BIOLOGICAL RELEVANCE OF SUBMESOSCALE DYNAMICS IN THE HIGHLY STRATIFIED, OLIGOTROPHIC OCEAN

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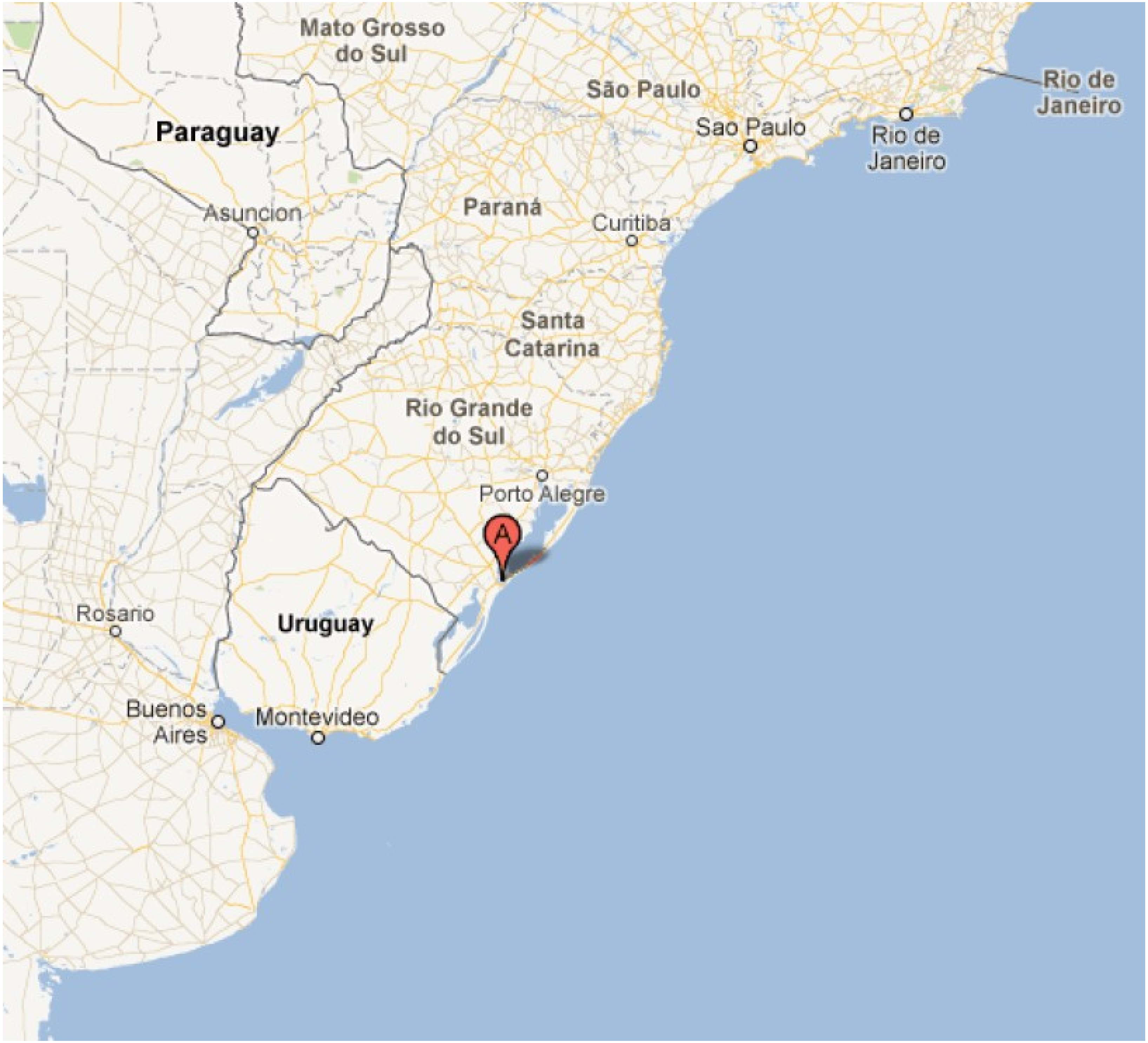
center for microbial oceanography: research and education
C-MORE linking genomes to biomes

High Performance Computing Facility – NIWA



Mato Grosso
do Sul
São Paulo
Rio de
Janeiro
Paraguay
Sao Paulo
Rio de
Janeiro
Asuncion
Paraná
Curitiba
Santa
Catarina
Rio Grande
do Sul
Porto Alegre
A
Rosario
Uruguay
Buenos
Aires
Montevideo

Motivation

Understand the role of submesoscale motions (if any) in the supply new nutrients into the euphotic zone in the oligotrophic ocean.

Possible new sources of new nutrients:

- **Nitrogen Fixation (Karl 1997).**

- **Vertical Migration of Diatom Mats (Singler and Villareal, 2005; Villareal 1999).**

- **Physical supply from the top of the nitracline:**
  1) Wind mixing (Letelier 2000).
  2) Mesoscale eddies (Johnson et al 2010, Letelier 2000, Lukas and Santiago-Mandujano 2001).
  3) Rossby Waves (Sakamoto et al 2004, Nicholson et al 2008).
  4) Frontal, episodic processes (Mahadevan and Archer 2000, Calil and Richards 2010).

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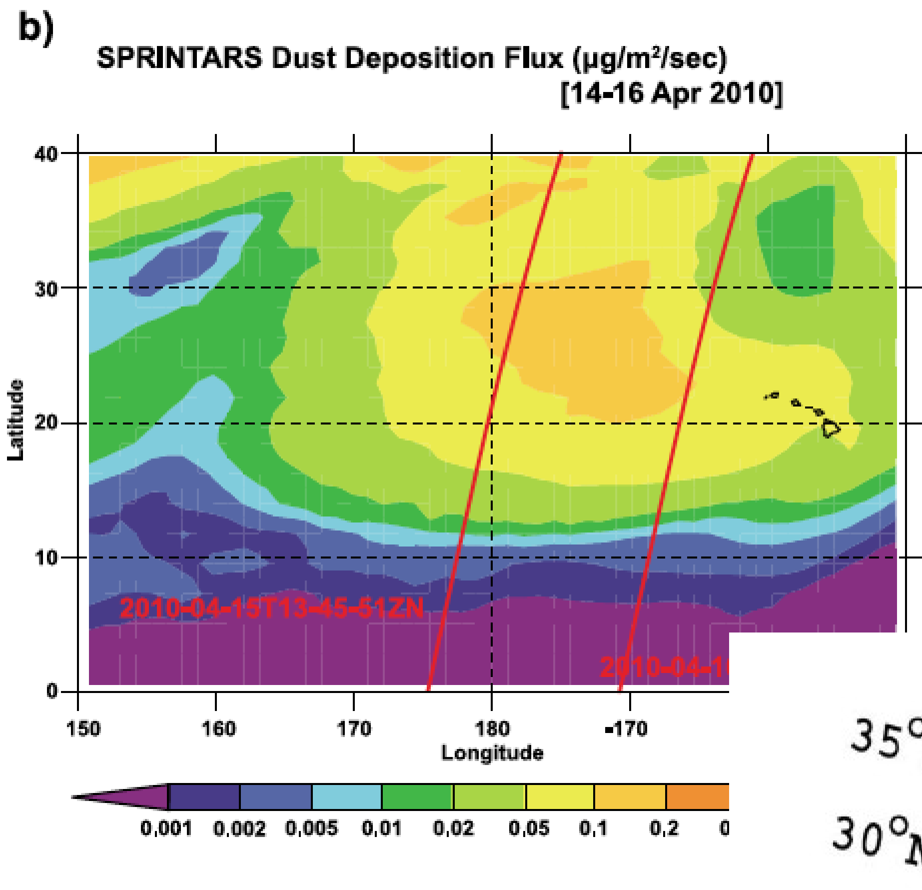
  4) Frontal, episodic processes (Mahadevan and Archer 2000, Calil and Richards 2010).

Are Submesoscale Processes Important in Highly Stratified Regions?

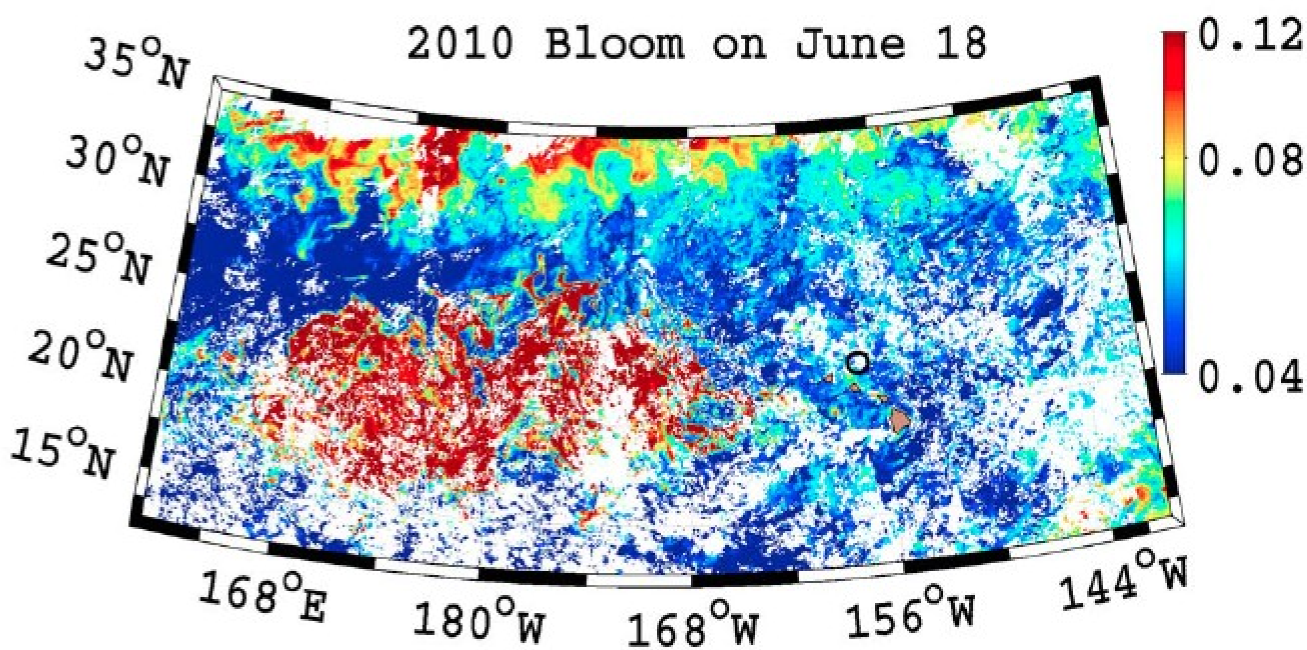
Ideal Conditions for Submesoscale:
Low stratification
Deep MLD

Oligotrophic Ocean:
Large stratification
Shallow MLD

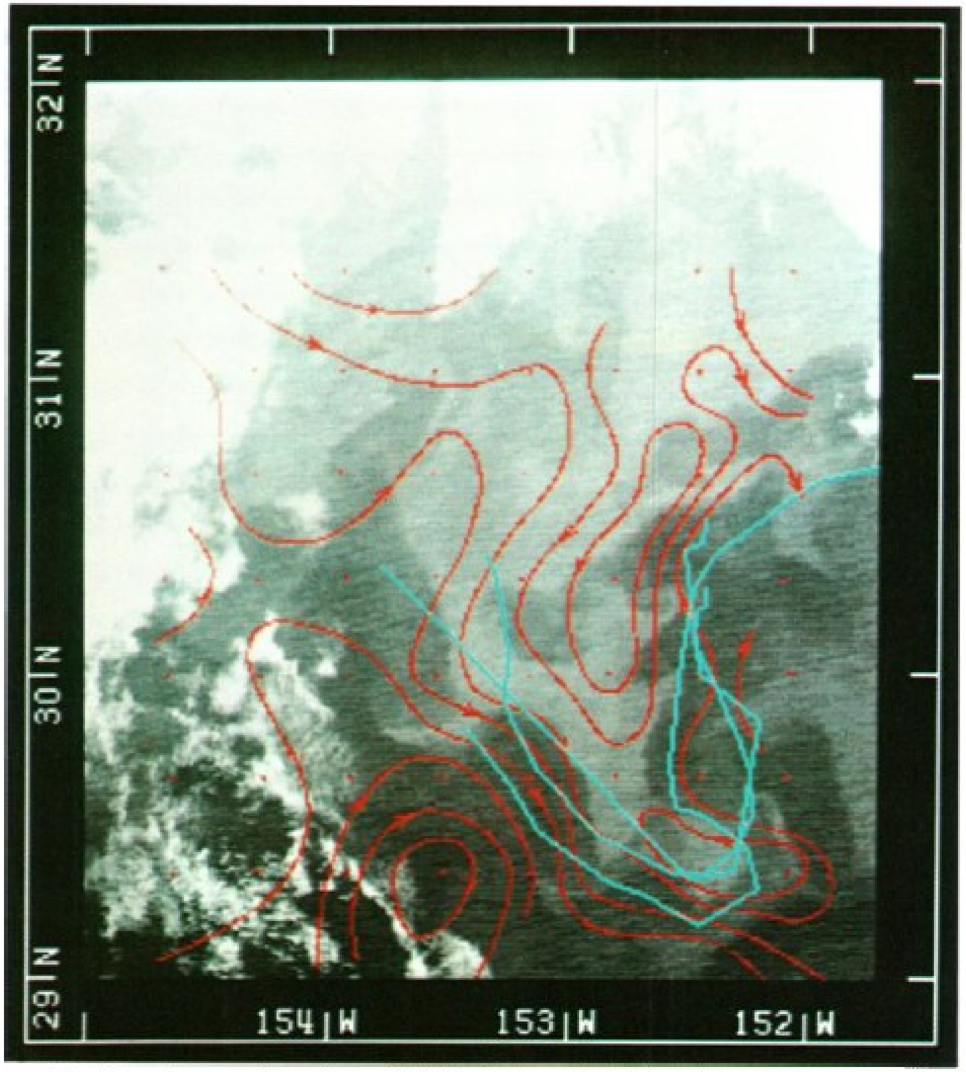
Dust Deposition May Stimulate Episodic Blooms

