introduction

The *National Science Education Standards* developed under the auspices of the National Research Council specifies "Science as Inquiry" as major content standard for all grade levels. The activities that students engage in during grades 9–12 and in undergraduate science courses should develop the students' understanding of and ability to do scientific inquiry. An understanding of the nature of scientific inquiry involves awareness of why scientists conduct investigations, the roles technology and mathematics play in scientific design and analysis, the criteria used to judge data and models, and the impact that communication has on the development of scientific ideas. Among the abilities identified as necessary to do scientific inquiry are

- identification of concepts and questions that guide scientific investigations
- use of technology and mathematics to improve inquiries and communication skills
- formulation and revision of scientific explanations and models based on logic and evidence.

One of the recommendations of the National Science Foundation Report, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology,* is that faculty "build into every course inquiry, processes of science...a knowledge of what [science, mathematics, engineering, and technology] practitioners do, and the excitement of cutting-edge research."

Both the National Council of Teachers of Mathematics in their publication, *Curriculum and Evaluation Standards for School Mathematics,* and the American Mathematical Association of Two Year Colleges in *Crossroads in Mathematics: Standards for Introductory College Mathematics Before Calculus* espouse the use of real-world examples and technology to teach and reinforce mathematical concepts.

To address the standards in both science and mathematics, the materials in this module were designed to use image processing technology to enhance a student's understanding of scientific inquiry using a well-publicized subject, the characteristics and dynamics of global land vegetation. The exercises employ "hands-on" data processing in the form of image generation and analysis to give students the opportunity to work with data as research scientists do. The electronic textbook provides the most current scientific thought with supporting data. Additional materials such as an introduction to basic image processing concepts, background on the ozone satellite and sensor, and format information for the data sets have been made available to address ancillary questions that may arise.

references

Crossroads in Mathematics: Standards for Introductory College Mathematics Before Calculus. American Mathematical Association of Two Year Colleges, 1995. http://www.richland.cc.il.us/imacc/standards/

Curriculum and Evaluation Standards for School Mathematics. National Council of Teachers of Mathematics. 1989. http://www.wnc.org/reform/journals/ENC2280/280dtoc1.htm

National Science Education Standards. National Research Council, National Academy Press, 1996. http://www.nap.edu/readingroom/books/nses/html/

Shaping the Future: New Expectations for Undergraduate Education in Science Mathematics, Engineering, and Technology. National Science Foundation, Directorate for Education and Human Resources, 1996 (NSF 96-139). http://www.ehr.nsf.gov/EHR/DUE/documents/review/96139/start.htm

exercises

Each exercise for the Polar Ice Processes Module was designed to illustrate concepts connected with issues in current global change research involving these atmosphere and ocean interactions. They are presented as guided inquiry activities. Working through an activity, students are asked to perform selected image processing steps using specified data sets. Questions associated with each operation direct attention to the concept being elicited or probe for a student's understanding of the tools being employed.

This instructor's guide provides the following for each exercise.

Learning objectives that specify the concepts and operations students are expected to investigate
Science process skills, those broadly transferable abilities used in scientific disciplines that students must employ to complete the exercise. A description can be found at http://www.science.cc.uwf.edu/narst/research/skill.htm
National Science Education Content Standards for grades 9–12 embodied in the exercise
Image processing skills or operations in *SEE Image* that students use to interpret the data sets
Mathematical tools that are required in the data processing or analysis
Resource materials where information to complete or enhance each exercise can be located
Answers to exercises with selected images.

We provided specific data files for your students to use with these exercises. This is so we could give you, the instructor, an unambiguous answer key. Once your students are comfortable with the concepts and master the software, encourage them to explore the entire PSI data set more fully. After all, they have almost 20 years of polar sea ice images right here on this CD or on our Web site. Have them complete the same exercises choosing other images or sequences of images.

exercise 1
generating north and south pole geographic reference maps

learning objectives

When students complete Exercise 1 they should be able to

- Understand the characteristics of sea ice data sets and land masks.
- Understand the relationships among pixel value, pixel color, and sea ice concentration.
- Determine a calibration for sea ice images; calibrate images and store the calibration file for future applications.
- Generate reference maps of the north and south polar regions using atlases to locate and label specific geographic features.

science process skills

observing

national science education content standards

G: Understand science as a human endeavor

image processing skills

opening an image
applying a predetermined color table (LUT)
selecting and measuring values for a specific image region
calibrating an image
saving a calibration file
printing an image

answers to exercise 1

NOTE: In addition to this *Instructor's Guide,* be sure to have the following four files available.

arctic.pdf
arctic.TIF
antarctic.pdf
antarctic.TIF

The PDF files are comprehensive maps of all of the geographic features the students are asked to label following Step D of this exercise. The two TIF files can be opened in SEE Image and are maps of the oceanographic circulation around the Arctic and Antarctic regions. Have a magnifying glass handy as well.

1. nm9603i.tif

2. March 1996

3. a. black

   b. light blue

   c. white

4. August 1996

5. a. 255

   b. 254

   c. 1

6. a. Areas that are white represent where there is about 100% ice concentration.

   b. From about 240 to 250.

7.

	X Pixel Value	Y Ice Cencentration (%)
1	17	8
2	63	25
3	91	38
4	120	49
5	145	58
6	172	69
7	215	86
8	234	94
9	248	99

8. August 1996

9. a. All the points should be on or very near the straight line.

   b. From the plot window, b ~0.4.

   c. From the plot window, a ~0.3.

exercise 2
observing northern hemisphere sea ice distribution and seasonal variability

learning objectives

When students complete Exercise 2 they should be able to

- Understand characteristics of sea ice growth such as rate, periods of greatest and least change, and growth points in the northern hemisphere.
- Describe sea ice distribution in northern seas in late winter.
- Compare winter sea ice distributions on the east and west costs of Greenland.
- Understand the characteristics of sea ice expansion and recession (melting) through time series.
- Compute mean sea ice concentration.
- Determine ice edges with maximum and minimum summer to winter changes and understand reasons for the extremes.
- Understand the characteristics of marginal ice zone.
- Determine the growth rates of sea ice for the northern hemisphere region.

science process skills

- observing
- inferring
- communicating
- interpreting data

national science education content standards

- A: Develop the ability to do science inquiry
- D: Understand energy in Earth systems
- E: Develop abilities of technological design
- G: Understand the nature of scientific knowledge

image processing skills

- opening multiple images
- stacking images
- applying a predetermined color table (LUT)
- animating an image stack
- making a montage from a stack
- calibrating an image stack
- applying density slicing
- generating a new image from a stack slice

mathematical tools

- evaluating a series of means and standard deviations
- generating and interpreting a graph
- solving an algebraic expression

answers to exercise 2

1. a. January, February, or March. It is difficult to say precisely using this qualitative tool. Later in this exercise you'll create a time series of sea ice areal extent and then will be able to answer this question precisely.

   b. August or September

2. In September ice covers much of the central Arctic Ocean and portions of the Canadian Archipelago and the Greenland Sea. By the end of October ice covers almost the entire Arctic Ocean and Canadian Archipelago and extends well south along the east coast of Greenland. The ice cover expands rapidly during the next 2 months (November and December) with most of Baffin Bay and the Kara Sea ice covered by the end of November, and Hudson Bay and the northern Bering Sea ice covered by the end of December. Expansion continues at a slower rate in January and February, with the ice by the March maximum generally covering almost the entire Arctic Ocean, Canadian Archipelago, Kara Sea, Baffin Bay, and Hudson Bay, plus large portions of the Sea of Okhotsk, Bering Sea, Greenland Sea, Davis Strait, and Barents Sea.

   Notice how unsymmetrical the Northern Hemisphere sea distributions are in wintertime. The warm Gluf Stream waters moving northeast across the North Atlantic help keep much of the North Atlantic free of ice year round even at latitudes north of 65°N, not just in 1985 but in all years of the modern record. In contrast, Hudson Bay is at much lower latitudes but is almost fully ice covered. The reason lies not only in the Bay's lack of access to warm waters from the south but also in its geographic placement in the midst of a continent. Because land surfaces heat and cool much more rapidly than do ocean surfaces subjected to the same intensity of solar radiation, continental areas tend to be warmer in summer and cooler in winter than midocean areas at the same latitude. This phenomenon is sometimes called the *continentality effect.* Hudson Bay, being in the midst of North America, is affected by the impacts of the land around it and thus tends to be colder in winter, and more likely to have ice formed, than midocean areas at the same latitudes.

3. Retreat generally proceeds slowly in March and April, when it tends to be most pronounced in the Sea of Okhotsk and northern Baffin Bay. By mid-May, noticeable retreat has also occurred in the Bering Sea and at the open water ice edge in the North Atlantic vicinity. By mid-June, major openings appear in the ice cover of the remaining regions, and by mid-July most of the ice of Hudson Bay, Davis Strait, and Baffin Bay has disappeared. By August, the ice cover is close to its September minimum, with significant coastal openings around much of the Arctic Ocean and little or no ice remaining in most of the peripheral seas and bays.

4. The warm Gulf Stream waters moving northeast across the North Atlantic help keep much of the North Atlantic, including the Barents and Norwegian Seas, free of ice year round even at latitudes north of 65°N, not just in 1985 but in all years of the modern record.

5. The continentality effect and lack of contact with warm water are two factors keeping the west coast of Greenland, including Baffin Bay, completely ice covered in late winter. The warm Gulf Stream, flowing from the south in the North Atlantic along the east coast of Greenland, restricts the ice cover along Greenland's east coast to the region of cold, low salinity waters in the southward flowing East Greenland Current.

6. a. The location of the ice edge changes the most in Hudson Bay, Davis Strait, and Baffin Bay and across the Chukchi Sea through the Bering Strait, and into the Bering Sea.

   b. The location of the ice edge changes the least in the Greenland, Norwegian, and Barents Seas.

   c. The most change is caused by the continentality effect and the least change is because of the moderating or warming effect of the Gulf Stream.

