National Snow and Ice Data
ADVANCING KNOWLEDGE

Sea Ice Index Version 3 Analysis

Special Report #19

19 October 2017

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Contents

Citation

Windnagel, A., M. Brandt, F. Fetterer, and W. Meier. 2017. Sea Ice Index Version 3 Analysis. NSIDC Special Report 19. Boulder CO, USA: National Snow and Ice Data Center. http://nsidc.org/sites/nsidc.org/files/files/NSIDC-special-report-19.pdf.

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Summary

The Sea Ice Index has been updated to Version 3 (V3). The key update in V3 is a change in the method for calculating the numerical monthly averages of sea ice extent and sea ice area data values; that is, the data distributed in .csv and .xlsx format. This change impacts only the monthly data values in the Sea Ice Index time series and not monthly sea ice extent and concentration maps that accompany the data product, that is, the .png, .tif, and shapefile archives. Daily data are also not impacted, nor are any current conclusions drawn from the Sea Ice Index data set about the state of sea ice in either the Arctic or the Antarctic. This change is being made in response to questions raised by users of the product concerning how the monthly average ice extent and areas are calculated. In this NSIDC special report, we present a full discussion behind the reasoning why the change was made and an in-depth analysis of the monthly Sea Ice Index time series for the user community.

Background

Basic Concepts for the Monthly Averaging of the Sea Ice Index

The Sea Ice Index data product is based on gridded fields of sea ice concentration data derived from passive microwave radiometers. Validation studies of concentration values that looked at where an ice edge would be placed by aerial overflight measurements have found that this ice edge is best matched by the 15 percent concentration value contour in satellite passive microwave data (Cavelieri et al. 1991). It is for this reason that the 15 percent threshold is an appropriate measure to mask out ice in lower concentrations for many applications such as the Sea Ice Index.

Monthly averages of numerical ice concentration data can be calculated through two different methods: 1) summing ice concentration data at each grid cell throughout a month, dividing by the number of days within a particular month to get average concentration for that grid cell, and then applying the 15 percent concentration threshold to the gridded field of average ice concentrations before deriving monthly area and extent, or 2) applying the 15 percent concentration threshold to the daily gridded field of concentration data before deriving that day's area and extent; and then simply averaging those daily values over the course of the month. The former method is the basis for the numerical algorithm in V2, while the latter describes V3. Both algorithms are valid and defensible ways to compute time-averaged data and are treated in greater detail in the Discussion section of this report.

Monthly averages represented as spatial plots can be made with two corresponding methods: 1) summing ice concentration data at each grid cell throughout a month, dividing by the number of days within a particular month to get average concentration for that grid cell, and then applying the 15 percent concentration threshold to the gridded field of average ice concentrations to yield a spatial map of average ice concentration and converting it to a binary ice/no ice extent map or 2) applying the 15 percent concentration threshold to the daily gridded field of concentration data, summing those gridded fields over a month, and then dividing the summed value for each grid cell by the number of days in the month to yield a spatial map of average ice concentration converting it to a binary ice/no ice extent map.

The former method is the basis for how monthly average spatial plots, or maps, are produced in both V2 and V3. While method 2) could be used, it produces a visualization of monthly average concentration and extent that is less likely to be representative of ice cover for the month in question than is the method of V2.

Reason for Changing the Monthly Averaging Algorithm

The Sea Ice Index has evolved over time, from a product that provided simple analyses showcasing spatial and time series plots on a monthly interval, to one that now includes numerical data for both monthly and daily temporal resolutions. Daily temporal resolution data was added in 2008, in response to requests from the user community. As time has gone on, changes in sea ice variability on sub-monthly timescales, which are the result of recent and rapid change in the Arctic, have raised questions relating to the ways in which monthly averages of the data can be constructed.

Florence Fetterer, the NOAA@NSIDC Program Manager, gives the following account of the reasoning behind the V2 method of calculating the monthly data values and the design of the product. Also see section 8.3 Product History in the Sea Ice Index user guide for further information.

> In 1999, Ken Knowles and I wanted to put out a representative map of sea ice every month built upon existing NASA gridded ice concentrations. Rather than publish daily images, we would post monthly average images. The primary reason was that daily gridded concentrations are not as reliable as are monthly averages, and changes in extent and concentration from day to day are not as significant as are trends in monthly extent and concentration.
>
> In constructing the monthly average concentration grids from daily grids, we had a choice to make. For each day, we could set any grid cell values with less than 15 percent concentration to zero, and then compute the monthly average value for each cell using the resulting monthly average grid to make the concentration and extent image. Alternatively, we could compute the monthly average value for each cell without zeroing out concentrations less than 15 percent first, and only after the monthly average grid was constructed in this way would cells with less than 15 percent be set to zero.
>
> We chose not to zero out daily concentrations less than 15 percent before constructing the monthly average. If the passive microwave algorithm estimates ice at any concentration, even less than 15 percent, there is a good chance ice is there. Validation studies have shown that it is much more likely for passive microwave to underestimate ice concentration than to overestimate it. Zeroing out cells less than 15 percent first and then constructing the monthly average concentration grid and image would compound this problem. If there was ice in a cell for any days in the month at any concentration, even less than 15 percent, we wanted to take that into account.
>
> In designing the Sea Ice Index, we were more concerned with representing spatial features of the ice field than with a temporal average number for extent and area over the course of a month. We did not anticipate that we would one day publish daily images and numbers, and that averaging the numbers would

> give users a different result than our method of deriving monthly average ice extent and area data values from the monthly average concentration grids. Sea ice variability over the course of a month was not as extreme as it often is now, and the inconsistency that the move to V3 addressees was not apparent.
>
> - Florence Fetterer, July 2017

The user community, which carefully fact-checks the monthly-average extent values presented in the popular Arctic Sea Ice News and Analysis blog against data distributed through the Sea Ice Index was not able to come up with the same values. The discrepancy stems from the different averaging methods, and user questions prompted internal discussions on how averages should be calculated. Discussions concluded with a decision to present monthly average data based on the averages of daily extent values because this method made most sense to users. The implications of the change are discussed further herein.

Data

The Sea Ice Index data are gridded onto polar stereographic projections that are true at 70 degrees north and south latitude to minimize distortion in the summer marginal ice zone. When computing monthly average extent and area values, the grid cell size must be taken into account. The nominal resolution of Sea Ice Index source data is 25 km x 25 km (625 sq km), such that the cells with center points closest to 70 degrees latitude have an area closest to 625 sq km. However, as latitude increases or decreases from 70 degrees, the area of each cell changes due to the stereographic mapping of the curved Earth onto a flat projection. For more information on this projection, see the NSIDC Polar Stereographic Projection and Grid web page.

For this analysis, the Sea Ice Index time series consists of two data sources, creating a monthly time series with a period of record spanning October 1978 to July 2017. The largest component of the time series comes from the *Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data* (NSIDC-0051) dataset, accounting for data between October 1978 and December 2015 as of October 2017. The most recent data come from the *Near-Real-Time DMSP SSMIS Daily Polar Gridded Sea Ice Concentrations* (NSIDC-0081) dataset, which has fewer quality control measures applied.

Methods: Algorithm Descriptions

Version 3 (New) Numerical Monthly Average Description

The Version 3 monthly average extent calculation is the average of all daily extent values in a given month. The daily extent is calculated using the 15 percent concentration cutoff for the concentration field; summing the area (size) of all grid cells containing ice at concentrations greater than or equal to 15 percent. The V3 monthly average sea ice area calculation is the average of all daily area values in a given month. The daily average area value is obtained through simple grid-cell by grid-cell arithmetic of multiplying the concentration by the size of the grid cell, for all grid cells that satisfy the 15 percent threshold.

Version 2 (Legacy) Numerical Monthly Average Description

The Version 2 monthly average extent calculation comes from the summation of daily concentration grids, followed by division of each cell's summed concentration by the number of days within a particular month. Then, the 15 percent concentration cutoff is applied to the

average concentration field to produce the binary ice/no ice extent field. For the average monthly *area* calculation, grid cells with ice concentration greater than or equal to 15 percent are multiplied by their concentration value.

Results

There are small differences between the monthly averages in V3 and the previous release of the monthly average time series product, Version 2 (V2). Most (~99%) of V3 monthly averaged sea ice extent data are smaller than V2 (Figure 1, left), while all V3 monthly averaged sea ice area data are larger than V2 (Figure 1, right), while. Figure 1 illustrates these results using the month of March, and is followed by a full discussion.

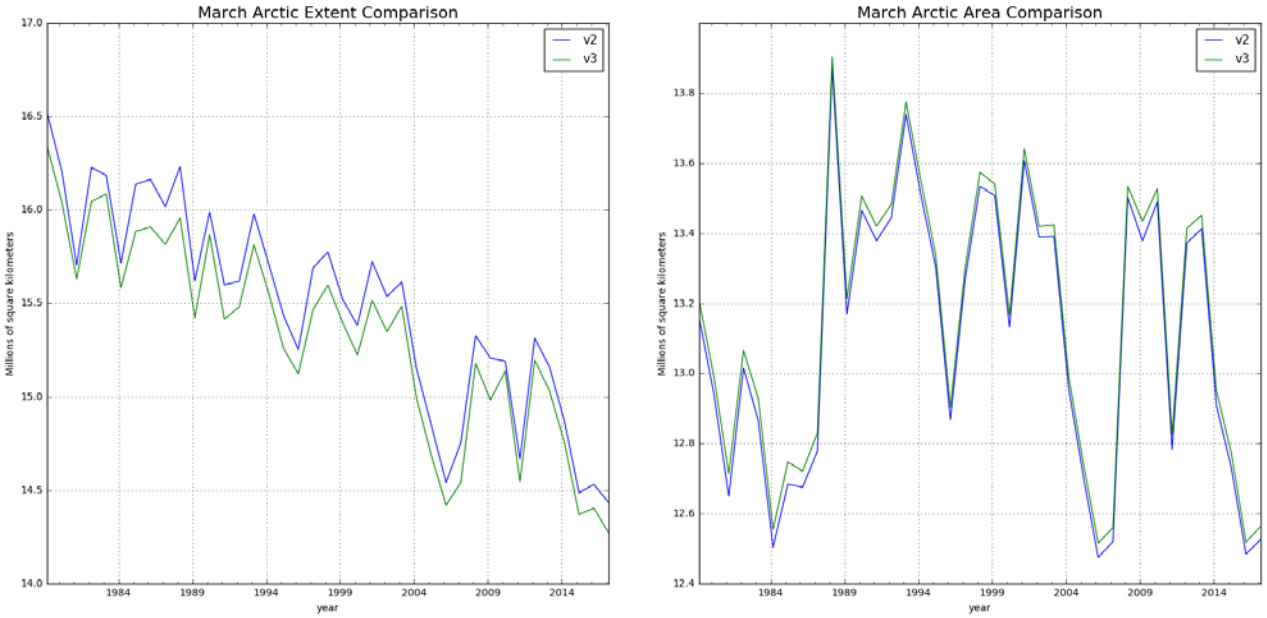

Figure 1. V3 and V2 Extent Values (left) and Area Values (right) for March from 1979 through 2017

Impact on Northern Hemisphere Data

Monthly Average Arctic Extent Values

Figure 2 shows differences in monthly average Arctic extent values over the entire times series between the two versions (V3 minus V2). Table 1 lists key statistical differences between V3 and V2. For all but three months (August 2002, August 2003, and August 2012), the V3 monthly average extent is lower than V2. The largest change is seen in October 2012 with a difference of -1.20. A list of the top ten differences can be seen in Table 2, and all are associated with the month of October. This is due to October being the beginning of the winter freeze-up, when ice is forming rapidly. See the When Monthly Averages from the Two Algorithms are Most Likely to Differ section for more information. For graphs of the differences for each month individually, see Appendix 1.

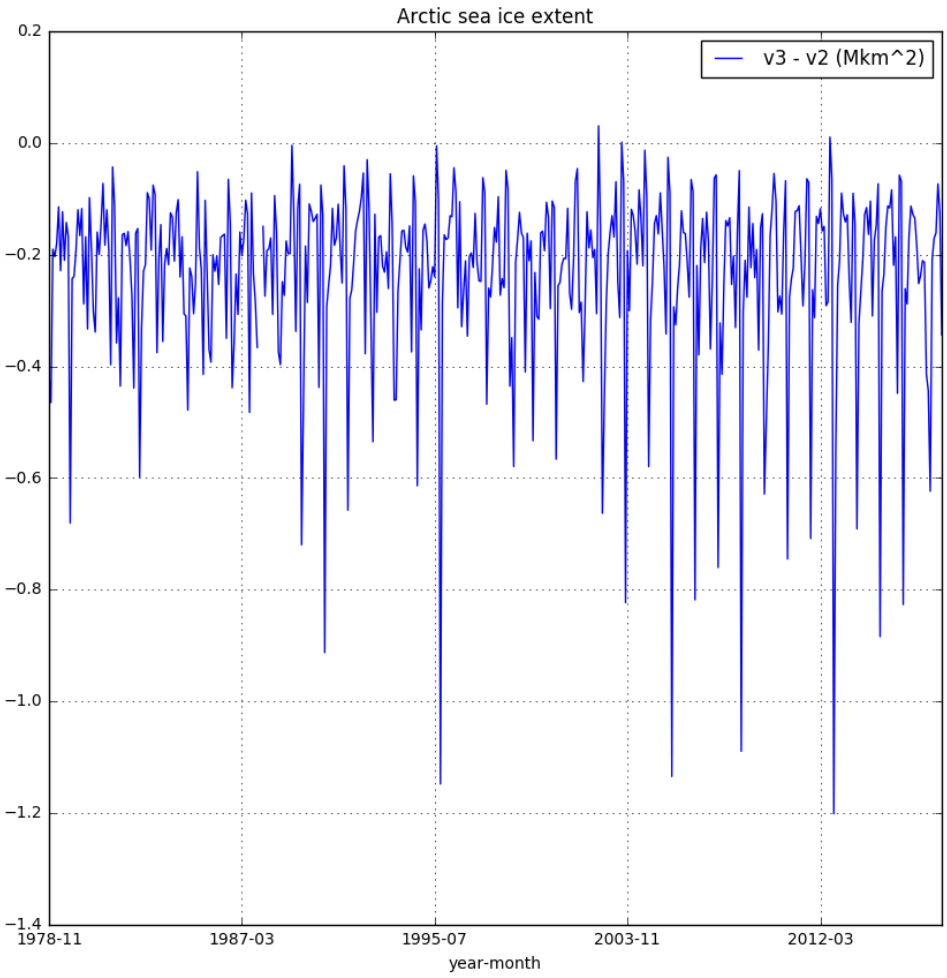

Figure 2. Arctic Monthly Extent Difference in Millions of sq km (V3 minus V2)

Table 1. Arctic Extent Difference Statistics (V3 minus V2). Statistics are derived from a sample size of N=462 months spanning Nov. 1979 –Jun. 2017.

Statistic	Value (Mil sq km)
Mean extent difference	-0.234
Standard deviation	0.168
Largest negative extent difference	-1.201
Largest positive extent difference	0.031

Table 2. 10 Largest Arctic Extent Differences in Millions of sq km

Year-Month (YYYY-MM)	Change (V3 – V2) (Mil sq km)
2012-10	-1.201
1995-10	-1.148
2005-10	-1.134
2008-10	-1.089
1990-10	-0.913
2014-10	-0.884
2015-10	-0.826
2003-10	-0.823
2006-10	-0.818
2007-10	-0.760

Changes in Minimum and Maximum Arctic Extent Rank

This section summarizes the changes in rank of sea ice extent during March and September, representing the Arctic maximum and minimum, respectively. For a complete list of all monthly rank changes, see Appendix 5 (Table 18 and Table 19).

For March in the Arctic, a lower rank number is synonymous with lower maximum extent. For example, the year with rank 1 (2017) means that the year had the lowest maximum monthly average extent over the span of the Sea Ice Index. The biggest changes in rank for March are for 1981, which went from 25th lowest to 29th lowest, and 2009, which went from 12th to 9th. The reigning lowest maximum in March 2017, at the time of this publication, did not change. Table 3 provides the complete list of Arctic rank changes for March.

For September in the Arctic, a lower rank number indicates smaller minimum extent. For example, the year with rank 1 (2012) means that the year had the lowest minimum monthly average extent over the whole Sea Ice Index record. The biggest change in rank for September is for 2016, which changed from 5th lowest to 3rd lowest. The reigning lowest minimum in September 2012, at the time of this publication, did not change. Table 3 provides the complete list of Arctic rank changes for September.

Table 3. Rank Changes for March and September for the Arctic through the Sea Ice Index Record

March			September		
YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank
2017-03	1	--	**2012-09**	1	--
2015-03	2	--	**2007-09**	2	--
2016-03	3	--	**2016-09**	3	↑ 2
2006-03	4	--	**2011-09**	4	↓ 1
2007-03	5	↑ 1	**2015-09**	5	↓ 1
2011-03	6	↓ 1	**2008-09**	6	--
2005-03	7	--	**2010-09**	7	--
2014-03	8	--	**2013-09**	8	↑ 1
2009-03	9	↑ 3	**2014-09**	9	↓ 1
2004-03	10	↓ 1	**2009-09**	10	--
2013-03	11	↓ 1	**2005-09**	11	--
1996-03	12	↑ 1	**2002-09**	12	↑ 1
2010-03	13	↓ 2	**2006-09**	13	↓ 1
2008-03	14	↑ 1	**2004-09**	14	--
2012-03	15	↓ 1	**1995-09**	15	↑ 0.5
2000-03	16	--	**2003-09**	16.5	↓ 1
1995-03	17	--	**1999-09**	16.5	↑ 1.5
2002-03	18	↑ 1	**1990-09**	18	↓ 1
1999-03	19	↓ 1	**2000-09**	19	--
1991-03	20.5	↓ 0.5	**1993-09**	20	--
1989-03	20.5	↑ 2	**1991-09**	21	--
1997-03	22	↑ 2	**1998-09**	22	--
2003-03	23.5	↓ 2.5	**1997-09**	23	↑ 0.5
1992-03	23.5	↓ 1	**1985-09**	24	↑ 1
2001-03	25	↑ 2.5	**2001-09**	25	↓ 1.5
1994-03	26	--	**1984-09**	26	↑ 1
1984-03	27	↑ 0.5	**1989-09**	27	↓ 1
1998-03	28	↑ 1	**1979-09**	28	--
1981-03	29	↓ 4	**1994-09**	29.5	↓ 0.5
1993-03	30	--	**1981-09**	29.5	↑ 0.5
1987-03	31	↑ 1	**1987-09**	31	↑ 1
1990-03	32	↓ 1	**1982-09**	32	↓ 1
1985-03	33	--	**1988-09**	33	--
1986-03	34	--	**1983-09**	34	--
1988-03	35	↑ 2.5	**1986-09**	35	--
1982-03	36.5	↑ 1	**1992-09**	36	--
1980-03	36.5	↓ 0.5	**1996-09**	37	↑ 1
1983-03	38	↓ 3	**1980-09**	38	↓ 1
1979-03	39	--			

Changes in Arctic Extent Trends

Table 4 shows the changes in the monthly Arctic extent trends due to the change in the algorithm. The largest trend difference is for October with 1.9 percent magnitude increase in slope from -7.4 to -9.3 percent per decade. This is due to the rapid freeze up occurring in October. For the months when the Arctic maximum and minimum occur (March and September, respectively), the trends are nearly identical. March remained the same and the September slope increased by 0.1 percent per decade.

Table 4. Changes in Arctic Monthly Extent Trends as of July 2017

Month	v2 (%/decade)	v3 (%/decade)	v3 - v2
Jan	-3.2	-3.2	0.0
Feb	-3.0	-3.0	0.0
Mar	-2.7	-2.7	0.0
Apr	-2.6	-2.5	0.1
May	-2.5	-2.6	-0.1
Jun	-3.7	-4.1	-0.4
Jul	-7.4	-7.4	0.0
Aug	-10.4	-10.5	-0.1
Sep	-13.3	-13.2	0.1
Oct	-7.4	-9.3	-1.9
Nov	-5.0	-5.1	-0.1
Dec	-3.4	-3.7	-0.3

Changes in the 1981-2010 Climatology Average Arctic Extents

Table 5 shows the changes in the 1981 to 2010 climatological average extents for the Arctic due to the change in monthly algorithms. The largest change is again seen in October, consistent with results for monthly ranking and extent trend.

Table 5. Changes in the Arctic 1981-2010 Climatology Average Extents in Millions of sq km

Month	V2	V3	V3 - V2	Month	V2	V3	V3 - V2
Jan	14.64	14.42	-0.22	**Jul**	9.78	9.47	-0.31
Feb	15.46	15.30	-0.16	**Aug**	7.28	7.20	-0.08
Mar	15.60	15.43	-0.17	**Sep**	6.54	6.41	-0.13
Apr	14.85	14.69	-0.16	**Oct**	8.94	8.35	-0.59
May	13.45	13.29	-0.16	**Nov**	11.03	10.70	-0.33
Jun	11.96	11.76	-0.20	**Dec**	13.13	12.84	-0.29

Monthly Average Arctic Area Values

The changes in the Arctic average monthly area values are shown in Figure 3. All monthly average sea ice area values calculated with the V3 algorithm are larger than those calculated with the V2 algorithm. For further discussion, see Why V3 Gives Lower Average Extents and Higher Average Areas than V2 in this document. Table 6 lists key statistical differences of the sea ice area values between V3 and V2. The spike of 0.374 million sq km seen in Figure 3 occurs for August 1987. See the Large Outlier in the Arctic Sea Ice Index V3 Minus V2 Sea Ice Area Difference Series section for more information. For graphs of the differences for each month individually, see Appendix 2.

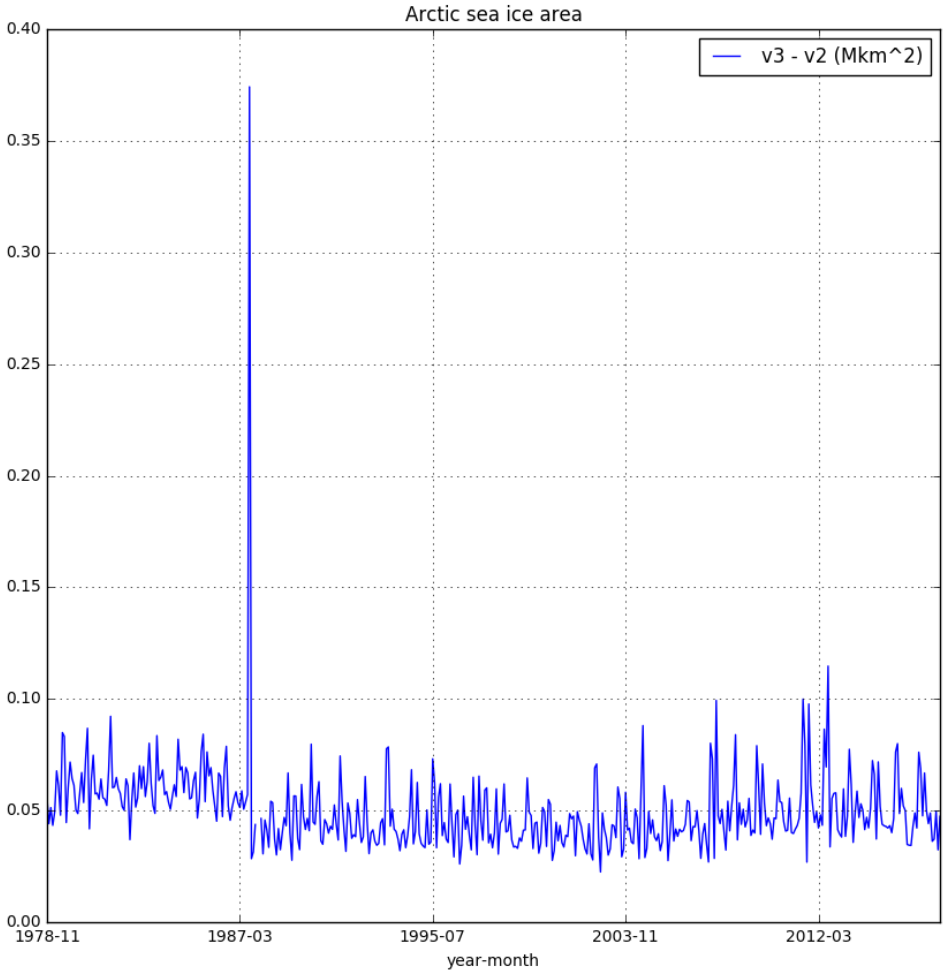

Figure 3. Arctic Monthly Area Differences in Millions of sq km (V3 minus V2)

Table 6. Arctic Area Difference Statistics (V3 minus V2). Statistics are derived from a sample size of N=462 months spanning Nov. 1979 –Jun. 2017.

Statistic	**Value (Mil sq km)**
Mean area difference	0.051
Standard deviation	0.022
Minimum area difference	0.022
Maximum area difference	0.374

Impact on Southern Hemisphere Data

Monthly Average Antarctic Extent Values

Figure 4 shows all the changes in the average monthly Antarctic extent values between the two versions (V3 minus V2). Note that changes are generally larger in the Antarctic because the Antarctic seasonal changes are larger than the in Arctic, particularly during the growth and melt season. Table 7 lists key statistical differences between V3 and V2. For all but five months (February 1979, 1983, 1985, 2009, and 2015), the V3 monthly average extent is lower than V2. The largest change is December 1981 with a difference of -1.27. A list of the top ten differences are listed in Table 8, all occurring in December. This is due to December being within the summer melt season in the Antarctic, when ice is receding rapidly. See the When Monthly Averages from the Two Algorithms are Most Likely to Differ section for more information. For graphs of the differences for each month individually, see Appendix 3.

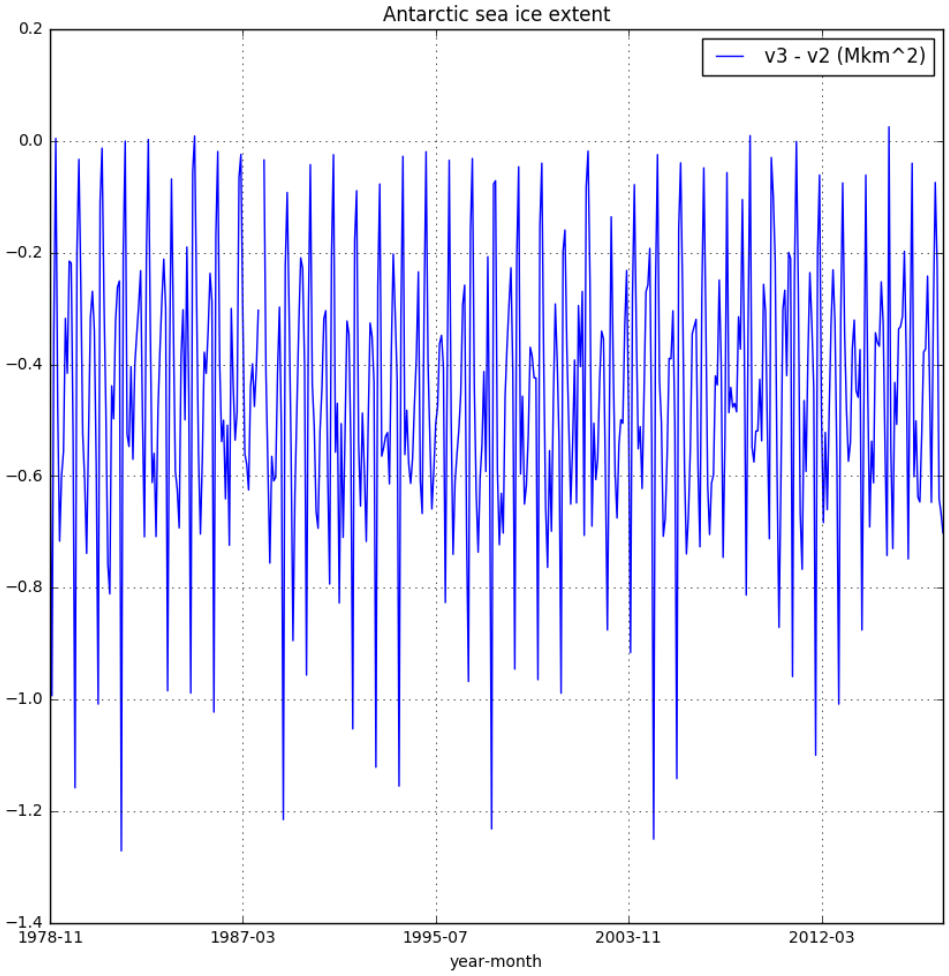

Figure 4. Antarctic Monthly Extent Differences in Millions of sq km (V3 minus V2)

Table 7. Antarctic Extent Difference Statistics (V3 minus V2). Statistics are derived from a sample size of N=462 months spanning Nov. 1979 –Jun. 2017.

Statistic	Value (Mil sq km)
Mean extent difference	-0.455
Standard deviation	0.241
Largest negative extent difference	-1.270
Largest positive extent difference	0.025

Table 8. 10 Largest Antarctic Extent Differences in Millions of sq km

Year-Month (YYYY-MM)	Change (V3 minus V2) (Mil sq km)
1981-12	-1.271
2004-12	-1.250
1997-12	-1.231
1988-12	-1.215
1979-12	-1.158
1993-12	-1.155
2005-12	-1.141
1992-12	-1.121
2011-12	-1.100
1991-12	-1.052

Changes in Minimum and Maximum Antarctic Extent Rank

This section summarizes the changes in rank of March and September, the minimum and maximum extent for the Antarctic, respectively. For a complete list of all monthly rank changes, see Appendix 5 (Table 20 and Table 21).

For March in the Antarctic, a lower rank number corresponds to a lower minimum extent. For example, the year with rank 1 (2017) indicates that the year had the lowest minimum monthly average extent over the Sea Ice Index record. The biggest change in rank for March occurred for 1987, which went from 20th lowest to 25th lowest for a two-way tie with 1998. The reigning minimum, at the time of this report publication, is 2017 and did not change. Table 9 provides the complete list of Antarctic rank changes for March.

For September in the Antarctic, a lower rank number corresponds to a lower maximum extent. For example, the year with rank 1 (1986) indicates that the year had the lowest maximum monthly average extent over the Sea Ice Index record. The biggest changes in rank for September are 1997, which went from 29th lowest to 20th lowest for a two-way tie with 1981; and 1979, which went from 4th to 10th. The reigning lowest maximum, at the time of this report publication, occurred in 1986 and did not change. Table 9 provides the complete list of Antarctic rank changes for September.

Table 9. Changes in rankings for March and September for the Antarctic through the Sea Ice Index Record

March			September		
YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank
2017-03	1	--	**month**		
2006-03	2	--	**1986-09**	1	--
1980-03	3	--	**2002-09**	2	--
2011-03	4	--	**2016-09**	3	↑ 2
1981-03	5	--	**1989-09**	4	↓ 1
1997-03	6	--	**2008-09**	5.5	↑ 3.5
1992-03	7	↑ 5	**1992-09**	5.5	↑ 1
1984-03	8	↓ 1	**2001-09**	7.5	↓ 1
1993-03	9	↑ 5	**1984-09**	7.5	↑ 5.5
1986-03	10	↑ 1	**1990-09**	9	↓ 1
1985-03	11	↓ 2.5	**1979-09**	10	↓ 6
2002-03	12	↓ 3.5	**1987-09**	11	↑ 3.5
1991-03	13	↑ 4	**2003-09**	12	↓ 1.5
2007-03	14	↓ 1	**1991-09**	13.5	↓ 3
2010-03	15	↓ 5	**1988-09**	13.5	↑ 1
1989-03	16	↓ 1	**1982-09**	15	↓ 3
1990-03	17.5	↑ 1.5	**1995-09**	16	--
1988-03	17.5	↑ 0.5	**2015-09**	17	↑ 1
1999-03	19	↑ 5	**1993-09**	18	↓ 1
1979-03	20	↑ 1	**1983-09**	19	--
1983-03	21	↓ 5	**1981-09**	20.5	--
2016-03	22	↑ 3	**1997-09**	20.5	↑ 9
2005-03	23	--	**1994-09**	22	↑ 1
2000-03	24	↓ 2	**1996-09**	23	↓ 2.5
1998-03	25.5	↑ 1.5	**1985-09**	24.5	↓ 0.5
1987-03	25.5	↓ 5.5	**1999-09**	24.5	↑ 0.5
1996-03	27	↓ 1	**2011-09**	26	↓ 4
1982-03	28	--	**2005-09**	27.5	↑ 2
2003-03	29.5	↓ 0.5	**2010-09**	27.5	↑ 5
2009-03	29.5	↑ 1.5	**1980-09**	29	↓ 3
2004-03	31	↓ 1	**2007-09**	30	↑ 4
1994-03	32.5	↑ 2.5	**2000-09**	31	↓ 3.5
2012-03	32.5	↑ 0.5	**1998-09**	32	↓ 1
1995-03	34	↓ 2	**2004-09**	33	↓ 5.5
2001-03	35	↓ 1	**2009-09**	34	↓ 1.5
2014-03	36	--	**2006-09**	35	--
2015-03	37	↑ 1	**2012-09**	36	--
2013-03	38	↓ 1	**2013-09**	37	--
2008-03	39	--	**2014-09**	38	--

Changes in Monthly Antarctic Extent Trends

Table 10 shows the changes in the monthly Antarctic trends resulting from the change in the algorithm. The largest changes in the trends are for January and December with a change in value from 3.5 to 2.7 percent per decade and 1.2 to 1.9, respectively. This is due to the rapid melting occurring in December and January in the Antarctic. For the months when the Antarctic maximum and minimum occur (September and March, respectively), the trends did not change significantly. September remained the same and March increased by 0.2 percent per decade.

Table 10. Changes in Antarctic Monthly Extent Trends as of July 2017

Month	v2 (%/decade)	v3 (%/decade)	v3 - v2
Jan	3.5	2.7	-0.8
Feb	3.0	2.7	-0.3
Mar	3.3	3.5	0.2
Apr	2.9	3.0	0.1
May	2.0	2.2	0.2
Jun	1.3	1.5	0.2
Jul	1.2	1.3	0.1
Aug	0.8	1.0	0.2
Sep	0.9	0.9	0.0
Oct	0.9	0.9	0.0
Nov	0.4	0.4	0.0
Dec	1.2	1.9	0.7

Changes in 1981-2010 Climatology Antarctic Extent Averages

Table 11 shows the changes in the 1981 to 2010 climatological average for the Antarctic due to the change in monthly algorithms. The largest change in December is consistent with other results for Antarctic monthly averages.

Table 11. Changes in 1981-2010 Climatology for the Antarctic in millions of sq km

Month	v2	v3	v3 - v2	Month	v2	v3	v3 - v2
Jan	5.23	5.00	-0.23	**Jul**	16.47	15.96	-0.51
Feb	3.11	3.07	-0.04	**Aug**	18.16	17.72	-0.44
Mar	4.44	4.03	-0.41	**Sep**	18.83	18.49	-0.34
Apr	7.42	6.85	-0.57	**Oct**	18.38	18.10	-0.28
May	10.81	10.16	-0.65	**Nov**	16.35	15.90	-0.45
Jun	13.96	13.35	-0.61	**Dec**	11.35	10.41	-0.94

Monthly Average Antarctic Area Values

The changes in the Antarctic average monthly area values between the two versions are shown in Figure 5 (V3 minus V2). All V3 area values are greater than the V2 values. For further discussion, see Why V3 Gives Lower Average Extents and Higher Average Areas than V2. Table 12 lists key statistical differences between V3 and V2. For graphs of the differences for each month individually, see Appendix 4.

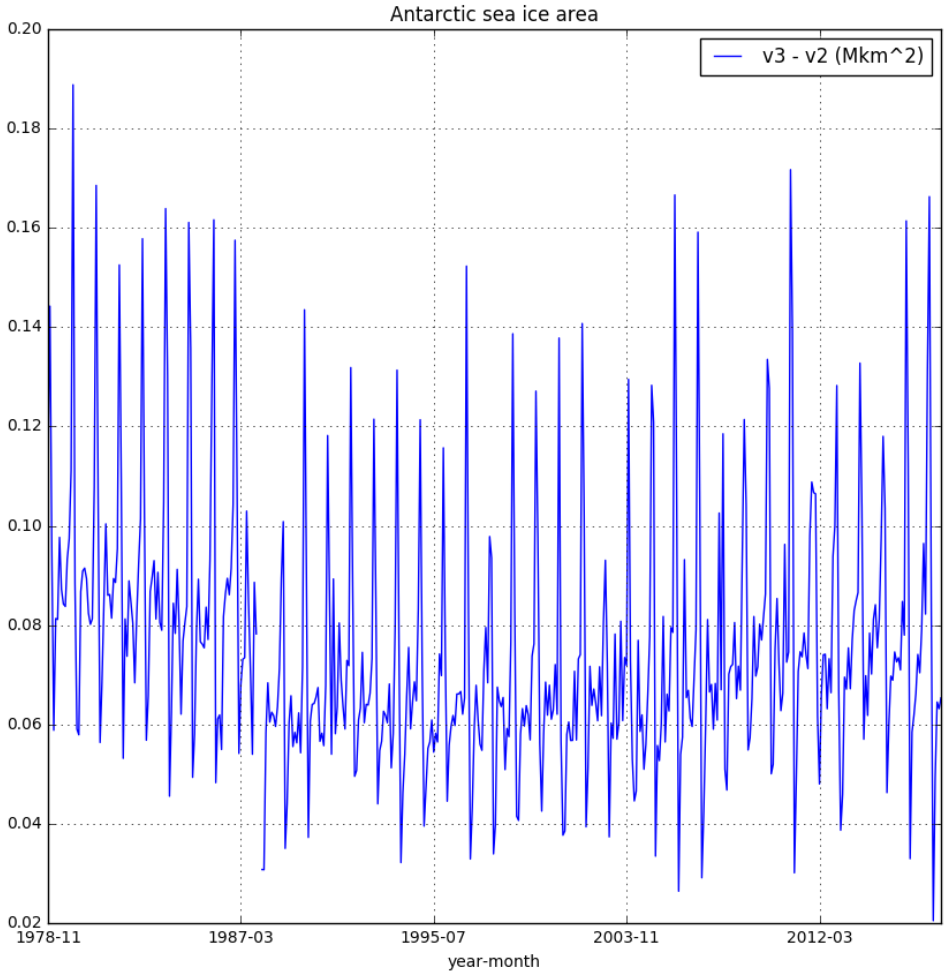

Figure 5. Antarctic Monthly Area Differences in Millions of sq km (V3 minus V2)

Table 12. Antarctic Area Difference Statistics (V3 minus V2). Statistics are derived from a sample size of N=462 months spanning Nov. 1979 –Jun. 2017.

