U.S. AMOC Science Team

www.usclivar.org/amoc

An U.S. inter-agency program

NASA Earth Science Division
Satellite data analyses, modeling and space-based observations

NOAA Climate Program Office
Observing systems, monitoring, climate modeling

NSF Geosciences Program
Process studies, models, and observations

U.S. Department of Energy
Climate and process modeling, climate impacts

Outline

- Background on Science Team objectives, organization, and history;
- A few examples of ongoing projects and recent results;
- Current and planned Science Team activities.

U.S. AMOC Program Scientific Objectives

- Implementation and evaluation of AMOC observing system;
- Assessment of AMOC state, variability, and change;
- Assessment of AMOC variability mechanisms and predictability;
- Assessment of the role of AMOC in global climate and ecosystems

58 funded projects supported by 4 agencies at the start of FY17

U.S. AMOC Program Organization

Science Team: Comprised of PIs, co-Is, post-docs, and students performing AMOC-relevant research designated by the funding agencies

Task Teams (TTs):

1. AMOC Observing System Implementation and Evaluation
   (Chair: M. Femke de Jong; Vice-chair: Magdalena Andres)
2. AMOC State, Variability, and Change
   (Chair: Matthias Lankhorst; Vice-chair: Zoltan Szuts)
3. AMOC Mechanisms and Predictability (Chair: Wilbert Weijer; Vice-chair: Michael Spall)
4. Climate Sensitivity to AMOC: Climate/Ecosystem Impacts
   (Chair: Rong Zhang; Vice-chair: Martha Buckley)

Executive Committee:

Science Team chair: Gokhan Danabasoglu

+ TT chairs and vice-chairs

The U.S. AMOC Executive Committee is charged with:

- Identifying research needs to achieve the program objectives;
- Encouraging and developing research activities to address these needs;
- Coordinating ongoing U.S., and whenever possible international, research activities to address the program objectives;
- Summarizing the state of the science and program progress;
- Developing input to AMOC program reports as necessary.

U.S. AMOC Program History

- January 2007: AMOC identified as a near-term priority by JSOST
- October 2007: U.S. AMOC Implementation Plan released
- March 2008: U.S. AMOC Science Team formed
- May 2009: 1st Annual PI Meeting (Annapolis, MD)
- June 2010: 2nd Annual PI Meeting (Miami, FL)
- July 2011: Joint U.S./U.K. AMOC Science Conference (Bristol, U.K.)
- August 2012: 3rd U.S. AMOC Science Team Meeting (Boulder, CO)
- 2012-2013: External Review of the Program
- July 2013: Joint U.S./U.K. International AMOC Science Meeting (Baltimore, MD)
- September 2014: 4th U.S. AMOC Science Team Meeting (Seattle, WA)
- July 2015: Joint U.S./U.K. International AMOC Science Meeting (Bristol, U.K.)

U.S. AMOC Program History

- May 2016: Workshop on Connecting Paleo and Modern Oceanographic Data to Understand AMOC over Decades to Centuries (Boulder, CO)
- May 2017: 5th U.S. AMOC Science Team Meeting (Santa Fe, NM)
- 24-27 July 2018: Joint U.S./U.K. International AMOC Science Meeting (Miami, FL)


Davis Strait
Norrona
OSNAP
Line W
Oleander
RAPID
MOVE
US CLIVAR
Climate Variability & Predictability
The OSNAP Array
1000m
2000m
3000m
4000m
53°N Array
West and East Greenland Arrays
Mid-Atlantic Ridge Array
US CLIVAR
Climate Variability & Predictability
GECCO2
ORAS4
NCAR-CORE
MOVE-CORE
SODA
DEPRESYS
ECDA
Winter sea ice change 1997–2007
Observed
Predicted
MORE SEA ICE LOST
MORE SEA ICE GAINED
D (m)
Full_AMV
Trop_AMV
SPG_AMV
Trop_AMV + SPG_AMV
2007 Winter
2008 Winter
US CLIVAR
Climate Variability & Predictability
2016 US AMOC SCIENCE TEAM REPORT ON
PROGRESS AND PRIORITIES
September 2016

Semi-annual Task Team Telecons

Task Team 3 Webinar Series

March 17, 2016
Size matters: Another reason why the Atlantic is saltier than the Pacific (video | pdf)
Paola Cessi, Scripps Institution of Oceanography

April 21, 2016
The salt advection feedback in eddying models (video | pdf)
Wilbert Weijer, Los Alamos National Laboratory

May 19, 2016
Robust and Nonrobust Aspects of AMOC Variability and Mechanism in the Community Earth System Model (video | pdf)
Gokhan Danabasoglu, National Center for Atmospheric Research

July 14, 2016
The impact of multidecadal North Atlantic Oscillation variations on Atlantic Ocean heat transport and rapid changes in Arctic sea ice (video | pdf)
Tom Delworth, NOAA/Geophysical Fluid Dynamics Laboratory

September 15, 2016
Observations of salt transport and salinity changes in the Florida Current, and implications for oceanic advection (video | pdf)
Zoltan Szuts, University of Washington

