Seasonal and interannual thermohaline variability in the Guaymas Basin of the Gulf of California

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Abstract—Temperature and salinity data for the years 1930–1983 are used to investigate seasonal and interannual scales of the hydrographic variability across the Guaymas Basin, which is located between 27° and 28°N in the Central Gulf of California. Winter conditions extend from December to April and summer conditions from June to October, with transition periods in May and November. Sea surface temperature increases from about 16°C in February–March to 31°C in August. No clear seasonal cycle in surface salinity was found. Typical values are above 36.1% even in winter, and up to 35.5% in November.

Relatively cold and low salinity near-surface waters observed in June 1957 and in June 1982, suggest advection of California Current Water to the Guaymas Basin. Subtropical Subsurface Water may occur around the year, but is obscured by vertical mixing with Gulf Water mainly during winter, when vertical stratification is weaker. The Intermediate and Deep Pacific Water masses successively fill the Guaymas Basin to the bottom (2000 m), showing very stable T–S characteristics.

Positive sea level anomalies at Guaymas increases during El Niño years, and anomalous low salinity and high temperature at the surface indicate the presence in the Guaymas Basin of water from the south. Observed differences reached 0.4% in surface salinity and 3°–5°C in surface temperature. There is evidence that the observed low salinities could not be due to abundant precipitation. An additional effect is a deepening of the winter pycnocline down about 200 m, compared to the usual depth of <100 m. In summer, this effect is not as clear as in winter, due to the strong stratification. The effects of the very strong 1982–1983 and 1957–1958 ENSO episodes may have lasted for one and two years, respectively. It is argued that during an ENSO event the Transition Water of the California Current meets and mixes near the Gulf entrance with the Tropical Surface Water of the Costa Rica Coastal Current. This mixed water could have been carried north into the Gulf by local surface circulation. In 1983 it was found at the surface in the Guaymas Basin above the southeastward flow of the colder and saltier Gulf Water.

INTRODUCTION

The Gulf of California is a marginal sea of the eastern North Pacific Ocean limited by the peninsula of Baja California in the west and mainland Mexico to the east (Fig. 1) and constitutes a large evaporative basin. It shows several interesting oceanographical features that have called the attention of scientists, since the first serious hydrographic cruise by Sverdrup in 1939 (SVERDRUP, 1941). Between 1956 and 1961 the Scripps Institution of Oceanography and the U.S. Fish and Wildlife Service made 10 cruises into the Gulf to study the hydrographic seasonal variability (RODEN and GROVES, 1959; RODEN, 1964). Using more recent data up to 1974, the variability of hydrographic and organic nutrients conditions in the Gulf was examined by ÁLVAREZ-BORREGO et al. (1978)

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and by **Alvarez-Borrego** and **Schwartzlose** (1979). This and earlier literature on the subject have been reviewed by **Alvarez-Borrego** (1983). Beginning in 1981 a renewed effort on physical and ecological investigations in the Gulf has been developed by Mexican and U.S.A. Institutes (Schrader and Baumgartner, 1983; Christensen et al., 1983; Candela et al., 1984, 1985; Baumgartner and Christensen, 1985; Badan-Dangon et al., 1985; Baumgartner, 1985; Marinone and Robles, 1985).

The Gulf has been divided in the literature into two main regions: the northern and the southern parts, mainly as a result of their disparate bathymetry (very shallow at the northern part and deepening towards the south) and because of their very different oceanographic regimes. These two regions are divided by the Salsipuedes–Tiburón Sill, about 500 m deep, near the island chain formed by Tiburon, San Esteban and San Lorenzo, which are indicated by T, E and L, respectively, in Fig. 1. Waters in the southern Gulf are basically those of the Eastern Tropical Pacific, modified at the surface by an excess of evaporation over precipitation (Roden, 1964; Wyrtki, 1967). The northern part is characterized by strong evaporation and large temperature range (Roden, 1958), and about 75% of the area is covered by <200 m of water. The evaporative effect seems to play an important role in the formation of a high salinity water mass (Sverdrup, 1941; Roden, 1964; Alvarez-Borrego and Schwartzlose, 1979).
The Guaymas Basin, which has a maximum depth of 2000 m and is approximately 160 km wide, is located in the transition zone between the two main regions of the Gulf. This transition zone was called the central part of the Gulf by RODEN and GROVES (1959). Important features of this Basin are: the occurrence of wind-generated coastal upwelling, the intrusion of plumes of surface cold water from the Salsipuedes–Tiburón Sill, and the formation of gyres as wide as the Basin (RODEN, 1958; RODEN and GROVES, 1959; BADAN-DANGON et al., 1985).

