Sea Ice

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Headlines

- Sea ice extent in September 2024 was the 6th lowest in the satellite record (1979 to present); the last 18 September extents (2007-24) are the 18 lowest in the record.
- The long-term negative trends in total extent and the amount of older, thicker ice continued. The more recent period since 2007 has been characterized by low extent, but without a significant trend.
- Average sea ice thickness for winter 2023/24 winter was lower than the previous winter, and close to the 2011-23 average thickness; volume at the end of the 2022/23 winter was nearly the same as the previous year.

Introduction

Arctic sea ice is the frozen interface between the ocean and the atmosphere. It reduces the absorption of solar energy because of its high albedo relative to the darker open ocean surface. As a physical barrier, it modifies the heat and moisture transfer between the atmosphere and ocean. Sea ice plays a key role in polar ecosystems, providing an essential habitat for marine life and modulating the biogeochemical balance of the Arctic. The sea ice cover has long played a practical and cultural role in Indigenous communities of the North. Historically, the presence of sea ice limited national and corporate activities in the Arctic, but sea ice decline is allowing an increase in maritime traffic and drives reevaluation of resource extraction and national security activities in the Arctic.

Ice freeze-up in winter 2023/24 was relatively rapid compared to recent years, particularly in the East Siberian and Laptev Seas. The autumn and winter sea ice growth rates brought the ice cover nearer to, but below, average in those months. The extent remained below average through spring, before starting a rapid decline in June.

Near-surface air temperatures during the 2023/24 winter were higher than the 1991-2020 average for most of the Arctic Ocean, particularly north of Greenland and the Canadian Archipelago (see essay *Surface Air Temperature*). Summer temperatures were also largely above average, particularly in the Barents Sea region; cooler than average summer temperatures were found over the Chukchi Sea.

Sea ice extent

Sea ice extent, defined as the total area covered by ice of at least 15% concentration, is one of the most commonly used indicators of long-term Arctic sea ice conditions. The primary source of extent observations is the 46-year record (starting in 1979) derived from satellite-borne passive microwave sensors.

This satellite record tracks long-term trends, variability, and seasonal changes from the annual extent maximum in late February or March to the annual extent minimum in September. In recent years, minimum extents are ~50% of the values in the 1980s. In 2024, March and September extents were similar to other recent years (Fig. 1), but much lower than the 1991-2020 average, and the long-term negative trends continue (Table 1). March 2024 was marked by near-average sea ice extent around most of the perimeter of the sea ice edge, with low ice cover in the Barents Sea and the Gulf of St. Lawrence (Fig. 2). At the beginning of the melt season, ice retreat was initially fairly slow through May. A notable exception was the extremely early opening of eastern Hudson Bay where substantial open water began appearing by mid-May 2024 due to strong easterly winds. This was unusual, since typically Hudson Bay's western sector opens up first and the eastern part of the bay remains largely ice-covered well into June.

