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Influence of EBES seamount and Farallon basin on coastal circulation in the Gulf of California, Mexico

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RESUMEN

Se analiza la circulación costera y la influencia del Bajo Espíritu Santo (EBES) sobre la circulación local a partir de observaciones directas de corrientes con ADCP e hidrografía. EBES se localiza en el extremo sur del Golfo de California frente a la Bahía de la Paz. La distribución de los campos hidrográficos indica la presencia anómala de agua superficial ecuatorial, asociada al intenso evento de El Niño 1997-1998. Las observaciones directas de corrientes, estimaciones geostróficas y distribuciones de temperatura superficial obtenidas por imágenes infrarrojas de satélite muestran la presencia de un giro ciclónico de ~120 km de diámetro en la capa superficial sobre la Cuenca de Farallón. Las mediciones directas de corriente muestran la presencia de un intenso flujo (> 0.5 ms^{-1}) en una angosta banda (~ 25 km) adyacente a la Península de Baja California. El análisis Lagrangeano del campo de corrientes sobre el EBES muestra claramente la presencia del intenso flujo costero y la convergencia del flujo inducido por efectos topográficos.

PALABRAS CLAVE: Montaña submarina, circulación costera, giro ciclónico, Golfo de California.

ABSTRACT

Hydrographic and current observations were gathered during a 1997 cruise in the southern Gulf of California, off La Paz Bay, to study coastal circulation and the influence of El Bajo de Espíritu Santo (EBES) seamount on the local flow. We detect an unusual presence of equatorial surface water related to the El Niño event of 1997-1998. In Farallón basin we describe a 120 km diameter near-surface cyclonic eddy from ADCP current measurements, geostrophic calculations and satellite imagery. Flow measurements show an intense (> 0.5 m s^{-1}) and narrow (25 km) coastal jet flowing north towards the interior of the Gulf along the Baja California coast. A Lagrangian analysis of the flow field over the seamount shows the coastal jet and the convergence of the impinging flows where bathymetry is important.

KEY WORDS: Seamount, coastal circulation, cyclonic eddy, Gulf of California.

1. INTRODUCTION

The bathymetry of the southern Gulf of California is characterized by deep (> 3000 m) basins. Along the mainland the continental shelf is up to 45 km wide but on the Baja California side it is very narrow and often the slope is very steep.

The study area is in the southern Gulf of California (Figure 1), some 150 km north of the mouth of the gulf. This is a region of complex bathymetric features west of Farallón basin. At least two seamounts, El Bajo de Espíritu Santo (EBES) seamount at 24° 41.5N, 110° 16.1W and El Charro seamount, are found. The latter is about 10 miles southeast of EBES. It does not appear on the charts but is well known to local fishermen (see also Figure 3).

The hydrographic field of the Gulf of California shows pronounced seasonal variability (Robles and Marinone, 1987). Volumetric analysis of water masses near the entrance of the gulf (Torres-Orozco, 1993) show four water masses in the upper 600 m (Table 1). In a typical year, as described by Torres-Orozco (1993), the Equatorial Surface Water (SEq) invades the surface of the gulf as far north as Farallón basin in fall. During spring this water is only found near the entrance, on the continental shelf of the mainland along the coast of Sinaloa. In contrast, during the spring of 1983 (1982-1983 El Niño) the volume of this water mass was four times higher than the historic average (1939-1990). It invaded the surface north of Farallón basin, well into Guaymas basin. Other studies (Bray and Robles, 1991; Lavín *et al.,* 1997) report a thicker upper layer during El Niño years. This is composed mainly of SEq water, which overlaps the more saline Gulf of California water. For El Niño 97-98 Castro *et*

