MedCLIVAR, Regional ocean climate change scenarios for the Mediterranean Sea: assessing the uncertainties along the 21st century

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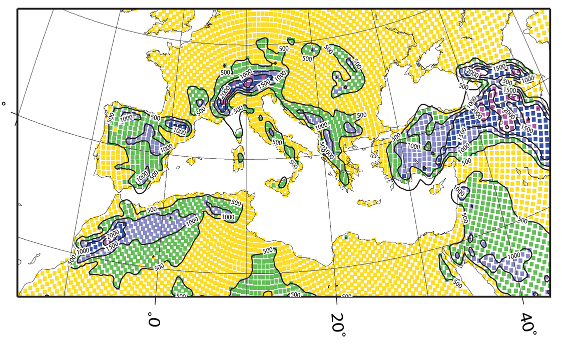
01 | INTRODUCTION

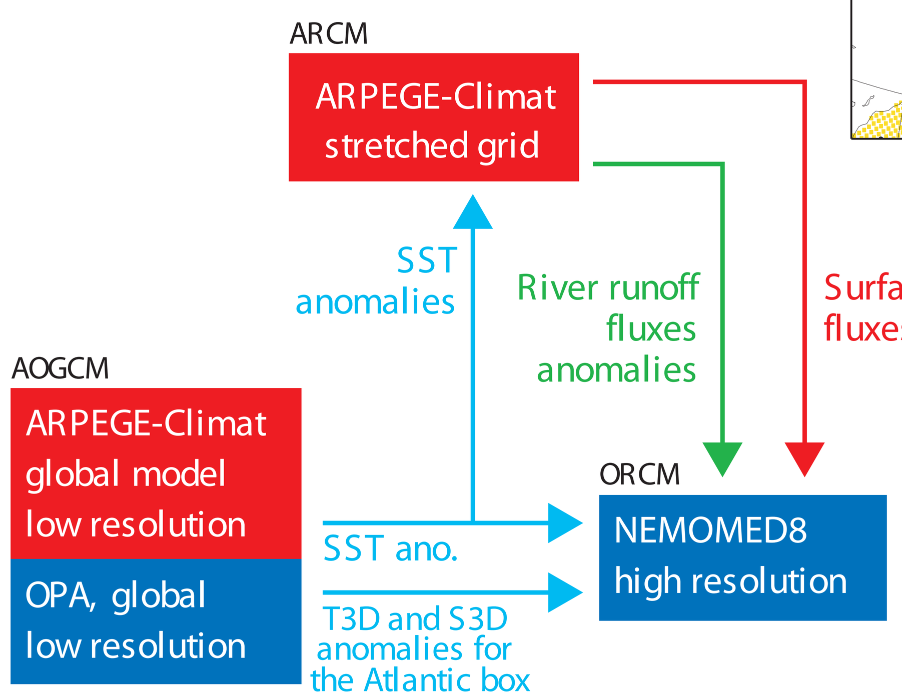
Following the IPCC scenarios (Gibelin and Déqué 2003, Giorgi 2006, IPCC 2007, Somot et al. 2008), the climate over the Mediterranean basin is foreseen to become warmer and drier during the 21st century. In terms of density, these two effects may have an opposite impact on the Mediterranean Sea surface waters (warmer and saltier), the winter ocean deep convection, the Mediterranean thermohaline circulation and the local steric sea level change. In this study, we use a suite of regional modeling techniques for the atmosphere-river-ocean regional climate system to assess the possible evolution of the Mediterranean Sea under a changing climate during the 21st century.

