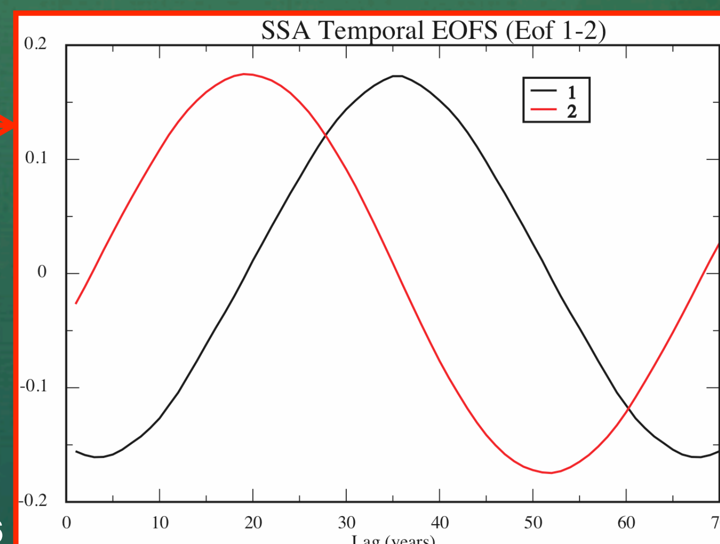
Autocorrelation coefficient for different world ocean regions

Mediterranean Multi-decadal SST Variability (SSA - Singular Spectral Analysis)



40% of the Total variance4



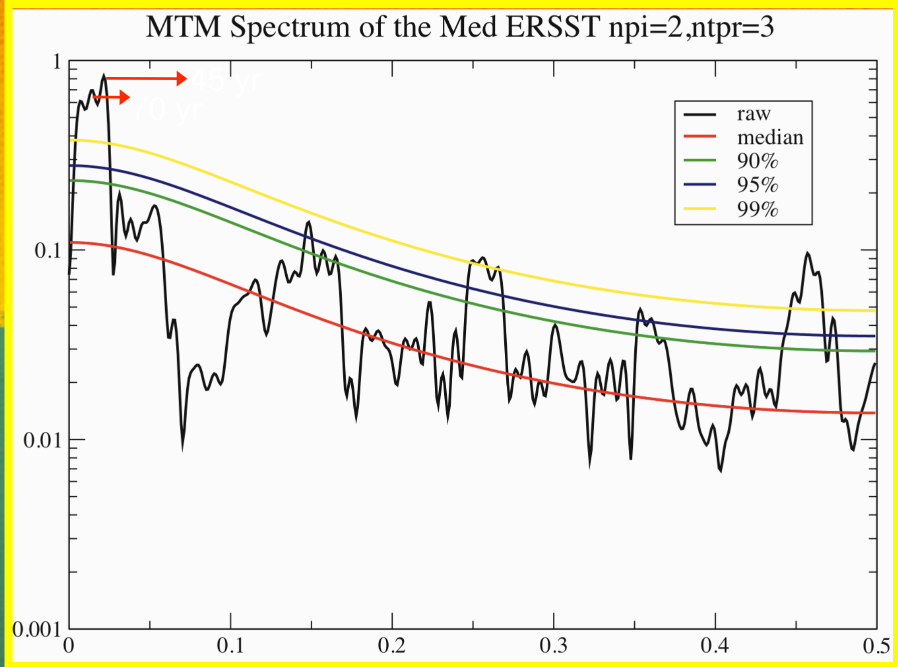


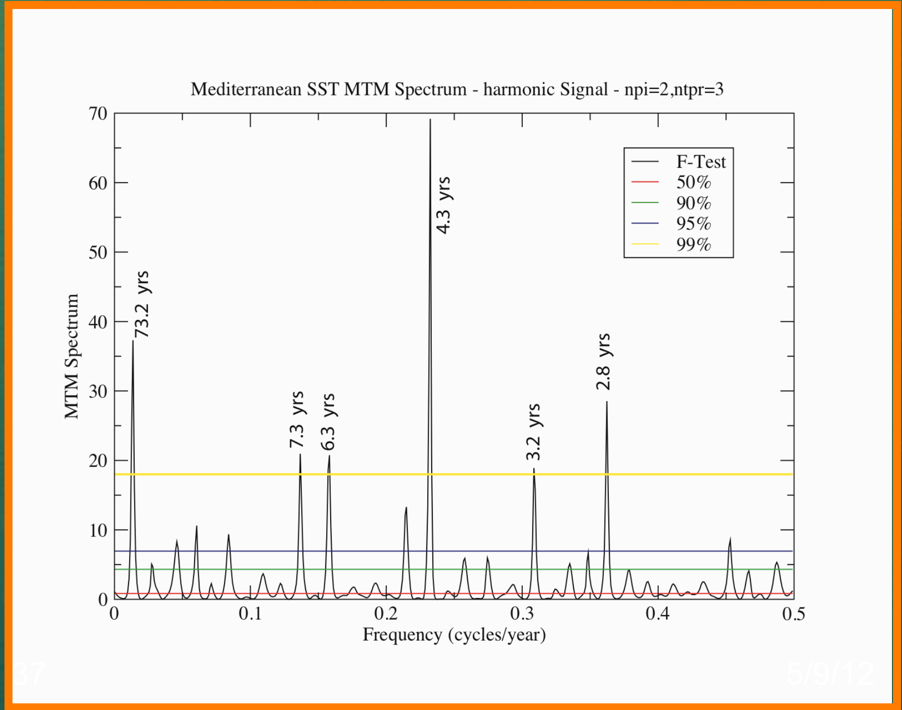
The first two leading EOFs have approximately the same amplitude and are in quadrature. They capture the main low frequency variability of the SST time series (about 70 years). This fact could be interpreted as the occurrence of a ghost limit cycle related to a physical oscillation of the dynamical system that has generated the SST time series (Ghill et al., 2001)

