STATE OF THE CLIMATE IN 2017

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STATE OF THE CLIMATE IN 2017

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Front: ©Ron_ Thomas/Spring desert wildflowers in Anza Borrego Desert State Park, CA/Getty Images.

Back: Smoke and Fire in Southern California: Thick smoke was streaming from several fires in Southern California when the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's *Terra* satellite acquired a natural-color image in the afternoon on December 5, 2017. On the same day, the Multi Spectral Imager (MSI) on the European Space Agency's Sentinel-2 satellite captured the data for a false-color image of the burn scar. Active fires appear orange; the burn scar is brown. Unburned vegetation is green; developed areas are gray. The Sentinel-2 image is based on observations of visible, shortwave infrared, and near infrared light.

NASA Earth Observatory images by Joshua Stevens, using MODIS data from LANCE/EOSDIS Rapid Response and modified Copernicus Sentinel data (2017) processed by the European Space Agency. Story by Adam Voiland.
Instrument(s):
Terra - MODIS
Sentinel-2

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principal empirical orthogonal function (EOF) of surface current (SC) anomaly and separately the first EOF of SST anomaly in the tropical Pacific basin (Fig. 3.20). The maximum correlation between SC and SST anomalies is R = 0.65 for 1993–2017, with SC leading SST anomalies by 76 days. The year 2017 began with a continued lessening of the dramatic negative SC anomalies of 2016, approaching zero values in January. Although the EOF amplitude for SC anomalies was negative throughout 2017, this lessening coincided with an increase in positive SST anomalies, with a maximum SST EOF amplitude in March of 0.9 standard deviations. As the year progressed the SC EOF amplitude decreased to a minimum of –1.9 standard deviations in October. The SST EOF followed this trend with a steady decrease after the peak in March to a minimum of –1.2 standard deviations in December. The year ended with SC anomalies again approaching zero.

2) Indian Ocean

The annually averaged near-equatorial current in the Indian Ocean basin is eastward, reflecting the dominance of the Southwest Monsoon Current in the annual average. During 2017, the mean current near the equator had peak values of 33–35 cm s^{-1}, somewhat elevated from its climatological average of 25–27 cm s^{-1} (Fig. 3.18a). Because these anomalies were much stronger in 2017 than in 2016, the 2017 minus 2016 tendencies (Fig. 3.18b) are negative on the equator. An examination of the month-by-month development of these anomalies reveal that they reflect a much stronger-than-average Southwest Monsoon Current during July–October 2017. Maximum eastward anomalies of 30–35 cm s^{-1} were observed at 1°–2°S, 65°–85°E, in August.

3) Atlantic Ocean

Annual mean anomalies in the Atlantic Ocean (Fig. 3.18a) indicate an ~15 cm s^{-1} strengthening of the eastward NECC at 5°–6°N, 33°–50°W and a 20–25 cm s^{-1} strengthening of the westward nSEC at 0°–1°N, 25°W–0°. The year began with the NECC anomaly established but with an anomalously weak (by 5–10 cm s^{-1}) nSEC (Fig. 3.19). In February, strengthening of the nSEC had developed east of 24°W and spanned the basin in March. These anomalies weakened through April and May, and in June–August the nSEC was close to climatology. Westward anomalies again developed in the nSEC in September and persisted through November. In December, the nSEC was close to its climatological December strength.

The changes in transport and location of several key surface currents and mesoscale rings associated with them in the Atlantic Ocean basin are continuously monitored using satellite altimetry observations (www.aoml.noaa.gov/phod/altimetry/cvar/index.php). During 2017, the number of rings shed by the Agulhas and North Brazil Currents, which are partly indicative of Indian–Atlantic and South–North Atlantic water mass exchanges, respectively, remained within their mean 1993–2017 values. The altimetry-derived transports of the Agulhas, Malvinas, Brazil, North Brazil, and Florida Currents did not exhibit 2017 variations beyond one standard deviation from their mean 1993–2017 values. In the southwest Atlantic Ocean, the separation of the Brazil Current from the continental shelf break (located at 37.6°S in the mean) reveals the intrusion of subtropical waters into the subpolar region. Since 1993, this current has separated farther to the south from the continental shelf break by 3° latitude (c.f., Lumpkin and Garzoli 2011; Goni et al. 2011). Compared to its mean value in 2016, the separation moved to the south by about 2° latitude (see www.aoml.noaa.gov/phod/altimetry/cvar/mal/BM_ts.php), the largest southward shift in the altimeter time period 1993–present.