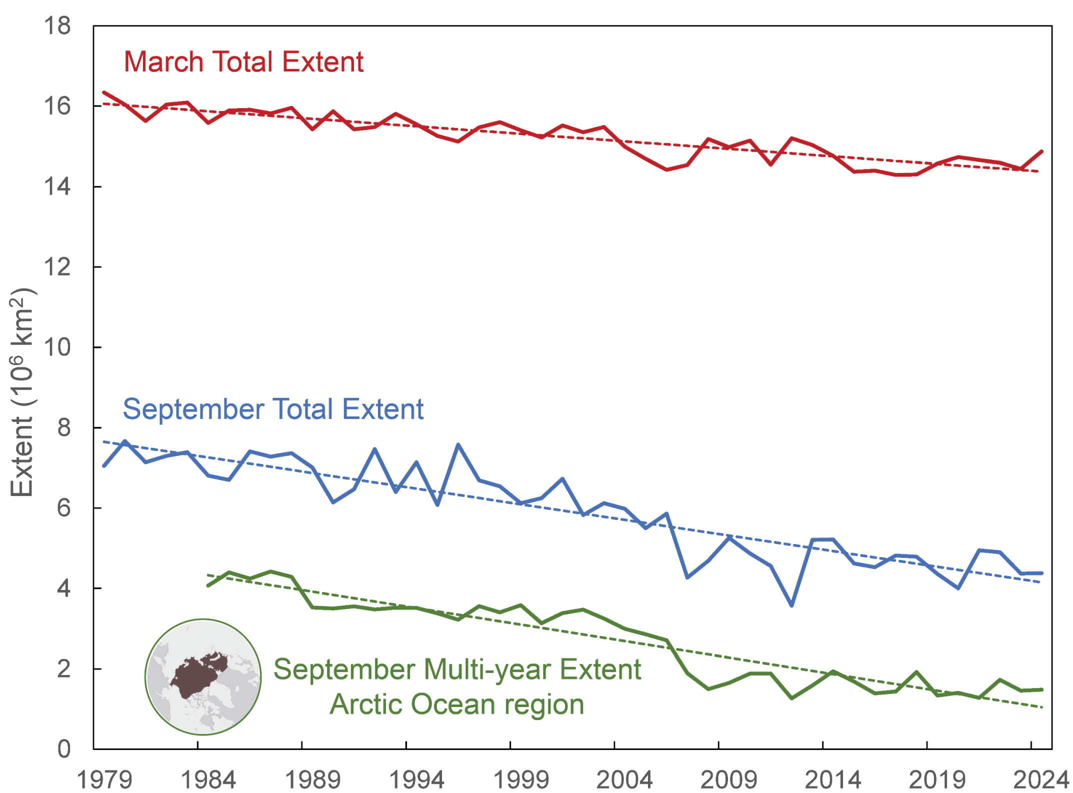

Fig. 1. March (red) and September (blue) total extent for 1979-2024, multi-year September extent (green) for 1984-2024 and linear trend lines (dashed lines). The Arctic Ocean region map is inset in the bottom left.

Table 1. March and September monthly averages and annual daily maximum and minimum extents for 2024 and related statistics. The rank is from least sea ice to most sea ice of the 46 years (1 = least, 46 = most).

Values	**March** Monthly Average	**March** Daily Maximum	**September** Monthly Average	**September** Daily Minimum
Extent (10^6 km^2)	14.87	15.01	4.38	4.28
Rank (out of 46 years)	15	15	6	7
1991-2020 average (10^6 km^2)	15.03	15.26	5.58	5.37
Anomaly rel. **1991-2020** average (10^6 km^2)	-0.16	-0.25	-1.20	-1.09
Trend, 1979-2024 (km^2/yr)	-37,400	-40,800	-77,800	-76,900
% change from 1979 linear trend value	-7.6	-8.3	-42.7	-42.5

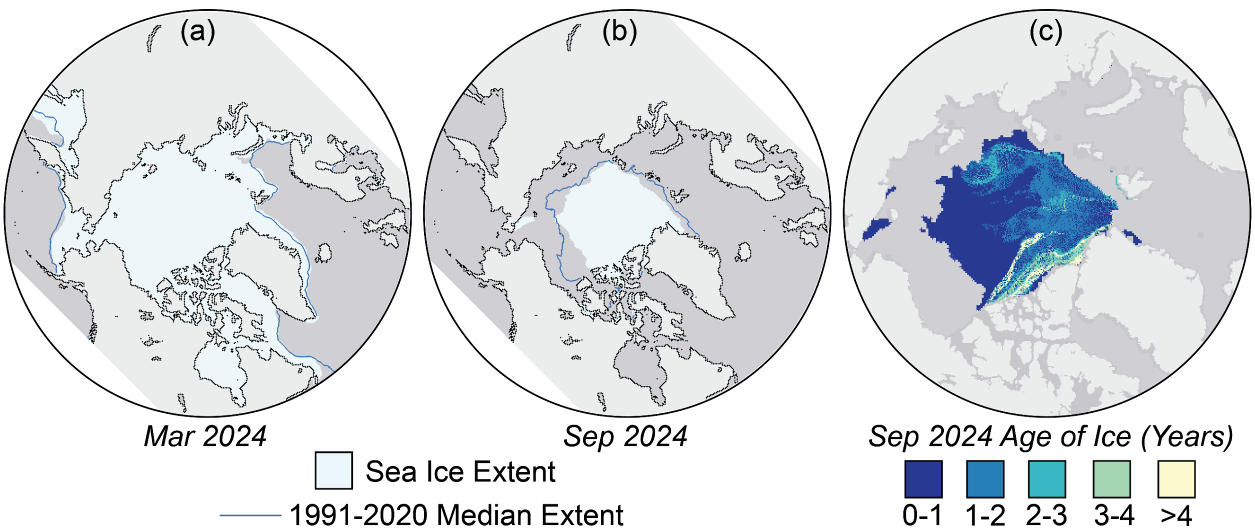

Fig. 2. Monthly average sea ice extent (light blue) for (a) March 2024, and (b) September 2024; the median extent for 1991-2020 is shown by the dark blue contour. (c) September sea ice age extent.

