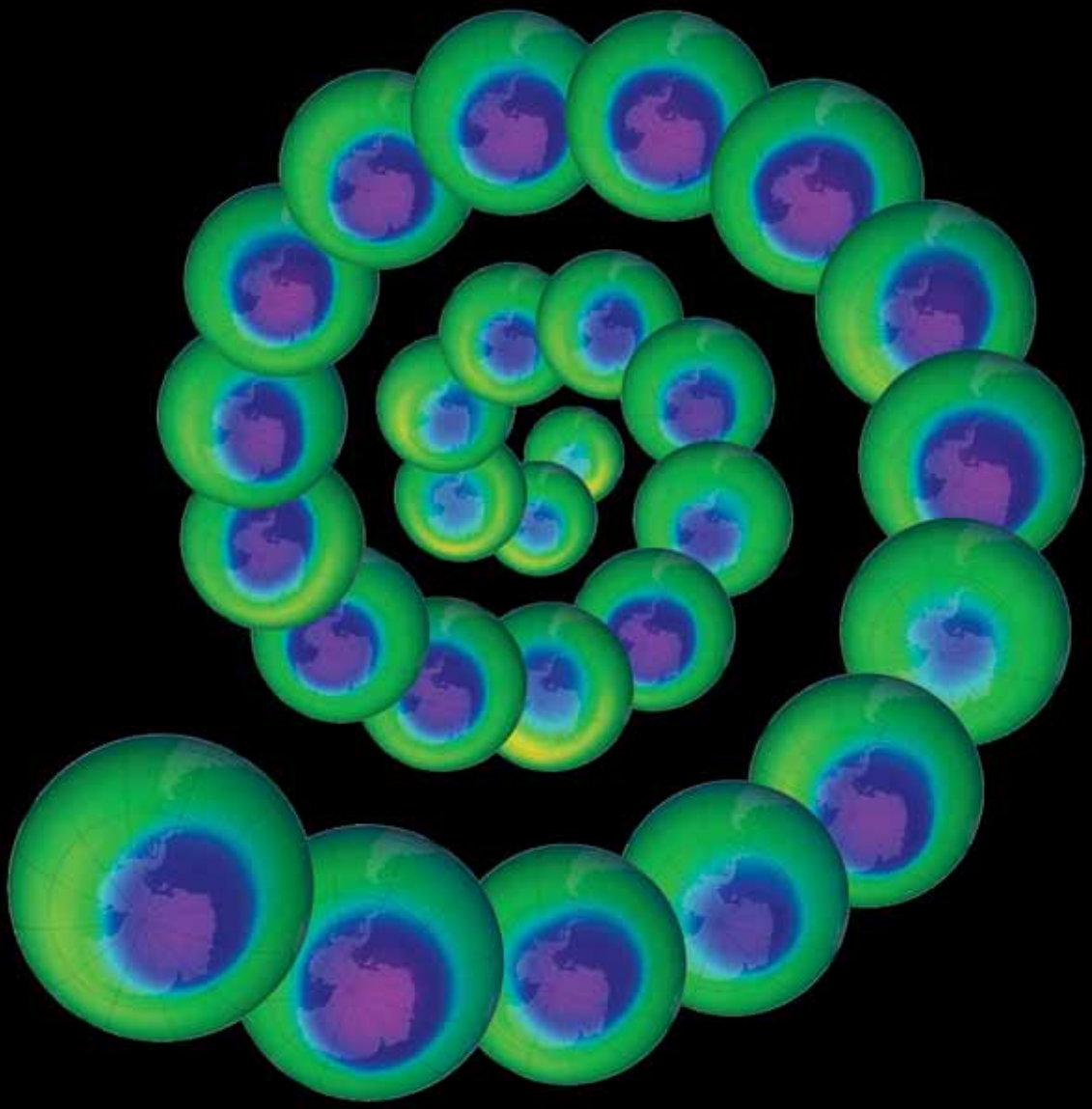


The spiral composite needs a brief description and see diagaram on inside back cover.

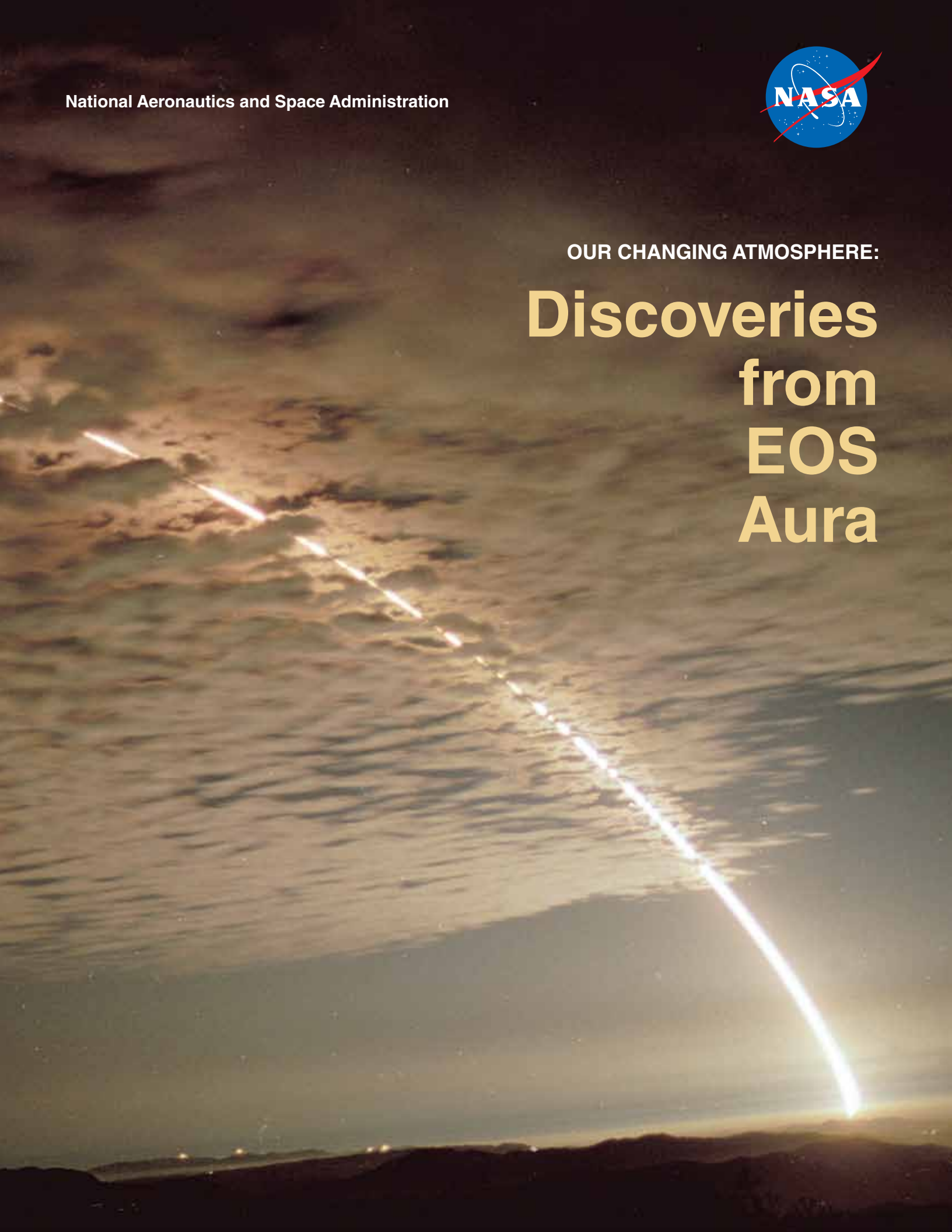
National Aeronautics and Space Administration

Earth Observing System Aura
Goddard Space Flight Center
Greenbelt, MD 20771

www.nasa.gov

publication number

National Aeronautics and Space Administration



OUR CHANGING ATMOSPHERE:

Discoveries from EOS Aura

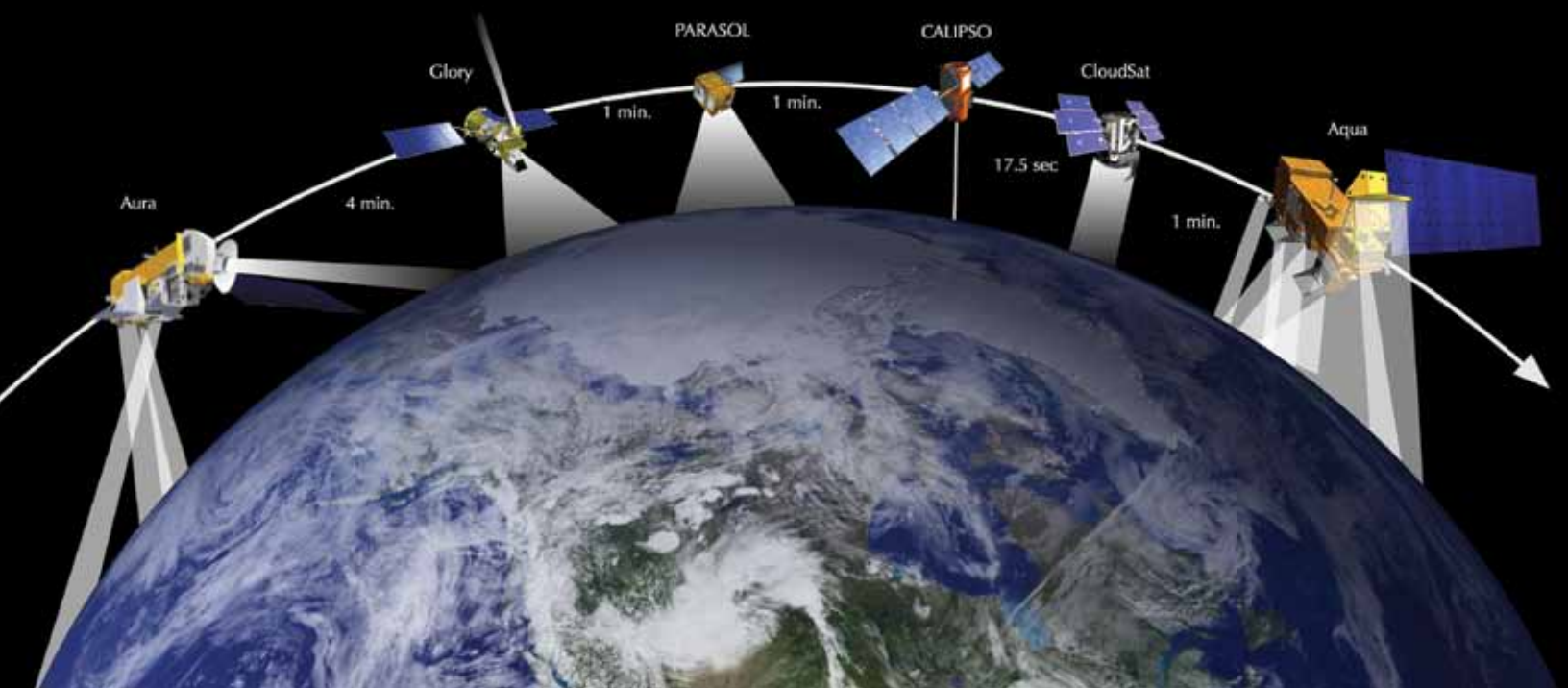
Why Aura

The atmosphere is changing!

As industrial activity and biomass burning have increased around the world, particulates (also known as aerosols), trace gas and other pollutants have affected air quality, caused a deterioration in the Earth's protective ozone layer, and contributed to global climate change. Aura was designed to measure gases and aerosols in the atmosphere—from the ground up to the ozone layer.

The A-Train

(NOT TO SCALE)



Contents

text TBD

Cover Image: More of a description of how it was taken? Or other information. will fill three lines with text will fill three lines. courtesy of Brian Lockett.

This is a two-frame composite shot on Kodacolor 200.

Aura was launched on a Delta-II on July 15, 2004 into an ascending-node 705 km sun-synchronous polar orbit with a 98° inclination and an equator-crossing time of 13:45±15 min. Aura was designed to answer three broad questions:

- Is the ozone layer changing as expected?
- What are the processes that control tropospheric pollutants?
- What are the roles of upper tropospheric aerosols, water vapor and ozone in climate change?

Aura carries four instruments

(NOT TO SCALE)

Ozone and Life

Ozone Facts

Most ozone is found between the tropopause (~10 km) and the stratopause (~50 km)

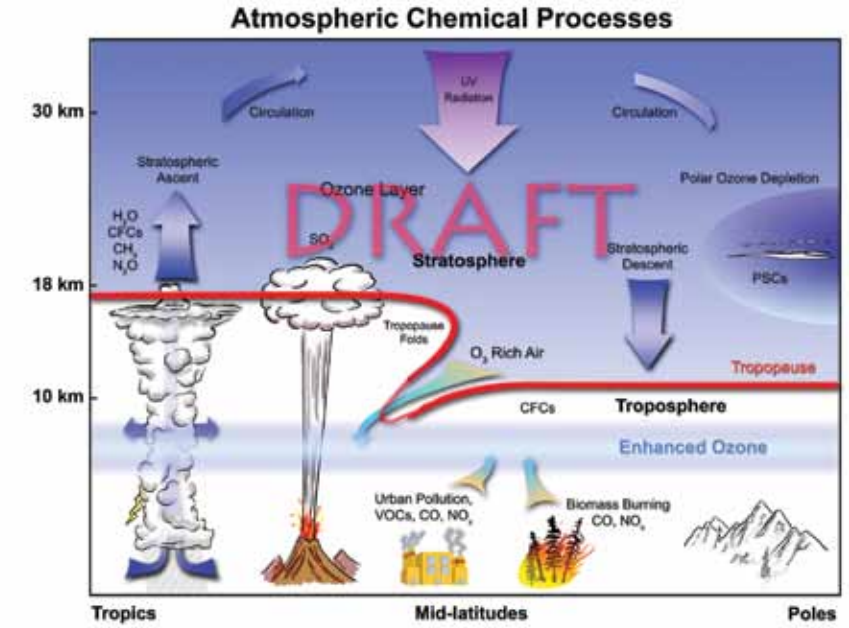
Stratospheric ozone absorbs almost all the harmful UV radiation from the sun, protecting the Earth's surface.

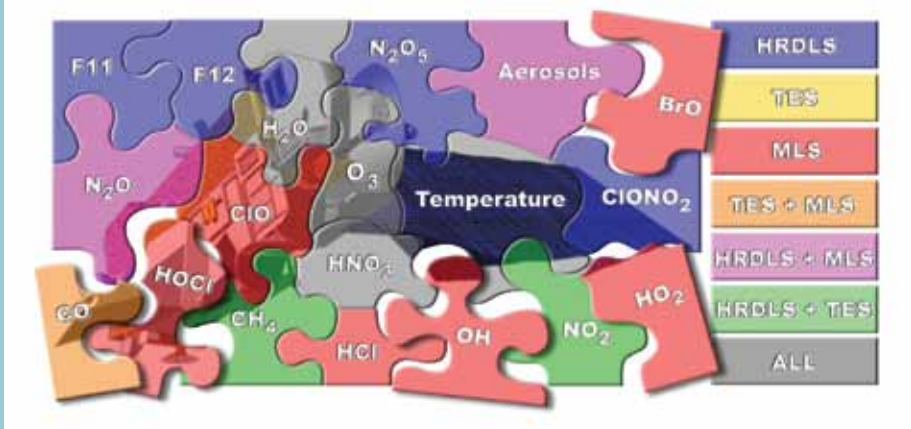
Stratospheric ozone is created when ultraviolet light splits oxygen molecules and is destroyed by chemical reactions with chlorine, nitrogen and hydrogen radicals.

Ozone is produced in the troposphere when pollutants react in the sunlight.

Ozone absorbs ultraviolet radiation in the stratosphere, and prevents harmful amounts of radiation from reaching the surface. Some ozone is found naturally in the troposphere, having been transported from the stratosphere, but some is formed from chemical reactions of pollutants in the presence of sunlight. The cartoon below illustrates some of the processes that control ozone.

The Sources of Tropospheric Ozone





Completing the Picture of Stratospheric Chemistry

Understanding the ozone layer involves measurements of ozone and the compounds that control production and loss of ozone. The instruments on Aura provide pieces of the puzzle.

RE-WRITE OF PAGES 2-3

EXPLAINING BAD AND GOOD OZONE, WHERE THEY ARE

The Ozone Layer

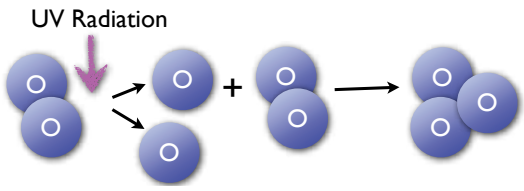
Oxygen molecules (O_2) make up 2x% of the Earth's atmosphere. Ozone (O_3) is a molecule made up of three atoms of oxygen (O). Most ozone resides in the stratosphere (a layer of the atmosphere between 10 and 40 km above us). The stratospheric ozone layer shields us from harmful solar ultraviolet radiation making life on earth possible. If the ozone layer thins, we would be more susceptible to skin cancer and cataracts, and our immune systems would be impaired. The amount of stratospheric ozone depends on a balance between processes that create ozone and those that destroy it. An upset in the ozone balance can have serious consequences for life on Earth.

Stratospheric ozone is created when high-energy ultraviolet rays strike ordinary oxygen molecules (O_2), breaking the molecule into two oxygen atoms, known as atomic oxygen. Each freed oxygen atom is likely to combine with an oxygen molecule to form a molecule of ozone (see diagram).

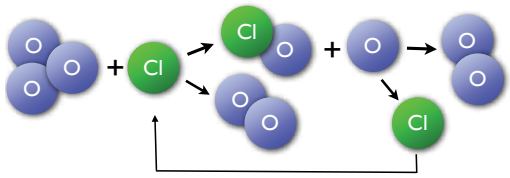
Ozone is destroyed when an oxygen atom reacts with an ozone molecule, creating two oxygen molecules. Ozone can also be destroyed by compounds from the nitrogen, hydrogen, chlorine or bromine families. These compounds are far less abundant in the atmosphere than oxygen molecules, but for each family the sequence of reactions is catalytic, that is ozone is destroyed but the ozone-destroying molecules are unchanged.

Even though there are 1000 times fewer ozone-destroying molecules than there are ozone molecules, the reactions take place so rapidly that each ozone-destroying molecule can remove (number) ozone molecules.

Ozone Formation

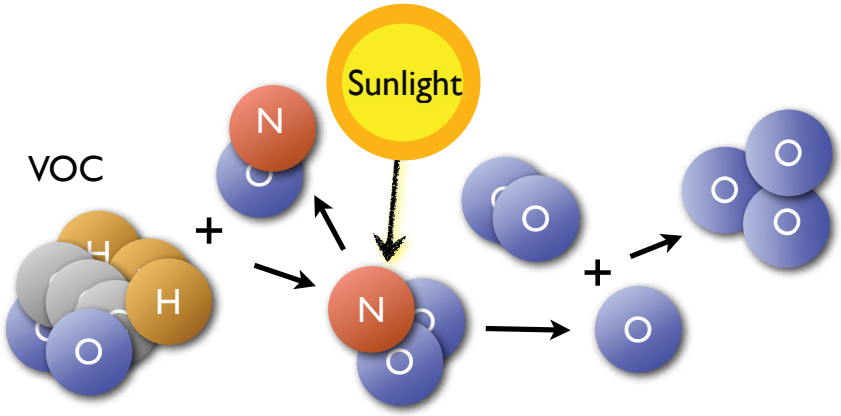


Ozone Destruction

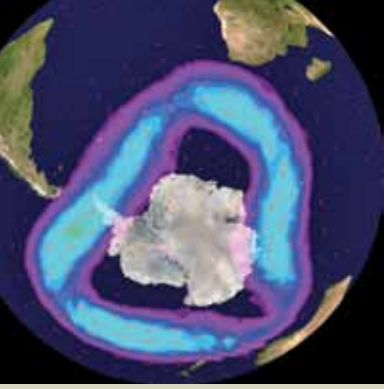


The diagram shows how destruction of ozone by chlorine species is a two-step process.

In the first step, a chlorine atom (Cl) reacts with ozone, forming an oxygen molecule and chlorine monoxide (ClO). In the second step, ClO reacts with atomic oxygen, forming another oxygen molecule and Cl. The chlorine atom will now react with another ozone molecule, beginning the sequence again.



Human production of chlorine-containing chemicals such as chlorofluorocarbons (CFCs) has made the sequence of chlorine reactions that destroy ozone important. CFCs are compounds made up of chlorine, fluorine and carbon bound together. Because they are extremely stable molecules, CFCs do not react with other chemicals in the lower atmosphere. One of the few forces that can break CFC molecules apart is ultraviolet



The Chemistry of the Ozone Hole Revealed by Aura MLS

The Polar Vortex

The polar vortex is a strong stratospheric wind jet that surrounds the polar region during winter. Above, the colored region shows where the winds are strongest as they follow the red arrows around the polar region. This band of winds acts to contain the unusual chemistry of the ozone hole. The polar vortex forms in the fall and reaches maximum intensity during the winter. It breaks up in the spring. The vortex is much stronger in the Southern Hemisphere than in the Northern Hemisphere because the stratosphere temperatures get far colder in the south polar stratosphere than in the north.

During Austral spring (Sept-Oct-Nov), ozone in the Antarctic lower stratosphere is destroyed by chemical reactions involving chlorine. The ozone column falls to very low levels, a phenomenon called the ozone hole. During the late 1980's and 1990's scientists pieced together the processes that cause ozone destruction using data obtained with instruments on the ground, high-flying aircraft and satellites. The daily maps of Aura ozone (O_3), hydrochloric acid (HCl), nitric acid (HNO_3) and chlorine monoxide (ClO) from Aura MLS reveal the events that create the ozone hole in full detail.

At the start of winter, the polar stratosphere cools and the vortex forms. Strong winds prevent mixing across the vortex boundary. The vortex is dark.

By midwinter, MLS measures very little gas phase HNO_3 or HCl in the vortex. Temperatures are so cold that HNO_3 has condensed, creating polar stratospheric clouds (PSCs). In the darkness, reactions on the surfaces of the PSCs have depleted HCl, producing chlorine compounds that are broken apart by the smallest amount of sunlight.

In spring, the sun returns. Chlorine atoms (Cl) immediately react with O_3, forming chlorine monoxide (ClO). A catalytic cycle of ozone destruction begins (see sidebar). ClO reacts with itself, forming a dimer Cl_2O_2 that is broken apart by sunlight, releasing Cl. Cl destroys ozone while reforming ClO; the cycle continues until all O_3 is destroyed. Without O_3, Cl builds up until HCl is produced efficiently by the reaction of Cl with CH_4 (methane). By October all of the O_3 in the vortex has been destroyed, nearly all of the chlorine in the polar vortex has been converted to HCl, and the ClO has returned to normal levels. O_3 remains depleted until solar heating changes the

Fall

The cooling of the stratosphere causes the polar vortex to form trapping gases HCl, HNO_3, and Ozone.

Winter

Temperatures approach 185K (-126F) and wispy clouds of nitric acid trihydrate and ices form. Nitric acid moves from gas phase to solid and disappears from the satellite sensors.

On the surfaces of the ice crystals, chlorine nitrate and hydrogen chloride react to form chlorine gas. HCl disappears from the satellite sensors.

