Origin and persistence of anomalously cold water in the halocline of the eastern Gulf of Alaska, 2002 to 2004.

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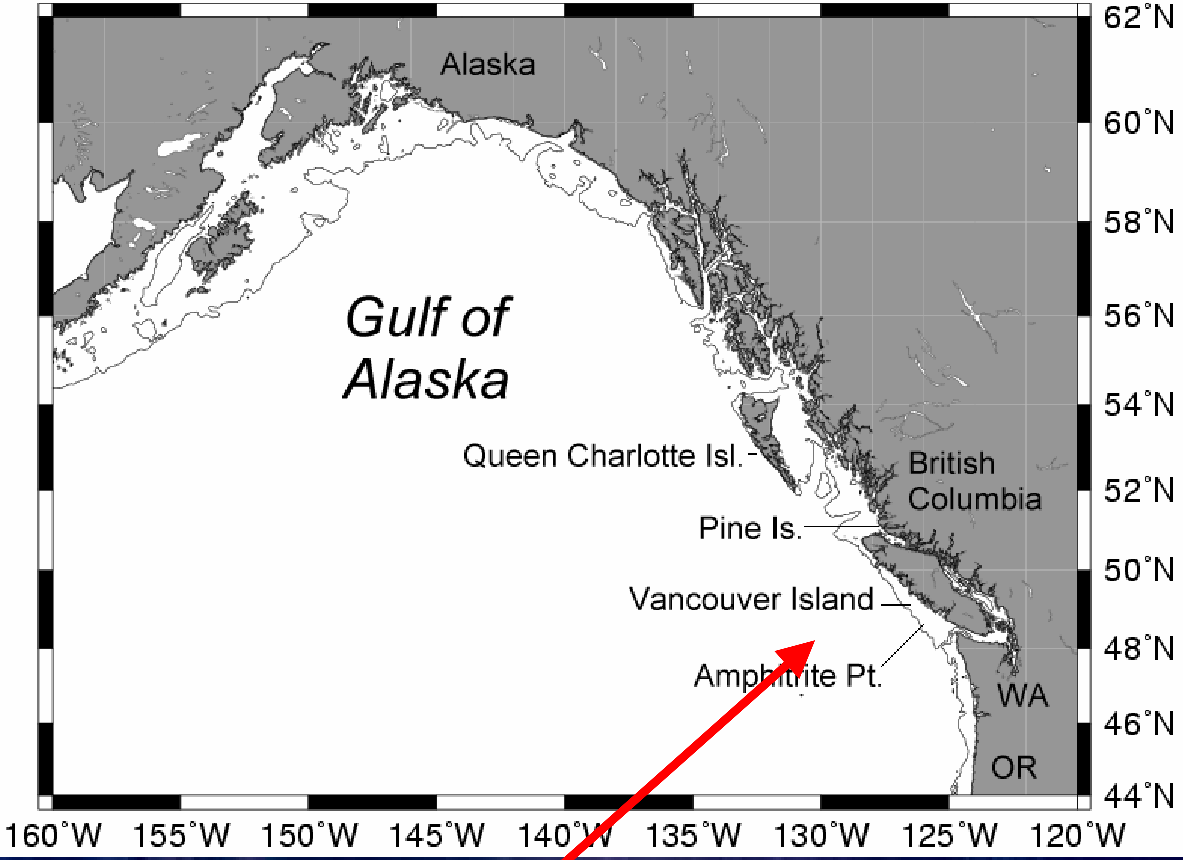
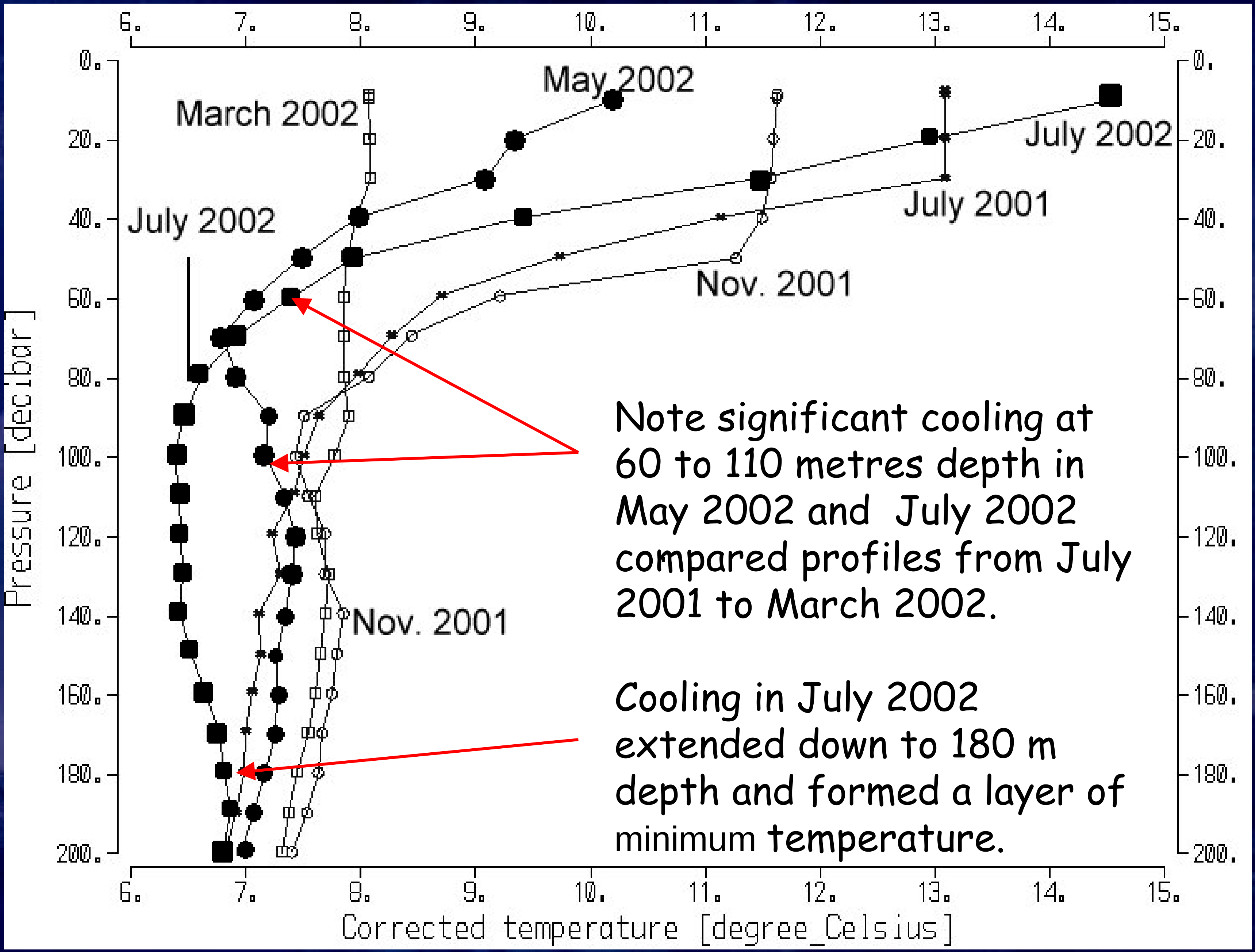
Much of the data derive from Argo profilers launched into the gulf over the past 5 years.

Best spatial coverage began in February 2002.



(Credit to H. Freeland, M. Robert, Fisheries & Oceans Canada, and Argo Program.)

Position of Argo Profiler 4900112, in 2000 m depth July 2001 to July 2002. Data plotted on next slide.



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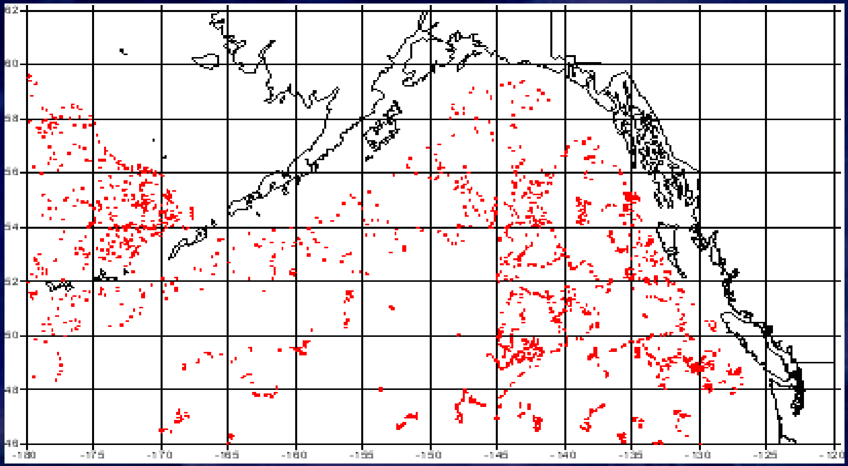
Argo database extends back to the 1990s, and is too sparse and too recent to provide insight on how anomalous this cold intrusion might be.

