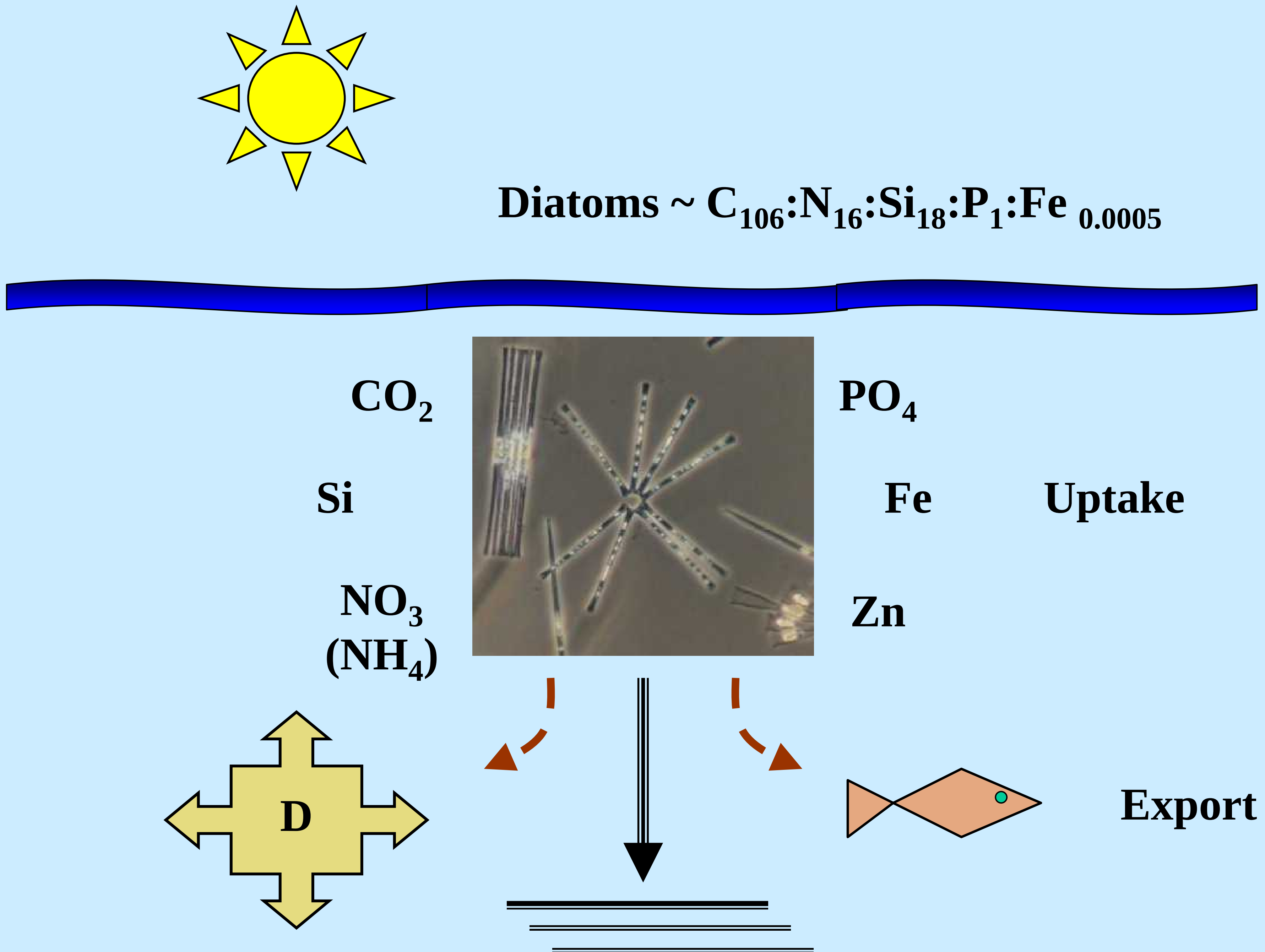
# Nutrient Transport in the Subarctic NE Pacific Ocean

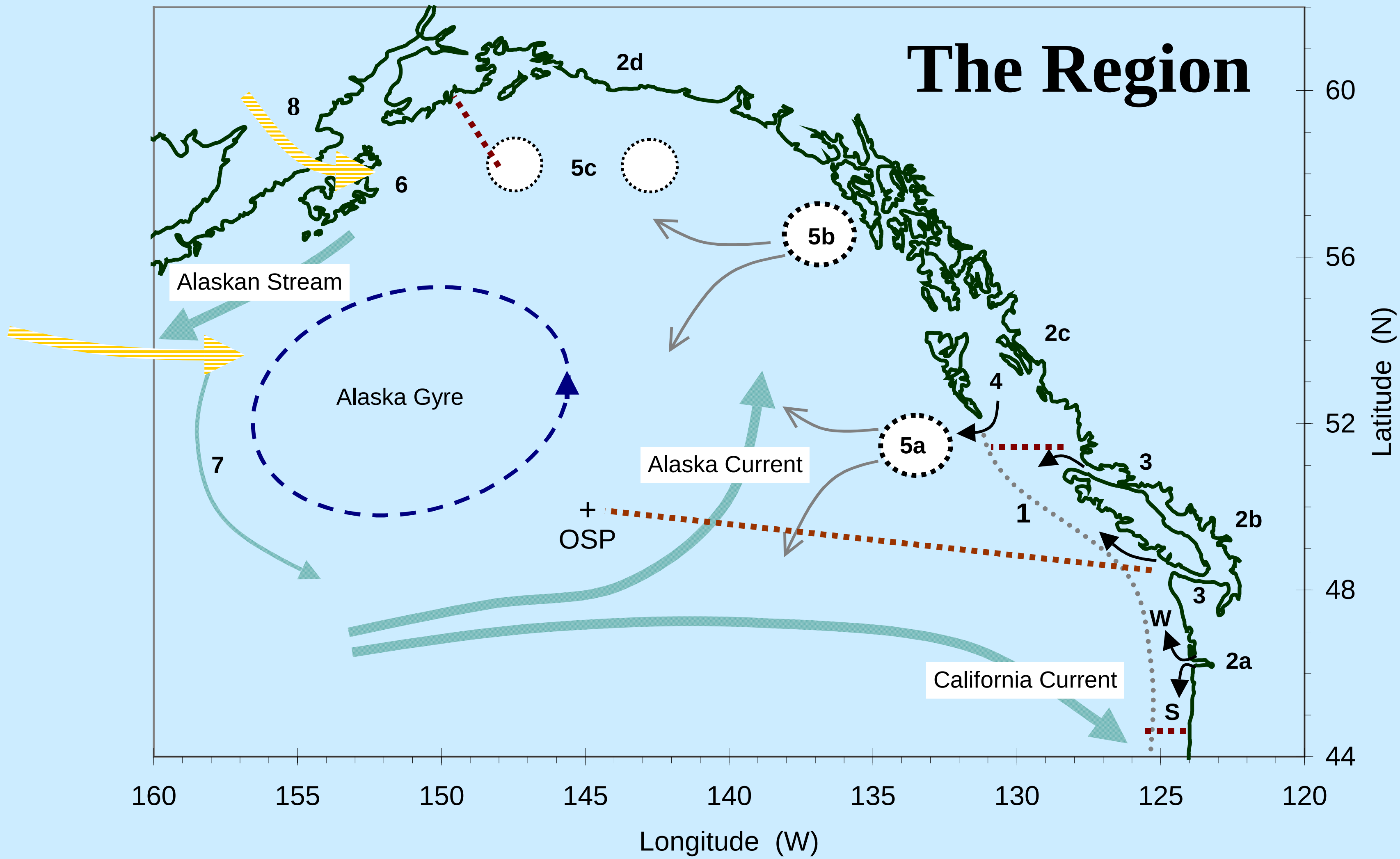
**F.A. Whitney[1], P.J. Harrison[2] and W.R. Crawford[1]**

1. Fisheries and Oceans Canada

2. Hong Kong University of Science and Technology


Diatoms ~ $C_{106}:N_{16}:Si_{18}:P_1:Fe_{0.0005}$
$CO_2$
Si
$NO_3$
$(NH_4)$
$PO_4$
Fe
Uptake
Zn
D
Export

