NASA's Goddard Space Flight Center
Earth Sciences Division: Atmospheres

Deputy Director for Atmospheres

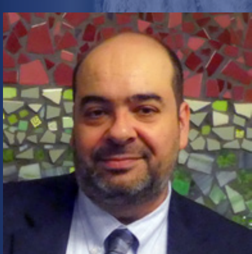
Dr. Steven Platnick
steven.e.platnick@nasa.gov

Associate Deputy Director for Atmospheres

Dr. Emily Wilson
emily.l.wilson@nasa.gov

Mesoscale Atmospheric Processes Laboratory

Chief: Dr. George Huffman
george.j.huffman@nasa.gov



Climate and Radiation Laboratory

Chief: Dr. Lazaros Oreopoulos
lazaros.oreopoulos@nasa.gov

Atmospheric Chemistry and Dynamics Laboratory

Chief: Dr. James Gleason
james.f.gleason@nasa.gov

Earth Sciences Wallops Field Support Office

Chief: David B. Wolff
david.b.wolff@nasa.gov

National Aeronautics and Space Administration

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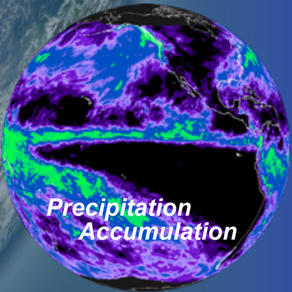
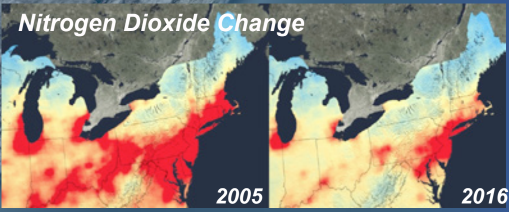
Earth Sciences: Atmospheres





Goddard Space Flight Center
Sciences and Exploration Directorate

Dr. Steven Platnick is the Deputy Director for Atmospheres at NASA's Goddard Space Flight Center's Earth Sciences Division (Code 610).

He received B.S. and M.S. degrees in electrical engineering from Duke University and the University of California, Berkeley, respectively, and a Ph.D. in atmospheric sciences from the University of Arizona. Dr. Platnick's research focuses on theoretical and experimental cloud remote sensing studies from satellite and aircraft observations. He has worked extensively on the development of NASA satellite cloud optical and microphysical data products, from the Moderate Resolution Imaging Spectroradiometer (MODIS), the Visible Infrared Imaging Radiometer Suite (VIIRS), and other imagers.

Welcome to Atmospheres Code 610AT

Dear Readers:

This brochure provides an overview of the portion of Earth atmospheric science activities at Goddard that comprise the Earth Sciences Division's *Atmospheres* organization (Code 610AT). Inside you will find descriptions of our scope of work, our people and facilities, our place in NASA's mission, and examples of recent accomplishments.

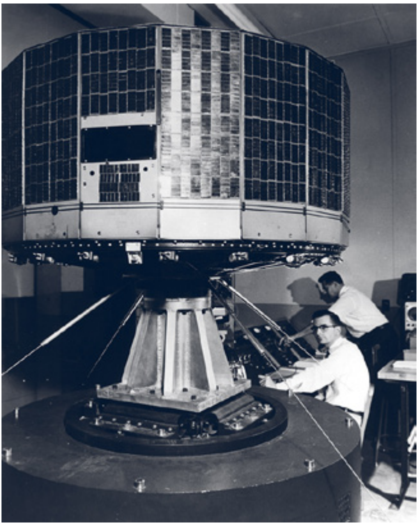
Our atmospheric scientists conduct basic and applied research using observations (laboratory, airborne, satellite, ground-based) and computer models. We also play an active role in developing new and improved instruments, including algorithm development and production of geophysical datasets from those observations. Just as important, communicating our work to the public and science community is essential. We are particularly proud to host NASA's Earth Observatory personnel in our organization (*earthobservatory.nasa.gov*).

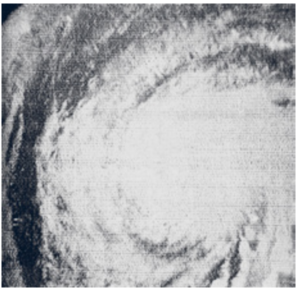
We enthusiastically invite you to take a glimpse into the work done by so many dedicated individuals and further explore the Earth Sciences Division web portal at: science.gsfc.nasa.gov/earth

Steven Platnick
Deputy Director for Atmospheres
NASA's Goddard Space Flight Center
Earth Sciences Division

On May 1, 1959, the Beltsville Space Center in Greenbelt, Maryland, became the Goddard Space Flight Center in commemoration of rocket pioneer Dr. Robert H. Goddard. Atmospheric science research began later that year with the formation of the Meteorology Branch headed by William Stroud in the Satellite Applications Division. The branch helped inaugurate the era of satellite meteorology, beginning with the Vanguard Project (transferred from the Naval Research Laboratory) and rapidly advancing to more sophisticated satellite experiments. The first observations from the Television Infrared Observation Satellite (TIROS) Program, managed and operated by Goddard, began in April 1960. Observations verified that Earth's cloud cover was highly organized with coherent structures associated with large-scale weather systems extending over thousands of miles.

