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## **Narrowing Uncertainties of Climate Projections using Data-driven Methods: the AMOC Case Study**

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Pierre Tandeo, Pierre Le Bras, Florian Sévellec, Pierre Ailliot, Juan Ruiz. Narrowing Uncertainties of Climate Projections using Data-driven Methods: the AMOC Case Study. NHM 2023: 6th International Workshop on Nonhydrostatic Models, Aug 2023, Sapporo, Japan. pp.1-13. <hal-04193133>

**HAL Id: hal-04193133**

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Submitted on 4 Sep 2023

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## Narrowing Uncertainties of Climate Projections using Data-driven Methods

*The AMOC case study*

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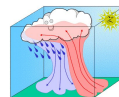
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### The 6th International Workshop on Nonhydrostatic Models (NHM-WS 2023)



31 August - 2 September 2023



Hokkaido University Conference Hall, Sapporo, Japan

# Context: Atlantic Meridional Overturning Circulation (AMOC)

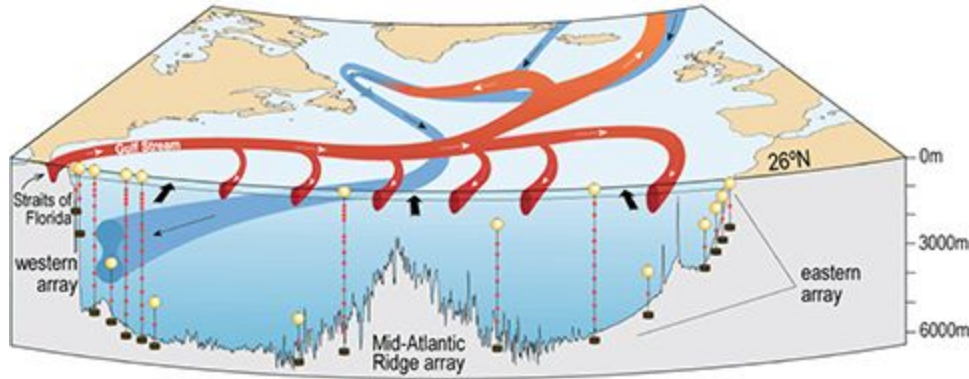


Fig.1: Schematic of AMOC  
<http://www.noc.soton.ac.uk/rapidmoc/>

[Source:

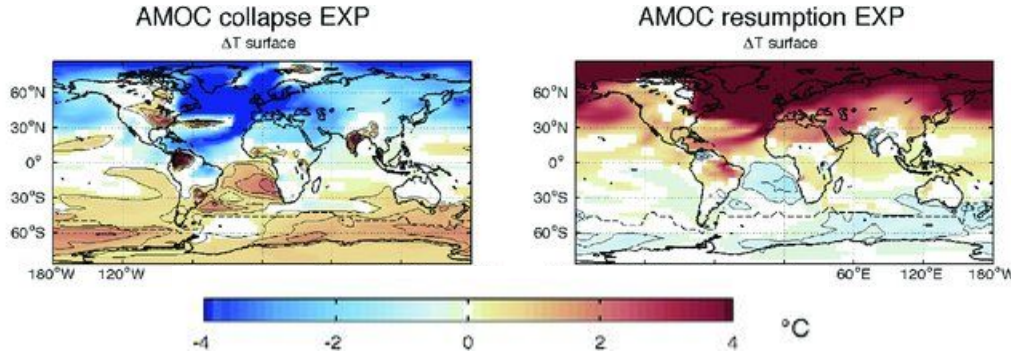


Fig.2: Experiences of AMOC collapse/resumption and influence on surface temperature anomalies  
[Source: *Pedro et al., 2018*]

## AMOC

- Circulation in the Atlantic ocean
  - Shallow warm water northward
  - Deep cold water southward

- Influence on climate of Atlantic regions
- Essential to monitor its evolution

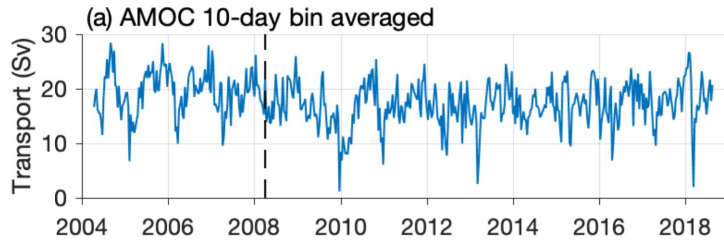


Fig.1: AMOC observations from RAPID/MOCHA system  
[Source: Moat et al., 2020]

