Modeling anthropogenic and oceanographic drivers of Domoic Acid production in the Southern California Bight

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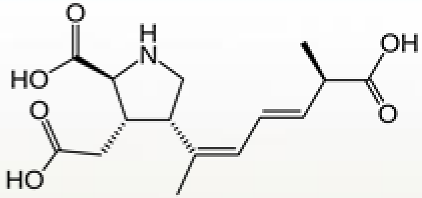
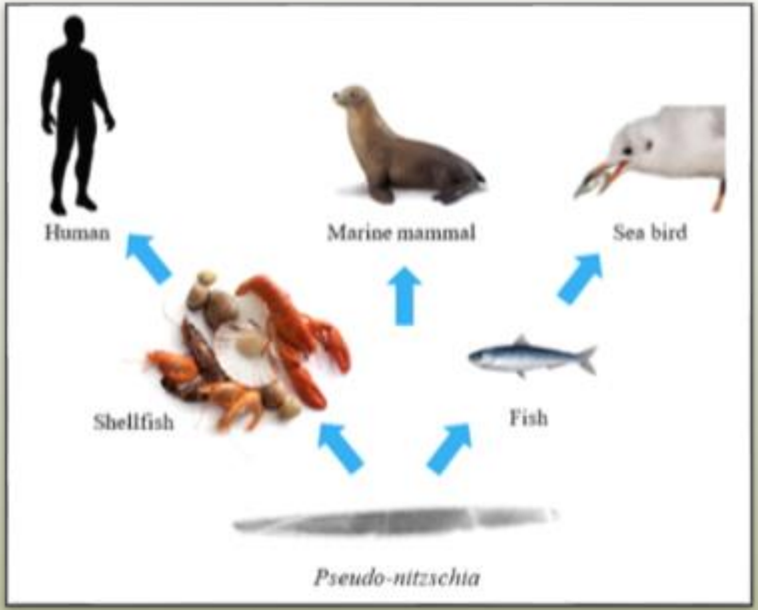
Domoic Acid (DA) HAB



- HAB in the West Coast of the US: Diatom *Pseudo-nitzschia spp.* (PN) which produces domoic acid (DA).
- Bioaccumulation and progress up the food chain.
- Particles with DA can sink reaching the sediments.

  Benthic feeders 
- Damage in local economies, tourism, etc.

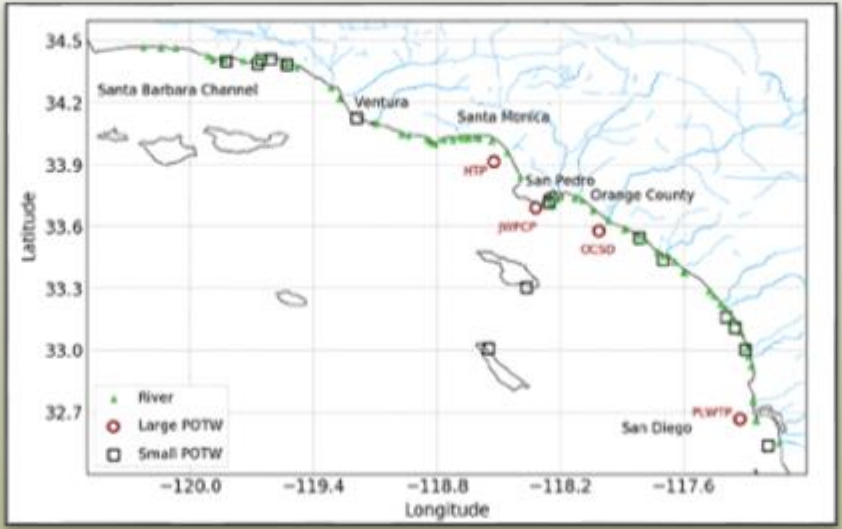


Saeed et al., 2017

Anthropogenic sources

Nutrients from land-based inputs (nitrate, ammonium) boost coastal productivity in the Southern California Bight (~23%) .

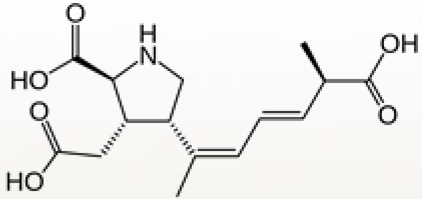
Land inputs potentially stimulate toxic blooms.



Kessouri et al., 2021b

How do DA HABs dynamics in the Bight respond to anthropogenic inputs?

Modelling of DA



From *Moreno et al., (2022)*:

Domoic Acid (DA)

- Diatoms DA (**DiDA**)
- Dissolved DA (**DDA**)
- Particulate DA (**pDA**)

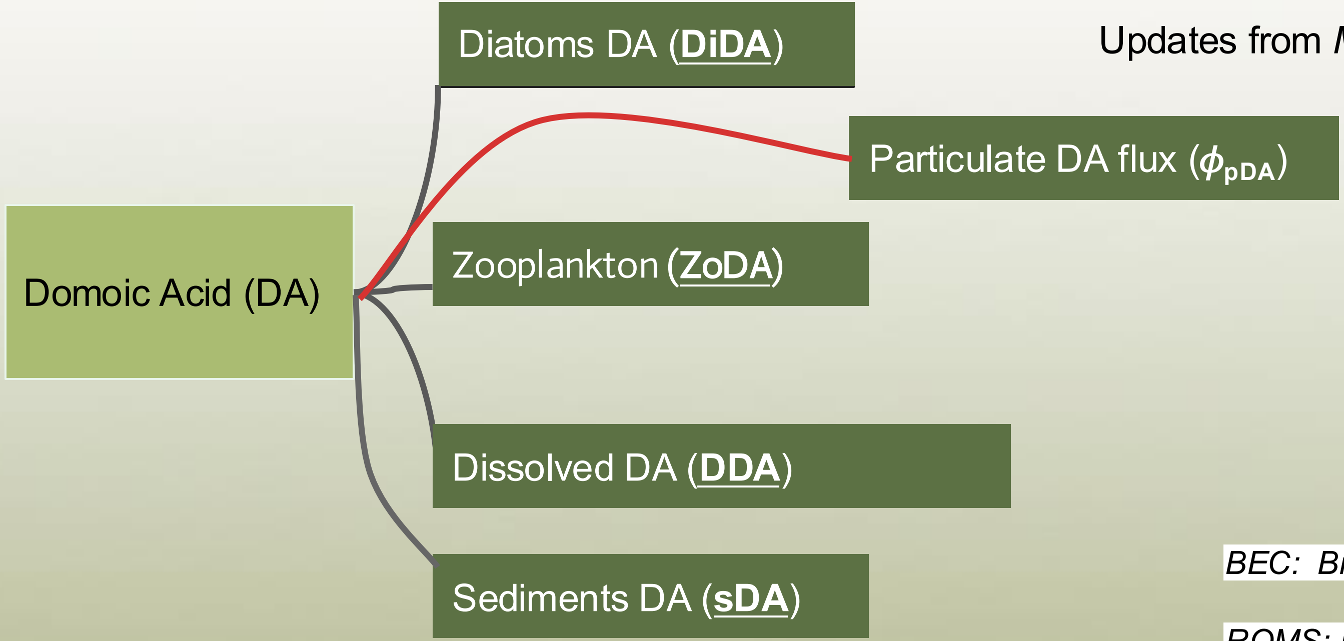
$\propto$ growth rate, diatom biomass, and nutrient limitation term:

P, Si limitation → DA

N limitation → no DA

Modelling of DA

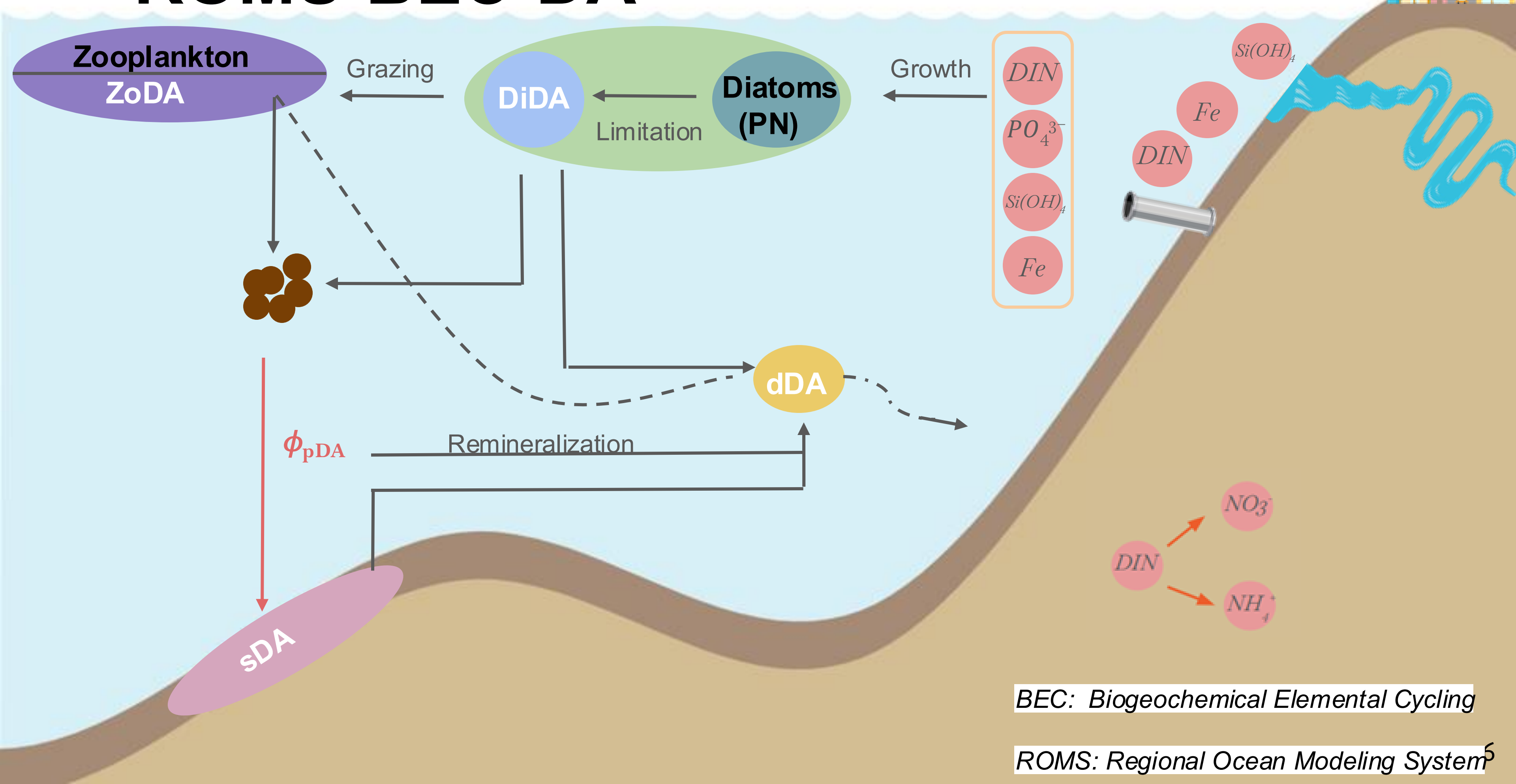
Updates from *Moreno et al., (2022)*:



BEC: Biogeochemical Elemental Cycling

ROMS: Regional Ocean Modeling System

ROMS-BEC-DA

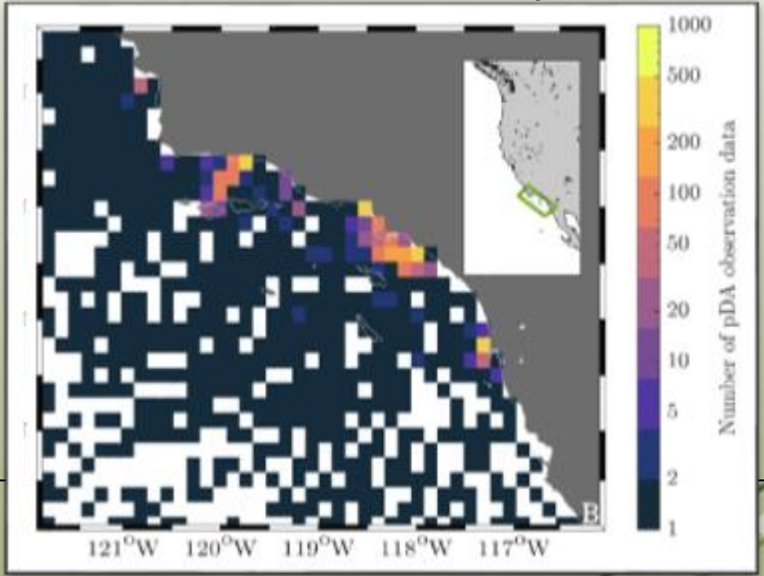


BEC: Biogeochemical Elemental Cycling

ROMS: Regional Ocean Modeling System

Model setup

pDA obs.



Model setup

Southern California Bight model daily 1-km resolution, from 2006 to 2017:

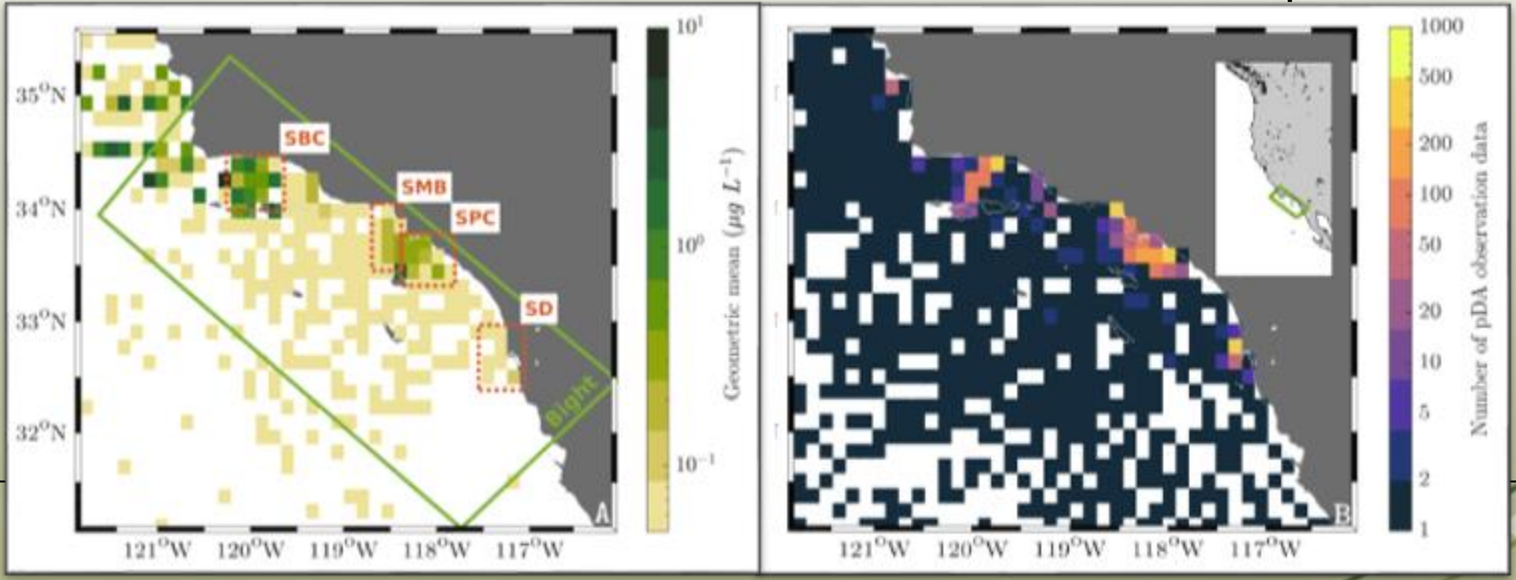
- CTRL: natural oceanic cycles nutrients and freshwater.
- ANTH: supplements with nutrient inputs from terrestrial sources.

Builds on *Kessouri et al., (2021b)*

Model domain

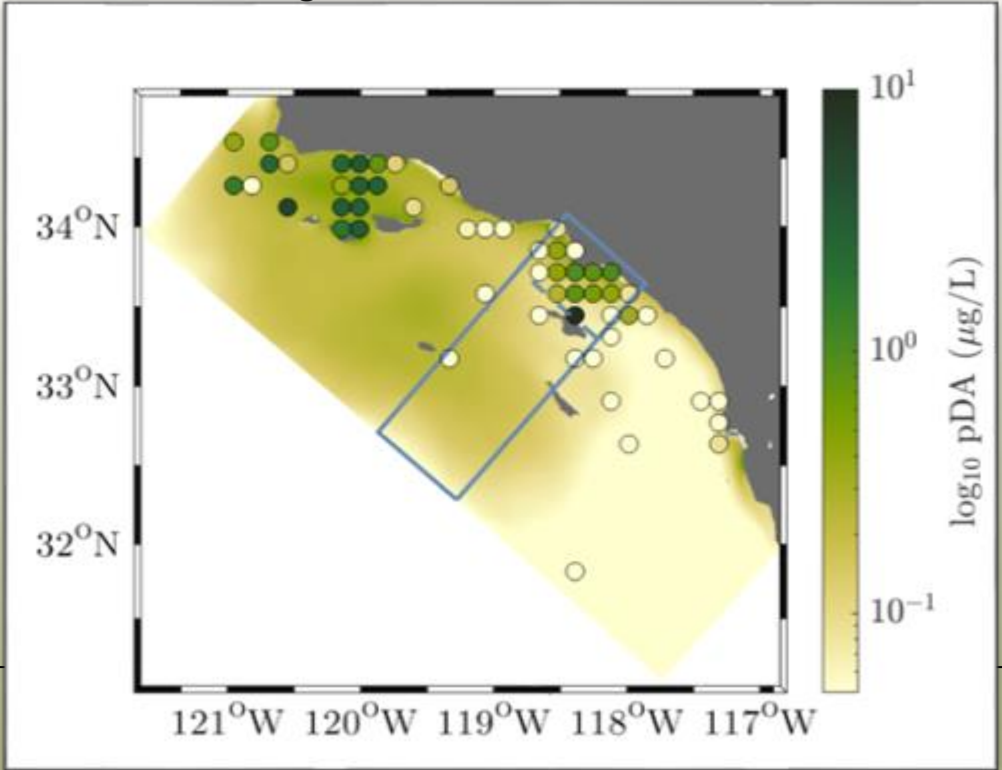
pDA mean

pDA obs.



Validation: Magnitude, correlation

Magnitude at the surface.



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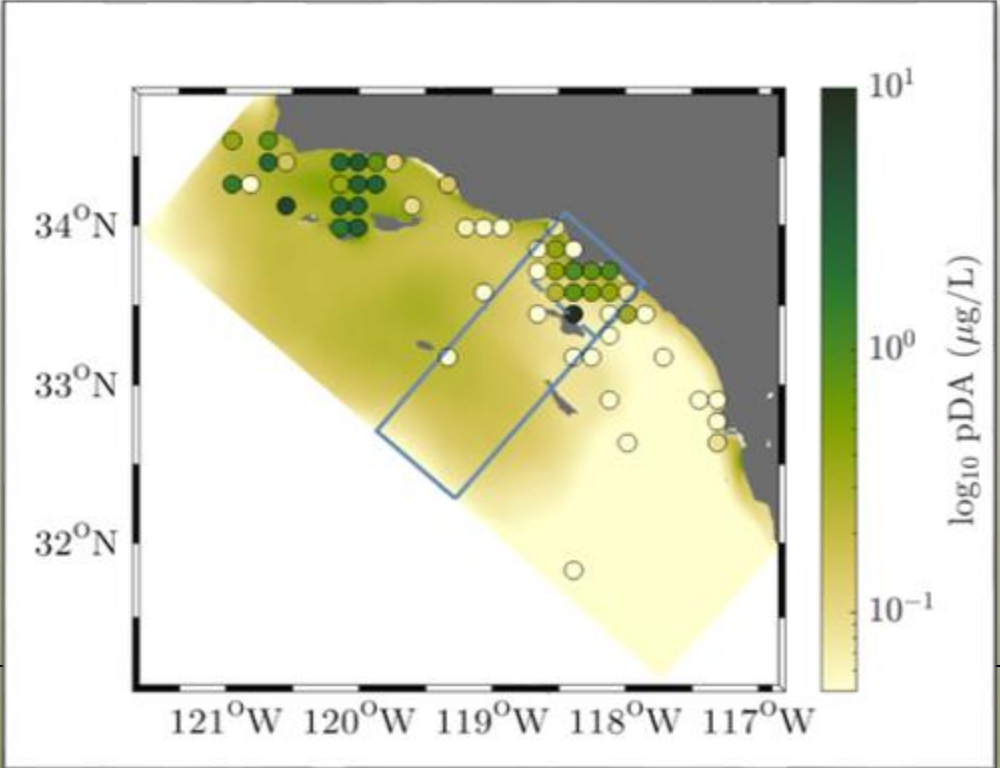
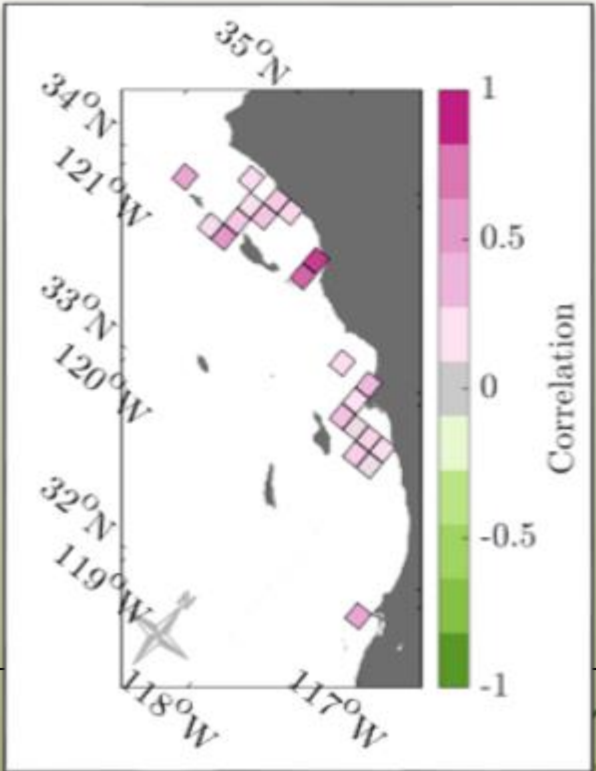
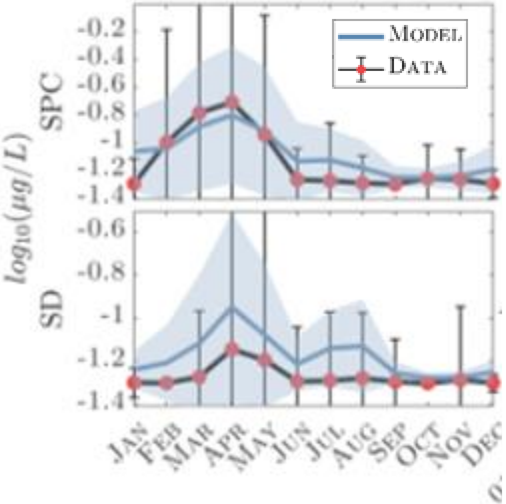