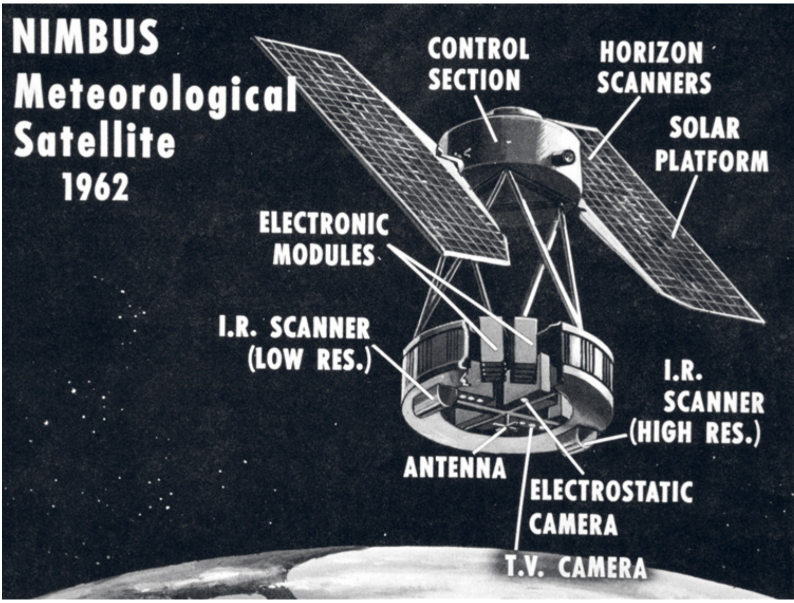
Dr. Goddard tested the first rocket to carry scientific instruments.





Left: TIROS vibration testing at RCA in Princeton, New Jersey. Above: TIROS III records the first image of a hurricane (Esther) from space in 1961.

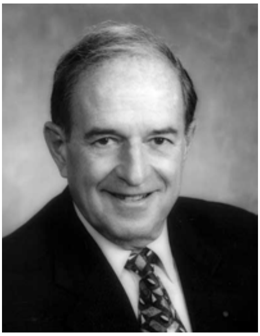
Nimbus 1, NASA's first Earth-observation research meteorological satellite, was launched in August 1964. This and six others in the series (the last one in 1978) collectively carried a broad array of instrumentation (covering the visible, infrared, far-infrared, ultraviolet, microwave, and radio spectrum) supporting a wide variety of Earth science research. The heritage of most modern operational space sensors trace back to the TIROS and Nimbus programs, both managed at Goddard.



Nimbus instruments led the way to revolutionizing weather forecasting to achieve accurate long-term forecasts.

Goddard's Earth Science research organizational structure evolved to include other disciplines within the Laboratory for Atmospheric and Biological Sciences Division under Nelson Spencer (1965-1970) and the Laboratory for Meteorology and Earth Sciences Division under William Nordberg (1970-1974). In 1974, the Atmospheric and Hydrological Applications Division (AHAD) was created in the Applications Directorate under William Bandeen, with 60 civil servants, which operated until 1977.

William Nordberg, Goddard scientist and pioneer in the investigation of the Earth and its environment using remote sensors on satellites (1959-1976) and director of Space Applications (1974-1976).



David Atlas, renowned radar meteorologist and founding director of the Laboratory for Atmospheric Sciences at Goddard (1977-1984).

In mid-1976, William Nordberg and Robert Cooper (Goddard Director) visited the National Center for Atmospheric Research (NCAR) and offered David Atlas the opportunity to build a new laboratory in atmospheric sciences. Atlas accepted the challenge and established the Goddard Laboratory for Atmospheres (GLAS), which provided a new vision and a balanced program of basic and applied research.

Emphasis was given to problem areas where satellite remote sensing data could make significant contributions in combination with numerical modeling. Toward this end, the global weather modeling activity under Milton Halem at the Goddard Institute for Space Studies (GISS) in New York was transferred to GLAS. The group became the Global Simulation and Modeling Branch and included top researchers such as Robert Atlas, Eugenia Kalnay, Yale Mintz, David Randall, and Jagadish Shukla. In 1979 Atlas hired Joanne Simpson to head the Severe Storms Branch. Simpson led the branch 1977-1988 and later served as the Goddard Chief Scientist for Meteorology.

