Assimilation of chlorophyll data into a stochastic ensemble simulation for the North Atlantic ocean

Insights from a 1-year experiment

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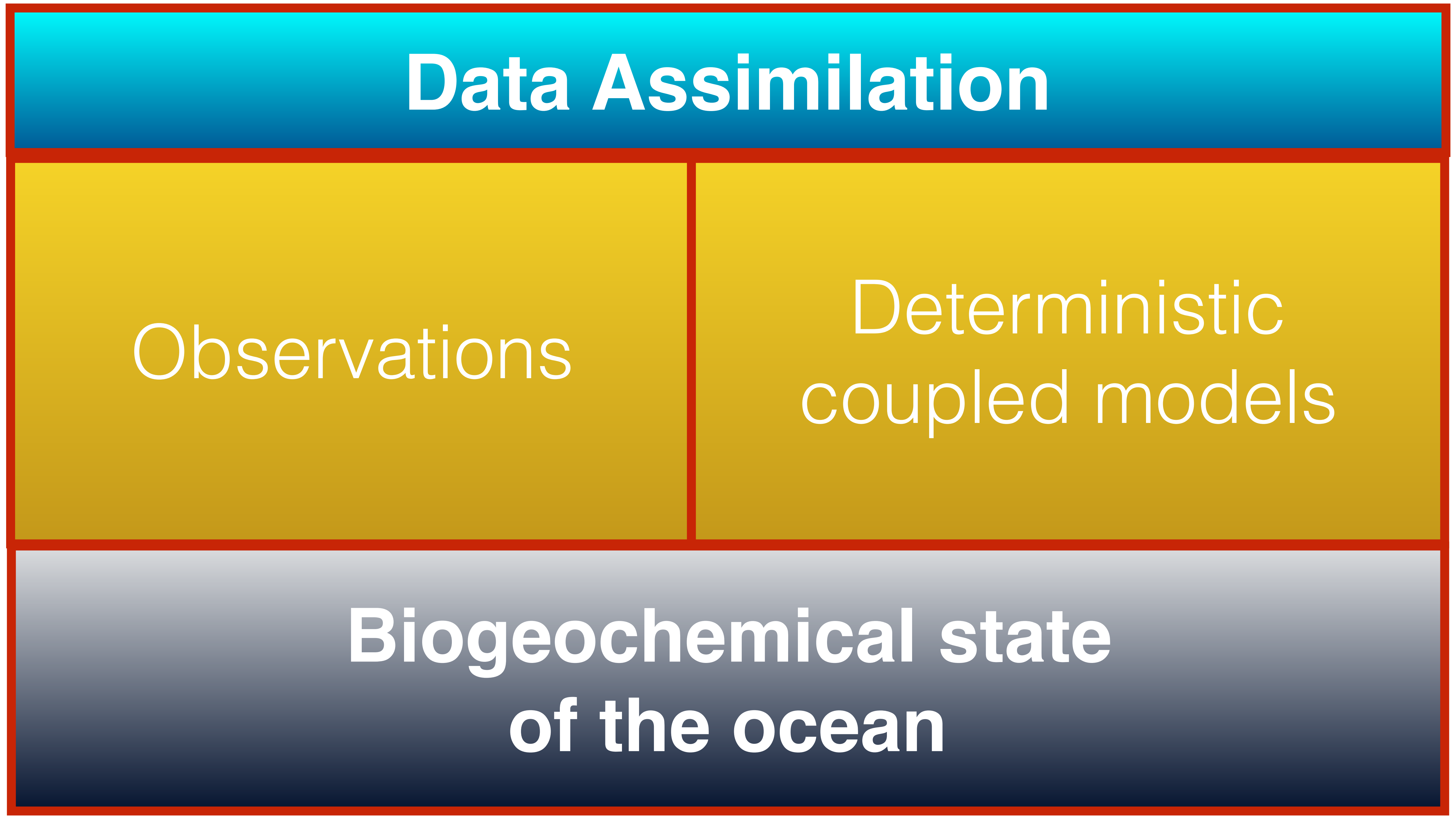
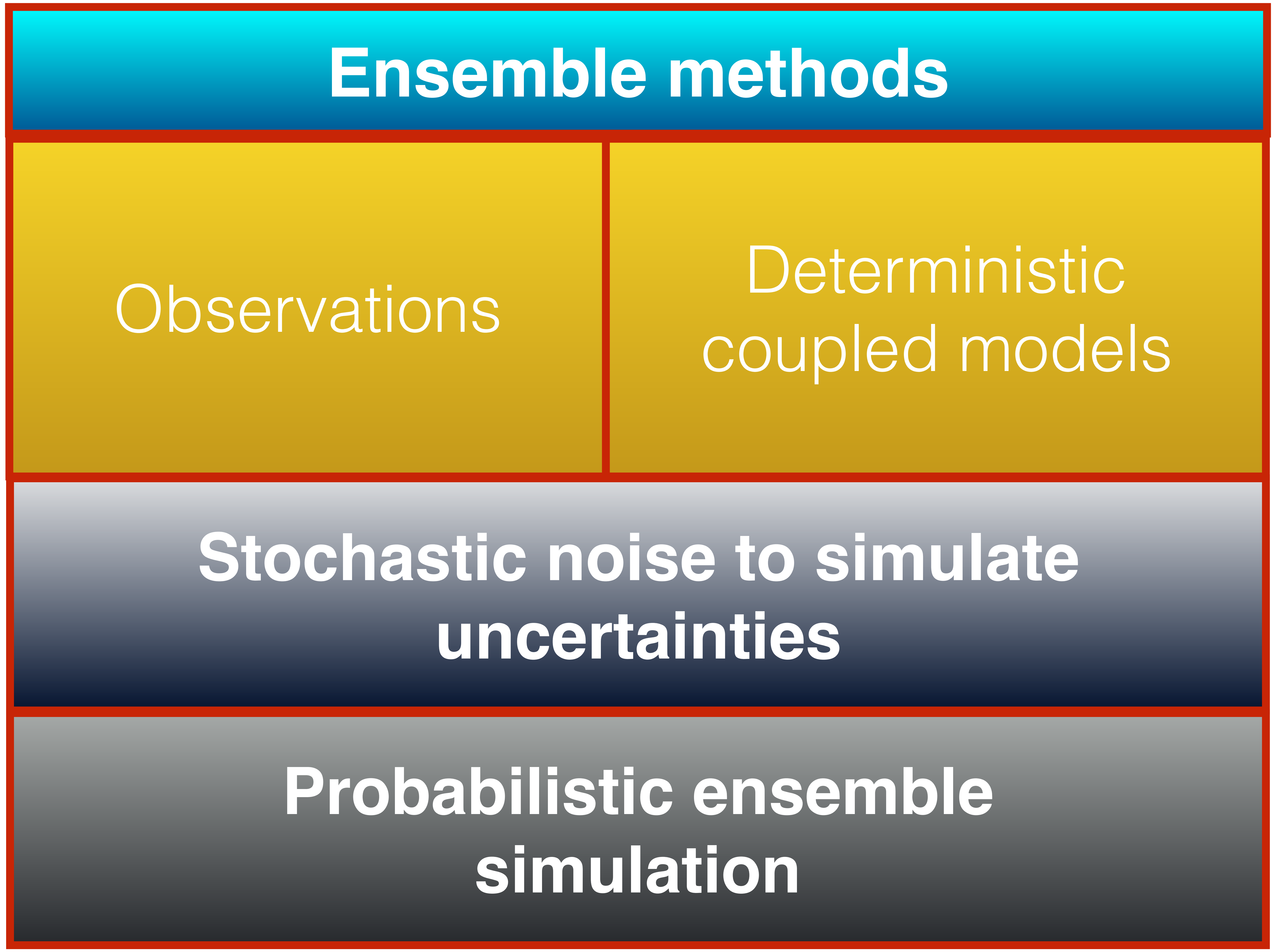
1. Context and objectives



