Chapter 1

Purpose of the visit

1.1 Scientific context

The aim of my PhD at the MPI for Meteorology (Hamburg, Germany) is to investigate the physical mechanisms responsible for the S1 sapropel formation in the Mediterranean Sea during the early Holocene (9 ka BP). The sapropels are organic-rich marine sediment which indicate the oxygen depletion of the deep waters. For this purpose, we set up a regional version of the ocean general circulation model MPIOM for the Mediterranean Sea (26 km horizontal resolution and 29 vertical levels) and we optimised it for the present-day climate.

As our goal is to perform simulations for paleo-time slices, we first decided to derive our atmospheric forcing from equilibrium simulations performed with an earth system model which is the fully coupled atmosphere / ocean / dynamical vegetation model ECHAM5 / MPIOM / LPJ. This approach led to satisfying results for the eastern Mediterranean, nevertheless we had some difficulties simulating an appropriate deep water convection for the western basin in the Gulf of Lion for the present-day. Because of the too coarse resolution of the earth system model used for obtaining the forcing, we applied a statistical downscaling method for computing the wind stress (with NCEP as reference) in order to get consistent regional wind patterns. Nevertheless, the wind stress remained far too weak in the Rhône valley and we did not obtain a coherent deep water convection in the Gulf of Lion. Since I want to investigate the shutdown/slowdown of the thermohaline circulation which is characteristic for the time of the sapropels, I need to simulate a correct deep water formation as well as consistent circulation cells in the Mediterranean, which can last after reaching an equilibrium state. The simulations with a correct well-ventilated state would then be used as baseline simulation for testing some hypothesis about the mechanisms that could lead to a state with stagnating deep waters. This step would be done through diverse perturbation experiments to see how we can reach a state with a reduced ventilation.

The group led by Samuel Somot at the institute of Météo-France has great experience in working with both coupled and forced high resolution Mediterranean regional ocean models for the past last decades as well as for climate projections (e.g. IPCC scenarios). They already performed several hindcast simulations.

An alternative to solve my problems with the representation of the deep water formation is to force the MPIOM Mediterranean ocean model with the ERA-Interim dataset (0.7 degree horizontal resolution) and validate the results for the present-day climate with the MEDATLAS climatology. I will detail the results of this work further down. The relatively low resolution of my model (1/4 degree) allows me to perform long term simulations (1500 years), what has never been done so far with a mediterranean ocean model. This provides us a lot of interesting informations about the time needed to reach a "quasi-equilibrium" state, as well as about the effect of the internal variability of the system on the formation of the deep water.

This could also give the opportunity to conduct an intercomparison study of Mediterranean regional ocean models forced by different hindcast datasets. It hasn't been done yet, but we might plan to do it.

Then, once I return to Hamburg, I could perform my paleo-experiments by superimposing the forcing anomalies (paleo minus CTRL) derived from the ESM runs onto my optimal forcing for the present-day climate.

Chapter 2

Description of the work carried out during the visit

I have been carrying out a 1500-year simulation with the Mediterranean version of the Max Planck Institute Ocean Model (MPIOM). A short description of the model is provided below. The ocean model was forced with the ERA-Interim Reanalysis atmospheric dataset.

2.1 Model description

2.1.1 MPIOM (ocean physics)

We use here the Mediterranean version of the Max Planck Institute Ocean Model (Marsland et al. [2003]). It covers the Mediterranean Sea, the Black Sea and a small buffer zone in the Atlantic, western from Gibraltar.

Detail of the main characteristics:

- Primitive equation ocean general circulation model
- Heat fluxes calculated interactively with bulk formulas
- Freshwater fluxes from prescribed precipitation, evaporation (calculated interactively from latent heat flux) and prescribed river runoff
- No restoring to sea surface temperature
- Sponge zone in the Atlantic (WOA hydrography) with monthly restoring to climatological temperature and salinity
- The atmospheric forcing is applied on a daily basis

Setups:

- 26 km horizontal resolution
- 29 levels (z-coordinates, irregular level thickness increasing with the depth)
- 36 min time step

2.1.2 Atmospheric forcing

We force the ocean model with atmospheric data from the ERA-Interim reanalysis for the time period 1989-2005, the dataset has a resolution of 0.7°.

