Significance of curl-driven upwelling to production in the Coastal Gulf of Alaska

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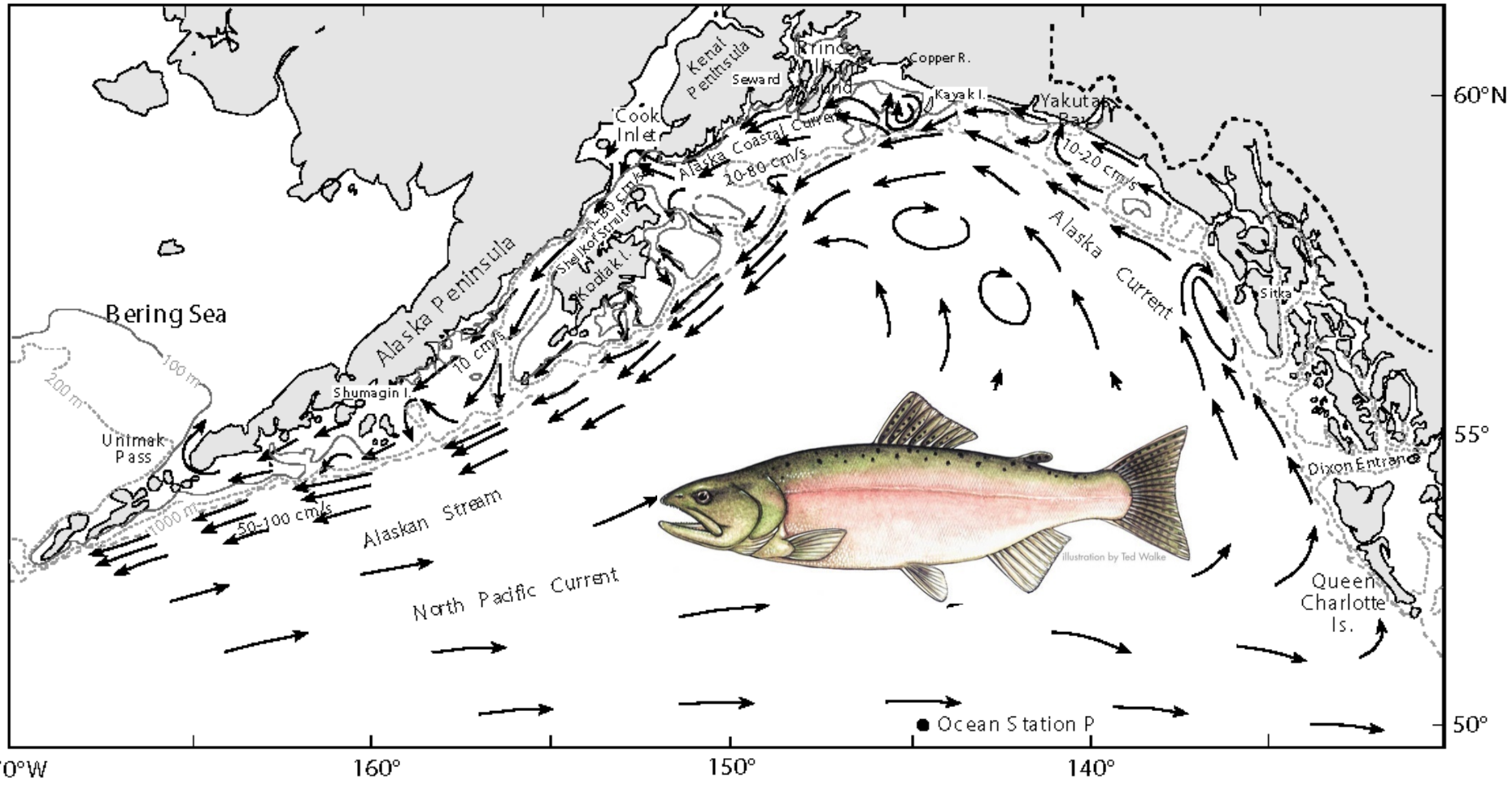
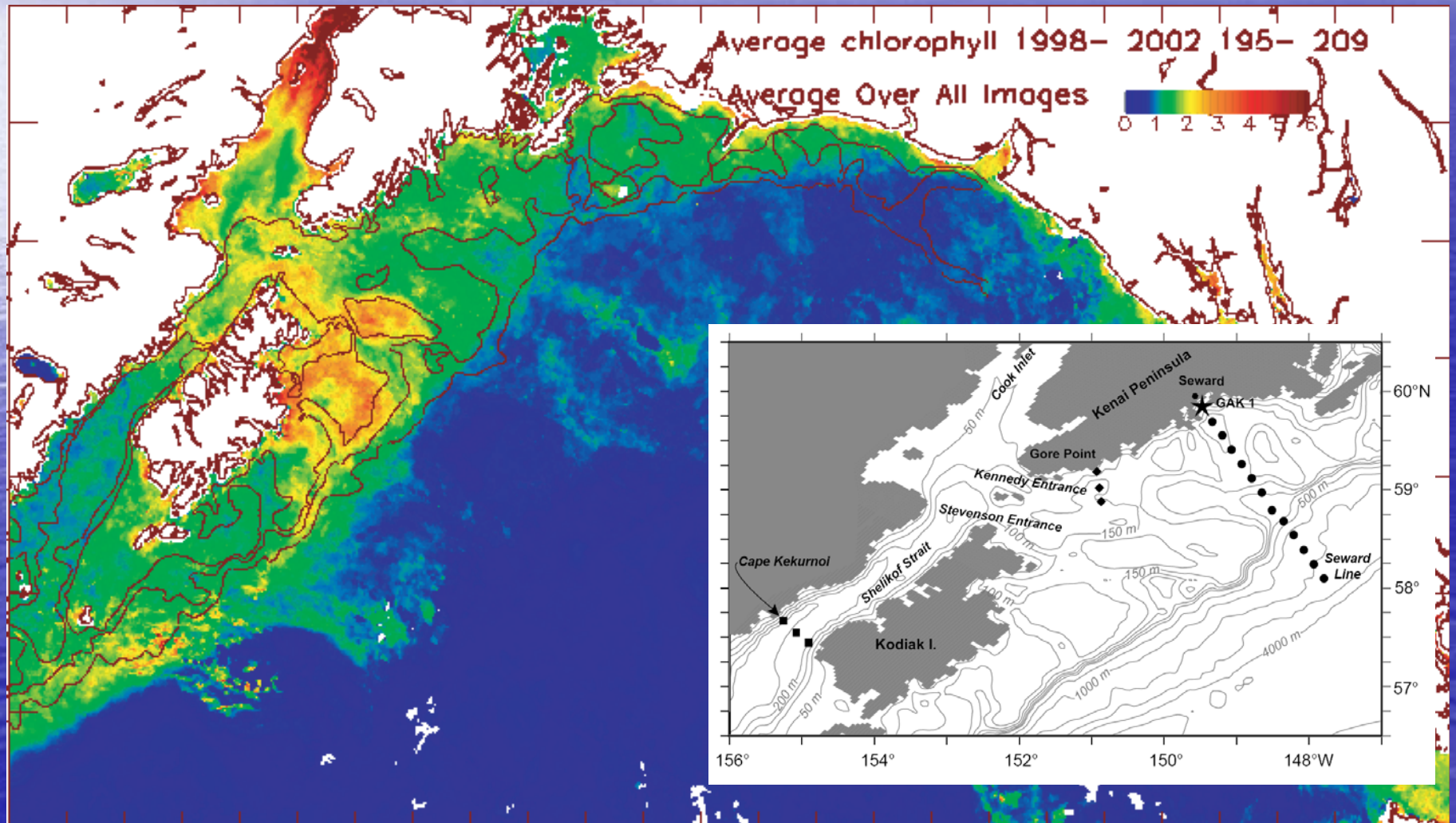
- Two major currents: Alaskan Stream and Alaska Coastal Current
- ACC forced by downwelling-favorable winds and distributed runoff
- Downwelling-favorable winds, yet very productive!



Average surface chlorophyll from SeaWifs data in the CGOA for late July, 1998- 2002 (data from S. Salo, PMEL)



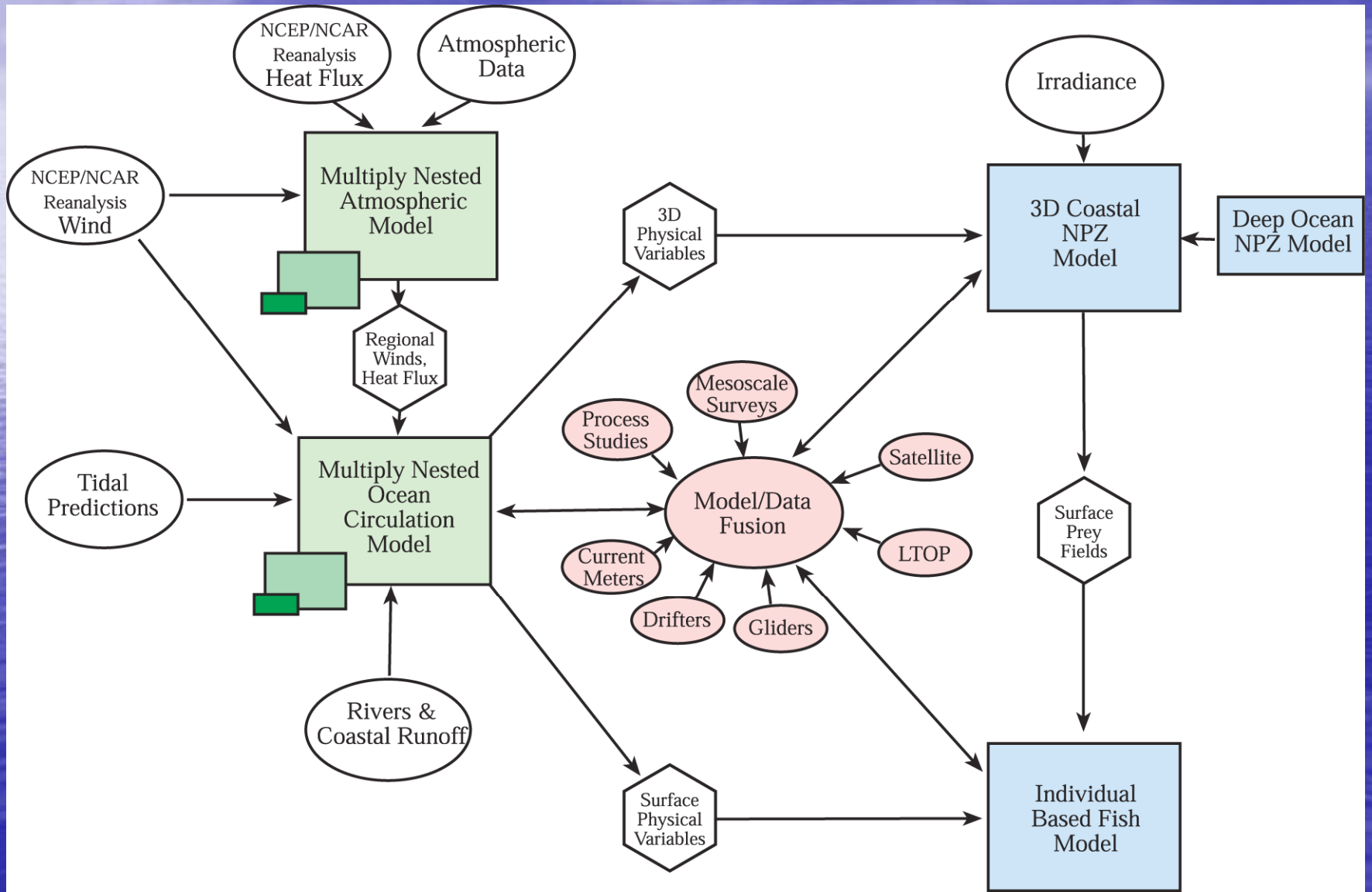
Why so productive? Alternate sources of new nitrogen

- "Traditional" 2D upwelling in the summer
- Upwelling driven by wind stress curl
- Onshore flux of HNLC waters
- Vertical mixing (deep pool replenished each year)
- Others!

Here, we seek to begin *quantifying* these candidates with a coupled biophysical model

Nested Biophysical Models for GLOBEC:

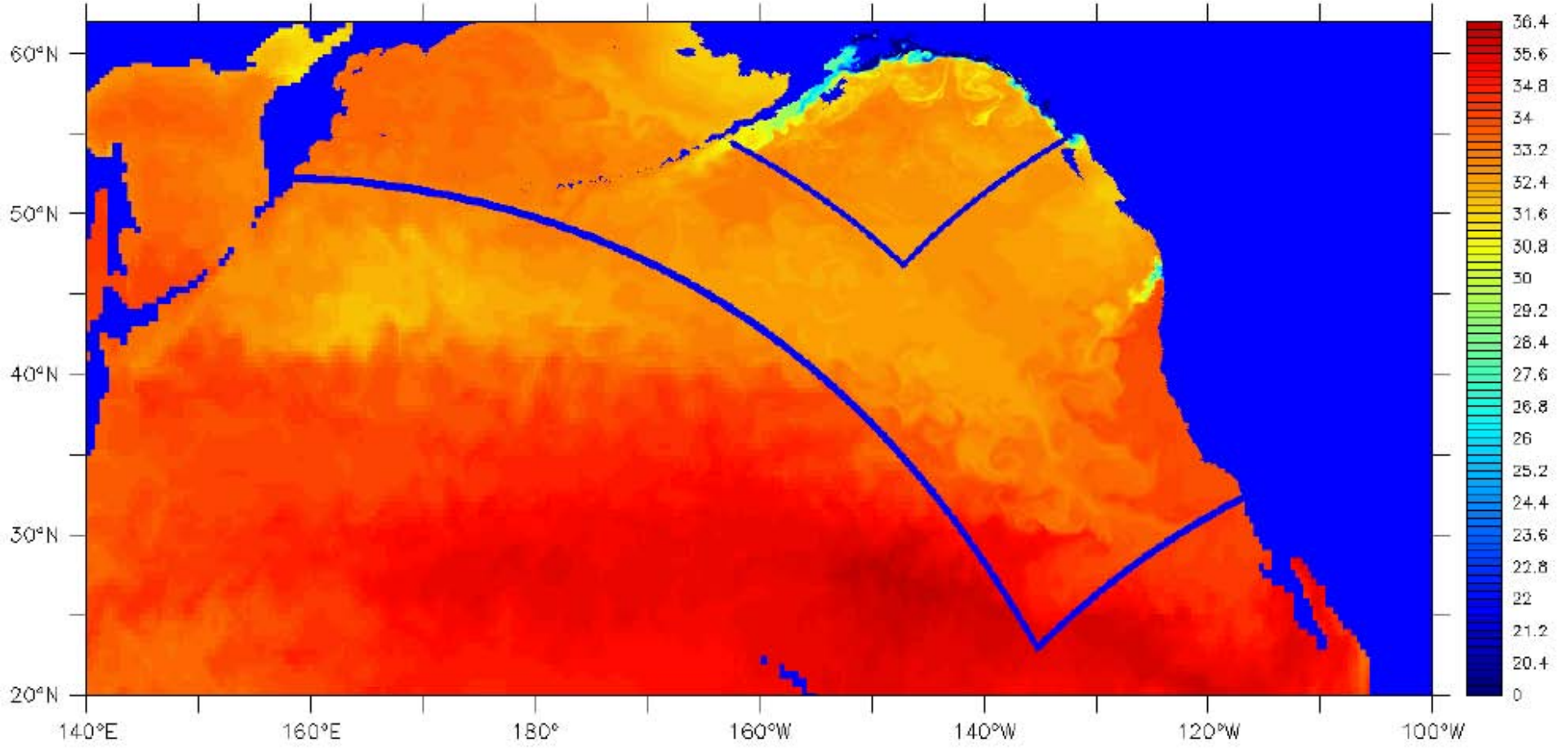
NCEP/MM5 -> ROMS/NPZ -> IBM



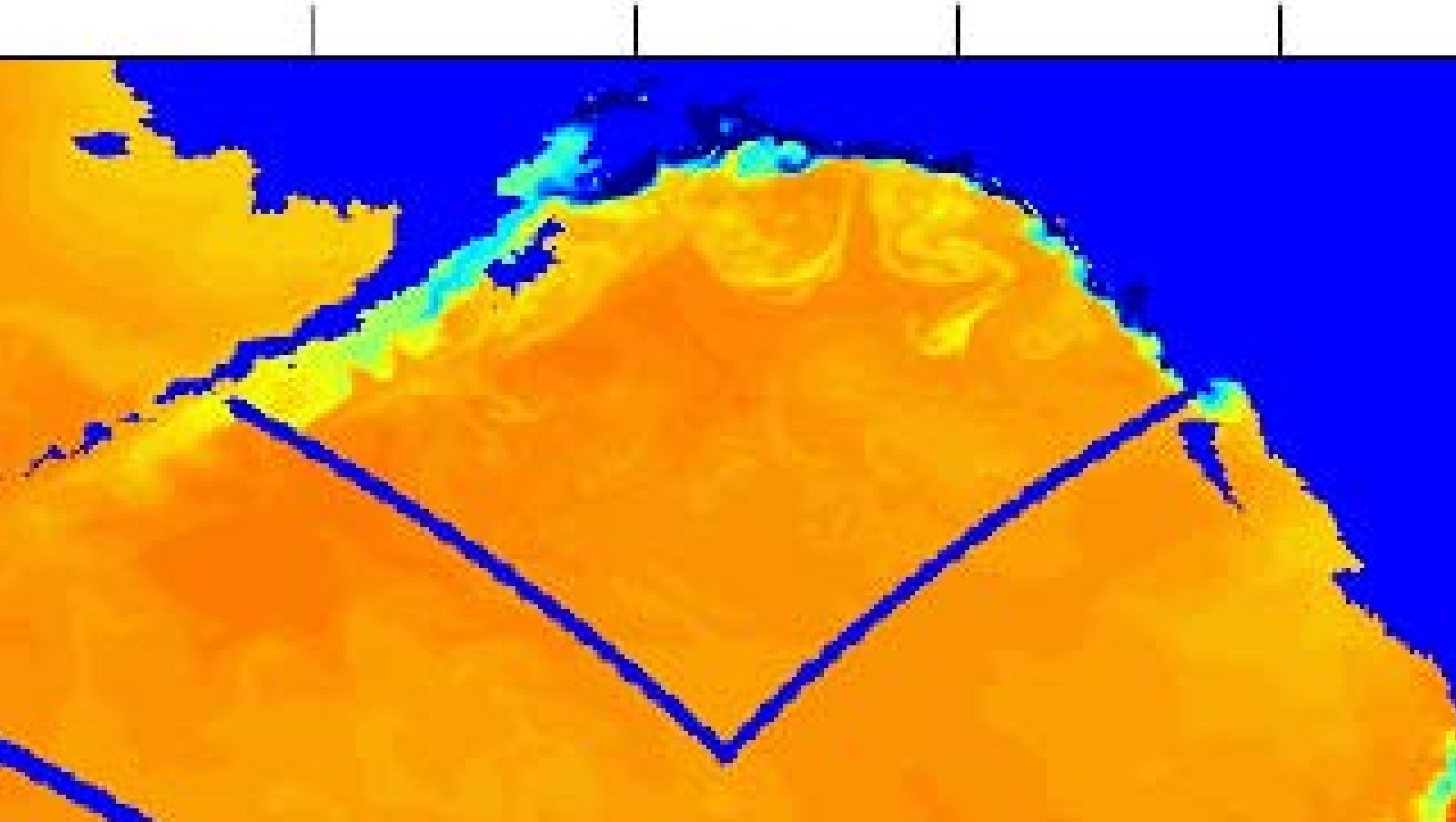
The Circulation Models

- Regional Ocean Modeling System (ROMS)
- Primitive Equations
- Terrain-following vertical coordinates (30 vertical levels)
- LMD mixed layer physics
- COADS/NCEP/MM5 wind and heat forcing
- Implemented on massively parallel (distributed memory) computers