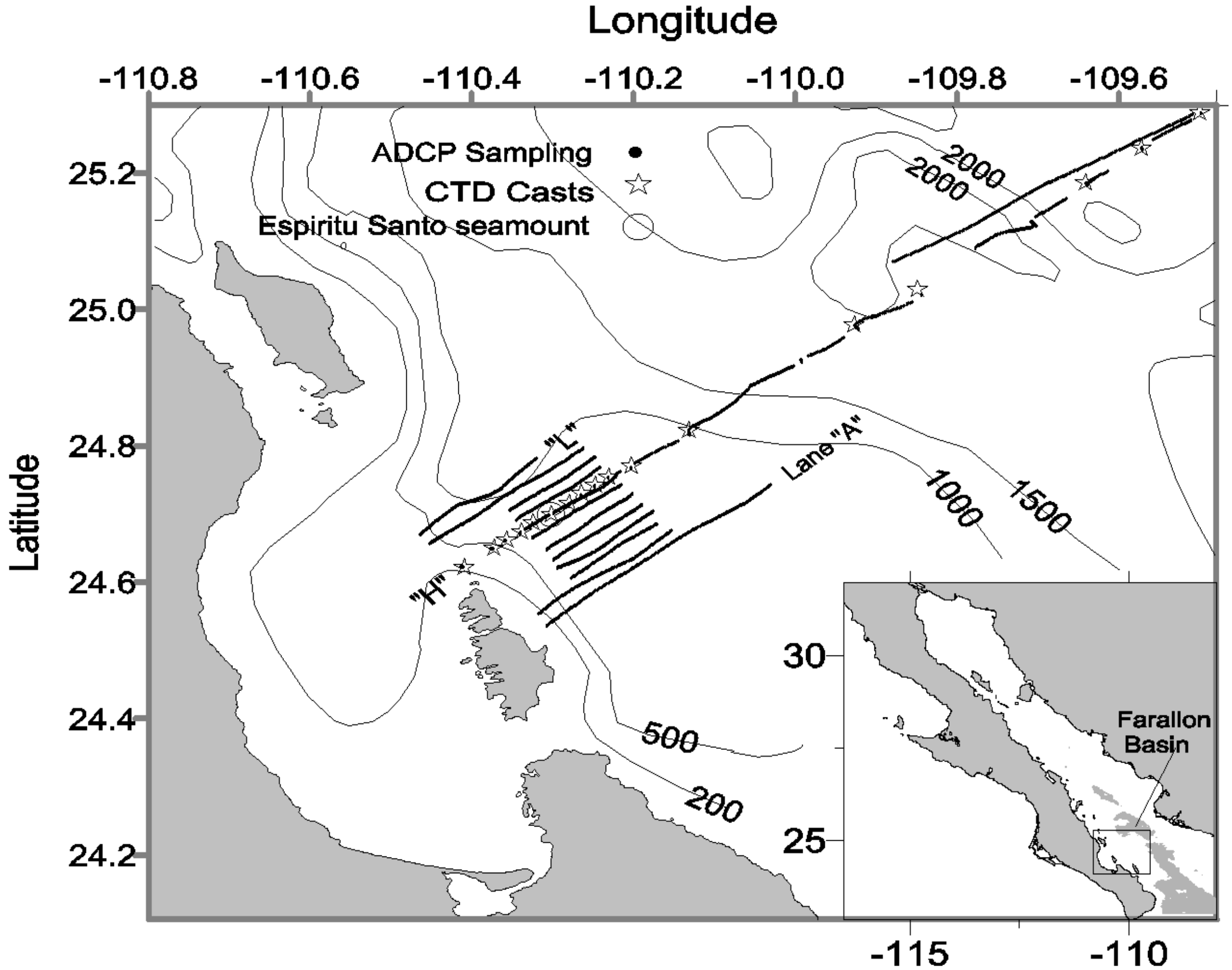

Fig. 1. Region of study, including the ADCP survey and CTD stations.

Table 1

Name	Range (m)	S (psu)	T °C
Gulf of California water (GC)	0-100	>35.0	>12
Surface Equatorial water (SEq)	0-100	<35.0	>18
Subtropical subsurface water (StSs)	100-500	34.5-35.0	9.0-18.0
Pacific Intermediate water (PI)	>500	34.5-34.8	4.0-9.0

al. (2000) reports the presence of SEq water over a thick surface layer of 100 meters in the mount of the gulf on November 1997.

Throughout the year the infrared satellite imagery distinctly shows the presence of eddies in the Farallón basin (e.g., Figure 2). Emilsson and Alatorre (1997), using Lagrangian drifters and geostrophic calculations, documented the presence of a cyclonic eddy in the Farallón basin during the summer. This eddy was about 100 km in diameter and it extended from the shelf break of the mainland to some 25 km east of Espíritu Santo Island, off the Bay of La Paz. It influenced the dynamics of the upper 50 to 70 m of the gulf. The speed of the flow at its periphery averaged 29 cm s^{-1}, with maximum speeds of 56 cm s^{-1} on its western side, off the Baja California coast. These authors also detected a narrow countercurrent towards the inside of the gulf, on the Baja California shelf and the shelf break. Geostrophic calculations reported by Warsh and Warsh (1971) show a similar coastal flow field.

Bathymetric features such as seamounts have long been recognized as capable of modifying the biology of the upper ocean; they modify the circulation and increase the primary productivity (Bakun, 1996; Roden 1987; Freeland, 1994). In the mouth and in the southern Gulf of California there are

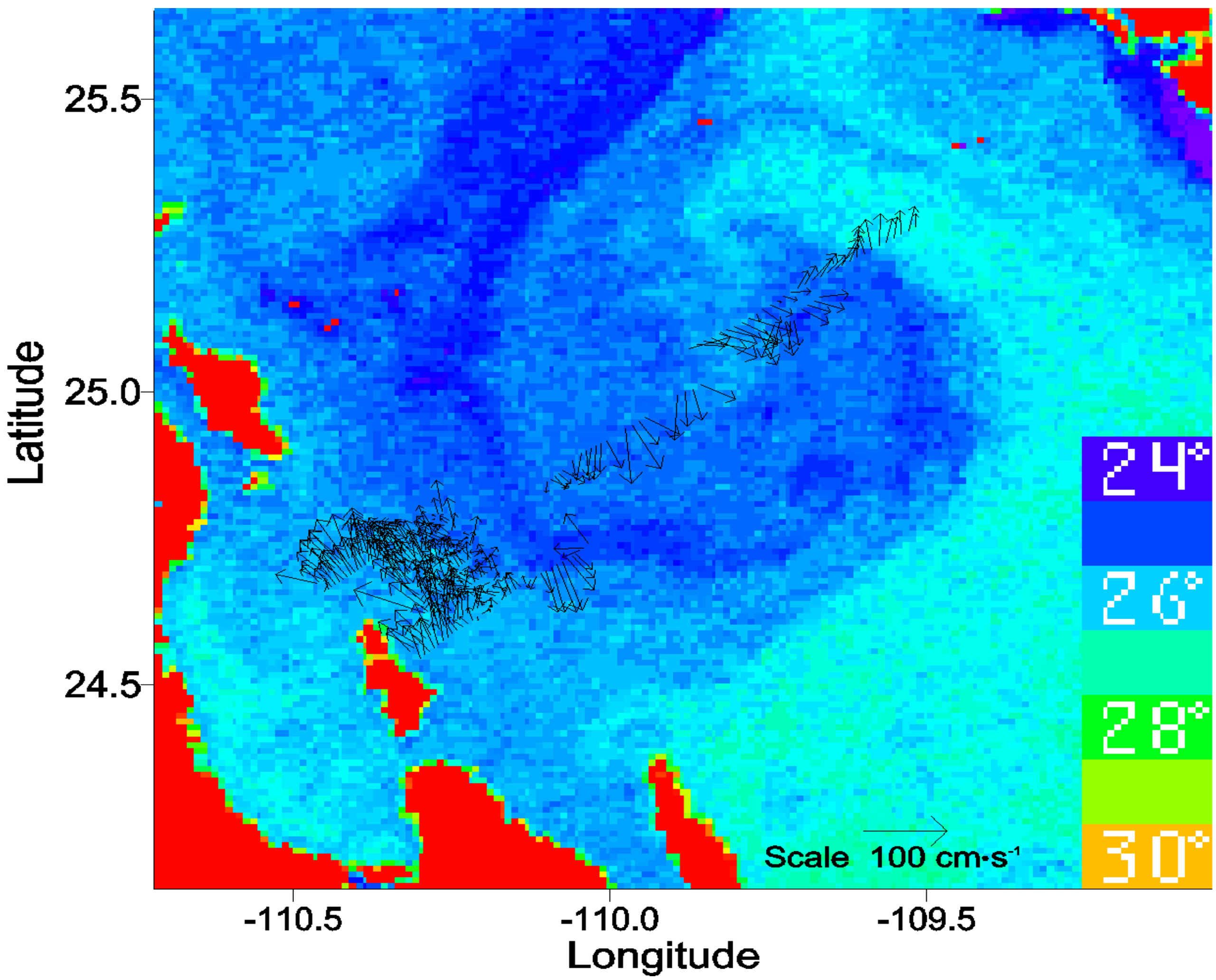

Fig. 2. Satellite image of 17 November 1995 showing temperatures in false color. Surface currents from the ADCP survey of 24 November 1997 are shown superimposed.

several seamounts (banks or 'bajos') well-known by commercial and sports fishermen.