The ERA-Interim dataset: comparison with observations

$(W.m^{-2})$	SW	LW	SH	LH	HB
Best estimate	185 [+/-4]	-84 [+/-1]	-14 [+/-1]	-90 [+/-4]	-3 [+/-4]
NOCS, 1°, 1980/2004	185	-84	-7	-89	+5
AJONC, 0.1°, 1996/2005	191				
HOAPS-G, 0.5°, 1988/2005			-14	-90	
OAFLUX, 1°, 1958/2008			-14	-88	
IFREMER, 1°, 1993/2007			-23	-112	
ERA40, 1.125°, 1958/2001	165	-79	-9	-93	-16
ERA-Interim, 0.7°, 1989/2008	198	-83	-12	-97	+6

The different components of the heat budget from the ERA-Interim Reanalysis are in a rather good agreement with the best estimates except for the short wave radiation (and consequently the latent heat flux) which seem to be overestimated (table from Dubois et al. [2010]).

Initial conditions

We started the simulation in August with initial conditions from the MEDATLAS climatology.

SW correction

Since the ERA-Interim SW radiations are overestimated, a 1-year daily spatially homogenous correction field as been added to the short wave field of the ERA-Interim Reanalysis. This correction is based the value of 20 $W.m^{-2}$ pro degree Kelvin difference between the SST from the Medatlas climatology and the modelled SST.

Chapter 3

Description of the main results obtained

The period covered by the ERA-Interim forcing (1989-2005) is a rather warm period which includes a particular event called 'Eastern Mediterranean Transient' (EMT): in the early 1990's, the occurrence of a strong heat loss and net evaporation over the Aegean basin leads to the formation of a large amount of water with high density in this region, the densest water overflows in the Levantine and in the Ionian through the Cretean Arc straits (Antikithira, Kassos and Karpathos straits).

The numerous observations available for this peculiar period allow us to make a robust validation and check if the model is able to reproduce the recorded changes in deep water formation.

The results presented here correspond to a climatology of the 7 last ERA-Interim forced cycles of the run (year 1399 to year 1500), except for the 1500-year time series.

3.1 Heat and water fluxes

Fluxes	MPIOM forced by ERA-Interim
Short Waves ($W.m^{-2}$)	178
Long Waves ($W.m^{-2}$)	-73
Latent heat flux ($W.m^{-2}$)	-97
Sensible heat flux ($W.m^{-2}$)	-12
Net heat flux ($W.m^{-2}$)	-4
Fresh water flux (E-P+R) mm/j	-1.86
Precipitation mm/j	1.05
River mm/j	0.35
BS outflow mm/j	0.22
Gib outflow mm/j	1.6
Evaporation mm/j	-3.22

This table summarizes the different components of the heat and water fluxes. MPIOM simulates a good total heat budget for the Mediterranean Sea. Nevertheless, despite the SW correction, the model still overestimates the SW heat gain what induces a too strong latent heat flux. Since we are prescribing the fresh water flux, we observe a strong drift in salinity (Fig.3.5).

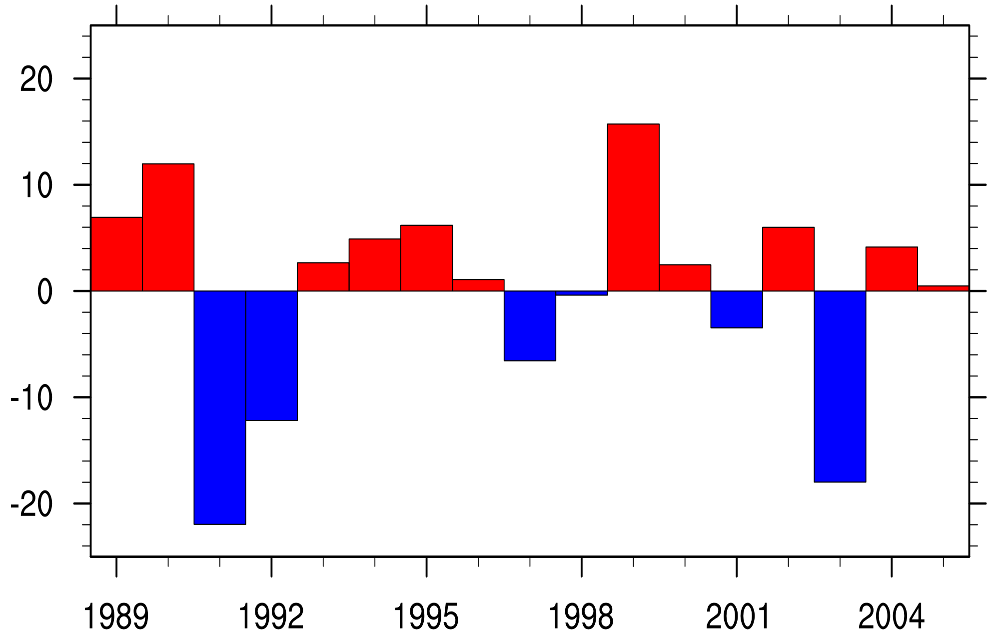

Figure 3.1: Net Heat Flux anomalies over the 1989-2005 period (W/m^2).

