Mesoscale eddies of the Northeast Pacific Ocean

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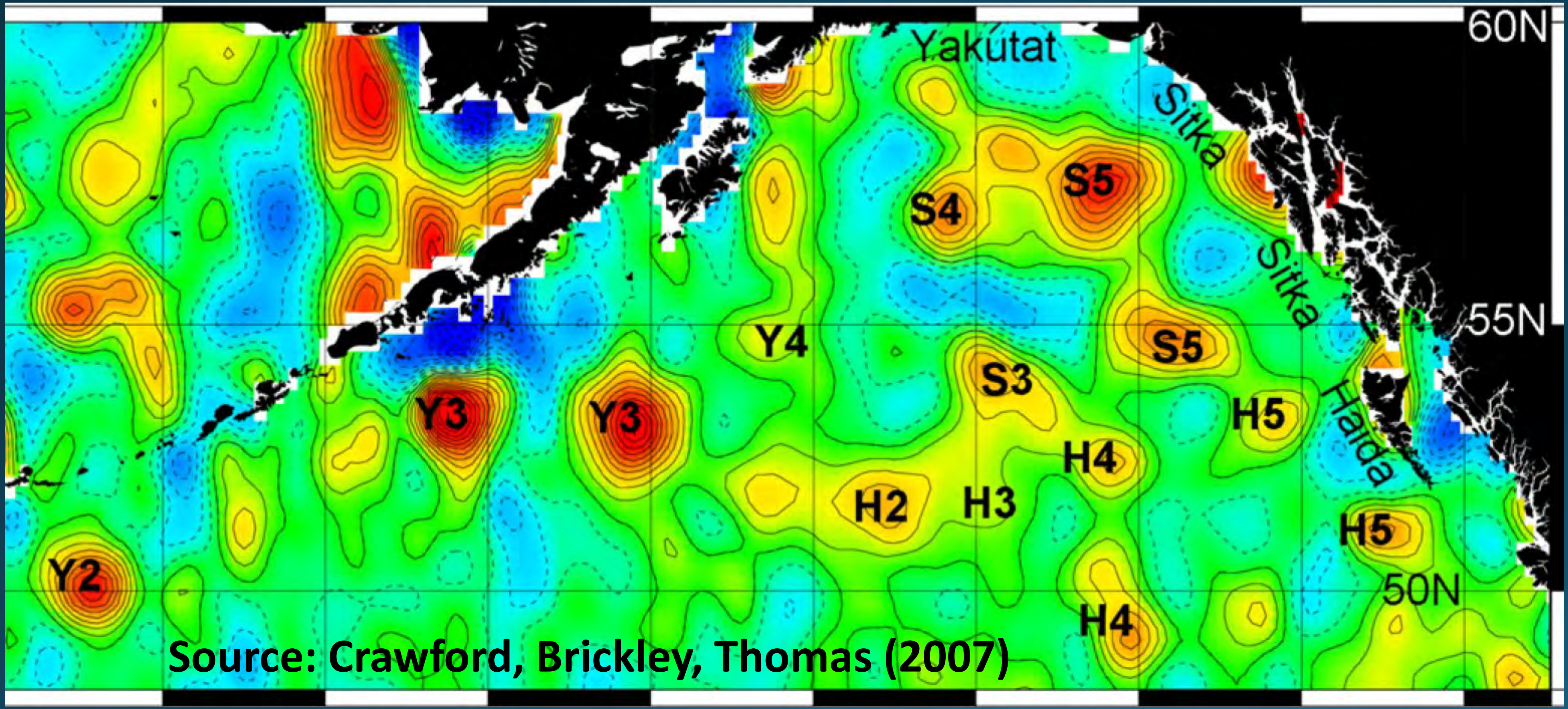


Fisheries and Oceans Canada | Pêches et Océans Canada

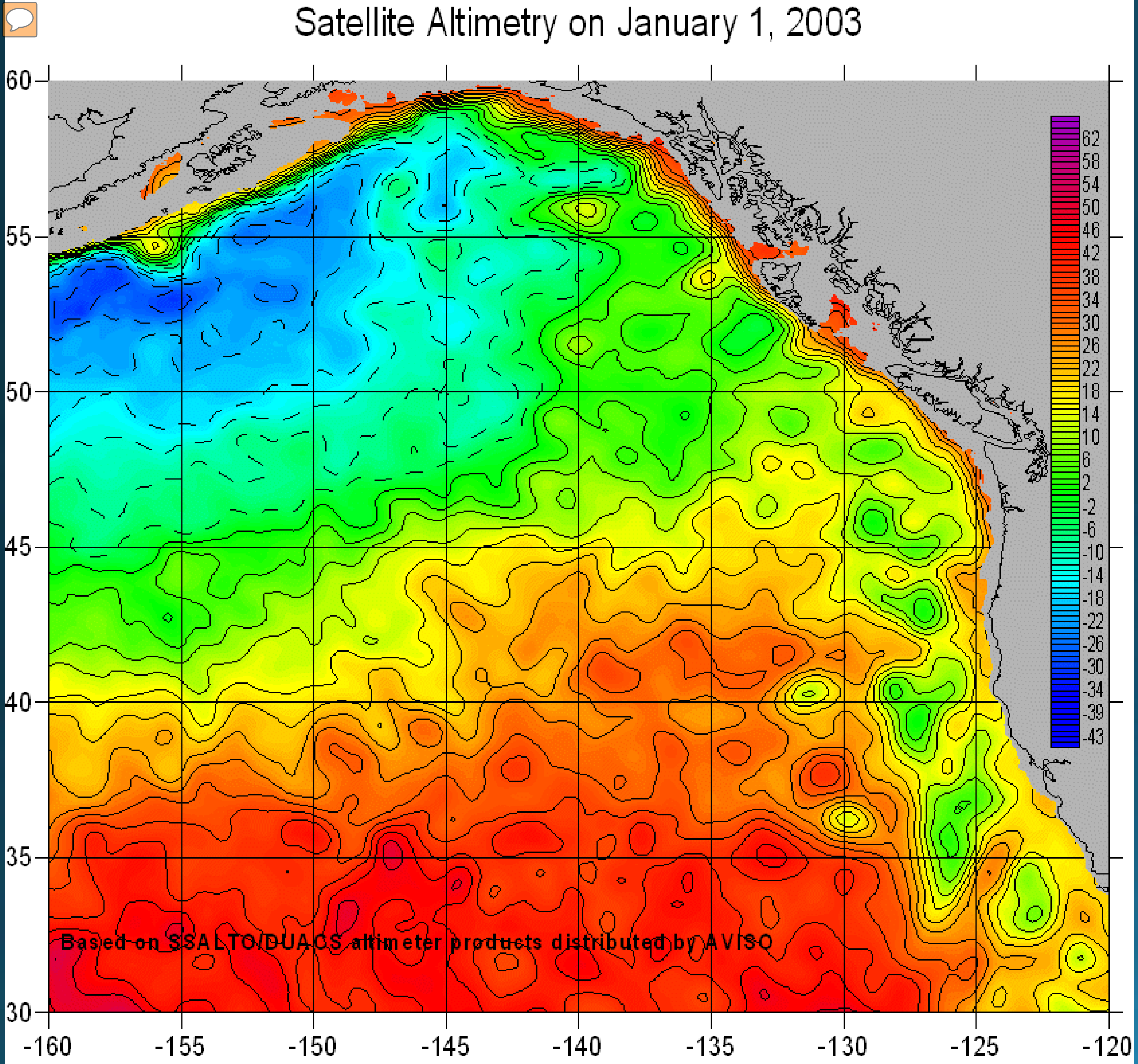
Bob Leben,
CCAR

Earlier studies:

Willmott and Mysak, 1980
McNally, 1981
Tabata, 1982
Gower and Tabata, 1995
Hamilton and Mysak, 1986
Cummins and Mysak, 1988
Gower, 1989
Okkonen, 1992
Melsom, Meyers, Hurlburt, Metzger, O'Brien, 1999
Swaters and Mysak, 1985
Matthews, Johnson, O'Brien, 1992
Okkonen, 1992
Paduan, Niiler, 1993
Bhaskaran, Lagerloef, Born, Emery, Leben, 1993
Meyers, Basu, 1999
Thomson, Gower, 1998
Onishi, Ohtsuka, Anma, 2000

Later studies:

Cherniawsky, Foreman, Crawford, Beckley, 2004
Combes, Di Lorenzo, 2007
Combes, 2010
Coyle, Pinchuk, 2005
Combes, Di Lorenzo, Curchitser, 2009
Crawford, 2002, 2005
Crawford, Cherniawsky, Gower, Foreman, 2005
Crawford, Brickley, Thomas, Peterson, 2005
Crawford, Brickley, Thomas, 2007
Di Lorenzo, Foreman, Crawford, 2005
Henson, Thomas, 2008
Ladd, Kachel, Mordy, Stabeno, 2005
Ladd, Kachel, Mordy, Stabeno, 2007
Ladd, Stabeno, Cokelet, 2005
Ladd, Mordy, Kachel, Stabeno, 2007
Lyman, Johnson, 2015
Martin, Lee, Eriksen, Ladd, Kachel, 2010
Maslowski, Roman, Kinney, 2008
Masson, Fine 2012
Nudds, Shore, 2011
Okkonen, Weingartner, Danielson, Musgrave, 1996
Okkonen, Jacobs, Metzger, Hurlburt, Shriver, 2001
Okkonen, Weingartner, Danielson, Musgrave, Schmidt, 2003
Shore, Stacey, Wright, 2008
Stabeno, Bond, Hermann, Kachel, Mordy, Overland, 2004
Strub, Thomas, 2004
Strub, Combes, Shillington, Pizarro, 2013
Xiu, Chai, Xue, Shi, Chao, 2012
Yelland, Crawford, 2005



Sea Surface Height (SSH)

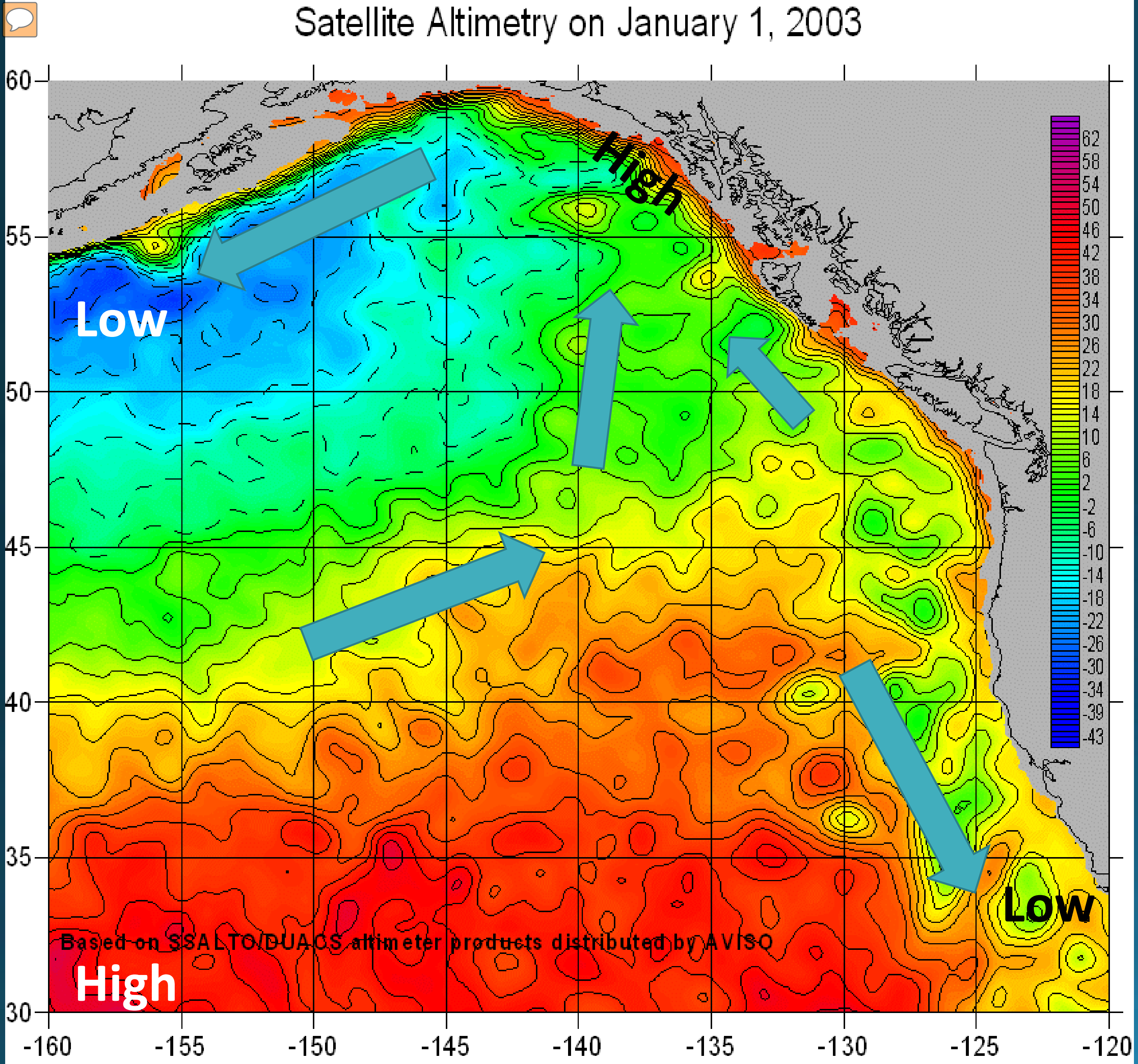
Image shows pressure-adjusted sea surface height derived from satellite altimetry and referenced in the vertical to Foreman et al. (2008).