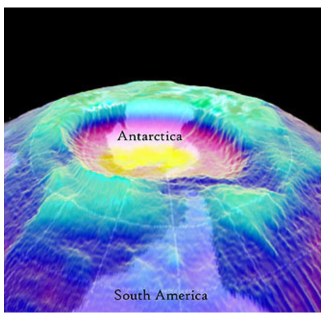
The 1970s became the turning point in the use of satellites to probe the atmosphere and oceans. Atmospheric scientists were beginning to get temperature and moisture soundings, stratospheric ozone measurements, land and ocean surface temperature readings, and many other geophysical quantities. This was also the time when global computer modeling came of age, using large mainframe computers such as the Amdahl 470V/6.

Joanne Simpson, first American woman to obtain a Ph.D. in meteorology and Goddard scientist (1979-2005). Dr. Simpson was head of the Severe Storms Branch (1977-1988), played a prominent role in the NASA Tropical Rainfall Measurement Mission (TRMM) launched in 1997, and was the Goddard Chief Scientist for Meteorology. She is shown here photographing clouds from a Woods Hole research aircraft in the 1950s.

Field experiments grew in importance by providing data for satellite operations and computer models. In the early 1980s, Halem, with help from Leslie Meredith (Director of Applications), purchased a CYBER 205 computer to compare the performance of two dozen space instrument system configurations to measure temperature, winds, moisture, and surface pressure. This would have taken over a year operating 24 hours per day with the Amdahl, but the study was completed in less than a month with the CYBER 205.

The first Amdahl 470V/6 mainframe produced was delivered to Goddard in 1975.

The Laboratory for Atmospheres was created in 1984 under Marvin Geller following the retirement of Atlas. Up to that time, the Applications Directorate and the Space Sciences Directorate operated as separate organizations. They were combined in 1984, creating the Space and Earth Sciences Directorate under Franklin Martin. Research of the late 1980s led to a new generation of atmospheric satellite sensors such as the Total Ozone Mapping Spectrometer (TOMS) and the Upper Atmosphere Research Satellite (UARS). These later became part of the Earth Observing System (EOS) Program, which came to fruition in the late 1990s and early 2000s.

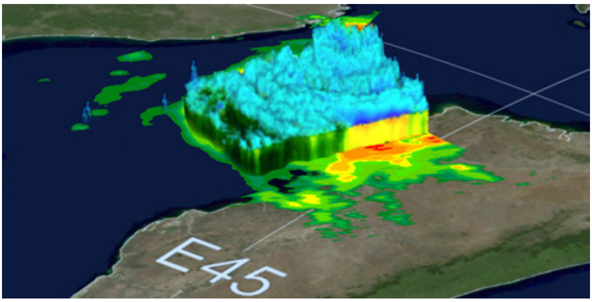


3D image product of the Antarctic ozone hole.

Mesoscale Atmospheric Processes Laboratory

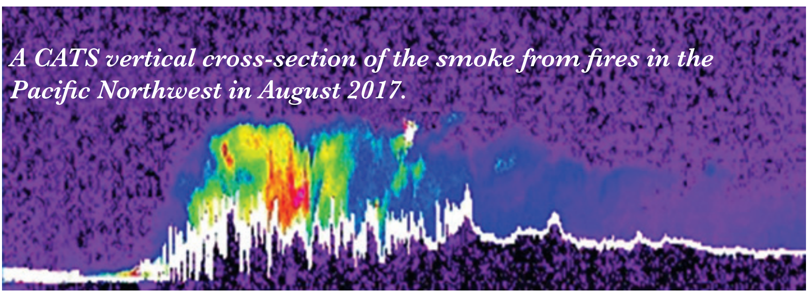
Mission: To understand how mesoscale atmospheric processes impact the global climate system. Weather, climate, and the global water and energy cycles are elements of the global system affecting life and the sustainability of human societies.

The Global Precipitation Measurement (GPM) mission, a consortium of international space agencies co-led by the Japan Aerospace Exploration Agency (JAXA) and NASA, makes frequent (every 2-3 hours) observations of Earth's precipitation. The GPM Core Observatory includes a Microwave Imager (GMI) and the Dual-frequency Precipitation Radar (DPR).



GPM image of Tropical Cyclone Idai (2019) in the middle of the Mozambique Channel. The DPR captured a well-developed eye, seen at the center of the image.

The Cloud Aerosol Transport System (CATS) is a lidar remote sensing instrument that provided range-resolved profile measurements of atmospheric aerosols and clouds from the International Space Station (ISS) for three years.

