Supplementary Materials 1 - Supplementary Figures and Tables

Table S1. Canadian Ice Service ice chart availability for November-April

	Western Arctic	Eastern Arctic
1996	Nov: weekly Dec: biweekly Jan-Apr: monthly	Nov: weekly Dec: biweekly Jan-Apr: monthly
1997-2000	Nov: weekly Dec: biweekly Jan-Apr: monthly	Nov: weekly Dec: biweekly Jan-Apr: monthly
2001-2005	Nov: weekly Dec: biweekly Jan-Apr: monthly	Nov: weekly Dec: biweekly Jan-Apr: monthly
2006	Nov-Dec: weekly Jan-Feb: monthly Mar-Apr: biweekly	Nov-Dec: weekly Jan-Feb: monthly Mar-Apr: biweekly
2007	Nov-Dec: weekly Jan-Mar: biweekly Apr: weekly	Nov-Dec: weekly Jan-Mar: biweekly Apr: weekly
2008-2010	Nov-Apr: weekly	Nov-Apr: weekly
2011-present	Nov-Apr: weekly	Nov-Apr: weekly

Table S2. List of used predictor features

Partial concentration New Ice	Partial concentration pancake ice
Partial concentration Nilas	Partial concentration small ice cake
Partial concentration Young Ice	Partial concentration ice cake
Partial concentration Grey Ice	Partial concentration small floe
Partial concentration Grey White Ice	Partial concentration medium floe
Partial concentration FYI	Partial concentration big floe
Partial concentration thin FYI	Partial concentration vast floe
Partial concentration first stage thin FYI	Partial concentration giant floe
Partial concentration second stage thin FYI	Partial concentration fast ice
Partial concentration medium FYI	Scatterometer backscatter
Partial concentration thick FYI	
Partial concentration Old Ice	
Partial concentration second-year ice	
Partial concentration MYI	

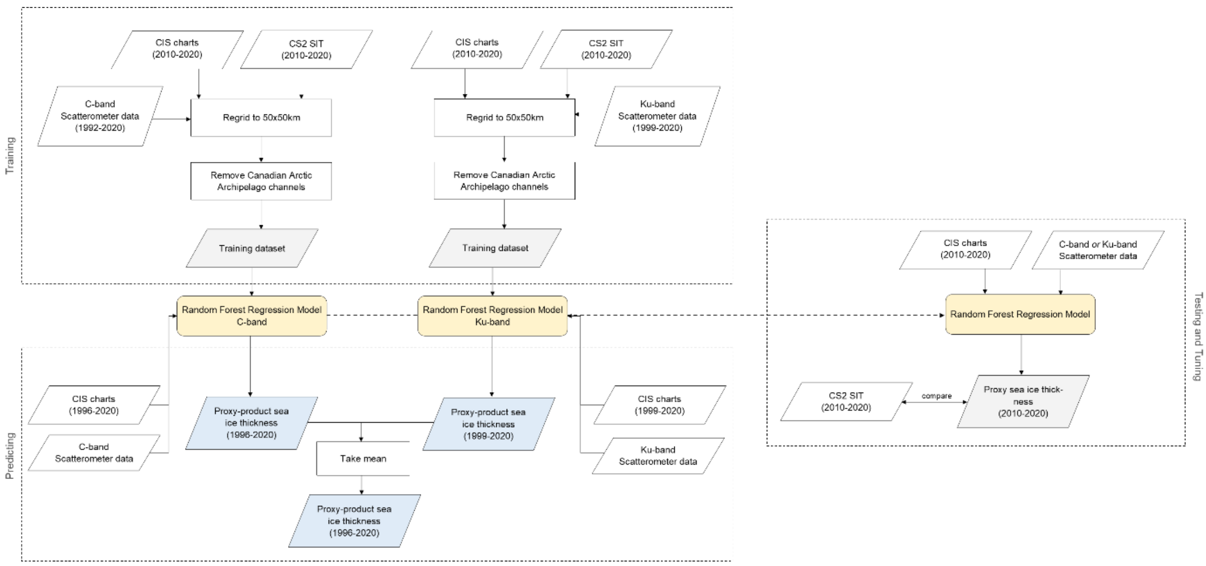

Figure S1. Schematic of applied data and methods to create the sea ice thickness proxy product.

