Seasonal to multi-annual marine biogeochemical prediction using GFDL's Earth System Model

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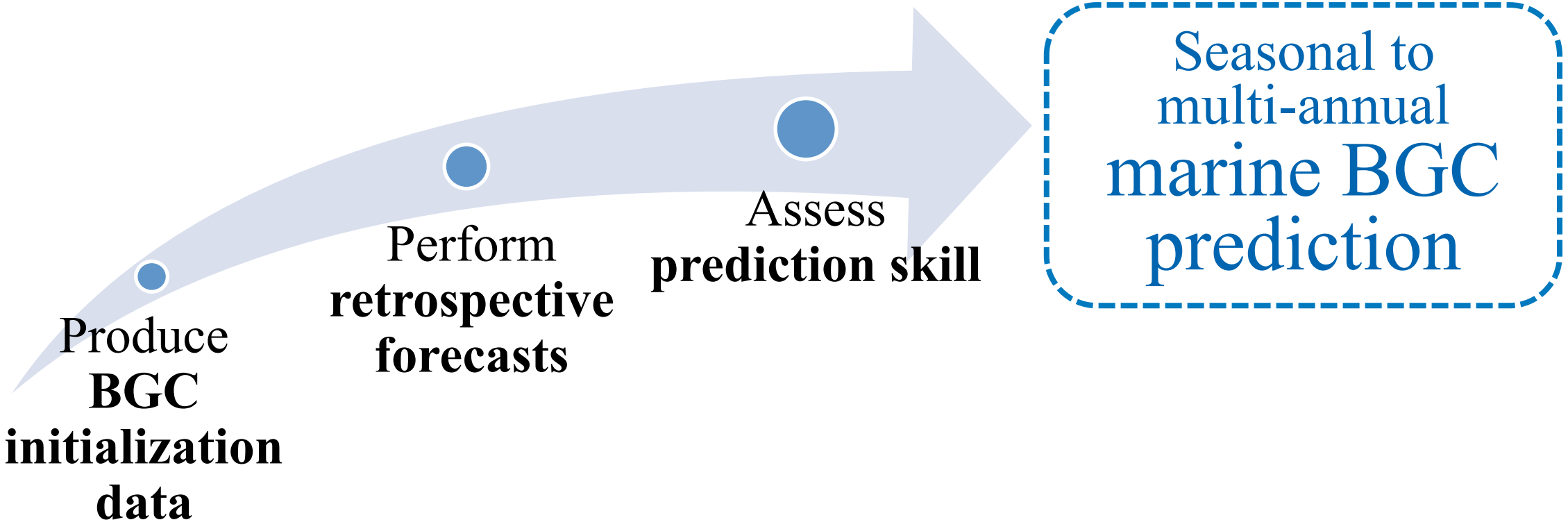
NOAA-GFDL / Princeton University

Toward global marine biogeochemistry prediction



Data Assimilation System + BGC model

➢ **GFDL's ECDA** (Ensemble Coupled Data Assimilation)

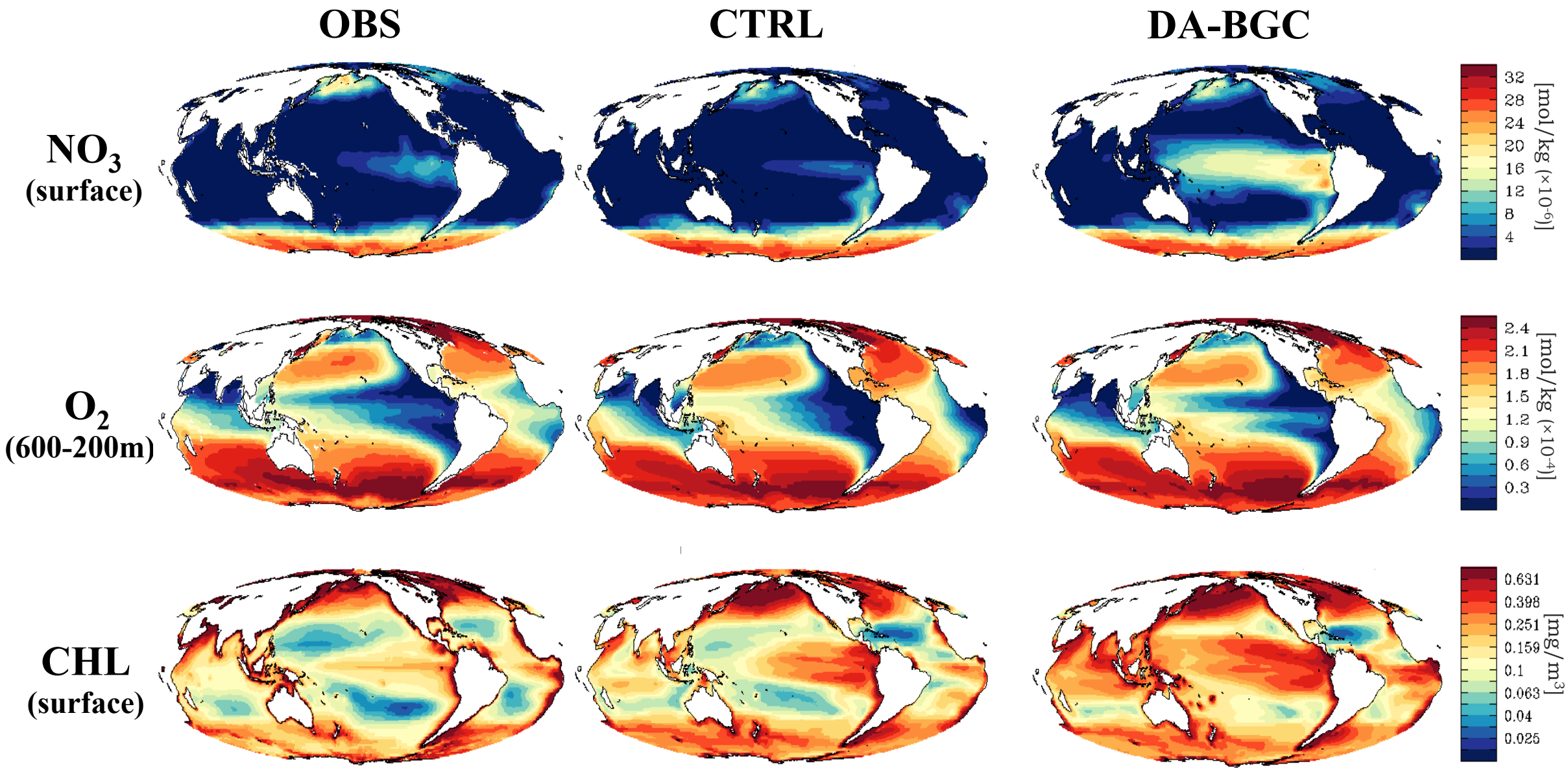
- Seasonal to decadal global climate prediction
- GFDL's coupled atmosphere-land-ocean-sea ice model (CM2.1)
- Physical assimilation

  - Atmos : u, v, temp (6 hourly NCEP2)
  - Ocean: Temperature and Salinity (XBT, MBT, CTD, OSD, MRB, gtspp, argo, AVHRR SST)
- Ensemble Kalman filter (12 ensemble members used)

➔ **ECDA + BGC model (COBALT)**

- Run period: 1991 - 2017
- Assumption: improved physical field better represents BGC

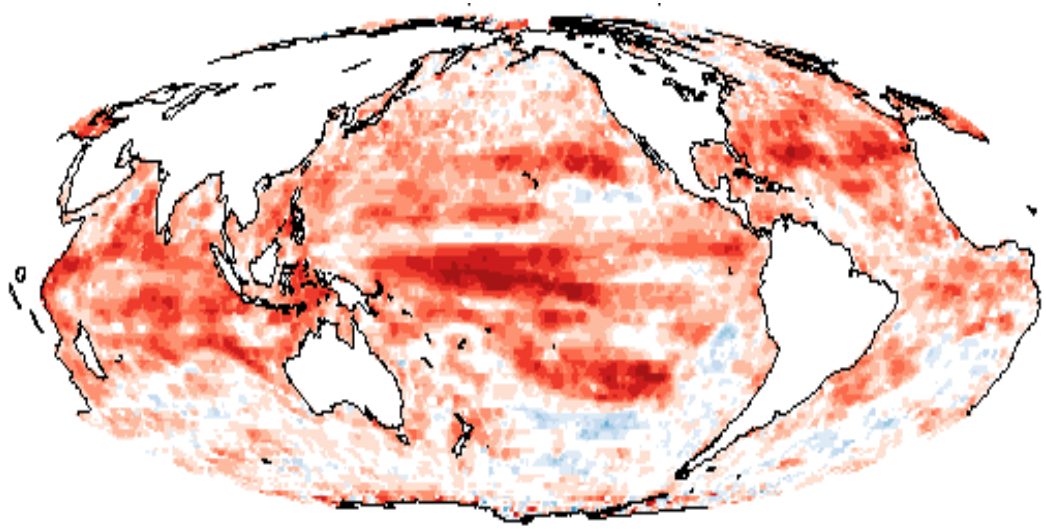
BGC well simulated in CTRL, but degraded in DA-BGC



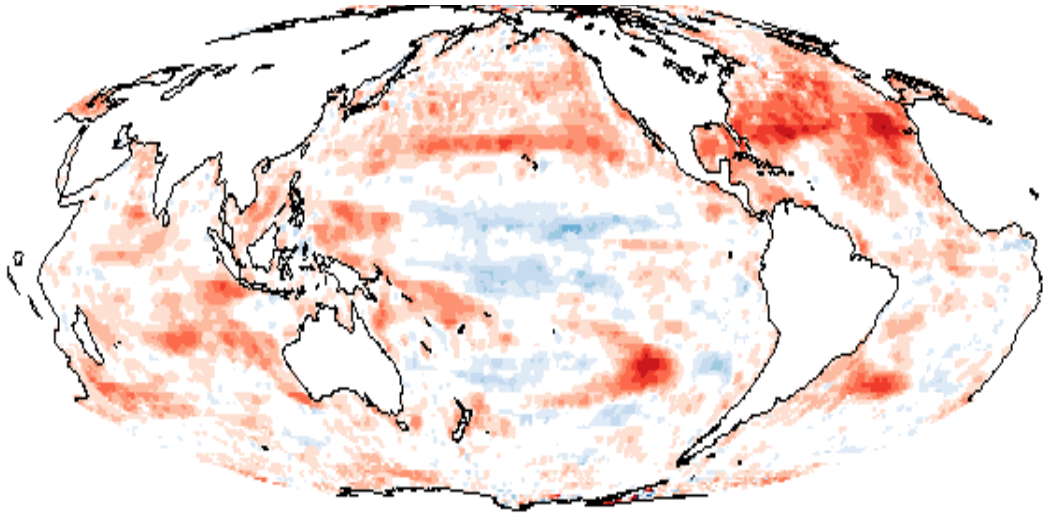
Degraded CHL correlation skill

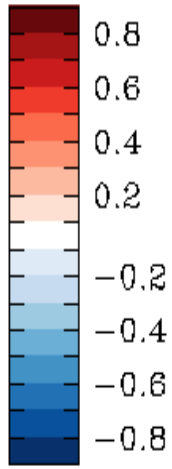
Monthly anomaly correlation (model-satellite)
Sep1997-dec2016

CTRL

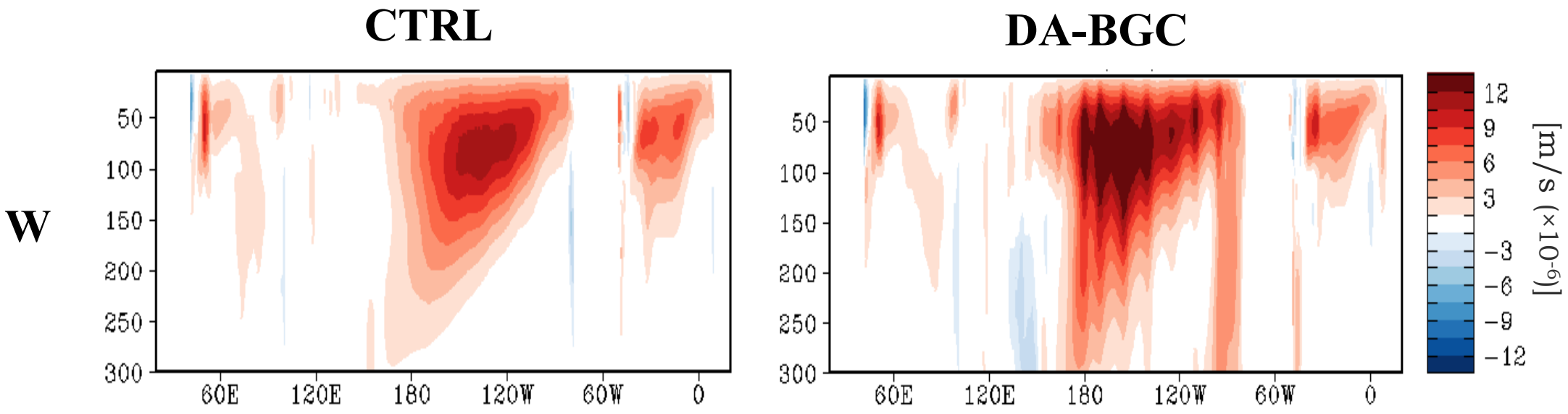


DA-BGC





Spurious velocity problem



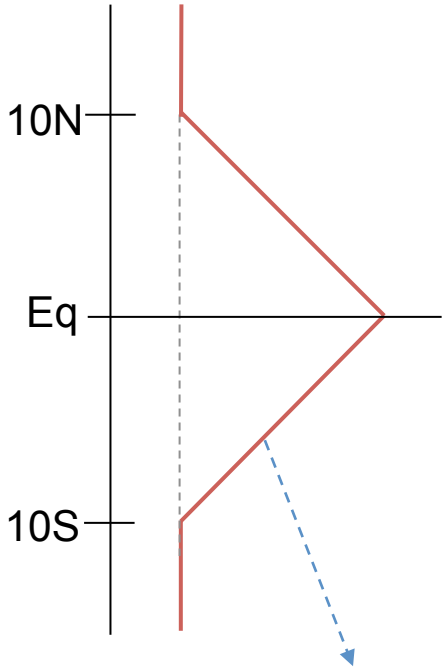
- ✓ Common feature in ocean assimilation system
  (e.g. Burgers et al. 2002, Xie and Zhu 2007, Waters et al. 2016)
- ✓ Due to lack of balance in assimilation increments
- ✓ Less harmful to eq. physics compared to gains from DA, but big obstacle toward BGC prediction

$$1/\rho\downarrow 0 \quad \partial p/\partial x \cong 1/\rho\downarrow 0 \; \partial\tau/\partial z$$