Statistic	**Value (Mil sq km)**
Mean area difference	0.076
Standard deviation	0.027
Minimum area difference	0.020
Maximum area difference	0.189

Discussion

Broader Questions Answered by Two Versions of the Numerical Averaging Algorithm

Both algorithms provide useful information for answering specific questions about time-averaged sea ice extent. The Version 2 algorithm, based upon a monthly average concentration field is more appropriate in answering the question:

"How much ocean was covered with an average concentration greater than 15 percent?"

The Version 3 algorithm, however, is better suited at answering the question:

"On average, how much ocean was covered each day by sea ice in concentrations greater than or equal to 15 percent?"

The key distinction between the two methodologies is that Version 3 is able to capture the temporal variation in extent values throughout a given month, while Version 2 is more appropriate for a spatial representation of ice extent.

A Thought Experiment on the V2 Algorithm

With pronounced changes in the ice cover over short periods of time, especially during the months where peak freeze-up and peak melt occur, the spatial and temporal average of sea ice concentration can be conflated in the Version 2 algorithm and lead to confusion amongst the Sea Ice Index user community. To better explain how the Version 2 algorithm handles ice extent on a cell-by-cell basis and how the V3 method differs, consider the following case typical of the marginal ice zone where both thermodynamic and dynamic forces can have significant influence on the ice.

Imagine a 3 km by 3 km region of ocean divided into nine 1-sq-km cells. For 20 days in a 30-day month, six cells have concentration values of 50 percent and three cells have concentration of 5 percent (Figure 6, left). On the remaining 10 days, six cells have a concentration of zero percent and the last three cells have concentration of 20 percent (Figure 6, right).

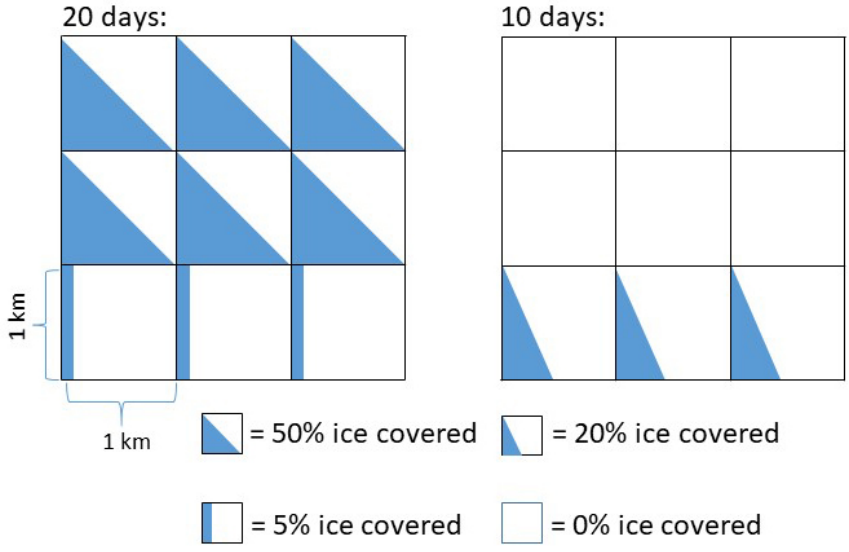

Figure 6. Version 2 Averaging Method. The top six cells correspond to Category 2 (Magenta) and the bottom three cells correspond to Category 4 (Gray) in Table 13.

Computing the V2 extent and area values begins with creating an average concentration grid for each grid cell over the month. For the top six grid cells that are 50 percent covered for 20 days and zero percent for 10 days in Figure 6, the average for each cell is the following:

$$\frac{(50\% * 20\ days) + (0\% * 10\ days)}{30\ days} = 33.33\% \qquad Equation\ 1$$

For the other three grid cells with 20 days of 5 percent and 10 days of 20 percent in Figure 6, the average for each cell is the following:

$$\frac{(5\% * 20\ days) + (20\% * 10\ days)}{30\ days} = 10\% \qquad Equation\ 2$$

Figure 7 provides a graphical display of Equations 1 and 2 and the average concentration grid, representing the top 6 and bottom 3 grid cells, respectively.

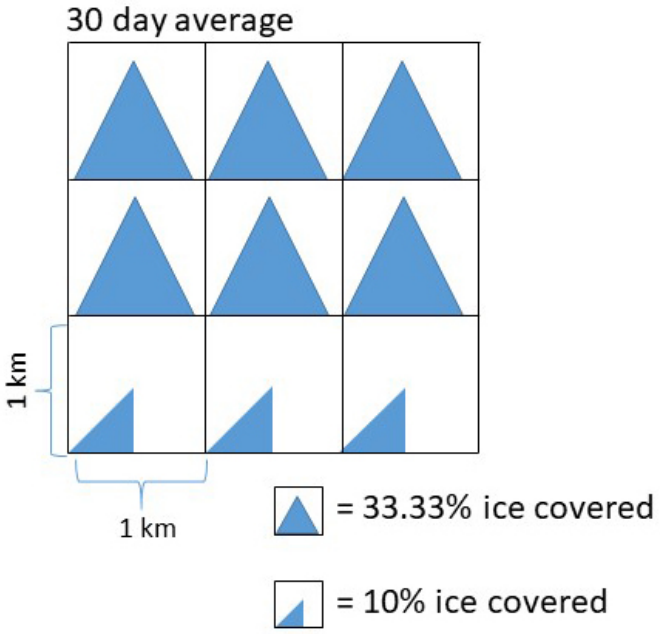

Figure 7. Monthly Average Concentration Grid from Version 2 Method

Using the average concentration grid from Figure 7, the extent is calculated by applying the 15 percent concentration cutoff. Therefore, the monthly extent for this example would be 6 sq km because the top six cells contain an average ice concentration that is greater than 15 percent and each cell is 1 sq km. The other three cells are not incorporated into the extent because they contain an average ice concentration below the qualifying threshold.

$$\frac{6\ cells * (100\% * 1\ sq\ km) + 3\ cells * (0\% * 1\ sq\ km)}{100\%} = 6\ sq\ km \qquad Equation\ 3$$

Next, the monthly area value is calculated where the concentration of each grid cell is taken into account, again treating anything less than 15 percent as zero percent. The area calculation would be the following:

$$\frac{6\ cells * (33.33\% * 1\ sq\ km) + 3\ cells * (0\% * 1\ sq\ km)}{100\%} = 2\ sq\ km \qquad Equation\ 4$$

Also note that the area is always less than extent because extent is the entire expanse within the ice edge and includes the Arctic pole hole, while area calculations take ice concentration within that edge into account and exclude the Arctic pole hole. The pole hole is excluded for area calculations because the concentration cannot be known in this unmeasured region. For a complete discussion on the difference between extent and area, see the Frequently Asked Questions on the Arctic Sea Ice Web page: What is the difference between sea ice area and extent?

How Version 3 Differs from Version 2 in this Example

Using the example from above (Figure 6) with the V3 method, a simple temporal average over the 30-day month is done; that is, the grid cells that are 15 percent or greater concentration are summed and then divided by 30. Thus, for 20 days, six cells contribute to the average; and for 10 days, three cells contribute to the average. This yields a 5 sq km average extent:

$$\frac{20\ days * (6\ cells * 1\ sq\ km) + 10\ days * (3\ cells * 1\ sq\ km)}{30\ days} = 5\ sq\ km \qquad Equation\ 5$$

Note that this is lower than the V2 method that returned an extent value of 6 sq km. This is to be expected because V2 allows any value of concentration in a grid cell on every day in a month to contribute to the average concentration, and therefore to extent, if the average concentration for that cell is greater than or equal to 15 percent. V3 only adds a grid cell's area to the extent on a given day if that cell's concentration is greater than or equal to 15 percent on that day. As a result of this difference, V2 extents are biased high relative to those from V3. Figure 1 (left) illustrates this. For further information, see the discussion Why V3 Gives Lower Average Extents and Higher Average Areas than V2 in this document.

The monthly area number is then calculated in a similar way where each daily area value is simply averaged together, but the concentration of the grid cell is taken into account where any grid cell that is less than 15 percent concentration is considered 0 percent concentration and any grid cell greater than 15 percent uses that percentage to multiply the grid cell size.

$$\frac{20\ days * (50\% * 6\ sq\ km) + 10\ days * (20\% * 3\ sq\ km)}{30\ days * 100\%} = 2.2\ sq\ km \qquad Equation\ 6$$

Note that this is higher than the V2 method that returned an area value of 2 sq km. This is as observed in the data; V3 areas are biased high relative to those from V2. Figure 1 (right) illustrates this. The discussion Why V3 Gives Lower Average Extents and Higher Average Areas than V2 in this document explains this bias.

Thus, the Version 2 algorithm is more sensitive to low values of ice concentration and to including expanses of ocean in the extent/area calculation where sea ice existed in high concentration for very short periods of time. This leads to, in most cases, to extent values being higher than V3's method of temporal averaging of daily extent values and area values being lower.

It is important to note that this case, while illustrative, is not representative of all cases. Even if the daily ice area and extent for the three by three grid remains the same, different spatial arrangements of ice over different time periods will give different results. In addition, in this example, all grid cells are the same size; however, in actuality, they are different due to the polar stereographic projection. The remainder of this report is a more in-depth analysis of how grid cells near the ice edge are likely to contribute to V2 and V3 differences.

When Monthly Averages from the Two Algorithms are Most Likely to Differ

There is a seasonality to V2 and V3 differences. In both the Arctic and Antarctic, the largest difference in monthly averages occur in the months when changes in the ice cover occur rapidly. In the Arctic, freeze up during the month of October is associated with the most dynamic changes in ice extent, and therefore the largest differences in V3 and V2 monthly averages. In the Antarctic, the quickly melting seasonal ice during the months of December and January is accompanied by the largest differences in V3 and V2 extent values. Overall, the southern hemisphere's ice-ocean-atmosphere system produces a more dynamic ice edge such that V3 minus V2 differences (Figure 4) are larger than the Arctic (Figure 2) on average.

As shown in the V2 thought experiment, short duration spatial features in the ice extent can be captured through the averaging of ice in high concentration when it is present for even short periods of time. Expanses of grid cells where ice was present in average concentrations greater than 15 percent are counted. In contrast, the Version 3 algorithm does not produce a monthly average concentration value for individual grid cells. Thus, the average values from V3 are more sensitive to movement and evolution of the ice edge throughout the month.

Large Outlier in the Arctic Sea Ice Index V3 Minus V2 Sea Ice Area Difference Series

The passive microwave sensors are unable to image an area around the North Pole. This area, called the Arctic pole hole, is determined by sensor swath width. Both algorithms handle the missing data in the same way: in calculating ice extent, algorithms assume the pole hole is covered by ice at greater than 15 percent, and in calculating ice area, both simply do not include the area of the pole hole. See section 4.2.3 Arctic Pole Hole in the Sea Ice index user guide for more information.

The large spike in the difference series of Northern Hemisphere ice area aligns with August of 1987 (Figure 3), a month for which V3 calculates a much higher area value than does V2. On August 21, the sensor changed from the SMMR instrument to the SSM/I instrument. SMMR and SSM/I have different swath widths. With the SSM/I sensor offering more coverage of the Arctic, the pole hole becomes smaller, and sea ice area on each of the final 11 days of the month is far greater than the values from the first 20 days, leading to a jump in V3 ice area. In V2, this jump was avoided through the use of the monthly Goddard Space Flight Center (GSFC) data (NSIDC-0051), which incorporated the larger SMMR hole for full month. V3, however, uses the daily GSFC data, which uses both the larger SMMR hole for the first 20 days and then the smaller SSM/I hole for the final 11 days.

Because the average value reflects the artificial jump in area over the course of the month, the August 1987 sea ice area value has been removed from the V3 Sea Ice Index record. The area

value from the V3 method is 4.9 million sq km, and the area value from the V2 averaging method was 4.5 million sq km.

Why V3 Gives Lower Average Extents and Higher Average Areas than V2

To arrive at a single value for monthly average hemisphere-wide ice extent and ice-covered area, the contribution to extent or ice-covered area from each grid cell is summed and divided by the number of days in the month. The steps differ from V2 to V3. These differences account for V3 ice extent always being less than V2 extent, with the exception of three months for the Arctic and five months for the Antarctic out of a total of 462 months. Conversely, monthly average ice area is greater in V3 than in V2, with no exceptions.

These V3/V2 differences are the result of the 15 percent threshold value that is applied as a cut off for the lowest allowed ice concentration. For V3, this step is applied to the daily concentration fields to arrive at that day's extent and area number before monthly averages are calculated by summing those numbers and dividing by days in the month. For V2, the 15 percent threshold is applied after the monthly average concentration field is calculated, and then area and extent is arrived at for that single field.

An evaluation from both the Arctic sea ice melt season (July) and growth season (October) helps to isolate the differences in the two methods of calculation and elucidate the changes in both extent and area. July 2011 and October 2012 were chosen as case studies since the two months are associated with the largest absolute difference in the V3 minus V2 series.

For V2, the 15 percent cutoff means a grid cell will add its size in sq km to ice extent if the average concentration in that grid cell is greater than 15 percent over the course of the month. Every day in the month contributes a concentration value to the tally, which is then divided by the number of days in the month. If the result is greater than 15 percent for that cell, the size of the cell contributes to extent; and the concentration within the cell contributes to the ice-covered area for the hemisphere-wide monthly averages. For V3, on a given day, only grid cells that have a concentration greater than 15 percent contribute ice extent or area to the month's total.

Each grid cell delimits a region on the earth's surface defined by the projection and other parameters. Each grid cell covers about 25 km x 25 km, but this varies with latitude. See the Background section for more information. For each cell, on any given day within a month, the cell may or may not contribute to the ice extent and area summation for the days in the month. What a single cell contributes in sum over all the days in the month can be greater in V3 than in V2, can be the same, or can be less.

At the grid cell level, there are four categories that can occur when comparing V3 and V2 area and extent averages:

1. V3 and V2 area and extent are equal
2. V3 and V2 area are equal but V3 extent is less than V2 extent
3. V3 area is less than V2 area and V3 extent is less than V2 extent
4. V3 area is greater than V2 area and V3 extent is greater than V2 extent

Each of these grid cell categories is determined by a five sets of conditions of the sea ice. The conditions along with their associated category are explained below and summarized in Table 13:

- **1a:** The mean sea ice concentration for the grid cell is less than 15 percent for the entire month, and all concentrations for each day of the month are zero or less than 15 percent. These cells occur in areas corresponding primarily to sea ice free ocean. These conditions result in V3 and V2 extent and area contributions of the cell to be equivalent.
- **1b**: The mean concentration for the grid cell is at or above 15 percent for the entire month, and all concentrations for each day of the month are 15 percent or greater. These cells correspond primarily to grid cells with high concentrations, far inside the ice edge. These conditions result in V3 and V2 extent and area contributions of the cell to be equivalent.
- **2**: The mean concentration for the grid cell is at or above 15 percent for the month, and one or more days over the month measured at a concentration equal to zero, and one or more days measured at a concentration greater than 15 percent, but concentrations of the grid cell were never between zero and 15 percent for any day in the month. This corresponds to periods of time when ice concentration can quickly change. For example, ice in high concentration being advected into adjacent ice free ocean, rapid melt out, or rapid freeze. These conditions result in V3 Area being equal V2 Area, while V3 Extent is less than V2 Extent.
- **3**: The mean concentration for the grid cell is at or above 15 percent for the month, and one or more days over the month measured a concentration greater than zero. This corresponds to more subtle and gradual changes in the sea-ice cover, than the category 2. These conditions result in both extent and area in V3 being smaller than V2.
- **4**: The mean concentration for the grid cell is less than 15 percent for the month, and one or more cells can be anywhere from zero to 100 percent concentration. This corresponds to areas near the ice edge where ice from cells in concentrations greater than 15 percent is passed into the V3 algorithm, but the ice is not persistent enough in a given cell to appear in the monthly average concentration field used by V2 in concentrations exceeding the 15 percent threshold. These conditions result in extent and area in V3 being larger than V2.

Table 13. Grid Cell Categories and the Conditions that Determine them

Categories			**Conditions**			
				Number of days where the concentration % of the grid cell (X) is...		
Category #	Area	Extent	Mean Concentration %	X = 0	0 < X < 15	15 ≤ X ≤ 100
1a	V3 = V2	V3 = V2	< 15	All		0
1b	V3 = V2	V3 = V2	≥ 15	0		All
2	V3 = V2	V3 < V2	≥ 15	1 or more	0	1 or more
3	V3 < V2	V3 < V2	≥15	0 or more	1 or more	1 or more
4	V3 > V2	V3 > V2	< 15	1 or more		1 or more

Figure 8 illustrates these cases. Each point on the scatterplot is the difference in the contribution to that month's extent and area given by an individual cell processed by V3 and by V2. Table 13 explains the color-coding.

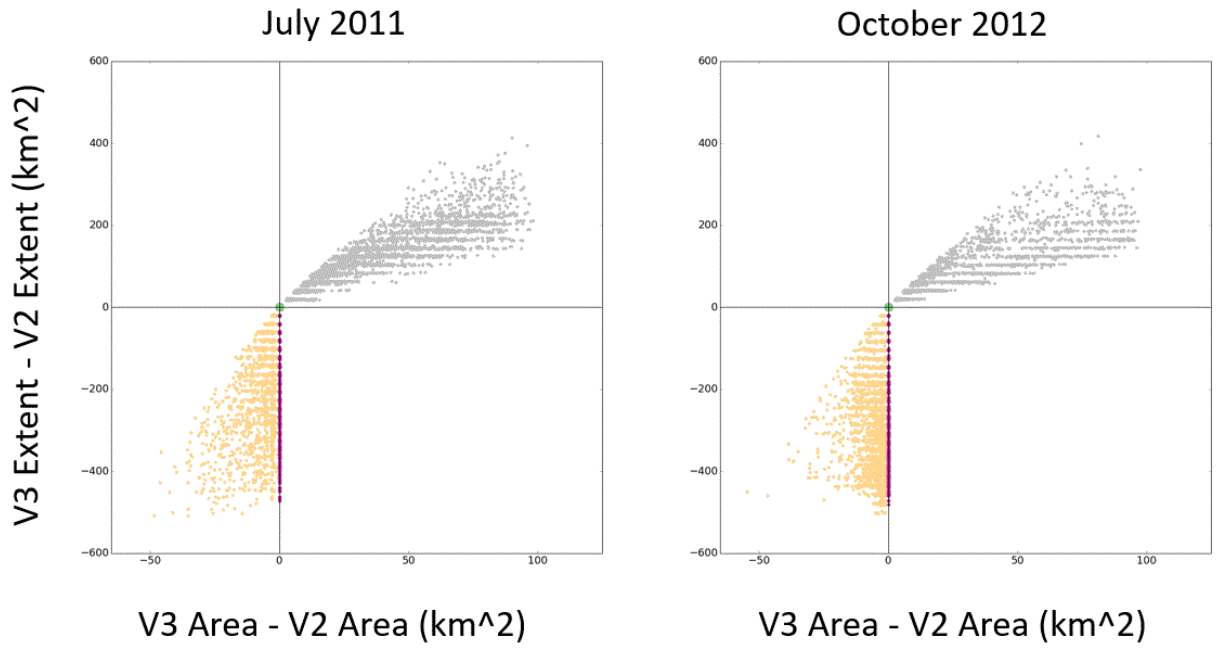

Figure 8. Differences (V3 minus V2) in monthly average area and extent contributed by individual cells. Each point represents one grid cell within the Arctic grid. Refer to Table 13 for description of the color coding. Green cells are all on (0,0) where V2 and V3 extent and area contributions are equal. Magenta cells are on the negative portion of the extent axis where contributions to area are the same in V3 and V2, while contributions to V3 extent are less than V2 extent. Yellow cells are in the bottom left quadrant where cells contribute less area and extent in V3 than in V2. Grey cells are in the upper right quadrant where cells contribute more area and extent in V3 than in V2.

The contribution to monthly average extent for a particular cell is constrained to the size in sq km of that cell. There are only certain values extent can have, which is why the extent values appear to be binned in horizontal rows. Area values, determined by the concentration of ice in a cell, can take on a range limited only by precision of the calculation; so the V3 minus V2 area differences can be at a point anywhere along the horizontal area difference axis.

No cells occupy the upper left quadrant of the scatterplots because if area given by V3 is less than that from V2, extent given by V3 cannot exceed that from V2. Most cells occupy (0,0) because the area and extent they contribute is the same for V2 and V3. The scatter of points in the upper right quadrant are cells that contribute more to area and extent in V3 than in V2, those in the lower left are cells that contribute less to area and extent in V3 than in V2. No cells occupy the lower right quadrant, where area is greater in V3 while extent is less, and yet this is the result we see for the hemisphere-wide monthly averages. Even though no single cell can give this result, the vector summation of all the points in the scatterplot lands in this quadrant.

Figure 9 ranks the differences in the contribution of each cell in order to illustrate this more clearly. The yellow and magenta area under the curve of negative V3 minus V2 extent

differences outweighs the grey area of positive V3 minus V2 extent differences in a) and b); the extent is lower when estimated using V3. The grey area under the curve of positive V3 minus V2 area differences outweighs the yellow area of negative V3 minus V2 area differences in c) and d); the area is higher when estimated using V3.

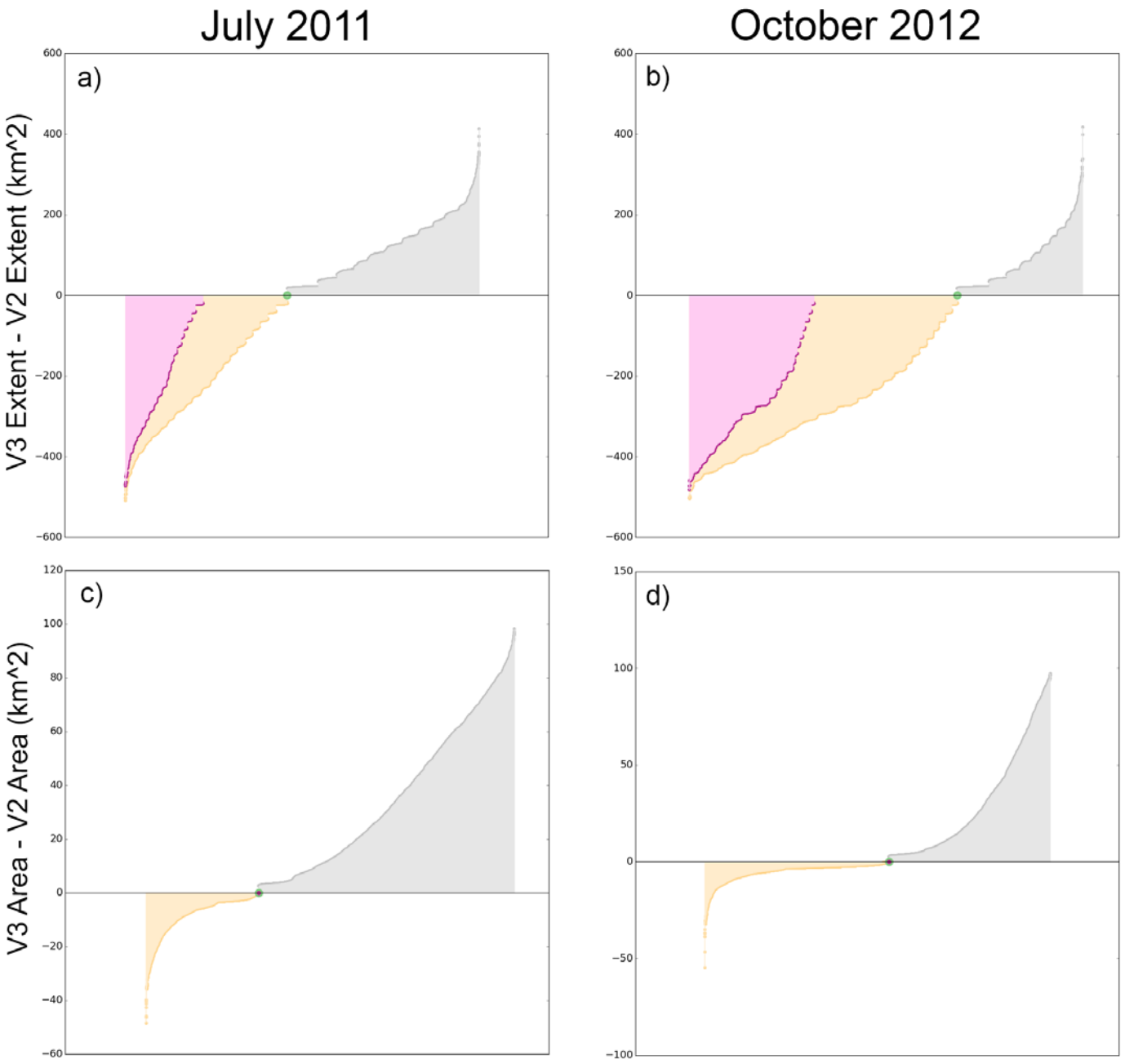

Figure 9. Differences (V3 minus V2) of the contribution of individual cells to July 2011 extent (a) and area (c), and to October 2012 extent (b) and area (d). These values have been sorted from lowest to highest to make visualizing the contributions of each category easier to interpret. Categories are listed in Table 13. Green cells are all on the zero line in (a), (b), (c), and (d). The magenta cells are all on the zero line in (c) and (d). This is consistent with where these colors fall in Figure 8 as well.

As noted, this V3/V2 difference is due to the way grid cell concentration values less than 15 percent are handled. Figure 10 shows where cells contributing to the V3/V2 difference in July 2011 and October 2012 are located. There are a set of five conditions into which a grid cell can

fall resulting in four categories. A grid cell falls into each category if and only if it satisfies one of the five sets of conditions. Categories, properties, and color-coding for all the figures are listed in Table 13.

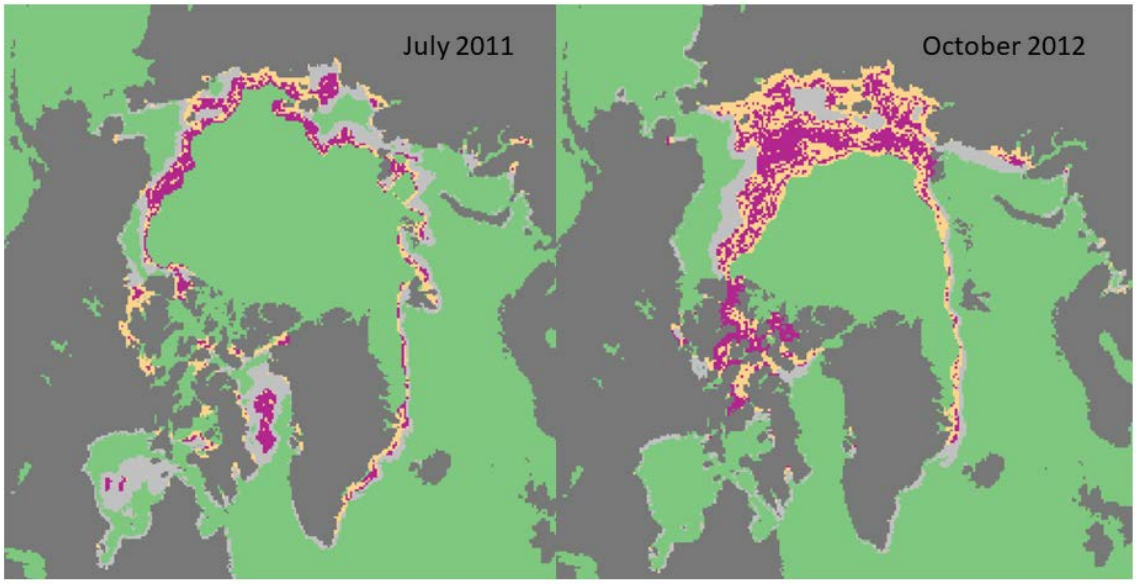

Figure 10. Cells are colored according to what quadrant of the scatterplots in Figure 8 they occupy. Refer also to Table 13.

Conclusion

This analysis of Sea Ice Index Version 3 details differences in how monthly average values of extent and area are calculated and how the resulting values differ from those published when Version 2 was in operation. Version 3 average monthly extents are typically slightly lower and average monthly areas are slightly higher. Monthly extent trends in V2 and V3 do not differ significantly, so conclusions about the nature of changing sea ice are consistent between V2 and V3.

The change was made so that the monthly average values would match the same values one would obtain by averaging the daily hemisphere-wide values over the course of a month. In V2, values did not match, because the average monthly concentration was calculated individually on a grid-cell by grid-cell basis to produce a monthly image, and that image was the basis for the monthly average values.

In summary, V2 and V3 give different values for monthly average hemisphere-wide extent and area. Neither one is more correct, they are simply different ways of representing a monthly average using passive microwave-derived sea ice cover.

The method of V2 is still used to produce the monthly average ice concentration and extent images. The concentration and extent images are a reasonable spatial representation of the average ice concentration field for the month that does not omit contributions from cells with less than 15 percent on days in the month.

The method of V3 gives a hemisphere-wide monthly average value that can also be created by summing each day's value and dividing by the number of days in the month. It omits contributions from cells with less than 15 percent on days in the month. There is no corresponding gridded monthly average concentration image that goes with this value. Version 3 is a simpler and more intuitive way to calculate the monthly extent and area data values when daily extent and area values are available.

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Appendix 1. Arctic Extent Differences by Month

Table 14. Mean, standard deviation, minimum, maximum, and number of values for each month for the Arctic extent differences (V3 minus V2). Units are millions of sq km.

Month	*Mean*	*Stddev*	*Min*	*Max*	*N*
January	-0.215	0.049	-0.316	-0.119	38
February	-0.152	0.040	-0.306	-0.089	39
March	-0.161	0.048	-0.274	-0.055	39
April	-0.150	0.044	-0.260	-0.051	39
May	-0.168	0.070	-0.302	-0.004	39
June	-0.207	0.081	-0.410	-0.054	39
July	-0.308	0.079	-0.482	-0.162	38
August	-0.087	0.062	-0.211	0.031	38
September	-0.130	0.067	-0.329	-0.046	38
October	-0.617	0.260	-1.201	-0.265	38
November	-0.331	0.095	-0.551	-0.193	39
December	-0.294	0.107	-0.626	-0.127	38

