MOSAIC Final Project
A Physics MOSAIC
RET 2010 (rev 2011)
MIT Haystack Observatory

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Teacher's Introduction

Background Information
The MOSAIC Final Project is part of *A Physics MOSAIC*, a set of lessons designed at MIT Haystack Observatory as part of a Research Experience for Teachers (RET) program in the summer of 2010 (and revised during 2011). This document is designed to get you up and running with MOSAIC as quickly as possible. The final project described here is designed as a 2-4 week final project/capstone experience to be completed towards the end of the school year in a high school physics class, but the project could also be used as a midterm project or for interested students as part of a science club or science fair. It is accessible at many levels, either at the introductory level by identifying patterns and explaining possible relationships between variables, or at the advanced level by utilizing the raw data and statistically determining the significance of possible relationships. For background on data analysis and interpretation of the error bars and values provided by MOSAIC, see the lessons "Numbers in Science" and "Data Analysis" from the *A Physics MOSAIC* unit. This document includes some guidance for students who are starting out relatively unfamiliar with MOSAIC and the atmosphere, so it can be used as a standalone project. It is also well-suited as a culminating final project for a physics course, especially one that has included some of the lessons from *A Physics MOSAIC*.

MOSAIC, or Mesospheric Ozone System for Atmospheric Investigations in the Classroom, utilizes the 11.0725 GHz resonant frequency of ozone to determine its concentration in the upper atmosphere (specifically, the mesosphere) at about 80 km above the surface of the Earth. This frequency conveniently lies within the range of detection for normal TV satellite receiving dishes, but outside the frequencies used by American satellite channels.

The observation of variation of ozone (O_3) in the mesosphere may indicate global changes in the atmosphere. Besides MOSAIC, there are very few other methods of observing mesospheric ozone in such a relatively inexpensive way. This is real-world, real-time, scientific research.

There are (as August, 2011) seven spectrometers operating, with more being added. Six of these spectrometers look at the same patch of sky, located off the coast of the mid-Atlantic region of the US, at latitude of about 37.8°N, 70.5°W. This allows data from the spectrometers to be combined for the purposes of averaging, since each spectrometer is effectively measuring the same signal. The seventh spectrometer is located in Alaska and looks at the mesospheric ozone in the northern part of the atmosphere. The names of the spectrometers are listed on the website as Chelmsford High School, MA, Haystack Observatory, Westford, MA, Bridgewater State University, MA, Union College, Schenectady, NY, University of North Carolina at Greensboro, NC, Lynnfield High School, MA, and Alaska Pacific University, AK.

Getting Familiar with the Interface

1. Go to the website http://haystack.mit.edu/ozone .

2. Pressing **submit** on the website above with the defaults selected will eventually (takes a while) bring up a plot of **antenna temperature** in milliKelvin (mK) on the y-axis against frequency on the x-axis, measured as the deviation from the zero line, which is the 11.0725 GHz. The central peak value is the part that we are interested in. This is the average since MOSAIC was started in 2008. The higher the **antenna temperature** the greater the **ozone concentration**. (0.8 mK/ppmv – see Memo #69).

3. Pressing reset then clicking ozone vs. localtime under Step 4 then **submit** will give you a plot of average ozone concentration on the y-axis versus time (measured in hours) on the x-axis. This allows you to see the effect of day and night since the beginning of 2008 (18.00 to 6:00 is defined as sunset to sunrise local time, regardless of the time of year or location of the site). Ozone concentration is lower during the day because it is being broken down into molecular oxygen by the ultraviolet radiation from the sun, and it recombines at night.

4. Pressing reset then clicking ozone vs. date under Step 4 then **submit** will give you the ozone concentration on the y-axis with date (measured in days) on the x-axis. This allows you to see the effect of the seasons since the beginning of 2008. Dates and times in MOSAIC are in Universal Time, which is EST + 5 hours or EDT + 6 hours. Ozone concentration varies from maximum to minimum with the seasons, with maxima occurring in spring and fall and minima occurring in summer and winter. This is believed to be due to interhemispheric circulation of water vapor from the summer pole to the winter pole. Water helps to break down ozone. The water is broken down into hydrogen and the hydroxyl radical (OH). The hydrogen then reacts with ozone to form OH and molecular hydrogen. (For more details, see the lesson "Waves and MOSAIC Basics" from the *A Physics MOSAIC* unit.)

Users can change the year and day settings so that they can compare variations in ozone concentration for particular days with local weather and temperature readings such as thunderstorms or ice storms (http://www.wunderground.com), solar weather such as solar flares (http://www.spaceweather.com), or average global ocean temperature (http://www.noaa.gov). Because MOSAIC detects *mesospheric* ozone, we do not expect any effect on the level of ozone from local (tropospheric) weather phenomena, but factors affecting the upper atmosphere are more likely to have an impact. For example, solar flares may bring protons to the upper atmosphere, which will breakdown ozone. A collection of graphs from each month that MOSAIC has been operating (through August, 2011) is included as an appendix to this document. Each graph includes labels for events occurring during that month that may have affected mesospheric ozone.

Rainstorms *do not* affect the concentration of ozone in the mesospheric (they occur in the troposphere), but they *do* affect the sensitivity of the spectrometer, often resulting in lower measured values for ozone that do not correspond to the actual concentration.

Students can also download the averaged data from each spectrometer. These data appear as a text file next to the graph plot as a number followed by **avout.txt** (for raw data from the spectral output) or **sum.txt** (for raw data from the time outputs). Information on the data contained in the file is available by clicking on the file ending with **info.html**. The text files can be opened in Excel (or any other favorite graphing program) as a fixed width file (should be the default), and students can then create their own plots based on the question of interest. An activity guiding this process is provided in this document.

Before beginning the research, students will need to gain some familiarity with ozone, the atmosphere, and the MOSAIC system. If students do not yet have this familiarity, the background information can be conveyed using the provided PowerPoint presentations (available at http://www.haystack.mit.edu/edu/pcr/MOSAIC/index.html, or see attached). This can be done through self-study where students can use the associated PowerPoint presentations as Web Quests to find the information if time allows, or the information may be relayed through class instruction using the Power Point presentations, or any combination thereof. Worksheets to guide students' learning are included in this unit.

Proposed Process for MOSAIC Final Project (2-4 weeks total classroom time)
1. Background on ozone, atmosphere, MOSAIC system (1 week)
   - Power Point Lessons, part of RET 2009 unit, *Meet Me in the Mesosphere,* provided at http://www.haystack.mit.edu/edu/pcr/MOSAIC/index.html
   - Could be completed as self-study or as classroom instruction
   - Worksheets (3) included in this document
2. Getting Familiar with MOSAIC interface and data (1-3 days)
   - Guided Activities (5) included in this document
   - Students need internet access to complete, but could be done in or out of class
3. Independent Research Process, using MOSAIC data (1-2 weeks)
   - Tutorial for downloading data from web interface and creating graphs in Excel (or other graphing program), included in this document
   - Suggested projects (5) included in this document, with varying degrees of guiding
   - Students may design their own research question and pursue independently (suggestions included)
   - If students are to design own topics and questions, teachers may want to remove the suggested projects from document before distributing to students
   - A month-by-month compilation of all the MOSAIC data is included as an appendix to this document, including potentially relevant events such as rocket launches, shuttle launches, meteor showers, and sudden stratospheric warming events
4. Reporting and Presenting Results (varies)
   - Students should present results via whatever process suits your classroom: a paper, poster, presentation, or website might be possible final outcomes
   - Possible rubric for evaluation included in this document

Student Introduction

Welcome to MOSAIC (Mesospheric Ozone System for Atmospheric Investigations in the Classroom). Here you can do original scientific research from the comfort of your own classroom or living room.

Mesospheric ozone is the ozone in the upper part of the atmosphere, about 100 km above the surface of Earth. There is very little ozone up there, but the MOSAIC system is uniquely designed to detect it from Earth's surface. Better yet, you can observe how much the concentration changes over time using any computer connected to the internet because the data is uploaded each day. Changes in concentration of mesospheric ozone over time may indicate larger changes in our atmosphere.

This information comes from *spectrometers* which are comparatively inexpensive and are actually made from parts of a satellite TV system, similar to ones you may have at home. They are located throughout Massachusetts and the US.