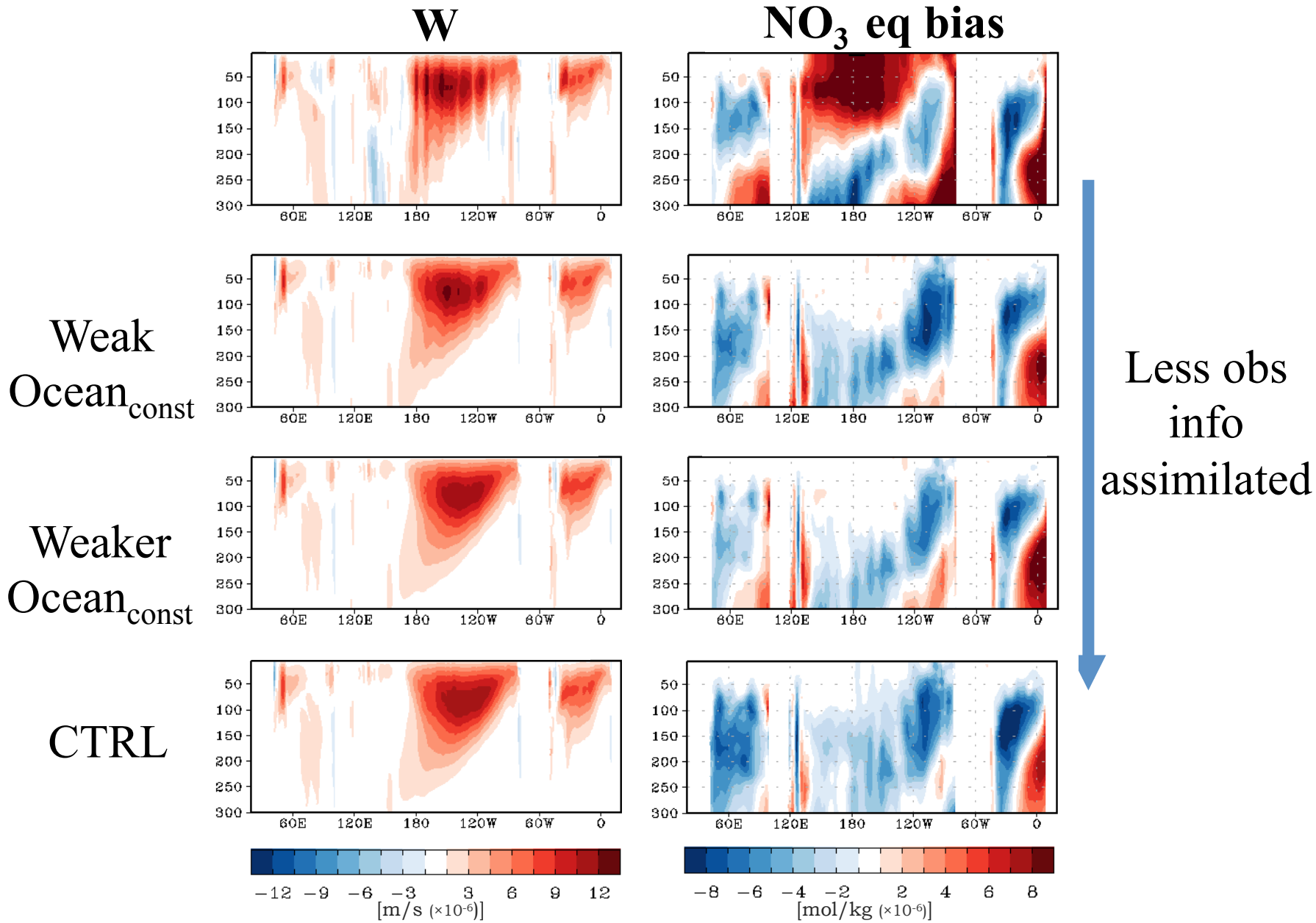
Zonal pressure gradient

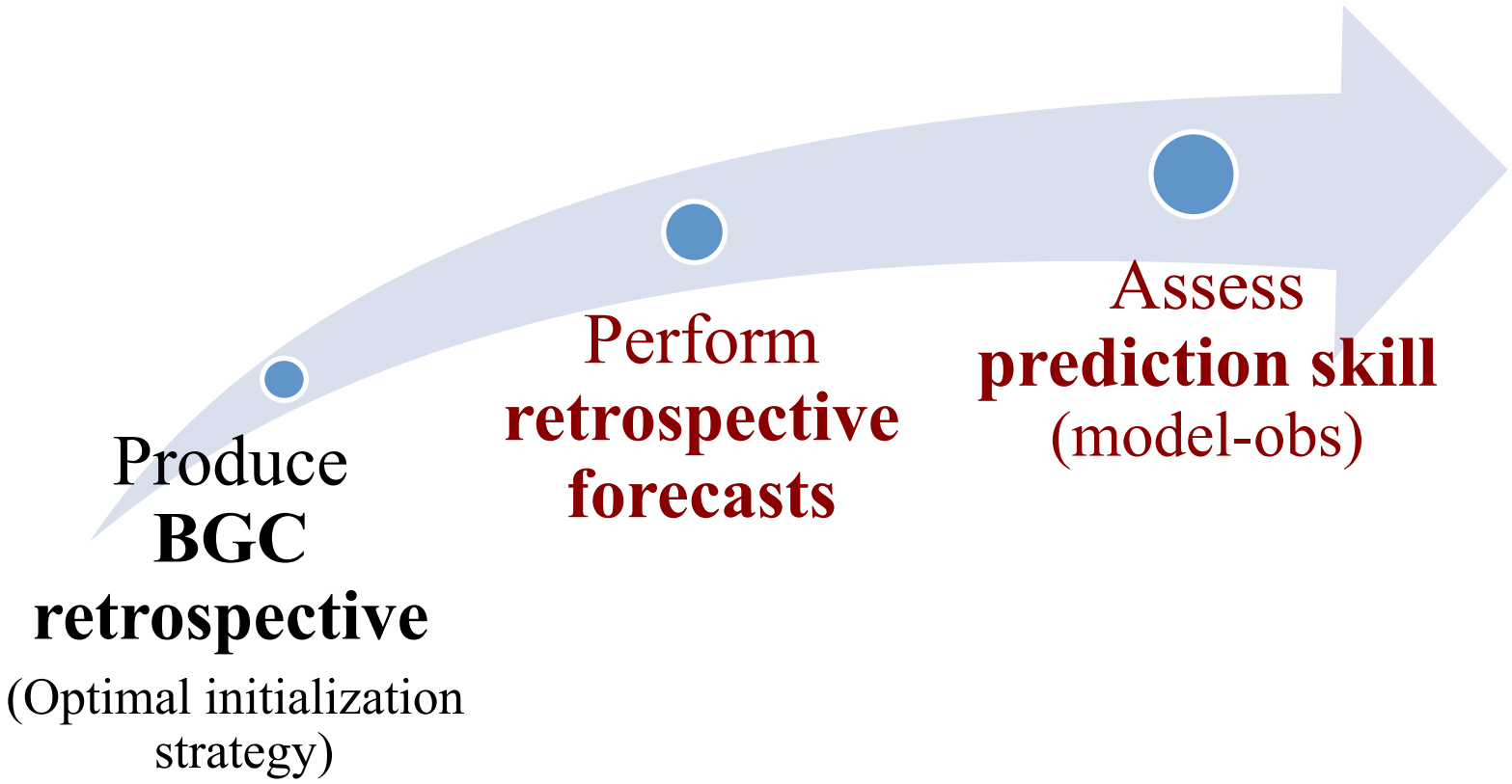
Wind stress

Remedy: weak equatorial ocean data constraint

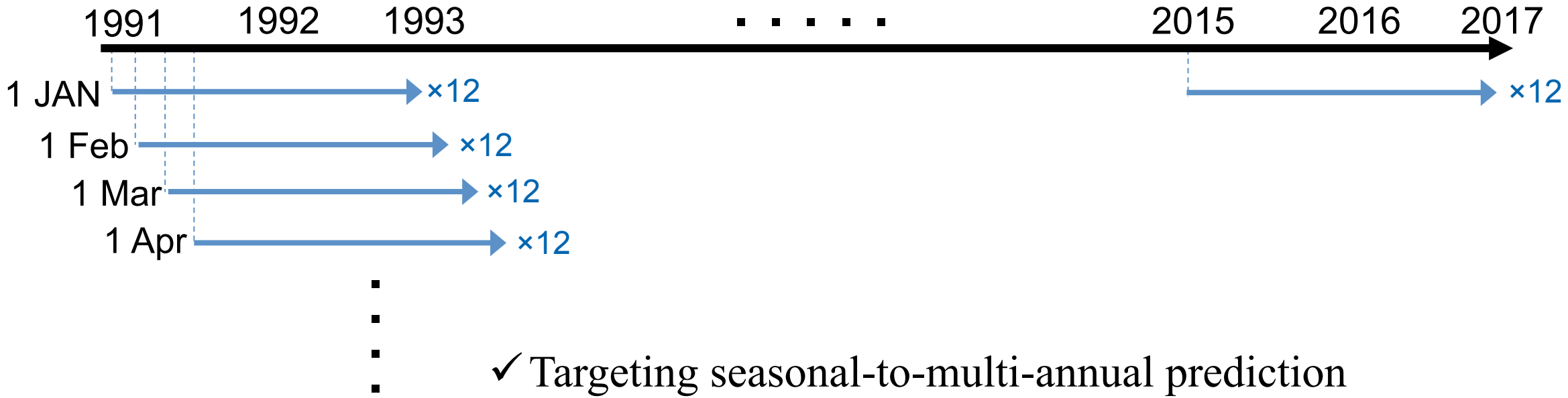


Linear latitudinal ramp




Produce
BGC retrospective
(Optimal initialization strategy)
Perform
retrospective forecasts
Assess
prediction skill
(model-obs)

Retrospective prediction



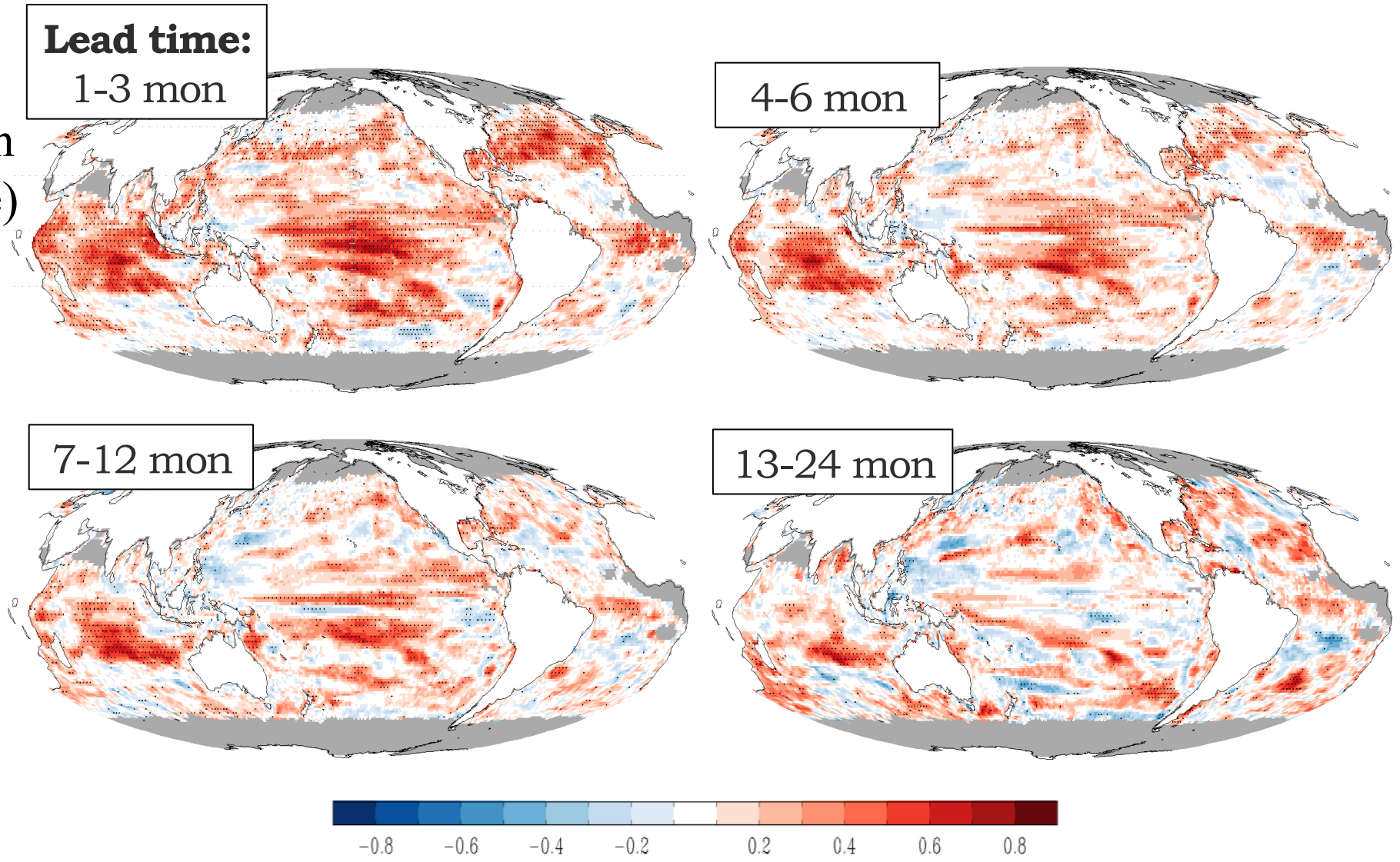
✓ Targeting seasonal-to-multi-annual prediction

✓ 2-yr-long, 12-ensemble prediction run started every months

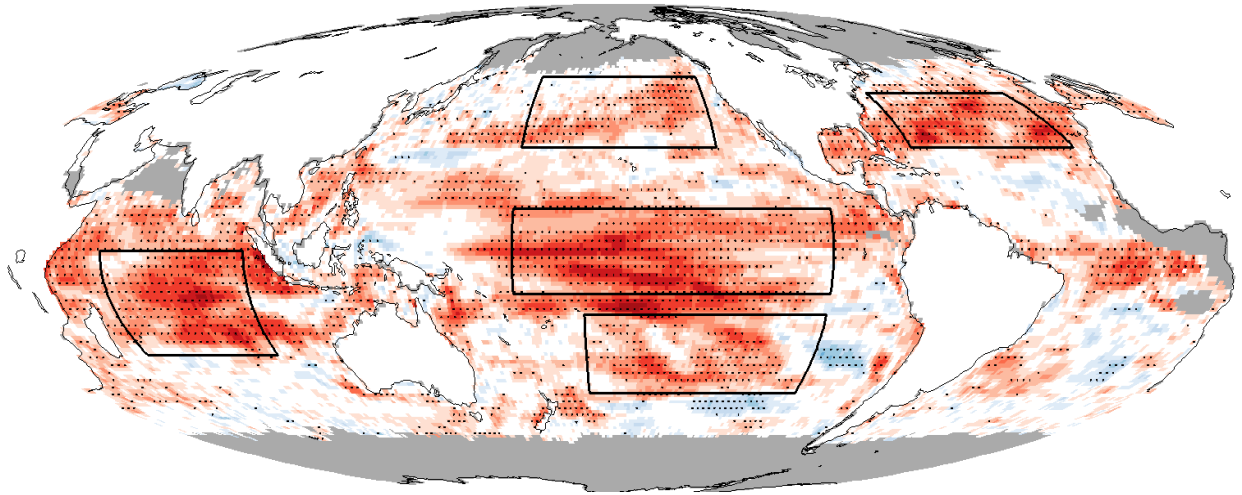
✓ Prediction skill assessment
: Anomaly Correlation Coeff. (ACC)
: Lead-time-dependent monthly-mean drift removed

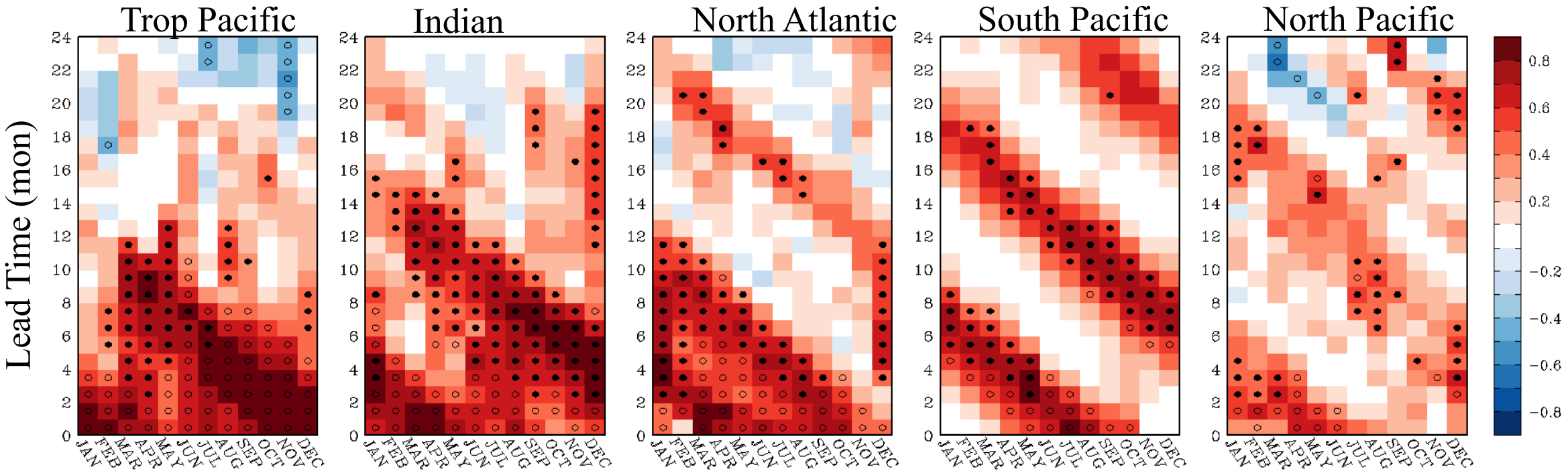
BGC prediction skill (global)

✓ Chlorophyll anomaly correlation (Model vs. Satellite)



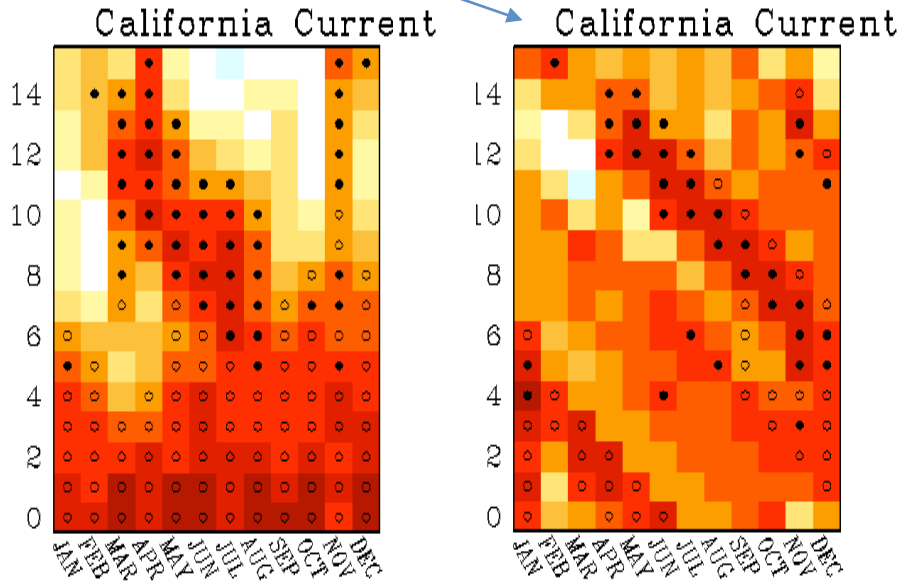
BGC prediction skill (regional)



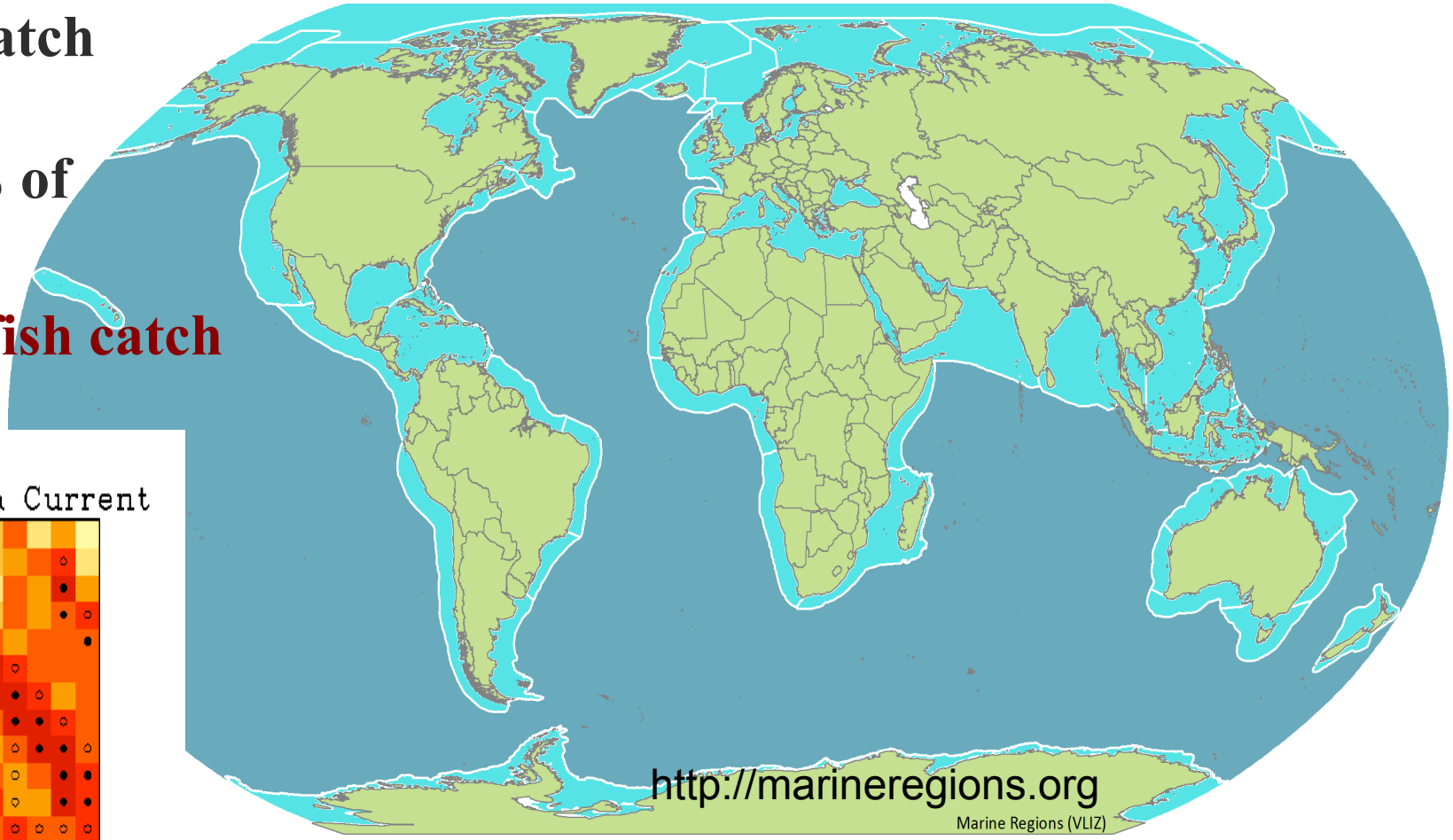


Potential utility for marine resources (fisheries)

- ✓ Reported annual fish catch data in LMEs
- ✓ LMEs account for 95% of global fish catch
- ✓ **Bottom-up forcing for fish catch : SST, CHL**



Large marine ecosystems (LMEs)

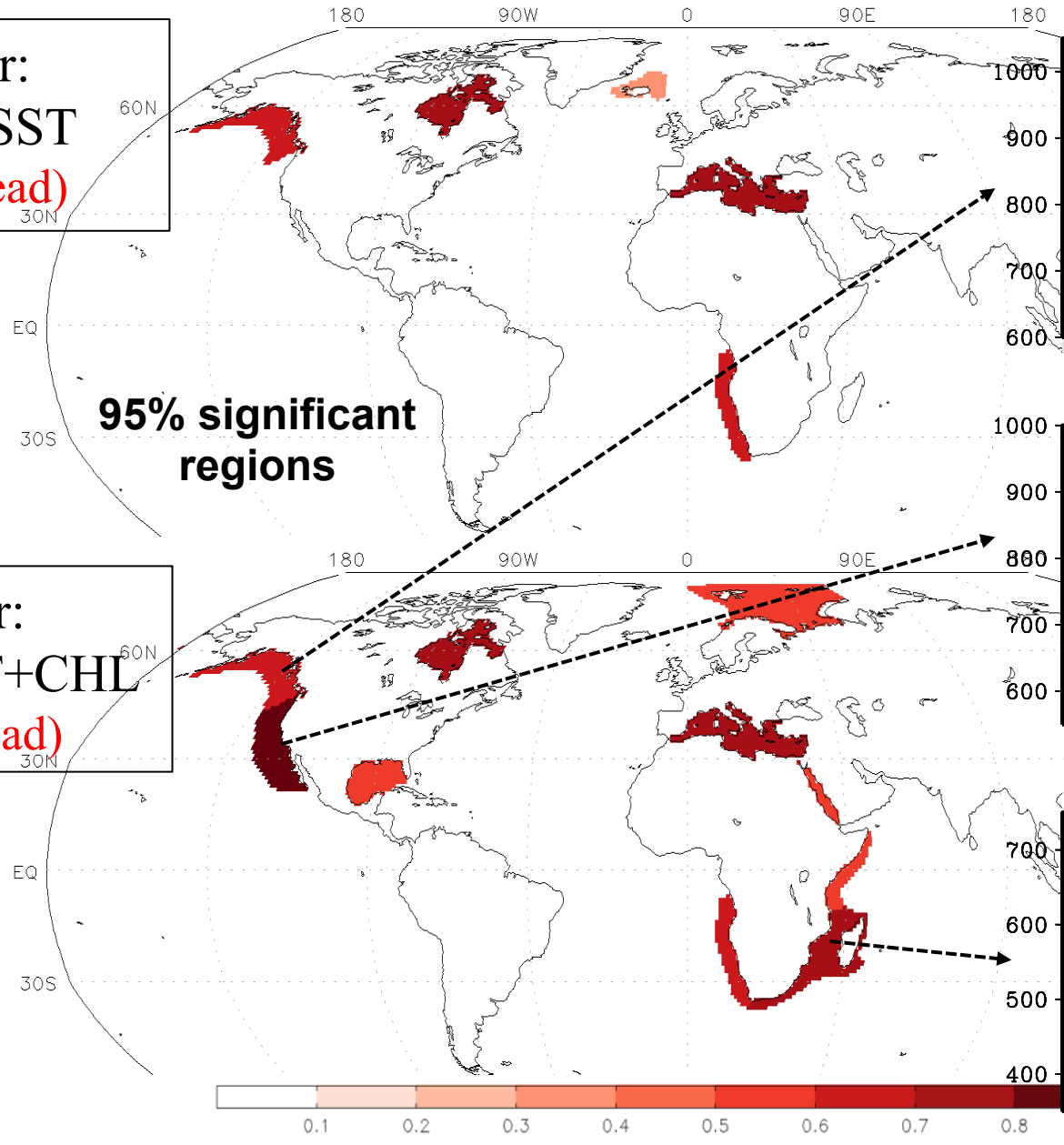


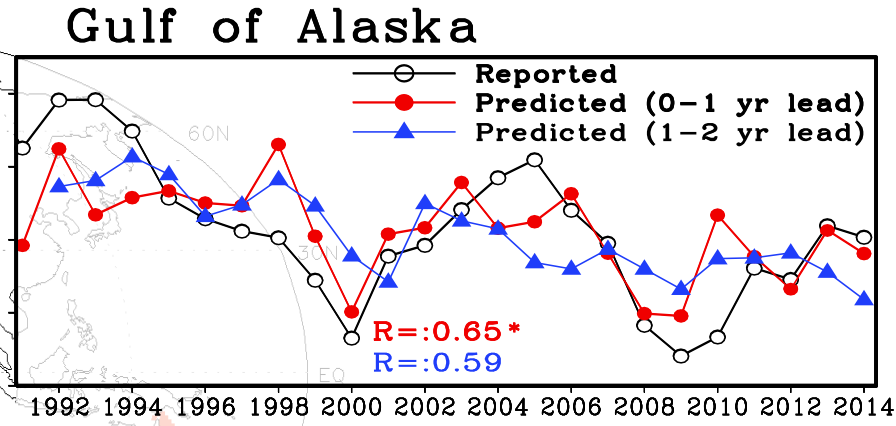
BGC Initialization data – **Retrospective Prediction**

