Towards a next generation AMOC observing system

presented by Eric Chassignet and Eleanor Frajka-Williams

on behalf of the CLIVAR AMOC Task Team

The CLIVAR AMOC Task Team

- The US CLIVAR AMOC Science Team is sunsetting *(was 2020, now 2022)*, after a decade in existence. This leaves a gap in coordination of AMOC research.
- In order to increase international participation, the international CLIVAR Atlantic Regional Panel formed the CLIVAR AMOC Task Team, with the intention to

  - to continue *some* of the work of the US CLIVAR AMOC Science Team, and

  - call attention to a couple pressing issues in the international AMOC community.
- Ideas were developed in 2020 and early 2021, to decide initial Terms of Reference and form the initial team.

Launching a CLIVAR AMOC Task Team, out of the CLIVAR Atlantic Region Panel…

Terms of Reference

1. To promote and coordinate international collaborations amongst observational and modelling studies.
2. To coordinate international workshops on AMOC science & impact topics (2023).
3. To produce a summary report with identified priorities of the AMOC community.
4. To improve data and product distribution from AMOC programs.
5. To develop strategies for cost-effective, sustained monitoring of the AMOC (e.g., through an assessment of the observing system using Observation System Simulation Experiments).

Initial team composition

Name	Country	Affiliation
Eleanor Frajka-Williams (co-chair)	UK	National Oceanography Centre
Eric Chassignet(co-chair)	US	Florida State Univ
Gokhan Danabasoglu	US	NCAR
Laura Jackson	UK	Met Office
Johannes Karstensen	Germany	Helmholtz Centre for Ocean Research Kiel
Brad de Young	Canada	Memorial University
Paquita Zuidema	US	University of Miami
Rong Zhang	US	GFDL
Maria Paz Chidichimo	Argentina	Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)/Servicio de Hidrografía Naval
Sabrina Speich	France	Ecole Normale Superieure
Helen Pillar	US	Univ Texas at Austin
Meric Srokosz	UK	National Oceanography Centre
Mike Patterson	US	US CLIVAR

Near-term plans for AMOC Task Team

1. Transition from US CLIVAR AMOC team to CLIVAR AMOC Task Team over 2nd half of 2022
2. Discussion within the Task Team – on observing system requirements & evaluation

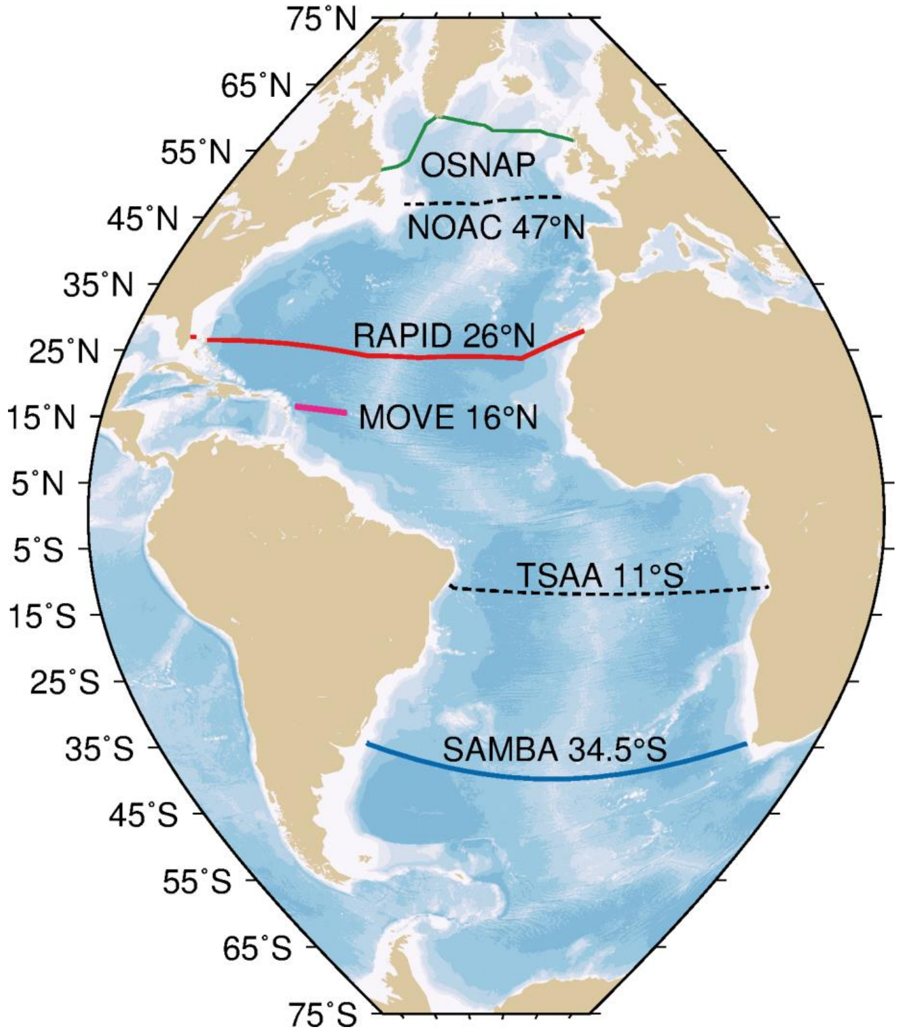
   From modelers: minimum requirements for a 'nature run'