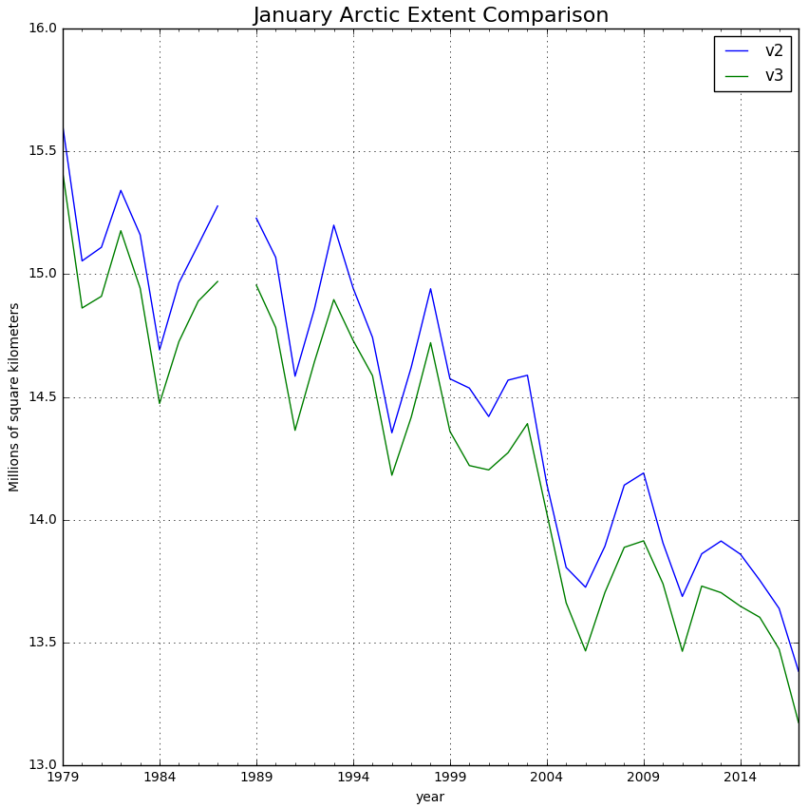

Figure 11. Comparison of V3 and V2 January Arctic Extent in millions of sq km

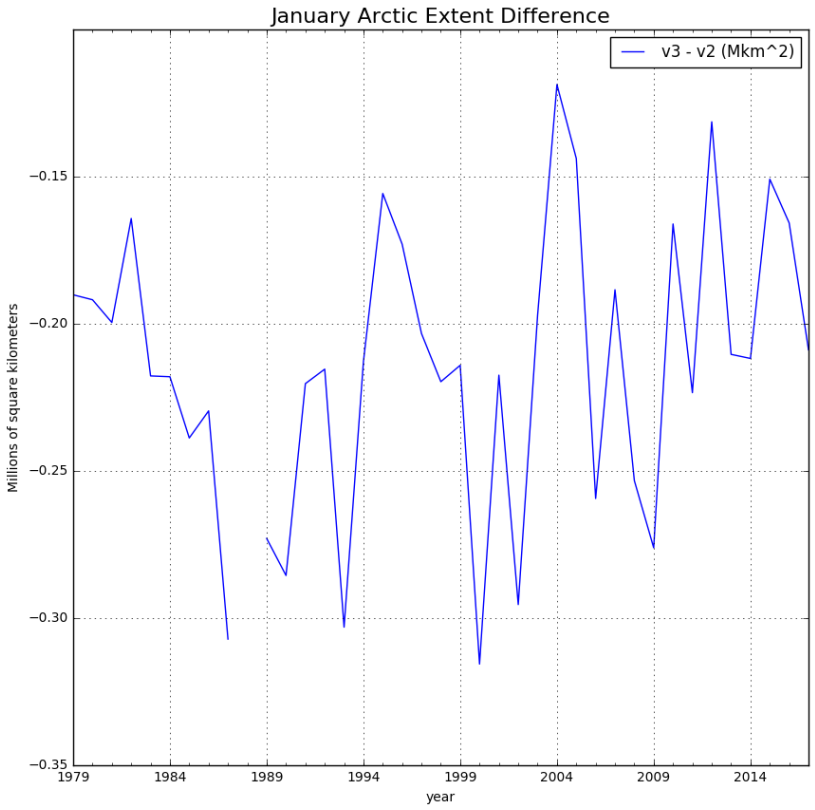

Figure 12. January Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

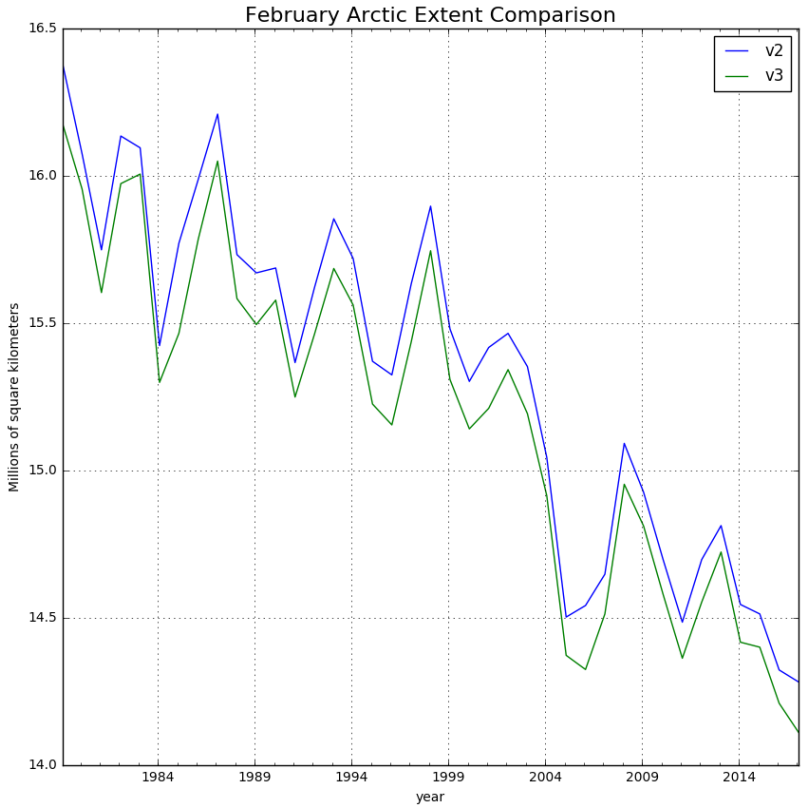

Figure 13. Comparison of V3 and V2 February Arctic Extent in millions of sq km

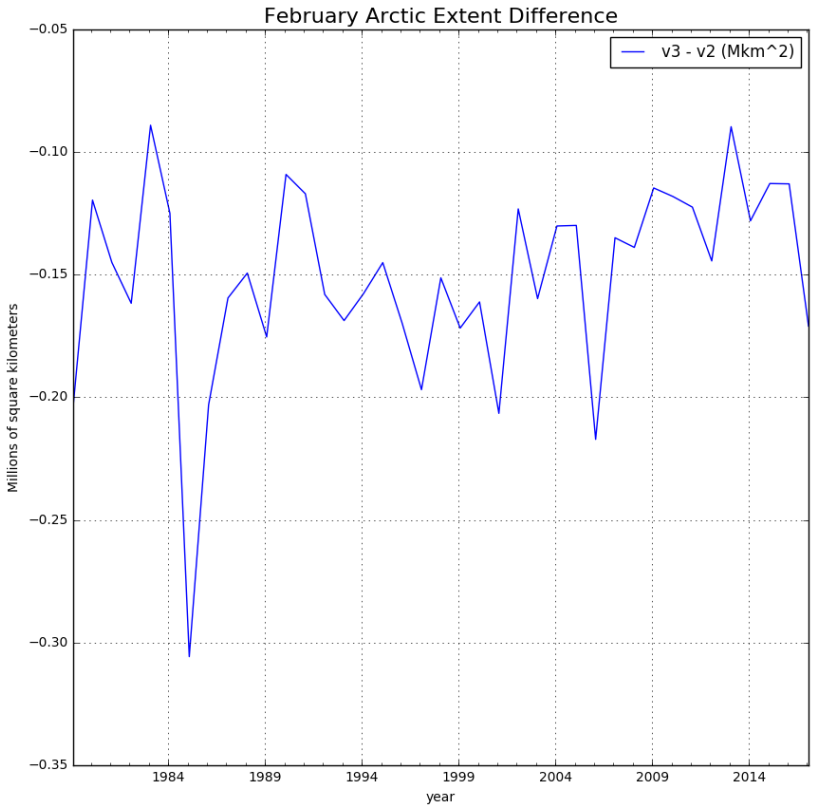

Figure 14. February Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

Figure 15. Comparison of V3 and V2 March Arctic Extent in millions of sq km

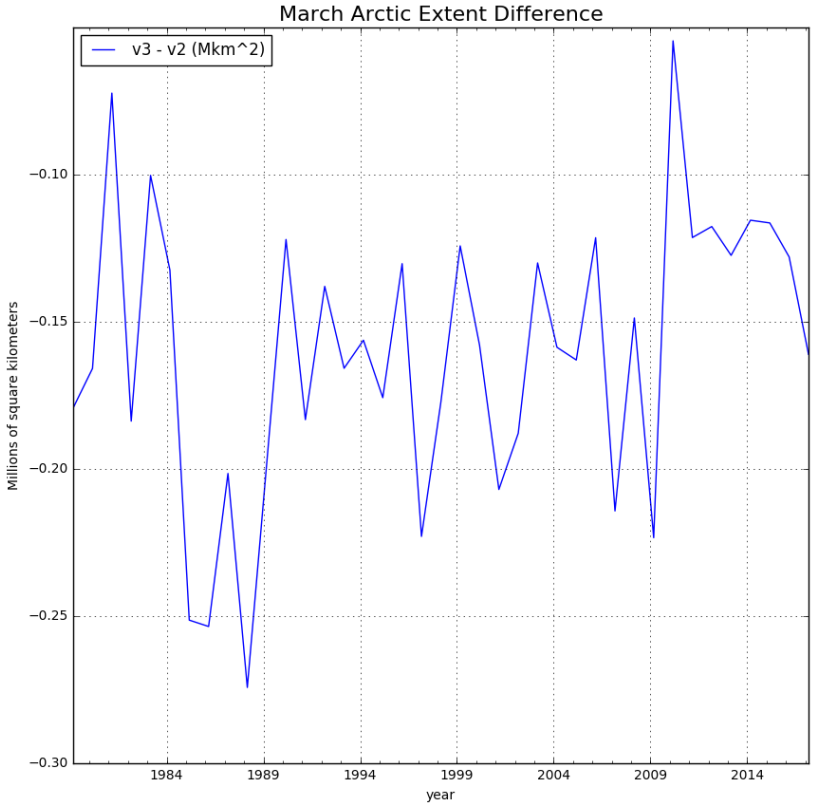

Figure 16. March Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

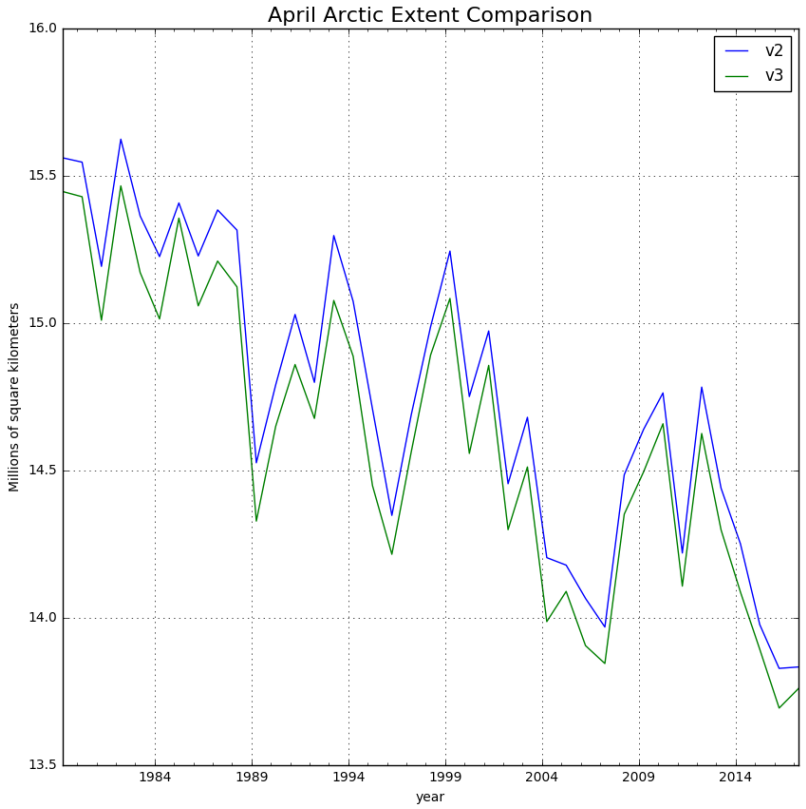

Figure 17. Comparison of V3 and V2 April Arctic Extent in millions of sq km

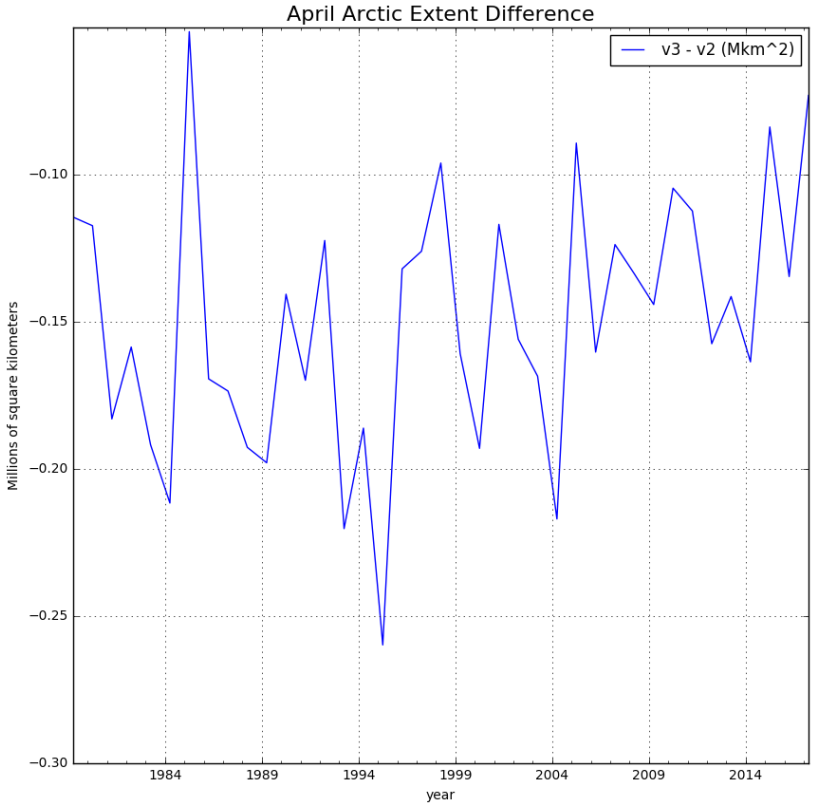

Figure 18. April Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

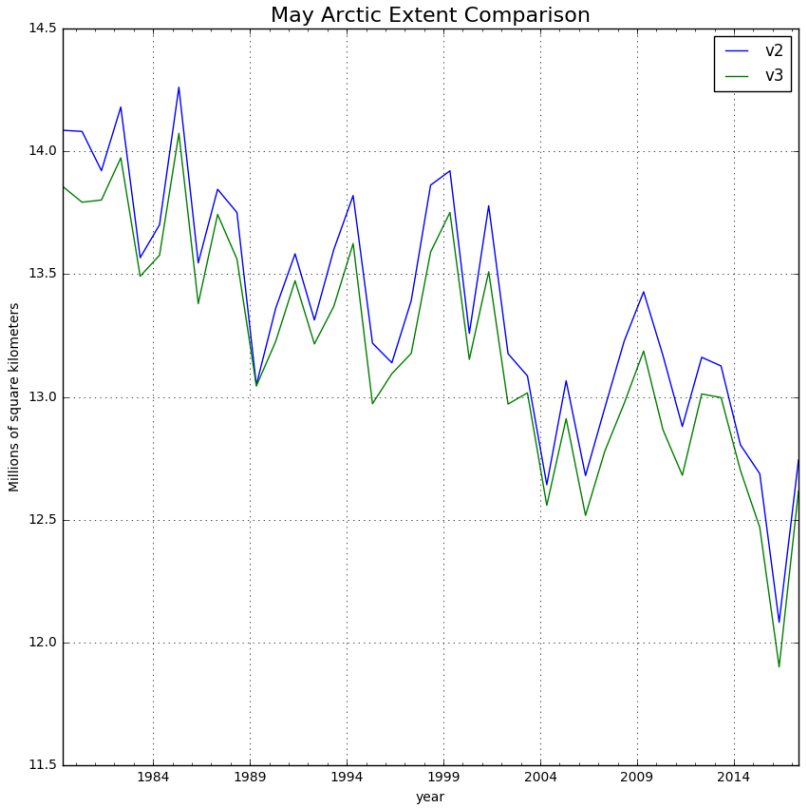

Figure 19. Comparison of V3 and V2 May Arctic Extent in millions of sq km

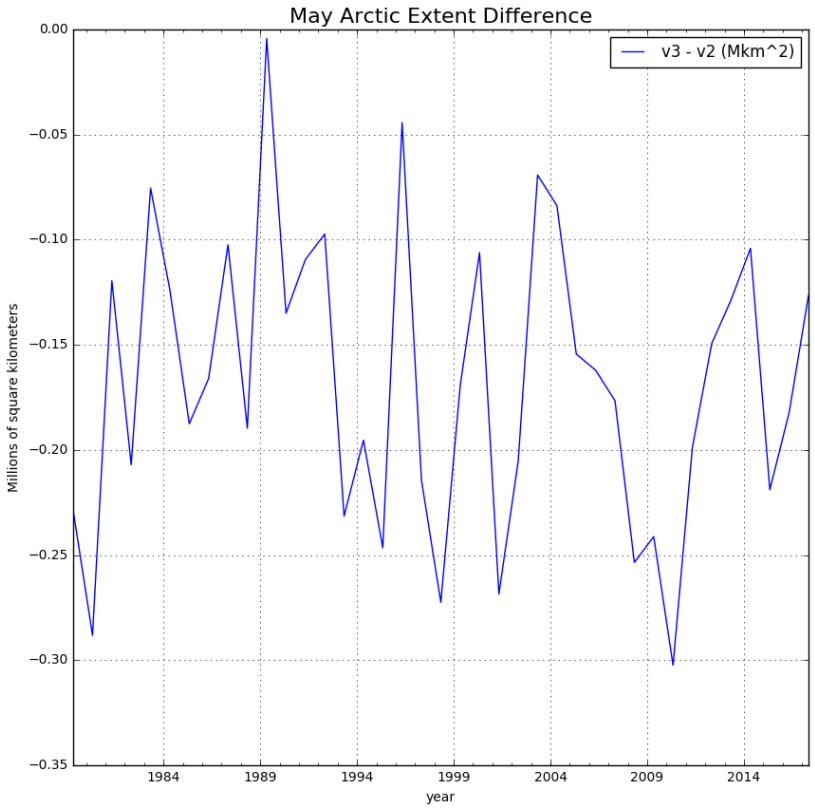

Figure 20. May Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

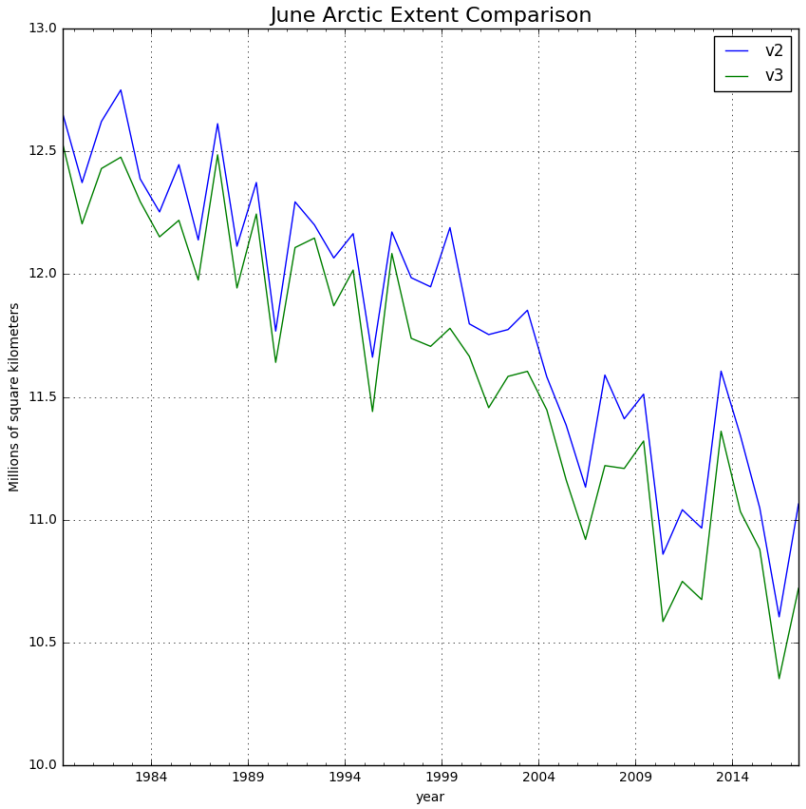

Figure 21. Comparison of V3 and V2 June Arctic Extent in millions of sq km

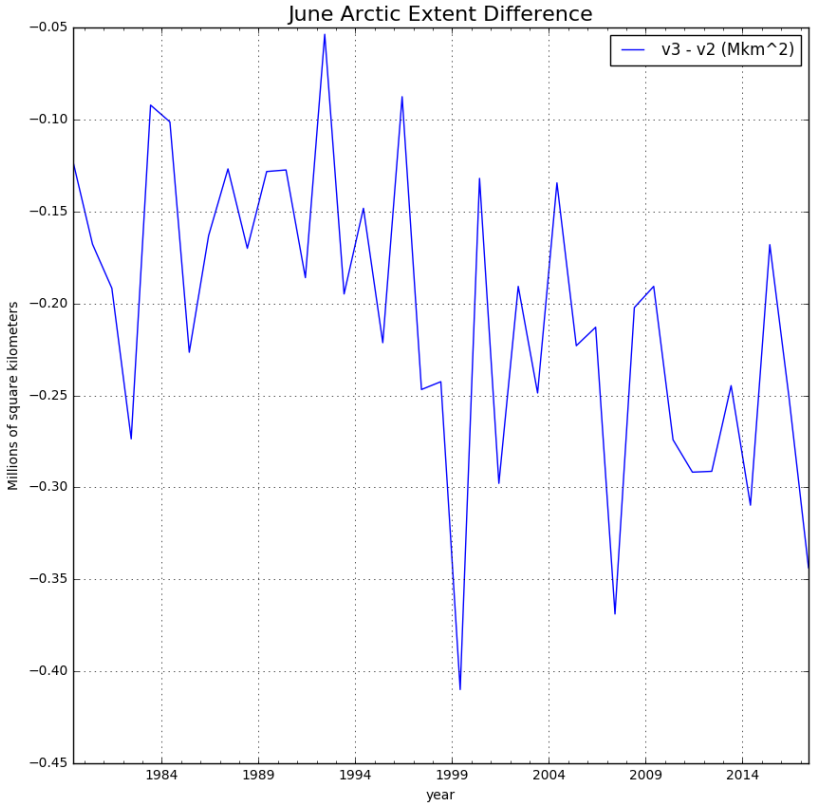

Figure 22. June Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

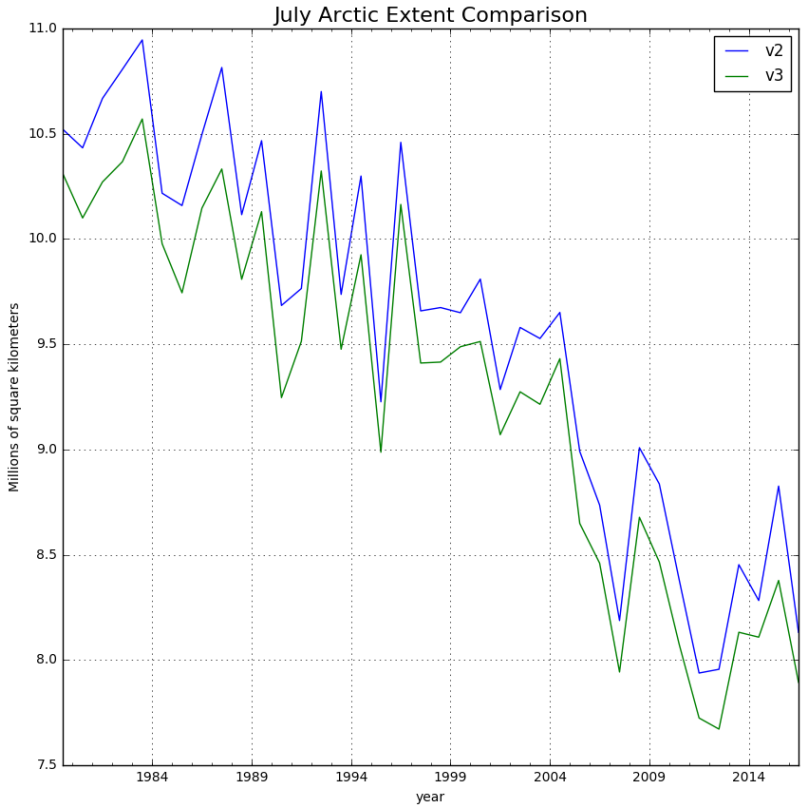

Figure 23. Comparison of V3 and V2 July Arctic Extent in millions of sq km

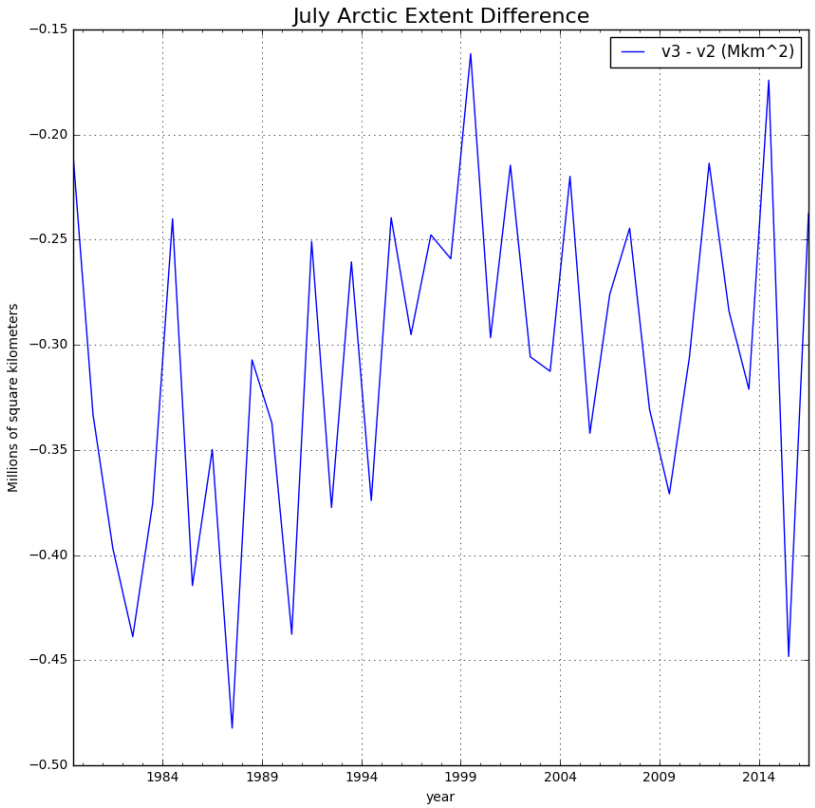

Figure 24. July Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

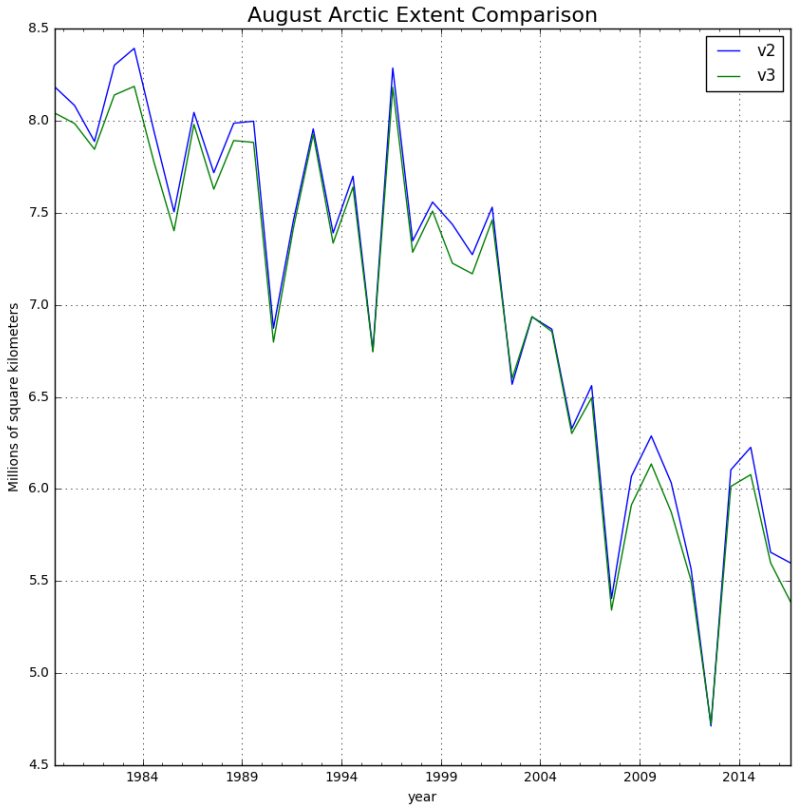

Figure 25. Comparison of V3 and V2 August Arctic Extent in millions of sq km

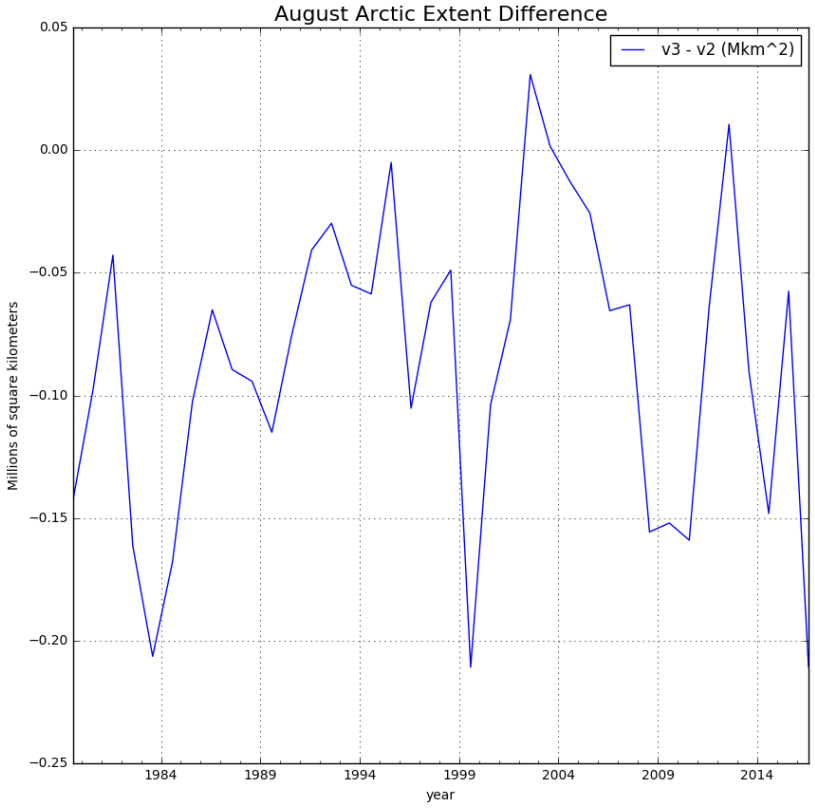

Figure 26. August Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

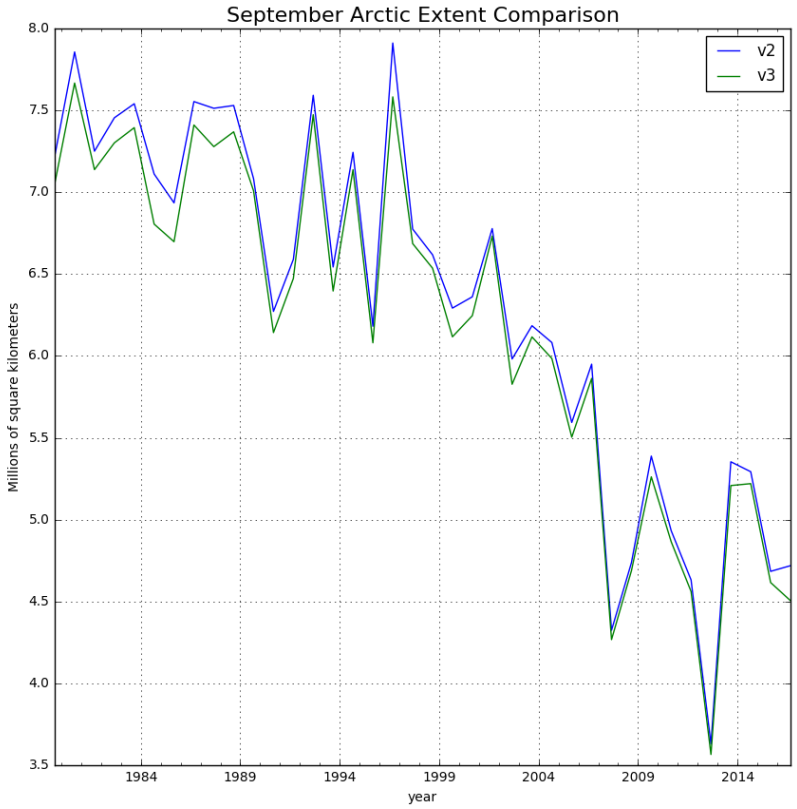

Figure 27. Comparison of V3 and V2 September Arctic Extent in millions of sq km

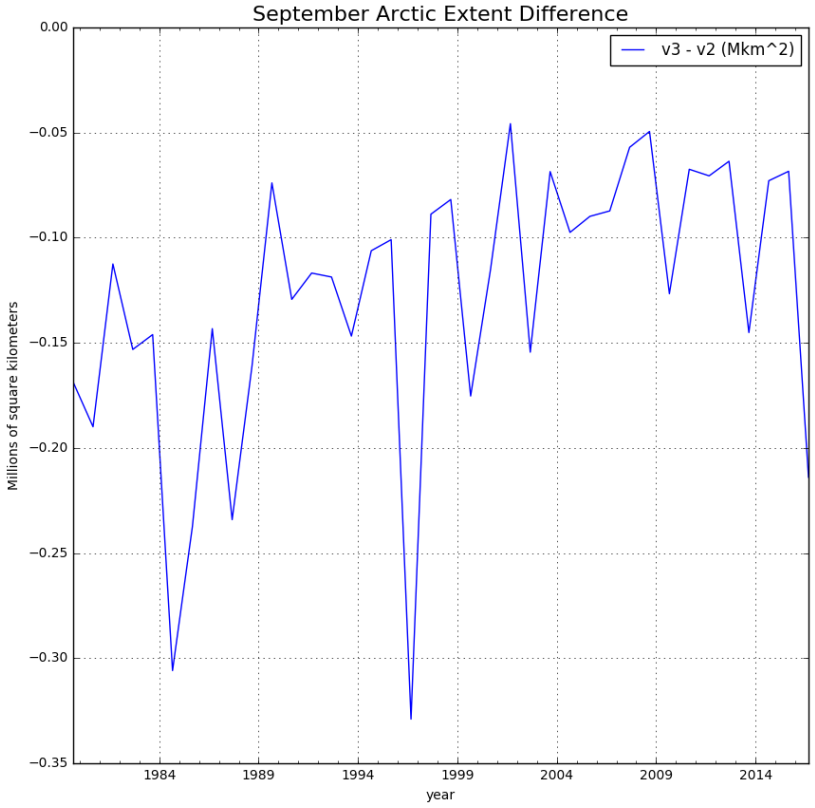

Figure 28. September Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

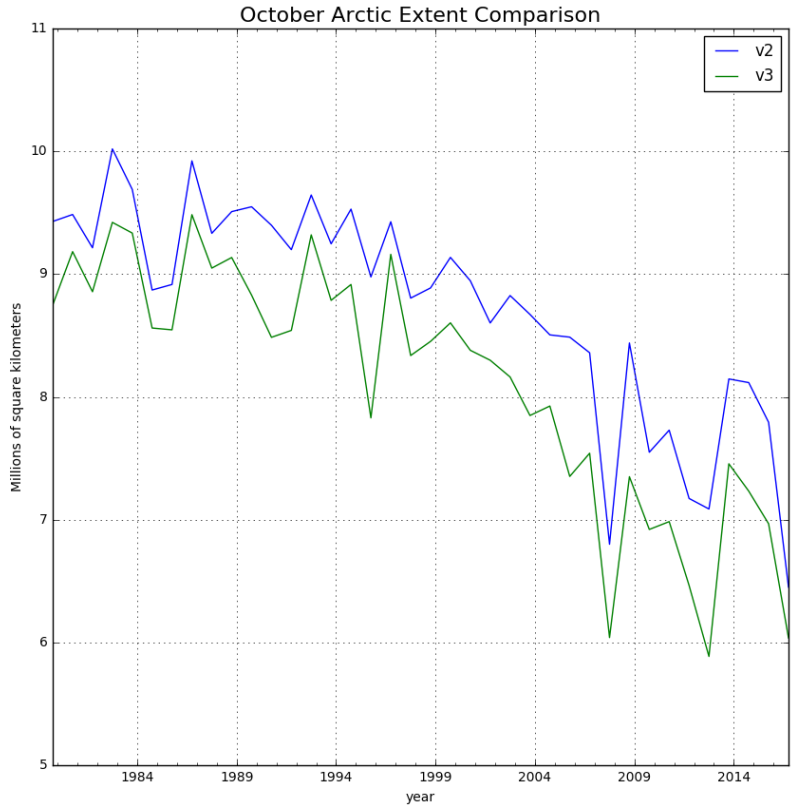

Figure 29. Comparison of V3 and V2 October Arctic Extent in millions of sq km

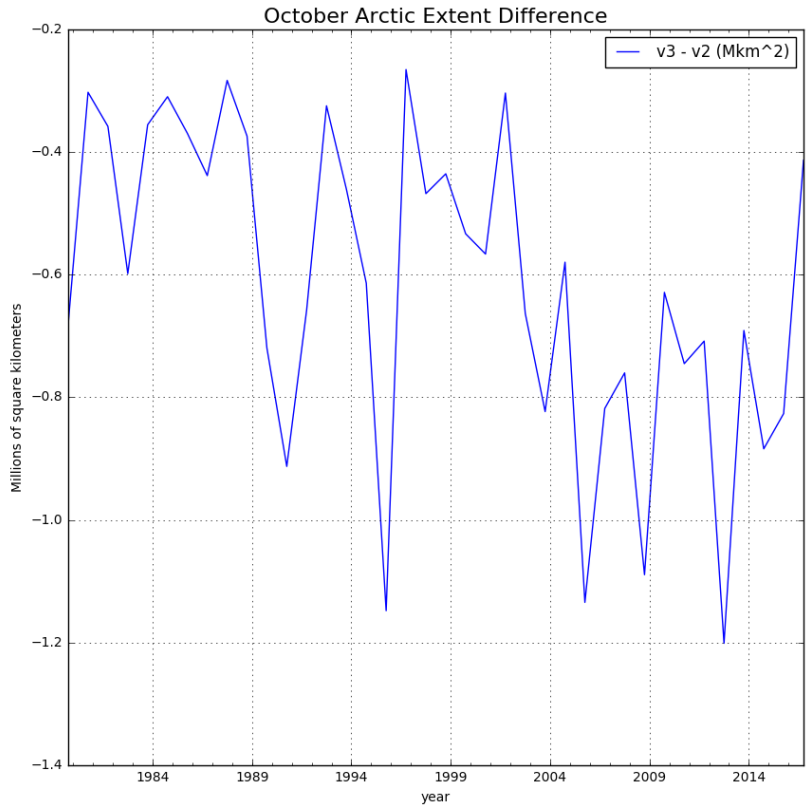

Figure 30. October Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

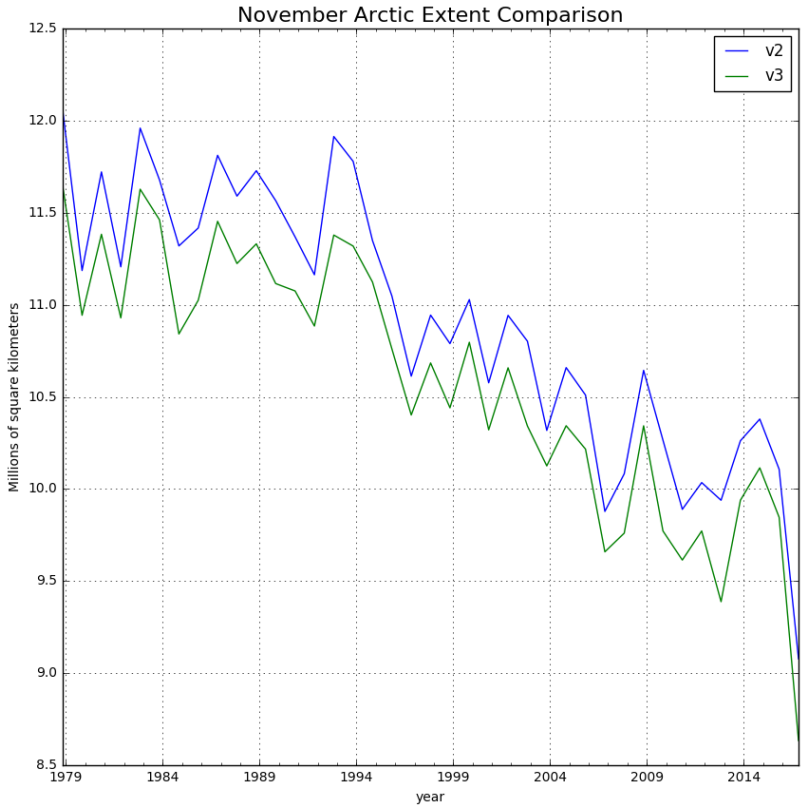

Figure 31. Comparison of V3 and V2 November Arctic Extent in millions of sq km

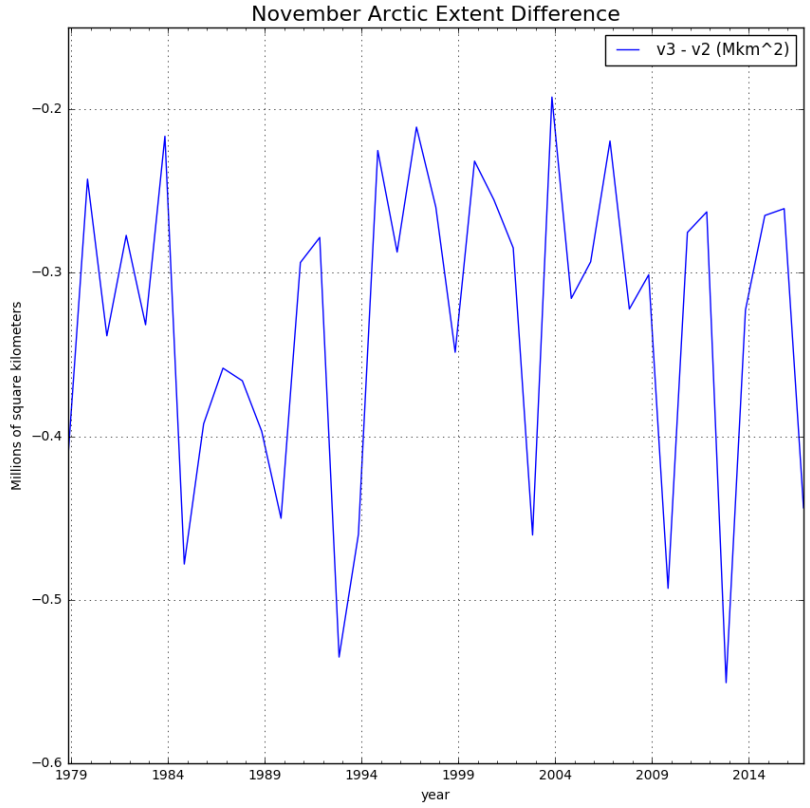

Figure 32. November Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

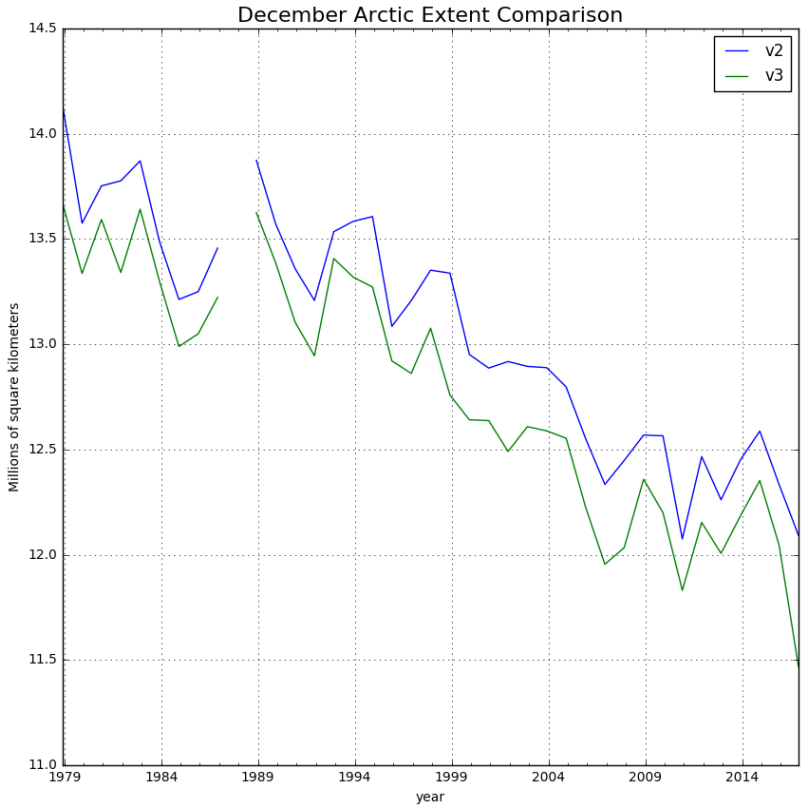

Figure 33. Comparison of V3 and V2 December Arctic Extent in millions of sq km

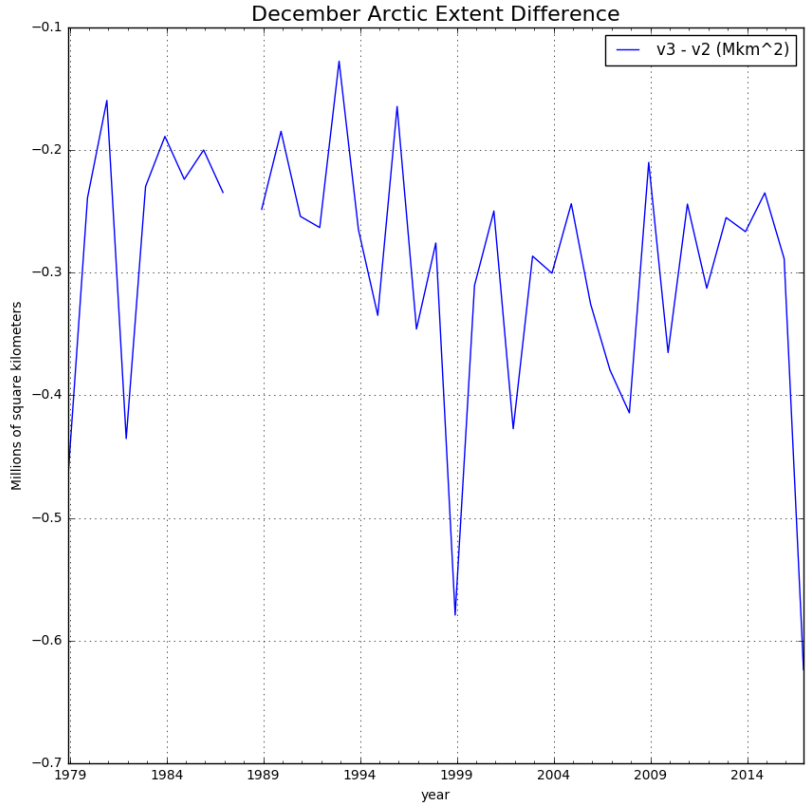

Figure 34. December Arctic Extent Differences: V3 Method minus V2 Method in millions of sq km

Appendix 2. Arctic Area Differences by Month

Table 15. Mean, standard deviation, minimum, maximum, and number of values for each month for the Arctic area differences (V3 minus V2). Units are millions of sq km.

