2007 ROMS/TOMS Users Workshop
University of California, Los Angeles - October 1-3, 2007

Biological productivity in Eastern Boundary Current systems: the Canary vs the California Current system

Z. Lachkar (1), N. Gruber (1), G. -K. Plattner (1), H. Frenzel (2), and M. Muennich (1)

(1) Environmental Physics, Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich, Zurich, Switzerland
(2) Institute of Geophysics and Planetary Physics, UCLA, Los Angeles CA, USA

1- Introduction

Eastern Boundary Currents systems (EBCs) are major oceanographic features that are well known for their high productivity and for playing an important role in the marine carbon cycle. Yet, the quantitative understanding of the mechanisms driving biological production in these systems is limited. Through a comparative study of the Canary Current System (CanCS) and the California Current System (CalCS), we investigate major environmental factors and leading physical processes that control the biological production in EBCs.

2- Methods

We used satellite derived observations of: (1) daily wind speed and direction from QuikSCAT on a 25 km grid from 1999-2004, (2) 8-day averaged chlorophyll-a concentration from SeaWiFS on a 9 km grid from 1997-2004, (3) 8-day averaged photosynthetically available radiation (PAR) also from SeaWiFS, (4) sea-surface temperature (SST) from AVHRR on a 9 km grid from 1985-2003, (5) eddy-kinetic energy (EKE) on a Mercator 1/3°grid from 1995-2003 calculated using the sea level anomaly (SLA) data obtained from merged AVISO maps. Additionally, we used a 1°x1° climatology of nitrate from the World Ocean Atlas 2001 (WOA01) data set.

The net primary production (NPP) was computed from chlorophyll-a, SST, and PAR using the Vertically Generalized Production Model (VGPM). The Ekman-driven upwelling along the coasts is characterized using the *upwelling index* defined as:

$$UWI = \frac{\tau_{ash}}{\rho \cdot f} \times 100$$

where ρ= 1025 kg/m^3 is the water density, f is the Coriolis parameter, and τ_{ash} is the alongshore wind stress calculated from the QuikSCAT wind. To characterize the Ekman induced nutrient supply in coastal areas, a vertical upwelling driven flux of nitrate was calculated as:

$$WflxNt = UWI \times \frac{\Delta Nt}{\Delta z}$$

where UWI is the upwelling index and $\frac{\Delta Nt}{\Delta z}$ is the vertical gradient of nitrate evaluated between the layer 0-75m and 75-150m.

Data were analysed for CalCS and CanCS, extending from the coastline to 500 km offshore and from 24°N to 48°N for the California CS, and from 12°N to 34°N for the Canary CS. For EKE the values in the nearshore 150 km were not included, as their errors are substantially larger. Data were then averaged over 2°bins in meridional direction and over the 500 km coastal strip.