02 | MODEL and SIMULATIONS

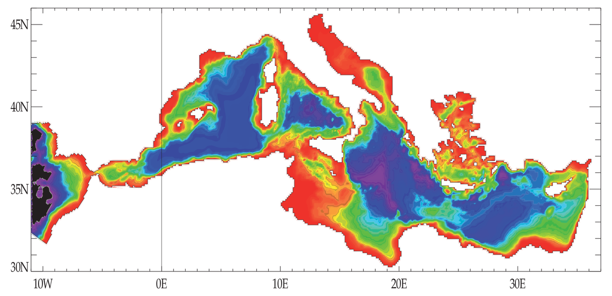
MODEL DESIGN:
Following the design described in Somot et al. (2006), seven140-year long numerical experiments (1961-2100) have been run with a 10km-resolution Mediterranean Sea regional ocean model (NEMOMED8) forced by varying the boundary conditions that is to say (i) the daily air-sea fluxes coming from 50-km regional climate models (two versions of the RCM ARPEGE-Climate), (ii) the Mediterranean river runoff fluxes and Black Sea freshwater inputs and (iii) the near-Atlantic water characteristics.

ARPEGE land-sea mask and orography (50km)

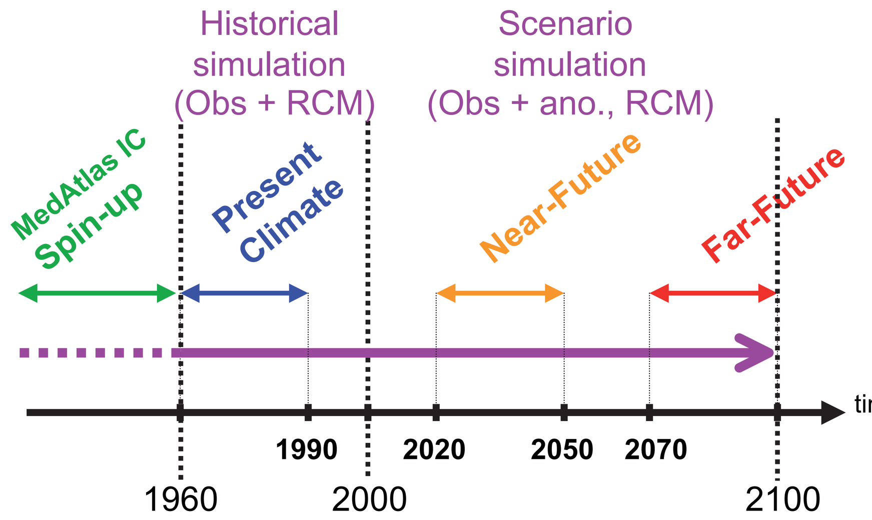




NEMOMED8 bathymetry (10km)



SIMULATIONS:
After the spin-up period (15 years), an historical run (1961-2000) have been carried out for checking the present climate conditions. Then scenario runs (2001-2100) have been done under the SRES-B1, A1B and A2 scenario forcings. For the historical run, up to 2000, SST as well as greenhouse gas and aerosol concentration are imposed from observed values. The air-sea fluxes come from the RCM and the other forcings are climatologic. Then, beyond 2000, the SRES scenarios are prescribed and the various forcings are extracted from scenario simulations previously run with low resolution coupled GCMs (near-Atlantic water characteristics, SST for the relaxation) or high resolution RCMs (fluxes, river, Black Sea).

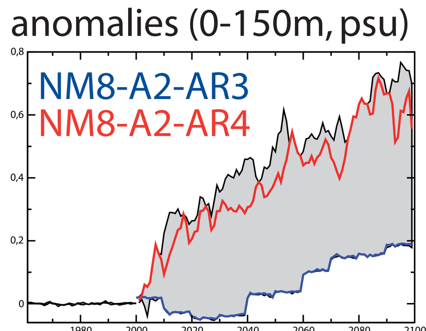


NEMOMED8 Ocean run	Atmosphere RCM	Rivers & Black Sea anomalies	Atlantic box and SST anomalies
NM8-A2-AR3	ARPv3-A2	ARPv3-A2	CNRM-CM1-A2
NM8-A2-AR4	ARPv4-A2	ARPv4-A2	CNRM-CM3-A2
NM8-A1B-AR4	ARPv4-A1B	ARPv4-A1B	CNRM-CM3-A1B
NM8-B1-AR4	ARPv4-B1	ARPv4-B1	CNRM-CM3-B1
NM8-A2-test	ARPv4-A2	*as NM8-A2-AR3*	*as NM8-A2-AR3*
NM8-A1B-test	ARPv4-A1B	*as NM8-A2-AR3*	*as NM8-A2-AR3*
NM8-B1-test	ARPv4-B1	*as NM8-A2-AR3*	*as NM8-A2-AR3*