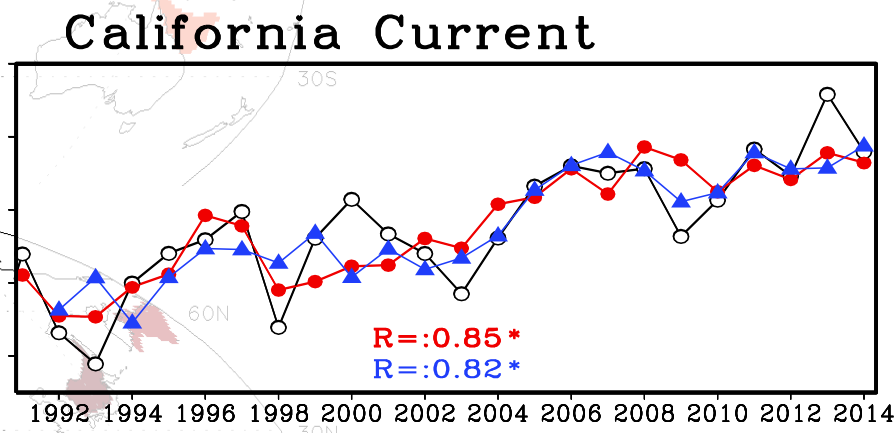
Annual fish catch prediction

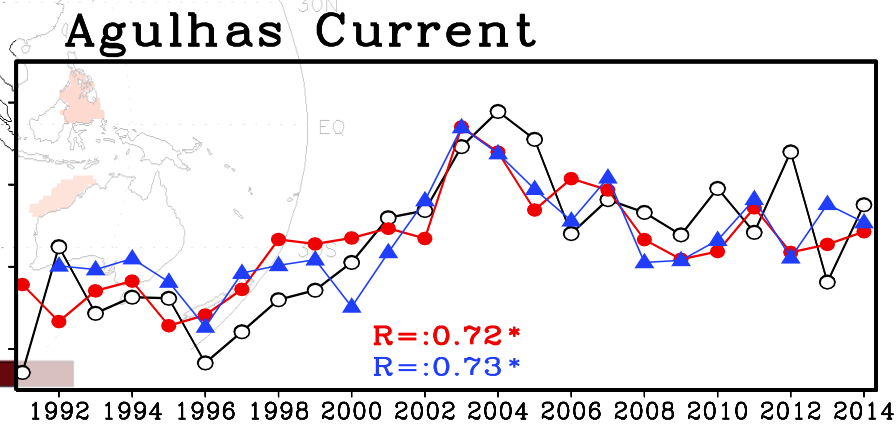
Predictor:
predicted SST
(0-1 year lead)

Predictor:
predicted SST+CHL
(0-1 year lead)

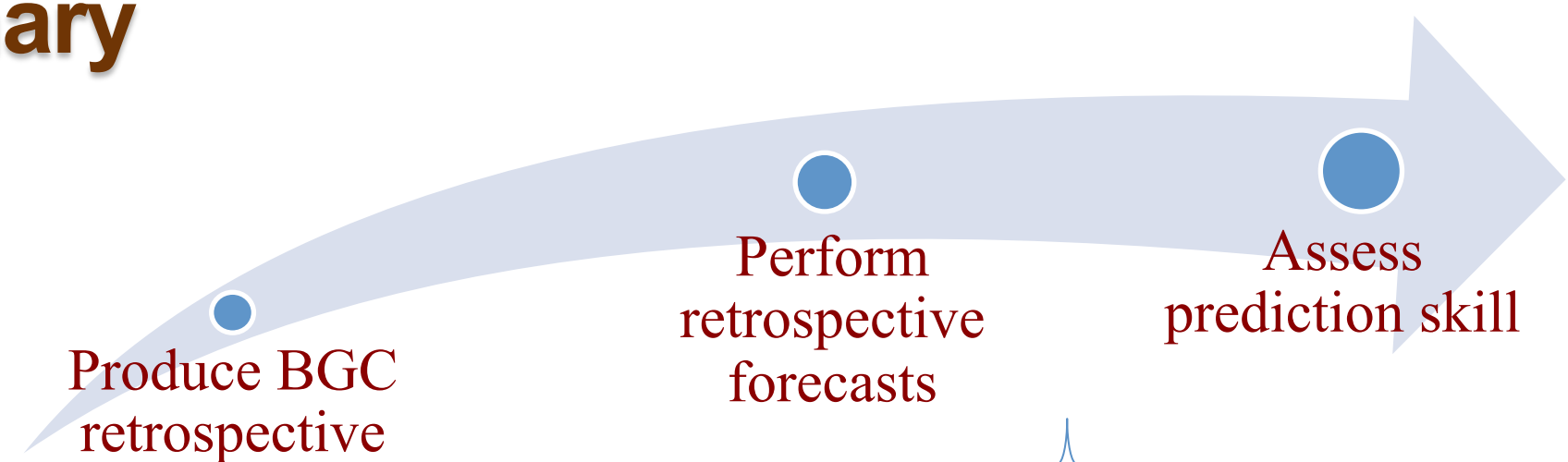








Summary



- ✓ Strategy: **Integrating BGC model with physical data assimilation**.
- ✓ **Substantial BGC bias** along the equator **due to spurious upwelling**.
- ✓ Addressed by **enforcing stricter fidelity to model dynamics** over ocean data constraints.
- ✓ **Improved BGC** with optimally constrained run.

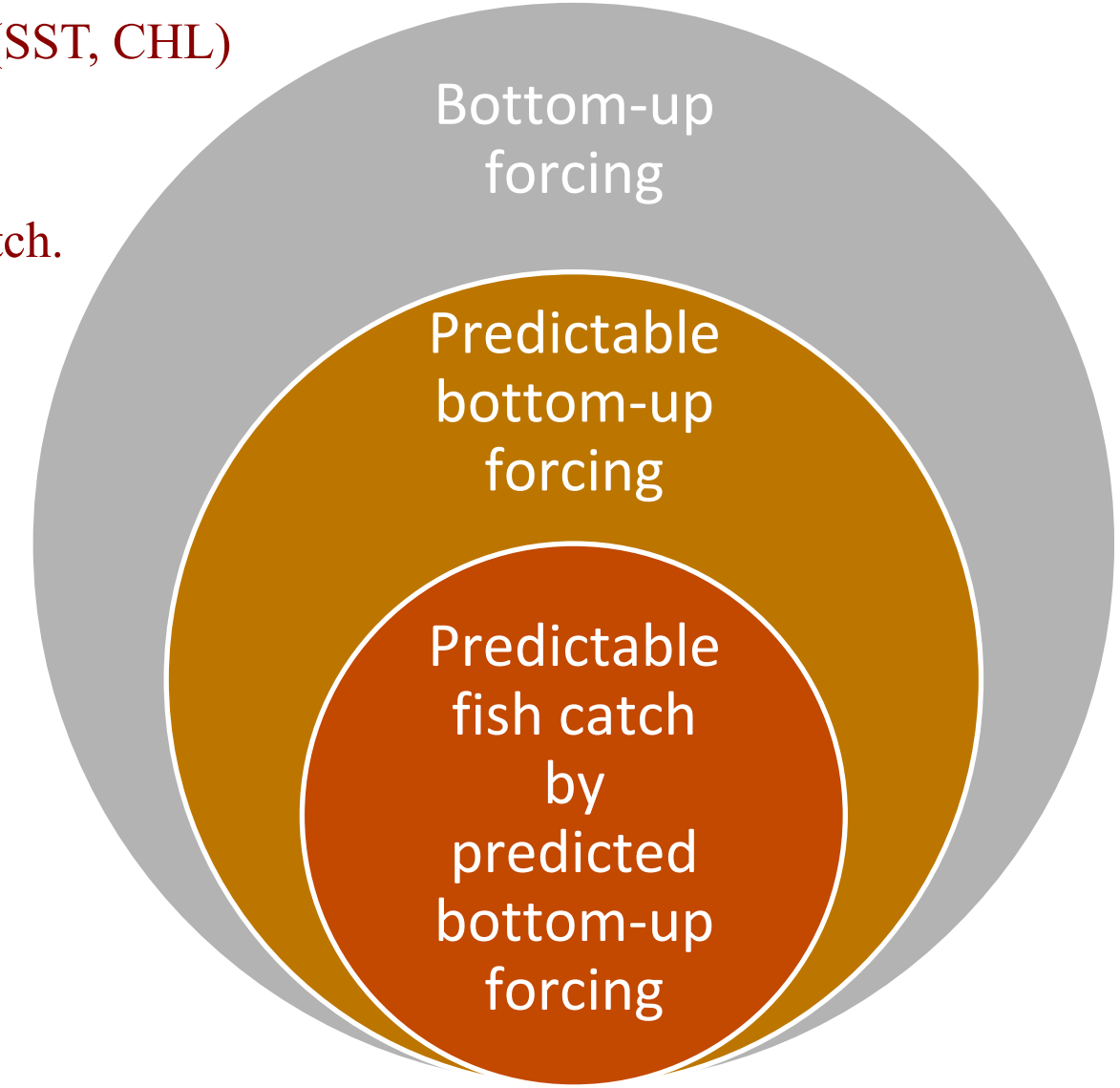
- ✓ **Up to 1-2 year** of CHL prediction skill depending on initialization month.
- ✓ **Potential utility for fish catch prediction is promising!**

"Thank you for your attention"

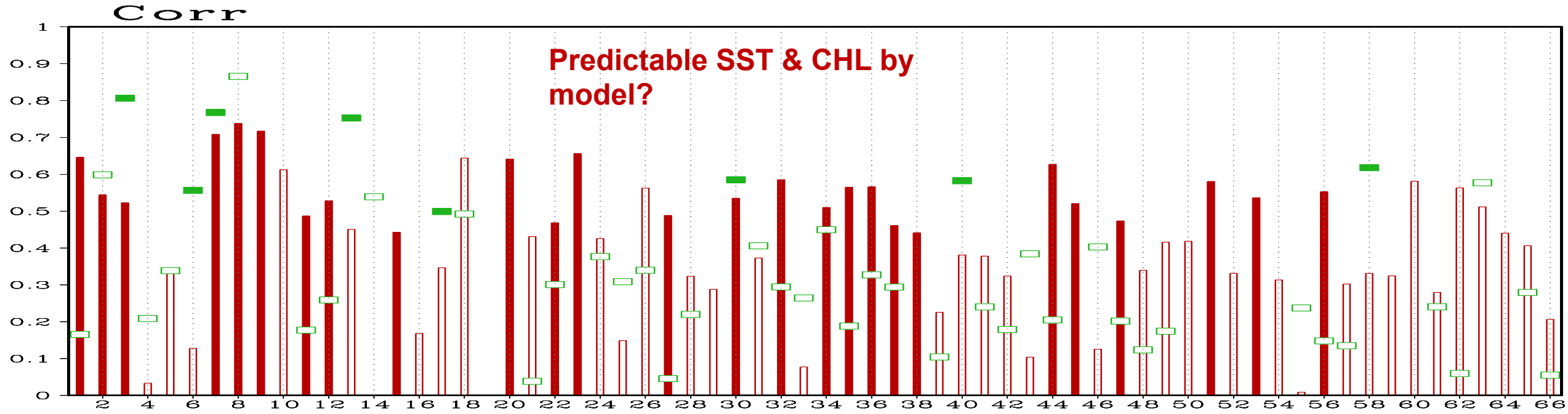
Back up

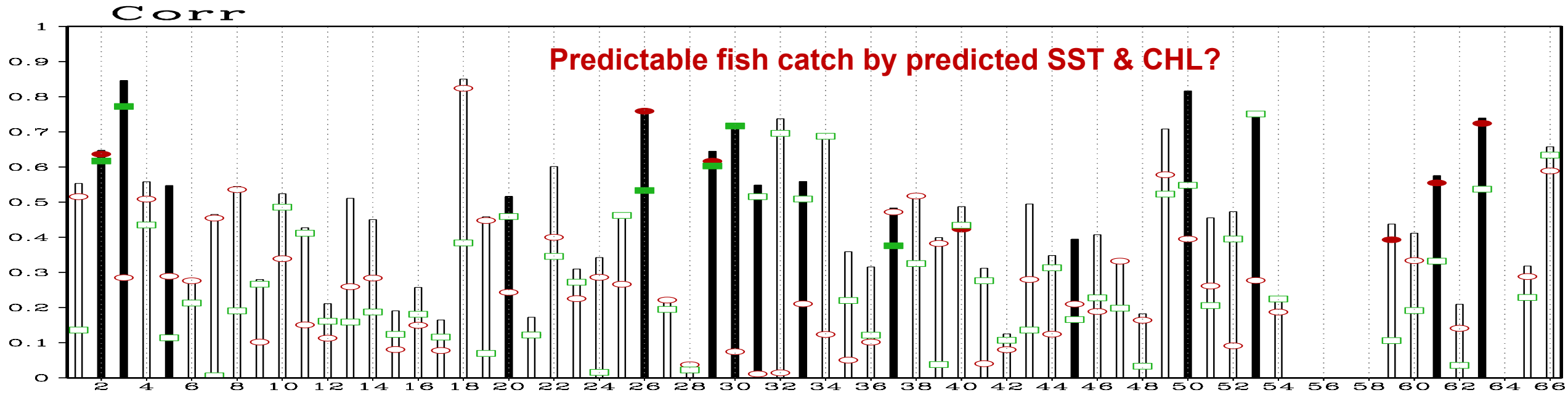
✓ **LMEs selection criteria:**

1. Fish catch is dominated by bottom-up forcing (SST, CHL)
   : Mcowen 2015
2. Model can predict SST & CHL.
3. Predicted SST & CHL explain reported fish catch.