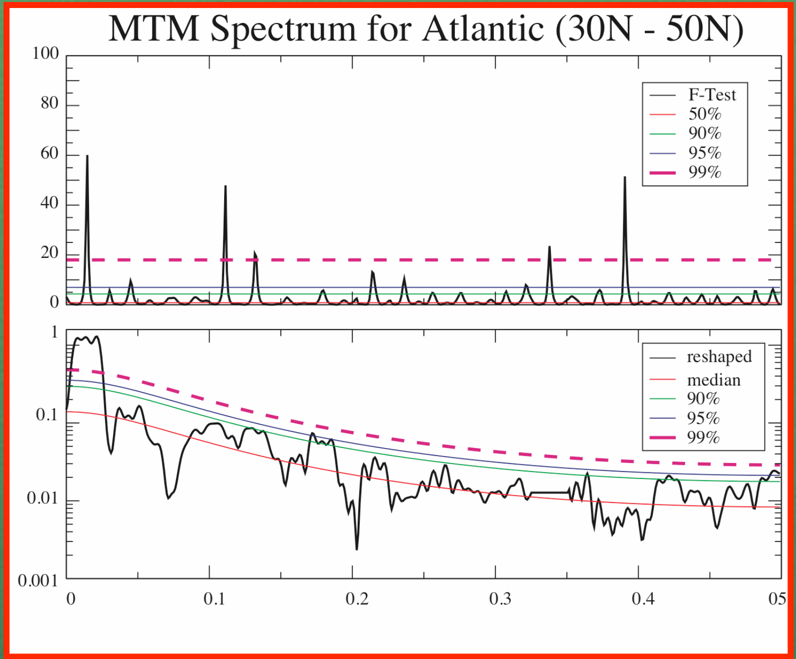
The low frequency variability of the Mediterranean was evaluated applying the Multitaper method (MTM) method to the detrended SST. The Multitaper method is a technique developed by D.J. Thomson (1982) to estimate the power spectrum of a stationary ergodic finite-variance random process.

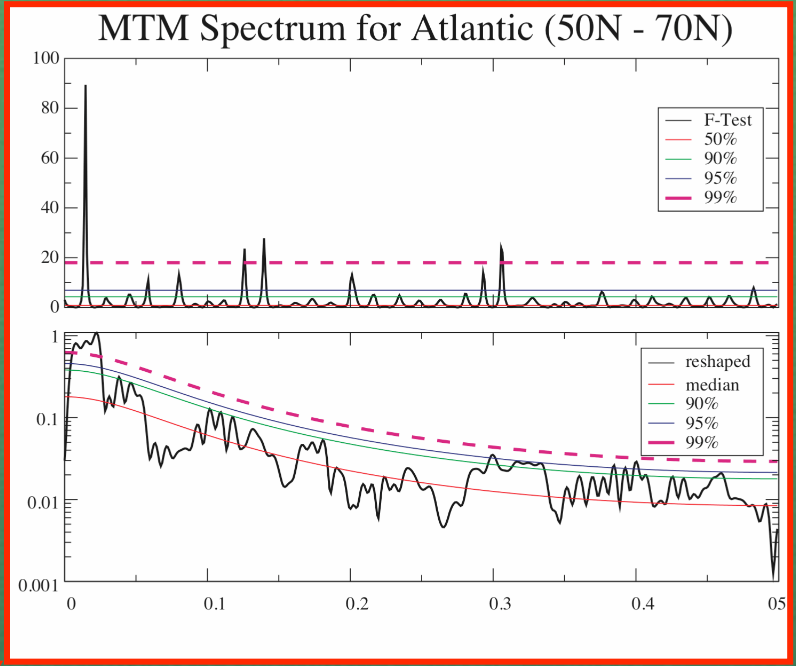
a)MTM spectrum of the Med ERSST time series, the estimated red noise background and associated 90%, 95%, 99% significance levels are shown by the four smooth curves.

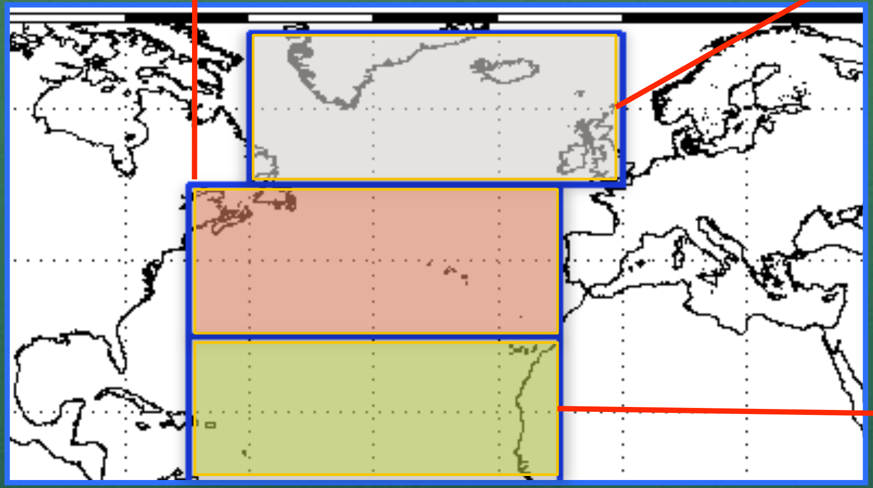
b) Six harmonic signals, significant at 99% level, with interannual (between 2.8 and 7.3 years) and multidecadal (73.2 years) frequencies.