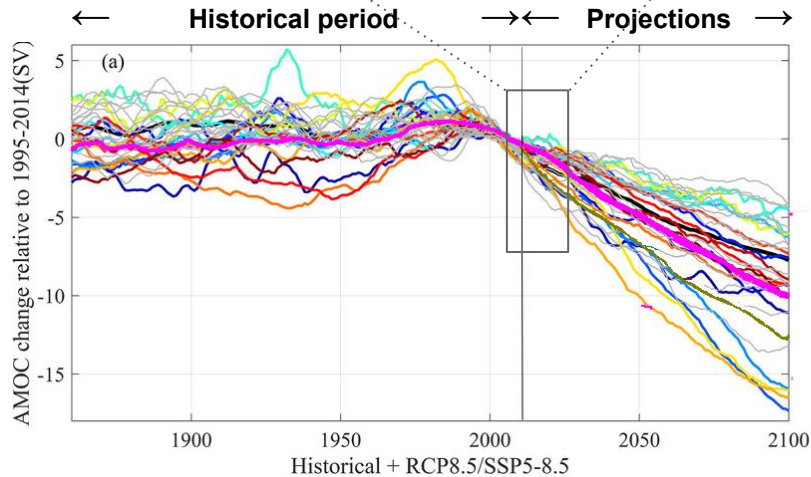


Fig.2: AMOC anomalies from different models (SSP5-8.5 in CMIP5-6)  
[Source: Lyu and Church, 2020]

## Observations:

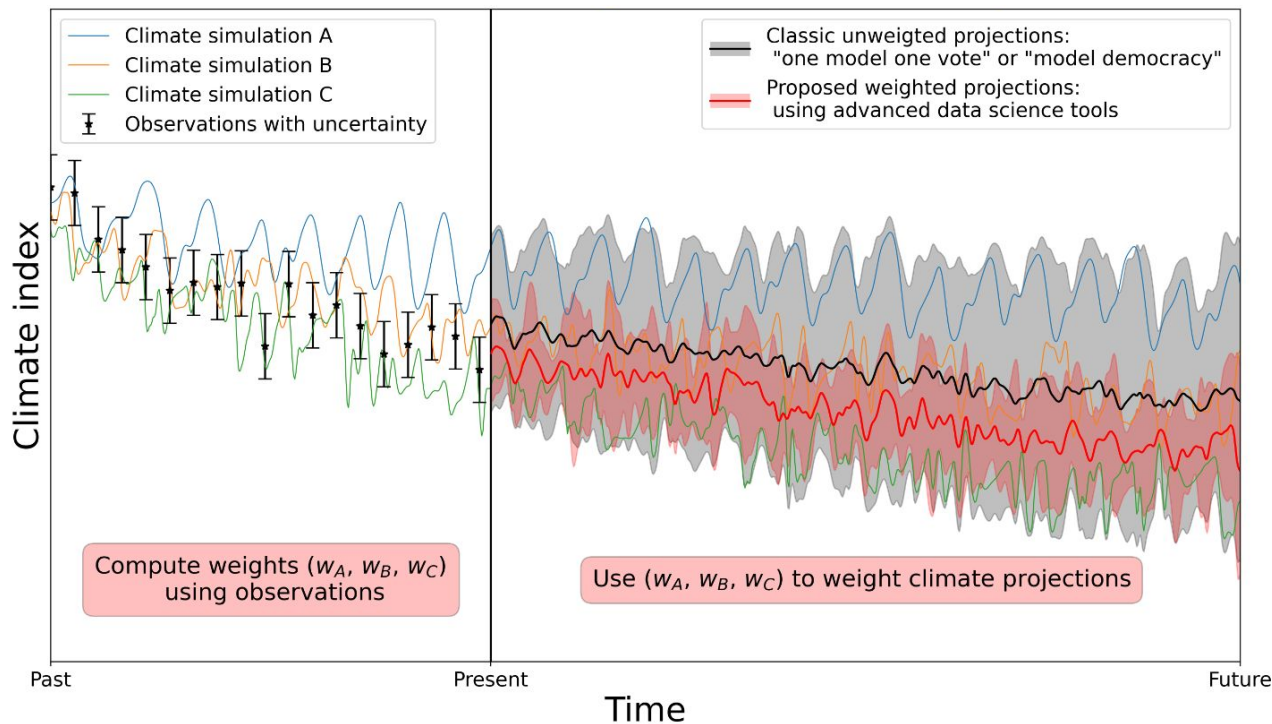
- Seasonal and interannual variability
- Hard to measure, lot of noise

