The eastern Gulf of Alaska:

A 37-year time series along Line-P and implications for biological impact.

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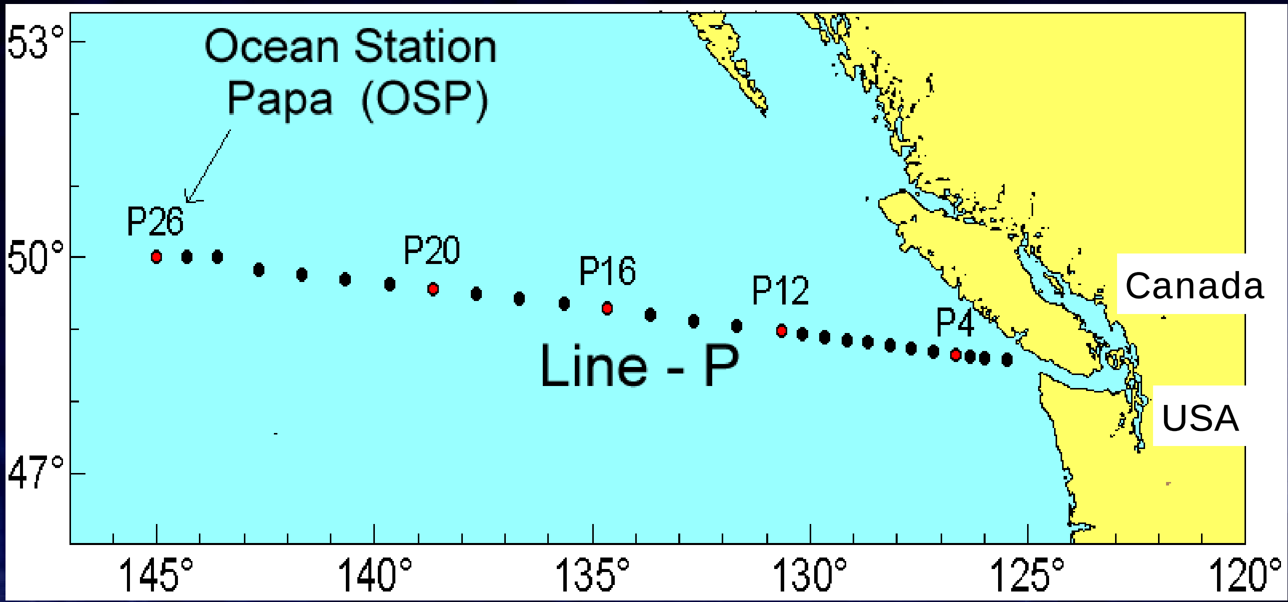
Our intent is to show **anomalies** in temperature along Line-P, a set of ocean stations west of Canada to 50N, 145W.



Oceanographic sampling along Line-P began in the 1950s. We present observations since 1968, when more regular sampling began.

Anomalies were computed relative to an average ocean along Line-P, for both summer (July to Sept.) and winter (Jan. to March). The average ocean was determined from all temperature profiles in data archives.

Early samples, beginning in 1929, were made with reversing thermometers and salinity titrations.

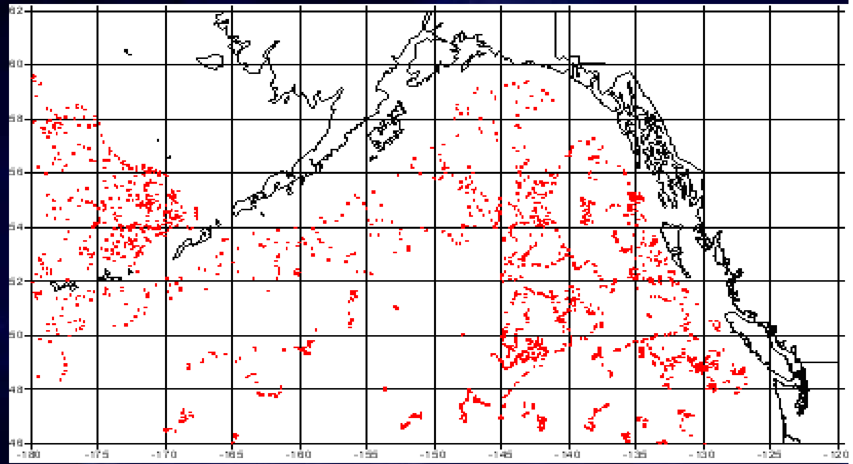
By the 1970s electronic CTDs took over, with additional sampling by Expendable Bathythermo-graphs (XBT).

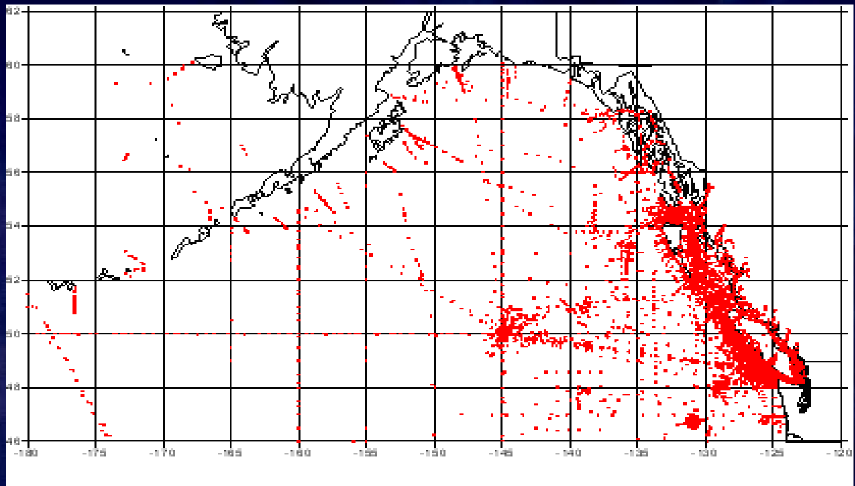
Argo profilers supplemented the Line-P sampling in the late 1990s.