# The Region

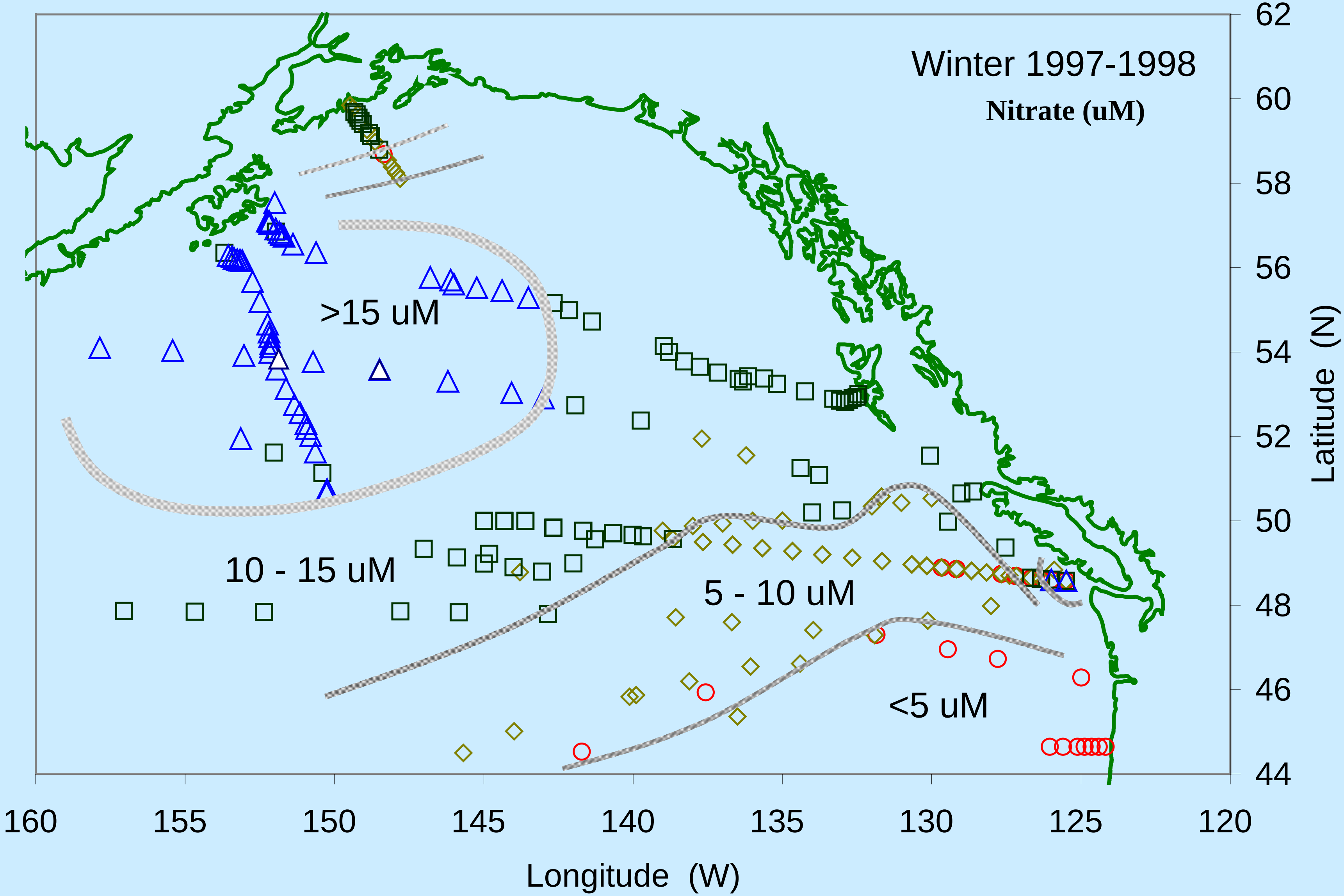



1. Upwelling Domain
2. River inputs of freshwater and Si
3. Tidal mixing regions
4. Hecate Strait estuarine circulation
5. Mesoscale eddy transport
6. Alaska coast transport (Ladd et al.)
7. Recirculation
8. Dust from erosion, fires, volcanoes

40to62coast.xls

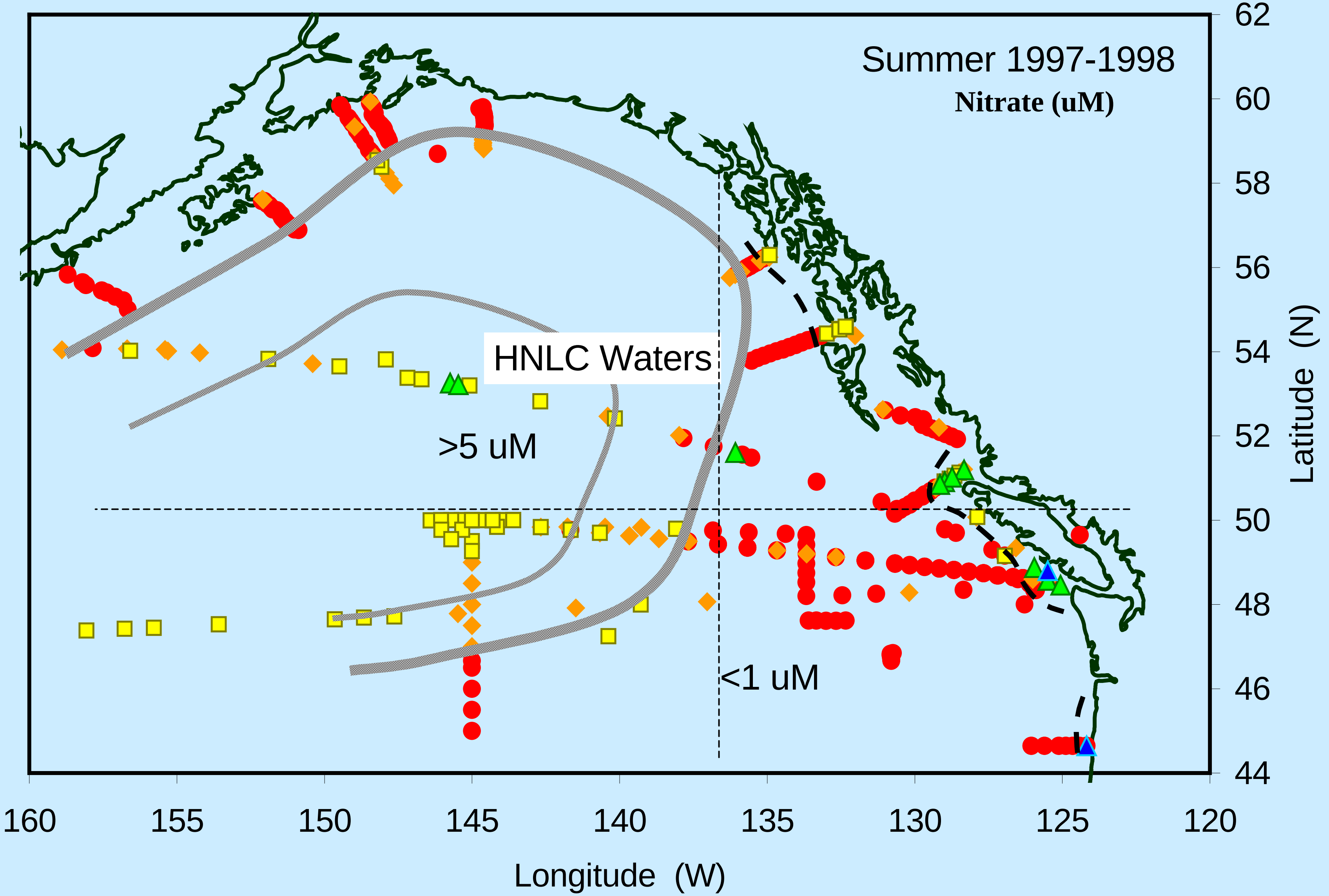
# 0. **Overview** of nutrient distribution in NE Pacific

