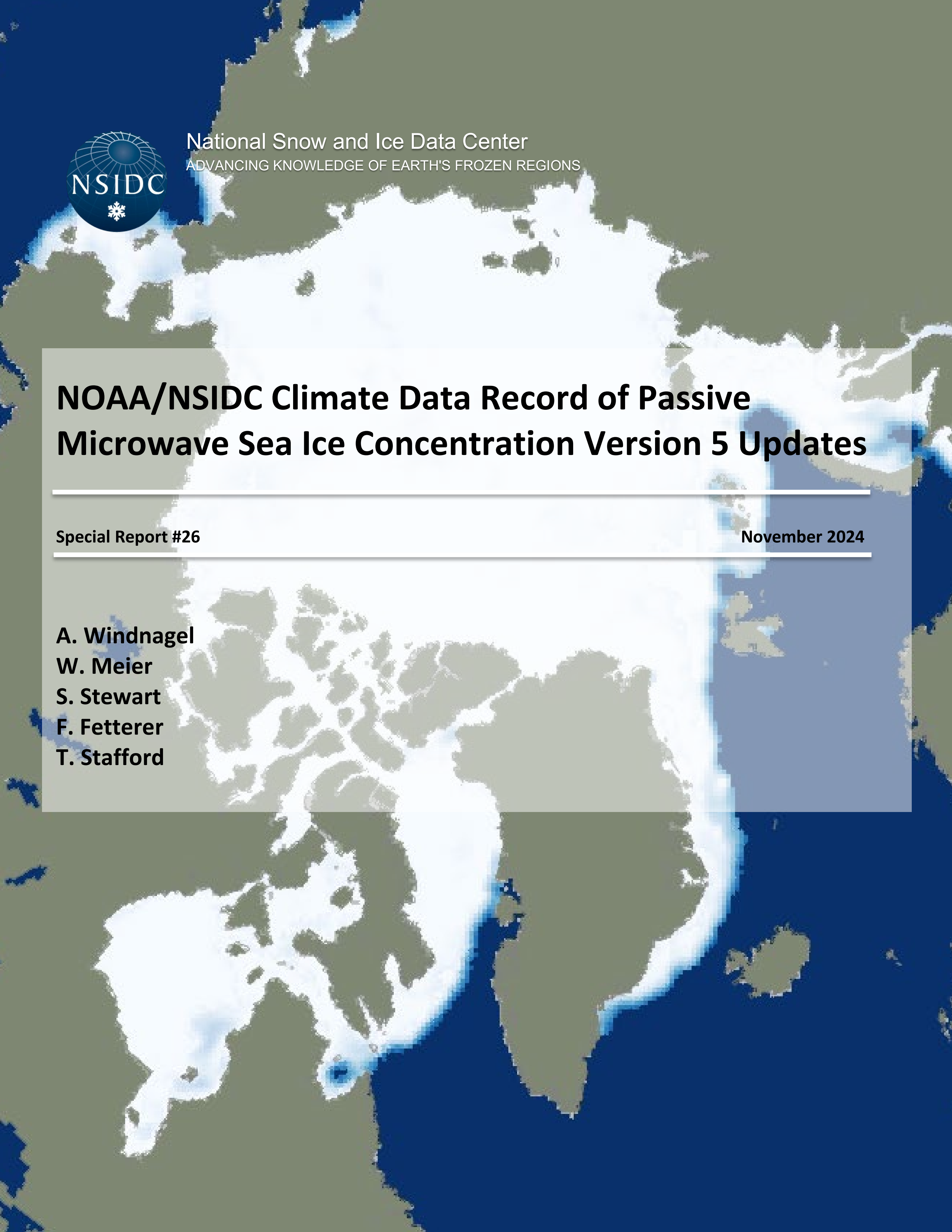

National Snow and Ice Data Center
ADVANCING KNOWLEDGE OF EARTH'S FROZEN REGIONS

NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration Version 5 Updates

Special Report #26

November 2024

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Contents

Citation

Windnagel, A., Meier, W., Stewart, S., Fetterer, F., & Stafford, T. (2024). NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration Version 5 Analysis. NSIDC Special Report 26. Boulder CO, USA: National Snow and Ice Data Center.

List of Tables

List of Figures

1. Summary

The *NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration* (Meier et al. 2024b) was updated to Version 5 in December 2024. This data set provides a Climate Data Record (CDR) of sea ice concentration (SIC) from passive microwave data beginning with the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) in October 1978 and continuing with the DMSP F08, F11, and F13 Special Sensor Microwave Imager (SSM/I) and the DMSP F17 Special Sensor Microwave Imager/Sounder (SSMIS) to present. This document describes the changes that were made to create Version 5. In addition, the near-real-time (NRT) counterpart to the sea ice concentration CDR, the *Near-Real-Time NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration* (Meier et al., 2024c), which uses the same code base but with NRT input data, was also updated to Version 3. The changes noted in this document also pertain to that data set.

The goal with the Version 5 SIC CDR product was to create a sea ice concentration data set that improved upon the automated quality controls that were implemented in the Version 4 SIC CDR (Meier et al., 2021). The aim is to be as consistent as possible with the Goddard NASA Team (NT) and Goddard Bootstrap (BT) sea ice concentration products: Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data (DiGirolamo et al., 2022) and Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS (Comiso, 2023), respectively. These two Goddard products have been manually corrected by NASA investigators to make them spatially and temporally complete and consistent data sets. These manual corrections are not reproducible, so do not conform to the NOAA CDR program criteria (NRC 2004). To be considered a CDR, a data product must be fully automated, reproducible, and documented. Therefore, to the extent possible, the Version 5 SIC CDR agrees with the Goddard products but does so using fully traceable, automated quality control procedures. It is created using open-source code that performs spatial and temporal interpolations to create an almost temporally and spatially complete data product and applies weather, land spillover, and valid ice filters so that the CDR data comport with the Goddard products. For Version 5, several of these automated procedures have been improved upon those used in Version 4 and other minor updates were implemented. This document describes these new procedures and document the updates. It also provides a comparison of the Version 5 SIC CDR with the Version 4 SIC CDR (Section 3).

