Mediterranean Sea Physical and Biogeochemical oceanography: Highlights

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Essential contributions of

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Workshop on deep Ocean Cabled Observatories

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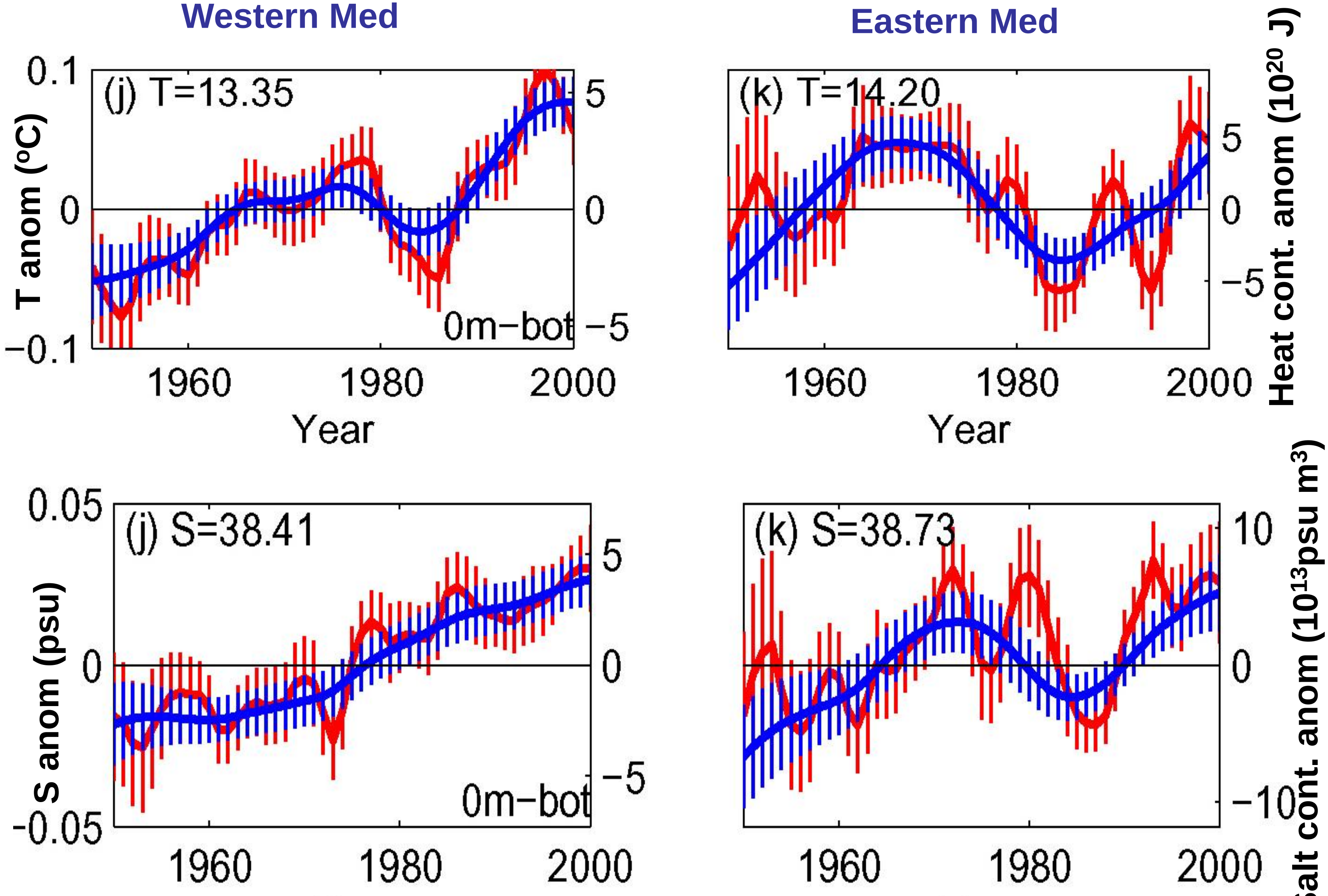
Outline

- Describe the Mediterranean Sea “functioning” trough numerical simulations
- The new data set from operational oceanography:1985-2007 Mediterranean Sea re-analysis
- Results from the coupled Physical biogeochemical model
- Questions asked:
  - How is the average basin scale circulation?
  - How is the decadal variability of the circulation?
  - How is the water mass formation rate varying in the past 20 years?
  - What are the T,S and sea level trends?
  - How circulation variability affects the biogeochemical dynamics
- Final remarks

Before re-analysis: objective analysis

Comprehensive Medatlas (2002) data set analysis

Western Med **Eastern Med**

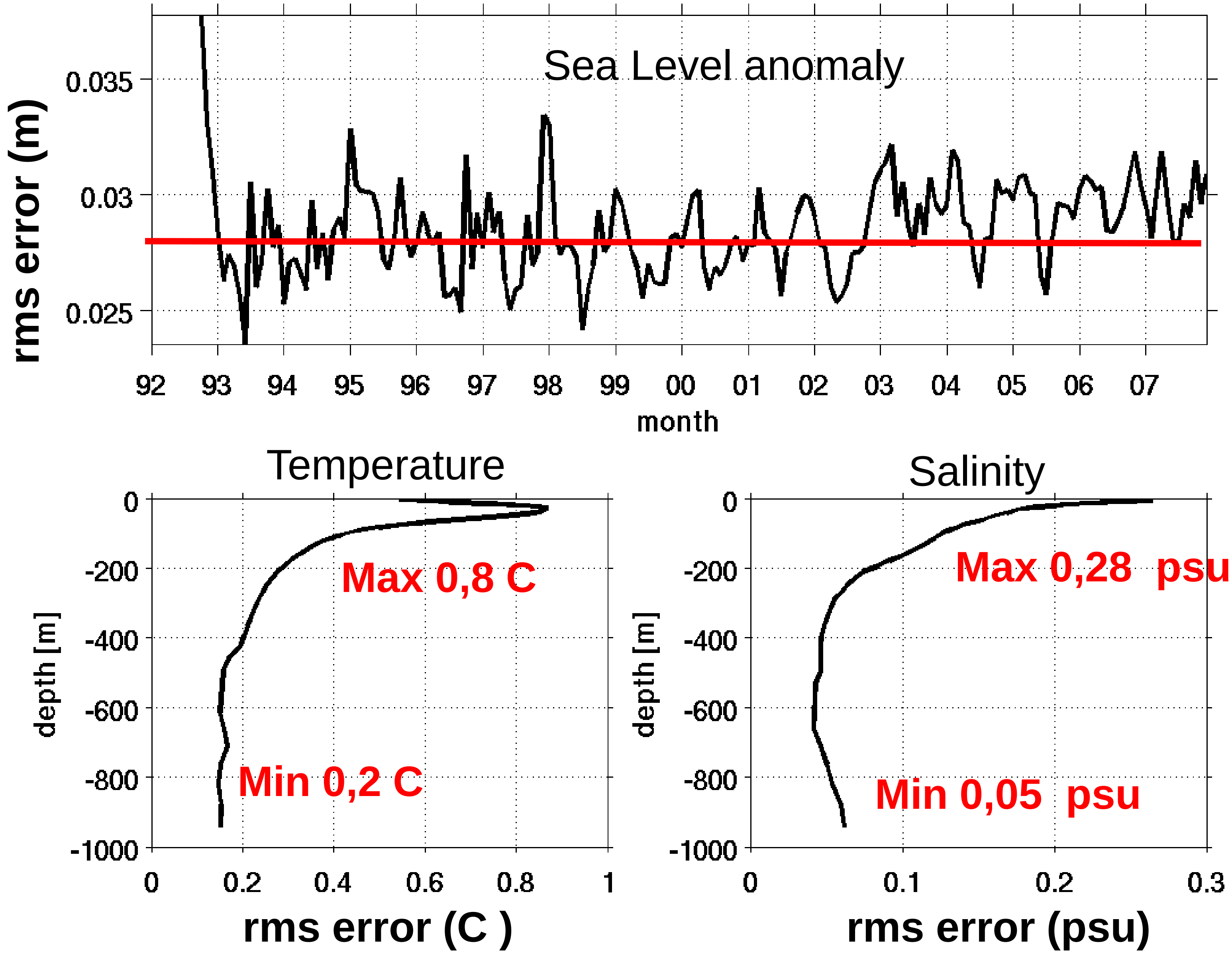


Rixen et al., 2006

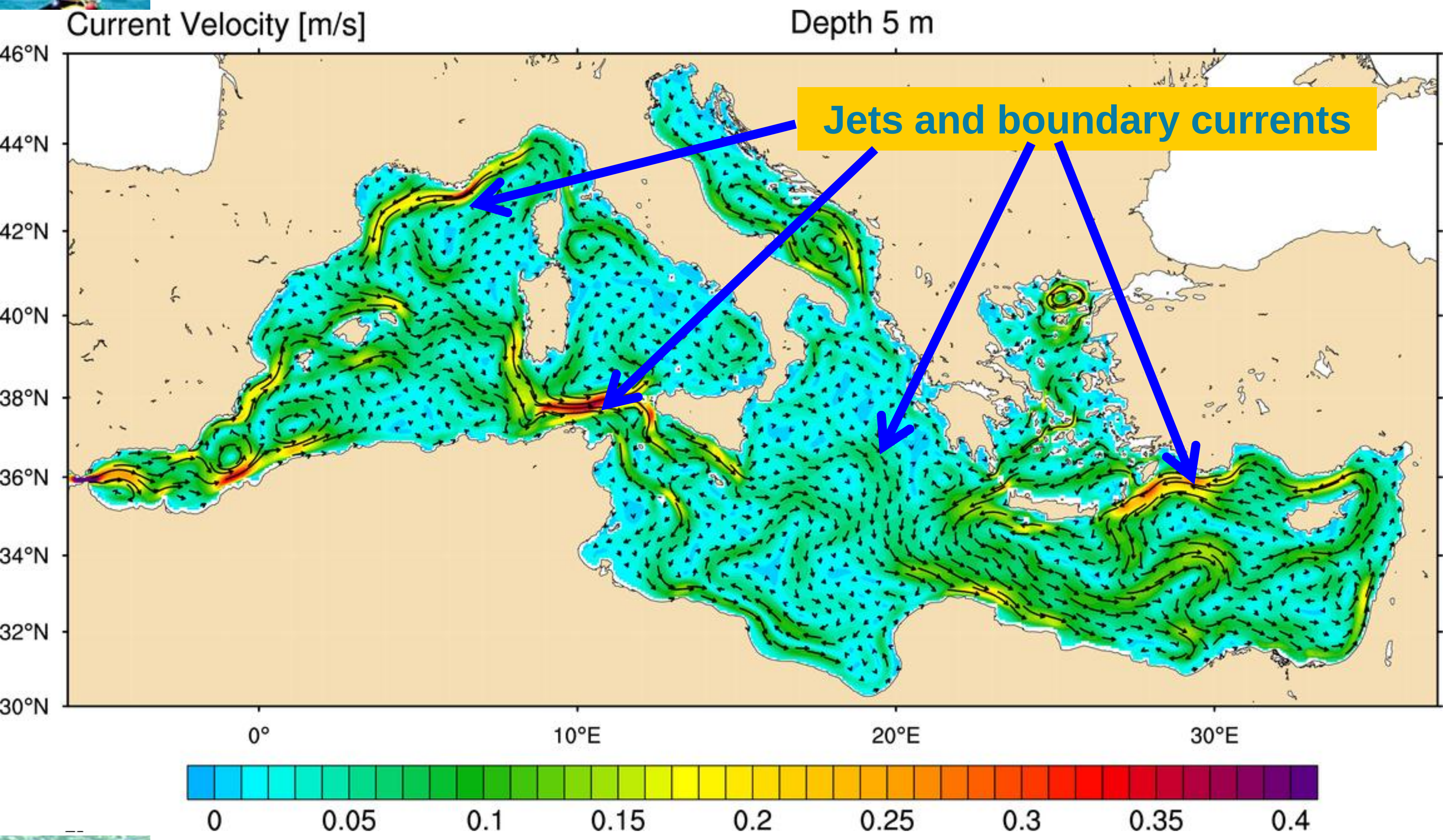
The 1985-2007 re-analysis (Adani et al., JAOT, 2010)

- Data assimilation scheme: 3Dvar (Dobricic and Pinardi,2008) with daily updates
- QC 'raw' observations:
  - 1985-2007 observations from MedAtlas data set: CTD, XBT,BT MBT
  - Along track satellite SLA from 1992 to today, all available satellites (ERS-1, T/P, Jason1, Envisat)
  - Satellite SST OA from Marullo et al. (2005)
  - MOON data set: SOOP XBT and MedArgo profiles
- Numerical model:
  - OPA, 1/16 x 1/16 deg resolution, 72 levels
  - ECMWF ERA15 forcing up to 1992, ECMWF analyses since then (change in resolution), 6hr fields, all fluxes interactive
  - Atlantic box relaxed to climatology (Tonani et al., 2008)
  - NCEP monthly mean precipitation