In June, the overall rate of retreat in ice extent was near-average, but then accelerated in July and August. Nonetheless, substantial ice remained in the Chukchi and East Siberian Seas into late August, delaying the opening of the Northern Sea Route. One factor was an unusually persistent area of ice between Wrangell Island and the northeastern Siberian coast that remained throughout the summer. This ice formed from strong convergence and deformation during the spring, which caused substantial ridging, enabling the ice to resist thermodynamic melt. The ice was brownish-gray, suggesting entrapment of shelf bottom sediment within the ice. A rapid and early sea ice retreat was observed in Fram Strait in the northern Greenland Sea, which was nearly ice free by mid-August, with the only traces of sea ice being landfast ice east of northeast Greenland.

By late August, sea ice finally retreated from the Siberian coast, opening up the Northern Sea Route, while the deformed Wrangell Island ice persisted. Summer extent remained closer to average for most regions on the Atlantic side in the Laptev, Kara, and Barents Seas (Fig. 2). The Northwest Passage through the Canadian Archipelago became clear of ice along the southern route in late August. The northern route was blocked at the western end of through most of the summer by ice in M'Clure Strait, but even here ice cleared in late September. The summer 2024 extent in the Passage reached the lowest observed in the satellite record, based on Canadian Ice Service ice charts (Sea Ice Today 2024).

The extent of older ice (here defined as >4 years old), observed by tracking the motion of ice with satellite imagery and buoys, was similar to recent years. Age is a proxy for ice thickness because multiyear ice generally grows thicker through successive winter periods. Multiyear ice was largely constrained near the north coast of Greenland and the Canadian Archipelago, with some drifting into the Beaufort and Chukchi Seas (Fig. 2c). Multiyear ice extent has shown interannual oscillations but no clear trend since 2007, reflecting variability in the summer sea ice melt and export out of the Arctic. After a year when substantial multiyear ice is lost, a much larger area of first-year ice generally takes its place. Some of this first-year ice can persist through the following summer, contributing to the replenishment of the multiyear ice extent. However, since 2012, old ice has remained consistently low, less than 5% of the levels in the 1980s. Thus, multiyear ice remains in the Arctic for fewer years than in earlier decades. At the end of summer 2024, multiyear ice extent was similar to 2022 and 2023 values (Fig. 1), 40% of the multiyear extents in the 1980s and 1990s.

Melt onset of sea ice

In spring, the snow cover on top of the sea ice begins to melt, which lowers the albedo and increases the potential absorption of solar radiation within the snow and sea ice cover. Sea ice melt typically begins in early March in the southern fringes of the ice cover and on average proceeds latitudinally, with melt in the high Arctic around the North Pole beginning in August, if it occurs at all (Fig 3a). The 2024 melt onset was mixed, with earlier melt in eastern Hudson Bay, Baffin Bay, northeast of Greenland and much of the Beaufort Sea (Fig. 3b). Melt was later than average along the Siberian coast, corresponding to the late decline of sea ice extent in that region. Overall, the average date of the melt onset has trended earlier since 1979, but with large year-to-year variability (Fig 3c). On average, melt starts about 15 days earlier today than in the 1980s.

