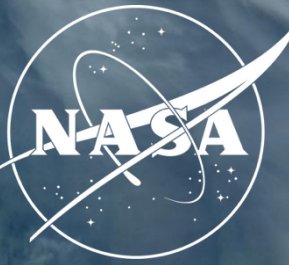


# Weakened carbon export and respiration during the extreme 2016 El Niño heatwave

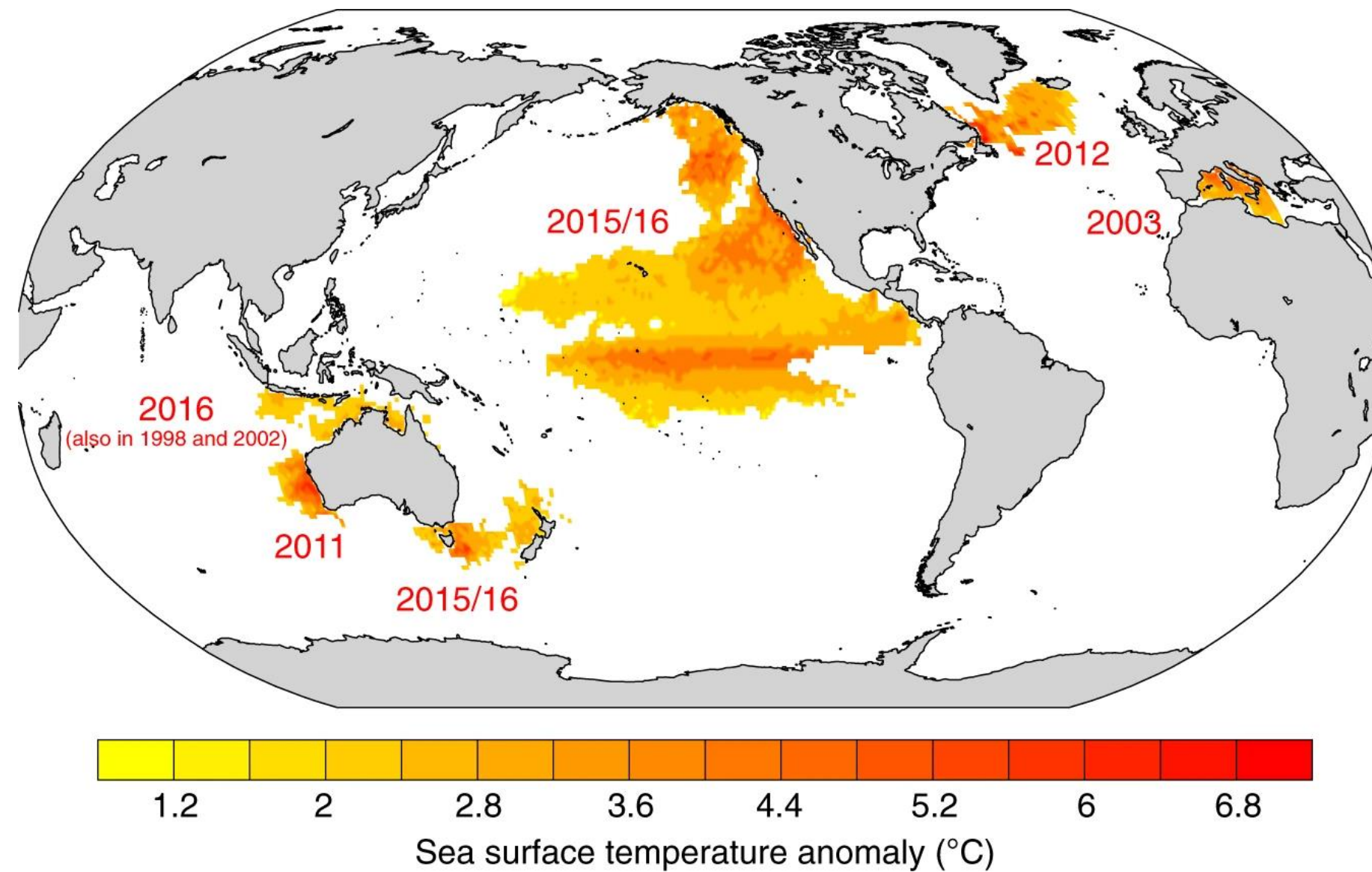
Lionel A. Arteaga<sup>1,2</sup>, Cecile Rousseaux<sup>1</sup>, Ivona Cetinic<sup>1,3</sup>, Seth Bushinsky<sup>4</sup>

<sup>1</sup>NASA GSFC, <sup>2</sup>UMBC, <sup>3</sup>MSU, <sup>4</sup>University of Hawaii

# Motivation: Marine heatwaves and ecosystems

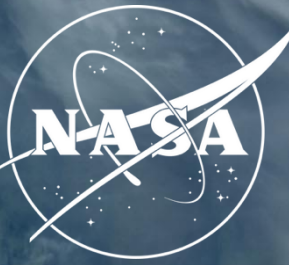


## Global MHWs

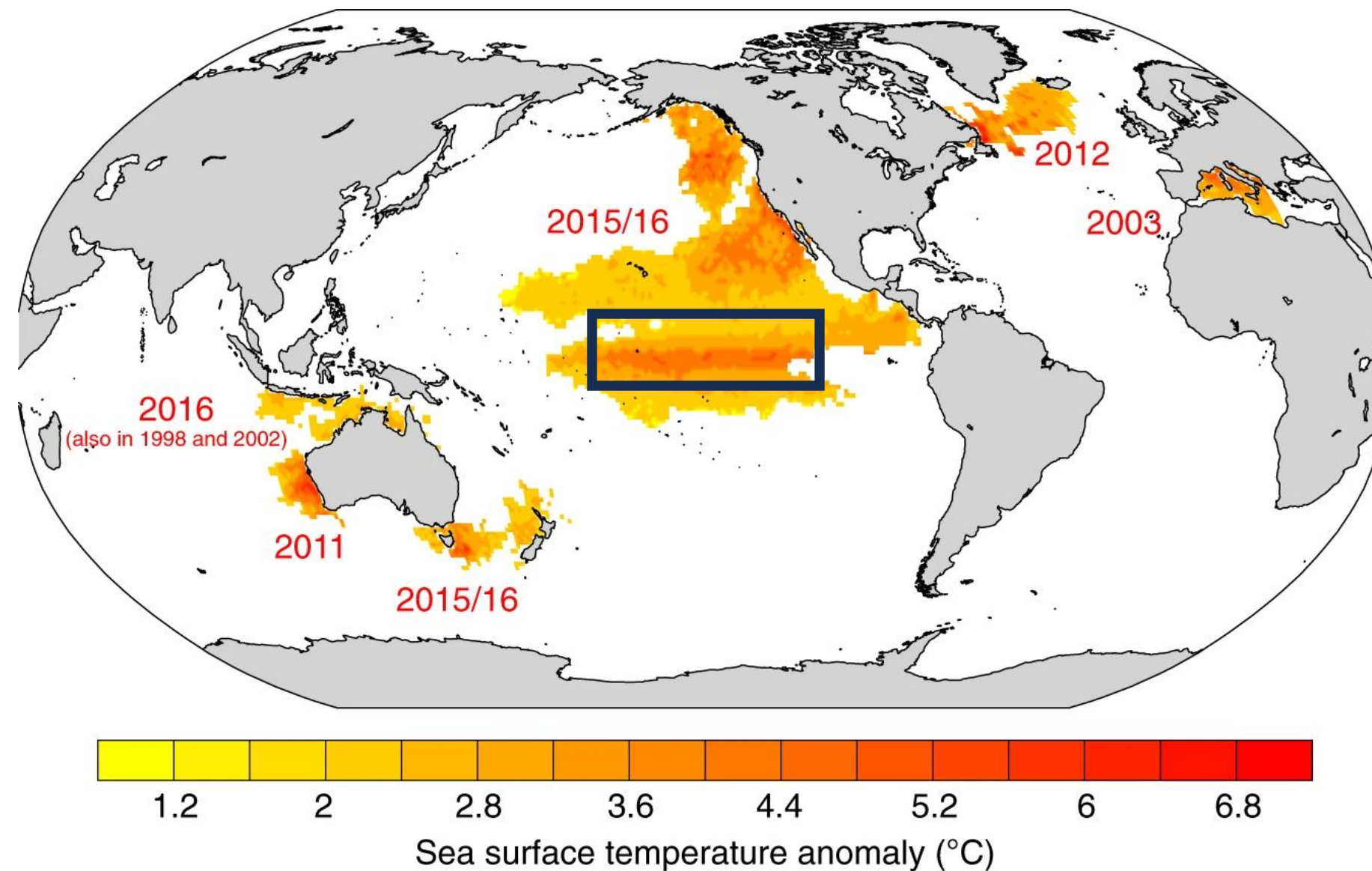


*Frölicher and Laufkötter (2018)*

# Motivation: Marine heatwaves and ecosystems

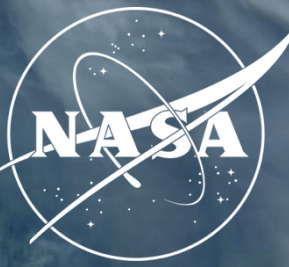


## Global MHWs

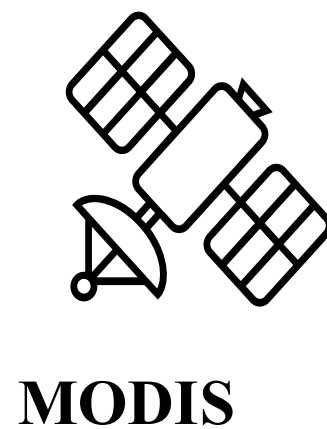
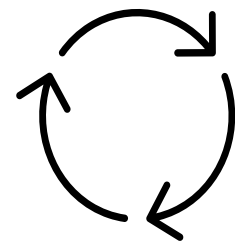


*Frölicher and Laufkötter (2018)*

# Tools: NASA Ocean Biogeochemical Model

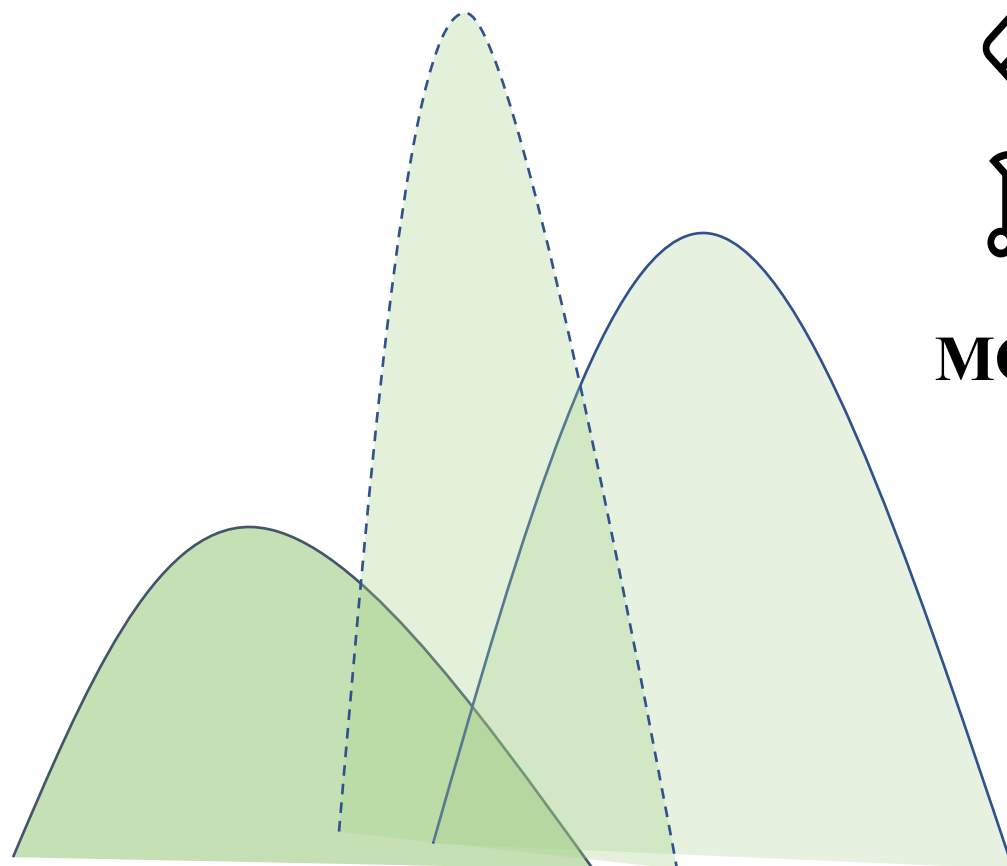
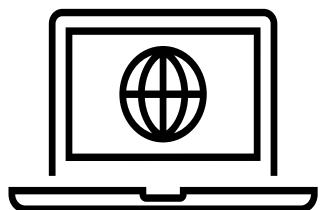