October 20, 2016
Rethinking the AMOC stability in climate models (video | pdf)
Wei Liu, Yale University

November 17, 2016
T/S structure of the North Atlantic circulation and associated heat/freshwater transports (video | pdf)
Xiaobiao Xu, Florida State University

January 19, 2017
Ocean response to katabatic winds on the east Greenland shelf (video | pdf)
Michael Spall, Woods Hole Oceanographic Institution

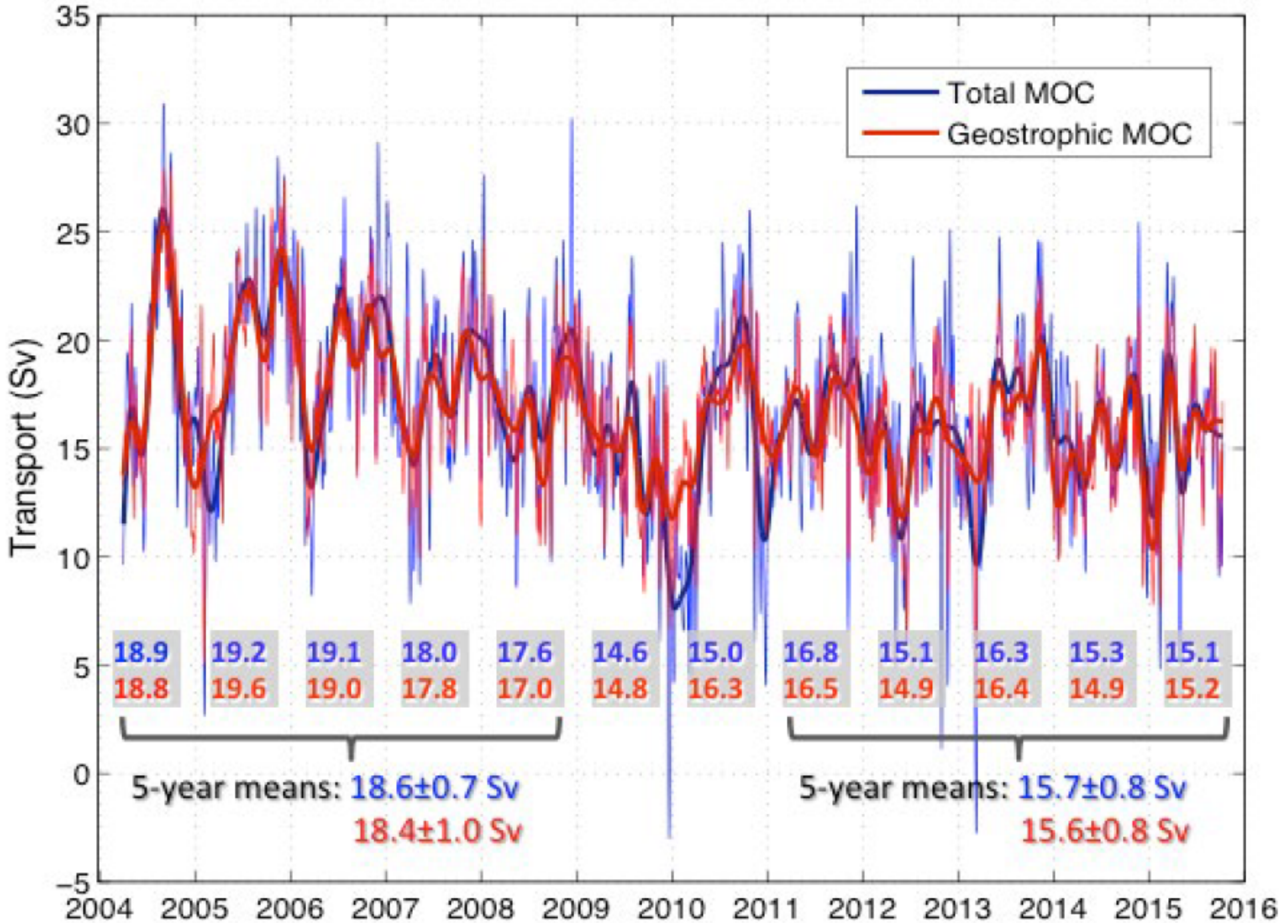
February 23, 2017
Role of African dust in the Atlantic meridional overturning circulation during Heinrich events (video | pdf)
Marlos Goes, University of Miami/NOAA Atlantic Oceanographic and Meteorological Laboratory

March 23, 2017
AMOC-related climate prediction using CESM (video | pdf)
Steve Yeager, National Center for Atmospheric Research

April 20, 2017
Thermal and haline effects on AMOC stability under different background climates
Aixue Hu, National Center for Atmospheric Research

May 18, 2017
Conceptual Constraints on Polar MOCs (video | pdf)
Tom Haine, Johns Hopkins University

