Sensitivity of modelled CO_2 air-sea flux in a coastal environment: impact of surface gradients, surfactants and data assimilation

PML | Plymouth Marine Laboratory

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Introduction

This work evaluates the sensitivity of CO2 air-sea gas exchange in a coastal site to four different model system configurations of the 1D coupled hydrodynamic-ecosystem model GOTM-ERSEM, towards identifying critical dynamics of relevance when specifically addressing quantification of air-sea CO_2 exchange. The European Sea Regional Ecosystem Model (ERSEM) is a biomass and functional group based biogeochemical model that includes a comprehensive carbonate system and explicitly simulates the production of dissolved organic carbon, dissolved inorganic carbon and organic matter.

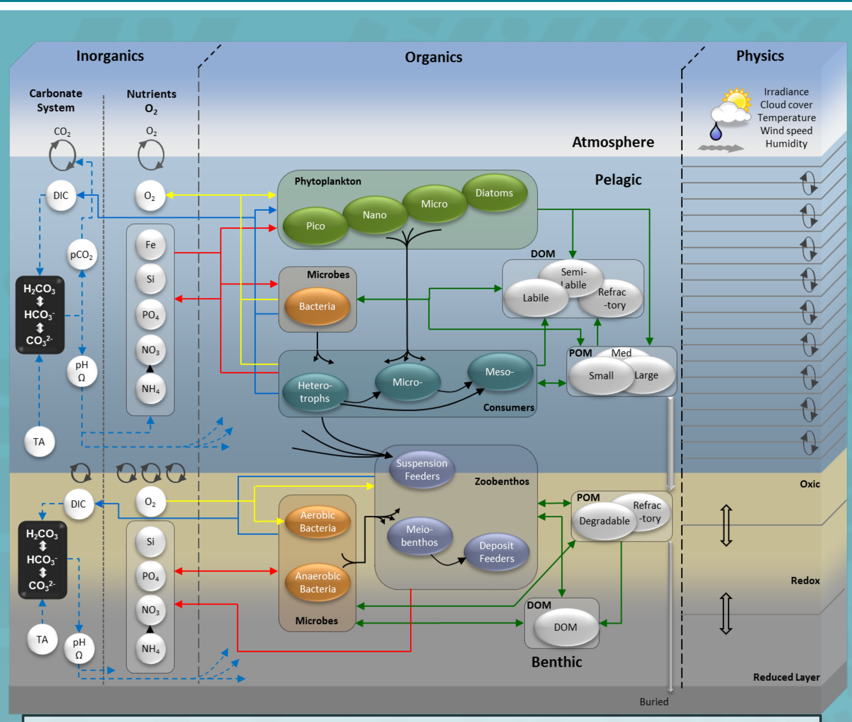


Figure 1. ERSEM schematic depicting the main nutrient and carbon mass fluxes and transformation pathways. The key characteristics are fully de-coupled nutrient to carbon and chlorophyll ratios and a comprehensive carbonate system. We have used the standard ERSEM setup in all 4 simulations considered here which consist of four phytoplankton and three zooplankton functional groups and a explicit bacteria loop. Full details can be found in Butenschön et al 2016.

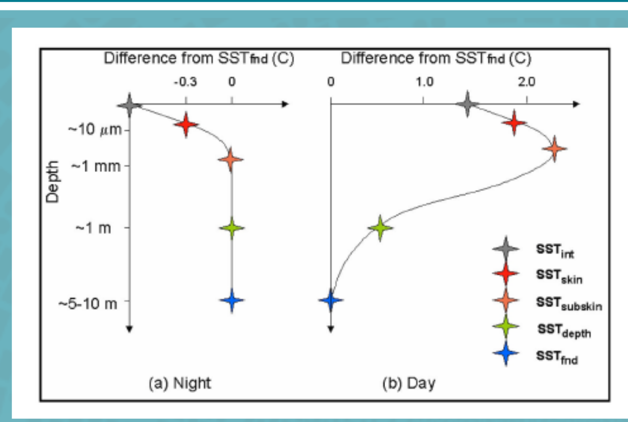


Figure 2 Idealised daily variation in SST from Donlon and the GHRSST-PP Science Team (2005). To achieve this GOTM vertical resolution was set to 2cm near the surface and increased logarithmically to 1m at 10m depth. No other differences with respect to the reference simulation were implemented.