**DA-NOBM**

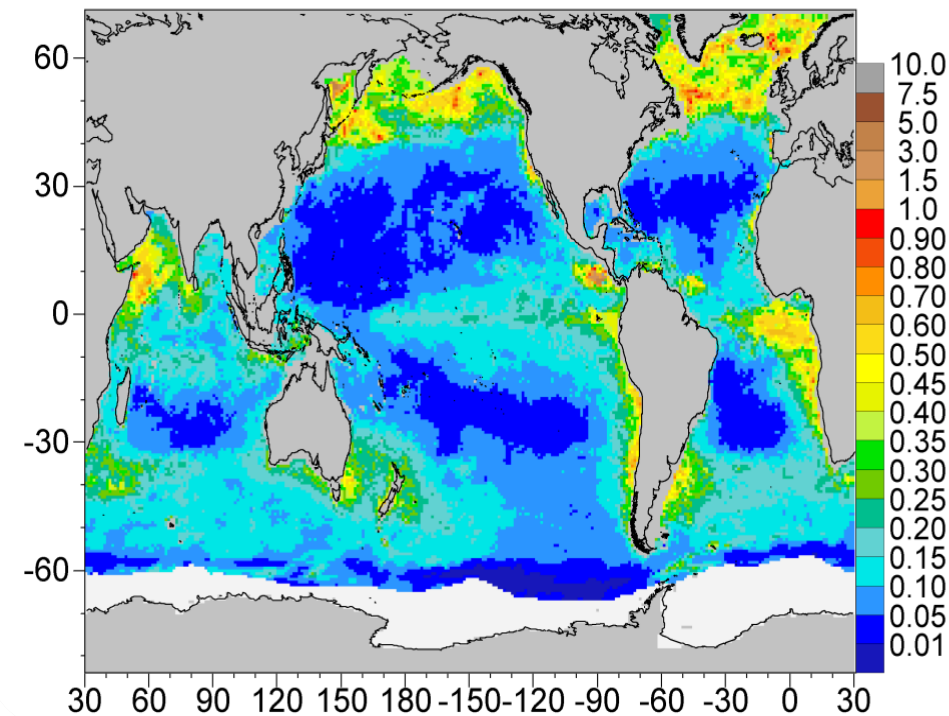


**MODIS**

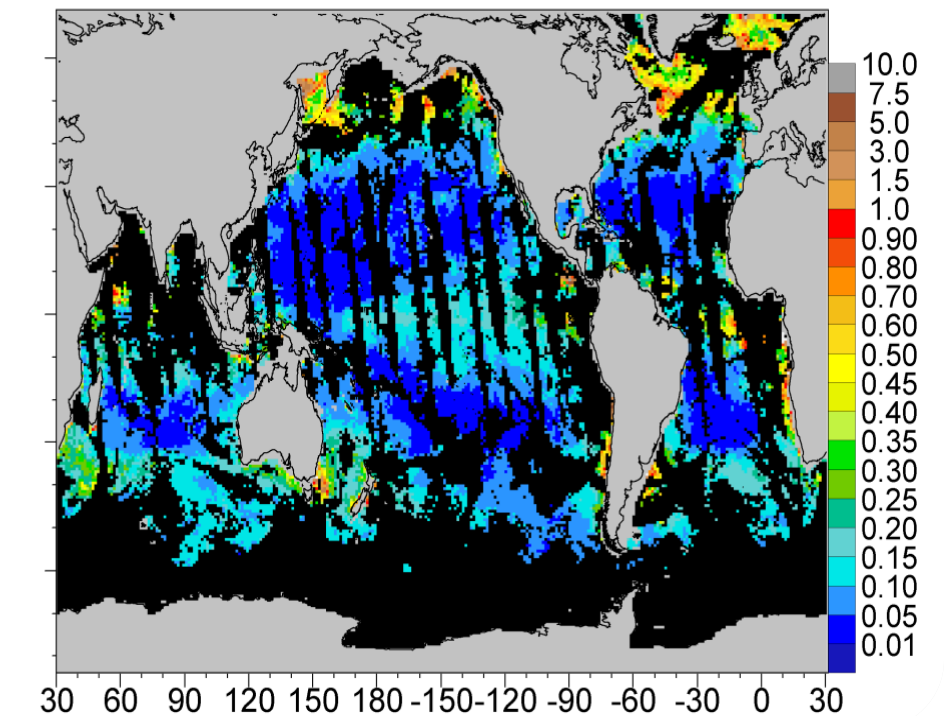
**NOBM  
forecast**



Assimilated VIIRS Chlorophyll Sep 1 2013



Daily VIIRS Chlorophyll Sep 1 2013

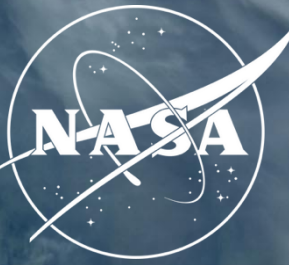


Level-4 products: Fill gaps in satellite retrievals and provide data that cannot be derived from current sensors

# Foundational work



# Foundational work: ENSO and chlorophyll



**communications  
biology**

ARTICLE

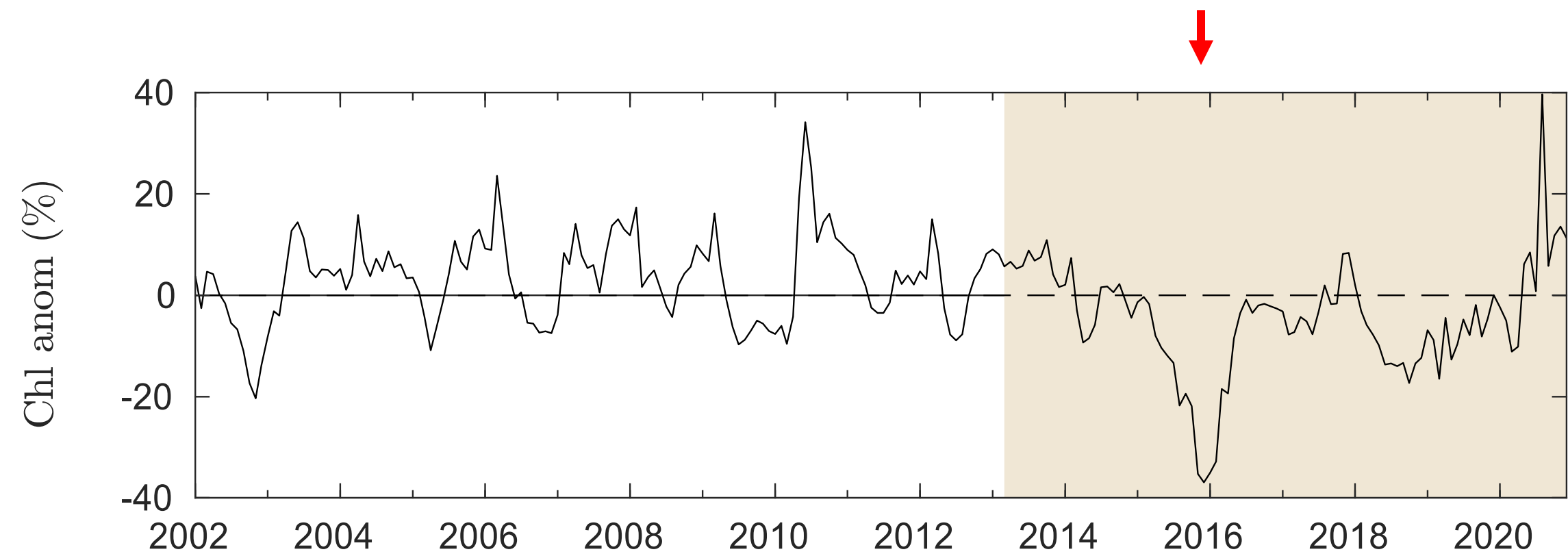
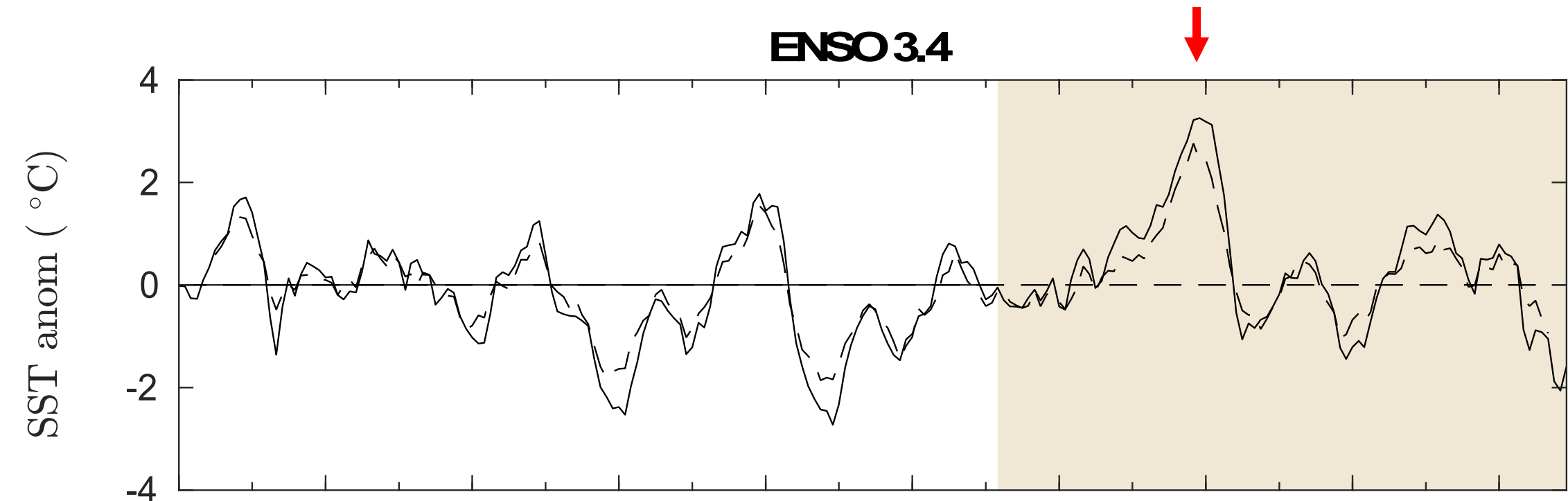
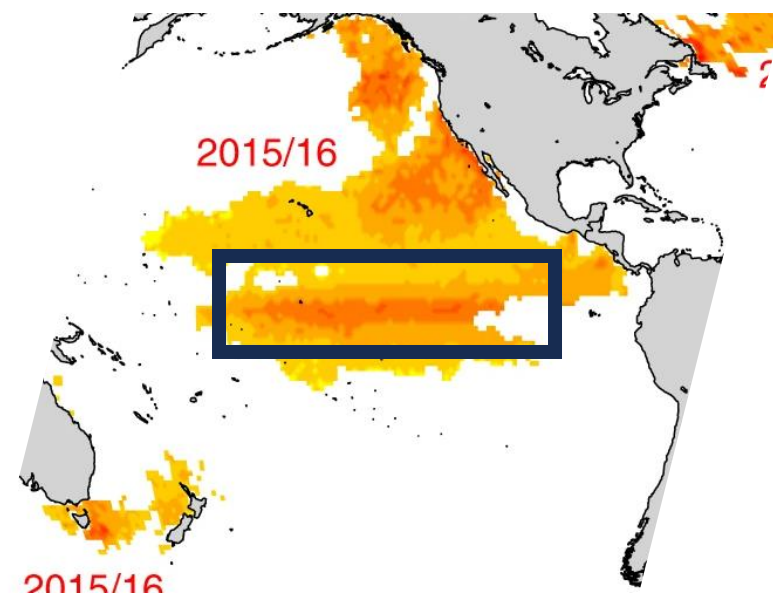
<https://doi.org/10.1038/s42003-023-04645-0>

OPEN

Impact of Pacific Ocean heatwaves on  
phytoplankton community composition

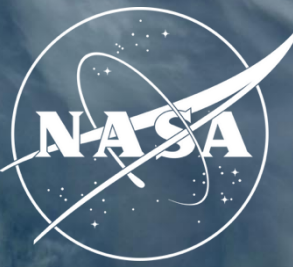
Lionel A. Arteaga<sup>1,2</sup> & Cecile S. Rousseaux<sup>3</sup>

**ENSO 3.4**



*Arteaga and Rousseaux (2023)*

# Foundational work: ENSO and phytoplankton ecology



**communications  
biology**

ARTICLE

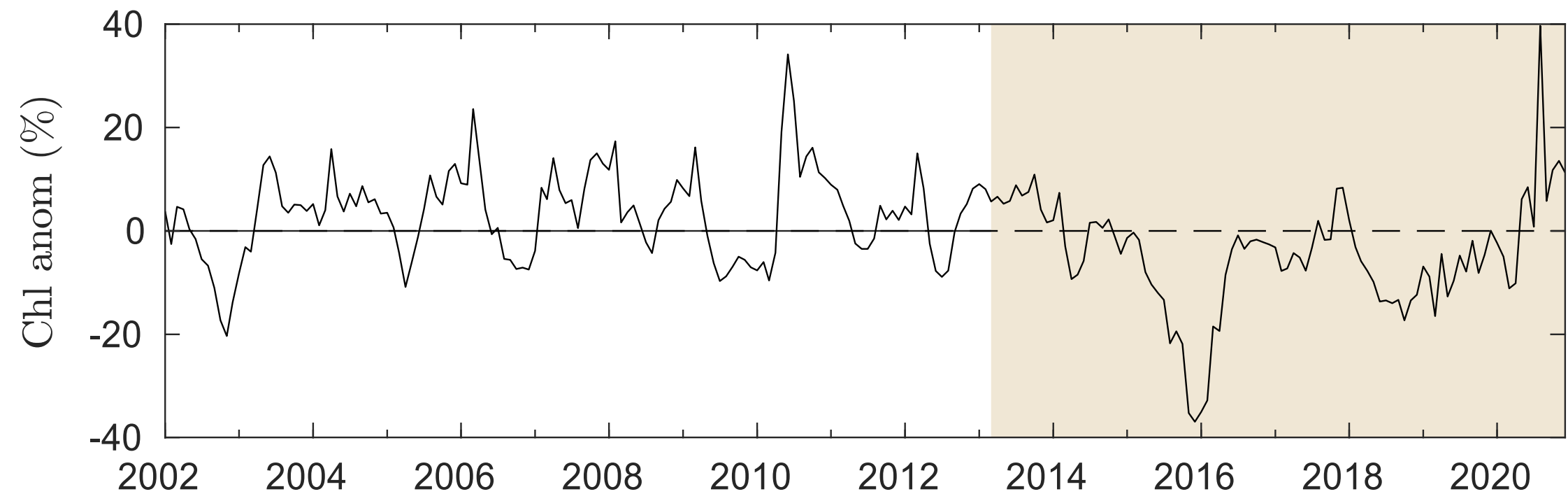
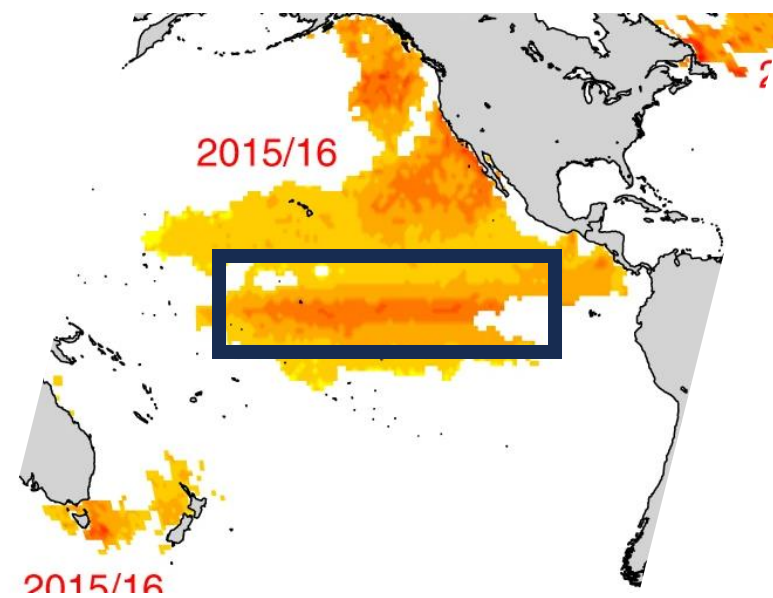
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OPEN