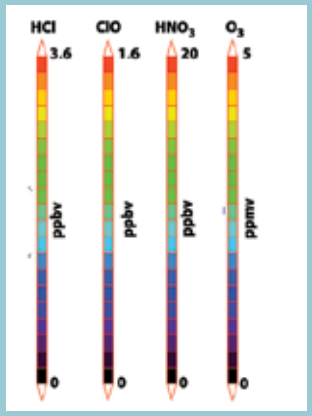
At the edges of the polar vortex where there is some sunlight, chlorine gas begins to react with ozone to form chlorine monoxide

Spring

As the sun rises on the pole, more and more chlorine monoxide is produced and ozone is rapidly depleted causing the ozone hole.

Late spring

All the ozone is gone, chlorine begins to react with methane reforming HCl creating an abundance of this gas where the ozone hole exists.



HNO_3
HCl
O_3
HNO_3
HCl
O_3
ClO
HCl
O_3
ClO
HCl
O_3
FALL
WINTER
SPRING
LATE SPRING

The Rise and Fall of Stratospheric Chlorine

Chlorine Facts

About 85% of chlorine in the stratosphere comes from man-made compounds, primarily chlorofluorocarbons or CFCs. CFCs were widely used for air conditioning, refrigeration, aerosol propellant, and foam blowing before they were banned by international treaties in the 1980's. Chlorine from CFCs cause the ozone hole to appear each spring in the Southern Hemisphere

CFCs have a very long atmospheric lifetime, and are now slowly decreasing in abundance. At the present rate of decrease, the ozone hole is predicted to disappear sometime after 2050.

CFCs are also greenhouses gases, and the agreement to stop CFC production to protect the ozone layer also helps to protect the Earth's climate.

Chlorofluorocarbons (CFCs) are man-made compounds that were used for many industrial purposes, including refrigerators and air conditioners. CFCs are harmless and nonreactive in the lower atmosphere. Their chemical bonds, however, can be broken by ultraviolet light. In the lower atmosphere CFCs are protected from ultraviolet radiation by the ozone layer, but as they are mixed throughout the atmosphere they eventually enter the stratosphere in the tropic. Once in the stratosphere, CFCs ascend above the ozone layer where their chemical bonds are broken by ultra-violet radiation, releasing chlorine radicals. Chlorine radicals then react with ozone in a catalytic cycle that can rapidly reduce the ozone concentration. Chlorine atoms can also react with methane (CH4) forming hydrochloric acid (HCl).

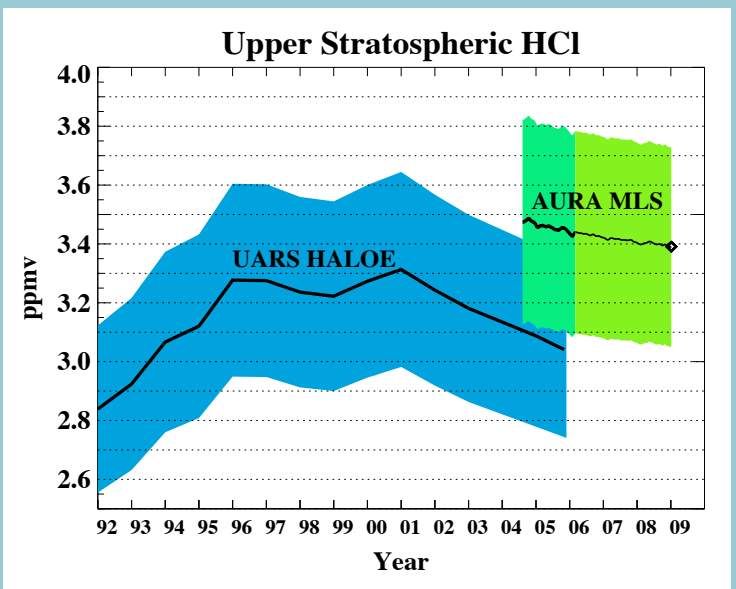
More than 95% of the chlorine in the upper atmosphere is HCl.

Because of the threat to the ozone layer, in 1987 the governments of the world agreed to the Montreal Protocol, restricting CFC production. The 1990 London amendments and the 1992 Copenhagen amendments set a schedule to eliminate production of CFCs. CFC amounts at the surface are no longer increasing.

The Halogen Occultation Experiment (HALOE) on the Upper Atmosphere Research Satellite measured HCl from late in 1991 until the end of 2005. During that time the HCl reached a peak value and began a slow decline. Aura MLS began measuring HCl in August 2004, and the slow decline continues.

Decline of Stratospheric Chlorine

Measurements from UARS HALOE show the increase in chlorine during the 1990s and the slow decrease thereafter. The Aura MLS measurements continue the time series. The shaded bands show the measurement accuracy for each instrument. Although the mean values are offset during the overlap period from Aura launch in July 2004 until HALOE ceased taking data in November 2005, they fall within each other's accuracy band.

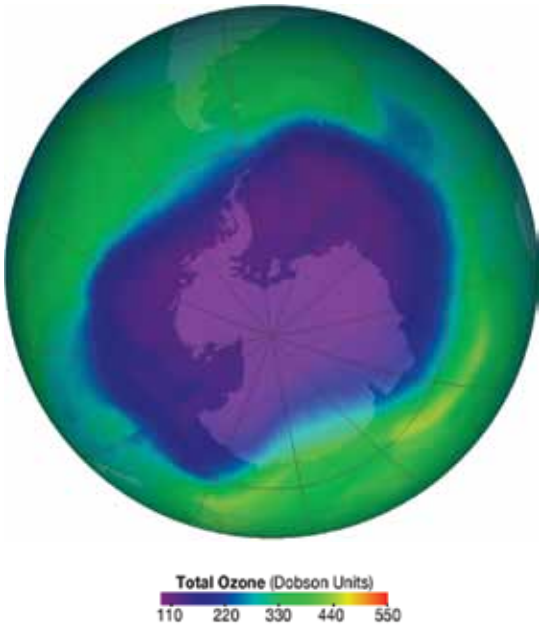


The Ozone Hole

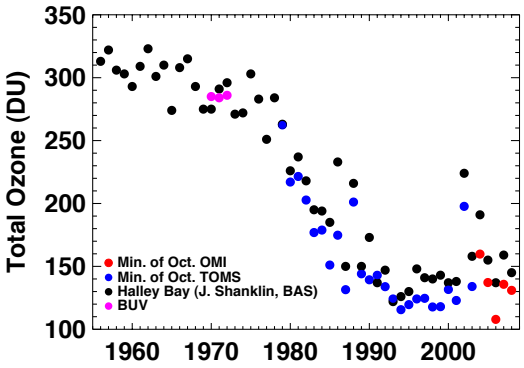
The ozone hole is a region of exceptionally depleted ozone in the stratosphere over the Antarctic. The ozone hole forms at the beginning of Southern Hemisphere spring (August-October). Aura's OMI instrument can provide us with daily images of ozone over the Antarctic region and this instrument continues the record begun by the total ozone mapping spectrometers (TOMS) series launched begun in 1979. The ozone hole image shown here is the largest ozone hole ever formed. It occurred on Sept 21, 2006 when the area covered by ozone column amounts less than 220 Dobson Units reached 11.4 million square kilometers. From the historical record, we know that total column ozone values of less than 220 Dobson Units were not observed prior to 1979.

The graph shows the October monthly mean minimum ozone amount over Antarctica from a variety of data sources including satellites and ground based measurements at Halley Bay in Antarctica. The onset of the ozone hole in the late 1970's is now believed due to the rapid increase in stratospheric chlorine as the industrial use of chlorofluorocarbons grew in the 1960's and 1970's. With the ban on chlorofluorocarbons in the late 1980's and the tightening of regulations in the 1990's stratospheric chlorine amounts peaked and are now in a slow decline.

Largest Ozone Hole



On Sept 24, 2006 the ozone hole reached a historical maximum and has not exceeded that size since. The area was 11.4 million square kilometers, larger than the area of North America. The figure on the right shows the historical change in Antarctic October ozone minimum values seen from ground based Halley Bay station as well as from satellites.



Minimum October ozone column amounts recorded over Antarctica since 1955 show the development of the ozone hole.Ground based (Halley Bay) October average measurements are shown in black. Satellite measurements began in the mid-1970's from different instruments shown in colors. Shown is the minimum October monthly mean over Antarctica.

The MLS instrument made the first spaceborne measurement of the OH radical using an ultra-high frequency radiometer developed specially for this purpose. The receiver is shown at the lower right below the main dish and operates at 2.5 ThZ.

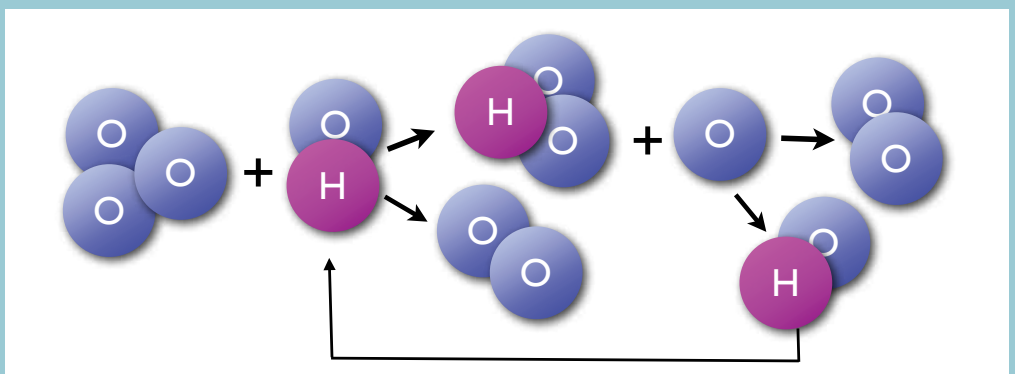
The Chemistry of the Upper Atmosphere

In the upper stratosphere there is a natural balance between production of ozone (O_3) and atomic oxygen (O) by photolysis of oxygen molecules (O_2) and loss of O_3 and O through the through of O + O_3 -> 2 O_2 or through catalytic cycles involving radical compounds like the hydroxyl radical (OH) and the (name) radical (HO_2). The OH and HO_2 radicals are produced when excited atomic oxygen (O_1D) reacts with water (H_2O).

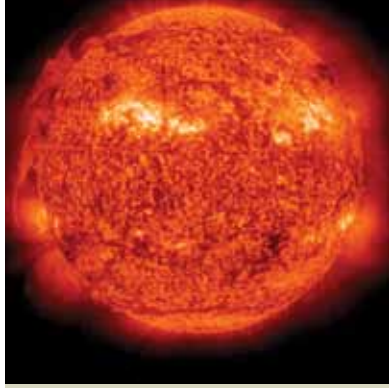
Aura MLS has made the first global measurements of both OH and HO_2. Before Aura was launched, there were very few measurements of OH, some from balloon borne instruments and some from an instrument on the space shuttle. The earlier measurements of OH did not agree with values calculated from measurements of H_2O and O_3 using photochemical reactions measured in the laboratory. The Aura measurements of OH and HO_2 agree with new balloon measurements using a far-infrared Fourier Transform Spectrometer (FIRS-2) and with calculated values. Since profiles measured by MLS cover the globe and have been made for several years, scientists can test their consistency with other measurements and the laboratory photochemical reactions at different altitudes, latitudes, time of day and seasons. Some fast photochemical reactions convert OH to HO_2 and back again, and comparing the ratio of HO_2/OH to its calculated value tests this very fast photochemistry. The calculated values and the ratio vary the same way as observed by MLS, showing that scientists understand and can model this important part of ozone chemistry.

Catalytic Ozone Destruction

Hydroxyl and hydroperoxy radicals (OH and HO_2) take part in catalytic ozone destruction. An ozone molecule (O_3) reacts with OH, forming an oxygen molecule (O_2) and HO_2. The HO_2 then reacts with atomic oxygen (O), forming another O_2 and re-forming OH. The OH may start the cycle over again by destroying another O_3 molecule.



Solar Flares create OH in the Mesosphere



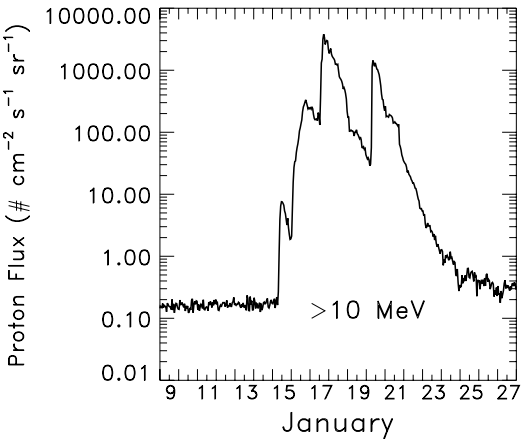
ESA/NASA

The January 20, 2005 flare—the most intense in 50 years—is visible along the center right edge of the Sun in this image captures by SOHO's Extreme ultraviolet Imagine Telescope.

Image of the Sun can be found at:

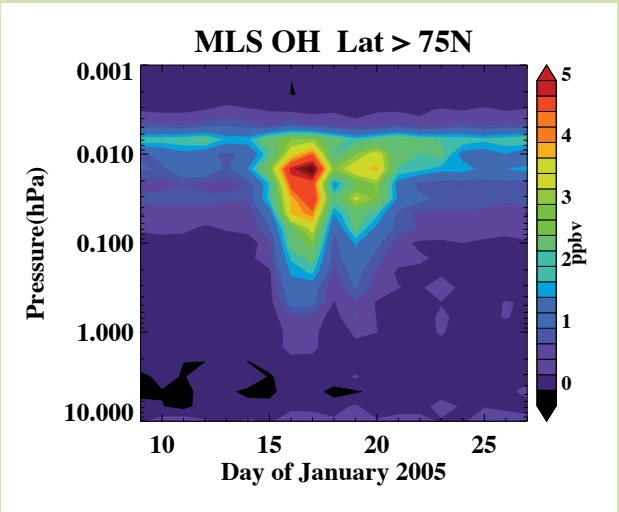
http://nasascience.nasa.gov/images/about-us/accomplishments/YIR2005_Solar-Flare.jpg

In 1973 scientists proposed that OH and HO_2 would be produced by solar protons that reach the Earth's atmosphere following intense solar flares. Their hypothesis was shown to be true in January 2005. Protons from a succession of solar flares in middle January reached the Earth's atmosphere and were guided into the polar mesosphere by the Earth's magnetic field. MLS detected an increase in OH and a decrease in O_3 in the Arctic polar night. The solar flare is a natural experiment—the observed ozone loss due to the increase in OH and HO_2 can be compared with simulations. Scientists confirmed their hypothesis and at the same time learned that their ideas make sense quantitatively.

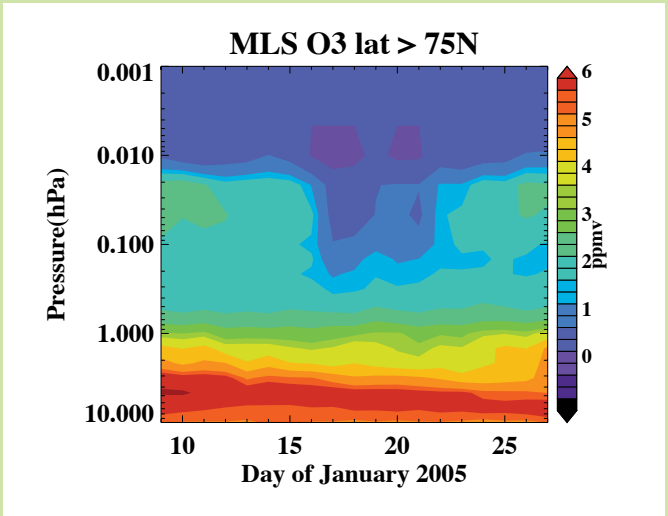


GOES -11 measurements show that the flux of protons with energy greater than 10 MeV increased dramatically in mid January 2005. A 10 MeV proton deposits its energy between about 0.001 and 0.1 hPa, thus a large portion of the proton energy flux above 10 MeV will be deposited in the mesosphere where MLS observes most of the increase in OH.

O_3 Decreases



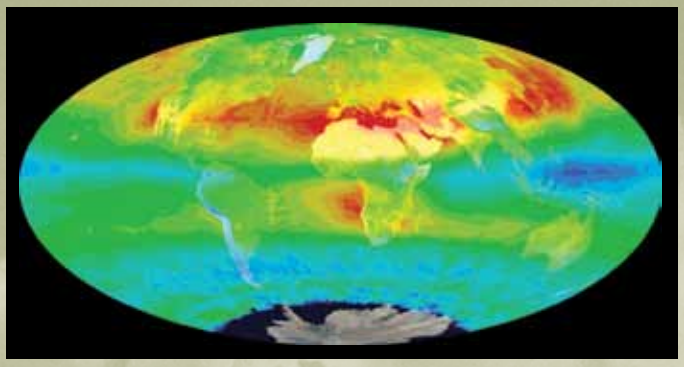
MLS measurements show that O_3 decreases at the same time in mid January, even though the high latitudes are in polar night darkness.



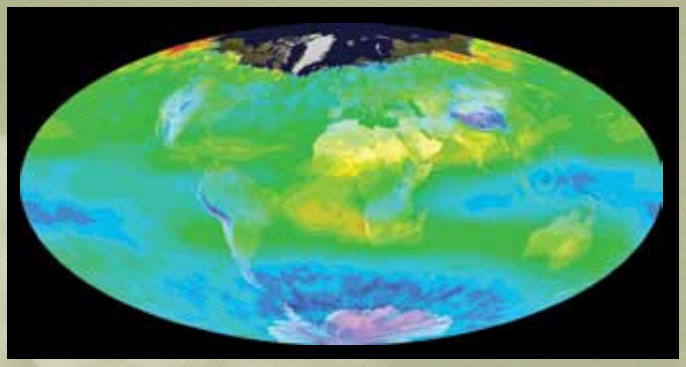
Computations show that the O_3 decrease seen by MLS is caused by chemical reactions with OH and HO_2 radicals in the dark polar night.

thought we were skipping the color bar?

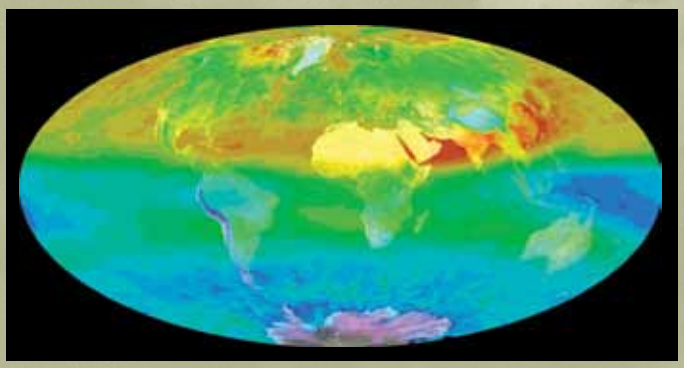
caption news revision



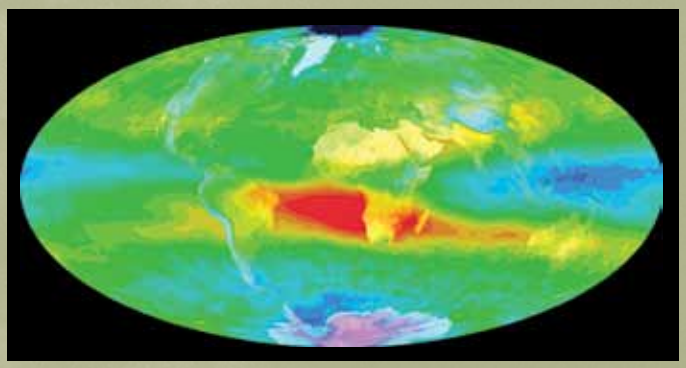
Ozone Residual for June-August 2008



Ozone Residual for Dec - Feb. 2007-8



Ozone Residual for March-Mary 2008



Ozone Residual for Sept.- Nov. 2008

This is another smog pollution photo of Toronto

The tropospheric ozone column for June – August 2007 obtained by subtracting the MLS stratospheric ozone column from the OMI total ozone column. Areas of high ozone (red and yellow) cover the northern hemisphere. In the southern hemisphere high values of tropospheric ozone are due to biomass burning. The color ranges from 0 to 50 Dobson units (black to red).

Air Quality

According to the World Health Organization, 2.4 million deaths each year are directly attributable to air pollution. Air pollution includes toxic gases and fine particles or aerosols. Aura provides information about all of the prevalent criteria pollutants identified by the US Environmental Protection Agency (NO_2, SO_2, O_3, CO, and aerosols) as well as important precursors such as volatile organic compounds (VOCs).

Nitrogen Oxides NO_2 and NO are oxides of nitrogen, or NOx, that form in high temperature combustion and lightning. High concentrations of NO_2 produce a brown haze that often envelopes cities. Nitrogen oxides are critical in the formation of ozone pollution, and they also lead to nitrate aerosols.

Volatile Organic Compounds (VOCs) VOCs are hydrocarbons that evaporate quickly. They include fumes from turpentine, gasoline, and other solvents. They are also produced naturally by some types of vegetation, especially when they are under stress from hot weather. VOCs are toxic in high concentration but are more important in contributing to ozone formation.

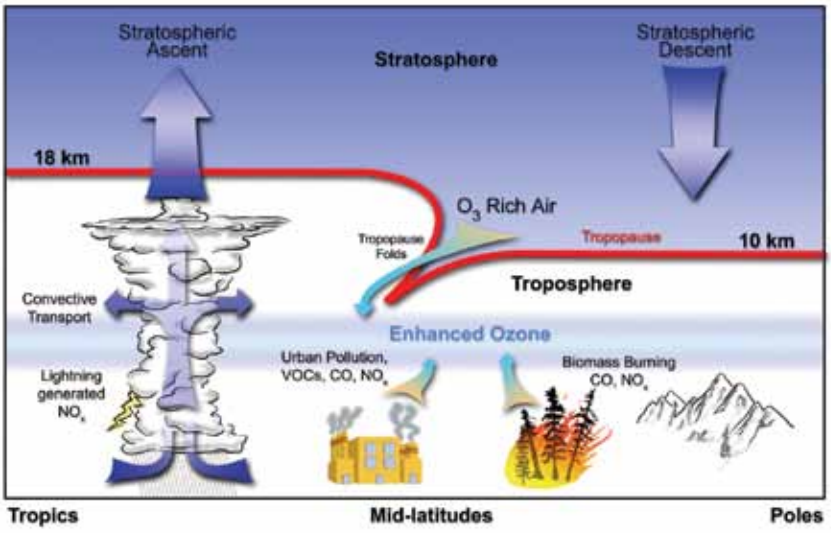
Ozone (O_3) O_3 is one of the most toxic pollutants, causing decreased lung function, and damage to vegetation and materials such as rubber. O_3 near the Earth's surface forms primarily from reactions in sunlight involving VOCs or CO and NO_2, both abundant in urban areas.

Natural and human-related processes contribute to ozone in the troposphere. Urban and industrial pollutants, biomass burning and lightning all produce molecules from which ozone is formed. Some high ozone air is mixed into the troposphere from the stratosphere.

Carbon Monoxide CO forms during incomplete combustion. It is odorless but toxic in high concentrations. CO is produced by automobiles and trucks and in agricultural burning. It has an atmospheric lifetime of approximately a month, and thus can serve as a good tracer for atmospheric mixing and transport.

Sulfur Dioxide SO_2 emissions lead to acid rain and sulfate aerosols. SO_2 sources are both natural (volcanoes) and man-made (smelters and power plants). Man-made sources are greater than volcanic by a factor of five.

