STATE OF THE CLIMATE IN 2011

Special Supplement to the
Bulletin of the American Meteorological Society
Vol. 93, No. 7, July 2012

STATE OF THE CLIMATE IN 2011

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Copies of this report can be downloaded from doi: 10.1175/2012BAMSStateoftheClimate.1 and http://www.ncdc.noaa.gov/bams-state-of-the-climate/

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Cover credits:

Front: ©Jakob Dall Photography — Wajir, Kenya, July 2011

Back: ©Jonathan Wood/Getty Images — Rockhampton, Queensland, Australia, January 2011

HOW TO CITE THIS DOCUMENT

Citing the complete report:

Blunden, J., and D. S. Arndt, Eds., 2012: State of the Climate in 2011. *Bull. Amer. Meteor. Soc.*, **93** (7), S1–S264.

Citing a chapter (example):

Gregg, M. C., and M. L. Newlin, Eds., 2012: Global oceans [in "State of the Climate in 2011"]. *Bull. Amer. Meteor. Soc.*, **93** (7), S57–S92.

Citing a section (example):

Johnson, G. C., and J. M. Lyman, 2012: [Global oceans] Sea surface salinity [in "State of the Climate in 2011"]. *Bull. Amer. Meteor. Soc.*, **93** (7), S68–S69.

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and continues the increasing trend since the 2008/09 season (Wang and Liu 2011). However, the value is still well below the reported average melt extent of the past decades, such as the 26-year (1978–2004) median melt extent (1 277 500 km^2) reported in Liu et al. (2006), and the 20-year mean (1980–99; 1 280 000 km^2) reported in Torinesi et al. (2003). The Melt Index (Zwally and Fiegles 1994; Torinesi et al. 2003; Liu et al. 2006) for austral summer 2010/11, calculated as an annual index by accumulating the number of melting days over a certain area (e.g., the entire Antarctica), was 40 280 625 day·km^2, slightly larger than last year's melt index (39 349 375 day·km^2; Wang and Liu 2011). The melt peak day (Fig. 6.7d) was 29 December 2010, with two smaller peaks in November 2010 and March 2011. The smaller peaks were caused by off-season melt events on the Wilkins Ice Shelf (Figs. 6.7a–b).

Melt area is strongly correlated with latitude; as expected, more melt occurred at lower latitudes than higher ones. Exceptions are the large area of short-period melt on the Ronne-Filchner Ice Shelf, and sporadic melt on Marie Byrd Land (Fig. 6.7c). Extensive melt was seen on the Peninsula, Wilkins, Queen Maud Land, Amery, Shackleton, and Abbot Ice Shelves. Little melt was detected on Ross Ice Shelf, Victoria Land, and Wilkes Land (see Fig. 6.7a for locations). Overall, the melt season of 2010/11 was relatively melt-intensive compared to the past few years in the Antarctic melt record (Tedesco 2009; Tedesco and Monaghan 2009). The magnitude and spatial pattern were similar to those of the previous melt season.

f. Sea ice extent and concentration—R. A. Massom, P. Reid, S. Stammerjohn, S. Barreira, and T. Scambos

During 2011, zonally-averaged Antarctic sea ice extent was characterized by three broad phases that were closely associated with the changes in large-scale patterns of atmospheric circulation described in section 6b.

From near-average levels at the beginning of the year (compared to the 1981–2010 mean), the zonally-averaged sea ice extent tracked at 1–2 standard deviations below the long-term mean from mid-January through mid-May (Fig. 6.8a)—including some brief times when it dipped below the 30-year record. Over this period, negative ice extent anomalies in the (1) eastern Bellingshausen Sea, (2) Weddell Sea (apart from in the southwest), (3) western Amundsen to Ross Seas, and (4) the West Pacific Ocean sector between 75°E and 120°E outweighed strong positive anomalies over much of the eastern Amundsen Sea and the Indian Ocean sector (10°E–70°E; Fig. 6.8b). These positive/negative ice-edge anomalies are likely to be due to a combination of wind-driven ice advection/compaction and in situ thermodynamic growth, the latter associated with the development of cold pools of SST (in the eastern Ross Sea in particular, e.g., in Fig. 6.8d).