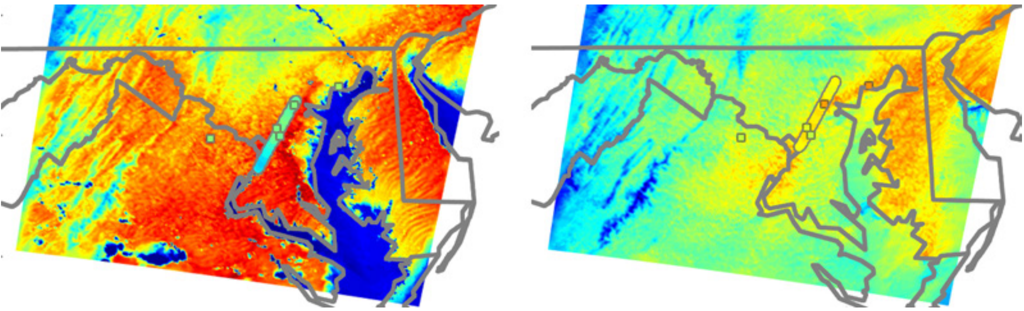


A CATS vertical cross-section of the smoke from fires in the Pacific Northwest in August 2017.

Our scientists participate in field work to validate satellite observations. Airborne instruments include the Cloud Physics Lidar (CPL), the ER-2 Doppler Radar (EDOP), High-Altitude Imaging Wind and Rain Airborne Profiler (HiWRAP), and the millimeter-wavelength Cloud Radar System (CRS).

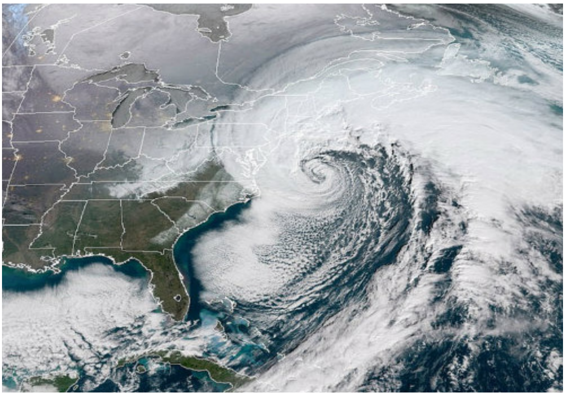
The HiWRAP radar.

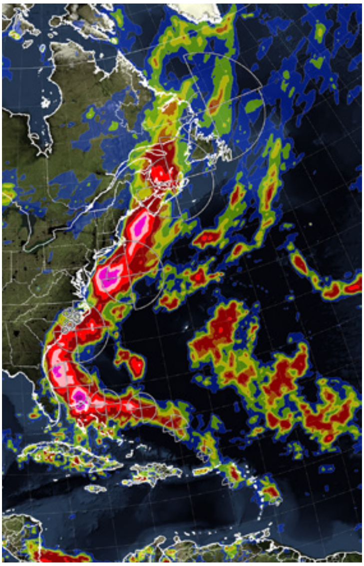
Our modelers focus on cloud systems with special emphasis on precipitating systems, working extensively with the National Center for Atmospheric Research/National Centers for Environmental Prediction/ Weather Research and Forecasting (NCAR/NCEP WRF) model and the Cloud Resolving Model (CRM). Key study areas include microphysical processes, surface interactions, and aerosol effects. The Integrated Multi-satellitE Retrievals for GPM (IMERG) algorithm combines observations



WRF-modeled planetary boundary layer heights (PBLHs) are evaluated against surface and satellite data on poor and moderate air quality days.

from a fleet of satellites, in near real-time, to provide near-global precipitation estimates every 30 minutes. Laboratory staff are supporting the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS).





Above: IMPACTS seeks to understand East Coast winter storms using in situ and remote aircraft data, satellite retrievals, and numerical modeling. Right: Near-real-time rain estimates from IMERG during Hurricane Dorian (2019).

Climate and Radiation Laboratory

Mission: To investigate atmospheric radiative energy, both as a driver for climate change and as a tool for the remote sensing of Earth's atmosphere and surface. Our Climate Research Program seeks to better understand how our planet reached its present state, and how it may respond to future drivers, both natural and anthropogenic.

Our scientists serve in lead roles for satellite missions such as **Aqua, Terra, SNPP, GOES-16, DSCOVR,** and **TSIS.** They also conceive, maintain, and improve aerosol and cloud retrieval algorithms while striving for continuity of derived aerosol and cloud properties among the different satellite platforms to enable climate studies. Lab scientists are also active in technology development such as compact submillimeter radiometers for CubeSats.

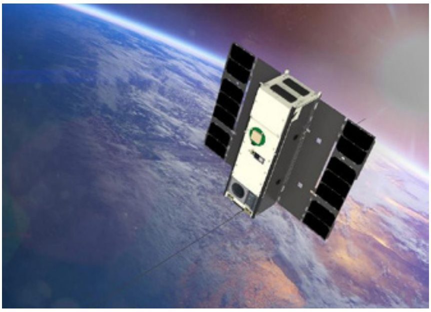
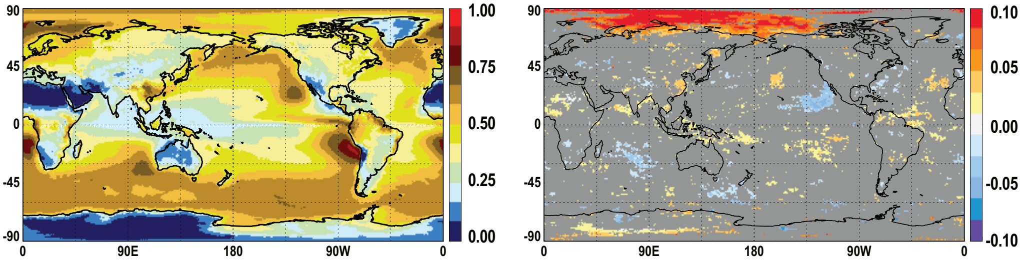


Illustration of the IceCube CubeSat in orbit.

