THE 1997–98 EL NIÑO: THE VIEW FROM LINE-P

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ABSTRACT

Though the earliest observations at Ocean Station Papa began in 1949, the useful oceanographic data along Line-P begin with 1956. Nevertheless, we do have 45 years of high-quality data describing the physical, chemical, and some aspects of the biological signals in the Gulf of Alaska. This note reviews the history of observations along Line-P, but focuses on the way the 1997–98 El Niño event manifested itself there. We were fortunate in being able to find the resources to mount an aggressive El Niño Watch program built around the long time series of Line-P and the La Pérouse project. This has allowed a thorough description of the evolution of El Niño as it progressed past the coast of British Columbia.

INTRODUCTION

As I began developing this presentation I became increasingly aware of the incredible value of the long time series, as exemplified by CalCOFI and by its northern colleague, Line-P. Both of these programs make it easy to compute and present plots of, for example, temperature anomaly fields. But we tend to forget that behind each of the anomaly fields is a mean field with 50 years of history behind it.

First, we must deal with some nomenclature. Ocean Station Papa, or Station P, is at 50°N, 145°W. The time series of observations at Station P is longer than the time series along "Line-P," which is the line of stations extending from the mouth of the Juan de Fuca Strait to Station P (fig. 1).

On 18 December 1949 the site subsequently known as Ocean Station Papa was occupied for the first time by a weather ship owned by the U.S. Weather Bureau, and the first oceanographic observations began with mechanical bathythermographs run once a day.

In December 1950 the U.S. ship was replaced by a Canadian weather ship, which did not immediately begin oceanographic observations. In July 1952, twice-daily mechanical bathythermograph observations began.

In July 1956, hydrographic stations were started. They usually sampled only to 1200 dbars, but occasionally they sampled to the bottom. This development represents the start of the really useful oceanographic program.

In April 1959 the Line-P program began, as hydrographic casts were started at five stations along a line leading to Station Papa. At various times improvements were made, and, in subsequent years, the number of stations constituting Line-P gradually expanded to 13.

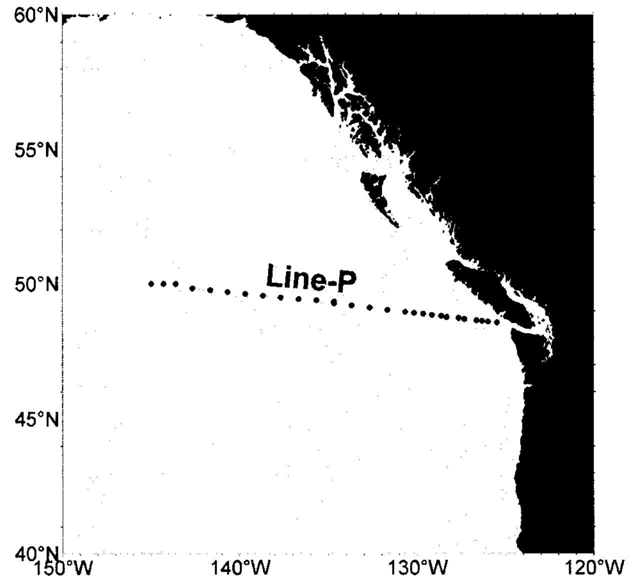

Figure 1. The location of Line-P in the Gulf of Alaska. Each dot represents a station.

In April 1969 a Bissett-Berman STD was used for the first time. In August 1974 a Guildline CTD was used for the first time.

In August 1981 the Canadian weather ship program was terminated. The value of the oceanographic program was well recognized, so the Line-P oceanographic program was maintained purely as a research program, with vessels operated by the Institute of Ocean Sciences. At that time the number of stations constituting Line-P was increased to 26, and a little later to 27, where it rests today.

