Water mass variations in the Mediterranean Sea from GRACE mission, Revisited

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Abstract

The total water mass flux in the Mediterranean Sea (F) is produced via the vertical flux of Precipitation minus Evaporation (P-E), and the horizontal fluxes of river discharge (R), exchange with the Black Sea through the Bosphorus and Dardanelles Straits (B) and with the Atlantic Ocean through the Gibraltar Strait (G).

$$\frac{dW}{dt} = P - E + G + R - B$$

dW/dt: Total water mass flux in the Mediterranean Sea
P: Precipitation
E: Evaporation
G: Water flux through the Gibraltar Strait
R: River runoff
B: Water exchange with Black Sea

Positive (negative) values represent gain (lost) of water by the Mediterranean

Data and analysis description

A) Time-variable gravity: GRACE
ftp://podaac.jpl.nasa.gov/pub/grace/data/L2/csr/RL04/

- 78 monthly sets of Spherical Harmonics from RL04 CSR are used. Span time: 09/2002 - 03/2009 (June 2003 is linearly interpolated).
- GRACE + GAD = Ocean Bottom Pressure.
- Degree-1 coefficients: Swenson et al. [2008].
- J_2: Substituted by SLR estimates [Cheng and Ries, 2007].
- C_{20}, C_{30}, C_{40}, C_{21} and S_{21}: Secular trends restored.

Filters

- The correlated errors in even and odd degrees is filtered [Swenson and Wahr, 2006; with the parameters from Chambers, 2006].
- Chen et al.'s (2006) filter is applied.

Further processing

- Amplitude restoration: A corrector factor of 1/0.46 is applied to restore the loss of amplitude caused by the filters [Velicogna and Wahr, 2006; Swenson and Wahr, 2007].
- Continental leakage: It is reduced accordingly to Wahr et al. (1998) and Chambers (2006).

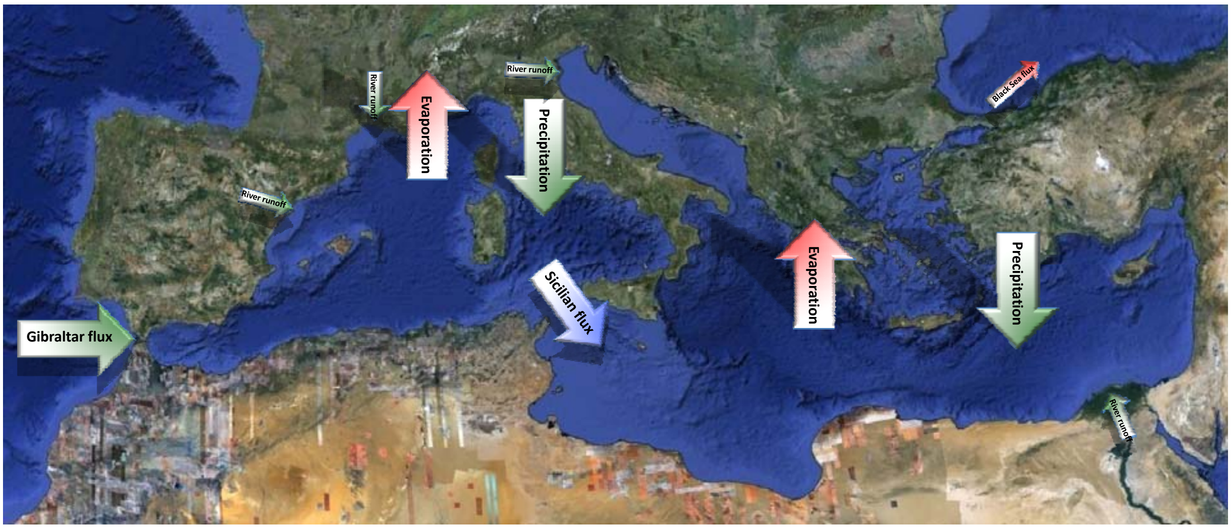
- GRACE OBP variations are transformed into water mass variations (W) subtracting the atmospheric pressure averaged over the global ocean[Willis et al., 2008]. Units are mm of equivalent water thickness (an increase of 1 kg/m^2 can be interpreted an increase of 1/1.029 mm of sea level, where 1029 kg/m^3 is the mean density of sea water).
- **dW/dt =** month-to-month derivative of W with units of mm/month

B) Precipitation minus Evaporation
Derived from the water vapor fluxes (Q) and the total water content of the atmosphere W [Oki et al, 1995]:

$$P - E = -\nabla_H Q - \frac{\partial W}{\partial t}$$

- Q and W are provided from the JRA-25 Reanalysis [Onogi et al, 2007].
- 1.125ºx1.125º regular 6-hours grids.
- Span time: 01/2002 - 12/2006.