Altimetry maps are always pressure-adjusted, which means sea level changes due only to local air pressure have been removed. (Inverse barometer effect).

Based on SSALTO/DUACS altimeter products distributed by AVISO.

Contours at 4 cm intervals.

Note the ~80 cm difference in height between **Low** and **High**.



Sea Surface Height (SSH)

Image shows pressure-adjusted sea surface height derived from satellite altimetry and referenced in the vertical to Foreman et al. (2008) geoid.

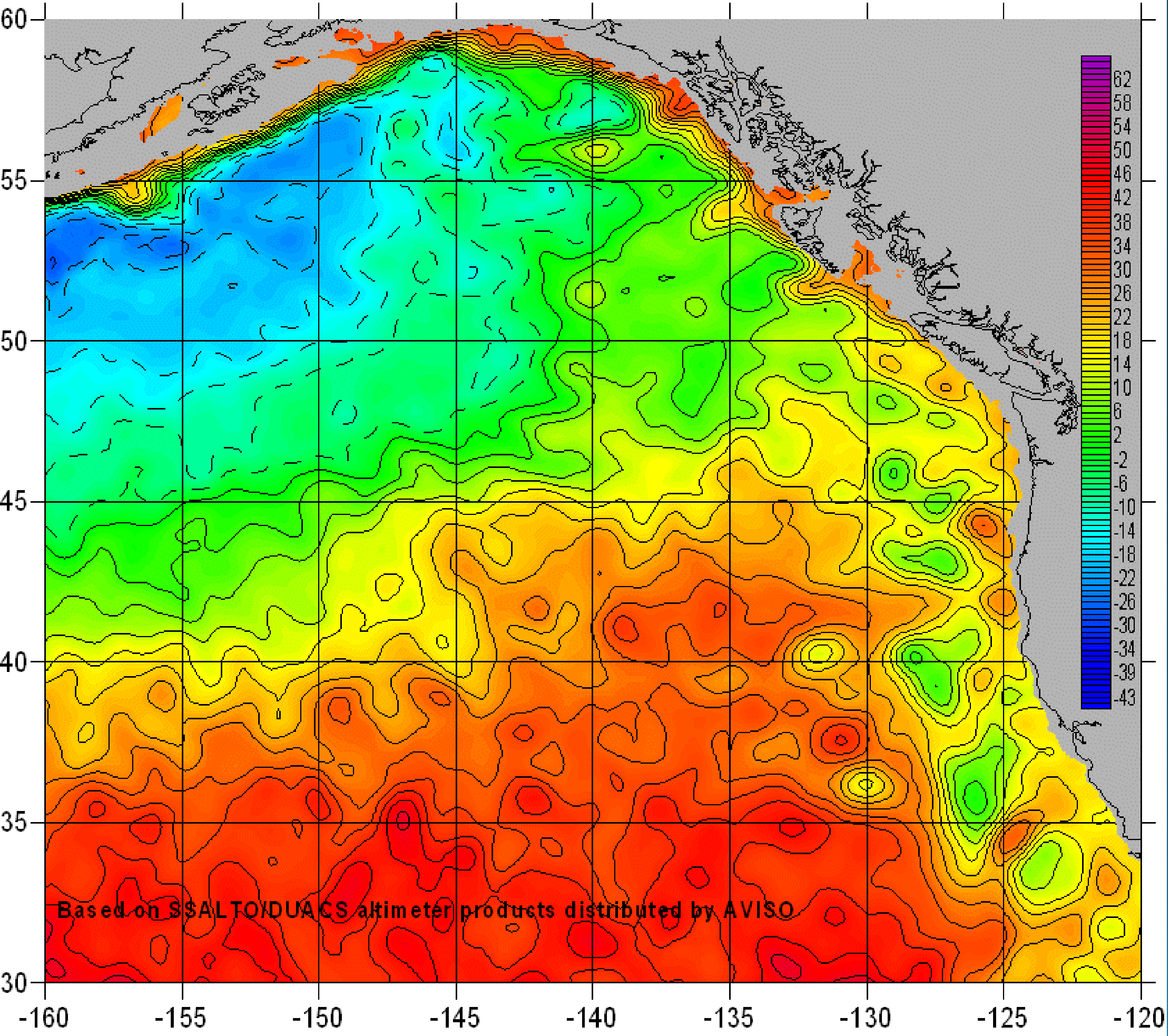
Altimetry maps are always pressure-adjusted, which means sea level changes due only to local air pressure have been removed. (Inverse barometer effect).

Based on SSALTO/DUACS altimeter products distributed by AVISO.

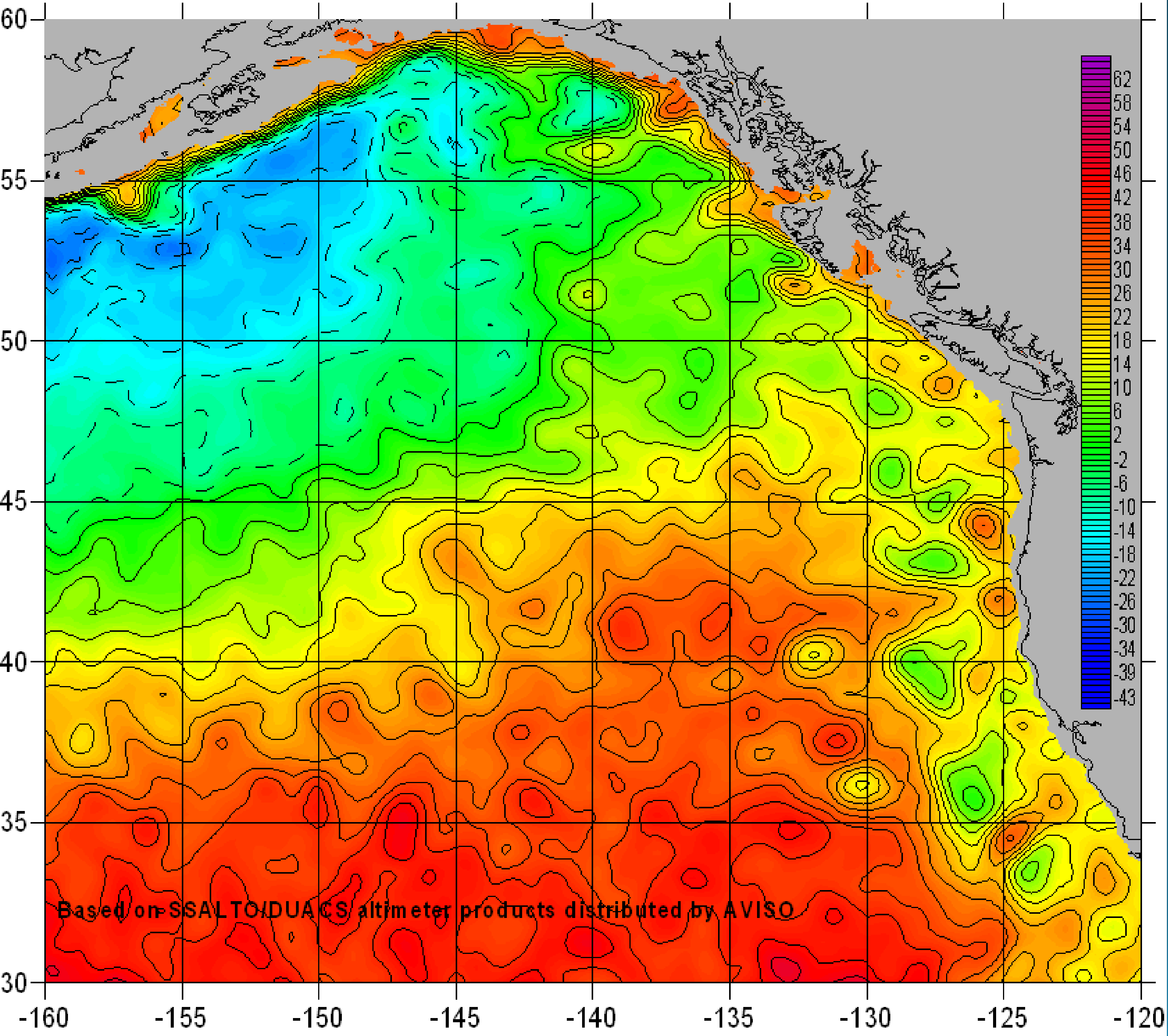
Contours at 4 cm intervals. High water to the right of currents.

Note the ~80 cm difference in height between **Low** and **High**.