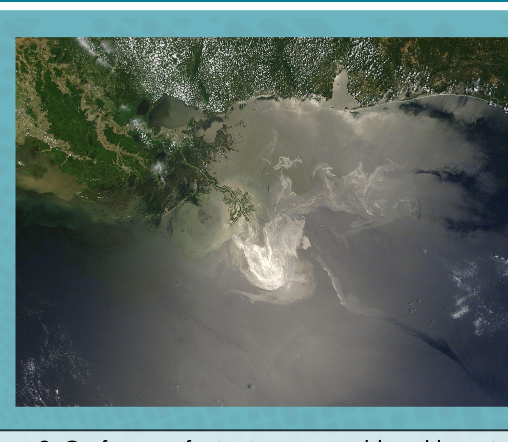


Figure 3. Surface surfactants are considered here to affect the transfer velocity of CO_2. We scale K_{CO2} with modelled gross primary production. K_{CO2} was reduced to a maximum of 70% of its wind dependent value (following Nightingale et al 2000) when gross productivity surpasses the 30% highest values in years 2008-2009.

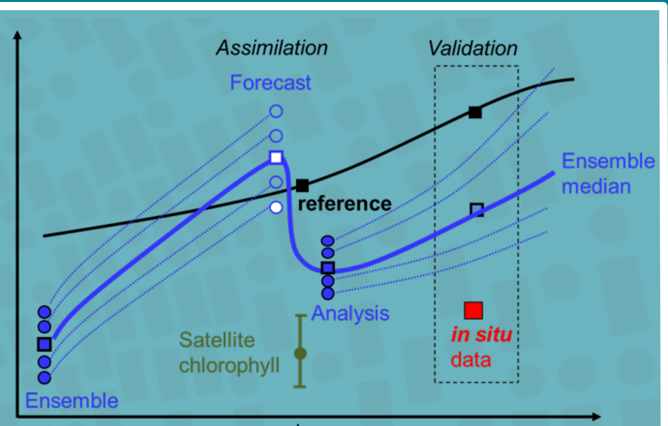


Figure 4 Surface chl-a assimilation is performed with the Ensemble Kalman Filter as described in Torres et al 2006. The variables in the analysis are log transformed by Gaussian anamorphosis as suggested in Ciavatta et al 2011. We run 100 ensembles with model errors included in the vertical mixing scheme and light attenuation.

We performed three experiments in addition to the a reference simulation. These include the resolution of the diurnal SST cycle (Fig 2), the presence of biological surfactants (Fig 3, https://commons.wikimedia.org/wiki/File:Deepwater_Horizon_oil_spill_-_May_24,_2010.jpg) and the assimilation of remotely sensed surface chlorophyll-a (Fig 4). Common setup included 6 hourly NCEP atmospheric data combined with oberved shortwave radtion; 15 tidal harmonics and relaxation to weekly temperature and salinity profiles.

Reference simulation

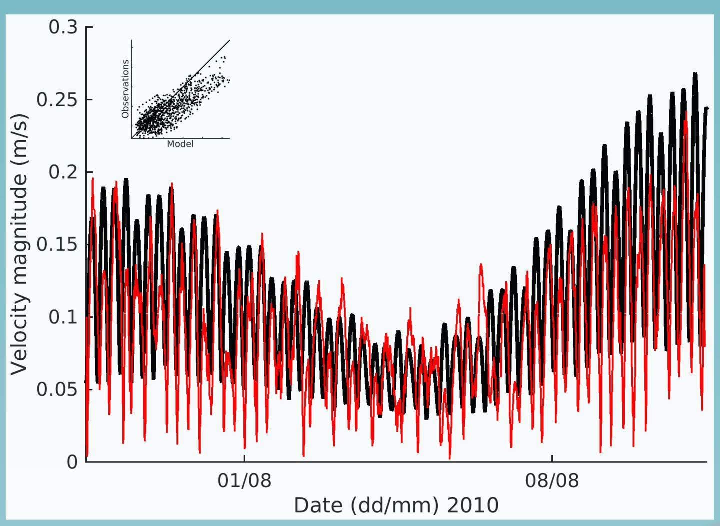


Figure 5. Comparison of bottom velocity magnitude averaged between 1 and 2 metres above the sea bed. Model results in black and data from the bottom mounted ADCP in red.

