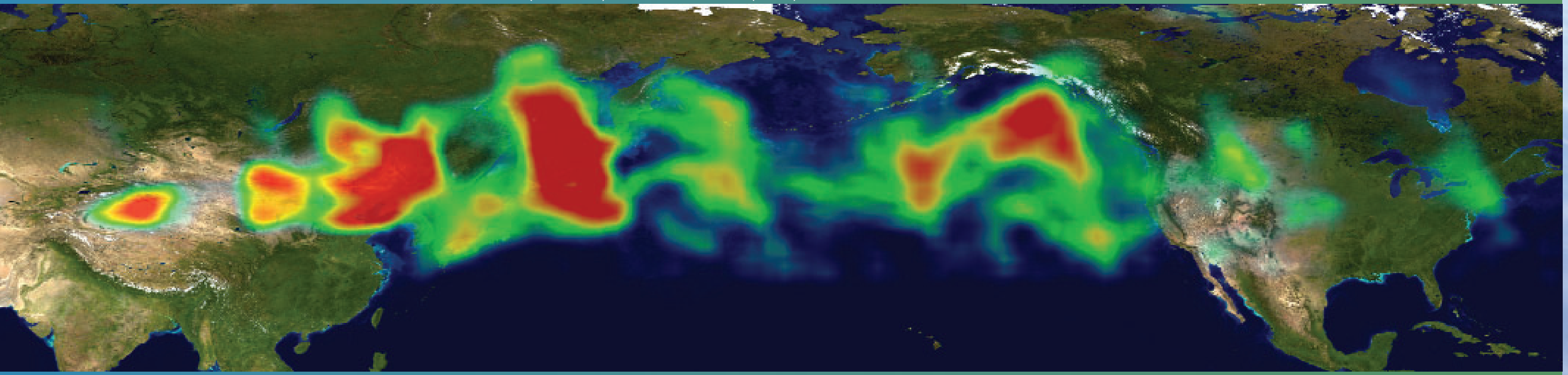
NASA Earth Science Enterprise

To Understand and Protect Our Home Planet

COLIN SEFTOR (RAYTHEON) AND CHRISTINA HSU (UMBC)



Earth Observing System Aura

Goddard Space Flight Center
Greenbelt, Maryland 20771

NP-2004-4-626-GSFC

PHOTOS OF EARTH'S ATMOSPHERE COURTESY OF EARTH SCIENCES AND IMAGE ANALYSIS LABORATORY, NASA JOHNSON SPACE CENTER. AURA SATELLITE IMAGE BY JESSE ALLEN (SSAI)

EARTH OBSERVING SYSTEM

Aura

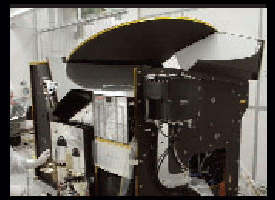
NASA EARTH SCIENCE ENTERPRISE

A Mission Dedicated to the Health of the Earth's Atmosphere

How is the Earth changing and what are the consequences for life on Earth?

The Aura mission will explore the atmosphere's natural variability and its response to human activity so that we can better predict changes in the Earth system.

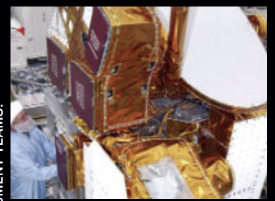
AURA INSTRUMENTS



HIRDLS: USA, United Kingdom

High Resolution Dynamics Limb Sounder

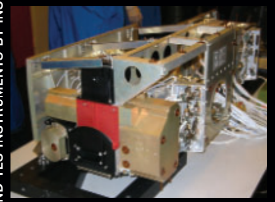
Stratospheric and upper tropospheric trace gases and aerosols measured by infrared limb emission



MLS: USA

Microwave Limb Sounder

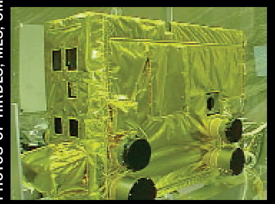
Stratospheric and upper tropospheric trace gases measured by microwave limb emission



OMI: Netherlands, Finland

Ozone Monitoring Instrument

Tropospheric and stratospheric ozone, aerosols, air quality and surface ultraviolet radiation measured by backscatter ultraviolet and visible radiation



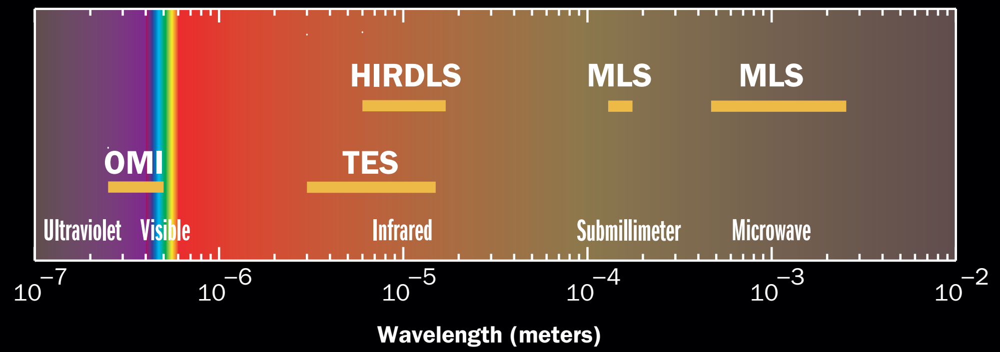
TES: USA

Tropospheric Emission Spectrometer

Tropospheric and lower stratospheric trace gases and aerosols measured by nadir and limb infrared emission

PHOTOS OF HIRDLS, MLS, OMI, AND TES INSTRUMENTS BY INSTRUMENT TEAMS.

Electromagnetic Spectrum



The various gases in the atmosphere absorb or emit radiation at specific wavelengths depending on their molecular structure. Aura's instruments will measure atmospheric constituents by observing the Earth over a large range in the electromagnetic spectrum. Measurements will be made of solar backscatter radiation in the ultraviolet and visible regions and of thermal emission in the infrared and microwave regions.

VISUALIZATION OF EARTH HORIZON BY JESSE ALLEN (SSAI)

Aura

A Mission Dedicated to the Health of the Earth's Atmosphere

Earth's atmosphere provides sustenance to all living things and protects life from the harsh space environment

The Earth's Ozone Shield protects all life

Stratospheric ozone has decreased 3% globally between 1980 and 2000 and thins by 50% over Antarctica in winter and spring. Depletion of the ozone layer allows more ultraviolet radiation to reach the surface. Increases in ultraviolet radiation are known to have harmful effects on living things. The Montreal Protocol and its amendments have banned the use of ozone destroying chemicals and the rate of ozone depletion seems to have slowed. Climate change will have an impact on how quickly ozone recovers.

The Earth's Air Quality is fundamental to public health and ecosystems

The atmosphere has no political boundaries; air pollution moves great distances across oceans and continents. The quality of air has degraded over certain parts of the world and has become a health issue. Severe air pollution episodes increase mortality.

The Earth's Climate is affected by changes in atmospheric composition

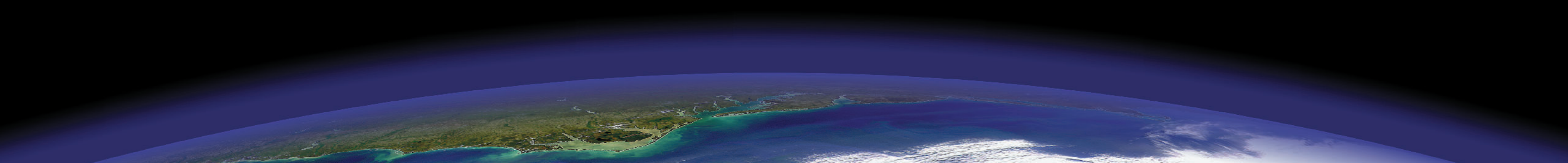
It is undeniable that human activity is beginning to alter the climate. The global rise in surface temperatures since the 1950's is correlated with the increase in greenhouse gases. Changes in carbon dioxide, methane, nitrous oxide, ozone, cloud cover, water vapor and aerosols all contribute to climate change.

Aura is designed to answer questions about changes in our life-sustaining atmosphere

Aura's four instruments will study the atmosphere's chemistry and dynamics. Aura's measurements will enable us to investigate questions about ozone trends, air quality changes and their linkage to climate change.

Aura's measurements will provide accurate data for predictive models and provide useful information for local and national agency decision support systems.

Aura is the third in a series of large Earth observing platforms to be flown by the National Aeronautics and Space Administration (NASA) with international contributions. Aura along with EOS Terra (launched December, 1999) and Aqua (launched May, 2002) will provide an unprecedented view of the global Earth system.



Ozone Facts

- In the present day stratosphere, the natural balance of ozone chemistry has been altered by man-made chemicals, such as chlorofluorocarbons (CFCs).
- Recent data show that ozone is being depleted at a slower rate than a decade ago, but it is too soon to tell if this trend is a result of the international protocols restricting CFC production.
- Aura's instruments will measure the total ozone column, ozone profiles and gases important in ozone chemistry.

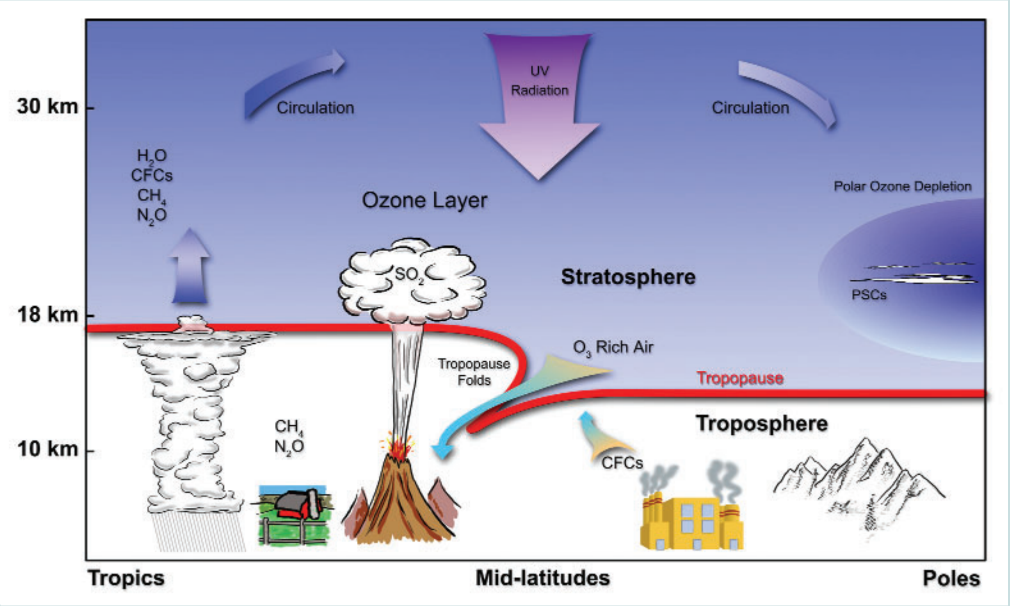
Is the stratospheric ozone layer recovering?

The stratospheric ozone layer shields life on Earth from harmful solar ultraviolet (UV) radiation (wavelengths shorter than 340 nm). Research has clearly shown that excess exposure to UV radiation is harmful to agriculture and causes skin cancer and eye problems. Excess UV radiation may suppress the human immune system.

Ozone is formed naturally in the stratosphere through break-up of oxygen molecules (O_2) by solar UV radiation. Individual oxygen atoms can combine with O_2 molecules to form ozone molecules (O_3). Ozone is destroyed when an ozone molecule combines with an oxygen atom to form two oxygen molecules, or through catalytic cycles involving hydrogen, nitrogen, chlorine or bromine containing species. The atmosphere maintains a natural balance between ozone formation and destruction.

The natural balance of chemicals in the stratosphere has changed, particularly due to the presence of man-made chlorofluorocarbons (CFCs). CFCs are non-reactive and accumulate in the atmosphere. They are destroyed in the high stratosphere where they are no longer shielded from UV radiation by the ozone layer.

Stratospheric Chemical Processes



The stratospheric ozone layer shields us from solar ultraviolet radiation. Chemicals that destroy ozone are formed by industrial and natural processes. With the exception of volcanic injection and aircraft exhaust, these chemicals arrive in the stratosphere through the tropical upwelling region. Methane (CH_4), chlorofluorocarbons (CFCs), nitrous oxide (N_2O) and water are injected into the stratosphere through towering tropical cumulus clouds. These compounds are broken down by the ultraviolet radiation in the stratosphere. Byproducts of the breakdown of these chemicals are radicals such as NO_2 and ClO that catalyze ozone destruction. Aerosols and clouds can accelerate ozone loss through reactions on cloud surfaces. Thus volcanic clouds and polar stratospheric clouds can indirectly contribute to ozone loss.

Polar Stratospheric Clouds

Thin clouds made of ice, nitric acid, and sulfuric acid mixtures form in the polar stratosphere when temperatures drop below -88 C (-126 F). In such polar stratospheric clouds (PSCs) active forms of chlorine are released from their reservoirs. This particular PSC appeared over Iceland at an altitude of 22 km on February 4, 2003. Its beautiful colors result from refraction of sunlight by its very small ice crystals.

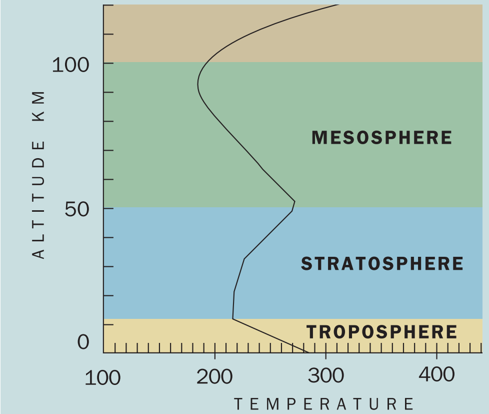
Destruction of CFCs yields atomic chlorine, an efficient catalyst for ozone destruction. Other man-made gases such as nitrous oxide (N_2O) and bromine compounds are broken down in the stratosphere and also participate in ozone destruction.

Satellite observations of the ozone layer began in the 1970s when the possibility of ozone depletion was just becoming an environmental concern. NASA's Total Ozone Mapping Spectrometer (TOMS) and Stratospheric Aerosol and Gas Experiment (SAGE) have provided long-term records of ozone. In 1985 the British Antarctic Survey reported an unexpectedly deep ozone depletion over Antarctica. The annual occurrence of this depletion, popularly known as the ozone hole, alarmed scientists. Specially equipped high-altitude NASA aircraft established that the ozone hole was due to man-made chlorine. TOMS and SAGE data also showed smaller but significant ozone

continues on page 4

Ozone Warms the Stratosphere

From the surface, temperatures decrease with altitude. Then, in the stratosphere, temperatures begin to rise, because ozone absorbs solar UV energy, heating the stratosphere. Above 50 km ozone heating falls off and the temperatures decrease again. Above 80 km very high energy solar radiation begins to heat the atmosphere again.



Sources, Reservoirs and Radicals

Source gases – These gases are nearly inert in the lower atmosphere, but they are sources of ozone-destroying radicals when broken apart by ultraviolet radiation, reactions with the hydroxyl radical (OH), or reactions with excited atomic oxygen (O^1D). CFCs are sources of chlorine radicals and N_2O is the source of nitrogen radicals.

Reservoirs – These gases are less inert than source gases but do not destroy ozone themselves. Reservoir gases are formed when radicals react with source gases, for example, chlorine atoms (Cl) react with methane molecules (CH_4) to produce the reservoir hydrochloric acid (HCl). Reservoirs are also formed when radicals react with each other, for example, OH reacts with nitrogen dioxide (NO_2) to produce nitric acid (HNO_3).

Radicals – These are the ozone destroying gases such as chlorine monoxide (ClO) and nitric oxide (NO). Radicals are freed from their reservoir gases by photolysis and by chemical reactions involving reservoir gases and other radicals.

When we try to pick out anything by itself, we find it is tied to everything else in the universe.

