# Oregon shelf oxygen dynamics and exchange with the deep ocean: a modeling approach

*Yvette H. Spitz and Harold P. Batchelder*

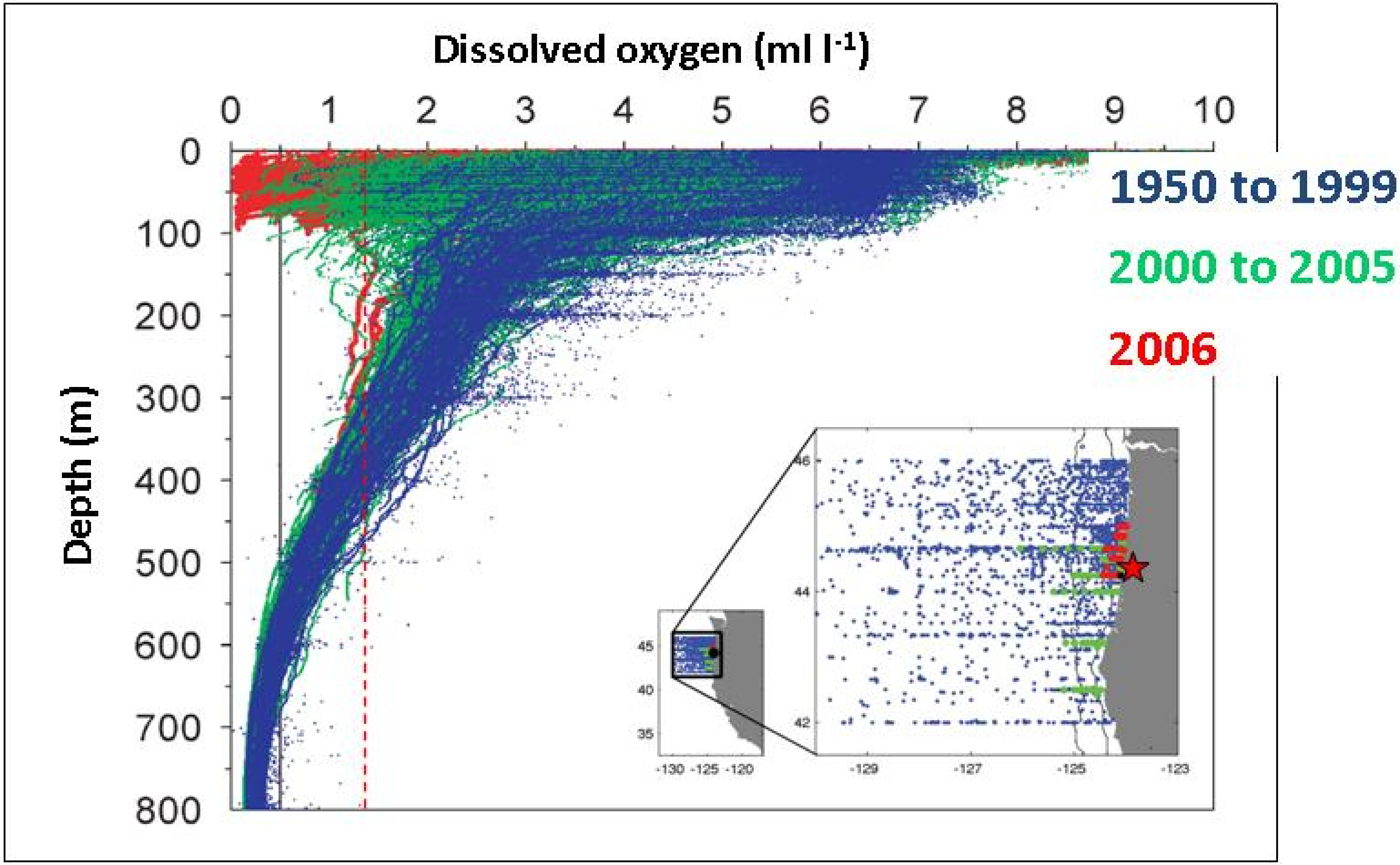
*College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis OR*

Collaborators:

R. Danielson
A. Koch

Funding Agencies:

# hypoxia/anoxia off Oregon?



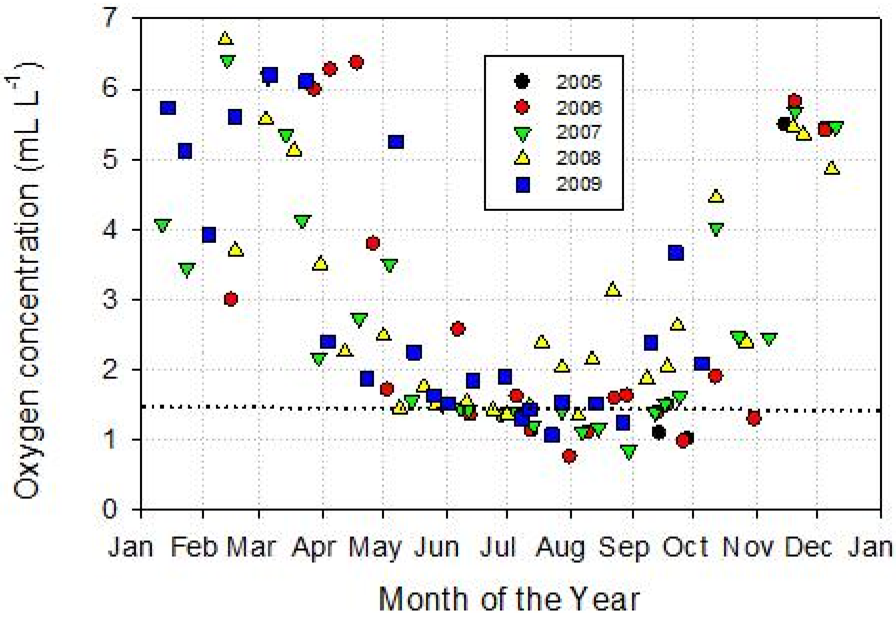

------ 1.4 ml $l^{-1}$

Chan et al. (2008, Science)

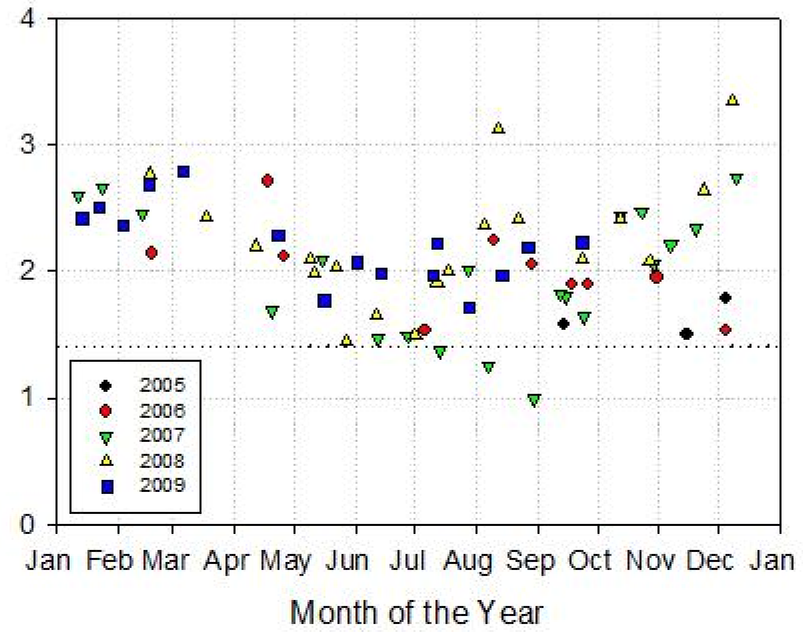
# What we know about recent hypoxic events on the Oregon (Wash.) shelf:

*It's seasonal (June-Oct); most severe in Aug/Sept*

## Seasonal Variability of NH5 $O_2$ at 50 m (bottom is 62 m)




## Seasonal Variability of NH25 $O_2$ at 150m (bottom is 300 m)




*Figures courtesy of Bill Peterson*

# Interannual Variability in Newport NH Line $O_2$ in September

## *Occurrence/Spatial Extent/Magnitude Vary Interannually*

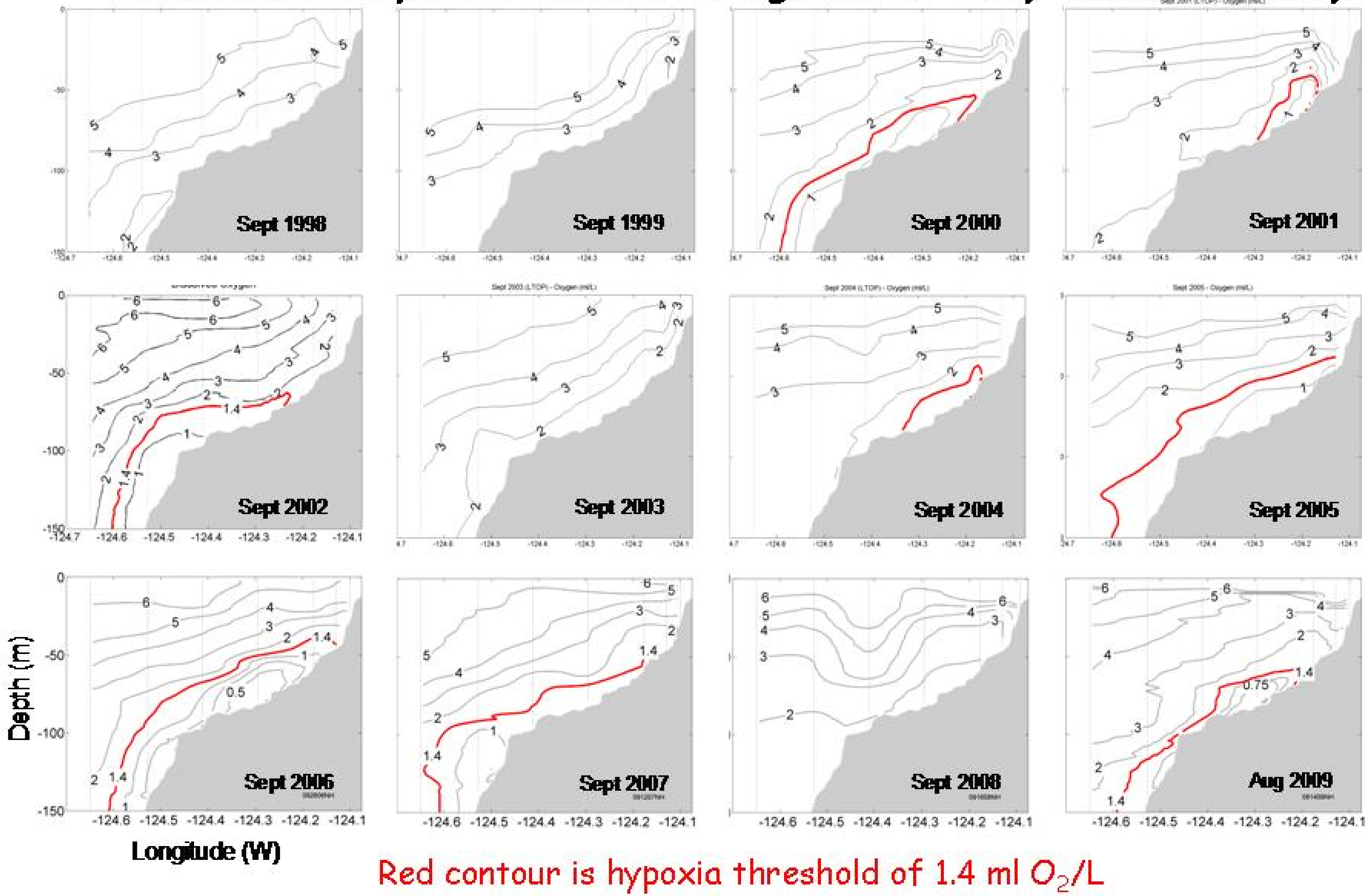
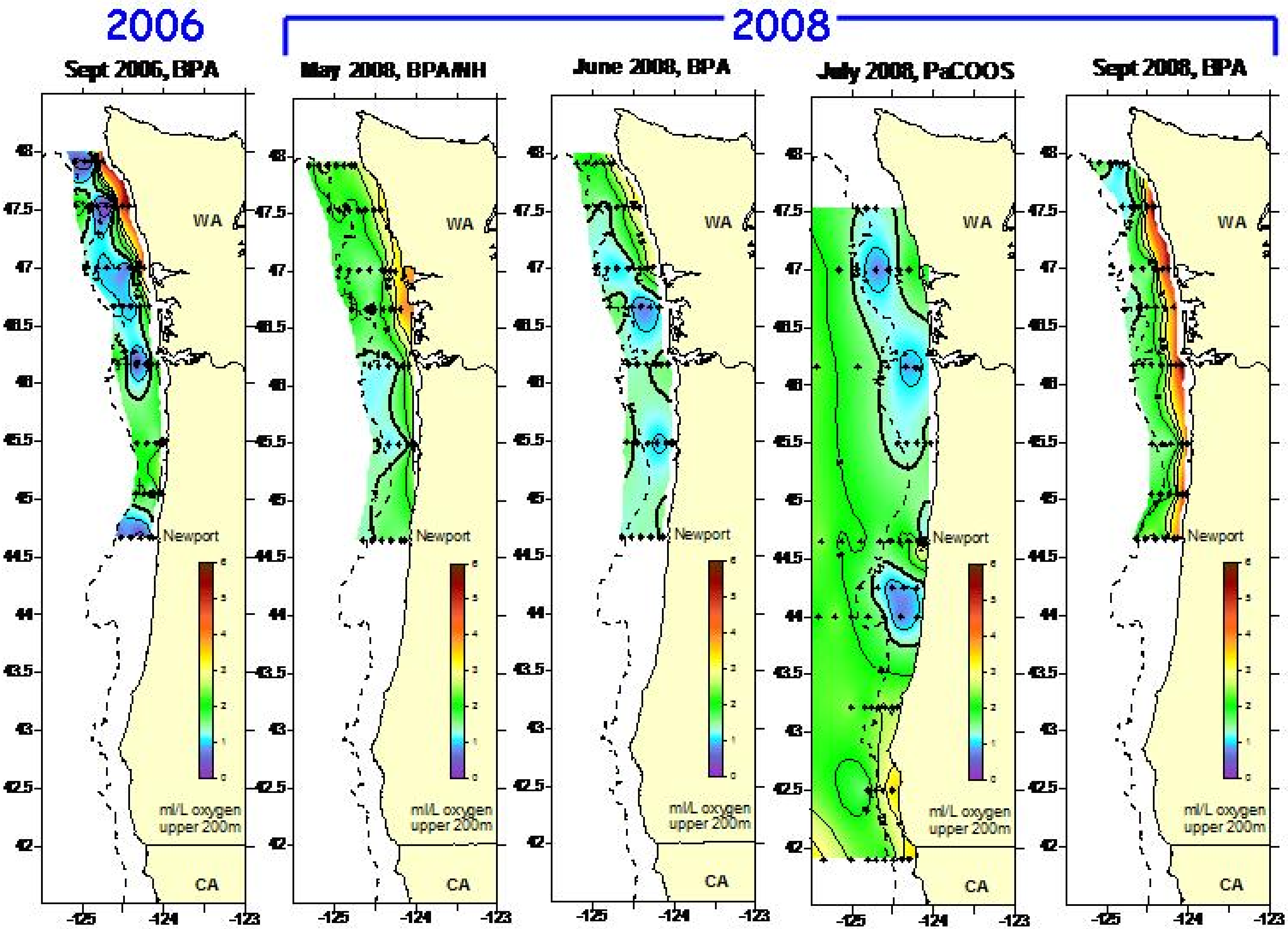



*Figure courtesy of Bill Peterson; data from GLOBEC and Peterson group*

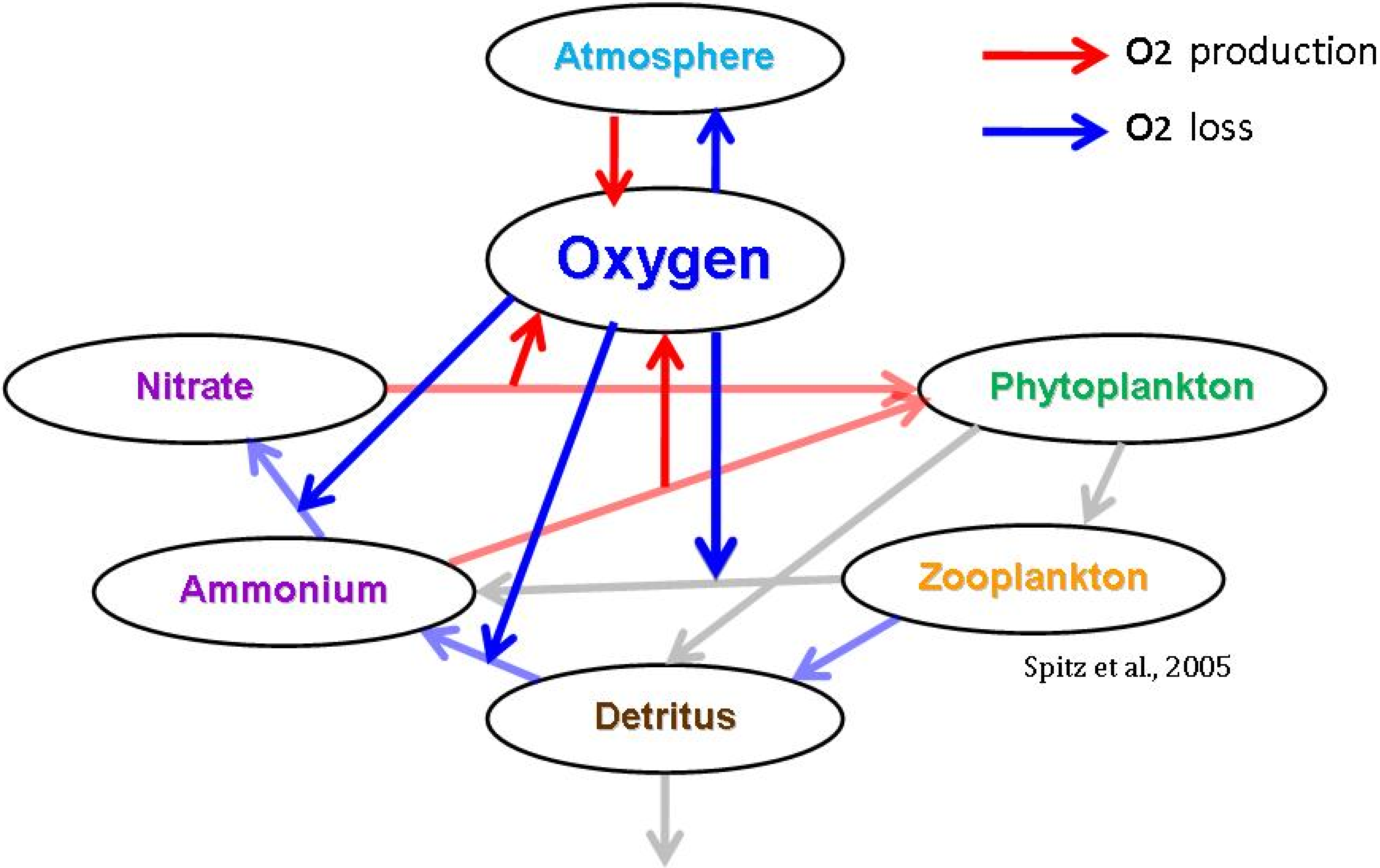
# Spatial Pattern: Washington & Heceta Bank (broader shelves)




$O_2$ values shown are the minimum value from vertical profiles of upper 200 m; most often, minimum is at the deepest depth

*Figure courtesy of Bill Peterson*

# Oregon Coast Upwelling System – Biological Model




Spitz et al., 2005

# *Net rate of oxygen change*

$$\frac{\partial O_2}{\partial t} = -\boldsymbol{u}.\nabla O_2 + \frac{\partial}{\partial z}\left(k_v \frac{\partial O_2}{\partial z}\right) + D_{O_2}$$

$$+V_m f(I)\left\{\frac{NO_3}{K_u + NO_3} e^{-\psi NH_4} r_{O2:NO3} + \frac{NH_4}{K_u + NH_4} r_{O2:NH4}\right\} P$$

$$-2\Omega NH_4 - \Gamma r_{O2:NH4} Z - \varphi r_{O2:NH4} D$$

air-sea flux at the top layer: $k_v \frac{\partial O_2}{\partial z} = \Delta z_n Q_{ge}(O_{2sat} - O_2)$

**net rate = advection + mixing + air-sea flux + $O_2$ production + $O_2$ loss**

physical forcing (advection + mixing + air-sea flux) | biological forcing ($O_2$ production + $O_2$ loss)

units: [mmol m$^{-3}$ day$^{-1}$] (oxygen concentration: 1 ml/l = 1.33 mg/l = 44 μM= 15% saturation)

# Oregon Upwelling System – Circulation Model

**Regional Ocean Model System (ROMS)**

3 km horizontal & 40 s-layers vertical resolution (Koch et al., 2010)