7. Because the Arctic Ocean is surrounded by land (and not by ocean as in the Antarctic), its surface waters tend to be lower in salinity (due to ice formation and melt and river input from the major Canadian and Acian rivers) than the surface waters surrounding the Antarctic. Because of these fresher surface waters and the lack of diverging winds and ocean currents acting on the ice edges (again, opposite the case with the Antarctic), the Marginal Ice Zone tends to be narrower than in the Antarctic. Therefore, the ice concentration values tend to increase quickly across the Marginal Ice Zone from open water (0%) to 100% ice cover.

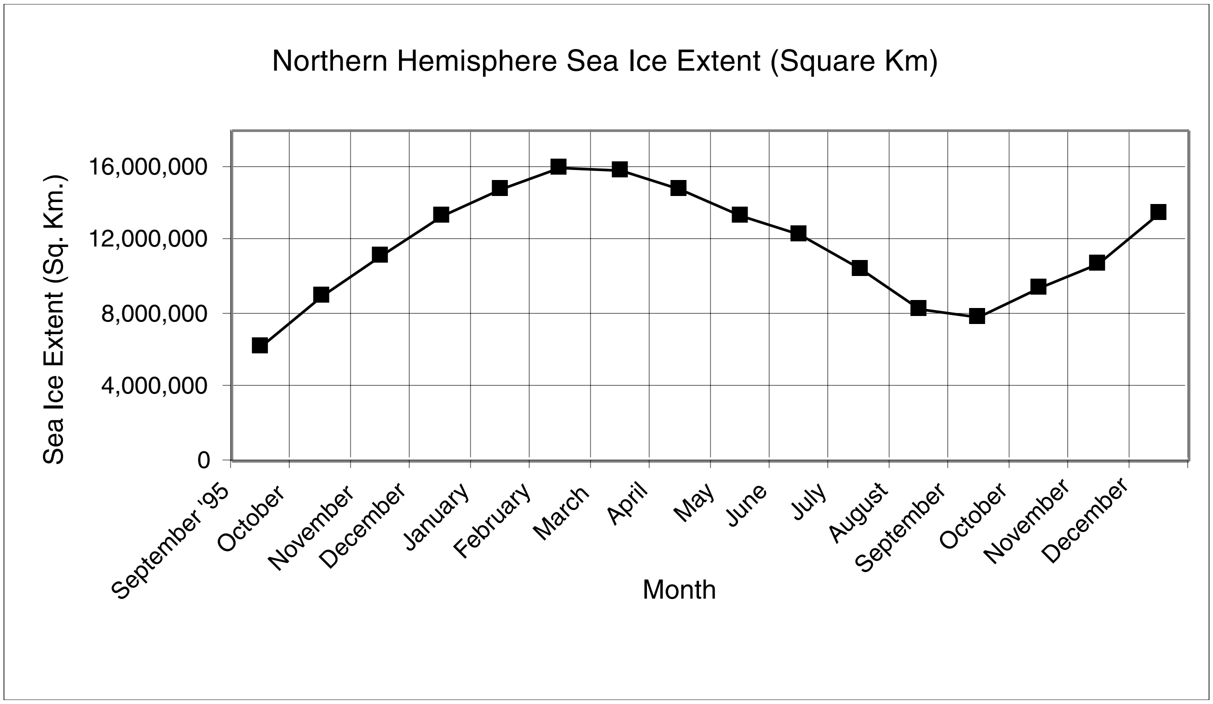
8. *Go to the next page.*

Northern Hemisphere Areal Sea Ice Extent

MONTH Years: 1995 – 1996	AREA (square kilometers)	MEAN SIC (in percent)	STANDARD DEVIATION (%)
September	5,930,000 6,222,500	72.73	23.94
October	8,685,000 8,977,500	67.12	27.08
November	10,886,875 11,179,375	81.15	24.86
December	12,993,125 13,285,625	84.76	22.07
January	14,468,750 14,761,250	84.33	23.27
February	15,652,500 15,945,000	84.27	22.62
March	15,599,375 15,891,875	84.29	22.41
April	14,494,375 14,786,875	85.43	23.35
May	13,070,625 13,363,125	85.93	21.30
June	11,976,875 12,269,375	81.21	21.48
July	10,210,000 10,502,500	71.19	25.04
August	7,998,750 8,291,250	69.73	24.60
September	7,611,875 7,904,375	72.13	23.61
October	9,093,750 9,386,250	80.84	21.53
November	10,405,000 10,697,500	82.41	24.00
December	13,163,125 13,455,625	83.21	23.89

Add missing data area to column 2 as appropriate—1,124,375 for years 1979–1987; 292,500 for years 1988–1996

9. a.



b. 6,222,500 sq. km in September '95

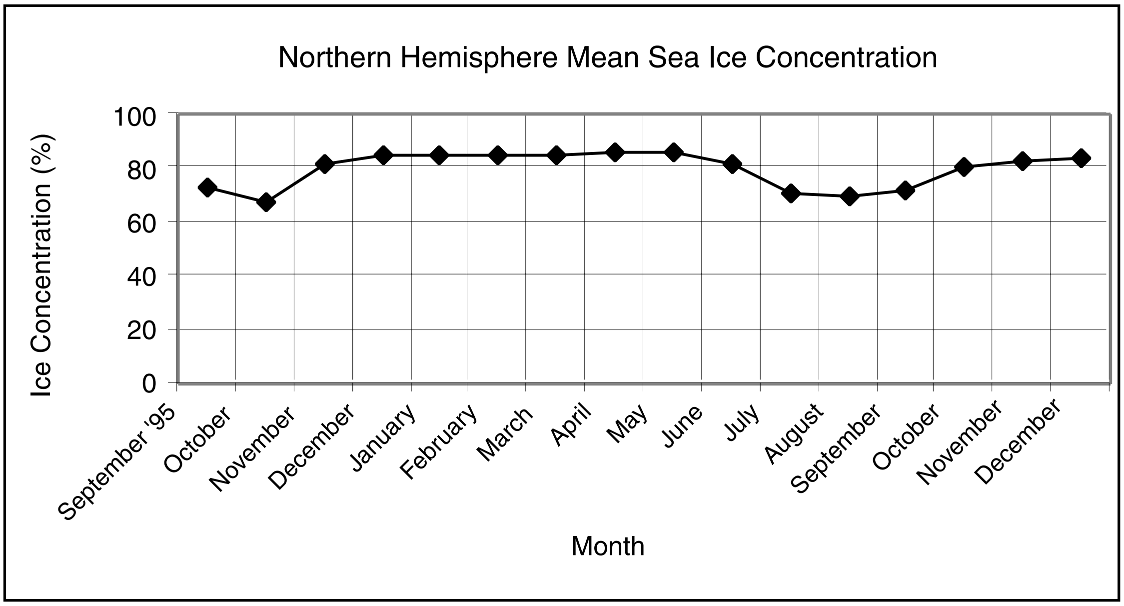
c. 15,945,000 sq. km in February '96

d. ((15,945,000 – 6,222,500) / 15,945,000) * 100 = 0.61 * 100 = 61%

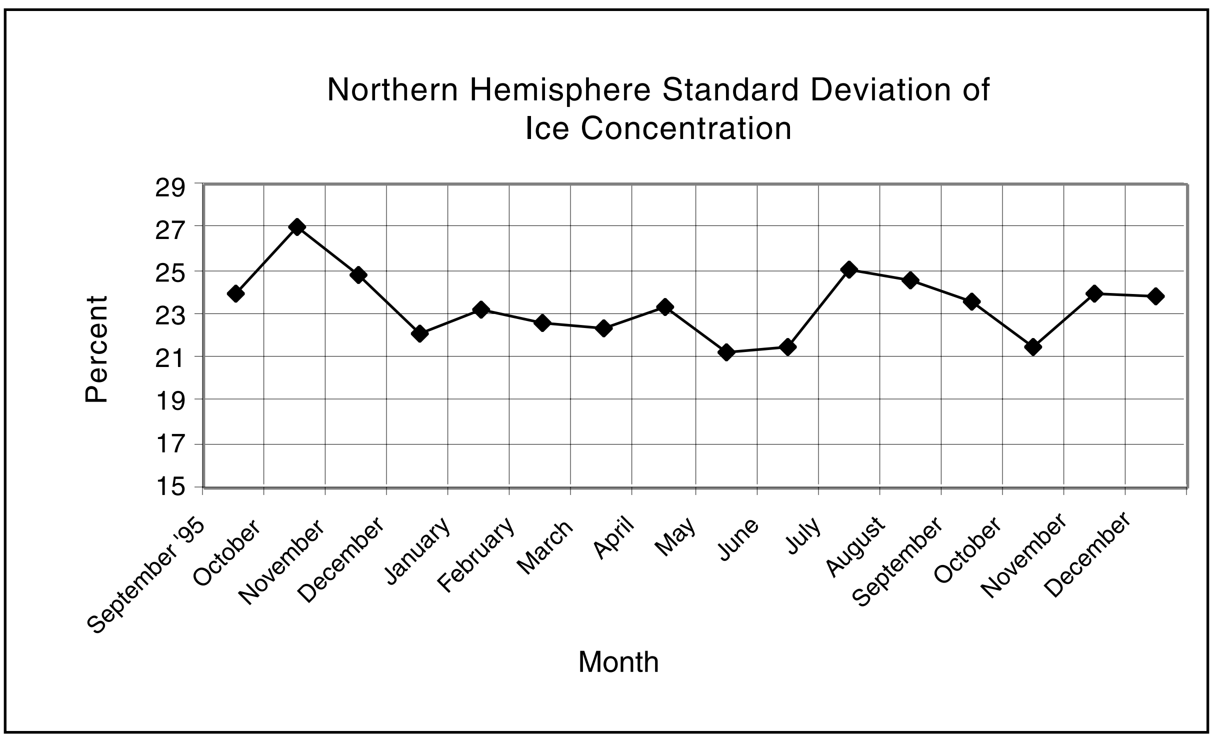
10. a. The average seasonal cycle of Northern Hemisphere sea ice extent varies from a maximum sea ice extent of 15.7 x 106 km^2 in late March to a minimum sea ice extent of 9.3 x 106 km^2 in early September. At the end of the melt season, the permanent ice pack retains about 60% of the ice covered area occurring at the winter maximum (Gloersen et al., 1992).

b. Individual student impression

11. a.



b.



c. In general, ice concentrations are higher and more uniform (i.e., the standard deviation is lower) in winter (December to June) than late spring. This is caused by the presence or absence of open water and thin ice within the ice pack.

