PICES-2018 Annual Meeting

Data assimilation of physical and chlorophyll observations in the California Current System using two biogeochemical models

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Chris A. Edwards[1], Andy Moore[1]
and Jerome Fiechter[1]

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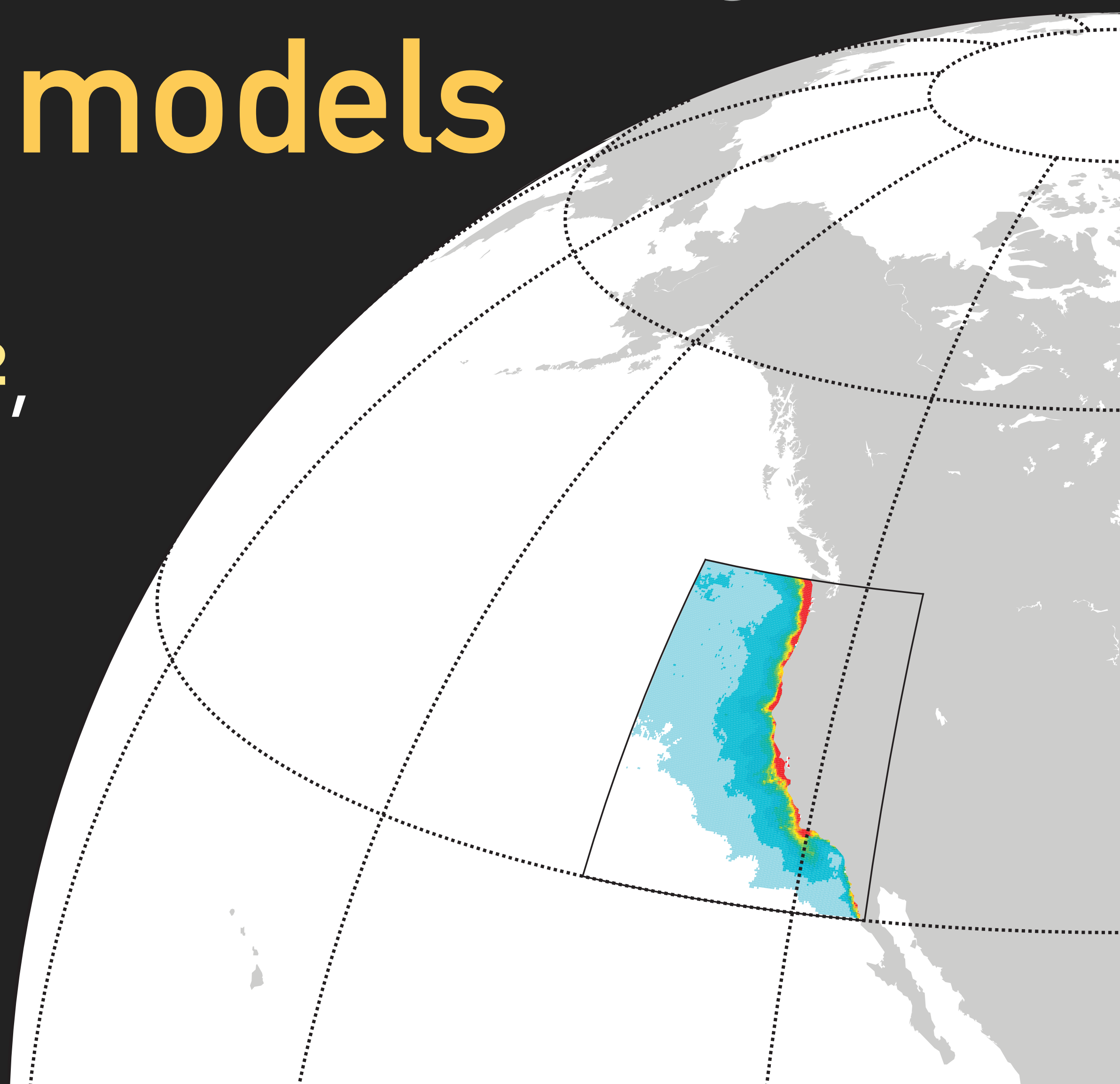

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Data assimilation of physical and chlorophyll *a* observations in the California Current System using two biogeochemical models

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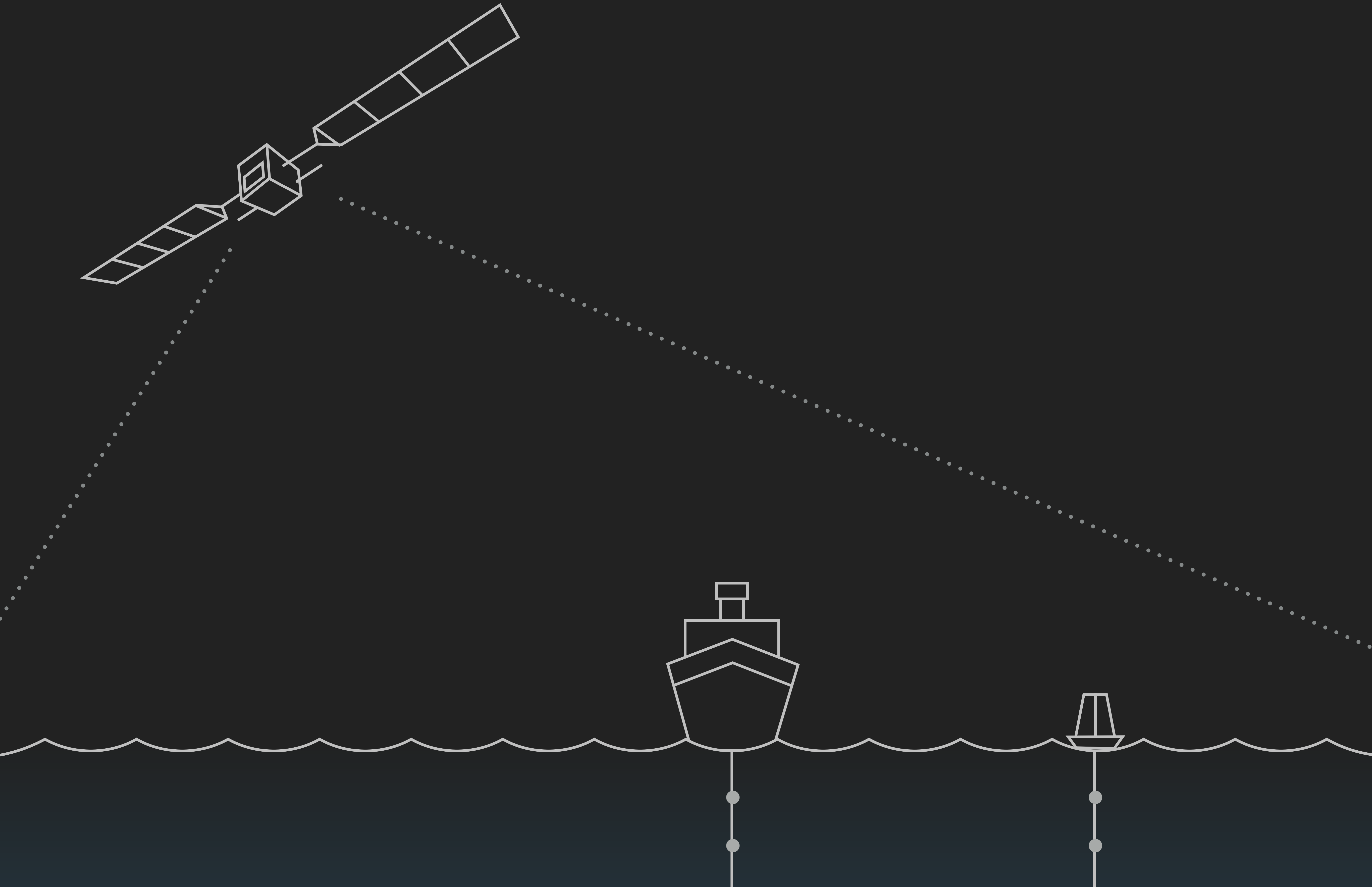
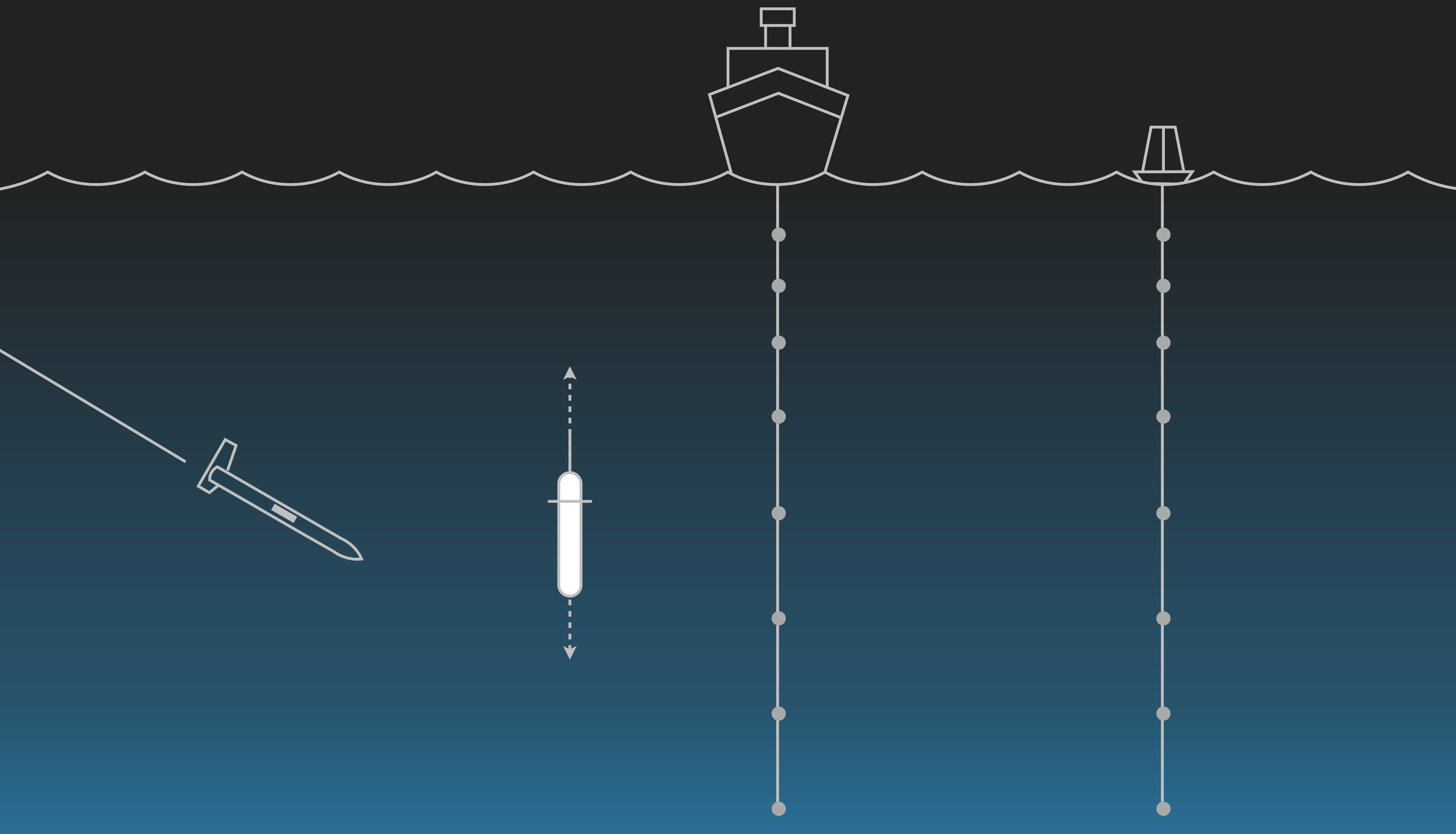
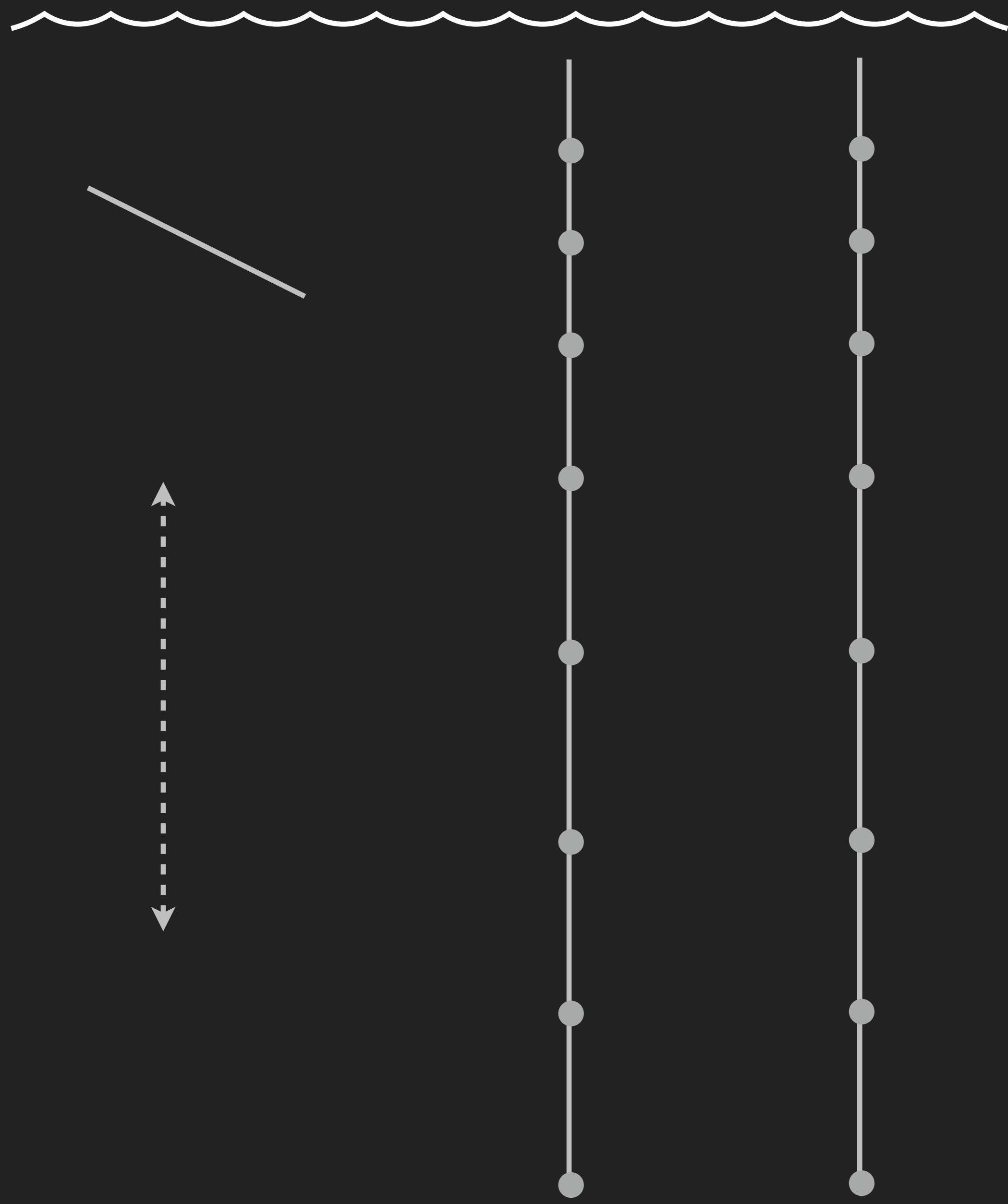
DATA ASSIMILATION: OBSERVATIONS



