# Mediterranean water-mass variability in Θ-S coordinates


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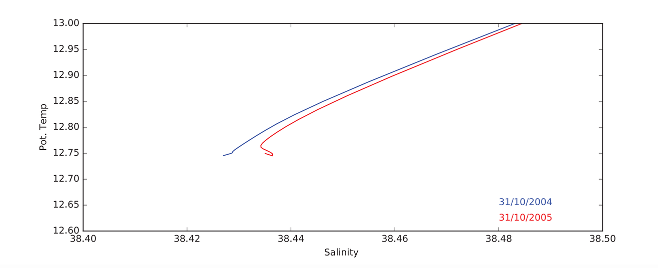
## Motivations

The Mediterranean Sea is a miniature ocean with an overturning circulation but with reduced time and spatial scales.

Two major transient events have driven drastic changes in the thermohaline properties of Mediterranean Bottom Waters:

- In the eastern basin, the Eastern Mediterranean Transient (EMT) resulted in a switch from the Adriatic Sea to the Aegean Sea as the main bottom water formation site in 1991-1992 [1].
- In the western basin, the Western Mediterranean Transition (WMT) resulted in the formation of a new, warmer, saltier bottom water between 200 and 2006 [2].




Change in Θ-S properties in the Western Mediterranean Basin during the intense episode of bottom water formation during the winter 2004-2005

**These water-mass anomalies spread across the basin in a few years allowing to investigate the impact of such changes on the Mediterranean Overturning Circulation**.

## Data and Methods

We use 33 years of output from the regional circulation model NEMO-MED12 model. The model has a horizontal resolution of $\frac{1}{12}^{\circ}$ (∼7km) and 75 vertical levels.
Boundary conditions:

- Exchanges with the Atlantic: Buffer zone from the 2005 World Ocean Atlas for Θ and S.
- Surface: daily evaporation, precipitation, radiative and turbulent heat fluxes, and momentum fluxes from the ARPERA data set
- River runoff and exchanges with the Black Sea included as surface freshwater forcing.

We investigate the contribution from air-sea fluxes and mixing (all mixing processes altogether) to water-mass transformation and variability in the Mediterranean Sea by projecting the model's output in a water-mass framework.

**Θ−S framework:** Cross-haline and cross-thermal fluxes (see [4] for example):

$$G_{\Theta} = \overbrace{-\frac{1}{c}\frac{\partial Q}{\partial \Theta}}^{air-sea fluxes} - \overbrace{\frac{1}{c}\frac{\partial F_{\Theta}}{\partial \Theta}}^{mixing} \quad (1)$$

$$G_S = \underbrace{\frac{\partial SE}{\partial S}}_{air-sea fluxes} - \underbrace{\frac{\partial F_S}{\partial S}}_{mixing} \quad (2)$$

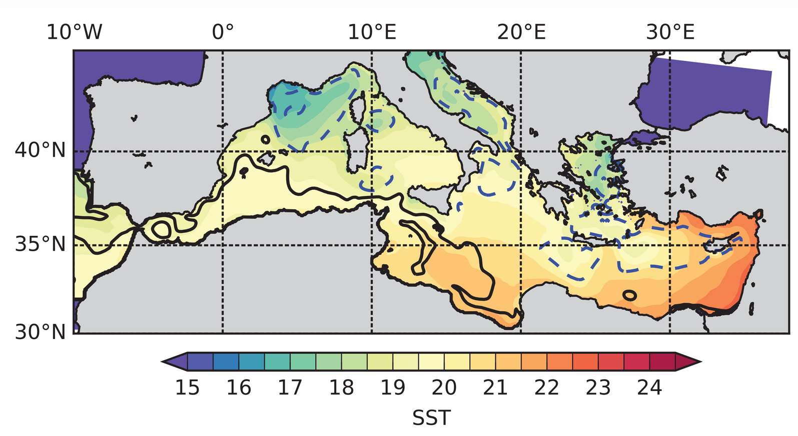
Cross-haline and cross-thermal fluxes from the water-mass transformation vector **J**:

$$\mathbf{J} = \left(\frac{\partial G_S}{\partial \Theta}, \frac{\partial G_{\Theta}}{\partial S}\right) \quad (3)$$