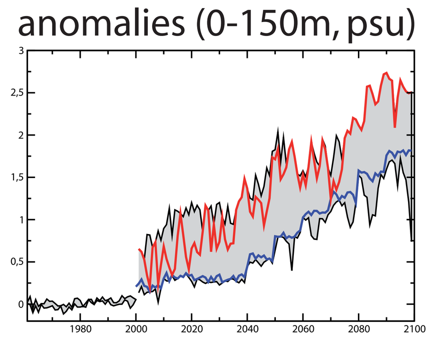
03 | OCEAN FORCING

Fields	1961-1990 moy ± sigma	2070-2099 uncertainty range
Freshwater inflow (mm/d) River and Black Sea	0.50	[-0.08 ; -0.23]
Surface Water Loss (mm/d)	1.7 ± 0.3	[+0.5 ; +1.0]
Surface Heat Flux (W/m2)	- 3.1 ± 4.8	[+1.1 ; +4.3]

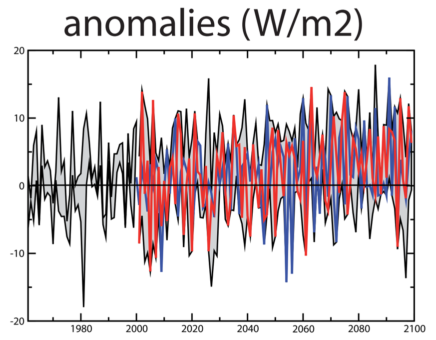
Near-Atlantic salt content anomalies (0-150m, psu)



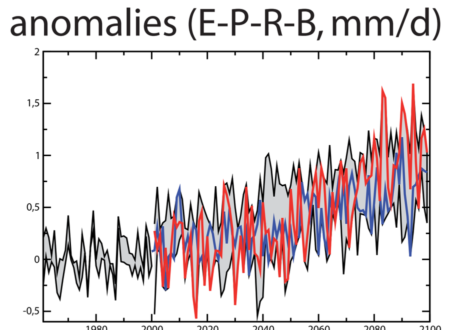
Near-Atlantic heat content anomalies (0-150m, psu)



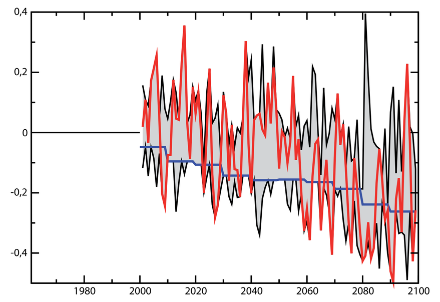
Surface heat flux anomalies (W/m2)



Surface water loss anomalies (E-P-R-B, mm/d)



Freshwater input anomalies (rivers and Black Sea, mm/d)



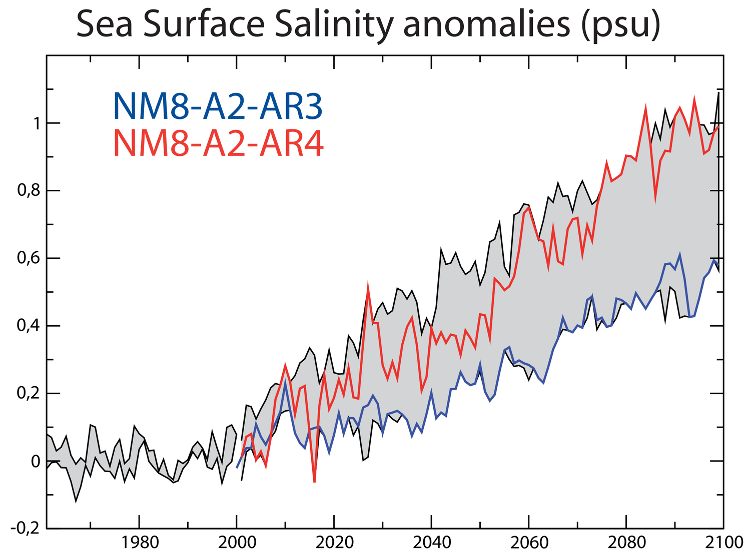
Along the 21st century and in all scenarios, the Near-Atlantic ocean becomes warmer and more salty, surface water loss increases partly due to the river runoff decrease and the surface heat loss decreases. Saltier and warmer Mediterranean Sea is expected.