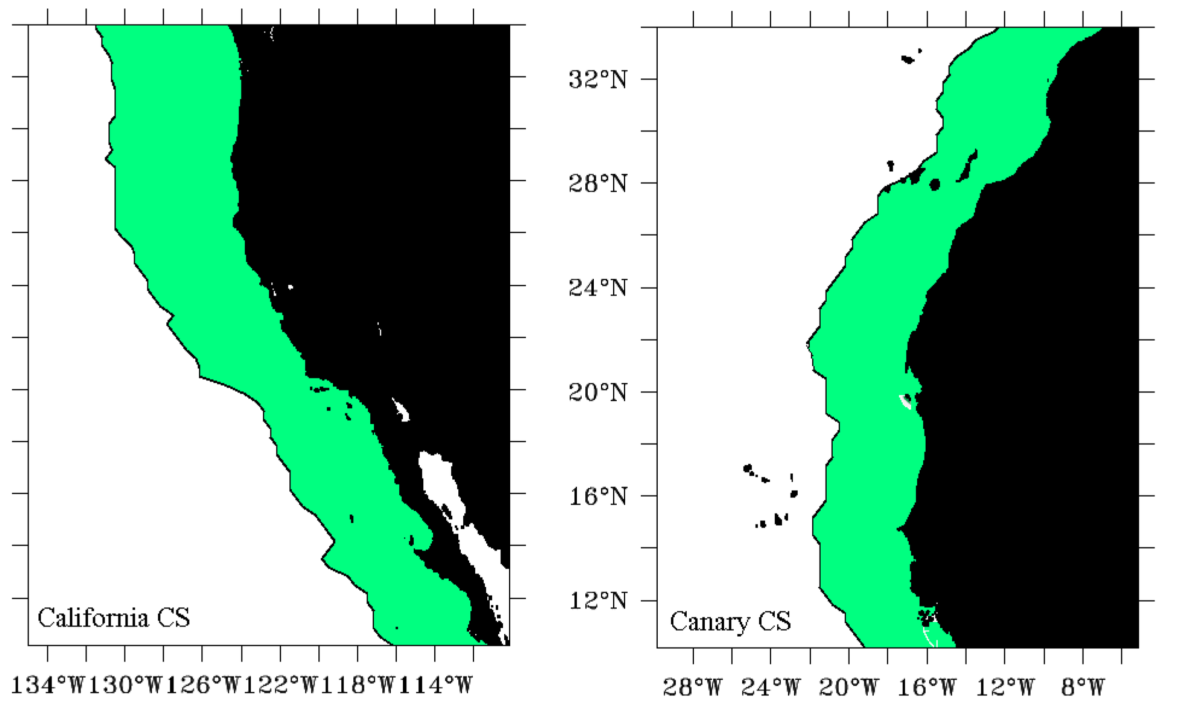

Fig 1. The 500 km coastal strips used for the data analysis from the California CS on the left and the Canary CS on the right.

3- Data-based comparative study CalCS vs CanCS

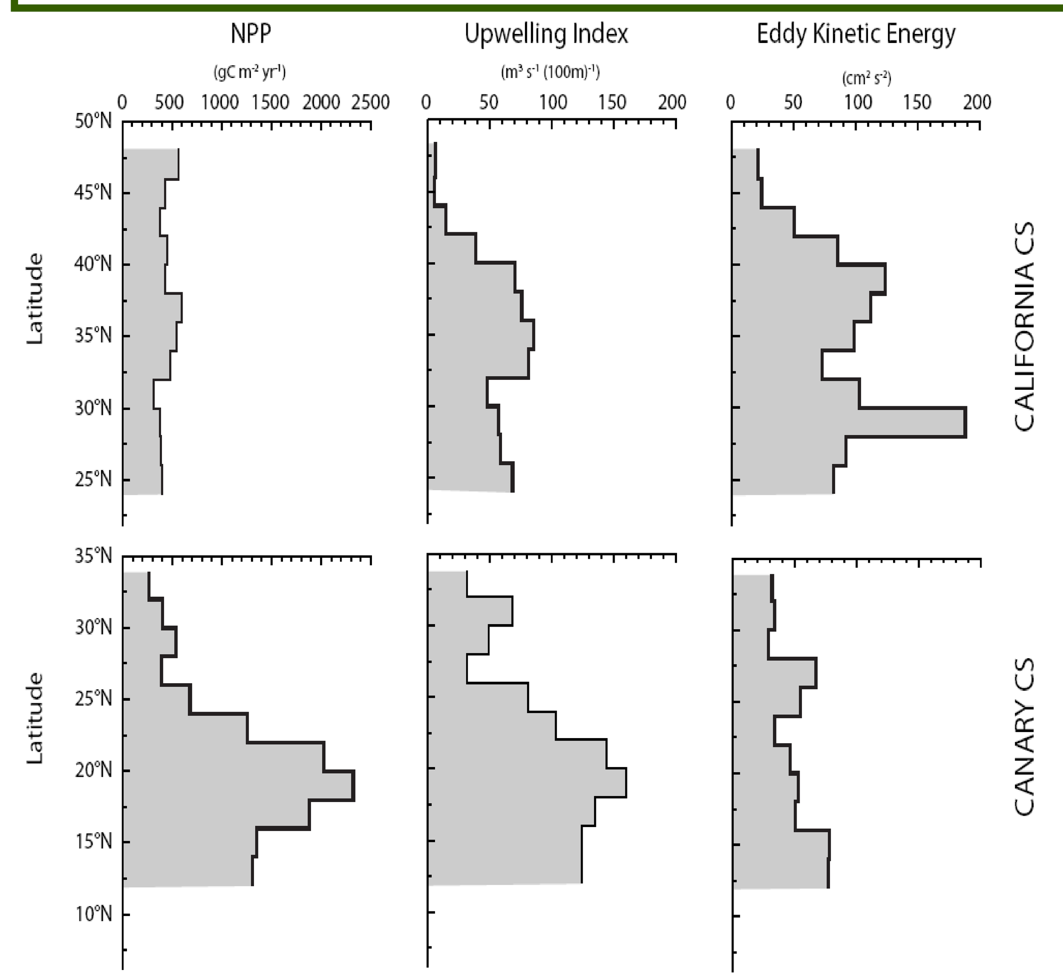

Fig 2. Plots of NPP (left column), upwelling index (center column), and EKE (right column), versus latitude for the California (top) and the Canary (bottom) CS. Shown are the 2° binned and shore to 500 km averages.