Now we usually manage three surveys per year along Line-P, in February, May, and September. This timing is aimed at observing the conditions following the winter nutrient injection period, the peak of spring production, and the consequences of spring and summer production. In August 1998 NOAA/PMEL deployed an optical/climate mooring at Station P.

Figure 1 shows the locations of the 27 stations that currently make up Line-P. The line runs roughly along the boundary between the Alaska Gyre and the California

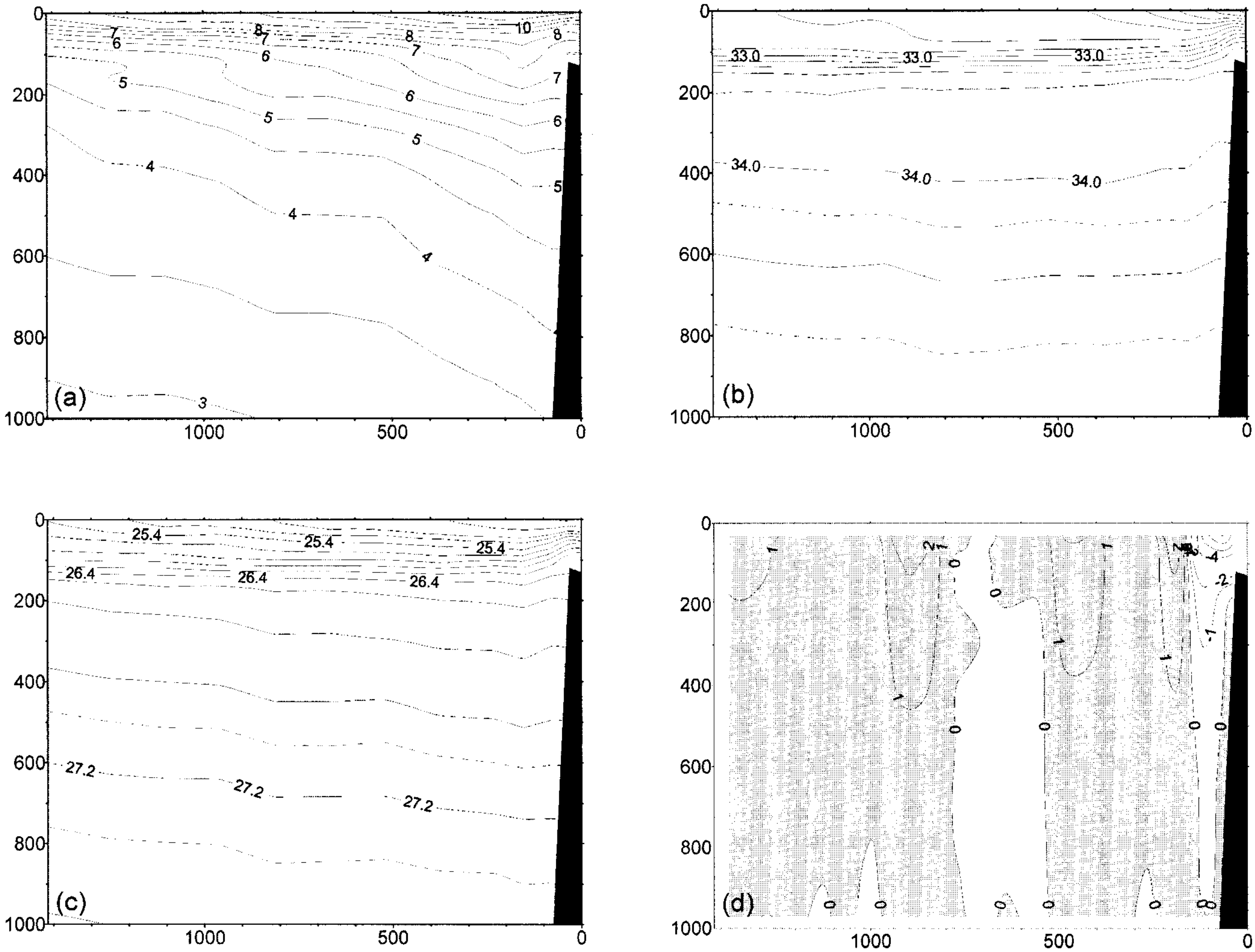

Figure 2. The mean state for June conditions along Line-P in (*a*) temperature, (*b*) salinity, (*c*) sigma-t, and (*d*) geostrophic velocity computed relative to 1000 dbars. In *d*, northward flows are shaded.