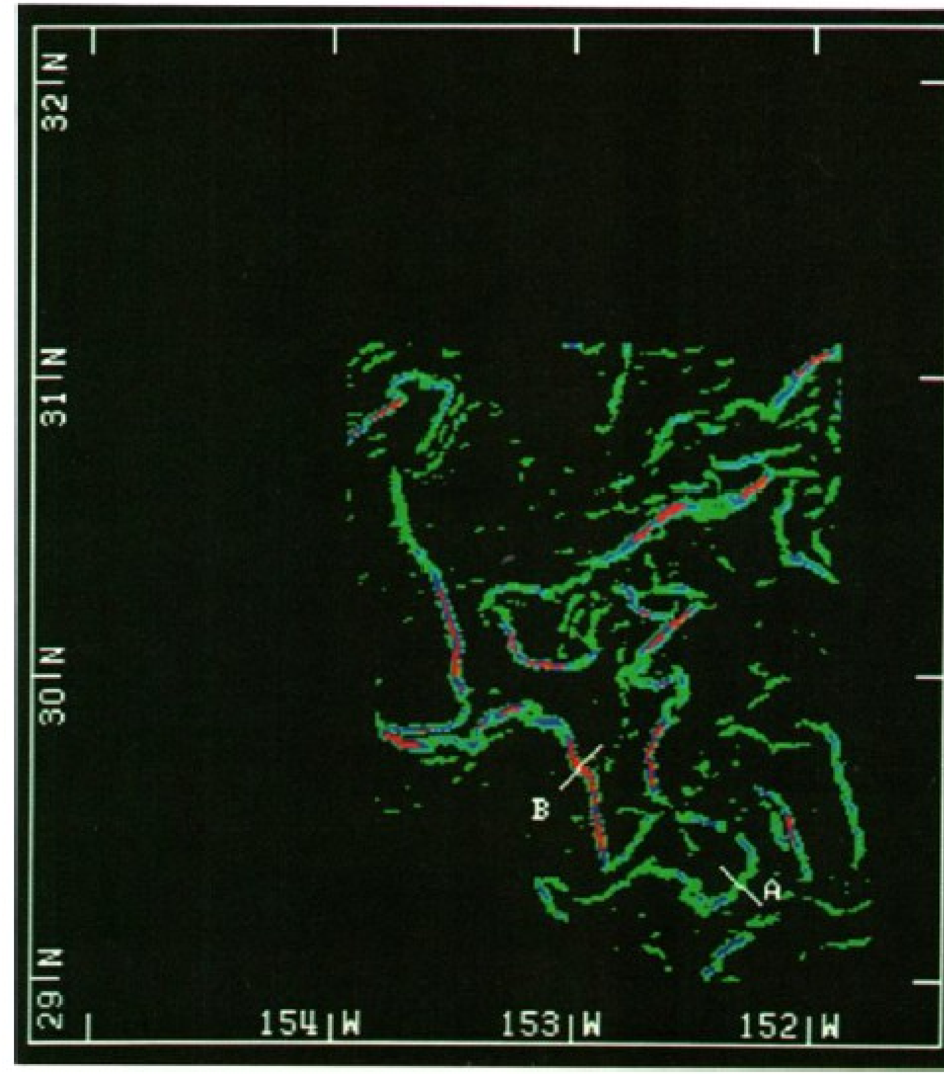


Calil et al. 2011



Observational Evidence –North Pacific Subtropical Front



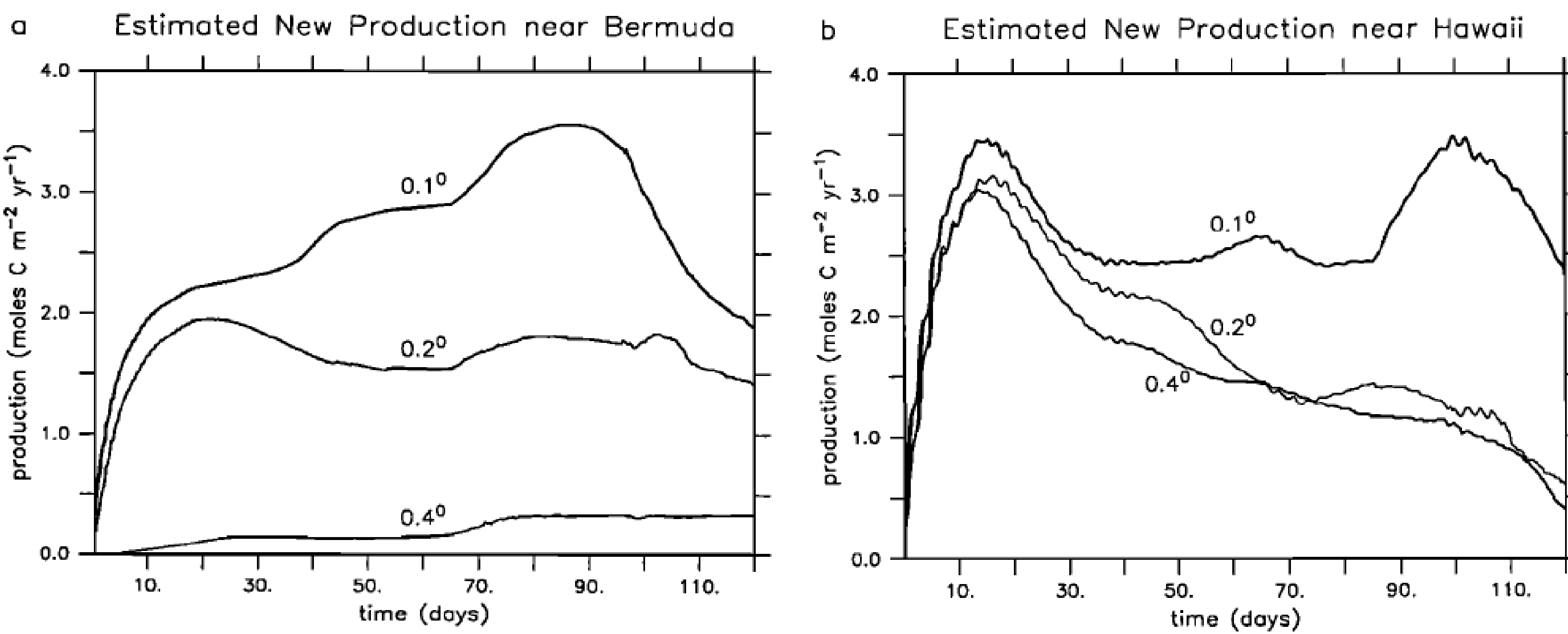


Van Moert 1982

Eddy interaction generates filaments and intensify existing horizontal density gradients

Biological Importance of Resolving Frontal Processes

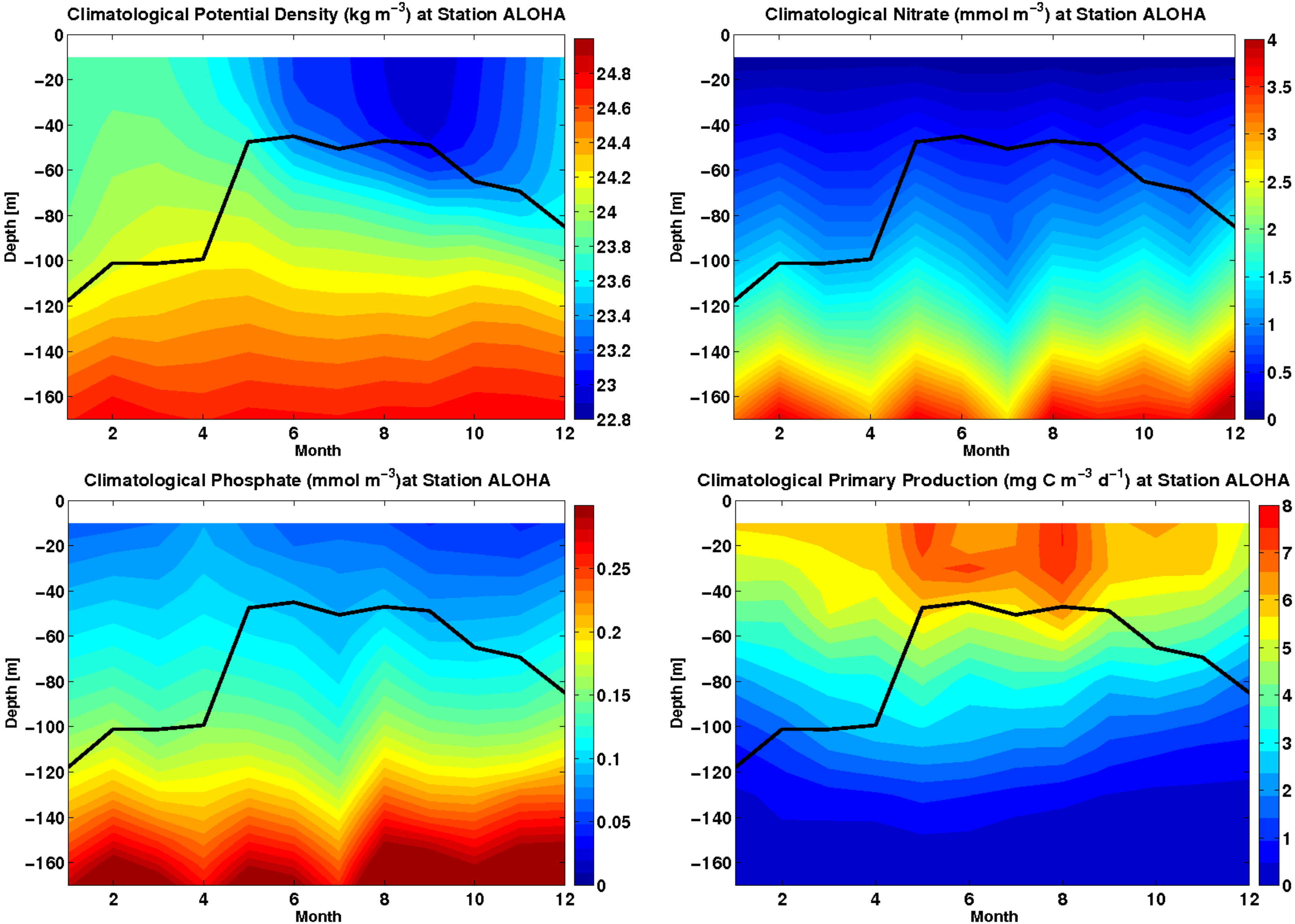
Horizontal scale = O(1-10 km)
Vertical scale = O(100 m) – Camada de Mistura



From Mahadevan and Archer 2000

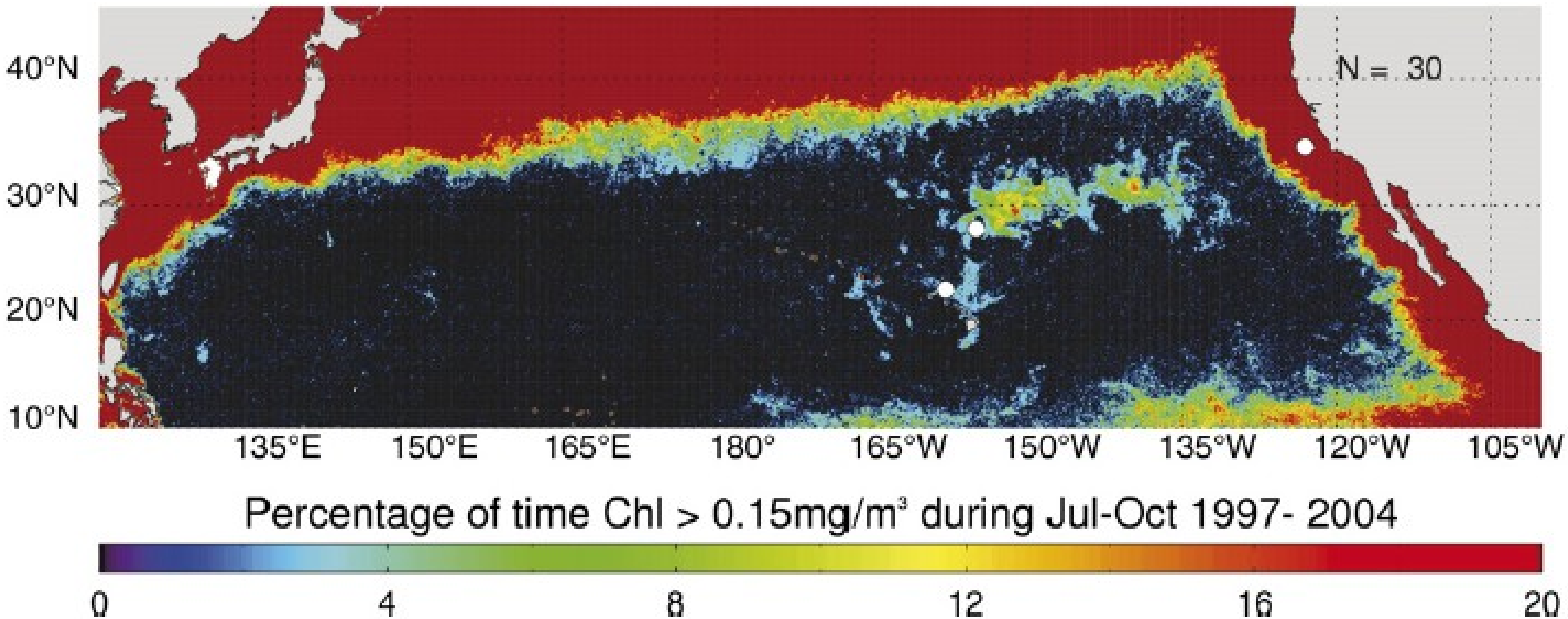
Increased resolution → Resolved Fronts → Increased Vertical Nutrient Flux

Hawaiian Ocean Time Series (HOT) Station ALOHA



Calil et al. 2011

Blooms in the North Pacific Subtropical Gyre

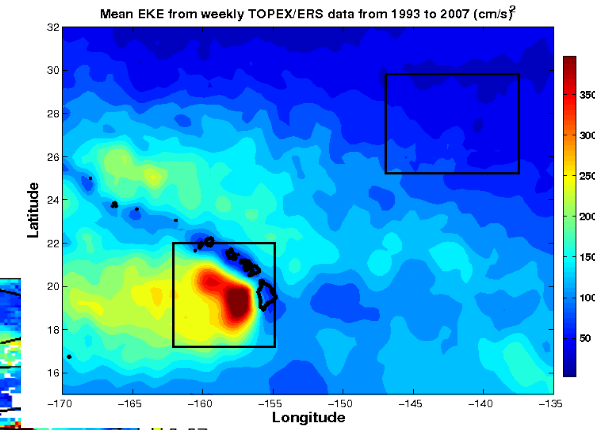


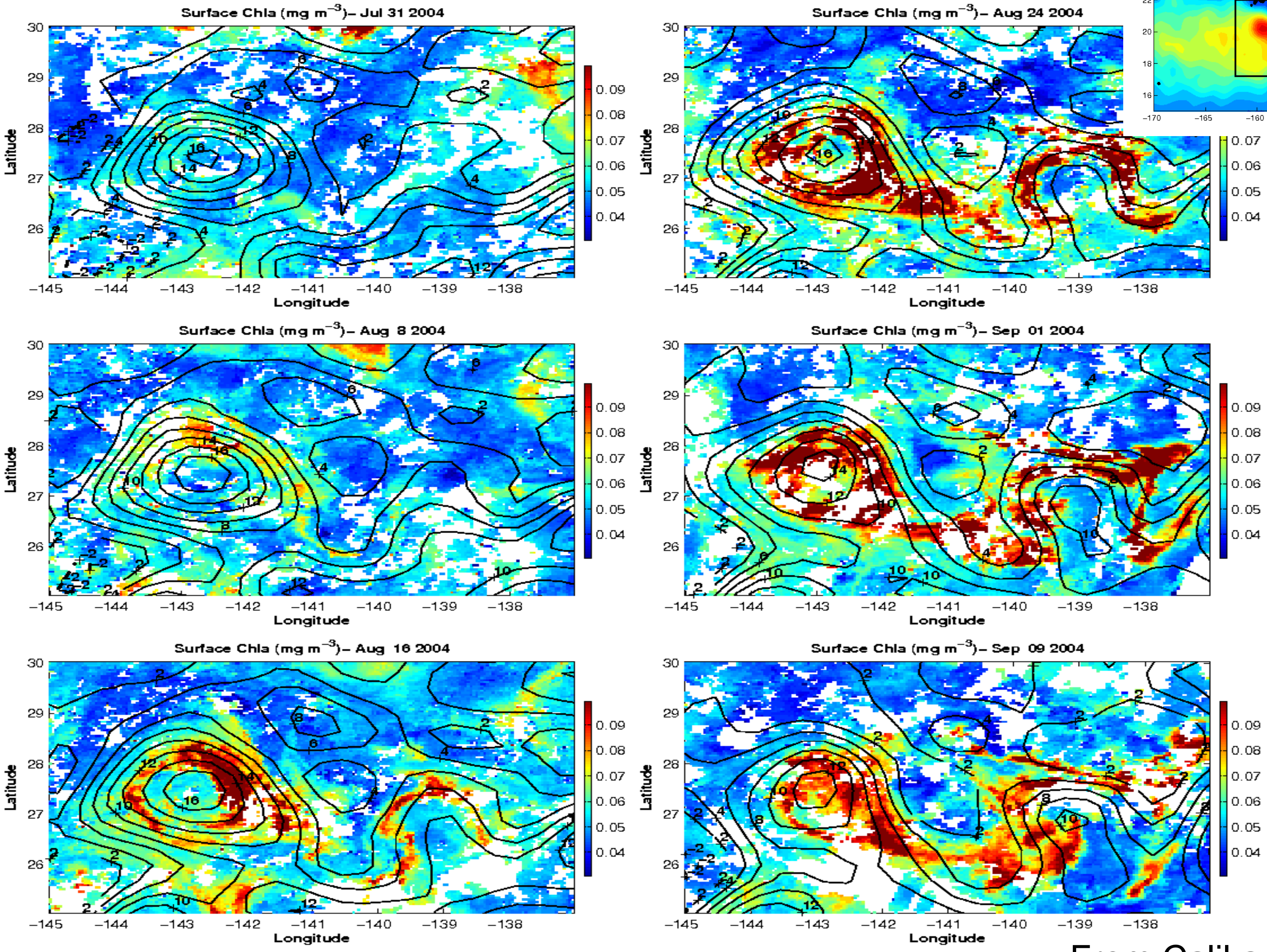
Wilson et. al 2008

Subtropical Front (~ 30N) - composed of larger organisms (e.g. diatoms) which require large nutrient delivery.

Oligotrophic Ocean around Hawaii –also composed of nitrogen fixers (e.g. Trichodesmium Spp. . Produce nitrogen, but are limited by phosphate and iron).