Nested model results (SSS)



Detail of CGOA results (SSS)



Gulf of Alaska Ecosystem Model

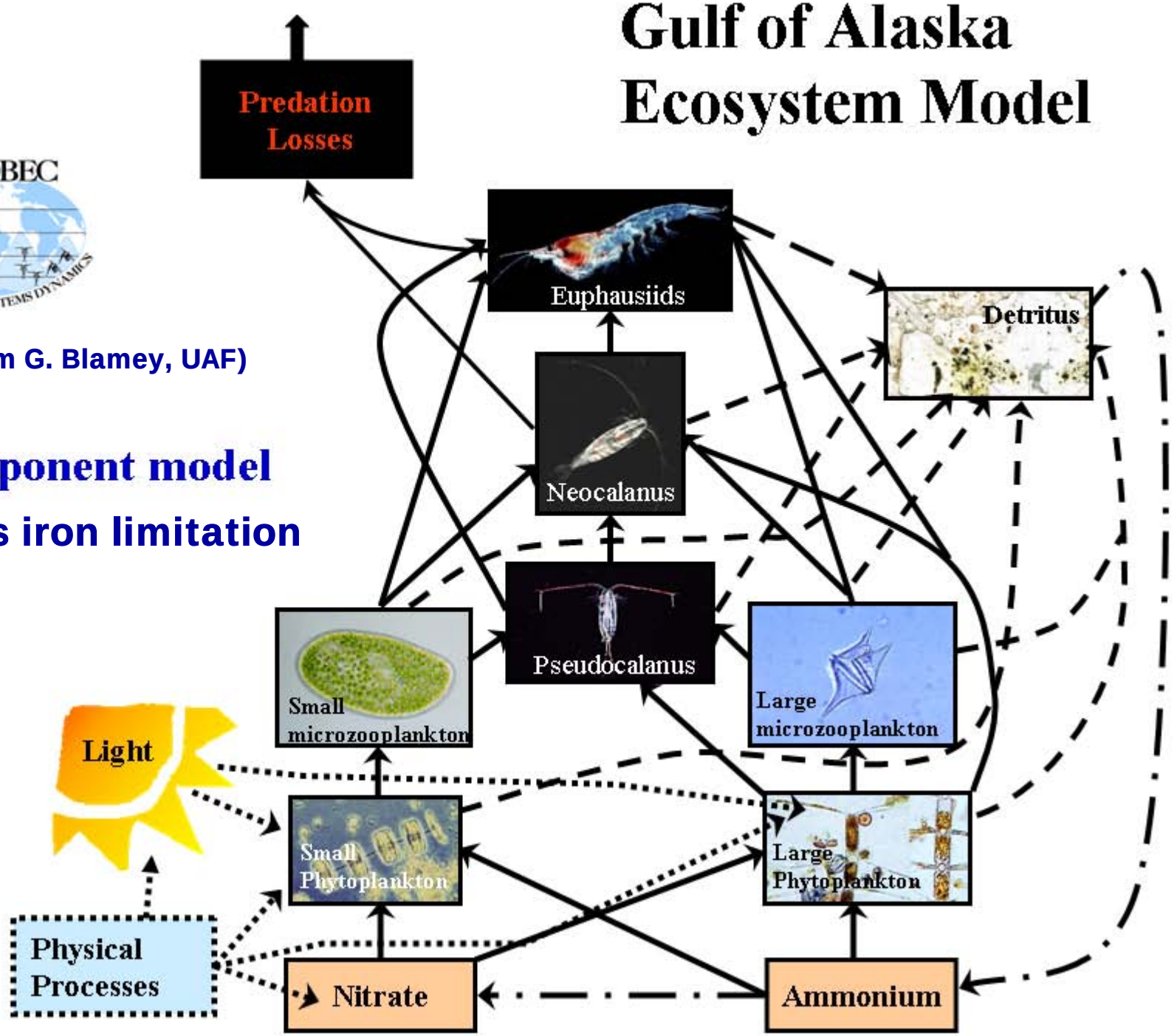
U.S. GLOBEC

GLOBAL OCEAN ECOSYSTEMS DYNAMICS

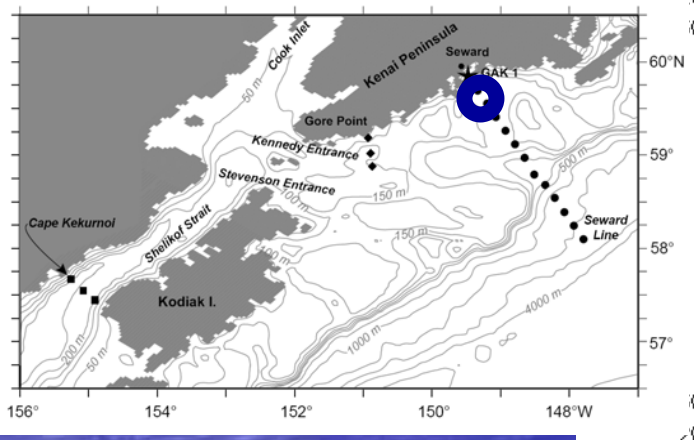
(diagram from G. Blamey, UAF)

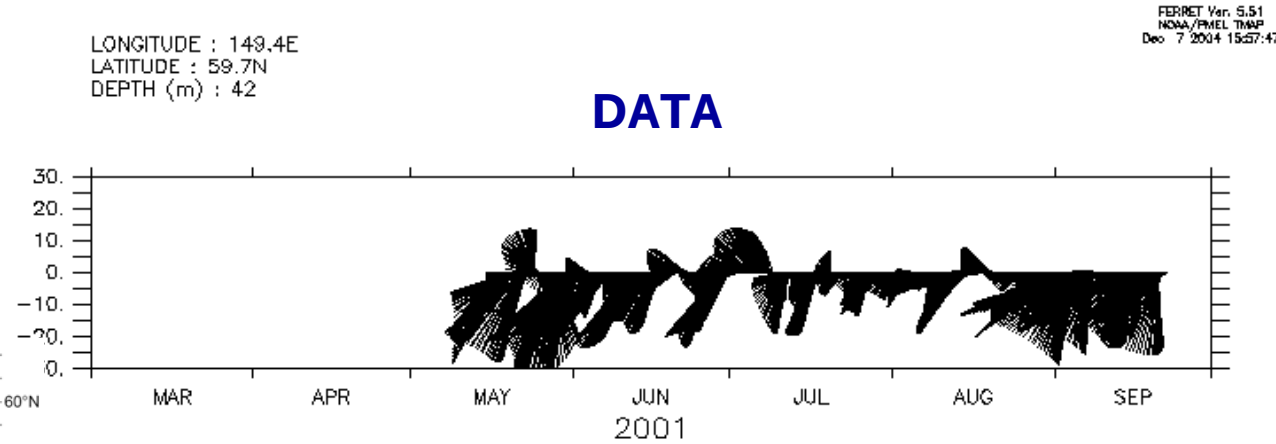
10 Component model

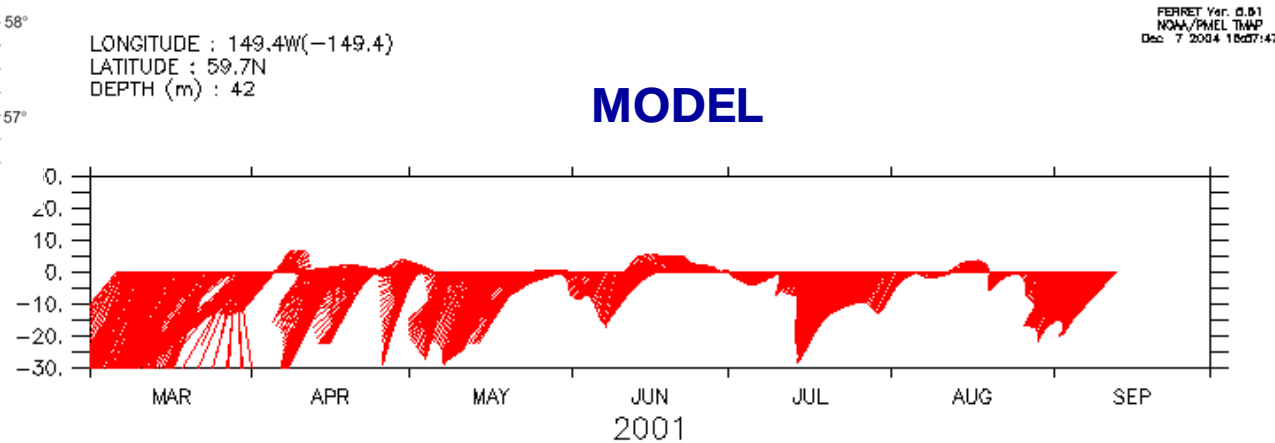
Includes iron limitation



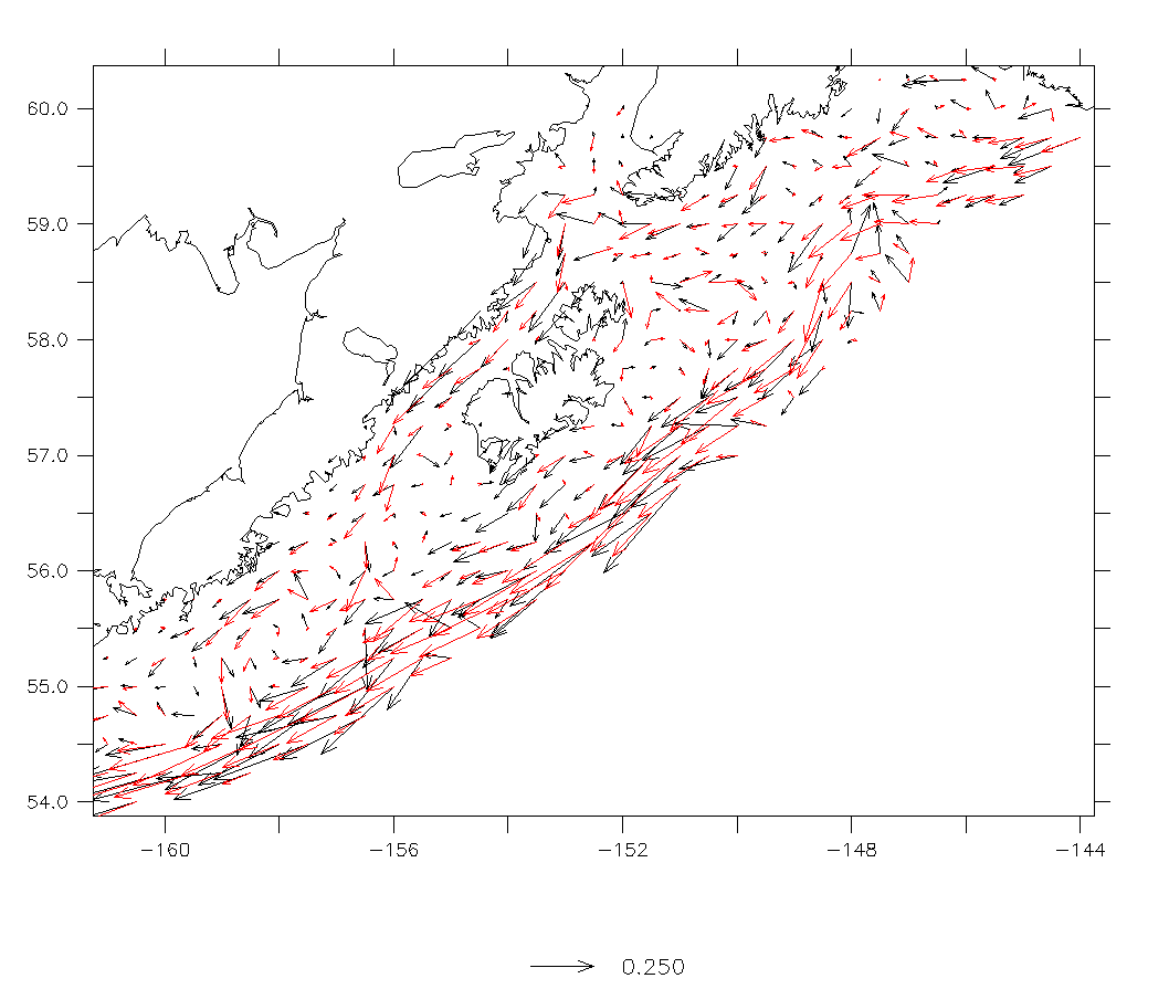
Daily velocity at GB-1







Mean velocity at 40 m on the CGOA shelf for May-September, computed from drifter data (black) vs model output (red).