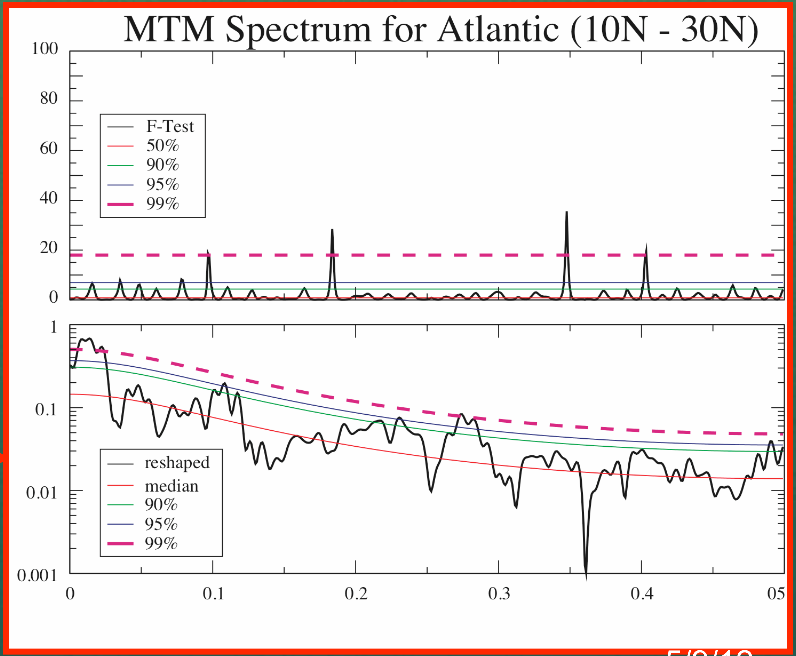




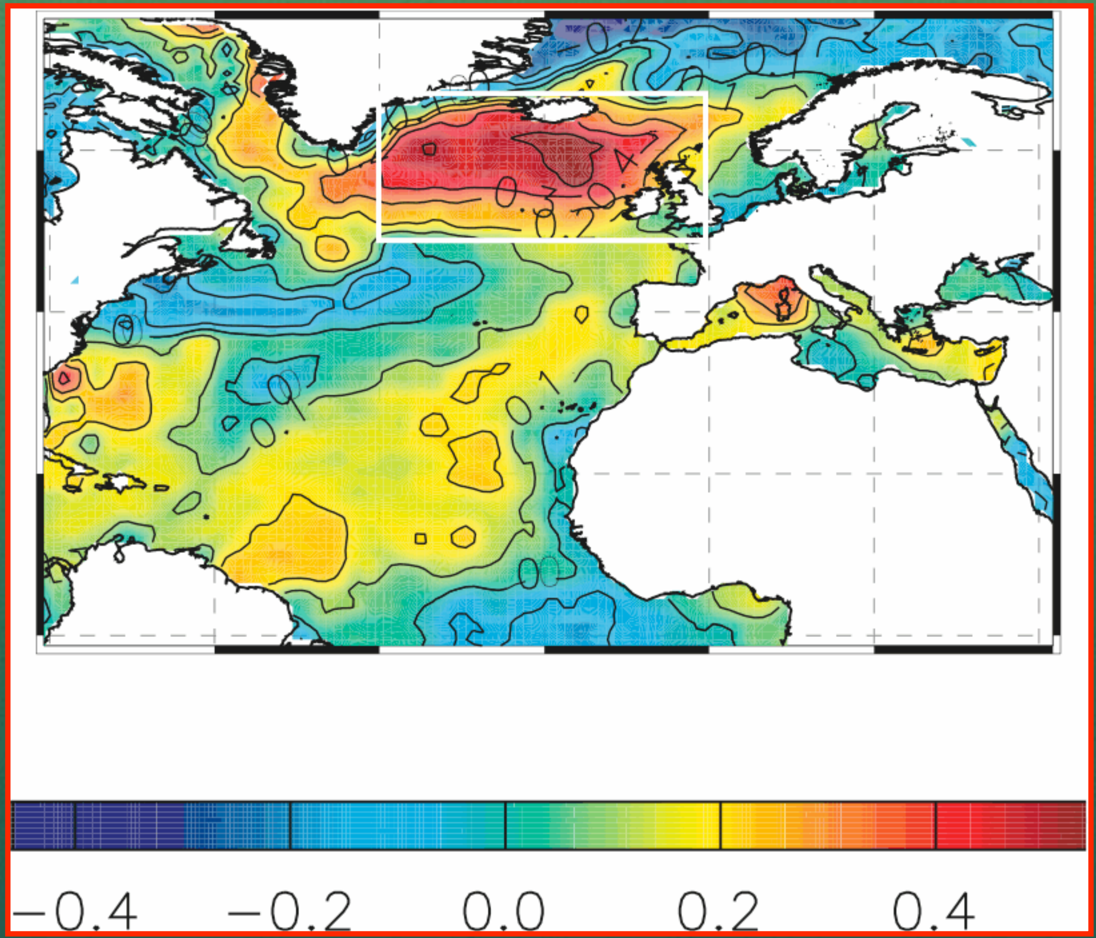

MTM Spectrum for Atlantic (30N - 50N)
F-Test
50%
90%
95%
99%
reshaped
median
90%
95%
99%

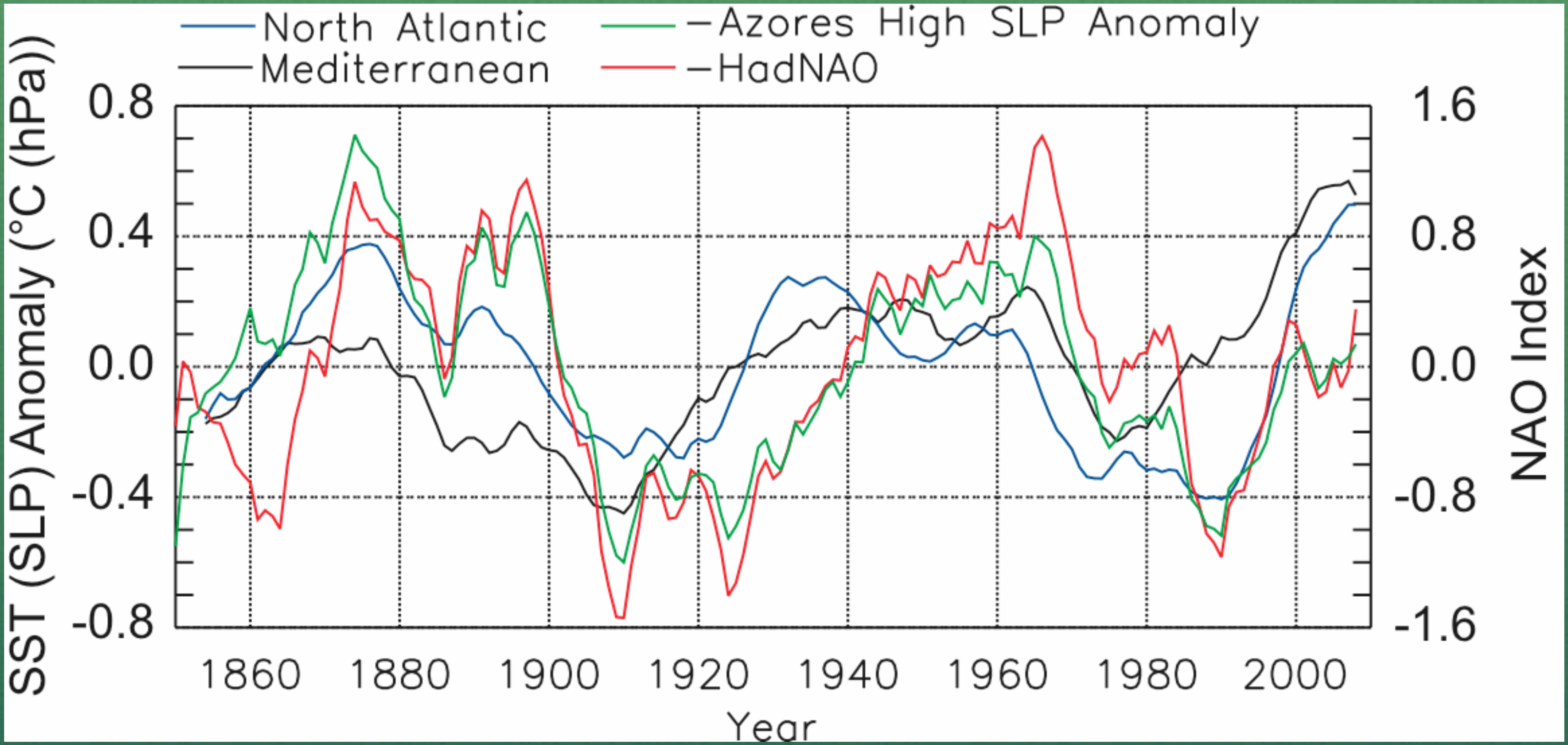

MTM Spectrum for Atlantic (50N - 70N)
F-Test
50%
90%
95%
99%
reshaped
median
90%
95%
99%



