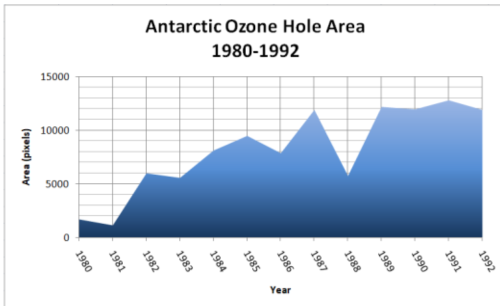
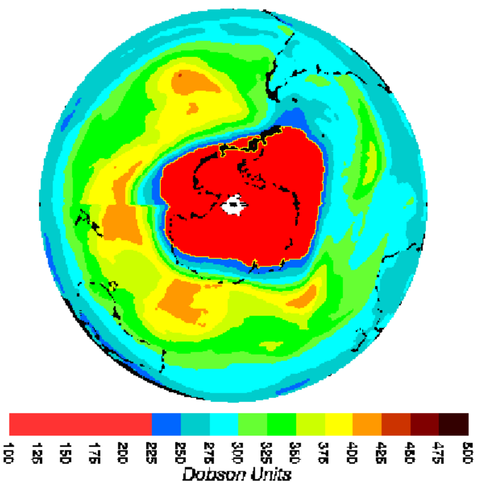
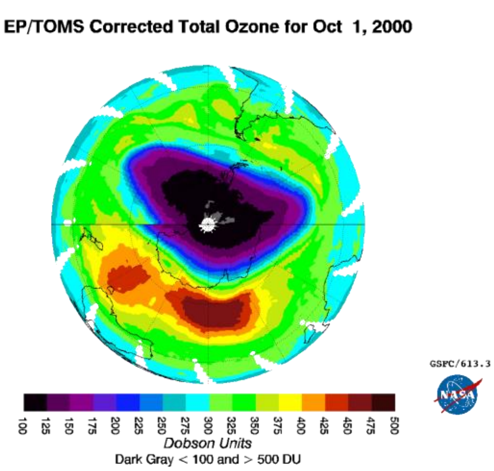


Analyzing the Antarctic Ozone Hole





More Lessons from the Sky
Satellite Educators Association
https://SatEd.org

Please see the Acknowledgements section for historical contributions to the development of this lesson plan. This form of the "Analyzing the Antarctic Ozone Hole" lesson plan was published in April 2012 in "More Lessons from the Sky," a regular feature of the SEA Newsletter, and archived in the SEA Lesson Plan Library. Both the Newsletter and the Library are freely available on-line from the Satellite Educators Association (SEA) at https://SatEd.org.

Content, Internet links, and support material available from the online Resources page revised and updated, July 2023.

SEA Lesson Plan Library Improvement Program

Did you use this lesson plan with students? If so, please share your experience with us to help improve the lesson plan for future use. Just complete the short, secure form found at https://SatEd.org/library/search.htm. Thank you.

Analyzing the Antarctic Ozone Hole

Invitation

Use satellite imagery to explore the Antarctic ozone hole. Is it increasing or decreasing? What causes this effect? Can we do anything about it? Download and display satellite imagery of stratospheric ozone. Measure the area of the thinning ozone using computer image processing tools. Graph the changes over a period of years. Extend your analysis to investigate ozone in other geographic areas and the relationship between ozone and other environmental factors.

Grade Level:	7-12
Time Requirement:	1-3 class periods
Prerequisites:	None
Relevant Disciplines:	Earth Science, Chemistry, Biology, Geography

Student Learning Outcomes

By the end of this lesson, students should be able to do the following:

- Access a NASA database of satellite remote sensing observations
- Explore satellite images of stratospheric ozone over selected geographic regions
- Utilize computer image processing tools to measure the area of low ozone
- Graph the changing extent of the low ozone area over time to identify trends
- Explain plausible causes for identified trends
- Critique data quality to determine the significance of identified trends
- Apply similar processes to studies of ozone in selected geographic regions

Lesson Description

This is an interactive image processing tutorial in which learners download satellite imagery from NASA, display and analyze the images with ImageJ, and graph the measurement results with Excel for further analysis. Learners work in groups of 2-4 per computer.

The lesson tutorial can be implemented as a stand-alone lesson or embedded in a lesson sequence adapted for the individual class and subject area. The teacher may wish to precede or follow this lesson with an exploration of one or more of the following:

- Ozone – properties and uses
- The oxygen-ozone cycle in the stratosphere
- Ultraviolet (UV) radiation
- Health effects related to ultraviolet radiation exposure
- Chlorofluorocarbon (CFC) chemistry
- Effects of CFC compounds on ozone
- Socioeconomic issues such as effects of the CFC ban
- Geography of “ozone hole” occurrence compared to population density and location of industrial concentration.
- Possible mitigation factors involving students

Including “Analyzing the Antarctic Ozone Hole” in a larger unit context addresses a broader range of standards than those listed above.

In this lesson, learners are asked to download and inspect images of ozone levels over the South Pole for each year where data are available from Total Ozone Mapping Spectrophotometer (TOMS) on the Nimbus-7 satellite. Since Antarctic ozone levels are lowest in the Antarctic spring (the end of September and beginning of October), the date October 1 was chosen for each annual image. From 1979 to 1992, the area of thinning ozone over the South Pole shows a drastic increase. However, data from the Ozone Monitoring Instrument (OMI) on the Aura satellite, same location from 2004 to 2017, shows a decrease. Learners will be asked to consider human factors that may have influenced the changes in the ozone “hole” size.

Important Terms

CFC	Mitigation	Ozone “hole”	Troposhpere
Freon	Ozone	Stratosphere	Ultraviolet radiation

Assessment Suggestions

- Teamwork and participation if students work in groups
- Quality and completeness of answers to questions in student activity
- Quality, completeness, and accuracy of report of findings including the spreadsheet of measurement data, graph, montage, and image stack file
- Quality, accuracy, and completeness of other suggested investigations

The evolving answers to the Student Activity Questions can serve as a summative assessment especially the answers for Questions 6-10. These represent important steps in developing student understanding and experience with the process of scientific investigation. The Your Turn section offers extension activities which can also be used for summative assessment. The Earth Exploration Toolbook offers more extension suggestions at https://serc.carleton.edu/eet/ozonehole/going_further.html.

Next Generation Science Standards

The following Next Generation Science Standards are addressed in this lesson.

Performance Expectations & disciplinary Core Ideas

Grade 5: Earth's Systems

PE- 5-ESS2-1 - Develop a model using an example to describe ways in which the geosphere, biosphere, hydrosphere, and/or atmosphere interact.

DCI- 5-ESS2.A - Earth's major systems are the geosphere, the hydrosphere, the atmosphere, and the biosphere. These systems interact in multiple ways to affect Earth's surface materials and processes; the ocean supports a variety of ecosystems and organisms, shapes landforms, and influences climate. Winds and clouds in the atmosphere interact with the landforms to determine patterns of weather.

Grades 6-8: Earth and Human Activity

PE- MS-ESS3-3 - Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
DCI- MS-ESS3.C - Typically as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth, unless the activities and technologies involved are engineered otherwise.

Grades 9-12: Earth and Human Activity
PE- HS-ESS3-5 - Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth's systems.
DCI- HS-ESS3.D - Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.

Science & Engineering Practices

- Apply scientific principles to design an object, tool, process, or system.
- Develop a model using an example to describe a scientific principle.
- Analyze data using computational models in order to make valid and reliable scientific claims.

Crosscutting Concepts

- Relationships can be classified as casual or correlational, and correlation does not necessarily imply causation.
- A system can be described in terms of its components and their interactions.
- Changes and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible.

Preparation

For this activity, an Internet-enabled computer is required with an acceptable browser, ImageJ, and a graphing program such as Microsoft Excel installed.

ImageJ is available from https://imagej.nih.gov/ij/ free of charge. A version pre-bundled with Java run-time is recommended. The bundled Java installs automatically and runs only with ImageJ. It does not interfere with any other programs or plug-ins (including Java) already installed on your computer. Windows users are cautioned to install ImageJ any place other than the default Program Files folder which has security protocols preventing ImageJ updates.

ImageJ's measuring routine saves listed measurements in a comma delimited text file (.csv). Newer versions of ImageJ have a built-in plotting utility. However, other graphing programs offer greater ease-of-use and flexibility. Microsoft Excel is recommended as it easily reads the saved CSV file. The graphing tutorial portions of the Student Activity were written using Microsoft Excel 2016. If Excel is not available, Vernier's Graphical Analysis is recommended. Graphical Analysis has several advantages over other data graphing utilities in that it can ingest data in both text and Microsoft Excel format such as that output by ImageJ's Results folder, and it has a single button for producing a linear regression line. Vernier offers a version download and use free-of-charge. Visit https://www.vernier.com/products/graphical-analysis/ for more information.

A note about obtaining ozone image data for the South Pole…NASA's Ozone & Air Quality site at https://ozoneaq.gsfc.nasa.gov/ is the best source. At the time of this lesson's latest revision, however, image maps could be downloaded from NASA's "ozoneaq" only by FTP (file transfer protocol). Over the last several years, all NASA and NOAA sites have been moving away from open FTP access. Many sites already have a new user interface to control FTP access. For now, and to simplify the lesson, the student tutorial for accessing imagery at the Ozone and Air Quality site has been removed from the Student Activity pages.

