Sea Ice

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Highlights

- Arctic sea ice extent was similar to 2021 values, higher than many recent years, but much lower than the long-term average.
- Open water areas developed near the North Pole through much of the summer, making the area easier to access for polar class tourist and research vessels; both the Northern Sea Route and Northwest Passage largely opened.
- Multiyear ice extent and sea ice thickness and volume rebounded after near-record low levels in 2021, but were still well-below conditions in the 1980s and 1990s, and the oldest ice continued to be extremely scarce.

Introduction

As the frozen interface between the ocean and atmosphere, sea ice plays a key role in the Earth's climate and polar ecosystems. Over the Arctic Ocean, surface albedo (the fraction of the sun's energy reflected by the surface) is increased by the presence of sea ice and its overlying snow cover, which reduces the absorption of solar radiation and seasonal warming. Sea ice also serves as a platform and interface for marine life and influences the biogeochemical balance of the Arctic. Sea ice in the Arctic has long played a practical and cultural role in Indigenous communities of the north and is increasingly influencing modern commercial transportation, resource extraction, and national security.

After the September 2021 minimum extent, sea ice growth followed a fairly typical pattern, with slower than average freeze-up in the more southerly Hudson and Baffin Bays and near-normal growth elsewhere. Winter and spring near-surface air temperatures over the Central Arctic were well above the 1991-2020 average, particularly in the Beaufort Sea where temperatures were 7°C (13°F) above average in March. However, temperatures reverted back to near-normal values in May. During the June to August summer, temperatures were again higher than average in the Beaufort, but lower than average on the Atlantic side of the Arctic (see essay *Surface Air Temperature*).

Sea ice extent

Sea ice extent, defined as the total area covered by ice of at least 15% concentration, is a common metric to assess seasonal and long-term changes in Arctic sea ice. Starting in 1979, there is now a 44-year record of ice extent derived from a consistent series of satellite-borne passive microwave sensors.

Arctic sea ice undergoes a typical seasonal cycle with an annual maximum extent reached in late February or March and an annual minimum extent reached in September. As in 2021, the March and September 2022 extents were not as extreme as in some recent years (2007-20), but they still ranked as among the lowest in the satellite record (Table 1). We note here that a new 30-year climatology, 1991-2020, is employed for comparison of trends and anomalies (2013-21 Arctic Report Cards used the 1981-2010 baseline period). March and September 2022 continue long-term downward trends in sea ice extent (Fig. 1).