Our average ocean includes all these measurements, provided the sampling location was within 100 km of Line-P.

Archived profile data: Hydro Bottles, CTD, XBT, Argo.

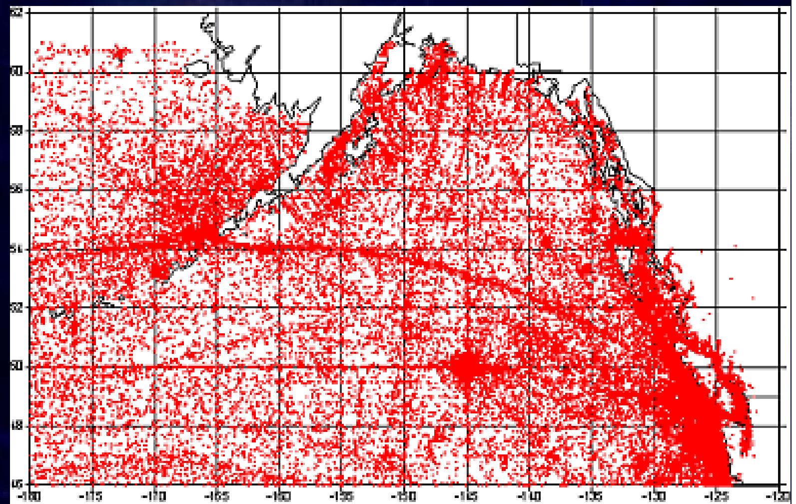
Argo profilers in gulf





CTDs in IOS Database

Profiles extracted from Canadian Marine Environmental Data Service (MEDS).



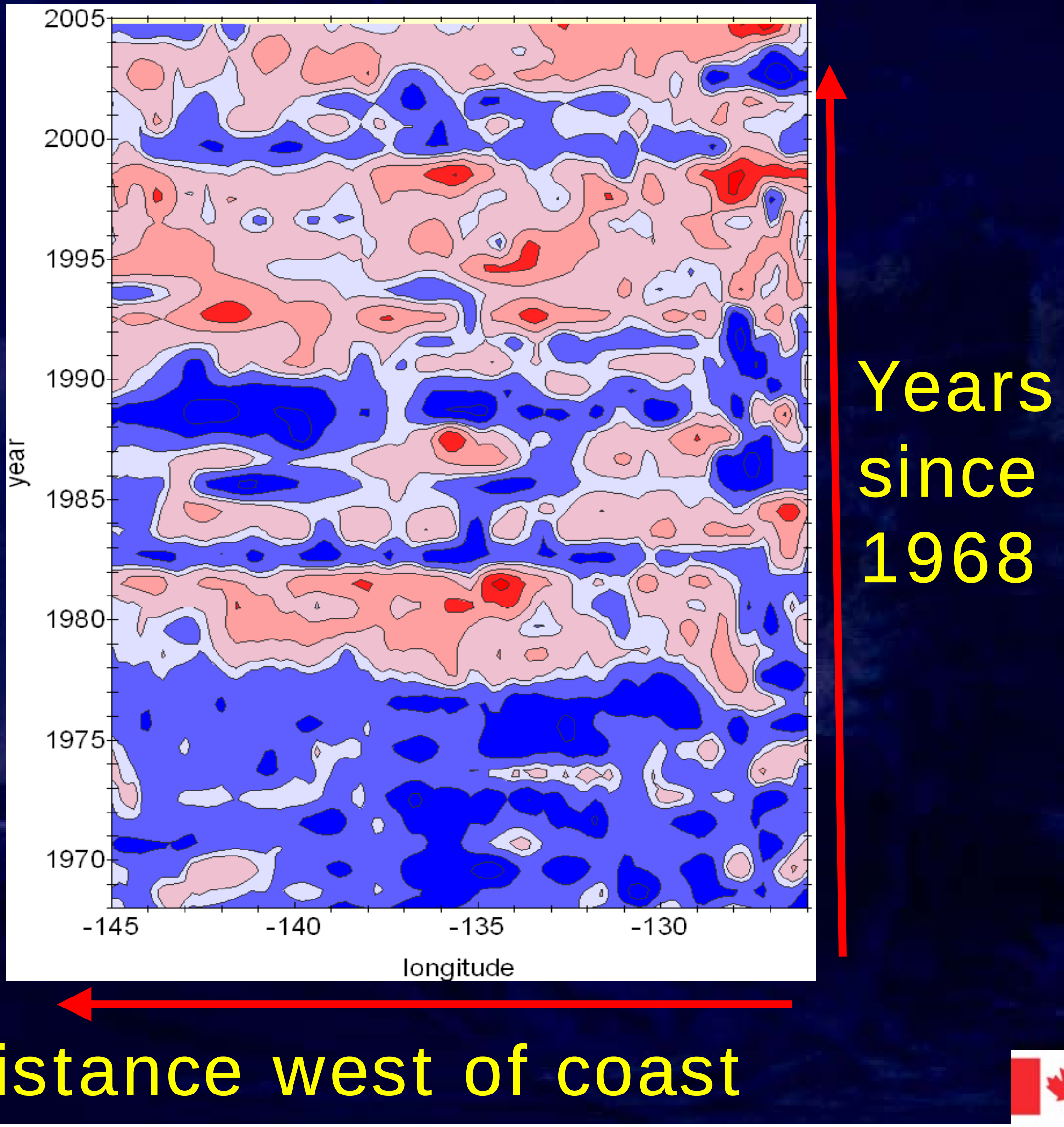
12800 summer profiles & 8600 winter profiles
(No duplicates; show summer only here.)