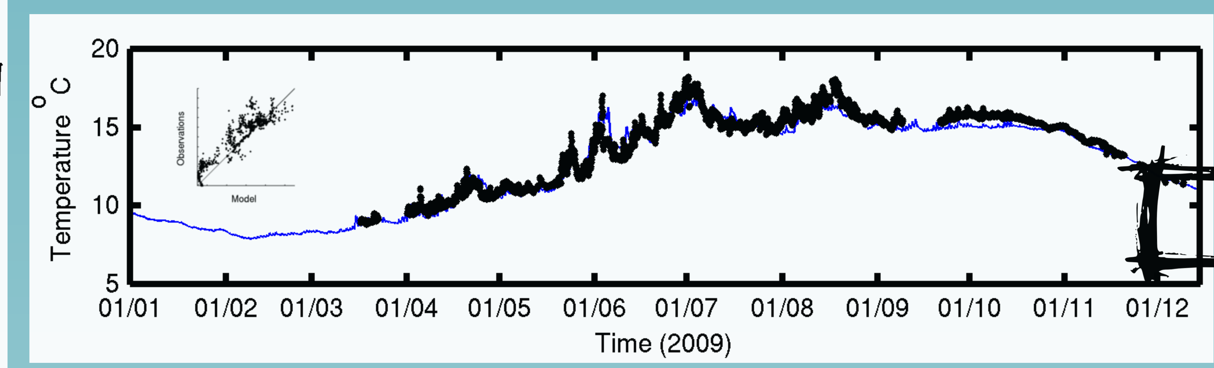


Figure 6. Six hourly evolution of SST as simulated with GOTM (blue solid line) and observed from the L4 buoy (dots). The one to one plot with all data is included in the left top corner. The axes have the same range as the main graph.

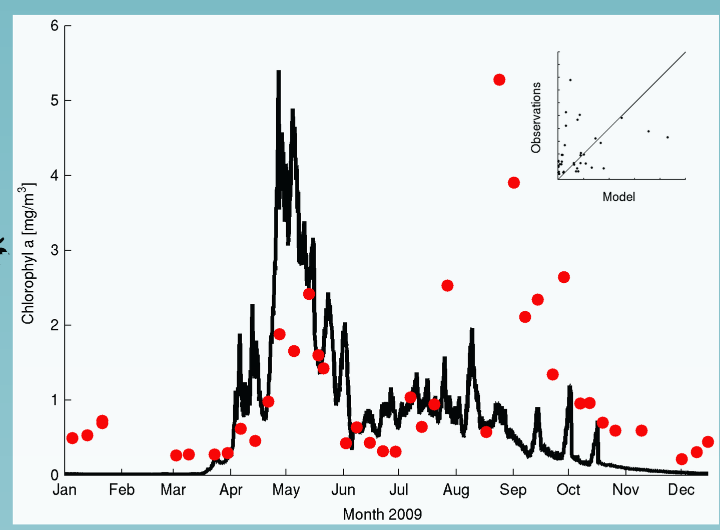


Figure 7. Evolution of total chl-a in 2009. The observations (red dots) were derived from HPLC analyses. Thumbnail graph illustrates the one to once correspondence.

