

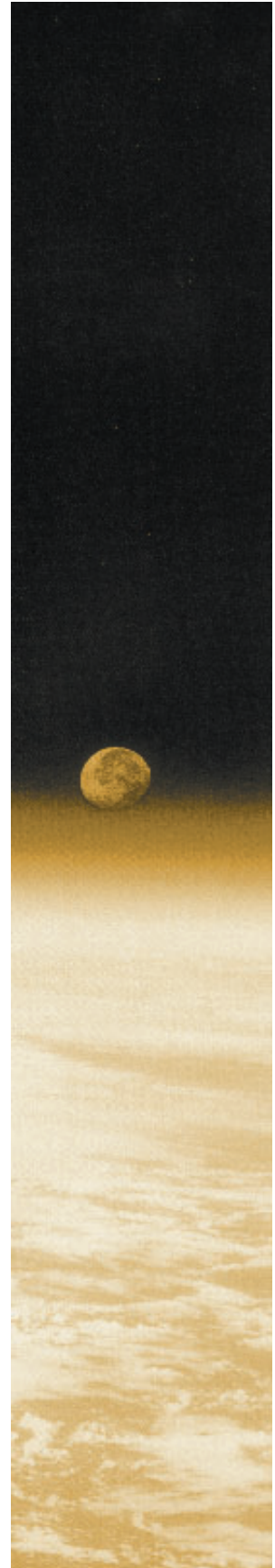
Studying Earth's Environment  
From Space  
Module 1: Stratospheric Ozone

# Instructor's Guide for Computer Resources

## STRATOSPHERIC OZONE MODULE

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## 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 role technology and mathematics plays 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 stratospheric ozone. 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 lectures provide 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/nse/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/docu->

## exercises

Each exercise for the Stratospheric Ozone Module was designed to illustrate concepts connected with the regional and temporal distribution of stratospheric ozone. 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 image processing or mathematical 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  
**National Science Education Content Standards** that are addressed by the activities

**Science process skills**, those broadly transferable abilities used in scientific disciplines that students must employ to complete the exercise—  
<http://www.science.cc.uwf.edu/narst/research/skill.htm>

**Image processing skills** or operations in SEE Image that students use to manipulate and 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

## **exercise 1**

### **investigating characteristics and the display of toms ozone data**

Before working with any set of data it is important to understand the characteristics of the data set. A knowledge of the data format, missing data, and data treatment is critical to ensure correct scientific interpretation. This activity is designed to investigate one way the TOMS ozone data has been formatted (the format used in the exercises), problems that may arise when using the data set, and ways in which the data can be displayed using an application called SEE Image.

#### **learning objectives**

When students complete Exercise 1 they should be able to

- Open, read, and interpret a TOMS ozone data file from the Nimbus-7 TOMS (Version 7) O<sub>3</sub> Gridded Data: 1978–1992 CD-ROM.
- Import a TOMS ozone data file into the application SEE Image to display data in image format.
- Color the resulting image using a predetermined color table (LUT) and determine ozone values associated with pixels on the image.
- Relate problems associated with the Nimbus-7 TOMS (Version 7) O<sub>3</sub> Gridded Data: 1978–1992 to satellite operations or environmental conditions.
- Add an overlay to an image to provide reference points for interpretation and understand consequences of this image modification.
- Generate projections of data using macros in SEE Image and investigate advantages and problems inherent in interpreting projected images.

#### **national science education content standards**

- A: Ability to do science inquiry  
Understanding about science inquiry
- E: Understanding about science and technology
- G: Science as a human endeavor  
Nature of scientific knowledge

#### **science process skills**

- observing
- inferring
- communicating
- interpreting data

#### **image processing skills**

- importing an image
- applying a predetermined color table (LUT)
- applying an overlay image
- projecting an image

#### **mathematical tools and skills**

- arithmetic computations
- projecting

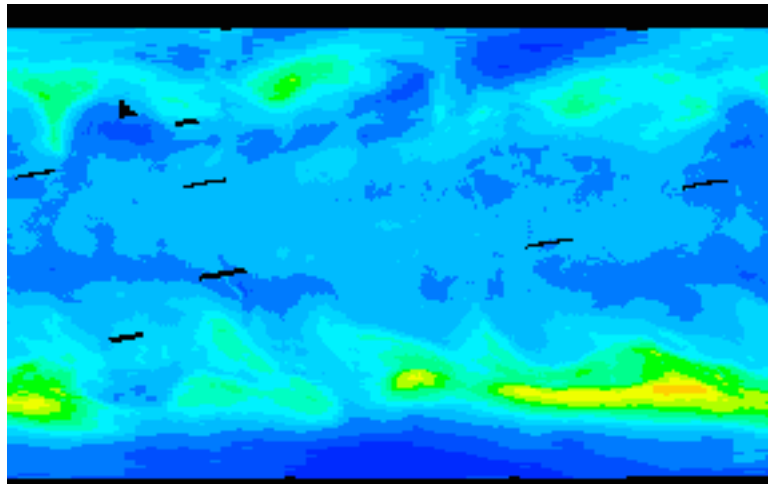
#### **resource materials**

- Computer Lab Resources, Data Section,  
Nimbus-7 TOMS (Version 7) O<sub>3</sub> Gridded  
Data: 1978–1992
- SEE Image Tutorial, Section 5.6

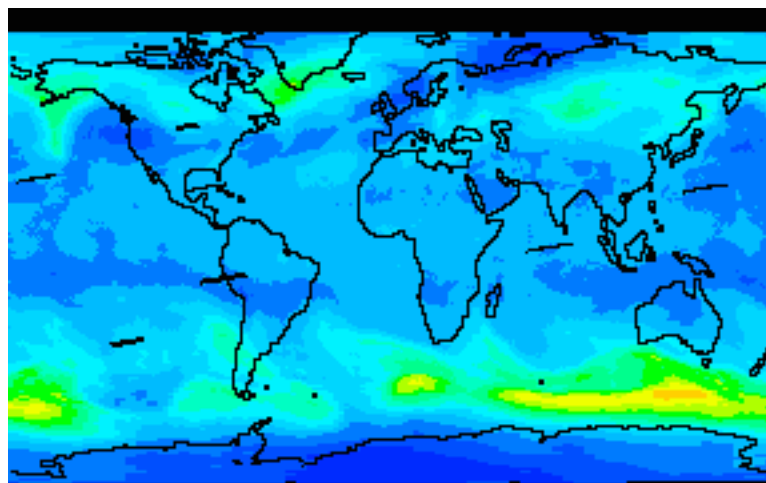
## answers to exercise 1

1. a. Day (out of 365) **275**      Date **Oct. 1, 1980**  
 b. When the satellite crossed the equator (local time) **11:51 AM**  
 c. Longitude      Starting to ending range      **179.375 W to 179.375 E**  
                          Center value      **0**  
                          Degrees between values      **1.25 degrees**  
 d. Latitude      Starting to ending range      **89.5 S to 89.5 N**  
                          Center value      **0**  
                          Degrees between values      **1 degree**
2. Only a and b will change; all data sets are gridded the same for longitude and latitude
3. a. 288 (same as "bins" in the heading)  
 $(179.375 \text{ degrees} \times 2) / 1.25 = 287$  plus 1 for starting or ending point  
 b. 180 (same as bins)  
 $(89.5 \text{ degrees} \times 2 / 1.00 = 179$  plus 1 for starting or ending point
4. a. Dobson Units (DU)  
 b. If you measure the ozone in a column of air, 1 DU is equivalent to a 0.01 mm thick layer of pure ozone gas at STP conditions.  
 c. 100 and 650 Dobson Units (DU) although most values fall between 200 and 500 DU.
5. a. 0 = no data  
 b. Because TOMS measures ozone using scattered sunlight, it is not possible to measure ozone when there is no sunlight impinging on the atmosphere. This condition may occur due to orbital position and timing or because of seasonal solar irradiance. Consequently, maps of the Antarctic ozone hole for August and September, for example, will always have areas of missing data due to polar night.

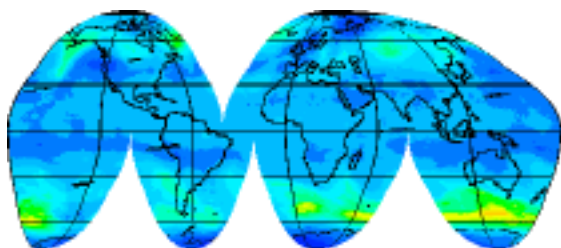
**Missing Data:** During 1978–1979 the TOMS instrument was turned off periodically to conserve power, including a 5-day period (6/14–6/18) in June 1979. On many days data were lost because of missing orbits or other problems.