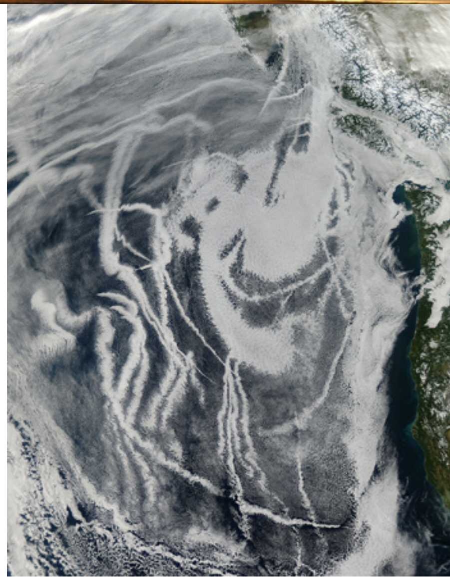


Mean MODIS Terra liquid water daytime cloud fraction for the 19-year period July 2000 through June 2019 (left) and the corresponding absolute fraction/decade trend masked by a 5% statistical significance (right). Derived from the MODIS MOD06 and MOD08 products.

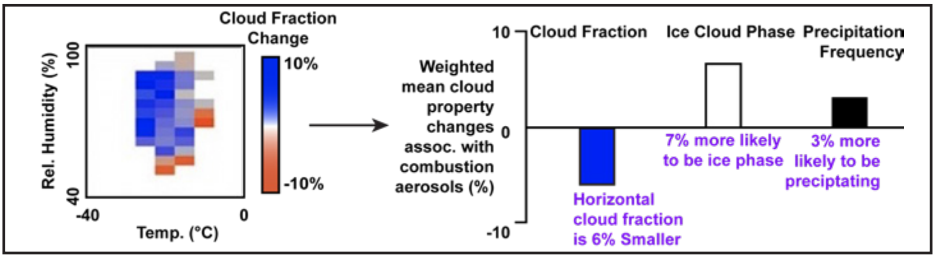
SMARTLabs (**SMART-COMMIT-ACHIEVE**) comprise a broad range of active and passive instruments measuring atmospheric solar and terrestrial radiation (**SMART**), the physiochemical properties of aerosols and precursor gases (**COMMIT**), and clouds through an array of microwave radars (**ACHIEVE**).

SMARTLabs' ACHIEVE.

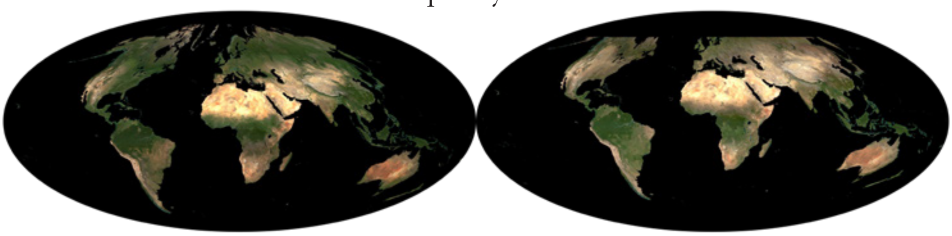
Our scientists are developing deep learning models to identify in satellite images marine clouds that have been modified by ship emissions, also known as ship tracks. This paves the way for routine automatic detection of ship tracks worldwide and the creation of a unique dataset for detailed aerosol-cloud interactions studies. In the rapidly changing Arctic, models have difficulty reproducing the energy budget. Large errors stem from uncertainties in aerosol impacts on cloud phase and cloud cover. Using NASA satellite data, our scientists characterize cloud properties in clean versus polluted conditions under similar meteorology to study how combustion aerosols affect freezing processes over large regions of the Arctic.



Ship tracks in northeast Pacific Ocean, MODIS Terra, January 2013.



The MAIAC MODIS MCD19 product (Multi-Angle Implementation of Atmospheric Correction/Moderate Resolution Imaging Spectroradiometer) incorporates advanced cloud and snow detection capabilities for improved atmospheric correction, in particular in the tropics and northern latitudes, regions of rapid climate change. MAIAC is the only algorithm providing reliable high-resolution (1km) aerosol retrievals over land and its capabilities over urban regions have attracted the attention of the air quality and health communities.