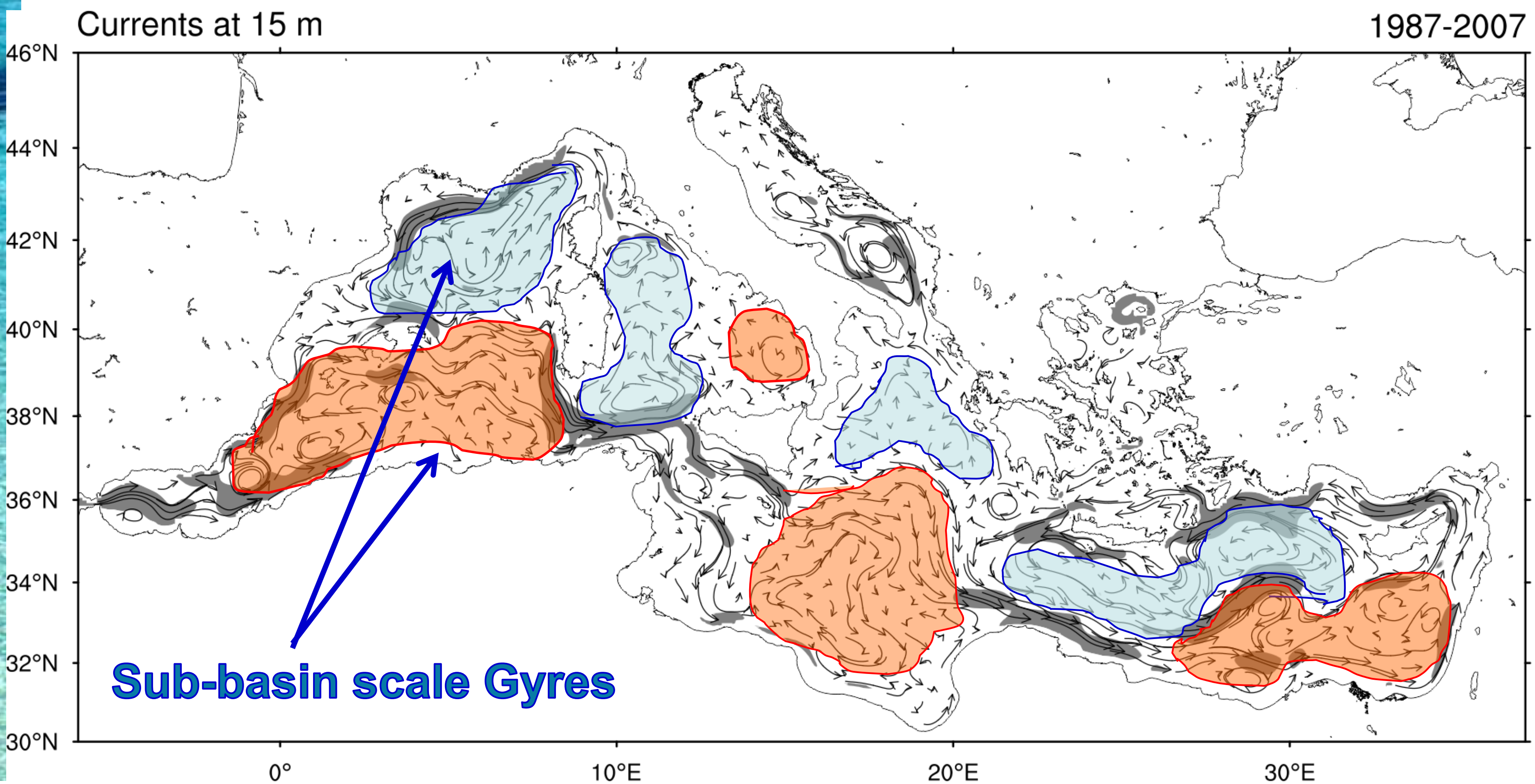
The re-analysis quality: rms error



The 1987-2007 *surface* mean circulation from re-analysis

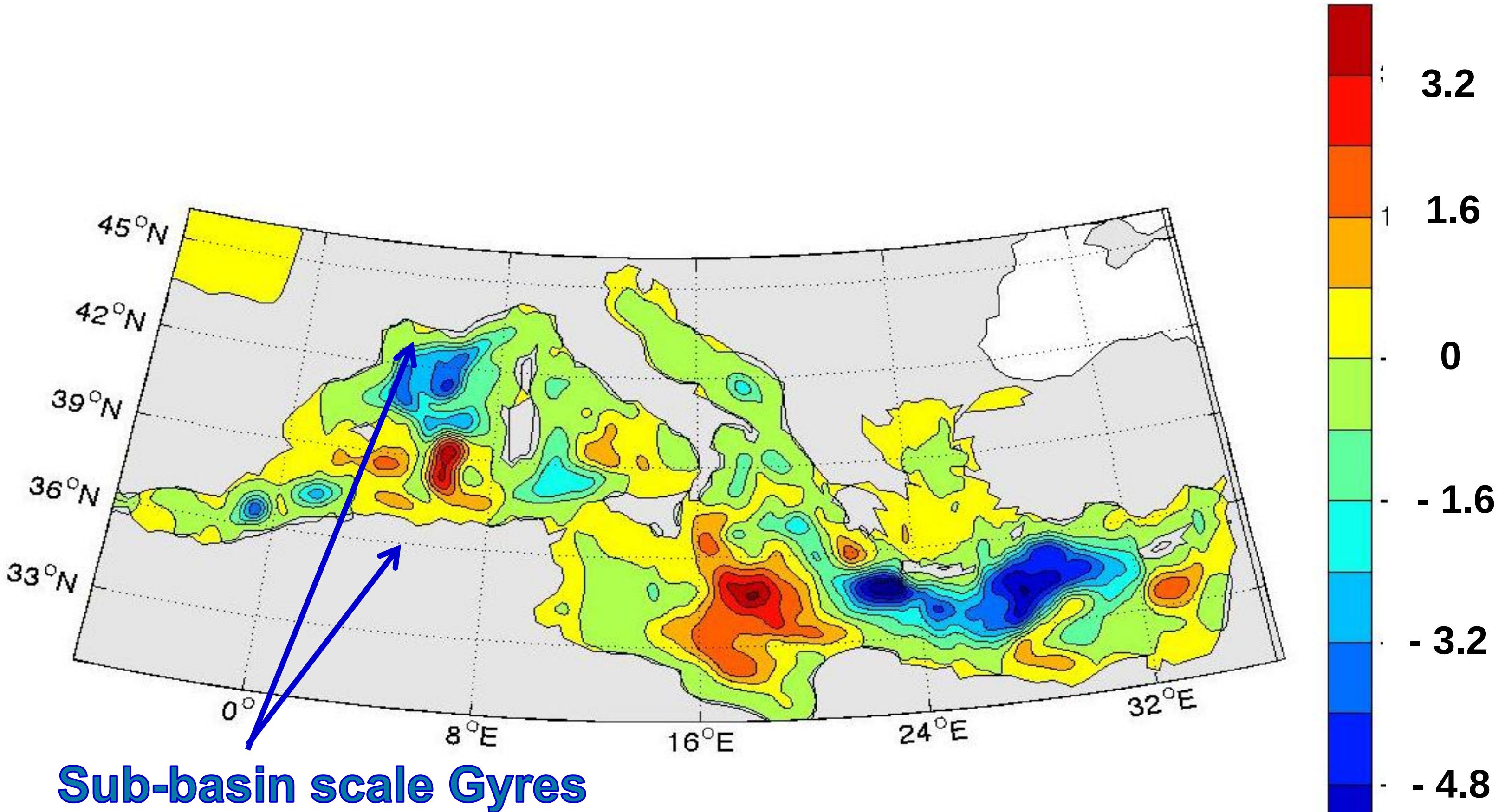


The 1987-2007 mean circulation: the ‘gyre’ structure



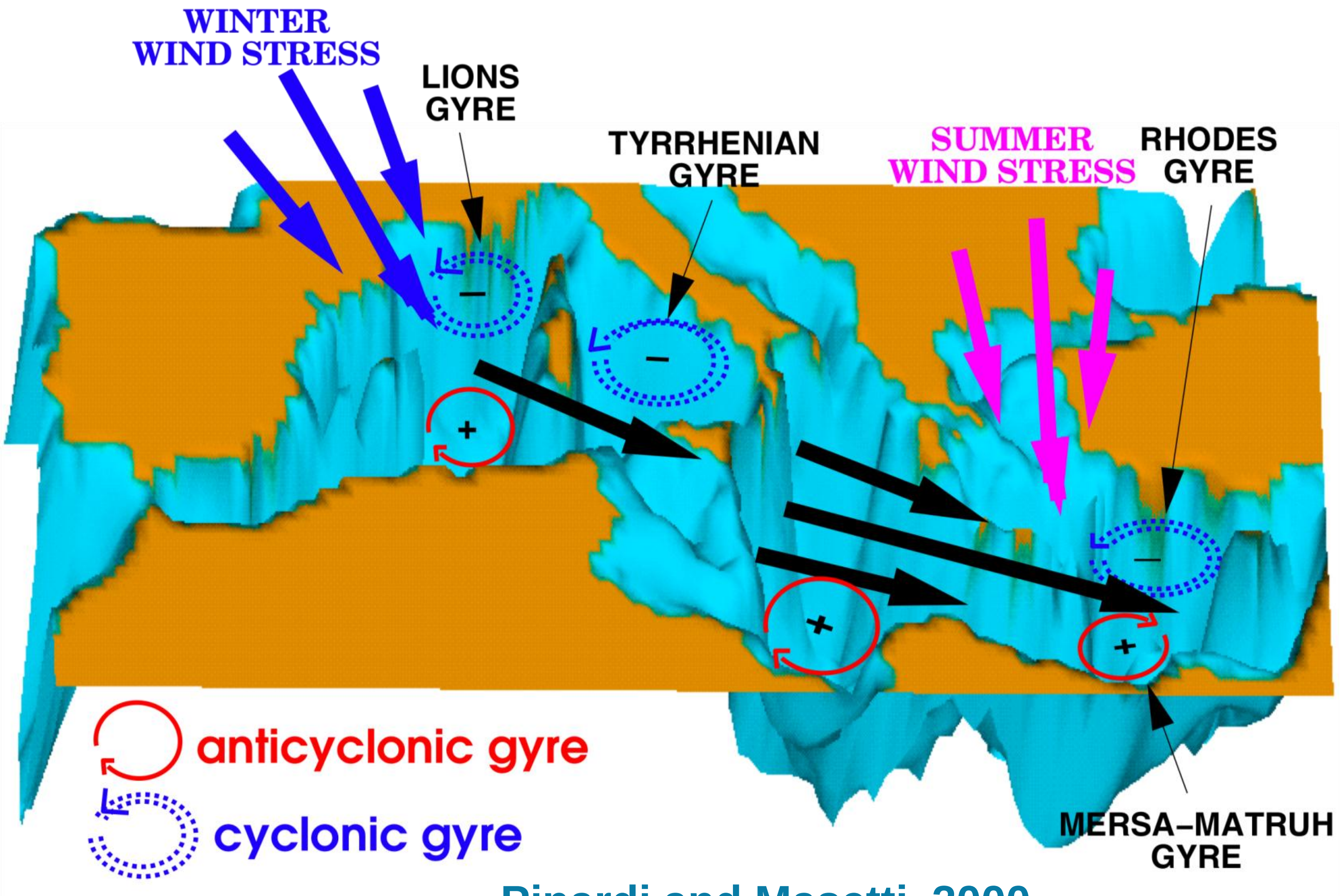
Grey shaded areas have velocities larger than 10 cm s^{-1}