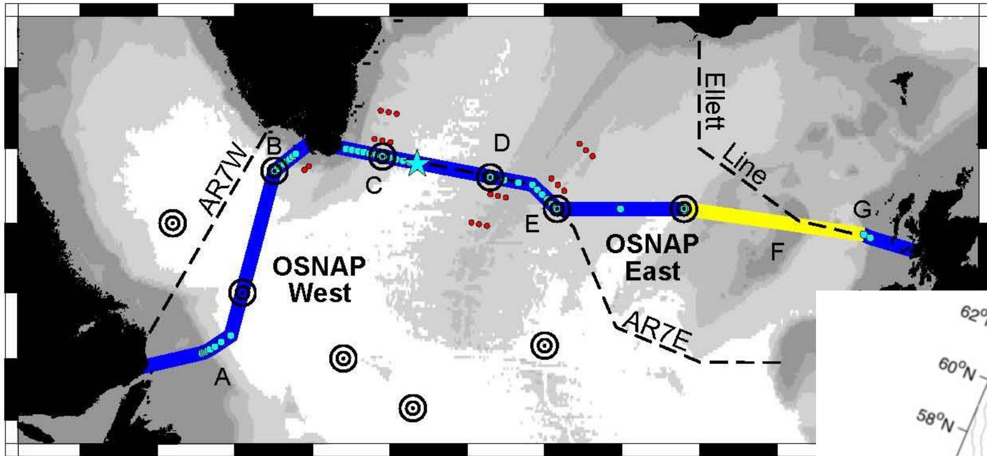
RAPID – MOCHA Array at 26.5°N



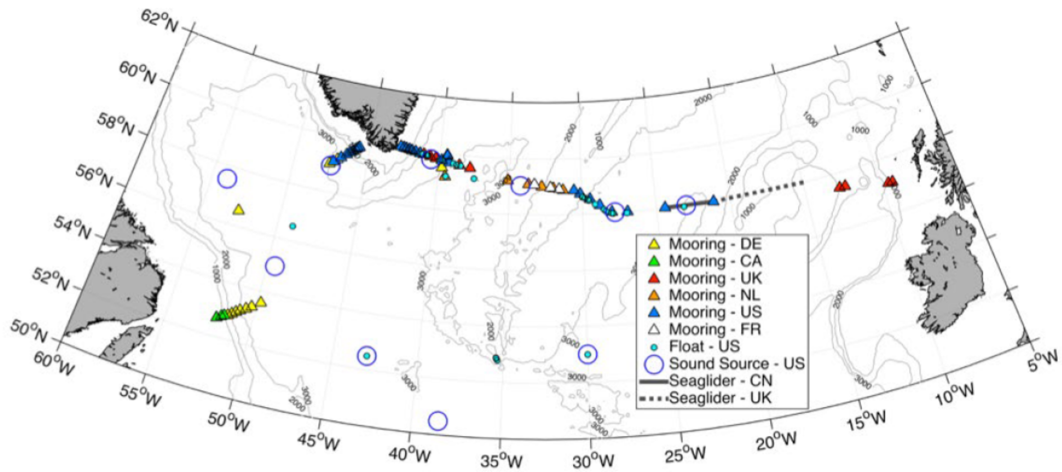
Johns et al.

AMOC declines from 18.6 Sv (2004-2008) to 15.7 Sv (2011-2015). There is a corresponding reduction in the heat transport from 1.33 PW to 1.17 PW.

OSNAP: Overturning in the Subpolar North Atlantic



Lozier et al.

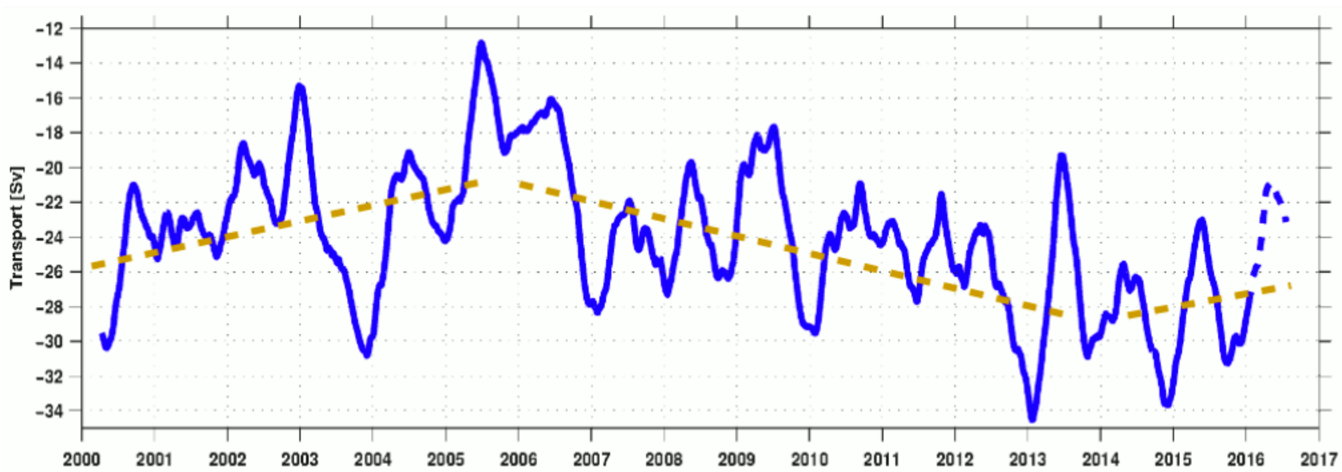


OSNAP objectives include:

- Quantify the subpolar AMOC and its intra-seasonal to interannual variability via overturning metrics, including associated fluxes of heat and freshwater.
- Determine the pathways of overflow waters in the NASPG to investigate the connectivity of the deep boundary current system.
- Relate AMOC variability to deepwater mass variability and basin-scale wind forcing.
- Determine the nature and degree of the subpolar-subtropical AMOC connectivity.

The entire OSNAP observing system was deployed in summer 2014. Initial sets of data have been recovered and calibrated. Initial results are in progress ….

MOVE: Meridional Overturning Variability Experiment (16°N)



Lankhorst et al.

www.usclivar.org/amoc/amoc-time-series

AMOC Time Series

This website lists available AMOC time series of transports and fluxes derived from instrument arrays. While the quality-controlled raw data collected from the individual instruments is commonly submitted to data repositories such as OceanSites or the World Ocean Data Base, there is no collection site for AMOC time series products. These products require substantial post-processing that may differ depending on the instrument array configuration (e.g., types of instruments, spatial and temporal coverage of the instruments). Here we provide a short overview of available time series of interest to the AMOC community with links to either the time series itself or the project website.

Line W

Data collected are analyzed to derive transport estimates of the Deep Western Boundary Current over the continental slope southeast of New England. The moored array time series, started in 2004 and completed in 2014, was maintained by the Woods Hole Oceanographic Institution (USA), with water property observations collected by investigators from Lamont-Doherty Earth Observatory (USA), Bedford Institute of Oceanography (Canada) and WHOI.

Record: May-01-2004 to May-02-2014

Sampling: Variable (depending on sensor and parameter: moored sensors typically logged at 15-30 minute interval; shipboard sampling done 1-2 times per year)

Uncertainty estimates available: Yes (in most cases)

SAMOC/SAMBA(South Atlantic Meridional Overturning Circulation/SAMoc Basin-wide Array)

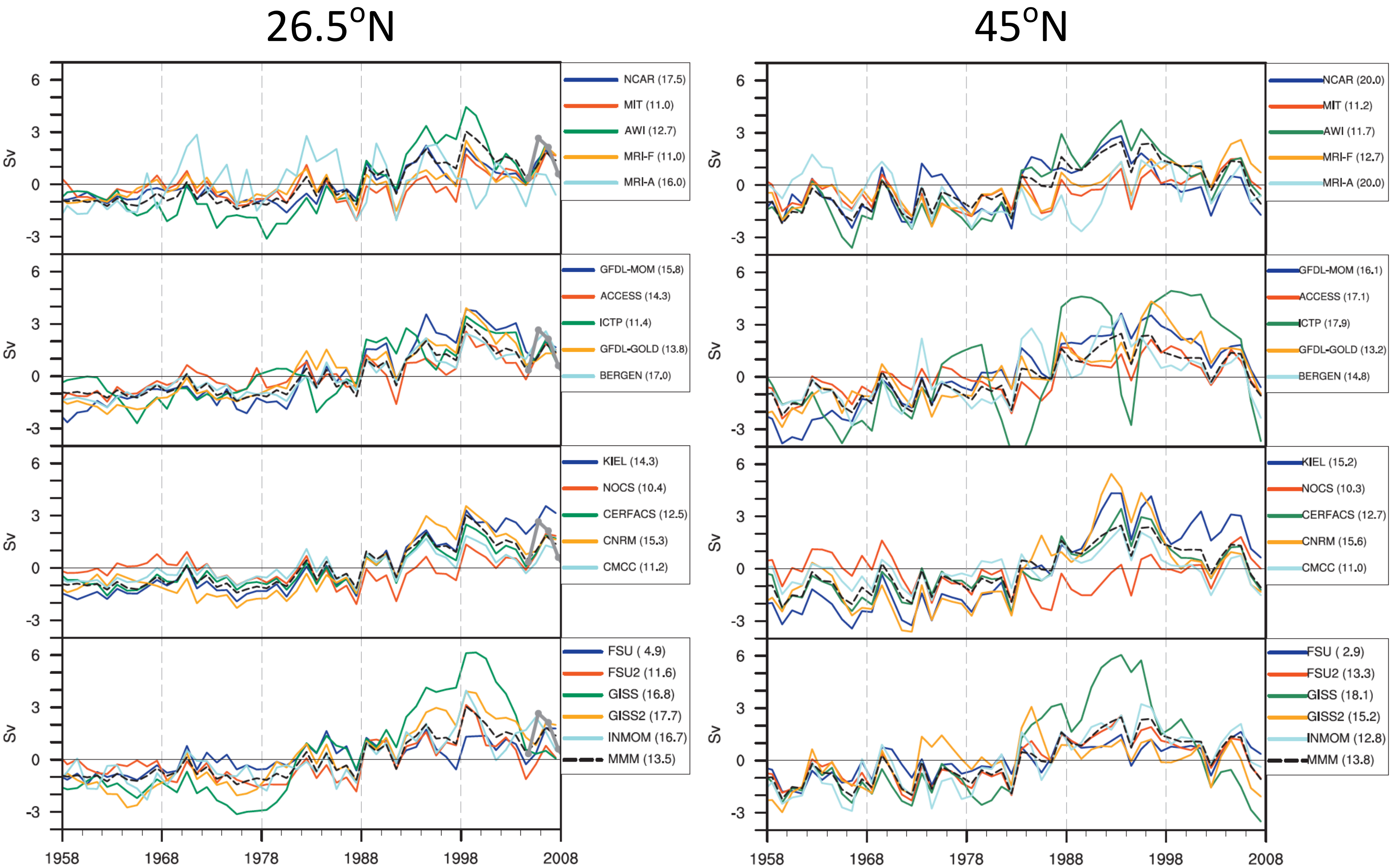
A trans-basin array of tall moorings, pressure-equipped inverted echo sounders, and current meters at 34.5˚S. Parts of the array have been in place since 2009; the full array has been in place since 2014. Participating institutions include: Department of Environmental Affairs (South Africa), Ecole Normale Superieure, Laboratoire de Meteorologie Dynamique (France), Laboratoire de Physique des Oceans - IFREMER (France), NOAA Atlantic Oceanographic and Meteorological Laboratory (USA), Servicio de Hidrografia Naval (Argentina), Universidad de Buenos Aires (Argentina), Universidade de Sao Paulo (Brazil), University of Cape Town (South Africa), and the University of Miami/CIMAS (USA). NOAA AOML maintains time series of western boundary data collected by the US here. AMOC estimates generated from 20-months of pilot array measurements are available upon request (Christopher.Meinen@noaa.gov).