- **Most comprehensive strategy for estimating the biogeochemical state of the ocean**

1. Context and objectives



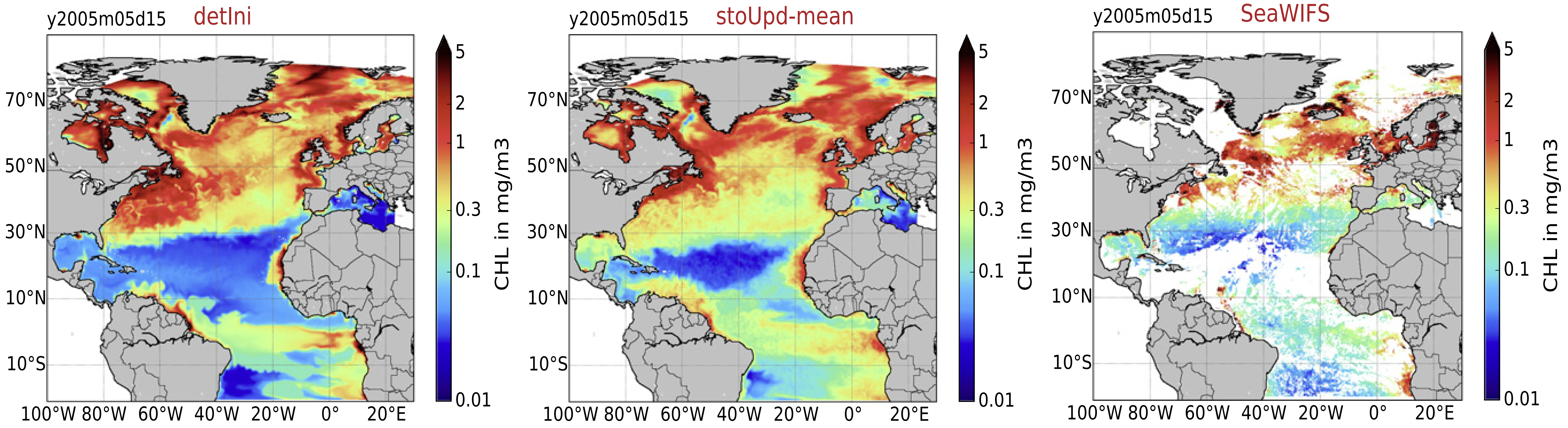
- **It is fundamental to identify the structure of observations and model errors**
- **Ensemble methods describe the evolution of the probability distribution**
  - An appropriate approach is by introducing stochastic noise into the model equations to simulate the effects of uncertainties

Deterministic model

- Online coupled NEMO-PISCES
- North Atlantic basin
- 0.25° horizontal resolution (eddy-permitting)
- 46 geopotential levels

Probabilistic ensemble model

- Stochastic perturbations to explicitly simulate model uncertainties
  - **Unresolved scales** in the presence of non-linear processes
  - **Uncertainties** in 7 biogeochemical parameters



Brankart, J. M. et al. (2015)
Garnier, F. et al. (2016)

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Objective

To what extent these parameterizations can be implemented to build a complete ensemble assimilation system

Strategy

Daily assimilation of <u>surface chlorophyll data</u> into a <u>probabilistic coupled configuration</u>

2. Methodology

2.1. Setup of the assimilation system

- Daily 4-km surface chl-*a* from MERIS
- Avoids interpolation before being integrated
- Partial coverage