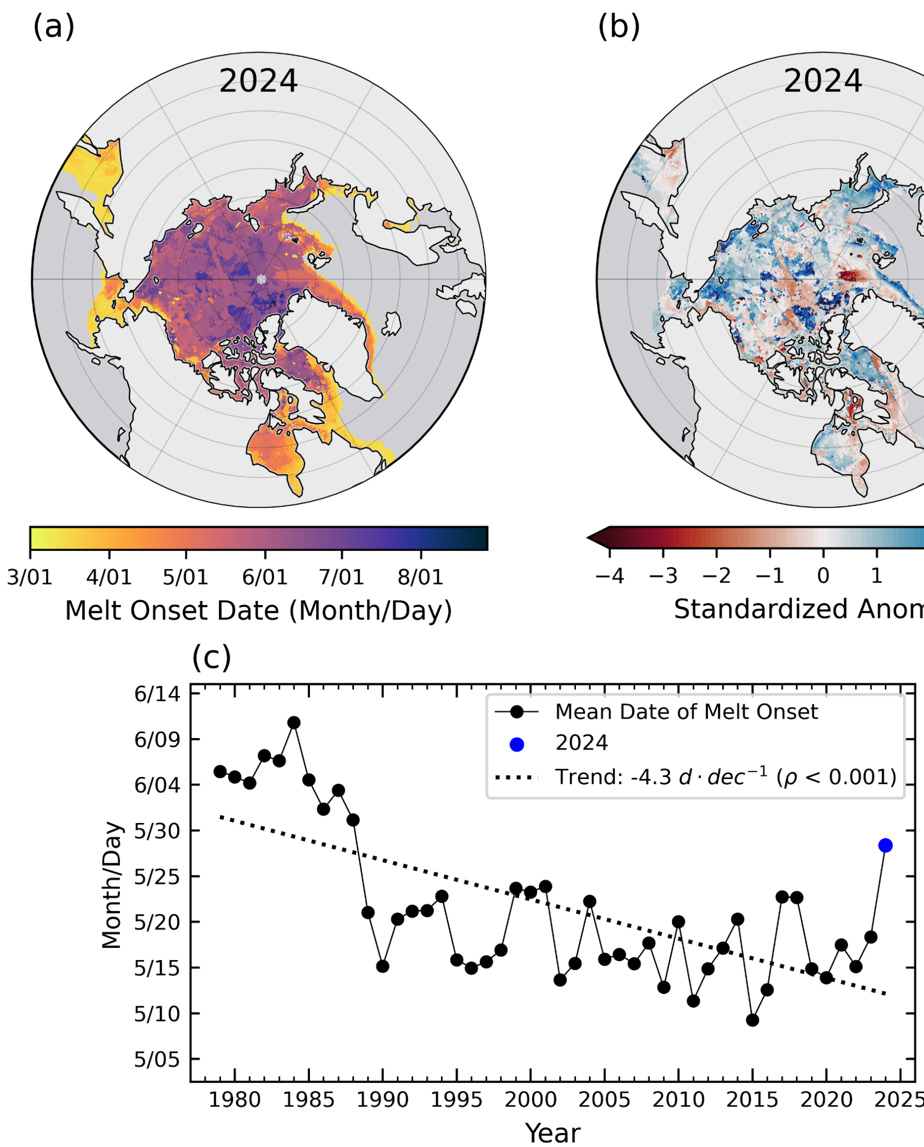

Fig. 3. (a) 2024 sea ice melt onset date; (b) 2024 melt standardized anomaly (anomaly divided by standard deviation) relative to the 1991-2020 average; (c) Arctic mean melt onset date for 1979-2024 and linear trend line for the Arctic Ocean Region, which includes the Arctic Ocean and the Kara and Barents Seas.

Sea ice thickness and volume

Estimates of sea ice thickness from satellite altimetry are used to more directly track this important metric of sea ice conditions, although the satellite altimeter record is shorter than that for extent, ice age, and melt onset. ICESat-2 and CryoSat-2/SMOS satellite data are used to track seasonal ice growth in winter between October and April (Fig. 4a). The timeseries since 2010 shows a slightly thinner ice cover during 2023-24, particularly during October 2023. The ice thickness anomaly map for April 2024 (Fig. 4b), derived from CryoSat-2/SMOS observations relative to the 2010-23 April mean, shows that ice in the Canada Basin between the Beaufort Sea and the pole was thinner than average, as was ice in the Laptev Sea, while for the Siberian side of the Arctic, ice was thicker than average. Although the 14-year time series is relatively short, there is a trend toward thinner ice across most of the thicker multi-year ice of the North American Arctic, offset to some degree by a thickening trend in the Siberian Arctic, particularly in the Kara Sea (Fig. 4c).