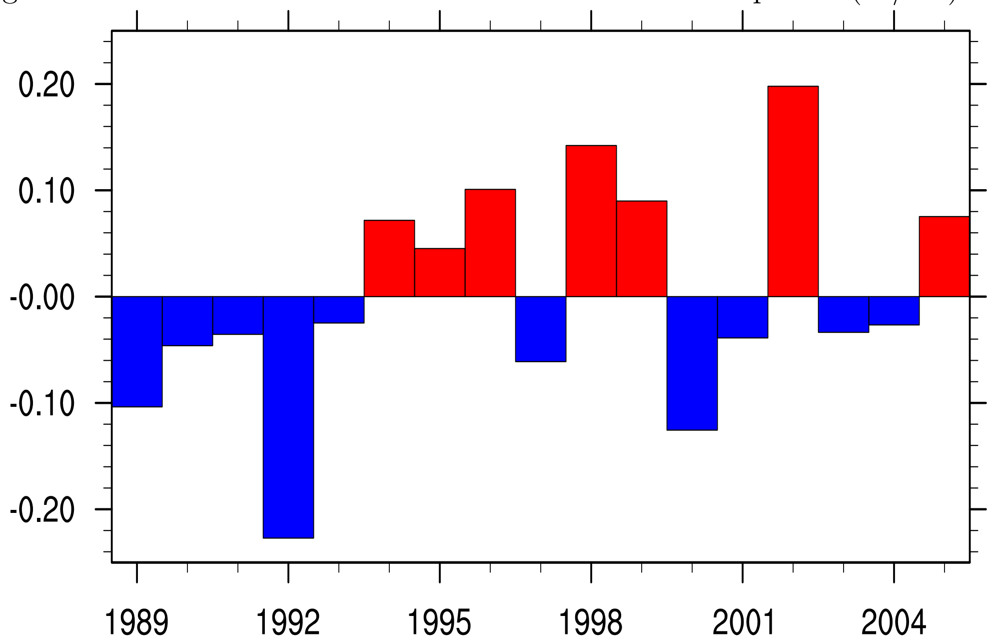

Figure 3.2: Water Flux anomalies (E-P-R) over the 1989-2005 period (m/yr).

The strong surface heat and water losses (Fig.3.1 and 3.2) for the two successives winter 1991/1992 and 1992/1993 which might trigger the EMT (Josey [2003]) are well-observed.

3.2 Winter mixed layer depth and circulation

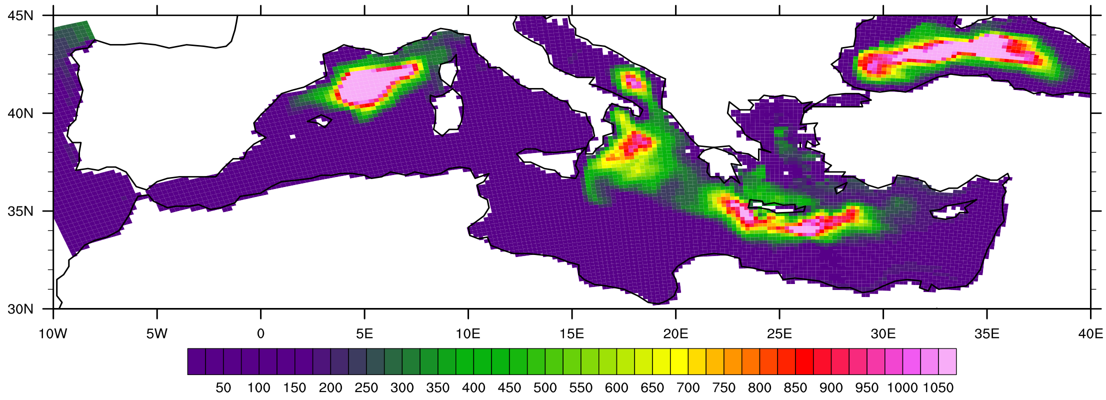

Figure 3.3: Mixed layer depth in march (in m) averaged over the 1989-2005 period.