The changes in ozone concentration in the mesosphere may reveal to us how the atmosphere changes with changing seasons or over time. Mesospheric ozone has not been thoroughly researched over a long period of time, so you may discover something new.

Before you start your research project, you will need to gain some understanding about the atmosphere, ozone, and how the spectrometer works. Your teacher may provide you with resources or, since this is essentially a self-directed research project, you should be able to use lessons provided at http://www.haystack.mit.edu/edu/pcr/MOSAIC/index.html to research the information for yourself.

Additional internet resources:

Here are some recommended websites that you could include in your research.

www.haystack.mit.edu   www.noaa.gov
www.nasa.gov   www.spaceweather.com

There may be other sites which you may find simpler or more useful. Whichever site you use, be sure to keep track of the exact address of the webpage you're using and the date the page was accessed. (You might also be able to use a bookmarking site such as Google Bookmarks or www.delicious.com so you can access the bookmarks from home).

You are now ready to start your research. Enjoy.

MOSAIC Background: Meet Me in the Mesosphere

These questions are based on, but not limited to, a series of units which may be found at the Haystack Observatory website as part of their education and outreach, pre-college resources at http://www.haystack.mit.edu/edu/pcr/MOSAIC/index.html. However, you may have to find the answers to these questions elsewhere on the internet.

Worksheet 1: Earth's Atmosphere
(Suggested starting point: Unit 1, "Atmosphere Introduction")

1. What is the atmosphere?

2. Name the layers of the atmosphere in order from lowest to highest.

3. About how far up is the mesosphere?

4. What is the approximate temperature of the mesopause?

5. As height increases how does the temperature change in the mesosphere compare to the temperature change in the stratosphere?

6. Why do scientists believe the temperature changes in this way?

7. How much of the air we breathe is oxygen?

8. What does the stratosphere contain and what does it do?

9. List three ways that changes in the atmosphere could affect you.

Worksheet 2: Ozone in the Atmosphere
(Suggested starting point: Unit 4, "Ozone in the Atmosphere")

1. What is the chemical formula for ozone?

2. Why is ozone in the lower troposphere a problem?

3. Why is ozone in the stratosphere beneficial?

4. Why is there a hole in the ozone layer over the Antarctic?

5. How much of the total percentage of the ozone in the atmosphere is actually in the mesosphere?

6. Why is the level of ozone greater at night than during the day?

7. What does water vapor do to ozone?

8. How do scientists think decreases in the ozone layer would affect life on earth?

Further Links:

http://Earthobservatory.nasa.gov/Features/GlobalTraveler
http://earthobservatory.nasa.gov/Features/Tango/
http://www.ozonelayer.noaa.gov/science/basics.htm

You may also want to investigate: Noctilucent Clouds.

Worksheet 3: Seeing The Ozone: The MOSAIC System
(Suggested starting point: Unit 5, "Seeing the Ozone")

1. What exactly is the radio frequency emitted by ozone in the 11 GHz range.

2. What does GHz mean?

3. Given that the speed of light in a vacuum is exactly 299,792,458 m/s, calculate the wavelength of the radio wave detected by the MOSAIC system described in Question 1.

4. Where relative to the satellite dish is the detector (LNB) of the MOSAIC system placed?

5. At what angle is MOSAIC pointed and why?

6.   Name three ways that the gain of a dish could be improved.

7. How is the signal from the mesospheric ozone detected above the background thermal noise?

8. How does MOSAIC correct for frequency drift in the local oscillator?

9. GUI stands for Graphical User Interface. What is the full web address for the GUI for MOSAIC?

10. What is the bandwidth used for the ozone line?

You now have some of the background information to understand some of how the MOSAIC system works and how it can detect the concentration of ozone in the atmosphere. To get a fuller understanding you may continue to do more research as you go along, research the MOSAIC memos link on the website (those listed with an M), or just start using the MOSAIC interface and learn as you go.

How to use MOSAIC

- Direct your browser to the following web site: http://www.haystack.mit.edu/ozone/
- Complete the activities and fill in the blanks as you go along.
- To enter dates in the interface and make sense of the data you produce, you may need an ordinal date calendar to convert from day of the year (1-365) to month and day (Jan 1 to Dec 31). Don't forget to account for leap years! www.fs.fed.us/raws/book/julian.shtml
- You can also enter your date requests as a month number: day number. For example, March 17 would be entered as 03:17. However, any graphs produced by the interface will label the dates in day number.

MOSAIC ozone data access

Plot ozone data in 4 easy steps:

Step 1: Select data by date (you can enter Day ddd or mm:dd i.e. 15 Feb is 46 or 02:15)

Start Year 2008   Start Day 1   Stop Year 2100   Stop Day 366

Step 2: Apply filters to data (optional)
☐ Show only data

    From Start Localtime 0   hr 0   min To Stop Localtime 24   hr 0   min Each Day

Localtime is defined so that sunrise and sunset occur at 6 and 18 hrs, respectively, every day.
☐ Show only data when the sun is - or check ☐ for nighttime data only

    Above -90   deg and Below 90   deg Elevation

Example: Setting "below" to -10 degrees selects data for which the sun is at least 10 degrees below the horizon.

Step 3: Select spectrometer(s)
☑ Chelmsford High School, MA ☑ Haystack Observatory, MA ☑ Bridgewater State University, MA ☑ Union College, Schenectady, NY
☑ University of North Carolina at Greensboro, NC ☑ Lynnfield High School, MA ☐ Alaska Pacific University, AK ☐ SP8 ☐ SP9

Step 4: Select plot type
◉ Ozone spectrum: ◉ above and below 80km fit together ○ above and below 80km fit separately
○ Ozone vs localtime: ○ 60 ◉ 30 ○ 20 ○ 10 minutes averaging time (turn off filters to get full range of localtime)
○ Ozone vs date: ○ 20 ◉ 10 ○ 4 ○ 2 ○ 1 days averaging time ○ modulo 1 year (use filter for nightime data)
Select "modulo 1 year" to wrap data by year (e.g., all data taken on January 3, regardless of year, are averaged and plotted as day 3)

Advanced Options: (requires a detailed knowledge of the spectrometer) see MOSAIC memos
☐ include total power in plots vs time ☐ include data with high Tsys (probably due to rain)
○ plot only total power vs time for selected time range ○ plot cal freq. vs time for start day
○ plot total power vs time for start day(high res) ○ high resolution spectrum ☐ use Tsys correction ☐ solve for Mesopause temperature

[Submit] [Reset]

Activity 1: Ozone Spectrum

- Press submit, requesting data with the default settings.
- You will get all the data since 2008. (This may take some time)
- It should look similar to the following graph.
- The y-axis of this graph is related to the average level of ozone in the atmosphere.
- The higher the antenna temperature (which is a measure of signal power received) the greater the amount of ozone in the mesosphere.
- **The relationship can be shown to be 0.8mK/ppmv** (ozone volume mixing ratio)
- The data are automatically fit with a curve, visible on your plot. The parameters of this curve fit are available in the file labeled with a number, then **sum.txt**. It will look like this (to the right of the spectrum):

  averaged data is in 717455avout.txt left_click to view right_click to save
  summary data is in 717455sum.txt left_click to view ⟵ This one!
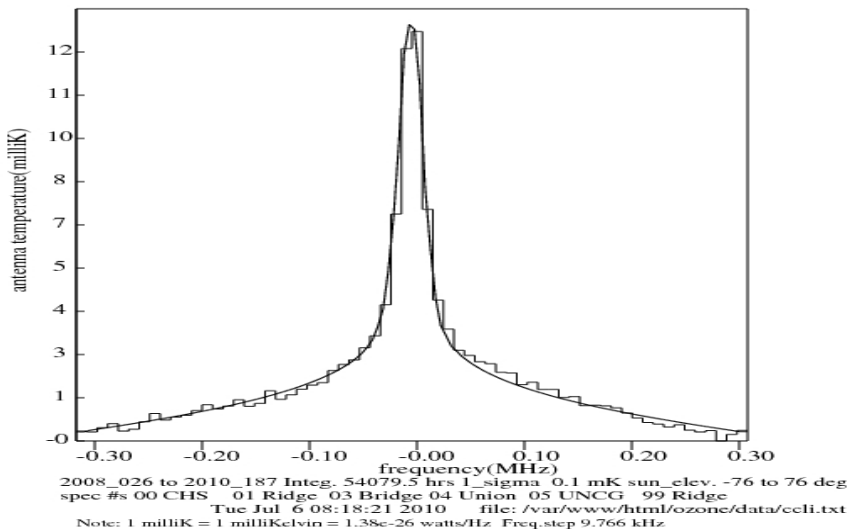 Information is in 717455info.htm left_click to view
  PostScript plot is in 717455spe.pos right_click to save