The open water area within the Arctic ice pack peaks in early summre and constitutes approximately 30% of the total ice extent at that time. The duration of enhanced open water area within the ice pack during the melt season is about 75 days (i.e., July–September). These areas of open water and thin ice within the ice pack have the effect of reducing the mean ice concentration and increasing the variability (the standard deviation) within the >15% ice concentration area highlighted by the density slice.

Open water area decreases during the winter, since vertical ice growth increases the average ice thickness and makes the ice pack resistant to deformation by winds and currents. At the time of the winter maximum sea ice extent (March–April), the amount of open water area within the total Arctic ice pack decreases to about 14% on average. However, the amount of open water area within the Arctic Ocean is only about 2.8% on average. In the peripheral seas, the open water area is notably larger (15–40%) than in the Arctic Ocean because of divergence along the ice edge driven by winds and currents. The decrease in open water area and thin ice, particularly in the interior ice pack, in winter results in the mean ice concentration within the >15% ice concentration area selected by the density slice increasing, and the standard deviation decreasing.

exercise 3
observing southern hemisphere sea ice distribution and seasonal variability

learning objectives
When students complete Exercise 3 they should be able to

- Understand characteristics of sea ice growth such as rate, periods of greatest and least change, and growth points in the Southern Hemisphere
- Understand the characteristics of sea ice expansion and recession (melting) through time series
- Understand the characteristics of the Marginal Ice Zone
- Determine the growth rates of sea ice for the Southern Hemisphere region
- Compare sea ice growth in the Northern and Southern Hemispheres.

science process skills
- observing
- inferring
- communicating
- interpreting data

national science education content standards
- A: Develop the ability to do science inquiry
- D: Understand energy in Earth systems
- E: Develop abilities of technological design
- G: Understand the nature of scientific knowledge

image processing skills
- opening multiple images
- stacking images
- applying a predetermined color table (LUT)
- animating an image stack
- making a montage from a stack
- calibrating an image stack
- applying density slicing
- generating a new image from a stack slice

mathematical tools
- evaluating a series of means and standard deviations
- generating and interpreting a graph
- solving an algebraic expression

answers to exercise 3

1. a. September or August

   b February

2. In February the Southern Hemisphere ice is concentrated in the Weddell, Bellingshausen, Amundsen, and eastern Ross Seas, with only a narrow fringe of ice existing around most of the rest of the Antarctic continent. Late summer expansion of the ice cover is generally most noticeable in the eastern Ross Sea, and early autumn expansion is most noticeable in the entire Ross See and the central and eastern Weddell Sea. By May, the ice cover has expanded northward to about 65°S in the Ross Sea and around much of the eastern portion of the continent, while lagging somewhat in the Bellingshausen and Amundsen Seas and extending outward to near 60°S in the western Weddell Sea. Growth continues around the continent for the next 3–4 months, although with temporary intervals of decay in individual localities. At maximum ice coverage, the ice surrounds the Antarctic continent and at most latitudes extends equatorward to between 55°S and 65°S. At this time the ice edge is generally farthest north in the eastern Weddell Sea near the Greenwich Meridian and farthest south in the western Bellinghshausen.

3. Decay of the ice proceeds slowly in the early spring, but then very rapidly from October to January. A primary anomaly in the generally southward retreat of the ice edge occurs in the Ross Sea, where a large polynya consistently opens off the coast of the Ross Ice Shelf in November or December and then expands northward, contributing to a local decay of the ice pack from the south to the north. By January, the western Ross Sea is nearly free of ice, although considerable ice remains to the east.

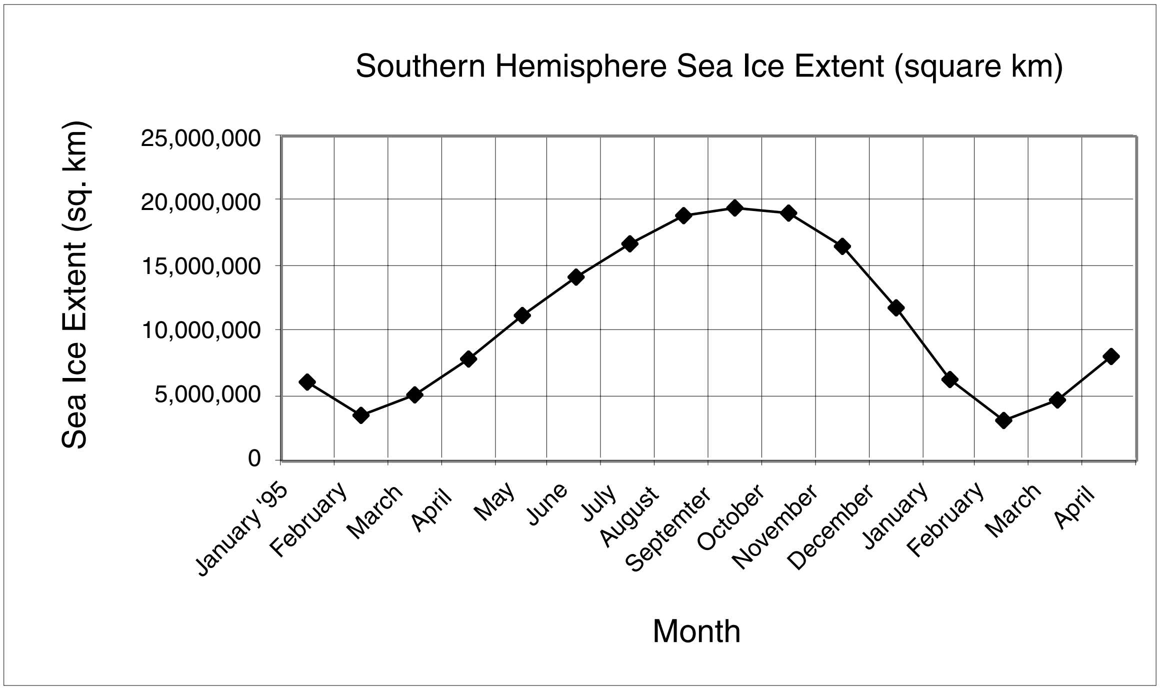
4 & 5. The asymmetry in the typical Antarctic growth and decay cycle, with the spring-summer decay occuring more rapidly (September to February) than the fall-winter growth (February to September), contrasts with the more symmetrical growth and decay cycle typical in the Arctic, where ice extent minima and maxima tend to be about 6 months apart, occurring in September and March. Gordon (1981) suggests that the contrast between the Northern and Southern Hemispheres reflects fundamental differences in the heat budgets of the sea ice in the two regions. In particular, the rapid decay of the Antarctic ice is likely related to significantly greater upwelling of relatively warm, deep water than occurs in the Arctic, as the atmosphere-to-ocean heat flux alone appears insufficient to account for the observed rate of melting, especially during the period of most rapid melt, from mid-November to mid-January.

6. *Go to the next page.*

Southern Hemisphere Areal Sea Ice Extent

MONTH Years: 1995 – 1996	AREA (square kilometers)	MEAN SIC (in percent)	STANDARD DEVIATION (%)
January	6,030,000	61.45	27.92
February	3,607,500	59.98	25.35
March	5,043,125	58.99	24.81
April	7,870,525	68.45	23.19
May	11,257,500	73.34	22.32
June	14,201,250	74.79	21.14
July	16,739,375	76.62	20.89
August	18,897,500	77.39	19.95
September	19,424,376	76.75	19.29
October	19,053,750	73.28	19.81
November	16,535,000	71.00	22.04
December	11,755,625	61.44	25.92
January	6,363,125	55.30	25.85
February	3,052,500	56.89	28.05
March	4,692,500	55.37	23.71
April	8,100,000	66.00	23.38

7\. a.



