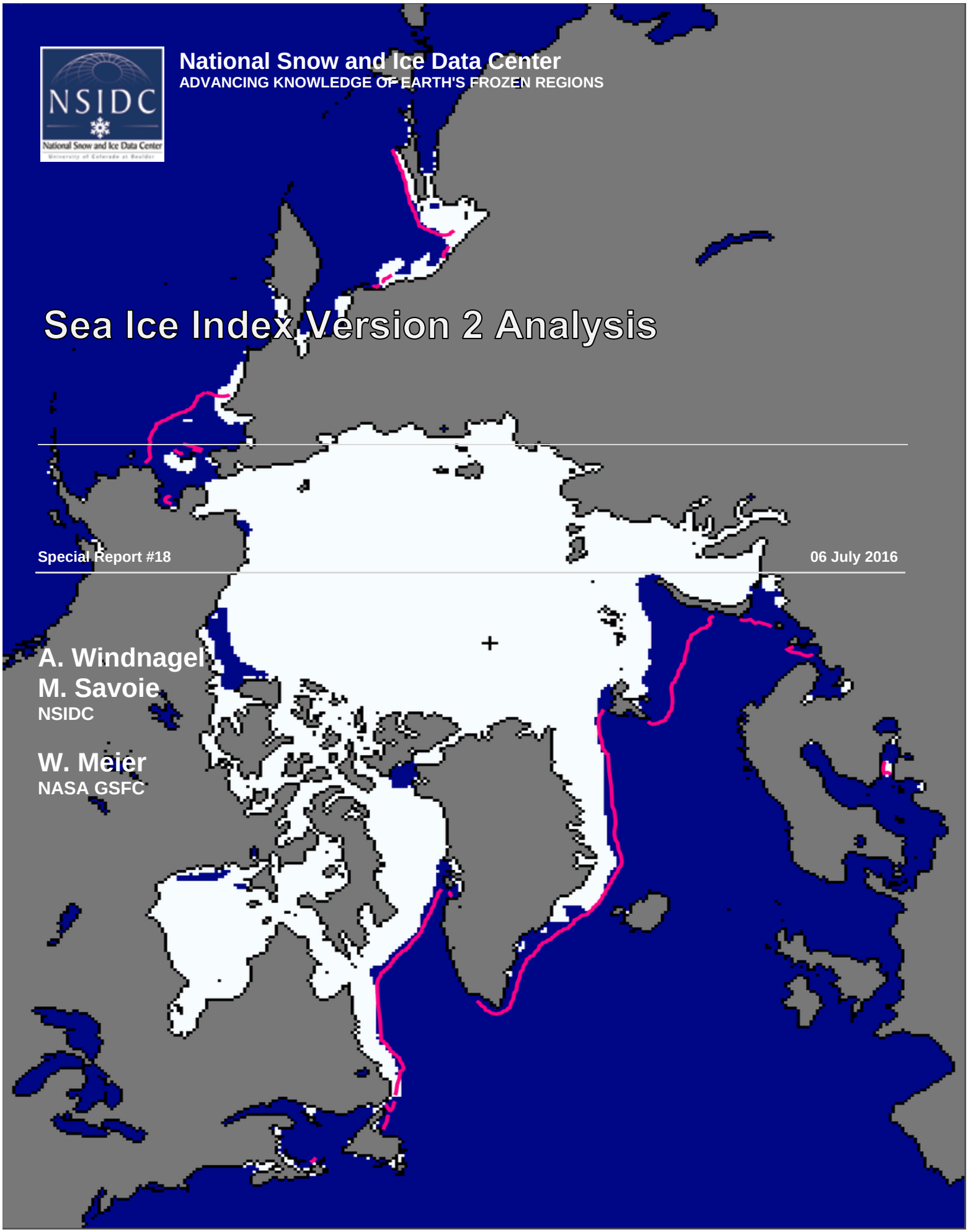

National Snow and Ice Data Center
ADVANCING KNOWLEDGE OF EARTH'S FROZEN REGIONS

Sea Ice Index Version 2 Analysis

Special Report #18

06 July 2016

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Contents

Citation

Windnagel, A., M. Savoie, and W. Meier. 2016. Sea Ice Index Version 2 Analysis. NSIDC Special Report 18. Boulder CO, USA: National Snow and Ice Data Center. http://nsidc.org/pubs/special/nsidc-special-report-18.pdf.