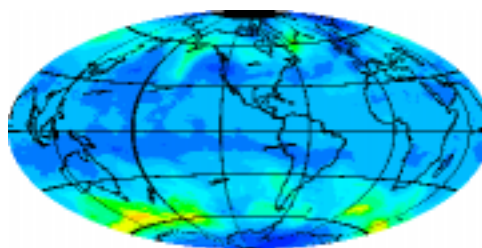
6. What value is associated with black? *93–95*      white? *601–603*
7. 95, 225–491
8.
  - a. Black = areas of no data or values below 95 DU
  - b. During 1978–1979 the TOMS instrument was turned off periodically to conserve power, including a 5-day period (6/14–6/18) in June 1979. On many days data were lost because of missing orbits or other problems.
  - c. Because TOMS measures ozone using scattered sunlight, it is not possible to measure ozone when there is low sun (in the polar regions in winter). Consequently, maps of the Antarctic ozone hole for August and September, for example, will always have areas of missing data due to polar night.
  - d. Data were lost due to missing orbits.



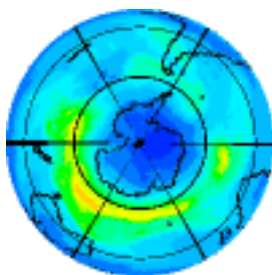
9. Map projections are used to represent a spherical object on a flat surface such as paper or a computer screen. The spherical object for the TOMS data is Earth.



*Goode Homolosine*



*Hammer 100 W*



*South Polar*

map projection	advantages	disadvantages
Original Image	continents appear as generally seen on map	very distorted; surface area of a pixel on equator ( $\sim 15400\text{km}^2$ ) is much greater than the surface area of pixel near the poles ( $\sim 100\text{ km}^2$ ); connecting features across the edges
South Polar (orthographic)	shows Earth as if viewed from deep space; often used to view the polar regions that are severely distorted by other projections	distortion occurs in the region around the equator
Hammer	area of features is not distorted; each pixel in the image represents the same area; excellent choice for global analysis	shapes of features distorted especially near the top and bottom edges of the projection; connecting features across the edges
Goode	equal area projection; each pixel in the image represents the same area	the globe is not presented as a continuous feature; interrupted so that all of the land masses are continuous with the exception of Antarctica

## **exercise 2**

### **comparing daily ozone values over the globe to the daily average and investigating ozone distribution patterns**

There is a variation of ozone values across the globe at any given time. In this exercise students work with a single date TOMS image. They start by calculating the global average ozone for September 1, 1991, and use this value as a reference to compare other ozone values in the image. Additional sites are located and the ozone value compared with the global average. Students are introduced to the stratification of ozone concentration across the globe.

#### **learning objectives**

When students complete Exercise 2 they should be able to

- Compute a global ozone average from an image and compare it to values at individual locations.
- Recognize and interpret ozone level stratification.
- Recognize the effect elevated Earth surface features have on recorded ozone levels.

#### **national science education content standards**

- A: Ability to do science inquiry
  - Understanding about science inquiry
- D: Energy in the Earth system
- E: Understanding about science and technology
- G: Nature of scientific knowledge

#### **science process skills**

- observing
- inferring
- communicating
- interpreting data

#### **image processing skills**

- importing an image
- applying a color table
- applying an overlay image
- using density slicing
- averaging image data using a prewritten macro

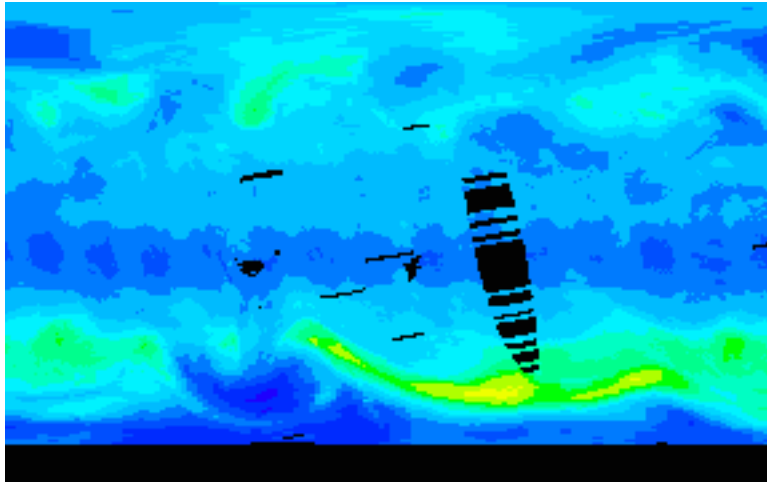
#### **mathematical tools and skills**

- averaging image data using a prewritten macro

#### **resource materials**

- Stratospheric Ozone eTextbook, Chapter 3—  
Morphology of Ozone
- Stratospheric Ozone eTextbook, Chapter 6—  
Stratospheric Dynamics and the Transport of  
Ozone and Other Trace Gases

## answers to exercise 2



C. Global Mean Value 299 DU

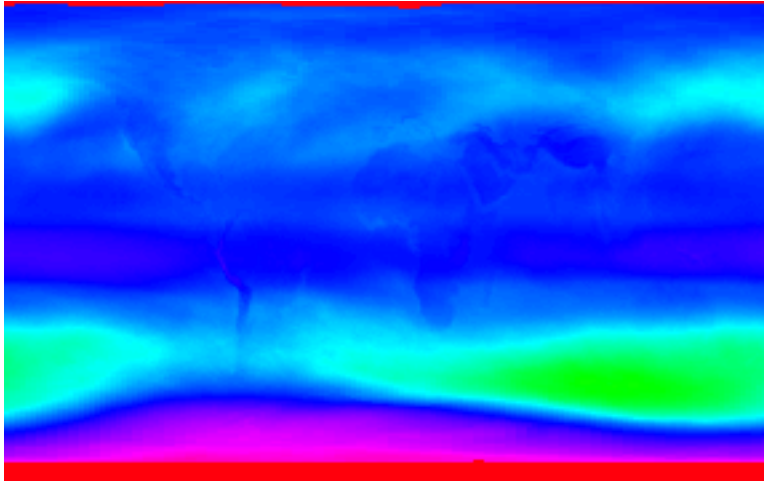
1. Black areas = no data

2.

pixel location (x,y)	latitudinal region	ozone value (du)	comparison to global mean (higher, lower, same)
10, 15	north polar	233	lower
125, 20	north polar	349	higher
50, 75	north tropical	289	lower
62, 72	north tropical	297	higher
15, 95	south tropical	245	lower
230, 100	south tropical	261	lower
20, 130	south mid-latitude	389	higher
100, 145	south mid-latitude (almost polar)	199	lower
185, 145	south mid-latitude (almost polar)	447	higher

3. a. What color or color ranges are associated with the following:  
global mean ( $\pm 10$ )                    ***intermediate blue (will show RGB value of 000 187 254)***  
values above the global mean   ***light blue through red***  
values below the global mean   ***medium blue through purple***
- b. Horizontal or zonal pattern is evident in the image with similar values in bands running east–west.
- c. Most extreme values (high and low) occur in south polar region; the low values close to the pole and the high values north of the lows are a result of dynamic processes; ozone rich air is transported toward the pole but is unable to mix with polar air because of a strong polar night jet that isolates the polar air in a polar vortex; ozone rich air forms a “collar” around the lower ozone isolated polar air.
4. a. Yes. There is a pattern in both the east-west and north-south directions.
- b. East-west transport is governed by zonal winds and so is “dynamically” controlled; north-south gradients are generally the result of photochemical processes that depend on the amount of incident sunlight.
5. a. highest            approx. 433–483  
lowest                approx. 105–155  
max. area          approx. 265–315 (this may vary slightly based on student judgment of area covered)
- b. Global mean is contained in area of maximum highlighting and is approximately centered in this range.
- c. Tropical regions < northern high latitudes; tropical regions < and > selected regions in southern high latitudes; tropical slightly less than north polar and greater than south polar.  
Would you expect the ozone values to be higher over high mountains or lower lying areas? Explain.  
Values should be lower over elevated features because of shorter air column; less air, less ozone.
6. a. Ozone values for “oblong” object < surroundings  
b. Himalayas and the Plateau of Tibet
7. a. Ozone values for “banana” object < surroundings  
b. Andes mountains

8. Ozone values over elevated areas are generally less than surroundings because of shorter air column, therefore less ozone to be detected.