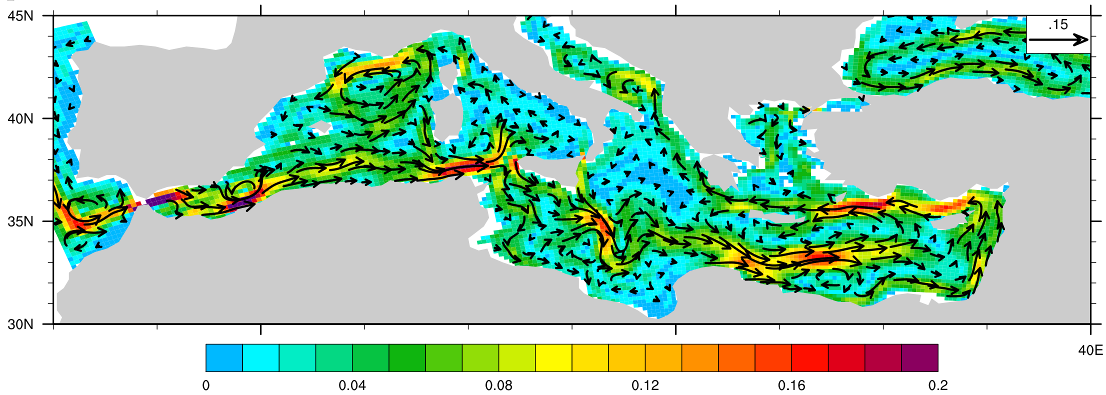

Figure 3.4: Near-surface circulation at 27 m depth (in m/s) averaged over the 1989-2005 period.

For this simulation, we set a new density criterium (0.011 vs. 0.125) according to the litterature to compute the mixed layer depth (a proxy for the deep water convection). As shown by the winter mixed layer depth pattern (Fig.3.3), we are now able to form dense waters in the Gulf of Lion. Nevertheless, the winter mixed layer depth pattern southern for Creta is much stronger than recorded in the literature. The modelled near-surface circulation is realistic (Fig.3.4).

3.3 Temperature, salinity and density content

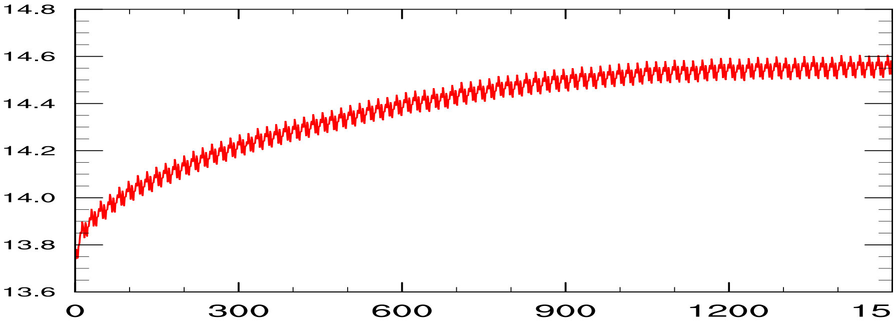

Figure 3.5: Heat content averaged over the entire water column.

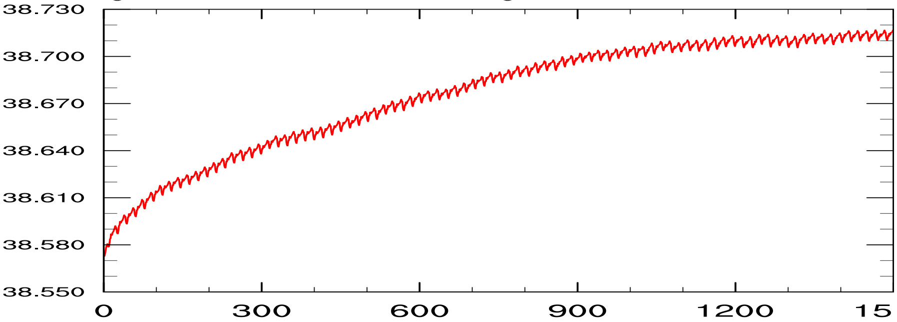

Figure 3.6: Salt content averaged over the entire water column.