DATA ASSIMILATION: OBSERVATIONS



DATA ASSIMILATION: COMBINING THE OBSERVATIONS AND THE MODEL



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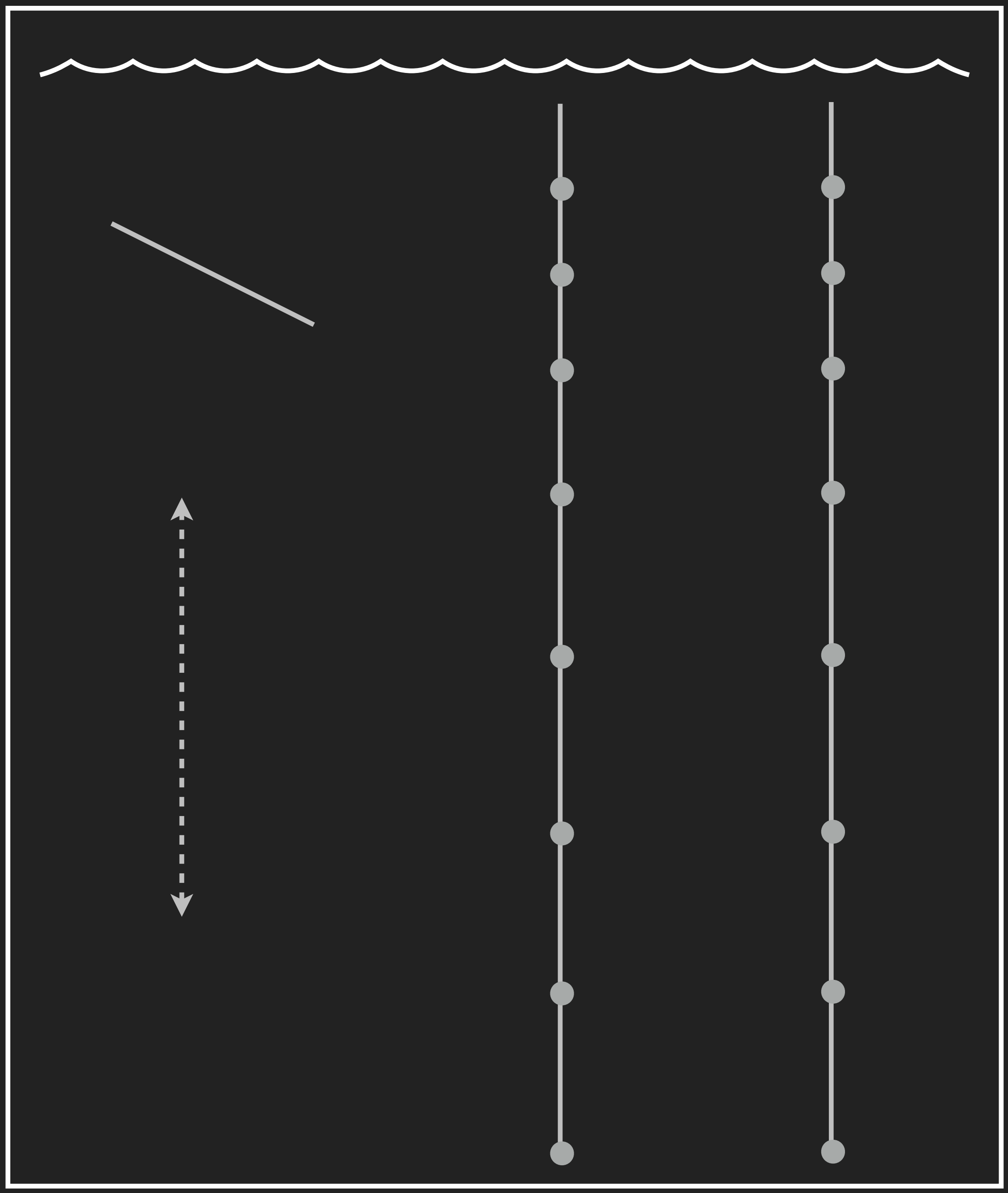
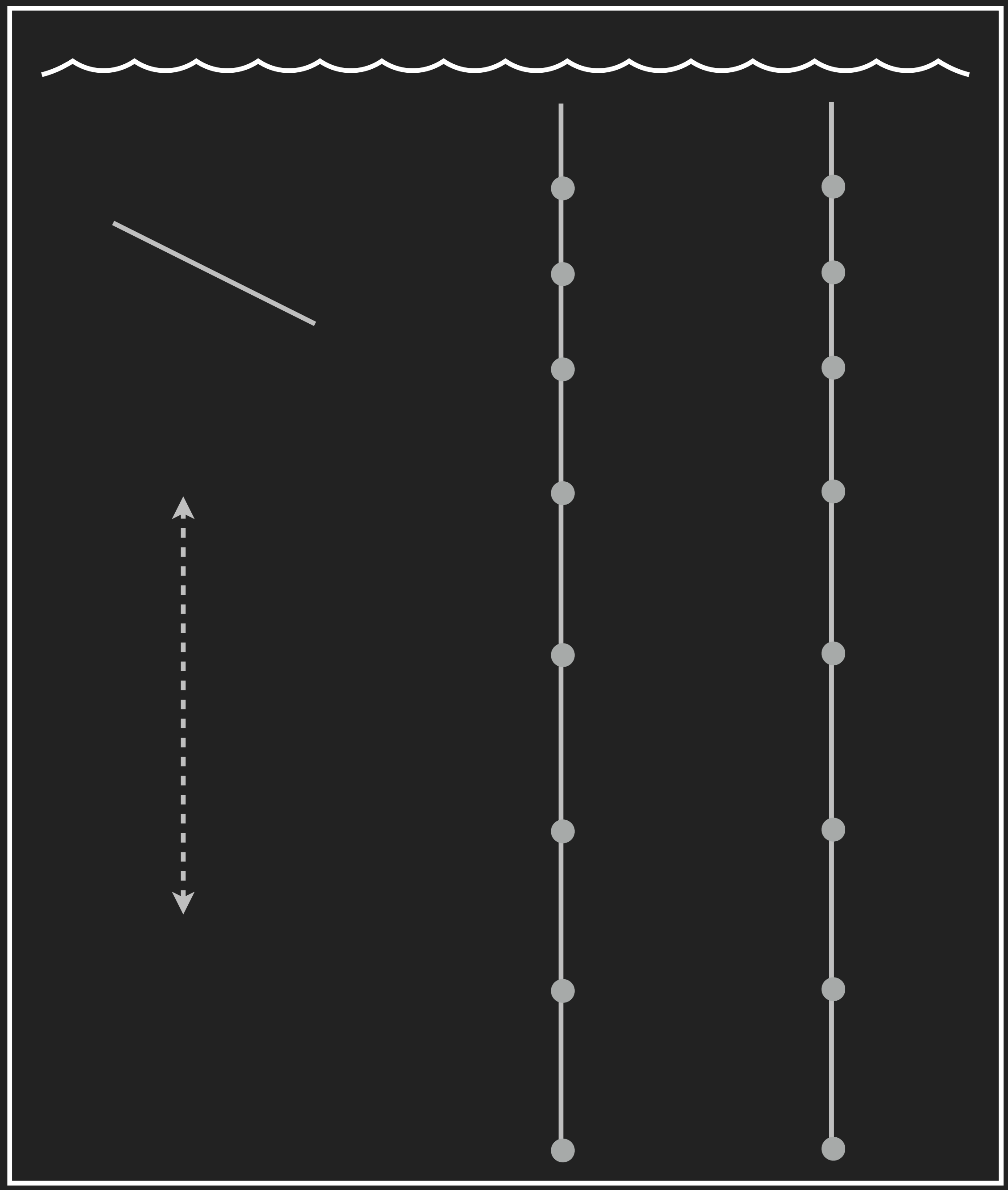