## CMIP Model projections:

- **Models predict severe decrease of the AMOC**
- **Wide spread** (model uncertainty)

**How to improve accuracy and reliability of AMOC projections?**

# Aim of this study: compute weights to constraint climate projections



## State of the art

- Model democracy (same weights)
- Questionable (e.g., Knutti et al., 2019)

## Our goal

- Weight the projections
- Using available simulations and observations
- Reduce the uncertainty

# Proposed methodology: combination of data assimilation and machine learning

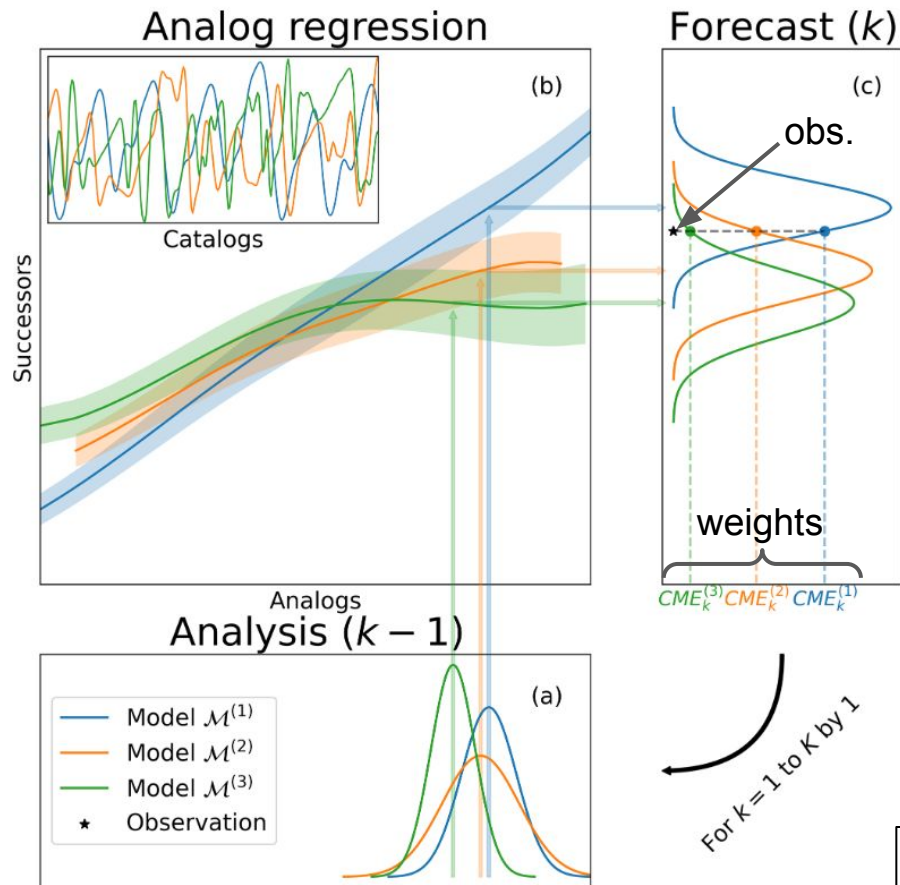


Fig.1: Scheme of the methodology  
[Source: Ruiz et al., 2022]

## Step (a): Data assimilation

- start from an accurate initial condition
- Ensemble Kalman filter (EnKF)

