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Short Communication

Connection between El Niño-Southern Oscillation events and river nitrate concentrations in a Mediterranean river

Teresa Vegas-Vilarrúbia [a,*], Javier Sigró [b], Santiago Giralt [c]

[a] Department of Ecology, Faculty of Biology, University of Barcelona, Barcelona, Spain
[b] Centre for Climate Change (C3), Physical Geography Department, University Rovira i Virgili, Tarragona, Spain
[c] Institute of Earth Sciences Jaume Almera, Spanish National Research Council (CSIC), Barcelona, Spain

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ABSTRACT

The causes of interannual nitrate variability in rivers remain uncertain, but extreme climatic events have been suggested as drivers of large nitrate inputs to rivers. Based on a 24-year data set (1983–2006), we suggest that El Niño-Southern Oscillation (ENSO) can affect nitrate behavior in a seasonal extra-tropical stream, the Llobregat (NE Iberian Peninsula), located thousands of kilometers away from the ENSO oscillating system via atmospheric teleconnections. Two commonly used indices, the Southern Oscillation Index (SOI) and the self-calibrating-Palmer Drought Severity Index (scPDSI) showed highly significant correlations with nitrate concentrations, which recurrently increased during La Niña phases, coinciding with severe droughts.

1. Introduction

During the 20th century, the global nitrogen (N) cycle has been severely disturbed, causing N enrichment of terrestrial and aquatic ecosystems (Schindler, 2006; Sutton et al., 2011). Nitrate leaching from river catchments is a useful indicator of N cycle disruption (Goodale et al., 2003; Gundersen and Bashkin, 1992). Today, high nitrate levels in freshwater bodies remain an important pollution target worldwide with implications for human and environmental health (Skeffington, 2002). A large body of published work assesses nitrate sources, concentrations fluxes and behavior, trying to understand its spatial and temporal behavior. However, its variability is still not thoroughly understood. While the causes of spatial and short-term (seasonal, annual) variations in freshwater nitrate concentrations are reasonably well known, the drivers of long-term (interannual, decadal) trends remain uncertain (de Wit et al., 2007; Stålnacke et al., 2003). Climatic factors have been suggested as potential causes of large interannual variations in nitrate concentration and export. Documented impacts of drought on stream biogeochemistry include reduced nitrate concentrations (Foster and Walling, 1978) due to reduced contribution of the catchment, with major flushes of nitrates to surface waters driven by storm events when drought ends, (Morecroft et al., 2000). Other studies reveal relationships of nitrate concentrations with the temperature-warming trend of last decade mediated by biological (Zweimüller et al., 2008) and geological processes (Baron et al., 2009). Recent investigations in the Northern Hemisphere have suggested some links between freshwater nitrate variations and the general atmospheric circulation systems. In the UK, synchronous patterns of variation in nitrate concentration observed in upland freshwaters showed significant correlations with the Northern Atlantic Oscillation's (NAO) index winter values (Monteith et al., 2000). Other studies on Swedish and Swiss lakes showed similar outstanding relationships between the NAO and nitrate concentrations (Straile et al., 2003; Weyhenmeyer, 2004). In a l6-year study conducted in Canada, the highest nitrate levels in upland streams were recorded after the strong La Niña episode of 1989 (Watmough et al., 2004). Hence, a more or less general pattern of interannual variability of nitrate concentrations and export is beginning to emerge in northern temperate areas, likely driven by low-frequency atmospheric modes (NAO, ENSO). More recently Marcé et al. (2010) found strong and consistent signatures of ENSO in the inflow and oxygen content of a reservoir located in the Northeast of the Iberian Peninsula (IP).

Our present research focuses on how selected climatic variables (precipitation, drought, atmospheric and sea surface temperature) influence river nitrate variations in time and which teleconnections are central to modulate these relationships in the northeast of the IP. To our knowledge, this approach has rarely been attempted before, and it should be taken into account as it has been demonstrated that a number of low-frequency Atlantic and European atmospheric modes (NAO,

* Corresponding author. Tel.: +34 934021508, fax: +34 934111438.
E-mail address: tvegas@ub.edu (T. Vegas-Vilarrúbia).

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ENSO, Mediterranean Oscillation, Western Mediterranean Oscillation, East Atlantic and Scandinavian patterns) affect precipitation/drought patterns on the IP, at different spatial and temporal scales (Barnston and Livezey, 1987; González-Hidalgo et al., 2009; Rodríguez-Puebla et al., 1998; Wibig, 1999).

The present paper is a preliminary analysis of a long-term data set (1983–2006) showing significant correlations of nitrate concentrations in river water with drought and precipitation patterns, as well as with both ENSO phases (La Niña and El Niño) in a Mediterranean river. Some hypotheses on the potential underlying physical mechanisms that could explain these relationships are also provided, in order to guide future research. ENSO teleconnections are known to be influential on the Iberian Peninsula climate by modifying the magnitude and frequency of precipitation, in a heterogeneous manner (Rodó et al., 1997; Rodríguez-Puebla et al., 1998). Indeed, some areas are affected by severe droughts during the final months of La Niña years and the initial months of the following year, whereas other regions are affected by dry conditions during the first months of El Niño years, as well as during the summer and autumn of the following year (Muñoz-Díaz and Rodrigo, 2005; Vicente Serrano, 2005). The dynamics of the ENSO-Mediterranean teleconnections is still poorly known, although several explanatory mechanisms have been proposed (Klein et al., 1999; Marshall et al., 2001; Shaman and Tziperman, 2011; Sutton et al., 2000; Trenberth and Hurrell, 1994).