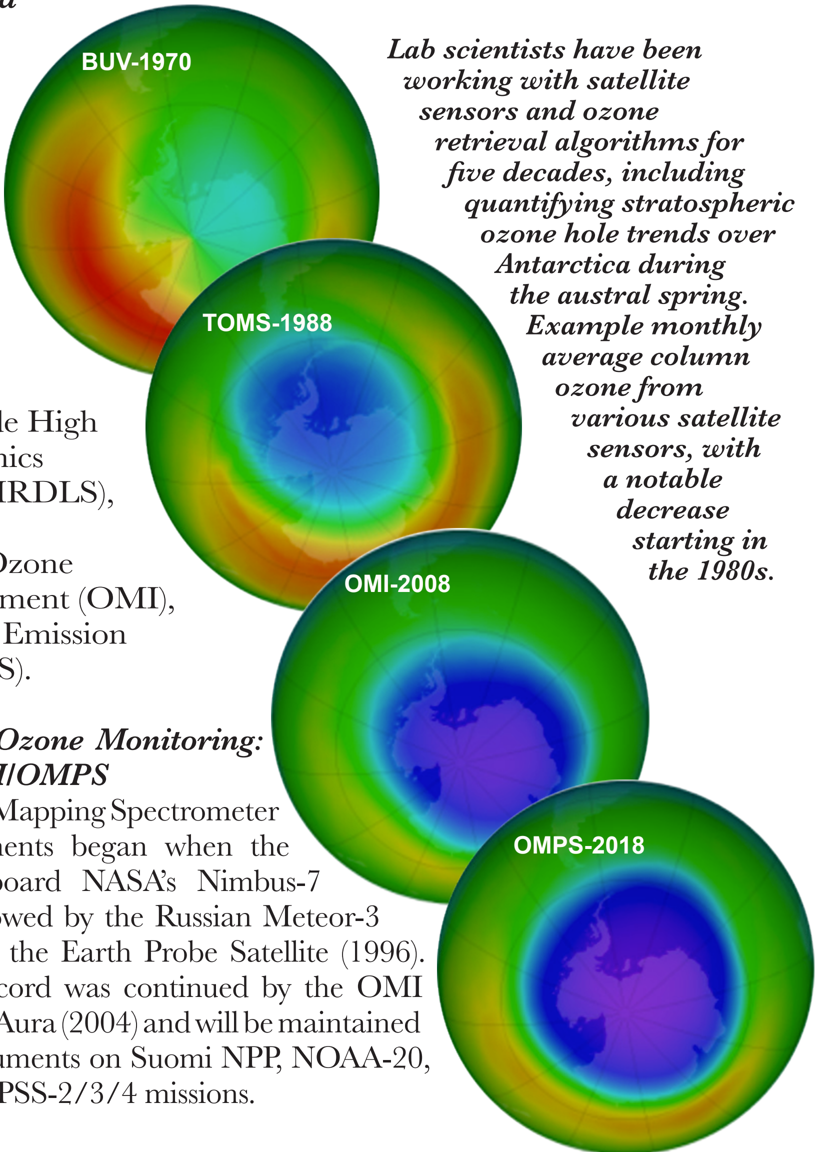


True color nadir-10 km reflectance over land from MAIAC for July (left) and December (right) 2016.

Atmospheric Chemistry and Dynamics Laboratory

Mission: Performs research on aerosols, ozone, and other trace gases in the Earth's atmosphere to understand the effect of human activities on global climate and chemistry.

Aura was launched in 2004 to study the atmosphere's chemistry and dynamics and answer questions about ozone trends, air quality changes, and their linkage to climate change. Aura's instruments include High Resolution Dynamics Limb Sounder (HIRDLS), Microwave Limb Sounder (MLS), Ozone Monitoring Instrument (OMI), and Tropospheric Emission Spectrometer (TES).



Lab scientists have been working with satellite sensors and ozone retrieval algorithms for five decades, including quantifying stratospheric ozone hole trends over Antarctica during the austral spring. Example monthly average column ozone from various satellite sensors, with a notable decrease starting in the 1980s.

Long-term Total Ozone Monitoring: TOMS/SBUV/OMI/OMPS

The Total Ozone Mapping Spectrometer (TOMS) measurements began when the instrument was aboard NASA's Nimbus-7 satellite (1978), followed by the Russian Meteor-3 satellite (1994), and the Earth Probe Satellite (1996). The total ozone record was continued by the OMI instrument on EOS Aura (2004) and will be maintained by the OMPS instruments on Suomi NPP, NOAA-20, and the upcoming JPSS-2/3/4 missions.

The Global Modeling Initiative (GMI) is part of the NASA Modeling, Analysis, and Prediction (MAP) program. GMI investigations support the development and integration of a state-of-the-art modular 3D chemistry and transport model (CTM) that includes full chemistry for both the troposphere and stratosphere.