We averaged temperatures over various depth ranges. We present results for two depth ranges:

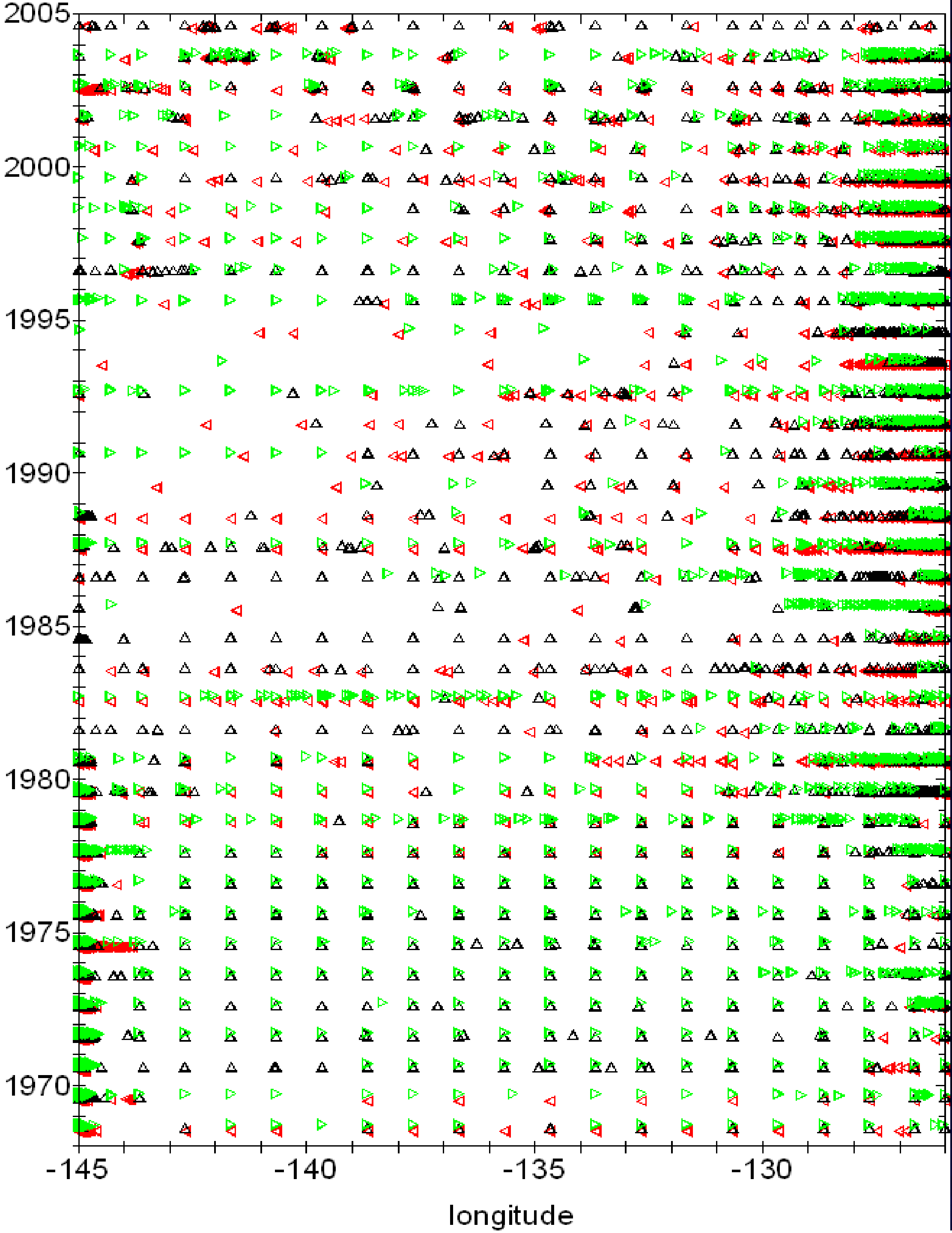
(1) 10 to 50 metres depth*.
(2) 100 to 150 metres depth.

*We found too many profiles with missing samples in the top 5 to 10 m to use depth ranges that began at ocean surface, so our shallow range begins at 10 m below the surface.

Results are plotted in a Hovmuller diagram for each range. Example below shows temperature anomalies in summer averaged over 10 to 50 metres depth.



