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Deconstructing the subtropical AMOC variability

Q. Jamet[1], W. K. Dewar[1,2], N. Wienders[2], B. Deremble[3], S. Close[4] and T. Penduff[1]





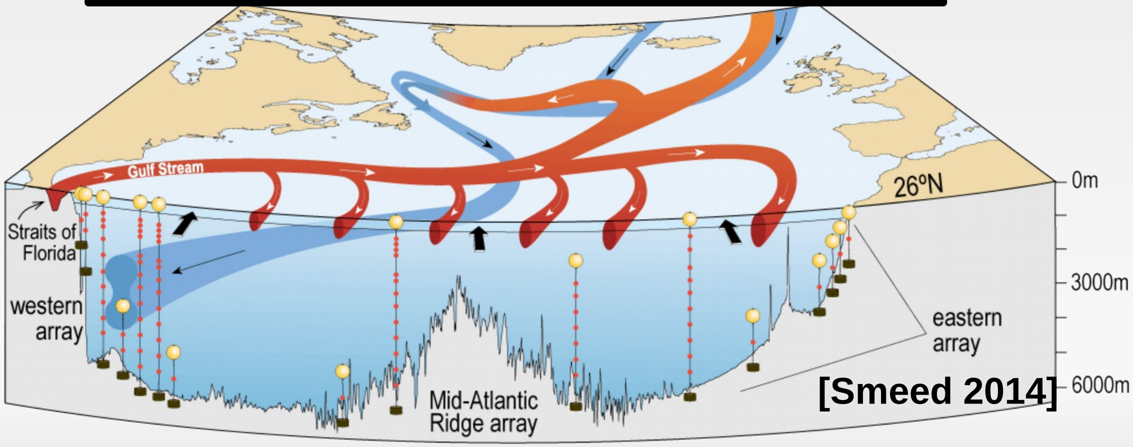

[1]Univ. Grenoble Alpes, CNRS, IRD, Grenoble INP, IGE, Grenoble, France
[2]Dept. of Earth, Ocean, and Atmospheric Science, FSU, Tallahassee, USA
[3]Laboratoire de Météorologie Dynamique, ENS, Paris, France
[4]Laboratoire d'Océanographie Physique et Spatiale, Univ. de Bretagne Occidentale, Brest, France

Background

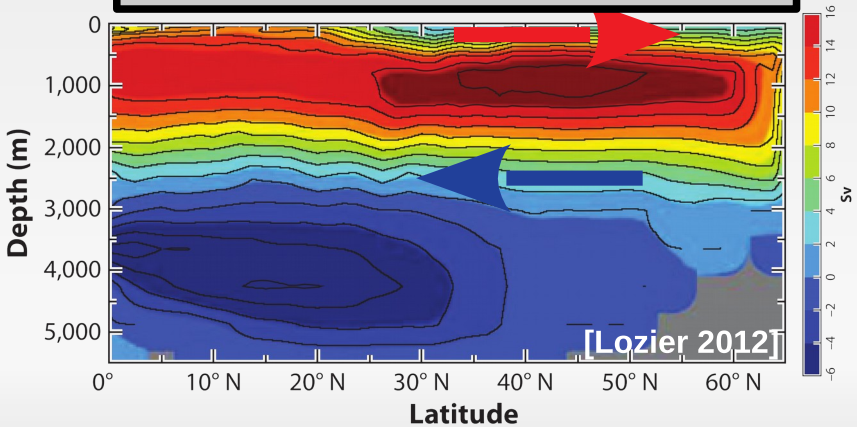
- The Atlantic Meridional Overturning Circulation (**AMOC**):
  - Synthetic representation in the y-z plan of the **complex North Atlantic ocean circulation**
  - Plays a central role in climate by **redistributing heat**, **freshwater** and **carbon**