All imagery needed for this lesson was previously downloaded from NASA by this lesson module's author and saved in four ZIP files. Each is readily and freely available from https://SatEd.org/library/Resources.htm. Download and unzip each file. Most newer operating systems include decompression and expansion utilities. If needed, however, StuffIt Expander (Mac) and 7-Zip (Windows) are recommended for unzipping. Distribute the resulting folders of image files to learners' computers. The following are available for download:

- **TOMSPics.zip** – 14 images, 1979-1992, 1 outlier, trendline without outlier has positive slope; for use with Student Activity tutorial
- **OMIPics.zip** – 14 images, 2004-2017, 1 outlier, trendline without outlier has negative slope; for use with required Your Turn activity
- **TOMSEPPics.zip** -- 10 images, 1996-2005, no outliers, trendline has negative slope; for use with optional Your Turn activities
- **OMPSPics.zip** – 9 images, 2012-2020, 1 outlier, trendline with outlier has positive slope, a negative slope without; for use with optional Your Turn activities

From the Student Activity pages, duplicate The tutorial instructions (pages 13 to 22) for each learner group. The Your Turn activities list and the answer sheet (pages 23-25) should be duplicated for each learner.

Learners will need hard copy of their montage and spreadsheet screens. If printing from student computers is not available or too time consuming, the montage and spreadsheet with graph pages for all four provided data sets are attached at the end of Student Activity pages. Duplicate and distribute as needed after learners in a student group show a completed montage and a finished graph on screen.

ImageJ Help

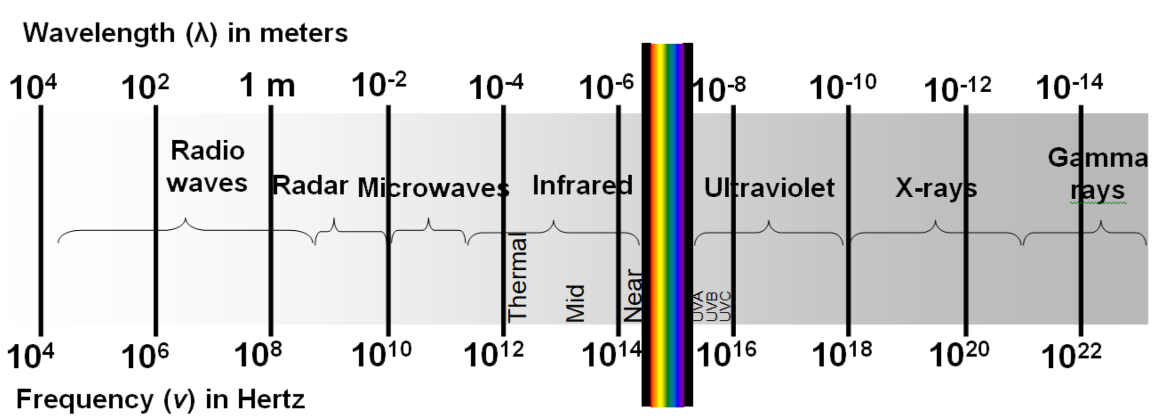
At any time during the use of ImageJ, click Help on the menu bar to link to a wide variety of helpful sites and documents. Additionally, *The ImageJ User Guide* prepared by Tiago Ferreira and Wayne Rasband can be downloaded in HTML or PDF versions. Click Help on ImageJ's menu bar and select Documentation. Or, visit the SEA Lesson Plan Library's Analysis Toolbox at https://SatEd.org/library/Tools.htm.

Background

Of all of the biogeochemical cycles, perhaps the most familiar is that of oxygen as it moves through the processes of photosynthesis and respiration. By itself, elemental oxygen is remarkably reactive and will rapidly bond with other oxygen atoms resulting in more stable oxygen molecules, O_2. In the ordinary conditions found in the lower troposphere, the layer of Earth's atmosphere within about 24 km (15 miles) of ground level, oxygen molecules form an odorless, tasteless, colorless, gas that constitutes about 20.95% of the air we breathe. It is second in atmospheric abundance only to nitrogen, N_2, another colorless, odorless, tasteless gas, and 78.08% of the air. All other atmospheric gases, including carbon dioxide (CO_2) and water vapor, account for less than 1% of the air. Earthly life is well adapted to the presence and use of oxygen at this concentration. Significant deviations from this percentage of oxygen threaten healthy life.

The atmosphere extends almost 10,000 km (more than 6000 miles) above the Earth decreasing in pressure with increasing altitude. Yet the atmospheric pressure is about half that of sea level air pressure at about 5.5 km (18000-19000 feet or about 3½ miles). The partial pressure of oxygen is low enough at this elevation that high-altitude mountain climbers often carry supplemental oxygen to aid breathing, and aircraft crews and passengers enjoy pressured cabins. The lowest layer of the atmosphere, the troposphere, is where we live, where airplanes fly, and where weather happens. It extends to approximately 18 km (11-12 miles) up except near the poles where it thins rapidly to about 6.5 km (4 miles). Predictably, as altitude increases in the troposphere, temperature decreases. Above the troposphere is the stratosphere where temperature actually increases with altitude. The stratosphere extends to almost 50 km (31 miles). At the top of the stratosphere, atmospheric density is very low, and gas molecules are exposed to most wavelengths of solar radiation including higher energy ultraviolet.

The colors of the visible light constitute only a very small portion of the entire electromagnetic spectrum. Just outside the blue end of visible light is invisible ultraviolet radiation (UV) with shorter wavelengths, higher frequencies, and more energetic photons than visible light. Three categories of ultraviolet radiation are described by the Environmental Protection Agency (EPA). UVA has wavelengths from 320 to 400 nanometers (nm). It is not absorbed by ozone. Higher energy UVB has wavelengths from 280 to 320 nm. Responsible for tanning and sunburns, UVB can also damage DNA molecules in the skin leading to melanomas and carcinomas and cataracts in the eyes. Skin cancer cases, skin cancer deaths, and cataract cases are monitored by the EPA. Increased UVB damages plants, upsets phytoplankton in marine ecosystems, and degrades synthetic polymers (plastics), among other things. UVC is extremely dangerous at less than 280 nm but almost completely absorbed by ozone and oxygen in the atmosphere.



In the stratosphere, a regular cycle of ozone formation and destruction takes place that effectively prevents UVB and UVC from reaching us at ground level. In the abbreviated chemical equations below, energy is represented by $h\nu$ where h is Plank's constant (6.626×10^{-34} Joules/Hz) and ν is frequency (Hz). A molecule of oxygen absorbs UV energy ($h\nu$) splitting the molecule into oxygen atoms:

$$O_2 + h\nu \rightarrow O + O$$

The very reactive oxygen atoms readily attach themselves to other oxygen molecules forming molecules of ozone, O_3, consisting of three oxygen atoms each:

$$O + O_2 \rightarrow O_3$$

These ozone molecules are unstable. They stabilize by either physically bumping into neighboring molecules such as O_2, O_3, and N_2 causing decomposition or by absorbing UV energy to decompose into molecular oxygen:

$$O_3 + h\nu \rightarrow O_2 + O$$

$$O + O_3 \rightarrow 2O_2$$

The overall reaction can be summarized:

$$3O_2 + h\nu \rightarrow 2O_3 + h\nu \rightarrow 3O_2$$

Thus, ultraviolet radiation, that is harmful to living things at ground level, is absorbed in the upper atmosphere during the cyclic formation and destruction of ozone.

Sources of more information about the harmful effects of ozone pollution at ground level and other industrial uses for ozone, such as water sanitation, can be found in the Resources section below.

The ground level release of chlorofluorocarbon (CFC) molecules, such as Freon used in refrigerators and air conditioners, does affect upper atmosphere ozone. Freons are colorless, odorless, nonflammable, noncorrosive, liquids and gases. They were first invented in 1928 as a safer alternative to the potentially deadly gases then used as refrigerants. By 1935, more than 8 million new refrigerators had been sold using the new Freon refrigerant. While there are many variations of Freon today, the name Freon is a patented trademark of DuPont. Since 1935, millions of refrigerators and air conditioners in homes, automobiles, and industrial and office buildings have leaked or been junked when replaced by upgrades thus releasing CFCs into the atmosphere. CFCs are relatively inert and not water soluble. They remain in the atmosphere for as much as 40-150 years. As they slowly decompose, they release chlorine into the upper atmosphere that reacts with ozone.

The action of CFC molecules on stratospheric ozone was described by Rowland and Molina at the University of California, Irvine in 1973. CFCs such as trichloro-fluoro-methane, $CFCl_3$, are devoid of hydrogen and thus decompose more easily in the upper atmosphere releasing free chlorine radicals:

$$CFCl_3 \rightarrow CFCl_2 + Cl$$

The free chlorine radical combines with ozone to form a chlorine oxide radical and molecular oxygen:

$$Cl + O_3 \rightarrow ClO + O_2$$

Other ClO radicals combine to form chlorine dioxide:

$$ClO + ClO \rightarrow Cl_2O_2$$

Unstable chlorine dioxide decomposes to form more stable chlorine gas and molecular oxygen:

$$Cl_2O_2 \rightarrow Cl_2 + O_2$$

The net effect is the formation of oxygen from ozone:

$$2O_3 \rightarrow 3O_2$$

This process succeeds in destroying ozone in the upper atmosphere thus bypassing the normal O_2-O_3-O_2 cycle that filters out harmful UVB and UVC radiation before it can reach living things at ground level. When the normal concentration of ozone in the upper stratosphere is significantly reduced over a broad geographic area, it is called an "ozone hole."