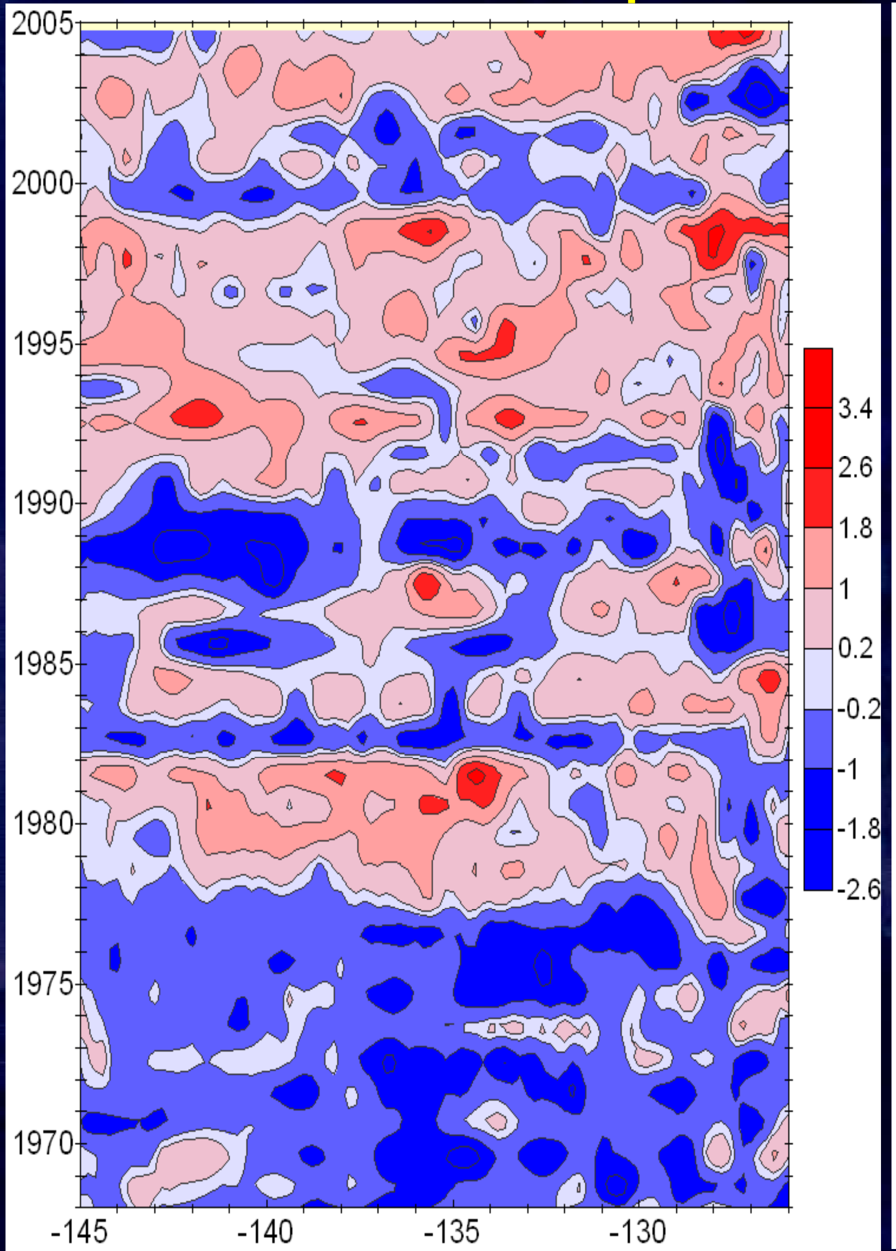
Contouring of temperature anomaly is carried out over distance along the X-axis and time along the Y-axis.



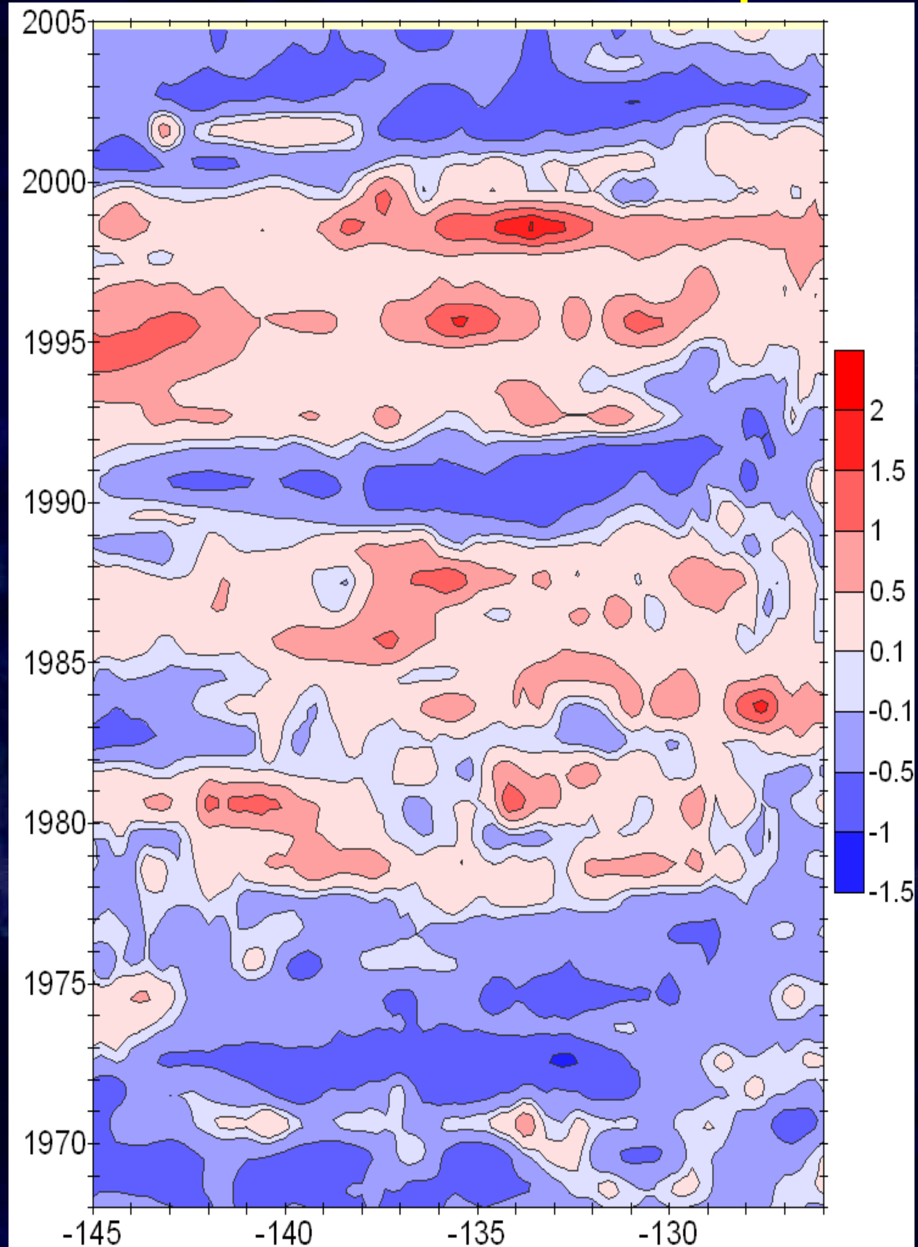
Data Points sampled for summer, 10 to 50 m depth within 100 of Line-P.