Available literature on interannual changes of oceanographic features within the Gulf of California is very scarce. There is, however, evidence suggesting that the entire pelagic ecosystem in the Gulf is altered during El Niño-Southern Oscillation (ENSO) phenomena. In a study on the ecological response of the Gulf to climatic changes, BAUMGARTNER et al. (1985) demonstrated a strong association between year-to-year sea level fluctuations in the Gulf and the ENSO index (QUINN et al., 1978). They suggest that biological productivity increases within the Gulf during ENSO periods, while an inverse relationship exists in the California and Peru Current Systems. The Gulf showed very high productivity rates in 1983 compared with values reported for normal years; these high rates are comparable only to very productive open-sea coastal upwelling ecosystems (LARA-LARA et al., 1984). In addition, BAUMGARTNER and CHRISTENSEN (1985), studying the source of interannual changes in sea level fluctuations, concluded that the interannual ocean climate in the Gulf is related only to the ENSO phenomenon. They proposed an intensification of the north equatorial cyclonic gyre (North Equatorial Current and North Equatorial Countercurrent) and consequently increased advection of the north-flowing Costa Rica Coastal Current. The gyre extends past the Gulf entrance during ENSO episodes, while the California Current is withdrawn to the north. In spite of these recent studies, as far as we know, no literature on the interannual thermohaline variability within the Gulf of California exists.

In this study we will describe a hydrographic section across the center of the Guaymas Basin (Fig. 1) extending from Guaymas on the mainland to Santa Rosalía on the Baja California peninsula. This section has been more frequently surveyed, at least during the last 1982–1983 ENSO episode, than other areas of the central Gulf.

This area was also chosen because the Guaymas Basin is located far from the more complicated oceanographic regimes in the midriff islands near 29°N, characterized by strong tidal currents and mixing; also from the Gulf entrance, around 23°N, where a number of surface water masses meet and fronts are typical. Our goal in this work is to identify patterns in the thermohaline structure in both seasonal and interannual scales of variability.

DATA

Most of the known hydrographic data collected in the Guaymas Basin was used in this study (Table 1). The dates of cruises extend back to 1939 and include data from more recent cruises (1981–1983) by Centro de Investigación Científica y de Educación Superior de Ensenada, B.C. México (CICESE). Only data from lines of stations normal to the Gulf’s axis and falling between 27°N and 28°N, in the central Gulf of California, were used in this study (Fig. 1). Data were collected using hydrographic bottles, with exception of the May 1983 cruise in which a Bissett-Berman STD was used. There are no data for the months of January, July, September and December.
Table 1. Cruises at the Guaymas Basin. First two numbers are the year and last two numbers the month of the cruise. Maximum depth sampled in any hydrographic cast is shown.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Date</th>
<th>Casts</th>
<th>Depth (m)</th>
<th>Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>3903</td>
<td>10-13 March</td>
<td>5</td>
<td>1388</td>
<td>E.W. Scripps</td>
</tr>
<tr>
<td>5602</td>
<td>12-13 February</td>
<td>3</td>
<td>1210</td>
<td>Black Douglas</td>
</tr>
<tr>
<td>5604</td>
<td>14 April</td>
<td>3</td>
<td>582</td>
<td>Black Douglas</td>
</tr>
<tr>
<td>5702</td>
<td>13-14 February</td>
<td>6</td>
<td>1476</td>
<td>Horizon</td>
</tr>
<tr>
<td>5704</td>
<td>12-13 April</td>
<td>6</td>
<td>521</td>
<td>Black Douglas</td>
</tr>
<tr>
<td>5706</td>
<td>13-16 June</td>
<td>5</td>
<td>574</td>
<td>Stranger</td>
</tr>
<tr>
<td>5708</td>
<td>16 August</td>
<td>5</td>
<td>568</td>
<td>Stranger</td>
</tr>
<tr>
<td>5904</td>
<td>25-30 April</td>
<td>5</td>
<td>1763</td>
<td>S.F. Baird</td>
</tr>
<tr>
<td>6110-11</td>
<td>31 Oct.-1 Nov.</td>
<td>6</td>
<td>1869</td>
<td>H.M. Smith</td>
</tr>
<tr>
<td>6110-11</td>
<td>8-9 Nov.</td>
<td>4</td>
<td>1340</td>
<td>H.M. Smith</td>
</tr>
<tr>
<td>7003</td>
<td>28-29 March</td>
<td>5</td>
<td>1937</td>
<td>A. Agassiz</td>
</tr>
<tr>
<td>7410</td>
<td>17-19 October</td>
<td>4</td>
<td>1900</td>
<td>A. Agassiz</td>
</tr>
<tr>
<td>8110</td>
<td>23-24 October</td>
<td>3</td>
<td>1530</td>
<td>M. Matamoros</td>
</tr>
<tr>
<td>8206</td>
<td>28-29 June</td>
<td>9</td>
<td>1681</td>
<td>El Puma</td>
</tr>
<tr>
<td>8303</td>
<td>18-19 March</td>
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<tr>
<td>8305</td>
<td>1-2 May</td>
<td>8</td>
<td>1458</td>
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<tr>
<td>8310</td>
<td>12-13 October</td>
<td>6</td>
<td>400</td>
<td>M. Matamoros</td>
</tr>
</tbody>
</table>