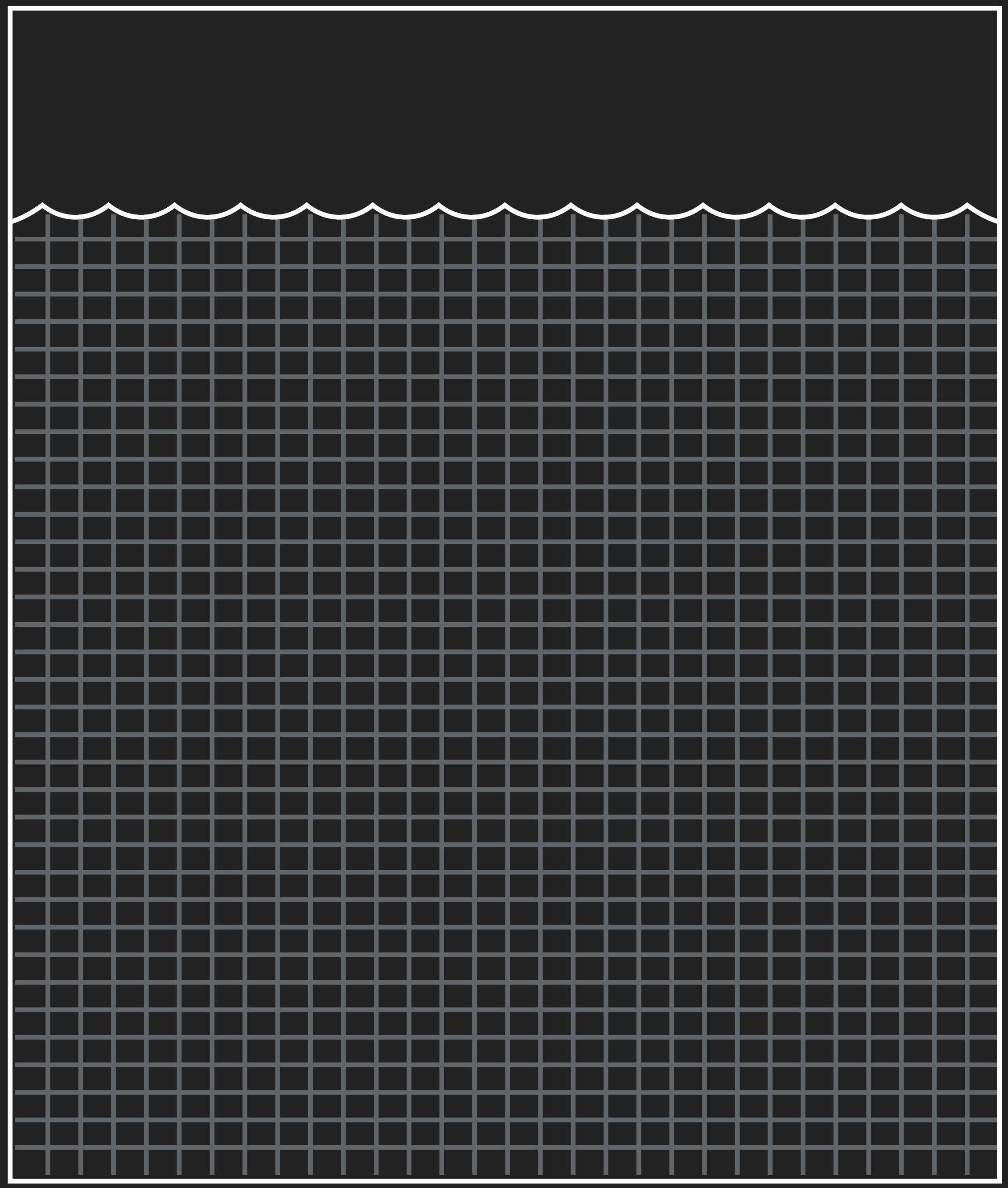
Observations

DATA ASSIMILATION: COMBINING THE OBSERVATIONS AND THE MODEL



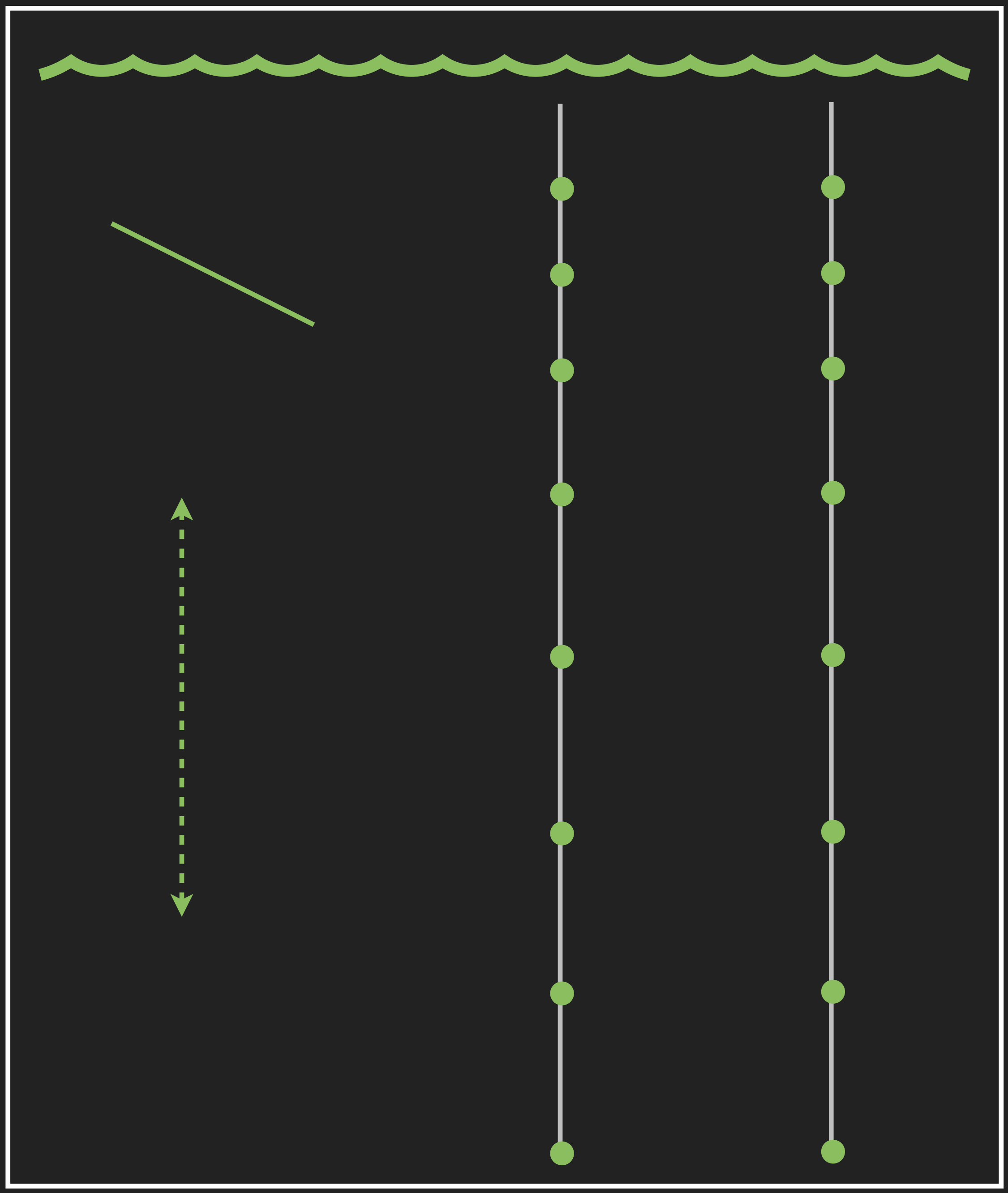
Observations

+



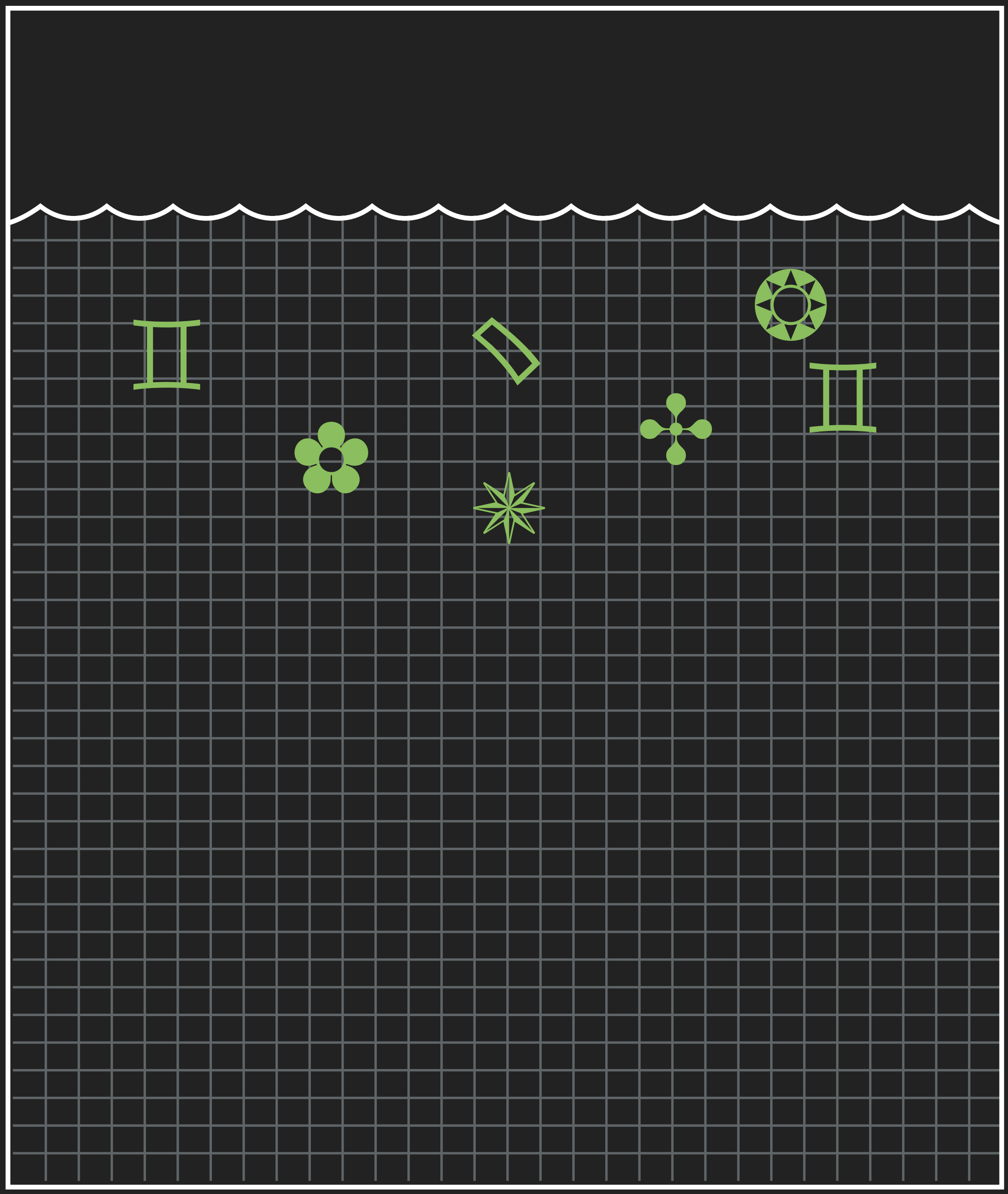
Numerical model

DATA ASSIMILATION: PHYSICAL AND BIOGEOCHEMICAL COUPLED MODEL



Observations

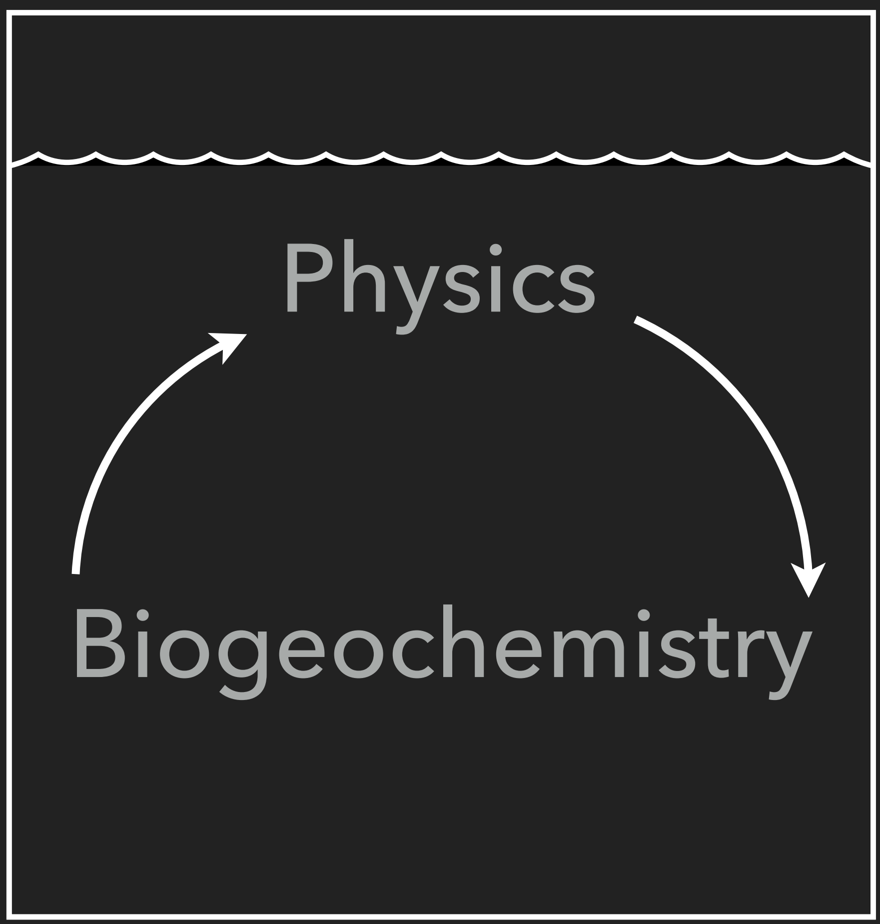
+

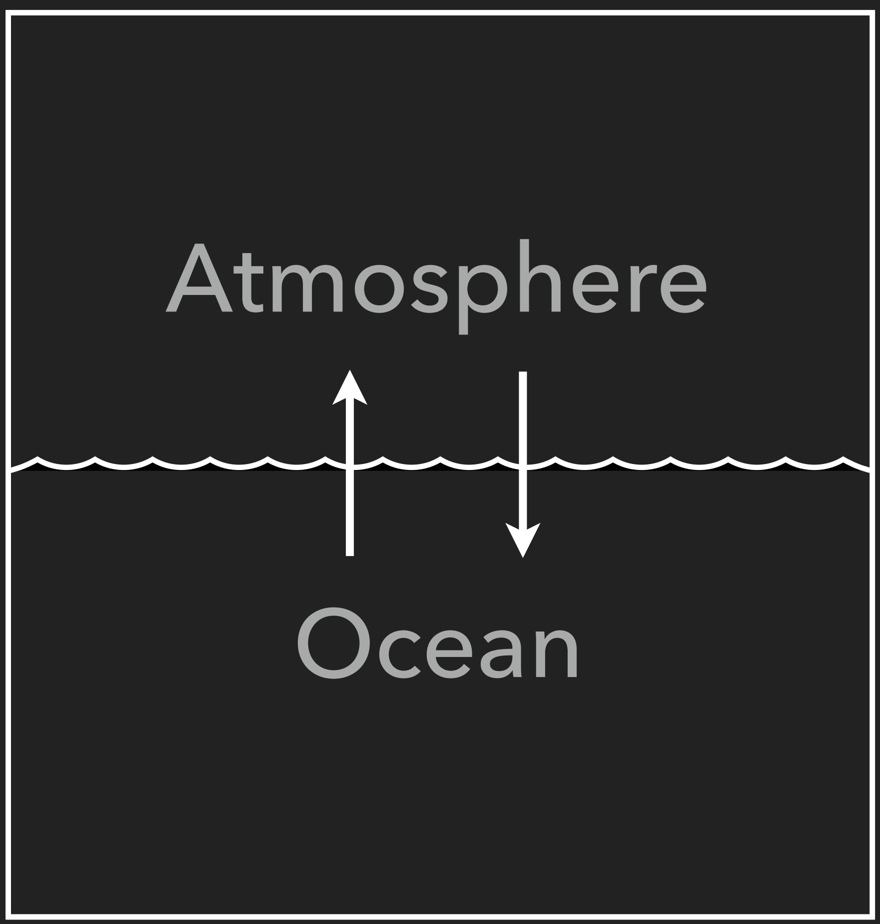


Numerical model

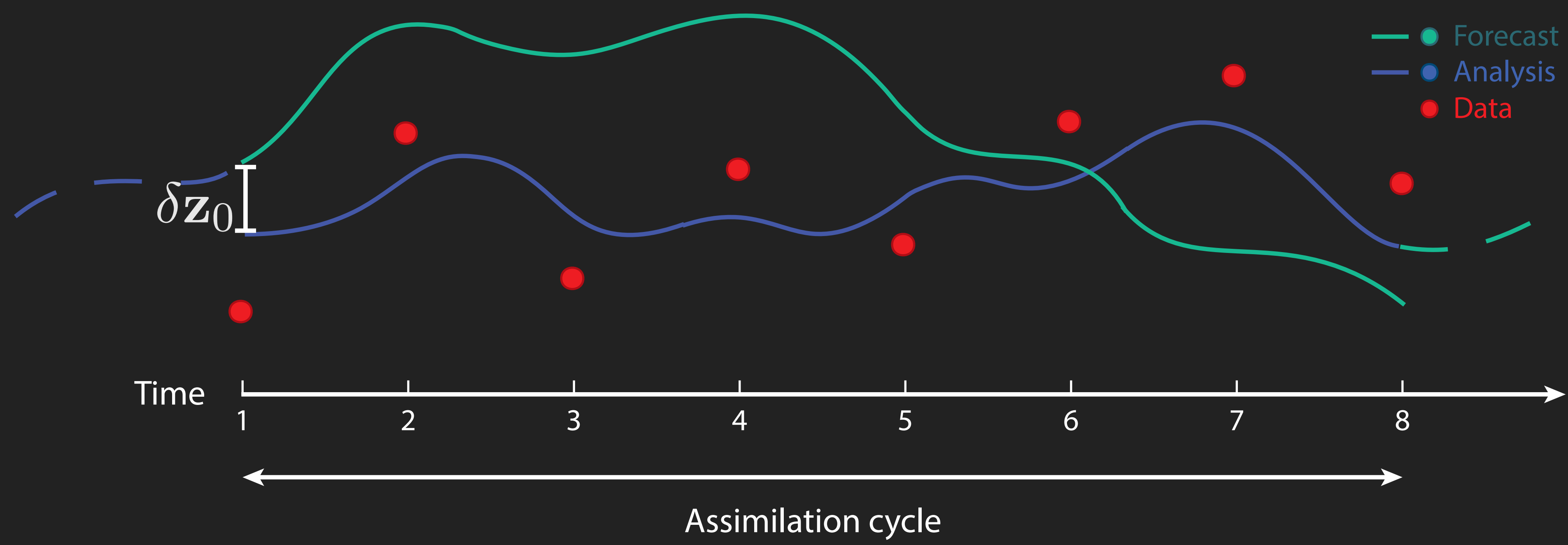
WHY COUPLED PHYSICAL-BIOGEOCHEMICAL DATA ASSIMILATION?

- Many applications : Fishery management …
- Remove errors from the physical data assimilation
- A good testbed for the coupled data assimilation





Data assimilation : incremental 4-D variational method



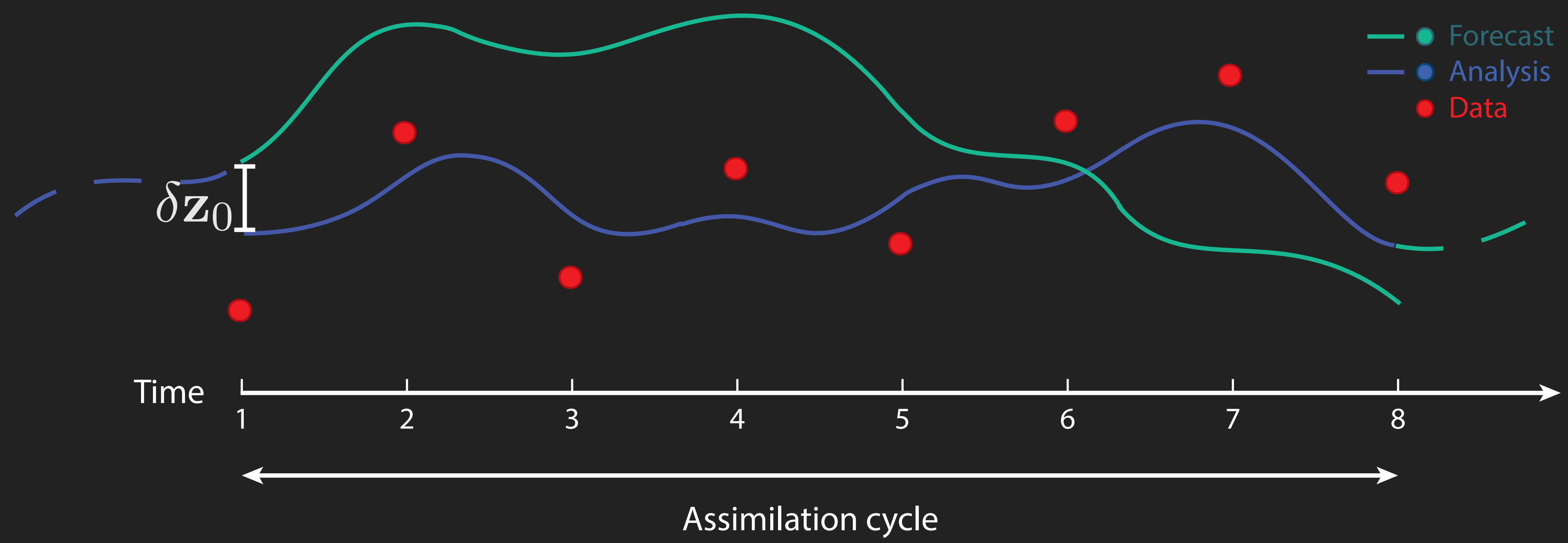
Edwards et al., 2015