   From observationalists: What questions can we not answer with the current observing system?
3. Discuss coordinating an open science meeting on AMOC observing requirements/open questions

Possible workshop:
Assessing and transforming the AMOC observing system

Motivating question: *Knowing what we know now – how should we observe the AMOC in the future?*

- How has the observing system been validated so far – what's missing?
- Moving forward - In what ways can we combine observations and models to define how effective our observing system is? (OSSEs, OSEs, adjoints, process / timescale / feedback evaluations)
- What do we require from a model to be used as a nature run? (e.g., should we just calculate OSSEs in as many models as possible or is there some filter to decide whether a model is 'good enough')



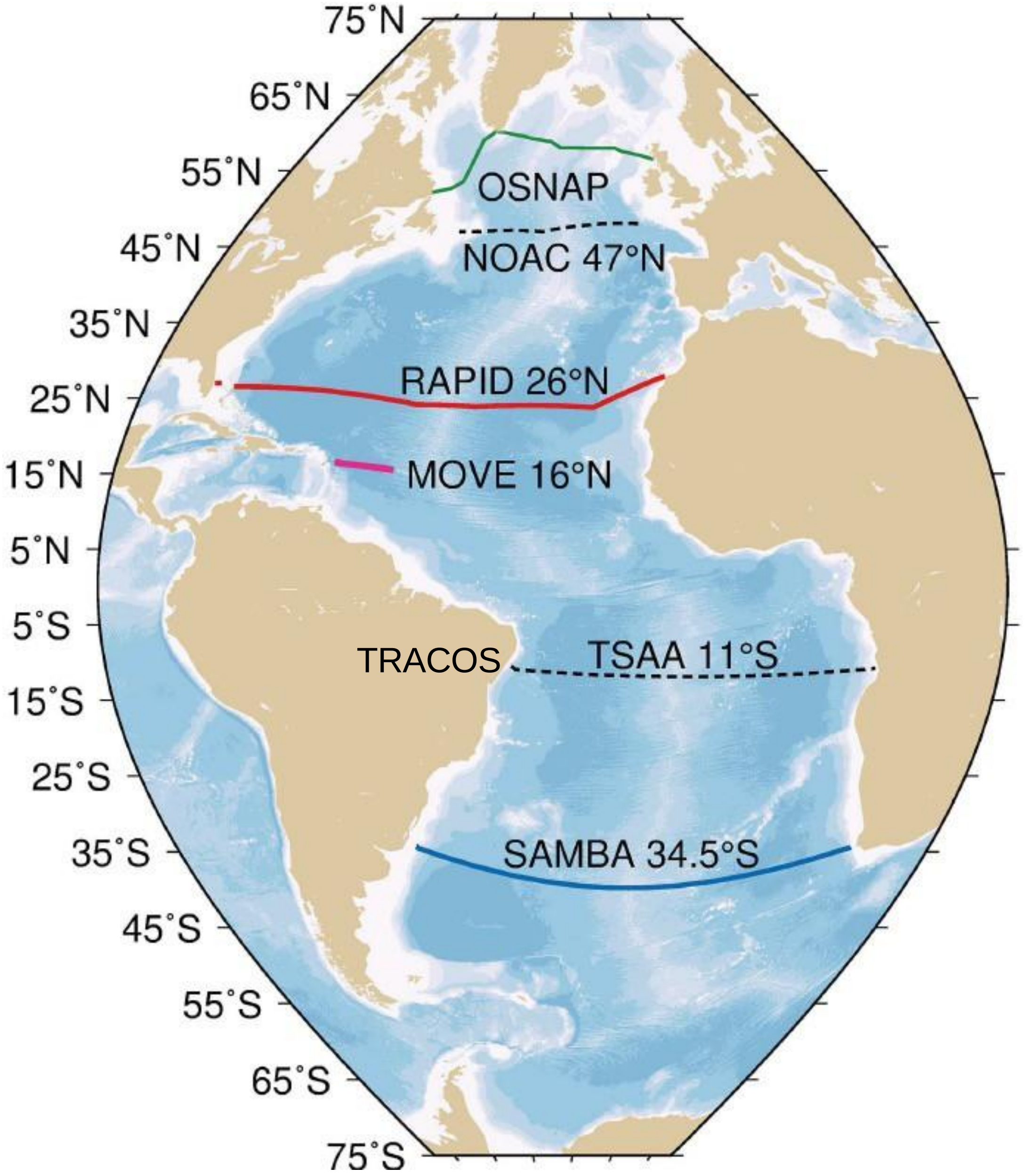
AMOC Observing System Implementation

Array	Configuration	Core variables
OSNAP	Trans-basin mooring array 53°N-60°N	MOC, MHT, MFT 30-day resolution 2014-present
NOAC	Trans-basin mooring + PIES array at 47°N	MOC Bi-monthly 2016-present
RAPID	Trans-basin mooring array at 26.5°N	MOC, MHT, MFT 10-day resolution 2004-present
MOVE	Western basin PIES array	MOC Daily resolution 2000-present
TRACOS	Trans-basin PIES array at 11°S	MOC 5-day resolution 2013-present
SAMBA	Trans-basin PIES array at 34.5°S	MOC, MHT Daily resolution 2009-2010; 2013-present