**Model runs:**

**Apr-Aug** 2002, 2006, 2008

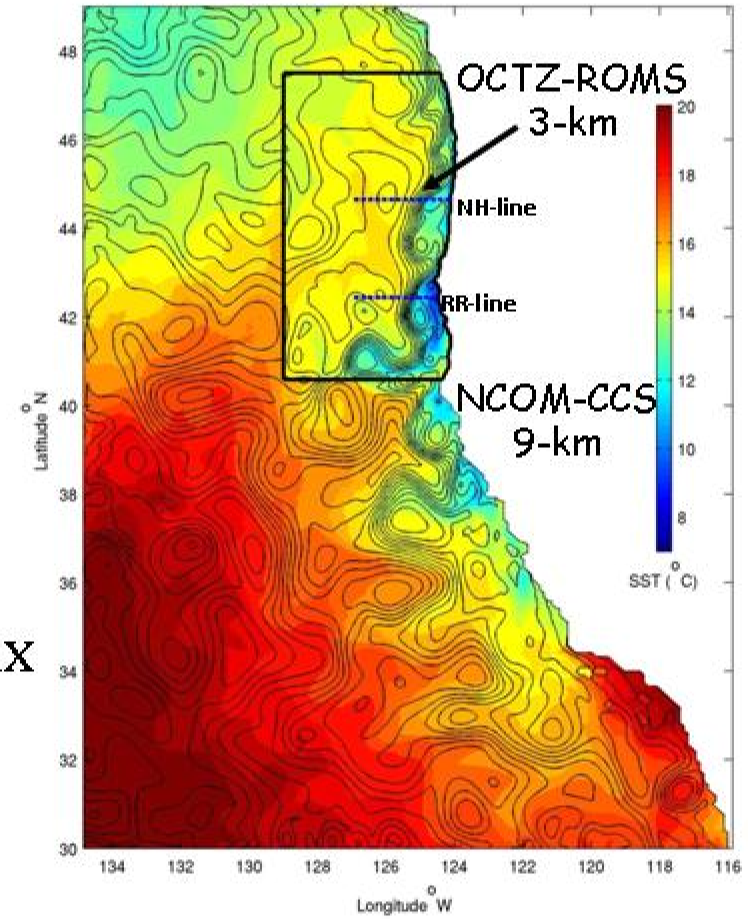
**Atmospheric forcing:**

2002: **COAMPS** winds & **NCEP** heat flux

2006 - 2008: **NAM** winds & heat flux

**Oceanic forcing (B.C.):**

**NCOM-CCS** (I. Shulman, S. DeRada)



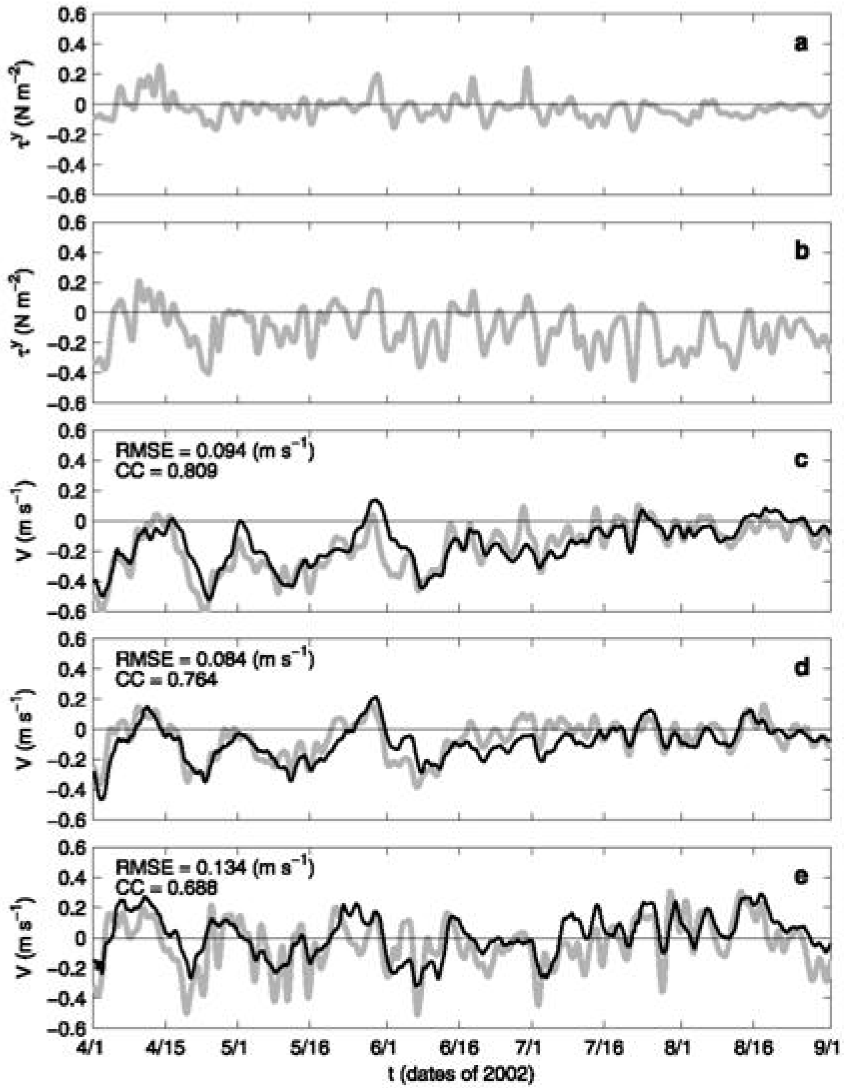
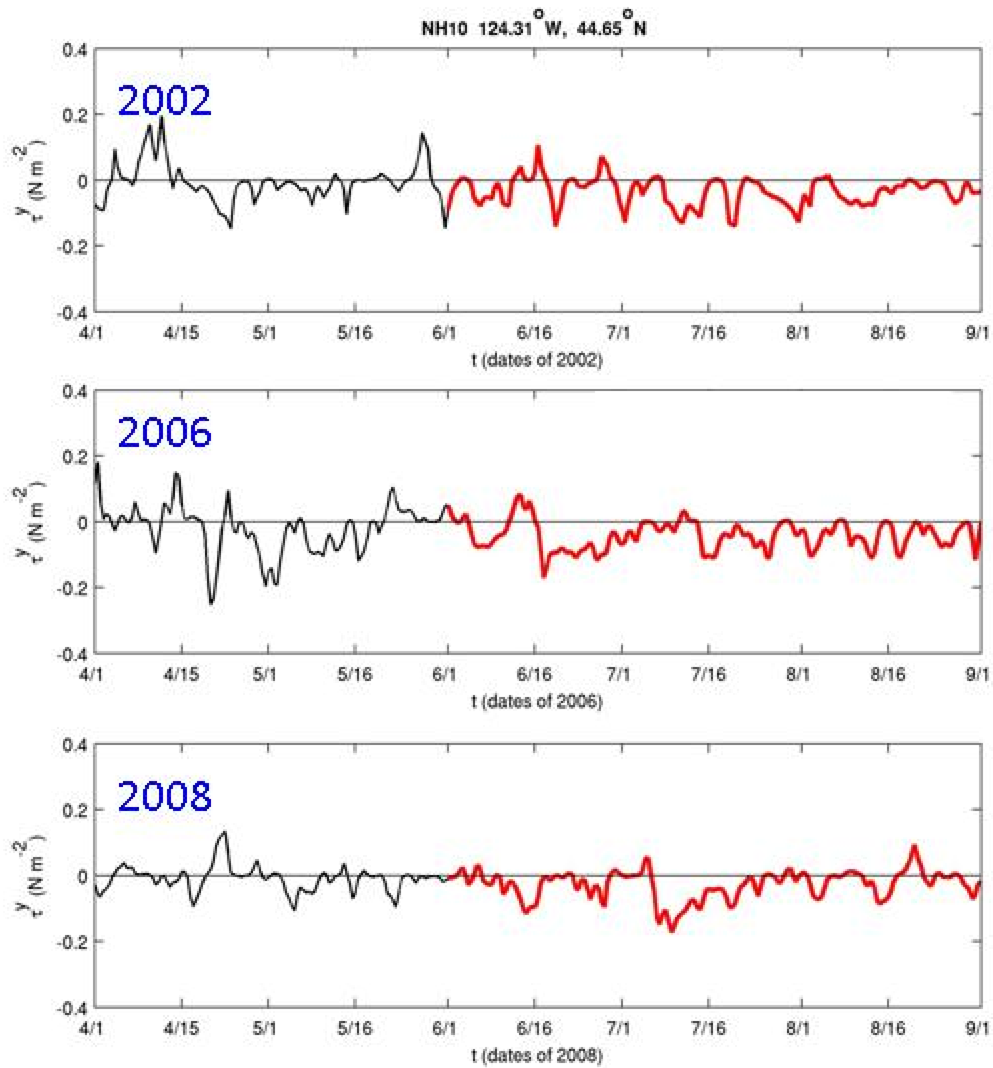



**Figure 2.** Alongshore COAMPS wind stress $\tau^y$ at the (a) NH10 (44.6°N) and (b) Rogue River (42.4°N) moorings, and depth-averaged alongshore current $V$ at (c) NH10 (44.6°N), (d) Coos Bay (43.2°N), and (e) Rogue River (42.4°N) mooring observations (shaded lines) and model (black lines). Variables are presented along respective major principal axes. Root mean square error (RMSE) and correlation coefficients (CC) for data and model are shown.

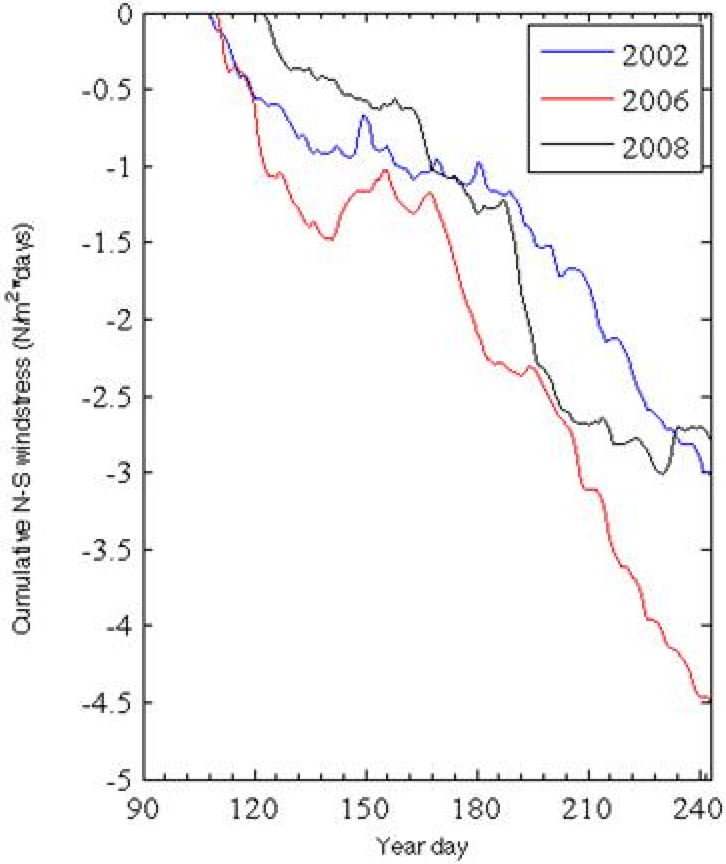
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, C08020, doi:10.1029/2009JC005704, 2010

