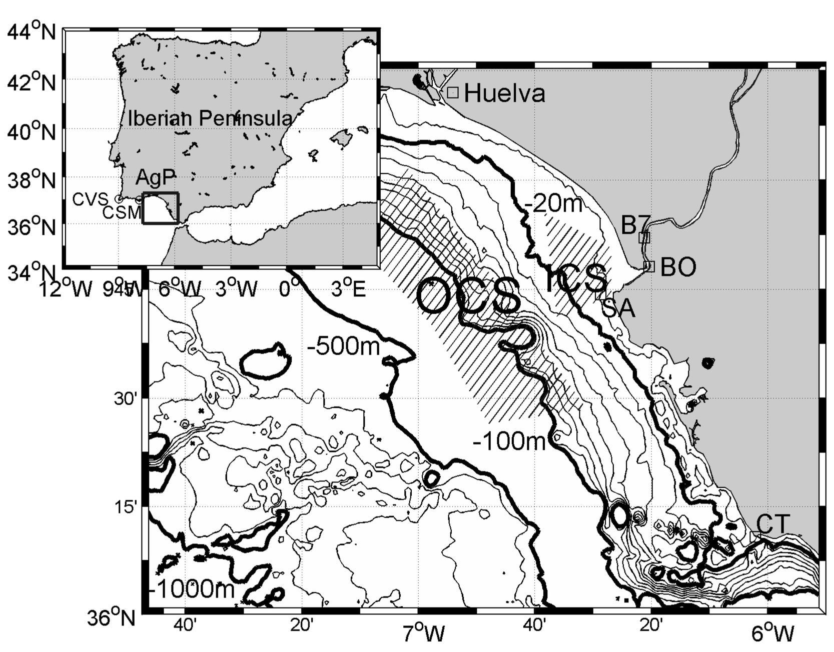
Heat fluxes between the Guadalquivir river and the Gulf of Cádiz Continental Shelf

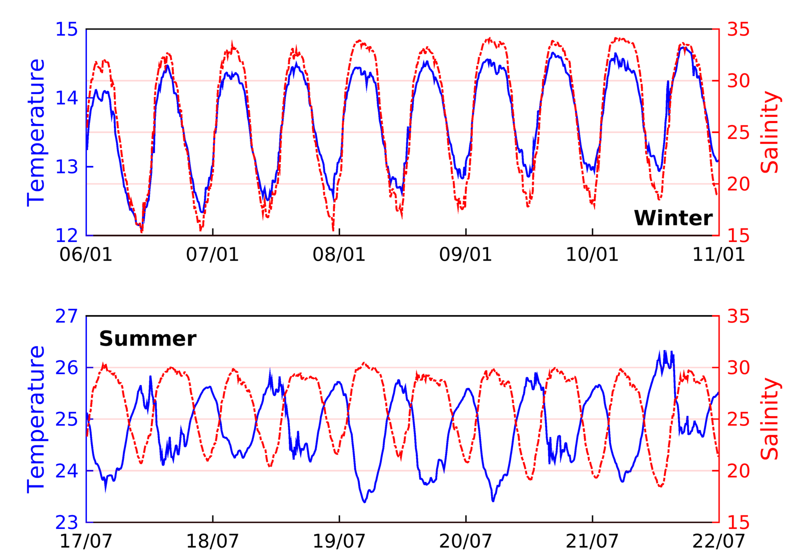
J. Delgado*[1], J. Moreno-Navas*[1], A. Pulido*[2], J. García-Lafuente*[1],
M. C. Calero Quesada*[1], R. García*[2]
*1 Málaga University, Spain, *[2] Autoridad Portuaria de Sevilla, Spain (jdcabello@uma.es)

Introduction

The Guadalquivir estuary is located on the SW coast of the Iberian Peninsula (see Figure 1) and is one of the Spain's most important estuaries. Connected with the Gulf of Cádiz by one mouth (SanLúcar de Barrameda), the estuary extends 110 km upstream to the Alcalá del Río's dam, which drains a basin of 63,822 km^2 and control 80% of the freshwater discharged to the estuary. Head dam's regulation keeps 40 m^3/s of mean discharge 75% of time (minimum ecological flow) but this value could rise above 400 m^3/s (high river-flow regime) during short periods of time (Díez-Minguito, et al. 2012).