- The first two numbers of this output are the most relevant, as they give the peak of the curve and the rms residual (a measure of uncertainty).

  peak 12.98 rmsresid 0.177 theory 0.08 mK fit_high 10.62 fith_err 0.10 fit_low 0.00 fitl_err 0.00 ppm avtpwr -1.81 dB 2008 26 to 2010 210

- How high is this peak antenna temperature in this graph? _____
- What is the rms residual for this curve? _____
- How much would the peak correspond to in ozone vmr (ozone volume mixing ratio) ppmv (parts per million by volume)? This will be the measure of the ozone concentration. _____
- The peak signal around 0.00 is the important 11.0725 GHz signal from the ozone in the mesosphere (above 80 km)
- (if you wish to separate the signals into above and below 80 km use Step 4: Ozone spectrum)
- When finished go back to previous web page and press reset (Do this after each investigation)

2008_026 to 2010_187 Integ. 54079.5 hrs 1_sigma 0.1 mK sun_elev. -76 to 76 deg
spec #s 00 CHS   01 Ridge 03 Bridge 04 Union 05 UNCG   99 Ridge
Tue Jul 6 08:18:21 2010   file: /var/www/html/ozone/data/cdli.txt
Note: 1 milliK = 1 milliKelvin = 1.38e-26 watts/Hz Freq.step 9.766 kHz
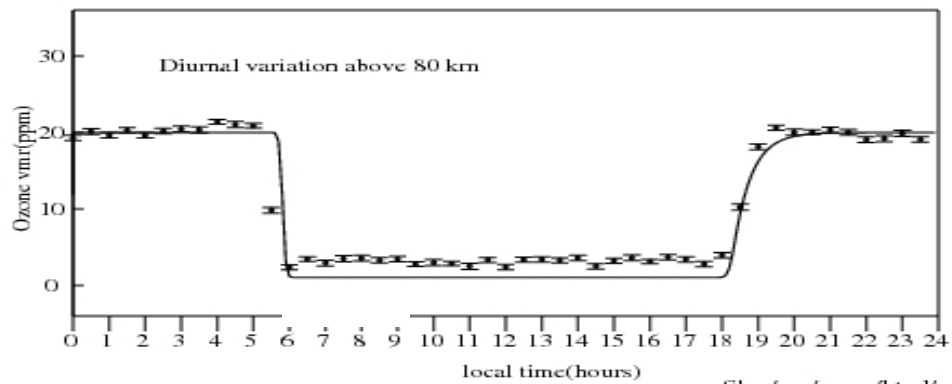
Activity 2: Seasonal Variation

- Press reset to return the interface to its default options.
- Check 'for nighttime data only' since most of the ozone is during the night
- Click on step 4 – ozone versus date – 10 day averaging time.
- Press submit.
- You should see a graph similar to the one below. It shows the variation in measured ozone concentration since about January 2008.
- Answer the following questions.
- Why do the early results have longer error bars and are further apart than the later results? _____
- Notice how the level of ozone seems to go up in the fall (around day 300 of each year). Why might this occur? _____
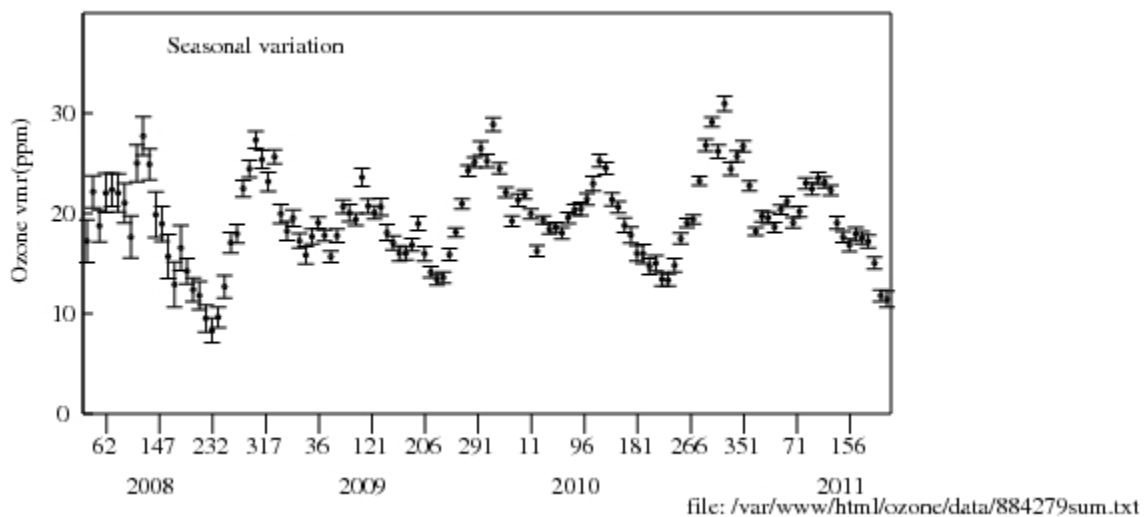
Activity 3: Diurnal Variation

- Press reset.
- Click on step 4: ozone versus local time
- Press Submit
- 1. Notice that the ozone level is highest at night (defined as 18 hours (sunset) to 6 hours (sunrise).) Why does this occur?_____


Diurnal variation above 80 km

local time(hours)

file: /var/www/html/ozone/data/431479sum.txt

Activity 4: Yearly Variations in Seasonal Variation

- Press reset to return the interface to its default options.
- Check 'for nighttime data only' since most of the ozone is during the night
- Click on step 4 – ozone versus date – 10 day averaging time.
- Click on step 4 – near spectrum – fit above and below 80 km fit separately
- Click on step 4 – ozone versus data – modulo 1 year
- Press submit.
- You should see a graph similar to the one below. It shows the variation in measured ozone concentration in time since January 2008 with each year overlaid on the one before it with a different color data point.
- Answer the following questions.
- Is the seasonal variation more pronounced in the upper atmosphere (above 80 km) or the lower atmosphere (below 80 km)? _____
- Notice how the level of ozone rises every fall, but seems to have been even higher in 2010. This could be due to southern oscillations (El Nino or La Nina).
- Read more about the Southern Oscillations at http://www.physicalgeography.net/fundamentals/7z.html
- A graph showing the effect is available at http://www.bom.gov.au/climate/current/soi2.shtml. Positive values on this graph correspond to La Nina, while negative values correspond to El Nino. Is the timing of the southern oscillation consistent with the increase in ozone level detected at the end of 2010? _____
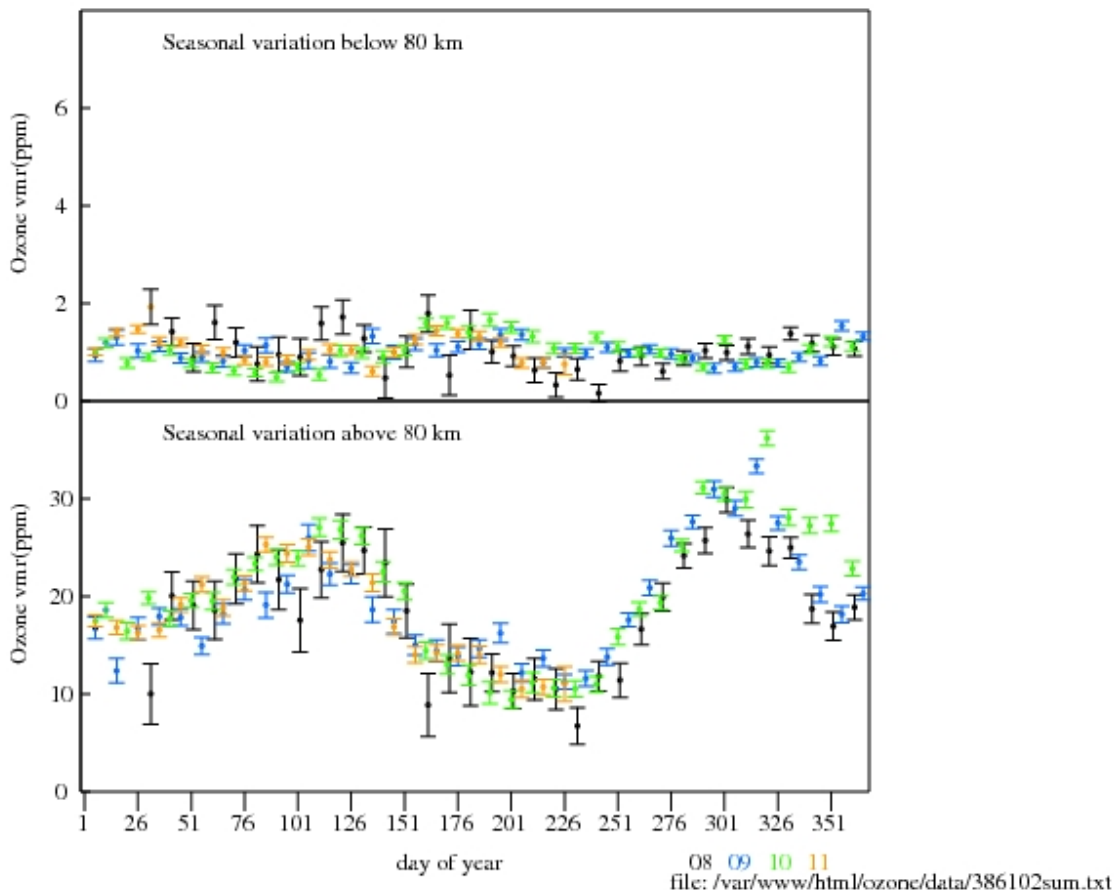
Activity 5: Start Dates