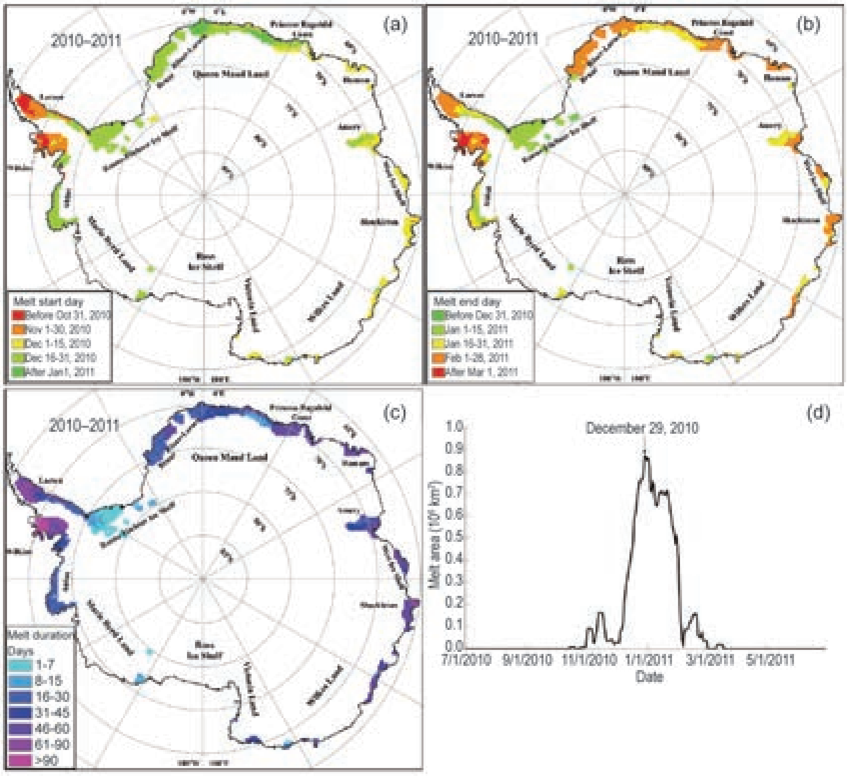

Fig. 6.7. Maps for (a) melt start day, (b) melt end day, and (c) melt duration of Antarctic ice sheet during 2010/11 austral summer. Daily melt extent is shown in (d) with melt peak day indicated.

The pattern of the 2010/11 season sea ice retreat and advance during the January–May period (not shown) to a large degree reflects the strong positive SAM/La Niña conditions, with generally negative surface pressure anomalies at higher latitudes, particularly in the Amundsen and Bellingshausen Seas, and below-average sea surface temperatures in

