

Laboratory for Atmospheres

PHILOSOPHY, ORGANIZATION, MAJOR ACTIVITIES, AND 1999 HIGHLIGHTS

January 2000

Doppler Lidar Winds

Altitude (km)

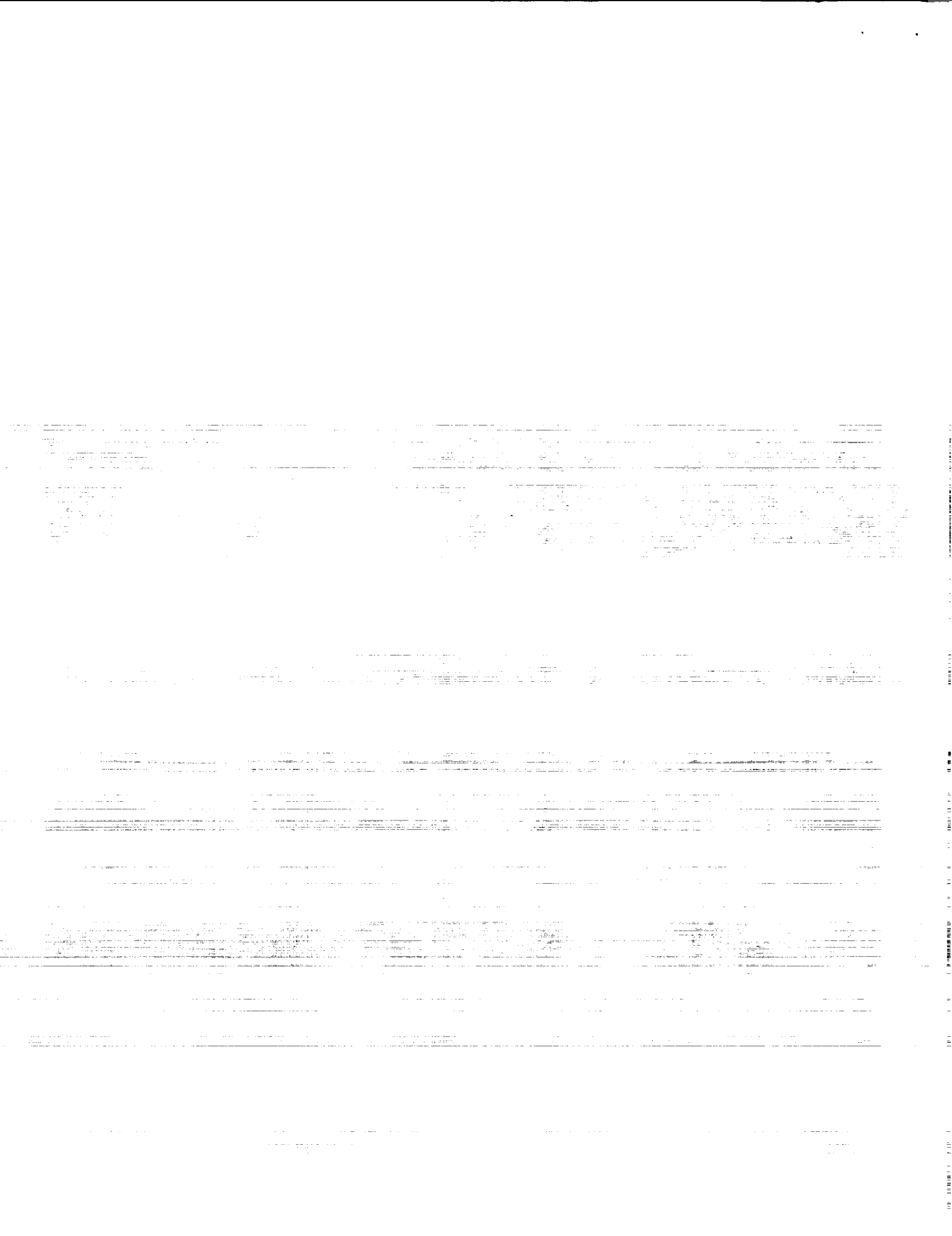
1979

1989

1998



National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, MD 20771

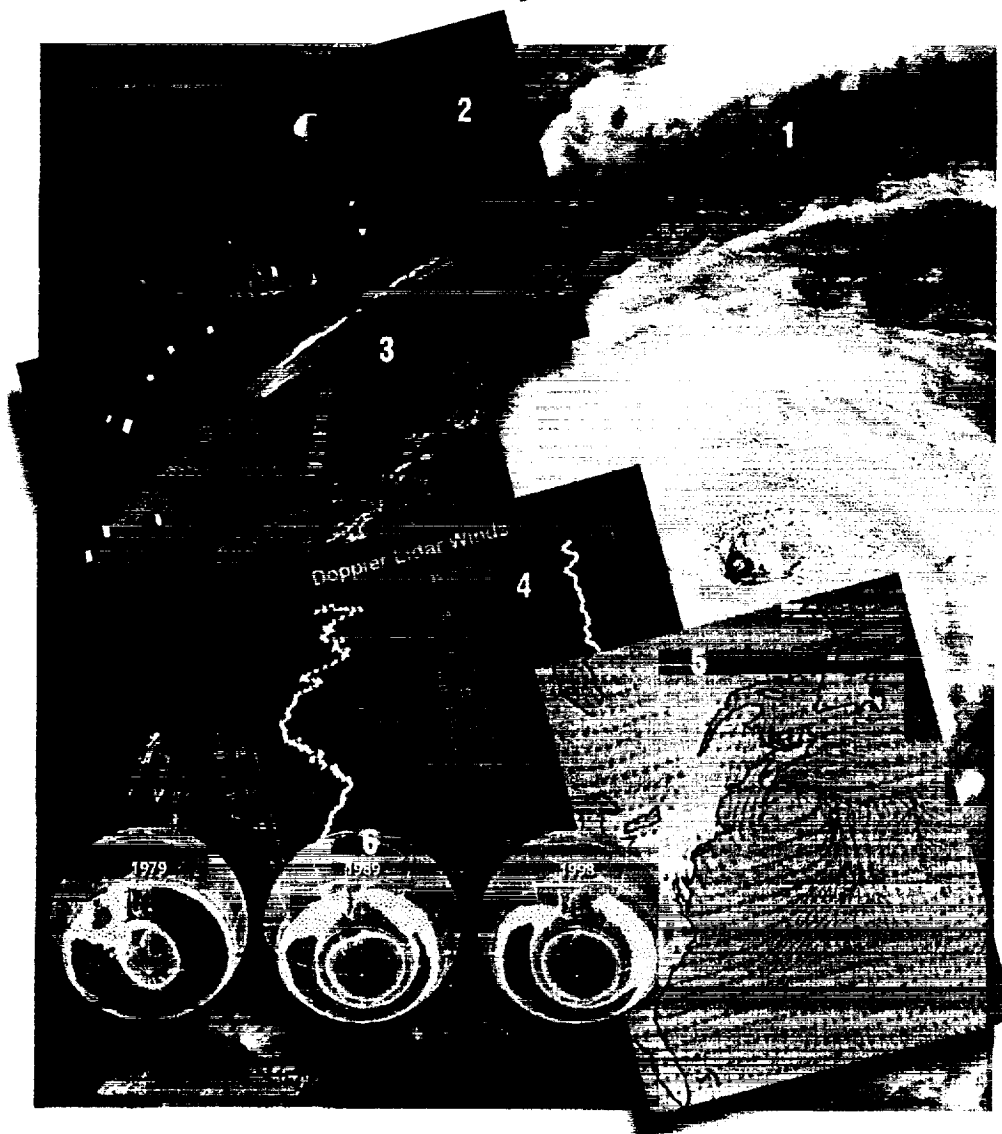


NASA GODDARD SPACE FLIGHT CENTER

Laboratory for Atmospheres

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1 Hurricane Fran as rendered on NASA computers using data captured by NOAA's GOES-8 satellite on September 4, 1996.

2 The Cassini Mission to Saturn and its moon, Titan.

3 The Leonardo-BRDF formation of microsatellites viewing the Himalayas and the Indian subcontinent.

4 The Goddard Lidar Observatory for Winds (GLOW), a mobile Doppler lidar system designed for field measurement of wind profiles from the surface into the stratosphere. A profile of wind speed and direction appears in the foreground, along with wind data obtained from a balloon sonde.

5 An example of the very realistic patterns of cyclones and fronts that appear in surface wind fields generated by the 1-degree latitude by 1-degree longitude version of the GEOS global atmospheric model.

6 October average total column ozone as measured by the Total Ozone Mapping Spectrometer (TOMS). Red and yellow indicate high overhead column amounts. Blue and purple show low values. The Antarctic Ozone hole appears as the very low column amounts in the two later years.

Cover designed by Bill Welsh



January 2000

Dear Reader:

Welcome to the Laboratory for Atmospheres and to our review of the Laboratory's accomplishments for 1999!

The Laboratory for Atmospheres consists of four hundred scientists, technologists, and administrative personnel working within the Earth Sciences Directorate of the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC). Together, we're dedicated to our mission of advancing the knowledge and understanding of Earth's atmosphere, as well as the atmospheres of other planets. In doing so, we contribute directly to two of NASA's primary activities, the Earth Science and Space Science Enterprises.

We publish this report each year for a diverse group of readers—from our managers and colleagues within NASA to scientists outside the agency, from graduate students in the atmospheric sciences to members of the general public. Inside, you'll find descriptions of our philosophy, our people and facilities, our place in NASA's mission, and our accomplishments for 1999.

Among our accomplishments for the year, Laboratory staff have hosted 85 seminars, conducted 26 workshops, published 176 refereed papers, hosted 212 short-term visiting scientists, and participated in an array of educational activities.

Among our workshops and seminars, I'm pleased to mention one event in particular, the *Symposium on Cloud Systems, Hurricanes and TRMM: Celebration of Dr. Joanne Simpson's Career - The First 50 Years*. The workshop was a magnificent tribute to Joanne Simpson, the scientist and role model. Many of the major contributors to the field of cloud convection described the pivotal role that Joanne Simpson played in its evolution from a small specialty to a major area of research in atmospheric sciences. The symposium also featured an extensive review of the original ideas and efforts that led to the Tropical Rainfall Measuring Mission (TRMM).

Among our recent scientific developments, we are all excited about the launch of Terra in December. Terra is the first of NASA's Earth Observing System platforms designed as a broadly scoped data-gathering system. The mission will enable new research into the ways that Earth's land mass, oceans, air, ice, and life interact as a whole climate system. Terra reflects years of work by many at Goddard and at other government and private organizations. I thank Yoram Kaufman for his leadership over many years as Terra's Project Scientist.

Scientists in the Laboratory have also played a leadership role in the SOLVE and TRMM KWAJEX campaigns. SOLVE signifies Stratospheric Aerosol and Gas Experiment (SAGE) III Ozone Loss and Validation

Experiment. SOLVE is a measurement campaign designed to examine the processes controlling ozone levels at mid-to-high latitudes. The measurements will allow us to better predict how ozone responds to changing climate and changing levels of chlorine. The TRMM KWAJEX experiment was designed to carefully observe cloud and precipitation structures of oceanic convection. Our observations will enable us to quantify the uncertainties in TRMM rainfall estimates and in cloud microphysical models. We also use these models to obtain latent heating profiles from observed rainfall structures.

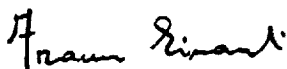
Our scientific efforts unfold within the context of NASA's Earth Science Enterprise. The Laboratory's Mark Schoeberl played a leadership role in formulating the Earth Science Vision for the Earth Science Enterprise, working closely with STAAC and AETD (Systems, Technology, and Advanced Concepts Directorate and Applied Engineering and Technology Directorate). The Earth Science Vision outlines NASA's strategy for the next 10-20 years to enable environmental forecasts at all scales. The Vision emphasizes the essential interplay of Earth-observing technology, information technology, and science in improving our ability to forecast weather and climate change.

Among our educational efforts, I am proud of the creation of the Goddard Howard University Fellowship in Atmospheric Sciences (GOHFAS). The program, funded by NASA Headquarters, is designed to attract outstanding under-represented minorities to the field of atmospheric sciences. Such under-representation is particularly noticeable within the African-American demographic. The American Meteorological Society reports that its African-American membership is only 0.9%. Of this number, few possess advanced degrees. In partnership with our Laboratory, Howard University selects ten minority undergraduates from any university in the country to spend their junior-year summer at Howard or in the Laboratory. They continue to be mentored by Laboratory scientists or by Howard during their senior year back at their home institution.

I hope you'll read further to learn more about the Laboratory for Atmospheres and our work. In addition, I invite you to visit us on the World Wide Web (http://dao.gsfc.nasa.gov/lab/lab_brochure.html) and to read the brochures and Web pages for each of the Laboratory's branches.

Before closing, I wish to pay tribute to Otto Thiele who retired last October after 46 years of distinguished government service. Otto was one of the original proponents of TRMM and was instrumental in organizing the TRMM ground truth program. I salute you, Otto, and thank you for your service to the Laboratory and the community.

Sincerely,



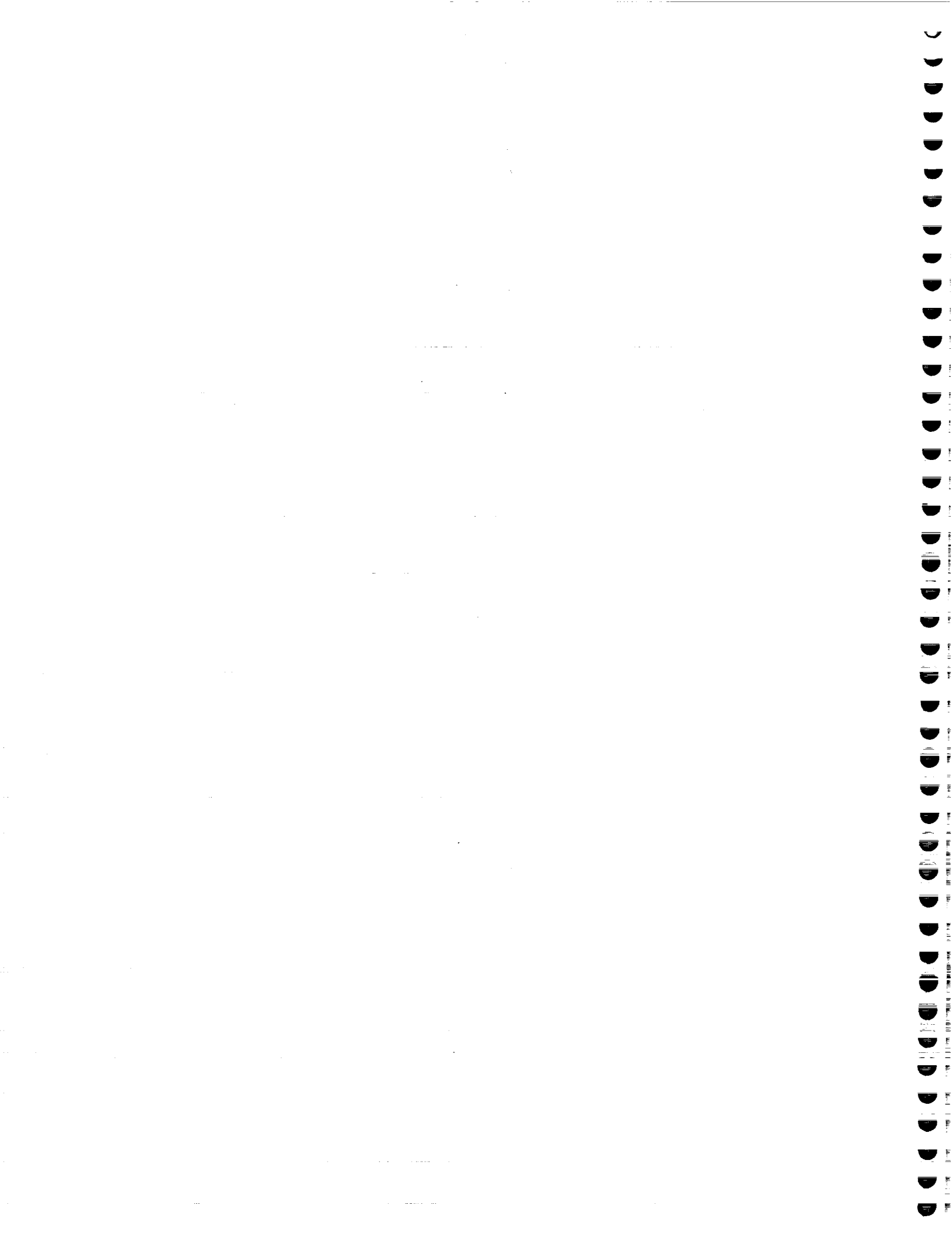
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Mission: The Laboratory for Atmospheres is dedicated to advancing knowledge and understanding of the atmospheres of the Earth and other planets.

1. INTRODUCTION

How can we improve our ability to predict the weather—tomorrow, next week, and into the future?

How is the Earth's climate changing? What causes such change? And what are its costs?

What can the atmospheres of distant planets teach us about our own planet?

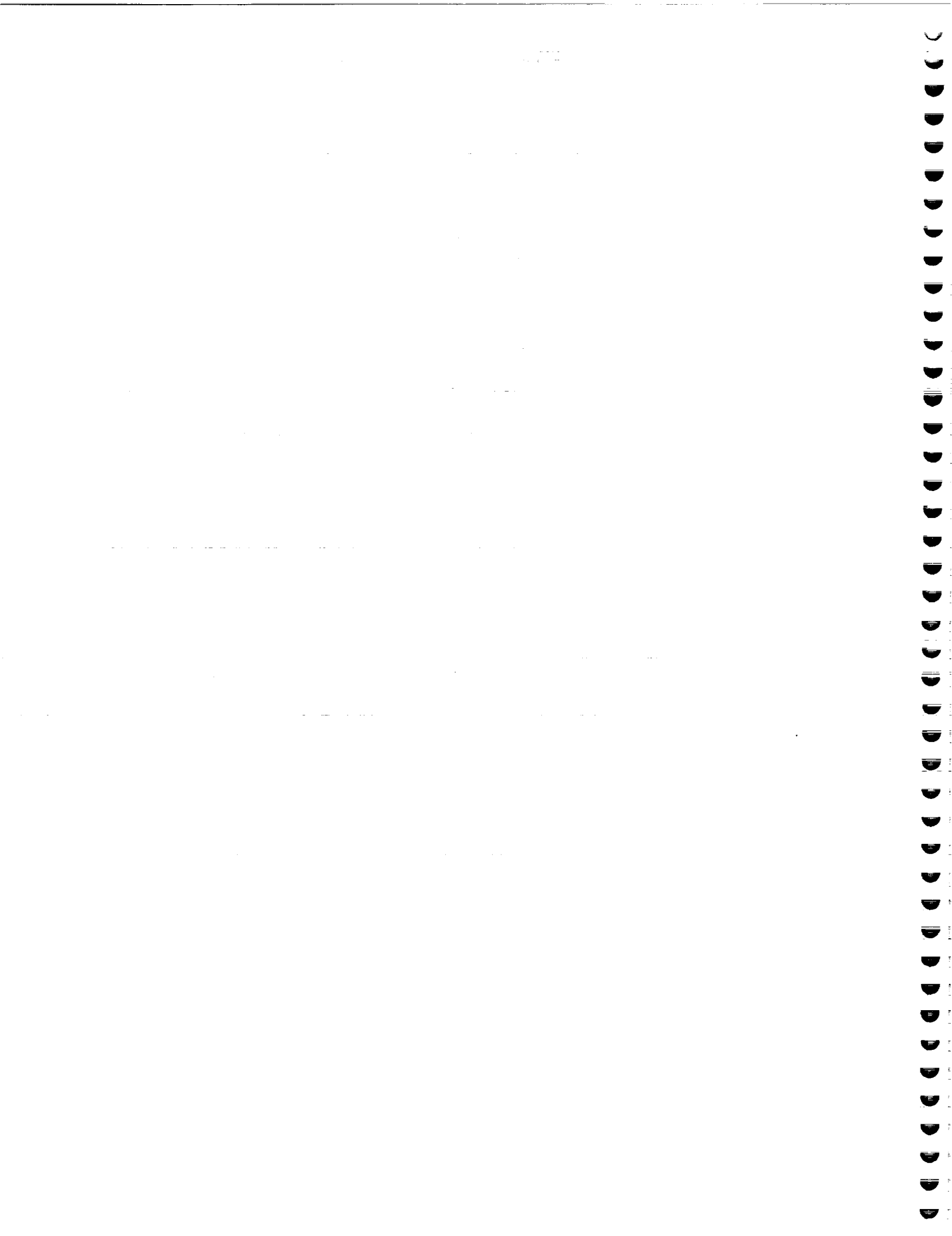
The Laboratory for Atmospheres is helping to answer these and other scientific questions about our planet and its neighbors. The Laboratory conducts a broad theoretical and experimental research program studying all aspects of the atmospheres of the Earth and other planets, including their structural, dynamical, radiative, and chemical properties.

Vigorous research is central to NASA's exploration of the frontiers of knowledge. NASA scientists play a key role in conceiving new space missions, providing mission requirements, and carrying out research to explore the behavior of planetary systems, including, notably, the Earth's. NASA scientists also supply outside scientists with technical assistance and scientific data to further investigations not immediately addressed by NASA itself.

The Laboratory for Atmospheres (Code 910) is a vital participant in NASA's research program. The Laboratory is part of the Earth Science Directorate (Code 900) based at NASA's Goddard Space Flight Center in Greenbelt, MD. The Directorate itself is comprised of the Global Change Data Center (GCDC), the Space Data and Computing Division (SDCD), and four science laboratories, including the Laboratory for Atmospheres. The three other labs are the Goddard Institute for Space Studies (GISS) in New York, NY, the Laboratory for Terrestrial Physics, in Greenbelt, and the Laboratory for Hydrospheric Processes, also in Greenbelt.

In this report, you'll find a statement of our philosophy and a description of our role in NASA's mission. You'll also find a broad description of our research and a summary of our scientists' major accomplishments in 1999. The report also presents useful information on human resources, scientific interactions, and outreach activities with the outside community.

For your convenience, we've published a version of this report on the Internet. Our Web site includes links to additional information about the Laboratory's Offices and Branches. You can find us on the World Wide Web at http://dao.gsfc.nasa.gov/lab/lab_brochure.html.



2. PHILOSOPHY

At the Laboratory for Atmospheres, we support the well-being of the Laboratory's individual members, maintain strong ties with our scientific partners, and extend our reach to the wider community.

Individual Well-being

Personal Freedom

Individuals are free and encouraged to express their views and offer diverging opinions. Laboratory scientists submit research proposals with different technical or technological approaches and, in some cases, may even compete with one another. This freedom promotes creativity, competition, and openness.

Programmatic and Research Balance

Unlike most universities, our Laboratory often has relatively large programs, sizable satellite missions, or observational campaigns that require the cooperative and collaborative efforts of many scientists. We aim to ensure an appropriate balance between our scientists' responsibility for these large collaborative projects and their need for an active individual research agenda. This balance allows members of the Laboratory to continuously improve their scientific credentials.

Research Quality

The Laboratory places high importance on promoting and measuring quality in its scientific research. We strive to assure high quality through peer-review funding processes that support approximately 90% of the work in the Laboratory. The overall quality of our scientific efforts is evaluated periodically by committees of advisors from the external scientific community, as detailed in Appendix 2 of this document.

Scientific Partnerships

Synergy Between Science and Technology

The Laboratory aims to increase its interaction with the Systems, Technology, and Advanced Concepts (STAAC) Directorate and the Applied Engineering and Technology (AETD) Directorate through the formation of joint teams to develop new technologies and engineering solutions for scientific questions.

Goddard offers enormous opportunities for synergy between engineering and scientific expertise. Experimental activities are spread across the Laboratory to foster communication and to maximize the direct application of technology to scientific goals. In addition, a major effort is underway to increase our interactions with engineering groups outside the Laboratory. Healthy collaboration between our scientists and the Center's engineers is vital to our success in the competitive research environment in which we operate.

Interactions with Other Scientific Groups

The Laboratory depends on collaboration with the academic community, with other NASA centers and federal laboratories, and with foreign agencies to achieve its goals. Section 5 discusses these relationships more fully.

Support for Project Scientists

Space flight missions at NASA depend on cooperation between two upper-level managers, the project scientist and the project manager, who are the principal leaders of the project.

The project scientist must provide continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large. Taking on the responsibilities of a project scientist provides a unique opportunity for Laboratory staff to obtain significant scientific management experience. Typically, the Laboratory invites candidates from the senior ranks to fill these roles.

Outreach and Education

Members of the Laboratory interact with the general public to support a wide range of interests in the atmospheric sciences.

Among other activities, the Laboratory raises the public's awareness of atmospheric science by presenting public lectures and demonstrations, by making scientific data available to wide audiences, by teaching, and by mentoring students and teachers.

Section 7 presents details of the Laboratory's outreach activities during 1999.

Human Resources

The Laboratory is committed to addressing the demographic imbalances that exist today in the atmospheric and space sciences. We must address these imbalances for our field to enjoy the full benefit of all the nation's talent. To this end, the Laboratory always seeks qualified women and underrepresented ethnic groups when hiring new scientists and technologists. The Laboratory will continue to make substantial efforts to attract new scientists to the fields of atmospheric and space sciences.

Opportunities for the Commercial Sector

The Laboratory fully supports government/industry partnerships, Small Business Innovative Research (SBIR), and technology transfer activities. The Laboratory hopes to devote at least 10% to 20% of its resources to joint activities with industry on a continuing basis.

3. STAFF, ORGANIZATION, AND FACILITIES

Staff

The current Laboratory staff is comprised of 87 civil servants. Of these, 74 are scientists, and 4 are engineers; 69 hold doctoral degrees. In addition, we host 78 visiting scientists (NRC, ESSIC, JCET, USRA) and 221 non-civil service specialists supporting the various projects and research programs throughout the Laboratory.

Organization

Figure 1 shows our present organization.

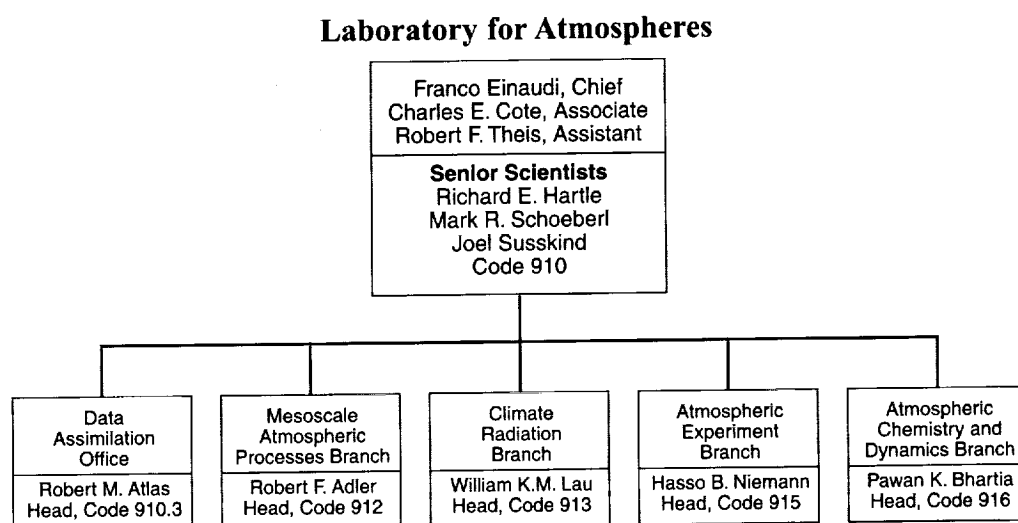


Figure 1. Laboratory for Atmospheres Organization Chart

Data Assimilation Office (DAO), Code 910.3

The DAO combines all available meteorologically relevant observations with a prognostic model to produce accurate time series estimates of the complete global atmosphere. The DAO:

- Advances the state of the art of data assimilation and the use of data in a wide variety of Earth system problems,
- Develops global data sets that are physically and dynamically consistent,
- Provides operational support for NASA field missions and Space Shuttle science, and
- Provides model-assimilated data sets for the Earth Science Enterprise.

For additional information on DAO activities, consult the World Wide Web (<http://dao.gsfc.nasa.gov/>).

Mesoscale Atmospheric Processes Branch, Code 912

The Mesoscale Atmospheric Processes Branch studies the physics and dynamics of atmospheric processes, using satellite, aircraft, and surface-based remote sensing observations as well as computer-based simulations. This Branch develops advanced remote sensing instrumentation (with an emphasis on lidar) and techniques to measure meteorological conditions in the troposphere. Key areas of investigation are cloud and precipitation systems and their environments—from individual cloud systems, fronts, and cyclones, to regional and global climate. You can find out more about Branch activities on the World Wide Web (<http://rsd.gsfc.nasa.gov/912/code912>).

Climate and Radiation Branch, Code 913

The Climate and Radiation Branch conducts basic and applied research with the goal of improving our understanding of regional and global climate. This group focuses on the radiative and dynamical processes that lead to the formation of clouds and precipitation and on the effects of these processes on the water and energy cycles of the Earth. Currently, the major research thrusts of the Branch are climate diagnostics, remote sensing applications, hydrologic processes and radiation, aerosol/climate interactions, and seasonal-to-interannual variability of climate. You can learn more about Branch activities on the World Wide Web (<http://climate.gsfc.nasa.gov/>).

Atmospheric Experiment Branch, Code 915

The Atmospheric Experiment Branch carries out experimental investigations to further our understanding of the formation and evolution of various solar system objects such as planets, their satellites, and comets. Investigations address the composition and structure of planetary atmospheres, and the physical phenomena occurring in the Earth's upper atmosphere. Neutral gas, ion, and gas chromatograph mass spectrometers have been developed and are continuously being refined to measure atmospheric gas composition using entry probes and orbiting satellites. You can find further information on Branch activities on the World Wide Web (<http://webserver.gsfc.nasa.gov/Code915/>).

Atmospheric Chemistry and Dynamics Branch, Code 916

The Atmospheric Chemistry and Dynamics Branch engages in four major activities. The Branch:

- Develops remote sensing techniques to measure ozone and other atmospheric trace constituents important for atmospheric chemistry and climate studies,
- Develops models for use in the analysis of observations,
- Incorporates results of analysis to improve the predictive capabilities of models, and
- Provides predictions of the impact of trace gas emissions on our planet's ozone layer.

For further information on Branch activities, consult the World Wide Web (<http://hyperion.gsfc.nasa.gov/>).

Facilities

Computing Capabilities

Computing capabilities in the Laboratory range from high-performance supercomputers to scientific workstations to desktop personal computers.

The supercomputers are operated for general use by the NASA Center for Computational Sciences (NCCS). Their flagship machine is a Cray T3E, with 512 DEC 21064 Alpha microprocessor processing elements, each with 64 Gbytes (Gb) of random access memory. Supercomputer resources are also available through special arrangement from NASA's Ames Research Center's Numerical Aerospace Simulation (NAS) facility.

Each Branch maintains a distributed system of workstations and desktop personal computers. The workstations are typically arranged in large clusters involving 30 or more machines. These clustered systems provide enormous computing and data storage capability, economical to maintain and easy to use. These machine clusters have been acquired to support specific programs, but may be made available for other research on a limited basis.

Mass Spectrometry

The Laboratory for Atmospheres' Mass Spectrometry Laboratory is equipped with unique facilities for designing, fabricating, assembling, calibrating, and testing flight-qualified mass spectrometers used for atmospheric sampling.

The equipment includes precision tools and machining, material processing equipment, and calibration systems capable of simulating planetary atmospheres. The facility has been used to develop instruments for exploring the atmospheres of Venus, Saturn, and Mars (on orbiting spacecraft), and of Jupiter and Titan (on probes). The Mass Spectrometry Laboratory will also be used in support of comet missions. In addition, the Laboratory has clean rooms for flight instrument assembly and equipment for handling poisonous and explosive gases.

Lidar

The Laboratory has well-equipped facilities to develop lidar systems for airborne and ground-based measurements of aerosols, methane, ozone, water vapor, pressure, temperature, and winds.

Lasers capable of generating radiation from 266 nanometer (nm) to beyond 1,000 nm are available, as is a range of sensitive photon detectors for use throughout this wavelength region. The lidar systems employ telescopes with primaries up to 30 inches in diameter and high-speed counting systems for obtaining high vertical resolution.

Lidars developed in the Laboratory include the Airborne Raman Lidar (ARL), to measure water vapor and temperature; the Stratosphere Ozone Lidar Trailer Experiment (STROZ LITE), to measure atmospheric ozone, temperature, and aerosols; the Large Aperture Scanning Airborne Lidar (LASAL), to measure clouds and aerosols; the Cloud

Lidar System (CLS), to measure clouds and aerosols; the Scanning Raman Lidar, to measure water vapor, aerosols, and cloud water; and the Edge Technique Wind Lidar System, to measure winds.

Radiometric Calibration and Development Facility

The Radiometric Calibration and Development Facility (RCDF) supports the calibration and development of instruments for space-based measurements of Space Shuttle demonstration flights for new techniques of ozone measurement.

As part of the Earth Observing System (EOS) calibration program, the RCDF will provide calibrations for future Solar Backscatter Ultraviolet/version 2 (SBUV/2) and Total Ozone Mapping Spectrometer (TOMS) instruments. Calibrations were conducted on the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) flying on European Space Agency's (ESA) Environmental Satellite (ENVISAT) mission (2001), ODIN Spectrometer and IR Imager System (OSIRIS) on the Canada/Sweden ODIN mission (2001), and the Israeli Mediterranean Israeli Dust Experiment (MEIDEX) shuttle instrument (2001). The facility also is the home of Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA) (IIP) and Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE).

The RCDF contains state-of-the-art calibration equipment and standards traceable to the National Institutes of Standards and Technology (NIST). Calibration capabilities include wavelength, linearity, signal to noise (s/n), instantaneous field of view (IFOV), field of regard (FOR), and goniometry. The facility is also capable of characterizing such instrument subsystems as spectral dispersers and detectors.

The Facility includes a class 10,000 clean room with a continuous source of N₂ for added contamination control.

4. OUR WORK AND ITS PLACE IN NASA'S MISSION

NASA's Enterprises

NASA's overall program, as outlined in the agency's strategic plan, is composed of four enterprises:

- Earth Science
- Space Science
- Aerospace Technology
- Human Exploration and Development of Space

The Laboratory for Atmospheres concentrates on two of these, the Earth Science and Space Science Enterprises.

Earth Science

The mission of NASA's Earth Science Enterprise (ESE) is to develop our understanding of the total Earth system and the effects of natural and human-induced changes on the global environment. Within this enterprise, the Laboratory for Atmospheres addresses both short-term weather forecasting and long-term climate studies. The wide array of our work reflects the Laboratory's history of atmospheric research, from the early days of weather satellites and emphasis on weather forecasting to our present focus on global climate change. Our goal is to increase the accuracy and lead-time with which we can predict weather and climate change.

In support of the U.S. Global Change Research Program and the U.S. Weather Research Program, the Earth Science divisions of the Earth Science Enterprise have established certain priorities:

- Atmospheric Chemistry
- Biology and Biogeochemistry of Ecosystems, and the Global Carbon Cycle
- Climate Variability and Prediction
- Global Water and Energy Cycles
- Solid Earth Science

The Laboratory for Atmospheres conducts basic and applied research in most of these priority areas.

Specifically, Laboratory scientists focus their efforts on the following areas:

- Aerosols and radiation
- Atmospheric hydrological processes
- Atmospheric ozone and trace gases

- Climate variability
- Mesoscale processes

Our work involves four primary activities or products: measurements, data sets, data analysis, and modeling. Table II depicts these activities and the topics they address.

Table I: Laboratory for Atmospheres Earth Science Activities

Measurements	Data Sets	Data Analysis	Modeling
Space Aircraft Balloon Ground Field campaigns	DAO assimilated products Global precipitation TOMS aerosols TOMS surface UV TOMS total ozone TOVS Pathfinder TRMM validation products	Aerosols Climate variability and climate change Clouds and precipitation Global temperature trends Ozone and trace gases Radiation UV-B measurements Validation studies	Atmospheric chemical Clouds and mesoscale Coupled climate/ocean General circulation Radiation transfer Retrievals and data assimilation

The divisions among measurements, data sets, data analysis, and modeling are somewhat artificial, in that activities in one area often affect those in another. These activities are strongly interlinked and cut across science priorities and the organizational structure of the Laboratory. The grouping corresponds to the natural processes of carrying out scientific research: ask the scientific question, identify the variable needed to answer it, conceive the best instrument to measure the variable, analyze the data, and ask the next question.

