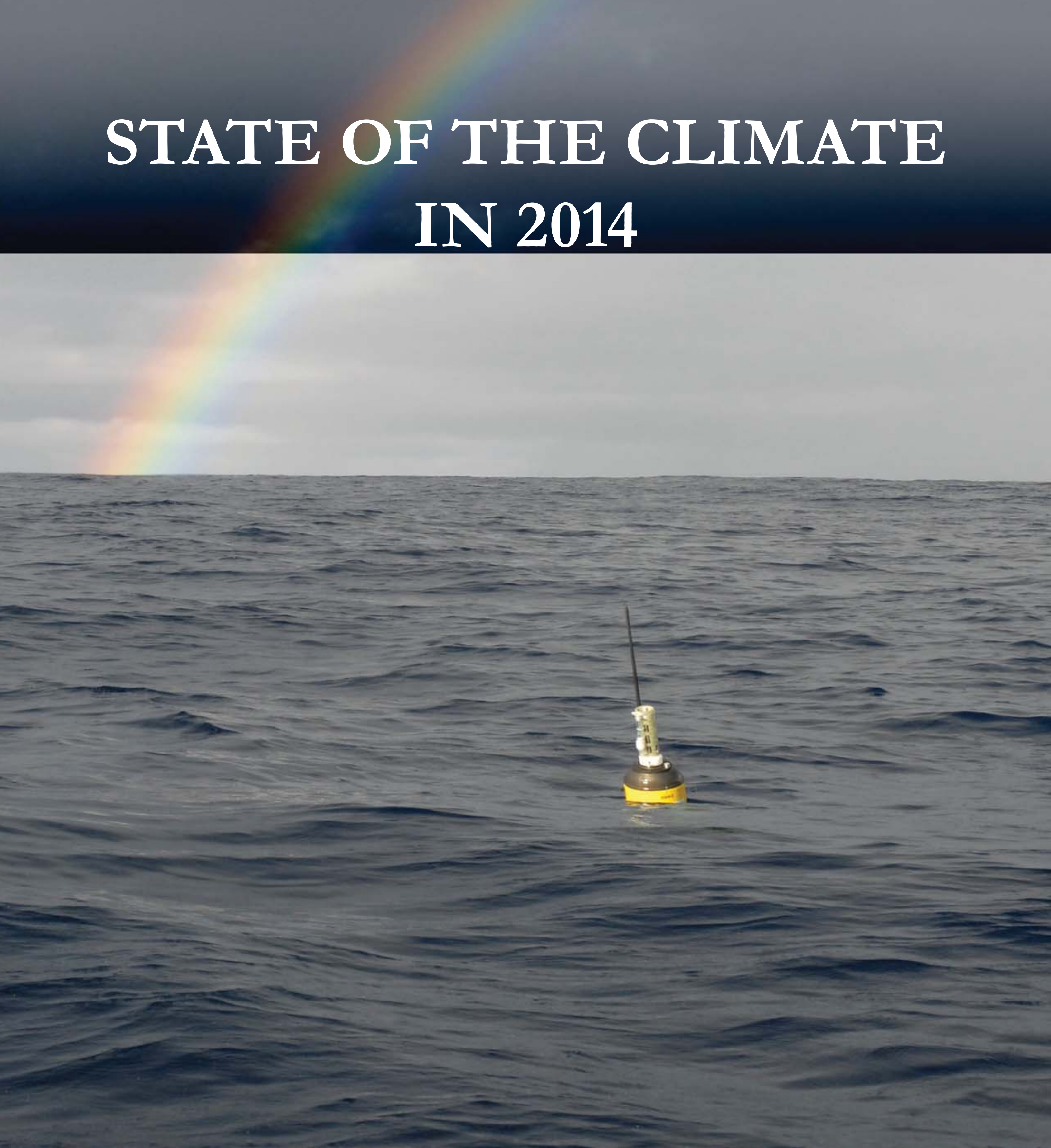
STATE OF THE CLIMATE IN 2014



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an intensification of the NECC eastward zonal band along 6°N between 40° and 20°W of 10 cm s^{-1}. These off-equatorial anomalies decreased during August, although westward anomalies persisted between 0° and 3°N. The currents remained close to climatology until December, when an intensification of the NECC at 6°N began again between 50° and 40°W with eastward anomalies over 40 cm s^{-1}.