The barotropic streamfunction from average 1987-2007 velocity field



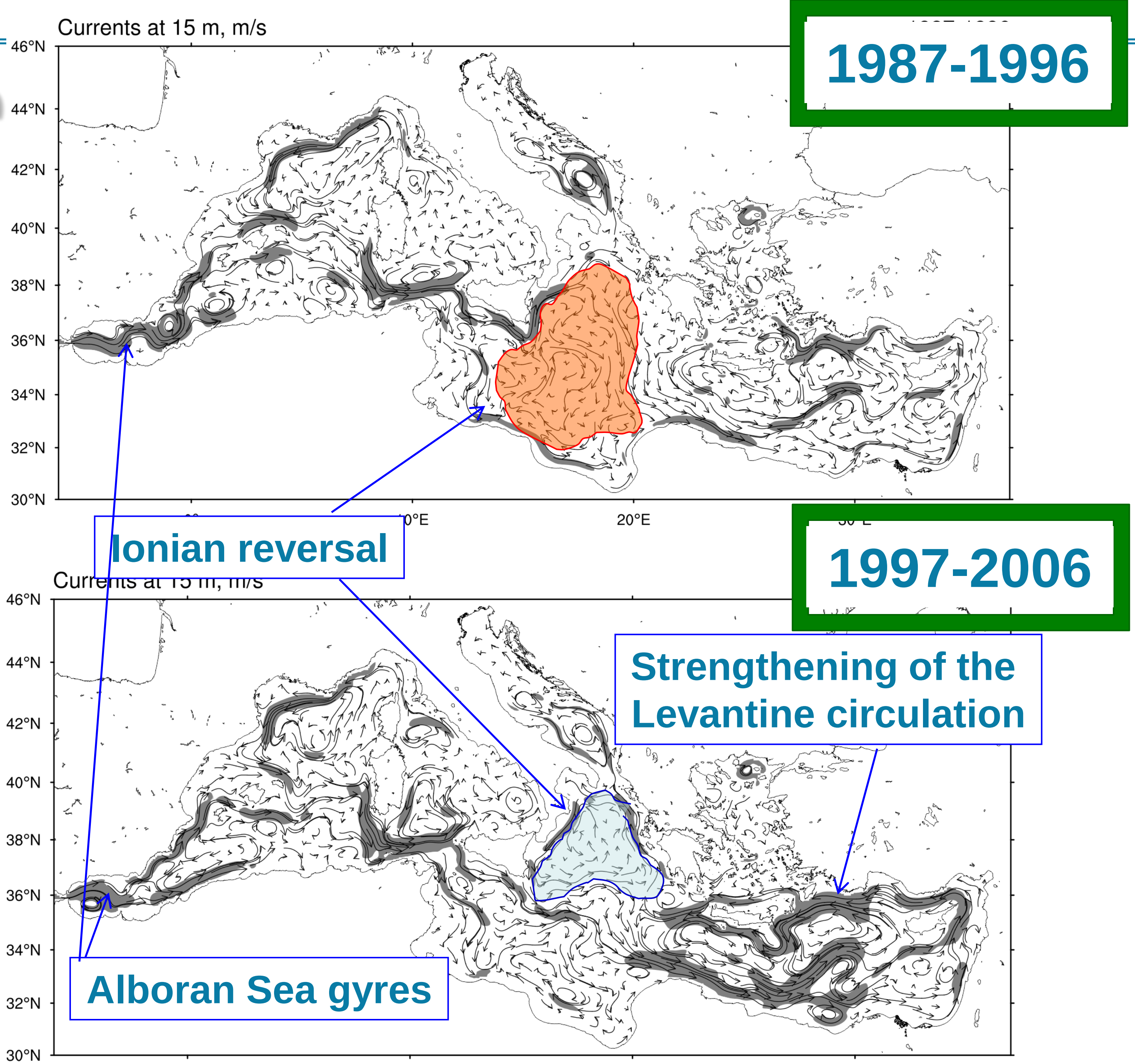
The barotropic, wind driven circulation is composed of sub-basin gyres as the baroclinic, geostrophic one

The interpretation: wind driven general circulation



Pinardi and Masetti, 2000

Decadal Variability

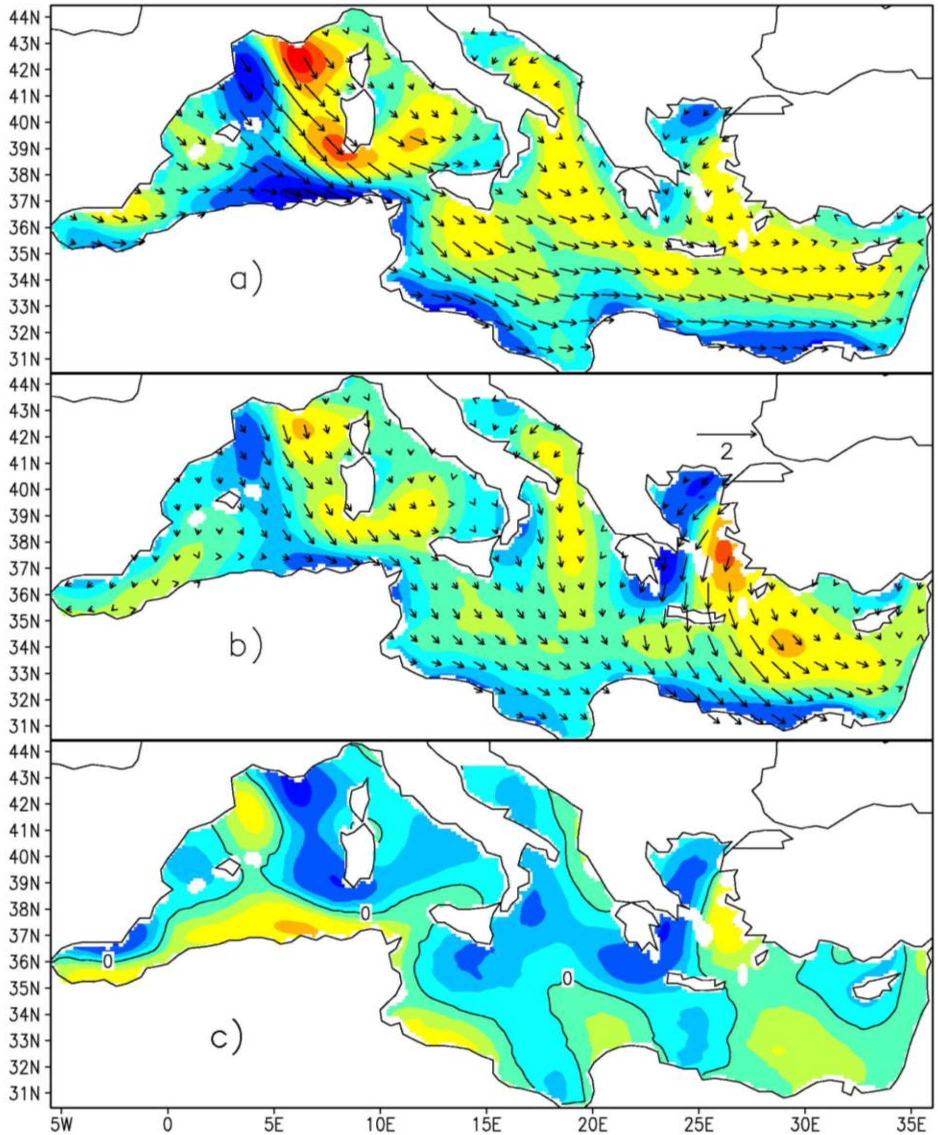


The Ionian reversal: connected to Wind stress decadal changes (Demirov and Pinardi, 2002)

Period I

Period II

Curl difference



Large Positive wind stress curl

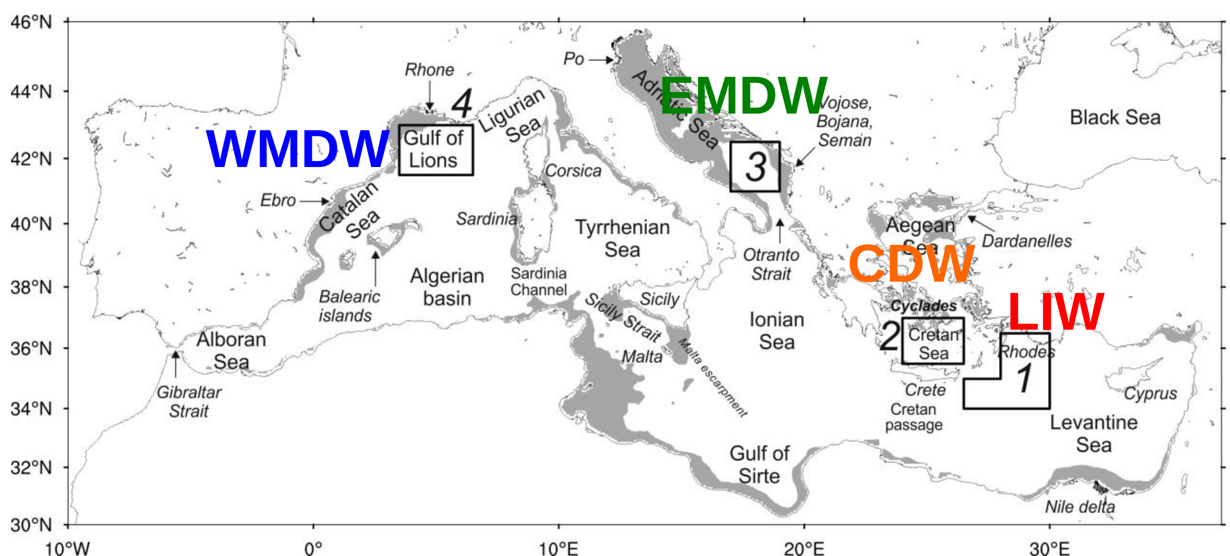
Relaxation of wind stress curl

Water mass formation rates: method

- A volume rate is calculated by summing grid volumes in the mixed layer that have densities larger than a threshold and dividing by time

TABLE 1. Density thresholds for the Water Mass Formation (WMF) rate computations in each of the four regions of Fig. 1. Density is in $kg\ m^{-3}$

Areas	Density thresholds for WMF rates
1	28.95/29.10
2	29.00/29.10
3	29.10/29.20
4	29.00/29.10



How much water forms in the selected areas?

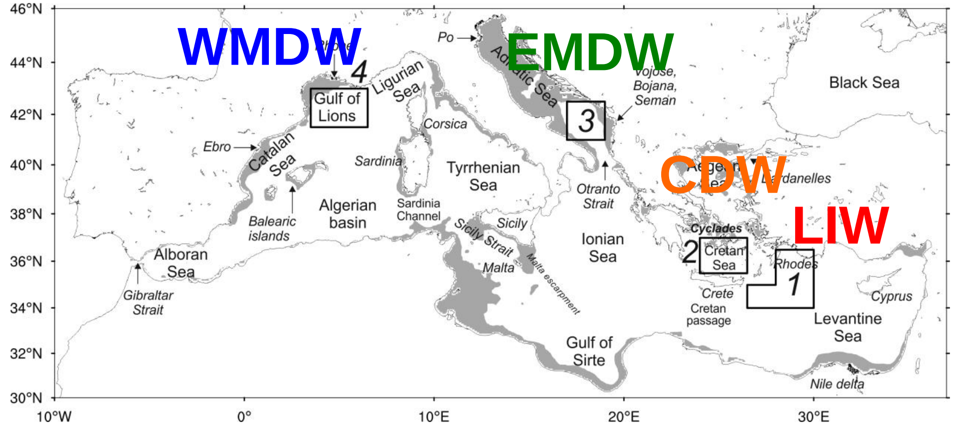
Four major events:

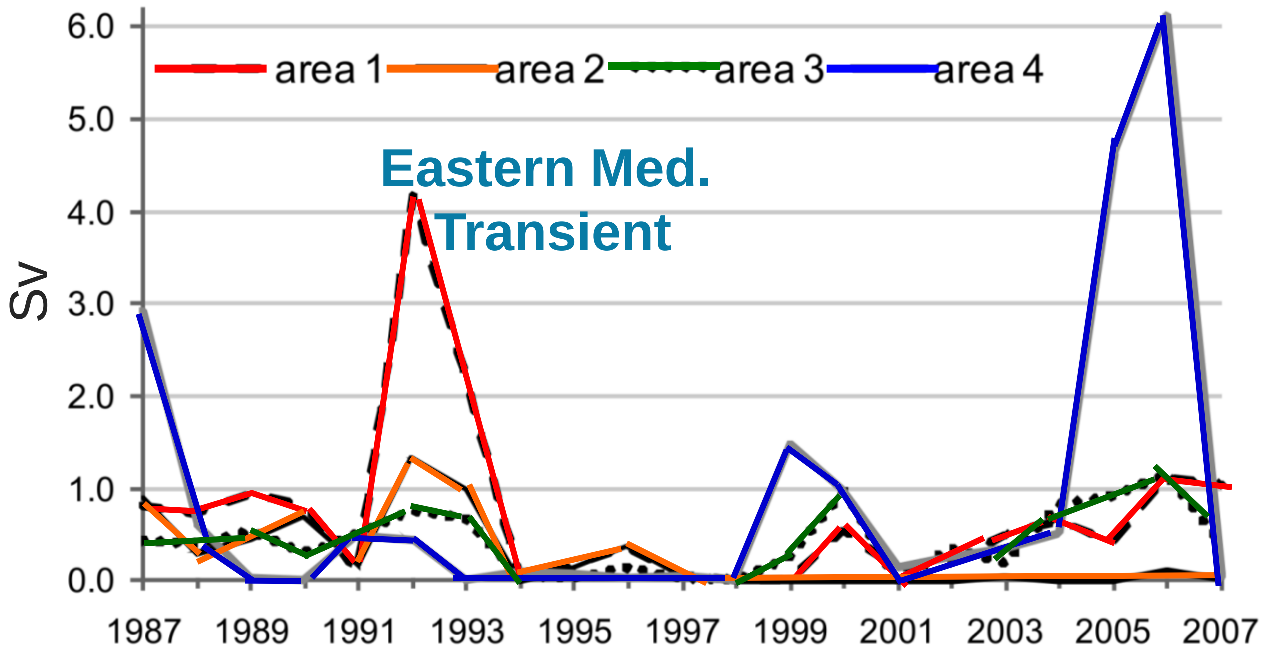
1) 1987 for WMDW

2) 1992-1993 for LIW, CDW and EMDW

3) 1999-2000 for WMDW and EMDW

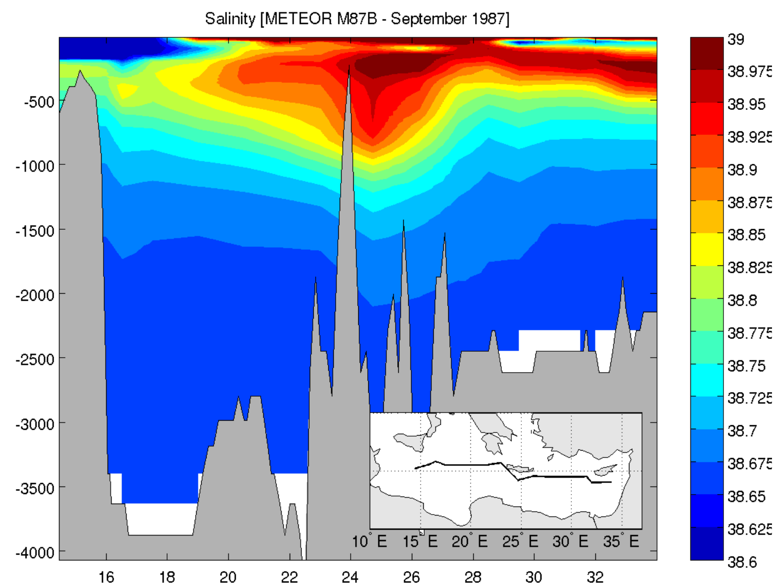
4) 2005-2006 WMDW, EMDW and LIW



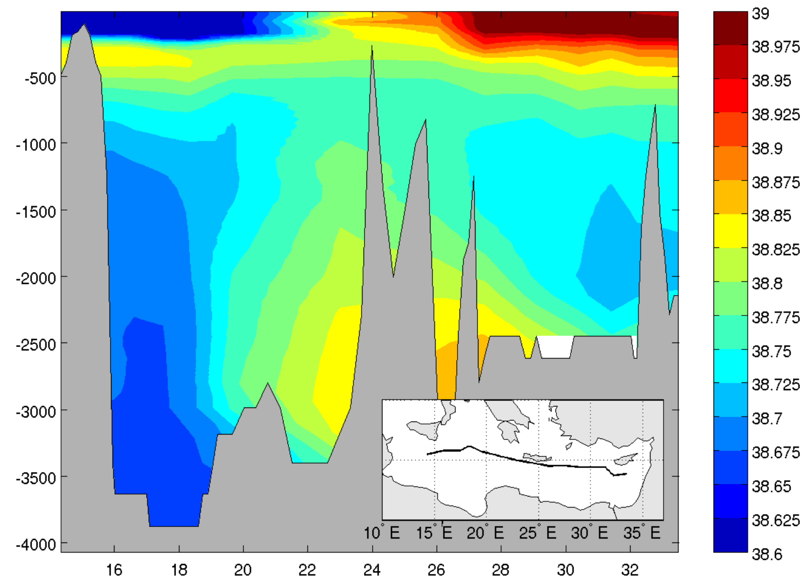


The Eastern Mediterranean Transient- EMT: the METEOR section, Jan 1995

Meteor September 1987



Meteor January 1995



Roether et al., 1995

The EMT : a multi-component event

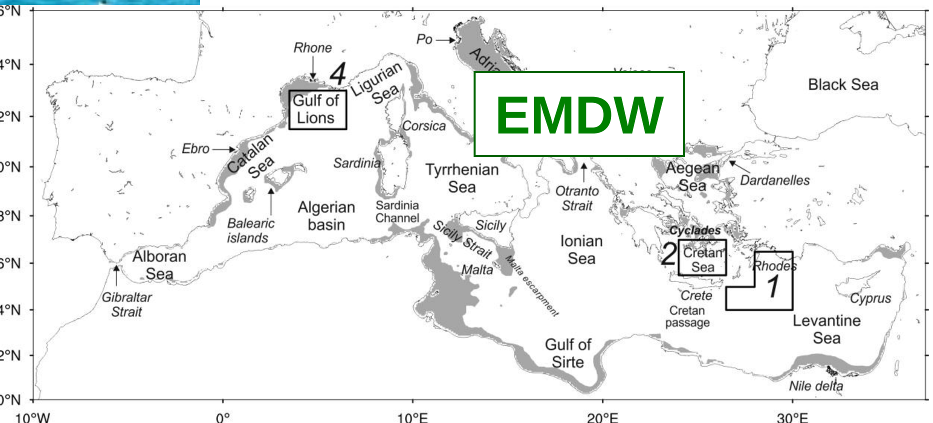
Three concomitant factors:

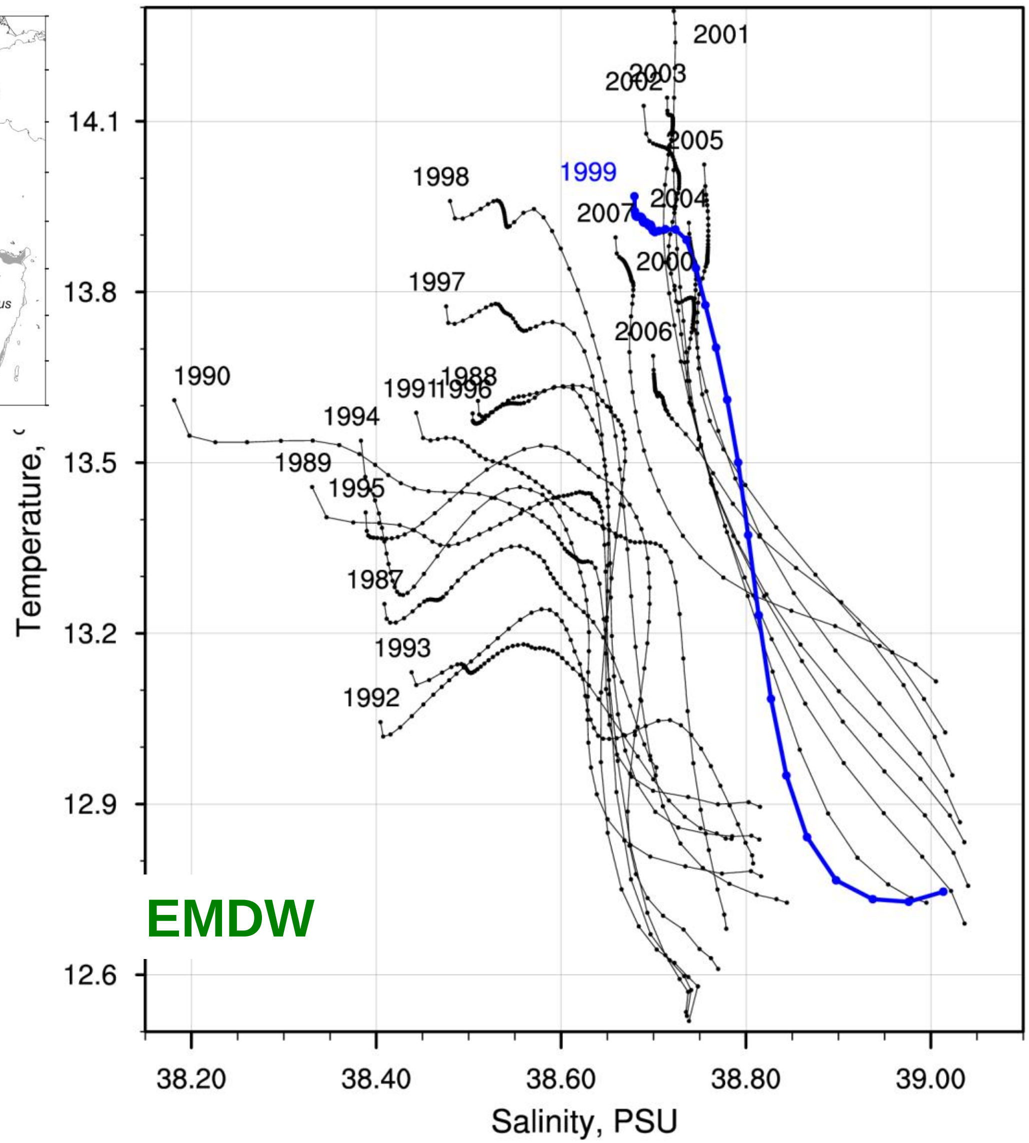
1) Entrance of very saline waters from the Levantine basin (IN CONNECTION WITH IONIAN REVERSAL)

2) Very intense heat losses

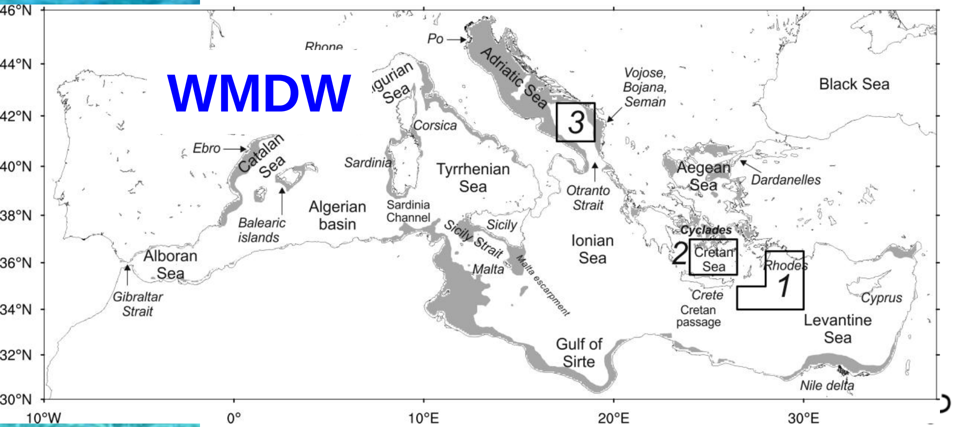
3) Low fresh water outflow of Black Sea waters

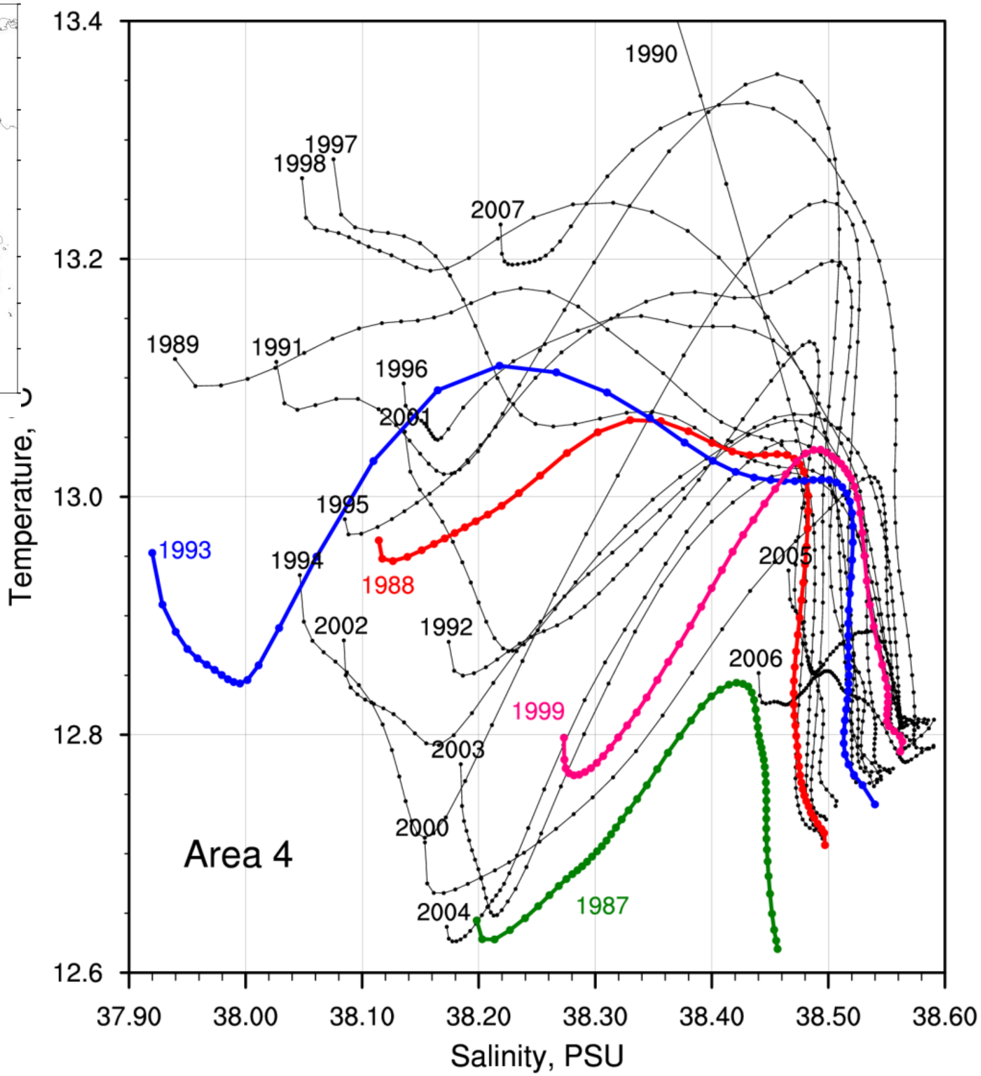
The effect of the EMT in the Adriatic Sea: the 1999 shift