The circulation in the adjacent sea, Gulf of Cadiz, is predominantly anticyclonic in spring-summer with mesoscale meanders (García-Lafuente et al., 2006), that show clear signatures on Sea Surface Temperature (SST) images (Vargas, et al. 2002). The flow along the continental slope of the Iberian Peninsula bounds the anticyclonic circulation at its northern edge (Delgado et al., 2012), and bound a shallow quasi-permanent mesoscale cyclonic cell between Cape Santa María and the Guadalquivir river mouth. The cell is strongly dependent on wind regime (García-Lafuente et al., 2006).



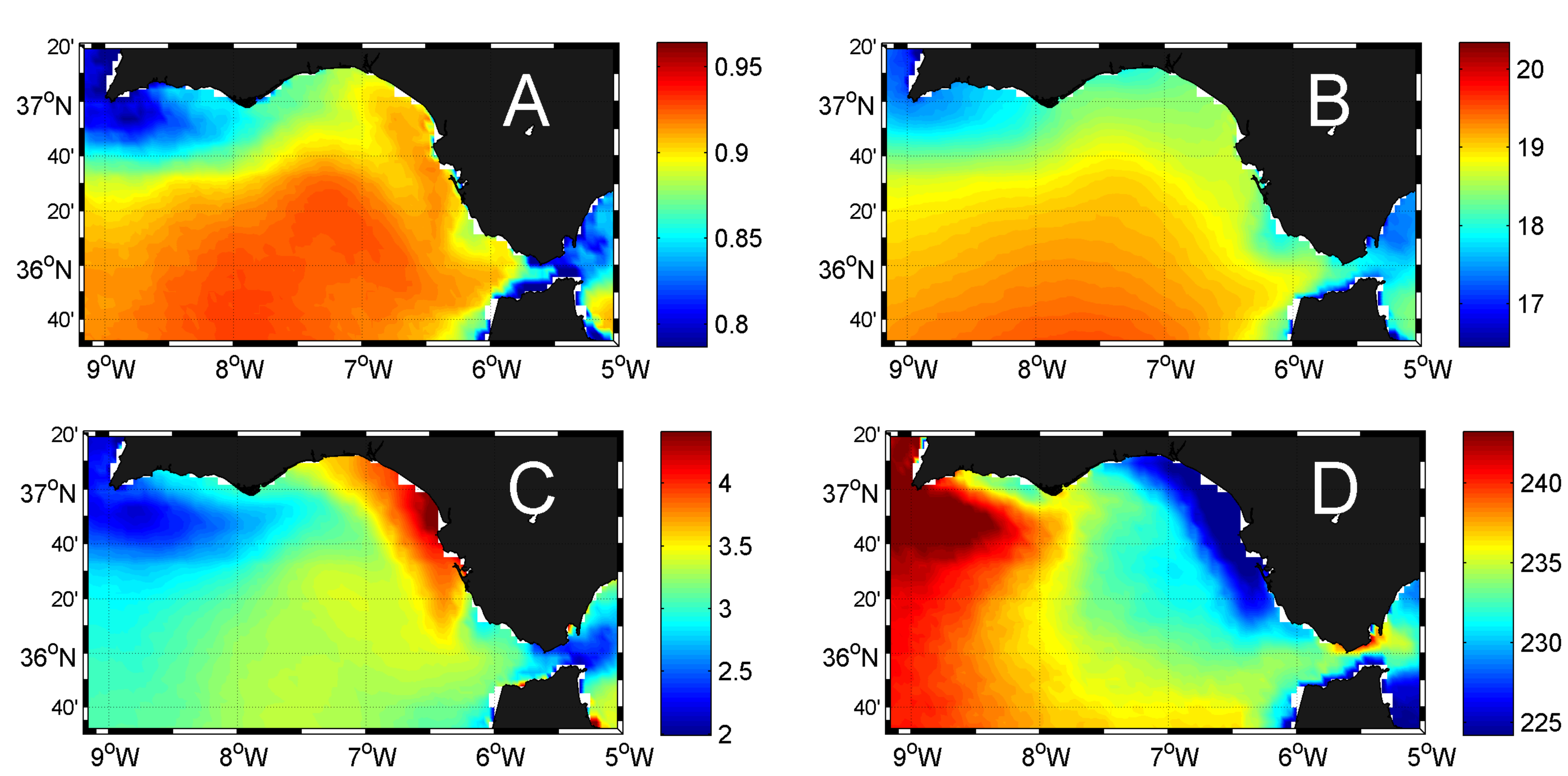


Left figure: Map shows the geographical position of the Guadalquivir estuary, in the Gulf of Cadiz area. ICS and OCS are the areas of the shelf closest to the Guadalquivir estuary and between this area and the center of the Gulf of Cadiz respectively; BO and B7 gives location of local buoy observation; SA, location of raw meteorological data.
Right figure: Time series of temperature (solid line, left axis) and salinity (dashed line, right axis) measured at Bonanza for two different periods of the year 2008 (upper panel winter, bottom panel summer) when the temperature signal is dominated by M_2.