*Data from Wheeler, Whitledge, Welch, Wong and Whitney*




Winter 97-8.xls

# HNLC = High Nitrate, Low Chlorophyll

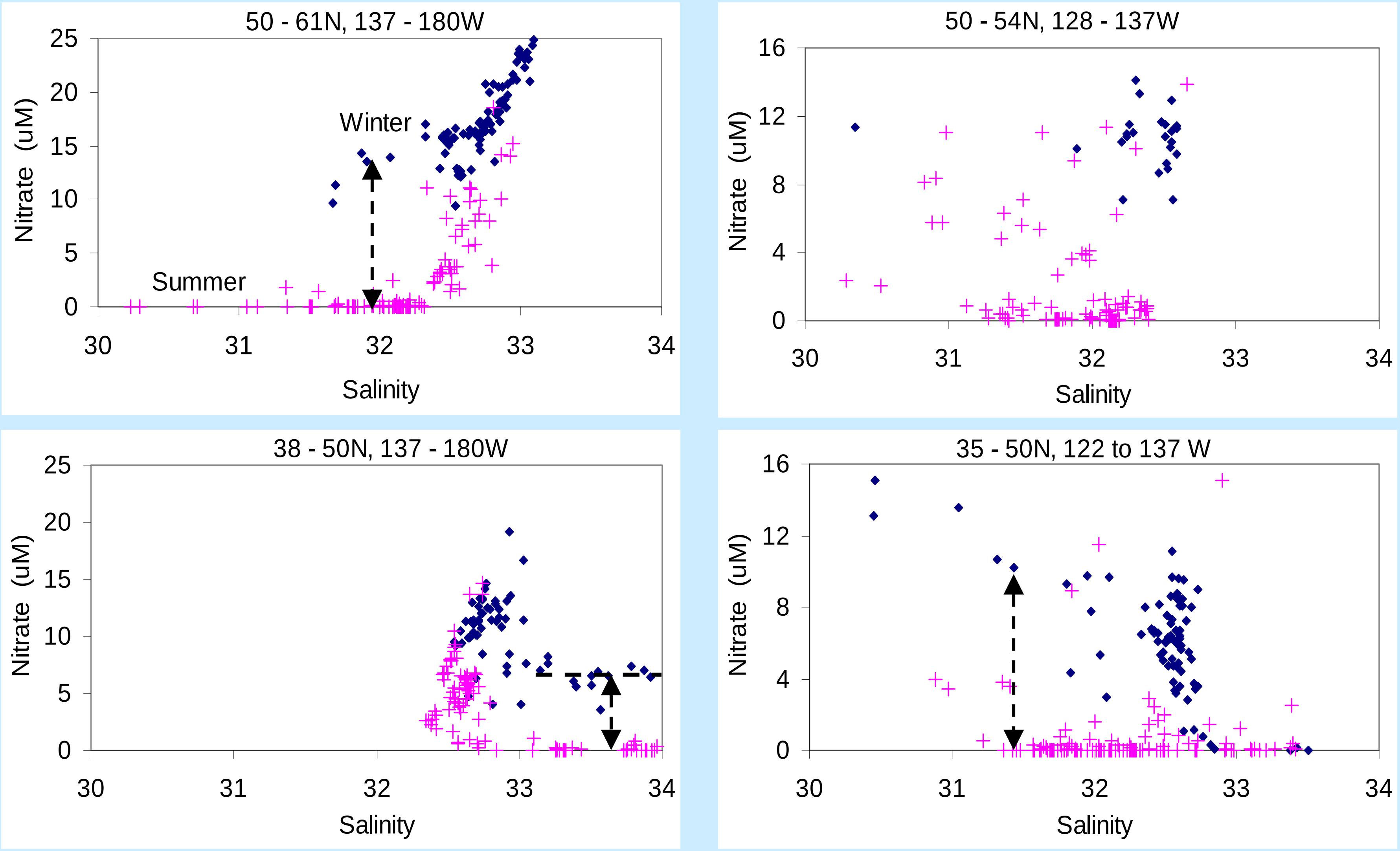



summer 97-8.xls

# Estimate nitrate drawdown in quadrants:

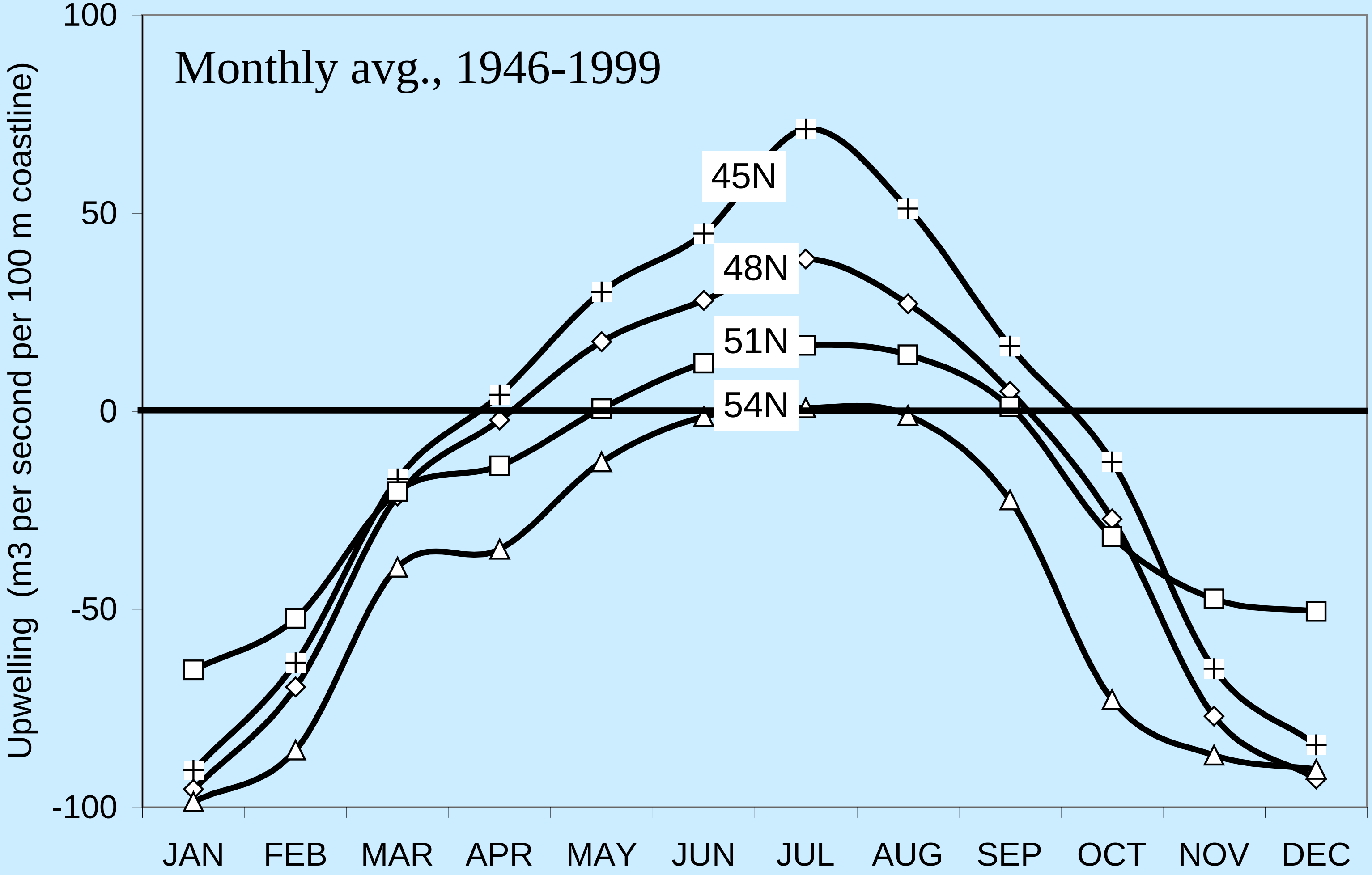
## note: HNLC is restricted to S ~ 32.4 to 33.0

**winter = Jan-Mar, summer = Jul-Sep**

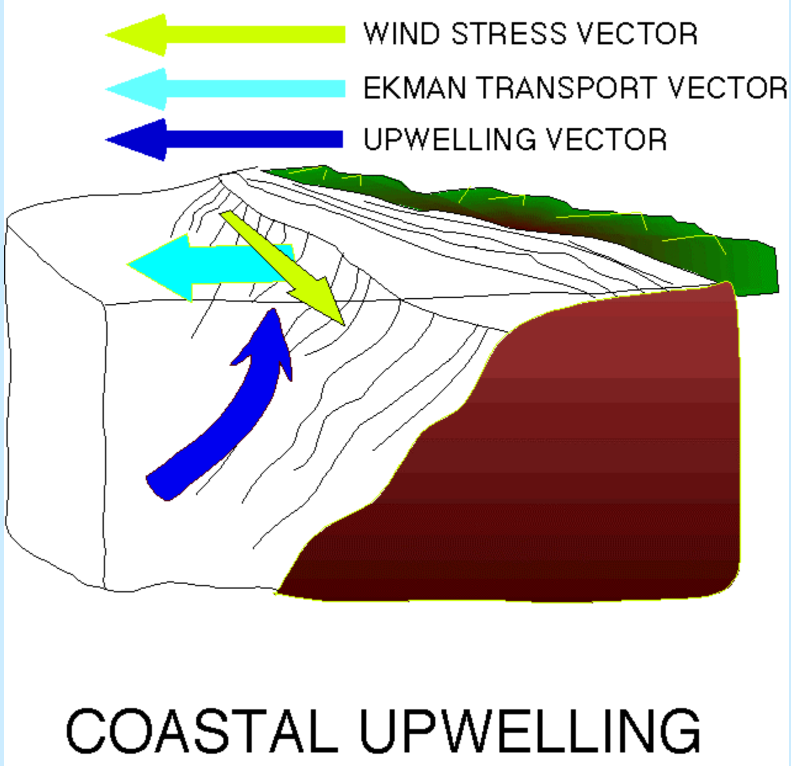



w&s 97-8.xls

**1**. **Coastal upwelling**, a persistent supply of nutrients in summer. Off the Oregon coast, wind induced upwelling is strong and frequent. A relaxation of downwelling is observed on the northern BC and Alaska coasts.