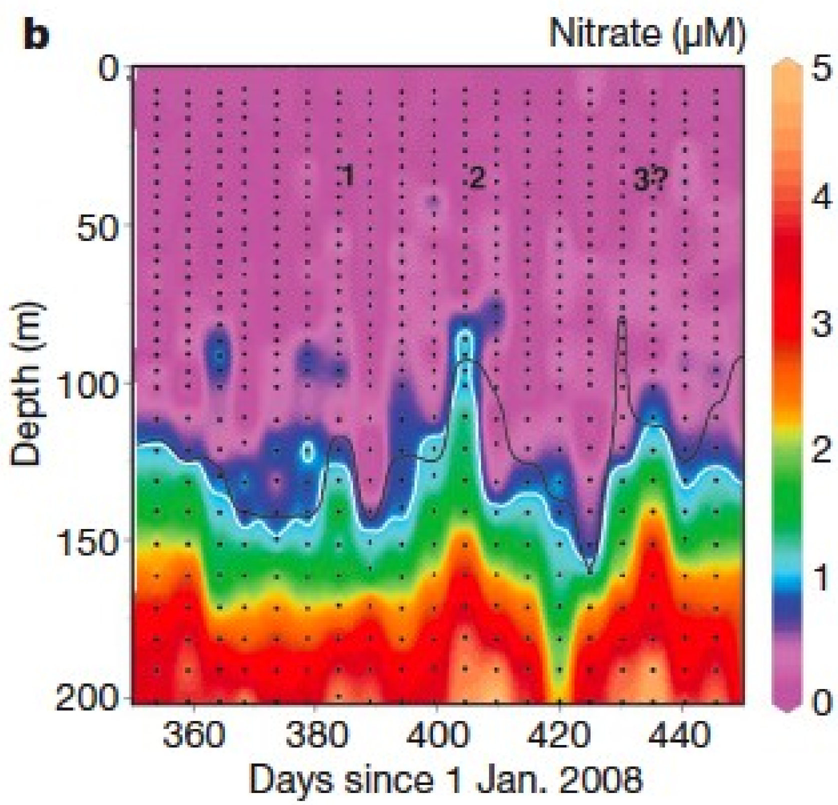
Variability 'Injected' at Small Scales





From Calil and Richards 2010

Episodic Injections



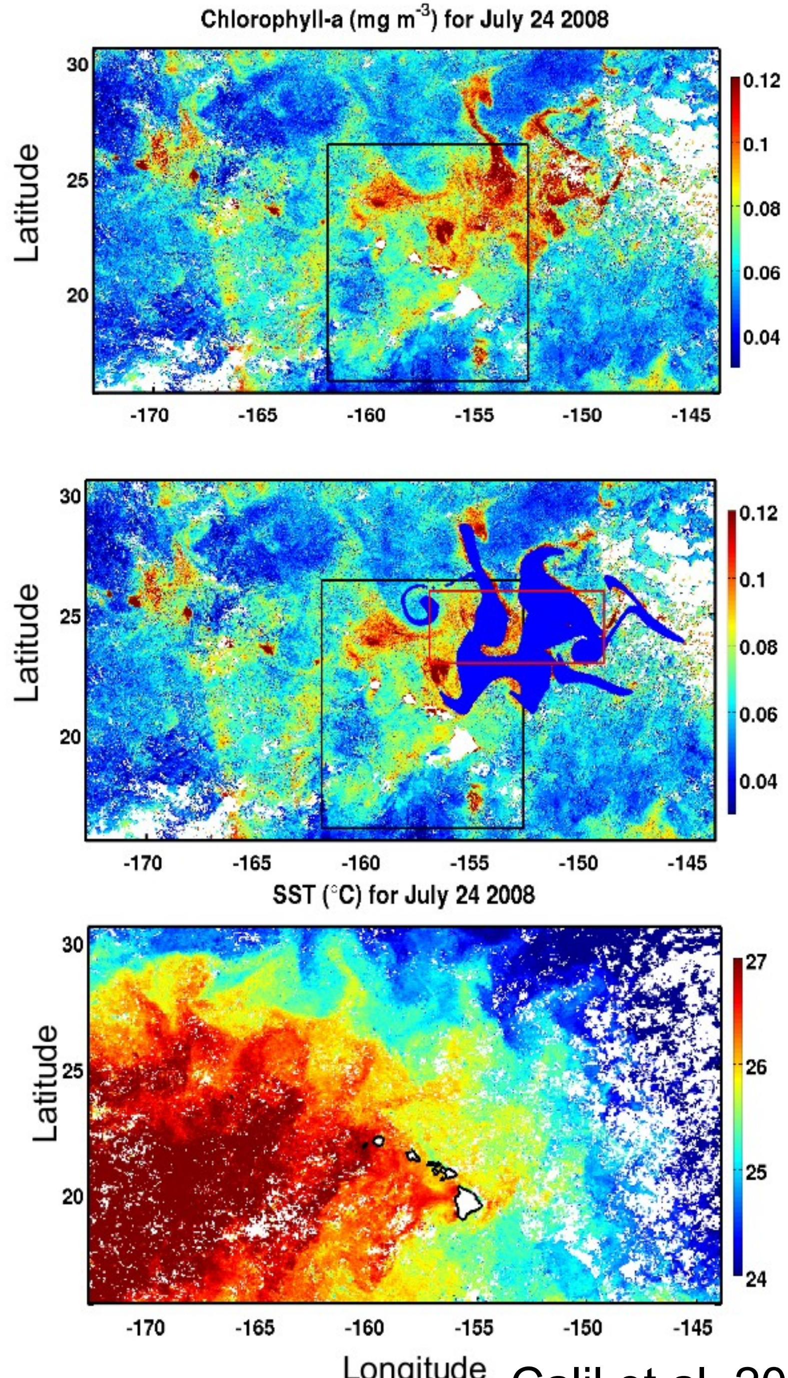
Johnson et al. 2010

ARGO floats.
1 profile every 5 days.

Authors relate this with the passage of cyclonic eddies.

Note very low NO3 concentrations in the upper 100m.

Evidence of Filamentation



Calil et al. 2011

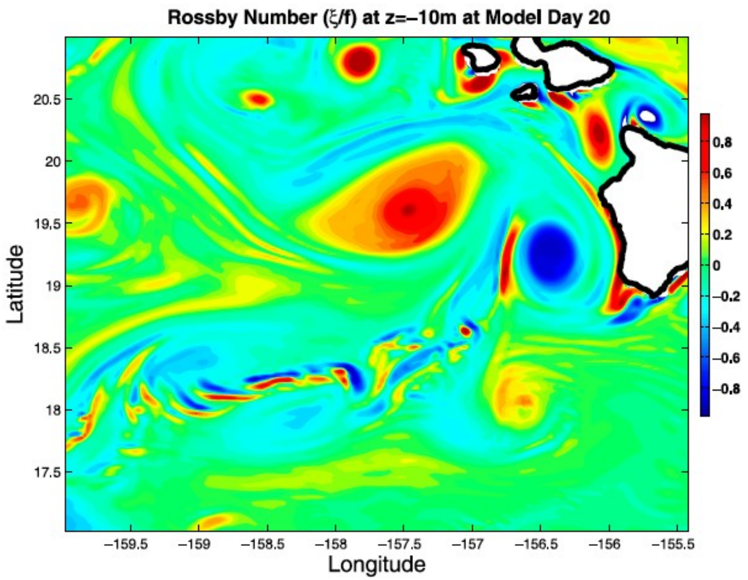
Seasonal forcing + eddy advection creates warm filaments.

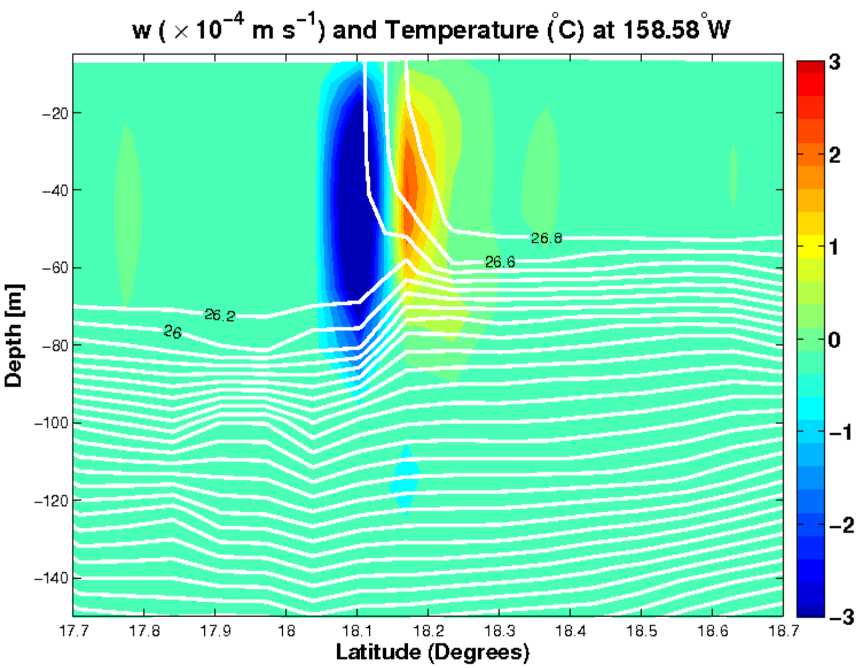
Provide conditions for frontogenesis as density gradients increase.

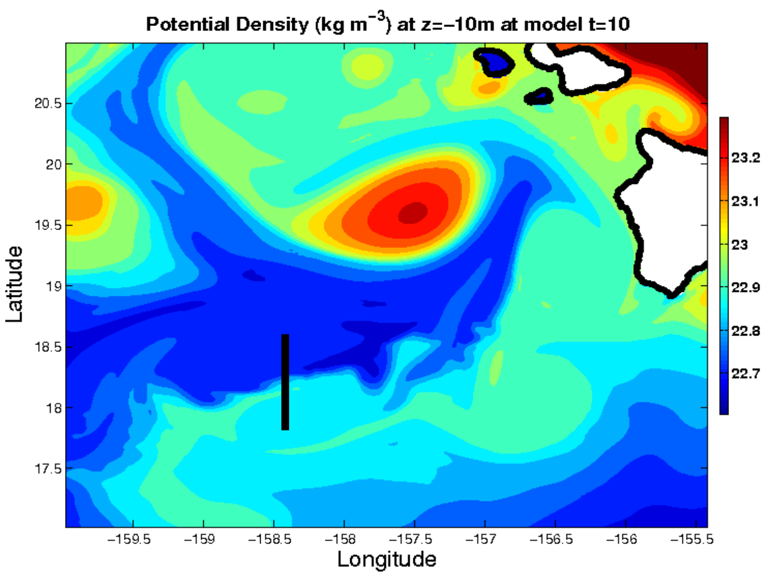
Advection of waters with different biogeochemical characteristics.

Horizontal stirring alone explains a large portion of the bloom evolution.

Signatures of Surface Frontogenesis in Model Simulations in HI







down(up)-welling on the cold(warm) of the front.

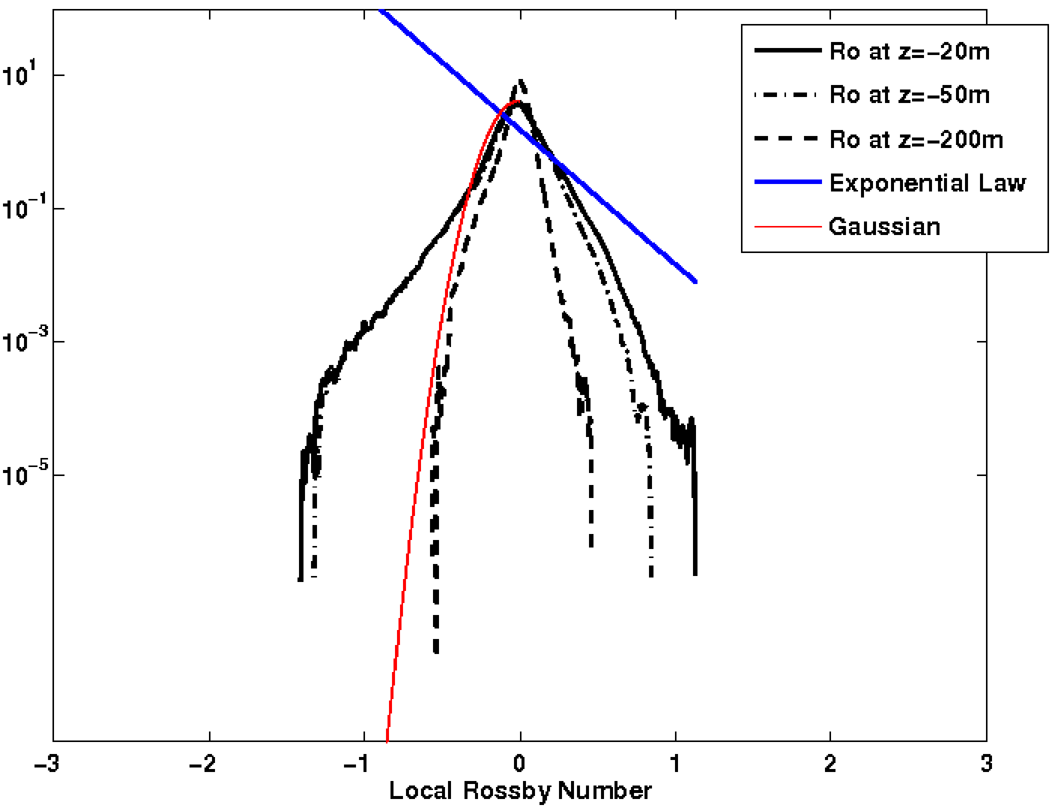
downwelling larger than upwelling.

Tendency to re-stratification (i.e. flattening of the isopycnals).

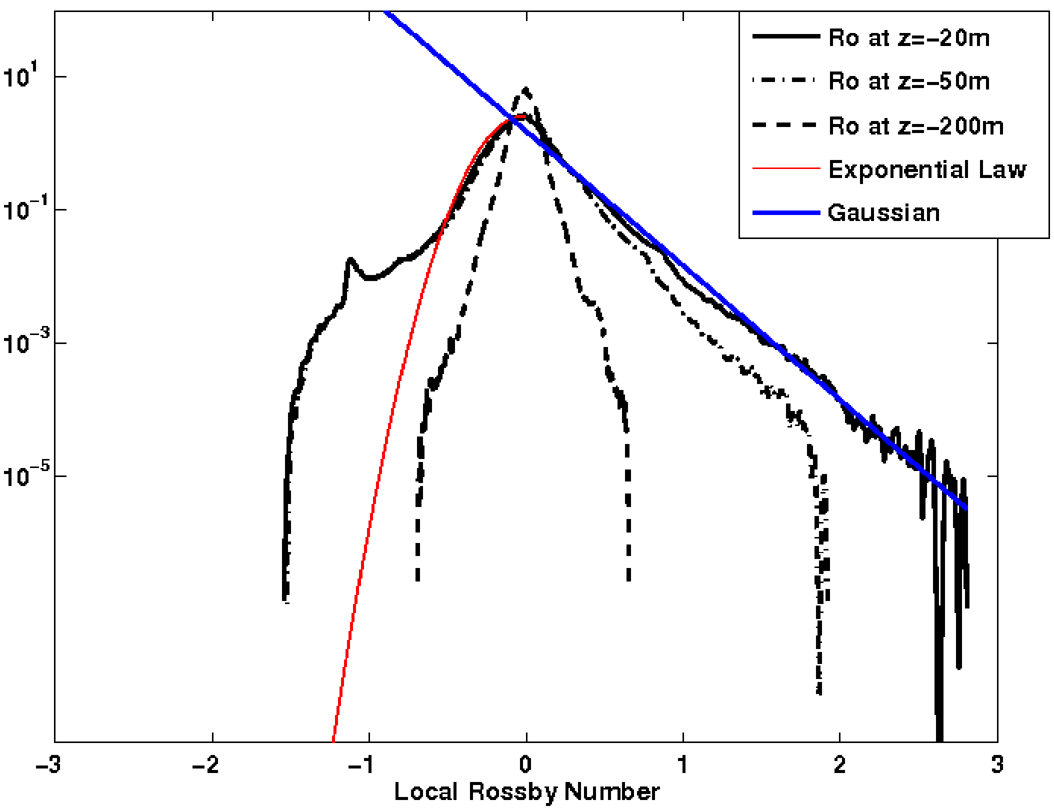
Calil and Richards 2010

At high resolution - positive vorticity bias/ high intermittency

Model Run – 8 km res.



Model Run – 2 km res.



Calil and Richards 2010

$$\frac{D}{Dt}\left(f + \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) = \left(f + \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)\frac{\partial w}{\partial z} \, .$$

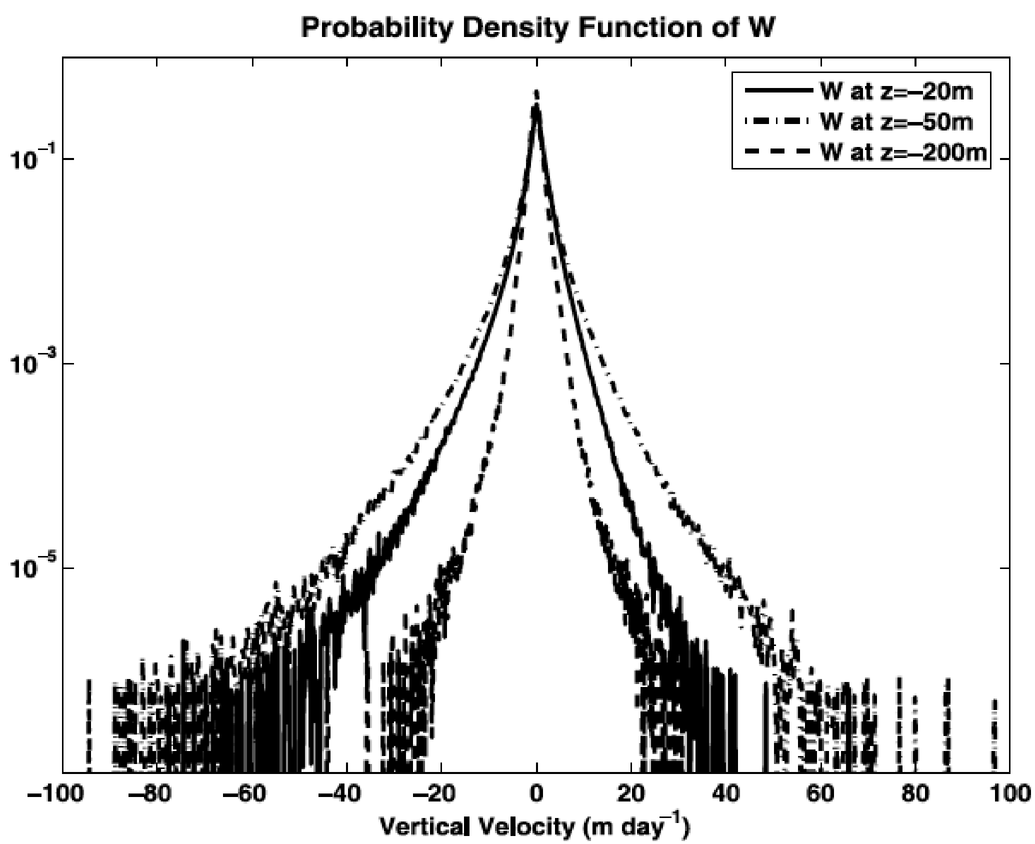
Symmetry in low Ro

Asymmetry:
In the convergence zone: increase in relative vorticity is enhanced in RHS.
Opposite occurs for anticyclonic vorticity

At high resolution - positive vorticity bias/ high intermittency

Model Run – 2 km res.