C) River runoff
Climatology from Boukthir and Barnier (2000).

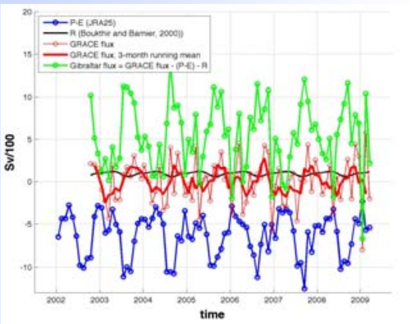


Gibraltar water mass flux

The water mass flux through the Gibraltar Strait is estimated as:

$$G = \frac{dW}{dt} - P + E - R$$

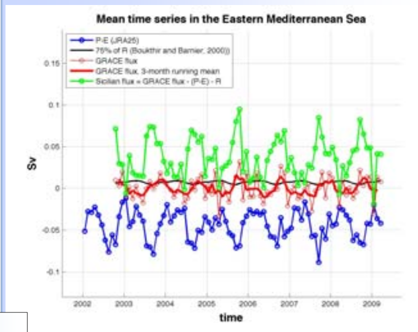
Due to the limited spatial resolution of GRACE, the Adriatic and the Aegean Seas are excluded from the computation of W. then, they are assumed to vary as the averaged Mediterranean. The exchange of water with the Black Sea is neglected.



Note:
1 Sv = 10^6 m^3 s^{-1}
1 Sv/100 = 10^4 m^3 s^{-1}

Sicilian water mass flux

The water mass flux through the Sicilian Strait is estimated following the same scheme than the Gibraltar flux, but estimating all the parameters at the East side of the Strait of Sicily.



Annual signals and mean values

Table 2. Annual amplitudes and phases (indicating the peak time in the year), and mean values for the period 2003-2008 of the estimated water fluxes. Positive values of both Gibraltar and Sicilian fluxes represent eastward fluxes. The annual amplitude and the mean are multiplied by 100 for clarity, then units are Sv/100.

	Annual Amplitude (Sv/100)	Annual Phase (°)	Annual peak around	Mean (Sv/100)
GRACE flux (F)	1.4±0.8	290±34	21st October	0
GRACE flux 3-month running mean	1.3±0.2	289±11	20th October	0
P-E	2.7±0.4	56±8	26th February	-6.3
Gibraltar flux: F-(P-E)	3.7±0.9	253±14	14th September	6.4
Gibraltar flux (G): F-(P-E)-R	3.9±0.8	253±13	14th September	5.5
Sicilian flux	2.3±0.5	267±12	28th September	3.7

Previous estimates of G

	Annual Amplitude (Sv/100)	Annual Phase (°)	Annual peak around
Fenoglio-Marc et al., 2006	5.4±1.4	269°±13°	30th September
García et al., 2006	1.6±1.4	215°±62°	6th August
García-Lafuente et al., 2002	7.7±4.4	234°±33°	25th August
García-Lafuente et al., 2004	3.2±2.0	244°±35°	4th September

Discussion

The water mass budget of the Mediterranean Sea varies annually. The reason is that evaporation exceeds precipitation throughout the year, and the deficit is balanced by water influx from the Atlantic through the Gibraltar Strait. However, this balance is not produced instantaneously, giving rise to the seasonal variations in the water mass budget. The latter has been estimated from GRACE data and the net evaporation from models and observations, via which the water flux through the Gibraltar Strait has been inferred. This flux shows an annual signal of 3.9±0.8 Sv/100 of amplitude and 253º±13º of phase (peak in early September), and a mean value of 5.5 Sv/100. Note that the reported errors are formal errors accordingly to the least square fitting procedure. However, real errors should be bigger due to errors in GRACE data, the atmospheric model, the use of a climatology for the river discharge, the exclusion of the Aegean and Adriatic seas, and neglecting of the water exchange between the Mediterranean and the Black Sea. In any case, the obtained Gibraltar flux signal is between previous reported estimations.

Similar to the estimate of the Gibraltar flux, the net water mass flux through the Strait of Sicily has also been estimated, showing, with respect to the Gibraltar flux, an annual amplitude 40% smaller, a delay around 14 days in the annual signal, and 2/3 of the mean flux. The estimate of both fluxes may be important to constrain local ocean models in Mediterranean sub-basins.

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