Argo/SSH lines at: 41°N, 20°S, 25°S, 30°S, 35°S

Commercial ships: Oleander, Nuka Arctica, Norröna

Hydrography: OVIDE, among others

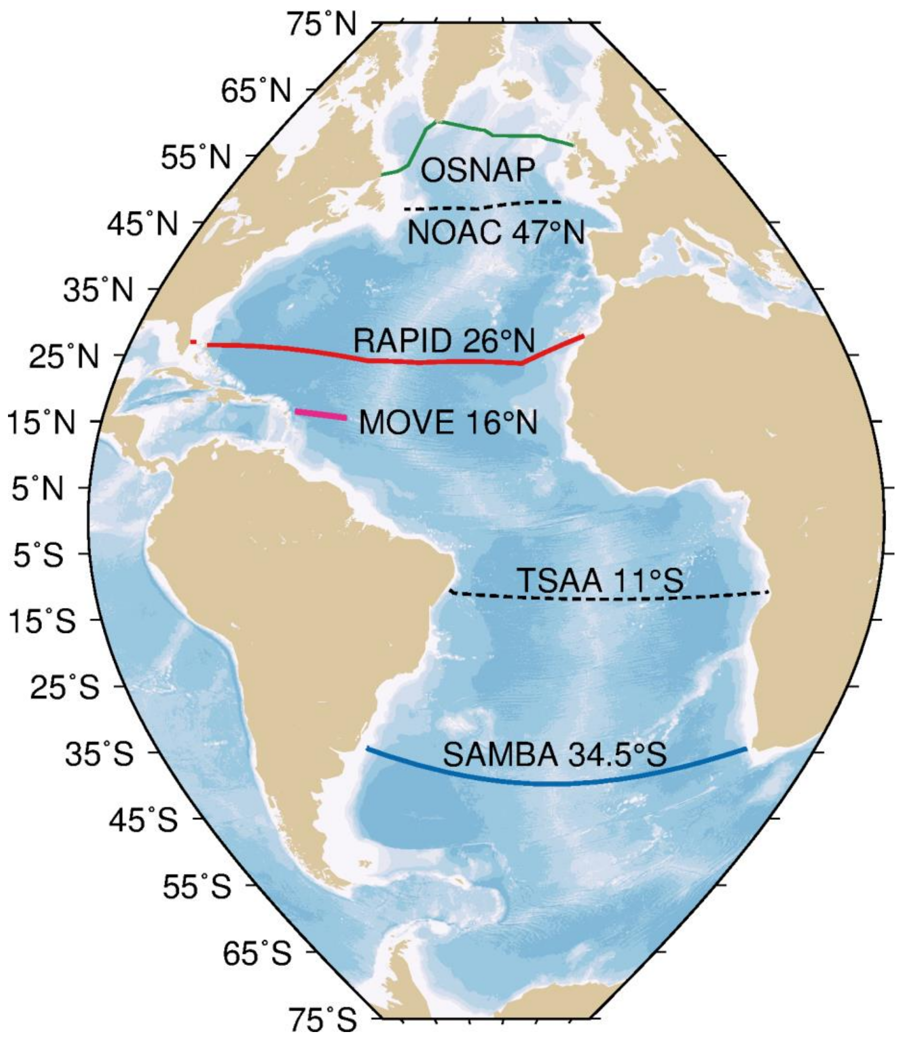


Frajka-Williams et al., 2019

Background & Rationale

- There are a multitude of observational efforts underway to estimate the Atlantic meridional overturning circulation, its volume, heat, freshwater and other property transports.
- The observations have been widely used to
  - Quantify variability of the large-scale ocean circulation variability and its response to atmospheric forcing
  - Determine consequences of transport variations on e.g., heat and freshwater content
  - Investigate meridional coherence
  - As a benchmark for numerical models: MOC/MHT/MFT strength and variability, and their relationship to forcing

- What questions are yet unanswered by the observing arrays?
- Going into the future, assuming a tightening of the funding situation, what would a sustainable AMOC observing system deliver?