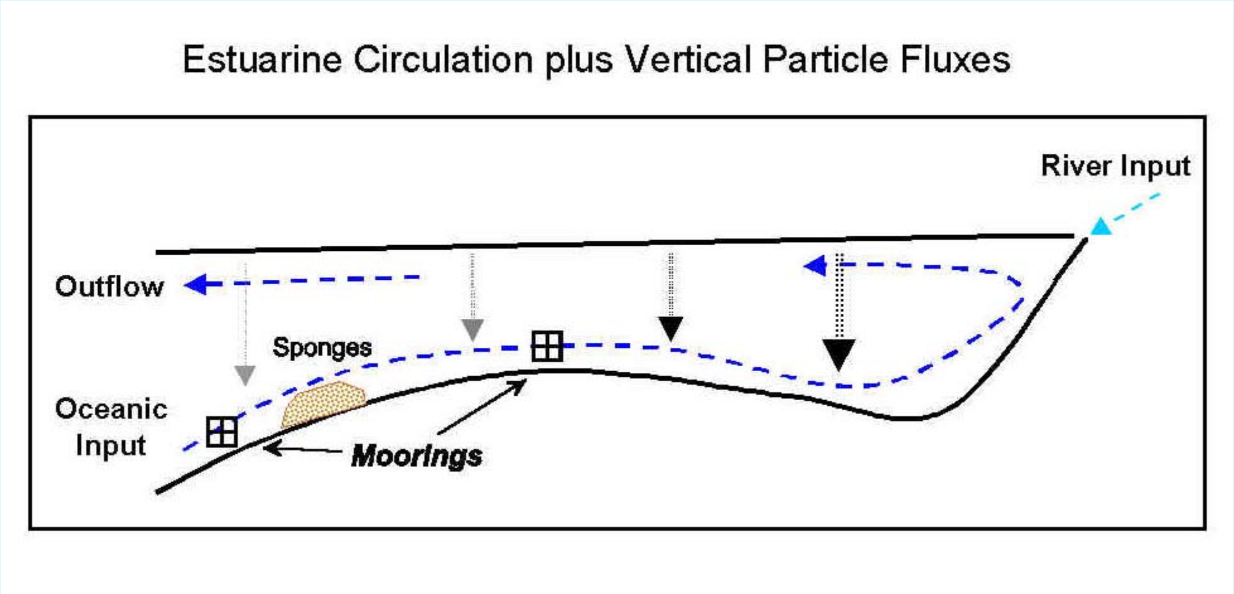



upwelling.xls

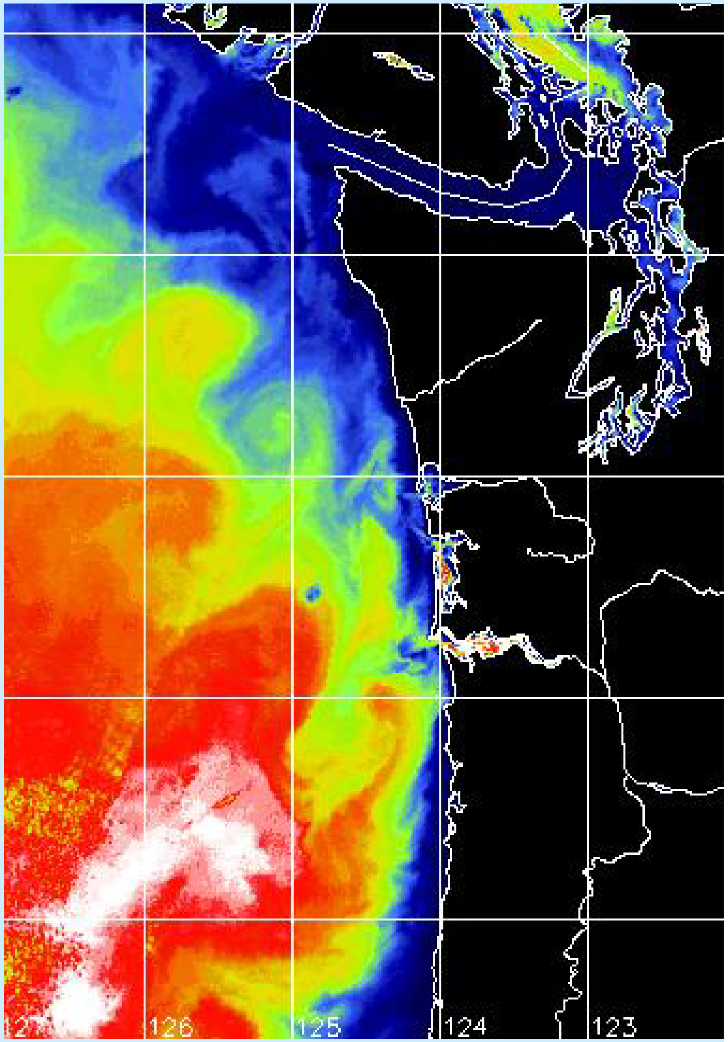



**Upwelling** and **estuarine circulation** will work together to supply nutrients to shelf regions.

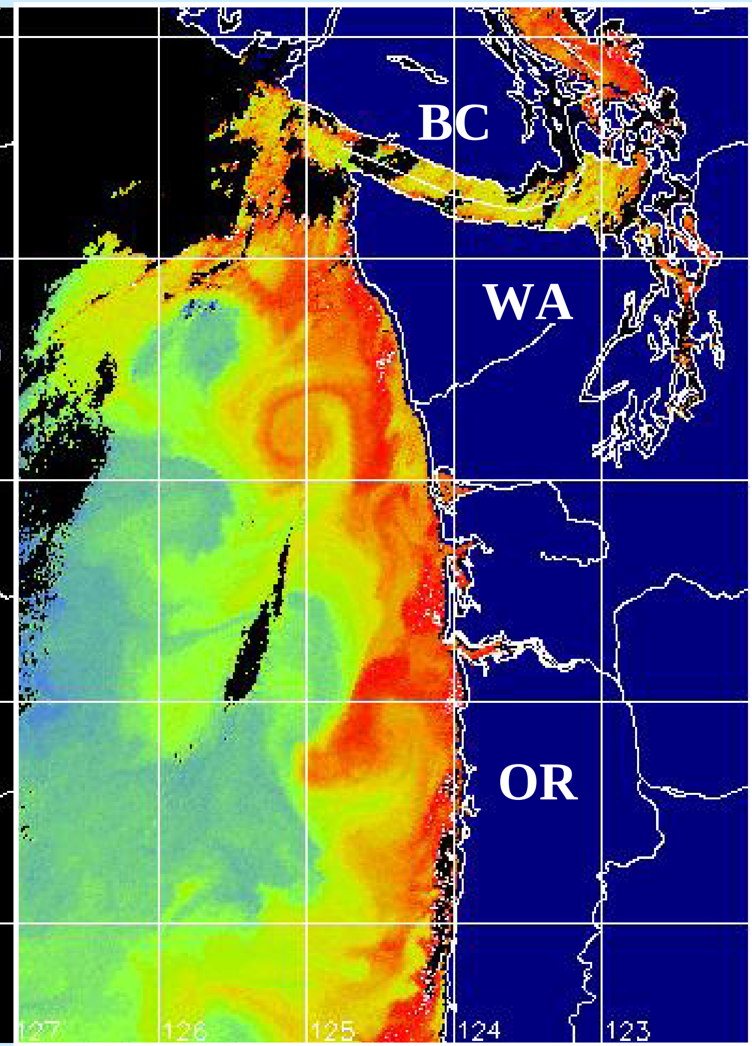
Below, a simple model of Hecate Strait shows that waters are drawn onto the shelf by estuarine circulation, the nutrient content of these waters (oceanic input) being dependent on the strength of upwelling.