$$J(\delta \mathbf{z}_0) \quad = \quad \frac{1}{2}\delta \mathbf{z}_0^T \mathbf{B}^{-1}\delta \mathbf{z}_0 + \frac{1}{2}\sum_{i=1}^{N_o}(\mathbf{d}_i - \quad \mathbf{H}_i \mathbf{M}_{i,0} \quad \delta \mathbf{z}_0)^T \mathbf{R}_i^{-1}(\mathbf{d}_i - \quad \mathbf{H}_i \mathbf{M}_{i,0} \quad \delta \mathbf{z}_0)$$

Courtier et al., 1994

$$\delta \mathbf{z}_0 = \mathbf{z}_{0,a} - \mathbf{z}_{0,b}$$

Data assimilation : incremental 4-D variational method



Edwards et al., 2015

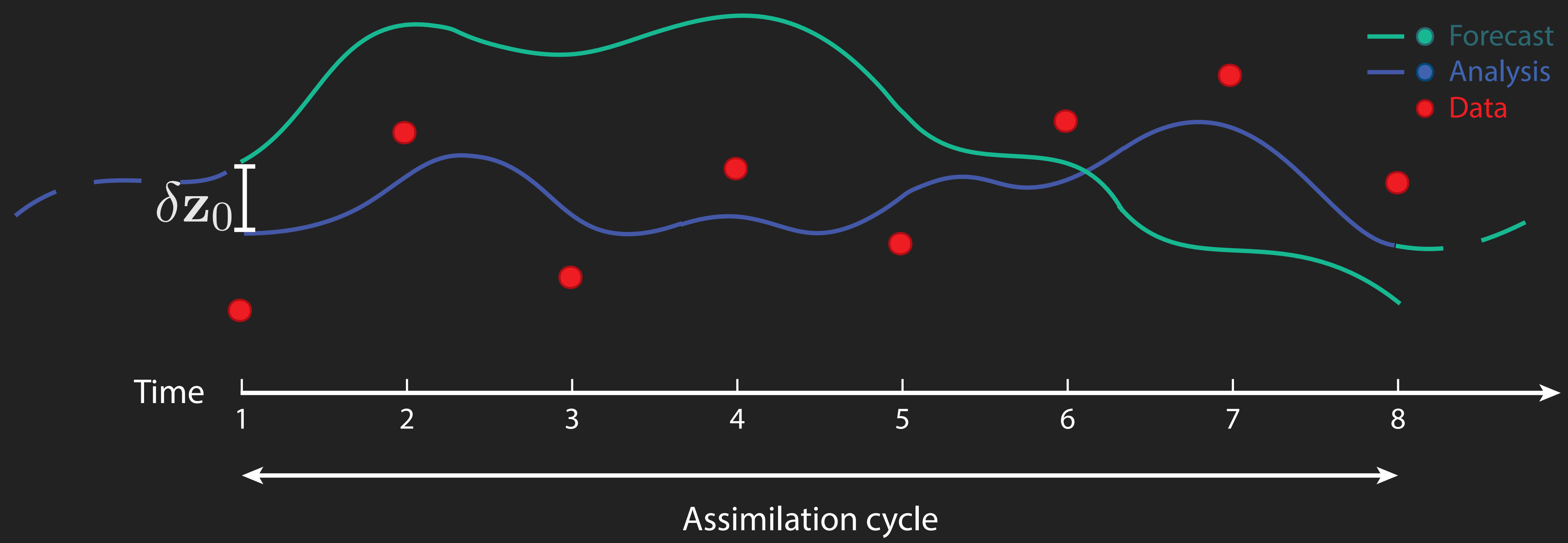
$$J(\delta\mathbf{z}_0) = \frac{1}{2}\delta\mathbf{z}_0^T\mathbf{B}^{-1}\delta\mathbf{z}_0 + \frac{1}{2}\sum_{i=1}^{N_o}(\mathbf{d}_i - \mathbf{H}_i\mathbf{M}_{i,0}\;\delta\mathbf{z}_0)^T\mathbf{R}_i^{-1}(\mathbf{d}_i - \mathbf{H}_i\mathbf{M}_{i,0}\;\delta\mathbf{z}_0)$$