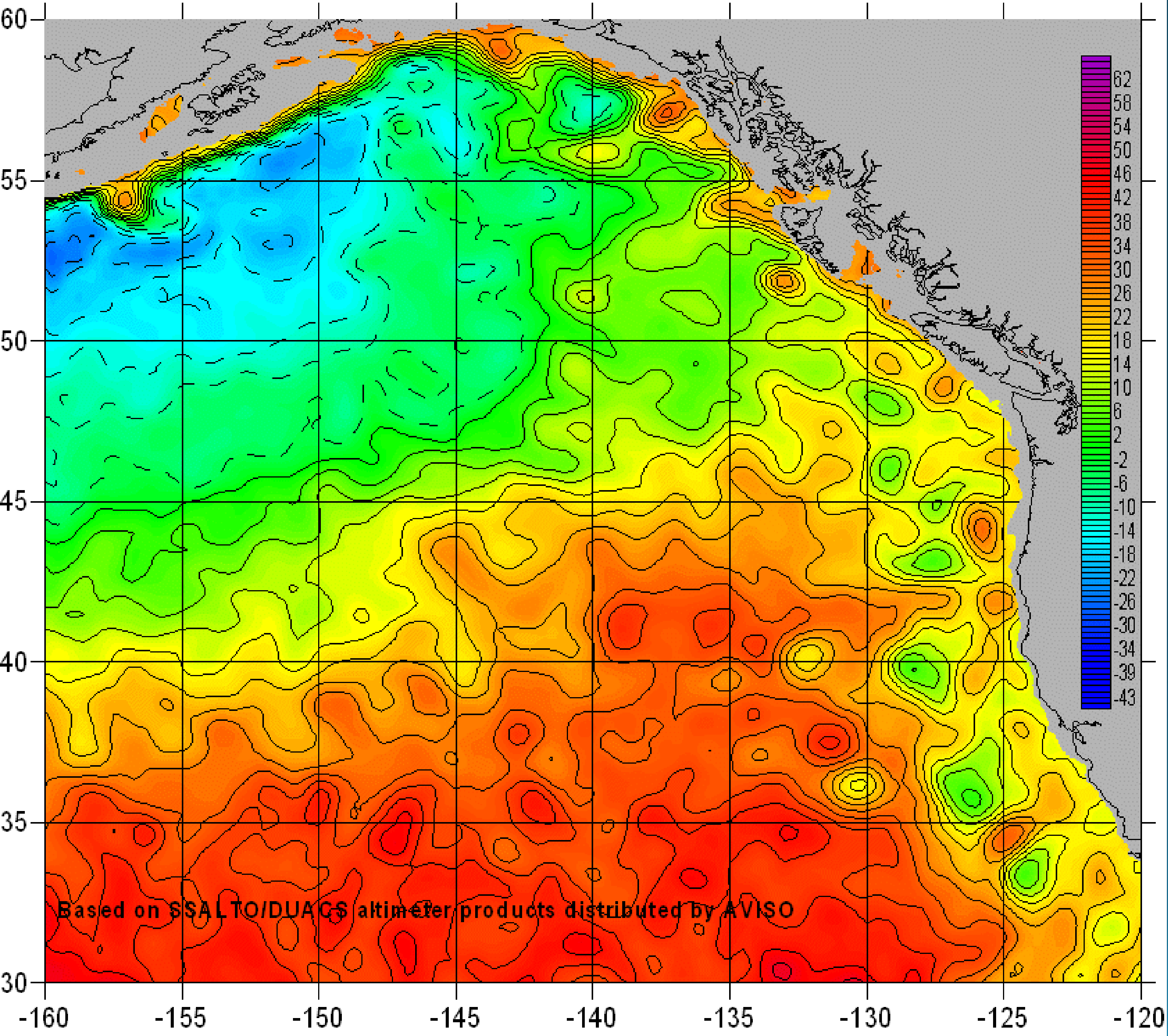
Satellite Altimetry on January 15, 2003

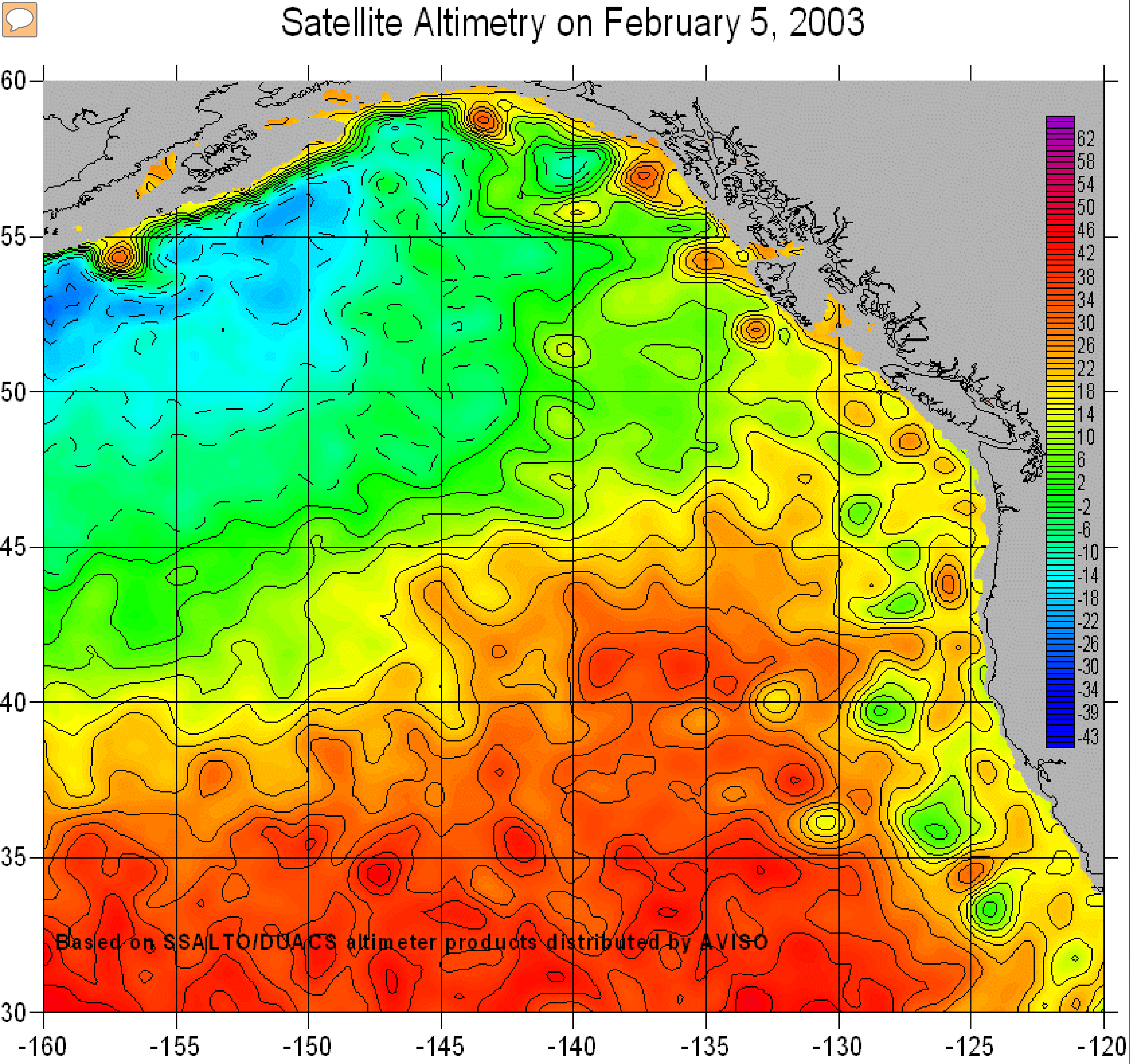


Satellite Altimetry on January 22, 2003



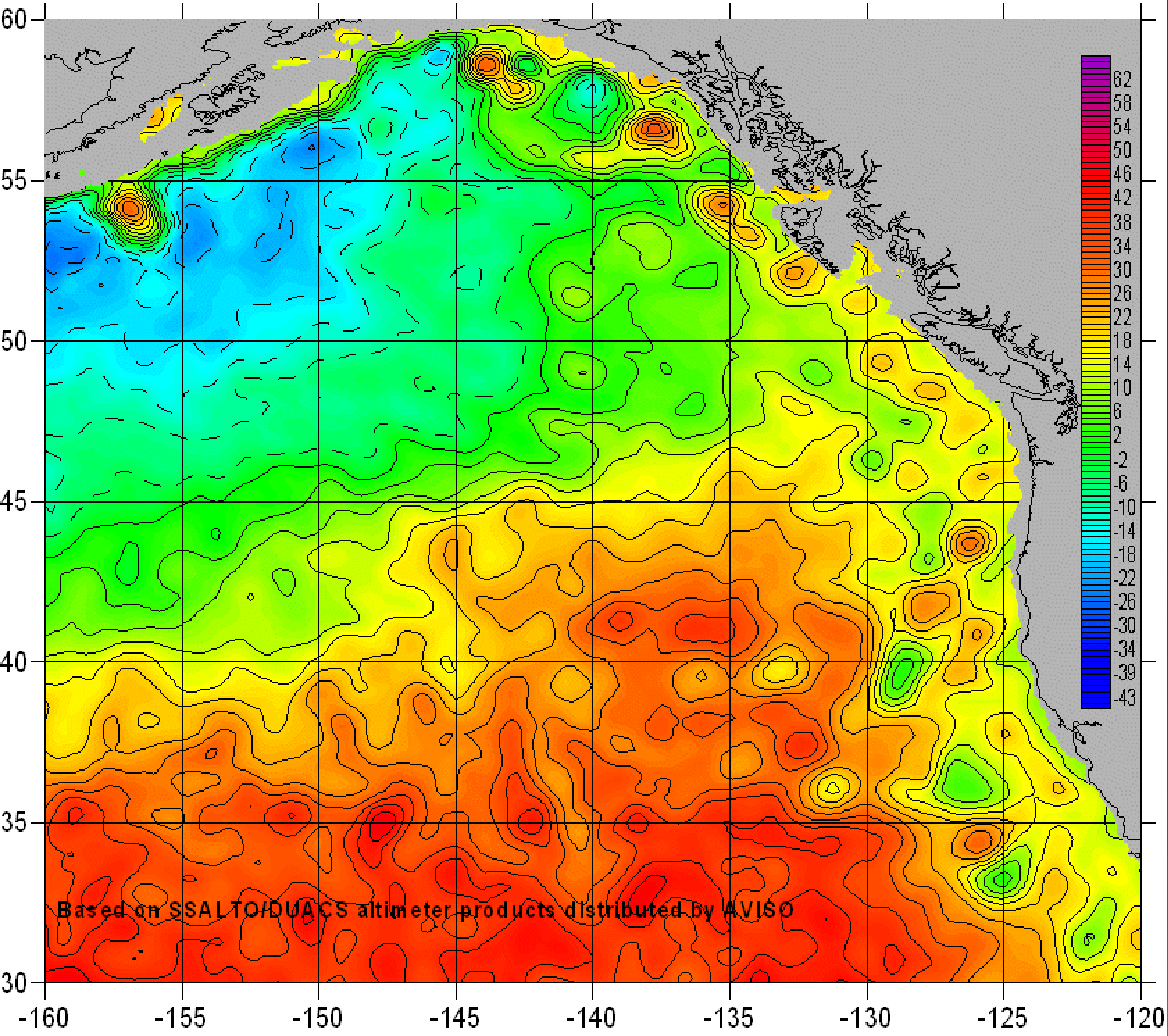
Satellite Altimetry on January 29, 2003



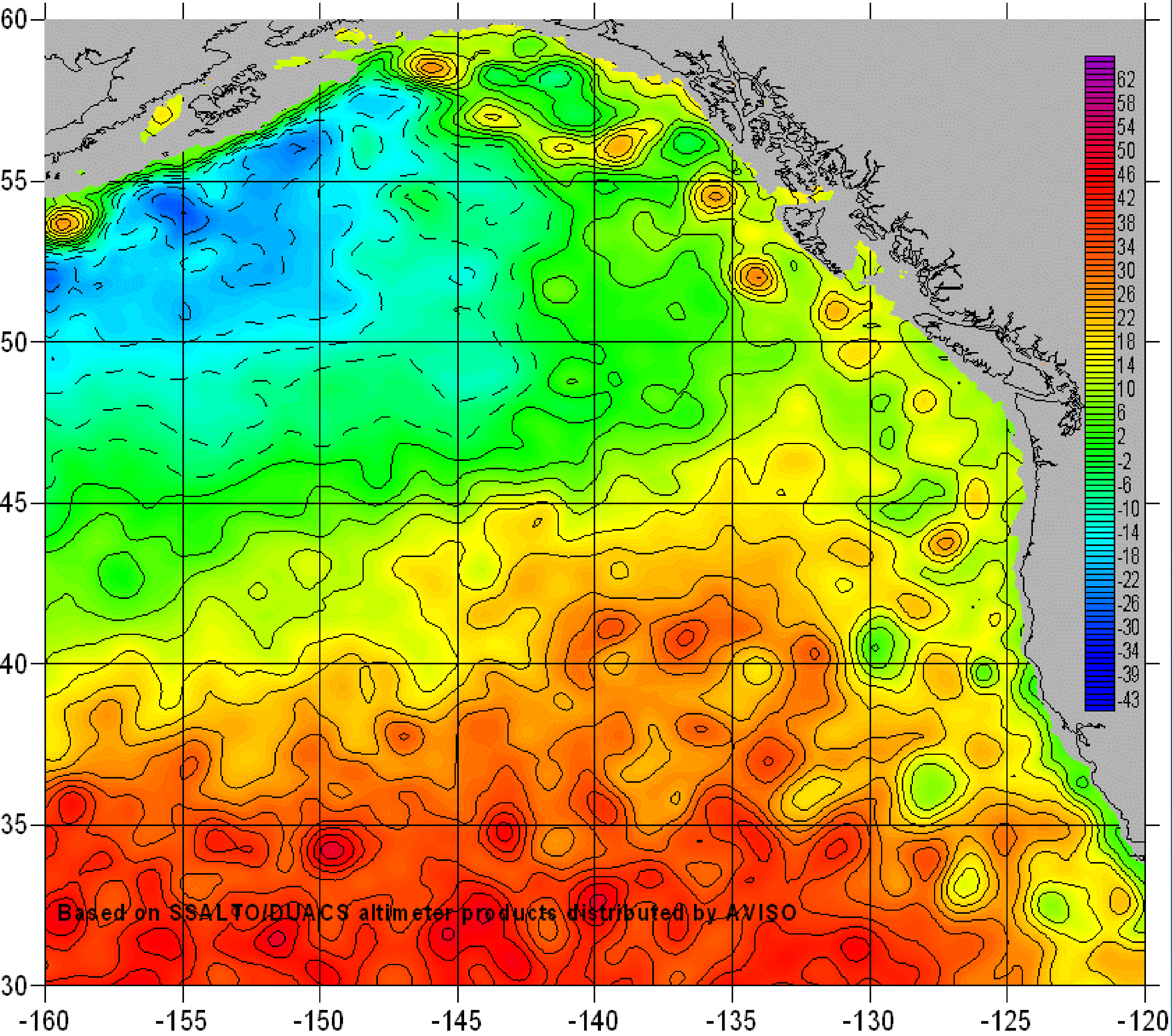


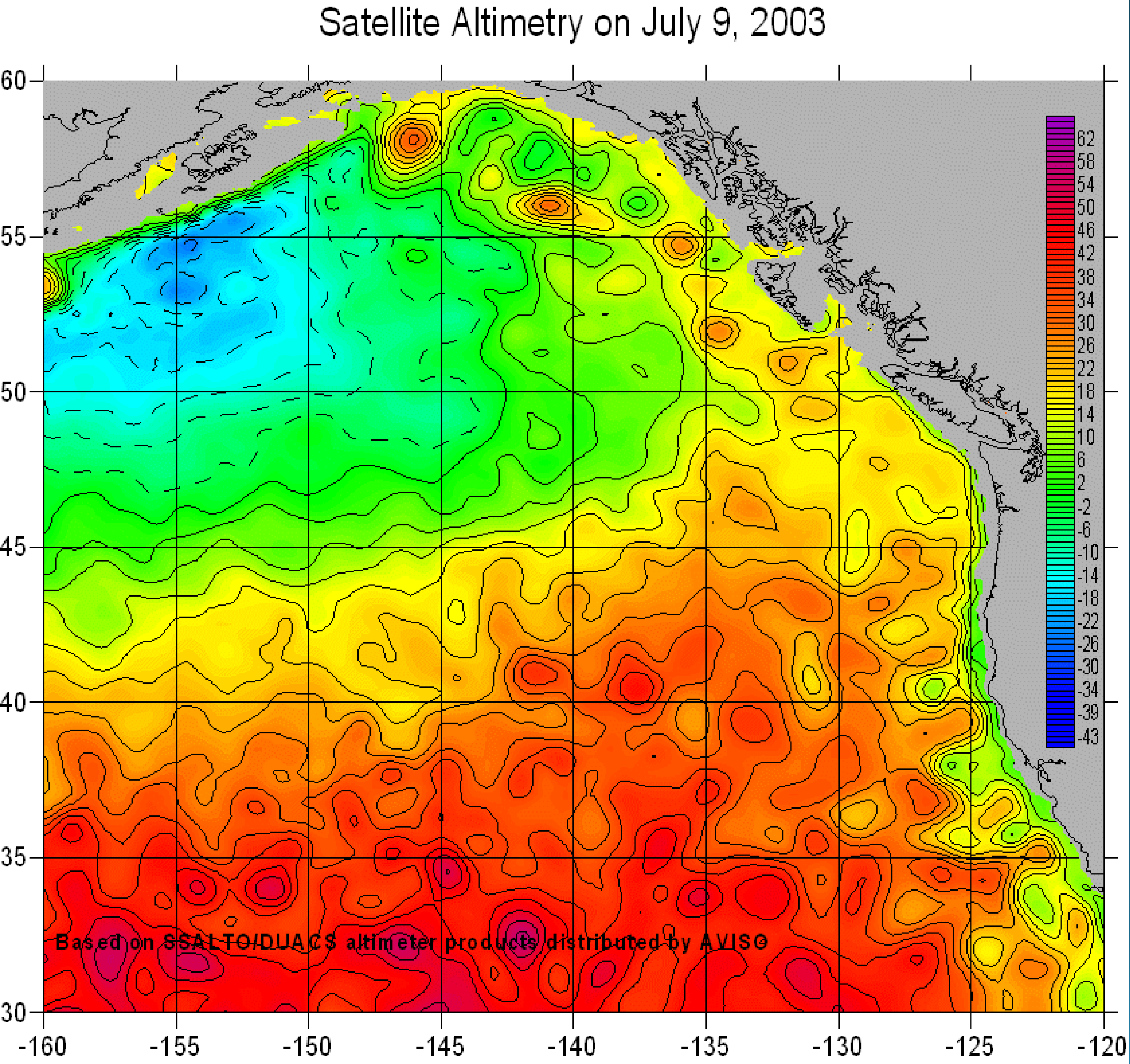
Satellite Altimetry on February 5, 2003
60
55
50
45
40
35
30
-160
-155
-150
-145
-140
-135
-130
-125
-120
62
58
54
50
46
42
38
34
30
26
22
18
14
10
6
2
-2
-6
-10
-14
-18
-22
-26
-30
-34
-39
-43
Based on SSALTO/DUACS altimeter products distributed by AVISO

Satellite Altimetry on March 5, 2003



Satellite Altimetry on May 7, 2003

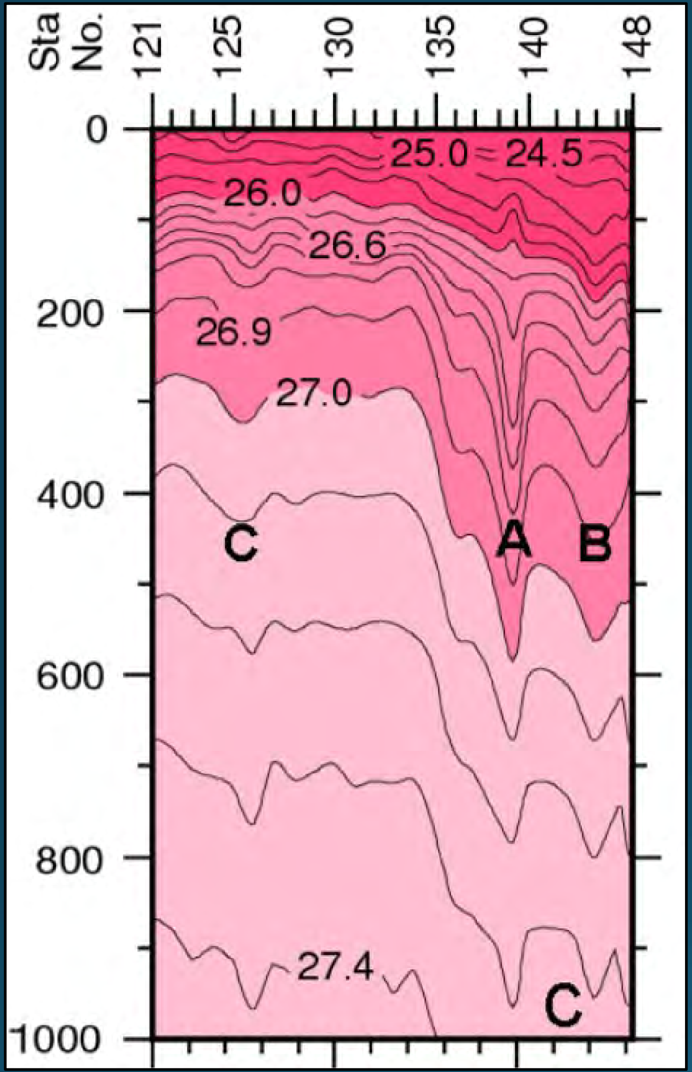