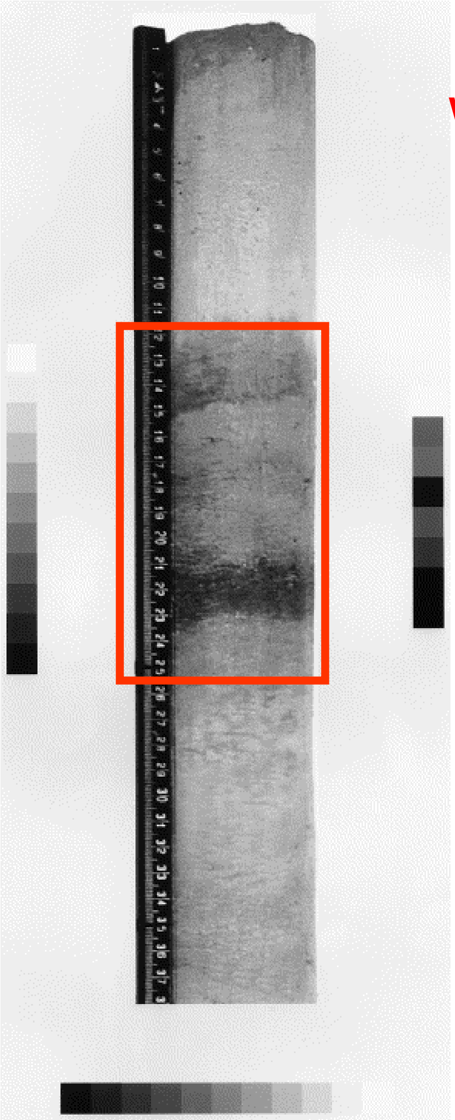


The WMDW warming and salting in the Gulf of Lion: 1988, 1993, 1999





Deep water formation rates are controlling the sapropel deposition: a model experiment



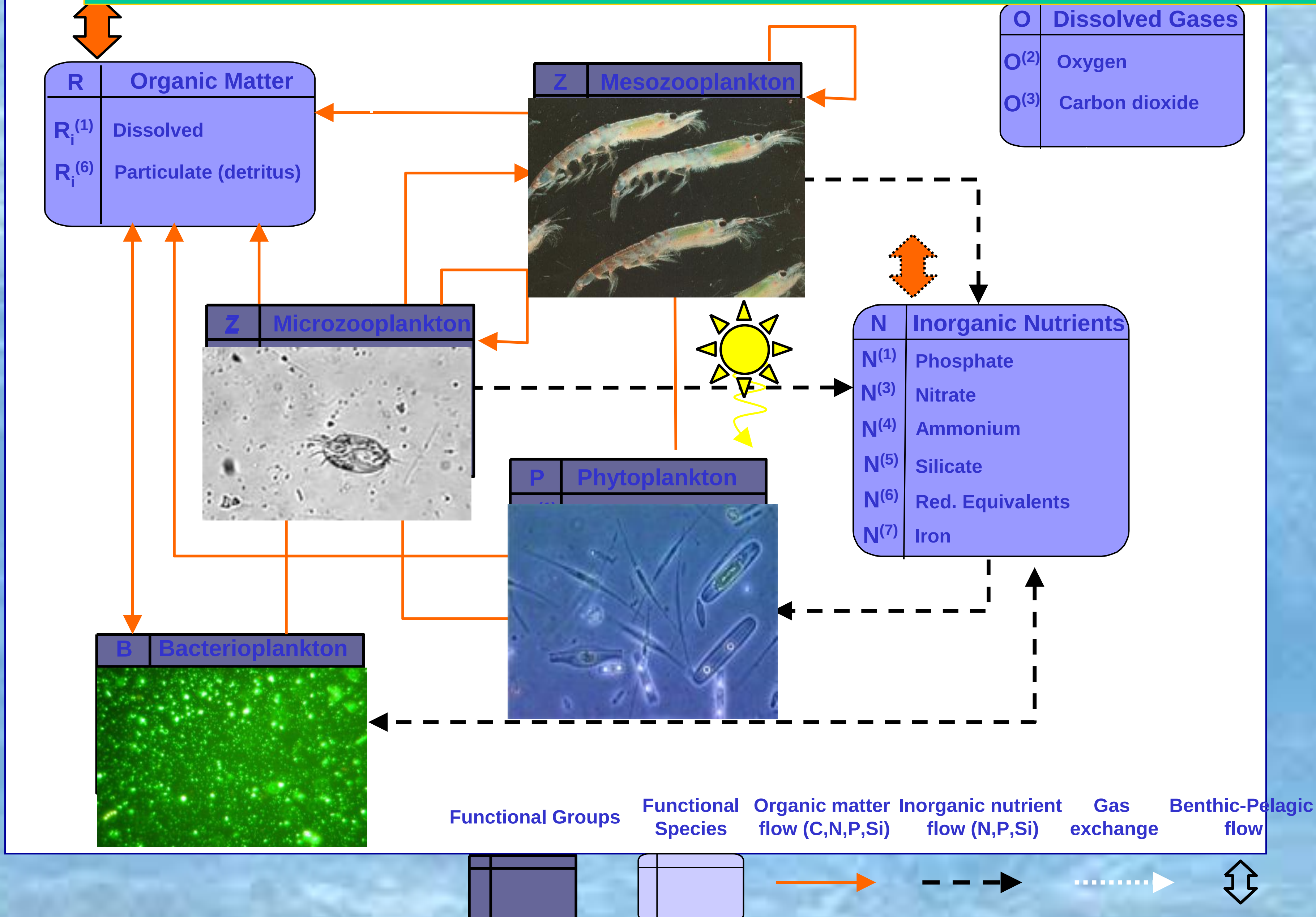
In the Mediterranean, conditions were very different 9000-6000 Years ago, sapropels were deposited

What are sapropels?

Layers of sediments rich of organic material (C_{org} greater than 2% of the weight, *Kidd et al, 1978)*

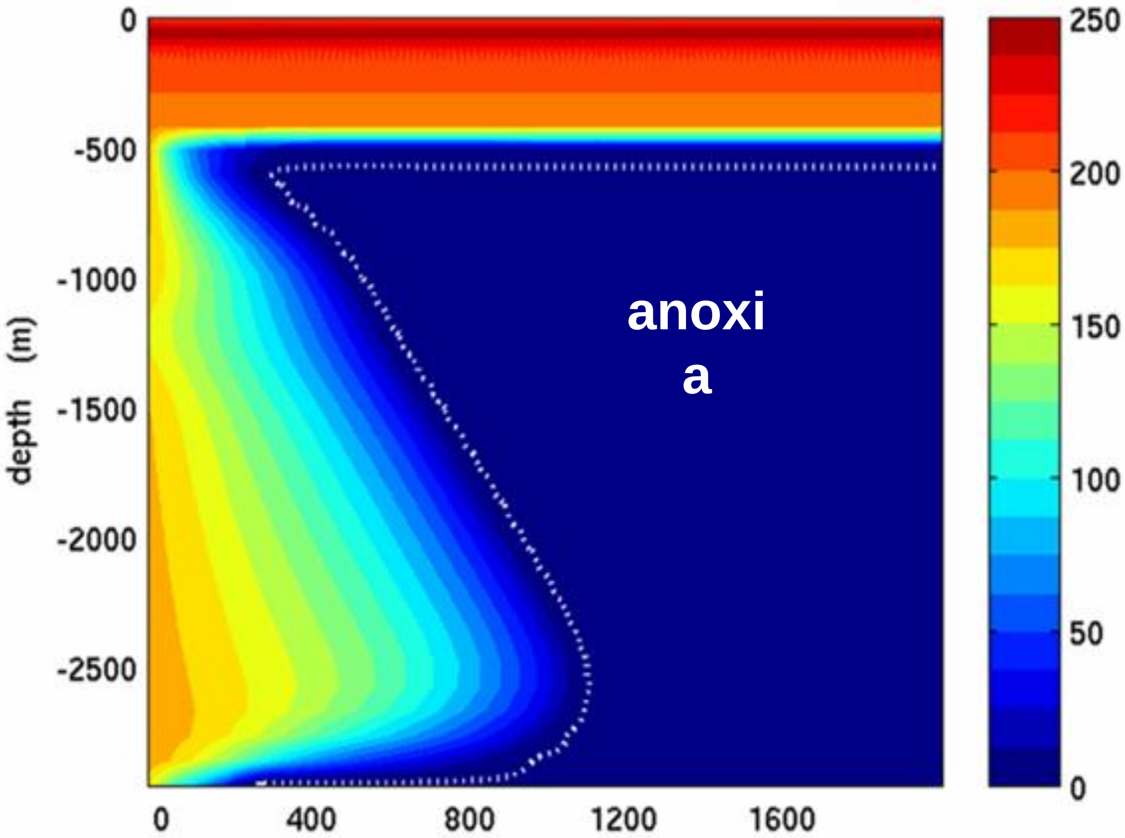
Hypothesis: no deep water formation (only down to 500 m, Myers et al., 1998) and larger primary productivity

The biogeochemical model (bfm)



Model results: Deep Water mass formation rates and surface productivity are the controlling mechanisms for the oxygen in the deep basins

Oxygen concentration



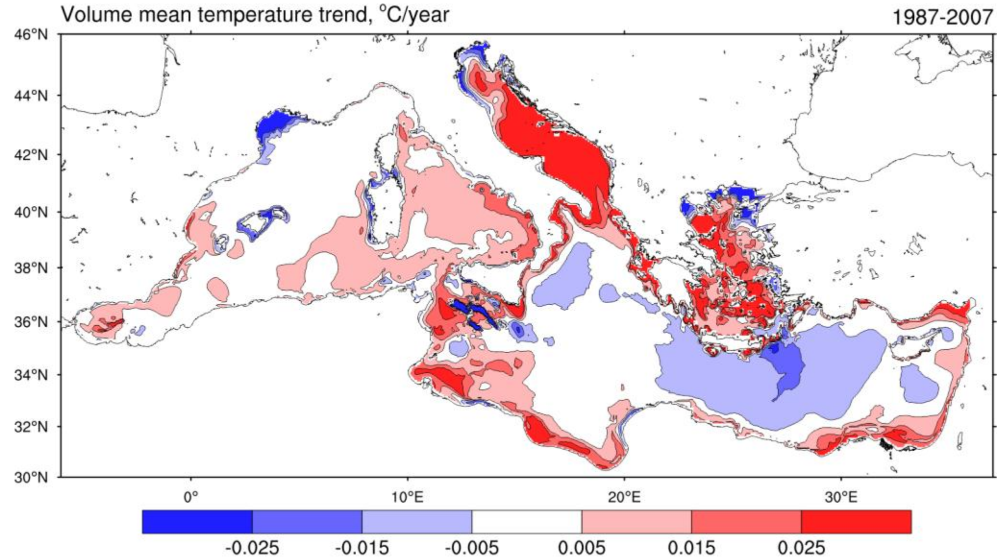
Time from start of simulation (years) →

Anoxic conditions can be generated in ecosystem models by reducing dense water formation depth and increasing surface productivity

Bianchi et al. (2006)

