The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

SMR/1837-8

2007 ICTP Oceanography Advanced School

30 April - 11 May, 2007

Decadal Thermohaline Oscillations of the Mediterranean Sea: advective and convective processes

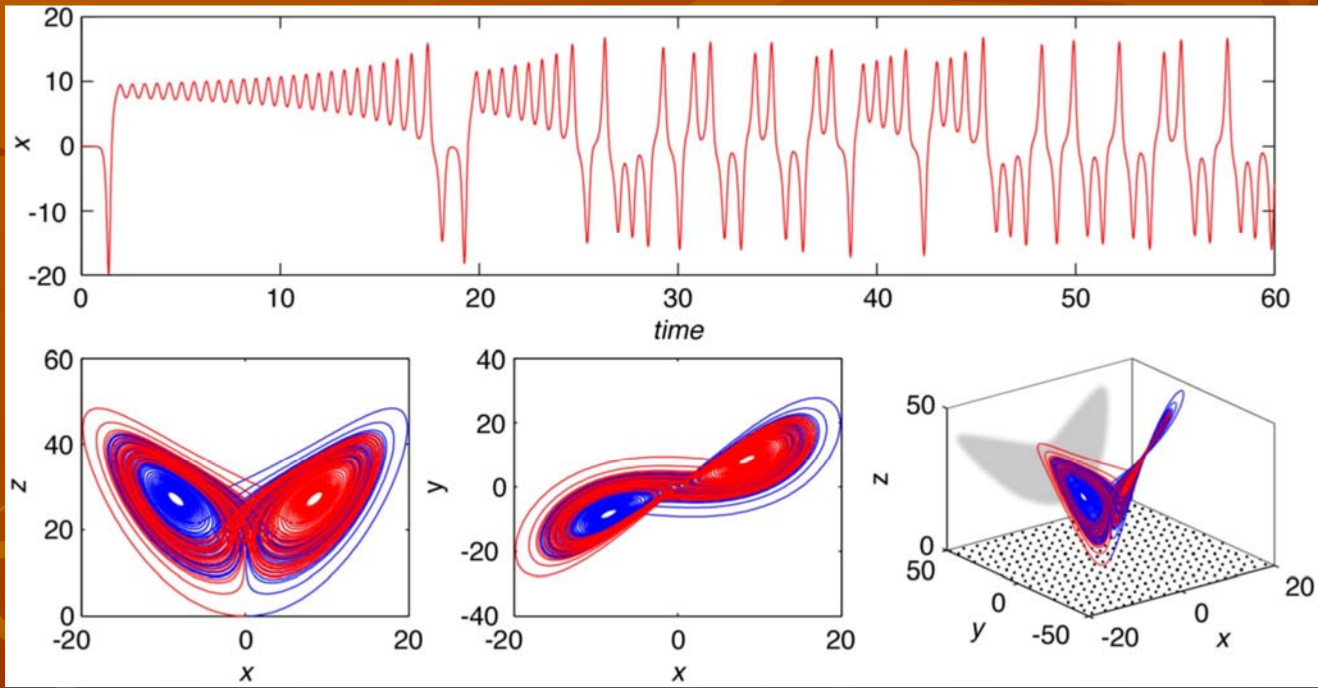
V. Artale

ENEA C.R. Casaccia,
Rome Italy

Second Part

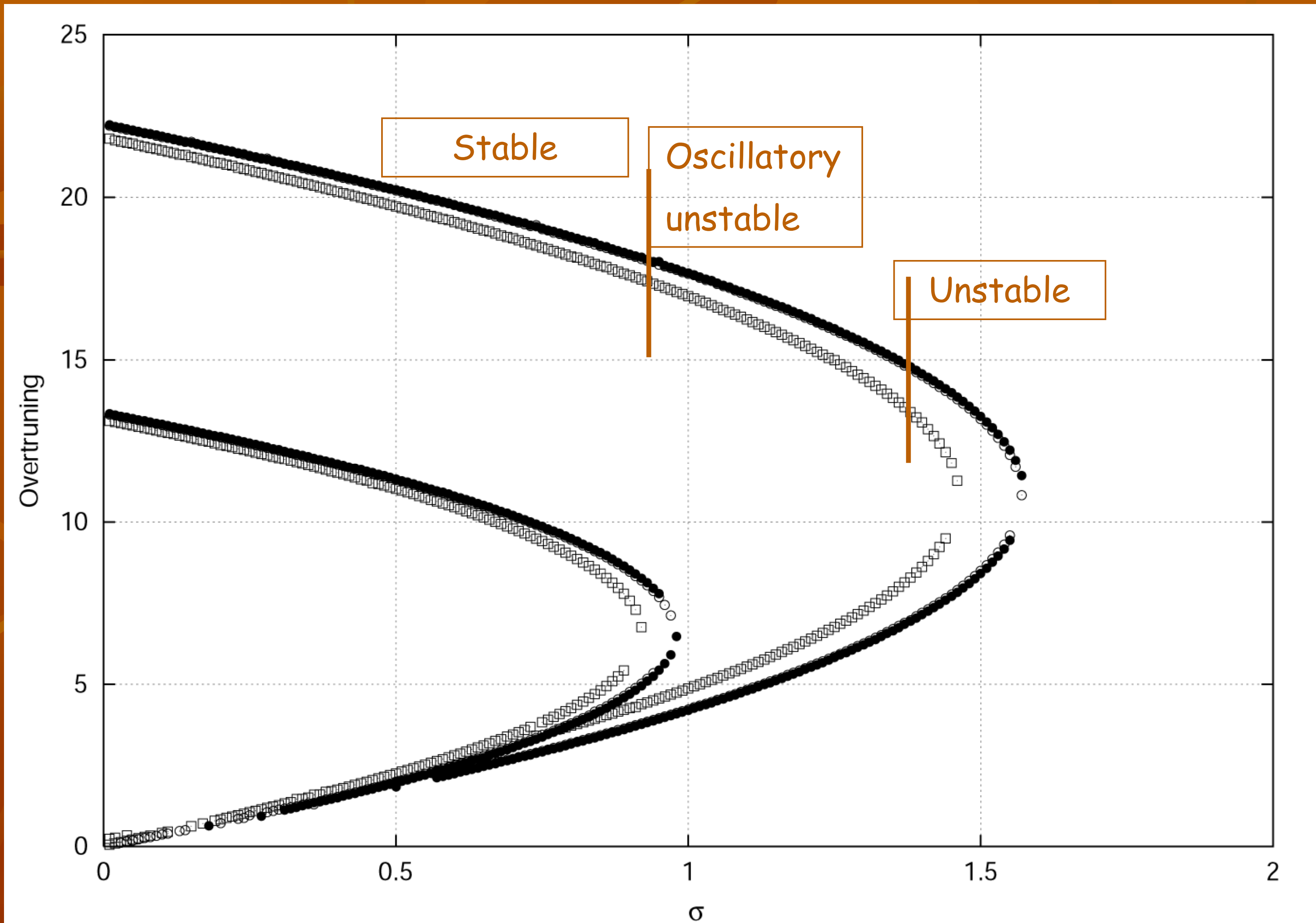
Decadal Thermohaline Oscillations of the Mediterranean Sea: advective and convective processes

Oscillations of climate can occur even if there were absolutely no variations of external forcing, purely by internal oscillations involving feedbacks among all of the components of the Earth-air-sea system it is possible that the swings in climate are the consequence of a steady forcing of an inherently unstable system that never achieves a true equilibrium



x
time
z
y

Bifurcation diagram



Climate scientific problems

- **Unknown long-term forcing**
- **Heterogenity and nonlinearity**:

  each domain (for example the ocean), in turn, is itself 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 advective fluxes in the fluid domains, 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

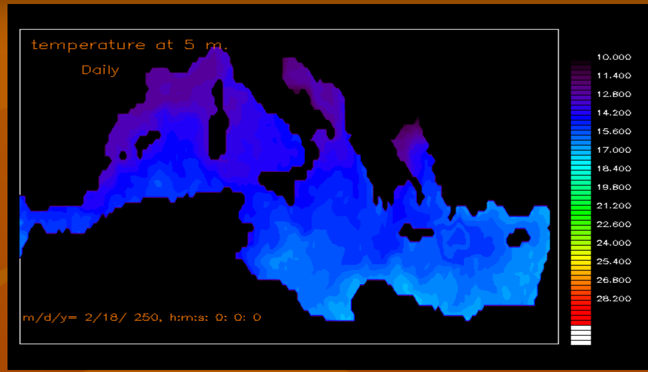
NUMERICAL EXPERIMENTS

The Modular Ocean Model (MOM) was used to represent the Mediterranean Sea circulation, and its sensitivity to different boundary conditions at the air-sea interface.

The control run, temperature and salinity of the first layer were relaxed to climatological values and the basin circulation was simulated for over a hundred years, after reaching a steady state.

Starting from the same stationary state, but switching to mixed boundary conditions, the model reached a different final steady state, in which the convective activity in the Eastern Basin and that in the Gulf of Lion seemed to be connected through a cyclic process of salty water intrusion in the Sicily Channel, over multi-decadal time scales.

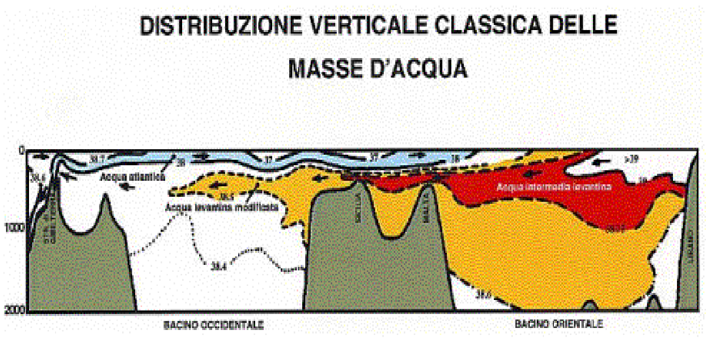
MEDMOM

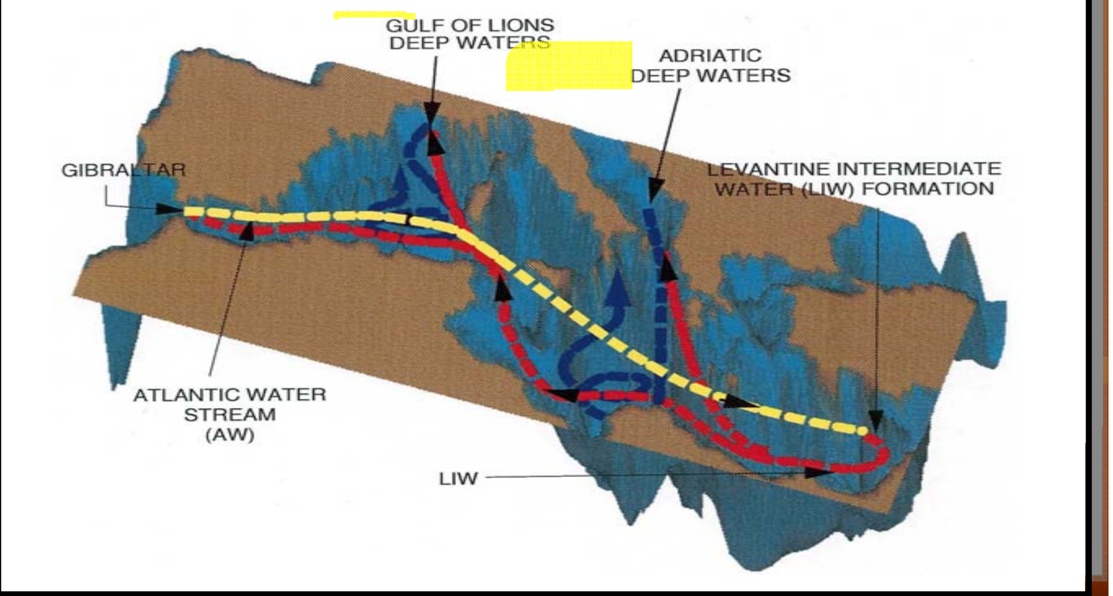


Surface temperature

- Primitive equation Cox – Bryan model for Climatic studies
- “Coarse resolution” 0.25° x 0.25° x 19 levels (deformation Rossby radius from 5 to 30 Km)
- Rigid lid, surface restoring conditions (SSST and MODB SSS)
- **Perpetual year forcing (different forcing, 1988)**
- **Horizontal** and vertical mixing scheme (different diffusivity parameterization)
- **Long integration experiments (equilibrium)**
- **Lagrangian trajectories and diagnostics**