Current system. It is frequently argued that Station Papa is in the wrong place, that it might be better to monitor either the California Current system or the center of the Alaska Gyre. There may be some merit to this view, but an alternative view is that the right place for it is where it has always been, emphasizing the continual nature of the monitoring program. I concur with the latter view.

The continual nature of the sampling allows for the definition of mean fields. The diagrams in figure 2 show plots of the mean state for June conditions along Line-P, computed on the basic 13 stations. In comparing panels a, b, and c, we see that the dominant stratification in near-surface waters is supplied by salinity rather than temperature. As will be seen later, however, the contributions from temperature cannot be ignored. Below 200 dbar, temperature decreases monotonically with increasing distance offshore, whereas salinity shows little variation along Line-P.

Geostrophic velocities were estimated with the methods outlined by Reid and Mantyla (1976). As expected, the velocity field shows somewhat variable mean flows across Line-P in the offshore regions. Near the continental slope we see southward flow at the shelf edge. The mean state for other months shows northward flow at the shelf edge during the winter months and southward flow during summer. This transition is well known and described, for example, by Freeland et al. 1984. I find it slightly surprising that we see little evidence in figure 2 for the California Undercurrent. It should be present, but may have been missed by the relatively coarse sampling along Line-P.

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Line-P is not the only monitoring program in the coastal regions of British Columbia. At 14 lighthouses around our coast, lighthouse keepers sample sea-surface temperature and salinity every day. The oldest stations