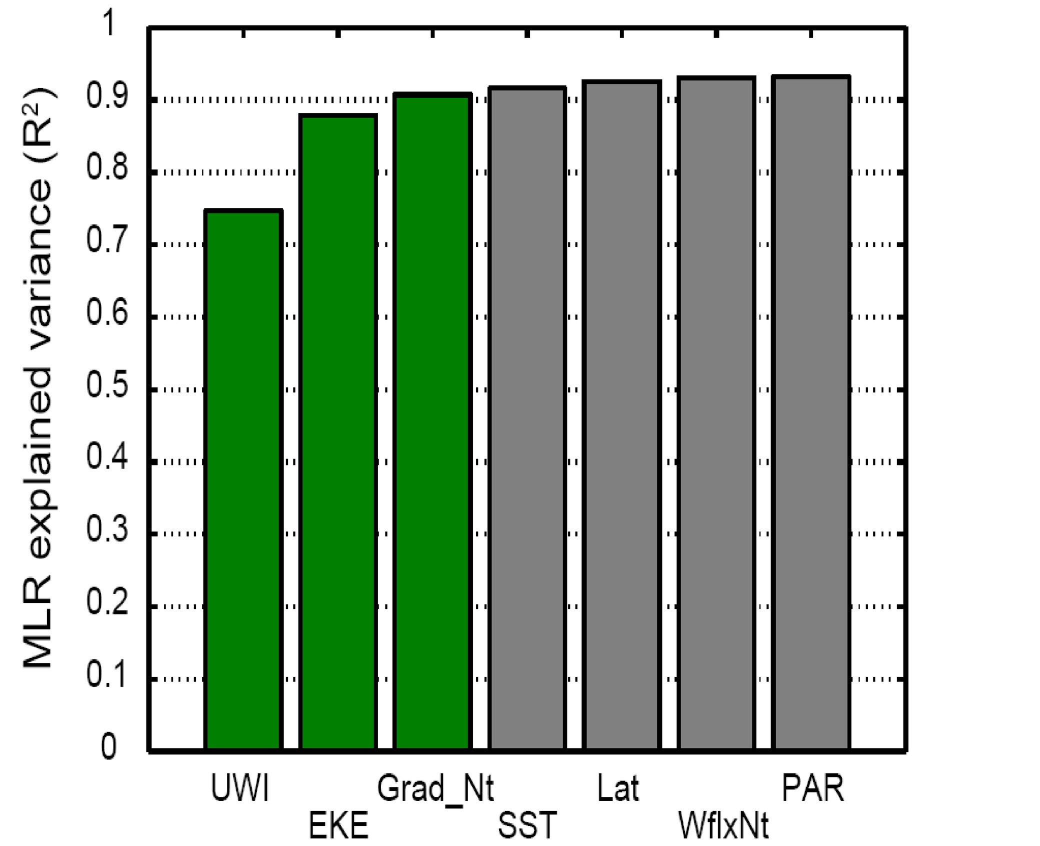

Fig 3. Plot from a stepwise multilinear regression showing the responses in the explained variance of NPP resulting from adding several variables to the regression model. Only three variables (shaded in green) add a statistically significant improvement to the multilinear regression (at the 95% confidence level): (1) upwelling index (UWI), (2) eddy kinetic energy (EKE), and (3) vertical gradient of nitrate; they explain, respectively 75%, 13% and 3% of the total variance in NPP. The coefficient of determination of the regression model, R^2, is 0.91. The remaining 4 variables yield a negligible improvement to the statistical model.

