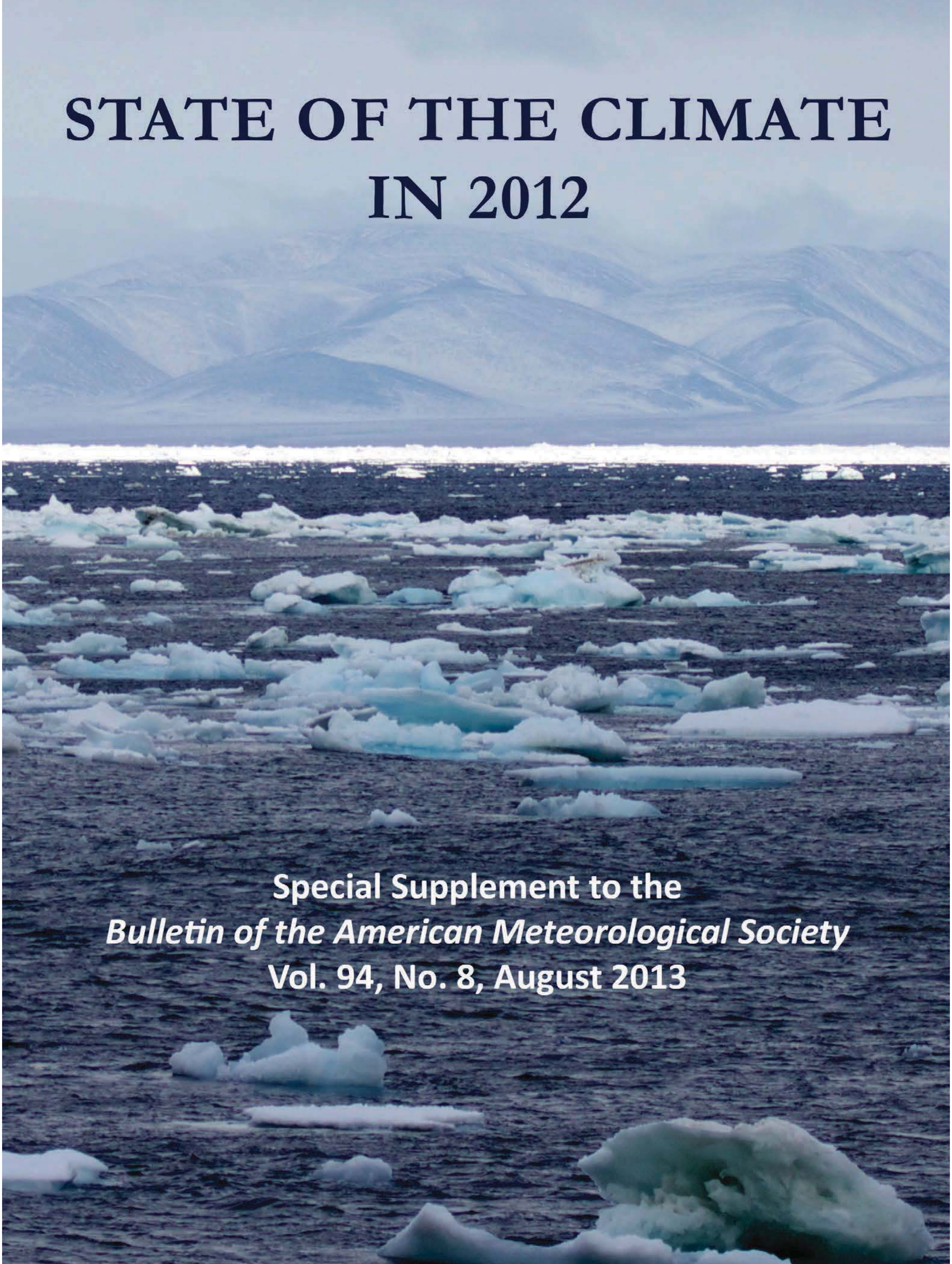

STATE OF THE CLIMATE IN 2012

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(although apparently not in the South Indian Ocean this year) are typical of the seasonal cycle and most likely owing to entrainment of fresher water from below in the winter (Johnson et al. 2012b).

f. *Subsurface salinity*—T. Boyer, S. Levitus, J. Antonov, J. Reagan, C. Schmid, and R. Locarnini

Evaporation minus precipitation (E–P) is well correlated with mixed layer salinity over much of the world's ocean (Yu 2011). It is difficult to accurately measure evaporation and precipitation over the ocean, so near-surface salinity can be used to constrain E–P estimates (Schmitt 2008; Yu 2011). E–P surface forcing has led to an intensification of the global hydrological cycle over the last 50 years, increasing salinity at the sea surface in areas dominated by evaporation and decreasing salinity in areas dominated by precipitation (Durack and Wijffels 2010; Durack et al. 2012). These surface changes are advected to the subsurface ocean. Globally, near-surface salt content has increased in recent times compared to long-term means, while intermediate waters have decreased in salinity (Roemmich and Gilson 2009; Helm et al. 2010; Boyer et al. 2012). These changes are reflected in changes to ocean water mass composition and circulation patterns.