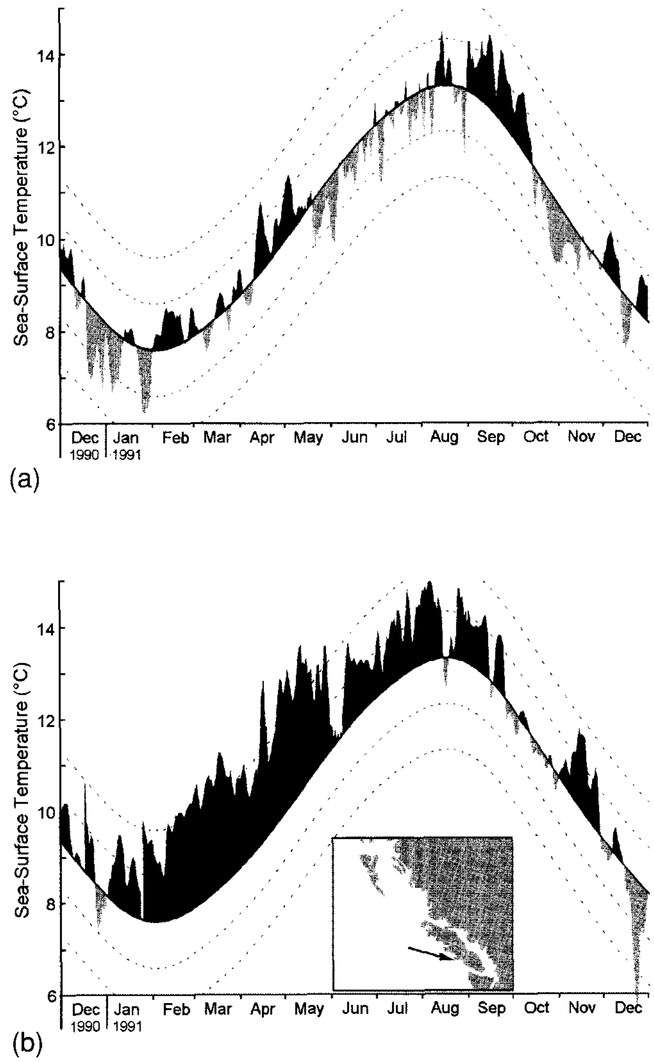

Figure 3. Sea-surface temperatures observed at Amphitrite Point, on the west coast of Vancouver Island (*inset*): *a*, December 1990–91; *b*, December 1982–83. Areas above the line show temperatures above normal; areas below the line, temperatures below normal.

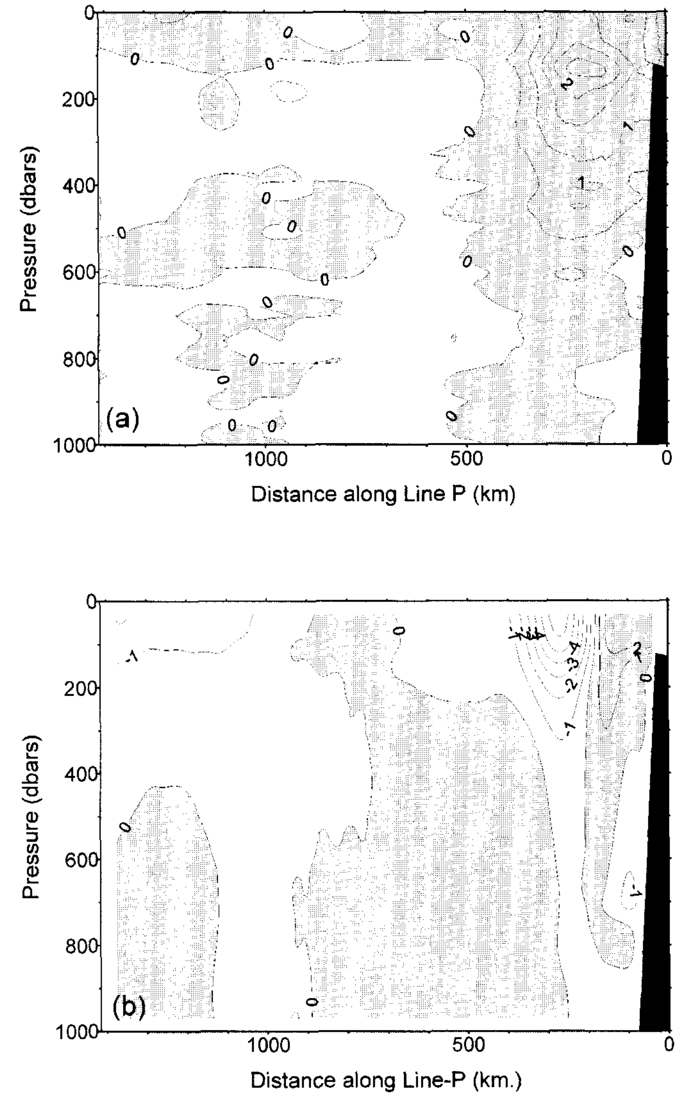

Figure 4. Temperature anomaly field *(a)* and velocity anomaly field (*b*) observed along Line-P during March 1983.

are poorly exposed to the open ocean but have data from 1914 to the present.

Figure 3a shows a plot of the temperature observations at Amphitrite Point for December 1990 to December 1991, a relatively "normal" year with nothing much going on. Figure 3b shows a plot for December 1982 to December 1983, indicating the response to the 1982–83 El Niño. The contrast is obvious: temperatures were considerably above normal for an extended period during 1983.

Figure 4 shows section plots of the temperature and geostrophic velocity anomalies along Line-P. The positive temperature anomalies and northward flows are shaded. It is striking how deep the maximum anomaly was in 1983, and we will be comparing this diagram with data from March 1998.