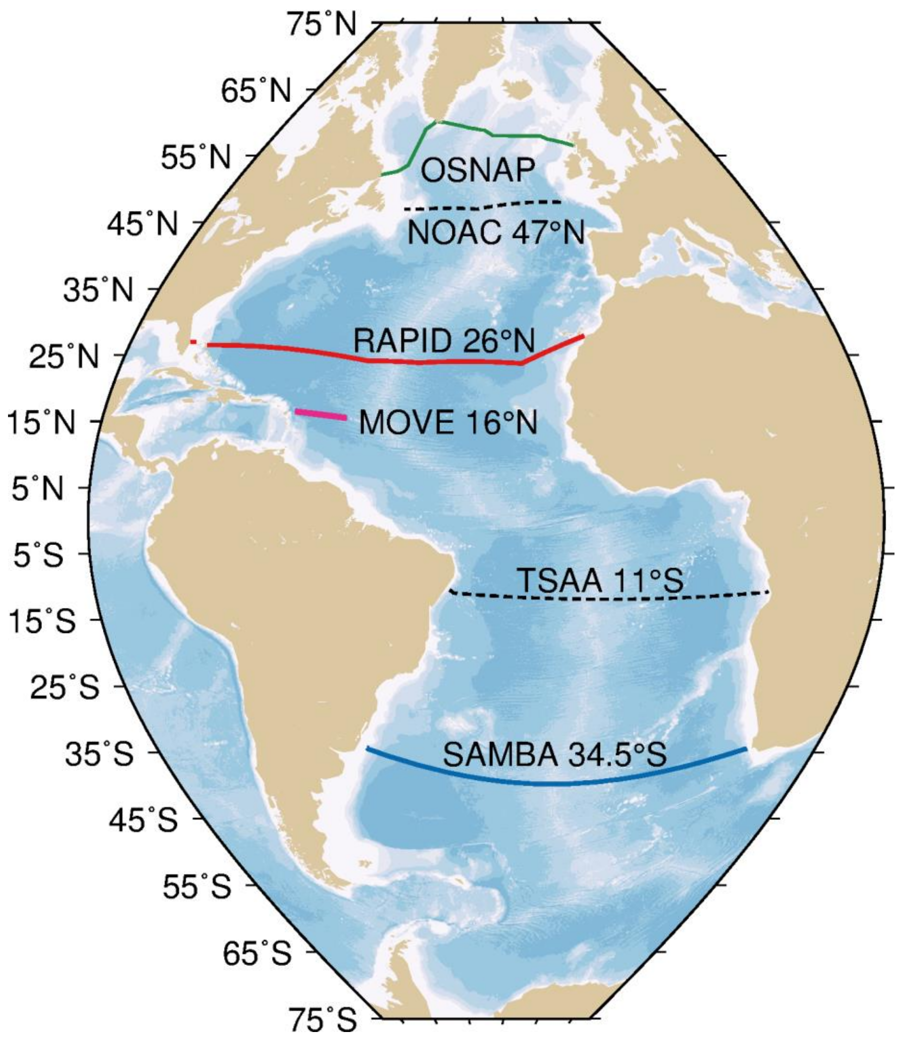


Future AMOC Workshop

- Going into the future, assuming a tightening of the funding situation, what should the AMOC observing system look like?

- Would it comprise mooring arrays at key latitudes? What latitudes?
- Would it blend boundary measurements with interior?
- Can the reference level problem be overcome?
- What processes can/should/must be captured?

Using observational or modelling tools, sketch out a proposed AMOC observing system.

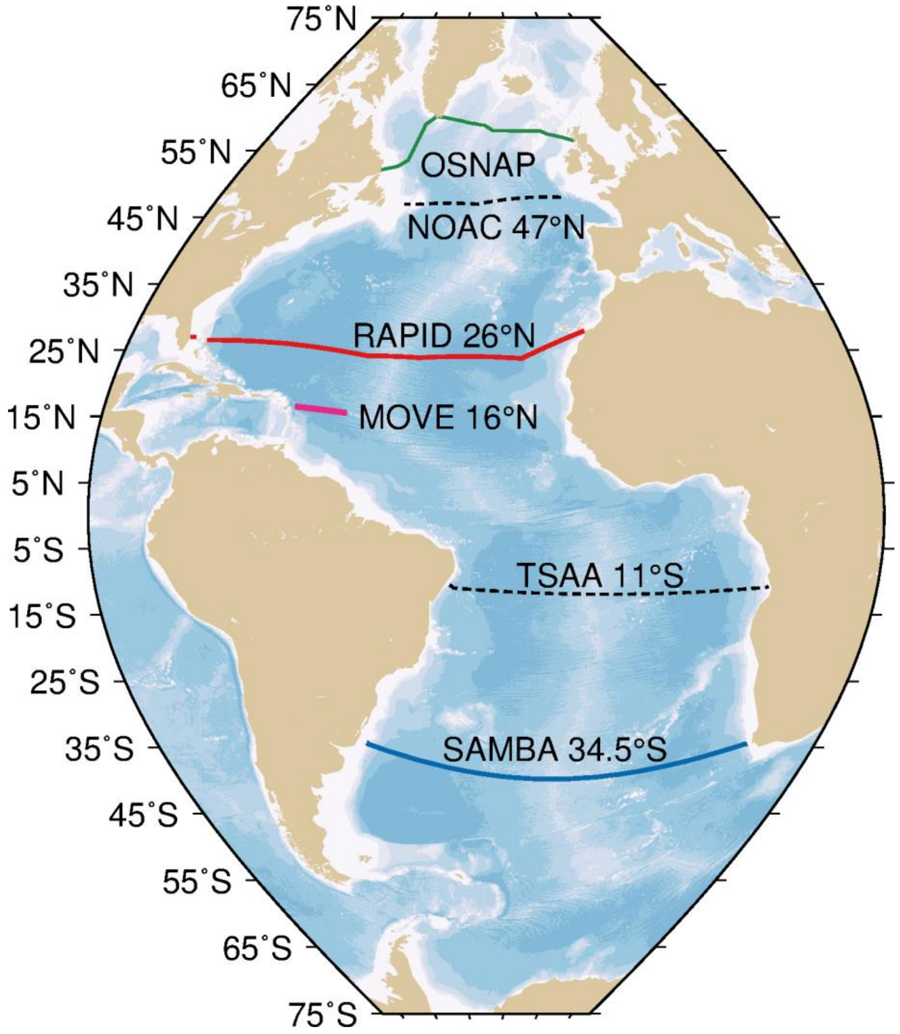


Unanswered AMOC questions

It may be worth considering what questions remain unanswered by the current set of observations