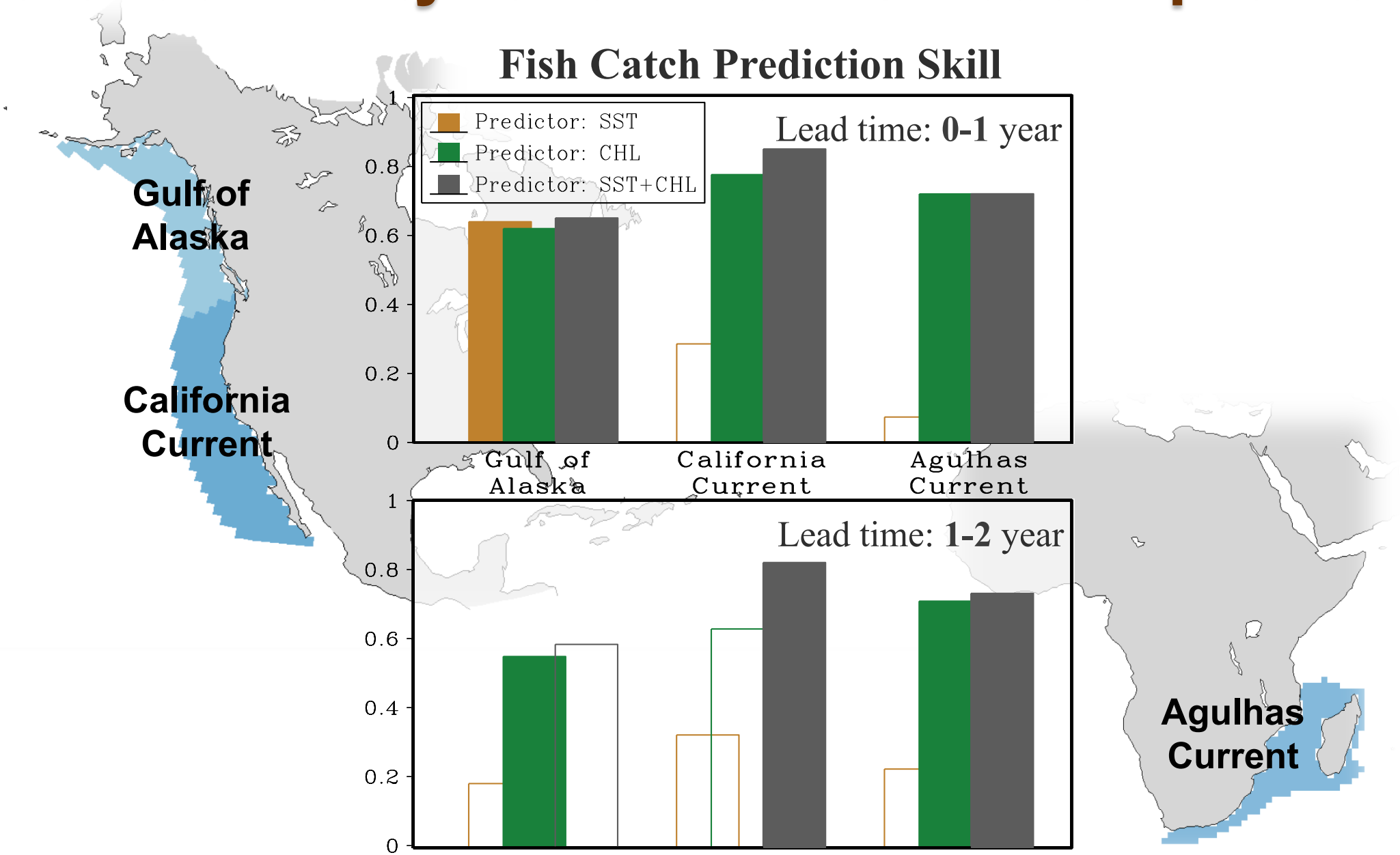


95% significance test

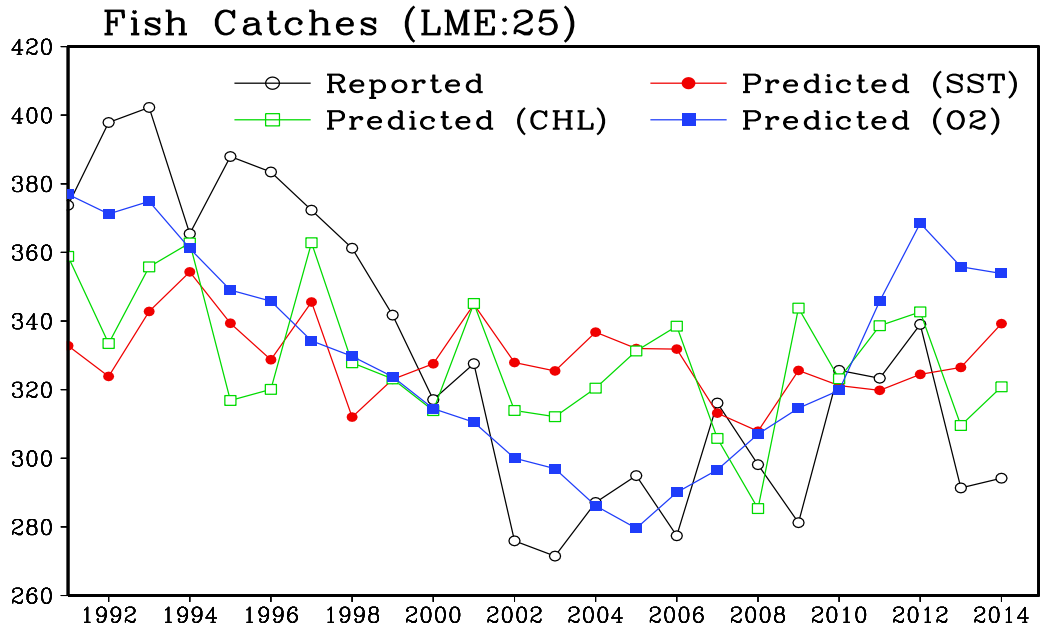


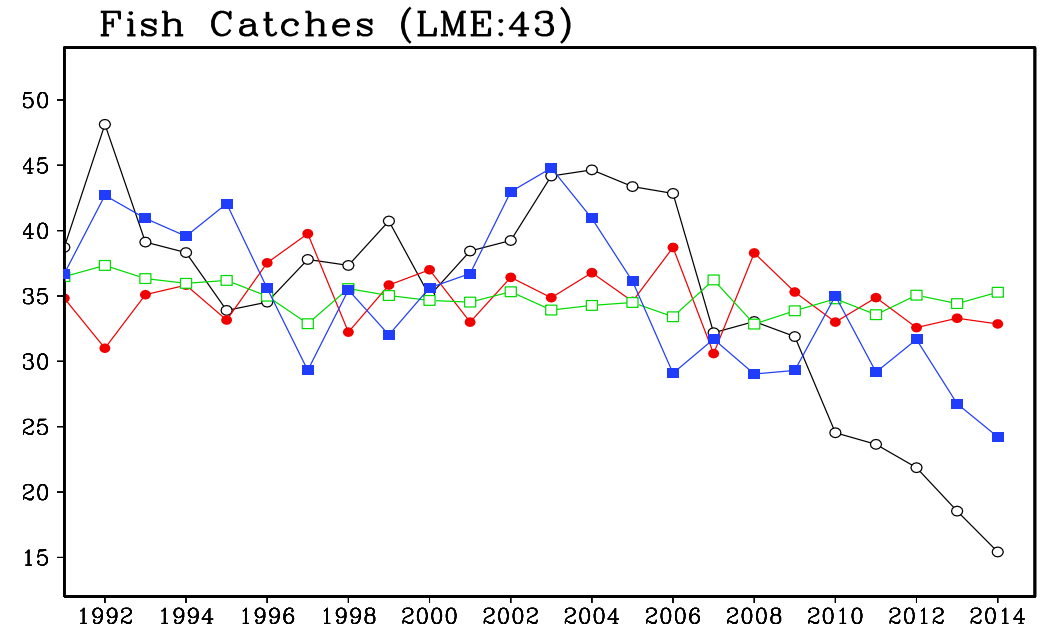


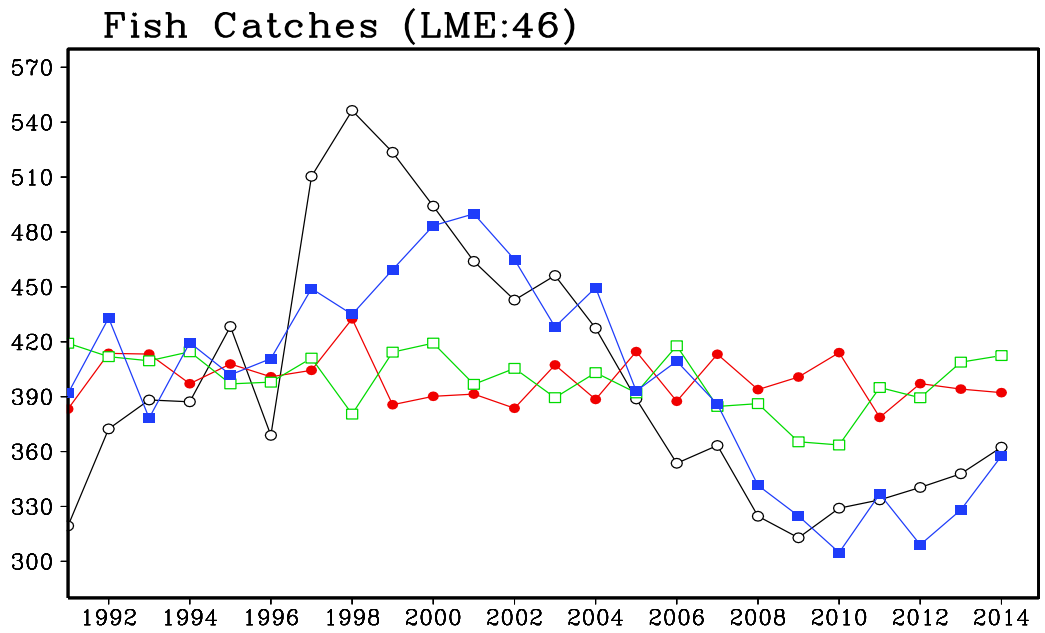
Potential utility for annual fish catch prediction

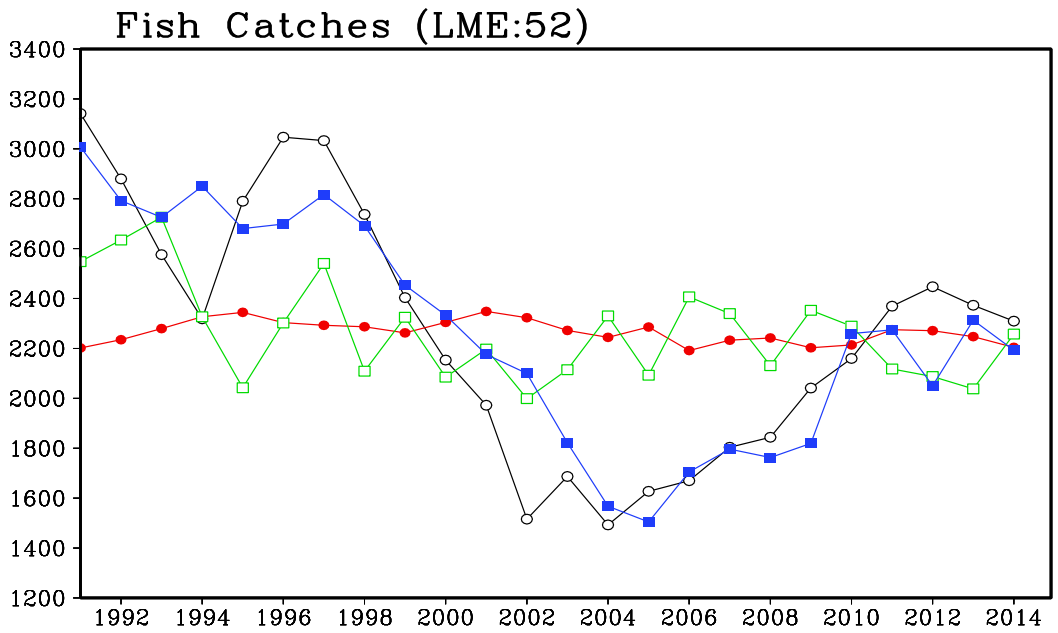


Potential utility for annual fish catch prediction



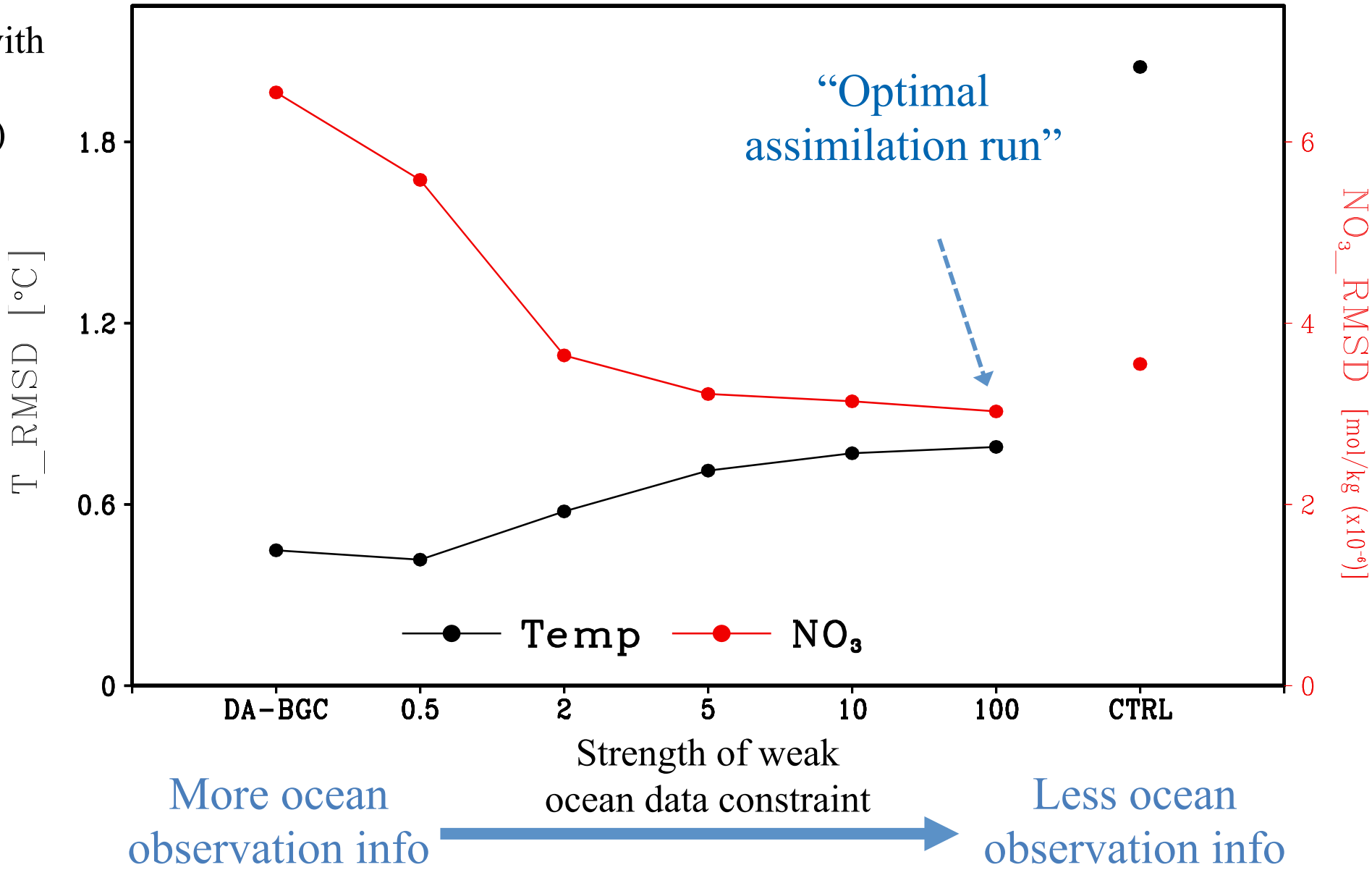






Tradeoff between BGC bias & Phy bias

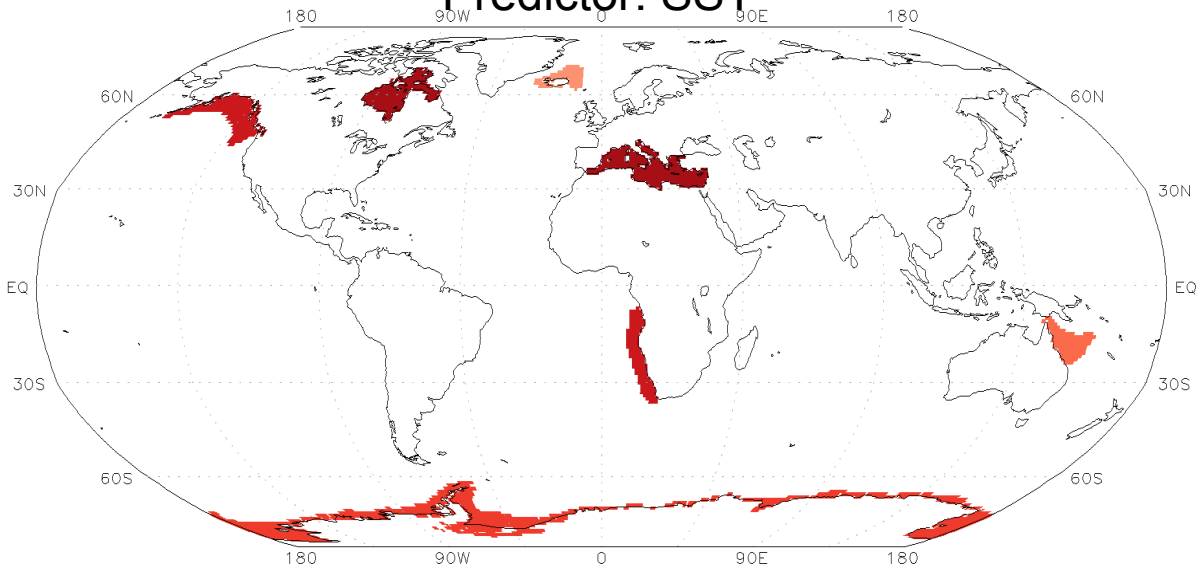
Compared with
EN4 (Temp)
WOA (NO3)



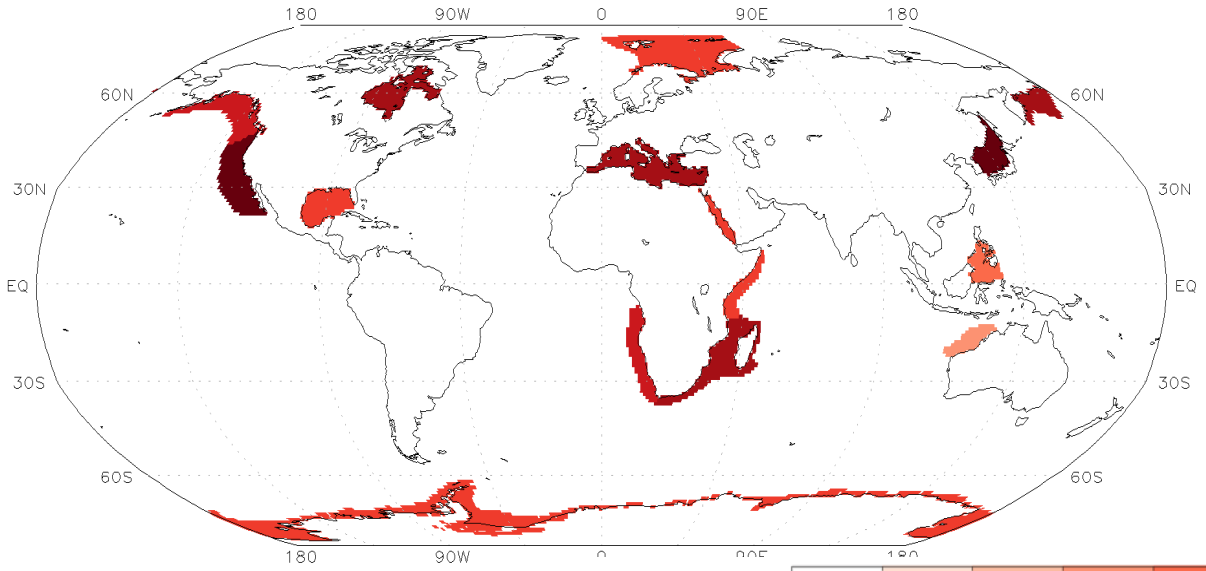
Potential utility for annual fish catch prediction

95% significant regions

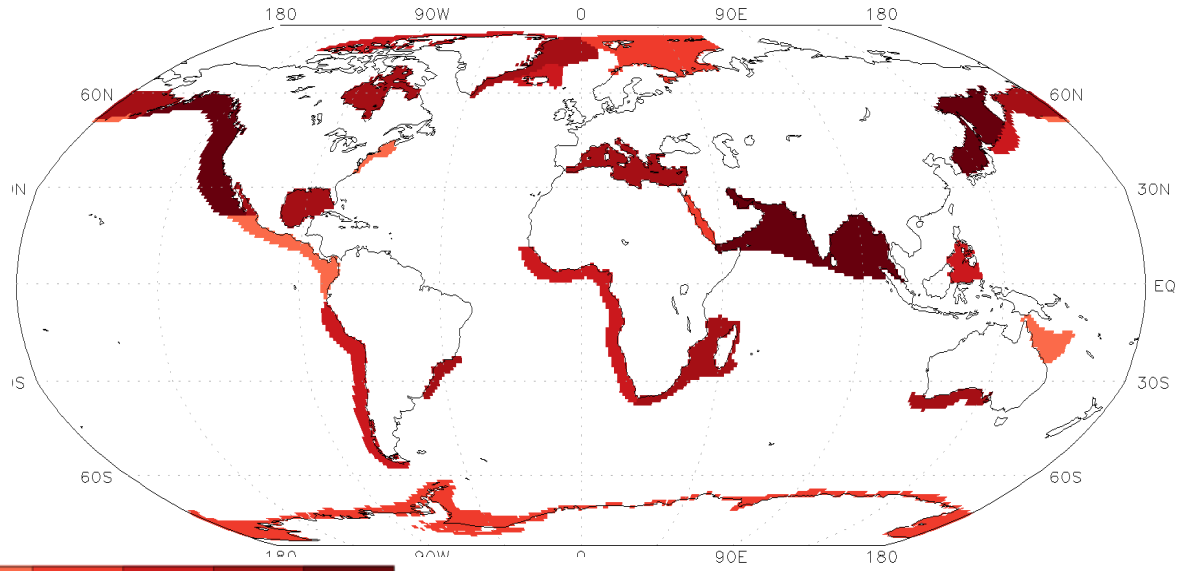
Predictor: SST



Predictor: SST+CHL



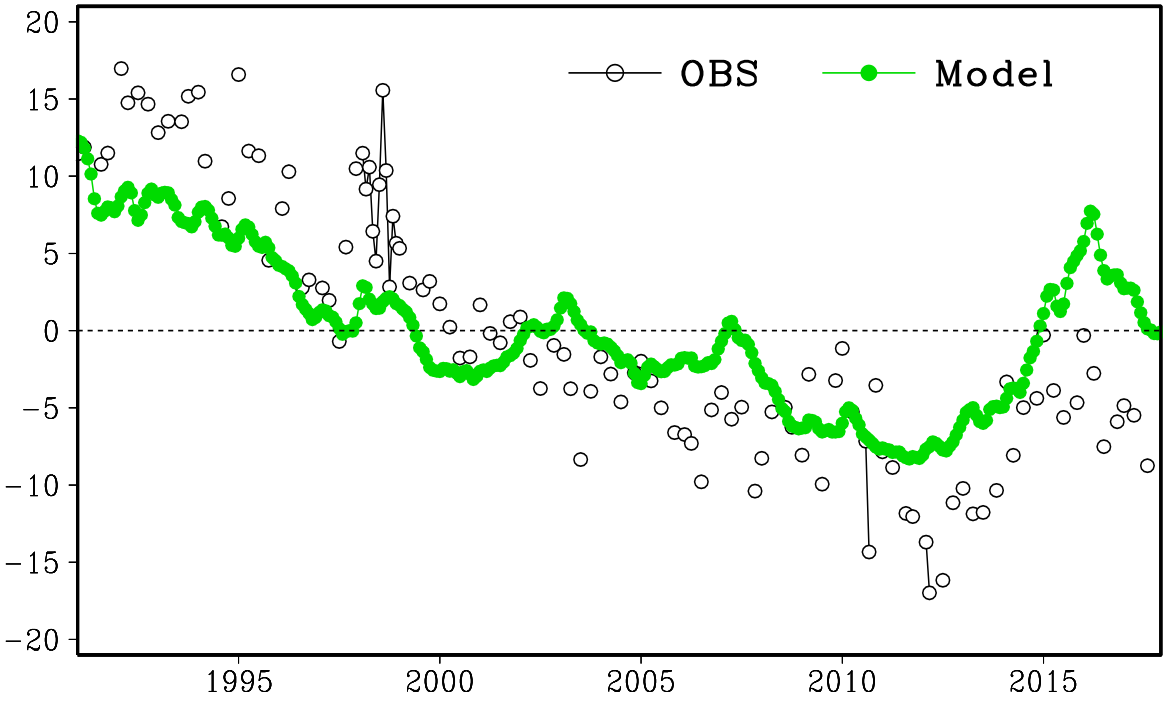
Predictor: SST+CHL+O2



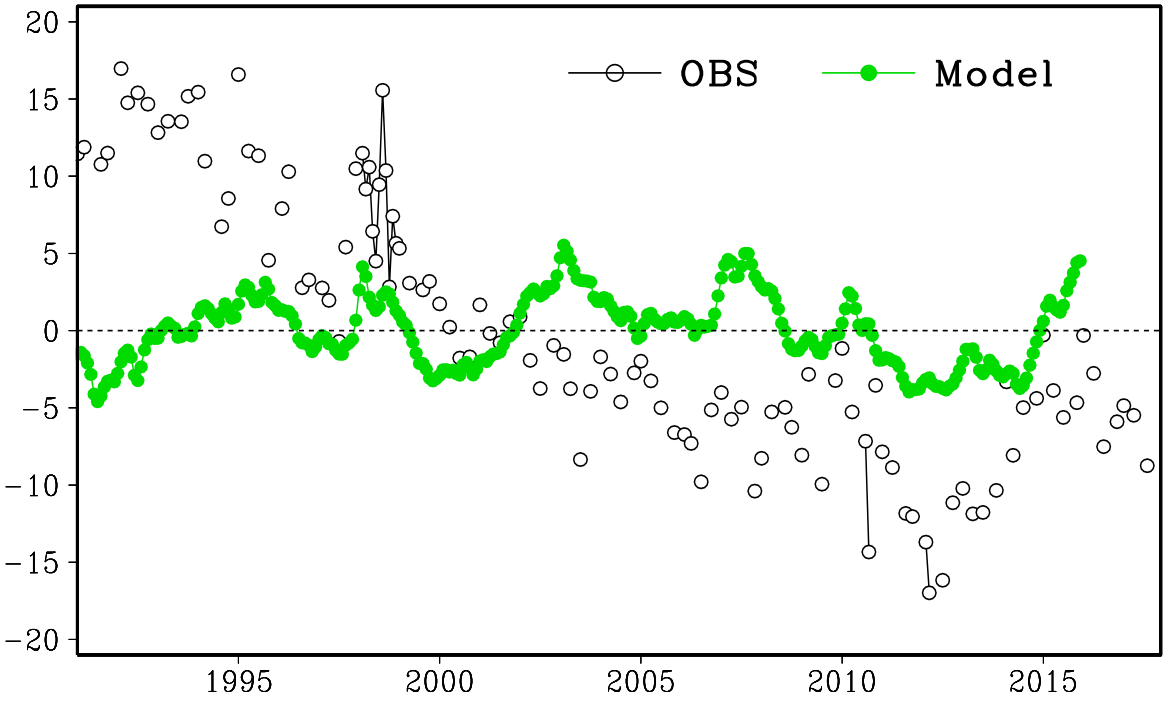
Improved subsurface O_2 by ocean data assimilation

