Climate change impacts on the biogeochemistry of the Mediterranean Sea: Results from a high-resolution model

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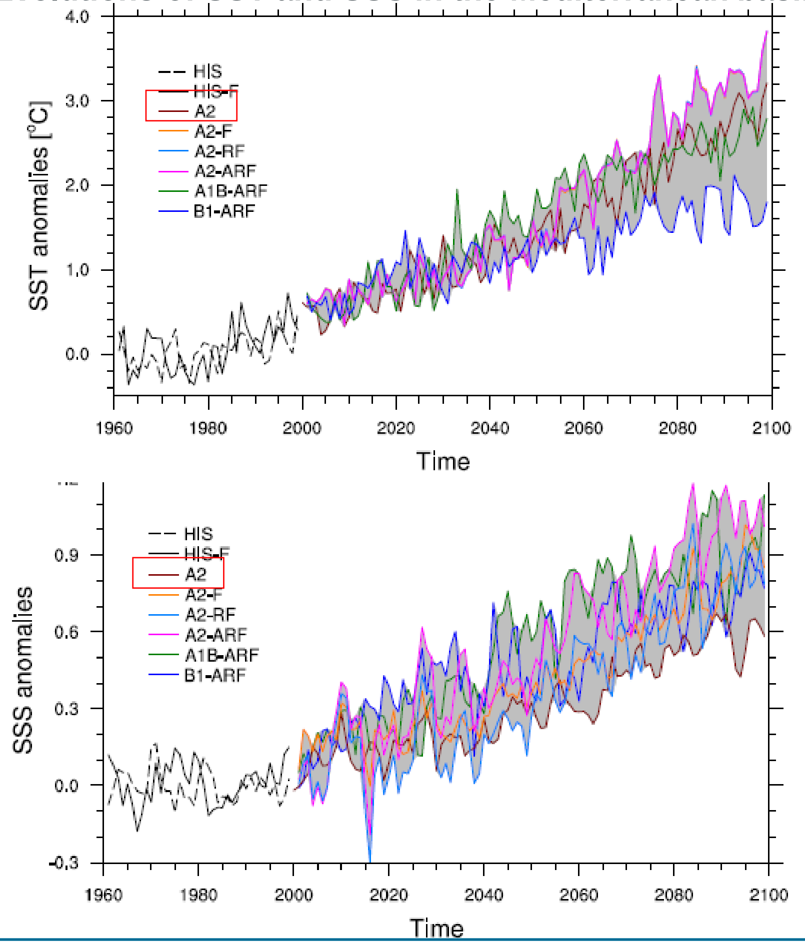
Introduction | Methods | Results | Results | Results | Conclusion

The Mediterranean Sea is a climate change “hot-spot” (Giorgi 2006) . In this semi-enclosed basin, the impacts of increasing greenhouse gas emissions may lead to increased temperature and salinity of the Mediterranean waters. In particular, high-emission scenarios lead to significant changes in the Mediterranean thermohaline circulation (MTHC), notably an increase in the stratification index (Adloff et al. 2015).

The Mediterranean Sea is one of the most oligotrophic regions in the world. Its surface productivity is strongly limited by macronutrients (N and P). The vertical supply of nutrients is critical to the onset of spring blooms, but many areas rely on other external nutrient sources such as the Strait of Gibraltar, rivers or atmospheric deposition to maintain their productivity. In this context, the future biogeochemical functioning of the Mediterranean may be influenced by changes both in climate and external nutrient supply.

Evolutions of SST and SSS in the Mediterranean basin over the 21st century



Adloff *et al.* 2015 Clim. Dyn.

- No transient modeling study of the Med. biogeochemistry
- A2 = Business as usual, only forcings available