To investigate changes to subsurface salinity, all available subsurface salinity profile data for year 2012 were used to calculate gridded 1° mean salinity anomalies at different depths from the surface to 2000 m. Anomalies were calculated as differences from a long-term mean for 1955–2006 (Antonov et al. 2010). Differences from similarly calculated salinity anomaly fields for 2011 are also used to investigate year-to-year variations in salinity. A full description of the method can be found in Boyer et al. (2012).

Currently, the single largest source of salinity profiles is the Argo program with its fleet of profiling floats (Roemmich et al. 2009a; Sidebar 3.1). Subsurface salinity anomalies for 2012 were calculated from 130 985 salinity profiles recorded on 4108 floats from this program. Of these, 16 713 passed through the higher level of delayed-mode quality control, including a correction of the salinity drift if necessary (Wong et al. 2003; Owens and Wong 2009). Because one year of data is needed to perform the salinity drift correction, real-time salinity data with basic quality control were also used in this study. Of the real-time data, 62 409 profiles include salinity drift adjustments calculated for earlier cycles in a floats lifetime.

In addition to the Argo data, another major source of salinity data is 27 743 daily mean profiles from tropical moored buoys (http://www.pmel.noaa.gov/tao/; TAO/TRITON, PIRATA, and RAMA). This analysis also used 11 947 CTD casts concentrated in the northwest Pacific (Japanese sources) and northwest Atlantic (Canadian and US sources). These salinity profiles came through the Global Temperature and Salinity Profile Project (GTSPP). Finally, GTSPP also made available 7337 profiles from gliders, localized geographically in the Gulf of Mexico, far western Pacific, and coastal eastern Pacific.

In order to examine the year-to-year change in salinity, salinity anomaly fields for 2011 were recalculated based on updated quality control provided by Argo. This study used 56 555 of the 123 471 Argo salinity profiles recorded in 2011, which have now been delayed-mode quality controlled. All salinity and salinity anomaly data were examined using quality control procedures outlined in Boyer et al. (2009) and are available through the World Ocean Database. All calculated fields and figures are available at http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/. Mean salinity anomalies for the upper 100 m on a 1° grid are also computed. The geographic distribution of these fields is similar to sea surface salinity (SSS) anomaly fields as presented in section 3e.

The zonal mean difference between salinities in the Pacific Ocean in 2012 and the long-term mean are shown in Fig. 3.14a. Much of the Southern Hemisphere Pacific was fresher in 2012 compared to the long-term mean, with the exception of the upper 250 m in the subtropics. South of 40°S there was significant freshening relative to the long-term mean below 1500 m. Meijers et al. (2011) attributes the freshening in the high latitude South Pacific to southward movement of the Antarctic Circumpolar Current and water mass changes possibly due to increased precipitation and ice melt. The differences between 2012 salinity in the South Pacific and the long-term mean are similar to the differences between 2011 salinity and the long-term mean (Boyer et al. 2012), with the patterns strengthened between 2011 and 2012 (Fig. 3.14b), particularly with increased freshening along 30°S above 500-m depth. Similar to 2011, 2012 differed from the long-term mean in the North Pacific, with saltier conditions in the upper 250-m near the equator and freshening at midlatitudes down to 750 m depth, consistent with the thermocline freshening described by Ren and Riser (2010). Freshening exceeding 0.06 at subsurface levels near 50°N occurred in 2012 relative to 2011. In the Bering Sea area, the salinity relative to 2011 decreased strongly enough that the salinity anomaly relative to the long-term mean changed from positive/saltier (2011) to negative/fresher (2012). Mean

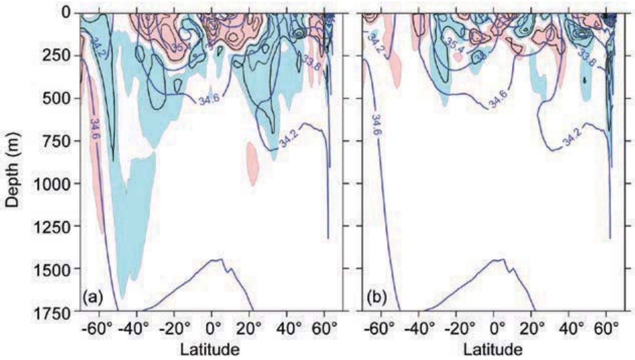

Fig. 3.14. Zonally averaged (a) 2012 salinity anomaly and (b) 2012 minus 2011 salinity field for the Pacific Ocean. Blue shading represents negative (fresh) anomalies <-0.01, red shading represents positive (salty) anomalies >0.01. The contour interval for the anomalies is 0.02. In the background of each figure (thick blue contours) is the zonally-averaged climatological mean salinity (WOA09). Contour intervals for the background are 0.4. All values are on the PSS.