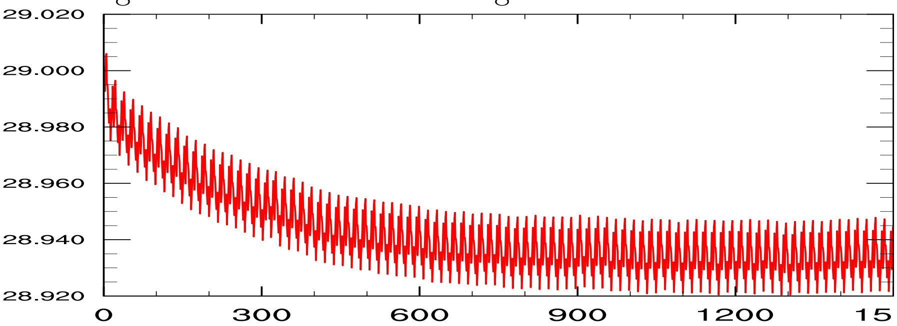

Figure 3.7: Density content averaged over the entire water column.

While looking at the potential temperature, salinity and potential density averaged over the entire basin and the full water column (respectively Fig.3.4, Fig.3.5 and Fig.3.6), it lasts 1500 years to get an equilibrium, nevertheless the deep layers are still drifting after this time.

3.4 Water transport through Gibraltar and Bosphorus

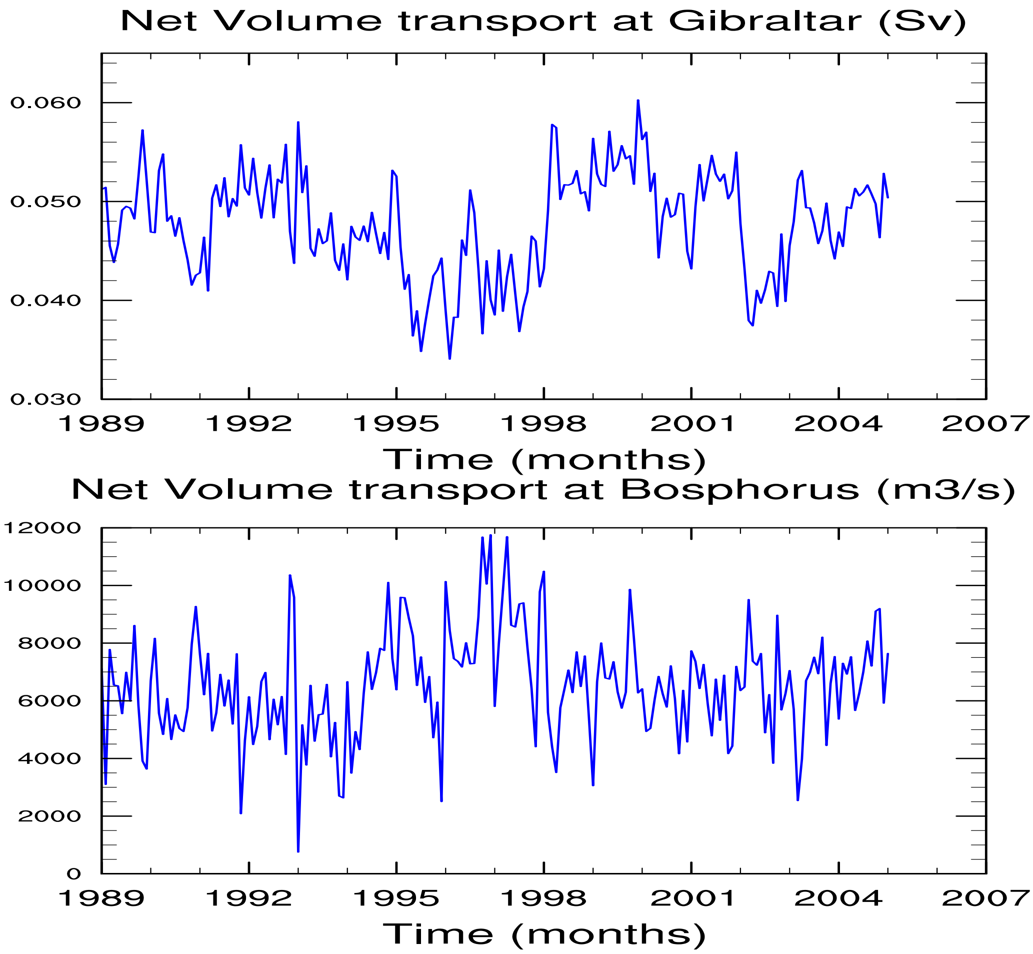

Figure 3.8: Net water transport through Gibraltar (in Sv) and Bosphorus (in $m^3.s^{-1}$) for the 1989-2005 period - 12 months-running mean.