S, T, NO3 along the GAK line in 2001

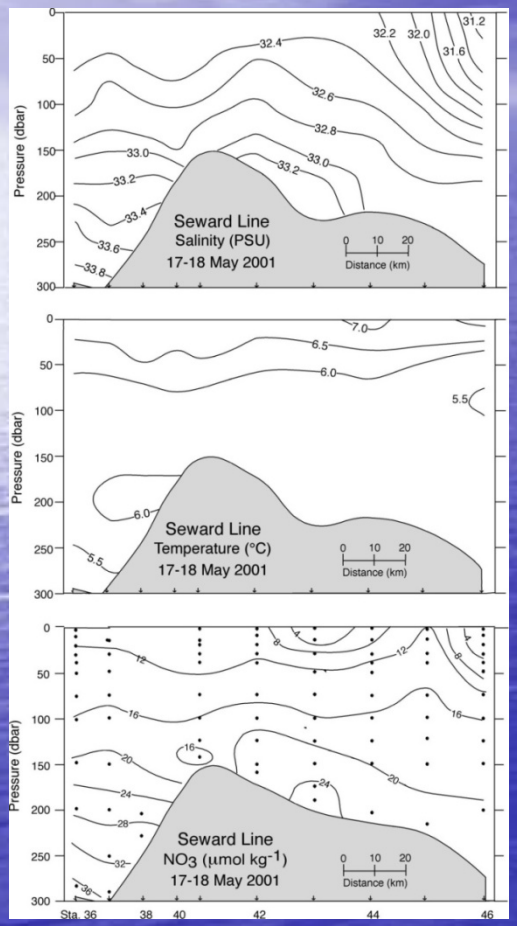
MAY

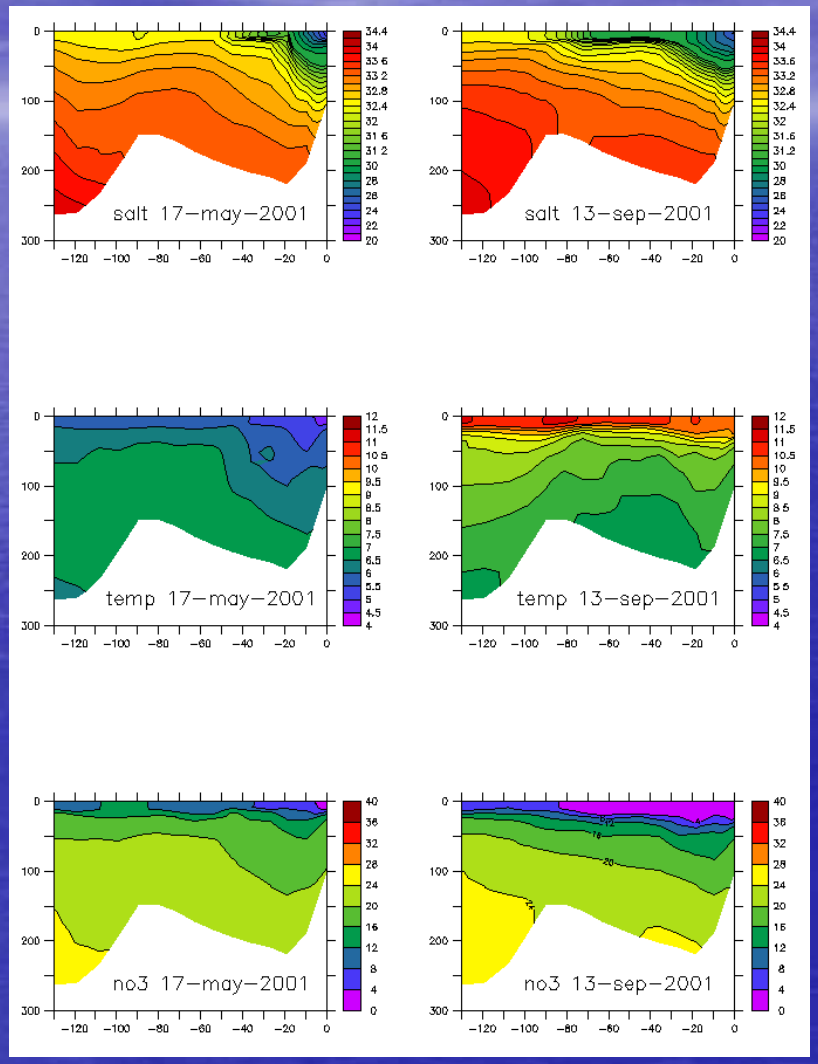
SEPT

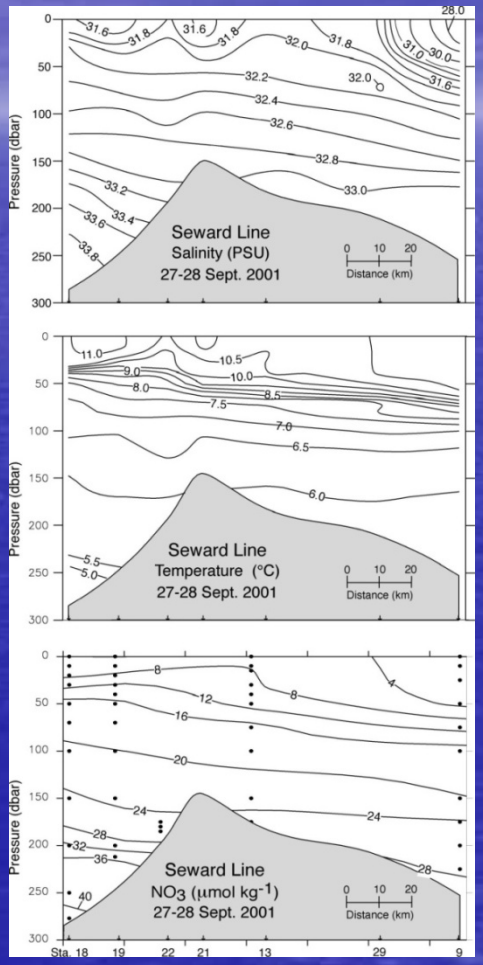
DATA

MODEL

DATA

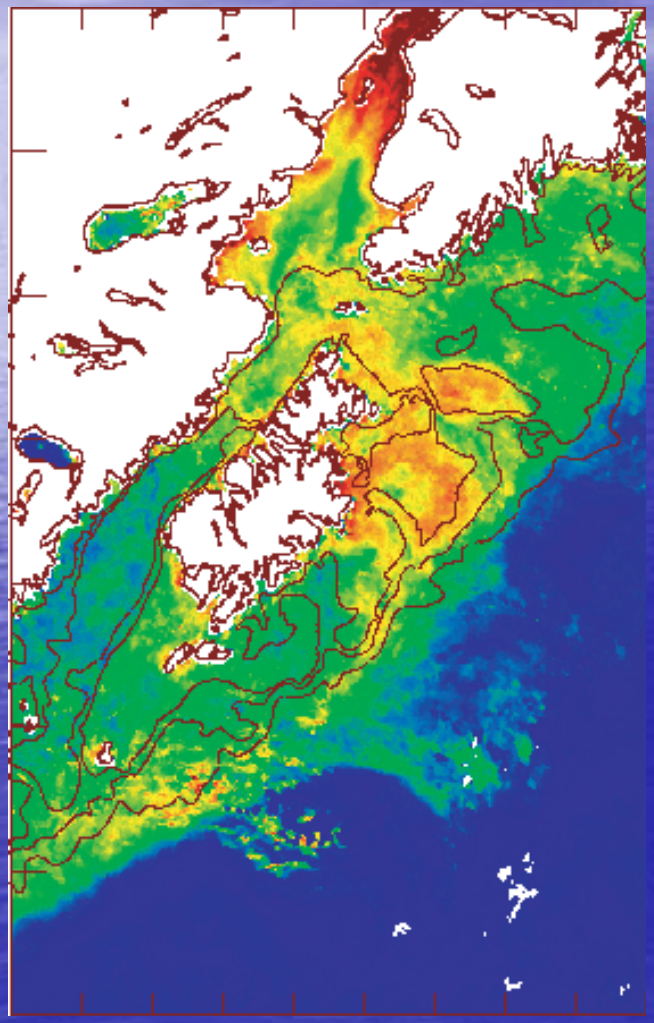




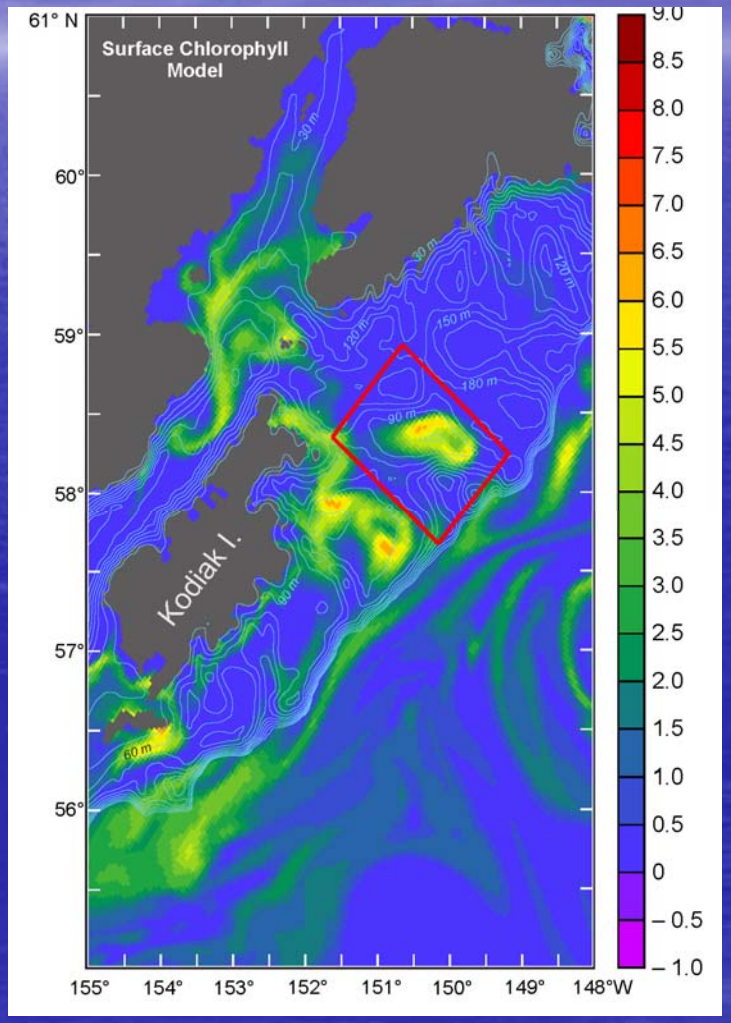


Rings of chlorophyll are a dominant feature

DATA



MODEL



Shelf budgets (top 15m)

Calculate the fluxes into and out of a *control volume* spanning the top 15m of the shelf waters

This construction is equivalent to a volume integral (from 15 m below mean sea level, up to the sea surface) of the local balance of terms:

$$C\_box_t = \iiint [-uC_x - vC_y - wC_z + (kC_z)_z]\, dx\, dy\, dz$$

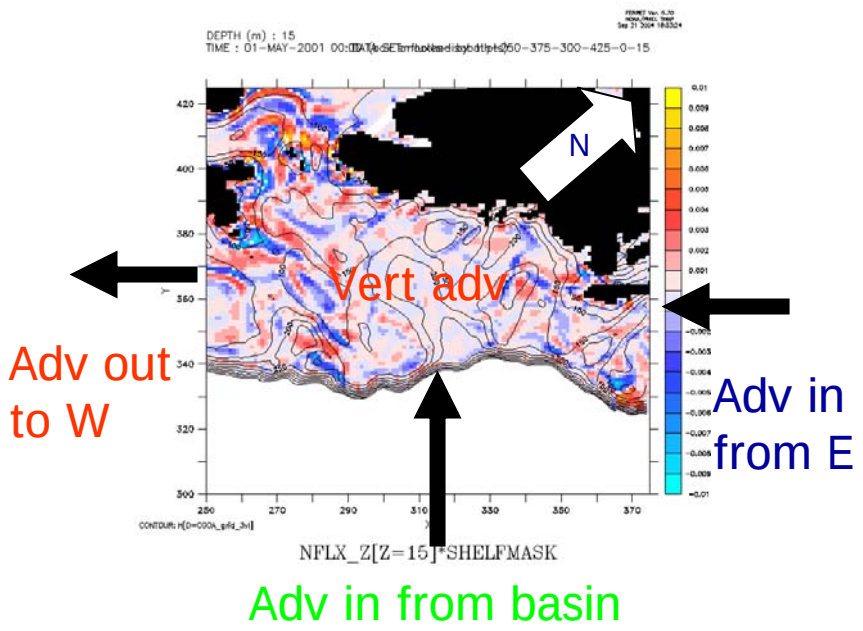
$$= C\_east + C\_west + C\_north + C\_south + C\_vertadv + C\_vertdiffu$$

$$+ \iiint \text{(nonconservative terms)}\, dx\, dy\, dz$$

Physical sources for nitrate

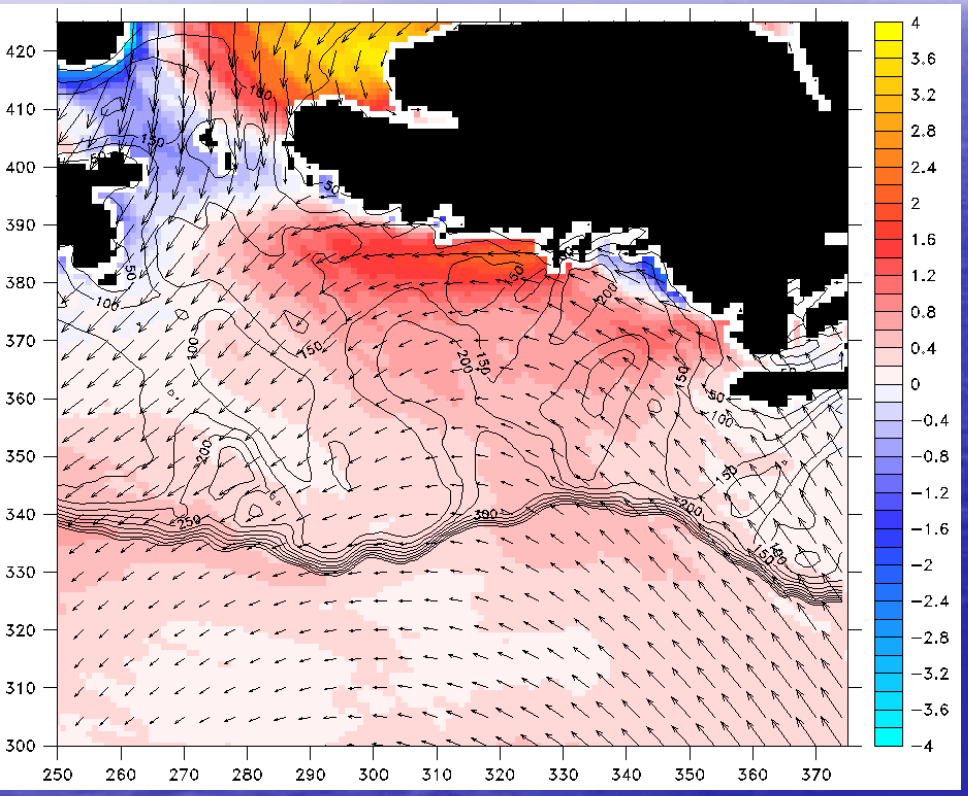
- Horizontal advection
- Vertical advection
- Vertical diffusion

- Seek to quantify these basic terms across the faces of a control volume
- Note: result depends on the dimensions of the box!

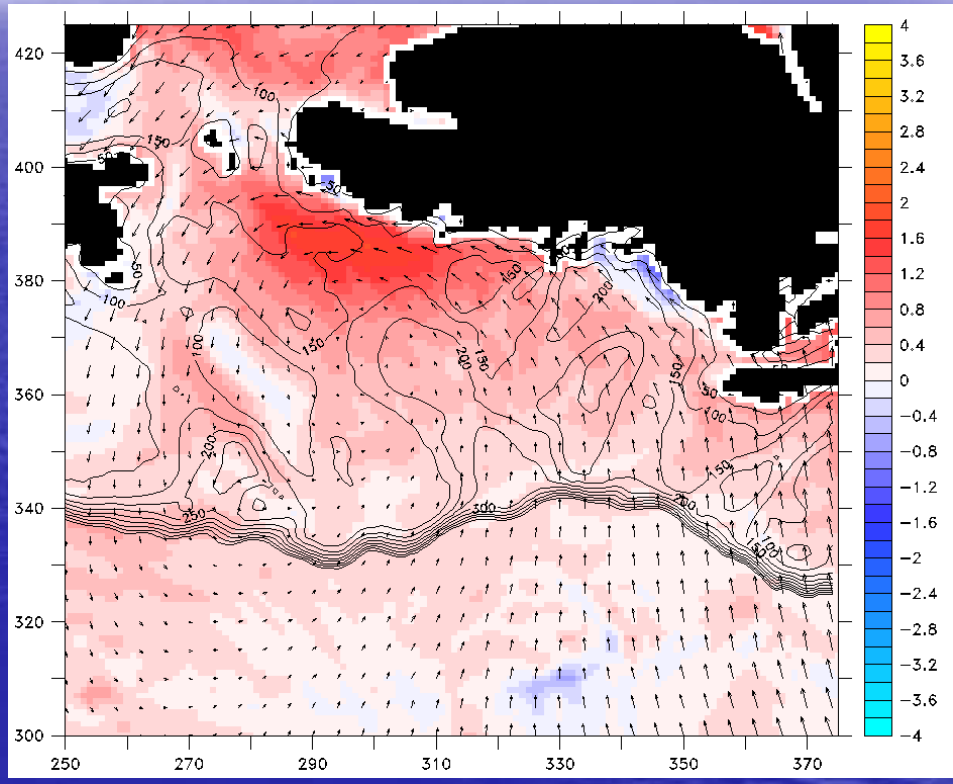


Monthly average wind stress vectors (N m^{-2}) and wind stress curl (N m^{-3} x 10^3, shaded)

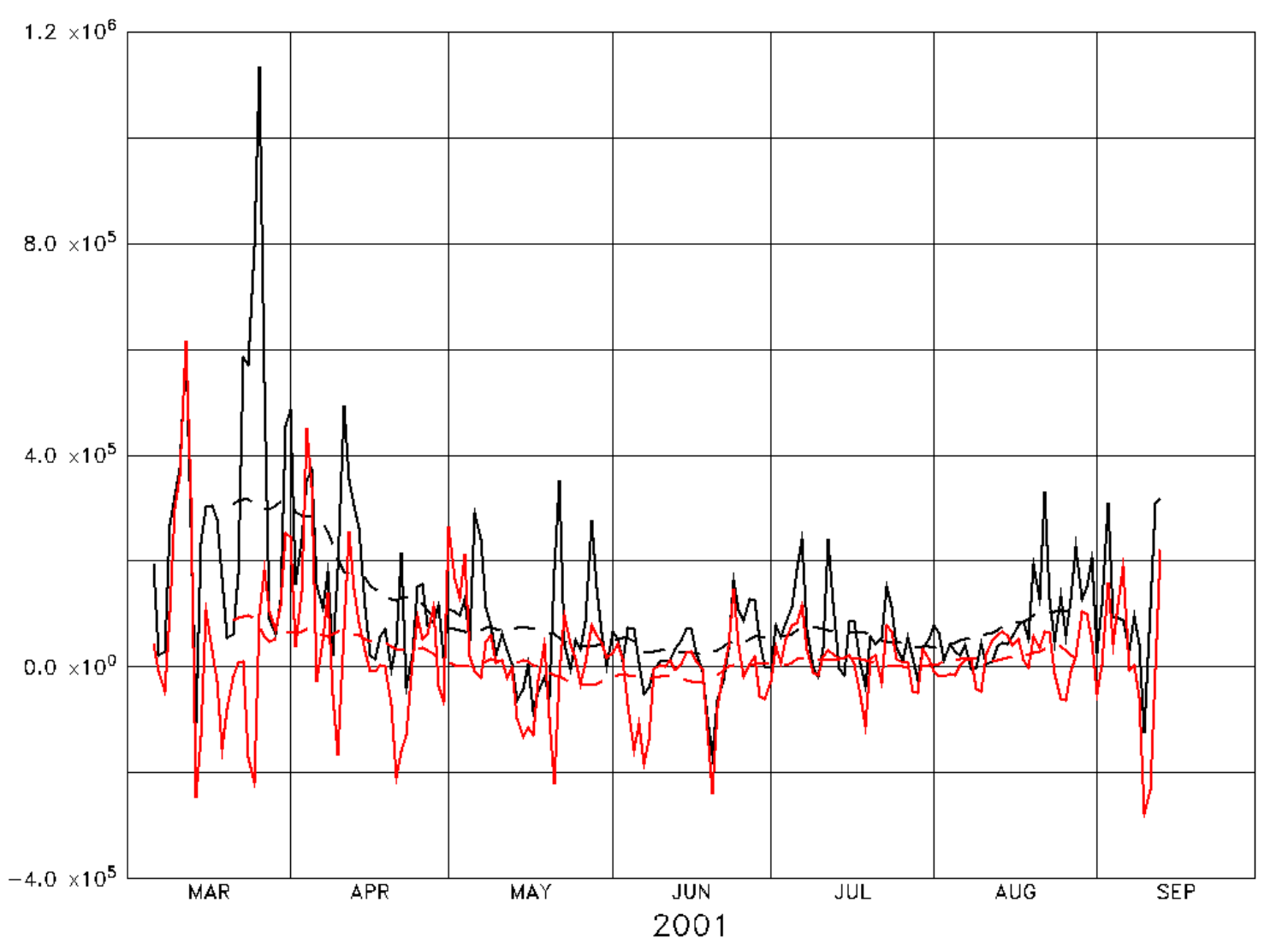
May 2001



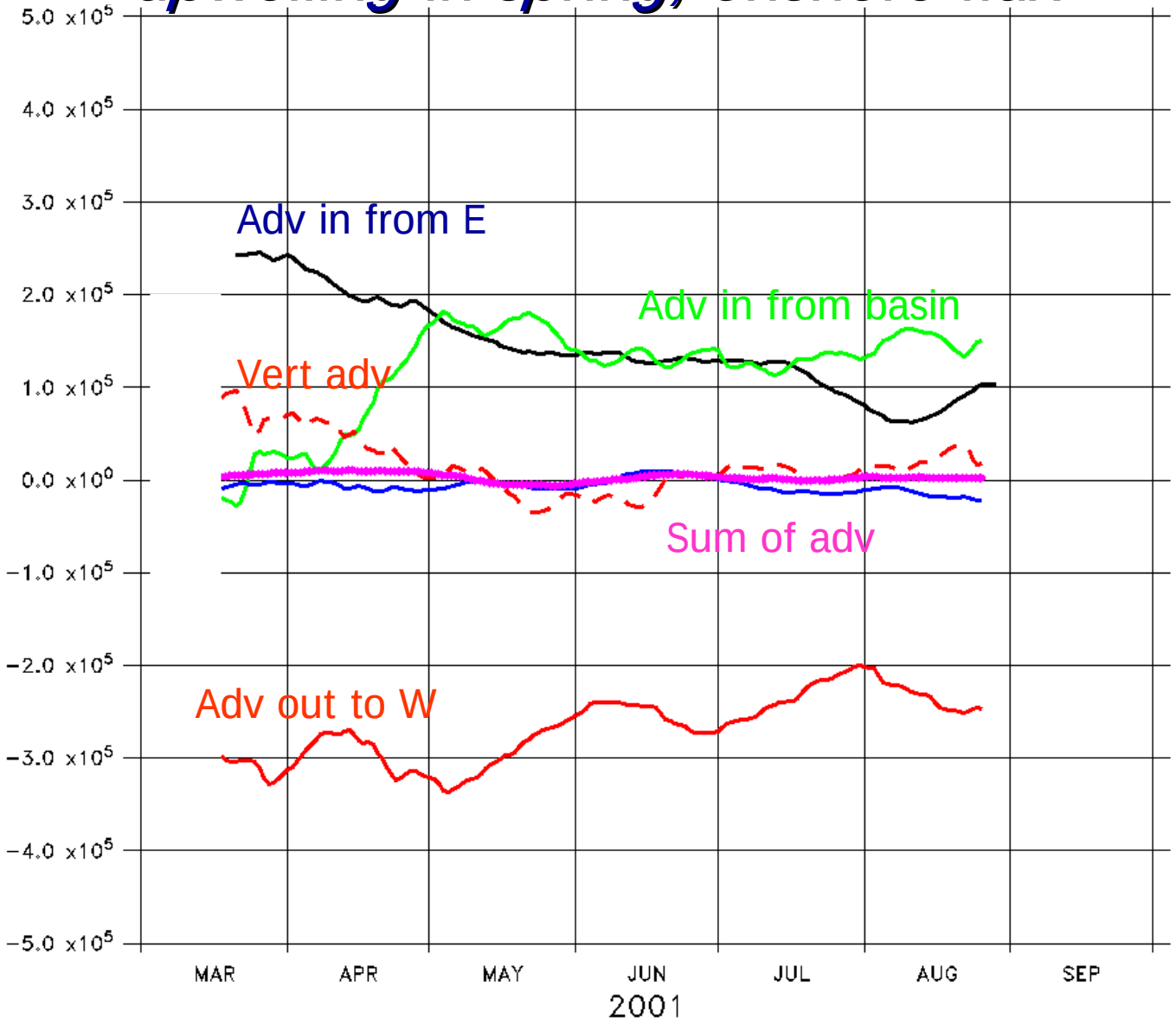
Aug 2001



Calculated Ekman pumping from winds (black line) vs ROMS vertical velocities at 15 m (red line) integrated over the control volume