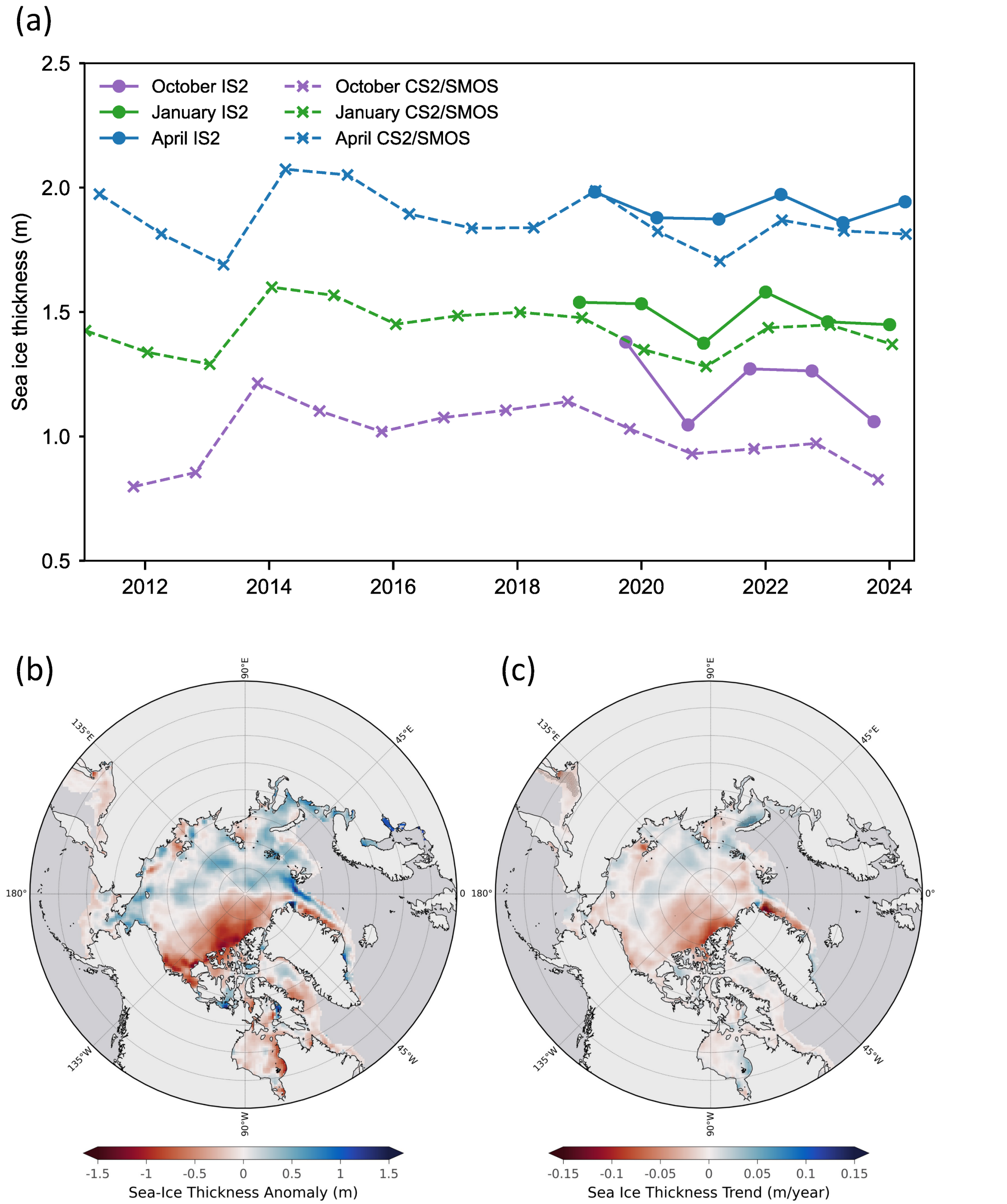

Fig. 4. (a) 2011-24 October (purple), January (green), and April (blue) monthly average sea ice thickness, calculated over an Inner Arctic Ocean Domain (Central Arctic, Beaufort, Chukchi, Laptev, East Siberian Seas), from ICESat-2 (circles) and CryoSat-2/SMOS (crosses); (b) April 2024 sea ice thickness anomaly map from CryoSat-2/SMOS (relative to the 2011-23 average); (c) CryoSat-2/SMOS March thickness trend map over the period of 2011-24.

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 13-year time series.