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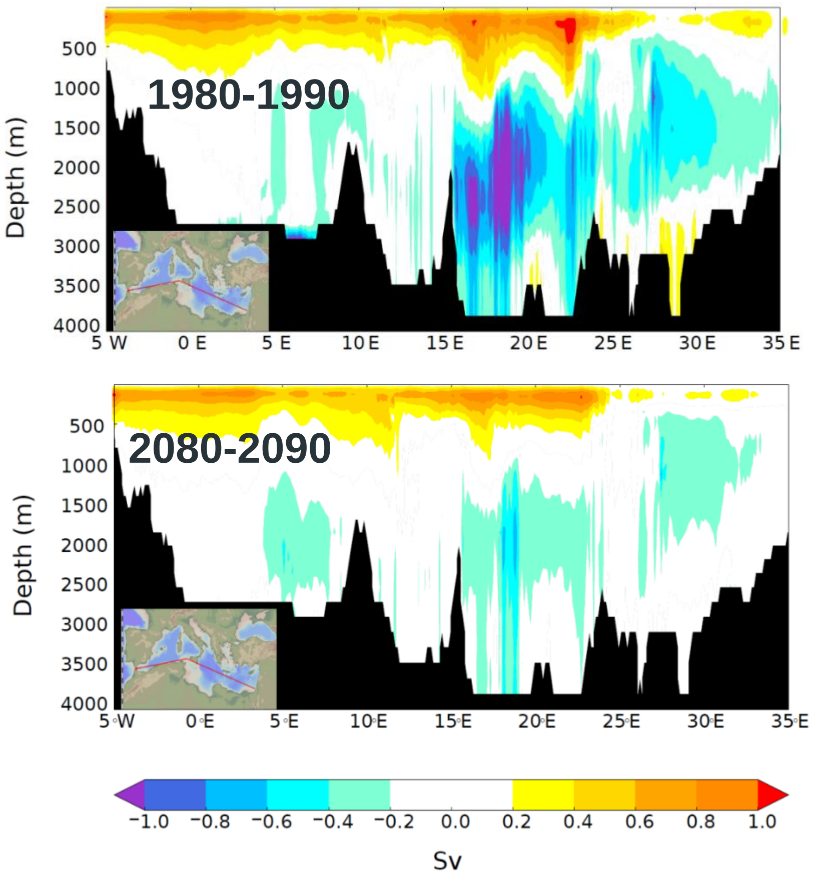
Ocean model:
- High resolution dynamical NEMOMED8/PISCES (1/8° horizontal resolution, 9-12km)
- 43 vertical levels

Biogeochemical model PISCES:
- 24 tracers (including 6 nutrients, 2 phytoplankton and 2 zooplankton groups)
- Redfieldian
- External nutrient forcings: Rivers, Gibraltar

Average zonal stream overturning function (ZOF) in March



- Dynamics

ARPEGE/NEMOMED8 (méteo France): HIS (1980-2000) and A2 (2001-2100) simulations from Adloff *et al.* (2015) Clim. Dyn.

The CO2 concentrations during the HIS period are driven by greenhouse gases forcing and by the SRES-A2 scenario after 2000.

- SST increase in the basin about 3°
- SSS increase > 0.5 PSU
- Stratification in the future

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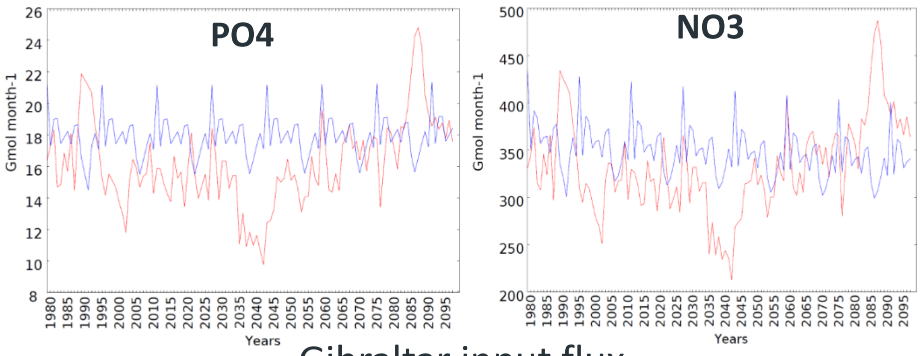
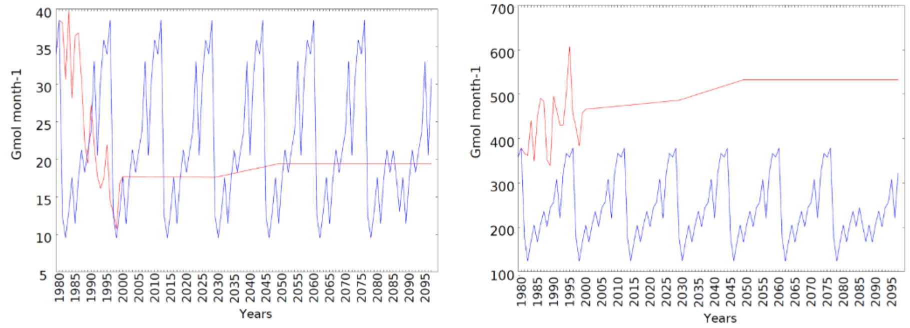