Space Science

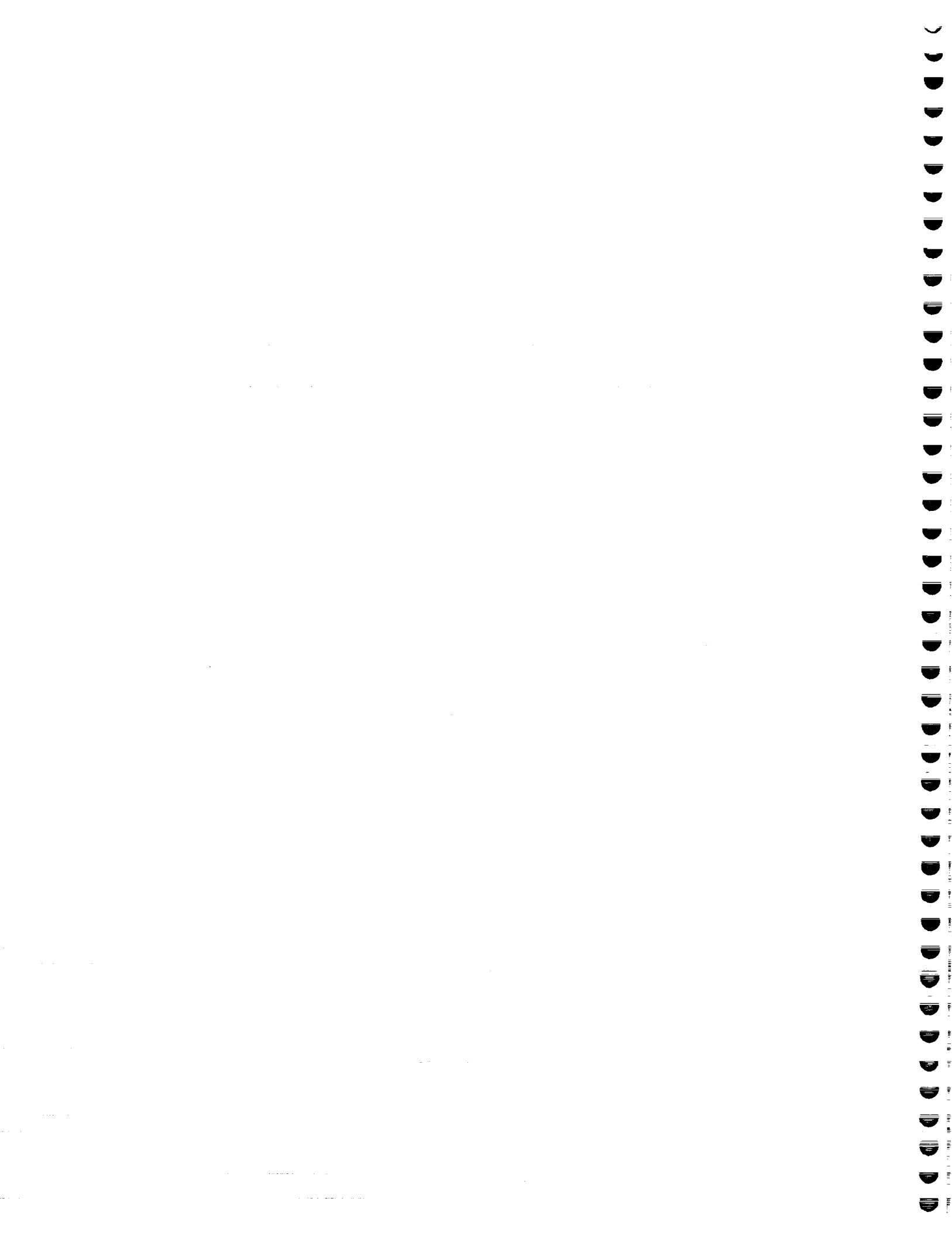
The mission of NASA's Space Science Enterprise is to solve mysteries of the universe; explore the solar system; discover planets around other stars; search for life beyond Earth; chart the evolution of the universe; and understand its galaxies, stars, planets, and life. Within this enterprise, the Laboratory studies the evolution, composition, and dynamics of the atmospheres of other planets. We've flown instruments aboard the Atmosphere Explorers, Dynamics Explorer, Pioneer Venus Orbiter, and Galileo missions. These instruments have measured ion and neutral gas composition, neutral gas temperature and wind, and electron temperature and density.

Laboratory for Atmospheres scientists have completed work on two instruments flying on the Cassini mission. The Gas Chromatograph Mass Spectrometer (GCMS) will measure the chemical composition of gases and aerosols in the atmosphere of Titan. The Ion and Neutral Mass Spectrometer (INMS) will measure the chemical composition of

positive and negative ions and neutral species in the inner magnetosphere of Saturn and in the vicinity of Saturn's icy satellites.

Laboratory scientists have also completed work on a Neutral Mass Spectrometer (NMS) to measure the neutral atmosphere of Mars. That instrument is being flown on a joint mission with Japan called "Nozomi." NOZOMI is scheduled to arrive at Mars in December 2003.

The Neutral Gas and Ion Mass Spectrometer (NGIMS) of the Comet Nucleus Tour (CONTOUR), is scheduled for launch in July 2002. It will measure the abundance and isotope ratios for many neutral and ion species in the coma of each comet during the flyby. These measurements, together with data from a dust experiment on this mission, will contribute to our understanding of the chemical composition of the nucleus itself and will allow us to study differences between the comets.



5. MAJOR ACTIVITIES

In the previous section, we provided a snapshot of the activities we pursue in the Laboratory for Atmospheres. Let's have a closer look. This section presents a more complete picture of our work in measurements, data sets, data analysis, and modeling. In addition, we'll discuss the Laboratory's support for the National Oceanic Atmospheric Administration's (NOAA) remote sensing requirements. Section 5 concludes with a listing of our project scientists, a description of our interactions with other scientific groups, and an overview of our efforts toward commercialization and technology transfer.

Measurements

Studies of the atmospheres of our solar system's planets—including our own—require a comprehensive set of observations, relying on instruments on spacecraft, aircraft, balloons, and on the ground. All instrument systems provide information leading to a basic understanding of the relationship between atmospheric systems and processes, serve as calibration references for satellite instrument validation, or perform both functions.

Many of the Laboratory's activities involve developing concepts and designs for instrument systems for spaceflight missions, and for balloon-, aircraft-, and ground-based observations, as well. Balloon and airborne platforms let us view such atmospheric processes as precipitation and cloud systems from a high-altitude vantage point but still within the atmosphere. Such platforms serve as a step in the development of spaceborne instruments.

Table II shows the principal instruments that have been built in the Laboratory or for which a Laboratory scientist has had responsibility as Instrument Scientist. The instruments are grouped according to the scientific discipline each supports. Table II also indicates each instrument's deployment—in space, on aircraft or balloons, or on the ground. Further information on each instrument appears on the pages following Table II.

**Table II: Principal Instruments Supporting Scientific Disciplines
in the Laboratory for Atmospheres**

	Atmospheric Structure and Dynamics	Atmospheric Chemistry	Clouds and Radiation	Planetary Atmospheres/ Solar Influences
Space		Total Ozone Mapping Spectrometer-Earth Probes (TOMS-EP) Shuttle Ozone Limb Sounding Experiment/ Limb Ozone Retrieval Experiment (SOLSE/ LORE) (Shuttle) Rayleigh Scattering Attitude Sensor (RSAS) (Shuttle) Triana/Earth Polchromatic Imaging Camera (EPIC)	Infrared Spectrometer Imaging Radiometer (ISIR) (Shuttle)	Solar EUV Flux Monitor Cassini Gas Chromatograph/Mass Spectrometer (GCMS) Cassini Ion and Neutral Mass Spectrometer (INMS) NOZOMI Neutral Mass Spectrometer (NMS) Neutral Gas and Ion Mass Spectrometer (NGIMS) CONTOUR Mission
Aircraft	Large Aperture Scanning Airborne Lidar (LASAL) ER-2 Doppler Radar (EDOP) Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)	Airborne Raman Lidar (ARL) (DC-8) GSFC Airborne Ozone, Temperature and Aerosol Lidar	Cloud Lidar System (CLS) Leonardo Airborne Simulator (LAS)	
Ground/ Laboratory	Scanning Raman Lidar (SRL) Direct Detection Doppler Wind Lidar (edge technique) Lightweight Rain Radiometer - IIP Lidar Atmospheric Raman Spectrometer (LARS) - IIP	Stratospheric Ozone Lidar Trailer Experiment (STROZ LITE) Tropospheric Ozone Lidar Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA) - IIP	Micro Pulse Lidar (MPL) cloud Thickness from Offbeam Returns (THOR) Lidar Scanning Microwave Radiometer (SMiR) Compact Vis IR (COVIR) - IIP	

Spacecraft-Based Instruments (launch dates are in parentheses)

The ***Total Ozone Mapping Spectrometer (TOMS)*** on Earth Probe has provided daily mapping and long-term trend determination of total ozone, surface UV radiation, volcanic SO₂, and UV-absorbing aerosols. (1996) For more information, contact Richard McPeters (Richard.D.McPeters.1@gsfc.nasa.gov).

The ***Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment (SOLSE/LORE)*** measured ozone profiles from the stratosphere down to the tropopause with high vertical resolution in 1997. SOLSE is a grating spectrometer that measured ozone in the upper stratosphere, while LORE is a filter radiometer that measured ozone in the lower stratosphere. The instruments are being reconfigured to more simulate the performance expected from the Ozone Mapper and Profiler System (OMPS). A reflight is planned in 2001 which will be an important risk mitigation activity for the National Polar Orbiting Environmental Satellite System (NPOESS) ozone instrument. For more information, contact Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov).

The ***Raleigh Scattering Attitude Sensor (RSAS)*** is a new low cost technique for determining spacecraft attitude. The hardware and theoretical basis were developed in the Laboratory and a patent is pending. The concept was flown twice on the Shuttle which demonstrated an ability to determine attitude to better than 0.01 degree. The concept has been proposed for chemistry missions in response to NASA AO's and will be employed in OMPS. A development is now underway, supported by the GSFC Commercial Utilization Office, to design a system for commercial application. For more information, contact Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov).

Triana/Earth Polychromatic Imaging Camera (EPIC): EPIC is a 10-channel spectroradiometer spanning the ultraviolet (UV) to the near-Infrared (IR) wavelength range (317.5 to 905 nm). The main quantities measured are 1) Column Ozone, 2) Aerosols (dust, smoke, volcanic ash, and sulfate pollution), 3) Sulfur Dioxide, 4) Precipitable Water, 5) Cloud Height, 6) Cloud Reflectivity, 7) Cloud Phase (ice or water), and 8) UV Radiation at the Earth's Surface. Other quantities related to vegetation, bi-directional reflectivity (hotspot analysis) and ocean color will also be analyzed. The two unique characteristics are 1) the first spaceborne measurements from sunrise to sunset of the entire sunlit Earth and 2) the first simultaneous measurements in both the UV and visible wavelengths. This will allow diurnal variations to be determined and permit extended measurements of aerosol characteristics. For more information, contact Jay Herman (Jay.R.Herman.1@gsfc.nasa.gov).

The ***Infrared Spectrometer Imaging Radiometer (ISIR)*** for the Space Shuttle will improve infrared techniques and technology for observing Earth's clouds and surface from the Space Shuttle in combination with microwave and active optical imaging. ISIR is based on smaller and more reliable IR imaging using uncooled detectors. (1997) For more information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The ***Solar EUV Flux Monitor*** measures the integrated solar Extreme Ultraviolet (EUV) and UV radiation above the Earth's atmosphere. The instrument uses a very small,

spherical, windowless photodiode with grids to control the photoelectrons. (2000) For more information, contact Walter Hoegy (Walter.R.Hoegy.1@gsfc.nasa.gov).

The *Gas Chromatograph/Mass Spectrometer (GCMS)* for the Cassini Huygens Probe measured the chemical composition of gases and aerosols in the atmosphere of Titan. (1997) For more information, contact Hasso Niemann (Hasso.B.Niemann.1@gsfc.nasa.gov).

The *Ion and Neutral Mass Spectrometer (INMS)* on Cassini will determine the chemical composition of positive and negative ions and neutral species in the inner magnetosphere of Saturn and in the vicinity of its icy satellites. (1997) For more information, contact Hasso Niemann (Hasso.B.Niemann.1@gsfc.nasa.gov).

The *NOZOMI Neutral Mass (NMS) Spectrometer* on Planet-B will measure the composition of the neutral atmosphere of Mars to improve our knowledge and understanding of the energetics, dynamics, and evolution of the Martian atmosphere. The mass spectrometer will be flown on a spacecraft developed by the Japanese Institute of Space and Astronautical Science. (1998) For more information, contact Hasso Niemann (Hasso.B.Niemann.1@gsfc.nasa.gov).

The *Neutral Gas and Ion Mass Spectrometer (NGIMS)* on the CONTOUR Mission will provide detailed compositional data on both gas and dust in the near-nucleus environment at precisions comparable to those of Giotto or better. For more information, contact Paul Mahaffy (Paul.R.Mahaffy.1@gsfc.nasa.gov).

Aircraft-Based Instruments

The *Large Aperture Scanning Airborne Lidar (LASAL)* measures atmospheric backscatter with an emphasis on boundary-layer height and structure. Capable of (raster) scanning at up to 90 degrees per second, it provides a three-dimensional view of the aerosol structure of the lower troposphere and boundary layer. For more information, contact Stephen Palm (Stephen.P.Palm.1@gsfc.nasa.gov).

The *ER-2 Doppler Radar (EDOP)* measures the vertical rain and wind structure of precipitation systems to improve our understanding of mesoscale convective system structure. The data are also used to validate spaceborne rain measurement algorithms. For more information, contact Gerald Heymsfield (Gerald.M.Heymsfield.1@gsfc.nasa.gov).

The *Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)* measures cloud and aerosol laser backscatter in 4 dimensions with high spatial and temporal resolution. Utilizing a unique conical scanning holographic telescope, this compact high performance lidar fits into most low to medium altitude aircraft as well as in a portable ground-based environmental housing for relatively low cost field experiment deployments. For further information contact Geary Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

The *Airborne Raman Lidar (ARL)* measures the structure and concentration of methane and water vapor in the troposphere and lower stratosphere to further understand the chemistry of this region. For more information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The GSFC *Airborne Ozone, Temperature and Aerosol Lidar* is a two wavelength lidar system (308 nm and 355 nm) that detects two elastically scattered wavelengths and N₂-Raman scattered radiation at 332 nm and 387 nm. The system uses 20 data channels spread over the four detected wavelengths. The instrument has been integrated on board the DC-8 for the SOLVE campaign. Colleagues at Langley contributed data channels for depolarization measurements at 532 nm and channels for aerosol backscatter at 1064 nm. Data products are aerosol backscatter and vertical profiles of ozone and temperature. For more information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The *Cloud Lidar System (CLS)* measures cloud and aerosol structure from the high altitude ER-2 aircraft, in combination with multispectral visible, microwave, and infrared imaging radiometers. The instrument operates at 1064, 532, and 355 nm wavelengths and a repetition rate of 5 KHz. The data are used in radiation and remote sensing studies. For more information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The *Leonardo Airborne Simulator (LAS)* is an imaging spectrometer (hyperspectral) with moderate spectral resolutions. LAS will measure reflected solar radiation to retrieve atmospheric properties such as column water vapor amount, aerosol loadings, cloud properties, and surface characteristics. This instrument is currently under development and will be deployed aboard NASA ER-2 during the Southern Africa Fire-Atmosphere Research Initiative (SAFARI) campaign. For more information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

Ground-Based and Laboratory Instruments

The *Scanning Raman Lidar (SRL)* measures light scattered by water vapor, nitrogen, oxygen, and aerosols to determine the water vapor mixing ratio, aerosol backscattering, and aerosol extinction, as well as their structure in the troposphere. These trailer-based measurements are important for studying radiative transfer, convection, and the hydrological cycle. They are also useful for assessing the water and aerosol measurement capabilities of surface-, aircraft-, and satellite-based instruments. For more information, contact Geary Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

Direct Detection Doppler Wind Lidar measures vertical wind profile from the surface to 12 km and 35 km, using the double-edge technique. Doppler measurements are derived from aerosol and molecular backscatter at 1064 nm and 355 nm. For more information, contact Bruce Gentry (Bruce.M.Gentry.1@gsfc.nasa.gov).

The small, *Lightweight Rain Radiometer* is a Laboratory development under the Instrument Incubator Program (IIP). The radiometer will employ a thinned array syn-

thetic antenna at 10.7 GHz for future measurements from space. The instrument will provide global high-temporal-resolution precipitation measurements from a constellation of small satellites. For more information, contact Christian Kummerow (Christian.D.Kummerow.1@gsfc.nasa.gov).

The ***Lidar Atmospheric Raman Spectrometer (LARS)*** is currently being developed under NASA's Instrument Incubator Program in collaboration with Code 924. It will address a large number of high priority atmospheric science measurement requirements, including water vapor, aerosol scattering, extinction and optical depth, temperature, cloud liquid water and drop size, and cloud top and bottom heights. A broad band spectrometer will permit full spectral tuning across the entire Raman band. This capability will allow us to attempt other experimental measurements such as cloud droplet temperature. For further information contact Geary Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

The ***Stratosphere Ozone Lidar Trailer Experiment (STROZ LITE)*** measures vertical profiles of ozone, aerosols, and temperature. The system collects elastically and Raman-scattered returns using Differential Absorption Lidar (DIAL). For more information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Tropospheric Ozone Lidar*** measures tropospheric ozone at wavelengths that have a large ozone absorption cross section. The system provides validation data for research and development programs aimed at monitoring tropospheric ozone from space. For more information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

The ***Compact Hyperspectral Mapper for Environmental Remote Sensing Applications (CHyMERA)*** instrument is in development under the Instrument Incubator Program (IIP). The primary objective is high-resolution measurement of NO₂, SO₂, aerosol, and other cloud components. The core design is a wide field-of-view (FOV) front-end telescope that illuminates a filter/focal plane array (FFPA) package. For more information, contact Scott Janz (Scott.J.Janz.1@gsfc.nasa.gov).

Micro Pulse Lidar (MPL) makes quantitative measurements of clouds and aerosols. MPL is a unique "eye-safe" lidar system that operates continuously (24 hours a day) in an autonomous fashion. Thirty instruments are currently deployed. For more information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The cloud ***THickness from Offbeam Returns (THOR) Lidar*** will determine the physical and optical thickness of dense cloud layers from the cloud Green's function, which is the halo of diffuse light up to 0.5 km from the entry point of a lidar beam incident on the cloud layer. Lidar returns at these wide angles are stronger for thicker clouds and are relatively insensitive to cloud microphysics. (2001). For more information, contact Robert Cahalan (Robert.F.Cahalan.1@gsfc.nasa.gov).

The ***Scanning Microwave Radiometer (SMiR)*** will measure the column amounts of water vapor and cloud liquid water using discrete microwave frequencies. This instru-

ment will be deployed with the upcoming series of SAFARI campaigns. For more information, contact Si-Chee Tsay (Si-Chee.Tsay.1@gsfc.nasa.gov).

Compact Vis IR (COVIR) is a Laboratory test model of an imaging radiometer for small satellite missions. The instrument is being developed under the Instrument Incubator program (IIP) and will measure visible and IR wavelengths in the following ranges: 10.3-11.3 μm , 11.5-12.5 μm , 9.5-10.5 μm , and 0.67-0.68 μm . The system employs uncooled microbolometer focal plane detectors. For more information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

Field Campaigns

Field campaigns typically use the resources of NASA, other agencies, and other countries to carry out scientific experiments or to conduct environmental impact assessments from bases throughout the world. Research aircraft, such as the NASA ER-2 and DC-8, serve as platforms from which remote sensing observations are made. Ground systems are also used for soundings and *in situ* measurements. In 1999, Laboratory personnel supported many such activities as scientific investigators or as mission participants in the planning and coordination phases. Field campaigns supported in this way include the following:

The Atmospheric Radiation Measurement Program (ARM) is a Department of Energy (DOE) program in which NASA participates. ARM is organized to study shortwave and longwave radiation, and cloud physics and dynamics. The program aims to determine how cloud structure is related to cloud albedo, transmission, and cloud absorption. ARM will also study the influence of all these factors on General Circulation Models (GCM). For more information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The **Photochemical Activity and Ultraviolet Radiation Modulation Factors (PAUR II)** campaign was a combined effort of European Union and invited NASA/GSFC scientists to simultaneously measure UV irradiance, aerosol optical depth, ozone, and aerosol plume height from Crete. GSFC's purpose was to compare ground-based estimates with those derived from the TOMS spacecraft instrument. The site was selected to study the influence of plumes of African dust that frequently pass over Crete during May. GSFC contributed an aerosol lidar, CIMEL sunphotometer, hand-held sunphotometer and ozone meter, and a UV-irradiance Ground-based Ultraviolet Radiometer (GUV) 100 meter. The data obtained has been shared with the entire PAUR team to put together a comprehensive study of the attenuation of UV radiation in the presence of clouds, ozone, and aerosols. For more information, contact Pawan K. Bhartia (Pawan.K.Bhartia.1@gsfc.nasa.gov).

The **Network for the Detection of Stratospheric Change (NDSC)** is an international program to determine changes in the physical and chemical state of the stratosphere, to obtain data to test and improve multidimensional stratospheric chemical and dynamical models, and to provide independent calibration of satellite instruments. For more information, contact Thomas McGee (Thomas.J.McGee.1@gsfc.nasa.gov).

Stratospheric Aerosol and Gas Experiment (SAGE) III Ozone Loss and Validation Experiment (SOLVE) is a measurement campaign designed to examine the processes controlling ozone levels at mid- to-high latitudes. Measurements made in the Arctic region in winter, conducted jointly with the European Commission-sponsored Third European Stratospheric Experiment on Ozone (THESEO 2000), will allow better prediction of ozone changes with changing climate and chlorine levels. For more information, see <http://cloud1.arc.nasa.gov/solve/> or contact Paul Newman (Paul.A.Newman.1@gsfc.nasa.gov).

The **Atmospheric Chemistry of Combustion Emissions Near the Tropopause (ACCENT)** mission is an interagency mission to examine the effects of exhaust from rockets and aircraft in the upper troposphere and lower stratosphere. The results will show how the emissions interact with the background atmospheric gases, aerosol, and cloud particles and how the emissions may affect chemistry and climate. For more information, see <http://hyperion.gsfc.nasa.gov/AEAP/FieldMissions.html> or contact Don Anderson (Donald.E.Anderson.1@gsfc.nasa.gov).

South China Sea Monsoon Experiment (SCSMEX) is an international field experiment to study the water and energy cycles of the Asian monsoon regions. The purpose of the experiment is to better understand the key physical processes in the onset, maintenance, and variability of the monsoon over southeast Asia and southern China. This understanding is expected to lead to improved forecasts of the monsoon. For more information, contact William Lau (William.K.Lau.1@gsfc.nasa.gov).

The **TRMM Field Campaigns (TRMM-LBA and KWAJEX)** were carried out to validate the physical assumptions made by the TRMM satellite algorithms. The experiments included a broad spectrum of ground-based and airborne sensors designed to obtain in-situ observations of cloud structures and their evolutions. The improved knowledge of cloud constituents and dynamics is vital to gain confidence that the rainfall structure and latent heat release derived by the TRMM satellite are not only correct, but correct for the right reasons. For more information, contact Christian Kummerow (Christian.D.Kummerow.1@gsfc.nasa.gov).

Data Sets

In the previous discussion, we examined the array of instruments we use to gather weather and climate data. Once we have obtained the raw data from these instruments, we arrange the information into data sets useful for studying various atmospheric phenomena.

Televised Infrared Operational Satellite (TIROS) Operational Vertical Sounder Pathfinder

The Pathfinder Projects are joint NOAA/NASA efforts to produce multi-year climate data sets using measurements from instruments on operational satellites. One such satellite-based instrument suite is the TIROS Operational Vertical Sounder (TOVS).

TOVS is comprised of three atmospheric sounding instruments: the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Spectral Sensor Unit (SSU). These instruments have flown on the NOAA Operational Polar Orbiting Satellite since 1979. We have reprocessed TOVS data from 1979 to the present, using an algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations.

The data are used to study global and regional natural variability and trends and relationships between surface and atmospheric anomalies. Real time processing began in August 1997 to study the 1997 El Niño. For more information, contact Joel Susskind (joel.susskind.1@gsfc.nasa.gov).

Tropospheric Ozone Data

Tropospheric column ozone (TCO) and stratospheric column ozone (SCO) gridded data in the tropics for 1979-present are now available from NASA Goddard Space Flight Center via either direct ftp, world-wide-web, or electronic mail. Until recently the primary method to derive TCO and SCO from satellite data was by combining TOMS and SAGE ozone measurements. At NASA Goddard, monthly averaged TCO and SCO data are derived in the tropics for January 1979-present using the convective cloud differential (CCD) method [Ziemke et al., 1998; J. Geophys. Res., 22115-22127]. Further details regarding methodology and new adjustments made for aerosol contamination are discussed in Ziemke et al. [Bull. Amer. Meteorol. Soc., in press, March, 2000]. These data have been recently used in several published studies within Code 916 to characterize tropospheric ozone variabilities from monthly to decadal time scales. The CCD TCO and SCO data may be obtained via World Wide Web (http://hyperion.gsfc.nasa.gov/Data_services/Data.html). For more information contact Sushil Chandra (sushil.chandra.1@gsfc.nasa.gov).

Aerosol Products from the Total Ozone Mapping Spectrometer

Laboratory scientists are generating a unique new data set of atmospheric aerosols by reanalyzing the 17-year data record of Earth's ultraviolet albedo as measured by the TOMS. Laboratory staff developed the technique for extracting aerosol information from ultraviolet in 1996. This technique differs from others in that the UV measurements can reliably separate UV absorbing aerosols (such as desert dust and smoke from biomass burning) from non-absorbing aerosols (such as sulfates, sea-salt, and ground-level fog). In addition, the UV technique can measure aerosols over land and can detect some types of aerosols over snow/ice and clouds.

TOMS aerosol data are currently available in the form of an (uncalibrated) index, which, nevertheless, is providing excellent information about sources, transport, and seasonal variation of a variety of aerosol types. Work is currently in progress to relate the index to aerosol optical thickness and single-scatter albedo. For more information, contact Jay Herman (Jay.R.Herman.1@gsfc.nasa.gov).

Multiyear Global Surface Wind Velocity Data Set

The Special Sensor Microwave Imagers (SSM/I) aboard three Defense Meteorological Satellite Program (DMSP) satellites have provided a large dataset of surface wind speeds over the global oceans from July 1987 to the present. These data are characterized by high resolution, coverage, and accuracy, but their application has been limited by the lack of directional information. In an effort to extend the applicability of these data, the DAO developed methodology to assign directions to the SSM/I wind speeds and to produce analyses using these data. This methodology has been used to generate a 12.5-year dataset (from July 1987 through December 1999) of global SSM/I wind vectors. These data are currently being used in a variety of atmospheric and oceanic applications and are available to interested investigators. For more information, contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

Global Precipitation Data Set

An up-to-date, long, continuous record of global precipitation is vital to a wide variety of scientific activities. These include initializing and validating numerical weather prediction and climate models, providing input for hydrological and water cycle studies, supporting agricultural productivity studies, and diagnosing intra- and inter-annual climatic fluctuations on regional and global scales.

At the international level, the Global Energy and Water Cycle Experiment (GEWEX) component of the World Climate Research Programme (WCRP) established the Global Precipitation Climatology Project (GPCP) to develop such global data sets. Scientists working in the Laboratory have led the GPCP effort to merge microwave data from low-Earth-orbit satellites, infrared data from geostationary orbit satellites, and data from ground-based rain gauges to produce the best estimates of global precipitation.

Version 2 of the GPCP merged data set provides global, monthly precipitation estimates for the period January 1979 to the present. Updates are being produced on a quarterly basis. The release includes input fields, combination products, and error estimates for the rainfall estimates. The data set is archived at World Data Center A (located at the National Climatic Data Center in Asheville, NC), at the Goddard Distributed Active Archive Center (DAAC), and at the Global Precipitation Climatology Centre (located at the Deutscher Wetterdienst in Offenbach, Germany). Evaluation of this long-term data set in the context of the new TRMM observations is ongoing. Development of data sets with finer time resolution (daily and 3-hr) has been initiated. For more information, contact Robert Adler (Robert.F.Adler.1@gsfc.nasa.gov).

Data Analysis

Atmospheric Ozone Research

The Clean Air Act Amendment of 1977 assigned NASA major responsibility for studying the ozone layer.

Data from many ground-based, aircraft, and satellite missions are combined with meteorological data to understand the factors that influence the production and loss of atmospheric ozone. Analysis is conducted over different temporal and spatial scales, ranging from studies of transient filamentary structures that play a key role in mixing the chemical constituents of the atmosphere to investigations of global-scale features that evolve over decades.

The principal goal of these studies is to understand the complex coupling between natural phenomena, such as volcanic eruptions and atmospheric motions, and human-made pollutants, such as those generated by agricultural and industrial activities. These nonlinear couplings have been shown to be responsible for the development of the well-known Antarctic ozone hole.

With the anticipated growth in air travel in the next few years, another area of important research underway in the Laboratory is aimed at understanding the effects of aircraft emissions on the atmosphere's chemistry and physics. For more information, contact Pawan K. Bhartia (Pawan.K.Bhartia.1@gsfc.nasa.gov).

Total Column Ozone and Vertical Profile

Laboratory for Atmospheres scientists have been involved in measuring ozone since the late 1960s when a satellite instrument—the Backscatter Ultraviolet (BUV) Spectrometer—was launched on NASA's Nimbus-4 satellite to measure the column amount and vertical distribution of ozone. These measurements are continuing aboard several follow-on missions launched by NASA, NOAA, and, more recently, by the ESA.

An important activity in the Laboratory is developing a high-quality, long-term ozone record from these satellite sensors and comparing that record with ground-based and other satellite sensors. This effort—already more than a quarter century in duration—has produced ozone data sets that have played a key role in identifying the global loss of ozone due to certain human-made chemicals. This knowledge has contributed to international agreements to phase out these chemicals by the end of this century. For more information, contact Pawan K. Bhartia (Pawan.K.Bhartia.1@gsfc.nasa.gov).

Surface UV Flux

The primary reason for measuring atmospheric ozone is to understand how the UV flux at the surface might be changing and how this change might effect the biosphere.

The sensitivity of the surface UV flux to ozone changes can be calculated by using atmospheric models. Yet, until recently, we had no rigorous test of these models, particularly in the presence of aerosols and clouds. By comparing a multi-year data set of surface UV flux generated from TOMS data and high-quality ground-based measurements, we are increasingly able to quantify the respective roles of ozone, aerosols, and clouds in controlling the surface UV flux over the globe. For more information, contact Jay Herman (Jay.R.Herman.1@gsfc.nasa.gov).

Data Assimilation

The DAO in the Laboratory has taken on the challenge of providing to the research community a coherent, global, near-real-time picture of the evolving Earth system. The DAO is developing a state-of-the-art Data Assimilation System (DAS) to extract the usable information available from a vast number of observations of the Earth system's many components, including the atmosphere, the oceans, the Earth's land surfaces, the biosphere, and the cryosphere (ice sheets over land or sea).

The DAS is made of several components including an atmospheric prediction model, a variational physical space analysis scheme, and models to diagnose unobservable quantities. Each of these components requires intense research, development, and testing. Much attention must be given to insuring that the components interact properly with one another to produce meaningful, research-quality data sets for the Earth-system-science research community. (See also modeling section).

Observing System Simulation Experiments

Since the advent of meteorological satellites in the 1960s, considerable research effort has been directed toward designing space-borne meteorological sensors, developing optimum methods for using satellite soundings and winds, and assessing the influence of satellite data on weather prediction. Observing system simulation experiments (OSSE) have played an important role in this research. Such studies have helped in designing the global observing system, testing different methods of assimilating satellite data, and assessing the potential impact of satellite data on weather forecasting.

At the present time, OSSEs are being conducted to (1) provide a quantitative assessment of the potential impact of currently proposed space-based observing systems on global change research, (2) evaluate new methodology for assimilating specific observing systems, and (3) evaluate tradeoffs in the design and configuration of these observing systems. For more information, contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

Seasonal-to-Interannual Variability and Prediction

Climate research seeks to identify natural variability on seasonal, interannual, and interdecadal time scales, and to isolate the natural variability from the human-made global-change signal. Climate diagnostic studies use a combination of remote sensing data, historical climate data, model outputs, and assimilated data. Climate diagnostic studies will be combined with modeling studies to unravel physical processes underpinning seasonal-to-interannual variability. The key areas of research include the El Niño Southern Oscillation (ENSO), monsoon variability, interseasonal oscillation, and water vapor and cloud feedback processes. Several advanced analytical techniques are used, including wavelets, multivariate empirical orthogonal functions, singular value decomposition, and nonlinear system analysis.

The Laboratory is also involved in NASA's Seasonal-to-Interannual Prediction Project (NSIPP). This collaboration between NASA and outside scientists is developing a sys-

tem to predict El Niño events by utilizing a combination of satellite and *in situ* data. NSIPP will also employ a high-resolution atmosphere-land data assimilation system that will capitalize on the host of new high-resolution satellite data. This capability will allow us to better characterize the local and remote physical processes that control regional climates and limit predictability.

Promoting the use of satellite data is a top priority. Important satellite-derived data sets include TOPEX/Poseidon and Jason-1 ocean topography, the Earth Radiation Budget Experiment (ERBE), the International Satellite Cloud Climatology (ISCCP), Advanced Very High Resolution Radiometer (AVHRR), SSM/I, QuikSCAT, MSU, and TOVS Pathfinder data. Data from TRMM and EOS Terra and EOS Aqua platforms will be used extensively, as they become available. For more information, contact William Lau (William.K.Lau.1@gsfc.nasa.gov).

Rain Measurements

Rain Estimation Techniques from Satellites

Rainfall information is a key element in studying the hydrologic cycle. A number of techniques have been developed to extract rainfall information from current and future spaceborne sensor data, including the TRMM satellite and the Advanced Microwave Scanning Radiometer (AMSR) on EOS Aqua.

The retrieval techniques belong to four categories: (1) physical/empirical relationships that exist between microwave measurements (active and passive) and rain rates; (2) a theoretical, multifrequency technique that relates the complete set of microwave brightness temperatures to rainfall rate at the surface; (3) an empirical relationship that exists between cloud thickness and rain rates, using TOVS sounding retrievals; and (4) an analysis technique that uses low-orbit microwave, geosynchronous infrared, and rain gauge information to provide a merged, global precipitation analysis.

The multifrequency technique (category 2) also provides information on the vertical structure of hydrometeors and on latent heating through the use of a cloud ensemble model. The approach has recently been extended to combine spaceborne radar data with passive microwave observations.

The satellite-based rainfall information has been used to study the global distribution of atmospheric latent heating, the impact of ENSO on global-scale and regional precipitation patterns, the climatological contribution of tropical cyclone rainfall, and the validation of global models. For more information, contact Robert Adler (Robert.F.Adler.1@gsfc.nasa.gov).

Rain Measurement Validation for the TRMM

The objective of the TRMM Ground Validation Program (GVP) is to provide reliable area- and time-averaged rainfall data from numerous representative tropical and subtropical sites world wide for comparison with TRMM satellite measurements. Rainfall

measurements are made at Ground Validation (GV) sites equipped with weather radar, rain gauges, and disdrometers. A range of data products derived from measurements obtained at GV sites is available via the TRMM Science Data and Information System (TSDIS). The list of data products has been developed to cover a range of space and time scales that will adequately reflect the rainfall variability and sampling characteristics of the TRMM Observatory. With these products, the validity of TRMM measurements will be established with accuracies that meet mission requirements.

The emphasis of this activity is the advancement of rainfall estimation from ground-based radars to allow for the climatological validation of the satellite products. To accomplish this task, rain measurement research, precipitation physics, procedural techniques for radar calibration, false echo removal and software for the generation of standard products all have to be developed and improved in concert. This is an ongoing process with results eventually benefiting not just the TRMM validation effort, but ground-based rainfall estimates in general. For more information, contact Christian Kummerow (Christian.D.Kummerow.1@gsfc.nasa.gov).

Aerosols/Cloud Climate Interactions

Theoretical and observational studies are being carried out to analyze the optical properties of aerosols and their effectiveness as cloud condensation nuclei. These nuclei produce different drop size distributions in clouds, which, in turn, will affect the radiative balance of the atmosphere.

Algorithms are being developed to routinely derive aerosol loading optical properties and total precipitable water vapor data products from data to be obtained by the EOS-era Moderate Resolution Imaging Spectroradiometer (MODIS). These algorithms are based on Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), MODIS Airborne simulator, AVHRR, and Landsat Thematic Mapper (TM) data.

Laboratory scientists are actively involved in analyzing data recently obtained from national and international campaigns. These campaigns include Smoke Cloud And Radiation-Brazil (SCAR-B), the Subsonic aircraft: Contrails and Cloud Effects Special Study (SUCCESS), and the Tropospheric Aerosol Radiative Forcing Observational eXperiment (TARFOX). For more information, contact Yoram Kaufman (Yoram.J.Kaufman.1@gsfc.nasa.gov).

Hydrologic Processes and Radiation Studies

Laboratory scientists are developing methods to estimate atmospheric water and energy budgets. These methods include calculating the radiative effects of absorption, emission, and scattering by clouds, water vapor, aerosols, CO₂, and other trace gases. The observational data include the ERBE radiation budgets, ISCCP clouds data, Geostationary Meteorological Satellite (GMS; Japan) radiances, National Center for Environmental Prediction (NCEP) sea surface temperature, and Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) observations. The models include the Goddard Earth Observing System (GEOS) GCM, the Goddard Cloud Ensemble model (GCE), and an ocean mixed layer model.