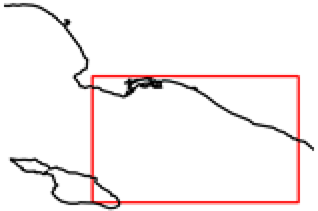
Correlation 0-40 m.

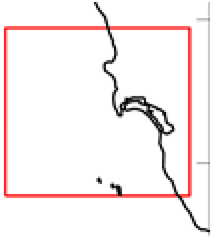


Validation: Time series

- Climatology for SPC (well-simulated) and SD (less accurate).

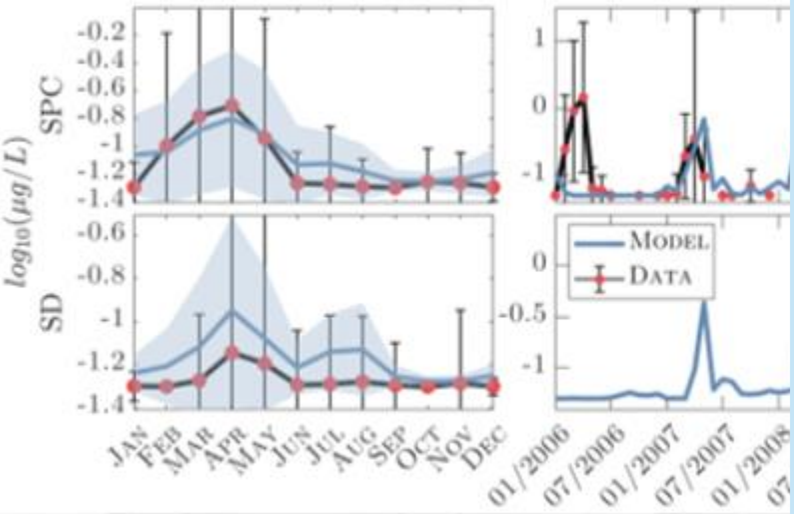




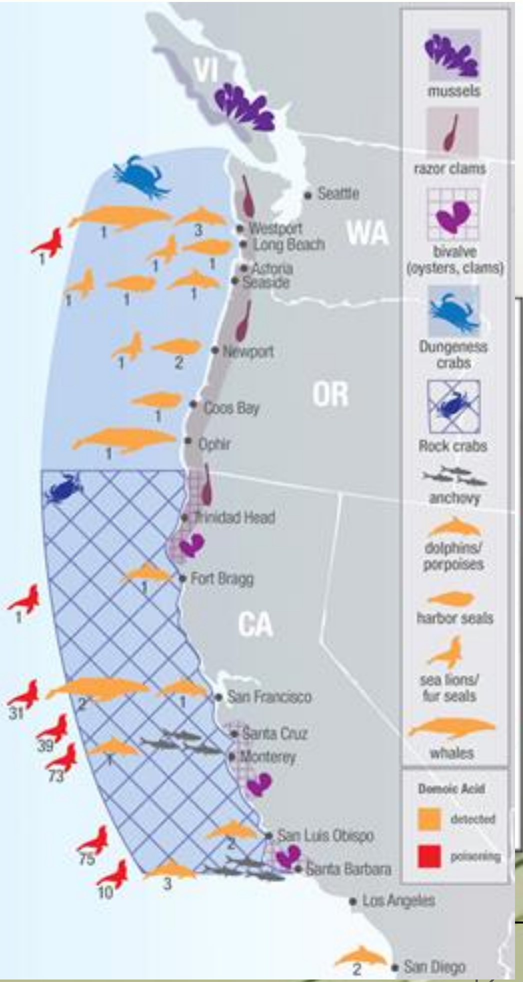


Validation: Time s

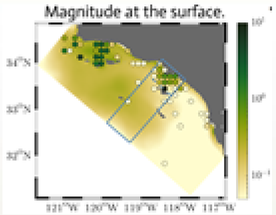
- Time series for SPC (well-simulated) a



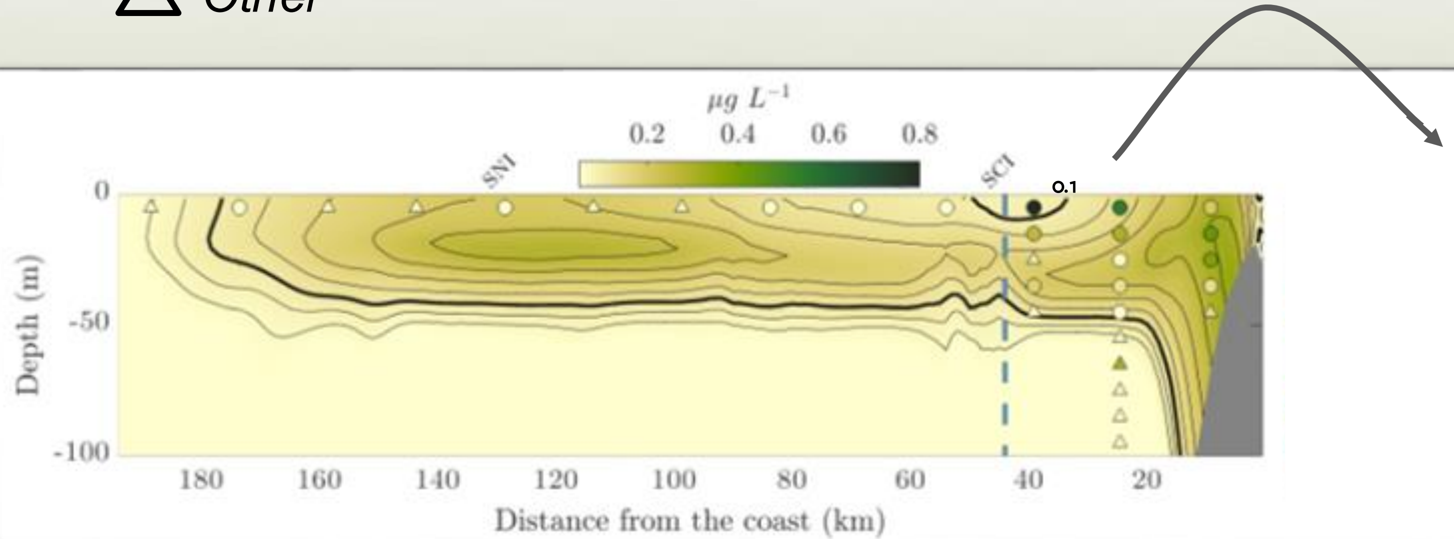
2015	Shellfish Harvest and Fishery Closures with Maximum Domoic Acid Values
7-May	Quinault tribe razor clam harvest closure (WA)
8-May	Commercial, tribal & recreational razor clam harvest closure (WA)
9-May	Razor clam harvest closure (northern OR)
14-May	State wide razor clam harvest closure (OR)
15-May	Shellfish harvest closure (BC Canada)
29-May	Anchovy viscera maximum 1671 ppm (CA)
1-Jun	Anchovy, sardine fishery closure (CA)
3-Jun	Dungeness crab maximum 65 ppm (WA)
5-Jun	Dungeness crab fishery closure (WA)
3-Jul	Anchovy, sardine, mussel, & clam closures expanded to southern CA
11-Sep	Dungeness crab maximum 140 ppm (northern CA)
27-Oct	Razor clam maximum 170 ppm (southern OR)
3-Nov	Dungeness crab & rock crab warning for recreational harvest (CA)
6-Nov	Commercial rock crab fishery closed (CA)
8-Nov	Dungeness crab maximum 70 ppm (southern OR)
11-Nov	Dungeness crab & rock crab recreational & commercial fishery closure (CA)
22-Nov	Dungeness crab maximum 270 ppm (northern CA)
23-Nov	Rock crab maximum 1000 ppm (southern CA)
23-Nov	Delayed opening of commercial Dungeness crab fishery (WA, OR, CA)
9-Feb-2016	CA seeks federal disaster declaration for commercial crab fishery