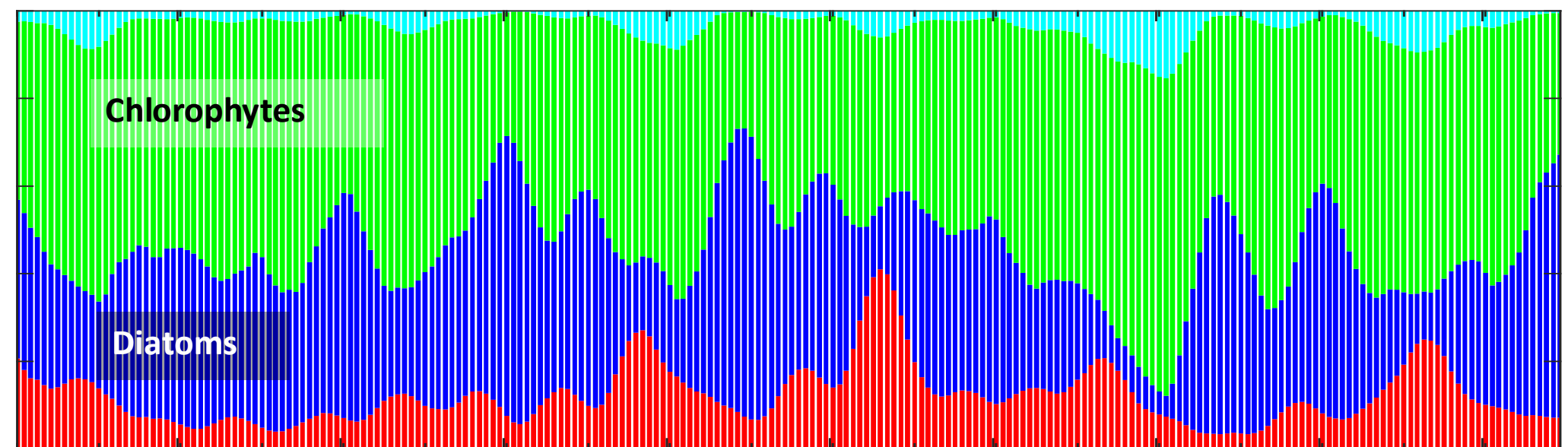
Impact of Pacific Ocean heatwaves on  
phytoplankton community composition

Lionel A. Arteaga<sup>1,2</sup> & Cecile S. Rousseaux<sup>3</sup>

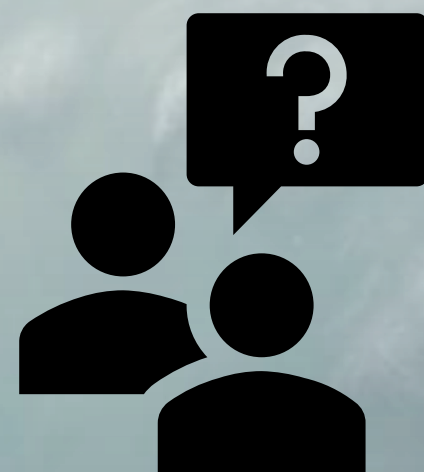
## ENSO 3.4



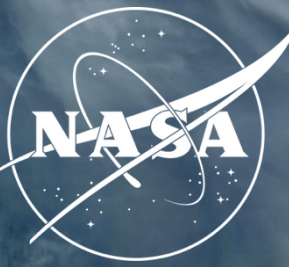
Biomass  
fraction (%)



These results suggest a strong decline in  
carbon export in 2016.  
Can we prove it?

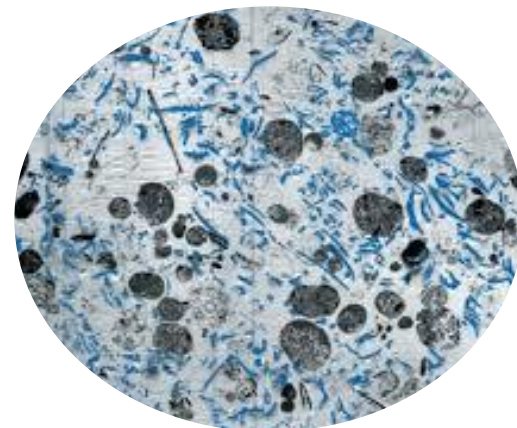


# Current tools: NOBM and ML products



## NASA Ocean Biogeochemical Model

- Assimilation of satellite ocean color
- Arteaga and Rousseaux (2023)



## SOCA-BBP

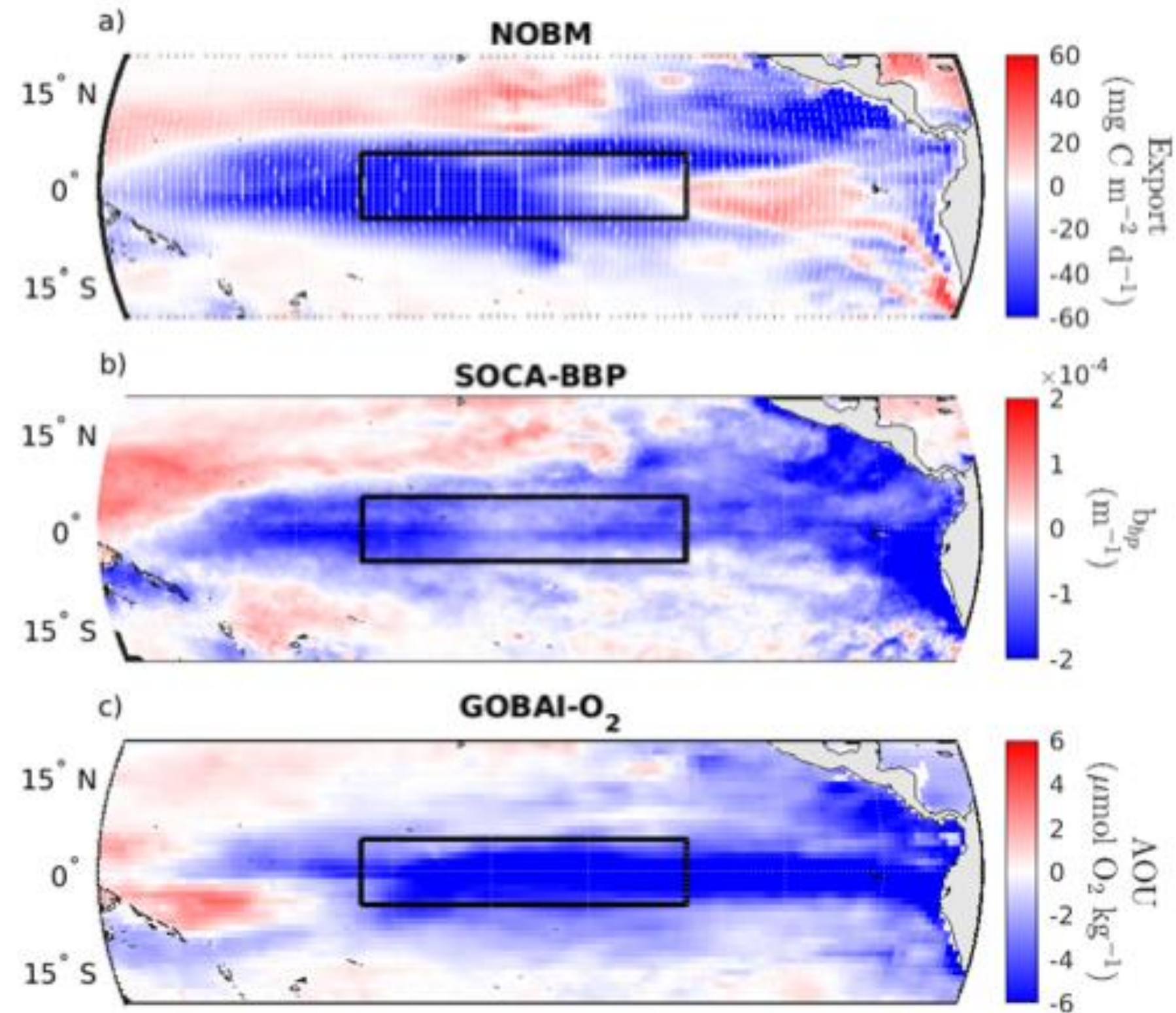
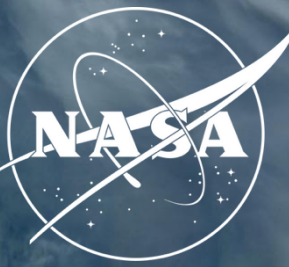
- ML-based on BGC-Argo and remote sensing
- Sauzede et al. (2016,2024)



## GOBAI-O<sub>2</sub> (Aparent Oxygen Utilization-AOU)

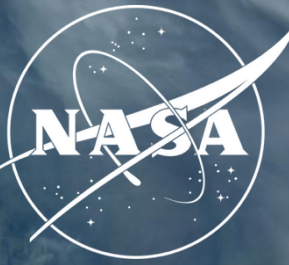
- ML-based on BGC-Argo and ship observations
- Sharp et al. (2023)

# Upper ocean patterns in export-related variables

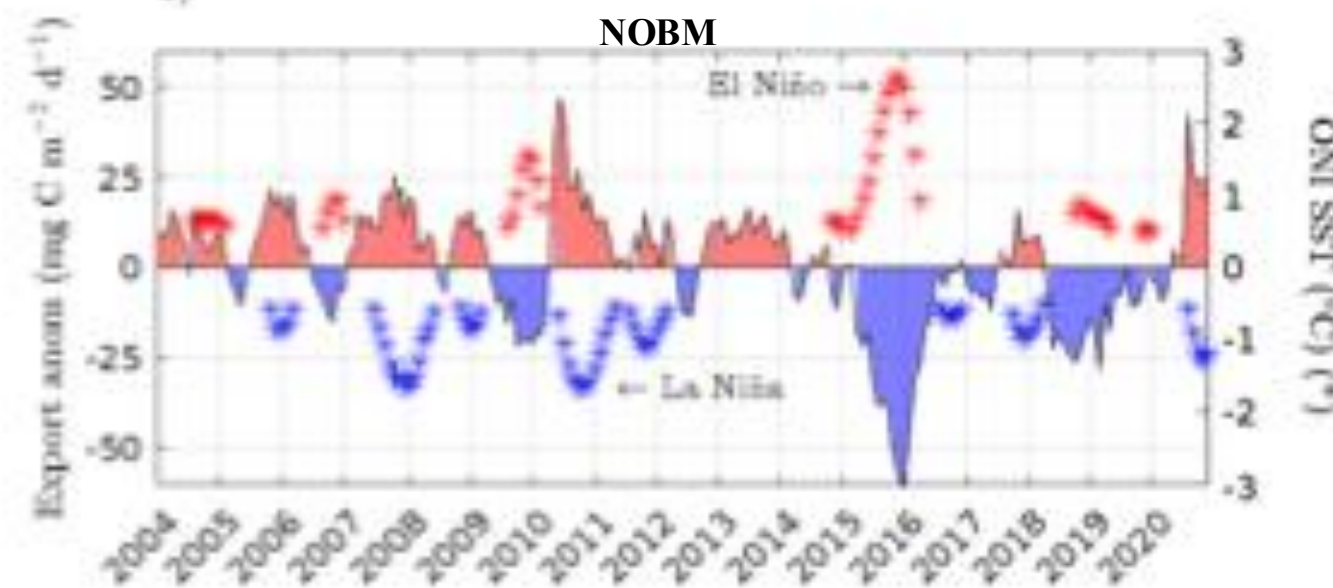


Anomalies during the 2016 El Niño

# Anomalies in export, $b_{bp}$ , and AOU

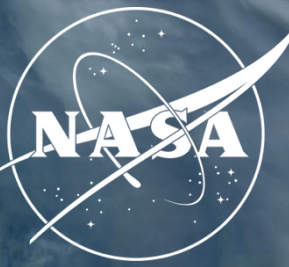


Total MLD POC flux  
anomalies (—)



ENSO (SST)  
anomalies (\*)