A secondary goal for Version 5 was to guarantee the longevity of the sea ice concentration product. To this end, a prototype sea ice concentration is also supplied. The prototype uses the AMSR2 instrument onboard the Japan Aerospace Exploration Agency (JAXA) Global Change Observation Mission - W1 (GCOM-W1) satellite. This record starts 1 January 2013. Because the DMSP satellites are aging, it is important to ensure the continuation of a quality-controlled sea ice concentration time series. We added this new sea ice concentration record to begin preparing for the eventual failure of the DMSP instruments. Furthermore, the AMSR2 instrument is a next-generation sensor with better spatial resolution than its predecessor SSM/I and SSMIS instruments. The better resolution suggests that an AMSR2 sea ice concentration field represents sea ice more accurately than the same ice represented in an SSMIS ice concentration field. This is true even after the AMSR2 field – whose native resolution is 12.5 km – is down-sampled to match the 25 km SSMIS grid. This is discussed further in Section 4.2.2 of the C-ATBD (Meier et al., 2024a). However, differences between SSMIS and AMSR2 fields suggest extending the CDR with AMSR2 ice concentration requires first intercalibrating the DMSP record for consistency with the more-accurate AMRS2 record. Differences are slight (leading to a less than 2% difference in sea ice extent, for example) but significant for a climate data record. Until that work can be done, the AMSR2 record can be used to investigate shorter term regional and hemispheric variability within the AMSR2 time-period and will provide higher effective spatial resolution.

We have designated the AMSR2 record a prototype sea ice concentration to make clear that it is not the sea ice concentration climate data record. Because of the discontinuity between records, the AMSR2 prototype should not be used in conjunction with the earlier NOAA/NSIDC SIC CDR for long-term climate studies. See Section 8 for a brief description of these differences.

2. Overview of Changes

Following are a list of the major changes implemented in the Version 5 sea ice concentration CDR which include using improved automated quality corrections and fixing minor bugs in the Version 4 data.

Improvements:

1. Added prototype AMSR2 sea ice concentration. See Section 8 for more information.
2. Replaced the original NT land spillover correction with the next generation NT2 land spillover correction. See Section 4 for more information.
3. Improved the spatial interpolation of the brightness temperatures. In CDR Version 4, a missing brightness temperature grid cell was only filled by averaging the four orthogonal grid cells that surrounded it. In Version 5, a weighted bilinear interpolation is used employing the four surrounding orthogonal cells plus the four surrounding diagonal cells where the orthogonal grid cells are given a higher weighting factor than the diagonal cells. See Section 3.4.1.4 Quality Control Procedures of the C-ATBD (Meier et al., 2024) for details.
4. Implemented a new improved land mask. See Section 5 for more information.
5. Improved the spatial interpolation of the sea ice concentrations in the Arctic pole hole. See Section 6 for more information.
6. Raw NT and BT sea ice concentration variables will keep their full range of values instead of being clipped at 100% for provenance and transparency. While physically impossible, sea ice concentration values can exceed 100 due to the nature of the NT and BT algorithms and brightness temperature data. In Version 5, these values are left as is in the raw NT (nsidc_nt_seaice_conc) and BT (nsidc_bt_seaice_conc) variables but all values over 100 are converted to 100 before they go through the CDR algorithm.
7. The sea ice concentration variable will no longer contain land mask values; it will only contain sea ice data and a fill value. This update is being made to make the sea ice data more easily usable in AI and machine learning techniques. A new land mask variable (surface_type_mask) has been added so that users can still apply a surface mask to their data if they wish.
8. The melt onset variable now has an added flag value of 0 that indicates ocean (i.e. areas that do not contain sea ice).

9. Added new variables and updated the layout and names of some variables. Added two netCDF groups to improve organization. See Section 7 for more information.
10. Order in which the automated filters (weather filters, land spillover, and invalid ice masks) are applied has changed. In Version 4, the automated filters were applied to the raw BT and NT concentrations and then merged into one concentration using the CDR algorithm. In Version 5, the automated filters are now applied to the CDR concentration after merging. This was changed to simplify processing and for clarity in where and when filters are applied. Our experience shows that this method does at least as good a job if not better than the previous method, and it makes tracking the filters simpler.

Minor bug fixes:

1. Use dynamic BT algorithm tie-points. The CDR V4 code had a bug that caused it to use the default BT tie points for the calculation of the BT sea ice concentration. This bug occurred because the code was applying an ice mask to the TBs before calculation of the BT tie-point. This masking caused the calculation to create “out-of-bounds” tie-points, so the code reverted to using the default tie-points. This has been corrected in Version 5 and the dynamic, daily-varying tie-points are now used to create the BT concentration estimate.
2. Clip CDR values below 10%. CDR V4 erroneously allowed concentration values below 10% in the gridded fields. With CDR V5, they are now explicitly clipped to only give values of 10% or greater.
3. CDR V4 had a bug in the temporal interpolation where it failed to perform the 1-sided gap filling when looking for data threes days into the future. This caused some extra gaps in the concentration fields that could have been filled. This has been fixed in Version 5 to provide the most complete fields possible.

3. Difference Between CDR V4 and CDR V5

With the addition of a new land mask and new land spillover correction, CDR V5 has some differences when compared to CDR V4. This section describes these differences for each hemisphere.

3.1 Northern Hemisphere

Figure 1 (top) shows a comparison of the complete sea ice extent time series from CDR V5 and CDR V4 from 1978 through 2023 and Figure 1 (bottom) shows the differences between them (CDR V5 minus CDR V4) for the Arctic. Due to the poor quality of the SMMR era data (1979 through mid-1987), there is a larger difference in the two versions. In general, Version 5 sea ice extent is lower, likely due to the improved land spillover correction (Section 4) that has removed erroneous ice that Version 4 missed. Table 1 provides statistics of the differences between Version 5 and Version 4.

Table 1. Northern Hemisphere extent difference statistics (CDR V5 minus CDR V4).
Statistics are derived from a sample size of N= 16436 days spanning 1 Jan. 1979 – 31 Dec. 2023.