Laboratory scientists study the response of radiation budgets to changes in water vapor and clouds during El Niño events in the Pacific basin and during westerly wind-burst episodes in the western tropical Pacific warm pool. We also investigate the relative importance of large-scale dynamics and local thermodynamics on clouds and radiation budgets and modulating sea surface temperature. In addition, we assess the impacts of basin-scale sea surface temperature fluctuations such as the El Niño on regional climate variability over the Indo-Pacific region, North America, and South America. For more information, contact William Lau (William.K.Lau.1@gsfc.nasa.gov).

Earth Observing System Interdisciplinary Investigations

The overall goal of NASA's EOS Program is to determine the extent, causes, and regional consequences of global climate change. This major scientific challenge will be addressed by more than 20 instruments flown on a series of spacecraft over a period of at least 15 years. In addition to the scientific investigations to be carried out by the instrument scientists, the EOS program also supports various interdisciplinary science investigations. Interdisciplinary investigations, such as the two described below, are designed to improve understanding of the Earth as a system by developing and refining integrated models that will use observations from EOS instruments.

Stratospheric Chemistry and Dynamics

The goal of Laboratory investigations of stratospheric chemistry and dynamics is to separate natural from human-made changes in the Earth's atmosphere, to determine their effects on ozone, and to assess radiative and dynamical feedbacks. We do this by analyzing stratospheric chemical and dynamical observations from current satellites and from aircraft campaigns. Studies include examining the processes that produce the Antarctic ozone hole and understanding similar processes that are occurring in the northern polar regions. The investigation combines Upper Atmosphere Research Satellite (UARS) data, trajectory modeling, and TOMS observations. This work will continue as new instruments are deployed on aircraft and satellites by the United States and by other nations. For more information, contact Mark Schoeberl (Mark.R.Schoeberl.1@gsfc.nasa.gov).

Regional Land-Atmosphere Climate Simulation (RELACS)

An end-to-end RELACS system is being developed in the Laboratory. RELACS consists of four components: A nested mesoscale model (MM5), a coupled land surface model, a regional four-dimensional data assimilation (4DDA) component, and a general circulation component. The investigation will provide downscaling of large-scale climate forcings derived from GCM and from 4DDA.

The core component of RELACS is a MM5 derived from the National Center for Atmospheric Research (NCAR)/Pennsylvania State University.

The MM5 is a non-hydrostatic meso-alpha- (200-2000km) and meso-beta- (20-200 km) scale primitive equation model. MM5 is an excellent tool for studying the multi-scale

dynamics associated with precipitation processes and their impact on regional hydrological cycles. Improved physics include microphysical processes, radiation, land-soil-vegetation, and ocean mixed-layer processes. These variables have been incorporated to produce realistic simulations of tropical-midlatitude precipitation systems and their relationship to the large-scale environment. Components of the physical package have been tested for various mesoscale convective systems, including monsoon depressions, supercloud clusters, and meso-scale convective complexes. In an effort to develop RELACS, the MM5 has been coupled with the Land Surface Model (LSM), the Parameterization for Land Atmosphere Cloud Exchange (PLACE) model. The MM5-LSM will be nested within the GEOS GCM over continental scale regions such as Southeast Asia, the continental United States, or the Amazon region.

This approach represents a new Laboratory effort geared toward regional climate data analysis and modeling studies, performed in response to the emphasis on regional climate assessment under the Earth Science strategic plan and the science priorities of the US Global Change Research Program (USGCRP). For more information, contact William Lau (William.K.Lau.1@gsfc.nasa.gov).

Effects of Aircraft on the Atmosphere

Atmospheric Effects of Aviation Project (AEAP)

The AEAP sponsors research to evaluate the impact current subsonic and proposed high-speed civil aircraft have on stratospheric and tropospheric ozone and climate. AEAP is funded by the Office of Aeronautics and Space Transportation Technology. The project operates in coordination with observational and theoretical programs in NASA's Earth Science Enterprise. Elements of this program include aircraft campaigns, modeling of photochemistry and transport, and modeling of cloud-radiation interactions. Recent aircraft campaigns will help us understand the declining summertime portion of the stratospheric ozone annual cycle.

Modeling within the AEAP is concentrated in the Global Modeling Initiative (GMI). The GMI is a multi-institutional effort that is assembling various contributed software modules to create a coupled chemical-transport model, with a shared code residing at Lawrence Livermore National Laboratory. All contributors analyze model output, including members of the Atmospheric Chemistry and Dynamics Branch. The model will be used for three-dimensional aircraft assessment calculations.

The Atmospheric Chemistry and Dynamics Branch also provides the project scientist and several principal investigators to the AEAP, which is managed by the Goddard Flight Projects Directorate, Code 400. For more information, contact Stephan Kawa (Stephan.R.Kawa.1@gsfc.nasa.gov).

Modeling

Coupled Atmosphere-Ocean-Land Models

To study climate variability and sensitivity, we must couple the atmospheric GCM with

ocean and land-surface models. Much of the work in this area is conducted in collaboration with Goddard's Laboratory for Hydrospheric Processes, Code 970. The ocean models predict the global ocean circulation—including the sea surface temperature (SST)—when forced with atmospheric heat fluxes and wind stresses at the sea surface. Land-surface models are detailed representations of the primary hydrological processes, including evaporation; transpiration through plants; infiltration; runoff; accumulation, sublimation, and melt of snow and ice; and groundwater budgets.

One of the main objectives of coupled models is forecasting seasonal-to-interannual anomalies such as the El Niño phenomenon. Laboratory scientists are involved in NSIPP, recently established in Goddard's Laboratory for Hydrospheric Processes. NSIPP's main goal is to develop a system capable of assimilating hydrologic data and using that data with complex, coupled ocean-atmosphere models to predict tropical SST with lead times of 6-14 months. A second goal is to use the predicted SST in conjunction with coupled atmosphere-land models to predict changes in global weather patterns. For more information, contact Max Suarez (Max.J.Suarez.1@gsfc.nasa.gov).

Global Modeling and Data Assimilation

Development of the Data Assimilation System

The DAO currently uses the GEOS-3 DAS to support the EOS Terra Mission. The GEOS-3 DAS is a major upgrade of the GEOS-1 DAS used for the first NASA reanalysis. The GEOS-3 DAS provides data products at a higher horizontal resolution (1° longitude by 1° latitude) and employs a new Physical-space Statistical Analysis System (PSAS). Other improvements include an interactive Mosaic-based land surface model, a state-of-the-art moist turbulence scheme, an online estimation and correction procedure for systematic forecast errors, and assimilation of space-borne observations of marine surface winds and total precipitable water. In the next upgrade scheduled before the EOS Aqua launch, the GEOS-3 DAS will be capable of assimilating interactively retrieved TOVS and advanced sounder data and precipitation data from TRMM and SSM/I instruments.

For the EOS-Aqua and beyond, the DAO is developing a next-generation numerical model for climate prediction and data assimilation in collaboration with NCAR. In addition, DAO is developing advanced data assimilation techniques using a combination of Kalman filtering and four-dimensional variational approaches. These techniques will allow us to make better use of a synoptic observations. DAO is also developing flow-dependent covariance models to maximize the benefit of high spatial resolution of the observations and of the model. For more information, contact Robert Atlas (Robert.M.Atlas.1@gsfc.nasa.gov).

Development of the Next-Generation Global Model

The DAO is collaborating with the NCAR to develop a unified global general circulation model for climate, numerical weather prediction, data assimilation, and chemical constituent transport applications. The prototype configuration consists of a finite-

volume, flux-form semi-Lagrangian dynamic core developed at the DAO, and physical parameterizations and land surface schemes available through NCAR. The DAO dynamic core, which is a candidate for incorporation into the NCAR Community Climate Model version 4 (CCM4), has been shown to be highly accurate in conservation properties; it also eliminates several known deficiencies of the spectral representation of the dynamic core. For more information, contact Shian-Jiann Lin (Shian-Jiann.Lin.1@gsfc.nasa.gov).

Cloud and Mesoscale Modeling

The MM5 and the cloud resolving GCE are used in several cloud and mesoscale studies.

These studies include the investigations of the dynamic and thermodynamic processes associated with cyclones and frontal rainbands, surface (ocean, land, and soil) effects on atmospheric convection, cloud-chemistry interactions, tropical and midlatitude convective systems, and stratospheric-tropospheric interaction. Other applications include investigating the effects of assimilating satellite-derived water vapor and precipitation fields on tropical and extra-tropical regional-scale (i.e., hurricanes, and cyclones) weather simulations.

Other areas addressed with these models include tropical climate applications involving long-term integrations. These allow the study of air-sea and cloud-radiation interactions and their application to the cloud-radiation climate feedback mechanisms; and surface energy, radiation, diabatic heating and water budgets associated with tropical and mid-latitude weather systems.

Such models also are used to develop retrieval algorithms. For example, the GCE model is providing TRMM investigators with four-dimensional data sets for the developing and improving TRMM rainfall and latent heating retrieval algorithms. For more information, contact Wei-Kuo Tao (Wei-Kuo.Tao.1@gsfc.nasa.gov).

Physical Parameterization in Atmospheric GCM

The development of physical parameterization and sub-models of the physical climate system is an integral part of climate modeling activities. Laboratory scientists are actively involved in developing and improving physical parameterizations of the major radiative transfer and moisture processes in the atmosphere. Both areas are extremely important for better understanding the global water and energy cycles.

For atmospheric radiation, we are developing efficient, accurate, and modular longwave and shortwave radiation codes. The radiation codes allow efficient computation of climate sensitivities to water vapor, cloud microphysics, and optical properties. The codes also allow us to compute the global warming potentials of carbon dioxide and various trace gases.

For atmospheric hydrologic processes, we are developing a new prognostic cloud liquid water scheme, which includes representation of source and sink terms as well as horizontal and vertical advection. This scheme incorporates attributes from physically

based cloud life cycles, including the effects of downdraft, full-cloud microphysics within convective towers and anvils, cloud-radiation interactions, cloud microphysics, and cloud inhomogeneity correction. We are testing both the radiation and the prognostic water schemes with *in situ* observations from the ARM and TOGA-COARE activities. For land-surface processes a new and improved snow physics package is being developed to better simulate the hydrologic cycle. For more information, contact William Lau (William.K.Lau.1@gsfc.nasa.gov).

Trace Gas Modeling

We have developed two- and three-dimensional models to understand the behavior of ozone and other atmospheric constituents. We use the two-dimensional models primarily to understand global scale features that evolve in response to both natural effects, such as variations in solar luminosity in ultraviolet, volcanic emissions, and human effects, such as changes in chlorofluorocarbons (CFCs), nitrogen oxides, and hydrocarbons. The three-dimensional models start with assimilated wind and other meteorological data generated by the DAO and apply chemistry and transport models to simulate short-term variations in ozone and other constituents seen in the measurements. Our goal is to improve our understanding of the complex chemical and dynamical processes that control the ozone layer.

The modeling effort has evolved in four directions: (1) *Lagrangian models* are closely coupled to the trajectory models of an air parcel. The Lagrangian modeling effort is primarily used to interpret aircraft and satellite chemical observations; (2) *Two-dimensional (2D) non-interactive models* have comprehensive chemistry routines, but use specified, parameterized dynamics. They are used both in data analysis and multidecadal chemical assessment studies, (3) *Two-dimensional interactive models* have interactive radiation and dynamics routines, and can study the dynamical impact of major chemical changes, (4) *Three-dimensional (3D) models* have a full chemistry package, and use the analyzed wind fields for transport.

We use trace gas data from sensors on the UARS and from various NASA-sponsored aircraft and ground-based campaigns to rigorously test models. The integrated effects of processes such as stratosphere troposphere exchange, not resolved in 2D and 3D models, are critical to the reliability of these models. For more information, contact Anne Douglass (Anne.R.Douglass.1@gsfc.nasa.gov).

Support for National Oceanic and Atmospheric Administration Operational Satellites

In the preceding pages, we examined The Laboratory for Atmosphere's work in measurements, data sets, data analysis, and modeling. In addition, Goddard supports NOAA's remote sensing requirements. Laboratory project scientists support the NOAA Polar Orbiting Environmental Satellite (POES) and the Geostationary Operational Environmental Satellite (GOES) Project Offices. Project scientists assure scientific integrity throughout mission definition, design, development, operations, and data

analysis phases for each series of NOAA platforms. Laboratory scientists also support the NOAA SBUV/2 ozone measurement program. This program is now operational within the NOAA/National Environmental Satellite Data and Information Service (NESDIS). A series of SBUV/2 instruments fly on POES. Post-doctoral scientists work with the project scientists to support development of new and improved instrumentation and to perform research using NOAA's operational data.

Laboratory members are actively involved in the NPOESS Internal Government Studies (IGS) and support the Integrated Program Office (IPO) Joint Agency Requirements Group (JARG) activities.

Geostationary Operational Environmental Satellites

NASA GSFC project engineering and scientific personnel support NOAA for the GOES operational satellites. GOES supplies images and soundings to study atmospheric processes, such as moisture, winds, clouds, and surface conditions. In particular, GOES observations are used by climate analysts to monitor the diurnal variability of clouds and rainfall and to track the movement of water vapor in the upper troposphere. In addition to high quality imagery, the GOES satellites also carry an infrared multichannel radiometer that NOAA uses to make hourly soundings of atmospheric temperature and moisture profiles over the United States. These mesoscale soundings are improving NOAA's numerical forecasts of local weather. The GOES project scientist at Goddard provides free public access to real-time weather images for regions all over the western hemisphere via the World Wide Web (<http://rsd.gsfc.nasa.gov/goes/>). For more information, contact Dennis Chesters (Dennis.Chesters.1@gsfc.nasa.gov).

Polar Orbiting Environmental Satellites

Algorithms are being developed and optimized for the HIRS-3 and the Advanced Microwave Sounding Unit (AMSU) launched on NOAA K in 1998. Real time analysis will be carried out thereafter, as was done with HIRS2/MSU data. For more information, contact Joel Susskind (joel.susskind.1@gsfc.nasa.gov).

Solar Backscatter Ultraviolet

NASA has the responsibility to determine and monitor the pre-launch and post-launch calibration of the SBUV/2 instruments that are included in the payload of the NOAA polar-orbiting satellites. We further have the responsibility to continue the development of new algorithms to determine more accurately the concentration of ozone in the atmosphere.

We have recently applied an upgraded version 7 algorithm for the total column ozone product being produced from the SBUV/2 data. The algorithm is similar to that now being used to produce TOMS data. It goes further than the TOMS algorithm because the SBUV/2 has extra shorter wavelengths designed for determination of the profile of concentration of ozone with altitude. One of these wavelengths, 305.6 nm, provides a sensitive measure of total ozone at the equator, where the sun is directly overhead and the column ozone amount is low. We use these equatorial measurements at this so-called "D-pair" wavelength to stabilize any long-term drift in calibration. Another outcome of

these studies was an evaluation of the non-linearity in the response of the photomultiplier tube and a determination of a hysteresis effect in the tube as measurements were made immediately after the instrument came into sunlight from the dark. These led to small corrections that have improved the quality of the data. For more information, contact Richard Stolarski (Richard.S.Stolarski.1@gsfc.nasa.gov).

National Polar Orbiting Environmental Satellite System

The first step in instrument selection for NPOESS was completed with Laboratory personnel participating on the Source Evaluation Board, acting as technical advisors. Laboratory personnel were involved in evaluating proposals for the OMPS (Ozone Mapper and Profiler System) and the Crosstrack Infrared Sounder (CrIS), which is a candidate to accompany an AMSU-like crosstrack microwave sounder. Collaboration with the IPO continues through the Operation Algorithm Teams (OAT), which will provide advice on operational algorithms and technical support on various aspects of the NPOESS instruments. In addition to providing an advisory role, members of the Laboratory are conducting internal studies to test potential technology and techniques for NPOESS instruments. For more information, contact Joel Susskind (joel.susskind.1@gsfc.nasa.gov).

For OMPS, Laboratory scientists continue to support the IPO through the Ozone Operational Algorithm Science Team, which conducts algorithm research and oversight of the OMPS developer. An algorithm to analyze SAGE III data when it operates in a limb scattering mode is being developed to simulate retrievals expected from the OMPS profiler. This work is an extension of the retrievals used for the SOLSE/LORE mission. The retrievals from this Shuttle mission demonstrated the feasibility of employing limb scattering to observe ozone profiles with high vertical resolution down to the tropopause. This research is enabled by the advanced UV and Visible (VIS) radiative transfer models developed in the Laboratory. Laboratory scientists also participate in the Instrument Product Teams to review all aspects of the OMPS instrument development. The IPO is supporting a reflight of SOLSE/LORE as a risk mitigation effort related to the OMPS. For more information, contact Ernest Hilsenrath (Ernest.Hilsenrath.1@gsfc.nasa.gov).

CrIS is a high-spectral-resolution interferometer infrared sounder with capabilities similar to those of the Atmospheric Infrared Sounder (AIRS), which will fly with AMSU A and the Humidity Sounder Brazil (HSB) on the EOS Aqua platform, to be launched in December 2000. Scientific personnel have been involved in developing the AIRS Science Team algorithm to analyze the AIRS/AMSU/HSB data. These data will be used in a pseudo-operational mode by NOAA/NESDIS and NOAA/NCEP. Simulation studies were conducted for the IPO to compare the expected performance of AIRS/AMSU/HSB with that of CrIS, as a function of instrument noise, together with AMSU/HSB. The simulations will help in assessing the noise requirements for CrIS to meet the NASA sounding requirements for the NPOESS Preparatory Project (NPP) bridge mission in 2005. Trade studies are also being done for the Advanced Technology

Sounder (ATMS), which will accompany CrIS on the NPP mission and replace AMSU/HSB. For more information, contact Joel Susskind (joel.susskind.1@gsfc.nasa.gov).

Tropospheric wind measurements are the number one priority in the unaccommodated Environmental Data Records (EDR) identified in the NPOESS Integrated Operational Requirements Document (IORD-1). The Laboratory is using these requirements in developing the Edge Technique Wind Lidar System to measure tropospheric wind profiles on a global scale. The IPO is supporting the effort through their IGS program. For more information, contact Bruce Gentry (Bruce.M.Gentry.1@gsfc.nasa.gov).

The IPO is also supporting a Goddard design study of a visible and infrared imaging radiometer based on advanced-technology array detectors. The goal is an imaging radiometer smaller, less costly, and more capable than previous instruments. The program is developing an instrument based on advanced microbolometer array (MBA) warm thermal detectors. A prototype MBA-based instrument, the ISIR, flew as a Shuttle small attached payload in August 1997. Its performance as a space-borne imager will be assessed from this Shuttle mission. A design study is planned for an array detector-based, operational, polar-orbiting, visible and infrared imager for a low-Earth-orbiter, applying the results of the ground and flight performance testing of ISIR. For more information, contact James Spinhirne (James.D.Spinhirne.1@gsfc.nasa.gov).

The IPO supports the development of the Holographic Optical Telescope and Scanner (HOTS) which investigates the feasibility of using this technology for lidar applications on NPOESS, including, but not limited to, a direct detection (edge) wind lidar system. For more information, contact Geary Schwemmer (Geary.K.Schwemmer.1@gsfc.nasa.gov).

Project Scientists

Space flight missions at NASA depend on cooperation between two upper-level managers, the project scientist and the project manager, who are the principal leaders of the project. The project scientist provides continuous scientific guidance to the project manager while simultaneously leading a science team and acting as the interface between the project and the scientific community at large.

Table III lists project and deputy project scientists for current missions.

**Table III: Laboratory for Atmospheres Project and
Deputy Project Scientists**

PROJECT SCIENTISTS		DEPUTY PROJECT SCIENTISTS	
Name	Project	Name	Project
Pawan K. Bhartia	TOMS	Anne R. Douglass	UARS, EOS Aura
Dennis Chesters	GOES	Ernest Hilsenrath	EOS Aura
Jay Herman	Triana	Arthur Hou	TRMM
Yoram Kaufman	EOS Terra		
Christian Kummerow	TRMM		
Charles Jackman	UARS		
Mark Schoeberl	EOS Aura		
Joel Susskind	POES		
EOS VALIDATION SCIENTIST		FIELD/AIRCRAFT CAMPAIGN CO-PROJECT/MISSION SCIENTISTS	
Name	Project	Name	Project
David O'C. Starr	EOS	Donald Anderson	AEAP
		P. Newman, M. Schoeberl	SOLVE
		Anne Thompson	SONEX
		Si-Chee Tsay	SAFARI-2000
		James Spinhirne	INDOEX
		James Spinhirne	SPARCLE

Interactions with Other Scientific Groups

Interactions with the Academic Community

The Laboratory depends on collaboration with university scientists to achieve its goals. Such relationships make optimum use of government facilities and capabilities and those of academic institutions. These relationships also promote the education of new generations of scientists and engineers. Educational programs include summer programs for faculty and students, fellowships for graduate research, and associateships for postdoctoral studies. The Laboratory frequently supports workshops on a wide range of scientific topics of interest to the academic community, as shown in Appendix 5.

NASA and non-NASA scientists work together on NASA missions, experiments, and instrument and system development. Similarly, several Laboratory scientists work on programs residing at universities or other federal agencies.

The Laboratory routinely makes its facilities, large data sets, and software available to the outside community. The list of refereed publications, presented in Appendix 7, reflects our many scientific interactions with the outside community; 70% of the publications involve co-authors from institutions outside the Laboratory.

Prime examples of collaboration between the academic community and the Laboratory include these recently established cooperative agreements with universities:

- Earth System Science Interdisciplinary Center (ESSIC), with the University of Maryland, College Park;
- Joint Center for Earth Systems Technology (JCET), with the University of Maryland, Baltimore County;
- Joint Center for Geoscience (JCG), with the Massachusetts Institute of Technology;
- Joint Center for Observation System Science (JCOS), with the Scripps Institution of Oceanography, University of California;
- Center for Earth-Atmosphere Studies (CEAS), with Colorado State University;
- Cooperative Center for Atmospheric Science and Technology (CCAST), with the University of Arizona; and
- Cooperative Institute for Atmospheric Research (CIFAR) with UCLA.

These joint centers have been organized to increase scientific interactions between the Earth Science Directorate at GSFC and the faculty and students at the participating universities.

University and other outside scientists visit the Laboratory for periods ranging from one day to as long as two years. (See Appendix 1 for list of recent visitors and Appendix 4 for seminars.) Some of these appointments are supported by Resident Research Associateships offered by the National Research Council (NRC) of the National Academy of Sciences; others, by the Visiting Scientists and Visiting Fellows Programs currently managed by the Universities Space Research Association (USRA). Visiting Scientists are appointed for up to two years and carry out research in pre-established areas. Visiting Fellows are appointed for up to one year and are free to carry out research projects of their own design. (See Appendix 3 for a list of NRC Research Associates, USRA Visiting Scientists, Visiting Fellows, and Associates of the Joint Institutes during 1999.)

Interactions with Other NASA Centers and Federal Laboratories

The Laboratory maintains strong, productive interactions with other NASA centers and federal laboratories.

Our ties with the other NASA centers broaden our knowledge base. They allow us to complement each other's strengths, thus increasing our competitiveness while minimizing duplication of effort. They also increase our ability to reach the agency's scientific objectives.

Our interactions with other federal laboratories enhance the value of research funded by NASA. These interactions are particularly strong in ozone and radiation research, data assimilation studies, water vapor and aerosol measurements, ground truth activities for satellite missions, and operational satellites.

Interactions with Foreign Agencies

The Laboratory has had several ongoing programs in cooperation with non-U.S. space agencies. These programs involve many of the Laboratory scientists.

Major efforts include the TRMM Mission with the Japanese National Space Development Agency (NASDA); the Huygens Probe GCMS, with the ESA (CNES); the TOMS Program, with NASDA and the Russian Scientific Research Institute of Electromechanics (NIIEM); the Neutral Mass Spectrometer (NMS) instrument, with the Japanese Institute of Space and Aeronautical Science (ISAS); and climate research with various institutes in Europe, South America, South Africa, and Asia.

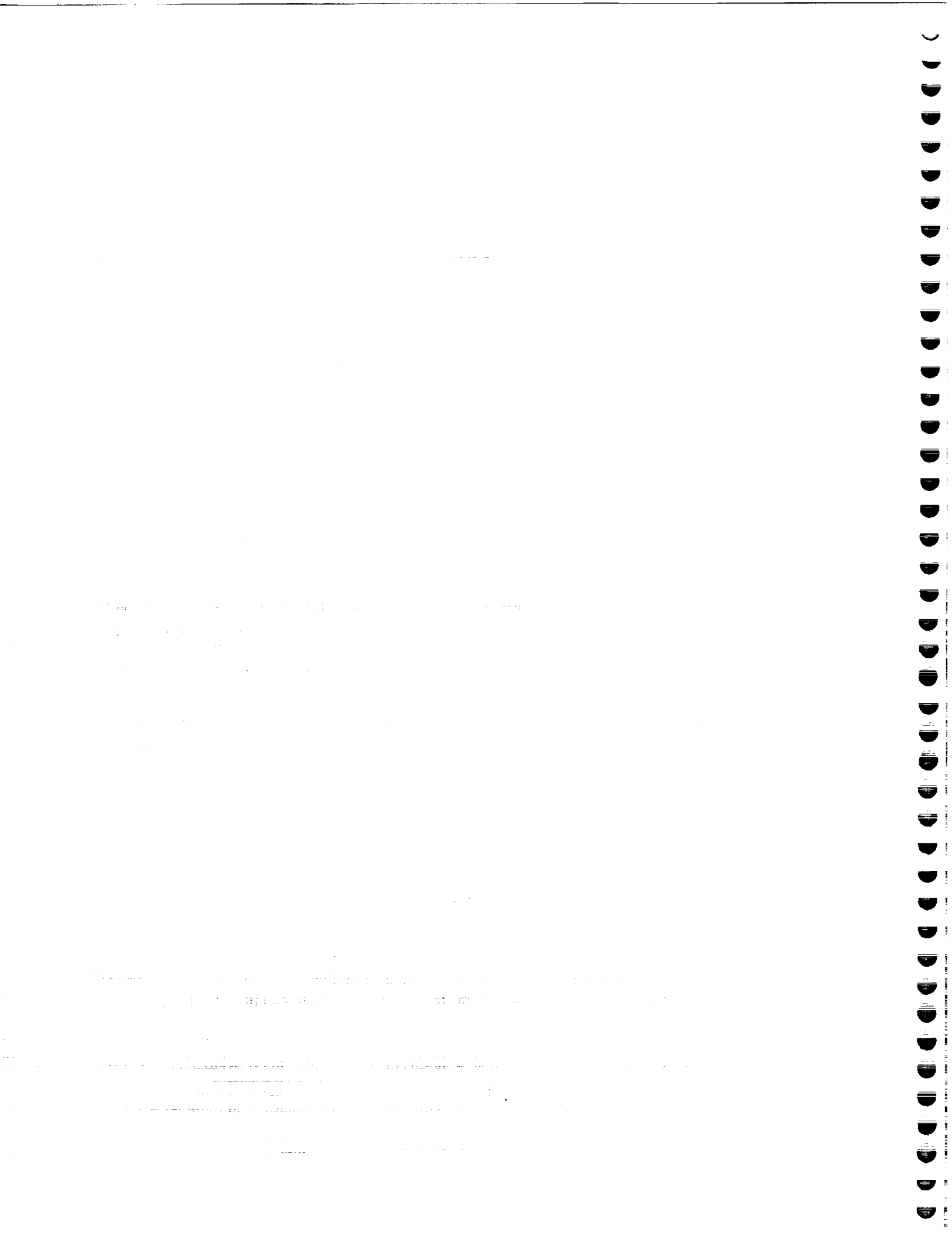
Laboratory scientists interact with about twenty foreign agencies, about an equal number of foreign universities, and two foreign companies. The collaborations vary from extended visits for joint missions to brief visits for giving seminars or, perhaps, working on papers.

Commercialization and Technology Transfer

The Laboratory for Atmospheres fully supports government/industry partnerships, SBIR's and technology transfer activities. The Laboratory was extremely proactive, and a key contributor, to development of the partnering process now used within Goddard. Through this process, government Principal Investigator's (PI) can team with industry to produce credible and competitive proposals that satisfy the Competition In Contracting Act (CICA) requirements. The Laboratory used this process three times under the Earth Systems Science Pathfinder (ESSP) Program and will continue to use this process on all major mission proposals. The Laboratory has four instrument development activities funded through the NASA IIP. Industry and university Co-Investigator's (Co-I) are important contributors on each program. Laboratory scientists also serve as Co-I's on proposals led by industry. These practices will continue on future proposals.

Prior to the last ESSP call, the Laboratory organized a partnering seminar for industry. Prospective PI's from NASA centers and universities presented outlines of their proposals for the express purpose of inviting collaboration. Over 140 companies were represented. Partnering interviews were arranged between PI's and industry representatives; over 60 interviews took place.

Successful technology transfer has occurred on a number of programs in the past and new opportunities will become available in the future. Past examples include the micro-pulse Lidar and holographic optical scanner technology. Industry now develops and markets micro-pulse Lidar systems to an international community. Twenty units have been sold and deployed thus far. A licensing agreement with industry permits the use of government patented holographic technology for commercial application to topographic mapping. New research proposals involving technology development will have strong commercial partnerships wherever possible. The Laboratory hopes to devote at least 10% to 20% of its resources to joint activities with industry on a continuing basis.



6. HIGHLIGHTS OF LABORATORY FOR ATMOSPHERES ACTIVITIES IN 1999

Measurements

Ground-Based Measurements

Tropospheric Wind Profiling Using Direct Detection Doppler Lidar

We've achieved two important milestones on the road to using direct-detection Doppler lidar to remotely measure wind profiles from space. The first is the completion of the Mobile Doppler Lidar System. The second is the development and demonstration of a new Doppler lidar receiver for measuring winds.

The mobile Doppler Lidar System is a van-based, multi-purpose lidar. We'll use the lidar in field experiments to measure winds from the surface into the stratosphere. The field measurements will be taken in a variety of atmospheric conditions and can contribute to our understanding of mesoscale atmospheric dynamics and transport. These field experiments will also give us important knowledge about direct-detection Doppler lidar systems. That knowledge will help us develop new satellite versions of these systems. The mobile Doppler lidar system has a modular design that allows us to test such new technologies as lasers, detectors, and telescopes. These technologies will be required for future space-based direct-detection Doppler lidar systems.

The new Doppler lidar receiver is designed to measure winds using the laser signal backscattered directly from air molecules. The first wind profiles measured with this molecular Doppler lidar system were obtained using the Mobile Lidar System operating from GSFC beginning in October 1999 (Figure 2). Profiles of horizontal wind speed and direction as a function of altitude are determined by combining wind velocity information obtained by looking in multiple directions. The lidar points in different directions using the rotating optical scanner mounted on the roof of the van. The altitude is determined by keeping track of the time of flight of the transmitted laser pulse.

In the example shown, wind speed and direction have been determined to an altitude of 35 km with a vertical resolution of 175 m. Winds below 7 km are not shown because the laser signal is too large for the photodetectors to effectively measure. Initial comparisons with co-located rawinsondes show excellent agreement with the lidar measured wind speed and direction. In early 2000, we'll conduct a more extensive measurement program including intercomparison with a variety of other wind measuring systems.

Why is this new capability important? Previous Doppler lidar systems relied on the laser signal backscattered from atmospheric aerosols. The results of these systems are impressive when aerosols are present. However, large areas of the global atmosphere have aerosols insufficient to allow lidar wind measurements from space using these methods. Aerosols are particularly sparse in the mid- to upper troposphere and lower

stratosphere (3-30 km altitude) and over the oceans. In these regions, a Doppler lidar measuring winds using molecular backscatter will be very useful.

Figure 3 is a composite of three different profiles of wind speed that we have obtained from the ground using various implementations of the direct-detection Doppler lidar approach. The profiles are all shown with the same altitude scale. The first two profiles from the left are determined using Doppler receivers optimized for aerosol backscatter operating at a wavelength of 1064 nm. As noted above, the performance of these systems is very good in regions where aerosols are present. This approach is particularly useful for high spatial and temporal resolution studies of atmospheric dynamics in the aerosol-laden boundary layer (0-2 km). The last profile is the most recent result obtained with the molecular backscatter Doppler receiver. The altitude range of the wind measurement is greatly extended, due to the molecular approach and its ability to measure winds from clear air returns.

Many important atmospheric science studies will be aided by spaceborne wind measurements using a Doppler lidar. Improved knowledge of the wind field is an objective of four of the five primary research areas described in the NASA Earth Science Enterprise Science Research Plan. Global wind measurements will also increase under-

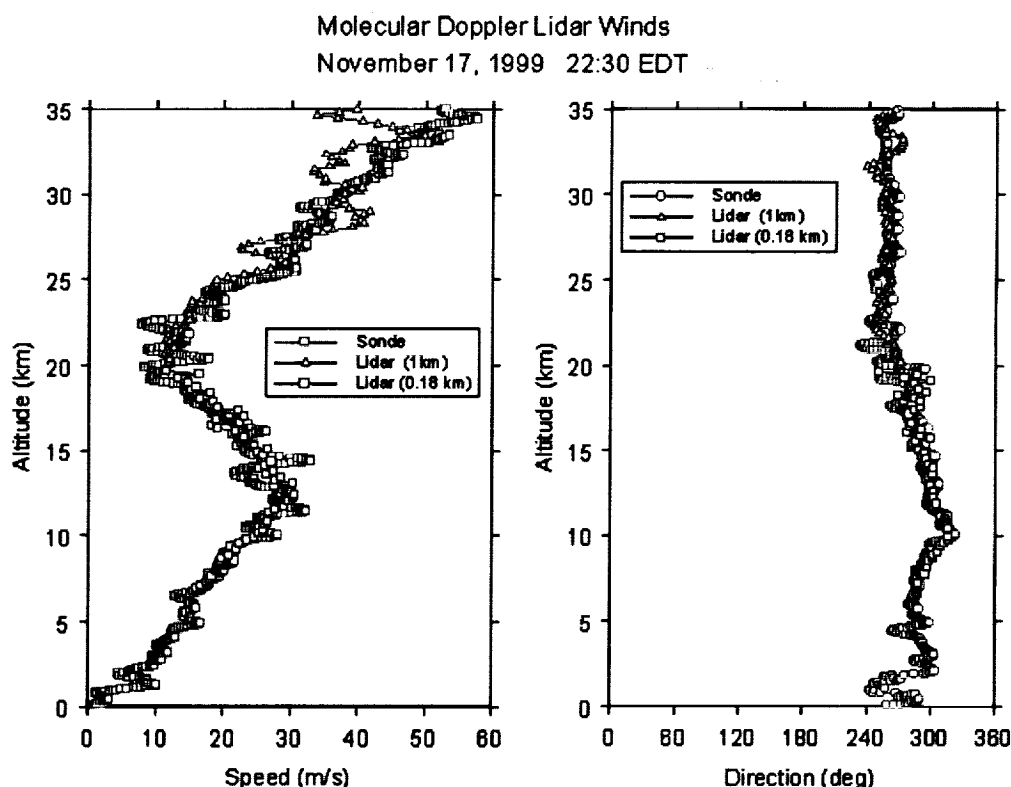


Figure 2. Profiles of wind speed and direction obtained with the new molecular Doppler lidar system are shown along with independently determined wind data from a co-located rawinsonde. The molecular Doppler lidar system allows measurement of wind profiles from clear air and thus will be useful in regions of the atmosphere where aerosols are sparse.

standing and prediction of interannual and long-term climate change. Wind data are fundamental to better understanding the role of greenhouse gases, the hydrologic cycle, heat and energy transport, radiative cloud processes, and the biogeochemical cycle. In the area of Natural Hazards Research, global wind measurements would aid in the prediction and tracking of hurricanes and severe storm outbreaks. Finally, wind measurements improve our understanding of the dynamics of weather systems. Including global wind measurements in our models will contribute to significantly improved short- and long-term weather forecasts.