Gibraltar input flux

Med. Sea is a remineralization basin

CTRL

HIS/A2



River input flux

- Biogeochemistry
- ➢ Buffer zone concentrations : Global model IPSL-CM5-LR (Dufresne *et al.* (2013) Clim. Dyn.)
- ➢ River inputs : Ludwig *et al.* (2010) GBC, « Business as Usual »

- ➢ Similar evolutions for NO3 and PO4 inputs from Gibraltar
- ➢ Strong decrease in PO4 river inputs, increase in NO3 river inputs → N/P ratio of river inputs changes

Different simulations to separate effects of dynamical vs Gibraltar flux vs river inputs

Name	Dynamics (NEMO years)	Buffer-zone concentrations	River inputs	N deposition	P deposition
CTRL	1966–1981	1966–1981	1966–1981	No	No
CTRL_R	1966–1981	1966–1981	1980–2099	No	No
CTRL_RG	1966–1981	1980–2099	1980–2099	No	No
HIS/A2	1980–2099	1980–2099	1980–2099	No	No

Richon et al. 2019 (Biogeosciences)

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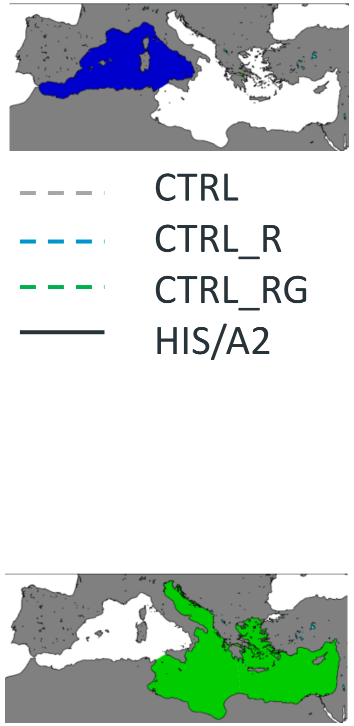
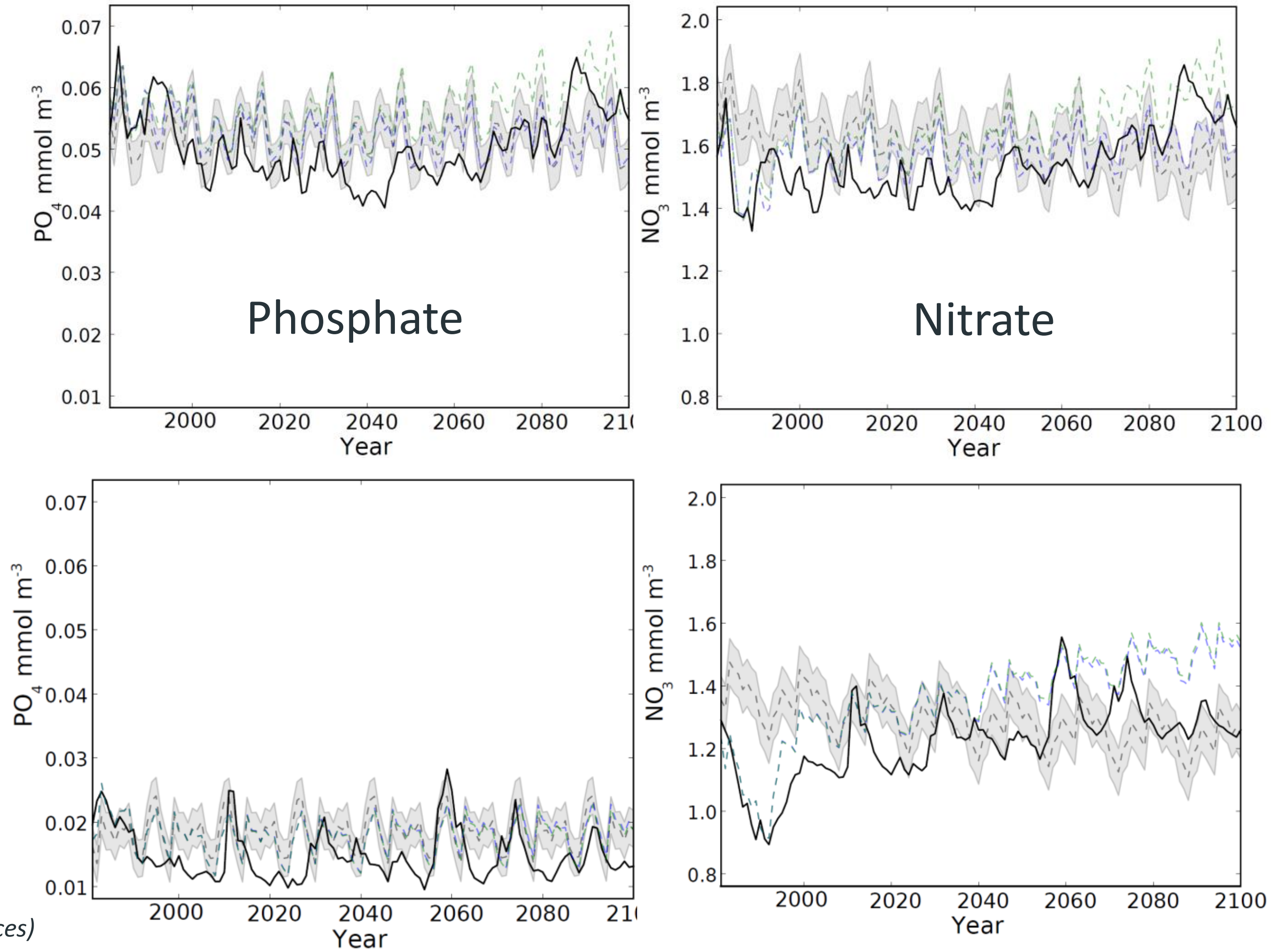
Evolutions of surface nutrient concentrations (0-200m)





