How accurately can we predict chlorophyll concentrations in the Northeast Pacific: the role of ecosystem model complexity and data assimilation?

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Motivation

"Marine Ecosystem Model Inter-comparison Project"

Ecosystem model complexity

- Do more complex ecosystem model formulations lead to more reliable ecosystem predictions?

Model parameterization

- Robustness of model solutions to parameterization
- Which parameters control variability in model solutions?

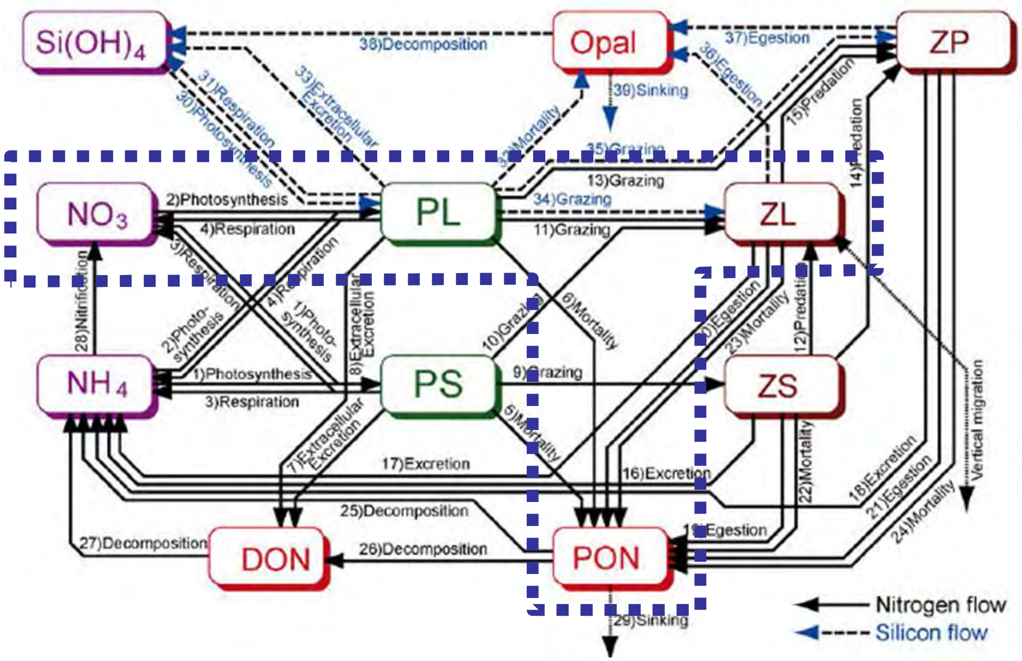
Data assimilation

- Do more reliable ocean circulation estimates lead to more reliable ecosystem predictions?

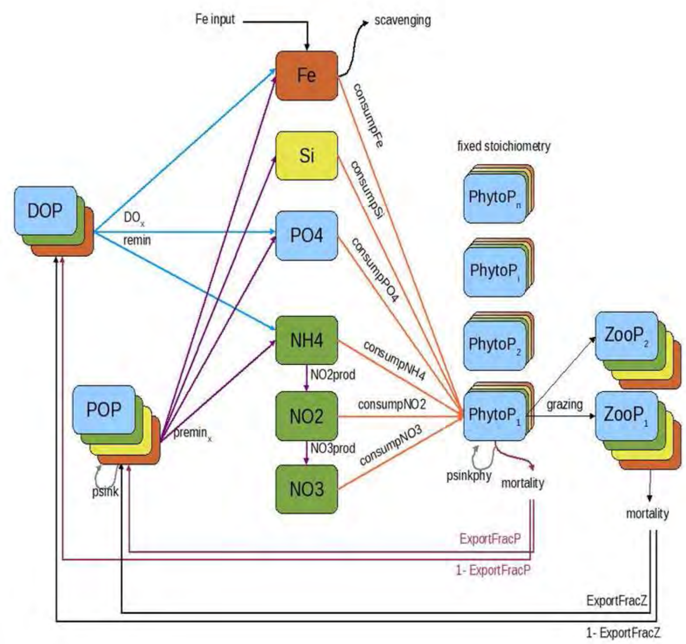
Lower Trophic Level Ecosystem Models

Similar NPZD-type formulation, different levels of complexity

- 4 components NPZD model (Powell et al., 2006)
- 11 components NEMURO model (Kishi et al., 2007)
- ~90 components “Darwin” model (Follows et al., 2007)
- Iron limitation for NPZD and NEMURO (Fiechter et al. 2009)



NEMURO / NPZD



Darwin

CGOA: Coupled Physical-Biological ROMS Model

ROMS ocean model

- 10 km horizontal resolution
- 42 terrain-following vertical levels

Boundary/initial conditions

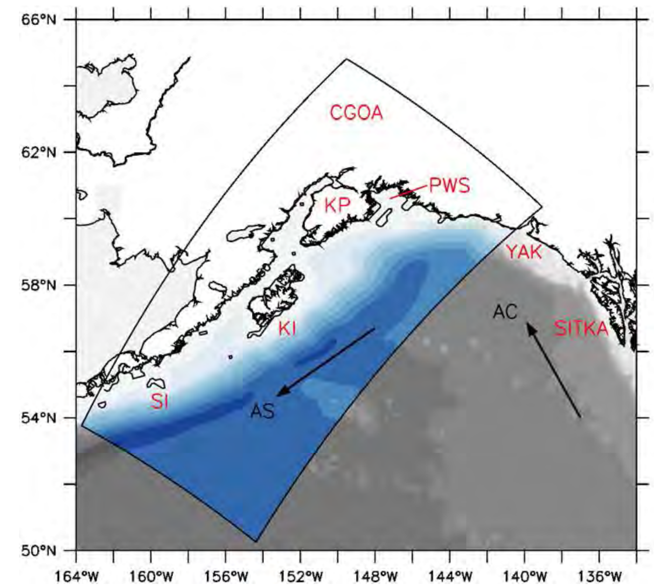
- Northeast Pacific (NEP) ROMS
  (Curchitser et al., 2005)

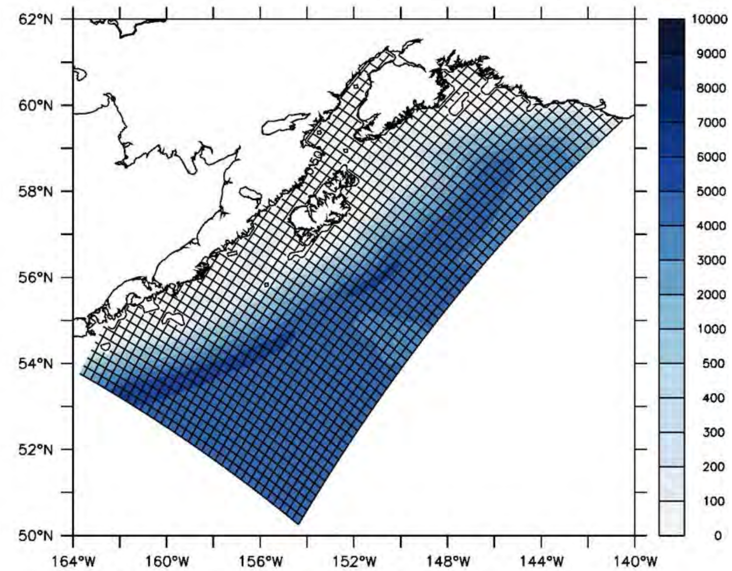
Surface and river forcing

- CORE2 (Large and Yeager, 2008)
- Freshwater runoff (Royer, 1982)

4D-Var data assimilation

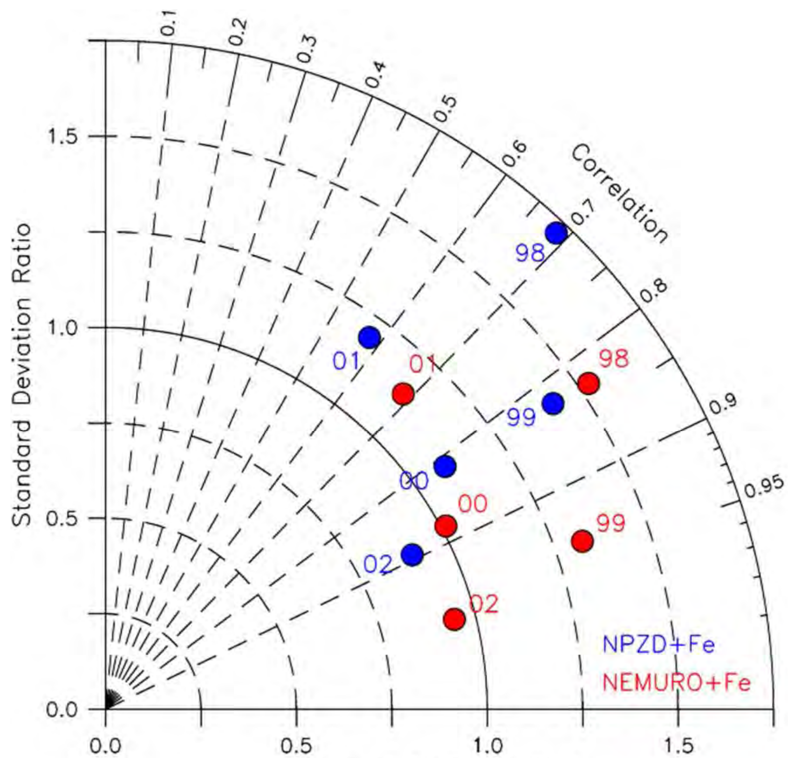
- Satellite SSH, SST
- In situ T, S (GLOBEC)