The shedding of rings by the North Brazil Current (NBC) is a pathway for Southern Hemisphere water into the North Atlantic basin. Sea surface height anomalies along the NBC ring corridor exhibited lower values in 2014 than during 2010–11, but average values with respect to the 1993–2010 mean (www.aoml.noaa.gov/phod/altimetry/cvar/nbc). The NBC shed six rings during 2014, which is average in the region. The largest sea surface height anomalies found in this region during the second half of 2014 represent larger-than-average rings shed by the NBC.

The Yucatan Current, the component of the North Atlantic surface circulation that flows through the Yucatan Straits, exhibited larger-than-average values (>3 Sv) during 2012 and 2013, and decreased to average values during 2014 (Fig. 3.19). The variability of this transport is of importance since the Florida Current transport variability, an indicator of the strength of the Atlantic meridional overturning circulation (section 3h), approximately follows the variability of the Yucatan Current.

Farther north in the Atlantic, the mean position of the Gulf Stream along the coast between 35.5° and 38°N sharpened and shifted 1° northward from 2013 to 2014. This is a slightly smaller shift north from the 1993–2007 mean for 2014, as 2013 was slightly shifted south of climatology. The mean position of the Loop Current extended fully into the Gulf of Mexico in 2014, in contrast to 2013 where the mean position only partly entered the Gulf.

In the southwest Atlantic Ocean, the separation of the Confluence Front from the continental shelf break continued to exhibit annual periodicity driven by wind stress curl variations (cf. Goni and Wainer 2001). The annual mean position of the front in 2014 was close to its climatological mean for the altimetric time period 1993–present (cf. Lumpkin and Garzoli 2010; Goni et al. 2011).

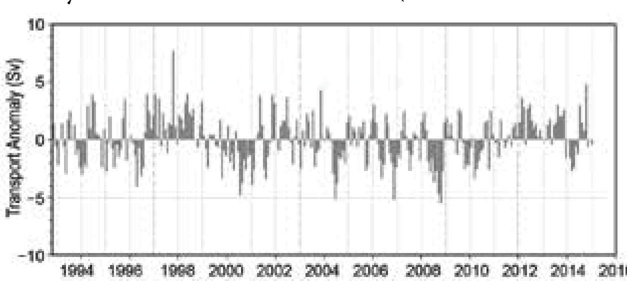

Fig. 3.19. Transport of the Yucatan Current estimated using a combination of sea surface height anomalies and climatological hydrography.

h. Meridional overturning circulation observations in the North Atlantic Ocean—M. O. Baringer, G. McCarthy, J. Willis, D. A. Smeed, D. Rayner, W. E. Johns, C. S. Meinen, M. Lankhorst, U. Send, S. A. Cunningham, and T. O. Kanzow

Within the large-scale ocean circulation known as the meridional overturning circulation (MOC) surface waters at high latitudes cool, become denser, sink, and return to lower latitudes. This circulation—identified as overturning because surface waters are transformed into deep and bottom waters and meridional in that waters are transported north and south, redistributing heat, fresh water, carbon, and nutrients—represents an important mechanism for how the ocean regulates climate. Previous *State of the Climate* reports (e.g., Baringer et al. 2013) and reviews (e.g., Macdonald and Baringer 2013; Lozier 2012; Srokosz et al. 2012) discuss the importance of the MOC and its impact on climate variability and ecosystems. This section reports the recent results provided by three time-series MOC observing systems in the North Atlantic at 16°N, 26°N, and 41°N.