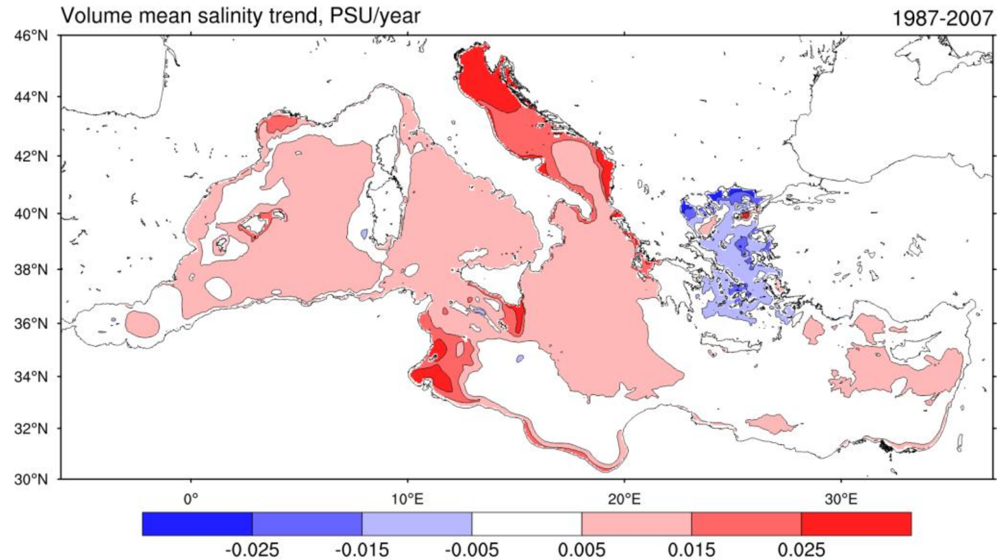
Volume mean Temperature and Salinity trends 1987-2007

Temperature

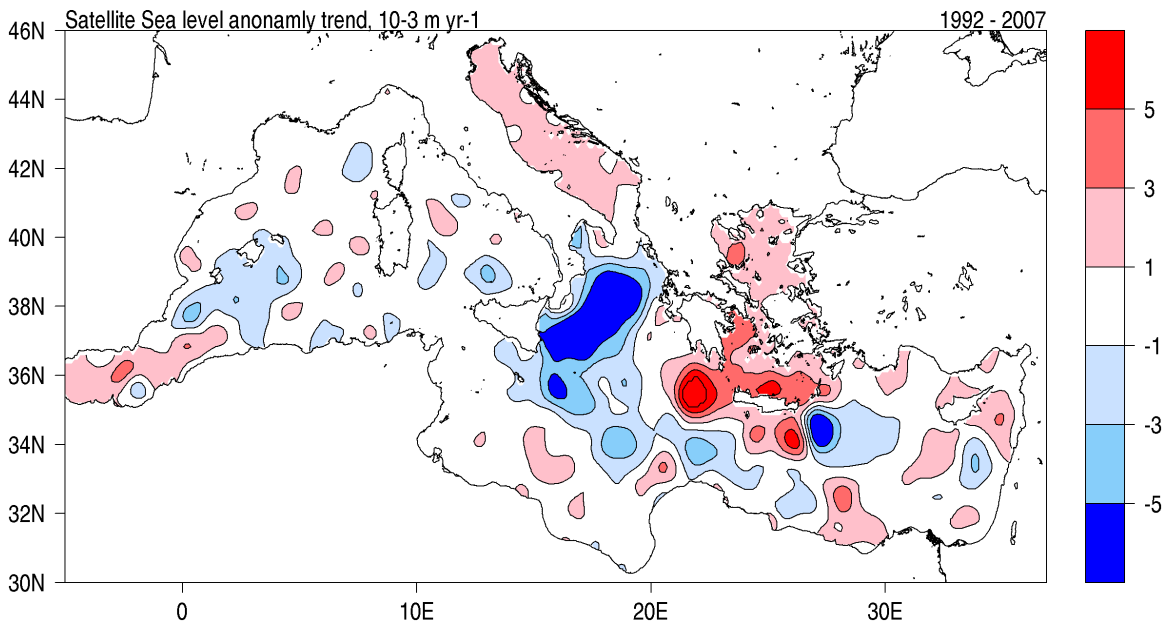


Linear trend spatial structure

Salinity

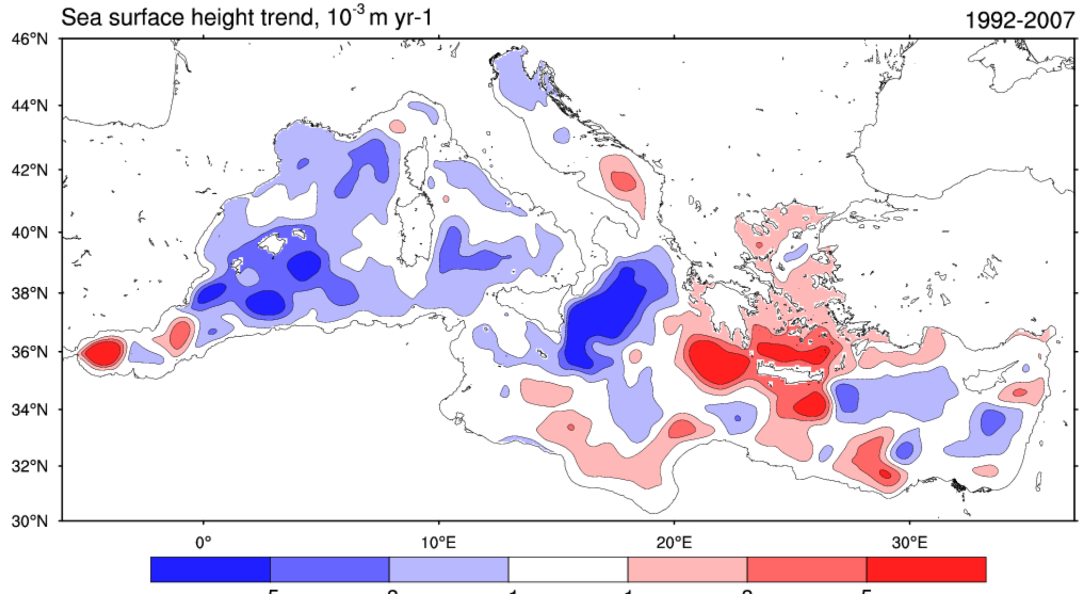


Sea Level trends 1992-2007



Combined altimetry SLA (without Steric)

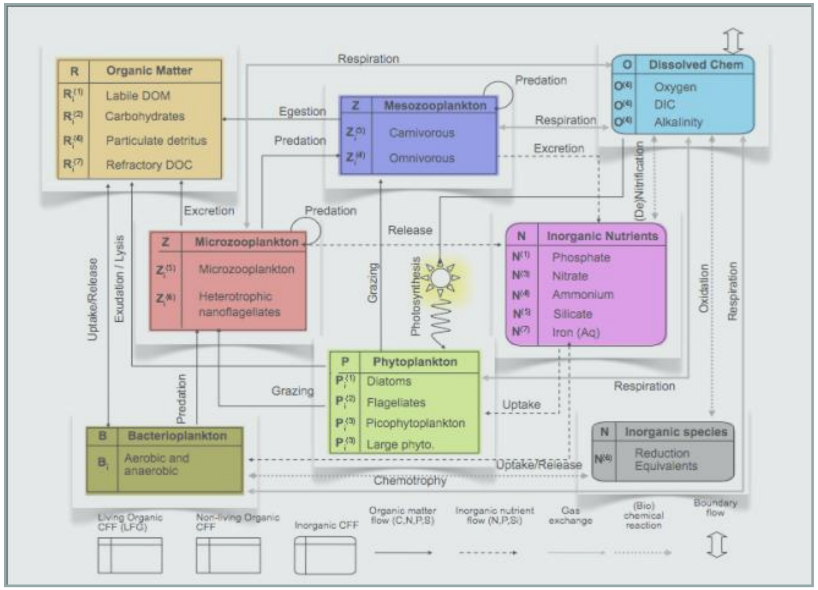
Re-analysis

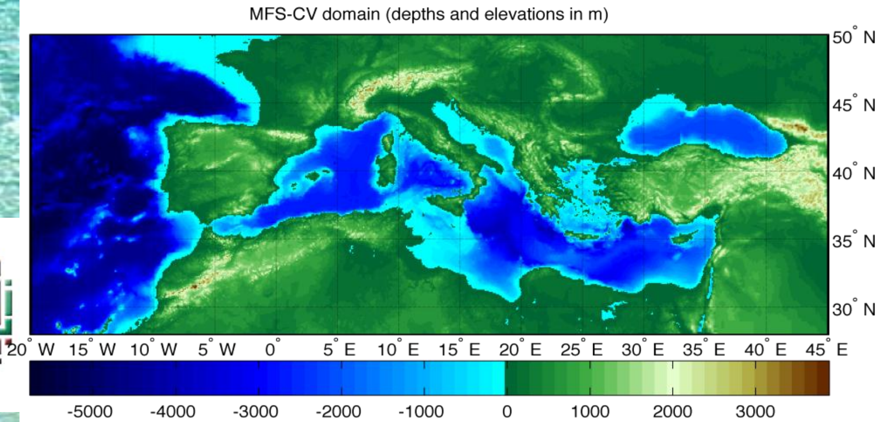


The wind-driven response of the Mediterranean Sea biogeochemistry to the Eastern Mediterranean Transient.

-BFM: Biological Flux Model (http://bfm.cmcc.it
Vichi et al. a,b 2007)
-Carbon based multi-nutrient food web description
-Carbon, Nitrogen, Phosphorus and Silica cycles
-Potential for multiple nutrient co-limitation (Nitrogen, Phosphorus and Silica)

- phytoplancton
- mesozooplancton
- microzooplancton
- bacteria

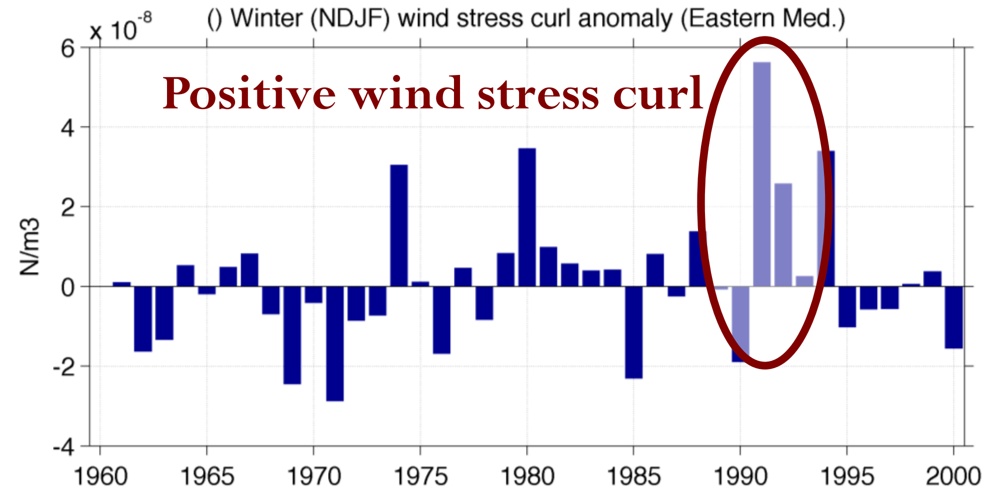


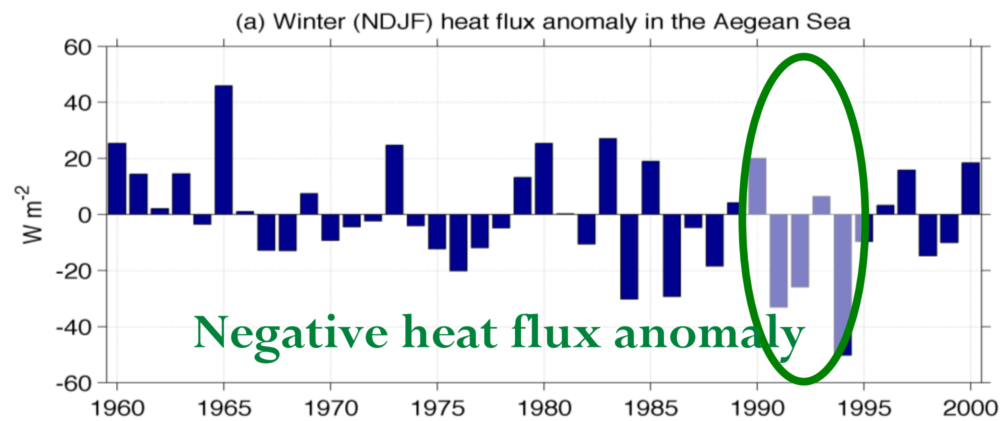


90’s are characterized by intense positive annually averaged winter (NDJF) stress curl over eastern Mediterranean.

Aegean sea are characterized by a negative heat flux anomaly. (1991,1992,1994).

