DEEP CARBON SEQUESTRATION IN THE MEDITERRANEAN SEA AND THE ROLE OF MARGINAL SEAS

Gianpiero Cossarini [1]*, Stefano Salon [1], Stefano Querin [1] and Giorgio Bolzon [1]
[1] OGS Istituto nazionale di oceanografia e di geofisica sperimentale - gcossarini@ogs.trieste.it

Abstract
A suite of 3D coupled hydrodynamic-biogeochemical models (CMEMS-Reanalysis and high-resolution MITgcm-BFM) has been used to estimate the carbon sequestration in the Mediterranean Sea and the processes that contribute to the transport of carbon into the deepest part of the marine ecosystem. Results of simulation show that the Mediterranean Sea is a net sink of atmospheric carbon of about 8 TgC/y. Carbon transport into the interior of the Mediterranean Sea is driven by both soft and hard tissue pumps, however, with different spatial and temporal impacts. Further, deep water formation and cascading flows in marginal seas, such as the Adriatic Sea, are other important mechanisms for the sequestration of carbon.

Keywords: Carbon, Models, Air-sea interactions, Mediterranean Sea, Otranto Strait

Materials. The carbon cycle in the Mediterranean Sea is investigated with two nested models. First, the CMEMS biogeochemical reanalysis for the Mediterranean Sea at 1/16 degree (available at marine.copernicus.eu) was carried out along the period 1999-2014, using the 3DVAR-OGSTM-BFM biogeochemical model [1, 2, 3]. The reanalysis is designed with a transport model (OGSTM) driven by physical forcing fields produced as output by the Med-Currents model. The Biogeochemical Flux Model (BFM) describes the energy and material fluxes through both "classical food chain" and "microbial food web". The carbonate system of BFM considers alkalinity and DIC, whose dynamics are driven by biological (e.g. photosynthesis and respiration, nitrification and de-nitrification, ion uptake and release and precipitation and dissolution of $CaCO_3$) and physical processes (exchanges at air-sea interface and dilution-concentration due to evaporation minus precipitation). The reanalysis is coupled with a 3DVAR data assimilation scheme that uses the ESA-CCI surface chlorophyll dataset of CMEMS-OCTAC. Second, the high-resolution (1/32°) coupled MITgcm-BFM model for the Adriatic - Ionian Seas (nested in the Mediterranean reanalysis) is used to estimate the specific impact of the continental shelf pump process of the Adriatic Sea (a combination of biological productivity and carbon transport associated to the dense water formation and spreading [4]). The simulations have been validated through quantitative skill assessment analyses for nutrients (nitrate and phosphate), chlorophyll, oxygen and the carbonate system variables (alkalinity and DIC) [5].

Results. Results of the 1999-2014 reanalysis show that Mediterranean Sea is a net weak sink of atmospheric carbon. The simulated mean annual value, about 8 TgC/y, is consistent with other recent estimates [6], however the interannual variability is significant (Figure 1) and correlated to the year-to-year variability of atmospheric and marine conditions.

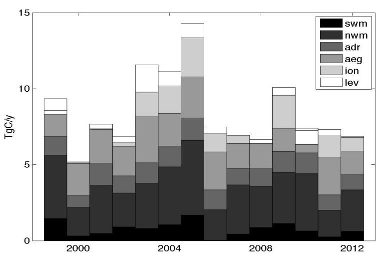

Fig. 1. Time series of the mean annual atmospheric carbon sequestration in southwestern (sam) and northwestern (nwm) Mediterranean Sea, Adriatic Sea (adr), Aegean Sea (aeg), Ionian Sea (ion) and Levantine basin (lev).

The air-sea CO_2 exchanges (overall average of 0.8 mmolC/m2/d) show very high spatial and seasonal variability. During summer the Mediterranean Sea is a source of CO_2 to the atmosphere (6.5 mmolC/m^2/d) while during winter is a sink (up to 9 mmolC/m^2/d). Marginal seas are the areas characterized by the highest mean rate of carbon sequestration (up to 4-5 mmol/m^2/d), while Levantine sub-basin and southern Ionian Sea are, on average, sources of CO_2 (from -2 to -1 mmolC/m^2/d). Sequestered atmospheric carbon is exported to the interior of the Mediterranean Sea by several processes, which involve both vertical and horizontal components. Soft tissue carbon pump (sink and export of organic carbon, up to 1 mmol/m2/d) is correlated to the spatial distribution of net primary production in the Mediterranean Sea [5] whereas the hard tissue pump (up to 0.2-0.3 mmolC/m2/d) is correlated to calcifier dynamics (i.e. precipitation and dissolution of $CaCO_3$). The Adriatic Sea works as a carbon pump because of the combination of the high biological productivity and of the dense water formation and transport [4]. Results of the MITgcm-BFM simulation shows that the Adriatic Sea exports to the interior of the Mediterranean Sea almost 4.7 TgC/y, which balances the import of carbon from rivers plus the atmosphere; and the inflow at the surface layer. At the Otranto strait, the surface outflow flux associated to WAC and the entering flux associated to the incoming Ionian water are almost in equilibrium, whereas the flux associated to the cascading dense water outflow at 600-900m is the mechanism for the carbon sequestration into the interior of the Mediterranean Sea (Figure 2).

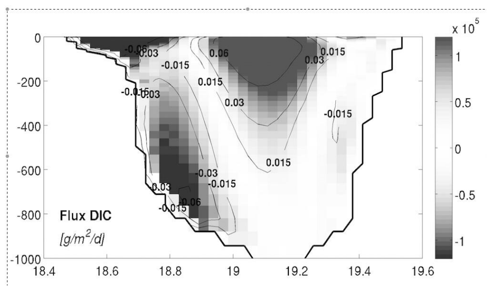

Fig. 2. Contour (solid black lines) of zonal velocities (positive velocities are oriented northwards, negative ones are oriented southward); and northward and southward (see sign of velocities) fluxes of DIC across the Otranto Strait.

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