# Upwelling, August 8, 2000

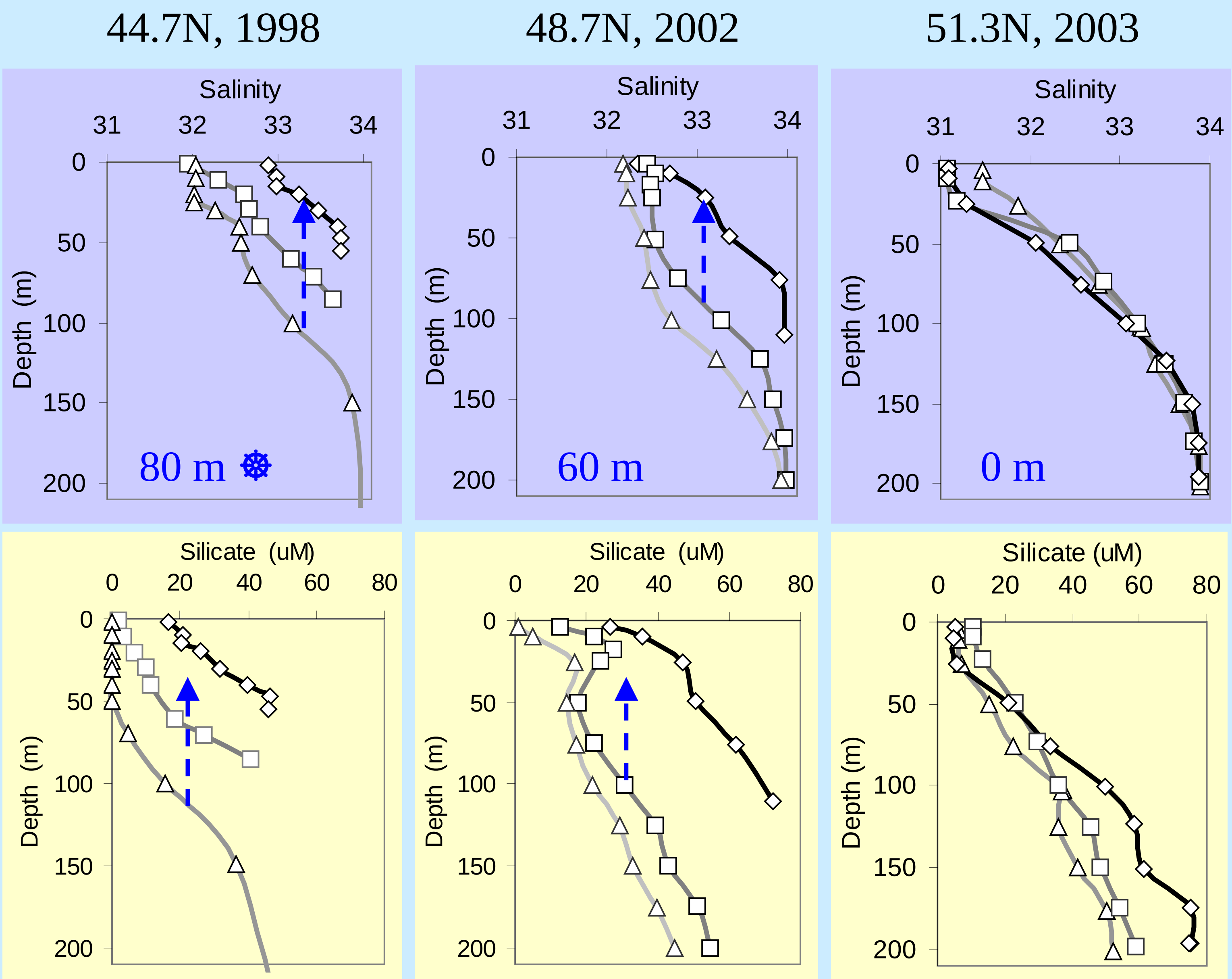



Temperature



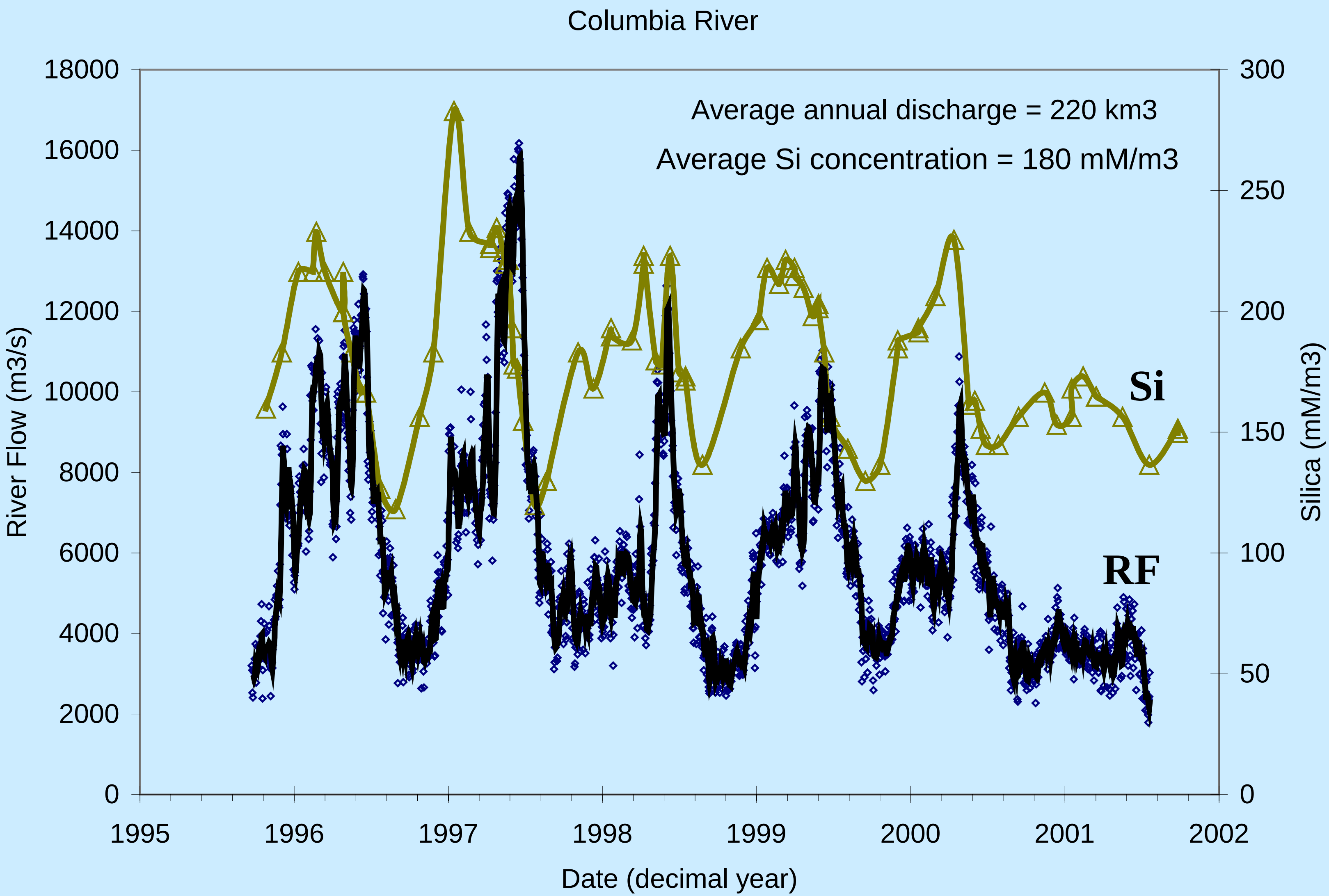

Chlorophyll

# Upwelling at 45 and 49 N but not at 51N in these September data

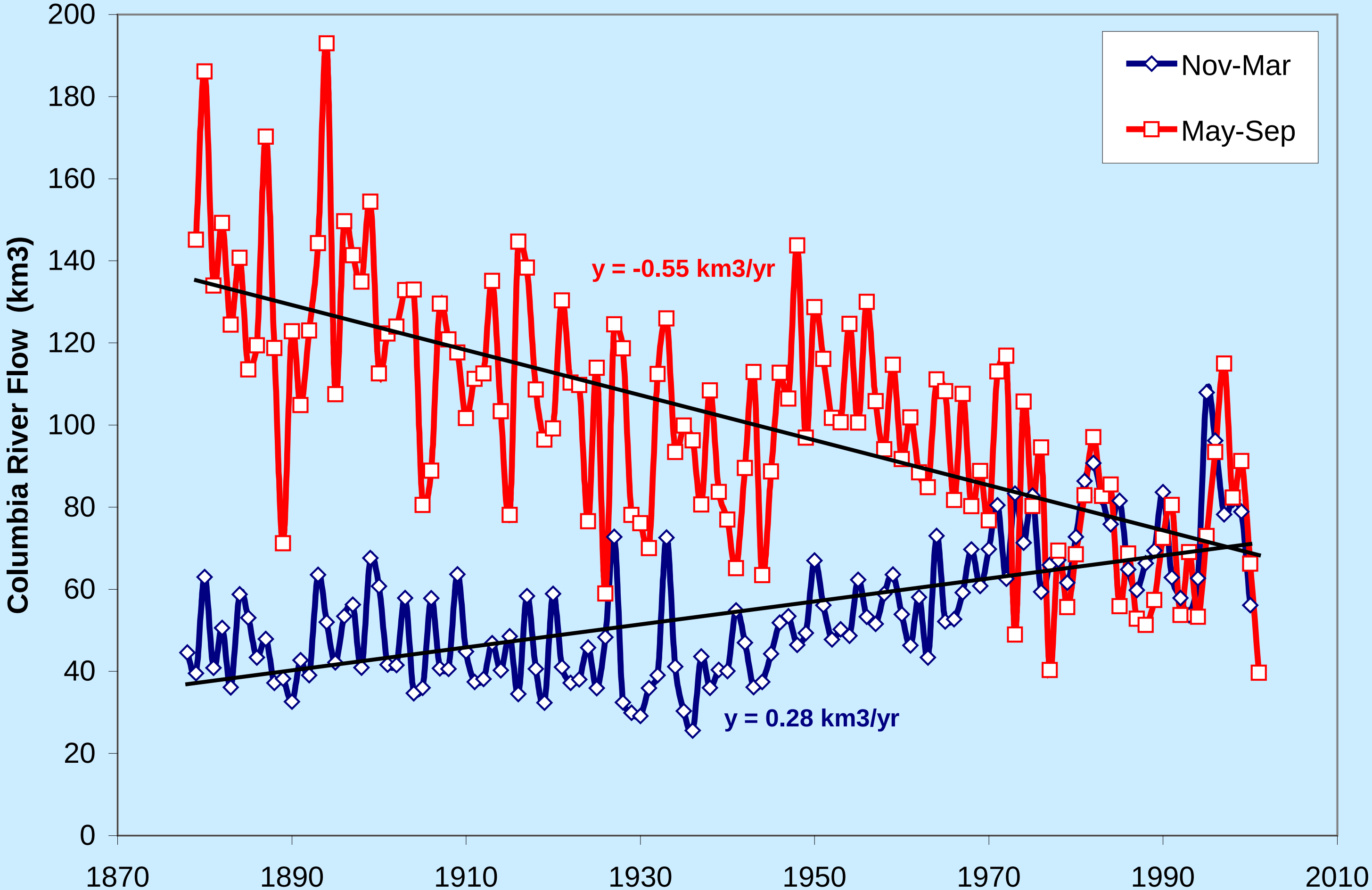



2002-30hyd.xls

# 2. **River discharge**, fresh water and silica (and iron).




Columbia at the Dalles.xls

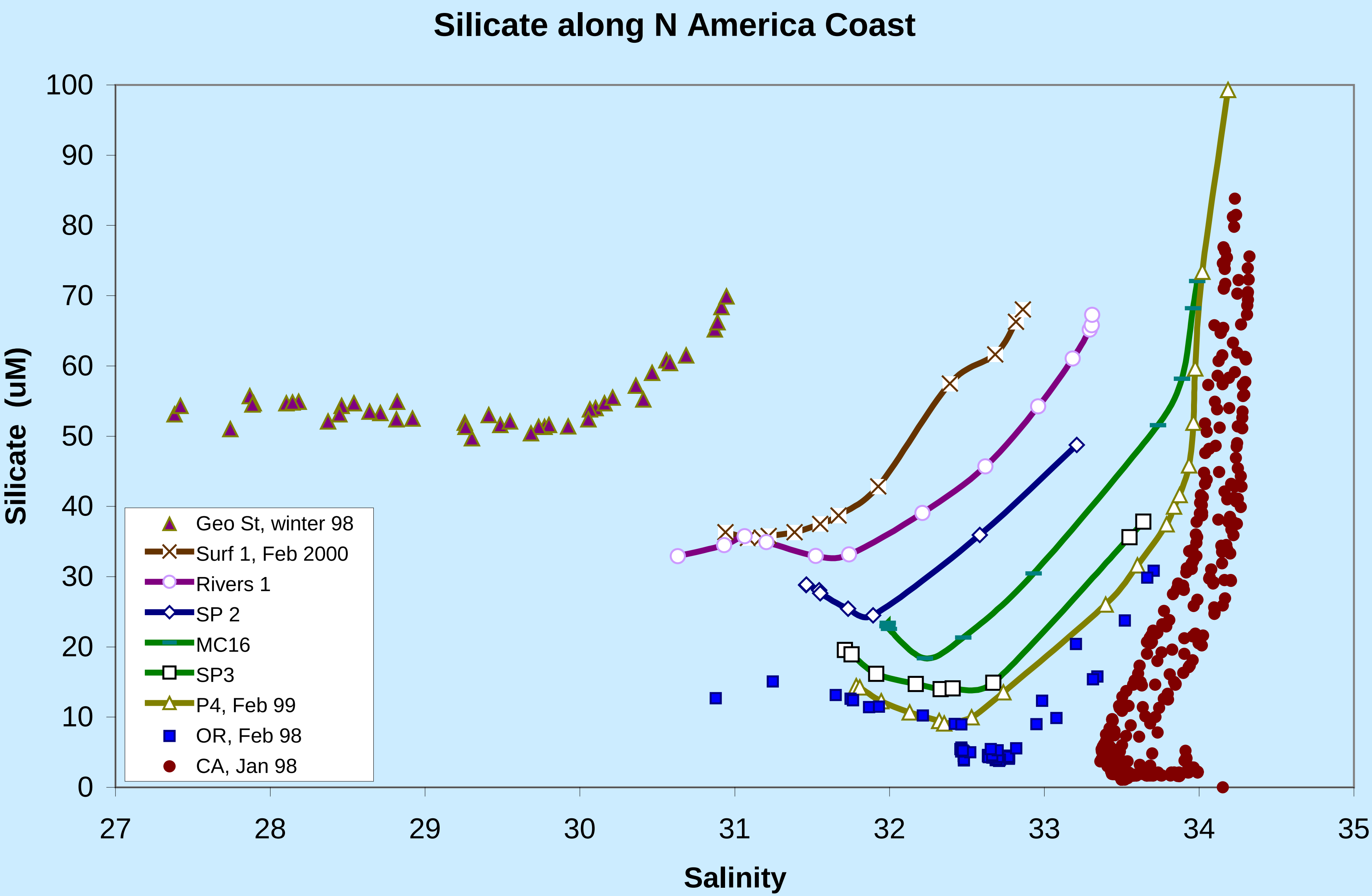



*Assuming current Si concentrations,*

1890s: **Winter** ~9.8 x $10^9$ mol (N), **Summer** ~21 x $10^9$ mol (S)

post 1973: **Winter** ~14 x $10^9$ mol (N), **Summer** ~12 x $10^9$ mol (S)

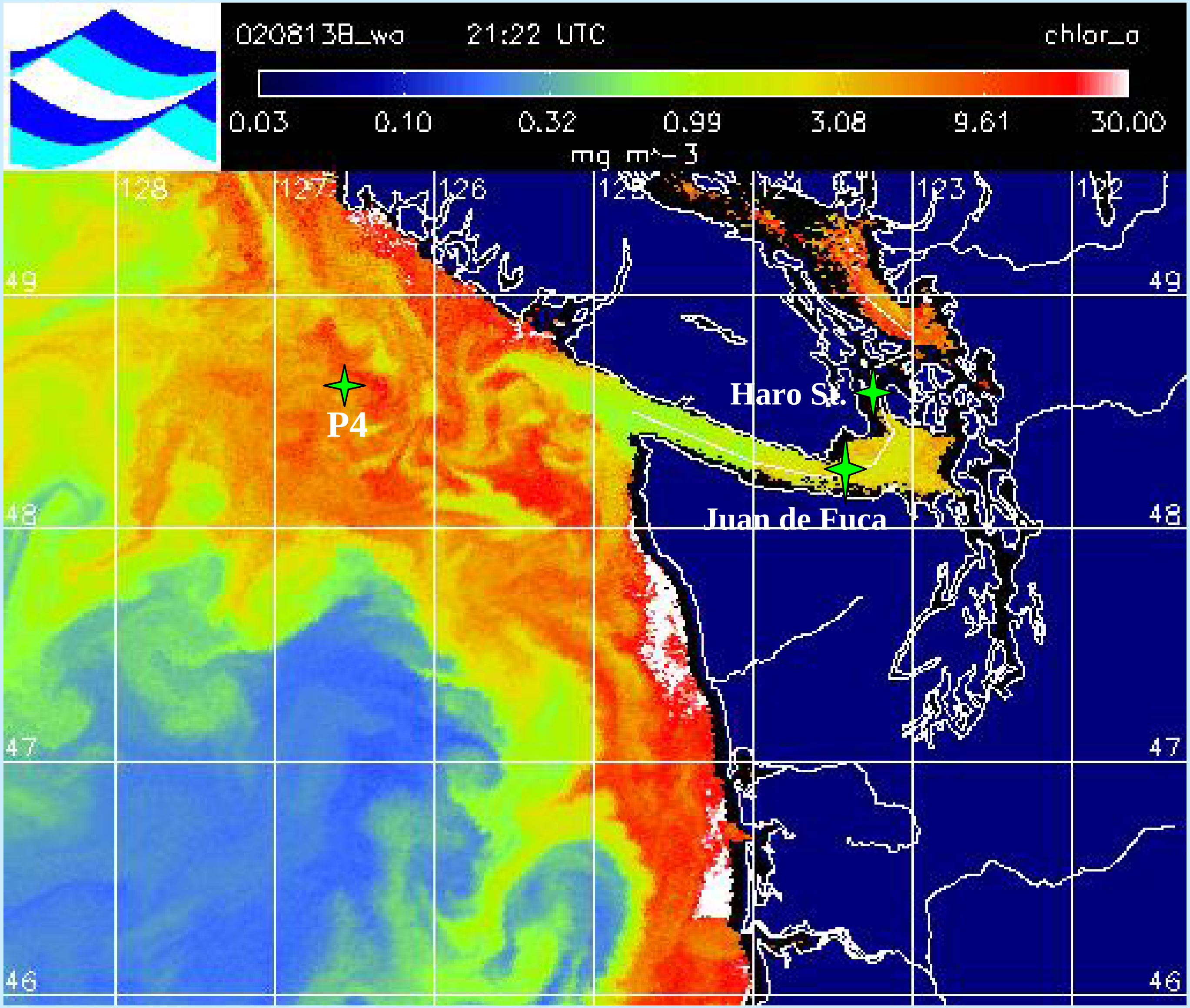
Columbia at the Dalles.xls




Major rivers increase coastal Si by ~10 uM $y^{-1}$ from N. California to S. Alaska