⇒ We compute $G_S$ and $G_{\Theta}$ from the model's velocity, temperature and salinity fields [3]
⇒ We compute air-sea contributions from the model's air-sea fluxes and deduce the water-mass transformation due to mixing (all mixing processes) as:

$$-\frac{1}{c}\frac{\partial F_{\Theta}}{\partial \Theta} = G_{\Theta} + \frac{1}{c}\frac{\partial Q}{\partial \Theta} \quad (4)$$

$$-\frac{\partial F_S}{\partial S} = G_S - \frac{\partial SE}{\partial S} \quad (5)$$




→ Negative SSH
→ Positive SSH

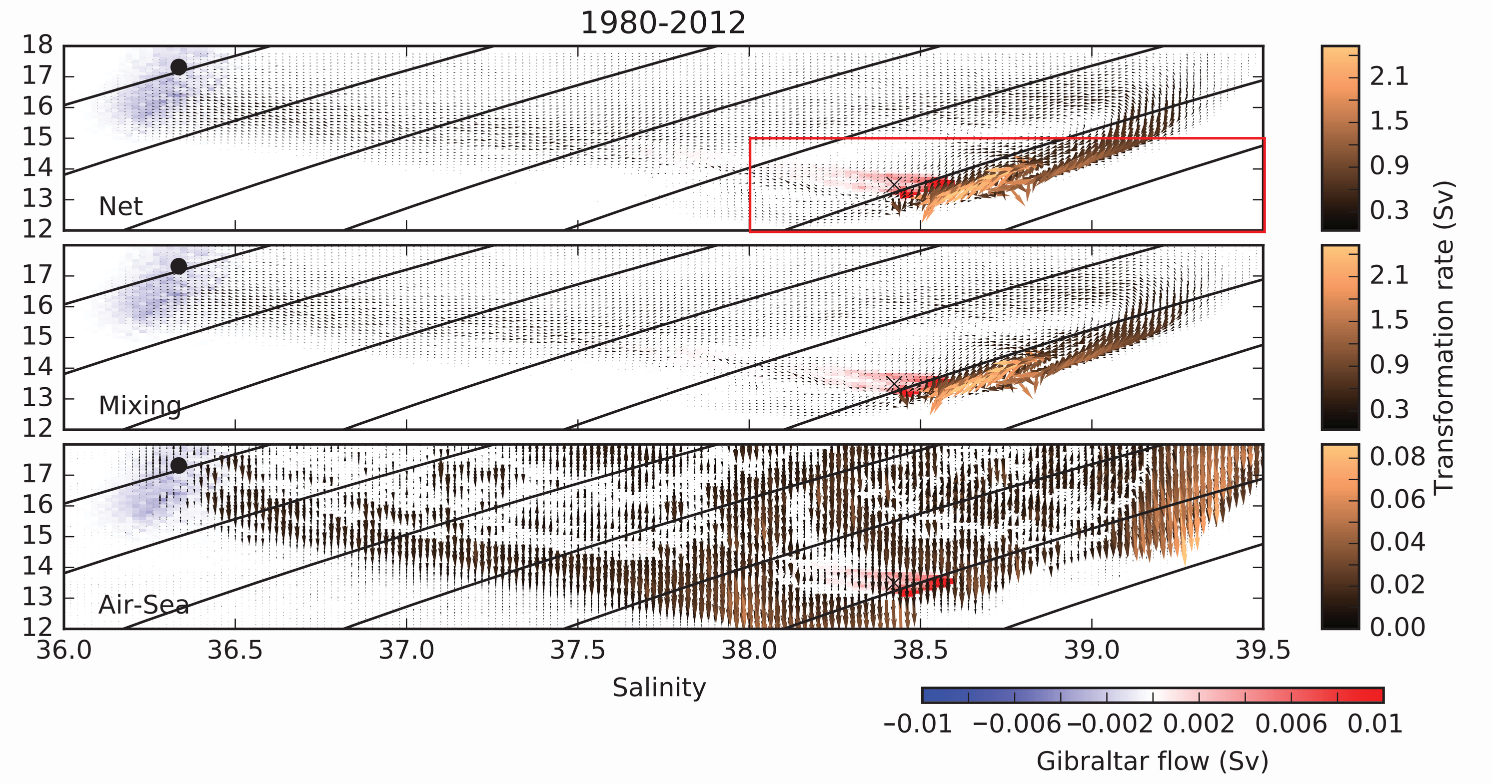
⇒ Mean (1980-2012) Sea Surface Temperature and sea surface height.