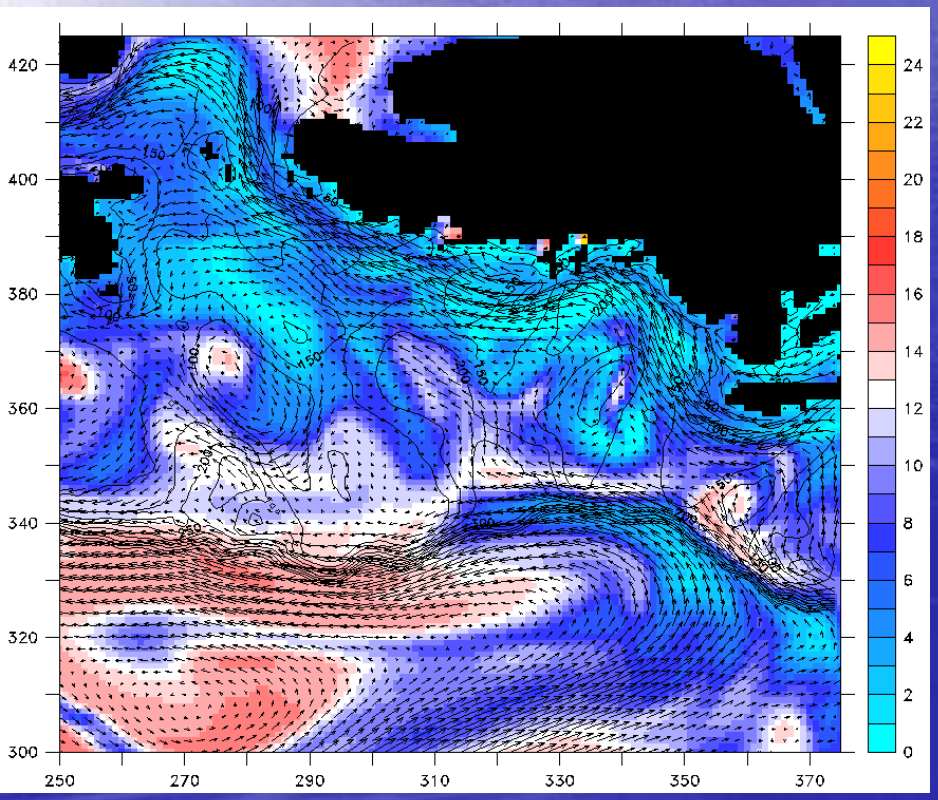


First, look at the *water* budget: *upwelling in spring, onshore flux*

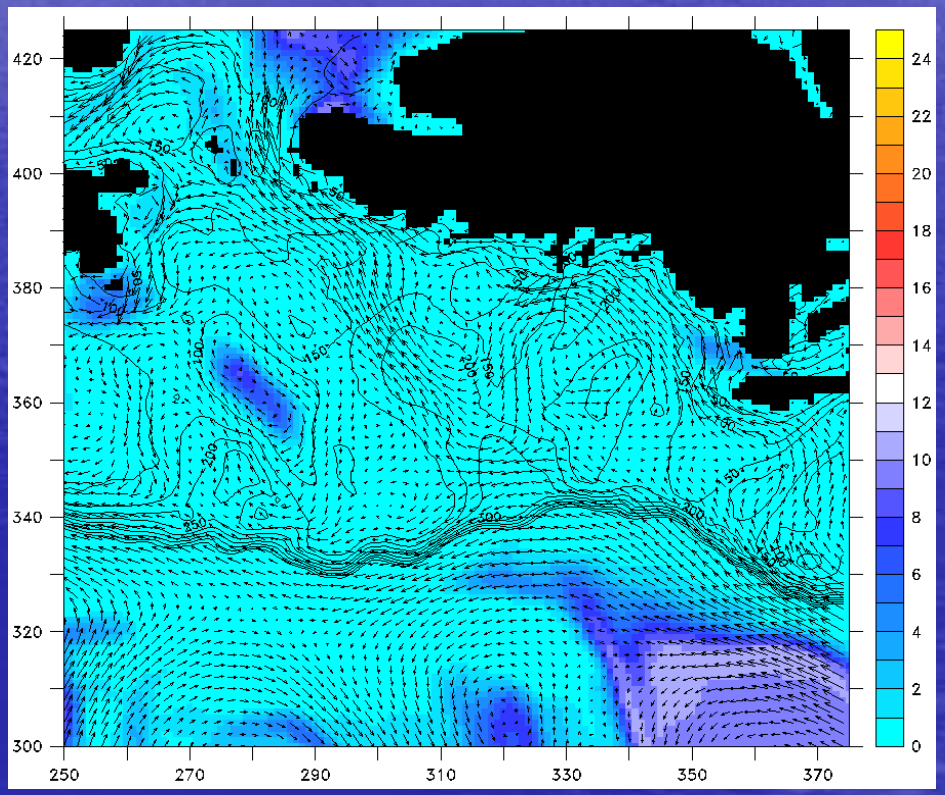


Modeled surface nitrate and velocity

May 15 2001

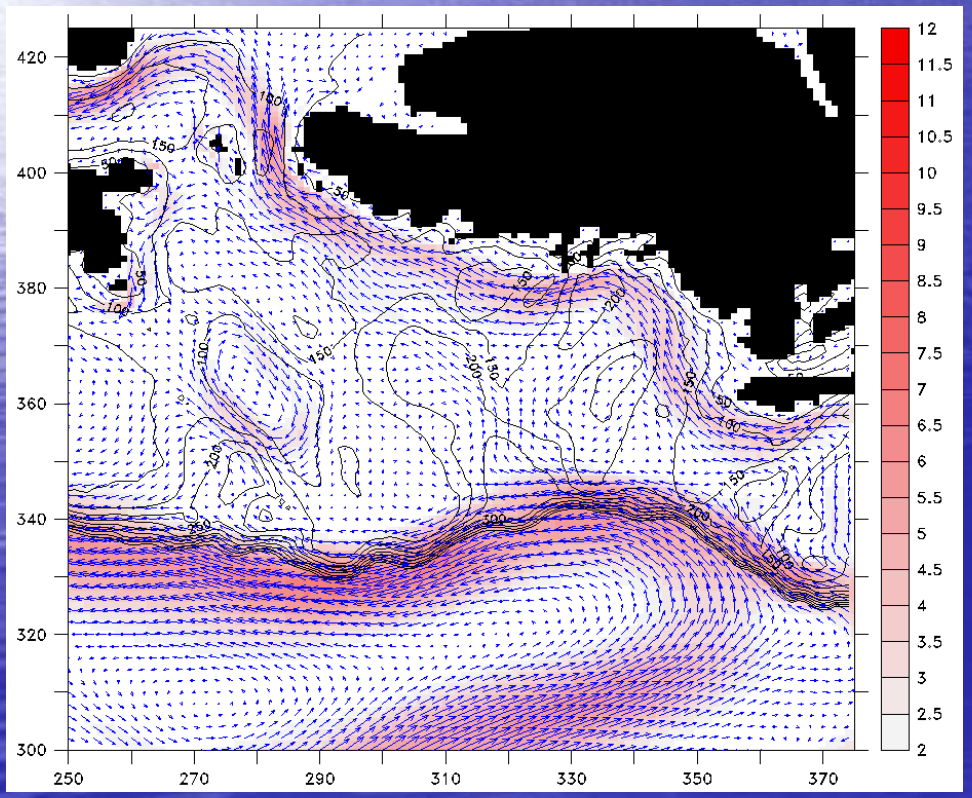


Aug 15 2001

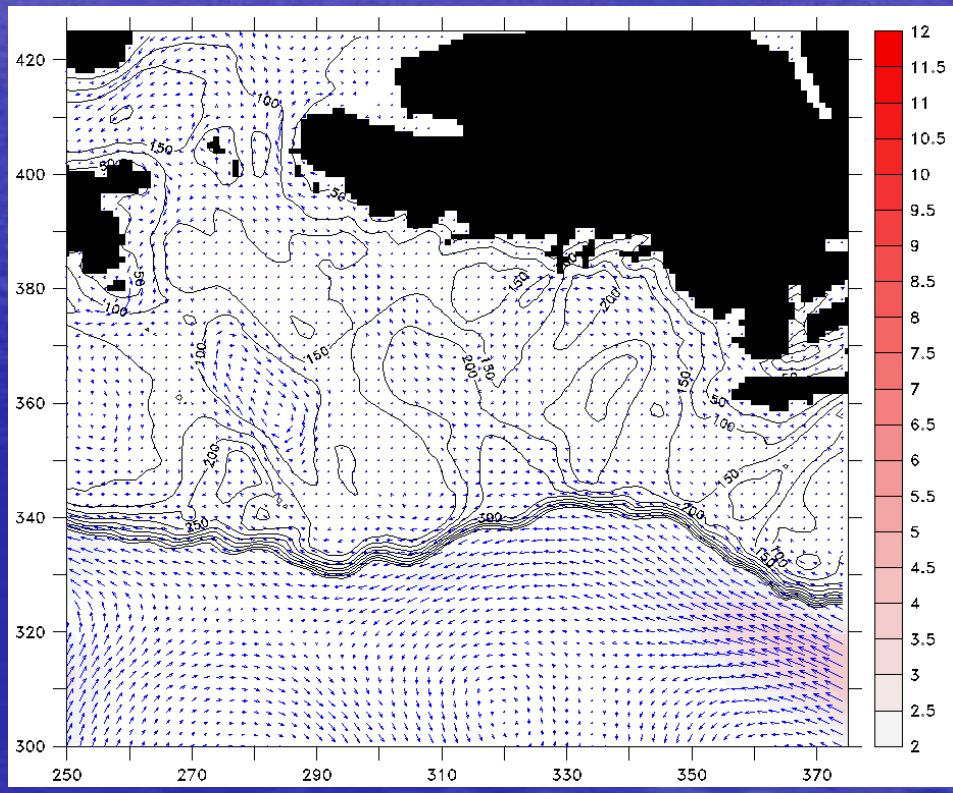


Modeled monthly average horizontal flux of nitrate at 15 m depth (millimole m^{-2} s^{-1})

May 15 2001

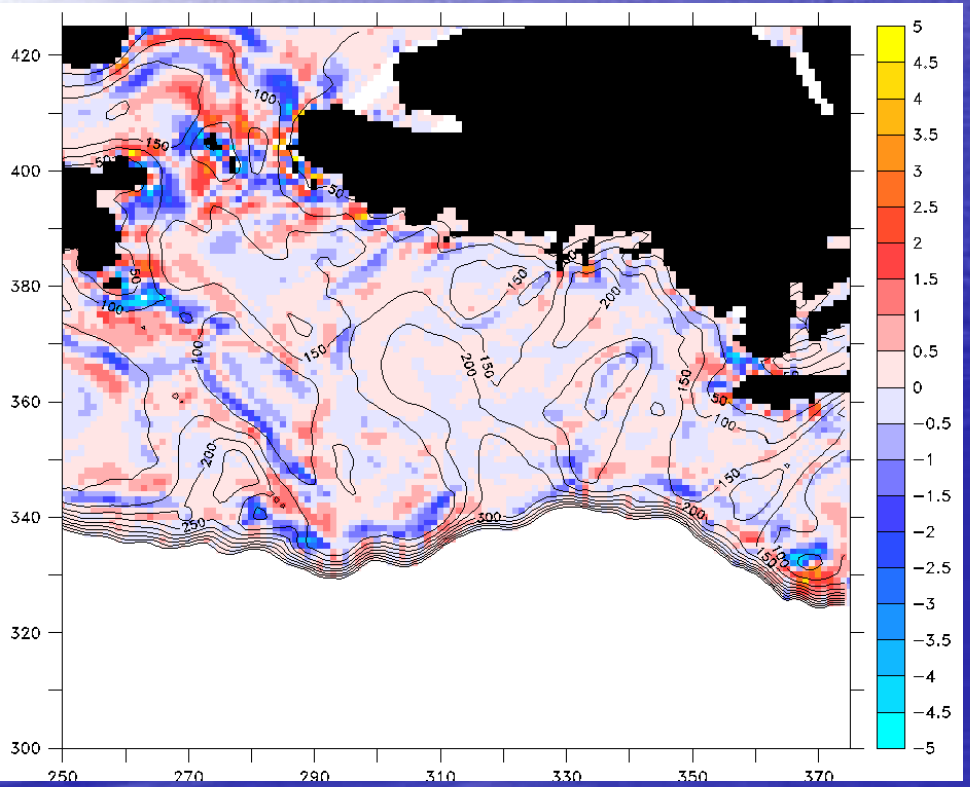


Aug 15 2001

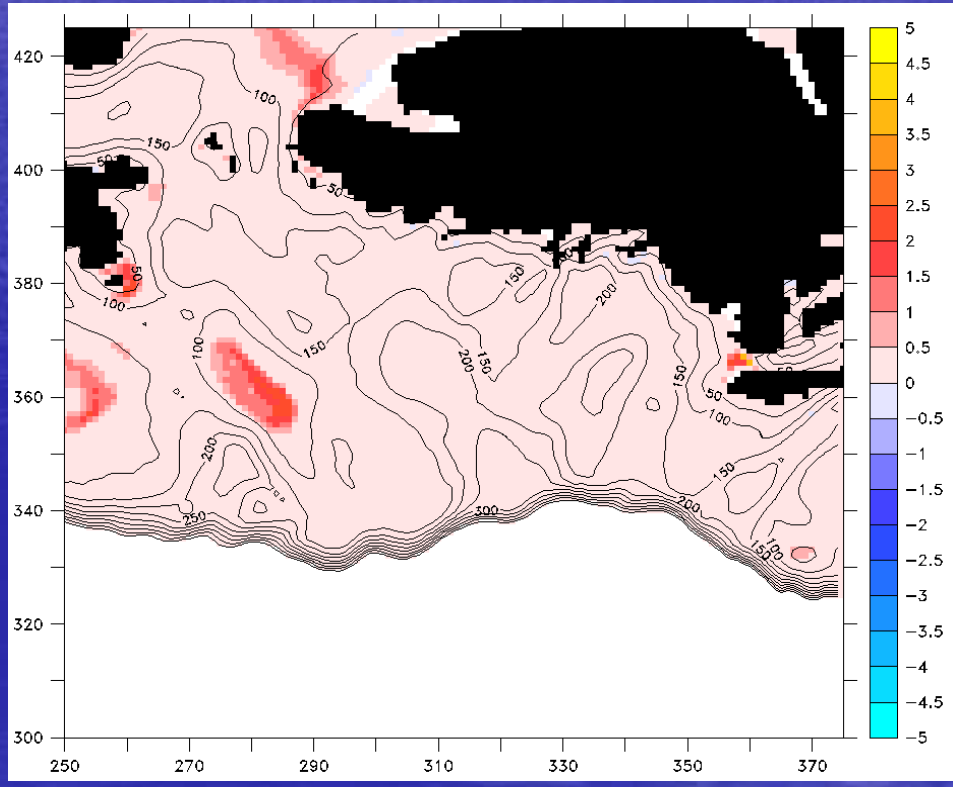


May 2001 average vertical advection and vertical diffusion of nitrogen across the 15m depth horizon (millimole m^{-2} s^{-1} x 10^3)