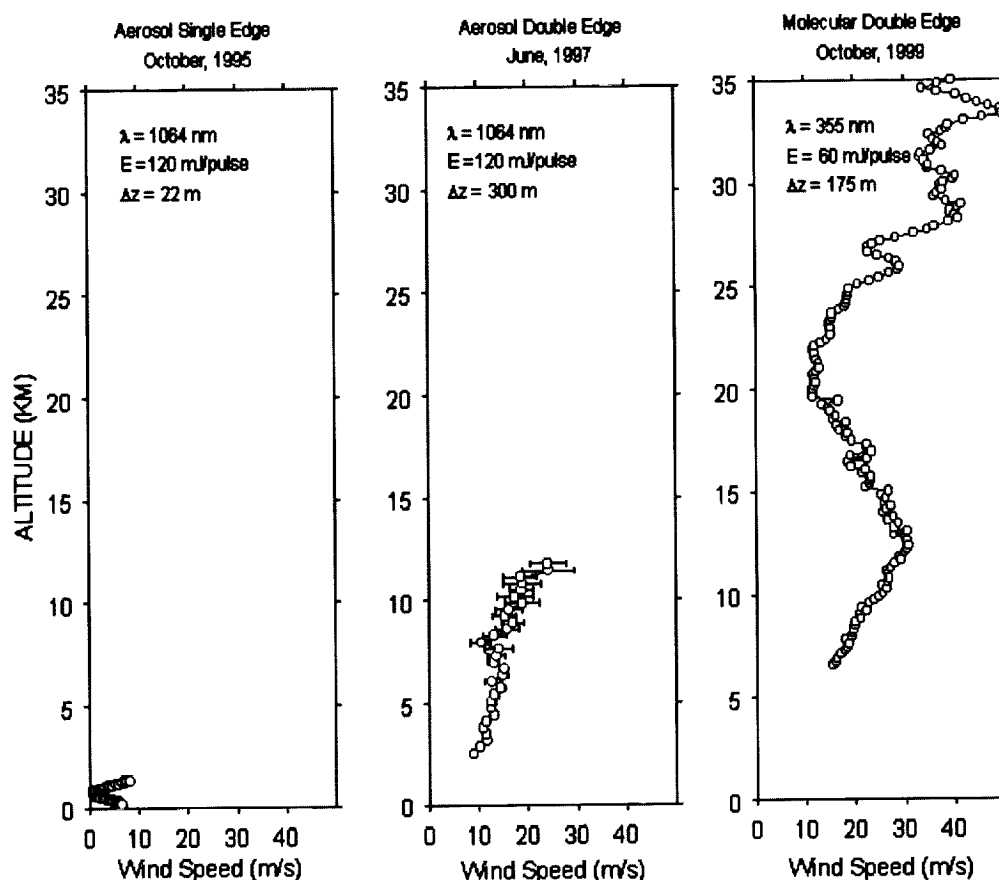


Figure 3. A composite of three wind speed profiles obtained with different versions of the direct detection Doppler lidar technique. The profiles are shown on the same altitude scale to illustrate the progression of capability, which we have now demonstrated with our ground based lidar program.

Gentry, B., H. Chen, and S. Li, 2000: Wind measurements with a 355 nm molecular Doppler lidar. Submitted for publication in *Optics Letters*.

Gentry, B., S. Li, S. Mathur, C. L. Korb, and H. Chen, 2000: Doppler lidar measurements of tropospheric wind profiles using the aerosol double edge technique. Submitted for publication in *Applied Optics*.

Field Campaigns

Distinct Regimes of Amazonian Convection from TRMM Field Campaign Ground-Based Radar Data

Radar observations of tropical convection in the Amazon region of Brazil during the TRMM-LBA field program are revealing that fundamental changes occur in the organization of precipitation as the large-scale flow pattern evolves during the wet season. These observations may lead to an improvement in the representation of convection in climate models. The observations will also aid in fine-tuning the retrieval of rainfall and latent heating from the TRMM satellite.

Ground-based radars deployed in the Brazilian state of Rondônia for TRMM-LBA provided two months of continuous measurements, every ten minutes, of the precipitation structure of convective systems. We processed the radar reflectivity measurements with techniques that allow us to distinguish active cells of intense convective rainfall from more uniform, widespread stratiform rain. We then applied a preliminary estimate of the conversion of radar reflectivity to rainfall rate. It's too early in the data analysis effort to produce absolute rainfall amounts. Still, we can use the resulting time series to study the time variation of rainfall intensity.

The relative amount of convective versus stratiform rainfall in a convective system highlights important properties, not only of rainfall intensity but also of the vertical distribution in the troposphere of the latent heat of condensation. One way to illustrate how the relative amount of these two kinds of rain structure varies with time is to plot the ratio of convective rain fraction (F_c) to stratiform rain fraction ($1-F_c$). This ratio increases exponentially with increasing convective rain fraction and thus emphasizes small changes in convective rain fraction for values of F_c greater than about 50%.

Figure 4 presents a time series of the ratio of convective rain fraction to stratiform rain fraction from the NASA/NOAA TOGA radar for TRMM-LBA. In two periods, 22-28 January and 10-20 February, precipitation was dominated by convective rainfall. These periods corresponded well to regimes of lower tropospheric easterly wind, as observed from radiosonde data. The intervening occurrence of lower convective vs. stratiform rain fraction was associated with westerly winds at low levels.

Composites of rain statistics between westerly and easterly regimes revealed that rain intensity was 50% higher during easterlies, yet systems were about 50% smaller in area. Furthermore, almost all of the difference in rain intensity between westerly and easterly wind regimes was associated with the convective portion of the rainfall. This implied that an environmental mechanism enhanced the vertical intensity of convective cells and limited the growth of stratiform rain during easterlies and/or limited convective intensity and expanded stratiform rain during westerlies.

This work has important implications for simulating tropical precipitation patterns in global climate models and increasing the accuracy of rainfall retrievals from satellites

such as TRMM. First, we may be able to infer important rainfall and latent heating characteristics of Amazonian convective systems by observing the large-scale wind patterns from conventional data. This could allow us to parameterize these characteristics in GCMs based on relatively simple aspects of flow patterns. Second, we may learn that precipitation and latent heating retrieval algorithms for TRMM perform differently in distinct rainfall regimes. If so, identifying the bulk differences in convective organization based on wind regimes may offer guidance to modify the algorithms and make them more accurate.

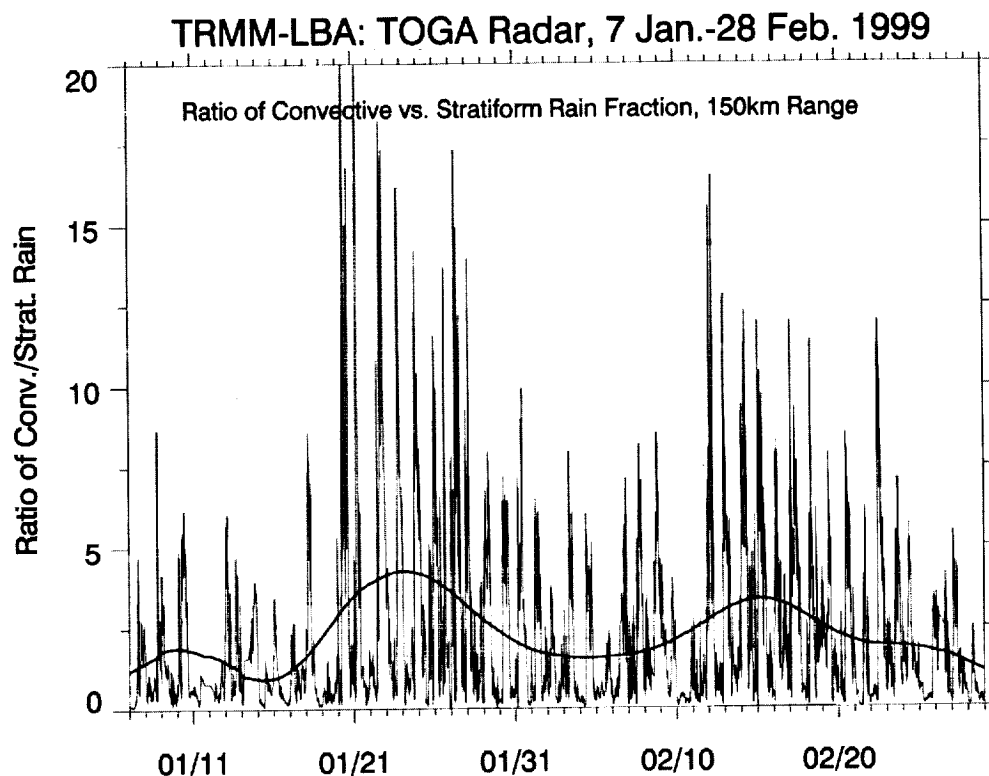


Figure 4. Time series of the ratio of convective rain fraction (F_c) to stratiform rain fraction ($1-F_c$), from the NASA/NOAA TOGA radar during the TRMM-LBA field experiment. The smoothed curve shows the same time series with variability less than eight days removed, which illustrates the variability on weekly time scales.

Rickenbach, T., R. Nieto Ferreira, and J. Halverson, 2000: Relationship between mesoscale properties of convection and large-scale regimes during TRMM-LBA in Rondônia, Brazil. AMS 6th Conference on Southern Hemisphere Meteorology and Oceanography, Santiago, Chile.

Aerosol Recirculation and Rainfall Experiment (ARREX) and Southern Africa Fire-Atmosphere Research Initiative-2000 (SAFARI)

Aerosol palls cover large expanses of the Earth's surface and arise from biomass burn-

ing, air pollution, dust storms, and other sources. These aerosols may directly scatter solar radiation back to space, thus increasing the Earth's albedo and cooling the Earth's surface and atmosphere. Aerosols also contribute to the Earth's energy balance indirectly. Hygroscopic aerosols act as cloud condensation nuclei and thus affect cloud properties.

Recent TRMM observations over Indonesia provide evidence for the first time that aerosols from biomass burning significantly affect the regional-scale hydrologic cycle. During the satellite's overpass, TRMM radar detected precipitation in smoke-free clouds, but almost none in the smoke-plagued clouds. While the intense smoke from forest fires can completely shut off rainfall, even the more subtle effects of urban pollution may cause significant rainfall reductions. Obviously, to assess the magnitude of such effects in densely populated regions (e.g., Africa, Asia), scientists have to acquire good measurements of aerosol microphysical and chemical properties with which to test the transport and radiation models that would form the basis of such assessments.

Under an agreement between scientists at NASA GSFC and the University of Witwaterand, South Africa, a team has been formed to guide and execute several scientific experiments to study the effects of aerosols on regional climate. The initiative focuses on inserting new technology developed by Goddard for airborne remote sensing (and eventually for spaceflight) and collocated ground-based remote sensing observations for validation. Figure 5 shows two Aerocommander 690 aircraft, provided by South Africa Weather Bureau, equipped with Goddard's remote sensing instruments (right) and University of Witwaterand's microphysical and chemical probes (left).



Figure 5. Two aircraft equipped with many remote sensing instruments (right) and microphysical and chemical probes (left) for formation flights. The Goddard's remote sensing instruments contain two shortwave spectrometers and one IR imager, in which the new technology forms the base for Leonardo Airborne Simulator.

In Figure 6, a suite of ground-based radiation instruments is deployed and collocated with aircraft or satellite observations. The scientific objectives are two: (1) to measure broadband shortwave and longwave irradiance at the surface, together with collocated satellite measurements, for studying the radiative energy budget at the Intensive Operations Period (IOP) area, and (2) to acquire narrowband visible, near-IR, microwave radiance measurements and lidar backscattering intensity at the surface for retrieving atmospheric parameters (e.g., column water vapor amount, ozone abundance, aerosol loading and size distribution, etc.).



Figure 6. The ground-based remote sensing instruments contain many broadband-short-wave and longwave radiometers (left parts on bench top), narrow-band sunphotometers (right parts on bench top) and spectrometer (center insert at bottom), micro-pulse lidar (left insert at bottom), and scanning microwave radiometer (right insert at bottom).

A huge volume of first-hand data was collected and post-mission calibration and preliminary analysis are underway. The Goddard team has participated in the ARREX wet season campaign (February - March 1999; Bethlehem, South Africa) and the dry season campaign (August - September 1999, Skukuza; South Africa), see Figure 7. An extended field observation is scheduled for August-September 2000, known as SAFARI-2000. The SAFARI-2000 initiative is an umbrella activity, national, regional, and international in nature, aimed at increasing our understanding of the southern African ecological and climate system as a whole, as well as its relationship to hemispheric and global climate.

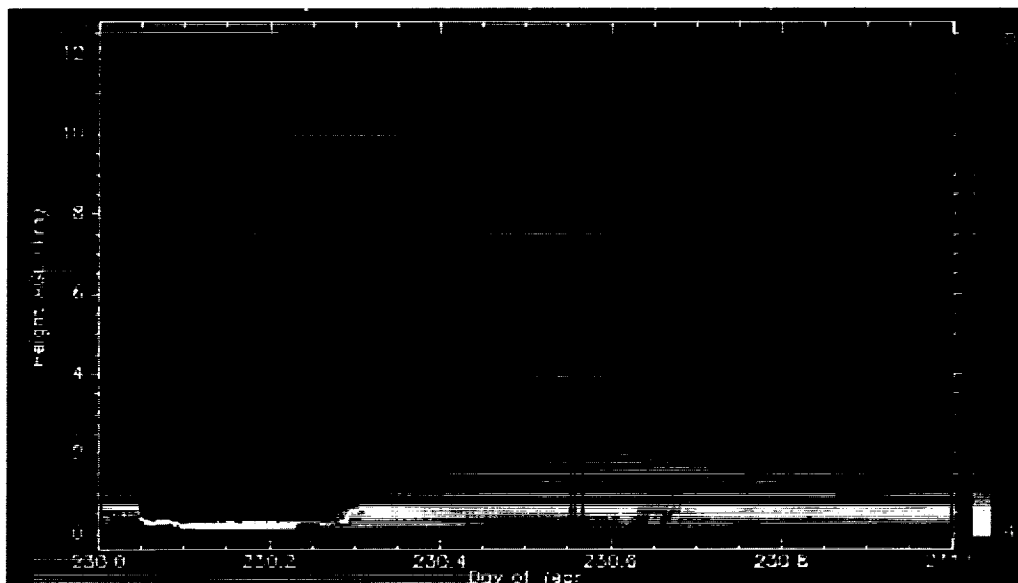


Figure 7. Time series of vertical distributions of biomass burning aerosols observed on 18 August 1999 at Skukuza airport during ARREX dry season campaign. During the nighttime (left) the surface site was covered by low level clouds (no lidar return signal above cloud layer); in the morning hours, multiple layers of aerosols were clearly seen (boundary layer capped around 2 km and aloft around 5 km); in the afternoon hours, a heavy smoke layer moved in from the border of Mozambique, about 60 km northeast of Skukuza.

Tsay, S. C., S. Piketh, Q. Ji, J. R. Campbell, and R.J. Swap, 2000. Radiation observations during the Aerosol Re-circulation and Rainfall Experiment (ARREX) in South Africa. *Bull Amer. Meteor. Soc.*, in preparation.

Data Analysis

Ozone and Trace Gases

Shipboard and Satellite Views of Elevated Tropical Tropospheric Ozone in January-February 1999

Tropospheric ozone is a key oxidant in the atmosphere and, in the upper troposphere, acts as a greenhouse gas. In the tropics, tropospheric ozone interacts with atmospheric dynamical processes both on the large-scale (showing changes during ENSO events, for example) and in convective systems. In addition, chemical influences on ozone are more complex in the tropics than in mid-latitudes because rapidly increasing industrial development, savanna burning, biogenic emissions, and lightning all produce ozone precursors. We use field data to gain insights into these processes and we produce high-resolution satellite maps of tropospheric ozone to give regional views of tropical ozone variability.

Figures 8 and 9 illustrate tropospheric ozone in early 1999 over the tropical Atlantic from in-situ and satellite perspectives, respectively. The altitude-vs-longitude cross-section

tion, from an oceanographic cruise on which daily ozone balloon-sondes were launched between the US and South Africa, shows two tropical sections (Zones 2 and 3, in Figure 8). Figure 9 shows integrated tropospheric ozone from Zones 2 and 3 overlaid on a TOMS map of tropospheric ozone. Agreement between the sonde and satellite data is good, with the satellite showing ozone elevated above background (25 Dobson Units) as an extensive feature from Africa to South America.

In Figure 8, the high ozone at 2-5 km between 8N and the equator originates from biomass burning in northern equatorial Africa. It was a surprise that even higher ozone concentrations were found between 7 and 10 km off southern Africa, which was not burning. Reasons for this "ozone paradox" may be complex. Interhemispheric transport through the Intertropical Convergence Zone (ITCZ) is one possibility, with stable ozone layers entering convective clouds, which transport it from lower troposphere to upper troposphere. The lightning sensor on TRMM shows that many flashes—injecting the essential ozone precursor, nitric oxide (NO), directly into the atmosphere at 7-13 km—are over southern Africa, upwind of the ozone peaks in Zone 3. Water vapor, which destroys ozone photochemically with high efficiency in the tropics, is anticorrelated with ozone in most of the soundings.

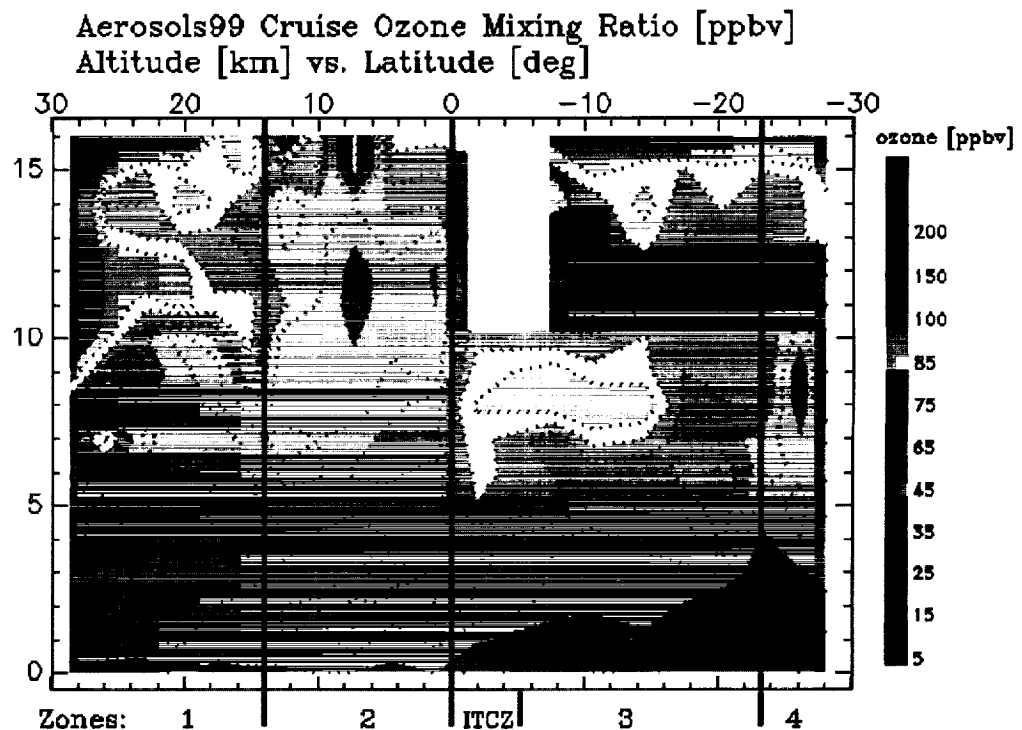


Figure 8. TOMS tropospheric ozone (in Dobson Units), averaged over January 1999, with integrated tropospheric ozone from sondes between 21 January and 3 February, shown in white. Gaps in modified-residual tropospheric ozone correspond to persistent clouds, where TOMS data are not used.

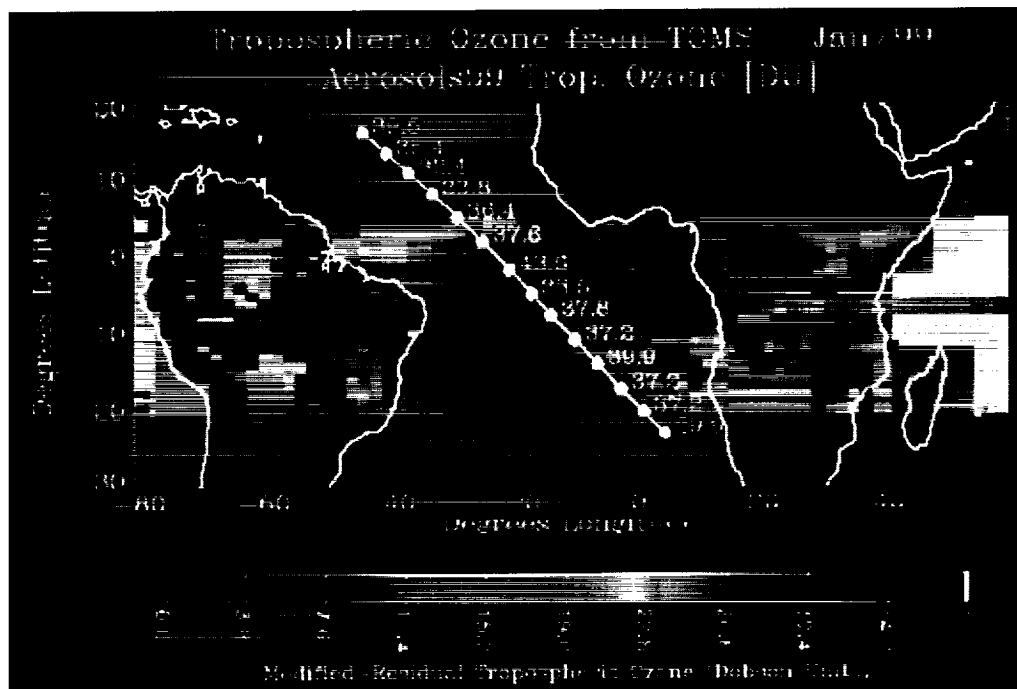


Figure 9. From the first North America-to-South African oceanographic cruise with ozonesonde launches (January and February 1999 on board the NOAA Research Vessel Ronald H. Brown), a composite of 22 ozone profiles is shown [altitude in km vs latitude, with ozone mixing ratio in parts per billion volume (ppbv)].

Thompson, A. M., B. G. Doddridge, J. C. Witte, R. D. Hudson, W. T. Luke, J. E. Johnson, B. J. Johnson, S. J. Oltmans and R. Weller, 1999: Shipboard and satellite views of elevated tropospheric ozone over the tropical Atlantic in January-February 1999. *Geophys. Res., Lett.*, submitted.

Assessment of the Effects of Stratospheric Aircraft

We've participated in assessing the potential atmospheric impacts of a proposed new generation of passenger aircraft. The high-speed civil transport (HSCT) would carry approximately 300 passengers, similar to current airliners. However, the HSCT would travel at more than twice the speed of conventional jetliners. This airplane would cruise at an altitude of 17 to 20 km (56,000 to 66,000 ft).

A primary environmental concern regarding HSCT emissions is the possibility of stratospheric ozone depletion. A flight altitude of 20 km would put the exhaust from the HSCT fleet well into the stratosphere where most of the atmospheric ozone resides (Figure 10). Concern about the impact of aircraft exhaust on ozone contributed to the decision not to develop a supersonic transport in the United States in the 1970s.

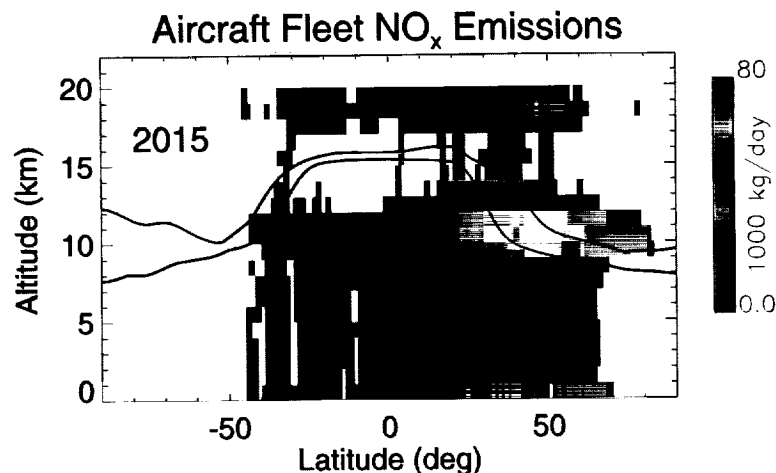


Figure 10. Annual average aircraft NO_x emissions as a function of altitude and latitude for the year 2015 from the NASA AEAP database. This scenario assumes a fleet of 500 HSCTs operating at an emission index for NO_x of $5 \text{ g}(\text{NO}_x)/\text{kg}(\text{fuel})$, in addition to the projected subsonic fleet background. Emissions above 14 km are from the HSCTs. The range of monthly zonal mean tropopause heights for 1993 is superimposed as solid black lines (from National Centers for Environmental Prediction data).

HSCT exhaust may affect ozone in several ways. The exhaust components of interest for ozone impacts are oxides of nitrogen (NO_x (= nitric oxide (NO) + nitrogen dioxide (NO_2))), H_2O , and particulate matter. Engine combustion produces NO_x , which is known to participate in one of the main catalytic chemical cycles destroying ozone in the atmosphere. Adding NO_x will, in much of the stratosphere, increase the chemical removal rate of ozone. The effect of added NO_x in some regions, however, is not so straightforward. NO_x interferes with other chemical loss processes and may even contribute to a net increase of ozone in the lowermost stratosphere.

HSCT engines will also produce H_2O . H_2O in the stratosphere is a source of oxides of hydrogen (HO_x), another chemical destroyer of ozone. In addition, H_2O plays a major role in condensation of cloud particles in the stratosphere, which in turn affect the balance of chemicals destroying ozone. Jet engine exhaust is also a source of soot and sulfate particles to the stratosphere. These products will interact with the other exhaust products and the components of the background atmosphere in a non-linear fashion to produce an overall impact on ozone.

The possible interactions of HSCT exhaust with the atmosphere are complex. The net chemical effect of the emissions depends strongly on the transport, dispersion and residence time of the effluent in the stratosphere. The HSCT fleet does not yet exist, and thus its effect cannot be measured. Nor do we have an analogous perturbation to compare it to. Because of this, the potential effects of HSCTs are calculated in numerical models of atmospheric chemistry and transport. Figure 11 shows an example of the changes in total ozone produced by introducing an HSCT fleet into atmospheric models. Such chemical transport models are necessarily incomplete representations of the real atmosphere because we have an incomplete understanding of how the atmosphere

works. Furthermore, computers have limited capacity to simulate the atmospheric system at all time and spatial scales. These factors lead to significant uncertainty in calculation of HSCT impacts. In our current work, we assess the current state of understanding of important processes, our ability to accurately simulate them in models, and the consequent uncertainty in predicted impacts of stratospheric aviation.

Percent Difference O_3 Column Scn 9 - Scn 1

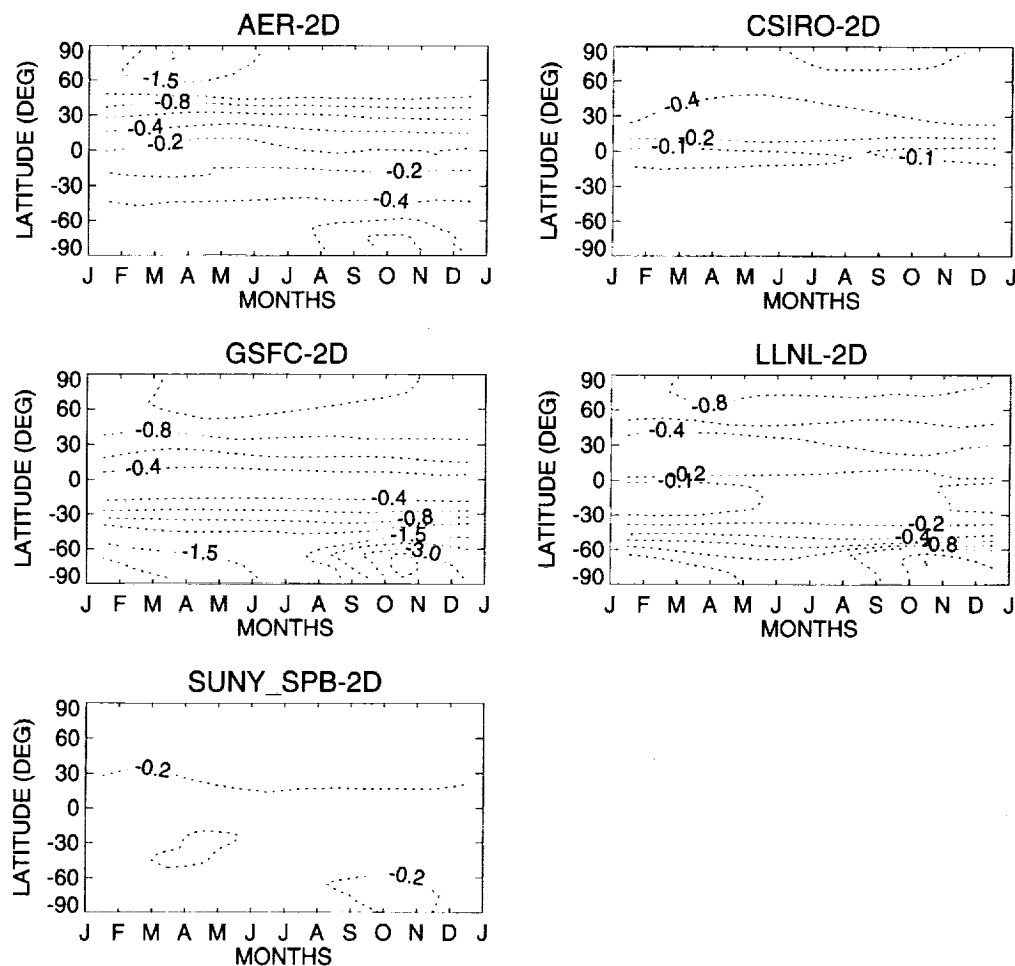


Figure 11. Seasonal and latitudinal dependence of calculated total column O_3 change in per cent for a scenario including HSCT emissions relative to subsonic aircraft only conditions. The average Northern Hemisphere O_3 change ranges from -0.3 to -0.8% in the 5 models which ran this scenario [Kawa et al., 1999].

Kawa, S. R., J. G. Anderson, S. L. Baughcum, C. A. Brock, W. H. Brune, R. C. Cohen, D. E. Kinnison, P. A. Newman, J. M. Rodriguez, R. S. Stolarski, D. Waugh, S. C. Wofsy, 1998: Assessment of the effects of high-speed aircraft in the stratosphere. NASA Tech. Pub. 1999-209236, NASA Goddard Space Flight Center, Greenbelt, MD.

Aerosol Studies**Comparison of TOMS and AVHRR Volcanic Ash Retrievals from the August 1992 Eruption of Mt. Spurr**

The North Pacific air traffic corridors pass over hundreds of volcanoes capable of destroying aircraft through sudden, explosive eruptions. Of equal concern are drifting clouds of volcanic ash that are a serious hazard to aviation even thousand of miles from an eruption. At least 80 aircraft have been damaged since 1980 by flying through volcanic clouds.

Our TOMS instruments have provided much information about the sulfur dioxide content in volcanic clouds. A new analytical technique also allows us to determine ash content and, thus, unambiguously identify volcanic clouds. The UV techniques are very robust and, during daylight hours, can detect both fresh clouds, minutes to hours old, and aging clouds. Data from NOAA's operational AVHRR instruments have also been used to locate volcanic clouds by their visible appearance and, under certain conditions, by spectral differences in ash absorption at thermal infrared wavelengths. The IR measurements are necessary for observations at night but are limited to aging, semi-transparent clouds above a warm surface.

Lately, we've compared UV and infrared retrievals by studying rare, near-simultaneous TOMS and AVHRR observations of the August 19, 1992, Mt. Spurr (Alaska) ash cloud (see Figure 12). Our study demonstrated agreement in key aspects of cloud mass, spatial extent and geometry. Our analysis suggests that we can use the UV TOMS measurements not only to track differences between the ash and sulfur dioxide cloud but also to determine time-dependent ash cloud densities over a broad variety of eruption conditions. This is the focus of a new NASA mission to provide more accurate and timely information on drifting volcanic clouds using a geostationary satellite for high time resolution. The proposed Volcanic Ash Monitor (VOLCAM) camera was recently selected as an alternate NASA ESSP mission and is also being considered as a joint NASA-NOAA experiment on the GOES-O satellite.

Krotkov, N.A., Krueger, A.J., P.K. Bhartia, Ultraviolet optical model of volcanic clouds for remote sensing of ash and sulfur dioxide, *J. Geophys. Res.*, **102**, 21897-21904, 1997.

Krotkov, N. A., O. Torres, C. Seftor, A. J. Krueger, W. Rose, A. Kostinski, G. Bluth, D. Schneider and S. J. Schaefer, Comparison of TOMS and AVHRR volcanic ash retrievals from the August 1992 Eruption of Mt. Spurr, *Geophys. Res. Lett.*, 1999, **26**, 455-458.

Krueger, A.J., Walter, L.S., Bhartia, P.K., Schnetzler, C.C., Krotkov, N.A., Sprod, I. and Bluth, G.J.S., Volcanic sulfur dioxide measurements from the Total Ozone Mapping Spectrometer (TOMS) instruments, *J. Geophys. Res.*, **100**, 14057-14076. 1995.

Seftor, C.J., N.C.Hsu, J.R.Herman, P.K.Bhartia, O.Torres, W.I.Rose, D.J. Shneider, and N.Krotkov, Detection of volcanic ash clouds from Nimbus-7/Total Ozone Mapping Spectrometer, *J. Geophys. Res.*, **102**, 16749-16759, 1997.

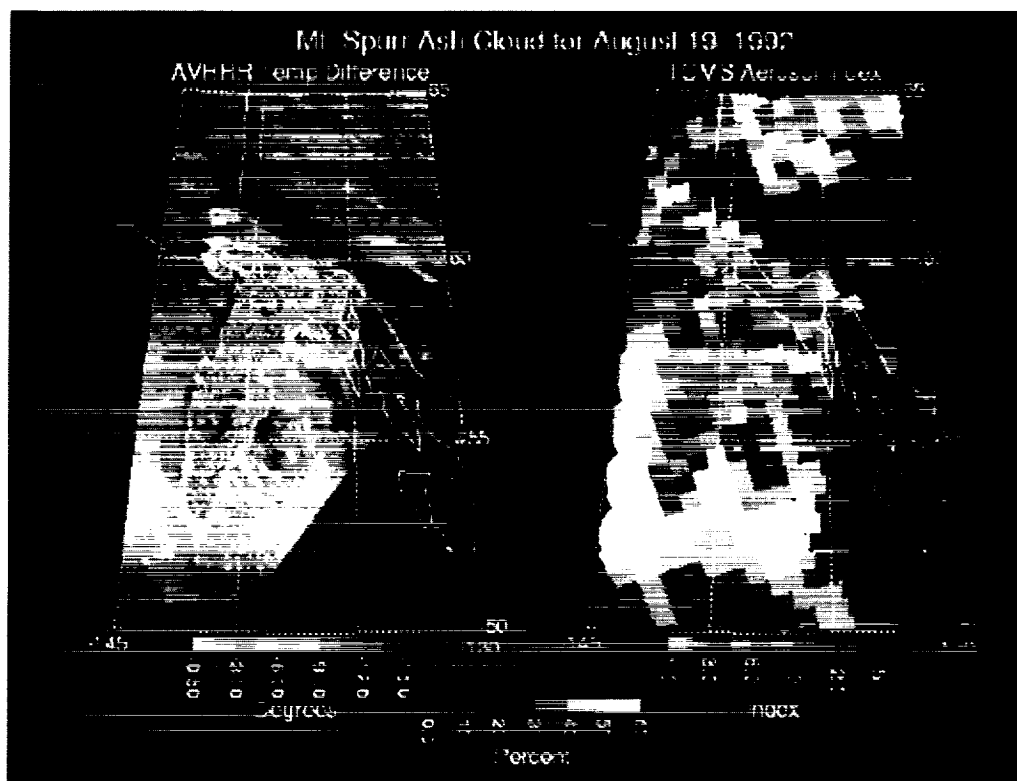


Figure 12. Satellite maps of the August 18, 1992, Crater Peak/Spurr eruption cloud as seen by the NOAA-12 AVHRR instrument and by the NASA's Nimbus-7/TOMS instrument on August 19 at 18:57Z. The AVHRR map (left) shows the brightness temperature difference ($T_4 - T_5$ with $-0.5K$ cutoff) as a color scale. The AVHRR band 1 is used to show the reflectivity of underlying water clouds (grey scale). The Nimbus 7 TOMS map (right) shows the Aerosol Index as a color scale. The TOMS $0.38\mu m$ band is used to measure the UV reflectivity of water clouds and Earth's surface (the same grey scale).

Aerosol and Cloud Distribution in the Indian Ocean Experiment

The Laboratory for Atmospheres participated in the 1999 Indian Ocean Experiment (INDOEX), an international project aimed at determining the proposed regional cooling effect of sulfates and other aerosols over the Indian Ocean. Extremely high aerosol concentrations have been found over the northern Indian Ocean. The majority of these aerosols come from India, but significant amounts are also transported from such areas as Indonesia and Saudi Arabia. The aerosols derive from a complex mixture of urban, biomass, and desert dust sources and have been found to be highly absorbing. In contrast, the southern Indian Ocean is quite clean and represents a typical marine atmosphere.

Members of the cloud and aerosol lidar group used MPL to measure the vertical distribution of aerosols and clouds during INDOEX-99. Measurements were conducted from both the Kaashidhoo Island Observatory (KCO) and from the NOAA ship R/V Ronald H. Brown. KCO is the primary long-term sampling site for the entire INDOEX program, and the MPL was the only lidar system in operation at KCO during the 1999

experiment. The MPL on board the R/V Ronald H. Brown obtained the only continuous lidar data set on a mobile platform, spanning both the southern and northern Indian Ocean. The MPL systems obtained nearly continuous data throughout the experiment and produced the largest lidar data set in all of INDOEX-99.