Red July
Black August
Green September

10 to 50 m depth



100 to 150 m depth



Summer anomalies (deg C)

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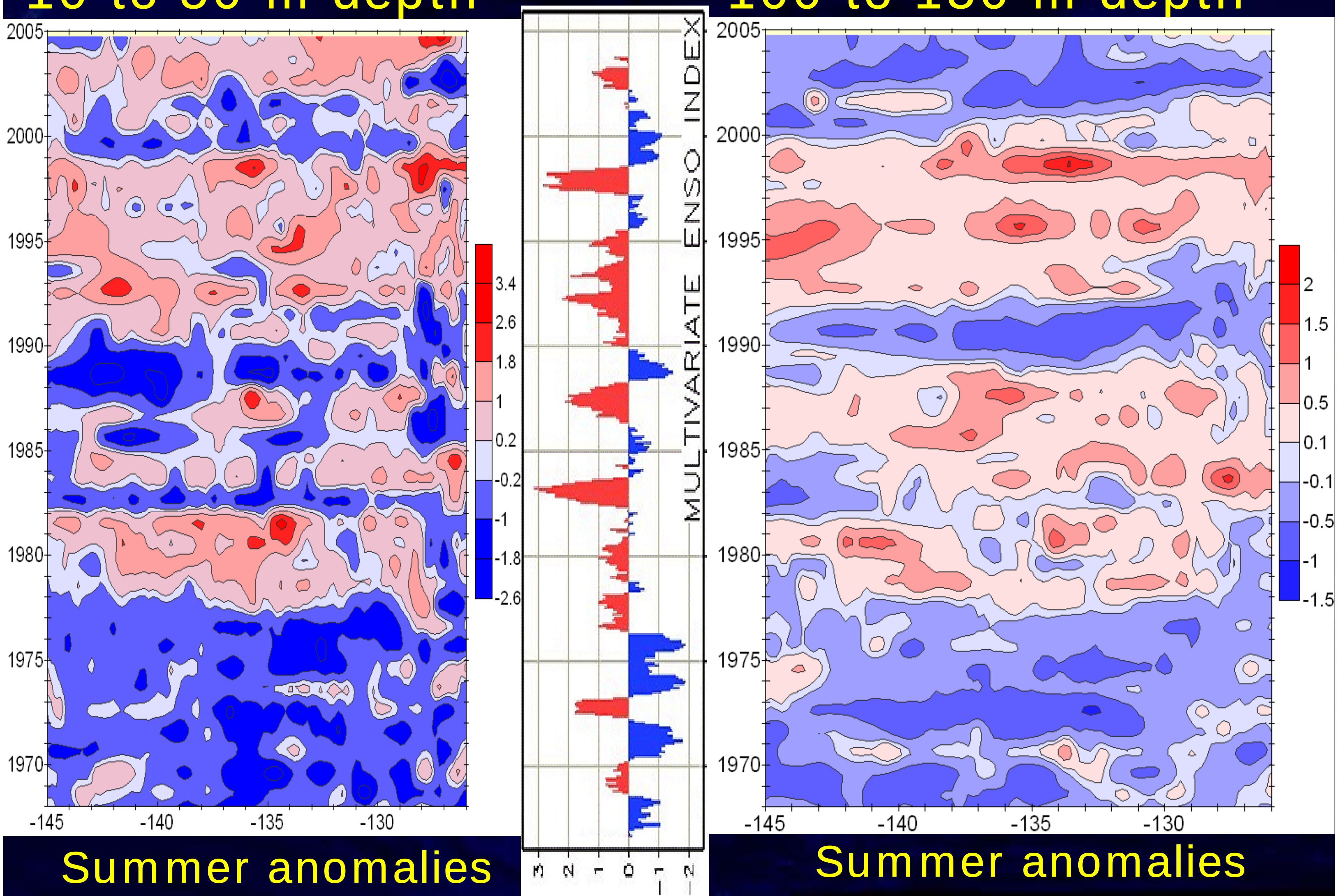
10 to 50 m depth | ENSO | 100 to 150 m depth



