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Earth Observing System Missions Benefit Atmospheric Research

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The Earth Observing System (EOS) Aura satellite mission is scheduled to launch in June 2004. The Aura mission will make significantly improved measurements of atmospheric constituents.

Aura is designed to tackle three science questions: Is the ozone layer recovering as expected? What are the sources and processes that control tropospheric pollutants? And, what is the quantitative impact of constituents on climate change? Aura will answer these questions by globally measuring a comprehensive set of trace gases and aerosols (Table 1) at high vertical and horizontal resolution. Figure 1 shows the Aura spacecraft and its four instruments.

The EOS Program consists of three core satellites—Terra (http://eos-am.gsfc.nasa.gov/), Aqua (http://eos-pm.gsfc.nasa. gov/), and Aura (http://eos-aura. gsfc.nasa.gov/)—as well as several smaller satellites.

Aura (Latin for "breeze") will be launched into an ascending node, 705-km Sun-synchronous polar orbit with a 98° inclination with an equator-crossing time of 13:45 ± 15 min. The design life is 5 years with an operational goal of 6 years. Aura will fly in the same orbit track about 15 min behind Aqua, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO; http://www-calipso.larc. nasa.gov/), and Cloudsat (http://cloudsat.atmos. colostate. edu/), which is to be launched in mid-2005 [*Stephens et al.*, 2002]. This group of satellites, including the Centre National d'Études Spatiales' PARASOL (http://smsc.cnes.fr/PARASOL/GP_mission.htm) and the Earth System Science Pathfinder program's Orbiting Carbon Observatory (OCO; http://oco.jpl.nasa.gov/), is referred to as the "A-Train." The measurements from Aura will be made within 30 min of measurements from these other platforms. The near-simultaneous measurements by the A-Train satellites will improve estimates of aerosol and cloud interaction and their role in precipitation and climate forcing.

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Science Objectives of the Aura Mission

When combined with field campaign data, other satellite measurements, and ground-based observations, Aura measurements will provide unprecedented insight into atmospheric chemical and dynamical processes.

Is the ozone layer recovering as expected? Total Ozone Mapping Spectrometer (TOMS) observations from 1978 show a strong secular decrease in column ozone at extra-tropical latitudes. Although the Antarctic ozone hole area growth has slowed, significant late-winter ozone depletions have now occurred in the Arctic [*WMO*, 2002]. Upper Atmosphere Research Satellite (UARS) data show a flattening in the stratospheric chlorine concentrations [*Anderson et al.*, 2000]. A decrease in chlorine should lead to recovery of the ozone layer, but this recovery may be altered because of increasing greenhouse gas cooling [e.g., *Shindel and Grewe*, 2002]. As a result of the uncertainty in stratospheric trace gas trends, temperatures, and dynamical feedback processes, current models used to assess the ozone layer do not agree on the timing of the ozone layer recovery [*WMO*, 2002].

The stratospheric measurements made by Aura will permit a complete assessment of the chemical processes controlling ozone. First, high vertical-resolution ozone profiling by MLS and HIRDLS will provide the best information ever on ozone change. Second, five of the major radicals that participate in ozone destruction (ClO, OH, HO_2, BrO, and NO_2) will be measured either by HIRDLS or MLS. Third, MLS and HIRDLS also measure the important reservoir gases, HCl, $ClONO_2$ and HNO_3. Fourth, the Aura instrument payload will make measurements of the long-lived source gases, including N_2O, H_2O, CH_4, and chlorofluorocarbons. Finally, OMI will continue the TOMS/SBUV global column and profile ozone trend measurements.

What are the sources and processes that control tropospheric pollutants? Tropospheric ozone production occurs when CO, volatile organic compounds (VOCs), and nitrogen oxides are exposed to sunlight. These ozone precursors are directly linked to urban sources, and the atmosphere can transport both ozone and its precursors over great distances. The Aura mission is designed to produce the first global assessment of tropospheric ozone and its precursors, as well as to assess the stratospheric contribution to the tropospheric ozone budget. The measurements from TES, as well as column measurements from OMI, combined with stratospheric measurements from HIRDLS and from MLS, will provide new information on pollution sources and transport.