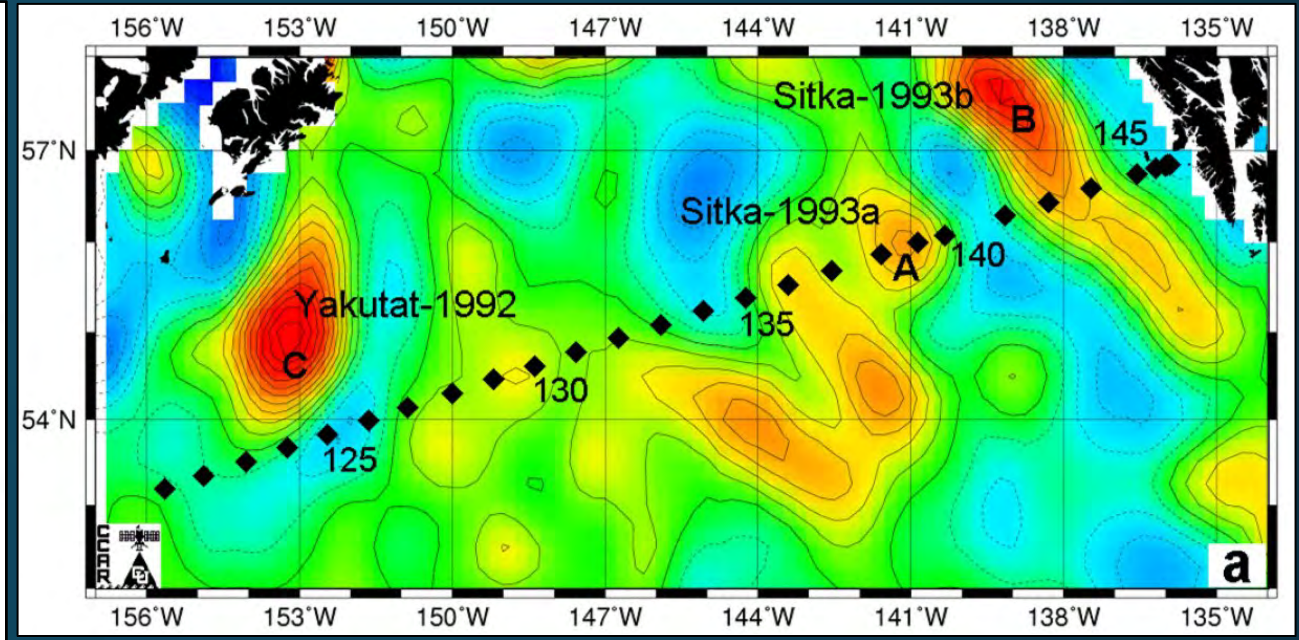

Satellite Altimetry on July 9, 2003
60
55
50
45
40
35
30
-160
-155
-150
-145
-140
-135
-130
-125
-120
62
58
54
50
46
42
38
34
30
26
22
18
14
10
6
2
-2
-6
-10
-14
-18
-22
-26
-30
-34
-39
-43
Based on SSALTO/DUACS altimeter products distributed by AVISO

Physical features

Core waters (~100 to 600 m depth) are from the continental margin, and once the eddies propagate into deep-sea regions, core waters are warmer and fresher than outside waters at the same depth, but warmer and saltier than waters of the same density.

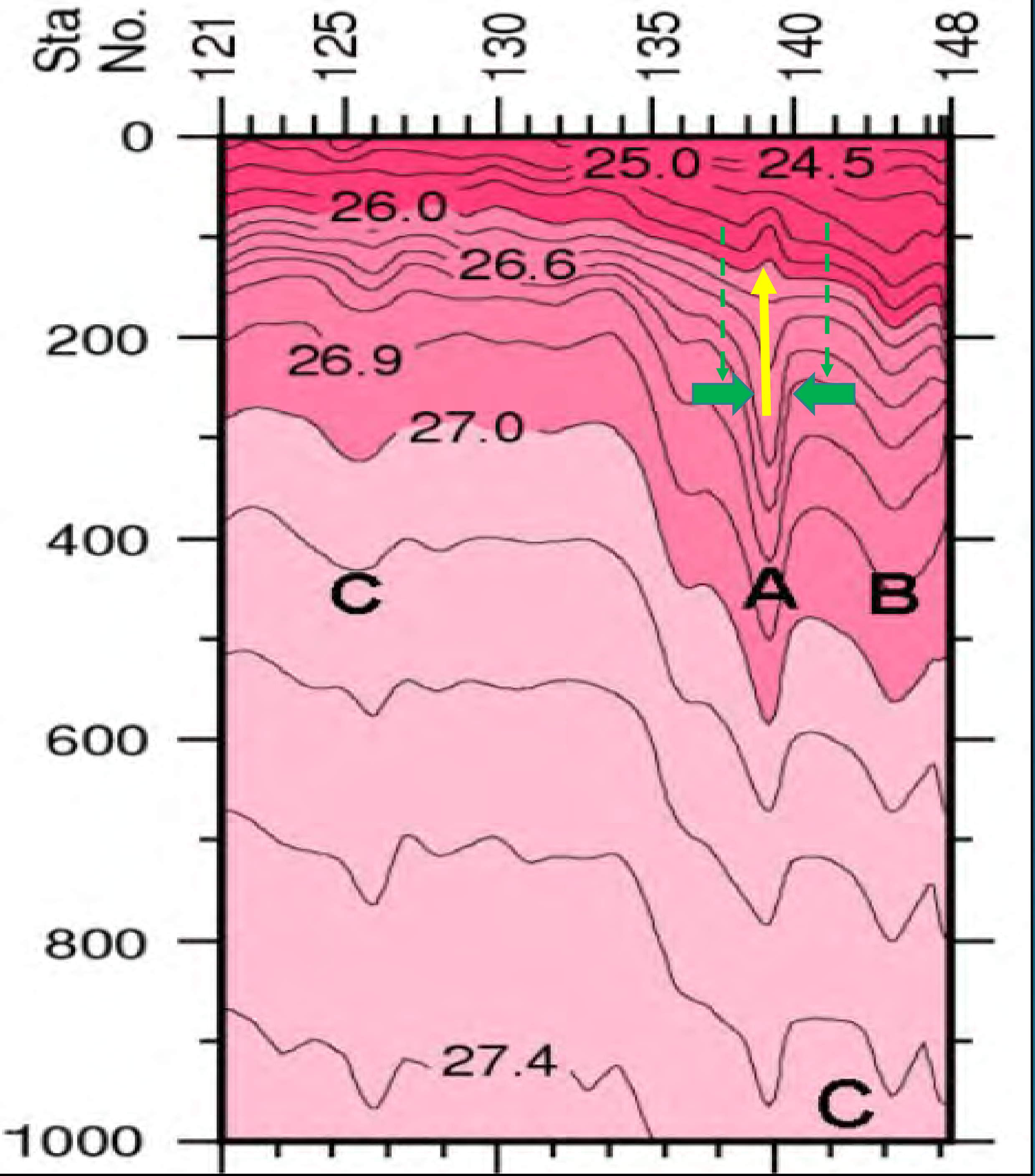
Core waters are rich in macro-nutrients and also micro-nutrients.