Intermittency of large, negative vertical velocities.



Calil and Richards 2010

$$\frac{D}{Dt}\left(f+\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)=\left(f+\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}\right)\frac{\partial w}{\partial z}.$$

Symmetry in low Ro

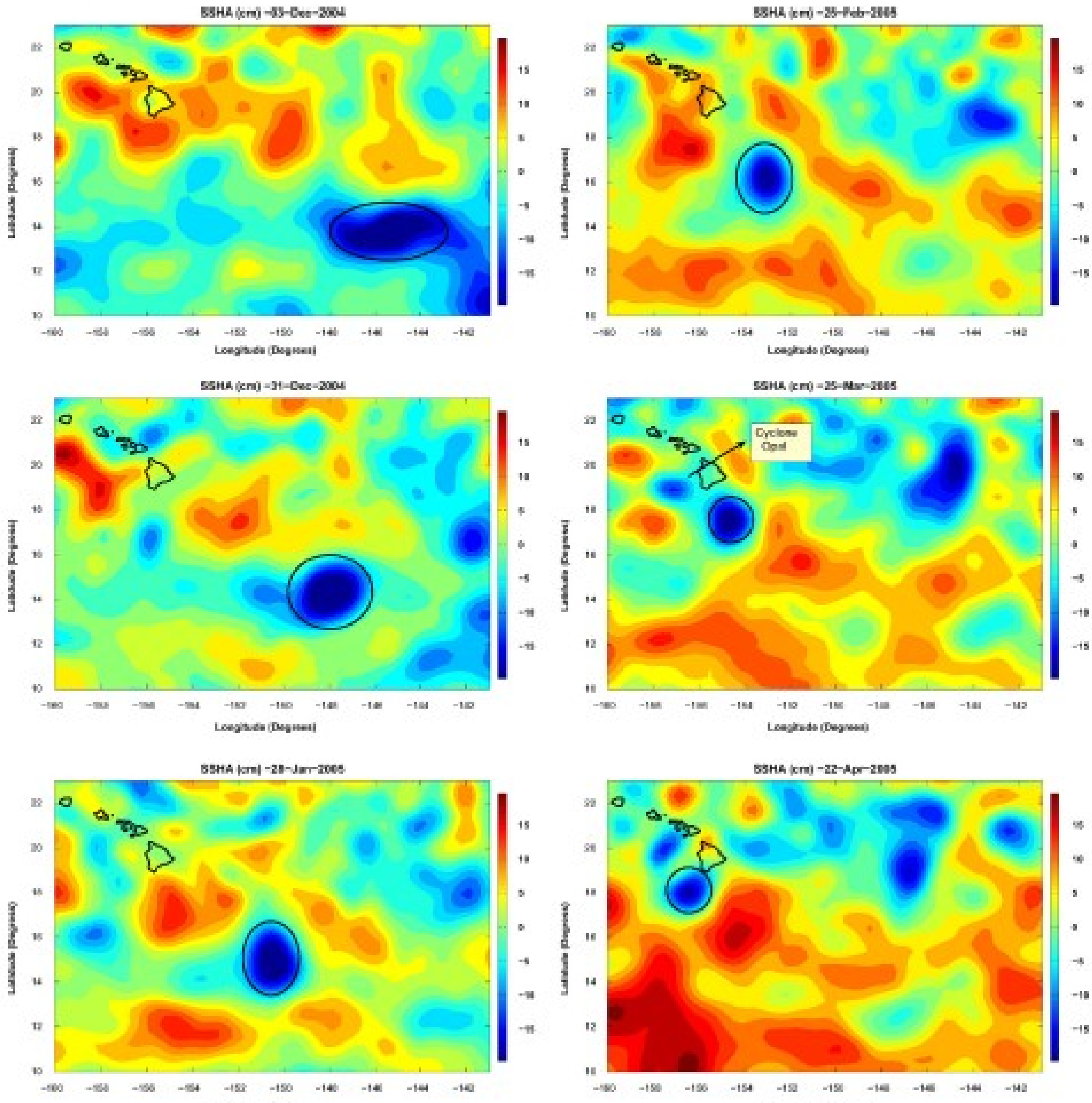
Wang 1993

What Are the Biological Consequences of Resolving Submesoscale Processes in the Oligotrophic Ocean?

Climatologically forced ROMS at 3 resolutions: 10 km, 3 km and 1 km.

Plankton model based on Fasham 1990 : NO3, NH4, SP, LP, SZ, LZ, SD, LD.

Major Caveat(?) : Missing Upstream Variability



Calil et al 2008

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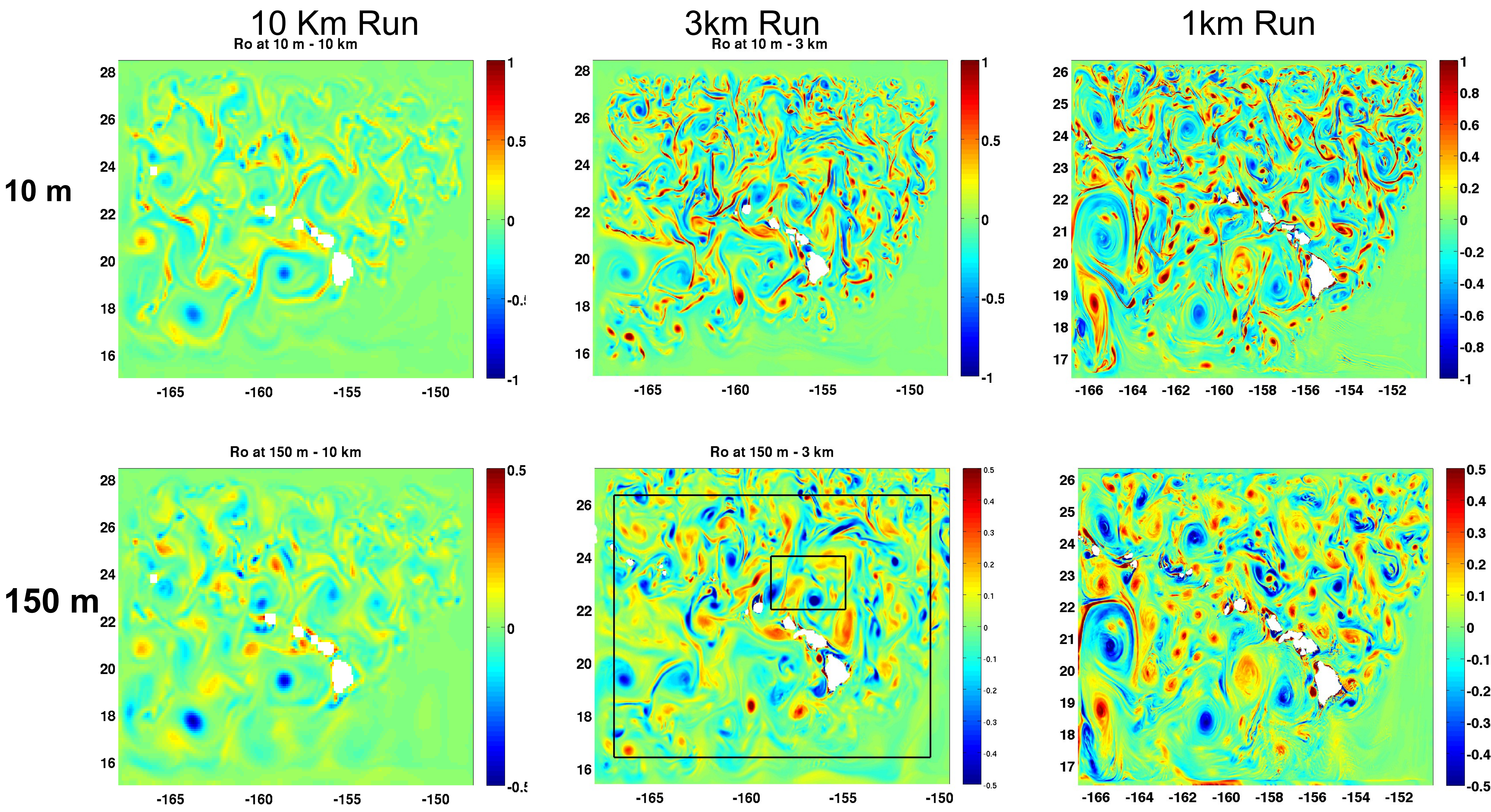
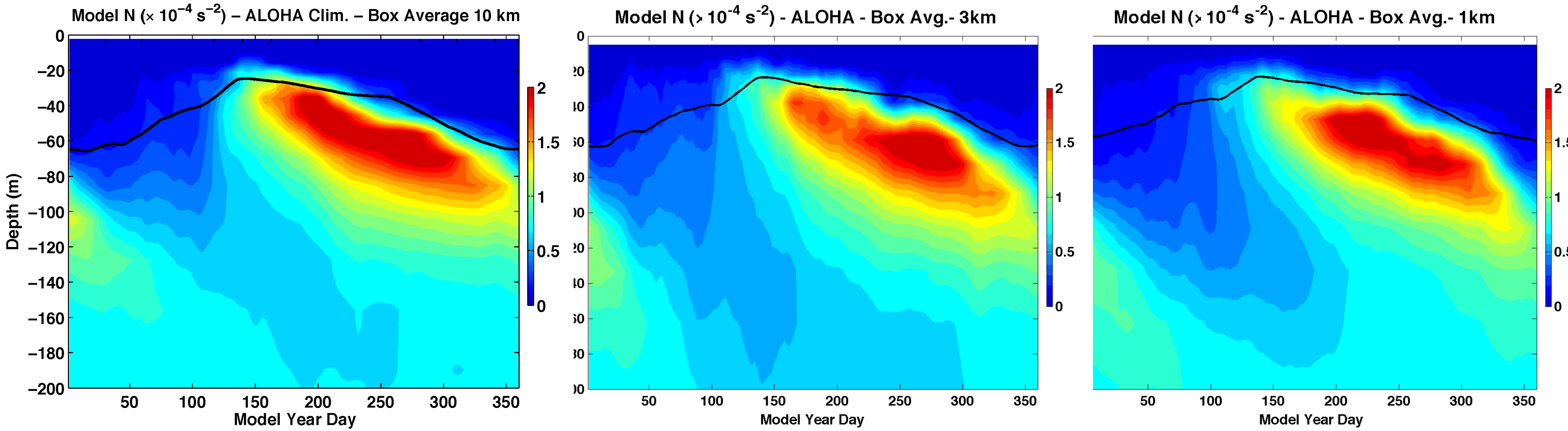