John Muir
(1838-1914)
U. S. naturalist,
explorer

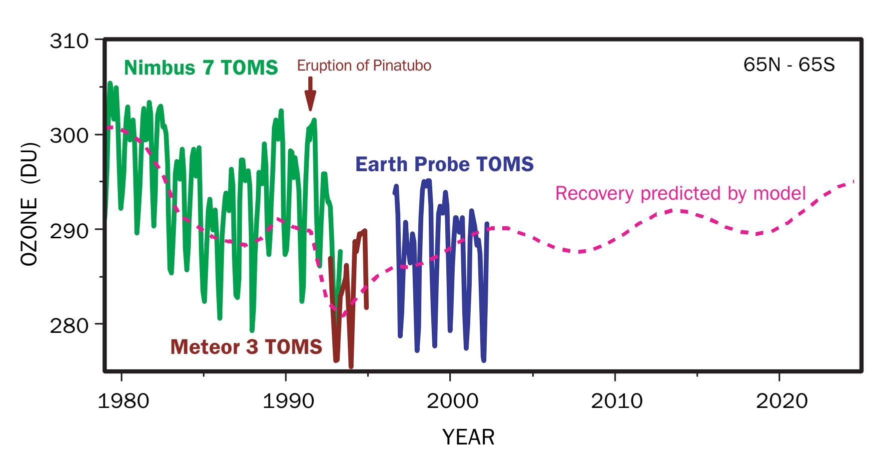
losses outside the Antarctic region. In 1987 an international agreement known as the Montreal Protocol restricted CFC production. In 1992, the Copenhagen amendments to the Montreal Protocol set a schedule to eliminate all production of CFCs.

Severe ozone depletion occurs in winter and spring over both polar regions. The polar stratosphere becomes very cold in winter because of the absence of sunlight and because strong winds isolate the polar air. Stratospheric temperatures fall below –88 C. Polar stratospheric clouds (PSCs) form at these low temperatures. The reservoir gases HCl and $ClONO_2$ react on the surfaces of cloud particles and release chlorine.

Ground-based data have shown that CFC amounts in the troposphere are leveling off, while data from the Halogen Occultation Experiment (HALOE) on the Upper Atmosphere Research Satellite (UARS) have shown that amounts of HCl, a chlorine reservoir that is produced when CFCs are broken apart, are leveling off as well (See Global HCl figure). Recent studies have shown that the rate of ozone depletion is also decreasing.

Recovery of the ozone layer may not be as simple as eliminating the manufacture of CFCs. Climate change will alter ozone recovery because greenhouse gas increases will cause the stratosphere to cool. This cooling may temporarily slow the recovery of the ozone layer in the polar regions, but will accelerate ozone recovery at low and middle latitudes.

TOMS Global Ozone Compared with Model

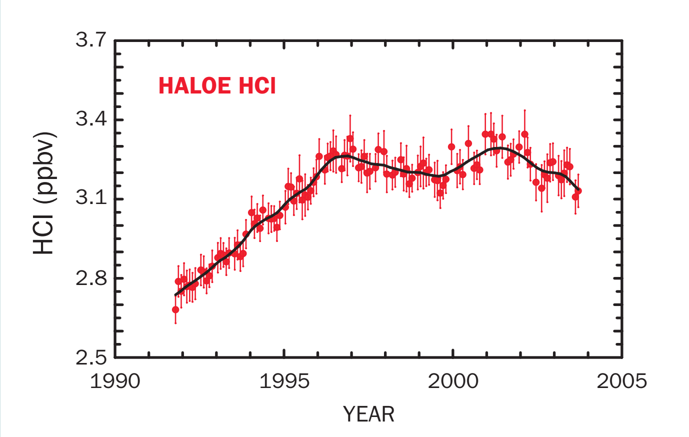


CHARLES JACKMAN AND RICHARD MCPETERS (BOTH NASA GSFC)

Comparing models with observations allows us to check how accurately we can predict stratospheric ozone trends. In the image to the left, TOMS global ozone measurements (Nimbus 7, Meteor 3, Earth Probe) show that ozone has a strong annual cycle, and decreases following a major volcanic eruption. Global ozone has decreased overall by about 3% since 1980. A model that calculates annual mean ozone amounts compares favorably with TOMS observations and predicts ozone layer recovery after 2020. The model total ozone varies slowly due to the 11-year solar cycle. Aura's OMI will continue the TOMS total ozone record.

Global HCl

UARS HALOE measurements of stratospheric chlorine (HCl) at 55km show that international controls on CFCs are working. HCl amounts have leveled off and are now decreasing. Aura's MLS will continue the HALOE HCl record.

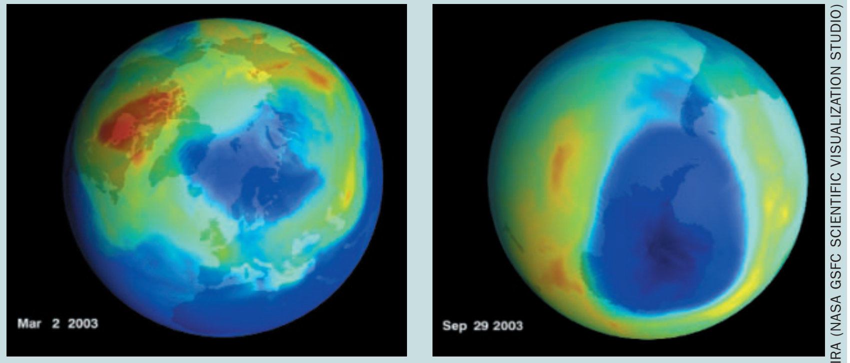


JAMES M. RUSSELL III (HAMPTON UNIVERSITY)

What will Aura do?

Aura's instruments will observe the important sources, radicals, and reservoir gases active in ozone chemistry. Aura data will improve our capability to predict ozone change. Aura data will also help untangle the roles of transport and chemistry in determining ozone trends.

Winter Polar Ozone in the Northern/Southern Hemisphere



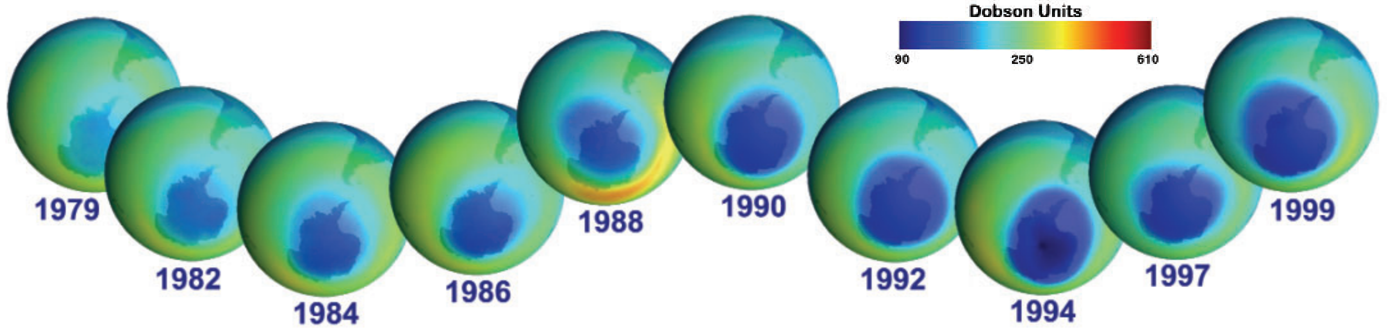
GREG SHIRA (NASA GSFC SCIENTIFIC VISUALIZATION STUDIO)

Northern Hemisphere

At both polar regions, climate and chemistry combine to deplete ozone during spring months. Dark blue indicates lowest ozone amounts. Arctic total ozone amounts seen by TOMS in March 2003 (above, left) were among the lowest ever observed in the northern hemisphere.

Southern Hemisphere

The Antarctic ozone hole of 2003 (above, right) was the second largest ever observed. The dark blue indicates the region of maximum ozone depletion. TOMS images (below) illustrate the development of the ozone hole during the 1980's and 1990's.



BARBARA SUMMEY (SSAI)

The Upper Atmosphere Research Satellite

The first comprehensive satellite measurements of stratospheric gases, solar particle and radiation fluxes and upper atmosphere winds were made by NASA's Upper Atmosphere Research Satellite (UARS). UARS was deployed in 1991 from the Space Shuttle Discovery and continues to gather data from five of its 10 instruments. UARS was designed to study the chemistry and dynamics of the middle and upper stratosphere while Aura is designed to study the lower stratosphere and upper troposphere. Aura will continue many of the measurements pioneered by UARS.

umpgal.gsfc.nasa.gov/uars-science.html

JESSE ALLEN (SSAI)

What are the processes controlling air quality?

Air Quality Facts

- Air quality is a continuing environmental concern because poor air quality impacts human health and agricultural productivity.
- Ozone precursors are pollutant gases such as carbon monoxide (CO), nitrogen dioxide (NO_2), methane (CH_4) and other hydrocarbons that react in the troposphere to produce ozone. Sulphur Dioxide (SO_2) is a precursor for sulfate aerosol.
- Worldwide emissions of nitrogen dioxide, carbon monoxide, volatile hydrocarbons and aerosols have increased considerably, but there is still uncertainty in the emission rates and distinctions between anthropogenic and natural sources of these emissions.
- Aura measures and maps five of the EPA's six "criteria pollutants," helping to improve emissions inventories and to distinguish between anthropogenic and natural sources.

Agriculture and industrial activity have grown dramatically along with the human population. Consequently, in parts of the world increased emissions of pollutants have significantly degraded air quality. Respiratory problems and even premature death due to air pollution occur in urban and some rural areas of both the industrialized and developing countries. Wide-spread burning for agricultural purposes (biomass burning) and forest fires also contribute to poor air quality, particularly in the tropics. The list of culprits in the degradation of air quality includes tropospheric ozone, a toxic gas, and the chemicals that form ozone. These ozone precursors are nitrogen oxides, carbon monoxide, methane, and other hydrocarbons. Human activities such as biomass burning, inefficient coal combustion, other industrial activities, and vehicular traffic all produce ozone precursors.

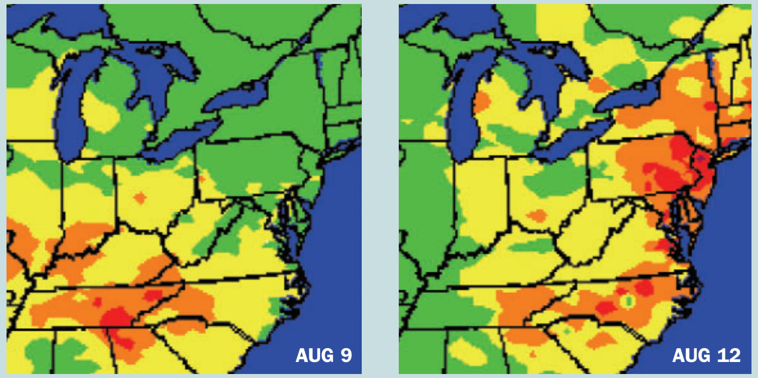
The U.S. Environmental Protection Agency (EPA) has identified six criteria pollutants: carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, lead, and particulates (aerosols). Of these six pollutants, ozone has proved the most difficult to control. Ozone chemistry is complex making it difficult to quantify the contributions to poor local air quality. Pollutant emission inventories needed for predicting air quality are uncertain by as much as 50 percent. Also uncertain is the amount of ozone that enters the troposphere from the stratosphere.

For local governments struggling to meet national air quality standards, knowing more about the sources and transport of air pollutants has become an important issue. Most pollution sources are local but satellite observations show that winds can carry pollutants for great distances, for example from the western and mid-western states to the east coast of the United States, and sometimes even from one continent to another. Observations and models show that pollutants from Southeast Asia contribute to poor air quality in India. Pollutants crossing from China to Japan reach the west coast of the United States. Pollutants originating in the United States can reduce air quality in Europe. Precursor gases for as much as ten percent of ozone in surface air in the United States may originate outside the country. We have yet to quantify the extent of inter-regional and inter-continental pollution transport.

continues on page 8

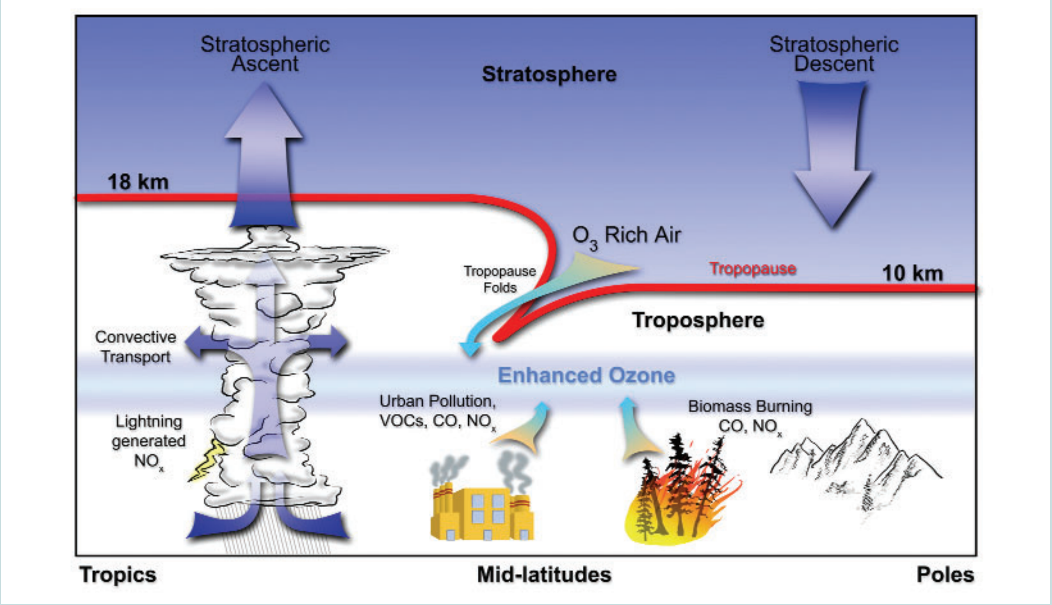
Forecasting Severe Pollution Events

NASA is working with the Environmental Protection Agency and the National Oceanographic and Atmospheric Administration to examine how models will be used to forecast pollution events. Models use satellite data to begin a forecast. Satellites launched before Aura provide rough estimates of ozone and aerosols. Aura will provide more detailed maps of pollutants such as ozone and NO_2 that can be combined with weather forecast models. These two images from the EPA AirNow website illustrate what these models will be able to do. The images show that the area of unhealthy surface ozone (red) moves from Tennessee (left panel) to eastern Pennsylvania and New Jersey (right panel) in the course of three days. In addition to forecasting, satellite data and models can discriminate between locally produced pollution and pollution that is brought by transport.



U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA) AND NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)

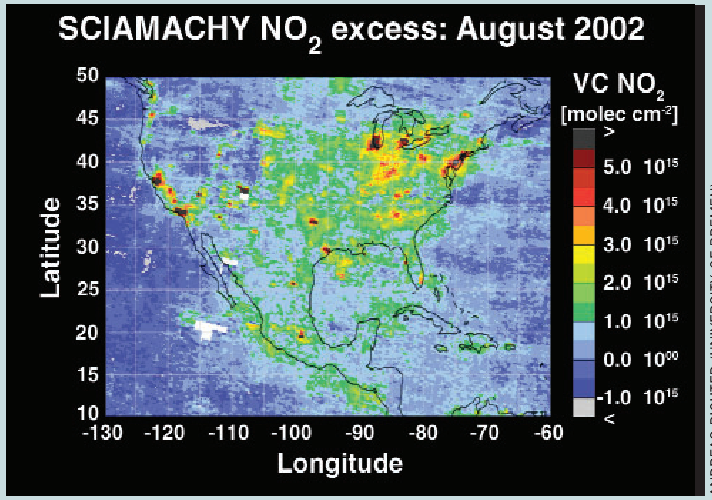
The Sources of Tropospheric Ozone



BARBARA SUMMEY (SSAI)

Tropospheric ozone comes from several sources. Biomass burning and industrial activity produce CO and volatile organic compounds (VOCs) which are oxidized to form ozone. Nitrogen oxides (NO_x) from industrial processes, biomass burning, automobile exhaust and lightning also form tropospheric ozone. A small amount of tropospheric ozone also comes from the stratospheric ozone layer.