Month	*Mean*	*Stddev*	*Min*	*Max*	*N*
January	0.048	0.015	0.034	0.123	38
February	0.044	0.017	0.029	0.136	39
March	0.044	0.017	0.031	0.129	39
April	0.053	0.011	0.038	0.080	39
May	0.045	0.010	0.030	0.067	39
June	0.044	0.012	0.027	0.086	39
July	0.064	0.014	0.038	0.100	38
August	0.076	0.052	0.046	0.374	38
September	0.040	0.010	0.026	0.070	38
October	0.051	0.018	0.022	0.099	38
November	0.054	0.010	0.033	0.075	39
December	0.047	0.009	0.032	0.069	38

Figure 35. Comparison of V3 and V2 January Arctic Area in millions of sq km

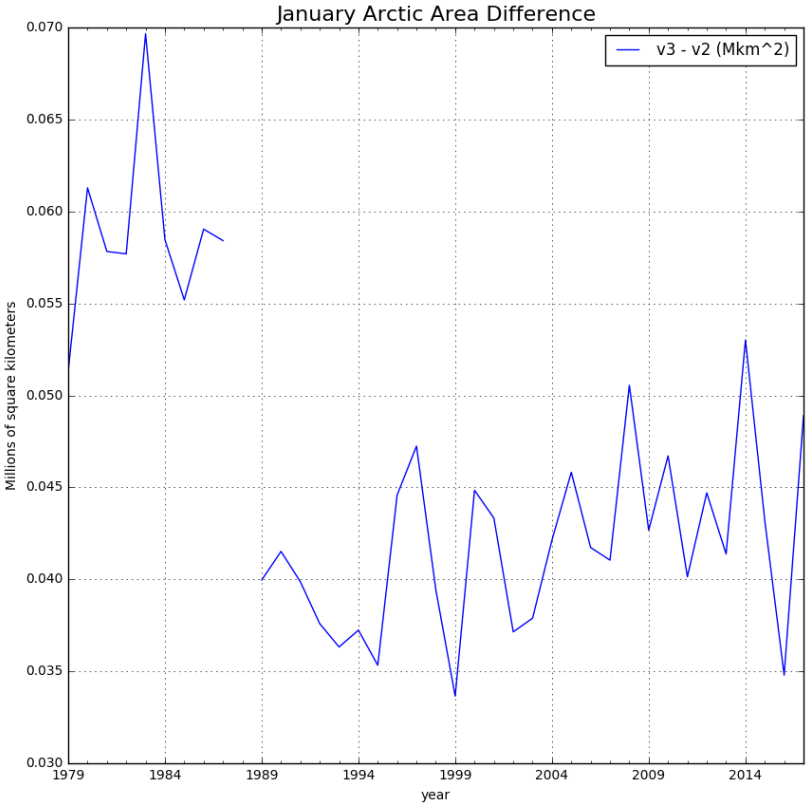

Figure 36. January Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

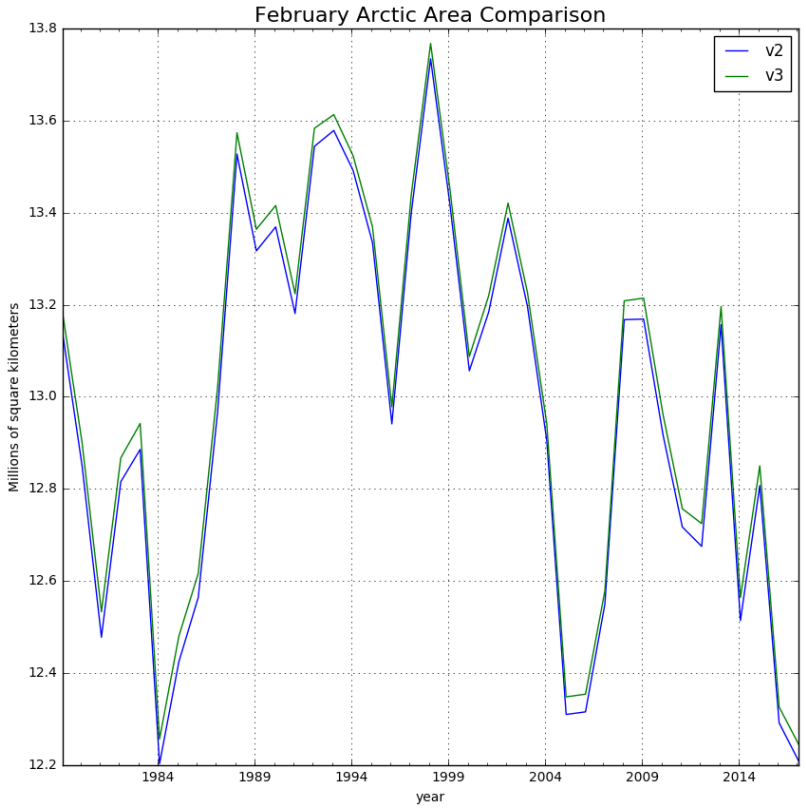

Figure 37. Comparison of V3 and V2 February Arctic Area in millions of sq km

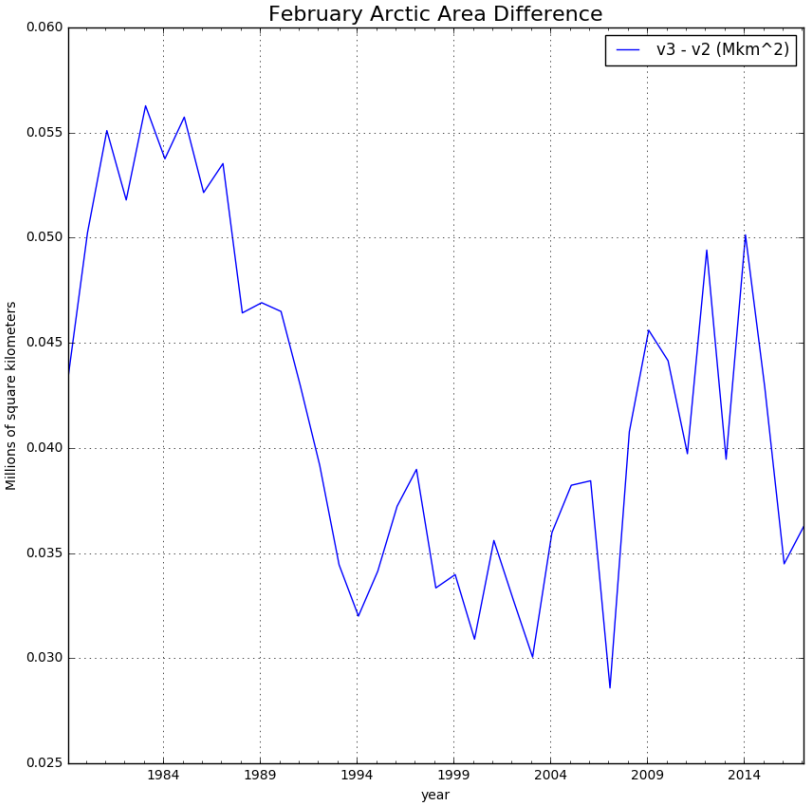

Figure 38. February Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

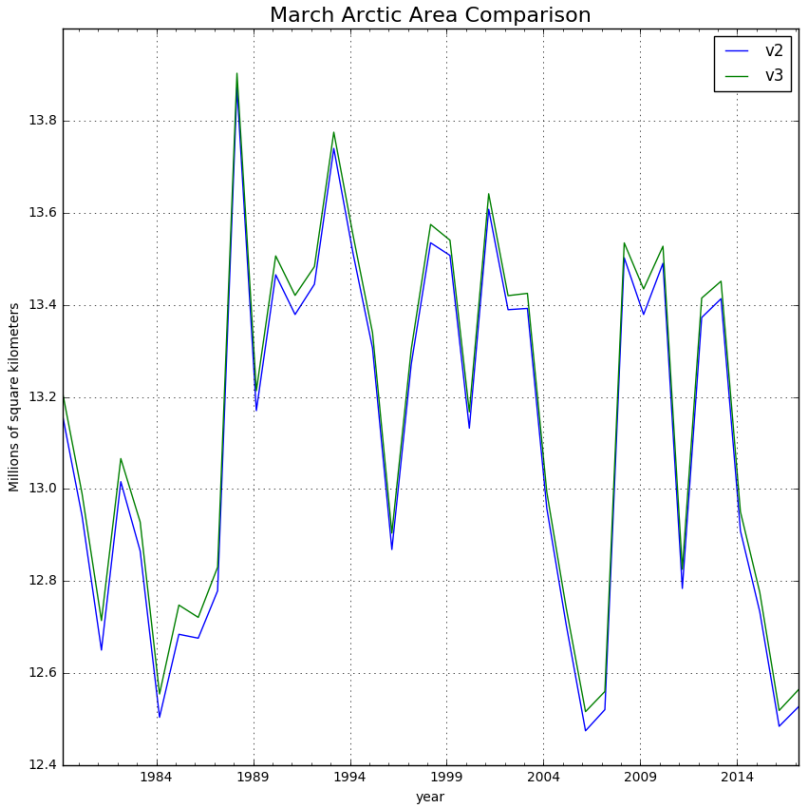

Figure 39. Comparison of V3 and V2 March Arctic Area in millions of sq km

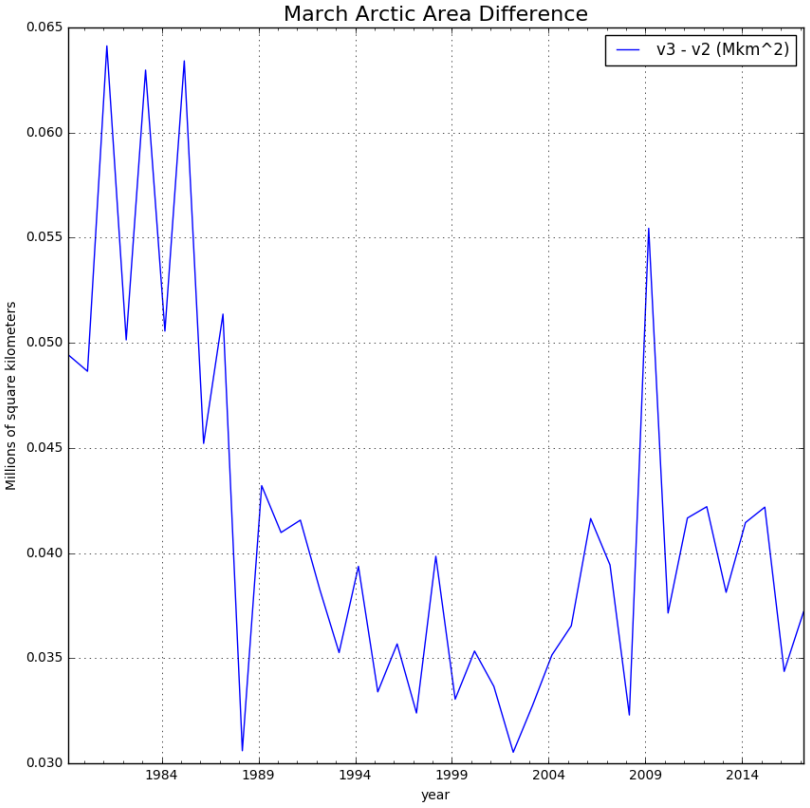

Figure 40. March Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

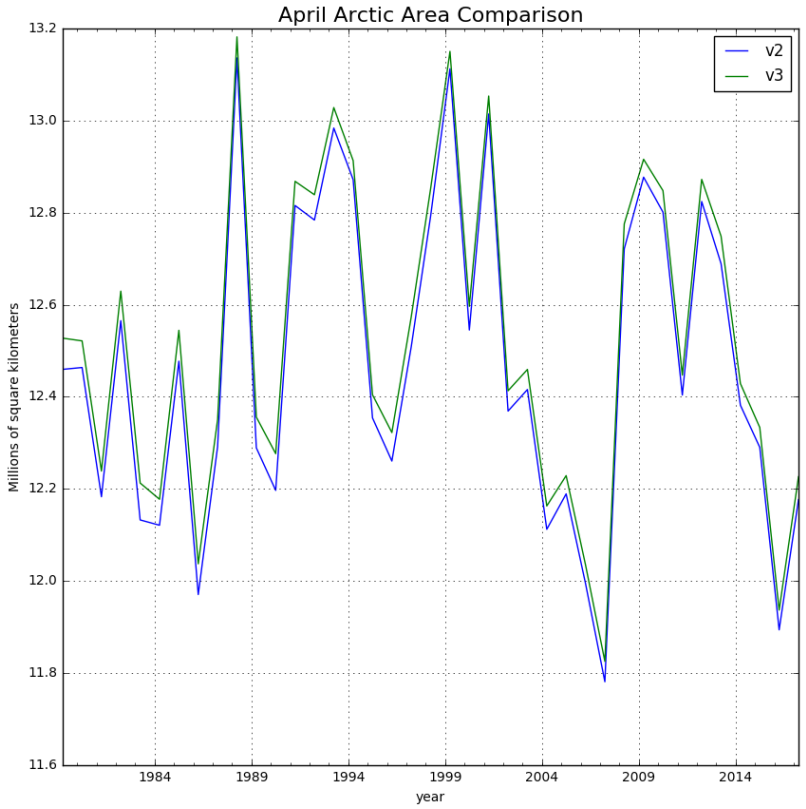

Figure 41. Comparison of V3 and V2 April Arctic Area in millions of sq km

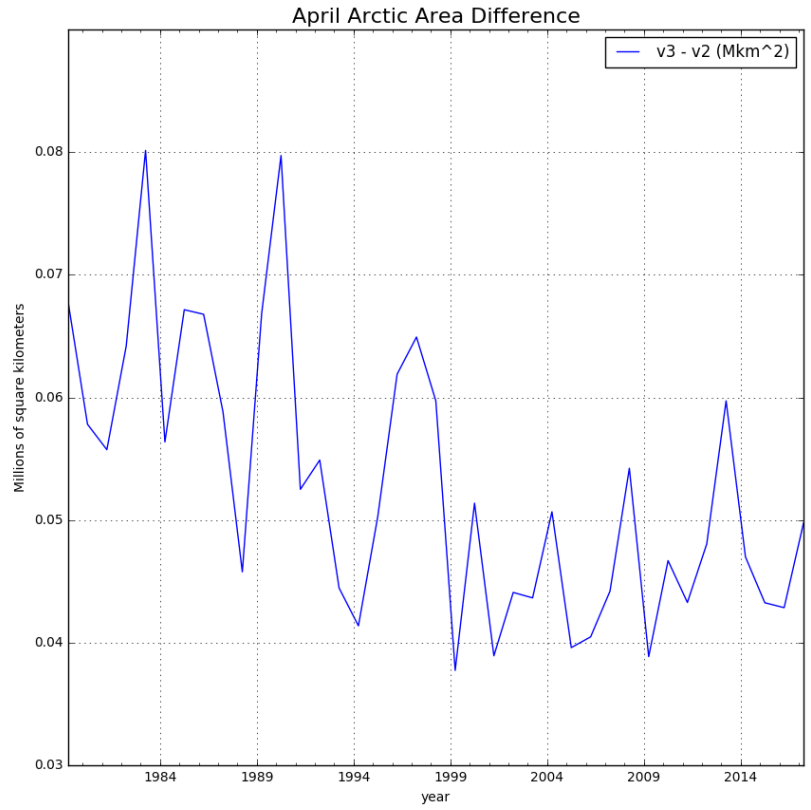

Figure 42. April Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

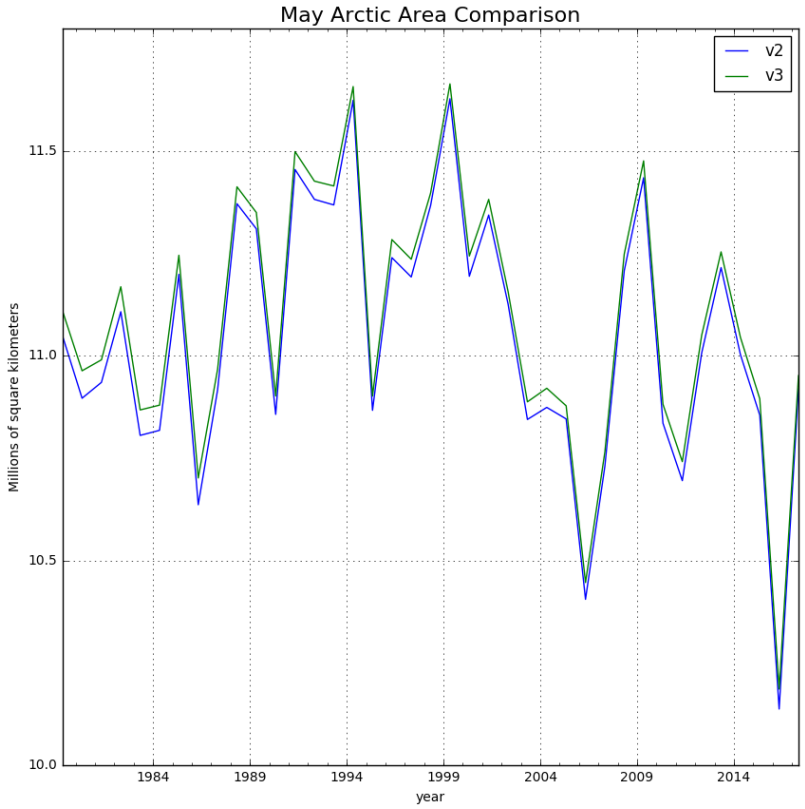

Figure 43. Comparison of V3 and V2 May Arctic Area in millions of sq km

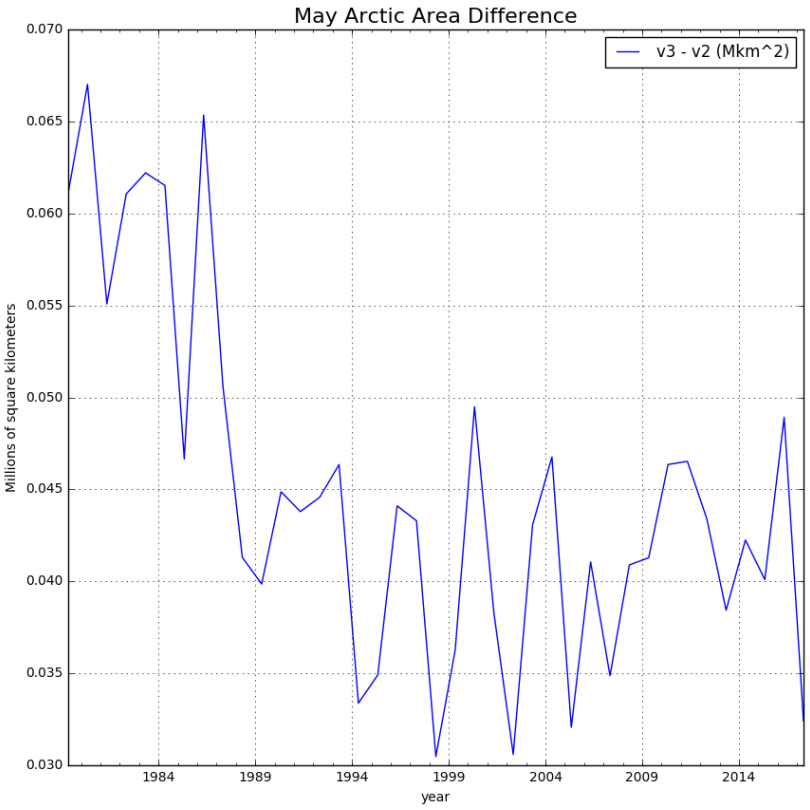

Figure 44. May Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

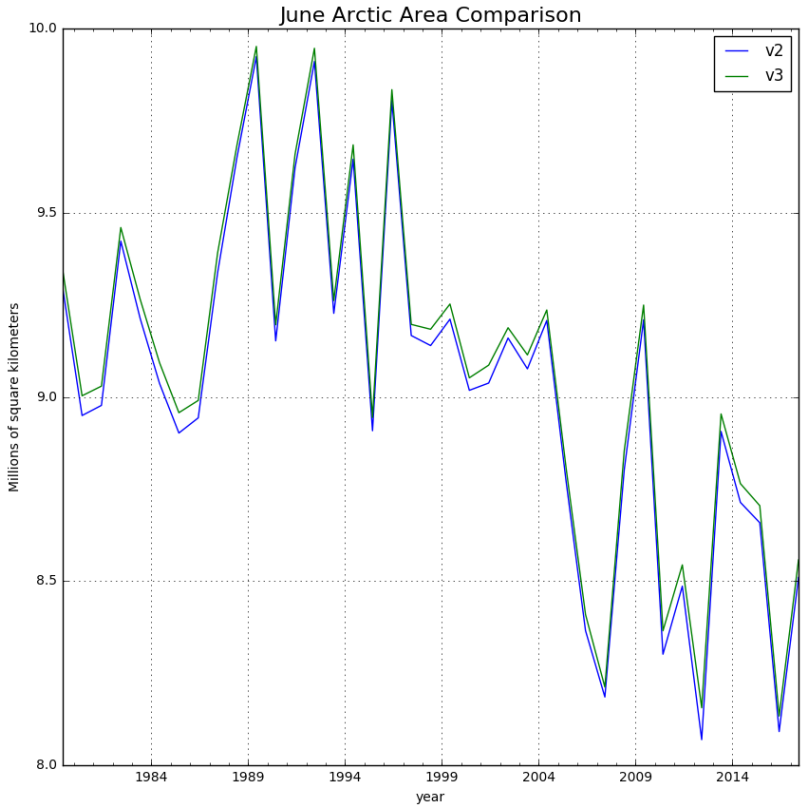

Figure 45. Comparison of V3 and V2 June Arctic Area in millions of sq km

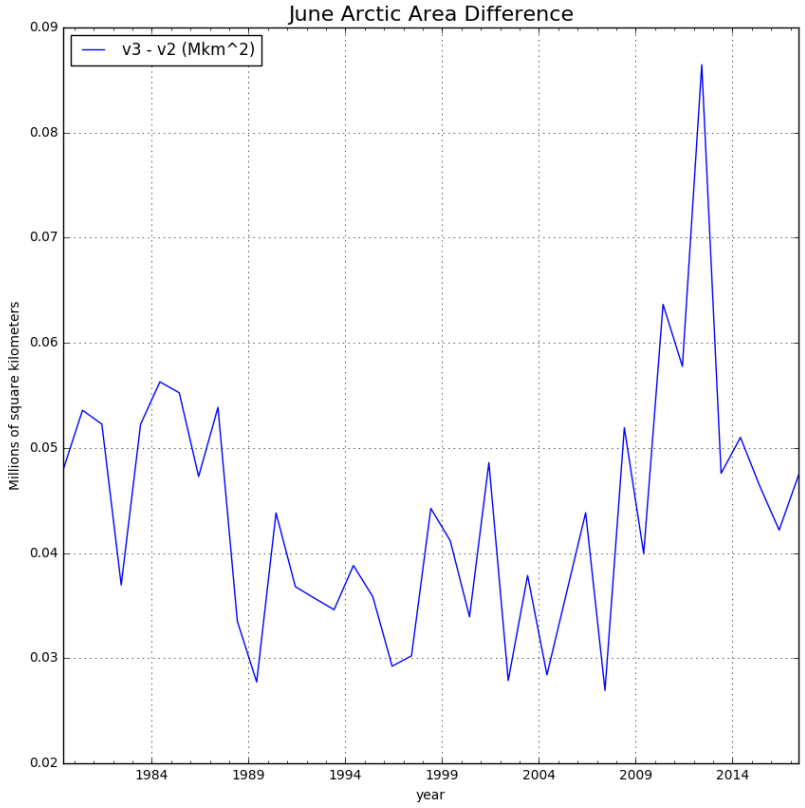

Figure 46. June Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

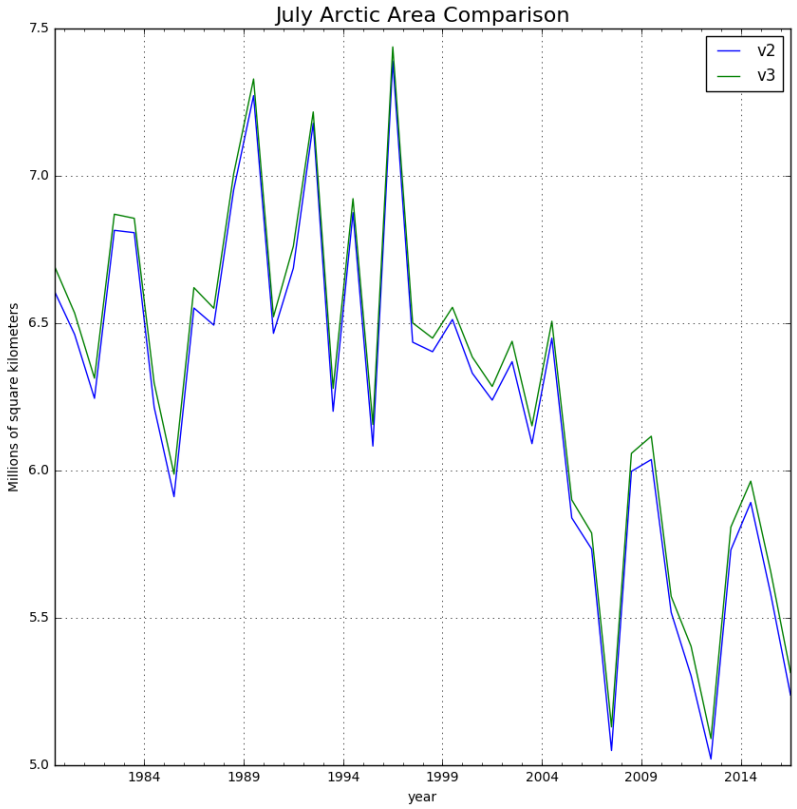

Figure 47. Comparison of V3 and V2 July Arctic Area in millions of sq km

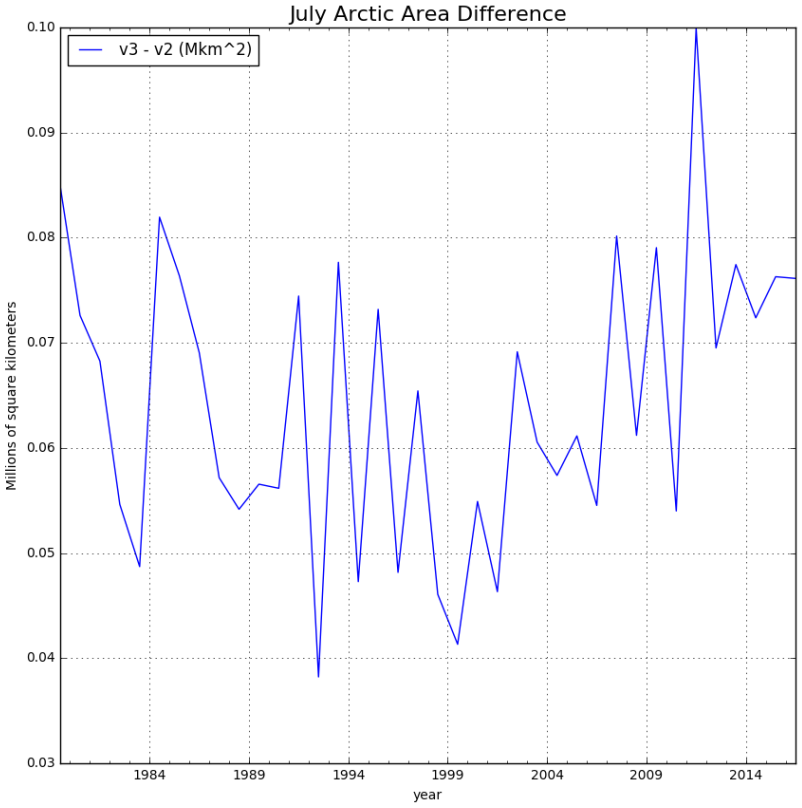

Figure 48. July Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

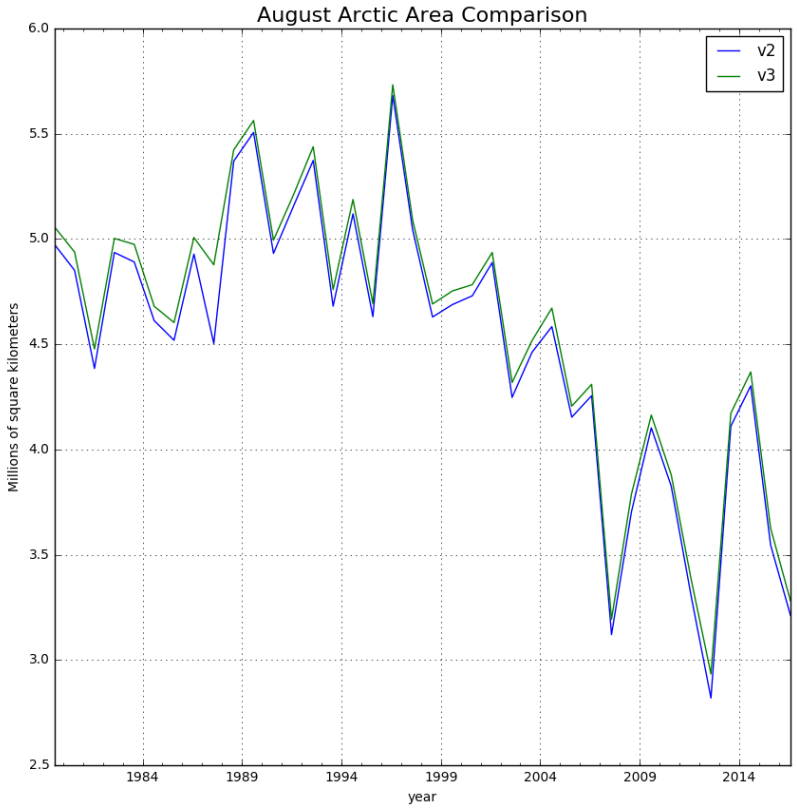

Figure 49. Comparison of V3 and V2 August Arctic Area in millions of sq km