3-year Average – ALOHA Subdomain



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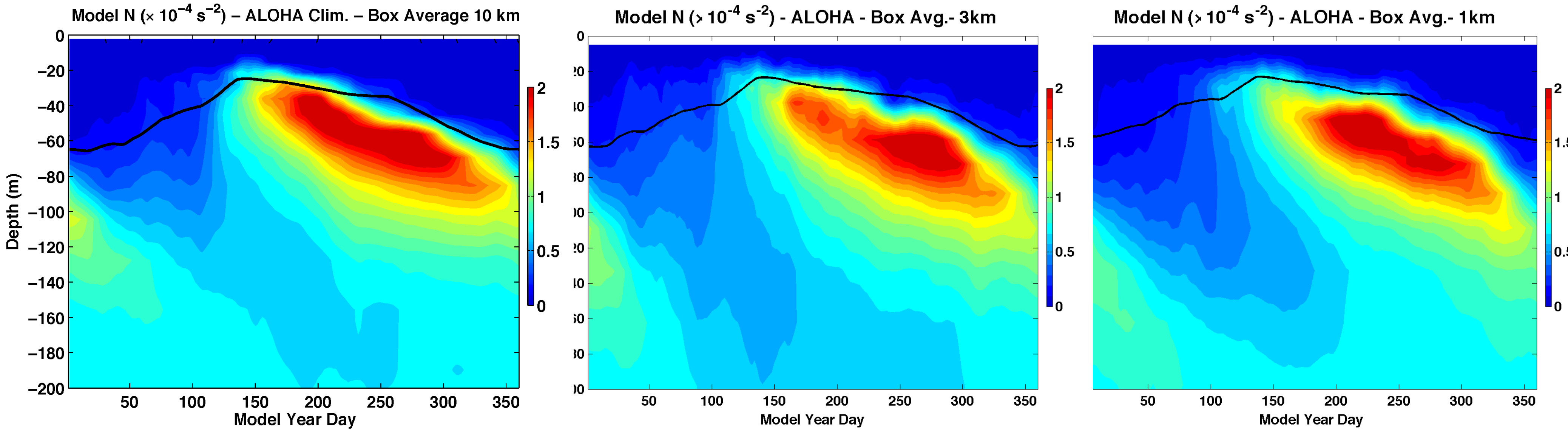
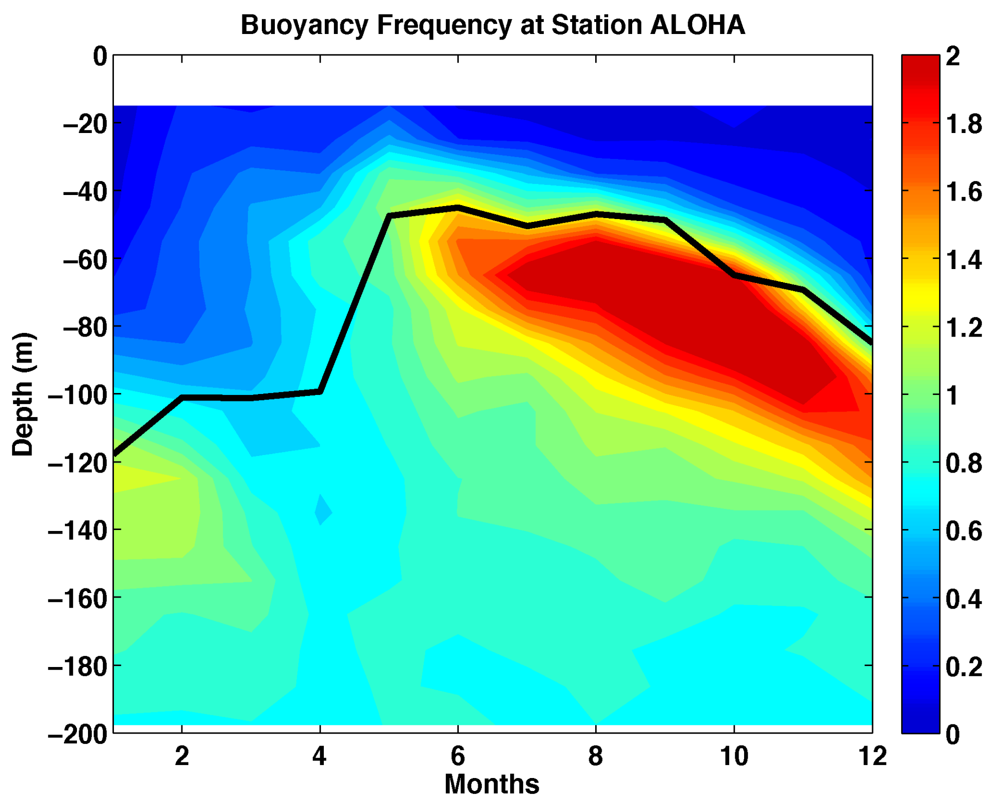
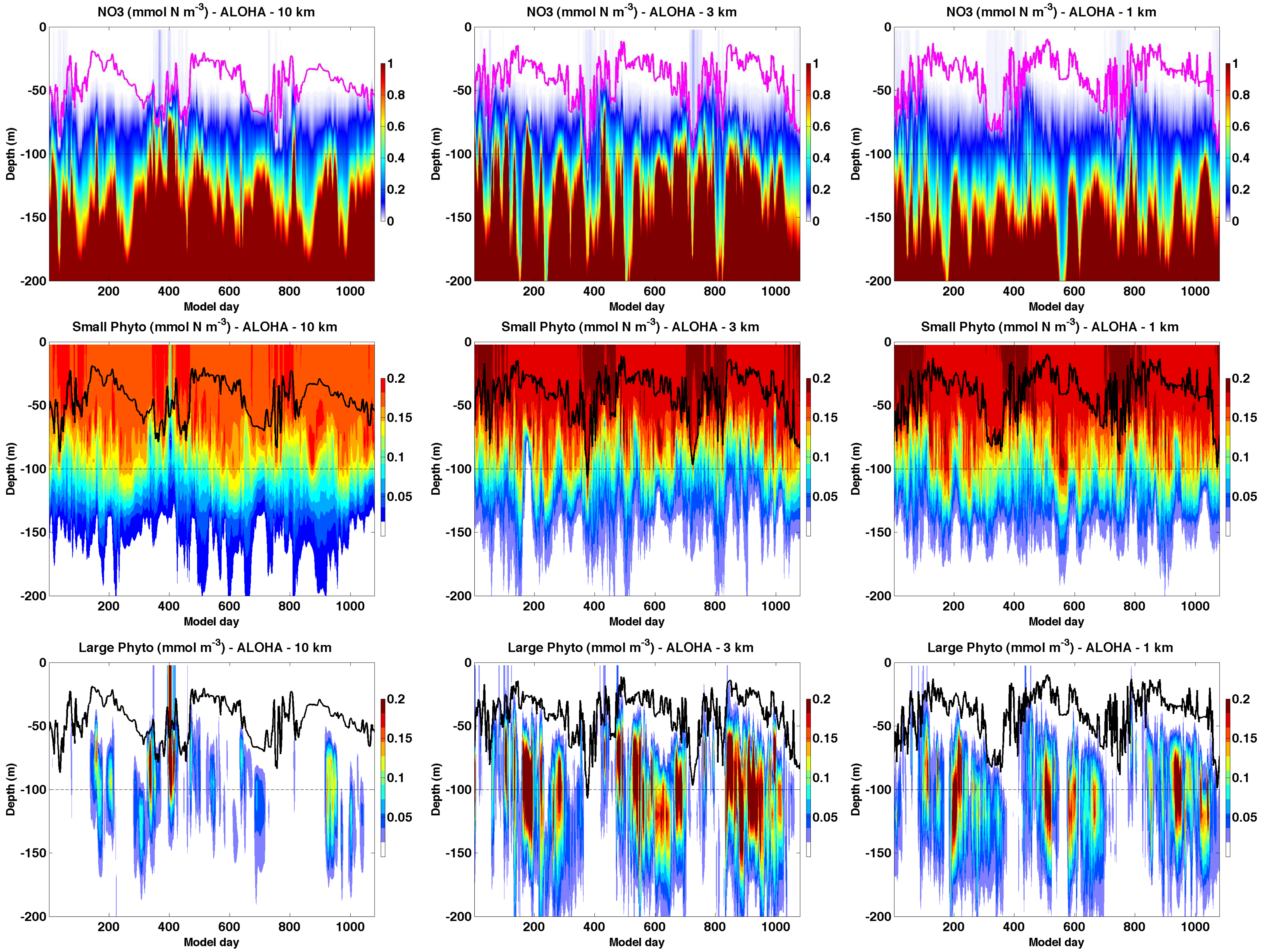
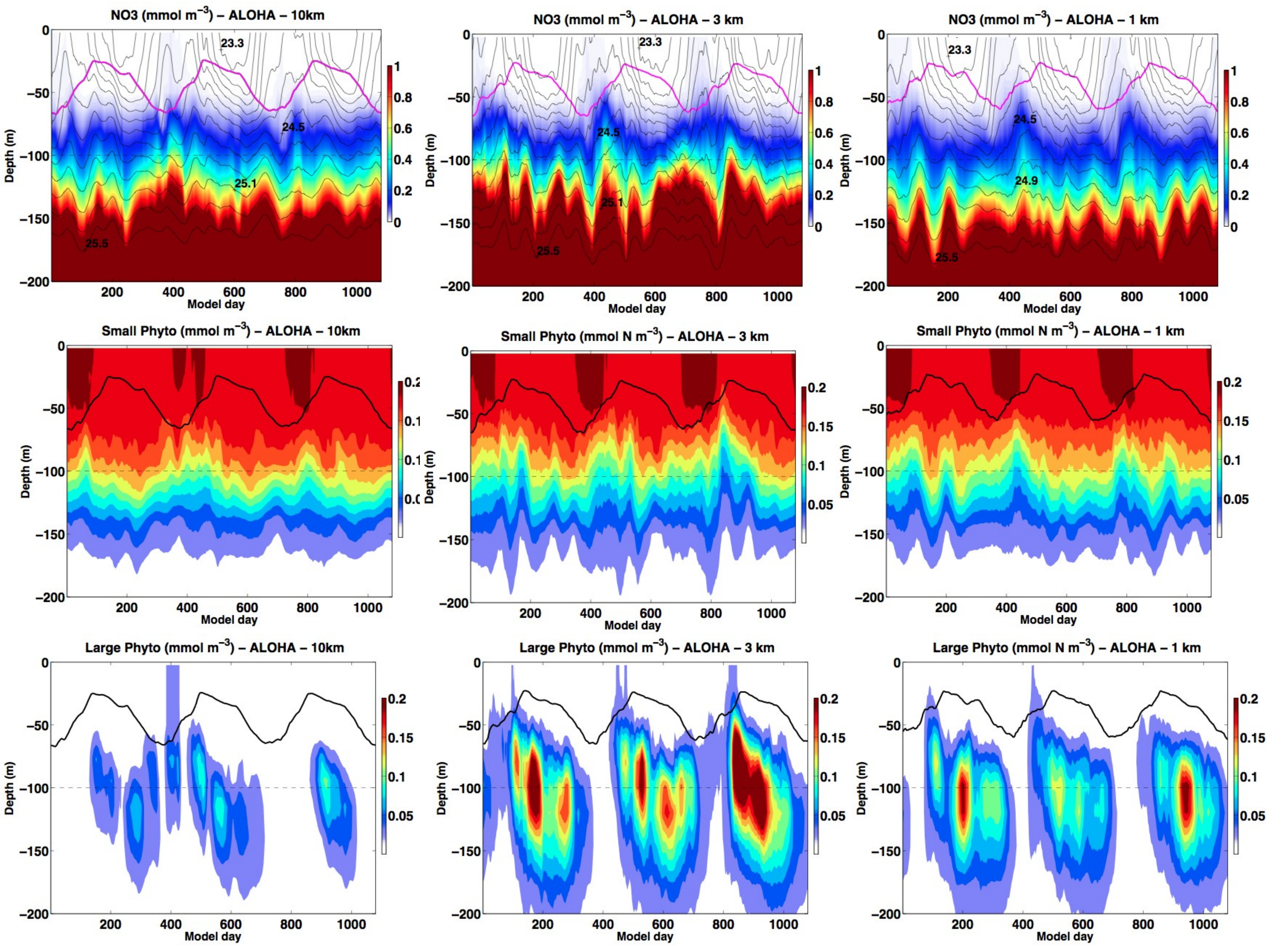
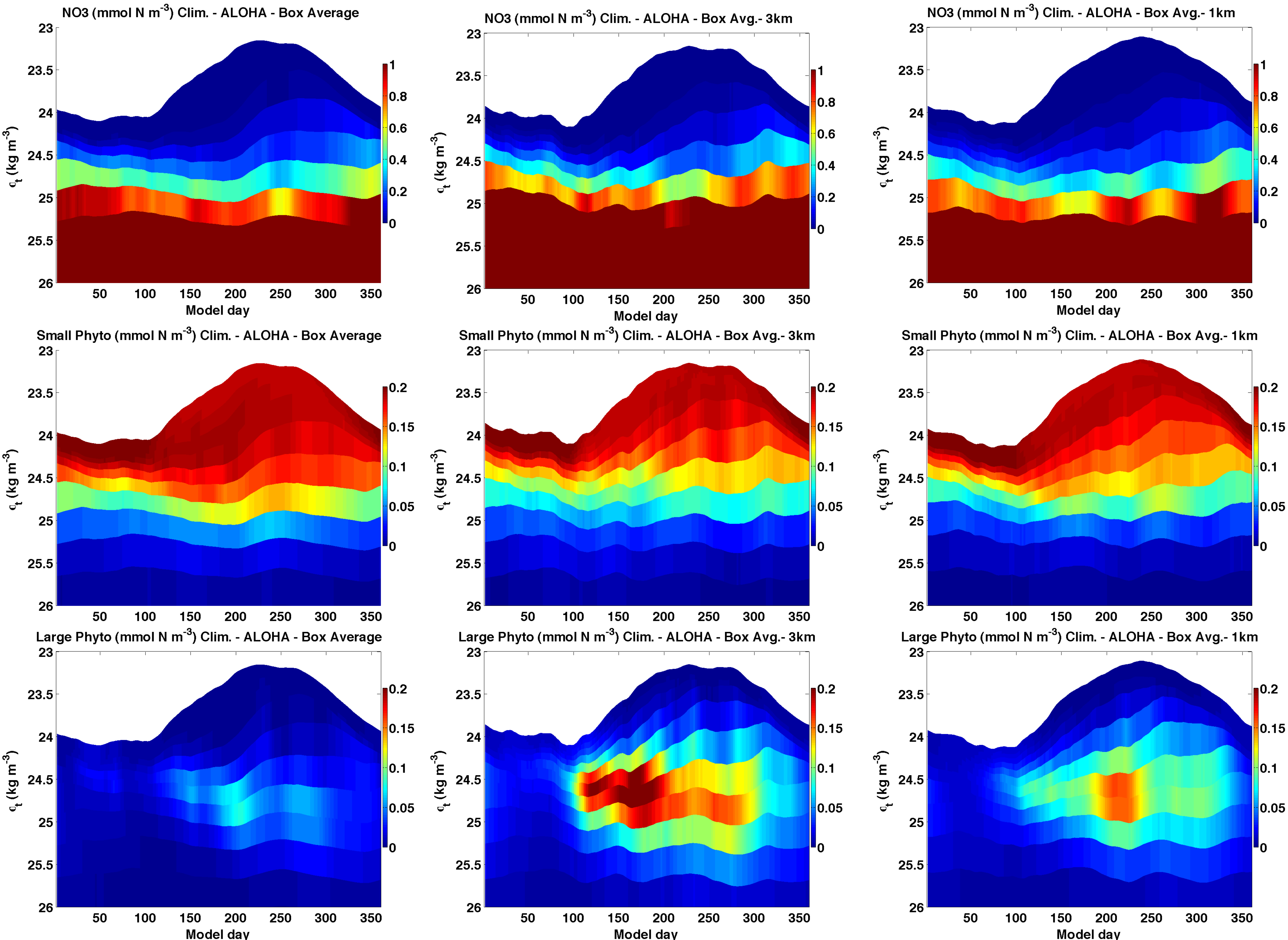




Climatology from HOT Cruises (20 years of monthly data).

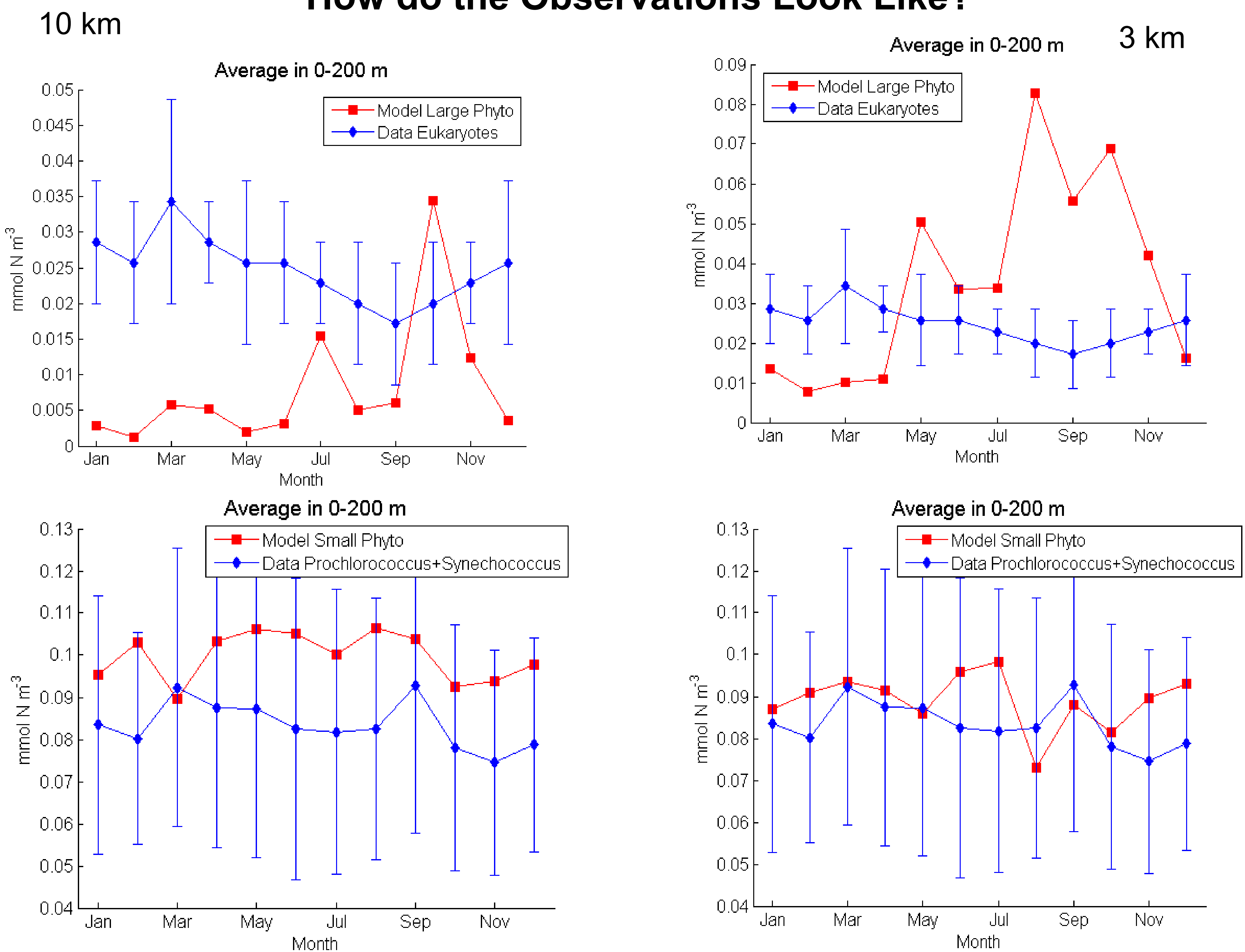

NO3 (mmol N m-3) - ALOHA - 10 km
NO3 (mmol N m-3) - ALOHA - 3 km
NO3 (mmol N m-3) - ALOHA - 1 km
Small Phyto (mmol N m-3) - ALOHA - 10 km
Small Phyto (mmol N m-3) - ALOHA - 3 km
Small Phyto (mmol N m-3) - ALOHA - 1 km
Large Phyto (mmol m-3) - ALOHA - 10 km
Large Phyto (mmol m-3) - ALOHA - 3 km
Large Phyto (mmol m-3) - ALOHA - 1 km
Depth (m)
Model day


NO3 (mmol m−3) – ALOHA – 10km
NO3 (mmol m−3) – ALOHA – 3 km
NO3 (mmol m−3) – ALOHA – 1 km
Small Phyto (mmol m−3) – ALOHA – 10km
Small Phyto (mmol N m−3) – ALOHA – 3 km
Small Phyto (mmol N m−3) – ALOHA – 1 km
Large Phyto (mmol m−3) – ALOHA – 10km
Large Phyto (mmol m−3) – ALOHA – 3 km
Large Phyto (mmol N m−3) – ALOHA – 1 km
Depth (m)
Model day
23.3
24.5
24.9
25.1
25.5