9. You should be able to see the west coasts of North and South America, outline of Africa and India, and the Arabian peninsula.

## exercise 3

### comparing polar and tropical monthly ozone distributions through histograms

This exercise allows students to analyze ozone distributions in two selected regions, tropics and Arctic circle using histograms.

#### learning objectives

When students complete Exercise 3 they should be able to

- Select a region of interest and generate a histogram of ozone value in that region.
- Use histogram interpretation to investigate latitudinal (zonal) ozone level stratification.
- Recognize the effect Earth surface features have on recorded ozone levels.

#### national science education content standards

- A: Ability to do science inquiry  
Understanding about science inquiry
- D: Energy in the Earth system
- E: Understanding about science and technology
- G: Nature of scientific knowledge

#### science process skills

- observing
- inferring
- communicating
- interpreting data

#### image processing skills

- importing an image
- applying a color table
- using a macro to determine geographic locations on an image
- defining a region of interest
- generating a histogram for a region of interest

#### mathematical tools and skills

- analyzing a histogram

#### resource materials

- Stratospheric Ozone eTextbook, Chapter 3—  
Morphology of Ozone
- Stratospheric Ozone eTextbook, Chapter 6—  
Stratospheric Dynamics and the Transport of  
Ozone and Other Trace Gases

## answers to exercise 3

- C. Arctic circle                      X = 0   Y = 23  
     Tropic of Cancer                X = 0   Y = 66  
     Tropic of Capricorn            X = 0   Y = 113

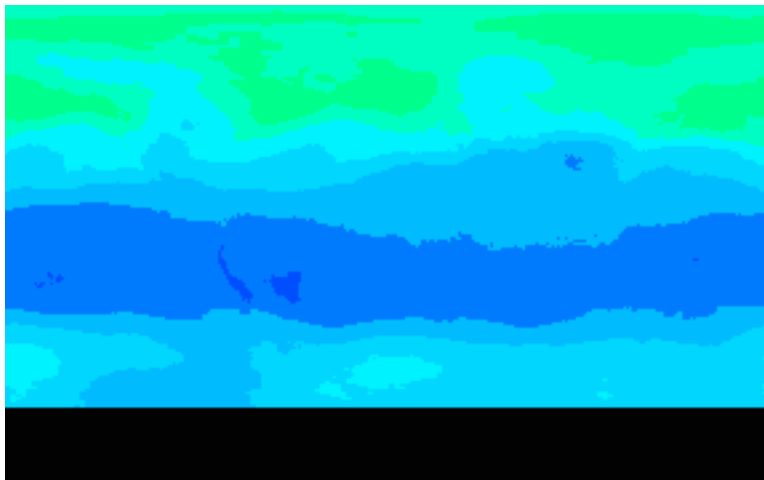
1. Arctic      min = 341      max = 397  
     Peaks expressed as Level (Count): 367 (556), 371 (646), 375 (596)



2. Tropical      min = 241      max = 313  
     Peaks expressed as Level (Count): 252 (1278), 283 (656)



3. Antarctic region would be a poor choice because of the large number of “no-data” pixels.



4. a. Tropics    **252**                      Arctic    **371**  
     b. Tropical   **241–313**      Arctic    **341–397**  
     c. Range of values is different; narrower range in Arctic region.  
     d. Tropical values are less than Arctic values.

## exercise 4

### observing global seasonal variations in total column ozone values using monthly average images

Ozone levels vary as the seasons change. In this exercise students compare ozone levels at different times of the year. They examine images gridded monthly averages for 1979 to observe global seasonal variations and finish the exercise by animating the images to visually observe the dynamics of ozone levels across the globe throughout the year.

#### learning objectives

When students complete Exercise 4 they should be able to

- Import, color, stack, and animate multiple data sets.
- Interpret seasonal variations in total column ozone levels from a montage or animation.

#### national science education content standards

- A: Ability to do science inquiry
  - Understanding about science inquiry
- D: Energy in the Earth system
- E: Understanding about science and technology
- G: Nature of scientific knowledge

#### science process skills

- observing
- inferring
- communicating
- interpreting data

#### image processing skills

- importing multiple images
- applying a color table
- applying an overlay image
- generating an image stack
- making a montage from an image stack
- animating an image stack

#### mathematical tools and skills

- determining maximum and minimum values from color coded data

#### resource materials

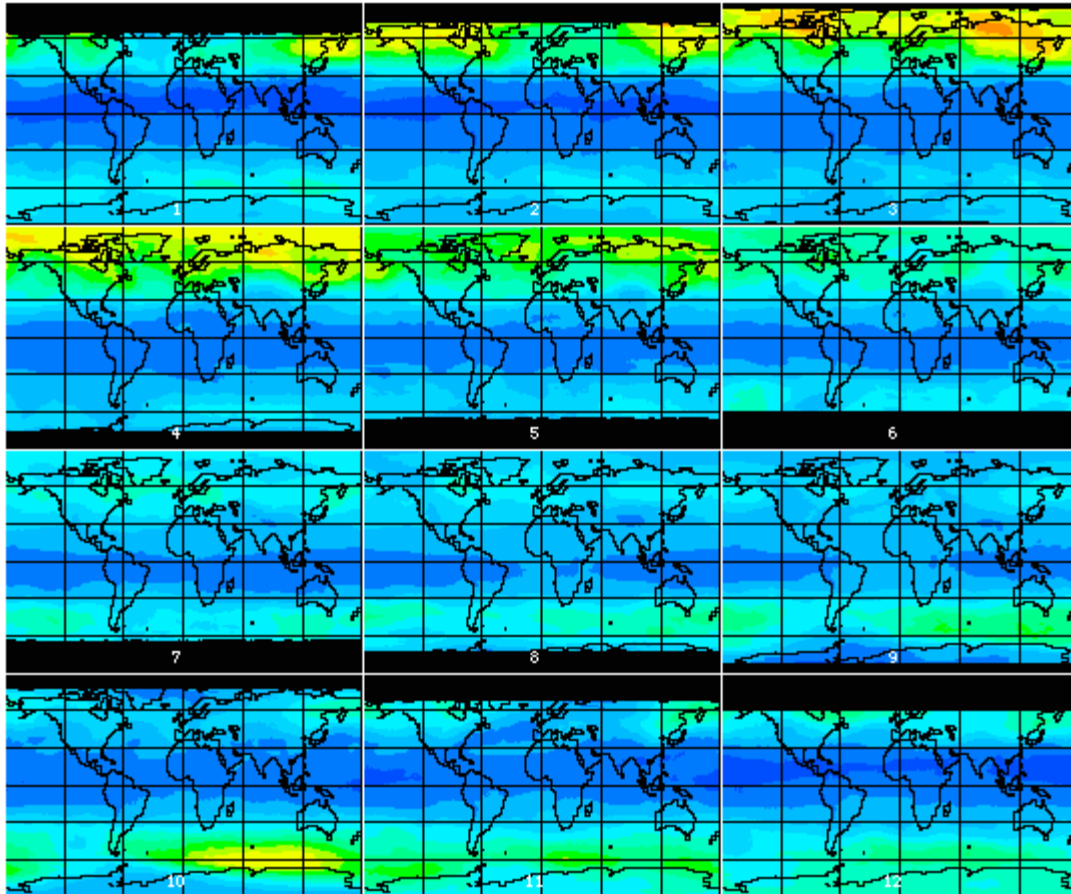
- Stratospheric Ozone eTextbook, Chapter 3—  
Morphology of Ozone
- Stratospheric Ozone eTextbook, Chapter 6—  
Stratospheric Dynamics and the Transport of  
Ozone and Other Trace Gases

## answers to exercise 4

1. Images are almost identical; minor pixel value differences ( $\pm 2$ ) at spots on the image.
2. a. Banding is more uniform in the monthly averages and appears to be strongly latitudinal (or zonal); daily (day 1) values show much more variation along a particular line of latitude.
- b. Advantages to using monthly averaged data:
  - Seasonal trends more obvious
  - Localized anomalous events of local atmospheric conditions minimized

Disadvantages to using monthly averaged data:

Loss of information on: daily fluctuations over a specific location, within latitudinal variations; or short-term phenomena



3. a. Global distribution appears to be “banded” horizontally or latitudinally.
- b. Banding is latitudinal because of global circulation patterns (west-east or zonal winds), which also makes longitudinal (meridional) mixing a slower process; photochemical processes also generate more ozone in the tropics than at higher latitudes.