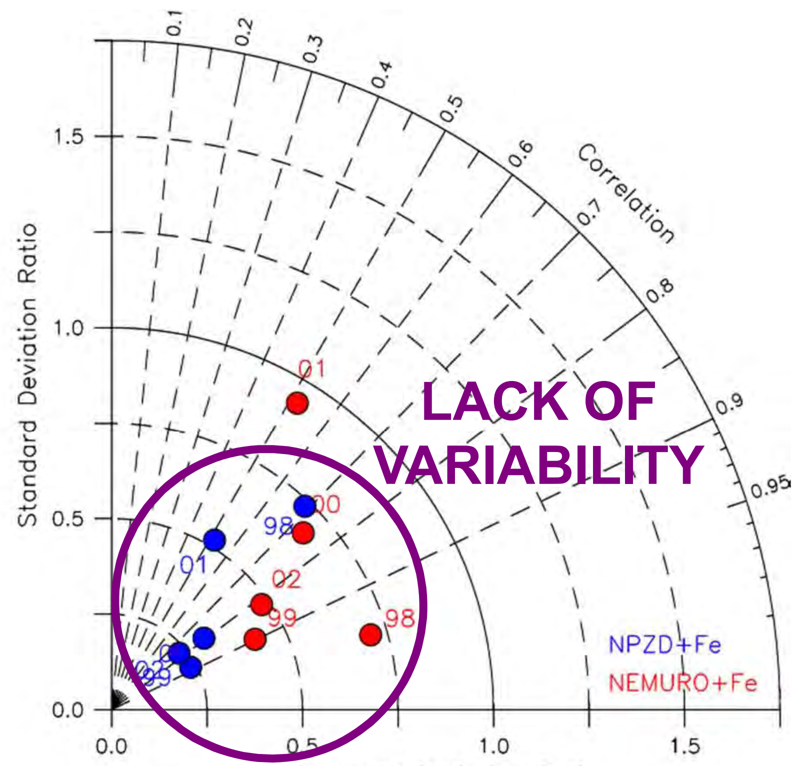


CGOA: Interannual Variability (1998-2002)

Taylor diagrams with respect to SeaWiFS Chlorophyll
(No data assimilation)



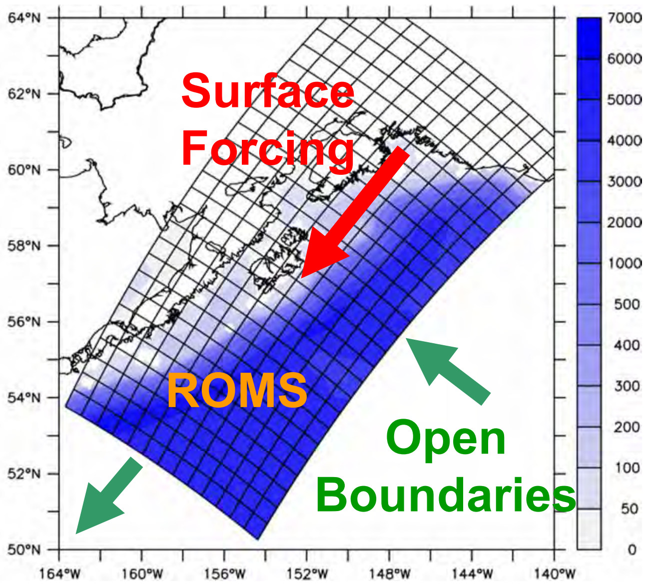
CGOA Shelf (<500m depth)

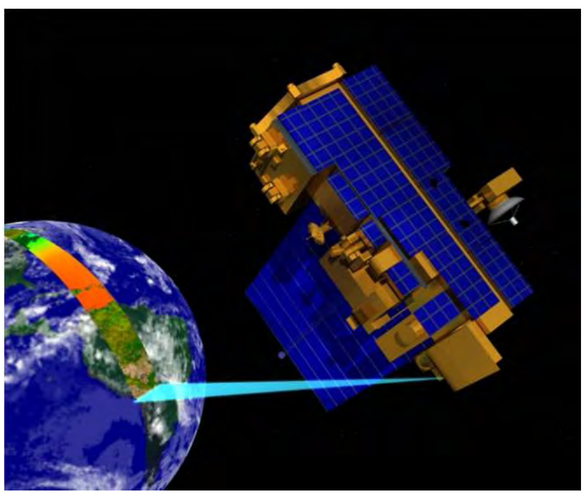


CGOA Basin (>500m depth)

NEMURO+Fe (16 components) NPZD+Fe (6 components)

Strong Constraint Variational Data Assimilation

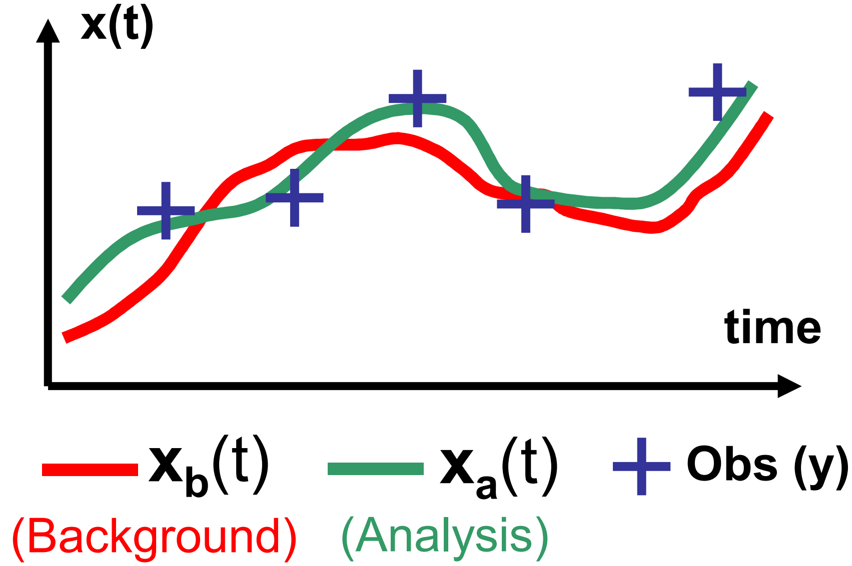




Model solution depends on:

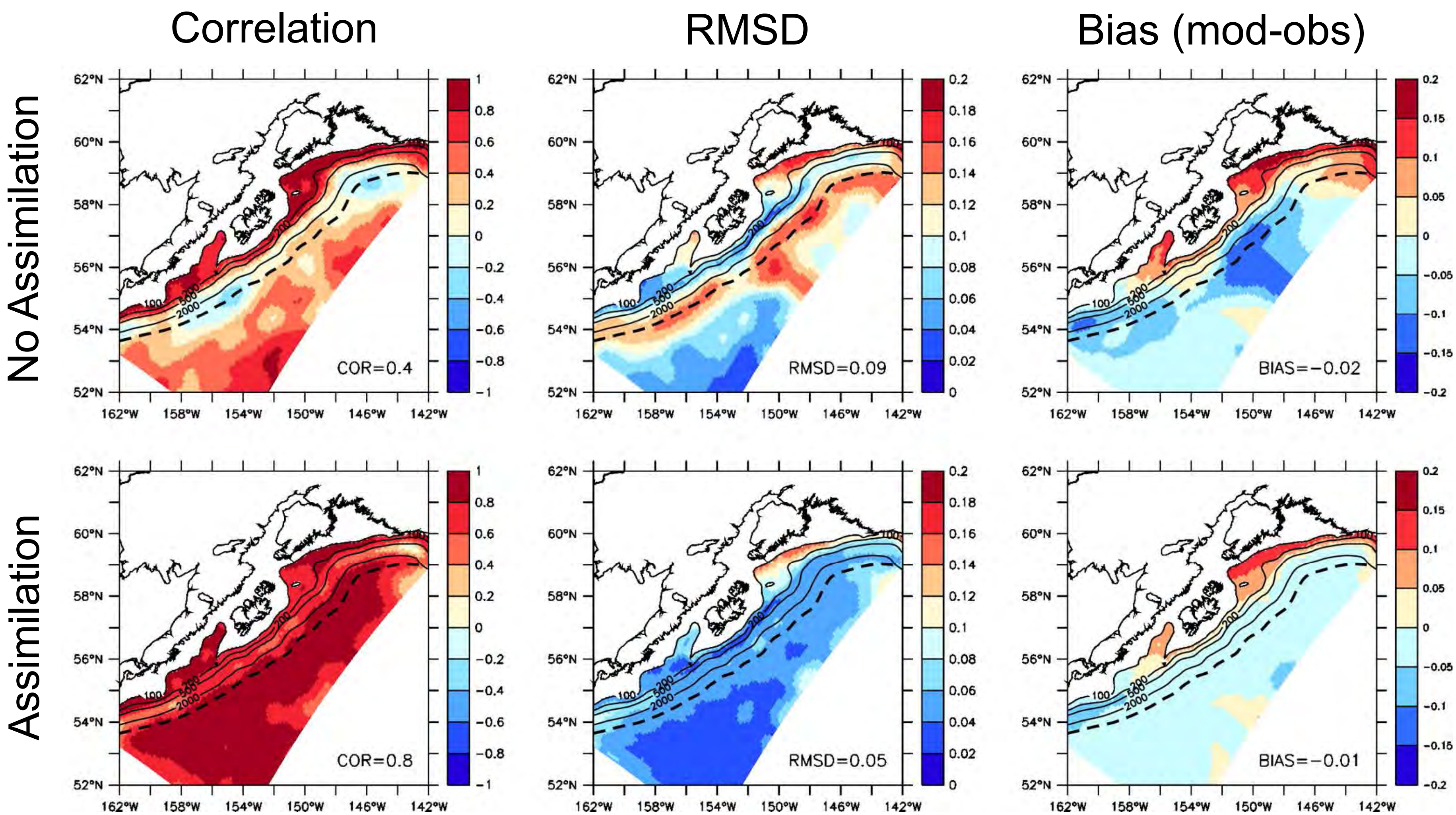
- Initial condition: x(0)
- Surface forcing: $f_b(t)$
- Boundary conditions: $b_b(t)$

(• Model error if weak constraint)



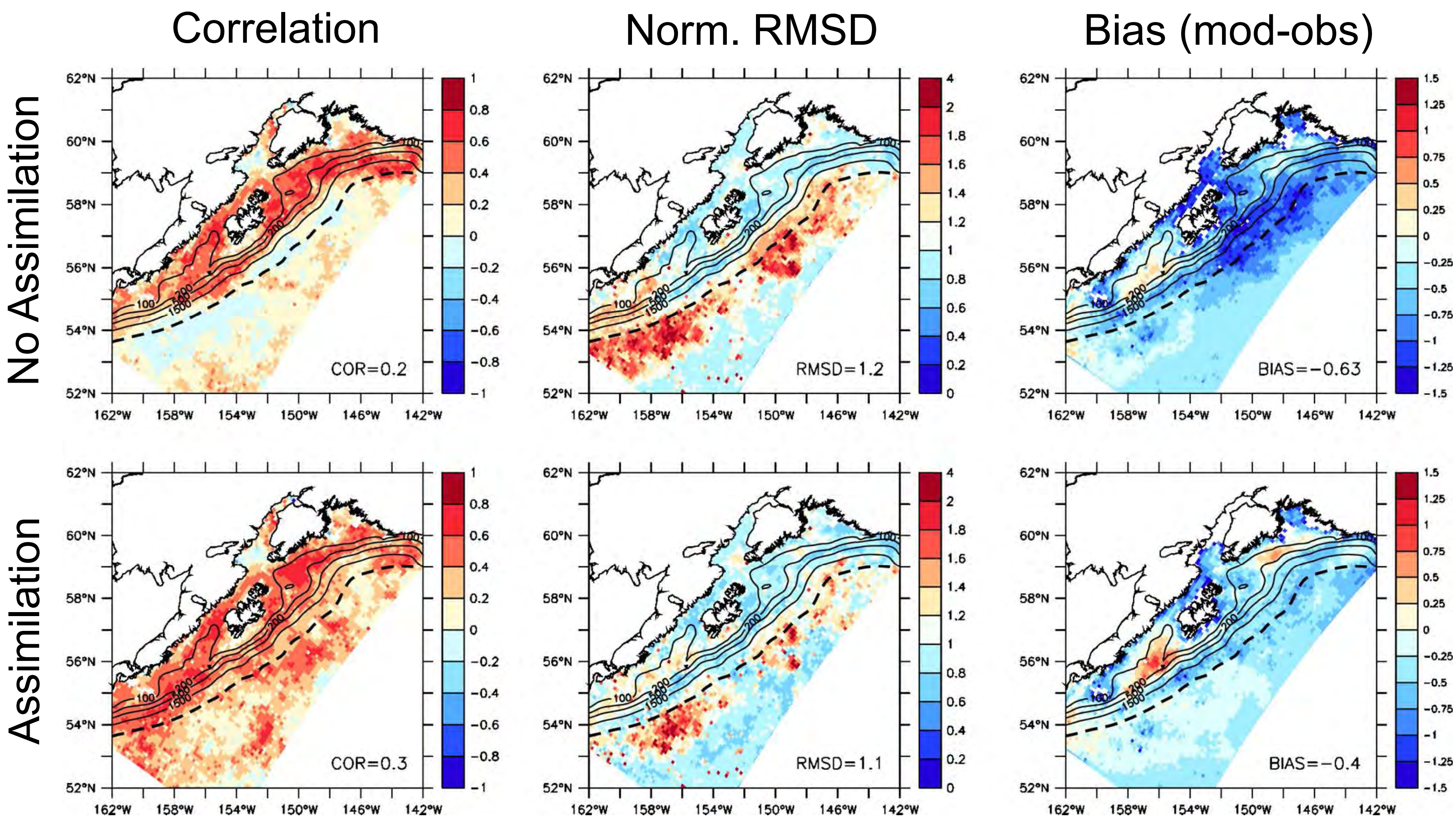
CGOA Sea Surface Height, 1998-2002

(Assimilated datasets: AVISO ADT, Pathfinder SST, GLOBEC T/S)



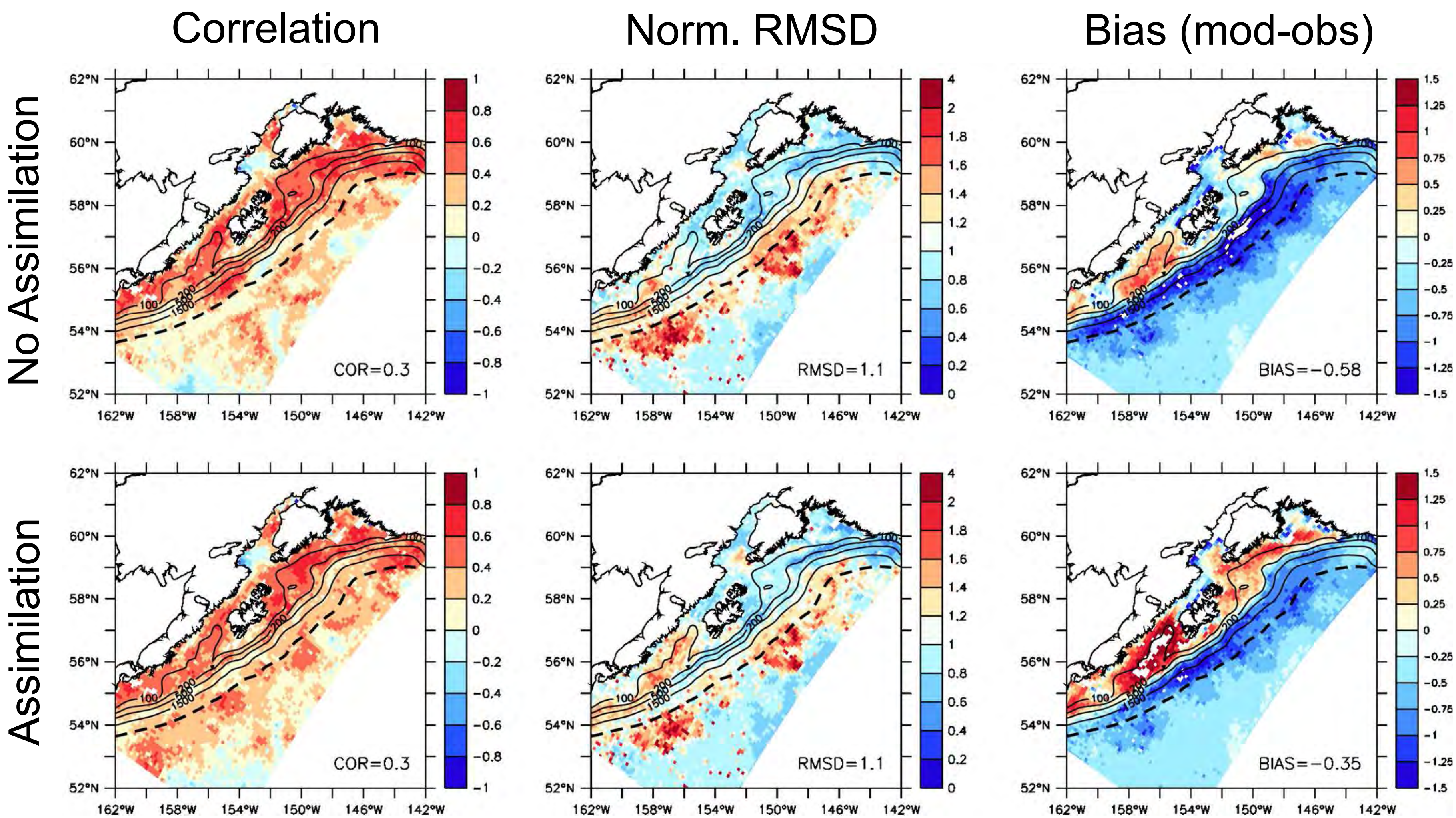
CGOA Surface Chlorophyll from NPZD, 1998-2002