Courtier et al., 1994

$$\delta\mathbf{z}_0 = \mathbf{B}\;\mathbf{M}^T\mathbf{H}^T\;(\;\mathbf{H}\mathbf{M}\;\mathbf{B}\;\mathbf{M}^T\mathbf{H}^T + \mathbf{R}^{-1})^{-1}\mathbf{d}$$

minimizes J

Data assimilation : incremental 4-D variational method



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Courtier et al., 1994

$$\delta \mathbf{z}_0 = \mathbf{B} \; \mathbf{M}^T \underbrace{\mathbf{H}^T (\mathbf{H}\mathbf{M} \; \mathbf{B} \; \mathbf{M}^T \mathbf{H}^T + \mathbf{R}^{-1})^{-1} \mathbf{d}}_{\hat{\mathbf{d}}}$$

$$\delta \mathbf{z}_0 = \mathbf{B}\mathbf{M}^T \hat{\mathbf{d}}$$

COUPLED DATA ASSIMILATION IN EQUATIONS

$$\delta \mathbf{z}_0 = \hat{\mathbf{B}}\mathbf{M}^T\hat{\mathbf{d}}$$

COUPLED DATA ASSIMILATION IN EQUATIONS

$$\delta \mathbf{z}_0 = \hat{\mathbf{B}}\mathbf{M}^T\hat{\mathbf{d}}$$

$$\mathbf{M} = \begin{bmatrix} \mathbf{M}_{phy} & \mathbf{M}_{b,p} \\ \mathbf{M}_{p,b} & \mathbf{M}_{bio} \end{bmatrix}$$

COUPLED DATA ASSIMILATION IN EQUATIONS

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$$\mathbf{M} = \begin{bmatrix} \mathbf{M}_{phy} & \mathbf{M}_{b,p} \\ \mathbf{M}_{p,b} & \mathbf{M}_{bio} \end{bmatrix}$$

Coupled data assimilation

$$\begin{bmatrix} \delta \mathbf{x}_{phy} \\ \delta \mathbf{x}_{bio} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{B}}_{phy} & 0 \\ 0 & \hat{\mathbf{B}}_{bio} \end{bmatrix} \begin{bmatrix} \mathbf{M}^T_{phy} & \mathbf{M}^T_{p,b} \\ \mathbf{M}^T_{b,p} & \mathbf{M}^T_{bio} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{d}}_{phy} \\ \hat{\mathbf{d}}_{bio} \end{bmatrix}$$

COUPLED DATA ASSIMILATION IN EQUATIONS

$$\delta \mathbf{z}_0 = \hat{\mathbf{B}}\mathbf{M}^T\hat{\mathbf{d}}$$

No feedback from BGC to physics

$$\mathbf{M} = \begin{bmatrix} \mathbf{M}_{phy} & \mathbf{0} \\ \mathbf{M}_{p,b} & \mathbf{M}_{bio} \end{bmatrix}$$

Coupled data assimilation

$$\begin{bmatrix} \delta \mathbf{x}_{phy} \\ \delta \ln \mathbf{x}_{bio} \end{bmatrix}_0 = \begin{bmatrix} \hat{\mathbf{B}}_{phy} & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{B}}_{\ln bio} \end{bmatrix} \begin{bmatrix} \mathbf{M}^T_{phy} & \mathbf{M}^T_{p,b} \\ \mathbf{0} & \mathbf{M}^T_{bio} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{d}}_{phy} \\ \hat{\mathbf{d}}_{bio} \end{bmatrix}$$

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$$\begin{bmatrix} \delta \mathbf{x}_{phy} \\ \delta \ln \mathbf{x}_{bio} \end{bmatrix}_0 = \begin{bmatrix} \hat{\mathbf{B}}_{phy} & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{B}}_{\ln bio} \end{bmatrix} \begin{bmatrix} \mathbf{M}^T_{phy} & \mathbf{M}^T_{p,b} \\ \mathbf{0} & \mathbf{M}^T_{bio} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{d}}_{phy} \\ \hat{\mathbf{d}}_{bio} \end{bmatrix}$$

$$= \begin{bmatrix} \hat{\mathbf{B}}_{phy}\mathbf{M}^T_{phy}\hat{\mathbf{d}}_{phy} + \hat{\mathbf{B}}_{phy}\mathbf{M}^T_{p,b}\hat{\mathbf{d}}_{bio} \\ \hat{\mathbf{B}}_{\ln bio}\mathbf{M}^T_{bio}\hat{\mathbf{d}}_{bio} \end{bmatrix}$$

COUPLED DATA ASSIMILATION IN EQUATIONS

$$\delta \mathbf{z}_0 = \hat{\mathbf{B}}\mathbf{M}^T\hat{\mathbf{d}}$$

No feedback from BGC to physics

$$\mathbf{M} = \begin{bmatrix} \mathbf{M}_{phy} & \mathbf{0} \\ \mathbf{M}_{p,b} & \mathbf{M}_{bio} \end{bmatrix}$$

Coupled data assimilation

$$\begin{bmatrix} \delta \mathbf{x}_{phy} \\ \delta \ln \mathbf{x}_{bio} \end{bmatrix}_0 = \begin{bmatrix} \hat{\mathbf{B}}_{phy} & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{B}}_{\ln bio} \end{bmatrix} \begin{bmatrix} \mathbf{M}_{phy}^T & \mathbf{M}_{p,b}^T \\ \mathbf{0} & \mathbf{M}_{bio}^T \end{bmatrix} \begin{bmatrix} \hat{\mathbf{d}}_{phy} \\ \hat{\mathbf{d}}_{bio} \end{bmatrix}$$

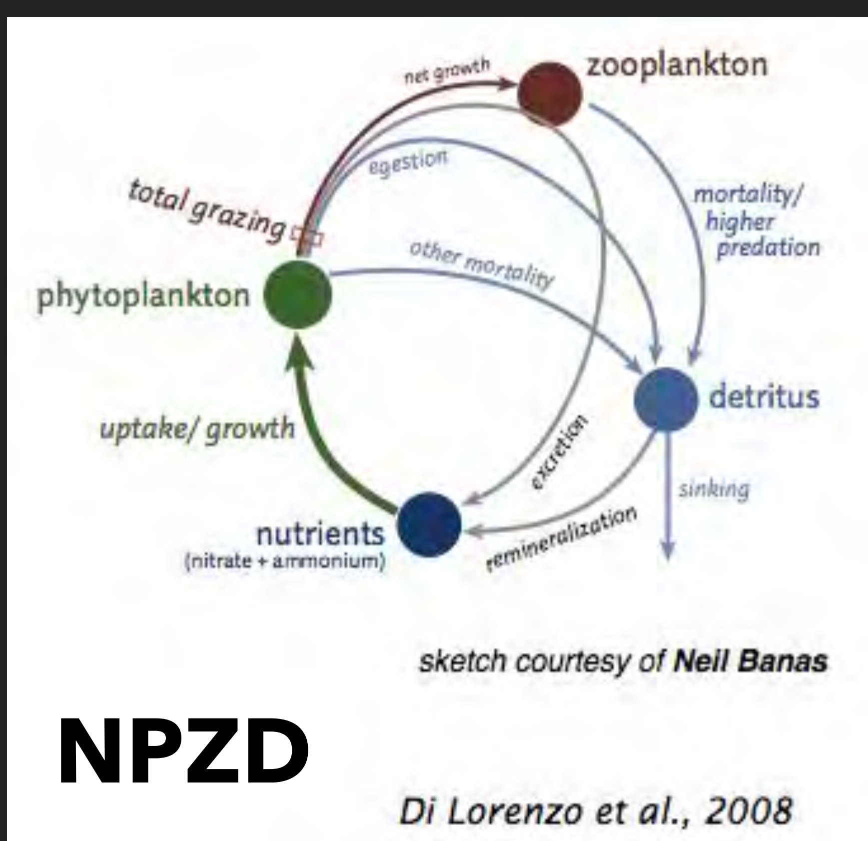
$$= \begin{bmatrix} \hat{\mathbf{B}}_{phy}\mathbf{M}_{phy}^T\hat{\mathbf{d}}_{phy} + \boxed{\hat{\mathbf{B}}_{phy}\mathbf{M}_{p,b}^T\hat{\mathbf{d}}_{bio}} \\ \hat{\mathbf{B}}_{\ln bio}\mathbf{M}_{bio}^T\hat{\mathbf{d}}_{bio} \end{bmatrix}$$

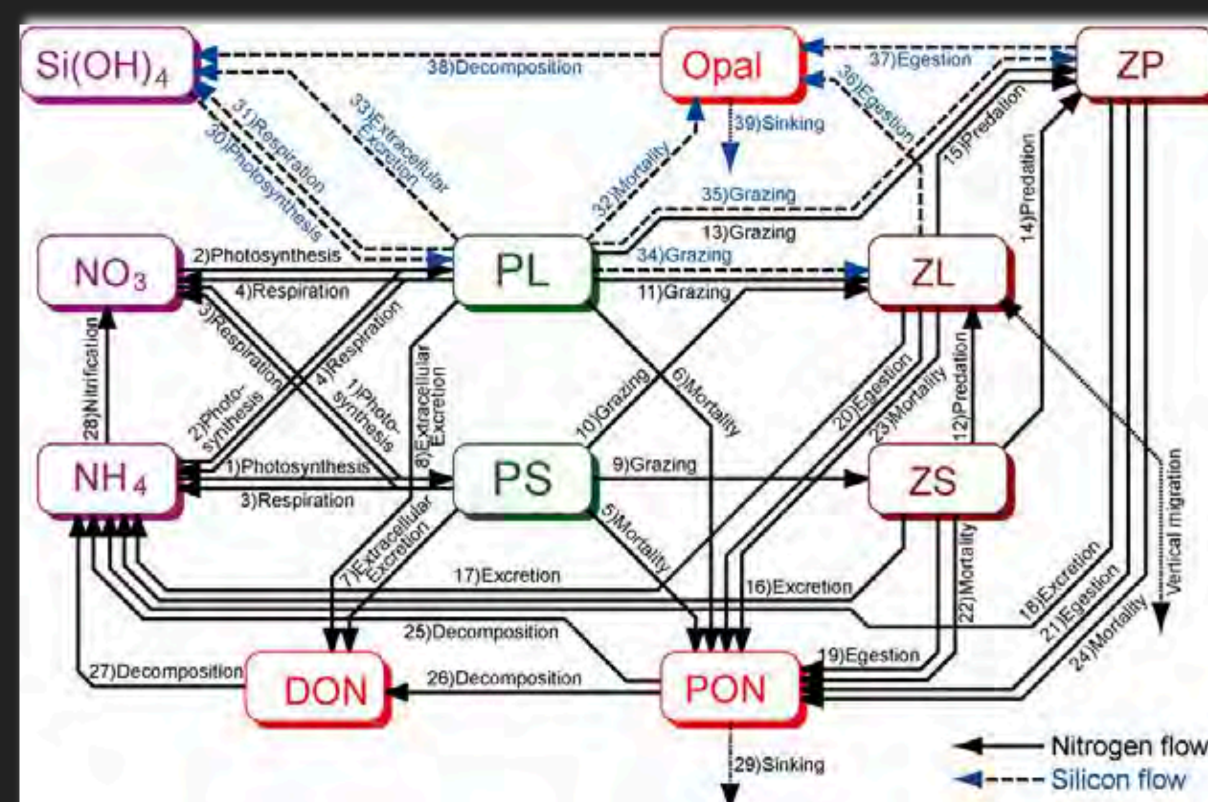
Chlorophyll observations can help improving ocean current estimation!!!