SCIAMACHY Measurement



ANDREAS RICHTER (UNIVERSITY OF BREMEN)

SCIAMACHY is a German, Dutch and Belgian instrument on the European Space Agency Envisat satellite. SCIAMACHY is able to estimate the monthly average of tropospheric NO_2 amounts over the United States. High levels of NO_2 correspond to urban locations and special emission sites like power plants. OMI will make similar measurements with higher horizontal resolution and daily global coverage.

The strongest arguments prove nothing so long as the conclusions are not verified by experience. Experimental science is the queen of sciences and the goal of all speculation.

Roger Bacon
13th Century English philosopher, scientist

Long Range Pollution Transport

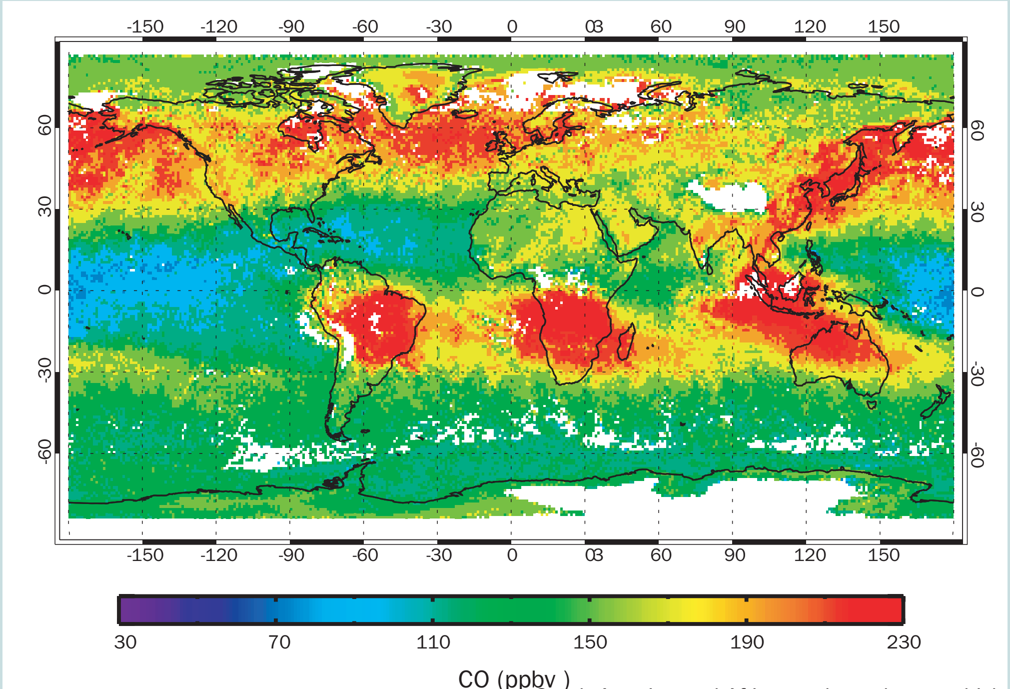
The atmosphere can transport pollutants long distances from their source. Satellite measurements by EOS Terra's MOPITT instrument have shown carbon monoxide streams extending almost 18,000 km from their source (this page). TOMS has tracked dust and smoke events from Northern China to the east coast of the United States (see back cover).

On July 7, 2002, MODIS on EOS-Terra and TOMS captured smoke from Canadian forest fires as the winds transported it southward (see page 9). This pollution event was responsible for elevated surface ozone levels along the east coast. TOMS has high sensitivity to aerosols like smoke and dust when they are elevated above the surface layers. OMI will make similar measurements with better spatial resolution and will provide new information about aerosol characteristics.

What will Aura do?

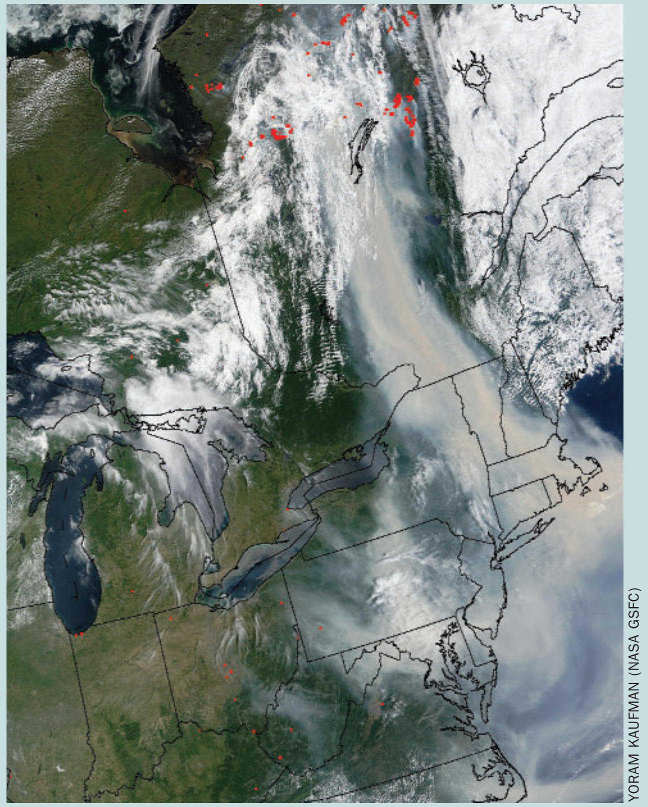
The Aura instruments are designed to study tropospheric chemistry; together Aura's instruments provide global monitoring of air pollution on a daily basis. They measure five of the six EPA criteria pollutants (all except lead). Aura will provide data of suitable accuracy to improve industrial emission inventories, and also to help distinguish between industrial and natural sources. Because of Aura, we will be able to improve air quality forecast models.

Carbon Monoxide

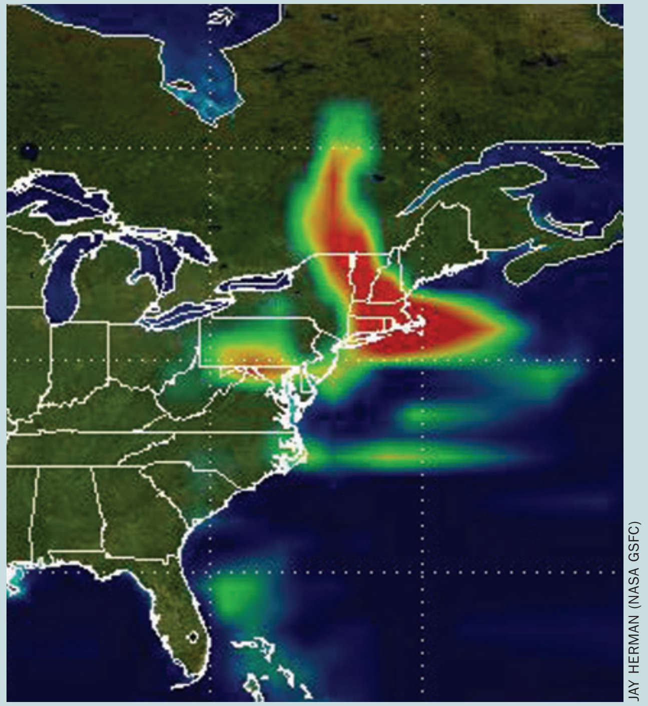


Biomass burning and urban pollution plumes can be followed using measurements of CO from MOPITT on EOS Terra. Agricultural burning in South America and Africa produce plumes which propagate into the South Atlantic. The African plume also propagates into the Indian Ocean. Biomass. Burning in Southeast Asia produces a plume that extends across the Pacific.

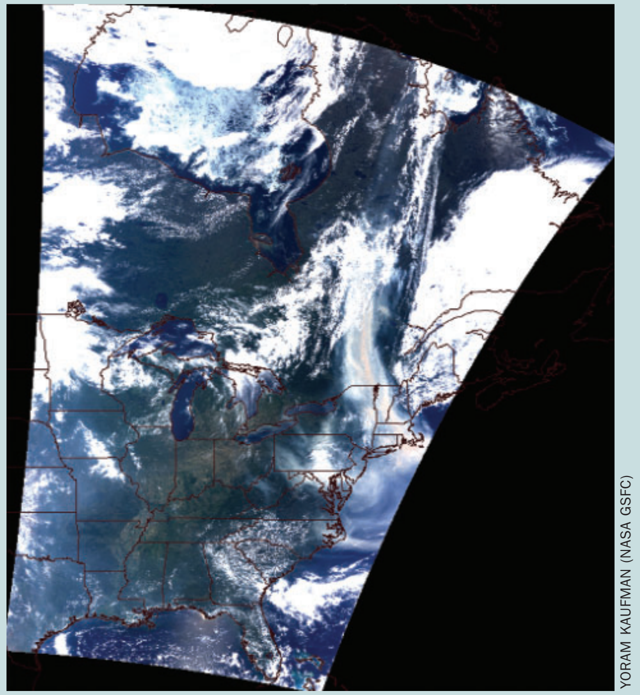
Two Satellite Views of Pollution Transport

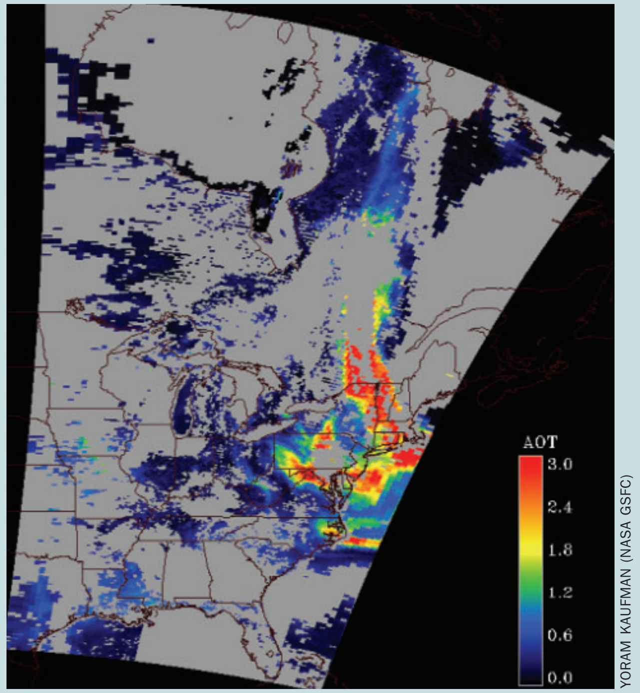


MODIS July 7 ortho-rectified image shows smoke streaming southward from forest fires (red) in Canada.



TOMS July 7 image shows smoke streaming southward from forest fires in Canada.





Upper image shows raw RGB MODIS view of July 7, 2002 smoke event. Lower image shows aerosol large mode particle fraction estimated using other MODIS data. Particles coagulate with time, so the largest particles are seen farthest from the fire.

How is Earth's climate changing?

Climate Change Facts

- Like carbon dioxide, ozone, aerosols, and water vapor contribute to climate change.
- Gases such as carbon dioxide (CO_2), water vapor (H_2O) and ozone heat the troposphere by trapping infrared radiation that would otherwise escape to space. Trapping infrared radiation is called "the greenhouse effect" and the gases that absorb this radiation are called "greenhouse gases."
- Improved knowledge of the sources, sinks and the distribution of greenhouse gases are needed for accurate predictions of climate change.
- Aura's measurements of ozone, water vapor and aerosols in the troposphere and lower stratosphere will improve climate prediction.

Carbon dioxide and other gases trap infrared radiation that would otherwise escape to space. This phenomenon, the greenhouse effect, makes the Earth habitable. Increased atmospheric emissions from industrial and agricultural activities are causing climate change. Industry and agriculture produce trace gases that trap infrared radiation. The concentrations of many of these gases have increased and thus have added to the greenhouse effect. Since the turn of the century, the global mean lower tropospheric temperature has increased by more than 0.4 C. This increase has been greater than during any other century in the last 1000 years.

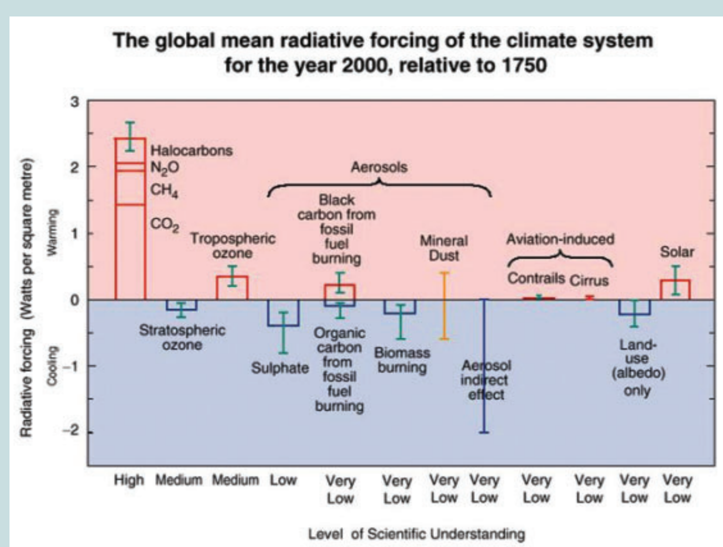
Ozone plays multiple roles in climate change, because it absorbs both ultraviolet radiation from the sun and infrared radiation from the Earth's surface. Tropospheric ozone is as important as methane as a greenhouse gas contributor to climate change. An accurate measurement of the distribution of tropospheric ozone will improve climate modeling and climate predictions.

Aerosols are an important but uncertain agent of climate change. Aerosols alter atmospheric temperatures by absorbing and scattering radiation. Aerosols can either warm or cool the troposphere. Therefore, aerosols also modify clouds and affect precipitation. Sulfate aerosols can reduce cloud droplet size, making clouds brighter so that they reflect more solar energy. Black carbon aerosols strongly absorb solar radiation, warming the mid-troposphere and reducing cloud formation. Poor knowledge of the global distribution of aerosols contributes to a large uncertainty in climate prediction.

Ozone absorbs solar radiation, warming the stratosphere. Man-made chlorofluorocarbons have caused ozone depletion, leading to lower temperatures. Low temperatures, in turn, lead to more persistent polar stratospheric clouds and cause further ozone depletion in polar regions.

Global Climate Change

The chart at right distinguishes among various human and natural agents of global climate change between 1750 and 2000. Greenhouse gases have been the most influential agents of warming, and sulphate aerosols have been the most influential agents of cooling. Aura measurements will help climate models by measuring stratospheric and tropospheric ozone and aerosol amounts. Aura measurements will also help untangle climate feedbacks by measuring upper tropospheric water vapor and cirrus clouds.



JAMES HANSEN (NASA GISS)

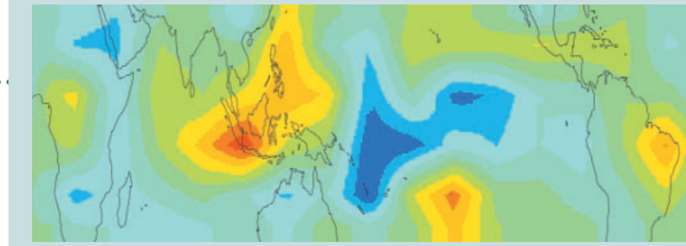
Increasing carbon dioxide also affects the climate of the upper atmosphere. Where the atmosphere is thin, increasing CO_2 emits more radiation to space, thus cooling the environment. Observations show that over recent decades, the mid to upper stratosphere has cooled by 1 to 6 C (2 to 11 F) primarily due to increases in CO_2. This cooling will produce circulation changes in the stratosphere that will change how trace gases are transported.

Water vapor is the most important greenhouse gas. Some measurements suggest that water vapor is increasing in the stratosphere. This increase may be due to changes in the transport of air between the troposphere and the stratosphere caused by climate change, or it could be due to changes in the microphysical processes within tropical clouds. More measurements of upper tropospheric water vapor, trace gases and particles are needed to untangle the cause and effect relationships of these various agents of climate change. We can verify climate models of the atmosphere only with global observations of the atmosphere and its changes over time.