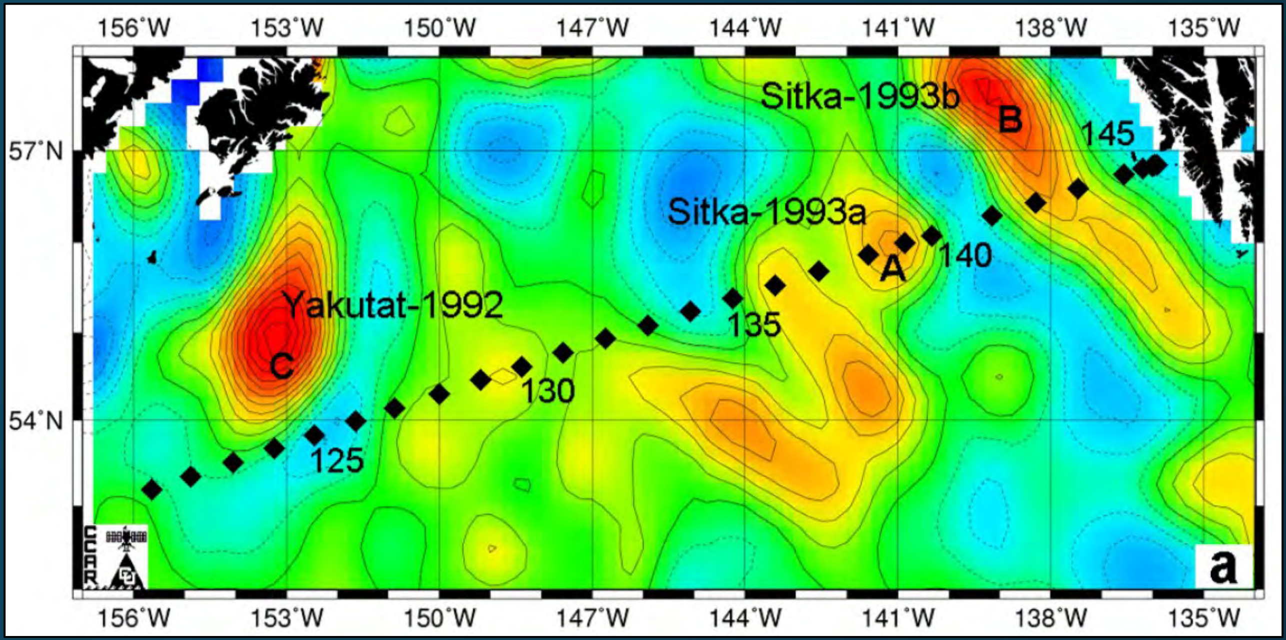




Above: SSHA along WOCE Line P17NE in May–June 1993 (D. Musgrave, chief scientist). Left: Contours of sigma-theta along Line P17NE, from station 121 to 148. Source: Crawford, Brickley, Thomas (2007)

Isopycnals in eddies are depressed at depths below 150 m, and usually elevated at shallower depths. As eddies propagate into the Alaska Gyre and decay, their water masses below 150 m will upwell through two mechanisms. 1: As eddies decay their depressed isotherms will rise. 2: Background isppycnals in mid-gyre are shallower than at shore where eddies form. **Nutrients upwell during the lifetime of the eddy.





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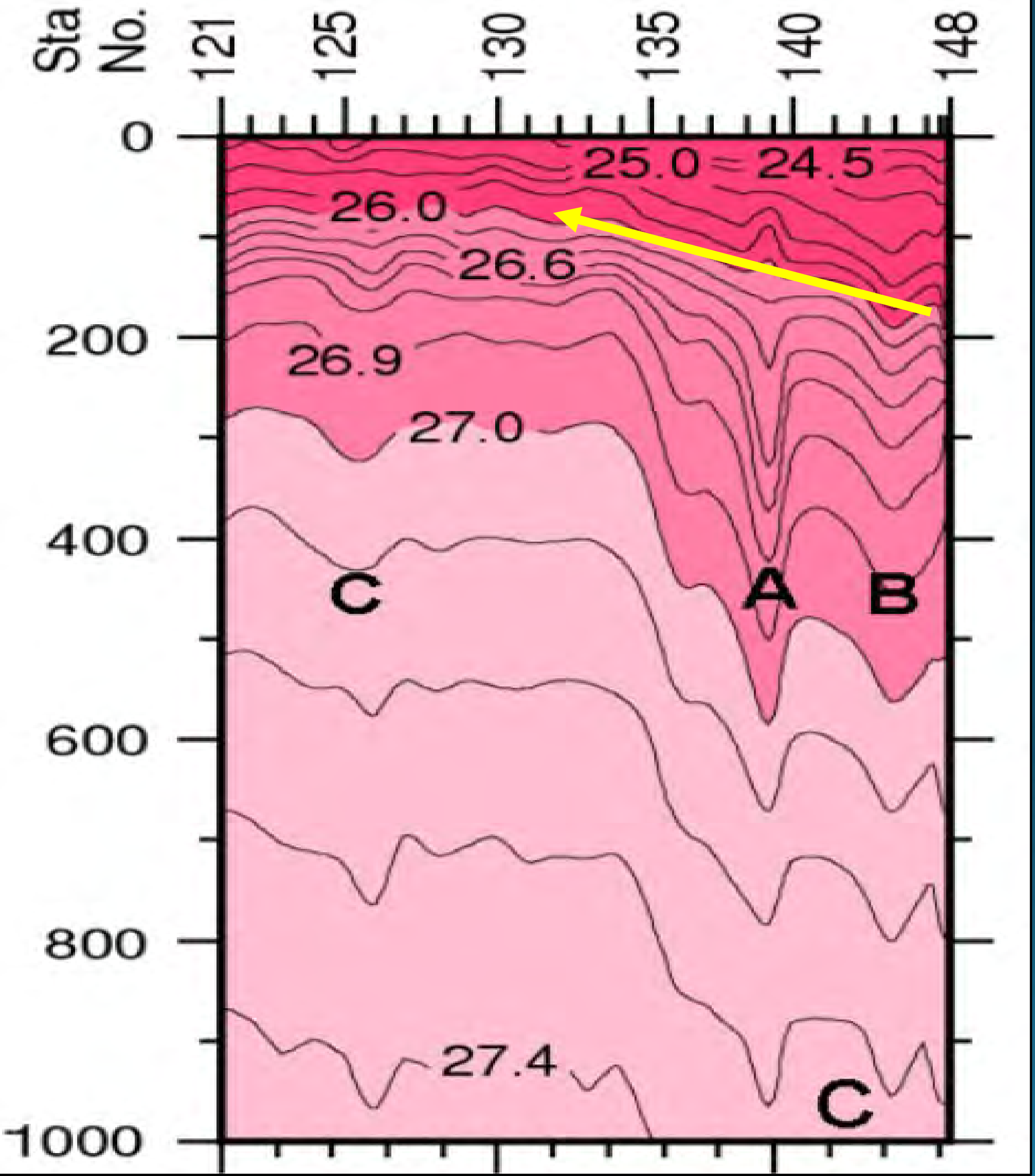
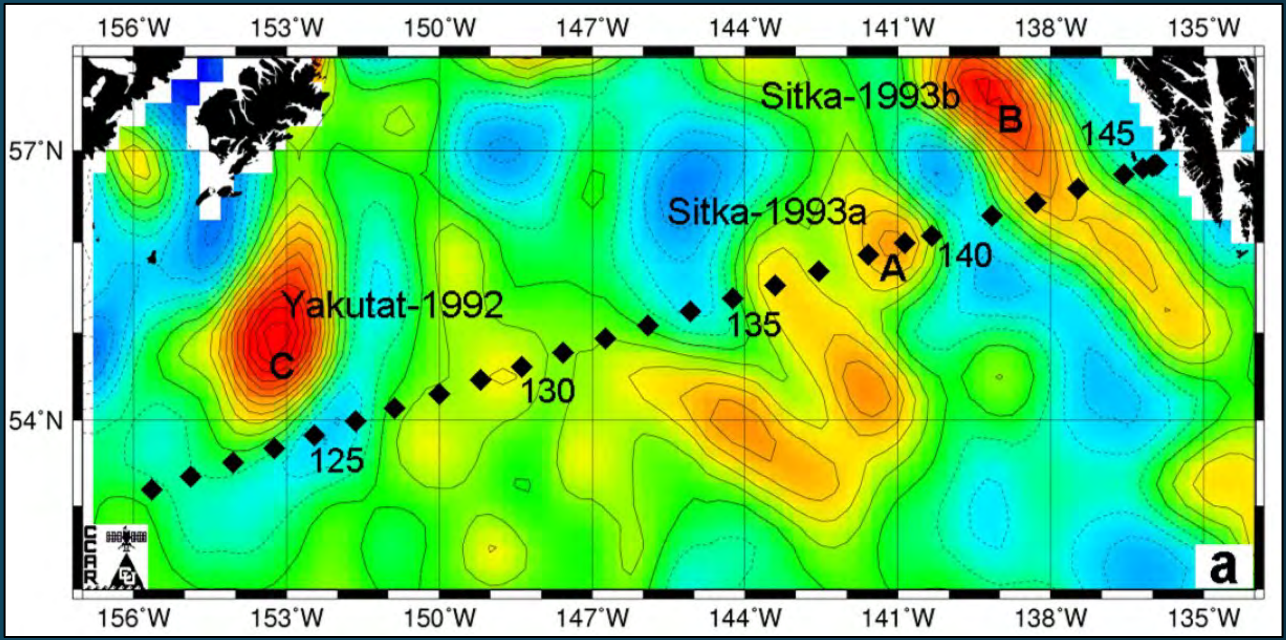
(1) This process is likely suppressed in Alaska Stream eddies of Northeast Pacific, since they often grow rather than decay.