Validation: Vertical slice



○ *Multi-seasonal and multi-year data*
△ *Other*



Validation: Vertical slice

○ *Multi-seasonal and multi-year data*
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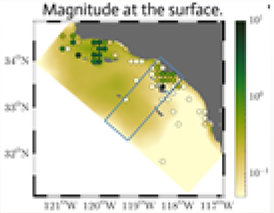
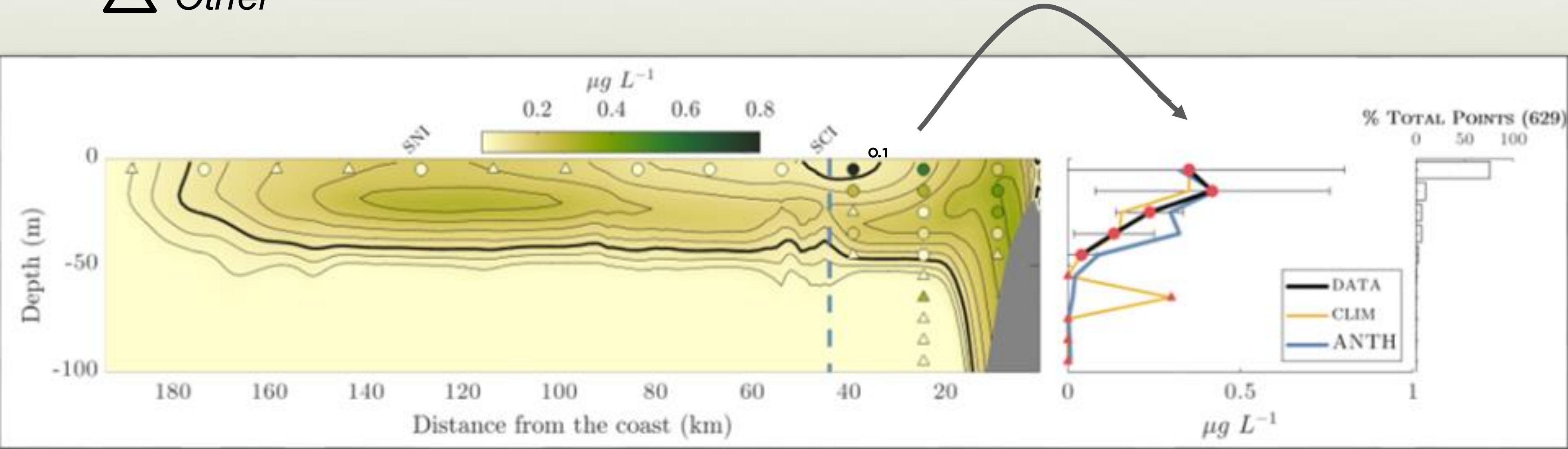
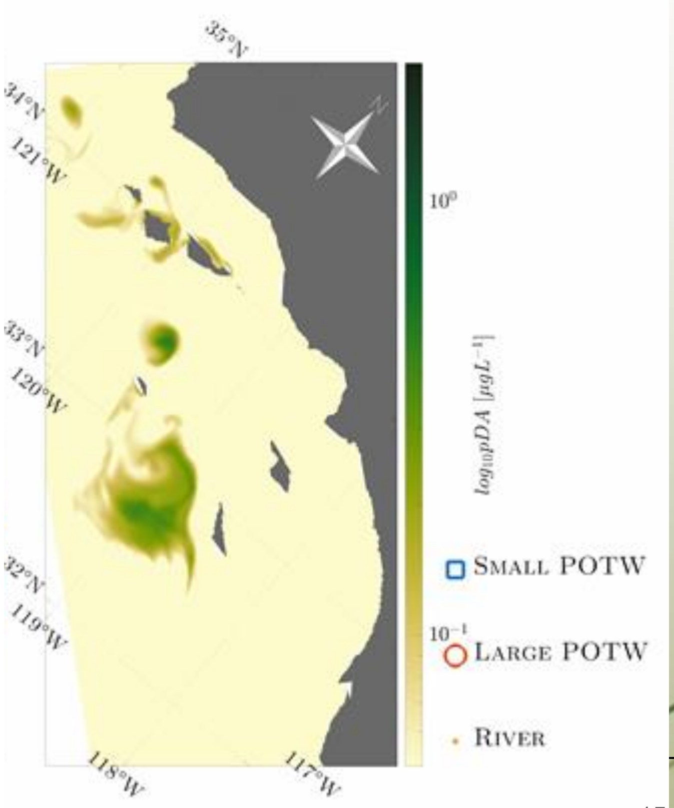




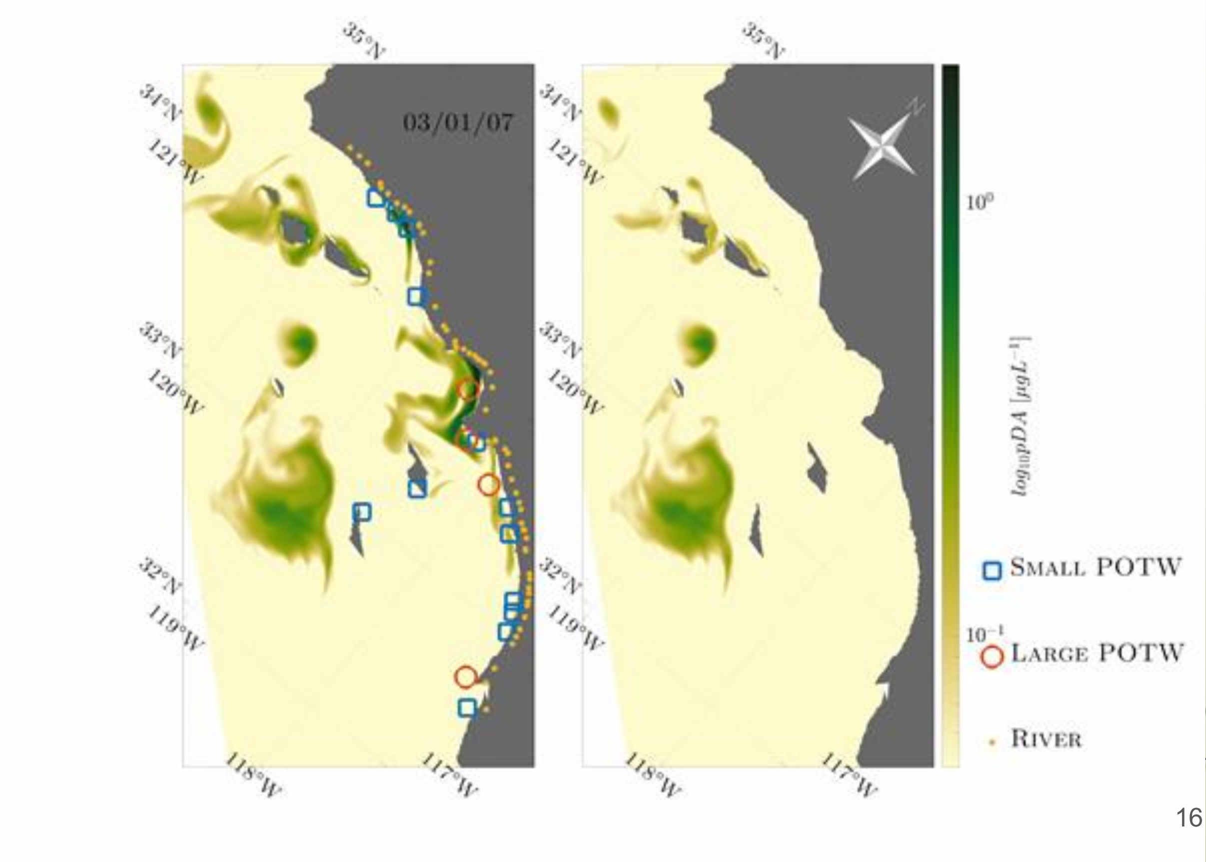
Bight Model and experiment

CTRL



Bight Model and experiment

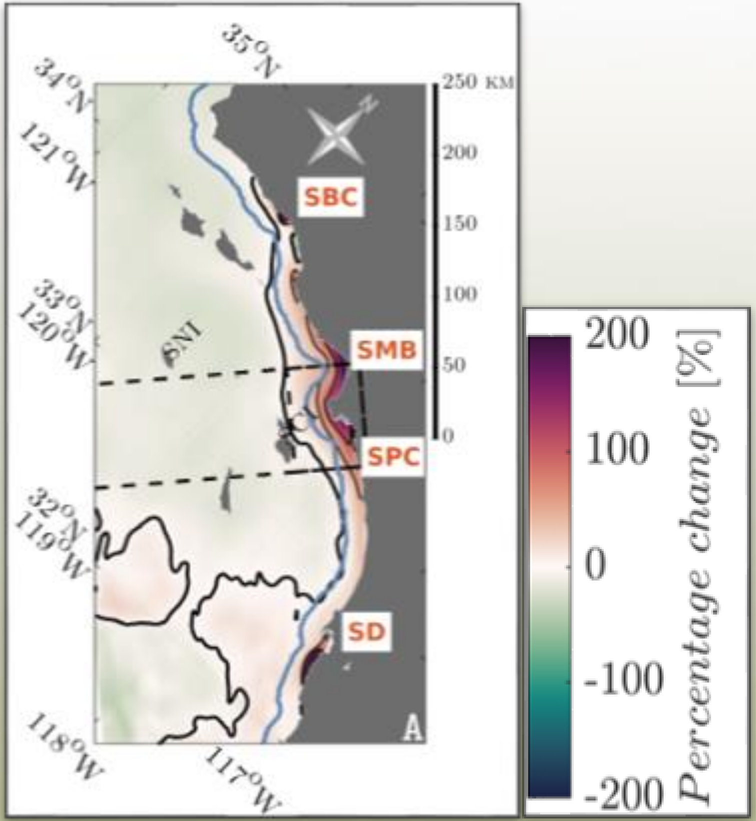
ANTH CTRL



Relative difference:

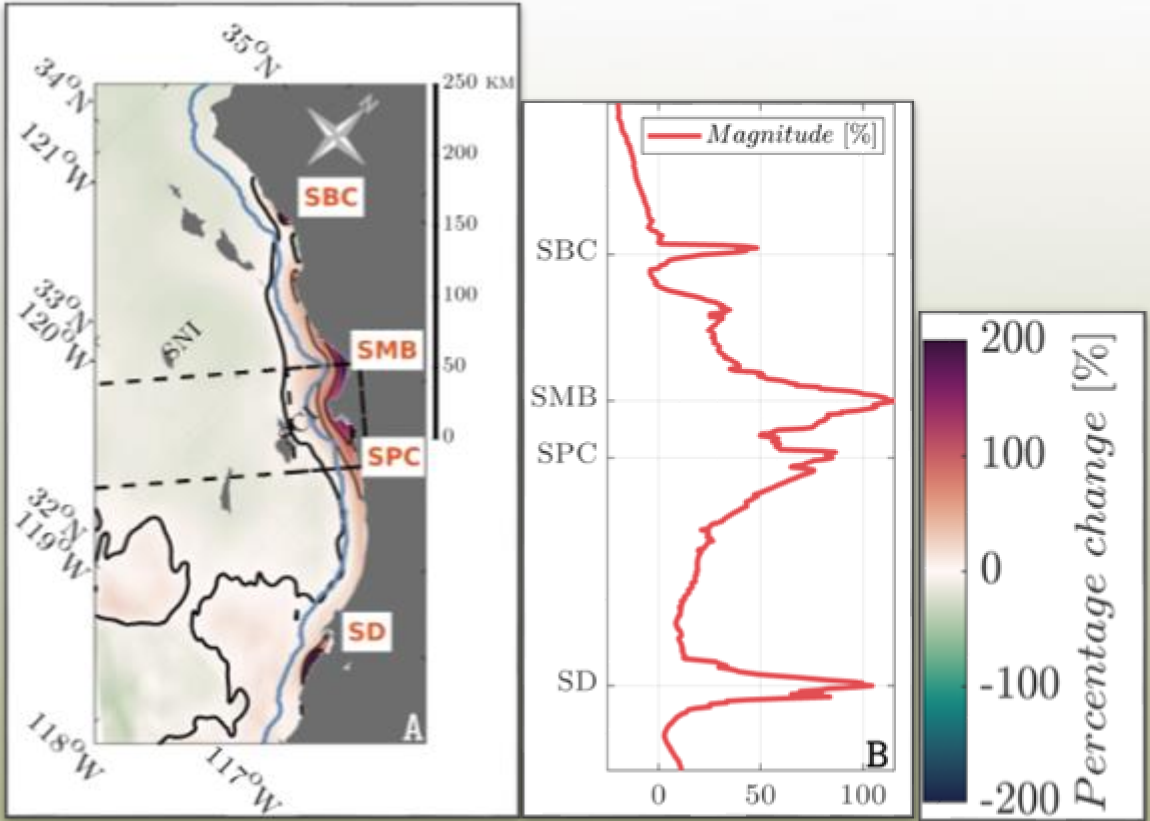
$$\left(\frac{ANTH - CTRL}{CTRL}\right) \times 100\%$$