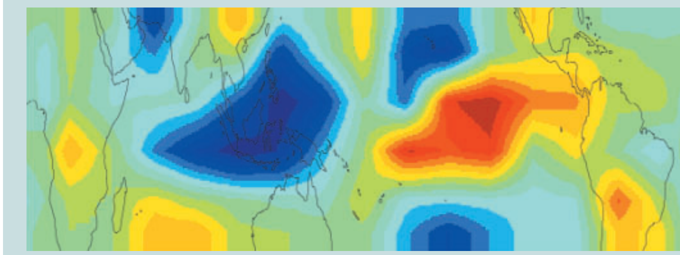
What will Aura Do?

Aura will measure greenhouse gases such as methane, water vapor, and ozone in the upper troposphere and lower stratosphere. Aura also will measure both absorbing and reflecting aerosols in the lower stratosphere and lower troposphere, water vapor measurements inside the high tropical clouds, and high vertical resolution measurements of some greenhouse gases in a broad swath (down to the clouds) across the tropical upwelling region. All of these measurements contribute key data for climate modeling and prediction.

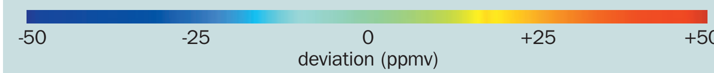
UARS MLS Upper Tropospheric Water Vapor and El Niño



Sept 1996 normal year



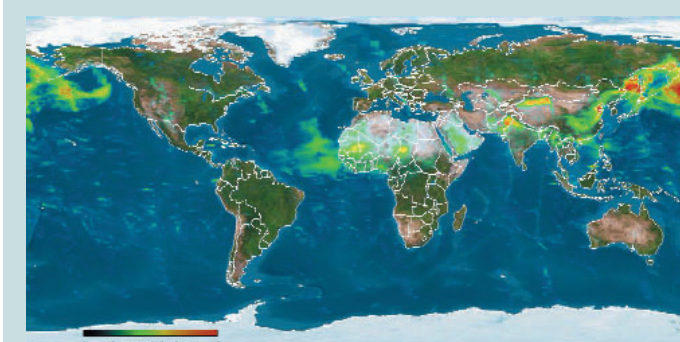
Sept 1997 developing El Niño Year



WILLIAM READ (NASA JPL)

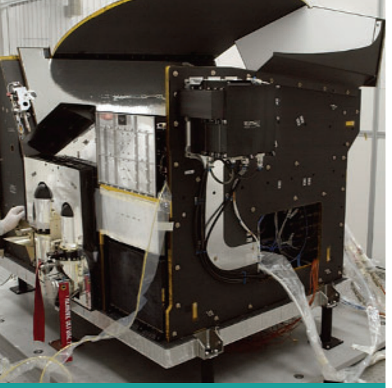
Water vapor measurements from MLS on UARS show the contrast between 1996 (a "normal" year) and 1997 (an "El Niño" year). In 1996 the most convection and the highest mixing ratios for tropical upper tropospheric water vapor (red) occur over Indonesia; the lowest mixing ratios for tropical upper tropospheric water vapor (blue) occur in the eastern Pacific. In 1997 the sea surface temperatures in the tropical eastern Pacific are much warmer than in 1996, and the region of intense convection shifts eastward away from Indonesia. The situation is reversed in 1997 from 1996 with the highest mixing ratios for upper tropospheric water vapor in the eastern Pacific, and very low mixing ratios over Indonesia.

Earth Probe TOMS Aerosol Index



JAY HERMAN (NASA GSFC)

Aerosols affect climate both directly by reflecting and absorbing sunlight and indirectly by modifying clouds. The TOMS aerosol index is an indicator of smoke and dust absorption. The image shows aerosols crossing the Atlantic and Pacific oceans. Dust from the Sahara desert is carried westward toward the Americas. Asian dust and pollution travel to the Pacific Northwest.



HIRDLS INSTRUMENT TEAM

High Resolution Dynamics Limb Sounder
HIRDLS

HIRDLS Instrument Characteristics

- HIRDLS is an advanced, scanning 21-channel infrared radiometer observing the 6-17 micron thermal emission of the Earth's limb.
- Infrared instruments, without HIRDLS horizontal scanning capability, have flown on previous NASA atmospheric research satellites such as Nimbus 7 and UARS.
- HIRDLS looks backward and scans both vertically and horizontally across the satellite track. Very precise gyroscopes provide instrument pointing information. To detect the weak infrared radiation from the Earth's limb, HIRDLS detectors have to be kept at temperatures below liquid nitrogen. An advanced cryogenic refrigerator will keep the detectors cool.

HIRDLS is an infrared limb-scanning radiometer measuring trace gases, temperature, and aerosols in the upper troposphere, stratosphere, and mesosphere. The instrument will provide critical information on atmospheric chemistry and climate. Using vertical and horizontal limb scanning technology HIRDLS will provide accurate measurements with daily global coverage at high vertical and horizontal resolution. The University of Colorado, the National Center for Atmospheric Research (NCAR), Oxford University (UK) and Rutherford Appleton Laboratory (UK) designed the HIRDLS instrument. Lockheed Martin built and integrated the instrument subsystems. The National Environmental Research Council funded the United Kingdom participation.

HIRDLS makes key contributions to each of Aura's three science questions. A summary of HIRDLS data products appears on page 29.

HIRDLS Contributions to Understanding Stratospheric Ozone

The largest ozone depletions occur in the polar winter lower stratosphere. HIRDLS will retrieve high vertical resolution daytime and nighttime ozone profiles in this region.

HIRDLS will measure NO_2, HNO_3 and CFCs, gases that play a role in stratospheric ozone depletion. Although international agreements have banned their production, CFCs are long-lived and will remain in the stratosphere for several more decades. By measuring profiles of the long-lived gases at 1.2 km vertical resolution, from the upper troposphere into the stratosphere, HIRDLS will make it possible to quantify the transport of air from the troposphere into the stratosphere.

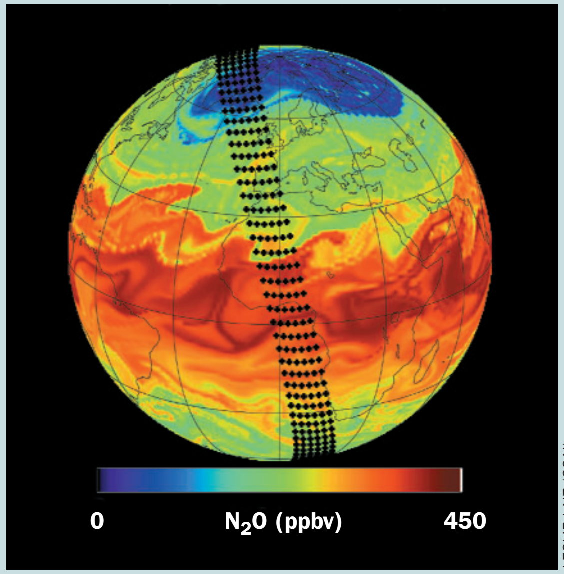
HIRDLS Contributions to Understanding Air Quality

HIRDLS will measure ozone, nitric acid, and water vapor in the upper troposphere and lower stratosphere. With these measurements, scientists will be able to estimate the amount of stratospheric air that descends into the troposphere and will allow us to separate natural ozone pollution from man-made sources.

HIRDLS Contributions to Understanding Climate Change

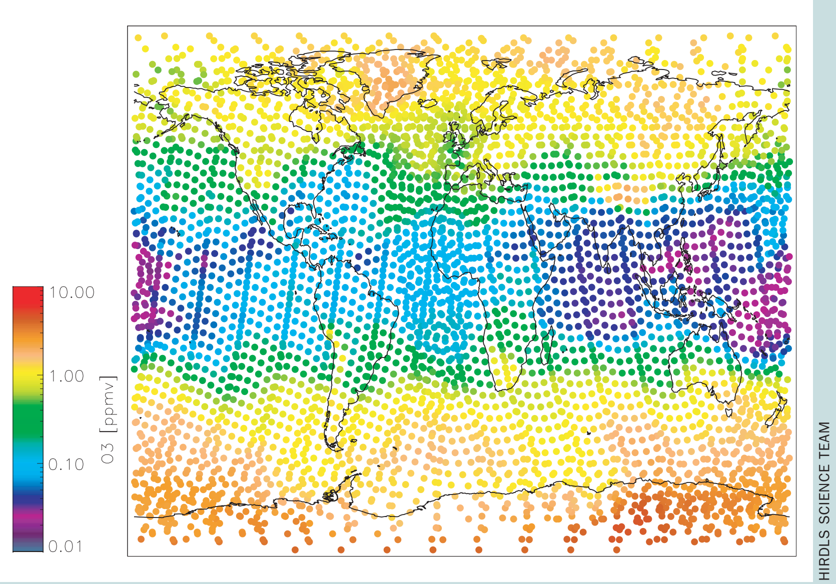
HIRDLS will measure water vapor and ozone, both important greenhouse gases. The instrument is also able to distinguish between aerosol types that absorb or reflect incoming solar radiation. HIRDLS will be able to map high thin cirrus clouds that reflect solar radiation.

Simulated HIRDLS Sampling



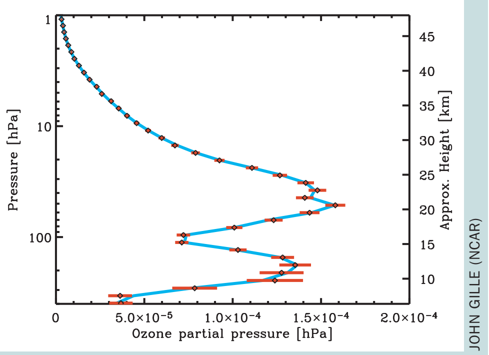
The need for high horizontal resolution measurements of the stratosphere is illustrated above. Using a model, the long-lived trace gas N_2O is transported by observed winds. The transport processes produce filamentary structures that are predicted but have never been observed globally. HIRDLS high horizontal resolution measurements will be able to observe these structures which are signatures of transport.

Simulated HIRDLS Ozone Measurements



HIRDLS spatial coverage has been simulated using an atmospheric chemistry model. The HIRDLS instrument team "flew" the spacecraft through the model to test the retrieval algorithm and demonstrate the ability of HIRDLS to map trace ozone. Colors represent ozone abundance at 16 km altitude.

Ozone Profile



HIRDLS high vertical resolution measurements have been demonstrated using model data. The solid line is the "true" profile taken from a model. The radiance that HIRDLS would observe is computed from this profile. The red horizontal lines show the ozone mixing ratio measurement and error retrieved with the HIRDLS algorithm.

HIRDLS Co-Principal Investigators Dr. John Gille (left), and Dr. John Barnett (right) hold a model of the Aura spacecraft. Gille and Barnett have led the development and application of IR limb sounding. Gille and Barnett and their team are responsible for the instrument calibration, development of the algorithms, monitoring instrument performance and data processing. Dr. Gille is a senior researcher at the National Center for Atmospheric Research and a professor at the University of Colorado. Dr. Barnett is a Lecturer in atmospheric physics at Oxford University.

Microwave Limb Sounder
MLS

MLS INSTRUMENT TEAM

MLS Instrument Characteristics

- MLS is an advanced microwave radiometer that will measure microwave emission from the Earth's limb in five broad spectral bands. These bands are centered at 118 GHz, 190 GHz, 240 GHz, 640 GHz, and 2.5 THz.
- MLS will measure trace gases at lower altitudes and with better precision and accuracy than its predecessor on UARS. MLS will obtain trace gas profiles with a vertical resolution of 3 km.
- MLS pioneers the use of planar diodes and monolithic-millimeter wave integrated circuits to make the instrument more reliable and resilient to launch vibration. MLS looks outward from the front of the spacecraft.

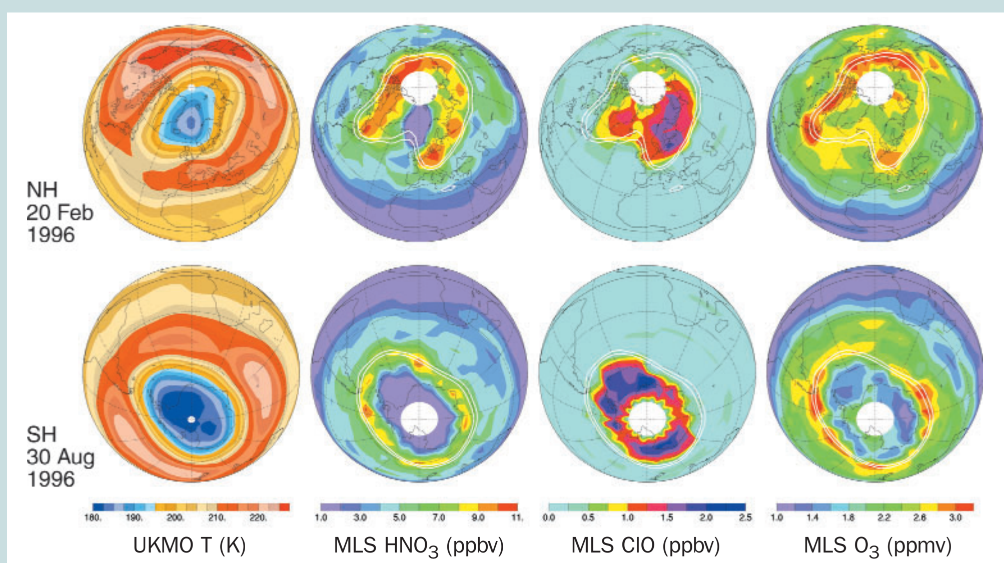
MLS is a limb scanning emission microwave radiometer. MLS measures radiation in the GHz and THz frequency ranges (millimeter and submillimeter wavelengths). Aura's MLS is a major technological advance over the MLS flown on UARS. MLS will measure important ozone-destroying chemical species in the upper troposphere and stratosphere. In addition, MLS has a unique ability to measure trace gases in the presence of ice clouds and volcanic aerosols. NASA's Jet Propulsion Laboratory (JPL) developed, built, tested, and will operate MLS.

MLS contributes to each of Aura's three science questions. A summary of MLS data products appears on page 29.

MLS Contributions to Understanding Stratospheric Ozone

Aura's MLS will continue the ClO and HCl measurements made by UARS. These measurements will inform us about the rate at which stratospheric chlorine is destroying ozone. MLS will also provide the first global measurements of the stratospheric hydroxyl (OH) and hydroperoxy (HO_2) radicals that are part of the hydrogen catalytic cycle for ozone destruction. In addition, MLS will measure bromine monoxide (BrO), a powerful ozone-destroying radical. BrO has both natural and man-made sources.

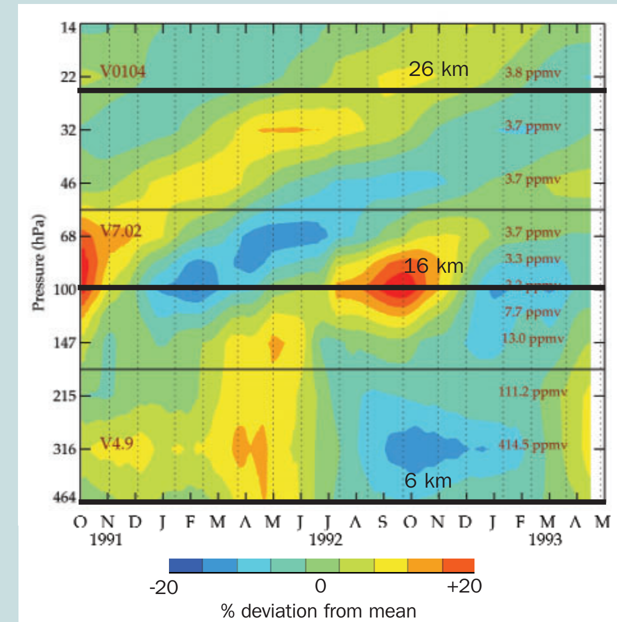
Earth's Lower Stratosphere in 1996 Northern and Southern Winters



MICHELLE SANTEE, IN WATERS, ET AL. "THE UARS AND EOS MICROWAVE LIMB SOUNDER (MLS) EXPERIMENTS," J. ATMOSPHERIC SCIENCES, VOL. 56, PP 194-218, 15 JAN 1999.