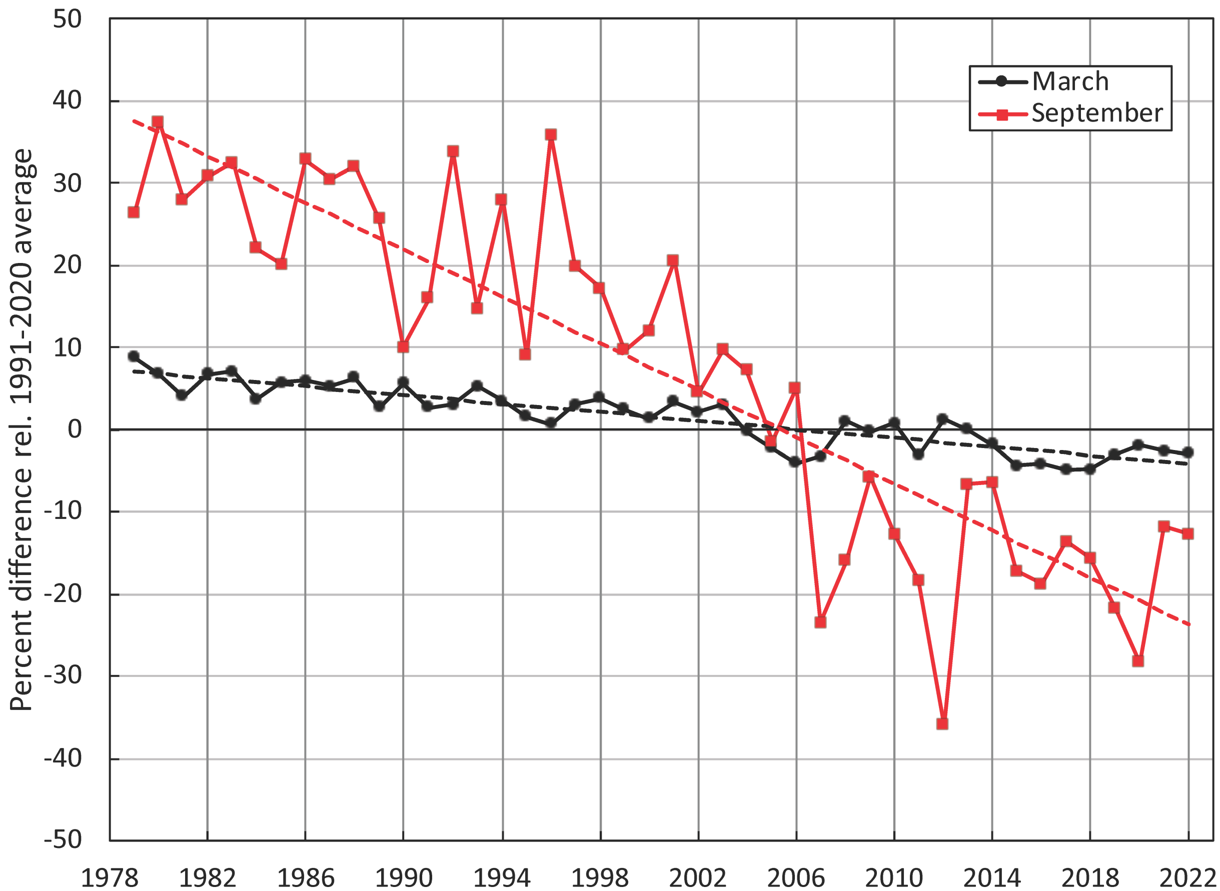

Fig. 1. Monthly sea ice extent anomalies (solid lines) and linear trend lines (dashed lines) for March (black) and September (red) 1979 to 2022. The anomalies are relative to the 1991 to 2020 average for each month (see Table 1); note that this represents a change from 2013-21 reports which used a 1981 to 2010 baseline average.

Table 1. March and September monthly averages and annual daily maximum and minimum extent for 2022 and related statistics. The rank is from least ice to most ice of the 44 years (1 = least, 44 = most).

Values	**March** Monthly Average	**March** Daily Maximum	**September** Monthly Average	**September** Daily Minimum
Extent (10^6 km^2)	14.59	14.88	4.87	4.67
Rank (out of 44 years)	9	9	13	10
1991-2020 average (10^6 km^2)	15.03	15.26	5.58	5.37
1981-2010 average (10^6 km^2)	15.43	15.70	6.41	6.19
Anomaly rel. **1991-2020** average (10^6 km^2)	-0.44	-0.38	-0.71	-0.70
Trend, 1979-2022 (km^2 per yr)	-39,200	-40,800	-79,400	-78,500
% change from 1979 linear trend value	-9.3	-9.1	-36.5	-37.2

March 2022 was most notable for low ice extent across the Sea of Okhotsk and part of the Barents Sea (Fig. 2). The ice was slightly more extensive than average in Baffin Bay and the Bering Sea. Through the summer, a tongue of ice between the East Siberian and Laptev Seas delayed the opening of the Northern Sea Route, though it did eventually open in August. Ice also remained along the coast in the Chukchi Sea well into summer due to cool temperatures and low winds (see essay *Sea Surface Temperature*). By the end of the summer, extent was well below normal throughout most of the Arctic except for the Barents and East Greenland Seas, where the ice edge was near normal. Notably, the Northwest Passage routes were largely open, including the wide, deep route through the Parry Channel (see essay *Arctic Shipping*). Another unusual feature was low sea ice concentration at high latitudes near the North Pole during July and August. Satellite imagery showed patches of open water near 87° N latitude, within ~300 km of the pole.