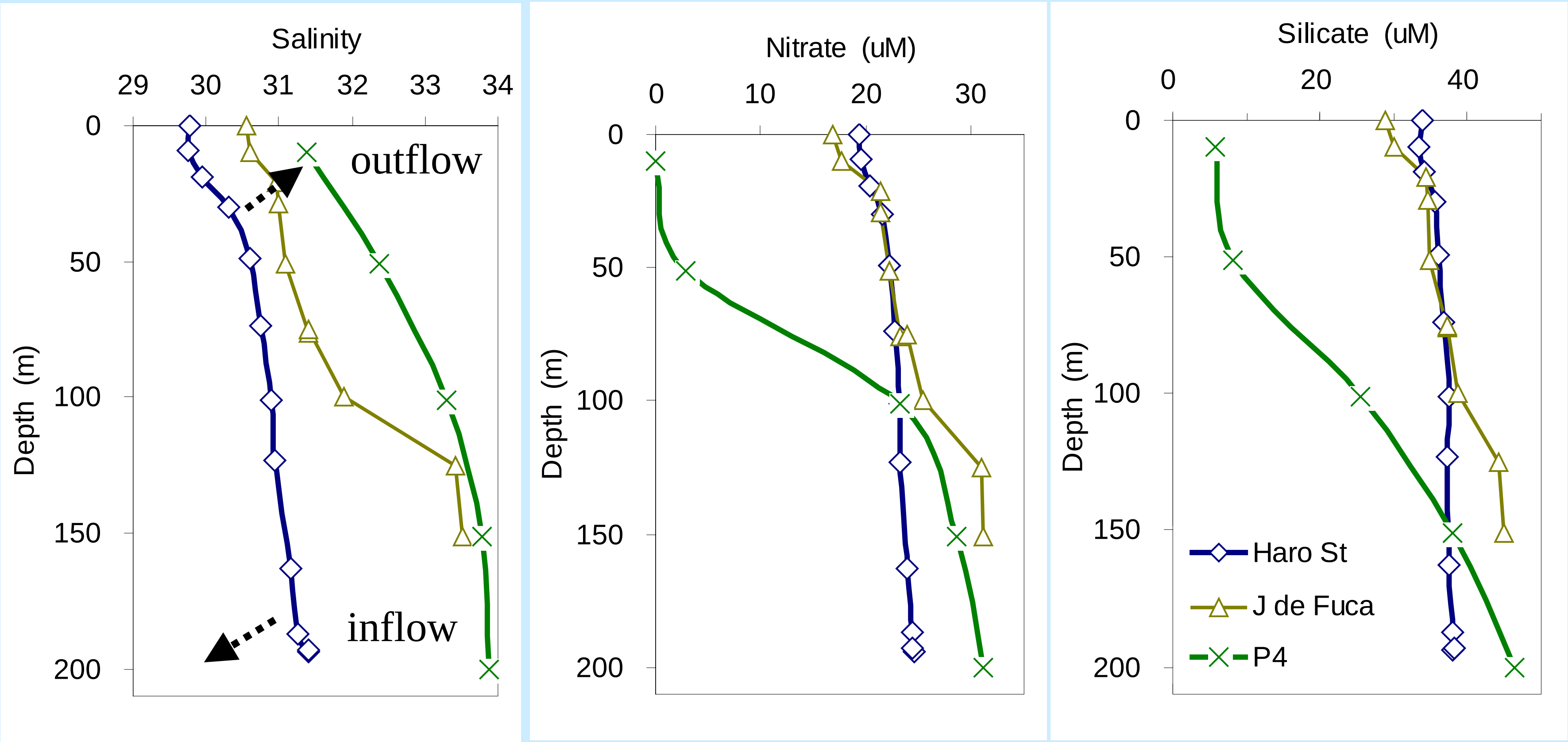
(1500 km coast x 100 km width x 40 m depth)

# 3. **Tidal mixing** and outflow onto the continental shelf




August 13, 2002 SeaWiFS chlorophyll. Note relatively low chlorophyll in Juan de Fuca Strait. These waters are rich in nutrients due to tidal mixing in Haro Strait.

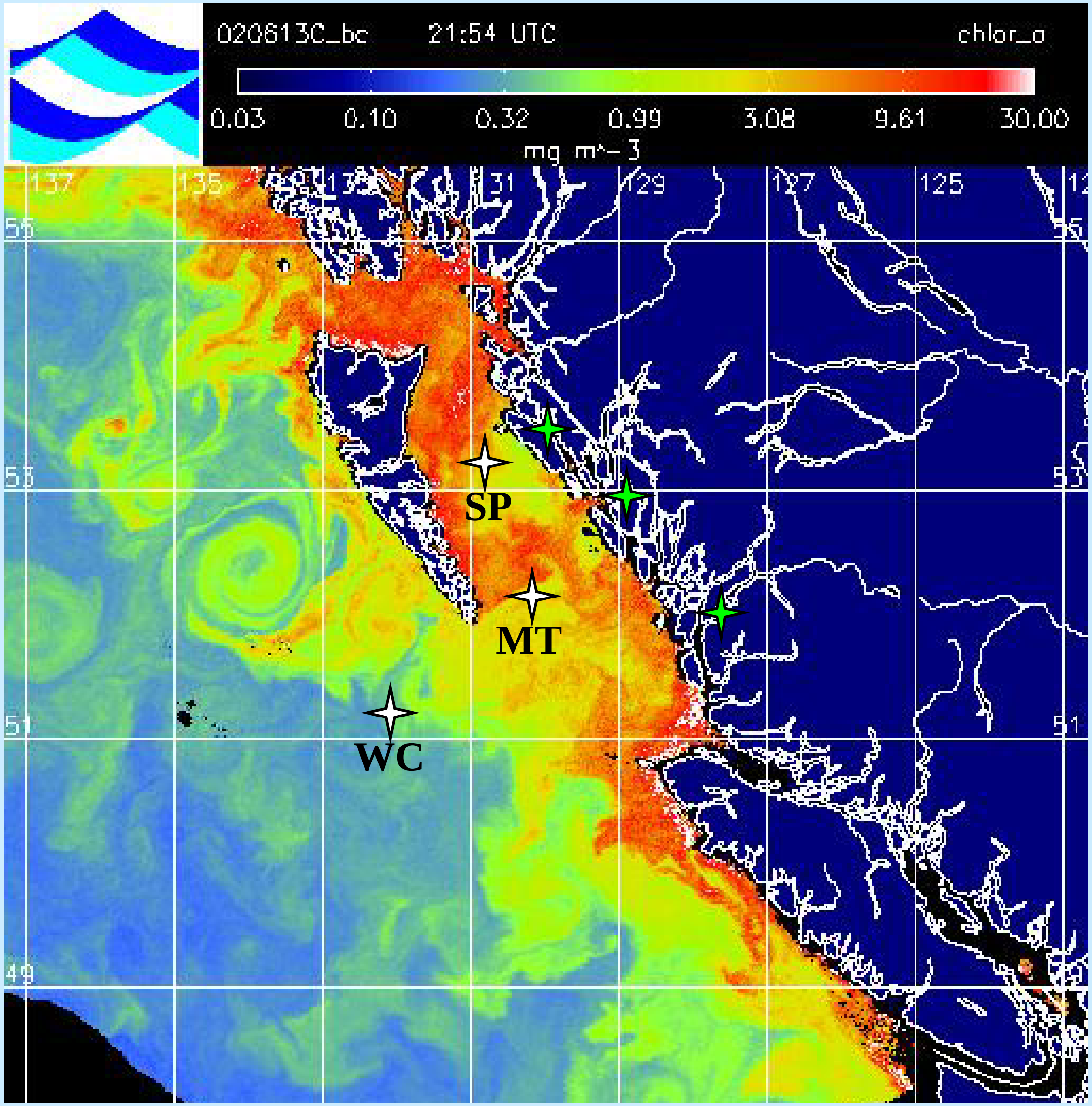
# May 1994




**Nutrients are distributed throughout the water column in strongly mixed tidal passes (Haro Strait). These nutrients are exported onto the shelf (estuarine circulation) where they support phytoplankton to blooms.**