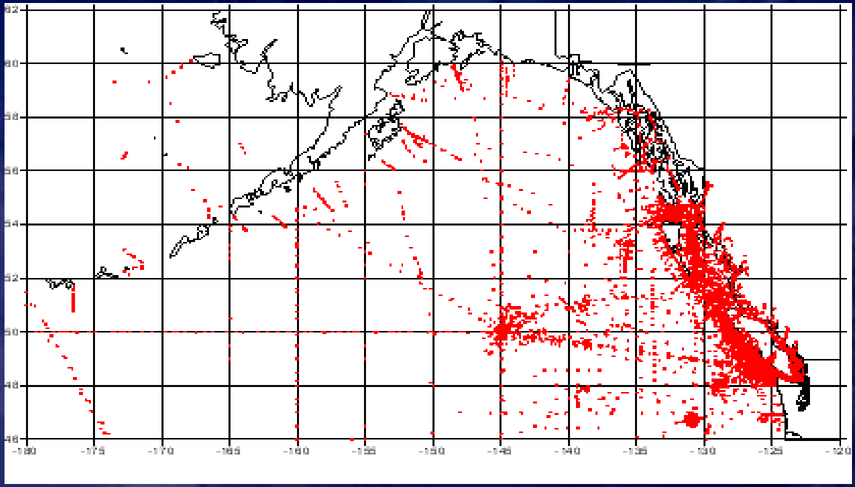
We analysed the complete archived set of temperature and salinity profiles back to the year 1929, to determine average ocean conditions at 46 standard depths from ocean surface to 2400 metres depth.

Anomalies can be computed relative to an this average ocean at the 46 standard depths.

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

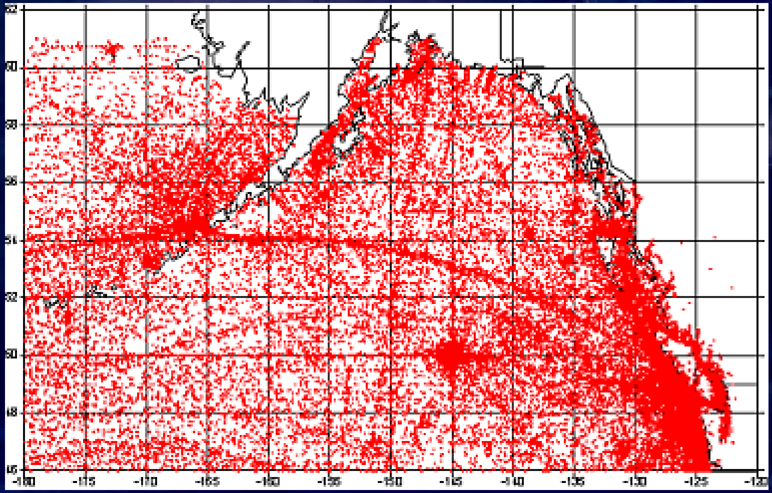
Argo profilers in gulf





CTDs in IOS Database

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



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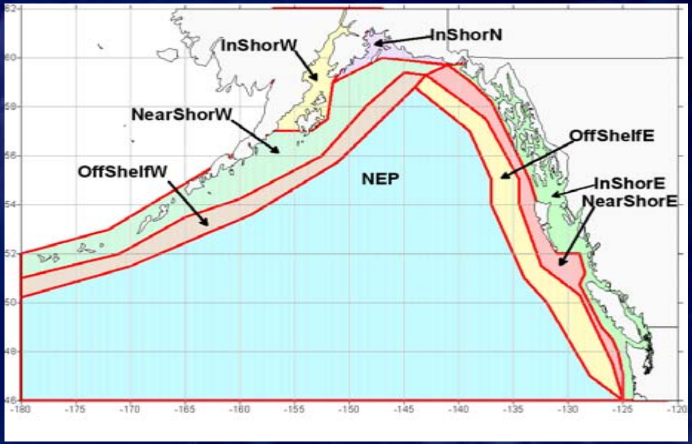
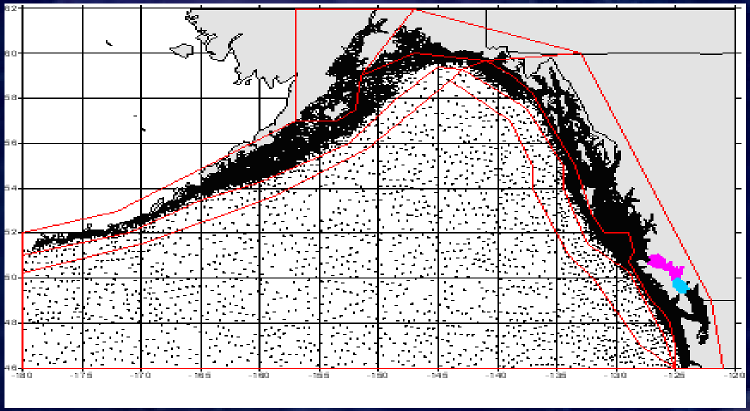
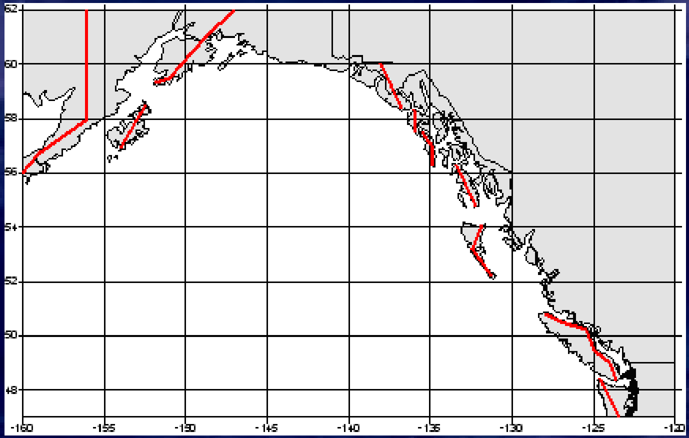
- Interpolate to 46 standard depths from surface to 2400 metres.
- Eliminate duplicate profiles.
- Quality control.
- Select summer and winter seasons.
- Select typical years for reference (non-Niño)
- Prepare contours of averages.



Used Surfer® and "nested-Kriging" to apply unique distance-weighting functions to each domain.

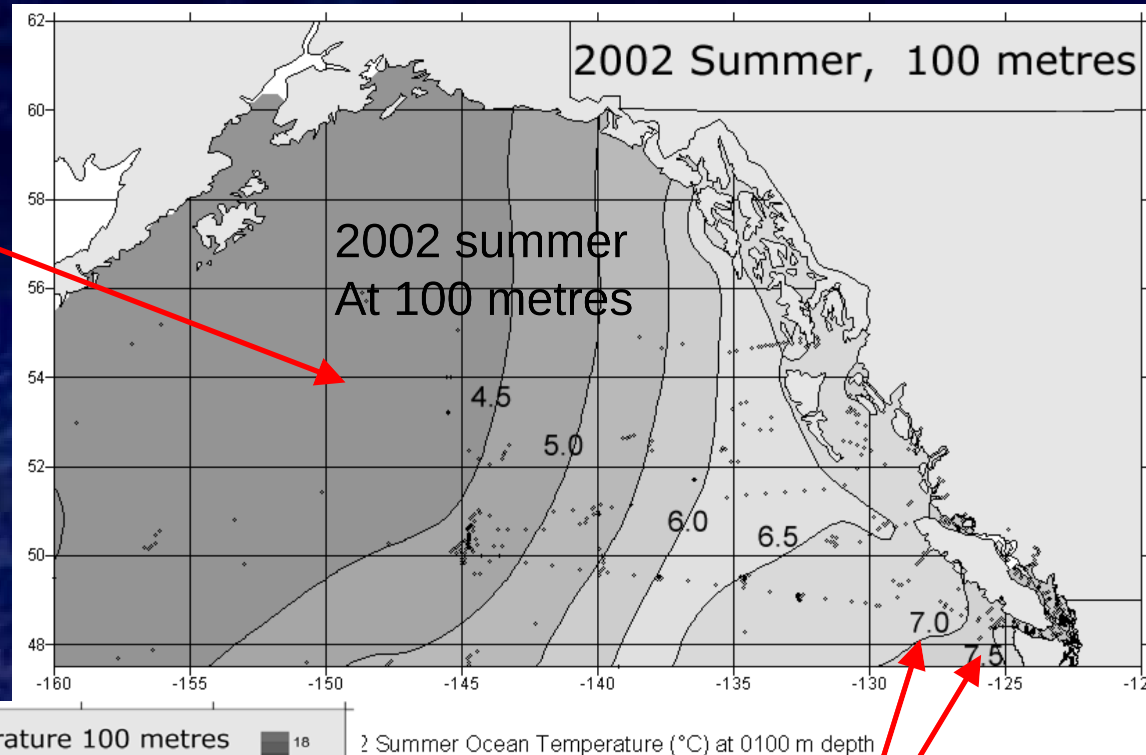
Map of carrier grid nodes (based on model developed by M. Foreman of IOS).