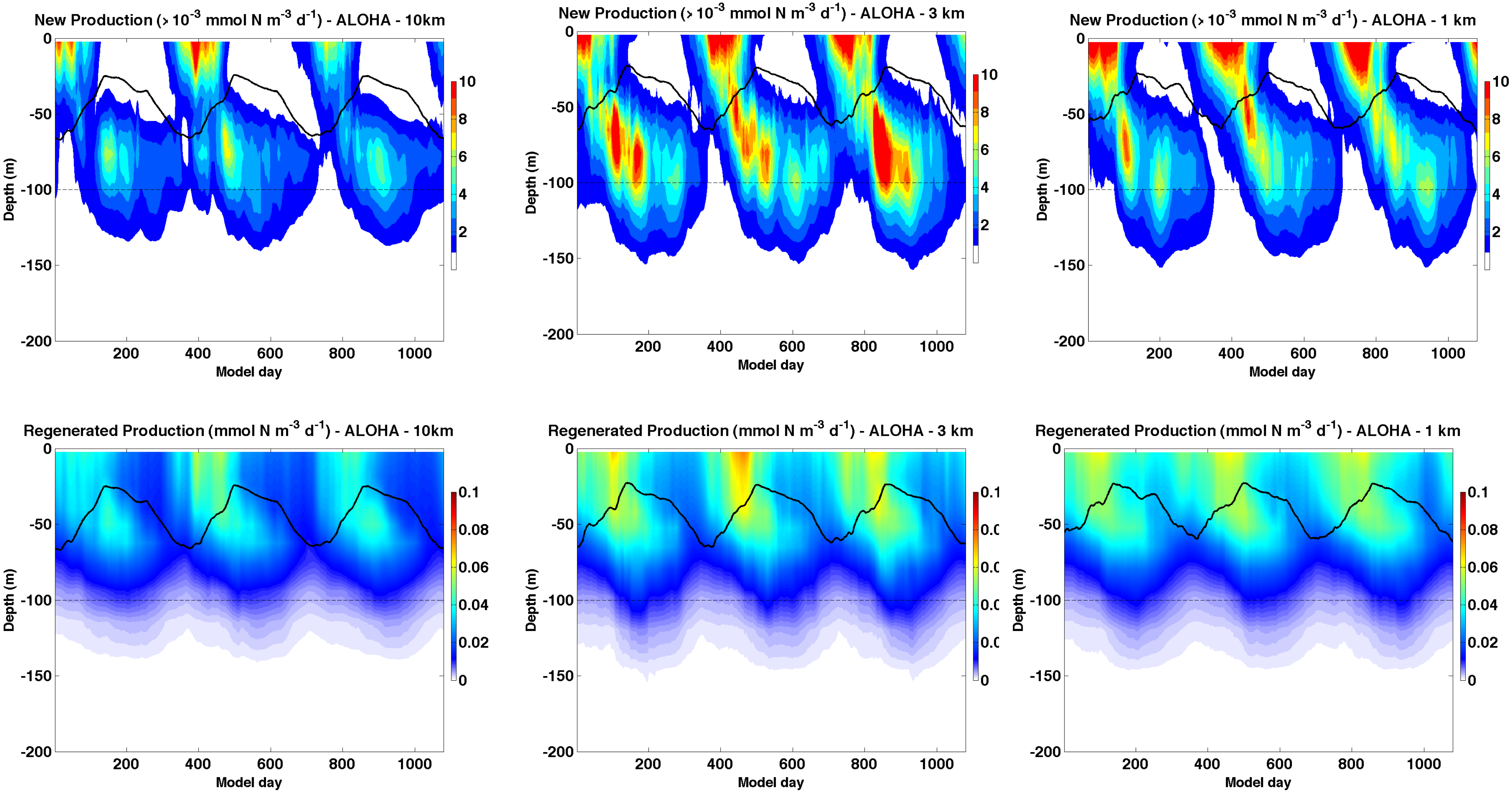


NO3 (mmol N m-3) Clim. - ALOHA - Box Average
NO3 (mmol N m-3) Clim. - ALOHA - Box Avg.- 3km
NO3 (mmol N m-3) Clim. - ALOHA - Box Avg.- 1km
Small Phyto (mmol N m-3) Clim. - ALOHA - Box Average
Small Phyto (mmol N m-3) Clim. - ALOHA - Box Avg.- 3km
Small Phyto (mmol N m-3) Clim. - ALOHA - Box Avg.- 1km
Large Phyto (mmol N m-3) Clim. - ALOHA - Box Average
Large Phyto (mmol N m-3) Clim. - ALOHA - Box Avg.- 3km
Large Phyto (mmol N m-3) Clim. - ALOHA - Box Avg.- 1km
σt (kg m-3)
Model day

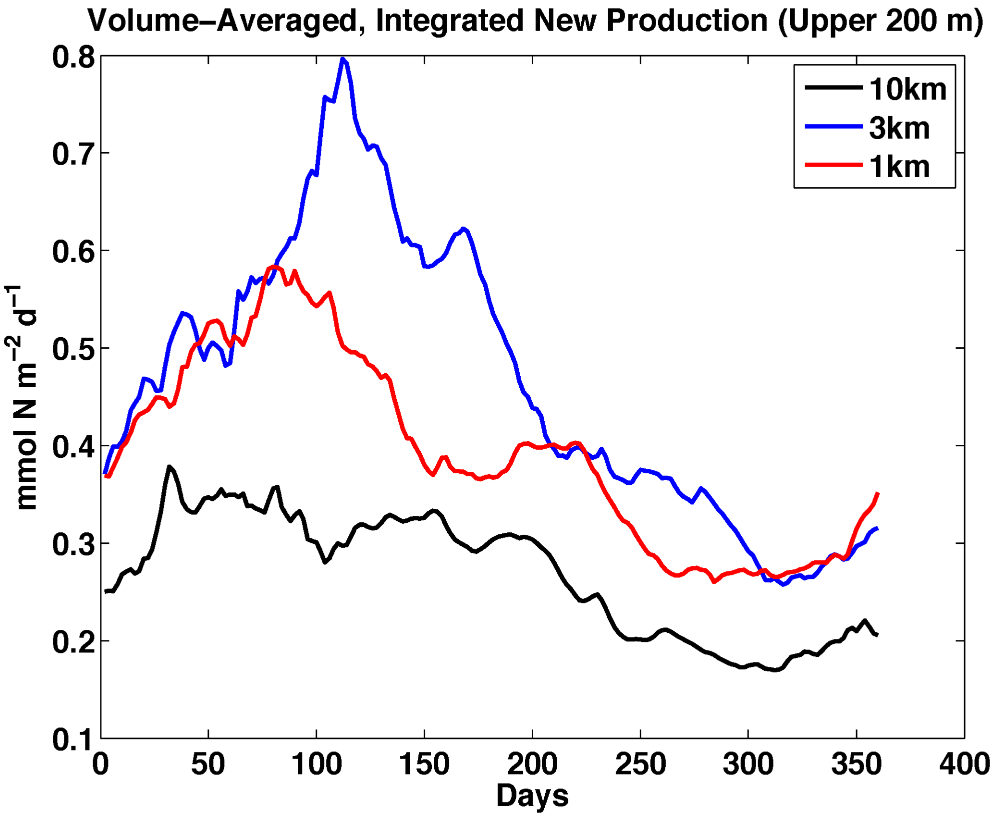
How do the Observations Look Like?

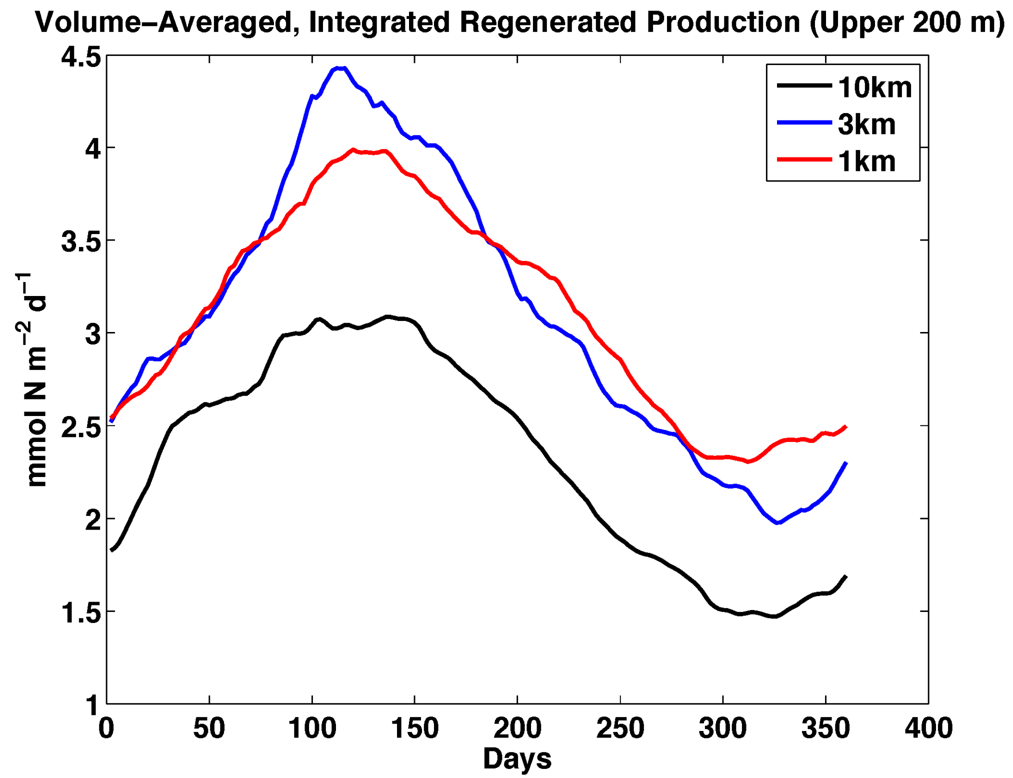


New and Regenerated Production



New, Regenerated and Export Production – ALOHA Subdomain

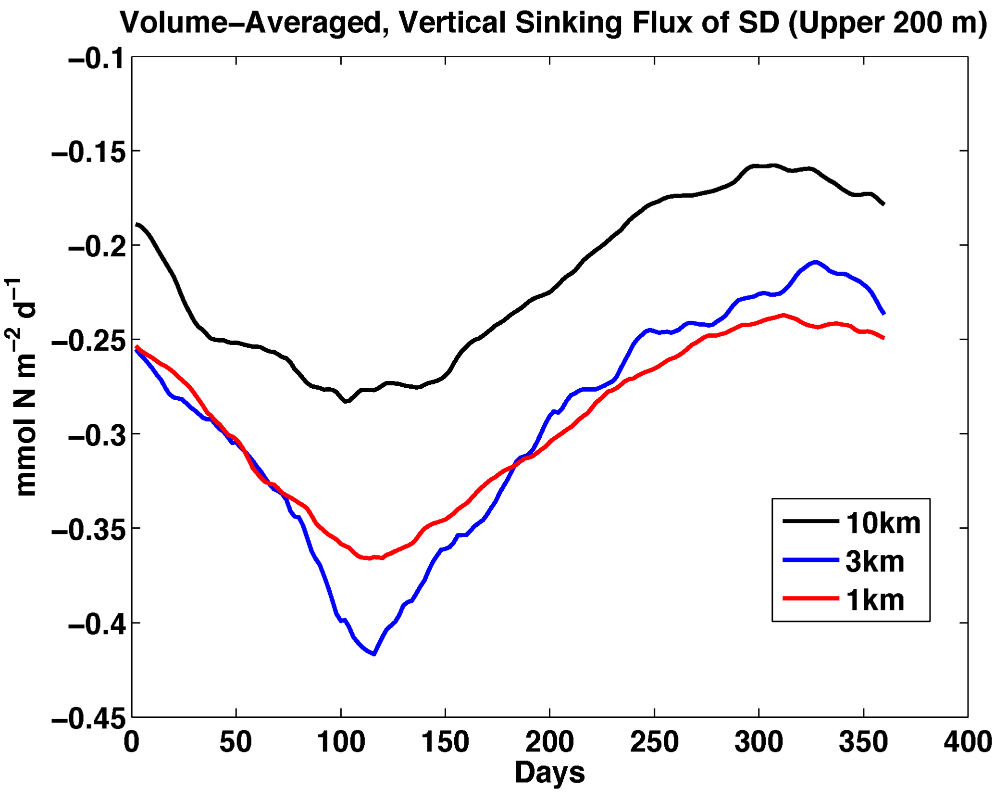


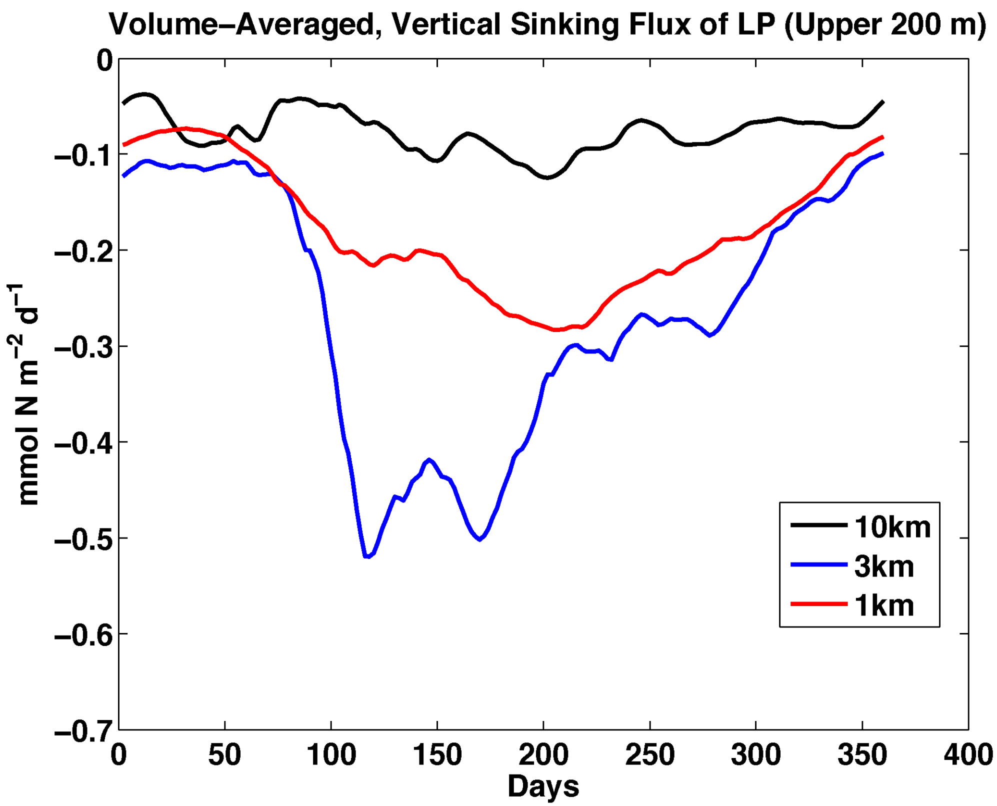


C:N ~ 7 yields new production values of ~ 60 mg C m-2 d-1
Regenerated Production ~ 500 mg C m-2 d-1

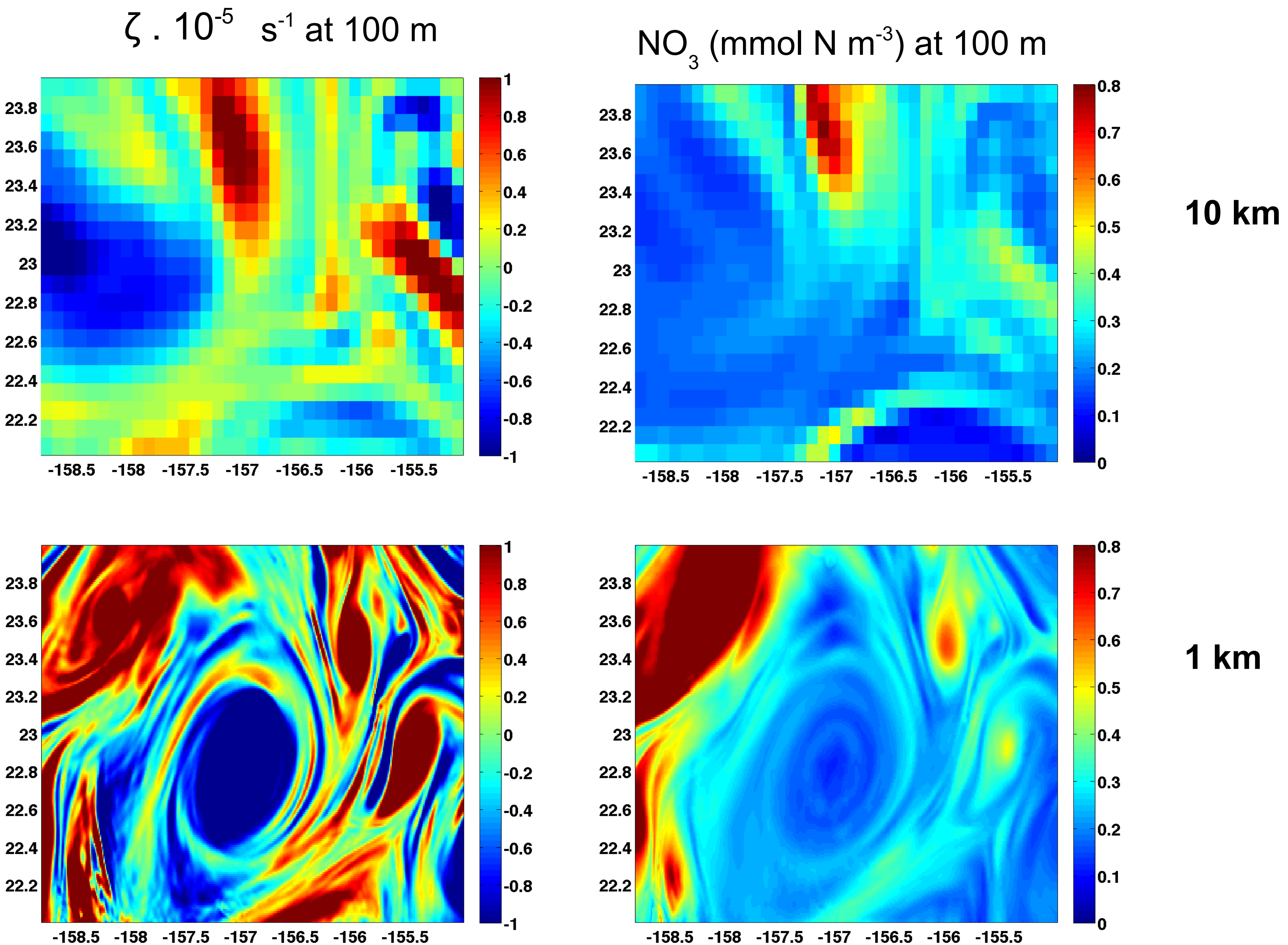
Average values measured at Station ALOHA ~ 600 mg C m-2 d-1