Experiment: relative difference



- At the surface

Experiment: relative difference

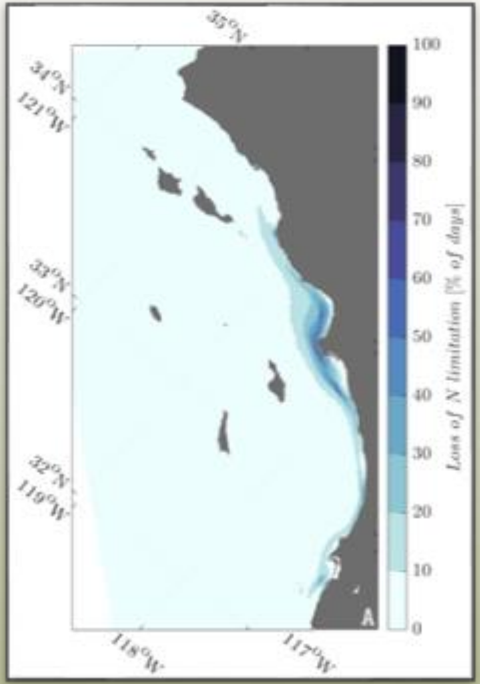


- At the surface
- **Within the first 15 km of the coast.**
- > ~25% on average

P, Si limitation → DA

N limitation → no DA

DA production

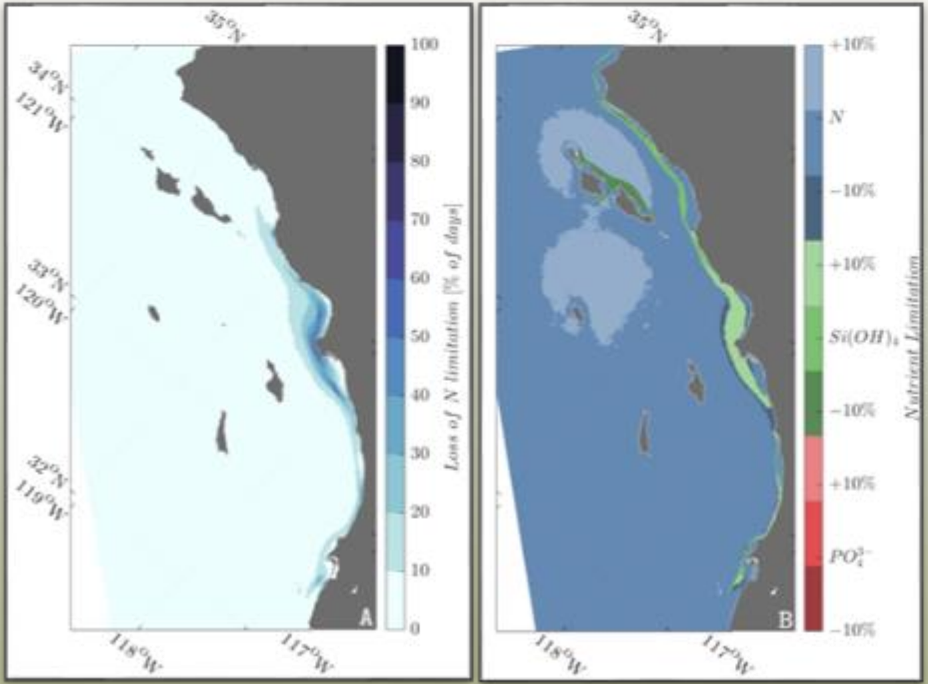


Loss of N limitation: % of days where CTRL was N-limited but ANTH was not

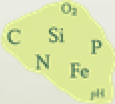
DA production

P, Si limitation → DA

N limitation → no DA



Loss of N limitation [% of days].



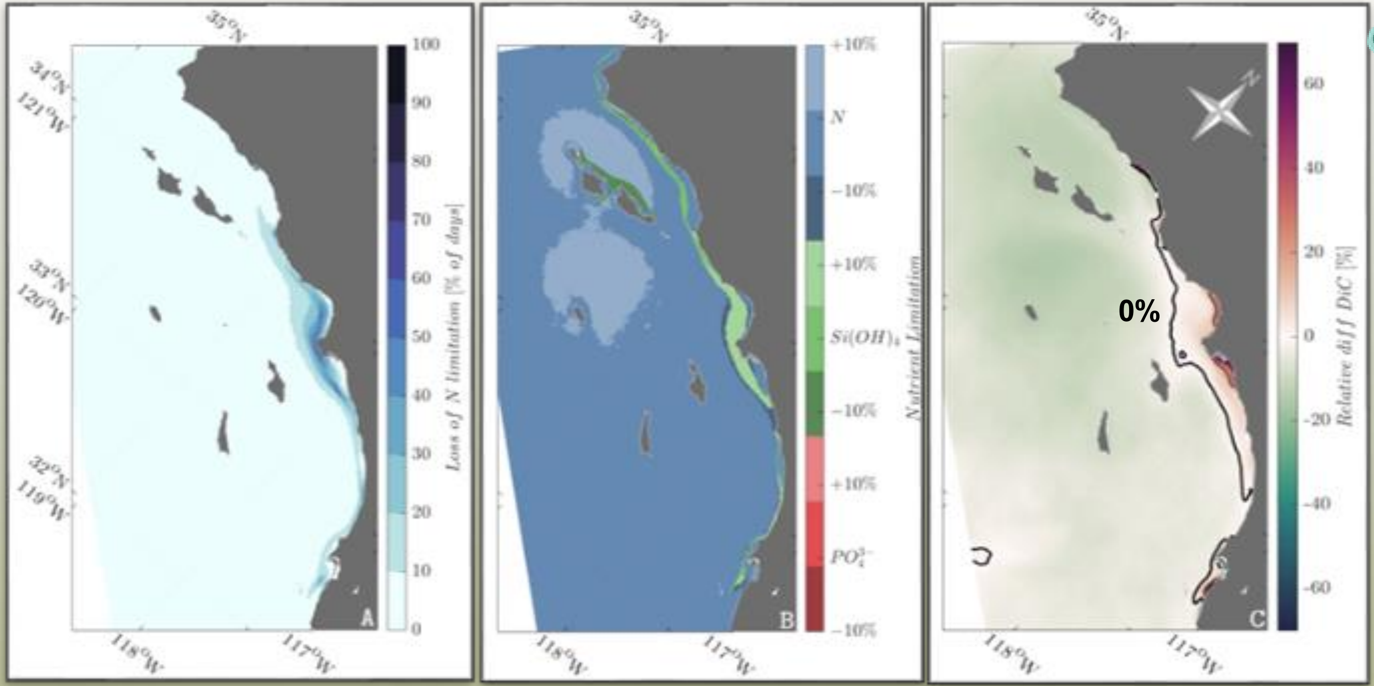
Primary limiting nutrient in ANTH.

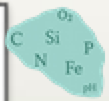
Darker (lighter) colors indicate at least a 10% **reduction** (**increase**) in nut limitation in ANTH compared to CTRL

DA production

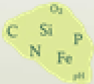
P, Si limitation → DA

N limitation → no DA

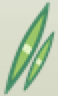




Loss of N limitation [% of days].



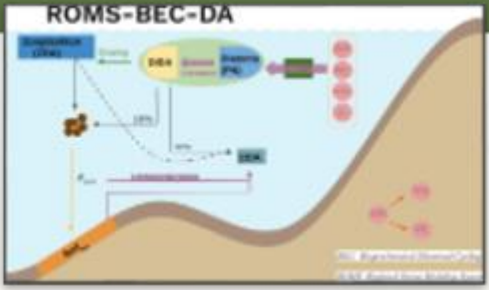
Primary limiting nutrient in ANTH.

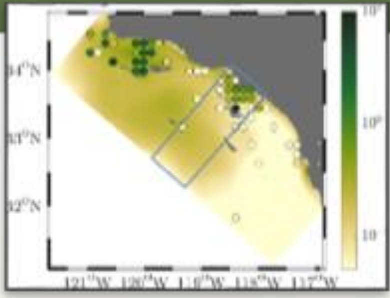


Relative difference in biomass of diatoms.

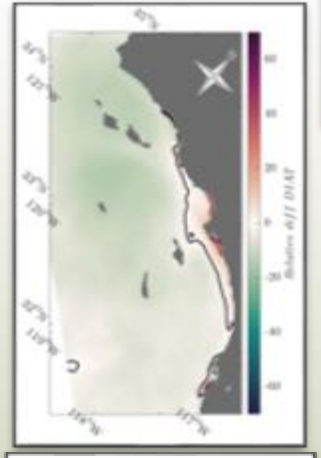
Summary

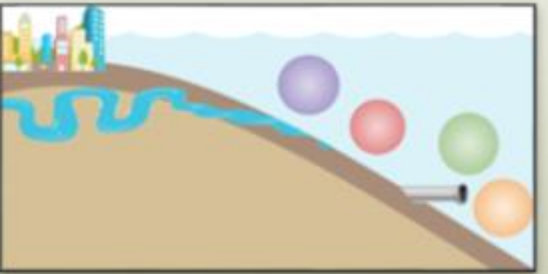
We develop a model that captures DA



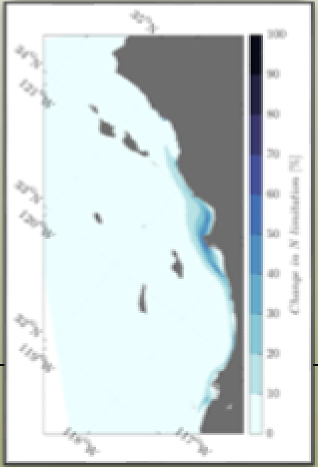


More Diatoms

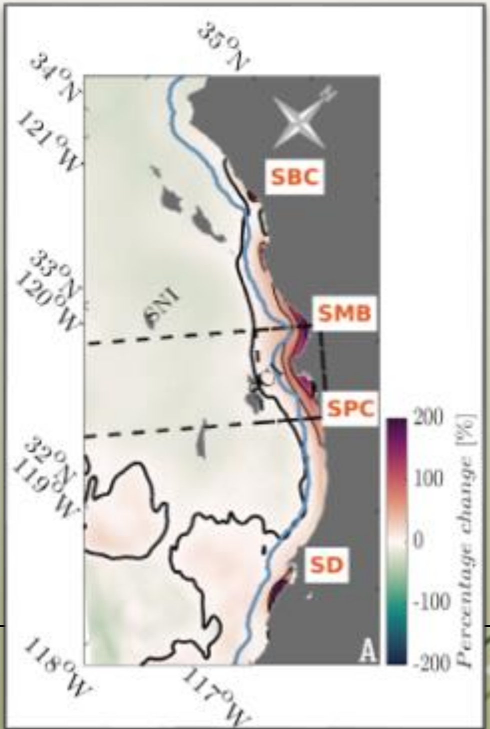




Less N limitation (more Si limitation)



~25% more pDA



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- James McWilliams (UCLA)
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Acknowledgements

AOS UCLA

BECAS CHILE

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Questions?