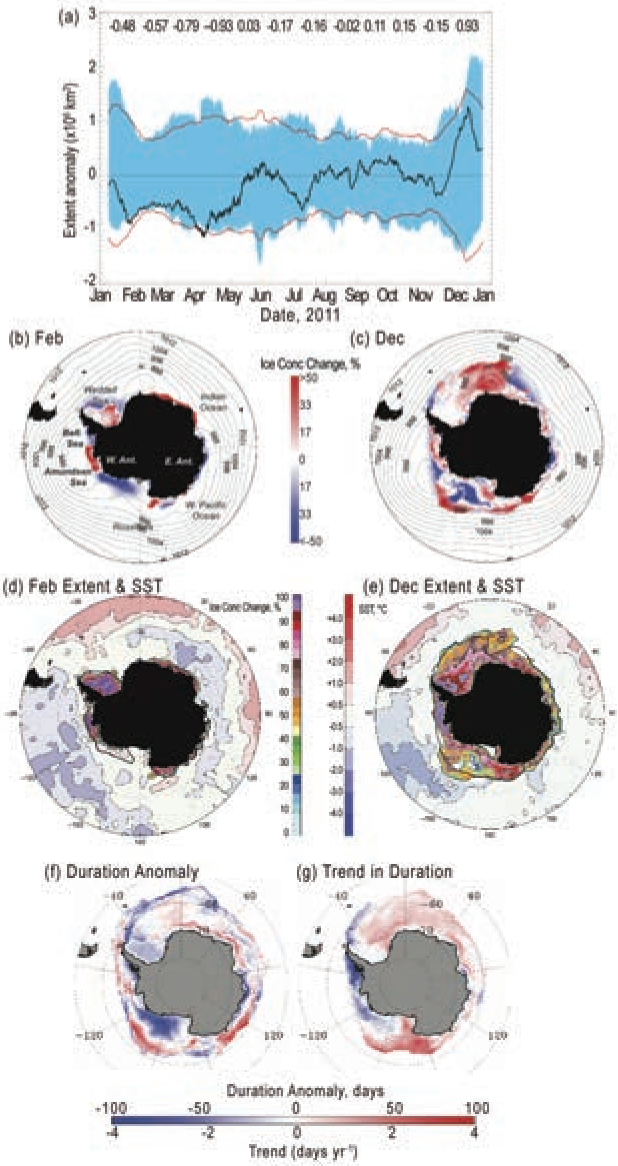

Fig. 6.8. (a) Plot of daily anomaly (black line) from the 1981–2010 climatology of daily Southern Hemisphere sea ice extent for 2011, based on satellite passive microwave ice concentration data from the GSFC Bootstrap Version 2 dataset (Comiso 1999). Blue banding represents the range of daily values for 1981–2010, while the red line represents ±2 standard deviations. Figures at the top are monthly mean extent anomalies ($\times 10^6$ km^2). (b) and (c) Sea ice concentration anomaly maps for February and December 2011 derived versus the monthly means for 1981–2010, with monthly mean contours of ACCESS MSLP. (Bell is Bellingshausen Sea.) (d) and (e) Maps of monthly mean sea ice concentration for February and December 2011, respectively, with mean ice edge/extent contours for 1981–2010 (black lines) and SST anomaly contours superimposed. The SST anomalies were calculated against the 1981–2010 mean and are based on data from the Optimal Interpolation SST version 2 dataset (Reynolds et al. 2002; Smith et al. 2008). (f) Sea ice duration anomaly for 2011/12, and (g) duration trend (see Stammerjohn et al. 2008). Both the climatology (for computing the anomaly) and trend are based on 1981/82 to 2010/11 data (Comiso 1999), while the 2011/12 duration-year data are from the NASA Team Near-Real-Time Sea Ice (NRTSI) dataset (Maslanik and Stroeve 1999).

the tropical Pacific. These conditions brought about earlier-than-normal sea ice retreat in the eastern Bellingshausen, western Weddell, and southern Ross Sea regions, contrasting with later-than-normal retreat in the outer eastern Ross Sea, Amundsen Sea, and Indian Ocean regions. For the most part, the sea ice advance anomaly pattern in 2011 mirrored the previous year's retreat pattern (in 2010/11) in that where the 2010/11 sea ice retreat was early, the 2011 sea ice advance was late (in the southern Bellingshausen Sea, western Weddell Sea, eastern Antarctica between ~80°E–120°E, and southern Ross Sea). Conversely, where the 2010/11 sea ice retreat was late, the advance was early (in the outer Amundsen Sea, outer Ross Sea, Indian Ocean between ~40°E–80°E, and the West Pacific sector between ~120°E and 160°E).

Of particular interest during April–May was a rapid change from a strongly negative to positive sea ice extent anomaly in the eastern Ross Sea sector. This was a result of a combination of high cyclonic activity, cold air advection, fresh water influx into the mixed layer (precipitation), and cool SSTs.

During the second phase, from mid-May to mid-November, the zonally-averaged extent largely fluctuated about the mean, with the exception of a dip towards two standard deviations below the long-term mean from mid-June to mid-July (Fig. 6.8a). The intervening wintertime dip occurred largely as a result of a southward incursion of the ice edge along a broad front from the tip of the Antarctic Peninsula eastwards across the Indian Ocean sector and in the western Ross Sea, coinciding with a band of anomalously warm SSTs in that region (not shown). This major incursion of the ice edge south of the long-term mean largely persisted through November, but was counterbalanced after mid-July by strong positive ice extent and concentration anomalies elsewhere (e.g., across the southwestern Pacific Ocean sector east of 120°E, the Ross Sea, and the northwestern Weddell and Bellingshausen Sea—the latter against the long-term negative trend; Comiso 2010; Stammerjohn et al. 2012). During this phase, the general atmospheric circulation reflected a weakening from near-neutral (mid-year) to moderately strong negative

SAM conditions (during austral spring; Fig. 6.2) and generally positive surface pressure anomalies at higher latitudes (Fig. 6.3e). As a consequence, the sea ice retreat anomaly pattern in 2011/12 was marked by late retreat across the Weddell, West Pacific, and outer Ross Sea regions, more or less opposite to that observed in the 2010/11 season.

The final phase, from mid-November onwards (Fig. 6.8a), entailed a rapid change to a strongly positive zonally-averaged ice extent anomaly and coincided with strong positive SAM/La Niña conditions with a classic ZW3 pattern in atmospheric pressure; low pressure centers in the eastern Weddell Sea, off East Antarctica at ~110°E, and in the Amundsen Sea (Figs. 6.2e; 6.8c). This resulted in the persistence of above-average ice extents and concentrations in the northeastern Weddell Sea, Ross Sea, and central West Pacific Ocean, plus near-average conditions elsewhere, with the exception of negative regional anomalies in the outer eastern Amundsen Sea, central Ross Sea, and northwestern Weddell Sea (Figs. 6.8c,e). The anomalously extensive sea ice in the Ross Sea also coincided with a region of cooler-than-average SSTs at this time (Fig. 6.8e). Overall Antarctic sea ice extent in December 2011 was the fifth highest since satellite records began in 1979.