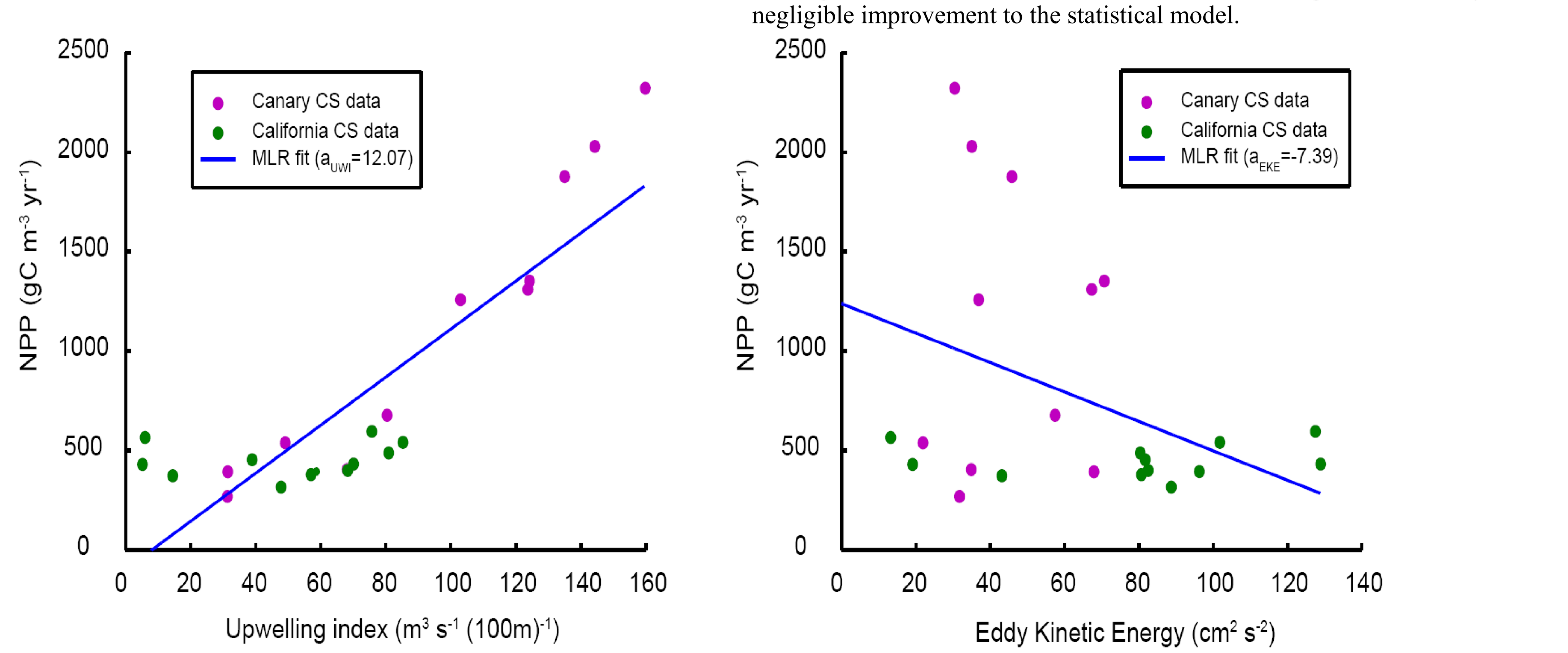

Fig 4. Projected results from multiple linear regression analyses. (left panel) NPP data as a function of upwelling index. (right panel) NPP as a function of EKE. The MLR fit of the NPP as a function of one independent variable has been normalized with regard to the other independent variable for the presentation. Also listed are the coefficients associated with the two independent variables. The purple (green) dots refer to the Canary CS (California CS). The Canary CS has a higher variability in NPP and shows a more straightforward NPP dependance on the upwelling index.