The velocity anomaly diagram is, however, baffling. Again this was computed with the methods recommended by Reid and Mantyla (1976) but produces an unusual picture. The contour of zero velocity anomaly separates a strong northward flow from a strong southward flow and coincides precisely with the maximum temperature anomaly. One might reasonably expect that the temperature anomaly feature should have an advective origin. In that case we might expect a bulls-eye pattern in the velocity anomaly, coincident with the temperature anomaly. To check the plausibility of the velocity anomaly field, we used the dynamic height estimates to compute the implied surface height anomaly at station P1; the implied height anomaly is about 4 cm.

The actual evolution of sea-surface height is shown in figure 5, which indicates actual height anomalies of more like 30 cm in March 1983. Clearly, our geostrophic velocity estimates are missing a large part of the actual signal, presumably a barotropic field.

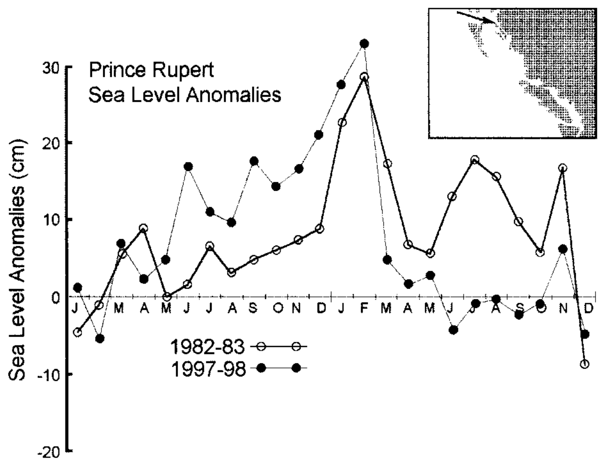

Figure 5. The evolution of monthly mean sea levels observed at Prince Rupert, B.C. (*inset*), for January 1982–December 1983 and January 1997–December 1998.

THE 1997–98 EL NIÑO EVENT

Figure 5 also shows the plot of sea-level anomalies for 1997–98, in comparison to those for the earlier event. The 1997–98 plot shows all the well-known and well-reported features of this El Niño event: the early start, the great intensity, and the abrupt collapse in March 1998. By this measure it is clear that the 1997–98 El Niño was the largest event of the century, at least in the response off the coast of British Columbia.

The Topex-Poseidon data set has been reanalyzed by Foreman, Crawford, and Cherniawsky (pers. comm.). Their analysis shows weak sea-level anomalies offshore from Vancouver Island immediately before the El Niño event, and eventually a very intense response, with maximum sea-level perturbations at the coast decaying monotonically offshore. Superficially, the distribution of sea level suggests Kelvin wave dynamics, but this has not been verified.

The six panels of figure 6 summarize the evolution of the large anomalies that dominated the northeast Pacific Ocean from spring 1997 into late 1999. In February 1997 (not shown here) the anomaly fields indicated very small perturbations throughout the northeast Pacific, or along Line-P. In the top pair of panels we see that by September 1997 the Gulf of Alaska was dominated by a major warm event. But the section plot shows that the warming was extremely superficial and confined to about the top 50 meters of the water column.

The middle pair of panels in figure 6, for March 1998, paints a dramatically different picture. The surface distribution suggests that a significant retreat of the warm waters of the Gulf of Alaska has taken place, but the section plot shows very large temperature anomalies concentrated below 150 dbars. This plot is remarkably similar to the plot in figure 4 showing the same anomalies for the 1983 event.

The final pair of diagrams in figure 6 shows the transition to the 1999 La Niña conditions. In this case the surface of the Gulf of Alaska is dominated by low temperature anomalies, and the right-hand panel indicates that the cooling is very superficial. However, we also see an intrusion of warm water in the offshore half of Line-P. At the present time it is not possible to speculate on the origin of this water mass.