What is the quantitative impact of aerosols and upper tropospheric water vapor and ozone on climate change? One of the sources of uncertainty in climate change comes from our poor understanding of the changing

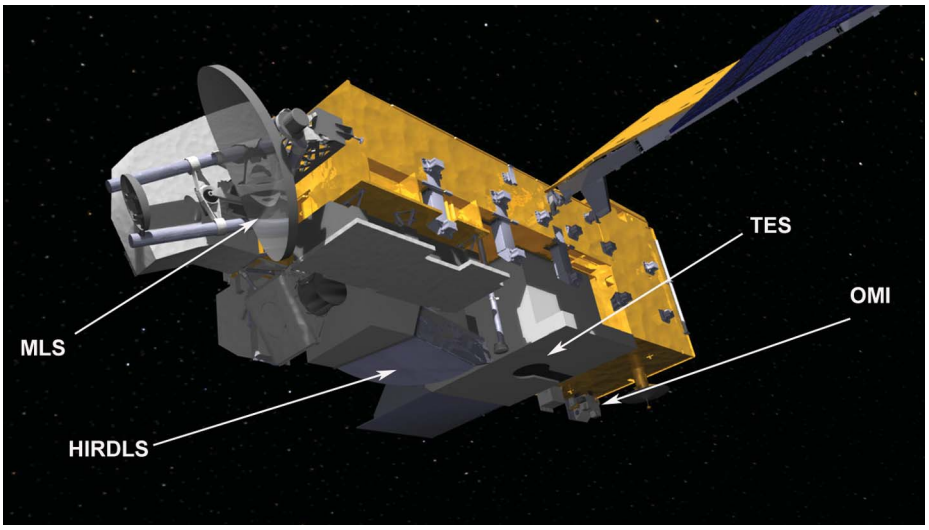

Fig. 1. This computer model of the Aura spacecraft shows the location of HIRDLS, MLS, OMI, and TES. (See Table 1.) Graphic by Jesse Allen, NASA Earth Observatory.

concentration of upper troposphere and lower stratospheric (UT/LS) constituents [*Houghton et al.*, 1995]. On decadal time scales, climate signals from greenhouse gas changes and changes in reactive constituents are intertwined. Aura's MLS and HIRDLS instruments have been specifically designed to study the UT/LS in unprecedented detail. MLS can make constituent measurements through thin clouds, while HIRDLS can scan vertically across the limb over a wide horizontal range through cloud gaps. The issues of climate radiative forcing cannot be solved by Aura alone. Data from Aqua, Cloudsat, and CALIPSO will also be needed to fully address climate issues.

Aura's Instruments

Figure 2 shows the instrument fields of view. MLS will make limb sounds observing forward. OMI and TES will make nadir soundings. HIRDLS and TES will make limb soundings observing backward. The advantage of this instrument configuration is that each of the instruments can observe the same air mass within ~13 min.

HIRDLS. HIRDLS is an infrared (6–17 μm) limb scanning, 26-channel filter radiometer. HIRDLS makes temperature and trace gas observations from the UT/LS to the mesosphere (Table 1) [*Gille et al.*, 2003]. HIRDLS was built jointly by the United Kingdom and the United States. HIRDLS can also detect clouds and thus determine the altitude of polar stratospheric clouds and tropospheric cloud tops. HIRDLS has higher horizontal resolution than any previous limb sounder through the use of a programmable azimuth scan in conjunction with a rapid elevation scan. Special observing modes can be used to observe geophysical events like volcanic clouds.

MLS. MLS is a 118 GHz–2.5 THz, limb-scanning microwave emission spectrometer that measures temperature and constituents from the UT/LS to the mesosphere (Table 1) [*Waters et al.*, 1999]. MLS also has the capability to measure upper tropospheric water vapor in the presence of cirrus clouds. Aura MLS is based on UARS MLS, but uses more advanced technology to make additional constituent measurements. These new constituents play an important role in stratospheric chemistry (that is, HCl, N_2O, OH, HO_2, and BrO). The UARS MLS was able to measure upper tropospheric water vapor [*Read et al.*, 2001], which is essential for understanding climate variability. Aura MLS will improve this measurement.

OMI. The OMI instrument is a contribution of The Netherlands' Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorological Institute (FMI) [*Levelt et al.*, 2000]. OMI will continue the TOMS record for total ozone and other atmospheric parameters related to ozone chemistry and aerosols. OMI is a 0.24–0.50 μm, visible-ultraviolet 740 band, cross-track, hyperspectral imager that will provide global coverage in one day at 13 x 24 km spatial resolution. A combination of backscatter ultraviolet retrieval algorithms and forward modeling will be used to generate the various OMI data products [*Ahmad et al.*, 2003].