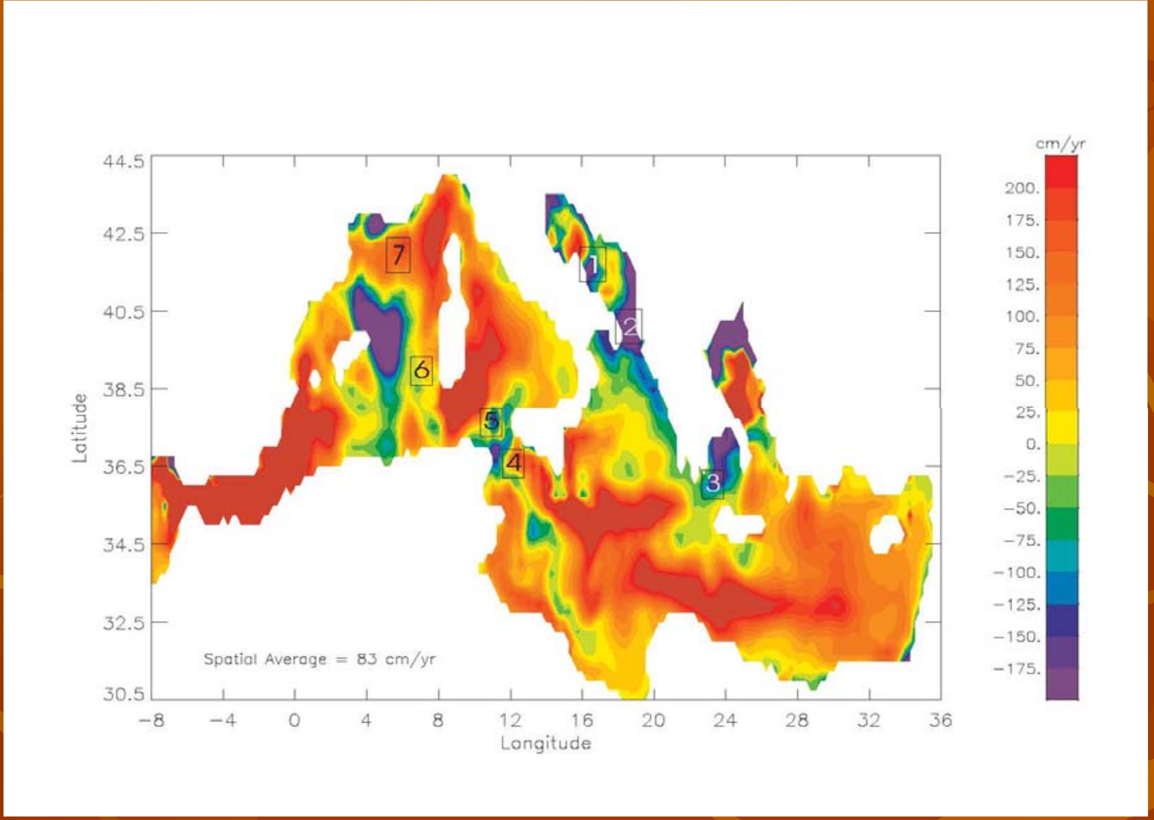
IN THE MEDITERRANAN THERMOHALINE CIRCULATION THE EXTERNAL FORCING ARE THE PRINCIPAL CAUSE OF CONVECTIVE PROCESSES AND INTERMEDIATE AND DEEP WATER FORMATION





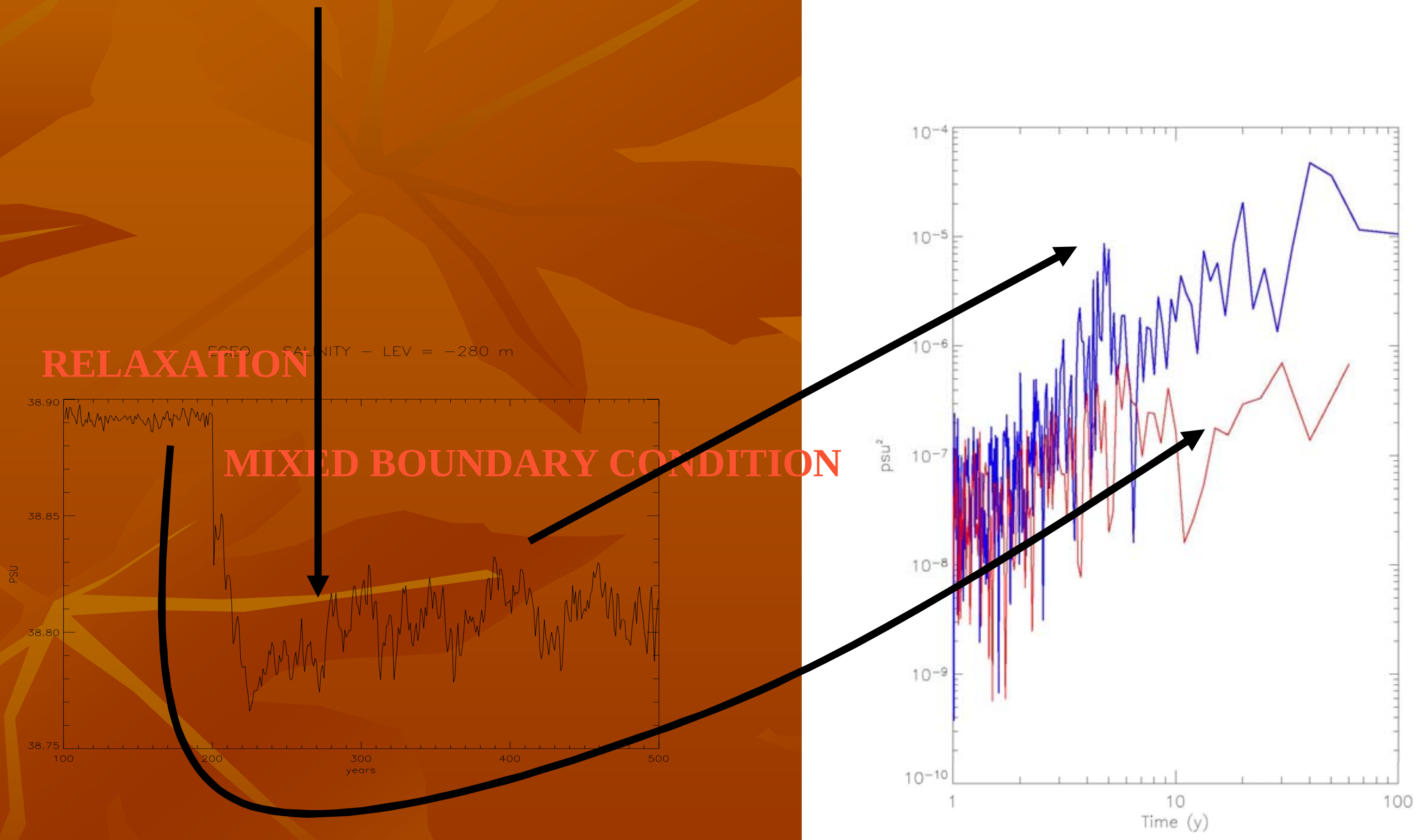
from Pinardi et al., 2000

Mean surface freshwater fluxes diagnosed over years 190-200 of EXP1. The spatial average is computed over the area enclosed in the Mediterranean Sea.

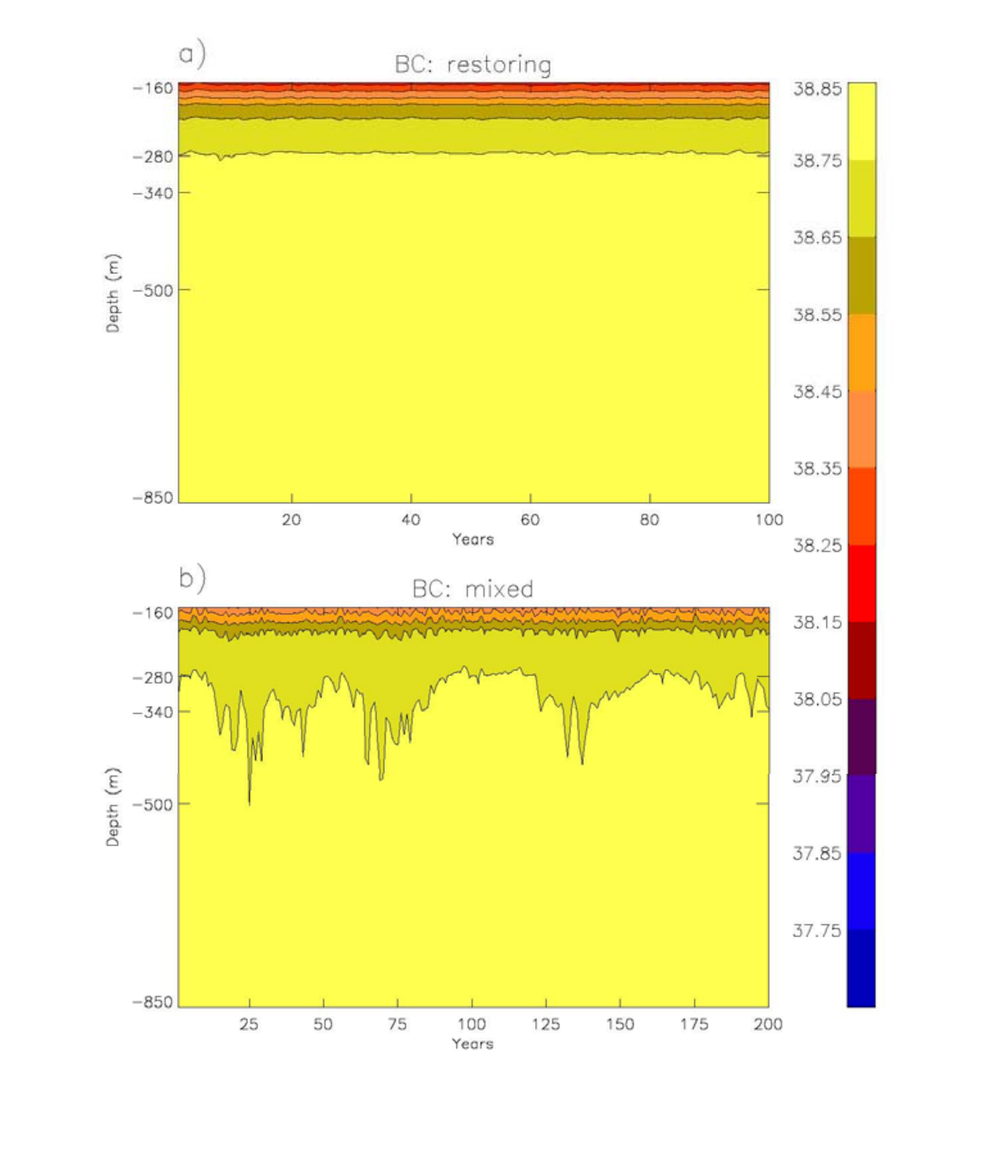


Locations where mean profiles of salinity and temperature are stored at high time resolution (5 days)

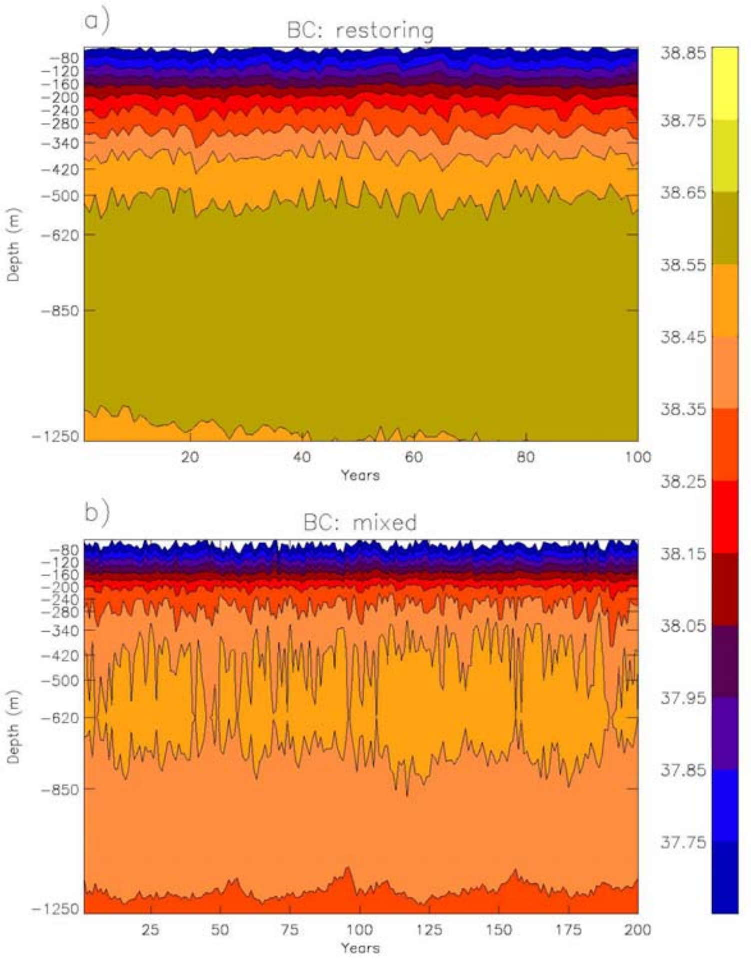
SALINITY AT 280m IN THE AEGEAN SEA



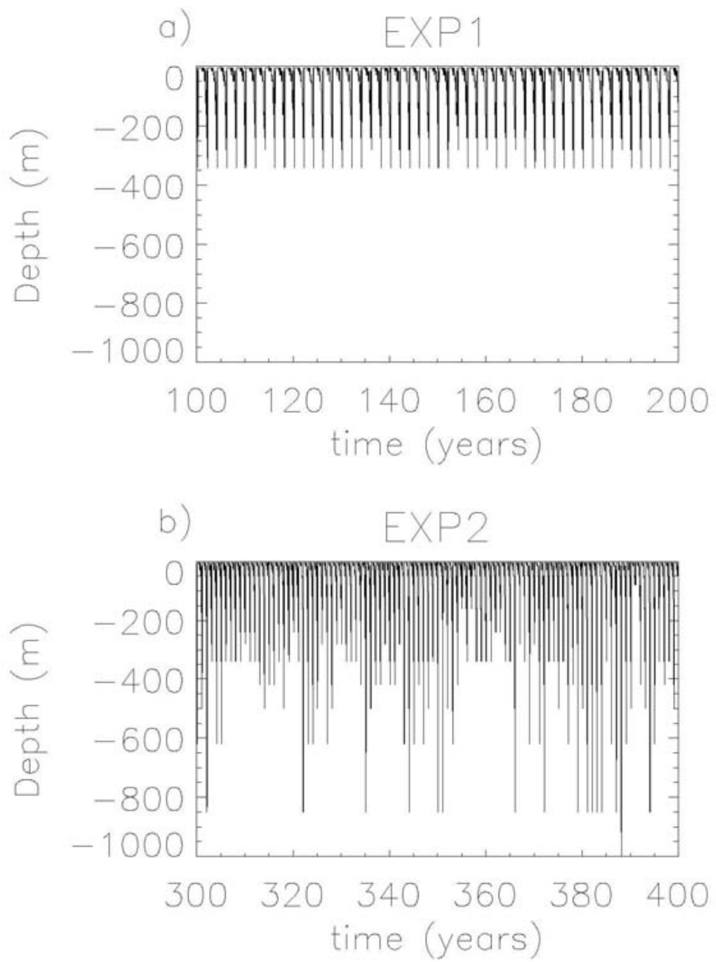
Spectra of the evolution of salinity in the Aegean Sea (280 m) for EXP1 (red line) and EXP2 (blue line)