The initial MPL data analysis is nearly complete. Examples of key data sets include time series of the structure of the aerosol boundary layer (continental outflow layer on top of the marine boundary layer), aerosol optical depth (AOD) of the boundary layer, the lidar ratio, and the identification of elevated cloud layers including thin cirrus (see Figure 13). Selected profiles of aerosol optical properties are also being performed. The results will be presented at the 1999 Fall American Geophysical Union meeting (Welton et al., 1999).

Joint work is also being conducted with other INDOEX-99 participants. The MPL data is being used as part of the satellite comparisons for assessing how well satellite algorithms can determine the AOD. Also, joint work is being conducted with NCAR researchers who have developed a state-of-the-art chemical transport model. Efforts are underway to assimilate the MPL data into the transport model to improve the model's 3-D performance.

The Goddard cloud and aerosol lidar group developed micro-pulse lidars in the early nineties as the first practical technology for full-time unattended lidar measurements. Over twenty instruments are now in use for a variety of international sites and field programs.

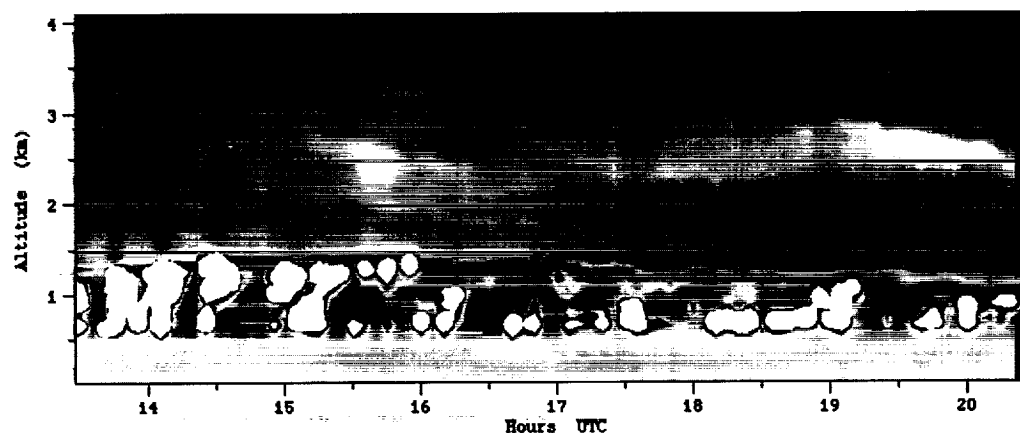


Figure 13. Aerosol and cloud backscatter cross-sections on March 7, 1999. The marine boundary layer extends to just over 1 km and contains scattered clouds (white). The continental outflow aerosol layer is visible on top and extends to just over 3 km.

Welton, E. J., P. J. Flatau, K.J. Voss, H. R. Gordon, K. Markowicz, J. R. Campbell, and J. D. Spinhirne, 1999: Measurements of the vertical distribution of aerosols and clouds during INDOEX 1999 using micro-pulse lidars. AGU Fall Meeting Program.

Angular and Seasonal Variation of Spectral Surface Reflectance Ratios: Implications for the Remote Sensing of Aerosol Over Land

When a satellite views the Earth it "sees" a combination of sunlight reflected from the Earth's surface (soil, vegetation, oceans) and the Earth's atmosphere (gases, particles, clouds). In order to use satellite data to learn about the atmosphere, we have to separate the part of the sunlight that reflects off the atmosphere, from the part that reflects off the surface. Luckily we can achieve this separation by using the different wavelengths of the light received at the satellite. The longer wavelengths of the solar spectrum, called the mid-Infrared (mid-IR), penetrate the atmosphere and return information about the surface properties uncontaminated by the atmosphere. In previous work, we demonstrated how the mid-IR could be used to estimate the surface properties of the visible wavelengths that are contaminated by the atmosphere. Using the mid-IR and visible wavelengths together is the key to the difficult problem of separating the signal.

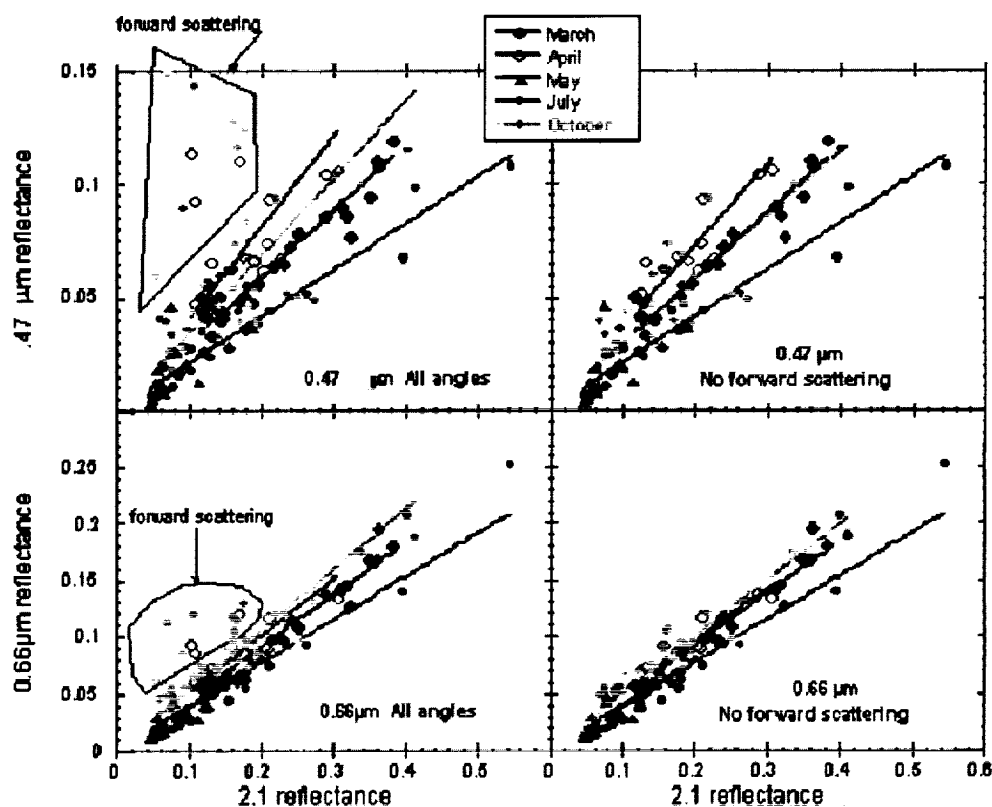


Figure 14. Surface reflectance for $0.47\ \mu\text{m}$ (top) and $0.66\ \mu\text{m}$ (bottom) as a function of $2.1\ \mu\text{m}$ surface reflectance with all flights plotted on the same axes. The targets viewed from the forward scattering direction are indicated and removed from the plots on the right hand side, bringing the April and October flights in closer agreement to the other months and to the spectral relationship established from purely nadir data.

In a recent study, we further explored the relationship between the mid-IR and visible reflectance of the surface that allows us to use mid-IR to estimate the visible. Our pre-

vious work revealed relationships between wavelengths that appeared to hold for average conditions almost everywhere. The instruments used to derive these relationships viewed the Earth's surface by looking only in the downward direction. In our recent work, we collected new data from an instrument that permitted variation with angle so that not all of the views were directly downward. We also broadened the time period to include data from early spring to late autumn.

Our results show an unexpected breakdown of the mid-IR/visible relationship when we point the instrument in the sun's direction if the sun is low in the sky (see Figure 14). This breakdown occurs because at special angles the sunlight reaching a vegetated surface is quickly reflected and never has an opportunity to interact with the pigments and liquid water within the leaves. Previous to these results, we were blind to this breakdown at special viewing angles. We would have introduced significant errors into our procedure for separating the satellite signal into surface and atmospheric components. We also found seasonal variations to the relationship between the mid-IR and visible. We are working now to exploit this information on seasonal variability and to improve our procedures.

Remer, L. A., A. E. Wald, and Y. J. Kaufman, 2000: Angular and seasonal variation of spectral surface reflectance ratios: Implications for the remote sensing of aerosol over land., *IEEE Trans. Geoscience Rem. Sens.*, in review.

Clouds and Precipitation

Approximate Co-Location of Precipitation and Low-Level Zonal Winds in Tropical Monthly Means

In the tropical monthly mean fields, westerly winds occupy the core precipitation region at low levels (the first 2 km above the surface) in both monsoon and non-monsoon seasons. Figure 15 shows an example of this phenomenon. These westerlies contradict our expectation of trade easterlies in the tropics. (This co-location of precipitation and low-level westerlies is only approximate in that there is a longitudinal phase shift between the two fields. This westerly region is flanked by easterlies to its north and south.)

To analyze this gross tropical circulation feature, we combined theoretical arguments with numerical simulation, using the GEOS GCM and its aqua-planet version. The results show that this gross tropical circulation feature is a natural atmospheric response, crucially influenced by the Earth's rotation, to the monthly-mean convective heating in the tropics. Figure 16 demonstrates the analytic solution. These results also provide a physical basis for cross validation of major NASA satellite missions; i.e., TRMM (tropical heating), QuikSCAT (surface wind), and 4DDA. In the tropical monthly mean fields, westerly winds occupy the core precipitation region at low levels (the first 2 km above the surface) in both monsoon and non-monsoon seasons.

Chao, W. C, and B. Chen, 1999: Approximate co-location of precipitation and low-level westerlies in tropical monthly means. Preprints Volume, American Meteorological Society Eighth Conference on Climate Variations, Sept. 13-17, 195-198.

February: 850 hPa U and Xie-Arkin Precip. (1979 - 1993 average)

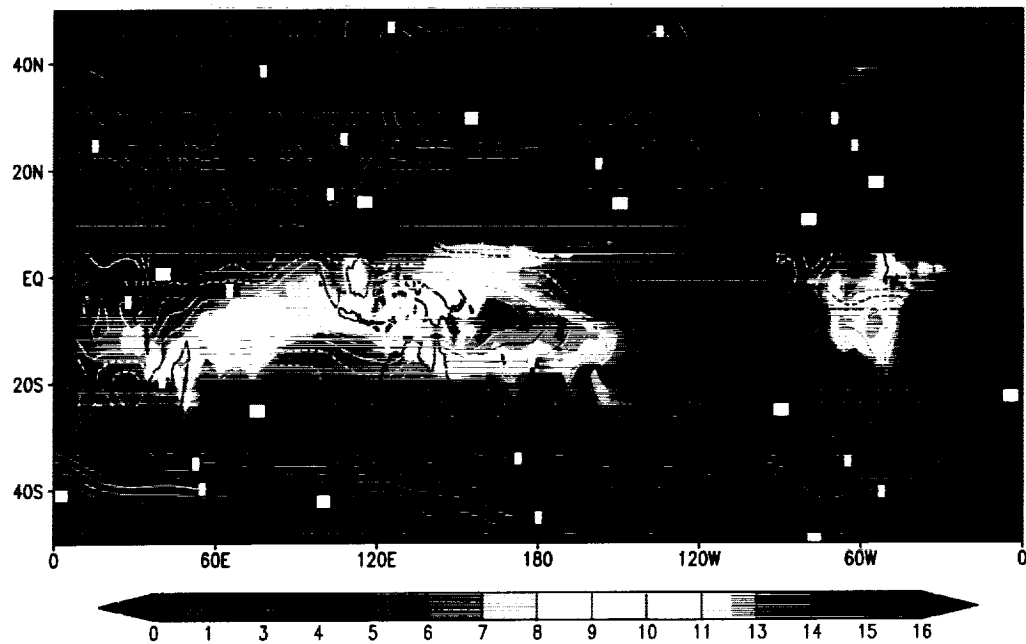


Figure 15. Observed 850 mb zonal wind (in m/s) and precipitation (in mm/day) averaged over four Februarys (1979-1993).

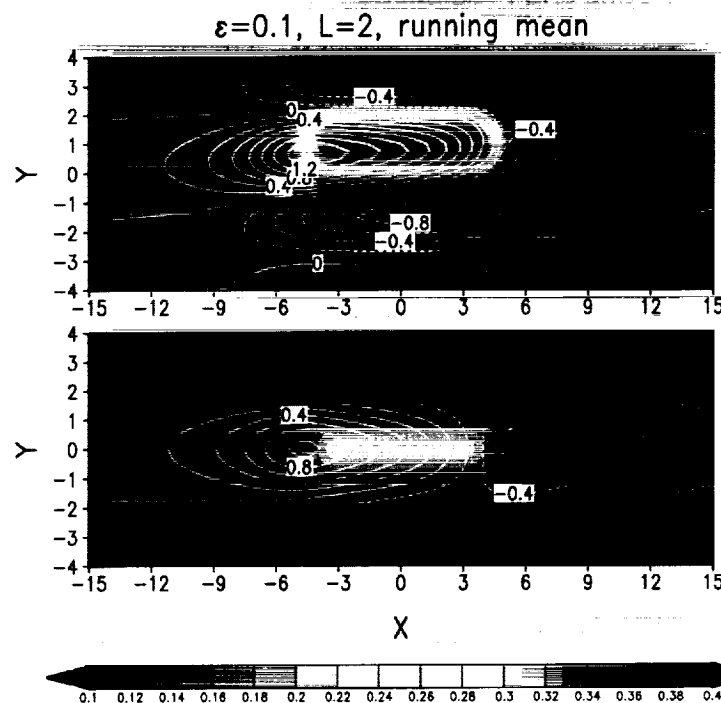


Figure 16. The nondimensional analytic solution of zonal wind response to ITCZ-like convective heating. Unity in length is about 1000 km. The heating region is color shaded and the zonal wind is in contours. The upper (lower) panel is for heating asymmetric (symmetric) with respect to the equator.

ENSO Precipitation Patterns and Indices

Laboratory staff have developed a global precipitation analysis at monthly time resolution for a 20-year (1979-1999) period as part of the international GPCP. We've used this satellite-based data set to conduct three investigations. Specifically, we've studied the ENSO precipitation patterns during the last 20 years, the evolution of the recent 1997-1999 El Niño/La Niña event, and the similarities and differences between this long-term analysis and the superior rainfall estimates from the TRMM.

We deduced monthly precipitation anomalies (from climatology) and developed ENSO precipitation indices (see Figure 17) based on the rainfall anomalies over the central/eastern Pacific Ocean and over the maritime continent. During an El Niño, it is dry over the East Indies and wet in the central to eastern Pacific. The El Niño Index (EI) at this time has a large positive value, capturing this gradient (see for example 1983, '87, '92, and '97). In major El Niños, including the 1997 event, the EI leads the Pacific SST index because of negative (dry) anomalies over the maritime continent occurring earlier than the central Pacific Ocean warming. During a La Niña the opposite conditions hold true, and these conditions are described by the La Niña Index (LI). The ENSO Precipitation Index (ESPI) is simply the normalized difference of EI minus LI.

The EI and LI are often mirror image. Even so, at the height of an El Niño, (e.g., February 1998) the LI indicates a La Niña essentially at the same time as an El Niño (Figure 17). This apparent paradox is due to the presence of both strong positive and negative rainfall anomalies in the central Pacific leading to a rapid switch from El Niño to La Niña. The precipitation indices are good monitors of the strength and position of the Walker circulation, detecting ENSO events up to two months in advance of traditional temperature indices. These indices are being used to monitor ENSO variations in real time.

We're using the precipitation indices to analyze and compare historic ENSOs and study the associated global precipitation patterns. Figure 18 shows the normalized (by variability) El Niño minus La Niña precipitation anomaly map based on the months of high/low values of the ESPI. The globally complete map shows many of the familiar ENSO features in the tropics. The map also shows newly realized coherent middle- and high-latitude patterns, especially in the Southern Hemisphere.

Initial results of comparing TRMM results to the GPCP fields confirm the ENSO anomalies during 1998 (TRMM was launched in November 1997) and indicate that the TRMM estimates are slightly (10%) higher than the routine GPCP analyses.

Bimonthly EI, LI, ESPI

Jan-Feb 1979 to Sep-Oct 1999

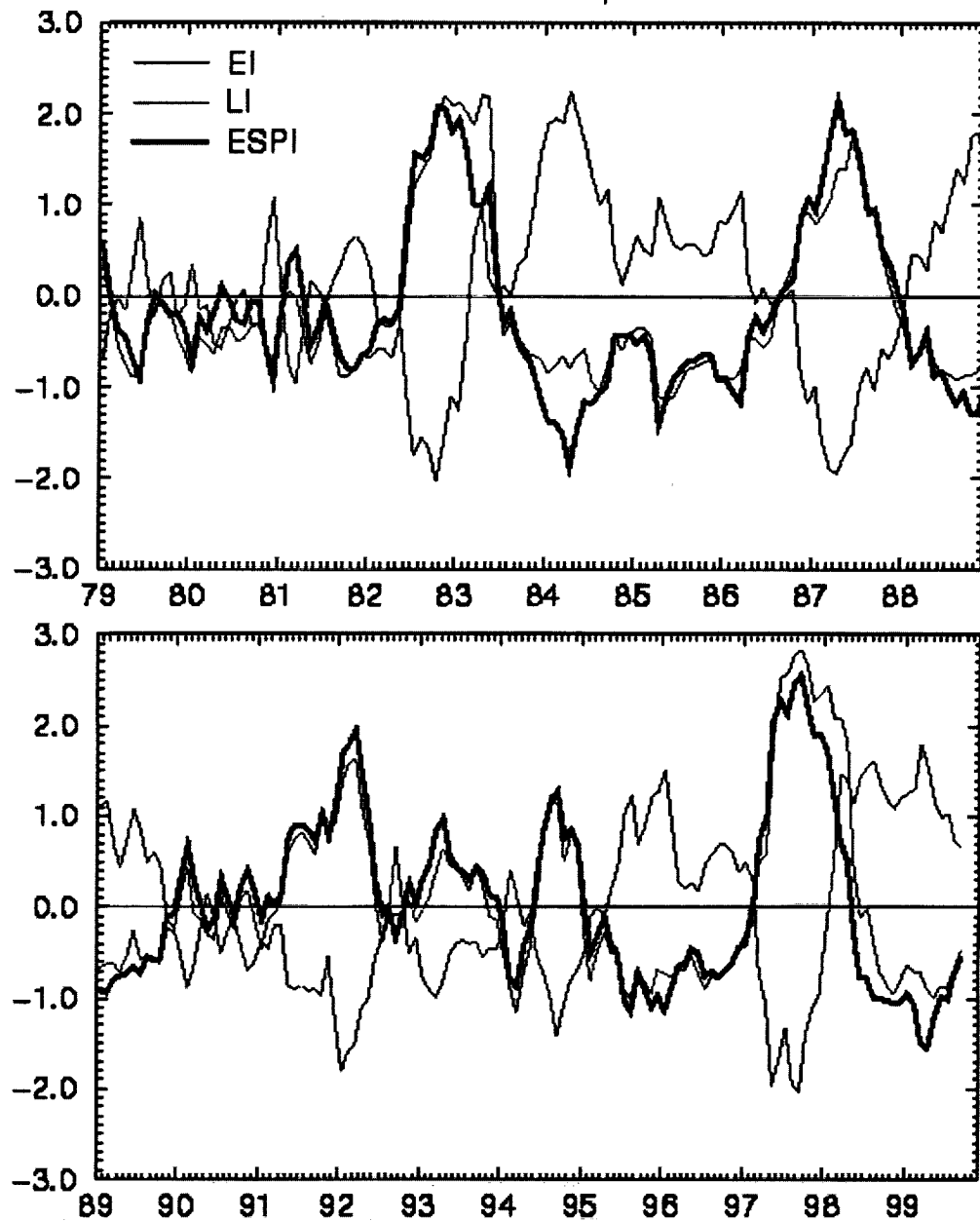


Figure 17. Bimonthly time series of the El Niño Index (EI), the La Niña Index (LI), and the ENSO Precipitation Index (ESPI). Period is January-February 1979 to September-October 1999.

El Niño minus La Niña Composites of Global Normalized Precipitation Anomalies

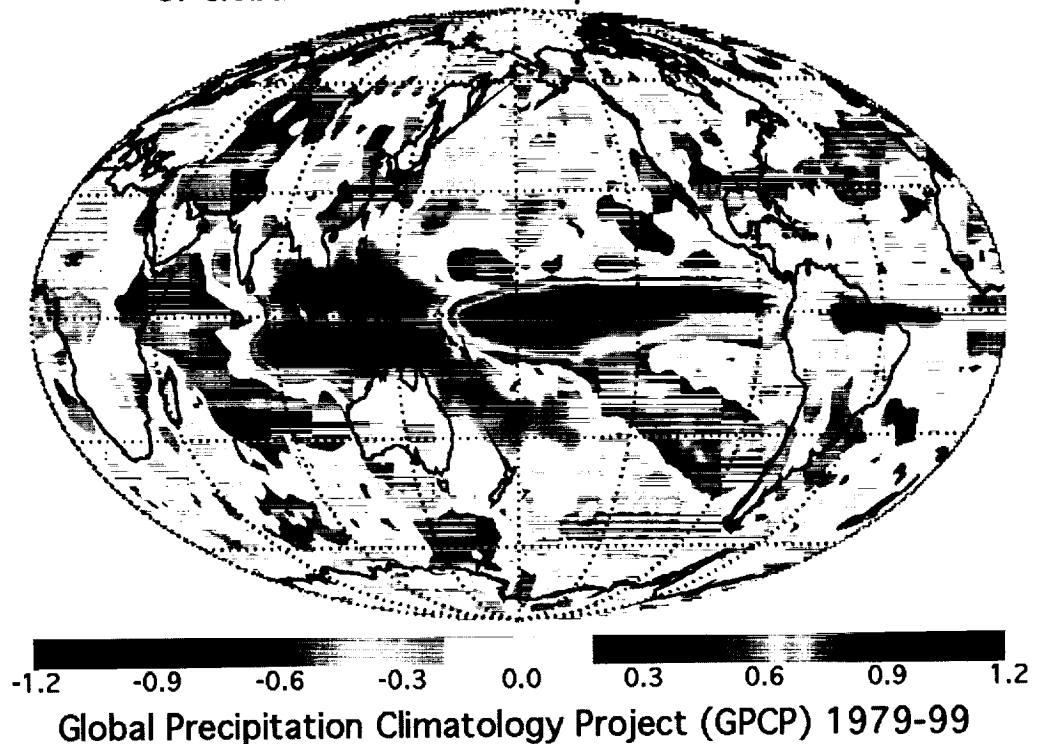


Figure 18. Normalized precipitation departures associated with the ENSO Precipitation Index (ESPI) during the period January 1979 to June 1999. Map shows the difference of normalized precipitation anomalies between an 81 month composite of high (El Niño) ESPI values ($= +0.6$) and an 82 month composite of low (La Niña) ESPI values ($= -0.26$).

Adler, R.F., G.J. Huffman, D.T. Bolvin, S. Curtis, E.J. Nelkin, 1999: Tropical Rainfall Distributions Determined Using TRMM Combined with Other Satellite and Raingauge Information, *J. Appl. Meteor.*, submitted.

Curtis, S. and R. Adler, 2000: ENSO indices based on patterns of satellite derived precipitation. *J. Climate*, in press.

Curtis, S., R. Adler, G. Huffman, E. Nelkin, D. Bolvin, 1999: Global precipitation during the 1997-98 El Niño and Initiation of the 1998-99 La Niña. *JGR-Atmospheres*, submitted.

Climate Variability and Climate Change

Cloud, SST, and Climate Sensitivity Inferred from Japan's GMS Measurements

High-level clouds have a significant impact on the radiation energy budget and, hence, on the climate of the Earth. Laboratory scientists have used data from Japan's GMS to study the relationship between high-level clouds and SST.

Convective cloud systems, which are controlled by large-scale thermal and dynamical conditions, propagate rapidly, within days. At this time scale, changes of SST are small. We used GMS radiances to characterize the relationship between high-level clouds and SST in the tropical western and central Pacific (30S-30N; 130E-170W). In that region, the ocean is warm and deep convection is intensive. We analyzed 20 months of GMS data (January 1998 - August 1999), which comprised the second half of the strong 1997-1998 El Niño. We found that when most of the deep convection moves to regions of high SST, the domain-averaged high-level cloud amount decreases. A $+2^{\circ}\text{C}$ change of SST in cloudy regions results in a relative change of -30% in high-level cloud amount (see Figure 19). This large change in cloud amount is due to clouds moving from cool regions to warm regions, not to the change in SST itself. A reduction of high-level cloud amount in the equatorial region implies a drier upper troposphere in the off-equatorial region. The greenhouse warming of high clouds and water vapor is reduced through increased longwave cooling to space.

Our results are important for understanding the physical processes relating SST, convection, and water vapor in the tropics. They are also important for validating climate simulations using global general circulation models.

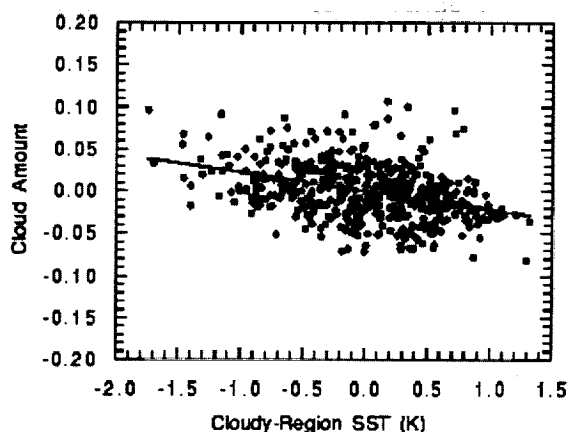


Figure 19. Relation between domain averaged high-level cloud amount and the sea surface temperature in cloudy regions in the period January 1998 - August 1999. Each point represents daily mean cloud amount and SST averaged over the domain 30S-30N and 130E-170W. Domain and monthly mean cloud amount and SST are removed, and only the deviations are shown.

Lindzen, R. S., M.-D. Chou, and A. Hou, 2000: Does the earth have an adaptive infrared iris? *Bull. Amer. Meteor. Soc.*, submitted.

Enhancement of Interdecadal Climate Variability in the Sahel by Vegetation Interaction

For decades, scientists have been trying to understand what caused the paralyzing drought that began in the 1970s, ravaging North Africa and causing the Sahara desert to take over arable Sahel grasslands. Some studies suggested that by using the land for farming and livestock grazing, humans were responsible for bringing about the drought and keeping the land from recovering. New research conducted by a team of Goddard and UCLA scientists shows that although a human hand can't be absolutely ruled out as a factor, the devastating drought may be a completely natural phenomenon, fueled by the land's naturally-changing vegetation cover.

In a paper to appear in *Science*, the Goddard/UCLA team described how vegetation dynamics might play a key role in leading to the interdecadal variation of drought in the Sahel during the 1970s, 80s and early 90s. The team used a biomass model coupled with an atmospheric general circulation model to simulate the growth and decay of vegetation in response to rainfall, sunlight, evapotranspiration and photosynthetic processes. The investigators found that interactive vegetation provides a positive feedback, more than doubling the severity of the long-term Sahelian drought, which was initiated by anomalous sea surface temperatures. This is the first time the effect of vegetation dynamics on long-term climate variability has been demonstrated in a realistic global model (see Figure 20).

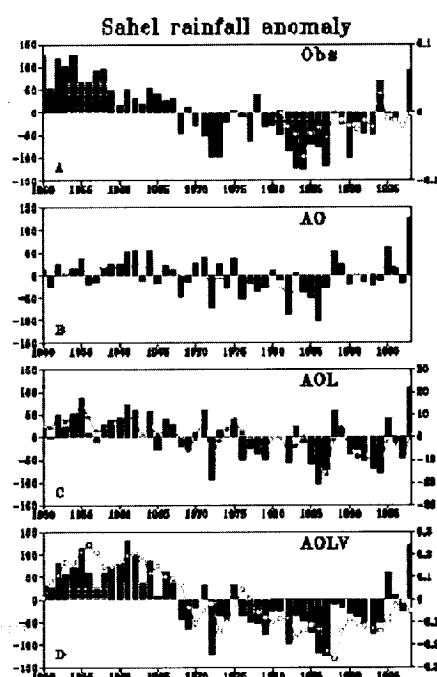


Figure 20. Annual rainfall anomaly in mm-y⁻¹ (vertical bars) over the West African Sahel (13N-20N, 15W-20E) from 1950 to 1998: (A) observations from Hulme (1); (B) model with non-interactive land-surface hydrology (fixed soil moisture) and non-interactive vegetation (SST influence only, AO); smoothed line is a 9-year running mean showing the low-

frequency variation; (C) model with interactive soil moisture and vegetation (AOLV). Also plotted (as connected circles; labeled on the right) are: (A) the Normalized difference Vegetation Index (NDVI) (31); (C) model simulated annual soil moisture anomaly (mm); (D) model simulated leaf area index (LAI) anomaly. All the anomalies are computed relative to the 1950-98 base period except that the NDVI data is relative to 1981.

Zeng, N., D. Neelin, W. Lau, and C. Tucker, 1999: Enhancement of Interdecadal Climate Variability in the Sahel by Vegetation Interaction. *Science*, **286**, 1537-1540.

Modeling

Data Assimilation

Improving Four-Dimensional Global Data Sets and Short-Range Forecasts Using TRMM and SSM/I-Derived Rainfall and Moisture Observations

Laboratory for Atmospheres research has shown that satellite data on rainfall and moisture can significantly enhance global data sets and short-term forecasts in the tropics. Assimilating satellite data improves not only the hydrological cycle but also key climate parameters in analyses produced by the GEOS DAS. Specifically, we investigated the impact on GEOS products of assimilating TRMM Microwave Imager (TMI) and SSM/I-derived rainfall and total precipitable water (TPW) observations.

Figure 21 shows the results of assimilating 6-hour averaged rainfall and TPW in the GEOS analysis for January 1998. We assimilated rainfall and TPW data that others produced. The figure presents the effect of that data on four of the parameters we examined: tropical precipitation, TPW, outgoing longwave radiation (OLR), and outgoing shortwave radiation (OSR). The monthly-mean spatial biases and error standard deviations are substantially reduced.

The apparent exceptions are biases in the tropical-mean precipitation and OLR. The slightly larger precipitation bias suggests that the rainfall assimilation algorithm is more effective in reducing precipitation than in enhancing it. The apparent increase in the OLR bias reflects the virtual elimination of the negative OLR bias associated with errors in precipitation. This change produces a tropical-mean bias dominated by the positive (but reduced) bias in the rain-free regions.

Overall, rainfall assimilation reduces the state-dependent errors in the moisture field to improve the longwave radiation in clear-sky regions. The OSR errors in the GEOS analysis are dominated by errors in clouds. The improved OSR indicates improved cloud patterns.

Our improved analysis also leads to better short-range forecasts in the tropics, as shown in Figure 22. This work demonstrates the potential of using space-based rainfall and TPW observations for improving numerical weather prediction and the quality of assimilated global data sets for climate research.

Hou, A. Y., D. Ledvina, A. da Silva, S. Zhang, J. Joiner, R. Atlas, G. Huffman, and C. Kummerow, 2000: Assimilation of SSM/I-derived surface rainfall and total precipitable water for improving the GEOS analysis for climate studies, *Mon. Wea. Rev.*, **128**, 509-537.

Hou, A. Y., S. Zhang, A. da Silva, W. Olson, 2000: Improving assimilated global datasets using TMI rainfall and columnar moisture observations, *J. Climate*, in press.

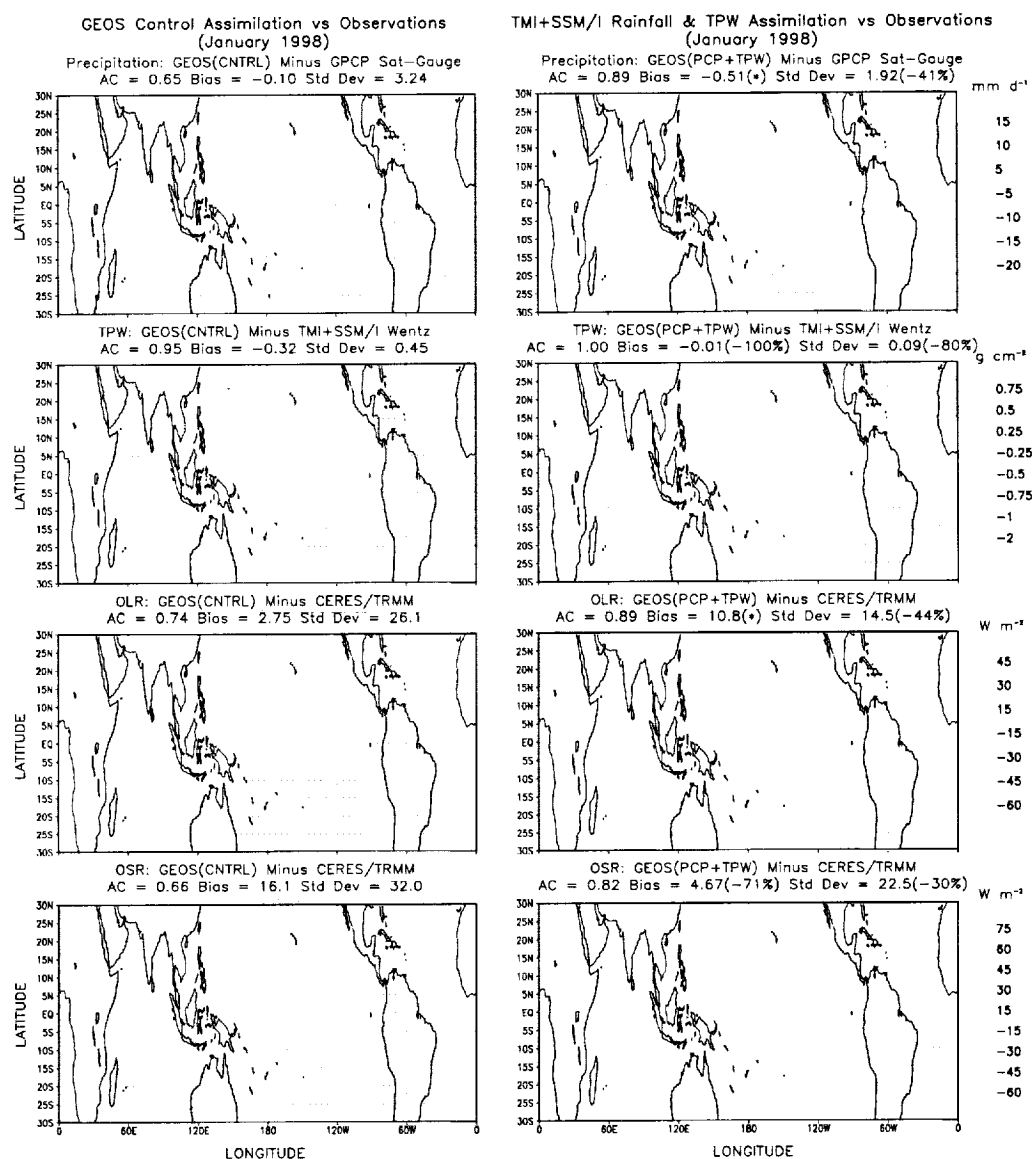


Figure 21. NASA GEOS assimilation results with and without TMI and SSM/I observations for January 1998. Left panels show errors in the monthly-mean tropical precipitation, total precipitable water, outgoing longwave radiation, and outgoing shortwave radiation in the GEOS control assimilation. Right panel shows the impact of assimilating TMI and SSM/I rainfall and TPW observations on these fields. Percentage changes relative to errors in the GEOS control are given in parentheses.