We study the circulation west of Farallón basin during the 1997-1998 El Niño event, and the effect of seamounts on surface circulation. The next section briefly describes the observational campaign. Section 3 discusses results of bathymetric, hydrographic and ADCP (acoustic current Doppler profiler) surveys, as well as available satellite imagery. A discussion and conclusions are presented in section 4.

2. OBSERVATIONAL CAMPAIGN

A three-day cruise was carried out from 22 to 24 November, 1997 on the B.O. Francisco de Ulloa (CICESE) on the western side of the Farallón basin, around the top of the EBES seamount. Figure 1 shows the track of the ADCP-thermosalinograph survey, as well as positions for a number of conductivity-temperature-depth (CTD) casts (line H). Infrared (AVHRR) satellite imagery gathered by CICESE's land station in La Paz was also analyzed.

A SBE9/11 CTD from Seabird Electronics was used to perform the casts. The CTD was calibrated prior to the cruise and consistency checks with historical data were carried out. The on-board current profiler was a broadband, 150 KHz ADCP from RD Instruments, and the thermosalinograph was an SBE 21 SEACAT from Seabird Electronics.

Bathymetric data were gathered throughout the campaign, which were later refined using small boats, with special attention given to the seamounts and off the east coast of Espíritu Santo Island.

3. DISCUSSION

3.1 Bathymetry

Depth measurements show a number of topographic features that are not present in the nautical charts of the area (Figure 3). One of these is the deep elongated basin between the EBES seamount and Espíritu Santo Island. Maximum depths are greater than 800 m, with steep eastern and western flanks (some 300 m/km in the slope adjacent to EBES). The EBES (24.7 N, 110.3' W) seamount and El Charro seamount to the east (24.7 N, 110.18' W) are also conspicuous features. The former covers some 78 km^2 at 500 m depth, some 2 km^2 at 200 m and only about 0.2 km^2 above the 50 m isobath. At least two small peaks reach depths between 15 and 25 m below the surface.

3.2 Hydrography

Sea surface temperature (SST) and salinity (SSS) varied only between 27.2 and 27.7 °C and between 34.5 and 34.7 psu, respectively (Figure 4). Oceanic waters were slightly cooler and saltier than those found closer to the coast. The temperature section (Figure 5a) along line H (see Figure 1) shows a deep upper mixed layer with temperatures above 26 °C. The base of the mixed layer lies at about 80 m depth and the base of the thermocline at about 100 m. In the salinity section (Figure 5b) this upper layer is characterized by salinities lower than 34.9 psu, decreasing towards the west (coastal side). Below the thermocline, at about 120 m depth, salinity increases to a subsurface maximum of 34.95 psu. Lower salinities are observed at these depths in the three easternmost casts, suggesting a transition to conditions more