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Summary

The Sea Ice Index has been updated to Version 2. Changes include using the most recently available version of the Goddard Space Flight Center (GSFC) input sea ice concentration data and adjusting three procedures in the Sea Ice Index processing routine. These four updates affect different portions of the Sea Ice Index time series (Table 1). However, these changes are generally quite small and do not alter current conclusions about Arctic or Antarctic sea ice conditions.

Table 1. Sections of the Sea Ice Index impacted by each update or correction.

Update/Correction	Final Monthly Data	NRT Monthly Data	Final Daily Data	NRT Daily Data
New version of GSFC input data	X		X	
Redundant 15% concentration threshold	X	X		
Satellite transition periods	X			
Fractional rounding errors	X	X	X	X

All of these updates affect the *final monthly* data; and two of them, the redundant 15 percent threshold and fractional rounding errors, minimally alter the *near-real-time (NRT) monthly* data. For the daily data, only two updates influence the data values: the new GSFC input data that affect the *final daily* data and fractional rounding errors that alter both the *final daily* data and the *NRT daily* data.

An in-depth analysis of the *final* daily and monthly data through December 2014 for both hemispheres was performed. Overall, the changes in the monthly sea ice extent trends due to these updates are small. The average change in the trends over all 12 months is on the order of 0.05 percent/decade (or approximately 500 km^2/year). Generally, trends in Version 2 are less negative than trends obtained with the Version 1 final values. Most of these changes are too slight to be noticeable in the images and graphs that make up the bulk of the Sea Ice Index data set. Processing updates are briefly described in Table 2 and their effects are fully described in the sections below, broken up by Northern Hemisphere and Southern Hemisphere.

Table 2. Sea Ice Index Version 2 updates.

Update/ Correction	Description
New version of GSFC input data	Sea Ice Index Version 2 uses V1.1 of the Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data (GSFC product) as the input data source for the *final* portion of the Sea Ice Index record. Version 1.1 of the GSFC product has these changes: • Additional manual quality control procedures applied to aid removal of spurious ice. • Changes in satellite transition dates (See Table 4). • Later end date of 31 December 2015, extending the final portion of the Sea Ice Index record. The NRT portion now begins on 01 January 2016. See more about GSFC V1.1 in the Version History section of the V1.1 document.
Redundant 15% concentration threshold	For the monthly Sea Ice Index data, a grid cell is considered ice if the concentration is 15% or greater. Thus, the ice edge is defined by the 15% concentration contour. This convention was established early on by those who developed the Nasa Team algorithm for passive microwave data (Cavalieri et al. 1991). It was found that ice concentration values less than 15% have greater uncertainty and may reflect weather effects or other factors. Also, because of the low spatial resolution of the sensors, 15% was found to be most consistent with the true ice edge location. Sea Ice Index V1 applied this 15% ice concentration threshold twice when computing the monthly average gridded fields. The threshold was applied first to the daily gridded concentration; any grid cell with a concentration less than 15% was set to zero. After the monthly average of those daily grids was determined, the 15% threshold was applied again to define the outer limit of that month's ice. Area and extent data values were calculated from this monthly field. Applying the threshold twice made these values smaller than they would have been with the threshold only applied once. This was updated in V2 so that the threshold is only applied to the monthly data after the gridded average has been computed from the daily data.
Satellite transition period adjustment	Satellites, and the instruments that they carry, have a variable but finite lifespan. To create the more than 30-year long Sea Ice Index time series, data from sensors on several satellites over different periods along the time series must be linked together to create the full time series. When a transition from one satellite to another occurs, the monthly average should be computed using data from the first satellite, up to the day of transition, and then data from the second satellite, for the rest of the month. Following a review of the processing code for Sea Ice Index V1, it was found that monthly averages, which included data during a satellite transition period, were being generated from the new satellite and not including partial data contributions from the preceding satellite. For months where these transitions occurred, July 1987, December 1991, and May 1995 (Table 4), the V1 monthly averages were not computed with a full month of data. This was corrected in V2, and the monthly gridded averages are now created from all available data. In addition, the every-other-day SMMR data are now counted twice so that they have the same weight as the daily SSM/I data when they are averaged over the transition month in 1987.
Fractional rounding errors	Sea Ice Index V1 was found to have several instances of fractional rounding errors in the computation of both the daily and monthly data that affected the second decimal place of some of the monthly extent and area values and was negligible in the daily values. These were corrected in V2.