- Press Reset
- Under step three click all the spectrometers except University of North Carolina, so that only that spectrometer is selected.
- Under step four click ozone versus date.
- Press Submit
- Where does the date start?_____
- Why do you think it starts there?_____
- Compare it to graphs from other sites
- List the dates each site started collecting data. (Remember to convert day number to calendar mm/dd/yy format.
    - Chelmsford High School: _____
    - Haystack: _____
    - Bridgewater State University: _____
    - Union College: _____
    - University of North Carolina at Greensboro: _____
    - Lynnfield High School: _____
    - Alaska Pacific University: _____

Seasonal variation above 80 km

file: /var/www/html/ozone/data/611959sum.txt
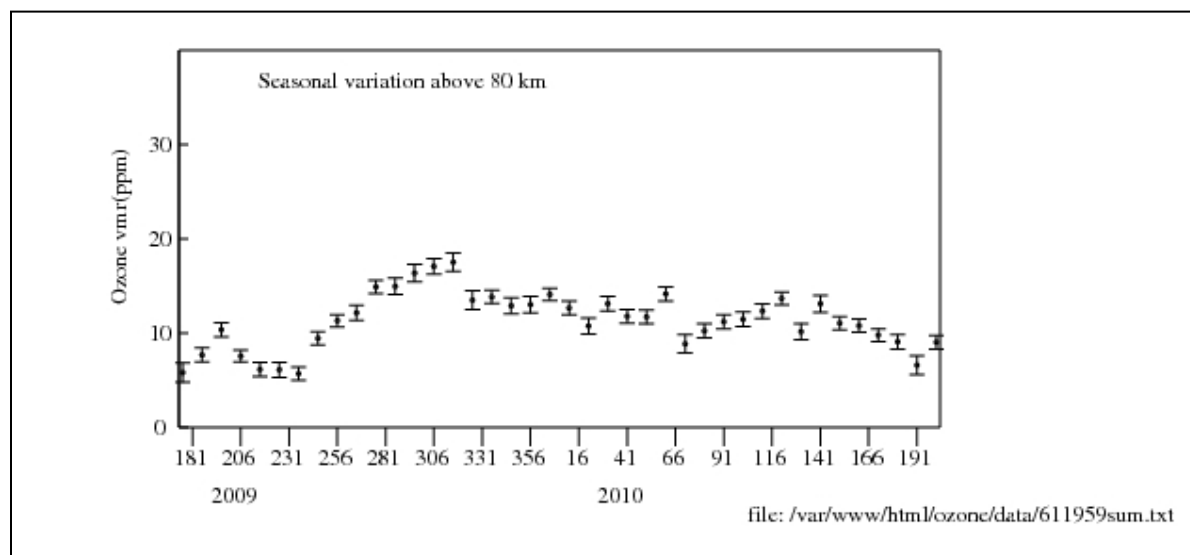
- Now you can start your research project. See the following pages. Remember ozone in the mesosphere (mesospheric ozone) is created at nighttime by collisions of O_2 and O in the presence of a nitrogen molecule catalyst and is broken down during the day by the action of sunlight, but there may be other factors involved. What could they be?

MOSAIC Research Project

Introduction
At the end of the project you are expected to communicate your findings to your class using a method described by your teacher.   You may be asked to prepare an oral or poster presentation, write a paper, or create a website.

Below is a list of possible variables that you can look at. Be sure that you include the latest data. Analyze the data carefully and see if you can detect any trends or differences in trends from year to year.

For example, you could measure the average night time concentration of ozone for each season for each year and compare the concentrations. Or, you could measure the average nighttime concentrations over periods of 10 days and compare them to the average temperature or barometric pressure for that time. Or, you could look for ten upper atmospheric events such as solar flares or rocket launches and check them with ozone concentration for those particular days and see if there is any effect. Remember, MOSAIC detects *mesospheric* ozone, so consider what type of events is likely to have an impact on the measured concentration.   There are some events that will *not* affect the mesospheric ozone concentration, but will interfere with the spectrometers' ability to detect a signal (local rainfall is one such event).

Nighttime ozone concentration and…	Possible websites for data access, reference
Air temperature for the local area	www.wunderground.com
Ocean temperature	www.noaa.gov
Meteor Showers	www.stardate.org
Sudden Stratospheric Warming	http://acdb-ext.gsfc.nasa.gov/Data_services/met/ann_data.html
Solar Activity (Solar flux)	http://www.ngdc.noaa.gov/stp/spaceweather.html
Solar Proton Event	www.spaceweather.com http://umbra.nascom.nasa.gov/SEP/
Effects of Southern Oscillations (El Nino, El Nina)	http://www.bom.gov.au/climate/current/soi2.shtml
Shuttle/satellite launches	http://www.spaceflightnow.com/tracking/launchlog.html
Phases of the moon	http://eclipse.gsfc.nasa.gov/phase/phase2001gmt.html
Alaska site vs. mid-Atlantic site	www.haystack.mit.edu/ozone
Average velocity of molecules	www.haystack.mit.edu/ozone
Appearances of noctilucent clouds. (Polar Mesospheric Clouds)	www.spaceweather.com
Effect of Mesospheric Temperature	http://saber.gats-inc.com/
Effect of Water Vapor in Upper Atmosphere	
Effect of solar tides in the atmosphere	

Project Outline

Teacher: Class:
Name: Date:

Topic Chosen:

Information I need:

Additional websites/books I should look at:

How I will report my findings:

Websites used:

Date	Website	Description

A possible layout for a research project paper, or sequence of presentation slides, would be Title, Authors and Affiliation, Abstract, Introduction, Methods, Results, Discussion, Acknowledgments, and Literature Cited,

(http://abacus.bates.edu/~ganderso/biology/resources/writing/HTWsections.html)

Possible RUBRIC

This rubric addresses 21st Century skills (www .p21.org), National Science Education Standards and Massachusetts Frameworks for Scientific Inquiry.