Record: Mar-18-2009 to present (updated sporadically after recovery cruises ~ once per year)

Sampling: Daily

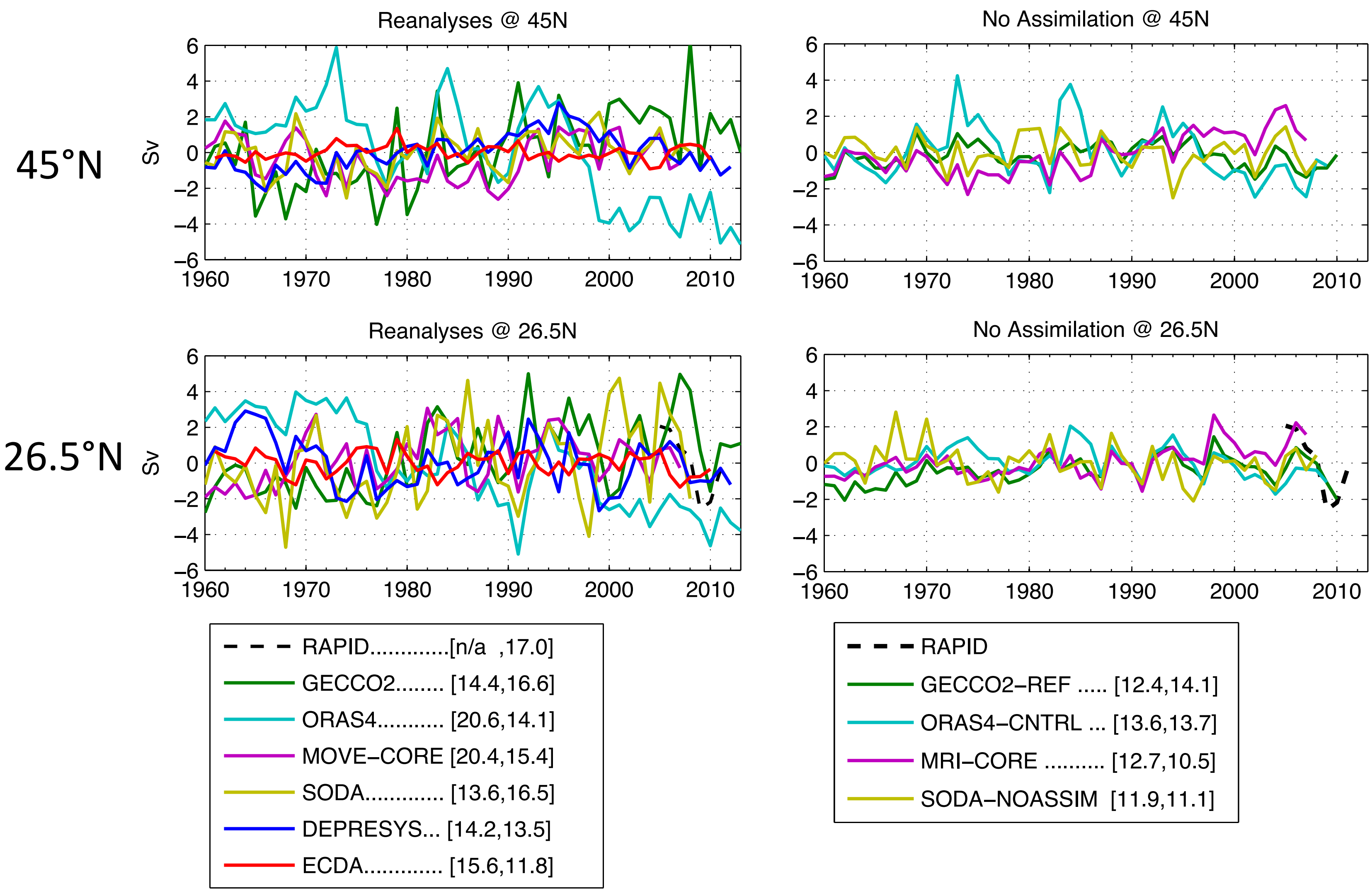
Uncertainty estimates available: Yes (in publications only, not in web data files)