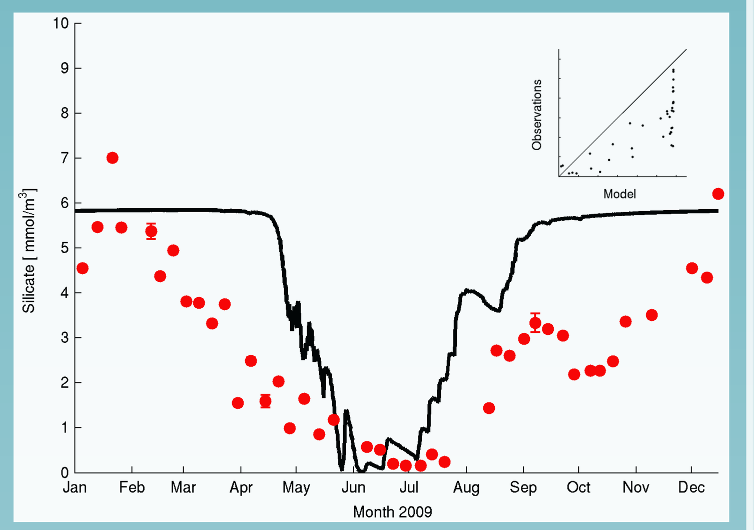


Figure 8. Evolution at the surface of dissolved silicate concentration during 2009. The observations (red dots) have error bars from triplicate analyses.

The model reproduces well the dominant tidal dynamics (Fig. 5, Pearson correlation (*p.c.*) of 0.8) surface temperature evolution (Fig 6, Pearson correlation > 0.9) and vertical column structure.

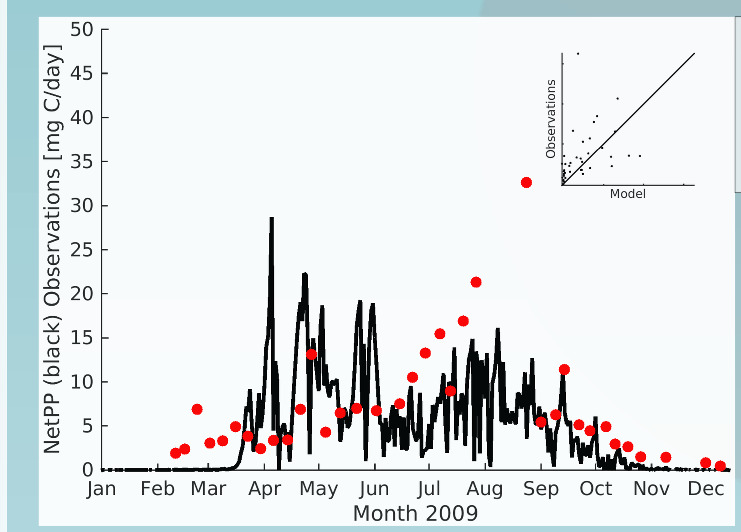


Figure 9. Evolution at 10m of total phytoplankton net production. Observations (red dots) were obtained from photosyntehsis-irradiance parameters based on 2-3 hour incubations.

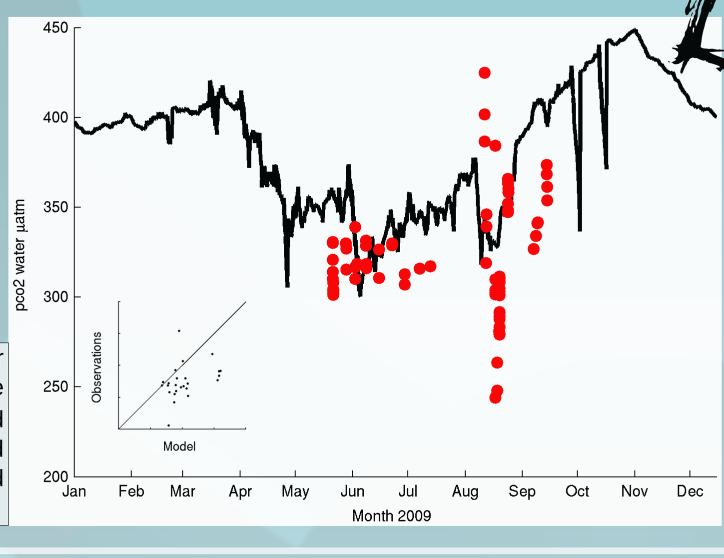


Figure 10. Evolution at 2m of in water CO_2 partial pressure. The observations (red dots) were obtained by tritation (for total alkalinity) and coulometric analysis for dissolved inorganic carbon.