Modelling system reacts to such conditions with limited formation of e. Mediterranean deep water of aegean origin and a rearrangement of the thermohaline circulation.





pre-EMT period

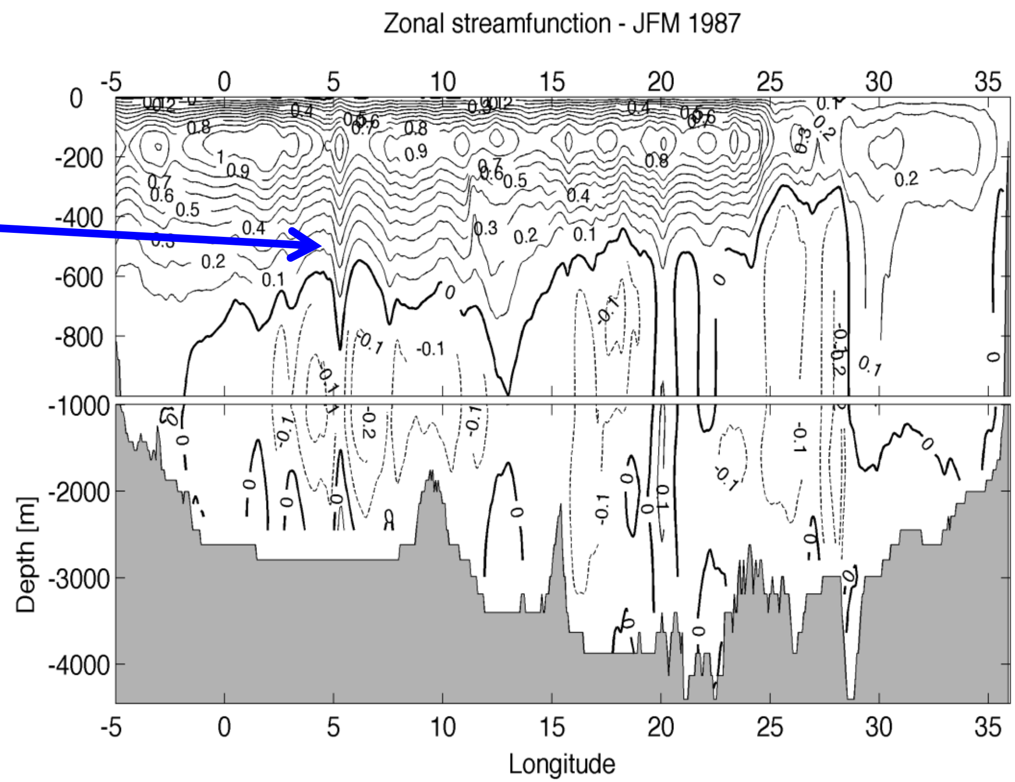
Thermohaline circulation

MAW-LIW system extending to the whole e. Levantine.

Upper 600 m positive value

(Liw ~ 200-300 m positive value)

Pre-EMT period (1987)



EMT period

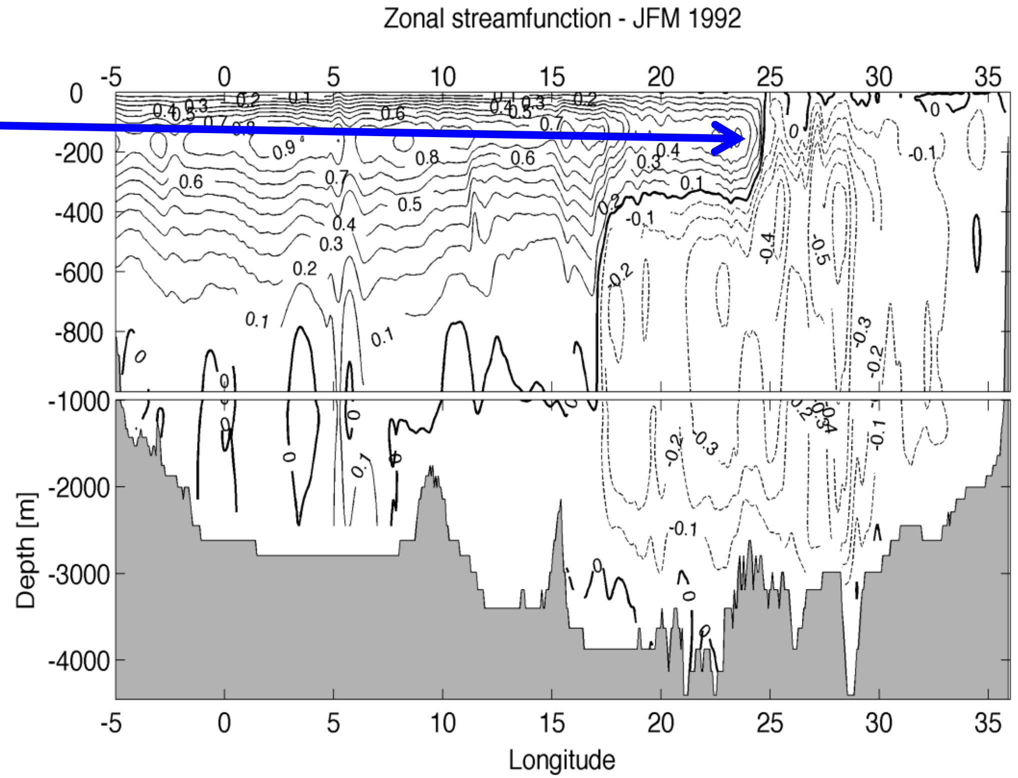
Thermohaline circulation

MAW-LIW system not extending in the e.Levantine.

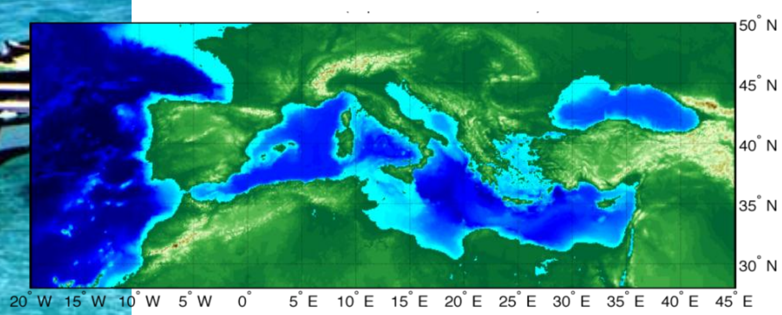
Separation between the e. Levantine and the rest of the basin.

Weakened EMED ventilation from Adriatic sea.

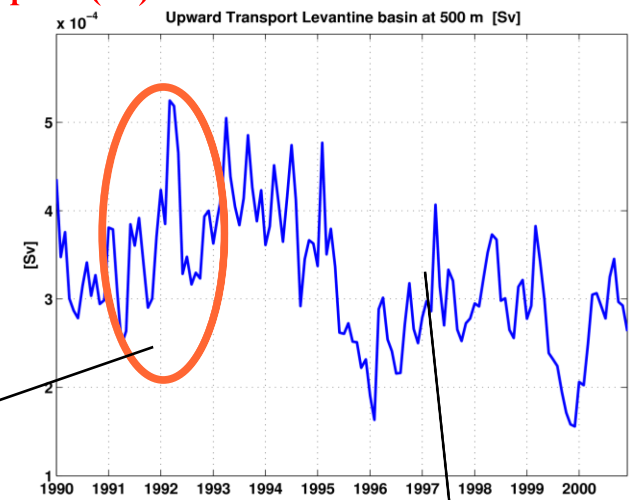
EMT period (1992)



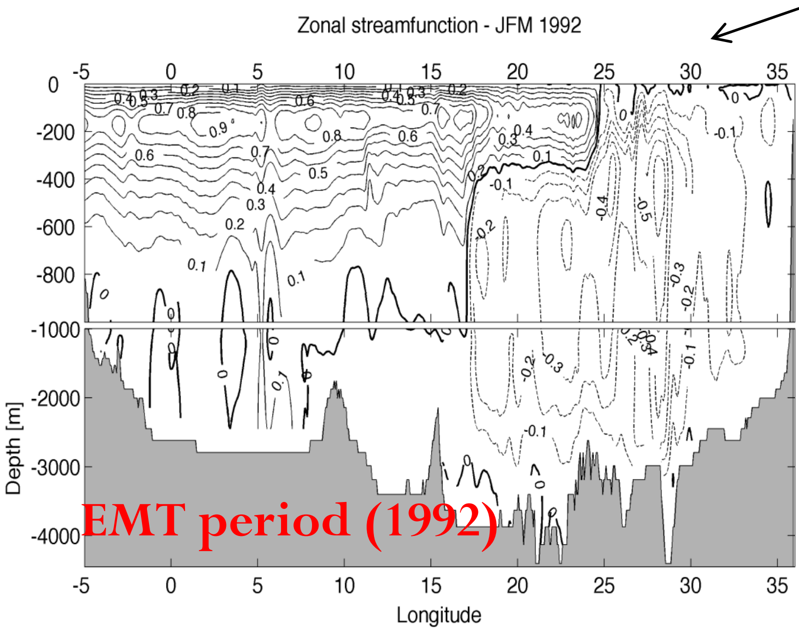
Changes in transport levantine



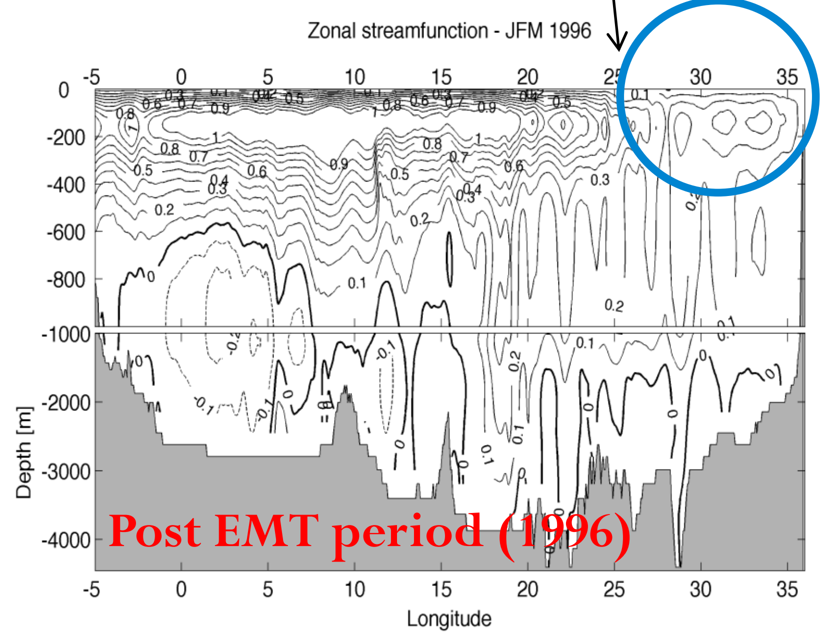
Upward transport (Sv) Levantine basin at 500 m



Enhanced upward transport in the Levantine basin.



EMT period (1992)



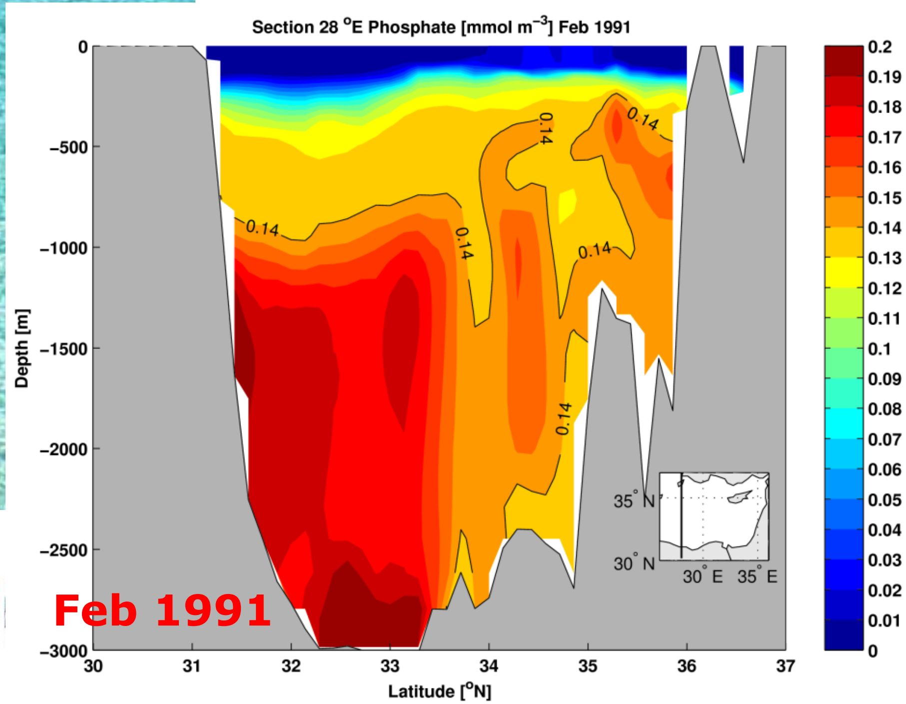
Post EMT period (1996)