→ Long-standing interests in **understanding its variability**

Schematic of the NA ocean circulation



Example of time mean AMOC

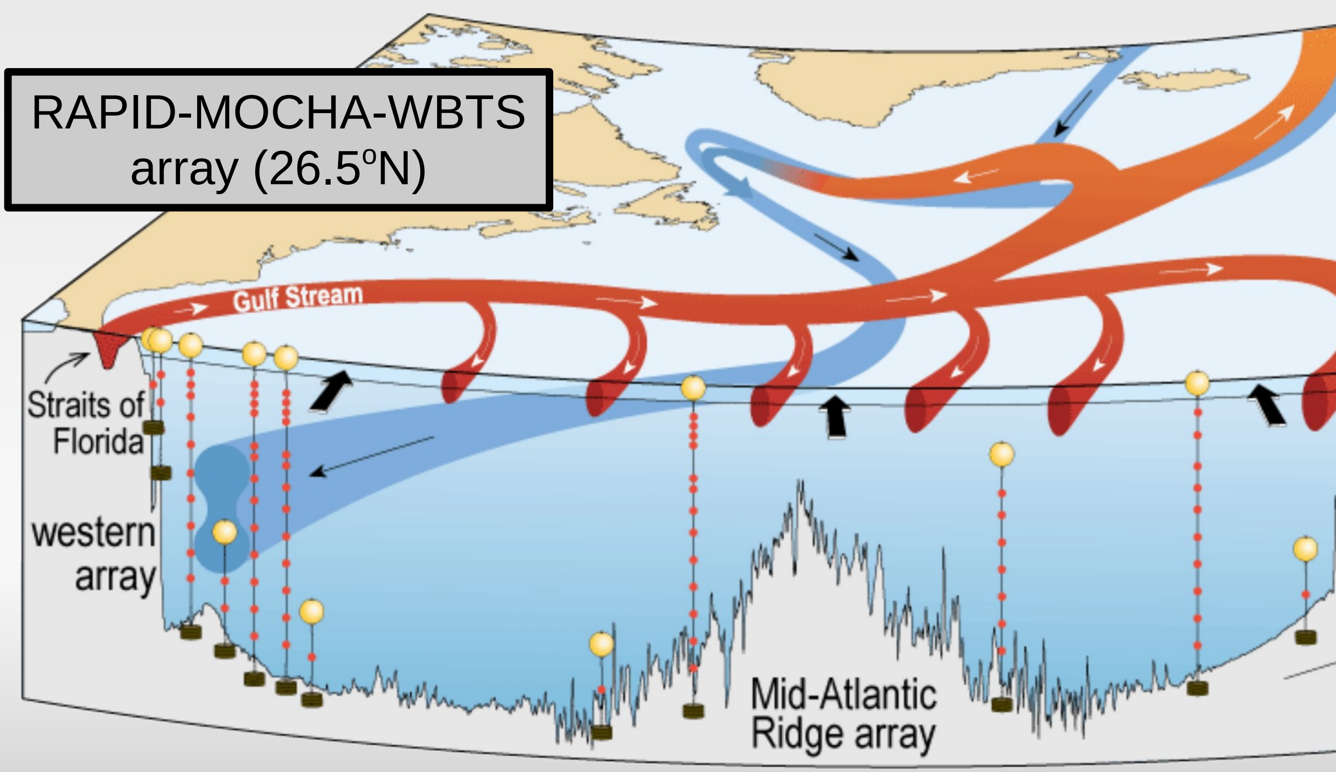


$$AMOC(y,z,t)=\int_{x_w}^{x_e}\int_{-H}^{z} v\,dz\,dx$$

Motivations

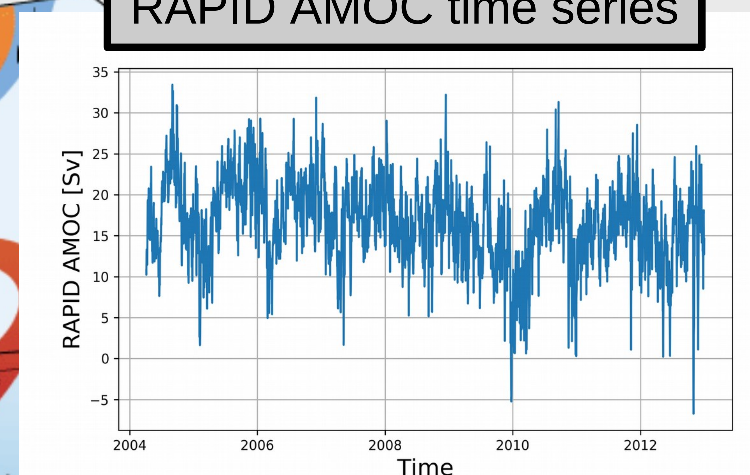
- Sources of AMOC variability **in the NA subtropical gyre:**
  - Adjustment to signals of **remote origin** (NA subpolar gyre, South Atl.) [Johnson 2002; Biastoch 2008a,b; Hodson 2012; Jackson 2016]
  - **Local atmospheric** forcing [Eden 2001a,b; Hirschi 2007; Deshayes 2008; Gastineau 2012]
  - **Local intrinsic** oceanic variability [Gregorio 2015; Leroux 2018; Jamet 2019]

→ Potentially, **complex interactions** [Spall 1996a,b; Bower 2000; Zhang 2007; Andres 2016] may complicate the interpretation of observations (RAPID) ...