UARS MLS simultaneously mapped key chemical constituents nitric acid, chlorine monoxide, and ozone over the winter polar regions in both Northern (upper) and Southern (lower) Hemispheres where the greatest ozone loss occurs. Aura MLS will map these and other chemicals with better coverage and larger altitude range than UARS MLS. Together with HIRDLS, Aura MLS will measure an array of source, radical and reservoir gases in the active region of the polar stratosphere to give a complete picture of the ozone depletion process and predicted recovery. MLS will also make global measurements of BrO, OH and HO_2.

MLS Measurements of Water Vapor



UARS MLS has made unprecedented measurements of water vapor in the lower stratosphere and upper troposphere. The tropical measurements indicate the year-to-year percentage variation in water vapor as a difference from the mean value at each level. The upper tropospheric measurement is possible because MLS can make measurements in the presence of thin clouds that block infrared measurements. Air ascends slowly into the stratosphere (above 16 km) carrying the water vapor signal from the tropical tropopause upward.

WILLIAM READ, "DEHYDRATION IN THE TROPICAL TROPOPAUSE LAYER: IMPLICATIONS FROM UARS MLS," J. GEOPHYS. RES., VOL. 109, NO. D6, DOI:10.1029/2003_JD004056, 2004."

MLS measurements of ClO and HCl will be especially important in the polar regions. The HCl measurements tell scientists how stable chlorine reservoirs are converted to the ozone destroying radical, ClO. Since the Arctic stratosphere may now be at a threshold for more severe ozone loss, Aura's MLS data will be especially important.

MLS Contributions to Understanding Air Quality

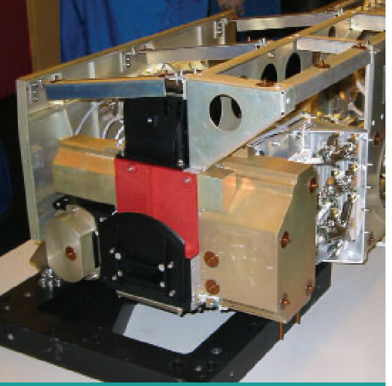
MLS measures carbon monoxide (CO) and ozone in the upper troposphere. CO is an important trace gas that can indicate the exchange of air between the stratosphere and troposphere. CO is also a tropospheric ozone precursor and its appearance in the upper troposphere can indicate strong vertical transport from pollution events.

MLS Contributions to Understanding Climate Change

MLS's measurements of upper tropospheric water vapor, ice content, and temperature will be used to evaluate models and thus reduce the uncertainty in climate forcing. MLS also measures greenhouse gases such as ozone and N_2O in the upper troposphere.

NATHANIEL LIVESEY (NASA JPL)

Joe Waters of the NASA's Jet Propulsion Laboratory is Principal Investigator for Aura MLS, as he was for UARS MLS. Dr. Waters has led the development and application of microwave limb sounding since starting it in 1974. His team at NASA's JPL, along with the MLS team at the University of Edinburgh (UK) led by Professor Robert Harwood, is responsible for development of the algorithms that generate MLS data products, monitoring instrument performance, data processing, validation, and analyses.



OMI INSTRUMENT TEAM

Ozone Monitoring Instrument
OMI

OMI Instrument Characteristics

- **OMI is an advanced hyperspectral imaging spectrometer with a 114° field of view. Its nadir spatial resolution ranges from 13 x 24 km to 24 x 48 km. OMI's swaths almost touch at the equator so OMI is able to produce global maps each day.**
- **OMI contains two spectrometers; the first measures the UV in the wavelength range of 270-365 nm, while the other spectrometer measures the visible in the range of 365 to 500 nm. Both spectrometers have a bandpass of about 0.5 nm with spectral sampling ranging from 0.15 to 0.3 nm/pixel, depending on wavelength.**
- **OMI uses a CCD solid state detector array to provide extended spectral coverage for each pixel across the measurement swath.**

OMI is a nadir viewing spectrometer that measures solar reflected and backscattered light in a selected range of the ultraviolet and visible spectrum. The instrument's 2600 km viewing swath is perpendicular to the orbit track, providing complete daily coverage of the sunlit portion of the atmosphere. OMI is Aura's primary instrument for tracking global ozone change and will continue the high quality column ozone record begun in 1970 by Nimbus-4 BUV. Because OMI has a broader wavelength range and better spectral resolution, OMI will also measure column amounts of trace gases important to ozone chemistry and air quality. OMI will map aerosols and estimate ultraviolet radiation reaching the Earth's surface. OMI's horizontal resolution is about four times greater than TOMS.

The Netherlands Agency for Aerospace Programs (NIVR) and the Finnish Meteorological Institute (FMI) contributed the OMI instrument to the Aura mission. The Netherlands companies, Dutch Space and TNO-TPD, together with Finnish companies, Patria, VTT and SSF, built the instrument.

OMI's contributes to each of Aura's three science questions. A summary of OMI data products appears on page 29.

OMI Contributions to Understanding Stratospheric Ozone

OMI will continue the 34-year satellite ozone record of SBUV and TOMS, mapping global ozone change. OMI data will support Congressionally mandated and international ozone assessments. Using its broad wavelength range and spectral resolution, OMI scientists will be able to resolve the differences among satellite and ground based ozone measurements. OMI will also measure the atmospheric column of radicals such as nitrogen dioxide (NO_2) and chlorine dioxide (OClO).

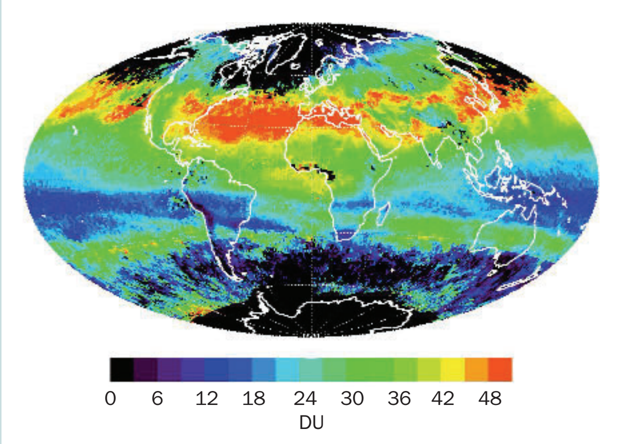
OMI Contributions to Understanding Air Quality

Tropospheric ozone, nitrogen dioxide, sulfur dioxide, and aerosols are four of the U. S. Environmental Protection Agency's six criteria pollutants. OMI will map tropospheric columns of sulfur dioxide and aerosols. OMI measurements will be combined with information from MLS and HIRDLS to produce maps of tropospheric ozone and nitrogen dioxide. OMI will also measure the tropospheric ozone precursor formaldehyde. Scientists will use OMI measurements of ozone and cloud cover to derive the amount of ultraviolet radiation (UV) reaching the Earth's surface. The National Weather Service will use OMI data to forecast high UV index days for public health awareness.

OMI Contributions to Understanding Climate Change

OMI tracks dust, smoke and industrial aerosols in the troposphere. OMI's UV measurements allow scientists to distinguish reflecting and absorbing aerosols and thus OMI measurements will help improve climate models.

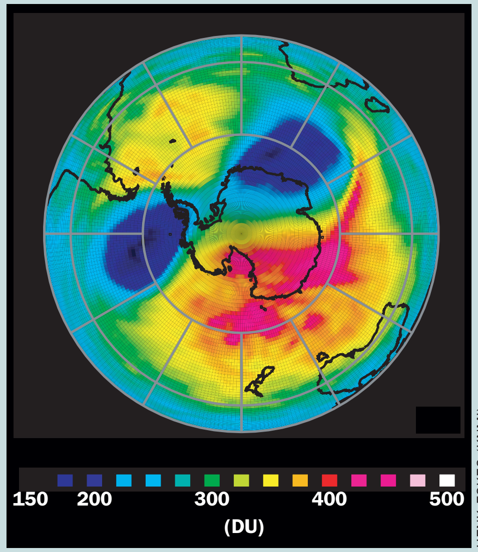
Tropospheric Ozone Map



S. CHANDRA AND J. ZIEMKE (BOTH NASA GSFC)

This monthly average map was made by subtracting the stratospheric ozone column from TOMS column ozone. The stratospheric column is calculated using UARS MLS measurements. Higher quality tropospheric ozone maps on a daily basis will be produced from OMI and HIRDLS data.

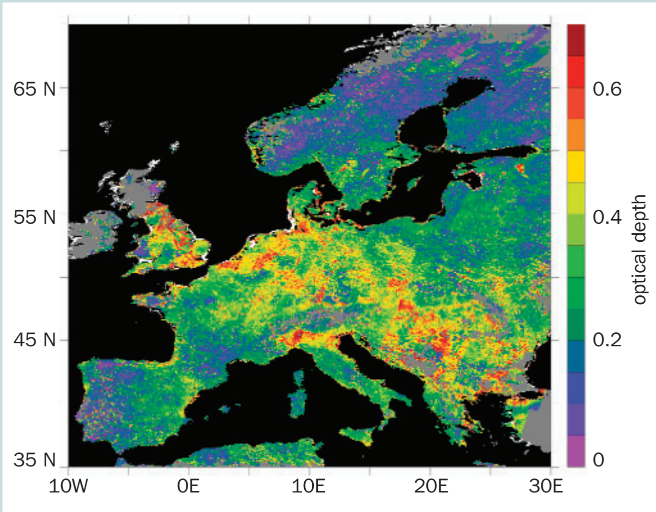
Satellite Ozone Data and Forecast Predict Ozone Hole Breakup



HENK ESKES (KNMI)

KNMI (Royal Netherlands Meteorological Institute) forecasted the unusual splitting of the Antarctic ozone hole in September 2002. This six-day forecast for column ozone on September 25, 2002 used data from the European Space Agency's Global Ozone Monitoring Experiment (GOME) with the wind fields obtained from a data assimilation system. Subsequent satellite data verified the prediction. KNMI, NASA and NOAA will use similar assimilation techniques with OMI data to make regular forecasts of the amount and distribution of total column ozone. OMI will deliver data three hours after observation.

Aerosol Optical Depth

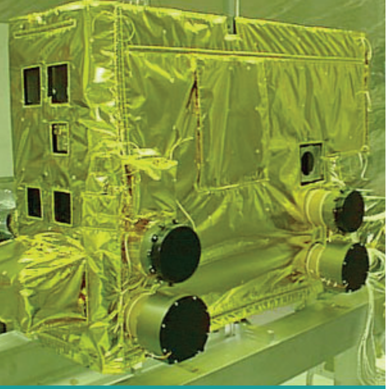


GONZALEZ, C.R., J.P. VEEFKIND AND G. DE LEEUW, AEROSOL OPTICAL DEPTH OVER EUROPE IN AUGUST 1997 DERIVED FROM ATSR-2 DATA, GEOPHYS. RES. LETT. 27, 955-958, 2000

OMI will collect data on aerosol optical thickness in the ultraviolet with eight times better spatial resolution than TOMS instruments. Optical thickness in the ultraviolet tells scientists whether the aerosols absorb or reflect radiation; this information is necessary for climate studies. The figure shows aerosol measurements (monthly average, August 1997) by ATSR-2 at an OMI resolution of 13 x 24 km.

KNMI

OMI Principal Investigator Pieternel Levelt is a research scientist at the Royal Netherlands Meteorological Institute (KNMI). Co-Principal Investigators are Ernest Hilsenrath, from NASA Goddard Space Flight Center (GSFC), and Gilbert Leppelmeier, from the Finnish Meteorological Institute. Pawan Bhartia leads the US science team. Bhartia and Hilsenrath have led the development and application of UV backscatter techniques for measuring trace gases. These scientists and their teams have overseen OMI instrument development and are responsible for calibration, developing algorithms, monitoring instrument performance, data processing, analysis and validation.



TES INSTRUMENT TEAM

Tropospheric Emission Spectrometer
TES

TES Instrument Characteristics

- TES is a high-resolution infrared-imaging Fourier Transform Spectrometer with spectral coverage of 3.2 to 15.4 μm at a spectral resolution of 0.025 cm^{-1}. The instrument can provide information on essentially almost all radiatively active gases in the Earth's lower atmosphere.
- TES makes both limb and nadir observations. In the limb mode, TES has a height resolution of 2.3 km, with coverage from 0 to 34 km. In the nadir mode, TES has a spatial resolution of 5.3 x 8.5 km. The instrument can be pointed to any target within 45 degrees of the local vertical.
- In order to detect the infrared radiation from the Earth's atmosphere, TES's detectors have to be kept at very cold temperatures. An advanced cryogenic refrigerator keeps the detectors cool.

TES is an imaging Fourier Transform Spectrometer observing the thermal emission of the Earth's surface and atmosphere, night and day. TES will measure tropospheric ozone and of other gases important to tropospheric pollution. Satellite tropospheric chemical observations are difficult to make due to the presence of clouds. To overcome this problem TES was designed to observe both downward (in the nadir) and horizontally (across the limb). This observation capability provides measurements of the entire lower atmosphere, from the surface to the stratosphere. NASA's JPL developed, built, tested, and will operate TES.

The TES primary objective is to measure trace gases associated with air quality. A summary of TES data products appears on page 29.

TES Contributions to Understanding Stratospheric Ozone

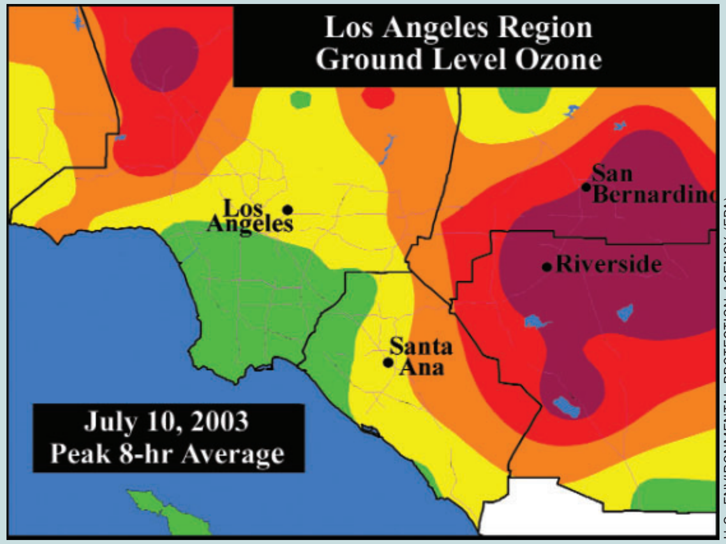
TES limb measurements extend from the Earth's surface to the middle stratosphere, and the TES spectral range overlaps the spectral range of HIRDLS. As a result, TES's high resolution spectra will allow scientists to make measurements of some additional stratospheric constituents as well as improve HIRDLS measurements of species common to both instruments.

TES Contributions to Understanding Air Quality

TES will measure the distribution of gases in the troposphere. TES will provide simultaneous measurements of tropospheric ozone and key gases involved in tropospheric ozone chemistry, such as HNO_3 and CO. TES data will be used to improve regional ozone pollution models.