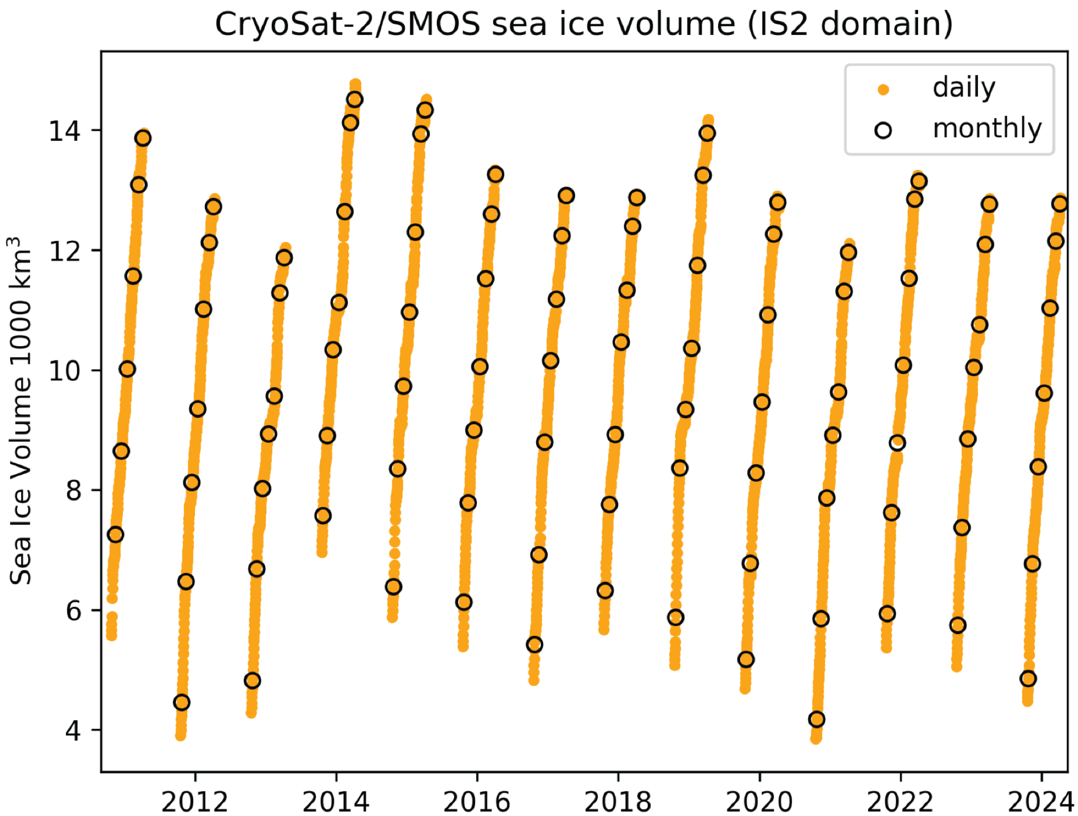

Fig. 5. Winter (October-April) sea ice volume for October 2010 to April 2024 from CrySat-2/SMOS. Each year volume increases from October (bottom of orange points) through April (top of orange points), with no data during the summer (May-September) melt season.

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; Maslanik and Stroeve 1999), though other high quality products exist (e.g., Lavergne et al. 2019).

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. Only the oldest age category is preserved for each grid cell.

Melt onset is estimated from passive microwave brightness temperatures, which change significantly when liquid water develops on snow and ice surfaces (Bliss 2023).

Satellite altimetry has enabled the continuous retrieval of sea ice freeboard for ice thickness and volume estimates over the entire Arctic basin during the freezing season (October-April). A consistent record began in 2010 with the launch of the European Space Agency (ESA) CryoSat-2 radar altimeter. This was followed in September 2018 by the launch of the NASA Ice, Cloud, and land Elevation 2 (ICESat-2) laser altimeter. Thus, there are now two independent altimetry sources for deriving sea ice thickness and volume estimates.

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 data gaps in the weekly CryoSat-2 fields and to merge the CryoSat-2 and SMOS estimates. The results here are from Version 206 (European Space Agency 2023). 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/.

The ICESat-2 thickness data (Petty et al. 2023a) used here are the gridded 25 km x 25 km monthly data using Version 6 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. (2023b).

Acknowledgments

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