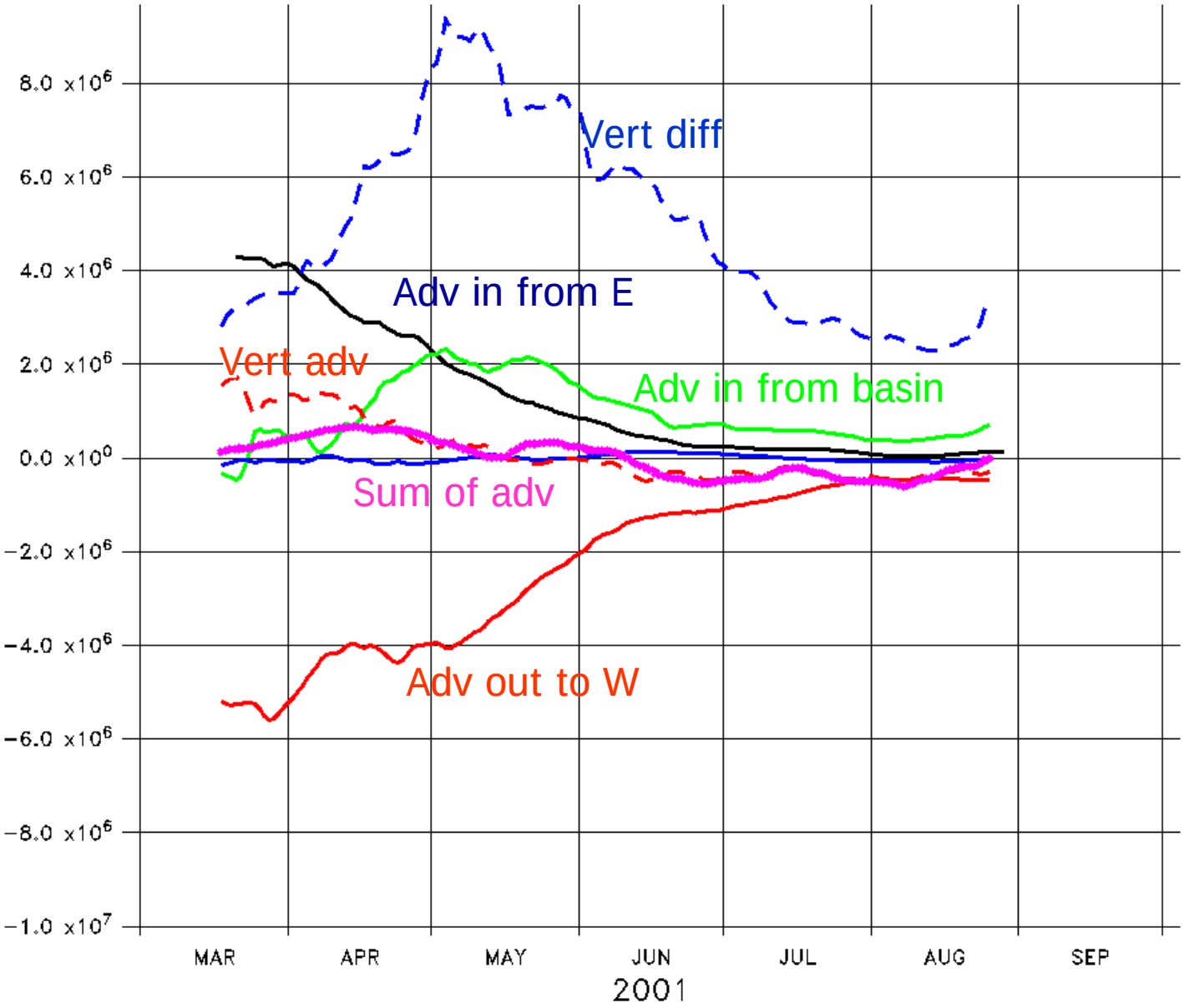
VERTICAL ADVECTION



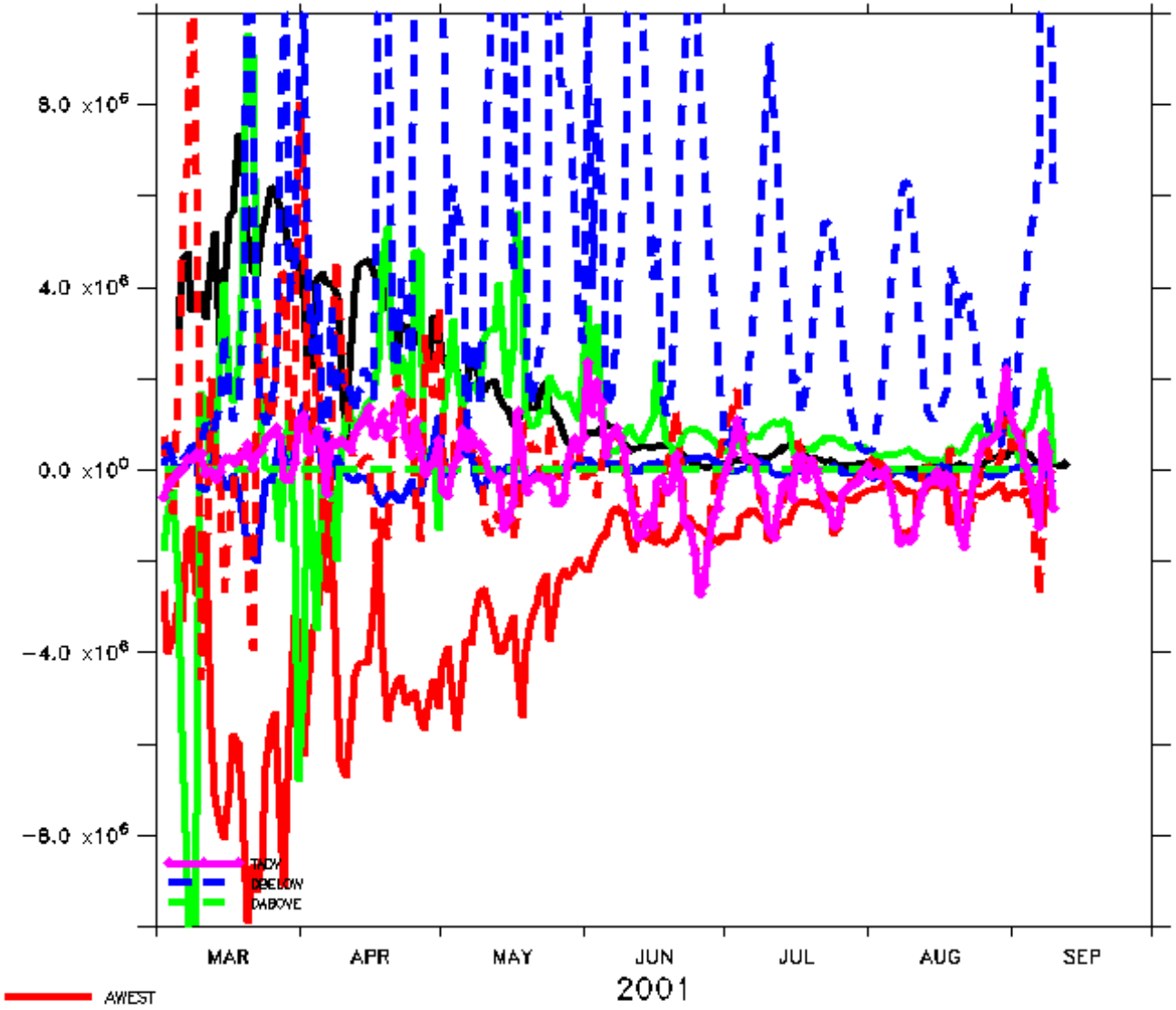
VERTICAL DIFFUSION



Nitrate flux summary (30-d lowpass)



Nitrate flux summary (unfiltered)



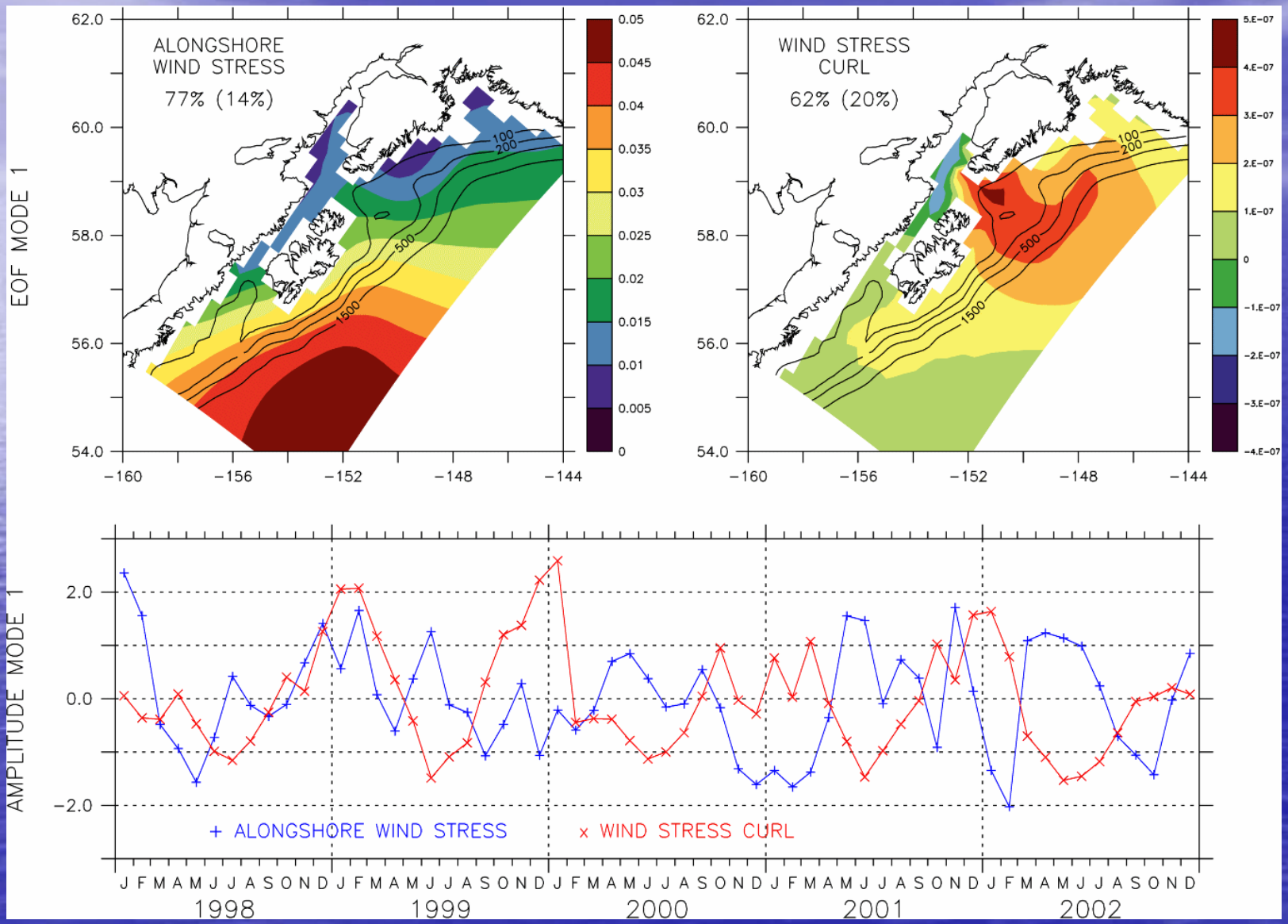
Monthly average fluxes of nitrate into the control volume for the advective and diffusive terms (millimole s^{-1} x 10^5)

	Advec east	Advec west	Advec south	Advec north	Advec below	Diffu below	Advec Total	A+D Total
Mar	42.82	-51.98	-3.34	-1.63	15.53	28.18	1.39	29.57
Apr	28.89	-40.45	10.02	-0.43	8.29	62.14	6.32	68.46
May	12.12	-31.63	20.44	-0.07	-0.35	73.28	0.52	73.80
Jun	3.71	-12.65	9.81	1.36	-4.80	59.12	-2.56	56.56
Jul	1.96	-7.74	5.83	-0.19	-2.06	28.97	-2.20	26.77
Aug	0.68	-4.36	4.33	-0.88	-3.51	22.93	-3.73	19.19

Time average value is 4.0 mmol nitrate m-2 d-1

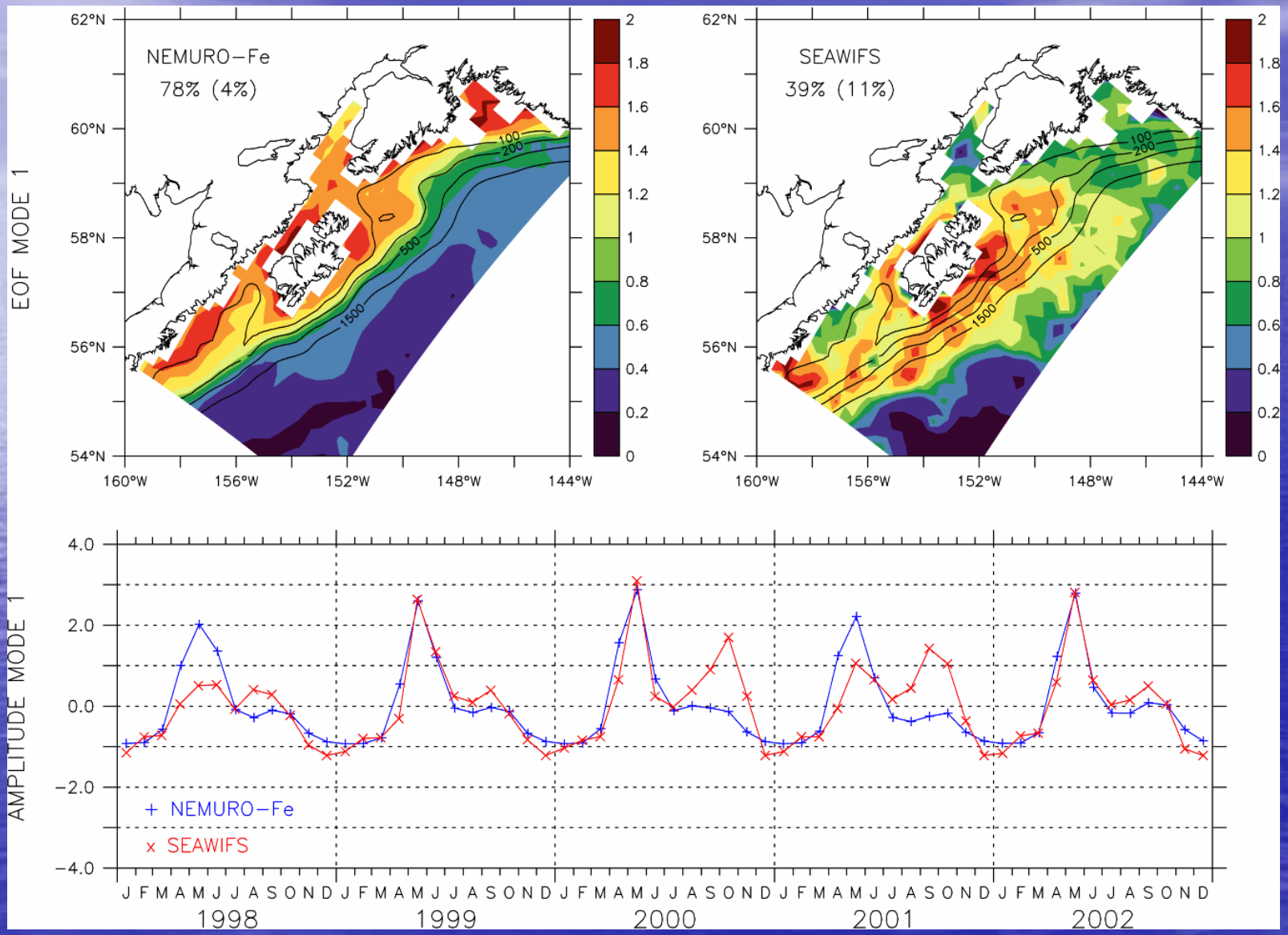
Childers et al. [2005] report 2.46-6.97 mmol nitrate m-2 d-1

Alongshore Wind Stress and Wind Stress Curl EOFs



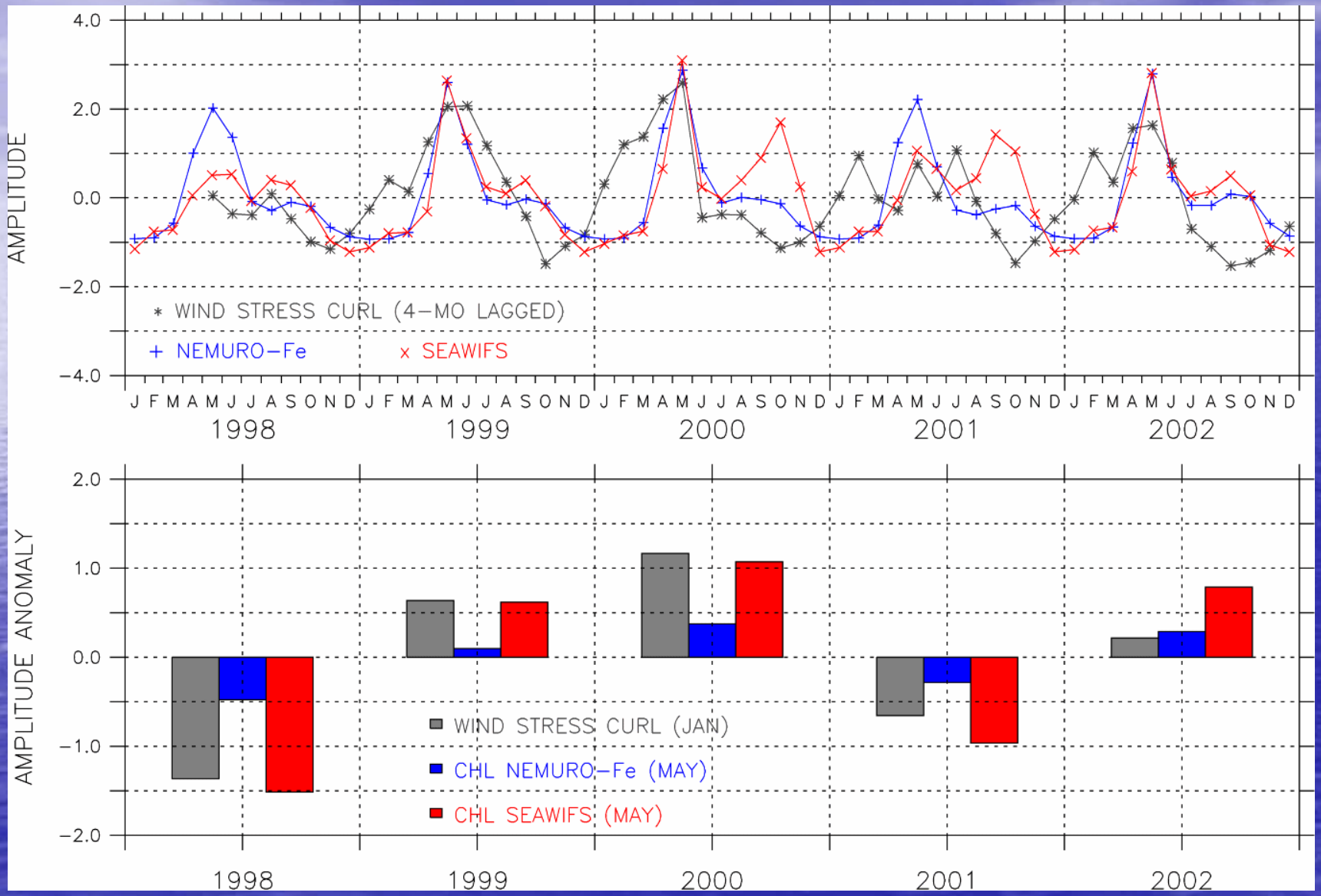
J. Fiechter, pers. comm.

Surface Chlorophyll EOFs: NEMURO-Fe vs. SeaWiFS



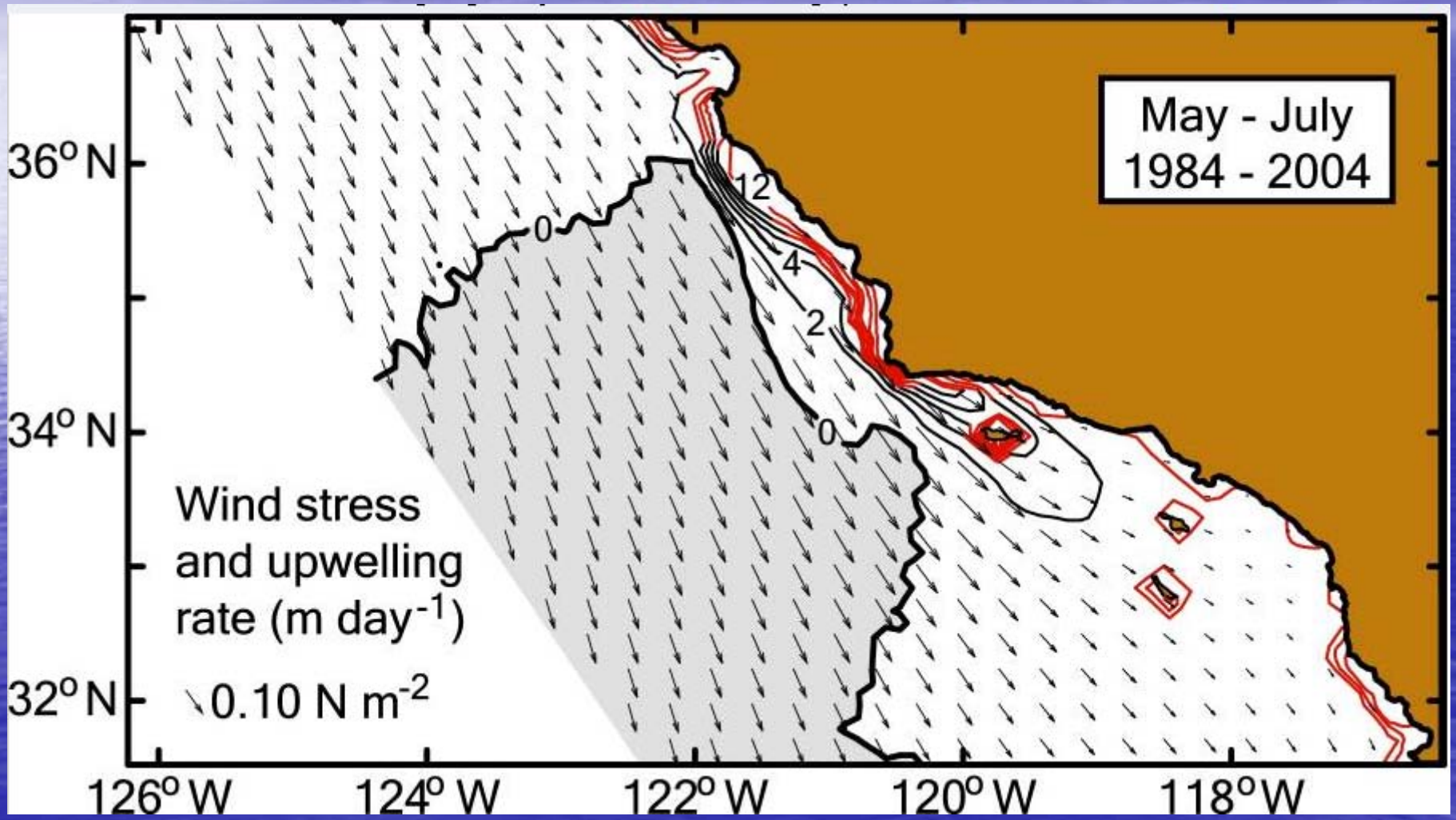
J. Fiechter, pers. comm.