Time evolution of the salinity profile in the Sicily Channel (site 4) for EXP1 (panel a) and EXP2 (panel b)

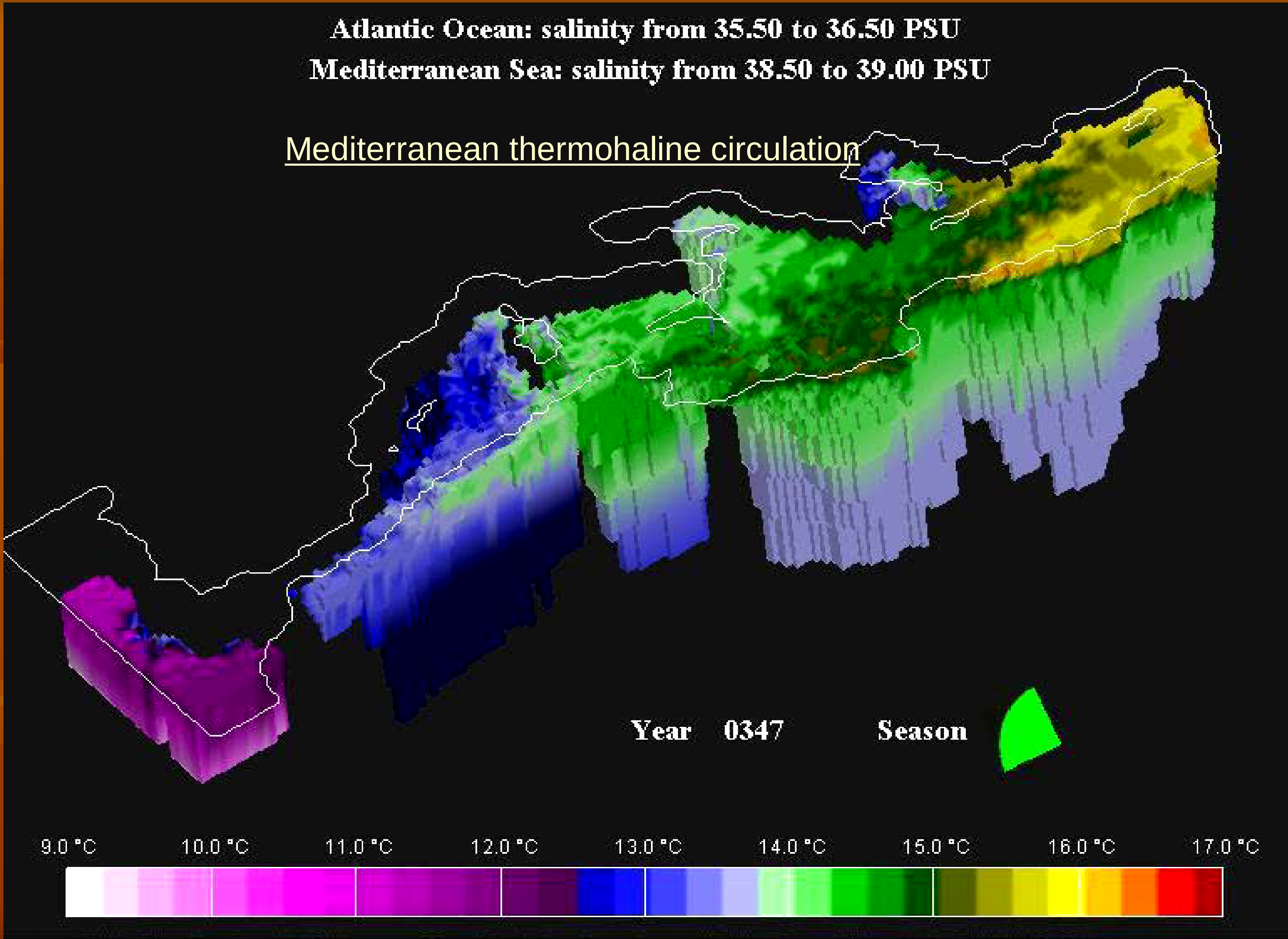


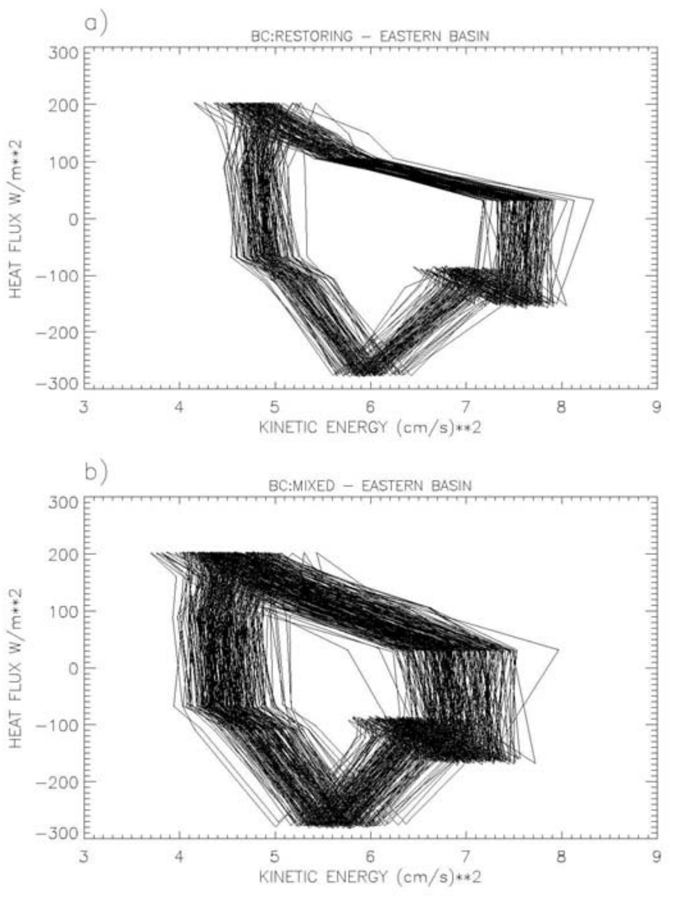
Time evolution of the salinity profile West of Sardinia (site 5) for EXP1 (panel a) and EXP2 (panel b).



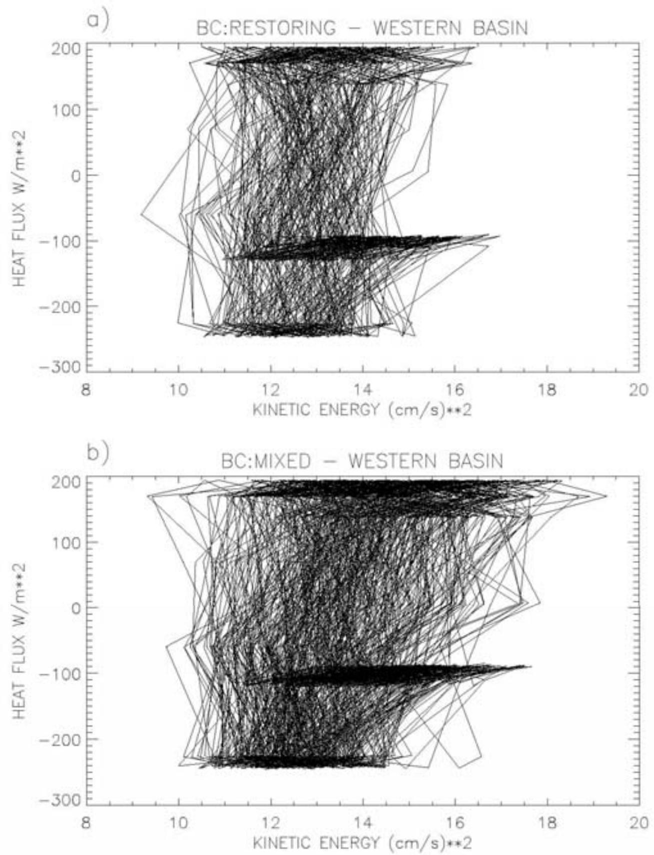
Deep convection in the Gulf of Lyon in the two experiments

Mediterranean thermohaline circulation





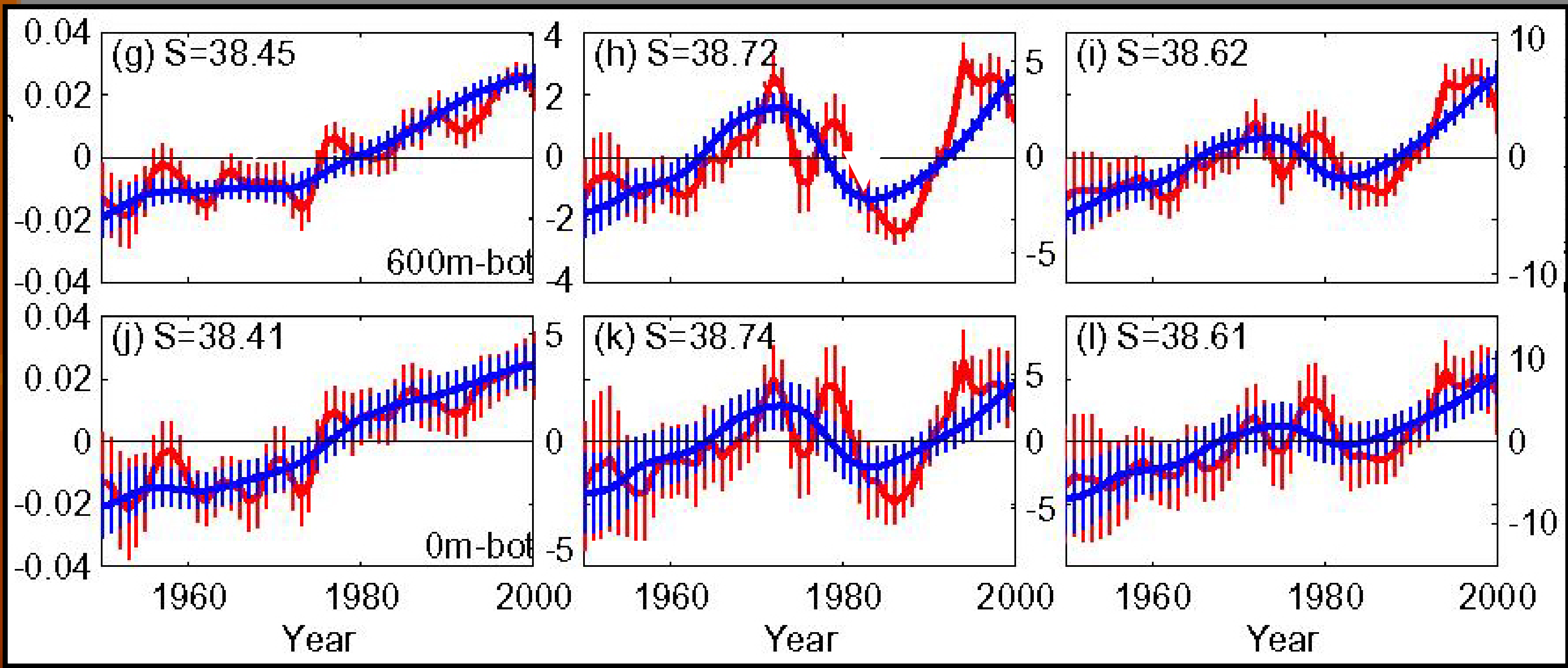
Phase diagram of the kinetic energy against heat fluxes for eastern and western basin, the upper and the below panel shows the restoring and flux boundary condition respectively.