Tide gauge data from Guaymas for the period 1952–1984, were used to calculate monthly sea levels anomalies (SLA). These SLA were obtained by subtracting a given monthly sea level value from the long-term mean for that month.

Monthly total precipitation data from land stations at Guaymas and Santa Rosalia (Fig. 1) were used to calculate monthly rainfall anomalies for the period 1957–1983. The source of these data were the Monthly Climatological Summaries and Hydrological Bulletins published by Servicio Meteorológico Nacional (Mexico).

RESULTS AND DISCUSSION

Seasonal variability

In Fig. 2 it is easy to identify the presence of the two deeper water masses found in the Gulf of California. The Pacific Intermediate Water (PIW) is characterized by a salinity minimum of 34.5‰ at about 700 m depth, and the Pacific Deep Water (e.g. Rodén, 1964) which fills the Guaymas Basin to the bottom is denoted by a slight increase of salinity with depth. Both water masses are always present in the Basin, showing no distinguishable variability in their temperature-salinity (T-S) characteristics on either seasonal or interannual scales. In view of this T-S variability, our discussion will be focused to the upper layers, above 600 m depth.

A seasonal cycle in the mean T–S structure can also be identified in Fig. 2. Starting in February (Fig. 2a), the T–S relationship above the PIW is approximately linear, from 7°C and 34.6‰ at about 500 m to 17°C and 35.3‰ at the surface. Two cruises in March (1939 and 1970) showed about the same surface temperature and salinity as in February.

T–S data for March 1983 are abnormal and will be discussed later in the section of interannual variability (Fig. 2b). In April the temperature increases noticeably in the upper layers, reaching almost 23°C at the surface. There is a small increase in surface salinity up to 35.4‰, although lower values (35.2‰) were also found at the surface in 1959 (Fig. 2c). A single cruise exists for May in 1983, showing surface salinities as low as
Fig. 2a,b. Caption on p. 722.
Fig. 2c-d. Caption on p. 722.
Fig. 2e,f. Caption on p. 722.
Fig. 2. Temperature salinity relationships at the Guaymas Basin grouped by month. The symbols denote observed T-S values from different cruises and the year of the cruise is shown. The mean T-S curve for stations across the Basin of a given cruise are drawn on the observed T-S values. The vertical dotted line shows $S = 35.1\%$, a common surface salinity value around the year. There were no T-S data available for the months January, July, September and December.
in March 1983 and surface warming (Fig. 2d). In June, surface temperature has a range 25–28°C and surface salinity ranges from 35.2‰ to slightly less than 35.5‰ (Fig. 2e). It should be noted here the difference in dates of occupation of the section (mid and late June) between the two cruises in 1957 and in 1982 for this month (see Table 1). Only one cruise was available for August (Fig. 2f), which shows maximum surface temperature of the data set, above 31°C, and a very wide range in surface salinity: from 34.9 to 35.4‰. By October (Fig. 2g), surface temperature decreases to about 28°C regardless of the year; on the other hand, surface salinity showed a broad range (34.9–35.4‰) because of the anomalously low values from 1983. Finally, in November (Fig. 2h) the temperature decreases to 24–25°C and the salinity increases above 35.5‰, the maximum detected in our data set. By this month, the T–S plot starts to approach the winter linear relationship (Fig. 2a).