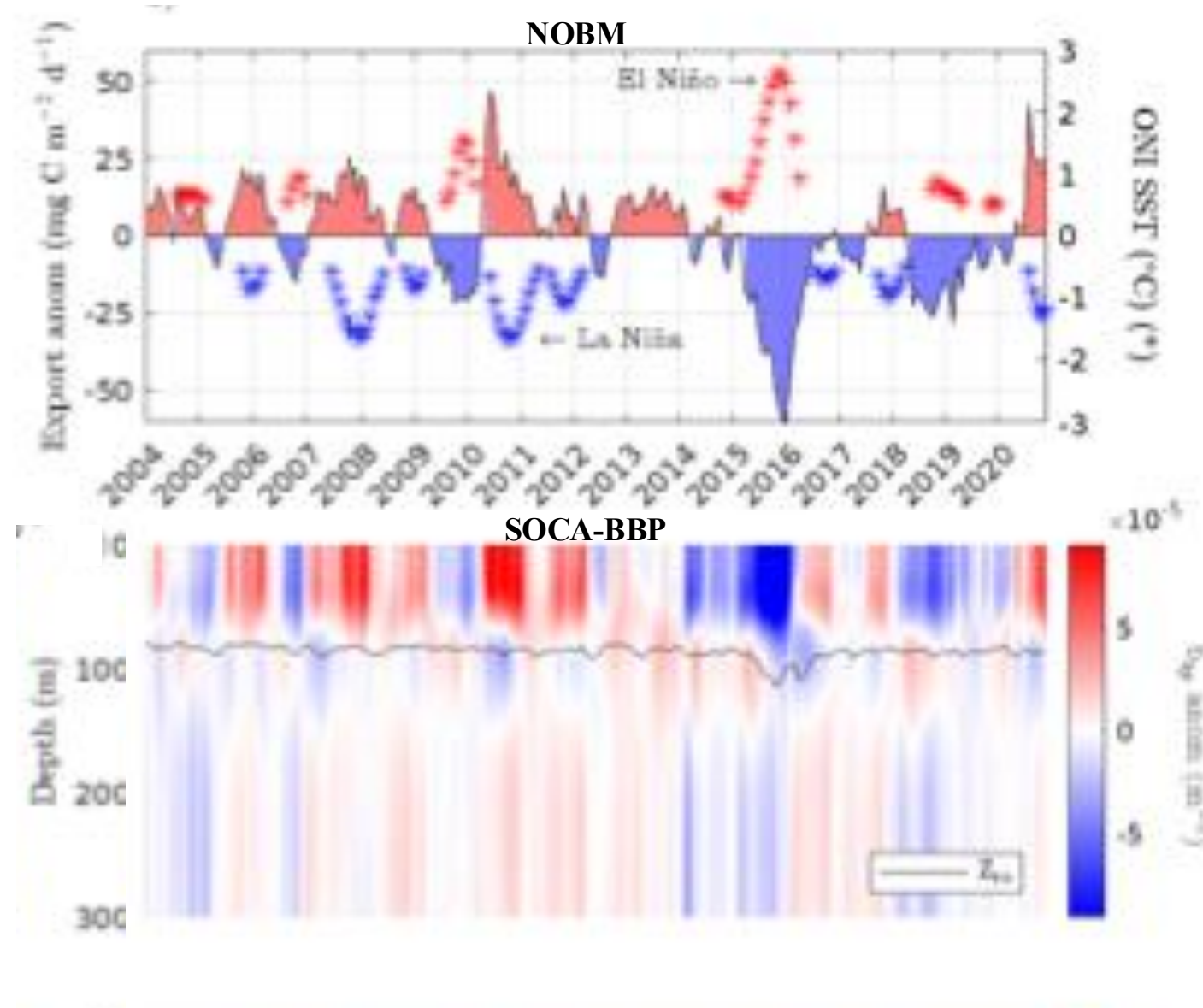
# Anomalies in export, $b_{bp}$ , and AOU



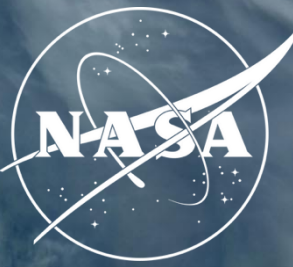
Total MLD POC flux  
anomalies (—)

Backscattering ( $b_{bp}$ )  
anomalies

ENSO (SST)  
anomalies (\*)



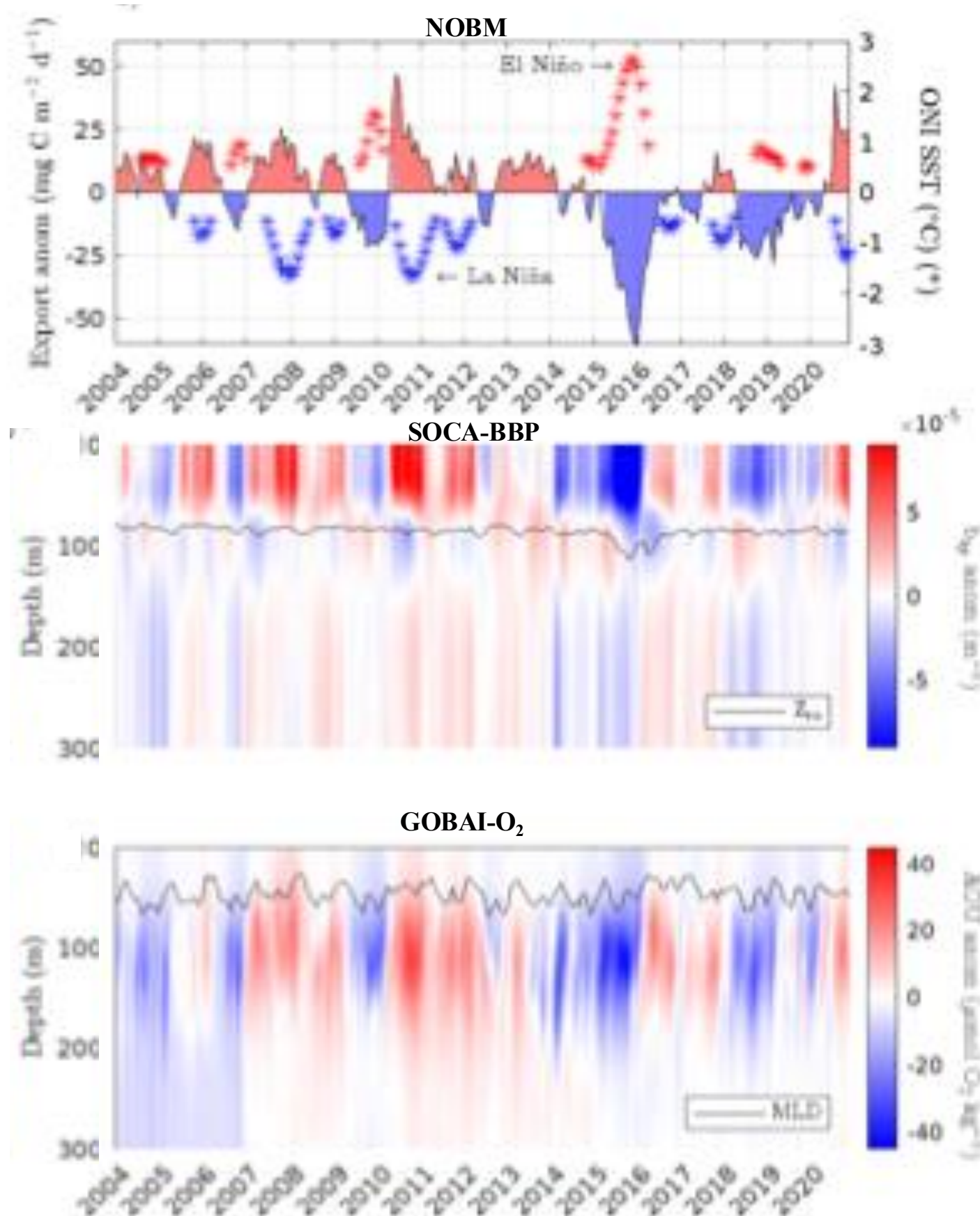
# Anomalies in export, $b_{bp}$ , and AOU



Total MLD POC flux  
anomalies (—)

Backscattering ( $b_{bp}$ )  
anomalies

Respiration (AOU)  
anomalies



ENSO (SST)  
anomalies (\*)

# Anomalies in export, $b_{bp}$ , and AOU

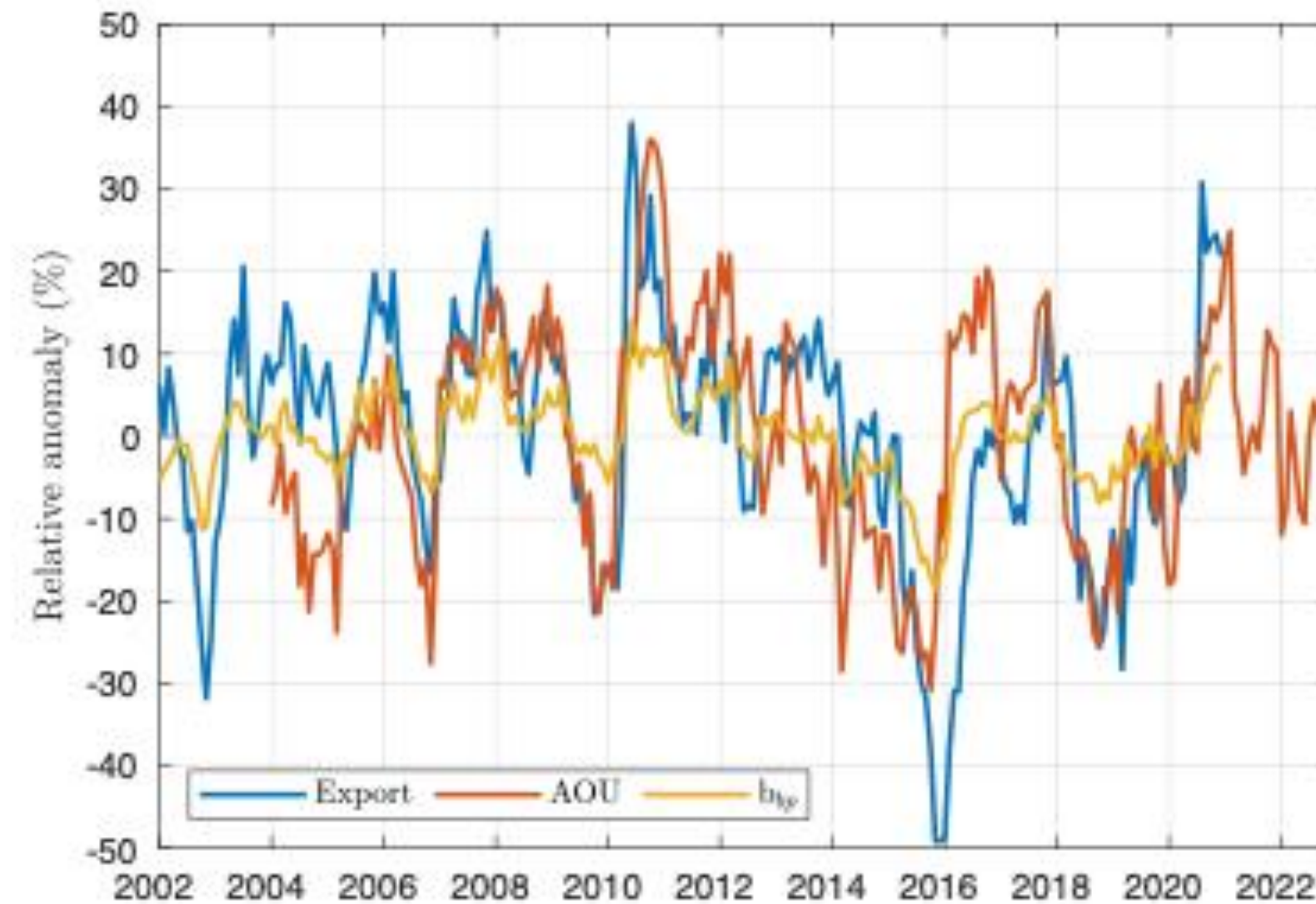
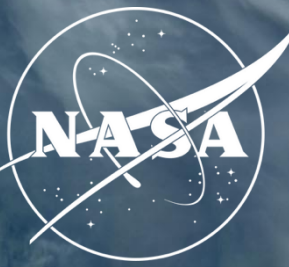
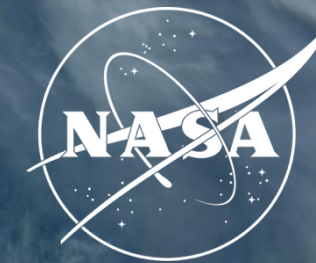


