The El Niño Signal along the West Coast of Canada – Temperature, Salinity and Velocity

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The Institute of Ocean Sciences, or its predecessors, have occupied a series of 26 stations extending from the mouth of the Juan de Fuca Strait to Ocean Station Papa, at 50°N and 145°W, since 1956. This line of stations is commonly called Line-P (see Figure 1). In the early years the line was occupied many times per year, but in recent years the line is routinely occupied in February, May and August of each year. The value of this long time series became particularly evident during the El Niño event of 1997/98 as we had good control over the definition of "normal" conditions along Line-P.

Having a definition of "normal" evidently allows the definition of a mean field and thence, an anomaly. In Figure 2 we show a plot of the temperature anomaly field associated with the 1982/83 El Niño event. It was astonishing that the temperature anomalies penetrated so deep. Ideally one would like to have computed the velocity anomalies associated with this event. We can compute velocity fields for both the mean state and for the observed conditions in March 1983, and subtract one from the other. The result makes no sense and is not shown here. The obvious conclusion from this exercise is that in that calculation we are missing a large barotropic signal associated with the 1982/83 event.

In the remainder of this note we will attempt to outline the evolution of the scalar fields through the 1997/98 El Niño event. We will then use TOPEX/Poseidon data to allow a more realistic estimate of the velocity anomaly field, and from that an estimate will be made of the anomalous heat flux associated with this El Niño event. In describing the evolution of the scalar fields we were greatly assisted by the existence of the Department of Fisheries and Oceans (DFO) El Niño Watch Program. This allowed us to use new resources to increase the sampling along Line-P. Thus, we have 10 anomaly sections between August 1997 and July 1998, inclusive. Some of these were obtained as part of the routine scientific surveys along Line-P. Some were

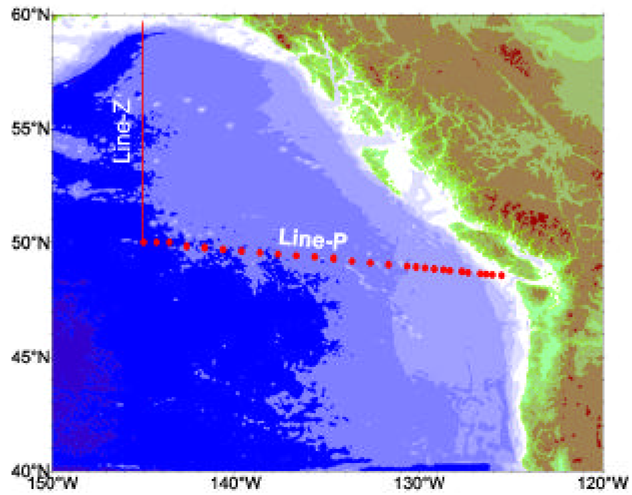

Figure 1. *Location of the stations comprising Line-P off the west coast of Canada.*

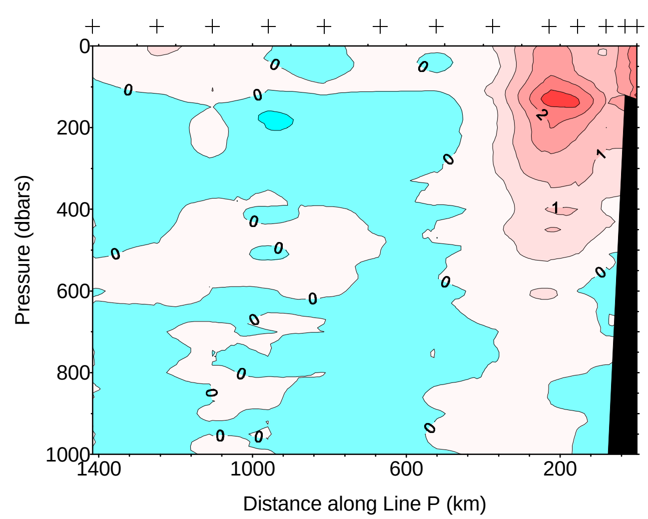

Figure 2. *Temperature anomalies versus depth and distance offshore along Line-P in March 1983.*

partial surveys, courtesy of the Canadian Coast Guard, and some were shallow surveys along the entire length of Line-P, courtesy of Department of National Defence AXBT surveys. By this means, the 1997/98 El Niño was observed more thoroughly than any previous climate event.

Figure 3 shows a selection of images illustrating the development of the 1997/98 El Niño of British Columbia. The first period, February 1997, shows conditions in the N.E. Pacific Ocean before the El Niño began. As expected, sea surface temperature anomalies are weak throughout the area of concern, and temperature anomalies are small along Line-P, at all depths. A significant salinity anomaly is visible as a longitudinal feature near a pressure of 120 dbar. This is reflected by the general shallowing of the mixed layer in the N.E. Pacific that has been reported elsewhere. By the autumn of 1997 a major warming event has occurred throughout the Pacific and we see extensive coastal warming throughout the N.E. Pacific The warming is visible at the surface but shows no penetration below the top few tens of metres. Again, as in February 1997, the only significant salinity anomaly is due to the shallow mixed layer, compared with the 1956 to present climatology. By the fall of 1997 the sea surface height was a little above normal, but shortly afterwards sea surface height anomalies began to grow rapidly (see paper by Crawford in this report). Coincident with this large change in sea level we began to see temperature anomalies at depth through the winter of 1997/98. This is illustrated in Figure 3 with the sections for February 1998, which is chosen to be the time when sea level reached its greatest height above normal. At this period, sea surface temperature anomalies remain large throughout the coastal regions of North America, but now the largest subsurface temperature anomalies appear, both suggestive of northward advection along the coast.