Critical Thinkers who: 1. identify and define problems **2.** Gather and analyze information **3.** Draw and apply conclusions
Communicators who: 1. Write effectively **2.** Speak effectively **3.** Read purposefully
Technology Users who: 1. connect technology to learning

Section	Advanced	Proficient	Needs Improvement
Title and Authors	Clear, succinct, title, self-explanatory.	Good Title, but needs some work	Title not understandable or not related to project
Abstract	Short clear, logical, summary of paper/presentation.	Some parts missing.	Cursory summary
Introduction	Problems identified and clearly explained. Good hypothesis and explanation.	Some steps missing or not clearly explained.	Brief description.
Methods	Logical explanation of procedure	Some steps missing or not clearly explained	Cursory description of method
Results	Results table, clearly labeled with units. Same with graph.	Results table and graph. One or two labels or units missing.	No table for results. Graphs incorrectly drawn.
Discussion	Concise and scientific analysis of results with conclusion and evaluation of possible errors.	Gives valid conclusion and explanation but little evaluation of validity of project.	Gives conclusion but no explanation or discussion of errors.
Literature Cited and Acknowledgements	Proper APA formatting and in-text citations.	Minor errors in APA formatting or in-text citations.	Incorrect format or no in-text citations

Tutorial: Creating your own graphs of MOSAIC data, with local weather

This tutorial is intended to guide you through how to import MOSAIC data into your favorite graphing program. Even if you are not specifically interested in studying mesospheric ozone variations in time, it may be useful to follow the directions here to practice. Additional data from other sources can also be downloaded and plotted to create graphs with multiple data sets.

Accessing the Data
Press Reset.
Request a start date of 2009, Day 1 (or 01:01) and an end date of 2009, Day 365 (or 12:31).
Click Ozone vs. Date, and average data over 4 days.
Right Click on summary data file which is a number followed by **sum.txt.** And choose Save Link as…, then save it to a suitable place on your computer (remember where it was saved).
Now open Excel. Go to File…Open… and under Files of Type… click 'all files'.
Go to the directory you saved **sum.txt** in, highlight the file and click open.
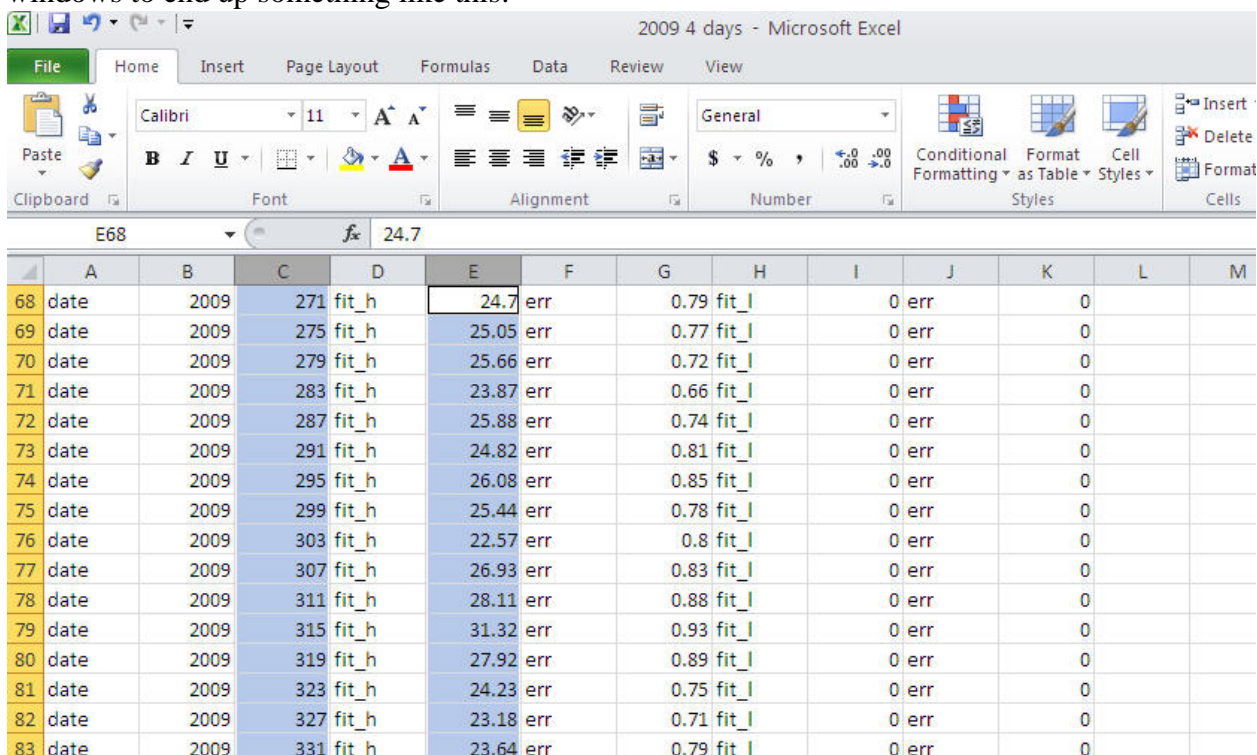
The file is already fixed width format so you should be able to accept the defaults in the next windows to end up something like this:

The important columns are C – the day number and E – the antenna temperature which is related to the ozone concentration. This will give you the average ozone concentration for every four day period in 2009.

Graphing
Select the columns for day number and antenna temperature by holding down the control button while highlighting the columns.

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Click on Insert chart or Chart and choose XY scatter and click on the icon for a scatter plot. You should get a chart similar to the following which you can then refine by adding suitable chart titles and labels for axes and even error bars. (If you are adding error bars, the relevant column in the data you have imported is the one to the right of the "err", for error.) This chart is for the average concentration (in parts per million) for the whole day, averaged over 4 day intervals. To plot against the more relevant nighttime concentration only, go back to the MOSAIC webpage and click on nighttime only.
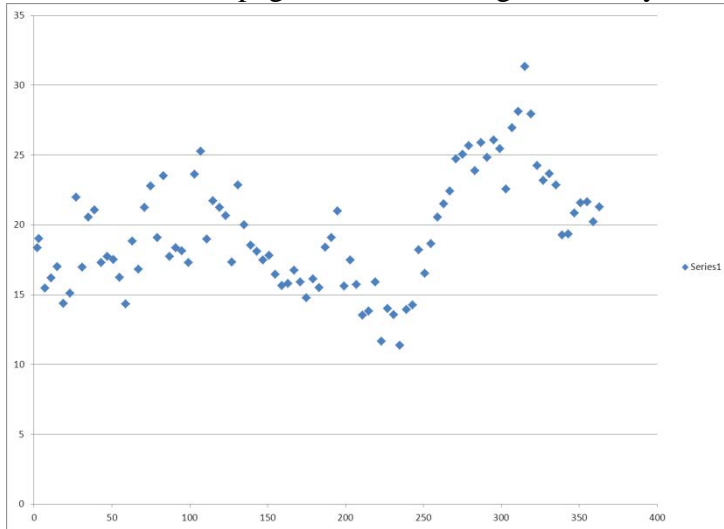
Accessing Weather Data

You can then go to Weather Underground (www.wunderground.com) and click on weather station, search for Westford, MA or your local weather. Once you have your local weather forecast, click on the name of the station to get almanac data. Although the local temperature is *not* expected to have an impact on the mesospheric ozone (why?), plotting temperature is a proxy for season, since temperatures are highest in summer and lowest in winter.

Click on yearly, then select January 1, 2009, then click on yearly, scroll all the way to the bottom and click on comma delimited file.

	Temp. (°F)			Dew Point (°F)			Humidity (%)			Sea Level Pressure (in)			Visibility (mi)			Wind (mph)			Precip (in)
	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	gust	sum
24	42	31	18	31	23	10	89	73	64	30.44	-	30.10	-	-	-	3	0	13	0.00
25	36	29	21	29	25	18	91	84	74	30.48	-	30.41	-	-	-	2	0	6	0.00
26	41	33	30	39	31	26	94	90	86	30.47	-	30.17	-	-	-	7	1	15	0.39
27	52	43	32	51	41	28	96	92	83	30.17	-	29.65	-	-	-	7	2	17	0.48
28	38	31	28	33	27	20	91	84	73	29.76	-	29.41	-	-	-	8	2	20	0.07
29	28	18	9	21	7	-2	77	61	50	30.17	-	29.44	-	-	-	13	5	25	0.00
30	26	13	8	15	0	-3	75	57	38	30.40	-	30.17	-	-	-	6	2	12	0.07
31	30	25	21	26	19	14	87	79	73	30.32	-	30.02	-	-	-	2	0	5	0.10
2010	Temp. (°F)			Dew Point (°F)			Humidity (%)			Sea Level Pressure (in)			Visibility (mi)			Wind (mph)			Precip (in)
Jan	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	gust	sum
1	35	29	24	29	26	22	90	87	78	30.01	-	29.66	-	-	-	2	0	7	0.00
2	30	27	19	27	23	15	92	86	79	29.66	-	29.23	-	-	-	10	2	22	0.23

Comma Delimited File ← **Click Here!**

Now, select all and copy and paste the output into notepad and save as txt file. Open this text file in Excel, and when prompted about delimiters, select commas. After selecting defaults and following prompts, you should get something like the following.