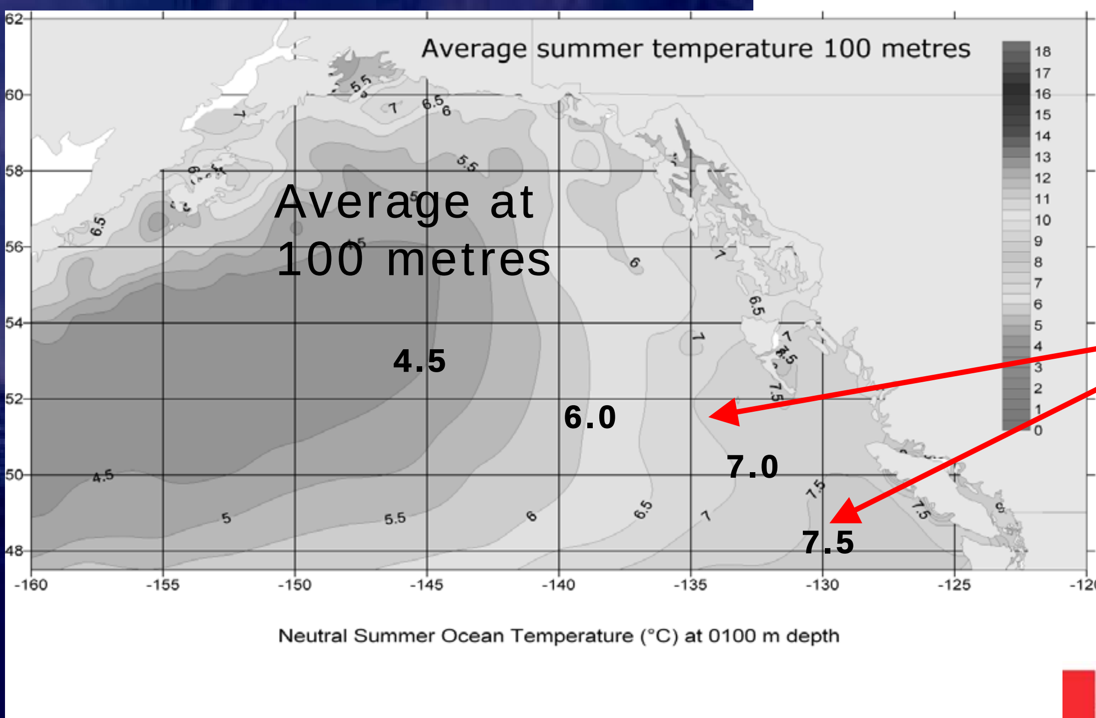


Applied Surfer® fault lines to prevent interpolation across land masses.

Summer 2002 observations in Central to NW gulf are too sparse for reliable contouring.

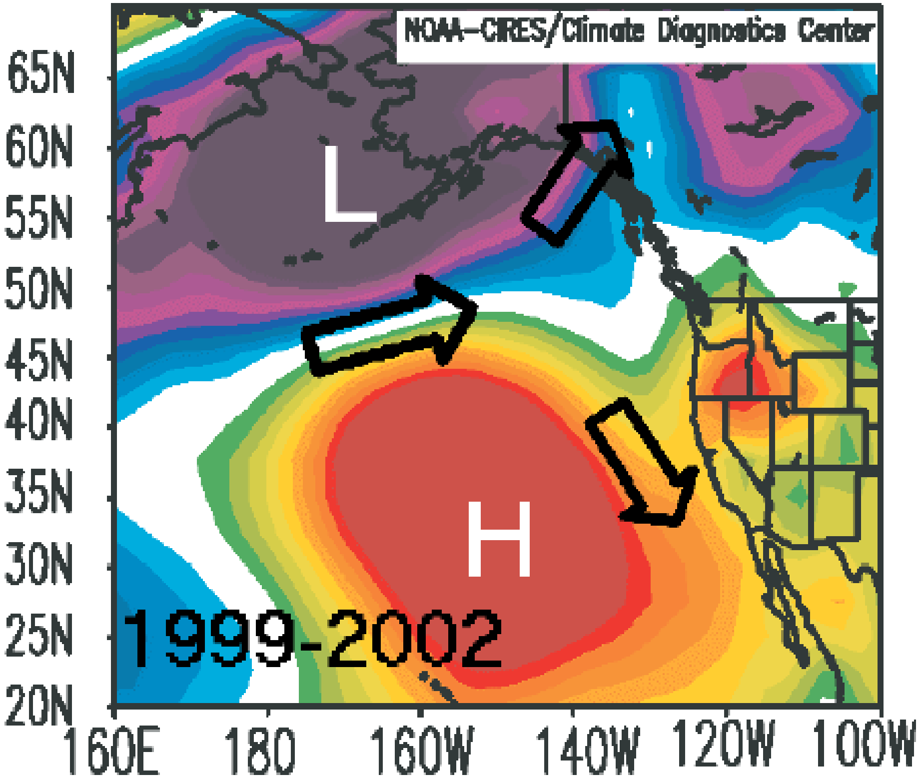


Below: Example of average T at 100 m in summer.



Note how far the 7.0°C and 7.5°C contours moved toward the West Coast in 2002.

How did this cold anomaly develop? Bond et al. (2003) show the winter sea-surface air pressure anomalies from 1999 to 2002 (below left) together with winter SST anomalies for these winters (below right). Black arrows show expected wind anomalies, which might have set up baroclinic gradients in top 100 to 150 m of the ocean that pushed cold water toward the West Coast.



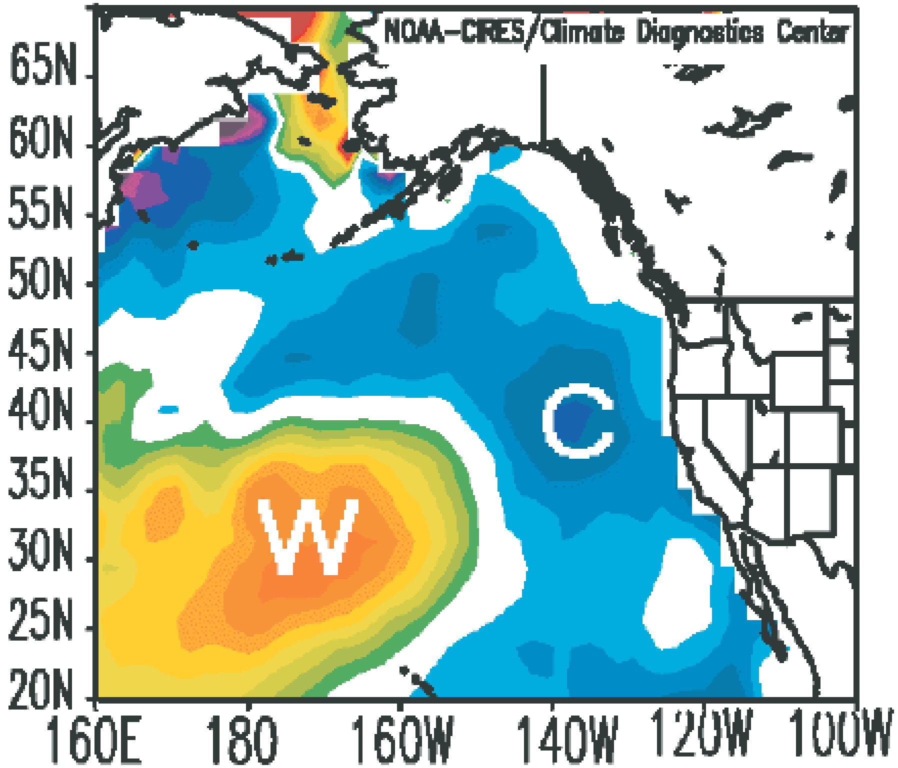


Figure 11c. Left panel presents sea-surface air pressure anomalies in winters of 1999-2002. Letters H and L denote high and low air pressure anomalies. Arrows indicate wind anomalies due to these air pressures. Right panel presents a map of sea surface temperature anomalies in these same winters with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

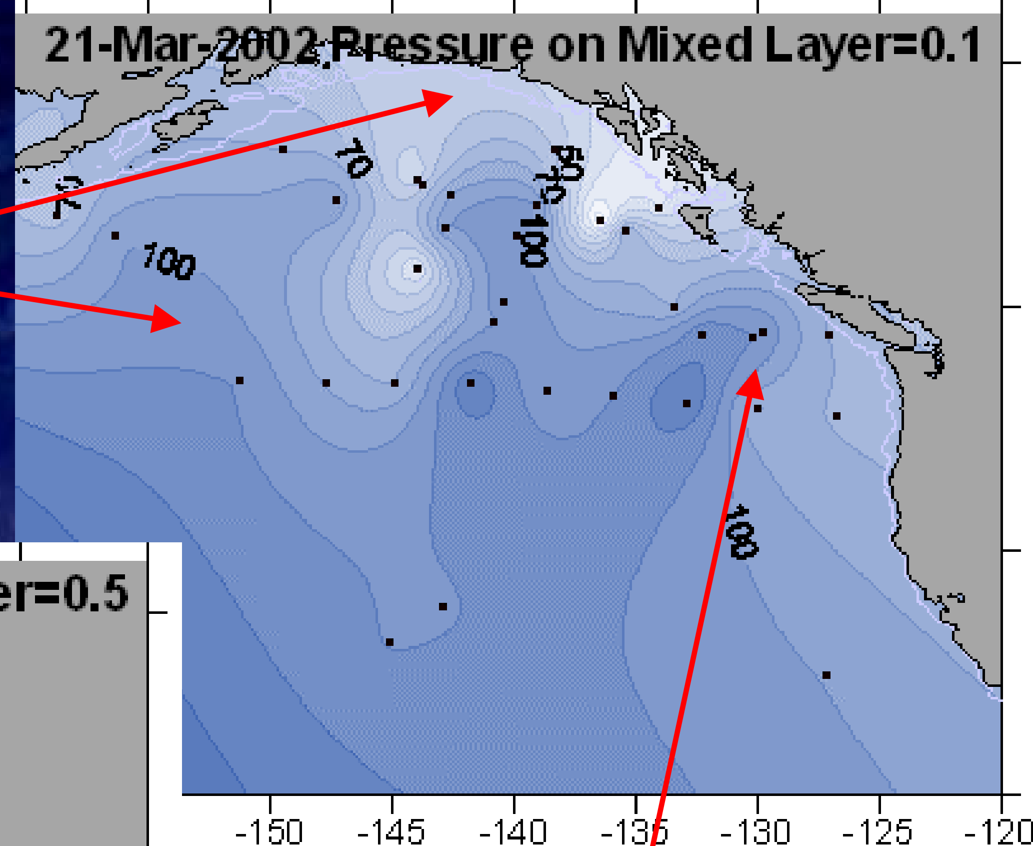
The cold water near 100 metres depth in the eastern Pacific must have advected horizontally into the region, because its temperature along the west coast was colder than observed previously in the year, even in March when surface mixed layer was deepest. The cold anomaly was on the 33.0 salinity surface.