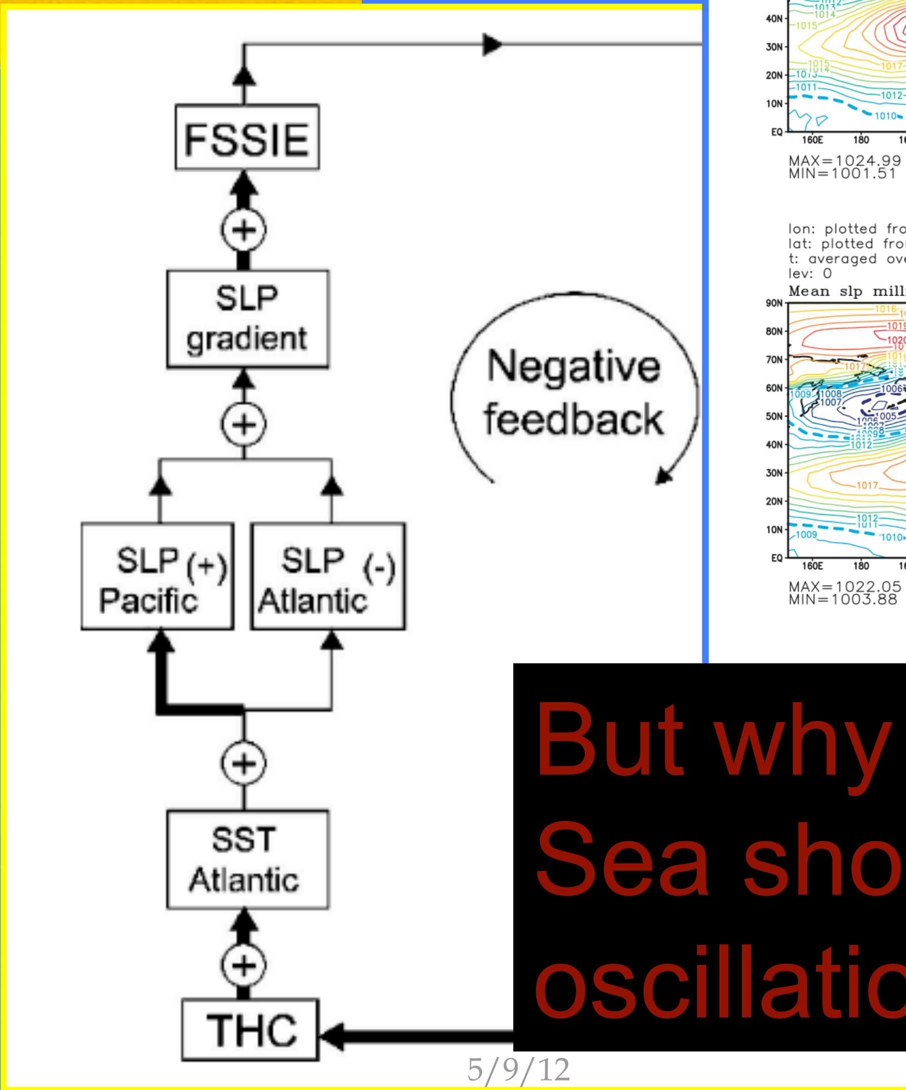

MTM Spectrum for Atlantic (10N - 30N)
F-Test
50%
90%
95%
99%
reshaped
median
90%
95%
99%

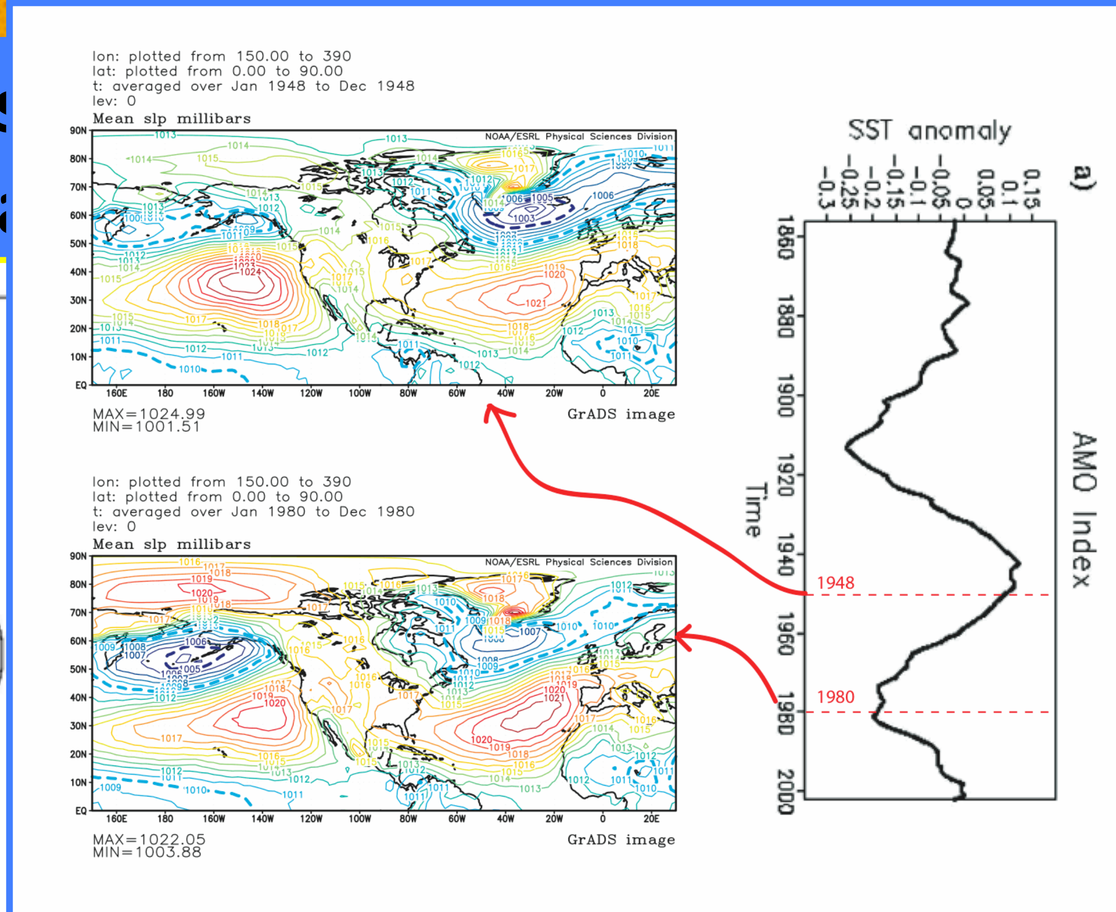
Correlation map between Azores High Sea Level Pressure Anomaly (sign changed) and Sea Surface Temperature Anomaly (Period 1870-2007). Areas with high correlation values indicate situations where periods of higher SLP at about 30-35 N in the Atlantic Ocean correspond to period of colder SST (and vice versa)