New, Regenerated and Export Production – ALOHA Subdomain





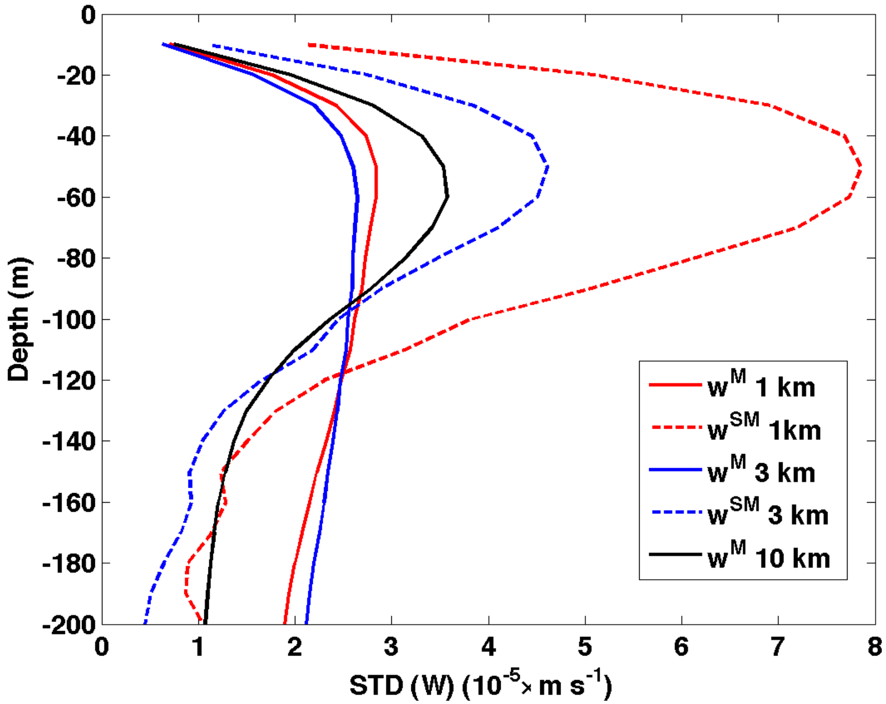
Correspondence Between Nitrate and Relative Vorticity



Meso- and Submesoscale Contribution to Vertical Fluxes

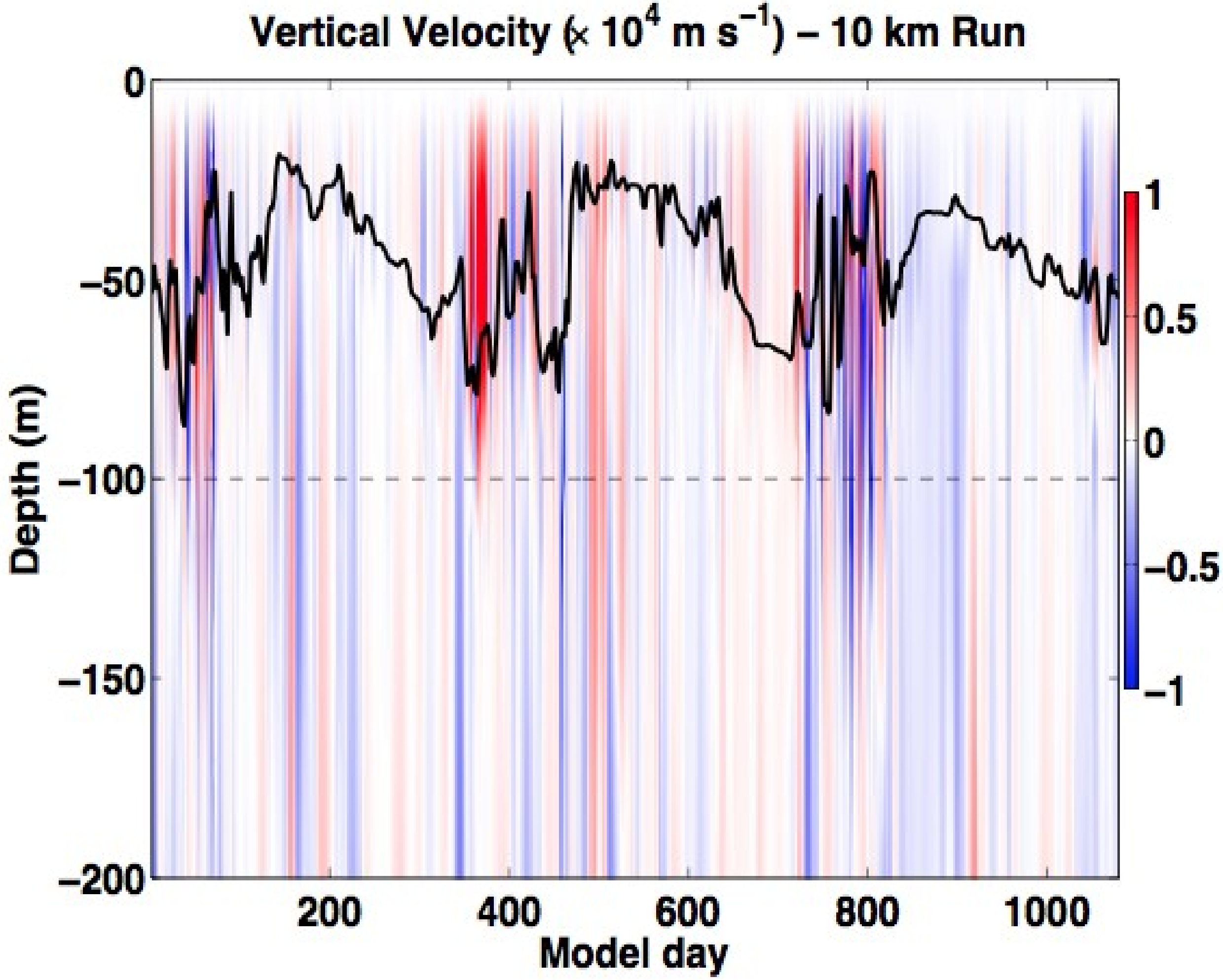
$$V = \overline{V} + \underbrace{(\tilde{V} - \overline{V})}_{V'} + \underbrace{(V - \tilde{V})}_{V''}.$$

Capet, Molemaker et al 2008

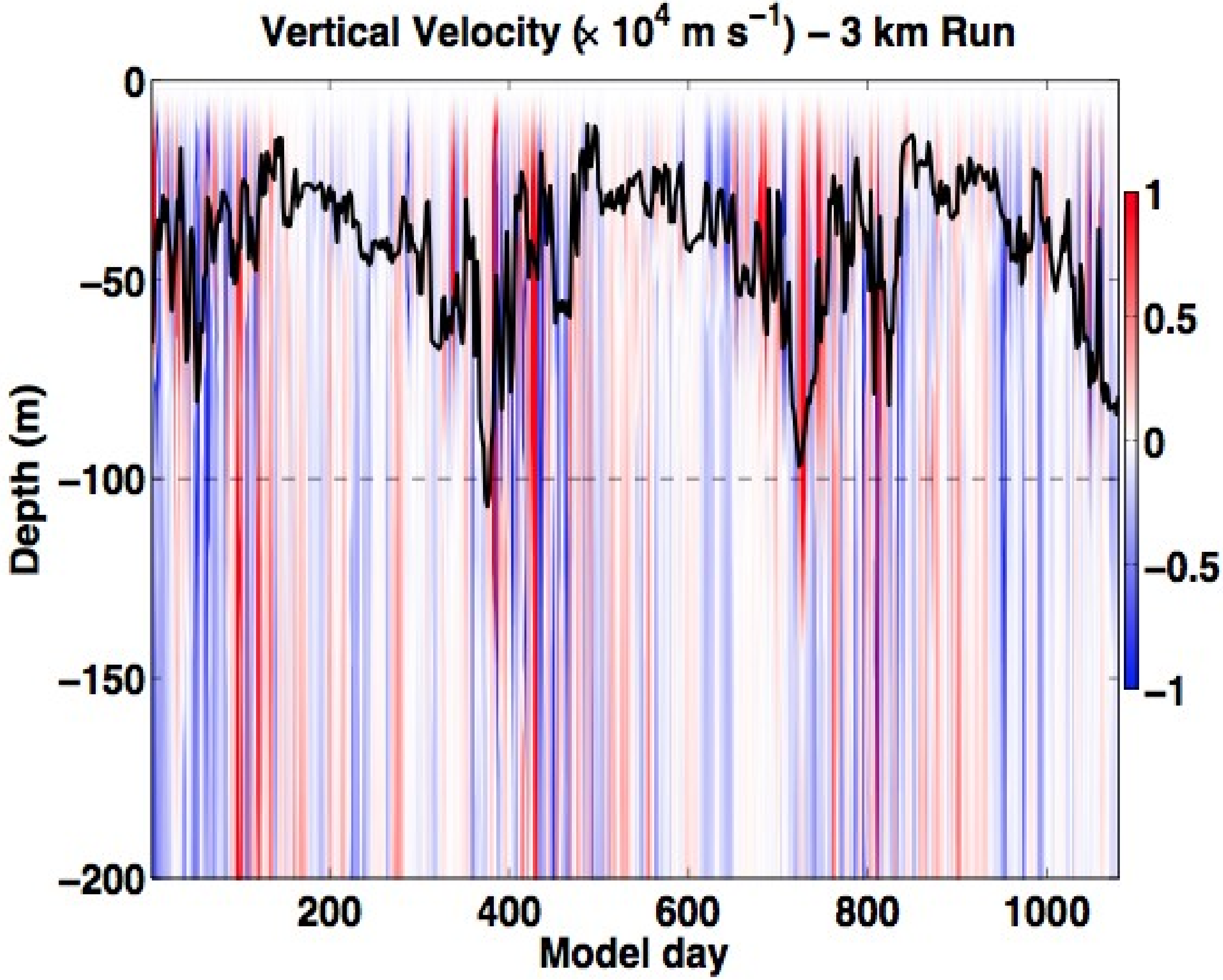


Vertical velocity variance goes preferentially to the submesoscale in the upper .

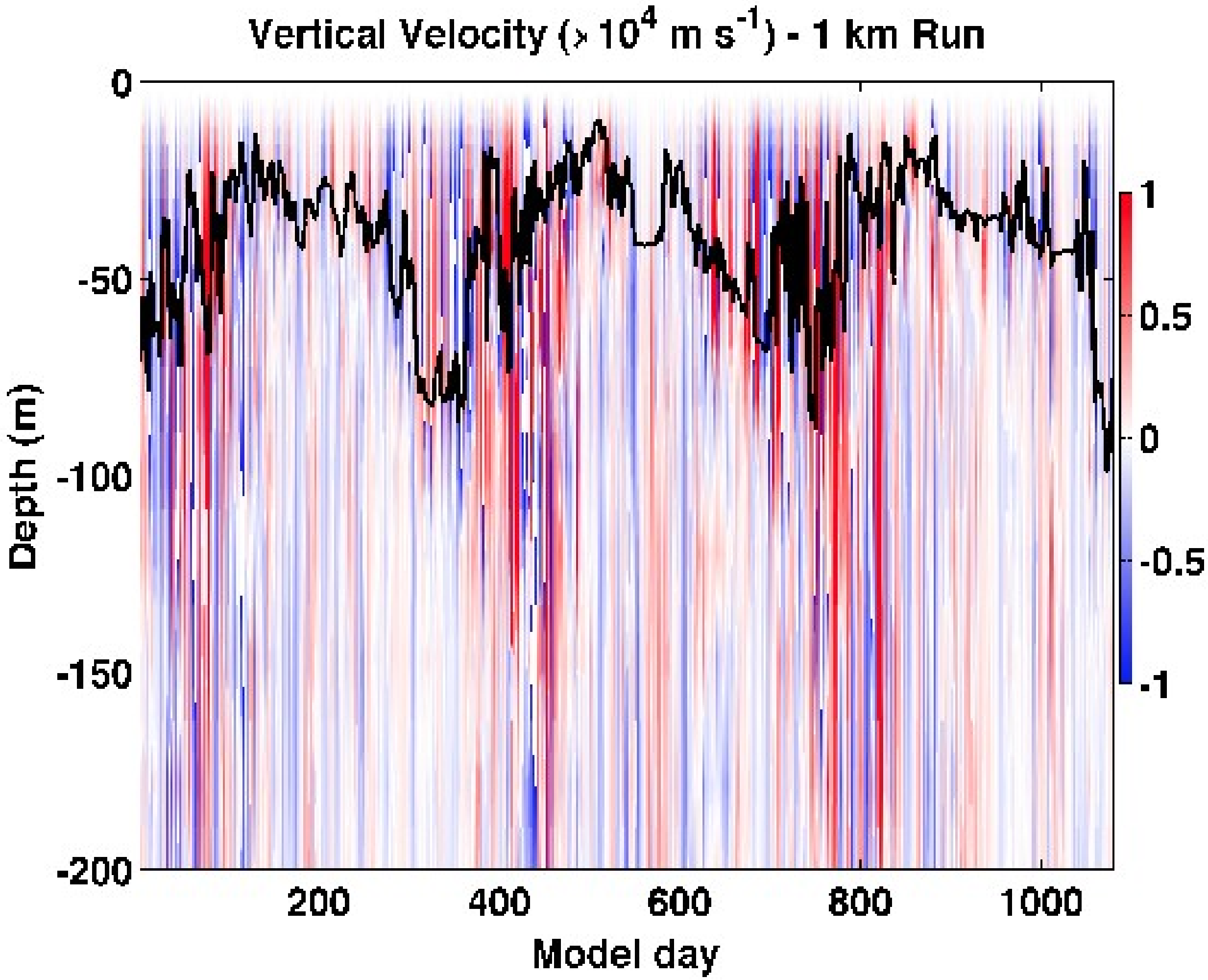
Over-estimation of subsurface mesoscale in high-resolution runs?



Vertical Velocity (× 10^4 m s^−1) – 10 km Run
Depth (m)
0
−50
−100
−150
−200
200
400
600
800
1000
Model day
1
0.5
0
−0.5
−1



Vertical Velocity (× 10⁴ m s⁻¹) – 3 km Run
0
−50
−100
−150
−200
Depth (m)
200
400
600
800
1000
Model day
1
0.5
0
−0.5
−1

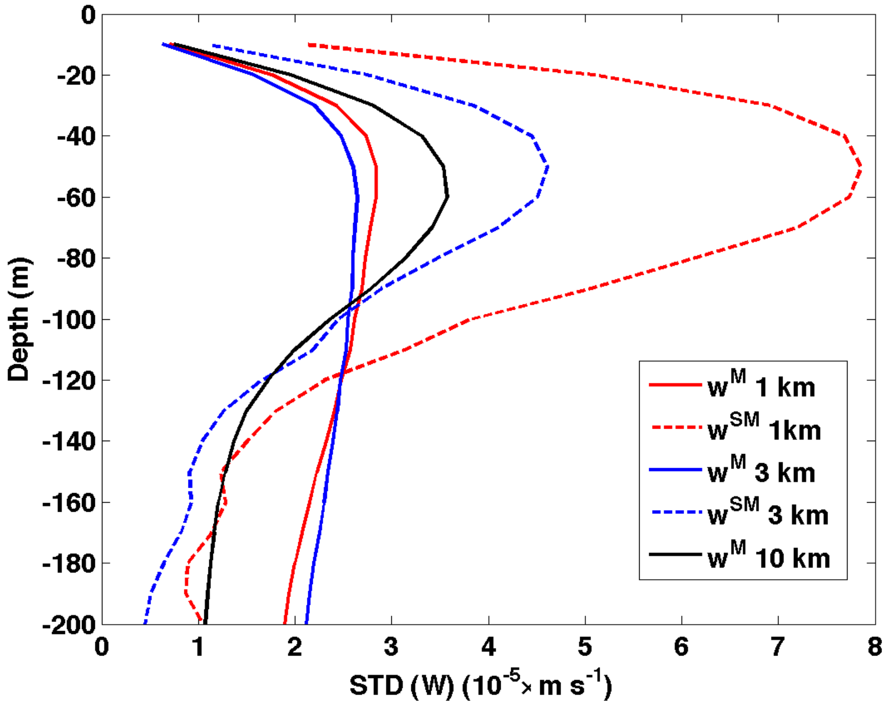


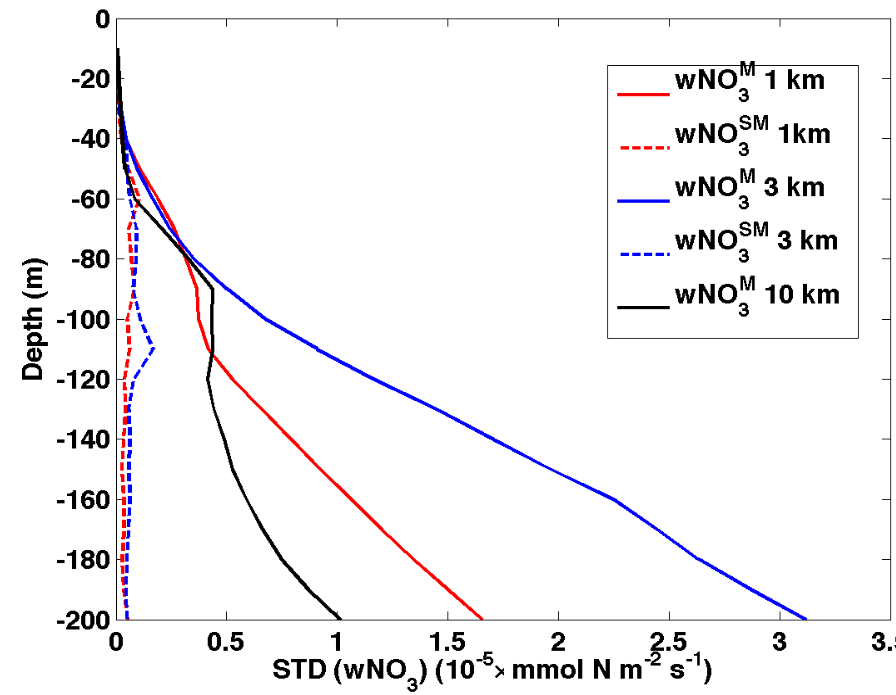
Vertical Velocity (× 10⁴ m s⁻¹) - 1 km Run
0
-50
-100
-150
-200
Depth (m)
200
400
600
800
1000
Model day
1
0.5
0
-0.5
-1

Meso- and Submesoscale Contribution to Vertical Fluxes

$$V = \overline{V} + \underbrace{(\tilde{V} - \overline{V})}_{V'} + \underbrace{(V - \tilde{V})}_{V''}.$$

Capet, Molemaker et al 2008





Vertical velocity variance goes preferentially to the submesoscale.