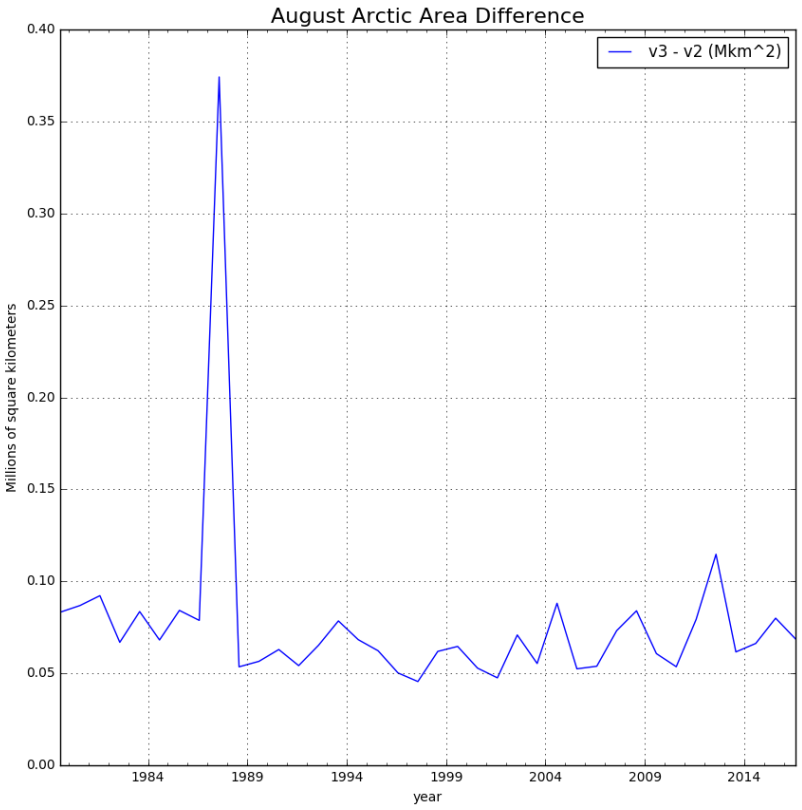

Figure 50. August Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

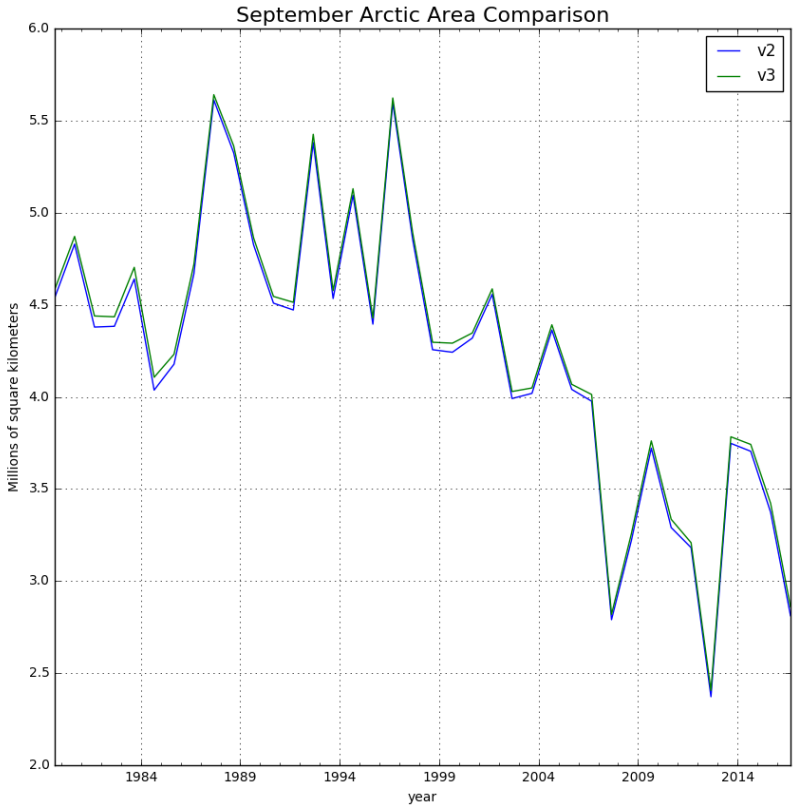

Figure 51. Comparison of V3 and V2 September Arctic Area in millions of sq km

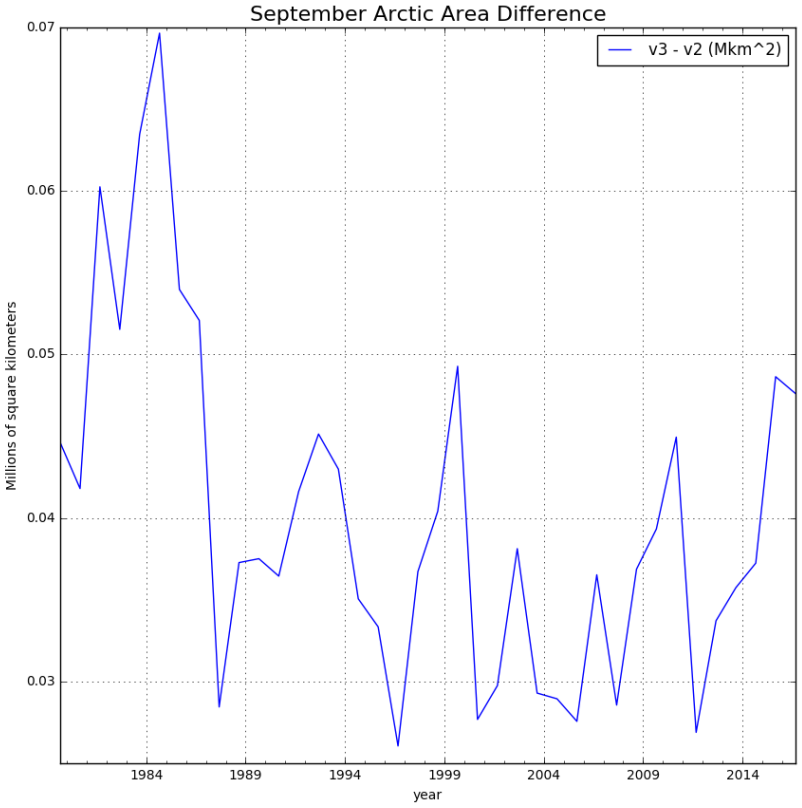

Figure 52. September Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

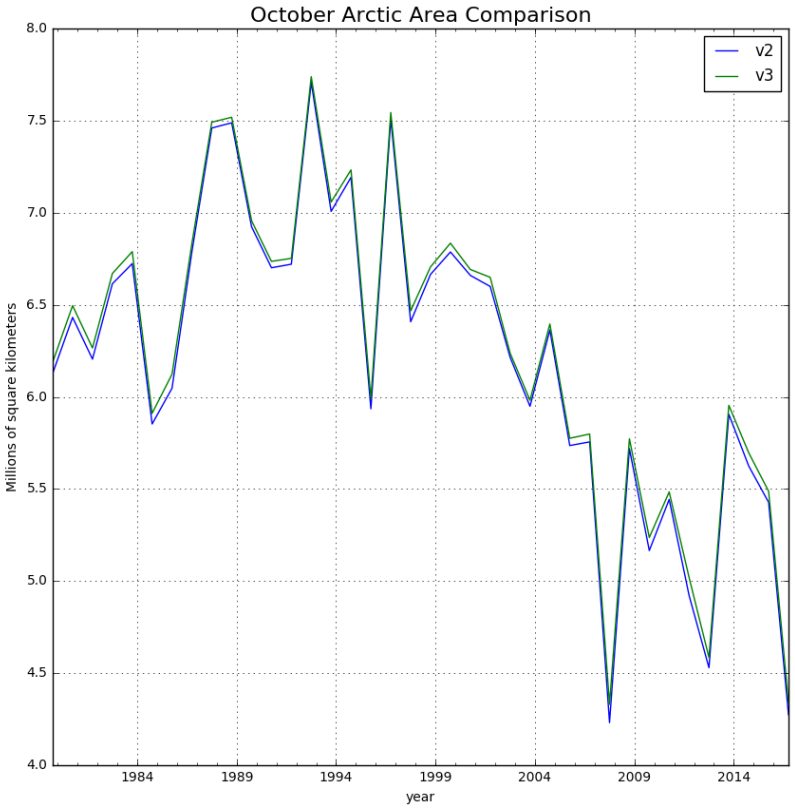

Figure 53. Comparison of V3 and V2 October Arctic Area in millions of sq km

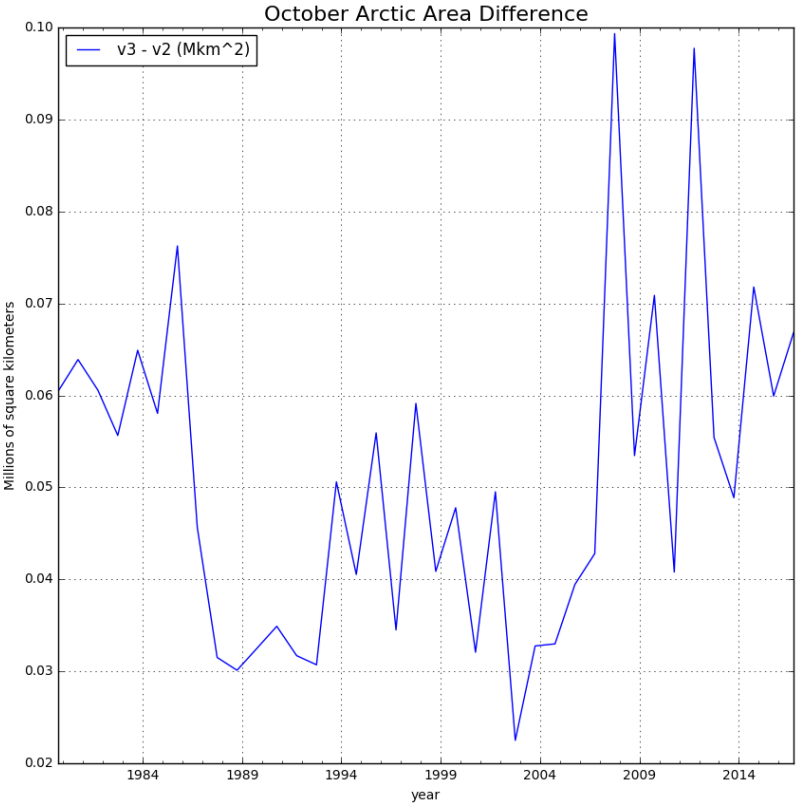

Figure 54. October Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

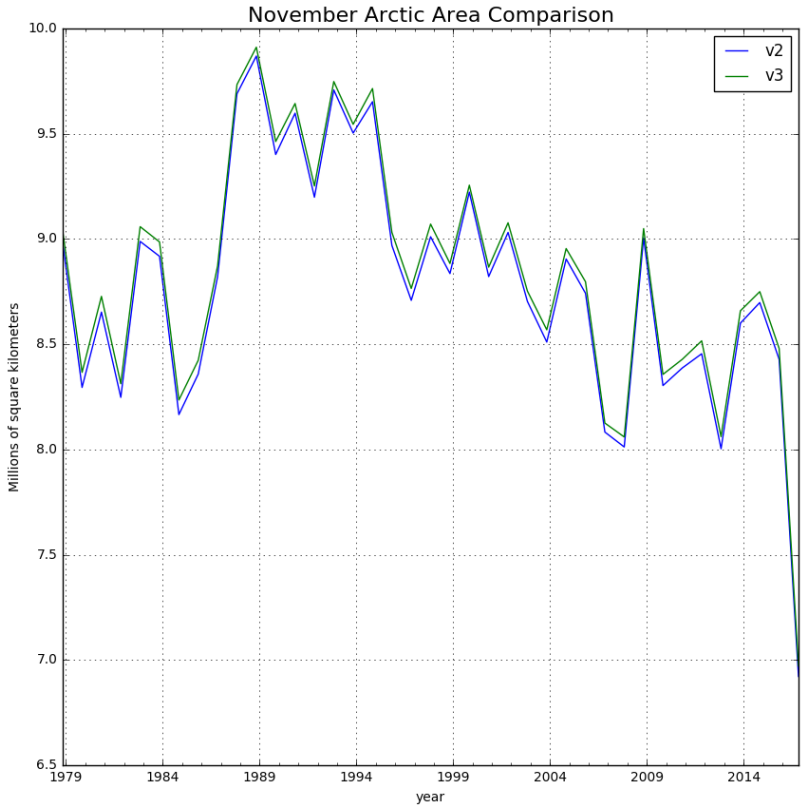

Figure 55. Comparison of V3 and V2 November Arctic Area in millions of sq km

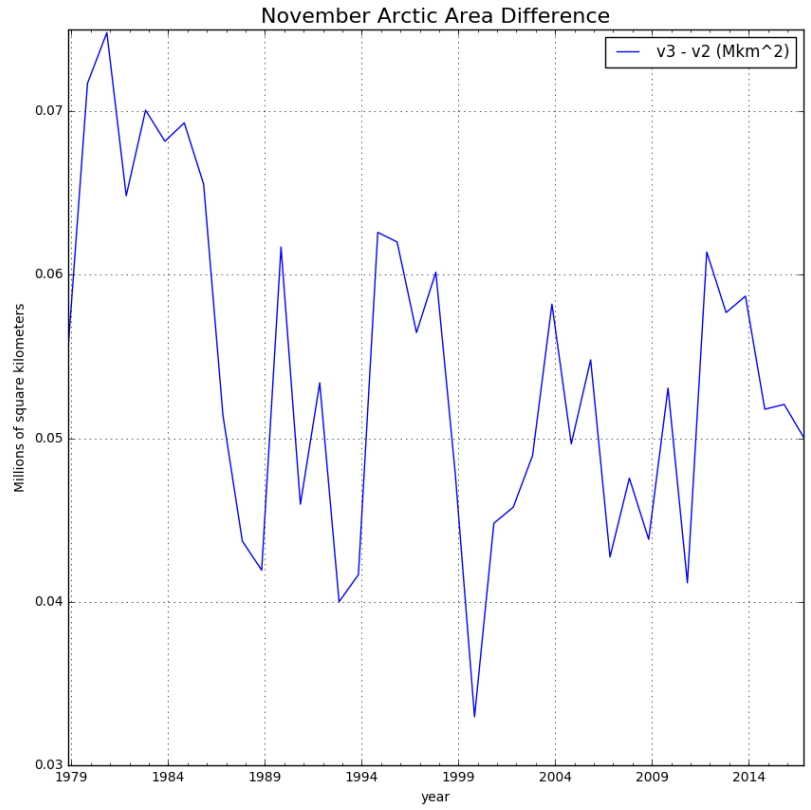

Figure 56. November Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

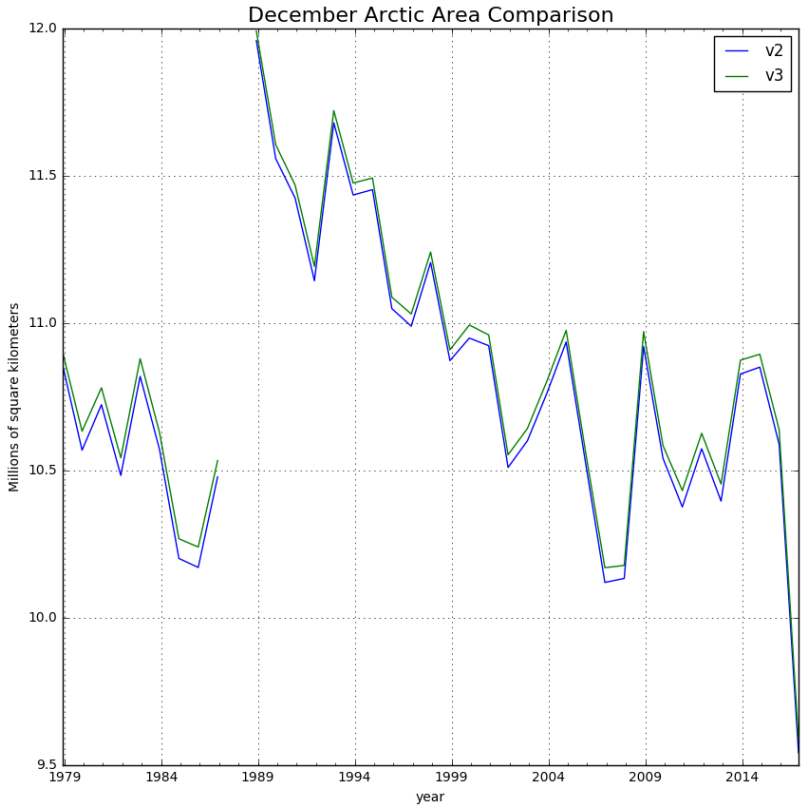

Figure 57. Comparison of V3 and V2 December Arctic Area in millions of sq km

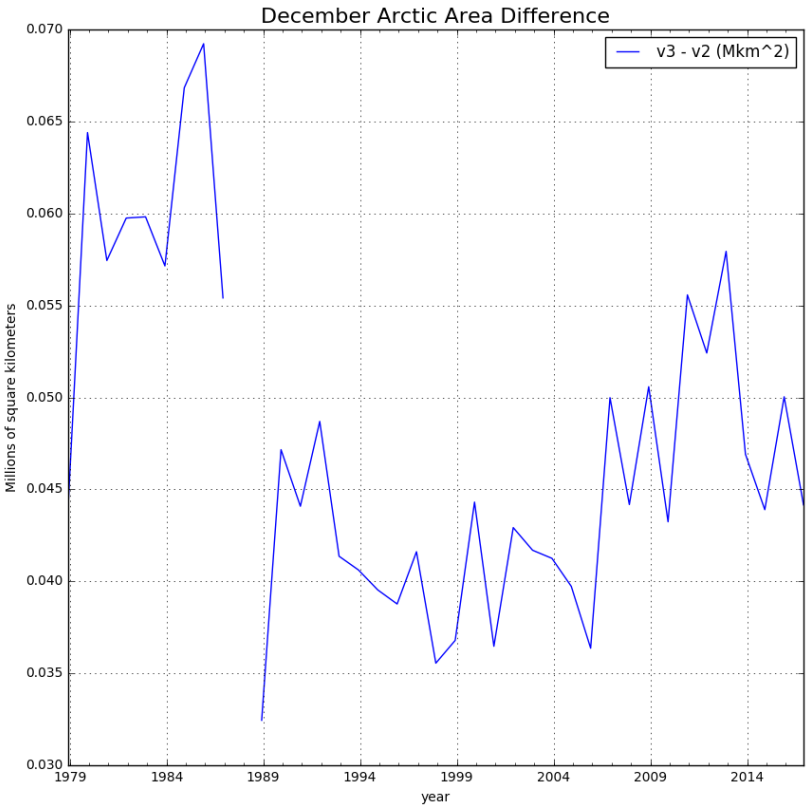

Figure 58. December Arctic Area Differences: V3 Method minus V2 Method in millions of sq km

Appendix 3. Antarctic Extent Differences by Month

Table 16. Mean, standard deviation, minimum, maximum, and number of values for each month for the Antarctic extent differences (V3 minus V2). Units are millions of sq km.

Month	*Mean*	*Stddev*	*Min*	*Max*	*N*
January	-0.257	0.144	-0.742	-0.030	38
February	-0.043	0.039	-0.160	0.025	39
March	-0.411	0.117	-0.605	-0.214	39
April	-0.583	0.082	-0.740	-0.441	39
May	-0.631	0.117	-0.894	-0.404	39
June	-0.608	0.076	-0.811	-0.465	39
July	-0.496	0.104	-0.717	-0.301	38
August	-0.417	0.100	-0.724	-0.267	38
September	-0.337	0.084	-0.592	-0.202	38
October	-0.289	0.081	-0.459	-0.105	38
November	-0.458	0.115	-0.697	-0.210	39
December	-0.928	0.198	-1.271	-0.485	38

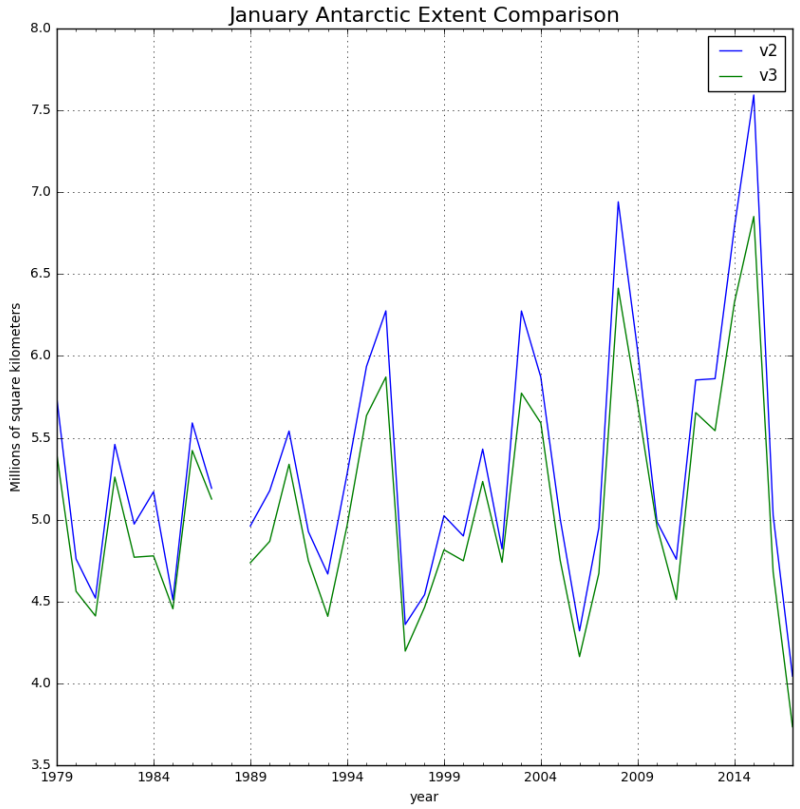

Figure 59. Comparison of V3 and V2 January Antarctic Extent in millions of sq km

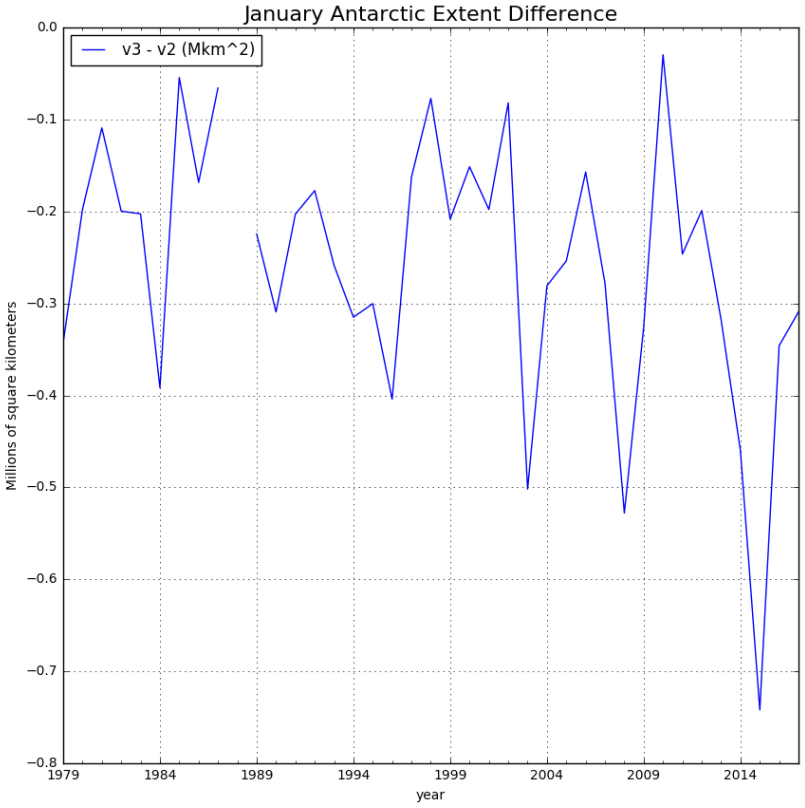

Figure 60. January Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

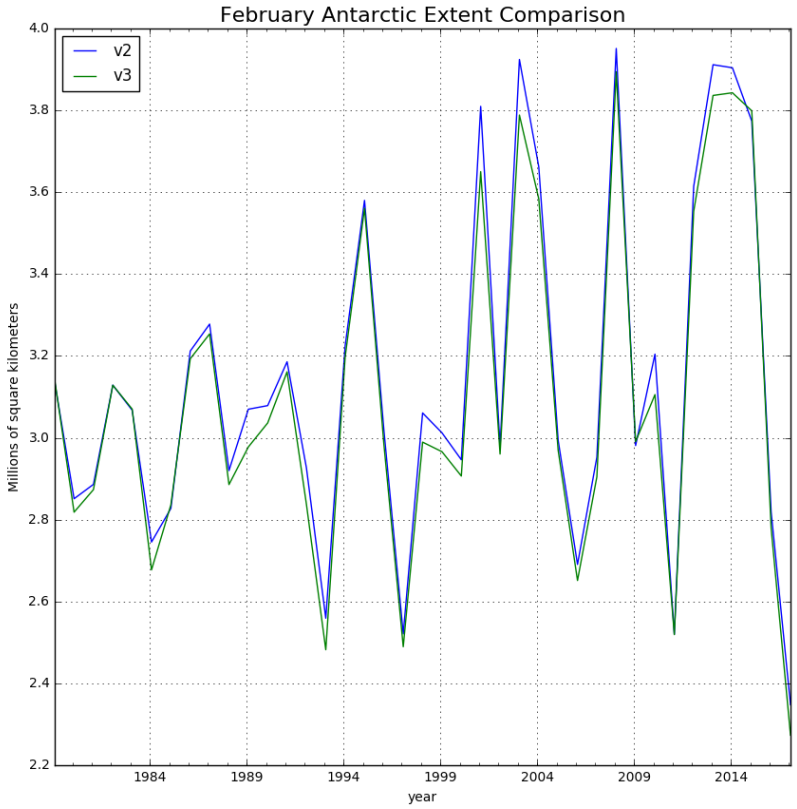

Figure 61. Comparison of V3 and V2 February Antarctic Extent in millions of sq km