Model vs. OBS (CalCOFI data)

With Ocean data assimilation

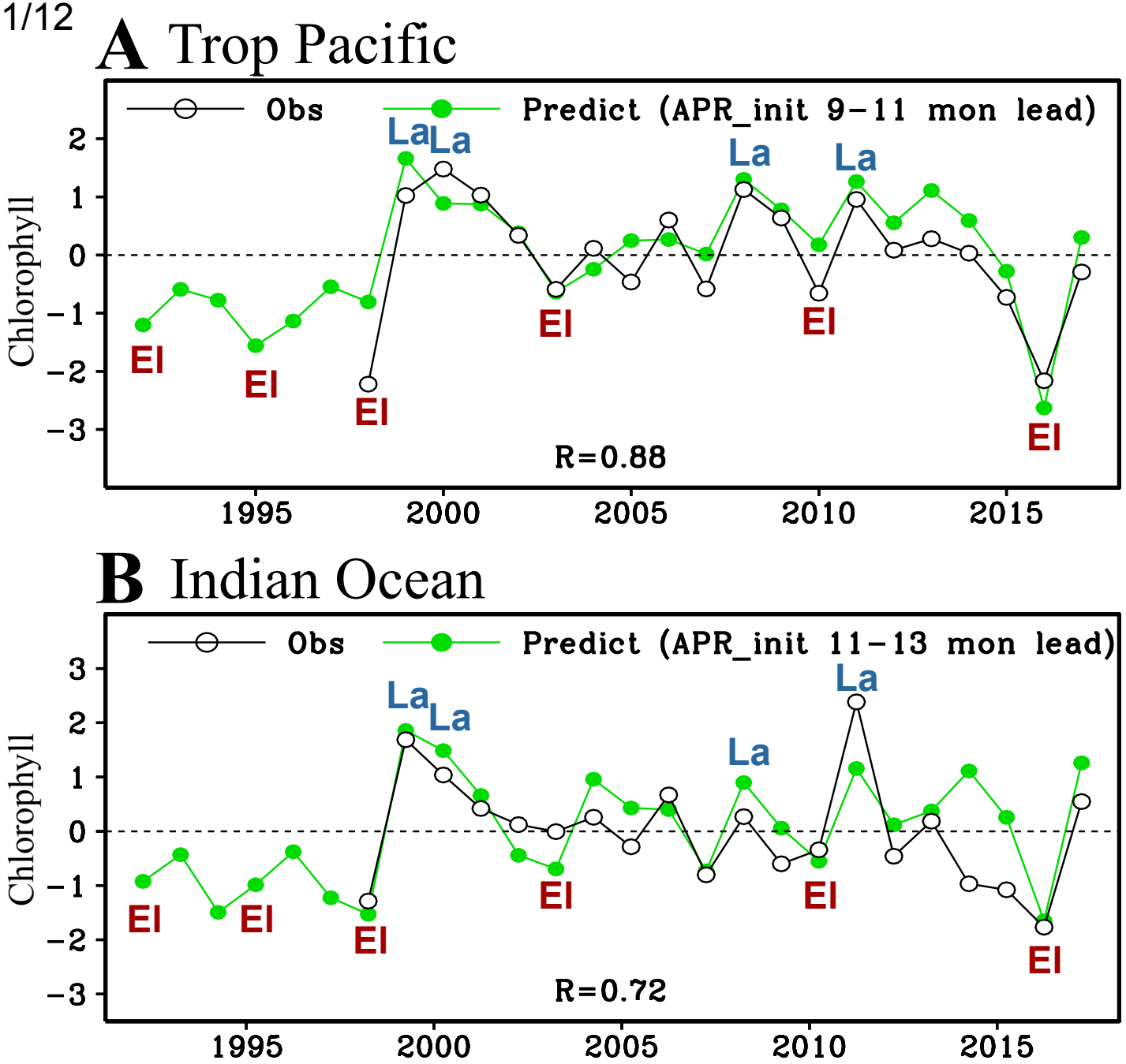


Without Ocean data assimilation
(Atmos data assimilation only)



O2: 200-500m averaged

La: **95/96, 98/99, 99/00**, 00/01, 05/06, **07/08**, 08/09, **10/11**, 11/12



El > 1^0C NINO34_ONDJF
La < -1^0C NINO34_ONDJF

North Atlantic

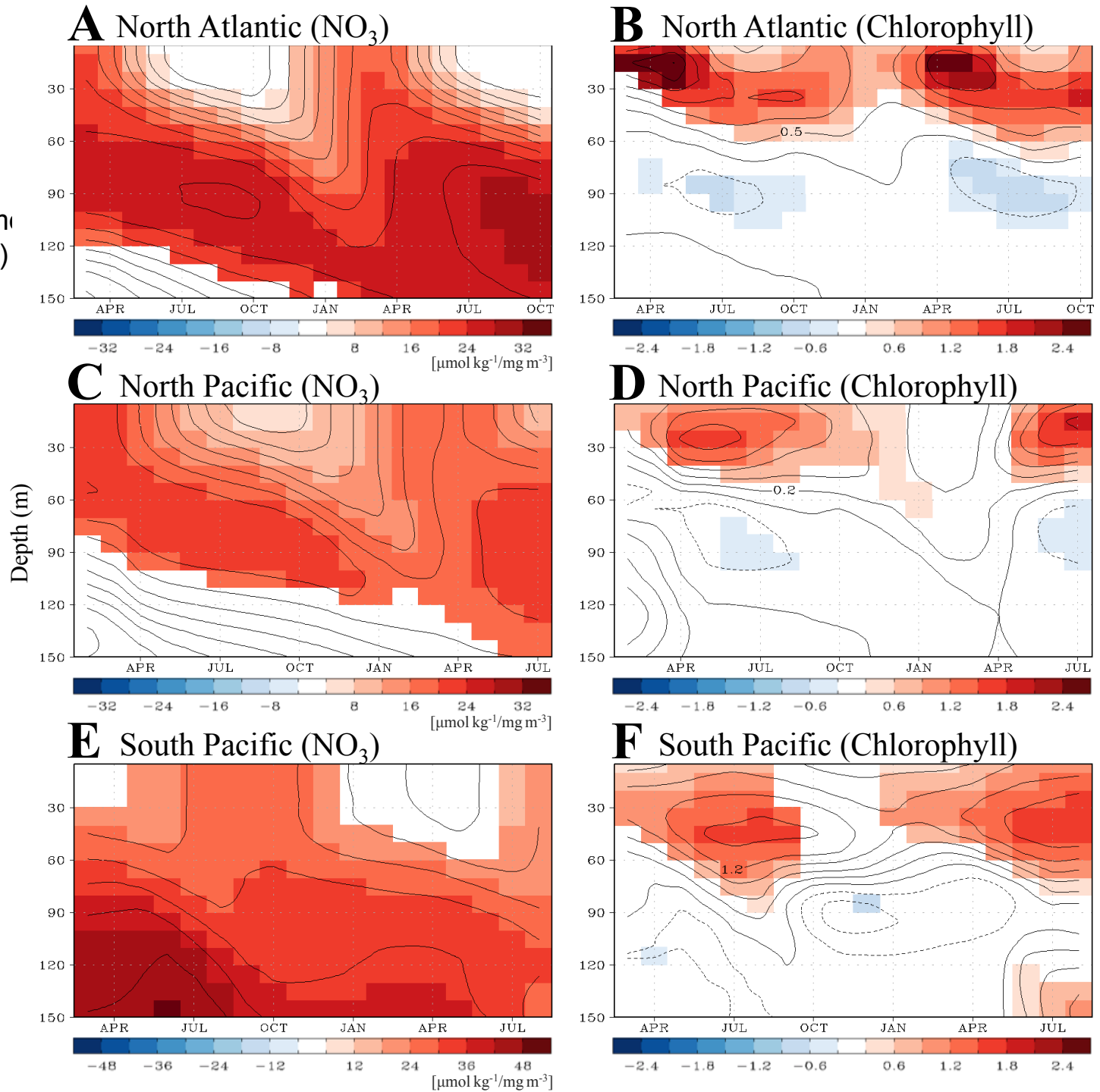
(Regression between March initialized NO3 anomaly forecast and March initialized SON (lead tim = 20 months) chl anomaly forecast)

North Pacific

(Regression between Feb initialized NO3 anomaly forecast and Feb initialized JJA (lead time = 18 months) chl anomaly forecast)

South Pacific

(Regression between March initialized NO3 anomaly forecast and March initialized JAS (lead time = 18 months) chl anomaly forecast)



Remedy to reduce momentum imbalance in DA

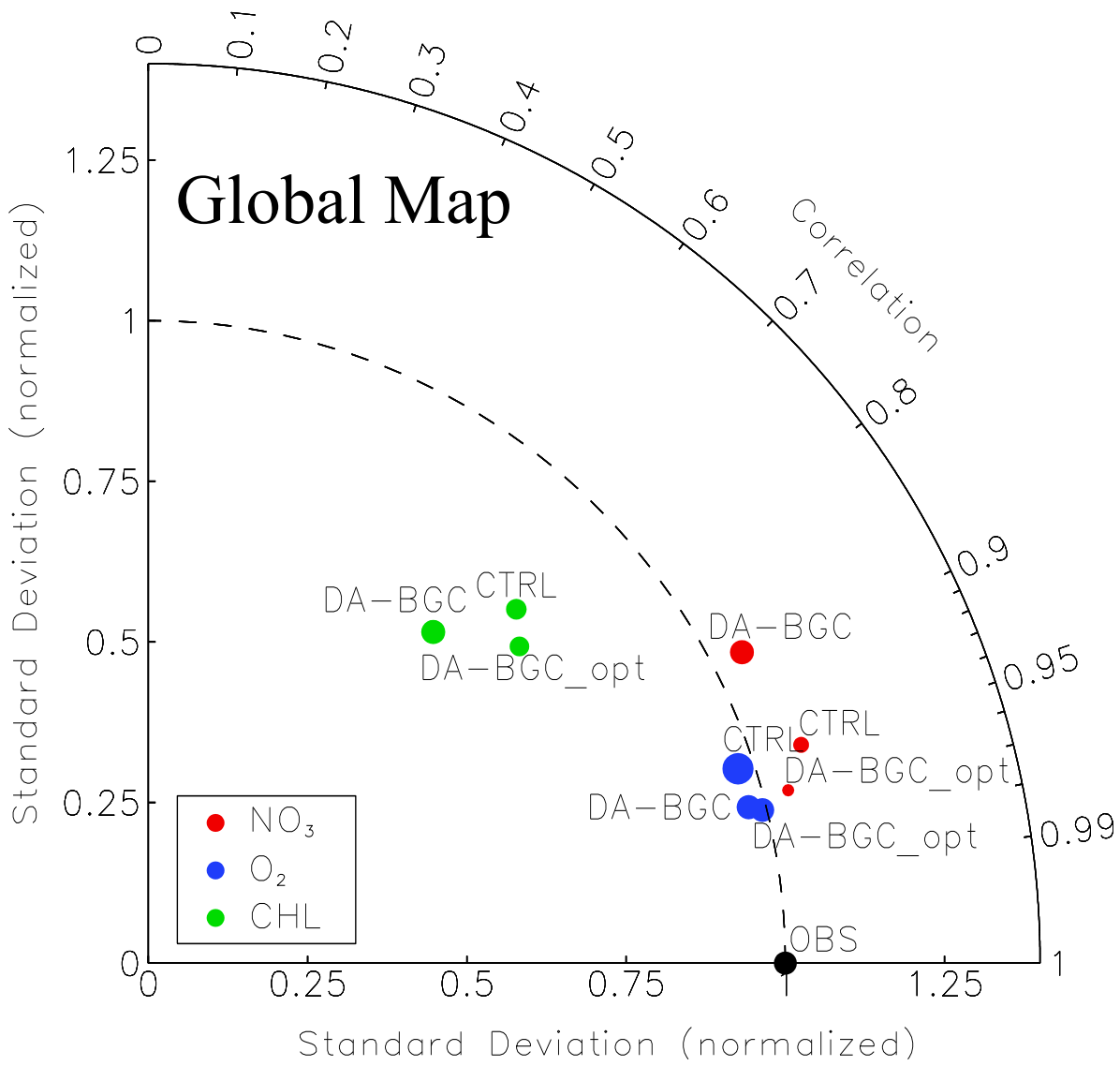
Remedy 1: strong atmosphere data constraint

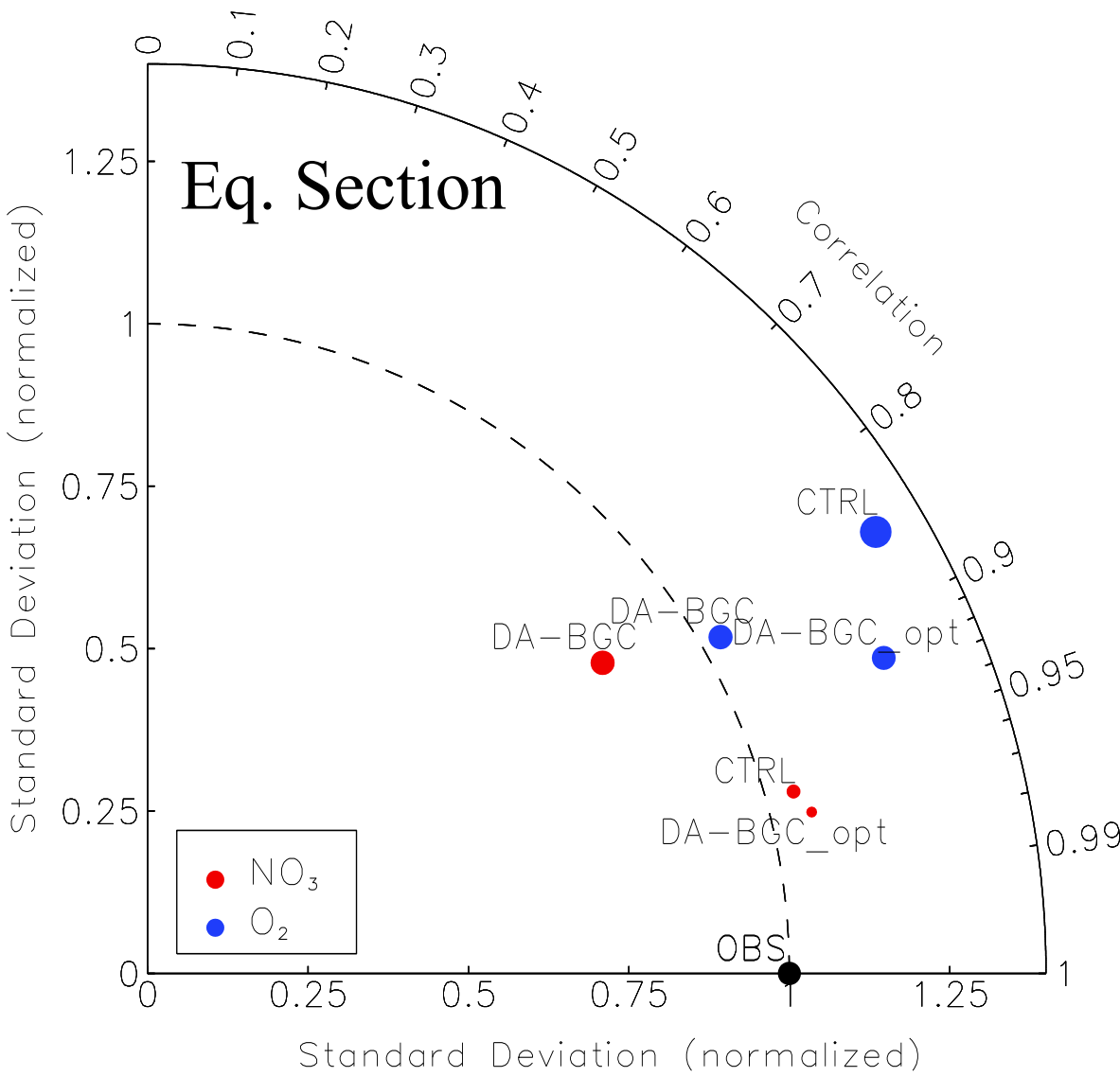
Remedy 2: weak equatorial ocean data constraint

Park et al. 2018 “Modeling global ocean biogeochemistry with physical data assimilation: A pragmatic solution to the equatorial instability”, *JAMES*

BGC Initialization data – Retrospective Prediction

Modified DA improves BGC simulations



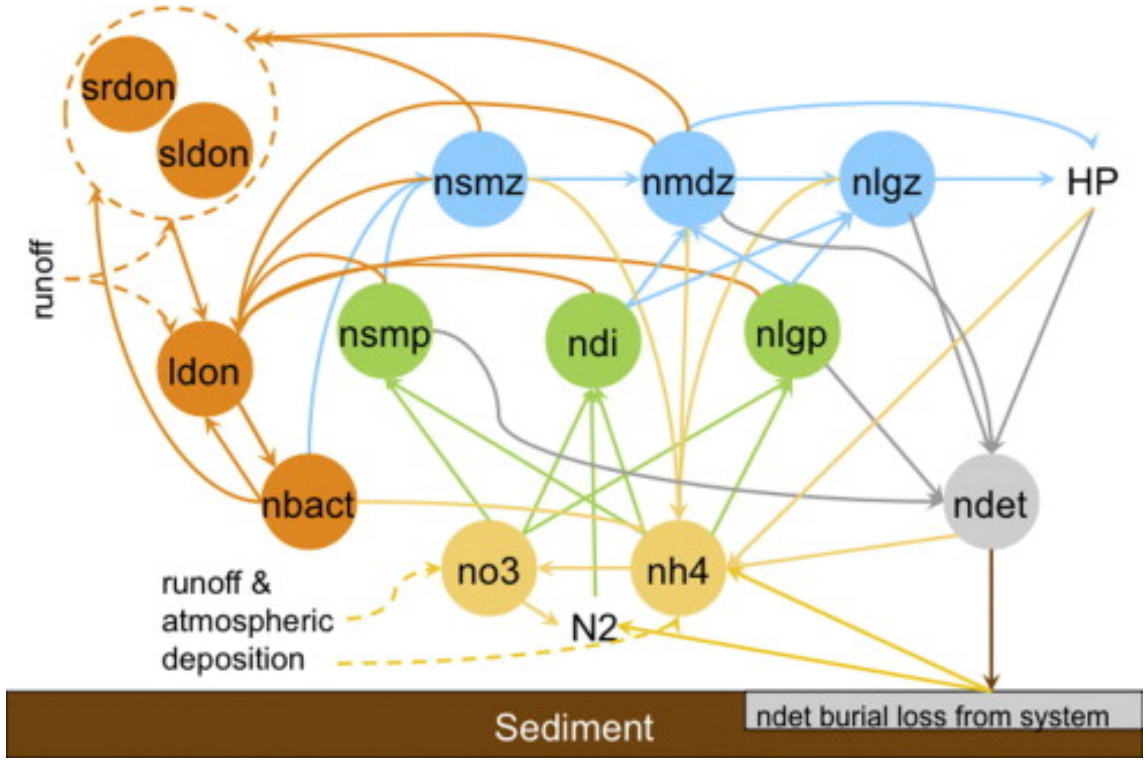


GFDL's marine biogeochemistry model

- COBALT

  : The Carbon, Ocean Biogeochemistry and Lower Trophics planktonic ecosystem model