4. a. maximum **517 (image 2)**      minimum **235 (image 12)**  
(93 or 95, which represents no data, is not the min)  
color **dark orange**                      color **dark blue**
- b. Maximum change over the year is evident in polar or high latitude regions. Caused by larger variations in incoming solar radiation (insolation) and atmospheric circulation and transport processes.
- c. Polar and high latitude regions have more variation in monthly ozone values with highest values occurring during spring months in each hemisphere.
5. Student response will vary.



## exercise 5

### comparing spring antarctic (14 Octobers) ozone values and arctic (15 marches) ozone values

There has been a significant amount of discussion of the variations in the size and extent of the Antarctic “ozone hole.” By viewing a sequence of TOMS monthly averages for the Spring Antarctic phenomena from October 1979 to October 1992, students observe how the size and shape of the ozone hole over the south pole has varied. Second, they observe the Spring Arctic fluctuations in ozone for monthly average data from March 1979 to March 1993 and compare it to the Antarctic ozone distributions.

#### learning objectives

When students complete Exercise 5 they should be able to

- Recognize patterns in ozone distribution that are regional and seasonal.
- Identify temporal trends in ozone levels for the Arctic and Antarctic regions.
- Investigate spatial symmetry of ozone distributions from an image.
- Identify stratospheric ozone features such as the Antarctic ozone hole from a TOMS image.

#### national science education content standards

- A: Ability to do science inquiry
  - Understanding about science inquiry
- D: Energy in the Earth system
- E: Understanding about science and technology
- F: Natural resources
  - Environmental quality
  - Natural and human induced hazards
- G: Nature of scientific knowledge

#### science process skills

- observing
- inferring
- measuring
- communicating
- predicting
- interpreting data

#### image processing skills

- importing multiple images
- stacking images
- applying a color table
- overlaying an image
- generating montage from an image stack
- projecting an image
- plotting a profile
- animating an image stack

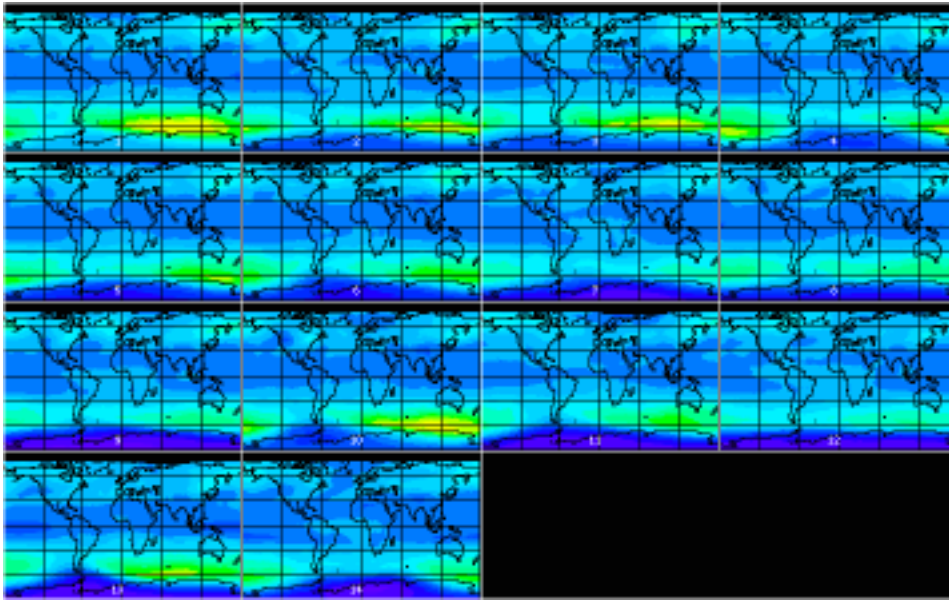
#### mathematical tools and skills

- determining maximum and minimum values from color coded data
- interpreting a graph

#### resource materials

- Stratospheric Ozone eTextbook, Chapter 6—  
Stratospheric Dynamics and the Transport of  
Ozone and Other Trace Gases
- Stratospheric Ozone eTextbook, Chapter 11—  
The Antarctic Ozone Hole

## answers to exercise 5



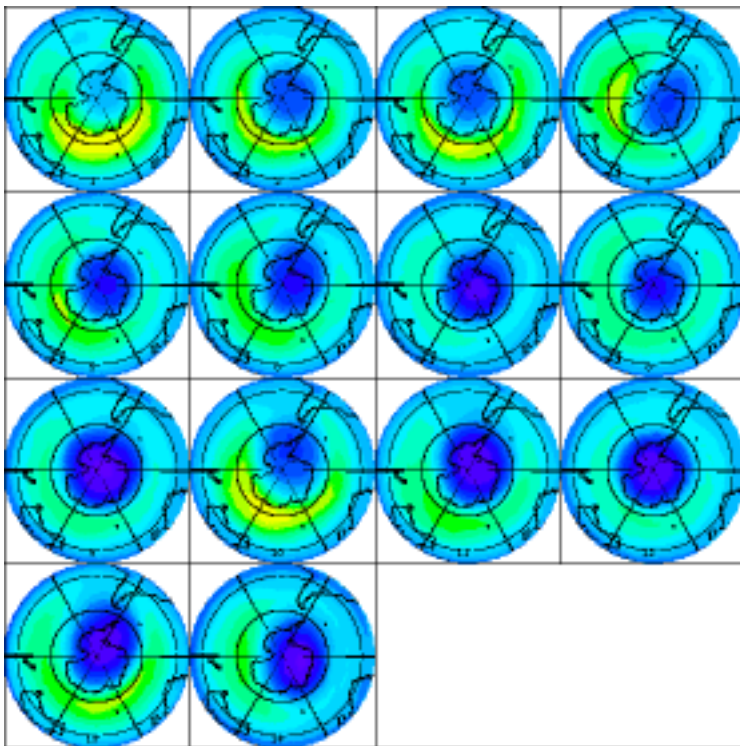
1.
  - a. Highest ozone value recorded on any image 473 on #1
  - b. Highest values are concentrated in area just north of Antarctica or south polar region (known as the “collar” region).
  - c. Lowest ozone value displayed on any image 143 on #9
  - d. Lowest values are concentrated on south polar region.
  - e. Atmospheric dynamic processes allow good latitudinal (zonal) mixing but slower longitudinal (meridional) mixing; the strong polar night jet isolates “ozone-poor” polar air in the polar vortex and prevents mixing of “ozone-rich” air from lower latitudes; the rich air forms a high ozone collar around the polar vortex; ozone-poor air in the vortex results from limited ozone production and chemical depletion processes involving CFCs and polar stratospheric clouds (see Ozone Lecture 10).
2.
  - a. There is a general overall decline in the minimum and maximum values with notable lows in 1985–87 and 1989–90.
  - b. What does this imply about southern hemisphere spring ozone levels during the period from 1979 to 1992?  
Some process is at work that is causing a decline in south polar spring ozone values.

- c. What factors may be responsible for the changes with time? Explain.

Students may have creative or knowledgeable answers for this question. If they work through the exercise they will be guided to the concept of the Antarctic ozone hole so you may wish to take speculative answers at this point.

Chapter 11 on the Antarctic Ozone Hole contains details on the processes that reduce ozone levels. Dynamics of the polar vortex isolate polar air from lower latitude air that is richer in ozone. Ozone destroying halogen reactions have increased with increasing chlorine and bromine levels in the stratosphere. Heterogeneous chemistry that occurs on polar stratospheric cloud particles and releases chlorine from reservoir species is also responsible. These PSCs form when extremely cold temperature conditions develop in the polar vortex as has occurred recently.

3.