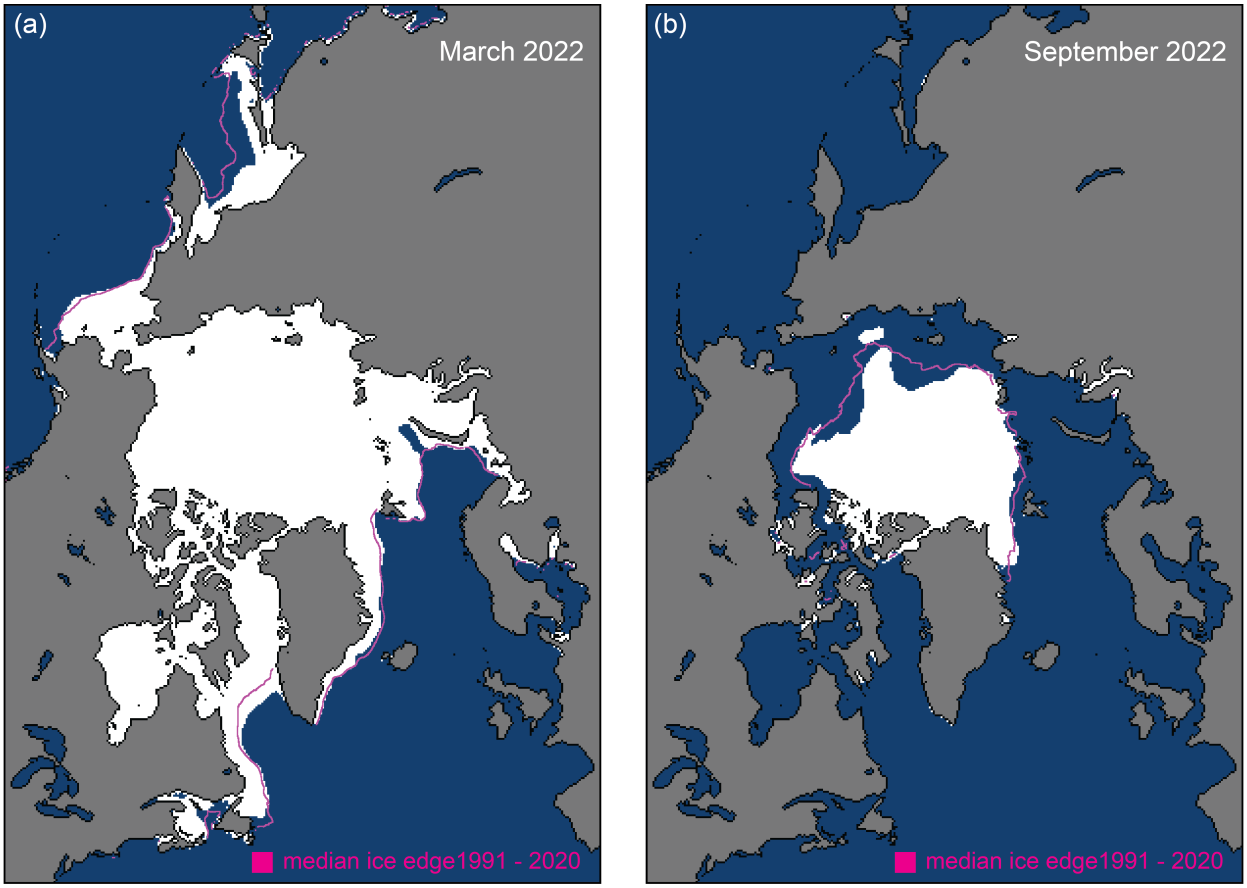

Fig. 2. Monthly average sea ice extent for (a) March 2022, and (b) September 2022. The median extent for 1991-2020 is shown by the magenta contour.

Sea ice age

Sea ice age is a proxy for ice thickness because multiyear ice thermodynamically grows thicker through successive winter periods. The multiyear ice has shown an interannual oscillation since 2007, reflecting variability in the summer transport and melt of sea ice. After a year when substantial multiyear ice is lost, a much larger area of first-year ice takes its place. Some of that first-year ice may survive the next summer, which can replenish the multiyear extent. However, old ice (which we define here as >4 years old) has remained consistently low since 2012. Thus, unlike in earlier decades, multiyear ice does not remain in the Arctic for many years. At the end of the summer 2022 melt season, multiyear ice showed a rebound from near-record low 2021 values, though still far below multiyear extents in the 1980s and 1990s (Fig. 3).