1. What are the key timescales / processes responsible for meridional coherence (or lack thereof)?
2. At individual latitudes, what are the dominant forcings of AMOC transport variability on seasonal to decadal timescales?
3. Are there key latitudes/chokepoints in ocean circulation that differ in models and matter for coherence or divergence of transports? That matter for how the AMOC imprints on ocean heat content / SST / air-sea fluxes?
4. What AMOC-type observations are useful to benchmark models (MOC strength as a function of latitude?

Identifying these in multiple models may show where to look in observations…



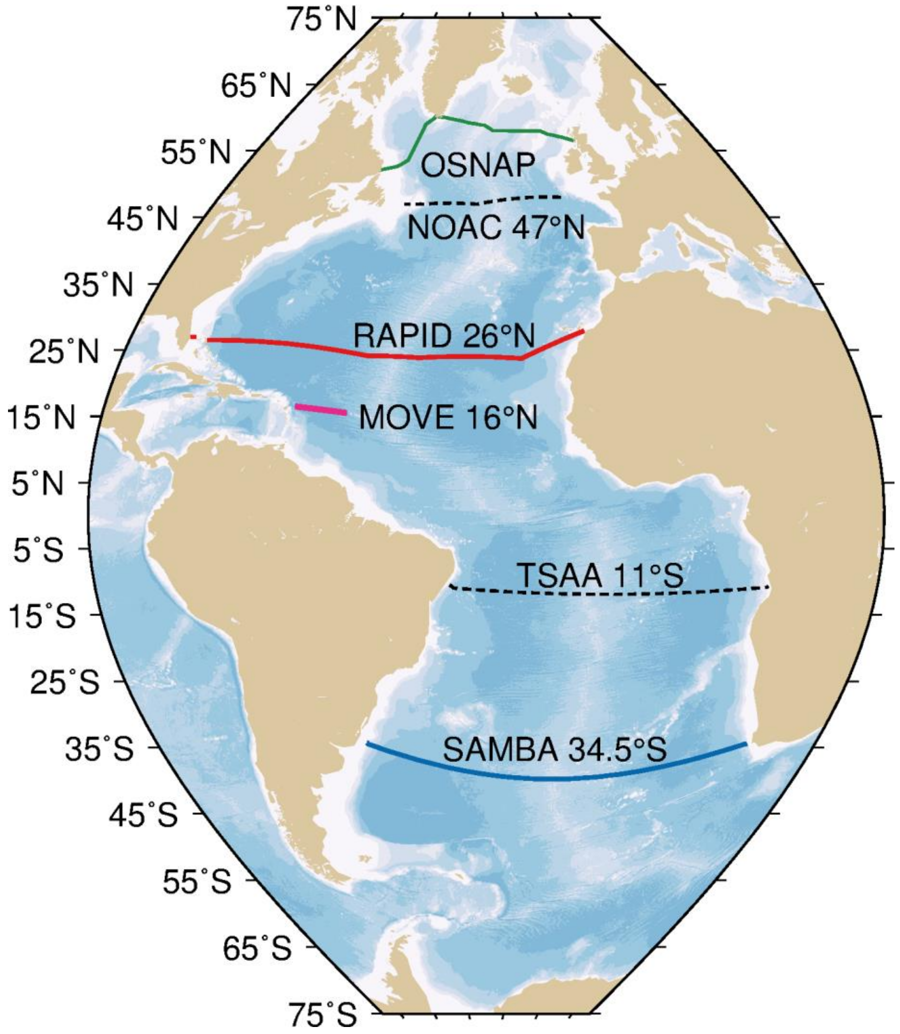
Unanswered AMOC questions

OSEs:

Can we use the AMOC Metrics tool to identify potential strengths / failures of the current AMOC observing system?