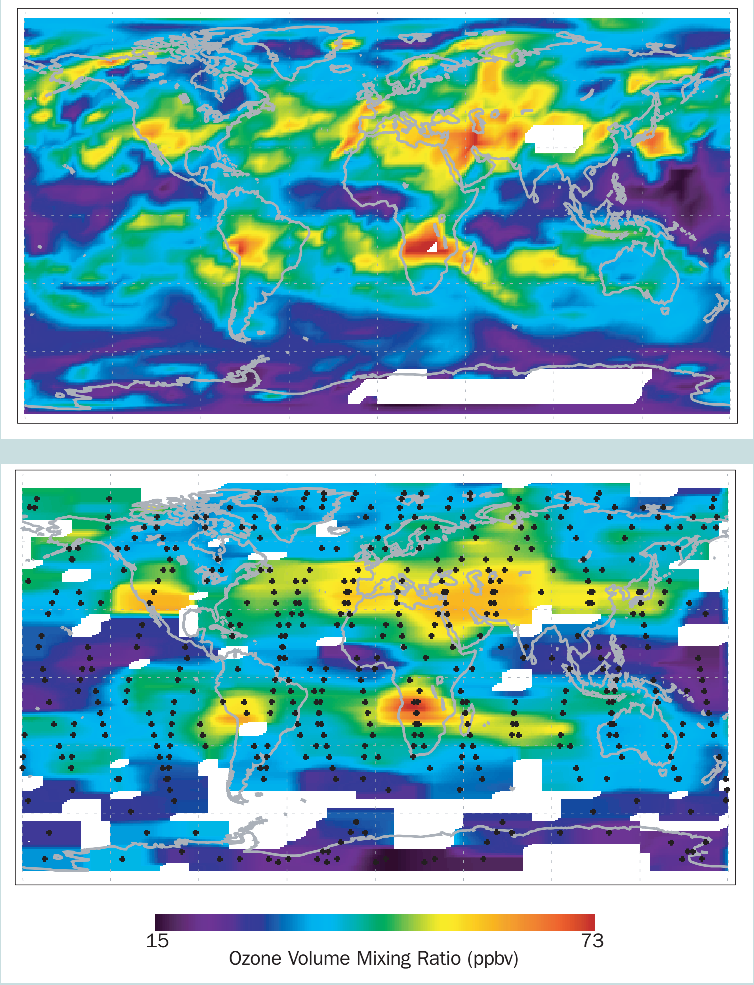
Ground Level Ozone

With its pointing capability and smal pixel size (5 x 8 km) TES can detect changes in ozone levels in large urban locations such as Los Angeles. The orange and red areas represent regions of unhealthy ozone levels. The orange area indicates ozone levels greater than 80 parts per billion by volume (ppbv) and the red area indicates levels greater than 125 ppbv.



U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA)

TES Simulated Data



DANIEL JACOB (HARVARD UNIVERSITY)

MINGZHAO LUO (NASA JPL)

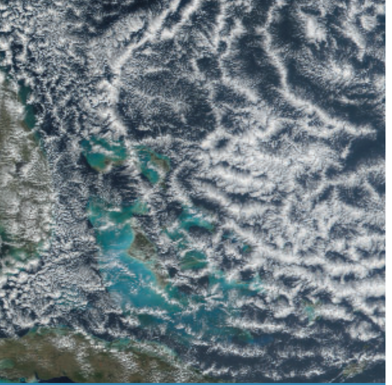
Harvard University's GEOS-CHEM model demonstrates that TES will observe the major features in tropospheric ozone on a single day. The top panel shows the GEOS-CHEM simulated ozone field at 681 hPa (about 3.1 km). The white areas are mountainous regions where the surface pressure is below 681 hPa. The '+' signs on the bottom panel indicate Aura's flight path and the locations of TES nadir measurements. White areas are found on the flight path where clouds obscure the entire TES footprint. The map in the lower panel is constructed from the simulated values at the '+' locations. The simulated map reproduces many of the features found in the original model field.

TES Contributions to Understanding Climate Change

TES will measure tropospheric water vapor, methane, ozone and aerosols, all of which are relevant to climate change. Additional gases important to climate change can be retrieved from the TES spectra.

KAREN YUEN (NASA JPL)

Reinhard Beer of the NASA's Jet Propulsion Laboratory serves as the Principal Investigator for TES. Beer is a pioneer in the development and application of Fourier Transform technology for remote sensing. Beer and his team are responsible for developing the atmospheric constituent retrieval algorithms, monitoring instrument performance, calibration, data processing and analysis.



Mission Synergy: Maximizing Science Results

Mission Synergy

- Aura measures a full range of gases active in ozone chemistry.
- Aura measures five of the six EPA criterion air pollutants.
- Aura measures upper troposphere ozone and water vapor, both important contributors to climate change.

The Aura instruments were selected and the satellite was designed to maximize science impact. The four Aura instruments have different fields of view and complementary capabilities. The instruments all observe the same air mass within about 13 minutes, a short enough time so the chemical and dynamical changes between observations are small.

Stratospheric Ozone

Understanding stratospheric ozone change involves measurements of both the ozone profile and the total column amount, as well as the chemicals responsible for ozone change.

All of Aura's instruments make ozone profile measurements. HIRDLS profiles have the highest vertical resolution and extend from cloud tops to the upper stratosphere. MLS measurements have lower vertical resolution than HIRDLS, but MLS can measure ozone in the presence of aerosols and upper tropospheric ice clouds. TES limb ozone measurements overlap the measurements from HIRDLS and MLS up to the middle stratosphere. OMI can also make broad ozone profile measurements using a modified SBUV technique.

To establish the scientific basis for ozone change, scientists must measure the global distribution of the source, reservoir, and radical chemicals in the nitrogen, chlorine, and hydrogen families. Together, the Aura instruments fill this requirement. For example, HIRDLS measures the halocarbons (chlorine source gases) and chlorine nitrate (one of the major chlorine reservoir gases), while MLS measures the radical chlorine monoxide and hydrogen chloride (the other major chlorine reservoir).

Stratospheric aerosols influence ozone concentrations through chemical processes that transform ozone-destroying gases. HIRDLS measures stratospheric aerosols with the best horizontal coverage and highest vertical resolution of Aura's four instruments. TES provides a backup for HIRDLS. MLS and HIRDLS both measure nitric acid and MLS measures HCl and chlorine monoxide (ClO), two gases that are transformed by the chemical processes involving aerosols.

Air Quality

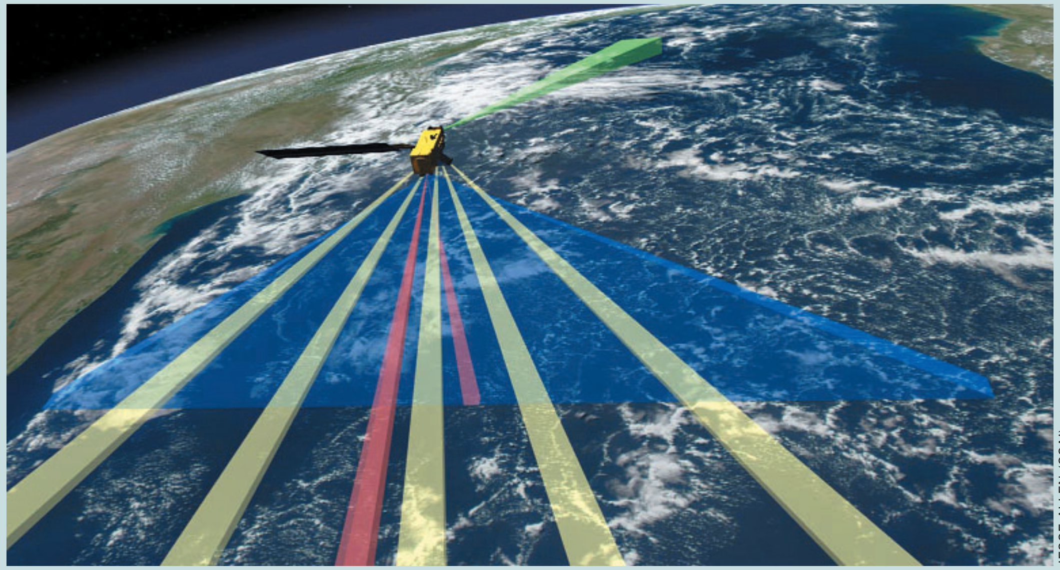
Measuring tropospheric ozone and its precursor gases is a major goal for Aura. Aura's instruments provide two methods of tracking ozone pollution. First, TES measures tropospheric ozone directly. The second estimate of the total tropospheric ozone amount can be obtained by subtracting HIRDLS stratospheric ozone measurements from OMI's total column ozone measurements. A similar procedure can be used to estimate the tropospheric amount of NO_2, an important ozone precursor.

In the clear upper troposphere, Aura instruments provide overlapping measurements of CO (MLS, TES), H_2O (MLS, TES, HIRDLS),

continues on page 22

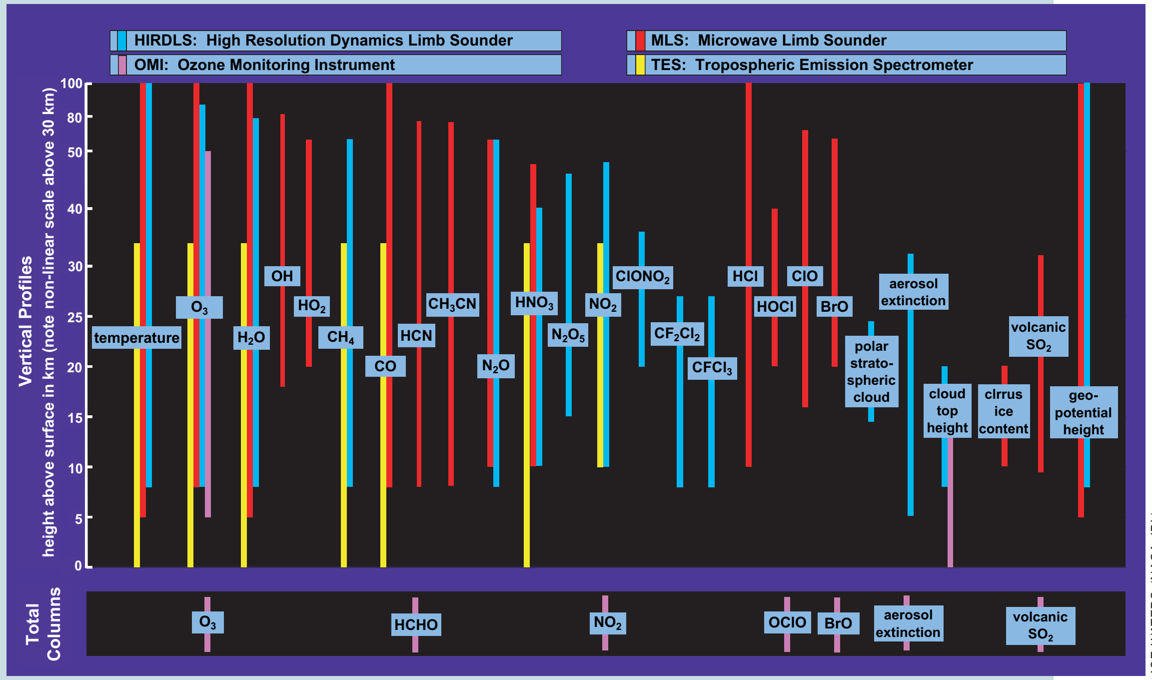
Fields of View

Fields of view for Aura's instruments appear in different colors: HIRDLS in yellow, OMI in blue, MLS in green, and TES in red. HIRDLS looks backward through the limb and scans the atmosphere's vertical profiles across the satellite track. MLS looks forward through the limb and scans the atmosphere vertical profiles along the satellite track. OMI looks downward and has a cross track swath of 2600 km. TES looks both in the nadir and limb and also has off nadir pointing capability.



JESSE ALLEN (SSAI)

Aura Atmospheric Measurements



JOE WATERS (NASA JPL)

Each of Aura's four instruments provides unique and complementary capabilities to enable daily global observations of Earth's atmospheric ozone layer, air quality, and climate. The chart (above) summarizes the specific atmospheric physical properties and chemical constituents measured by each instrument. OMI also measures UVB flux and cloud top height and coverage. The altitude range for measurement appears as the vertical scale. In several cases instrument measurements overlap, which provides independent perspectives and cross calibration. These measurements will result in the most comprehensive set of atmospheric composition ever measured from space.

If the air is altered ever so slightly, the state of the psychic spirit will be altered perceptibly.

Maimonides, 12th Century philosopher

HNO_3 (MLS, TES, HIRDLS). Carbon monoxide (CO) is an ozone precursor and HNO_3 is a reservoir gas for NO_2. The combination of TES nadir measurements and MLS limb measurements through clouds will provide important new information on the distribution of CO and H_2O.

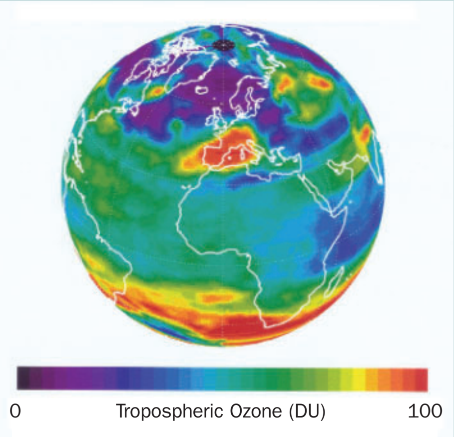
An emerging problem in air quality is the increasing amount of aerosols in the air we breathe. OMI measures aerosols, and distinguishes between smoke, mineral dust, and other aerosols. Both TES and HIRDLS measure aerosol characteristics in the upper troposphere to help understand how aerosols are transported.

Climate Change

Atmospheric chemistry and climate are intimately connected. Ozone, water vapor, and N_2O take part in tropospheric chemical processes and are also greenhouse gases. Changes in these and other greenhouse gases can upset the atmosphere's heat balance and alter climate. Measurements of these gases, their sources and sinks are essential if we are to understand how the climate is changing as a result of human activity. All of the Aura instruments provide information on tropospheric ozone.

Clouds and aerosols are also important contributors to climate change. HIRDLS and MLS will measure cirrus clouds. OMI will measure aerosol distributions and cloud distributions and their heights.

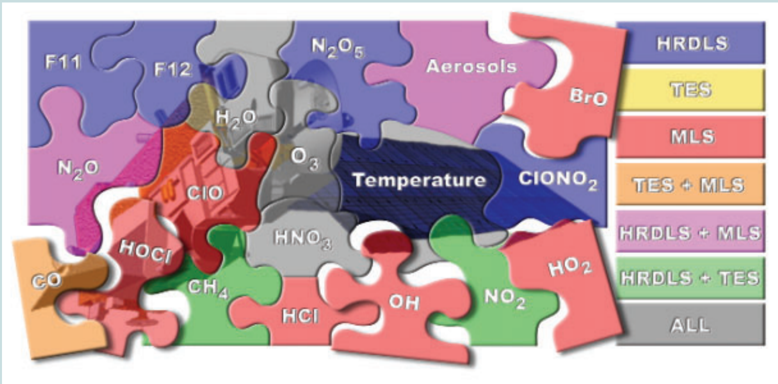
Simulated Tropospheric Ozone



SUSHIL CHANDRA AND JERRY ZIEMKE (NASA GSFC)

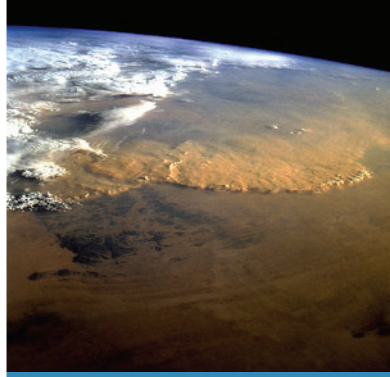
Atmospheric scientists derive tropospheric ozone amounts by combining measurements from different satellites, such as subtracting stratospheric amounts from NASA's UARS MLS or NOAA's SBUV/2 instruments from TOMS column amounts. These show how tropospheric ozone is transported across continents and oceans. Aura will provide more accurate tropospheric ozone by subtracting the HIRDLS stratospheric profiles from OMI column amounts as simulated in this figure. The high spatial resolution of these two instruments will provide data necessary to quantify chemical and dynamic processes controlling tropospheric ozone.

Completing the Picture of Stratospheric Chemistry



BARBARA SUMMEY (SSAI)

Chemical and transport processes have led to changes in the stratospheric ozone layer, and scientists need measurements of many different chemical species to puzzle out the causes for these observed changes. Measurements of ozone-destroying radicals such as ClO, NO_2, BrO and OH and reservoir gases such as N_2O_5, $ClONO_2$ and HNO_3 help solve the chemical part of the puzzle. Measurements of long-lived gases such as N_2O and CH_4 tell scientists about the puzzling effects of transport. Ozone and some other constituents are measured by all the instruments; some constituents like hydrochloric acid are measured by only one. New Aura measurements, such as OH, will help us complete the picture. The new measurements are shown as detached pieces.