Aerosols Natural aerosols include sea salt, dust, and smoke from forest fires. Man-made sources include industrial smoke and agricultural burning. Another important source of aerosols is from conversion of the pollutant gases NO_2, SO_2, and VOCs. In addition to their impact on human health, aerosols also affect climate by reflecting and absorbing sunlight.



Pollution Facts

Unhealthy air leads to many deaths worldwide each year.

High concentrations of ozone and fine aerosols are the leading causes of air pollution-related illness and death.

Ozone near the surface forms from chemical reactions involving nitrogen oxides and organic gases in sunlight.

Fine aerosols come from natural and man-made sources.

Sulfur dioxide leads to acid rain.

© MARK SCHOEBERL

Nitrogen Dioxide (NO_2)

NO_2 Facts

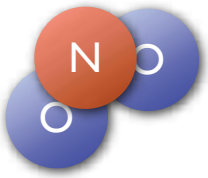
Most NO_x is emitted as NO during combustion.

NO is very quickly converted to NO_2 by reactions with O_3 or other oxidizers in the atmosphere.

NO_2 absorbs incoming sunlight, primarily at blue and ultraviolet wavelengths.

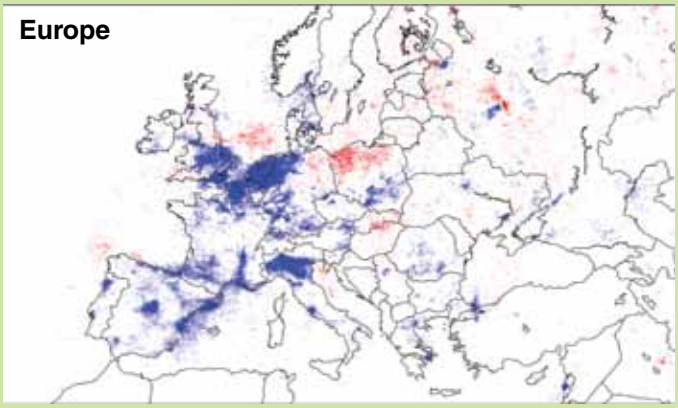
NO_2 is formed from both natural and anthropogenic processes. Power plants, internal combustion engines, fertilizer application, and agricultural burning are examples of anthropogenic sources of NOx. Lightning, wildfires, and soil emissions not related to farming are natural sources of NOx. NO2 has a relatively short lifetime (of the order of a day) and is therefore concentrated near its sources.

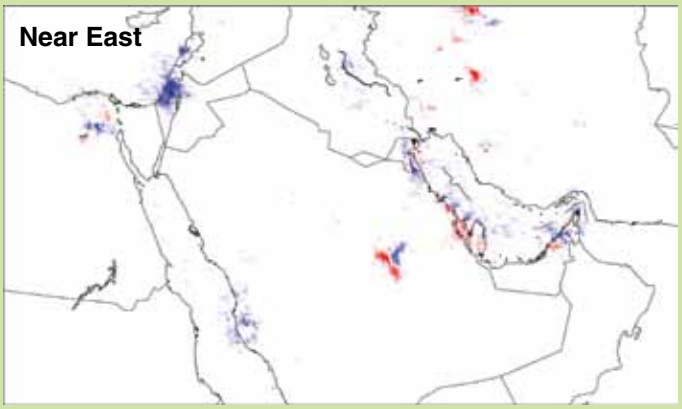
The dramatic maps of NO_2 produced by the OMI team give us a clear picture of industrial and agricultural activity across the globe. The inset shows a map of the US with a zoom on power plants in the western US.

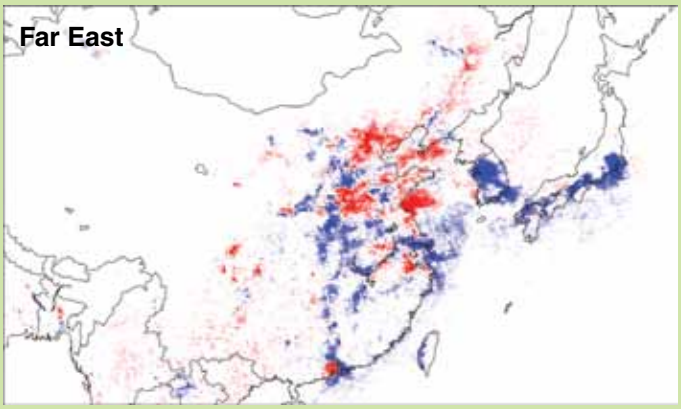


p. 13: I think we need to have some big words right on the figures or just above saying what exactly they are. For example, the top two and middle right should say “Weekday average - Sunday” or whatever it is, I’m not sure (Christian?). The middle left should say “Weekday average - Saturday”. The bottom left should say “~10:00 AM local time (SCIAMACHY)”; lower right “~1:30 PM local time (OMI)”

NO_2 - the Fingerprint of Civilization

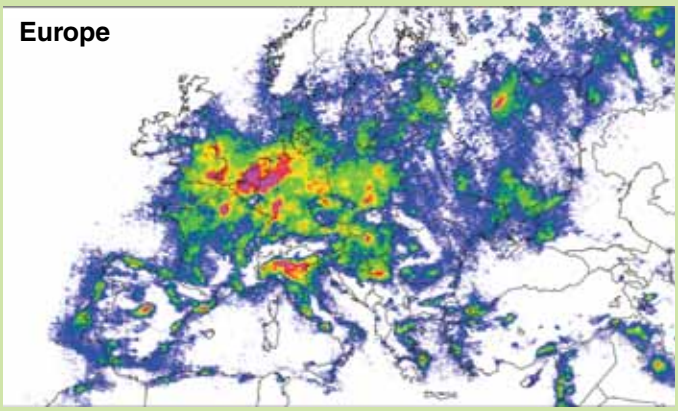


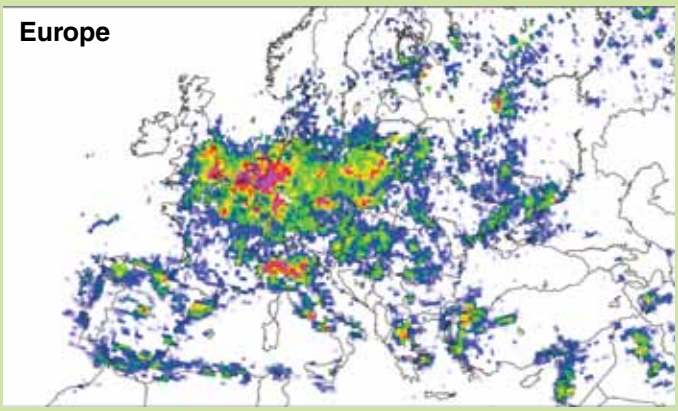




One interesting observation is that NO_2 varies during the week. The plots below show a big decrease in NO_2 on Sunday in Europe, the Americas and East Asia, while the same decrease is seen in Israel on Saturday compared to mid-week NO_2 values.

NO_2 varies during the day to changing emissions from traffic and sunlight-driven chemistry. The left image is from SCIAMACHY which passes over Europe at 10 am, the right images is from OMI that passes over Europe at 1:30 pm. NO_2 tropospheric column density [1016 molec. / cm_2]





Formaldehyde (HCHO) and Volatile Organic Compounds

Isoprene

Isoprene is the common name for the chemical compound 2-methyl-1,3-butadiene.

Isoprene is the predominant hydrocarbon emitted from trees, such as oak and poplar.

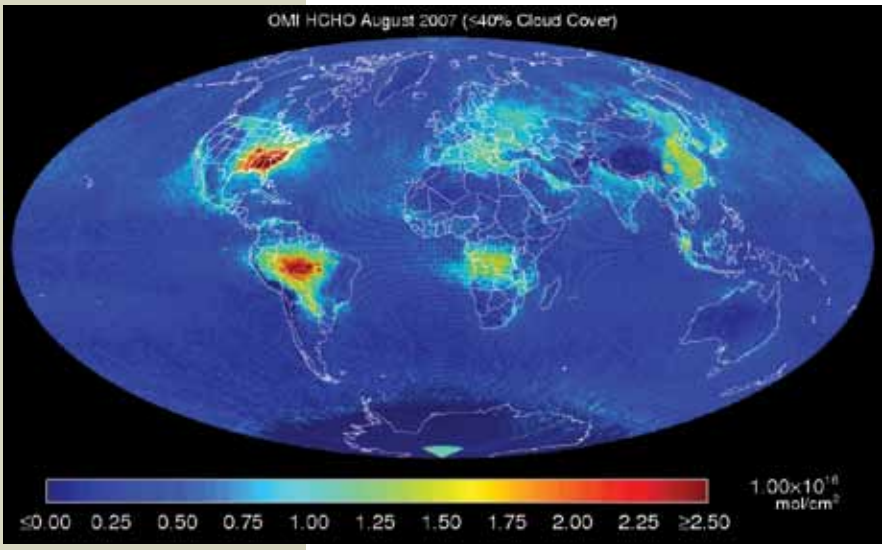
Terpenes are the natural hydrocarbons emitted from vegetation that are responsible for the characteristic scents of many trees, such as pinene from pine.

Isoprene molecules have 5 carbon atoms and are the building blocks for terpenes, which can contain several isoprene units. Long chains of many isoprene units are called polyterpenes.

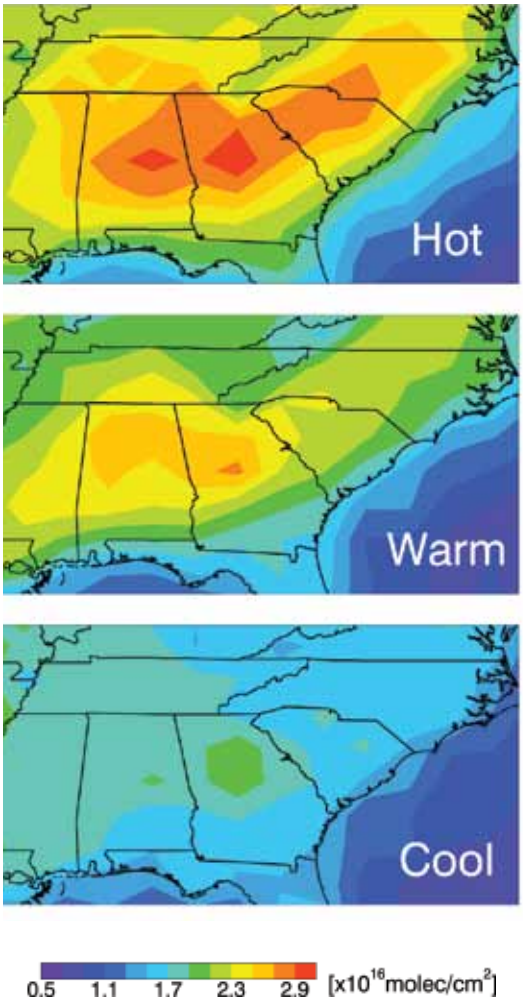
The Ozone Monitoring Instrument (OMI) measures the hydrocarbon, formaldehyde (HCHO). Formaldehyde is produced during the oxidation of other hydrocarbons, including the hydrocarbon, isoprene, that is emitted naturally from trees. The global map of HCHO, measured by OMI, shows that areas with the highest HCHO levels correspond to heavily forested regions, such as the southeastern U.S. and the Amazon in South America, where isoprene emissions are high.

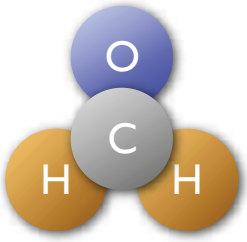
It is not well understood why plants emit isoprene, especially since some plants do not. One hypothesis is that it may be part of a process that helps protect leaves from environmental stresses, such as hot conditions and drought. Isoprene appears to also provide protection from oxidants such as ozone.

A map of global HCHO as measured by the Ozone Monitoring Instrument (OMI).

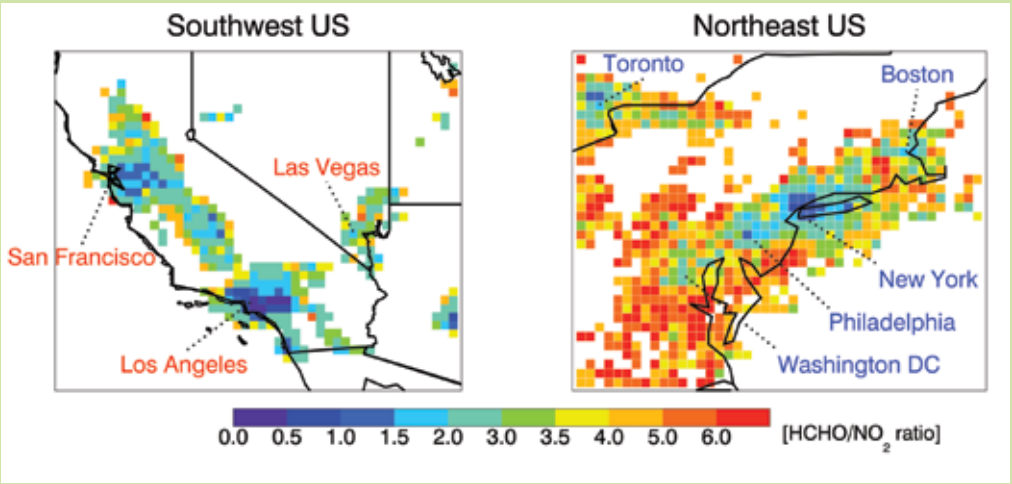


In some regions lowering nitrogen oxides are more important for reducing ozone, but lowering hydrocarbons are more important in other regions. For instance, the ratio in the northeastern United States (see figure) indicates that the effective way to reduce unhealthy levels of surface ozone is to reduce emissions of nitrogen oxides, except in New York City where reductions in both hydrocarbons and NO_2 would be beneficial. On the other hand, most areas in the southwestern United States would benefit from a reduction in hydrocarbons, except in Los Angeles and San Francisco where a reduction in both hydrocarbons and nitrogen oxides would be better.





Strategies to control pollution



Ratio of OMI HCHO/NO_2. When the ratio is less than one, the better strategy to reduce ozone is to reduce hydrocarbons. When the ratio is greater than one, nitrogen oxides should be reduced. In areas where the ratio is around one, both hydrocarbons and nitrogen oxides should be reduced.

Laboratory experiments show that the amount of isoprene emitted from trees depends on the ambient temperature. More isoprene is emitted during hot summers because isoprene helps plants protect themselves from environmental stresses. The maps (where on the page?) for summer months in the southeastern United States show that the amount of HCHO seen by OMI is greatest during the warmest month and least during the coolest month.

HCHO has both natural and anthropogenic sources. In the United States HCHO is produced mainly by oxidation of isoprene, but in China HCHO is also produced by the oxidation of anthropogenic hydrocarbons and is also emitted directly from use of biofuels. For regions without dense vegetation OMI HCHO reveals the distribution and intensity of anthropogenic hydrocarbon emissions.

Unhealthy levels of surface ozone are formed by a complex set of chemical reactions involving hydrocarbons, nitrogen oxides, and sunlight. The ratio of OMI HCHO to NO_2 tells air quality scientists whether chemical reactions involving hydrocarbons or nitrogen oxides are more important to ozone production, information that is needed to develop effective strategies to reduce unhealthy levels of surface ozone.

In the 1980s, hydrocarbons from cars and industry were reduced in an attempt to control unhealthy levels of ozone in the United States. However, the natural hydrocarbon, isoprene, is so high in the eastern part of the country that ozone was relatively unaffected by the hydrocarbon reductions.

Some plants emit isoprene but some do not. Isoprene may protect leaves from environmental stresses, such as heat and drought.

Isoprene emission appears to protect plants from oxidants such as ozone.

Since trees emit isoprene and isoprene can play an important part in the formation of unhealthy levels of surface ozone, some people have said that trees cause pollution. Without nitrogen oxides from cars, industry, and power plants, surface ozone would be low even when isoprene is high.

The Chemically Complex Troposphere

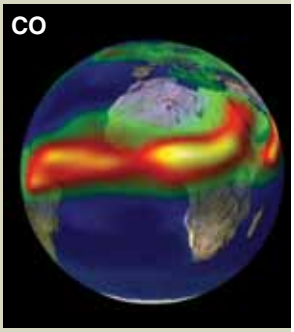
TES Fact

TES makes direct measurements of ozone and CO and unique measurements of methanol and ammonia. These measurements are valuable in testing our knowledge of the complex tropospheric chemistry.

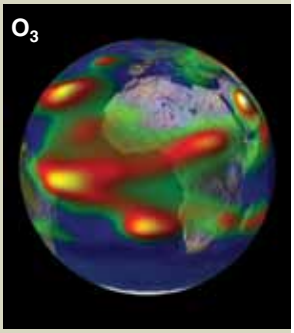
The TES measurements provide new insights into the complexity of the tropospheric chemistry. The global maps of tropospheric ozone that we now have from Aura show that the emissions from biomass burning are quite large, and the CO emitted forms ozone far out over the Atlantic Ocean. We also see clear evidence of the flow of pollution from the continents of the Northern Hemisphere.

TES can measure two other tropospheric gases, methanol (CH_3OH) and ammonia (NH_3). Methanol is predicted to be an important source of formaldehyde (HCHO) over land and the remote atmosphere, and it is thought that growing plants are the largest atmospheric source. Previously, our knowledge about methanol concentrations primarily came from a few aircraft measurement campaigns. TES, can provide a more complete picture of the global distribution of methanol and perhaps better estimate how much comes from plants.

Ammonia comes from many sources (animal waste, fertilizers, soil, industrial emissions) and only stays in the air a few hours, because reacts with other gases to make tiny particles. We know little about how ammonia is distributed around the globe, and because it rapidly converts to aerosols, knowing more about ammonia will help us learn more about the aerosols in air pollution.

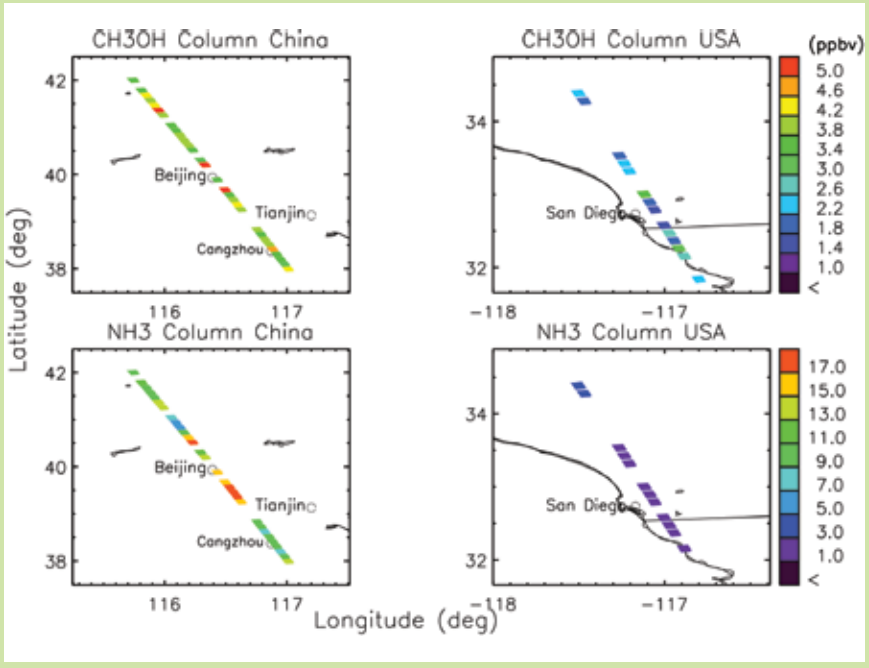


Simultaneous measurements of ozone and CO made by TES



CH3OH Column Measurements

caption text?



Changes in Air Pollution During the 2008 Olympic Games

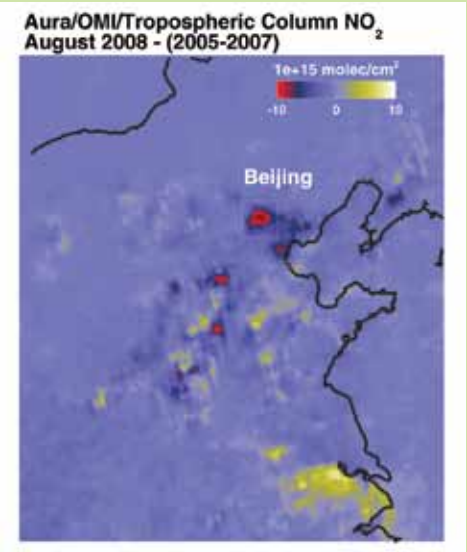
China is now believed to be among the largest emitters of anthropogenic air pollutants in the world. Aware of China's air quality issues and their growing reliance on coal based energy and vehicular transportation, the Chinese government developed the Beijing Olympic Action Plan with the goal to meet the World Health Organization air quality standards for the duration of the August-September 2008 games.

The Chinese pollution reduction strategy included the following: Reduction in coal-burning pollution, the primary anthropogenic source of SO_2, lowering motor vehicle emissions by restricting vehicular transportation, the main source of NOx ($NO+NO_2$), ground-level O_3 and volatile organic compounds (VOC), and reduction in industrial pollution from metallurgical, chemical, and cement industries. These emission controls were instituted from July through September 2008 in conjunction with the Olympic Games.

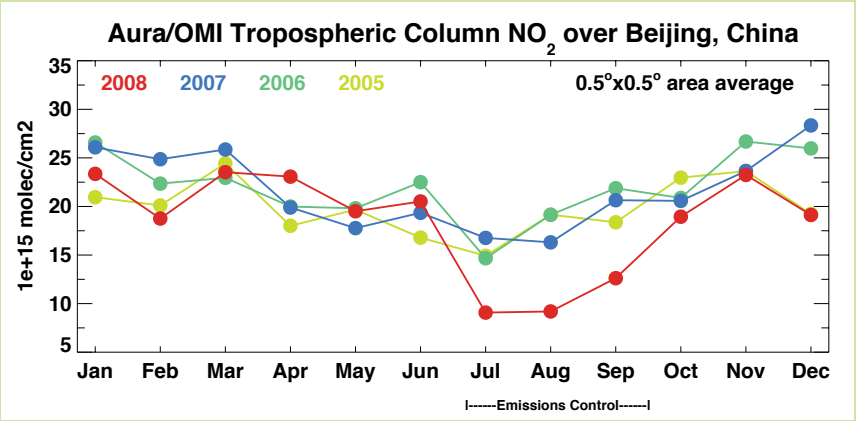
Aura measurement show dramatic reductions of tropospheric nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and measurable reductions in tropospheric column ozone (O_3). The MOPITT instrument onboard the Terra spacecraft also showed a reduction in CO. The drastic measures imposed by the Chinese government appear to have been fairly successful in reducing air pollution; however, pollution levels rose again after the Olympic period.

Air quality in Beijing is believed to be among the worst in the world due rapid industrialization. Olympic athletes and visitors were very concerned about air quality during the games.

The Great Wall of China, built in the 5th century, cannot stop the pollution flowing northward from Beijing.



Change in Beijing NO_2 for August compared to previous years



Tracking monthly changes in NO_2 and SO_2 over Beijing shows the pollution reduction compared to previous years

Ozone Pollution

Ozone is a very toxic gas and is used industrially to sterilize materials. Surface ozone concentrations exceeding 80 ppbv are considered unhealthy even though commonly occur in industrial centers when the air mass is stagnant.