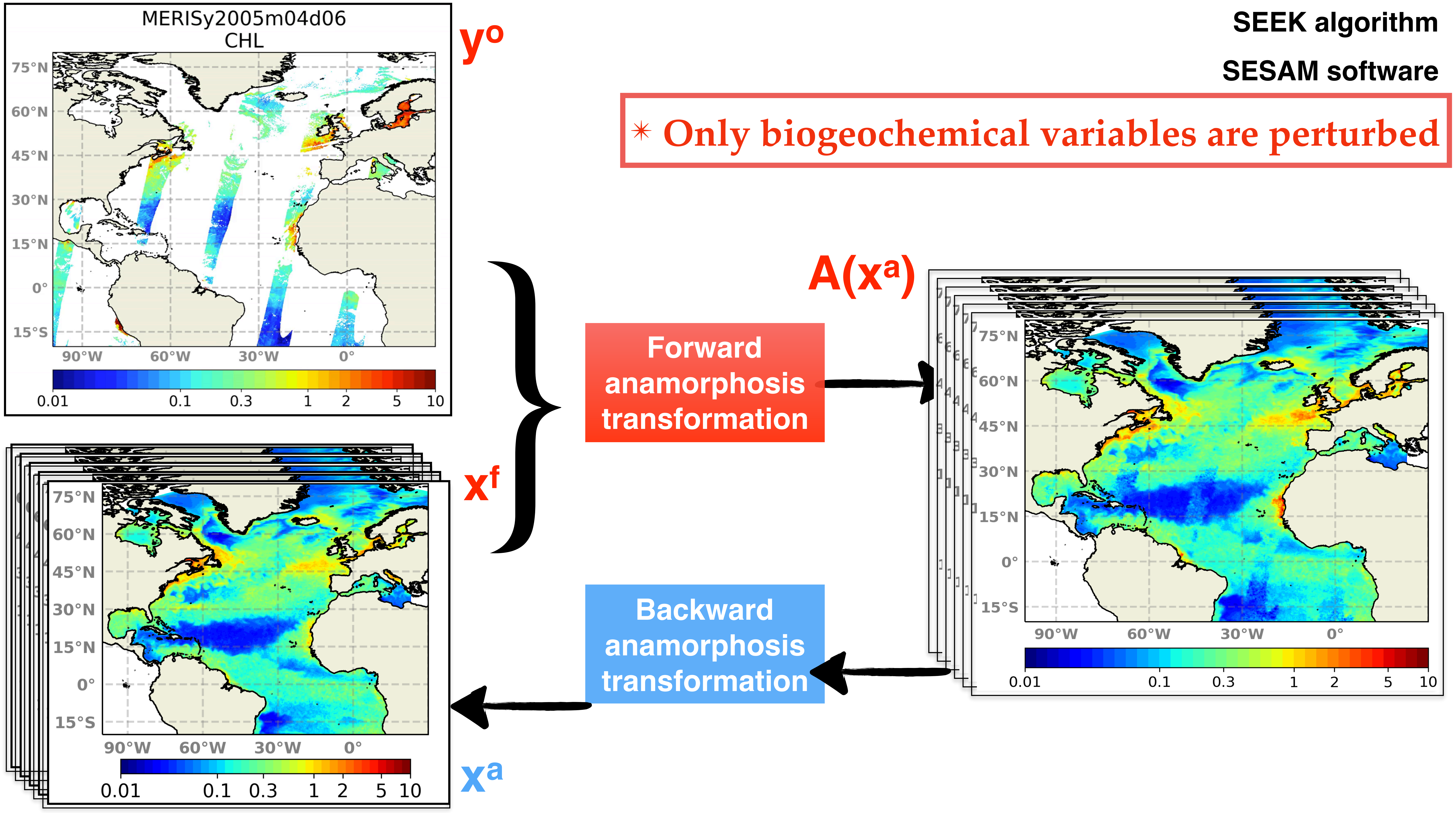
Square root observational update

(Brasseur and Verron, 2006)

SEEK algorithm

SESAM software

✴ Only biogeochemical variables are perturbed



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24-members ensemble simulation

- **1 year (2005 - 2006) assimilation experiment**
- **Analogous Free Run**

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SESAM software

✴ **Only biogeochemical variables are perturbed**

24-members ensemble simulation

- **Perform data assimilation**
- **Includes uncertainties**
- **Objectively comparable with observations**

3. Global diagnosis

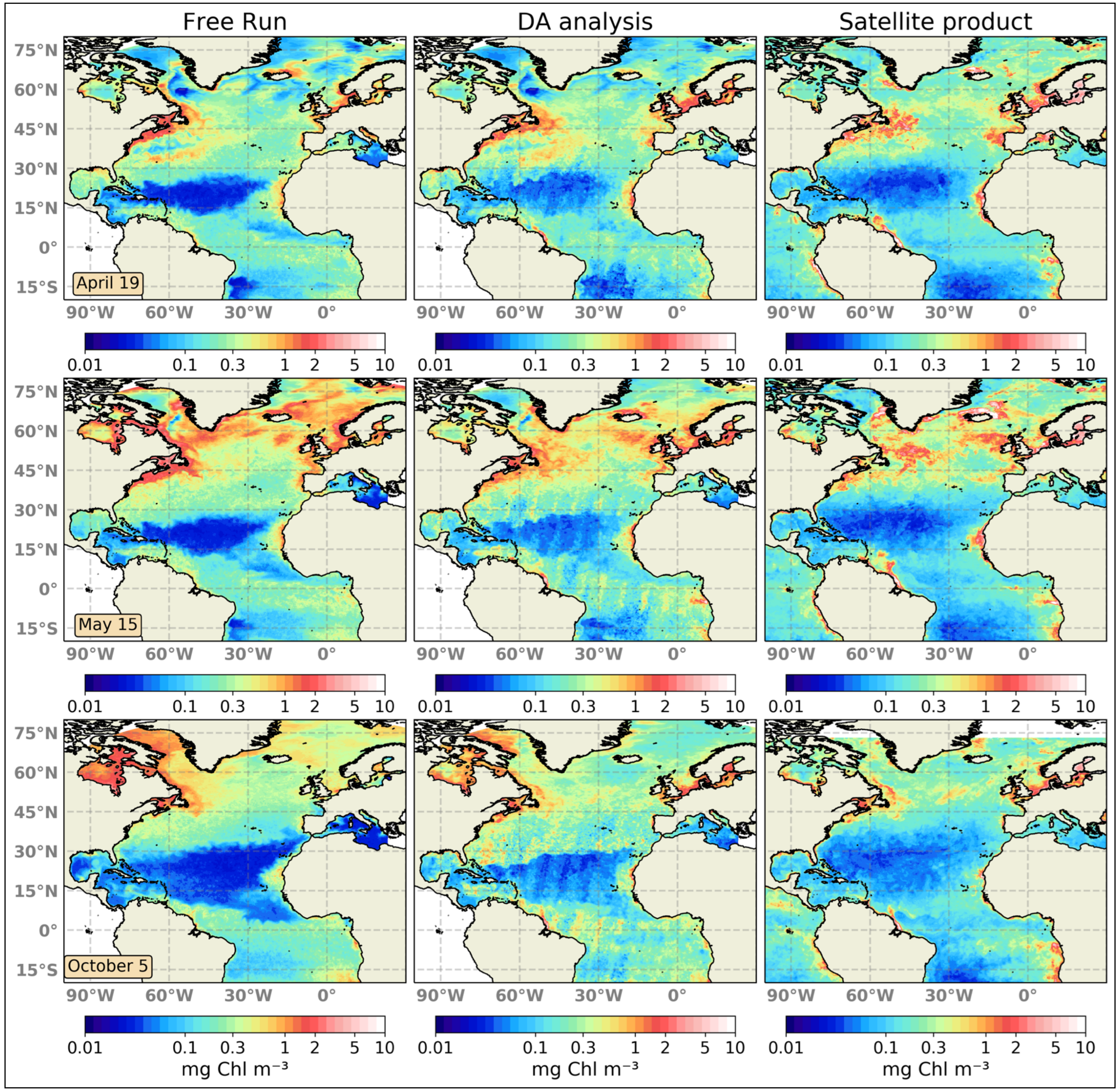
3.1. Reproducing ocean color data

Daily 24-members ensemble median

Merged daily-integrated satellite product

✳ **Non-assimilated analogue Free Run**

- Forecast restores the uncertainty of the system to match the satellite's
- Large-scale spatial pattern is reproduced
- Good performance at highly productive regions
- Improvements over the free run simulation
  - Underestimation of oligotrophic region
  - Overestimation of Gulf Stream and high latitudes
- Strong transition between oligotrophic to temperate waters
  - Misfits increase during autumn