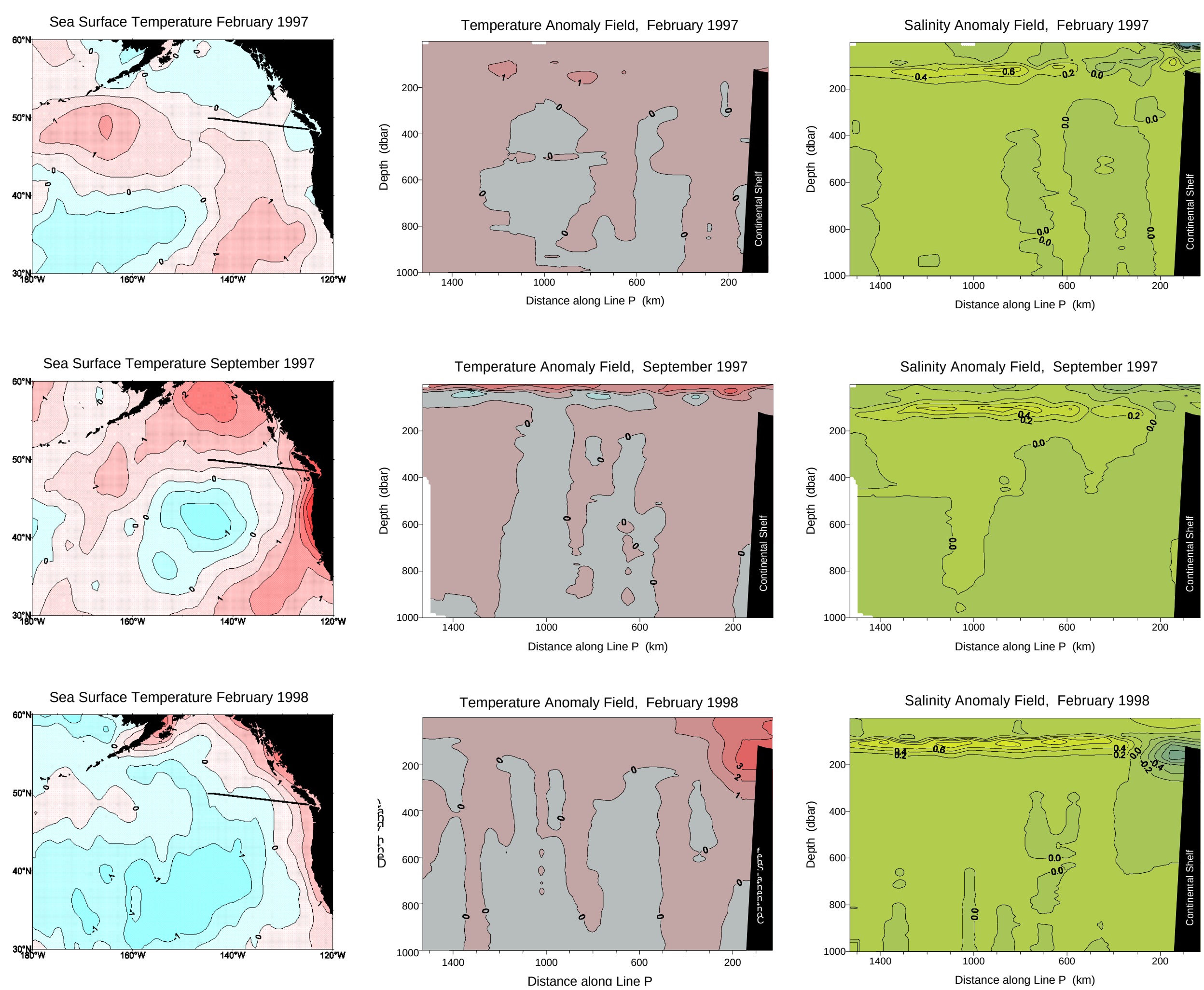

Figure 3. *Sea surface temperature (SST), and cross-sections of temperature and salinity anomaly for February 1997, September 1997 and February 1998. The solid line on the SST maps shows the position of Line-P.*

We suggest that the early, superficial warming in the N.E. Pacific is due to an atmospheric teleconnection and that this superficial warming induced a small sea level change owing to thermal expansion. The sea level change seen after November 1997 is far larger than could be explained by thermal expansion, and we propose that this event is due to the arrival of a Kelvin wave from the south. This fits with the observations of a deep anomaly appearing during the winter of 1997/98.