## Step (b): Data-driven forecast

- make forecasts without equations
- analog method

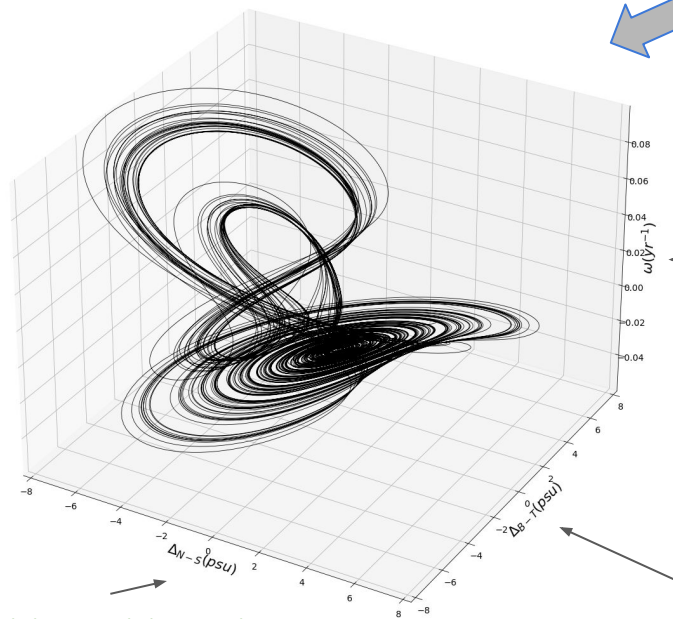
## Step (c): Weighting procedure

- compute observation-forecast distance
- contextual model evidence (CME)

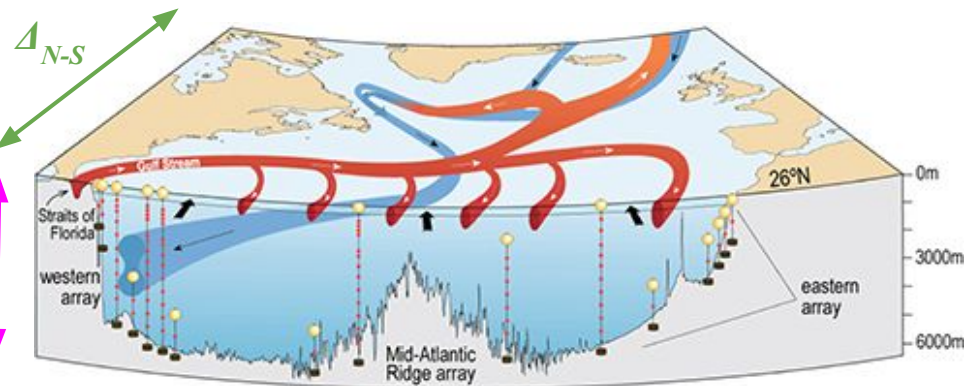
Ruiz, J., Ailliot, P., Chau, T. T. T., Le Bras, P., Monbet, V., Sévellec, F., & Tandeo, P. (2022). Analog data assimilation for the selection of suitable general circulation models. *Geoscientific Model Development*, 15(18), 7203-7220.

## 3-variable AMOC chaotic model

(Sévellec and Fedorov, 2014)



$\Delta_{B-T}$ : Stratified salinity



$\omega$   
overturning strength

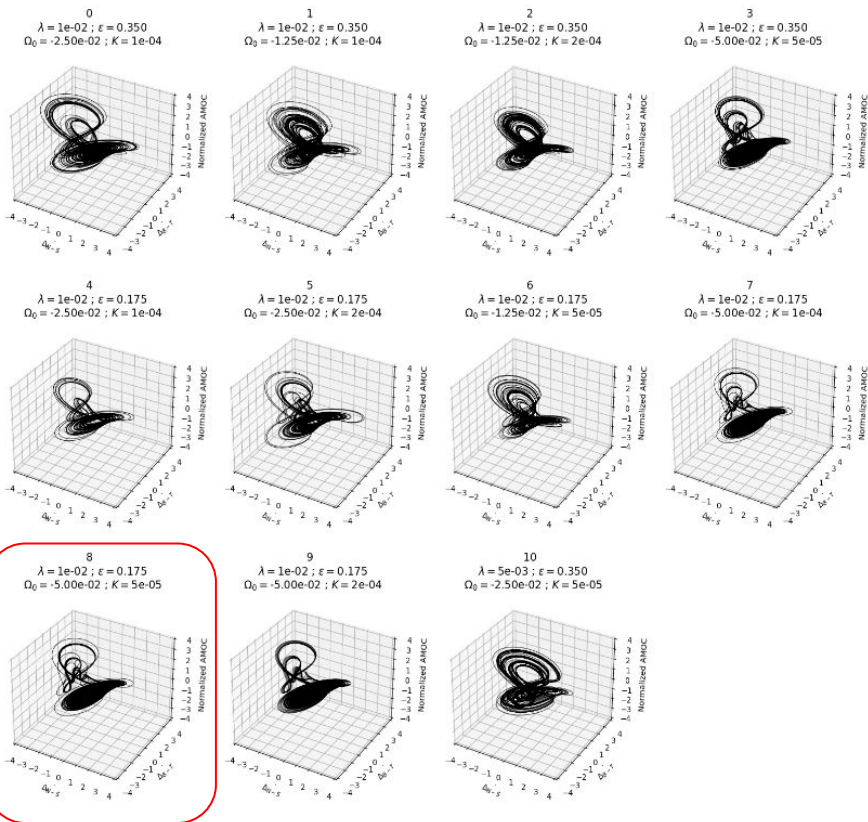
$$\frac{d\omega}{dt} = -\lambda\omega - \epsilon\beta S_{NS},$$

$$\frac{dS_{BT}}{dt} = (\Omega_0 + \omega) S_{NS} - K S_{BT} + \frac{F_0 S_0}{h},$$