Summer anomalies

Summer anomalies

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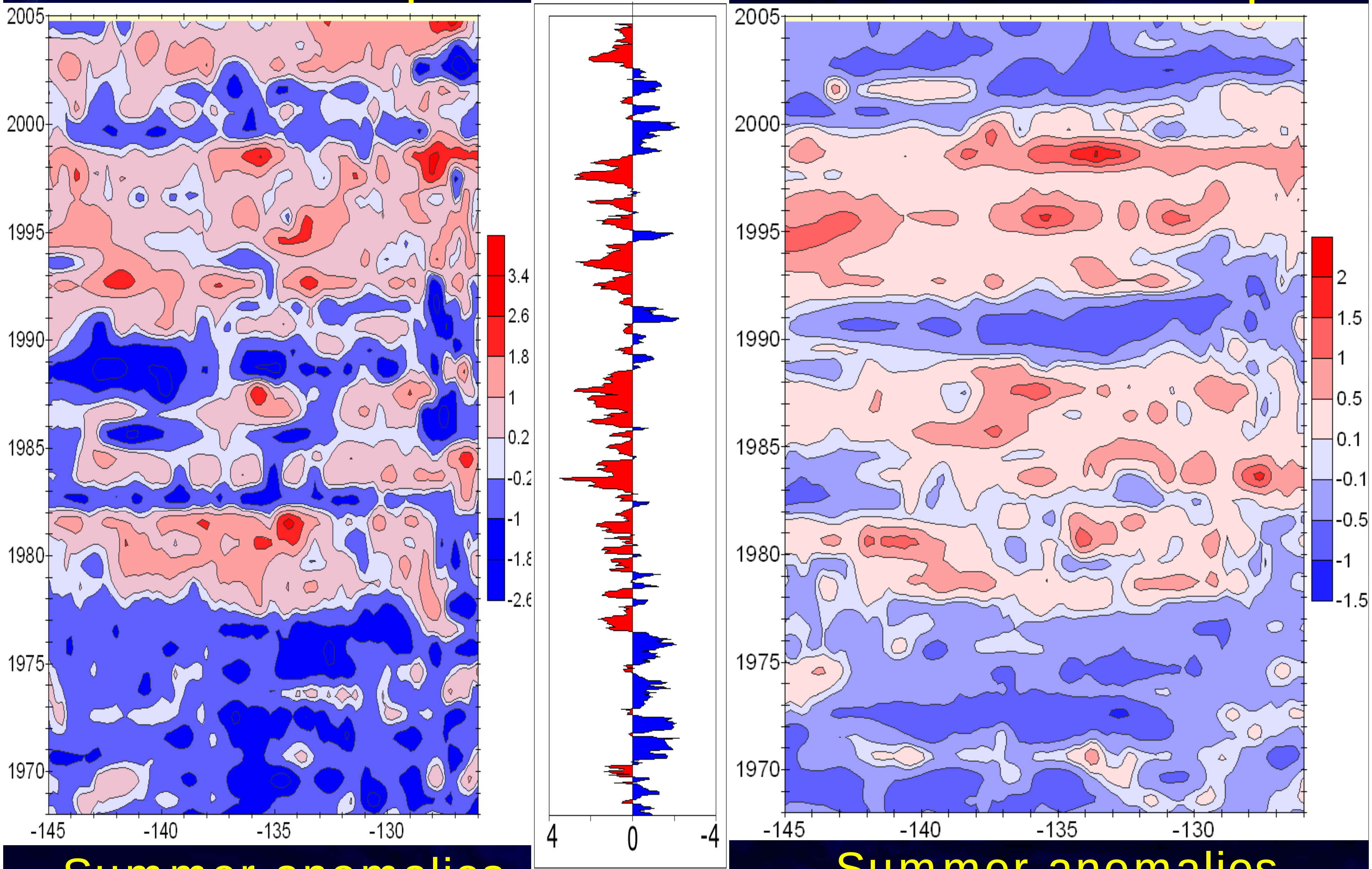
10 to 50 m depth

PDO*

100 to 150 m depth



Summer anomalies

Summer anomalies

*http://tao.atmos.washington.edu/pdo/

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Results:

- ENSO events visually correlated with Line-P temperatures, with some lag.
- PDO is visually correlated with the 1977 and 1998 regime shifts and might account for the absence of the 1972 El Niño impact in Line-P temperatures.
- No evidence of westward propagating internal Rossby waves (too far north).
- Many mid-line warm events are Haida eddies (eg. 1995, 1998).
- McKinnell observes that surface temperatures along west coast of Vancouver Island, Canada, correlate well with air pressure over warm pool in western tropical Pacific.
- Surface warming in summer 2004 is mainly due to local summer weather. Aug 2004 was similar to Aug 1997.

Mechanisms:

- Stronger Aleutian low pressure system in El Niño winters, and during PDO warm phase in eastern Pacific.

- Northward propagating warm coastal trapped waves in El Niño winters.

- Storms hitting California coast in El Niño winters push these warm coastal trapped waves farther north.

- Cumulative effect of these is stronger than each by itself. For example, McKinnell has observed that the correlation of west coast Vancouver Island temperatures with air pressure in western Pacific warm pool is stronger than with Aleutian low pressure index.

Pacific Decadal Oscillation shift can account for the 1977 regime shift.

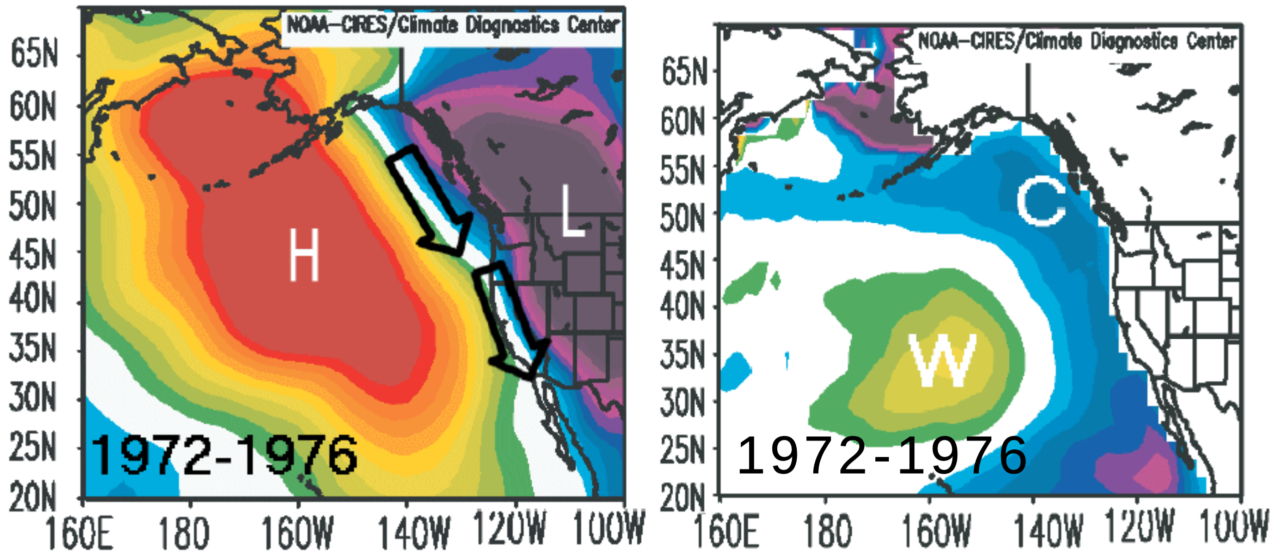


Figure 11a. Left panel presents sea-surface air pressure anomalies in winters of 1972-1976. Letters H and L denote high and low air pressure anomalies. Arrows indicate wind anomalies due to these air pressures. Right panel presents a map of sea surface temperature anomalies in these same winters with W and C for warm and cold (adapted from Bond *et al*., 2003).