These processes are nicely visualized in several narrated video clips listed in the Resources section below.

Due to the amount of CFCs released into the atmosphere over a 40-50 year period, the problems caused by the thinning of ozone in the upper atmosphere will be with us for decades to come. The Montreal Protocol called for a cessation of all CFC production and elimination of CFC propellants in aerosol sprays in the 1980s. Alternatives to the original Freons were developed by DuPont that include one hydrogen atom in the molecule thereby changing the chemical properties while maintaining many of the physical properties that make it useful as a refrigerant. Eventually, other, very slow, natural processes will eliminate the catalytic free chlorine from the upper stratosphere. If the Montreal Protocol is adhered to by every nation including those that did not ratify it, it is predicted that upper atmospheric ozone levels could be returned to 1980 levels by 2070.

NASA has measured global atmospheric ozone concentrations from space since 1978 with only two breaks. Atmospheric ozone was measured by the Total Ozone Mapping Spectrophotometer (TOMS) instrument that was first launched on the Nimbus-7 weather satellite in 1978. A second TOMS measured ozone until December 1994 on a Russian Meteor-3 satellite. Another TOMS on an Earth Probe satellite measured ozone from July 1996 to December 2005. The newer Ozone Monitoring Instrument (OMI) is carried on Aura. Launched in 2004, Aura is one of NASA's A-Train (or Afternoon Constellation) Earth Observation System (EOS) satellites. The Ozone Mapping and Profiler Suite (OMPS) is carried on the current polar-orbiting weather satellites Suomi NPP and NOAA 20. Several other instruments on other satellites also measure atmospheric ozone today.

The OMI uses hyperspectral imaging to observe solar backscatter radiation in the visible and ultraviolet wavebands. In addition to measuring stratospheric ozone, the OMI monitors air quality components such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), oxides of halogens such as BRO and OClO; can distinguish between types of aerosol particulates such as smoke, dust, and sulfates; measures cloud pressure and coverage and indicators of tropospheric ozone. OMPS data products include total column ozone, total column sulfur dioxide (SO_2), vertical ozone profile swath, and aerosol index.

Acknowledgements

In addition to publication of original lesson plans, *More Lessons from the Sky* endeavors to highlight creative excellence found in lesson plans already published by others, lessons that enhance student understanding of space-based technologies especially satellites and the use satellite-based remote-sensing environmental data. Here, the spotlight is on the **Earth Exploration Toolbook**, in "Analyzing the Antarctic Ozone Hole" in which students engage mathematical and spatial thinking as they process remote-sensing data imagery to better understand the changes in stratospheric ozone in the Antarctic.

This lesson was originally written by Kristina Piccirilli of Lesley University and by LuAnn Dahlman and Tamara Ledley of the Center for Science Teaching and Learning at TERC. It is available as an on-line lesson in the Earth Exploration Toolbox at https://serc.carleton.edu/eet/ozonehole/index.html. It was first produced in 2004 and updated in 2011. The original lesson contains numerous reference links useful in teaching about ozone.

The Earth Exploration Toolbook is a collection of online lessons designed by K-12 educators, college faculty and their students. The collection is in the National Science Digital Library and the Digital Library for Earth System Education. The collection was developed in partnership by the Science Education Resource Center at Carleton College, the Center for Earth and Space Science Education at TERC, the Complex Systems Research Center at the University of New Hampshire, and the Center for International Earth Science Information Network at Columbia University. It was funded by the National Science Foundation under NSF Award #0226199. You are encouraged to explore the Earth Exploration Toolbook, a superb teaching resource, at https://serc.carleton.edu/eet/index.html.

This lesson arrangement is based on and inspired by a lesson by the same name from the Earth Exploration Toolbook. This lesson plan also offers a tutorial format for use by students at a variety of image processing skill levels and emphasizes the importance of assessing data quality in addition to analyzing for data trends. This lesson arrangement, supplemental materials, and this edition of Teaching Notes were developed by J.P. Arvedson for the Satellite Educators Association, Inc. as part of “More Lessons from the Sky,” a regular feature of the Satellite Educators Association Newsletter online. More information about the Satellite Educators Association, its annual Satellites & Education Conference for teachers, international environmental research collaborative for K-12, and access to the online Newsletter can be found at https://SatEd.org.

All *More Lessons from the Sky* lesson plans are archived in the on-line SEA Lesson Plan Library available at https://SatEd.org. The web site features a description of the library contents, how the lessons are matched to the National Science Education Standards and the Next Generation Science Standards, several search tools for finding lessons easily, separate resource files for lessons where needed, and the library’s Analysis Toolbox.

Resources

Note: All of these URLs were current and active as of this writing. If any are unreachable as printed, the use of on-line search engines such as DuckDuckGo, Ask, or Google is suggested to find current links.

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Answers to Student Activity Questions

1. Identify and describe the area that would be considered a part of the "ozone hole."
The area that would be considered a part of the "ozone hole" seems to approximate the size and shape of Antarctica but is shifted slightly towards South America.

2. Describe how the ozone levels and the size of the low ozone area change through the fourteen years.
The 1980-81 images show relatively small areas with ozone levels less than 225 DU compared to later years. The 1979 image shows none. The ozone level and the size of the low ozone area vary up and down from 1979 to 1992. There is a distinct upward trend in the data indicating an increasing area of low ozone.

3. What trend in changing size do you observe in the "ozone hole" over the fourteen years?
There is a very obvious increase in area of thinning ozone from 1979 to 1992.

4. How does the area selected by thresholding on each slice (area shown in red and outlined in yellow) compare with your description of the "ozone hole" size and area in Questions 1 and 2?
The area of less than 225 DU is more precisely defined and measured using highlighting and outlining in ImageJ than by the verbal description given for Questions 1 and 2.

5. Are there any significant variations in the area of the ozone hole from year to year shown in the Results window? How do you account for the variations?
The area varies from 1121 pixels to 307200 pixels. Environmental factors and human factors that vary from year to year can impact the area of thinning ozone. However, except for the 307200 measurement there seems to be an overall increase in the area of thinning ozone layer suggesting, perhaps, that more CFCs have reached the stratosphere and are interacting with (destroying) ozone.

6. Did the area with less than 225 DU of ozone increase or decrease or stay the same over the fourteen years you analyzed?
The linear regression line (trendline) has a negative slope indicating the trend over these fourteen years is a decrease in the area of thinning ozone.

7. What might account for the trend identified in Question 6? Answers will vary. Students may want to do some background research before attempting an explanation. The expected trend for this time period is an increase in the area of thinning stratospheric ozone over Antarctica when considering the socio-political conditions of the time. Or, curious students may question the data point in the graph for 1979 as in Questions 8-9.

8. Which graphed points, if any, are significantly apart from this trend enough to be considered outliers? Why should the outlying point(s) be set aside when considering trends shown in the data? Give a very specific reason for each outlier set aside.
If the learner clicked the wand tool anywhere in the 1979 slice when looking for a red, thresholded area, ImageJ recorded a pixel count of 307200. Since there were no thresholded or red areas in the 1979 slice, ImageJ just counted all pixels in the image and listed that number in the Results window for slice 1. This data point (307200) should be considered an outlier and ignored. The Excel spreadsheet should be changed to either omit 1979 or change the pixel count for 1979 to zero.

9. Does the identification of outliers change your answer to Question 6?

Answers will vary. Learners may do some background research to provide a detailed explanation. With the point for 1979 included, the graph shows an overall decreasing trend where reason suggests it should show an increasing trend. The increasing trend is clear when the outlying point is set to zero. Learners might consider the socio-political conditions of the time in their explanations. During this time period, chloro-fluoro-carbon (CFC) based refrigerants and aerosol spray can propellants were in common use and freely escaped into the atmosphere. When CFC compounds made their way to the stratosphere, they interacted with the natural oxygen-ozone cycle resulting in a significant decrease in ozone concentration. Eventually, S.C. Johnson banned the use of CFC propellants in its own aerosol spray cans in 1975, the Montreal Protocol agreements of 1987, and the cessation of CFC production in the United States and Europe in 1996 drastically slowed the release of additional CFC into atmosphere although it was predicted these changes would take 30-50 years to produce a favorable result. Learners might also consider environmental effects such as annual changes in the *global* ozone levels or the global impact of significant weather events. The key is that learners demonstrate an understanding of the reasons suggested and how they connect with the data presented in this lesson.

10. In Question 9, you stated a hypothesis to explain a trend in the size of the low ozone area that is supported by just fourteen data points. Devise a detailed plan for gathering, analyzing, and communicating enough evidence to clearly describe and support your hypothesis.

Learners will likely suggest obtaining more imagery from a reliable online source such as NASA. Already downloaded and zipped image sets are available from this lessons online Resources page as described earlier in these Teaching Notes. Essentially, the provided data sets cover Antarctic ozone from 1979 (the earliest available satellite-based data) to 2020. That includes 2 years of the COVID-19 pandemic. The teacher must only unzip the downloaded files and distribute the folders of image files as needed. For analysis, learners will likely suggest following the same procedure they just completed in the Student Activity pages. Depending on the subject area of your class and the lesson sequence in which this lesson is presented, other research may be needed on the part of the learner to suggest reasonable social, political, economic, and/or environmental explanations for the trends. The learner or learner group should consult the teacher to decide the best mode of communicating the project details and conclusions to the class.