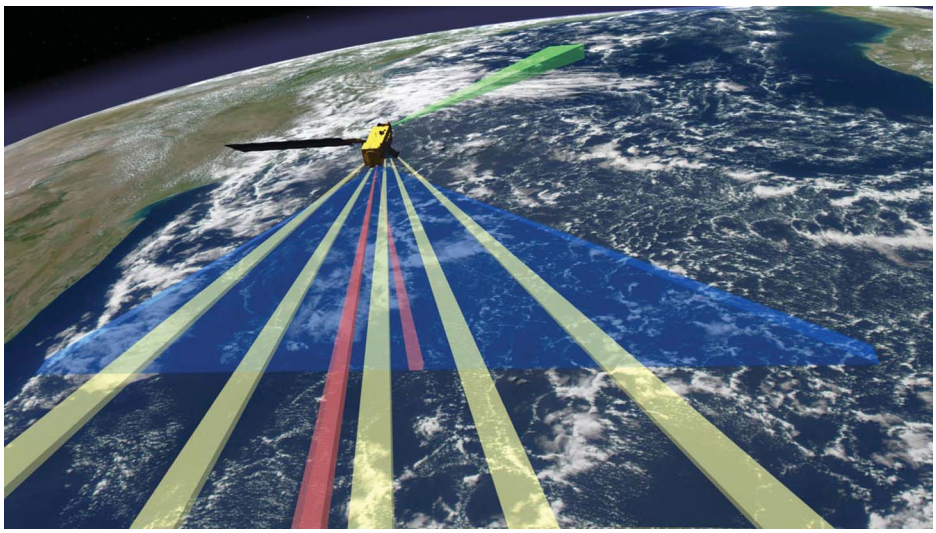

Fig. 2. Aura instrument instantaneous fields of view are shown, looking toward the back of the spacecraft. MLS limb measurements (green); OMI nadir measurements (blue swath); TES limb and nadir measurements (red); HIRDLS measurements (yellow). Limb sounders scan vertically. Graphic by Jesse Allen, NASA Earth Observatory.

TES. TES is a 3.2–15.4 μm, high-resolution, infrared-imaging Fourier Transform spectrometer. TES has a spectral resolution of 0.025 cm^{-1} measuring most of the radiatively active molecular species in the Earth's atmosphere [*Beer et al.*, 2001]. TES can make both limb and nadir observations and it can target within 45° of the local vertical, or produce regional transects over clear regions up to 885 km in length. TES will provide global maps of the trace gases listed in Table 1. Because TES measures the entire infrared spectrum, the potential exists to retrieve a large number of other gases—for example, ammonia—although the retrieval of these gases will be done in a research mode.

Table 1. Aura Instruments, Principle Investigators, and Measurements. Most measurements will have a precision of 10% or better.

Acronym	*Name*	*Instrument PI*	*Constituent*	*Instrument Description*
HIRDLS	High Resolution Dynamics Limb Sounder	John Gille, National Center for Atmospheric Research and University of Colorado; John Barnett, Oxford University	Profiles of T, O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CF_3Cl, CF_2Cl_2, $ClONO_2$, Aerosols	Limb IR filter radiometer from 6.2μ to 17.76μ 1.2 km vertical resolution up to 80 km
MLS	Microwave Limb Sounder	Joe Waters, Jet Propulsion Laboratory	Profiles of T, H_2O, O_3, ClO, BrO, HCl, OH, HO_2, HNO_3, HCN, N_2O, CO, HOCl, CH_3CN, Cloud ice	Microwave limb sounder 118 GHz to 2.5 THz 1.5-3 km vertical resolution
OMI	Ozone Monitoring Instrument	Pieternel Levelt, KNMI, Netherlands	Column O_3, SO_2, aerosols, NO_2, BrO, OClO. HCHO, UV-B, cloud top pressure Profile O_3	Hyperspectral nadir imager, 114° FOV, 270-500 nm, 13 x 24 km footprint for ozone and aerosols
TES	Tropospheric Emission Spectrometer	Reinhard Beer, Michael Gunson, Jet Propulsion Laboratory	Profiles of T, O_3, NO_2, CO, HNO_3, CH_4, H_2O	Limb (to 34 km) and nadir IR Fourier transform spectrometer 3.2-15.4μ Nadir footprint 5.3 x 8.5 km, limb 2.3 km

Aura Instrument Synergy

Because Aura instruments observe the same air mass within ~13 min, it will also be possible to better interpret photochemical processes involving constituents measured simultaneously, as has been done with UARS data [e.g., *Douglass et al.*, 1995]. In addition, HIRDLS and MLS limb sounding will provide ozone profiles that can be combined with the OMI column ozone observations. It will then be possible to separate the stratospheric component of the column ozone, and thus estimate the tropospheric ozone column. The tropo-spheric column can be compared with the TES direct measurement of tropospheric ozone.