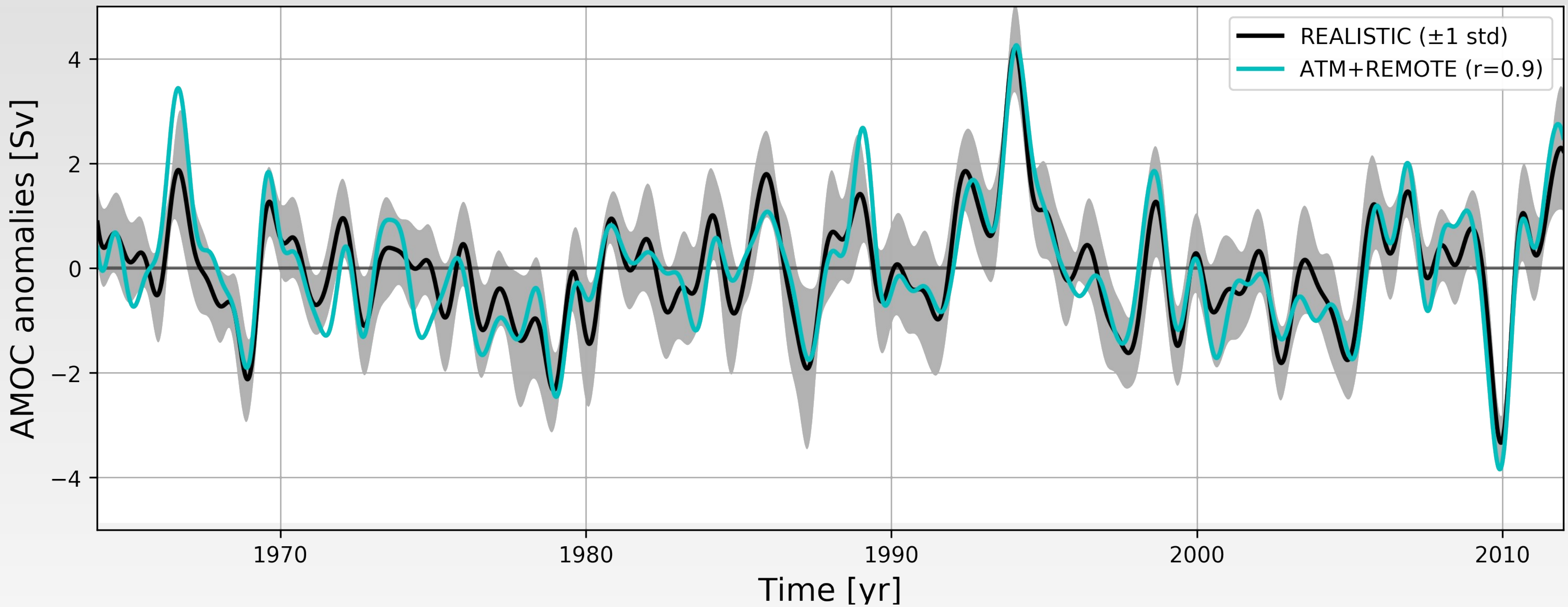
[Smeed 2014]

RAPID AMOC time series



Take-home message

➔ Nonetheless, we show that AMOC can be understood as a **linear combination** of signals with different origin



$$AMOC \approx AMOC^{ATM} + AMOC^{REMOTE} + AMOC^{INTRINSIC}$$

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Method

- Isolating the NA dynamics from the rest of the world:
  - Regional, **eddy-resolving (1/12°)** oceanic configuration of the MITgcm
  - Partially coupled (CheapAML [Deremble 2013])
  - Atmospheric forcing: DFS4.4 [Brodeau 2010]
  - Boundary conditions: ORCA12 [Molines 2014]
  - **50 yr long simulations**

- Isolating the forced variability from its intrinsic counterpart:
  - 12 ensemble members simulations
  - Micro initial conditions [Stainforth 2007]
  - Ensemble spread → **intrinsic signal**

$$\sigma_I^2 = \overline{\frac{1}{N}\sum_{i=1}^{N}\left[f_i(t) - \langle f_i(t)\rangle\right]^2}$$

  - Ensemble mean → **forced signal**

$$\sigma_F^2 = \frac{1}{T}\sum_{t=1}^{T}\left[\langle f_i(t)\rangle - \overline{\langle f_i(t)\rangle}\right]^2$$

- Isolating local atmospheric forcing from signals of remote origin:

Atmosphere / Open boundaries	*Normal year* *Aug 2003 – July 2004*	*Fully Varying* *1963-2012*
Climatological	**RESIDUAL**	**ATM**
Fully Varying	***REMOTE***	**REALISTIC**