(Assimilated datasets: AVISO ADT, Pathfinder SST, GLOBEC T/S)



CGOA Surface Chlorophyll from NEMURO, 1998-2002

(Assimilated datasets: AVISO ADT, Pathfinder SST, GLOBEC T/S)



Model Robustness and Parameter Uncertainty

Lower trophic level ecosystem model

- 4-component NPZD (Powell et al., 2006)
- Iron limitation (Fiechter et al., 2009)

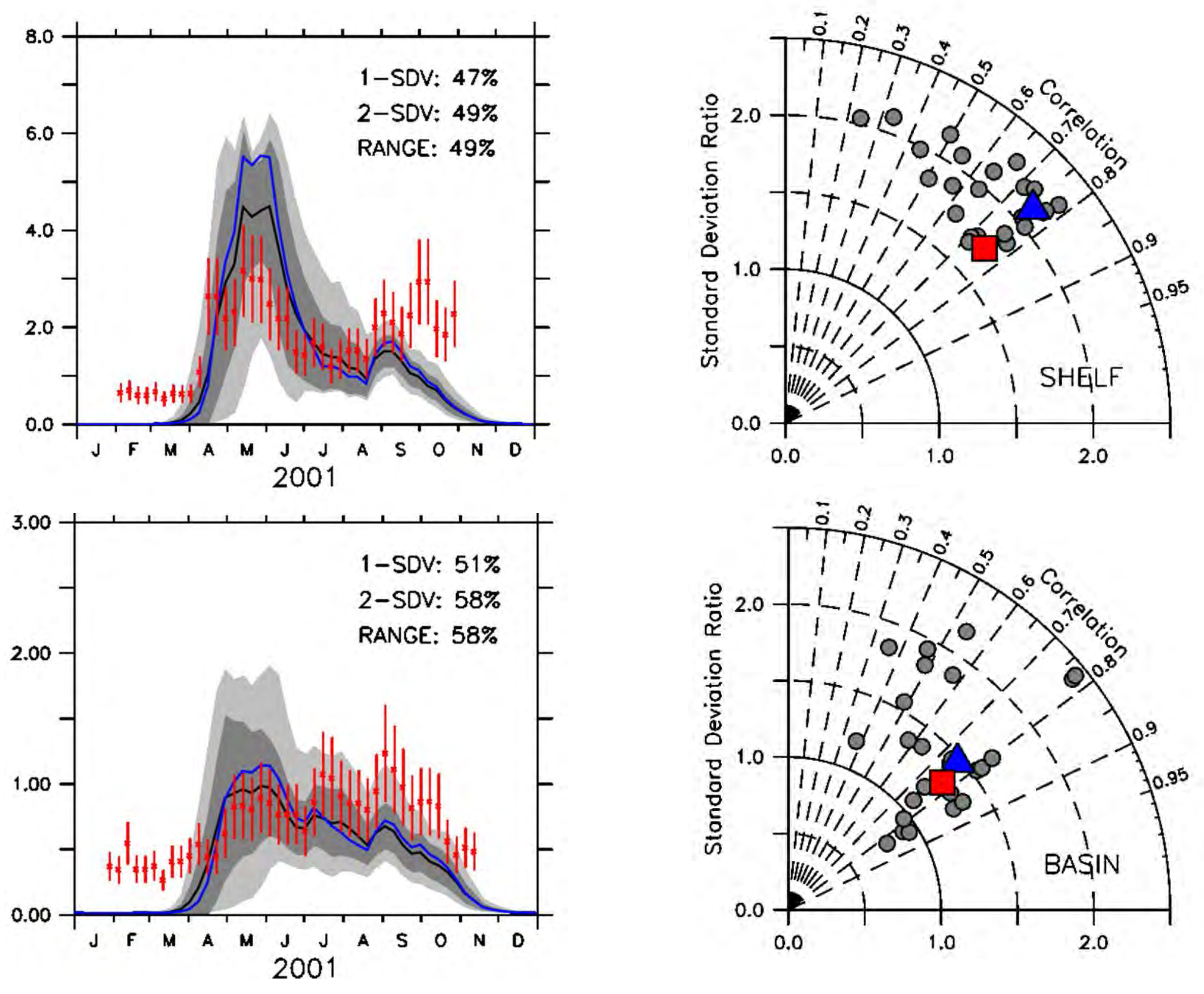
Ensemble calculations

- 7 random parameters out of 17 model parameters:
  - a) Phytoplankton maximum growth rate (VmNO3) and limitation by light (PhyIS), nitrogen (KNO3) and iron (KFeC)
  - b) Zooplankton maximum grazing rate (ZooGR)
  - c) Remineralization rates for nitrogen (DetRR) and iron (FeRR)
- Parameter ranges: ±10%, ±25%, ±50%, and half-double
- Ensemble size: 25 members w/ Latin Hypercube Sampling

25-Member Ensemble, ±50% Parameter Range

Weekly-averaged
Shelf Chlorophyll

Weekly-averaged
Basin Chlorophyll



Parameter Control on Phytoplankton Concentrations

Multivariate linear regression on monthly phytoplankton concentrations:

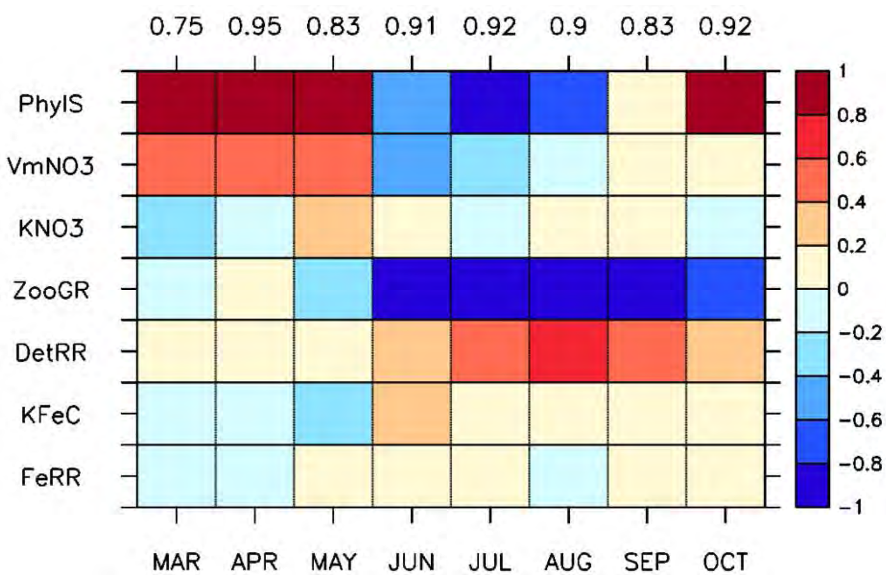
$$P_n = a_1\theta_{1,n} + a_2\theta_{2,n} + a_3\theta_{3,n} + a_4\theta_{4,n} + a_5\theta_{5,n} + a_6\theta_{6,n} + a_7\theta_{7,n}$$