AMOC Maximum Transport Anomaly Time Series from CORE-II Simulations



Danabasoglu et al.

AMOC Maximum Anomaly Time Series from Reanalysis Products at 1000 m Depth



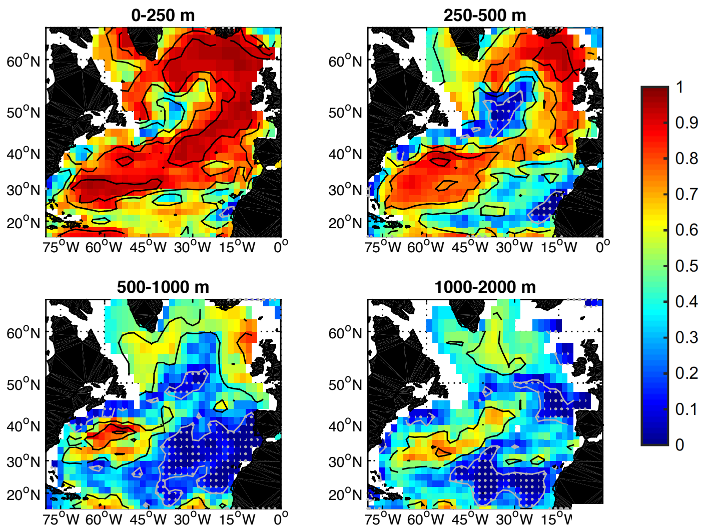
Karspeck et al.