Impact of Updates on Northern Hemisphere Data

Changes in Monthly Arctic Data

Table 3 lists key statistical differences between Sea Ice Index V2 and V1 final monthly data for the Northern Hemisphere. Of the 432 final monthly data values, 417 values (96.5%) have a difference between 0.01 and 0.1 million km^2, and 15 values (3.5%) have a difference greater than 0.1 million km^2. Figure 1 shows a time series of the differences in Arctic V2 ice extent minus V1 ice extent by month over the period 1979 through 2014.

Table 3. Primary statistics for final monthly Northern Hemisphere ice extent for V2 minus V1. Statistics are derived from a sample size of N=432 months spanning Nov. 1979 – Dec. 2014.

Statistic	Value (million km^2)
Mean Extent Difference	0. 060648
Standard Deviation	0. 044784
Minimum Extent Difference	0.000000
Maximum Extent Difference	0.830000

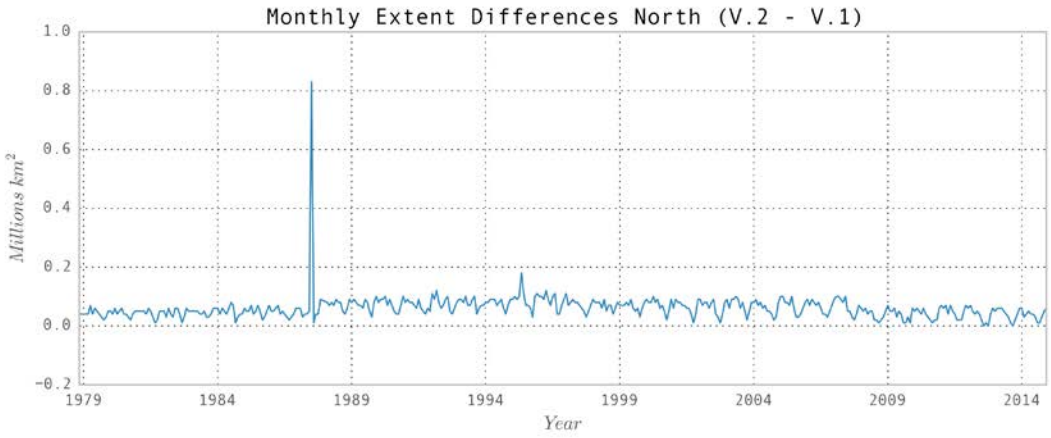

Figure 1. Differences in final monthly extent values (V2 minus V1) for the Northern Hemisphere

As seen in Figure 1, the majority of the differences in the Arctic data are small and on the same order of magnitude. The primary contributor to these small systematic changes across the entire time series is the result of correcting the redundant 15 percent ice concentration threshold because making this adjustment added ice back into the calculations.

The outlier is the maximum difference of 0.83 million km^2 seen in July 1987. A combination of three of the four updates caused this large difference:

1. **Satellite transition period adjustment**: This is the largest contributor to the increase to the July 1987 data value and caused approximately 85 percent of the increase. In Sea Ice Index V1, the July 1987 monthly data values were computed using only SSM/I data that started on 09 July, thus using only 22 days of data for the computation. This erroneously omitted available data for the first eight days of July from the SMMR instrument. Due to summer temperatures, July's ice extent was dropping rapidly as temperatures warmed, so missing one third of the data at the

beginning of the month skewed the monthly average. When ice from the first eight days is accounted for in V2 and all 31 days of data are used, it significantly increases the average sea ice value for that month. Note, for V1, the 22 days came from the SSM/I instrument. For V2, all 31 days come from the SMMR instrument, where the every-other-day SMMR data are now counted twice so that they have the same weight as the daily SSM/I data. The change in instruments is due to the switch from V1.0 to V1.1 of the GSFC input data. See #3 below for a discussion of this change.

2. **Redundant 15 percent threshold**: Revising the redundant 15 percent threshold caused approximately a 10 percent increase in the July 1987 data value. It affected the July 1987 value more than other months because SMMR data are affected somewhat differently than the SSM/I data. This is due to the slight differences in the instrument frequencies, spatial resolutions (satellite footprints), and weather filter parameters between the two sensors.
3. **GSFC V1.1 input data**: Switching to Version 1.1 of the GSFC input sea ice concentration data caused approximately 5 percent of the increase to the July 1987 data value. GSFC V1.1 extends the time period for which SMMR instrument data are used by 42 days (Table 4). Therefore, for Sea Ice Index V2, the July 1987 monthly data are computed entirely from SMMR data. The August 1987 monthly data are computed using SMMR data from 01 August to 20 August and SSM/I data from 21 August to 31 August. Other satellite transition dates also impacted their respective monthly averages but not considerably. For a complete description of the changes to GSFC V1.1 see the Version History section of the V1.1 documentation.