The longest time series of ocean transport to serve as an index of the MOC's strength in the North Atlantic (e.g., Duchez et al. 2014) is from the Florida Current (FC, as the Gulf Stream is called around 26°N), which has been measured since 1982. Measurements continue through 2014 and beyond, with two brief gaps in the time series during 1–3 January 2014 and 8–13 March 2014. The median 1982–2014 transport of the FC is 31.9 ± 0.26 Sv (one standard error of the mean based on an integral time scale of about 20 days) with a small downward trend of −0.31 ± 0.27 Sv decade^{-1} (errors using 95% significance with a decorrelation time scale of about 20 days; Fig. 3.20). In 2014 the annual median was 30.5 ± 1.2 Sv, the third lowest since 1982. The daily FC transport values as compared to all previous years (Fig. 3.20) indicate that 2014, like 2013, had several unusually low transport anomalies (extremes defined as outside the 95% confidence limits for daily values) during 8 January, 18 April–5 May, 26–29 August, and 9–11 December 2014. The lowest transport observed occured on 2 May, reaching 20.7 Sv. Transports less than 23 Sv persisted for a 5-day period centered on this date. This value is the 18th lowest transport recorded since 1982. During 2014 there were no high transport events that exceed the 95% confidence limits; the highest transport was 37.9 Sv on 15 October.

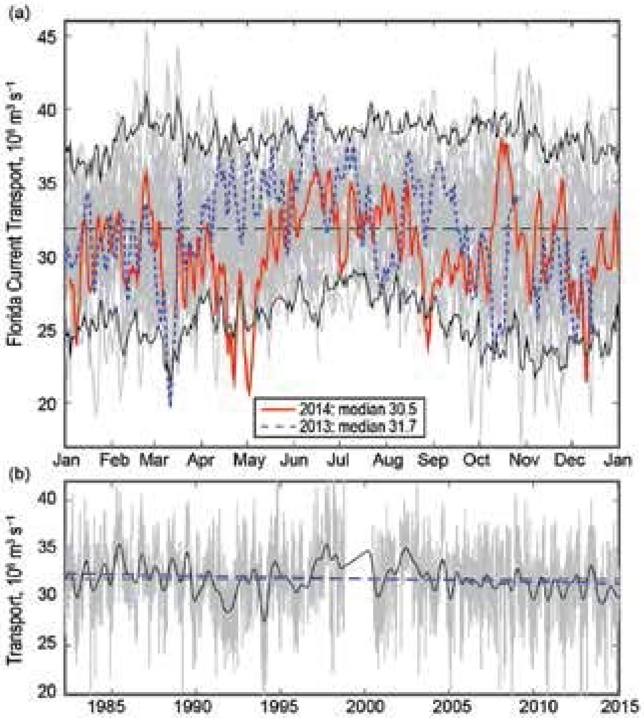

Fig. 3.20. (a) Daily estimates of FC transport during 2014 (red solid line), 2013 (dashed blue line), and 1982–2012 (light gray lines) with the 95% confidence interval of daily transport values computed from all years (black solid line), and the long-term annual mean (dashed black). (b) Daily estimates of FC transport for the 1982 to present (light gray), transport smoothed using a 12-month second-order Butterworth filter (heavy black line), mean transport for the full record (dashed black line), and linear trend (dashed blue line).

The FC time series is part of the larger RAPID/MOCHA/WBTS 26°N mooring array, which provides a twice-daily estimate of basinwide MOC strength (Fig. 3.21). (RAPID/MOCHA/WBTS is the UK National Environmental Research Council Rapid Climate Change Program, the National Science Foundation's Meridional Overturning and Heatflux Array, and the NOAA Western Boundary Time Series project.) The 26°N array measured the full water column across the full basin and absolute transports in the boundary currents; it is thus the most complete MOC observing system (see McCarthy et al. 2015). The array measures a statistically significant downward trend in MOC transport from 2004 to 2012, particularly starting in 2008 (Smeed et al. 2014). Individual low transport events are caused by both a decrease in the northward Ekman transport as well as an increase in the southward interior transport; thus the overturning weakened as the gyre strengthens (McCarthy et al. 2012). A decrease in the strength of the MOC at this latitude has been linked to decreased heat content in the subtropical North Atlantic (e.g., Cunningham et al. 2013; Bryden et al. 2014).