We can estimate the velocity anomaly field in the following way:

Absolute velocity = (g/f) × (surface pressure gradient) + (geostrophic velocity computed relative to the surface).

We can calculate the geostrophic velocity field (relative to the surface) both from the February 1998 observations, and the long-term mean fields for February, set up the above equation for both February 1998 and the long-term mean and look at the difference, thus:

Velocity anomaly = (g/f) × (surface pressure gradient anomaly) + (geostrophic velocity anomaly relative to the surface).

The surface pressure anomaly is strictly not known, but here we choose to represent that by the difference in sea level as seen by TOPEX/Poseidon, between February 1998 and February 1997, i.e. El Niño sea level minus pre-El Niño sea level. Then, having computed the velocity anomaly (v'), we can multiply by the temperature anomaly field (T') to estimate the heat flux anomaly, $T'v'$.

The velocity anomaly field illustrated above is supported by various ancillary observations. Current meters on the continental slope installed in support of the DFO El Niño Watch Program suggest very clearly that flows at the shelf edge were anomalous and that the typical northward flow in February 1998 was about 10 cm/s above normal. Profiling Alace floats deployed near Station Papa suggest that any velocity anomaly is in the direction along Line-P, with near zero anomaly perpendicular to Line-P.

The heat flux in Figure 4 are in cgs units. Integrating under the contour of *T¢v¢* = 1.0 cal s^{-1} cm^{-2} we estimate the total heat flux transported by the El Niño ocean signal in February 1998 as 6.8×10^{12} cal s^{-1}. To give some idea of the magnitude of this flux, it would be sufficient to warm the coastal area north of Line-P 200 km from the coast and to a depth of 200 metres by 1°C in 70 days. It would be interesting to run a model analysis of the ocean response in 1997/98 and estimate the total heat required in the ocean, north of Line-P. By this means we should be able to estimate the importance of the oceanic teleconnection in the high latitude ocean response.

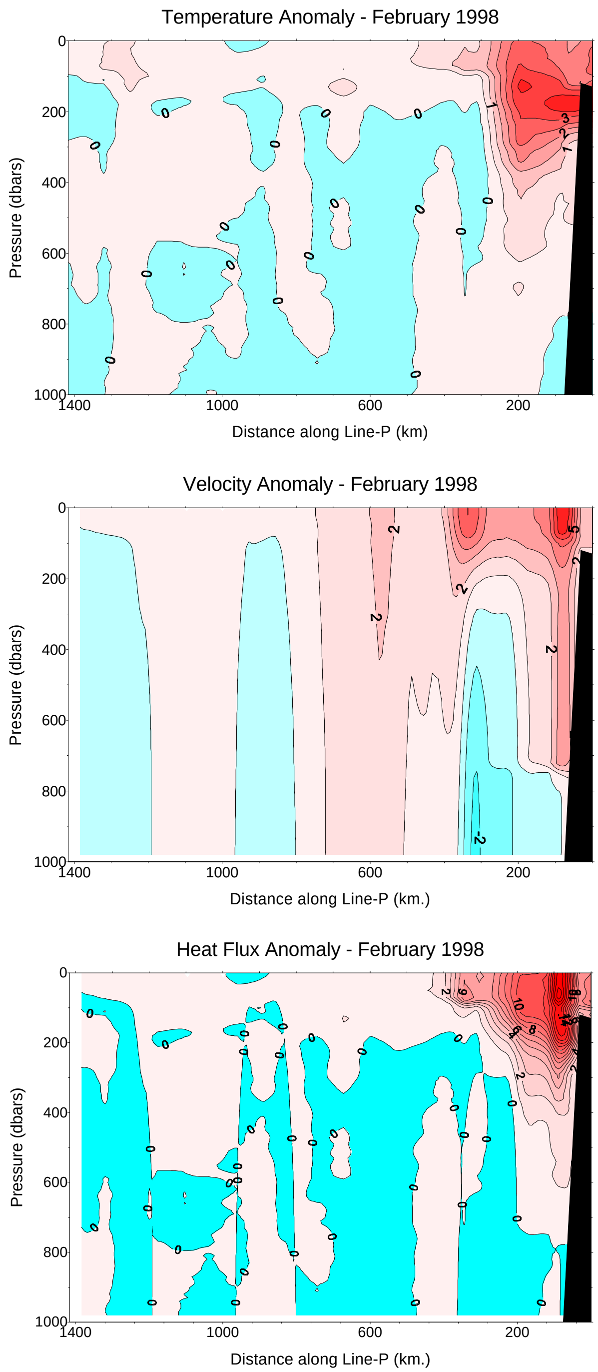

Figure 4. *Anomalies of temperature, velocity and heat flux in February 1998.*

In summary, we successfully observed the evolution of the temperature and salinity anomalies off the coast of British Columbia as various phases of the El Niño affected the coastal regions. The late response may be an oceanic Kelvin wave that transports heat to the north. We have estimated the heat flux associated with this event and would like to make a comparison with model analyses.