Figure 2 also shows that seasonal changes are not restricted to surface waters, but they may also occur in subsurface layers. The linear T–S relationship observed during winter above the Pacific Intermediate Water (PIW) is broken in summer. This is most clearly seen in June 1957 and in June 1982, when a shallow salinity minimum (S_min) occurs at about 75 m (Fig. 2e). This S_min, associated with temperatures between 15 and 20°C, may be an evidence of the California Current Water (CCW) in the Guaymas Basin. Because of this S_min a relative salinity maximum (S_max) arises at about 200 m, with sigma-t close to 26.5. This S_max has been found much better defined at or near the Gulf entrance, denoting the presence there of the Subsurface Subtropical Water (SSW) (e.g. WYRTKI, 1967; RODEN, 1972).

The extent and seasonality of the CCW into the Gulf of California have been described by STEVENSON (1970) and ALVAREZ-SANCHEZ (1974) found CCW as far as 25°N. This is to our knowledge, the first notice of the CCW reaching the Guaymas Basin (27–28°N).

The idea of advection of cold, low salinity CCW to the Guaymas Basin in June 1957 and 1982 is supported by the fact that the S_min could be traced out to the Guaymas Basin with June 1957 data not shown here; the S_min decreased to 34.2‰ at the Gulf entrance. In addition, the April 1957 data also presented an S_min intrusion extending from the entrance to 26°N into the Gulf. Cold, low salinity subsurface waters in the southern Gulf, during April and June 1957 are also evident in RODEN’s (1964) Fig. 12. At the Guaymas Basin in June 1957 and 1982, the CCW laid between saltier, warmer Gulf Water above, and the also saltier but colder SSW below (Fig. 2c). The increased value of the S_min from the Gulf entrance (34.2‰) to the Guaymas Basin (34.7‰) could be due to mixing of these water masses and the CCW.

In summary, seasonal heating is evident from the data shown in Fig. 2. It is more clearly illustrated by the mean monthly T–S plots in Fig. 3. Heating is also evident in mean monthly temperature integrated for different layers in Fig. 4. Surface warming begins in April, reaches a maximum in August and starts to decrease by October. Minimum surface temperatures (16–17°C) were observed in February–March. On the other hand the seasonal cycle in surface salinity is not clear as in temperature. Neglecting anomalous low values in August 1957 and 1983, surface salinities are always above 35.1‰, marked with a broken line in Fig. 2. Surface salinities up to 35.4‰ were observed as early as April, but the maximum, slightly higher than 35.5‰, occurred in November. The CCW is more likely to occur in the Guaymas Basin during late spring and early summer. SSW appears to occur around the year in the Guaymas Basin, albeit with its S_max being obscured by mixing with lower levels of the saltier Gulf Water. This mixing is
enhanced in winter when stratification is weaker (see linearity in T–S plots, above the PIW, in Figs 2 and 3) and when the pycnocline is shallower (Fig. 6).

In addition to seasonality, there are processes with different time scales, which also modify the T–S characteristics of near-surface Eastern Tropical Pacific Water entering the Gulf. Short time scale variability cannot be described with this data base. However, from 31 October to 9 November 1961, the section across the Guaymas Basin was occupied twice. In about 8 days, surface temperature decreased by 2°C (Fig. 2h). This cooling, as well as the relatively wide range in T–S values mentioned earlier for June 1957 vs 1982 (Fig. 2e) could have been related to local short-term processes, such as coastal upwelling or mesoscale gyres in the Guaymas Basin.