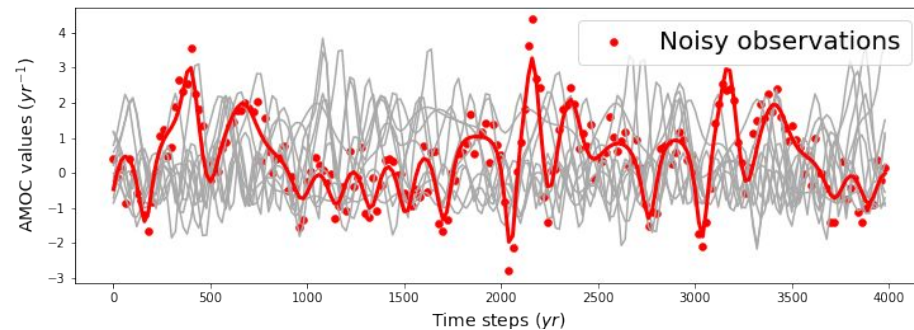
$$\frac{dS_{NS}}{dt} = -(\Omega_0 + \omega) S_{NS} - K S_{NS}$$

$\Delta_{N-S}$ : Meridional salinity gradient

# Experimental set up: generation of different versions of the idealized AMOC model

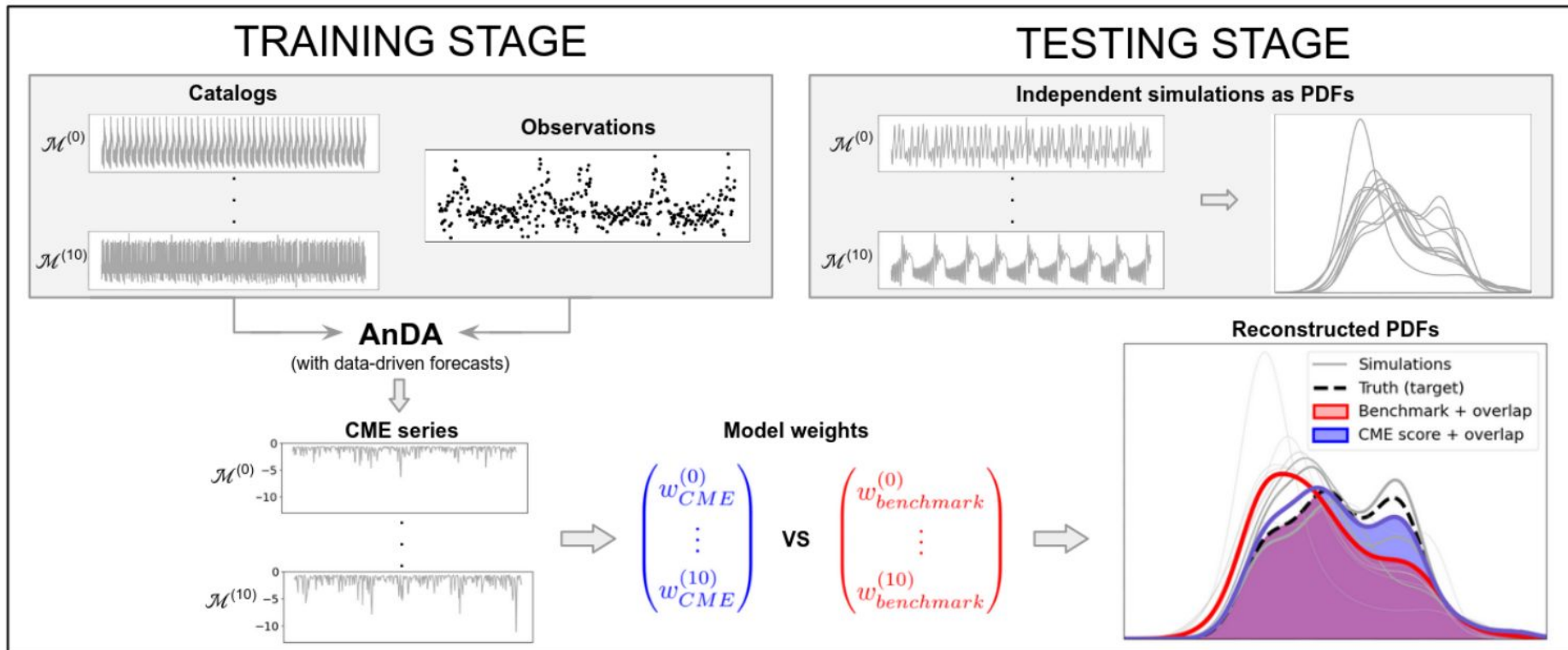


- 11 perturbed-parameter versions
- Leave-One-Out strategy
- Mimic 10 climate simulations and **1 observation**



Schematic of the Leave-One-Out strategy

