Temporal and spatial variation of the surface winds in the Gulf of California

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[1] Satellite-derived data (NSCAT and Quicksat) are used to study the annual variability of the sea surface winds over the Gulf of California. Our results indicate that the monsoon character of the winds has been exaggerated. Particularly erroneous is the concept that the wind has two symmetrically, gulf-following, preferred directions. For some years, this has been the main characteristic used to explain the dynamics of the gulf and it has influenced the development of the ocean circulation models of the region. The surface winds have an average direction that follows that of the gulf, but generally track in a south-eastward direction. The summer reversal (i.e. wind flowing from the south-east) occasionally occurs only in the southern regions. The magnitude and standard deviation of the winds are largest in winter. There is an important east-west gradient in their magnitude and the winds on the peninsular side are generally stronger than those of the continental side. INDEX TERMS: 3339 Meteorology and Atmospheric Dynamics: Ocean/atmosphere interactions (0312, 4504); 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 4504 Oceanography: Physical: Air/sea interactions (0312). Citation: Parés-Sierra, A. A. Mascarenhas, S. G. Marinone, and R. Castro. Temporal and spatial variation of the surface winds in the Gulf of California, Geophys. Res. Lett., 30(6), 1312, doi:10.1029/2002GL016716, 2003.

1. Introduction

[2] The wind is one of the main driving forces of the ocean movement. For many years, the lack of wind data over the sea surface has been a drawback in the advance of oceanography. The Gulf of California, a marginal sea in the subtropical eastern Pacific (Figure 1), is certainly no exception. It has been established that its circulation is mainly the result of forcing by the Pacific Ocean and by winds at the sea surface [Ripa, 1997]. The later has very important consequences in the dynamics and thermodynamics of the gulf. The wind field has been known to cause large evaporation rates and important wind driven currents. The numerical studies of the gulf’s circulation have been based upon the assumption that the wind blows more or less symmetrically up-and-down the gulf during summer and winter, respectively. This monsoonal behavior has been believed to exist for many years [see for example, Roden, 1958; Hales, 1972; Alvarez-Borrego, 1983; Badan-Dangon et al., 1991]. There are also important events in smaller temporal scales in the gulf; e.g., breezes [Delgado-González et al., 1994], surges [Hales, 1972]. However, the knowledge of actual atmospheric circulation over the gulf has been derived from only a few meteorological coastal stations and from even fewer observations over the sea. Some sea level pressure maps have also been used to remedy this situation. Measurements are scarce over the gulf and the spatial and temporal variability of the surface winds are not well known at present.

[3] Based mostly on those few coastal observations, the atmospheric circulation in the gulf has been described as having two main seasons: a mid-latitude winter when the winds are southward and a subtropical summer when the winds are northward [Reyes and Lavin, 1997]. In the first case, an anticyclone is positioned over the southwestern Great Basin in the United States and drives the southward flow. In the second, the synoptic circulation is dominated by a low-pressure located over the Sonora desert, and this favors the advection of tropical air masses up the gulf. Southward winds are stronger and less humid than the northward winds [Badan-Dangon et al., 1991].

[4] The atmospheric circulation is mainly along the gulf axis because of the elevated topography on both sides. It is a semi enclosed basin in the meteorological sense, as well as in the oceanographical sense [Badan-Dangon et al., 1991]. Over the Baja California peninsula, the mountain elevations range from 700–1000 m and over the mainland, the Sierra Madre is approximately 1500 m. (Figure 1). This topography funnels the flow along the gulf. From an oceanographic point of view, one of the most important features of the atmospheric circulation over the gulf is its cross-gulf variation that generates atmospheric vorticity. This is transferred to the sea through turbulent momentum fluxes. With respect to the climate of northwestern Mexico and southwestern United States it is also important to recognize that the gulf is an open channel from the tropical Pacific and the dominant moisture source for those regions.

[5] In the present report we examine the surface winds over the Gulf of California using satellite derived data. Our goal is to establish its seasonal spatial structure and to challenge the oceanographic community’s common belief in a monsoonal symmetric structure for the winds over the gulf. These findings are not only relevant for modelers and physical oceanographers, but for others as well, such as fishery ecologists and biological oceanographers [vg., Luch-Cota et al., 2001].

2. The Data

[6] The availability of satellite derived data has made possible an unprecedented coverage, both in time and space,
of oceanographic parameters and surface winds in particular. Satellite scatterometers send microwave pulses to the earth’s surface and collect the backscattered signal as they move along polar orbits. Over the ocean, the backscatter is largely due to small centimeter waves on the surface. The concept of remote sensing of ocean surface winds is based on a model which relates the roughness of the sea surface to the wind speed. As expected from crests and troughs tending to be perpendicular to wind direction, the roughness is anisotropic and this is the key to determine wind direction and speed [Thomas and Minnett, 1986]. What makes the scatterometer unique is its ability to measure both wind speed and direction. The Quickscat and NSCAT data used in this study had been objectively analyzed and gridded to a uniform spatial grid (0.5° by 0.5°) with a 12 hours temporal resolution by Liu, Tang and others [i.e., Tang and Liu, 1996; Liu et al., 1998] and made available through the net at the Physical Oceanography Distributed Active Archive Center - Jet Propulsion Laboratory (PO.DAAC-JPL). The NSCAT data covers the period from September 15, 1996 to June 30, 1997 and Quickscat from September 3, 1999 to the present.