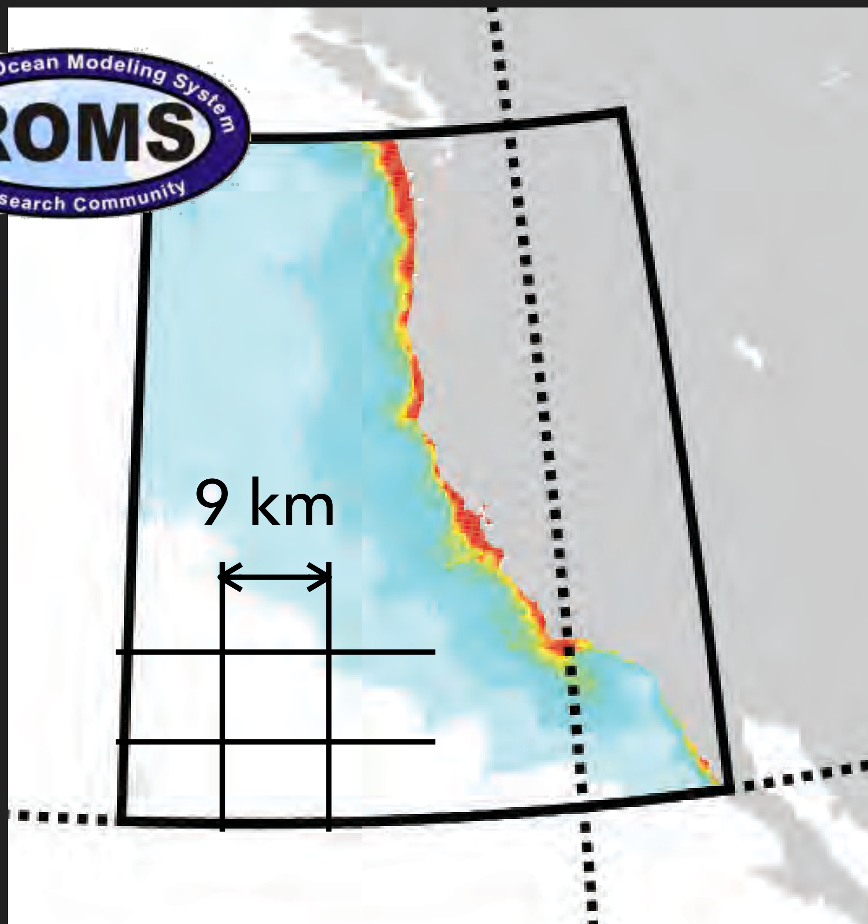
$$\delta \mathbf{z}_0 = \hat{\mathbf{B}}\mathbf{M}^T\hat{\mathbf{d}}$$

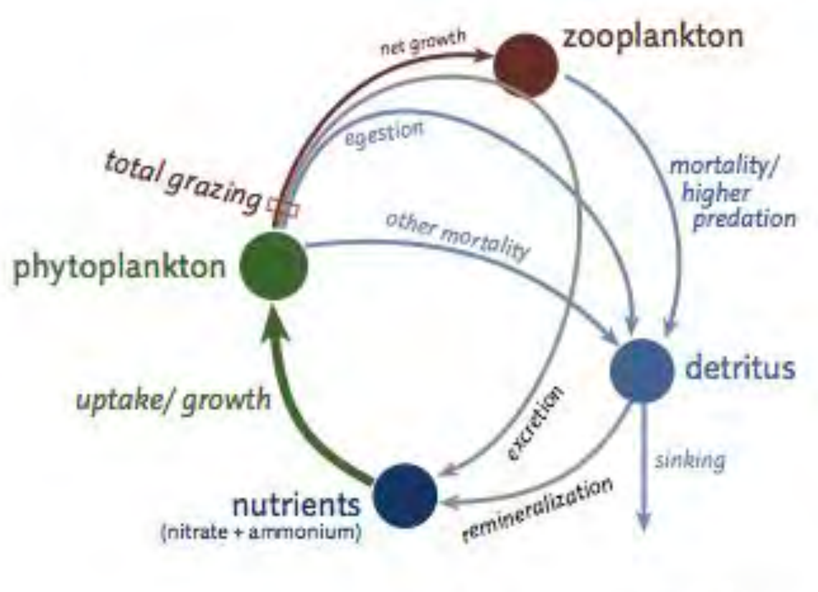
$$\mathbf{M} = \begin{bmatrix} \mathbf{M}_{phy} & \mathbf{0} \\ \mathbf{M}_{p,b} & \mathbf{M}_{bio} \end{bmatrix}$$

NEMURO









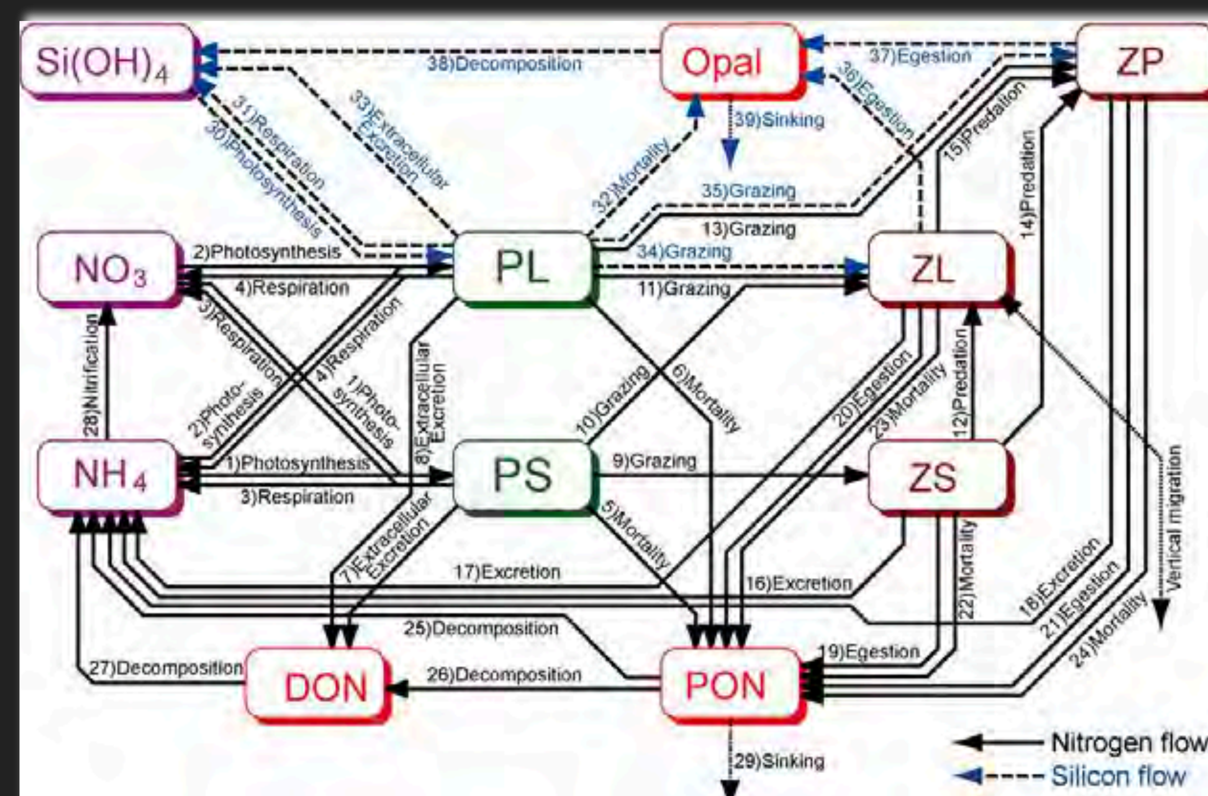
sketch courtesy of **Neil Banas**

NPZD

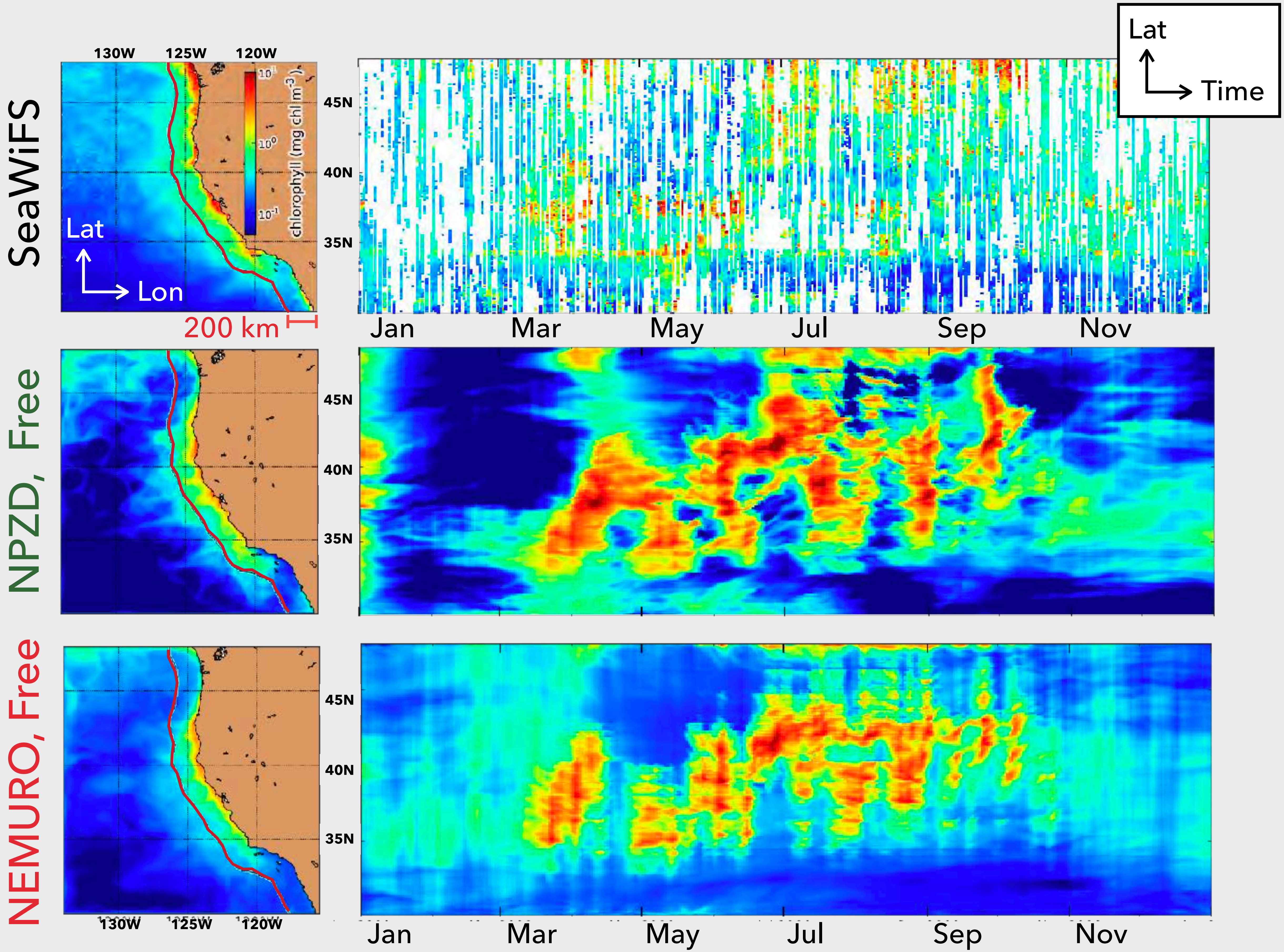
Di Lorenzo et al., 2008

- 1 year experiment.
- Updating model states @ every 4 days
- SSH, SST, in situ T/S and surface chlorophyll