# Alongshore Wind Stress

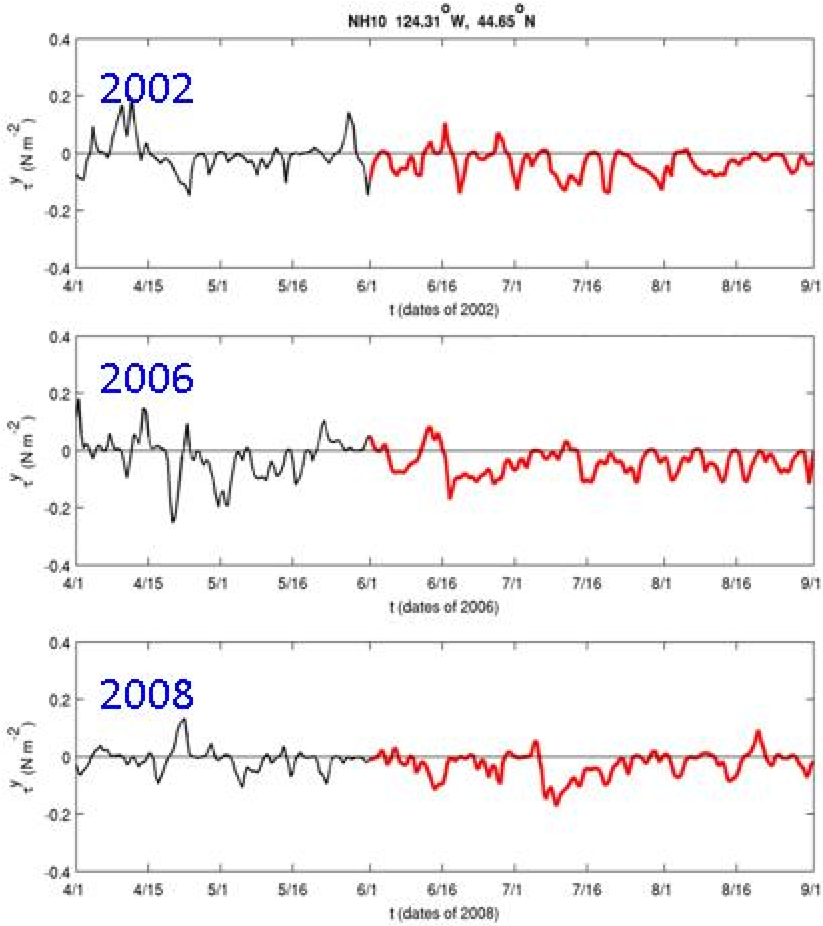
- 2002 and 2006 had relaxations of southward winds, but no significant wind reversals after mid-July
- Reversal will cause downwelling of high $O_2$ waters and push low $O_2$ bottom waters further offshore
- 2008 upwelling started later



## Cumulative wind stress
## Newport NDBC buoy




## COAMPS and NAM models



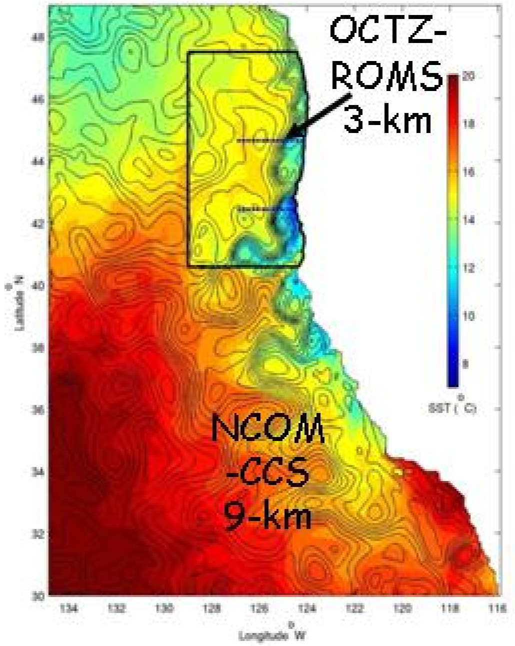

http://damp.coas.oregonstate.edu/windstress/ J.A. Barth and S.D. Pierce (OSU)

# Oregon Coast Upwelling System – Biological Model

**Biological forcing: all tracers but oxygen**

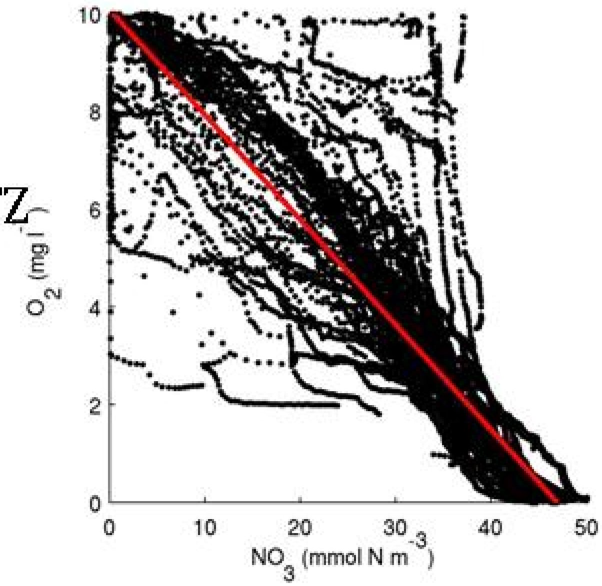
**NCOM-CCS 2006, 2008**

**NCOM-CCS nitrate modified based on LTOP obs.**

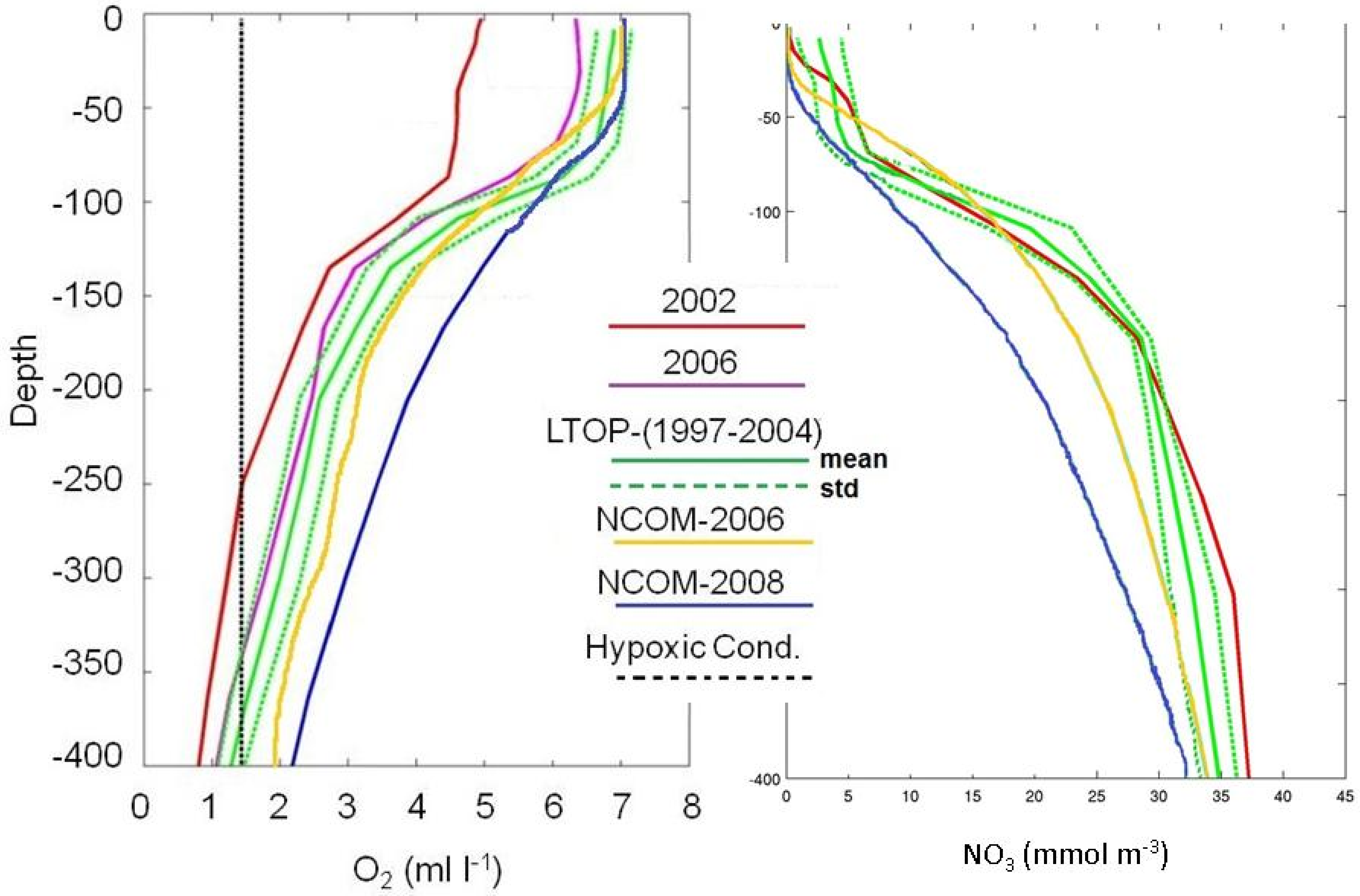



**Oxygen OBC & IC:**

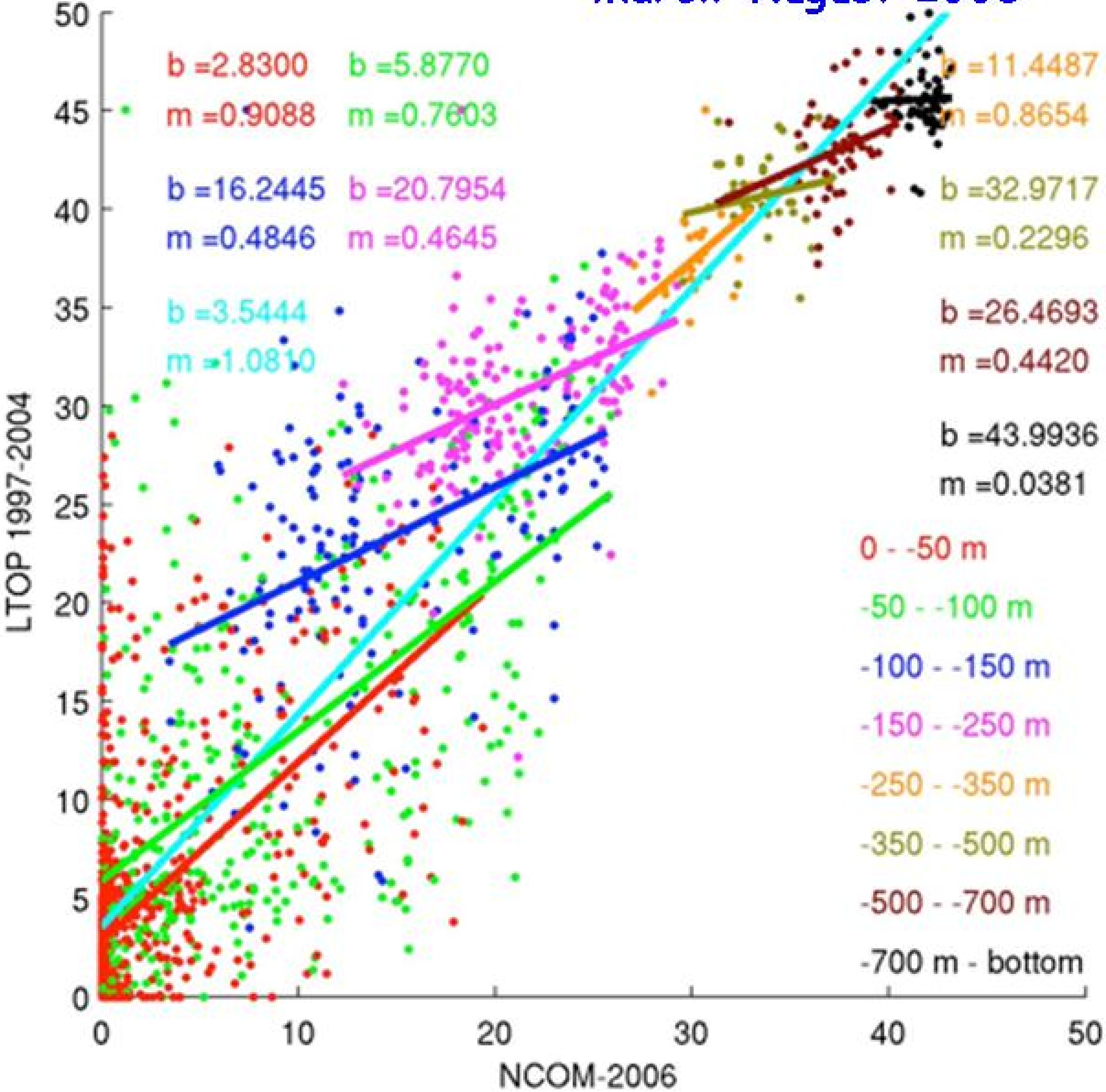
- Empirical **NO3:O2 ratios** derived from **GLOBEC-LTOP** observations in the Oregon CTZ
- In situ measurements for a specific year