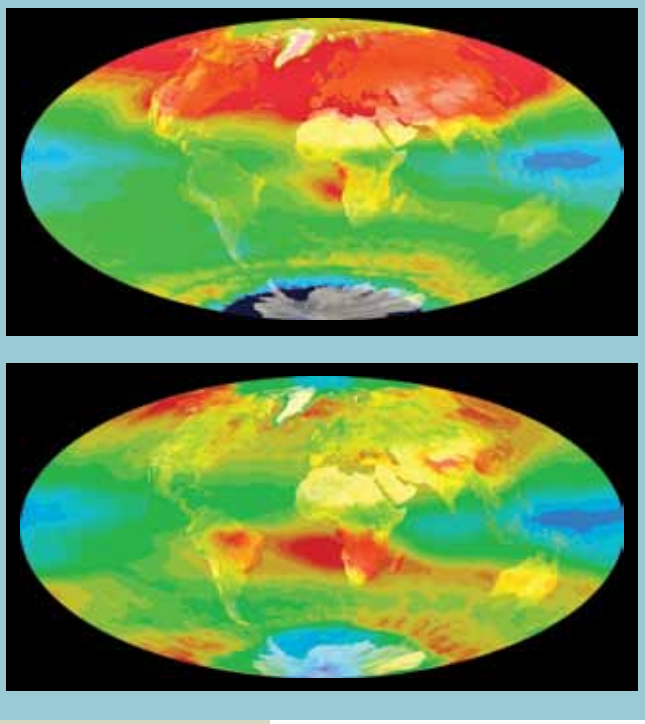
Ozone pollution near the surface is difficult to measure from space because satellite instruments have to look through the stratospheric ozone layer, which contains about 90% of atmospheric ozone, and

Tropospheric Ozone (new title)

Tropospheric ozone is formed when NOx and VOCs or CO react in the presence of sunlight (page 11). Controlling toxic ozone pollution has been a challenge. Although there have been small but significant improvements in hourly sampled ozone levels in the United States, no significant change in daily averaged levels has been observed. Human sources of nitrogen oxide (NOx) emissions are the most important contributors to excess ozone in the east-central U.S. because natural VOCs are abundant. In the West, control of both VOCs and NOx are important.

Aura can gather information about tropospheric ozone from TES which looks at ozone absorption in the infrared (page 16). We can also estimate the tropospheric ozone amount by subtracting the OMI nadir measurement of total column ozone from the MLS limb measurement of the stratospheric column. The difference between the total column and the stratospheric column is called the Tropospheric Ozone Residual or TOR (page 10). The averaged tropospheric ozone mixing ratio can be computed using the TOR and measured depth of the troposphere. In the average mixing ratio plots below, ozone pollution plumes stream away from biomass burning regions in Africa and South America and from industrialized areas in northern hemisphere in summer. The tropical West Pacific is a persistent low average mixing ratio region. Over the tropical oceans convection lifts clean marine surface air into the upper troposphere. The average mixing ratio is highly correlated with surface ozone in regions where there is strong coupling between the surface and the mid troposphere, such as convective regions.

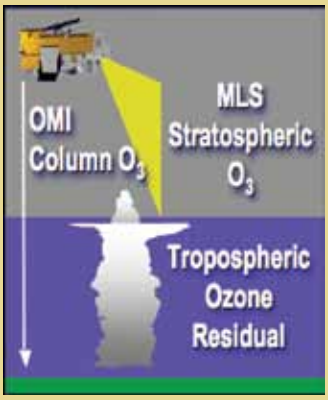
Average Tropospheric Ozone Mixing Ratio



SUMMER Ozone pollution in the Northern Hemisphere peaks. Ozone produced in East Asia moves toward Canada and the U.S. Ozone from the Eastern U.S. moves toward Europe and ozone from Europe moves toward China. Biomass burning in Africa sends a plume into the Atlantic.

FALL Ozone production decreases in the Northern Hemisphere as winds increase and sunlight decreases. Biomass burning generates ozone plumes that extend from Africa and South America into the Atlantic and Indian Ocean.

Tropospheric Ozone Residual



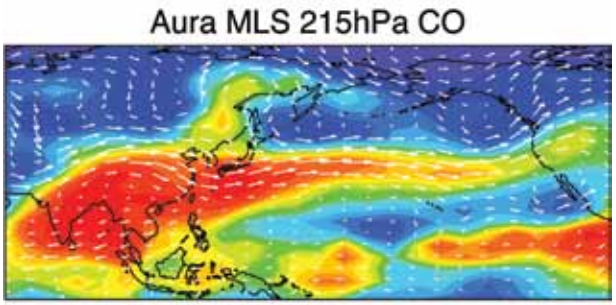
The Tropospheric Ozone Residual (TOR) is calculated by subtracting the MLS stratospheric ozone column from the OMI total column ozone. The average mixing ratio is computed using the TOR and the depth of the troposphere.

Long range transport of pollution

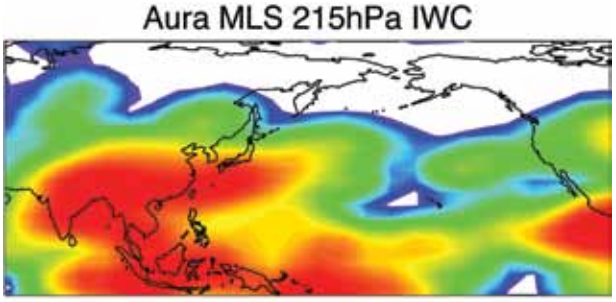
Some pollutants, notably CO and O_3, have a lifetime of a week or more. These gases and other pollutants are transported up into the jet stream by convective systems where they may travel thousands of miles before dissipating or being brought back to the surface by descending air in a high pressure system. Is such long range transport important for air quality? Usually the contribution of such plumes to air quality is small but in rare circumstances can contribute to pollution levels.

Over the Asian summer monsoon region, the upper troposphere CO abundance peaks, when convection is strongest. This is a period when bio-mass burning CO emissions are low, so anthropogenic sources from urban areas dominate.

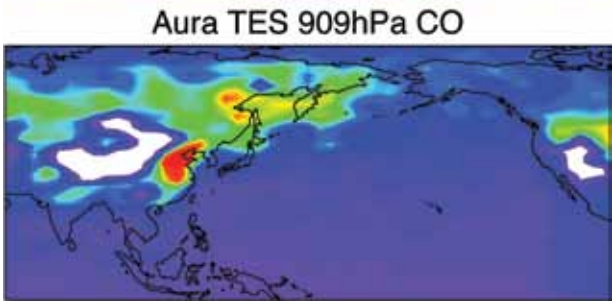
Strong convection associated with the Asian monsoon lifts surface pollution into the upper troposphere. The polluted air can then be transported by eastward winds across Pacific to North America as seen in these observations by MLS. The presence of convection is indicated by the high ice water content (IWC) measured in the upper troposphere.



Upper figure, MLS CO observations in the upper troposphere.



Middle figure, MLS ice water content (IWC) which indicates the location of convective clouds.



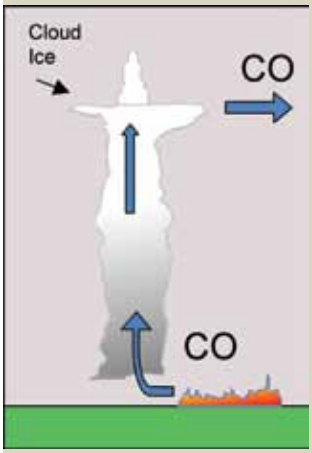
Lower figure from TES shows CO measurement near the surface locating pollution regions.

Carbon Monoxide

Carbon monoxide is an odorless, colorless gas that is produced through incomplete combustion.

The lifetime of CO is long enough that it can be a good marker for long-range transport.

Carbon monoxide reacts with NO_2 to form tropospheric ozone



Carbon monoxide (CO) is produced at the surface by biomass burning and industrial processes. Storm clouds transport air from the surface to high altitudes in the troposphere. Since CO is not removed by rain, this transport efficiently moves CO from the surface to the upper troposphere where it can be detected by Aura's MLS.

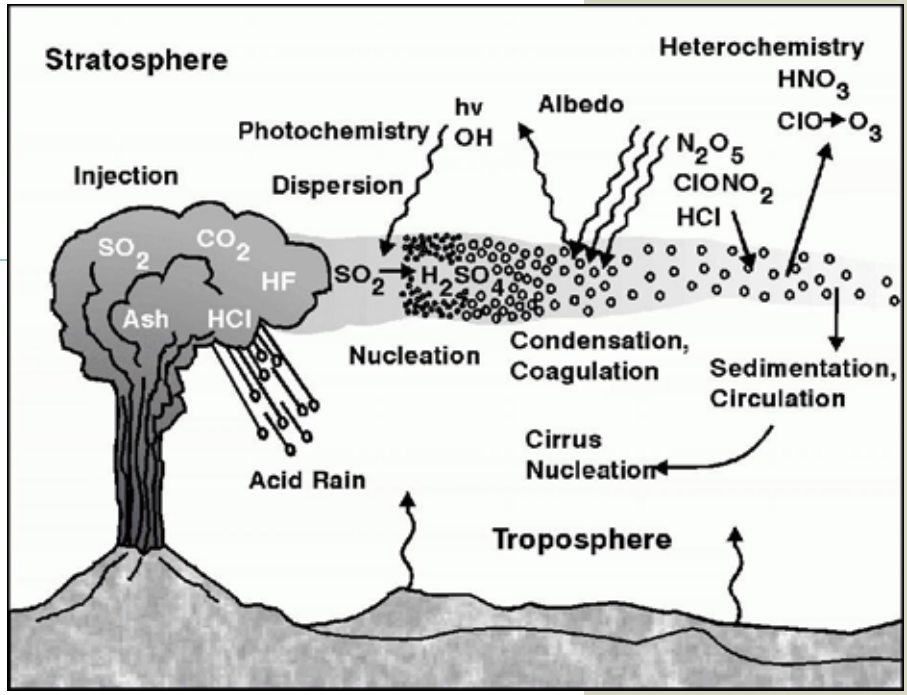
Volcanoes

Above, Chile's Mt Chaiten ash plume streams across Argentina in May 2008.

The Tungurahua volcano in central Ecuador.

Mt. Cleveland Volcano erupting in on May 23, 2006 photographed from the International Space Station.

Volcanoes



Huge amounts of volcanic gases, aerosol droplets, and ash are injected into the lower stratosphere and upper troposphere during major explosive eruptions. Some gases, such as CO_2, contribute to global warming, while other, like SO_2, lead to cooling (by transformation into sulfate aerosol) and also cause ozone destruction. Volcanoes also emit lower levels of these gases intermittently between large-scale eruptions. This is called passive degassing.

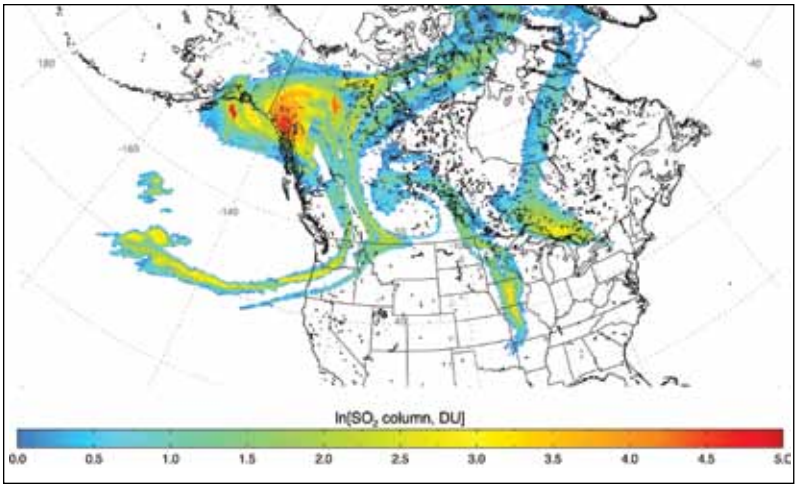
Aura and other A-train measurements are used to track drifting volcanic eruption clouds. This is important because ash contained in volcanic plumes is extremely hazardous to aircraft. OMI measurements at ultraviolet wavelengths can be combined with infrared measurements from TES and other sensors to provide information about the height of SO_2 plumes.

Between August 7 and August 8, 2008, three explosive eruptions rocked the Kasatochi Volcano in the Aleutian Islands of Alaska. In addition to sending a thick plume of ash at least 35,000 feet into the atmosphere, the volcano released a large cloud of SO_2. In the days that followed the eruption, OMI tracked a dense cloud that contained about 1.5 million tons of SO_2. It was one of the largest volcanic SO_2 clouds scientists have observed since Chile's Hudson volcano erupted in August 1991. The cloud may be associated with otherwise unseen ash. Therefore, airlines canceled flights or diverted around the cloud. As of August 11, Alaska Airlines had cancelled 44 flights to avoid the ash, affecting some 5,200 passengers, said Reuters. Because the volcano is located in a remote, uninhabited region, the eruption caused no further damage.

The most abundant gas emitted by volcanoes is typically H_2O. CO_2 and SO_2 are the next most plentiful gases. Volcanoes also release small amounts of hydrogen sulfide, H_2S, (which has the odor of rotten eggs), hydrochloric acid (HCl), hydrogen (H_2), carbon monoxide (CO), and hydrofluoric acid (HFl) as well as volatile minerals.

Fine volcanic ash can clog jet engines, causing them to stall. Ash also damages windshields and metal on aircraft.

Exposure to acidic volcanic gases such SO_2 can damage eyes, mucous membranes, and the respiratory system. Under extreme conditions, this can lead to death.



OMI captured this SO_2 image on August 12, 2008. At this time, winds were spreading streamers of SO_2 across the Arctic. The logarithmic color scale shows exponentially increasing SO_2 column amounts (in Dobson Units). A logarithmic scale is one in which the values represented by the colors increase exponentially, not linearly.

Page 22

Add clean air act somewhere in the text

Industrial Sulfur

Sulfur Dioxide Facts

Most SO_2 dumped into the atmosphere comes from fossil fuel burning (almost 5 times more than from all the world's volcanoes).

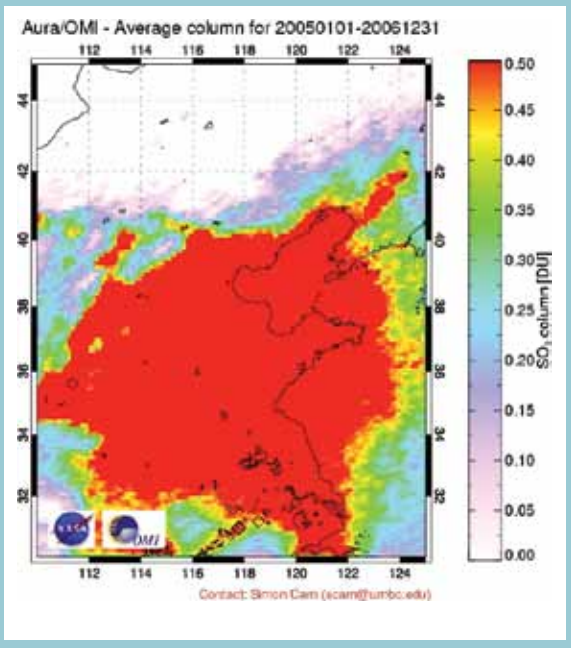
Coal-fired power plants spew out about 60% of the total SO_2 emissions in the U.S. In the U.S., regulation and the use of smoke stack scrubbers have greatly reduced SO_2 emissions.

25.5 million tons of SO_2 was emitted by Chinese factories in 2005, up 27% from 2000.

Sulfur dioxide (SO_2) is produced by industrial processes, including fossil fuel burning in power plants, oil refining, and metal smelting as well as by natural sources such as volcanoes. Emitted SO_2 reacts with other constituents in air or cloud droplets to produce sulfate aerosol, which can be rapidly deposited as acid rain in the lower atmosphere or transported great distances when lofted into the upper atmosphere. Both SO_2 and sulfate aerosol are noxious pollutants and hazardous to health, while sulfate particles also create haze that impairs visibility, influences cloud properties and precipitation, and directly impact climate by reflecting solar radiation, counteracting global warming. The lifetime of SO_2 and derived sulfate aerosol, and their climate impact, increases with altitude and is most significant when explosive volcanic eruptions inject SO_2 directly into the stratosphere.

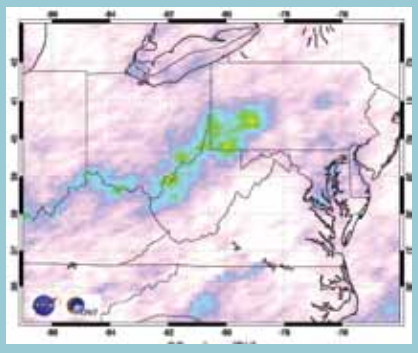
Measurements by OMI are providing an unprecedented global view of SO_2 concentrations, allowing us to detect individual anthropogenic sources, such as copper smelters, from space for the first time. These measurements are being used to update inventories of SO_2 emissions, to examine long-range transport and fate of SO_2, and to study the impacts of SO_2 emissions on climate.

Ozone and Sulfur Dioxide



	Northern Hemisphere	Southern Hemisphere	Global
Marine and Terrestrial DMS	7.5	11.0	**18.5**
Volcanic SO_2	10.0	4.0	**14.0**
Explosive degassing	0.5-4		
Passive degassing	5-10		
Biomass Burning	1.0	1.5	**2.5**
Fossil Fuel Use and Industry	60.5	6.3	**66.8**
TOTAL (S, Tg)	79.0	22.8	**101.8**

Emitted sulfur in terra-grams from nature and anthropogenic sources.



These figures show the total column of SO_2 averaged over two years over eastern China (right) and the U.S.

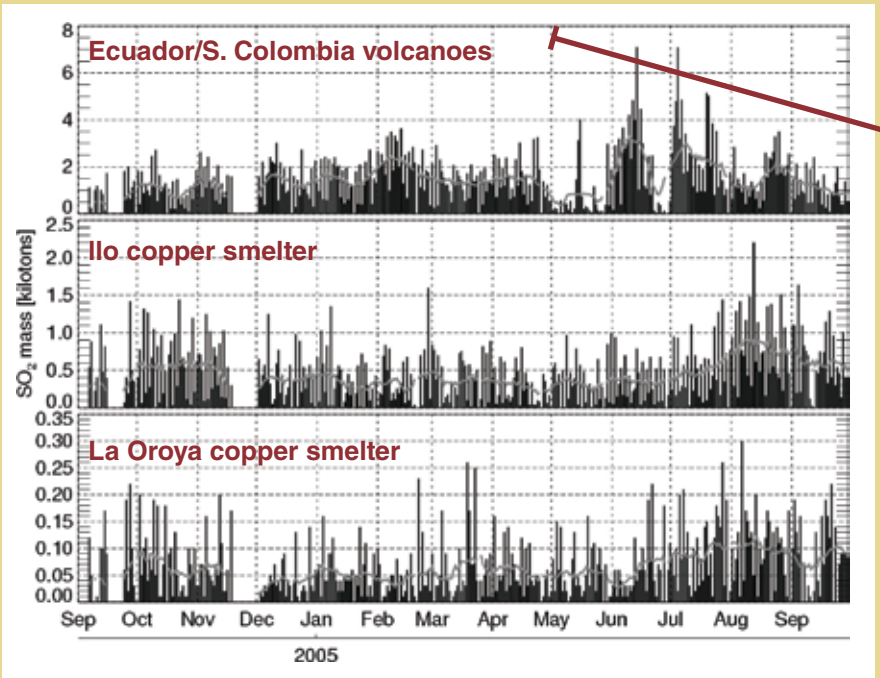
Volcanoes

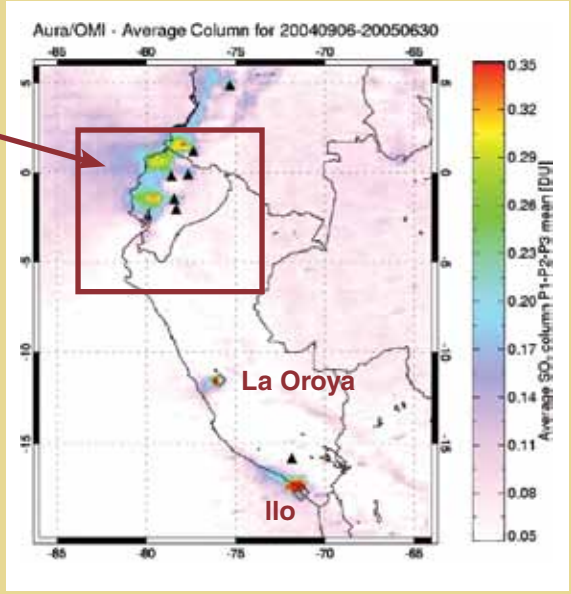
This picture is by AP

Aura measurements of volcanic and anthropogenic SO_2 emissions allow scientists to compare volcanic gas output (from active eruptions as well as passive degassing) to man-made emissions and to assess the effects of both past and future eruptions of Earth's climate and air quality.

OMI has the smallest footprint on the Earth of any instrument of its type. This high spatial resolution, coupled with it's ability to view the Earth at many different wavelengths, gives OMI about 100 times more sensitivity to SO2 than heritage instruments such as the Total Ozone Mapping Spectrometer (TOMS) series that flew between 1979 and 2005.

The Peruvian copper smelters are among the world's largest industrial point sources of SO_2. La Oroya is one of the 10 most polluted cities in the world.





Copper rich ores produced by volcanoes in the distant past are being mined and smelted in Peru. These smelters produce tons of SO_2 per day and rival the SO_2 production by volcanoes just to the North in Ecuador and Colombia

Aerosols

Montana forest fires, August 24 2007.

Dust storm in Texas 1935.

Smoke plume, agricultural fires in Central California

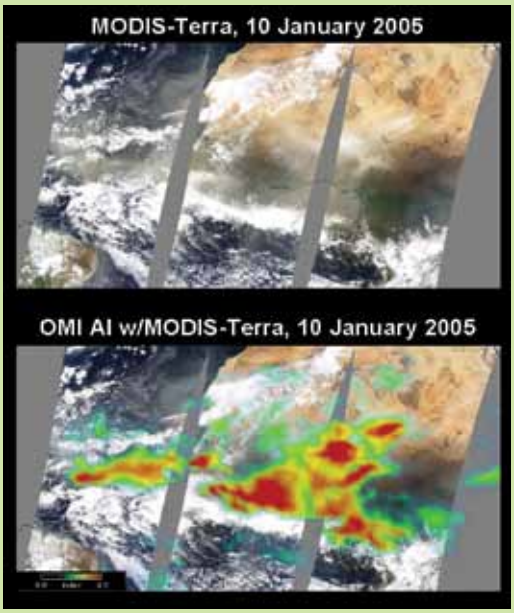
Smoke and Dust

Aerosols are tiny particles and droplets suspended in the air. They are formed in nature by volcanoes, dust storms, sea spray, and emissions from vegetation. Humans create aerosols and alter their natural sources by burning fossil fuels and modifying land cover. Fires are another important source of aerosols; some are natural, such as wildfires started by lightning strikes, while others are from human-caused burning of vegetation for cooking, heating, and land clearing.