h. Meridional overturning and oceanic heat transport circulation observations in the North Atlantic Ocean—M. O. Baringer, J. Willis, D. A. Smeed, B. Moat, S. Dong, W. R. Hobbs, D. Rayner, W. E. Johns, G. Gonil, M. Lankhorst, and U. Send

The Atlantic meridional overturning circulation (AMOC) and the Atlantic meridional heat transport (AMHT) carry warm near-surface water northward, provide heat to the atmosphere at northern latitudes, and carry colder deep water southward. Buckley and Marshall (2016) present a summary of the dynamical forcing mechanisms of the AMOC and AMHT and the role they play in regulating climate variability around the Atlantic sector. Owing to the large amounts of heat, carbon, and fresh water transported by the AMOC, climate models suggest accurate estimation of its rate of change is critical to understanding and predicting our changing climate (e.g., W. Liu et al. 2017; Rahmstorf et al. 2015). Even on short time scales the AMOC/AMHT can impact climate (e.g., Duchez et al. 2016). These recognitions have led to the implementation of enhanced observing systems of the strength of the AMOC in the subpolar North Atlantic (Lozier et al. 2017) and the subtropical South Atlantic (Ansorge et al. 2014). These new observing systems will eventually provide a more complete spatial picture of the state of the AMOC.

In general, estimating the AMOC/AMHT amounts to summing ocean-spanning measurements of the velocity/heat transport horizontally and vertically over the full water column. As all relevant time and space scales cannot be simultaneously measured, all the current AMOC/AMHT time series estimates include trade-offs between one quantity and another and can have errors and biases that are dependent on observing system design (e.g., Sinha et al. 2018). The systems described herein include the AMOC/AMHT observing systems at 41°N, 26°N, and 16°N and AMHT at 41°N, 26°N, and 35°S, which represent the most complete, longest time AMOC/AMHT series currently available.

Studies have shown that density anomalies along the western boundary in particular are essential predictors of the strength of the AMOC (e.g., Le Bras et al. 2017; Yashayaev and Loder 2016), and subpolar density anomalies precede those in the subtropical gyre by 8–10 years; hence, observing systems that measure western boundary variability are particularly essential. The Florida Current (FC; as the Gulf Stream is called at 26°N) observing system is one such example that can provide a longer time perspective of possible AMOC variations (e.g., Frajka-Williams 2015). Providing data since 1982, this is the longest open ocean transport time series (Fig. 3.21). Additionally, FC and AMOC transport variations at all time scales are inversely linked to sea level variations along the east coast (e.g., Domingues et al. 2016). The median FC transport from the full record (1982–2017) is 31.9 (±0.25) Sv (one standard error of the mean assuming a 20-day integral time scale) with a small downward trend of −0.29 (±0.23) Sv decade^{-1} (errors estimating 95% significance as above). The 2017 median FC transport was 32.3 (±1.6) Sv, slightly above the long-term average and the 2016 annual average. Daily FC transports compared to those of all previous years (Fig. 3.21a) indicate that 2017, unlike previous years, had few unusual transport anomalies (extremes defined as outside the 95% confidence limits for daily values). During 2017 there were no high transport events and the only low transport anomaly that was sustained for more than a day occurred during 10–11 December 2017 (averaging 23.6 Sv). The FC lagged by 8 years has its maximum positive correlation with the NAO (Fig. 3.21b). The FC lagged by 5 years has its maximum negative correlation with the Atlantic multidecadal oscillation (AMO). It continues to be inversely correlated with the difference between observed and astronomically predicted sea level at the Lake Worth tide gauge station (Fig 3.21a, significant at over the 99% significance level, correlation coefficient −0.57 and 28% of variance explained).