Richon et al. 2019 (Biogeosciences)

PO4 and NO3 global budget of the Mediterranean increase by 8.5% and 9.7% respectively in our HIS/A2 simulation, due to strong increases in concentrations in the intermediate and deep layers.
In the western basin, nutrient inputs from Gibraltar strongly influence surface PO4 and NO3 concentrations (Pearson correlation between nutrient concentrations and Gibraltar inputs >0.8).

Eastern Mediterranean basin is more oligotrophic than the western basin (up to 50% lower nutrient concentrations). In the eastern basin, the increase in surface NO3 is influenced by the riverine inputs but surface stratification reduces the effects of riverine inputs. PO4 concentrations in the surface eastern Med decrease as a result of stratification.

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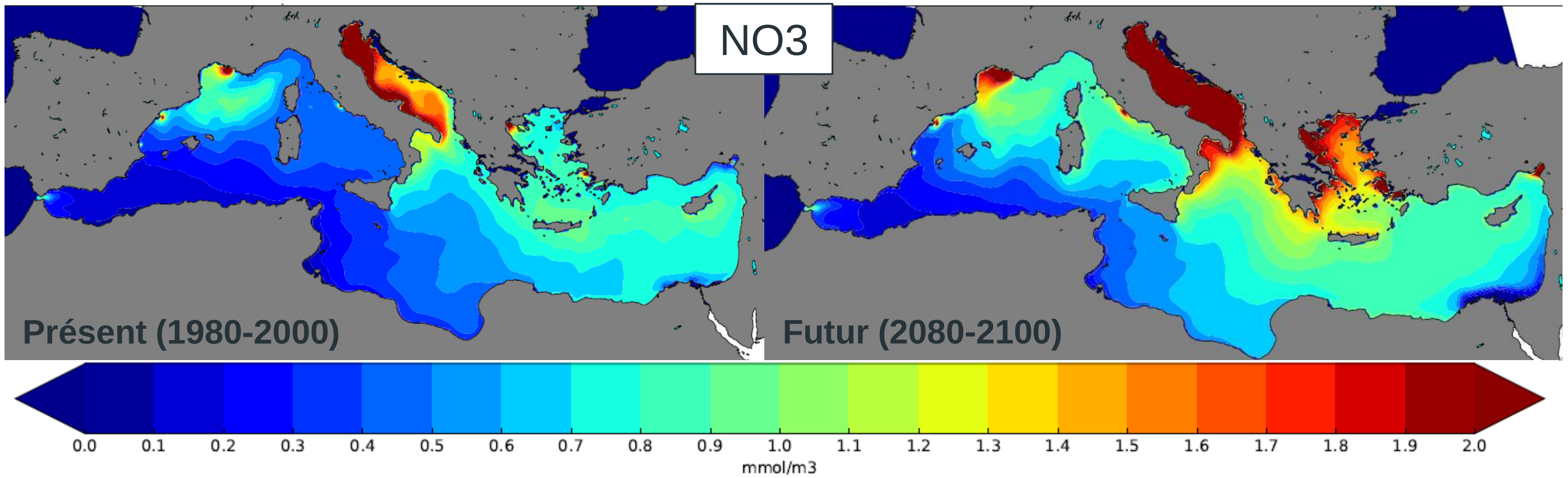