Statistic	Northern Hemisphere Value (Mil sq km)
Mean extent difference	-0.023
Standard deviation	0.082
Maximum extent difference	3.369
Minimum extent difference	-0.343

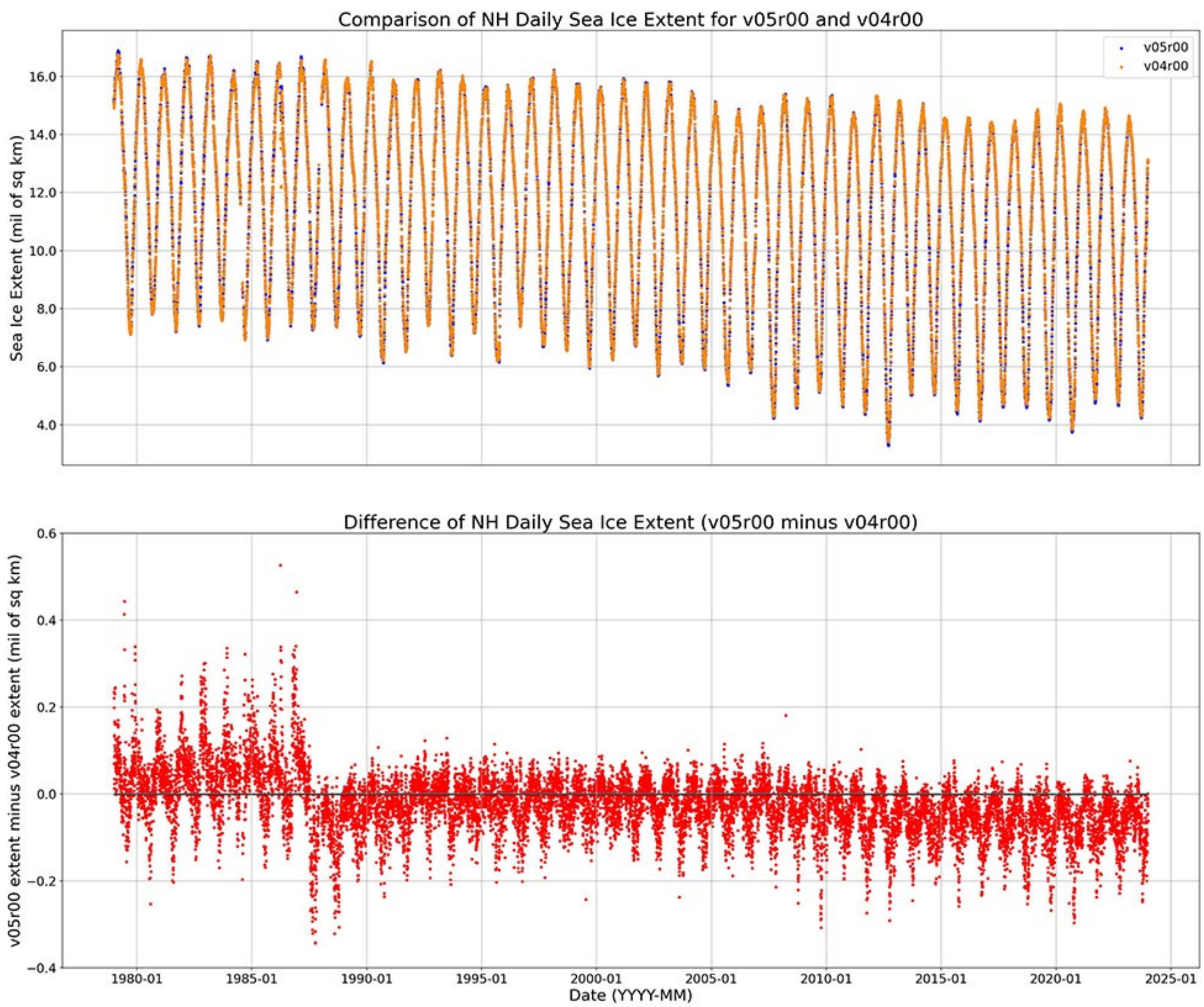

Figure 1. Northern hemisphere plot of sea ice extent from V5 (blue) and V4 (orange) (top) and the difference between the V5 and V4 sea ice extent (V5 minus V4) (bottom)

Figure 2 shows a zoomed in section of the scatter plot of the extent values for the Arctic from CDR V5 (blue) and CDR V4 (orange) plotted together for the year 2023.

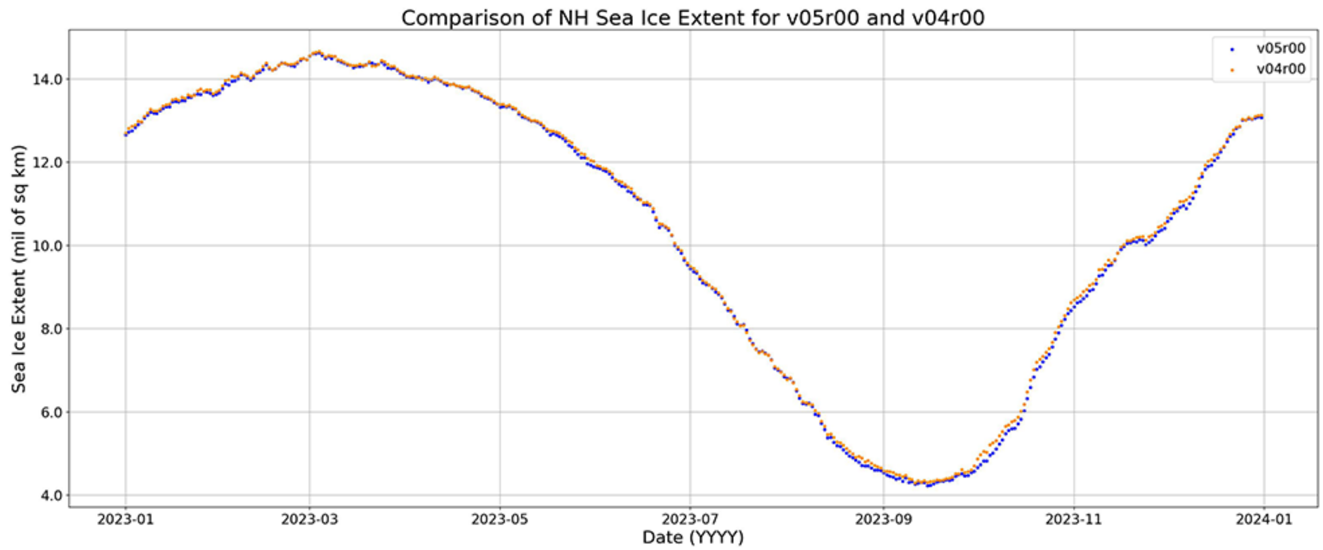

Figure 2. Zoomed in view of the sea ice extent from V5 (blue) and V4 (orange) for the year 2023 for the Northern Hemisphere.