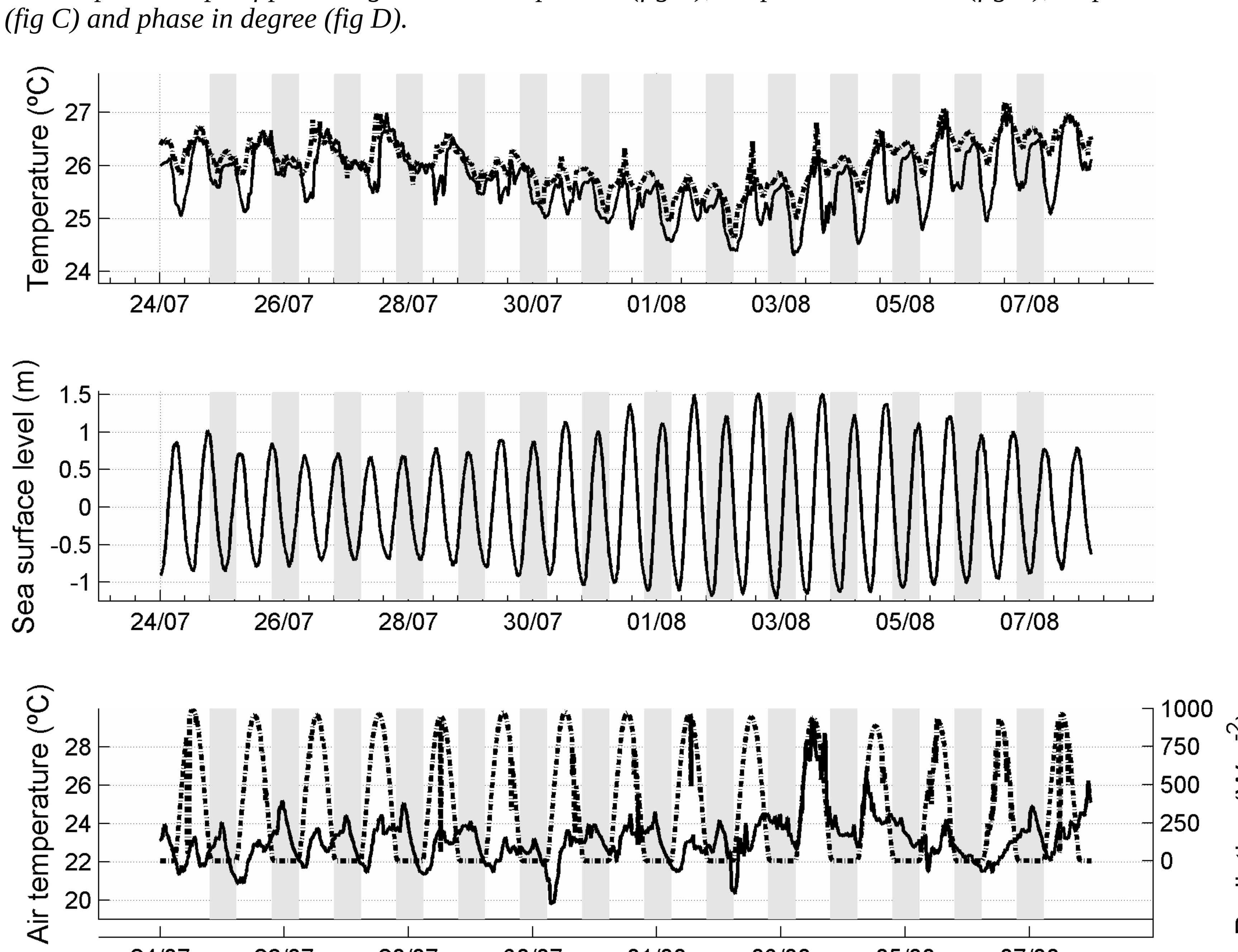
Data set

18-years time series of daily sea surface temperature of Gulf of Cadiz and a 18-months time series of temperature were collected in the vicinity of the Guadalquivir estuary mouth to investigate the heat exchange between the estuary and the adjacent continental shelf. The first time series identified a continental shelf area where the seasonal thermal oscillation signal (amplitudes and phase) changed abruptly. A second data set allowed a fully description of the thermal fluctuations in a wide range of frequencies and an estimation of the upstream heat budget of the Guadalquivir estuary.

The final data sets have been completed with tidal gauge observations at several positions, meteorological data and water discharges from Alcala's dam.



18 years of SST data over each pixel is fitted to a sinusoidal function with amplitude, phase and a mean value. Spatial maps of percentage variance explained (fig A), temporal mean in ºC (fig B), amplitude in ºC (fig C) and phase in degree (fig D).



Top figure shows the temperature observed in BO (solid line) and B7 (dashed line) between July 24 and August 8 of 2008. Both, water and air temperature have been smoothed with a filter period of 6 hours cut-off to remove high frequency fluctuations. Night time is indicated by light gray rectangles. Middle figure shows the sea level referenced to its mean value in BO. Bottom figure the solar radiation measured at the meteorological station of Salmedina (solid line, left axis) and air temperature (dashed line, right axis).