Total chl-a (Fig 7, *p.c.* of 0.45) and nutrients (Fig 8, *p.c.* of 0.8 for silicate and phosphate, 0.9 for nitrate) display the seasonality observed in the data. The main differences correspond to low winter growth resulting in overestimation of nutrient concentrations and understimation of net primary productivity (Fig 9, *p.c.* of 0.4). The evolution of observed variables related to the carbonate system (pH and CO2 partial pressure, *p.c.* of 0.4) follow the available data (Fig 10) although the model underestimates the large daily fluctuations seen in the data. Behaviour (e.g. increased pCO2 in winter and autumn) and low pCO2 during summer and spring as well as the observed seasonal ranges are well captured by the 1D model.

Model experiments

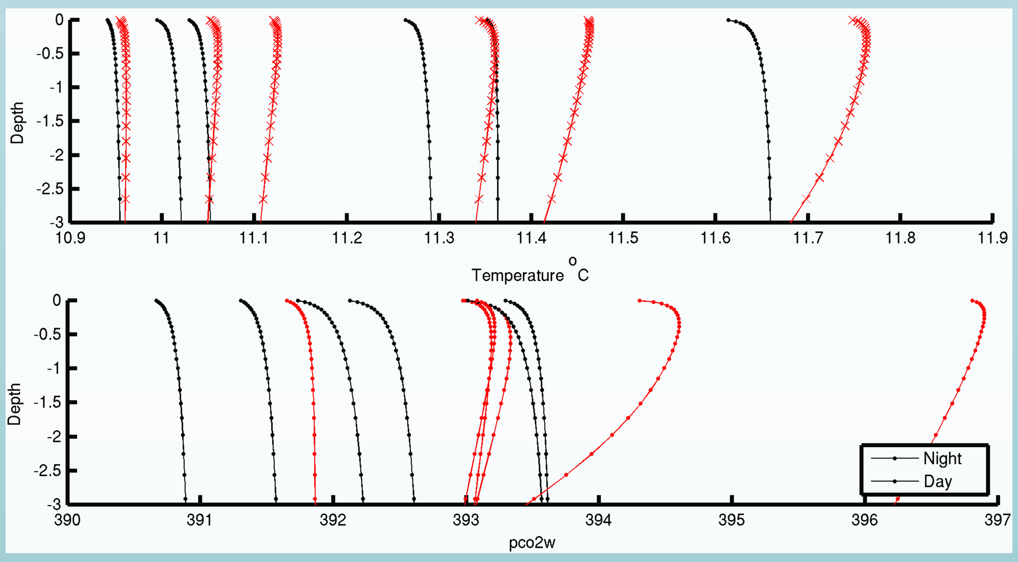


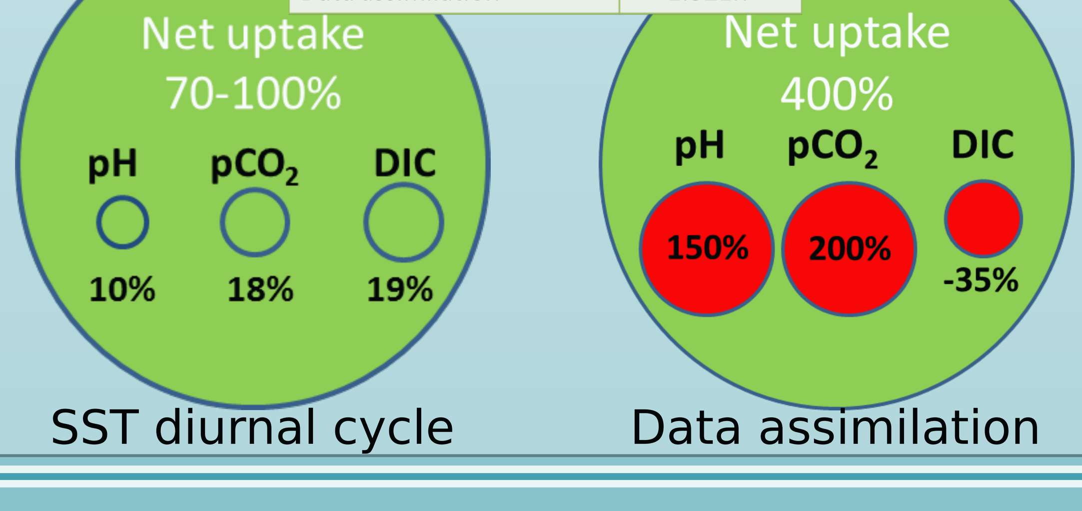
Figure 11. Examples of near surface profiles of temperature (top) and pCO_2 (bottom) during two days in May 2009. Wind speed averaged 9m/s. Black lines are night time profiles (03 and 21 hours) while red lines correspond to day time profiles (09 and 15 hours).