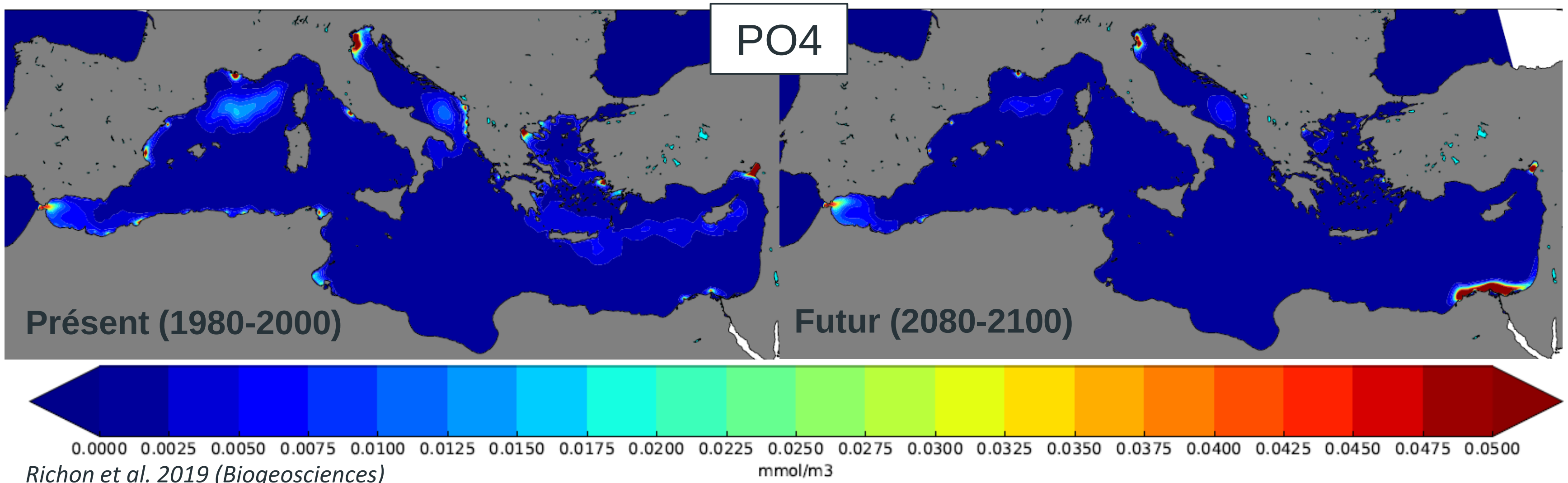

Richon et al. 2019 (Biogeosciences)

Surface concentrations of NO3 increase by the end f the century. The increase is stronger in the Ionian basin and the Adriatic (up the 50%).

Surface PO4 concentrations decrease strongly, in particular in the eastern basin (halving of PO4 concentration in the Aegean, Levantine and Adriatic).

We observe a strong decrease in nutrient concentrations in the Gulf of Lion which is linked to the decrease in vertical fluxes.