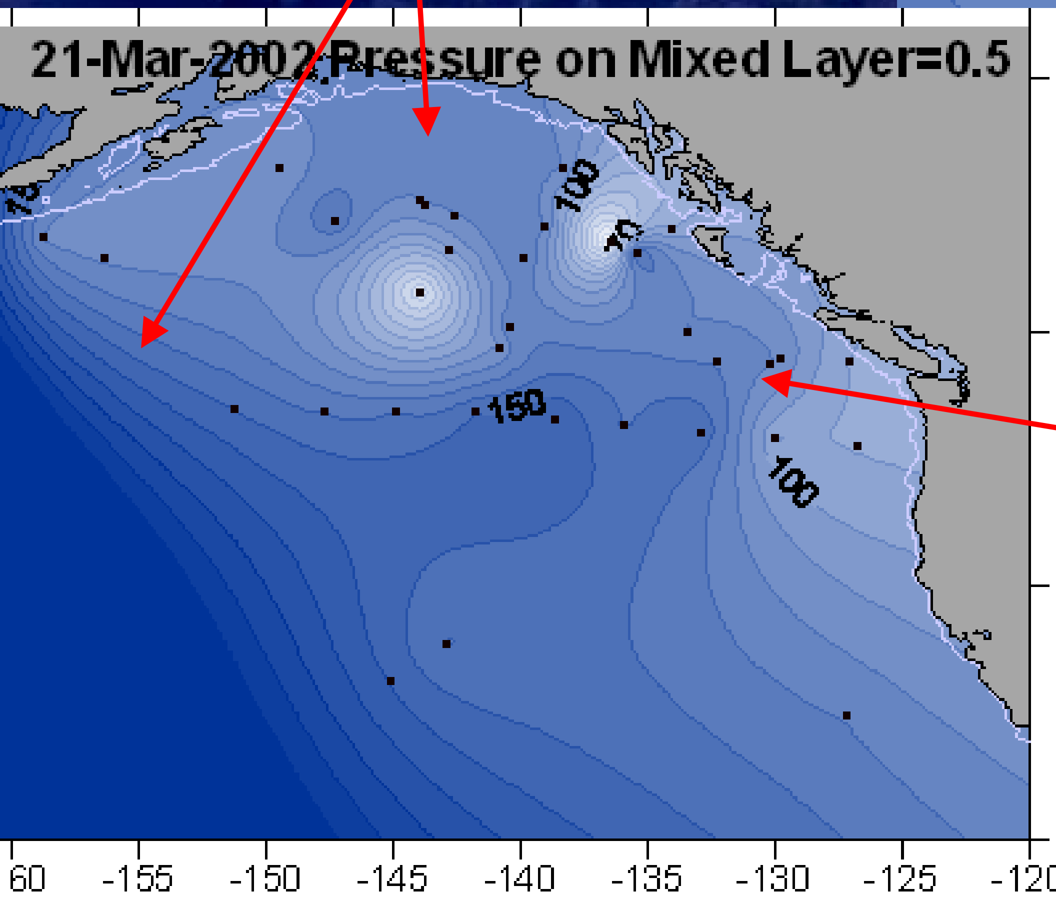
Next slides show:

- Depth of surface mixed layer in March 2002,
- Depth of 33.0 salinity surface below base of mixed layer,
- Temperature on 33.0 salinity surface,
- Flow along 33.0 salinity surface.

March 2002 mixed layer.

Too few observations to determine mixed layer depth in western and northern gulf.





Deepest mixed layer was in March 2002 in eastern gulf. Typical mixed layer depth was 100 m (0.1 sigma-t) to 120 m (0.5 sigma-t).