Interannual variability

On noticing that the temperature in the Gulf of California appeared to be higher in 1957 than in 1956, Roden and Groves (1959) pointed out how little information there was, at the time, on the year-to-year variations. Since then the amount of hydrographic
data available has increased by a factor of two, and sea level has been recorded for about 30 years at Guaymas. Therefore, it is possible to attempt the first investigation of interannual variability of the hydrography.

Sea level anomalies at Guaymas. Monthly sea levels anomalies (SLA) from a tide gauge at Guaymas, near 28°N, 111°W (see Fig. 1) for the period 1952–1984 are shown in Fig. 5. These anomalies were obtained by subtracting a given monthly sea level value from the long-term mean for that month.

According to Baumgartner et al. (1985) there is a strong association between SLA inside the Gulf and the El Niño-Southern Oscillation (ENSO) index given by Quinn et al. (1978). Therefore, the SLA record at Guaymas is used here as an index of ENSO events in the Guaymas Basin. These events are denoted by positive (shaded) SLA values, while normal or anti-El Nino periods are denoted by negative (unshaded) SLA values. The
three strongest ENSO events during the last 30 years had the highest SLA peaks: about 20, 15 and 30 cm during 1957–1958, 1972–1973 and 1982–1983, respectively (Fig. 5).

Vertical solid lines on the time axis in Fig. 5 represent the date of the cruises in Table 1, when T–S data were collected at the Guaymas Basin. Hydrographic data are available for the El Niño years 1957 and 1982–1983, and for the normal or anti-El Niño years 1956, 1959, 1961, 1970, 1974 and 1981. The year 1939, for which there are T–S data but no SLA at Guaymas, was classified as a “moderate” El Niño by QUINN et al. (1978). There are no T–S data for the strong 1972–1973 El Niño episode.

T–S Variability. In addition to seasonal changes described earlier in this work, the interannual T–S variability is also apparent in Fig. 2, as data from different years are grouped by month. The surface warming in 1957 vs 1956, observed by RODEN and GROVES (1959) is also evident here for the Guaymas Basin. In addition, it can be seen that 1959 was about 2°C warmer than 1957 and about 5°C warmer than 1956 (Figs 2a,c). This warming period was associated with low near-surface salinities in August 1957 and (less evident) in April 1959 (Figs 2c,f). Advection of low salinity waters from the south in August 1957 was suggested by RODEN (1964).

A very noticeable feature in Fig. 2b is how much fresher and warmer the near-surface water was in 1983 in comparison to 1939 and 1970, for the same month (March). The
surface temperature in 1983 was 3 and 5°C warmer than 1970 and 1939, respectively; surface salinity was slightly less than 34.9% in 1983, fresher than the 35.2% in 1939 and 35.3% in 1970. A subsurface salinity maximum, slightly higher than 35.1%, at about 75 m is evident in March 1983 only. In 1983 the T-S plots for May and October (Figs 2d,g) resemble those from March, except for the seasonal surface warming. October surface salinities were about the same, regardless of the year, but in 1983 surface salinity in October remained as low as in March (34.85%). The subsurface salinity maximum is also evident in May and October 1983.

A complementary visualization of the interannual variability in terms of the mean temperature of different layers across the Guaymas Basin is shown in Fig. 4; the abnormal warming in 1959 and March 1983 is quite evident. Although the interannual effect at the surface may have been masked by seasonal heating in May and October 1983 (see also Fig. 2g) the interannual warming is evident in deeper layers for any month in 1983, as well as for April 1959, down to at least 150 m.

Persistence of anomalous conditions. The ENSO event in 1957 may have initiated in July, according to both the SLA anomalies at Guaymas (Fig. 5) and the low salinities observed in August: as low as 34.9% at the surface and around 34.8% in relatively warm near-surface layers (Fig. 2f). These salinities are lower than those observed earlier in February, April and June 1957. No T–S data later than August in 1957, nor in 1958 exist; however, a single survey in 1959 showed that warmer and relatively fresher surface waters could have persisted until April in that year (Figs 2c and 4). So, anomalous hydrographic conditions in the Guaymas Basin initiated by mid-year 1957 may have extended to mid-year 1959, as well as in the positive SLA at Guaymas (Fig. 5). Near-surface salinities as low as those from August 1957 were found only in the three 1983 surveys.