P_n = phytoplankton concentrations from n^{th} ensemble member

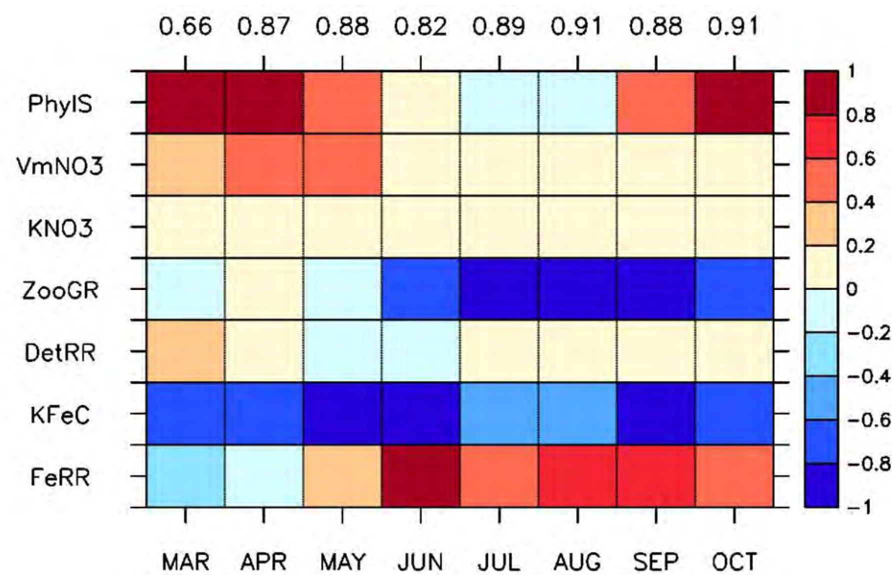
$\theta_{i,n}$ = i^{th} parameter value associated with n^{th} ensemble member

- a_i = regression slope for i^{th} parameter ("parameter control")

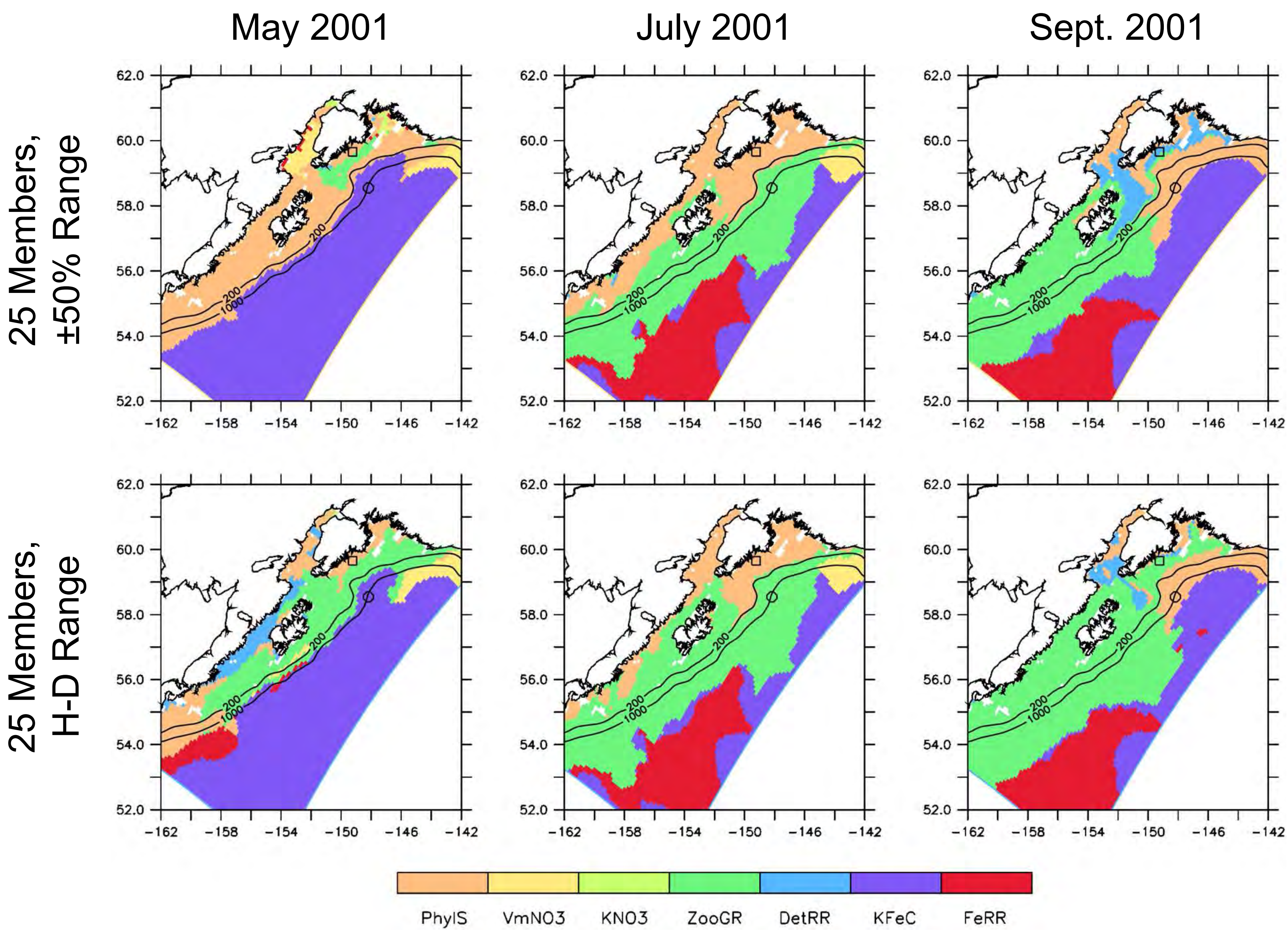
Shelf (25 members, ±50%range)



Basin (25 members, ±50% range)



Parameter Control on Phytoplankton Concentrations

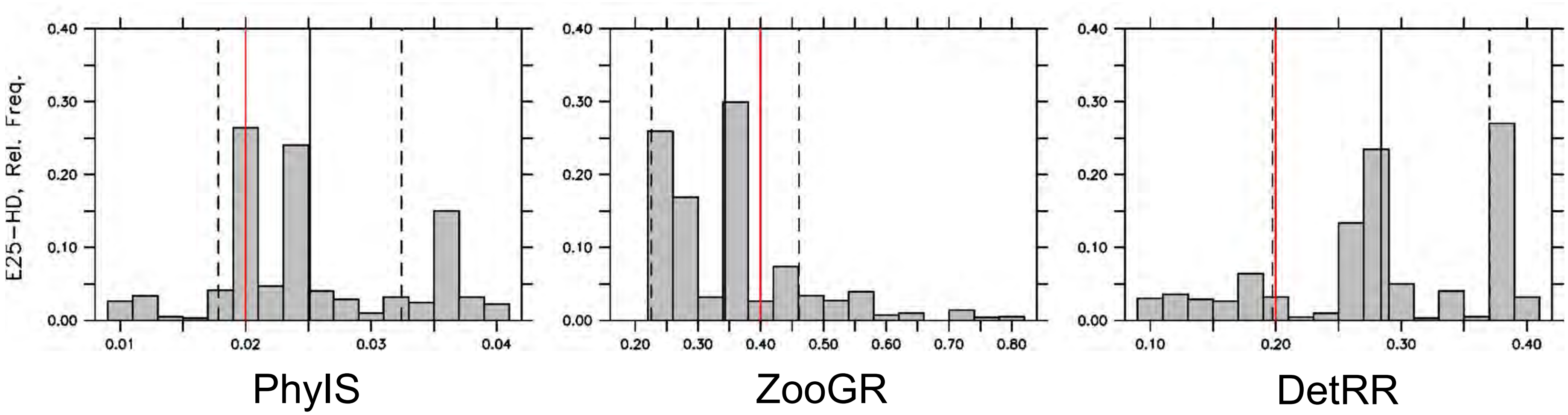


Parameter Estimation from Ensemble Members

- Parameter estimates from best ensemble members

Experiment	PhyIS	VmNO3	KNO3	ZooGR	DetRR	KFeC	FeRR
Control	0.02	0.8	1.0	0.4	0.2	16.9	0.5
Shelf best	0.029	0.55	0.81	0.42	0.12	24.79	0.61
Basin best	0.029	0.66	1.32	0.28	0.24	22.40	0.71
Domain best	0.029	0.73	0.92	0.34	0.16	21.76	0.67

- Parameter estimates from frequency histograms (shelf)