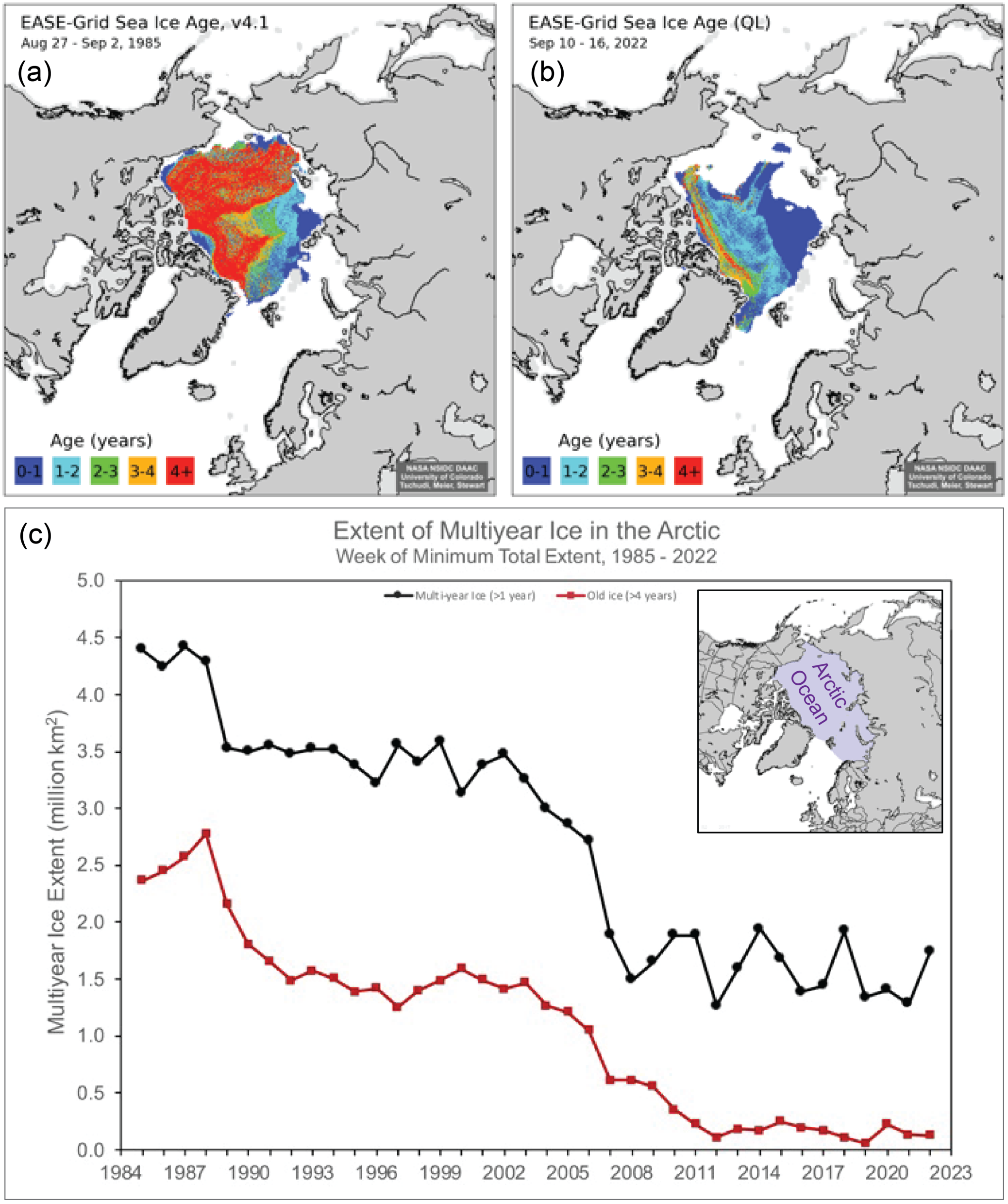

Fig. 3. Sea ice age coverage map for the week before minimum total extent (when age values are incremented to one year older) in (a) 1985, and (b) 2022; (c) extent of multiyear ice (black) and ice >4 years old (red) within the Arctic Ocean for the week of the minimum total extent.