The 5-year EOS Aura mission will provide significantly improved tropospheric and stratospheric constituent measurements. Although there are only four instruments on Aura, the breadth of their capability combined with the other "A-Train" measurements will provide powerful tools for addressing future questions about changing atmospheric composition and its impact on climate.

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Ocean Commission Report Includes Key Recommendations for Science and Governance

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The preliminary report of the U.S. Commission on Ocean Policy, released on 20 April, calls for ecosystem-based management of the oceans, dramatically restructuring federal governance oversight of ocean issues, and doubling the federal ocean and coastal research budget over the next 5 years to $1.3 billion per year.

The report by the congressionally-mandated and presidentially-appointed commission includes nearly 200 recommendations for establishing a coordinated and comprehensive national ocean policy framework.

These include establishing a National Ocean Council and a non-federal Presidential Council of Advisors on Ocean Policy within the Executive Office of the President, and also creating a system of voluntary regional councils. The report calls for strengthening the National Oceanic and Atmospheric Administration (NOAA) by urging Congress to pass an "organic act" that codify's the agency's establishment and mission within the Department of Commerce. The report does not recommend creating an overarching department of natural resources at this time, because of political complications.

Other recommendations call for funding the Integrated Ocean Observing System within the NOAA budget, and for promoting international coordination and capacity building regarding global ocean observing; enhancing formal and informal education efforts; acceding to the United Nations Convention on the Law of the Sea; and addressing a range of specific issues including water monitoring, nonpoint source pollution, and fisheries management.

The report proposes establishing an Ocean Policy Trust Fund in the U.S. Treasury to supplement existing appropriations for ocean and coastal activities The fund would include about $4 billion annually in currently unallocated revenues the government receives for offshore oil and gas leasing and other offshore activities.

The report notes that the U.S. currently does not have an effective and integrated national strategy for ocean and coastal research, exploration, and marine operations. More than 60 congressional committees and subcommittees oversee about 20 federal agencies and permanent commissions that are involved with implementing at least 140 federal ocean-related statutes, in addition to state and local authorities, according to the report.

An "Historic Opportunity" to Improve Management

Commission Chair James Watkins, former U.S. secretary of energy, said the nation's oceans and coasts are in trouble, and that there is an "historic opportunity" to improve the management of these resources. "We are calling on Congress and the President to establish a new national ocean policy that balances use with sustainability, is based on sound science and educational excellence, and moves toward ecosystem-based management approach."

Watkins said the report outlines reasonable, straightforward recommendations that can be enacted in an orderly, step-by-step manner. He added that, for the U.S. to be an international leader in ocean management, "we have got to demonstrate that we have got our own act together, which we do not have today."

Robert White, who served on the science advisory panel of the commission, compared the report favorably with that of the Stratton Commission, a presidentially-appointed body of which White was a member. The Stratton report recommendations, released in 1969, led to the establishment of NOAA, the Coastal Zone Management Act, the Fisheries Management and Conservation Act, and other changes.

White, who was NOAA's first administrator, called the new document comprehensive, and said he hopes it has the same kind of impact as the Stratton report. However, he criticized the new report for not having a larger focus on the atmosphere and its connection to the ocean. He also said that "the opportunity to establish an independent agency that could put the United States in a position to do what needs to be done with regard to achieving an environmentally sustainable world was missed."

White told *Eos* that he had been referring specifically to the de-coupling of NOAA from the Department of Commerce; and that he had suggested this in a talk with the commission.

The commission's report is now open for public comment through 21 May 2004. No date has been determined for the release of the final report. For more information, visit the Web site: http://www.oceancommission.gov.

General Support for Commission's Recommendations

Commission member James Coleman, professor at the Coastal Studies Institute of Louisiana State University in Baton Rouge, said that, from a research standpoint, the report's most important recommendations include doubling the federal ocean science budget, and support for an ocean exploration program and the Integrated Ocean Observing System.

Richard West, president of the Consortium for Oceanographic Research and Education, said the toughest scientific challenge is improving data management. "We have got to agree on a common set of data management procedures for the federal government, so that we can take the [existing] data and make some use of it," he said. The environmental community and industry generally expressed support for the report. William Reilly, chairman of the