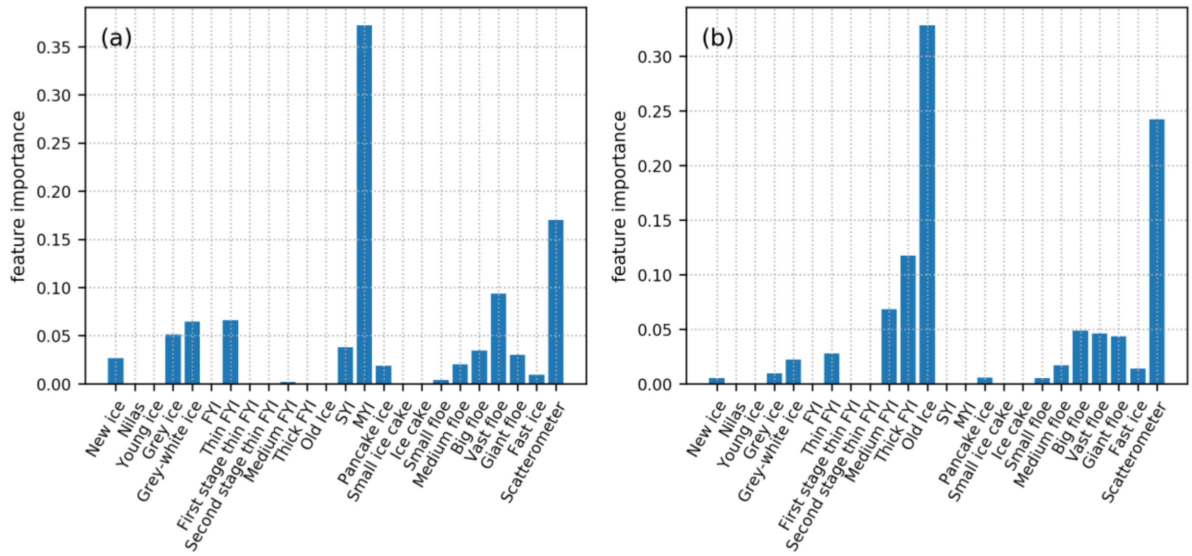

Figure S2. Feature importance in the Random Forest Regression model for (a) November C-band and (b) April C-band.

Table S3. Number of datapoints Random Forest Regression models are trained on.

	C-band	Ku-band
November	21935	14642
December	29326	23529
January	28829	25873
February	27225	20378
March	29135	20643
April	30601	25004

Supplementary Materials 2 – Scatterometer record

One of the features used in the Random Forest Regression model is scatterometer data. As there is no continuous record of one instrument over the entire 1996-2020 record, we use data of multiple instruments. We've used data from both C-band and Ku-band scatterometer instruments. C-band scatterometers work in the 4-8 GHz frequency range and Ku-band in the 12-18 GHz frequency range. As these wavelengths interact differently with snow and ice (Ontstott, 1992), we expect C-band and Ku-band instruments to give different results and do not combine scatterometer data from the different bands into one record. Instead, we create a C-band record combining ERS-1, ERS-2, and ASCAT, and a Ku-band record combining QuickSCAT, OSCAT-1, and OSCAT-2 (Figure 3). This section discusses why we believe these records can be combined.

NASA's QuickScat (Quick Scatterometer) was an Earth observation satellite carrying the Ku-band (13.4 GHz) dual polarization scatterometer SeaWinds. QuickScat was launched on 19 June 1999 and stopped collecting data on 21 November 2009. Daily horizontal polarization gridded data was retrieved from NASA SCP for 1 July 1999 to 21 November 2009 (https://www.scp.byu.edu/data/Quikscat/SIRv2/Quikscat_sirV2.html).

The Indian Space Research Organisation's (ISRO) OSCAT-1 scatterometer was carried by Oceansat-2 and operated in Ku-band (13.515 GHz). The instrument provides daily global coverage at a resolution of 25 km. Horizontal polarization gridded scatterometer data was retrieved from NASA SCP for 5 November 2009 to 21 February 2014 (https://www.scp.byu.edu/data/OSCAT/SIR/OSCAT_sir.html). The follow-on mission ScatSat-1 carried OSCAT-2. Daily horizontal polarization data was obtained from MOSDAC for 1 November 2016 to 31 December 2020 (https://mosdac.gov.in/satellite-catalog).