North Atlantic
Mediterranean
−Azores High SLP Anomaly
−HadNAO
SST (SLP) Anomaly (°C (hPa))
0.8
0.4
0.0
-0.4
-0.8
1.6
0.8
0.0
-0.8
-1.6
NAO Index
1860
1880
1900
1920
1940
1960
1980
2000
Year

Mechanis
multidec





But why the Mediterranean Sea should follow the same oscillation?

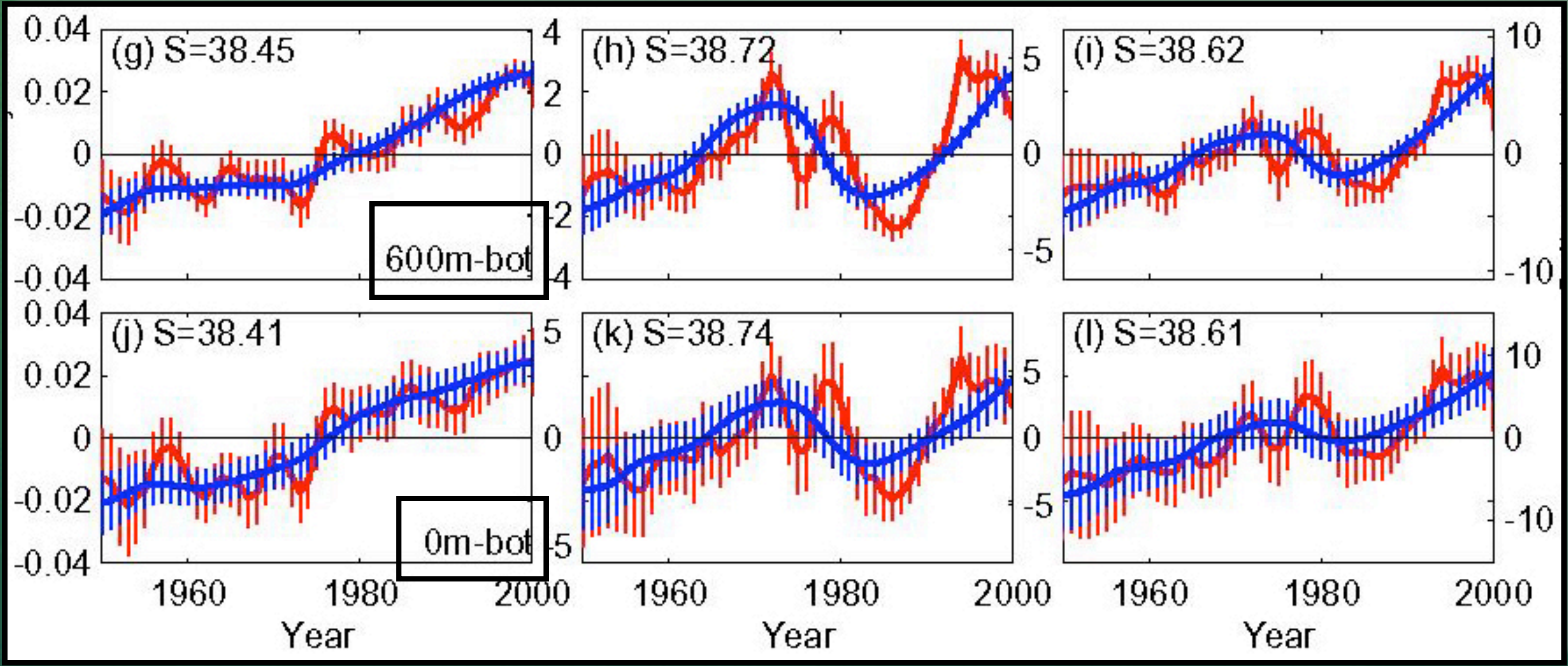
Third Santa Fe Conference on Global and Regional Climate Change;
Santa Fe, New Mexico, 30 October to 4 November 2011

…..Within the natural internal oscillations associated with ocean-atmosphere coupling, the most notable of these couplings is the
Atlantic Multidecadal Oscillation (AMO), which was suggested to account for up to one half
of regional rapid warming since 1970 and
for the relatively constant global temperature
signal seen subsequent to 2000.