Analyzing the Antarctic Ozone Hole

Introduction

Use satellite imagery to explore the Antarctic ozone hole. Is it really a hole? Is it increasing or decreasing in size? What causes this effect? Can we do anything about it? Download and display satellite imagery of stratospheric ozone. Measure the area of the thinning ozone using computer image processing tools. Graph the changes over a period of years. Extend your analysis to investigate ozone in other geographic areas and the relationship between ozone and other environmental factors.

Ozone (O_3) is formed by the action of ultraviolet light (UV) from the sun on oxygen (O_2) molecules. Ozone is then destroyed by more UV radiation in a natural cycle in the stratosphere. This cycle effectively filters out the harmful UV wavelengths before they reach living things at ground level. Harmful UV radiation can damage DNA causing skin cancer and eye cataracts. Human-made chlorofluorocarbon (CFC) molecules are used in refrigerators and air conditioners. For many years, they were also used as propellants in aerosol spray cans. Many CFC molecules have been released into the atmosphere where they decompose to release free chlorine radicals. The chlorine reacts with ozone before the ozone can absorb UV radiation. The result is a decrease in the amount of ozone in the upper atmosphere allowing more harmful UV to reach ground level.

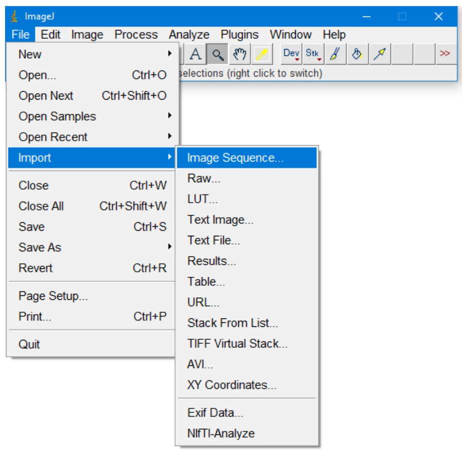
NASA launched Total Ozone Mapping Spectrophotometer (TOMS) instruments on Earth-orbiting satellites starting in 1978 to measure the amount of ozone in the atmosphere. The TOMS mission ended in 2005 due to an irreconcilable equipment problem. In 2004, a newer sensor, the Ozone Monitoring Instrument (OMI) was launched on NASA's Aura satellite to continue ozone measurements from space. OMI is a straight-down-looking, wide-field-of-view spectrometer that measures key air quality components including ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), oxides of bromine (BrO) and chlorine (OClO), as well as dust, smoke, volcanic ash, and other aerosols. The Ozone Mapping and Profiler Suite (OMPS) continues to monitor the same atmospheric components. It is carried by several NOAA polar-orbiting weather satellites including Suomi NPP, NOAA 20, and NOAA-21.

In this lesson you will process, and analyze images of TOMS data from the Nimbus 7 satellite for the years 1979 to 1992 to investigate and define the "ozone hole." Then, for comparison, you will have an opportunity to similarly analyze OMI data from 2004-2017. If time permits, your teacher may provide access to additional data sets with imagery up to 2020.

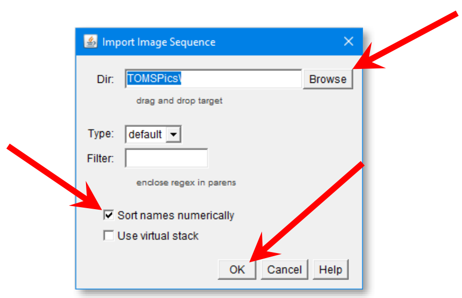
Exploring TOMS Images with ImageJ

You will use ImageJ to view and analyze TOMS Nimbus 7 imagery for 1979-1992.

- **Launch ImageJ. Click** File > Import > Image Sequence**.**



- **Click** Browse **and navigate to the** TOMSPics **folder provided by your teacher. Ensure** Sort names numerically **is checked. Click** OK**. All fourteen images should open in a stack.**



- **Before proceeding, you need to save the stack. Stacks saved by ImageJ must be saved in TIFF file format: Click** File > Save As**, select** Tiff**. In the Save As dialog, navigate to your TOMSPics folder, name the file** TOMSPics-stack.tif**. Click** Save**.**

The images you opened show the amount of ozone overhead measured in Dobson Units. The measurements can be thought of as showing the "thickness" of the ozone layer. The ozone is actually spread throughout the stratosphere, an atmospheric layer that can be up to 50 km (30 miles) thick. At this altitude the atmosphere is so sparse that if all of those ozone molecules could be brought down to Earth's surface, this "layer" of ozone would only be about 3 millimeters thick – about the same height as two stacked pennies. This amount of ozone has a Dobson Unit value of 300 DU. The ozone "hole" is defined as an area where the total amount of ozone is less than 220 DU.

Look at the color scale below the first image in the stack to determine where ozone is “thickest” and “thinnest.”

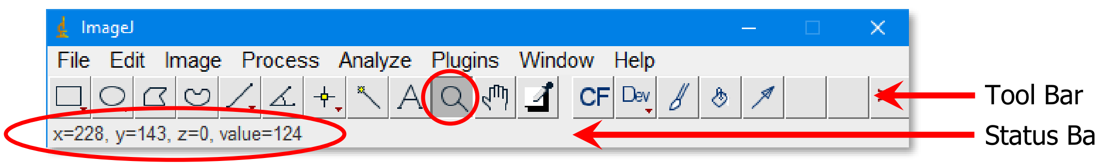
1. *Identify and describe the area that would be considered a part of the “ozone hole.”*

Use the < and > keys to move through the stack. Examine and compare each slice.

2. *Describe how the ozone levels and the size of the low ozone area change through the fourteen years.*

If this is your first experience with ImageJ, take a moment now to familiarize yourself with several of its most common tools.

Click the magnifier tool  **in the ImageJ tool bar. Then** left-click the image to zoom in **or** right-click the image to zoom out**. Read the location of the cursor on the image given for X,Y,Z axes, and read the pixel value of the pixel under the cursor (0-255 where higher numbers mean brighter) in ImageJ’s status bar.**



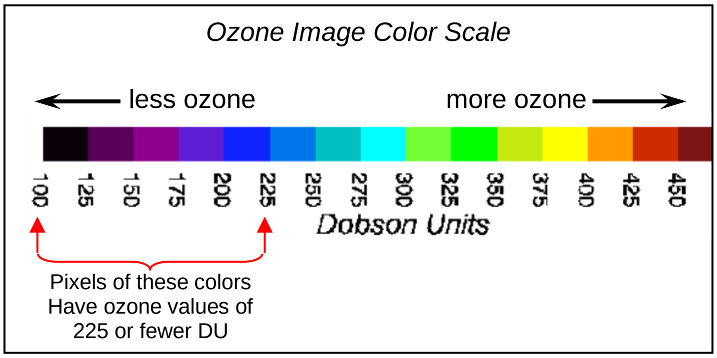
To animate the stack, use one of these actions: click the play/pause button on the left end of the slider under the image; or, select Image > Stacks > Animation > Start/Stop Animation**; or, press the backslash key \ on the keyboard to start, press again to stop. To control animation speed:** Image > Stacks > Animation > Animation Options**. For this stack, a frame rate of 2 frames per second (fps) is sufficient.**

3. *What trend in changing size do you observe in the “ozone hole” over the fourteen years?*

Images centered on the South Pole allow us to see the shape and size of the ozone “hole” in comparison with the rest of the globe. The surface area represented by each pixel in the images is not equal, but as all the yearly images use the same viewpoint, we can measure changes in the hole by counting the number of pixels that are part of the hole each year. You won’t have to count the pixels by hand – ImageJ gives you a convenient way to highlight and measure the number of pixels that represent the hole each year.

Highlighting the “Ozone Hole”

Scientists who study the atmosphere consider areas with less than 220 Dobson Units (DU) of ozone to be part of the “ozone hole.” These images from the TOMS on the Nimbus 7 satellite show ozone levels in increments of 25 DU, so you will count pixels with 225 DU or fewer to estimate the area of the ozone hole. Using ImageJ, you will highlight and then automatically outline the pixels with these values to measure the ozone hole in each yearly image.



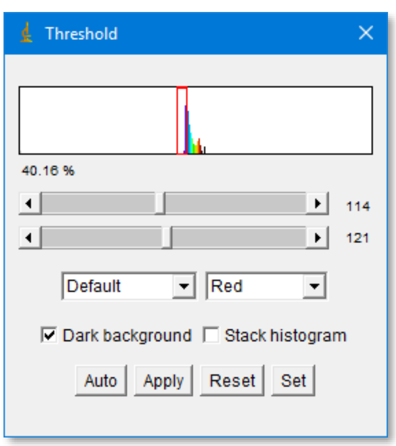
- **If you made any changes to the stack during your exploration, you may need to return the stack to its original properties: First, double-click the magnifier tool on the tool bar to return the stack to normal size. Then,** File > Revert **to the stack images to their original properties.**

You will use **thresholding** to highlight pixels representing 225 DU or less.