The persistence of heavy pack and fast ice conditions along the Indian Ocean coastal sector during December continued to severely affect shipping operations and the resupply of Mawson Station (~62.9°E, 67.6°S). Conversely, in February, a strong storm in the McMurdo Sound area removed multiyear fast ice completely, during the early period of lower-than-normal sea ice extent in the southern Ross Sea. This resulted in damage to the ice pier at McMurdo Station, and probably contributed to the calving of two large icebergs from the McMurdo Ice Shelf at the southern end of the sound.

Given the midyear transition in the atmospheric circulation and sea ice anomaly patterns, the resulting sea ice season duration showed generally weak anomalies (Fig. 6.8f) overall (compared to 2010/11, for example). This was due to the fact that sea ice advance and retreat anomalies in most regions largely canceled each other out. In the western Weddell Sea, for example, the annual advance was late but the retreat was also late, so the ice season duration was near normal [relative to the long-term trends (Fig. 6.8g); see also Stammerjohn et al. 2012]. Greatest differences in 2011/12 compared to the long-term trends in annual sea ice season duration occur in the inner eastern Ross Sea (more strongly negative in 2011/12) and the relatively narrow zone in the Indian Ocean sector between ~110°E and 150°E (more strongly positive). The notable regional "hot-spot" of a long-term trend towards shortening of the sea ice season in the Amundsen-Bellingshausen Sea was less extensive in 2011/12 (Figs. 6.8f,g). Although ice extent and concentration anomalies were negative in this region in the first half of the year (in line with the long-term trend; Comiso 2010), the switch to positive anomalies for the remainder of the year created a near-zero duration anomaly for 2011/12.

g. Ozone depletion—P. A. Newman, E. R. Nash, C. S. Long, M. C. Pitts, B. Johnson, M.L. Santee, J. Burrows, and G. O. Braathen

The Antarctic ozone hole was moderately more severe in 2011 compared to the 1990–2011 period (average taken after the marked depletion in the 1980s). Figure 6.9 displays select October averages of total ozone derived from NASA instruments between 1970 and 2011. Prior to 1980 (top row), severe ozone depletion over Antarctica was not apparent. After 1990, nearly every year has seen a severe loss. As is clear from the bottom right panel (2011),

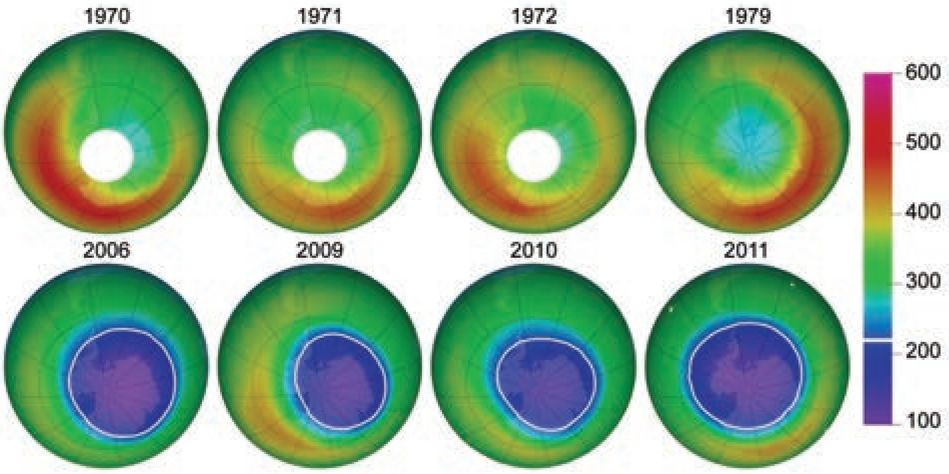

Fig. 6.9. October averages of total column ozone (Dobson Units, DU) derived from the Nimbus-4 BUV (1970–72), Nimbus-7 TOMS (1979), and OMI instruments (2006, 2009–11). The white line denotes the 220 DU (a nominal indicator of ozone depletion). Images courtesy of NASA (see http://ozonewatch.gsfc.nasa.gov).