9402hyd.xls

# 4. **Hecate Strait**, a large estuary



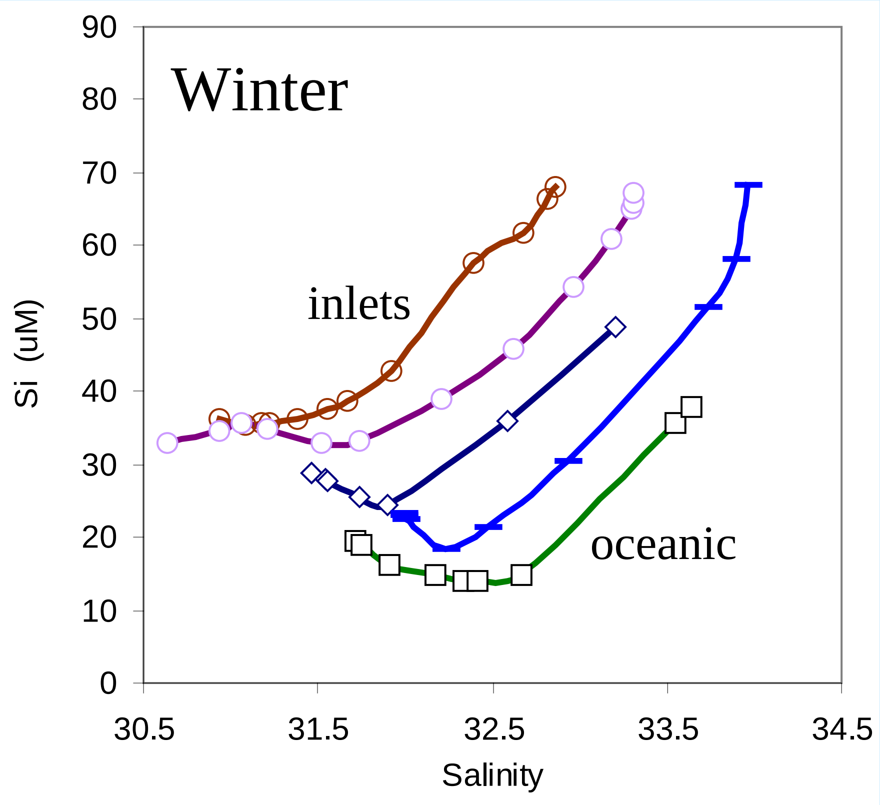

**June 13, 2002 SeaWiFS chlorophyll.**

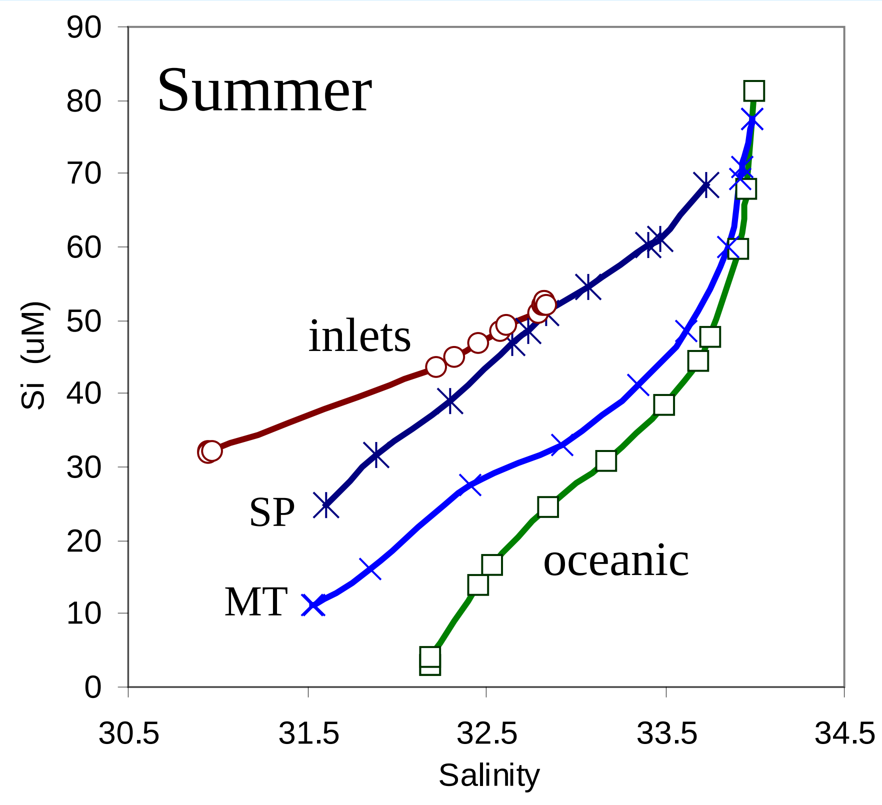
Circulation across the broad shelf region in Hecate Strait is strongly influenced by winds (upwelling during this image). Summer is generally a period of inflow at depth and outflow at the surface.

Waters are enriched with nutrients as they flow up canyons.

Note 2 Haida-2002 eddies west of the Queen Charlotte Islands.

# Hecate Strait and coastal inlets



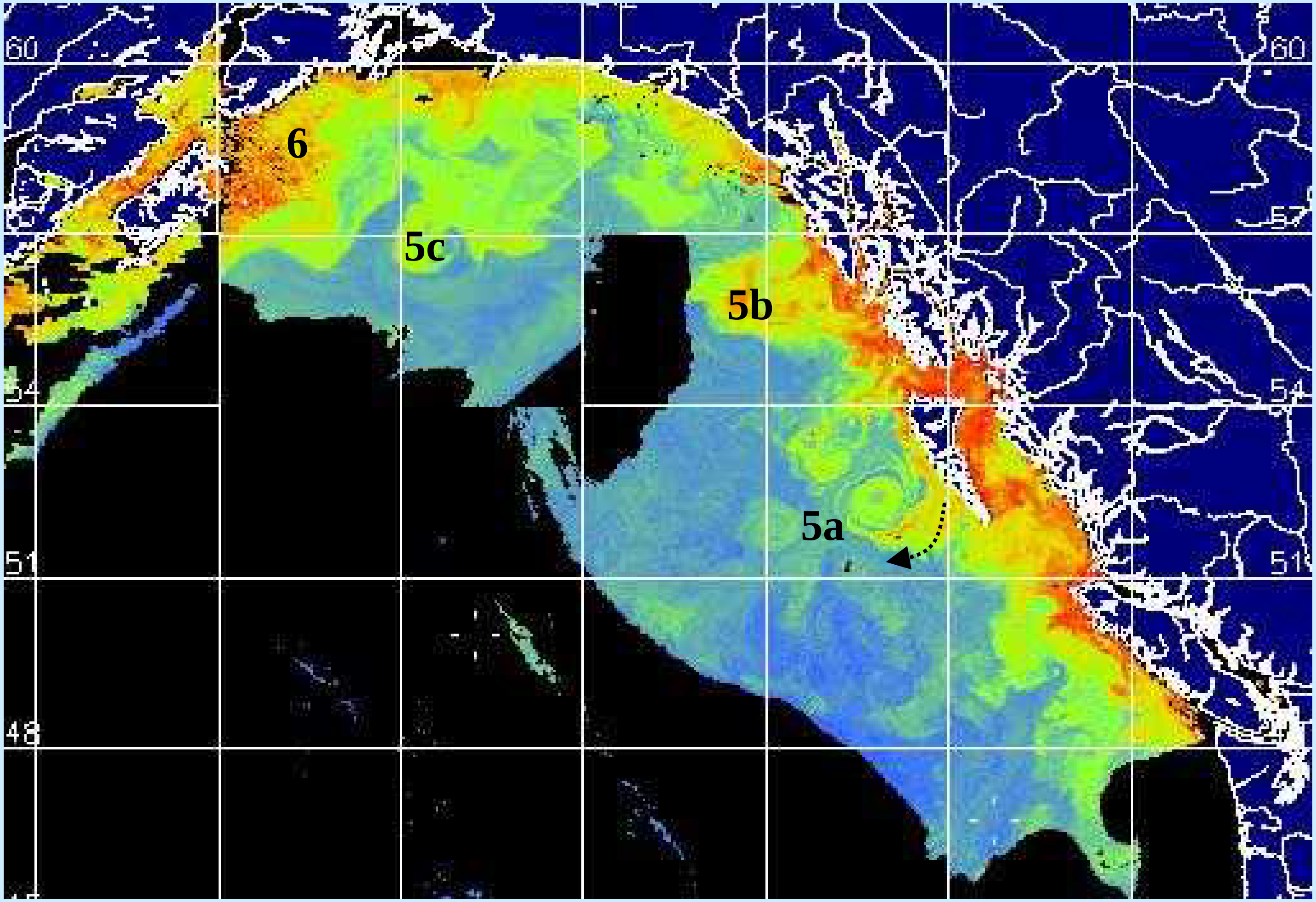




Nutrient levels are higher both at the surface and near bottom on the shelf, compared with open ocean.

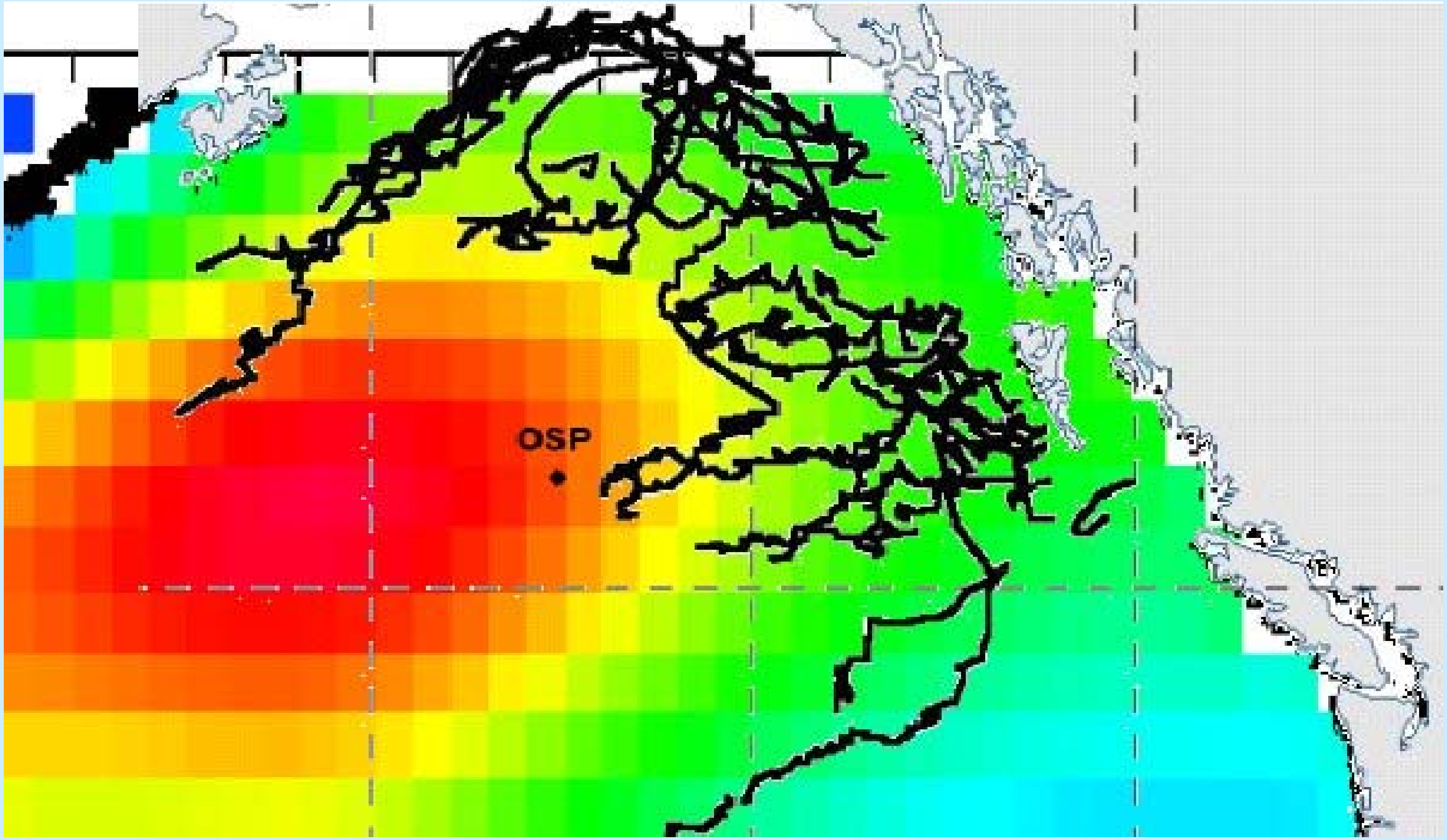
Estuarine circulation allows the coastal ecosystem to trap nutrients.