Aerosols have complex effects on Earth's climate. In general, they tend to cool the surface by reflecting (scattering) radiation from the sun back into space. Some aerosols, like dust and smoke, absorb solar radiation and heat the atmosphere where they are concentrated. Additionally, aerosols change the properties of clouds. Indeed, it would be very difficult to form clouds in the atmosphere without aerosols to act as "seeds" for water to condense on. In aerosol polluted environments clouds tend to have smaller droplets than clouds formed in cleaner environments; these polluted clouds actually appear brighter from space because they reflect more sunlight, and they may persist longer and not rain as intensely.

We can see aerosols clearly from space. If you took a picture from the space station with your digital camera the aerosols below you might appear as a muddy haze. With a smarter camera, like OMI, you could take your picture at very precise colors (wavelengths). Because of the different sizes and compositions of aerosols, they scatter and absorb the various wavelengths of light differently than clouds or the land surface, which makes it possible to discriminate aerosols more precisely from the rest of the view of the Earth.

Observations of Aerosols



The top picture shows a false color image from the MODIS instrument on Terra. Clouds and aerosols (most likely a mixture of Saharan dust and smoke) are visible over the Atlantic ocean off the west coast of Africa. It is more difficult to discern aerosols over the brighter African continent.

The bottom picture shows the Absorbing Aerosol Index derived from OMI overlaying the MODIS image, where warmer colors (yellows to red) indicate the presence of significant amounts of absorbing aerosol such as dust and smoke. These absorbing aerosols are clearly seen over bright land surfaces as well as clouds.

Aerosols and Air Quality

Aerosols Facts

Aerosols are a component of air pollution; High concentrations degrade air quality.

Aerosols interact with Earth's climate by reflecting and absorbing incoming shortwave sunlight and outgoing longwave radiation emitted by the Earth (see p. 29 for a diagram of the Earth's radiation budget).

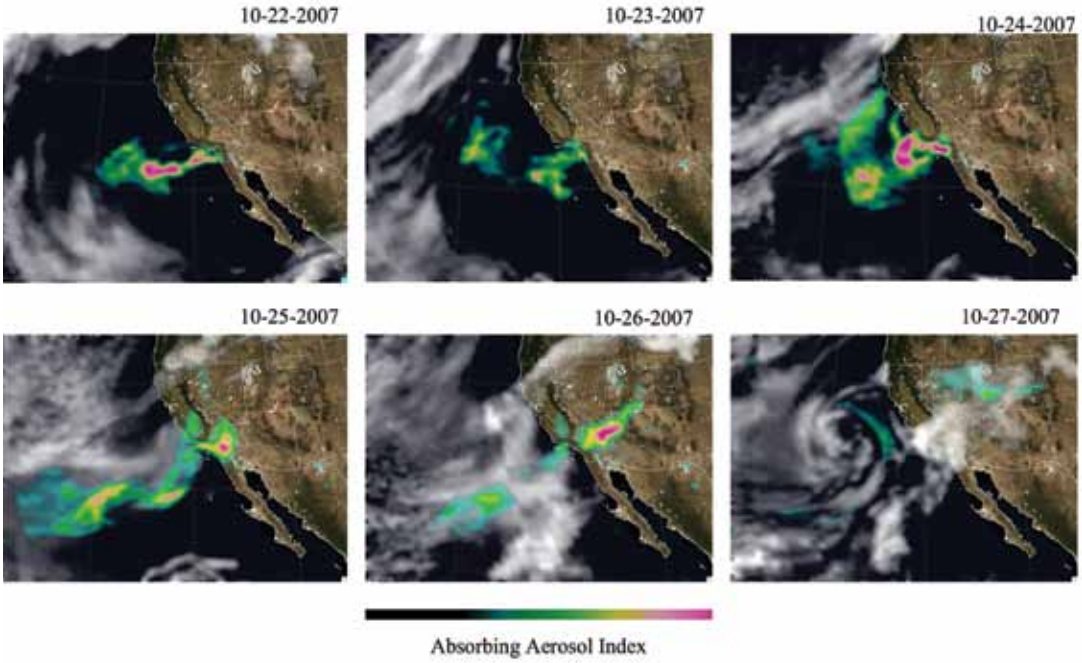
Aerosols also affect the properties of clouds by making them brighter and changing their lifetimes, extent, and precipitation.

Because of their size, aerosols can adversely affect air quality. Small particles penetrate into the lungs. Exposure to particulate pollution is linked to increased risk of heart and lung disease. This is why the U.S. Environmental Protection Agency monitors and enforces particulate air quality standards nationwide.

Long-range transport of aerosols across continents and oceans can impact air quality even in normally pristine environments. To quantify the impacts of long-range transport of aerosols on air quality it is helpful to monitor them from space.

The OMI instrument can measure aerosols over bright surfaces like deserts and clouds. OMI can do this because it makes measurements in the ultraviolet (UV) part of the spectrum. Earth's surface is very dark in the UV, making it easier to discriminate the reflectance of light by aerosols from the surface reflectance. Over clouds, which do reflect strongly in the UV, OMI can detect absorbing aerosols—like smoke and dust—because those aerosols absorb different amounts of light at different wavelengths ("colors") of light, while clouds have similar properties at all wavelengths.

California Fires 2007



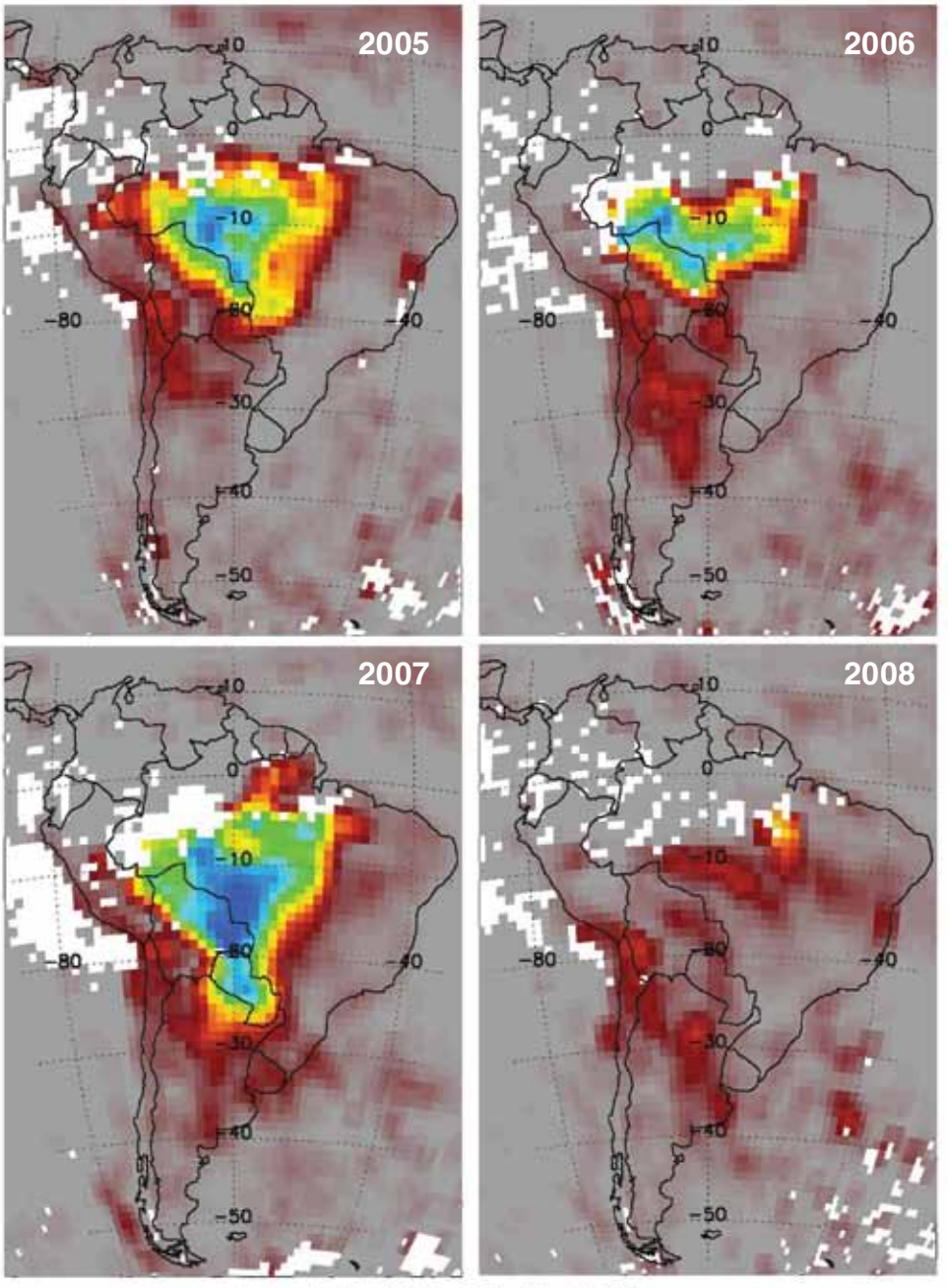
During October 2007 OMI captured these images of aerosols from wildfires burning in southern California. The color indicates a satellite-derived quantity called "Absorbing Aerosol Index." Hotter (redder) colors indicate greater amounts of absorbing aerosols from the smoke plumes, while cooler colors (blues and greens) indicate fewer aerosols. The white and grey colors indicate the presence of clouds, as seen by the Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument on the NASA Aqua spacecraft.

Other images can be found:

http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=35930

http://alg.umbc.edu/usaq/archives/002495.html

OMI Observes Large Decrease in South American Biomass Burning in 2008



There is a seasonal cycle to biomass burning in South America that peaks each year in September, when large tracts of land and forest are cleared for agricultural purposes by burning residual vegetation.

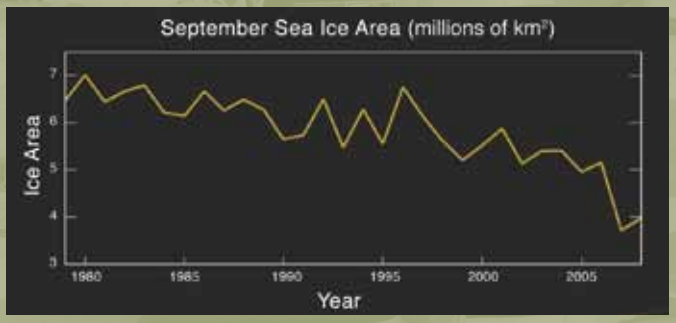
The aerosols produced by the burning are readily detectable by OMI. The figure at left shows the amount of aerosol present in the atmosphere over South America during September for each of the years 2005-2008. The aerosol quantity is represented as the Absorbing Aerosol Optical Depth, a measure of how much aerosol there is and how much it absorbs incoming sunlight.

There is a marked decline in biomass burning in 2008 relative to other years. Other satellites that measure the number of fires indicate a decrease in the amount of fires by at 50% for 2008 relative to 2007, with a decrease of 62% in Brazil alone versus a 4% decrease over the rest of the continent. The amount of aerosol in 2008 is about 1/3 the amount in other years.

We do not at present have an explanation for this decline in biomass burning, although it does not appear to be related to meteorology. The precipitation in South American is not significantly different in 2008 from other years.

Heating the Planet

caption



Arctic sea ice decrease compared to previous years.

Heating the Planet

Climate and atmospheric composition have a two-way interaction. Clouds, aerosols, and radiatively-active gases, such as ozone and water vapor, impact climate through their effects on the Earth's radiation budget. The Earth's climate affects atmospheric motion and physical processes, such as precipitation and evaporation, that are in turn linked to composition. Aura makes several measurements that help scientists to untangle these complex interactions.

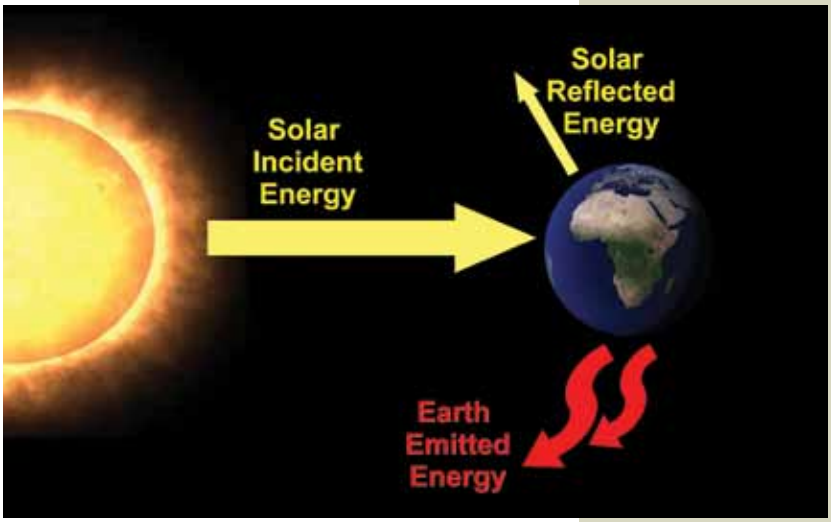
The Earth receives energy from the sun, mostly at visible wavelengths. About 30% of this incoming sunlight is scattered back to space by the atmosphere, surface, clouds, and aerosols. The remainder is absorbed in the atmosphere and at the surface.

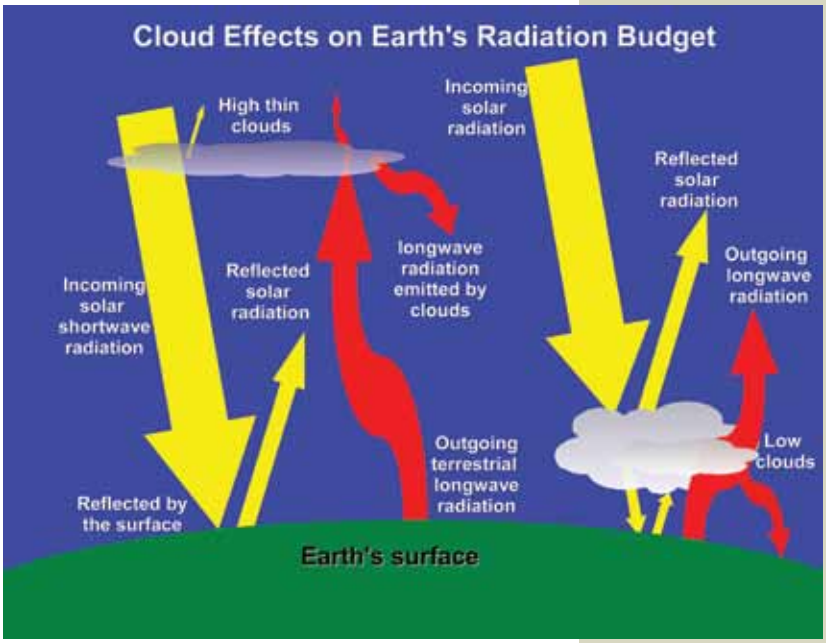
The Earth emits energy, mainly in the infrared part of the electromagnetic spectrum, from the atmosphere and surface. Some of this heat is trapped by clouds and atmospheric gases and reradiated back to the surface (the greenhouse effect).

Clouds significantly impact the Earth's radiation budget and present one of greatest uncertainties in predicting future climate.

Clouds warm the Earth by trapping infrared radiation emitted by the atmosphere and the surface. They also cool the Earth by reflecting sunlight to space. The net effect of clouds on climate depends on how they change with surface temperature and at what altitude the changes occur.

Clouds also interact radiatively with atmospheric gases. They increase the path of visible light through the atmosphere when they backscatter sunlight to space. This increases absorption by gases that lie above the clouds. Clouds also decrease the greenhouse effect produced by atmospheric gases.





Can cloud feedback slow climate change?

Cloud Facts

The role of clouds is one of greatest uncertainties in predicting future climate.

Clouds warm the Earth by trapping infrared radiation emitted by the atmosphere and the surface.

Clouds also cool the Earth by reflecting sunlight to space.

The net effect of clouds on climate change depends on how clouds change with surface temperature and at what altitude the changes occur.

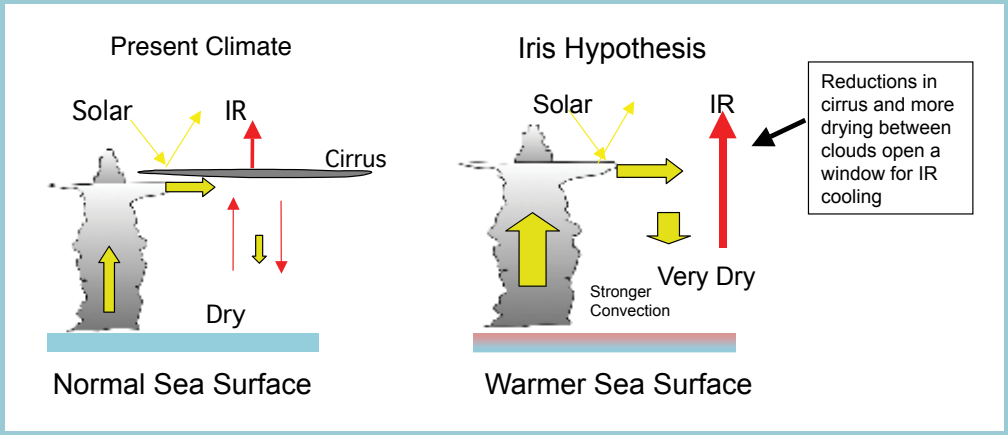
Clouds are closely linked with water vapor, which is an important greenhouse gas.

The "iris hypothesis" stated that the areal coverage of cirrus anvil clouds would shrink when surface warms, leading to a strong negative climate feedback.

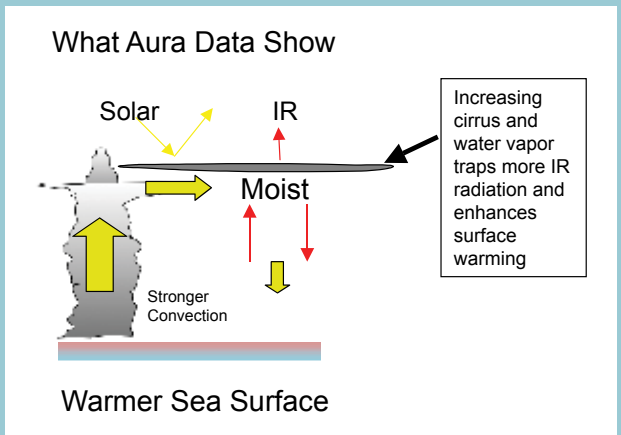
Analysis using measurements from NASA Aura and other satellites showed a different story.

The iris hypothesis (Lindzen et al., 2001, BAMS) suggests that strong cloud and water vapor feedbacks will blunt global warming. The cartoon below shows how this might work. As sea surface temperatures rise, more energy is available for tropical storms. This would speed up the circulation in storms and the increased descending motion between clouds would dry the air reducing cirrus and water vapor and allowing more radiation to escape to space. Inside the storms, increased precipitation may reduce the outflow of cloud ice particles, which would also cause less trapping of radiation by clouds and cool the planet. The decrease of cirrus cloud coverage with increasing temperature is analogous to the shrinkage of human eye's iris when exposed to strong light.

Blunt Global Warming?



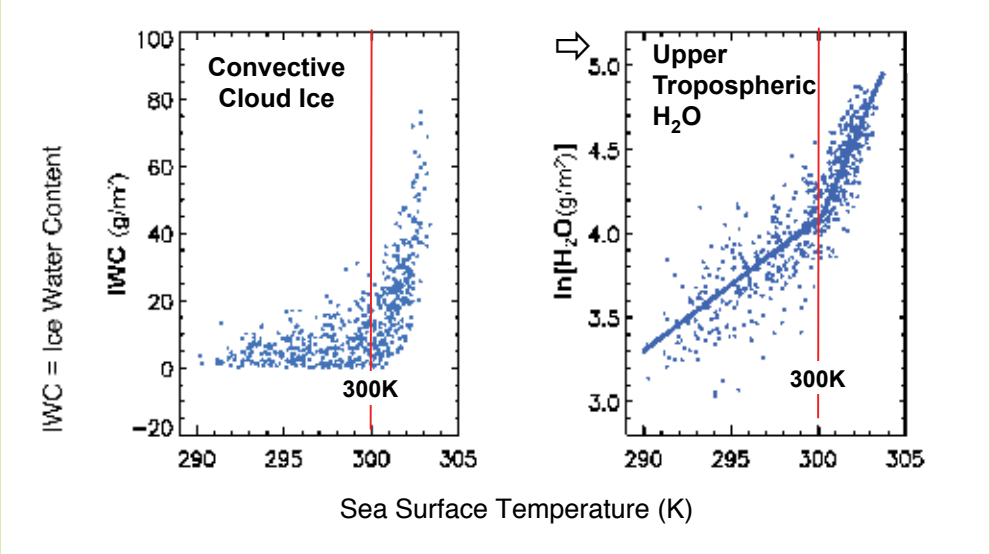
The Microwave Limb Sounder (MLS) on Aura measures upper tropospheric (UT) water vapor and cloud ice water content (IWC). Both are important components that govern global hydrological and energy cycles.



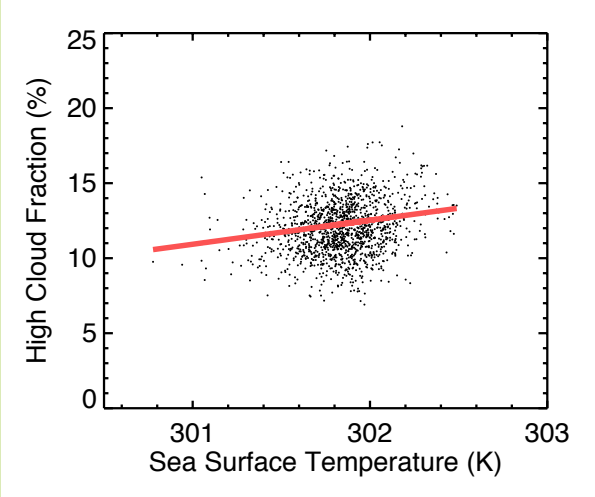
Water vapor and cloud feedback

Measurements from MLS show that cloud and water vapor feedbacks actually amplify global warming. Water vapor and cirrus increase in the upper troposphere over warm seas. This result is inconsistent with the iris hypothesis. The result has now been confirmed by CloudSat.

Upper Troposphere



These figures show how tropospheric cloud ice (left) and water vapor (right) increase as sea surface temperature rises.



Tropical upper tropospheric cloud fraction versus sea surface temperature weighted by cloud fraction. Each dot corresponds to a daily mean from 1 September 2002 to 30 September 2006. The red line is the least squares linear fit to the data.

Cloud Facts

Upper tropospheric cloud ice (a measure of convection), increases rapidly with sea surface temperature when sea surface temperature is greater than ~300 K. This is primarily due to increased convective transport at high sea surface temperatures.

Increases in upper tropospheric water vapor enhance the greenhouse effect and warm the Earth.

The increase of cloud fraction and cloud ice with sea surface temperature refutes the "iris hypothesis". Since high clouds have a net radiative warming effect, their increase leads to a positive climate feedback.

However, when cloud ice increases by more than 50%, the increased reflection of sunlight reduces the positive feedback.

Ozone as a Greenhouse Gas

Ozone Facts

Tropospheric ozone ranks as the third most important man-made climate gas behind carbon dioxide (CO_2) and methane (CH_4).