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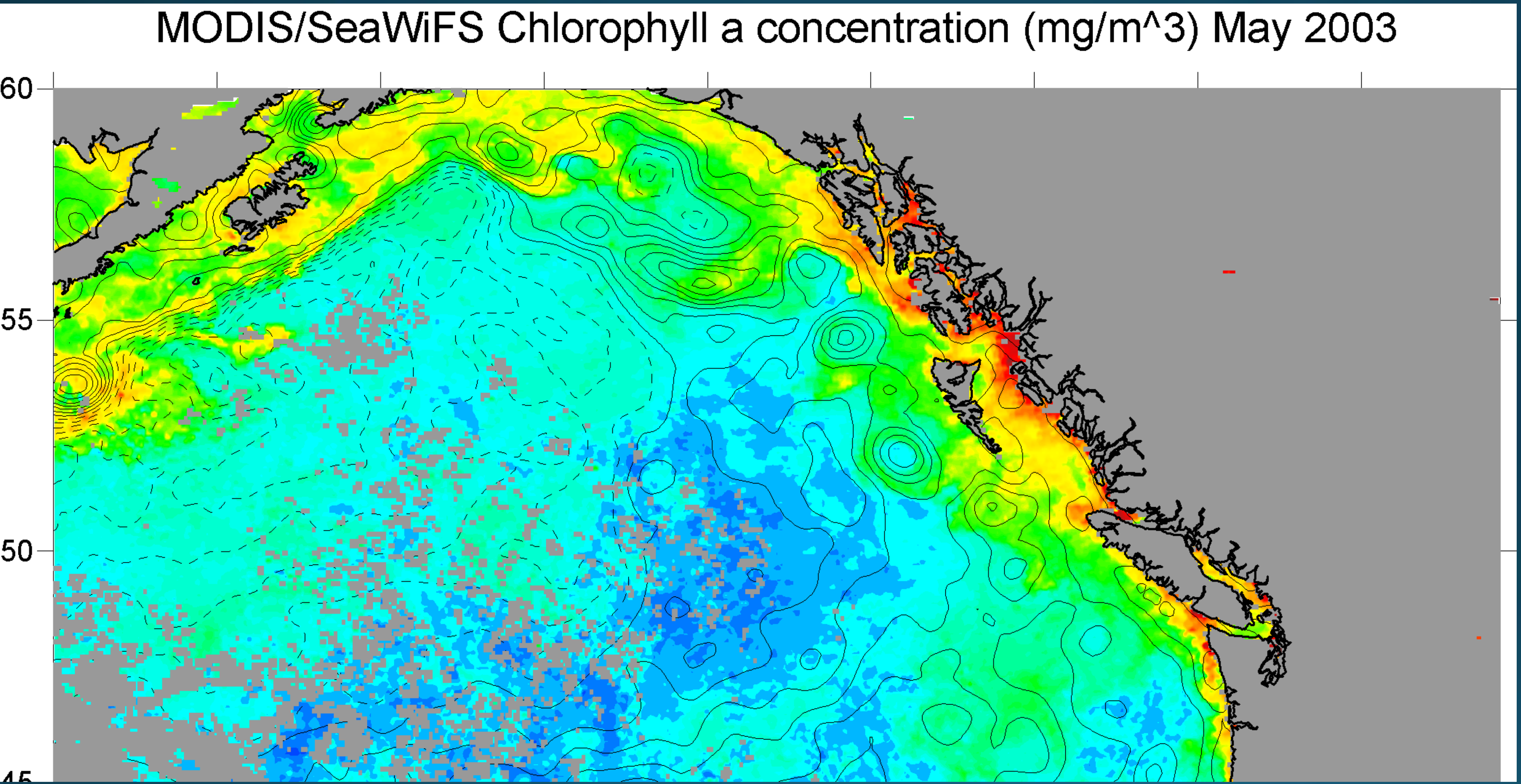
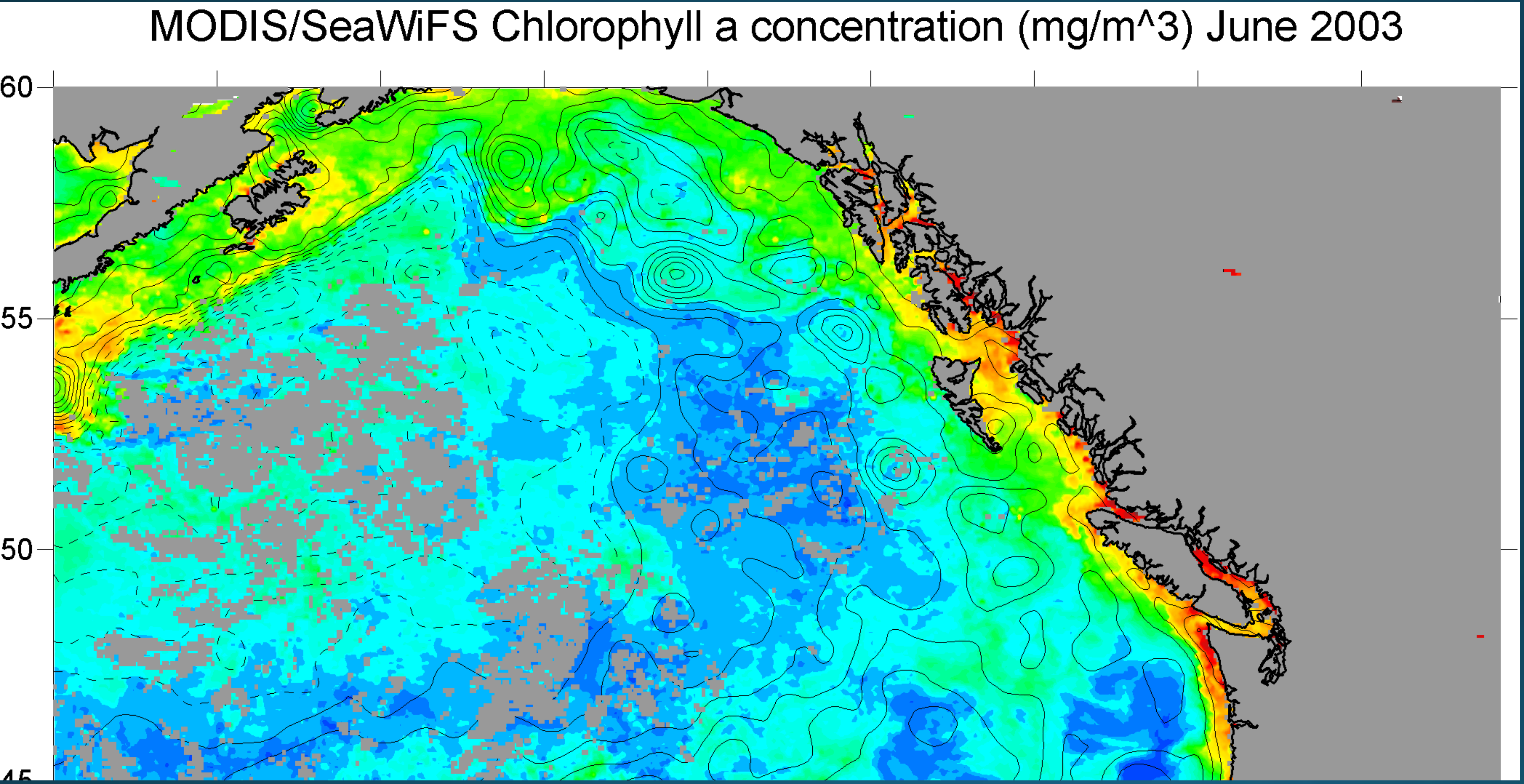
(2) This process is likely suppressed in Alaska Stream eddies of Northeast Pacific, since they are not propagating into mid-gyre.

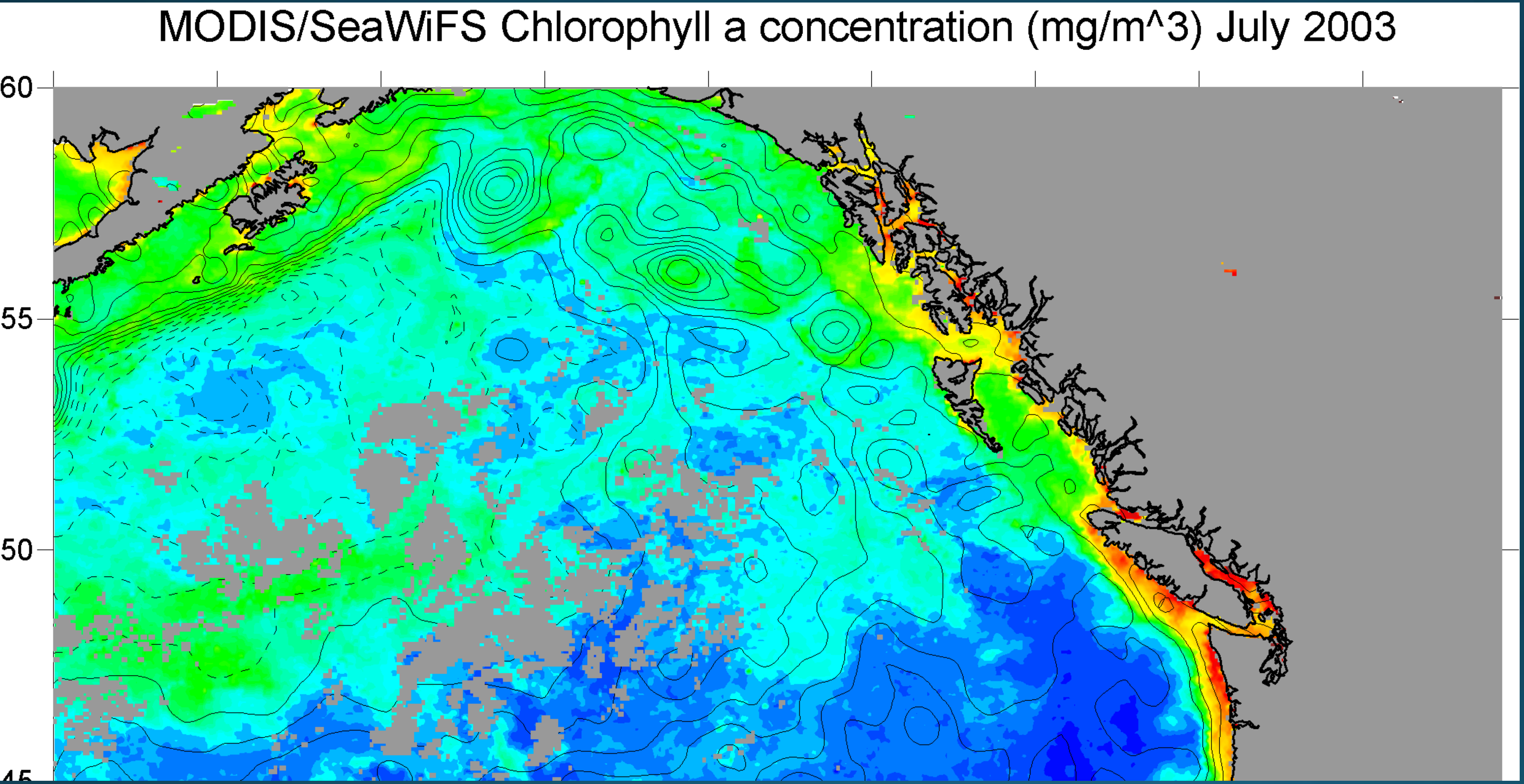


Batten, Crawford, 2005
Brown, Lippiatt, Lohan, Bruland, 2012
Chelton, Gaube, Schlax, Early, Samelson, 2011
Chierici, Miller, Whitney, Johnson, Wong, 2005
Clark, 1986
Crawford, Brickley, Peterson, Thomas, 2005
Crawford, Brickley, Thomas, 2007
Cullen, Chong, Ianson, 2009

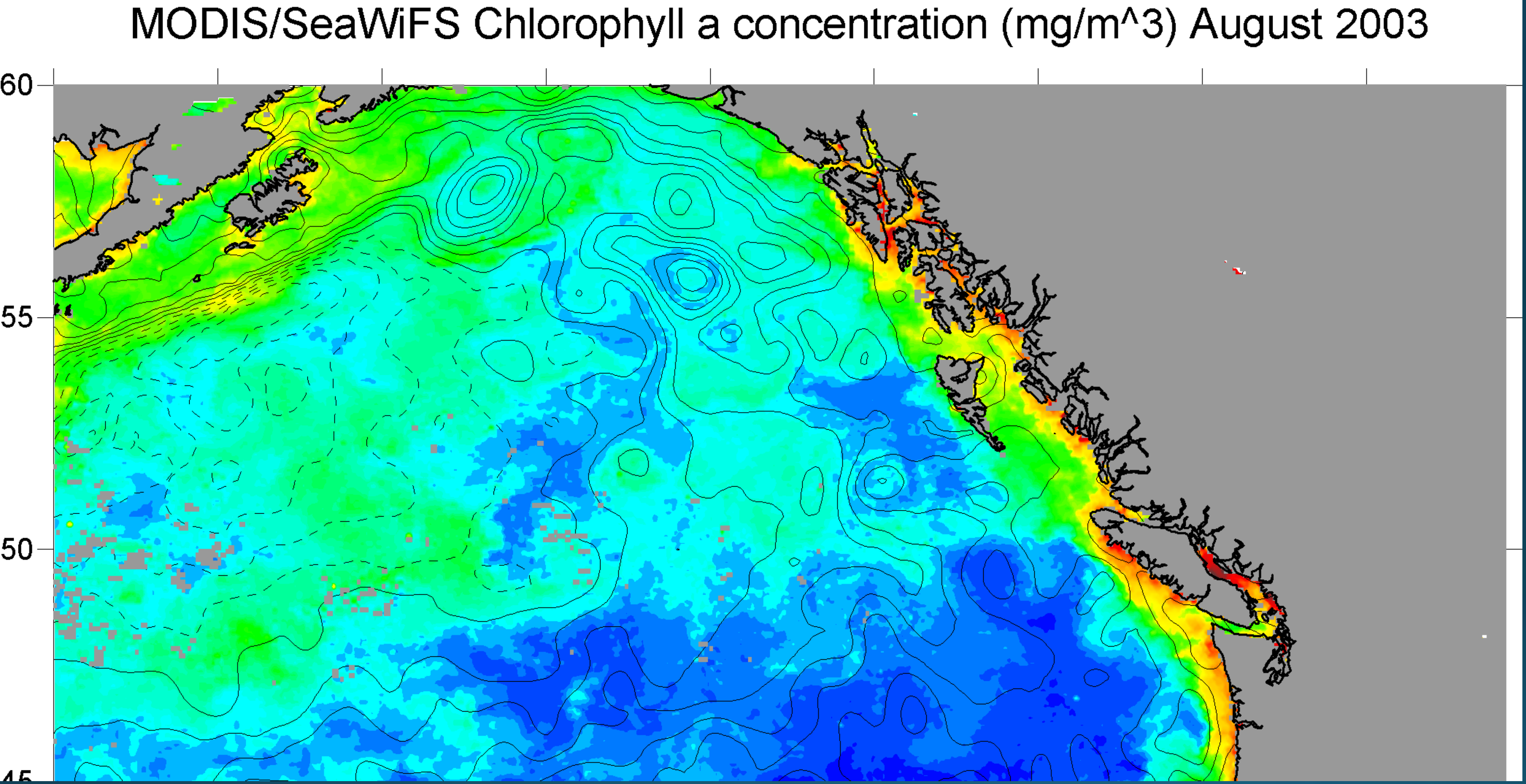


Ladd, Crawford, Harpold, Johnson, Kachel, Stabeno, Whitney, 2009
Lippiatt, Brown, Lohan, Bruland, 2012
Peterson, Whitney, Harrison, 2005
Peterson, Crawford, D.W., Harrison, 2011a, 2011b