Thus the development of the large anomalies of 1997–99 shows several distinct phases:

1. A superficial warming of the entire Gulf of Alaska between the onset of El Niño and the winter of 1997–98.
2. During the winter of 1997–98 and early spring of 1998 the Gulf of Alaska remained under the influence of warm anomalies, but much weaker ones at the surface. The largest anomalies appeared near the continental slope, perhaps in the coastal waveguide, though not necessarily as a Kelvin wave.
3. Finally, a rapid transition from warm-water anomalies to cold anomalies began in 1998 and intensified in 1999. As in phase 1, the anomalies were confined to the near-surface layers.

The velocity anomalies associated with the temperature and salinity anomaly fields of March 1998 can be estimated much more exactly than was possible in 1983, because of the availability of altimetry data from the Topex-Poseidon satellite. We computed the dynamic height fields for March 1998 and for the March mean, in both cases referenced to the surface, and computed the anomaly field of zero-referenced dynamic heights. We then adjusted this anomaly field to create an estimate of the absolute velocity field by using a surface height anomaly field determined to be the difference in Topex heights seen along Line-P in March 1998 and the distribution in February 1997, before the El Niño signal arrived.

Figure 7 shows the resultant velocity field, which is considerably more satisfactory than that estimated for the data gathered in March 1983 in that it does suggest that the temperature anomaly field is an advective feature. We can multiply the velocity anomaly field of figure 7a into the temperature anomaly field of figure 6 to map the heat-flux anomaly field shown in figure 7b. In this case the negative anomalies are all extremely weak. The only significant feature is the large northward heat flux over the continental shelf and slope. The total heat flux suggested by this calculation is too small to be the dominant warming influence in the Gulf of Alaska, but is large enough to be a major contributor to the El Niño heat budget.

Finally, we must ask how the 1997–98 El Niño affected the northeast Pacific ecosystem. This question can only be answered in the context of the systematic trends