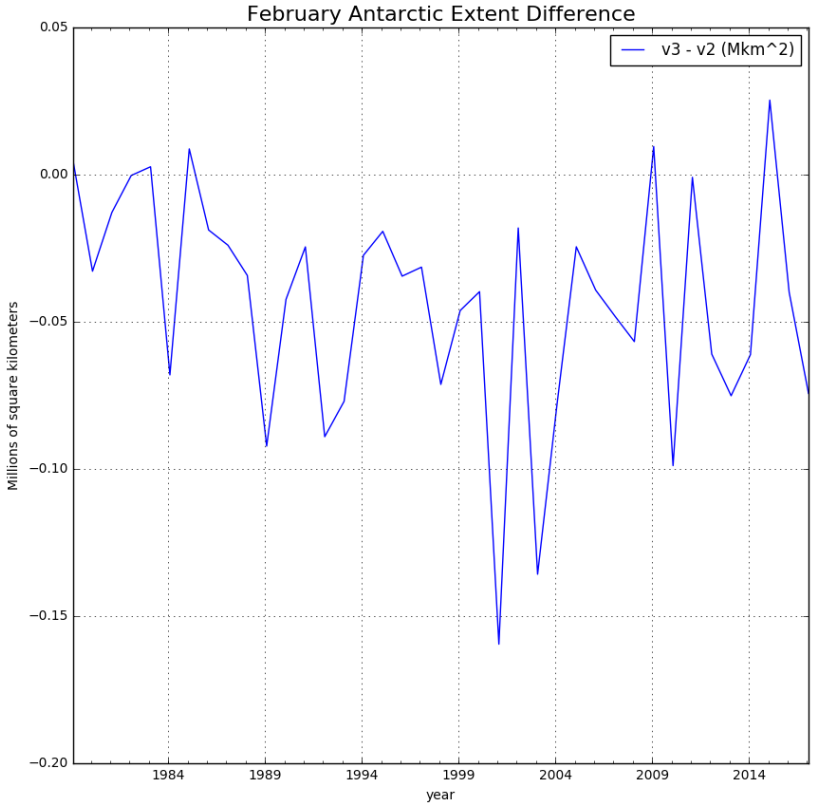

Figure 62. February Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

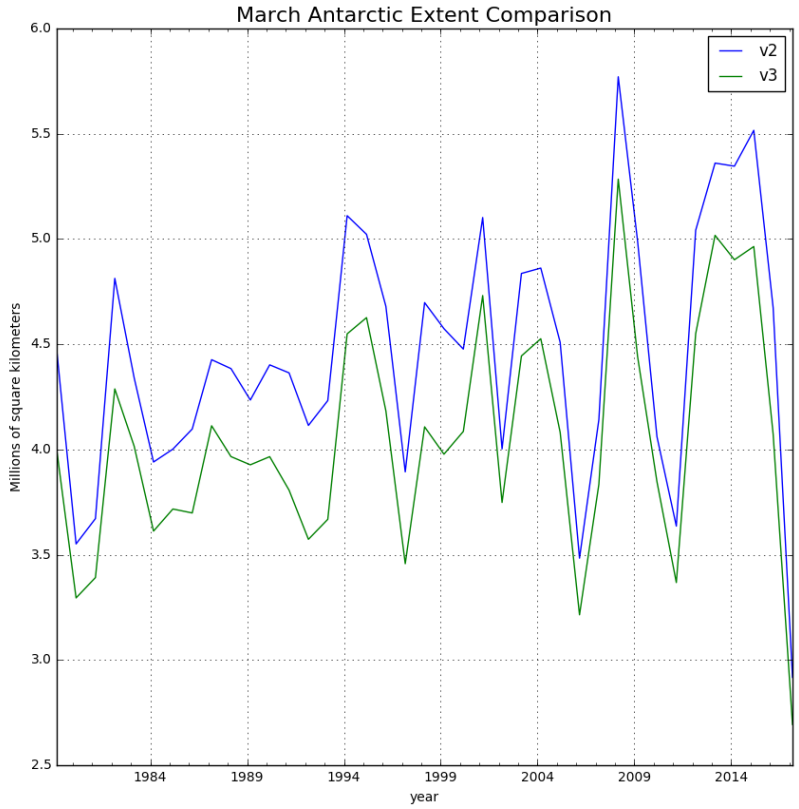

Figure 63. Comparison of V3 and V2 March Antarctic Extent in millions of sq km

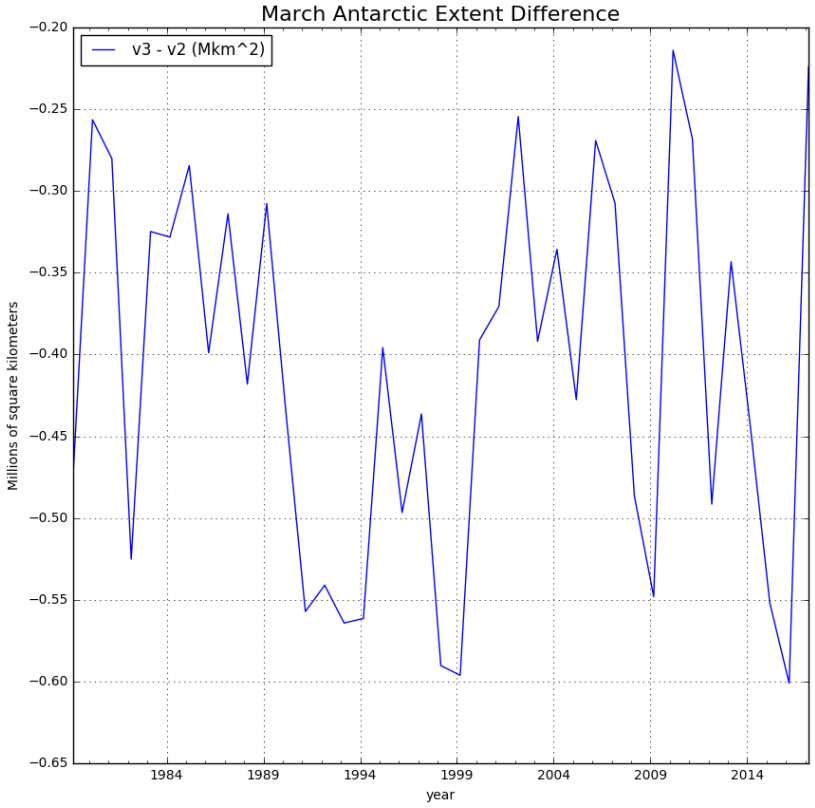

Figure 64. March Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

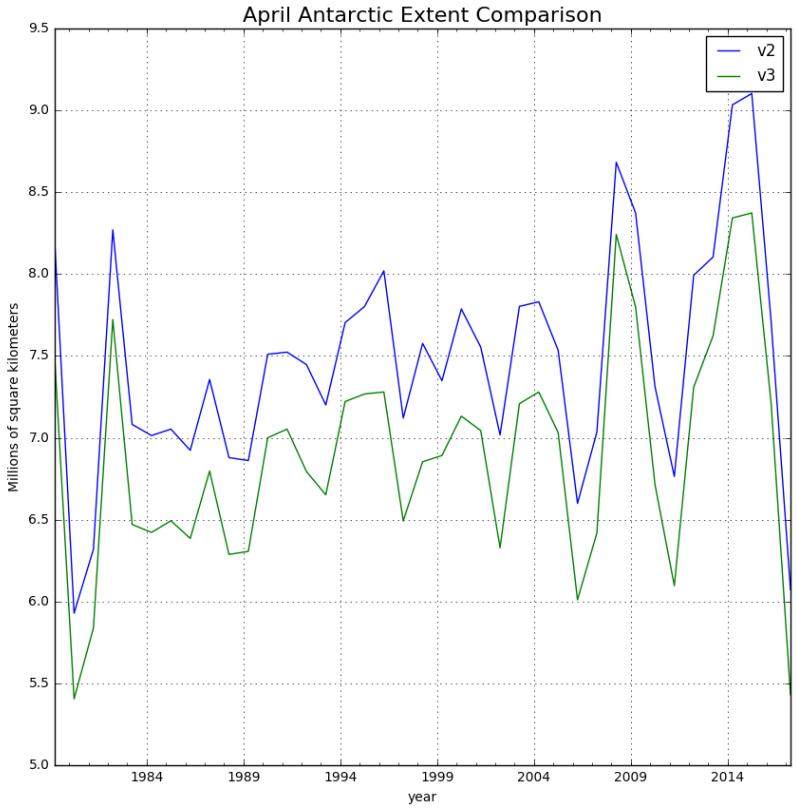

Figure 65. Comparison of V3 and V2 April Antarctic Extent in millions of sq km

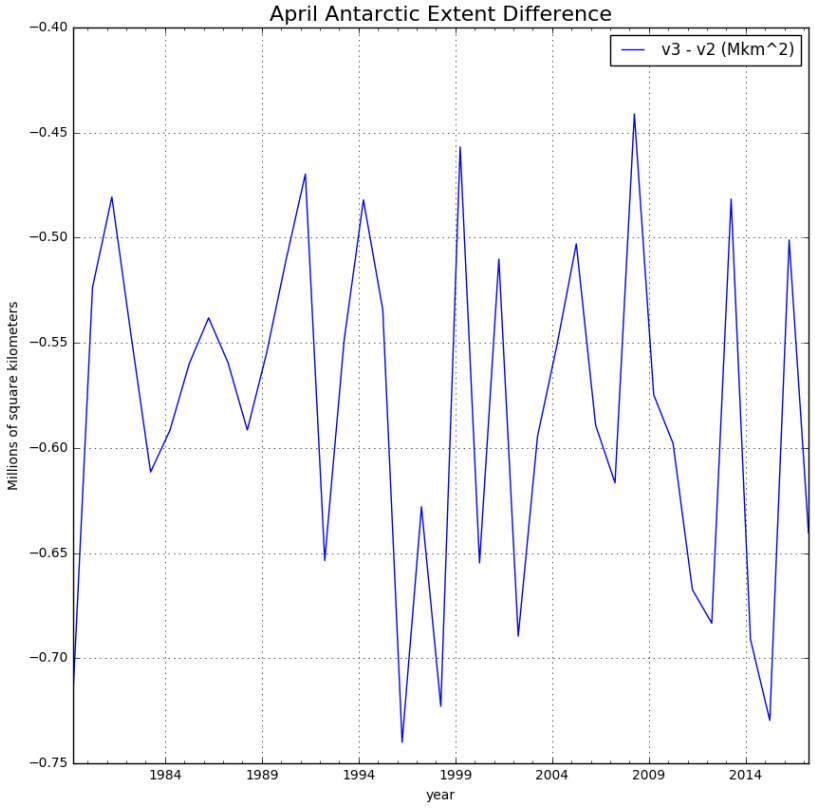

Figure 66. April Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

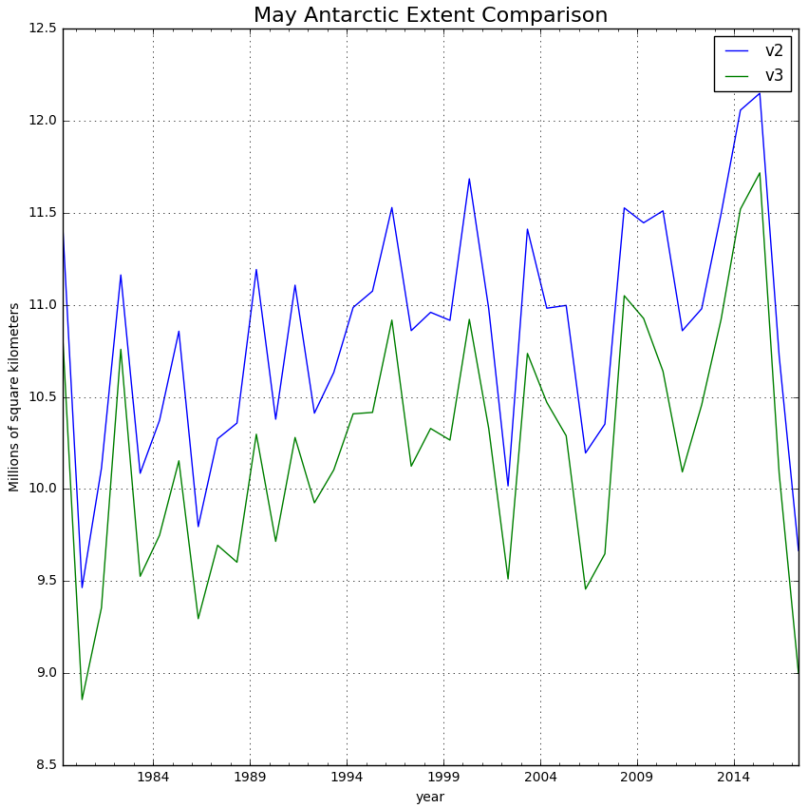

Figure 67. Comparison of V3 and V2 May Antarctic Extent in millions of sq km

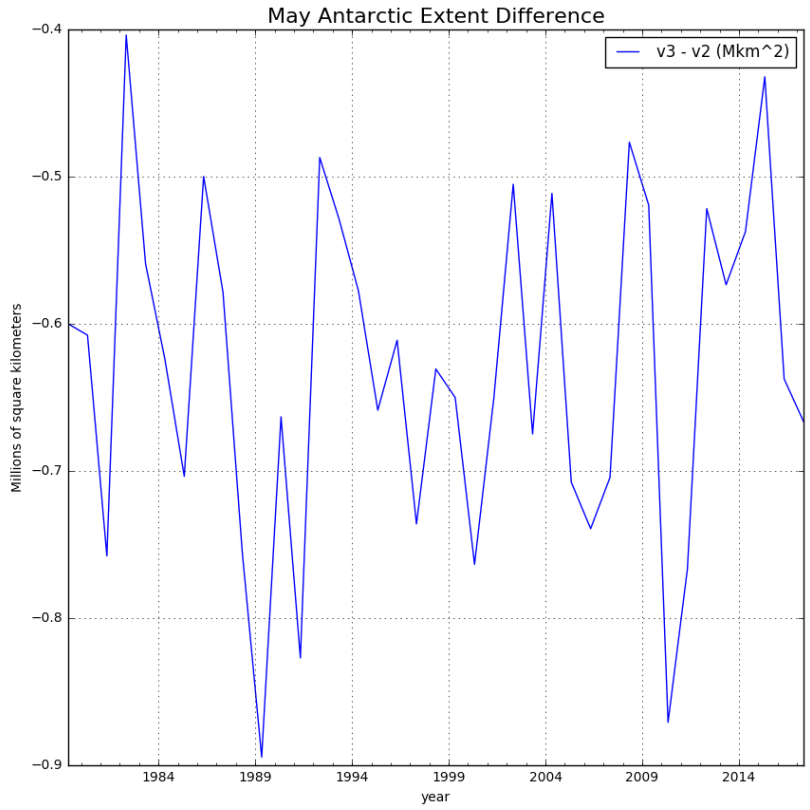

Figure 68. May Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

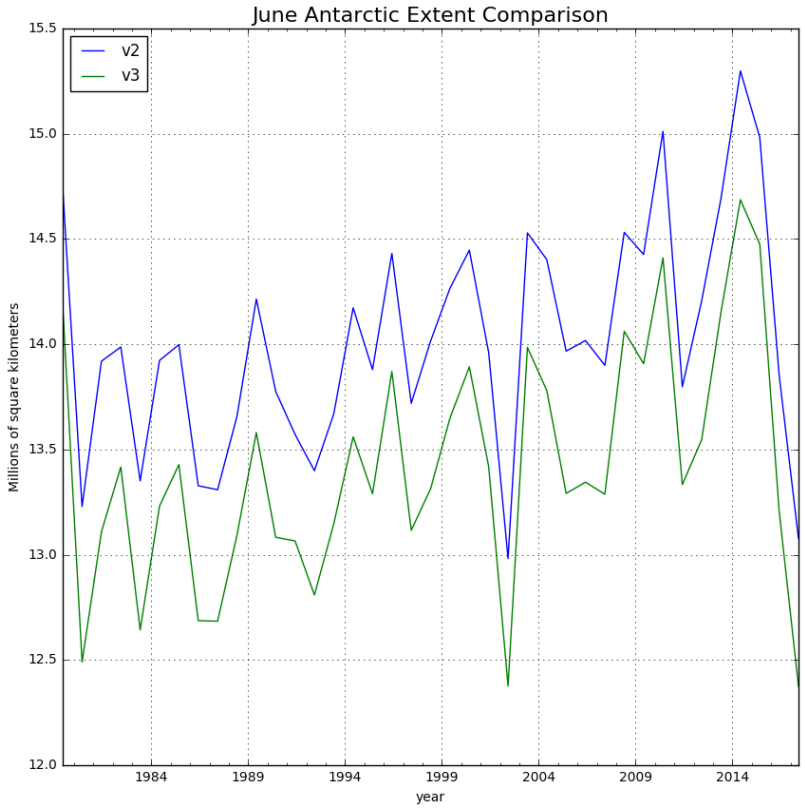

Figure 69. Comparison of V3 and V2 June Antarctic Extent in millions of sq km

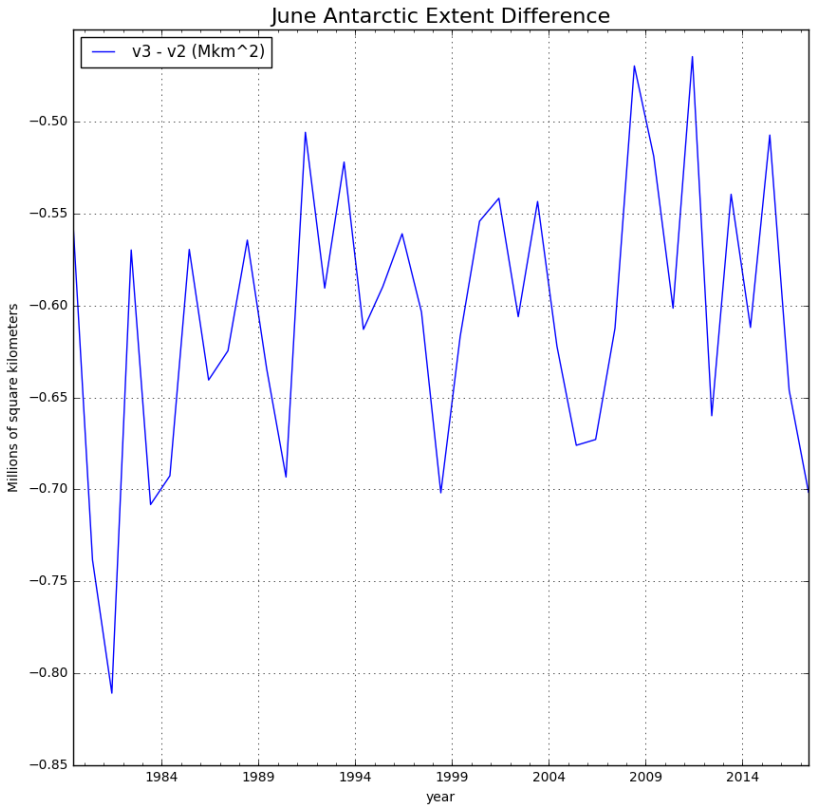

Figure 70. June Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

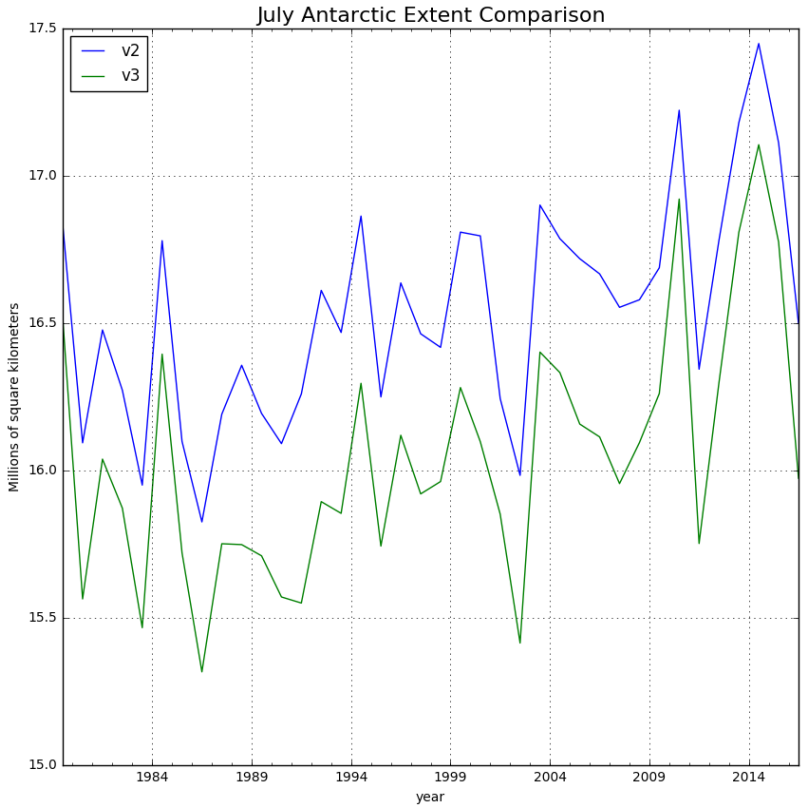

Figure 71. Comparison of V3 and V2 July Antarctic Extent in millions of sq km

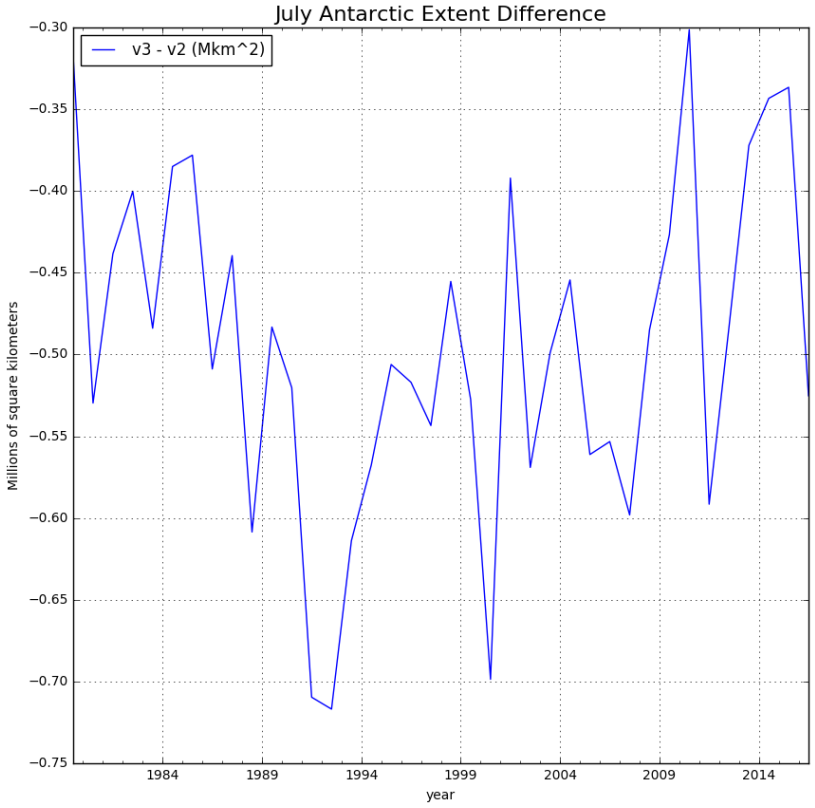

Figure 72. July Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

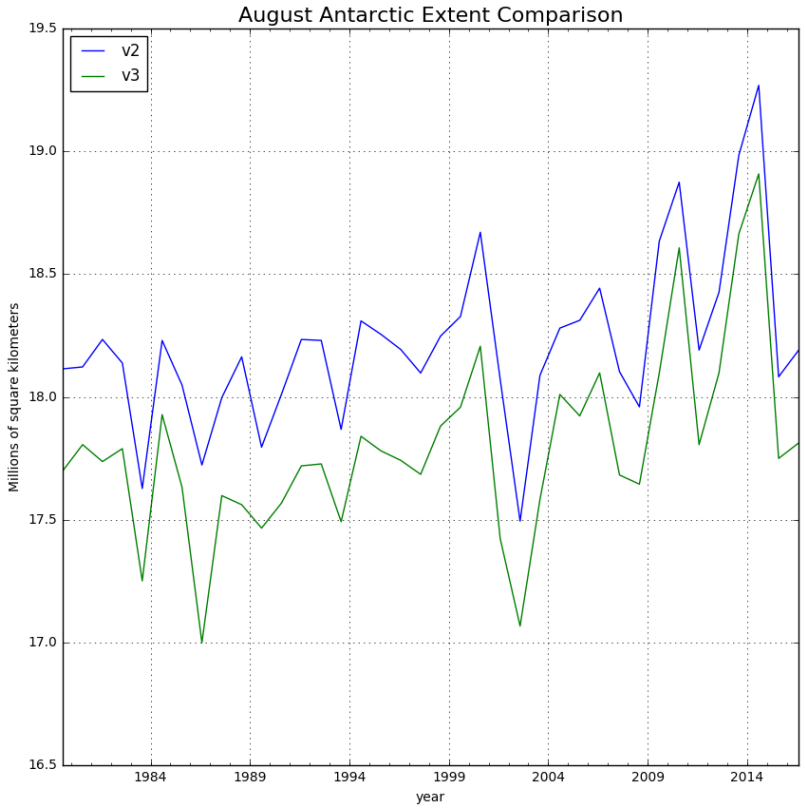

Figure 73. Comparison of V3 and V2 August Antarctic Extent in millions of sq km

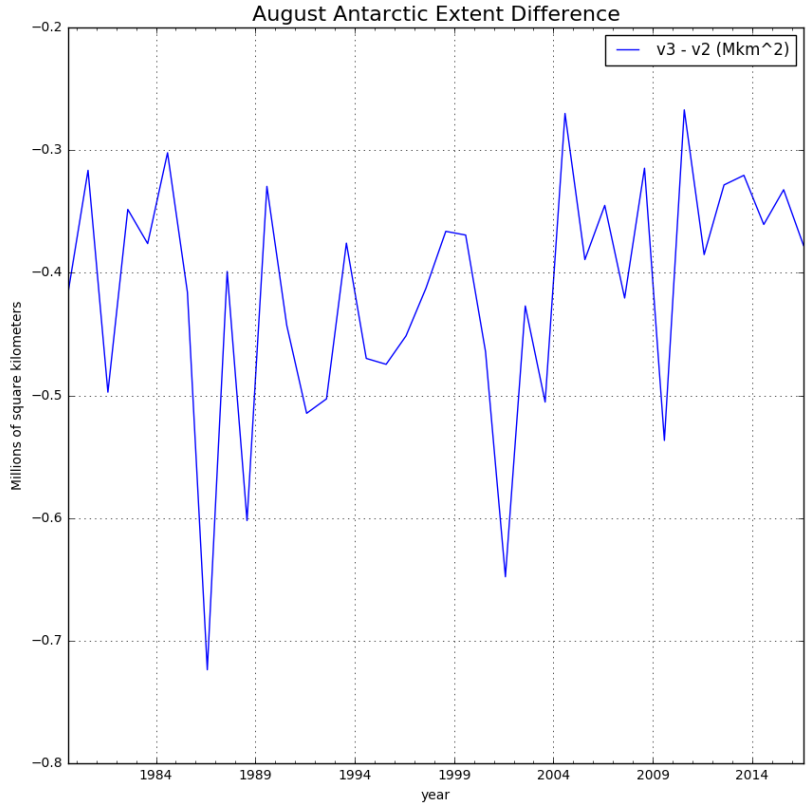

Figure 74. August Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

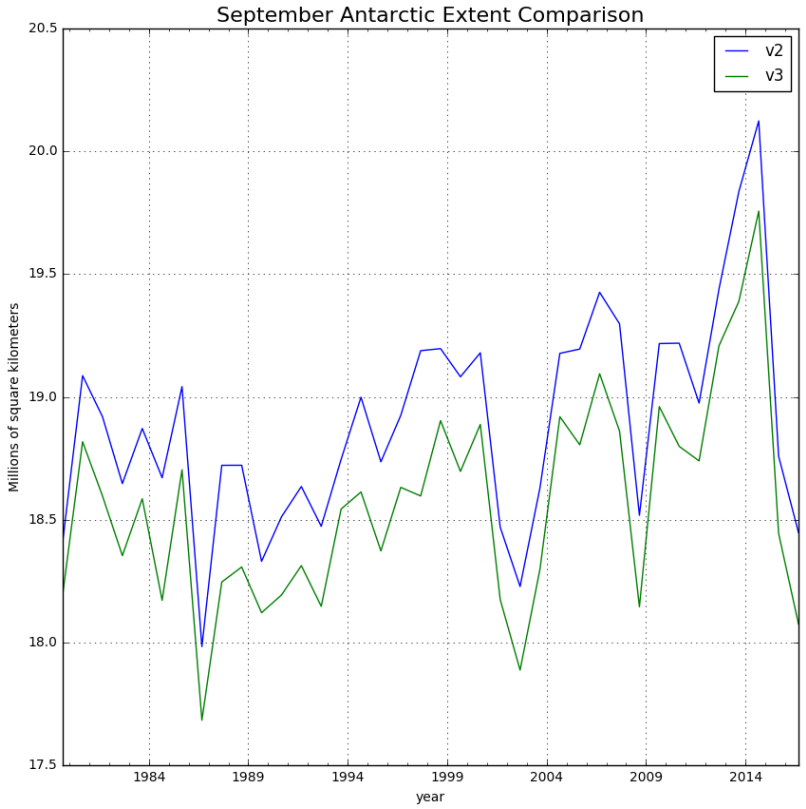

Figure 75. Comparison of V3 and V2 September Antarctic Extent in millions of sq km

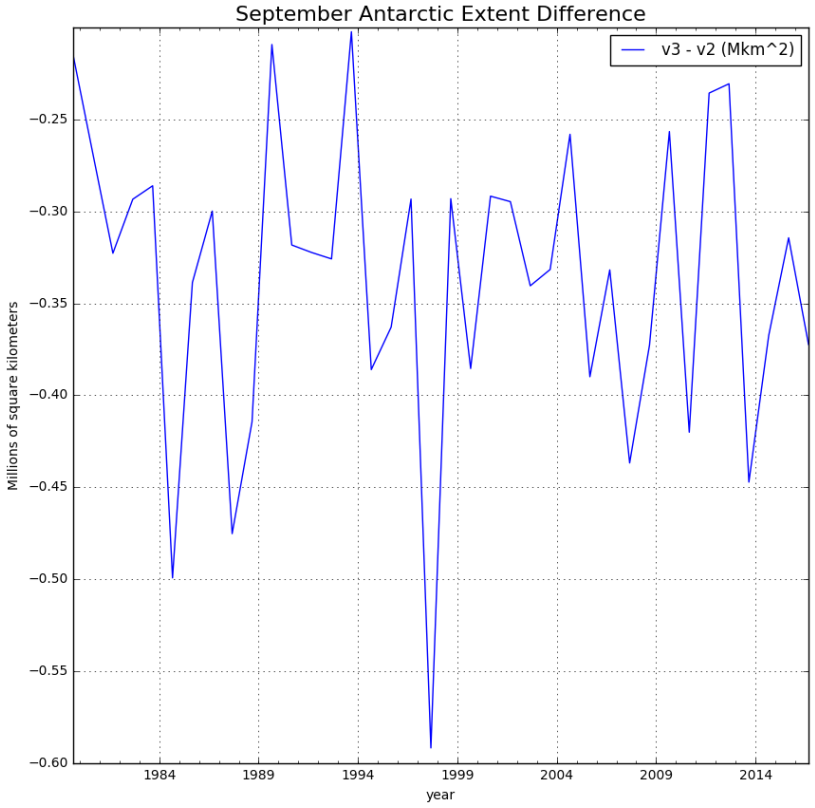

Figure 76. September Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

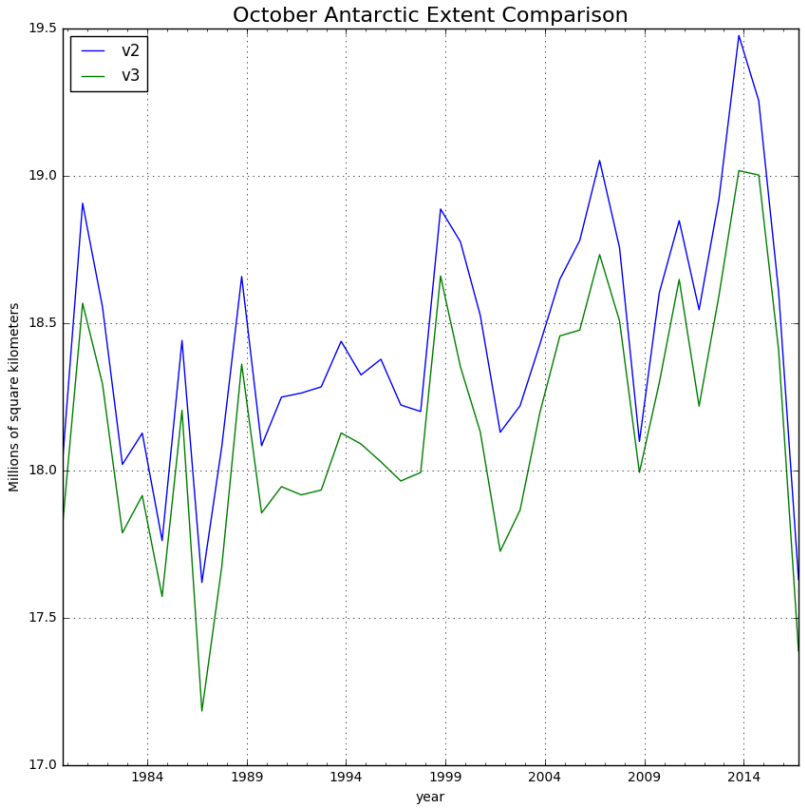

Figure 77. Comparison of V3 and V2 October Antarctic Extent in millions of sq km

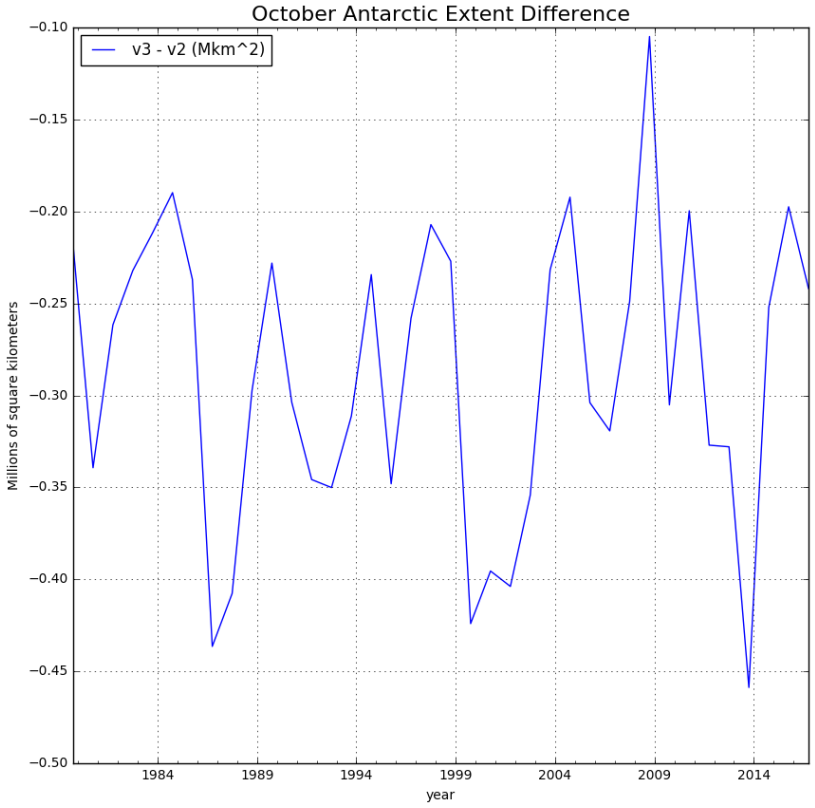

Figure 78. October Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

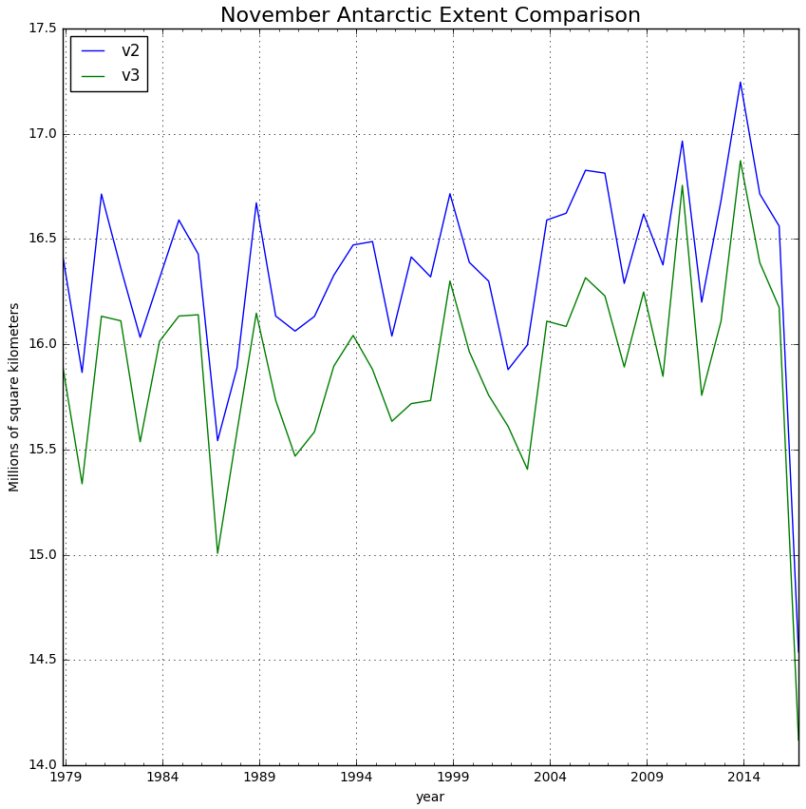

Figure 79. Comparison of V3 and V2 November Antarctic Extent in millions of sq km

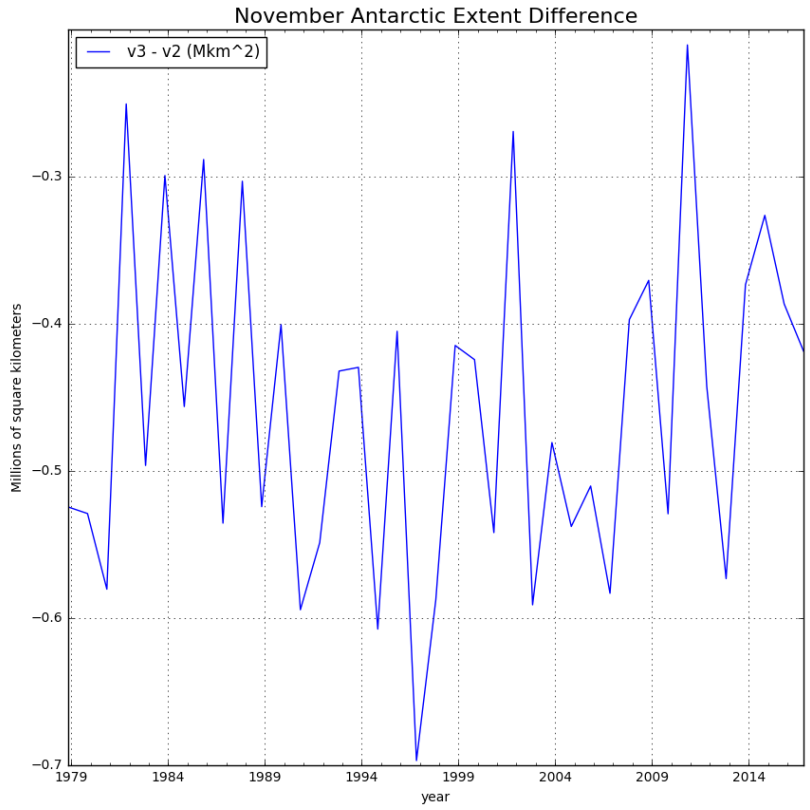

Figure 80. November Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

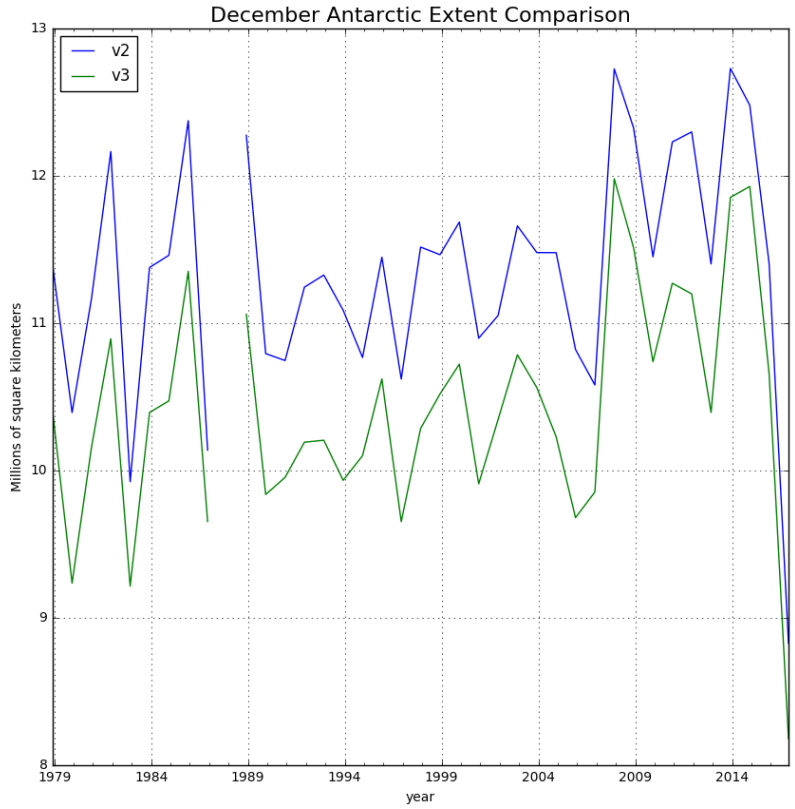

Figure 81. Comparison of V3 and V2 December Antarctic Extent in millions of sq km

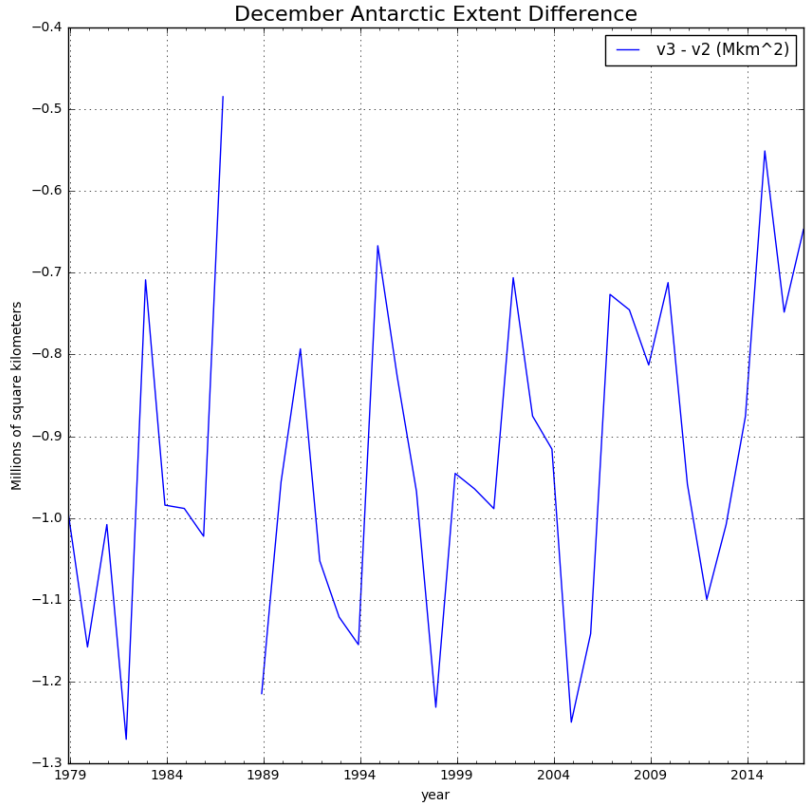

Figure 82. December Antarctic Extent Differences: V3 Method minus V2 Method in millions of sq km

Appendix 4. Antarctic Area Differences by Month

Table 17. Mean, standard deviation, minimum, maximum, and number of values for each month for the Antarctic area differences (V3 minus V2). Units are millions of sq km.

Month	*Mean*	*Stddev*	*Min*	*Max*	*N*
January	0.100	0.022	0.057	0.162	38
February	0.044	0.011	0.020	0.062	39
March	0.055	0.013	0.031	0.089	39
April	0.066	0.010	0.047	0.087	39
May	0.073	0.012	0.055	0.100	39
June	0.072	0.012	0.053	0.103	39
July	0.069	0.010	0.054	0.089	38
August	0.068	0.010	0.051	0.091	38
September	0.070	0.012	0.051	0.096	38
October	0.075	0.012	0.054	0.098	38
November	0.086	0.016	0.062	0.131	39
December	0.136	0.026	0.067	0.189	38