Sea ice thickness and volume

Estimates of sea ice thickness from satellite altimetry can be used to estimate the crucial third dimension of sea ice conditions. The ICESat-2 and CryoSat-2/SMOS satellite products tracked the seasonal October to April growth over the past four years during which all missions were in operation (Fig. 4a) (ICESat-2 data were missing in April 2022 due to a safehold event). The 2021/22 winter Inner Arctic mean thickness time series shows notably thicker ice than the previous winter, which was the lowest in the ICESat-2 (since winter 2018/19) and CryoSat-2/SMOS (since winter 2010/11) records. This is in line with surface air temperatures that were generally cooler as ice began to form and advance during autumn 2021 compared to autumn 2020 (see essay *Surface Air Temperature*); advection and ridging also likely contributed to the thickness difference between the years. April 2022 thickness (Fig. 4b) from CryoSat-2/SMOS was higher than the 2010-21 April mean (Fig. 4c) across much of the Beaufort Sea and into the Laptev Sea. Thickness was lower than normal in the rest of the Laptev and Kara Seas. CryoSat-2/SMOS sea ice thicknesses were also notably thinner along the northern Canadian Archipelago and Greenland.

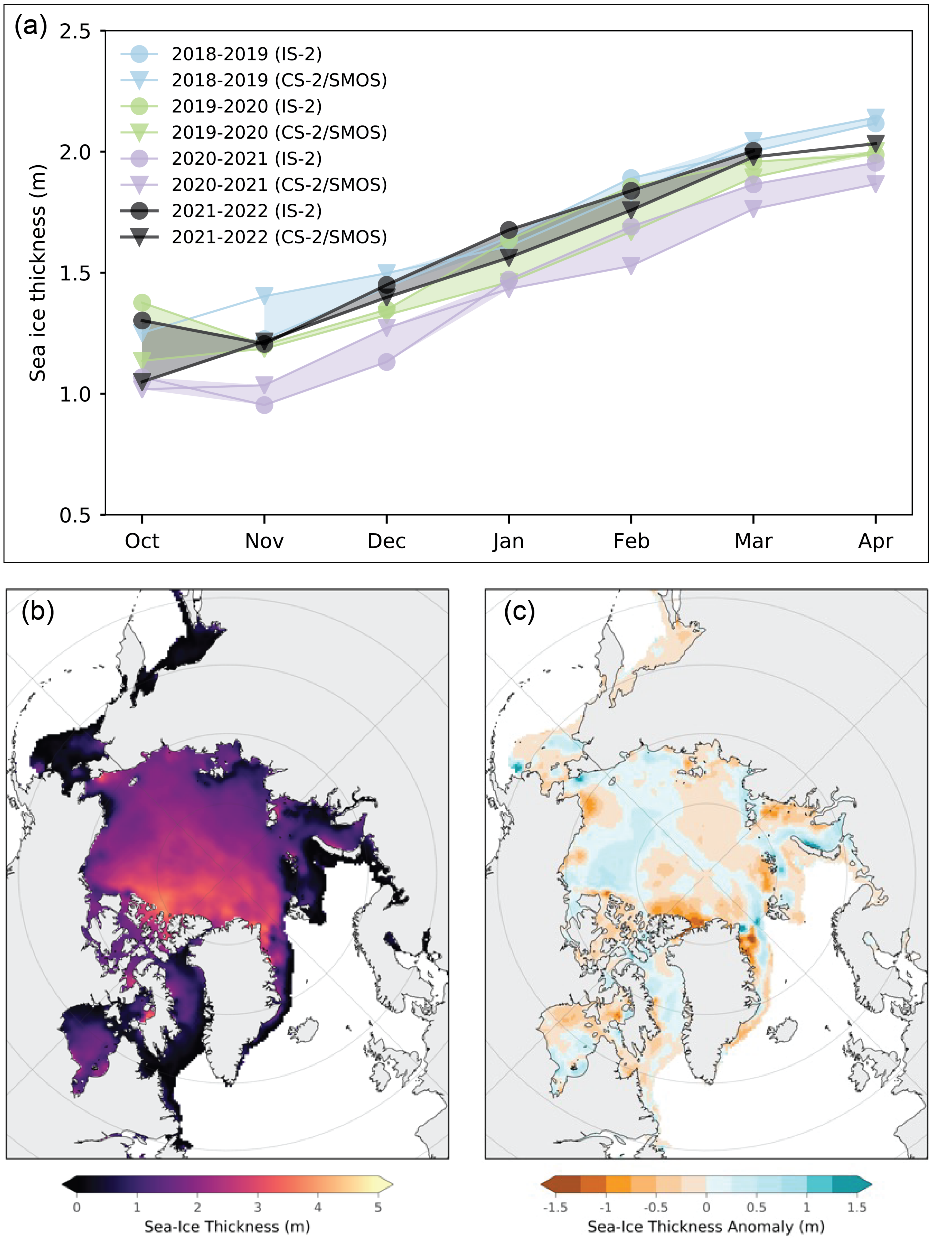

