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Variability of sea surface temperature in the southwestern Gulf of Mexico

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ABSTRACT

The seasonal and interannual variability of sea surface temperature (SST) in the southwestern Gulf of Mexico (SGM) is related to changes in atmospheric forcing, subsurface water inputs, advection and surface currents. However, little is known about temperature variability in the gulf on decadal and multidecadal timescales. Temperature time series (1900–2010) were analysed in 36 $2^\circ \times 2^\circ$ geographic quadrants that covered the SGM. A cluster analysis was applied to the data for the seasonal cycle and for the annual anomalies in each quadrant to describe SST variability, with a special focus on low frequencies (i.e. >10 years). Temperature anomalies were correlated with the identified cyclic components of the Atlantic Multidecadal Oscillation (AMO), and temperature variability in coastal quadrants of the gulf was described using multivariate analysis and harmonic analysys. There is a latitudinal separation of quadrants regading the seasonal cycle and a longitudinal separation in the total variability that is related to the Loop Current. The highest SST correlations were those related to a ~60-year cycle of the AMO and were found on the Yucatan shelf. The ~60-year variability is present in the entire gulf, but signals with periods shorter than ten years are more evident in the northern part. Extrapolation of the dominant sea surface temperature cycles in coastal areas of the gulf, shows that there will be a cooling event in the next 20 years.

1. Introduction

The analyses of the sea surface temperature (SST) in the southwestern Gulf of Mexico (SGM) have focused on describing the seasonal cycle and year-to-year variations (Adem et al., 1991; Mendoza et al., 2005; Manzano-Sarabia and Salinas-Zavala, 2008), however multidecadal variability remain poorly known. Here we investigate SST variability in the gulf with an emphasis on multidecadal variability by using time series analysis and multivariate methods. We project future SST conditions in the SGM for the next 30 years.

The seasonal variability of SST in the SGM has been characterised by thermodynamic models that use the velocity and direction of winds, oceanic currents, subsurface water inflows and the saturation vapour pressure of water at the sea surface as inputs (Zavala-Hidalgo et al., 2002). This indicates that the annual SST cycle in the region is influenced by heat transport, particularly through the Yucatán Channel, that is caused by atmospheric dynamics at a monthly scale and advection processes (Adem et al., 1991).

On annual time scales, the oceanic dynamics in the eastern edge of the gulf are controlled by the Loop Current (LC), which enters through the Yucatán strait and exists through the Florida strait. Anticyclonic circulation of the LC extends northward in the form of a quasi-stationary eddy and shows marked variability in the characteristics of its boundaries (Nürnberg et al., 2008). Small mesoscale eddies (200–400 km) detach periodically (between 3 and 21 months; Nürnberg et al., 2008) from the LC and can be found to the north. These eddies spread westward and southward from the western part of the gulf and constitute the predominant oceanographic structures of local circulation (Hamilton, 1990).

Little is known about decadal and longer-term SST variability in the SGM. Studies based on foraminiferal Mg/Ca, $\delta^{18}O$ of speleothem calcite, coral $\delta^{18}O$ and dendrochronology have been conducted in some selected sites of the northern SGM and the Caribbean Sea. Some of these studies reported permanent temperature signals with periods ranging from 60 to 80 years that might be associated with low-frequency variation in the Atlantic Multidecadal Oscillation (Grey et al., 2004; Kilbourne et al., 2008; Poore et al., 2009).

These large-scale climatic oscillations affect the natural resources of the states on the coast of the SGM. For example, coffee

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and citrus fruit plantations in the eastern part of the Sierra Madre Oriental have been damaged by recurrent frosts that are the local manifestation of climatic phenomena that affect the SGM basin (Pérez-García, 1996). There are commercially important regional fish resources that have been shown to be particularly sensitive to changes in SST, having direct effect on the magnitude of marine catches (Arreguín-Sánchez, 2010). Cyclic decadal fluctuations in the SGM correlated with large-scale environmental changes have been observed in some populations of marine turtles, which are the focus of intensive conservation efforts (Del Monte-Luna et al., 2012).

Studies that describe the variability of climate indicators that can be accessed readily, such as SST, will yield information that can improve climate prediction at time scales relevant to the sustainable exploitation of natural resources. The present study is intended to describe SST variability, particularly of low-frequency signals, in the SGM and to extrapolate SGM SST over the next decades.

2. Methods and materials

2.1. Temperature data

Annual SST data were obtained from the Extended Reconstructed Sea Surface Temperature (ERSST V3b; Smith et al., 2008) database of the United States National Oceanic and Atmospheric Administration (NOAA). This SST series is publicly available at http://lwf.ncdc.noaa.gov/ersst. The data were spatially arrayed in 36 2° × 2° quadrants that covered the entire southwestern gulf and the Caribbean Sea (Fig. 1). Annual temperature anomalies in each quadrant were computed by first averaging raw monthly SST data and then subtracting the long term mean (1900–2010) from each annual observation. Although ERSST database covered the period 1854–2010 (at the time when the analyses were performed), we chose to shorten the series from 1900 to 2010 because there were too few SST observations prior to 1900.