3.2 Southern Hemisphere

Figure 3 (top) shows a comparison of the complete sea ice extent time series from CDR V5 and CDR V4 from 1979 through 2023 and Figure 3 (bottom) shows differences CDR V5 minus CDR V4 for the Arctic. Due to the poor quality of the SMMR era data (1979 through mid-1987), there is a larger difference in the two versions. In general, Version 5 sea ice extent is higher. Table 2 provides statistics of the differences between Version 5 and Version 4.

Table 2. Southern Hemisphere extent difference statistics (CDR V5 minus CDR V4). Statistics are derived from a sample size of N= 16436 days spanning 1 Jan. 1979 – 31 Dec. 2023.

Statistic	Southern Hemisphere Value (Mil sq km)
Mean extent difference	0.132
Standard deviation	0.091
Maximum extent difference	3.124
Minimum extent difference	-0.054

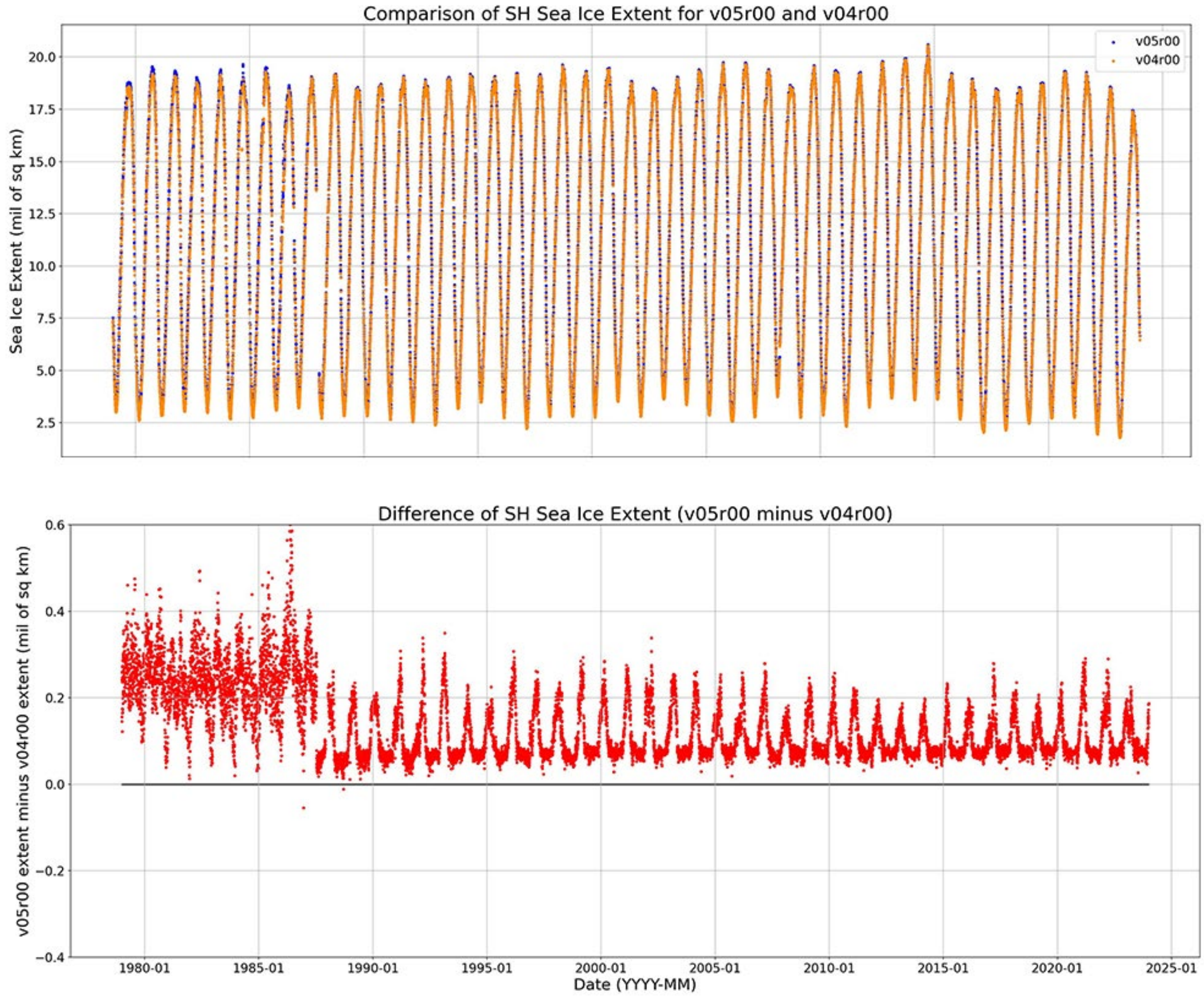

Figure 3. Northern hemisphere plot of sea ice extent from V5 (blue) and V4 (orange) (top) and the difference between the V5 and V4 sea ice extent (V5 minus V4) (bottom)

Figure 4 shows a zoomed in section of the scatter plot of the extent values for the Arctic from CDR V5 (blue) and CDR V4 (orange) plotted together for the year 2023.