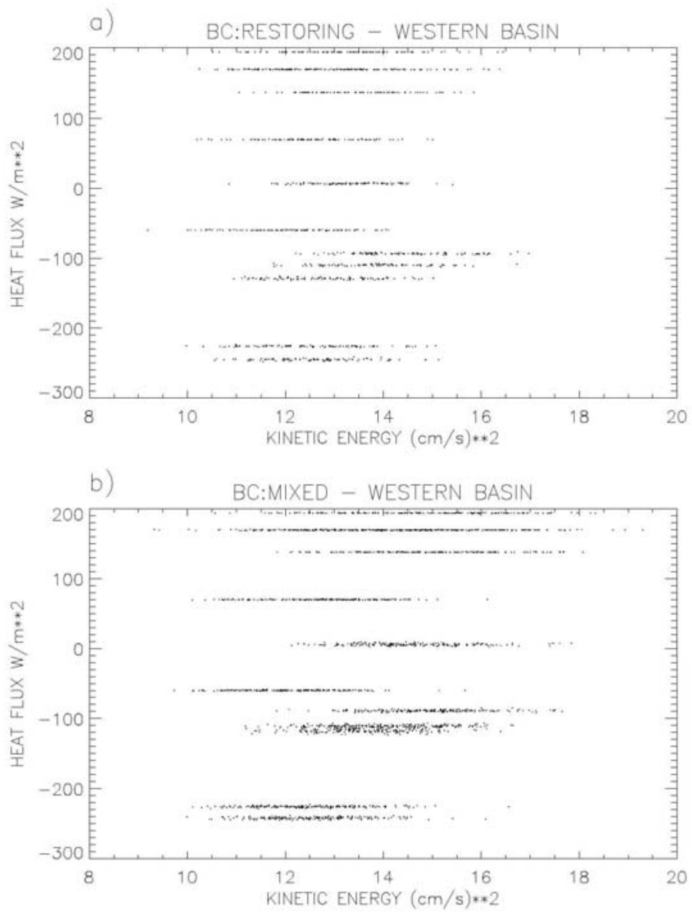

a)
BC:RESTORING – WESTERN BASIN
HEAT FLUX W/m**2
KINETIC ENERGY (cm/s)**2
b)
BC:MIXED – WESTERN BASIN
HEAT FLUX W/m**2
KINETIC ENERGY (cm/s)**2

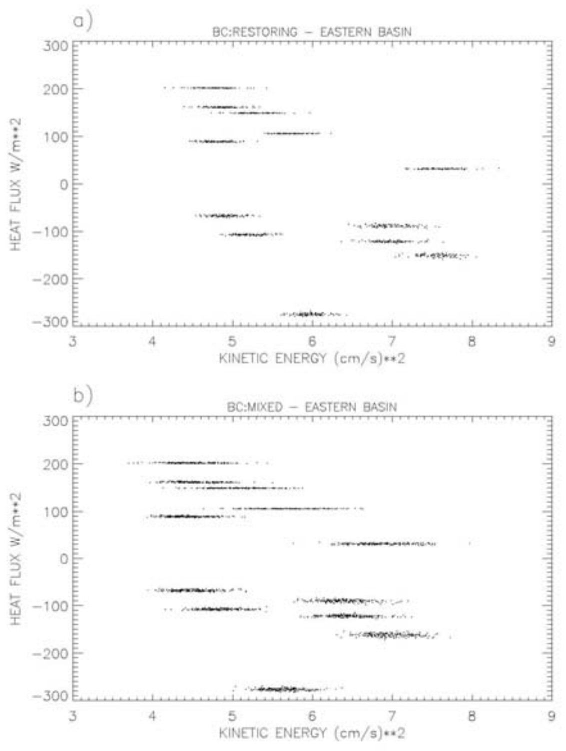
Time series (MEDAR-MEDATLAS) for the period 1950-2000 of volume mean salinity (left scale) and salt content (10^{13} PSU*m^3, right scale) anomalies

600m –bottom and 0-bottom (from Rixen et al, 2005)

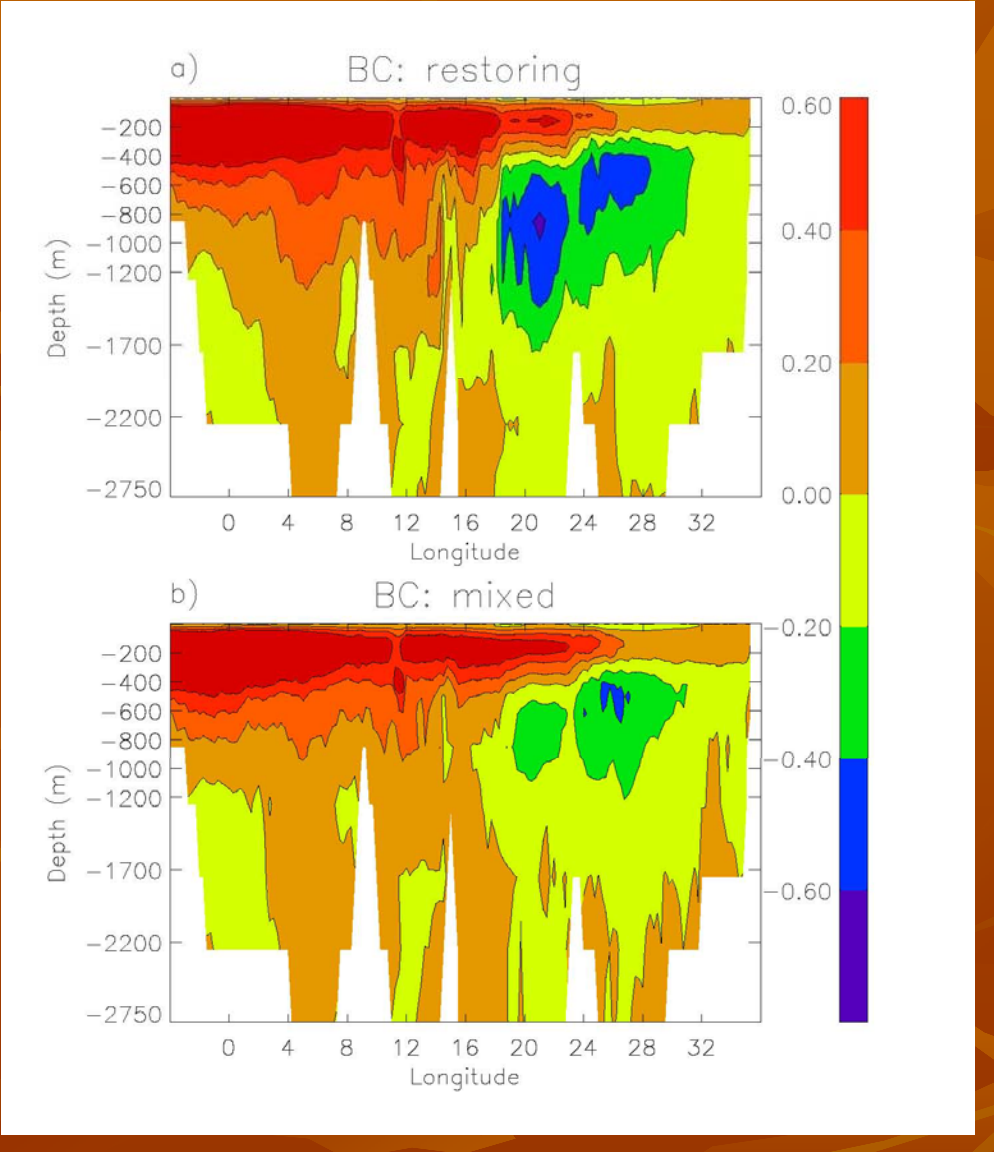
Western Mediterranean	Eastern Mediterranean	Mediterranean



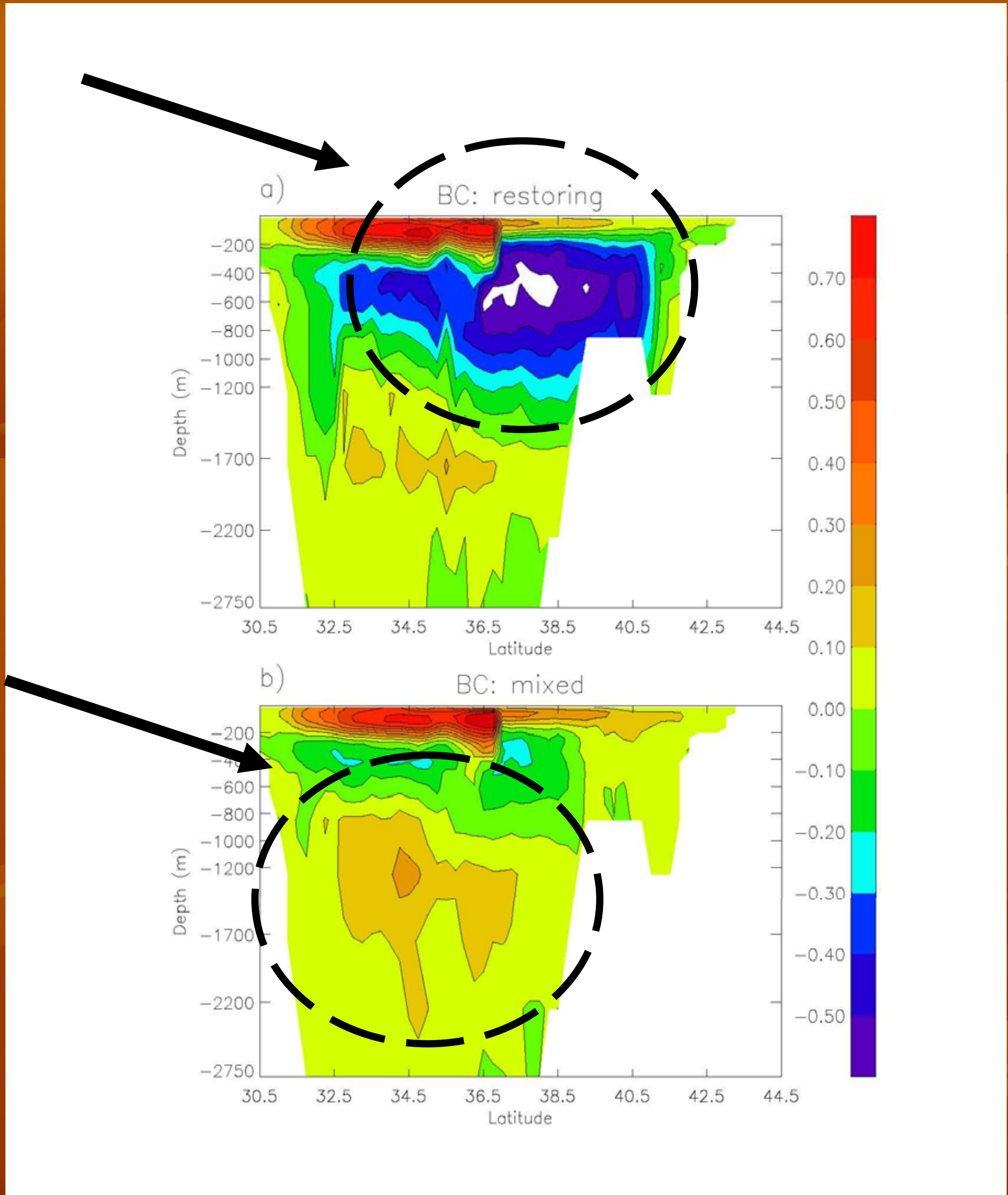

a)
BC:RESTORING – WESTERN BASIN
HEAT FLUX W/m**2
KINETIC ENERGY (cm/s)**2
b)
BC:MIXED – WESTERN BASIN
HEAT FLUX W/m**2
KINETIC ENERGY (cm/s)**2



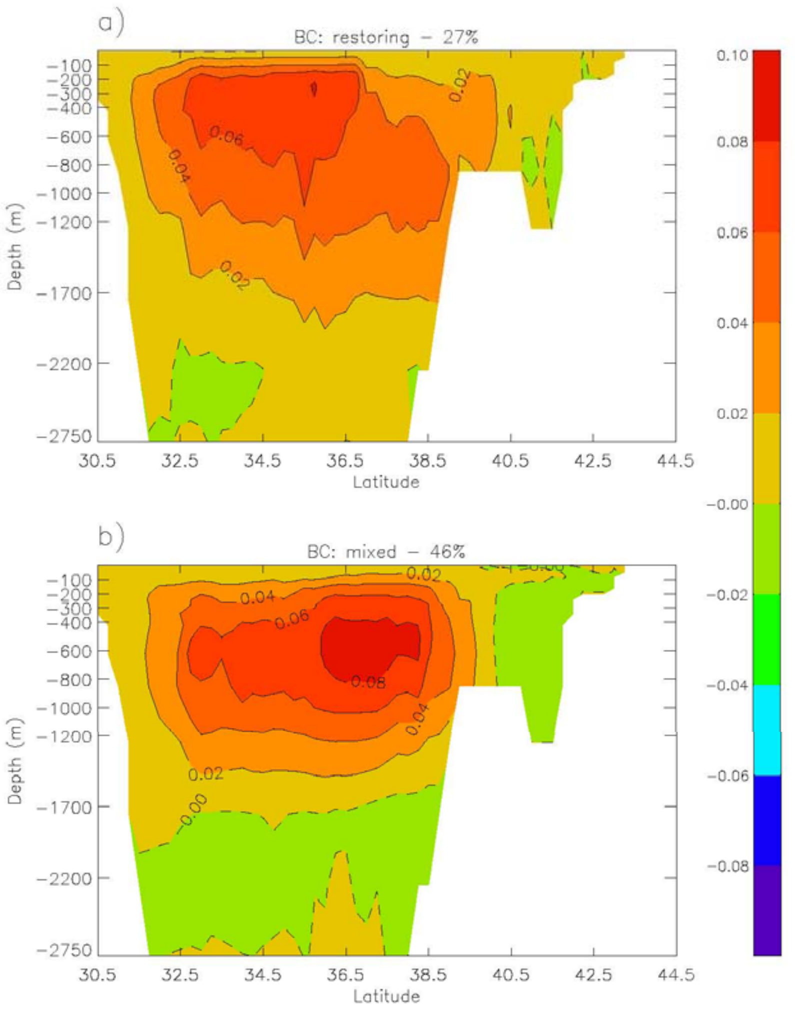
a)
BC:RESTORING – EASTERN BASIN
HEAT FLUX W/m**2
KINETIC ENERGY (cm/s)**2
b)
BC:MIXED – EASTERN BASIN
HEAT FLUX W/m**2
KINETIC ENERGY (cm/s)**2