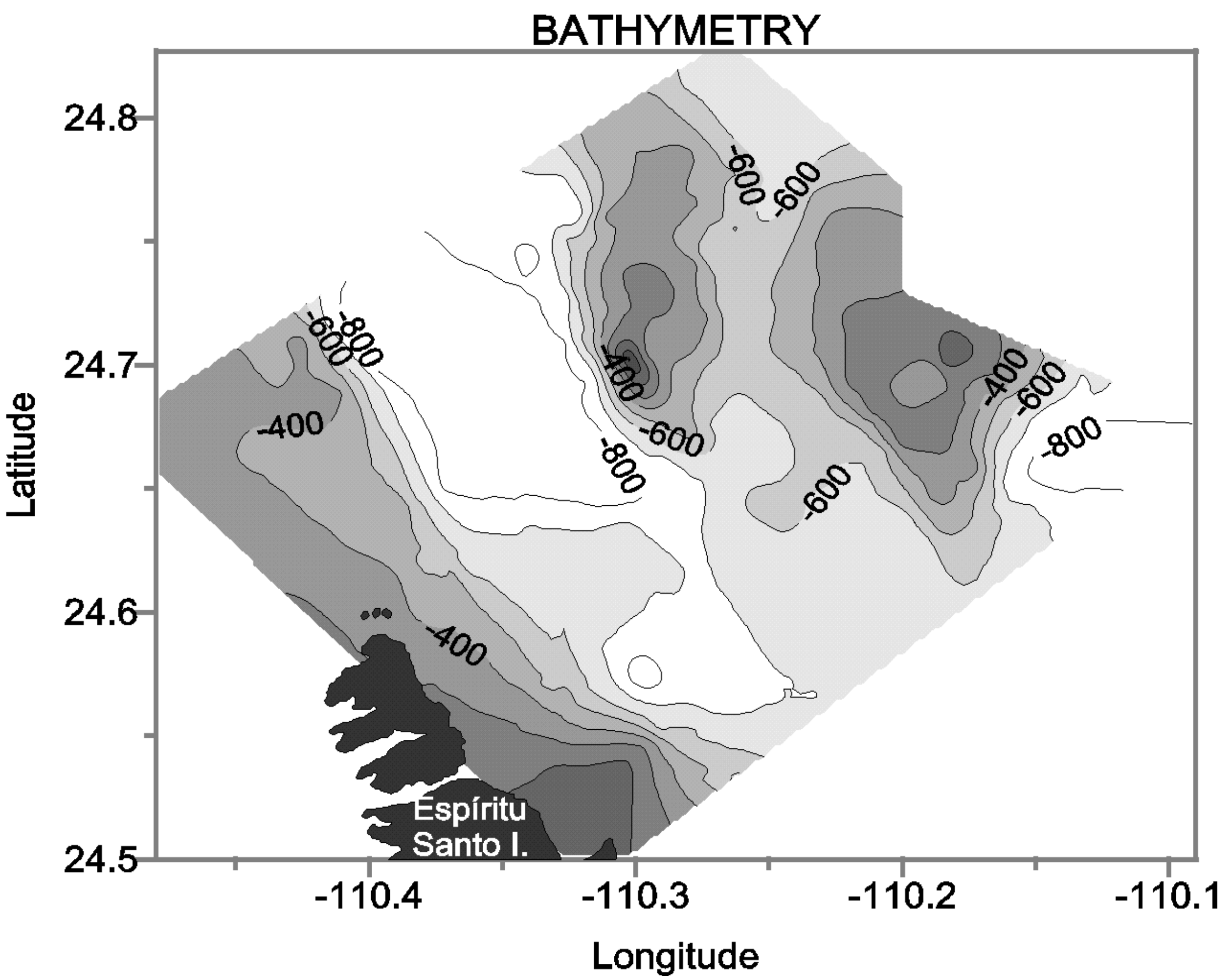

Fig. 3. Bathymetry of the area around the seamount.

representative of the gulf's interior. Such conditions are a consequence of the advance of SEq waters in the upper 80 m of the survey area. This represents over 10% of the total volume in the coastal region. Previously this had only been observed during the 1982-1983 El Niño (Torres-Orozco, 1993). This increased volume of SEq in the south of the Gulf during El Niño 97-98 was also observed at the mouth of the Gulf by Castro *et al*. (2000) in a survey during november 1997.

3.3 Circulation

The flow fields shown in Figure 6a come from one minute time-averaged profiles. This is one profile about every 130 m along the track. Although the nominal range of the 150 KHz ADCP used here is of 250 m, valid data (over 95% signal return) were only obtained to 150 m depth. Also shown are dynamic calculations of the geostrophic flow (Figure 6b) based on temperature and salinity casts along line H (see Figure 1).

Figure 6a shows contours of the longitudinal component of the ADCP currents along line H (see Figure 1) from the surface to 150 m depth. In most of the section the currents flow towards the entrance to the gulf. This flow is coherent to at least 150 m depth and has a maximum speed of about 0.40 m s^{-1}. Near the offshore side of the section this component of the flow weakens to about 0.1 m s^{-1} and flows towards the interior of the gulf. A region of significant horizontal shear occurs in the transition of the flow regimes, at about 109.7 W. In the density section along line H (Figure 6c) a weak but unambiguous slope of the pycnocline supports the existence of the observed flows towards the entrance to the Gulf, and is consistent with the influence of a cyclonic eddy. Surface currents from the ADCP survey are shown superimposed on a temperature image showing an eddy (Figure 2). Even though the image does not correspond to the date of the survey, it shows great consistency with the circulation pattern. The coastal side, west of the seamount (west of 110.2W), exhibits a clear baroclinic behavior. An intense (up to 0.60 m s^{-1}) surface-intensified jet towards the interior of the gulf dominates the upper 80 m. Below 100 m the currents change to a weak (some 0.20 ms^{-1}) flow towards the entrance. A comparison with the geostrophic currents (Figure 6b) shows good agreement throughout the section, except close to the coast where more ageostrophic conditions are to be expected.

With few exceptions the vertical current sections around the seamount, such as that in Figure 7, show stronger flow near the surface. Its average magnitude in the upper 70 m varies between 0.40 and 0.70 m s^{-1}. Figure 7 shows a typical section from the along-flow (NW-SE) average of all measurements made on the grid around the seamount. The section is clearly separated in layers. Tidal currents do not contribute significantly to the large scale flow. It has been estimated (Marinone and Lavín, 1997) that its average magnitude is only about .08 m s^{-1} and this particular survey took place during neap tides. For these reasons the horizontal flow field around the seamount is separated for its discussion into three layers. Note that the circulation of the eddy is not evident in Figure 7 because only the area surrounding the seamount is shown. The three layers are a surface layer which extends to 70 m depth (Figure 8a), a transitional layer coinciding with the thermocline (between 70 and 100 m, figure not shown) and a deep layer from 100 to 150 m (Figure 8b). A simple statistical analysis of the variability of the flow finds less variability in both the surface and deep layer, as compared to the transitional one (Std. Dev. 4.2 at the surfer layer, 3.6 at the deep layer and 8.5 at the transitional one).

The dominant flow in the surface layer (0 to 70 m) is directed towards the northwest (Figure 8). Between the Espíritu Santo Island and the EBES seamount the flow appears uniform, reaching 0.50 m s^{-1}. Over the EBES and El Charro seamounts the dominant direction of the flow remains to the northwest but shows greater spatial variability. In the entire region there is a clear tendency to have higher speeds closer to shore. East (offshore) of the position of the EBES seamount the currents tend to be weaker: in the steep slope west of EBES the currents flow at speeds greater than 0.50 m s^{-1}, whereas to the east they average about 0.20 m s^{-1}. This suggests the influence of a large scale counter-flow. The cyclonic eddy influencing the region offshore of the seamount easily accounts for this characteristic.

Consistent with the discussion of the vertical structure of the flow along line H, in many sections the deep flow (100 to 150 m, Figure 9) is predominantly directed towards the entrance to the gulf. The observed variability most of it is probably associated to implicit observational errors. The currents are weak and slight navigational errors produced by the degradation of the GPS signal can account for the variability.