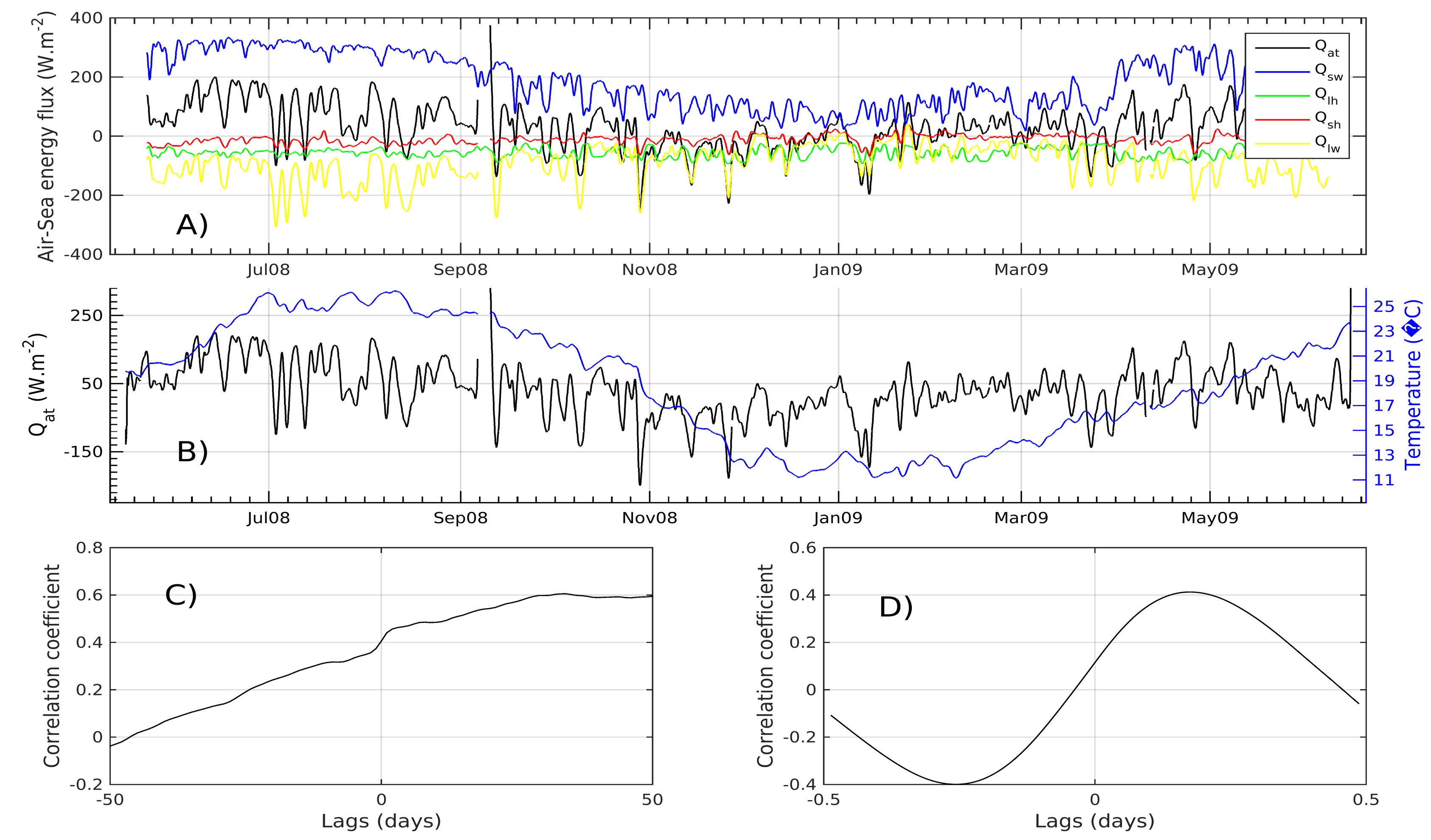