Over-estimation of subsurface mesoscale in high-resolution runs?

Too much submesoscale in mesoscale components?

“Meso” fluxes at higher resolutions larger than “meso” at 10 km.

Very low nitrate values in the upper 100 m also make it problematic.

Summary

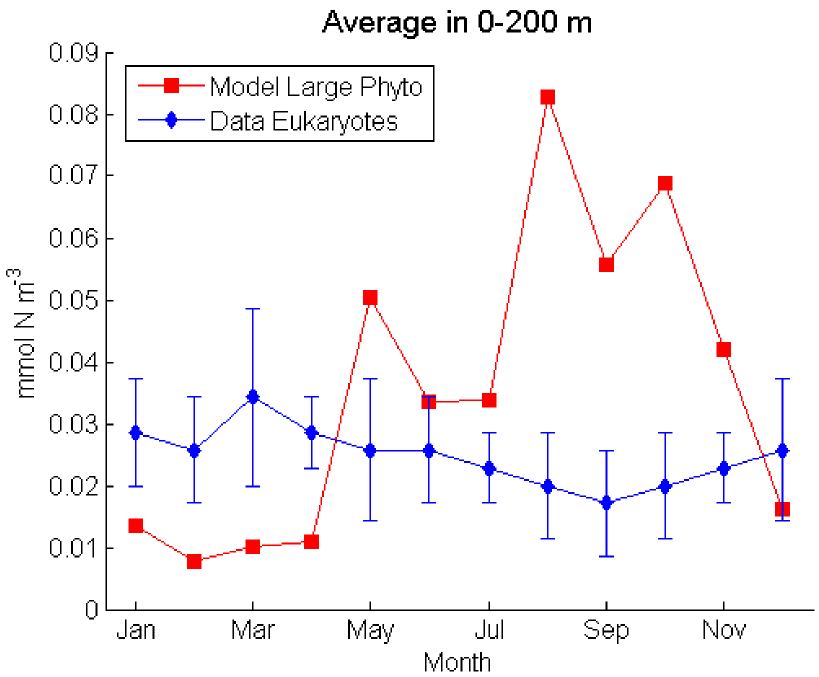
An increase in episodic events is observed in the high resolution runs.

High NO_3 values are usually associated with positive vorticity patches and filaments. Episodic injections associated with large straining increase productivity (consistent with previous idealized modeling studies).

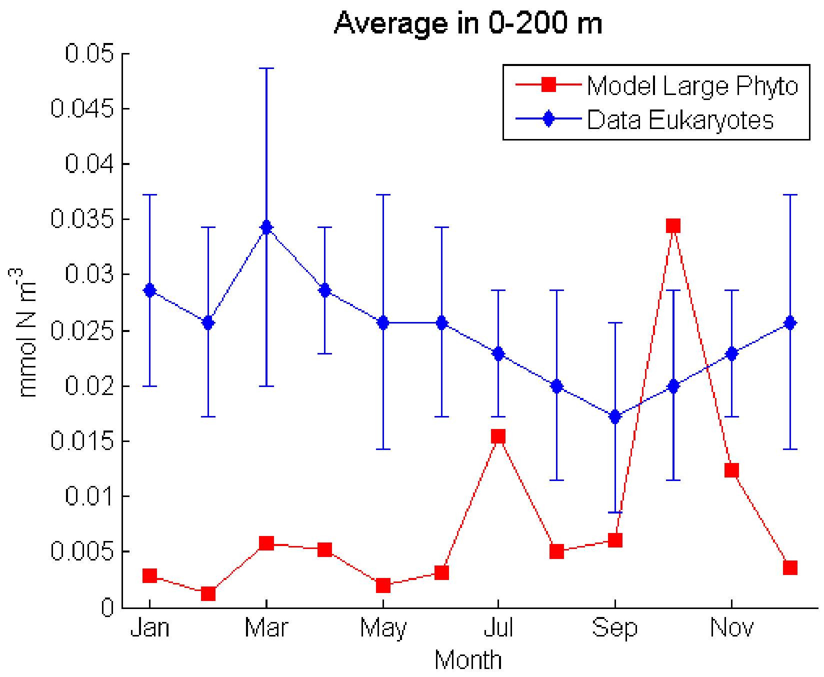
Food-web structure is altered by the emergence of large phytoplankton species in the high resolution runs. Large species located in the lower euphotic zone. Consistent with observations of a two-layer ecosystem structure.

Implications for N_2-fixation : In regions where the NO_3:PO_4 ratio is low, episodic injections supply more PO_4 than NO_3. In the summertime, the high stratification associated with episodic PO_4 injections could ignite blooms of diazotrophs.

Model-Data Comparison

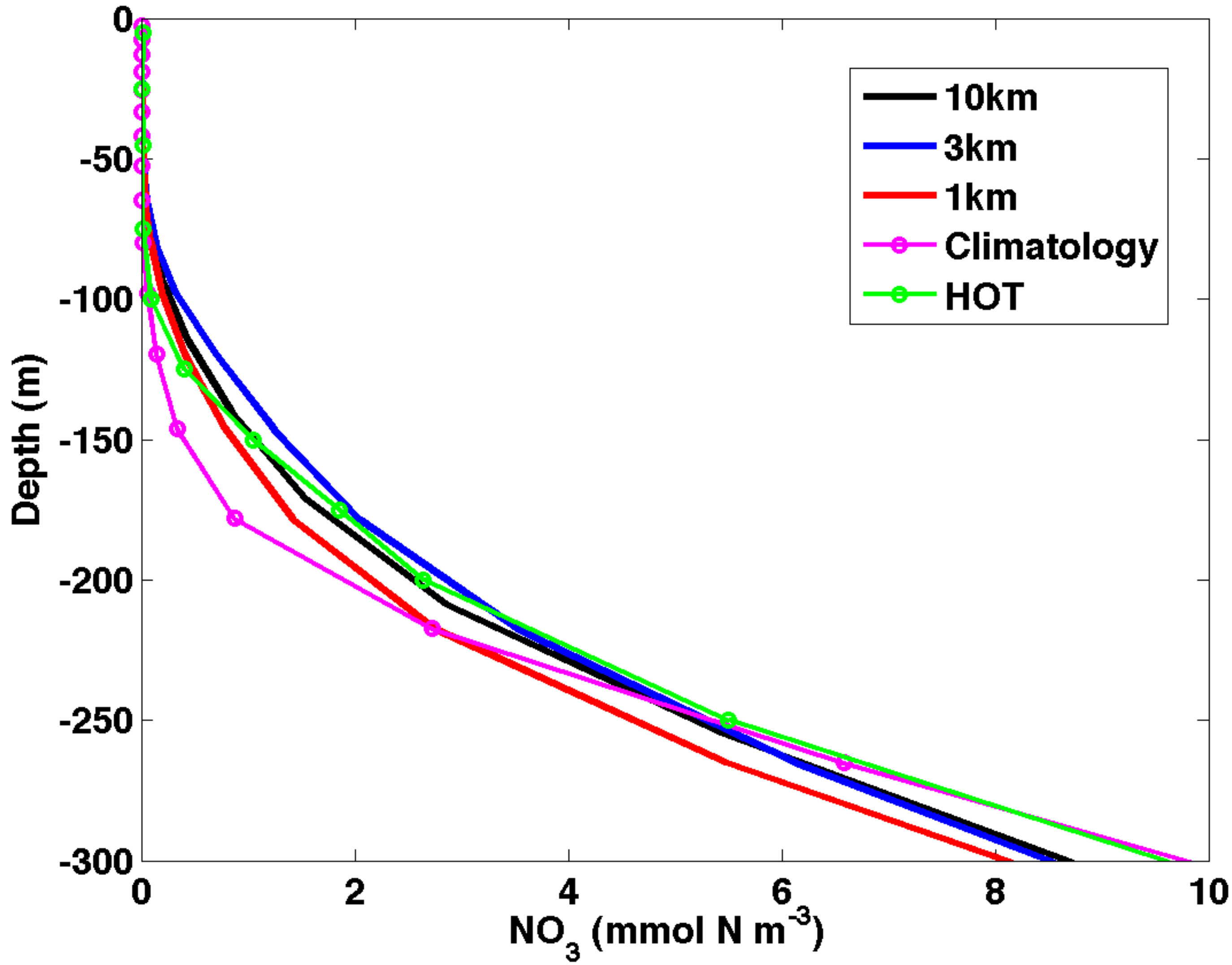


3km

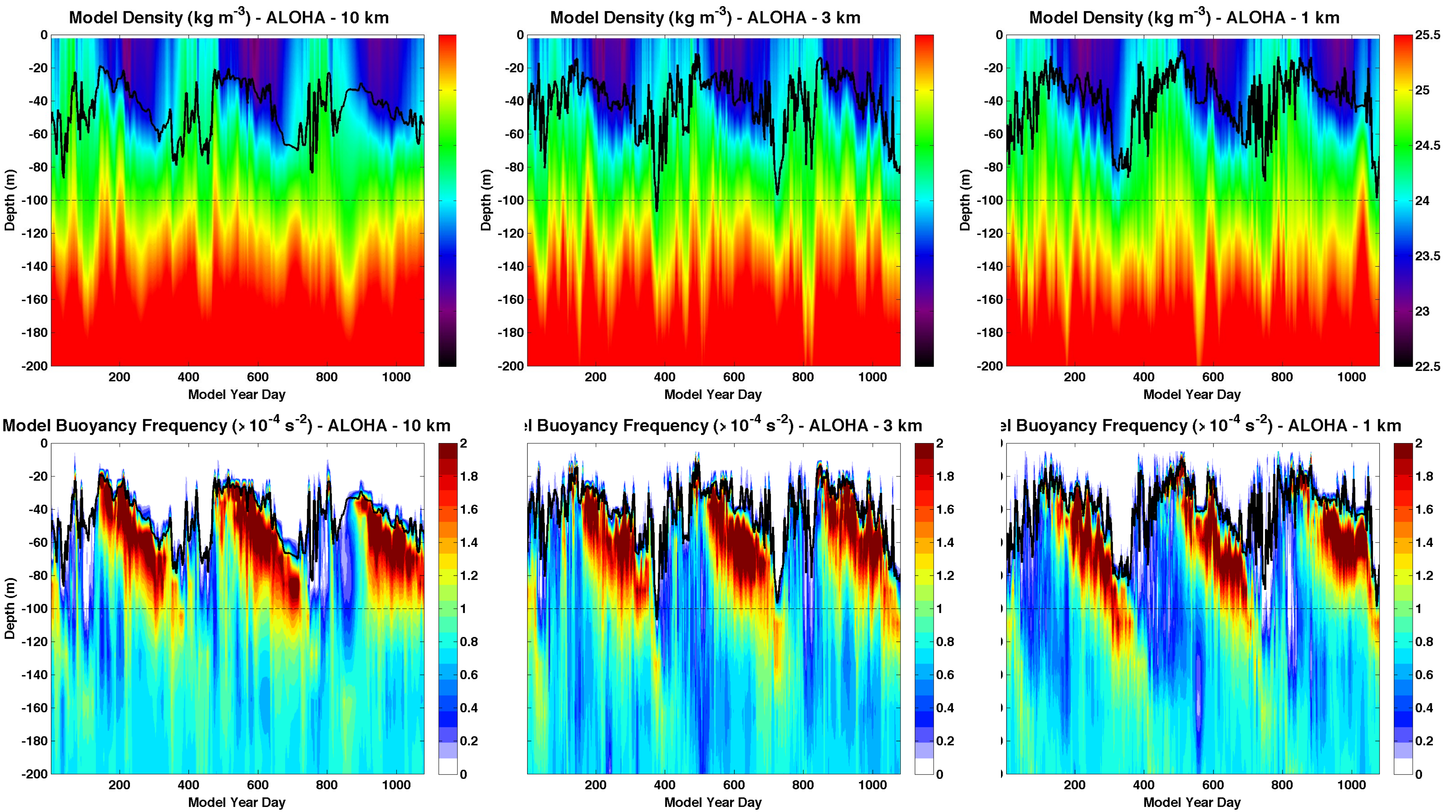


10km

Mean Nitrate Profile Comparison – Subdomain ALOHA



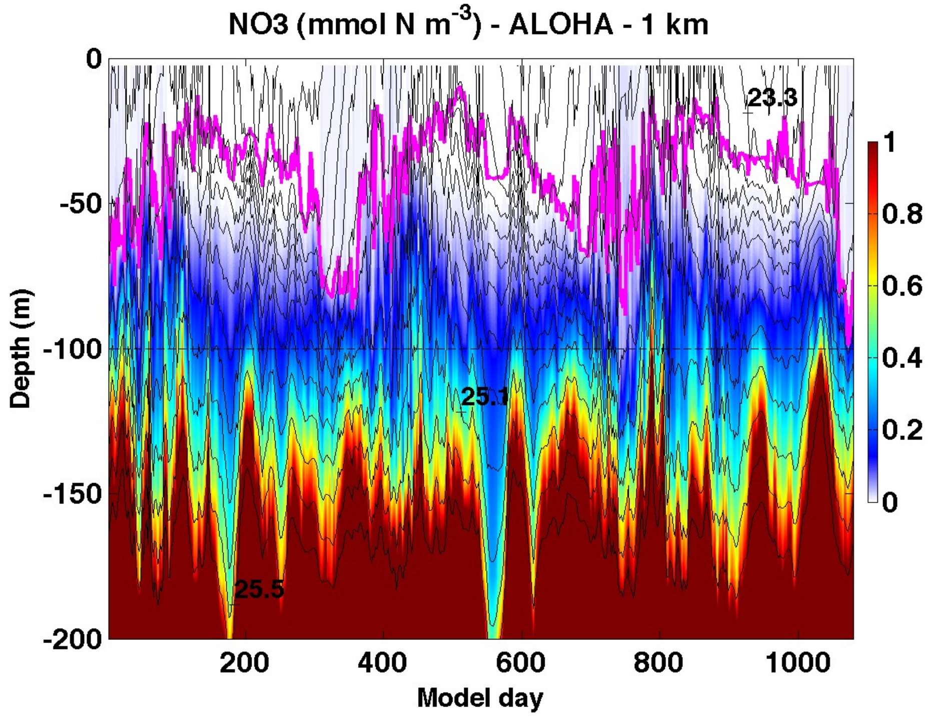
Time-Series – Vertical Profile of Single Grid-Point

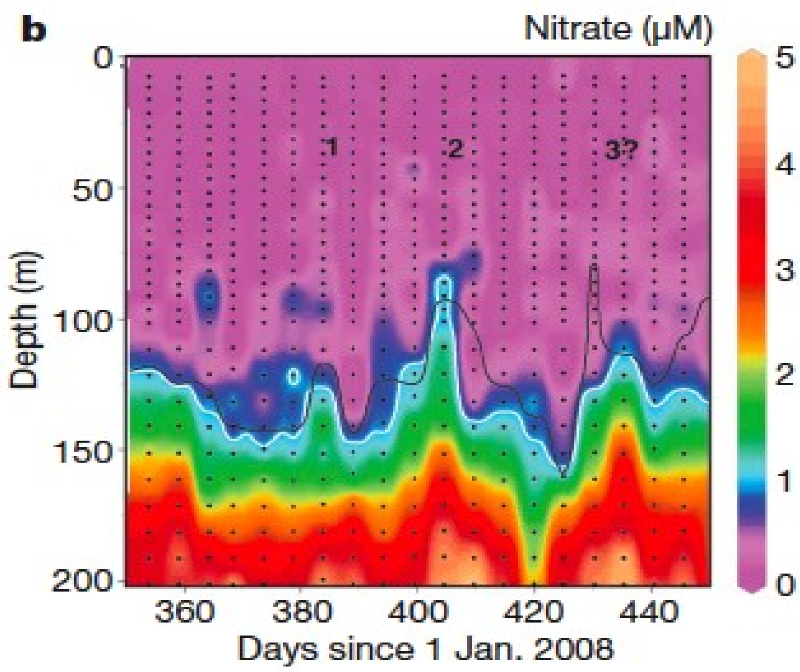


Episodic NO3 injections

Frequency of events is increased (15 vs 4)

As in Johnson et al 2010 – surface NO3 is extremely low in the upper 100m





Some seasonality. More events during winter, but some events during summertime (mostly subsurface).