The mean net water transport at Gibraltar which really conditions the circulation of the different water masses in the Mediterranean is consistent with the observations (Bryden [1994], Tsimplis and Bryden [2000]) with the value of 0.05 Sv (Fig.3.8 top). The Bosphorus mean net outflow is around 6500 $m^3.s^{-1}$ (Fig.3.8 bottom), which is also consistent with the observations (Stanev et al. [2000]). A decrease in the Black Sea fresh water input is observed in the early 1990's, this could also be one of the mechanisms leading to the EMT (Zervakis et al. [2000], Stanev and Peneva [2002]).

3.5 Stratification

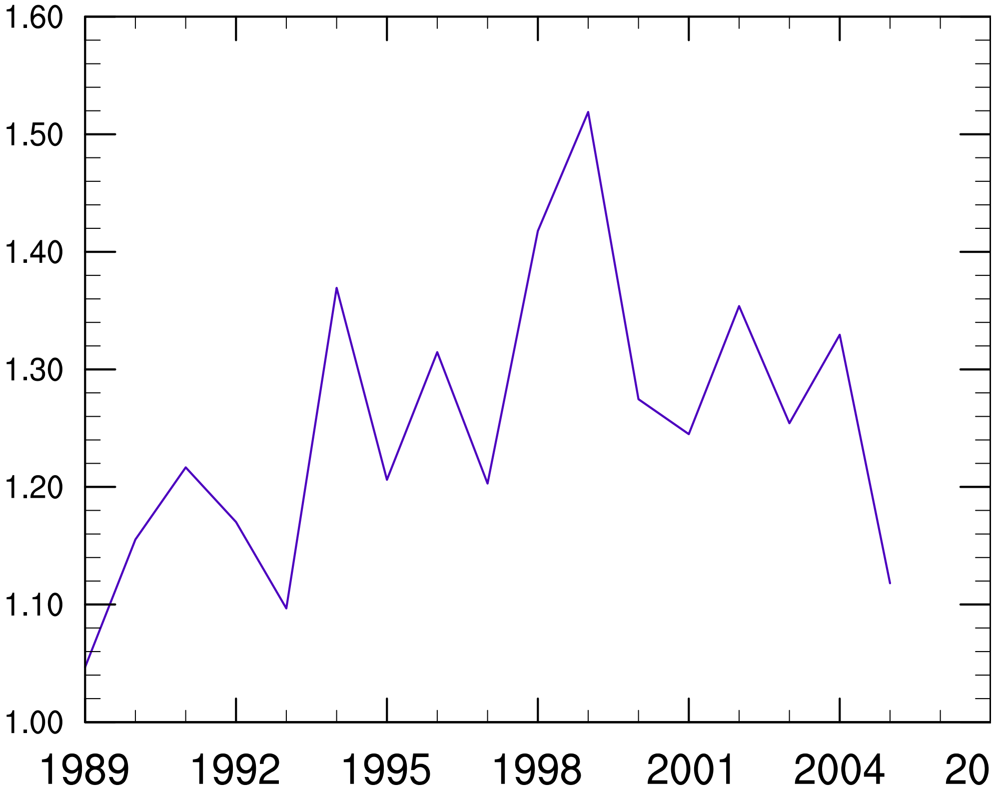

Figure 3.9: Stratification Index per basin.

A stratification index has been computed to investigate the changes in the vertical stratification for the Aegean Sea (in $m^2.s^{-2}$, see Lascaratos [1993]; Somot [2005] and Hermann et al. [2008]).
The lower the index, the more likely is the convection to occur. The Fig.3.9 shows that is stratification in the Aegean is rather low in the beginning of the 1990's which is favorable to the formation of dense deep water.