b. 3,607,500 sq. km in February 1995

c. 19,424,376 sq. km in September 1995

d. ((19,424,376 – 3,607,500) / 19,424,376) * 100 = 81%

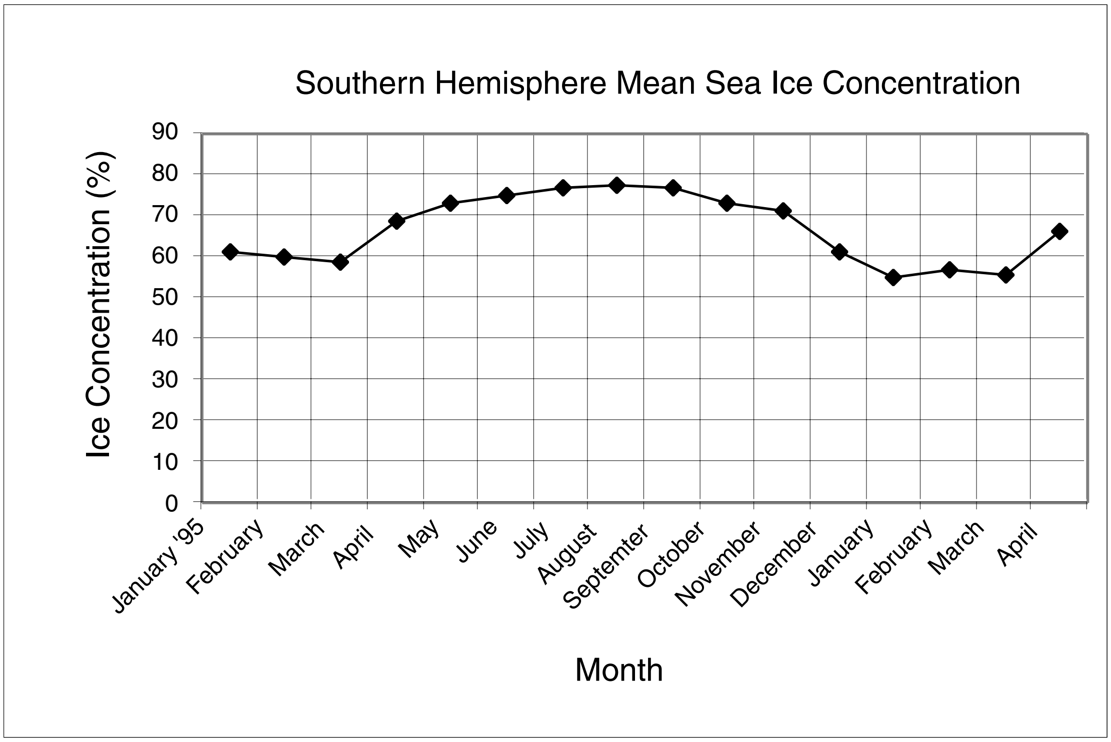
e. compared to 61% for the Arctic

8\. a. On "average" the ice cover in the Southern Hemisphere varies from a minimum sea ice extent of 3.4 – 4.3 x 106 km^2 in February to a maximum sea ie extent of 18 – 20.2 x 106 km^2 in August to October. Only 13% of the winter maximum ice covered area is retained in summer in the Southern Hemisphere (Gloersen et al., 1992).

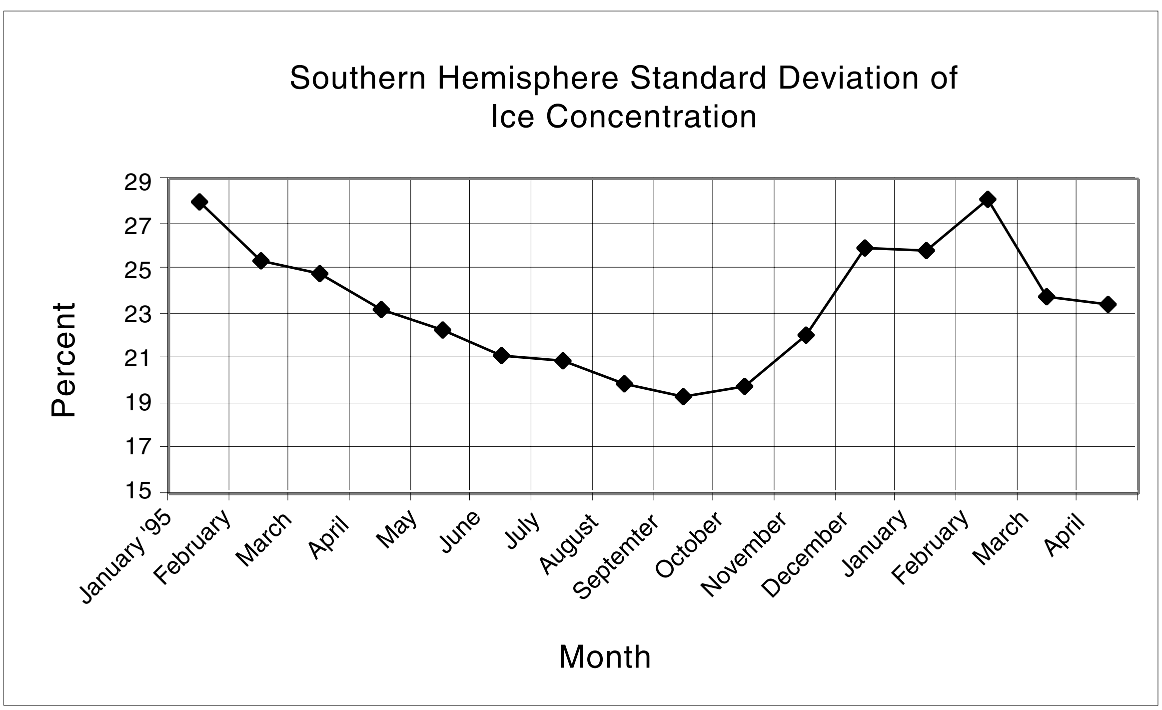
b. Individual student impression

9\. The asymmetry in the typical Antarctic growth and decay cycle, with the spring and summer decay occurring more rapidly (September to February) than the fall and winter growth (February to September), contrasts with the more symmetrical growth and decay cycle typical in the Arctic, where ice extent minima and maxima tend to be about 6 months apart, occurring in September and March. Gordon (1981) suggests that the contrast between the Northern and Southern Hemispheres reflects fundamental differences in the heat budgets of the sea ice in the two regions. In particular, the rapid decay of the Antarctic ice is likely related to significantly greater upwelling of relatively warm, deep water than oceans in the Arctic, as the atmosphere-to-ocean heat flux alone appears insufficient to account for the observed rate of melting, especially during the period of most rapid melt, from mid-November to mid-January.

10. a.


Southern Hemisphere Mean Sea Ice Concentration
Ice Concentration (%)
90
80
70
60
50
40
30
20
10
0
January '95
February
March
April
May
June
July
August
Septemter
October
November
December
January
February
March
April
Month

b.


Southern Hemisphere Standard Deviation of
Ice Concentration
Percent
29
27
25
23
21
19
17
15
January '95
February
March
April
May
June
July
August
Septemter
October
November
December
January
February
March
April
Month

c. The results here are simiar to the results for the Arctic (Exercise 2). In general, mean sea ice concentrations are higher and more uniform (i.e., standard deviation is lower) between April and October, the winter months. As with the Arctic, this is due to the presence or absence of open water and thin ice within the ice pack. These open water and thin ice areas have the affect of reducing the mean ice concentration and increasing the variability (the standard deviation) within the >15% ice concentration area highlighted by the density slice.

   Open water area decreases during winter, since vertical ice growth increases the average ice thickness and makes the ice pack resistant to deformation by winds and currents. At the time of the winter maximum sea ice extent (September), the amount of open water area within the total Antarctic ice pack is 21% of the total area (compared to 14% for the Arctic). The decrease in open water area and thin ice, particularly in the interior ice pack, in winter results in the mean ice concentration within the >15% ice concentration area selected by the density slice increasing, and the standard deviation decreasing.

   In contrast to much of the Arctic sea ice pack, the Antarctic sea ice pack has an outer boundary unconstrained by land. Further, the Antarctic sea ice pack is subject to strong circumpolar winds that produce on average an outward stress component on the sea ice. Consequently, the Antarctic sea ice cover, surrounded by open ocean and acted on by circumpolar winds, is generally more divergent than much of the 'Arctic sea ice cover. Greater divergence of the ice pack produces a larger amount of open water and thin ice within the ice pack. Therefore, the mean ice concentrations within the >15% ice concentration area highlighted by the density slice are less in the Antarctic (–75-77% at maximum ice extent) than in the Arctic 84-85% at maximum ice extent).

exercise 4
observing northern hemisphere interannual variability

learning objectives
When students complete Exercise 4 they should be able to

- Identify time periods with largest and smallest ice extent in selected Northern Hemisphere regions
- Make conclusions about the long-term trend in ice extent in the Northern Hemisphere
- Determine areal extent, mean area, mean ice concentration, and standard deviation
- Identify periods of maximum and minimum sea ice extent and compute percent difference
- Understand the connection between north polar sea ice cover and global warming.

science process skills
- observing
- inferring
- communicating
- interpreting data
- drawing conclusions

national science education content standards
- A: Develop the ability to do science inquiry
- D: Understand energy in Earth systems
- E: Understand science and technology
- G: Understand the nature of scientific knowledge

image processing skills
- opening multiple images
- stacking images
- applying a predetermined color table (LUT) to an image stack
- animating an image stack
- making a montage from a stack
- calibrating an image stack
- using density slicing to highlight concentration ranges

mathematical tools
- evaluating a series of means and standard deviations
- calculating percent difference

answers to exercise 4

1. February or March

2. a. Barents Sea: 1979, 1981, 1982, 1987

   b. Bering Sea: 1984, 1995

   c. Sea of Okhotsk: 1979, 1980, 1983

   d. Labrador Sea: 1982, 1983, 1990, 1993

   e. Greenland-Norwegian Seas: 1979, 1982, 1988

3. a. Barents Sea: 1983, 1984, 1993, 1994

   b. Bering Sea: 1979, 1982, 1996

   c. Sea of Okhotsk: 1984, 1991

   d. Labrador Sea: 1979, 1981, 1996

   e. Greenland-Norwegian Seas: 1993, 1994, 1995

4. In general, we can see a great deal of interannual variability, but it is very difficult to see any clear trend. The regional year-to-year fluctuations are much greater than any trend for the Arctic as a whole.

