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Why does the Mediterranean Outflow vary through time?

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The Gibraltar Exchange regulates the amount of water supplied to the Mediterranean to balance net evaporation, but also the a major term in the of buoyancy (i.e. heat and freshwater) budget of the North Atlantic Ocean. As such, it is a critical term to determine in order for the palaeoceanographic behaviour of two ocean basins to be understood. We present a new quantitative analysis of the past behaviour of this exchange combining empirical data and simple 1-deminssional modelling experiments. We are able to show that it is almost impossible to explain the known changes in the vertical position of the plume of Mediterranean Outflow Water (MOW) in the open North Atlantic by realistic changes in the Mediterranean system east of Gibraltar. In fact, observed changes in vertical position can only be explained by changes in the mid-depth (300 to 2000m) vertical density gradient in the North Atlantic, and observed position of the MOW during the Last Glacial Maximum indicates that vertical density decreased by at least 50%. Even lower position of the MOW on the Portuguese slope during Heinrich Events suggests that vertical density gradient was reduced even further at these times.

Similarly, we find that it is difficult to explain observed changes in the intensity of MOW flow during the last glacial cycle according to previously proposed concepts of sea level or atmospheric temperature forcing. Sea level changes on an Antarctic rhythm, and does not show the Dansgaard-Oeschger cyclicity argued to be dominant in long-term records of MOW flow. Temperature changes do not induce sufficient variability in the properties of the Gibraltar Exchange to significantly alter MOW flow. We find the most likely explanation is that lower sea surface temperature during Dansgaard-Oeschger stadials results in lower evaporation and therefore lower density in MOW, which consequently settles at shallower depth in the North Atlantic. Lower net evaporation during the early Holocene results in a prominent "Contourite Gap" in the Gulf of Cadiz, which reflects insufficient density anomaly at Gibraltar to drive a maximal exchange.

Resolution of how and why MOW has changed through time requires spatially resolved (time-slice) data showing direct hydrographic consequences of behaviour at Gibraltar. To assist in achieving this goal we also present a new approach to generate and analyse the necessary empirical data.