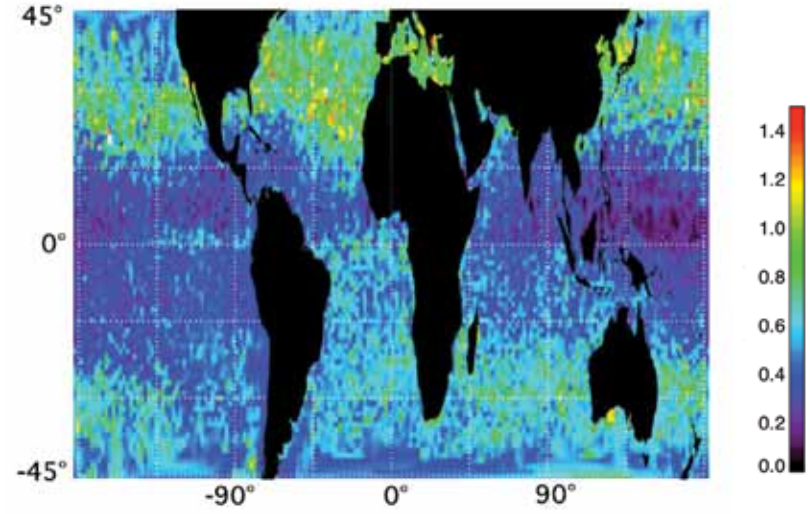
Ozone absorbs heat (infrared radiation) from the Earth's surface, reducing the amount of radiation escaping to space.

Ozone also absorbs visible light from the sun.

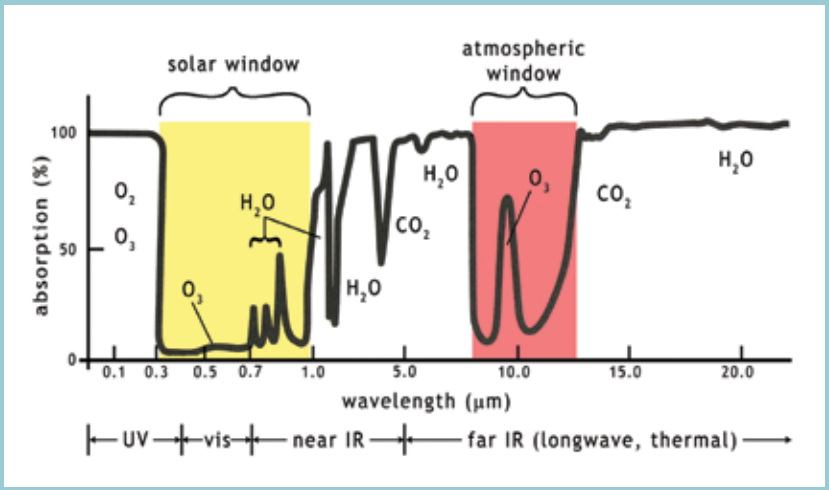
Stratospheric ozone is well known for absorbing harmful ultraviolet radiation. While this absorption is beneficial to life on the Earth's surface, absorption of radiation by tropospheric ozone in other parts of the electromagnetic spectrum causes heating in the atmosphere and contributes to global warming. Tropospheric ozone has increased significantly as a result of industrial activity and biomass burning and will likely continue to increase throughout the century.

The impact of man-made ozone on the global radiation budget and climate has been estimated mainly using chemical-transport models. Observations from Aura and Aqua can help to evaluate these models.

Greenhouse Effect



This map shows the annual average outgoing long-wave (infrared) radiation (in Watts per square meter) that is trapped by upper tropospheric ozone when no clouds are present as estimated from TES. High values at northern middle latitudes are the result of lofted pollution. Ozone formed from biomass burning produces a similar band in the southern hemisphere.

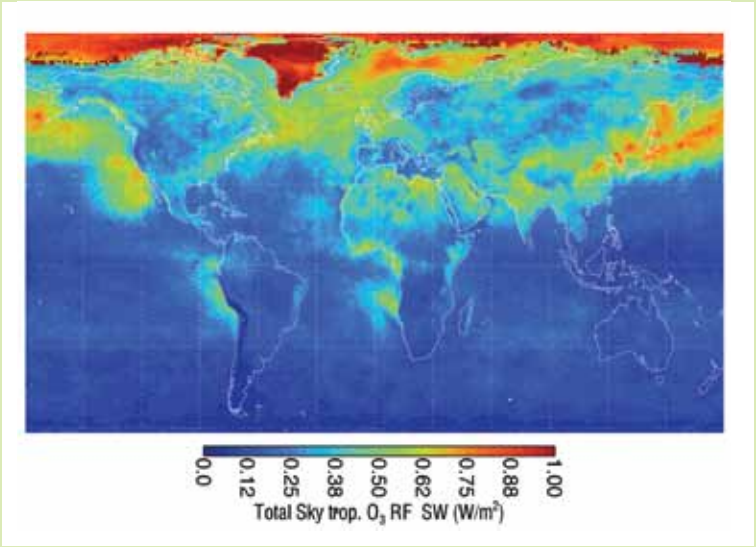


Major absorbers in the Earth's atmosphere. Ozone absorbs the Earth's outgoing heat in the infrared (IR) portion of the spectrum (red) and also absorbs sunlight at visible wavelengths (yellow).

Clouds and Ozone

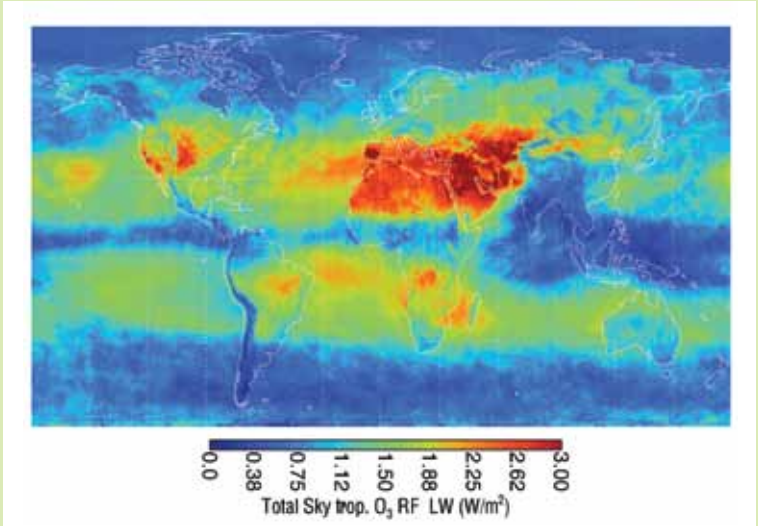
Clouds change ozone's contribution to the radiation budget. Cloud properties from Aqua's MODIS imager and Aura's OMI can be used with daily tropospheric ozone derived from OMI and MLS to accurately estimate the impact of clouds on ozone absorption and its associated radiative forcing.

Radiative Forcing



The map, at left, shows the average instantaneous short-wave radiative forcing (due to ozone absorption of sunlight) in Watts per square meter in July 2005. Over clouds and ice (Greenland), a portion of the reflected light is absorbed by ozone, trapping radiation that would have otherwise escaped the lower atmosphere.

The map, at right, shows long-wave radiative forcing (due to ozone absorption of heat) in July 2005. The long-wave effect is largest over the hot, dry, clear deserts where there is more available heat from the surface to be absorbed. High clouds along a band near the equator decrease the radiative forcing.



Climate Change

We need to be able to compare the strengths of different human and natural agents that cause climate change. Radiative forcing is a concept that scientists use to do this.

Instantaneous radiative forcing is defined as the change in net irradiance (downward minus upward) at the tropopause. It includes sunlight and the Earth's heat and is usually expressed in Watts per square meter (W/m2).

Clouds increase ozone's absorption of sunlight, which heats the Earth.

In general, clouds decrease ozone's greenhouse effect.

Nitrogen oxides form a brown layer over polluted regions. This cloud was observed imbedded in a polluted layer over Baltimore, Maryland.

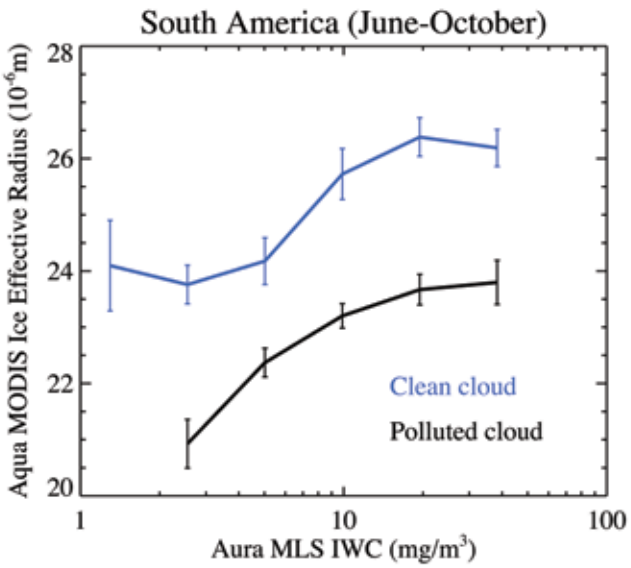
Observing Dirty Clouds

Aerosols can affect the Earth's radiation budget and climate in two important ways: directly and indirectly. Aerosols absorb incoming sunlight and also reflect it back to space. This is called the aerosol direct effect. Aerosols also indirectly affect climate by modifying clouds and precipitation when they act as cloud condensation nuclei. This is called the aerosol indirect effect. Although evidence of the aerosol indirect effect has been found, there is scant data on its magnitude and resulting consequences. It therefore presents one of the largest uncertainties in climate prediction.

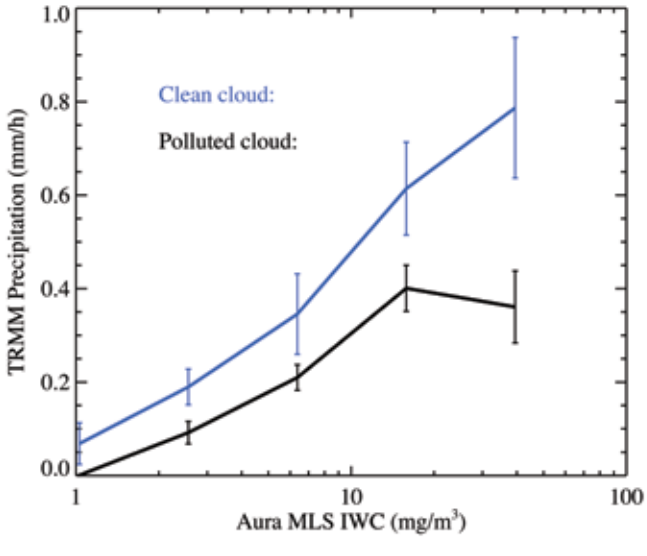
One reason for the lack of information on the aerosol indirect effect is that it is extremely difficult to observe. Because clouds and aerosols both scatter light, aerosols cannot be easily detected by satellite sensors when they are inside or near clouds. One way to infer the presence of aerosols near clouds is to use another observable pollutant as a "proxy" for aerosol. One such aerosol proxy in some seasons and regions is carbon monoxide (CO). CO and aerosols are both produced by incomplete combustion that occurs for example in fires. CO can be measured by MLS inside high clouds.

Once dirty clouds have been identified with MLS, other data from the A-train, such as cloud particle size from Aqua MODIS and precipitation from TRMM, can be used to examine the aerosol indirect effect. In the top right panel, polluted clouds over South America in the dry (biomass burning) season are shown to contain smaller particles. These polluted clouds reflect more light to space than similar clean clouds. Dirty clouds in the region also rain less than clean clouds as shown on the bottom right.

Cloud radius vs. cloud amount



Precipitation vs. cloud amount

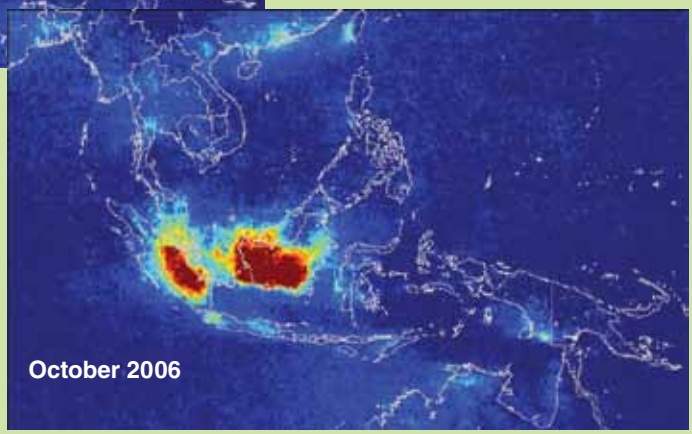


El Niño's Fingerprint

The El Niño-Southern Oscillation is associated with global effects on the Earth system, including floods, droughts, and fires that can cause widespread socio-economic hardships and environmental degradation.

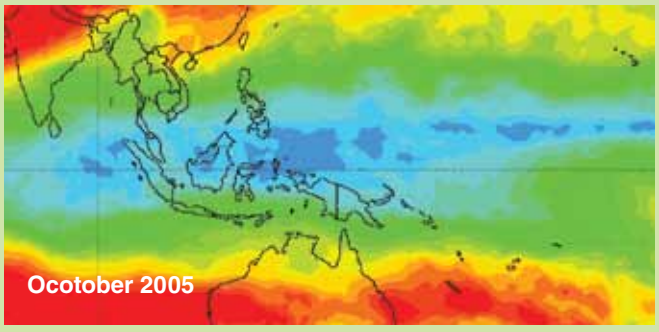
An El Niño episode occurred in September 2006 and lasted into early 2007. Dry conditions in the western Pacific led to severe fires in Indonesia. The fires produced large amounts of formaldehyde (HCHO) that were observed by OMI. HCHO is short-lived and is therefore observed near its source.

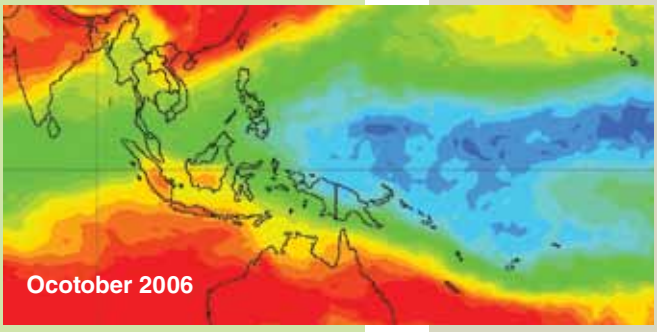
The El Niño fires increased the production of ozone precursors such as NOx, CO, and VOCs like HCHO. The production of NOx by lightning was also affected. Because tropospheric ozone has a significantly longer lifetime than HCHO, its distribution is also influenced by changes in atmospheric circulation that occur with El Niño.



HCHO monthly mean total columns from OMI

Mean tropospheric O_3 mixing





El Niño

An El Niño episode is said to occur when sea surface temperatures are at least 0.5o warmer than normal across the central tropical Pacific ocean and the duration is 5 months or more.

The 2006-7 episode was a relatively weak El Niño. However, it produced the worst Indonesian fires since the devastating El Niño of 1997-8.

Deforestation and agricultural burning, particularly in Borneo and Sumatra, make Indonesia more prone to massive fires during El Niños.

TES and other NASA instruments observed large carbon monoxide plumes over Indonesia from the fires.

The fires led to poor air quality throughout the western tropical Pacific.

In the seasonal cycle page I noted that the caption (first paragraph) has pole-ward hyphenated.

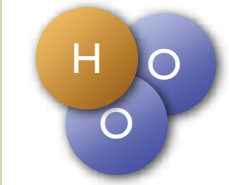
The Water Cycle

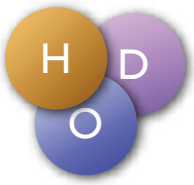
Water Facts

Most water molecules are made of two hydrogen atoms and one oxygen atom (H_2O)

One hydrogen atom is replaced by deuterium (a hydrogen atom with an extra neutron) in about 0.031% of all water molecules

The ratio HDO/H_2O in the ocean is much more uniform than in the atmosphere because of the water cycle When water condenses, it is easier to condense HDO than H_2O so rainwater has a higher concentration of HDO and the atmosphere becomes HDO depleted.



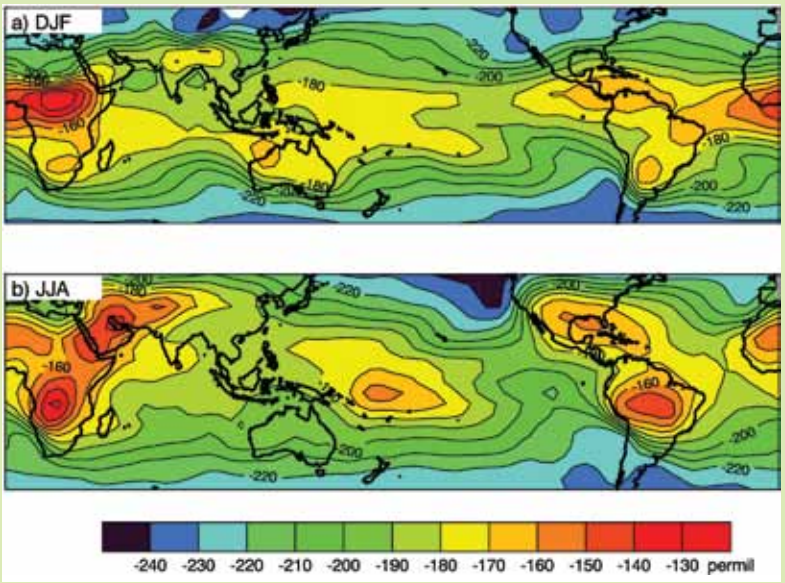


Rain falls and flows to streams, rivers, and on to the ocean. Heating liquid water changes it to a gas (evaporation), increasing the humidity in the air. Air rises and cools, and the water turns into liquid or ice particles (condensation), forming clouds. Transformation of water from gas to liquid or solid and back again, and movement of air that contains water from one part of the Earth to another are parts of the water cycle.

Heavy water molecules (HDO) condense and evaporate differently than normal lighter water molecules (H_2O). By comparing the ratio of HDO to H_2O in the atmosphere to that of the ocean we can identify the source of the water and its history of transformation between vapor and liquid. TES measures H_2O and the heavy water isotope (HDO), and as such informs us about the strength of the water cycle.

The isotope measurements are helping us understand the water cycle over rainforests and the ocean by identifying the source of the water and how efficiently it is transformed to rainfall. The data are also helping us examine the transport of water from the equator to the poles. Many records of climate stretching back from thousands to hundreds of thousand years are based on water isotopes and by comparing these records with current observations from TES we can find out how the water cycle changed in the past and better predict how the water cycle will change in the future.

Seasonal cycle of HDO/H_2O



Lower HDO/H_2O ratio with latitude indicates condensation as the water vapor moves pole-ward

High HDO/H_2O ratio over land indicates strong evaporation and convection

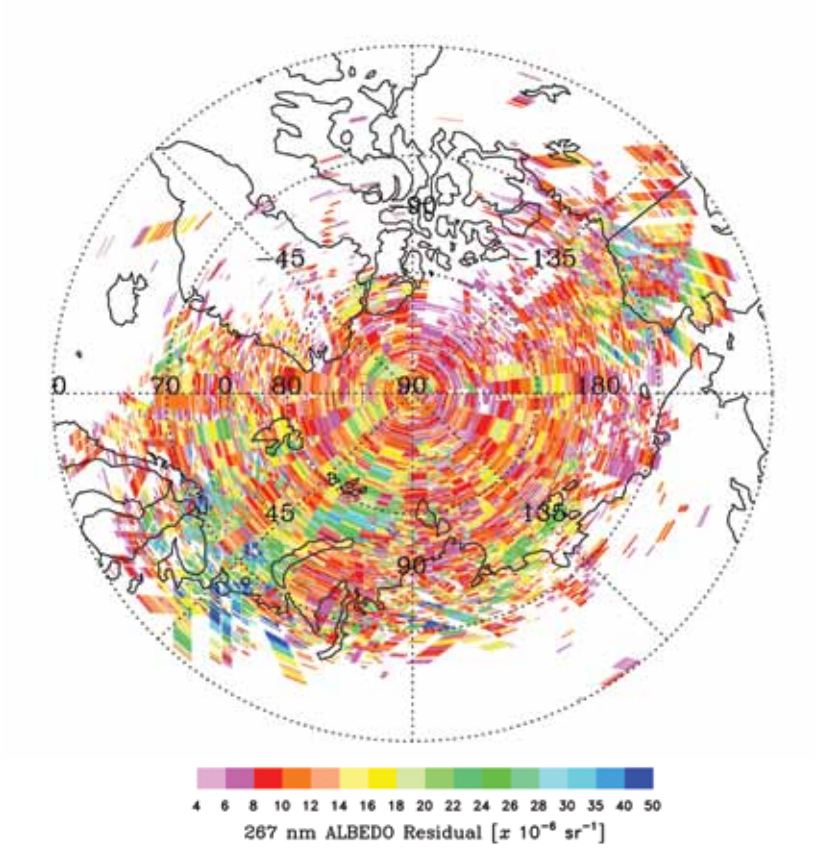
Relatively low HDO/H_2O ratio in regions of tropical precipitation indicates strong re-cycling of rainfall to vapor and back again

page 37 look for facts - from befroe 4/20

Polar Mesospheric Clouds

Far above the stratosphere, wispy clouds form at the summer poles. They are called noctilucent clouds, or polar mesospheric clouds (PMCs), and occur more than 80 km (50 miles) above the Earth. PMCs are believed to be microscopic ice particles that condense on meteoric dust in the very cold summer mesosphere. PMC's are visible from the ground when then are seen illuminated by the sun against the dark sky. PMCs have been observed more frequently in recent decades and there may be two reasons for this. The global increase in methane will lead to an increase in mesospheric water. This will increase the condensation temperature and make it easier for PMCs to form. Increasing CO2 will also make a difference. With increasing CO2, stratosphere and mesosphere temperatures will get colder again making it easier for PMCs to form.

OMI is making some of the best maps of PMCs ever obtained. PMCs are so faint that they are difficult to see with a down looking instrument. But PMCs reflect enough UV so that they are visible at short wavelengths. OMI's small pixels improve the likelihood of PMC detection, and OMI's wide field of view makes it possible to identify PMC spatial structures and follow their evolution. With the overlapping measurement swaths above 65° latitude, OMI also allows us to observe PMC variability on time scales less than < 1 day.



OMI PMC results for July 10, 2005. The brightness of each PMC detection is indi-cated by the color scale at the bottom of the figure.

OMI Facts

OMI's improved spatial and spectral measurement capabilities compared to SBUV/2 make its data much more useful for PMC studies for numerous reasons.

The smaller OMI pixels improve the likelihood of PMC detection and reveals more spatial structure. The OMI results shown in the figure represent ~300 times more information measurements than SBUV/2 on the same date.

OMI's wide field of view makes it possible to identify spatial structures and follow their evolution. Recent measurements by the NASA AIM satellite show the presence of both extended bright regions and coherent "voids" with almost no PMCs even at high latitudes. OMI results show similar features.

OMI offers an unprecedented opportunity to systematically investigate PMC variability on time scales less than< 1 day due to its, with the overlapping measurement swaths above 65° latitude.

OMI's continuous spectral coverage allows a much more robust identification of each PMC.