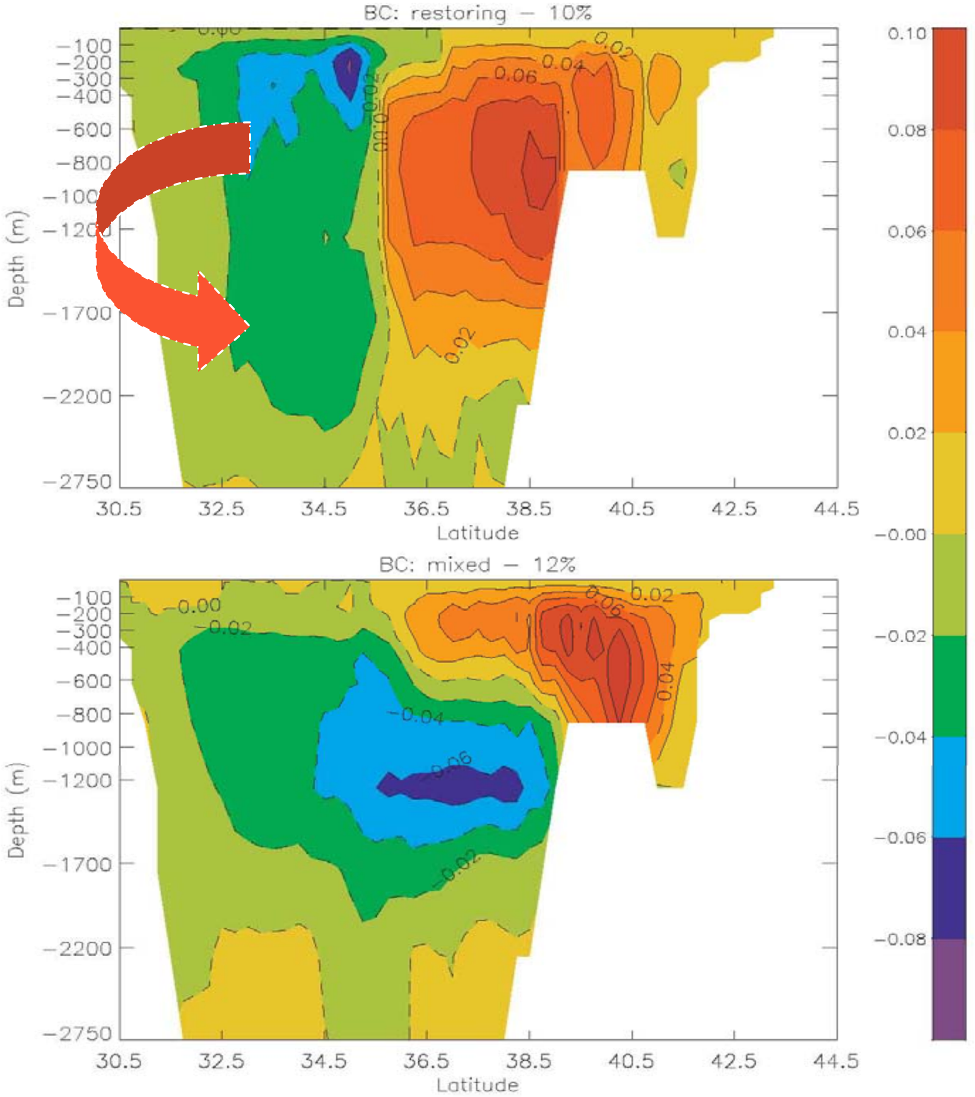
Mean Zonal Transport field (units Sv) for the period 15 Jun/14 Jul: EXP1 (a) and EXP2 (b).



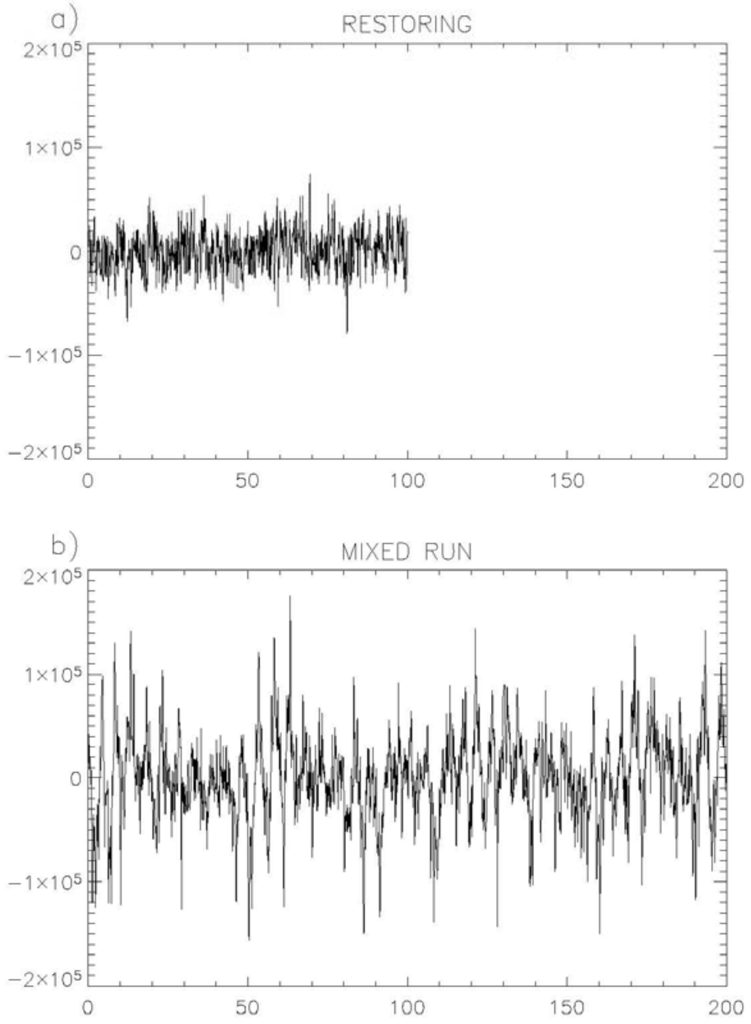
Mean Meridional Transport field (units Sv) in the Eastern Basin for the period 15 Jul/14 Aug: EXP1 (a) and EXP2 (b).



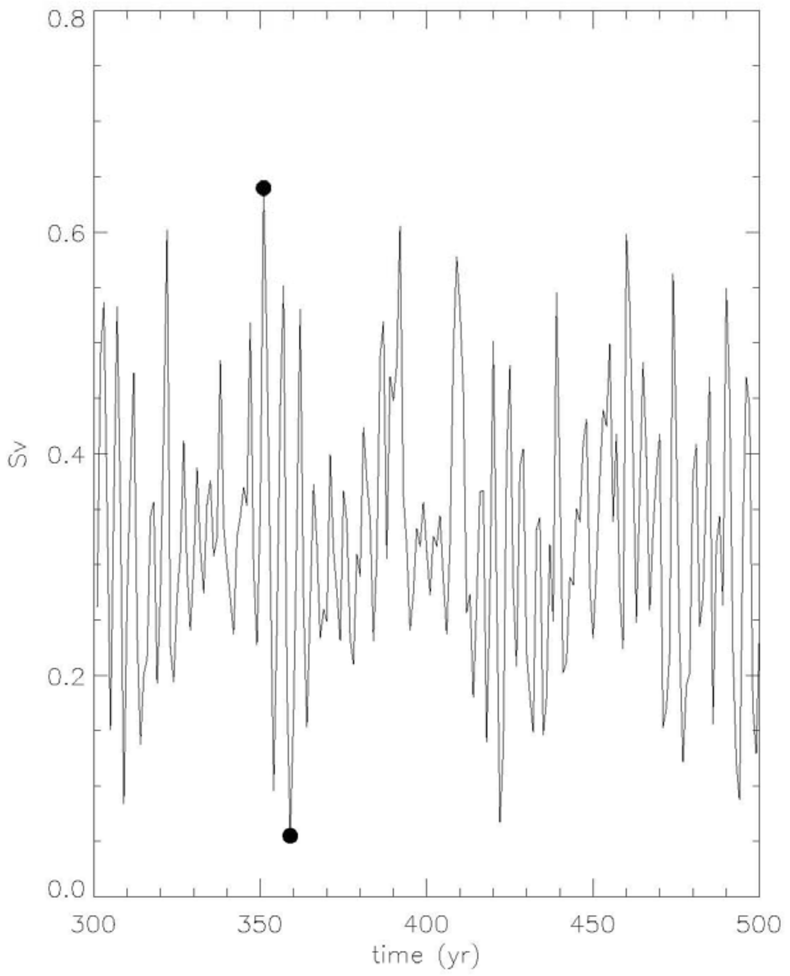
Meridional Transport (units Sv) in the Eastern Basin: first mode of the EOF decomposition for EXP1 (a) and EXP2 (b).



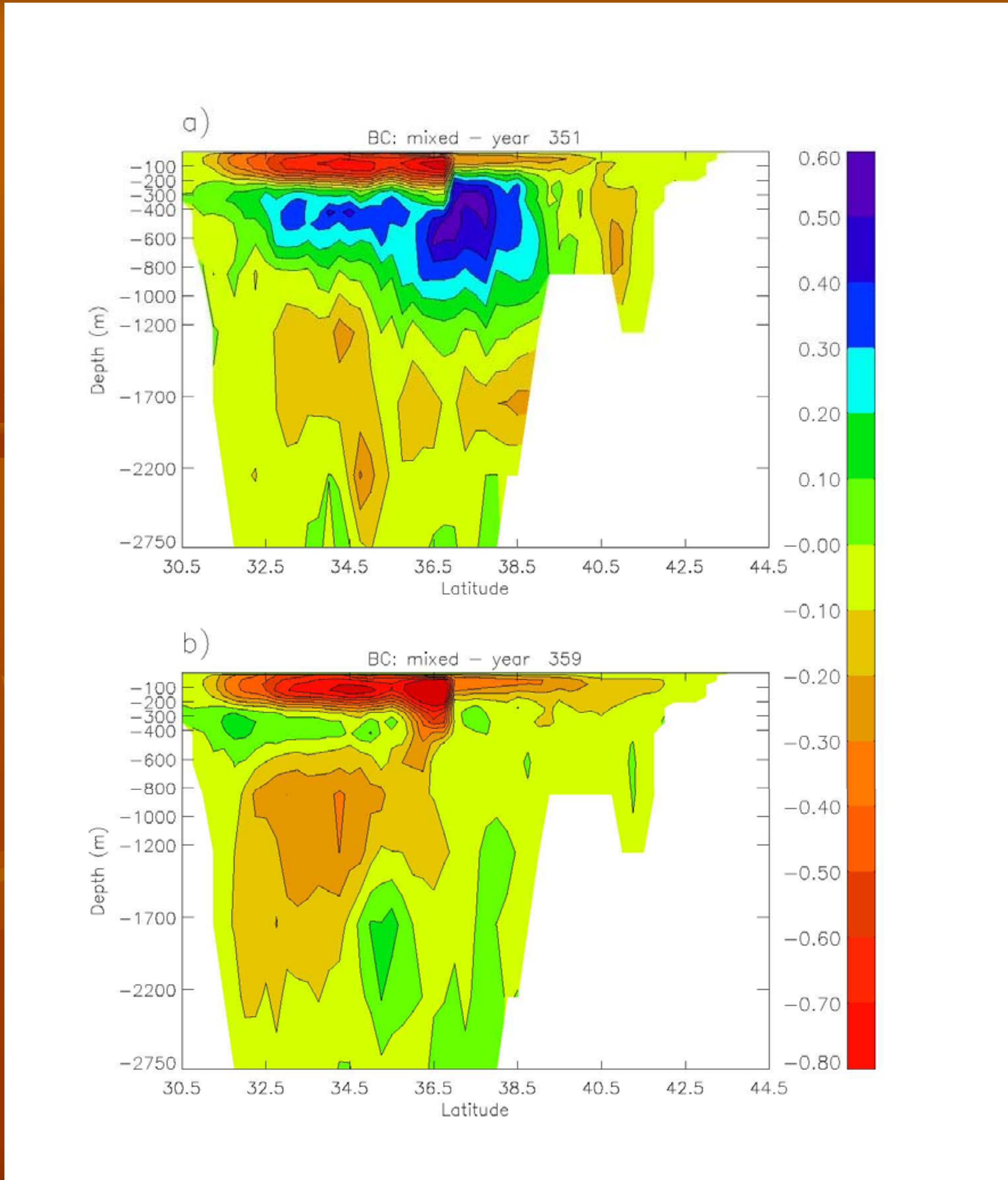
Meridional Transport (units Sv) in the Eastern Basin: second mode of the EOF decomposition for EXP1 (a) and EXP2 (b).



Meridional Transport (units Sv) in the Eastern Basin: time evolution of the principal component relative to mode 1 for EXP1 (a) and EXP2 (b).



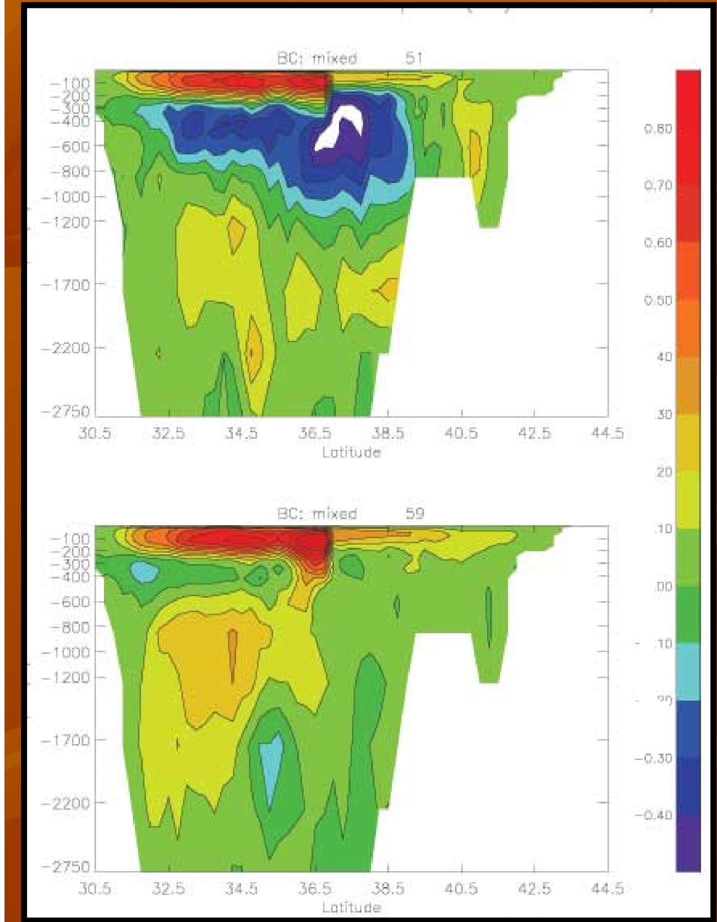
Evolution of the maximum meridional streamfunction (units Sv) in the Eastern Mediterranean.during EXP2 (July).