Plotting column A (the date) for 2009 and column C (the average temperature) will show the temperature variation for 2009.

Graphing Both Sets of Data
In order to put both sets of data (for ozone and local temperature) on the same axes, however, we need to put the temperature data in terms of the same day numbers that the MOSAIC data have been imported in. The easiest way to do this may be by entering a simply recursive formula whereby each cell is equal to one more than the one above it. Make sure your last day is equal to day 365. If it isn't, you are missing a day of temperature data, which you will need to modify the day after the missing day by adding one yourself. The rest should update automatically. Create this "day number" value in a new column, and select it as the x-axis values for this data set on the same graph as created for the ozone.

Because the values for the ozone concentration are so much smaller than the values for temperature in Fahrenheit, it may be useful to scale your ozone data by multiplying all values by 3. The result, once labels and titles have been added, may look something like what follows.

Ozone Concentration (x 3) and Average Daily Temperature, 2009
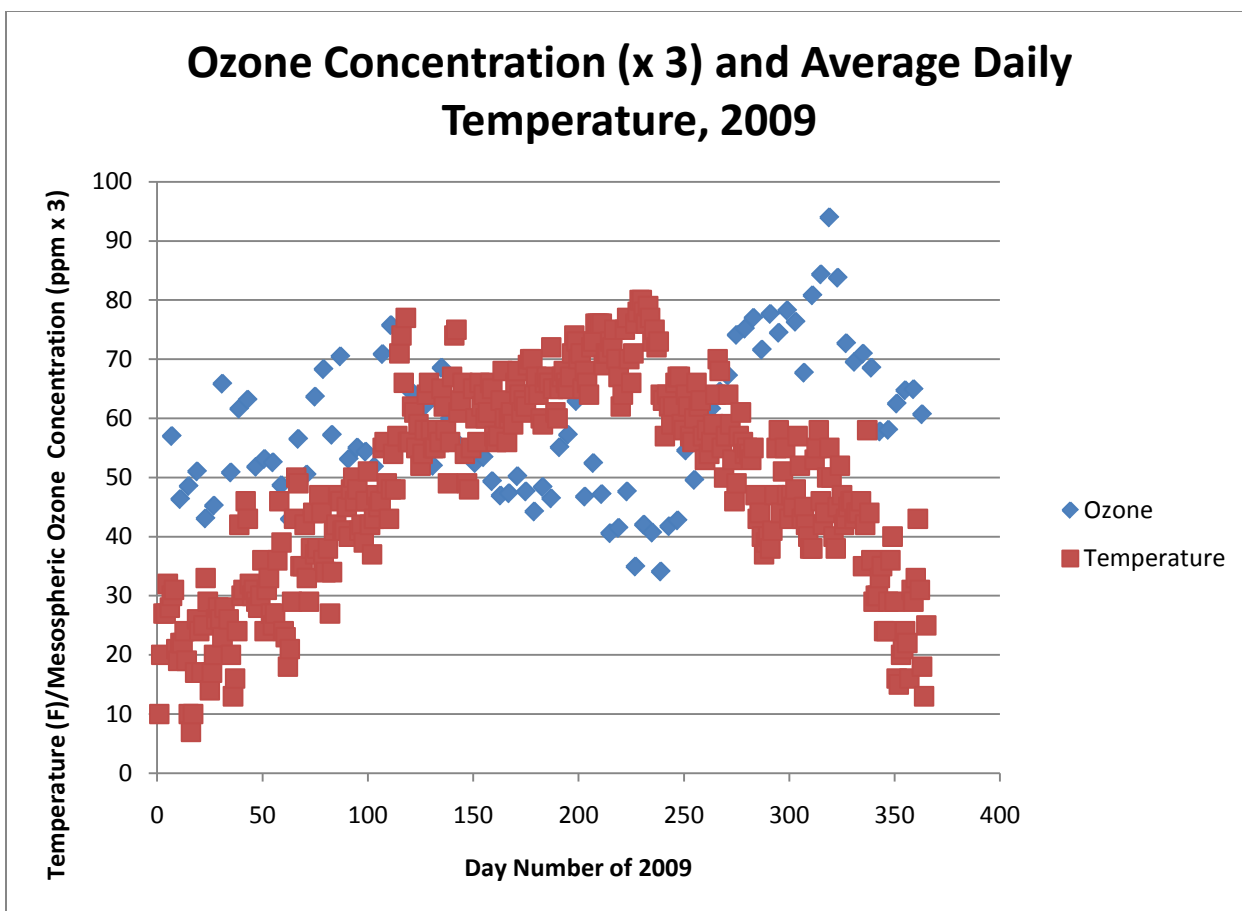
Drawing Conclusions

Once the ozone and temperature vs. time graph (as shown above) is created, you should ask yourself what, if anything, the graph tells you.

> Is there a relationship between temperature and ozone concentration?
> What evidence would strengthen your conclusion?
> If there is a relationship, does one variable affect the other? Or are both affected by another variable?
> Physically, what produces the trends in the data sets?
> How does your graph reflect the inherent uncertainty in these measurements? (You may want to add error bars, or at least consider approximately where they would fall.)

Once you have done that graph, you may want to try plotting ozone concentration as a function of temperature; that is, you may want to make your x-axis variable temperature instead of time. This will result in messy data, but this is a key step to identifying correlations between variables.

Suggested Project 1: Space Shuttle Launches and Mesospheric Ozone Concentration

Is there any connection between Space Shuttle Launches and the level of ozone in the mesosphere?

Background information

The Space Shuttle was launched from Kennedy Space Center in Florida.

The Space Shuttle carried 535,000 gallons (about 2000 m^3) of liquid fuel in its main tank,[1] which was mainly used up in the first 8 minutes of flight. This liquid fuel is actually liquid hydrogen and oxygen, which, when combined together explosively, form water. This reaction was what gave the Space Shuttle its initial thrust.

The flight path of the space shuttle made its main engine cutoff just off the coast of Cape Cod or "at 520 seconds Discovery [the space Shuttle] is 259 miles South East of Nantucket" [2] (about 40° North 68° West about 60 miles or 100km high).
The intersection of MOSAIC and the ozone layer at 100km altitude is 37.8° N and 70.5° West. (Rogers, 2009)
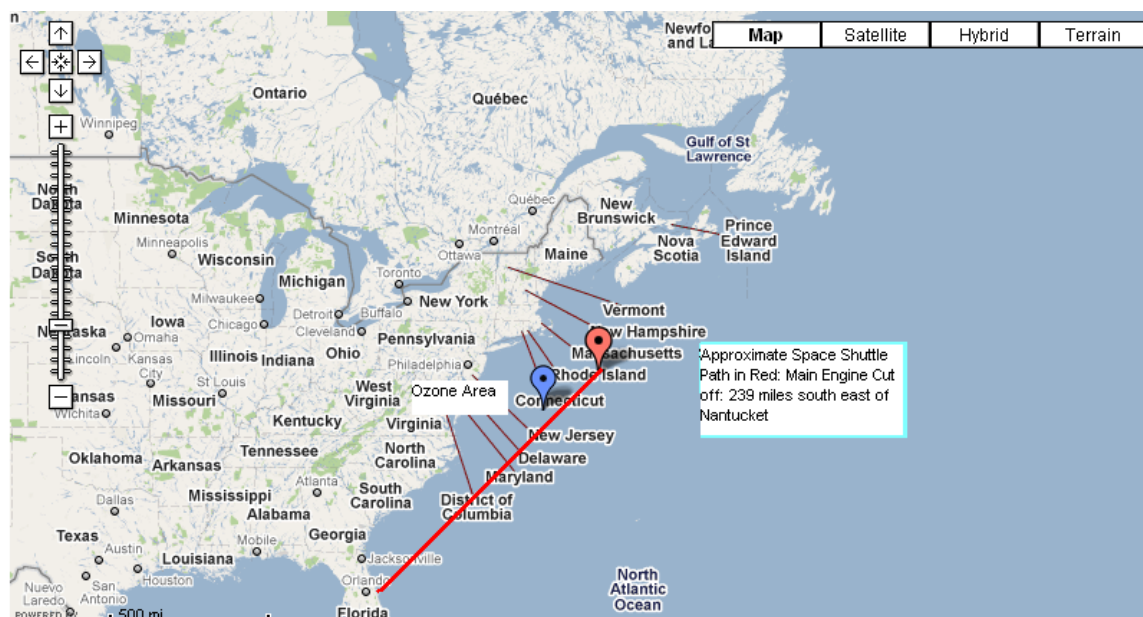
Water vapor breaks down and atomic hydrogen combines with ozone to form oxygen and OH, so we might expect ozone concentration to decrease after a shuttle launch releases its huge amounts of water vapor into the atmosphere.

