ENSO Characteristics during Different States of the Atlantic and Pacific Meridional Overturning Circulations

Maria J. Molina, Aixue Hu, and Gerald Meehl
National Center for Atmospheric Research, Boulder, Colorado
The Atlantic meridional overturning circulation (AMOC) is a large-scale ocean circulation that redistributes heat from low to high latitudes (Hu et al. 2012).
Current Atlantic Meridional Overturning Circulation weakest in last millennium

L. Caesar1,2, G. D. McCarthy3, D. J. R. Thornalley3, N. Cahill4 and S. Rahmstorf2,5

The Atlantic Meridional Overturning Circulation (AMOC)—one of Earth’s major ocean circulation systems—redistributes heat on our planet and has a major impact on climate. Here, we compare a variety of published proxy records to reconstruct the evolution of the AMOC since about AD 400. A fairly consistent picture of the AMOC emerges: after a long and relatively stable period, there was an initial weakening starting in the nineteenth century, followed by a second, more rapid, decline in the mid-twentieth century, leading to the weakest state of the AMOC occurring in recent decades.

The Atlantic Meridional Overturning Circulation (AMOC) is a major mechanism for heat redistribution on our planet and an important factor in climate variability and change. The AMOC is a sensitive nonlinear system dependent on subtle thermohaline density differences in the ocean, and major AMOC transitions have been implicated, for example, in millennial climate events during the last glacial period1. There is evidence that the AMOC is slowing down in response to anthropogenic global warming—as predicted by climate models—and that the AMOC is presently in its been related to the AMOC2,3. The records going the furthest back in time (AD 400) are taken from marine sediments ( sortable-silt data4), proxy records of subsurface ocean temperatures5, δ18O in benthic foraminifera6, δ18O of deep-sea gorgonian corals, relative abundance of certain planktic foraminifera (Turborotalita quinqueloba)7). The temperature-based AMOC index8, however, is based on a Northern Hemisphere land-and-ocean temperature reconstruction that uses a range of terrestrial proxies, including, for example, tree rings and ice-core data9. Data taken from Greenland ice cores (the methanesulfonic acid concentration) furthermore provide an estimate for AMOC-related changes in productivity in the subpolar gyre region10. Most of these records extend into the modern era, for which additional AMOC proxies exist that are based on instrumental temperature records1,2,5.

Despite the different locations, timescales and processes represented by these proxies, they provide a consistent picture of the AMOC evolution since about AD 400: before the nineteenth century, the AMOC was relatively stable. A decline in the AMOC, beginning during the nineteenth century, is evident in all the proxy records.
A global circulation…

...with global impacts.
…with global impacts.

CESM1 experiments spanning 800 years were created.

- AMOC collapse without PMOC results in N. Pac./Atl. cooling.
- AMOC collapse with active PMOC reduces N. Pac./Atl. cooling.
- Active AMOC and PMOC results in N. Pac. warming.
AMOC and PMOC can strongly influence the SST annual cycle in the tropics.
The dominant frequency in SST patterns sees stark changes across the tropical Pacific.
Molina et al. (2022).
Molina et al. (2022).
Molina et al. (2022).

Seasonal Mixed Layer Depth

- a) DJF CESM1 Control
- b) DJF 0.2 Sv Global - Control
- c) DJF 0.4 Sv Global - Control
- d) DJF 0.2 Sv Pacific - Control
- e) DJF 0.4 Sv Pacific - Control
- f) DJF Pacific Salt - Control
- g) JJA CESM1 Control
- h) JJA 0.2 Sv Global - Control
- i) JJA 0.4 Sv Global - Control
- j) JJA 0.2 Sv Pacific - Control
- k) JJA 0.4 Sv Pacific - Control
- l) JJA Pacific Salt - Control

Latitude: -10 to 10
Longitude: 170°E to 160°W

Mixed Layer Depth (m):
-20 to 20
Anomaly (Experiment - Control):
-20 to 20
• Pacific Subtropical Cells (STCs) exhibit asymmetrical changes based on hemisphere.
Key Takeaways

- ENSO amplitude increases as a result of an AMOC shutdown irrespective of PMOC development (within CESM1 experiments).
- Active overturning circulations in both the Atlantic and Pacific basins reduce ENSO amplitude.
- ENSO extends into the eastern equatorial Pacific during AMOC collapse.

Molina et al. (2022).
Future Work Could Address…

- Does this relationship persist in a changing climate?
- What role do other modes of variability play?
- Causal inference analysis to quantify influence of physical mechanisms.

Source: NASA/Goddard Space Flight Center

Molina et al. (2022).
For more information, please check out our paper in Journal of Climate.