Lagrangian trajectories were estimated from the ADCP surface currents assuming a stationary flow. These are the trajectories that particles would follow for 12 hours in the average surface flow (Figure 9). Particles were 'liberated' over a regular grid throughout the field and overlaid trajectories were eliminated for clarity. Circles/asterisks mark initial/final positions. Since the flow approaches the seamount from the southeast, particles converge while approaching and while on the topography. This is a clear indication that three-dimensional motion is likely to occur when the flow approaches the seamount. Along the coastal jet the predominance of parallel 'streaks' is consistent with a more laminar

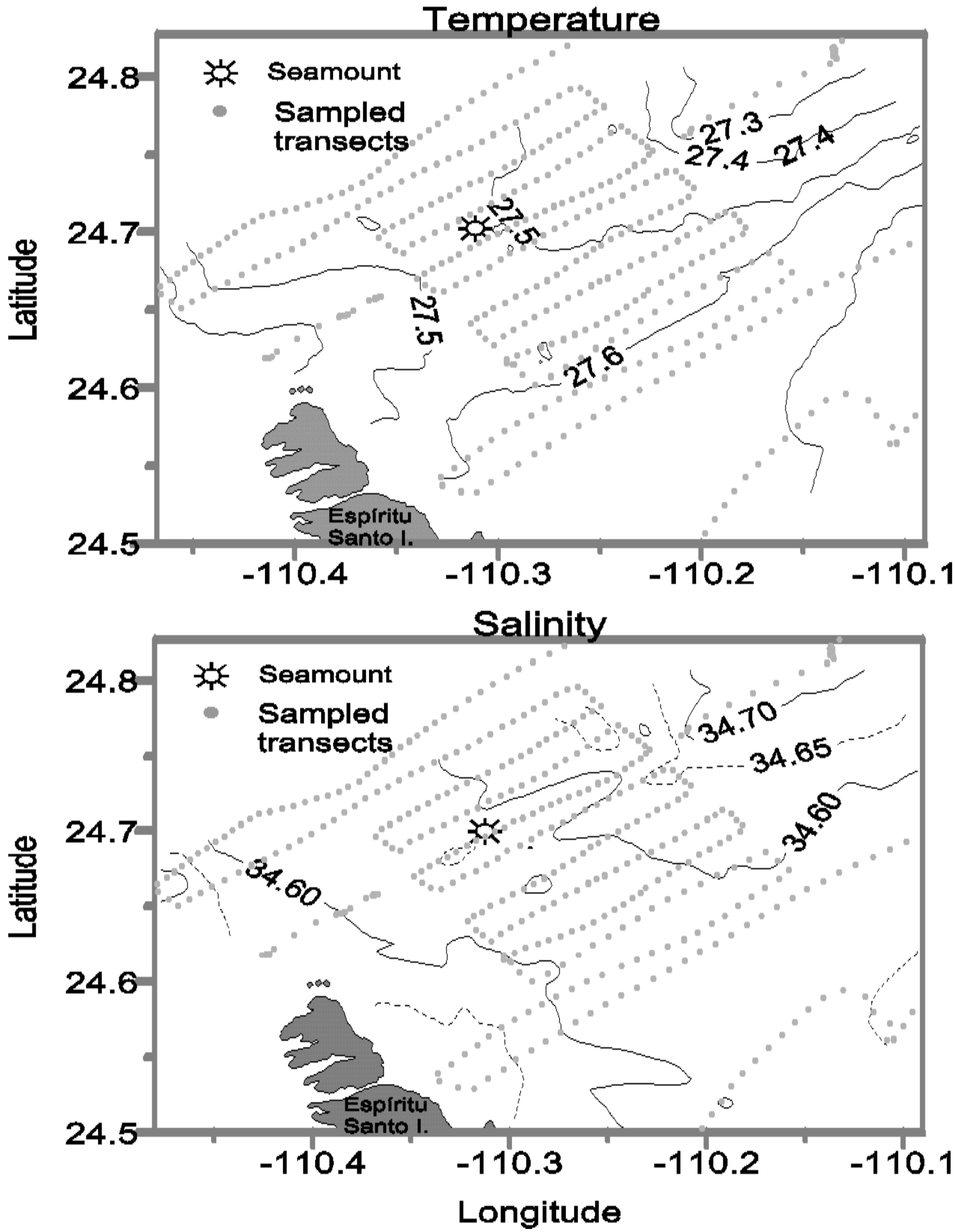

Fig. 4. a) surface temperature map from the on-board thermosalinograph; b) surface salinity map.