NEMURO



RESULT: SURFACE CHLOROPHYLL BEFORE DATA ASSIMILATION



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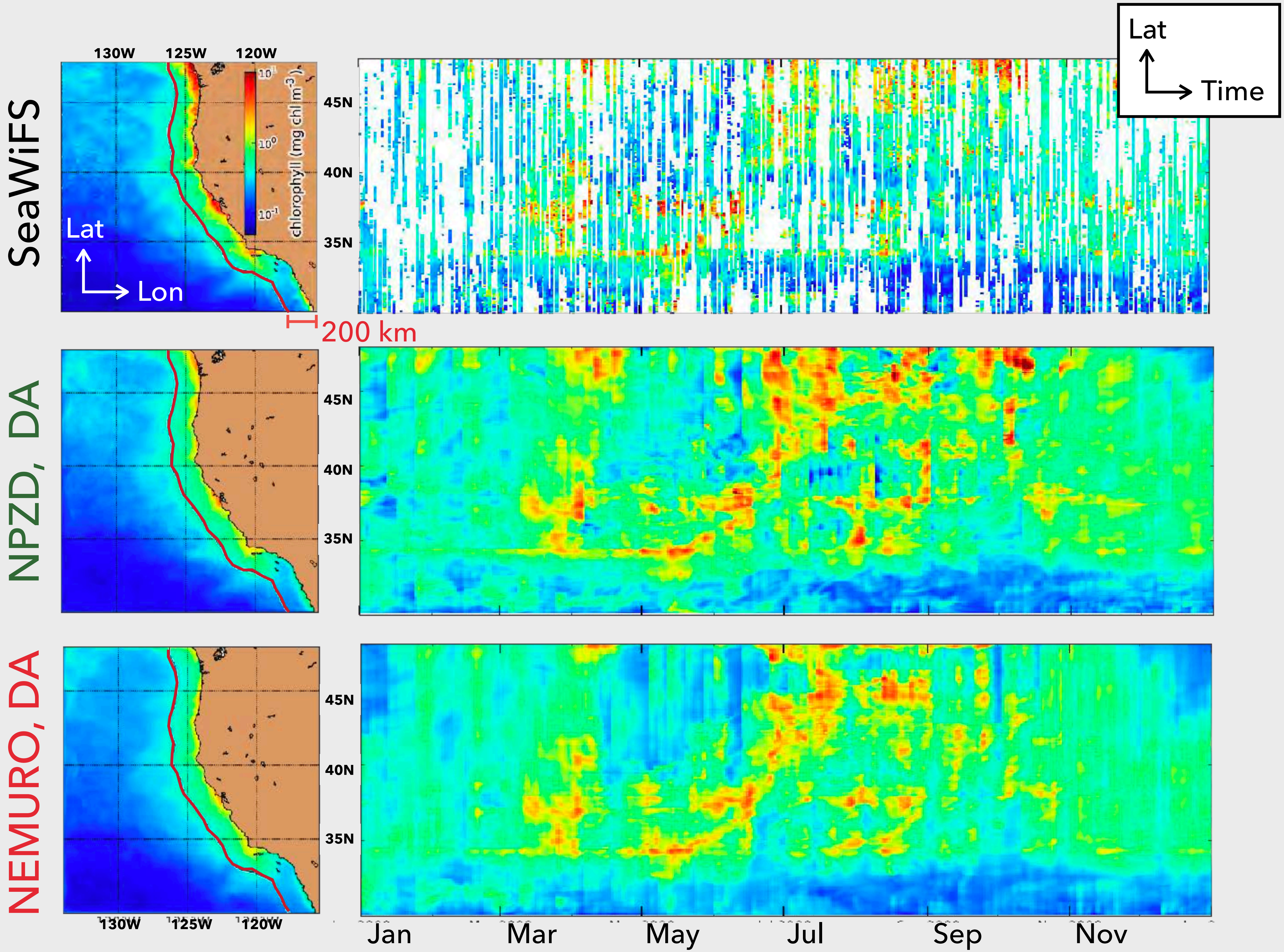
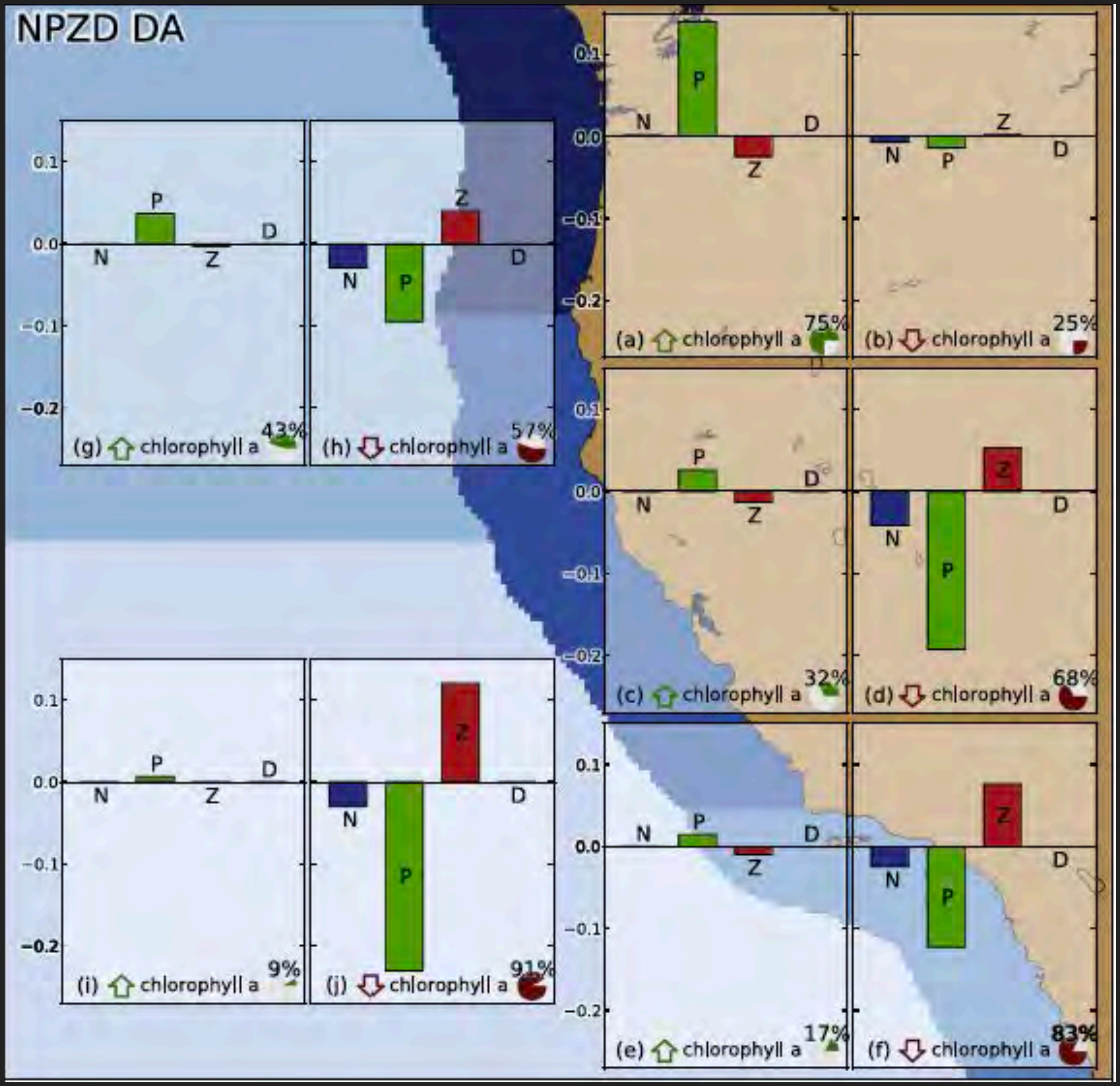


RESULT: HOW THE MODEL FITS THE DATA?: NPZD MODEL



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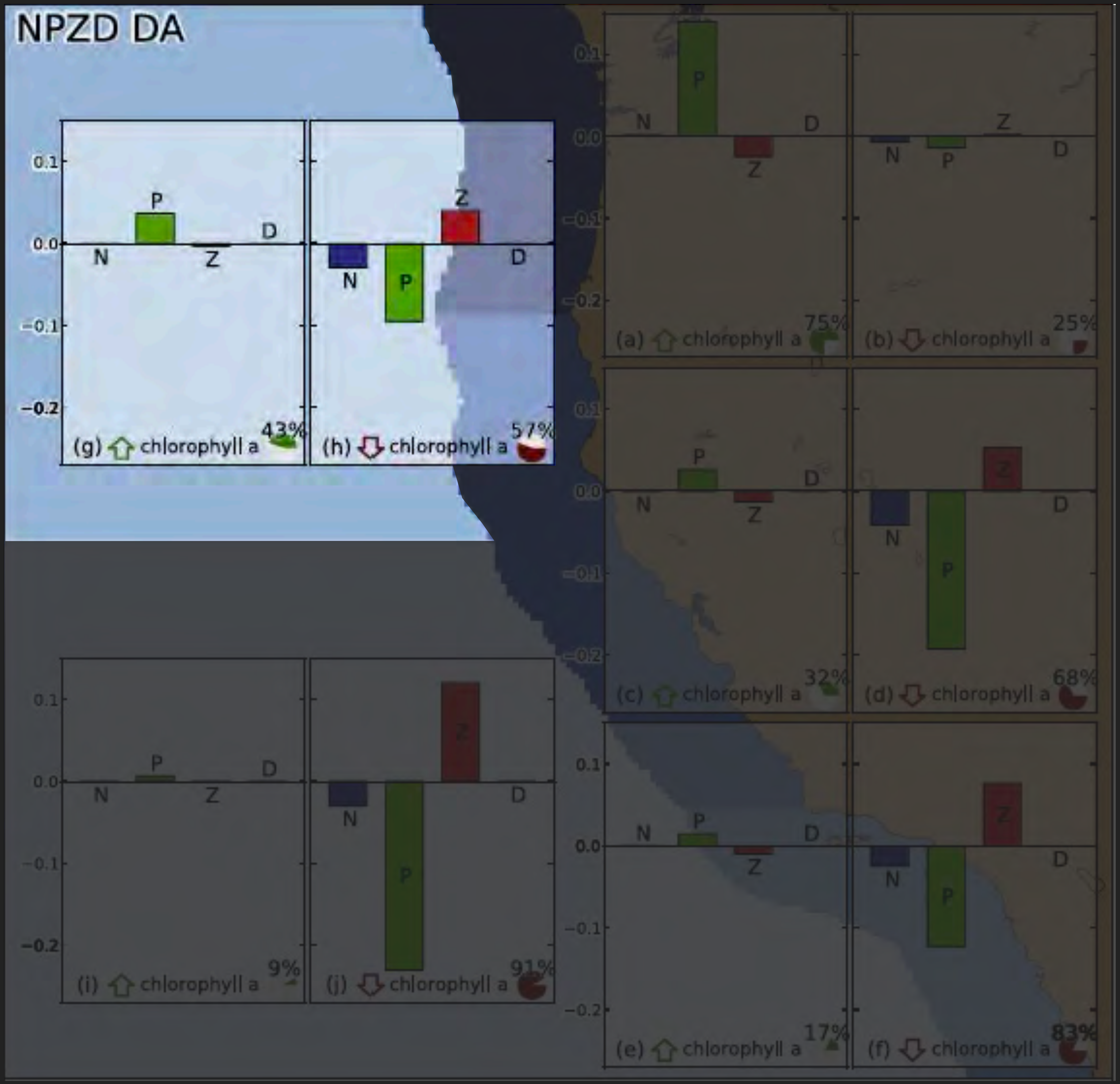