5. *Go to the next page.*

Northern Hemisphere Areal Sea Ice Extent Maximums

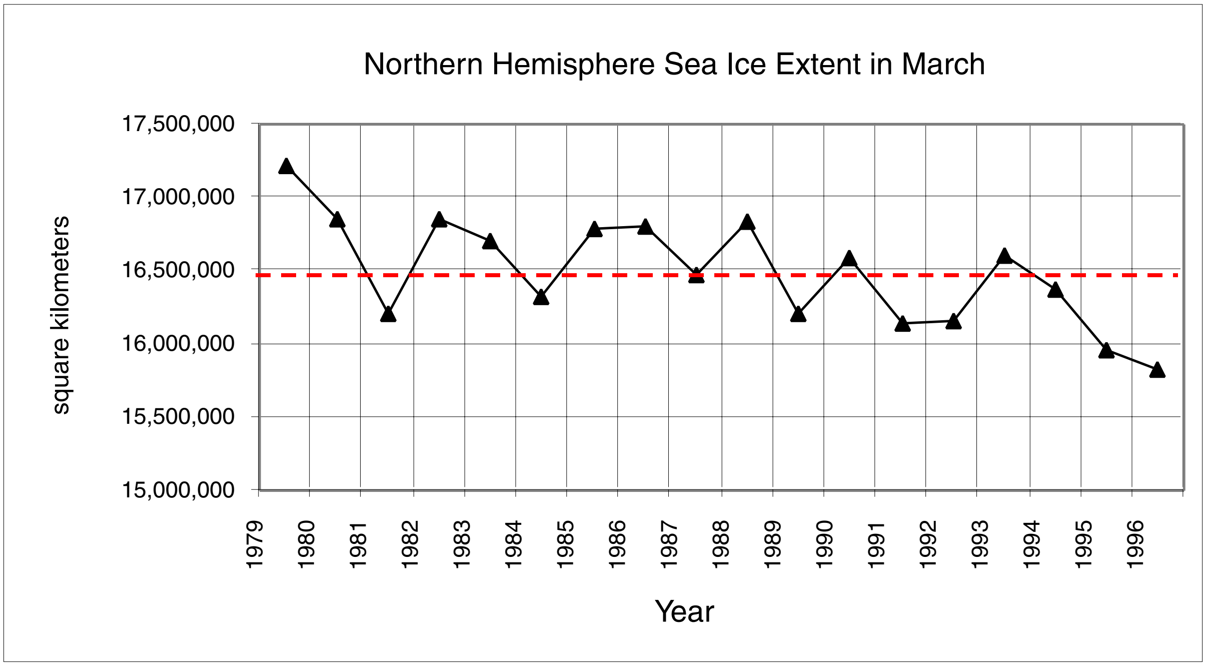
YEAR Month: March	AREA (square kilometers)	MEAN SIC (in percent)	STANDARD DEVIATION (%)
1979	16,091,250 17,215,625	84.56	21.21
1980	15,735,625 16,860,000	84.64	21.96
1981	15,081,875 16,206,250	85.75	20.78
1982	15,723,125 16,847,500	85.21	21.66
1983	15,586,250 16,710,625	84.63	21.31
1984	15195,625 16,320,000	84.67	21.12
1985	15,656,250 16,780,625	83.42	22.33
1986	15,683,750 16,808,125	83.39	21.52
1987	15,341,875 16,466,250	85.07	21.24
1988	16,547,500 16,840,000	85.50	22.56
1989	15,913,125 16,205,625	84.41	23.09
1990	16,305,000 16,597,500	84.25	21.36
1991	15,856,875 16,149,375	85.86	22.15
1992	15,871,250 16,163,750	86.28	22.52
1993	16,308,125 16,600,625	86.14	21.48
1994	16,083,750 16,376,250	86.10	21.96
1995	15,667,500 15,960,000	86.44	22.04
1996	15,541,875 15,834,375	84.55	22.04

Add missing data area to column 2 as appropriate—1,124,375 for years 1979–1987; 292,500 for years 1988–1996

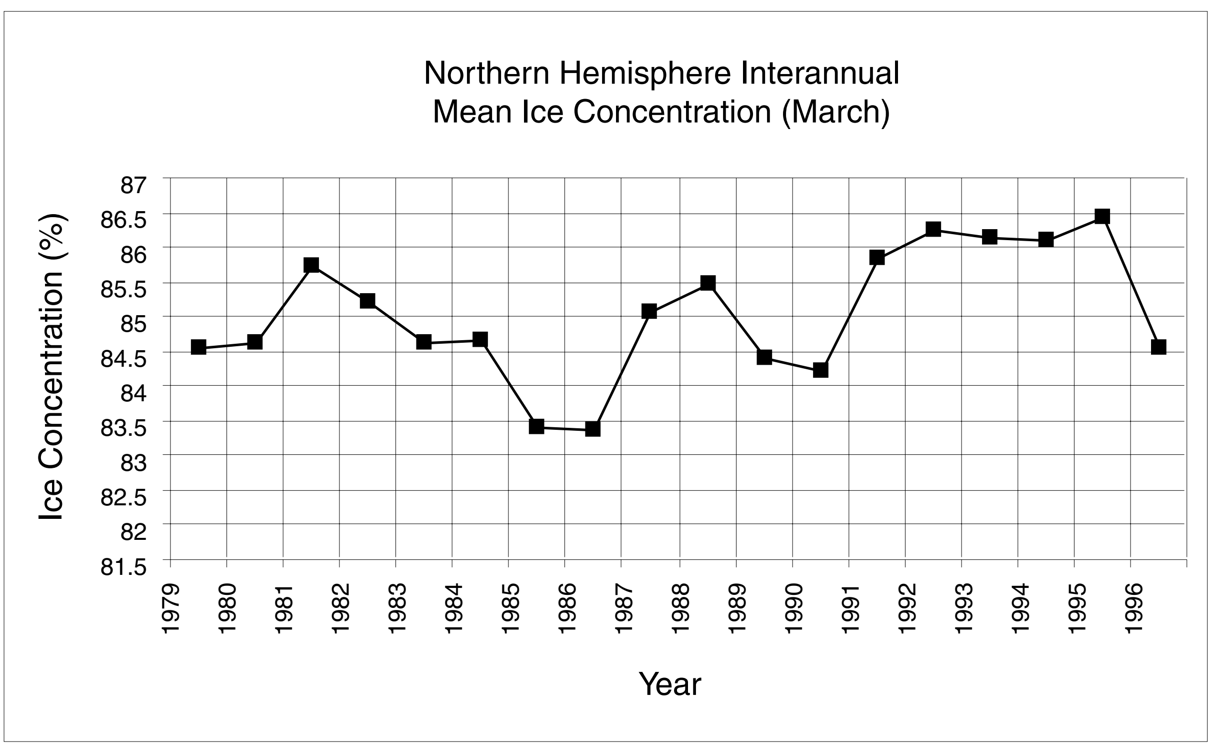
6. a. 16,496,806 sq. km

   b. Between 1979 and 1988, the macimum sea ice extent was often greater than the Climatological average. After 1988, however, the sea ice extent was less than the average for March.

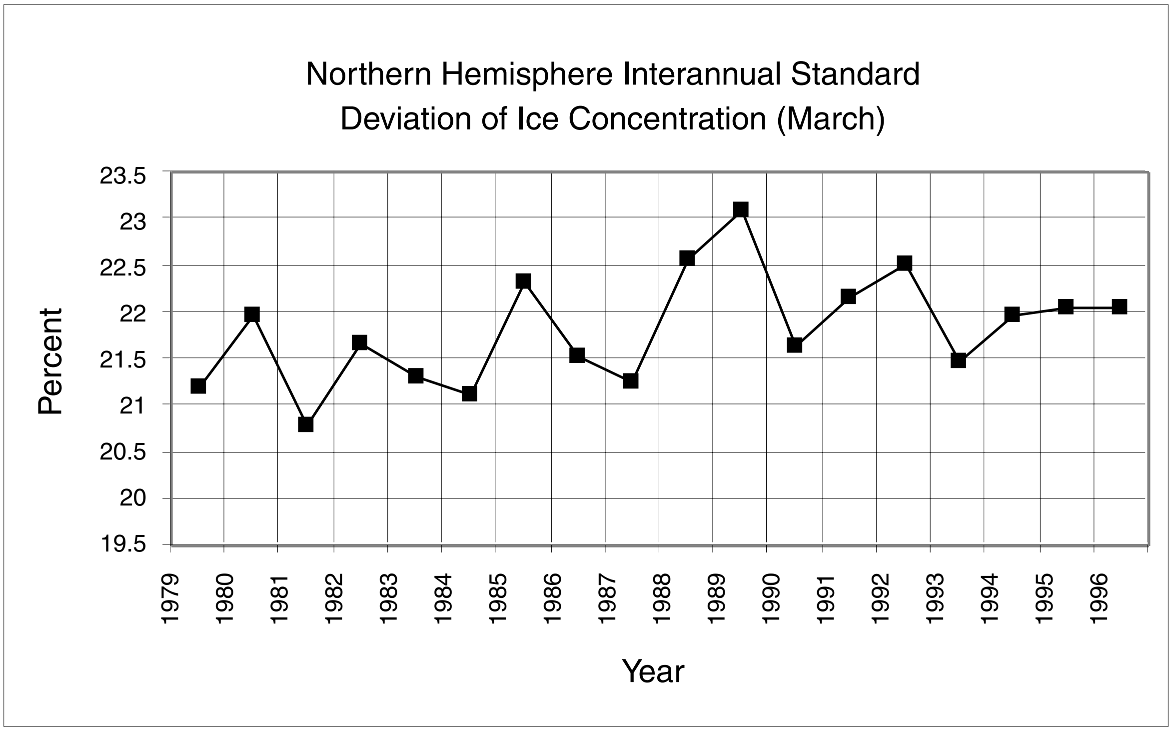
7. a.



   b.



c.



8. a. 1979 and 1980

   b. 1996 and 1995

   c. 5%

9. Student answers will probably vary depending on their best fit line.

10. Variations in the monthly sea ice extent and monthly mean ice concentration indicate the variability of the sea ice cover with time. The standard deviation values indicate the amount of spatial variability within the >15% ice concentration ice cover. The greater the standard deviation, the more areas of open water and reduced ice concentration exist within the >15% ice cover. The smaller the standard deviation, the more spatially uniform the sea ice cover. Looking at the time series plots, it appears that the larger the mean ice concentration within the >15% ice cover, then typically the smaller the standard deviation; i.e., the mean ice concentration is higher because the ice cover is more uniform with less area of open water and reduced ice concentration. Conversely, we typically observe when the mean ice concentration is lower, the standard deviation is higher; i.e., the mean ice concentration is lower because there are more regions of open water and reduced ice cover within the >15% ice cover.