Table 4. Differences in the date ranges for the input data to monthly Sea Ice Index V1 and V2 data for Oct 1978 to Dec 2014.

Instrument	Version 1 Date Ranges	Version 2 Date Ranges
Nimbus-7 SMMR	26 October 1978 - 30 June 1987*	26 October 1978 - 20 August 1987
DMSP-F8 SSM/I	09 July 1987 - 30 November 1991*	21 August 1987 - 18 December 1991
DMSP-F11 SSM/I	03 December 1991 - 30 April 1995*	19 December 1991 - 29 September 1995
DMSP-F13 SSM/I	05 May 1995 - 31 December 2007	30 September 1995 - 31 December 2007
DMSP-F17 SSMIS	01 January 2008 - 31 December 2014	01 January 2008 - 31 December 2014

*Note the missing data at these satellite transitions.

Changes in Monthly Arctic Trend Values

The changes in the monthly data values described above impacted monthly trend values. Amending the redundant 15 percent threshold systematically changed the monthly data values across the entire Sea Ice Index time series. When monthly trends were computed using V2 final data, the slope of some regression lines changed. Most changes ranged from 0.02 to 0.06 percent/decade (150 km^2/year to 500 km^2/year) compared to V1. These changes are within the uncertainty range of the monthly trends. See Table 5 for differences in the Arctic trend values between the two versions.

July is the month for which the change in the trend is largest, changing from -7.4 percent/decade to -7.6 percent/decade for the 1979 to 2014 period of record. This can be attributed to the satellite transition period adjustment in July 1987.

In addition, the redundant 15 percent threshold removed more ice from SMMR than from SSM/I data. Therefore, correcting this error "adds back" ice; but it adds more to SMMR than to SSM/I due to differences in data resolution and channel frequency of the two instruments. As a result, every July mean from 1979 through 1987 has higher extent values than it did before the redundant threshold correction. The difference for July 1987, when combined with the changed number of days used, is enough to change the trend by 0.2 percent.

Table 5. Northern Hemisphere final monthly extent trends (%/decade) for the 1979 through 2014 period of record. Trend uncertainty listed in parentheses with identical units.

Month	V1 Trend (%/decade)	V2 Trend (%/decade)	Difference (V2 - V1)
January	-3.2 (+/- 0.5)	-3.1 (+/- 0.5)	0.1
February	-3.0 (+/- 0.5)	-2.9 (+/- 0.5)	0.1
March	-2.5 (+/- 0.6)	-2.5 (+/- 0.6)	0.0
April	-2.4 (+/- 0.6)	-2.4 (+/- 0.6)	0.0
May	-2.3 (+/- 0.7)	-2.2 (+/- 0.7)	0.1
June	-3.6 (+/- 0.6)	-3.5 (+/- 0.6)	0.1
July	-7.4 (+/- 1.3)	-7.6 ((+/- 1.3)	-0.2
August	-10.3 (+/- 2.1)	-10.3 (+/- 2.1)	0.0
September	-13.3 (+/- 2.8)	-13.3 (+/- 2.9)	0.0
October	-6.9 (+/- 1.7)	-6.9 (+/- 1.7)	0.0
November	-4.7 (+/- 0.9)	-4.8 (+/- 0.9)	-0.1
December	-3.4 (+/- 0.5)	-3.4 (+/- 0.5)	0.0

Changes in Daily Arctic Data

The GFSC input data is the only update that impacted the final daily data in Version 2 of the Sea Ice Index. Fractional rounding errors and GFSC V1.1 affected both NRT products. Table 6 lists the key statistical differences between V2 and V1 for the final daily Northern Hemisphere data.

Table 6. Primary statistics for final daily Northern Hemisphere sea ice extent for V2 minus V1. Statistics derived with a sample size N = 11,565 days spanning Nov. 1978 – Dec. 2014.