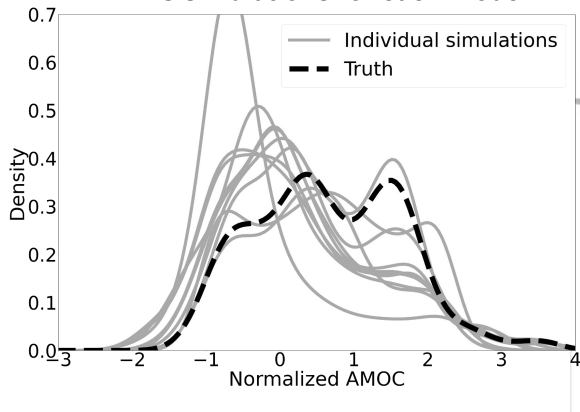
- Compute 10 weights
- Approximate observation distribution



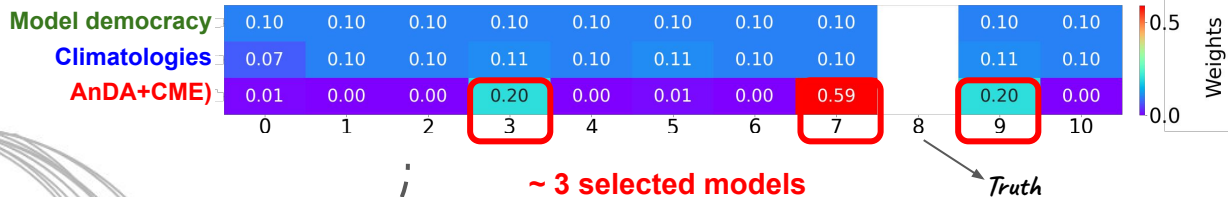
# Application results for one experiment: applying the weights to reconstruct the truth

## → Out-of-training simulations

PDFs simulations for each model

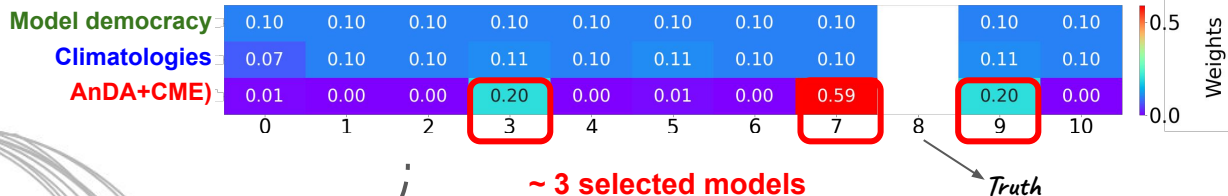
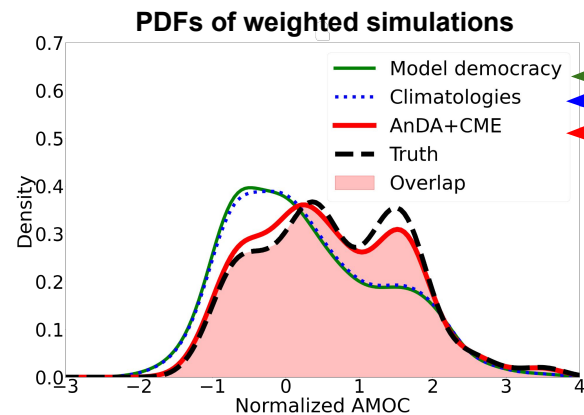
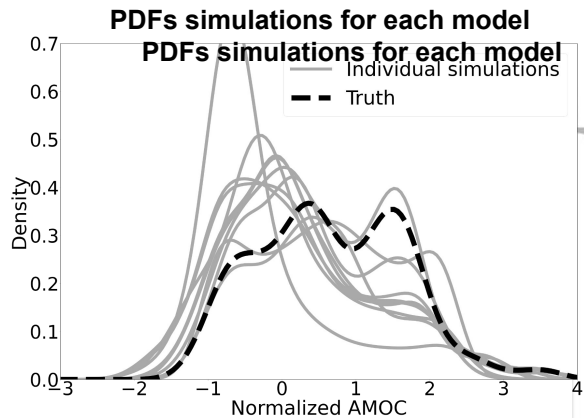