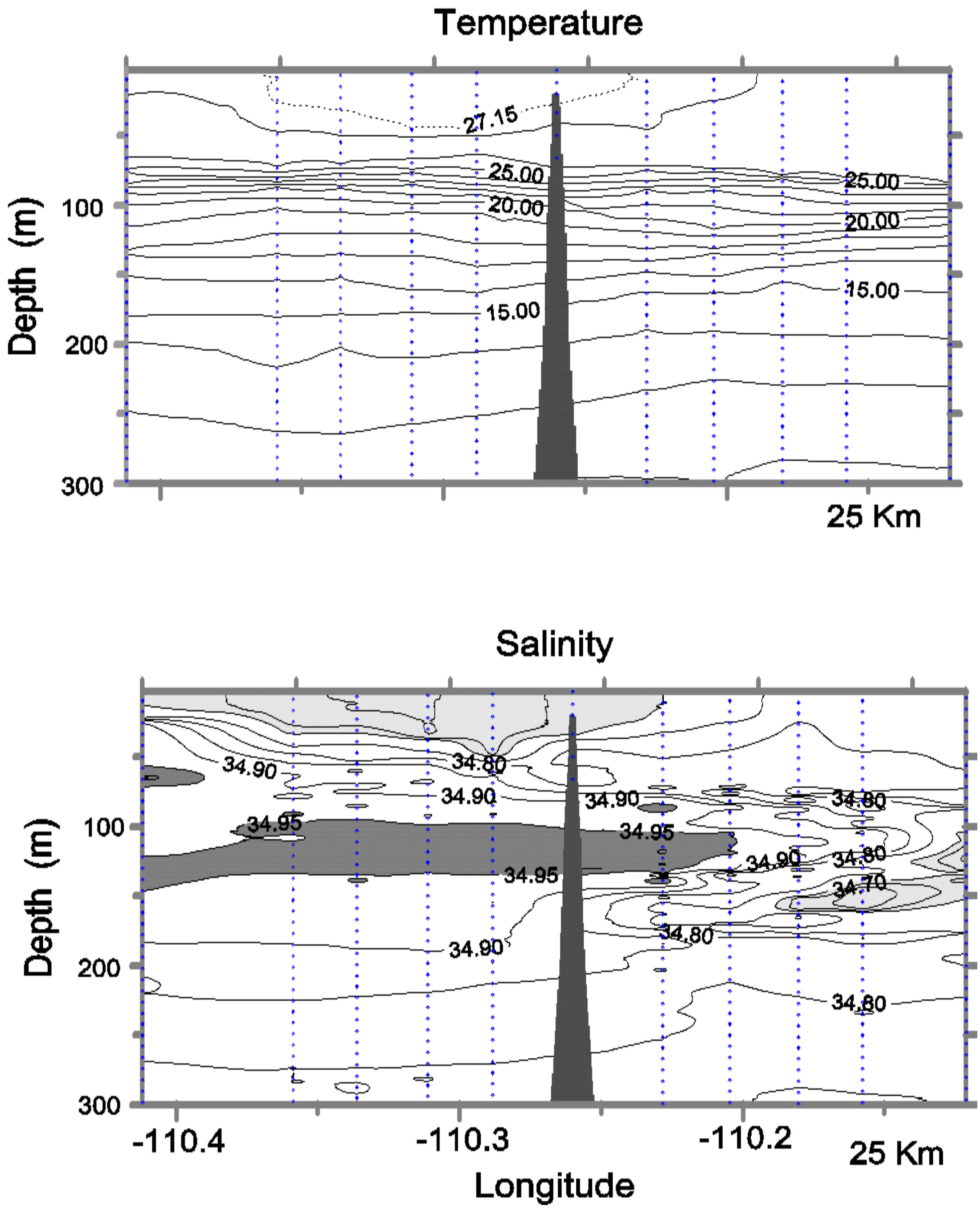

Fig. 5. Vertical section around the seamount (first 10 stations of line H): a) temperature section from CTD casts; b) salinity section from CTD casts.

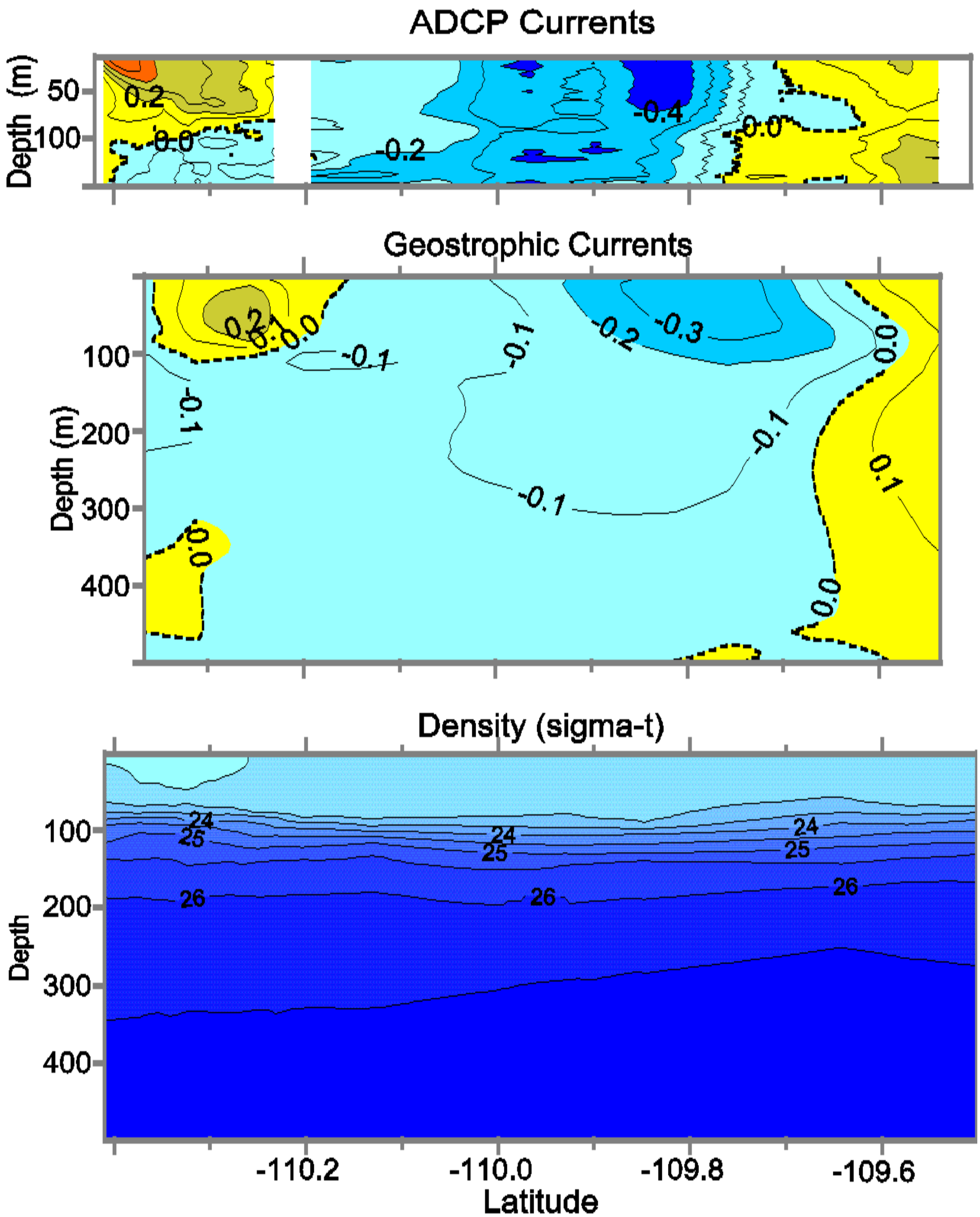

Fig. 6. Large scale vertical behavior of (all stations in Line H): a) ADCP current component perpendicular to the line; b) geostrophic currents; c) density section.