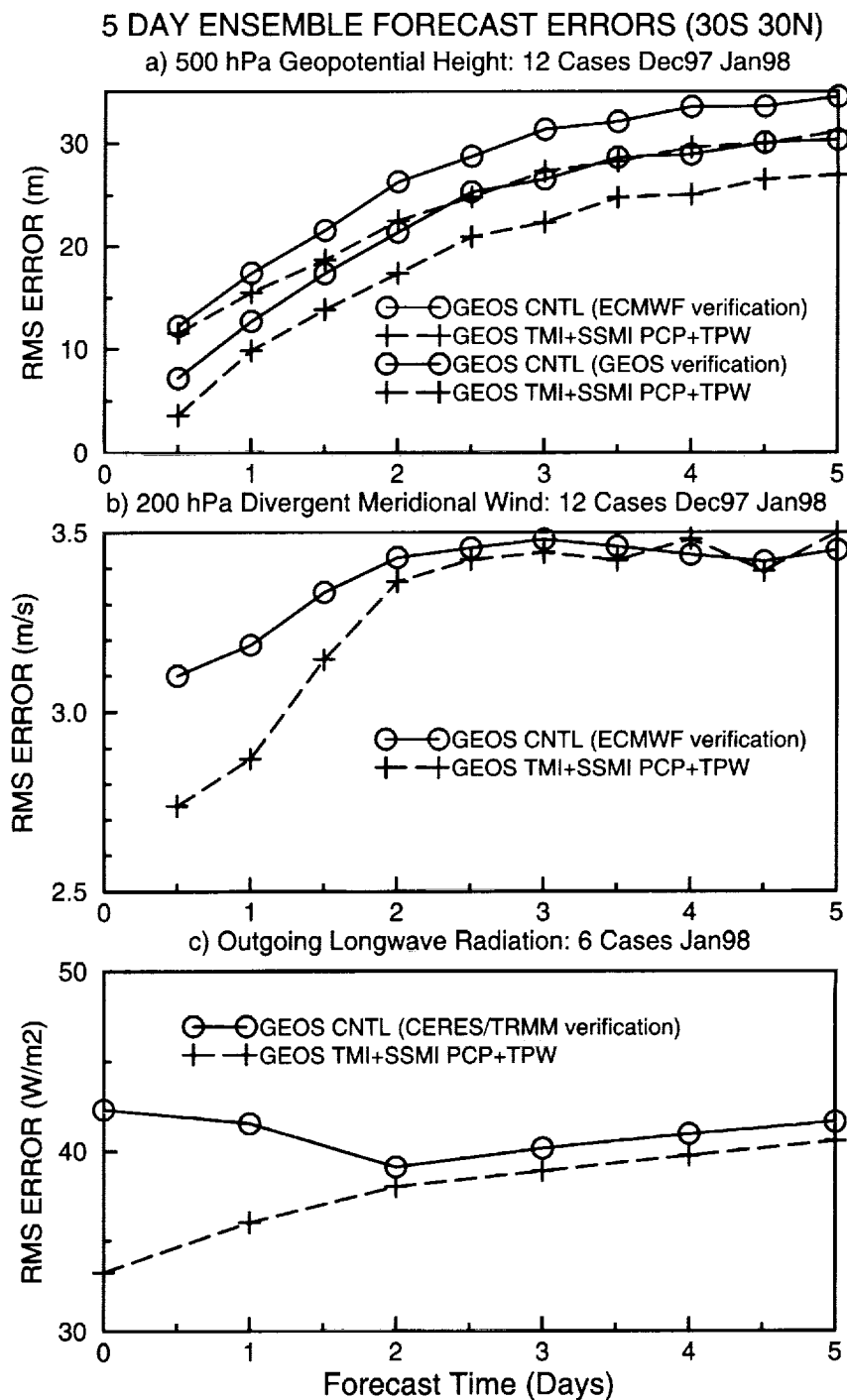


Figure 22. (a) Five-day ensemble forecast rms errors in tropical geopotential height at 500 hPa. Results in green are verified against the ECMWF analysis and results in red are verified against the average of the GEOS control analysis and the TMI and SSM/I rainfall and TPW assimilation. (b) Same as (a) except for the 200 hPa divergent meridional wind verified against the ECMWF analysis. (c) Same as (a) except for the OLR verified against CERES/TRMM observations.

1-D Variational Retrieval of Temperature and Humidity from GPS/MET

The Laboratory for Atmospheres has collaborated with Meteo France and the Jet Propulsion Laboratory in developing a technique for retrieving temperature and humidity simultaneously from Global Positioning Satellite (GPS) data. The technique is a 1-dimension variational (1DVAR) analysis of radio occultation refractivity data from the GPS.

We validated temperatures retrieved from GPS with nearby radiosonde data. Our analysis shows that GPS can accurately measure tropopause temperatures. The GPS data has a vertical resolution similar to radiosonde data. In addition, the GPS has the advantage of observing areas not covered by the existing radiosonde network. The results also show that accurate temperatures can be obtained from GPS data in a cost-effective manner (i.e. analysis can be done on existing workstations or PC's).

The 1DVAR was shown to be superior to the more traditional approach of assuming a humidity profile to retrieve a temperature profile. This so-called direct retrieval lacks the 1DVAR's highly accurate first guess temperature derived from a numerical weather prediction model forecast (see Figure 23).

Occultation: Lat 58.94deg, Lon -65.88deg, 1995 07 03, 12:21UTC, Transmitter 16

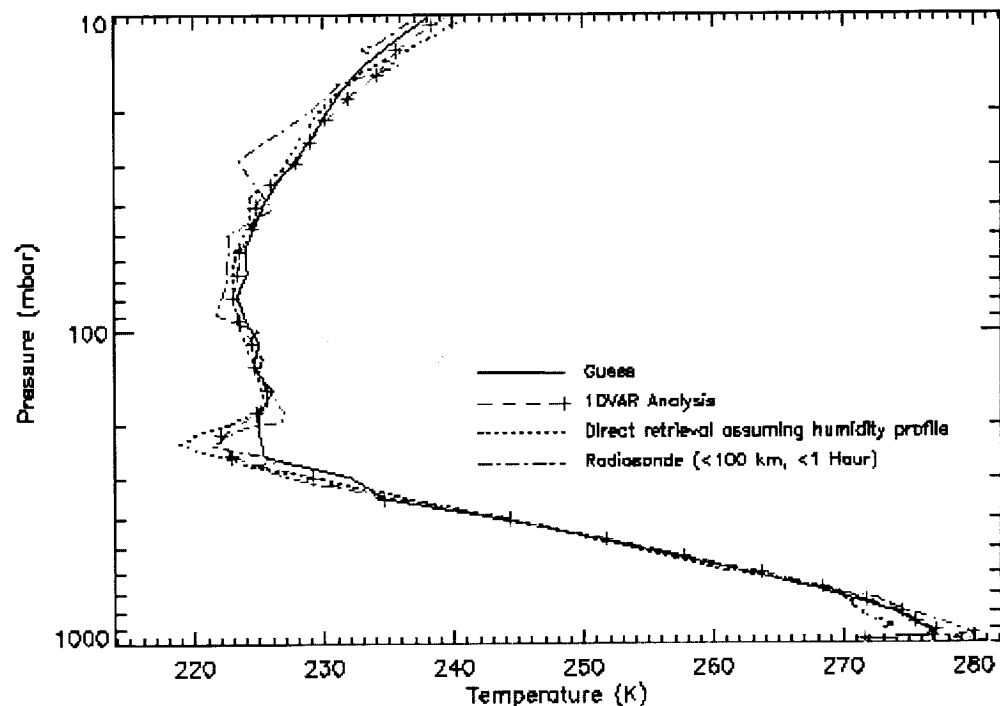


Figure 23. Example of a single GPS temperature retrieval by two methods: 1DVAR and direct retrieval. The model's first guess for the 1DVAR is shown (solid line) as well as a collocated radiosonde. Note that both retrievals capture the cold tropopause seen by the radiosonde. However, the 1DVAR gives an improved result in the lower troposphere.

Poli P., J. Joiner, E. R. Kursinski, and M. Kolodner, 2000: 1DVAR analysis of temperature and humidity using GPS radio occultation data. Preprint of the 10th Conference on Satellite Meteorology and Oceanography, 80th AMS, Long Beach, CA, January 9-14.

Poli P., J. Joiner, and E. R. Kursinski, 2000: 1DVAR analysis of temperature and humidity using GPS radio occultation data. *J. Geophys. Res.*, to be submitted.

ENSO and Weather

We've learned that our ability to predict short-term climate variations depends on whether the ENSO is in a warm or cold phase.

The ENSO, is characterized by major changes in the tropical Pacific SSTs. Widespread warming of the central and eastern tropical Pacific occurs during EL Niño, and widespread cooling occurs during La Niña.

The ENSO phenomenon also has major impacts on the weather over many parts of the globe. The impact of ENSO on middle latitudes is particularly strong in the Pacific/North American region during the winter. To understand the link between weather and the anomalous tropical Pacific SSTs associated with ENSO, we must know how the SSTs impact the larger scale (planetary) waves. Furthermore, we need to understand how the planetary scales affect, and are affected by, weather.

ENSO's effect on the middle latitudes extends beyond the atmosphere's seasonal average response to SSTs. ENSO also modulates the variability and intensity of the planetary waves and weather systems. This influence is manifest, for example, as a change in the sensitivity to initial conditions in forecasts run with a GCM.

In Figure 24, we show the results of 27 seasonal forecasts for the 1983 El Niño and the 1989 La Niña events, using an early version of the GEOS GCM. The forecasts are for January through March (JFM) and are started 15 days earlier in mid-December using SST and sea ice specified from observations. The 27 forecasts for each year differ only in that they are started from slightly different initial conditions.

Figures 24a and 24b show selected stream lines at 200mb for the 27 JFM forecasts. There is a clear difference in the "spread" or noise in the seasonal forecasts for the two years. The 1998 La Niña event displays considerably greater noise or sensitivity to initial conditions in the Pacific region. The greater noise reflects a more frequent occurrence of blocking highs and quasi-stationary low pressure anomalies during 1989 compared with 1983. Figures 24c and 24d show the mean zonal wind and E-vectors associated with the JFM anomalies at 200mb.

How can we explain this difference? During 1983 the jet is extended eastward across the United States, while during the cold event (1989) the jet is retracted. During both years the E-vectors point up the gradient of the jet indicating that the noise is gaining

energy from the jet. During 1989 the E-vectors are, however, much larger. Their size indicates a much greater generation of noise (or uncertainty) for the retracted jet.

Figure 25 shows the variability of the 500mb height field associated with weather systems (time scales less than 10 days). Figures 25a and 25b show the case-to-case variability of the weather variance. The contours represent a particular value of the weather variance plotted for all 27 members. Comparing 1983 to 1989, we see that during the La Niña year the weather systems tended to be diverted to the north over the eastern Pacific.

Consistent with Figure 24b, 1989 also shows more north/south scatter in the position of the Pacific storm track. This pattern suggests considerable uncertainty in the statistics of the storm systems moving onto the west coast of North America. The mean difference in the weather variance between the two years (Figure 25c) highlights the tendency for weather systems to occur further north during the cold event.

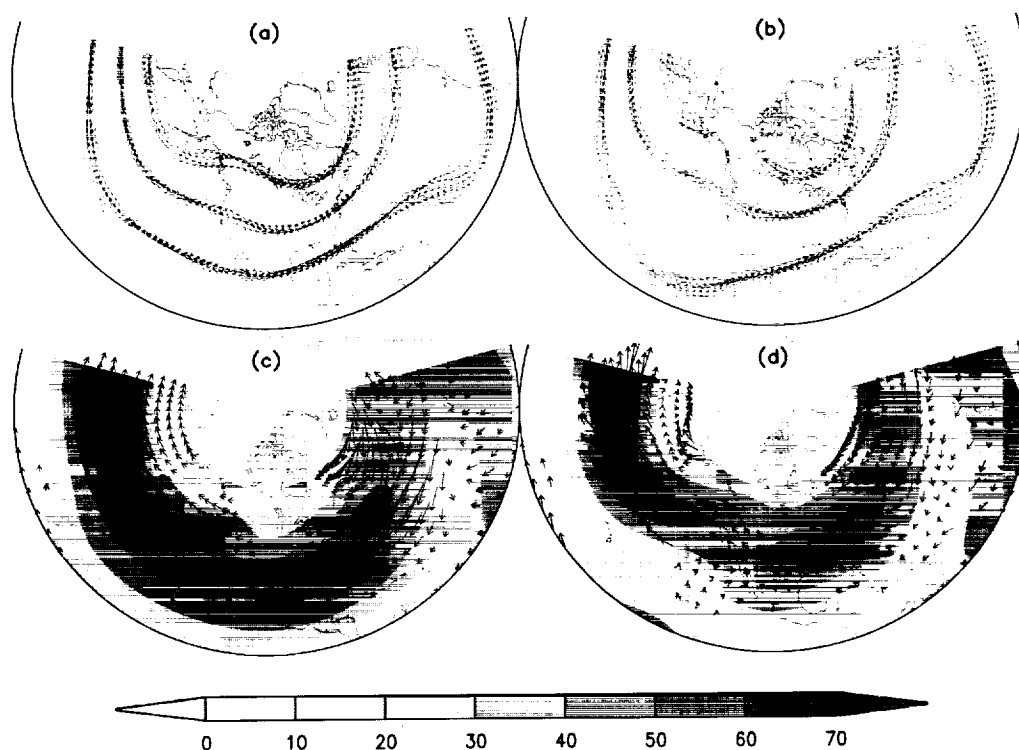


Figure 24: (a) Three different stream lines of the 1983 JFM stream function at 200 mb plotted for all 27 ensemble members. (b) The same as (a) but for 1989. (c) The 200 mb zonal wind (shaded), and the extended E-vectors computed from the intra-ensemble variability of the 1983 JFM mean winds at 200 mb. (d) Same as (c) but for 1989. Units for the u-winds are m/s.

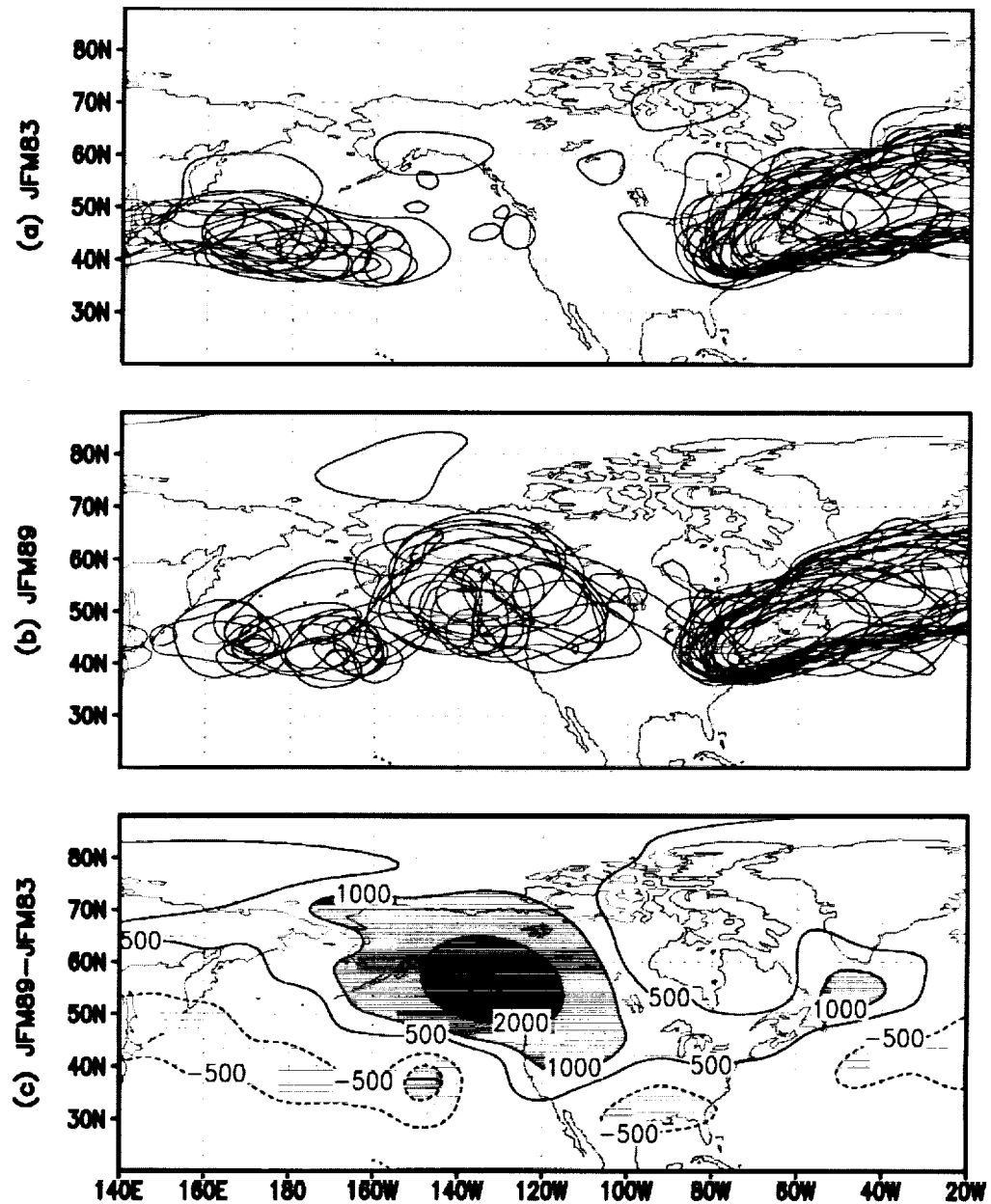


Figure 25: (a) The variance of the 1983 500 mb height field filtered to retain time scales less than 10 days. The different curves represent the 6000 m² contour of the JFM mean weather variance for the 27 cases. (b) The same as (a) but for 1989. (c) The difference (1989-1983) in the mean weather variance. Units are m².

Schubert, S. D., M. J. Suarez, Y. Chang, and G. Branstator, 2000: The impact of ENSO on extratropical low frequency noise in seasonal forecasts. Submitted to *J. Climate*.

Hurricanes

High-Resolution Simulations of Hurricanes

Hurricanes derive much of their energy from the exchanges of heat and moisture near the ocean surface. However, observations of these exchanges in the inner-core region of hurricanes are rare. This lack of data forces modelers to use boundary layer parameterizations that apply largely to lower wind-speed conditions. We need to know how our hurricane simulations are affected by our assumptions regarding the character of surface fluxes and vertical mixing within the boundary layer. We may then understand the limitations of current assumptions and have some direction for future observational studies.

We used a research-quality mesoscale model capable of representing multiple scales simultaneously (from the synoptic to the cloud scale) to simulate the intensification of Hurricane Bob (1991) along the eastern coast of the United States (Figure 26). A simulation using a horizontal grid spacing of 4 km reproduced well the track and intensity of the storm. Simulations using several different parameterizations of atmospheric boundary layer processes reveal a strong sensitivity of the simulated hurricane intensity (Figure 27) and precipitation structure to the specification of the exchanges of heat, moisture, and momentum near the sea surface. The study identifies key aspects of the boundary layer parameterizations that contribute to or inhibit intensification of the hurricane. The study suggests possible improvements to the parameterizations and areas of further research.

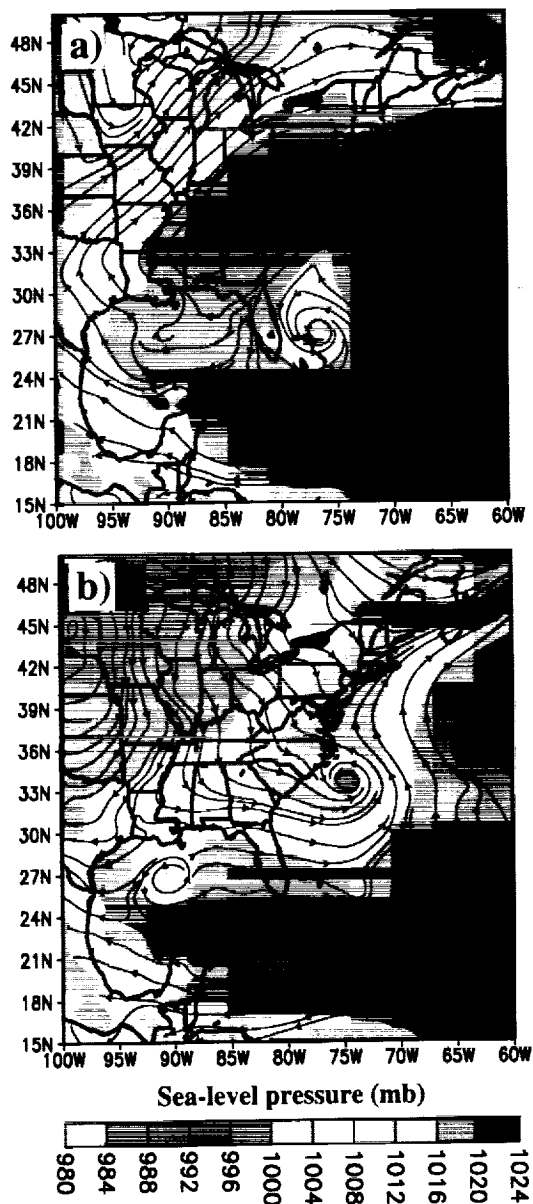


Figure 26. Simulated sea-level pressures (color shading) and 850-mb streamlines for forecasts at 24 and 72 h (initial time at 0000 UTC 16 August 1991) from a simulation using a 36-km grid spacing. Panel (a) shows the initial stages of the hurricane as it forms just north of the Bahamas. Panel (b) shows Hurricane Bob near its maximum intensity just southeast of the North Carolina coast.

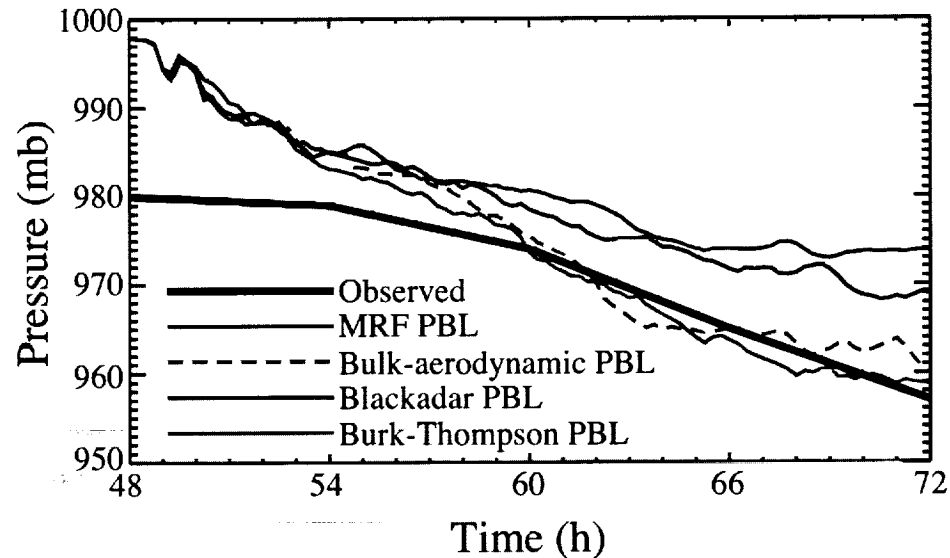


Figure 27. Time series of Hurricane Bob's minimum central pressure, a measure of the storm's intensity, from observations (thick black line) and from simulations (thin lines). The simulated pressures are from 24 h simulations using a 4 km grid and using various boundary layer parameterizations. During the initial 6 h, the simulations show nearly identical pressure falls, but after 6 h, the solutions diverge significantly. The Medium-Range Forecast (MRF) model and Blackadar boundary layer schemes produce the weakest storms while the bulk-aerodynamic and Burk-Thompson boundary layer schemes yield the strongest storms. The differences in intensity are related mainly to differences in the parameterizations of surface moisture and momentum fluxes, but the manner in which vertical mixing in the boundary layer is parameterized also contributes to these differences.

Braun, S. A., and W.-K. Tao, 1999: Sensitivity of high-resolution simulations of Hurricane Bob (1991) to planetary boundary layer parameterizations. (Submitted to *Monthly Weather Review*).

Numerical Simulations of Hurricanes Using a High-Resolution Global Model

Laboratory scientists have demonstrated the feasibility of simulating and forecasting hurricanes and intense tropical cyclones using a novel high-resolution General Circulation Model jointly developed by NASA/GSFC and the NCAR.

This joint NASA/NCAR global model is designed as a unified modeling system that is suitable not only for long-term, low-resolution climate change assessments but also for high-resolution weather predictions and data assimilation. What major advantage do we gain by using a global modeling system for simulation, prediction, and, ultimately, data assimilation of hurricanes? No lateral boundary conditions need to be specified. Therefore, we can better simulate and better understand the interaction between hurricane-scale and synoptic-scale motions.

Based on the highly accurate, finite-volume numerical algorithms developed at GSFC, this model is capable of simulating the complete life cycle of a hurricane from its formation to the ultimate dissipation at the relatively coarse resolution of about 55 km. As shown in Figure 28, the formation of a distinct eye-wall and the spiral rain-bands are simulated with unprecedented details for a global model.

Further development to the modeling system includes coupling to a global data assimilation system. This coupling will enable scientists to assimilate satellite data (e.g., TRMM and QuikSCAT) into the model for theoretical studies as well as for the practical application of predicting the formation, track, and intensity of hurricanes.

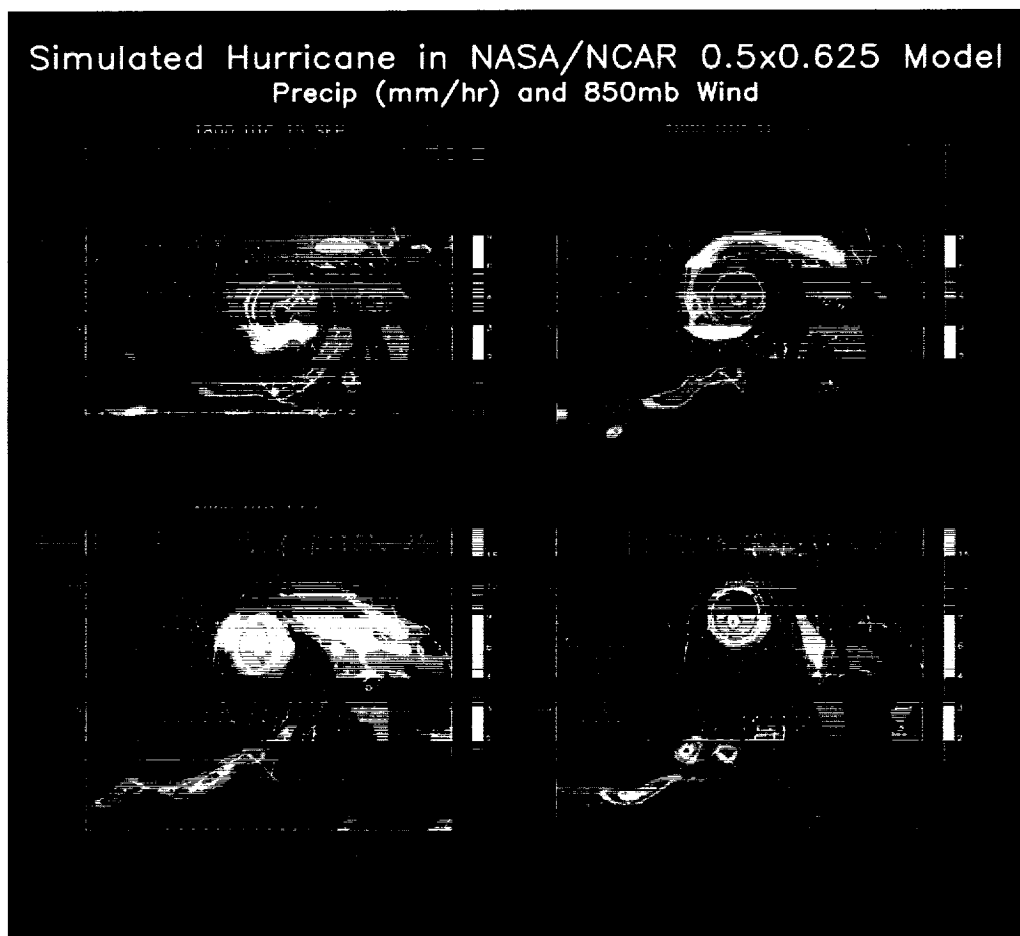


Figure 28. Simulated hurricane generated by the NASA/NCAR model at the 0.5x0.625 degree horizontal resolution (roughly 55 km). Instantaneous precipitation was shaded according to intensity (see color bar). This is one of many examples of intense tropical cyclones simulated in a multiyear run.

Lin, S. J., and R. B. Rood, 1998: A flux form semi-Lagrangian general circulation model with a Lagrangian control-volume vertical coordinate. Rossby-100 Symposium.

Physical Processes

Goddard Cumulus Ensemble (GCE) Model as a Physics Resolving Process Model

The highest science priority identified in the Global Change Research Program (GCRP) is the role of clouds in climate and hydrological systems. Accordingly, the Global Energy and Water Cycle Experiment (GEWEX) formed the GEWEX Cloud System Study (GCSS) specifically to study the effects of clouds. Cloud resolving models (CRMs) were chosen as the primary approach.

Recently, Laboratory scientists used several CRMs to study the tropical water and energy cycles and their role in the climate system. Two CRMs produced different quasi-equilibrium states (warm and humid vs. cold and dry) even though both used similar initial thermodynamic profiles, horizontal wind, and fixed SST. The GCE model showed that the differences in the CRM-simulated quasi-equilibrium state can be attributed to the treatment of atmospheric horizontal wind throughout the integration. The model that had weaker surface wind (caused by the convective mixing) produced a cooler and less humid thermodynamic equilibrium state (see Figure 29). Consequently, the cooler and less humid equilibrium state had smaller latent heat fluxes from the ocean. Current climate models do not account at all for convective momentum transport processes.

We've also used the GCE model to investigate the trigger of moist convection over heterogeneous land surface domains (inhomogeneous distribution of land usage). Simulation results and theoretical applications identified important variables (i.e., patch size of land, horizontal gradient in the heat fluxes from land, the atmospheric background wind, planetary boundary layer height, and thermodynamic properties of the boundary layer). These variables can be used to represent the convection generated by heterogeneous land surfaces in regional- and global-scale atmospheric models.

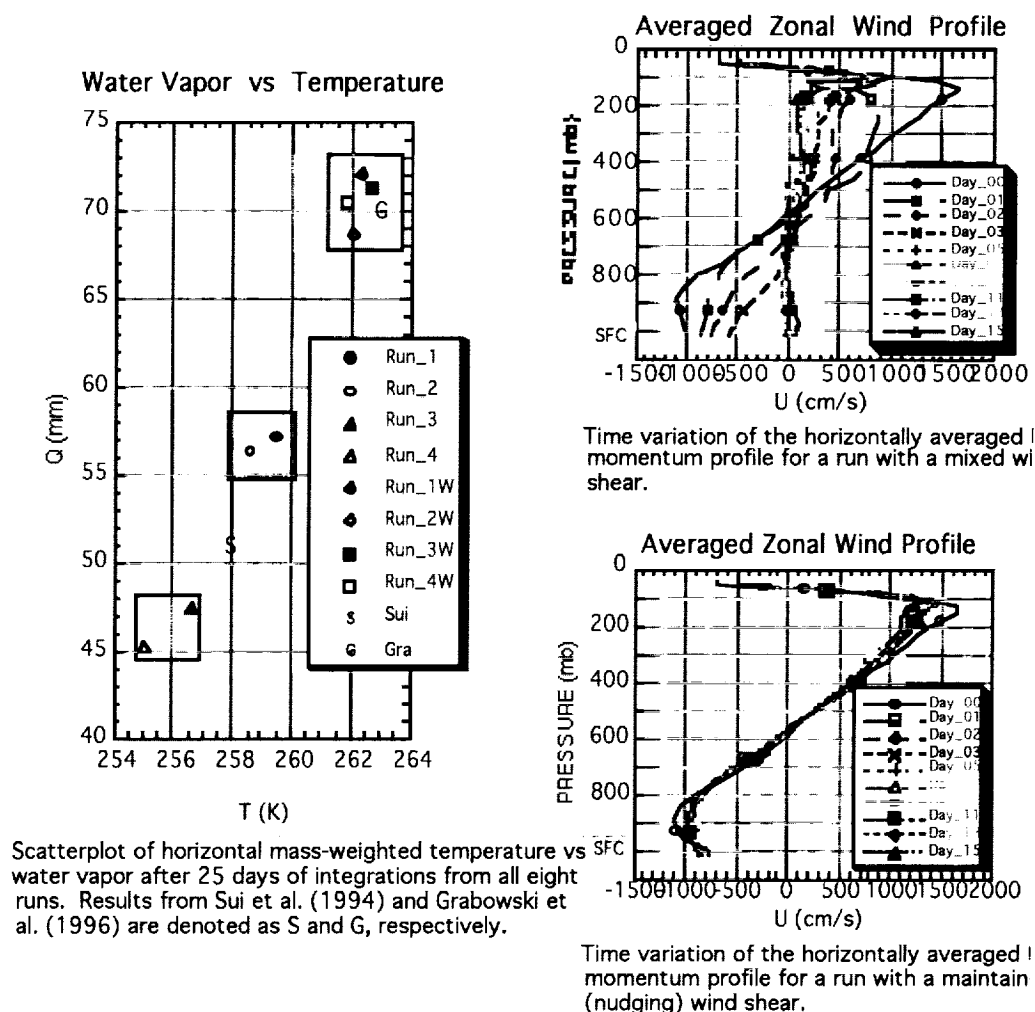


Figure 29. Left Panel: Scatter plot of mass-weighted temperature and water vapor. G and S, respectively, denote warm/humid and cold/dry tropical quasi-equilibrium states. Upper-right and lower-right panels show the model horizontal winds both allowing and not allowing convective momentum transport processes, respectively.

Tao, W.-K., J. Simpson, C.-H. Sui, C.-L. Shie, B. Zhou, K. M. Lau, and, M. Moncrieff, 1999: On equilibrium states simulated by Cloud-Resolving Models. *J. Atmos. Sci.*, **56**, 3128-3139.

Lynn, B. H., W.-K. Tao and F. Abramopoulos, 1999: A parameterization for the triggering of landscape generated moist convection, Part I: Analyses of high resolution model results. *J. Atmos. Sci.*, accepted.

Lynn, B. H., W.-K. Tao and F. Abramopoulos, 1999: A parameterization for the triggering of landscape generated moist convection, Part II: Zero and first order closure. *J. Atmos. Sci.*, accepted.

Planetary Sciences

Galileo Mission Highlights

Laboratory scientists have improved their estimate of the abundance of noble gases on Jupiter. Their new results will enhance our understanding of Jupiter's formation and, by analogy, the formation of giant planets around other stars.

The improved estimate of Jupiter's noble gases arises from ongoing analysis of data from the Galileo Probe Neutral Mass Spectrometer (GPMS) and from post-encounter calibration studies carried out on the Engineering Unit (EU) of the GPMS. Figure 30 summarizes the results. The figure shows the abundances of noble gases and other Jovian elements relative to the major species, H, ratioed to the solar value.

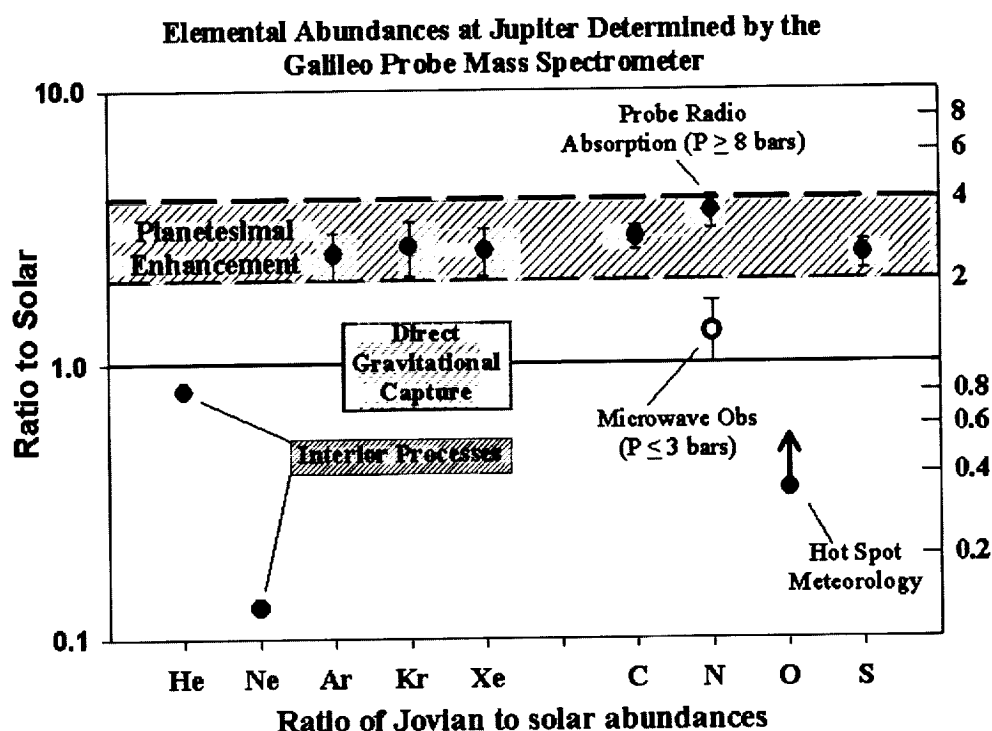


Figure 30. Models of solar nebular evolution suggest that the giant planets formed by accretion of the equivalent of several earth masses of planetesimals early in their development. Direct gravitational capture of gases not trapped in planetesimals could occur only when a large enough mass had converged. Planetesimals formed inward of the Uranus-Neptune region of the solar nebula, such as those that eventually were ejected to the Oort cloud, are expected to be highly depleted of argon and nitrogen since these gases are not efficiently trapped in ices formed at 50 K or higher. In fact, nitrogen depletion in at least one planetesimal was confirmed by observations of Halley's comet in 1986.

The helium and neon ratios shown above would be expected to be solar in the absence of fractionation of these elements into the interior of Jupiter. The surprisingly high values of argon and nitrogen suggest that the planetesimals that contributed to Jupiter

formed at temperatures lower than approximately 30K. Otherwise argon and nitrogen should fall much closer to the "direct gravitational capture" line shown in the figure.