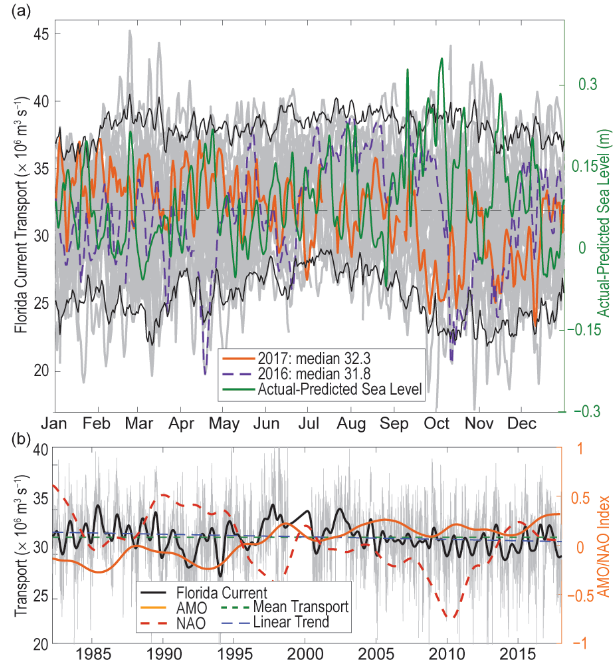

Fig. 3.21. (a) Daily estimates of FC transport (× 10^6 m^3 s^{-1}) during 2017 (orange solid line), 2016 (dashed purple line), and 1982–2015 (light gray lines) with 95% confidence interval of daily transport values computed from all years (black solid line) and the long-term mean (dashed black line). Actual sea level minus predicted sea level at the Lake Worth tide gauge station (dark green line). (b) Daily estimates of FC transport (× 10^6 m^3 s^{-1}) for the full time series record (light gray), smoothed using a 12-month second-order Butterworth filter (heavy black line), mean transport for the full record (dashed black line), and linear trend from 1982 through 2017 (dashed blue line). Two-year low-passed AMO (orange line) and NAO (red dashed line) indices are also shown.

The FC time series contributes to the estimate of the AMOC at 26°N (Figs. 3.22, 3.23), where the AMOC is measured with full-water column moorings that span the full basin and include direct transport measurements in the boundary currents as part of the large RAPID-MOC/MOCHA/WBTS 26°N mooring array (Smeed et al. 2017). The data from these moorings are collected every 18 months, with AMOC data presented in this section extending from April 2004 to February 2017. In the latest update, adding data from October 2015 through February 2017, the AMOC has increased slightly with average AMOC of 17.2 Sv in 2016 and 17 Sv in part of 2017. This seeming stabilization of the downward trend in the AMOC has resulted in a statistically insignificant downward trend estimate of −1.99 (±2.01) Sv decade^{-1}, half the −5.3 Sv decade^{-1} trend first noted in Smeed et al. (2014). This trend is entirely due to the in-

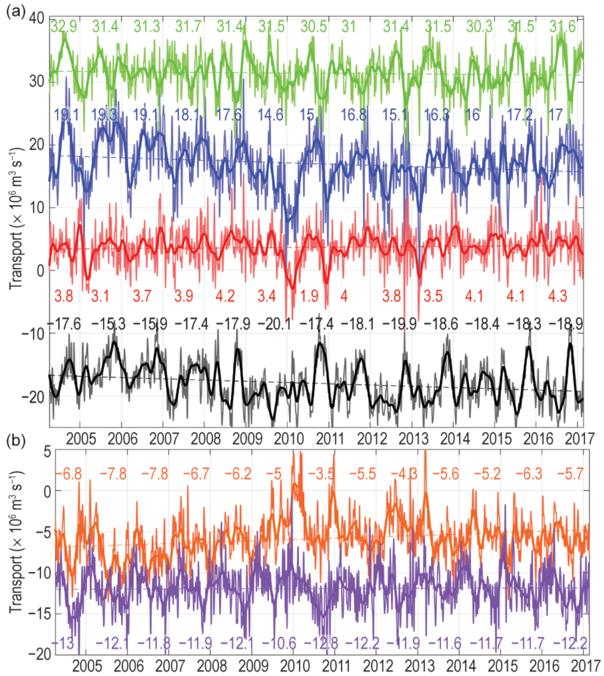

Fig. 3.22. (a) Daily estimates of the volume transport (× 10^6 m^3 s^{-1}) of the meridional overturning circulation (blue line) and its components, the FC (green line), wind-driven Ekman transport (red line), and the geostrophic interior (black line), as measured by the UK National Environmental Research Council (NERC) Rapid Climate Change Program (RAPID-WATCH), the National Science Foundation's Meridional Overturning and Heat transport Array proposal, and the NOAA Western Boundary Time Series project (WBTS). The volume transports have a 10-day low-pass filter applied to the daily values and the annual median transports for each year are shown in the associated color text (Sv). (b) The deepest part of the MOC can be divided into upper deep water (1000–3000 m; orange) and lower deep water (3000–5000 m; purple) transports (× 10^6 m^3 s^{-1}).

crease in the southward near-surface interior flow of –2.05 (±1.35) Sv decade^{-1} (Fig. 3.22, black dashed line), while the decrease in FC transport balances the increase in Ekman transport. The decrease in the AMOC at this latitude can be explained by the decreased export, 1.65 (±1.07) Sv decade^{-1}, of upper North Atlantic Deep Water in the 1–3 km depth range, while the lowest layer remains fairly stable. Change-point analysis shows that the AMOC time series trend is not linear but rather consists of a significant break or jump in the time series in 2008 (Smeed et al. 2018), and the baseline shift toward decreased AMOC was concurrent with changes of a southward shifting Gulf Stream and large-scale changes of sea surface temperature, sea surface height, and heat content.