11. September

12. *Go to the next page.*

Northern Hemisphere Areal Sea Ice Extent Minimums

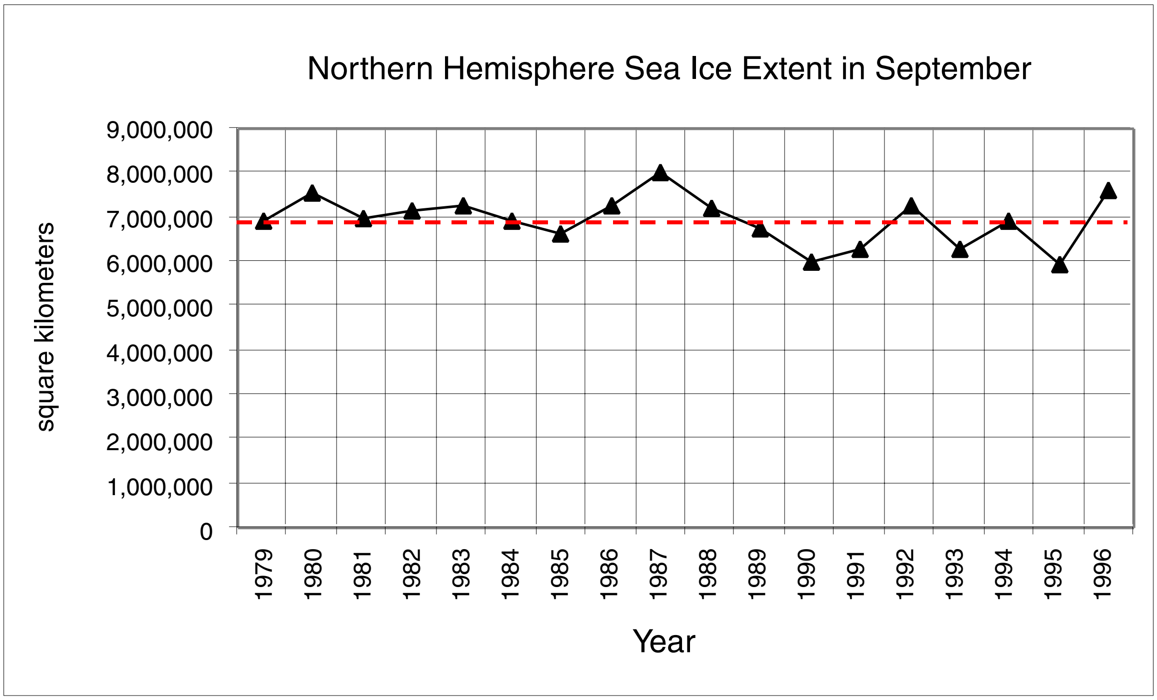
YEAR Month: September	AREA (square kilometers)	MEAN SIC (in percent)	STANDARD DEVIATION (%)
1979	5,796,975 6,911,250	75.62	22.85
1980	6,419,375 7,543,750	72.64	21.91
1981	5,830,000 6,954,375	72.36	22.21
1982	6,028,750 7,153,125	70.14	20.98
1983	6,135,000 7,259,375	73.16	23.13
1984	5,776,250 6,900,625	67.79	23.77
1985	5,528,125 6,652,500	72.94	23.25
1986	6,120,625 7,245,000	73.54	21.79
1987	6,923,125 8,047,500	77.96	23.45
1988	6,939,375 7,231,875	73.79	21.65
1989	6,485,625 6,778,125	71.40	20.61
1990	5,706,875 5,999,375	75.79	22.46
1991	6,022,500 6,315,000	71.35	20.91
1992	6,995,625 7,288,125	74.03	20.74
1993	5,970,625 6,263,125	72.77	22.56
1994	6,651,875 6,944,375	73.66	21.11
1995	5,625,000 5,917,500	74.93	22.18
1996	7,315,625 7,608,125	73.69	22.42

Add missing data area to column 2 as appropriate—1,124,375 for years 1979–1987; 292,500 for years 1988–1996

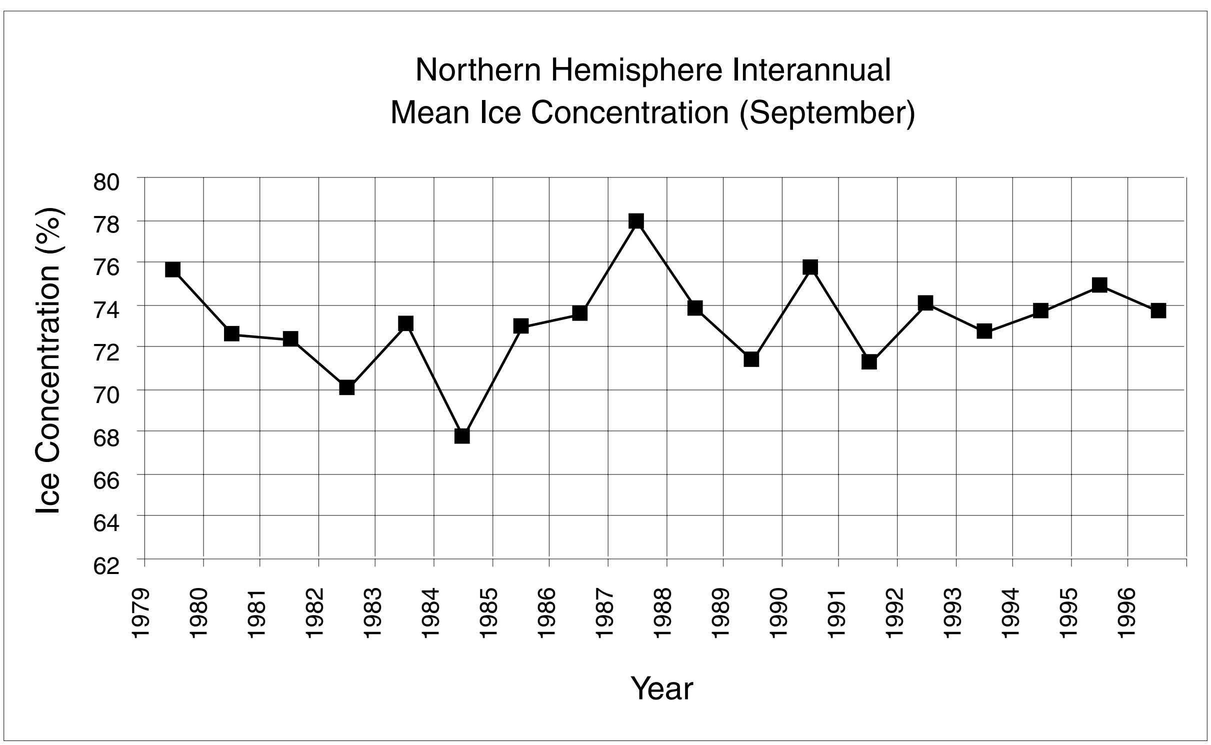
13\. a. 6,945,174 sq. km

b. From 1979 until about 1990, the minimum ice extent was at or slightly above the Climatological Mean. After 1990, the minimum ice extent was at or slightly below the Climatological Mean.

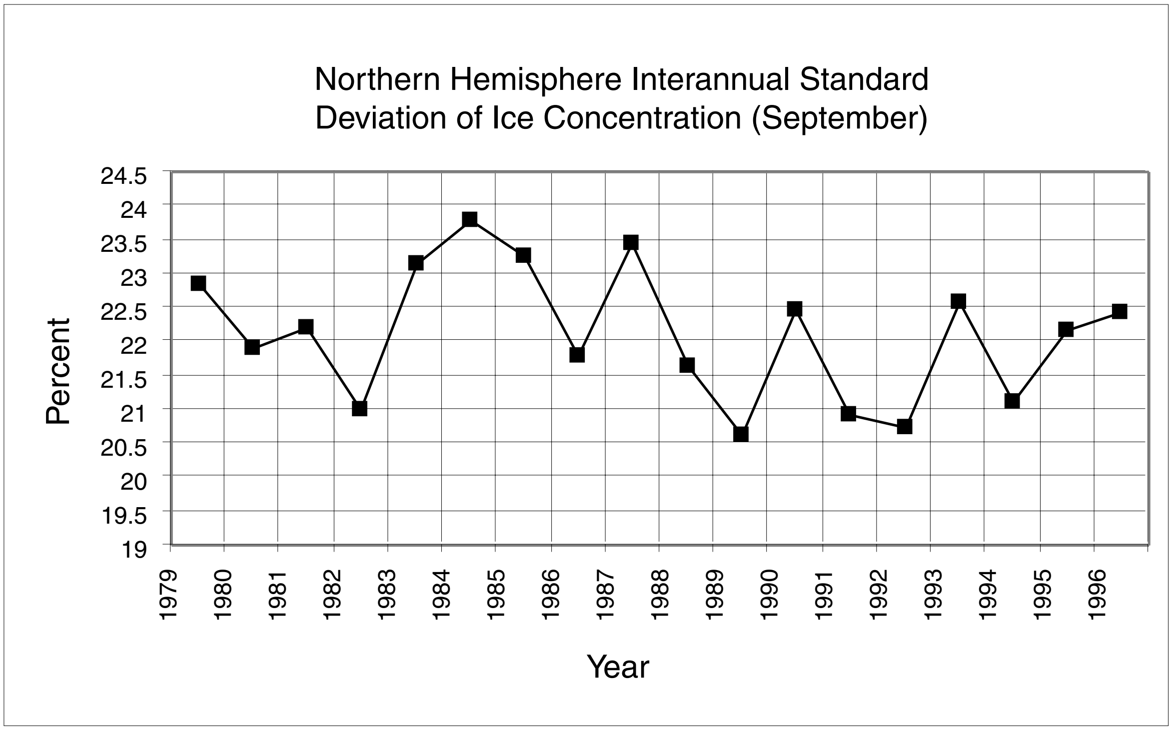
14\. a.



b.



c.