Attributed weights to each model



# Application results for one experiment: applying the weights to reconstruct the truth

## → Out-of-training simulations



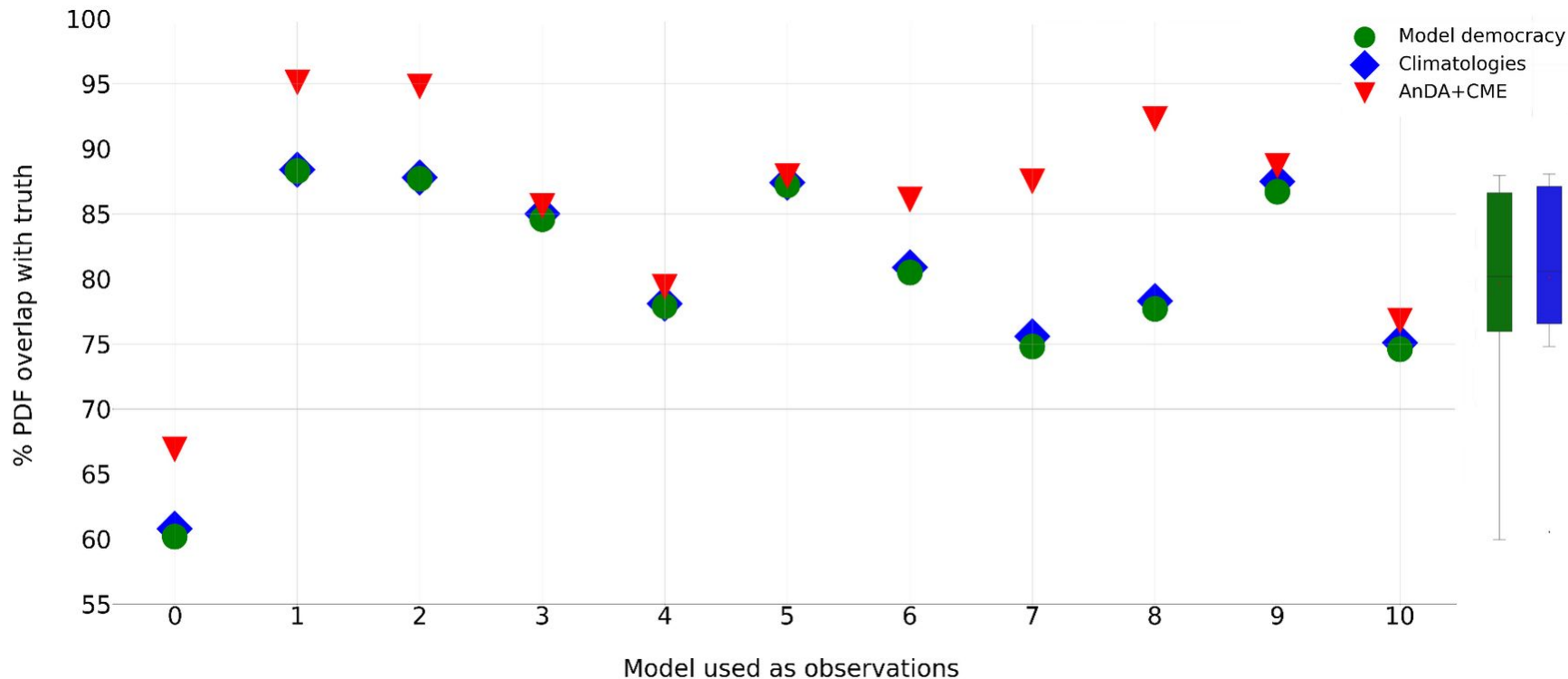
**Weighting**

## Results: reconstruction skillness

| % PDFs overlap  | One experiment |
|-----------------|----------------|
| Model democracy | 77.6           |
| Climatologies   | 78.3 (+0.7)    |
| AnDA+CME        | 92.3 (+14.7)   |