3.6 Evolution of the volume of dense water per basin

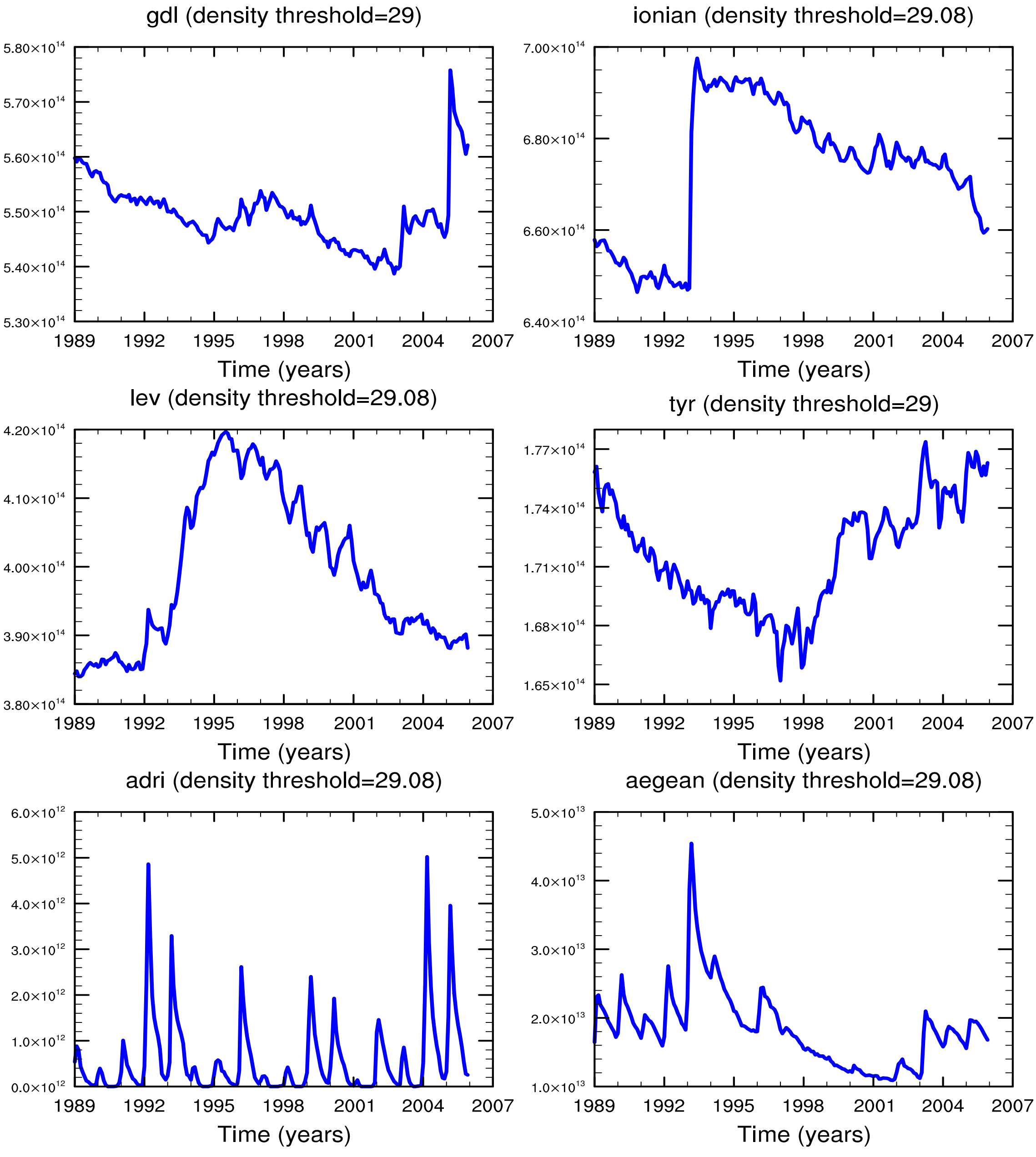

Figure 3.10: Volume of dense water contained per basin (in $m^3.s^{-1}$).

Here we define the dense water by setting 2 density threshold:

- 29 kg.m^{-3} is the threshold set for the Western Mediterranean. It corresponds to the potential density at 1000 m in the Gulf of Lion. This value is used for computing the volume of dense water in the Gulf of Lion, as well as in the Tyrhenian Sea.

- 29.08 kg.m^{-3} is the threshold set for the Eastern Mediterranean. It corresponds to the potential density at 1000 m in the Ionian Sea. This value is used for computing the volume of dense water in the Adriatic, the Agean, the Levantine and the Ionian basins.