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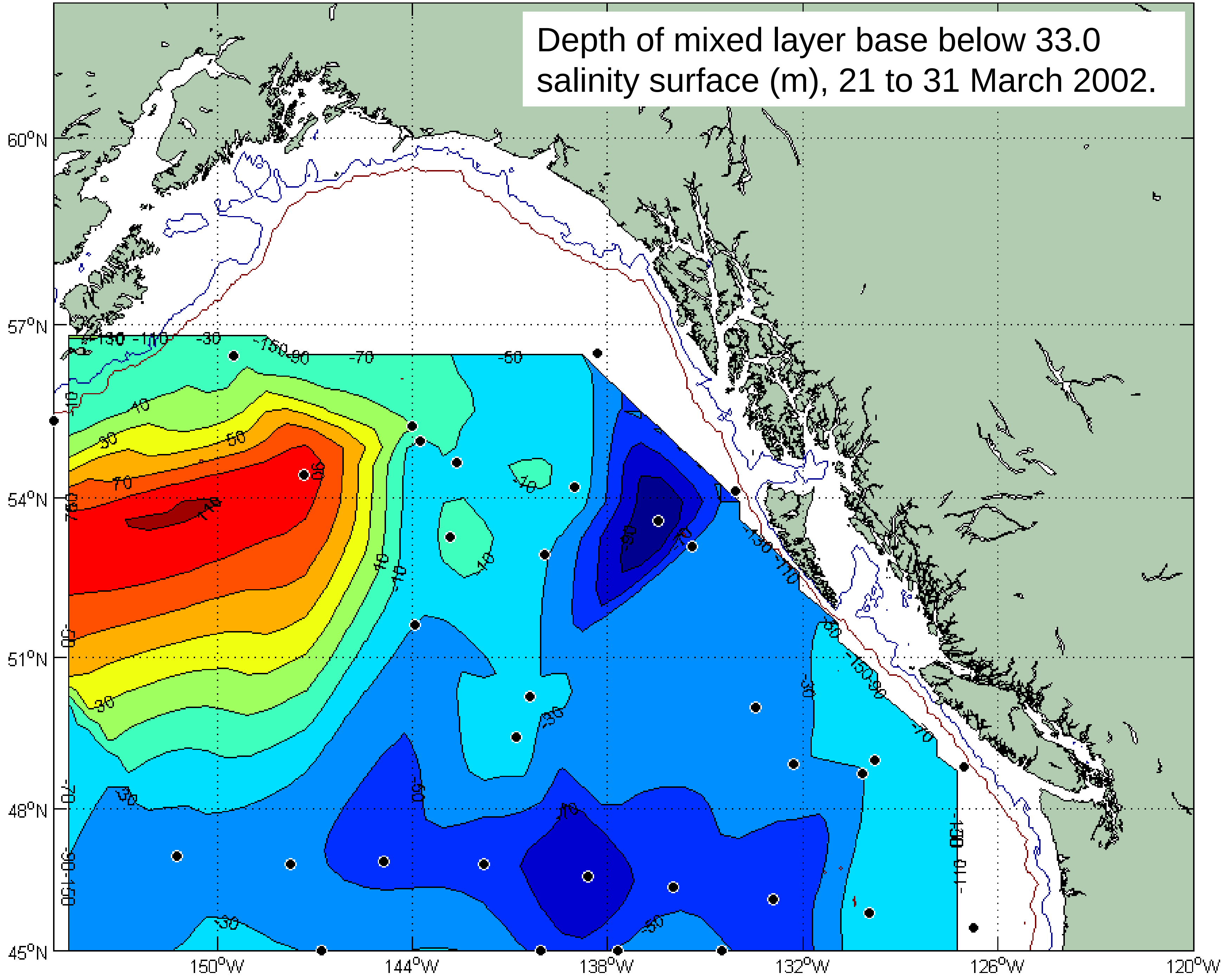
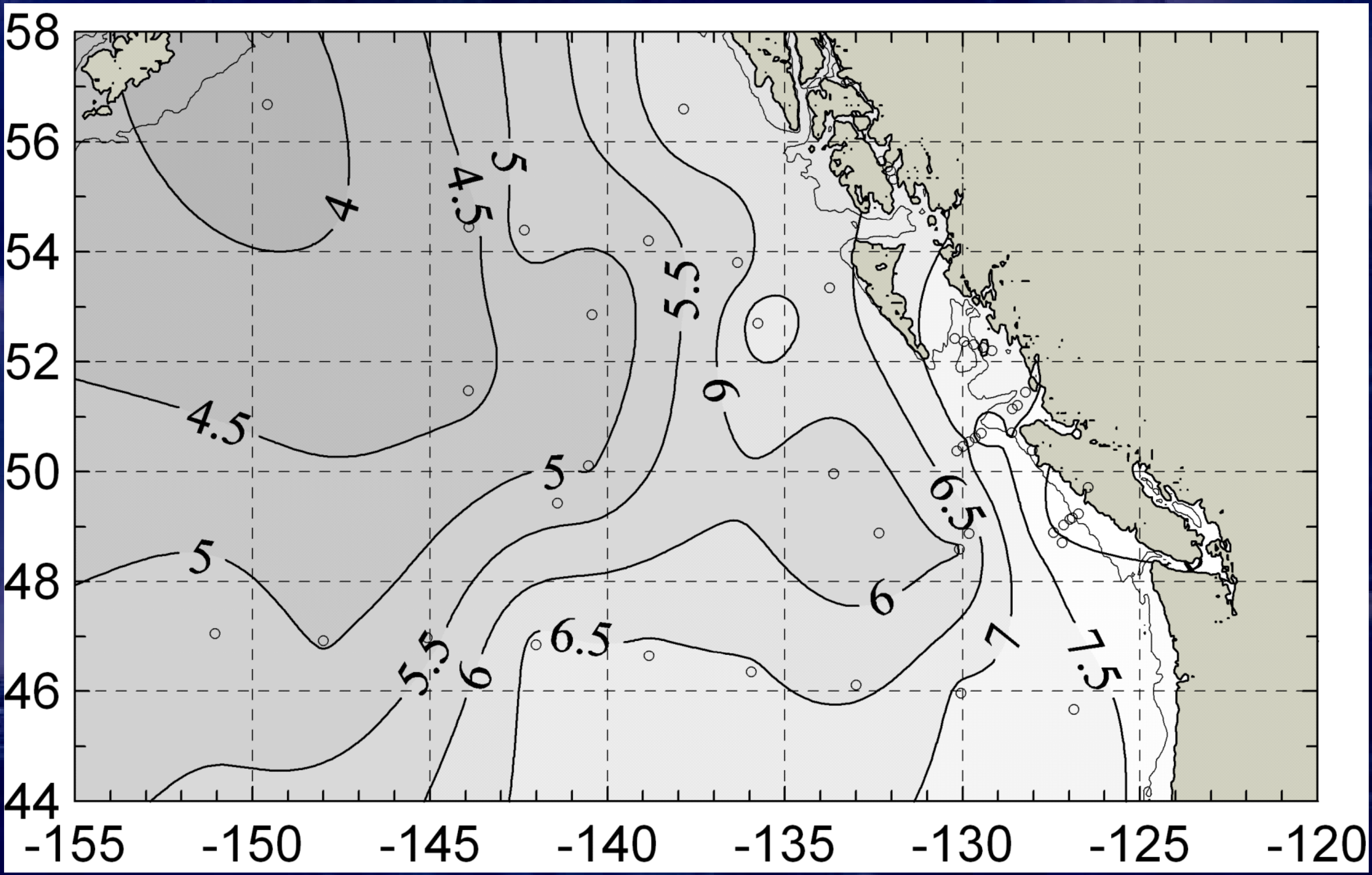
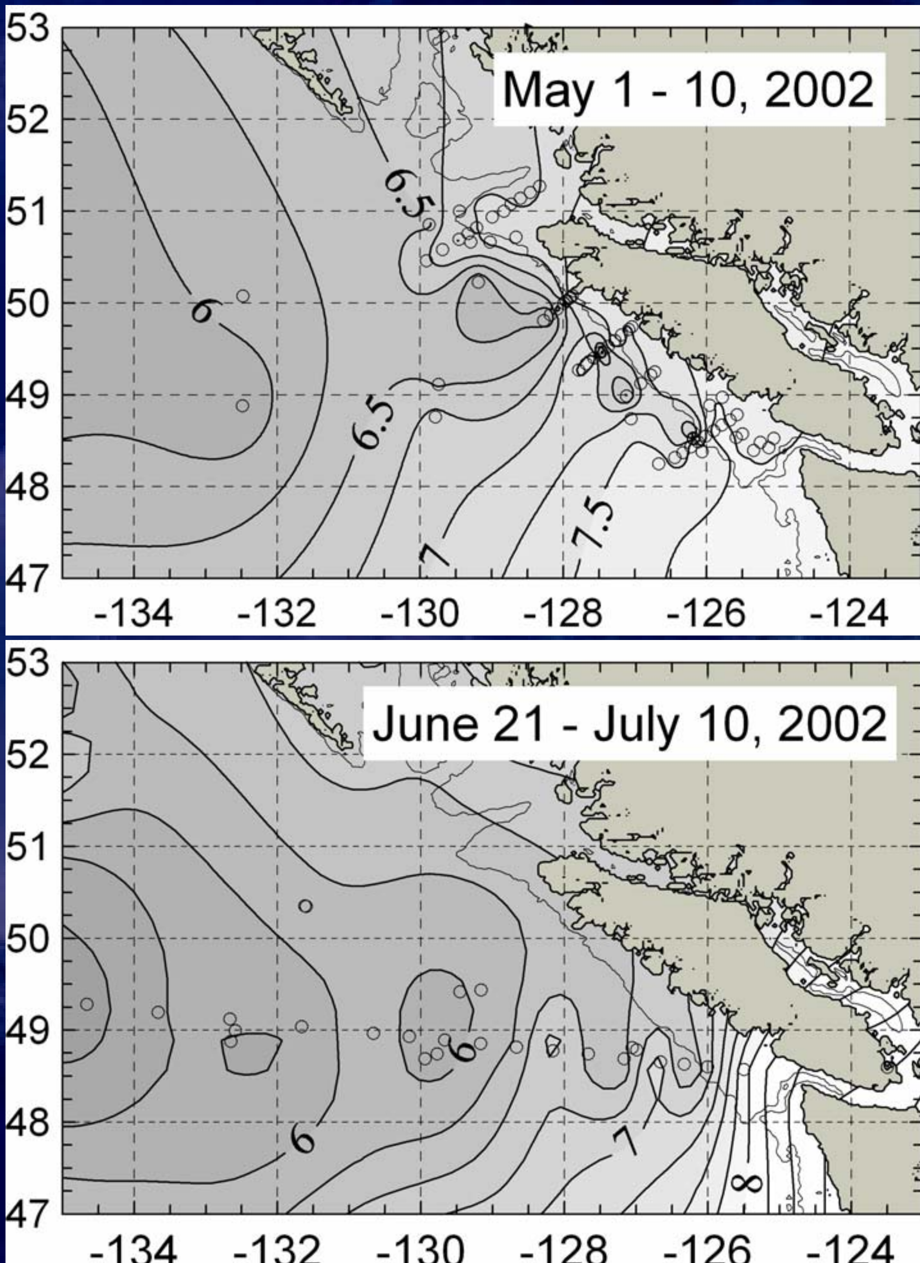


Depth of mixed layer base below 33.0 salinity surface (m), 21 to 31 March 2002.
60°N
57°N
54°N
51°N
48°N
45°N
150°W
144°W
138°W
132°W
126°W
120°W

Temperature on the 33.0 salinity surface between 1 and 10 March, 2002. All data from Argo profilers.



Temperature on the 33.0 salinity surface, continued.



Best observations in spring 2002 took place in May, and included Line-P sampling.

The 7.0 °C isotherm was much closer to shore than normal.

Sampling along Line-P in June-July 2002 also showed 7.0°C isotherm even closer to shore.