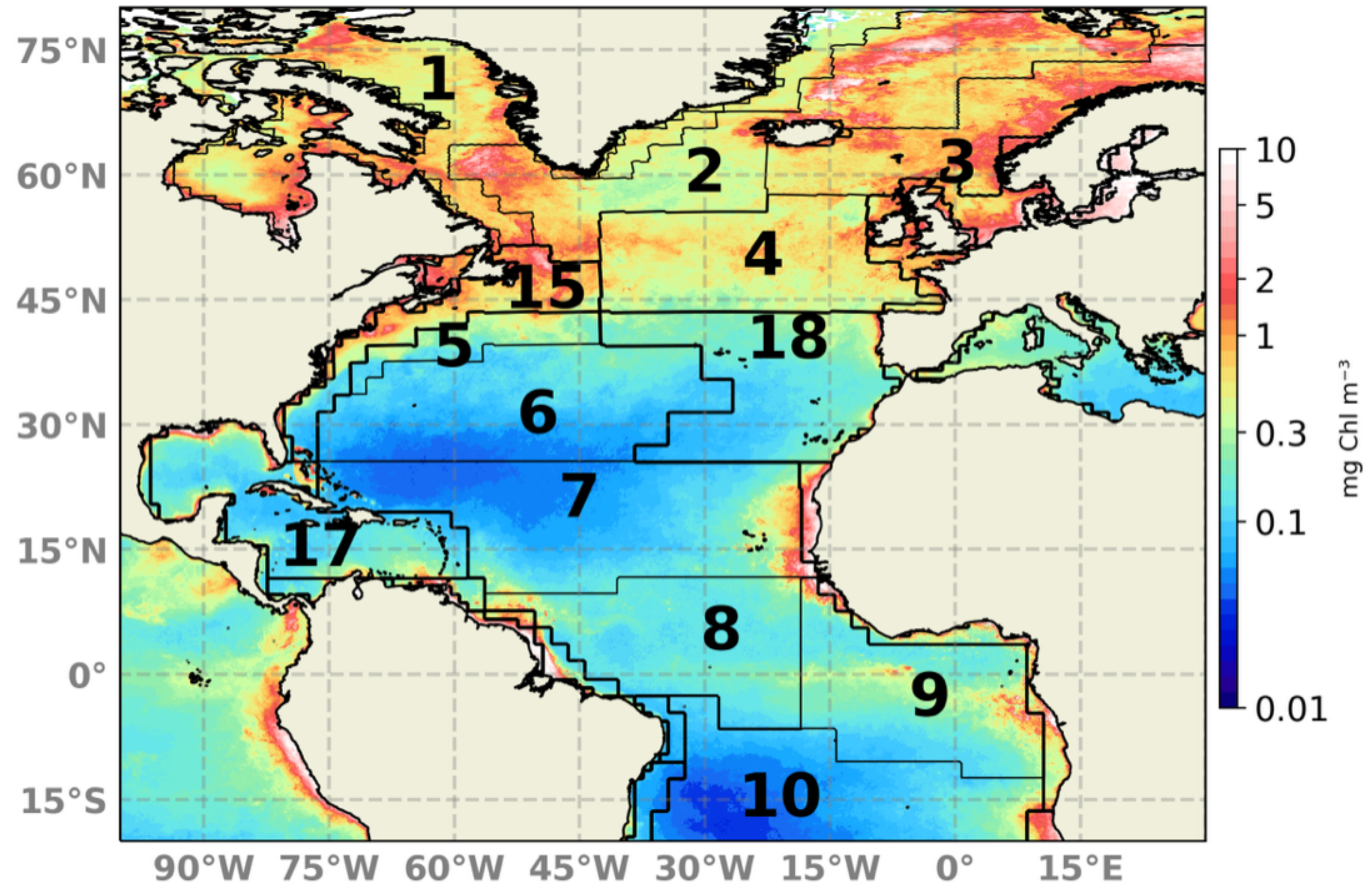


4. Regional diagnosis

4.1. Spatial probabilistic assessment

Daily rank histograms for provinces 4, 7, 18, and 6

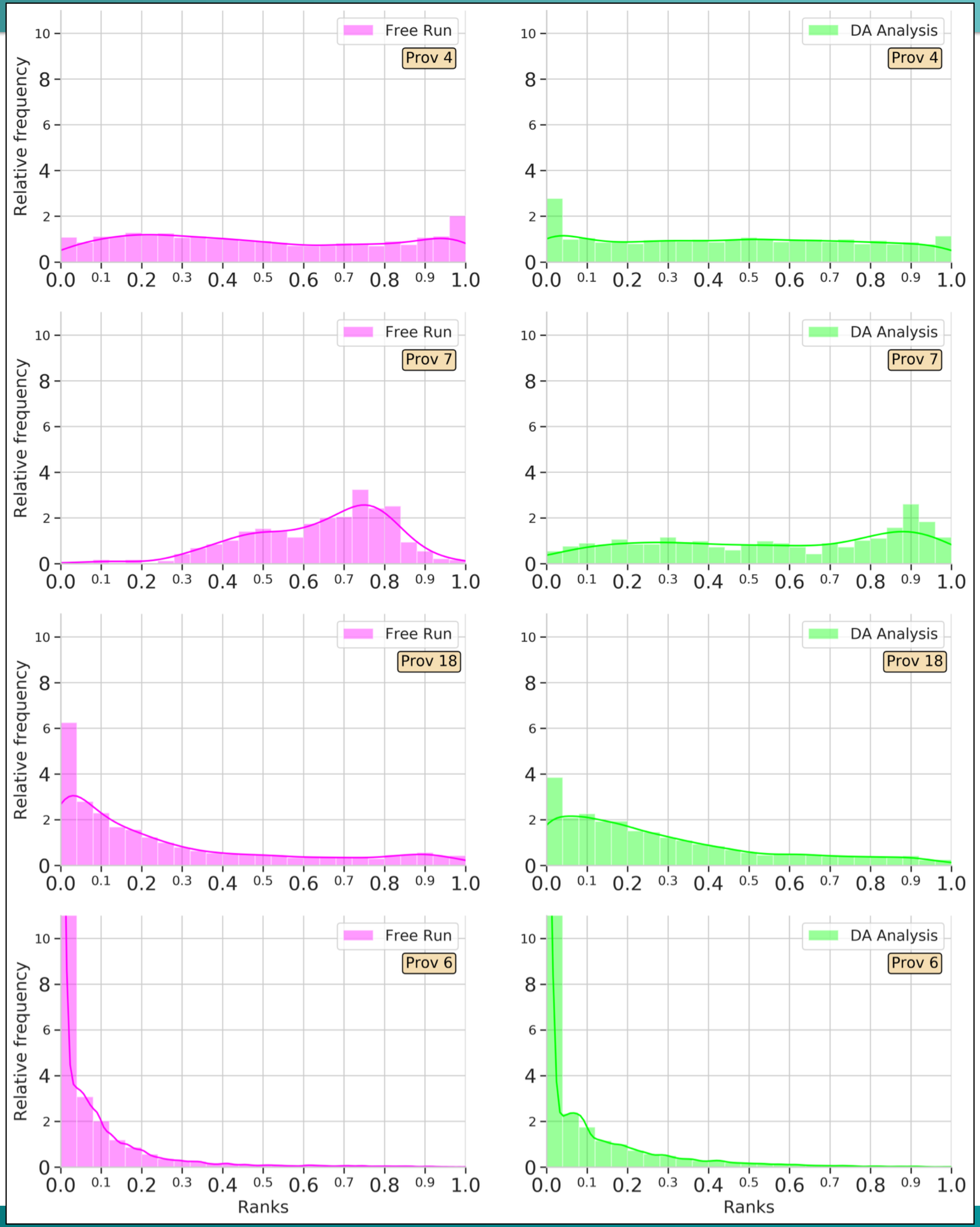
SeaWiFS data with 30% of error



- Rank distribution flattens after assimilation at provinces 4 and 7

