# SEASONAL VARIABILITY OF THE EXCHANGE THROUGH THE STRAIT OF GIBRALTAR AND THE MEDITERRANEAN MEAN SEA LEVEL

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## Abstract

Currentmeter observations at the eastern section of the Strait of Gibraltar were used to determine the seasonal signal in the exchanged flows. The computed signal of the net barotropic flow is compatible with the water mass balance within the Mediterranean sea at a seasonal scale. The enhanced response of the inflow to the annual cycle of the density contrast between Mediterranean and surface Atlantic waters appears to be the cause of this cycle. This enhanced response is possible if the exchange is submaximal, in which case seasonally-induced variations of the size of the Western Alboran Gyre can become an effective mechanism to induce the observed seasonal signals.

*Keywords: Alboran Sea, Strait of Gibraltar, sea level.*

### Seasonal signal in the flows through the Strait

From October 1995 to May 1998 a mooring array of recording currentmeters was deployed in the eastern part of the Strait of Gibraltar within CANIGO Project. The observed velocities were used to produce time series of the slowly-varying inflow ($Q_1$), outflow ($Q_2$), and the depth of the interface ($\eta_2$), defined as the surface of null along-strait velocity. Time series were fitted to a sinusoidal model of annual and semiannual periodicity in order to investigate the existence of seasonal signals [1]. Table 1 shows the annual parameters, the cycle in which the present work concentrates.

**Table 1. Annual parameters of the model. All phases are referred do the year-day 1.**

| *Variable* | $A_a$ | $\varphi_a$ |
|---|---|---|
| $Q_{1,a}$ (Sv) | 0.101±0.038 | 225°±21° |
| $Q_{2,a}$ (Sv) | 0.028±0.025 | 201°±51° |
| $Q_{0,a}$ (Sv) | 0.077±0.044 | 234°±33° |
| $\eta_{2,a}$ (m) | 4.557±3.269 | 61°±42° |
| $(\Delta\rho)_a$ (kg/m$^3$) | *0.29* | *238°* |

### The net barotropic signal and the Mediterranean Sea level cycle

The simplest model to balance the net barotropic signal in the Mediterranean Sea is $Q_{0,a}=dV_{MED}/dt= A_{MED}\, d\xi/dt$ ($V_{MED}$ is the volume of the Mediterranean Sea, $A_{MED}= 2.5\ 10^{12}\ m^2$ its area, and $\xi$ the sea level), and ignores the evaporative seasonal cycle $(E-P)_a$. Taking $Q_{0,a}$ from Table 1, this equation would imply an unrealistic annual signal in $\xi$ of 15±9 cm with maximum value in November. TOPEX/POSEIDON altimetry data provide evidence of a seasonal cycle in the Mediterranean mean sea level of 8 to 10 cm of amplitude with maximum value in October [2]. This annual signal is quite evident in longer time series of altimetry data (P.Y. LeTraon, personal communication). However, part of this signal is due to steric effects. In [1] and using the MEDATLAS data set, these anomalies (averaged over the whole Mediterranean) are computed to give an amplitude of 5.5±0.4 cm and a phase of 253±12° for the thermal contribution and non-significantly different from zero for the haline part (0.11±0.24 cm).

Taking into account the thermal steric anomaly, the effective mass variation within the sea is $\xi_m =\xi_{obs} - \xi_{str}$, where $\xi_{obs}$ is the observed sea level signal mentioned in [2] and $\xi_{str}$ the steric contribution. The RHS of the aforementioned balance equation should be 0.02 Sv at 230°, far from the value of $Q_{0,a}$ reported in Table 1. The correct mass balance must include the climatological $(E-P)$ forcing, $Q_{0,a}-(E-P)_a=A_{MED}\, d\xi m/dt$, where $(E-P)_a$ is the annual signal in the net evaporation. Using the previous value for the RHS and $Q_{0,a}$ of Table 1, we obtain 0.06 Sv at 237° for $(E-P)_a$.

The seasonal net evaporative cycle is difficult to measure. [3] suggests a cycle of around 6 cm/month (0.06 Sv) that peaks in August (215°), while [4] indicates a seasonal signal of 7.1cm/month (0.07 Sv) at 181° using the *World Survey of Climatology*. The agreement of these amplitudes with the amplitude deduced from the mass imbalance is good. Phases will probably agree within the confidence intervals of the aforementioned values of $(E-P)_a$. The estimate of $Q_{0,a}$ from our observations is consistent with the requested mass balance within the Mediterranean.

### Driving force for the net barotropic flow annual signal

Table 1 includes the seasonal signal of the density contrast between Atlantic and Mediterranean waters given in [4]. The phase agreement between $(\Delta\rho)_a$ and $Q_{0,a}$ suggests a cause-effect relationship. A simple unidimensional two-layer model for the exchange [1] shows that under maximal exchange, a positive net barotropic signal, for instance, is achieved by means of an increase of half this signal in $Q_1$ and a similar diminution in $Q_2$. Table 1 shows that this is not the case since both $Q_{1,a}$ and $Q_{2,a}$ oscillate near-in-phase with $(\Delta\rho)_a$. The seasonal signal in $Q_0=Q_1-Q_2$ arises because the amplitude of $Q_{1,a}$ is greater than the amplitude of $Q_{2,a}$, that is, the inflow is more sensitive to $\Delta\rho$ variations than the outflow. The model shows that this "asymmetry" is only compatible with submaximal exchange. The observed composite Froude number at the eastern section during CANIGO was clearly subcritical [1], which implies submaximal exchange [5] according to our reasoning.

The hydraulic theory says that if the exchange is submaximal, the conditions in the adjacent reservoirs are able to influence the exchange [5]. For instance, well-developed anticyclonic gyres in the Western Alboran Basin may favour the inflow and hamper the outflow by sinking the interface near the eastern entrance of the Strait (the opposite if the gyre reduces), thus linking the seasonal signals in the exchange with the hydrographic features in the Western Alboran Sea. This possibility is explored in [1] to put forward that the $(\Delta\rho)_a$ signal favours the presence of greater (smaller) and more (less) stable anticyclonic gyres during summer (winter), a fact easily observable in SST imagery. This seasonal pattern would induce a phase of the interface depth like that in Table 1.

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