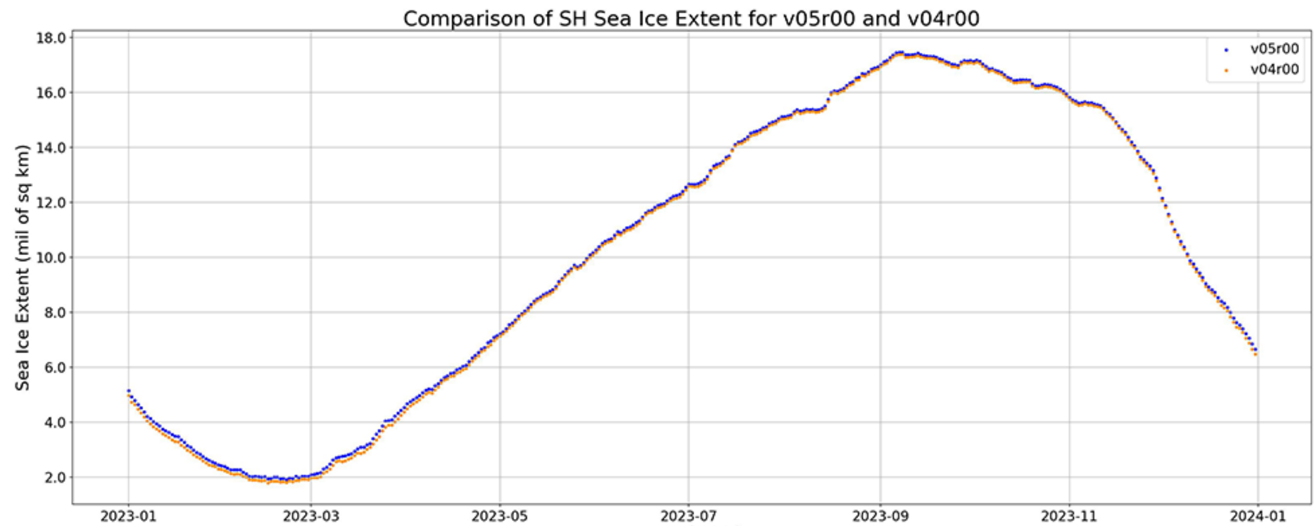

Figure 4. Zoomed in view of the sea ice extent from V5 (blue) and V4 (orange) for the year 2023 for the Southern Hemisphere.

4. Change in Land Spillover Method

The land-spillover effect is a consequence of microwave emission from the land surface "spilling over" into ocean grid cells. These mixed ocean/land grid cells have a signature that is often interpreted by the NT and BT algorithms as sea ice. To attempt to remove this spurious ice, corrections algorithms are applied to the concentration fields. In Version 4, two such corrections were applied: the NT land spillover and the BT land spillover. In Version 5, the BT land-spillover correction is still applied, but the NT land-spillover algorithm has been replaced by the improved NT2 land-spillover algorithm. Figure 5 shows an example of the improvement of spurious ice removal with the NT2 method. See Section 3.4.1.4 Quality Control Procedures of the C-ATBD (Meier et al., 2024) for a description of the NT2 land-spillover method.

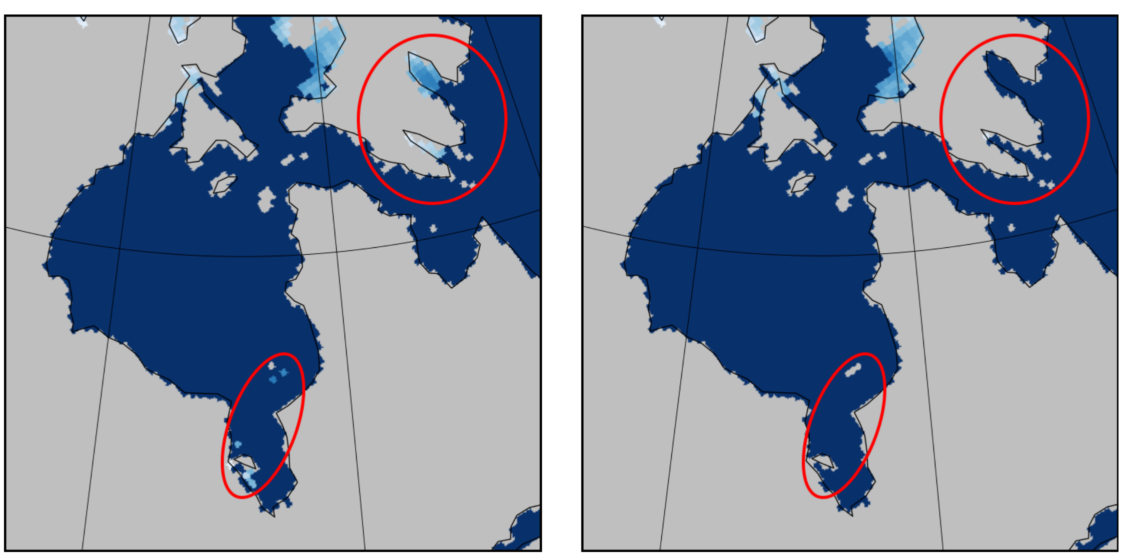

Figure 5. Differences in the effectiveness of NT (left) and NT2 (right) land-spillover corrections for 13 August 2023. The areas circled in red show areas of ice not removed by the NT algorithm (left) but that are removed by the NT2 algorithm (right).

5. New Land Mask

CDR Version 5 uses a new land mask modified from the *Arctic and Antarctic Regional Masks for Sea Ice and Related Data Products* (Meier & Stewart, 2023). The Meier & Stewart (2023) land mask was primarily derived from a MODIS Land Cover product. For complete details, see Meier & Stewart (2023). Improvements over the previous land mask include a reproducible methodology for creating the mask, the inclusion of up-to-date input sources, and self-consistency with masks of other resolutions and grid projections. For the purposes of the CDR, the Meier & Stewart land mask was modified so that all values that are not ocean – e.g. land, iceshelf, land ice (glaciers), and lakes – are considered land, so do not yield sea ice concentration estimates. Figure 6 shows a close-up view of an area around the Canadian Arctic Archipelago and Greenland highlighting the differences between the V4 and V5 land masks. Full difference maps for the Arctic and Antarctic can be found in Appendix 1 and Appendix 2, respectively. The new V5 land mask has 144 more grid cells marked as ocean for the Arctic and 112 more grid cells marked as ocean for the Antarctic than V4 (Table 3).