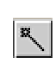
- **To remove parts of the continent outlines that can interfere with the highlighting, select** Process > Noise > Despeckle**. When queried to process all 14 images, click** Yes**.**

- **Select** Image > Adjust > Threshold**. Threshold allows you to specify a range of pixel values and highlight them in the image.**

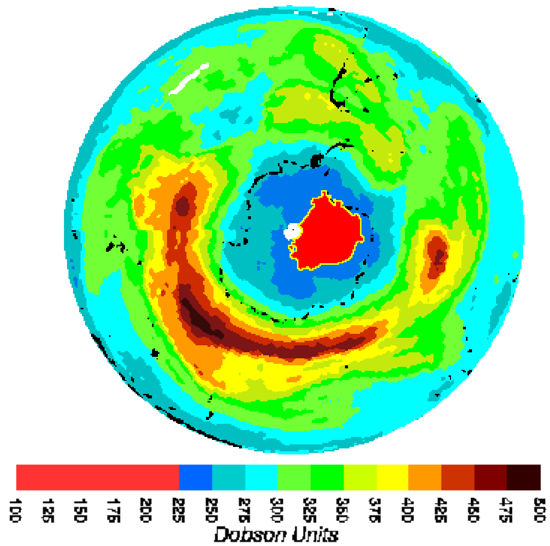
- **In the Threshold dialog, below the two horizontal sliders, set the drop-down menus to** Default **and** Red**. Drag the top and bottom sliders (or use the arrow buttons to move them) so that pixels representing ozone measurements of 225 and lower are red and everything else in the image remains unchanged.**



HINT: Start with the top slider at 1 and the bottom slider at 255. Move the bottom slider to the left one step at a time until the ozone values *above* 225 in the image's color scale all look normal. Then move the top slider to the right one step at a time until all the numbers in the color scale and the text in the image appear black.

- **Ensure the image displays slice 1. On the ImageJ tool bar, click the wand tool**  **(for tracing/outlining). Carefully move the cursor to the right edge of the group of red**

pixels that represent the ozone hole and click once. This will automatically trace a yellow selection line around the red pixels. See the example below. (HINT: If the outline is not yellow, double-click **the** Point Selection **tool, change** Color **to** Yellow**, click** OK**, return to the** Wand Tool**.)**



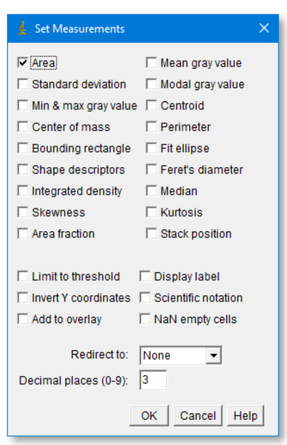
Measuring the Ozone Hole's Area

The actual area covered by the selected pixels will be shown in red. Once the ozone hole area has been selected (outlined in yellow), you will use ImageJ to count the pixels in the selected area.

- **Select** Analyze > Clear Results **to ensure the program is not holding any old measurements.**

- **Select** Analyze > Set Scale**. Highlight the word in the** Unit of Length **field and type** pixel**. Click** OK**.**

- **Select** Analyze > Set Measurements**. In the Set Measurements dialog, check** Area **only. Uncheck all others. Click** OK**.**



- **Select** Analyze > Measure**. The area you selected and measured (in pixels) is displayed in the Results window. If needed, to bring the Results window forward, select** Window > Results**.**

- **Advance the stack to the next slice.**

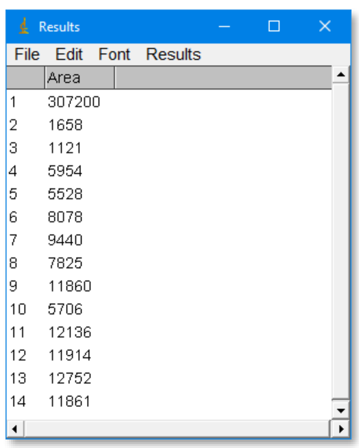
- **Select the wand tool again and click on the right side of the ozone hole (red area) of the image in this slice. If there is more than one red area, hold down the** Shift **key while clicking in each red area.**

- **Select** Analyze > Measure **to record the ozone hole area measurement for this slice. Notice the second measurement was added to the Results window.**

- **Repeat the last three steps until you have measured the area of the ozone hole for all slices in the stack.**

4. *How does the area selected by thresholding on each slice (area shown in red and outlined in yellow) compare with your description of the "ozone hole" size and area in Questions 1 and 2?*

When you are done, the Results window should have fourteen measurements corresponding to the years 1979 through 1992. Your area measurements may not be exactly the same as those in the illustration below.



	Area
1	307200
2	1658
3	1121
4	5954
5	5528
6	8078
7	9440
8	7825
9	11860
10	5706
11	12136
12	11914
13	12752
14	11861

5. *Are there any significant variations in the area of the ozone hole from year to year shown in the Results window? How do you account for the variations?*

- **Save the measurement results: Click the Results window to activate it. In the Results menu bar, click** File **and select** Save As**. Navigate to your TOMSPics folder. Accept the default file name** Results.csv**. Click** Save**. The measurement results have been saved in comma delimited form (CSV) which can be read and graphed with Microsoft Excel.**

Making a Montage

Before leaving ImageJ, it will be helpful to assemble your TOMSPics images in a montage for reference.

First, let's return to the unaltered TOMSPics-stack.tif:

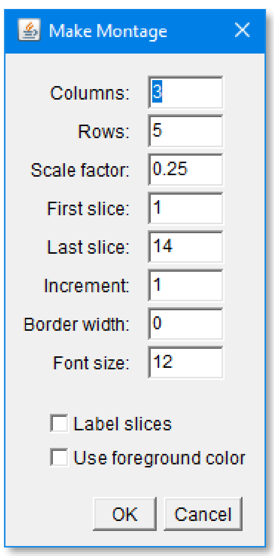
- Close **both the** Results **and** Threshold **windows.**

- **Click the Image panel to activate it. On the ImageJ menu bar, click** Edit > Selection > Select None**. Then click** File > Revert**.**

For later analysis, you may find it helpful to have your TOMSPics images printed in a montage. An ImageJ montage is a single image created by assembling a group of individual images together. Here, you will make a montage from the thirteen images in your TOMSPics-stack.

- **On the ImageJ menu bar, select** Image > Stacks > Make Montage**.**

- **In the Make Montage dialog, set Columns to** 3**, Rows to** 5**, Scale factor to** 0.25**, First slice to** 1**, Last slice to** 13**, Increment to** 1**, Border width to** 0**, and Font size to** 12**. Uncheck** Label slices **and** Use Foreground Color**. Click** OK**.**



- **Save the montage: select** File > Save As > Tiff**, navigate to your TOMSPics folder, accept the default file name** Montage.tif **and click** Save**.**

- **Follow your teacher's directions to obtain a printed copy of your montage.**

- **When finished,** File > Quit **ImageJ.**

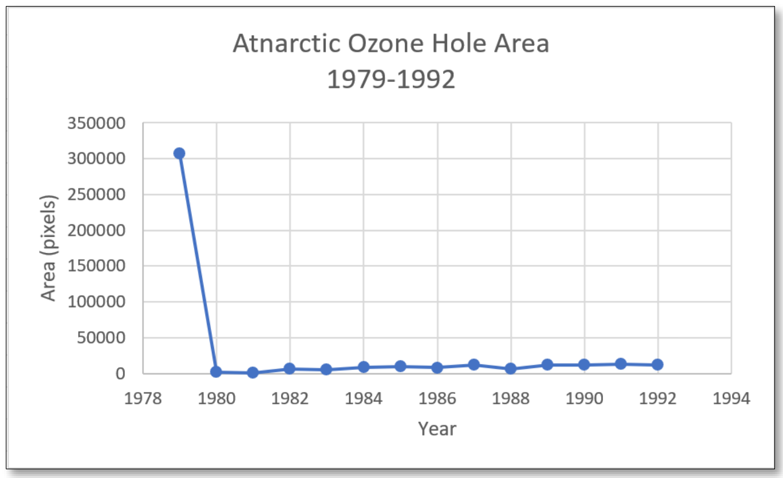
Importing and Graphing Results with Excel

You will use Microsoft Excel to graphically analyze the measurements you made with ImageJ.

- **Launch** Excel. **Open the Results.csv file you stored in your TOMSPics folder. [In the Open dialogue, you may need to change File Type to** Text Files (*.prn;*.txt;*.csv).**]**

- **On the spreadsheet, highlight cell A1 and type** Year. **Highlight cell A2 and change 1 to** 1979. **Then in cell A3, change 2 to** 1980. **Continue down column A changing each succeeding number to a succeeding year until the 14 in cell A15 has been changed to** 1992. **Then Highlight cells** A1 to B15.

	A	B
1	Year	Area
2	1979	307200
3	1980	1658
4	1981	1121
5	1982	5954
6	1983	5528
7	1984	8078
8	1985	9440
9	1986	7825
10	1987	11860
11	1988	5706
12	1989	12136
13	1990	11914
14	1991	12752
15	1992	11861



- **Click the** Insert **tab on Excel's ribbon. In the Charts section, click** Scatter **and select** Scatter with Straight Lines and Markers.

- **Click the graph title, then highlight it. Change it to** Antarctic Ozone Hole Area. **Press the** ENTER (or Return) **key and type** 1979-1992. **Then click once outside the title frame.**

- **Click inside the chart frame to activate its window. Click the** Chart Elements **button next to the chart. In the list, check** Axis Titles. **Then roll the cursor over Axis Titles to display the arrow on the right. Click the** arrow **and ensure** Primary Horizontal **and** Primary Vertical **are checked. Highlight the horizontal axis title frame on the chart and type** Year. **Highlight the vertical axis title frame and type** Area (pixels). **Click outside the chart.**

- **To save your spreadsheet with the graph, click** File > Save as, **then** Browse. **Navigate to your TOMSPics folder. Change** Save as type **to** Excel Workbook (*.xlsx). **Accept the default file name of** Results.xlsx. **Click** Save.

