

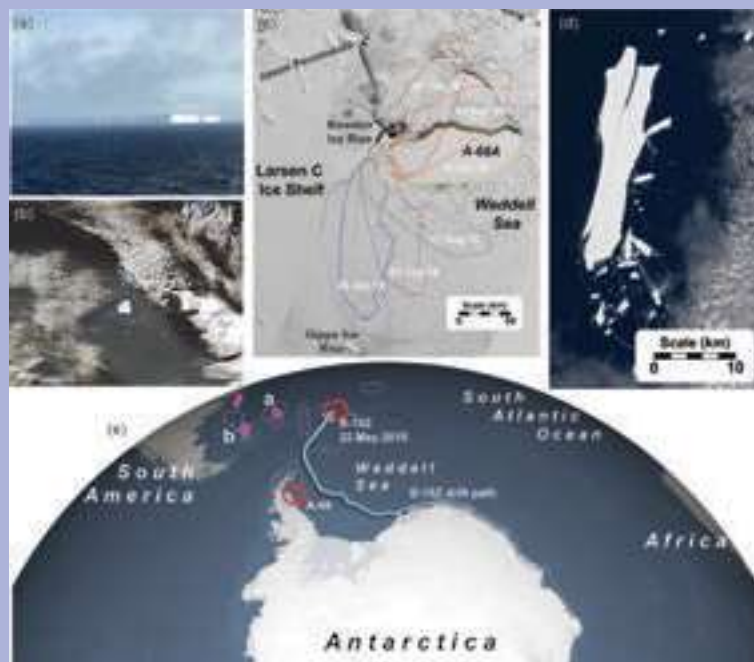
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CONT. SIDEBAR 6.2: **RECENT DRIFT AND EVOLUTION OF LARGE ICEBERGS IN THE SOUTHERN OCEAN**—A. SCARDILLI, F. CLAUS, C. A. SHUMAN, AND T. SCAMBOS



**FIG. SB6.2. Bottom map: regions of the Southern Ocean and Weddell Sea with extensive iceberg activity in 2018. Dashed white areas show northernmost regions of iceberg swarms as of Sep 2018. Magenta dots indicate locations of specific icebergs in the anomalous region, with (a) and (b) locations shown in images. Red ovals indicate locations of two very large icebergs, with the recent (since 2014) drift path of the ~18+ year old and ~170 km<sup>2</sup> Iceberg B-15Z (<https://earthobservatory.nasa.gov/images/92238/end-of-the-journey-for-iceberg-b-15z>) shown as light blue line. (a) Photo of iceberg at 54°S taken from the passing bulk carrier *Orient Sky*; (b) MODIS *Aqua* image from May 2018 showing iceberg disintegration event; (c) rotation and drift of Iceberg A-68A near the Larsen C Ice Shelf front. Original position of A-68 just after calving was in the broad embayment of the Larsen C just north of Gipps Ice Rise. Bawden Ice Rise (black outline) and extensive shoal area (white outline) had pinned A-68A, which rotated due to the strong northward sea ice drift and underlying current in the adjacent Weddell Sea; (d) break-up and partial disintegration of Iceberg B-15Z captured in astronaut photo from the International Space Station (<https://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS055&roll=E&frame=74583>).**

Iceberg disintegration is likely due to processes similar to ice shelf disintegration (Scambos et al. 2008; Wagner et al. 2014; Massom et al. 2018), proceeding from water-line erosion and bottom crevassing to hydrofracture-driven collapse as surface melt saturates the overlying snow and firn layers.

Using satellite image analysis, sea surface and air temperatures from both reanalysis and in situ observations, as well as surface ocean current measurements, we infer that the

anomalous northward drift of the icebergs was likely a result of a combination of the following factors: the presence of large icebergs outside the sea ice field during austral winter; seasonally below-average air and ocean surface temperatures (prolonging iceberg stability); and a more rapid advection than is typical by the Malvinas Current. This unusual situation, with many large icebergs in the Argentine Sea (and, inevitably, the more numerous and thus dangerous smaller pieces) was of great concern for shipping safety, because icebergs and smaller ice blocks are rarely anticipated in this area.

At the opposite end of iceberg life cycle is the A-68 iceberg, a 5800 km<sup>2</sup> berg that calved from the Larsen C ice shelf in July 2017. In 2018, A-68A (the largest piece of the initial iceberg) ran aground and pivoted around a small ice rise and shoal just north of its original calving location from the Larsen C Ice Shelf. This is typical of the initial drift patterns of many large icebergs, because their draft can extend more than 250 m below the surface. The Bawden Ice Rise is a stabilizing pinning point for the Larsen C Ice Shelf (Borstad et al. 2013). The extensive shoal to the east and north was recognized from earlier groundings of small icebergs over the past several years (Lavoie et al. 2016). Over the course of 2018 and in early 2019, northward drift of sea ice and the western boundary current of the Weddell Sea forced the massive berg to rotate by nearly 180° around a shallow seabed area beneath what was its initial seaward edge (Fig. SB6.2c). The ~170-km long iceberg finally cleared the submarine obstruction by March 2019.

All information related to the position of icebergs in the Argentine Sea and adjacent areas of the Southern Ocean and sea ice field is broadcast to navigators via SafetyNet, NAVTEX, and through the website [www.hidro.gob.ar](http://www.hidro.gob.ar).