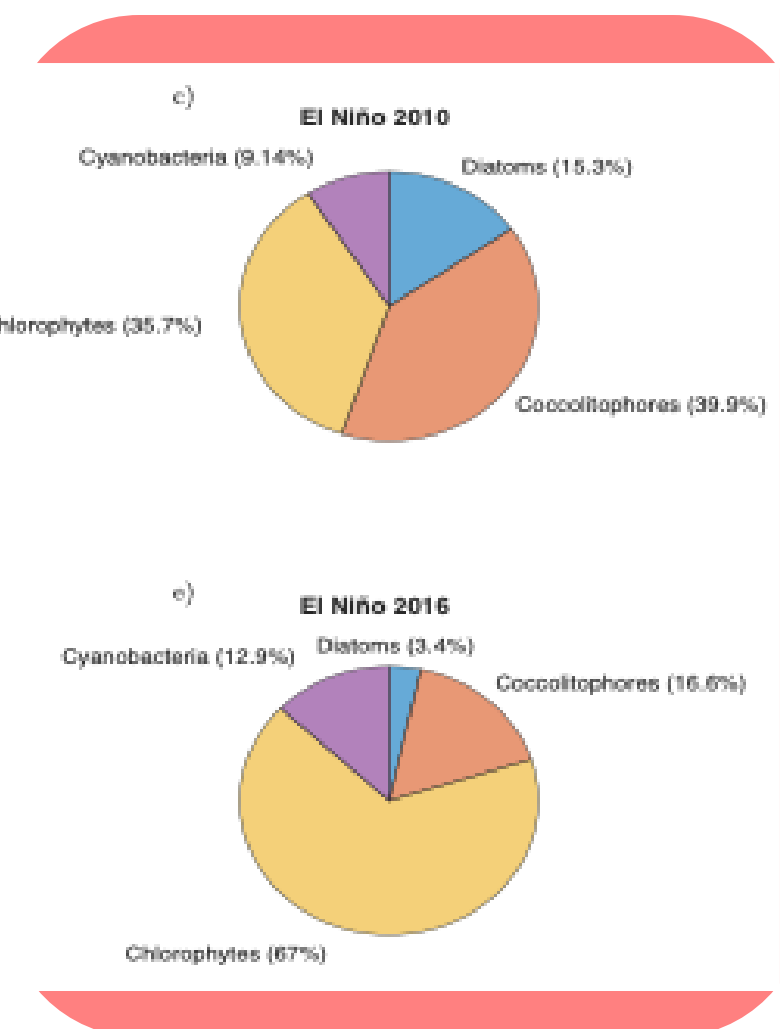
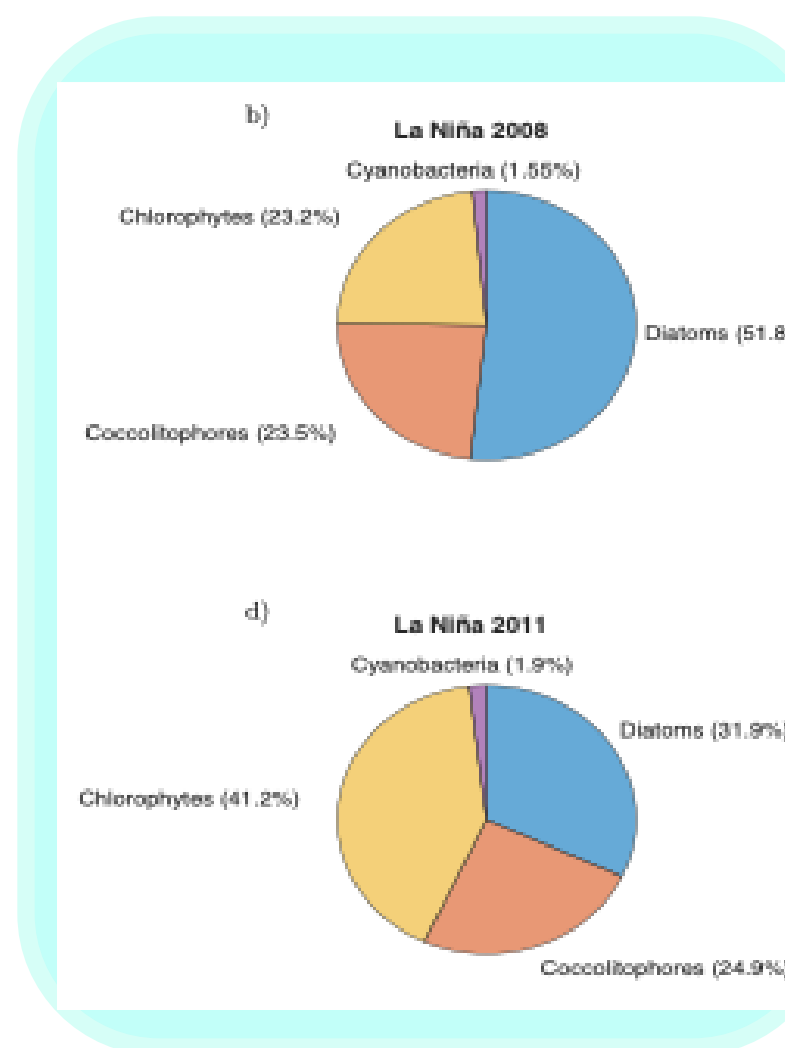
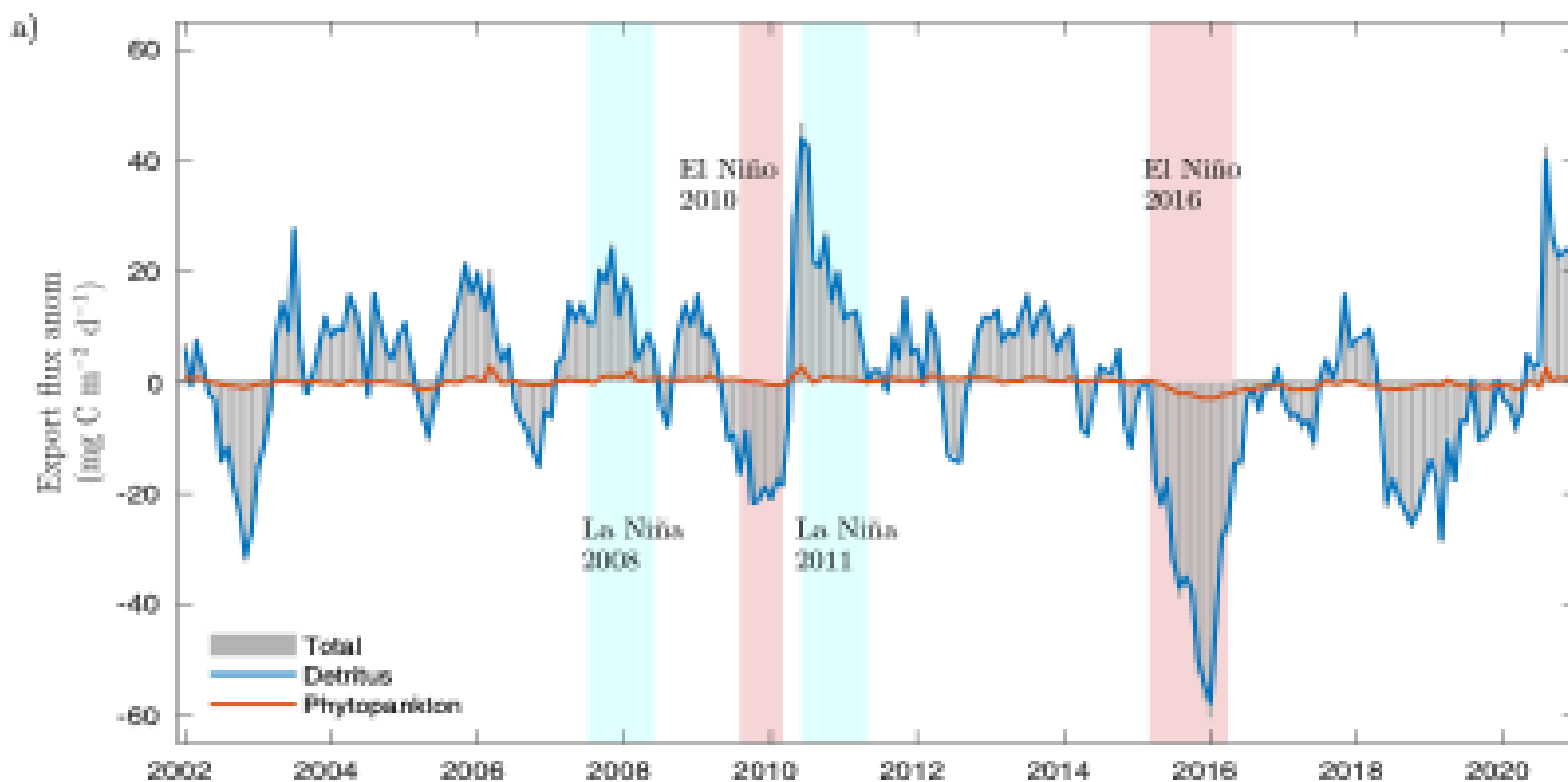
Figure 3: **Similarity in the interannual change of export, particles, and respiration in the central equatorial Pacific.** Relative monthly anomalies (%) in modeled mixed layer export, particle backscatter ( $b_{bp}$ ) (averaged for the top 50 m), and Apparent Oxygen Utilization (AOU) (averaged between 100 – 200 m). Model export output and Argo-based  $b_{bp}$  were obtained for 2002–2020. Argo-based dissolved oxygen is available from 2004 to 2022. Similarly as in Figure 2, variables are computed at a monthly temporal resolution and averaged for the ENSO 3.4 region.

# Plankton composition impact on export



## POC carbon flux across main ecosystem compartments

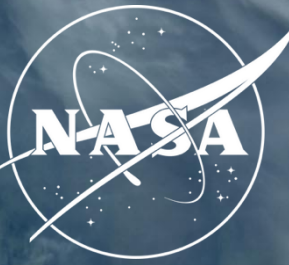
## Community composition in El Niño vs La Niña years



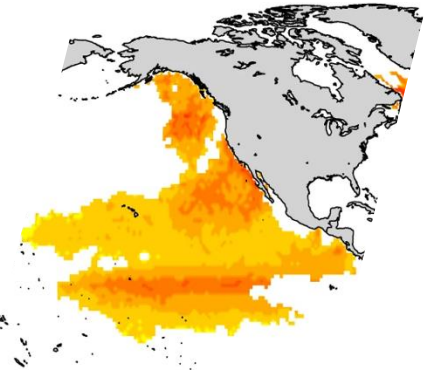
# Conclusions, Gaps, & Priorities



# Conclusions

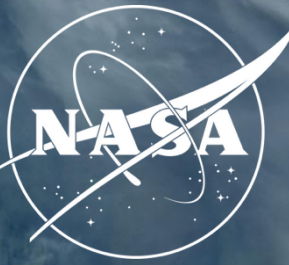


## Weakened carbon export and respiration during the extreme 2016 El Niño heatwave

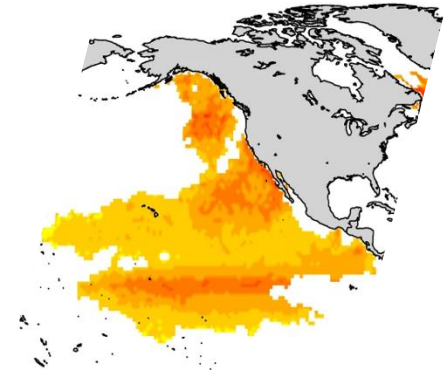


- ✓ Multiple lines of evidence point to a significant decline in equatorial Pacific carbon export during the 2016 El Niño
  - How much further weakening can we expect as ENSO/MHWs intensify?
  - Are there important implications for the global carbon cycle?
  - How about other marine regions under heat stress?
  - Do we believe these results?

# Conclusions

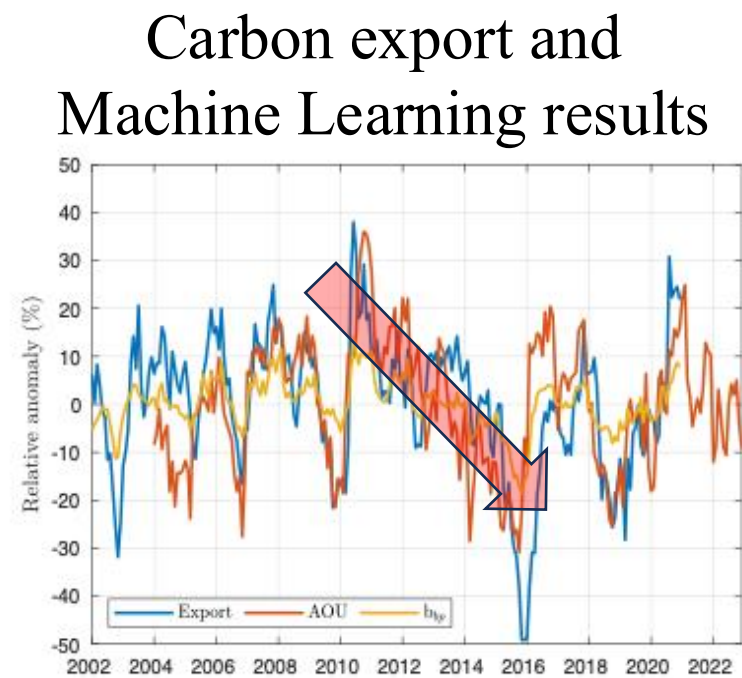


## Weakened carbon export and respiration during the extreme 2016 El Niño heatwave

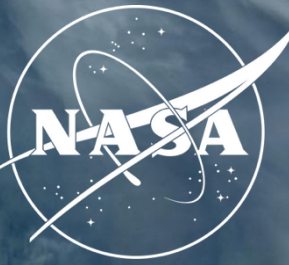


✓ Multiple lines of evidence point to a significant decline in equatorial Pacific carbon export during the 2016 El Niño

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# Conclusions

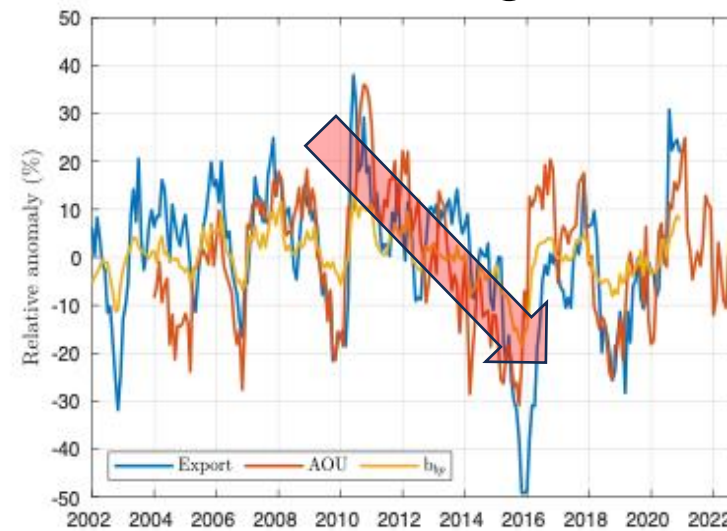


## Weakened carbon export and respiration during the extreme 2016 El Niño heatwave

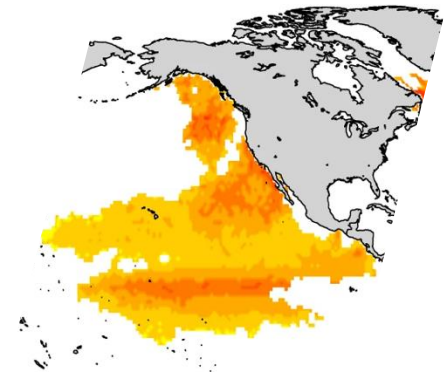
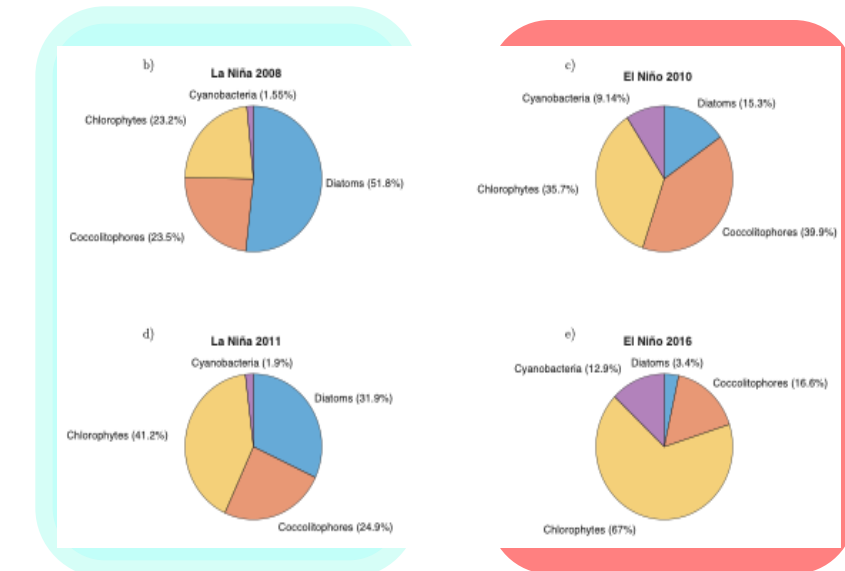
✓ Multiple lines of evidence point to a significant decline in equatorial Pacific carbon export during the 2016 El Niño