Statistic	Value (million km^2)
Mean Extent Difference	-0.000349
Standard Deviation	0.006774
Minimum Extent Difference	-0.204000
Maximum Extent Difference	0.195000

Of the two updates that affected the daily Arctic data, the use of the new GSFC V1.1 input data caused the largest differences in the Arctic daily final data values. Differences arise for two reasons

1. GSFC V1.1 data have more manual quality control applied to data during the SMMR and SSM/I F8 operational periods (1979 through 1991) that affects derived ice extent and area.
2. The satellite transition dates are shifted in the GSFC V1.1 data (Table 4).

For a complete description of the changes to GSFC V1.1 see the Version History section of the V1.1 documentation. However, changes in GSFC V1.1 cause relatively small changes to Sea Ice Index V2. Of the 11,565 daily final northern data values, 602 (5.2%) experienced a changed. 336 values (2.9%) have a

difference between 0.01 and 0.1 million km^2, and 7 values (0.06%) have a difference greater than 0.1 million km^2. See Figure 2.

The addition of more manual quality control in GSFC V1.1 resulted in a decrease of ice extent throughout much of the SMMR era. The largest decrease is on the order of -0.05 million km^2. Differences in ice extent exceeding 0.1 million km^2, during the SSM/I era, can be attributed to the change in the satellite transition dates (Table 4). GSFC V1.1 input data are responsible for 145 (1.3%) altered daily data values of 0.01 or greater. For Sea Ice Index V2, the every-other-day temporal resolution SMMR data are used for all of July 1987 and for 01 to 20 August 1987 (counted twice to match the daily temporal resolution SSM/I data). SSM/I data are used for the final 11 days of August (21 to 31). This is different from Version 1 in which daily data values for July 1987 came from the every-other-day SMMR data for 01 to 08 July and then the daily SSM/I data for the rest of July and all of August. None of these updates changed the ranking of the ten lowest September sea ice minimums nor did they affect the average September minimum for the 30-year base period of 1981 to 2010.

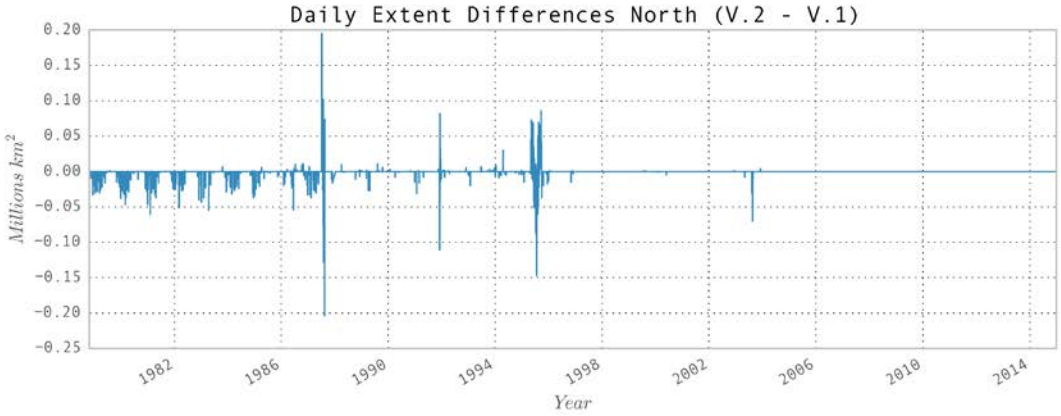

Figure 2. Differences in final daily extent values (V2 minus V1) for the Northern Hemisphere

Impact of Updates on Southern Hemisphere Data

Changes in Monthly Antarctic Data

Table 7 outlines key statistical differences between Sea Ice Index V2 and V1 for the Southern Hemisphere. Of the 432 final monthly Antarctic data values, 353 values (81.7%) have a difference between 0.01 and 0.1 million km^2, and 11 values (2.5%) have a difference greater than 0.1 million km^2. Figure 3 shows a time series of the differences in Antarctic V2 ice extent minus V1 ice extent by month over the period 1979 through 2014.

Table 7. Primary statistics for final monthly Southern Hemisphere ice extent for V2 minus V1. Statistics are derived using a sample size of N = 432 months spanning Nov. 1978 – Dec. 2014.