Further information on iceberg locations worldwide is reported at the U.S. Navy/NOAA/Coast Guard National Ice Center ([www.natice.noaa.gov/pub/icebergs/Iceberg\\_Tabular.pdf](http://www.natice.noaa.gov/pub/icebergs/Iceberg_Tabular.pdf)) and at Brigham Young University's Antarctic Iceberg Tracking Database ([www.scp.byu.edu/data/iceberg](http://www.scp.byu.edu/data/iceberg)). Note, the National Ice Center also announces specific events such as initial calvings and subsequent breakup of icebergs ([www.natice.noaa.gov](http://www.natice.noaa.gov)).

stability were computed relative to the climatological (2000–10) seasonal cycle (Figs. 6.10a–e). In 2018, the MLD was up to 100 m deeper than average in the Pacific east of 120°W. This contrasts with the west Pacific MLD where there was a trend toward net shoaling. The split across the Pacific MLDs appears to be driven by mixed-layer temperatures that were anomalously high in the west and low in the east, with respective increases and decreases in vertical stability (Fig. 6.10d). Such a mode of variability in the South Pacific was observed by Cerovečki et al. (2019 in press), who suggest it may be wind-driven and related to the relative phases of the SAM and ENSO atmospheric modes. The 2018 Southern Ocean temperature anomaly exhibited an almost identically opposite quadrupole pattern to that observed in 2016 (Mazloff et al. 2017). In 2016, both SAM and ENSO were strongly positive, whereas SAM and ENSO were largely out of phase and weak over most of 2018 (after a period of in-phase condition early in the year; Fig. 6.5e; note that SOI and ENSO indices have opposite sign for El Niño and La Niña). Elsewhere, there was weak MLD shoaling in the Atlantic sector associated with strong mixed-layer warming of up to 2.5°C north of the polar front, contrasting with strong cold anomalies seen in this same sector in 2017 (Swart et al. 2018).

South of the polar front there was a consistent circumpolar deepening of the MLD in 2018, which appears to be associated with an increase in salinity. This increased salinity may be due to enhanced entrainment from below by the deeper mixed layers or reduced freshwater export by the largely reduced sea ice extent in 2018 (Section 6e, Fig. 6.9c). The increase in salinity is particularly strong in the Pacific sector and extends farther to the east than a similar positive salinity anomaly seen in 2017, suggesting a possible advective influence. This salinification also contributed to a reduction in the stability of the upper ocean north of the sea ice edge in the Ross Sea sector, as well as farther north in the Tasman Sea and western Pacific (Fig. 6.10e). The reduced mixed-layer stability over Maud Rise (~66°S, 3°E) is notable given the large open-ocean polynya present there in 2016–17 (Swart et al. 2018), and suggests that it may continue to impact the region despite not appearing in 2018.

## 2) OCEAN COLOR: PHYTOPLANKTON ABUNDANCE

Phytoplankton abundance, as indicated by chlorophyll *a*-concentration, was slightly higher in the 2017/18 growing season (July 2017–June 2018) than the 20-year climatological mean (1998–2018), but well within the bounds of natural variation. This con-

tinues a long-term trend of increasing phytoplankton abundance that has been observed since 1998 (Arrigo et al. 2008). Both the largest decreases and increases in mean surface chlorophyll-*a* in 2017/18 (Fig. 6.10g) relative to the climatological mean (Fig. 6.10f) were observed in the Ross Sea—the decrease on the continental shelf associated with the Ross Sea polynya (where the sea ice edge retreat in 2017/18 was exceptionally early; Reid et al. 2018), and the increase in coastal waters of the eastern and western Ross Sea. This is consistent with the Ross Sea being both highly productive and highly variable. The generally productive coastal polynyas around the Antarctic continent were less productive in 2017/18 compared with the 1998–2018 climatology, likely due to an unusually early spring–summer ice edge retreat in 2017/18 (Reid et al. 2018).

## 3) AIR–SEA CARBON DIOXIDE FLUXES

Observation-based flux estimates for this critical region have traditionally relied on sparse and seasonally biased shipboard measurements. Autonomous biogeochemical-Argo floats, deployed by the Southern Ocean Carbon and Climate Observations and Modelling (SOCCOM) project, now provide year-round observations of pH, oxygen, nitrate, and ocean optics in the upper 2000 m of the open ocean (Johnson et al. 2017), permitting new estimates of air–sea CO<sub>2</sub> fluxes (Gray et al. 2018). Including 2018, the SOCCOM data span four full years, presenting the first opportunity to examine interannual variability in these flux estimates.

Overall, the Southern Ocean appears to have absorbed more CO<sub>2</sub> in 2018 than the 2015–18 average, with four of five regions showing increased uptake or reduced outgassing (Fig. 6.11). The largest difference occurred in the Subantarctic Zone (SAZ), where substantially more CO<sub>2</sub> uptake occurred in 2018. The strong wintertime outgassing revealed by the float observations in the high-latitude Antarctic Southern Zone (ASZ) during 2015–17 was reduced slightly in 2018. Given that the 2015–17 float-based carbon flux estimates are well outside the range of variability in ship-based estimates (Le Quere et al. 2018; Gray et al. 2018), these results suggest a shift toward increased carbon uptake by the Southern Ocean in 2018, notwithstanding the persistence of strong wintertime outgassing south of the polar front. However, any assessment of interannual variability at present is limited by the number of observations and their spatial and temporal coverage.