Seasonal upwelling and primary production of the Gulf of Panama: ENSO implications

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1. INTRODUCTION

The Gulf of Panama is sited at the Eastern Tropical Pacific, north of the equator. This is the location of the Eastern Pacific Warm Pool (EPWP), one of the major convection centres of the global atmosphere. From May to December the position of the Intertropical Convergence Zone (ITCZ) coincides with the EPWP migrating south during the dry season (from January to April). Throughout that season sea level pressure is normally higher over the Gulf of Mexico and the Caribbean Sea forcing strong wind jets to cross Central America through three major mountain gaps at the Gulfs of Tehuantepec, Papagayo and Panama. Those jets produce curl-induced upwelling/downwelling phenomena at the ocean surface and local thermocline shoaling that brings nutrients to the euphotic zone enhancing biological production. The wind jets intensity together with their associated cold SSTs and ocean biological production seems to vary from one year to another. El Niño Southern Oscillation is considered the main source of interannual variability in the area although its influence has not been precisely explained yet. Variation in physical conditions and biological production in the Gulf of Panama seem to exhibit lagged and weaker responses to the onset of ENSO episodes when compared with the other two Central American seasonal upwelling systems.

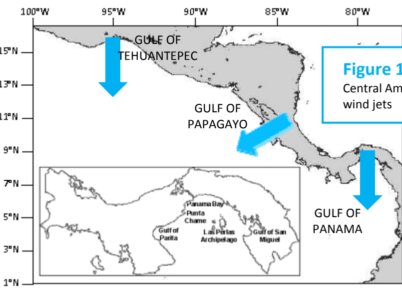
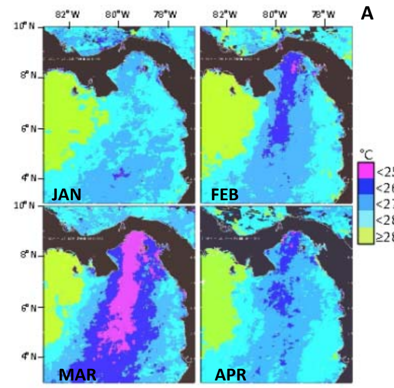


Figure 1. Central American wind jets

2. Sea Surface Temperature and Chlorophyll data

Monthly satellite composites for the Gulf of Panama of AVHRR SST and SeaWiFS chl*a* concentration at Local Area Coverage (LAC) were analyzed from January 1998 to April 2004. This period comprised several ENSO events including the exceptional 1997-1998 El Niño. From the AVHRR maps it was observed that average SST during the non-upwelling season is normally above 28°C. During January the local upwelling starts to develop as a plume of decreasing temperatures from the north and centre of the Gulf towards the south. In February a well formed tongue of SSTs below 26°C is placed at the centre of the Gulf reaching the 5°N latitude. SSTs below 25°C are registered at Las Perlas Archipelago. During March the strongest annual upwelling conditions are recorded. SSTs are at least one degree below those registered for the previous month. For April cold SSTs start to retreat. Non-upwelling season SSTs are completely recovered by May.

Chlorophyll *a* (chl*a*) concentrations have a marked response to the annual upwelling onset with large areas of the Gulf of Panama showing values above the wet season averages (below 1 mg m^{-3}) in January. During February and March average concentrations are well above 1 mg m^{-3} over the whole Gulf. Phytoplankton biomass is higher within a triangle formed by the Panama Bay, Las Perlas Archipelago and Punta Chame. By April high chl*a* concentrations (above 2 mg m^{-3}) start to retreat and have completely disappeared by May.



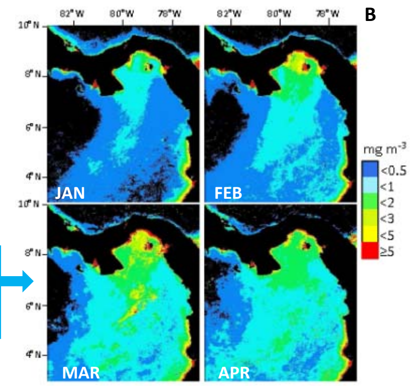


Figure 2. Average SSTs (A) and chl*a* concentrations (B) at the Gulf of Panama during the dry season months for the 1998-2004 period

3. Regression and principal components analysis

SST and chl*a* concentration data showed high negative correlation (ρ= -0.69; P<0.001). The regression performed for those variables was also significant (Figure 3) suggesting that satellite SST is a good proxy for nutrient concentration in the Gulf of Panama. SST seems to be a better tool than wind data to describe the seasonal upwelling because its intensity is also affected by the thermocline depth (D'Croz *et al.*, 2003).

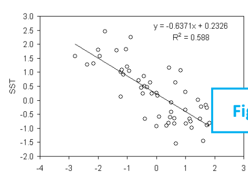


Figure 3.