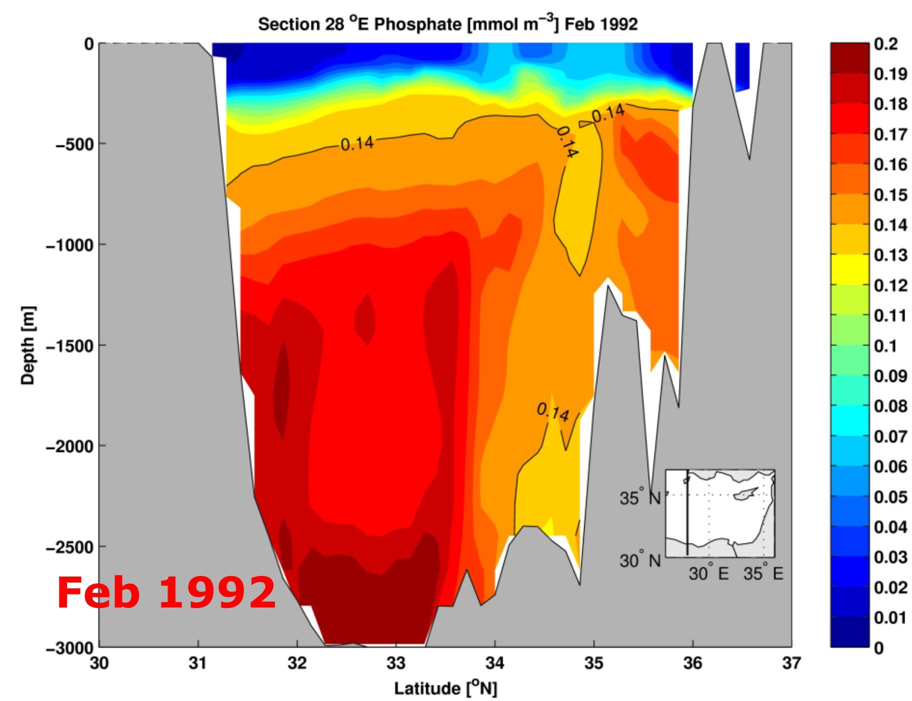
Model response to the physical forcing

The large recirculation cell in eastern Levantine and the positive Ekman pumping linked to the wind curl anomaly induced a vertical transport that modified the vertical distribution in the first 500m.

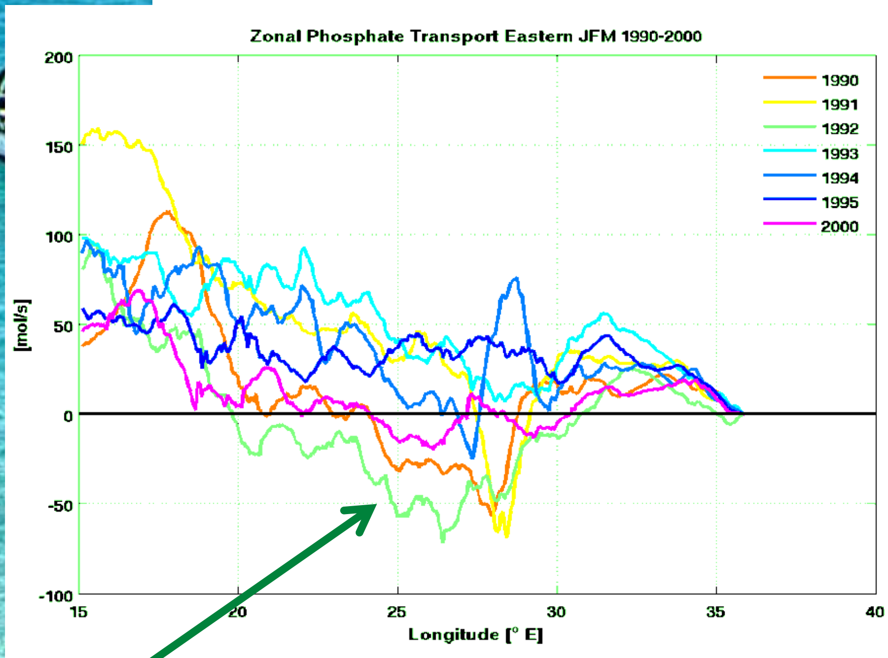
The deep isoline of 0.14 mmol/m^3 shifted upward and the vertical distribution became more homogenous.

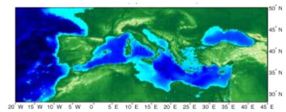
PHOSPHATE (SECTION @ 28° E)



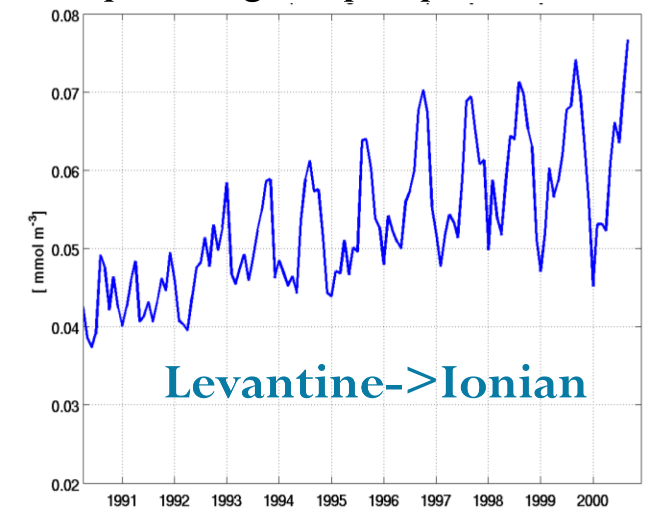


Model response to the physical forcings





Transport-weighted phosphate concentrat

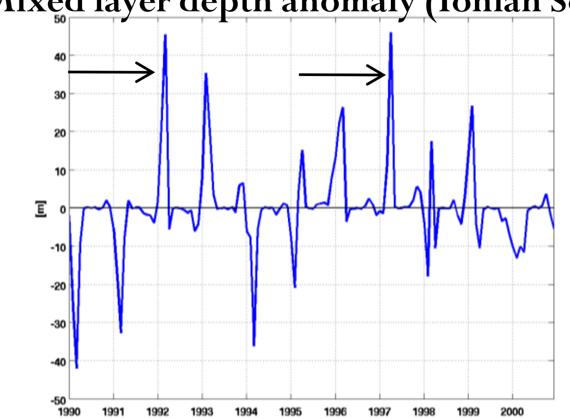


Increase of phosphate concentration

1992 is characterized by a negative transport.
Enhanced westward nutrient transport
in "transient" years (EMED).

Strong vertical mixing events (Ionian) in subsequent years

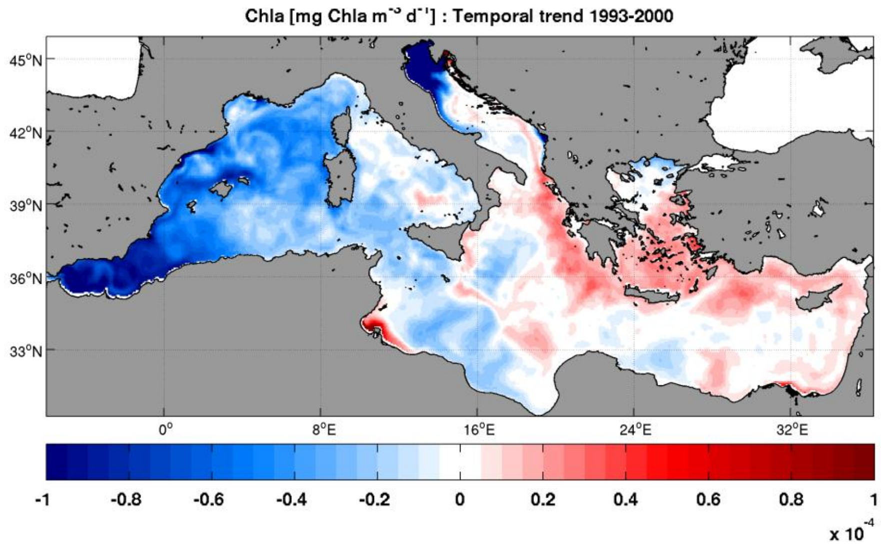
Mixed layer depth anomaly (Ionian Sea)



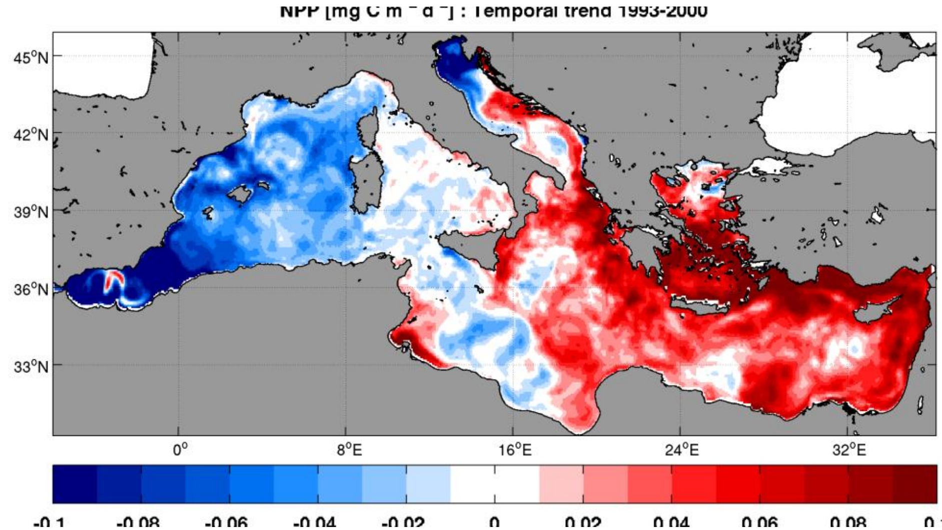
Changes in the biogeochemistry

Linear trend 1993-2000

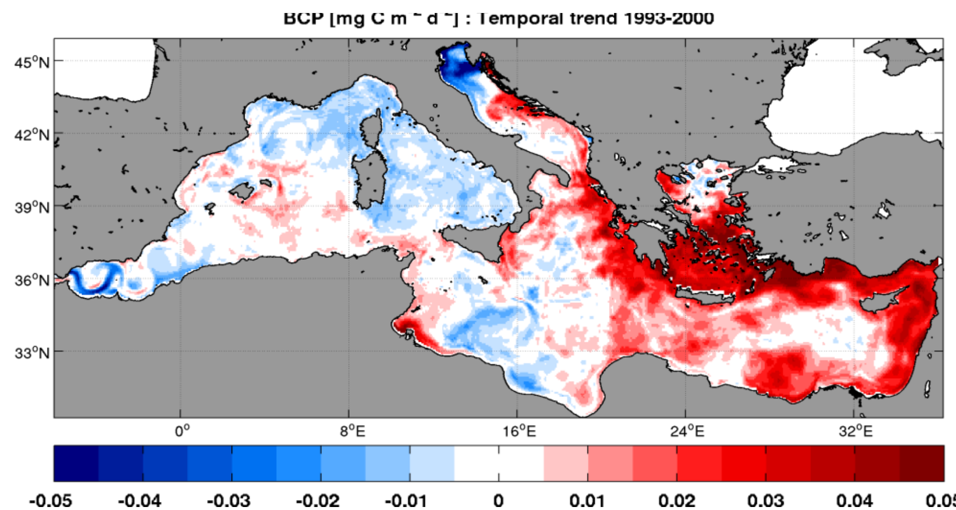
Chlorophyll-a trend (mg Chl-a m^{-3} d^{-1})



Net Primary Production trend (mg C m^{-2} d^{-2})



Bacterial Carbon Production trend (mg C m^{-2} d^{-2})



An overall tendency to the enhancement of NPP, BCP and surface Chl-a in the Levantine and the Ionian.

Decrease in the western part, in the Alboran and Adriatic.

Final remarks

- The past 20 years mean circulation confirms to be formed by cyclonic/anticyclonic sub-basin scale gyres and open ocean, as well as boundary intensified, jets
- The decadal variability is dominated by the Ionian reversal between 1987-1996 and 1997-2006 and the Levantine basin intensification of the circulation
- Water mass formation rates show high production ‘events’: warming and salting of EMDW associated with EMT while WMDW gradual and consistent for the past 20 years
- EMT event in re-analysis produced by two concomitant effects: Ionian reversal and Aegean heat losses
- Atmospheric forcing changes are the main triggers of all circulation changes in the basin, in particular wind stress curl for the Ionian reversal

Final remarks

The simulated EMED basin experienced an upwelling of nutrients driven by Ekman pumping at the beginning of the 90's, with a peak in 1992 that uplifted the permanent nutricline.

In combination with this process the model simulated a net westward transport of phosphate that likely distributed part of the upwelled nutrients from the Levantine to the Ionian sea.

Surface chlorophyll concentration such as primary and bacterial production responded with a positive growth trend in the eastern Levantine, in the Aegean, northeastern Ionian and partly in the eastern Adriatic.