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Additional slides

DA formulation: updates

- ❑ **Modified partitioning of DA after diatom cell lysis**:
  - ❑ Reduced dDA allocation from 95% → 90%

- ❑ **Introduced depth-dependent pDA fluxes**:
  - ❑ Used POC-based remineralization formulation
  - ❑ Shortened remineralization length scale to 63 m based on sediment trap data

- ❑ **New sediment DA cycling**:
  - ❑ Sinking pDA reaching the bottom accumulates in sediments (sDA)
  - ❑ Remineralized at a rate of 0.0681 d^{-1}, consistent with aerobic sediment studies (Li *et al.*, 2024b)

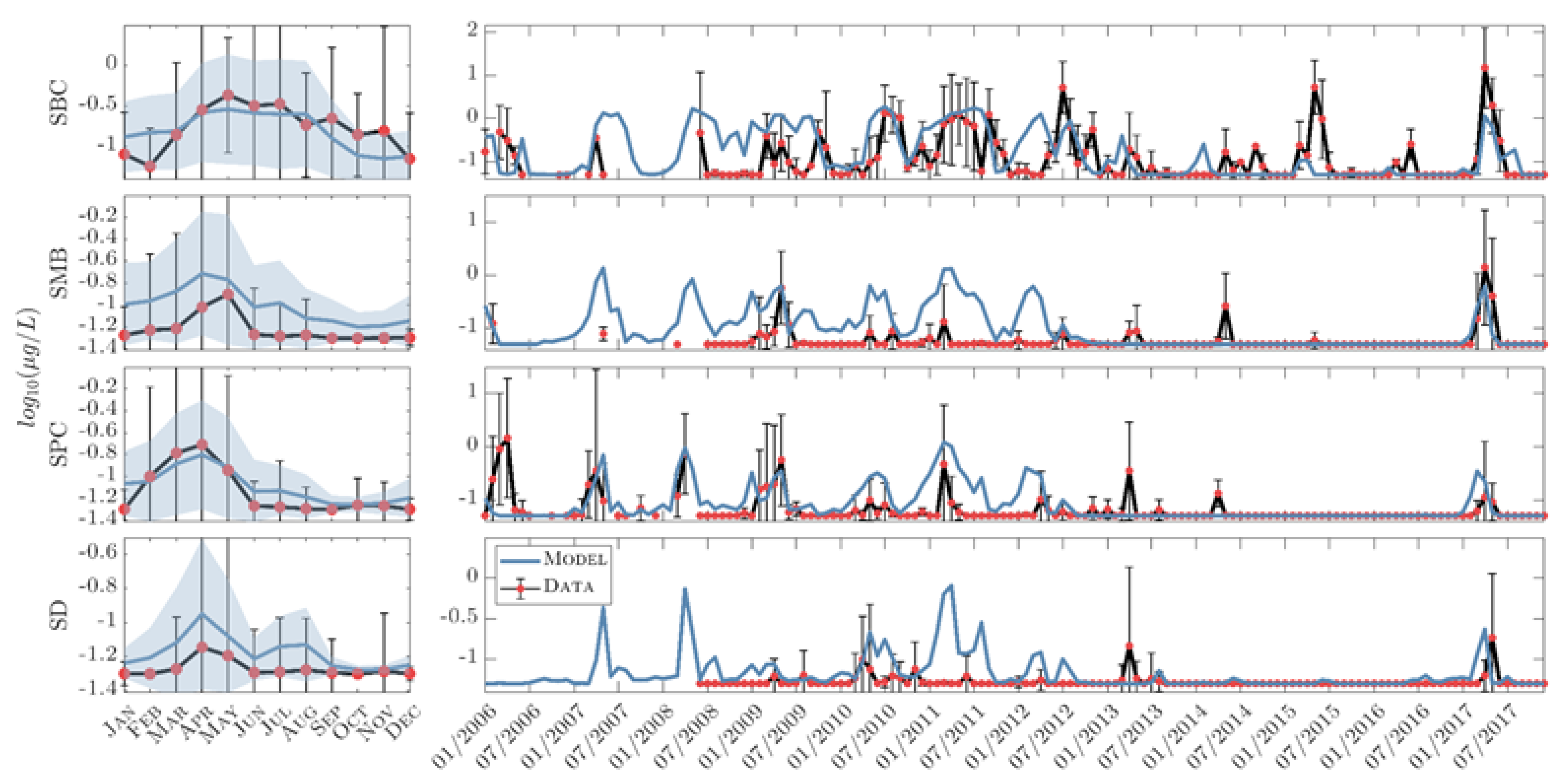
- ❑ **Enhanced dDA degradation and adjusted remineralization pathway:**
  - ❑ Upon remineralization of ϕ_{pDA} and sDA, a fraction of DA is fully degraded, while the remainder is released as dDA
  - ❑ Increased from 0.01 d^{-1} → 0.1 d^{-1} to better match observed pDA:dDA ratios (0.7–1.2)

Categories of events

Table 1. Number of no events, weak events, and strong events calculated using the daily grid with a 5 x 5 km resolution from 2006-2017.

	No event (pDA < 0.05 μg/L)	Weak event (0.05 < pDA < 0.2 μg/L)	Strong event (pDA > 0.2 μg/L)
SBC			
Data	662	138	333
Model	456	131	546
SMB			
Data	623	54	41
Model	260	78	380
SPC			
Data	1041	289	305
Model	959	231	445
SD			
Data	801	42	17
Model	593	117	150

Validation: Time series



Some Numbers: (Sutula et al., 2021)

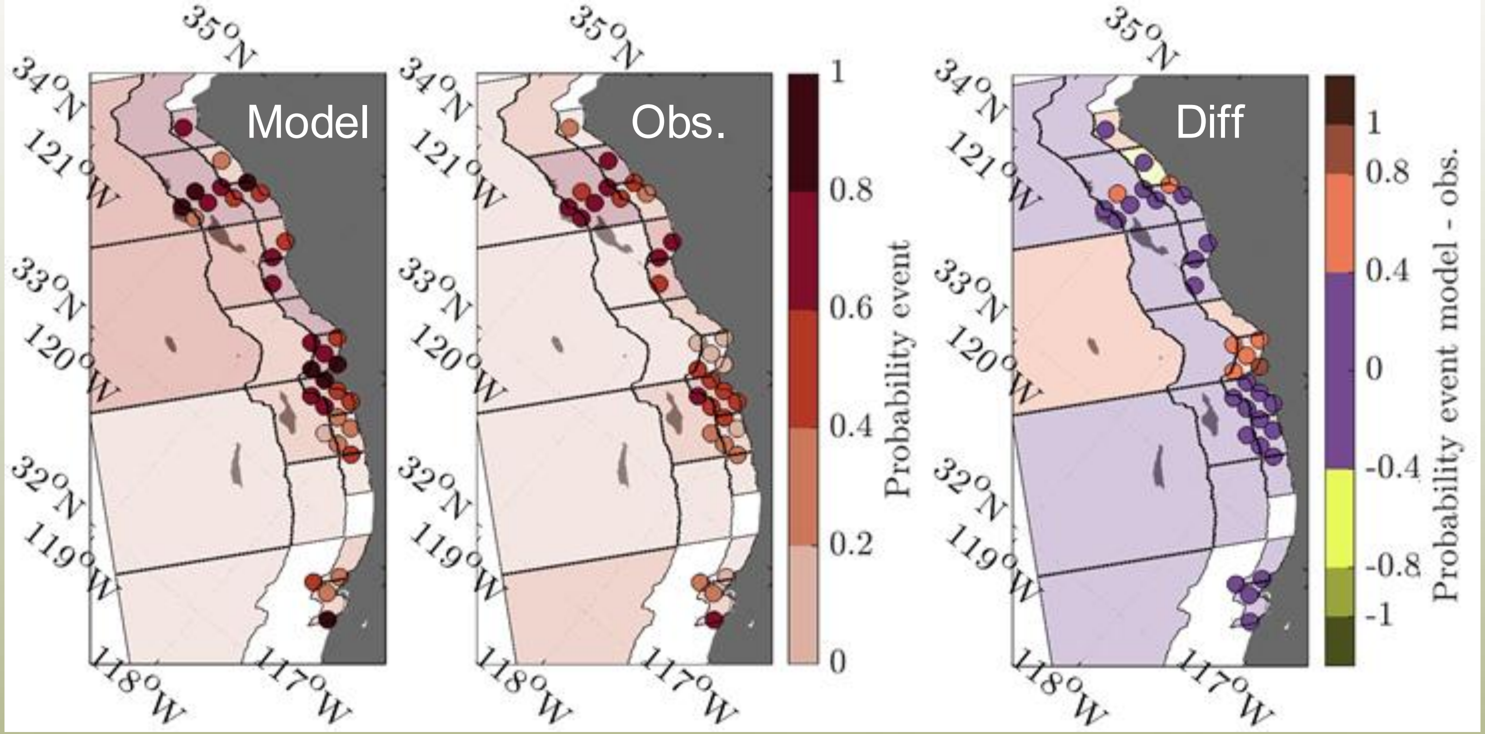
- ❑ The SCB receives ~4050 kg N km^{-2} yr^{-1}, among the highest globally.
- ❑ ~95–97 % of coastal nitrogen is anthropogenic.
- ❑ Point sources (mainly wastewater outfalls) deliver ~70 % of freshwater and ~97 % of nitrogen; rivers supply the remaining ~30 % freshwater / ~5 % nitrogen.
- ❑ Of that riverine nitrogen, <1 % is natural — the rest is urban or wastewater-derived.
- ❑ ~92 % of total N comes from wastewater outfalls, mostly ammonium (NH_4^+; ~80 %) from primary/secondary treatment.
- ❑ Central Bight (SMB–SPC) receives ~60 % of all anthropogenic N, doubling nearshore N levels.
- ❑ Smaller outfalls (~20 % of N) discharge into the euphotic zone, with direct effects on blooms.