04 | SEA SURFACE CHARACTERISTICS

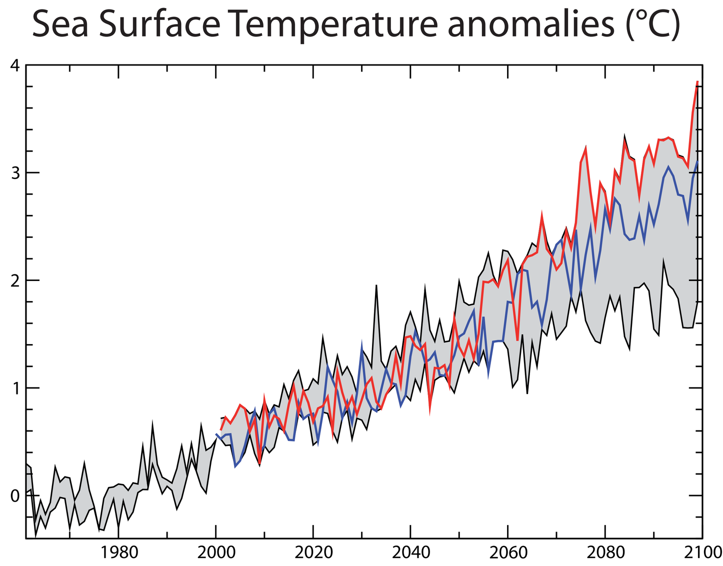
Fields	1961-1990 moy ± sigma	2070-2099 uncertainty range
SST (°C)	19.0 ± 0.2	[+1.7 ; +3.0]
SSS (psu)	38.1 ± 0.1	[+0.5 ; +0.9]

Along the 21st century and in all scenarios, SSS and SST increase as expected from the forcing analysis. Surface water density response is not straightforward.

Sea Surface Salinity anomalies (psu)

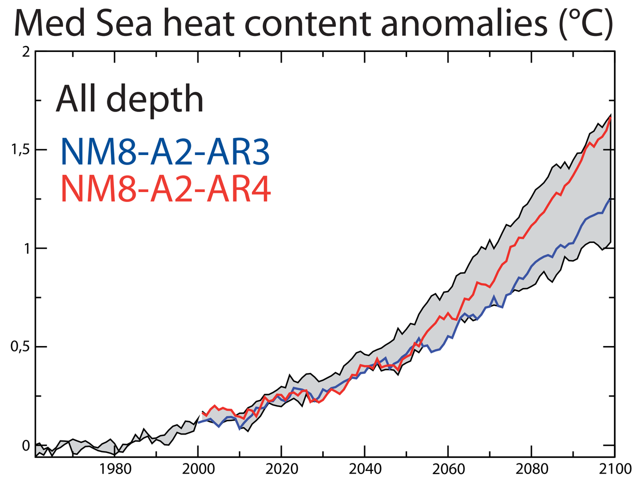


Sea Surface Temperature anomalies (°C)