- 33 tracers (3 phytoplankton groups, 3 zooplankton groups, free-living bacteria, organic matter, C, N, P, Si, ...)
- Light, temperature, nutrient limitations
- Coupled with physical ocean model (1deg resolution)

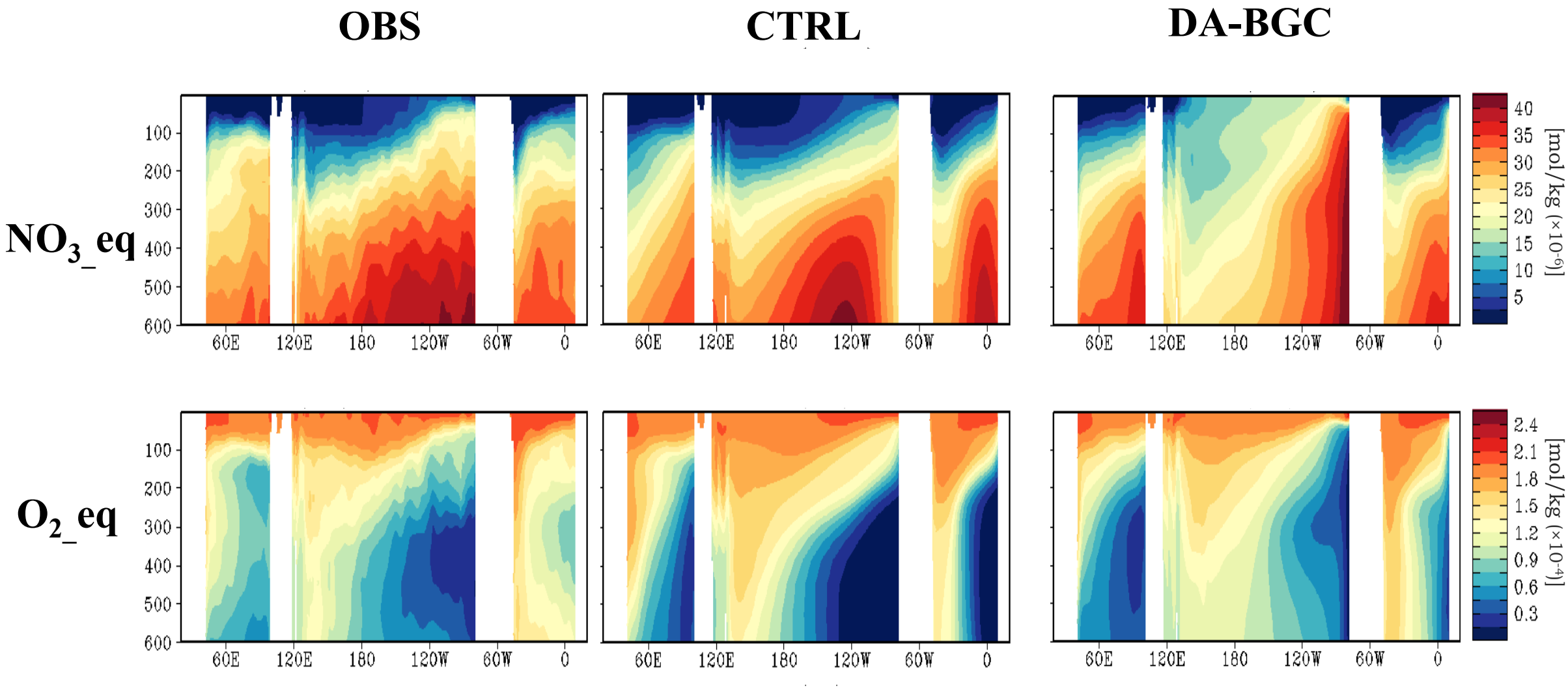


Stock et al. 2014

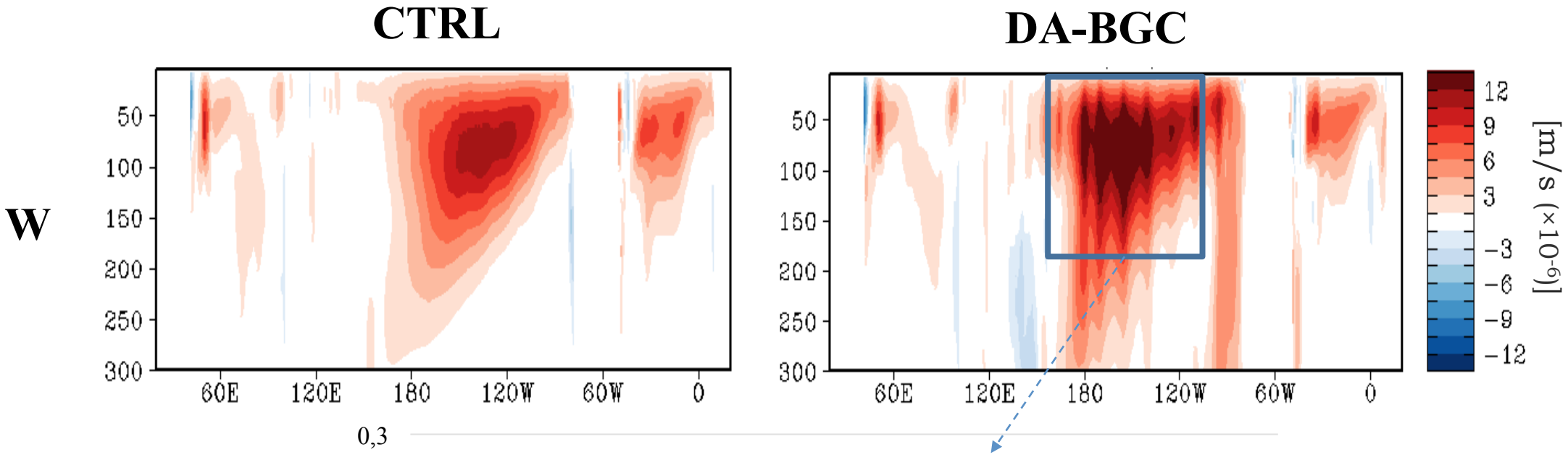
Experiments

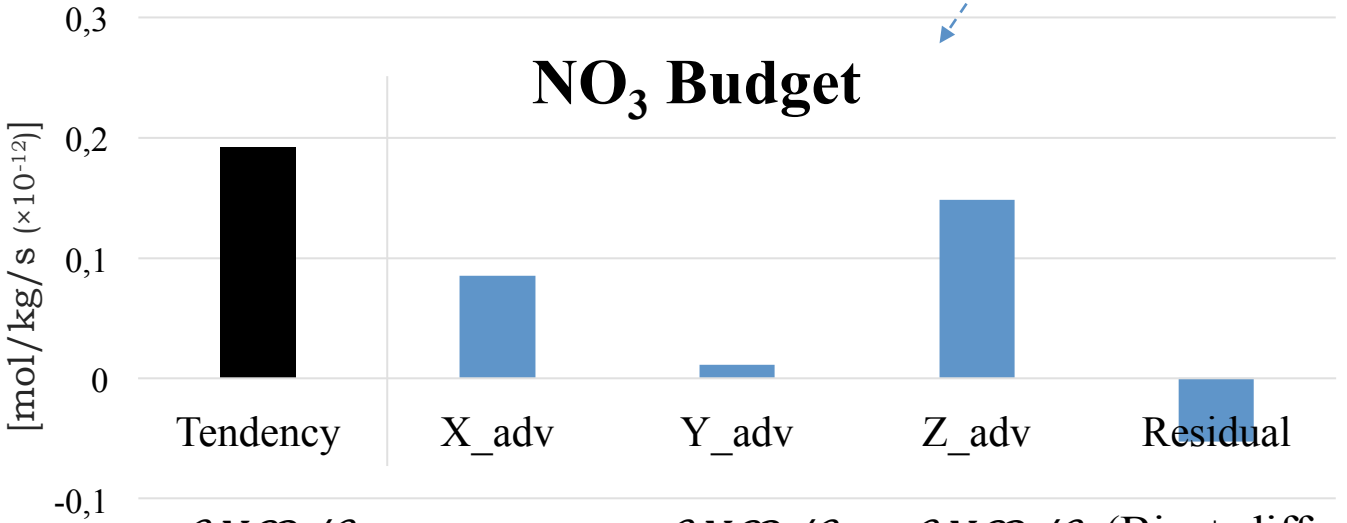
Experiments	Description
CTRL	No ocean data assimilation
DA-BGC	Baseline data assimilation run
A series of modified DA-BGC	Sensitivity runs with changing atmosphere/ocean data constraint

Degraded subsurface BGC at the Equator



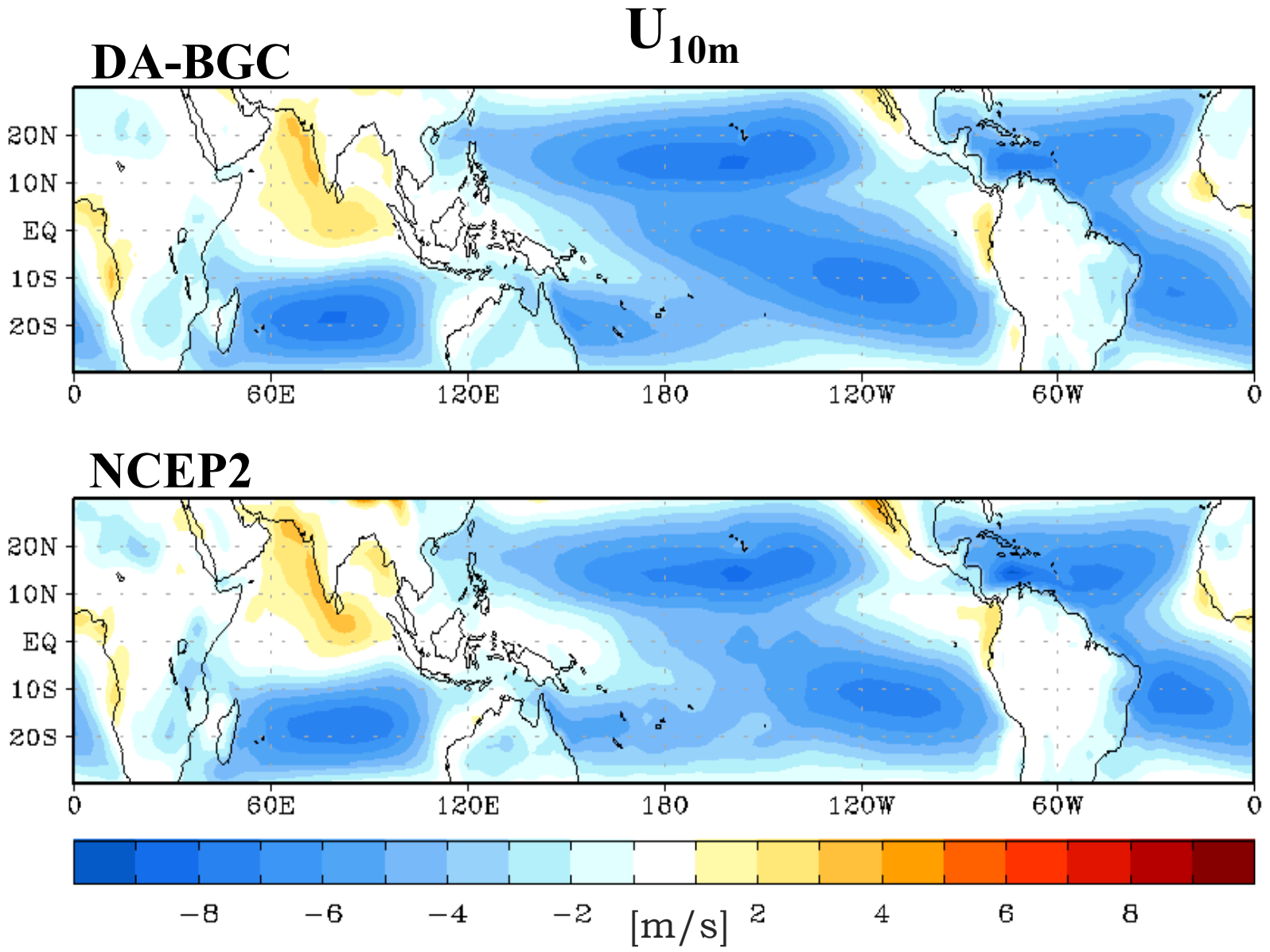
Spurious velocity problem





$\partial NO3/\partial t = -u\partial NO3/\partial x - v\partial NO3/\partial y - w\partial NO3/\partial z$ (Bio + diffusion + nonlinear high frequency advection)