AMOC estimates are also provided at 41°N, where a combination of profiling Argo floats (that measure ocean temperature and salinity for the upper 2000 m on broad spatial scales, as well as velocity at 1000 m) and altimetry-derived surface velocity (Willis 2010; Hobbs and Willis 2012) are used to estimate the AMOC (Fig. 3.23) and AMHT (not shown). This time series has been updated since last year's report (Baringer et al. 2017), extending from January 2002 to October 2017. Near 16°N, the AMOC is estimated using a mooring array of inverted echo sounders, current meters, and dynamic height moorings (Send et al. 2011) that measure the flow below 1000 m (the southward flowing part of the AMOC "conveyor belt"); hence, the AMOC estimate at this latitude (Fig. 3.23) is a negative number (southward deep flow) to distinguish these observations from the full water column systems. These data have not been updated since last year's report and remain from February 2000 to September 2016. At 35°S in the South Atlantic, the AMOC and AMHT are estimated

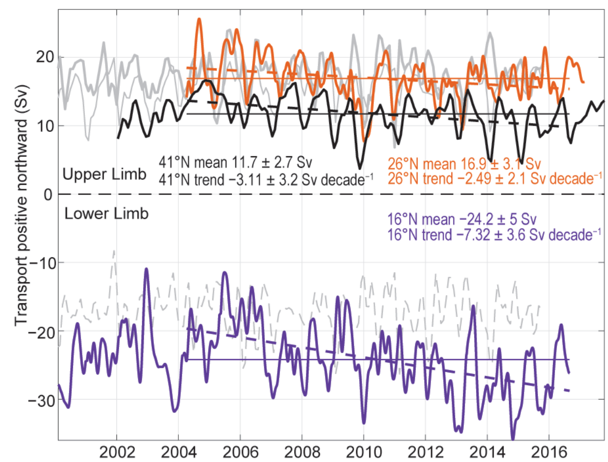

Fig. 3.23. Estimates of AMOC transports (1 Sv = × 10^6 m^3 s^{-1}) from the Argo/Altimetry estimate at 41°N (black; Willis 2010), the RAPID-MOC/MOCHA/WBTS 26°N array (orange; Smeed et al. 2017), and the German/NOAA MOVE array at 16°N (purple; Send et al. 2011) shown vs. year. All time series have a 3-month 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 time period with data available for all three series (Apr 2004 through Aug 2016). For MOVE data, the net zonal and vertical integral of the deep circulation represents the lower limb of the AMOC (with a negative sign indicating southward flow), and hence a stronger negative (southward) flow represents an increase in the AMOC amplitude. Light gray lines show ECCO2-derived transports (Menemenlis et al. 2008): (top) thin gray is the 41°N transport, thick gray is the 26°N transport, (bottom) the negative meridional overturning circulation in the model shown for ease of comparison with the 16°N data.

using a combination of high-density (closely spaced) expendable bathythermograph (XBT) and broader-scale Argo profiling float data (Dong et al. 2014, not shown; www.aoml.noaa.gov/phod/soto/mht/ax18/report.php). These data are collected and analyzed in near-real time, with values spanning July 2002 to September 2017.

Similar to 26°N, at 41°N the AMOC and AMHT are decreasing less rapidly (Fig. 3.23), changing to −0.08 (±2.7) Sv decade^{-1} and −0.03 (±0.04) PW decade^{-1} as compared with −1.2 (±3.0) Sv decade^{-1} and −0.09 (±0.21) PW decade^{-1} reported last year. Farther south, the MOC/MHT trends are positive, but decreasing in the past three years as the annual means at 16°N increased from −29.2 Sv in 2014 to −27.8 Sv in 2015 to −23.8 in 2016. This recent reduction in southward flow has led to a reduced estimate of the long-term trend of the AMOC from February 2000 to September 2016 at 16°N to be +3.4 (±2.4) Sv decade^{-1}. While the 35°S AMOC transport estimate has remained fairly constant for the last three years (median AMOC of about 20 Sv), during 2017 it was dominated by the Ekman component whereas in previous years it had been dominated by the geostrophic component. The variability at all latitudes in the Atlantic is not well correlated and, therefore, data from more than one latitude are needed to describe the state of the ocean.