Hydrographic Similarities*

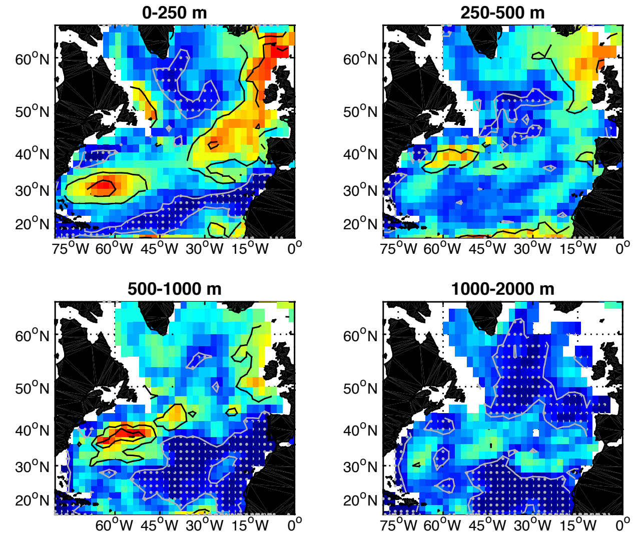
Temperature

Upper 500 m

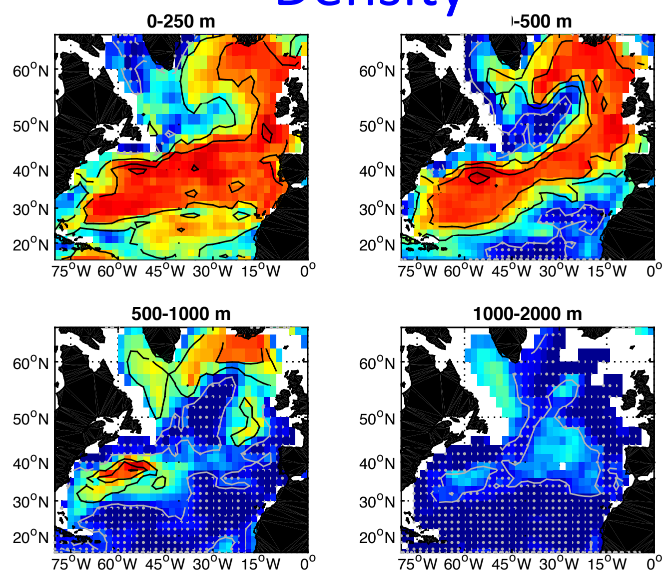
500-2000 m



Salinity

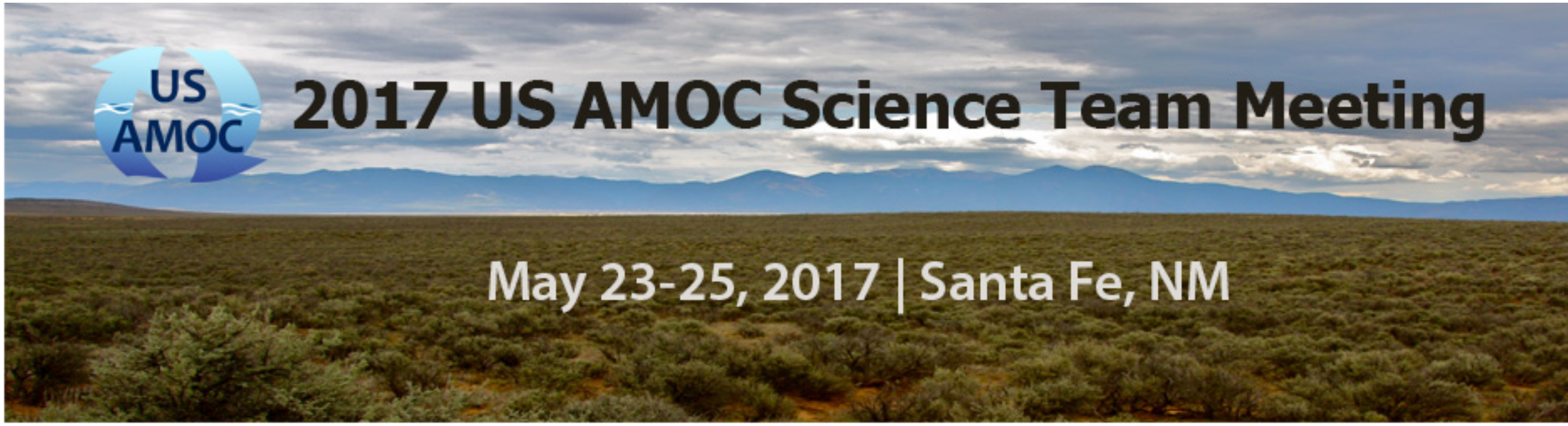


Density



Karspeck et al.

*measured by average model-model correlation



Organizing Committee

Wilbert Weijer, DOE LANL (chair)

Gokhan Danabasoglu, NCAR; Femke de Jong, Duke University;

Matthias Lankhorst, SIO; Mike Patterson, US CLIVAR;

Jill Reisdorf, UCAR; Kristan Uhlenbrock, US CLIVAR; Rong Zhang, NOAA GFDL

Primary goals for the meeting include:

- Providing updates on progress within the community,
- Reviewing near-term and long-term priorities for each Task Team and identifying emerging research gaps and questions,
- Enhancing collaborations among the Science Team members,
- Discussing future opportunities and legacy activities as the Science Team plans to wrap-up in 2020.

- 80+ participants
- Meeting Highlights / Summary are available via the US AMOC web site
- Two Special Science Sessions:
  - ✓ Relative contributions of ocean dynamics and stochastic atmospheric forcing to the creation and driving of the Atlantic Multidecadal Variability (AMV)
  - ✓ Role of freshwater transport into the Atlantic – mostly across its southern boundary at 35°S – on the stability of AMOC

A new Task Team (TT5) on Paleo-AMOC to foster collaborative relationships and facilitate cross-disciplinary learning and understanding between AMOC and paleo-climate / -oceanography communities

Near Term Priorities

Use new and existing observations in combination with modeling experiments to refine our understanding of the present and historical circulation (and related transports of heat and freshwater) in the North and South Atlantic. An emerging priority is to provide a more detailed characterization of AMOC flow pathways and their impact on variability.

Seeking new potential funding mechanisms to sustain key elements of the US AMOC observational networks is a new near-term priority.

Improving understanding of the meridional coherence (and/or lack thereof) of the AMOC and the mechanisms that control AMOC changes continues to be a high near-term priority. The development of dynamically consistent model-data synthesis methods to combine the heterogeneous observational pieces will also play an important role in achieving this priority.

Develop a more comprehensive understanding of the strengths and weaknesses of existing global ocean reanalysis products and hindcasts.

Investigate the role of freshwater forcing and South Atlantic freshwater transports in determining the variability and stability of AMOC.

The interaction between the AMOC and the hydrological cycle, including clouds.

Expand the use of eddy-resolving models, particularly in regional/process studies designed to: i) test the robustness of AMOC variability mechanisms identified in coarser GCMs or idealized models; ii) address the origins of persistent model bias in the North Atlantic region (e.g., Gulf Stream separation and the North Atlantic Current path); and iii) assess the role of ocean turbulence in AMOC variability.