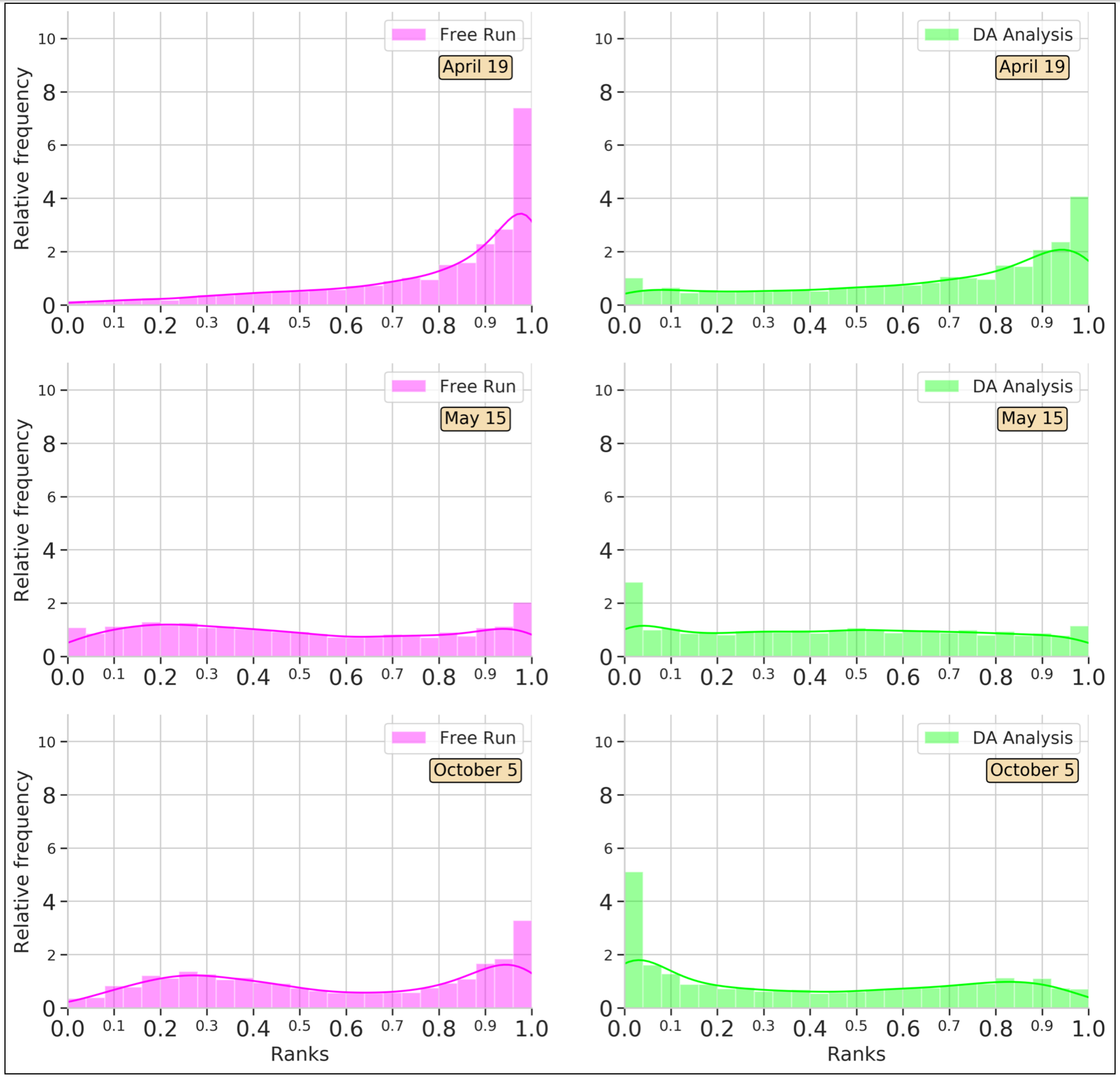
- Redistribution of the lowest ranks to the right at province 18. Improvements are limited however

- At province 6, the assimilation dos not avoid the accumulation of lower values not included within the prior ensemble