Aura and the A-Train

By 2006, Aura will be a member of a constellation of satellites flying in formation. This formation is referred to as the "A-Train." Flying with Aura in the A-Train are Aqua, CloudSat, CALIPSO, and OCO. The French space agency, Centre National d'Etudes Spatiales (CNES), plans to send a sixth satellite, PARASOL, to join the A-Train. All six satellites will cross the equator within a few minutes of one another near 1:30 p.m. local time and again in the early morning, about 1:30 a.m.

While each satellite has an independent science mission, these complementary satellite observations will enable scientists to obtain more information than they could using the observations of a single mission.

The A-Train formation allows us to focus on new science questions. For example:

- **What are the aerosol types and how do observations match global emission and transport models?**

Data from Aura's OMI will provide information on the global distribution of absorbing aerosols. Aerosol height information obtained by CALIPSO can be combined with data on aerosol size distribution and composition from PARASOL and Aqua's MODIS.

- **What is the role of polar stratospheric clouds in ozone loss in the Antarctic vortex?**

Aura's MLS and HIRDLS will provide cloud height and temperature data, and ozone, nitric acid and chlorine monoxide concentrations. CALIPSO measures precise polar stratospheric cloud height and cloud type.

- **What is the vertical distribution of cloud water and ice in upper tropospheric cloud systems?**

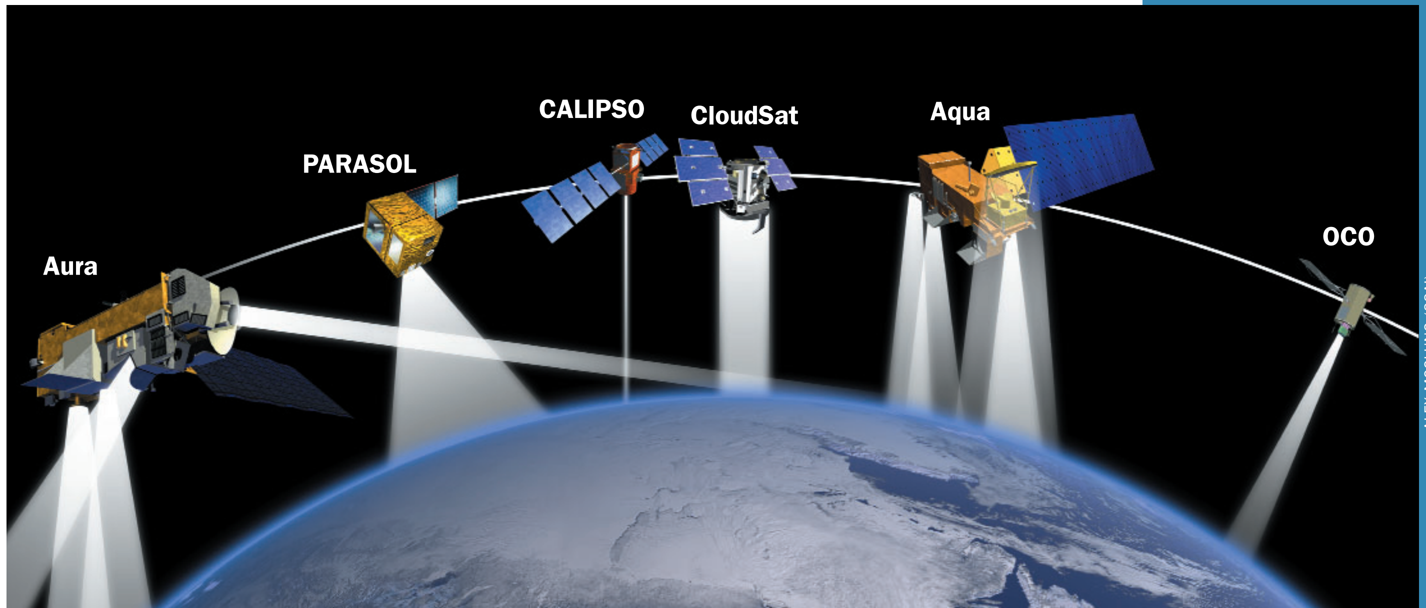
Aura's MLS will provide water vapor measurements in the presence of clouds while CloudSat will measure cloud height. PARASOL will provide particle type information while Aqua's MODIS will give particle size information.

Satellite Constellation

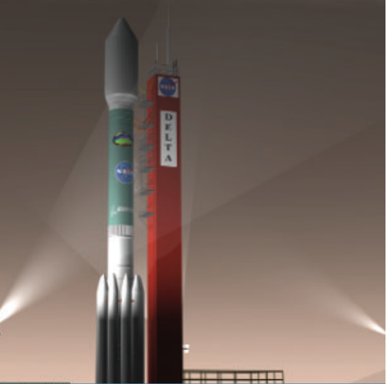
Aura will fly in a carefully-designed constellation of six Earth-observing satellites that gather concurrent science data in a virtual platform. Constellation flying increases mission capability while it lowers total mission risk and mission cost.

Aura contributes to the collective science mission, particularly with regard to questions about the role of polar stratospheric clouds in polar ozone loss, and the vertical distribution of water and ice in cloud systems.

The satellites of the A-Train.



ALEX MCCLUNG (SSAI)

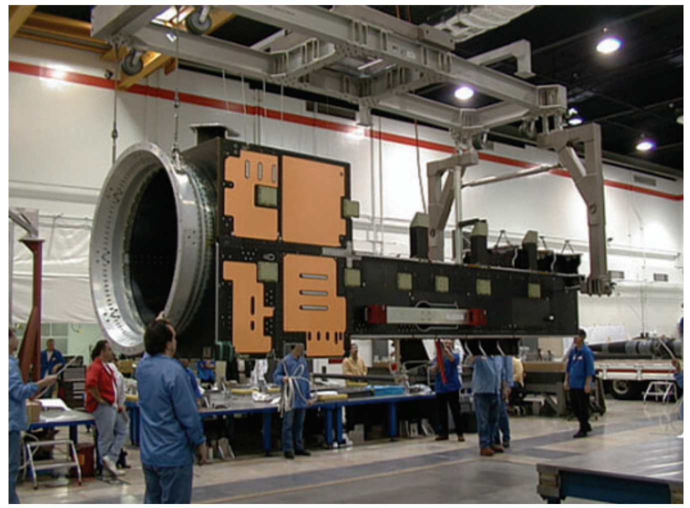


The Aura Spacecraft

The Aura spacecraft provides the essential services for operating the four scientific instruments over the life of the mission. The spacecraft, based on the EOS Common Spacecraft design, was built by Northrop Grumman Space Technology and adapted for the Aura instrument payload.

Building a complex spacecraft requires an engineering team with a diverse set of technical skills. The team has to translate the scientific requirements of the mission into the technical requirements for the spacecraft to assure that when the subsystems and instruments are brought together to form the observatory (spacecraft plus instruments), they function as one cohesive system.

The spacecraft is made up of the following subsystems: command and data handling; communications; electrical power; electrical distribution; guidance, navigation and control; propulsion, software and thermal control. Each subsystem requires designers, engineers, analysts and technicians with specialized training. A team of integration and test specialists assembles the observatory and tests it as a system, simulating the launch and on-orbit environments as closely as possible. For example, the spacecraft is exposed to vibrations similar to what it would experience during launch. As the observatory comes together, the flight operations team learns and practices how to operate the observatory well before launch.



Spacecraft delivery

Spacecraft assembly

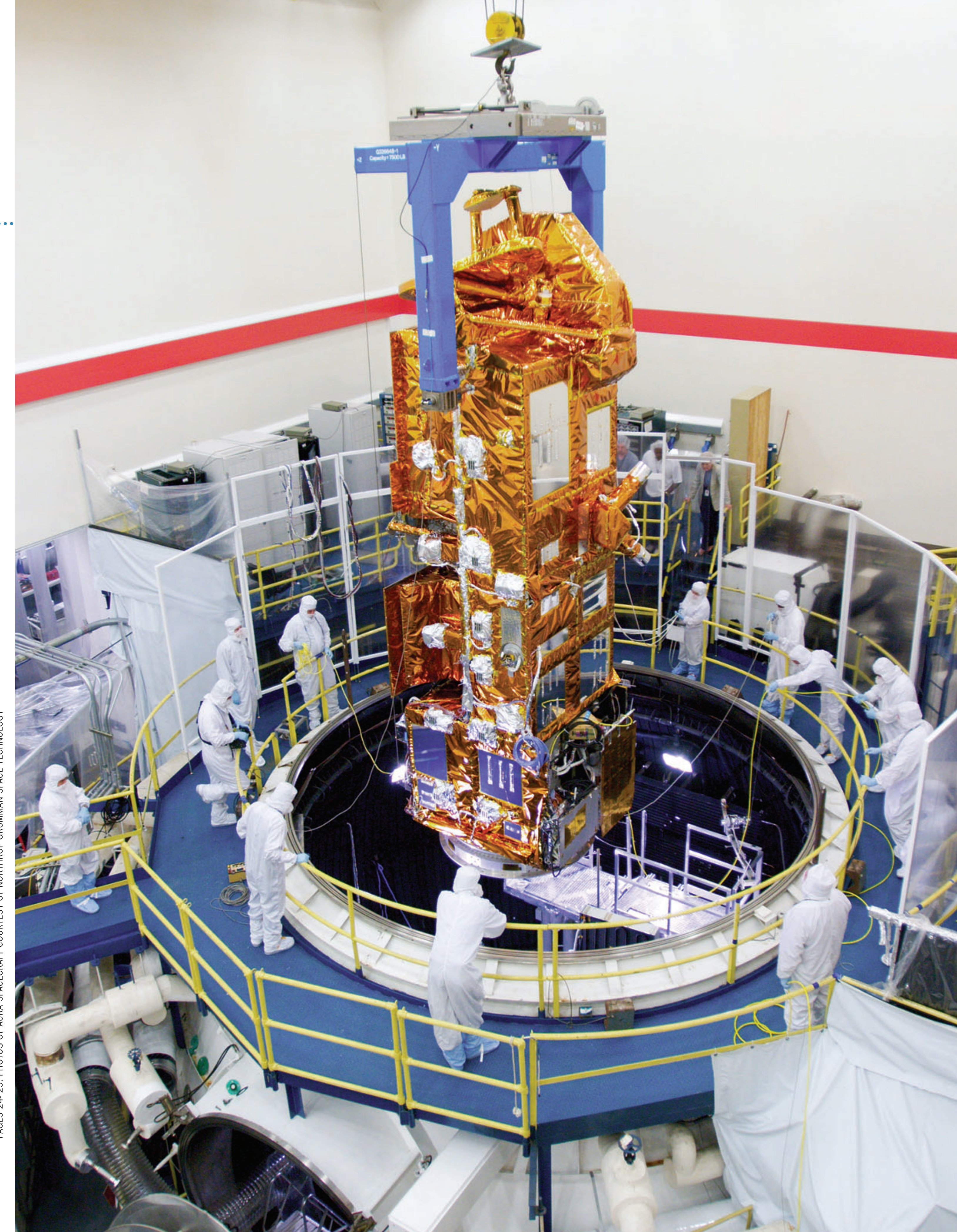
The Aura observatory will be launched on a Delta II 7920 rocket from Vandenberg Air Force Base in California into a near polar, sun-synchronous orbit of 438 mi (705 km), with a period of approximately 100 minutes and a 1:45 PM equator crossing time. The spacecraft repeats its ground track every 16 days.

Right, Spacecraft descending into thermal vacuum test chamber, October 2003.

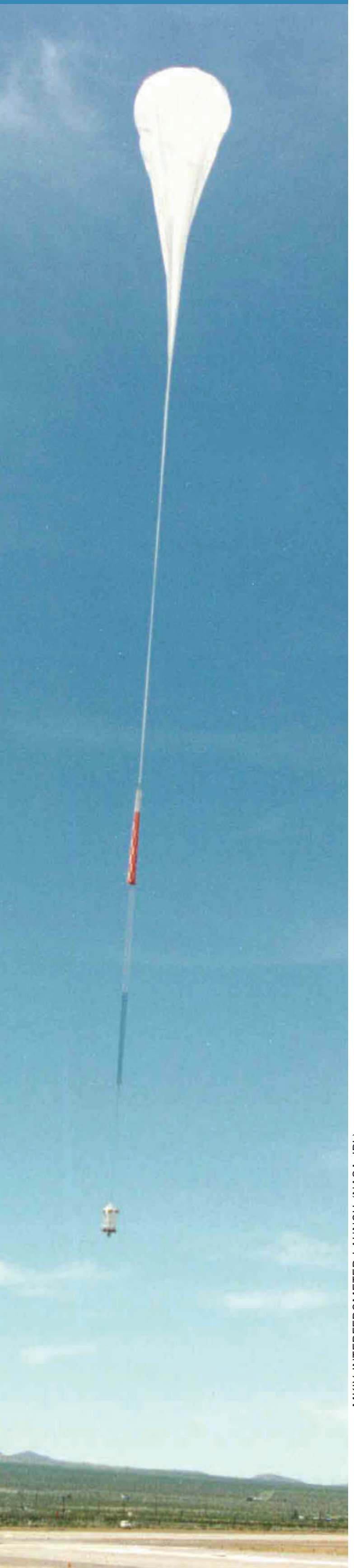
Spacecraft Subsystems

- **Structure—**Graphite epoxy composite over honeycomb core
- **Electrical Power—** The deployable flat-panel solar array with over 20,000 silicon solar cells provides 4800 watts of power in sunlight and charges a 24-cell nickel-hydrogen battery for the night phase of the orbit
- **Command and Data Handling System—**Stores over 100 gigabits of scientific data on-board
- **Communications—**X-band (high data rate) for science data, S-band (low data rate) for command and telemetry, via polar ground stations
- **Guidance, Navigation and Control—**Stellar-inertial, and momentum wheel-based attitude controls
- **Propulsion—**System of four one-pound thrust hydrazine monopropellant rockets
- **Software—**The satellite systems are managed by a flight computer that is responsible for the health and safety of all the instrument subsystems

PAGES 24- 25. PHOTOS OF AURA SPACECRAFT COURTESY OF NORTHROP GRUMMAN SPACE TECHNOLOGY



High altitude balloon measurements will provide trace gas profiles for Aura validation.



MKIV INTERFEROMETER LAUNCH (NASA JPL)

Aura Validation

Validation is the process by which scientists show that their space-based measurements have their expected accuracy. Validation of Aura measurements involves making similar atmospheric measurements from airplanes, balloons or ground-based sites. Scientists compare Aura data with calibrated measurements collected as the satellite passes overhead.

Ground-based radiometers and spectrometers make column measurements similar to those flying on Aura. Lidars measure temperature and some trace gas constituent profiles. Aircraft such as the DC-8 (medium altitude) and the ER-2 (high altitude) carry airborne spectrometers, radiometers, and air samplers to measure upper atmospheric constituents.

Instruments on board the NASA DC-8 will measure tropospheric and lower stratospheric trace gases.

MARK SCHOEBERL (NASA GFSC)

The Aura validation program capitalizes on routine sources of data such as the ozonesonde network and the Network for Detection of Stratospheric Change (NDSC). Balloon-borne instruments will measure profiles of stratospheric constituents up to 25 miles (40 km). Smaller balloons will carry water vapor instruments in the tropics to validate Aura's measurements of this important gas. Aircraft flights provide tropospheric profiles of ozone, carbon monoxide, and nitrogen species. Aircraft lidars will measure profiles of ozone and temperature for long distances along the satellite track. Scientists will also compare profiles of stratospheric constituents from Aura with those from other satellites, including the NASA UARS, the ESA Envisat, and the Canadian SCISAT, and use data assimilation techniques to identify systematic differences among the data sets.

The Aura project has adopted a strategy to increase the scientific return from the validation program. Some of the validation activities will be embedded within focused science campaigns. These campaigns have been selected to obtain data needed to unravel complex science questions that are linked to the three main Aura science goals. Scientists will use the satellite data to understand the overall chemical and meteorological environment during the campaigns. Aircraft measurements will be used to both validate Aura data and address the science by making additional measurements.

