North Pacific Gyre Oscillation modulates seasonal timing and ecosystem functioning in the California Current upwelling system

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[1] On interannual and longer time scales, dynamical and biogeochemical fluctuations in the North Pacific are dominated by two modes of variability, namely the Pacific Decadal Oscillation and the North Pacific Gyre Oscillation (NPGO). In this study the regional expression of the NPGO in the California Current System (CCS) is detailed. The statistical relationship between the NPGO index and nearshore wind variability (mostly upwelling favorable) along the U.S. West coast is strongest in the wintertime (December to March) off Central California. Most importantly, NPGO fluctuations are associated with a seasonal shift of 1–2 months in the onset of the upwelling season. Regional numerical simulations show that an early (late) onset of upwelling during the positive (negative) phase of the NPGO leads to a more (less) productive planktonic ecosystem throughout spring and summer, i.e., several months after the direct NPGO effects on the system have ceased. These results bring new light on the California ecosystem variability as observed in atypical years such as 2005 and 2007. **Citation:** Chenillat, F., P. Rivière, X. Capet, E. Di Lorenzo, and B. Blanke (2012), North Pacific Gyre Oscillation modulates seasonal timing and ecosystem functioning in the California Current upwelling system, *Geophys. Res. Lett.*, *39*, L01606, doi:10.1029/2011GL049966.

1. Introduction

[2] The climate system is always changing and this large scale variability in time and space of the ocean-atmosphere system can be characterized by different modes of variability. A mode of variability is a specific pattern that presents identifiable characteristics, a regional signature and a long-term oscillatory behavior. Oscillations of only one mode or combined modes of variability are useful to rationalize observed climate fluctuations. They are also increasingly helpful to understand regional climate.

[3] Two oceanic climate patterns dominate in the North Pacific: the Pacific Decadal Oscillation (PDO) [*Mantua et al.*, 1997] and the recently identified North Pacific Gyre Oscillation (NPGO) [*Di Lorenzo et al.*, 2008]. The PDO is the leading mode of sea surface temperature (SST) variability and is connected to the El Niño Southern Oscillation (ENSO) [*Alexander et al.*, 2002]. The NPGO is the second mode of sea surface height anomalies (SSHa). It is associated with changes in strength of the central and eastern parts of the North Pacific gyre [*Di Lorenzo et al.*, 2008] and is the oceanic expression of the North Pacific Oscillation (NPO) [*Chhak et al.*, 2009; *Di Lorenzo et al.*, 2009], an atmospheric mode of variability that captures an important fraction of wintertime storm track variability [*Linkin and Nigam*, 2008] and which is also known to be linked with the central Pacific El Niño [*Di Lorenzo et al.*, 2010] - a different flavor of El Niño that has become more frequent in the last decades (see *Ashok et al.* [2009] for a review). The NPGO explains a significant fraction of interannual to decadal salinity, nutrient and chlorophyll-*a* (Chl-a) variance off the United States (US) West Coast [*Di Lorenzo et al.*, 2008, 2009]. There are strong indications that the relationship between the NPGO index and fluctuations of salinity, nitrate and Chl-a concentrations along the US West Coast is related to a modulation of upwelling favorable winds [*Di Lorenzo et al.*, 2008]. The details of this modulation are unknown and are the main subject of this study: our main result is that the NPGO is robustly associated with a modulation of the timing of the upwelling season (lag in upwelling onset) off the central part of the California Current System (CCS).

[4] Numerous recent studies dedicated to the CCS have reported that the upwelling onset, also called the "Spring transition", is a key factor for marine biology [*Bograd et al.*, 2009]. Interannual variability (or possibly long-term variability in relation with global climate change) of the spring transition timing has important biological consequences on the timing of nutrient input to the coastal system, with implications that propagate up the food chain (match/mismatch mechanisms) and an effect on the overall productivity of the system [*Barth et al.*, 2007].

[5] In this study, we clarify the statistical relationship between the NPGO index and the variability of upwelling favorable winds along the US West coast, based on alongshore wind patterns (section 2) and upwelling indices derived from station measurements (section 3). We find a clear link between NPGO and the timing of the spring transition. Because of the importance of regional changes in phenology (in particular in the context of climate change) we investigate numerically the ecosystem response of the CCS to a modulated upwelling season onset in relation with the NPGO (section 4). We show that the timing of the upwelling onset has important implications on the response of the California Current Ecosystem throughout the year. These results bring new insight into the functioning of the California ecosystem, especially for atypical years such as

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