The strong 1982–1983 El Niño started to develop in the Equatorial Pacific Ocean in June 1982. Positive sea surface temperature (SST) anomalies of about 0.5°C were reported near the Gulf entrance in October 1982 (CAC, 1982; its Fig. 5). These anomalies increased to 1.0°C by November 1982 (F. Miller, personal communication). The November pattern in SST anomalies persisted at least until June 1983 (Simpson, 1983). This information is consistent with the absence of anomalies in the T–S data from June 1982 (Fig. 2e) and their presence in March 1983 (Fig. 2b) at the Guaymas Basin. These anomalous T–S characteristics were still present in October 1983 (Fig. 2b), and positive SLA at Guaymas extended to March 1984. Therefore, this ENSO event should have lasted at least for one year.

Deepening of the pycnocline. The depth of the 26.0 σ, surface, which represents the bottom of the pycnocline, and is common to all the sections across the Guaymas Basin is shown in Fig. 6. Interannual, seasonal and shorter term fluctuations in the depth of the pycnocline are evident: (a) sometimes the pycnocline slopes towards mainland Mexico, probably due to coastal upwelling events in winter, e.g. for February 1956 (5602) and February 1957 (5702) in Fig. 6b; (b) the pycnocline is shallower (<100 m depth) during winter–spring and deeper (150–200 m) in summer–autumn, when stratification is weaker and stronger, respectively (Figs 6a,b); (c) the pycnocline is deeper during El Niño (1983 and 1957–1959) than in anti-El Niño years. The 26.0 σ, surface in March 1983 (8303) was as deep or deeper as in summer–autumn of any other year, and slightly shallower than in October 1983 (almost 200 m in 8310; Fig. 6a). In April 1959 (5904) it was as deep as in June 1957 (100–150 m), and deeper than in 5604 or 5704. It was shallower than in 5708,
Fig. 6. Fluctuations in depth of the 26.0 sigma-t isopycnal across the Guaymas Basin: (a) for cruises in March and October 1939–1983; (b) for all cruises during 1956–1959.

...probably due to the joint seasonal (August) and interannual effects in that year (Fig. 6b). This coupled seasonal plus interannual deepening of the pycnocline was also evident in 1983 for October; i.e. in 8310 it was deeper than in 6110, 7410 and 8110 (Fig. 6a).

On the origin and propagation of anomalous conditions. The anomalous T–S characteristics, in particular the low salinities observed at the Guaymas Basin during El Niño years 1957 and 1983 suggest an invasion of water from outside the Gulf, because there is no source for such low salinity surface waters inside the Gulf. An investigation on the origin and mechanism of their propagation to the interior of the Gulf is beyond the scope of this work. However, it is convenient to show here some previous results and to infer from them an hypothesis on the subject for the 1982–1983 ENSO event in the Gulf.

McCready (1976) suggests an intensification of poleward geostrophic flow along the eastern Pacific Ocean, associated with El Niño and induced by poleward propagating Kelvin waves which originate in the Tropical Pacific. Wyrtki (1985) indicates that part of the El Niño cycle is the transport of heat toward the poles by an advective process. According to Chavez et al. (1983) SST anomalies observed in late August 1982 in the Galapagos Islands, propagated to the east and then along the coast of South America, at
a rate of about 1200 km month$^{-1}$. Assuming that the signal propagated to the north with the same constant speed, the SST anomalies would take about 2 months to reach the Gulf entrance. Further, an enhancement of the northward-flowing Costa Rica Coastal Current and a complete blanketing of the Gulf entrance with Tropical Surface Water, above 50 m depth, is expected during the peak phase of an El Niño; on the other hand, during anti-El Niño periods, exchange with the Gulf above 150 m should be limited to the Transition and Subarctic Waters of the California Current (Baumgartner and Christensen, 1985).