One possible source of contamination, and hence limitation, for the use of scatterometer wind data is rain [Jet Propulsion Laboratory (JPL), 2001]. The data sets include rain-flags to account for this. Fortunately for our area of study, this is not an important issue since the area experiences very little precipitation. Another possible source of error comes from the fact that radar returns from land and ice correspond to different scattering processes than those over the open ocean. This can contaminate wind vector estimates, mainly when the swath goes from land to the ocean. A land mask has been applied to the Quikscat data in order to negate most contamination due to land and ice [JPL, 2001]. This latter possible source of contamination was further minimized by averaging both the ascending and descending passes to produce daily map for the region before the spatial and monthly averages were computed.

[7] A preliminary comparison of satellite versus measured surface wind data was made using data from the Comprehensive Ocean-Atmosphere Data Set (COADS) [Woodruff et al., 1993]. The problem with COADS is its very poor spatial and temporal coverage for most of the gulf. COADS distribution is not uniform with a larger data concentration at the gulf entrance in comparison to the region of the upper gulf where data is almost non-existent. A cross gulf bias is also observed, with more data concentrated in the Baja California side. However for the areas where there is data from COADS such as the southern occidental part of the gulf (i.e. along the southern part of Baja California), there is good agreement between the two data sets.

3. Results

[8] Figure 2 shows a typical time series of along and across gulf wind components corresponding to a geographical point in the southern regions of the gulf (108°W, 24°N). The period September 1996–June 1997 corresponds to the available NSCAT data and the period September 1999–March 2002 correspond to the Quikscat data set. Annual and semi-annual period harmonics were fitted to these data sets by minimizing the square deviation. As seen in the figure, a large percentage of the variance is found in the annual harmonic; almost 50 percent at this particular location and a similar amount for the rest of the gulf.

[9] Figure 3 shows the amplitude of the annual period for the whole gulf. In general, the magnitude of the oscillation decays toward the north and west, with a weak maximum around the island region and a stronger one at the mouth of the gulf. This oscillation is not, however, around zero but has a strong negative component. The climatological average winds are shown in Figure 4. For the winter period (December–February, Figure 4a) homogeneously north-westerly winds dominate the whole gulf. The average magnitude is 4.93 m s⁻¹ and the average direction is 333.5°. Only around the island region is the magnitude of the winds slightly weaker and tend to have a slightly more...
southern component. By the March–May period (Figure 4b) the wind intensity has diminished everywhere and especially toward the mainland coast. This is relevant from an oceanographic point of view as it implies the existence of a positive wind-curl that, once established, drives most of the wind-driven ocean circulation. Toward the end of May (not shown) the winds weaken further veering southeastward toward the mainland. In summer (June–August, Figure 4c) when the winds are diminished everywhere, they attain a distinct northeasterly direction in the southern and central gulf, i.e. blowing toward the oriental gulf’s coast. The reduction in magnitude and the change in direction are not as pronounced in the northern region. In fact, in the islands and northern region the direction is essentially the same as in the previous season, i.e. south-easterly, with a slightly more easterly direction. It is worthwhile to note that from early August to early September the winds in the southern gulf region do indeed reverse for short periods. However, these reversals are smoothed out by the averaging processes. By the fall season (September–November, Figure 4d) the winds return to the winter conditions from north to south, i.e. the southern part seems to maintain the summer “anomalous” direction for a longer period of time. At the seasonal and monthly time scales, the mean winds never reverse direction completely.

To synthesize our results the Gulf of California was divided into 4 regions loosely based on its dynamic characteristics. Following Soto-Mardones et al. [1999] we established latitudinal zones as follows: Northern zone (29.5–32° N), Island zone (28–29.5°N), Central zone (26–28°N) and Southern zone (23–26°N). The seasonal climatology of the winds, calculated for these gulf zones are shown in Figure 5 in the form of stick diagrams. Only in the southernmost regions, the wind actually has a positive component but not even in this area they attain a “reverse direction”. For all the areas the magnitude of the wind diminishes during the summer months and peak in the winter. The weakest winds occur in the central area during the summer months. For the northernmost area, the winds...
are almost consistently to the south-east and only the June vector has an easterly direction. The seasonal variability of the wind magnitude (Figure 6) is larger in the North and Island regions than in the South region. For the southern areas, their is a large difference in the variance of magnitude between summer and winter, with the winter being the season with greater variability and strongest winds.

4. Conclusions

[11] The monsoonal character of the prevailing surface winds over the Gulf of California has been greatly exaggerated. This is specially evident in the numerical ocean modeling community where most of the circulation models of the gulf have been driven by symmetrical south-easterly - north-westerly winds [v.g., Carbajal, 1993; Beier, 1997; Palacios-Hernández et al., 2002; S. G. Marinone, A three-dimensional model of the mean and seasonal circulation of the Gulf of California, submitted to Journal of Geophysical Research, 2003].

[12] For most of the gulf, at the ocean surface, the wind has a large percentage of its energy (~50%) at the annual frequency but the mean has a strong southward component so that its actual reversal (i.e. northwesterly direction) occurs only occasionally, primarily in the southern part of the gulf. The variability in the magnitude of the winter winds is larger than that of the summer, especially for the southern regions. It is probable that ephemeral reversals do occur during June, July and September but a consistent northwestward wind is only observed for short periods during August.

[13] The concept of symmetrical monsoonal ocean surface atmospheric circulation comes mainly from extrapolating it from the upper layer winds, where the wind reversal apparently does occur [e.g., Douglas et al., 1993], down to the sea surface. It might also be attributed to the numerical ocean modeling community’s tendency to look for seasonally contrasting circulations in their models, or perhaps simply from the natural human desire to see symmetries at the slightest hints of their existence.

[14] Finally, it is important to recognize that these conclusions were extracted from a time series of about three years, a period that includes part of the ENSO warm event of the 1997–1998 and the 1999 cool event. It is possible that a longer time series may alter the results but we believe that it would not change the final conclusion; that a symmetrical monsoonal surface wind circulation over the Gulf of California is a myth.

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