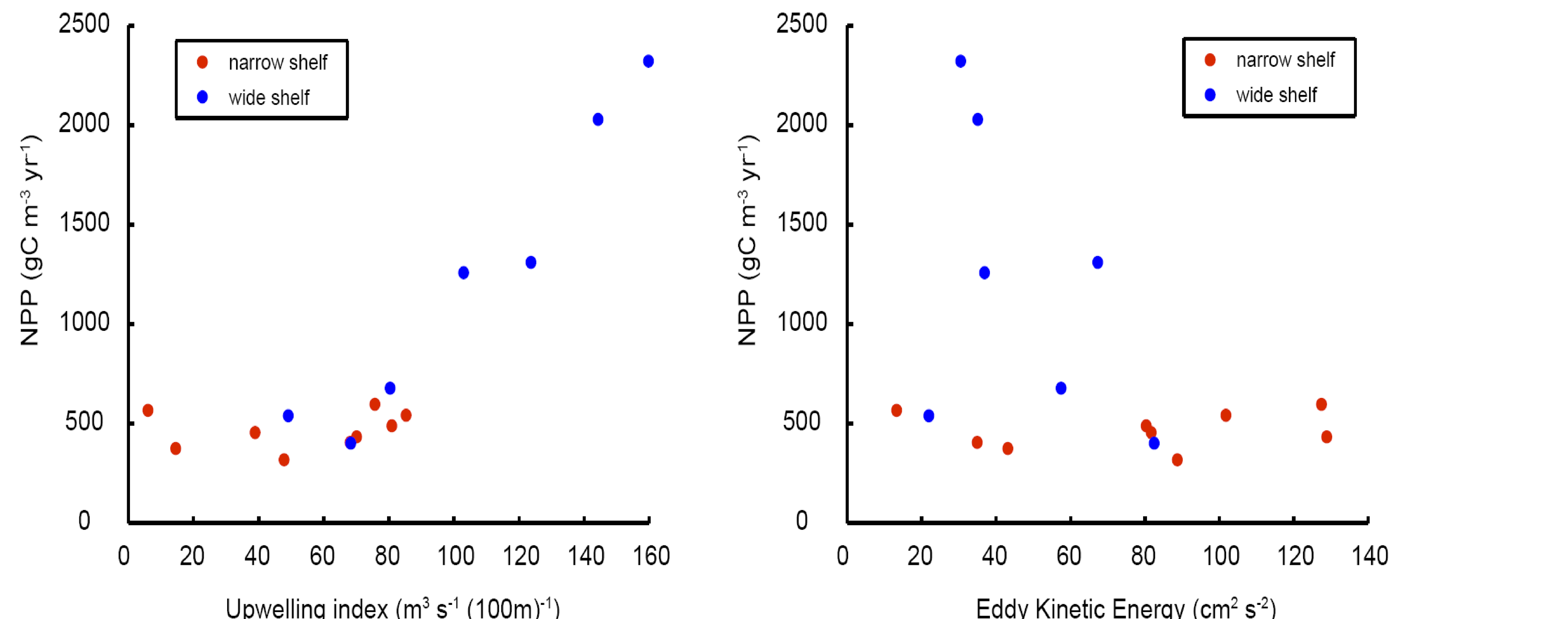

Fig 5. Plot of the NPP as a function of (left panel) upwelling index and (right panel) eddy kinetic energy. The blue (red) dots show the data associated with a wide (narrow) continental shelf. The shelf width has been caracterized using the offshore extent of the isobath 200m. The sites where the isobath 200m extends 60km offshore or more are labled 'wide shelf', while those where it does not reach 20km are labeled 'narrow shelf'. The plots suggest that a wider shelf favors higher biological productivity.

5- Results & Conclusions

- The upwelling strength, the eddy kinetic energy, and the vertical gradient of nitrate provided the best multi-linear regression model for the net primary production. Together, they explain more than 90% of variance. (Fig 3)
- The wind-driven upwelling dominates the physical processes controlling biological production in each EBCs. (explains 75% of variance). (Fig 3 & 4)
- The intense eddy activity seems to be a limiting factor to the primary production in these upwelling systems (explains 13% of variance). (Fig 3 & 4)
- Our findings suggest that a wide shelf favors high productivity. (Fig 5)
- The shelf offshore extent appears to control the magnitude of the biological response to the wind and the eddy forcing. (Fig 5)

Future work

In order to gain insight into the physical mechanisms leading to the statistical correlations demonstrated in the present study, we initiated a model-based comparative study of these two EBCs. A first validation of the simulated circulations was achieved by comparing model outputs with climatologies from satellite and in-situ data. It shows the skills of the model to reproduce the regional circulation. (Fig 6)

Related publications:

- Gruber, N., H. Frenzel, S. C. Doney, P. Marchesiello, J. C. McWilliams, J. R. Moisan, J. Oram, G. K. Plattner, and K. D. Stolzenbach, Eddy-resolving simulation of plankton ecosystem dynamics in the California Current System, Deep-Sea Research I, 53, doi:10.1016/j.dsr.2006.06.005, 2006.
- Gruber, N., H. Frenzel, Z. Lachkar, P. Marchesiello, J. C. McWilliams,, T. Nagai, and G. K. Plattner, Mesoscale eddy-induced reduction of biological production in coastal upwelling systems, *in prep. for Nature.*