Owen et al. [1999] have postulated several new scenarios for Jupiter's formation based on these observations. These are (a) formation of Jupiter at great distances from the sun (>30 AU) and subsequent inward migration (several recently discovered giant planets are very close to their sun), (b) a colder solar nebula than was previously assumed, and (c) early formation of planetesimals in the interstellar cloud that survived intact in the solar nebula. These possibilities can be explored by further theoretical models and by future missions to comets and the atmospheres of other giant planets.

Mahaffy, P. R., H. B. Niemann, A. Alpert, S. K. Atreya, J. Demick, T. M. Donahue, D. N. Harpold, and T. C. Owen, 1999: Noble gas abundance and isotope ratios in the atmosphere of Jupiter from the Galileo Probe Mass Spectrometer. Submitted to *JGR*.

7. EDUCATION AND PUBLIC OUTREACH

The Laboratory for Atmospheres actively participates in NASA's efforts to serve the education community at all levels and to inform the general public. The Laboratory's educational outreach component is consistent with the Agency's objectives to enhance educator knowledge and preparation, supplement curricula, forge new education partnerships, and support all levels of students. Laboratory activities include continuing and establishing collaborative ventures and cooperative agreements; providing resources for lectures, classes, and seminars at educational institutions; and mentoring or academically-advising all levels of students. The public outreach component seeks to make scientific and technological advances of the Laboratory accessible to the public and increase their understanding of why and how such advances affect their lives. The public outreach activities within the Laboratory are very effective and in some cases, world class. Through these programs, the Laboratory seeks to ensure that the Nation's diversity is reflected and utilized effectively.

Interaction with Howard University and Other Historically Black Colleges and Universities

A part of NASA's mission is to initiate broad-based aerospace research capability by establishing research centers at the nation's Historically Black Colleges and Universities (HBCUs). The Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEa) was established in 1992 at Howard University in Washington, D.C. as a part of this initiative. The Laboratory for Atmospheres started its collaboration with CSTEa in the second five-year period of NASA funding. It is the goal of NASA and mission of CSTEa to establish at Howard a self-supporting, world-class facility for the study of terrestrial and extraterrestrial atmospheres, with special emphasis in training African Americans in aerospace-based sciences and engineering.

The Laboratory continues its research and educational activity with Howard University's CSTEa program. A Technical Review Committee site visit was held to evaluate the CSTEa program, make recommendations for their cooperative agreement with the Laboratory, help them with their strategic planning for future growth, and develop new funding sources for their atmospheres program. The Laboratory works with CSTEa to promote the Howard University Program in Atmospheric Sciences (HUPAS), the only HBCU program that offers the Masters and Ph.D. degrees in atmospheric science. Scientists from our Laboratory contribute to the HUPAS program as lecturers, advisors to graduate and undergraduate students, and adjunct professors teaching a number of their courses. A series of seminars has been given at Howard University as supplemental instruction in their Atmospheric Sciences Program.

The Laboratory also continued its cooperative agreement with Howard University, CSTEa HBCU Academic and Research Consortium (CHARC). CHARC is a partnership that includes the Howard University's CSTEa, five Historically Black Colleges and Universities, and GSFC. This consortium funds students from the five HBCUs to earn a Masters degree from Howard University in the atmospheric sciences while par-

ticipating in NASA research. Laboratory scientists served as mentors for some of the CHARC students during the summer. Additionally, the Goddard Howard Fellowship in Atmospheric Sciences (GoHFAS) was established in 1999 to broaden the mentor, research, and degree opportunities to HBCU students not affiliated with the CHARC agreement. In the first year, approximately five GoHFAS students matriculated within the Laboratory. They conducted important research and interacted with scientists and engineers. Collaborative experimental programs included aerosol satellite validation measurements using ground-based and airborne instruments, and Raman Lidar measurements of ozone using the Howard-Beltsville optical site.

In addition to the Laboratory involvement with CSTEa, the Laboratory interacted with HBCUs in other capacities. The Laboratory hosted research faculty on sabbatical from Howard University's Department of Mathematics and Chemistry throughout the year. A recent HUPAS graduate joined the Laboratory's Atmospheric Chemistry Branch and will pursue his doctoral degree through a Goddard-sponsored research and study fellowship. The Laboratory also participated in a NASA/Morgan State University research exchange to explore potential research collaborations between the two institutions.

Graduate Student Summer Program

The Laboratory for Atmospheres participated in a program administered by the Universities Space Research Association, in collaboration with the Goddard Space Flight Center's Earth Sciences Directorate. This program offered a limited number of graduate student research opportunities each Summer. The program was designed to stimulate interest in interdisciplinary Earth science studies by enabling selected students to pursue specially tailored research projects in conjunction with Goddard scientific mentors. For further information, consult the World Wide Web (<http://phoenix.gvsp.usra.edu/gssp/>).

K-12 Education

Laboratory staff participated in K-12 education in a variety of ways. Laboratory scientists routinely presented lectures and demonstrations to K-12 schools and youth groups to help develop an early interest in science. Many Laboratory scientists have also mentored students in grades K-12. The Eleanor Roosevelt High School Science and Technology Internship Program enabled high school students to perform research on mesoscale atmospheric processes under the mentorship of Laboratory scientists. This program exemplifies a unique three-way partnership between the Laboratory, its contractors, and Eleanor Roosevelt High School. Members of the Laboratory served as judges for local science fairs and made presentations at High School Career Days to foster interest in NASA-related research. Additionally, Laboratory scientists continued to mentor K-12 students through the Summer High School Apprenticeship Research Program (SHARP). One Laboratory scientist was awarded Director's Discretionary Funding for FY2000 for outreach related to Girl Scouts of Maryland and Earth Science education.

In the areas of curriculum development and educator training, the Laboratory played a significant role in 1999. Several Laboratory scientists served on panels for local school districts (e.g. Montgomery County) to decide on high school re-districting and new curricula. As a result, Earth Science material has been or will be included as part of an enhanced science program at several area schools.

Key Laboratory scientists were also instrumental in collaborating with the GSFC Education Office to host a Meteorology conference for K-12 educators in Maryland, New Jersey, and Pennsylvania. This conference provided background information and curriculum material on Goddard missions related to weather and climate and how to effectively integrate them into classroom discussion. Also, Laboratory scientists conducted workshops on various weather and climate-related topics for visiting K-12 educators in summer programs like Students United with NASA Becoming Enthusiastic About Math and Science (SUNBEAMS) and NASA Educational Workshop for Secondary Math, Science, and Technology Teachers (NEWMASST). A Laboratory scientist was also the keynote speaker at the 1999 Baltimore City School Title I Educators' Workshop. Additionally, the same scientist continues to serve as a Host Researcher for the JASON Foundation for Education's JASON XI expedition "Going to Extremes". The JASON expeditions reach thousands of students and teachers around the world with interactive learning experiences.

University Education

At the university level, Laboratory scientists have taught undergraduate and graduate courses at universities; given seminars and lectures; participated in mentorships for teachers and students under a variety of GSFC programs; and advised degree-seeking students. Four Laboratory scientists supervised undergraduate students and twenty-two supervised graduate students. Twenty-two Laboratory scientists have official affiliations (i.e. adjunct or visiting professor) with a university and fourteen regularly teach university-level courses.

Our scientists are involved as teachers in a variety of other settings. In a venture with other Goddard Laboratories, our scientists participated in delivering an MIT course for credit on the subject of Techniques in Remote Sensing. This course for MIT students took place during the winter semester break 1999-2000. The course was an Independent Activity Period course (IAP) during which students spent a week at Goddard and a week at MIT. The Laboratory presented lectures for 1 1/2 days during this seminar series. One Laboratory scientist taught a two-week course at Federal University in Rio de Janeiro, Brazil on global warming. He also spent a one-month sabbatical at Scripps Institute of Oceanography interacting with faculty and students.

Laboratory scientists mentored five undergraduate students and nine graduate students during the summer of 1999 through various programs. Additionally, the Code 910/970 Summer Institute on Atmospheric and Hydrospheric Science brought about fifteen undergraduate students to Goddard for two months of intensive research. Some of the

students return to the Laboratory to work on other programs, and some are mentored by Laboratory scientists for their thesis work at their home institutions.

Monsoon 2 CD-ROM and Other Educational Tools

The Monsoon is an interactive multimedia application on CD-ROM created to stimulate students and faculty in grades 9-12 to investigate and understand monsoon and data assimilation processes. In 1999, the CD-ROM passed the Earth Science Education Product review which certifies the material for distribution to the education community. The CD-ROM contains three primary elements: the Monsoon Presentation, the Data Visualizer, and the Teacher's Guide.

The Data Visualizer gives graphical answers to questions about temperature, precipitation, and wind for six cities over the period 1980 to 1995. There are 12,000 graphs embedded in the CD-ROM, which may be accessed by clicking on one interface screen. Teachers and students can do comparison studies using both assimilated and station data products. Examples for using the Visualizer in student research projects are included in the Teacher's Guide.

The Teacher's Guide and Student Activity book are available on the CD-ROM and in print. They include curriculum materials that focus on climate variation and development of data analysis skills. The books provide a performance-based format that aligns with new education standards. In addition to the monsoon resources already on the CD-ROM, this guide includes temperature data captured every 5-10 minutes for a few weeks of the winter of 1998-1999. The guide also includes global data extracted from the Interdisciplinary Data collection at the Goddard Space Flight Center. Teachers and students can also select from a variety of hands-on activities, classroom demonstrations, three short-term research exercises, and six long-term investigation projects. A variety of resources are offered, including connections to Global Learning and Observations to Benefit the Environment (GLOBE) program activities, and guidance on writing lab reports and grading student research. Selections from the National Research Council's National Science Education Standards (NSES) have been included to assist teachers in adopting the inquiry-driven learning methodology and style that is supported by the Monsoon CD-ROM Teacher's Guide and Data Visualizer.

An additional file contains long-term, monthly, temperature and precipitation data that encourage the user to explore further. Included are data sets for Bombay, Calcutta, London, Los Angeles, Seoul, and Washington, D.C. Further information on the CD-ROM may be obtained from World Wide Web (http://dao.gsfc.nasa.gov/monsoon_cd/).

In addition to the Asian-Monsoon CD-ROM, Laboratory groups also submitted various lithographs, fact sheets, and posters to the Earth Science Enterprise Product review on subject matter related to clouds, El Niño/La Niña, global warming, aerosols, and ozone. A Laboratory scientist received Director's Discretionary Funds to develop mini-education supplements for use by the weathercasters and educators to expose students to

science related to the TRMM. The supplements were distributed to educators and broadcasters and are currently available on-line at the TRMM Web site (<http://trmm.gsfc.nasa.gov>).

Public Outreach

Informing the public of how their tax dollar investments are working for them within the Laboratory is a critical subset of the Center and Agency public outreach mission. Laboratory scientists, working with other laboratories at Goddard and outside institutions, have passed their knowledge and interest in Earth and space science to the general public via public information and education programs.

The TRMM project continued its comprehensive Education/Outreach program in which Laboratory personnel were funded by Director's Discretionary Fund (DDF) resources to promote TRMM science to the public. Seventy on-air weathercasters around the country were served by this effort in 1999. TRMM scientists in the Laboratory regularly appeared on major media outlets (Earth and Sky Radio, CBS, NBC, ABC, and CNN) this year in support of the mission. In addition, Laboratory personnel have spoken at and conducted several outreach workshops in support of TRMM.

In addition to TRMM, Laboratory science stories routinely penetrated major media outlets. The Goddard Public Affairs Office estimates that 50 million viewers tuned in to Laboratory-related science news in 1999. The Laboratory's scientists, images, and animations have appeared in the media, including TV segments with ABC's Peter Jennings and NBC's Tom Brokaw, and top billing of Goddard and NOAA images of hurricanes in *Time*, *Life*, and the covers of *Popular Science*, *Newsweek*, *Der Spiegel*, *National Geographic* and *The Weekly Reader*. Four Laboratory scientists were featured in popular radio programs for public education reaching a combined audience of more than 2 million listeners. They discussed subject matter related to ozone, global warming, and clouds.

The Laboratory's presence in the media will likely expand due to new initiatives established in 1999. A collaboration with the Discovery Channel was initiated with Total Ozone Mapping Spectrometer Camera (TOMS-CAM) to raise awareness about atmospheric ozone issues. Various projects are in development to release TRMM, TOMS, and AVHRR products to the public through The Weather Channel. Two groups within the Laboratory were awarded DDF resources to produce a documentary on ozone and to develop a presentation for popular weather broadcasters, respectively.

Laboratory efforts were not limited to formal outreach outlets (e.g. media). Several informal public outreach venues were utilized. Laboratory staff created a permanent display on the three-dimensional temperature structure of the Earth for the GSFC Visitor Center. The TRMM Office provided a booth for visiting teachers. Laboratory scientists forwarded answers to science and engineering questions to The Mad Scientist Network, a group based at Washington University in St. Louis that answers questions submitted to them by students all over the world. Laboratory scientists contributed to

Goddard Scientific Visualization Studio efforts to collaborate with the Smithsonian Institution, the American Museum of Natural History (NYC), Disney World EPCOT, and the White House in communicating scientific discoveries to the public.

The Laboratory has also received its share of awards in the area of public outreach in 1999. The Terra outreach effort received the Goddard Annual Award for Outreach. The group also was recognized by Popular Science magazine for its award-winning Web site: NASA's Earth Observatory.

GOES Server

A Web server continues to provide recent GOES images on-line, including full-resolution sectors for all of the United States for the last two days. In addition, there are extensive scrapbooks of digital movies and pictures of important weather events observed by the GOES-8 and GOES-9 satellites since they were launched in 1994 and 1995, respectively.

Terra Outreach Synopsis

Under the direction of Yoram Kaufman (Code 913), Claire Parkinson (Code 971), and David Herring (Code 913), a coordinated effort is underway to foster greater cooperation and synergy among various outreach groups within the EOS community. As such, each of the activities described below receives contributions from various persons strategically located in different organizations and/or codes within the community.

The Terra Project Science Office has written and printed thousands of copies of a Terra mission overview brochure (hardcopies available from Charlotte Griner). The layout and design of the brochure, as well as funding for its printing, came from Code 900. Additionally, this brochure, as well as many more images, animations, and information, is available on the Terra Web site (<http://terra.nasa.gov>), which is also maintained by the Terra Project. An EOS Aqua Overview Brochure is being developed by the Aqua Project Scientist and Outreach Scientist.

The Terra and Aqua project teams created NASA's Earth Observatory Web site (<http://earthobservatory.nasa.gov>). This Web environment is the NASA Web portal where the general public goes to learn about the Earth. It showcases new images and science results from EOS missions. The focus in its first year of operation was Sea-viewing Wide Field-of-View Sensor (SeaWiFS), TRMM, Landsat-7, SeaWinds, and Terra. All resources produced for the Earth Observatory are freely available for use by the EOS community, museums, educators, public media, regional "stakeholders," environmental awareness groups, and interested members of the general public. (While leadership for this site resides in Code 913, significant contributions to its development are coming from Codes 900, 902, 912, 921, 922, 923, 935, 971, and 3200 at the Jet Propulsion Laboratory (JPL); as well as the American Museum of Natural History and East Carolina University.)

As a pathfinder for the Earth Observatory, the Terra Outreach Team continued to maintain the Global Fire Monitoring Web site, under the direction of Drs. Chris Justice (U. of Virginia) and Yoram Kaufman. The URL is http://modarch.gsfc.nasa.gov/fire_atlas. (Significant contributions toward construction of this site came from Dr. Justice's team at UVa, as well as Codes 902, 912, 913, and 922.)

To provide overarching guidance and review for the Terra outreach activities, as well as to flag mature new science results ready for public release, an Executive Committee for Science Outreach (ECSO) continues to operate. This committee is chaired by Dr. V. Ramanathan, of the Scripps Institute's Center for Clouds, Chemistry, and Climatology. The purpose of this committee is to "harvest" new Terra science results that are ready for public release, as well as to help temper the presentation of new results with respect to socio-political implications they may have.

Finally, to meet the public media's (primarily TV, newspapers, and our Earth Observatory Web site) requirements for quick access to satellite imagery relevant to significant, newsworthy Earth events (e.g., severe storms, floods, El Niño, volcanic eruptions, wildfires), the Terra Project formed a Rapid Response Network, headed by David Herring (Code 913), Asst. Terra Project Scientist. After launch, this network will enable us to access and produce remote sensing imagery over targets of interest within a matter of hours to days after acquisition.

NASA/NOAA: Earth Science Electronic Theater 2000

The NASA/NOAA Earth Science Electronic Theater (Etheater) uses interactive computer driven displays at near "IMAX" size to give a powerful tool for promoting Earth science. Scientists from the various Earth science disciplines work directly with the Visualization and Analysis Laboratory (VAL) visualizers to develop scientifically accurate visualizations. The Electronic Theater takes on new dimensions each time another scientist speaks to imagery designed and assembled in support of their area of expertise. Etheater visualizations are rendered at High Definition TV (HDTV) quality, the highest resolution possible, and thus can be immediately used in a host of other applications (i.e. National Television Standards Committee (NTSC) TV, QuickTime movies, Web graphics, etc.). QuickTime versions of each Etheater visualization, will be added to the e-theater Web page (<http://Etheater.gsfc.nasa.gov>) along with an explanation of the scientific significance and the origin of the data.

Using advanced computer technology and a very large, panoramic projection screen, the e-theater allows the presenter to interactively manipulate imagery and data animations. The impressive scale achieved by the wide e-theater display contributes to the unique audience impact. Furthermore, these unique capabilities allow for spontaneous speaker/audience interactions.

Visualizations produced by the NASA Goddard VAL/912, as well as other Goddard and NASA groups using NASA, NOAA, ESA, and NASDA Earth science datasets contin-

ue to be shown around the world using new display technologies. The Electronic Theater has been presented at universities, high schools, museums, and Government laboratories to scientists and the general public. Most recently, the Etheater traveled to South Africa in support of the Safari 2000 Terra ground truth experiment.

We continue to demonstrate methods for visualizing, interpreting, comparing, organizing and analyzing immense HyperImage remote sensing data sets and three-dimensional numerical model results. We call the data from many new Earth sensing satellites: HyperImage data sets, because they have such high resolution in the spectral, temporal, and spatial domains. The traditional numerical spreadsheet paradigm has been extended to develop a scientific visualization approach for processing HyperImage data sets and 3-D model results interactively. The advantages of extending the powerful spreadsheet style of computation to multiple sets of images and organizing image processing were demonstrated using the Distributed Image SpreadSheet (DISS). The DISS is being used as a high performance testbed application for the Next Generation Internet (NGI).

HDTV: Video Server: "Turn Key" HDTV

The introduction of commercial HDTV technology signals a profound paradigm shift in the ability to scientists to communicate scientific information to other scientists, managers and the general public. The quality improvement over standard NTSC television is so great that it must be seen to be appreciated. The US sponsored HDTV digital video standard allows the utilization of extremely low-cost standard computer technology for the distribution and display of HDTV material. This makes it possible to avoid the purchase of extraordinarily expensive proprietary HDTV equipment. The VAL has had considerable experience over the last several years in making ultra-high (HDTV) resolution scientific visualizations for the Earth Science Electronic Theater. This puts the VAL in a unique position to capitalize on the conversion from NTSC to HDTV. The VAL is developing short HDTV pieces featuring different science concepts.

The VAL is putting these clips on a computer based HDTV video server. This enables us to project finished, high definition presentations with affordable, lightweight equipment. Using this new technology, scientists can easily give polished, portable, wide screen HDTV presentations. This "turn-key capability also enables NASA to use the HDTV quality at NASA HQ, for museums, and the broadcast media. It is worth noting that HDTV is the new TV broadcast standard. TV networks will phase out NTSC standards within the next 6 years.

Museum Support

VAL actively works with several museums in creating new, innovative Earth Science displays. A short list of some of these museums include the Smithsonian National Museum of Natural History (NMNH), the Smithsonian Air & Space Museum, the American Museum of Natural History (AMNH) in NY, the Virginia Science Center,

and the Houston Museum of Natural History. In conjunction with large museums, we are developing science presentations that will be made accessible and available to smaller museums.

One successful museum activity is the Earth Today exhibit. The "Earth Today" exhibit evolved from an earlier Smithsonian exhibit, the HoloGlobe exhibit. The Earth Today is a permanent exhibit in the Smithsonian National Air & Space Museum. It contains all of the original information contained in the HoloGlobe exhibit, but has expanded the focus to include near-real-time data displays. These near-real-time data presently include global cloud cover, global water vapor, sea surface temperature, sea surface temperature anomalies, biosphere, and earthquakes. Earth Today won the virtual exhibition category of the Smithsonian Exhibition Awards Program in 1999. VAL personnel were actively involved in all phases of the development of this exhibit. VAL personnel continue to actively promote advancements in this exhibit. These refinements include: improvements in the computer coding, the inclusion of new and/or higher resolution data sets, (such as products from TRMM, TOMS, Terra and, when available, Aqua), and establishing a version of Earth Today that will run on many mid-level PC's and also a version that will run on the Web.

Another Museum effort is Global Links. Global Links is an exhibition in the planning phase at the Smithsonian National Museum of Natural History (NMNH). This exhibit will feature the four main earth science spheres, atmosphere, biosphere, hydrosphere and geosphere. The exhibit will focus on these different systems and explain what we know about the interdependency and delicate balance between these systems. VAL staff worked closely with the museum and NASA scientists to develop the initial concepts used in this exhibit. The VAL personnel continue to work with the museum in the refinement of those concepts. The Global Links exhibit provides the perfect opportunity to develop strong content material to explain Earth Science concepts.

Global Learning and Observations to Benefit the Environment (GLOBE)

The Laboratory continues to contribute to the Goddard Scientific Visualization Studio effort in support of the GLOBE Project, jointly with the Goddard Scientific Applications and Visualization Branch. GLOBE is a White House program led by Vice President Al Gore as a worldwide science and education program coordinating the work of students, teachers, and scientists to monitor the global environment.

NASA/NBC-4 (WRC-TV) ESIP-3 Cooperative Agreement

Laboratory scientists are continuing to participate in a Cooperative Agreement Notice (CAN) Earth Science Information Partners (ESIP-3) Project with NBC-4. The NASA/NBC-4 Meteorological/Scientific Visualization for Broadcast Television News project is intended to accomplish two goals. The first is to increase the exposure of Earth Science data to a much broader user community, the American people, by promoting such EOS missions as TRMM, Landsat 7 and newly launched Terra through

innovative visualizations on WRC-TV and WeatherNet4. The second is to optimize the previously developed tools for rapid display and value-added product creation of both ESE and commercial remote sensing data sources through valuable partnerships with public and corporate organizations. In addition, we will merge the power of GIS technology and visualization technology to provide easy-to-understand pictures in two and three dimensions for television news and weather broadcasts. These data sets are integrated into television weathercasts on WRC-TV in Washington, DC, and offered to other NBC owned and operated facilities worldwide. The Goddard developed technology for animation of long day/night sequences of colorized GOES images is being transferred to WRC-TV for use in regular weather broadcasts. Visualization and Analysis Lab has considerable experience in making ultra-high resolution weather visualizations. These visualizations are of great utility for HDTV and are made available to WRC-TV for use in the early broadcast phases of HDTV as the station converts from standard NTSC.

Digital Library

The digital library Web site is presently under construction. VAL has been tasked to collect earth science imagery and presentation material for NASA HQ. The images come from all the Earth Science disciplines from different NASA centers. This collection of images is being used in the NASA Earth Science Enterprise Science Implementation Plan. In the near future, this database will be available to NASA public outreach personnel, such as the Headquarters staff, the speakers bureau, museums, and teachers. We plan to expand this existing collection to also contain a comprehensive collection of EOS images, Quicktime animations of data, and scientific explanations along with appropriate meta data collected from the different NASA centers.

8. ACKNOWLEDGMENTS

Two members of the Laboratory's staff deserve special recognition for their contributions to this report. Patty Golden managed the report's evolution, assembled the work from our many contributors, and readied these pages for printing. Natalie Thompson worked steadily throughout the year to maintain our data on refereed publications.

We'd also like to thank Don Swenholt for his counsel on the tone and organization of this report and for his work in writing original text and editing the contributions of others.

Finally, Laura Rumburg turned her keen proofreader's eyes on our copy to help us catch our errors. In addition to the normal proofreading function, Laura diligently researched, edited, and checked factual items, figures, tables, and formatting.



APPENDIX 1. 1999 SHORT-TERM VISITORS

Laboratory for Atmospheres

Professor Donald Johnson February 10, April 23,
University of Wisconsin, Madison November 29

Maurice Blackmon March 9
NCAR

Professor Perona July 9
Politecnico of Turin, Italy

Jeffrey Anderson October 8
NOAA GFDL, Princeton, NJ

Eric Smith October 29, November 3
Florida State University

William Brune December 6
Pennsylvania State University

Data Assimilation Office

Elizabeth Espinoza September 9, 1998
Instituto de Previsao de Tempo e March 1, 1999
Estudos Climaticos (INPE)

Mike Tippett November 30, 1998-
Instituto de Previsao de Tempo e January 28, 1999
Estudos Climaticos (INPE)

Paul Poli January 4-June 4
Ecole Nationale de la Meteorologie

Minghua Zhang January 14-June 30
SUNY

Jagdish Shukla February 8
Center for Ocean-Land-Atmosphere
Studies

Jim Kinter February 8
Center for Ocean-Land-Atmosphere
Studies

Larry Marx February 8
Center for Ocean-Land-Atmosphere
Studies

Dave Dewitt February 8
Center for Ocean-Land-Atmosphere
Studies

Ed Schnieder February 8
Center for Ocean-Land-Atmosphere
Studies

Noah Wolfson February 16-March 1
Meteo-Tech Ltd

Sid-Ahmed Boukabara March 3
AER

Samsung Cheung March 5
NASA/Ames (MRJ)

Takayuki Matsumara March 12
UCAR/NCEP/EMC

Mike Kelly April 28
Colorado State University

Zhan Zhang April 30
Florida State University

Daniel Keyser May 13-14
SUNY, Albany

Takeshi Horinouch June 13-16
Kyoto University

Zhijin Li June 21-22
Florida State University

Jeffrey Walker July 1-September 30
University of Newcastle

Victor Lupo July 27-September 29
Merant

Marino Tsidulko August 2-6
Tel Aviv University

Pinhas Alpert August 1-11
Tel Aviv University

Wei-Wu Tan State University of New York	August 2-6	Mesoscale Atmospheric Processes Branch	
Tsann Wang Yu NOAA/National Weather Service	August 3-September 30	Ramesh Kakar NASA/HQ	January 28, March 23, May 20
Professor Bram Van Leer University of Michigan	August 9-12	Carlos Morales Independent Research Scientist	January 1-March 31, April 29-30, June 28-30, July 12-September 30
George Blaha University of Michigan	August 9-12	Nadya Reinhand Russian Academy of Sciences	February 2
Prasad S. Kasibhatla Duke University, School of the Environment	August 9-20	Liming Xu University of Arizona	February 3-5
Rick Hammond Merant	August 23-September 23	Doug Scalley NOAA/NDBC	February 9
Richard Renshaw UK Meteorological Office	August 26	Christopher Kidd University of Bristol	February 15-22, November 1
Brett Harris Australian Meteorological Office	August 26	Hui Liu Florida State University	February 17-19
Yan Yang Florida State University	September 1- 10	David Wolff TAMU	February 22-26
Michael Ghil Laboratoire de Meteorologie Dynamique (LMD)	September 12-14	Alan Koivunen Independent Visitor	March 2-8
Zoltan Toth NCEP	September 24	Arlene Laing University of South Florida	March 8-September 9, June 1-July 9, December 20-30
Istvan Szunyogh NCEP	September 24	Jeff Stith NCAR	March 23
Bruce Wielicki NASA/Langley	October 7	Barbara Butler Independent Visitor	March 24
Oreste Reale International Centre for Theoretical Physics (COLA)	October 7	John Gerlach WFF	March 31
Ron Errico NCAR	October 28	Sandra Yuter University of WA	April 5
Qin Xu Naval Research Laboratory	November 19	Reggie Blake GISS	April 7-8
		Winfield Sylvester GISS	April 7-8

1999 SHORT-TERM VISITORS

Song Yang Florida State University	April 8-9, August 19-20	Anne Garnier CNRC	June 14-16
Emmanouil Anagnostou University of Connecticut	April 28-May 2	Shuliang Zhang Woods Hole Oceanographic Institution	June 22
Gelsomina Pappalardo IMAAA-CNR, Italy	May-November	Jonathan Jiang York University	June 25
Wojciech W. Grabowski National Center for Atmospheric Research	May 5-7	Ping Ping Xie NOAA/NCEP	June 30
Chichang Lin UCLA	May 6-7	Gabella Marco Dip Elettronica, Politecnico DI	July 1
Sanchez-Sesma Mexican Institute of Water Management Technology	May 11	Ben Kedem UMD	July 1
Daya Gilra Raytheon ITSS	May 12, May 21	Charles Jones University of CA, Santa Barbara	July 1-9
Jun-Ichi Yano New York University	May 13-14	Leila Carvalho University of Sao Paulo	July 1-9
Eric Barrett University of Bristol	May 18	Jose Hernandez University of Puerto Rico	July 6
Gus Emmanuel NCAR	May 19	Tristan L'Ecuyer Colorado State University	July 28-30
Karyn Sawyer NCAR	May 19	Tufa Dinku University of Connecticut	July 29-August 12
Donald Martin Howard/summer faculty	May 24	Ren-Yow Tzeng National Central University in Taiwan	August 9-10
Lynn Rose Aeromet	June 3	Peter Bauer German Remote Sensing Data Center	August 20
David Short Nagoya University	June 3, July 1	Rhoni Chamberlain Wallops	August 31- November 5
Jeffrey Nystuen UWA	June 4	Allesandro Battaglia Institute ISAO-CNR Bologna	September 1-30
Matthias Steiner Princeton University	June 10-11	Frank Marks Hurricane Research Division	September 26-30
James Sieveking University of Saint Louis/ summer student	June 14	Robert Gall NCAR	September 26-30

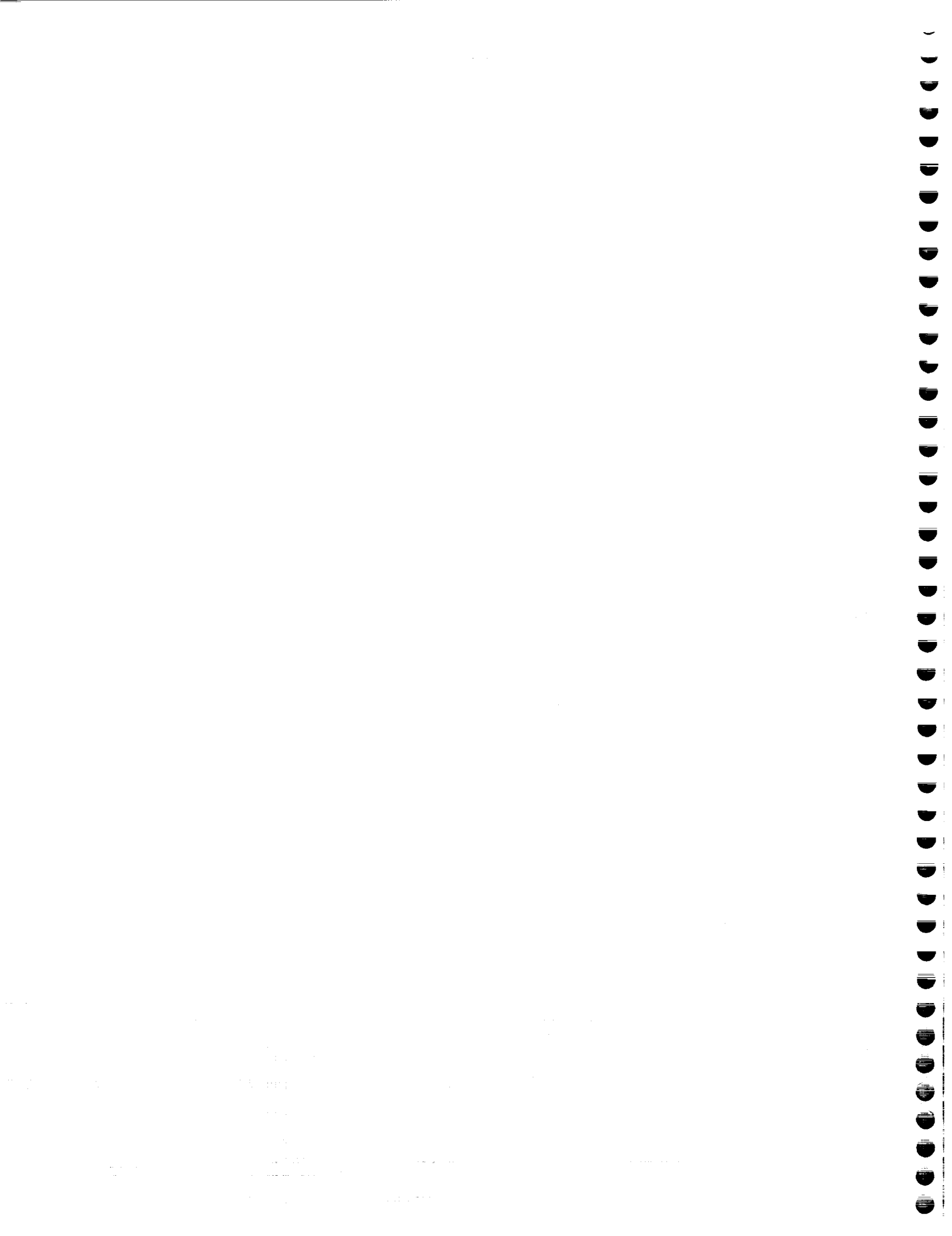
Michael Hardesty Environmental Technology Laboratory	September 26-30	Ina Tegen NASA/GISS Columbia University	February 26
Eric Smith Florida State University	September 26-30	Robert Pincus University of Wisconsin, Madison	March 1
Shoichi Shige Graduate School of Science Kyoto University	October 12	Jun-Ichi Yano New York University	March 8-9
Victoria Sanderson University of Bristol	November 1	Osman Yildiz Penn State University	April 19-23
Nicolas Viltard CETP/CHRS	November 4	Harshvardhan Purdue University, IN	May 3-5
Martin Kohler Geophysical Fluid Dynamics Lab NOAA/GFDL	November 15	Jeff Reid SPAWARSYSCEN	May 5-June 4
Matthew Wheeler NCAR Advanced Study Program	November 15-17	Jaya Ramaprasad George Mason University	May 14
Mary Floyd Westover	December 6	Aline Procopio Federal University, Brazil	May 15
Riko Oki EORC	December 6-8	Jyh-Long Chern National Cheng-Kung University	May 26, 28
Lisa Chang EPA	December 22	Tsung Hsun Yang National Cheng-Kung University	May 26, 28
Steve Siedel EPA	December 22	Siao-Lung Hwong National Cheng-Kung University	May 26, 28
Climate and Radiation Branch		Tsong-Shin Lim National Cheng-Kung University	May 26, 28
Kyu-Tae Lee National Kangnung University	January 4, July 6	Deepak Vaidya Dalhousie University	June 1-4
Anthony Davis Los Alamos National Lab	January 4	Stuart Piketh University of Witwatersrand	June 1-2
Jung-Moon Yoo Ewha Womens' University	January 15, June 28	Bruno Combal Universite Blaise Pascal, France	June 7-8
Chang-Hoi Ho Seoul National University	January 18, June 21	Thierry Faure Universite Blaise Pascal, France	June 7-8
W. Tim Liu Jet Propulsion Lab	February 9	Frederic Szczap Universite Blaise Pascal, France	June 7-8

Harumi Isaka Universite Blaise Pascal, France	June 7-8	Kung-hua Wang Central Weather Bureau, Taiwan	October 13-15
Andrey Ioltukhovskiy Keldysh Institute of Applied Math, Russia	June 7-8	Pay-liam Lin National Central University	December 7-9
Tatiana Zhuravleva Russian Academy of Science, Russia	June 7-8	Wang-Chen, Tai-Chi National Central University	December 7-9
Prigarin Mikhailovich Institute of Computational Math, Russia	June 7-8	Po-Hsiung Lin National Taiwan University	December 7-9
Aleksey Rublev Russian Research Center	June 7-8	Jong-Dao Jou Lin National Taiwan University	December 7-9
Vladimir Golovko Institute of Atmospheric Optics, Russia	June 7-8	Chung-Kyu Park Long-Range Weather Forecast Division, Korea	December 20-24
Jen-Cheng Chang CWB/RDC	June 14-18	Atmospheric Experiment Branch	
Po-Hsiung Lin National Taiwan University	July 1	Bruce Block University of Michigan	various times
Arnon Karnieli Ben Gurion University of the Negev	July 19-24	John Maurer University of Michigan	various times
Byung-Ju Sohn Seoul National University	August 2-6	Ms. Dana Burket Southwest Research Institute	November 16
Ismail Sabbah University of Alexandria	August 9-16	Paul Parrish (summer student) University Research Foundation	May 24-November 24
Zev Levin Tel-Aviv University	August 15-September 30	Jaime Demick (summer student) Auburn University, AL	April 5-June 11
Jose Vanderlei Martins University of Sao Paulo	August 18-23	Carol Kostak (summer student) Purdue University, IN	January 10-August 1
Grahm Feingold Colorado State University	August 23	Carol Gray (high school teacher) Arcadia High School, VA	June 10-August 1
Yuan Gao Rutgers University	September 22-24	Jeffrey Komives (summer student) Purdue University, IN	June 10-August 10
James Riddering NASA EPSCore Program, Montana	October 1-30	Brian Mohr (summer student) Bowdoin College, ME	June 10-August 10