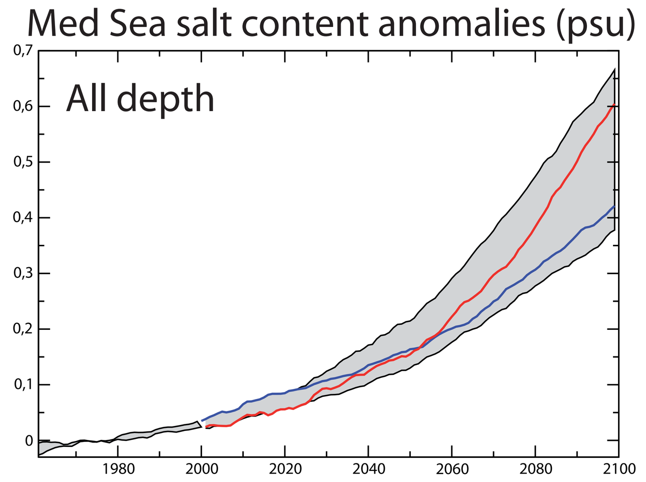


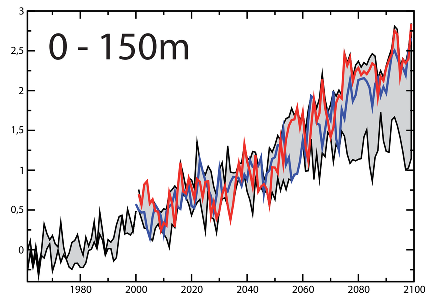
05 | DEEP LAYERS

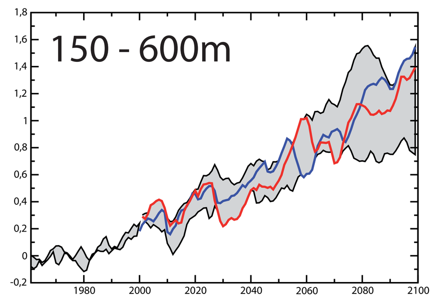
Med Sea heat content anomalies (°C)

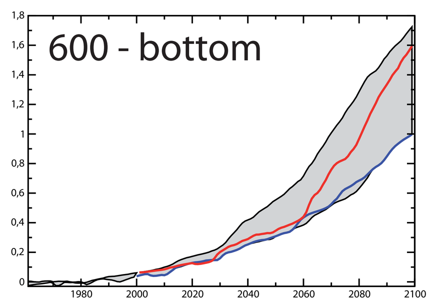


Med Sea salt content anomalies (psu)

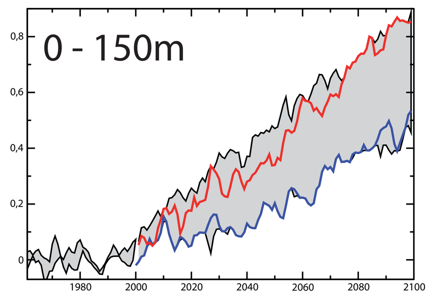


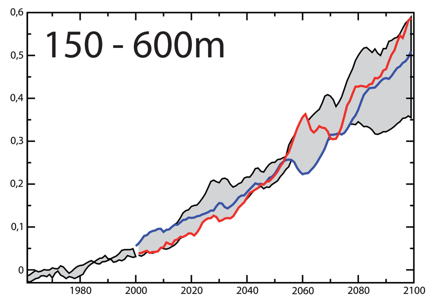


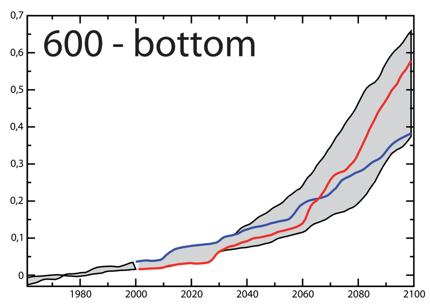




Fields	1961-1990 moy ± sigma	2070-2099 uncertainty range
T3D (°C)	13.6 ± 0.1	[+0.9 ; +1.4]
T3D 0-150m (°C)	15.7 ± 0.2	[+1.3 ; +2.3]
T3D 150-600m (°C)	13.9 ± 0.1	[+0.8 ; +1.4]
T3D 600-bottom (°C)	13.3 ± 0.1	[+0.9 ; +1.4]
S3D (psu)	38.63 ± 0.01	[+0.30 ; +0.52]
S3D 0-150m (psu)	38.23 ± 0.03	[+0.40 ; +0.72]
S3D 150-600m (psu)	38.73 ± 0.02	[+0.34 ; +0.47]
S3D 600-bottom (psu)	38.66 ± 0.02	[+0.26 ; +0.51]