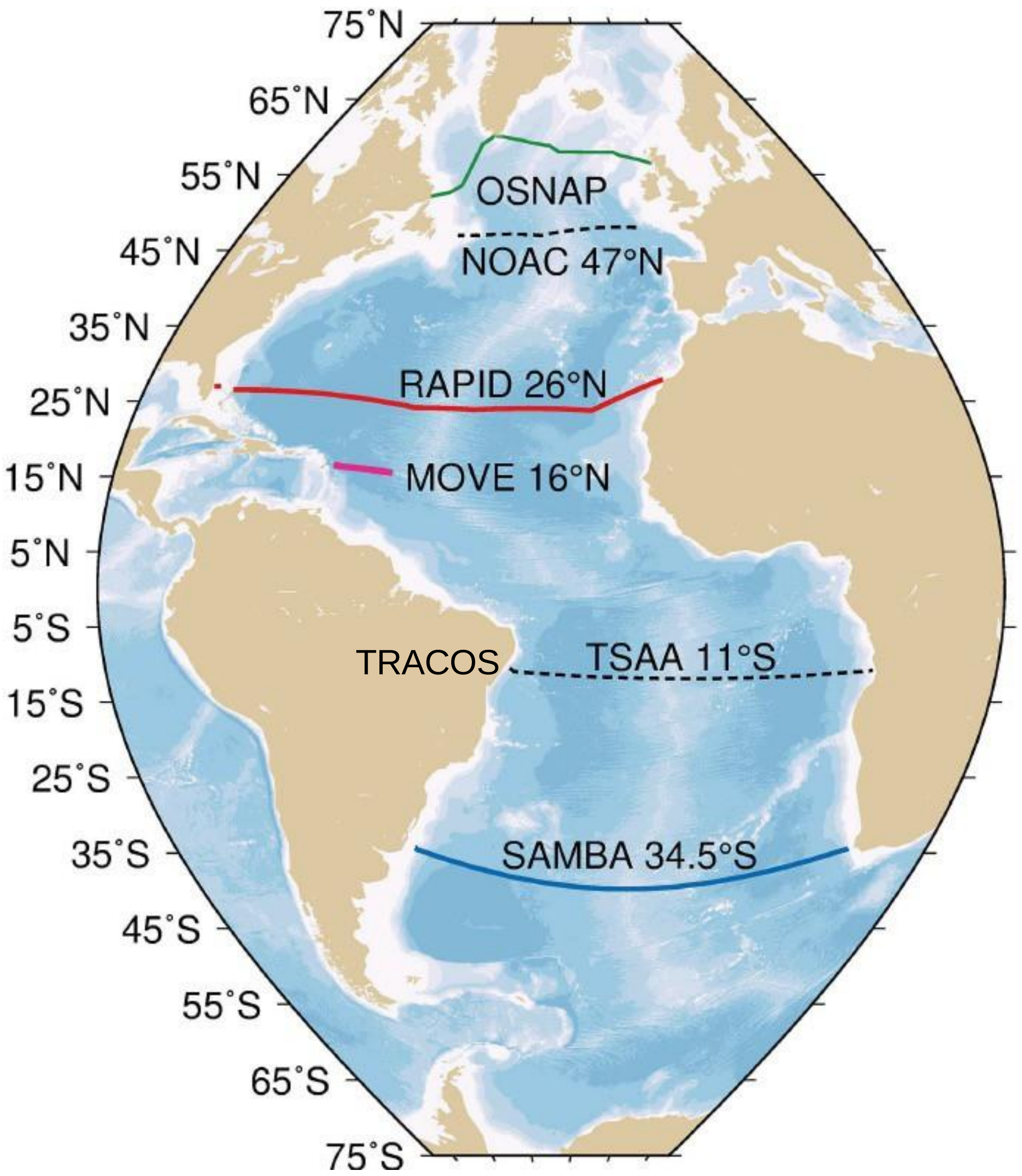
Is there a way to test whether / how the observing gaps can be filled with altimetry (current generation or SWOT) and other autonomous observations can improve/reduce uncertainty in observations?

What about reanalyses? Where are there unacceptably large uncertainties in reanalysis-based estimates of AMOC transport / variability / key metrics.



AMOC Observing System Implementation

Array	Reference velocity	Coordinate
OSNAP	Time-mean altimetry + barotropic velocity chosen to zero the net mass transport	Density
NOAC		Density
RAPID	Chosen to zero the net mass transport	Depth
MOVE	Level of no motion	Depth
TRACOS	Time-varying barotropic velocity from PIES + time-mean level of no motion at 1130 m	Depth
SAMBA	Time-varying barotropic velocity from PIES + time-mean from ECCO2	Depth



Frajka-Williams et al., 2019

AMOC Observing System Evaluation (N. Foukal)

Some recommendations to facilitate evaluation

1. Adopt a common set of standards between mooring arrays:
    a. Report overturning in density space
    b. Reference velocity shear to satellite altimetry
    c. Publish time series of compensation transports
2. Conduct more Observing System Simulation Experiments (OSSEs):
    a. Use the entire AMOC observing system rather than individual arrays
    b. Evaluate MHT and MFT in addition to MOC
    c. Compare OSSE results across multiple models

LEVERAGE EXISTING PROJECTS – EU HORIZON

EPOC: Explaining and Predicting the Ocean Conveyor

Central question:

How conveyor-like is the great ocean conveyor?