Statistics

	Number of Months	Max	Median	Geometric Mean	Standard deviation	r_{month}	r_{clim}	MAEn
SBC								
Data	125	26.1	0.02	0.37	3.44			
Model	125	1.94	0.10	0.29	0.49	0.39*	0.66*	0.28
SMB								
Data	117	3.28	0	0.06	0.43			
Model	117	1.41	0.04	0.15	0.27	0.32*	0.84*	0.48
SPC								
Data	135	8.13	0	0.11	0.94			
Model	135	1.30	0.02	0.10	0.22	0.36*	0.92*	0.28
SD								
Data	115	0.69	0	0.02	0.09			
Model	115	0.87	0.02	0.07	0.14	0.06	0.88*	0.88

$$\frac{1}{N}\sum_{n=1}^{N}\frac{|D_n - M_n|}{\sigma_D},$$

Validation: Probability of event (>0.05 µg/l)



Overprediction

Good

Underprediction

Insights into the DA cycle

pDA:dDA ≈ 0.7

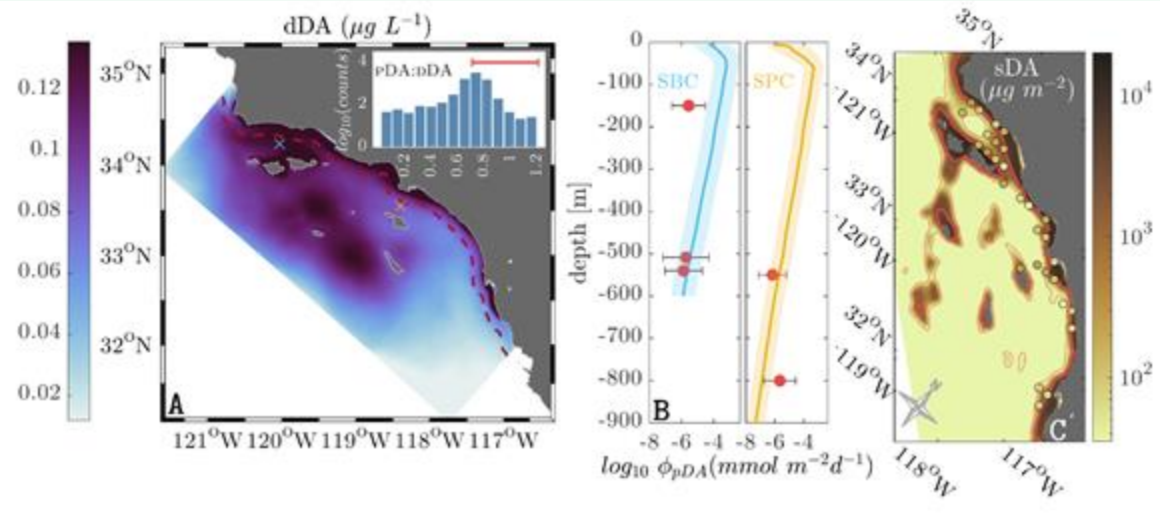
Flux too high at 147 m (SBC)

Flux too low at 800 m (SPC)

sDA overestimated → needs better burial/removal

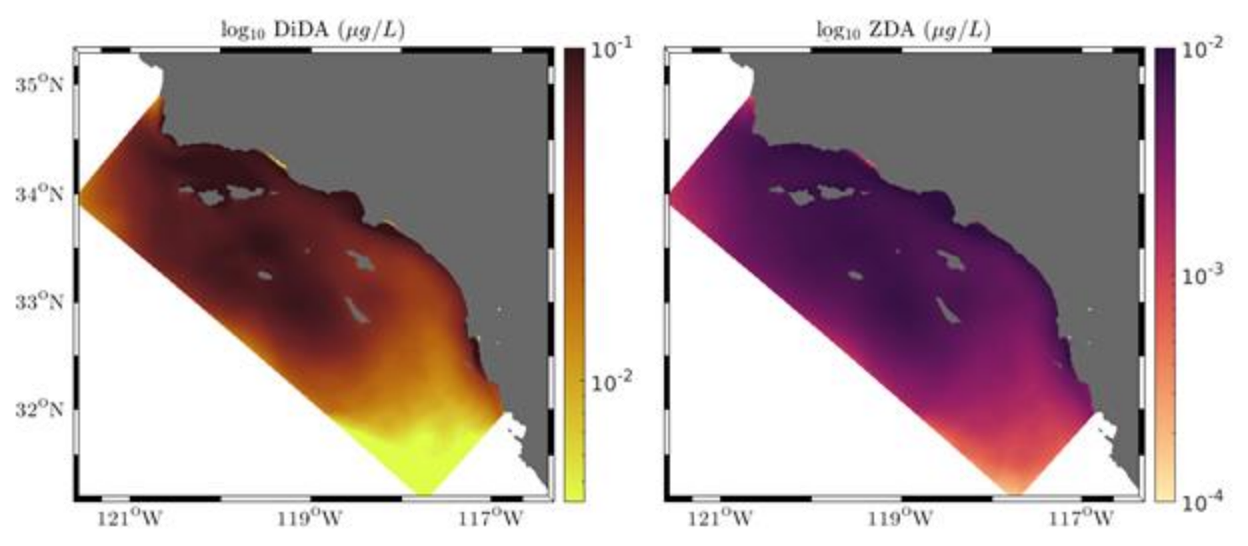
Sparse trap data = key limitation

Oher: More ZoDA:ZoC→ DA biomagnification potential



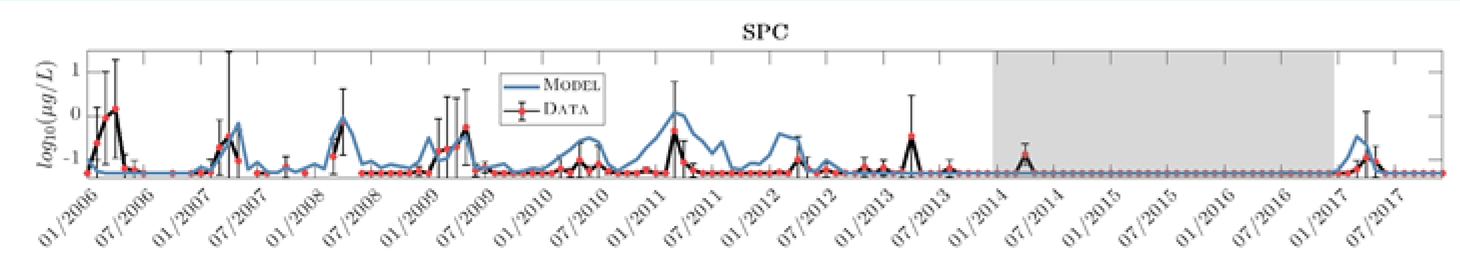
DA components

- Climatological DA concentration in Diatoms (DiDA) and the concentration of DA in Zooplankton (ZDA)



What about 2015 in SCB?

- 2014 to 2016 low pDA
- 2015 warm “blob”



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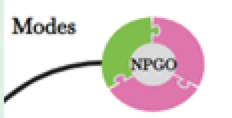
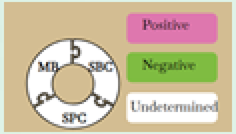
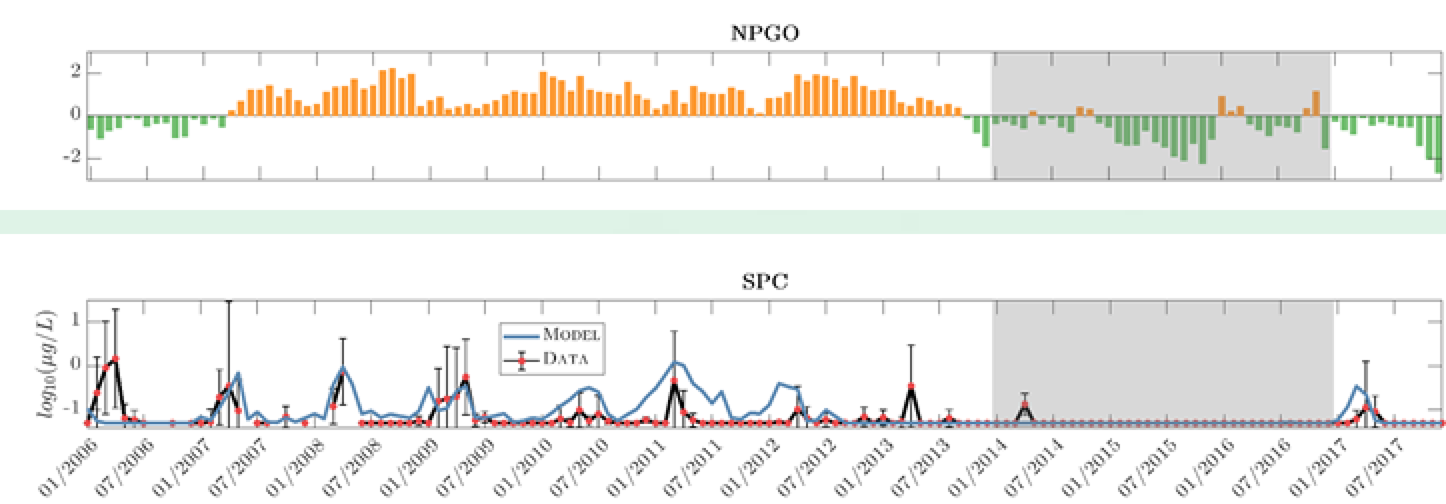


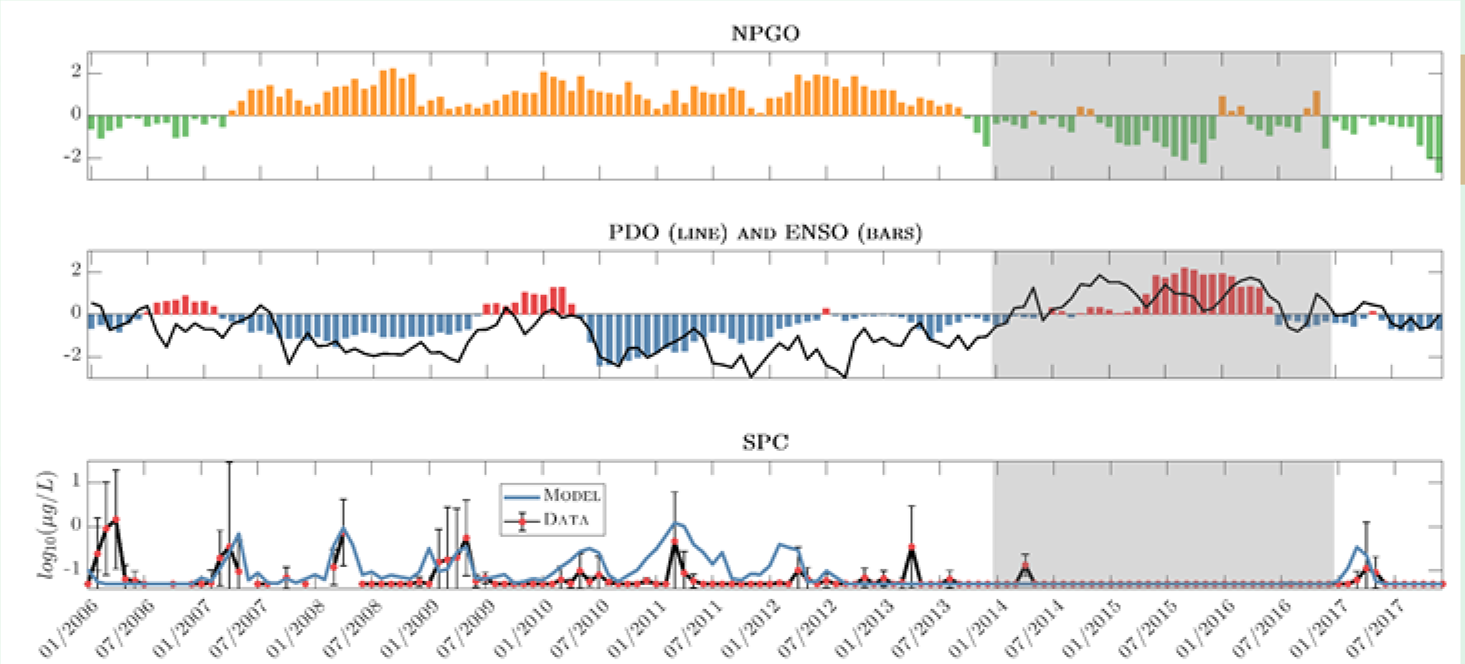


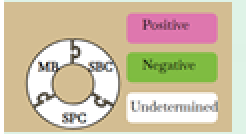


Sandoval-Belmar et al., 2023

What about 2015 in SCB?