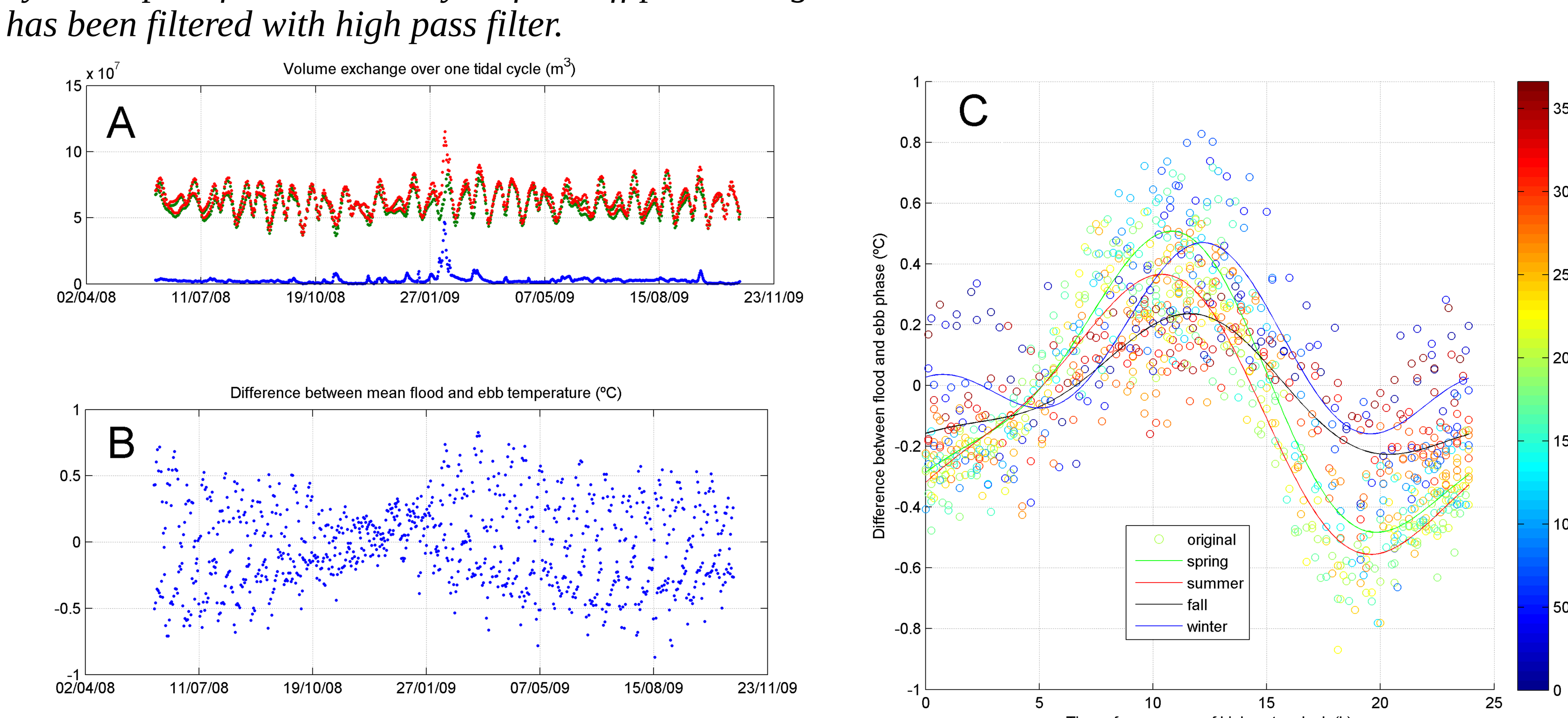