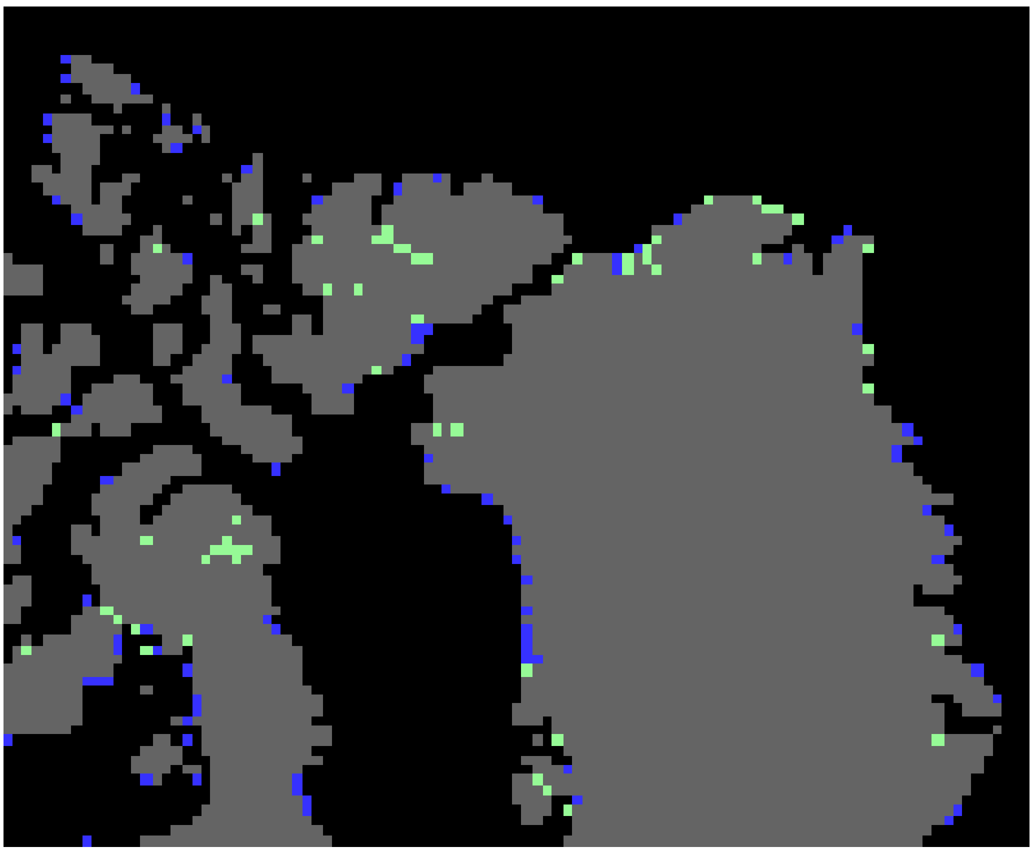

Figure 6. Cropped area of the Arctic showing the differences between the V4 and V5 land mask around the Canadian Arctic Archipelago and Greenland. Black: Both V4 and V5 agree that a grid cell is ocean. Gray: Both V4 and V5 agree that a grid cell is land (i.e. land, lake, or coast). Bright green: V5 indicates that a grid cell is land whereas V4 had it as ocean. Bright blue: V5 indicates that a grid cell is ocean, whereas V4 had it as land.

Table 3. Difference in land surface counts between V4 and V5 for the Arctic and Antarctic

Arctic Count	Antarctic Count	Interpretation
67032	82735	Both V5 and V4 ocean
371	284	V5 is ocean; v4 was land
227	172	V5 is land; V4 was ocean
68562	21721	Both V5 and V4 land

6. Improved Pole Hole Filling

In CDR Version 5, a slightly improved pole hole filling is applied. Figure 7 shows an example of the Arctic pole hole where tan cells are where data never occurs, and red cells are where data occasionally occur. In Version 4, tan and red cells were considered the pole hole even when occasional real data occurred at the red grid cells. The pole hole was filled with an average of the sea ice concentrations surrounding the tan and red cells (the white cells in Figure 7). In Version 5, the red cells are used in the average so that the interpolation uses as much actual data as possible.

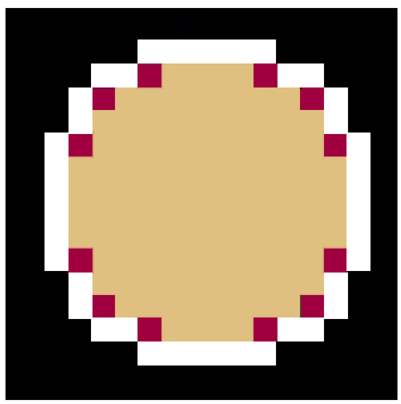

Figure 7. Arctic Pole Hole: Tan grid cells are where there is never any data. Red cells are where data occasionally occur.

7. Variable name changes, organization, and additions

Several variables were renamed in Version 5 or moved into netCDF groups to improve organization. These are noted in Table 4. For supplementary information, a cdr_supplementary group was added. Beginning with the 2013 files, a prototype_am2 group was added for the AMSR2 data. The new variables are listed in Table 5. Note that for the new Version 3 NRT CDR, the AMSR2 variables are provided in their own data files instead of within the SIC CDR files. See the Version 3 NRT CDR user guide for further information.

Table 4. Variable name changes and deletions

Applicable File	Old V4 Variable Name	New V5 Variable Name
Daily	spatial_interpolation_flag	cdr_seaice_conc_interp_spatial_flag
	temporal_interpolation_flag	cdr_seaice_conc_interp_temporal_flag
	qa_of_cdr_seaice_conc	cdr_seaice_conc_qa_flag
	stdev_of_cdr_seaice_conc	cdr_seaice_conc_stdev
	melt_onset_day_cdr_seaice_conc	cdr_melt_onset_day (moved to cdr_supplementary group)
	nsidc_bt_seaice_conc	raw_bt_seaice_conc (moved to cdr_supplementary group)
	nsidc_nt_seaice_conc	raw_nt_seaice_conc (moved to cdr_supplementary group)
	latitude and longitude	Name unchanged (moved to cdr_supplementary group)
	projection	crs
	xgrid	x
	ygrid	y
Monthly	qa_of_cdr_seaice_conc_monthly	cdr_seaice_conc_monthly_qa_flag
	stdev_of_cdr_seaice_conc_monthly	cdr_seaice_conc_monthly_stdev
	melt_onset_day_cdr_seaice_conc_monthly	cdr_melt_onset_day_monthly (moved to cdr_supplementary group)
	latitude and longitude	Name unchanged (moved to cdr_supplementary)
	nsidc_bt_seaice_conc_monthly	Removed from monthly files
	nsidc_nt_seaice_conc_monthly	Removed from monthly files
	projection	crs
	xgrid	x
	ygrid	y

Table 5. New Variables

Applicable File	New V5 Variables
Daily	surface_type_mask (located in cdr_supplementary group)
	am2_seaice_conc (located in prototype_am2 group)
	am2_seaice_conc_interp_spatial_flag (located in prototype_am2 group)
	am2_seaice_conc_interp_temporal_flag (located in prototype_am2 group)
	am2_seaice_conc_qa_flag (located in prototype_am2 group)
	am2_seaice_conc_stdev (located in prototype_am2 group)
Monthly	surface_type_mask (located in cdr_supplementary group)

8. AMSR2 Prototype

As noted in the summary, a prototype sea ice concentration using the AMSR2 instrument satellite is now available starting 1 January 2013 and going through the present. We have designated this as a prototype sea ice concentration because the AMSR2 sea ice concentrations have not been intercalibrated to provide consistency between the AMSR2 and SSMIS F17 sensor, so there is a discontinuity between the two sensors. Because of this discontinuity, the AMSR2 prototype should not be used in conjunction with the earlier NOAA/NSIDC SIC CDR for long-term climate studies. Figure 8 and Figure 9 show the differences between SSMIS F17 and AMSR2 for the Northern and Southern hemispheres, respectively; and Table 6 provides statistics of the differences between the two for 1 January 2013 to 31 December 2023.