Peterson, Harrison, 2012
Whitney, Robert, 2002
Whitney, Crawford, Harrison, 2004

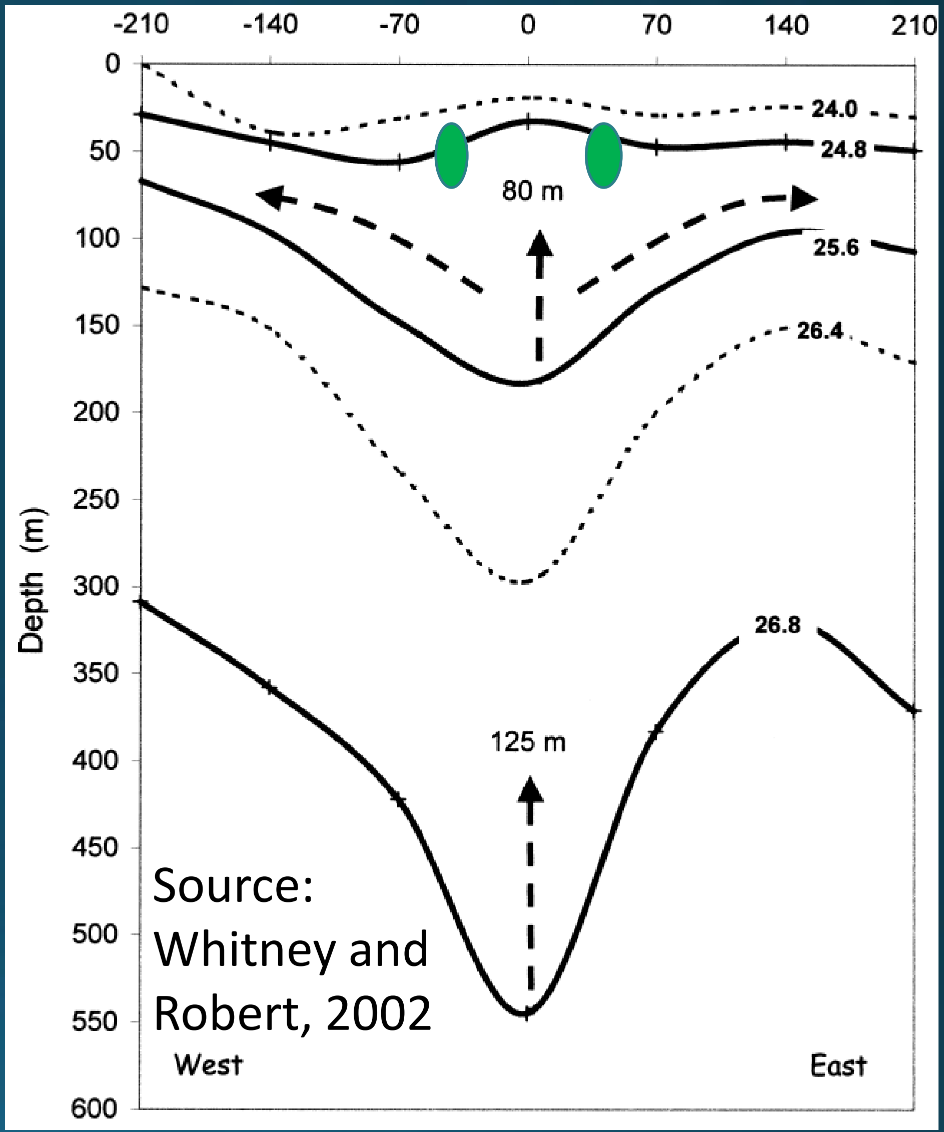


Whitney, Crawford, D.W., Yoshimura, 2005
Xiu, Palacz, Chai, Roy, Wells, 2011
Xiu, Thomas, Chai, 2014

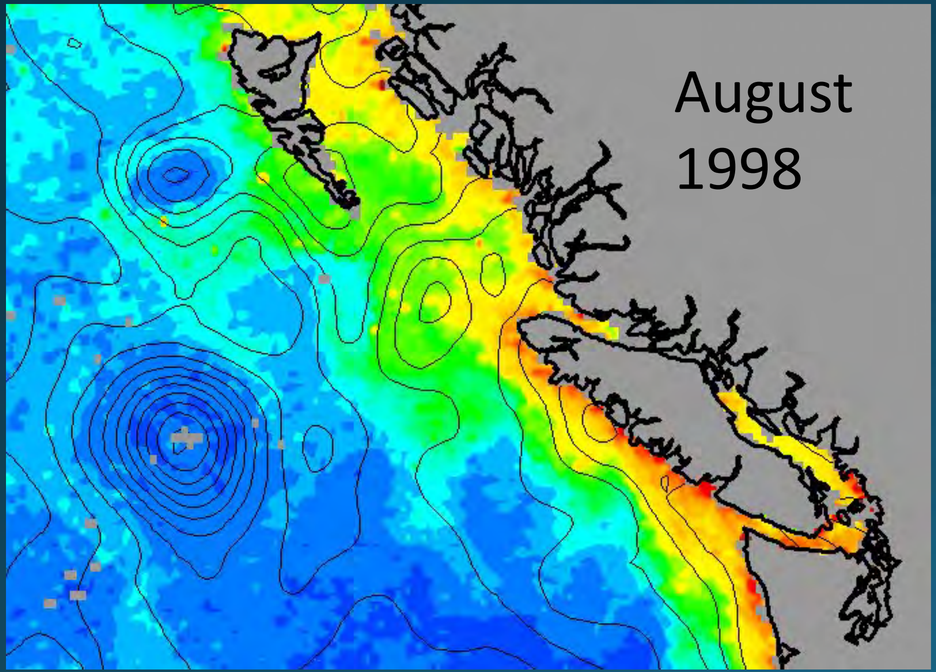


MODIS/SeaWiFS Chlorophyll a concentration (mg/m^3) August 2003
60
55
50

Right: "Density structure (sigma-t) of Haida-1998 in September 1998, with estimates of the degree of isopycnal rebound between September 1998 and June 1999 for the 25.4 layer which sits near the base of the winter mixed layer, and 26.8 layer which is the maximum density at which anomalous water properties are seen. Outward-directed arrows show the path of water loss from the eddy core." Whitney and Robert, 2002

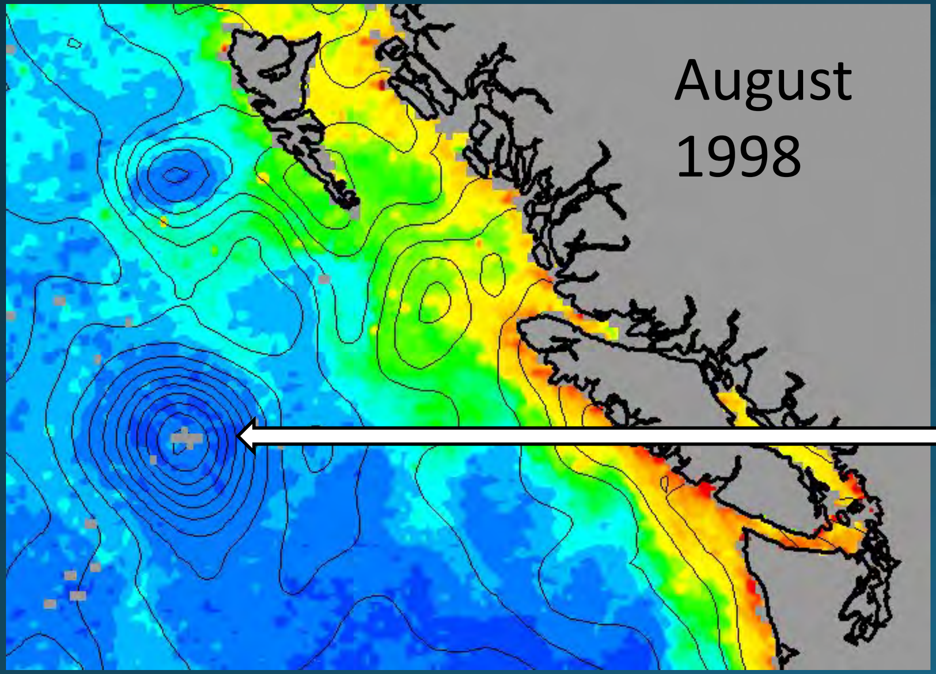


Green ovals denote regions of enhanced particulate concentration, indicating more phytoplankton and zooplankton.



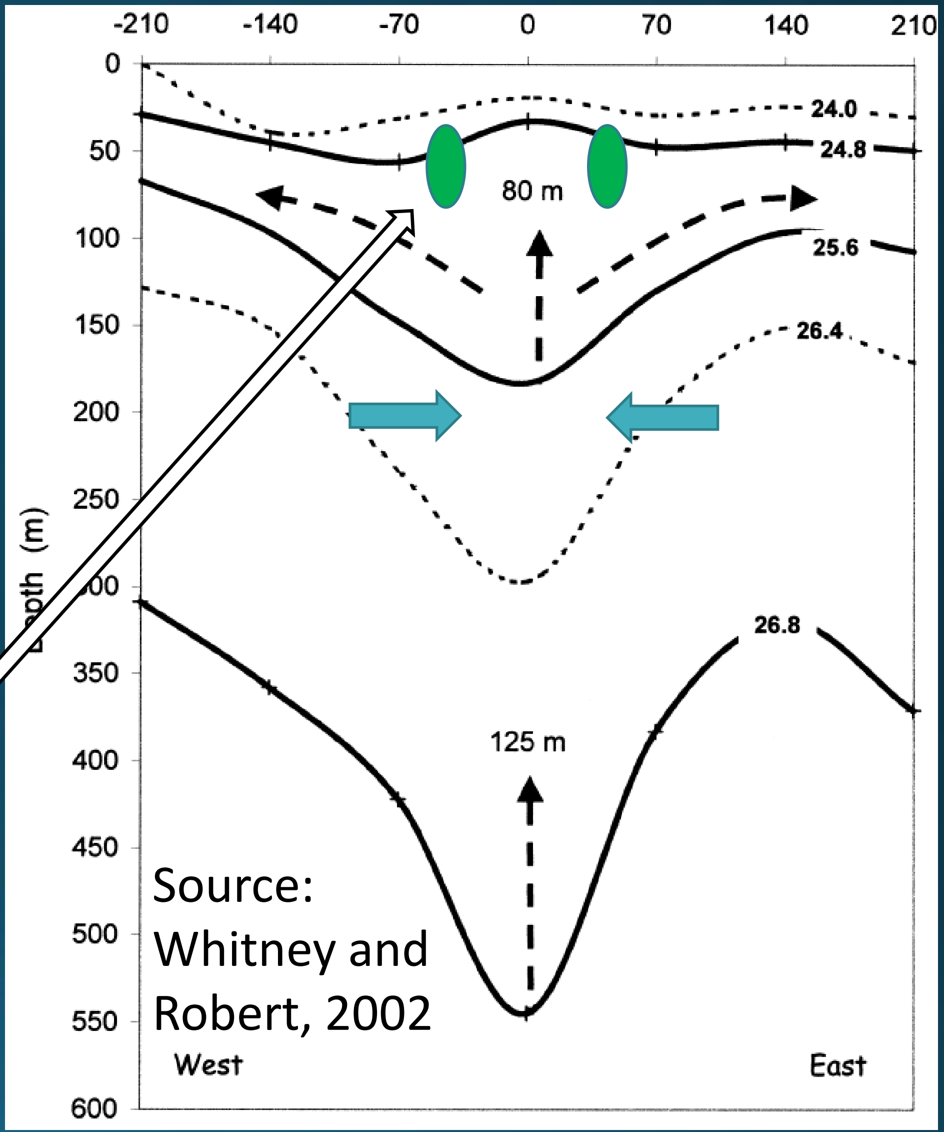
Contours show SSHA.
Colours show phytoplankton concentration.