Monthly mean meridional Transport (units Sv) in the Eastern Basin for the period 15 Jul/14 Aug in two selected years of EXP2: year 351 (a); year 359 (b).

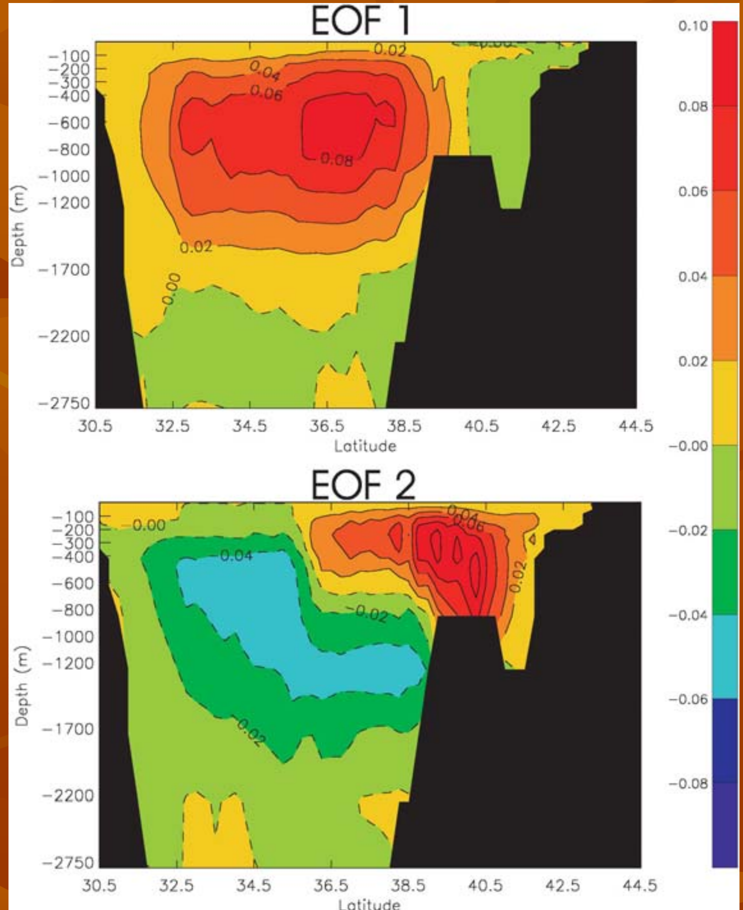
MERIDIONAL TRANSPORT IN THE EASTERN BASIN

EOF (1ST (46%) AND 2ND (13%) MODE) OF THE MERIDIONAL TRANSPORT



THC (+) ADRIATIC DW

THC (-) EAGEAN DW



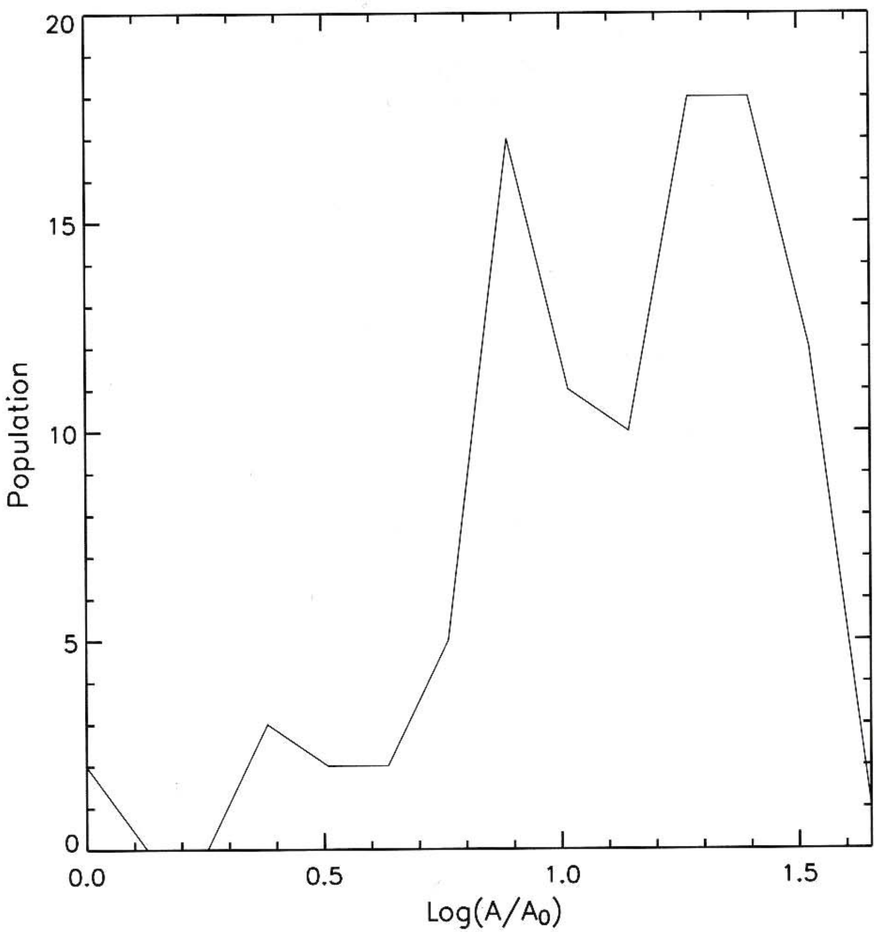


Fig. 17. Probability density function of peak-to-peak amplitude of the oscillation of maximum meridional overturning (Fig. 15). Amplitude A is normalized with a reference amplitude A_0 = 0.01 Sv. Natural logarithm of ratio A/A_0 is considered in order to account for the increase in relative spacing of single peak-to-peak amplitudes in the case of large oscillations

Probability density function of the peak-to-peak amplitude of the oscillation of the maximum meridional overturning (figure 15). The amplitude A is normalized with a reference amplitude A0 = 0.01 Sv. The natural logarithm of the ratio A/ A0 is considered in order to account for the increase of the relative spacing of single peak-to-peak amplitudes in the case of large oscillations.

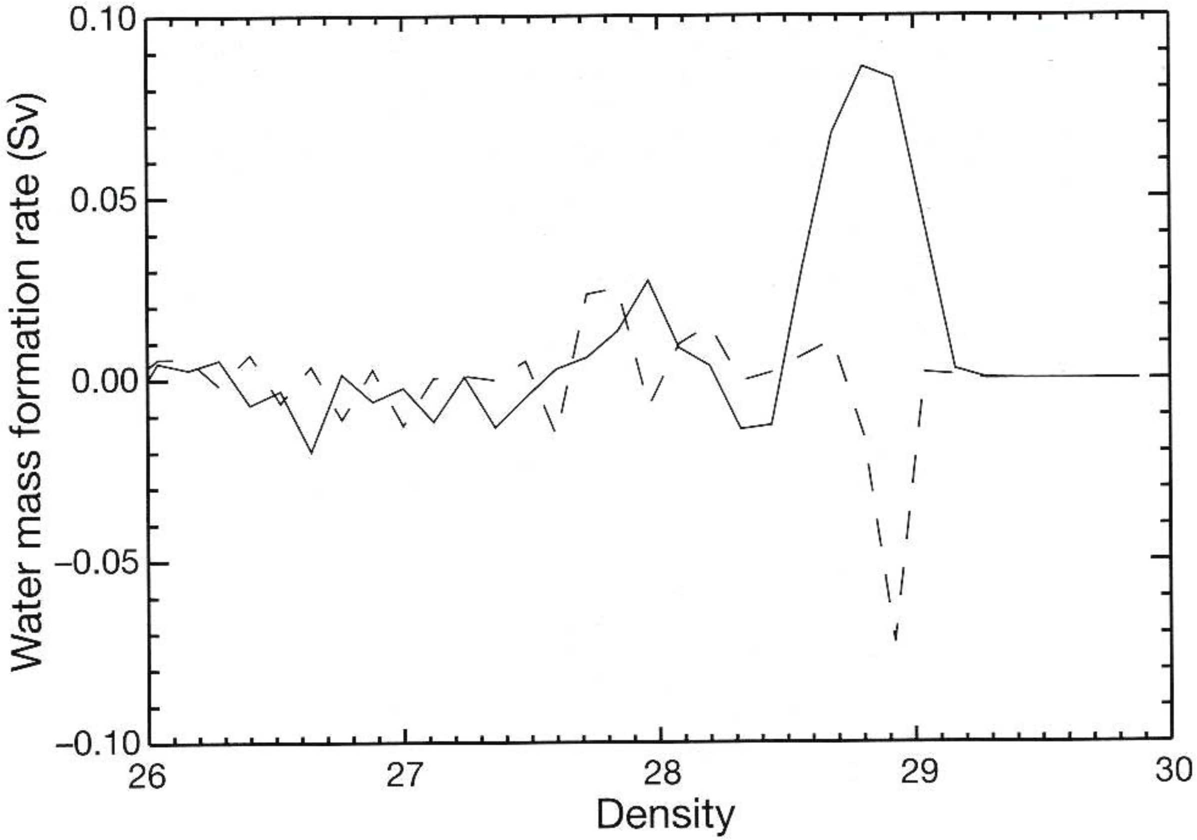
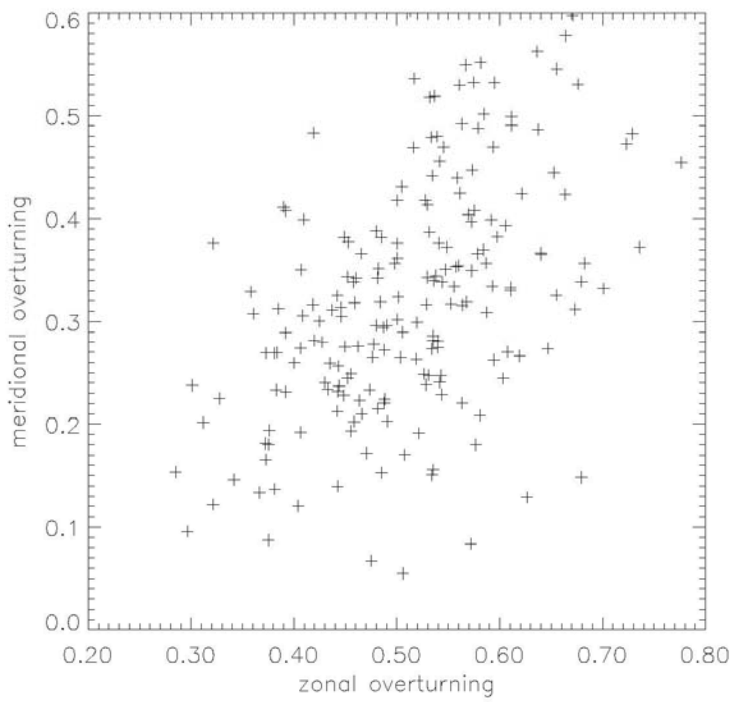
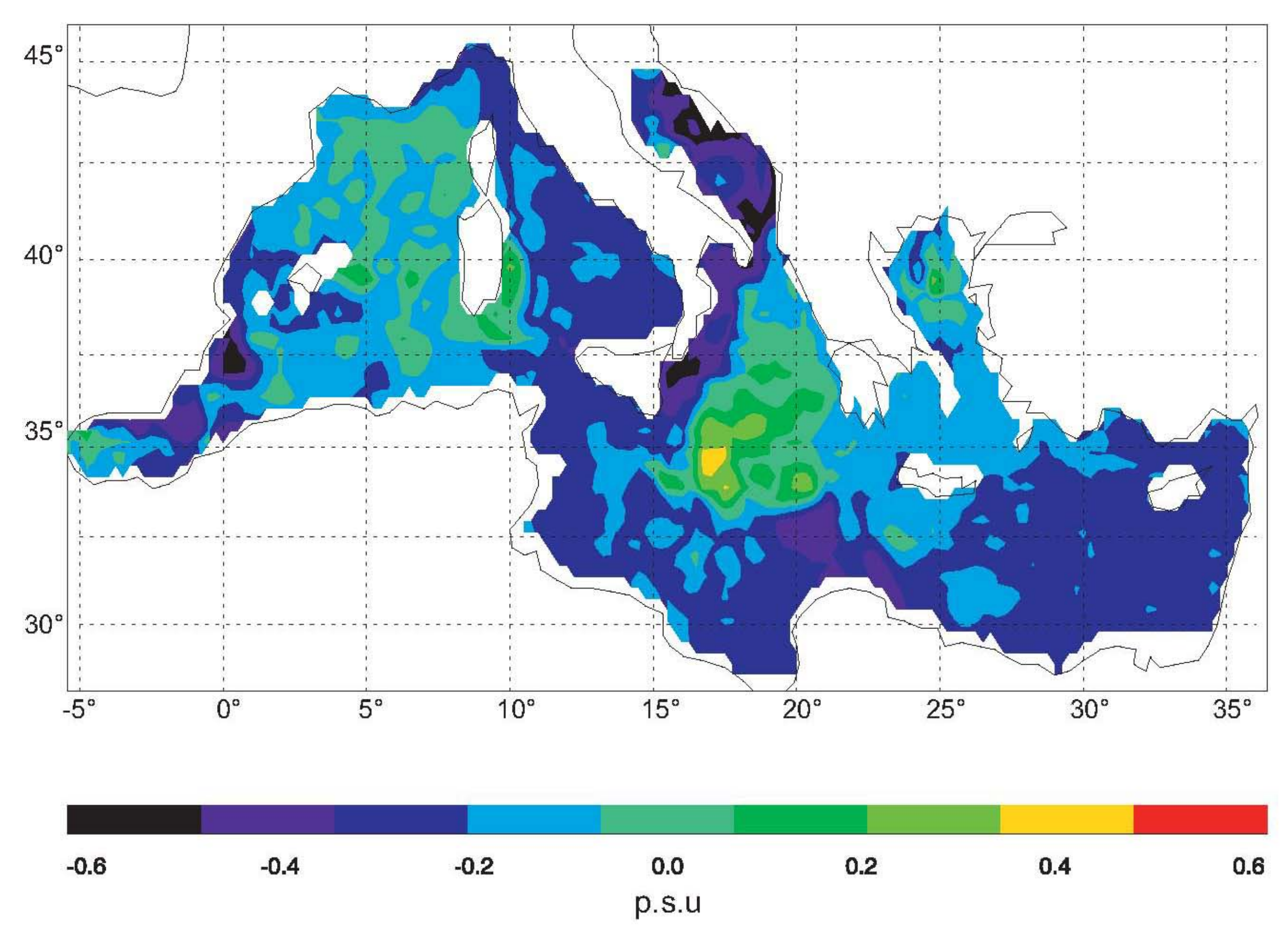