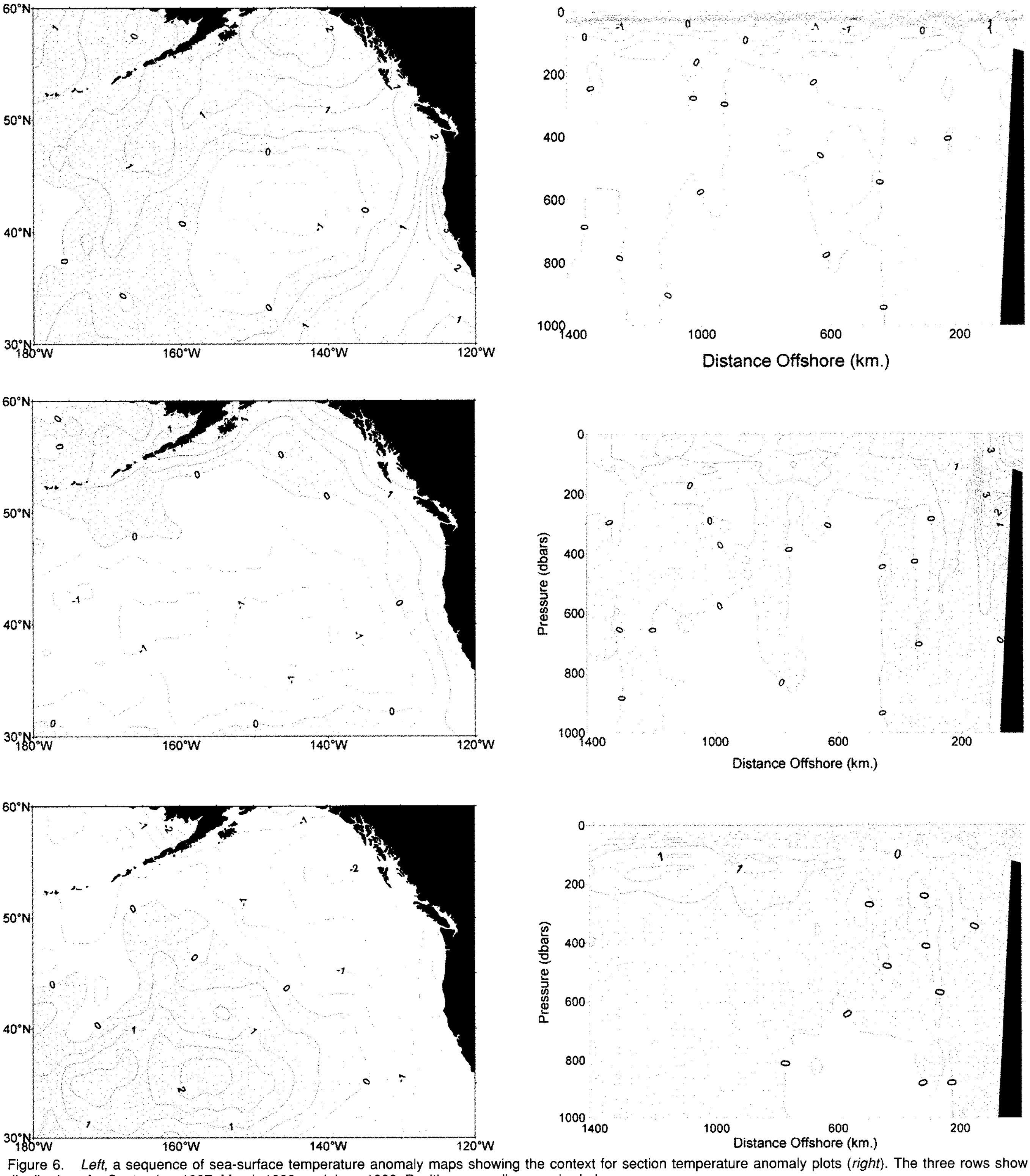

Figure 6. *Left,* a sequence of sea-surface temperature anomaly maps showing the context for section temperature anomaly plots (*right*). The three rows show distributions for September 1997, March 1998, and June 1999. Positive anomalies are shaded.

being seen along Line-P. A paper by Freeland et al. (1997) reported the shallowing mixed layer at Ocean Station Papa, attributed to a decrease in the salinity of the upper layer in the northeast Pacific.

Figure 8 shows the shallowing trend in midwinter mixed layer depth at Station Papa. The shallowest depth recorded in the history of observations at Station Papa is marked "B" on the plot. It occurred in the winter of