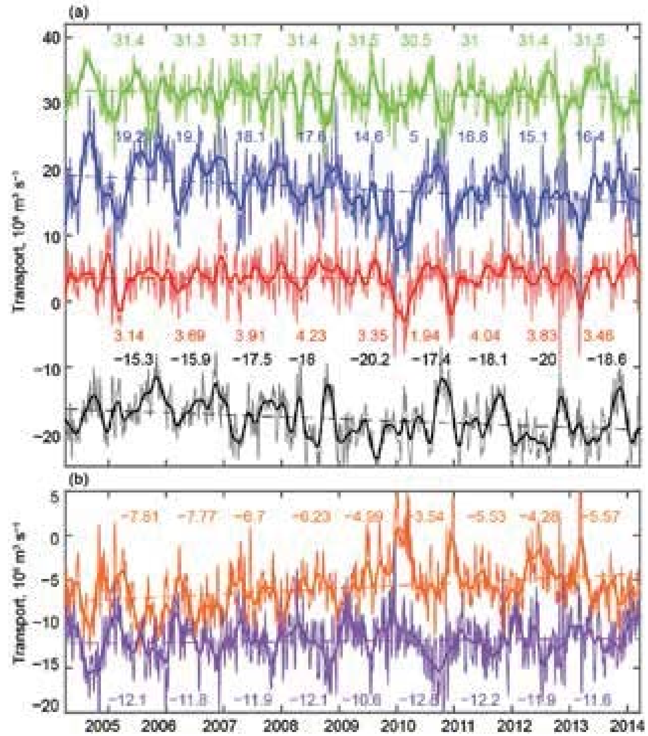

Fig. 3.21. (a) Daily estimates of the strength of the meridional overturning circulation (blue line) and its components: FC (green), wind-driven Ekman transport (red), and geostrophic interior (black), as measured by the RAPID/MOCHA/WBTS. A 10-day low-pass filter is applied to the daily transport values (McCarthy et al. 2015) and associated annual median transports values (Sv) for each year are shown associated color text. (b) Deepest MOC transports divided into upper deep water (1000–3000 m; orange) and lower deep water (3000–5000 m; purple).

This report includes the MOC-related transports, extending the record reported last year (Baringer et al. 2014) from October 2012 to March 2014 (Fig. 3.21). MOC estimates based on mooring data currently have an 18-month reporting delay due to the time scale of the mooring servicing. The MOC, with a median value of 17.0 ± 0.7 Sv from 2004 to 2014, is the sum of the Ekman (3.7 ± 0.3 Sv), FC (31.6 ± 0.4 Sv), and interior components (–18.1 ± 0.6 Sv) at this latitude. During the updated portion of the record, the MOC median was slightly below average (16.4 Sv) and there were significantly lower MOC transports (outside the 95% daily confidence limits) during 26 October–1 November 2012, 20–25 November 2012, 28 February 2013, and 1–16 March 2013. During the most extreme low transport event (1–16 March 2013) the MOC reached values as low as –3.1 Sv with an average of 2.1 Sv. The Ekman transport contributed the most to this low transport event (–8.5 Sv lower than the long-term median); followed by the FC (about –6 Sv). The interior transport contribution was negligible.

The updated long-term trend of the MOC is –4.2 ± 2.5 Sv decade^{-1} (using 95% confidence, assuming a 20-day integral time scale); this means there is 95% confidence the decrease in the MOC is greater than 2 Sv decade^{-1}, slightly less than reported last year. This trend is due largely to the increase in southward gyre transport (–3.2 ± 2.0 Sv decade^{-1}), with the FC playing a minor role (–1.2 ± 1.4 Sv decade^{-1}) and a negligible trend in Ekman transport (0.3 ± 1.1 Sv decade^{-1}). At 26°N, where both the upper and deep southward flows are directly measured, the decreasing MOC was seen to be compensated by a reduction in the southward export of lower North Atlantic Deep Water in the depth range of 3–5 km (3.2 ± 1.8 Sv decade^{-1}); whereas upper North Atlantic Deep Water in the depth range of 1.1–3 km showed no significant change (Fig. 3.21). Changes in MOC transport are coincident with different physical mechanisms depending on the time scale or the particular event in question (e.g., interior flow appears to be important for long time scales, while Ekman transports are important on shorter time scales).