**5. Mesoscale eddy** transport is evident in 3 locations

June 13-15, 2002 composite image




**6**. High chlorophyll in vicinity of Kodiak Island, resulting from tidal mixing, canyon transport and strong shelf currents (Ladd et al., this session)

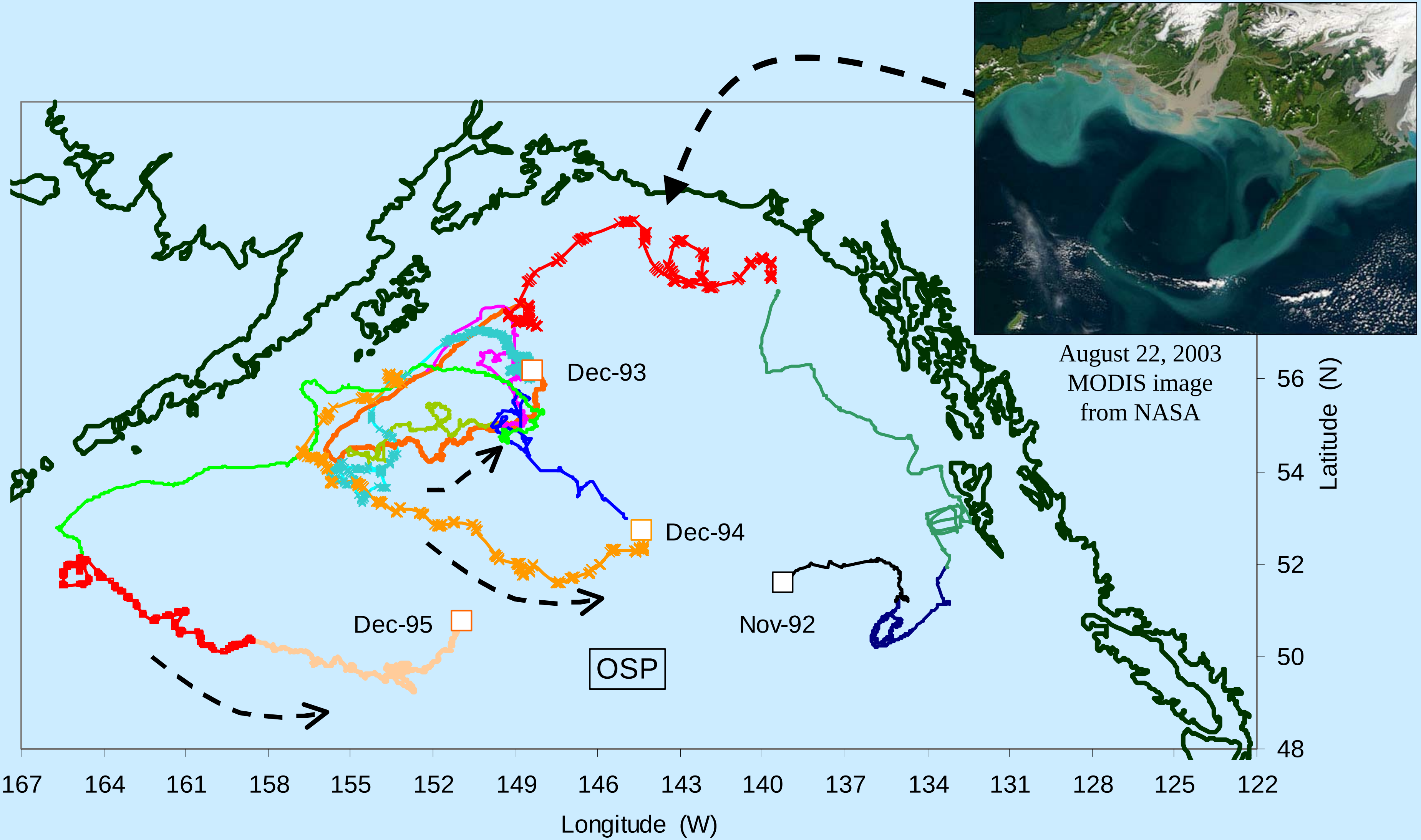



Annual average nitrate concentrations in colour, plus 10 years of Sitka and Haida Eddy tracks. The image implies that HNLC waters are outside the eddy domain, likely due to iron and silicate transport by eddies.

(Credit to Levitus 1994 for nitrate, and to R. Bowen and R. Leben for eddy tracks.)

# 7. **Recirculation** of coastal waters around the gyre. One surface drifter completed 3 loops away from the Alaskan coast over 3 years.

(Colour change every 3 months, red/pink in summer, orange in fall)




August 22, 2003
MODIS image
from NASA

1993_pac.xls

**8**. **Dust**: iron and silica from the atmosphere - unpredictable

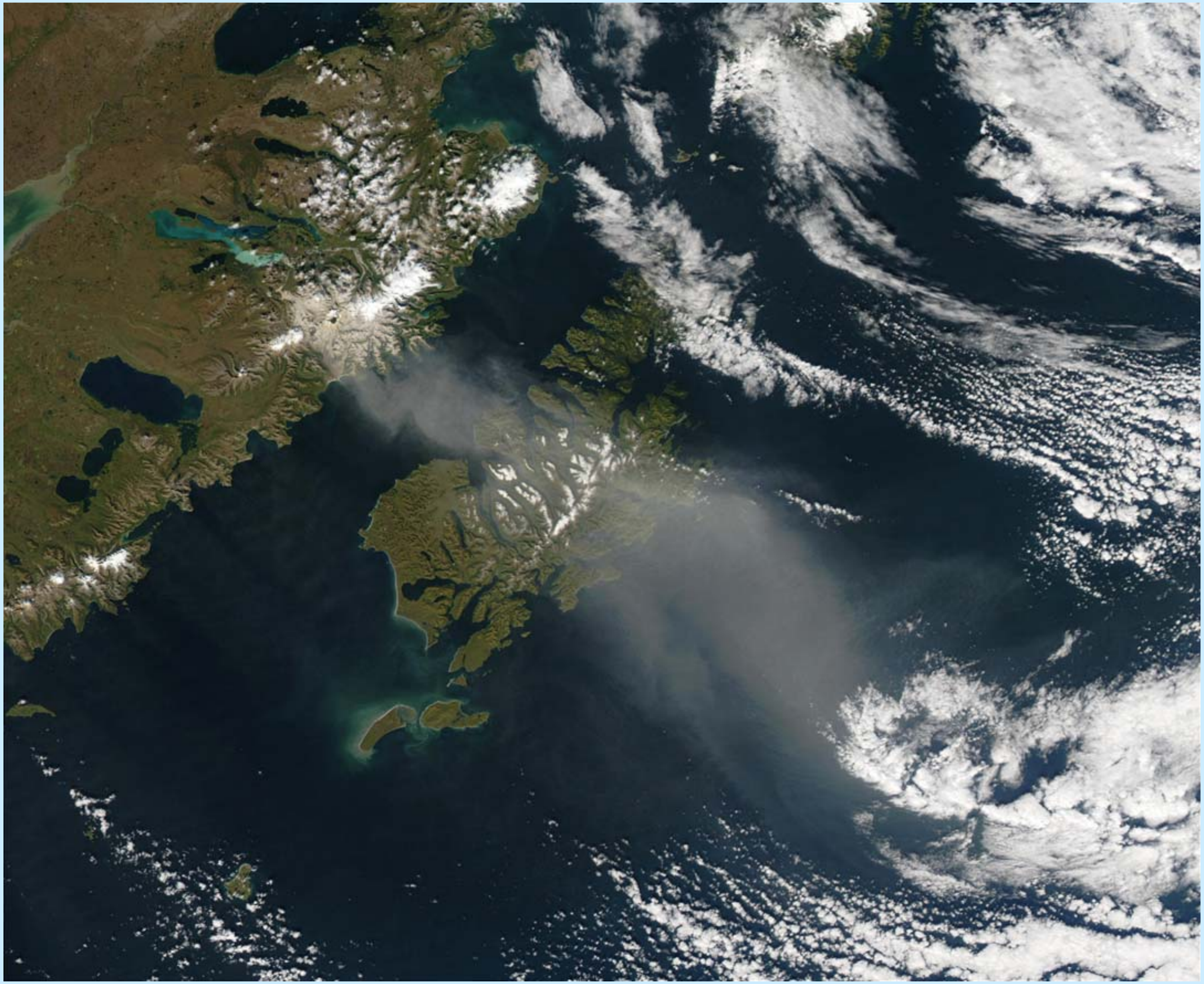


Image from *Moderate Resolution Imaging Spectroradiometer* (MODIS), on September 21, 2003 (provided by NASA)

## Summary:

- Onshore transport at depth results from upwelling and estuarine circulation
- As bottom waters cross shelf regions, they are enriched with nutrients
- Surface waters enriched in nutrients by tidal mixing support shelf regions of high productivity
- Surface waters flowing off the shelf are commonly depleted in nutrients
- Mesoscale eddies and recirculation from the Alaska coast carry coastal nutrients into the HNLC region
- Atmospheric transport can sporadically inject Fe and Si