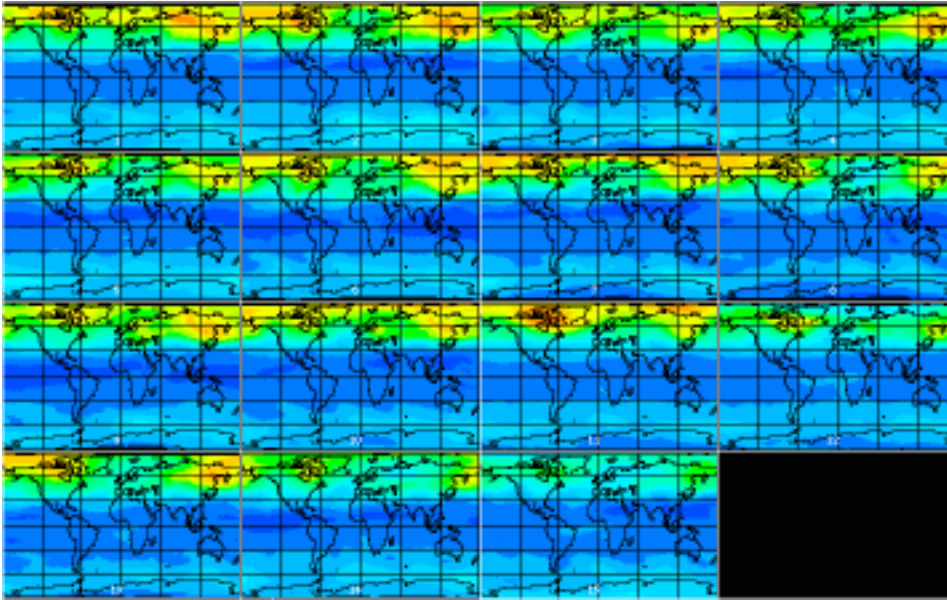


- A zonal distribution of ozone levels can be seen in the ringed color bands or circular features in the projections.
- The basic shape of one of the most prominent features on a majority of the South Pole projected images is a circle or ellipse (of low ozone values).

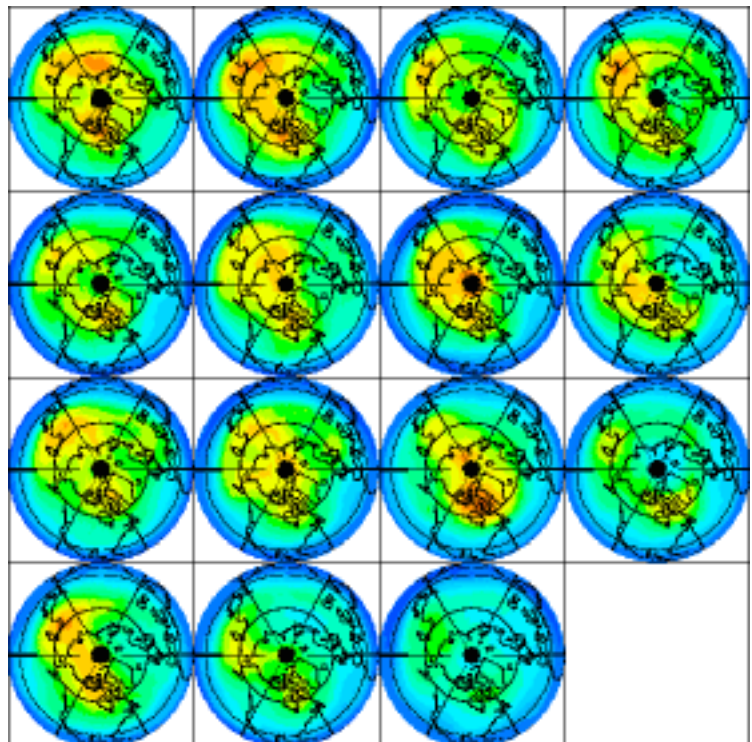
Other feature evident in a significant number of the images: crescent moon or banana shaped feature (partial circle) of high ozone levels at latitudes just north of the Antarctic continent.

- c. Range of ozone values associated with ellipse: *~ 145–281 DU*  
Range of ozone values associated with banana: *~ 370–470 DU*
  - d. Ellipse is the ozone hole; banana is ozone collar.
  - e. Lowest levels of ozone along with largest elliptical feature **1987 (#9)**
  - f. See Chapter 11. The banana feature results from ozone that is delivered from tropical latitudes to higher latitudes via Brewer-Dobson circulation. The strong winds of the polar night jet isolate the polar region in the polar vortex and minimize ozone transport into the polar regions. Therefore, higher ozone concentrations develop “outside” (lower latitudes) of the polar vortex and low ozone values occur within the polar region.
- 4. a. The source of the downward spikes on the plot is the continental overlay. Remember that overlays destroy underlying data (in this case replacing data with a value of 95). These spikes should be ignored when interpreting the plots.
  - b. Since the horizontal slice plot is reasonably symmetrical it may be safe to assume that the feature (ozone hole) is also reasonably symmetrical along this cross-section.
  - c. Multiple slices should all show a symmetrical pattern. This would imply that there is symmetry along a line of longitude (or longitudinal great circle) passing roughly through the South Pole.
  - d. The feature (ozone hole) appears to have circular or elliptical symmetry.
- 5. a. Size: generally increases
  - b. Shape: appears to cycle from circular to elliptical to circular to elliptical
  - c. Position with respect to Antarctica: center of feature moves on and off the center of Antarctic continent
- 6. High ozone collar increases and decreases in magnitude as well as shifting its longitudinal position.
  - 7. This is open for speculation by students based on what they saw with the 14 Octobers. It would be logical to conclude that the same pattern would hold in the northern hemisphere.

8.



9. a. Orange **501–525** (One section on Image #11 has values in 530 range—dark orange)
- b. Year sustaining the highest values over the largest area **1979 or 1980 or 1989**  
 Year showing the lowest values in the north polar region **1993**
- c. Values in the north polar region seem to increase and decrease over the period but there is no strong pattern or trend in the ozone values you observe in the northern hemisphere. unlike the southern hemisphere.



10. There may be a wide range of answers for this question depending on the background of the students.
- a. There is some zonal (latitudinal) distribution of ozone apparent from this set of images but it is not as well defined as in the south pole spring images. Arctic spring ozone values (above 300 DU) are much higher than ozone levels in the southern hemisphere Antarctic spring.
  - b. There are regions of high ozone values rather than low ozone values that form an irregular feature but it is not as well defined as the Antarctic ozone hole. The areas of high ozone values are greater than the extent of the Antarctic ozone hole. There is no obvious collar feature as was evident similar in the Antarctic spring images.
  - c. March ozone distributions on individual images (years) may be longitudinally symmetrical along one cross-section but not along others. This feature has poor symmetry.
11. a. Responses will vary. Pattern is less obvious than with Antarctic spring values.
- b. Less isolation of the north polar vortex. See Chapters 6 and 10 for the difference in atmospheric transport dynamics in the northern and southern hemisphere.

### *NOTE TO INSTRUCTORS*

You may wish to have students obtain more recent data for the northern hemisphere from the Goddard NASA Goddard Space Flight Center Toms Web site (<http://toms.gsfc.nasa.gov/ozone/ozone01.html>) to investigate lower ozone levels over the Arctic from 1994 to the present. A strong polar night jet and extremely cold temperatures in the north polar vortex have permitted formation of PSCs and heterogeneous chemistry processes that deplete ozone and provide observations similar to those in the southern hemisphere.

## exercise 6

### further examination of the differences between spring arctic and antarctic ozone distribution

To demonstrate how ozone is distributed and varies in the spring for either the North or South Pole, students will compare two monthly average images from March 1979 and October 1979.

#### learning objectives

When students complete Exercise 6 they should be able to

- Evaluate similarities and differences in ozone distributions from histograms.
- Generate plots to explore seasonal trends in ozone distributions.
- Generate and interpret a ratio image of ozone values from two monthly images.
- Compare zonal ozone distribution for two specified years using ratio images.

#### national science education content standards

- A: Ability to do science inquiry
  - Understanding about science inquiry
- D: Energy in the Earth system
- E: Understanding about science and technology
- F: Natural resources
  - Environmental quality
  - Natural and human induced hazards
- G: Nature of scientific knowledge

#### science process skills

- observing
- measuring
- communicating
- predicting
- interpreting data

#### image processing skills

- importing multiple images
- applying a color table
- generating a histogram
- exporting histogram data
- plotting profiles
- using image math to ratio two images
- applying an image overlay

#### mathematical tools and skills

- generating and interpreting a histogram
- generating and interpreting a profile
- generating and interpreting a ratio image

#### resource materials

- Stratospheric Ozone eTextbook, Chapter 6—  
Stratospheric Dynamics and the Transport of  
Ozone and Other Trace Gases
- Stratospheric Ozone eTextbook, Chapter 11—  
The Antarctic Ozone Hole

## answers to exercise 6

1-2.