- **Close all open windows and exit all programs.**

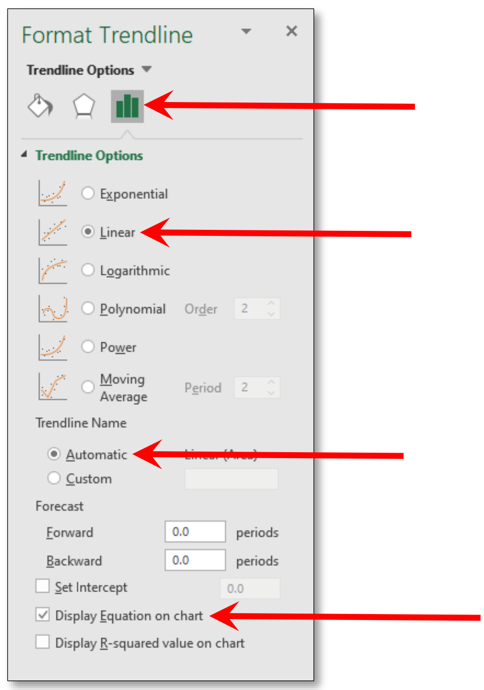
Analyzing the Data - Adding a Trendline

Adding a linear regression line to your graph will help you determine the overall trend in the area of the thinning ozone is increasing or decreasing. You can visually inspect the line for slope direction or examine the line's equation to determine if the slope is positive or negative.

- **Open** Results.xlsx **with Excel. Click the chart area to activate its window.**

- **Click the** Chart Elements **button and check** Trendline**.**

- **In the** Chart Elements **list, click the** arrow **to the right of Trendline, and select** More Options **to open the** Format Trendline **panel. Select the button at the top of the panel that looks like a histogram; click the radio button for** Linear**; accept the radio button for** Automatic Trendline Name**; and check** Display Equation on chart**.**



- **Close the Format Trendline panel.**

A linear regression trendline has appeared on the chart with an equation.

- **Open the Chart Elements list again and check Legend. Click and hold inside the equation's frame and drag the frame into an open area in the legend. If desired, resize the chart by grabbing and dragging one of the corners.**

- **Save your spreadsheet with revised graph by clicking** File > Save**.**

- **Leave Excel open and the spreadsheet with chart displayed on the screen.**

Analysis & Interpretation

Using your graph and montage as reference, answer these questions.

6. *Did the area with less than 225 DU of ozone increase or decrease or stay the same over the fourteen years you analyzed?*

7. *What might account for the trend identified in Question 6?*

8. *Which graphed points, if any, are significantly apart from this trend enough to be considered outliers? Why should the outlying point(s) be set aside when considering trends shown in the data? Give a very specific reason for each outlier set aside.*

If you identified any outliers and want to change your Excel spreadsheet, you may do so here. Any changes you make to the spreadsheet will be automatically reflected in the chart. Save the changes in a new file named Results-modified.xlsx**.**

9. *Does the identification of outliers change your answer to Question 6? If so, list and give a detailed explanation of factors that might contribute to the change.*

10. *In Question 9, you stated a hypothesis to explain a trend in the size of the low ozone area that is supported by just fourteen data points. Devise a detailed plan for gathering, analyzing, and communicating enough evidence to clearly describe and support your hypothesis.*

Exit **Excel.**

YOUR TURN

- Repeat the procedure you followed above to analyze OMI data from 2004-2017. Compare the overall trends in the two data sets. Are they alike or different? If different, what factors could have caused the difference. Prepare a short essay about your findings. Be sure to include a description of the image data, your measurements, your analysis of the data, any problems with your measurements, and how they may or may not have affected your conclusions. Submit your report to your teacher.

Then complete one or more of the following investigations:

- When the COVID-19 virus spread to create a global pandemic in 2019, did it impact the Antarctic ozone "hole?" Your teacher will provide access to OMPS imagery from 2012-2020. Visualize and analyze these image data to determine if such an impact happened. Is there enough data in these images to support a cause-and-effect conclusion about COVID-19 and the area of thinning ozone in Antarctica? What other information would help you answer that question? How can that information be obtained? With guidance from your teacher, do the research to learn more. Then prepare a report for your class using PowerPoint or other presentation software.

- Investigate the change in air temperature with increasing altitude. Determine at which altitudes the boundaries between atmospheric layers are found and explain them using the results of your investigation. How does this thermal characteristic affect the size of the "ozone hole?" In your explanation, consider atmospheric temperature and pressure and the chemical changes taking place of the oxygen-ozone cycle in the stratosphere.

- Your teacher may assign other application activities here.

Analyzing the Antarctic Ozone Hole

1. Identify and describe the area that would be considered a part of the “ozone hole.”

2. Describe how the ozone levels and the size of the low ozone area change through the fourteen years.

3. What trend in changing size do you observe in the “ozone hole” over the fourteen years?

4. How does the area selected by thresholding on this image (area shown in red and outlined in yellow) compare with your description of the “ozone hole” size and area in Questions 1 and 2?

5. Are there any significant variations in the area of the ozone hole from year to year shown in the Results window? How do you account for the variations?

6. Did the area with less than 225 DU of ozone increase or decrease or stay the same over the fourteen years you analyzed?

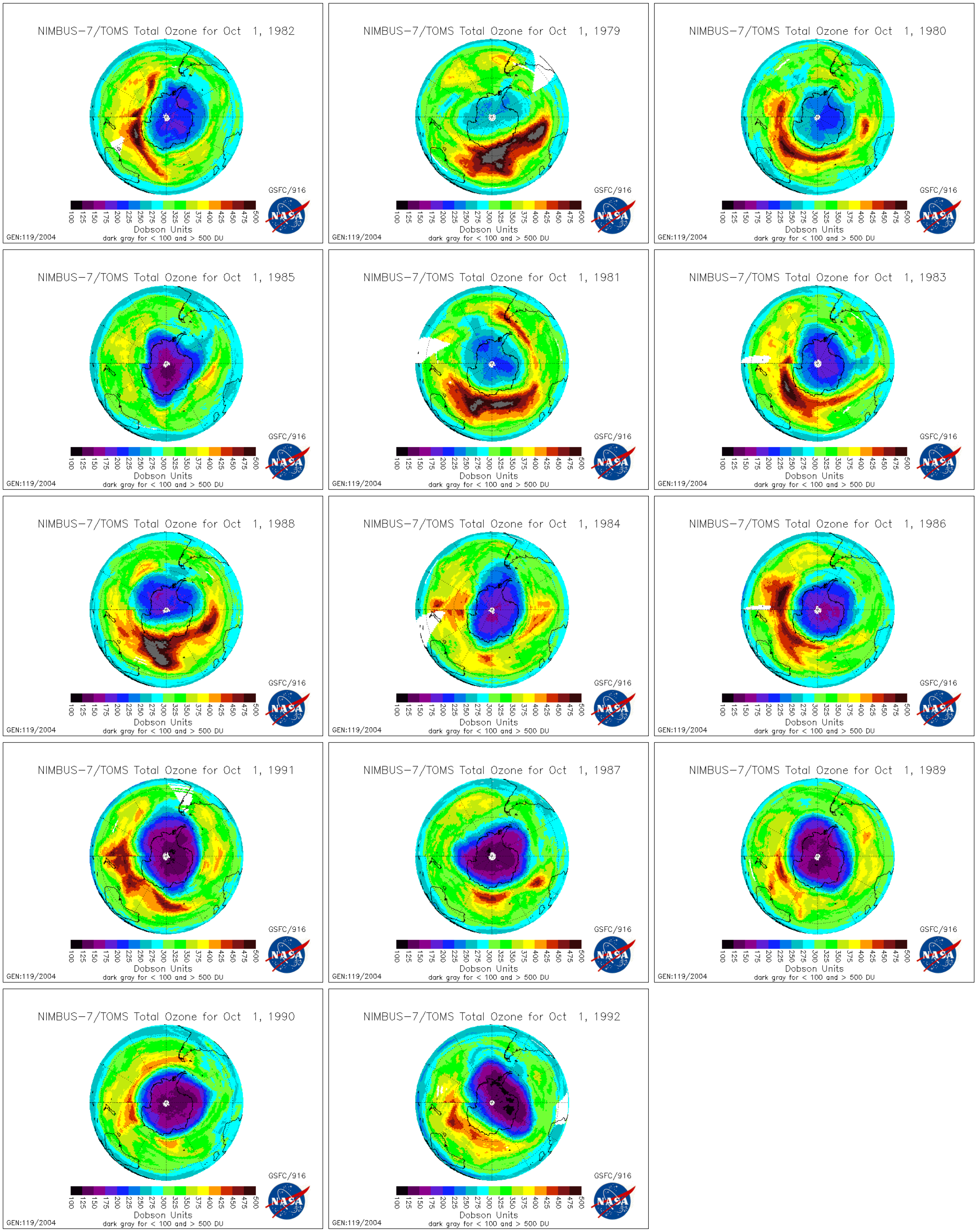
7. What might account for the trend identified in Question 6?

8. Which graphed points, if any, are significantly apart from this trend enough to be considered outliers? Why should the outlying point(s) be set aside when considering trends shown in the data? Give a very specific reason for each outlier set aside.

9. Does the identification of outliers change your answer to Question 6? If so, list and give a detailed explanation of factors that might contribute to the change.