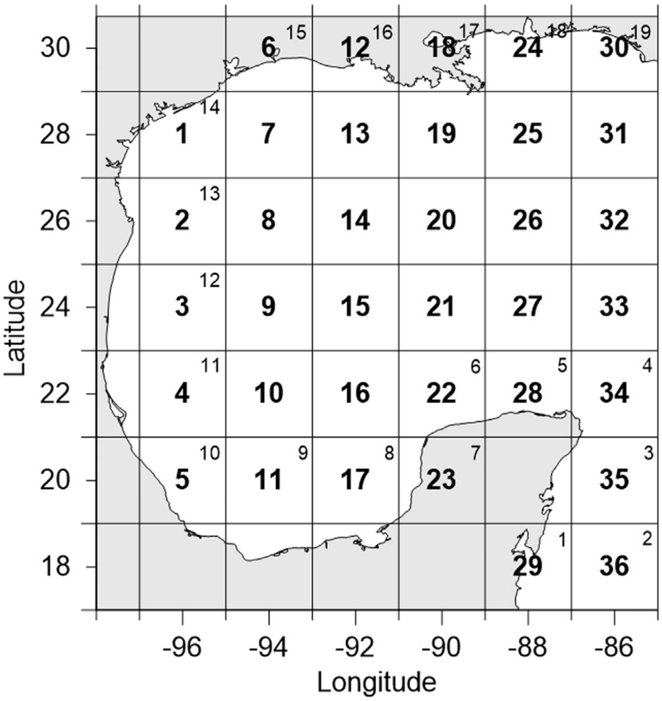

Fig. 1. Spatial array of the 36 2° × 2° geographic quadrants used in the present study for the analysis of the sea surface temperature (SST) of the southwestern Gulf of Mexico. An SST time series (1900–2010) is associated with each quadrant. For the analysis of the coastal zone, we considered only those 19 quadrants that have numbers in the upper right corner of the quadrant. Temperature data were obtained from the ERSST database (Extended Reconstructed Sea Surface Temperature) of NOAA (National Oceanic and Atmospheric Administration). SST data are available at http://lwf.ncdc.noaa.gov/ersst.

The large-scale oceanographic conditions, that were correlated with regional temperature data, were represented by the Atlantic Multidecadal Oscillation Index (AMO), which is available in the form of monthly anomalies for the period 1856–2010 (http://www.esrl.noaa.gov/psd/data/correlation/amon.us.long.data). Only values for the period 1900–2010 were used in this study. The spatial extension of the AMO in the Northern Hemisphere corresponds to the Atlantic Ocean (Enfield et al., 2001). Monthly values of the series were averaged for each year of the considered period.

2.2. Analysis

A hierarchical cluster analysis (complete linkage and Euclidean distances criteria) was applied to the average seasonal cycle data and to the annual anomalies in each quadrant.

A correlation analysis with the AMO (B) was conducted in two steps, the first consisted of identifying cyclic signal representatives of AMO variability, and the second consisted of correlating these signals with the annual SST anomalies in the gulf. A combination between periodic regression (Bliss, 1958) and cyclic descent (Bloomfield, 1976) was applied to extract the main harmonics that explain the observed variability. The combination of these two statistical techniques will be named as Periods hereafter and its specific routine in the programming environment R (v 3.0; R Development Core team, 2013) is available upon request to the authors. Periods identifies the harmonic components of a time series for which there is no previous information about its periodicity. Compared with other techniques, such as Fourier, Periods is particularly sensitive to low-frequency cyclic signals. It also allows the statistical significance of successively adding a new harmonic to be assessed by an *F*-test, instead of differentiating signals using spectral density as in Fourier analysys.

First, the linear trend of the raw data is removed and then a series of periodic regressions are applied, testing each value for a range of periods from three to *n* years, where *n* is the duration in years of the time series. The periodic regression equation is:

$$Y_i = a_1 \cdot \cos\left(2\pi p^{-1} \cdot t\right) + b_1 \cdot \sin\left(2\pi p^{-1} \cdot t\right) \tag{1}$$

where $a1$ and $b1$ are the multiple regression parameters that are used subsequently to obtain the amplitude and phase of each harmonic; p is the period, and t is the time vector. The amplitude (A) and phase (θ) are obtained from $a1$ and $b1$ by the use of the equations:

$$A = \sqrt{\left(a_1^2 + b_1^2\right)} \tag{2}$$

$$\theta = \arctan\left(\frac{b_1}{a_1}\right) \tag{3}$$

The optimum period (OP), A and θ were calculated according to the sum of squares (SS) that was calculated from each fit (the reciprocal of the SS is maximised). After the OP is calculated, the fitted values are subtracted from the data, and a new periodic regression is applied to the remaining series to identify the next OP (which is based on the magnitude of the SS). This process of “cyclic descent” is repeated until the last significant harmonic component is found. A likelihood ratio is used (Draper and Smith, 1981) to determine if the addition of a new harmonic component is statistically significant. The sum of squares that results from the