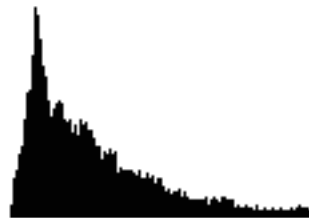
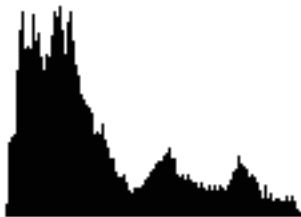
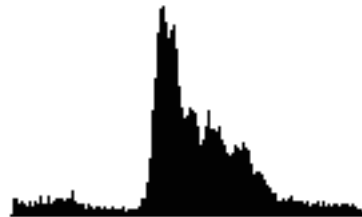
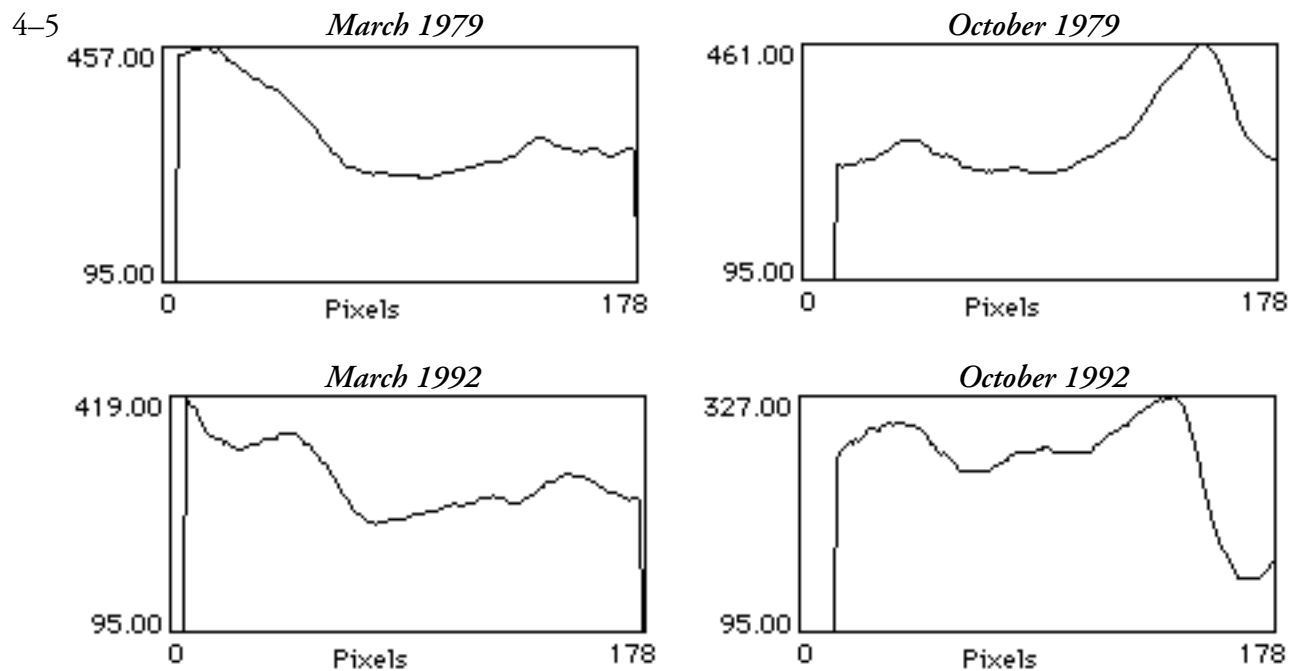
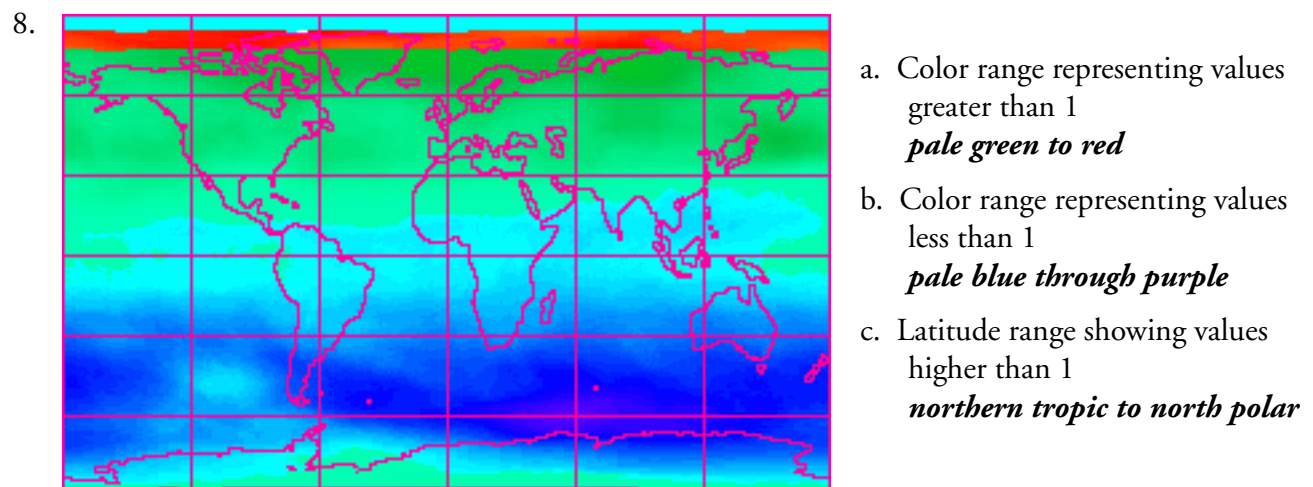
*March 1979**October 1979**March 1992**October 1992*

image	most frequent ozone value	lowest ozone value	highest ozone value	range for ~75% of pixels
March 1979	259	247	521	247 ~ 341
October 1979	267	247	479	247 ~ 331
March 1992	281 (several close)	241	467	241 ~ 371
October 1992	261	147	421	247 ~ 347

3. a. Major similarities: Both peak near same values and have most values in same range.  
Major differences: March shows a slightly wider range of values and a more bimodal distribution.
- b. Same, ozone distribution pattern should be similar in distribution based on latitude but be in the opposite hemisphere.
- c. For 3 of the 4 images there is a similar pattern.
- d. The October 1992 distribution is dissimilar with a tail in the lower ozone values not seen on the other three histograms.
- e. The low value tail on the October 1992 histogram comes from low values in the Antarctic ozone hole.



6.
  - a. The precipitous rise at the beginning of each plot comes from the change from no data (black regions) to the data section. It should be ignored when interpreting the profile.
  - b. Plots are similar as would be expected since similar processes should be at work to generate the ozone distributions.
  - c. Highest ozone values occur just outside of the vortex in late winter-early spring for a particular hemisphere.
7.
  - a. Plots are not the same. There is more variation in values in 1979. There is a steep drop near 178 on 1992 plot. There are lower values in the vortex and lower max. values in the collar in 1992.
  - b. Steep drop in plot near 178, which shows part of the ozone hole.

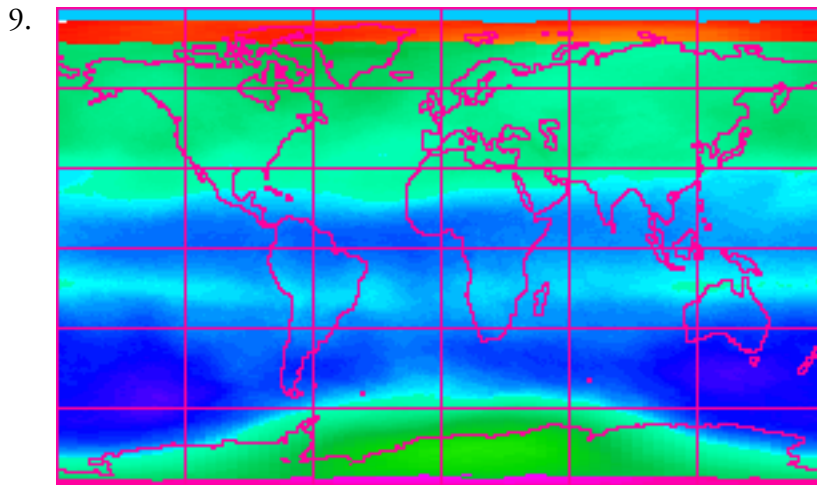


Why would you expect this? Ozone values are higher in spring hemispheres and since the ratio is March:October, values of greater than 1 will show in the March spring hemisphere, which is the northern hemisphere.