Fig. 4. (a) October through April monthly average sea ice thickness, calculated over an Inner Arctic Ocean Domain (see Methods and data section), from ICESat-2 (circles) and CryoSat-2/SMOS (triangles) for 2018-19 (blue), 2019-20 (green), 2020-21 (lilac), and 2021-22 (black); (b) average April 2022 sea ice thickness map from CryoSat-2/SMOS; (c) CryoSat-2/SMOS thickness anomaly map (relative to the 2010-21 average).

Sea ice thickness is integrated with ice concentration to provide winter volume estimates for the CryoSat-2/SMOS measurement time period. Seasonal change, from winter maximum to summer minimum and back, shows the strong seasonal cycle and interannual variability (Fig. 5). There is little indication of a trend through the relatively short 11-year time series. After a record low maximum volume in April 2021, there was a relatively small summer loss followed by a strong increase through the October 2021 to April 2022 winter. This resulted in a notable increase in volume compared to April 2021, as was indicated also in the average thickness (Fig. 4a). However, new upward-looking sonar sea ice thickness data from moorings in Fram Strait from 1990 to 2018 (Sumata et al. 2022) also illustrate the changed conditions of recent decades compared to the 1990s and early 2000s. Fram Strait is the region where the largest export of sea ice out of the central Arctic Ocean occurs and is thus representative of ice from the central Arctic.