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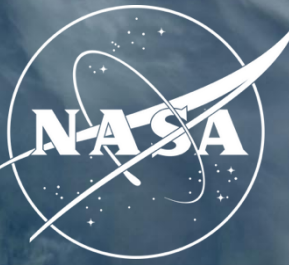
Carbon export and Machine Learning results



Ecological changes



# Conclusions



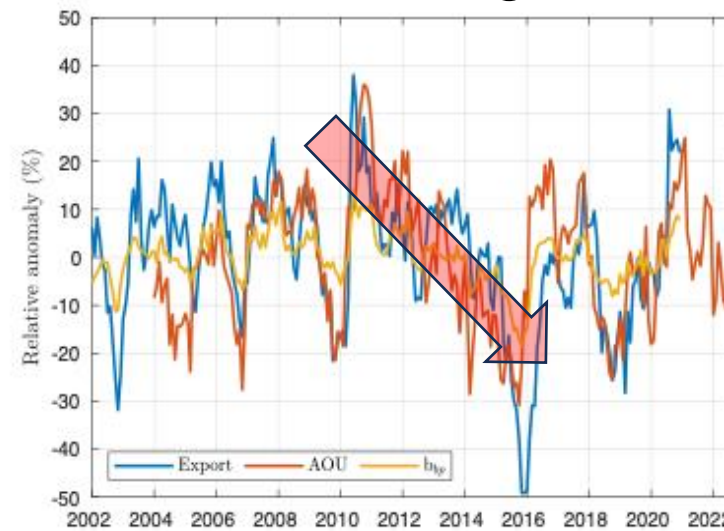
## Weakened carbon export and respiration during the extreme 2016 El Niño heatwave

✓ Multiple lines of evidence point to a significant decline in equatorial Pacific carbon export during the 2016 El Niño

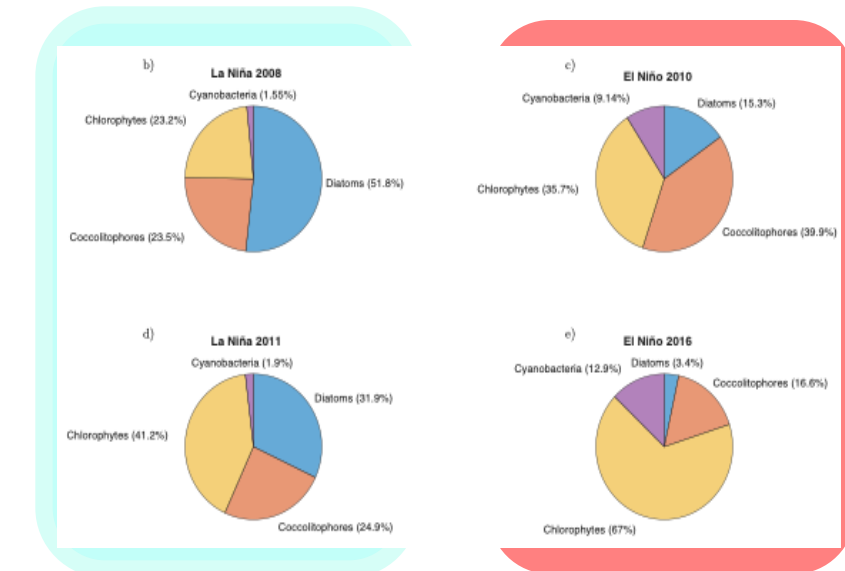
- How much further weakening can we expect as ENSO/MHWs intensify?
- Are there important implications for the global carbon cycle?
- How about other marine regions under heat stress?

• Do we believe these results?

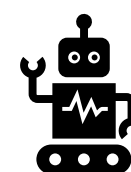
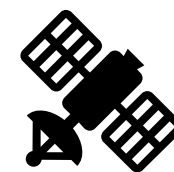
Carbon export and Machine Learning results



Ecological changes



## Gaps & next steps



Phytoplankton ecology products



1 – 5  
years

10  
years



# Weakened carbon export and respiration during the extreme 2016 El Niño heatwave

Arteaga et al (in review) – [lionel.arteagaquintero@nasa.gov](mailto:lionel.arteagaquintero@nasa.gov)



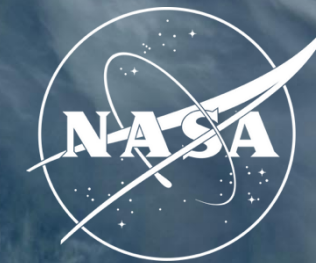
Ocean Biology &  
Biogeochemistry



Ocean Carbon From Space (2025)



# ML-products validation



## SOCA-BBP

## GOBAI-O<sub>2</sub>

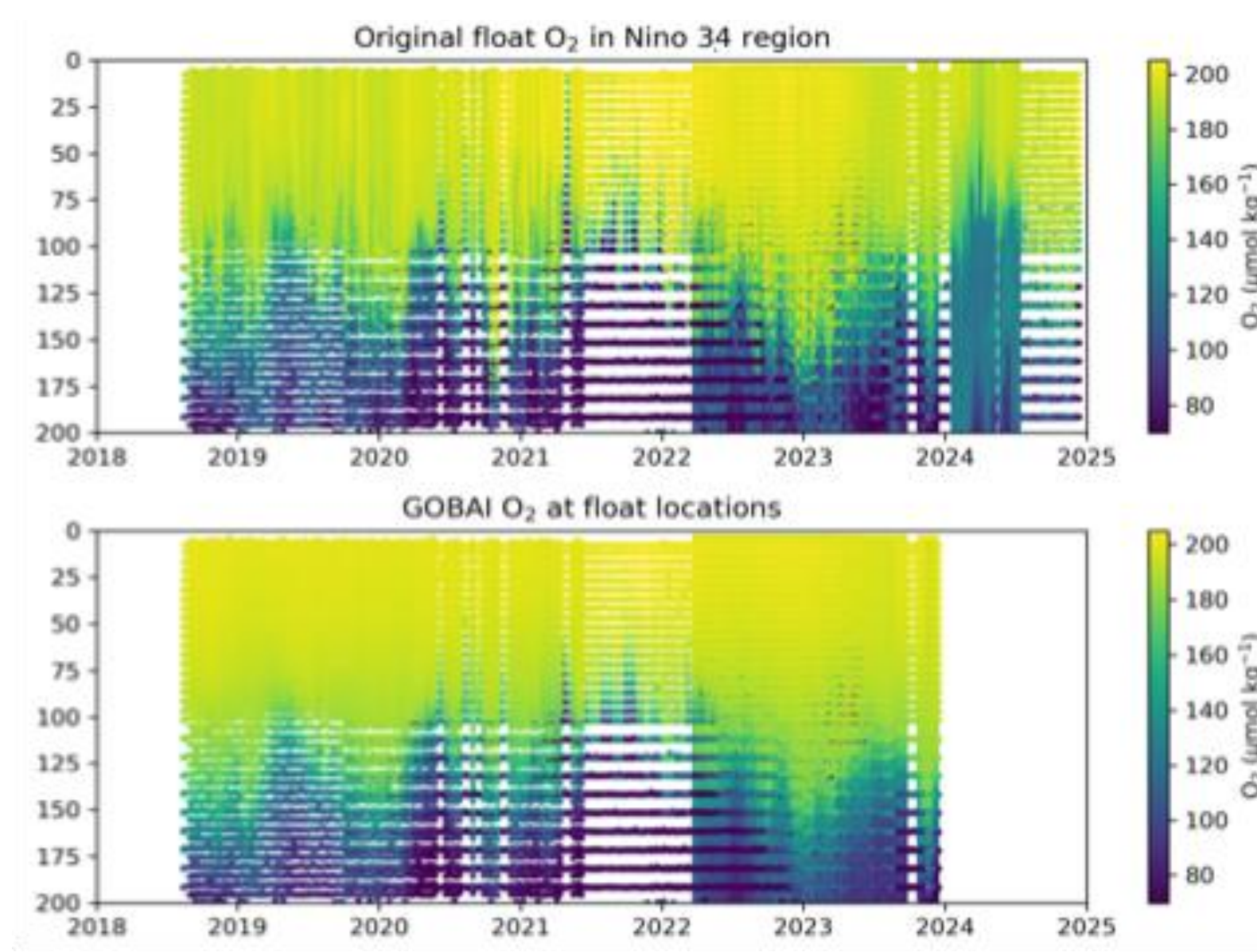
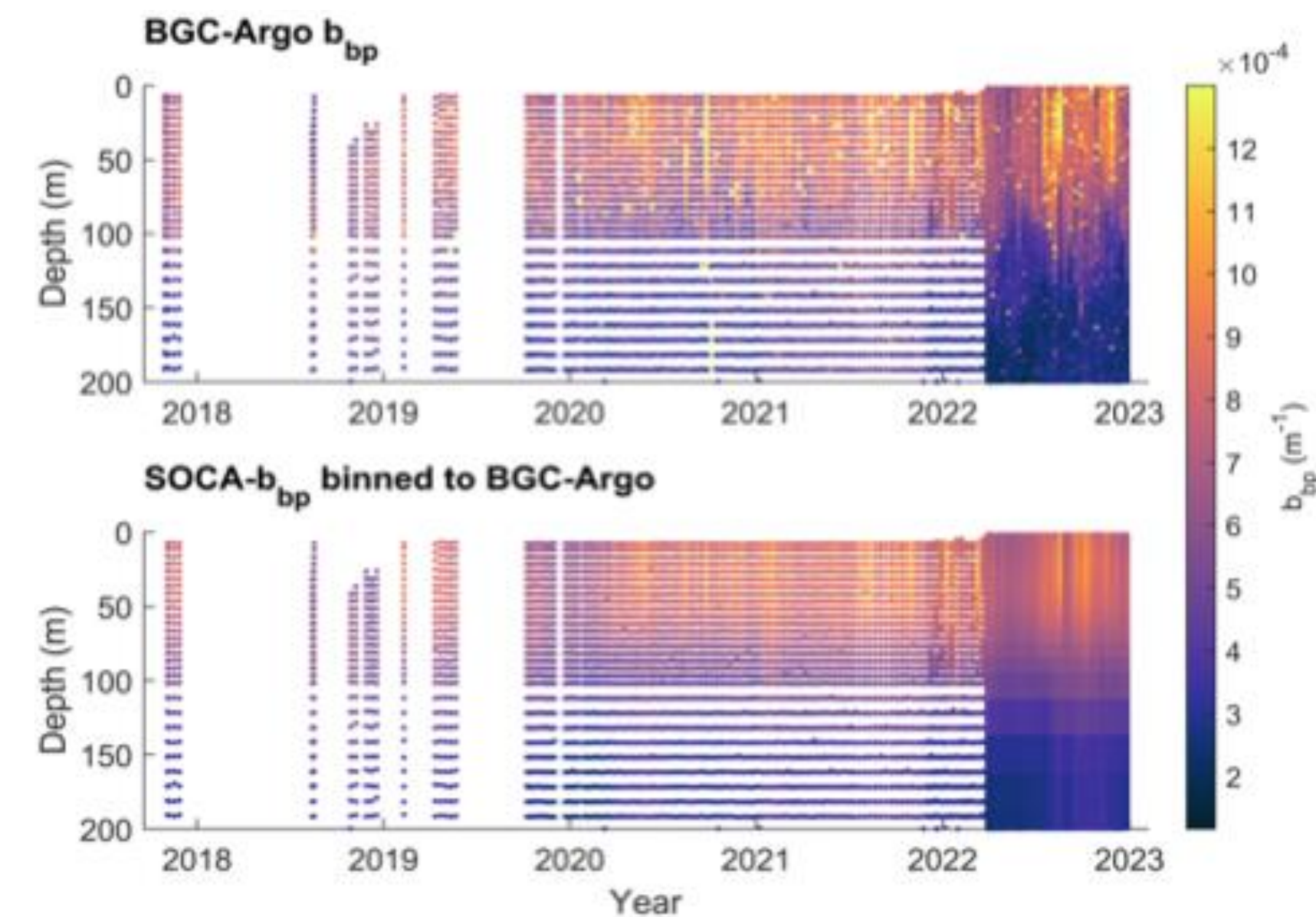
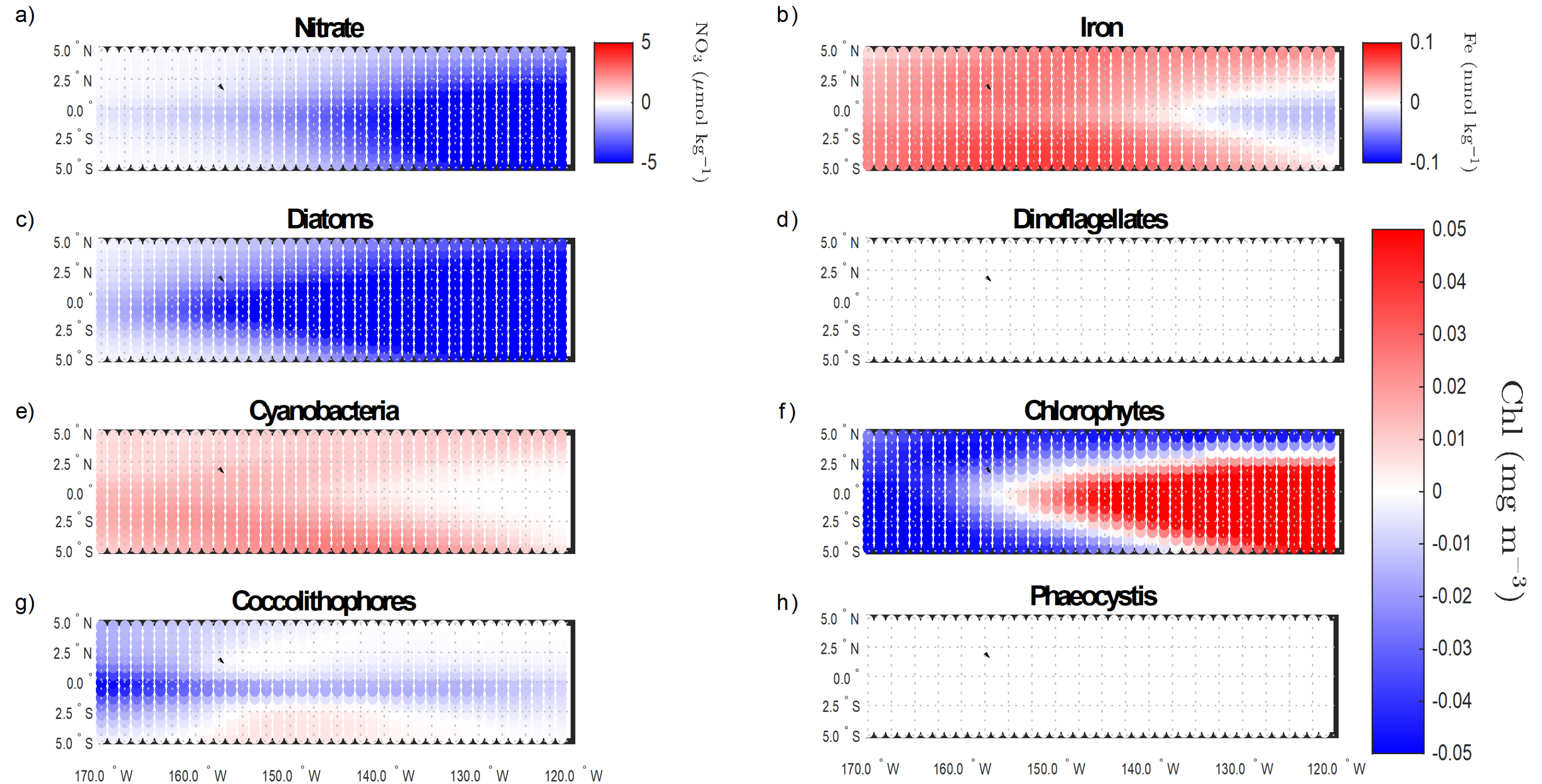
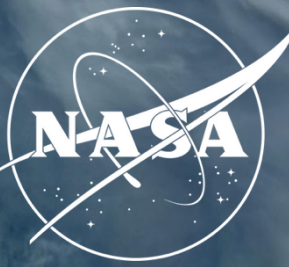