# April-May Oxygen and Nitrate Profiles offshore of Newport (44.65°N, 126.05°W)



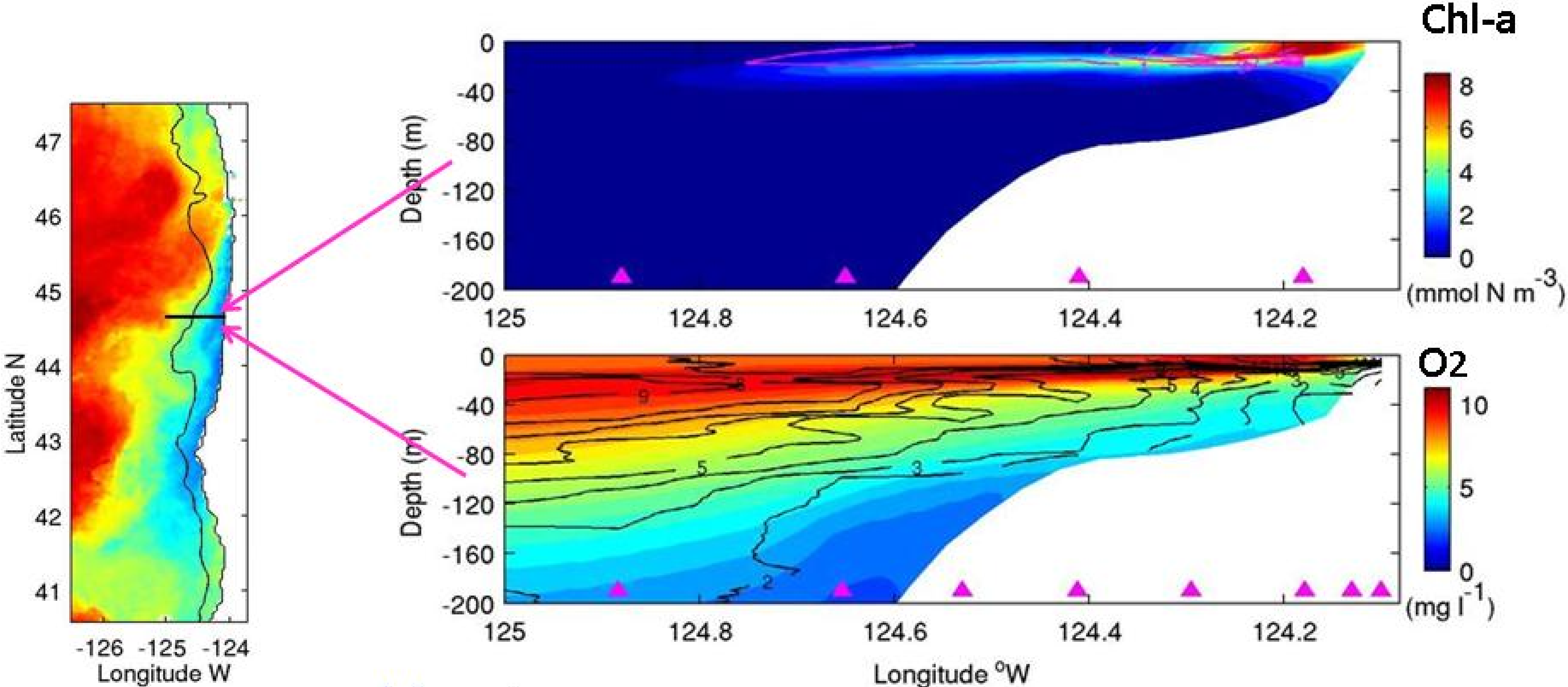
# GLOBEC-LTOP and NCOM-2006 nitrate concentration
# March-August 2006