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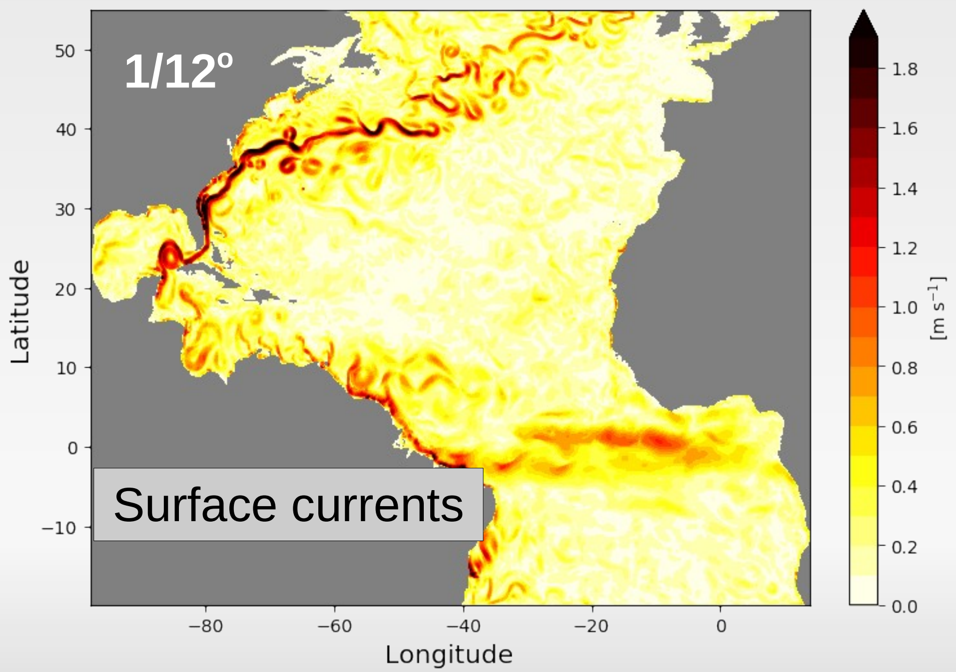
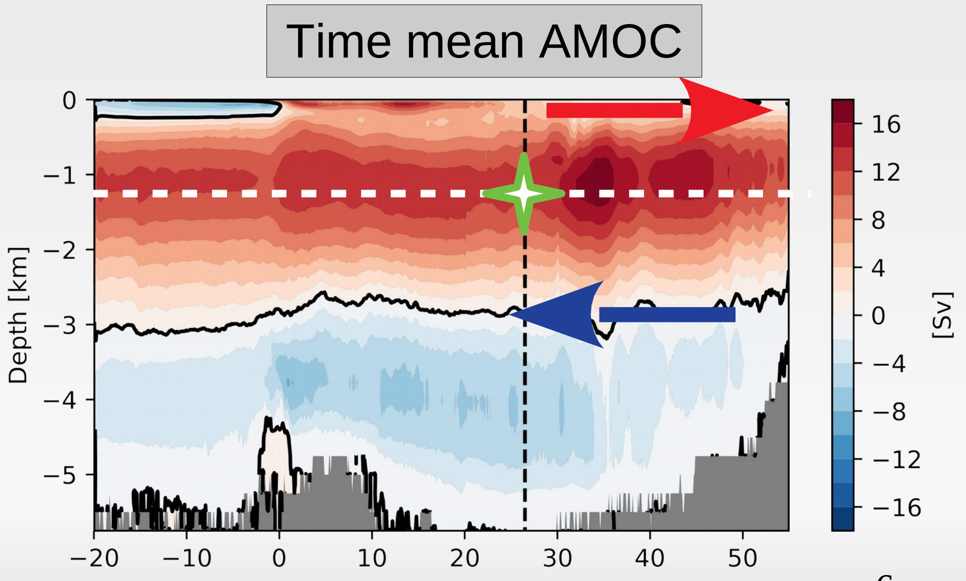
Method

- The simulation delivers a reliable representation of the North Atlantic ocean circulation
- Ensemble production represents about 8,000,000 cph and 150 TB
- Model configuration and outputs are available at: **https://github.com/quentinjamet/chaocean**