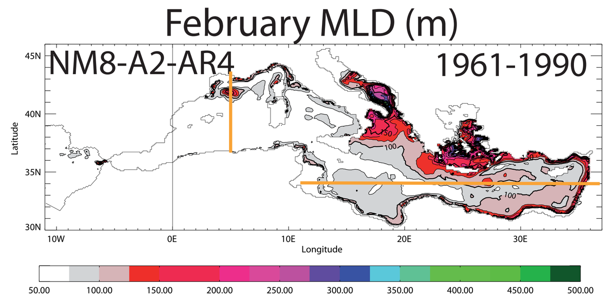


Along the 21st century and in all scenarios, the Mediterranean deeper layers become warmer and saltier. This warming and saltening trend is accelerating along the 21st century, particularly in the bottom layer after the 2050s.
In most of the runs, the Mediterranean Sea become denser at depth.

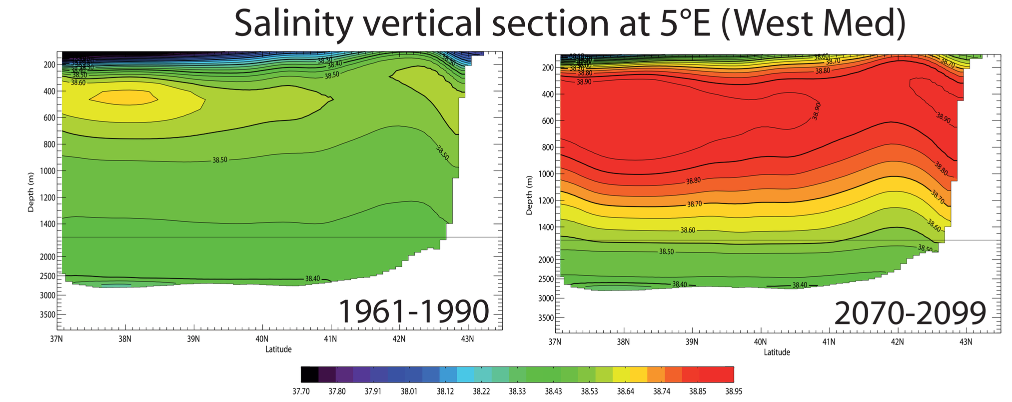
06 | WATER MASS FORMATION PROCESS

We analyse here the Mediterranean THC in the NM8-A2-AR4 run.

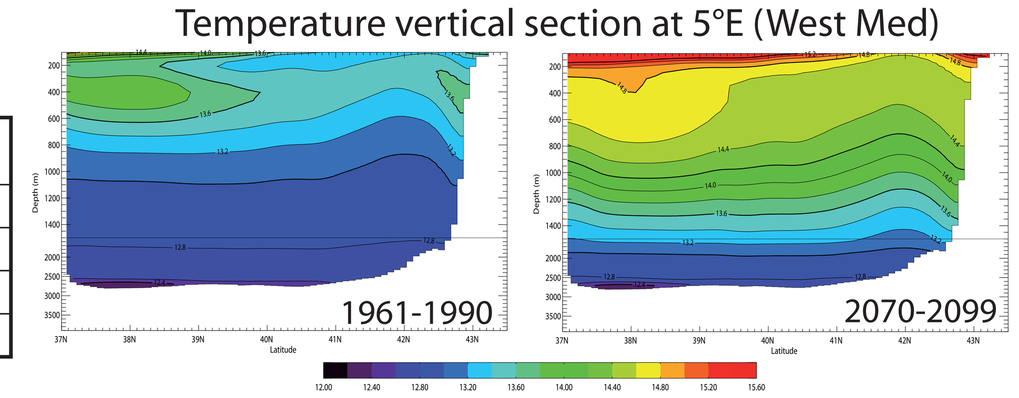
February MLD (m)