Statistic	Value (million km^2)
Mean Extent Difference	0.038542
Standard Deviation	0. 036658
Minimum Extent Difference	-0.120000
Maximum Extent Difference	0.440000

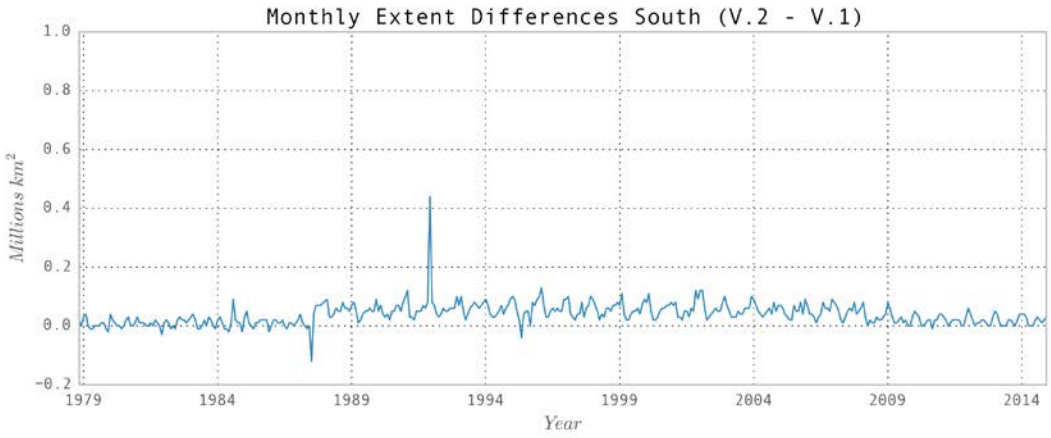

Figure 3. Differences in final monthly extent values (V2 minus V1) for the Southern Hemisphere

Consistent with the Northern Hemisphere data, the largest difference between Version 1 and Version 2 final monthly data values is attributed to adjustments in the satellite transition period. For the Southern Hemisphere, however, the biggest change is the transition from SSM/I F8 to SSM/I F11 in December 1991 with a change of 0.44 million km^2. December is summertime in the Antarctic. This means that December's ice extent is dropping rapidly, so missing data skews the monthly average. For V1, only 29 days of December 1991 are used to calculate the monthly average. All 31 days are used in the V2 monthly calculation. Despite V1 omitting just the first 2 days of December 1991, the large rate of change in ice extent due to melting that went uncaptured impacted the monthly mean noticeably. In addition, the change of the satellite transition dates in GSFC V1.1 had a minimal effect on changing the data values. For V1, the 29 days of data came from the SSM/I F11 instrument from 03 December through 31 December 1991. For V2, the data for the monthly average come from the SSM/I F8 instrument for 01 December through 17 December and then from the SSM/I F11 instrument for 18 December through 31 December (Table 4).

There is also a noticeable change from the transition period adjustment in July 1987 where previously only 22 days of SSM/I data were used to compute the average. For V2, all 31 days in July now come from the SMMR instrument, where the every-other-day SMMR data are counted twice so that they have the same weight as the daily SSM/I data.

Changes in Monthly Antarctic Trend Values

Correcting the redundant 15 percent threshold has a similar effect on the Southern Hemisphere as it did on the Northern Hemisphere. A majority of the trends, calculated through 2014, changed from -0.01 to 0.09 percent/decade (-100 km^2/year to 650 km^2/year). These changes are within the uncertainty of the trend values. The largest changes occurred in the January trend with a change of 0.18 percent/decade (2400 km^2/year). This is not surprising since January is summer time in the Antarctic when the ice is rapidly melting; and thus, the ice edge is rapidly changing. This is the time of the year when removing the extra cutoff procedure, hence adding more ice, would be expected to have the largest effect for the Southern Hemisphere. However, the resulting changes to trend values are well within the uncertainty for these months. See Table 8.

Table 8. Southern Hemisphere final monthly extent trends (%/decade) for the 1979 through 2014 period of record. Trend uncertainty listed in parentheses with identical units.