Previous results cited above support the idea of long-term advection from the Tropical Pacific to the poles during an ENSO event. However, Simpson (1983, 1984a,b), explaining the evolution of anomalous oceanographic conditions of Southern California during the 1982–1983 El Niño, suggested a wind-induced regional forcing, rather than the long-term advection from the tropics proposed in theoretical papers (e.g., McCreary, 1976) and by Baumgartner and Christensen (1985). Many Californian El Niño and anti-El Niño events are resonant (El Niño) and anti-resonant (anti-El Niño) responses of the normal seasonal cycle of the California Current to the intensification of the Aleutian low and weakening of the North Pacific high; the transport of the California Current during late spring and early summer was increased during the 1982–1983 El Niño (Simpson, 1984b).

Consequently the Transition Water of the California Current and the Tropical Surface Water from the Costa Rica Coastal Current, could have met and mixed at the Gulf entrance during the stronger 1957–1958 and 1982–1983 ENSO events. In such a case, the “mixed El Niño Water” could have been carried north into the Gulf by local surface circulation patterns (e.g., Alvarez-Sanchez, 1974). Meanwhile, the surface temperature and salinity should have been decreased and increased, respectively, since in the mean, surface temperature decreases and surface salinity increases going north into the Gulf to the Salsipuedes–Tiburón Sill.

During the 1982–1983 El Niño, the saltier and colder Gulf Water should have sunk near the sill, then following southward to the entrance, immediately below the mixed Transitional–Tropical Water entering the Gulf. This is supported by the subsurface salinity maximum observed at the Guaymas Basin in 1983 (Figs 2b,d,g).

Precipitation. Monthly rain anomalies (MRA) at Guaymas and Santa Rosalia, in opposite margins of the Guaymas Basin, are shown in Fig. 7. Each El Niño year is indicated by EN and its intensity by S (strong), M (moderate) and W (weak), after Quinn et al. (1978).

Some interesting features are evident in Fig. 7, and pertinent results on the possibility of increased rainfall during El Niño years and surface freshening by precipitation, can be inferred from them.

(a) There are positive, relatively high MRA peaks, indicating abundant rainfall, for the strong El Niño years 1958, 1972 and 1983, and for anti-El Niño years 1959, 1962 and (more evident) 1967. Some moderate and weak El Niño years have normal or lower than normal precipitation, e.g., during the 1965 moderate El Niño. Independently of the year, most of the higher MRA peaks fall between August and October, the season of tropical hurricanes in the eastern North Pacific. For instance the noticeable MRA peak of 114 mm (130 mm in total precipitation) during August 1983 (an El Niño year) at Santa Rosalia, coincides with the development of hurricane Ismael, off the west coast of Baja California, and also with a tropical depression near 23°N in southern Baja California.
(b) It did not rain at Guaymas nor at Santa Rosalia from April to June 1957, nor from January to June 1982. Consequently the cold, low salinity subsurface waters observed in the Guaymas Basin during June 1957 and June 1982, were not related to precipitation.

(c) The year 1957 had normal or below normal precipitation at Guaymas, but there were two peaks of MRA at Santa Rosalia. However, the higher MRA peak (56 mm) was in October, after the observations were done, and the lower peak (17 mm) was in March, 6 months before the low salinities were observed in August 1957. Consequently, there is no evidence that rainfall instead of advection from the south, could be the source of the low salinities observed in August 1957 in the Guaymas Basin.

(d) In 1982 it did not rain at Santa Rosalia except in September, and it rained abundantly (101 mm) at Guaymas only in November. Normal rainfall (10–20 mm) continued from January to April 1983 at Guaymas. However, relatively high surface salinities (about 35.1‰) were observed in nearshore stations off Guaymas in March 1983. Lesser precipitation at Santa Rosalia than at Guaymas from January to May, would not explain the lower surface salinities (34.9‰) observed in the central and western Guaymas Basin during March and May 1983.

(e) Precipitation during October 1983 was lower than normal in both, Guaymas and Santa Rosalia (4 and 15 mm totals, respectively). However, as noted before, it rained abundantly (130 mm) at Santa Rosalia during August 1983, about 2 months before the low salinities were observed. Consequently, the October low surface salinities could be due to the August abundant precipitation, only if the effect of the latter persisted off Santa Rosalia for about 2 months.
In summary: (1) Abundant precipitation in the Guaymas Basin region can be due to
hurricanes, rather than to ENSO events. (2) As it did not rain during June 1957 and June
1982, the only other source for the observed cold, low salinity subsurface waters would be
the California Current in the Gulf entrance, and (3) low surface salinities in El Niño
years 1957 and 1983 were not due to abundant precipitation, except perhaps in October
1983.