10. In Question 9, you stated a hypothesis to explain a trend in the size of the low ozone area that is supported by just fourteen or fewer data points. Devise a detailed plan for gathering, analyzing, and communicating enough evidence to clearly describe and support your hypothesis.

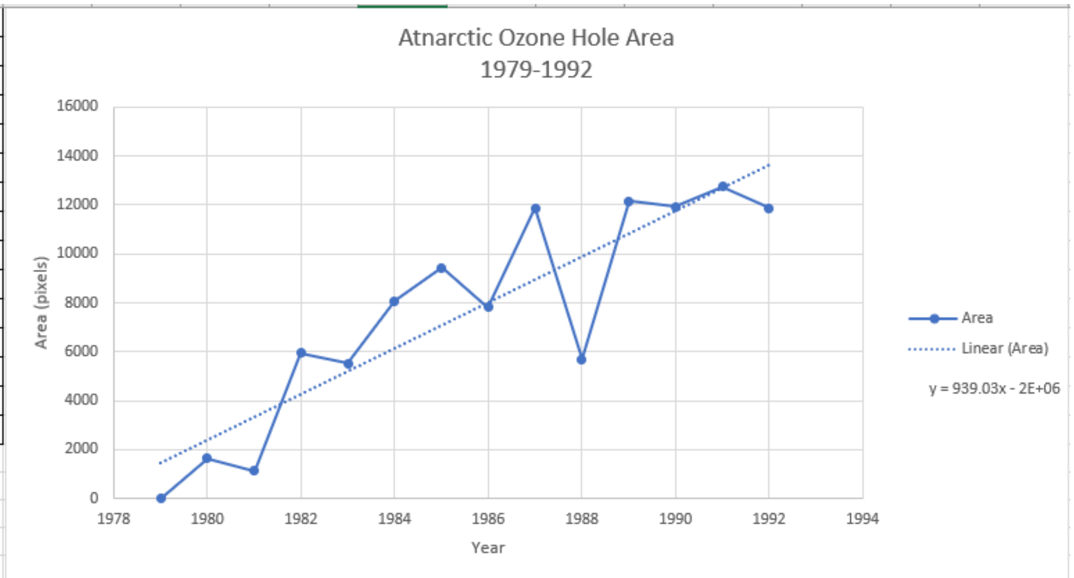
TOMS – Nimbus-7 – South Pole – 1979-1992



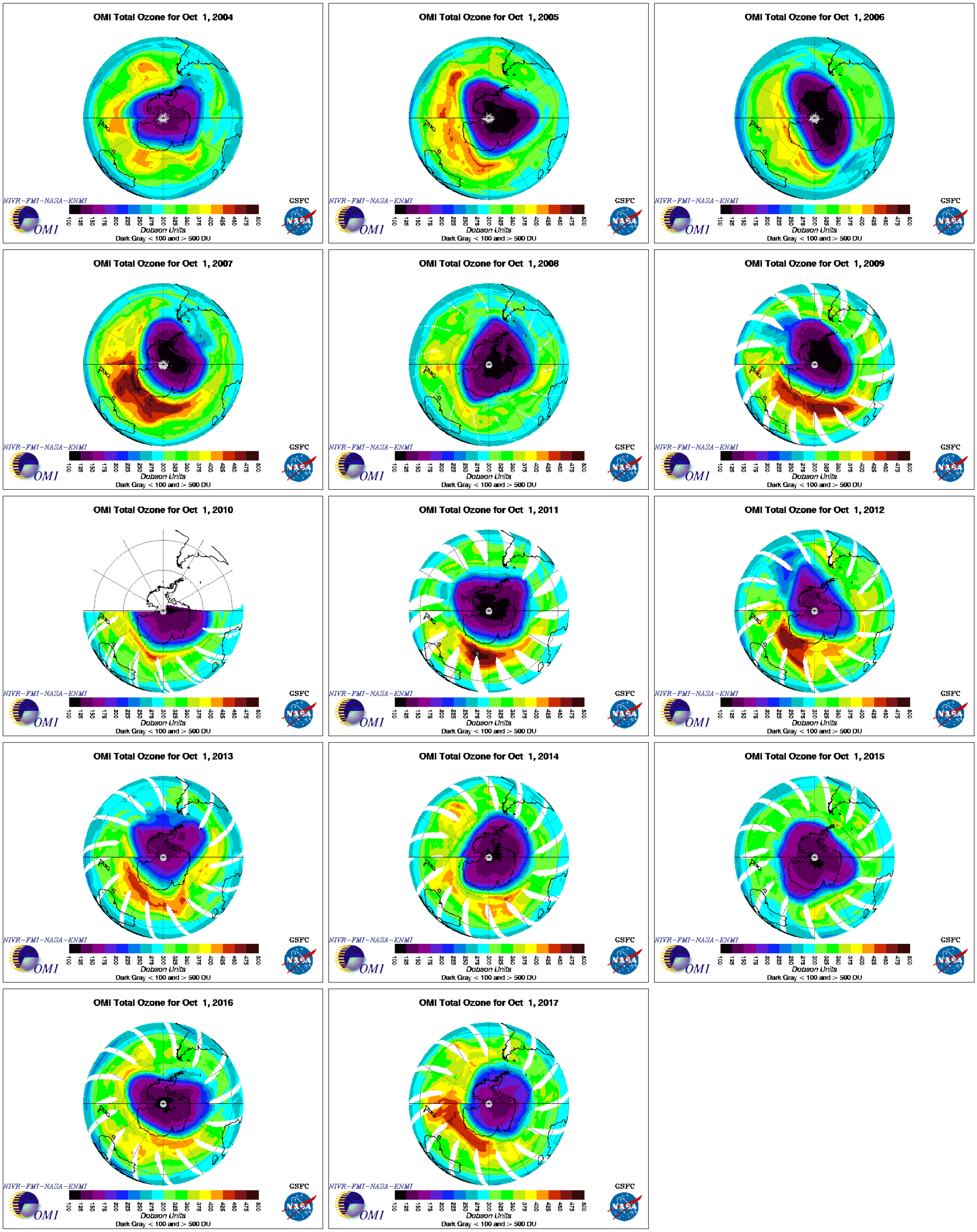
Name____ Class___________________ Date__________

TOMS – Nimbus-7 – South Pole – 1979-1992

Year	Area
1979	0
1980	1658
1981	1121
1982	5954
1983	5528
1984	8078
1985	9440
1986	7825
1987	11860
1988	5706
1989	12136
1990	11914
1991	12752
1992	11861