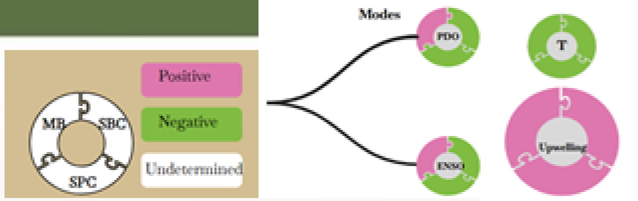
- 2014 to 2016 low pDA
- 2015 warm "blob"
- "*...water temperature above 19℃ did not result in PN dominance or DA production in the SCB…*" (Smith *et al*., 2018b)

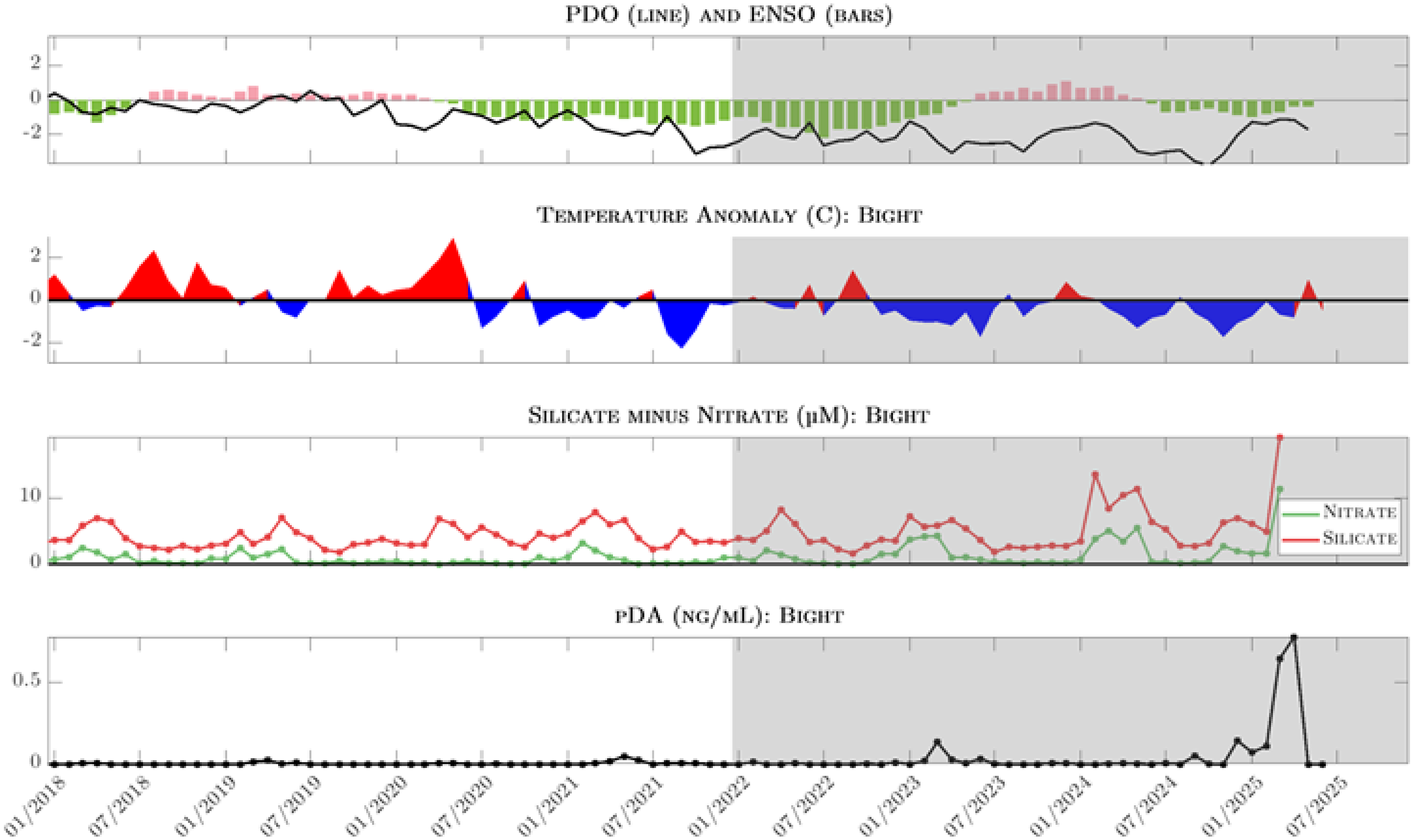




Sandoval-Belmar et al., 2023

HAB this year

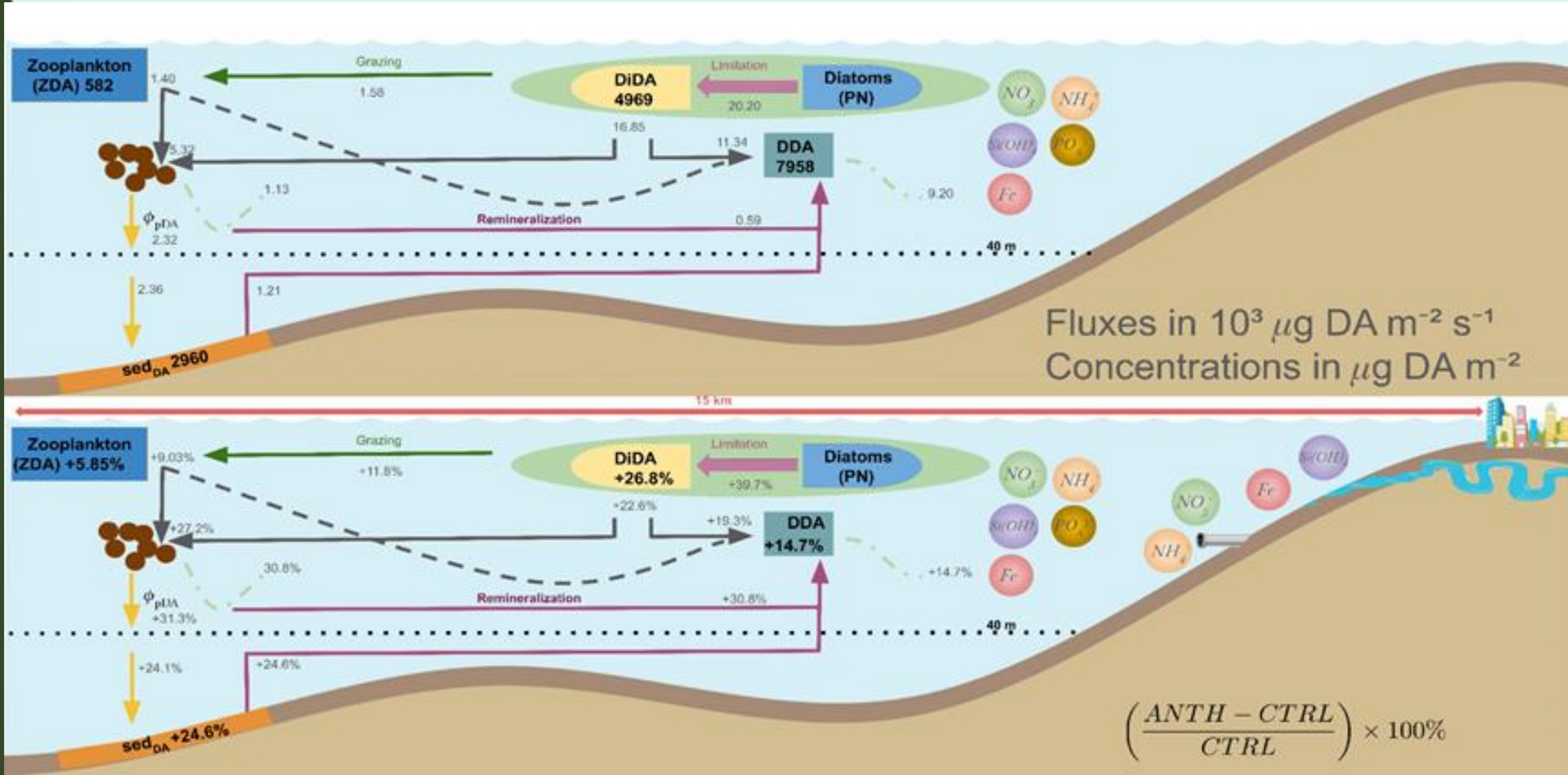




A La Niña-driven cold water episode, longest since 2011, promoted:

- Early upwelling, helping sustain blooms from Dec–Apr.
- Elevated silicic acid and nitrate

Synthesis


Zooplankton (ZDA) 582
Grazing
1.40
1.58
Limitation
DiDA 4969
Diatoms (PN)
20.20
16.85
11.34
DDA 7958
5.32
1.13
9.20
ϕ_{pDA}
2.32
Remineralization
0.59
40 m
2.36
1.21
sed$_{DA}$ 2960
Fluxes in 10^3 μg DA m^{-2} s^{-1}
Concentrations in μg DA m^{-2}
15 km
Zooplankton (ZDA) +5.85%
+9.03%
+11.8%
DiDA +26.8%
+39.7%
+22.6%
+19.3%
DDA +14.7%
+27.2%
30.8%
+14.7%
ϕ_{pDA}
+31.3%
+30.8%
+24.1%
+24.6%
sed$_{DA}$ +24.6%
$\left(\frac{ANTH - CTRL}{CTRL}\right) \times 100\%$

Future

- ❑ Direct effects of temperature and light on DA production are not considered.
- ❑ A more gradual nutrient limitation response instead of a on/off switch.
- ❑ Parameters related to DA production, remineralization, and degradation need further refinement through sensitivity analysis and optimization.
- ❑ Future studies should differentiate between PN species to better assess DA production during events.
- ❑ There is a need for better understanding of DA biomagnification in zooplankton and the toxin retention duration.
- ❑ Improving the model’s spatial resolution is critical for capturing submesoscale processes