- d. The latitude range showing the least difference in ozone levels from March to October will have values close to 1, which occurs in the tropical zone within about 20°S to 20°N. Consistent solar energy levels and atmospheric distribution systems keep values steady.

Would you expect the same ratio values if you compared March and October data from 1992? Explain why or why not.

The answer to this question will vary based on the student. It is designed to have the student take a moment to reflect and make a prediction based on the previous set of steps before exploring further data sets.



The ratio values for March:October in the northern hemisphere are similar for 1979 and 1992 with values above 1. However, there is a significant difference in the southern hemisphere values.

10. a. The most significant changes in the ratio values from 1979 to 1992 is seen in a segment of the southern polar region where the 1992 values are greater than 1 (pale blue to green) and were below 1 in 1979. This indicates that March values in this region are higher than October values, which is not normally the case for a southern polar spring (October).
- b. The reason for the values greater than 1 for the south polar region in 1992 is the Antarctic ozone hole where total column ozone levels have declined since 1979.
11. Responses will vary with the student.

## **exercise 7**

### **using monthly and annual averages to monitor seasonal changes and change in total global ozone for 1979 and 1992**

In Exercise 4 students used monthly images of TOMS ozone values to observe the seasonal fluctuations of atmospheric ozone levels for 1979. In this exercise they observe seasonal changes in the monthly average images for 1992 and compare these values to 1979 images to note changes that may have occurred over time.

#### **learning objectives**

When students complete Exercise 7 they should be able to

- Visually analyze temporal trends in ozone levels from images in a montage and an animation.

- Generate a yearly average image for comparison with monthly average images.

#### **national science education content standards**

- A: Ability to do science inquiry
  - Understanding about science inquiry
- D: Energy in the Earth system
- E: Understanding about science and technology
- G: Nature of scientific knowledge

#### **science process skills**

- observing
- measuring
- inferring
- communicating
- predicting
- interpreting data

#### **image processing skills**

- importing multiple images
- applying a color table
- applying an overlay image
- generating an image stack
- calculating the average image of an image stack using a macro
- making a montage from an image stack
- animating an image stack

#### **mathematical tools and skills**

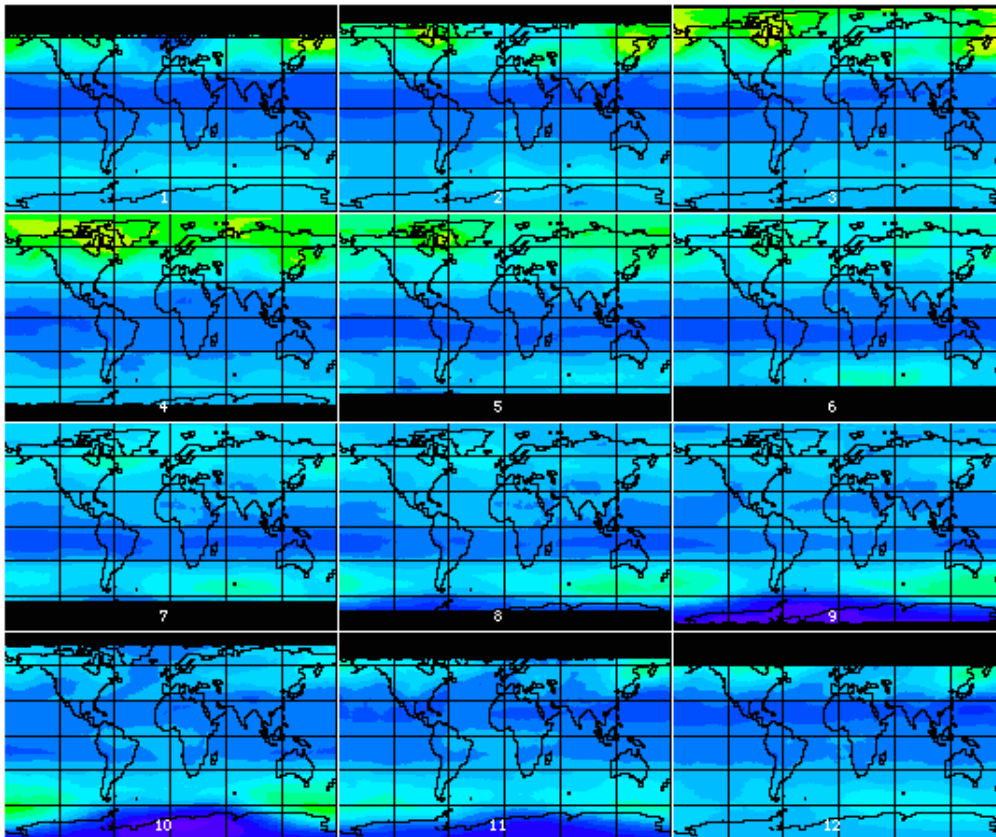
- averaging image data using a prewritten macro

#### **resource materials**

- Stratospheric Ozone eTextbook, Chapter 3—Morphology of Ozone

## answers to exercise 7

1. Ozone values are higher over a larger region of the north polar regions during its spring. Values generally decrease in the southern polar region for its spring.



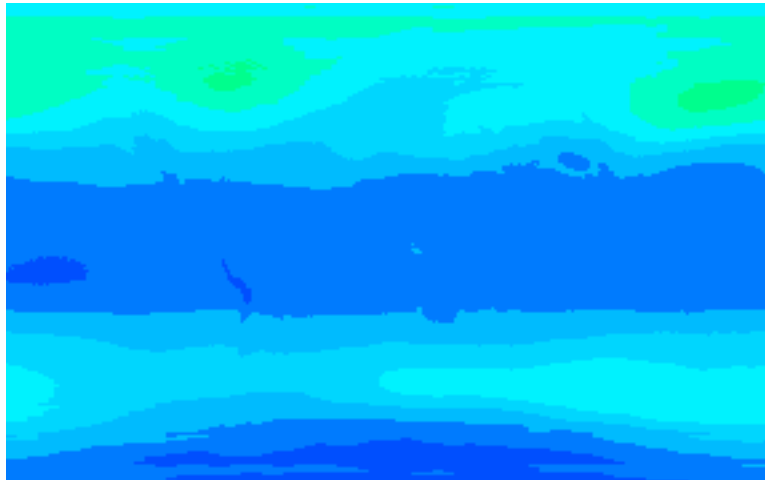
2. a. Ozone seems to be distributed along lines of latitude more than longitudinally.  
b. Meridionally. Zonal winds allow mixing within a latitude band on a relatively short time scale. Meridional mixing (i.e., Brewer Dobson circulation) involves larger scale circulation dynamics and takes longer.

3. a. Maximum **463 (#3)**      Minimum **147 (#10)**  
Color **bright yellow**      color **purple**

Greatest changes in ozone values occur in the north and south polar regions. Changes are based on atmospheric transport processes and differential production rates caused by varied solar insolation at the poles.

- b. Greatest changes in polar regions with highs occurring in northern hemisphere spring and lows in southern hemisphere spring; tropical and mid-latitudes ozone values do not vary as widely with seasons.

4. There is a visible decrease in the ozone values in the northern hemisphere for the first four months of 1992 compared to 1979.
5. Looking at all the months on both montages for the tropical regions there has been a decline in the ozone values.
6. Both the north polar and south polar regions have values that vary as much as 100 DU with 1992 values being less than 1979. Ozone values in the south polar region hit lows near 150 DU. The south polar region has experienced a large change in values from September through December.
7. Answers will vary. Each pixel on the average should have values closer to the mean so the image will have less color variation.