Bond, N. A., Overland, J. E., Spillane, M., Stabeno, P., Recent shifts in the state of the North Pacific. *Geophys. Res. Lett.*, Vol. 30, No. 23, 2183.

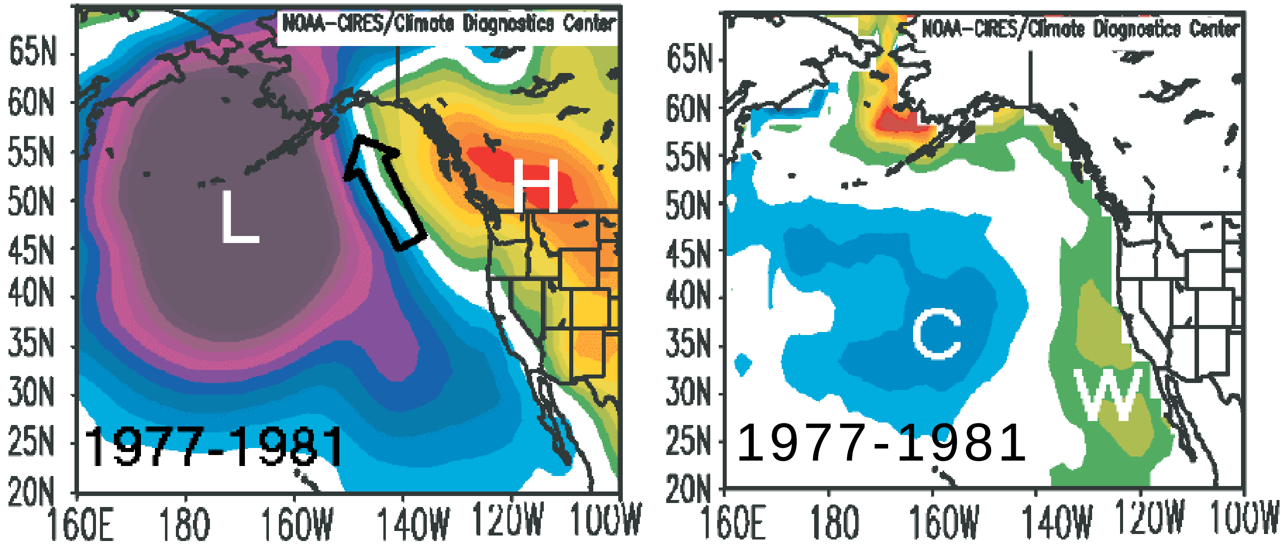


Figure 11b. Left panel presents sea-surface air pressure anomalies in winters of 1977-1981. Letters H and L denote high and low air pressure anomalies. Arrows indicate wind anomalies due to these air pressures. Right panel presents a map of sea surface temperature anomalies in these same winters with W and C for warm and cold (adapted from Bond et al., 2003).

Second mode of Pacific Decadal Oscillation, informally called the Victoria Mode, can account for the 1998 regime shift.

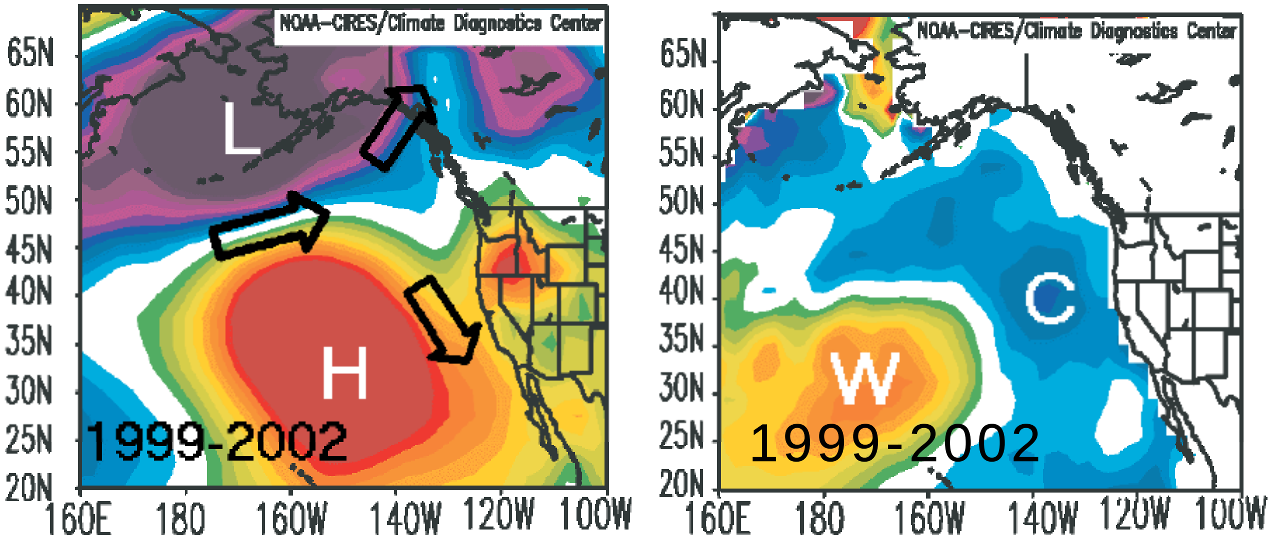


Figure 11c. Left panel presents sea-surface air pressure anomalies in winters of 1999-2002. Letters H and L denote high and low air pressure anomalies. Arrows indicate wind anomalies due to these air pressures. Right panel presents a map of sea surface temperature anomalies in these same winters with W and C for warm and cold (adapted from Bond *et al.*, 2003).