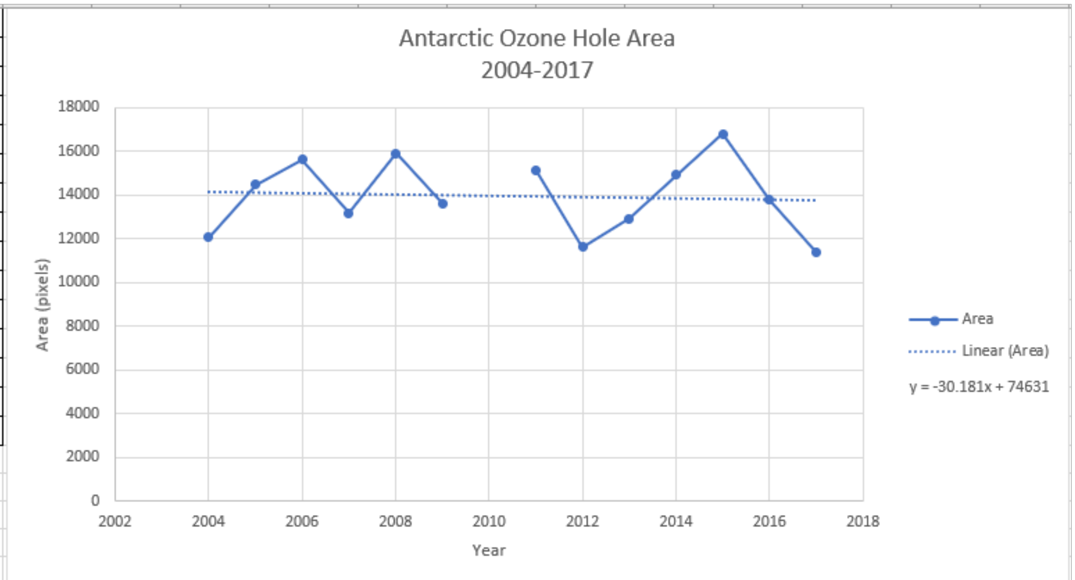


OMI – Aura – South Pole – 2004-2017

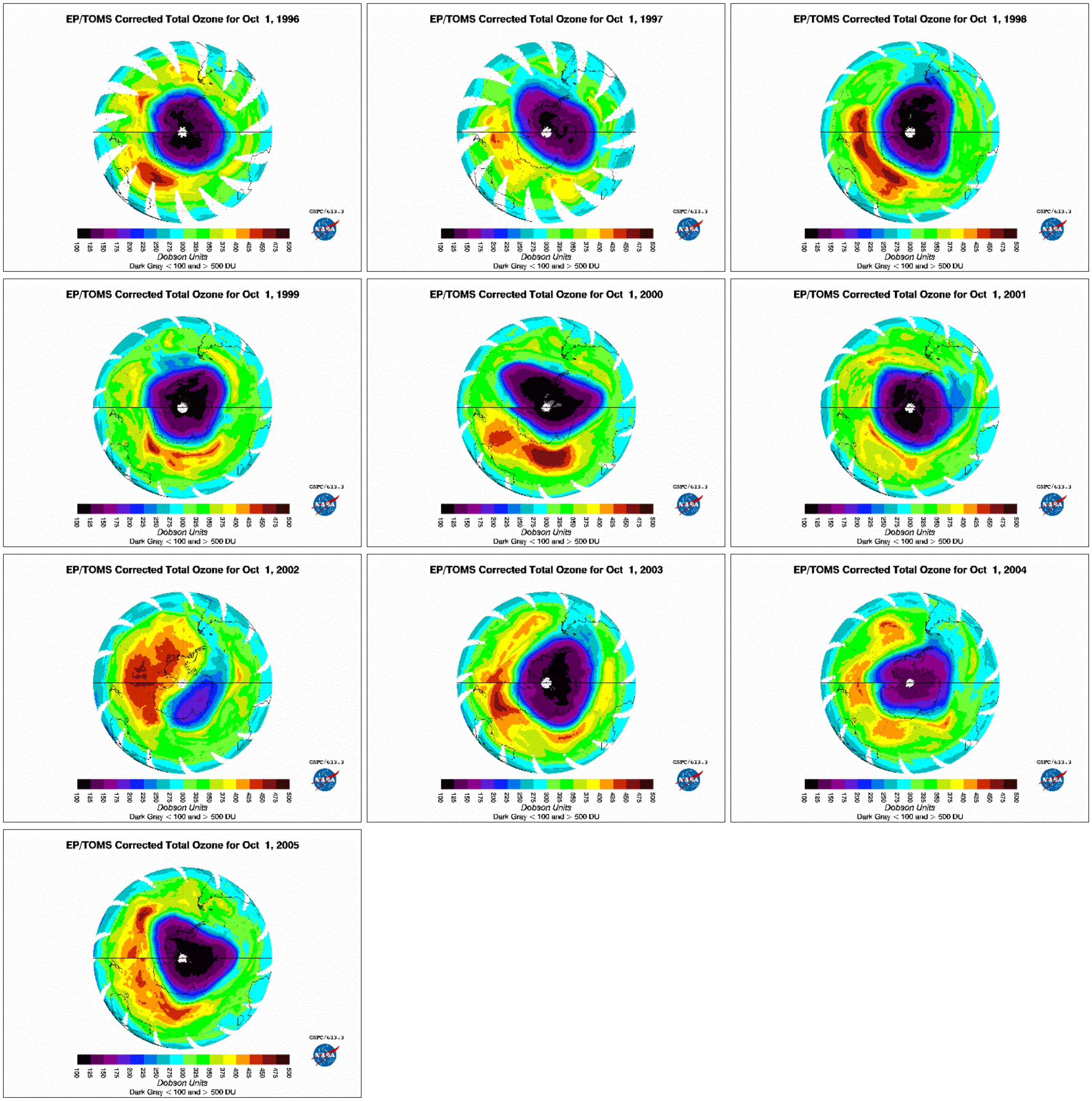


OMI – Aura – South Pole – 2004-2017

Year	Area
2004	12073
2005	14482
2006	15610
2007	13162
2008	15892
2009	13634
2010	
2011	15116
2012	11612
2013	12936
2014	14916
2015	16781
2016	13769
2017	11380

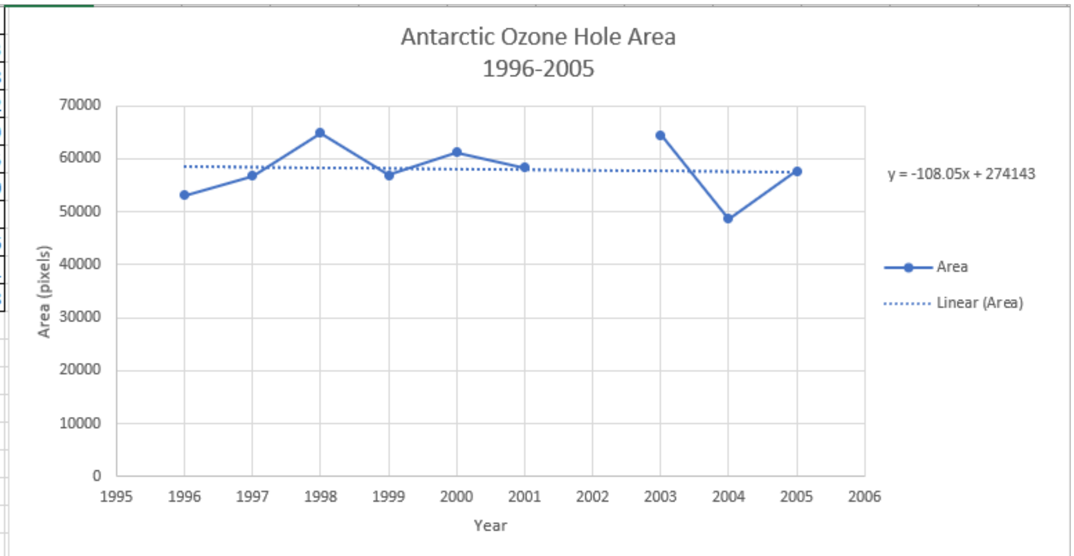


TOMS – Earth Probe – South Pole – 1996-2005

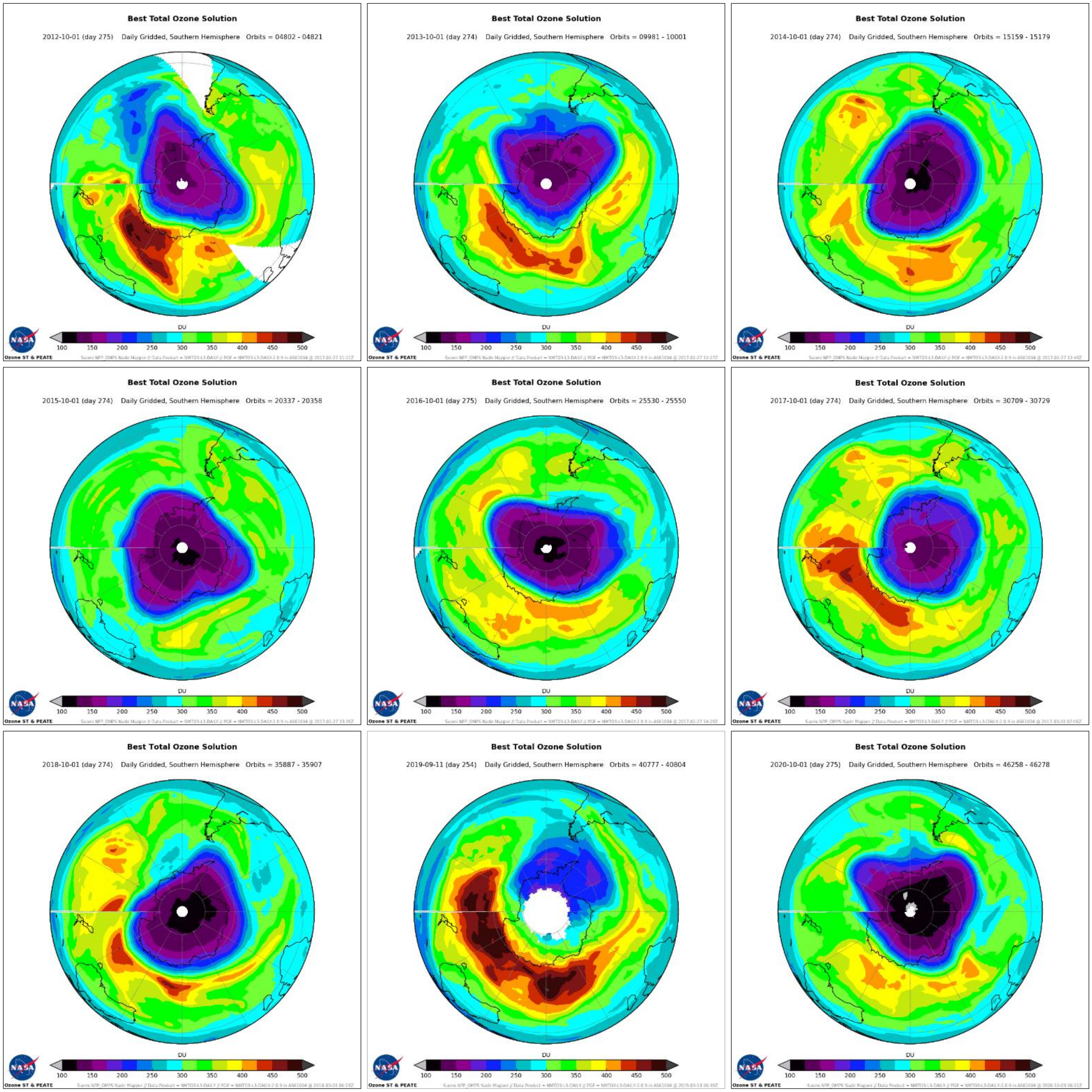


TOMS – Earth Probe – South Pole – 1996-2005

Year	Area
1996	53103
1997	56768
1998	64882
1999	56889
2000	61175
2001	58400
2002	
2003	64446
2004	48661
2005	57668



OMPS – Suomi NPP/NOAA-20 – South Pole – 2012-2020



OMPS – Suomi NPP/NOAA-20 – South Pole – 2012-2020

Year	Area
2012	42104
2013	46750
2014	54561
2015	62622
2016	51022
2017	42937
2018	52291
2019	21040
2020	56556