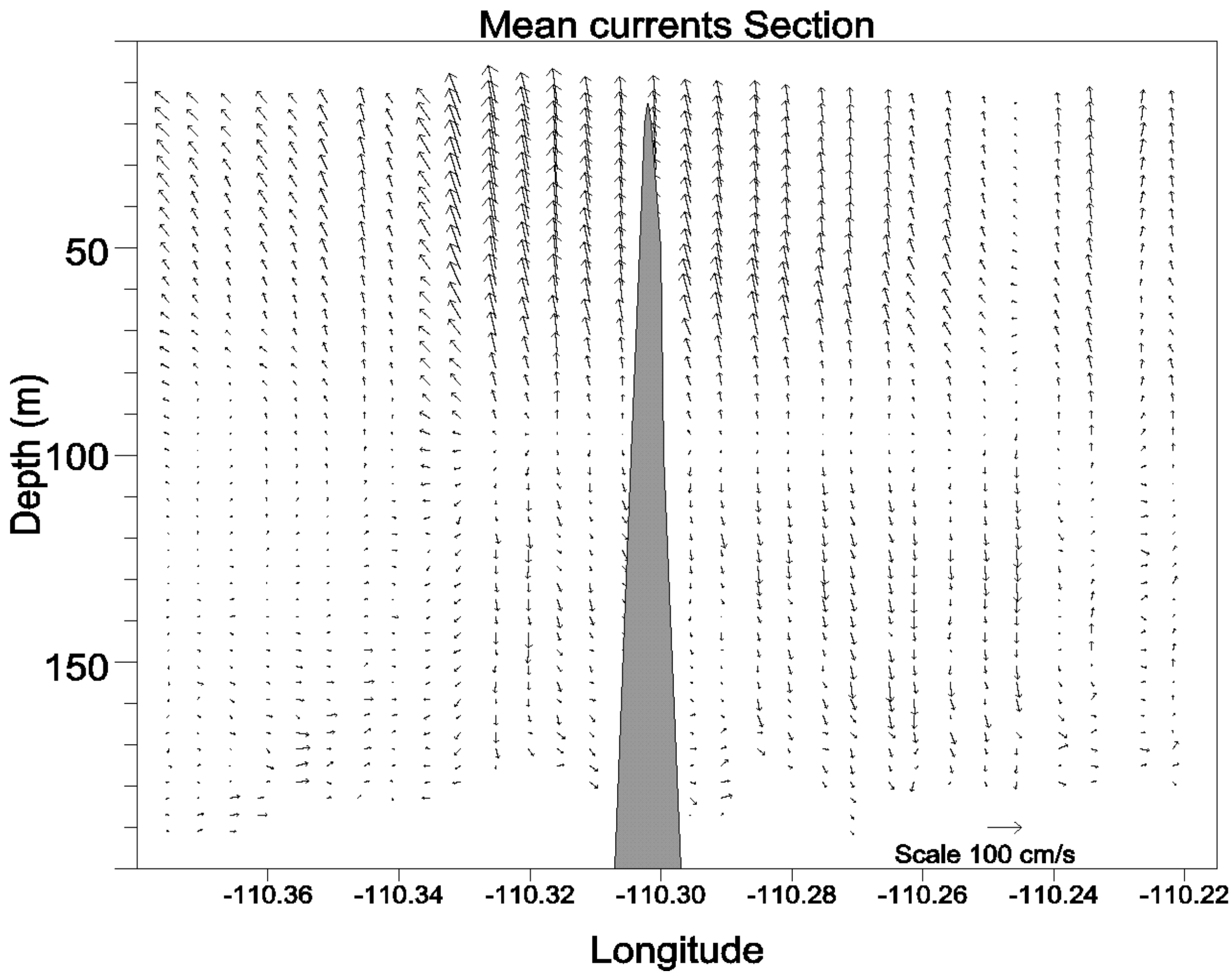

Fig. 7. Mean current section from the NW-SE average of all ADCP measurements around the seamount.

character in the flow. At the northern end of the observations of the coastal jet, particles tend to aggregate suggesting that convergence increases here as well. This is probably due to the narrowing of the topographic features surrounding the flow.

4. CONCLUSIONS

Hydrographic conditions during the cruise show the presence of a thick (80 m) layer of surface equatorial waters. Based on previous estimates (Torres-Orozco, 1993), this would represent about 10% of the total volume of the coastal region and occur as a result of the 1997-1998 El Niño event. Such conditions had only been observed previously in this region of the Gulf of California during the 1982-1983 El Niño.

The circulation on the vicinity of the seamount consists mainly of two features. One is a surface-layer coastal flow towards the interior of the gulf. The other is a subpycnocline coherent large scale flow towards the entrance to the gulf. Farther offshore ADCP and geostrophic currents are consistent with the presence of a cyclonic eddy in the oceanic region of the Gulf of California. Due to its influence the coastal circulation surrounding the seamount weakens towards the interior of the gulf. There are indications of the topographic steering of the flow in the vicinity of the EBES. Also, the convergence of the coastal jet while approaching the topography is consistent with a three-dimensional flow capable of inducing vertical motion around the mount.

These complex kinematic conditions contrast with relatively uniform surface hydrographic features produced by the invasion of the equatorial waters associated with El Niño of 1997-1998. The presence of a thick and homogeneous surface layer acts to inhibit local processes capable of enhancing the productivity on the seamount.