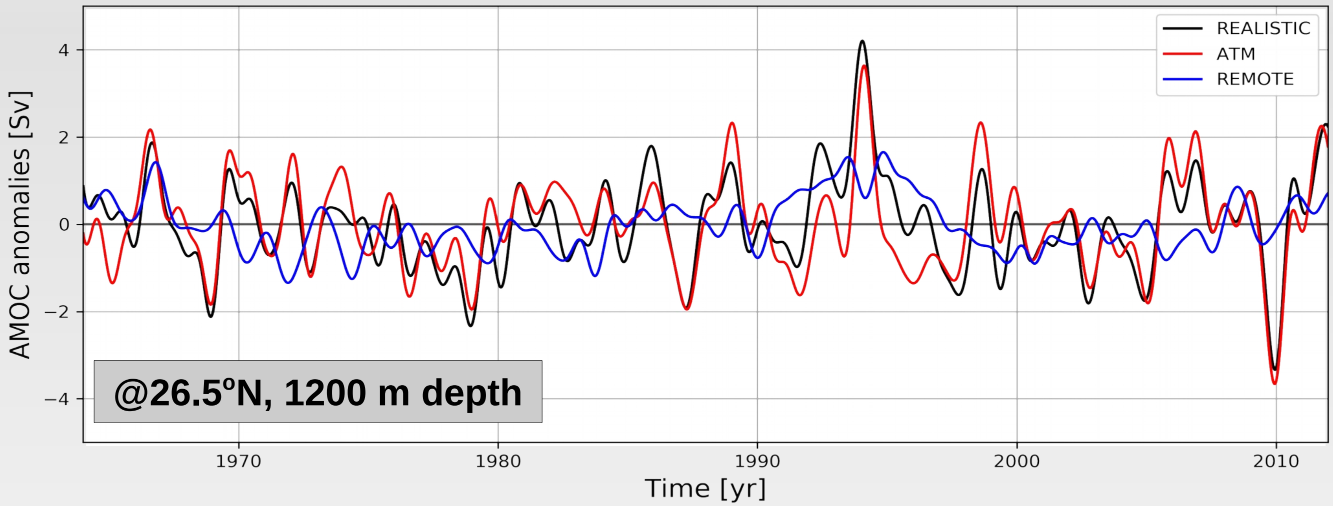


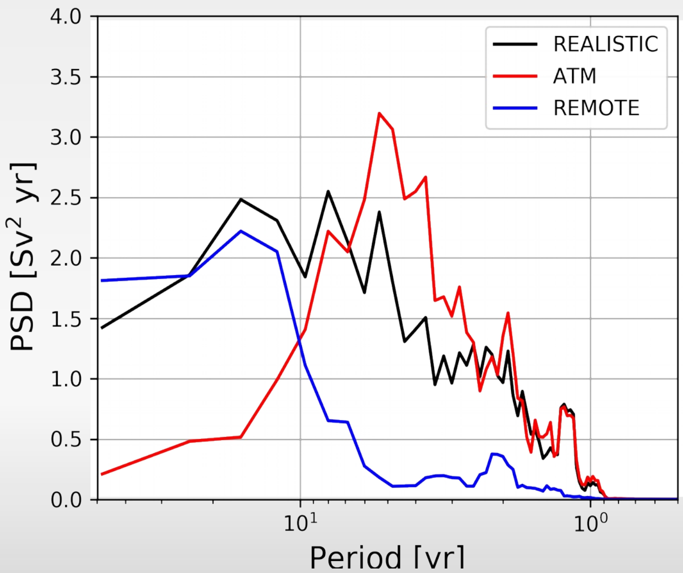


AMOC at 26.5°N

Forced variability - ensemble mean

- Compare the **forced AMOC variability** simulated by the 3 ensembles **REALISTIC**, **ATM**, and ***REMOTE***