Surface warming from late 2004 to present can be accounted for by El Niño winter conditions in 2002-2003 winter, and strong PDO* in summer 2004.

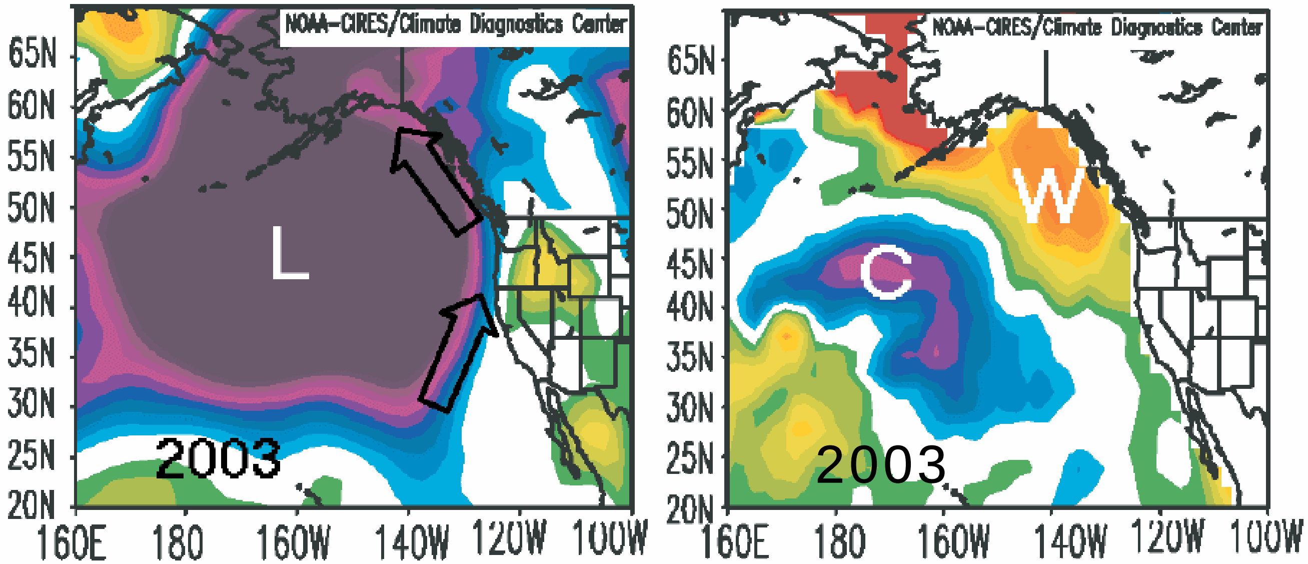


Figure 11d. Left panel presents air pressure anomalies in winter of 2003. Letters L denotes low pressure anomaly. Arrows indicate wind anomalies due to these air pressures. Right panel present a map of sea surface temperature anomalies in these same winters, with W and C for warm and cold. (adapted from Bond et al., 2003).

- Hare, S. R., and N. J. Mantua, 2000: Empirical evidence for North Pacific regime shifts in 1977 and 1989. *Prog. Oceanogr.*, *47*, 103–145.

- Mantua, N., S. Hare, Y. Zhang, J. Wallace, and R. Francis, A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Am. Meteorol. Soc. 78*, 1069–1079, 1997.

Noted impact of PDO mode 1. Relative impact declined in 1990s.

Bond, N. A., Overland, J. E., Spillane, M., Stabeno, P., 2003: Recent shifts in the state of the North Pacific. *Geophys. Res. Lett.* 30, 2183.

Noted impact of PDO Mode 2. Relative impact declined in 2003.

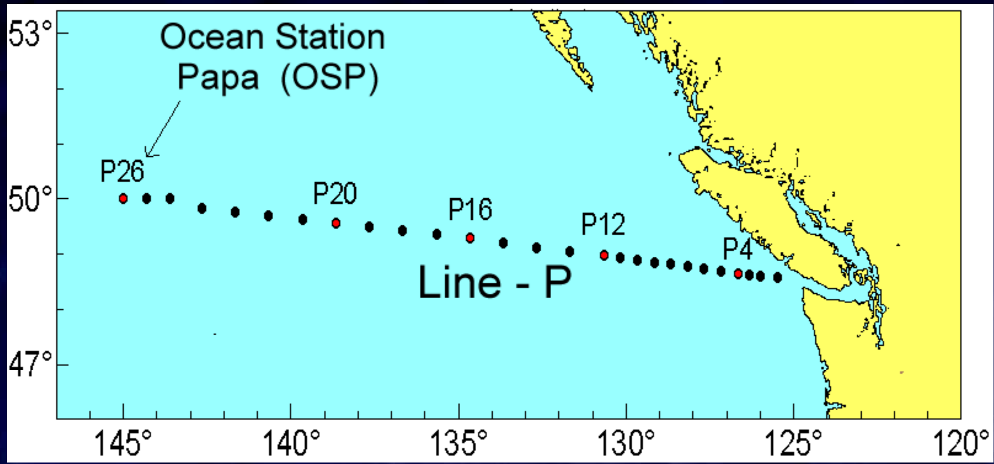
DFO, 2004, Pacific Region State of the Ocean. *DFO Ocean Science Report 2003.*

Noted impact of winter winds. Relative impact declined in summer 2004.

Message: Beware of using indices for predictions.

Biological impacts:

The warm regime of 1990s was accompanied by increase in biomass of hake and southern phytoplankton species along West Coast of Canada. Both populations declined during 1999-2002 cool years.



Very cool waters advected onto continental shelf in summer at the end of the 1999-2002 cool regime, at 60 to 150 m depth. These cold waters were found between British Columbia and Oregon, accompanied by low oxygen levels attributed to high productivity, and mortality of some bottom species. Some of these impacts continued into summer 2004.

These cool sub-surface waters slowly returned to normal temperatures in the next two years, but surface waters have increased in temperature.