⇒ The inflow of Atlantic Water is illustrated by the positive SSH

⇒ Main gyres are shown

## water-mass transformation

The net water-mass transformation vectors (**J** top) as well as the contribution from mixing (middle) and air-sea fluxes (bottom - **Mind the smaller values on colorbar**) for the entire Mediterranean basin.



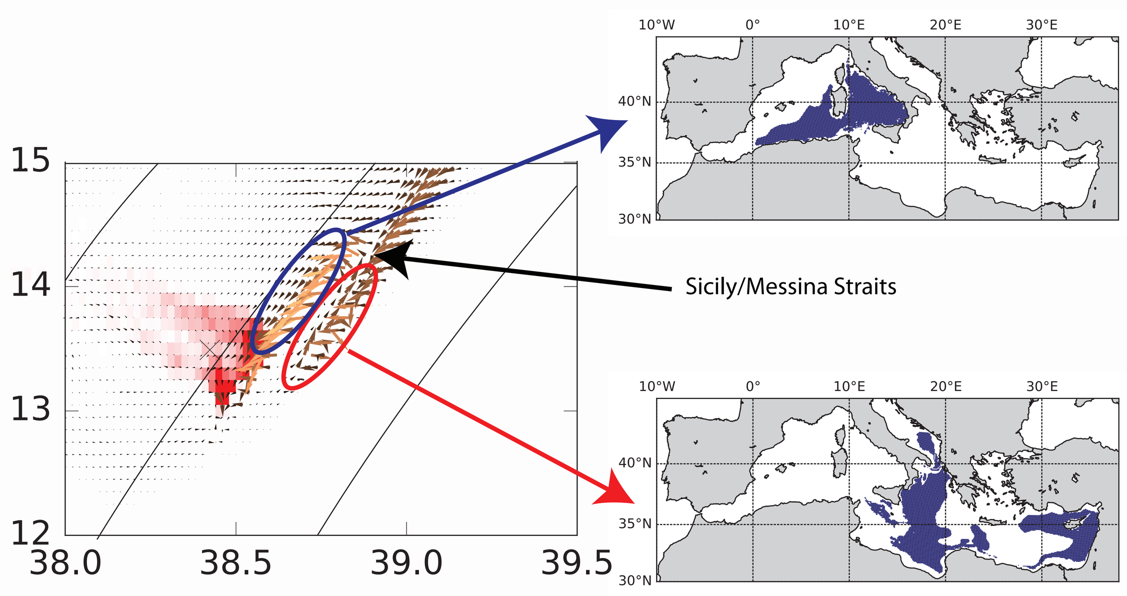

Strong salinification (36 to 39) followed by cooling and freshening.

Mixing seems to be the dominant player.

Air-sea fluxes induce a cooling and salinification particularly in the Eastern Basin.

Intense water-mass transformation in the high salinity water-masses (in the Eastern Basin).

**Zoom on the Θ-S range where strong water-mass changes occur and map into geographical space:**




⇒ Intense cooling and freshening in the Tyrrhenian Sea and Algerian Basin

⇒ Complex changes in the Ionian Basin, upstream of the Sicily Strait.

**Complex water-mass transformations (involving both diapycnal and isopycnal mixing) on both sides of the Sicily Strait to reach Θ-S properties of the outflow at Gibraltar Strait.**

## Take Home message

⇒ Θ-S framework allows to track the water-mass transformation between inflow and outflow at Gibraltar

⇒ Mixing (isopycnal and diaycnal) plays a dominant role

⇒ Hot spots of water-mass transformations in the Eastern and Tyrrhenian basins.

⇒ Sicily and Messina Straits seem to play a pivotal role where diapycnal mixing occurs.

⇒ Bottom waters span a small $\Theta - S$ range

## Perspectives

⇒ Investigate changes in water-mass transformation vectors for different time periods (pre/post EMT and WMT)

⇒ Focus on deep water cells

⇒ What are the dominant mixing processes involved?


[1] Roether et al. *Science* **271** (1996) 333
[2] Schroeder et al. *Geophys. Res. Lett.* **35** (2008) L18605
[3] Groeskamp et al. *J. Phys. Oceanogr.* **44** (2014) 1735
[4] Pemberton et al. *J. Phys. Oceanogr.* **45** (2015) 1025



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