2. Materials and methods

The Llobregat River system drains a large part of Catalonia, at the north-eastern Iberian Peninsula, its basin comprising 4957 km^2 (Fig. 1). The climate is of the Mediterranean type, characterized by intense summer droughts and a remarkable, interannual variability in precipitation patterns. In this region, rainfall of torrential nature concentrates in autumn and the month of December (Martín-Vide et al., 2008). Average precipitation in the Llobregat basin ranges from <550 to 900 mm/yr. The mean annual river discharge is bimodal and highly variable, with maxima recorded in May and December. The basin is subjected to intense human activity and several sewage treatment plants are active at present, but its catchment is not targeted as a nitrate vulnerable zone (European legislation, Nitrate Directive) by the official management agency (ACA, 2007, 2011).

For this study, we used the public database of the Catalonian Water Agency (ACA, 2007, 2011). Of the 11 sampling stations in the Llobregat watershed, only two provided suitable long-term nitrate time series (continuous sampling and less than 10% of data missing); these are located in the middle (Castellbell i El Vilar: CieV) and lower (Sant Joan Despí: SJD) reaches, respectively. Nitrate (NO_3) concentrations were measured by spectrophotometry (Clescerl et al., 1985–2005). Monthly nitrate time series was compared with available river discharge ($m^3\,s^{-1}$) time series (1990–2004) in the two selected sampling stations, in order to derive potential statistical correlations. Precipitation data were obtained from 26 stations of the Spanish Meteorological Service (AEMET) network (1983–2006). We applied the World Meteorological Organization (WMO) recommendations for quality control (Aguilar et al., 2003) and tested the homogeneity with the Standard Normal Homogeneity Test (Alexandersson and Moberg, 1997). Monthly series of accumulated precipitation were calculated to correlate with monthly nitrate series. To compare precipitation and nitrate series, regional time series of precipitation have been constructed by averaging daily anomalies (Jones and Hulme, 1996) and separating climate series into climatology and anomaly components. Drought conditions were identified using the self-calibrated Palmer Drought Severity Index — scPDSI (Wells et al., 2004), which has been used in the past to study summer moisture across Europe (van der Schrier et al., 2006). The scPDSI data (1983 to 2002) were obtained from the Climate Research Unit, University of East Anglia.

To characterize ENSO phases, we utilized the Southern Oscillation Index (SOI), calculated as the series of standardized differences in monthly standardized sea level pressure (SLP) between Tahiti and Darwin (Rasmusson and Carpenter, 1982; Ropelewski and Jones, 1987). Available monthly values of SOI (1983–2006) were obtained from the Climate Research Unit (East Anglia University). We used the 5-month running mean values of the SOI remaining below −0.5 standard deviations for 5 months or longer for the El Niño phases, and over +0.5 standard deviations for 5 months or longer for the La Niña events (Rasmusson and Carpenter, 1983; Ropelewski and Halpert, 1996; Vicente-Serrano, 2005). The 1980s and 1990s included eight El Niño (1982/83, 1986/87, 1991–1993, 1994/95, 1997/98, 2002, 2004, 2006), five La Niña episodes (1984/85, 1988/89, 1995/96, 1999, 2000) and two of the strongest El Niño episodes of the century (1982/83 and 1997/98), as well as a set of consecutive periods of

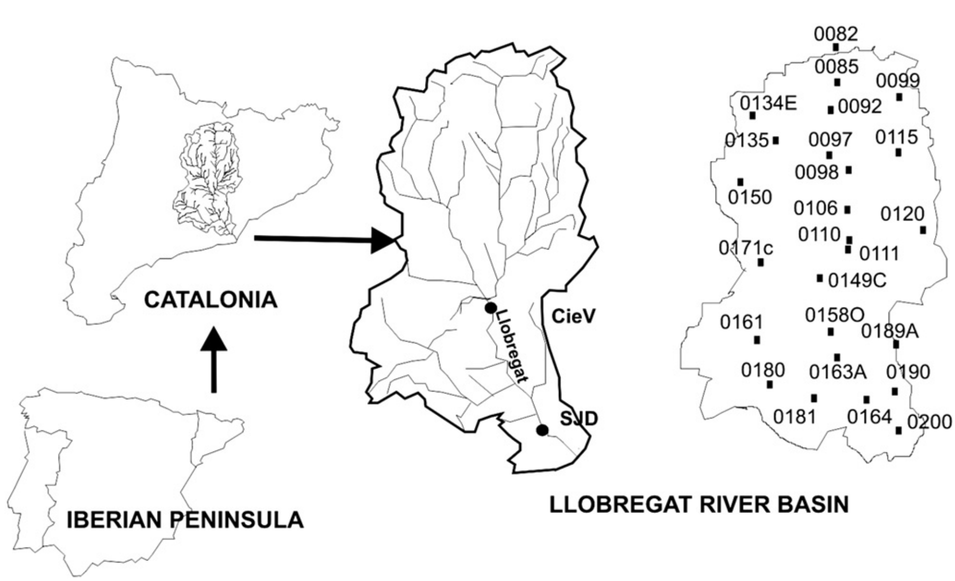

Fig. 1. Geographical location of the Llobregat basin (left) and water sampling stations (middle); distribution of the meteorological station within the basin (right).