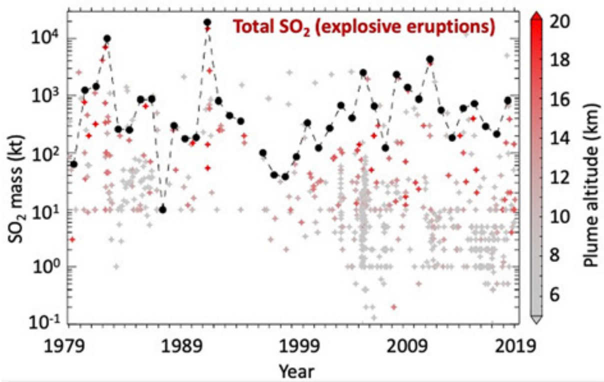
The Goddard chemistry climate model (GEOSCCM) is based on the NASA Global Modeling and Assimilation Office (GMAO) general circulation model integrated with various chemical packages.

SHADOZ (Southern Hemisphere ADditional OZonesondes) coordinates ozonesonde stations operating in the tropics, subtropics, and southern hemisphere. SHADOZ standardizes ozone profile data, coordinates, launches, and provides a central archive location, making datasets available since 1998.

Pandora, part of the Pandonia Global Network, monitors levels of ozone, nitrogen dioxide, and formaldehyde in the atmosphere.

Pandora Tracker.

Network for the Detection of Atmospheric Composition Change (NDACC) Ozone Lidars: Three ground-based portable atmospheric lidars provide aerosol, ozone, temperature, and water vapor measurements and include the Tropospheric Ozone (TROPOZ) Lidar, a Stratospheric Ozone (STROZ) Lidar, and an Aerosol, Temperature, and Water Vapor (AT) Lidar.



The volcanic SO_2 climatology from 1978-present.

Volcanic Sulfur Dioxide (SO_2): This 40-year global database was released as part of the Making Earth System Data Records for Use in Research Environments (MEaSUREs) SO_2 project. Collectively these data products have garnered significant interest for their potential role in sustaining the persistent, background stratospheric aerosol layer, which is an important factor in global climate forcing.

Global Troposphere Research: This effort combines airborne observations from NASA's Atmospheric Tomography (ATom) mission with OMI retrievals of formaldehyde (HCHO) to infer the distribution of total-column hydroxyl radical (OH) throughout the remote troposphere.

Multi-Angle Stratospheric Aerosol Radiometer (MASTAR): Ideally sized for flying on a CubeSat platform, MASTAR would observe the type and distribution of aerosols in the stratosphere.

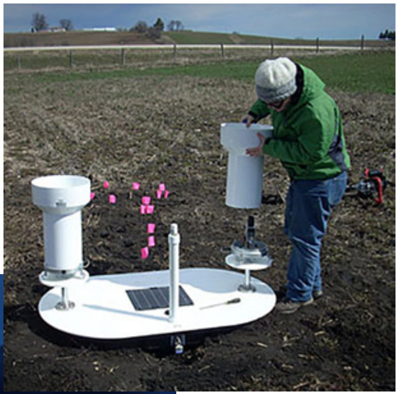
MASTAR.

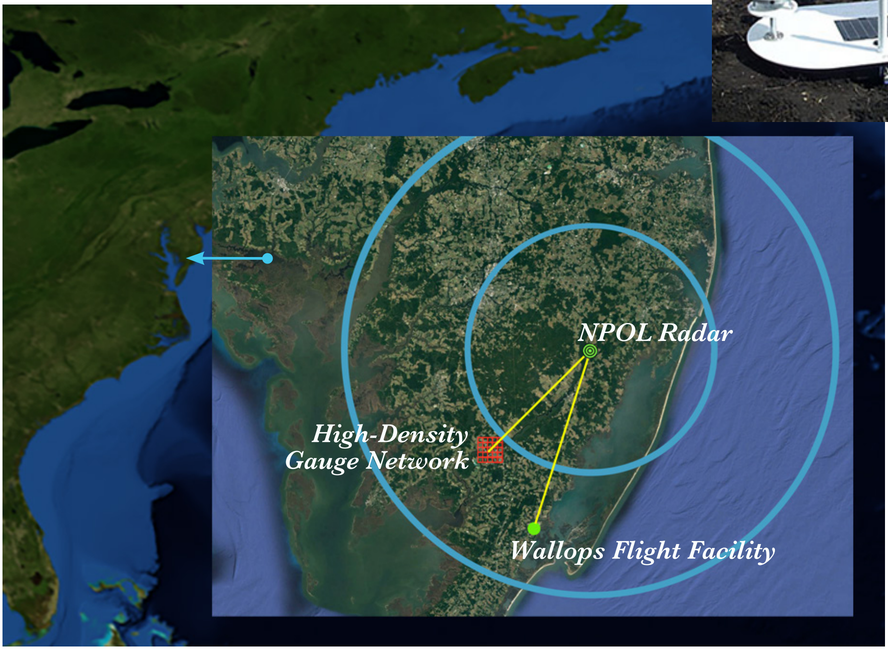
Earth Sciences Field Support Office

Mission: The Earth Sciences Field Support Office (FSO) and GPM Ground Validation (GV) System Manager supports the Earth science research activities of Goddard scientists at NASA's Wallops Flight Facility. FSO supports science efforts for NASA's GPM GV, the Airborne Topographic Mapper (ATM), ICESat-2 (Ice, Cloud, and land Elevation Satellite-2), the Upper Air Instrumentation Research Project (UAIRP), as well as the Advancing Earth Research Observations with Kites and Atmospheric/Terrestrial Sensors (AEROKATS) program.

