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Violent storms within the sea: Dense water formation episodes in the Mediterranean.

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The Mediterranean is a semi enclosed basin which receives surface water from the Atlantic Ocean. Most of this water is returned into the Ocean with higher density, spreading at more than 1000 m depth (the rest is transported by the atmosphere and the rivers to the Ocean surface). In terms of water budget, the Mediterranean is considered an evaporation basin, but the loss of water is neither the only process that increases the water density nor it is a steady or uniform process. The factors affecting the water density, temperature and salinity, are driven by mass and heat exchanges with the atmosphere. Those exchanges may be by direct contact or mediated by the land. Therefore, changes in water density depend on the water circulation and local weather conditions, both with seasonal and geographical constraints.

As the compressibility of water is very low, stratification is expected and horizontal motion is the predominant in the sea interior. Among the few processes that may introduce a vertical component in the water motion are surface heat loss or evaporation that increase the surface water density triggering convective cells. Such processes will be enhanced by surface cooling or by dry continental winds, and counterbalanced by rain, river runoff, solar heating and condensation. Therefore dense water formation are more likely to occur when sea surface temperature is higher than the surface air temperature.

There are several scales of convective motions in the ocean, starting from the formation of the surface mixed layer during summer, by night cooling, breezes, and occasional wind storms. During autumn and winter, the vertical scale of the mixing is increasing by steps, through wind storms and progressive cooling, to easily reach the bottom over the continental shelves, typically not deeper than 150 m. However, as the Gibraltar sill is relatively shallow ($\sim$350 m) in relation to the average Mediterranean basin (2000-3000 m), the stratification of the deeper layers is weak. Therefore, where and when the surface layer becomes well mixed, typically in winter, in the northern regions, conditions are given (pre-conditioning phase) to the occurrence of dense water formation episodes. Those episodes require the participation of strong cold and dry winds which force an intense evaporation. In the NW Mediterranean, such forcing may act over the continental shelves, like that of the Gulf of Lions, or over deep open seas, typically the central part east of Catalonia and south of Provence. Over the shelf, surface water is expected to be fresher because of the runoff (e.g. the Rhône). Along the continental margin the water circulation, geostrophically adapted, is cyclonic and the stratification in the centre is lower, then density reached may be higher in the central part than on the shelf. However, cooling will be more effective over the shelf as the heat content of the water column is lower because it is much shorter. Once density over the shelf is high enough, the bottom water overflows and violently sinks along the slope in relatively narrow areas through what has been called a cascading event. In the central part, dense water formed sinks almost vertically in funnels not larger than a few kilometres in diameter, and is accompanied by a compensating rise of water from great depth on all sides. In such open sea winter convection events, the dense water can sink some 800 m within a matter of hours and may reach the bottom level, >2500 m deep, within a couple of days.

Such short and violent episodes, cascading or open sea convection, of a few days' duration supply enough water to feed the lower layer to compensate the outflow through the Strait of Gibraltar for several weeks. The repeated events in some few points across the Mediterranean, like those above mentioned, are maintaining the Mediterranean circulation and the water exchanges with the Ocean. The overall amount of dense water formed however is highly variable from one year to another according to the forcings involved and perturbations of the water circulation.