Month	V1 Trend (%/decade)	V2 Trend (%/decade)	Difference (V2-V1)
January	3.7 (+/- 4.1)	3.9 (+/- 4.0)	0.2
February	4.5 (+/- 4.1)	4.6 (+/- 3.9)	0.1
March	4.6 (+/- 3.8)	4.7 (+/- 3.7)	0.1
April	3.4 (+/- 2.6)	3.5 (+/- 2.6)	0.1
May	2.6 (+/- 1.6)	2.6 (+/- 1.6)	0.0
June	1.7 (+/- 1.1)	1.7 (+/- 1.1)	0.0
July	1.2 (+/- 0.6)	1.2 (+/- 0.6)	0.0
August	1.0 (+/- 0.5)	1.0 (+/- 0.5)	0.0
September	1.3 (+/- 0.6)	1.3 (+/- 0.6)	0.0
October	1.2 (+/- 0.6)	1.2 (+/- 0.6)	0.0
November	0.9 (+/- 0.6)	0.9 (+/- 0.6)	0.0
December	2.4 (+/- 1.9)	2.5 (+/- 1.8)	0.1

Changes in Daily Antarctic Data

The GFSC V1.1 input data and fractional rounding errors impacted the final daily data in Version 2 of the Sea Ice Index. The GFSC input data only impacted the final daily data, while the fractional rounding errors affected both the final and NRT data. Table 9 lists key statistical differences between Sea Ice Index V2 and V1 for the daily final data in the Southern Hemisphere.

Table 9. Primary statistics for final daily Southern Hemisphere sea ice extent for V2 minus V1. Statistics derived from a sample size of N = 11,565 days spanning Nov. 1978 – Dec. 2014.

Statistic	Value (million km^2)
Mean Extent Difference	-0.001003
Standard Deviation	0.006217
Minimum Extent Difference	-0.125000
Maximum Extent Difference	0.193000

Of the two updates that affected the daily Antarctic data, the use of the new GSFC V1.1 input data caused the largest difference in the Antarctic daily final data values. Differences arise for two reasons:

1. GSFC V1.1 data have more manual quality control applied to data during the SMMR and SSM/I F8 operational periods (1979 through 1991) that affects derived ice extent and area.
2. The satellite transition dates are shifted in the GSFC V1.1 data (Table 4).

For a description of the changes to GSFC V1.1 see the Version History section of the V1.1 documentation. However, changes in GSFC V1.1 lead to relatively minimal changes in Sea Ice Index V2. Of the 11,565 daily southern data values, 1,870 data values (16%) are impacted. 393 values (3.4%) have a difference between 0.01 and 0.1 million km^2 and 2 values (0.02%) have a difference greater than 0.1 million km^2 (Figure 4). The addition of more manual quality control resulted in a consistent decrease in ice extent during the SMMR era. The maximum decrease during this era is on the order of 0.04 million km^2. Magnitude differences greater than 0.1 million km^2. are attributed to the change in the satellite transition dates (Table 4) in the new V1.1 GSFC input data. 161 values (1.4%) changed by 0.01 or greater. For Sea Ice Index V2, the every-other-day temporal resolution SMMR data are used for all of July 1987 and for 01 to 20 August 1987 (counted twice to match the daily temporal resolution SSM/I data). SSM/I data are used for the final 11 days of August (21 to 31). This is different from Version 1 in which daily data values for July 1987 came from the every-other-day SMMR data for 01 to 08 July and then the daily SSM/I data for the rest of July and all of August.

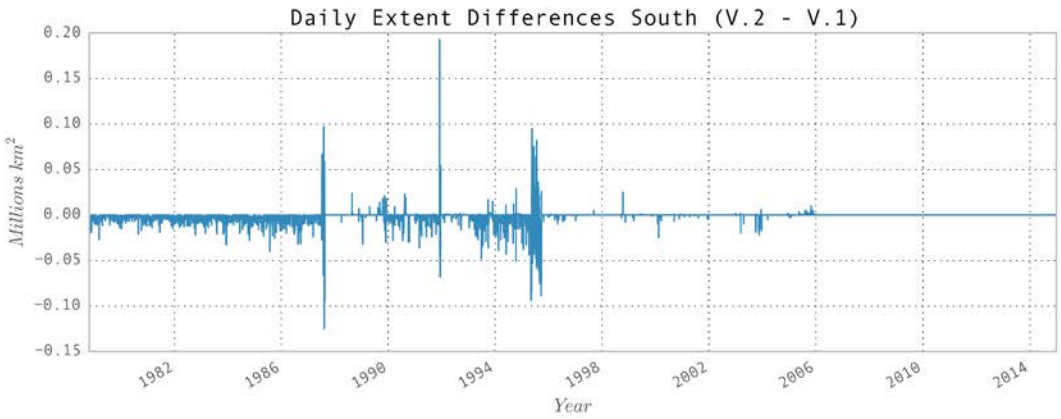

Figure 4. Differences in final daily extent values (V2 minus V1) for the Southern Hemisphere

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