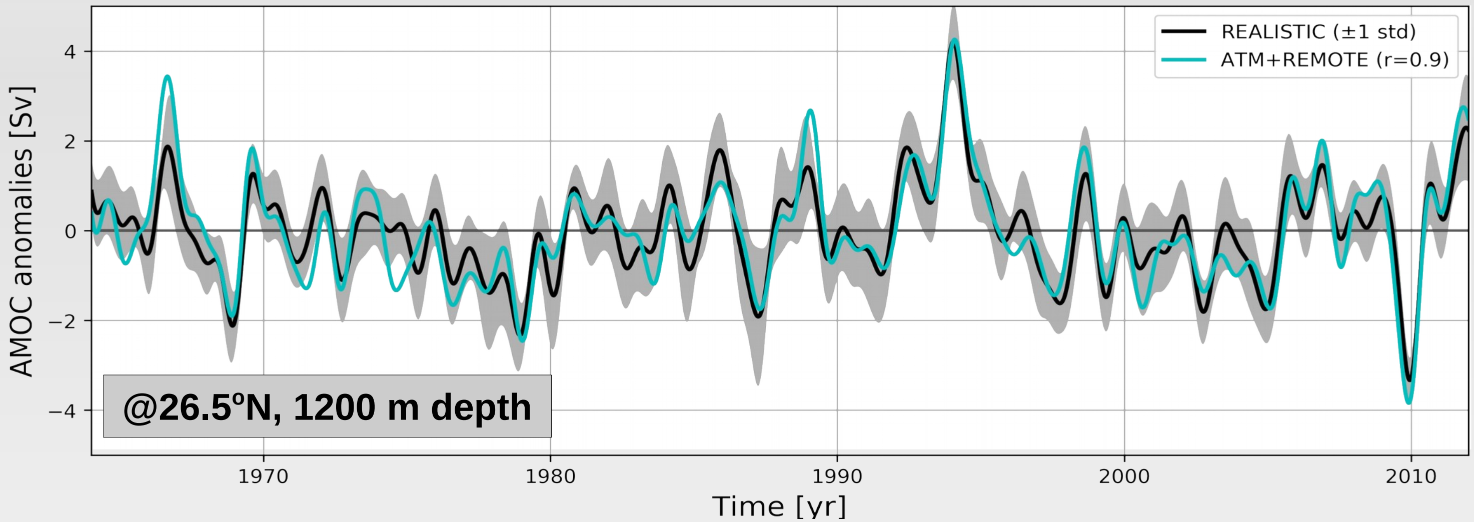
➔ Marked time scales separation

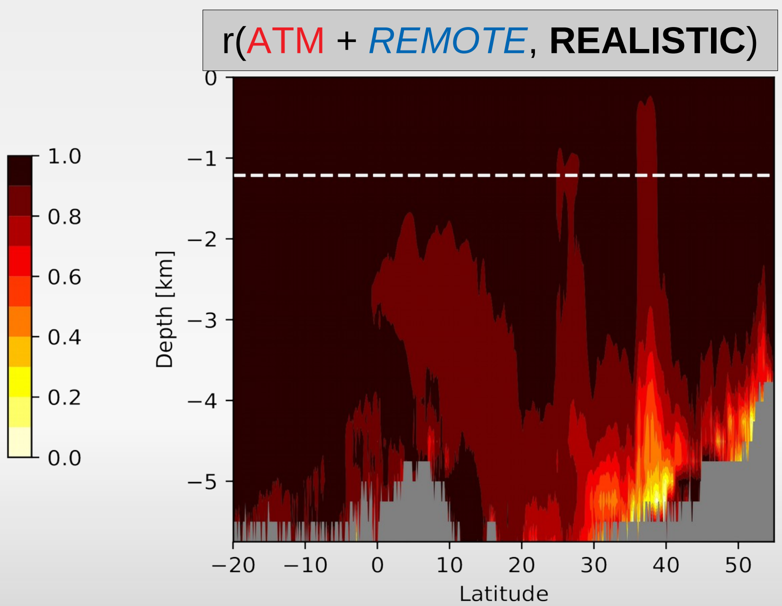
- Remote (boundary) signals: → decadal time scales
- Local (atmospheric) forcing: → interannual time scales

AMOC at 26.5°N

Forced variability - ensemble mean

- Compute a **linear reconstruction** as **ATM** + ***REMOTE*** and compare it with **REALISTIC**





- High correlations between reconstructed and realistic AMOCs in most of the basin

→ Forced AMOC variability can be understood as a linear combination:

$$\langle AMOC \rangle \approx \langle AMOC^{ATM}_{.<10\,yr} \rangle + \langle AMOC^{REMOTE}_{.>10\,yr} \rangle$$