i. *Global ocean phytoplankton*—B. A. Franz, E. M. Karaköylü, D. A. Siegel, and T. K. Westberry

Marine phytoplankton contribute roughly half the net primary production (NPP) on Earth, fixing atmospheric CO_2 into food that fuels global ocean ecosystems and drives biogeochemical cycles (e.g., Field et al. 1998; Falkowski et al. 1998). Phytoplankton growth is dependent on availability of light and nutrients (e.g., iron, nitrogen, phosphorous) in the upper ocean euphotic zone, which in turn is influenced by physical factors such as ocean temperature (e.g., Behrenfeld et al. 2006). SeaWiFS (McClain 2009) and MODIS (Esaias et al. 1998) are satellite ocean color sensors that provide observations of sufficient frequency and geographic coverage to globally monitor changes in the near-surface concentration of the phytoplankton pigment chlorophyll-*a* (Chl*a*; mg m^{-3}), which serves as a proxy for phytoplankton abundance. Here, global Chl*a* distributions for 2017 are evaluated within the context of the 20-year continuous record provided through the combined observations of SeaWiFS (1997–2010) and MODIS on *Aqua* (MODISA, 2002–present). All Chl*a* data used in this analysis correspond to NASA process-

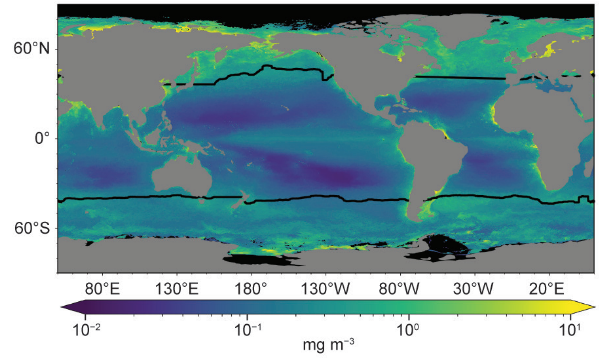

Fig. 3.24. Annual mean Chl*a* distribution mg m^{-3} derived from MODIS on *Aqua* for 2017. Also shown is the location of the mean 15°C SST isotherm (black lines) delineating the boundary of the PSO. Chl*a* data are from NASA Reprocessing version 2018.0. Data are averaged into geo-referenced equal area bins of approximately 4.6 × 4.6 km^2 and mapped to an equi-rectangular projection centered at 150°W.

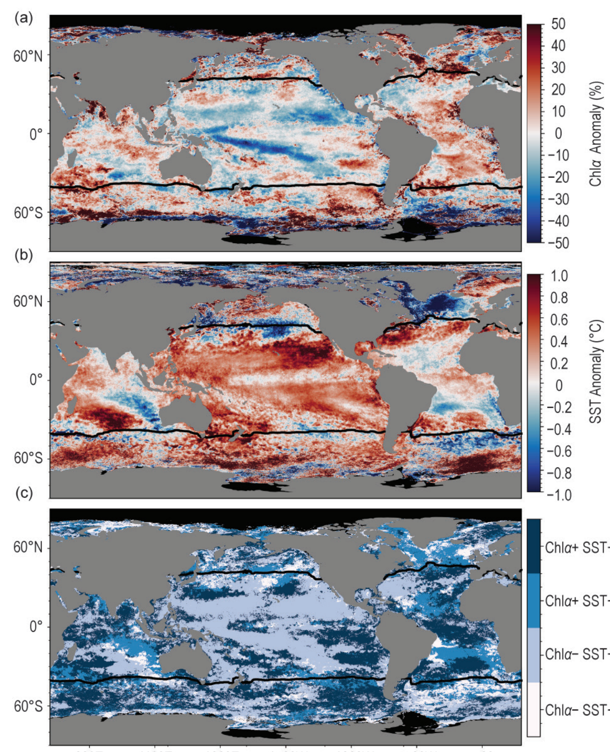

Fig. 3.25. Spatial distribution of average monthly (a) MODISA Chl*a* anomalies and (b) SST anomalies where monthly differences were derived relative to the MODISA 9-year climatological record (2003–11). Chl*a* is expressed as % difference from climatology, while SST is shown as an absolute difference (°C). (c) identifies relationships between the sign of SST and Chl*a* anomalies from panels (a) and (b), with colors differentiating sign pairs and missing data masked in black. Also shown in each panel is the location of the mean 15°C SST isotherm (black lines) delineating the PSO.