REVIEW SUMMARY

OCEAN CIRCULATION

Observing the Atlantic Meridional Overturning Circulation yields a decade of inevitable surprises

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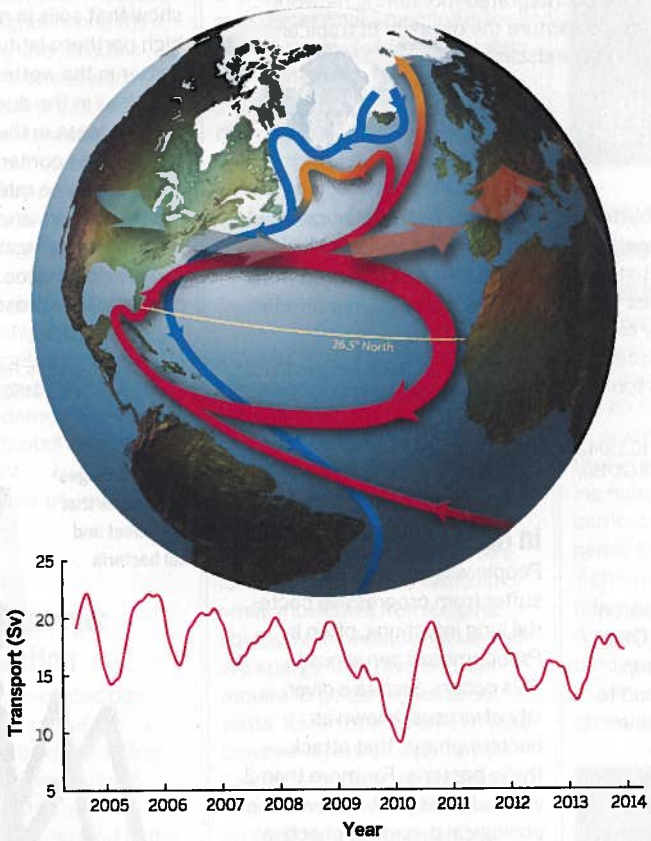
BACKGROUND: A 2002 report, *Abrupt Climate Change: Inevitable Surprises*, highlighted the North Atlantic circulation as possibly subject to abrupt change in a warming climate. Likewise, the 2001 Intergovernmental Panel on Climate Change (IPCC) report suggested that the Atlantic Meridional Overturning Circulation (AMOC) could weaken over the 21st century. As this circulation carries heat northward, giving the United Kingdom and northwest Europe a temperate climate, this generated renewed efforts to make observations of the AMOC. In particular, it led to the deployment of an observing system across the Atlantic at 26.5°N in spring 2004, which last year achieved a decade of measurements.



A simplified schematic (top) of the AMOC. Warm water flows north in the upper ocean (red), gives up heat to the atmosphere (atmospheric flow gaining heat represented by changing color of broad arrows), sinks, and returns as a deep cold flow (blue). Latitude of the 26.5°N AMOC observations is indicated. The actual flow is considerably more complex. (**Bottom**) The 10-year (April 2004 to March 2014) time series of the AMOC strength at 26.5°N in Sverdrups (1 Sv = 10^6 m^3 s^{-1}). This is the 180-day filtered version of the time series. Visible are the low AMOC event in 2009–2010 and the overall decline in AMOC strength over the 10-year period.

ADVANCES: In addition to the baseline decade of 26.5°N observations, there have been other ongoing measurements that capture components of the AMOC, some of which are not continuous or of much shorter duration. Together these observations are leading to a more complete picture of the AMOC. The 26.5°N AMOC observations have produced a number of surprises on time scales from subannual to multiannual. First, the range of AMOC variability found in the first year, 4 to 35 Sv (Sverdrup, a million cubic meters per second, the standard unit for ocean circulation), was larger than the 15 to 23 Sv found previously from five ship-based observations over 50 years. A similarly large range to that at 26.5°N has subsequently been observed at 34.5°S. Second, the amplitude of the seasonal cycle, with a minimum in the spring and a maximum in the autumn, was much larger (~6.7 Sv) than anticipated, and the driving mechanism of wind stress in the eastern Atlantic was unexpected as well. Third, the 30% decline in the AMOC during 2009–2010 was totally unexpected and exceeded the range of interannual variability found in climate models used for the IPCC assessments. This event was also captured by *Argo* and altimetry observations of the upper limb of the AMOC at 41°N. This dip was accompanied by significant changes in the heat content of the ocean, with potential impacts on weather that are the subject of active research. Finally, over the period of the 26.5°N observations, the AMOC has been declining at a rate of about 0.5 Sv per year, 10 times as fast as predicted by climate models. Whether this is a trend that is a decline due to global warming or part of the so-called Atlantic Multidecadal Oscillation/Variability, inferred from sea surface temperature measurement, is also a subject of active research. There is no doubt that continuously observing the AMOC over a decade has considerably altered our view of the role of ocean variability in climate.

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OUTLOOK: The 26.5°N AMOC observations are stimulating the development of further AMOC observing systems both to the north, in the North Atlantic subpolar gyre, and to the south, in the South Atlantic. The aim is to obtain a holistic picture of the AMOC from south to north. Given the surprises and insights into the Atlantic circulation that observations have produced to date, it is not too much to expect that with the new observations there will be future "inevitable surprises." ■

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