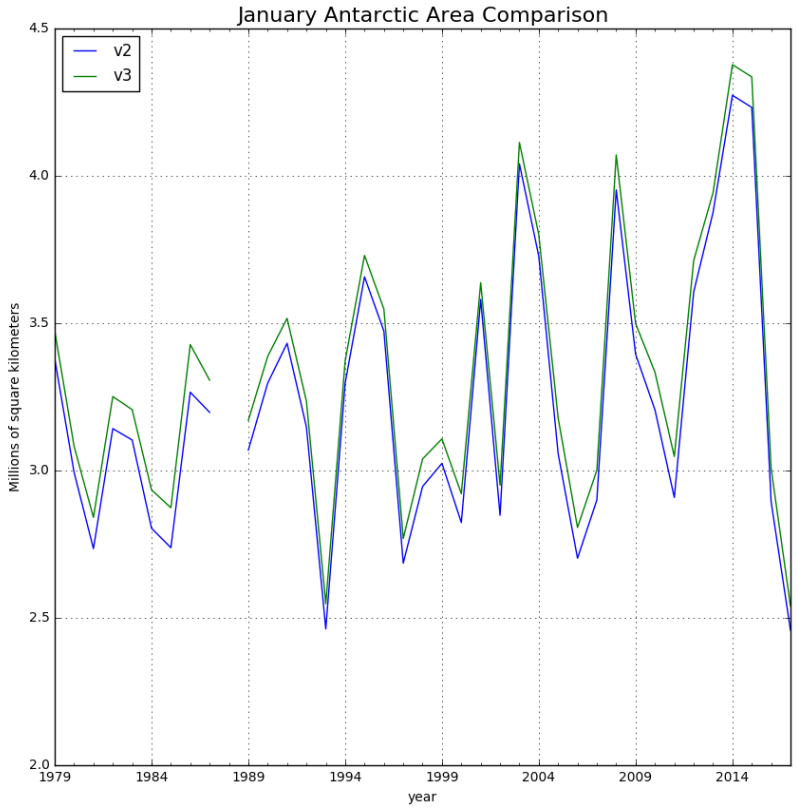

Figure 83. Comparison of V3 and V2 January Antarctic Area in millions of sq km

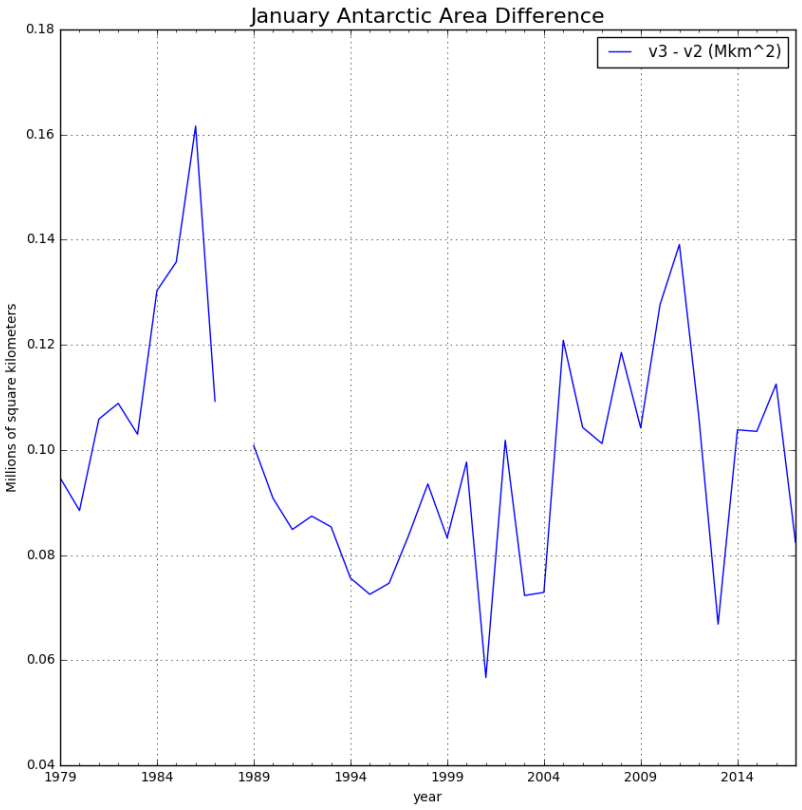

Figure 84. January Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

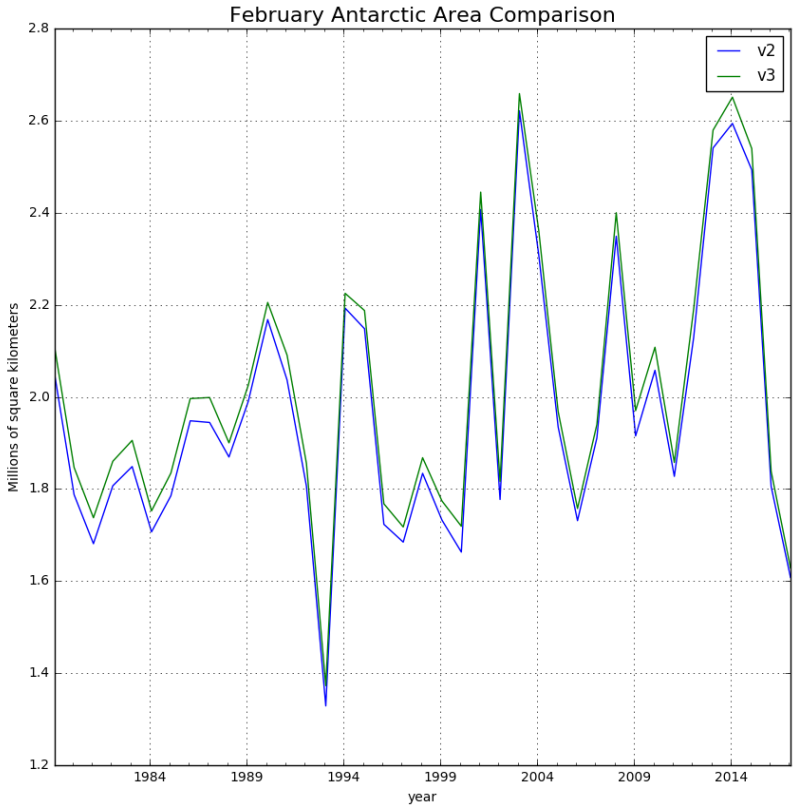

Figure 85. Comparison of V3 and V2 February Antarctic Area in millions of sq km

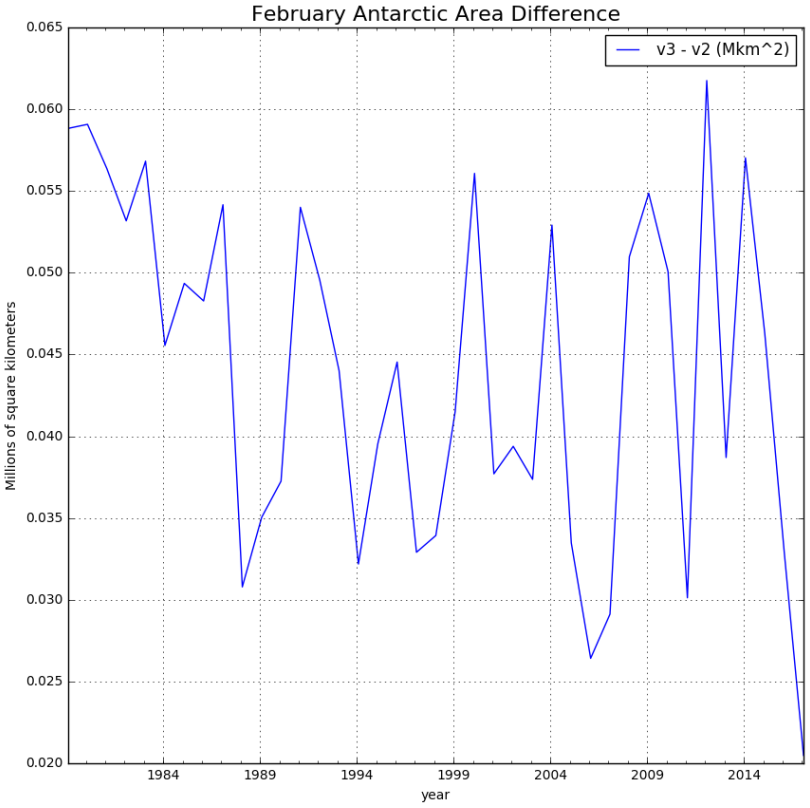

Figure 86. February Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

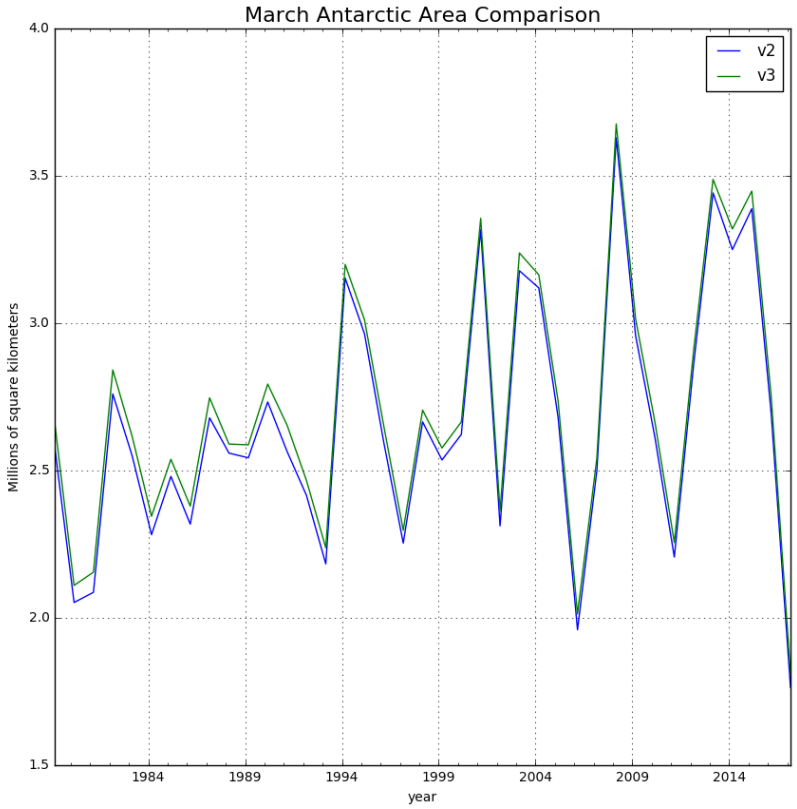

Figure 87. Comparison of V3 and V2 March Antarctic Area in millions of sq km

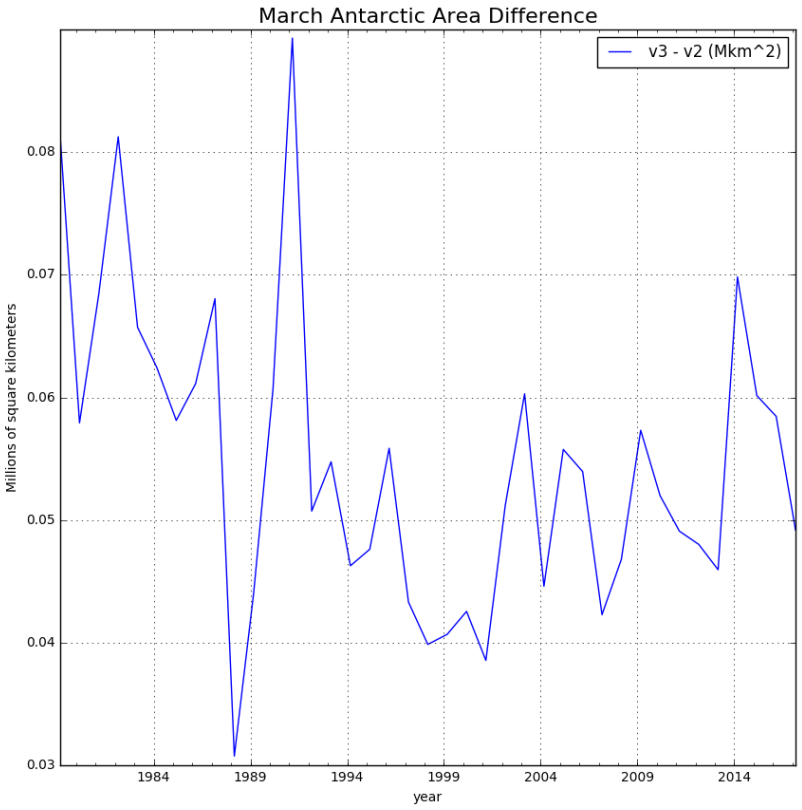

Figure 88. March Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

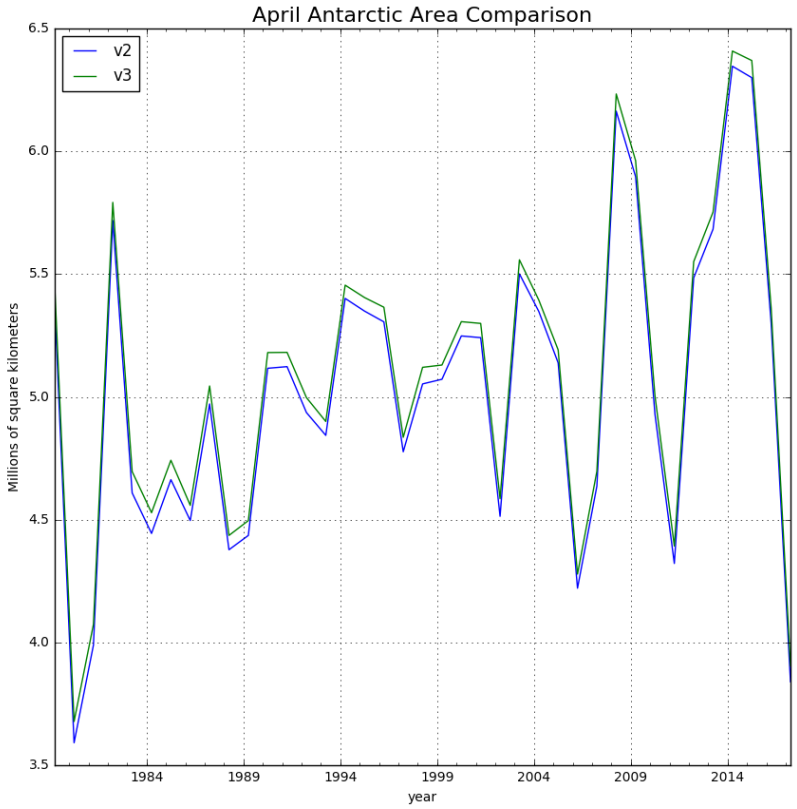

Figure 89. Comparison of V3 and V2 April Antarctic Area in millions of sq km

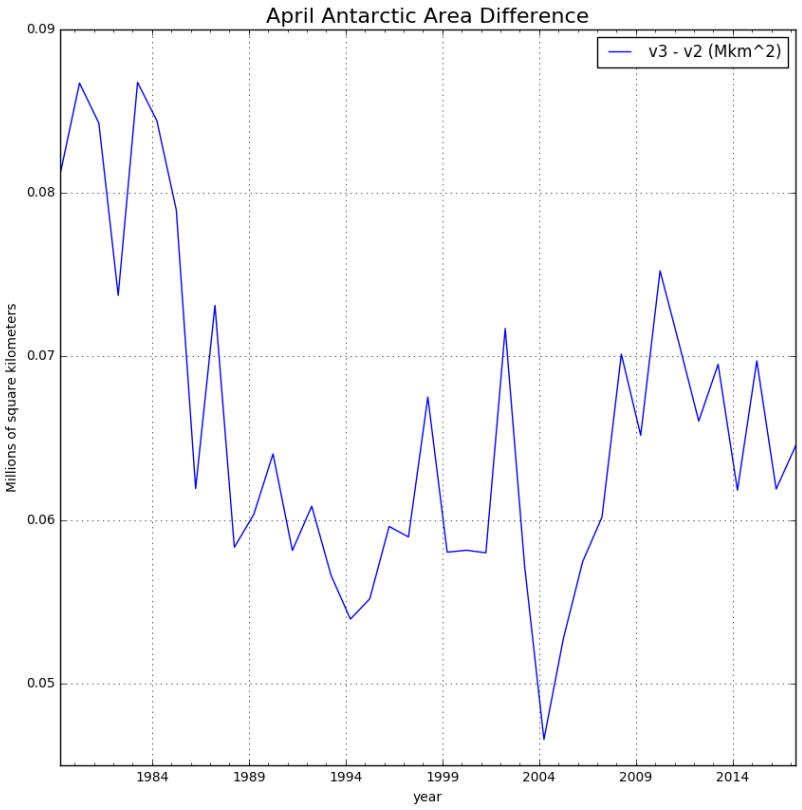

Figure 90. April Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

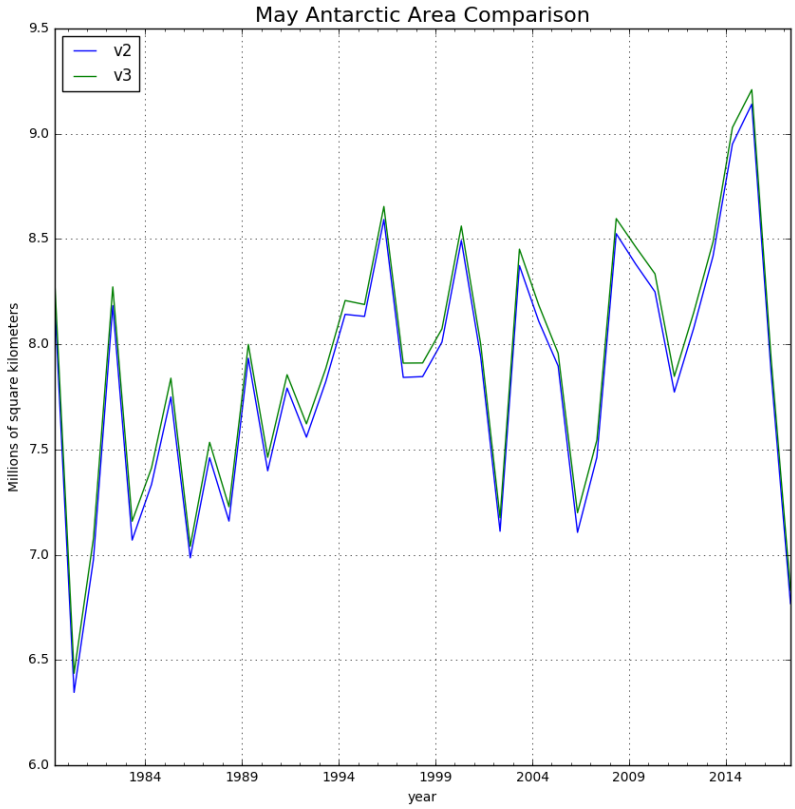

Figure 91. Comparison of V3 and V2 May Antarctic Area in millions of sq km

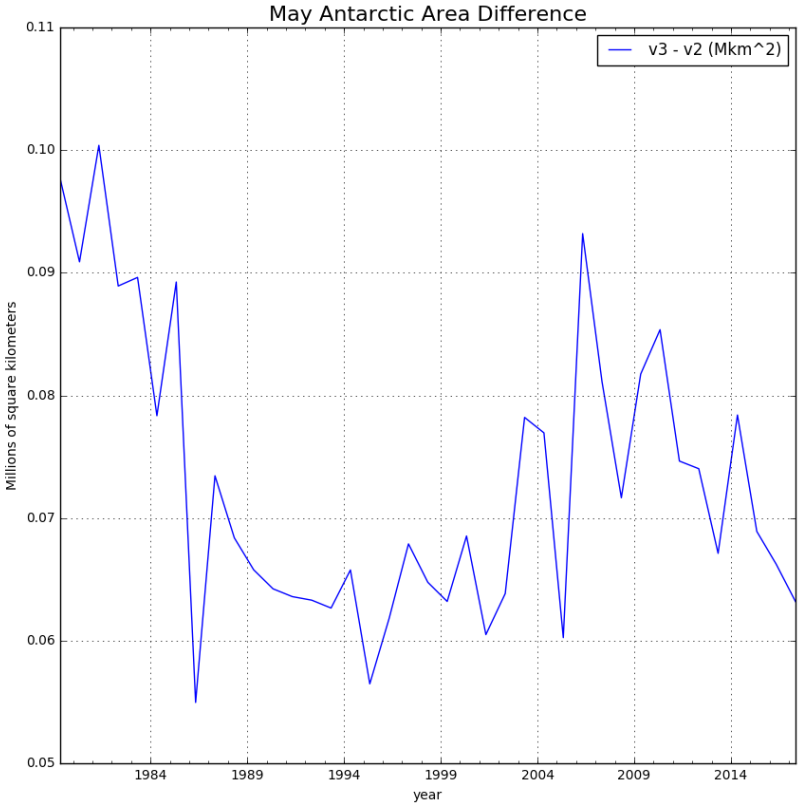

Figure 92. May Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

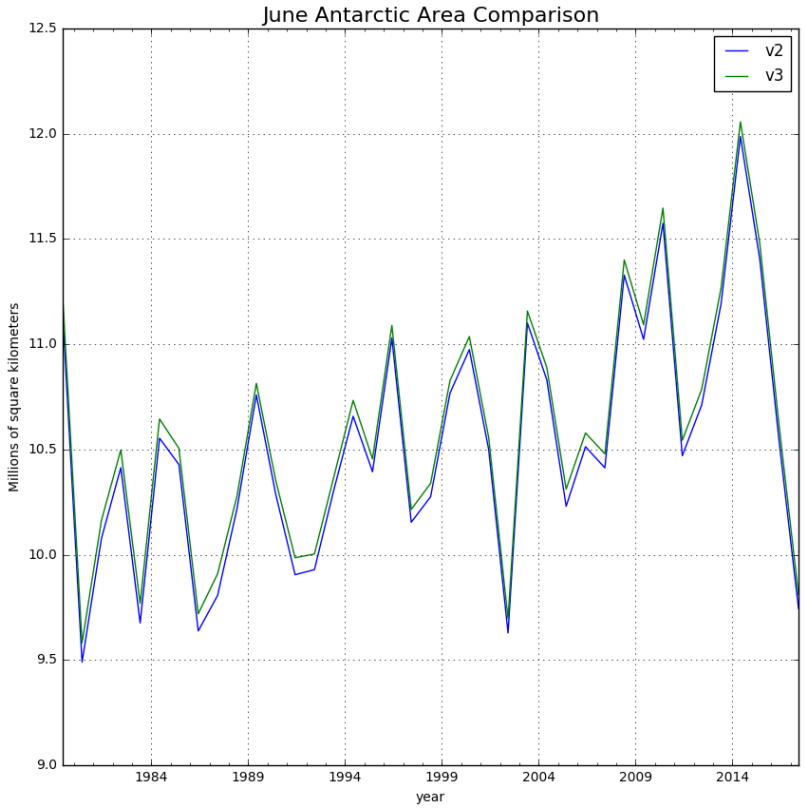

Figure 93. Comparison of V3 and V2 June Antarctic Area in millions of sq km

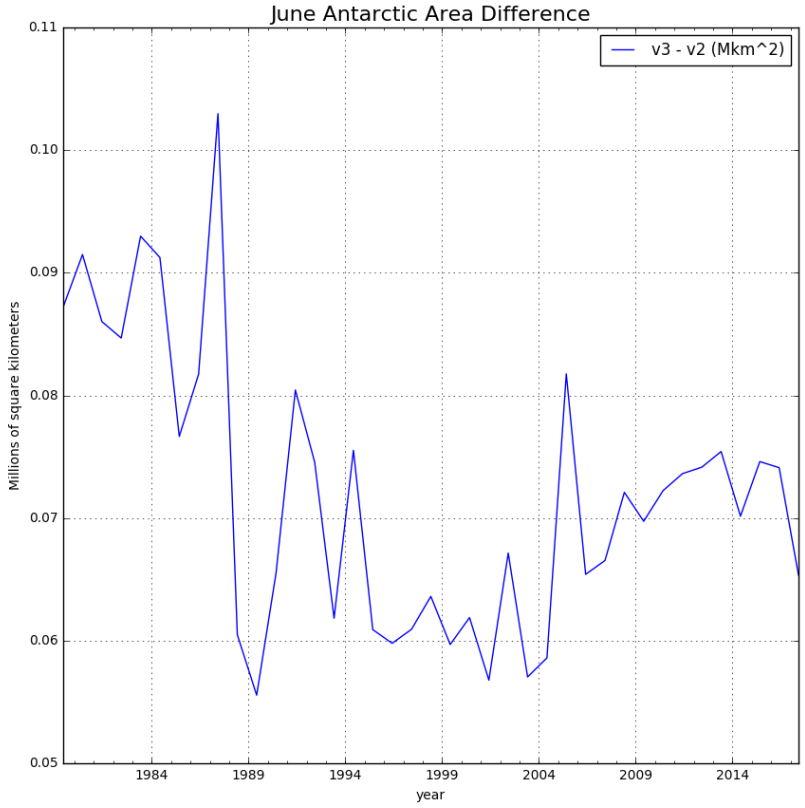

Figure 94. June Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

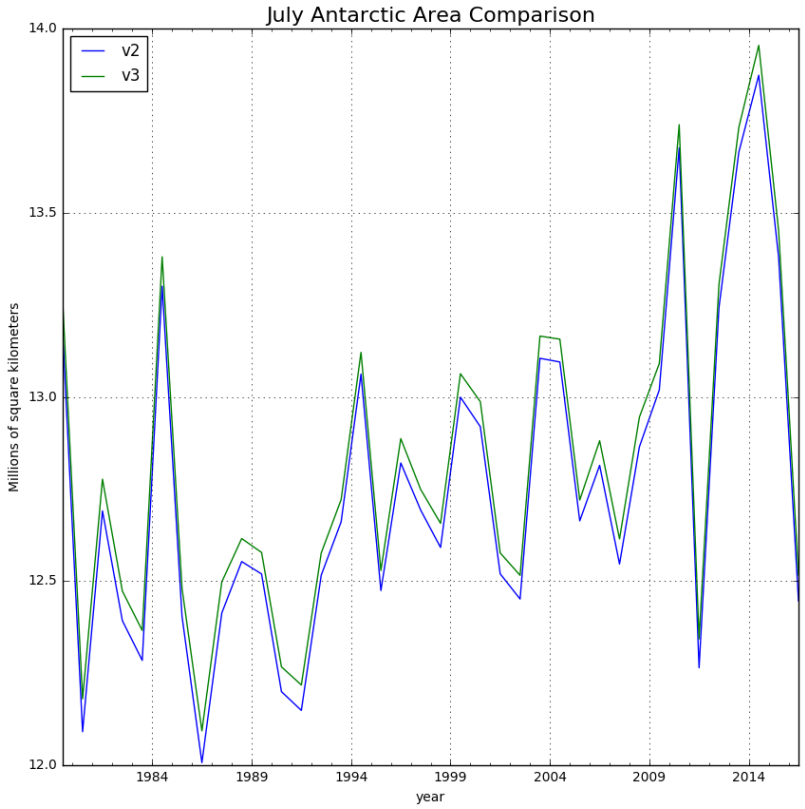

Figure 95. Comparison of V3 and V2 July Antarctic Area in millions of sq km

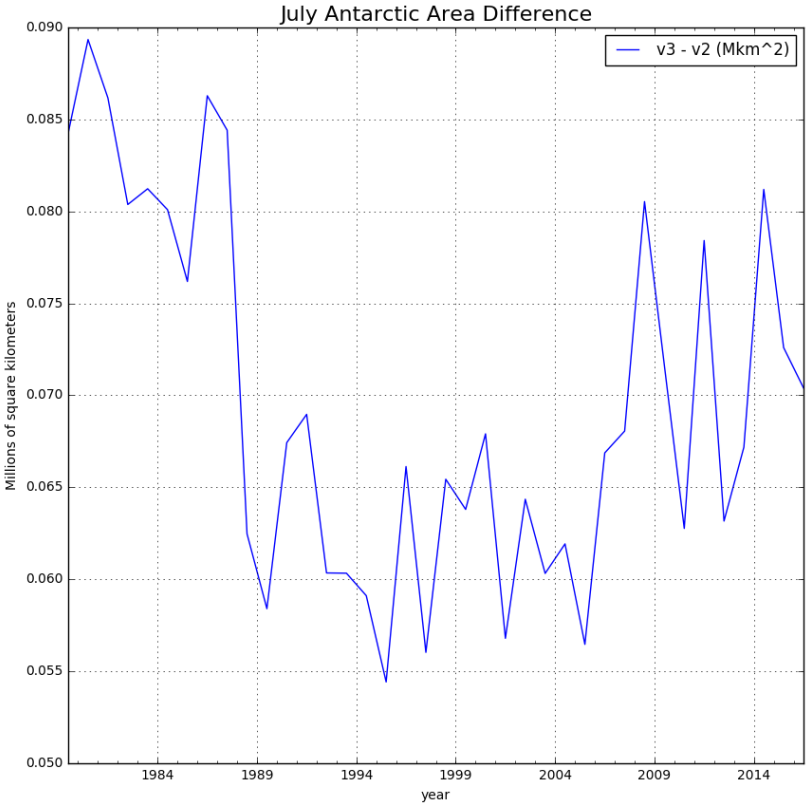

Figure 96. July Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

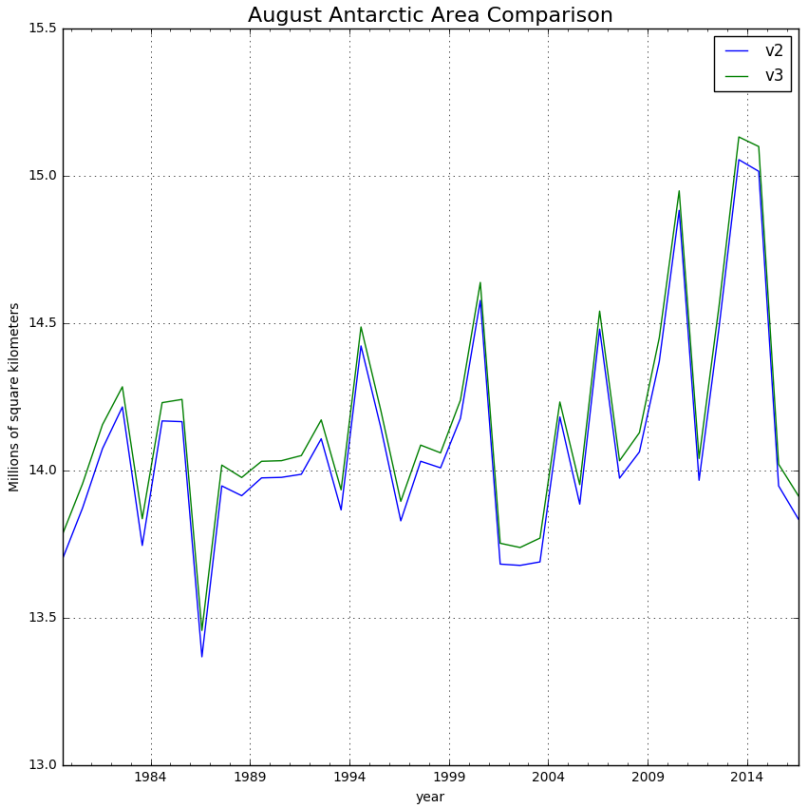

Figure 97. Comparison of V3 and V2 August Antarctic Area in millions of sq km

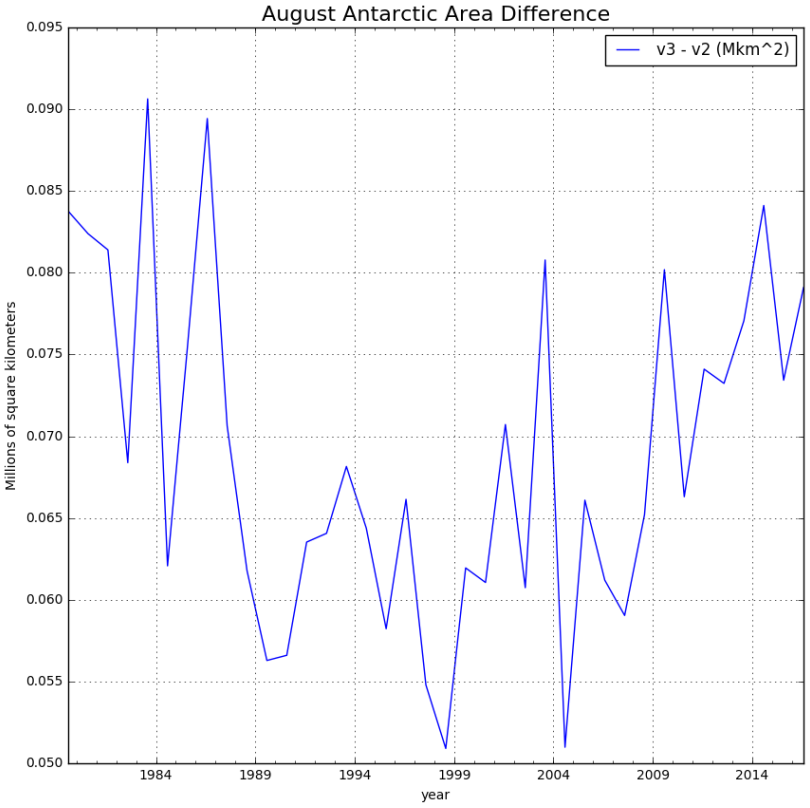

Figure 98. August Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

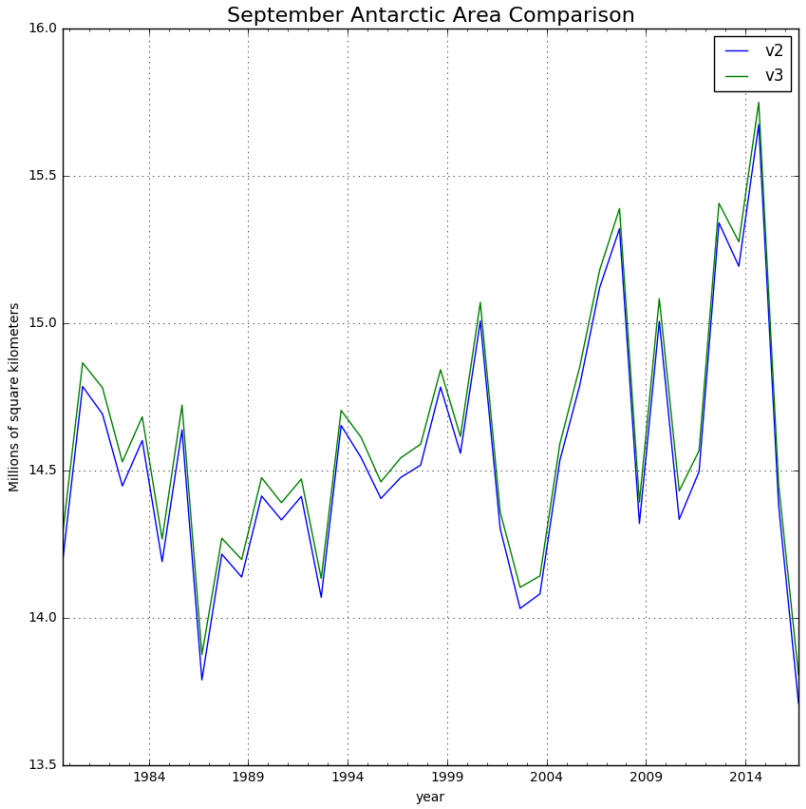

Figure 99. Comparison of V3 and V2 September Antarctic Area in millions of sq km

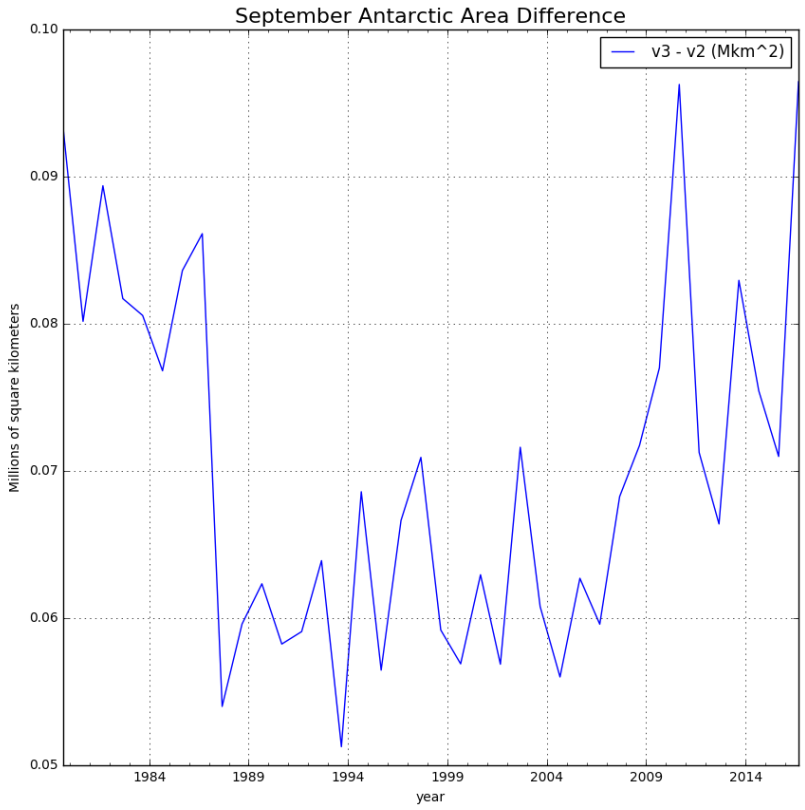

Figure 100. September Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

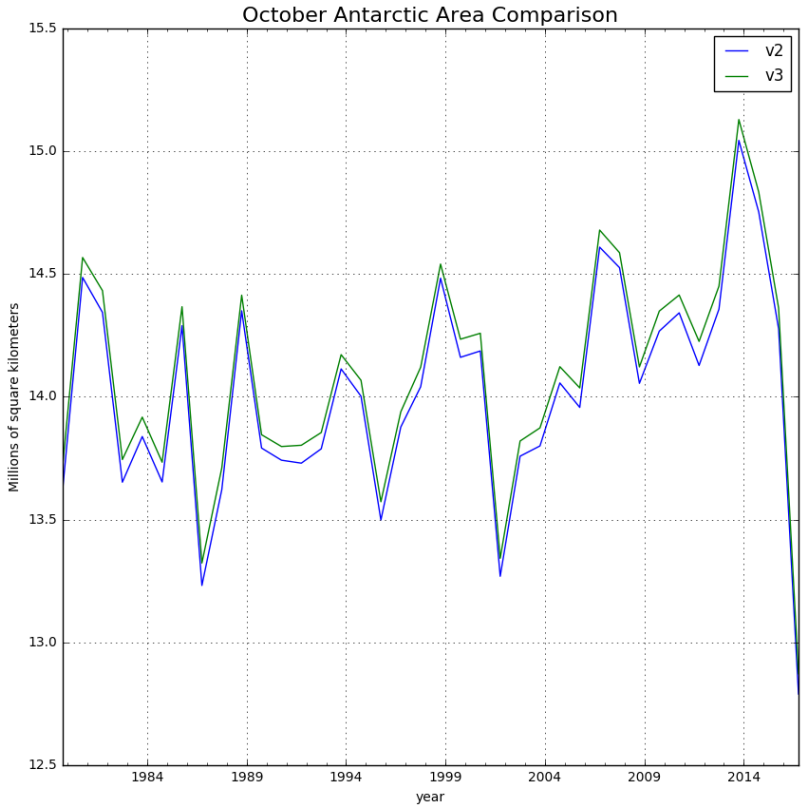

Figure 101. Comparison of V3 and V2 October Antarctic Area in millions of sq km

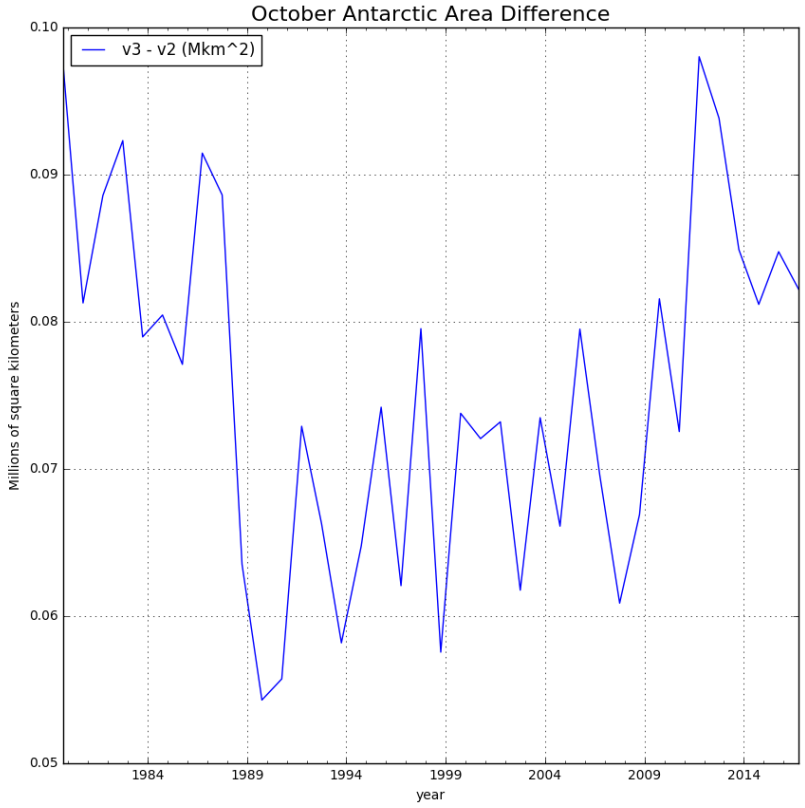

Figure 102. October Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

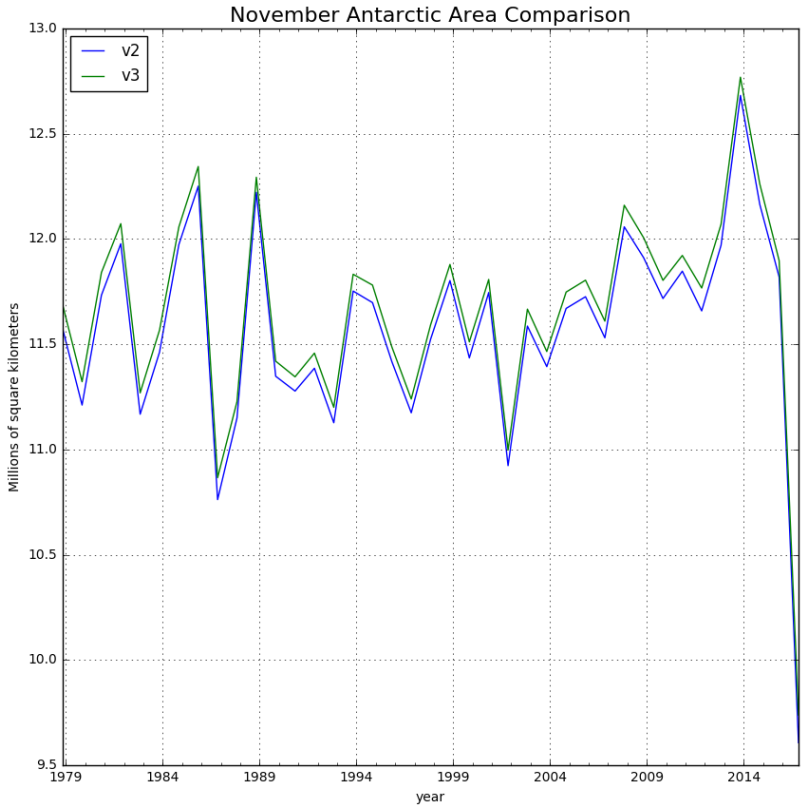

Figure 103. Comparison of V3 and V2 November Antarctic Area in millions of sq km

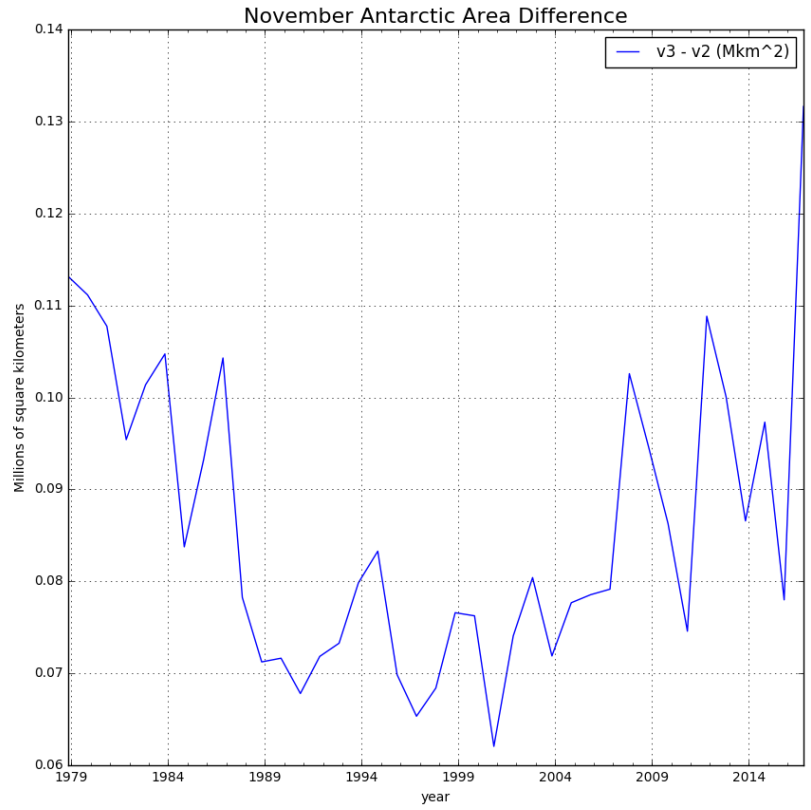

Figure 104. November Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

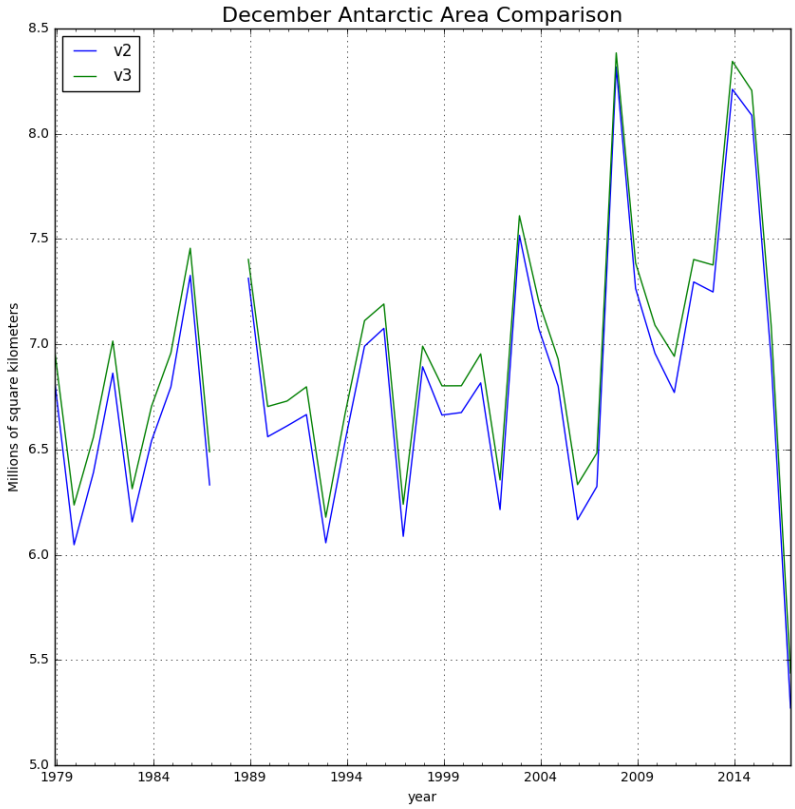

Figure 105. Comparison of V3 and V2 December Antarctic Area in millions of sq km

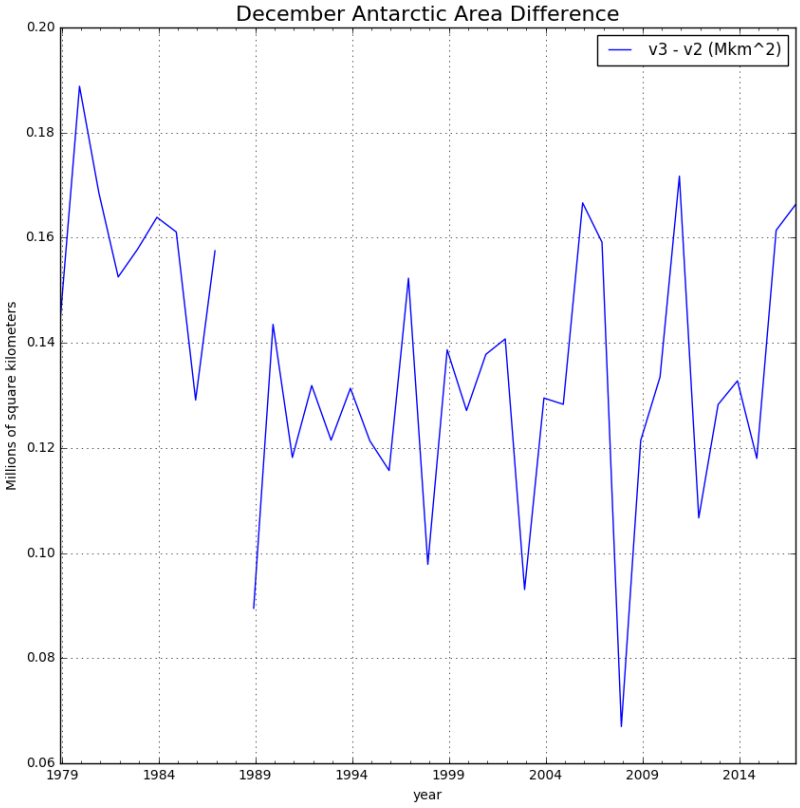

Figure 106. December Antarctic Area Differences: V3 Method minus V2 Method in millions of sq km

Appendix 5. Monthly Ranking Changes

Table 18. Changes in Monthly Rankings for the Arctic for January through June

January			February			March			April			May			June		
YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank
2017-01	1	--	**2017-02**	1	--	**2017-03**	1	--	**2016-04**	1	↑ 0.5	**2016-05**	1	--	**2016-06**	1	--
2011-01	2	↑ 1	**2016-02**	2	--	**2015-03**	2	--	**2017-04**	2	↓ 0.5	**2015-05**	2	↑ 2	**2010-06**	2	--
2016-01	3.5	↓ 1.5	**2006-02**	3	↑ 3	**2016-03**	3	--	**2007-04**	3	--	**2006-05**	3	--	**2012-06**	3	--
2006-01	3.5	↑ 0.5	**2011-02**	4	↓ 1	**2006-03**	4	--	**2015-04**	4	--	**2004-05**	4	↓ 2	**2017-06**	4	↑ 2
2015-01	5	--	**2005-02**	5	↓ 1	**2007-03**	5	↑ 1	**2006-04**	5	--	**2017-05**	5	--	**2011-06**	5	↓ 1
2014-01	6	↑ 1.5	**2015-02**	6	↓ 1	**2011-03**	6	↓ 1	**2004-04**	6	↑ 1	**2011-05**	6	↑ 1	**2015-06**	6	↓ 1
2005-01	7	↓ 1	**2014-02**	7	--	**2005-03**	7	--	**2014-04**	7.5	↑ 1.5	**2014-05**	7	↓ 1	**2006-06**	7	--
2013-01	8.5	↑ 2	**2007-02**	8	--	**2014-03**	8	--	**2005-04**	7.5	↓ 1.5	**2007-05**	8	--	**2014-06**	8	--
2007-01	8.5	↑ 0.5	**2012-02**	9	↑ 0.5	**2009-03**	9	↑ 3	**2011-04**	9	↓ 1	**2010-05**	9	↑ 6	**2005-06**	9	--
2012-01	10	↓ 2.5	**2010-02**	10	↓ 0.5	**2004-03**	10	↓ 1	**1996-04**	10	--	**2005-05**	10	--	**2008-06**	10	--
2010-01	11	↓ 0.5	**2013-02**	11	--	**2013-03**	11	↓ 1	**2013-04**	11.5	↓ 0.5	**2002-05**	12	↑ 4	**2007-06**	11	↑ 2
2008-01	12	--	**2009-02**	12	--	**1996-03**	12	↑ 1	**2002-04**	11.5	↑ 0.5	**1995-05**	12	↑ 5	**2009-06**	12	↓ 1
2009-01	13	↑ 1	**2004-02**	13	--	**2010-03**	13	↓ 2	**1989-04**	13	↑ 1	**2008-05**	12	↑ 6	**2013-06**	13	↑ 1
2004-01	14	↓ 1	**2008-02**	14	--	**2008-03**	14	↑ 1	**2008-04**	14	↓ 1	**2013-05**	14	↓ 2	**1995-06**	14	↑ 1
1996-01	15	--	**2000-02**	15	--	**2012-03**	15	↓ 1	**1995-04**	15	↑ 3	**2012-05**	15	↓ 1	**2004-06**	15	↓ 3
2001-01	16	--	**1996-02**	16	--	**2000-03**	16	--	**2009-04**	16	↓ 1	**2003-05**	16	↓ 5	**2001-06**	16	--
2000-01	17	--	**2003-02**	17	--	**1995-03**	17	--	**2003-04**	17	↓ 1	**1989-05**	17	↓ 8	**2002-06**	17	↑ 0.5
2002-01	18	↑ 0.5	**2001-02**	18	↑ 2.5	**2002-03**	18	↑ 1	**1997-04**	18.5	↓ 1.5	**1996-05**	18	↓ 5	**2003-06**	18	↑ 2
1991-01	19.5	↑ 0.5	**1995-02**	19	↓ 0.5	**1999-03**	19	↓ 1	**2000-04**	18.5	↑ 0.5	**2000-05**	19	--	**1990-06**	19	↓ 1.5
1999-01	19.5	↓ 1	**1991-02**	20	↓ 1.5	**1991-03**	20.5	↓ 0.5	**2012-04**	20	↑ 1	**1997-05**	20	↑ 2	**2000-06**	20	↓ 1
2003-01	21	--	**1984-02**	21	↓ 0.5	**1989-03**	20.5	↑ 2	**1990-04**	21	↑ 1	**2009-05**	21	↑ 2	**1998-06**	21	--
1997-01	22	--	**1999-02**	22	↑ 1	**1997-03**	22	↑ 2	**2010-04**	22	↓ 2	**1992-05**	22	↓ 2	**1997-06**	22	--
1984-01	23	--	**2002-02**	23	↓ 1	**2003-03**	23.5	↓ 2.5	**1992-04**	23	--	**1990-05**	23	↓ 2	**1999-06**	23	↑ 5
1995-01	24	--	**1997-02**	24	↑ 1	**1992-03**	23.5	↓ 1	**2001-04**	24.5	↓ 0.5	**1993-05**	24	↑ 3	**1993-06**	24	↓ 1
1992-01	25	--	**1992-02**	25	↓ 1	**2001-03**	25	↑ 2.5	**1991-04**	24.5	↑ 1.5	**1986-05**	25	↓ 1	**1988-06**	25	↓ 1
1998-01	26.5	--	**1985-02**	26	↑ 5	**1994-03**	26	--	**1998-04**	26.5	↓ 1.5	**1991-05**	26	--	**1986-06**	26	↓ 1
1985-01	26.5	↑ 1.5	**1989-02**	27	↓ 1	**1984-03**	27	↑ 0.5	**1994-04**	26.5	↑ 0.5	**1983-05**	27	↓ 2	**1994-06**	27	↓ 1
1994-01	28	↓ 1.5	**1994-02**	28	--	**1998-03**	28	↑ 1	**1984-04**	28.5	↑ 1	**2001-05**	28	↑ 2	**1996-06**	28	↓ 1
1990-01	29	↑ 1	**1990-02**	29.5	↓ 2.5	**1981-03**	29	↓ 4	**1981-04**	28.5	↓ 0.5	**1988-05**	29	--	**1991-06**	29	↑ 2
1980-01	30	↓ 1	**1988-02**	29.5	↓ 0.5	**1993-03**	30	--	**1986-04**	30	↓ 0.5	**1984-05**	30	↓ 2	**1992-06**	30.5	↓ 1.5
1986-01	31	↑ 1	**1981-02**	31	↓ 1	**1987-03**	31	↑ 1	**1993-04**	31.5	↑ 0.5	**1998-05**	31	↑ 2	**1984-06**	30.5	↓ 0.5
1993-01	32	↑ 2	**1993-02**	32	--	**1990-03**	32	↓ 1	**1999-04**	31.5	↓ 0.5	**1994-05**	32	↓ 1	**1980-06**	32	↑ 0.5
1981-01	33	↓ 2	**1998-02**	33	--	**1985-03**	33	--	**1988-04**	33	--	**1987-05**	33	↓ 1	**1985-06**	33	↑ 2
1983-01	34	↓ 1	**1986-02**	34	--	**1986-03**	34	--	**1983-04**	34	--	**1999-05**	34	↑ 0.5	**1989-06**	34	↓ 1.5
1989-01	35	--	**1980-02**	35	--	**1988-03**	35	↑ 2.5	**1987-04**	35	--	**1980-05**	35	↑ 1	**1983-06**	35	↓ 1
1987-01	36	--	**1982-02**	36	↑ 1	**1982-03**	36.5	↑ 1	**1985-04**	36	--	**1981-05**	36	↓ 1.5	**1981-06**	36	↑ 1
1982-01	37	--	**1983-02**	37	↓ 1	**1980-03**	36.5	↓ 0.5	**1980-04**	37	--	**1979-05**	37	--	**1982-06**	37	↑ 2
1979-01	38	--	**1987-02**	38	--	**1983-03**	38	↓ 3	**1979-04**	38	--	**1982-05**	38	--	**1987-06**	38	↓ 2
1988-01	NaN	--	**1979-02**	39	--	**1979-03**	39	--	**1982-04**	39	--	**1985-05**	39	--	**1979-06**	39	↓ 1

Table 19. Changes in Monthly Rankings for the Arctic for July through December

July			August			September			October			November			December		
YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank
2012-07	1	↑ 1	**2012-08**	1	--	**2012-09**	1	--	**2012-10**	1	↑ 2	**2016-11**	1	--	**2016-12**	1	↑ 1
2011-07	2	↓ 1	**2007-08**	2	--	**2007-09**	2	--	**2016-10**	2.5	↓ 1.5	**2012-11**	2	↑ 2	**2010-12**	2	↓ 1
2016-07	3	--	**2016-08**	3	↑ 1	**2016-09**	3	↑ 2	**2007-10**	2.5	↓ 0.5	**2010-11**	3	--	**2006-12**	3	↑ 1.5
2007-07	4	--	**2011-08**	4	↓ 1	**2011-09**	4	↓ 1	**2011-10**	4	--	**2006-11**	4	↓ 2	**2012-12**	4	↓ 1
2010-07	5	↑ 1	**2015-08**	5	--	**2015-09**	5	↓ 1	**2009-10**	5	--	**2007-11**	5	↑ 1	**2007-12**	5	↑ 1.5
2014-07	6	↓ 1	**2010-08**	6	--	**2008-09**	6	--	**2015-10**	6	↑ 1	**2011-11**	6.5	↓ 1.5	**2015-12**	6	↓ 1.5
2013-07	7	--	**2008-08**	7	--	**2010-09**	7	--	**2010-10**	7	↓ 1	**2009-11**	6.5	↑ 2	**2011-12**	7	↑ 1
2015-07	8	↑ 1	**2013-08**	8	--	**2013-09**	8	↑ 1	**2014-10**	8	--	**2015-11**	8	↓ 1	**2013-12**	8	↓ 1.5
2006-07	9	↓ 1	**2014-08**	9	--	**2014-09**	9	↓ 1	**2008-10**	9.5	↑ 1.5	**2013-11**	9	↓ 0.5	**2009-12**	9	↑ 1
2009-07	10	--	**2009-08**	10	--	**2009-09**	10	--	**2005-10**	9.5	↑ 2.5	**2014-11**	10	↑ 1	**2005-12**	10	↓ 1
2005-07	11	--	**2005-08**	11	--	**2005-09**	11	--	**2013-10**	11	↓ 2	**2003-11**	11	↓ 1	**2014-12**	11	↑ 1
2008-07	12	--	**2006-08**	12	--	**2002-09**	12	↑ 1	**2006-10**	12	↓ 2	**2005-11**	12	--	**2008-12**	12	↓ 1
1995-07	13	--	**2002-08**	13	--	**2006-09**	13	↓ 1	**1995-10**	13	↑ 9	**2000-11**	13	--	**2001-12**	13	↑ 4
2001-07	14	--	**1995-08**	14	--	**2004-09**	14	--	**2003-10**	14	↑ 1	**2008-11**	15	--	**2004-12**	14	↓ 1
2003-07	15	--	**1990-08**	15	↑ 0.5	**1995-09**	15	↑ 0.5	**2004-10**	15	↓ 2	**2004-11**	15	↑ 1	**2003-12**	15	--
1990-07	16	↑ 5	**2004-08**	16	↓ 0.5	**2003-09**	16.5	↓ 1	**2002-10**	16	↑ 1	**2002-11**	15	↑ 3	**2002-12**	16	↓ 1
2002-07	17	↓ 1	**2003-08**	17	--	**1999-09**	16.5	↑ 1.5	**2001-10**	17	↓ 3	**1996-11**	17	↓ 3	**1999-12**	17.5	↑ 0.5
1997-07	18	↑ 1	**2000-08**	18	--	**1990-09**	18	↓ 1	**1997-10**	18	↓ 2	**1998-11**	18	↓ 1	**2000-12**	17.5	↓ 2.5
1998-07	19	↑ 1	**1999-08**	19	↑ 2	**2000-09**	19	--	**2000-10**	19	↑ 2	**2001-11**	19	↑ 0.5	**1998-12**	19	↑ 5
2004-07	20	↓ 2.5	**1997-08**	20	↓ 1	**1993-09**	20	--	**1998-10**	20	↓ 1	**1997-11**	20	↓ 0.5	**1996-12**	20	↑ 1
1993-07	21	↑ 1	**1993-08**	21	↓ 1	**1991-09**	21	--	**1990-10**	21	↑ 7	**1995-11**	21	↑ 1	**1995-12**	21	↓ 2
1999-07	22	↓ 4.5	**1985-08**	22	↑ 1	**1998-09**	22	--	**1991-10**	22	↑ 2	**1999-11**	22	↓ 1	**1991-12**	22	↓ 1
2000-07	23.5	↑ 0.5	**1991-08**	23	↓ 1	**1997-09**	23	↑ 0.5	**1985-10**	23	↓ 3	**1984-11**	23	↑ 3	**1984-12**	23	↓ 2