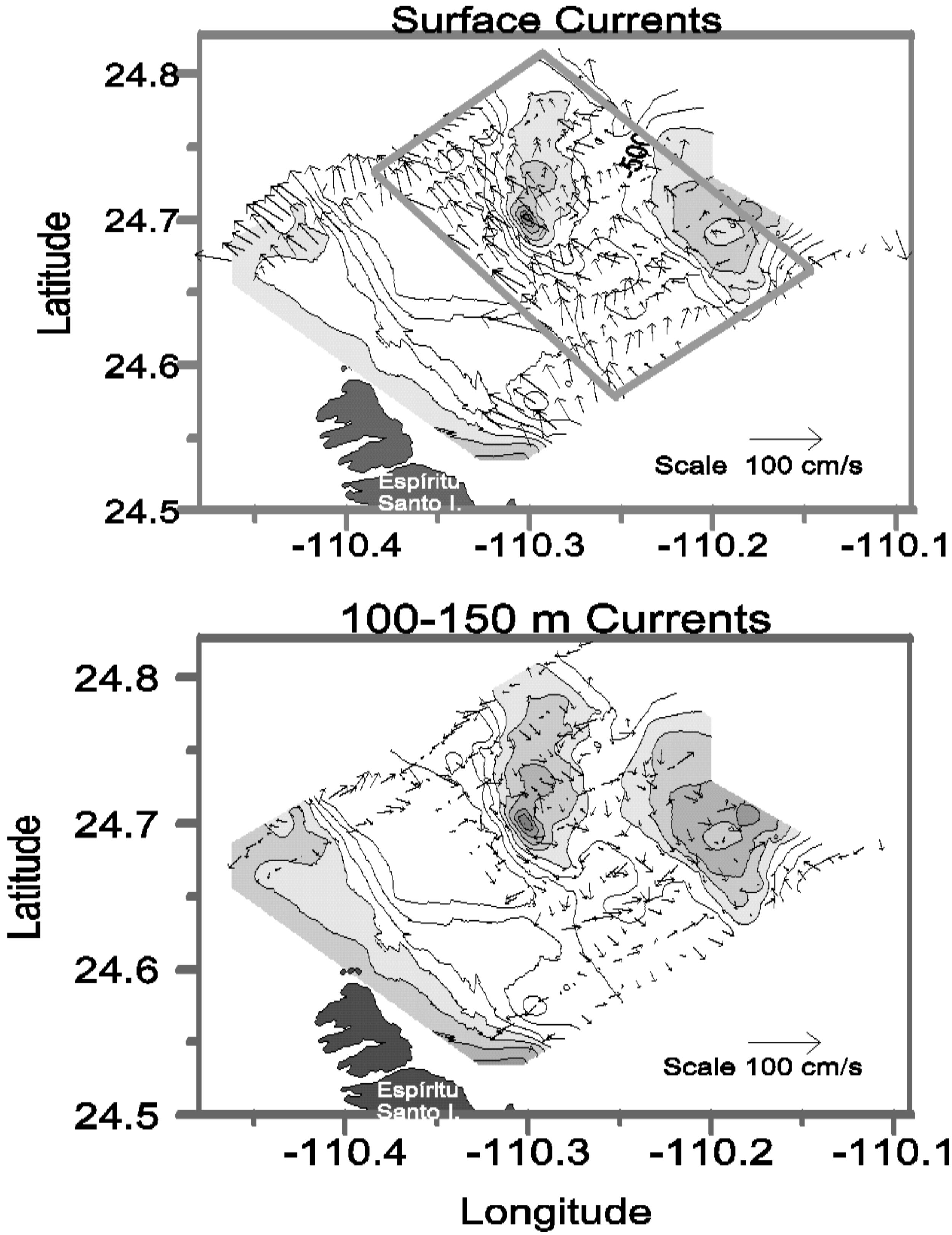

Fig. 8. Mean (vertical average) two-layer flow: a) surface (0 – 70 m) layer; b) subsurface (100-150 m) layer.

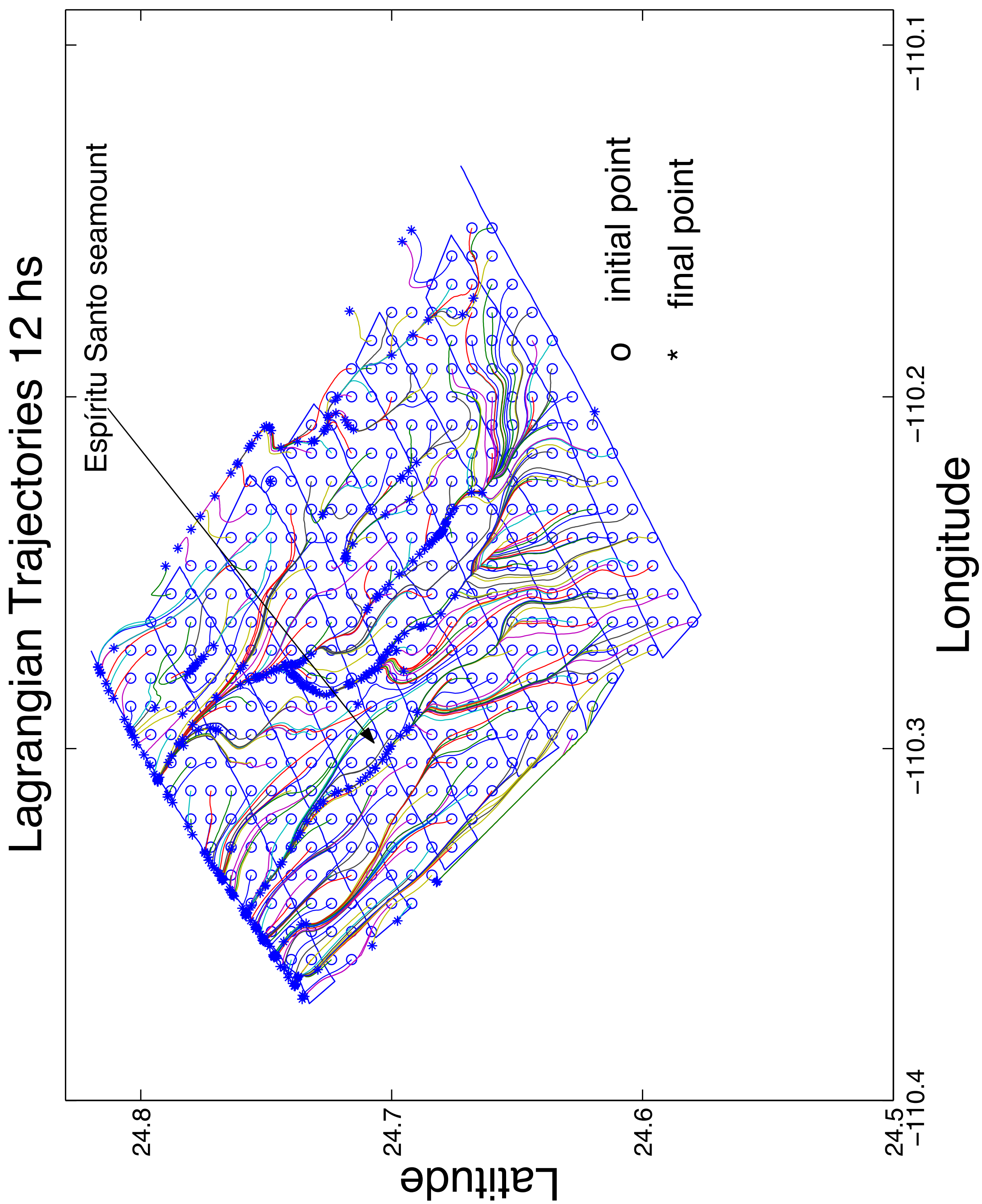

Fig. 9. Lagrangian trajectories of regularly spaced particles in the surface flow field during a 12-hour simulation, assuming stationary flow.

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