Table 6. Northern Hemisphere extent difference statistics (CDR V5 F17 minus AMSR2 prototype). Statistics are derived from a sample size of N=4017 days spanning 1 Jan. 2013 – 31 Dec. 2023.

Statistic	Northern Hemisphere Value (Mil sq km)	Southern Hemisphere Value (Mil sq km)
Mean extent difference	0.212	0.1
Standard deviation	0.103	0.079
Maximum extent difference	0.594	0.573
Minimum extent difference	-0.104	-0.514

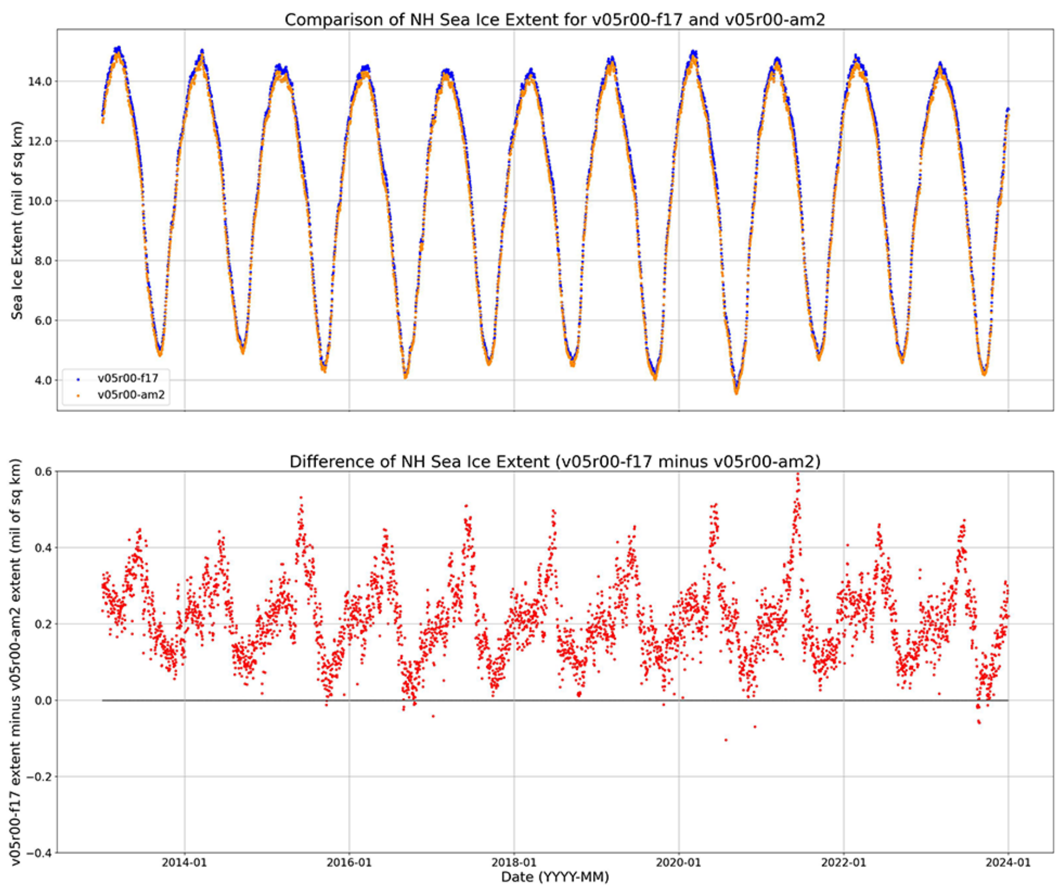

Figure 8. Northern Hemisphere F17 sea ice extent (v05r00-f17, blue) plotted with AMSR2 sea ice extent (v05r00-am2, orange) for 2013 to 2023 (top). Difference plot of F17 sea ice extent minus AMSR2 sea ice extent (bottom).