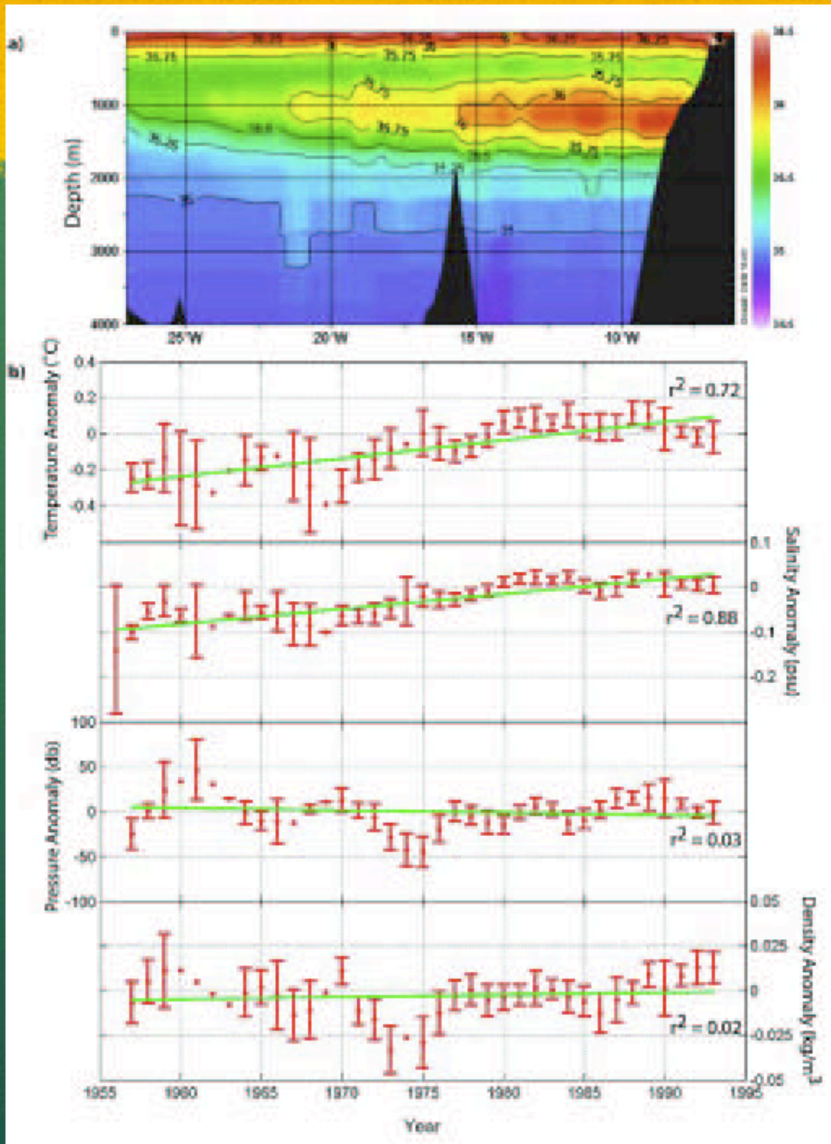
2- Change of temperature and salinity for the entire water column in the last 50 yrs

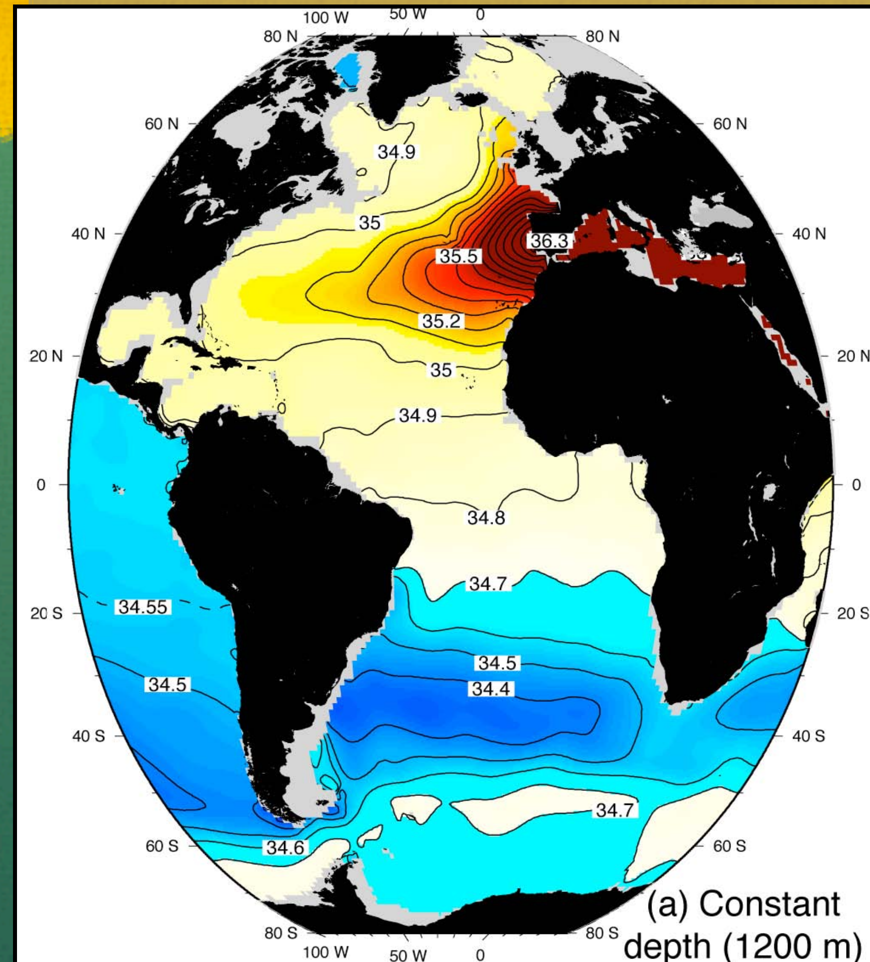
Time series (MEDAR-MEDATLAS) for the period 1950-2000 of volume mean salinity (left scale) and salt content (10^{13} PSU*m^3, right scale) anomalies <u>600m –bottom</u> and <u>0-bottom</u> (from Rixen et al, 2005)

Western Mediterranean	Eastern Mediterranean	Mediterranean



The Mediterranean outflow: source of heat and salt at intermediate depth (1000m)