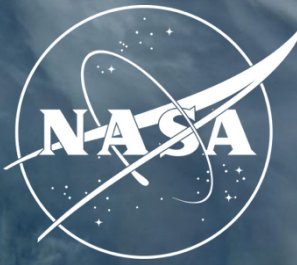
Figure S7: Vertical patterns and interannual changes in depth-resolved  $b_{bp}(700)$  within the ENSO 3.4 region from (top) BGC-Argo floats and (bottom) the SOCA-BBP product binned to the resolution of matching float profiles.

Figure S10: Vertical patterns and interannual changes in depth-resolved dissolved oxygen in the central equatorial Pacific (box coordinates) from (top) BGC-Argo floats and (bottom) the GOBAI- $O_2$  product binned to the resolution of matching float profiles.

# ENSO 3.4: Ecological re-arrangement (early 2016)



# Foundational work: ENSO and phytoplankton ecology



## communications biology

ARTICLE

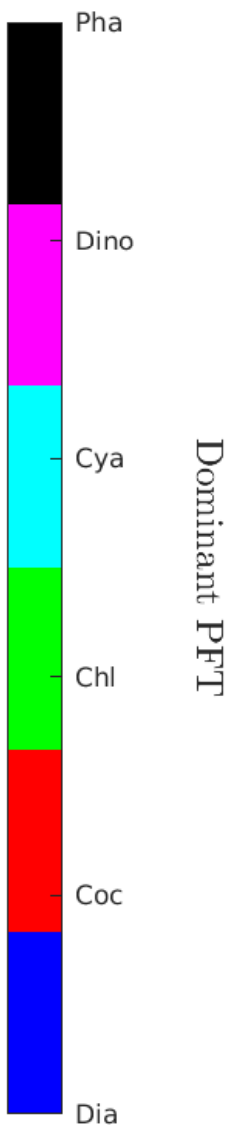
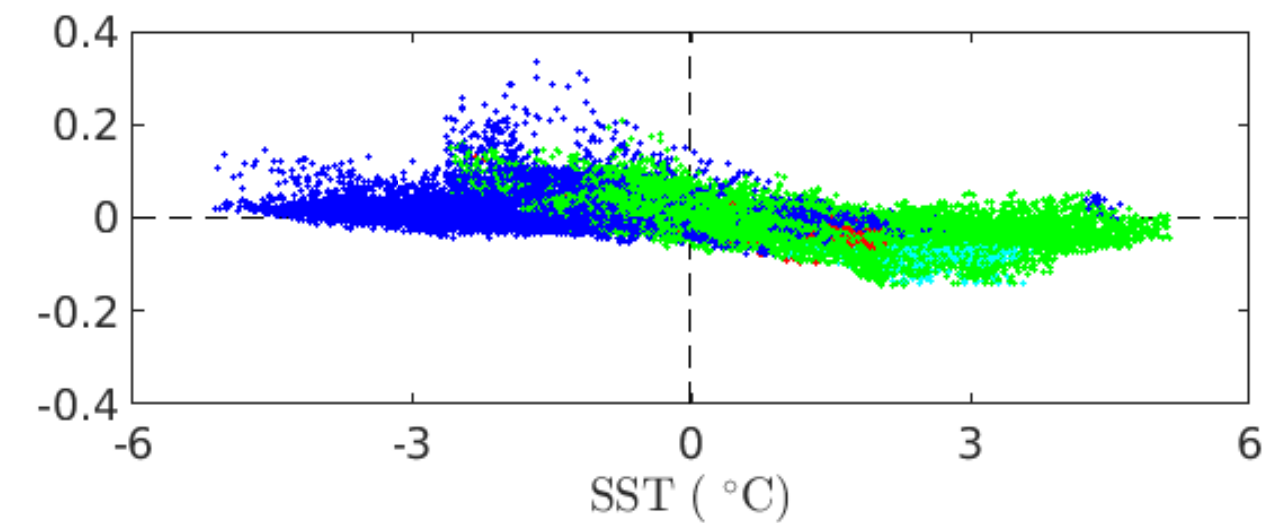
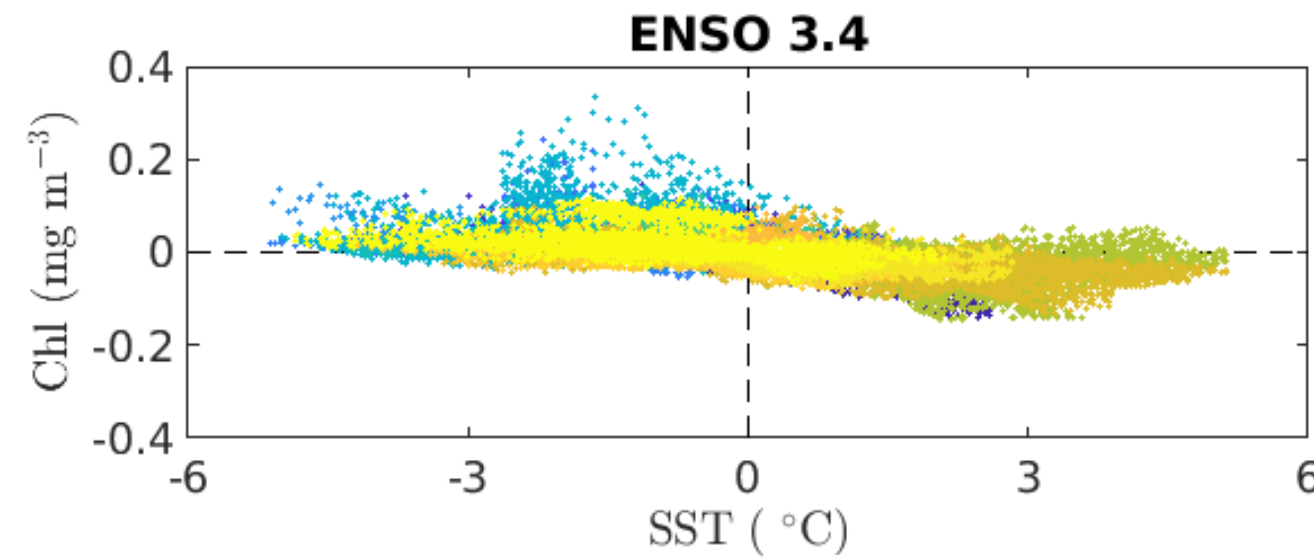
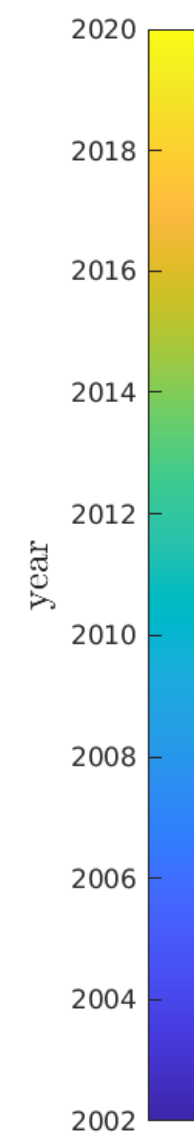
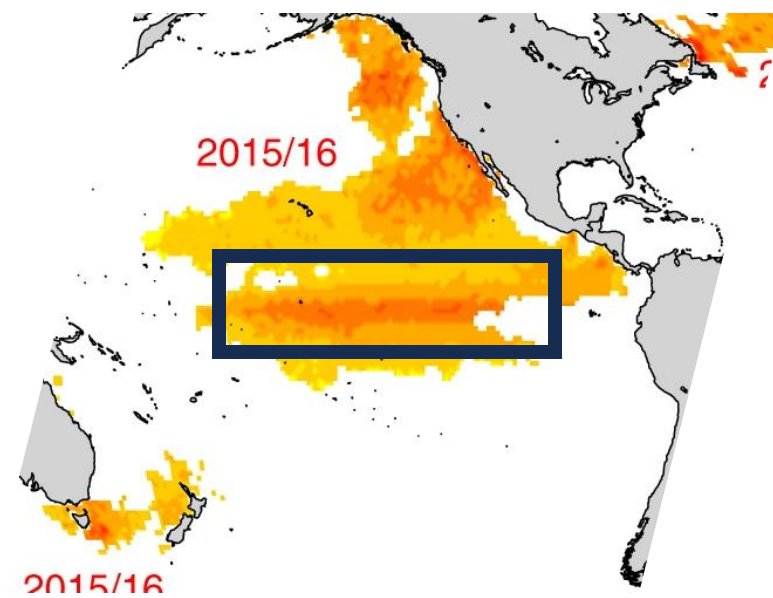
<https://doi.org/10.1038/s42003-023-04645-0>