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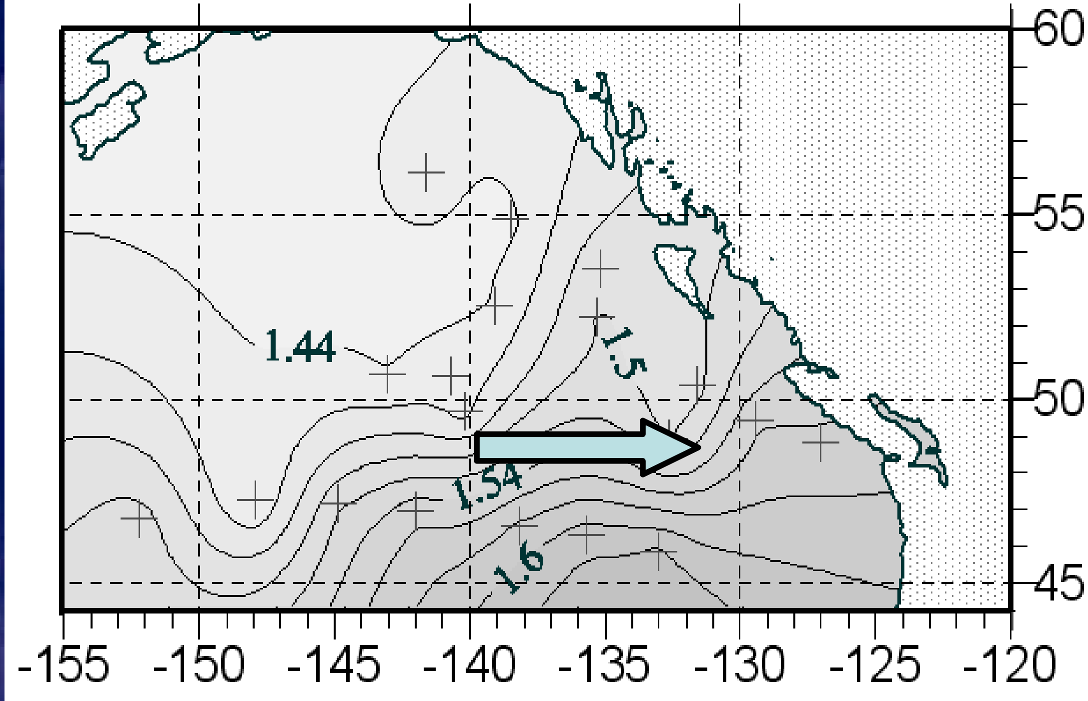
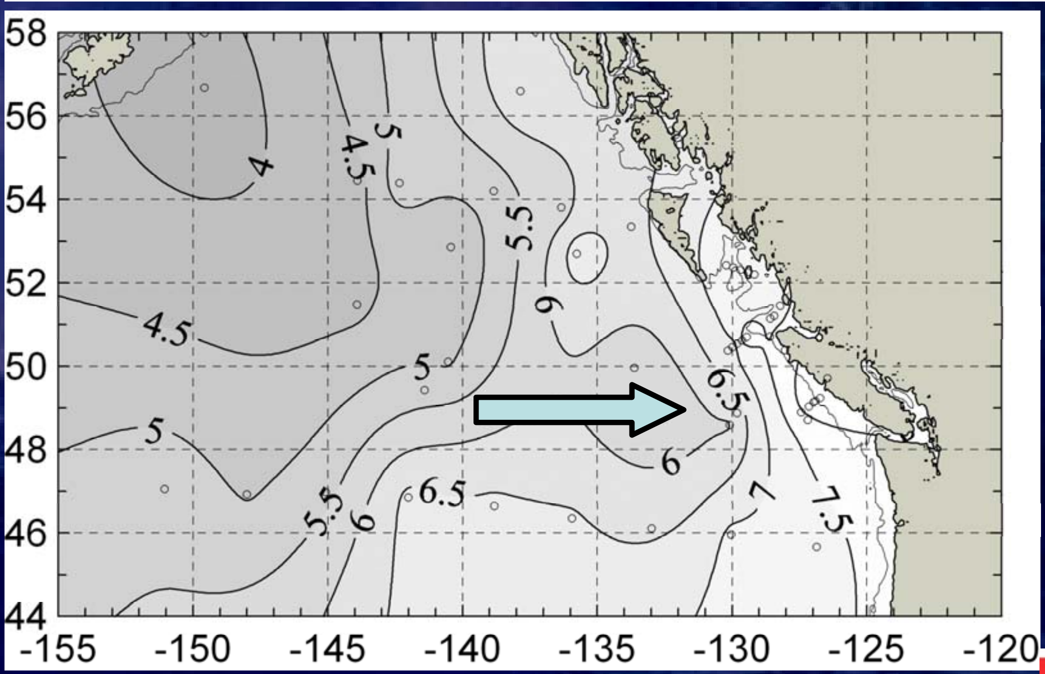
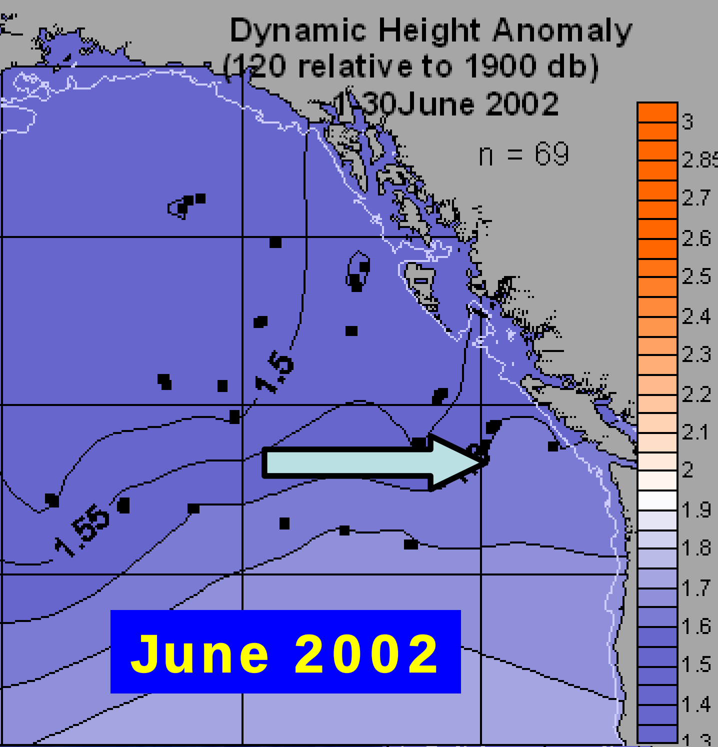


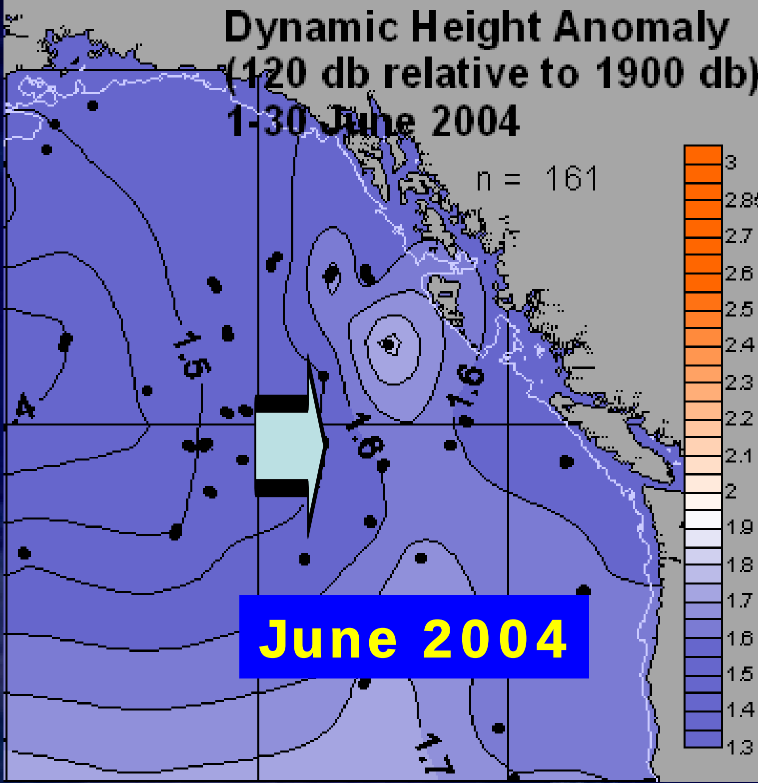


Left: Dynamic height anomaly of the 120 m surface relative to the 1900 m surface, June 2002. Arrow represents a flow of about 10 cm/s.

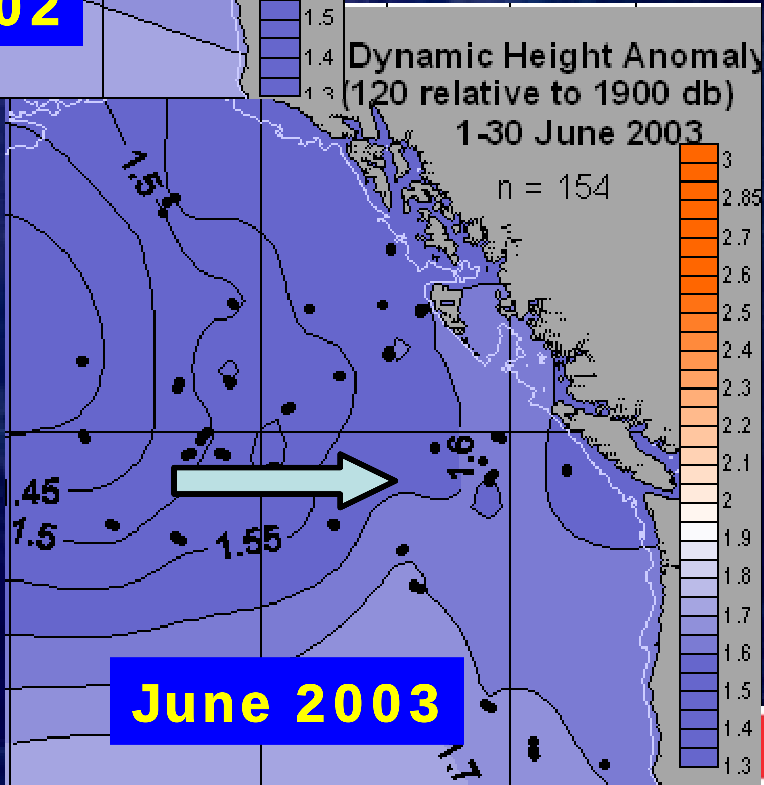
Images are based on Argo profilers from nominal depth of 2000 m every 10 days.



Contours of dynamic height at 120 metres depth, relative to 1900 metres depth, in June of three years.