In addition to the 26°N array, two other measurement systems are used to estimate the strength of the MOC in the North Atlantic. At 41°N, a combination of profiling Argo floats (that measure the ocean temperature and salinity in the upper 2000 m on broad spatial scales, as well as velocity at 1000 m) and altimetry-derived surface velocity (Willis and Fu 2008) are used to estimate the MOC; these data sources are available in near real-time and hence the time series has been extended from October 2013 (reported last year) to December 2014 (Fig. 3.22). Additionally, at 16°N, an array of inverted echo sounders, current meters, and dynamic height moorings (Send et al. 2011) measures the deep circulation (the southward flowing part of the MOC "conveyor belt") that sends North Atlantic Deep Water toward the equator. The 16°N data have not yet been updated past the October 2013 date reported last year.

To intercompare the MOC estimates at these three latitudes, the data are low-pass filtered (Fig. 3.22); means are computed for the overlapping time periods (2 April 2004–26 October 2013). The mean MOC and its variability (based on the standard deviation of these estimates) decreases to the north (23.1 ± 4.7 Sv at 16°N; 16.7 ± 3.3 Sv at 26°N; 14.3 ± 3.0 Sv at 41°N). The median and standard deviation of each unique time series are listed in Fig. 3.22. All three time series have a seasonal cycle but with slightly different phases; 41°N has a maximum MOC in May–July, 26°N has a broad maximum in July–November (Kanzow et al. 2010), and 16°N has a maximum southward flow (and hence stronger MOC) in November–January. Reported longer-term MOC trends range from zero (Willis 2010, using the first 7 years of data from 41°N) to a –3 Sv decade^{-1} decrease (Send et al. 2011, using the first 9.5 years of data from 16°N), to the largest decrease of –5.4 Sv decade^{-1} (Smeed et al. 2014, using the first 8.5 years of data from 26°N). Using the overlapping time period of these observations (2 April 2004–26 October 2013), which includes more recent data than reported by Willis (2010) and Send et al. (2011), there was an insignificant trend in the MOC of –3.0 ± 7.1 Sv decade^{-1} at 41°N, while at 26°N there was a significant decrease in the MOC of –4.1 ± 3.2 Sv decade^{-1} (using 95% confidence limits; Fig. 3.22). At 16°N the deep southward flow contains no new data since last year's report and the suggested increased MOC remains unchanged at +8.4 ± 5.6 Sv decade^{-1} (an increase in southward flow is a stronger MOC). For the full time series at 41°N and 16°N, the MOC trends decrease, becoming insignificant (–1.3 ± 4.9 Sv decade^{-1} at 41°N and –2.3 ± 2.9 Sv decade^{-1} at 16°N). At these time scales, there appears to be no consistent trend in the MOC between these latitudes.

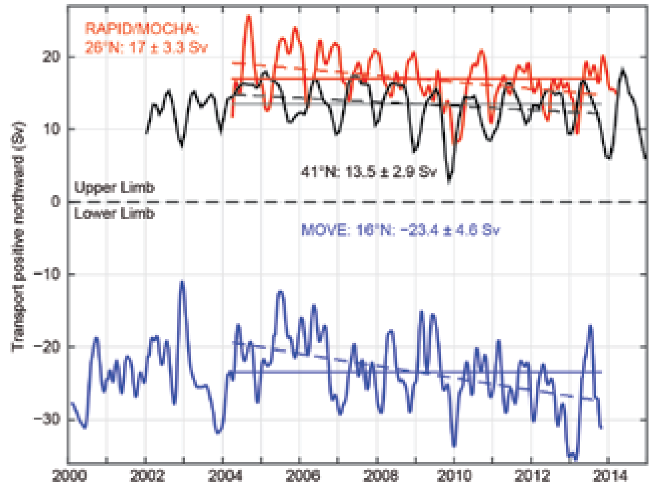

Fig. 3.22. Estimates of Atlantic Ocean meridional overturning circulation from the Argo/Altimetry estimate at 41°N (black; Willis 2010), the RAPID/MOCHA/WBTS 26°N array (red; McCarthy et al. 2015), and the German/NOAA MOVE array at 16°N (blue; Send et al. 2011) shown versus year. All time series have a 3-month second-order Butterworth low-pass filter applied. Horizontal lines are mean transports during similar time periods as listed in the corresponding text. Dashed lines are trends for each series over the same time period. For the MOVE data, the net zonal and vertical integral of the deep circulation represents the lower limb of the MOC (with a negative sign for southward flow) and hence a stronger negative southward flow represents an increase in the MOC.