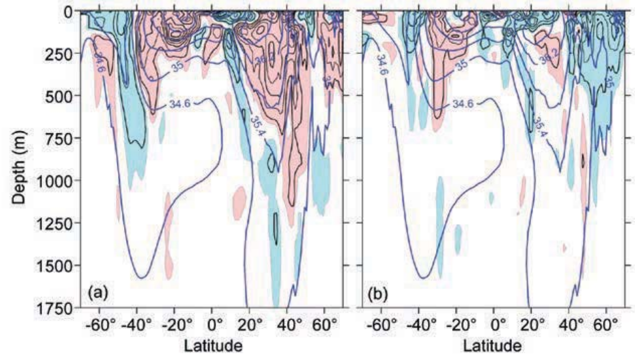

Fig. 3.15. Zonally averaged (a) 2012 salinity anomaly and (b) 2012 minus 2011 salinity field for the Atlantic Ocean. Blue shading represents negative (fresh) anomalies <-0.01, red shading represents positive (salty) anomalies >0.01. The contour interval for the anomalies is 0.02. In the background of each figure (thick blue contours) is the zonally-averaged climatological mean salinity (WOA09). Contour intervals for the background are 0.4. All values are on the PSS.

salinity in the upper 100 m (not shown, but closely resembles Fig. 3.11a) shows a large positive salinity anomaly relative to the long-term mean under the South Pacific convergence zone (SPCZ), although this feature has weakened compared to 2011 (not shown, but closely resembles Fig. 3.11b). The western equatorial Pacific south of the equator has freshened since 2011, but otherwise the tropical Pacific waters in the upper 100 m are saltier than the long-term mean and this positive salinity anomaly increased from 2011 to 2012 between the equator and 15°N (not shown, but closely resembles Fig. 3.11b).

For the most part, 2012 salinity anomalies with respect to the long-term mean (Fig. 3.15a) in the subtropical and sub-polar North Atlantic agree with the salinity increase reported by Boyer et al. (2007) and Wang et al. (2010), with the exception of a reversal around 45°N. However, most of the North Atlantic freshened between 2011 and 2012 (Fig. 3.15b). North of 40°N, this freshening was consistent down to 500 depth. South of 40°N, freshening was generally exceeding 0.02 above 200-m depth, with anomalies exceeding 0.01 m to 500-m depth in the tropics. 2012 experienced a mostly negative North Atlantic Oscillation (NAO) index, while 2011 had mostly a positive NAO index, with the exception of the months May–July; Tropical Rainfall Measuring Mission (TRMM) recorded greater precipitation in 2012 than in 2011 from 30°N to 40°N, while from the equator to 25°N less precipitation was recorded. (No data are available outside 40°S–40°N.) These factors could contribute to the observed freshening, at least in the mixed layer. Another factor could be changes in the ice melt (both Arctic Ocean and Greenland). It remains to be seen if this freshening is a short-term phenomenon or a reversal of the signal present over the last 15 years. In contrast, the southern Atlantic salinity signal for 2012, compared to the long-term trend, strengthened with respect to the same signal for 2011. Positive salinity anomalies exceeding 0.04, compared to the long-term trend, are found for 2012 down to 250 m in depth from the equator to 40°S, with anomalies exceeding 0.02 down below 500 m between 30°S and 40°S. South of 40°S in the Atlantic Ocean, a deep freshening is observed, to depths exceeding 700 m, shoaling to the south, where the freshening is limited to the upper 200-m depth. These trends were strengthened and deepened between 2011 and 2012 (Fig. 3.15b) over most of the South Atlantic, with the exception of the high latitudes, where conditions were saltier in the upper 200 m in 2012 than 2011.

In the Indian Ocean, the difference between 2012 salinity zonal means and the long-term mean (Fig. 3.16a) includes deep (below 1000 m) freshening south of the equator, interrupted by increased salinity in the midlatitude South Indian Ocean from the surface to at least 250-m depth. In the upper 100 m (not shown, but closely resembles Fig. 3.11a), the positive/salty anomaly at latitudes north of 30°S is confined to the western half of the Indian Ocean, with freshening in the eastern Indian Ocean. South of 30°S, the positive anomaly extends across the entire basin. The salinity change from 2011 to 2012 in the South Indian Ocean was small (Fig. 3.16b). Most of the North Indian Ocean zonal mean anomalies for 2012 are positive/salty compared to the long-term mean to depths ex-