Resources & opportunities:

Existing observations

Observations at a range of latitudes: Moorings, Argo, altimetry, gravimetry + multi-observational methods

High resolution sediment cores spanning the western boundary of the Atlantic

New observations

Field programme at 47°N: for process-level understanding of meridional connectivity

New sensors and platforms:

- BGC sensors
- Gliders
- Drift-free bottom pressure

Existing + new simulations

Existing and new model runs: CMIP6 + high resolution coupled, idealised forcing scenarios to understand past and future change

V. high resolution coupled simulations: ICON with ≤ 5km ocean/atmos for small-scale coupled processes

EPOC science objectives (linked to 5 science work packages)

WP leaders

1. **Quantify past AMOC change.** Generate comprehensive records of AMOC transports across the whole Atlantic, to assess the timescales of transport variability and the degree to which the AMOC behaves as a conveyor belt. — **Joel Hirschi, Laura de Steur**
2. **Elucidate key processes of meridional connectivity.** Determine key processes that make or break meridional connectivity of ocean transports, & assess their representation in models, especially in high resolution coupled simulations. — **Monika Rhein, Jochem Marotzke**
3. **Explain past AMOC changes.** Identify the processes and drivers of recent change in the AMOC, and infer the likely roles of natural and anthropogenic forcings, and internal variability. — **Jon Robson, David Thornalley**
4. **Evaluate future AMOC evolution, impacts and abrupt change.** Assess the key processes of future AMOC changes and identify indicators of abrupt changes and AMOC- related climate impacts with societal relevance. — **Rym Msadek, Dian Putrasahan**
5. **Optimise AMOC observing.** Design, and deploy elements of, a next generation observing system for the entire system of the AMOC. — **Eleanor Frajka-Williams, Pete Brown**

WP6. Dissemination, engagement & impact — **Vikki Gunn**, Seascape Consultants

WP7. Project management & coordination — **Eleanor Frajka-Williams**

National Oceanography Centre

Universität Bremen

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

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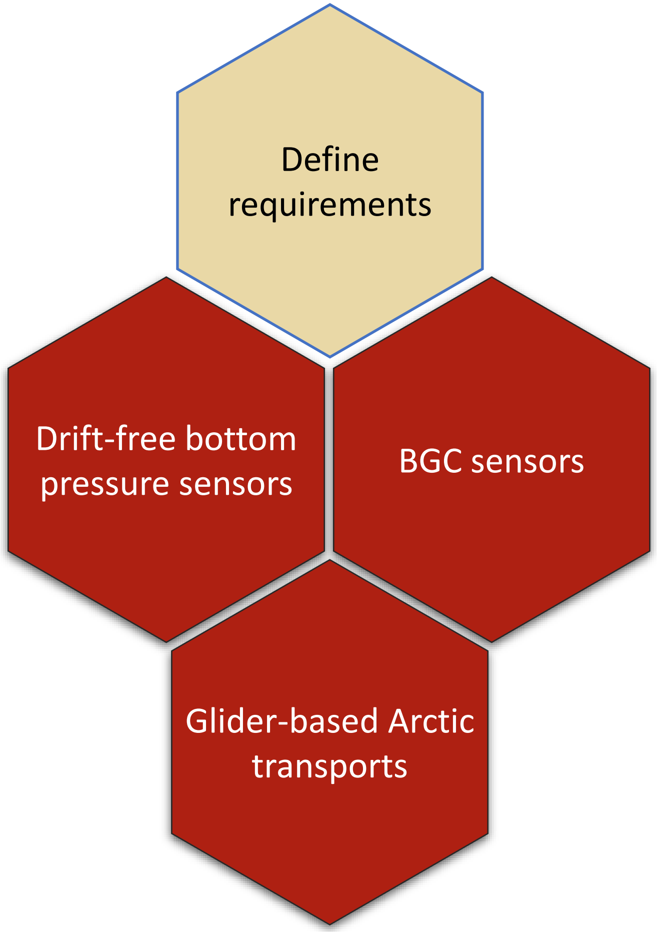
AWI

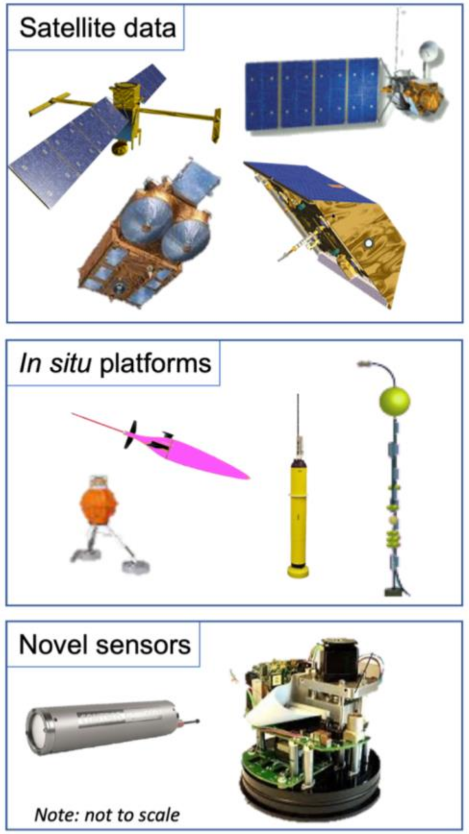
Work Package 5: Designing an effective & sustainable AMOC observing system

Design – and deploy elements of – a next generation observing system for the entire-system of the AMOC.