The increased vertical resolution was enough to develop negative near surface gradients in the top 20cm (in temperature and in pCO2 Fig 11). The largest impacts were recorded in the air-sea gas exchange. Other variables were also affected but the changes concentrated in the top 3m. All carbonate system variables improved with respect to the reference (10-20%).

The effect of PP mediated surfactants was found to have no impact on the carbonate system variables.

The yearly net CO2 uptake (molCm^{-2} year^{-1}) in 2009 and % changes in the correlations of the carbonate system variables for the 4 model simulations illustrates the potential impact of modelling approaches and setup in coastal regions.

Reference simulation	-0.3
SST diurnal cycle	-0.6
Surfactants	-0.3
Data assimilation	1.3±1.7



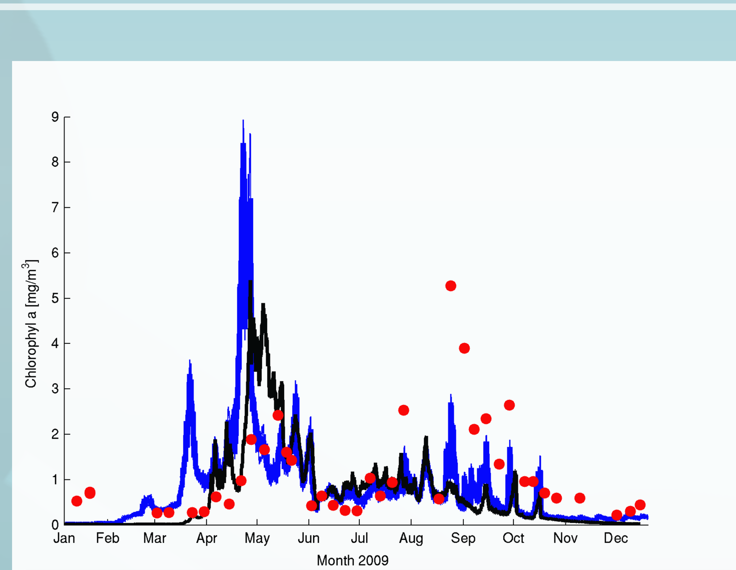


Figure 12. Model 10m chl-a for the assimilation experiment (blue line) and the reference simulation (black) with in-situ surface chl-a observations (red dots).

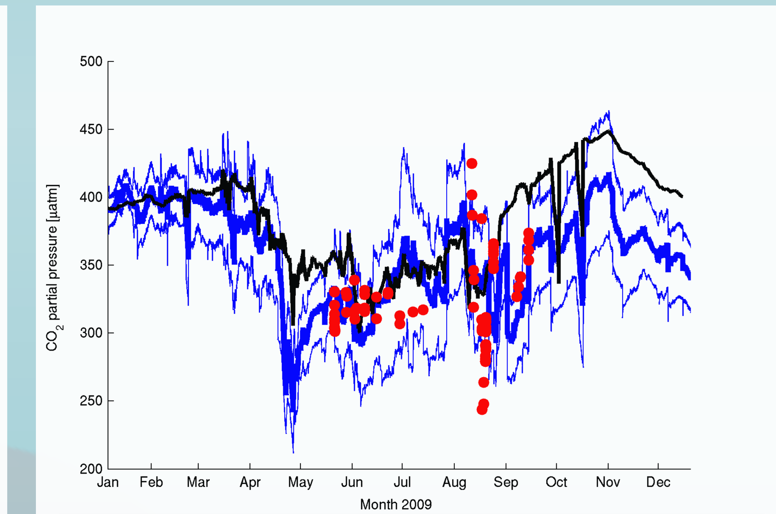


Figure 13. Model mixed layer pCO_2 for the assimilation experiment (blue, thick is ensemble mean, thin are one standard deviation), reference (black) and observations (red dots).