4- Model-based comparison: ROMS Canary configuration

Data

Model

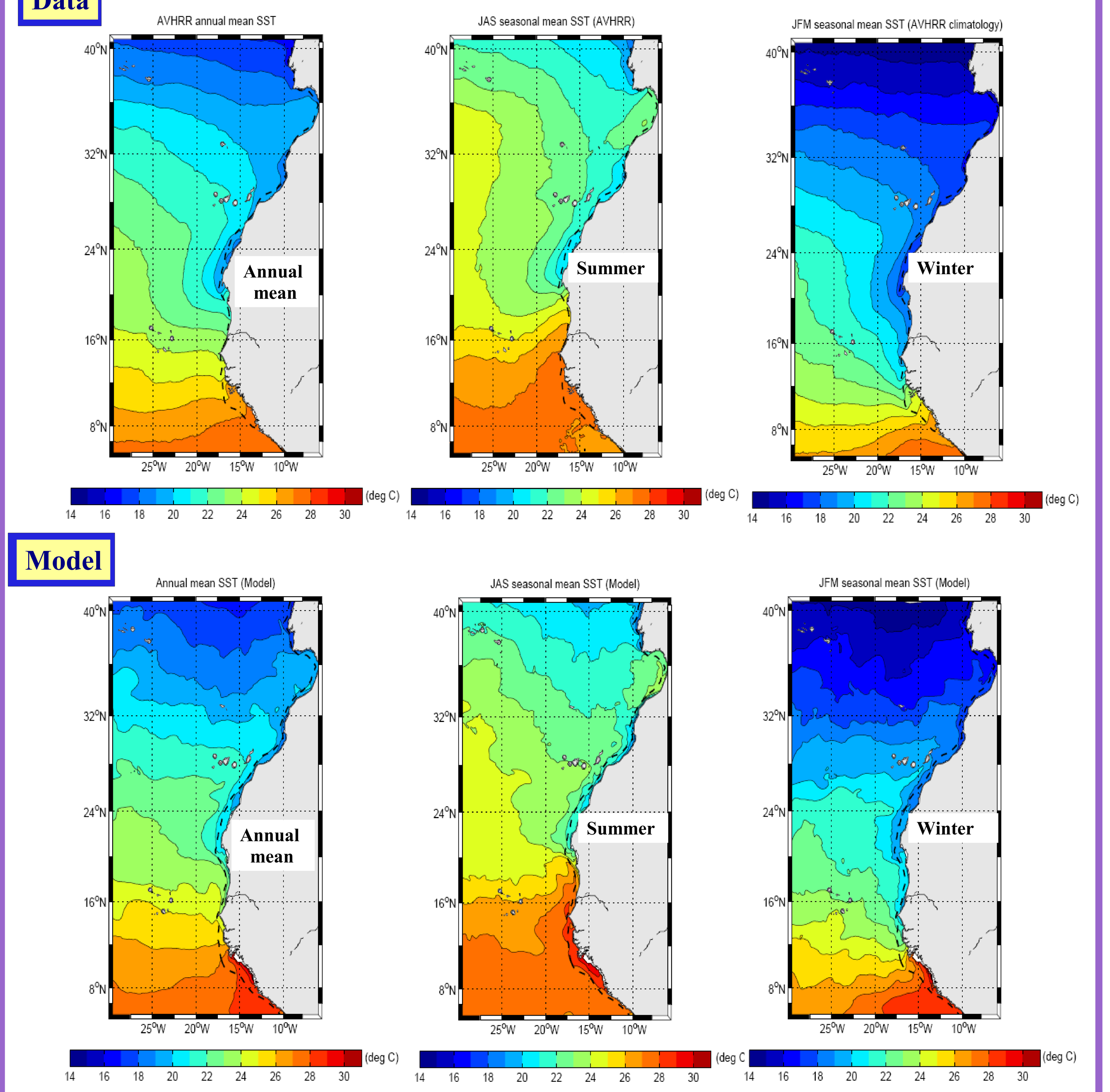

Fig 6. Sea surface temperature as observed from AVHRR climatology (top) and simulated by the ROMS Canary configuration (bottom). The left column shows the annual mean. The middle and the right columns show the summer and the winter seasonal means respectively. In the nearshore area, the model properly reproduces the sea surface temperature patterns associated with the coastal upwelling and its seasonal cycle. The ROMS configuration used for this simulation has a horizontal resolution of 12km and 32 vertical levels. Monthly averaged data from COADS are employed to force the model for the heat, fresh water and momentum fluxes. The model is initiated from rest with the January climatology of World Ocean Atlas 2001 (WOA2001). Monthly means of this climatology are also used for the prescription of temperature, salinity, and momentum fluxes along the three lateral open boundaries following a radiative scheme.