The space shuttle launches for 2008-2011are listed below. Find the ozone concentrations before and after the space shuttle launches and calculate the change. Also, look at the graphs for that month and note anything of interest. Depending on the time of launch, you may want to look ahead 2 days instead of just one. The launch dates and times are in local (Eastern) time, while the MOSAIC system provides data based on Universal Time (UT). Further statistical analysis may be required to prove your hypothesis.

2011

Mission	Launch Date and time (EST/EDT)	Orbiter	Further Information	Day Number	Ozone concentration (Before, Day of, after, change)
STS-135	07.08.11 11:29 am	Atlantis	› STS-135 Site › Launch and Landing Coverage	189	
STS-134	05.16.11 8.56 am	Endeavour	› STS-134 Site › Launch and Landing Coverage	136	
STS-133	02.24.11 4.53 pm	Discovery	› STS-133 Site › Launch and Landing Coverage	55	

2010

Mission	Launch Date and time (EST/EDT)	Orbiter	Further Information	Day Number	Ozone concentration (Before, Day of, after, change)
STS-132	05.14.10 2.20pm	Atlantis	› STS-132 Site › Launch and Landing Coverage	134	
STS-131	04.05.10 6.21am	Discovery	› STS-131 Site › Launch and Landing Coverage	95	
STS-130	02.08.10 4.14am	Endeavour	› STS-130 Site › Launch and Landing Coverage	39	

2009

Mission	Launch Date and time	Orbiter	Further Information	Day Number	Ozone concentration (Before, Day of, after, change)
STS-129	11.16.09 2.28pm	Atlantis	› STS-129 Site › Launch and Landing Coverage	320	
STS-128	08.28.09 8.53pm	Discovery	› STS-128 Site › Launch and Landing Coverage	240	
STS-127	07.15.09 6.03pm	Endeavour	› STS-127 Site › Launch and Landing Coverage	196	
STS-125	05.11.09 2.01pm	Atlantis	› STS-125 Site › Launch and Landing Coverage	131	
STS-119	03.15.09 3.14pm	Discovery	› STS-119 Site › Launch and Landing Coverage	74	

2008

Mission	Launch Date and time	Orbiter	Further Information	Day Number	Ozone concentration (Before, Day of, after, change)
STS-126	11.14.08 7.55pm	Endeavour	› STS-126 Site › Launch and Landing Coverage	319	
STS-124	05.31.08 5.02pm	Discovery	› STS-124 Site › Launch and Landing Coverage	124	
STS-123	03.11.08 2.28	Endeavour	› STS-123 Site › Launch and Landing Coverage	71	
STS-122	02.07.08 2.45pm	Atlantis	› STS-122 Site › Launch and Landing Coverage	38	

For further information, check out the "Rocket Launches from Cape Canaveral" at www.spaceflightnow.com Launch Log and see if they have any effect on ozone concentration.

http://www.nasa.gov/centers/kennedy/shuttleoperations/archives/2005.html

Bibliography for Suggested Project 1:

[1] ^ "NASA Takes Delivery of 100th Space Shuttle External Tank". NASA, August 16, 1999. (http://www.msfc.nasa.gov/news/news/releases/1999/99-193.html)retrieved August 4 ,2010

[2] "NASA Space Shuttle Takeoff Flight Path"
 http://www.airliners.net/aviation-forums/military/read.main/49152/
retrieved August 4, 2010

Suggested Project 2: Meteor Showers and Mesospheric Ozone Concentration

The following is a list of dates for meteor showers in 2011. The dates are similar from year to year. The dust from meteors may stay in the upper atmosphere for days. This may affect the concentration of ozone in the mesosphere. Find out about the history and origin of meteor showers and compare the concentration of ozone before and after the showers. Is there any relationship between meteor showers and ozone concentration?

Name	Date of Peak	Moon
Quadrantids	night of January 3	New
Lyrids	night of April 21	Rises after midnight
Eta Aquarids	night of May 5	Sets in early evening
Perseids	night of August 13	Full
Draconids	night of October 8	Nearly full
Orionids	night of October 21	Rises after midnight
Leonids	night of November 17	Rises around midnight
Geminids	night of December 13	Just past full

http://stardate.org/nightsky/meteors/

You may wish to observe these meteor showers outside with plenty of bug spray or it may be possible to listen to them with your FM radio:

> You tune into a high-powered radio station that is out of your listening area. You will be listening to constant static on the receiver. As a meteor falls through the atmosphere, it will amplify the stations radio signal that you are tuned into. You will perceive this amplification as a 'Ping' on your receiver. Viola! There you have it. (Taken from http://phoxes.com/Classroom/tabid/54/EntryID/10/Default.aspx)

For a full calendar for each year go to the International Meteor Association (IMO) at http://www.imo.net/calendar.

Suggested Project 3: Solar Proton Events and Mesospheric Ozone Concentration

The sun is constantly changing. Not only does the surface of the sun change with the sunspot cycle, the sun also periodically expels matter from its surface into the solar system. This solar wind extends throughout the solar system, and the interaction of the solar wind with Earth's magnetic field is responsible for space weather effects on Earth.

When the Sun emits protons as part of the solar wind and those protons encounter Earth's atmosphere, we anticipate a response in the ozone level in the mesosphere. This is because the protons from the solar wind (hydrogen atoms) will interact with the ozone molecules, causing them to breakdown.

Solar Proton events are listed by date at http://umbra.nascom.nasa.gov/SEP/. The site lists the proton events according to the date and time (in Universal Time) when the event left the sun. Of course, the effect on Earth's atmosphere occurs when the protons reach our planet. This is usually 2 or 3 days after the proton event leaves the Sun.   The date and approximate time of the arrival of the proton event can be determined by using the archive feature of www.spaceweather.com, by looking at the site for the days following the proton event listed at the site above. Note that because of the extended solar minimum, there were no proton events in 2008 or 2009.

In order to determine whether there is an effect on the mesospheric ozone from a proton event, the mesospheric concentration should be measured before, during, and after the event.   You may also want to take into account the strength of the proton event, listed as proton flux in the data table linked to above.

Suggested Project 4: Sudden Stratospheric Warming and Mesospheric Ozone Concentration

Sometime in late January in most years there is a sudden warming (more than 25 K increase occurring over less than a week) at one or more levels of the stratosphere above the poles. This warming is measured by radar. As the stratosphere warms, there is a sudden mesospheric [1] cooling which should produce an increase in ozone concentration in the mesosphere.
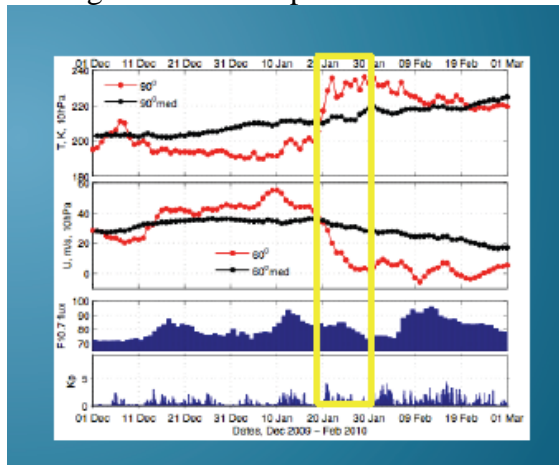
Data on stratospheric temperatures can be downloaded from
http://acdb-ext.gsfc.nasa.gov/Data_services/met/ann_data.html.

On this site, look for the following:

From the above boxes, one can investigate SSW by choosing a variable (temperatures at 90 N, perhaps), a pressure level (10 hPa, perhaps), and a year (2010-2011, perhaps) and produce a graph, looking for a characteristic sharp increase in temperature in the winter months.