1991-07	23.5	↓ 0.5	**2001-08**	24	--	**1985-09**	24	↑ 1	**1984-10**	24	↓ 6	**1991-11**	24	↓ 1	**1985-12**	24	↓ 1
1985-07	25	↑ 1	**1998-08**	25	--	**2001-09**	25	↓ 1.5	**1999-10**	25	↓ 2	**1981-11**	25	--	**1997-12**	25	--
1988-07	26	↓ 1	**1987-08**	26	↑ 1	**1984-09**	26	↑ 1	**1979-10**	26	↑ 3.5	**1979-11**	26	↓ 2	**1990-12**	26	--
1994-07	27	↑ 1	**1994-08**	27	↓ 1	**1989-09**	27	↓ 1	**1993-10**	27	↓ 1	**1985-11**	27	↑ 2	**1986-12**	27	--
1984-07	28	↓ 1	**1984-08**	28	↑ 1	**1979-09**	28	--	**1989-10**	28	↑ 6	**1990-11**	28	--	**1994-12**	28	↑ 5
1980-07	29	--	**1981-08**	29	↓ 1	**1994-09**	29.5	↓ 0.5	**1981-10**	29	↓ 4	**1994-11**	29.5	↓ 2.5	**1983-12**	29	↓ 1
1989-07	30	↑ 1	**1989-08**	30	↑ 2	**1981-09**	29.5	↑ 0.5	**1994-10**	30	↑ 3	**1989-11**	29.5	↑ 0.5	**1993-12**	30	↑ 1.5
1986-07	31	↑ 1	**1988-08**	31	--	**1987-09**	31	↑ 1	**1987-10**	31	↓ 4	**1987-11**	31	--	**1981-12**	31.5	↑ 3.5
1996-07	32	↓ 2	**1992-08**	32	↓ 2	**1982-09**	32	↓ 1	**1988-10**	32	--	**1993-11**	32	↑ 3	**1979-12**	31.5	--
1981-07	33	↑ 1	**1986-08**	33.5	↓ 0.5	**1988-09**	33	--	**1996-10**	33	↓ 3.5	**1988-11**	33	↑ 1	**1989-12**	33	↓ 3
1979-07	34	↓ 1	**1980-08**	33.5	↑ 0.5	**1983-09**	34	--	**1980-10**	34	↓ 3	**1992-11**	34.5	↑ 2.5	**1992-12**	34	↓ 5
1992-07	35	--	**1979-08**	35	--	**1986-09**	35	--	**1992-10**	35	--	**1980-11**	34.5	↓ 1.5	**1980-12**	35	↓ 1
1987-07	36	↑ 0.5	**1982-08**	36	↑ 1	**1992-09**	36	--	**1983-10**	36	--	**1986-11**	36	--	**1988-12**	36	↑ 0.5
1982-07	37	↓ 0.5	**1996-08**	37	↓ 1	**1996-09**	37	↑ 1	**1982-10**	37	↑ 1	**1983-11**	37	↓ 5	**1982-12**	37	↓ 0.5
1983-07	38	--	**1983-08**	38	--	**1980-09**	38	↓ 1	**1986-10**	38	↓ 1	**1982-11**	38	--	**1978-12**	38	--
												1978-11	39	--	**1987-12**	NaN	--

Table 20. Changes in Monthly Rankings for the Antarctic for January through June

January			February			March			April			May			June		
YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank
2017-01	1	--	**2017-02**	1	--	**2017-03**	1	--	**1980-04**	1	--	**1980-05**	1	--	**2017-06**	1	↑ 1
2006-01	2	--	**1993-02**	2	↑ 2	**2006-03**	2	--	**2017-04**	2	--	**2017-05**	2	--	**2002-06**	2	↓ 1
1997-01	3	--	**1997-02**	3	↓ 0.5	**1980-03**	3	--	**1981-04**	3	--	**1986-05**	3	--	**1980-06**	3	--
1981-01	4.5	↑ 0.5	**2011-02**	4	↓ 1.5	**2011-03**	4	--	**2006-04**	4	--	**1981-05**	4	↑ 2	**1983-06**	4	↑ 2
1993-01	4.5	↑ 2.5	**2006-02**	5	--	**1981-03**	5	--	**2011-04**	5	--	**2006-05**	5	↑ 2	**1987-06**	5	↓ 1
1985-01	6.5	↓ 2.5	**1984-02**	6	--	**1997-03**	6	--	**1988-04**	6	↑ 1	**2002-05**	6	↓ 2	**1986-06**	6	↓ 1
1998-01	6.5	↓ 0.5	**2016-02**	7	--	**1992-03**	7	↑ 5	**1989-04**	7	↓ 1	**1983-05**	7	↓ 2	**1992-06**	7	--
2011-01	8	↑ 0.5	**1980-02**	8	↑ 1	**1984-03**	8	↓ 1	**2002-04**	8	↑ 2	**1988-05**	8	↑ 2	**1991-06**	8	--
1980-01	9	↓ 0.5	**1992-02**	9.5	↑ 2.5	**1993-03**	9	↑ 5	**1986-04**	9	↓ 1	**2007-05**	9	--	**1990-06**	9	↑ 3
2007-01	10	↑ 3	**1985-02**	9.5	↓ 1.5	**1986-03**	10	↑ 1	**1984-04**	10.5	↓ 1.5	**1987-05**	10	↓ 2	**1988-06**	10	↓ 1
2016-01	11	↑ 8	**1981-02**	11	↓ 1	**1985-03**	11	↓ 2.5	**2007-04**	10.5	↑ 0.5	**1990-05**	11	↑ 1	**1981-06**	11	↑ 6.5
2002-01	12.5	↓ 2.5	**1988-02**	12	↓ 1	**2002-03**	12	↓ 3.5	**1983-04**	12	↑ 1	**1984-05**	12	↓ 1	**1997-06**	12	↓ 1
1989-01	12.5	↑ 1.5	**2007-02**	13	↑ 0.5	**1991-03**	13	↑ 4	**1997-04**	13.5	↑ 0.5	**1992-05**	13	--	**1993-06**	13	↓ 3
2000-01	15	↓ 4	**2000-02**	14	↓ 0.5	**2007-03**	14	↓ 1	**1985-04**	13.5	↓ 1.5	**2011-05**	14.5	↑ 2.5	**2016-06**	14	--
2005-01	15	↑ 2	**2002-02**	15	↑ 0.5	**2010-03**	15	↓ 5	**1993-04**	15	--	**2016-05**	14.5	↑ 0.5	**1984-06**	15	↑ 2.5
1992-01	15	↓ 3	**2005-02**	16.5	↑ 0.5	**1989-03**	16	↓ 1	**2010-04**	16	--	**1993-05**	16	↓ 2	**2005-06**	17	↑ 3
1983-01	17	↓ 2	**1999-02**	16.5	↑ 1.5	**1990-03**	17.5	↑ 1.5	**1992-04**	17	↑ 2	**1997-05**	17	--	**1995-06**	17	↓ 2
1984-01	18	↑ 2	**1989-02**	18.5	↑ 3	**1988-03**	17.5	↑ 0.5	**1987-04**	18	--	**1985-05**	18	↓ 1	**2007-06**	17	↓ 1
1999-01	19	↓ 1	**1996-02**	18.5	↑ 0.5	**1999-03**	19	↑ 5	**1998-04**	19	↑ 5	**1999-05**	19	--	**1998-06**	19	↑ 4.5
1990-01	20	↑ 1	**2009-02**	20.5	↓ 5	**1979-03**	20	↑ 1	**1999-04**	20	↓ 3	**1991-05**	20	↑ 7	**2011-06**	20	↓ 7
2010-01	21	↓ 5	**1998-02**	20.5	↓ 0.5	**1983-03**	21	↓ 5	**1990-04**	21	↓ 1	**2005-05**	21	↑ 4	**2006-06**	21	↑ 2.5
1994-01	22	↑ 1	**1990-02**	22	↑ 1	**2016-03**	22	↑ 3	**2005-04**	22	--	**1989-05**	22	↑ 7	**1982-06**	22.5	↓ 1.5
1987-01	23	↓ 1	**1983-02**	23	↓ 1.5	**2005-03**	23	--	**2001-04**	23	--	**1998-05**	23.5	↓ 3.5	**2001-06**	22.5	↓ 3.5
2001-01	24	--	**2010-02**	24	↑ 3	**2000-03**	24	↓ 2	**1991-04**	24	↓ 3	**2001-05**	23.5	↓ 1.5	**1985-06**	24	↓ 2
1982-01	25	--	**1982-02**	25	↓ 1	**1998-03**	25.5	↑ 1.5	**2000-04**	25	↑ 2	**1994-05**	25	↓ 1	**2012-06**	25	↑ 1.5
1991-01	26	--	**1979-02**	26	↓ 1	**1987-03**	25.5	↓ 5.5	**2016-04**	26.5	↓ 0.5	**1995-05**	26	--	**1994-06**	26	↓ 1
1979-01	27	↑ 1	**1991-02**	27	↓ 1	**1996-03**	27	↓ 1	**2003-04**	26.5	↑ 2	**2012-05**	27	↓ 5	**1989-06**	27	↓ 0.5
1986-01	28	↓ 1	**1986-02**	28	--	**1982-03**	28	--	**1994-04**	28	↓ 3	**2004-05**	28	↓ 6	**1999-06**	28	--
2013-01	29	↑ 1	**1994-02**	29	--	**2003-03**	29.5	↓ 0.5	**1995-04**	29	↓ 0.5	**2010-05**	29	↑ 5	**2004-06**	29	--
2004-01	30	↑ 1	**1987-02**	30	--	**2009-03**	29.5	↑ 1.5	**1996-04**	30.5	↑ 1.5	**2003-05**	30	--	**1996-06**	30	↑ 0.5
1995-01	31	↑ 1	**2012-02**	31	↑ 1	**2004-03**	31	↓ 1	**2004-04**	30.5	↓ 0.5	**1982-05**	31	↓ 3	**2000-06**	31	↑ 1
2012-01	32	↓ 3	**1995-02**	32	↓ 1	**1994-03**	32.5	↑ 2.5	**2012-04**	32	↓ 1	**1979-05**	32	↓ 1	**2009-06**	32	↓ 1.5
2009-01	33	--	**2004-02**	33	--	**2012-03**	32.5	↑ 0.5	**1979-04**	33	↑ 1	**2000-05**	34	↑ 3	**2003-06**	33	↑ 0.5
2003-01	34	--	**2001-02**	34	↑ 1	**1995-03**	34	↓ 2	**2013-04**	34	↓ 1	**1996-05**	34	↑ 1.5	**2008-06**	34	↓ 0.5
1996-01	35	--	**2003-02**	35	↑ 3	**2001-03**	35	↓ 1	**1982-04**	35	--	**2013-05**	34	↓ 1	**2013-06**	35	--
2014-01	36	--	**2015-02**	36	↓ 2	**2014-03**	36	--	**2009-04**	36	--	**2009-05**	36	↓ 4	**1979-06**	36	--
2008-01	37	--	**2013-02**	37.5	↓ 0.5	**2015-03**	37	↑ 1	**2008-04**	37	--	**2008-05**	37	↓ 1.5	**2010-06**	37	↑ 1
2015-01	38	--	**2014-02**	37.5	↓ 1.5	**2013-03**	38	↓ 1	**2014-04**	38	--	**2014-05**	38	--	**2015-06**	38	↓ 1
1988-01	NaN	--	**2008-02**	39	--	**2008-03**	39	--	**2015-04**	39	--	**2015-05**	39	--	**2014-06**	39	--

Table 21. Changes in Monthly Rankings for the Antarctic for July through December

July			August			September			October			November			December		
YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank	YYYY-MM	v3 rank	Δrank
month			month			month			month			month			month		
1986-07	1	--	1986-08	1	↑ 2	1986-09	1	--	1986-10	1	--	2016-11	1	--	2016-12	1	--
2002-07	2	↑ 1	2002-08	2	↓ 1	2002-09	2	--	2016-10	2	--	1986-11	2	--	1982-12	2	--
1983-07	3	↓ 1	1983-08	3	↓ 1	2016-09	3	↑ 2	1984-10	3	--	1979-11	3	--	1979-12	3	↑ 1
1991-07	4	↑ 7	2001-08	4	↑ 6	1989-09	4	↓ 1	1987-10	4	↑ 2.5	2002-11	4	↑ 2	1986-12	4.5	↓ 1.5
1980-07	5	↓ 0.5	1989-08	5	↓ 1	2008-09	5.5	↑ 3.5	2001-10	5	↑ 4.5	1990-11	5	↑ 4	1996-12	4.5	↑ 1.5
1990-07	6	↓ 1.5	1993-08	6	↓ 1	1992-09	5.5	↑ 1	1982-10	6	↓ 2	1982-11	6	↑ 1	2005-12	6	↑ 4
1989-07	7	↑ 0.5	1988-08	7	↑ 11	2001-09	7.5	↓ 1	1979-10	7	↓ 2	1991-11	7.5	↑ 3	1989-12	7	↑ 2
1985-07	8	↓ 2	1990-08	8	--	1984-09	7.5	↑ 5.5	1989-10	8	↓ 1.5	1987-11	7.5	↓ 2.5	2006-12	8	↓ 3
1995-07	9	↑ 1	2003-08	9	↑ 3	1990-09	9	↓ 1	2002-10	9	↑ 3.5	2001-11	9	↓ 5	2000-12	9	↑ 2
1988-07	11	↑ 3	1985-08	10	↓ 1	1979-09	10	↓ 6	1983-10	10.5	↓ 1	1995-11	10	↓ 2	1993-12	10	↑ 3
2011-07	11	↑ 2	2008-08	11	↓ 5	1987-09	11	↑ 3.5	1991-10	10.5	↑ 4.5	1996-11	11	↑ 10	1990-12	11	↓ 4
1987-07	11	↓ 3.5	1987-08	12	↓ 5	2003-09	12	↓ 1.5	1992-10	12	↑ 4	1997-11	12.5	↑ 3.5	1994-12	12	↓ 4
2001-07	13.5	↓ 4.5	1997-08	13.5	--	1991-09	13.5	↓ 3	1990-10	13	↑ 1	1989-11	12.5	↓ 2	1980-12	13	↑ 1
1993-07	13.5	↑ 3.5	2007-08	13.5	--	1988-09	13.5	↑ 1	1996-10	14	↓ 1.5	2011-11	14.5	↓ 2.5	1991-12	14	↑ 1
1982-07	15	↓ 3	1979-08	15	--	1982-09	15	↓ 3	2008-10	15.5	↓ 7.5	2000-11	14.5	↓ 0.5	1992-12	15	↑ 1
1992-07	16	↑ 6	1991-08	16	↑ 7.5	1995-09	16	--	1997-10	15.5	↓ 4.5	2009-11	16	↑ 3	2004-12	16	↑ 9.5
1997-07	17	↓ 1	1992-08	17	↑ 6.5	2015-09	17	↑ 1	1995-10	17	↑ 1	1994-11	17	↑ 8	1997-12	17	↑ 10
2007-07	18.5	↑ 1.5	1996-08	18.5	↑ 1.5	1993-09	18	↓ 1	1994-10	18	↓ 1	2007-11	18	↓ 5	2001-12	18	↓ 6
1998-07	18.5	↓ 3.5	1981-08	18.5	↑ 5	1983-09	19	--	1993-10	19.5	↑ 1	1978-11	19.5	↑ 2.5	2012-12	19.5	--
2016-07	20	↓ 1	2015-08	20	↓ 9	1981-09	20.5	--	2000-10	19.5	↑ 2.5	1992-11	19.5	↓ 2.5	1983-12	19.5	↓ 2.5
1981-07	21	↓ 3	1995-08	21	↑ 5.5	1997-09	20.5	↑ 9	1985-10	21.5	↓ 1	1999-11	21	↓ 1	1978-12	21	↓ 3
2008-07	22	↓ 1	1982-08	22	↓ 5	1994-09	22	↑ 1	2003-10	21.5	↓ 2.5	1983-11	22	↓ 7	1984-12	22	↑ 1.5
2000-07	23	↑ 7	2016-08	24	↓ 4	1996-09	23	↓ 2.5	2011-10	23	--	1993-11	23	↑ 1	1998-12	23	↑ 0.5
2006-07	24	--	2011-08	24	↓ 4	1985-09	24.5	↓ 0.5	1981-10	24	--	2004-11	24	↑ 5.5	2003-12	24	↑ 1.5
1996-07	25	↓ 2	1980-08	24	↓ 8	1999-09	24.5	↑ 0.5	2009-10	25	--	2012-11	26	↑ 6	1995-12	25	↓ 3.5
2005-07	26	--	1994-08	26	↑ 3.5	2011-09	26	↓ 4	1999-10	26	↑ 4.5	2003-11	26	↑ 1.5	2015-12	26	↓ 6.5
2009-07	27	↓ 2	1998-08	27	↓ 0.5	2005-09	27.5	↑ 2	1988-10	27	↑ 1	1981-11	26	↓ 8	1999-12	27	↑ 2
1999-07	28	↑ 3	2005-08	28	↑ 1.5	2010-09	27.5	↑ 5	2015-10	28	↓ 2	1984-11	28.5	↓ 1	2009-12	28	↓ 6.5
1994-07	29.5	↑ 3.5	1984-08	29	↓ 5.5	1980-09	29	↓ 3	2004-10	29	↓ 2	1980-11	28.5	↑ 5	2002-12	29	↓ 1
2012-07	29.5	↓ 2	1999-08	30	↑ 1	2007-09	30	↑ 4	2005-10	30	↑ 0.5	1985-11	30	↓ 7	1981-12	30	--
2004-07	31	↓ 2	2004-08	31	↓ 3	2000-09	31	↓ 3.5	2007-10	31	↓ 2	1988-11	31	--	1988-12	31	↑ 1
1984-07	32.5	↓ 5	2006-08	33	--	1998-09	32	↓ 1	1980-10	32	↑ 2	2015-11	32	↓ 6	2011-12	32	↑ 1
2003-07	32.5	↑ 1.5	2009-08	33	↑ 1	2004-09	33	↓ 5.5	2012-10	33	↑ 2	2006-11	33	↑ 3	2010-12	33	↓ 2
1979-07	34	↓ 2	2012-08	33	↓ 1	2009-09	34	↓ 1.5	2010-10	34	↓ 2	2008-11	34	↓ 4.5	1985-12	34	↑ 1
2015-07	35	--	2000-08	35	--	2006-09	35	--	1998-10	35	↓ 2	1998-11	35	--	2008-12	35	↓ 1
2013-07	36	--	2010-08	36	--	2012-09	36	--	2006-10	36	--	2005-11	36	↑ 1	2013-12	36	↑ 1.5
2010-07	37	--	2013-08	37	--	2013-09	37	--	2014-10	37	--	2014-11	37	↓ 3.5	2014-12	37	↓ 1
2014-07	38	--	2014-08	38	--	2014-09	38	--	2013-10	38	--	2010-11	38	--	2007-12	38	↓ 0.5
												2013-11	39	--	1987-12	NaN	--