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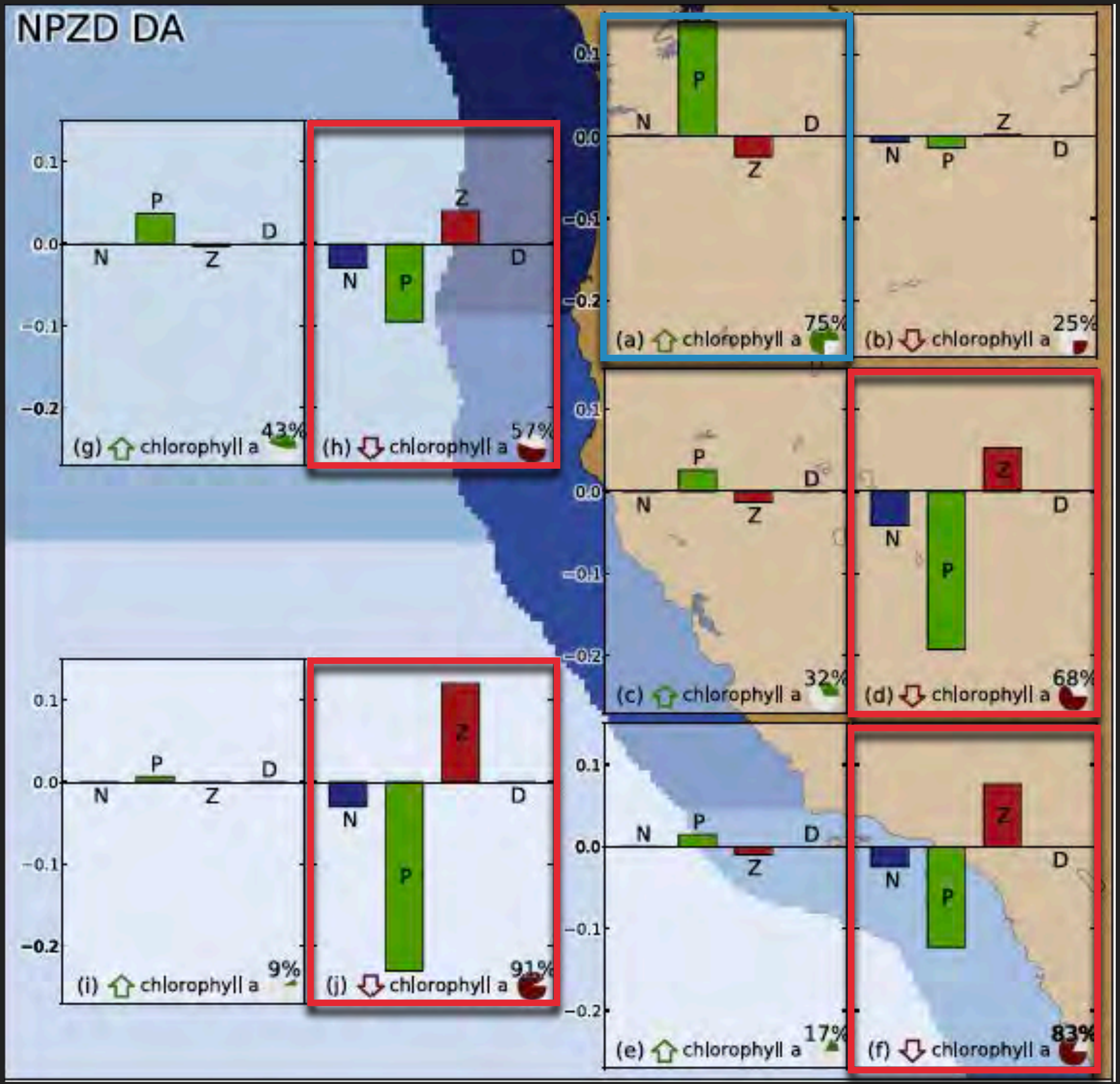
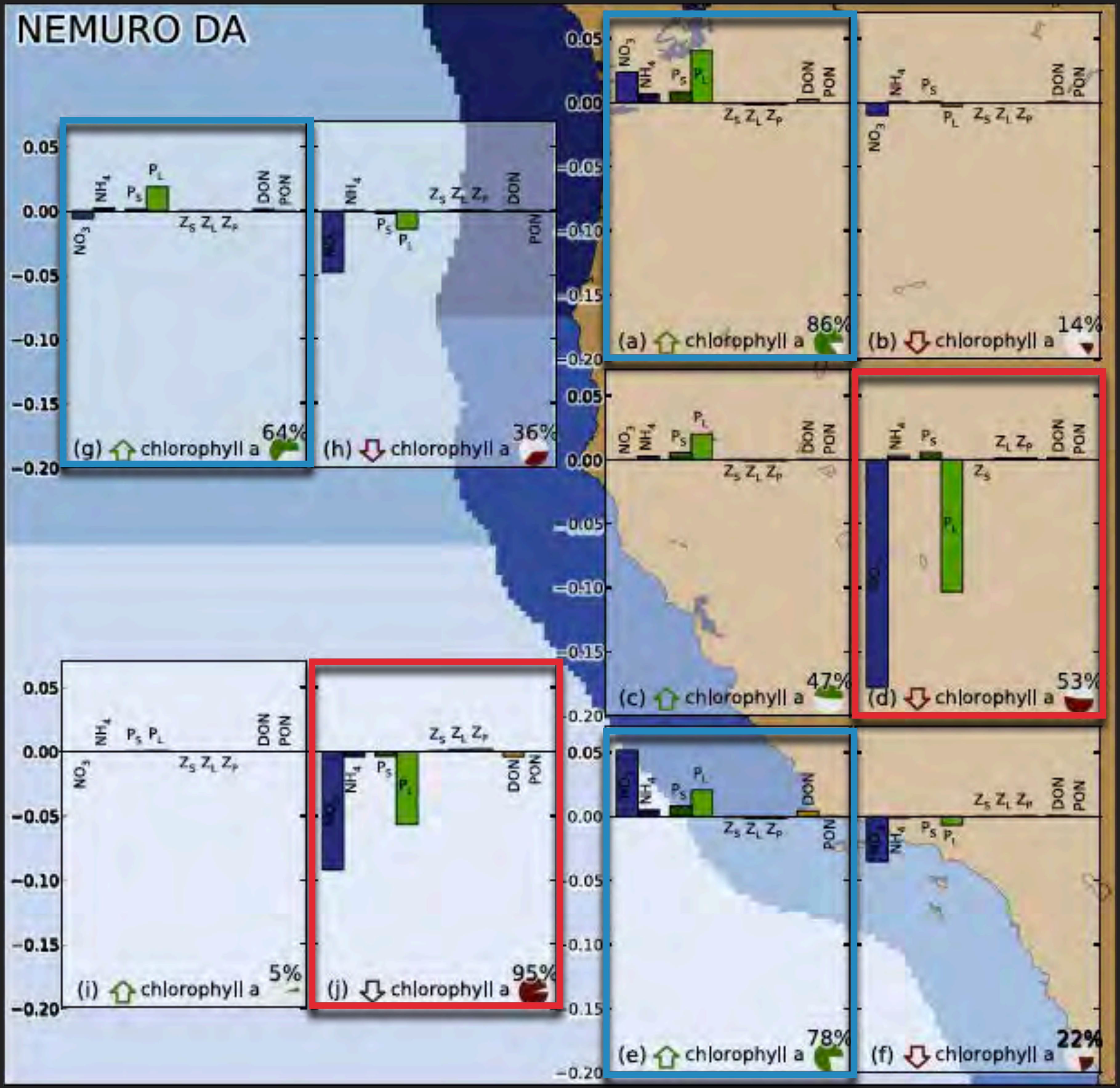
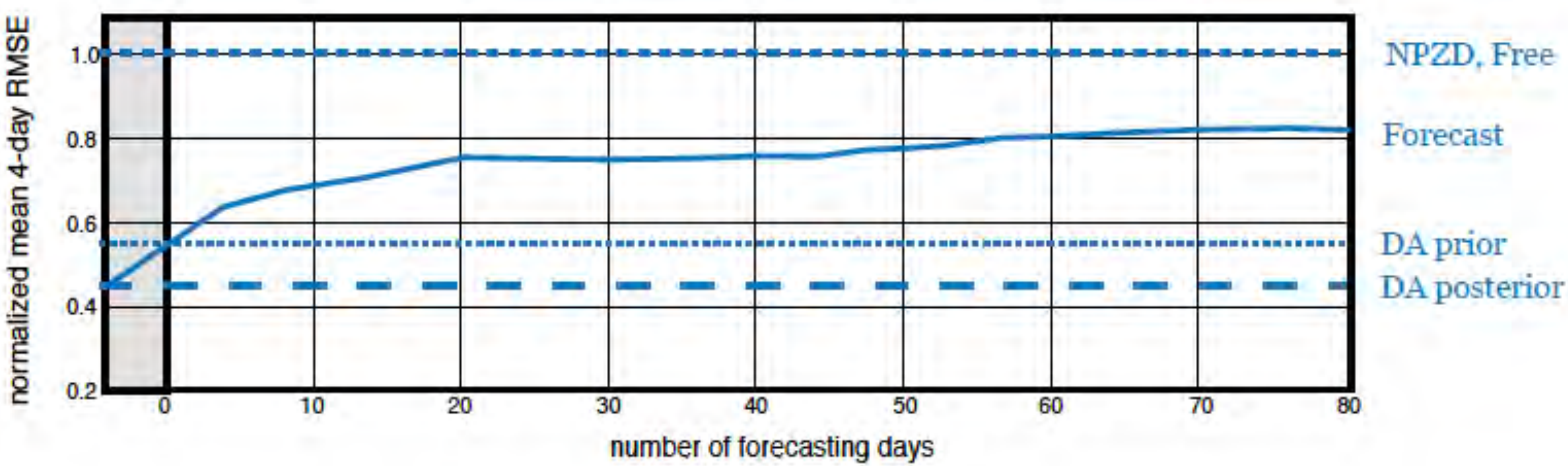
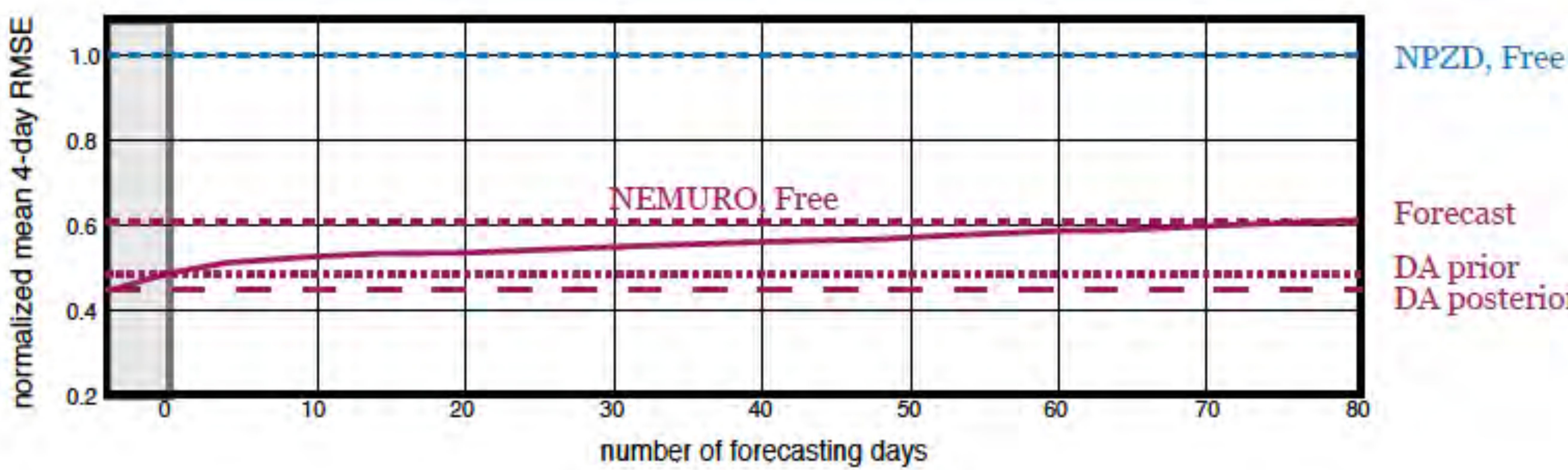


RESULT: HOW THE MODEL FITS THE DATA?: NEMURO MODEL



RESULT: FORECAST





SUMMARY

- Coupled physical-biogeochemical data assimilation
- Both NPZD and NEMURO fit the satellite chlorophyll data.
- The coupled DA system works! (but depends on **B** as always)

NPZD	NEMURO
Simpler	More complex
Adjusting P and Z	Adjusting N and P
Lower forecast skill	Higher forecast skill
Longer memory from abs	Shorter memory from abs