When submitted, a graph like the following will be produced.

28
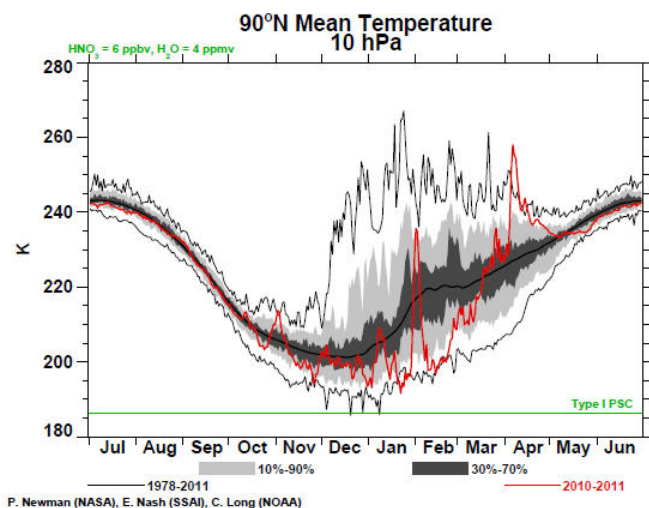
In this graph, the sudden increase in temperature (the red line) at the start of February is good indication that a SSW event may have occurred.

An animation of a SSW event in 2008 is available at http://www.youtube.com/watch?v=mIXfYTSmBg0.

Look at the level of ozone in the mesosphere before, during, and after these (and any other) SSW events. Are there any connections? Again, you may need to do some statistical analysis to prove your hypothesis.

Sudden Stratospheric Warming (SSW) events are included and labeled on the month-by-month graphs included as an appendix to this document.

[1] Goncharenko, L., and S.-R. Zhang (2008), Ionospheric signatures of sudden stratospheric warming: Ion temperature at middle latitude, *Geophys. Res. Lett.*, 35, L21103,

Suggested Project 5: Mesospheric Temperature and Ozone Concentration

Students can obtain the data for mesospheric temperature from SABER (Sounding of the Atmosphere from Broadband Emission Radiometry). SABER is one of 4 instruments on NASA's TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics) mission, and SABER makes measurements of the mesosphere and lower thermosphere, from 60 km to 180 km above Earth's surface.

To find the kinetic temperature of the mesosphere (ktemp), do the following:
1. Go to following website: - http://saber.gats-inc.com/
2. Click on **Data Services**
3. Click on **Browse Data**
4. Click on **Level 2A**
5. Click on, and select a **Year** of interest
6. Click on, and select a **Month** of interest
7. Click on, and select a **Day** of interest
8. Click on **Quicklook** for the file, you should see something like this:

9. You will now see a list of available data sets, corresponding to different orbits of the satellite. You should look for the file closest to the MOSAIC measuring area—about 40˚ latitude (will be listed as +40) and 70˚ W longitude, which, since positive longitude is measured to the east and the SABER system uses a 0˚–360˚ system, corresponds to about +290˚ longitude. Click on Plot, and you should come up with this:
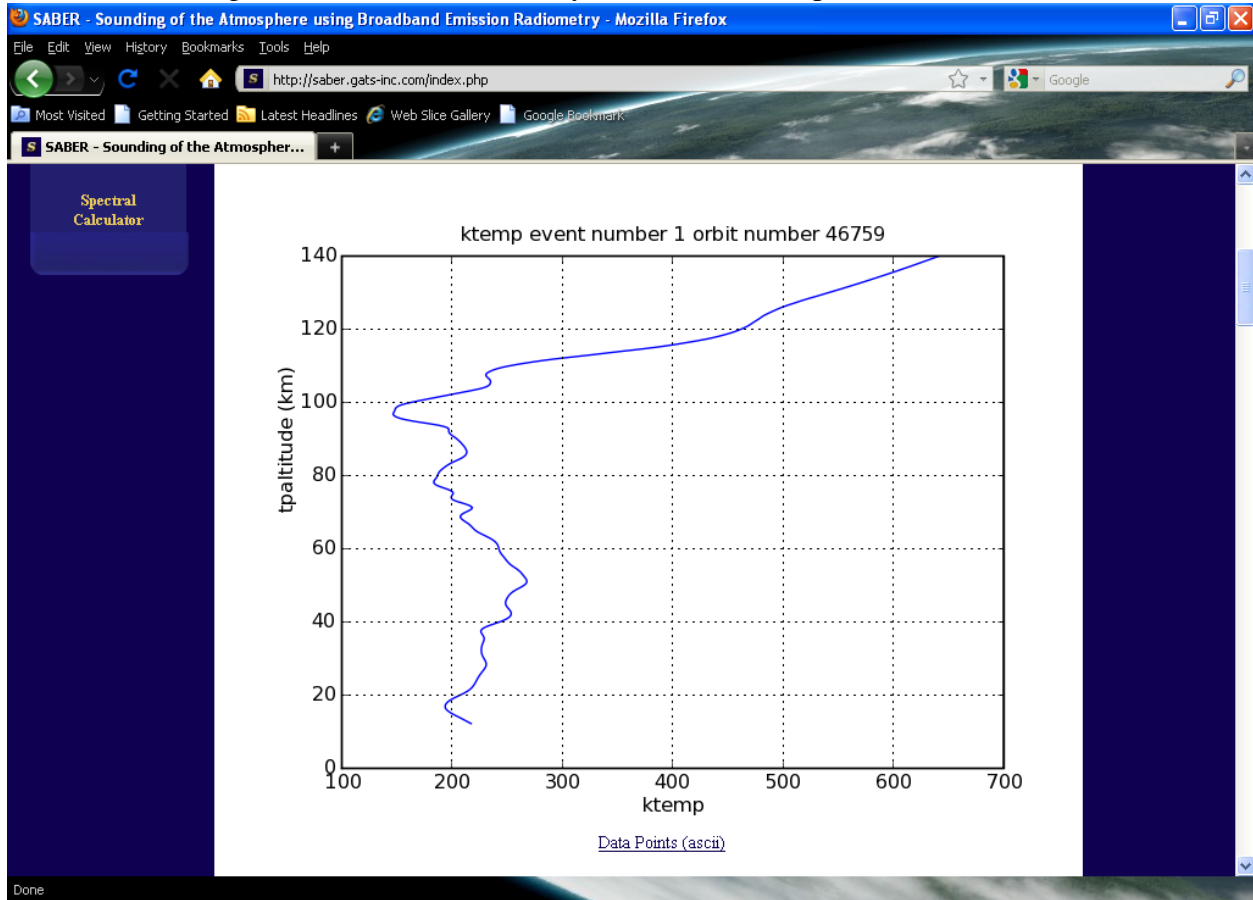
This indicates that the temperature at 100 km is about 160 K. For more detail click on 'Data Points (ascii) to get:

Filename: SABER_L2A_2010208_46759_01.07.nc

ktemp event number 1 orbit number 46759

===
=======================
ktemp	tpaltitude (km)	Pressure
===
=======================
640.856567383	139.910385132	9.37241657084e-06
637.551635742	139.55519104	9.50793310039e-06
634.245300293	139.19984436	9.64643277257e-06
630.938415527	138.844436646	9.78796742857e-06
627.624145508	138.488235474	9.93293269858e-06
624.320922852	138.133224487	1.00806073533e-05

Scroll down to tpaltitude 100.0 km to find the temperature at this altitude.

From this output, one can find the temperature for the particular altitude, and the particular latitude and longitude for the area of mesospheric ozone interest (40° N, 70° W/+40˚, +290˚) for particular days.

In addition to temperature, SABER also provides access to ozone data, available as O3_96 and O3_127. These data can be accessed as graphs using the same process as above, with the selection of O3_96 or O3_127 instead of ktemp. The graphs can be used to identify the altitude at which ozone is most concentrated, which might allow for a more specific selection of altitude when temperature data are collected.

Another interesting way to look at the data is to look at the "Survey Plot" under Data Services which gives you daily maps for ktemp and O3_96 (ozone) that the students can compare. This may be an easier way to extract approximate temperatures for our latitude and longitude of interest.

Another possible resource for online data is MADRIGAL, which has upper atmospheric data as well as access to the solar and geomagnetic indices at http://madrigal.haystack.mit.edu/madrigal/.