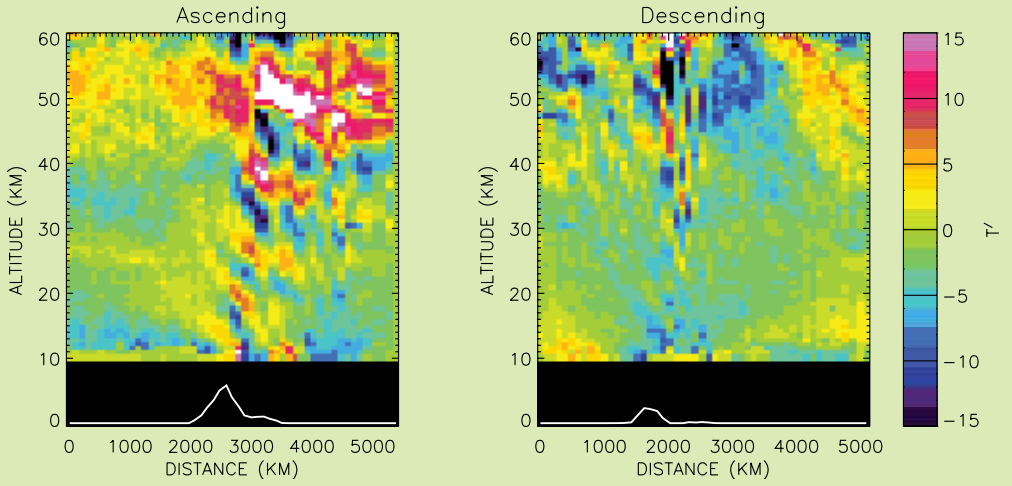
Gravity Waves

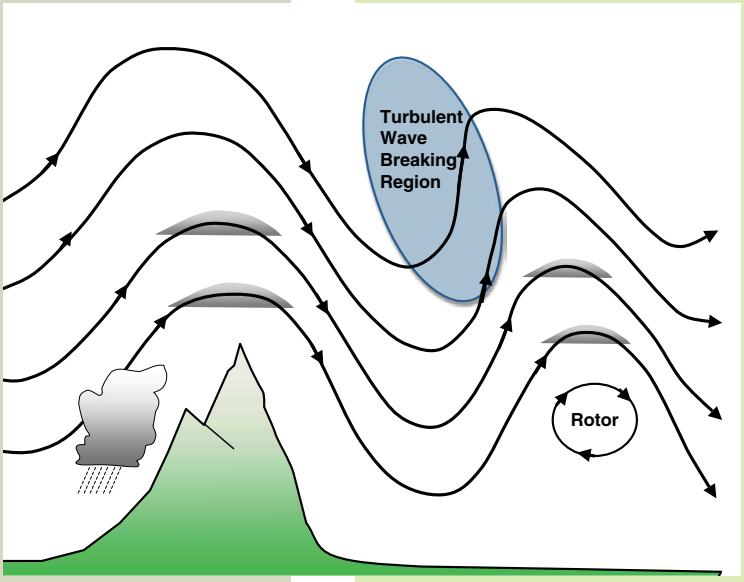
Gravity Facts

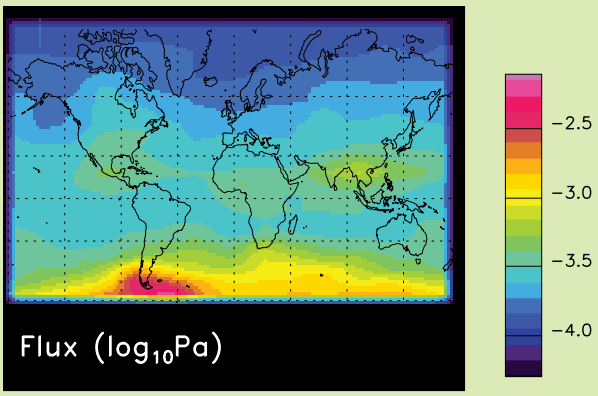
"Gravity waves" is the term used to described atmospheric waves that have the natural buoyancy of the atmosphere and gravity as the restoring force. Gravity waves are formed winds blowing over mountains (above) and by convection. As these wave propagate vertically into the low density upper atmosphere their amplitude grows exponentially. Eventually the waves "break" and dissipate. Where the gravity waves break they decelerate the atmospheric winds; their momentum is transferred to the flow.

Where gravity waves break in the upper atmosphere they act as a breaking force on the flow. HIRDLS, with its high vertical resolution, can make direct measurements of the gravity waves and the momentum they deposit as they break. HIRDLS captured the spectacular mountain gravity wave breaking event near the tip of South America. Gravity wave drag is an important component of the momentum budget of the upper stratosphere and mesosphere. Models of the stratosphere parameterize gravity wave effects, but these parameterizations are crude. Using data from HIRDLS, we can improve these models.

Mountain Wave







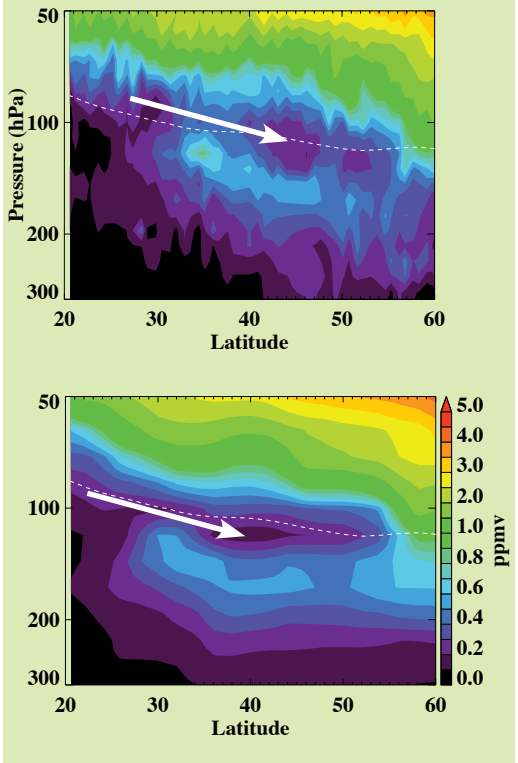
Mountain waves—a type of gravity wave—form as winds blow over steep topography. Mountain waves can propagate well into the stratosphere and HIRDLS observed this mountain wave that formed over the southern tip of South America. The wave produces tilted "stacked" temperature anomalies (T') shown in the figure. Gravity waves increase in amplitude with altitude as the air density decreases until the wave breaks (in this case near 50 km) depositing wave momentum into the flow. The figure above shows that the global upward flux of gravity wave momentum was dominated by this event.

Stratospheric Mixing

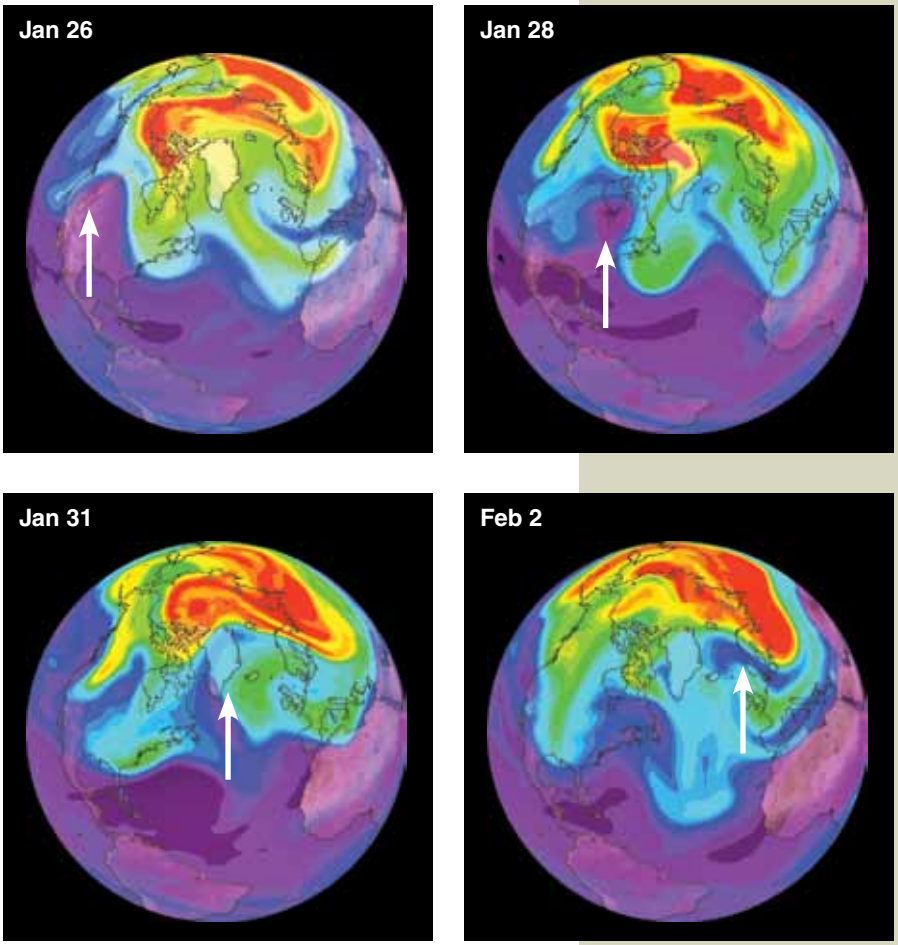
The tropical stratosphere has a low ozone concentration because air is moving upward from the troposphere. The middle latitude stratosphere has a high ozone concentration because there is continuous downward motion of high-ozone air from the upper stratosphere. The upward motion in the tropics and downward motion is the extra tropics therefore sets up a strong north-south gradient in the ozone.

Stratospheric waves that propagate upward from the troposphere pull ozone poor out of the tropics and ozone rich air from the high latitudes and mix them forming streamers and filaments as seen in the model simulation on the left. Below we can see ozone poor being pulled from the tropical region and being extruded toward the polar region. The model simulation is confirmed by HIRDLS observations near the white arrow in the top figure. The transport of ozone and other gases out of the tropics into the middle latitudes by stratospheric waves has never before been seen in such detail and from these measurements we can improve our calculation of the ozone budget.

HIRDLS Observations Model Simulation



Model simulations at the 405K level which is along the dotted line for the cross-sections on the right.



Stratosphere Facts

Stratosphere means "stable region." Despite the name it is a region rapid air movement and very strong winds.

These winds can move trace gases rapidly north and south especially during winter. During such events, filaments and streamers form quickly and are mixed with ambient field.

The Aura Mission

Aura was launched July 15, 2004 into an ascending-node 705-km sun-synchronous polar orbit with a 98° inclination and an equator-crossing time of 13:45±15 min.

High Resolution Dynamics Limb Sounder

HIRDLS

The High Resolution Dynamic Limb Sounder (HIRDLS) is designed to study transport processes that influence the distributions of trace gases, especially in the lowest part of the stratosphere. The year-to-year variability in the northern hemisphere ozone layer is controlled by these transport processes.

HIRDLS measures profiles of temperature, ozone and trace gases that control the chemistry of the ozone layer with unprecedented vertical resolution of ~1 km. HIRDLS measurements of long-lived trace gases including CH_4 and chlorofluorocarbons provide information on the stratospheric transport and circulation. HIRDLS also measures cirrus clouds, important for climate change since they reflect solar radiation and emit infrared radiation. HIRDLS can also detect the polar stratospheric clouds that play a critical role in polar ozone depletion.

HIRDLS is a limb viewing filter radiometer that looks at the infrared emission of molecules against the cold background of space. HIRDLS has 21 channels in the spectral range of 6.12-17.76 microns, and measures profiles with a vertical range of ~8-50 km with 1 km vertical resolution. Due to a problem with some closeout material blocking part of the instrument aperture the HIRDLS team has had to redo their entire algorithm, which delayed the delivery of some of their data products.

HIRDLS Data Products

- **Temperature**
- **O_3**
- **$CFCl_3$ (CFC-11)**
- **CF_2Cl_2 (CFC-12)**
- **CH_4**
- **HNO_3**
- **H_2O**
- **NO_2**
- **Aerosols**
- **Cloud Top Height**

The HIRDLS instrument was built by Lockheed Martin Corp. The data are processed at the U. of Colorado and are archived at the Goddard DISC. http://www.eos.ucar.edu/hirdls/

High Resolution Dynamics Limb Dynamics Limb Sounder

Co-Pis: John Gille, NCAR & U. of Col.; John Barnett, Oxford Univ, U.K.

HIRDLS is a limb emission, filter radiometer that looks at the IR emission of molecules against the cold background of space. HIRDLS scans the atmospheric limb.

HIRDLS characteristics

- 21 Channels
- Spectral Range 6.12 - 17.76 µm
- 1 km Vertical Resolution
- Vertical Range ~8-80km

Due to a problem with some closeout material blocking the instrument aperture HIRDLS team had to redo their entire algorithm which has delayed the delivery of some of their data products. The blockage restricts HIRDLS view of the atmosphere to an azimuth angle of 47o from the orbit plan on the side away from the sun.

HIRDLS obtains data between 65S and 82N.

Microwave Limb Sounder

MLS

MLS Data Products

- **Temperature**
- **O_3**
- **BrO**
- **CH_3CN**
- **CH_3Cl**
- **ClO**
- **CO**
- **HCl**
- **HCN**
- **HNO_3**
- **H_2O**
- **HO_2**
- **HOCl**
- **N_2O**
- **OH**
- **SO_2**
- **Cloud Ice**
- **Geopotential Height**

The MLS instrument was built by the Jet Propulsion Laboratory. The data are processed at the Jet Propulsion Laboratory and are archived at the Goddard DISC. http://mls.jpl.nasa.gov/

The Microwave Limb Sounder (MLS) provides measurements needed to (1) determine if the stratospheric ozone layer is recovering as expected, (2) improve our understanding of the interactions between atmospheric composition and climate, and (3) study the role of air pollution in Earth's upper troposphere.

In addition to ozone (O_3), MLS stratospheric (and mesospheric) profile measurements include stable and reactive forms of chlorine (e.g., HCl, ClO, HOCl) and other species involved in polar processing and chemical ozone loss (e.g., BrO, HNO_3, H_2O, OH, HO_2). MLS observations of long-lived trace gases (e.g., N_2O) are used to distinguish composition changes due to atmospheric motions from those due to chemistry. MLS observations provide information on the current state of the stratosphere and how it may be affected by climate change.

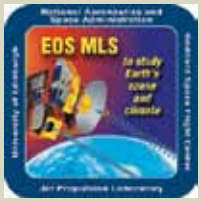
MLS upper tropospheric profile observations include H_2O and O_3 (both strong greenhouse gases in this region), carbon monoxide (CO, which is a tracer of polluted air) and HNO_3. These are needed to quantify important processes that exchange air between the troposphere and stratosphere, and also to study the long-range transport and chemical evolution of air pollution. MLS cloud ice observations provide information that helps improve the representation of processes such as deep convection in climate and weather models.

MLS is a sensitive limb-viewing spectrometer observing microwave emission of molecules from 118 GHz to 2.5 THz. MLS measures profiles for many species from about 8 km to 80 km.

The Microwave Limb Sounder

PI: Nathaniel Livesey, JPL

The Microwave Limb Sounder (MLS) is a limb sounding microwave spectrometer with spectral range 118 GHz-2.5 THz and 1.5-3 km vertical resolution. The vertical measurement range is ~8-80km.



EOS MLS contains three modules

- The GHz radiometer module, which includes the 118 through 640 GHz receivers and a scanning antenna.
- The THz radiometer module, which contains the 2250 GHz receivers and the THz telescope and scan mirror.
- The spectrometer module, which receives signals from the GHz and THz radiometer modules.

The Ozone Monitoring Instrument

OMI

The Ozone Monitoring Instrument (OMI) is designed to track global ozone change and continues the column ozone record begun in 1979 with the Total Ozone Mapping Spectrometer.

OMI measures the ozone layer recovery as trace gas concentrations in the atmosphere change (e.g., reduction in chlorofluorocarbons and increase in carbon dioxide.) OMI measurements will be used to study sources and transport of aerosols and trace gases that both affect global air quality and play a role in climate change.

Besides the ozone column, OMI measures other trace gases including NO_2, HCHO, SO_2, BrO, OClO and O_3 profile. OMI will also measure cloud top heights and cloud coverage, map aerosols and estimate ultraviolet radiation reaching the Earth's surface.

OMI is an ultraviolet-visible (270 – 500 nm) nadir looking imaging spectrograph that measures the solar radiation absorbed and scattered by the Earth atmosphere. The innovative optical design uses two-dimensional CCD solid state detector arrays to register at the same time the spectrum on one axis and the spatial information on the other, perpendicular to the flight direction. OMI's 115° (2600 km) wide swath provides nearly global coverage in one day with spatial resolution of 13 x 24 km2 (nadir). The high spatial resolution of OMI is unprecedented and enables almost daily detection of air pollution on urban scale resolution. OMI also provides near-real-time data for operational agencies in Europe and the U.S. for improving the forecasts of weather and air quality.

The Netherlands Agency for Aerospace Programs (NIVR), and the Finnish Meteorological Institute (FMI) contributed the OMI instrument to the Aura mission. The international OMI science team consists of Dutch, Finnish and US science team members and is lead by KNMI (The Netherlands).

The Ozone Monitoring Instrument

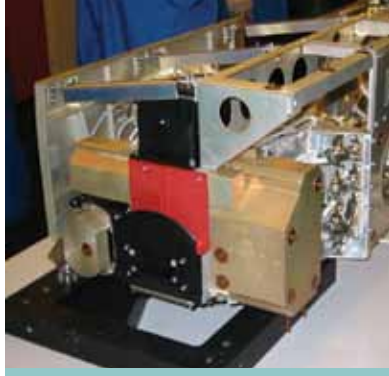
PI: Pieternel Levelt (KNMI, NL)
Co-PI: Johanna Tamminen (FMI, FI)
US Science Team Leader: P.K. Bhartia (NASA GSFC, USA)

The Ozone Monitoring Instrument (OMI) is a hyperspectral imager with spectral range 270 – 500 nm and a nadir footprint of 13 x 24 km2

OMI has a 2600km swath and thus provides global coverage each day.

OMI characteristics

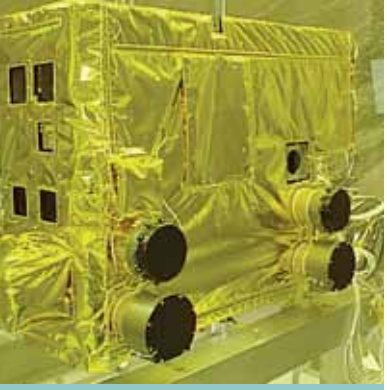
- Nadir Solar Back-Scatter Spectrometer
- Spectral Range 280-500 nm
- 13x24 km Footprint at Nadir
- Swath Width 2600 km



OMI Data Products

- O_3 Column
- O_3 Profiles
- BrO Column
- CHOCHO Column
- HCHO Column
- NO_2 Column
- OClO Slant Column
- SO_2 Column
- Aerosol Absorption
- Optical Centroid Cloud Pressure
- Surface UVB

The OMI instrument was built by Dutch Space and TNO-TPD, together with Finnish companies, Patria, VTT and SFF . The data are processed at in the Netherlands and at Goddard Space Flight Center and archived at the Goddard DISC. http://aura.gsfc.nasa.gov/instruments/omi/index.html



Tropospheric Emission Spectrometer

TES

TES Data Products

Temperature

O_3

CH_4

CO

H_2O

HDO

HNO_3

The TES instrument (above and on the spacecraft) was built by the Jet Propulsion Laboratory. The data are processed at the Jet Propulsion Laboratory and are archived at the Langley DAAC. http://tes.jpl.nasa.gov/

The Tropospheric Emission Spectrometer (TES) instrument is designed to primarily to measure the vertical structure of ozone (O_3) and carbon monoxide (CO) in the troposphere (surface -10 km). Ozone has three roles in the troposphere. Near the surface ozone high concentrations of ozone contribute to poor air quality. O_3 in the middle troposphere is an important source of the hydroxyl radical (OH) which acts as a removal agent for many pollutants like sulfur dioxide. In the upper troposphere, ozone is a greenhouse gas, trapping outgoing infrared radiation and warming the surface. CO comes from biomass burning and industrial activity. In the presence of nitrogen oxides (NOx) CO produces ozone. Profiles of CO are good indicators of long range pollutant transport.

TES also measures water vapor (H_2O) and isotopic water (HDO). The ratio of HDO to H_2O gives information on the hydrological cycle. Water that has evaporated directly from the ocean is rich in HDO but water that has evaporated from land is depleted in HDO.

TES can stare at a specific location for over 3 minutes, conduct a transects 400 km long or step-and-stare over 4000 km with footprints 35 km apart.

Tropospheric Emission Spectrometer

PI: Reinheard Beer, JPL

The Tropospheric Emission Spectrometer (TES) is an infrared, high resolution, Fourier transform type spectrometer covering the spectral range 650 - 3050 cm-1 (3.3 - 15.4 µm) at a spectral resolution of 0.1 cm-1. TES has near nadir viewing resolution of 5 x 8 km. TES can also view the limb with a higher spectral resolution of 0.025 cm-1. The limb view has a 2.5 km vertical resolution

TES characteristics

- Nadir and Limb Fourier Transform Emission Spectrometer
- Limb Mode, 2.3 km Vert. Res., Vertical Coverage 0-34 km
- Nadir Mode, 5.3x8.5 km
- Spectral Coverage 3.3 - 15.4 µm

The Aura Spacecraft

The space craft is called “the bus” because it carries passengers - the instruments. The spacecraft provides power, downloads the data, controls the instruments and provides telemetry information to the instruments. The instruments are bolted to the bus on the earth facing side except for MLS which is in front.

The Aura spacecraft was built by Northrop - Grumman Space Technologies


NASA
AURA

Launching Aura

Aura was launched on July 15, 2004 from Vandenberg AFB on a Delta II rocket. The launch takes place very early in the morning and the rocket heads south so that the boosters fall into the Pacific ocean west of Los Angles, California.

Shortly after launch, Aura achieved a sun-synchronous orbit at 705 km, near its sister satellite Aqua. Over the next month the satellite continues to fire its small rockets to adjust the Aura orbit to be 15 minutes behind its sister satellite Aqua.

Almost immediately after achieving orbit instrument check out began and within a few weeks most of the instruments began operation.

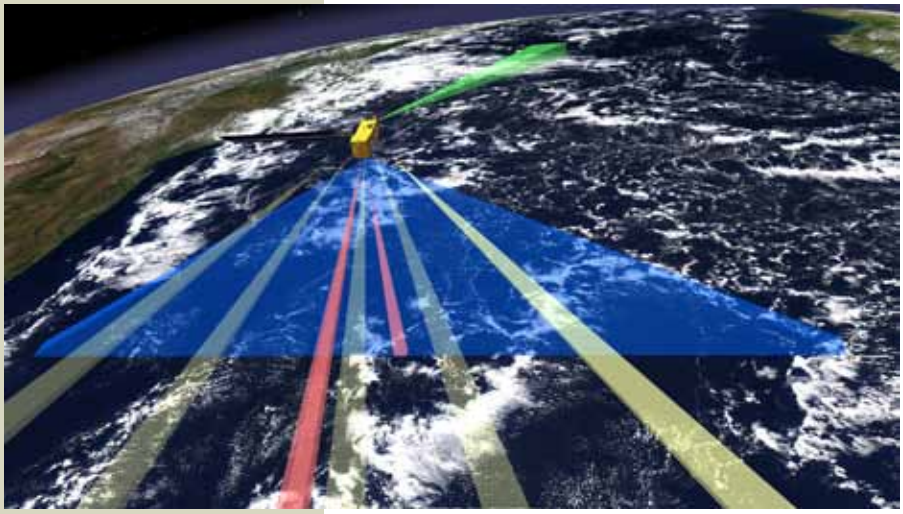
In 2007 the Aura orbit was adjusted to move Aura to be 8 minutes behind Aqua. This change was implemented to improve the combined science from Aura and Aqua.