Spring Bloom Variability and Winter Ekman Pumping

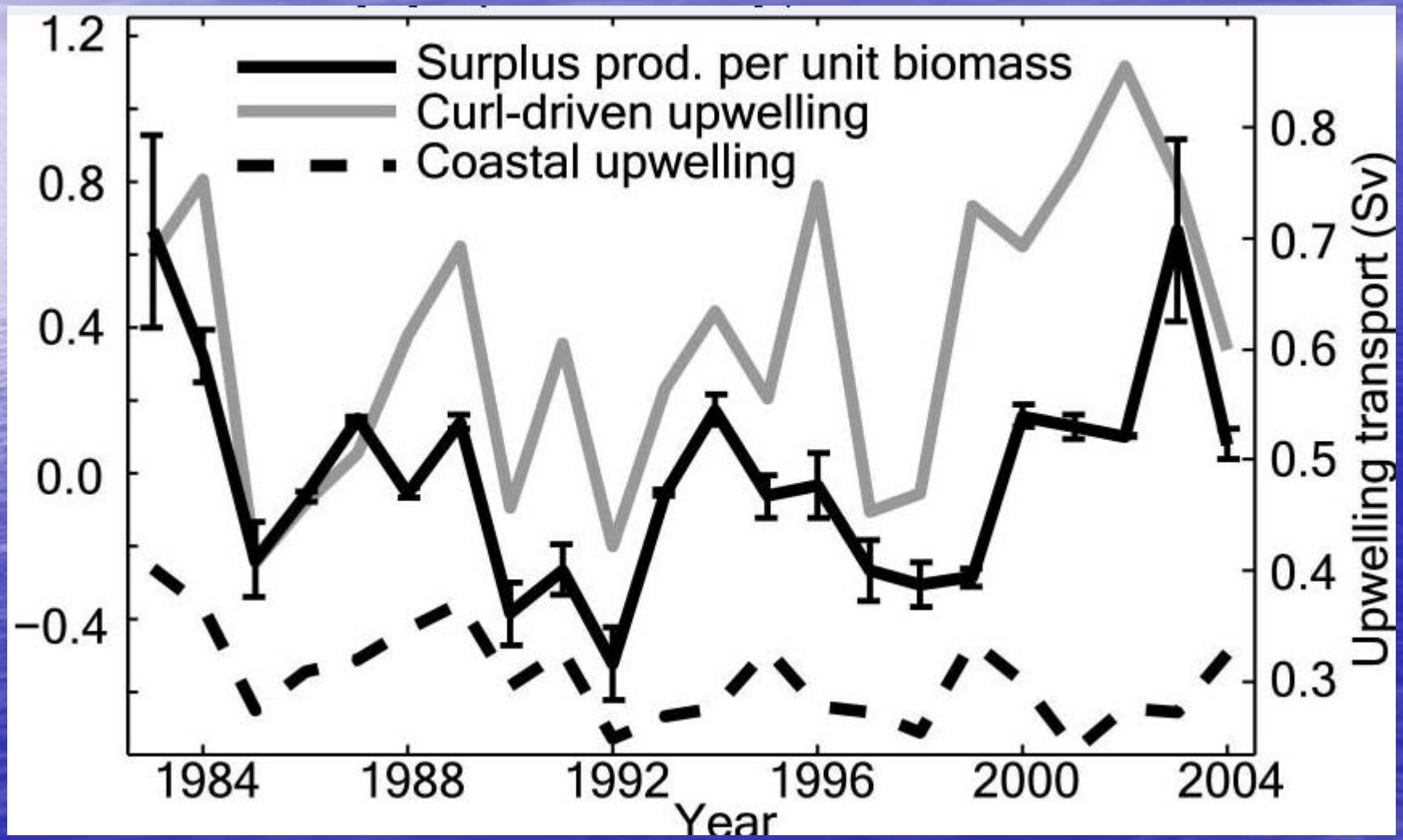


J. Fiechter, pers. comm.

Mean summertime (May–July) wind stress and upwelling rate from 1984 to 2004. (Rykaczewski and Checkley, 2008)



Upwelling and surplus production per unit biomass of Pacific sardine (Rykaczewski and Checkley, 2008)



SUMMARY

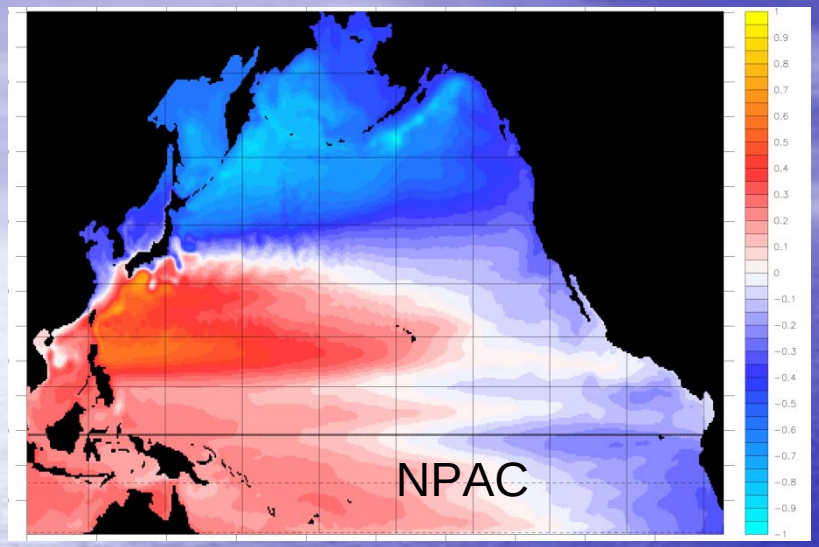
- Nitrate flux can be consistently budgeted using coupled circulation/NPZ models. These indicate:
  - Tidally-driven mixing
  - A patchy pattern of vertical velocity.
  - Net upwelling of water and nutrients during spring (March and April)
- Conclude: wind stress curl is an important contributor to Gulf of Alaska production; apparently true in other coastal regions as well!

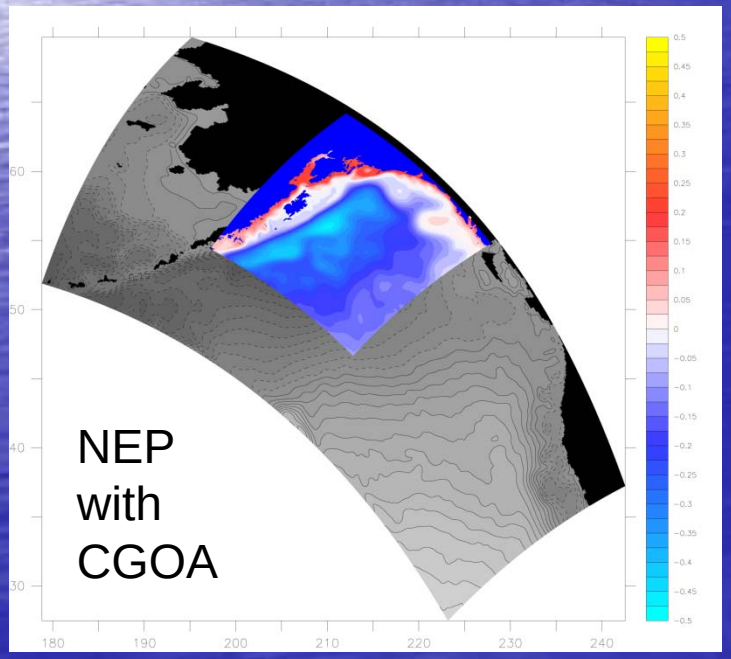
FUTURE WORK

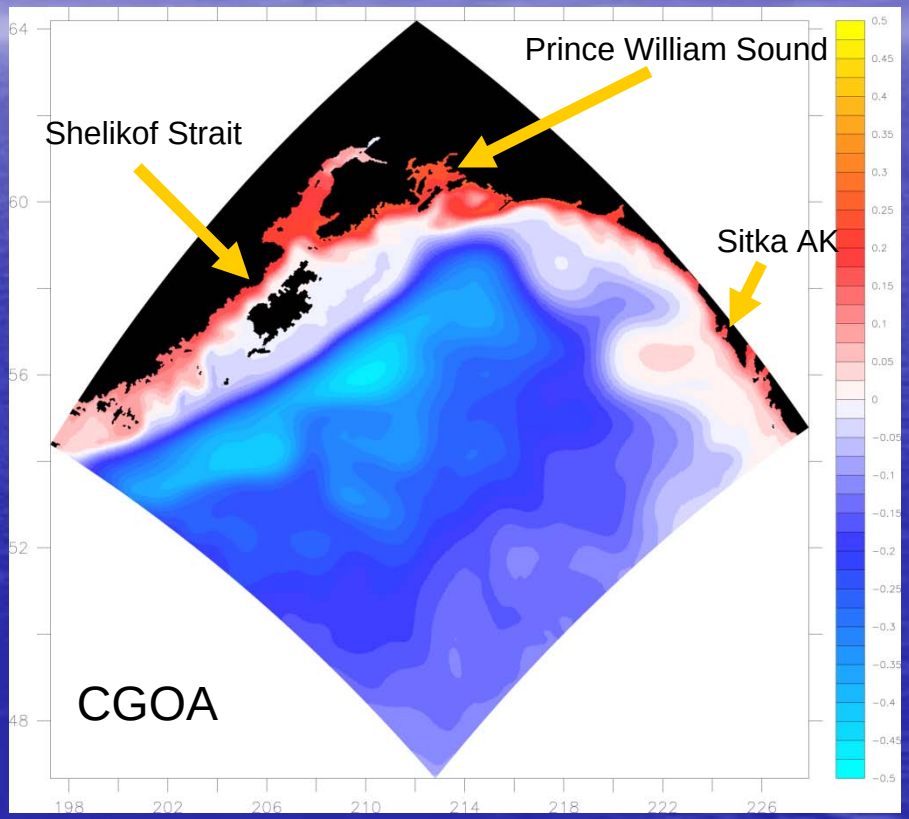
- Improved circulation/NPZ models
- Data assimilation
- Different coordinate systems (e.g. isopycnal layers)

FIN!

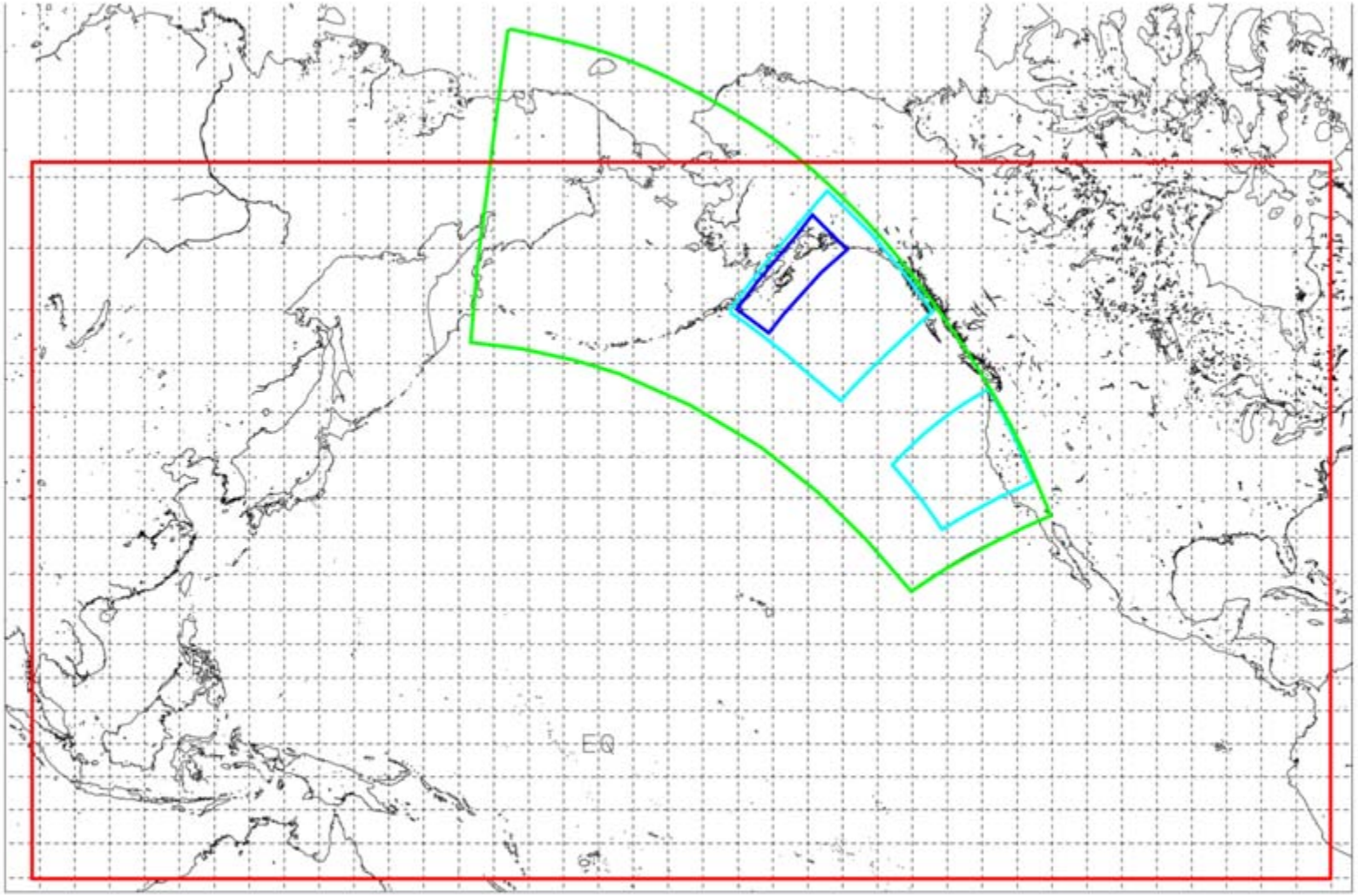
Nested model domains with SSH





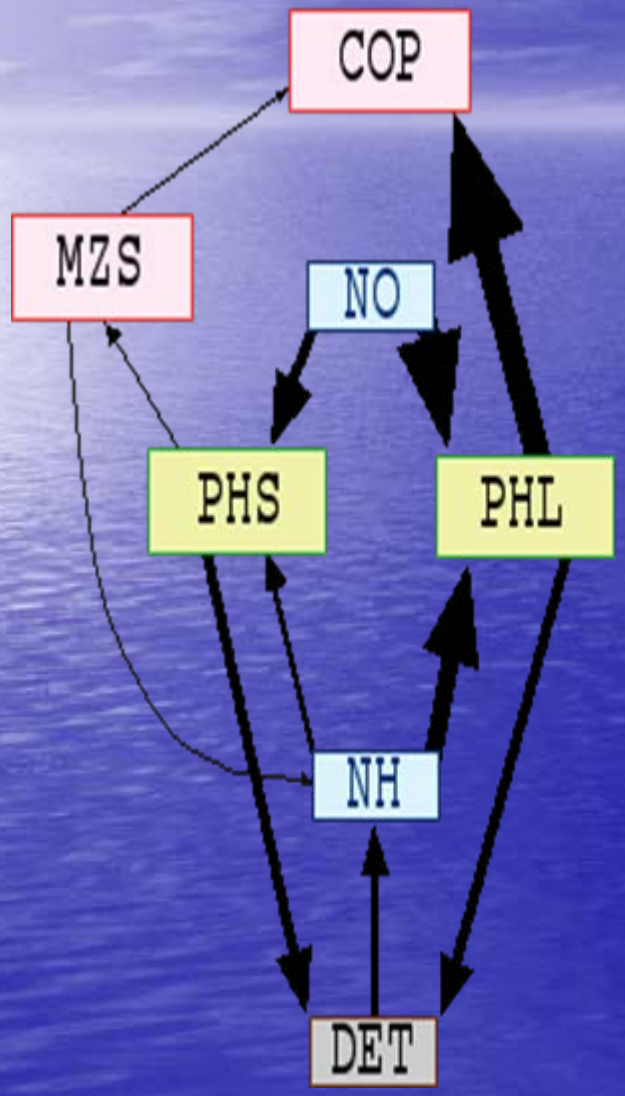


NESTED CIRCULATION MODEL DOMAINS



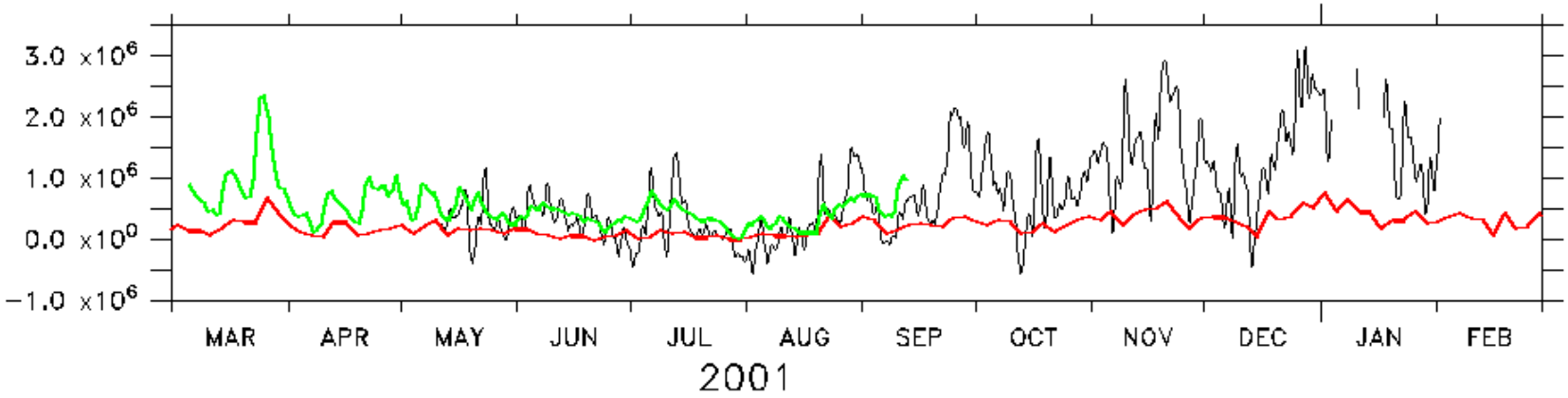
Delta x = 20 40 km Delta x = 10 km Delta x = 3 km Delta x = 1 km

NPZ model
(arrows indicate *nitrogen flux*)

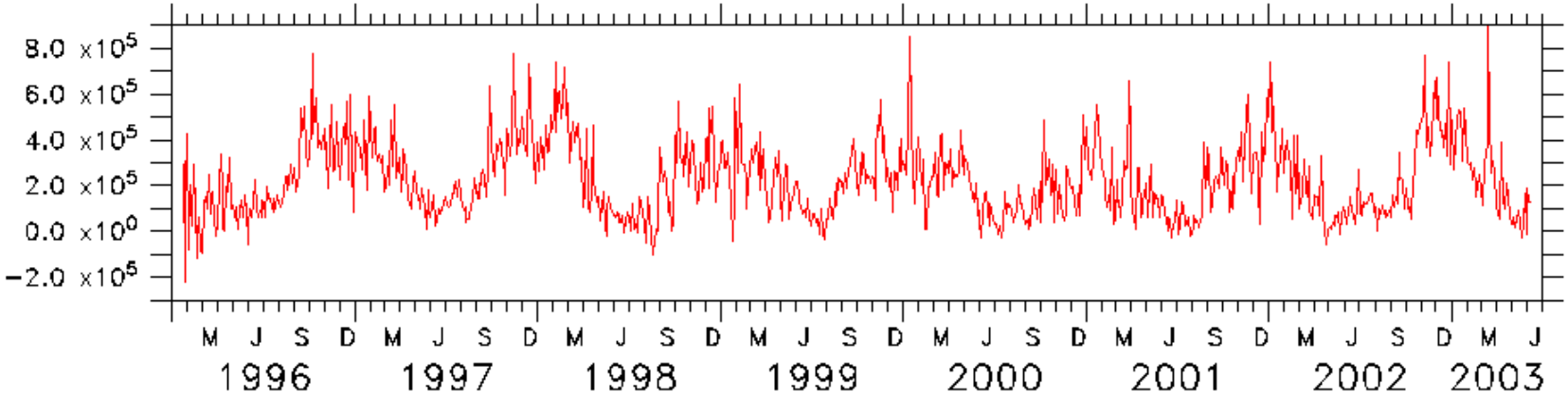


- *Nutrients (Nitrate, Ammonium, Iron)*
- *Phytoplankton (Small and Large)*
- *Microzooplankton (Small and Large)*
- *Copepods (Small, Large Oceanic)*
- *Euphausiids*
- *Detritus*

How well do NEP and CGOA models replicate flow thru Shelikof Strait?