CCS Coupled Physical-Biological ROMS Model

California Current Grid

- 10 km horiz. Resolution
- 42 vertical levels

Run duration

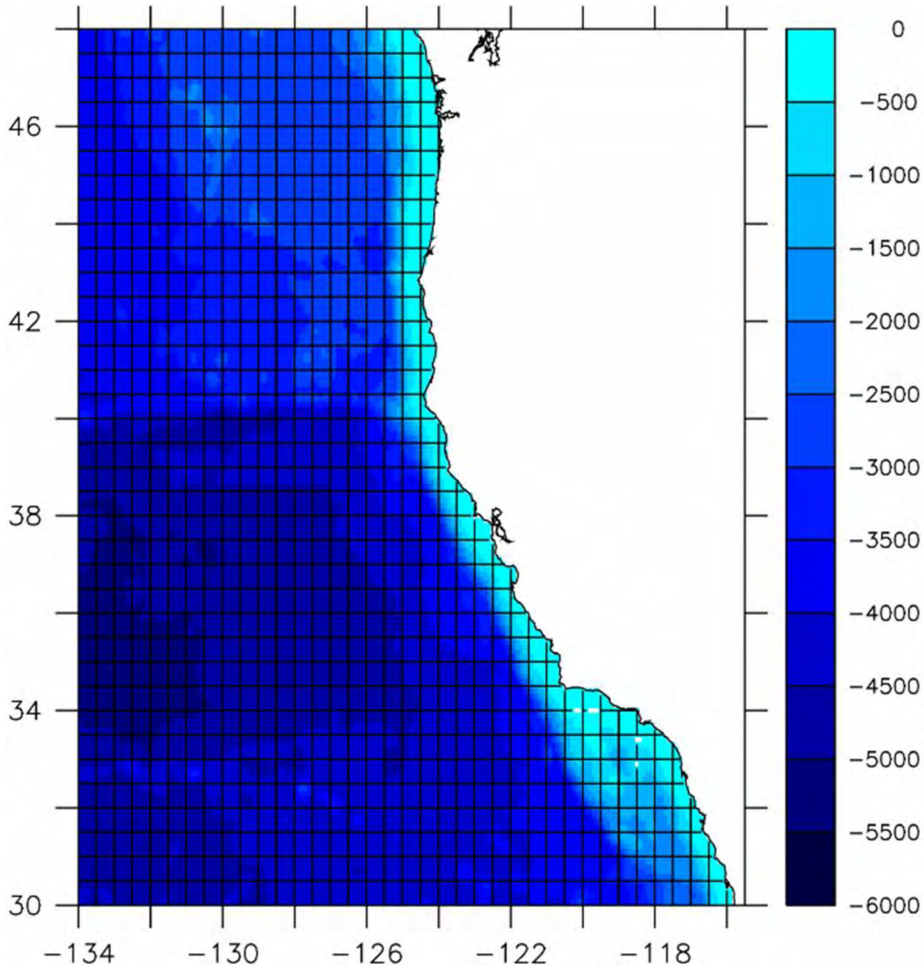
- 7 years (1999-2005)

BC/IC: SODA-POP

- Monthly SSH, U, V, T, S (Carton et al., 2000)

Surface forcing: COAMPS

- Daily wind stress, heat fluxes, solar and longwave radiation



ROMS grid and bottom topography (m)

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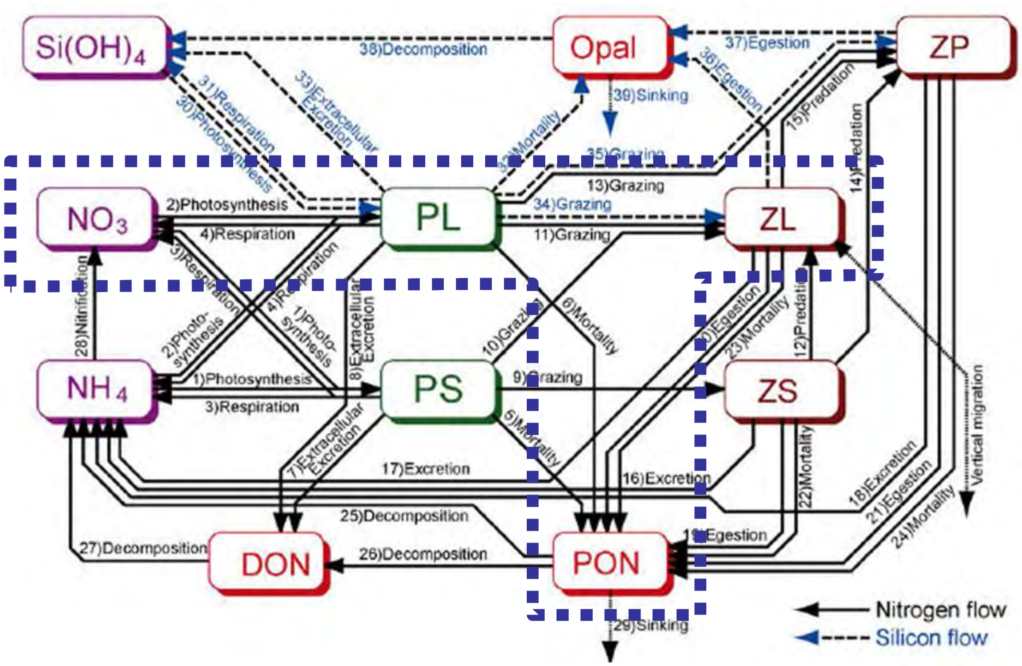
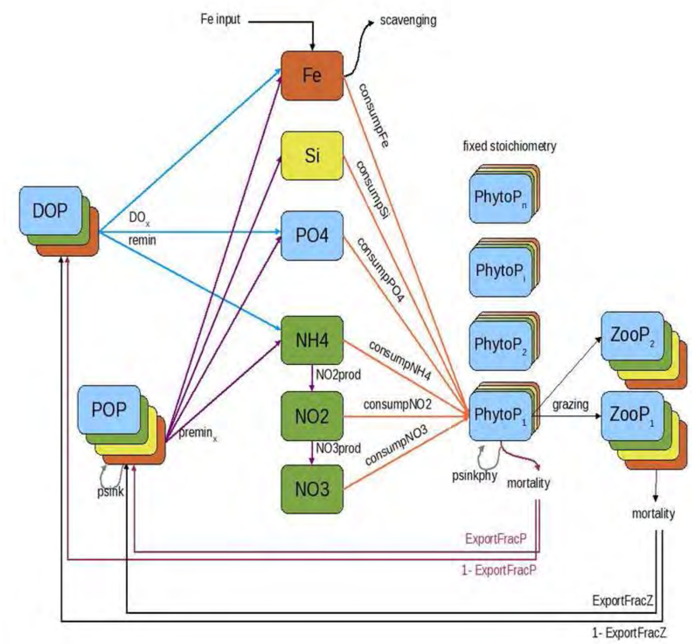
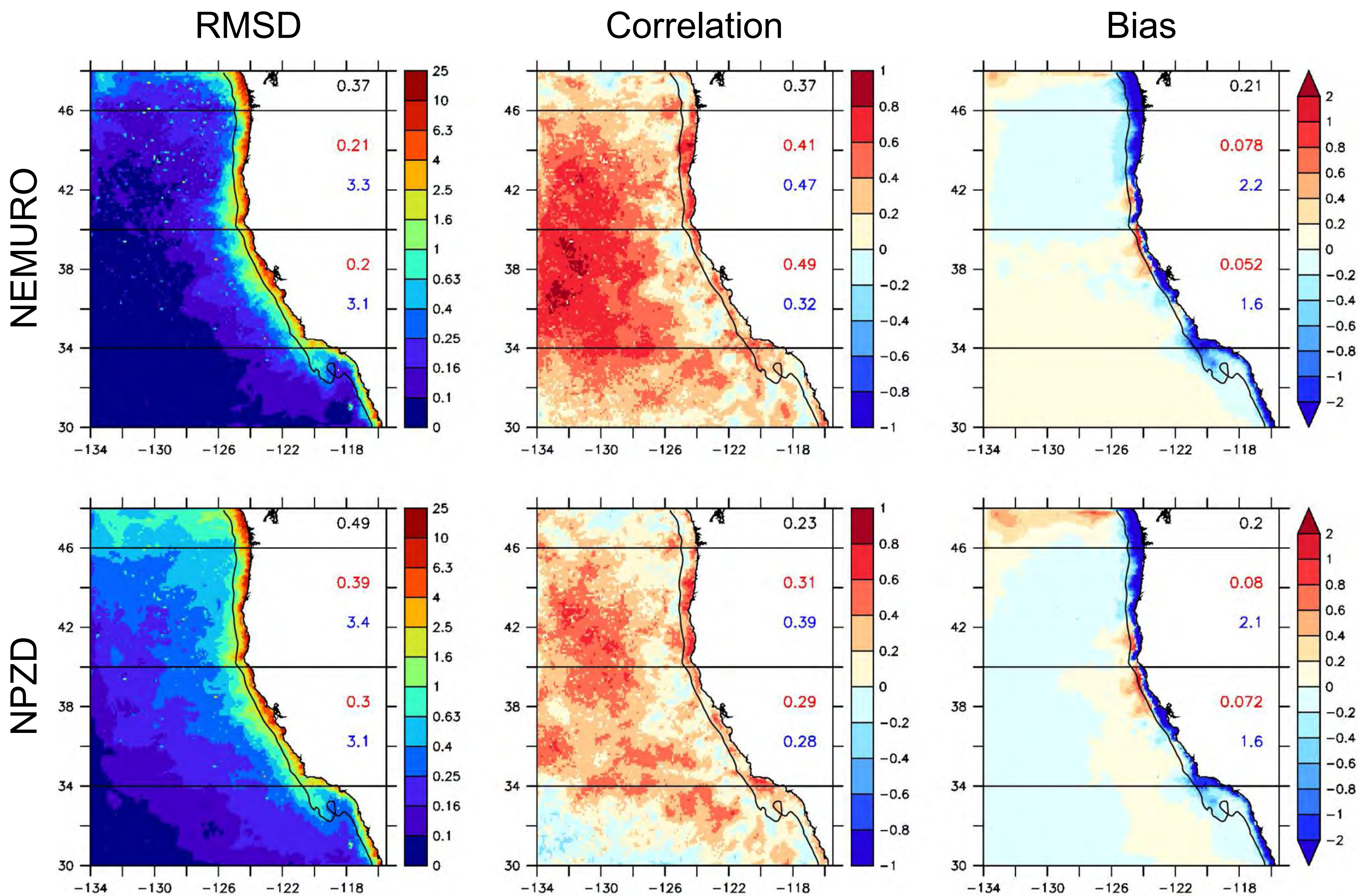