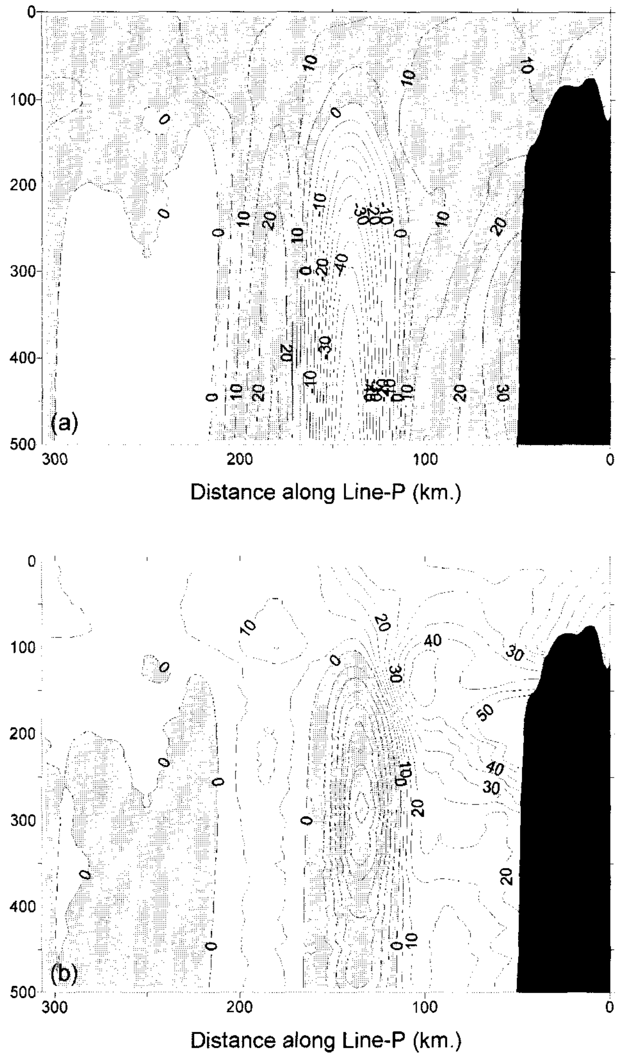

Figure 7. *a*, Velocity anomaly field estimated from Line-P hydrography and Topex-Poseidon observations; *b*, heat-flux anomaly field. Positive velocities and negative heat-flux anomalies are shaded.

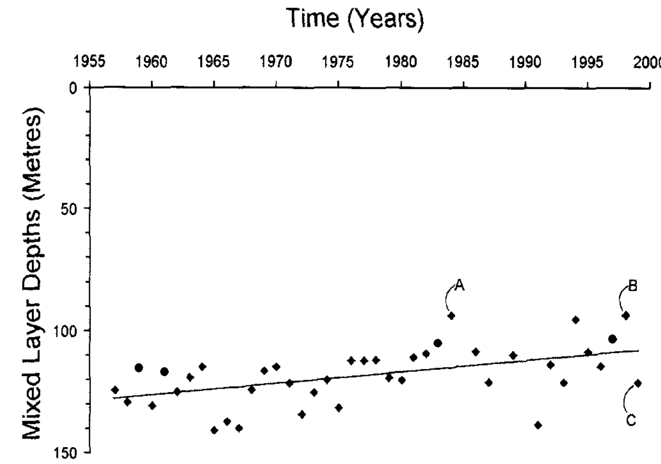

Figure 8. Midwinter mixed layer depth at Station Papa, updated through the winter of 1998–99. The value labeled A immediately followed the 1982–83 El Niño event. Value B indicates the shallowest depth recorded in the history of observations at Station Papa. Value C indicates the deeper mixed layer in winter 1998–99.

1997–98 and presumably resulted from the extreme warm conditions that prevailed at that time. By the end of 1998 the surface of the northeast Pacific was substantially cooler than normal, and this resulted in a decreased stratification and therefore a deeper mixed layer in the winter of 1998–99, labeled "C" in figure 8. The value labeled "A" immediately followed the 1982–83 El Niño event.

The shallow mixed layer of winter 1997–98 restricted the supply of nutrients to the upper ocean. This allowed normal spring primary production to reduce the nitrate in near-surface waters to undetectable levels by April 1998. By the summer of 1998 it was evident that the entire Gulf of Alaska was under the influence of a major nitrate depletion event. Observations along Line-P suggest that primary production was reduced by at least 50%, and Mackas (pers. comm.) indicates that zooplankton were also depleted in coastal waters. This was a major anomaly in the food supply of the Gulf of Alaska.

At the same time reports were arriving from fishers that salmon were "in poor condition." Other reports indicated that salmon migrating to the Fraser River were migrating up the wrong rivers, in some cases rivers on the west coast of Vancouver Island.

In summary, for the period January 1997 through fall of 1998 we witnessed:

- Record surface temperature anomalies in the northeast Pacific Ocean
- Record deep temperature anomalies
- Record sea-level anomalies
- Record low midwinter mixed layer depths
- Record low supply of nitrate to the near-surface layers
- Very low primary production
- Probably, low secondary production
- Record perturbations to the salmon fisheries.

We have to conclude that these perturbations are all related.

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