8.
  - a. There is less variation at any latitude on the yearly average image than on any of the monthly average images. The difference between north and south polar distributions is still evident.
  - b. This answer will depend on what a student predicted previously.
  - c. Values range from 235 to 381 DU with higher values in south mid-latitudes, north mid-latitudes, and north polar regions. Lowest values occur in the south polar region. The southern hemisphere polar values are 50–100 DU lower than comparable values in the northern hemisphere polar regions.



## exercise 8

### investigating ozone distributions in 1979 and 1992 using monthly and yearly global ozone values

This activity is an extension of Exercise 7 that investigates changes in ozone value from 1979 to 1992. Students generate and analyze standard deviation images from monthly average images and compute means for monthly and yearly average ozone distributions to investigate temporal changes.

#### learning objectives

When students complete Exercise 8 they should be able to

- Generate and interpret a standard deviation image from monthly average images of ozone distribution.
- Compute global monthly and yearly mean ozone values from monthly average images.
- Analyze temporal trends in ozone levels through mean and standard deviation images.

#### national science education content standards

- A: Ability to do science inquiry
  - Understanding about science inquiry
- D: Energy in the Earth system
- E: Understanding about science and technology
- G: Nature of scientific knowledge

#### science process skills

- observing
- measuring
- inferring
- communicating
- predicting
- interpreting data

#### image processing skills

- importing multiple images
- applying a color table
- generating an image stack
- calculating the average image of an image stack using a macro
- calculating the standard deviation image of an image stack using a macro
- calculating a ratio image from two images using image mathematics

#### mathematical tools and skills

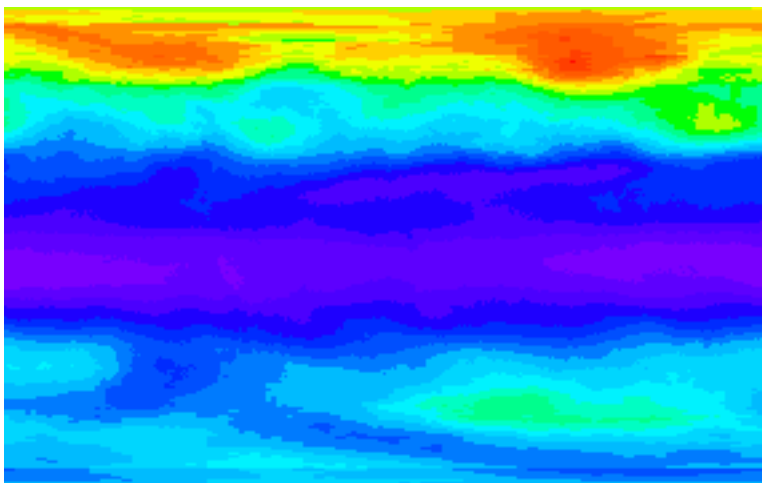
- averaging image data using a prewritten macro
- generating and interpreting a standard deviation image
- interpreting ratios

#### resource materials

- Stratospheric Ozone eTextbook, Chapter 3—Morphology of Ozone

## answers to exercise 8

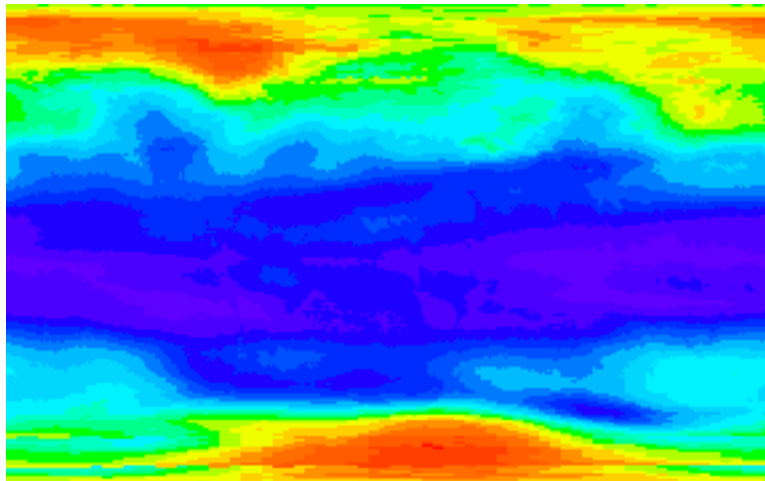
1. a. color for least SD  
*purple*
- b. color for greatest SD  
*red*



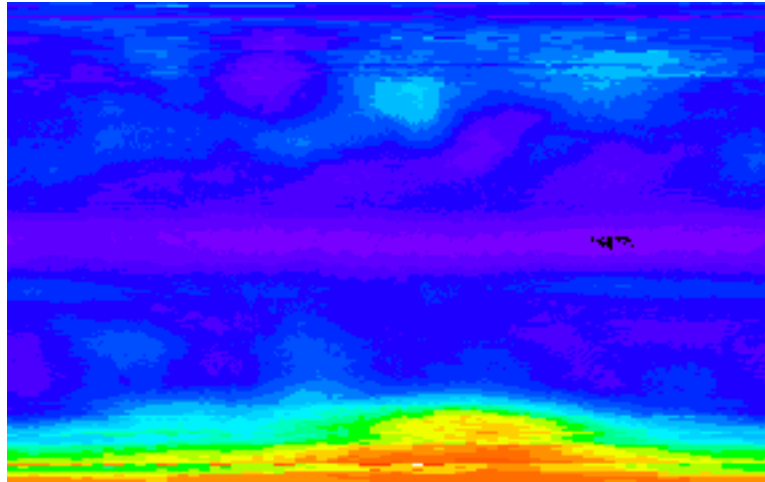
2. a. Tropical region shows least standard deviation in ozone values. Tropical ozone distributions do not generally exhibit seasonal changes.
- b. Greatest change is seen in the north polar region where there are significant seasonal changes caused by varied amounts of insolation and atmospheric dynamics.

image		mean		standard deviation (sd)	
#	month	1979	1992	1979	1992
1	January	293	284	47	43
2	February	296	288	55	43
3	March	301	290	55	45
4	April	304	292	50	44
5	May	303	292	44	39
6	June	301	289	37	37
7	July	300	289	32	31
8	August	302	289	31	30
9	September	304	289	35	30
10	October	301	286	47	32
11	November	296	282	42	31
12	December	293	277	40	30
13	Yearly Avg. Ozone	300	287	37	31

3. a. The seasonal cycle in ozone shows lowest values in the northern hemisphere winter months. The seasonal cycle is a complex combination of ozone transport, production, and destruction cycles that differ in magnitude in the northern and southern hemispheres. See Chapter 8 on Ozone Variability for a detailed discussion of the factors affecting this cycle.
- b. Month(s) varying the most: February–April and October; these are spring and fall months when changes in dynamics and insolation will affect ozone levels more.
- c. In general, you should note that the spring and autumn values standard deviation values are greater than comparable values for summer and winter months. Have students graph the standard deviation values as a function of month to see the pattern.



4. a. Months varying the most: December  
See answer to 3
- b. Months varying the least: February and October  
August and December might be expected since they are summer and winter months  
See answer to 3
5. a. All monthly mean values are lower in 1992 than in 1979.
- b. The average yearly value in 1992 is 4% lower than the comparable value for 1979.
- c. The same trend can be seen in both sets of values except for the period from June to September and December. For 1979 and 1992, February, March, April deviate more. October stands out in the standard deviation in 1979 but not in 1992.
- d. There is greater variation in the standard deviation values for 1979, showing seasonal differences. There is less variation in 1992 notable in the period from August to December indicating that some process(es) that influences southern hemisphere spring values is different in 1992 than in 1979.



6.
  - a. All regions except the tropics show ratio values higher than 1 (tropics are near 1).
  - b. There are spots in the tropics (lighter purple) that have ratios of 0.98–0.99 so ozone values in 1992 would be greater here than in 1979.
  - c. The region with greatest change is the south polar region with ozone values as much as 33% higher in 1979 than in 1992.
  - d. As evident in previous activities, the tropics show the least change in yearly average.

As an additional process you can have students do some image math to compute differences in yearly average ozone values,.

1. Open **GlobalAve79** and **GlobalAve92**.
2. Pull down **PROCESS** and select **Image Math**.
3. In the drop down box select **GlobalAve79** followed by **GlobalAve92** as the second image.
4. Select “–” as the first arithmetic operation.
5. Set the multiplication factor to 1.000 and the addition value to 0.00
6. Be sure the Real Result box is checked before you click OK.