A pic of dense water is well observed in the Aegean between the years 1992-1994, in coherence with the observations; this triggers the increase in the volume of dense water for both Levantine and Ionian basin.
For the Gulf of Lion, the strong deep water convection event of the winter 2004/2005 (Schroeder et al. [2008], Herrmann et al. [in prep.]) is reflected by the sudden increase in the volume of dense water.

3.7 Outflow of dense water from the Aegean Sea

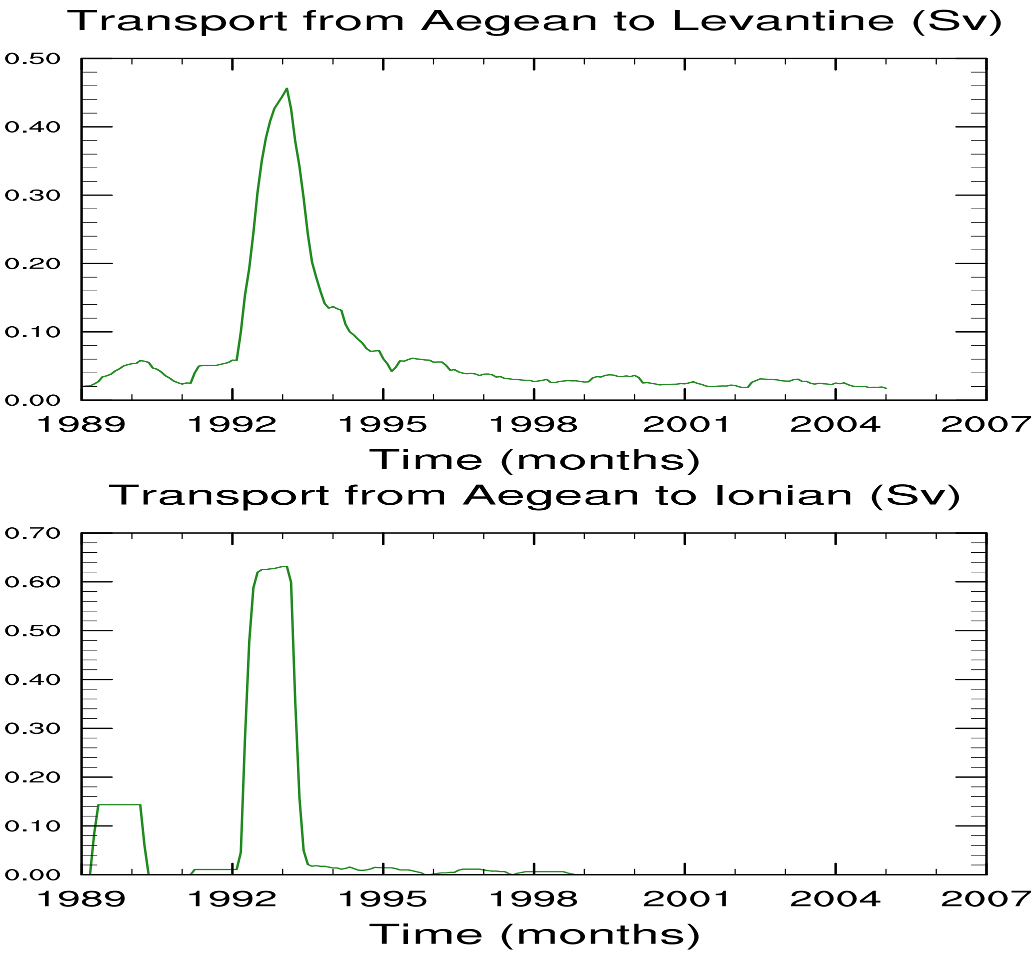

Figure 3.11: Volume of dense water flowing out of the Aegean (in Sv).

The Fig.3.11 shows that the outflow of aegean dense water (threshold 29.08 kg.m^{-3}) happens only in 1993 through both the western and eastern straits of the Cretean Arc; while in 1994, it only flows into the Levantine, which is consistent with the modelling study from Beuvier et al. [2010]. Nevertheless, our modelled outflow of dense water through the western strait is slightly greater than the one through the eastern strait with is not consistent with the study from Beuvier where the eastern outflow of aegean dense water is much bigger than the one from the west.

Chapter 4

Future collaboration with the host institution - projected publication

The next step would be to study the effect of the internal variability of the system on the formation of the deep water. This could eventually lead to a paper.

An intercomparison study of Mediterranean regional ocean models forced by different hindcast datasets could be achieved as well.

Chapter 5

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