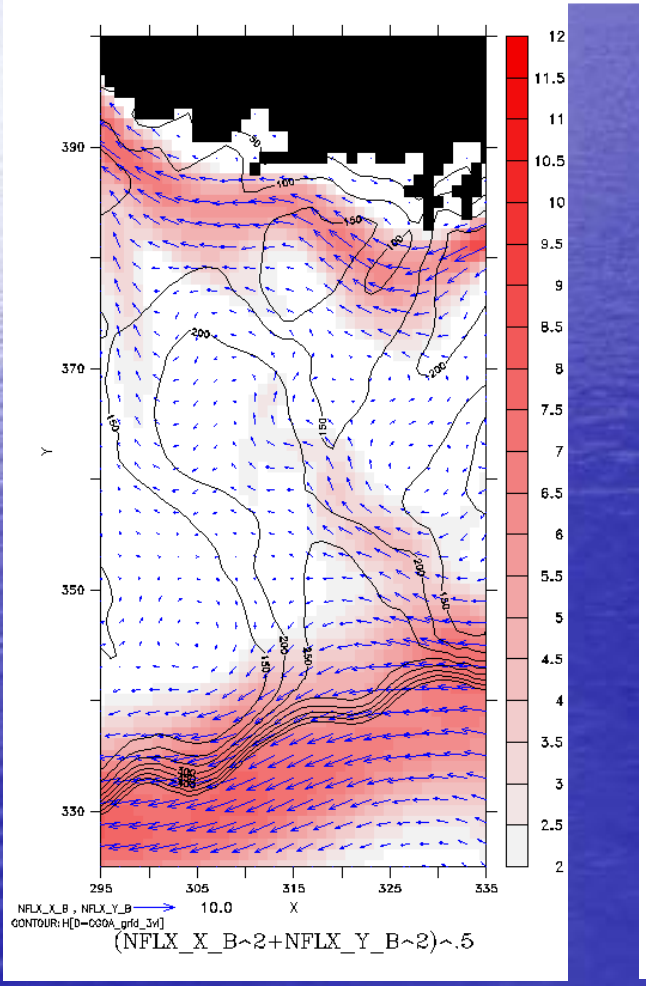
model−data comparison (sv) (NEP− red; CGOA− green; data− black)



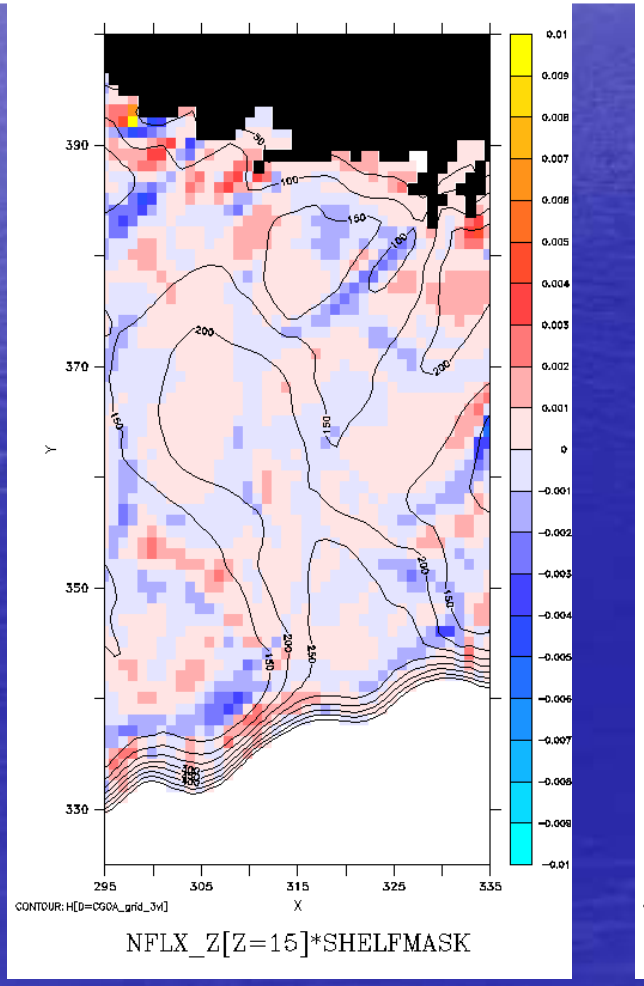
Flux through Shelikof Strait (sv) (NEP model)

Amatouli Trough May 01, 2001

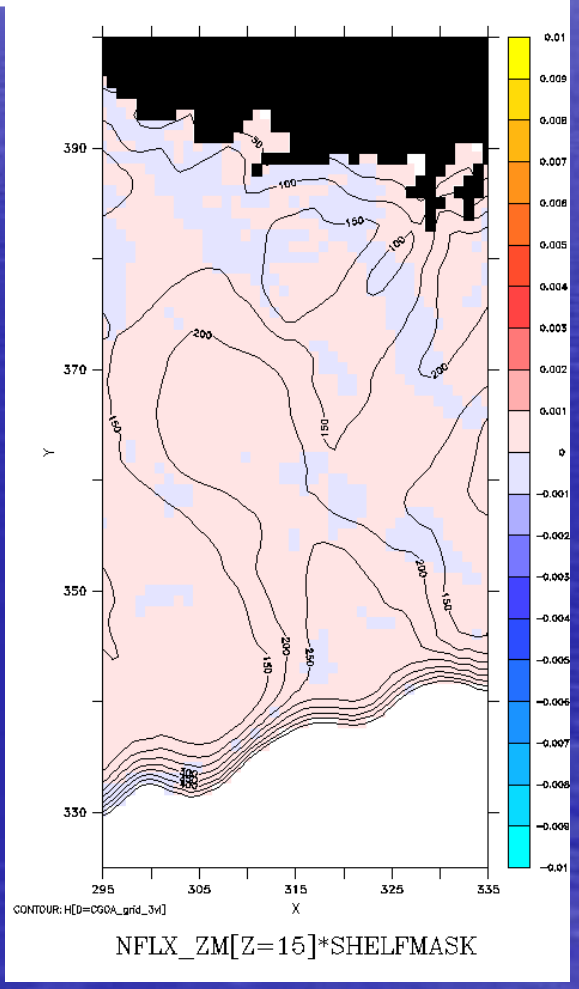
Horizontal advection



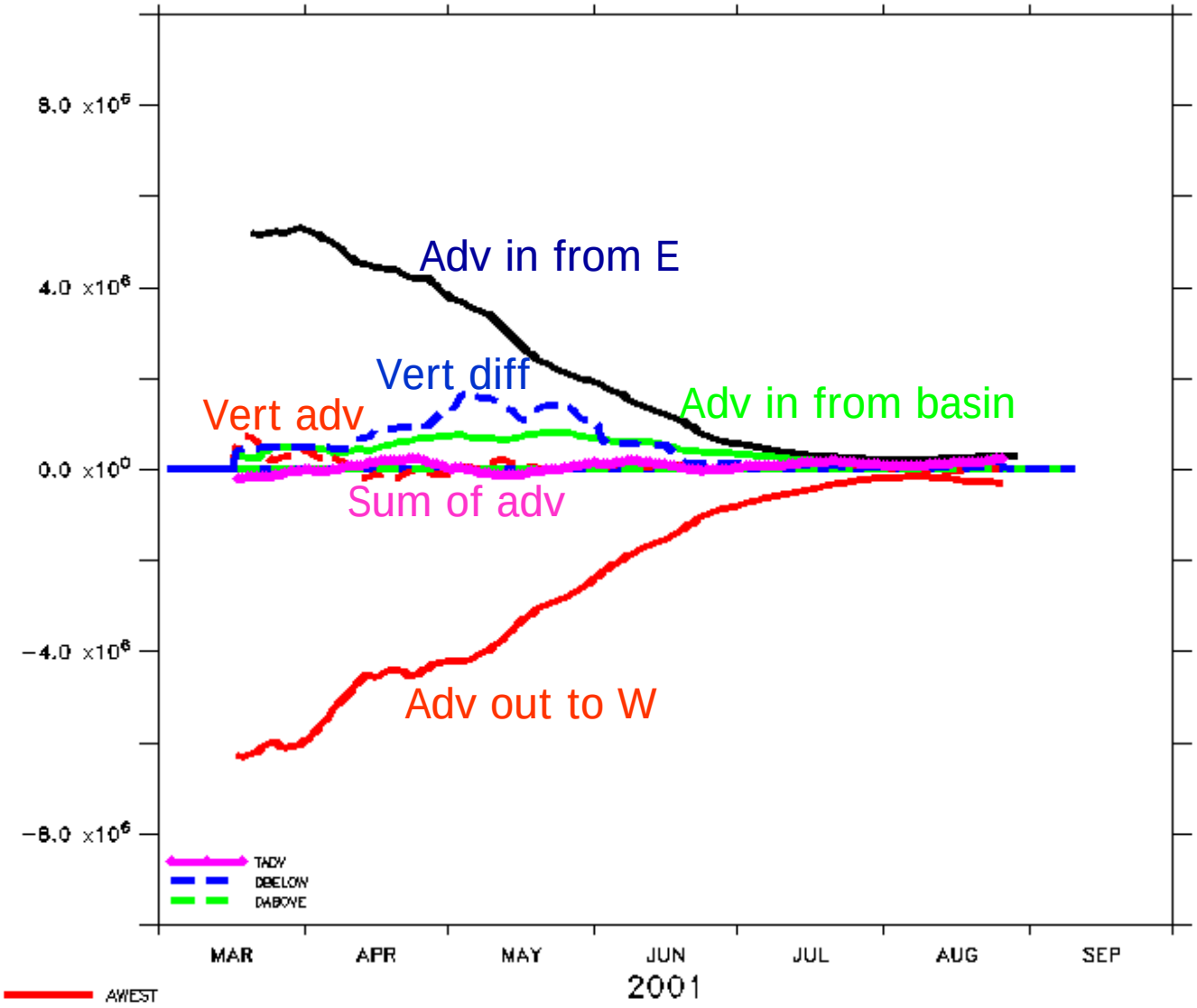
Vertical advection



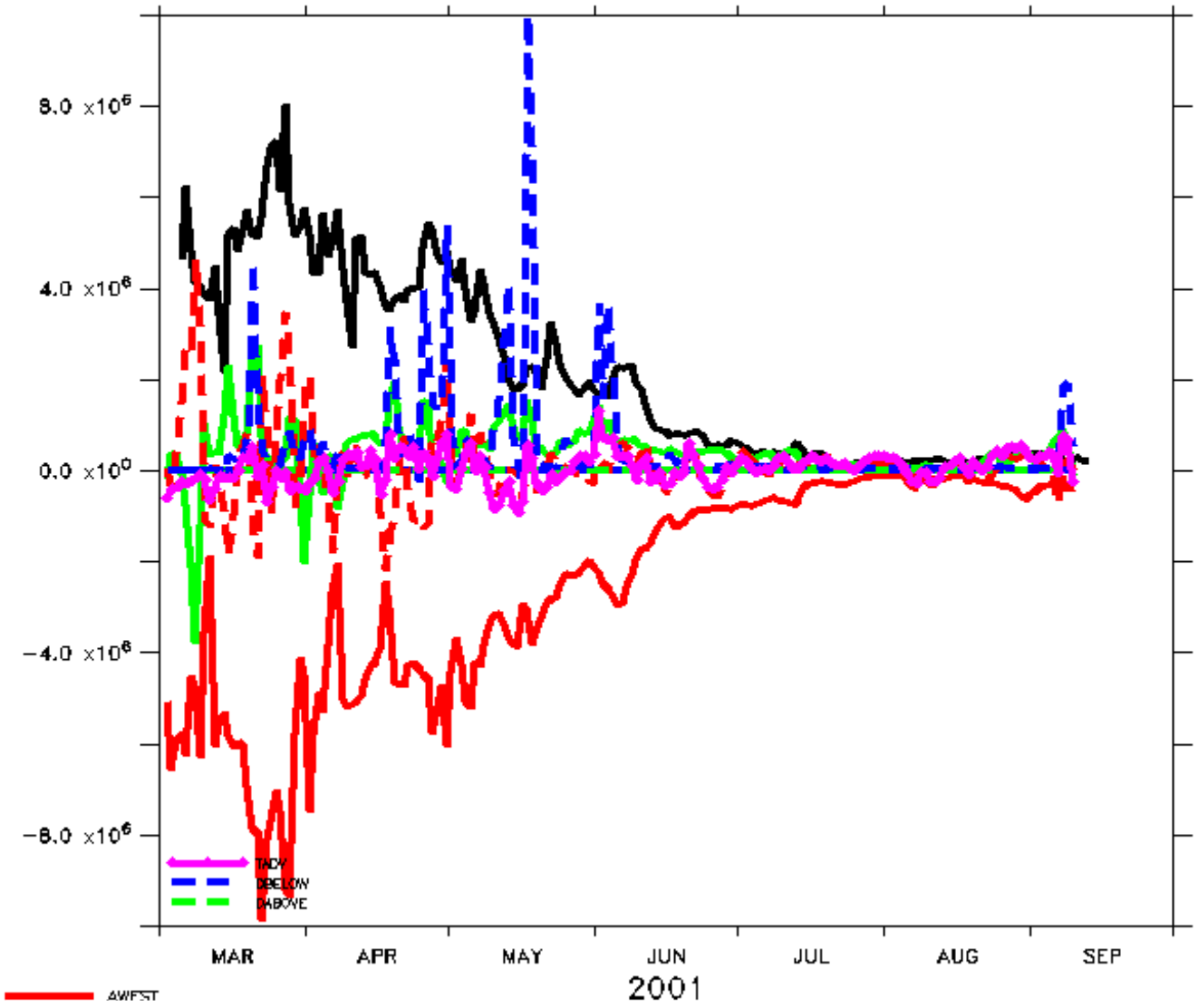
Vertical diffusion



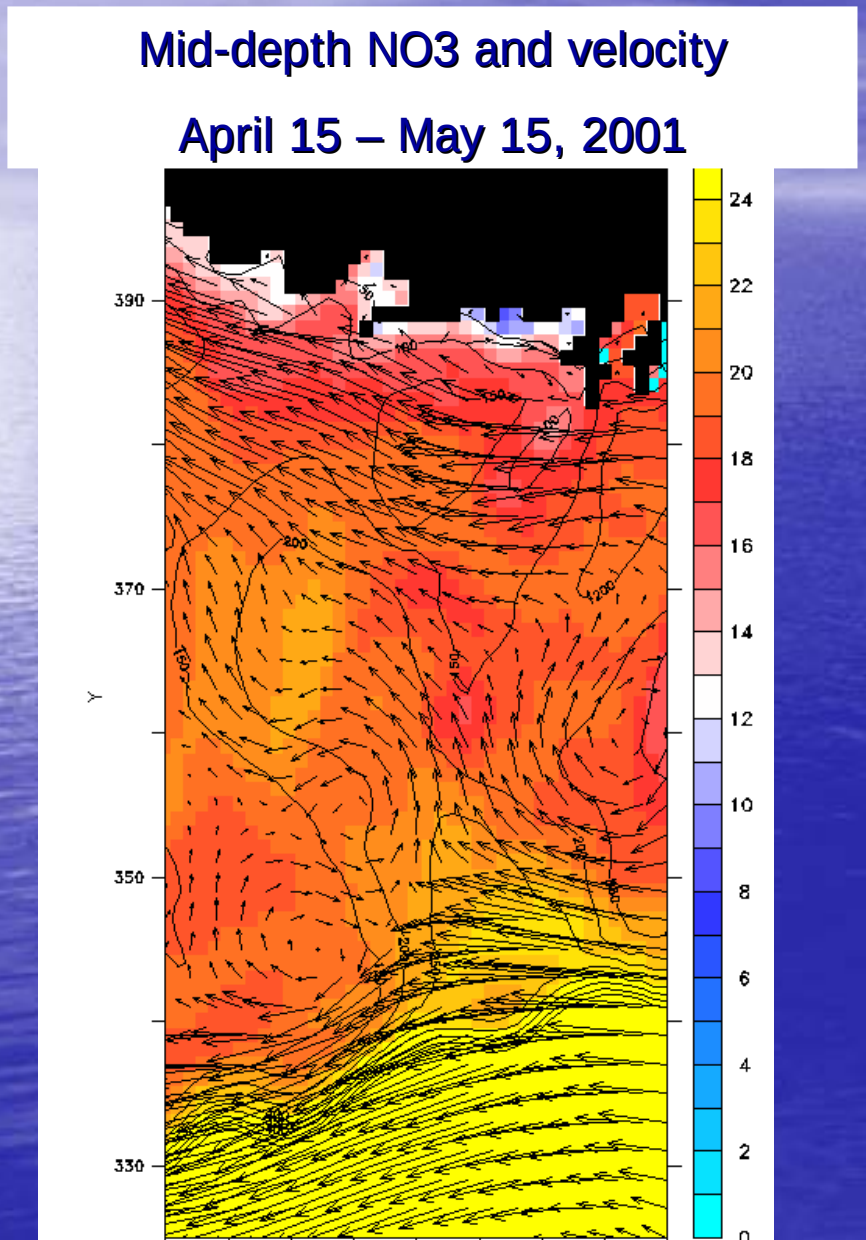
Amatouli NO3 flux summary (lowpass)



Amatouli NO3 flux summary (unfiltered)



Why upwelling in spring? The cross-shelf scenario



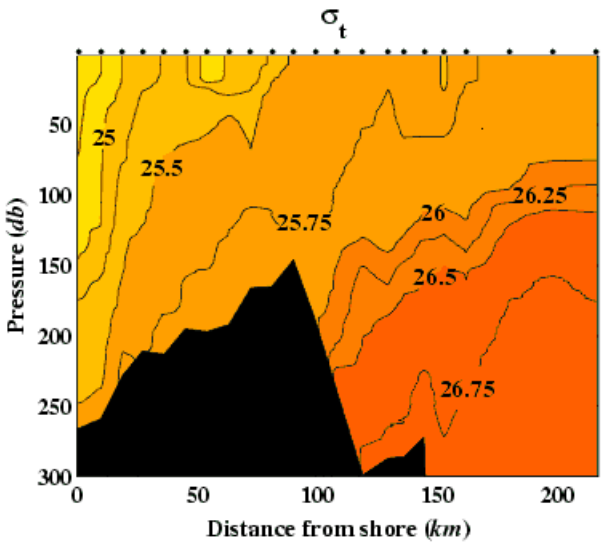
- Western outflow > Eastern inflow
- Input of water from deep basin
- Flow at mid-depth goes up canyons
- Upwelling in spring!