New initials and boundary conditions for nitrate and oxygen

# *Model Results - Data Comparison: Chl-a and $O_2$*

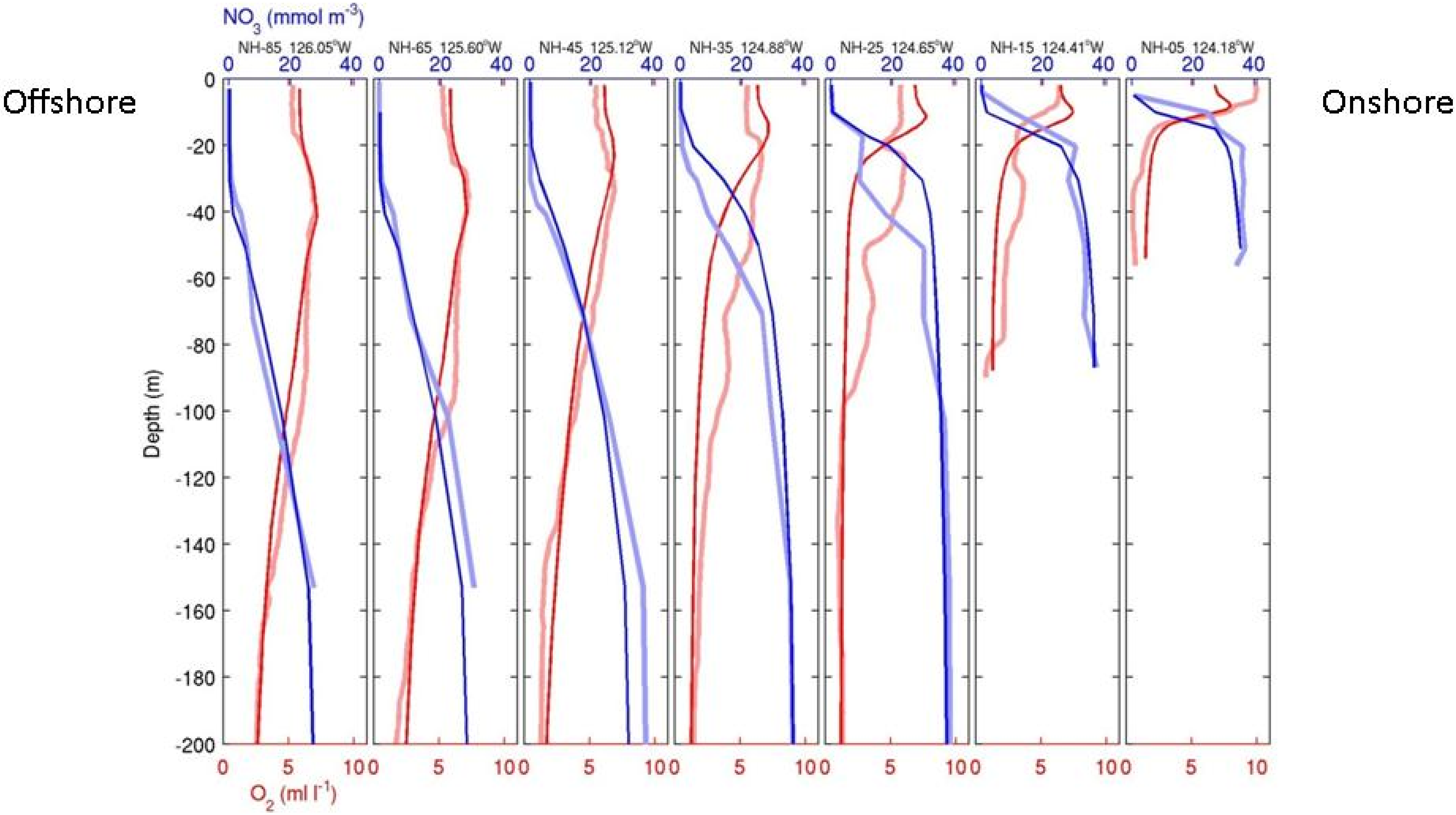
## 44.65°N on 10 July 2002




model – color

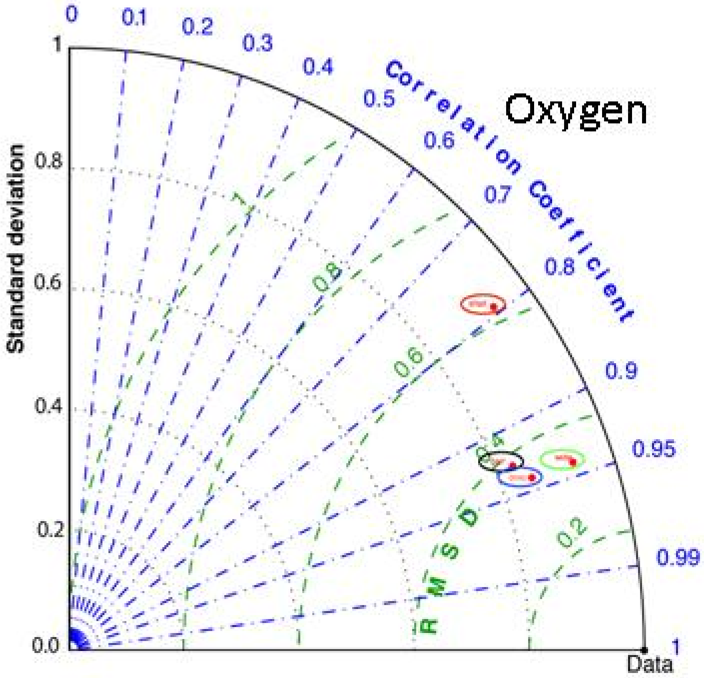
data – contours

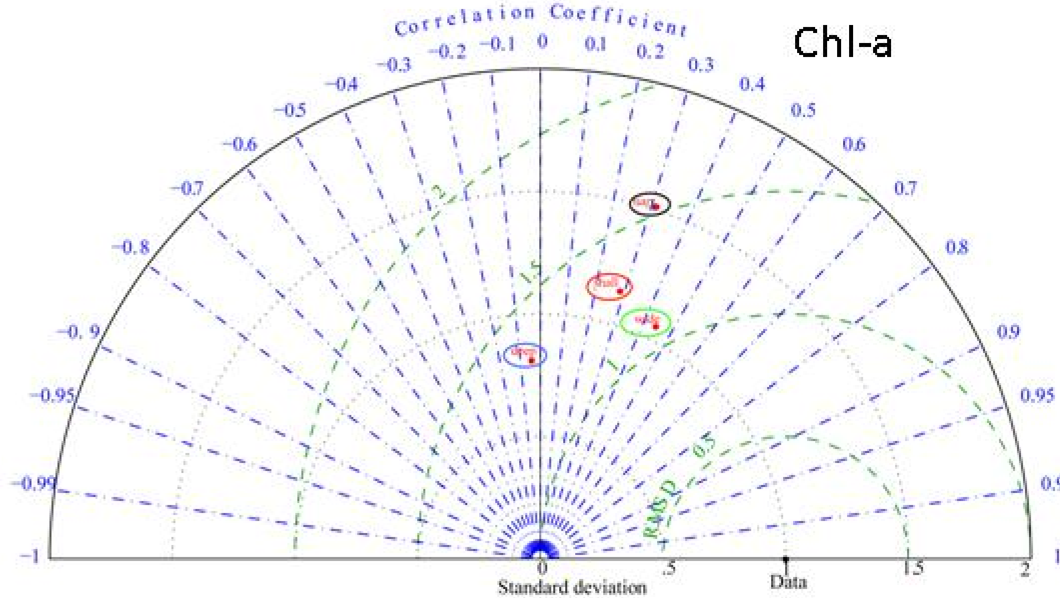
# *Newport line - 44.65°N on 10 July 2002*




**$NO_3$ (blue) and $O_2$ (red) : pale/thick – data, bright/thin – model**

# All available oxygen and chlorophyll-a from GLOBEC cruises and model April – September 2002




Shallow measurements - onshore of the 200m isobath

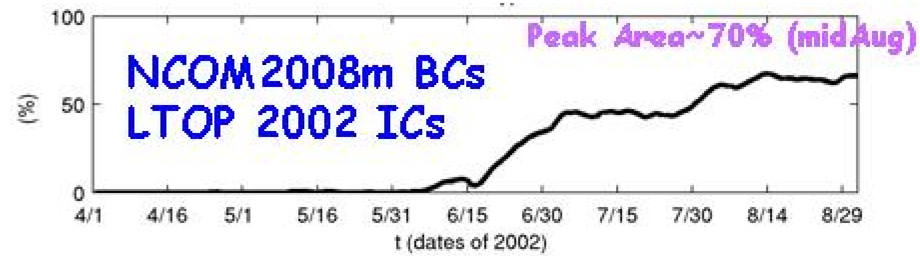
Deep measurements = offshore of the 200m isobath

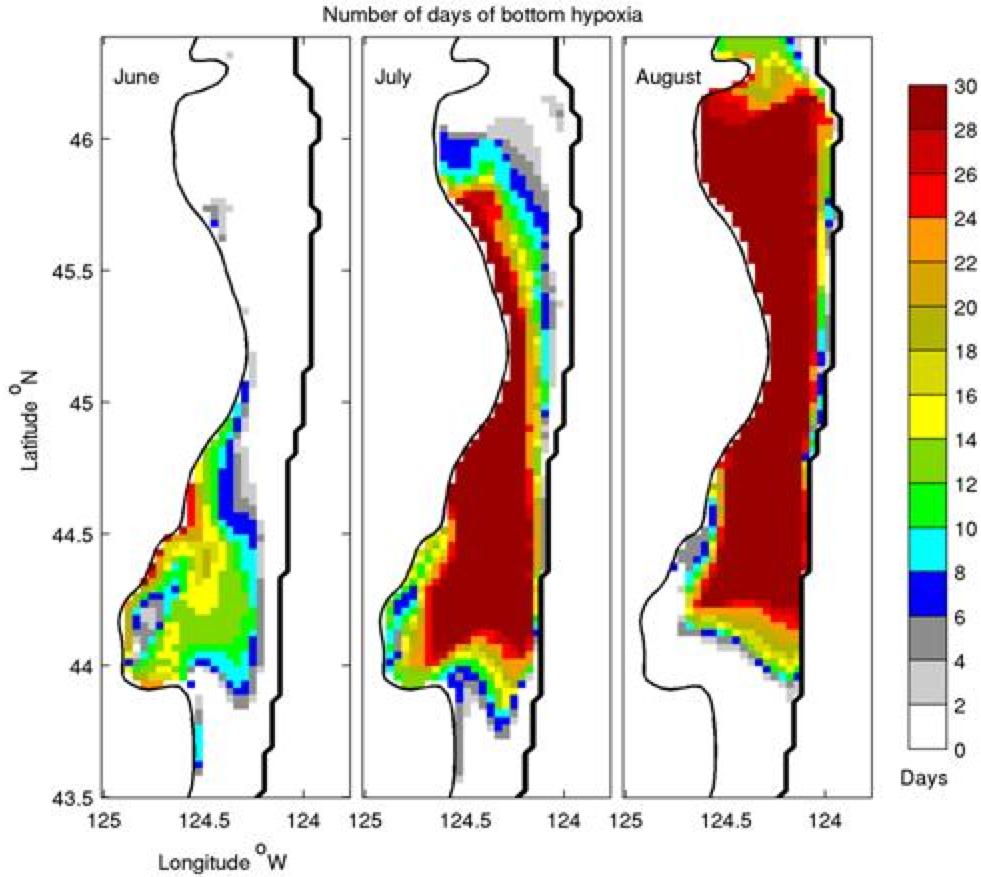
Wide shelf measurements - mean distance of the 200m isobath = 40.5km from shore

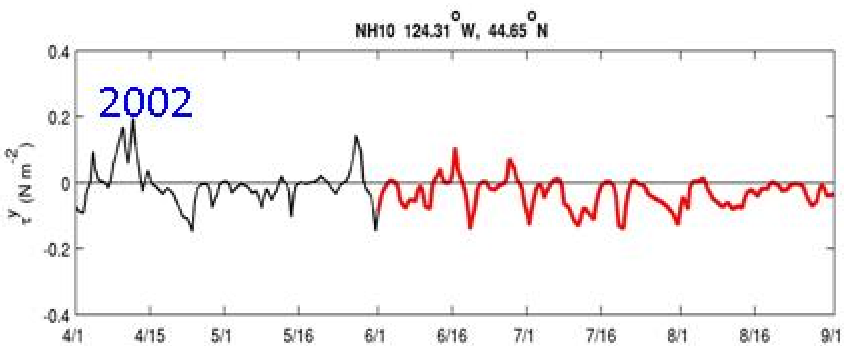
Narrow shelf measurements - mean distance of the 200m isobath = 24km from shore

# Model-Data 2002 Spatial-Temporal Patterns of Hypoxia Development

- 2002 was a year of strong hypoxia
- June hypoxia on Heceta Bank
- Strongest July Hypoxia on Heceta Bank
- Hypoxia extends in August and remain high until the end of August

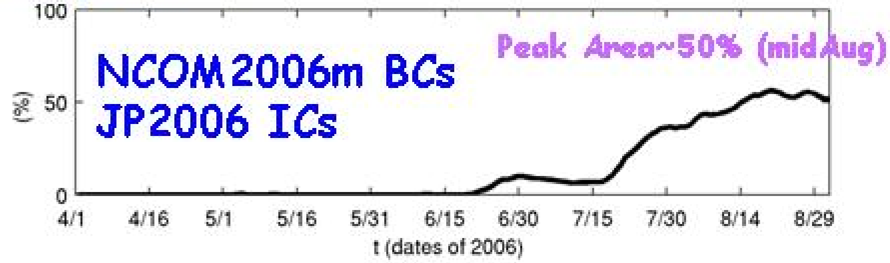


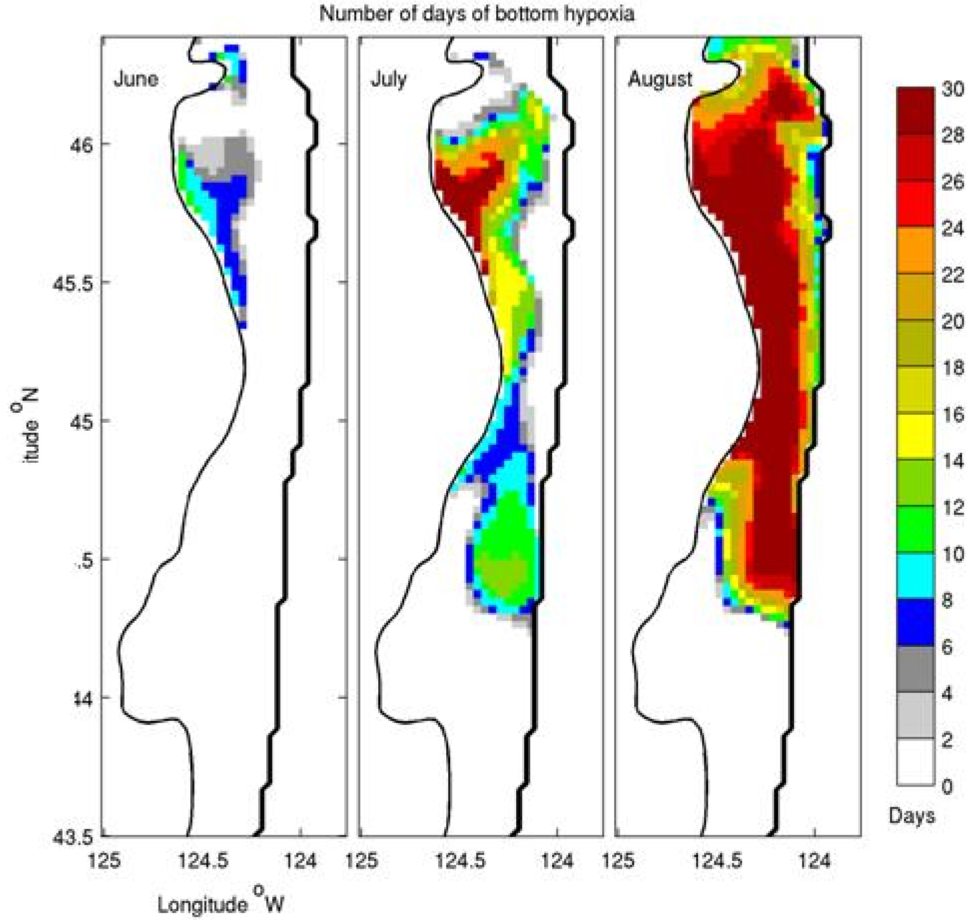



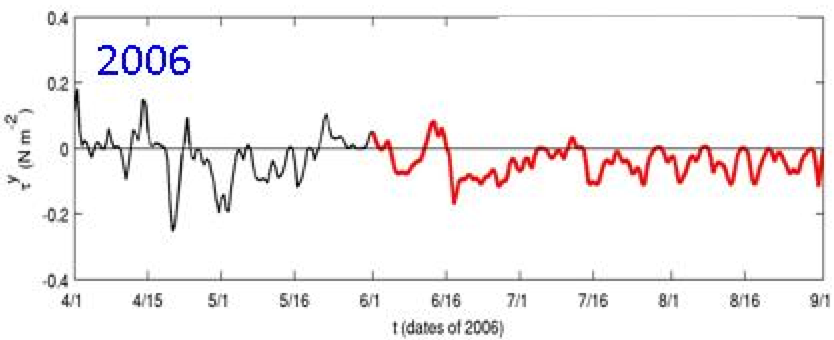



# Model-Data 2006 Spatial-Temporal Patterns of Hypoxia Development

- June hypoxia only in the north
- Strongest July hypoxia in the north, hypoxia near the cost at Newport
- Hypoxia extends in August and remain high until the end of August, except nearshore north of Newport