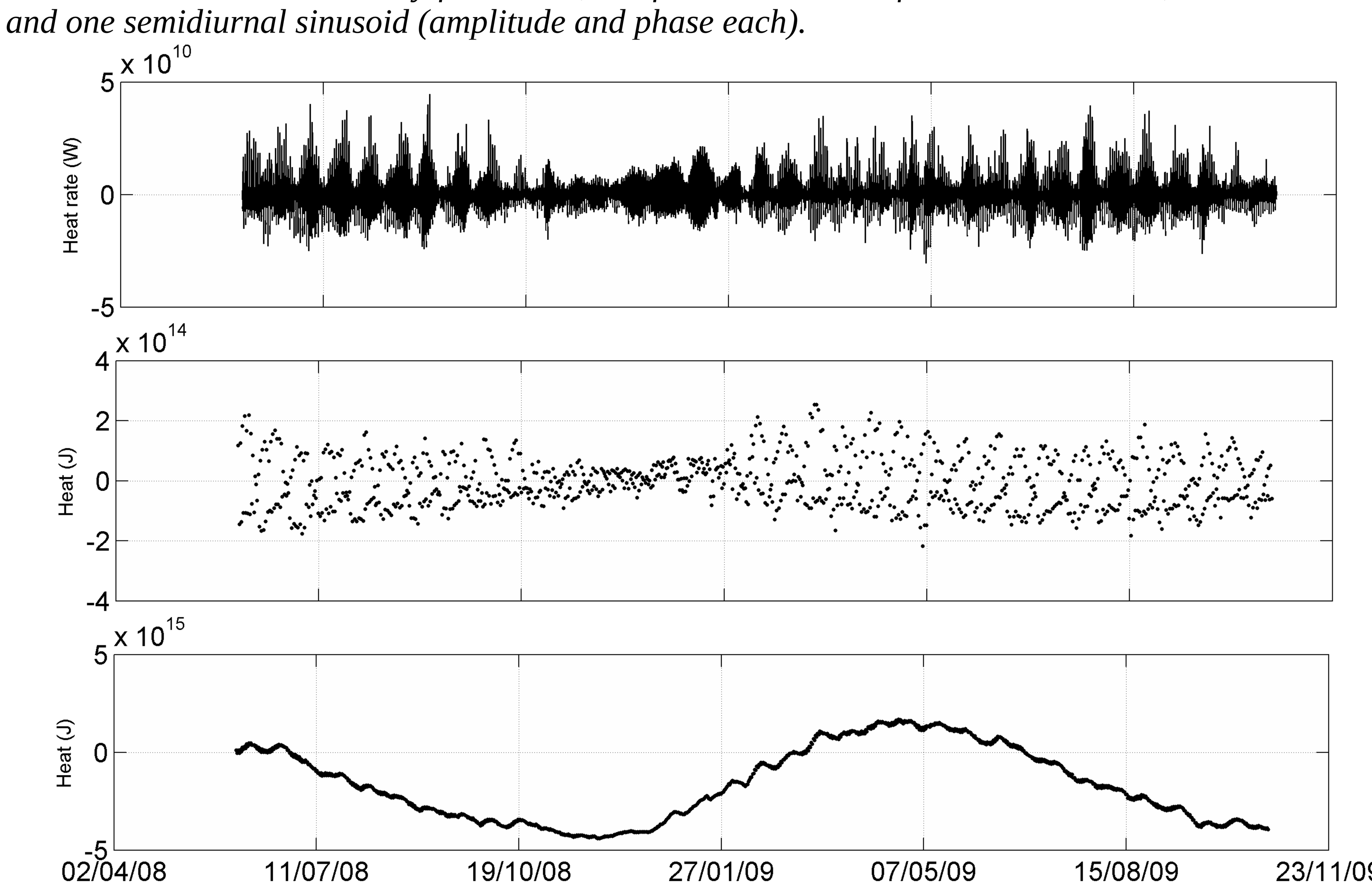