Fig. 18. Difference in yearly water mass formation rate (expressed in Sv as a function of density anomaly) between Years 359 and 351 (corresponding to strong and weak meridional overturning, respectively, in the Eastern Mediterranean Sea). Positive values are indicative of greater formation rates in the year characterized by strong meridional overturning. - - - -: Aegean Sea; ———: Adriatic and north Ionian Seas



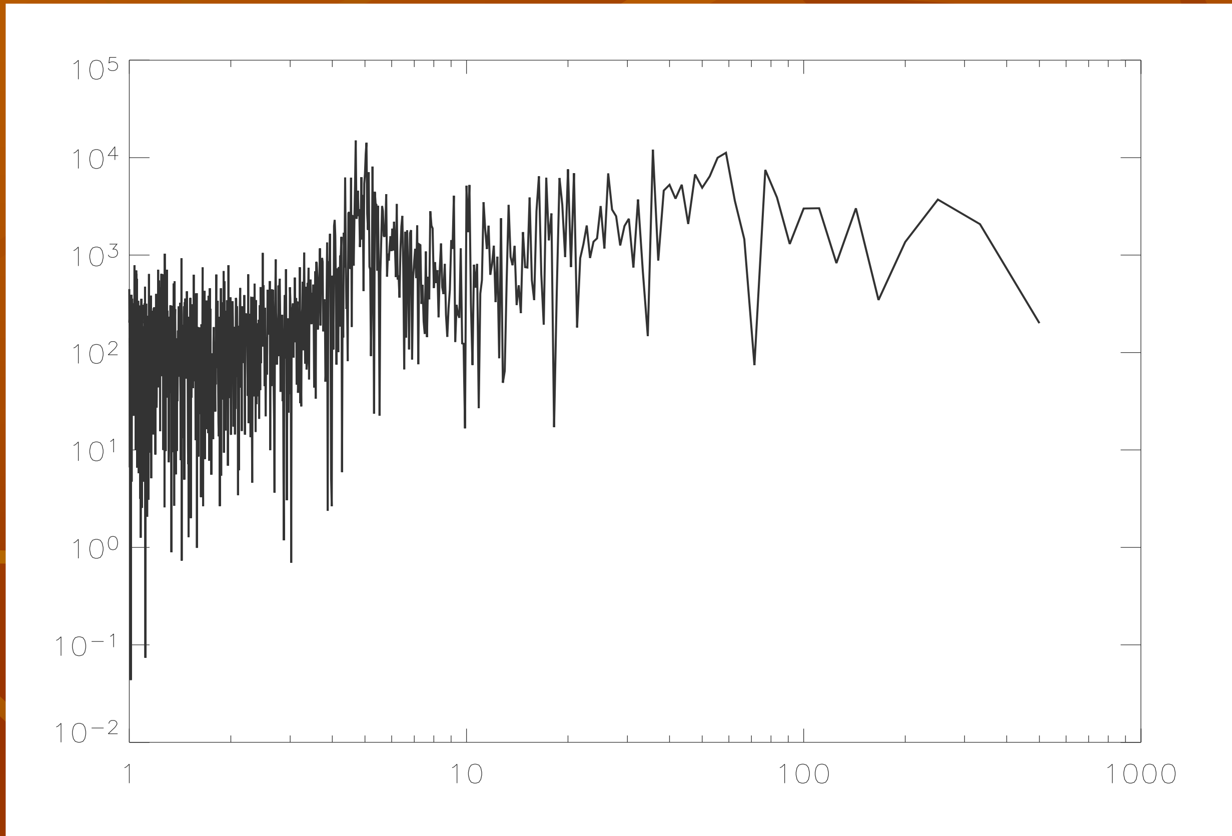
Scatter diagram of the meridional versus zonal overturning. The correlation coefficient is r = 0.5.

Salinity difference at surface between 351-359 yrs

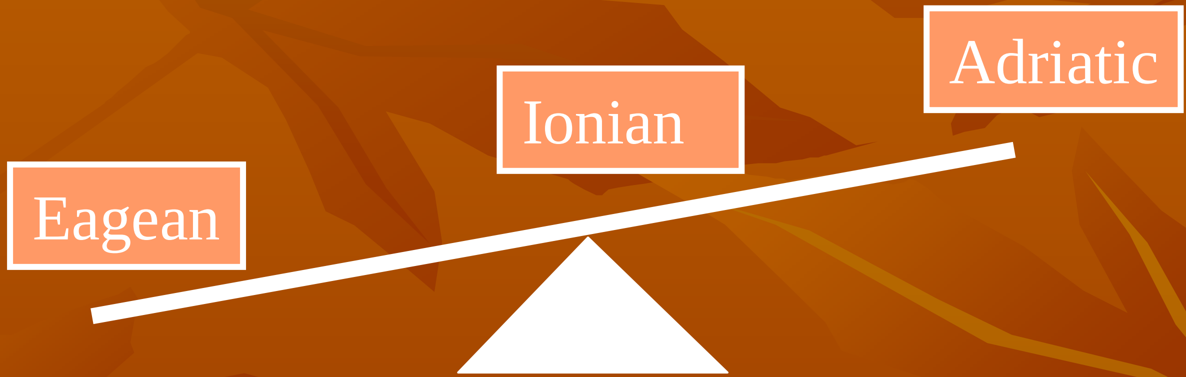


- We found that the meridional circulation was crucially affected by the change in surface forcing, and that mixed boundary conditions acted to destabilize the main circulation cell in the Eastern Basin, and to stabilize that in the Western Basin.

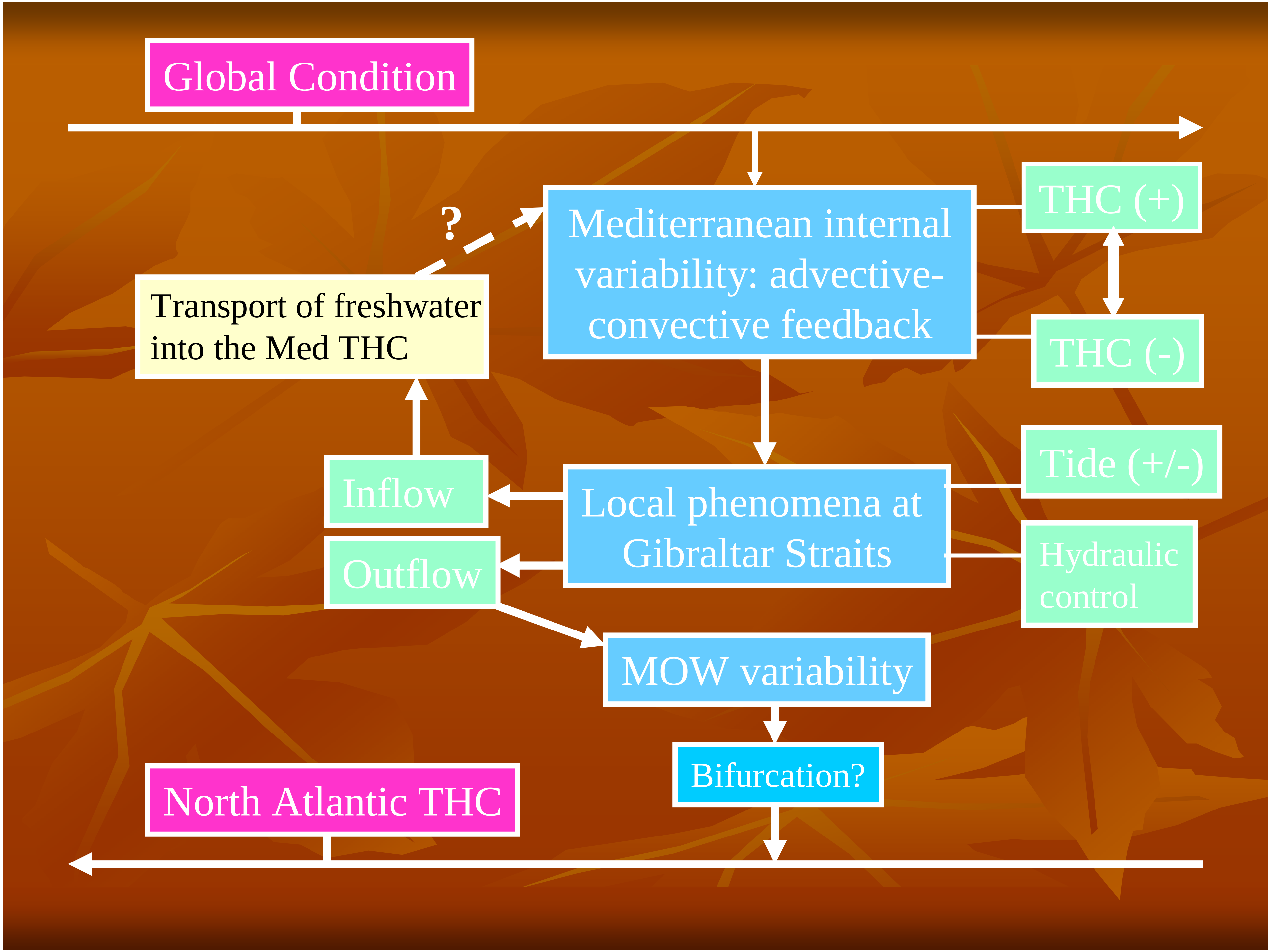
PC FIRST MODE



Mechanism of Eastern sub-basin variability

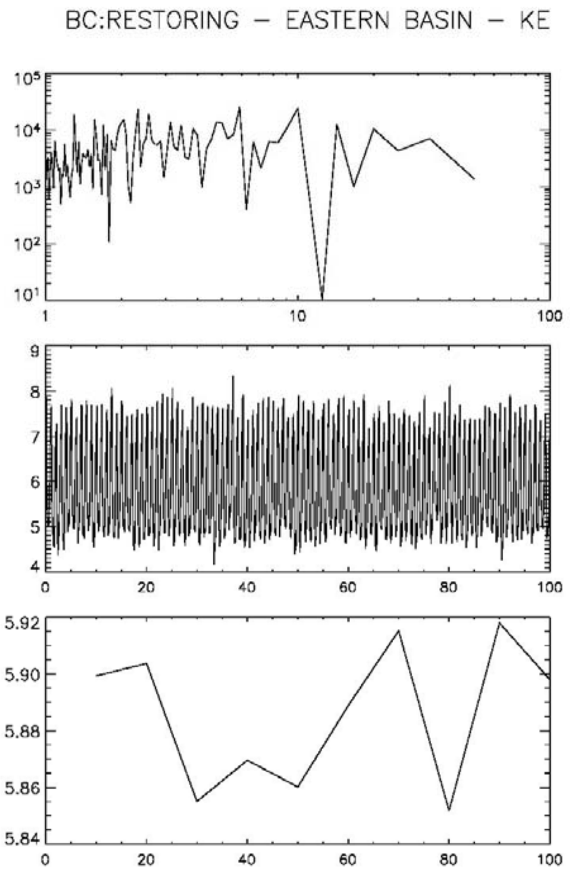


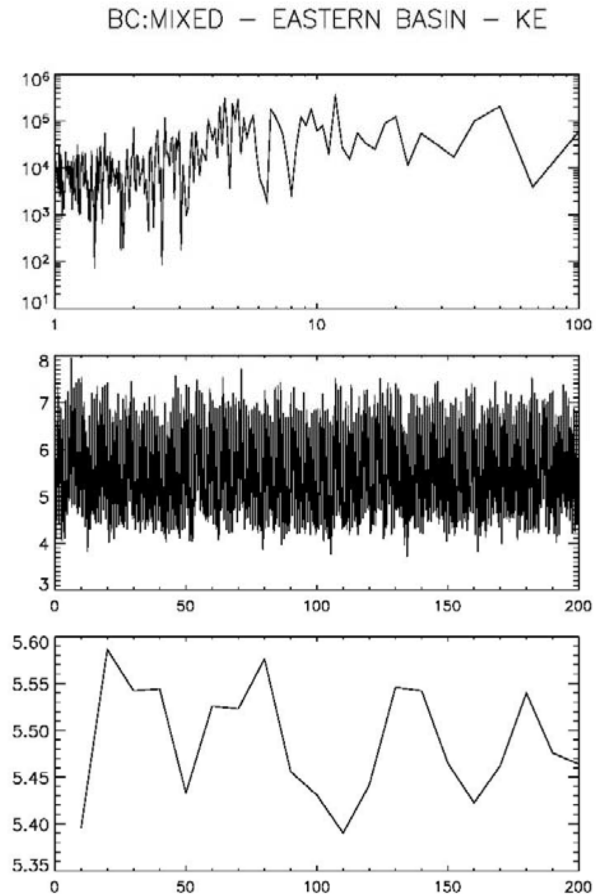
Production of salt anomalies drive the seesaw