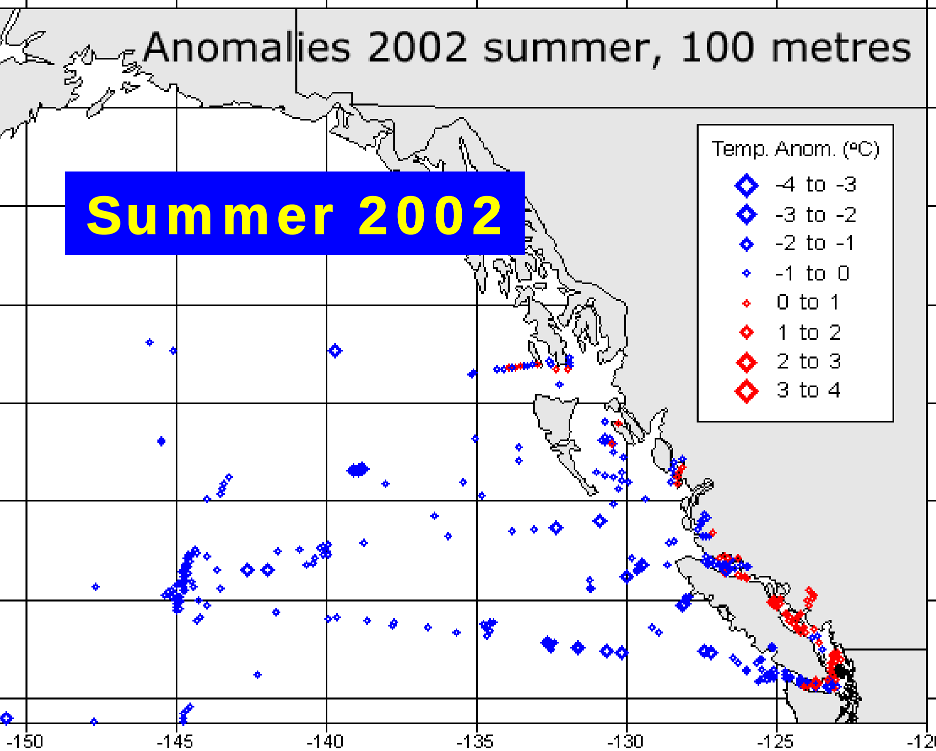


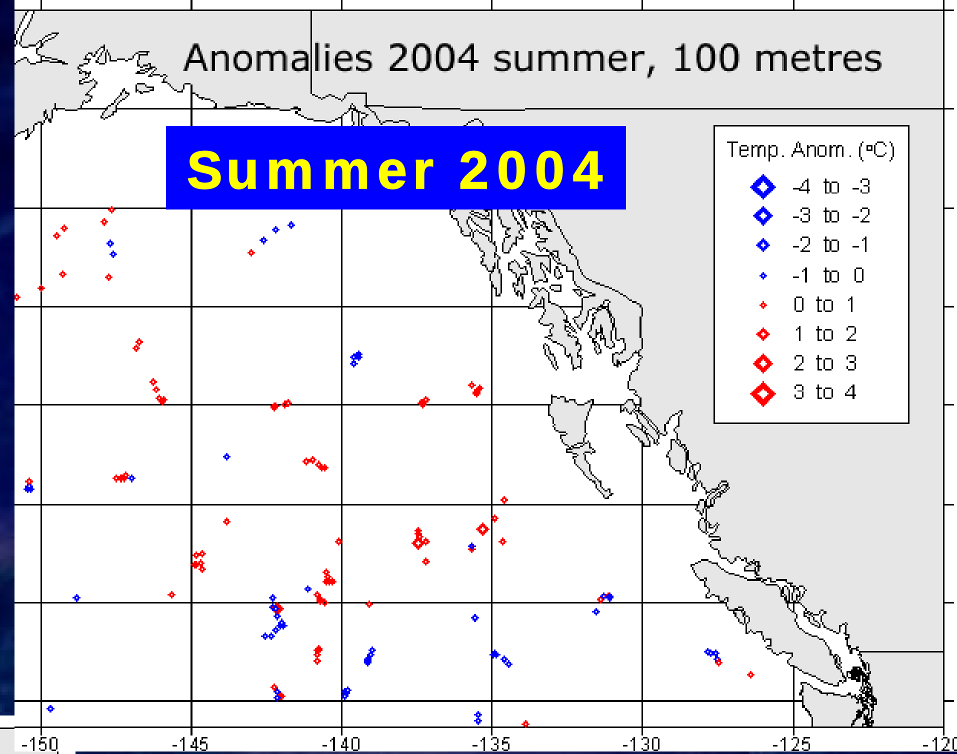
Images are based on Argo profilers from nominal depth of 2000 m every 10 days.

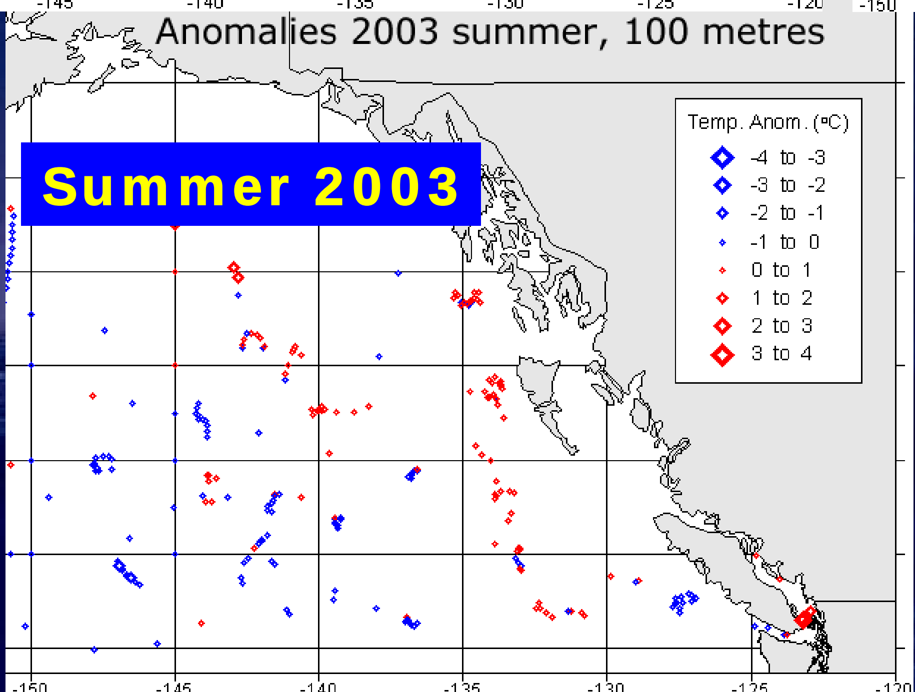


Arrows show flow direction suggested by dynamic height contours. Only in June 2002 do they suggest flow of water all the way to the continental margin.

Black dots indicate locations of Argo profiles used to compute dynamic heights.







The cold anomaly of 2002 at 100 m depth has faded in the past two years in the eastern gulf, but some cool waters persist, especially in the SE of this domain.

Argo profilers provided most data points.

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This winter wind pattern (Bond et al., 2003), labelled the Victoria anomaly of the PDO, ended with the 2003-2003 El Niño. The figures below show anomalous winter air pressures (left) and SSTs (right) of the 2002-2003 winter.

Winds carried warm surface water from the south along the west coast at surface from northern California to Alaska, as shown in the image at right.