Figure A: Calculated atmospheric heat fluxes at Salmedina weather station. Figure B: Air-sea exchange (solid line, a net heating/cooling of the estuarine water mass are indicated with positive/negative values) and temperature (dash-dot line). Figure C: cross-correlation between air-sea exchange and temperature time series for those time lags specified in the x-axis. In both time series, high frequency has been removed by a low pass filter with 1 day^{-1} of cut-off period. Figure D: the same cross-correlation but the time series has been filtered with high pass filter.



(A) Time series of volume of water flushed out at Bonanza during ebb (upper dash-dot line) with correction (red) or without correction (green) and during ebb-flood (lower blue solid line), basically is the total river discharge. (B) Time series of weighted (by velocities) mean temperature differences between flood and ebb water masses. (C) The same as (B) but x-axis label as hour of occurrence of high water slack. The lines are seasonally fitted data; the functions used to fit it used the mean, one diurnal sinusoid and one semidiurnal sinusoid (amplitude and phase each).



Top figure shows the instantaneous heat exchanged by pure advection, Q_a. Middle figure the integration of Q_a over each flood-ebb and the lower figure integrate Q_a from the first day.

Results

There is no trace at the estuary's mouth of daily heat exchanges between intertidal mudflats. So, the mudflat horizontal exchanges play a secondary role in the heat exchange with the continental shelf platform. The results also showed the fluctuations of estimated air-sea fluxes forced several variations of temperature in a quite homogeneous estuarine, with a delay of 20 days. The along-channel thermal energy gradient reached magnitudes of 300-400 Jm^{-4} near the mouth during the summer and winter and also drives the estuary-shelf exchange of thermal energy at seasonal scale. The thermal heat imported by the estuary from the shelf area during late fall-winter-early spring of 2008/2009 was balanced by the thermal heat that the estuary exports to the continental shelf during late spring-summer of 2008.

In summary, insolation over estuarine or ICS water is similar. The sensible, latent and long-wave heat fluxes did not differ too much neither. However, the depth, colour (due to high turbidity levels) and the dynamics changed from side to side and provided different energy storages, absorptions and redistribution in the water column respectively and it was observed up to seasonal scale. Guadalquivir river removes/imports excess of thermal energy towards/from the continental shelf seasonally as a mechanism to accommodate excess of heat from one side respect to the other side. Close to BO, but in the continental shelf side, the brackish water that comes from the estuary, refill (if buoyancy allow it) the first meters of the water column. This water mass moves mainly parallel to the coastal shore and are highly influenced by winds. Therefore, the zero balance of 2008-2009 period could shift greatly from year to year.

References

Delgado, J., García-Lafuente, J., & Naranjo, C. (2012). Two decades of mesoscale phenomena on either side of the Strait of Gibraltar. *Scientia Marina*, *76*(S1), 95–102. http://doi.org/10.3989/scimar.03609.18E

Díez-Minguito, M., Baquerizo, a., Ortega-Sánchez, M., Navarro, G., & Losada, M. a. (2012). Tide transformation in the Guadalquivir estuary (SW Spain) and process-based zonation. *Journal of Geophysical Research: Oceans*, *117*(3), 1–14. http://doi.org/10.1029/2011JC007344

García-Lafuente, J., Delgado, J., Criado-Aldeanueva, F., Bruno, M., del Río, J., & Miguel Vargas, J. (2006). Water mass circulation on the continental shelf of the Gulf of Cádiz. *Deep-Sea Research Part II: Topical Studies in Oceanography*, *53*(11-13), 1182–1197. http://doi.org/10.1016/j.dsr2.2006.04.011

Vargas, J. M., Garca-Lafuente, J., Delgado, J., & Criado, F. (2002). Seasonal and wind-induced variability of Sea Surface Temperature patterns in the Gulf of Cadiz. *Journal of Marine Systems*, *38*(3), 205–219.