Strong trade winds bias at the Equator

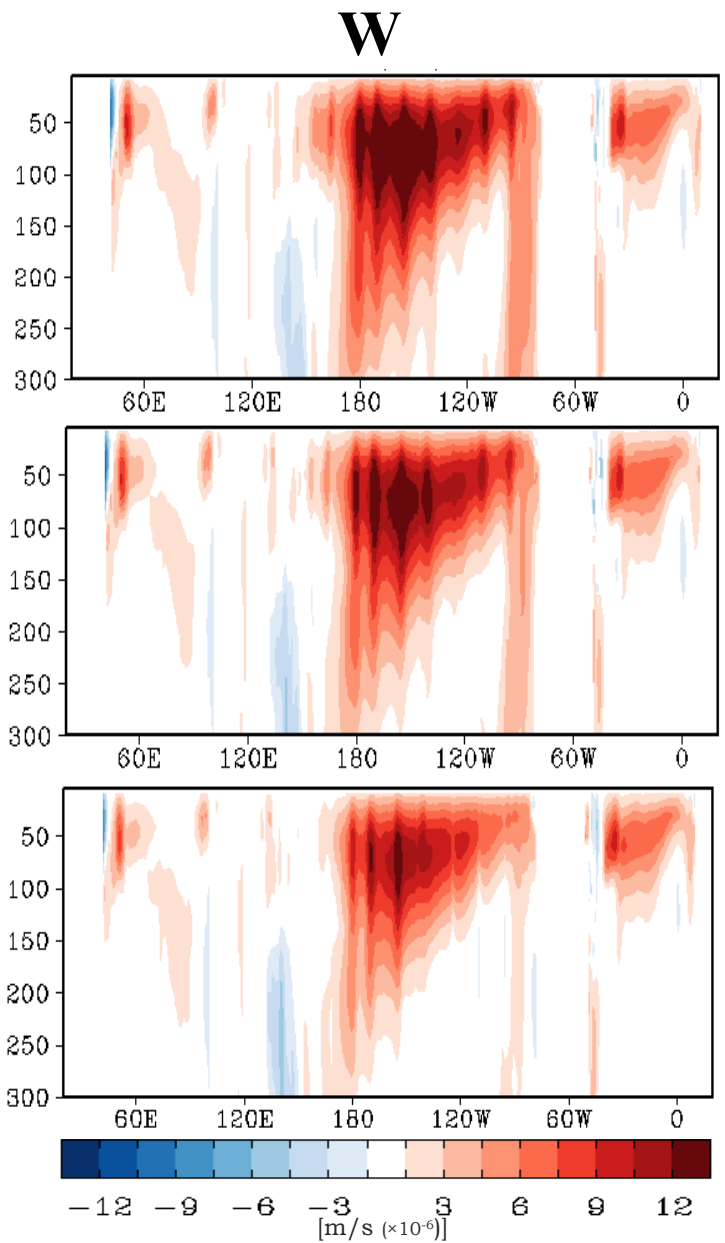


Remedy 1: strong atmosphere data constraint

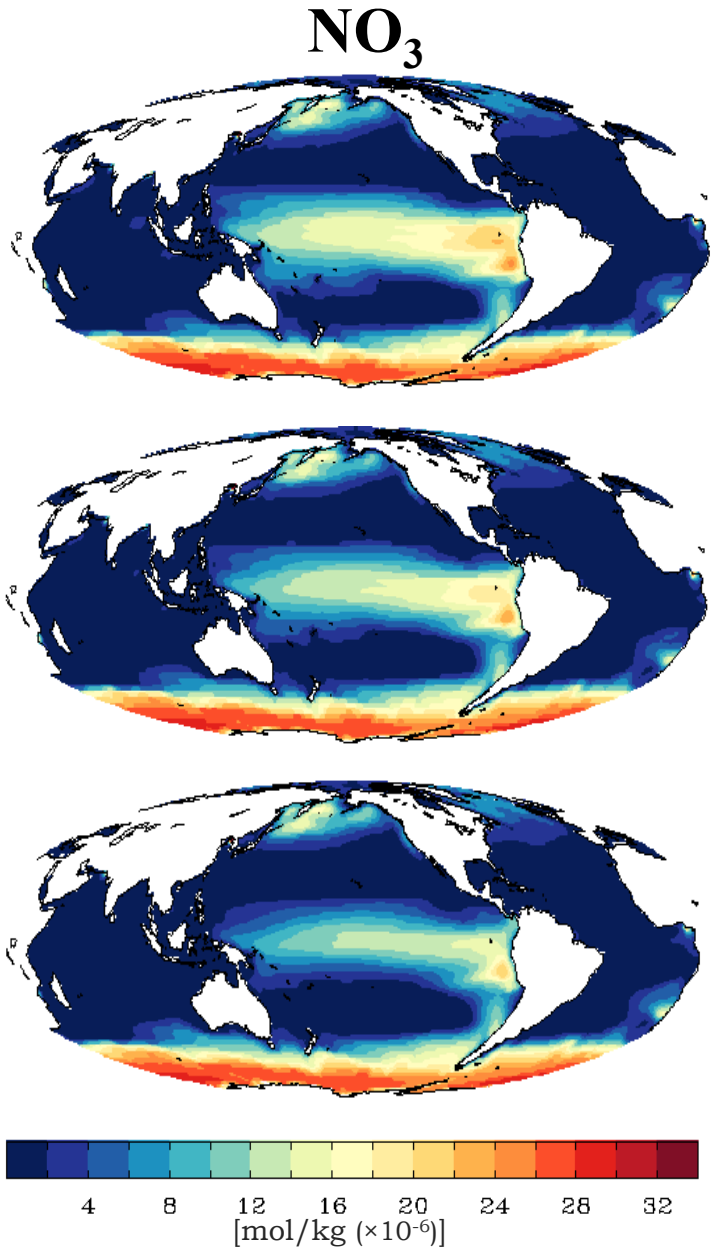
DA-BGC

Strong Atmos$_{const}$

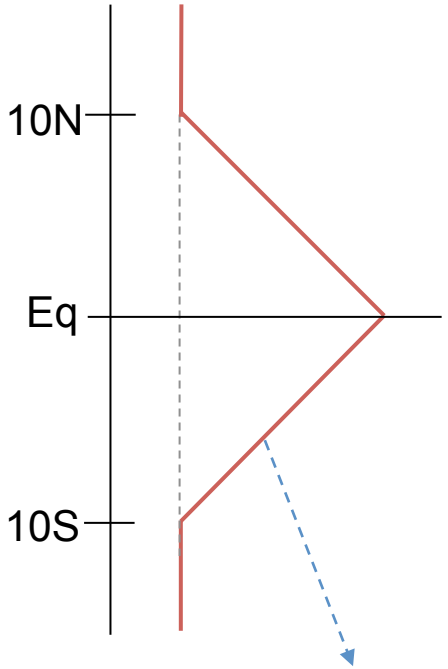
Stronger Atmos$_{const}$



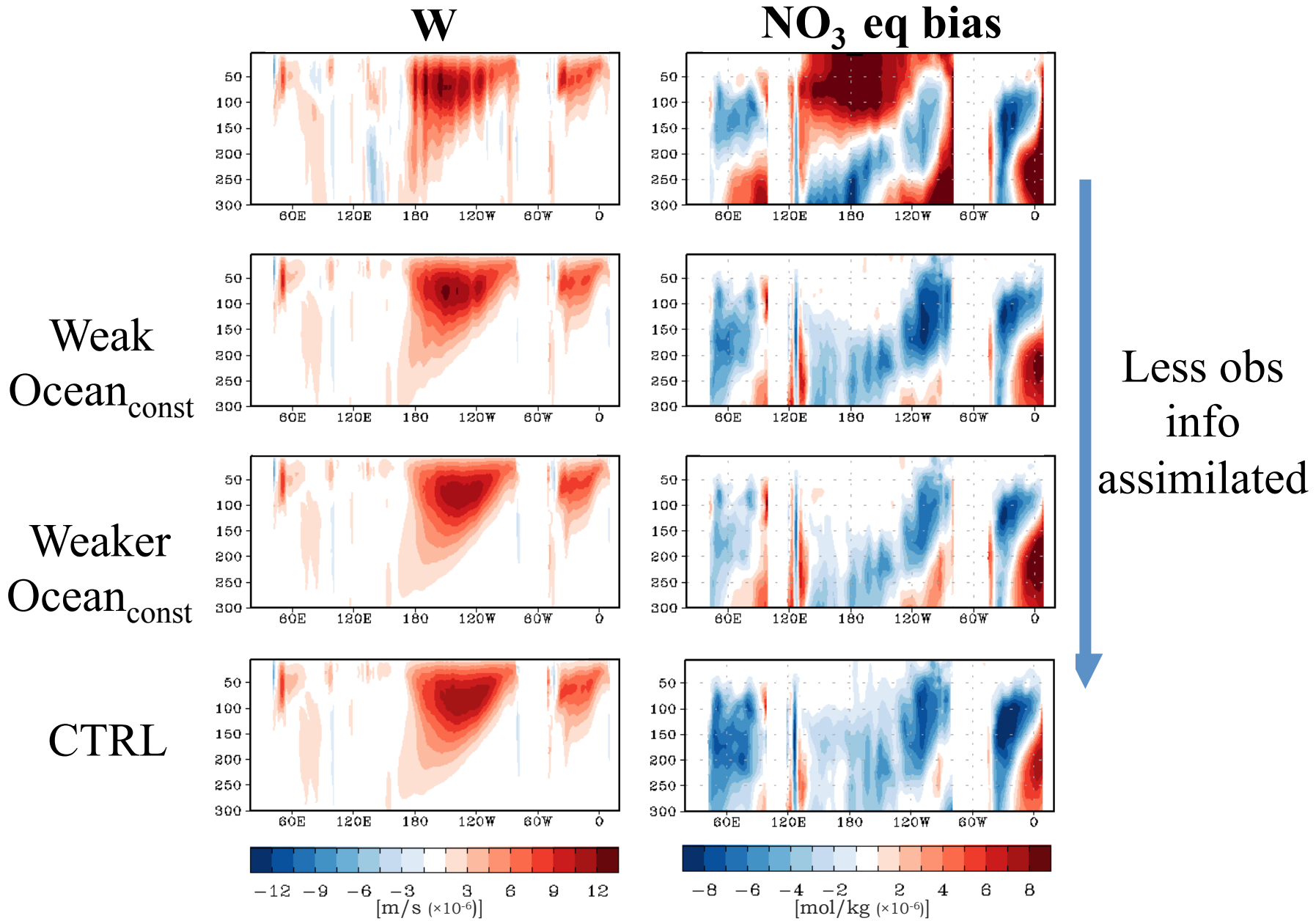
more atmos obs info assimilated



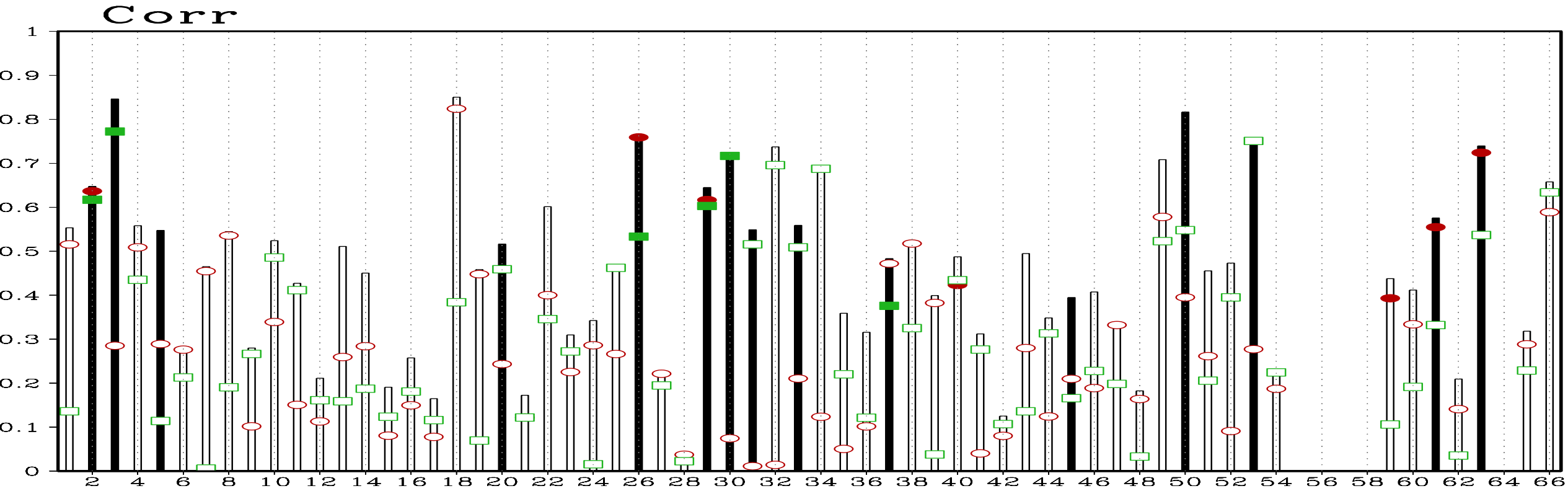
Remedy 2: weak equatorial ocean data constraint



Linear latitudinal ramp

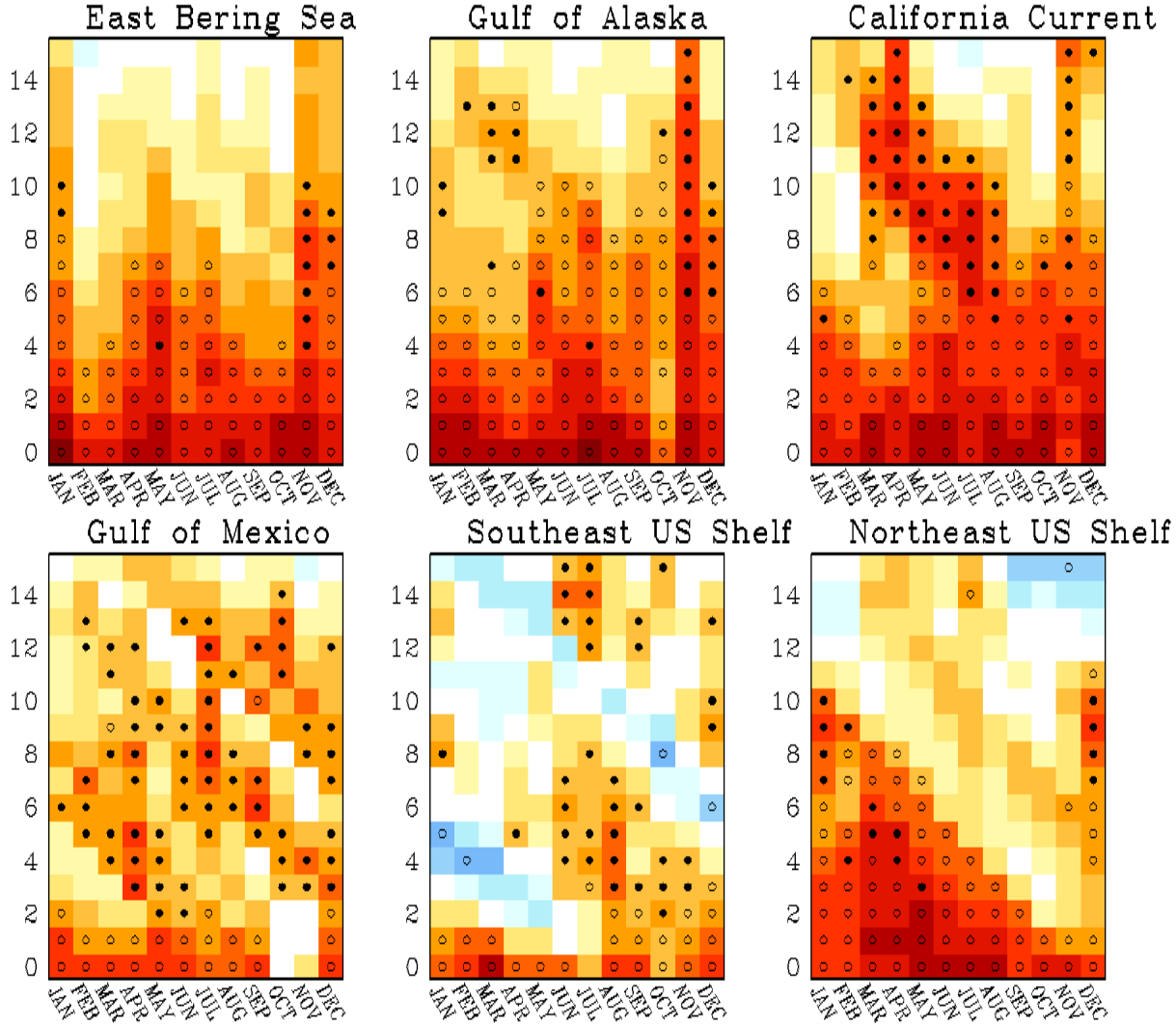


Predictable fish catch by predicted SST & CHL?