The assimilation of remotely sensed chl-a (Fig 12) had a significant impact in the carbonate system (Fig 13) but mostly by reducing the bias in DIC, pH or pCO_2 The correlations deteriorated for all three variables (from *p.c.* of 0.5, 0.4 and 0.4 to 0.3, -0.2 and -0.2) but the concentration of the observations around the May to September months precludes a definitive assessment of the effect of surface chl-a assimilation on simulating the seasonality of the carbonate system. Chl-a assimilation also corrected the simulation of chl-a (5%) and the nutrients silicate and phosphate (10%).

Conclusions

The 1D GOTM-ERSEM model has skill in simulating both the pelagic ecosystem and the variables related to the dynamics of CO_2 at the coastal station L4. Resolving the near-surface temperature gradients induced by the diurnal heating has the most efficient (lowest computational cost and skill requirements) impact at short, seasonal and annual time scales and results in improvements across the evaluated variables that are comparable to the results from the assimilation of chl-a experiment. The correlation of carbonate system variables (DIC, pCO_2 and pH) improve by up to 19% while annually integrated values of CO_2 exchange with the atmosphere changed by up to 100% with respect to the reference simulation, increasing the net source nature of L4. At the L4 site, the introduction of a dependence of the CO_2 gas transfer velocity on gross production has a non-significant impact on the dynamics of CO_2 .The assimilation of surface chl-a has a mixed effect on the skill of the model. As expected the simulation of chl-a improves and while the correlation for nutrients do not significantly change, their bias decreases. The effect on the carbonate system variables is similar; the bias decreases for DIC and pH but so do the correlations. The largest impact of assimilation is on the net air-sea gas exchange where the results indicate the potential for L4 to be a weak net source of carbon to the Atmosphere (1.3± 1.7 molCm^{-2} year^{-1}). The results of the three sensitivity experiments indicate that resolving the temperature profile near to the surface appears the most important aspect of those investigated here for a skilled simulation of the biogeochemistry at L4.

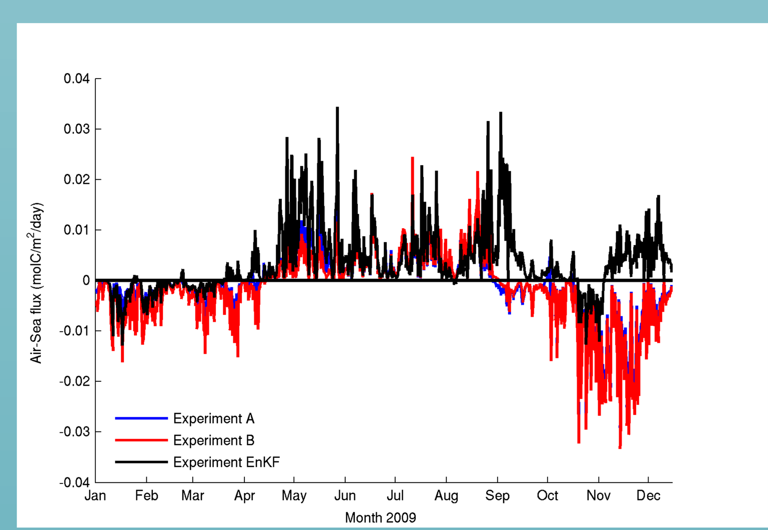


Figure 14. Modelled evolution of the air-sea flux of CO2 for the reference simulation (blue), SST diurnal cycle (red) and data assimilation (black) experiments.

References and further information

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Acknowledgements

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