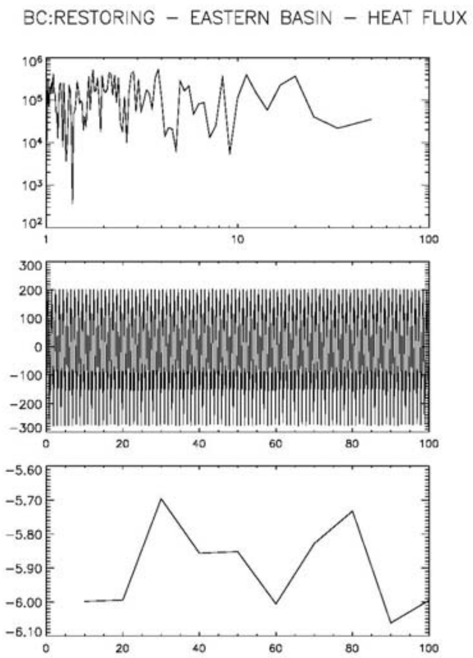


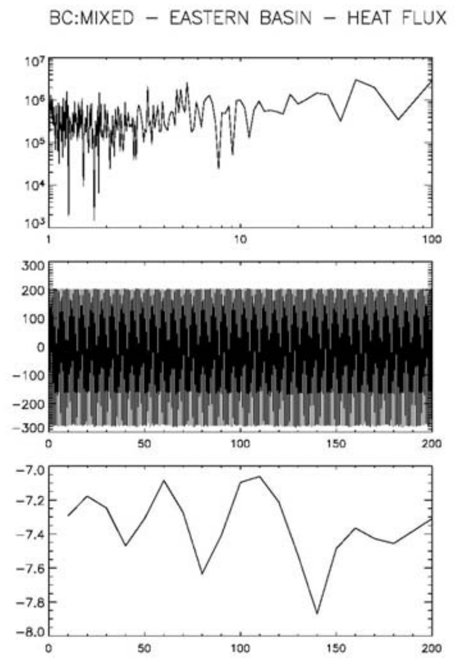
Global Condition
Mediterranean internal variability: advective-convective feedback
?
Transport of freshwater into the Med THC
THC (+)
THC (-)
Tide (+/-)
Hydraulic control
Local phenomena at Gibraltar Straits
Inflow
Outflow
MOW variability
Bifurcation?
North Atlantic THC

The last 200-yr of east basin mean kinetic energy and surface heat flux

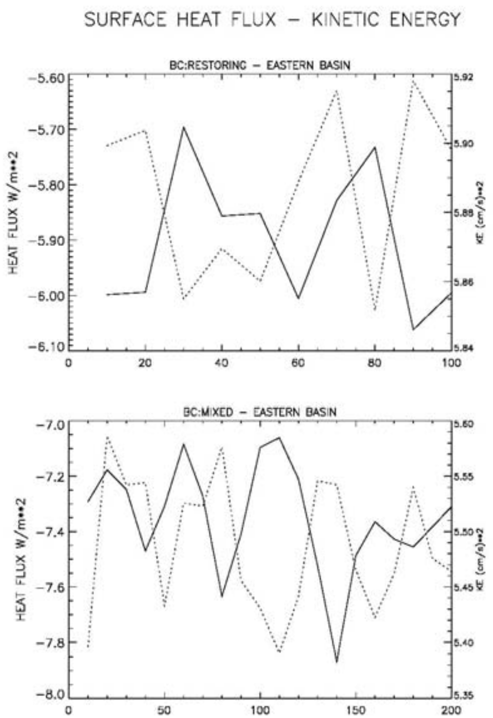


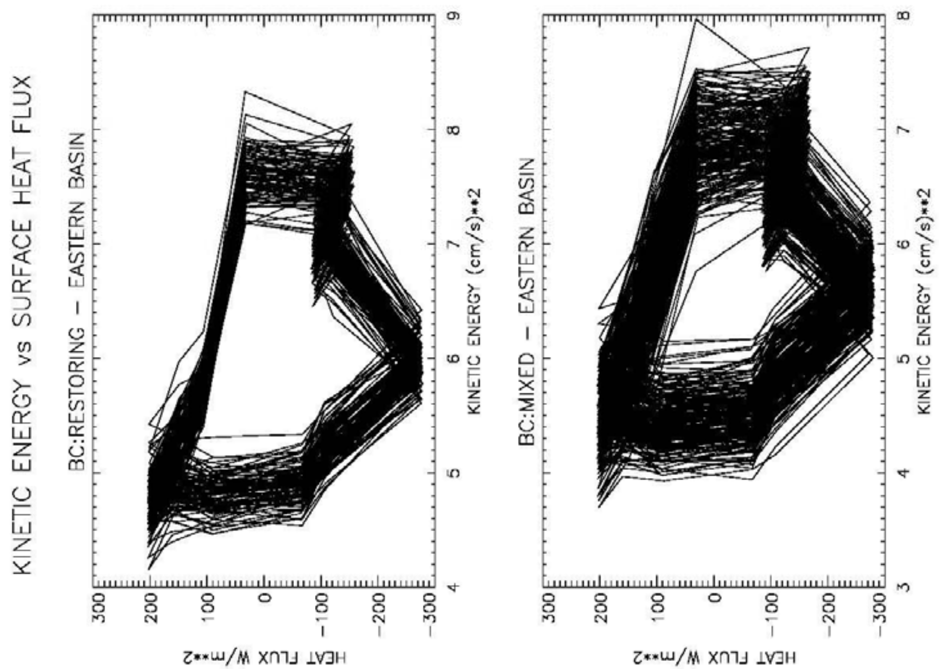


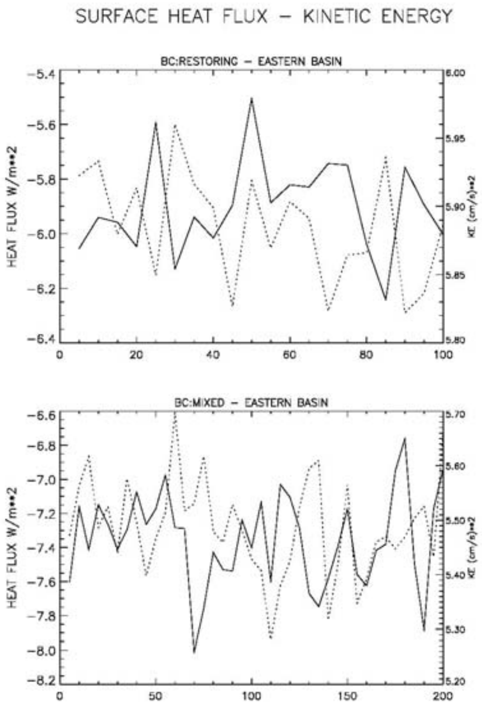

BC:RESTORING – EASTERN BASIN – HEAT FLUX

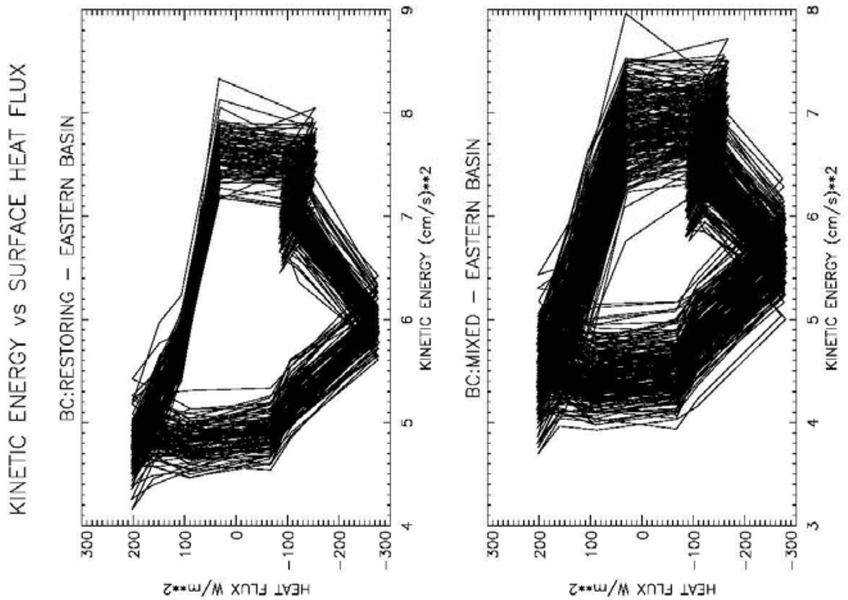

BC:MIXED – EASTERN BASIN – HEAT FLUX

Ke vs Hf trajectory for te last 200-yr

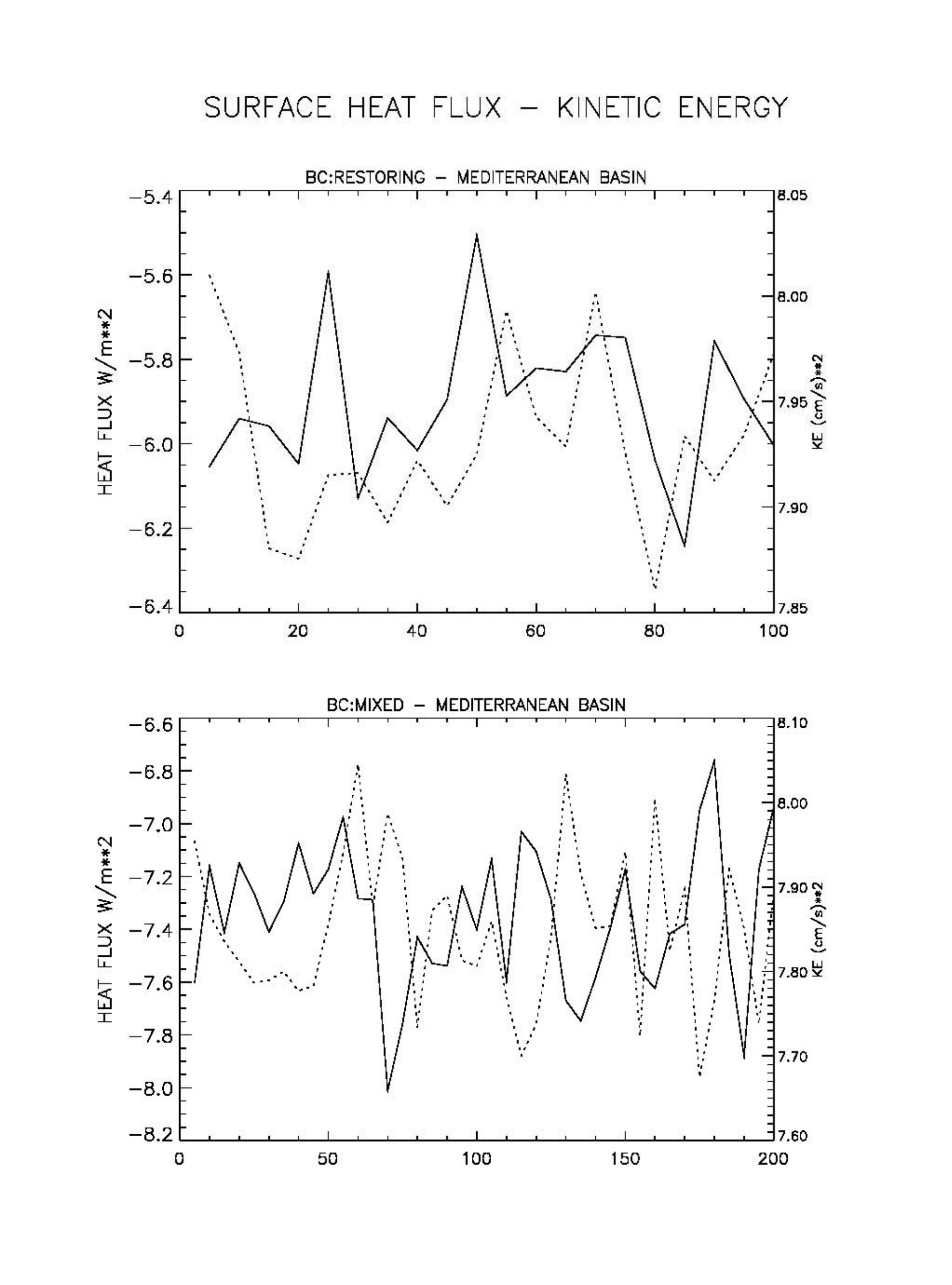








HF linea continua time series filtrata a 5-yr


SURFACE HEAT FLUX – KINETIC ENERGY
BC:RESTORING – MEDITERRANEAN BASIN
HEAT FLUX W/m**2
KE (cm/s)**2
-5.4
-5.6
-5.8
-6.0
-6.2
-6.4
8.05
8.00
7.95
7.90
7.85
0
20
40
60
80
100
BC:MIXED – MEDITERRANEAN BASIN
HEAT FLUX W/m**2
KE (cm/s)**2
-6.6
-6.8
-7.0
-7.2
-7.4
-7.6
-7.8
-8.0
-8.2
8.10
8.00
7.90
7.80
7.70
7.60
0
50
100
150
200