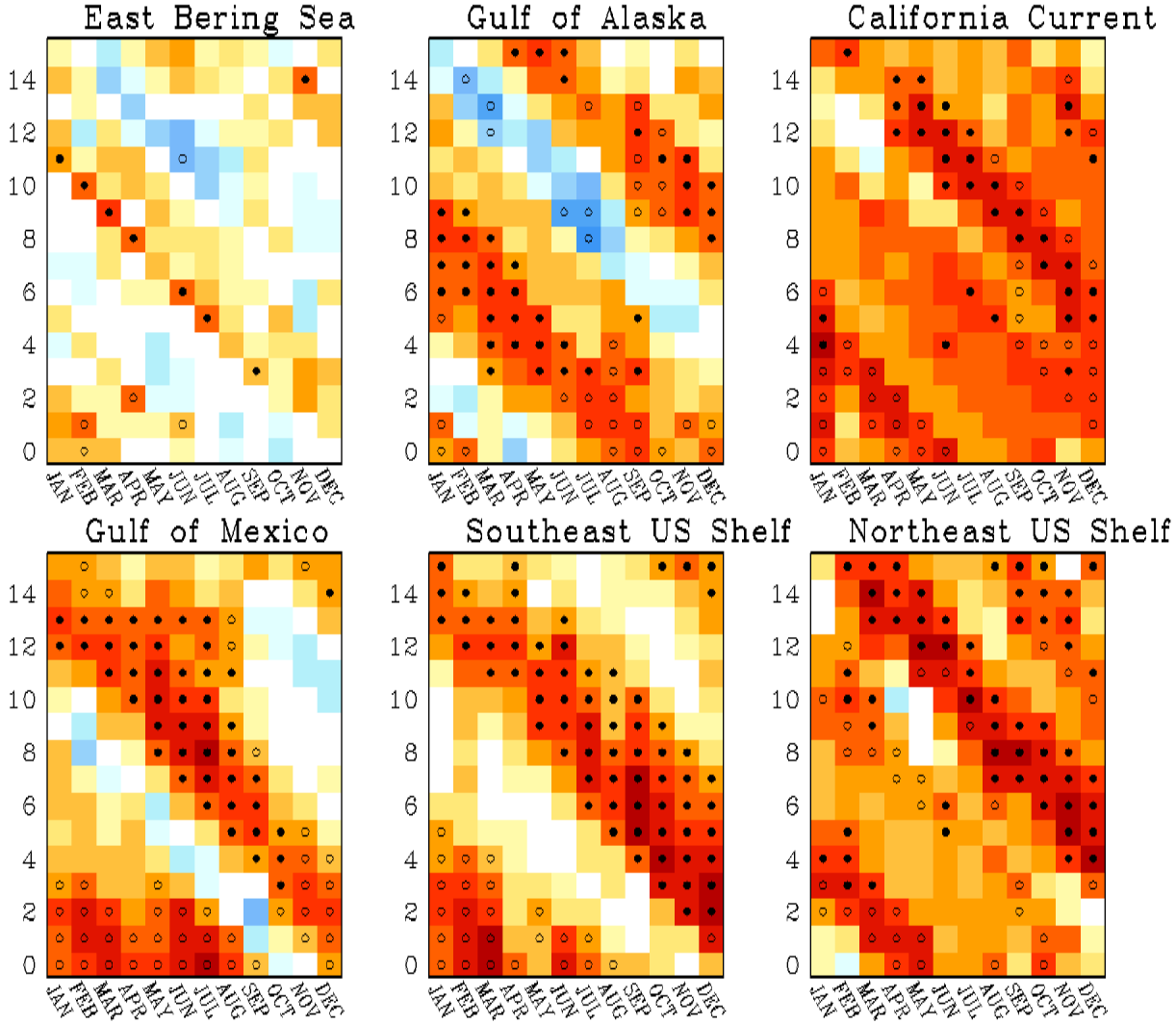


Prediction skill

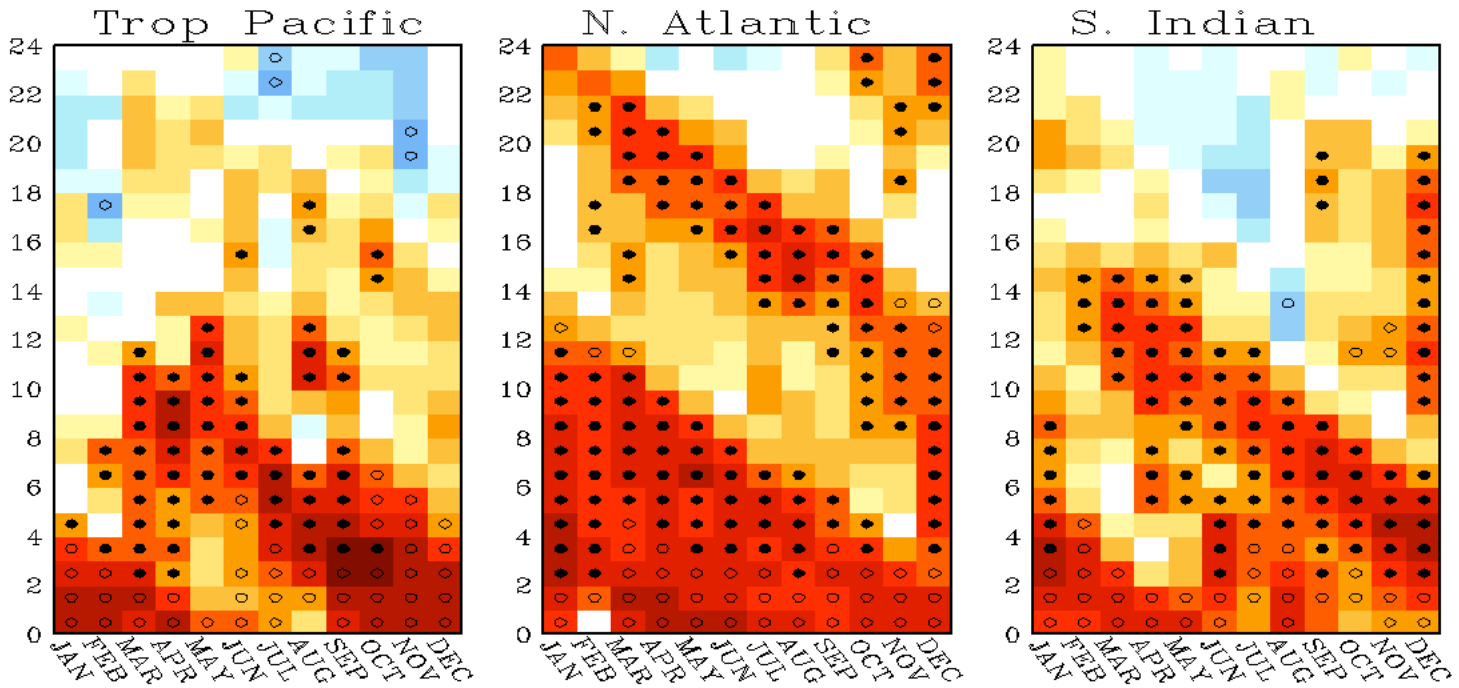
SST



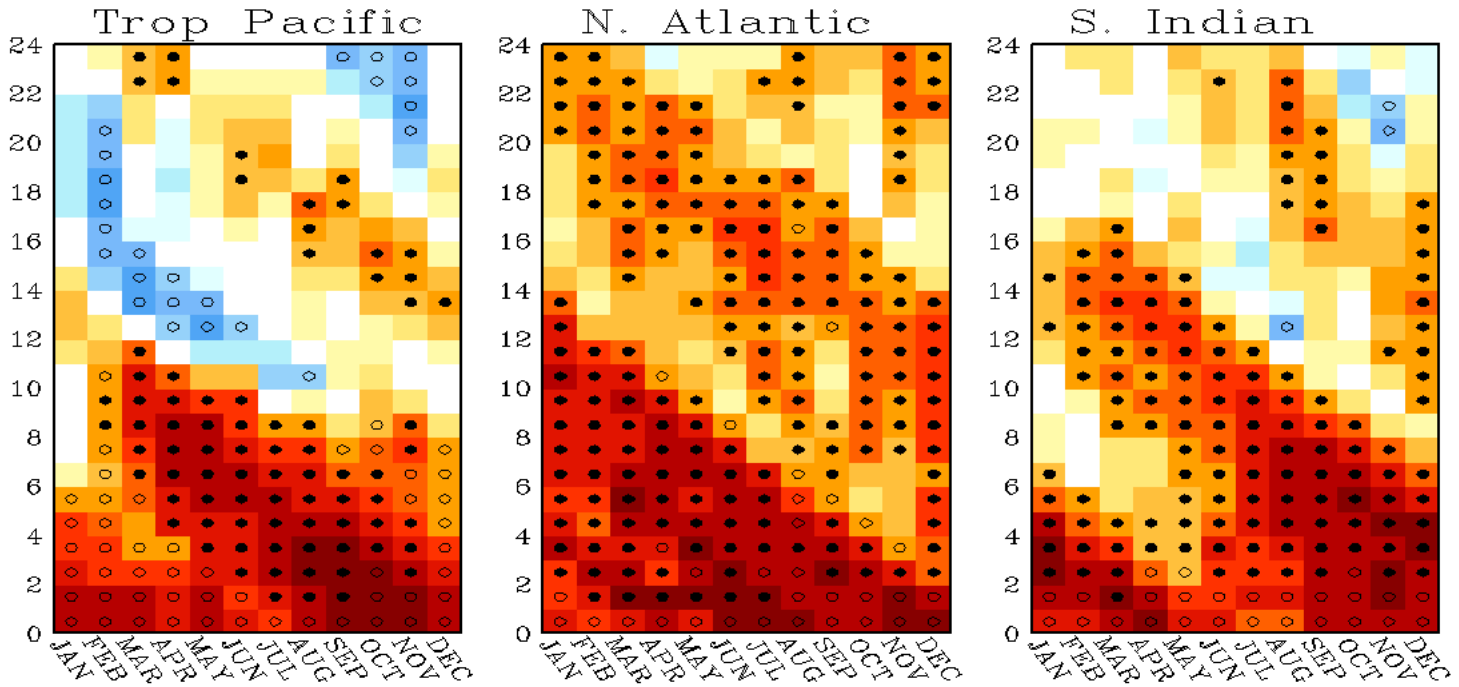
Chlorophyll



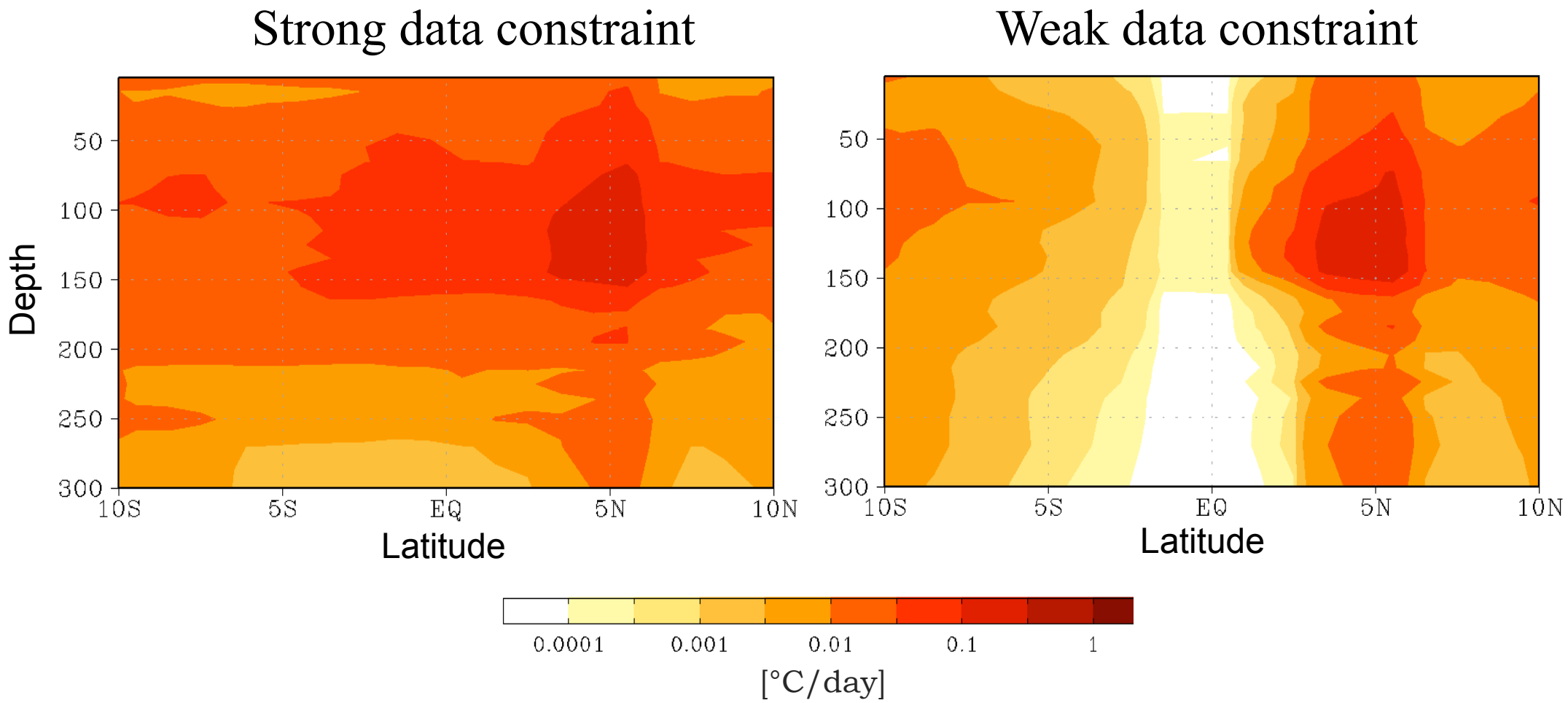
Prediction skill



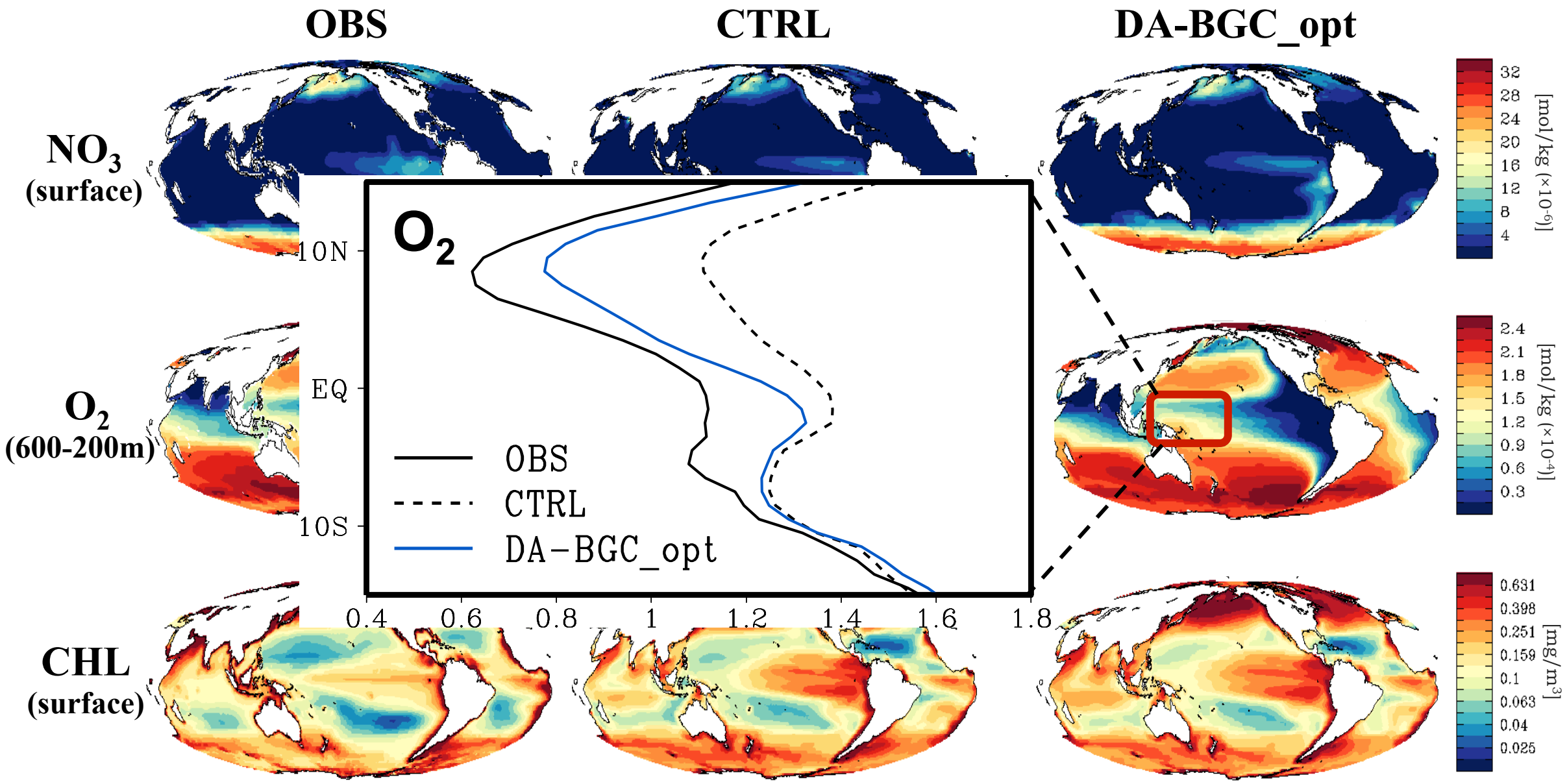
Predictability



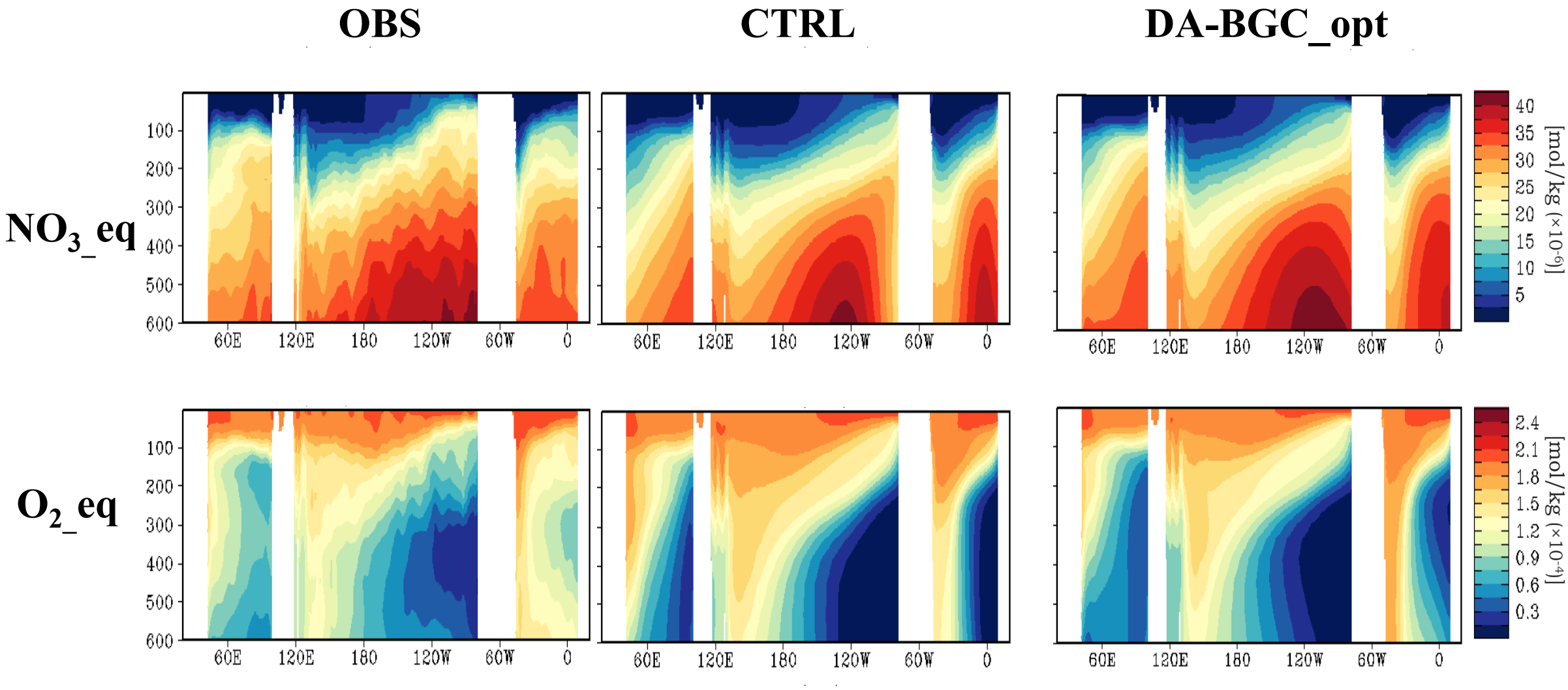
Off-equatorial ocean data constraints



Modified DA improves global BGC simulation

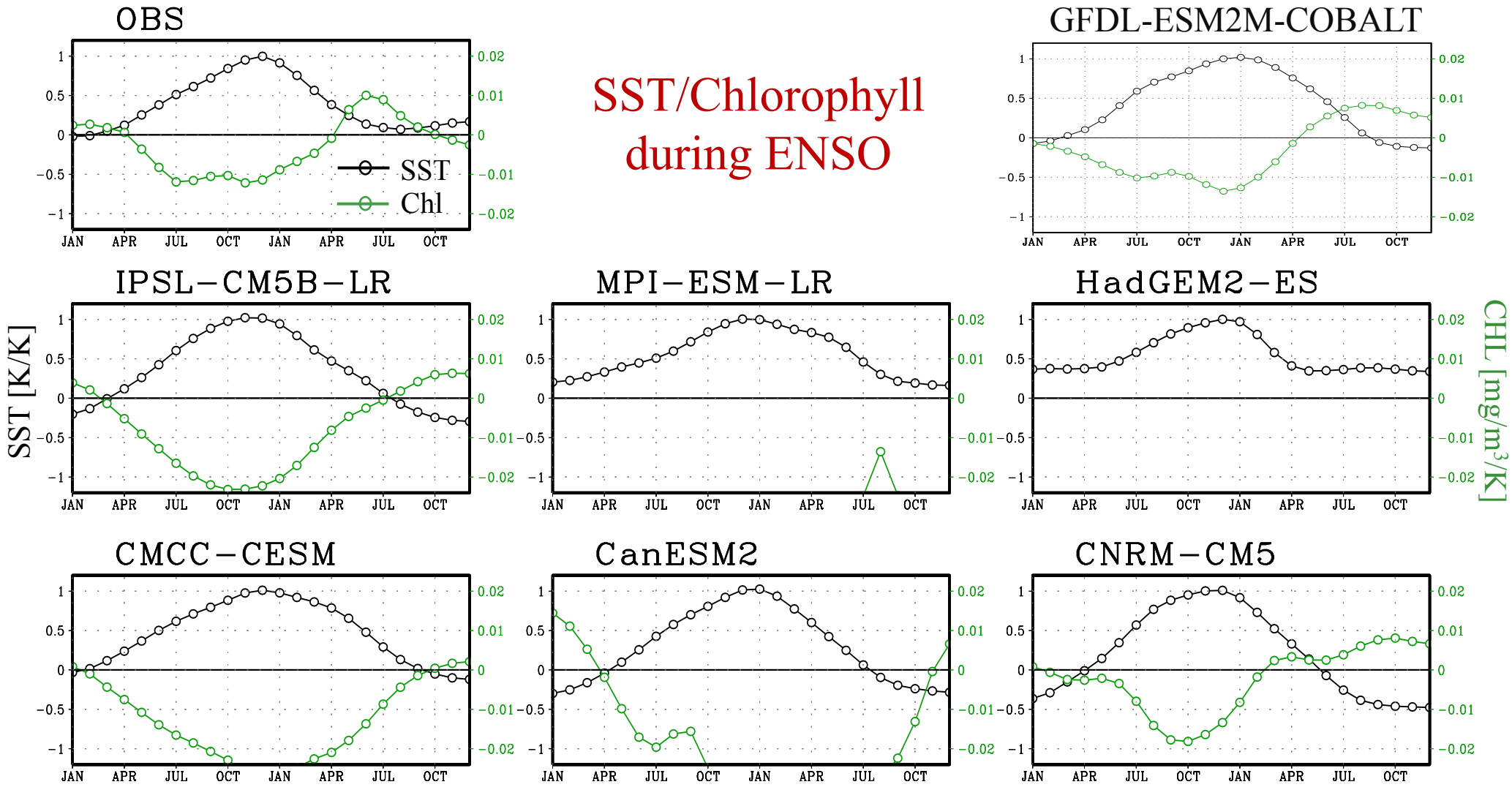


Modified DA improves subsurface BGC simulation



Challenges in BGC prediction using ESM

- Model uncertainties (physics and BGC)



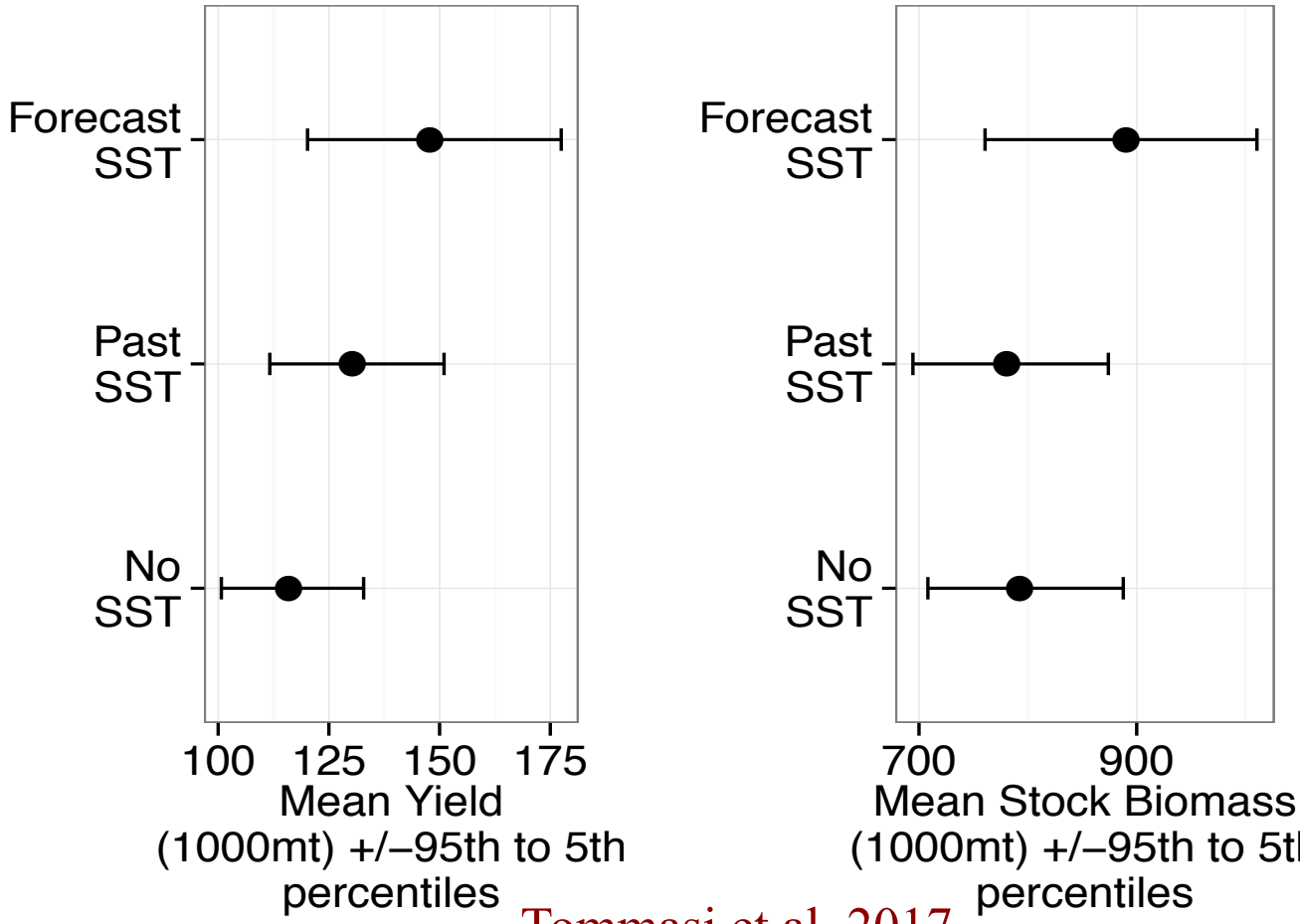
ESM, tool for global BGC prediction

➢ Prediction from ESM can provide climate-informed marine resource management.

- e.g. Tommasi et al. 2017

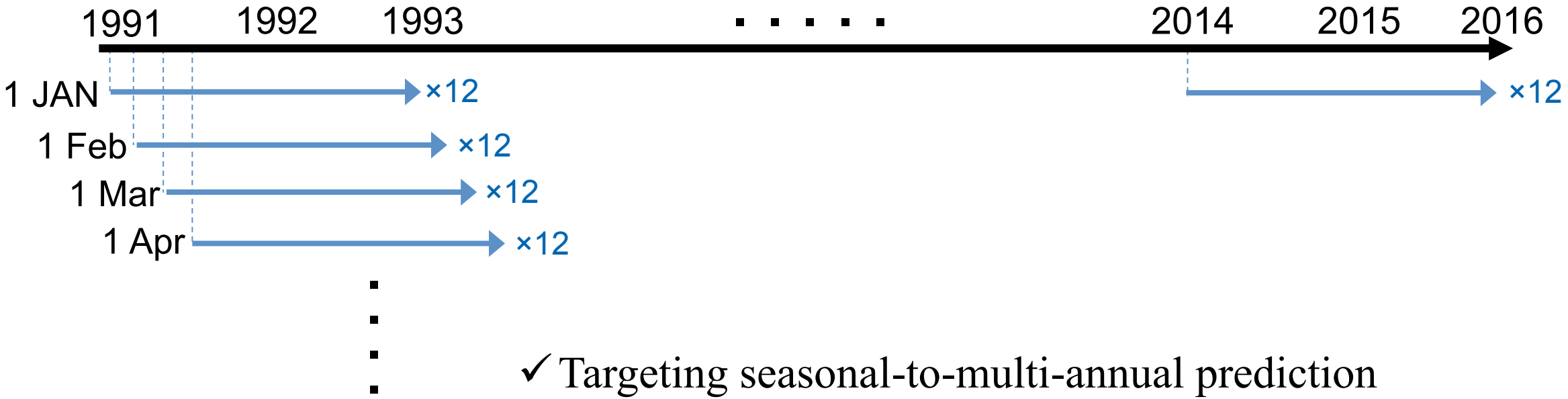
: Seasonal climate prediction can be used to improve marine resource management.

: Higher average catch and stock biomass of Pacific sardines using future SST information.



Tommasi et al. 2017

Retrospective prediction



✓ Targeting seasonal-to-multi-annual prediction

✓ 12-ensemble, 2-yr prediction run started every months

✓ Prediction skill assessment
: Anomaly correlation coeff (ACC)
: Lead-time-dependent monthly-mean drift removed