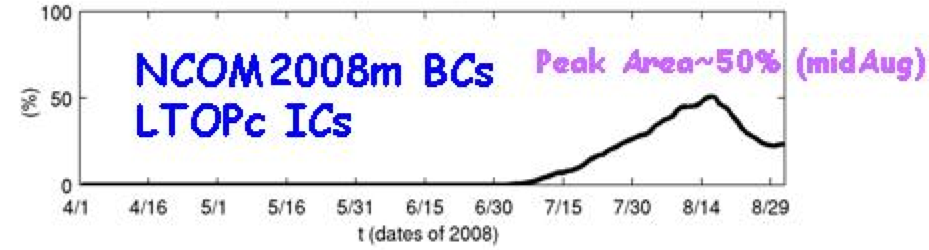


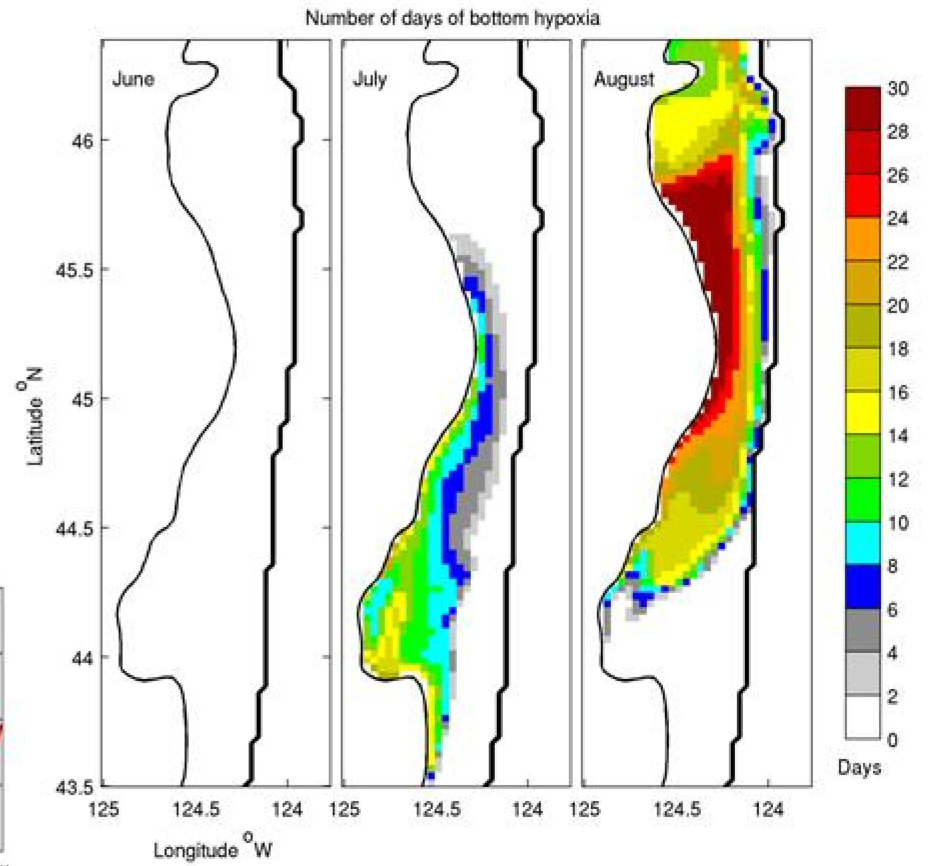



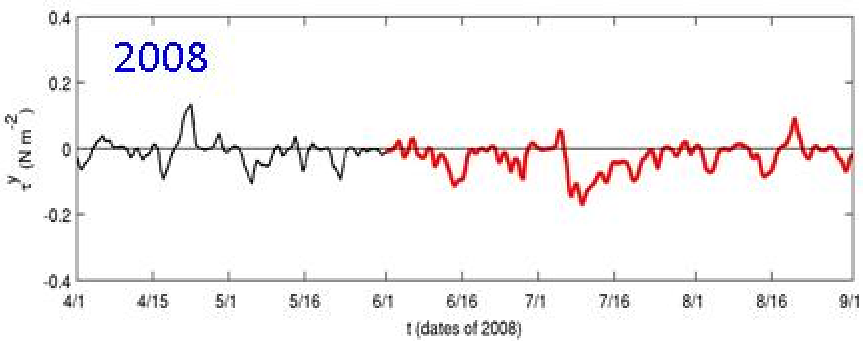



# Model-Data 2008 Spatial-Temporal Patterns of Hypoxia Development

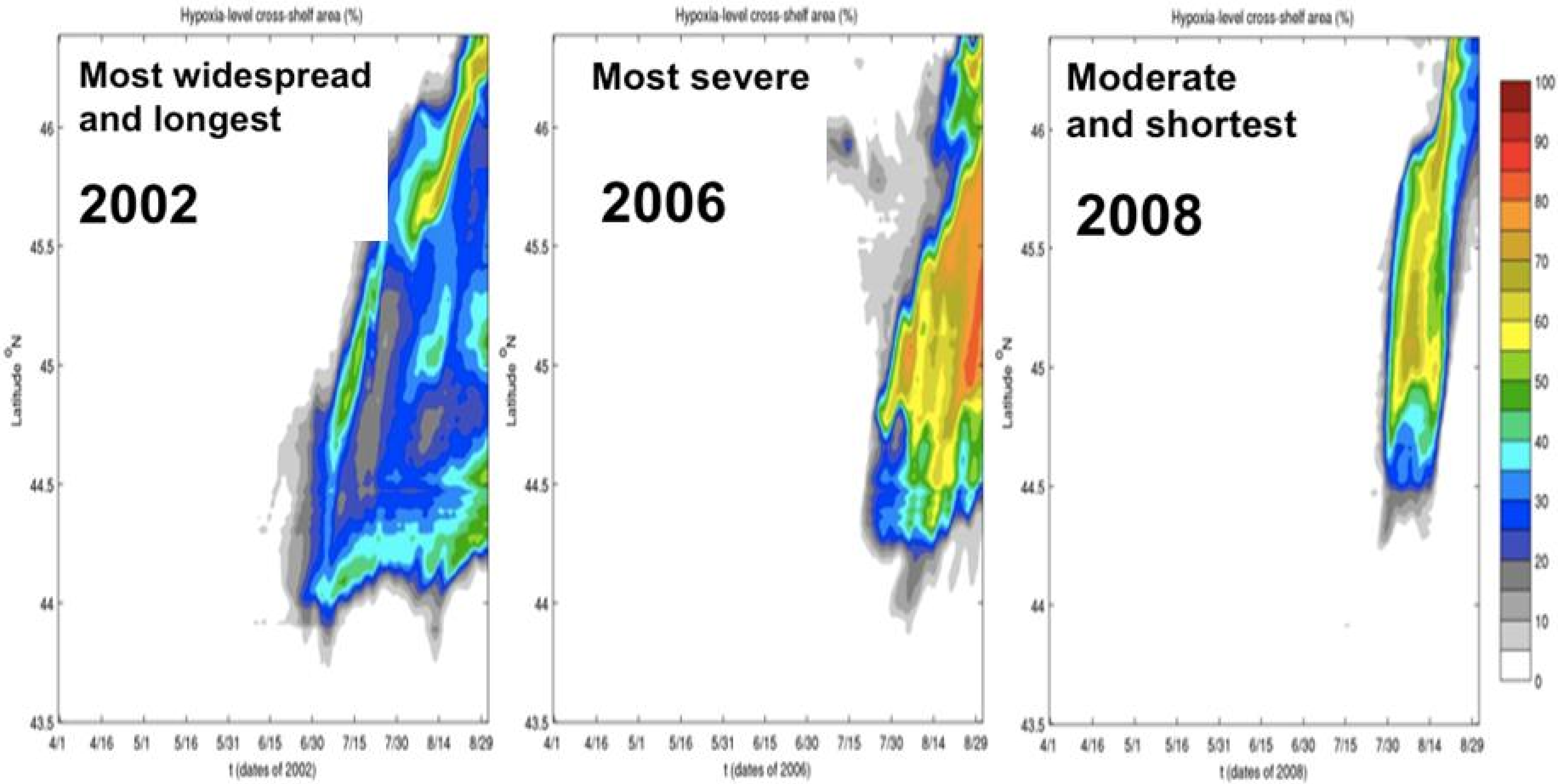
- 2008 was a year of relatively weak hypoxia
- No June hypoxia
- Strongest July Hypoxia on Heceta Bank
- Strongest Aug Hypoxia beneath Columbia River plume region (further North)
- Hypoxia extent at end of August reduced 50% from mid-August peak