CONCLUSIONS

A strong seasonal signal in surface temperature was observed, ranging from 16°C in
February–March to 31°C in August. Winter conditions extend from December to April
and summer conditions from June to October, with transitions in May and November. A
seasonal cycle in surface salinity is not seen as clearly as in temperature. In normal
conditions surface salinity is always above 35.1‰. Its highest value was slightly above
35.5‰ in November.

California Current Water, distinguished by a shallow salinity minimum and tempera-
ture as low as 15°C at about 75 m depth, is more likely to occur in the Guaymas Basin
during spring–summer. Subsurface Subtropical Water may occur around the year, at
about 200 m depth, often obscured by mixing with lower levels of the saltier Gulf Water.

This mixing may be enhanced in winter by cooling and weaker stratification in near-
surface layers; stratification is stronger in summer. At greater depths, the Intermediate
and Deep Pacific Waters occur successively, filling the Guaymas Basin to the bottom.
These water masses have very stable T–S characteristics in both the seasonal and
interannual time scales. Seasonal changes in the depth of the pycnocline, shallower than
100 m in winter–spring and around 150 m during summer–autumn, were observed in the
Guaymas Basin.

There is an interannual signal in the sea level at Guaymas, as well as in T–S
characteristics in the Guaymas Basin, related to the El Niño-Southern Oscillation
(ENSO) phenomenon. The highest peaks in monthly sea level anomalies at Guaymas
were 20 cm in 1957–1958, 18 cm in 1972–1973 and 30 cm in 1982–1983, the three
strongest ENSO episodes in the last 30 years. On the other hand, the available T–S data
for 1957 and 1983 suggest an invasion of anomalous lower salinity and relatively warmer
surface waters during those El Niño years. Observed differences in surface salinity were
as high as 0.4‰ in the 1983 El Niño vs the 1970 or 1974 anti-El Niño. Corresponding
differences in surface temperature were about 3°C. However, differences about 5°C were
1983 is about 3°C warmer than the mean SST value shown in charts for the same month
and area by ROBINSON (1973). Saltier and colder Gulf Water was found below the
anomalous lower salinity water in 1983 only.

Year-to-year changes in the depth of the pycnocline were also observed in the
Guaymas Basin. Regardless of the season the pycnocline was deeper in El Niño than in
anti-El Niño years. However, these interannual changes were more evident in winter–
spring, due to the weaker stratification during this season. In March 1983 the pycnocline
sunk as deep or deeper than 150 m, compared to its depth <100 m in March 1939 and
March 1970. It reached the greatest depth (almost 200 m) in October 1983, when
seasonal and interannual effects were acting together. The deepening of the pycnocline
was also evident during the 1957–1959 El Niño, from August 1957 to April 1959.
There was no clear evidence of abundant rain to which the low salinities observed in August 1957 and in March, May and perhaps October 1983, could be related. Because no other source for such low salinity (34.8–34.9%) surface water exists inside the Gulf, its immediate source would be at or near the Gulf entrance. In El Niño years, we suggest an enhancement of the north-flowing Costa Rica Coastal Current, carrying Surface Tropical Water to this region. This low saline, relatively warm water met and mixed with the surface expression of the lesser saline and colder California Current Water. This "mixed El Niño Water" may be advected by local circulation into the Gulf, at least as far as the Guaymas Basin.

The presence of the surface water masses cited above is a common feature near the Gulf entrance. Historical T–S data, however, did not show anomalous characteristics, neither in magnitude nor in its intrusion to the north inside the Gulf, as those observed in the Guaymas Basin in 1983, with the exception of the 1957–1958 ENSO episode. The anomalous hydrographic conditions related to these ENSO phenomena may have lasted at least 1 year in 1982–1983 (October 1982 to October 1983) and about 2 years in 1957–1959 (July 1957 to mid-year 1959).

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