NEMURO / NPZD

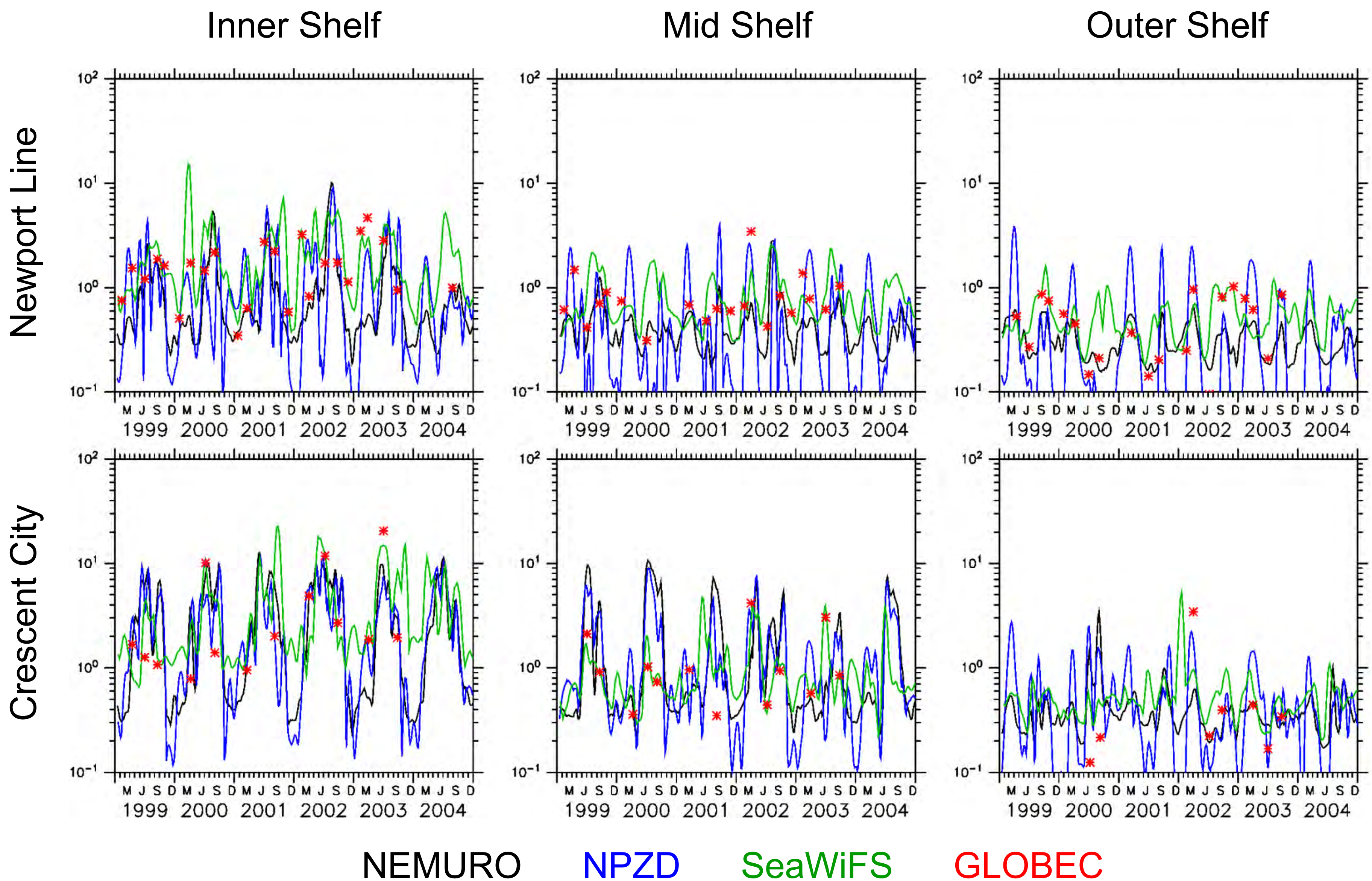


Darwin

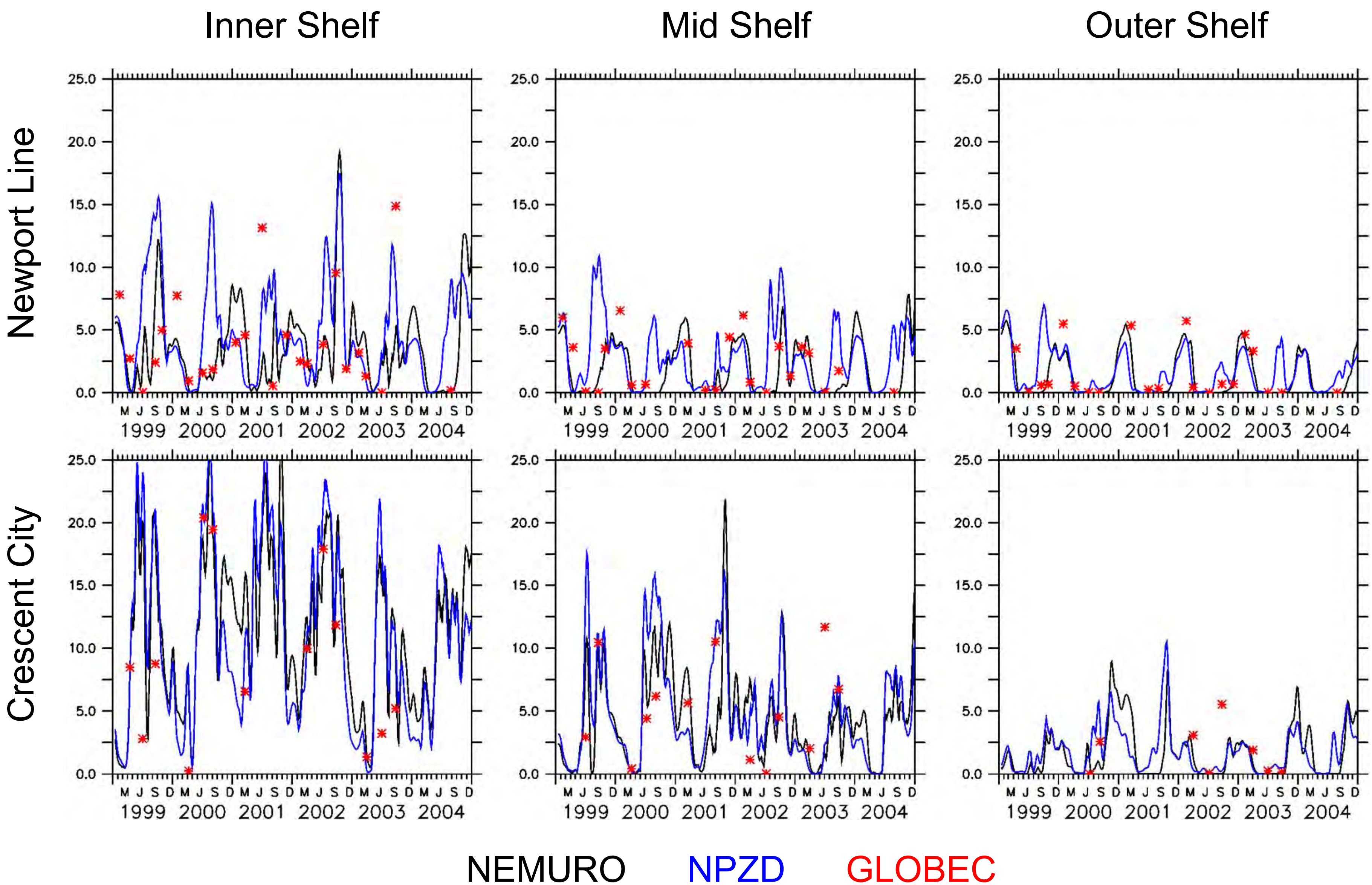
NEMURO/NPZD Chlorophyll vs. SeaWiFS, 2000-2005