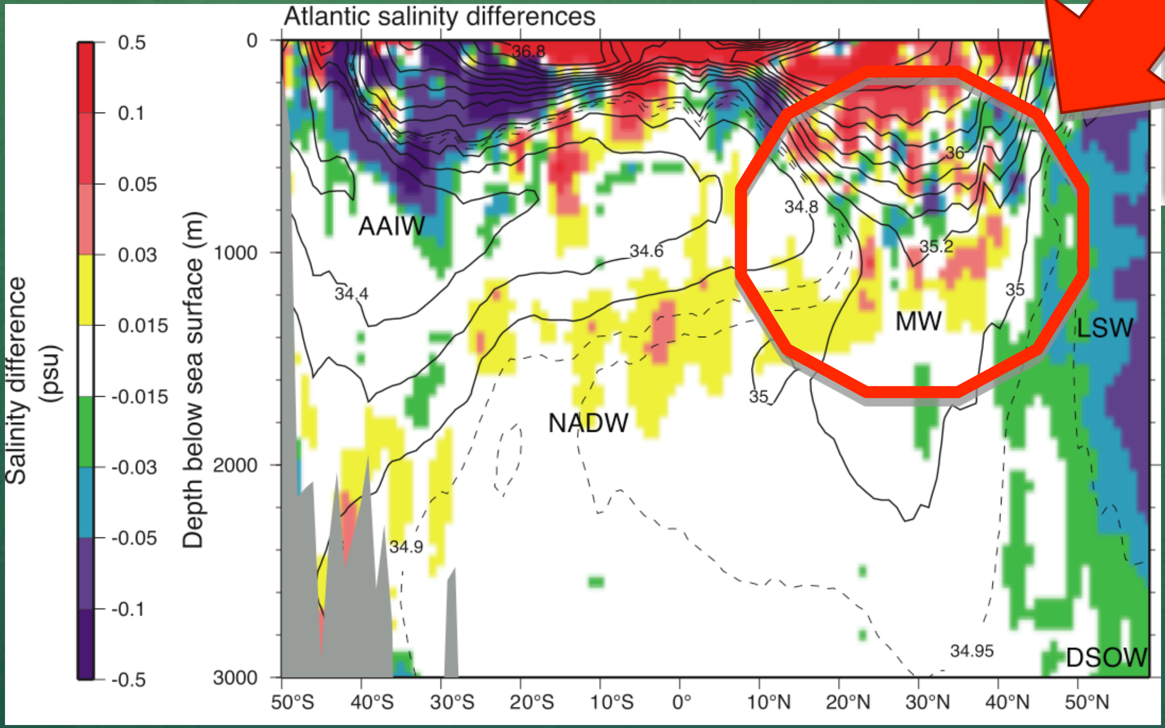


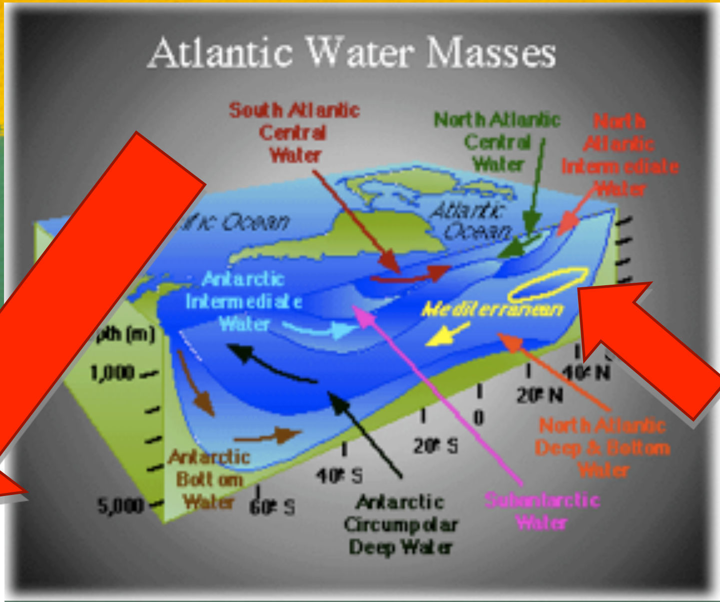


(Potter and Lozier, GRL, 2004 and Fusco, Artale, 2008)

SALINIFICATION OF MEDITERRANEAN OUTFLOW

Meridional sections of differences in salinity (psu) of the Atlantic Ocean for the period 1985 to 1999 minus 1955 to 1969

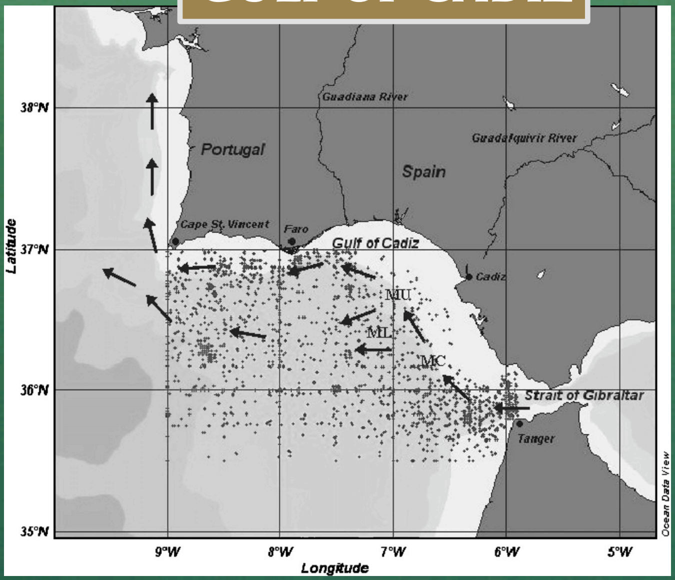




(Potter and Lozier, GRL, 2004)

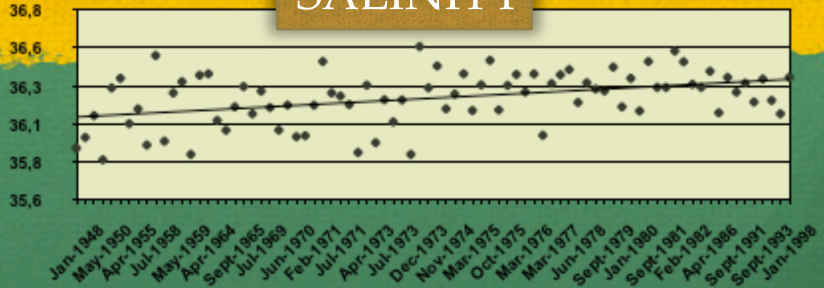
MEDITERRANEAN OUTFLOW: SOURCE OF WARMING AT MID-DEPTH

GULF OF CADIZ

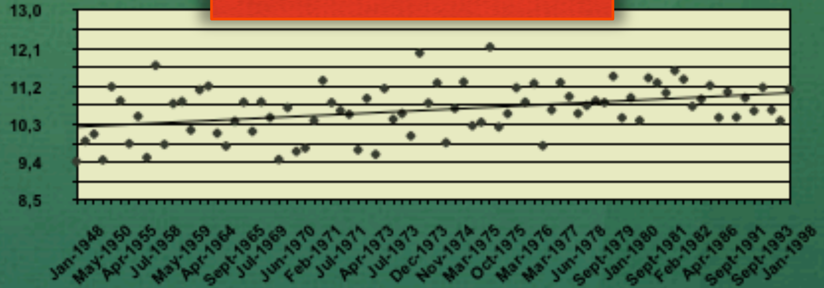


(Fusco et al., 2008)