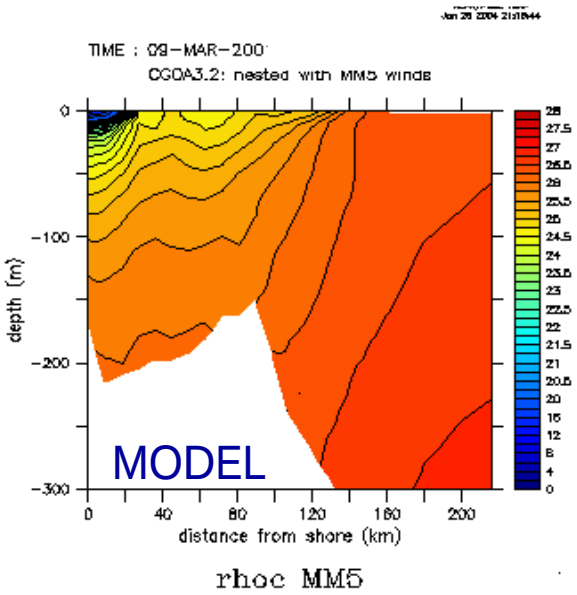
Summary: fluxes of no3 in the upper 15m of the shelf indicate

- Patchy w with upwelling in the spring!
- Vertical diffusion is the biggest term on the shelf as a whole
- Advective balance: onshelf flow and vertical advection feed the alongshore deficit

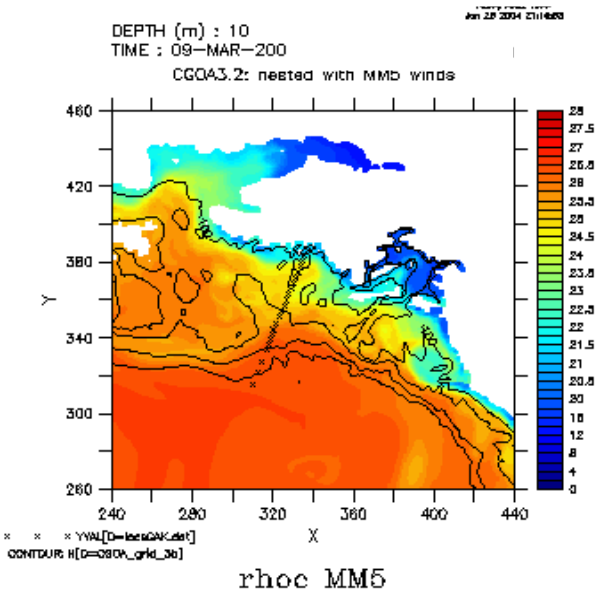
Compare density at GAK line with CGOA model Mar 2001

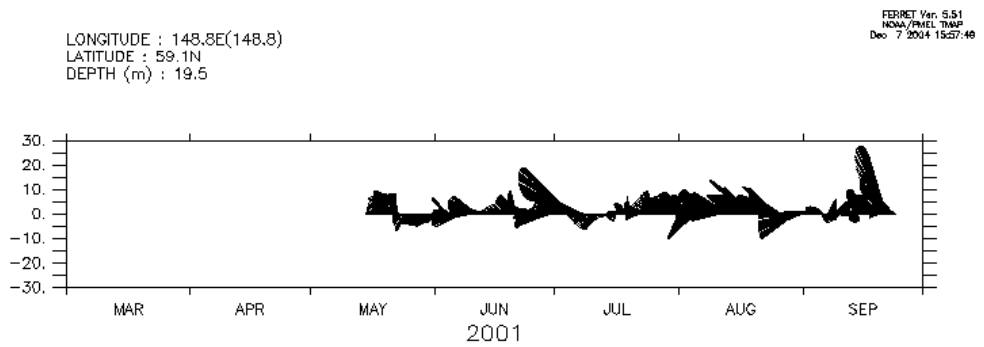
DATA





MODEL

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NOAA/PMEL TMAP
Dec 7 2004 15:57:49
LONGITUDE : 148.8E(148.8)
LATITUDE : 59.1N
DEPTH (m) : 19.5
30.
20.
10.
0.
−10.
−20.
−30.
MAR
APR
MAY
JUN
JUL
AUG
SEP
2001
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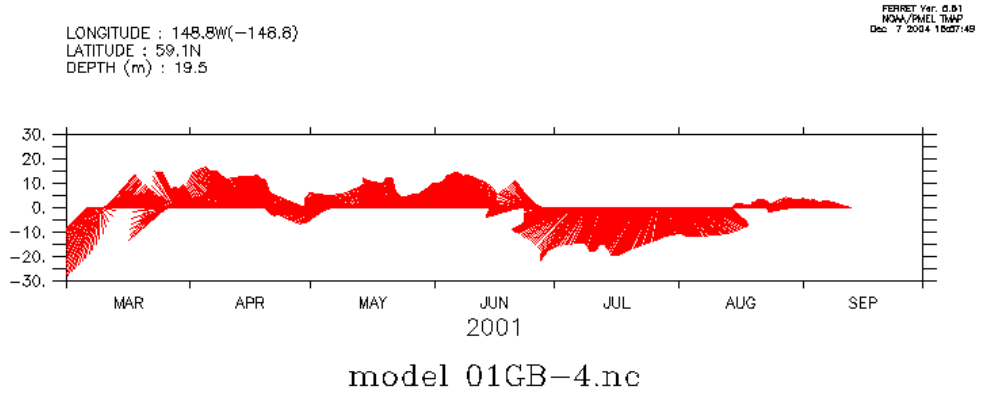
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LATITUDE : 59.1N
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30.
20.
10.
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MAR
APR
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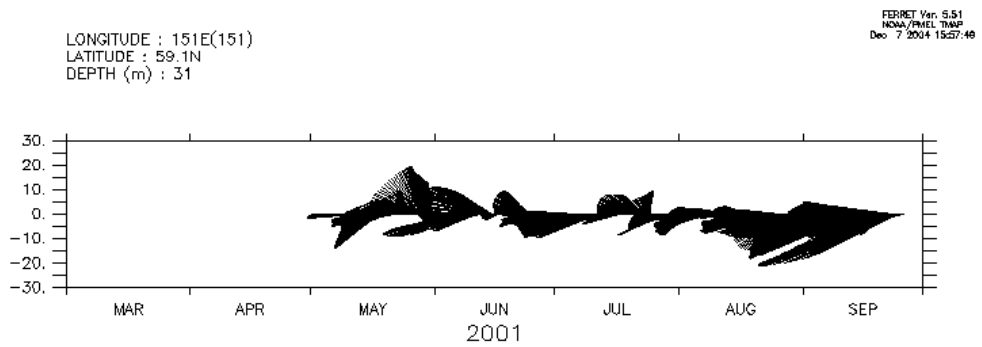

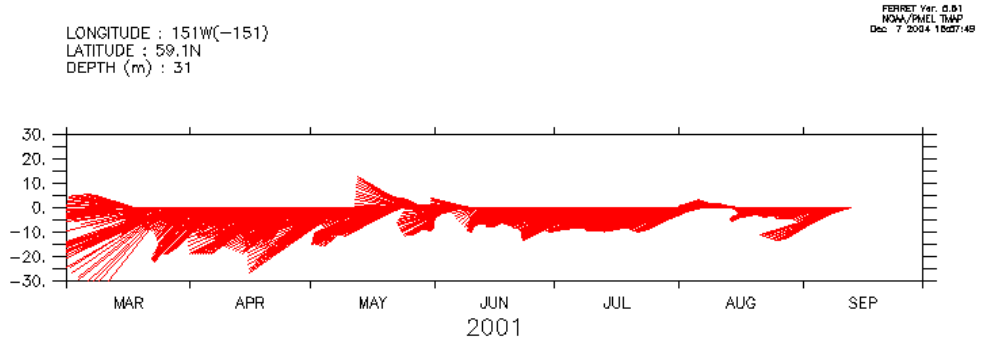

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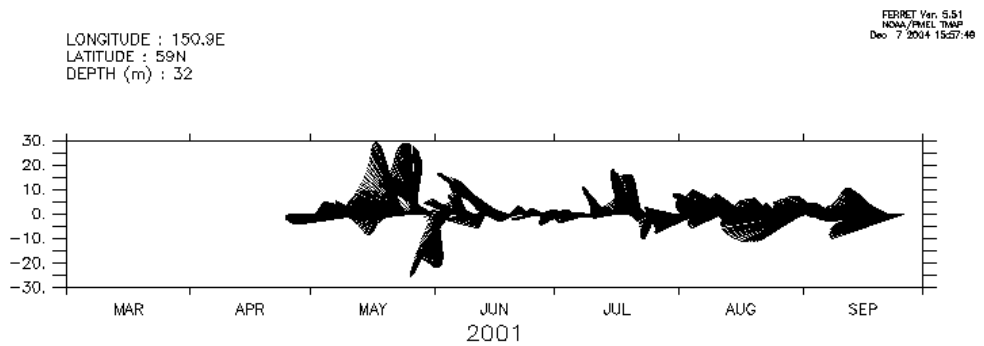
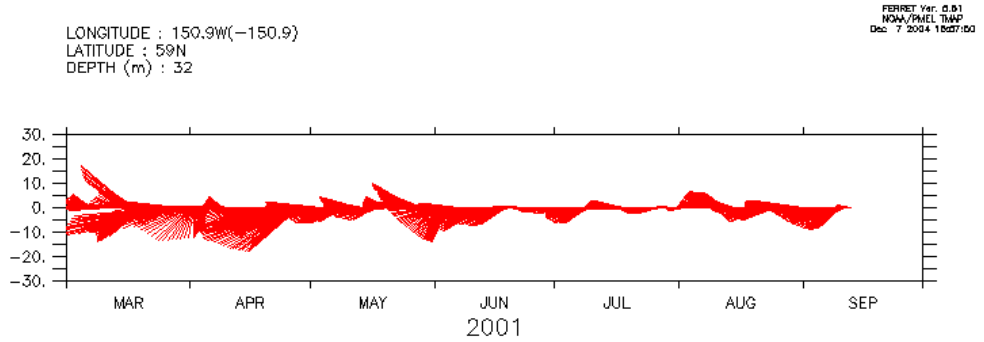
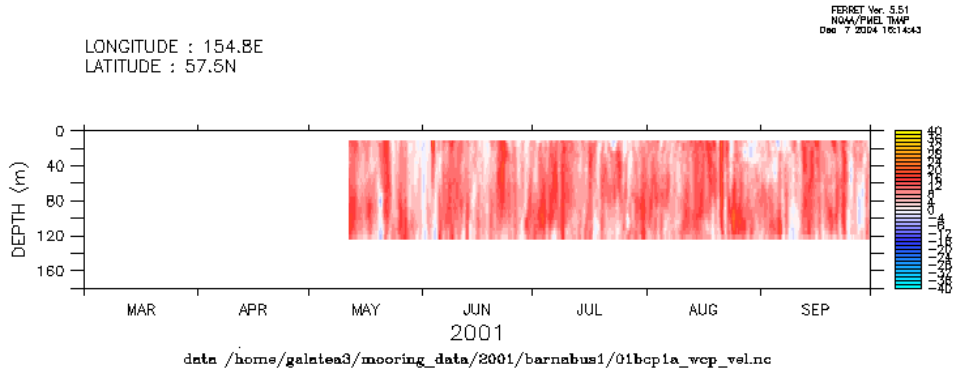
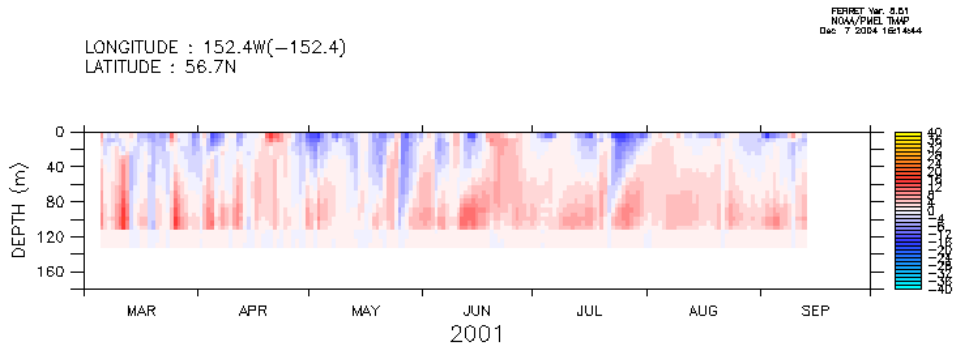


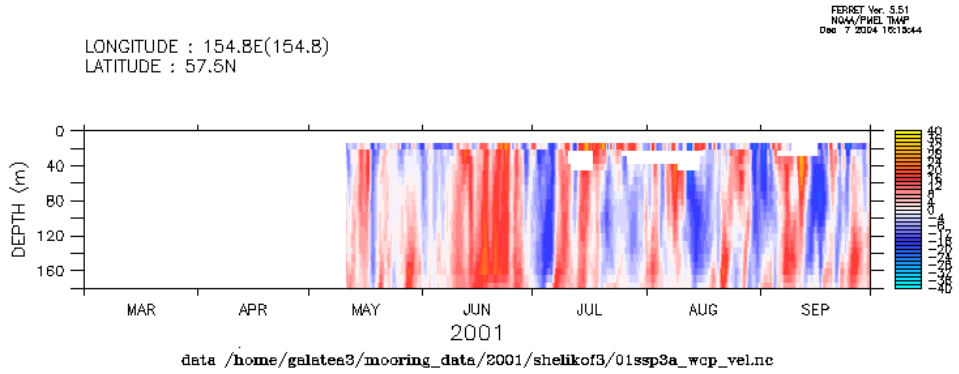


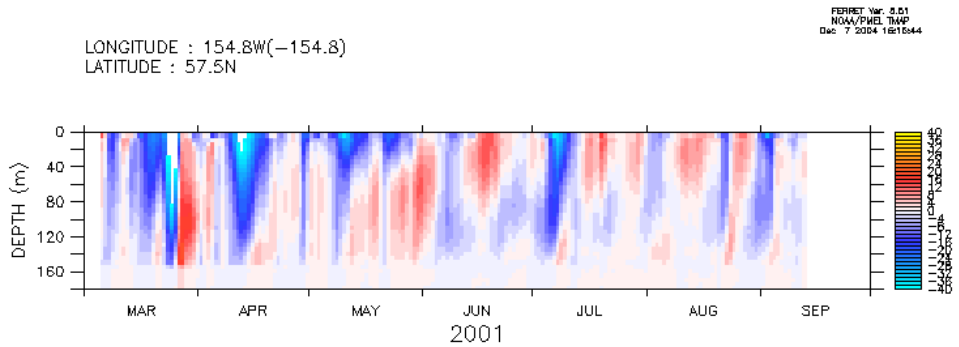
model 01GP−34.nc





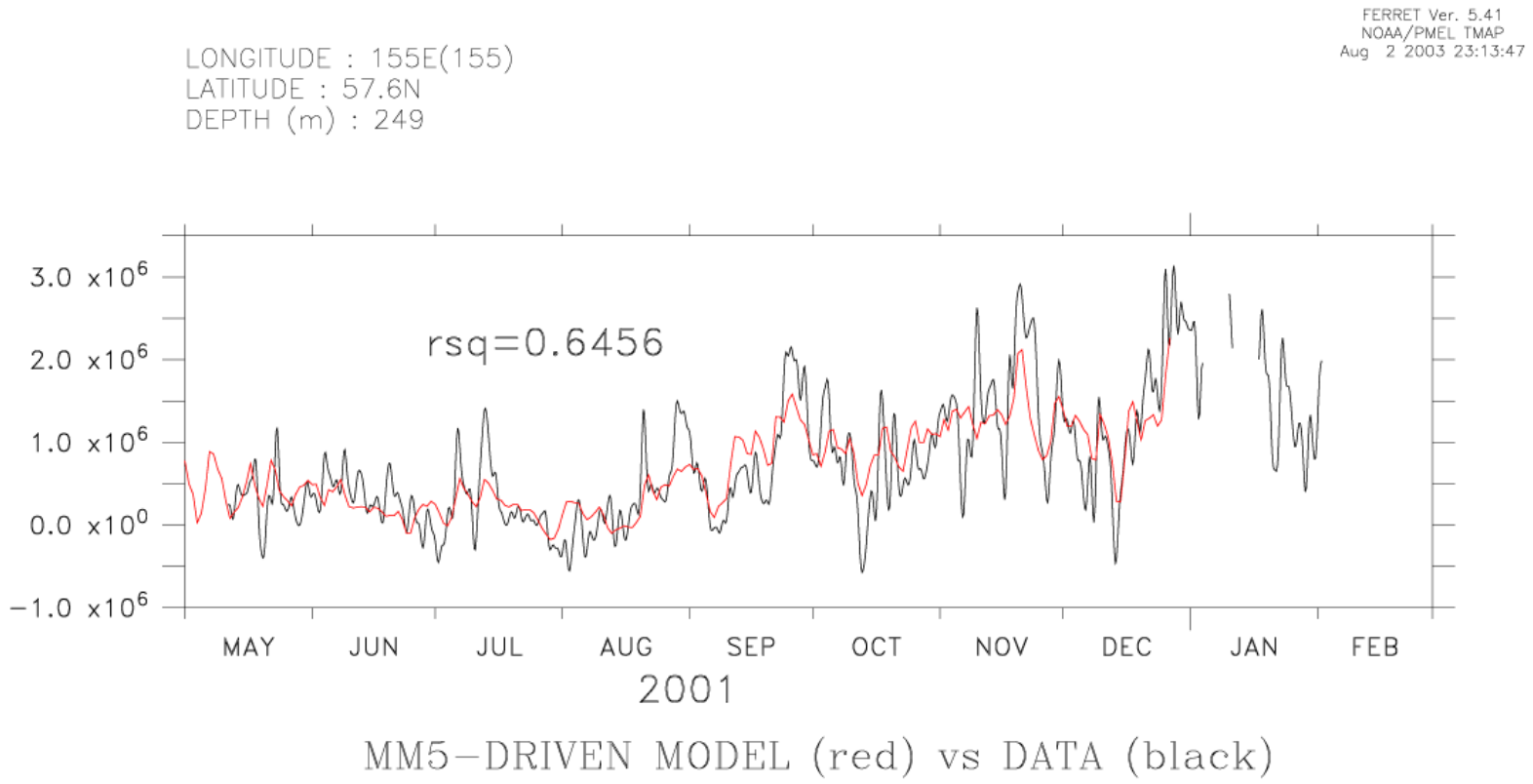
model 01BC−1.nc





model 01SS−3.nc

Compare velocity in Shelikof Strait with NEP model



TOTAL depth-integrated flux (m^3/s)