This strategy emphasizes the strengths of both data sets. Campaign instruments make constituent measurements that are more complete than can be obtained from satellites. Campaign data are obtained for much smaller spatial scales and with high temporal resolution compared to satellite data. Aircraft missions take place a few times each year at most and are limited to a small portion of the globe, while the Aura instruments will make global observations throughout the year. The Aura instruments will provide datasets that will tell scientists whether or not the campaign observations are truly representative of the atmosphere's chemistry.

Aura's focus on the upper troposphere and lower stratosphere (UT/LS) presents challenges for validation, because the UT/LS exhibits much more spatial and temporal variability (weather) than the middle and upper stratosphere. The Aura validation program includes an instrument development program and field campaigns between October 2004 and Autumn 2007.

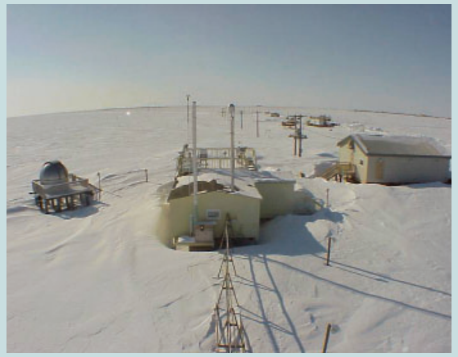
NASA DFRC

High altitude aircraft will make in situ measurements of stratospheric and tropospheric constituents. Above, the Proteus, and below, the NASA ER-2 have been frequently used in satellite validation.

NASA DFRC

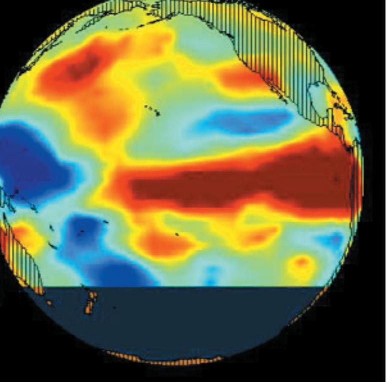
NASA DFRC

Unpiloted aerial vehicles (UAVs), such as NASA's Altair shown above, will be used in Aura validation to make measurements along the satellite track. Aura is pioneering the use of UAVs for validation.



NOAA CLIMATE MONITORING AND DIAGNOSTICS LABORATORY

Ground-based measurements from sites like the one pictured above at Barrow, Alaska, will provide a long time series of constituent measurements for validation.



The EOS Aura Ground System

The EOS Aura ground system has two equally important functions: to operate the Aura satellite, and to process, archive and distribute the Aura data. NASA's EOS Data and Information System (EOSDIS) supports both of these.

Operating the Aura Satellite

Mission operations are based at the NASA Goddard Space Flight Center in Greenbelt, Maryland. The Flight Operations Team at the EOS Operations Center (EOC) will command and control the Aura spacecraft and instruments, monitor their health and safety and perform mission planning and scheduling. Instrument teams at NASA's JPL, University of Colorado and KNMI, Holland are responsible for day-to-day planning, scheduling, and monitoring of their instruments through the EOC. The data collected by the Aura instruments will be recorded onboard the spacecraft and relayed to ground stations in Alaska and Norway when the satellite passes overhead.

ANGIE KELLY (NASA GSFC)

Data Processing, Archive and Distribution

The data will be transmitted from the ground stations to the EOS Data and Operations System (EDOS). From there the data for HIRDLS, MLS and OMI will be sent to the Goddard Distributed Active Archive Center (DAAC); data for TES will be sent to the Langley Research Center (LaRC) DAAC. Each Science Investigator-led Processing System (SIPS) will receive the data from the DAAC for further processing. The SIPS will produce scientific data such as profiles and column amounts of ozone and other important atmospheric species. Each instrument team will monitor the data products to ensure that they are of high quality. The data products will then be sent back to the DAACs where they will be archived. The DAACs are responsible for distribution of data to scientists all over the world.

Getting the data

Researchers, government agencies and educators will have unrestricted access to the Aura data via the EOS data gateway (eos.nasa.gov/imswelcome). Data seekers can search for and order data from any of the EOS DAACs.

NORTHROP GRUMMAN SPACE TECHNOLOGY

Aura Instruments and Data Products

Acronym	Name	Constituent	Instrument Description
HIRDLS	High Resolution Dynamics Limb Sounder	Profiles of T, O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CF_3Cl, CF_2Cl_2, $ClONO_2$, aerosol composition	Limb IR filter radiometer from 6.2 to 17.76 µm 1.2 km vertical resolution up to 80 km
MLS	Microwave Limb Sounder	Profiles of T, H_2O, O_3, ClO, BrO, HCl, OH, HO_2, HNO_3, HCN, N_2O, CO, cloud ice HOCl, CH_3CN	Microwave limb sounder from 118 GHz to 2.5 THz, with 1.5-3 km vertical resolution
OMI	Ozone Monitoring Instrument	Column O_3, aerosols, NO_2, SO_2, BrO, OClO, HCHO, UV-B, cloud top pressure, O_3 profiles	Hyperspectral nadir imager, 114° FOV, 270-500 nm, 13x24 km footprint for ozone and aerosols
TES	Tropospheric Emission Spectrometer	Profiles of T, O_3, NO_2, CO, HNO_3, CH_4, H_2O	Limb (to 34 km) and nadir IR Fourier transform spectrometer 3.2-15.4µm Nadir footprint 5.3x8.5 km, limb 2.3 km

Man and Nature must work hand in hand. The throwing out of balance of the resources of nature, throws out of balance the lives of men.

F. D. Roosevelt, 1935,
President of the United States

Aura Education and Public Outreach

NASA missions to study the Earth and other planets continue to inspire the next generation of explorers. Aura's three areas of science investigation—stratospheric ozone, climate change, and air quality—are issues of everyday concern. Aura investigators have partnered with the Smithsonian Institution, the American Chemical Society, and the GLOBE Program to reach multiple audiences.

Hundreds of thousands of visitors to the Smithsonian Institution's National Museum of Natural History will have the opportunity to experience a new permanent exhibit based on Aura science, The Atmosphere: Change Is In the Air. The new exhibit resides in the Forces of Change exhibit hall, where connections among land, oceans and atmosphere are explored. Interactive displays immerse visitors in the early history, evolution, and structure of the atmosphere. Northrop Grumman Space Technology has contributed a one-eighth scale model of the Aura satellite to the exhibit, and the Smithsonian's Department of Education has developed learning activities for student group visits. In association with the exhibit, the Smithsonian Press will publish a book by Nobel Prize Winner, Sherwood Rowland, *Atmosphere*.

By the time the Aura satellite achieves orbit, every high school chemistry teacher in the United States will have received four special issues of the high school magazine, *Chem Matters*, devoted to Aura mission science, mathematics, engineering, and technology. The American Chemical Society (ACS) and NASA collaborated in the production of these magazines. The first issue (2001) introduces students to the Aura mission itself; the second issue (2002) portrays the professional and personal lives of the people who make Aura possible; the third issue (2003) explores atmospheric chemistry and transport; and the fourth issue (2005) will focus on Aura results. In association with the National Chemistry Week theme *The Earth's Atmosphere and Beyond!* ACS and NASA have also collaborated to conduct workshops for teachers at all of the regional National Science Teachers Association meetings from 2002 to 2004.

The Aura team supports the GLOBE Program (Global Learning and Observations to Benefit the Environment) to involve young researchers in atmospheric chemistry. More than 13,000 kindergarten through 12th grade schools in 100 countries participate in the GLOBE program. Aura supported the development of inexpensive instruments to measure UV radiation, surface ozone, and aerosols. GLOBE develops protocols for students to follow when making measurements and reporting their data. Schools in the Netherlands are particularly active in Aura science observations through a partnership between GLOBE Netherlands and KNMI, the OMI PI institute. About 20 Dutch schools plan to become part of the data validation program for Aura.

The Aura team has published six articles about atmospheric science on Earth Observatory, NASA's award-winning website, earthobservatory.nasa.gov. The articles include "Ultraviolet Radiation: How It Affects Life on Earth"; "Highways of a Global Traveler"; and "Watching Our Ozone Weather". About 300,000 individuals visit this website each month, and 36,000 subscribe to a weekly update. More articles, including one on scientist-teacher-student partnerships, are under development.

For current information on education opportunities, visit the Aura website at:

eos-aura.gsfc.nasa.gov

Website Addresses

- See National Museum of Natural History online at:
  www.nmnh.si.edu/
- See Chem Matters online at:
  www.acs.org/education/curriculum/chemmatt.html
- See the GLOBE Program online at:
  www.globe.gov/fsl/welcome/welcomeobject.pl
- For current information on education opportunities, visit the Aura website at:
  eos-aura.gsfc.nasa.gov

DANA STENCLOVA

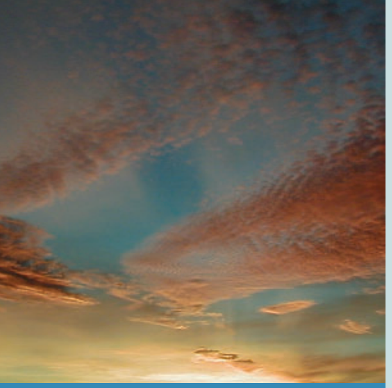
Students and teachers in Czechoslovakia investigate surface ozone amounts through GLOBE, an international science and education program. Trainers from the U.S. pose with them and their teacher.

GLOBE students measure injury to plant leaves for ozone air quality studies.

MS. CERNOCHOVA

JOKE VAN DEN BOVENKAMP (KNMI)

A GLOBE teacher and students learn how to measure aerosols with a hand-held sun photometer.



This brochure is dedicated to the memory of Professor James Reed Holton (1938-2004), an inspirational atmospheric scientist and a member of the UARS and Aura Science Teams. Jim Holton made countless contributions to atmospheric science and enriched the lives of his students and colleagues.

Acknowledgements

Goddard Project Office

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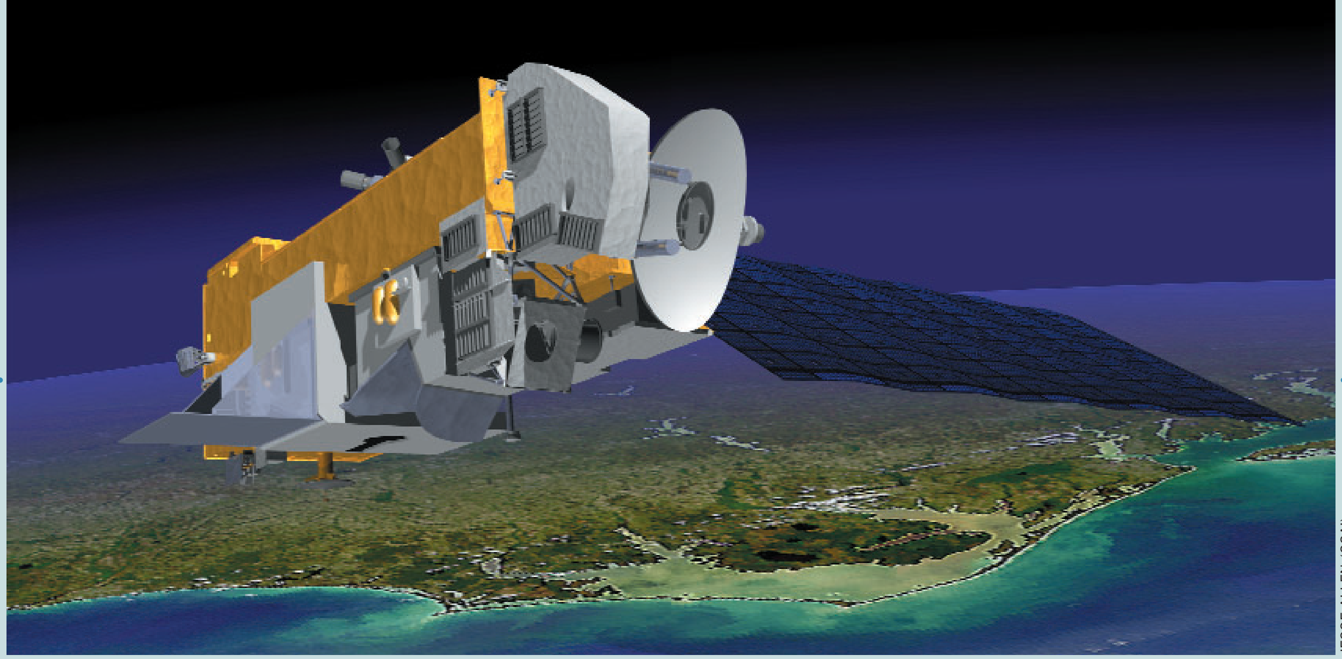

JESSE ALLEN (SSAI)

Chemicals

BrO	Bromine monoxide	$ClONO_2$	Chlorine nitrate	HNO_3	Nitric acid	NO_x	Nitrogen oxide
CF_2Cl_2	Dichlorodifluoromethane	CO	Carbon monoxide	HO_2	Hydroperoxy radical	O_2	Oxygen
$CFCl_3$	Trichlorofluoromethane	CO_2	Carbon dioxide	HOCl	Hypochlorous acid	O_3	Ozone
CH_3CN	Methyl cyanide	H_2O	Water	N_2O	Nitrous oxide	OClO	Chlorine dioxide
CH_4	Methane	HCl	Hydrogen chloride	N_2O_5	Dinitrogen pentoxide	OH	Hydroxyl
Cl	Chlorine	HCHO	Formaldehyde	NO	Nitric oxide	SO_2	Sulfur dioxide
ClO	Chlorine monoxide	HCN	Hydrogen Cyanide	NO_2	Nitrogen dioxide		

Acronyms

ACS	American Chemical Society
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTR	Along Track Scanning Radiometer
BUV	Backscatter Ultraviolet Instrument
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite
CCD	Charge Coupled Device
CFC	Chlorofluorocarbon
CNES	Centre National d'Etudes Spatiales
DAAC	Distributed Active Archive Center
DFRC	Dryden Flight Research Center
DU	Dobson Unit
EOC	EOS Operations Center
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EPA	Environmental Protection Agency
ESA	European Space Agency
GISS	Goddard Institute for Space Studies
GLOBE	Global Learning and Observations to Benefit the Environment
GOME	Global Ozone Monitoring Experiment
GSFC	Goddard Space Flight Center
HALOE	Halogen Occultation Experiment, instrument on UARS satellite
HIRDLS	High Resolution Dynamics Limb Sounder (One of the four Aura instruments)
JPL	Jet Propulsion Laboratory
KNMI	Royal Dutch Meteorological Institute
MLS	Microwave Limb Sounder (One of the four Aura instruments)
MODIS	Moderate-resolution Imaging Spectroradiometer
MOPITT	Measurements of Pollution in the Troposphere
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NDSC	Network for the Detection of Stratospheric Change
NGST	Northrop Grumman Space Technology
Nimbus 7	NASA satellite, operated from 1978-1994 carrying a TOMS instrument
Nimbus-4	NASA satellite,operated from 1970-1980 carrying the BUV instrument
NOAA	National Oceanic and Atmospheric Administration
OCO	Orbiting Carbon Observatory
OMI	Ozone Monitoring Instrument (One of the four Aura instruments)
OMPS	Ozone Mapping Profiler Suite
PARASOL	Polarization and Anisotropy of Réflectances for Atmospheric Sciences coupled with Observations from a Lidar
ppbv	Parts per billion volume
SAGE	Stratospheric Aerosol and Gas Experiment
SBUV	Solar Backscatter Ultraviolet
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SIPS	Science Investigator Processing Systems
SSAI	Science Systems & Applications, Inc.
TES	Tropospheric Emission Spectrometer (One of the four Aura instruments)
TOMS	Total Ozone Mapping Spectrometer
UARS	Upper Atmosphere Research Satellite
UK	United Kingdom
UMBC	University of Maryland Baltimore County
UV	Ultraviolet
VOC	Volatile Organic Compound