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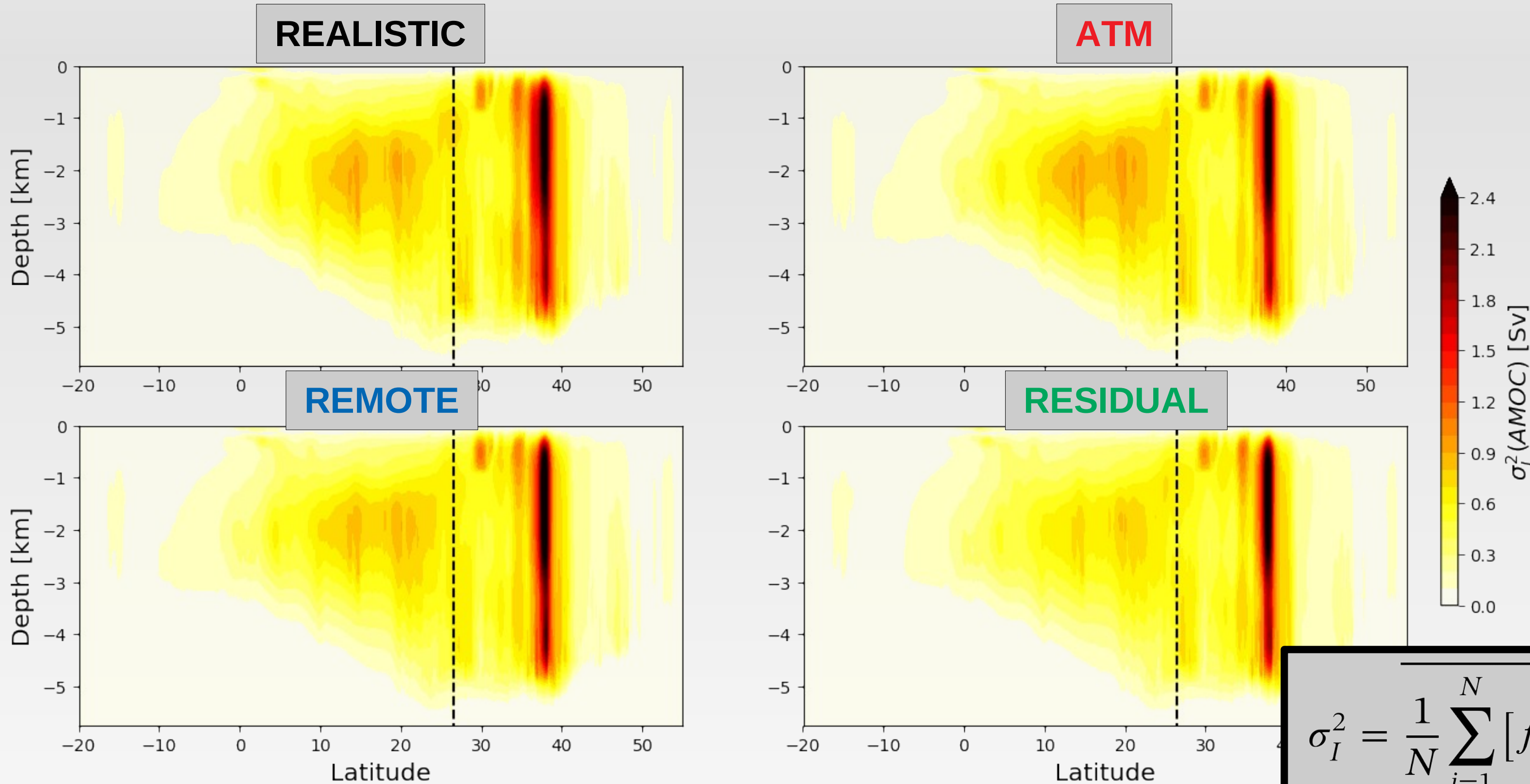
AMOC at 26.5°N

Intrinsic variability – ensemble spread

- Compare **intrinsic AMOC variability** in each ensemble and assess its sensitivity to the sourrounding forced signal



$$\sigma_I^2 = \overline{\frac{1}{N}\sum_{i=1}^{N}\left[f_i(t) - \langle f_i(t)\rangle\right]^2}$$

- Each ensemble exhibits specific ensemble mean AMOC variability, **BUT** they all simulate a similar ensemble spread

➔ **No causal relationship between intrinsic and forced AMOC**

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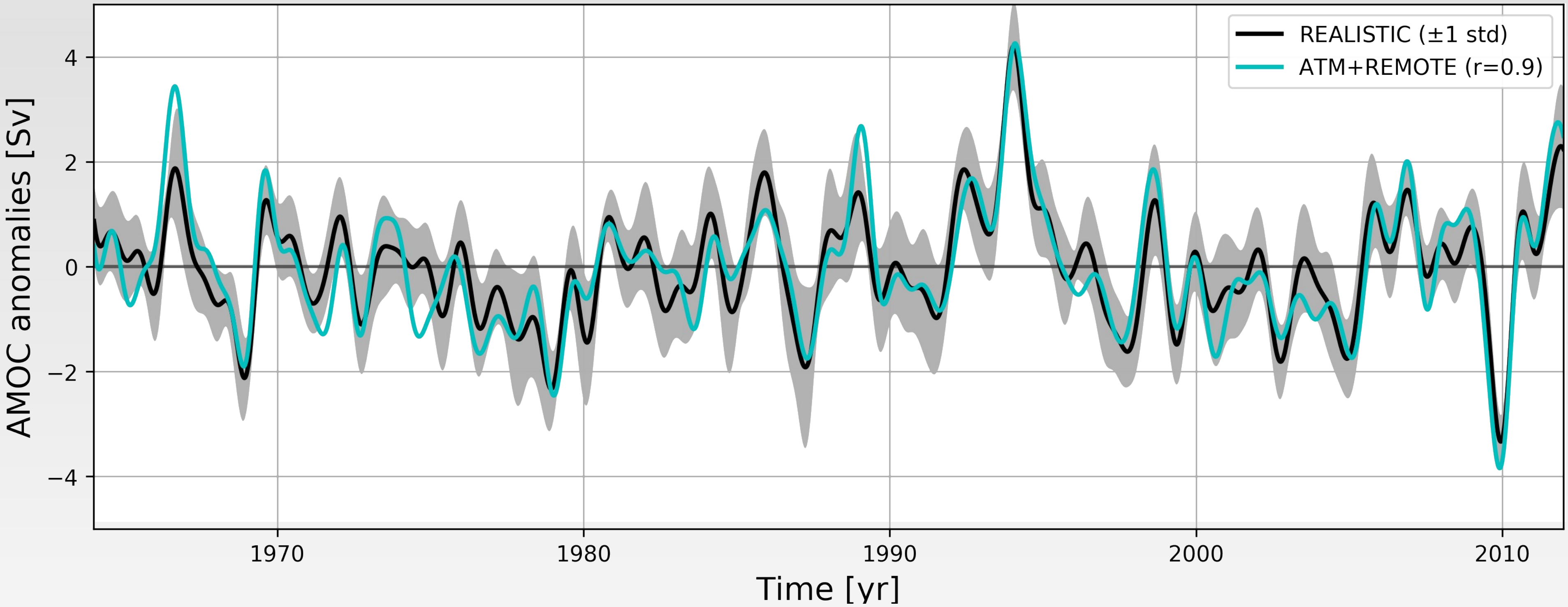
Take-home message