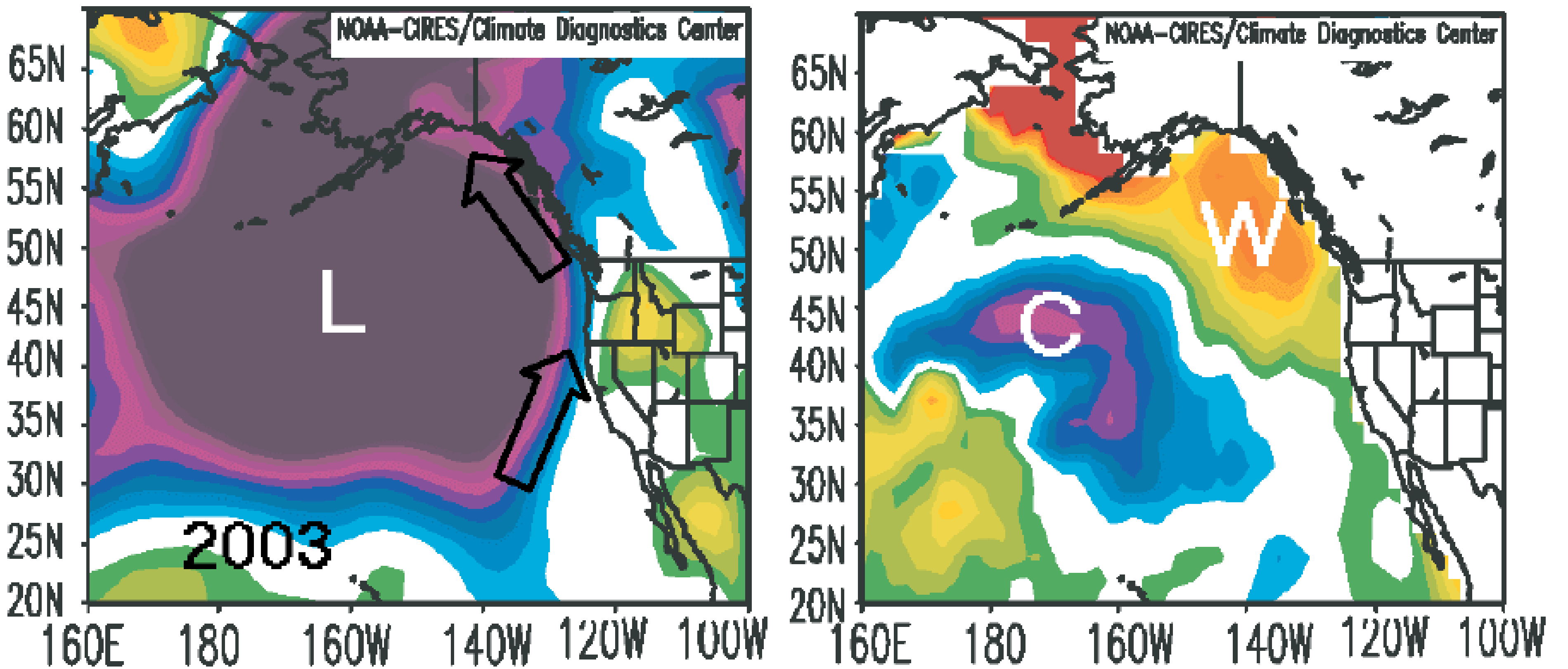
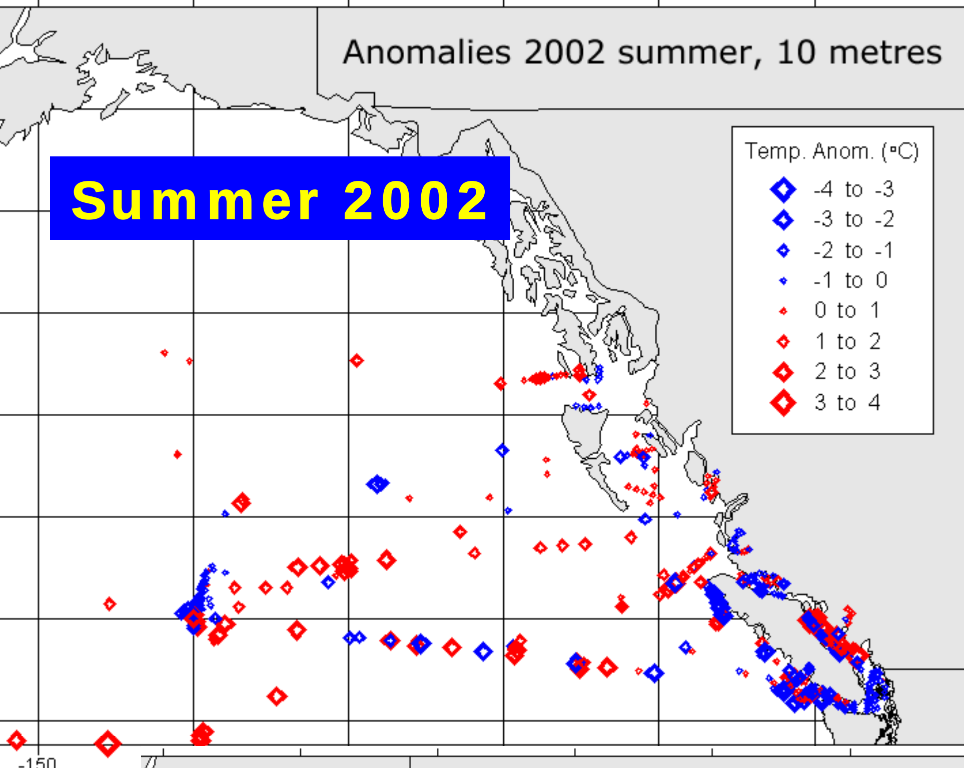
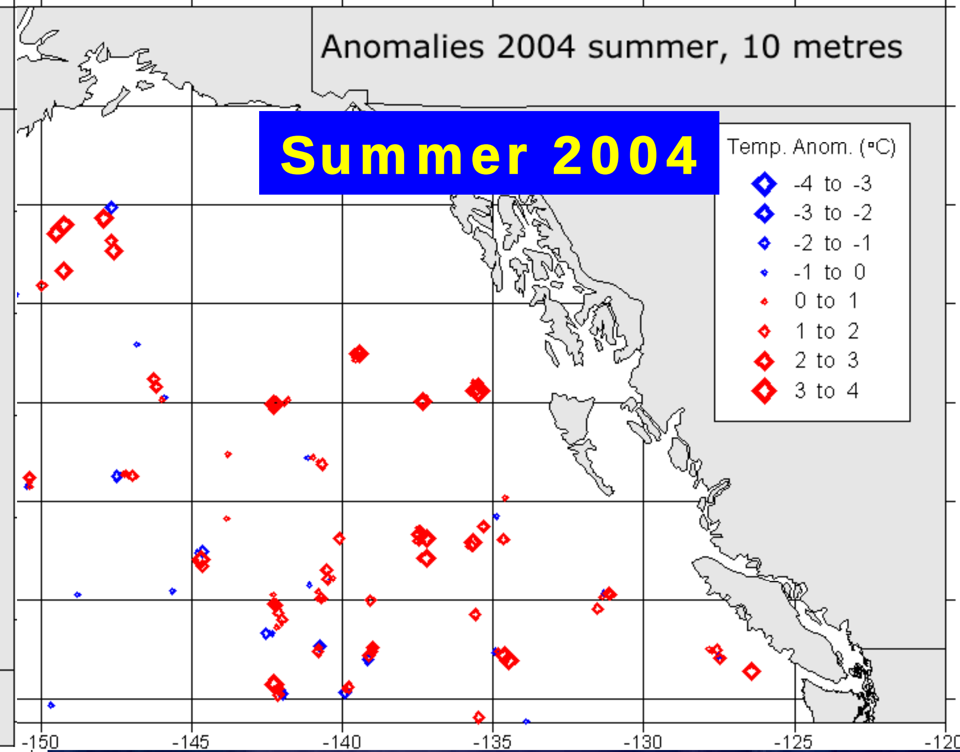
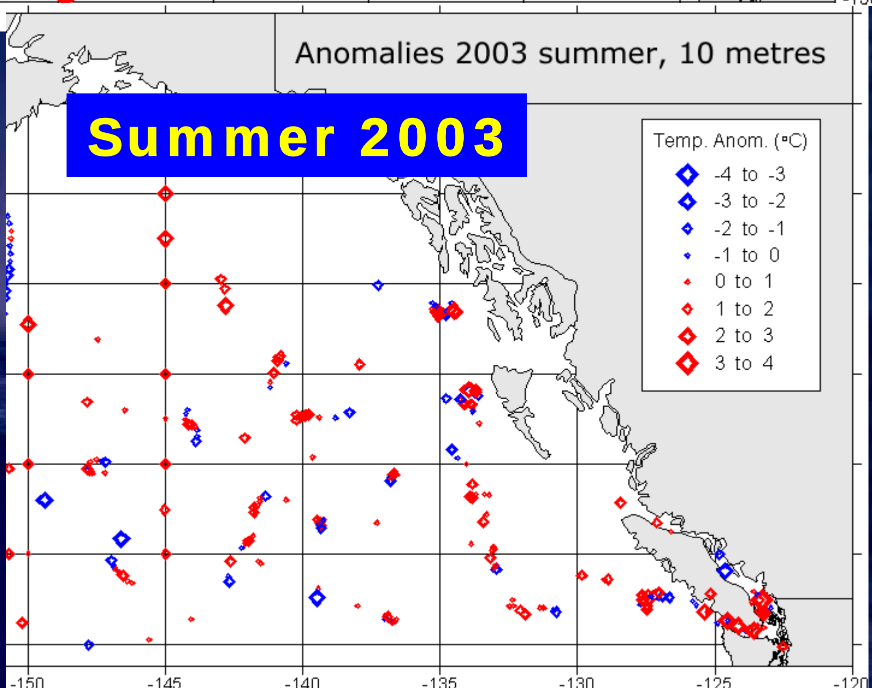


Figure 11d. Left panel presents air pressure anomalies in winter of 2003. Letters L denotes low pressure anomaly. Arrows indicate wind anomalies due to these air pressures. Right panel present a map of sea surface temperature anomalies in these same winters, with W and C for warm and cold. (adapted from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







The waters at 10 m depth have warmed in the past two years in the eastern gulf, due to the warm winds of 2003-2003 El Niño and the anomalous summer of 2004 (high PDO).

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The ocean off the West Coast of Canada and northern USA in late summer 2004 was much warmer at surface than in previous years, but close to normal at 100 m depth.

Cooling

The subsurface cooling of 2002 was likely a contributing factor in the low oxygen found at bottom of the Oregon to BC continental shelf.

Warming

The warming in 2003 was accompanied by increase in biomass of southern zooplankton in Canadian waters (Batten, Mackas), decrease in Vancouver Island eulachon index (Perry), more sardines in southern Canada (Schweigert), and lower survival for most seabirds off northern Vancouver Island (Hepfner).

Source: 2003 Pacific Region State of the Ocean Report, Pacific Science Advice and Review Committee, Canada. (http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/OceanStatus2003.pdf)

Warming in 2004 created problems for Fraser River salmon, due to very warm waters in river, and possibly is linked to increased biomass of hake on Vancouver Island shelf.