D5.1: Report on moored biogeochemical measurements in the Atlantic, their performance and use on transport mooring arrays

D5.2: Synthesis recommendation for an effective and sustainable AMOC observing system



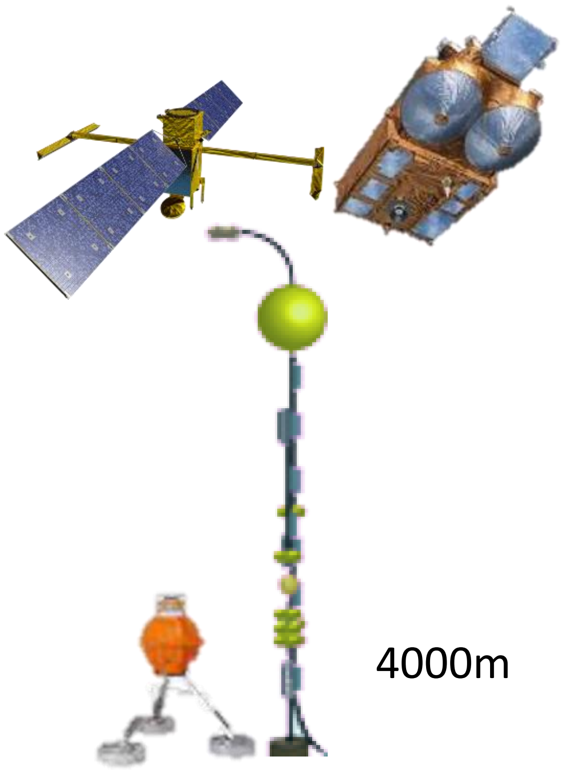


- Quantitatively evaluate AMOC observing systems including new autonomous observing approaches
- Carry out a proof-of-concept using drift-free bottom pressure recorders - evaluated against altimetry (including SWOT) and formally quantified uncertainties
- Evaluate accuracy and stability of new BGC sensors deployed for 2 years (on RAPID 26°N)
- Evaluate glider-based Arctic transport estimates against the Fram Strait mooring array

Proof-of-concept for ocean transports from A-0-A sensors

Evaluate the use of drift-free bottom pressure sensors to directly measure reference level velocities (for geostrophic ocean currents).

In EPOC project - Explaining and Predicting the Ocean Conveyor (2022-2027, Horizon Europe, PI: Frajka-Williams)



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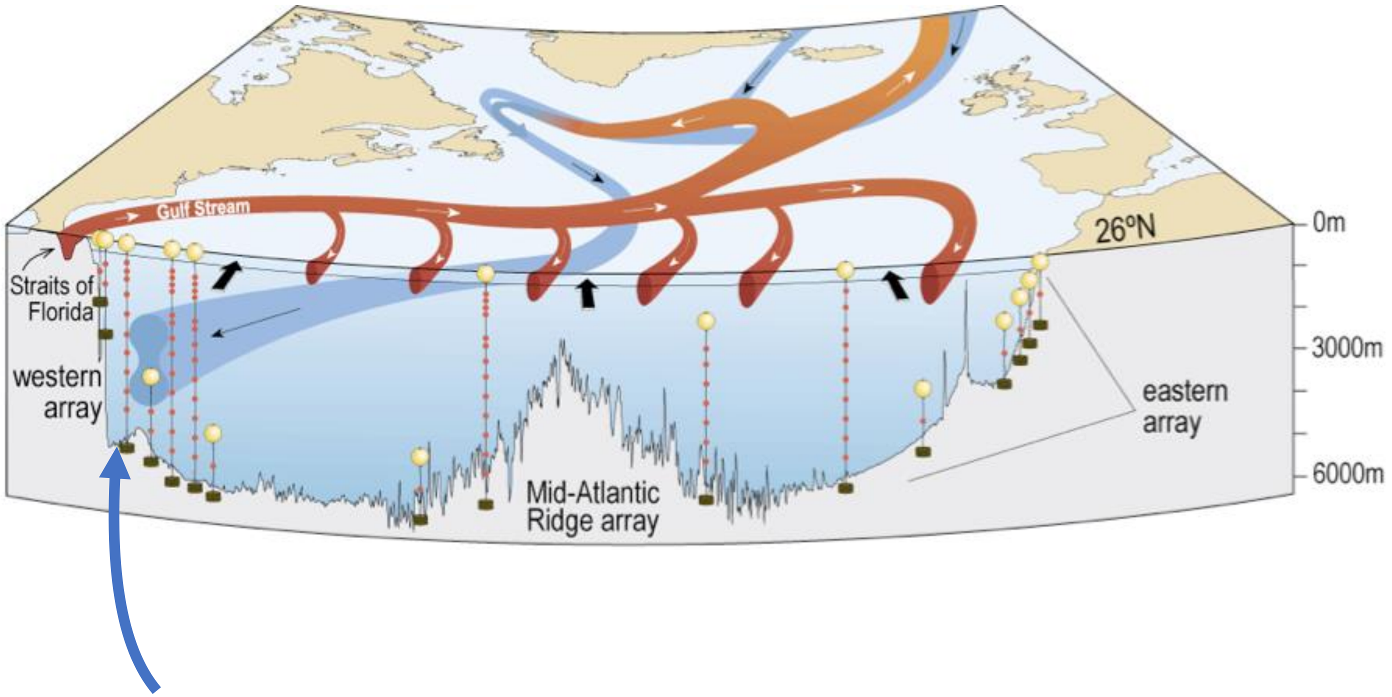

26°N

Planned measurements (2023-2025):

- A-0-A pressure sensors,
- Moorings with T&S, current meters,
- Underneath a SWOT calval swath (not crossover) at 26°N

Questions?