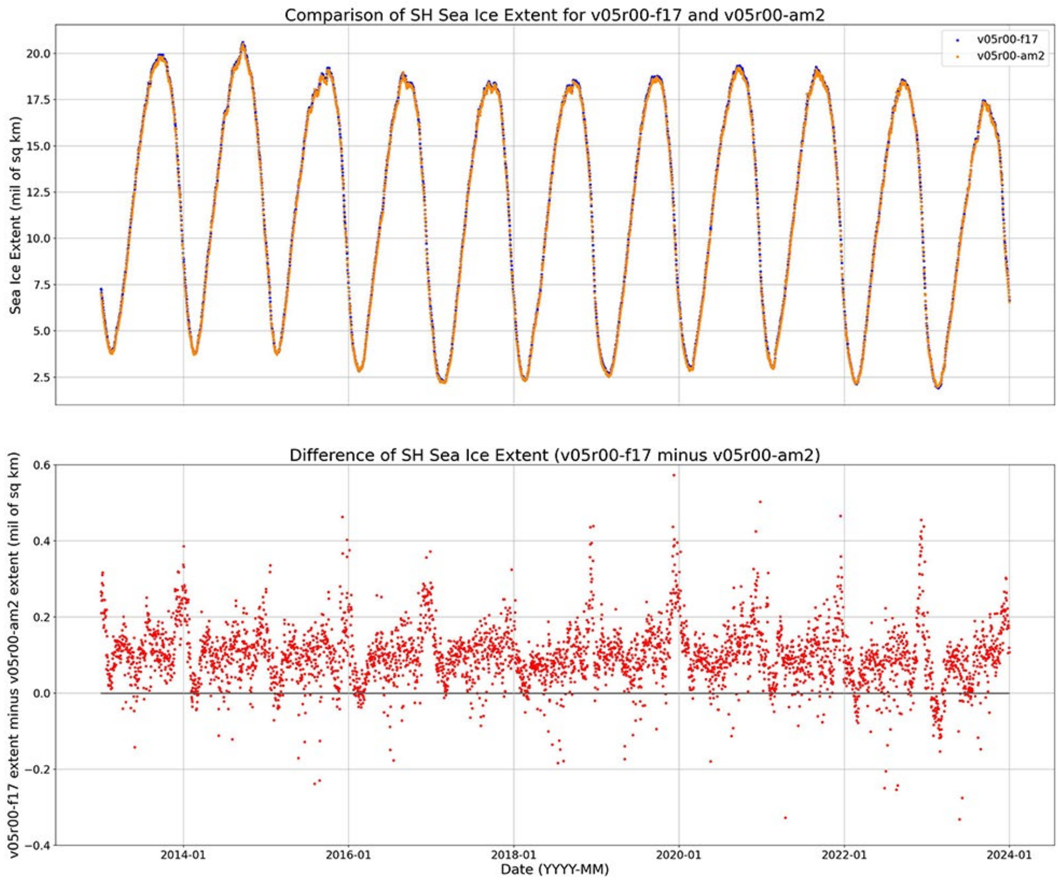

Figure 9. Southern Hemisphere F17 sea ice extent (v05r00-f17, blue) plotted with AMSR2 sea ice extent (v05r00-am2, orange) for 2013 to 2023 (top). Difference plot of F17 sea ice extent minus AMSR2 sea ice extent (bottom).

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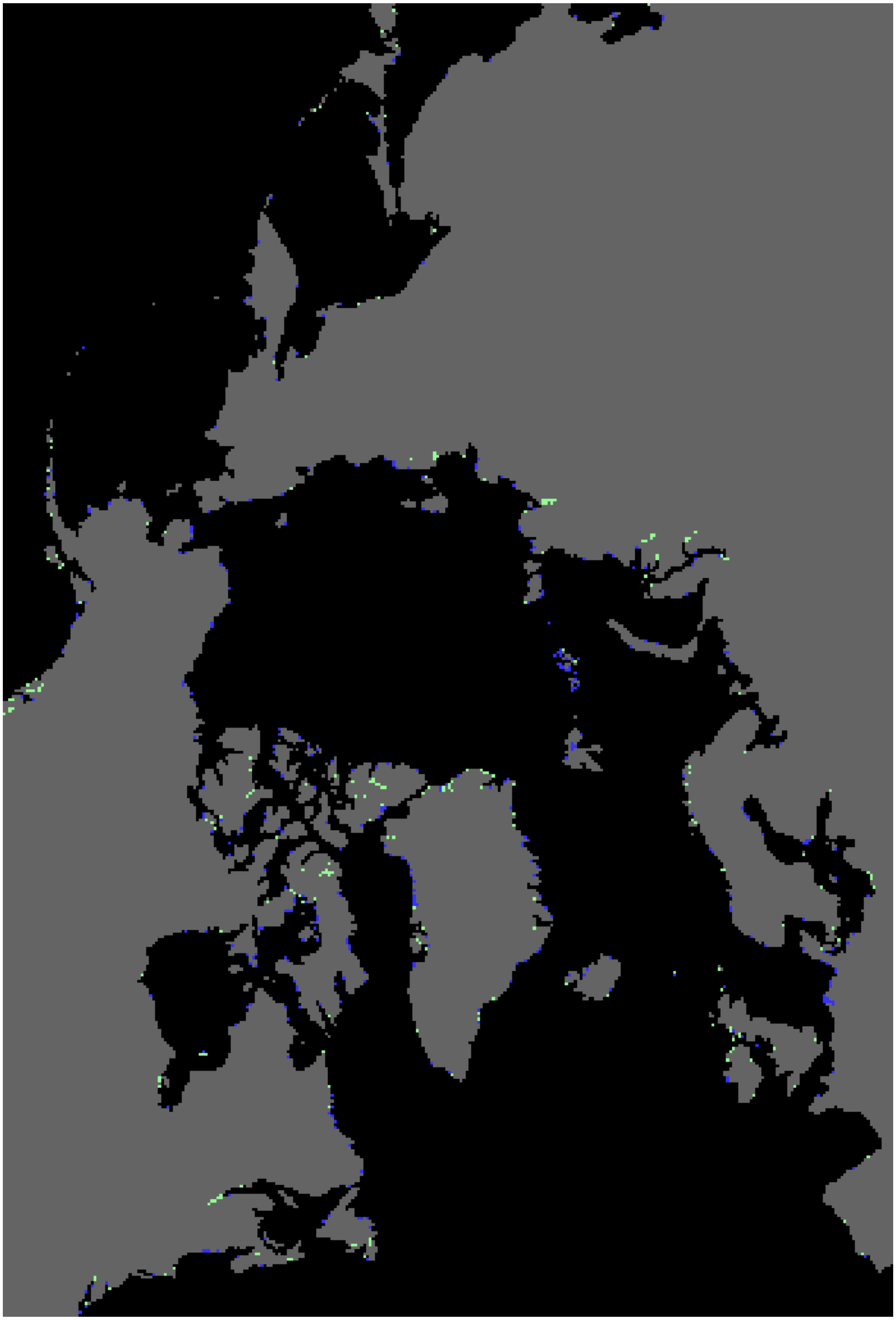
10. Appendix 1: Arctic Land Mask Difference Between V4 and V5

Black: Both V4 and V5 agree that a grid cell is ocean. Gray: Both V4 and V5 agree that a grid cell is land (i.e. land, lake, or coast). Bright green: V5 indicates that a grid cell is land whereas V4 had it as ocean. Bright blue: V5 indicates that a grid cell is ocean, whereas V4 had it as land.



11. Appendix 2: Antarctic Land Mask Difference Between V4 and V5

Black: Both V4 and V5 agree that a grid cell is ocean. Gray: Both V4 and V5 agree that a grid cell is land (i.e. land, lake, or coast). Bright green: V5 indicates that a grid cell is land whereas V4 had it as ocean. Bright blue: V5 indicates that a grid cell is ocean, whereas V4 had it as land.