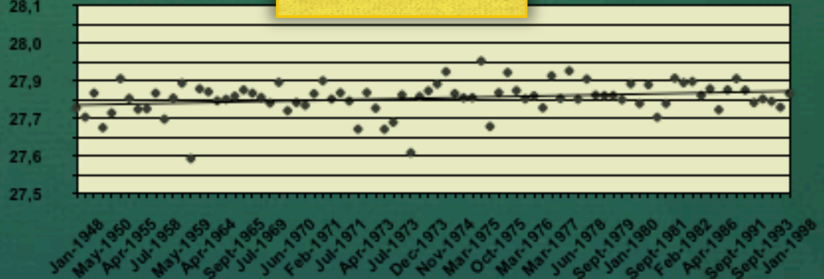
SALINITY



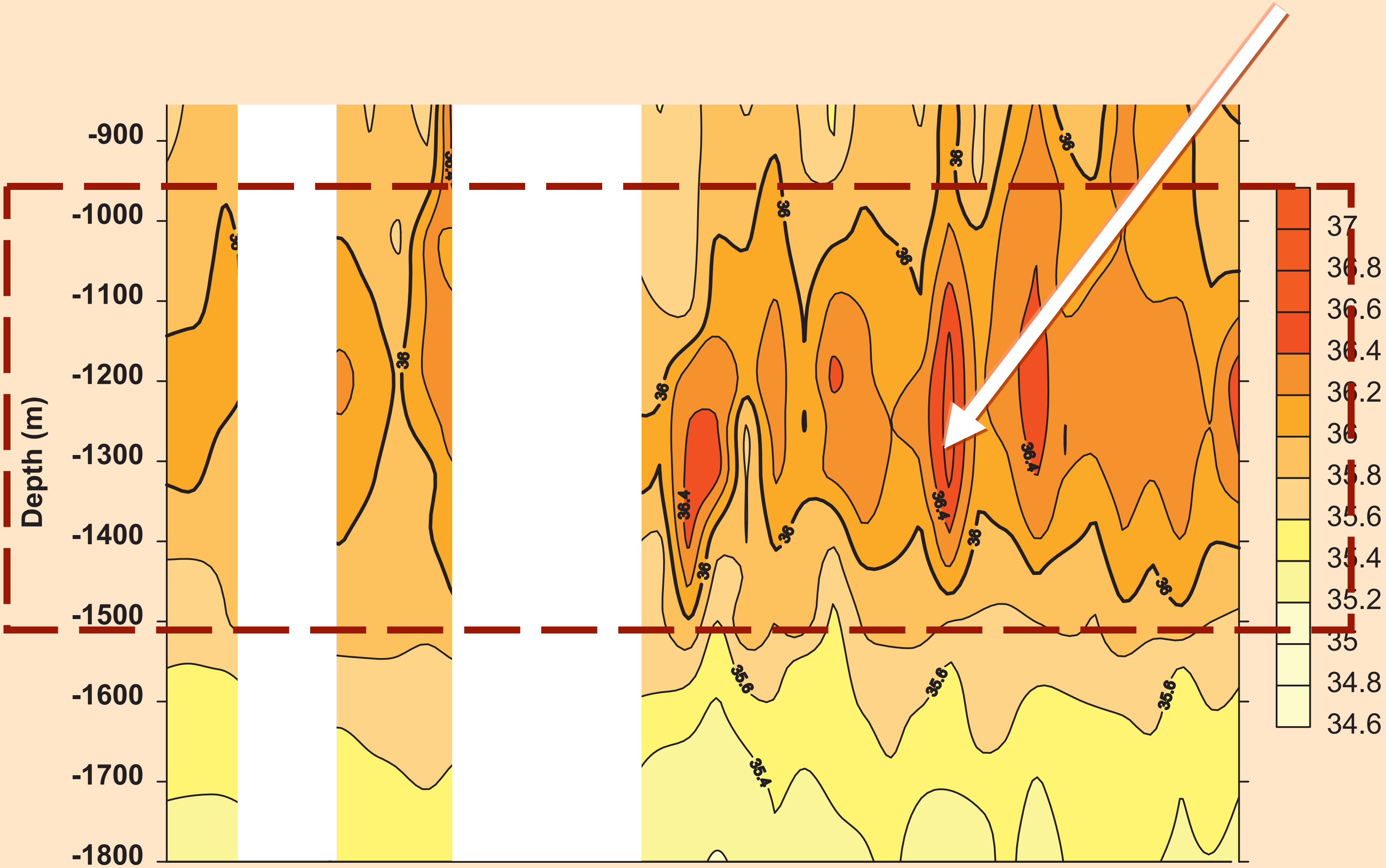
TEMPERATURE



DENSITY



IN THE GULF OF CADIZ SEVERAL EVENTS OF SALT ANOMALY ARE OBSERVED (Fusco, Artale, Cotroneo, 2008)



Some Conclusion

From a review of all available data set for the Mediterranean Sea we found an warming trend of 0.022 °C/decade in SST over the last 150 yrs, moreover in the Gulf of Cadiz the MOW displays a trend of 0.16 °C/decade and 0.05/decade in salinity over the last 50 yrs;

The Mediterranean isn't a isolated basin, but is a relevant component of the North Atlantic climate system, e.g. the northern part of Atlantic and Mediterranean show an high correlated multi decadal variability typically of 70-yrs;

The coupled model (Protheus System) predicts significant interannual variability including EMT and acceleration of warming in particular after the 2020 with an average value of 0.16 °C/decade (not shown);

But more significantly is relevant that the numerical models have to represent in the next future, beside the air-sea interaction processes, the driver mechanisms of the Mediterranean thermohaline circulation like

- the physics and hydrological characteristics within the Gibraltar Strait (Salinity Valve),
- the advection-convection feedback (multiple steady state of ocean circulation, EMT can be considered an element of its),
- the internal salt anomaly in the North Atlantic due to the MOW, that can contribute to stabilize the MOC (not shown);
- further investigation have to be dedicated on the relation between natural modes of variability and the observed changes of heat, chemistry and circulation in the ocean

…… in what sense does the fact that a model cannot duplicate a warming of a few tenths of a degree constitute evidence that anthropogenic forcing is necessary? The alternative hypothesis is that the warming is simply natural unforced internal climate variability. It is well known that the climate does indeed fluctuate without any external forcing. There are several reasons for this. At the most fundamental level, the atmosphere and oceans are turbulent fluids, and it is a general property of such fluids that they can fluctuate widely without external forcing.

There are moreover specific features of the oceans and atmosphere that lend themselves to such changes. The most obvious is that the oceans are never in equilibrium with the surface. There are exchanges of heat on all time scales between the abyssal oceans and the near surface thermocline region. Such exchanges are involved in phenomena like El Nino and the Pacific Decadal Oscillations, and produce large variable forcing for the atmosphere. (from Lindzen, 2007)

Thanks for your attention !!