➔ AMOC can be understood as a linear combination of signals with different origin



$$AMOC \approx AMOC^{ATM}_{.<10\,yr} + AMOC^{REMOTE}_{.>10\,yr} + AMOC^{INTRINSIC}$$

- For further details, see Jamet et al. J. Clim 2020

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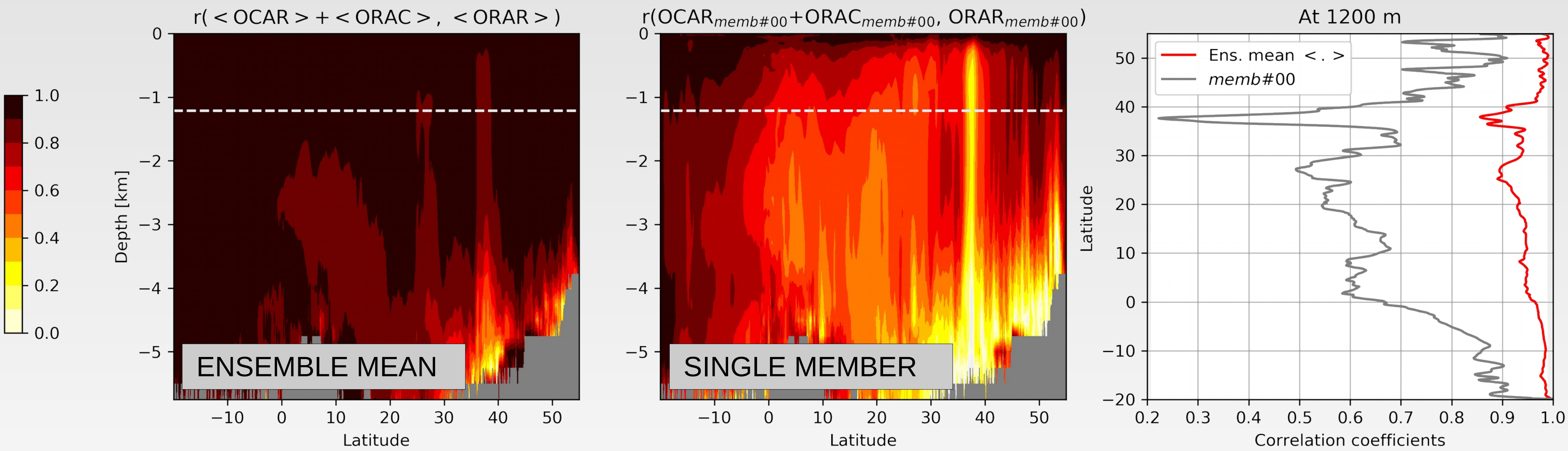
Supplementary

- Compare **ensemble results** with those obtained with **single simulations**, i.e. without ensemble averaging

r(ATM + *REMOTE*, **REALISTIC**)



→ Correlations decrease to **r=0.6 in the subtropical gyre**, and to **r=0.2 in the eddying Gulf Stream**

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Supplementary

$$\sigma_F^2 = \frac{1}{T}\sum_{t=1}^{T}\left[\langle f_i(t)\rangle - \overline{\langle f_i(t)\rangle}\right]^2$$

$$\sigma_I^2 = \overline{\frac{1}{N}\sum_{i=1}^{N}\left[f_i(t) - \langle f_i(t)\rangle\right]^2}$$

$$\sigma_T^2 = \sigma_F^2 + \sigma_I^2$$