The Ku-band record consists of QuickScat (data from NASA SCP available for August 1999 to 23 November 2009), OSCAT-1 (data available 5 November 2009 to 21 February 2014), and OSCAT-2 (data from MOSDAC available for November 2016 to present). OSCAT-1 and OSCAT-2 are similar instruments. The NASA SCP OSCAT-2 dataset is only available until 2019, so we decide to use the MOSDAC OSCAT-2 dataset. OSCAT-1 and OSCAT-2 do not have a temporal overlap, so a direct comparison is not possible. Figure S3 shows that the seasonal cycle of the retrieved backscatter signal is very comparable between the two products, so we do not apply a correction and assume the records can be combined. OSCAT and QuickScat are very similar instruments. OSCAT measurements are at a slightly different incidence angle than QuickScat. OSCAT-1 and QuickScat have a 19-day temporal overlap in November 2009. The backscatter from both instruments in this period are compared (Figure S4) and deemed similar enough to combine the record.

ERS-1 was a European Space Agency (ESA) spacecraft launched on 17 July 1991 to provide microwave spectrum-based environmental monitoring. The spacecraft carried a range of instruments, including the Wind Scatterometer and Synthetic Aperture Radar (SAR) instruments, which worked in tandem in a configuration called the Active Microwave Instrument (AMI). The instrument measures C-band in a frequency of 5.3 GHz and has a spatial resolution of about 50 km. The ERS-1 mission ended on 10 March 2000. Gridded ERS-1 scatterometer data was retrieved from the NASA Scatterometer Climate Record Pathfinder (SCP) for 1 January 1996 to 2 May 1996 (https://www.scp.byu.edu/data/ERS/SIR/ERS_sir.html).
ERS-2 was launched in the same orbit as ERS-1 on 21 April 1995 and carried the same instruments as ERS-1. ERS-2 was taken out of service on 5 September 2011. Gridded ERS-2 scatterometer data for 1

June 1996 to 18 January 2001 was also retrieved from NASA SCP (https://www.scp.byu.edu/data/ERS/SIR/ERS_sir.html).

The Advanced Scatterometer ASCAT is a C-band (5.255 GHz) advanced version of the AMI instrument flown on ERS-1 and ERS-2. ASCAT was carried by ESA's Meteorological operational satellite A (Metop-A), which was part of the EUMETSAT Polar System, and Metop-B and -C. Metop-A was launched on 19 October 2006 and retired on 15 November 2021. Metop-B and -C were launched in 2012 and 2018 respectively and are still operational. It provides global coverage in 1.5 days and has a 12.5 km spatial resolution. ASCAT's vertical polarization scatterometer gridded data was retrieved from NASA SCP for 1 January 2007 to 31 December 2020 (https://www.scp.byu.edu/data/Ascat/SIR/Ascat_sir.html).

The C-band record consists of ERS-1 (data from NASA SCP available for January 1992 to April 1996), ERS-2 (data available June 1996 to mid-January 2001), and ASCAT (January 2007 to present). ERS-1 and ERS-2 are designed to be identical twins, with the same scatterometer instrument and flying in the same orbit. They can thus be applied together. ASCAT differs from ERS by its higher observation density, better noise characteristics, and slightly higher incidence angles. As we use a low-resolution product for the scatterometer data (GRD), we believe the difference in noise is removed. The lower observation density of ERS is no issue because only monthly data is used. There is no temporal overlap in ERS-2 and ASCAT, so a direct assessment of their comparison is not possible. As the period between ERS-2 and ASCAT has seen a decline in older ice, we do not expect the scatterometer data to be directly comparable. We have compared the backscatter results for ERS-2 and ASCAT for different ice ages (obtained from the EASE-grid Sea Ice Age product from NSIDC, https://nsidc.org/data/nsidc-0611/versions/4), and show that the backscatter distribution for ice of the same age is similar for ERS-2 and ASCAT (Figure S5).