Figure 4 shows the results of the PCA performed with SST, chl*a* concentration and photosynthetic available radiation (PAR) satellite data. When the PCA scores are flagged by "season" a **clear seasonal pattern** emerges. But while the variance of the scores flagged as "dry season" is driven mainly by SST and chl*a* concentration the variance of the wet season data is determined predominantly by light availability. No structure is found when the coordinates are labelled by the **Multivariate ENSO Index** (MEI) values. From the PCA **it seems that there is no ENSO influence in the Gulf or that the seasonal signal is stronger.**

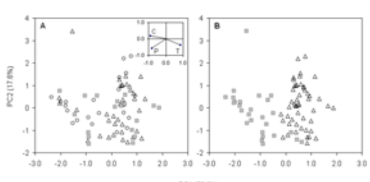


Figure 4. (A) PCA scores labelled by MEI values. Inset plot shows the loadings. (B) PCA scores labelled by season

4. Primary production and VGPM

Ocean primary productivity in the Gulf of Panama was calculated using the vertically generalised production model (VGPM) proposed by Behrenfeld and Falkowski (1997) that uses satellite SST, chl*a* concentration and PAR data as major parameter inputs.

$$\text{VGPM} \quad NPP = 0.66125 \times P^{B}_{opt} \times [E_0/E_0+4.1] \times C_{sat} \times Z_{eu} \times D_{irr}$$

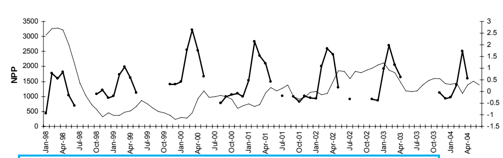


Figure 5. Monthly mean time series of NPP (mgC m^{-2} d^{-1}) vs. MEI

	1998	1999	2000	2001	2002	2003	2004
Dry season	169	191	294	264	238	249	194
Annual	*398*		*566*	*521*	*473*		

Table 1. Dry season and annual (*estimated*) NPP (gC m^{-2})

NPP peaks every year in February/March, during the upwelling season.

Although there is noticeable interannual variability in NPP (see Figure 5 and Table 1) the influence of ENSO events it is not clear. Total dry season productivity is the highest for two La Niña years (2000 and 2001). However, NPP for 1999 (during another strong La Niña event) is similar to that of 1998 under a strong warm event.

5. ENSO Anomalies during the strong 1997/1998 El Niño and 1998/2000 La Niña events

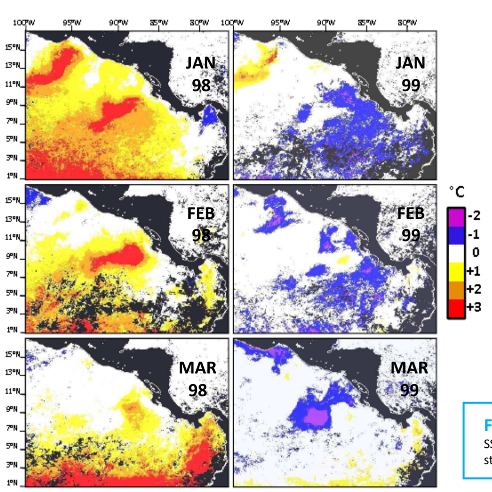


Figure 5. SST Anomalies in the Central American Pacific during strong El Niño and La Niña phases

Weekly satellite composites for the Central American Pacific Ocean were analyzed to study SST anomalies during strong warm and cold ENSO events in the Gulf of Panama dry seasons of 1998 and 1999.

During January 1998, at the end of the mature phase of the strong El Niño event, severe anomalies of 3°C above normal SSTs are registered in the Gulfs of Tehuantepec and Papagayo. During the following months anomalies still affect the upwelling phenomenon at the Gulf of Papagayo and retreat to the south highlighting the end of the warm phase. The Gulf of Panama seems to be affected only at the very end of that event.

At the beginning of the following cold phase (from January to March 1999) cold anomalies seems to migrate to the north following the Central American coast. The coldest anomalies are observed in areas influenced by the Tehuantepec and Papagayo upwellings. Anomalies are not noticed in the Gulf of Panama.

6. Conclusions

The seasonal upwelling in the Gulf of Panama lasts from January to April each year enhancing phytoplankton production.

SST and chl*a* concentration variation in the Gulf has a seasonal pattern dominated by the upwelling phenomenon presence

NPP in the Gulf of Panama is maximum during February/March each year.

Although there is interannual variation in upwelling intensity and NPP the influence of ENSO events in the area remains unclear

During strong ENSO events SST anomalies migrate along the Central American coast without noticeably affecting the Gulf of Panama

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D'Croz, L., Kwiecinski, B., Maté, J.L., Gómez H., J.A., Del Rosario, J.B., 2003. El afloramiento costero y el fenómeno de El Niño: implicaciones sobre los recursos biológicos del Pacífico de Panamá. Tecnociencia 5 (2), 35-49.