Daily rank histograms for province 4

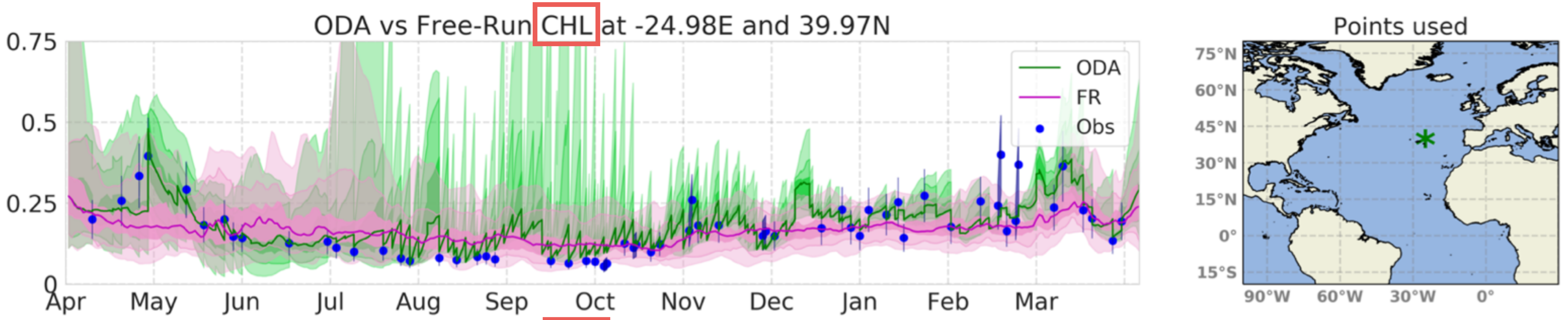
SeaWiFS data with 30% of error

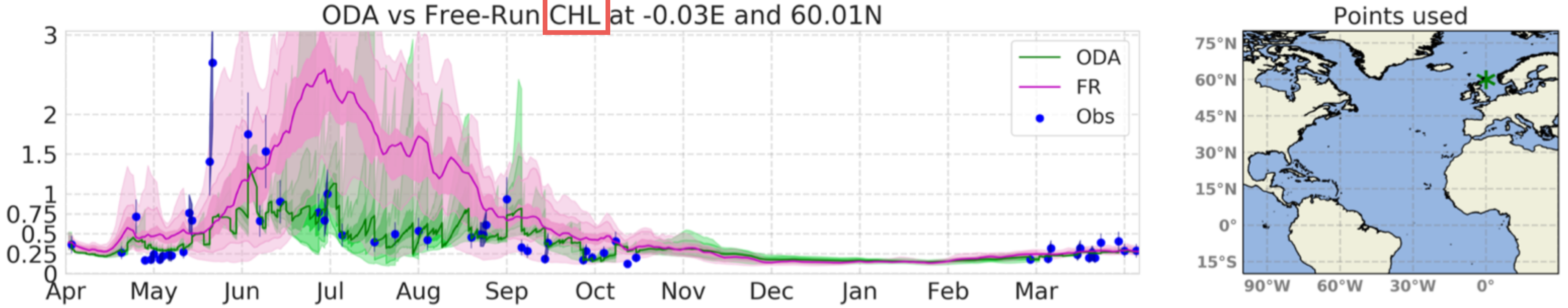


- The assimilation reduces the negative bias of the prior ensemble at the beginning of the experiment
- The histogram flattens during the beginning of the spring bloom period
- During October, prior ensemble tends to accumulate ranks at the right
- The assimilation accumulates ranks on the left side, though improve the ensemble distribution

Yearly time-series of quantiles of the assimilation and free run ensembles

Available observations are included





- Relative agreement between the assimilation system and observations
- The assimilation system reproduces the regional seasonal variability
- MERIS info is integrating into the system every 6 - 7 days

- Both ensembles display a wide range of values within the first 100 m

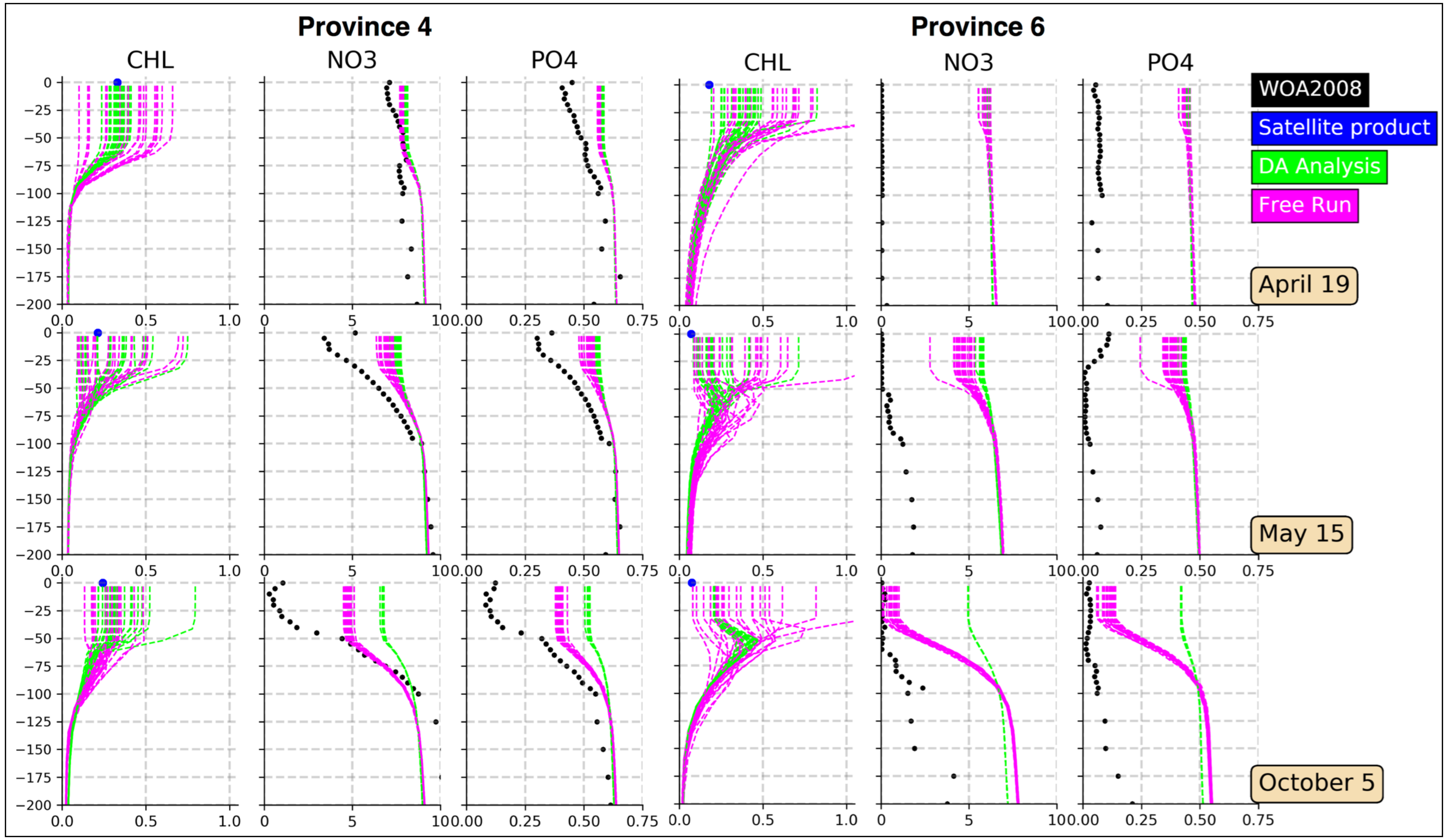
- The spread is reduced accordingly after assimilation