Right: "Density structure (sigma-t) of Haida-1998 in September 1998, with estimates of the degree of isopycnal rebound between September 1998 and June 1999 for the 25.4 layer which sits near the base of the winter mixed layer, and 26.8 layer which is the maximum density at which anomalous water properties are seen. Outward-directed arrows show the path of water loss from the eddy core."
Whitney and Robert, 2002



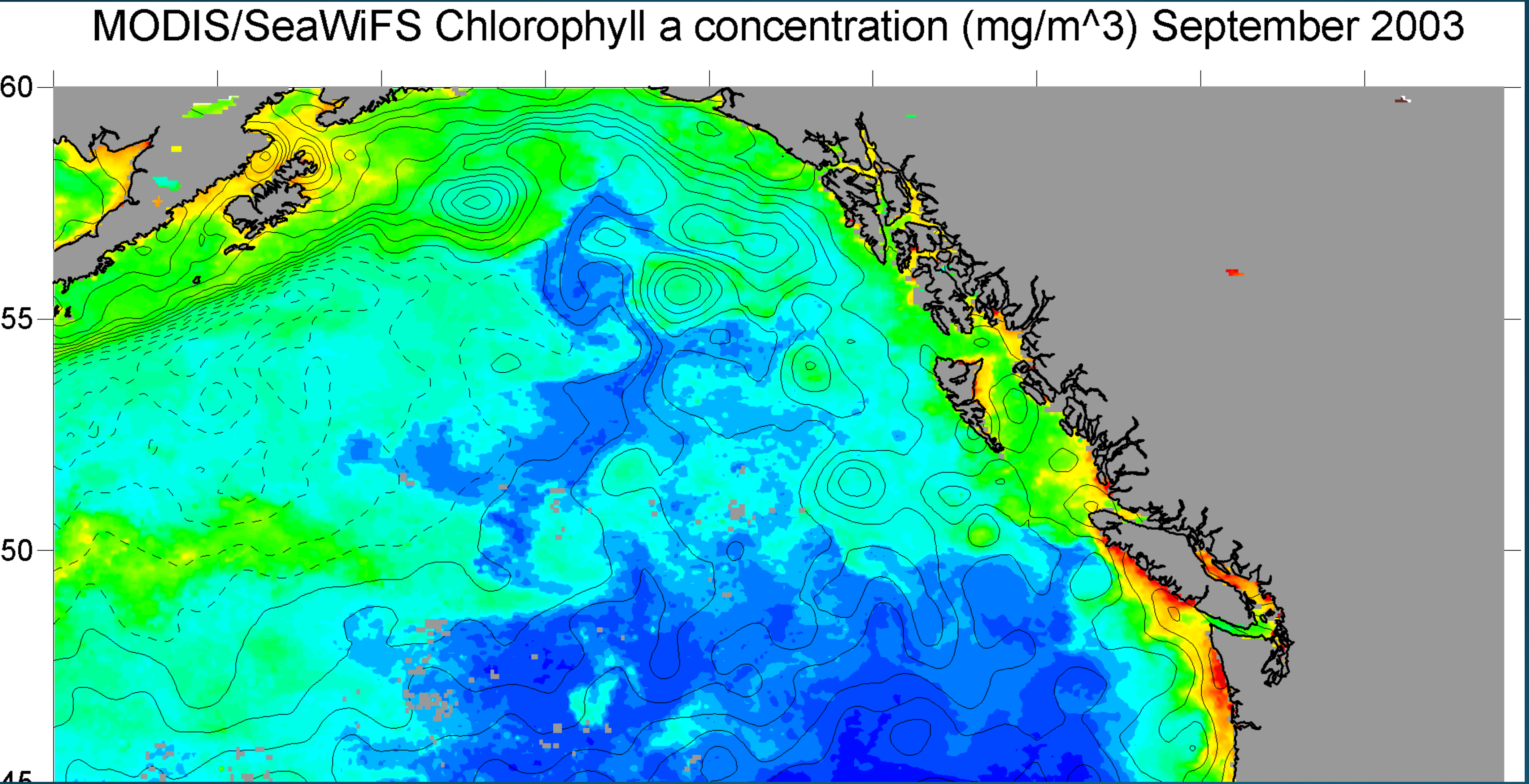
Many phytoplankton at 50 m depth.

Very few phyto-plankton at surface.

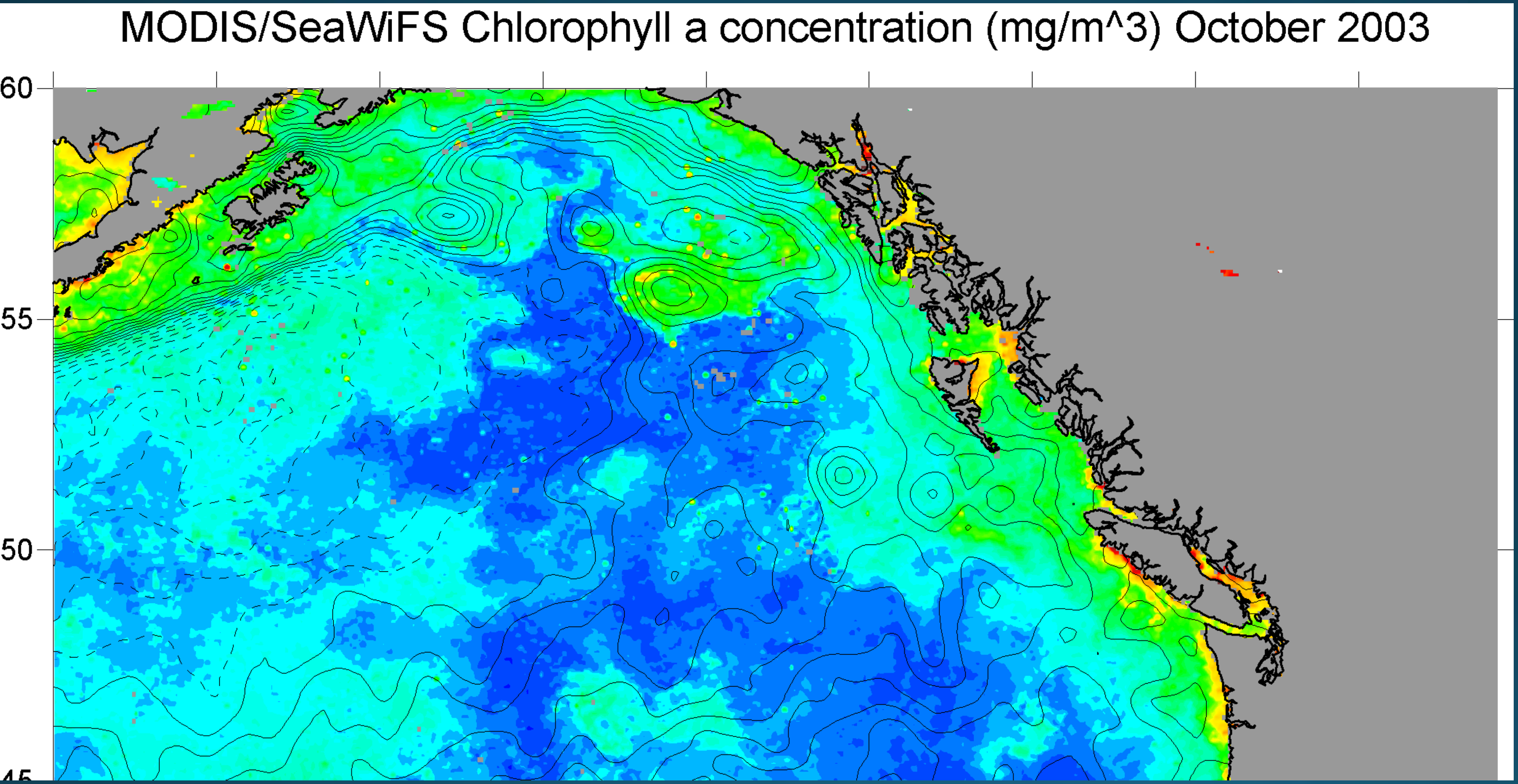


Contours show SSHA.
Colours show phytoplankton concentration.

Blue arrows show possible inflow of re-mineralized nutrients as eddies and marine life both decay.



MODIS/SeaWiFS Chlorophyll a concentration (mg/m^3) September 2003
60
55
50


MODIS/SeaWiFS Chlorophyll a concentration (mg/m^3) October 2003
60
55
50
45

Peterson, T.D., Crawford, D.W, Harrison, P.J., 2011,

Mixed water from 10m inside an eddy with water from 10 m outside an eddy in an incubation experiment (Haida 2001, early June 2001).

“After one week of incubation, rates of primary production were significantly higher in the mixed water compared to both the eddy and outside treatments.”

Zooplankton, juvenile fish

Mackas, D.L., Galbraith, M.D., 2002.
Mackas, D.L. , M. Tsurumi, M., M.D. Galbraith, M.D., D.R. Yelland, D.R., 2005

- Followed several Haida Eddies from continental margin to deep-sea.
- Noted that Taxa of shelf/slope-origin are transported seaward in the eddies.
- Abundances in young eddies are intermediate between coastal and offshore mixing end-member regions, initially forming a significant fraction of the total eddy zooplankton.
- Absolute and relative abundance of shelf/slope origin taxa usually declines with increasing age of the eddy.
- The coastal origin taxa most successful at colonization and retention in the eddies are those that avoid the surface layer some or all of the day.

See also:
Atwood, Duffy-Anderson, Horne, Ladd, 2010: *Ichthyoplankton species differ in eddies from those outside.*
Batten, Crawford, 2005: *Haida and Sitka Eddies carry coastal zooplankton seaward.*
Batten, Gower, 2014: *Evidence of more zooplankron following iron fertilization of Haida Eddy.*
Kline, 2010: *Cross-shelf transport by mesoscale eddy favourable for juvenile salmon.*
Ladd, Crawford, Harpold, Johnson, Kachel, Stabeno, Whitney, 2009: *Census of life and nutrients in 3 eddies*
Tsurumi, M., Mackas, D.L., Whitney, F.A., Galbraith, M.D., DiBacco, C., Wong, C.S., 2005: *Pteropods enhanced*

- Zooplankton, juvenile fish

Moss, Trudel, Beckman, Crawford, Fournier, Fergusson, Beacham (2013)

Examined juvenile salmon in regions of Sitka eddies in July 2010

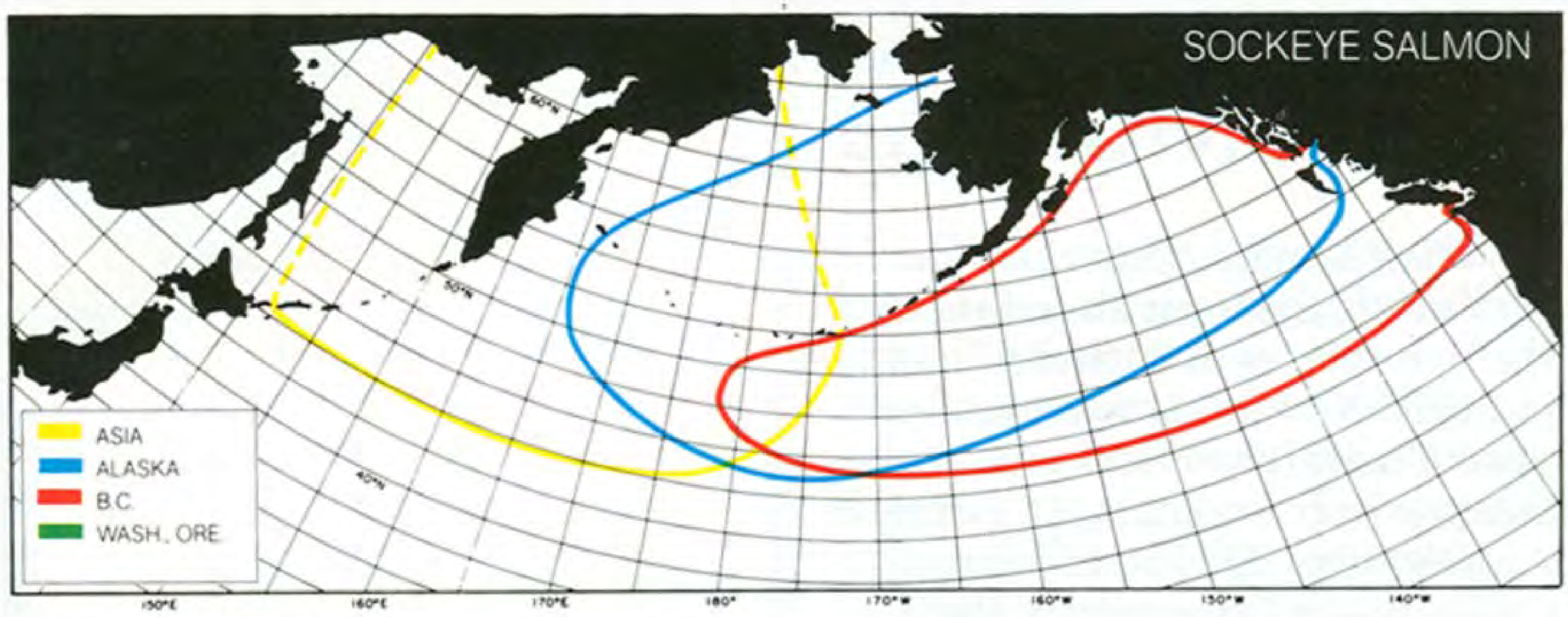
"Insulin-like growth factor 1 (IGF1) was measured from blood collected from juvenile chum, pink, and sockeye salmon in order to provide an index of short-term growth rate for fish at each survey station. Plankton and chlorophyll samples were also collected aboard the vessel at each survey station."

"Fish caught at locations along the [Sitka] eddy perimeter displayed the highest levels of insulin-like growth factor, indicating that juvenile salmon located in this ocean habitat experienced elevated short-term growth rates. Zooplankton and phytoplankton density was also greatest around the eddy perimeter"

Future research: Higher trophic levels

I believe there is a need for sampling of adult salmon in the high seas, now that DNA allows scientists to determine the salmon stock of any fish, and satellite altimetry allows scientists to evaluate whether eddies are in fact "feeding stations" in the Gulf of Alaska.

DNA analyses allows assessment of locations of individual stocks of salmon in offshore waters, and of the effect of eddies on annual growth of individual stocks.



Sockeye Salmon Migration Map

Source: http://www.pac.dfo-mpo.gc.ca/fm-gp/species-especes/salmon-saumon/facts-infos/sockeye-rouge-eng.html