15. a. Largest: 1987, 1996, 1980

    b. Smallest: 1995 and 1990

    c. 22%

16. Student answers will probably vary depending on their best fit line.

17. Variations in the monthly sea ice extent and monthly mean ice concentrations indicate the variability of the sea ice cover with time. The standard deviation values indicate the amount of spatial variability within the >15% ice concentration ice cover. The greater the standard deviation, the more areas of open water and reduced ice concentration exist within the >15% ice cover. The smaller the standard deviation, the more spatially uniform the sea ice cover. Looking at the time series plots, it appears that the larger the mean ice concentration within the >15% ice cover, then typically the smaller the standard deviation; i.e., the mean ice concentration is higher because the ice cover is more uniform with less area of open water and reduced ice concentration. Conversely, we typically observe when the mean ice concentration is lower, the standard deviation is higher; i.e., the mean ice concentration is lower because there are more regions of open water and reduced ice cover within the >15% ice cover.

exercise 5
observing southern hemisphere interannual variability

learning objectives

When students complete Exercise 4 they should be able to

- Make conclusions about the long-term trend in ice extent in the Souther Hemisphere
- Identify periods of maximum and minimum sea ice extent and computer percent difference
- Understand the connection between south polar sea ice cover and global warming.

science process skills

- observing
- inferring
- communicating
- interpreting data
- drawing conclusions

national science education content standards

- A: Develop the ability to do science inquiry
- D: Understand energy in Earth systems
- E: Understand science and technology
- G: Understand the nature of scientific knowledge

image processing skills

- opening multiple images
- stacking images
- applying a predetermined color table (LUT) to an image stack
- animating an image stack
- making a montage from a stack
- calibrating an image stack
- using density slicing to highlight concentration ranges

mathematical tools

- evaluating a series of means and standard deviations
- calculating percent difference

answers to exercise 5

1. September

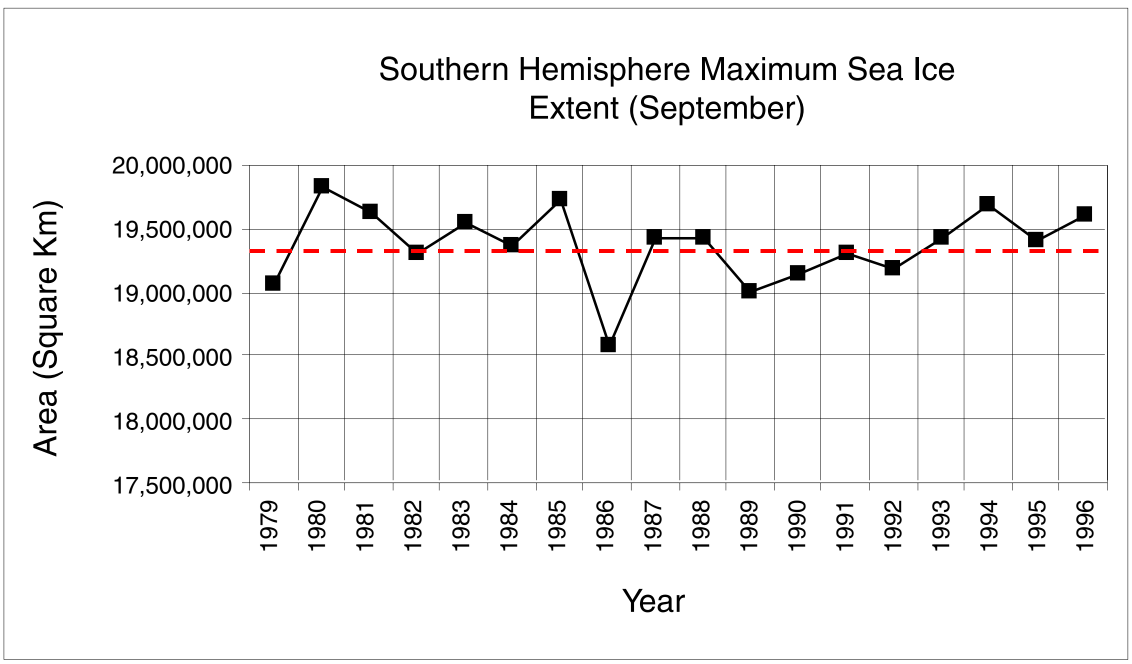
2. In general, we can see a great deal of interannual variability, but it is very difficult to see any clear trend. The regional year-to-year fluctuations are much greater than any trend for the Antarctic as a whole.

3. *See the next page.*

4. a. 19,379,896 sq. km

   b. Between 1980 and 1985, the sea ice extent was higher than the climatological average, while from 1986 through 1992, the sea ice extent was less than the climatological average. In 1986, in particular, the sea ice extent was much lower than usual.

5. a.



Southern Hemisphere Areal Sea Ice Extent Maximums

YEAR Month: September	AREA (square kilometers)	MEAN SIC (in percent)	STANDARD DEVIATION (%)
1979	19,069,376	76.97	20.03
1980	19,849,124	77.36	19.45
1981	19,645,624	77.53	20.34
1982	19,307,500	77.40	19.16
1983	19,557500	77.29	19.46
1984	19,372,500	75.68	20.92
1985	19,737,500	76.72	19.65
1986	18,583,124	76.52	20.01
1987	19,435,000	75.75	21.07
1988	19,434,376	75.38	20.59
1989	19,007,500	78.53	19.59
1990	19,150,000	77.28	19.53
1991	19,315,000	77.23	19.43
1992	19,202,500	75.93	19.87
1993	19,443,750	78.03	18.62
1994	19,696,876	76.41	19.11
1995	19,424,376	76.75	19.29
1996	19,607,500	76.32	19.36

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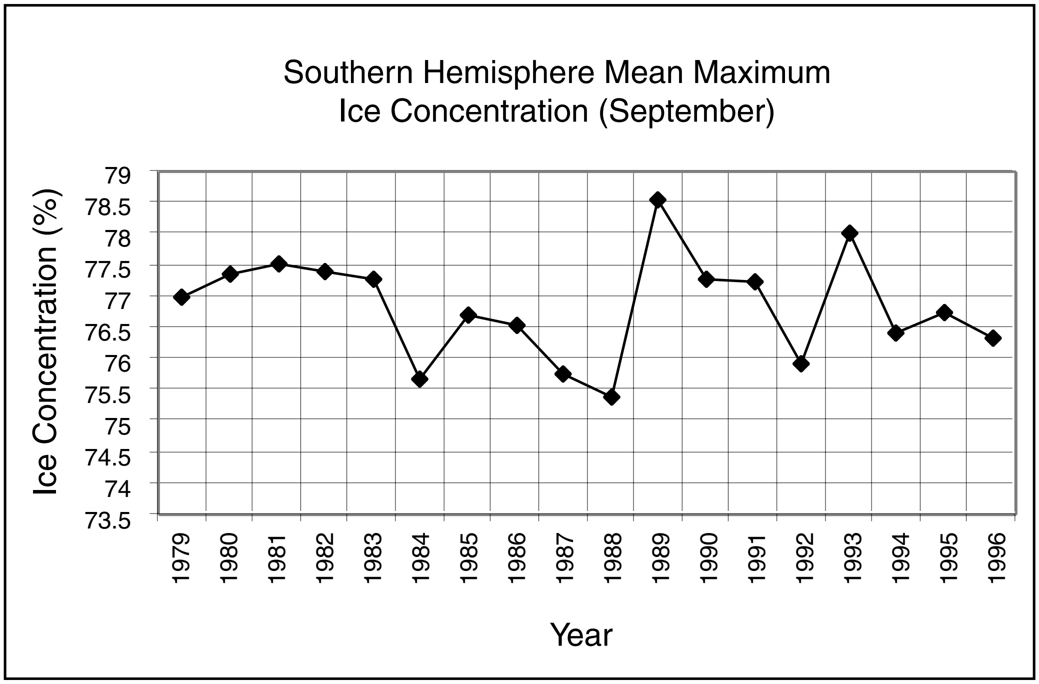
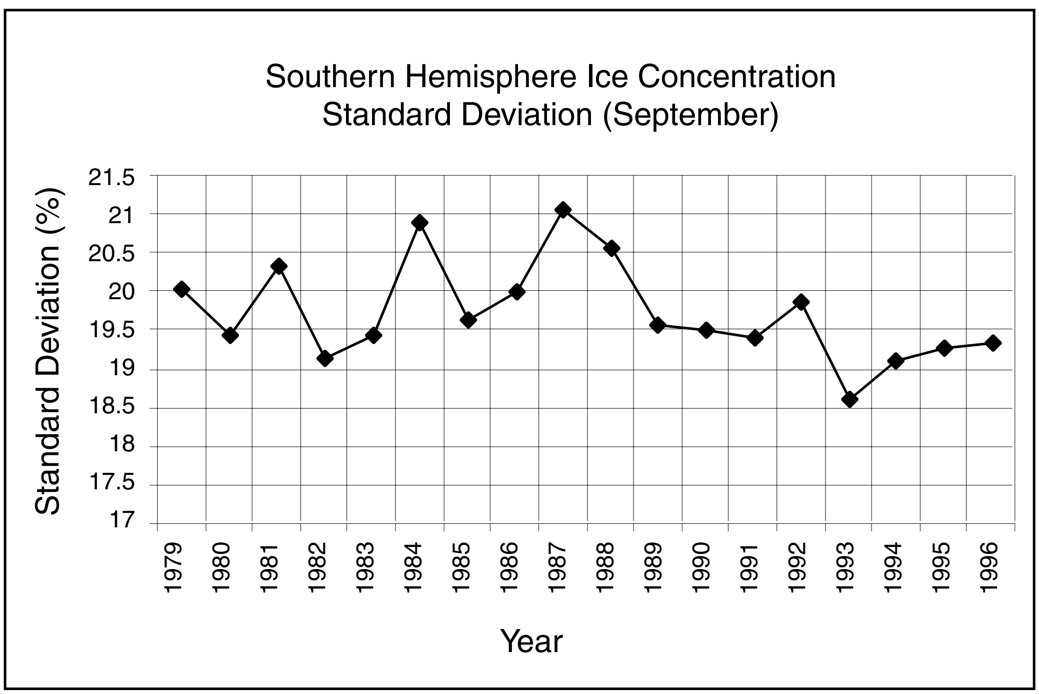
b.



c.