- **Province 4;** values decrease towards October though remaining higher than WOA data
  - Mixed layer nutrient's availability increases after assimilation, but surface chlorophyll is correctly simulated

- **Province 6;** nutrient are further overestimated
  - The assimilation ensemble is unable to include surface chl-*a* observations

Chlorophyll and nutrient vertical profiles for provinces 4 and 6

WOA2008 and satellite data included



4.2. Multivariate assessment

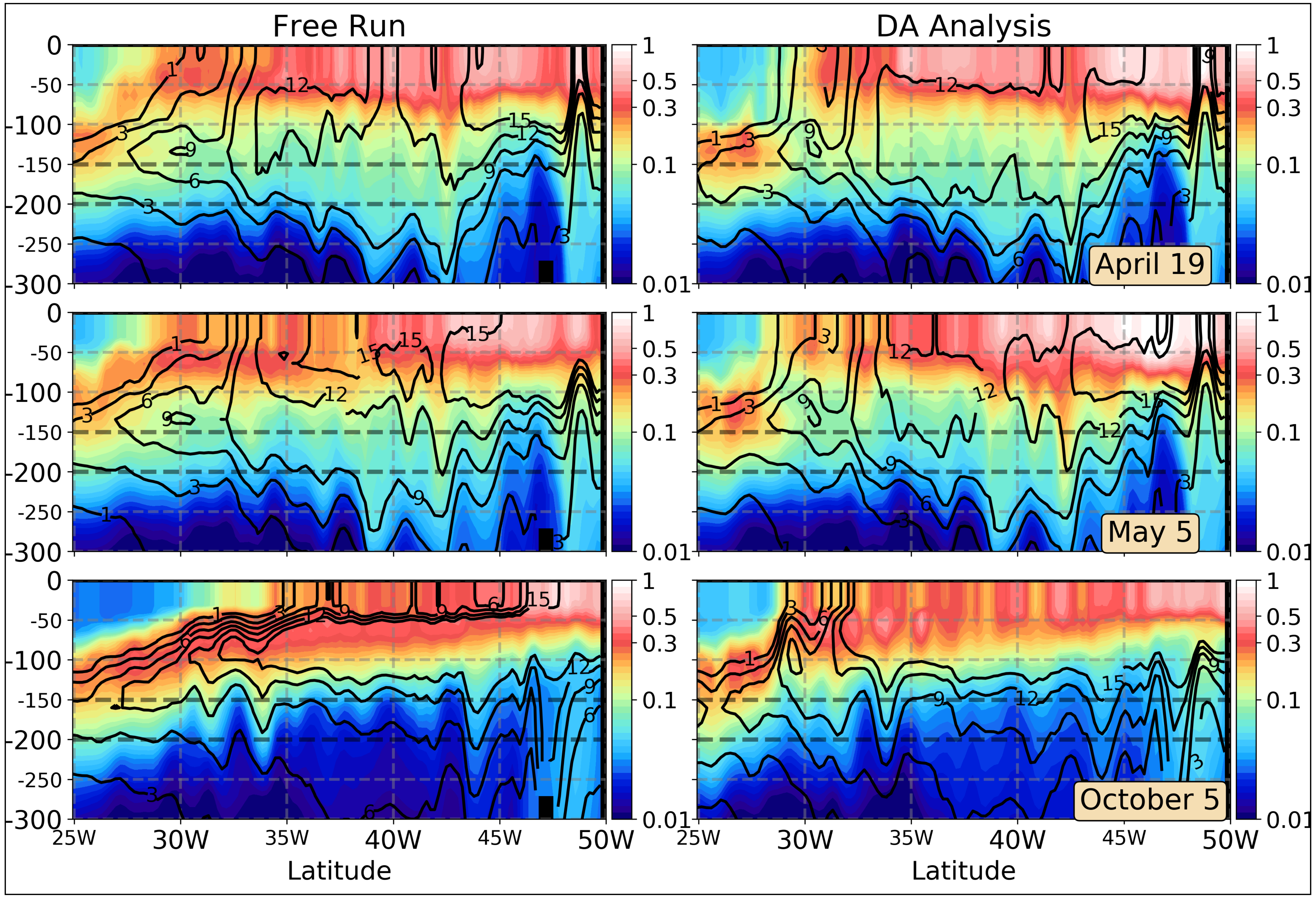
- Erratic behaviour representing the transition between subtropical and temperate waters

Chlorophyll and nutrient vertical sections at 45ºW

- **April**; oligotrophic region reaches further north after the assimilation due to a deeper nutrient-depleted subsurface layer south of ~30ºN

- **May**; strong gradient of nutrients isolines. Patchy high chl-*a* values caused by propagation of surface corrections

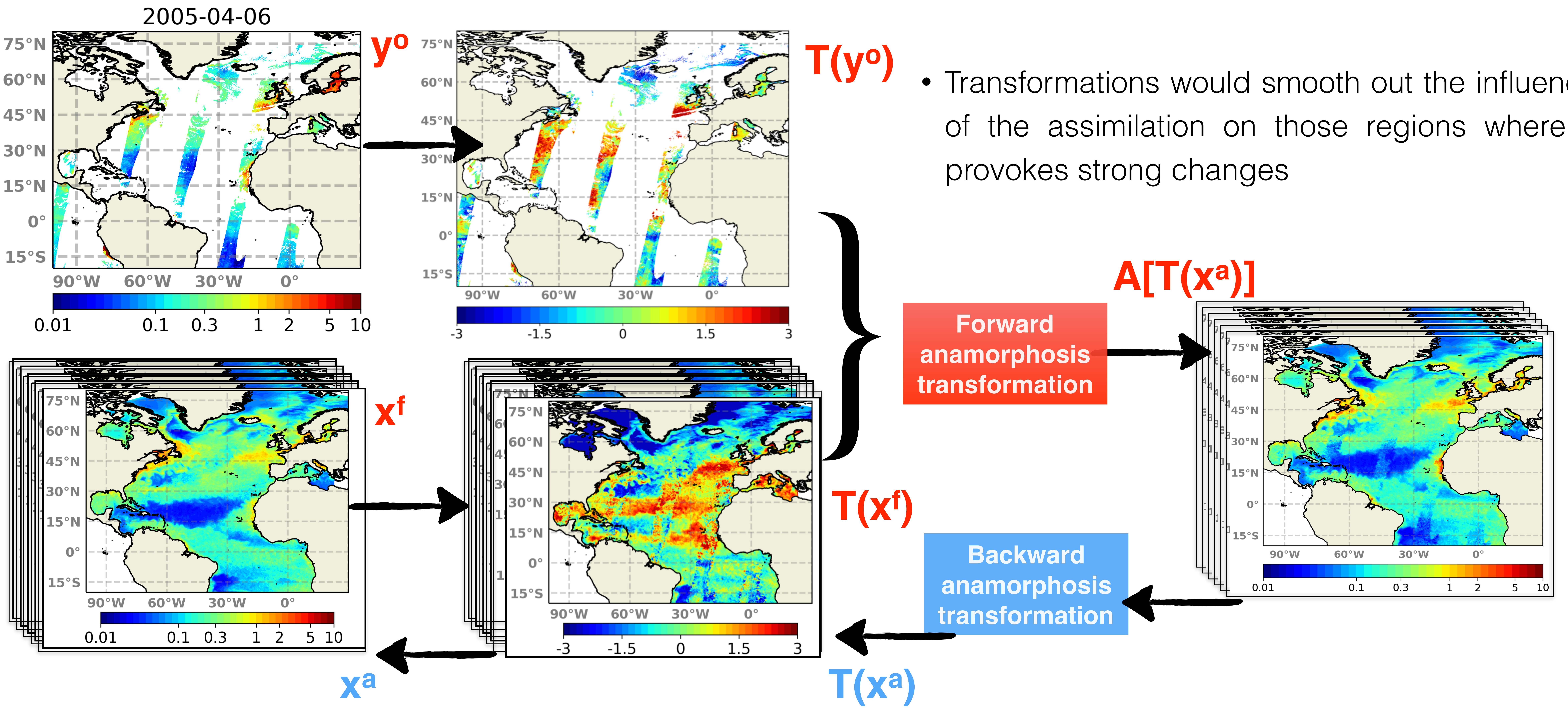
- **October**; since the free run overestimates surface chl-*a*, corrections increase its concentrations. Nutrients accumulate north of 30ºN after the update
    - It destabilises the equilibrium between the biomass of producers (decreases) and the availability of nutrients (increases) leading to a severe overestimation of chl-*a* over time