Top. around 3 am PDT on July 15 photographer Rick Baldridge captured the launch of Aura. Against the stars the long trail of the Delta II rocket is seen lofting NASA's Aura spacecraft into Earth orbit from a vantage point about 200 miles north of the Vandenberg Air Force. The trail represents the first five minutes of the rocket's powered flight with the ignition of additional solid fuel strap-on motors visible after liftoff, near the beginning of the track. The rocket trail ends at first stage shutdown.

Facing page is a photo of the Aura rocket seconds after ignition. The cluster of strap-on booster are seen in the lower part of the rocket. The satellite sits inside the fairing atop the rocket.

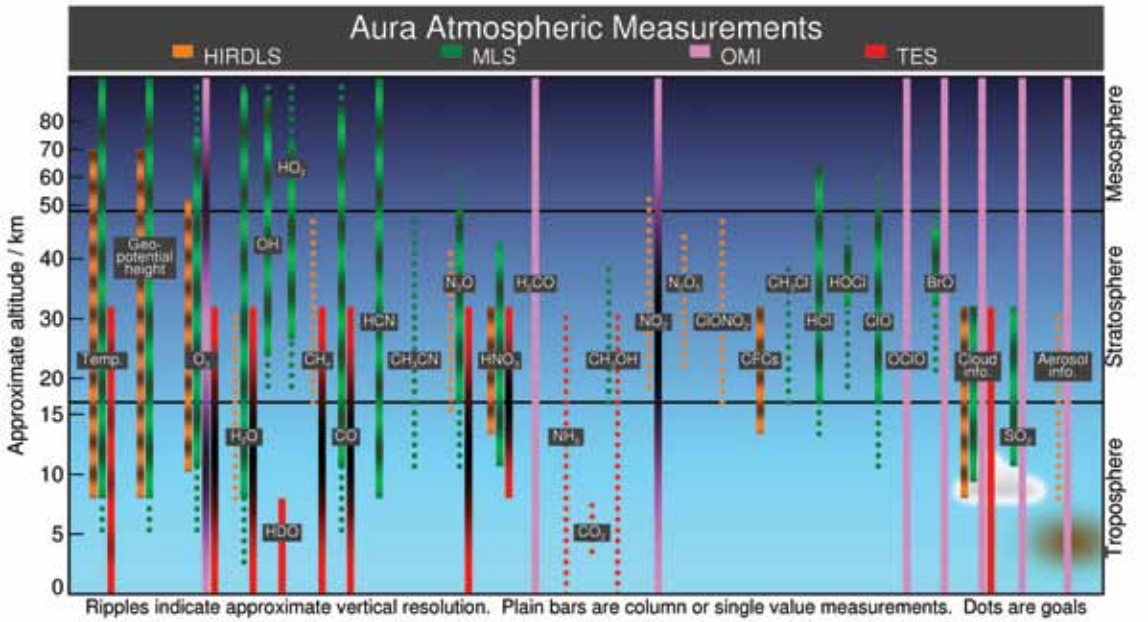
How Does Aura Work?

Aura's instruments detect the trace gases in the atmosphere by detecting the unique spectral signature for each gas. MLS uses the faint microwave emission from rotating and vibrating molecules. HIRDLS and TES use the Infrared thermal emission also due to molecular vibrations and rotations. OMI uses the molecular absorption of backscattered sunlight in the visible and ultraviolet wavelengths.



Aura's remote sensing geometry is shown on the right. Limb sounders (MLS, TES and HIRDLS) slice through the atmosphere, profiling the gases. Nadir sounders (OMI and TES) look straight down. Since MLS looks out the front of the spacecraft it first profiles the gases. The OMI and TES look at the same air mass as it passes beneath the spacecraft. As the spacecraft moves on, HIRDLS and TES slice through the atmosphere again. This unique observing geometry allows the instruments to combine their measurements to and get a larger picture of chemistry of the atmosphere.

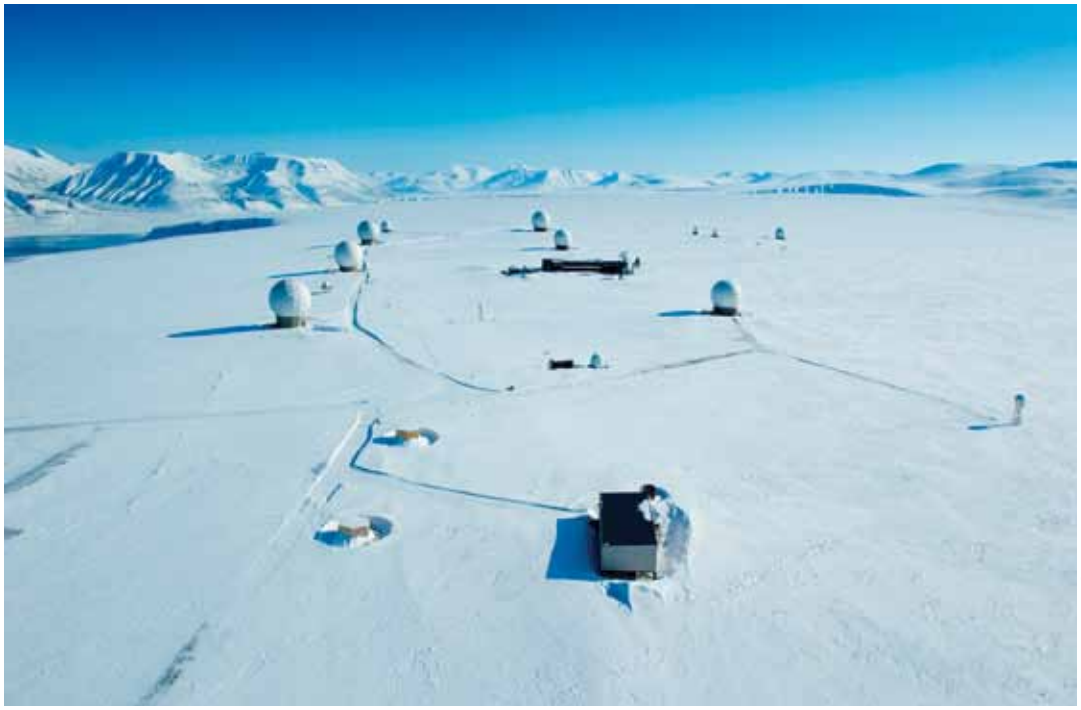
The chart below shows all the chemicals measured by Aura instruments and the altitude range of those measurements.



A-Train Ground System

Data taken by the satellite instruments is stored until it can be broadcast to a downlink facility through a high speed X-Band data link. Because polar orbiting satellites frequently pass over the Arctic and Antarctic, the data downlink facilities are located at high latitudes. NASA's major down link facilities are Poker Flat, Alaska, McMurdo Base, Antarctica and Svalbard, an archipelago in the Arctic Ocean north of mainland Europe. Svalbard at 74º-81º N is part of Norway. The Svalbard downlink antenna array (the domes) are shown below. Once the data are received at the downlink facility, they are sent via optical fiber network to processing facilities at Goddard Space Flight Center. The data are then distributed to the instrument teams for processing into geophysical measurements. The data are then sent to NASA Data Active Archive Centers where they are made available to users. The Finnish direct broadcast station receives OMI data as the satellite passes overhead. The data are processed at FMI and distributed over the web shortly after the overpass.

The Aura satellite also has direct broadcast capability through a smaller downlink antenna. This capability allows an investigator to receive data in near real time. The small building with the dome is the Finnish direct broadcast station that receives OMI data as the satellite passes overhead.



ANGIE KELLY, NASA

NASA's downlink facility in Svalbard, Norway located at 78^o North latitude. This is an ideal site for receiving data from polar-orbiting satellites like Aura, because these satellites pass within range of the station on every orbit.

The Finnish Meteorological Institute (FMI) hosts a Direct Broadcast receiving station in Sodankylä, Finland, 120 km north of the Arctic Circle.

Where to find Aura data

Aura data is delivered through the NASA Data and Information Services Center (DISC).

For HIRDLS, MLS and OMI, the data are held at the Goddard Earth Science DISC (http://daac.gsfc.nasa.gov/). Data can also be access through Giovanni (http://disc.sci.gsfc.nasa.gov/giovanni/)

For TES, the data is held at the NASA Langley Atmospheric Sciences Data Center (http://eosweb.larc.nasa.gov/)

The Aura validation data is held at the Aura validation data center at Goddard Space Flight Center (http://avdc.gsfc.nasa.gov/Overview/)

Aura Data users should download the user guides available at the instrument web sites and should contact the PI for additional questions about the data.

NASA operates a highly-modified McDonnell Douglas DC-8 jetliner as an airborne science laboratory. This aircraft has been used in several Aura validation campaigns.

Validation

Using validation data researchers adjust their algorithms and can detect subtle instrument problems.

Validating Aura Measurements

How do scientists know if the measurements made from a satellites orbiting 705km above the atmosphere are correct? Showing that the data are credible is called "validation." To validate Aura data the instrument teams compare their measurements against other satellite, aircraft, balloon and ground based measurements. Aura validation began shortly after launch and continued through 2008. The validation effort included a series of aircraft missions and balloon launches. Validation continues throughout the life of a satellite mission since instruments can change in subtle ways while in orbit.

In its initial phase measurement validation is simply a one-to-one comparison of Aura data with the validating data. Frequently this validating data is obtained in a campaign environment featuring observations from aircraft or the launch of specially instrumented balloons. However as time passes the validation teams began to build up long term data sets and statistical methods are used to uncover subtle differences between the Aura data and the validating data. The long term data is often obtained at ground-based sites which make almost continuous measurements during every satellite overpass.

Campaign	Location	Date
AVE Houston	Houston, TX	Oct.- Nov. , 2004
Polar AVE	Portsmouth, NH	Jan. -Feb., 2005
Costa Rica AVE	San Jose, Costa Rica	Jan. – Feb., 2006
INTEX-B	Western US, Hawaii, Alaska	March – May, 2006
TC4	San Jose, Costa Rica	July-Aug, 2007
ARCTAS	Canada, Alaska, Greenland	May-July, 2008

This is a list of field campaigns that utilized a variety of aircraft and ground-based platforms in support of Aura validation.

pg 50

The balloon comes from the NASA's Colombia Scientific Ballooning Facility

so the credit is just NASA.

Aircraft Campaigns

NASA's fleet of specially equipped high performance aircraft have been invaluable in gathering validation data for Aura.Measurements from aircraft are used to validate satellite observations over a broad range of latitudes. Aircraft measurements are obtained in campaigns that are designed to combine validation activities with investigations of other atmospheric processes. NASA uses several different aircraft for these campaigns in which validation measurements complement satellite measurements in scientific investigations. Three NASA aircraft are pictured above during a 2007 campaign in Costa Rica.

The WB-57 and ER-2 are high altitude aircraft, capable of flying into the lower stratosphere with a full payload of autonomous operated instruments.

Aura will be the first satellite to use an Unpiloted Aerial Vehicle (UAV), the Global Hawk for validation in the spring, 2009

A typical DC-8 instrument setup where a scientist flies along with his or her instrument. Air sample tubes are mounted on the wings and in windows. Aura scientists, like MLS team member Michele Santee shown above, often participate in field campaigns.

Balloon and Ground Based Validation

High altitude balloons with instrumented payloads are used to validate stratospheric measurements above the reach of the highest flying aircraft The instruments that can make the needed measurements are massive, and launching the balloons that can carry these instruments requires special launch facilities. There have been two Aura high altitude balloon launches during winter from a launch facility in northern Sweden and three during spring in the southwest United States. The payloads are usually recovered.

Small balloons (balloon sondes of the type shown here) are launched by hand, often at sites where ground based instruments are located or where aircraft campaigns are based. Balloon sondes provide inexpensive measurements with high vertical resolution up to the lower stratosphere. Small balloon instruments are limited to measurements of ozone, water vapor, temperature, and aerosols. The payloads are disposable.

Ground based remote sensing instruments used for validation of satellite data are part of an international network called the Network for Detection of Atmospheric Composition Change. Ground based instruments include lidars for profiles of ozone, aerosol, temperature, and water vapor as well as microwave radiometers, UV/Visible spectrometers and, FTIR spectrometers for other trace gases. These ground based measurements are often accompanied by balloon sonde launches for obtaining of ozone, aerosols, and water vapor profile measurements. Observations most useful for validation are made when the satellite is nearly overhead. Simultaneous measurements of the same constituent using different instruments are useful in sorting out differences between the ground-based measurements and satellite measurements. This approach lends confidence to satellite data set.

High altitude balloons can carry large payloads with complex instruments deep into the stratosphere. These balloons are launched using special equipment only once or twice a year.

The Mauna Loa observatory in Hawaii (below) has played an important role in validating Aura measurements

HOLGER VÖMEL, UNIVERSITY OF COLORADO, BOULDER

A 1200-g latex balloon is launched from Alajuela, Costa Rica carrying the University of Colorado Cryogenic Frostpoint Hygrometer (CFH) and an Electrochemical Cell (ECC) ozonesonde. It will ascend to 30 km, providing high-accuracy, high-resolution vertical profiles of water vapor, ozone, and temperature for Aura validation.

CHUCK BARDEEN, UNIVERSITY OF COLORADO, BOULDER.

Dr. Henry Selkirk and students from the Universidad de Costa Rica (UCR) steady the CFH/ECC balloon while it is filled during the Tico-sonde campaign.

The Table Mountain facility, located about 1.5 hours from the main JPL lab in Pasadena, CA houses the Fourier Transform Ultra-Violet Spectrometer (FTUVS) that has been used to validate Aura data. An intercomparsion of several ground-based instruments measuring NO_2 was also conducted there.

CHUCK BARDEEN

Karla Cerna, a student of the Universidad Nacional (UNA) in Heredia, Costa Rica, explains the preparation of the CFH/ECC sonde to Aura project scientist Mark Schoeberl.

The SAUNA campaigns took place in Sodankyla, Finland in spring 2006 and 2007. The main purpose was to verify the accuracy of several differrent types of ground-based ozone measurements for satellite validation in challenging high latitude conditions.

RICHARD MCPETERS

(Above and below and opposite page) Ozone damaged plant in the NASA Ozone Biomonitoring Garden.

The garden is full of plants that scientists have found to be ozone-sensitive. Many of the ozone sensitive species are fairly common and easy to grow, so they serve well for educational gardens.

Outreach E&PO

Aura Education and Public Outreach continues to build its educational portfolio. Aura has delivered a wealth of data to the scientific community. As a result, a wide variety of data are now available for educational purposes. These data have been distilled and distributed in various formats, depending on the audience.

Formal Education

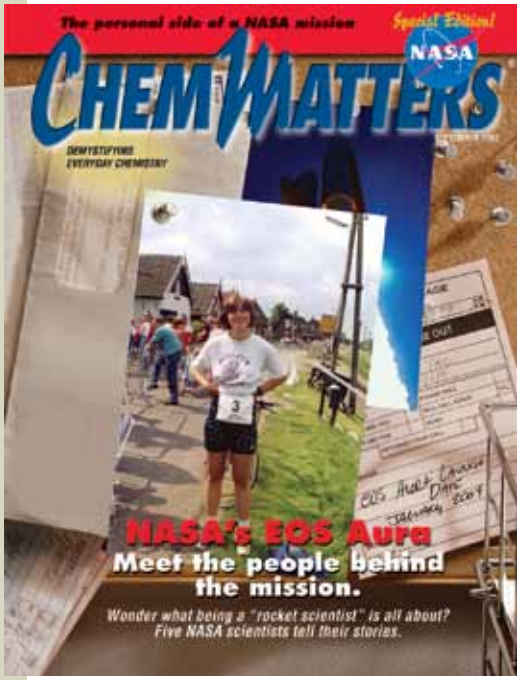
Air quality data have been the focus for the formal education activities. Lessons have been developed that study connections between energy production and air quality. These lessons make use of Aura data in graphical as well as numerical formats. All of the lessons that have used Aura data have been published in electronic format and can be found at the MY NASA DATA and Earth Exploration Toolbook websites.

In a partnership with the Howard B. Owens Science Center in Lanham, MD. Sixth-grade students from Prince George's County, MD are brought to Goddard and are given the opportunity to view Aura data using the Science on a Sphere facility. The ongoing partnership between Aura and the Owens Science Center has enabled over 1,000 students from the local area to view air quality data.

Aura Scientists also participate in the Netherlands Global Learning and Observations to Benefit the Environment (GLOBE) program.

Informal Education

The Aura team has developed a unique approach to engaging the public in atmospheric science data. In this approach we



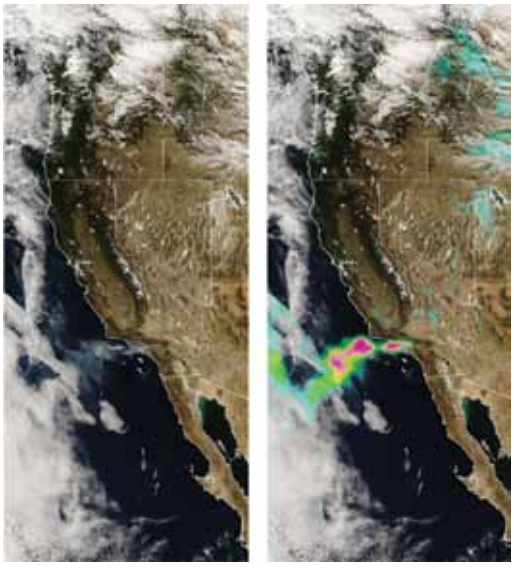
Aura published several issues in Chem Matters a high school newsletter sponsored by the American Chemical Society.

(lower right) Earth Today Kisok at NASA day in Annapolis Maryland. These Aura sponsored kiosks allow students to explore relationships between Aura data and other processes.

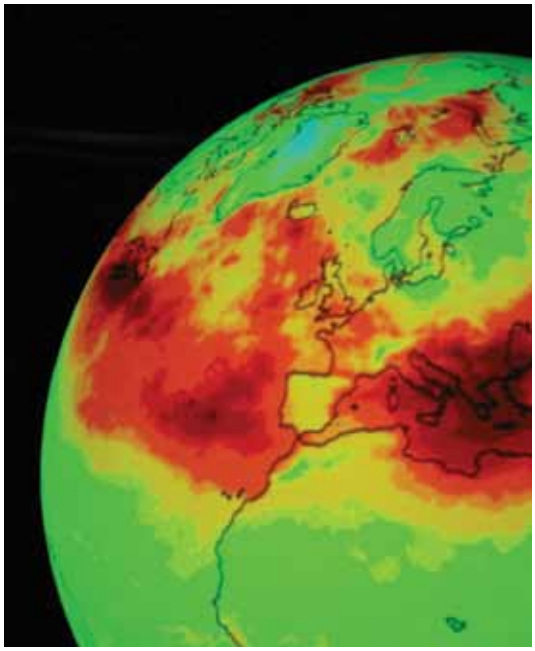
produce near real time image data products for display in a variety of systems. Aura images include NO_2, column ozone, tropospheric ozone, and aerosols. These are provided to Earth Today which is shown in the Smithsonian Air and Space Museum and Baltimore Museum of Science among others. Earth Today display system allows students to overlay Aura data with city lights (cities are a strong source of NO_2), clouds, rain, fires (from MODIS) and CO from (AIRS). Aura data is also being made available in near-real-time to Science on a Sphere and we are proposing to extend our capability to Magic Planet, and portable inflatable planetarium domes. These data are used to tell intriguing science stories through a variety of formats.

Outreach

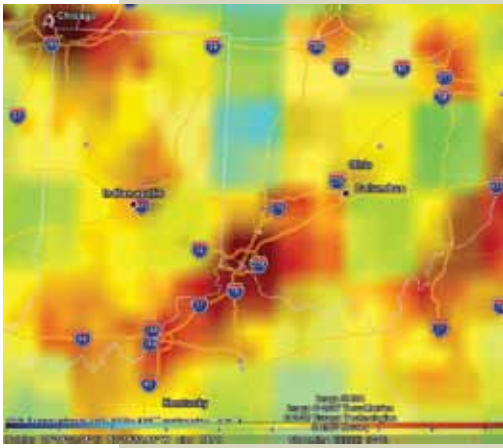
The Aura web site (http://aura.gsfc.nasa.gov/) provides the latest Aura news. The Aura team also works with the Earth Observatory to generate "Images of the Day" and has generated a variety of short movie clips showing the Aura orbit and instrument system and Aura in the A-Train. These clips are available through the web site.



(Left) Earth Observatory image of smoke over clouds detected by OMI off the coast of California



Science on the sphere showing tropospheric ozone data.



NO_2 displayed on Google Earth from MY NASA DATA.

Acknowledgements and Credit List

Project Science Office

M. R. Schoeberl, A. Douglass, J. Joiner

Project Scientist

E. Hilsenrath

Science Teams

HIRDLS

U. S. A. TEAM: L. Avallone, B. Boville, G. Brasseur, M. Coffey, T. Eden, D. Edwards , D. Kinneson, C. Leovy, B. Nardi , C. Randall, W. Randel, B. Toon

U. K. TEAM: D. Andrews, R. Harwood, M. McIntyre, H. Muller, C. Mutlow, A. O'Neill, J. Pyle, C. Rodgers, F. Taylor, G. Vaughan, R. Wells, J. Whitney, E. Williamson

MLS

U. S. A. TEAM: R. E. Cofield, L. Froidevaux, R. Jarnot, A. Lambert, N. Livesey, G. Manney, H. Pickett, W. Read, M. Santee, P. Siegel, J. Waters, D. Wu

U. K. TEAM: M. J. Filipiak, R. Harwood, H. Pumphrey

OMI

DUTCH TEAM: B. van den Oord, J. Claas, M. Dobber, M. Kroon, P. Veefkind, S. van Broekhoven, J. van den Bovenkamp, E. Brinksma, J. de Haan, R. Dirksen, R. Noordhoek, R. Voors

FINNISH TEAM: G. Leppelmeier, A. Mälkki, E. Kyrö, A. Tanskanen

U. S. A. TEAM: P. Bhartia, R. Cebula, K. Chance, D. Cunnold, J. Fishman, A. Fleig, L. Flynn, J. Gleason, D. Heath E. Hilsenrath, J. Joiner, A. Krueger, R. McPeters, G. Mount, S. Sander,I. Stajner, O. Torres, C. Trepte

INTERNATIONAL TEAM: I. Isaksen, D. Hauglustaine, U. Platt, P. Simon, I. Aben, F. Denterer, H. Kelder, P. Stammes, D. Swart, G. de Leeuw, F. Boersma, R. van Oss

TES

U. S. A. TEAM: S. Clough, M. Gunson, D. Jacob, J. Logan, F. Murcray, D. Rider, C. Rinsland, S. Sander, H. Worden

U. K. TEAM: C. Rodgers, F. Taylor

Brochure Team

Authors: M. R. Schoeberl, A. Douglass, J. Joiner with contributions from the Science Team.

Project Coordinator: Brooke and Heather?

Designer: Ellen Baker Smyth, Elle Designs

Contributing Writer/Editor: ?

Aura Team (L-R) R. Beer, J. Gille, P. Levelt, E. Hilsenrath, A. Douglass, M. Schoeberl, J. Waters, P. K. Bhartia, P. DeCola