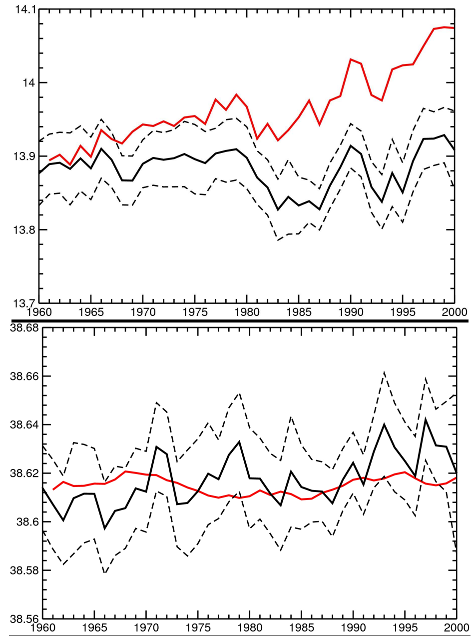
First step towards a multi-decadal high-resolution Mediterranean sea reanalysis using dynamical downscaling of ERA40

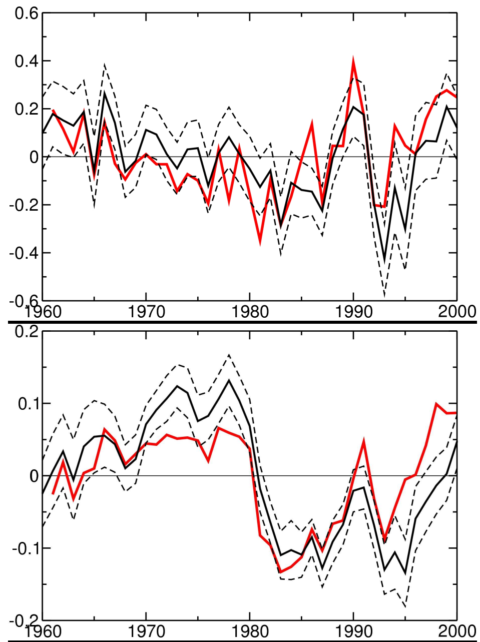
Samuel Somot and Jeanne Colin
Centre National de Recherches Météorologiques, Météo-France.
42 avenue Coriolis F-31057 Toulouse Cedex, France, samuel.somot@meteo.fr

The Mediterranean Sea is known to show a high interannual variability in terms of deep water formation (Mertens and Schott 1998), surface circulation and other physical processes. It also experiences decadal variability as proved by the Eastern Mediterranean Transient event (Roether et al. 1996) and the existence of long-term trends in the deep layers with an increase in temperature and salinity (Rixen et al. 2005). Considering theses facts, it appears that simulating and understanding the evolution of the Mediterranean Sea over the last decades can be considered as quite a challenging task for the ocean and climate modeling community. Besides, the first scenarios of climate change applied to the Mediterranean Sea displayed a quick and strong impact on its hydrology and thermohaline circulation (Somot et al. 2006). An improved accuracy in the modeling of the past trends would give a better confidence in the model's representation of the processes implied and therefore would allow more reliable projections.

Pursuing this goal requires to work with high resolution models forced by high resolution atmospheric forcings which would follow the observed chronology. In agreement with this statement, we performed a dynamical downscaling of the ERA40 reanalysis with the ARPEGE-Climate model (Atmosphere General Circulation Model with a stretched grid, Déqué and Piedelievre 1995). This configuration has been set up running ARPEGE-Climate with its grid focused on the area of interest (50 km horizontal resolution over the Mediterranean Sea) and driving its large scales by ERA40, by dint of a spectral nudging method. The 40-year long simulation thus obtained is called ARPERA and has already been used in Herrmann and Somot (2008) for a deep convection modeling case study. Conducting the present study, we extracted the air-sea fluxes (radiative and turbulent fluxes) from this ARPERA simulation to force a Mediterranean version of the OPA model whose horizontal resolution reaches about 10 km (Somot et al. 2006). We computed the surface temperature relaxation using the ERA40 SST dataset. An additive constant correction to the climatological river runoff fluxes has been applied to obtain a realistic over-all water budget, however we let the surface salinity field entirely free. This simulation can be considered as a first step towards a 40-year reanalysis of the Mediterranean Sea in which only realistic air-sea fluxes and SST would be imposed.
The temporal evolution of the heat and salt content of the whole Mediterranean Sea, as well as the associated spatial patterns, have been analyzed using recent observed dataset (Rixen et al. 2005). Looking at the results, one can tell that the average value and the interannual variability of the heat content are well simulated by the Mediterranean model apart from a weak bias of about 0.1°C at the end of the 20th century (see figure 1 and table 1). The heat content's interannual variability of the surface and intermediate layers are very well reproduced (cf. figure 2) with time



<u>Figure 1:</u> Time series (1 point per year) of (top) the Mediterranean Sea heat content (expressed as a 3D mean temperature in °C) and (bottom) the salt content (expressed in psu). In black, the observed values with the 2.σ range in dashed line (Michel Rixen, personal communication) and in red, the simulated values.



<u>Figure 2:</u> Same as Figure 1 but for the heat content anomaly (in °C) for (top) the upper layer (0-150m) and (bottom) the intermediate layer (150-600m).

correlations equal to 0.76 and 0.85 respectively. The decadal cold events of the 80s (Brankart and Pinardi 2001) and of the 90s (EMT, Roether et 1996) are well seen by the simulation. Concerning the salinity, only the average value is well reproduced (see figure 1) proving a deficiency in the way the sources of the salinity interannual variability are modeled.