5. Corrections on the fluctuating component

Time-independent transformations are applied prior the analysis update

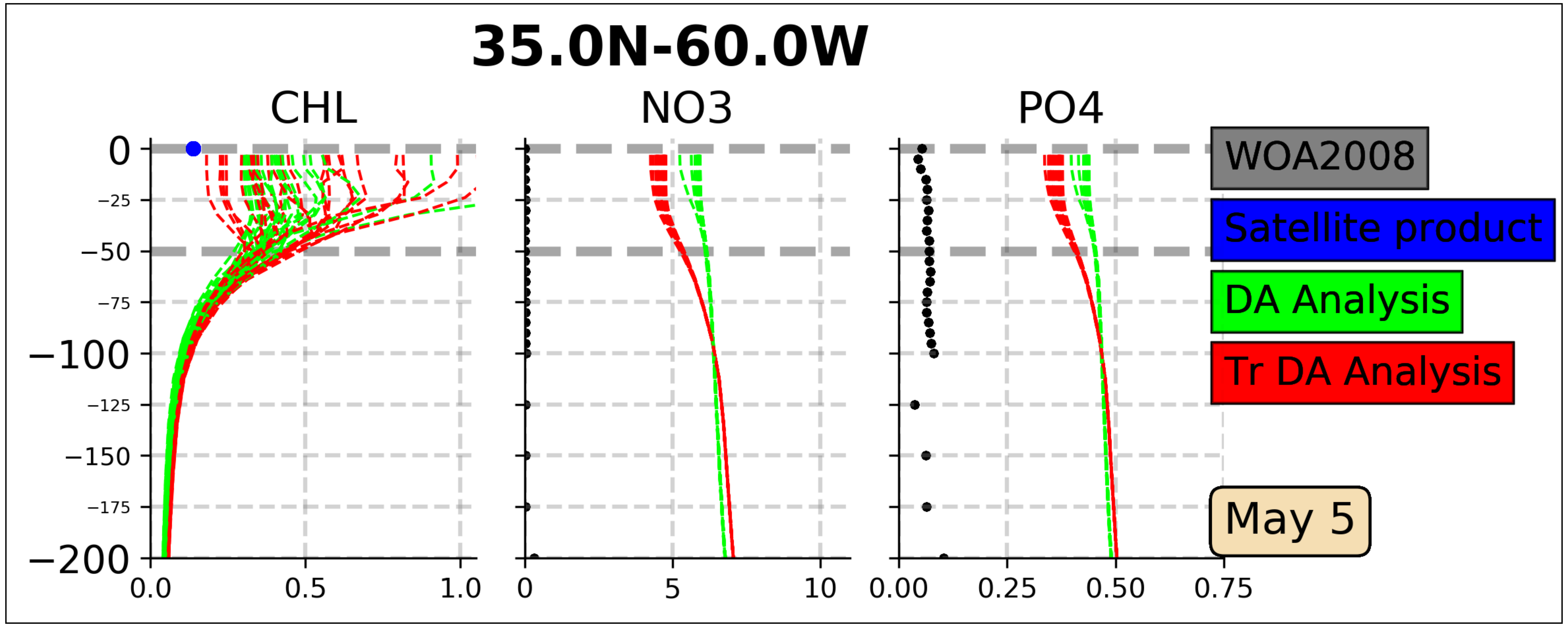
- Transformations would smooth out the influence of the assimilation on those regions where it provokes strong changes



- One-month experiment with transformations
- The increasing on nutrients is reduced after the transformations
- The transformed ensemble keeps the values displayed by the non-transformed simulation, while it increases the envelope of the ensemble by reproducing lower values
- Reducing the effects of the assimilation in regions where the spread of the ensemble is insufficient, may diminish the inconsistencies

Chlorophyll and nutrient vertical profiles for province 6

WOA2008 and satellite data included



6. Summary and perspectives

Non-Gaussian ensemble coupled assimilation system

- Assimilation problem in probabilistic terms

Parameterisations are valid for a major part of the domain

- Improves several misfits associated with a non-assimilated simulation

Main problem arises in the transition zone between the oligotrophic and temperate waters

- Imbalances between chlorophyll and nutrients’ increments

Assimilation applied only to the fluctuating component

- We expect to alleviate inconsistencies due to the model strong attractors

Short term

Publication

Santana-Falcón, Y., Brankart, J. M., Brasseur, P., and Garnier, F. Assimilation of chlorophyll data into a stochastic ensemble simulation for the North Atlantic ocean, Ocean Science Discussion, doi:10.5194/os-2020-6

Long term

Sophistication of the system

Assimilation of physical variables, *in situ* data from Bio-Argo profiles

Re-structure of the methodology

Use of *AI* for developing simpler coupled assimilation systems