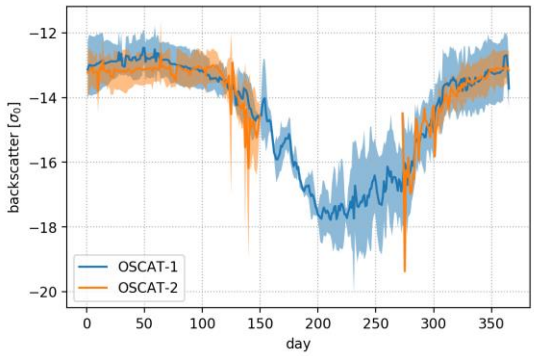

Figure S3. Seasonal cycle of scatterometer backscatter from OSCAT-1 and OSCAT-2.

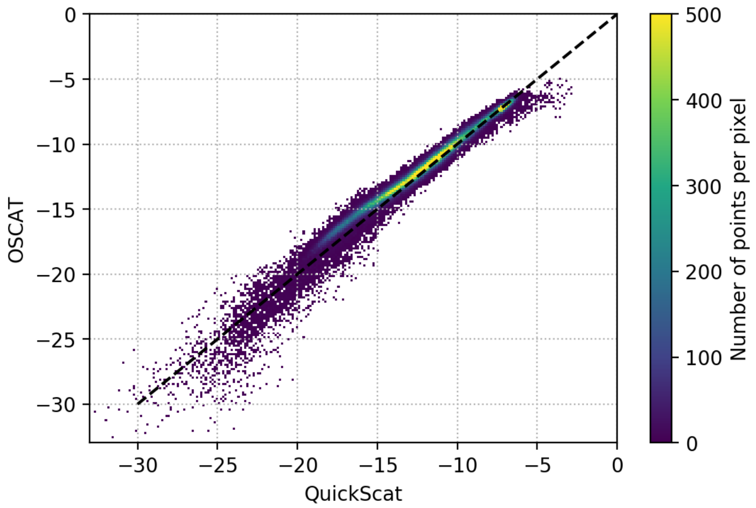

Figure S4. Backscatter from OSCAT-1 and QuickScat for the overlapping period.

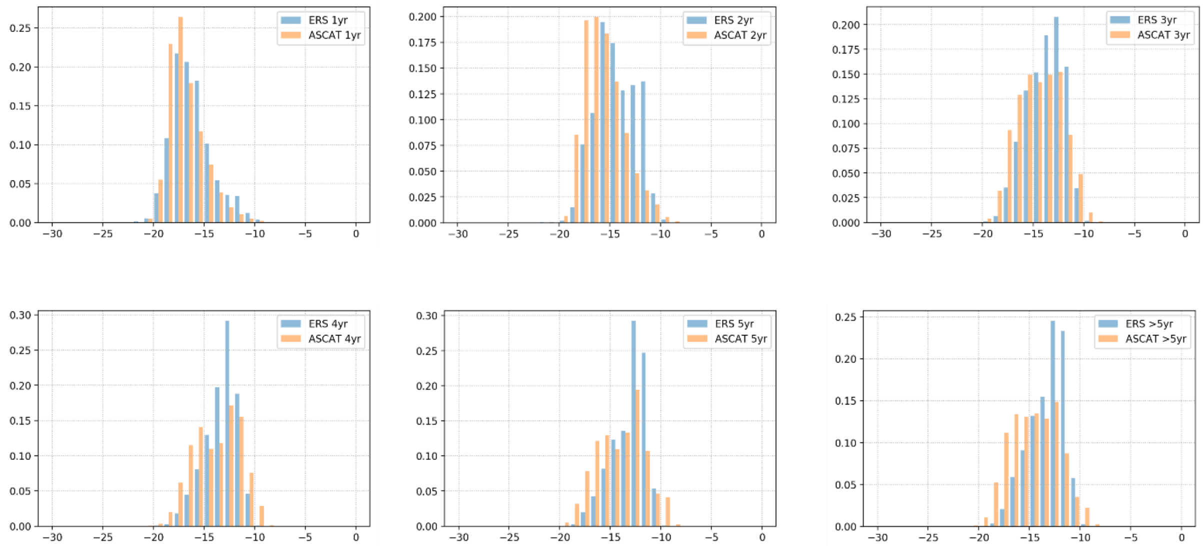

Figure S5. PDF of backscatter on different ice ages for ERS-2 and ASCAT.