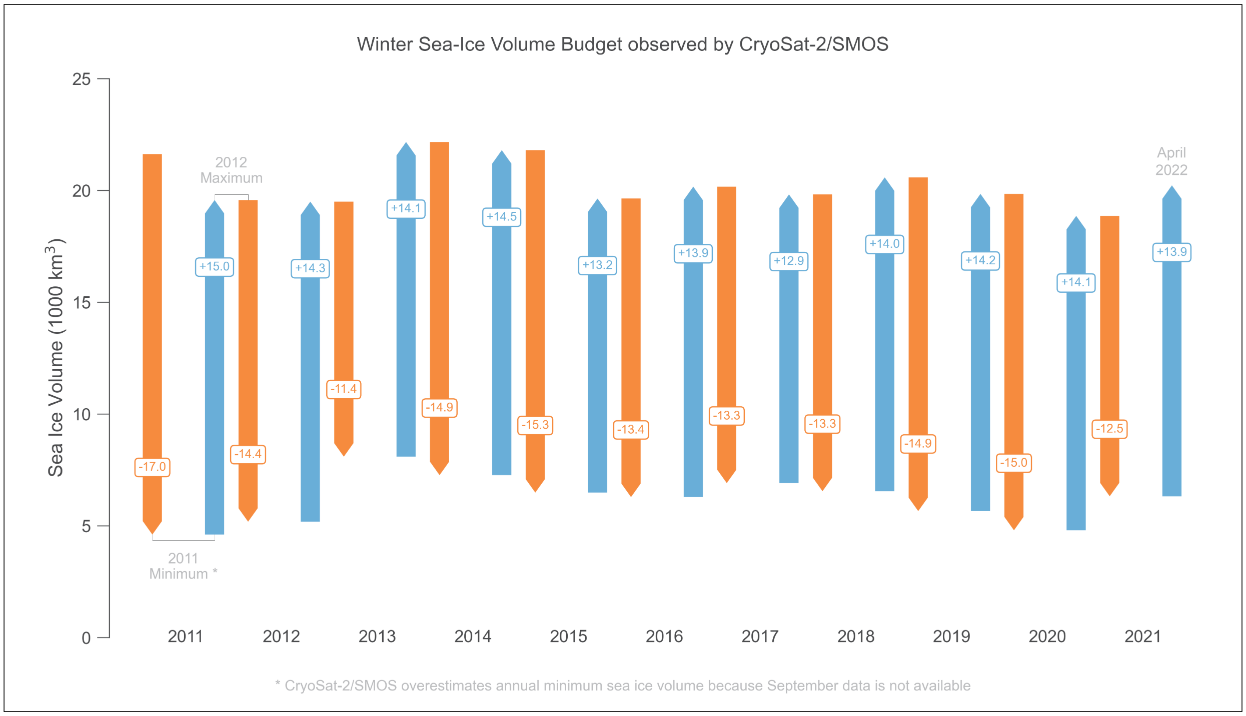

Fig. 5. Annual sea ice volume loss (orange) and gain (blue) between annual maximum and minimum from CryoSat-2/SMOS. Values are in 1000 km^3.

Methods and data

Sea ice extent values are from the NSIDC Sea Ice Index (Fetterer et al. 2017), based on passive microwave derived sea ice concentrations from the NASA Team algorithm (Cavalieri et al. 1996; Meier et al. 2021). There are several other passive microwave derived products available (e.g., Ivanova et al. 2014), including the EUMETSAT OSI-SAF CCI climate data record (Lavergne et al. 2019). All products have some limitations and uncertainties (e.g., Kern et al. 2019), but overall, the trends agree well (Comiso et al. 2017).

Sea ice age data are from the EASE-Grid Sea Ice Age, Version 4 (Tschudi et al. 2019a) and Quicklook Arctic Weekly EASE-Grid Sea Ice Age, Version 1 (Tschudi et al. 2019b) archived at the NASA Snow and Ice Distributed Active Archive Center (DAAC) at NSIDC. Age is calculated via Lagrangian tracking of ice parcels using weekly sea ice motion vectors (Tschudi et al. 2020). Age is generally a proxy for thickness because older ice is typically thicker, via thermodynamic growth and potential dynamic thickening (i.e., ridging and rafting). Only the oldest age category is preserved for each grid cell.

Satellite altimetry has enabled the continuous retrieval of sea ice thickness and volume during the freezing season from ESA CryoSat-2 radar altimeter, launched in 2010 and the NASA Ice, Cloud, and land Elevation 2 (ICESat-2) laser altimeter, launched in 2018.

Weekly CryoSat-2 estimates have been combined with thin ice (<1 m) estimates from the ESA Soil Moisture Ocean Salinity (SMOS) instrument, launched in 2009, to obtain an optimal estimate across thin and thick ice regimes (Ricker et al. 2017) on a 25 km resolution EASE2 grid. Optimal interpolation is used to fill in data gaps in the weekly CryoSat-2 fields and to merge the CryoSat-2 and SMOS estimates. The uncertainty in estimates varies with thickness and other factors, but much of the uncertainty is due to systematic biases that largely cancel out when calculating anomaly fields. When combined with sea ice concentration, the CryoSat-2/SMOS record of ice thickness is used to compute sea ice volume; data are available at ftp://ftp.awi.de/sea_ice/product/cryosat2_smos/v204/.

ICESat-2 estimates here focus on an Inner Arctic Domain (Central Arctic, Beaufort, Chukchi, Laptev, East Siberian Seas—the same domain as for Fig. 3 except without the Barents and Kara Seas) due to poorer knowledge of snow conditions in the more peripheral seas. The data used here are the gridded 25 km x 25 km monthly data (Petty et al. 2021) originally presented in Petty et al. (2020), now using Version 5 ATL10 freeboards from the three strong beams of ICESat-2 and v1.1 NESOSIM snow loading (depth and density) as described in Petty et al. (2022). Data are available at: https://nsidc.org/data/IS2SITMOGR4/versions/2.

Acknowledgments

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