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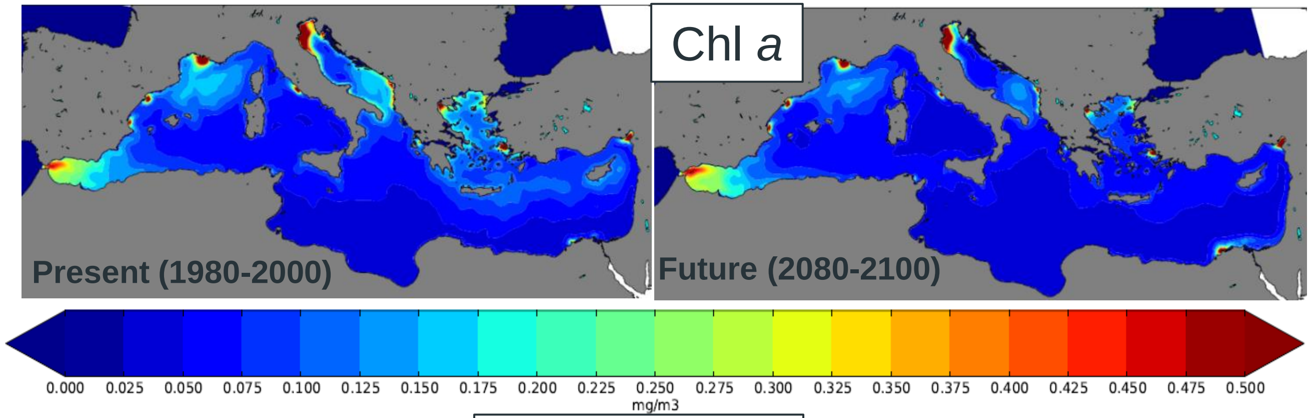