OPEN

## Impact of Pacific Ocean heatwaves on phytoplankton community composition

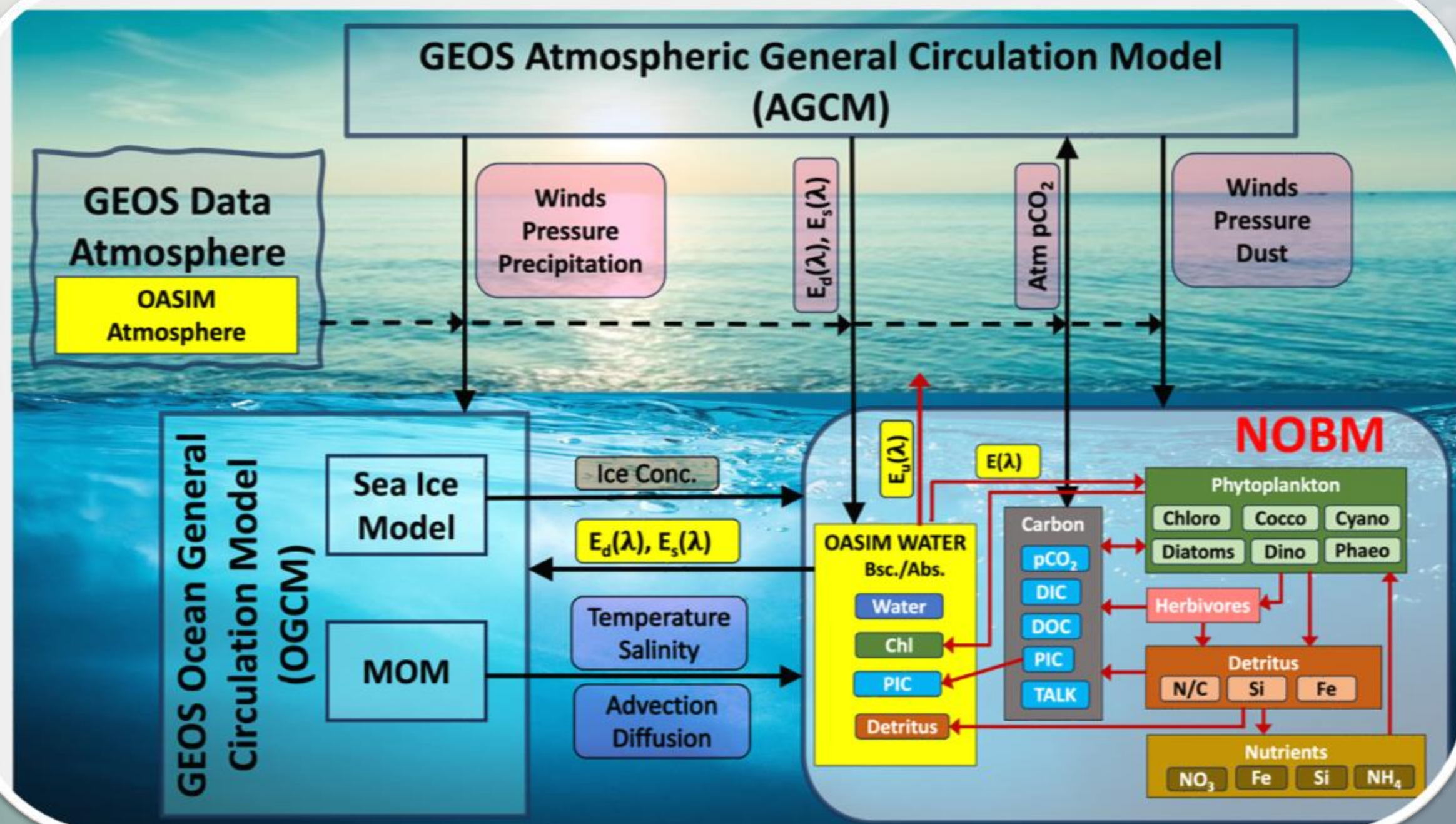
Lionel A. Arteaga<sup>1,2</sup> & Cecile S. Rousseaux<sup>3</sup>

### ENSO 3.4



# NASA Ocean Biogeochemical Model (NOBM)

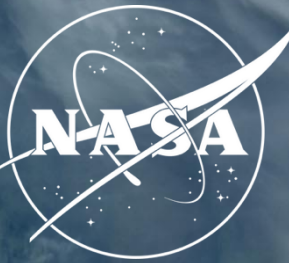
A medium complexity BGC-model for  
assimilation of satellite ocean color



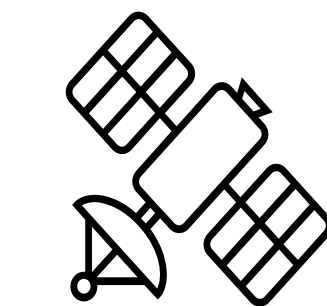
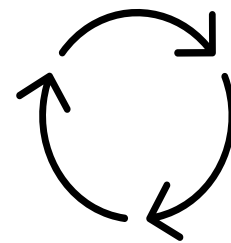
## Model features

- Assimilation: Chlorophyll, absorption of CDOM, and PIC (MODIS-Aqua).
- Domain: Global, waters < 200 m.
- Time: 2002-2020
- Forcing: Reanalysis products (winds, humidity, shortwave, longwave radiation, etc.) and satellite data (aerosols and clouds).
- Resolution:  $2/3 \times 1.25$  degrees (Poseidon).

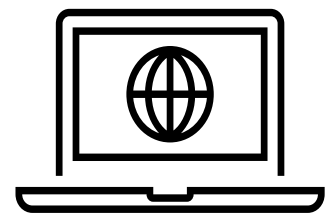
# Backup: NASA Ocean Biogeochemical Model (NOBM)



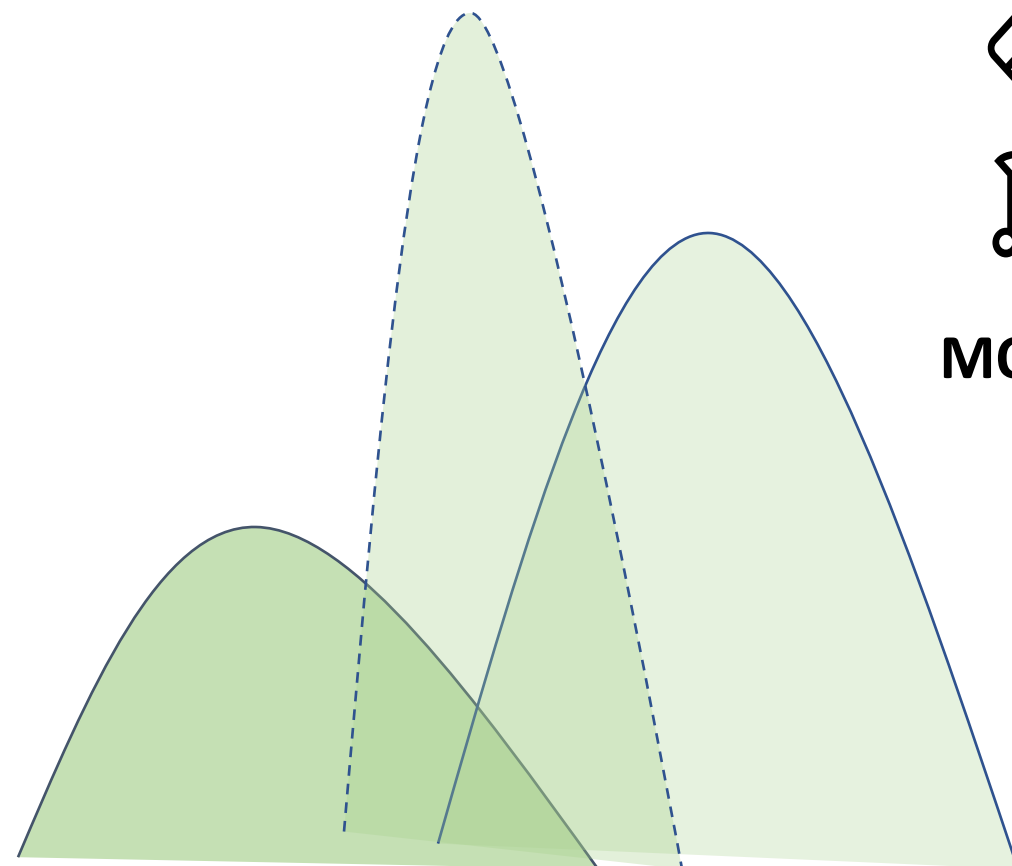
DA-NOBM



MODIS-A

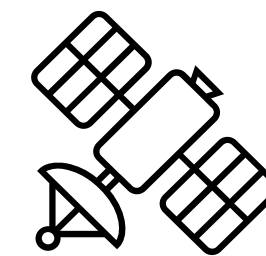
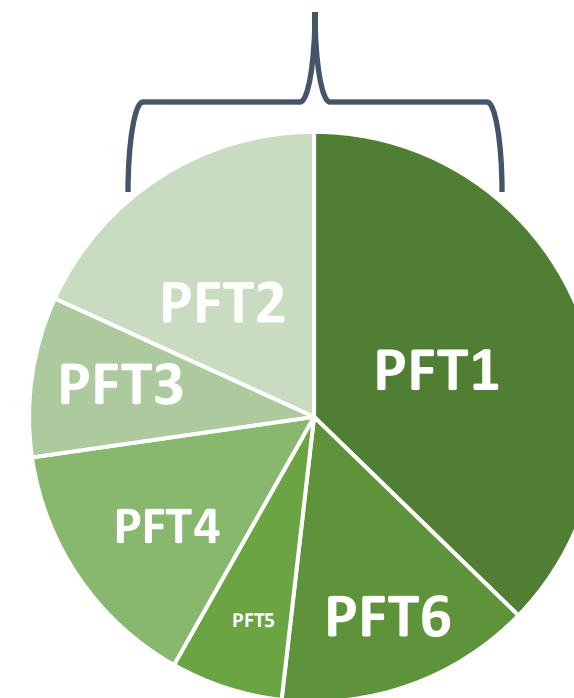


NBOM

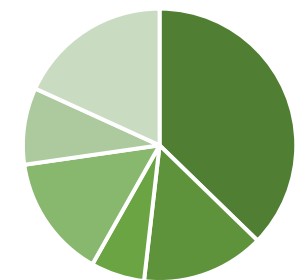


Sequential DA of Chl, PIC, and aCDOM

Chlorophyll



DA-step



Phytoplankton Functional Types (PFTs)

cyanobacteria



diatom



dinoflagellate



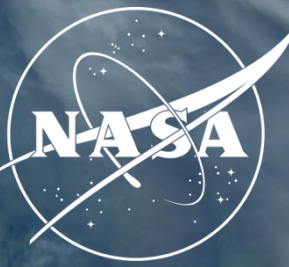
green algae



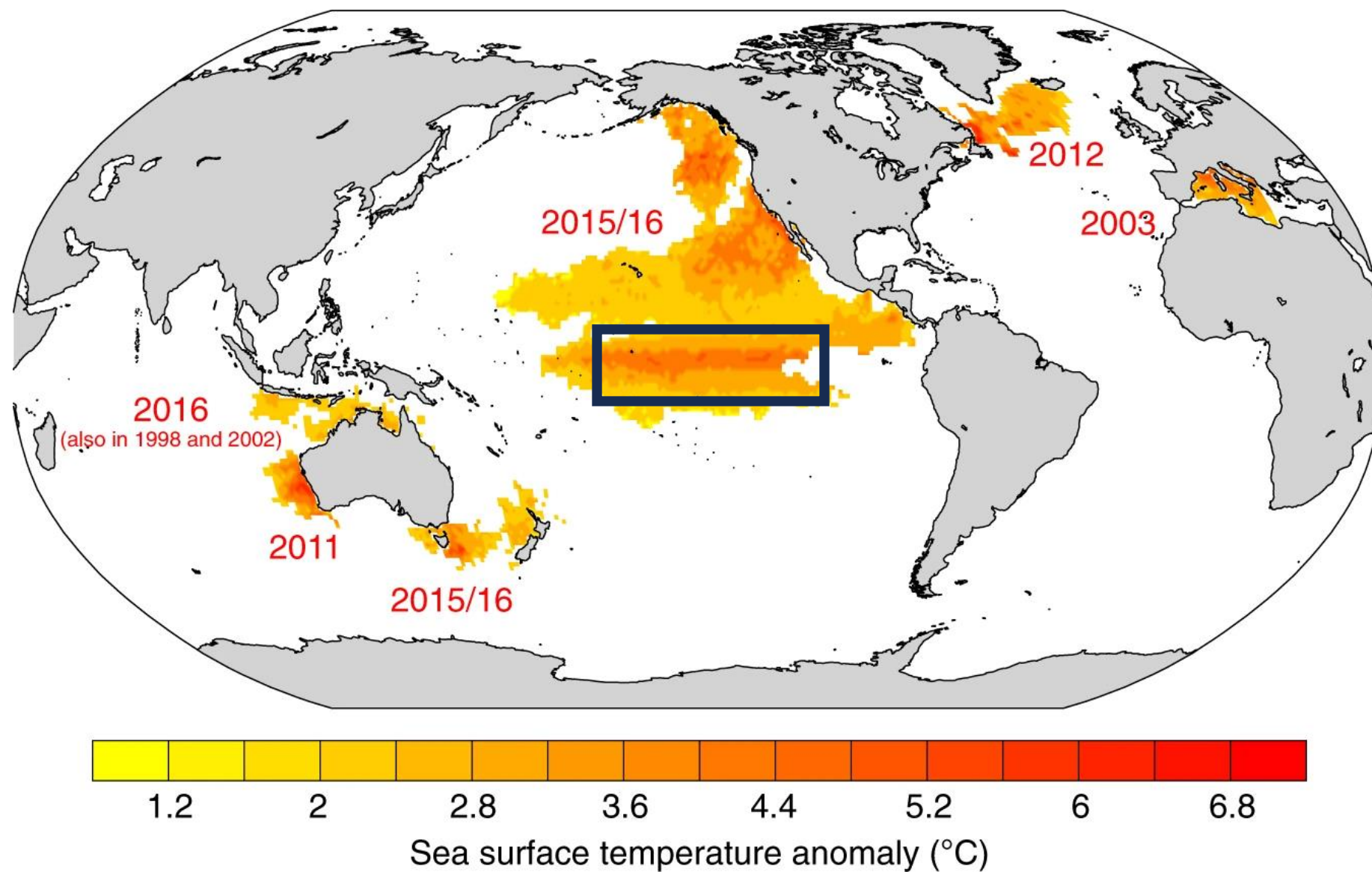
coccolithophore



# Motivation: Marine heatwaves and ecosystems



## Global MHWs



*Frölicher and Laufkötter (2018)*

## Ecosystem impacts

### Losers



**Subarctic copepods, krill**  
Lack of food reduced population,  
distribution moved northward

**Market squid 2015–2016**  
Reduced in south as distribution  
moved far north



**Dungeness crab and mussels**  
Fishery closed due to toxicity

**Salmon**

Warm temperatures decreased  
recruitment for some species



**Groundfish**

Potential loss of habitat due to hypoxia



**Seabirds, seals, and sea lions**  
Massive die-offs due to lack of food



**Baleen whales**

Expected to decline due to lack of food

### Winners



**Toxic phytoplankton**  
Massive bloom closed important fisheries

**Tropical, subtropical copepods**

Northward range expansion with warm water



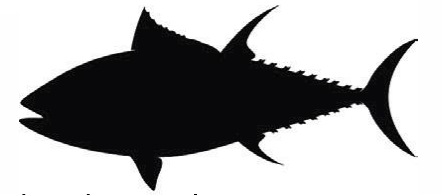
**Market squid 2014–2015**

Increased fishery in north caused by range expansion



**Rockfish**

Increased recruitment in California



**Tuna**

Increased abundances along coast  
with increased sport fishing

**Orcas**

Increased birth rate caused by increased  
salmon abundances in some regions  
through population movements



# Backup: Validation