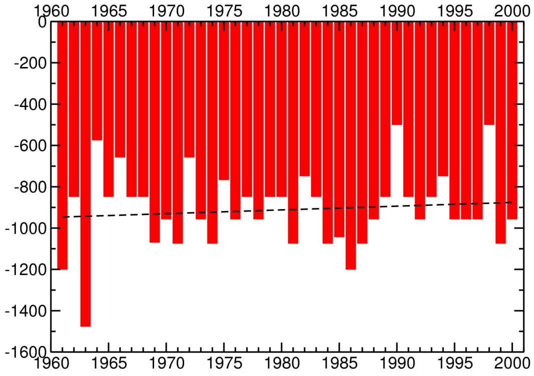


Figure 3: *Time series (1 point per year) of the spatial maximum of the daily mixed layer depth in the North-Western part of the Mediterranean Sea (in m)*

In the Western Basin, the open-sea deep convection and the formation of the WMDW show a realistic interannual variability (see figure 3). However no clear time correlation (not shown) is found with the observed time series (Mertens and Schott 1998) because the long-term temporal evolution of the vertical stratification appears to be too difficult to simulate without assimilating in-situ ocean data.

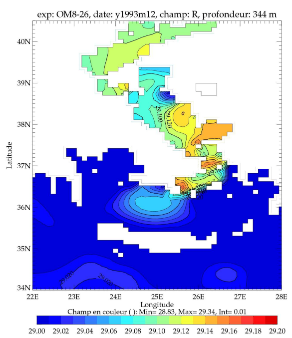


Figure 4: *Density (in kg.m^{-3}) horizontal section in the Aegean Sea at a 344m-depth for December 1993 (after the main 1992 and 1993 winters of the EMT event).*

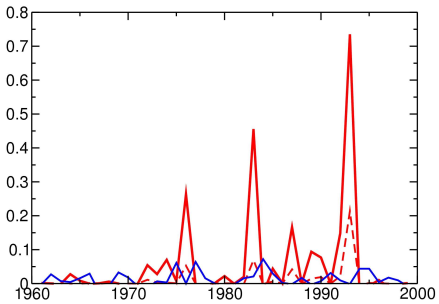


Figure 5: *Yearly deep water formation rate (in Sv) in the northern part of the Aegean Sea (in red) and in the southern part (in blue). Two different density thresholds are used: waters denser than 29.10 kg.m^{-3} (full line) and denser than 29.20 kg.m^{-3} (dashed line).*

Contrary to the WMDW formation, the Eastern Mediterranean Transient is mainly due to atmospheric flux anomalies and therefore is partly reproduced by our simulation without tuning the precipitation or the Black Sea freshwater input. Very cold winter and dense water formation are observed in 1993 filling the Aegean Sea (see figures 4 and 5). This newly formed water goes outside the Aegean Sea but does not sink to the bottom layer of the Levantine Basin as it actually did in reality.

1961-2000	Bias	Corr	Model trend	Observed trend
T3D (surf.-bottom)	+0.1°C	0.87	4.10^{-3} °C/yr	1.10^{-4} °C/yr
T3D (0-150m)	+0.2°C	0.76	3.10^{-3} °C/yr	-4.10^{-3} °C/yr
T3D (150-600m)	+0.6°C	0.85	-1.10^{-3} °C/yr	-4.10^{-3} °C/yr
T3D (600-bottom)*	-0.01°C	0.62	5.10^{-3} °C/yr	3.10^{-3} °C/yr
S3D (surf.-bottom)	-0.003 psu	N.S.	1.10^{-5} psu/yr	5.10^{-4} psu/yr

Table 1: *Mediterranean Sea average bias (model minus observations), interannual time correlation, model trend and observed trend for the heat content expressed in °C for different layers and for the salt content in psu (* : only the 1980-200 period, N.S.: Not Significant)*

In conclusion, we performed a 40-year run of the Mediterranean Sea using high resolution air-sea fluxes coming from a dynamical downscaling of the ERA40 reanalysis. In this simulation, the heat content evolution and the Eastern Mediterranean Transient event are at least partly reproduced whereas the salinity chronology and the WMDW formation process do not follow the observed chronology. In the future, improvements could be achieved by introducing interannual variability for the river runoff fluxes and for the Atlantic T-S characteristics as well as by assimilating in-situ ocean data. In forthcoming studies, this simulation will also be used as a reference to study the interannual variability of Mediterranean physical processes over the recent past years and consequently better foresee their possible evolution in the future.

References

1. Déqué M. and Piedelievre J.P. (1995) High-Resolution climate simulation over Europe. *Clim. Dyn.*, 11:321-339
2. Herrmann M. J., Somot S. (2008) Relevance of ERA40 dynamical downscaling for modeling deep convection in the Mediterranean Sea, *Geophys. Res. Lett.*, 35, L04607
3. Mertens C. and Schott F., 1998. Interannual variability of deep-water formation in the Northwestern Mediterranean. *J Phys Oceanogr*, 28: 1410-1424
4. Rixen M., Beckers J.-M., Levitus S., Antonov J., Boyer T., Maillard C., Fichaud M., Balopoulos E., Iona S., Dooley H., Garcia M.-J., Manca B., Giorgetti A., Manzella G., Mikhailov N., Pinardi N. and Zavatarelli M., 2005. The Western Mediterranean Deep Water: A proxy for climate change. *Geophys. Res. Lett.*, 32: L12608
5. Roether W., Manca B., Klein B., Bregant D., Georgopoulos D., Beitzel W., Kovacevic V. and Luchetta A., 1996. Recent changes in Eastern Mediterranean Deep Waters. *Science*, 271: 333-334
6. Somot S., Sevault F. and Déqué M., 2006. Transient climate change scenario simulation of the Mediterranean Sea for the 21st century using a high-resolution ocean circulation model. *Clim. Dyn.*, 27(7-8):851-879