The GPM ground validation team at Wallops obtains measurements of precipitation from a variety of instruments including multi-frequency radars, disdrometers, and rain gauges. The flagship instrument is NASA's S-band dual-polarimetric radar (NPOL), which provides high-resolution estimates of precipitation rates as well as types.

NPOL (left) is NASA's premier weather radar. It is one of only two mobile S-band dual-polarization radars.





Sites in the GPM GV instrument network (left) are part of the Precipitation Research Facility at Wallops and include a high-density network of rain gauges (above).

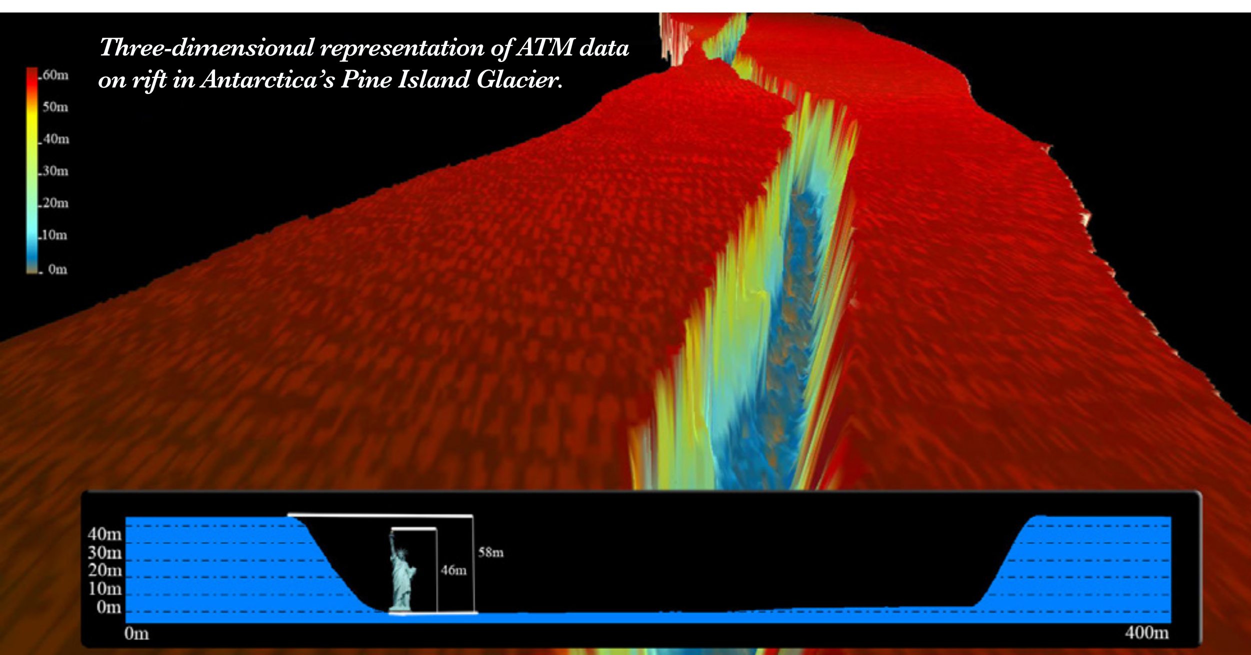
The AEROKATS program designs low-altitude custom remote sensing platforms, called Aeropods, for agricultural and environmental research purposes.

Adapted to Science, Technology, Engineering, and Math (STEM), AEROKATS enables middle and high school teachers and students to experience remote sensing firsthand.

The UAIRP group has supported ozone measurements at Wallops for more than 50 years (ozonesonde launches since 1970 and Dobson Total ozone since the mid-1960s). UAIRP has also supported the SHADOZ (Southern Hemisphere ADditional OZonesondes) program for more than 40 years and is the custodian of the Natal, Brazil, site.

Dobson Ozone Spectrophotometer.

FSO modelers develop and improve the science data processing software to produce level 0-3a data for ICESat-2. The ATM group is assisting in ICESat-2 validation during field campaigns in Antarctica. By flying along set ICESat-2 tracks, ATM is able to "fill in the blanks" where there are ICESat-2 discrepancies.



Three-dimensional representation of ATM data on rift in Antarctica's Pine Island Glacier.