6. a. 1980 and 1985

   b. 1986

   c. 7.5%

7. Student answers will probably vary depending on their best fit line.

8. Variations in the monthly sea ice extent and monthly mean ice concentration indicate the variability of the sea ice cover with time. The standard deviation values indicate the amount of spatial variability within the >15% ice concentration ice cover. The greater the standard deviation, the more areas of open water and reduced ice concentration exist within the >15% ice cover. The smaller the standard deviation, the more spatially uniform the sea ice cover. Looking at the time series plots, it appears that the larger the mean ice concentration within the >15% ice cover, then typically the smaller the standard deviation; i.e., the mean ice concentration is higher because the ice cover is more uniform with less area of open water and reduced ice concentration. Conversely, we typically observe when the mean ice concentration is lower, the standard deviation is higher; i.e., the mean ice concentration is lower because there are more regions of open water and reduced ice cover within the >15% ice cover.

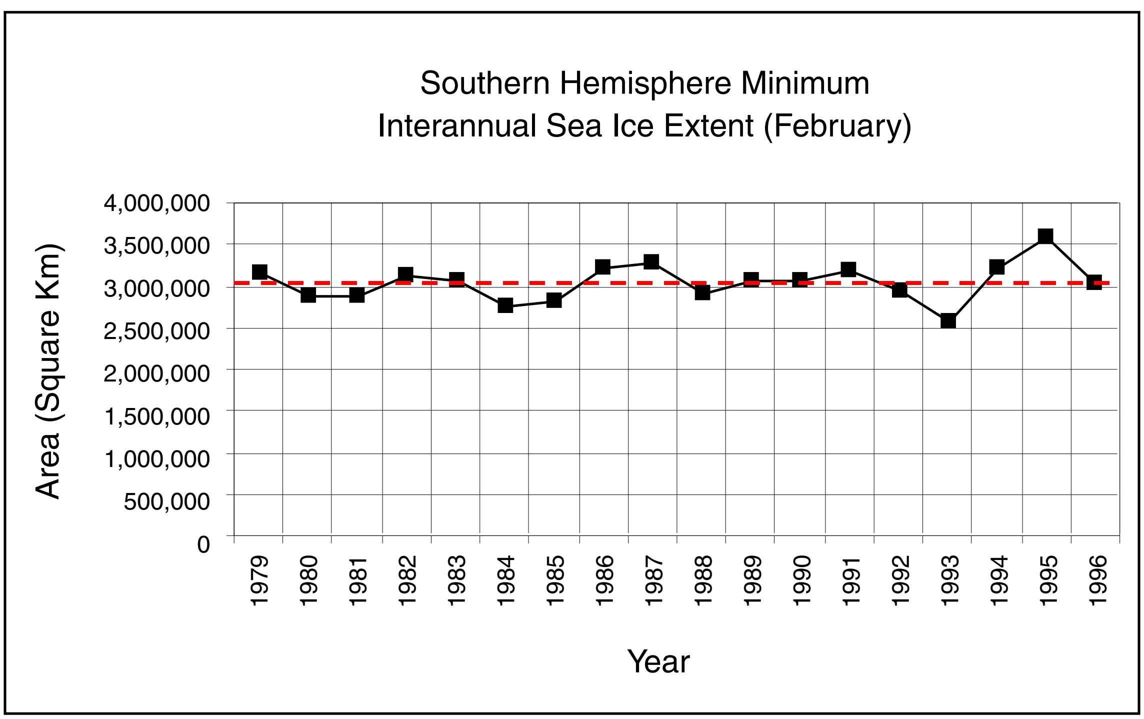
9. February

10. *Go to the next page.*

11. a. 3,053,854 sq. km

    b. The minimum sea ice extent is at or very near the Climatological Mean from 1979 until 1992. In 1993. the sea ice extent was anomalously low, while in 1995, it was anomalously high.

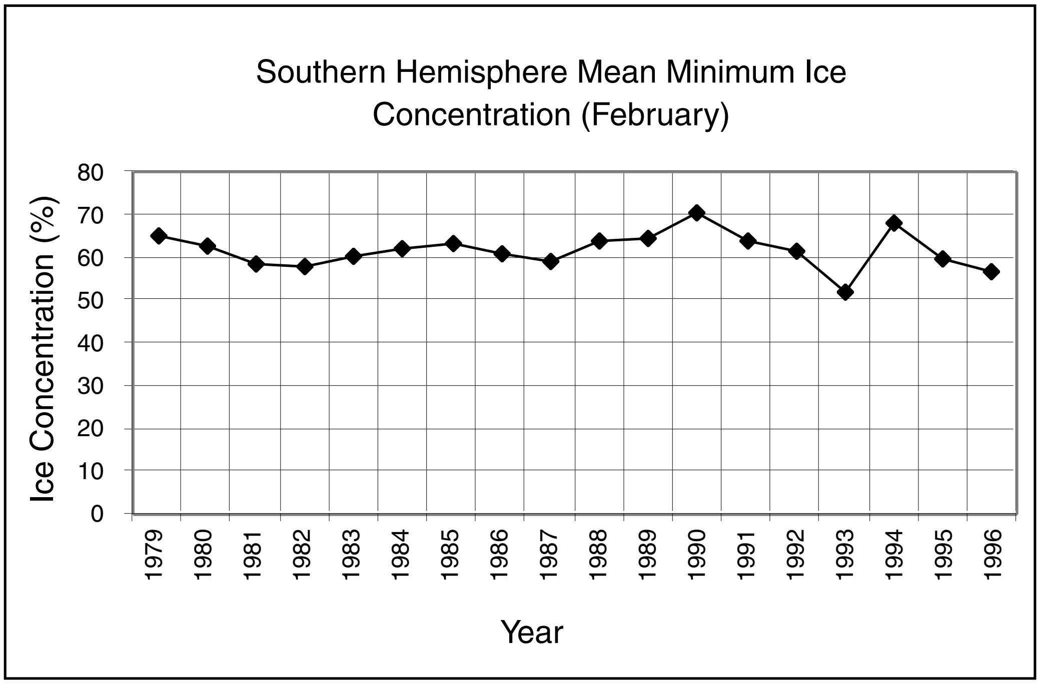
12. a.



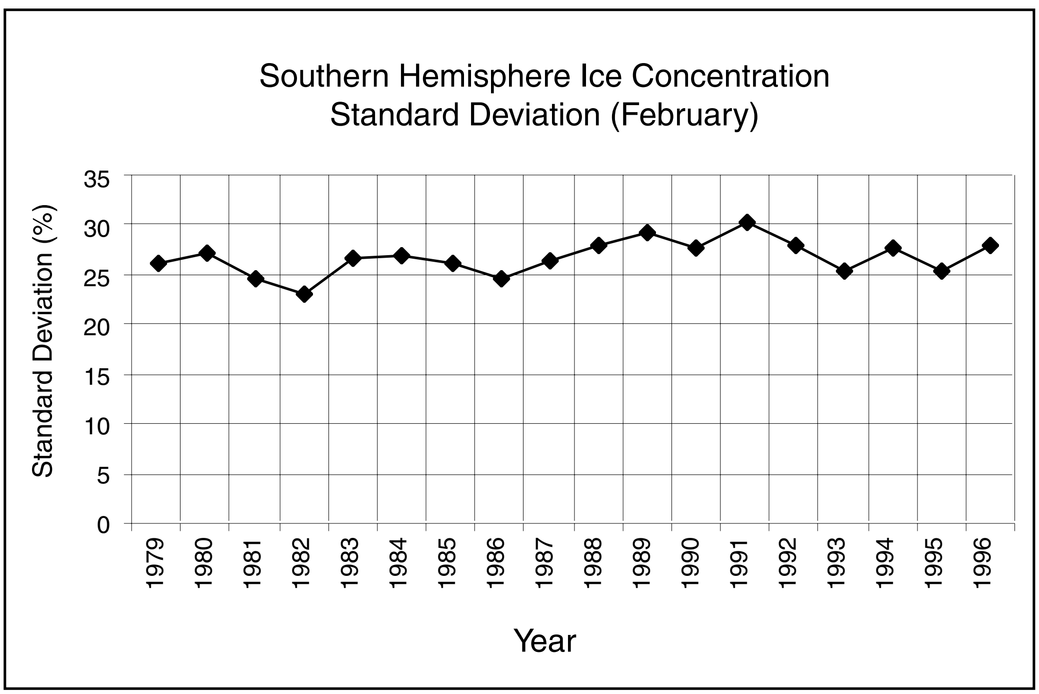
Southern Hemisphere Areal Sea Ice Extent Minimums

YEAR Month: February	AREA (square kilometers)	MEAN SIC (in percent)	STANDARD DEVIATION (%)
1979	3,156,875	65.24	26.35
1980	2,881,875	62.55	27.32
1981	2,902,500	58.21	24.67
1982	3,134,375	57.74	23.15
1983	3,073,750	60.26	26.85
1984	2,754,375	62.17	26.92
1985	2,828,750	63.11	26.37
1986	3,221,250	60.67	24.81
1987	3,282,500	59.26	26.42
1988	2,926,250	64.05	27.95
1989	3,091,250	64.74	29.39
1990	3,083,125	70.37	27.68
1991	3,208,750	63.74	30.48
1992	2,952,500	61.57	28.11
1993	2,574,375	51.83	25.37
1994	3,236,875	67.90	27.81
1995	3,607,500	59.98	25.35
1996	3,052,500	56.89	28.05

b.



c.



13. a. Largest: 1995

b. Smallest: 1993

c. 6.3%