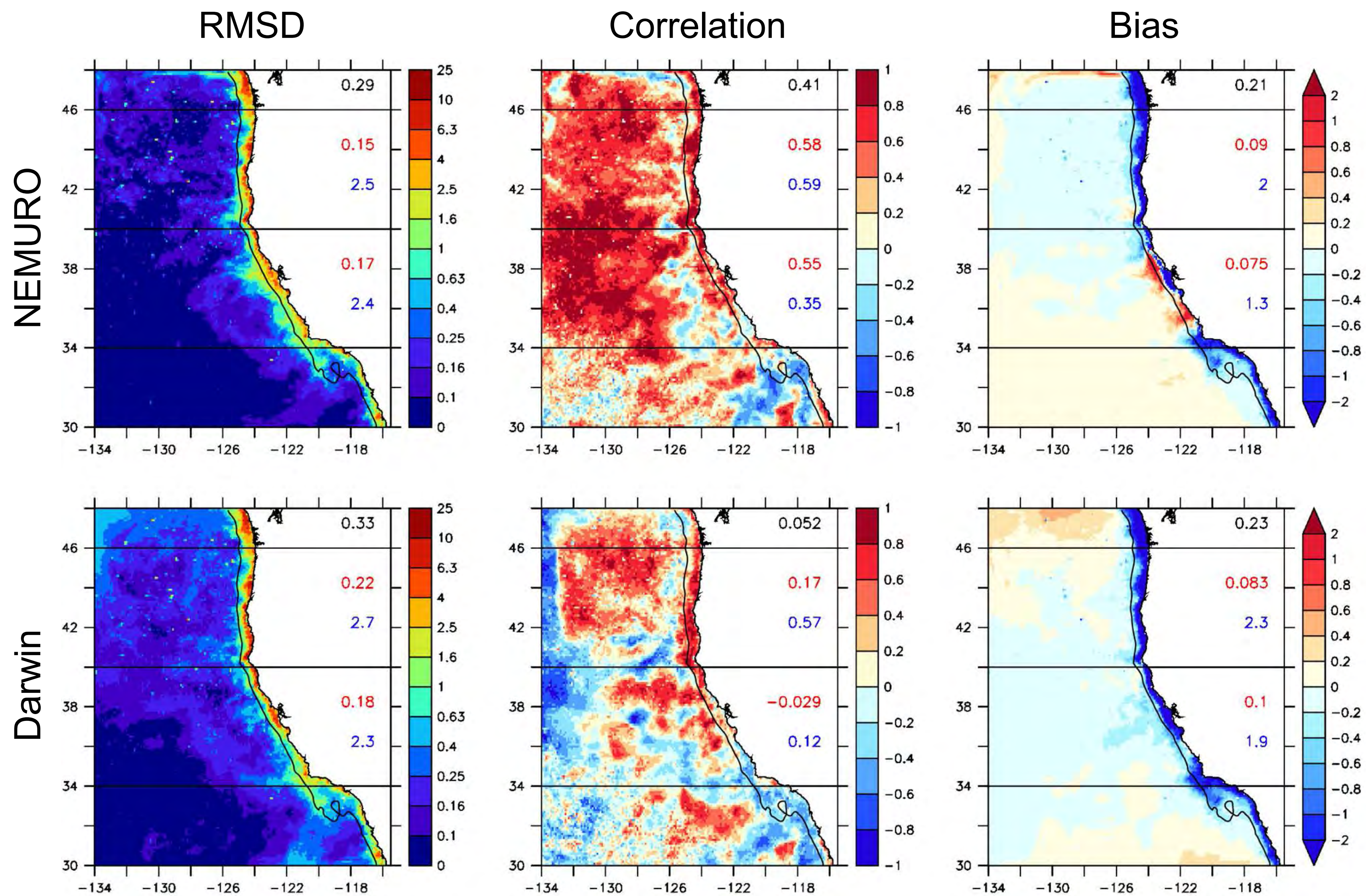
NEMURO/NPZD Chlorophyll vs. GLOBEC, 1999-2005



NEMURO/NPZD Nitrate vs. GLOBEC, 1999-2005

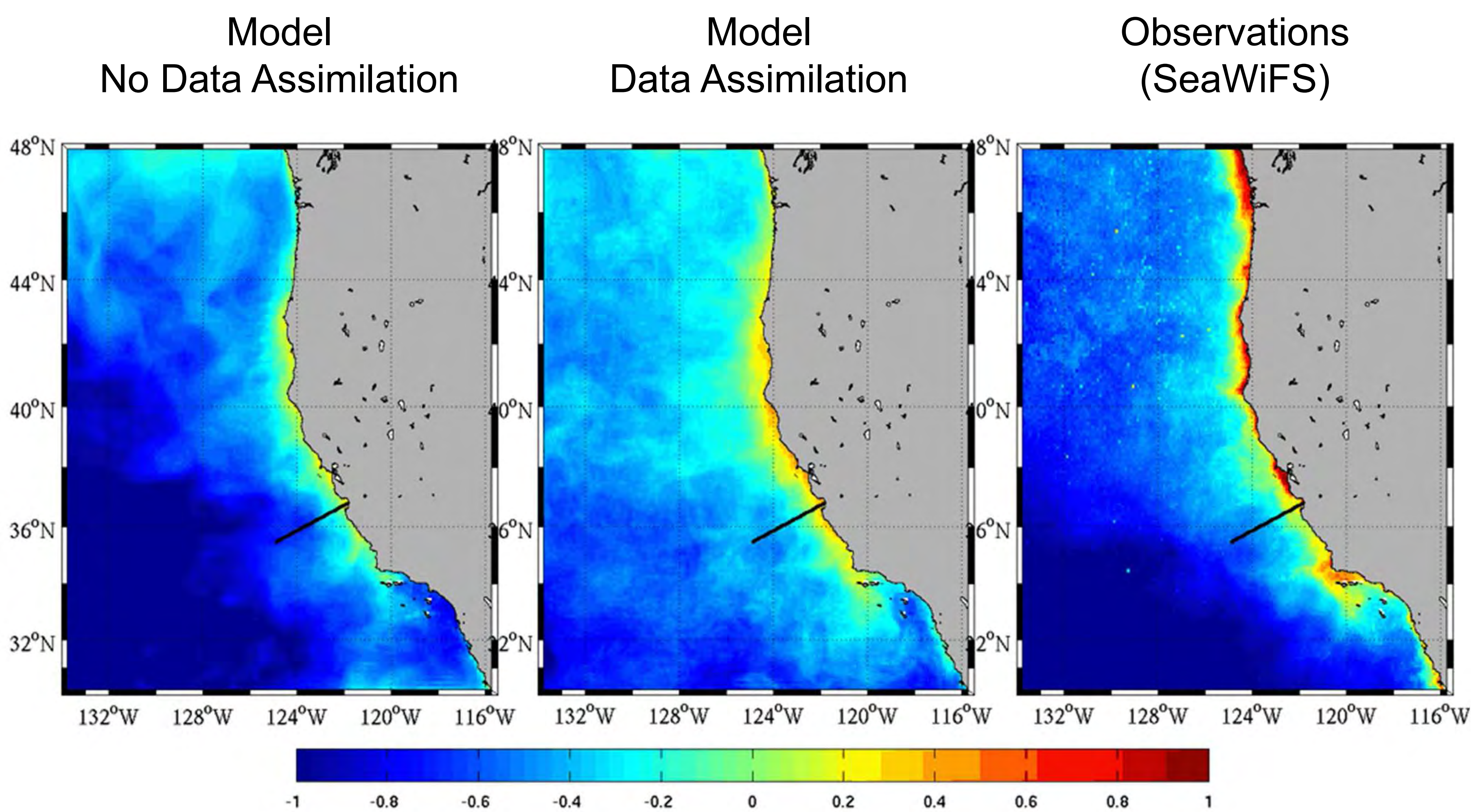


NEMURO/Darwin Chlorophyll vs. SeaWiFS, 2003



Darwin Chlorophyll w/ Physical Data Assimilation, 2003

Assimilated datasets: satellite SSH/SST; in situ T/S (CALCOFI, GLOEBC, Argo)



Summary

Ecosystem model complexity

- Complexity level depends on scientific question
  - a) CCS upwelling region: NPZD may be sufficient
  - b) Zooplankton prey fields: NEMURO may be preferred
  - c) Biodiversity, ecological niche: Darwin may be needed

Model parameterization

- Ensembles are useful to:
  - a) assess robustness in ecosystem model solutions
  - b) identify biological processes controlling variability
- Bayesian models for formal parameter estimation

Data assimilation

- Physical data assimilation improves ecosystem model solutions where mesoscale activity affects biology