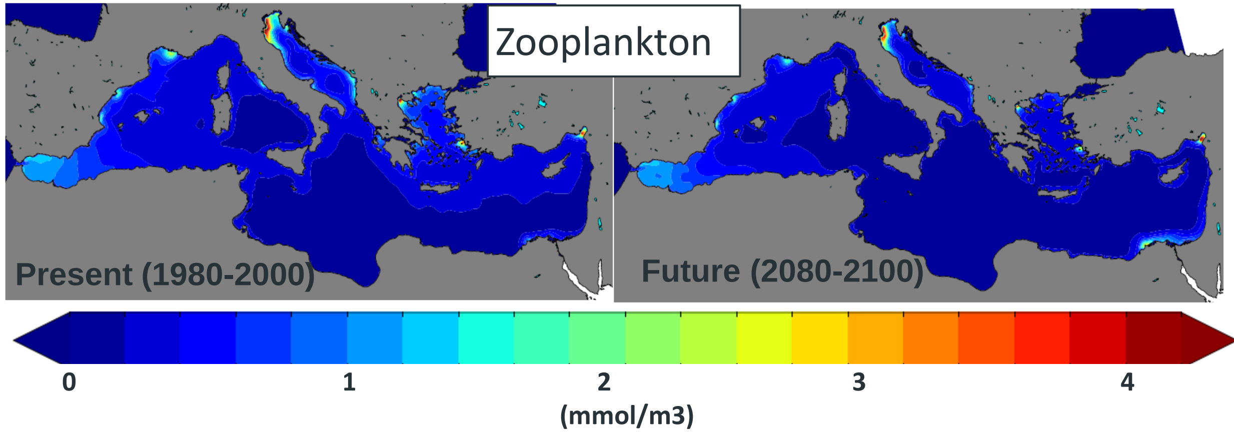

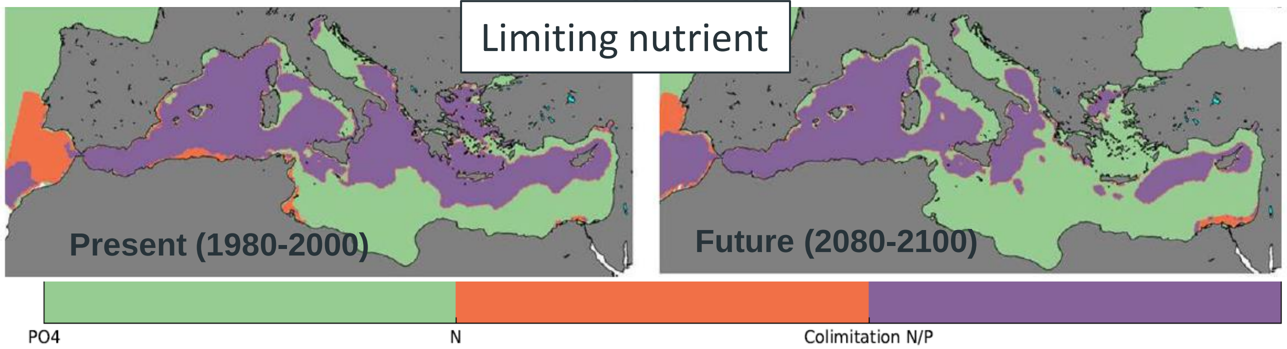

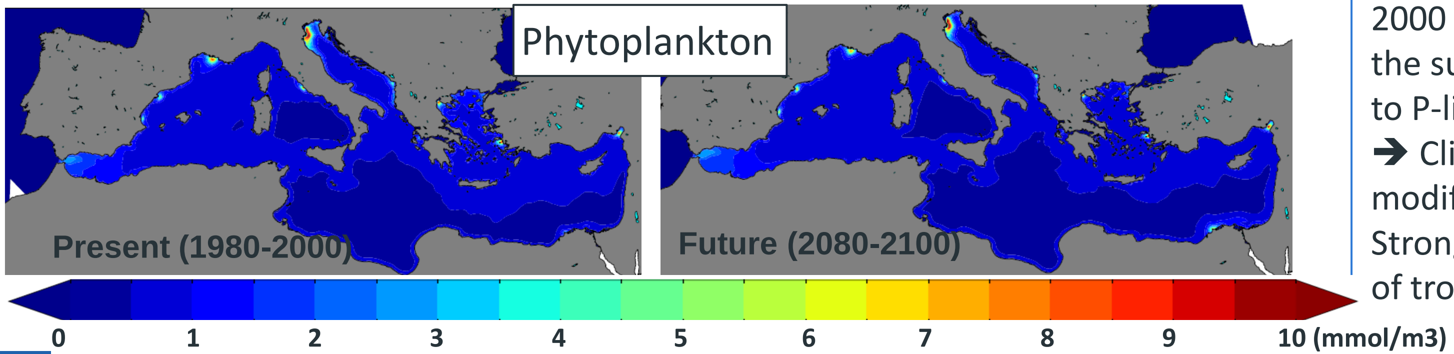

Surface chlorophyll concentrations decrease by the end of the 21st century in the Mediterranean (-8.9% on average in the whole basin, -5.1% in the western basin and -11% in the eastern basin). In particular, we observe a strong decrease in Chl a in the Gulf of Lions, around Cyprus and Crete, where both PO4 and NO3 concentrations decrease strongly.

Most of the Mediterranean surface is P or N and P co-limited in the 1980-2000 period. By the end of the century, the accumulation of nitrogen in the surface eastern Mediterranean modifies the nutrient balance, leading to P-limitation in most of the eastern basin.

➔ Climate change and biogeochemical forcing changes lead to modifications of surface nutrient limitations

Stronger decline in zooplankton biomass than phytoplankton ➔ Evidence of trophic amplification

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- First transient simulation A2 in high resolution global Med Model
- accumulation of N, decrease of P concentration (over 30 % in the eastern basin)
- Intensification of P limitation in the future ➔ decrease in productivity (10 % reduction of average PP, 5.1% reduction in average Chl a)
- Changes in surface nutrient limitation may increase the Mediterranean sensitivity to atmospheric deposition.
- Important stratification leads to reductions of DCM (> 50 % in intensity)
- Signs of trophic amplification (loss of Chl a and PP are translated into larger loss in phytoplankton and zooplankton biomass, see Richon et al. 2019, Biogeosciences for all results).

Perspectives

- Simulation of climate change impacts using more recent scenarios (RCPs)
- Deconvolution of climate effect and change in nutrient forcings (sensitivity tests)
- Influence of atmospheric deposition on the future Mediterranean
- Use of different circulation and river inputs scenario ➔ More integrated modeling framework
- PISCES developement (adaptation mechanisms, bacterial activity…)