Long Term Priorities*

Task Team 1

Find and/or develop new technologies and methods for studying the AMOC and its key components to address the overall observing goals for AMOC in a world of finite resources.

Develop plans to observe and study the shallow and deep pathways of the AMOC through the basin at locations away from the places of the few trans-basin arrays.

Test data assimilation schemes to better understand how the systems are using the data collected, and improve communication between the US AMOC community and the data assimilation community.

Task Team 2

Synthesize modeling and observational evidence, including data assimilation, to build scientific consensus on the variability and change of the AMOC over the last 50 years.

Task Team 3

Explore the mechanisms associated with AMOC variability on centennial-to-millennial timescales, and evaluate the realism of GCMs on these timescales relative to available paleo proxy data.

Translate the knowledge developed about AMOC variability and predictability mechanisms into reliable decadal climate forecasts.

Incorporate mesoscale eddy-resolving ocean models more fully into the toolkit used for AMOC mechanisms/prediction work, including long coupled GCM simulations.

Synthesize results from theoretical, idealized models, and complex GCM investigations into a common conceptual framework regarding key AMOC variability mechanisms and identify the resulting predictability of the AMOC.

Task Team 4

Understand how AMOC variability affects other components of the Earth system – its climate, hydrologic cycle, atmospheric circulation, coupled phenomena (e.g., ENSO, monsoons), cryosphere, sea level, marine and terrestrial ecosystems, biogeochemical cycles, and carbon budgets – both locally and remotely.

* Long-term reflects program priorities and goals that will be achieved by additional resources and / or technological advancements over the next 5+ years. Developments in observational technologies that enable more observational coverage at reduced costs and in computational technologies that empower more extensive use of high-resolution models represent two examples of advancements. As such, the long-term priories do not reflect lower priority areas, but currently are limited by resources.

AMOC Review / Synthesis Papers

As the Science Team sunsets in 2020, we would like to produce a collection of review / synthesis articles that highlight the advancements in AMOC-related science made during the existence of the US AMOC Science Team as well as the UK RAPID Program.

Joint effort between the US AMOC Science Team and the UK RAPID Program with authors drawn from both communities and their collaborators.

Virtual Special Issue

Feeds into both the UK RAPID Program Review in 2018 – 2019 time frame and the Ocean Obs '19.

Tentative submission deadline: February 2018

Preliminary List / Contents of Potential Papers

- US AMOC / UK RAPID observations: why they were deployed; what has been learned about AMOC and best practices in AMOC observations,
- Meridional coherency of AMOC in observations (and simulations),
- Robust and non-robust AMOC signals / features in both observations and simulations,
- AMOC in data-assimilating models (current and past states),
- AMOC stability, particularly focusing on the role of freshwater transport across 35°S,
- High-resolution models of the AMOC, including regional studies of key components such as the Southern Ocean, Gulf Stream, and high-latitude convection regions,
- Linkages between AMOC variability and the AMV and associated impacts, including both modern and paleo observational linkages,
- Relationships between AMOC and sea level changes,
- Impacts of AMOC on ocean tracers.

AMOC Metrics* Project: Bringing Models and Data into a Common Framework for Evaluating the State, Circulation, and Impacts of the Atlantic Ocean

Need for a dedicated effort to facilitate the joint analysis of models and observations

- Comparing model simulations with observations of the natural world is essential for assessing the quality of our models and advancing their fidelity.
- This has been widely acknowledged within the AMOC community and the concept of a common framework into which both observations and models can be mapped and subsequently analyzed has emerged under the term "AMOC Metrics."
- The need for a metrics activity has been highlighted in the last four US AMOC Science Team Reports (US CLIVAR Office 2013; Danabasoglu et al. 2014; 2015; 2016;).
- The concept has also emerged as a priority from the US CLIVAR sponsored meeting "Connecting Paleo and Modern Oceanographic Data to Understand AMOC Over Decades to Centuries" (Kilbourne 2017).

* Not just AMOC time series, but SPG, SSH, upper-ocean heat content,

Need for a dedicated effort to facilitate the joint analysis of models and observations

Comparison of model-simulated data with observations can be prohibitively difficult for individual researchers due to:

- Data format and infrastructure barriers: In general, simulated and observed data are not made available in consistent data formats or through well-publicized common public archives.
- Incommensurability: In general, models do not simulate the same quantity that observations measure and there tend not to be explicitly outlined, reproducible protocols to achieve a consistent mapping between "model space" and "observation space."
- Social/scientific barriers: Observationalists and modelers typically operate within separate disciplinary spheres, reducing the opportunity for nuanced discussions of the most consistent methods for comparing model output and data.

The goals and expected outcomes of AMOC Metrics Project

The AMOC Metrics Project is a *service-activity* that will

- Promote the use of metrics in intercomparison projects that are relevant to advancing understanding of the Atlantic Ocean state, circulation, and influence,
- Reflect the science advances being driven by the AMOC community,
- Facilitate the joint interpretation of models and data,
- Promote objectivity in model-intercomparisons.