AnDA with CME outperforms model democracy

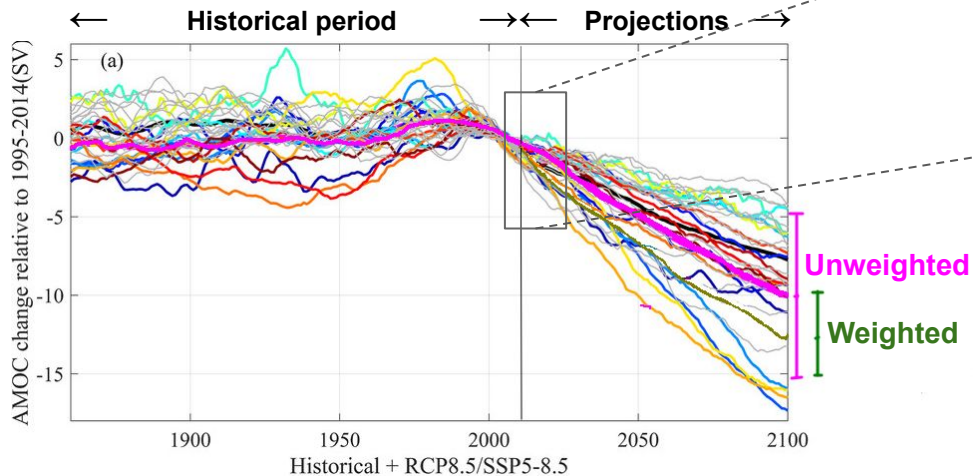
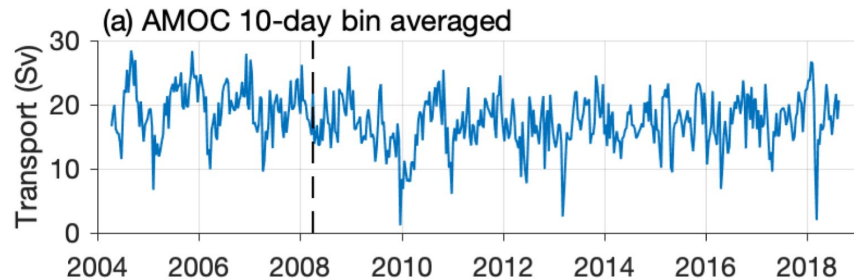
LOO results: % PDF overlap between each weighted PDF and the true one



AnDA with CME performs at least as good as model democracy

# Conclusion & perspectives

- **Weight climate simulations using noisy observations**
- **Data-driven approach (no need to run climate models)**
- **Combination of Data Assimilation & Machine Learning**
- **Application to synthetic data of the AMOC**
- **The proposed method outperforms “model democracy”**



## Article


Articles / Volume 15, Issue 18 / GMD, 15, 7203–7220, 2022

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<https://doi.org/10.5194/gmd-15-7203-2022>  
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Methods for assessment of models | 

## Analog data assimilation for the selection of suitable general circulation models

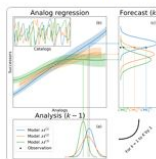
Juan Ruiz , Pierre Ailliot, Thi Tuyet Trang Chau, Pierre Le Bras, Valérie Monbet, Florian Sévellec, and Pierre Tandeo

### Abstract

Data assimilation is a relevant framework to merge a dynamical model with noisy observations. When various models are in competition, the question is to find the model that best matches the observations. This matching can be measured by using the model evidence, defined by the likelihood of the observations given the model. This study explores the performance of model selection based on model evidence computed using data-driven data assimilation, where dynamical models are emulated using machine learning methods. In this work, the methodology is tested with the three-variable Lorenz model and with an intermediate complexity atmospheric general circulation model (a.k.a. the SPEEDY model). Numerical experiments show that the data-driven implementation of the model selection algorithm performs as well as the one that uses the dynamical model. The technique is able to select the best model among a set of possible models and also to characterize the spatiotemporal variability of the model sensitivity. Moreover, the technique is able to detect differences among models in terms of local dynamics in both time and space which are not reflected in the first two moments of the climatological probability distribution. This suggests the implementation of this technique using available long-term observations and model simulations.

 
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