Salinity vertical section at 5°E (West Med)



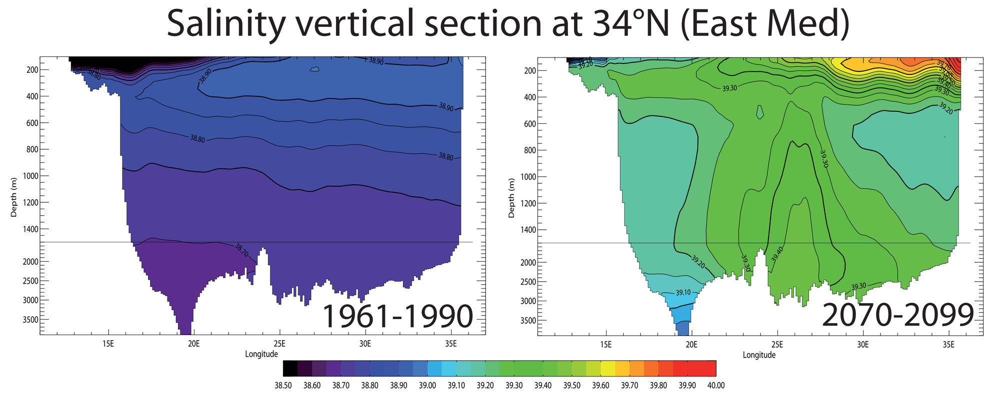
Temperature vertical section at 5°E (West Med)



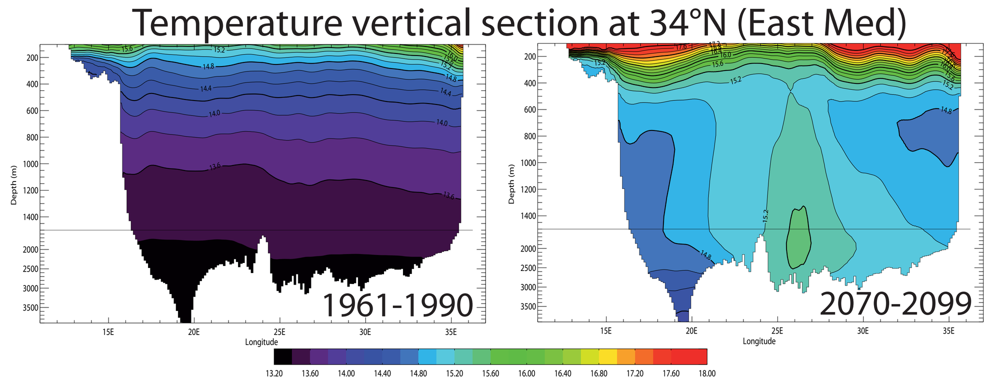
Fields (all except for NM8-A2-AR3)	1961-1990 moy ± sigma	2070-2099 uncertainty range
MLDmax G. of Lions (m)	890 ± 700	[-58% ; +54%]
MLDmax Aegean (m)	760 ± 370	[+24% ; +65%]
MLDmax Adriatic (m)	810 ± 270	[-14% ; +5%]
MLDmax Levantine (m)	470 ± 220	[+41% ; +245%]

In the Western Basin, the warming and saltening is concentrated in the surface and intermediate layers (LIW)

Salinity vertical section at 34°N (East Med)



Temperature vertical section at 34°N (East Med)



In the Eastern Basin, the warming and saltening deeply propagate as the bottom water masses are strongly ventilated by an EMT-like process: very dense water formation in the Aegean Sea, overflow through the Cretan Arc Straits and bottom propagation in the Levantine and Ionian Seas.

07 | FUTURE PLANS

- Intercomparison of diverse regional ocean and atmosphere models in a coordinated international framework (HyMeX and Med-CORDEX)
- The use of fully coupled Regional Climate System Models
- The use of eddy-resolving ocean models
- A better description of the near-Atlantic influence and of the Gibraltar Strait (sea level issue)

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