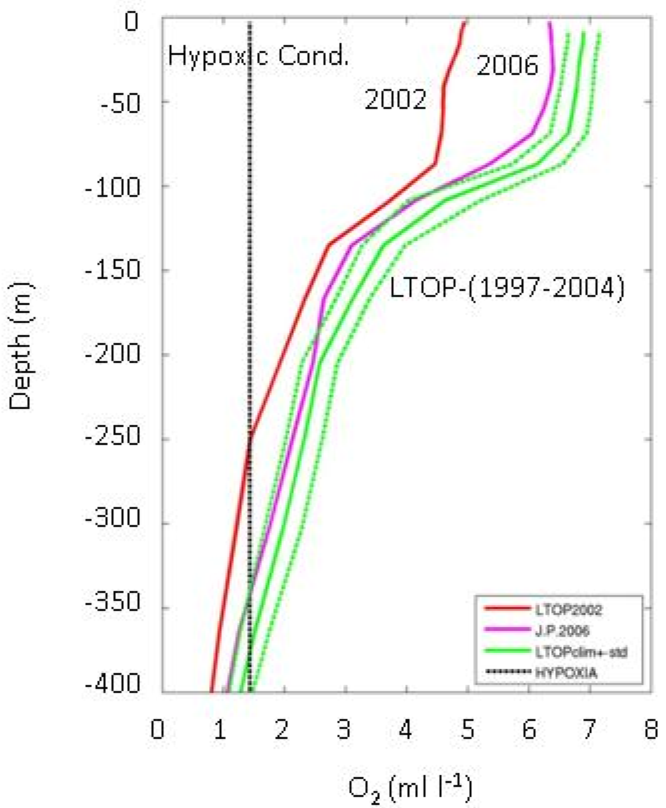



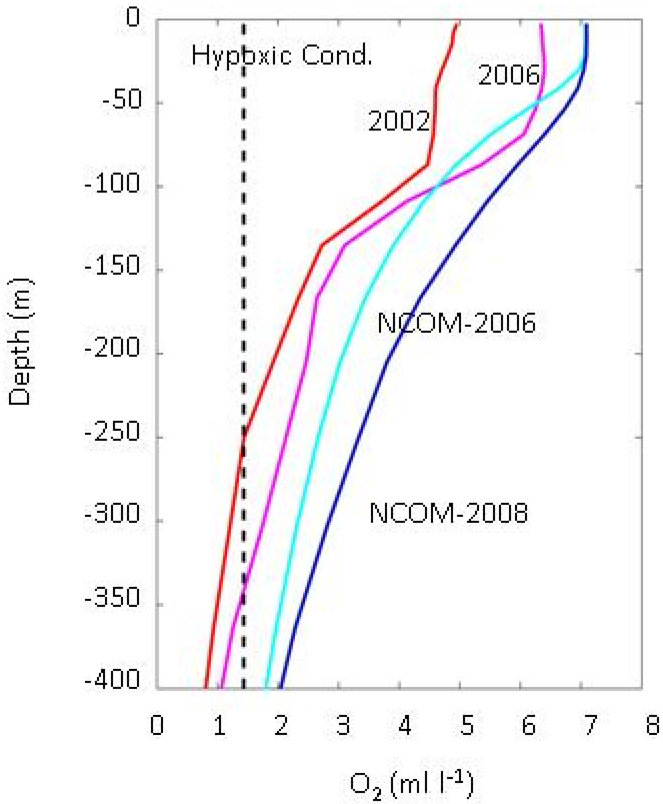
# Percentage of area with hypoxic condition



# Do the spring conditions in the deep ocean matter?

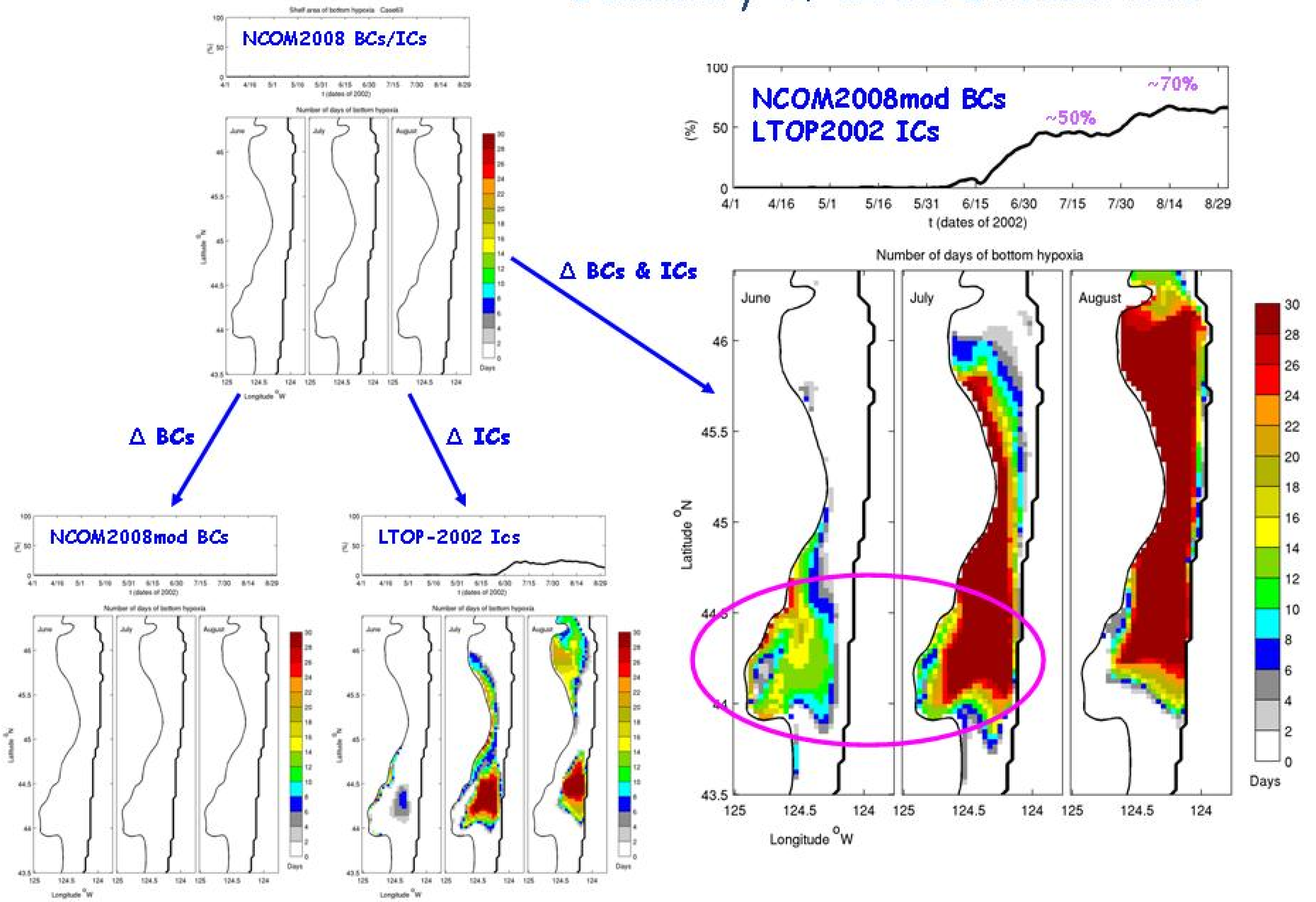
# Do the N-S and W boundary conditions matter?



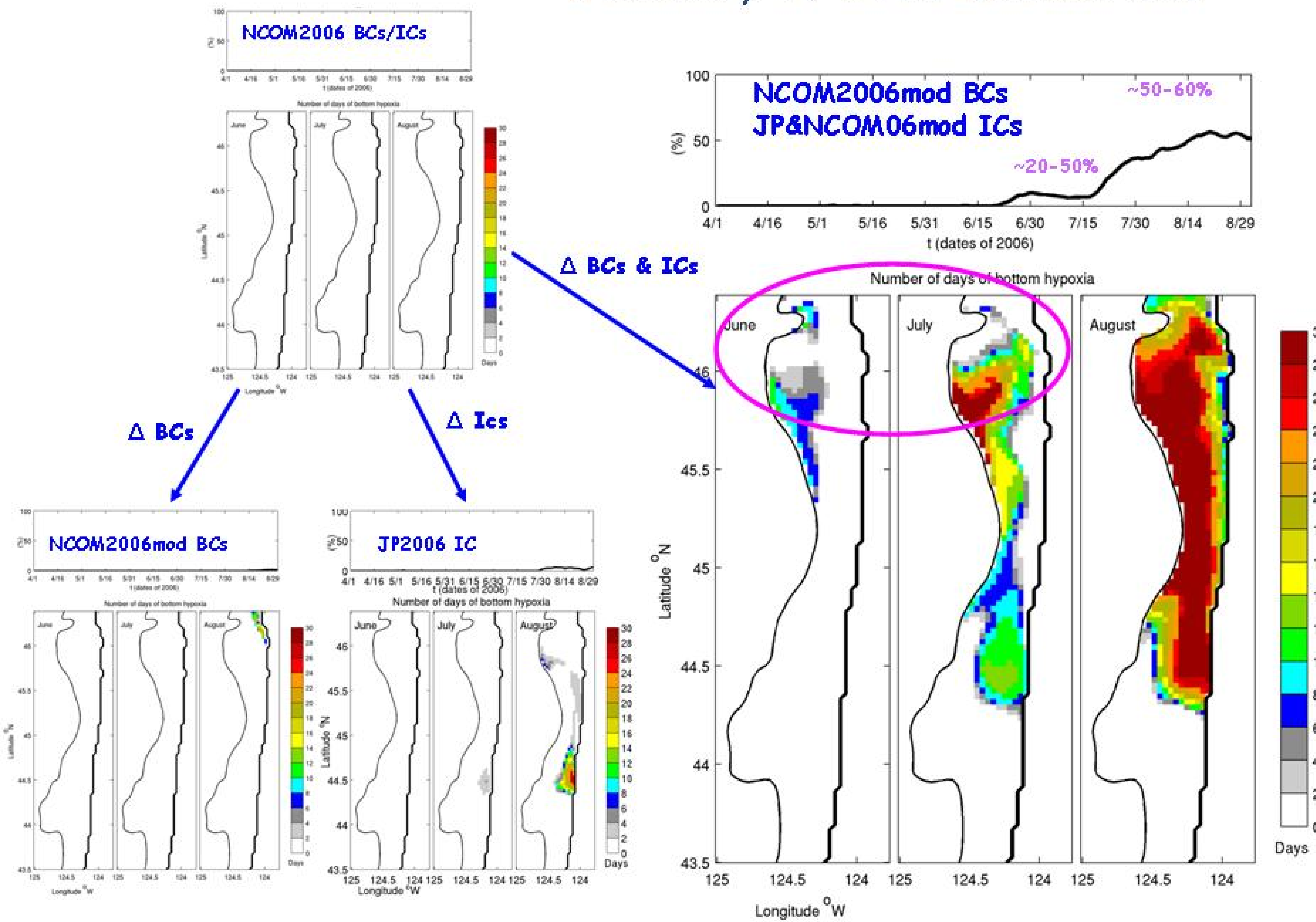




April-May Oxygen Profiles offshore of Newport (44.65°N, 126.05°W)

# Summary of 2002 Simulations



# Summary of 2006 Simulations



# Conclusions

- Starting with inadequate initial DO and $NO_3$ conditions in late-spring 2002 led to either no hypoxic or delay of hypoxic conditions
- Offshore and esp. Northern boundary conditions are very important to simulate hypoxic events on the Oregon Shelf, especially in 2006 for early hypoxic events on the shelf north of 45°N.
- Hypoxia earlier in the north in 2006 and in the south (Heceta) in 2002; perhaps difference in local residence time due to year specific wind forcing (more analysis needed)
- Hypoxic conditions were less severe in 2008, started later than in 2002 and 2006, and were shorter (few weeks)
- For accurate forecasting of summer-autumn oxygen on the OR shelf, it is crucial to have accurate "ecosystem" boundary conditions (esp. for nitrate and DO) and late-spring ICs.
- Need for basin scale simulations BUT