**Atmospheric Chemistry and Dynamics
Branch**

		Ken Bowman Texas AMU	March 25
Mohan Gupta UCLA	January 11	Darryn Waugh The Johns Hopkins University	March 30
Drew Shindell Columbia University	January 12	Peter Fabian University of Munich	April 5
Darryn Waugh The Johns Hopkins University	January 12	Ruben Piacentini Instituto de Fisica Rosario	April 5-9
Colin Hines Canada	January 19-22	Ulrich Schumann Institut fuer Physik der Atmosphaere	April 16
Jerry Lumpe Computational Physics Inc.	January 28	Dave Virgillito Lambda Physik	April 21-25
Bernd Mielke Licel Corporation	January 29	Thomas McElroy Atmospheric Environment Service	April 26-28
Thomas McElroy Atmospheric Environment Service	February 1-4	Zhao NOAA NESDIS	May 4-November 4
Xiao Biao Fan University of Maryland	February 11	John DeLiusi NOAA	May 4
Jessica Neu Massachusetts Institute of Technology	February 17-18	Kwing L. Chan University of Space and Technology	June 7-9
Elizabeth Weatherhead University of Colorado	March 10	Jun Ma Independent Research Scientist	June 10
Sam Yee Applied Physics Laboratory	March 11	Herman Smit Max Planck Institute	June 10
Dave Flittner University of Arizona	March 12	Jim Slusser USDA	June 11
Ulli Hartmann Orbital Sciences	March 16	Dominique Jeker Swiss Federal Institute of Technology	June 26-30
Burt Roeder Orbital Sciences	March 16	Gerald Nedoluha Naval Research Laboratory	July 29
Darryn Waugh The Johns Hopkins University	March 17	John Burrows University of Bremen	August 24-September 3
Lyatt Jaegle Harvard University	March 25	Irina Petopavlovskikh University of Colorado	September 16

Kelly Chance Smithsonian Astronomical Observatory	September 16
Geir Braathen The Norwegian Institute for Air Research	October 18
Georgios Amanatidis European Commission	October 18
Pat Lucker Science Technology Co.	October 6-14
Mike Lawrence Wyle Laboratories	October 6-14
Bill Hunt Wyle Laboratories	October 7-14
Darryn Waugh The Johns Hopkins University	October 7
Arun Gopalan NCAR	October 14-15
Alexander Sinyuk National Academy of Science of Belarus	October 21
Joachim Joseph Tel Aviv University	November 5-9
Adam Devir Tel Aviv University	November 5-9
Yoram Noter Tel Aviv University	November 5-9
Yoav Yair Tel Aviv University	November 5-9
Meir Moalem Tel Aviv University	November 5-9
Aby Har-Even Tel Aviv University	November 5-9
Jun Wu University of Maryland	November 15- May 15, 2000



APPENDIX 2. 1999 COMPOSITION OF THE VISITING COMMITTEES FOR THE LABORATORY

Laboratory Visiting Committee (October 1993)

Alan K. Betts, Chairperson
Atmospheric Research Corporation, Pittsford, VT

Michael Ghil
Department of Atmospheric Science
University of California at Los Angeles, CA

Donald R. Johnson
Space Science and Engineering Center
University of Wisconsin, Madison, WI

Timothy L. Killeen
Space Physics Research Laboratory
University of Michigan, Ann Arbor, MI

Jose M. Rodriguez
AER, Inc., Cambridge, MA

Edward Westwater
CIRES, Boulder, CO

Data Assimilation Office Advisory Panel (October 1992, October 1993, January 1995, June 1996, May 1998)

Roger Daley, Chairperson
Naval Research Laboratory, Monterey, CA
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

Jeffrey Anderson
GFDL/NOAA
Princeton University, Princeton, NJ
(served Advisory Panel 1995, 1996, 1998)

Andrew F. Bennett
College of Oceanography
Oregon State University, Corvallis, OR
(served Advisory Panel 1995, 1996, 1998)

Guy Brasseur*
National Center for Atmospheric Research, Boulder, CO
(served Advisory Panel 1992, 1993, 1995)

Phillippe Courtier
Laboratoire d'Océanographie Dynamique et de
Climatologie (LODYC), Paris, France
(served Advisory Panel 1995, 1996, 1998)

Robert E. Dickinson
Department of Atmospheric Science
University of Arizona, Tucson, AZ
(served Advisory Panel 1995, 1996, 1998)

Anthony Hollingsworth*
European Centre for Medium-Range Weather
Forecasts (ECMWF), Reading, England
(served Advisory Panel 1992, 1993)

Daniel J. Jacob
Division of Engineering and Applied Science
Harvard University, Cambridge, MA
(served Advisory Panel 1995, 1996, 1998)

Donald R. Johnson
Space Science and Engineering Center
University of Wisconsin, Madison, WI
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

Kikuro Miyakoda*
GFDL/NOAA
Department of Commerce
Princeton University, Princeton, NJ
(served Advisory Panel 1992, 1993, 1995)

James J. O'Brien
Professor of Meteorology and Oceanography
Florida State University, Tallahassee, FL
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

Alan O'Neill
The Center for Global Atmospheric Modelling
Department of Meteorology
University of Reading, Reading, England
(served Advisory Panel 1992, 1993, 1995, 1996, 1998)

Data Assimilation Office Computer Advisory Panel (March 1996, August 1997)

William E. Farrell, Chairperson
SAIC, San Diego, CA

Tony Busalacchi
Laboratory for Hydrospheric Processes,
Code 970
NASA Goddard Space Flight Center,
Greenbelt, MD

Bill Dannevik
L262, Environmental Programs
Lawrence Livermore National Laboratory,
Livermore, CA

Alan Davis
Center for Ocean-Atmosphere Prediction Studies
Florida State University, Tallahassee, FL

Geerd-R. Hoffmann, Head
Computer Division
European Centre for Medium-Range Weather
Forecasts (ECMWF), Reading, England

Menas Kafatos
University Professor of Interdisciplinary Science
Director, Institute for Computational
Sciences and Informatics
George Mason University, Fairfax, VA

Reagan W. Moore
Enabling Technologies Group
San Diego Supercomputer Center,
San Diego, CA

John Sloan*
NCAR/SCD, Boulder, CO

Thomas Sterling*
Lawrence Livermore National Laboratory,
Livermore, CA

**Mesoscale Atmospheric Processes Branch,
External Review Committee Report,
NASA GSFC, November 9, 1999**

Dr. Robert Gall, Chair
Mesoscale Microscale Meteorology Division
National Center for Atmospheric Research
Boulder, CO

Dr. Michael Hardesty
Environmental Technology Laboratory
National Oceanic and Atmospheric Administration
Boulder, CO

Dr. Frank Marks
Hurricane Research Division
National Oceanic and Atmospheric Administration
Miami, FL

Dr. Eric Smith
Department of Meteorology
Florida State University
Tallahassee, FL

**Edge Technique Review Committee,
NASA GSFC August 6-7, 1997**

R. Michael Hardesty (Chair)
NOAA ERL, Boulder, CO

Edwin Eloranta
University of Wisconsin, Madison, WI

Chester Gardner
University of Illinois, Urbana, IL

Robert Menzies
NASA Jet Propulsion Laboratory, Pasadena, CA

**Atmospheric Chemistry and Dynamics
Branch, NASA GSFC, Bldg. 21, Room 183,
April 16-18, 1997**

Dr. William L. Chameides
School of Earth and Atmospheric Sciences
Georgia Institute of Technology, Atlanta, GA

Douglas D. Davis
School of Geophysical Science
Georgia Institute of Technology, Atlanta, GA

Matthew H. Hitchman
Dept. of Atmospheric and Oceanic Sciences
University of Wisconsin, Madison, WI

David J. Hoffman
Climate Monitoring and Diagnostics Laboratory
National Oceanic and Atmospheric Administration,
Boulder, CO

Susan Solomon
Environmental Research Laboratory
National Oceanic and Atmospheric Administration,
Boulder, CO

Joe W. Waters
Microwave Atmospheric Science Group
NASA Jet Propulsion Laboratory, Pasadena, CA

** No longer on the committee*

APPENDIX 3. 1999 VISITING SCIENTISTS AND ASSOCIATES OF JOINT CENTERS

CCAST (University of Arizona)

Robert Loughman

Columbia University

Barry Lynn

Distinguished Visiting Scientist

David Atlas

ESSIC

David Considine
Andrew Dessler
Michael Fox-Rabinovitz
Jay Larson
Peter Lyster
Vikram Mehta
Kenneth Pickering
Will Sawyer
Maria Tzortziou
Zihou Wang

George Mason University

Bart Kelley

Georgia Tech.

Mian Chin
Paul Ginoux

JCET

Eyal Amitai
Chaing Chen
Robert Cifelli
Scott Curtis
Belay Demoz
Keith Evans
Brad Ferrier
Jeff Freemire
Jeffrey Halverson
Scott Janz
Mark Kulie
Yong Li
S. J. Lin
David Marks
Alexander Marshak
Richard Menard
Gyula Molnar
William Olson
Lazaros Oraopoulos

Steven Platnick
Paul Poli
Tom Rickenbach
Lars Peter Riishojgaard
Mike Robinson
Laurie Rokke
Dev Roy
David Silberstein
Peter Soulen
Lynn Sparling
Andrew Tangborn
Ali Tokay
Omar Torres
Jose Vanderlei Martins
Tamas Varnai
Andrew Wald
Jianxin "Jerry" Wang
Jian-Jain Wang
Guoyong Wen
Song Yang

Johns Hopkins University

Donald Anderson

NRC

R. Raghavarao
Anna Rozwadowska
Sam Shen

NSF

Sankar-Rao Mopidevi

Tel Aviv University

Pinhas Alpert

UCLA

Ning Zeng

URF

Larry Brace
Liela Garcia
David Graff
Willis Wilson

University of Arizona

Liming Xu

University of Maryland

Tijana Janjic

USRA

David Baker

Alessandro Battaglia

Michael Bosilovich

Pui-King Chan

David Erickson

Rosana Nieto Ferreira

Charles Gatebe

Jose Hernandez

Kyu-Myong Kim

Sonia Kreidenweis

Ruei-Fong Lin

Annarita Mariotti

Steven Pawson

James Pierson

Aline Procopio

Zhaoxia Pu

Joshua Qian

Anil Rao

Suhasini Ravipati

Steve Sherwood

Richard Swinbank

Didier Tanre

Lin Tian

Joshua Xian

APPENDIX 4. 1999 SEMINARS

Laboratory for Atmospheres Seminar Series

Drew Shindell, NASA GISS, "Interactions of Stratospheric Ozone and Climate Change," January 12.

Eric Smith, Florida State University, "Quantitative Assessment of Day One TRMM Precipitation Algorithms: Improvements from SSM/I Intercomparison Era," January 26.

Thomas Donohue, University of Michigan, "Water on the Terrestrial Planets, Now and in The Past," February 9.

Yoram Kaufman, NASA GSFC, "Use of the EOS-AM Data to Reduce the Uncertainties in the Aerosol Effect on Climate," February 23.

Frank Marks, NOAA/Hurricane Research Division, "The Asymmetric Distribution of Vertical Motions and Precipitation in the Hurricane Eyewall," March 9.

Joanna Joiner, NASA GSFC, "Improving the Use of Passive Microwave and Infrared Sounding Information in the GEOS-DAS," March 23.

Mary-Anne Carol, University of Michigan, "The Program for Research on Oxidants: Photochemistry, Emissions, and Transport - Research Objectives and Preliminary Results of the 1997 and 1998 Measurement Intensives," April 13.

Chris Kummerow, NASA GSFC, "Comparison of Radar and Radiometer Estimates of Rainfall from TRMM," April 27.

Anthony Davis, Los Alamos National Laboratory, "From Landsat Cloud Scenes and Lite's Stretched Pulses to Future "THOR" Lidars," May 11.

Wayne Kasprzak, NASA GSFC, "The Martian Atmosphere," May 18.

William Collins, NCAR, "Effects of Enhanced Shortwave Absorption on Simulations of the Tropical Pacific Ocean/Atmosphere System," May 25.

Robert D. Cess, Marine Sciences Research Center, State University of New York, "Atmospheric General Circulation Models: Can Seasonal and Latitudinal Changes of Cloud-Radiative Forcing be Used to Validate Cloud-Climate Feedback?" September 14.

Mark R. Schoeberl, NASA GSFC, "NASA's Earth Science Vision," September 21.

Bruce Wielicki, NASA Langley Research Center, "New Results from TRMM on Clouds, Radiation and Climate," October 7.

Robert E. Dickinson, University of Arizona, "What Does Nitrogen Have to do with Evapotranspiration?" October 19.

James H. Butler, NOAA/CMDL, "Obtaining Atmospheric Histories of Trace Gases from Analyses of Polar Firm Air," November 2.

Matthew Wheeler, National Center for Atmospheric Research (NCAR), "Synoptic to Intraseasonal Modes of Coherent Tropical Convective Variability," November 16.

Kevin Trenberth, National Center for Atmospheric Research (NCAR), "The Global Monsoon," December 7.

Leonard J. Pietrafesa, North Carolina State University, "Atmospheric Winds, Ocean Waves and Currents in a Coupled Model," December 21.

Data Assimilation Office

Dr. Michael Fox-Rabinovitz, Data Assimilation Office/GSFC, "Stretched Grid GEOS GCM and DAS," February 5.

Dr. Sid-Ahmed Boukabara, AER, "The Combined Use of C-Winds and AMSR Data," March 3.

Takayuki Matsumara, NCEP/EMC/UCAR, "GPS Radio Occultation Techniques," March 12.

Bram Van Leer, University of Michigan, "Genuinely Multi-Dimensional Methods in Computational Fluid Dynamics," August 12.

Michael Bosilovich, Data Assimilation Office/GSFC, "Land-Atmosphere Interactions in Hydrometeorology," September 3.

Dr. Michael Ghil, UCLA, Laboratoire de Meteorologie Dynamique (LMD), "ENSO: A Unified Theory and Implications for Prediction," September 13.

Richard Rinshaw, UK Meteorological Office, "Use of Satellite Data at UKMO," September 24.

Brett Harris, Australian Meteorological Office, "Use of Satellite Data at BMRC," September 24.

Zoltan Toth and Istvan Szunyogh, NCEP, "Targeted Observations at NCEP," September 24.

Ron Errico, NCAR, "Precipitation Assimilation," October 25.

Joseph Jaja, University of Maryland, College Park, "Parallel Computing," November 22.

Ivanka Stajner, Data Assimilation Office/GSFC, "The GEOS Ozone DAS: Initial Results and Validation of a 9-month Ozone Assimilation," December 17.

Mesoscale Atmospheric Processes Branch

Steven J. Goodman, NASA/Marshall Space Flight Center, "Recent Observations of the Distribution and Variability of Global Thunderstorm Activity," February 19.

Arlene Laing, University of South Florida, "The Large-Scale Environments of the Global Population of Mesoscale Convective Complexes," March 8.

Song Yang, Florida State University, "Precipitation and Latent Heating Retrieved from Satellite Measurements," April 8.

Christopher R. Williams, CSU/CIRES, "UHF and S-band Profilers Used in Support of Ground Validation of the TRMM Satellite During TEFLUN-B," May 13.

Jeffrey Nystuen, University of Washington, "Rainfall Analysis Using Underwater Sound," June 4.

David Atlas, NASA GSFC, "An Observationally Based Conceptual Model of Precipitation Growth in Warm Tropical Convective Clouds," June 10.

Anne Garnier, Service d'Aeronomie du CNRS, "OHP Rayleigh-Mie Doppler Lidar for Atmospheric Wind Measurements," June 14.

Shuliang Zhang, Woods Hole Oceanographic Institution, "Surface Fluxes and their Influence on Sea Surface Temperature in the Western Equatorial Pacific during COARE," June 22.

David Short, Institute for Hydrospheric and Atmospheric Sciences, "Storm Height Distributions and Shallow Rain From the Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar," July 1.

Ronald Gelaro, Naval Research Laboratory, Monterey, CA, "A Predictability Study Using Geostationary Satellite Wind Observations During NORPEX," October 4.

Climate and Radiation Branch

Andy Moore, University of Colorado, "The Non-Normal Nature of ENSO and Intraseasonal Variability," February 3.

Timothy Liu, Jet Propulsion Laboratory, "Scientific Application of NSCAT Data," February 10.

Dave Carlson, Hal Cole, NCAR, "Dry Bias in Global Radiosonde Humidity Data: Cause, Correction, and Consequences," February 23.

Steven Platnick, Climate and Radiation Branch/GSFC, "Cloud Retrievals in the Solar Spectrum," February 24.

Samuel Shen, University of Alberta, Canada, "Optimal Estimation of Climate Parameters," March 3.

Jun-Ichi Yano, New York University, "Some Aspects of the Tropical Atmospheric Dynamics," March 8.

Tamas Varnai, University of Arizona, "Calculating the Statistical Properties of Simulated Cloud Reflectance, Fields Using Interactive Empirical Bayesian Updating," March 11.

Charles K. Gatebe, Climate and Radiation Branch/GSFC, "Optimal Estimation of Climate Parameters," March 12.

Lorraine Remer, Climate and Radiation Branch/GSFC, "What Will We Learn from MODIS Data about Global Aerosols?" March 24.

John Bates, NOAA/ERL/CDC, "The Humidistat Hypothesis: Tropical Air-Sea Interactions and the Hydrological Cycle," April 6.

Zhanqing Li, Canada Centre for Remote Sensing, "FIRE 3M/3S Project: Monitoring, Mapping and Modeling of Fire Spots, Scars and Smoke over Boreal Forests," April 7.

Vikram Mehta, Climate and Radiation Branch/GSFC, "Decadal Variability of ENSO and its Teleconnections," April 14.

Arun Kumar, NOAA/NCEP, "An Analysis of Variability in the Extratropical Response to Changes in Tropical SST Forcing," April 21.

Roger Davies, University of Arizona, "A Multiangle Perspective of Cloud Properties," May 5.

Anthony Delgenio, NASA/GISS, "Climatic Implications of the Observed Temperature Dependence of the Liquid Water Path of Low Clouds," May 19.

David Neelin, UCLA, "Variations of ENSO Phase Locking," May 21.

Peter Pilewski, NASA/Ames Research Center, "A Moderate Resolution View of the Solar Spectrum in Earth's Atmosphere," June 2.

Siegfried Schubert, Data Assimilation Office, "The Seasonal Prediction Problem," June 16.

Byung-Ju Sohn, Seoul National University, "SSM/I Water Vapor Retrieval and the Study of East Asian Summer Monsoon," August 4.

Reinout Boers, CSIRO, Australia, "Ground-based Remote Sensing of Cloud Microphysical and Optical Properties," August 23.

Prabakara Cuddapah, Climate and Radiation Branch/GSFC, "Rain Estimation Over Land and Ocean from TRMM Microwave Imager Data," September 8.

Yogesh Sud, Climate and Radiation Branch/GSFC, "Cloud Microphysics in GEOS II GCM - Parameterization, Problems, and Prospects," September 29.

Ning Zeng, Climate and Radiation Branch/GSFC, "Does Vegetation Interaction Enhance Tropical Climate Variability?" October 13.

Klaus Pfeilsticker, University of Heidelberg, "Recent Observations on 3D Effects of Clouds on the Radiative Transfer: Geometrical Pathlengths, Radiative Smoothing and the Multifractality of the Zenith Sky Radiances," November 10.

David Starr, Climate and Radiation Branch/GSFC, "Comparison of Cirrus Cloud Models: A Project of the GEWEX Cloud System Study (GCSS) Working Group on Cirrus Cloud Systems," November 17.

Ernesto Hugo Berbery, University of Maryland, "Mesoscale Circulations in the American Monsoons," November 23.

Grzegorz Jan Ciach, University of Oklahoma, "The Estimation/Validation Problem for Remote Sensing of Rainfall," December 8.

Kikuro Miyakoda, George Mason University/COLA, "The ENSO-monsoon System as Viewed by Six Indices," December 15.

Sonia Kreidenweis, Colorado State University, "Observations of Smoke Aerosol from Biomass Burning in Mexico," December 21.

Atmospheric Chemistry and Dynamics Branch

Drew Shindell, NASA-GISS/Columbia University, "Interactions of Stratospheric Ozone and Climate Change," January 12.

Colin Hines, National Research Council, "The Eulerian Tail in Wave Spectra and Its Application to Gravity-wave Saturation in the Middle Atmosphere," January 20.

Jerry Lumpe, Computational Physics Inc., "Solar Occultation for POEM," January 28.

Jessica Neu, Massachusetts Institute of Technology, "An Investigation of Stratospheric Transport Using the "Leaky Pipe" Method," February 18.

Elizabeth Weatherhead, University of Colorado, "Detecting Ozone Recovery," March 10.

Sam Yee, Applied Physics Laboratory, "Stellar Occultation," March 11.

Robert Loughman, CCAST/University of Arizona, "Examination of the Calibration of the SOLSE Instrument Using Nadir Viewing Images," March 18.

Lyatt Jaegle, Harvard University, "Ozone Production in the Upper Troposphere: Evidence for NO_x-Saturated Conditions," March 25.

Peter Fabian, University of Munich, Germany, "Climate Change and Vegetation," April 5.

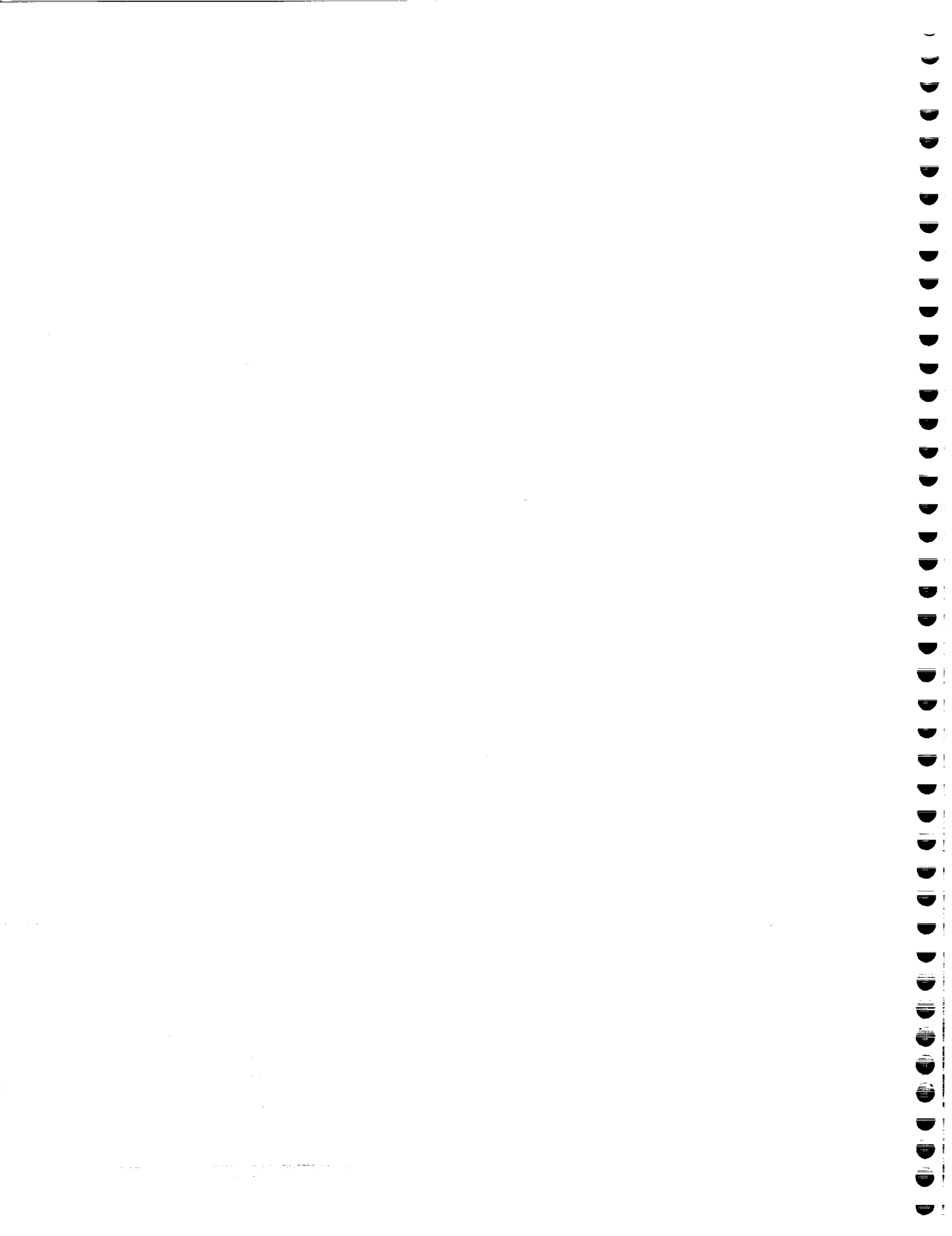
Ken Pickering/Dale Allen, "SONEX Nox had no Unique Aircraft Fingerprint but Fresh Nox Looks Like Lightning," April 8.

Ulrich Schumann, DLR-Institut fuer Physik der Atmosphaere, "Aviation induced Aerosols and Cloudiness," April 16.

Andrew Gettelman, University of Washington, "3D Simulations of Water in the Tropopause Region," May 28.

Jun Ma, University of Chicago, "A Lagrangian Method to Correlate and Map UARS Data to Diagnose Trends and Dynamical Processes," June 10.

Irina Petrapavlovskikh, University of Colorado, "Recent Reanalysis of Umkehr Record," September 16.



APPENDIX 5. 1999 SCIENCE TEAM MEETINGS AND WORKSHOPS

SCIENCE TEAM MEETINGS

Tropical Rainfall Measuring Mission

TRMM Meeting, October 25-29, UMUC Inn and Conference Center, College Park MD.

Sounder Research Team

Atmospheric Infrared Sounder (AIRS) Team Meeting, February 23-27, Santa Barbara, California.

AIRS Team Meeting, July 14-16, Jet Propulsion Laboratory, Pasadena, California.

AIRS Team Meeting, October 19-21, Baltimore, Maryland.

Mesoscale Atmospheric Processes Branch

First CONDUIT Working Group Meeting; USWRP, NASA GSFC, December 10, Cliff Mass (Univ. Washington), chair.

Climate and Radiation Branch

European Geophysical Society, section on "Geophysical Experiments," April 19-23, den Haag, Netherlands, Co-Convenor: Robert F. Cahalan with S. Malinowski, U. Warsaw & W. Fruh, U. Edinburgh.

Special Session on SCSMEX, AGU Spring Meeting, May 31-June 4, Boston, Massachusetts, Convenor: William K.M. Lau.

AGU, May 31-June 4, Boston, Massachusetts, Co-Convenor: Alexander Marshak.

Atmospheric Chemistry and Dynamics Branch

916 Branch Retreat, January 6-7, University of Maryland and Goddard Space Flight Center, 27 attendees, P. K. Bhartia, Chair.

TOMS Science Team Meeting, April 7-9, Patuxent Wildlife Refuge, 50 attendees, P. K. Bhartia, Chair.

Atmospheric Effects of Aviation Project Science Team Meeting and Program Review, April 18-23, Virginia Beach, VA, 163 attendees, Donald E. Anderson and Stephan R. Kawa, chairs.

UARS Science Team Meeting, October 26-28, Virginia Beach, VA, 100 attendees, Charles H. Jackman, Chair.

WORKSHOPS

Laboratory for Atmospheres

Symposium on Cloud Systems, Hurricanes and TRMM: Celebration of Dr. Joanne Simpson's Career - The First 50 Years, December 1-3.

Sounder Research Team

Tenth International TOVS Study Workshop, January 27 - February 2, Boulder, Colorado.

Data Assimilation Workshop, August 23-25, University of Maryland, College Park, Maryland.

Data Assimilation Office

National Modeling Workshop, April 27-28, Steve Zebiak and Richard Rood, Chairs.

Mesoscale Atmospheric Processes Branch

Workshop on High-Resolution Thermal Imaging, NASA GSFC; 17 June 1999; Dennis Chesters and Marshall Shepherd, chairs.

Climate and Radiation Branch

GCSS Working Group on Cirrus Cloud Systems (WG2) Second Workshop on Modeling Cirrus Clouds, Geesthacht, Germany, May 19-21, Chairman: David O'C. Starr.

JCET International Workshop on Radiative Transfer, Baltimore, Maryland, June 7-8, Chairman: Alexander Marshak.

Planning Workshop for Integration of Satellite Calibration/Validation and Research-Oriented Chemistry Field Missions in the Next Decade (1999), Snowmass, Colorado, August 23-27.
Chairman: Joe McNeil and Michael Kurylo (NASA HQ), Co-Convenor: David O'C. Starr.

7th U.S.-Japan Joint Workshop on Global Change, November 15-18, Tokyo, Japan, and Co-Convenor: William K.M. Lau.

First International Workshop on "Intercomparison of 3D Radiation Codes," Tucson, Arizona, November 17-19, Chairman: Robert F. Cahalan and co-hosted by Prof. Roger Davies, Inst. of Atmos. Physics, U. Arizona.

'99 Kyoto Aerosol-Cloud Workshop (The CCSR COE Symposium/3rd Aerosol-Cloud Remote Sensing Workshop), Kyoto, Japan, December 1-10, Chairman: Teruyuki Nakajima (CCSR, Univ. of Tokyo), Organizing Committee: Yoram J. Kaufman (NASA GSFC).

CLIVAR Asian-Australian Monsoon Panel Meeting and Workshop, December 6-10, University of Hawaii, East-West Center, Co-Convenor: William K.M. Lau.

Atmospheric Chemistry and Dynamics Branch

First SHADOZ Science Team Workshop, November 1-3, San Jose dos Campos, Brazil, 50 attendees,
Anne. M. Thompson, Chair.

Rocket Engine Emissions Workshop, November 17, Goddard Space Flight Center, 30 attendees, Donald
E. Anderson, Chair.



APPENDIX 6. 1999 NASA TECHNICAL MEMORANDA AND OTHER PUBLICATIONS

Sounder Research Team

Mehta, A. and J. Susskind, 1999: Longwave radiative flux calculations in the TOVS pathfinder path A data set. NASA CR-1999-208643.

Data Assimilation Office

Takacs, L., W. Sawyer, M. J. Suarez, and M. S. Fox-Rabinovitz, 1999: Filtering techniques on a stretched grid general circulation model. NASA/TM-1999-104606, Vol. 16, Technical Report Series on Global Modeling and Data Assimilation, Max J. Suarez, Editor.

Atmospheric Chemistry and Dynamics Branch

Herman, J. R., S. McKenzie, S. Diaz, J. Kerr, S. Madronich, and G. Seckmeyer, 1999: UV radiation on the Earth's Surface, 1999: Chapter 9, WMO, UNEP/WMO Scientific Assessment of Ozone Depletion, edited by D. L. Albritton, R. T. Watson, and P. J. Aucamp, *WMO Global Ozone Res. and Monit. Proj.*, Geneva.

Kawa, S. R., J. G. Anderson, S. L. Baughcu, C. A. Brock, W. H. Brune, R. C. Cohen, D. E. Kinnison, P. A. Newman, J. M. Rodriguez, R. S. Stolarski, D. Waugh, and S. C. Wofsy, 1999: Assessment of the effects of high-speed aircraft in the stratosphere. *NASA Technical Publication*, NASA/TP-1999-209237.

Lelieveld, J. and A. M. Thompson, 1999: Tropospheric ozone and related processes. Chapter 4, WMO, UNEP/WMO Scientific Assessment of Ozone Depletion, edited by D. L. Albritton, R. T. Watson, and P. J. Aucamp, *WMO Global Ozone Res. and Monit. Proj.*, Geneva.



APPENDIX 7. 1999 REFEREED PUBLICATIONS

Laboratory for Atmospheres

Allen, D. R., M. R. Schoeberl, and J. R. Herman, 1999: Trajectory modeling of aerosol clouds observed by TOMS. *J. Geophys. Res.*, **104**, 27,461-27,471.

Atlas, D., C. W. Ulbrich, F. D. Marks, E. Amitai, and C. R. Williams, 1999: Systematic variation of drop size and radar-rainfall relations. *J. Geophys. Res.-Atmos.*, **104**, 6155-6169.

Grivet-Talocia, S., F. Einaudi, W. L. Clark, R. D. Dennett, G. D. Nastrom, and T. E. VanZandt, 1999: A 4-yr climatology of pressure disturbances using a barometer network in central Illinois. *Mon. Wea. Rev.*, **127**, 1613-1629.

Sounder Research Team

Mehta, A., and J. Susskind, 1999: Outgoing longwave radiation from the TOVS Pathfinder A data set. *J. Geophys. Res.-Atmos.*, **104**, 12193-12212.

Data Assimilation Office

Alpert, P., M. Tsidulko, and D. Itzigsohn, 1999: A shallow, short-lived meso-beta cyclone over the Gulf of Antalya, eastern Mediterranean. *Tellus Series A—Dynamic Meteor. and Oceano.*, **51**, 249-262.

Atlas, R., S. C. Bloom, R. N. Hoffman, E. Brin, J. Ardizzone, J. Terry, D. Bungato, and J. C. Jusem, 1999: Geophysical validation of NSCAT winds using atmospheric data and analyses. *J. Geophys. Res.*, **104**, 11405-11424.

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APPENDIX 8. ACRONYMS

1DVAR	1-dimension variational	CIMEL	Sun Photometer (French word)
2D	two-dimensional	CLS	Cloud Lidar System
3D	three-dimensional	CNES	Center Nationale d'Etude Spatiales
4DDA	four-dimensional data assimilation	Co-I	Co-Investigator
ACCENT	Atmospheric Chemistry of Combustion Emissions Near the Tropopause	CONTOUR	Comet Nucleus Tour
AEAP	Atmospheric Effects of Aviation Project	COVIR	Compact Vis IR
AETD	Applied Engineering and Technology Directorate	CrIS	Crosstrack Infrared Sounder
AIRS	Atmospheric Infrared Sounder	CRM	Cloud Resolving Model
AMNH	American Museum of Natural History	CSTEA	Center for the Study of Terrestrial and Extraterrestrial Atmospheres
AMSR	Advanced Microwave Scanning Radiometer	DAAC	Distributed Active Archive Center
AMSU	Advanced Microwave Sounding Unit	DAO	Data Assimilation Office
AOD	aerosol optical depth	DAS	Data Assimilation System
ARL	Airborne Raman Lidar	DDF	Director's Discretionary Fund
ARM	Atmospheric Radiation Measurement	DIAL	Differential Absorption Lidar
ARREX	Aerosol Recirculation and Rainfall Experiment	DISS	Distributed Image Spreadsheet
ATMS	Advanced Technology Microwave Sounder	DMSP	Defense Meteorological Satellite Program
AVHRR	Advanced Very High Resolution Radiometer	ECSSO	Executive Committee for Science Outreach
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer	EDOP	ER-2 Doppler Radar
BUV	Backscatter Ultraviolet	EDR	Environmental Data Record
C	Celsius	EI	El Niño Index
CAN	Cooperative Agreement Notice	ENSO	El Niño Southern Oscillation
CCAST	Cooperative Center for Atmospheric Science and Technology	ENVISAT	Environmental Satellite
CCD	Convective Cloud Differential	EOS	Earth Observing System
CCM4	Community Climate Model version 4	EPIC	Earth Polychromatic Imaging Camera
CEAS	Center for Earth-Atmosphere Studies	ERBE	Earth Radiation Budget Experiment
CFCs	chlorofluorocarbons	ESA	European Space Agency
CHARC	CSTEA HBCU Academic and Research Consortium	ESE	Earth Science Enterprise
CHyMERA	Compact Hyperspectral Mapper for Environmental Remote Sensing Applications	ESIP	Earth Science Information Partners
CICA	Competition In Contracting Act	ESPI	ENSO Precipitation Index
CIFAR	Cooperative Institute for Atmospheric Research	ESSIC	Earth System Science Interdisciplinary Center
		ESSP	Earth Systems Science Pathfinder
		Etheater	Electronic Theater
		EU	Engineering Unit
		EUV	Extreme Ultraviolet
		FFPA	filter/focal plane array

FOR	field of regard	INMS	Ion and Neutral Mass Spectrometer
ft	feet	IOP	Intensive Operations Period
GCE	Goddard Cumulus Ensemble model	IODR	Integrated Operational Requirements Document
GCM	General Circulation Model	IPO	Integrated Program Office
GCMS	Gas Chromatograph Mass Spectrometer	IR	Infrared
GCRP	Global Change Research Program	ISAS	Institute of Space and Aeronautical Science
GEOS	Goddard Earth Observing System	ISCCP	International Satellite Cloud Climatology Project
GEWEX	Global Energy and Water Cycle Experiment	ISIR	IR Spectrometer Imaging Radiometer
GLOBE	Global Learning and Observations to Benefit the Environment	ITCZ	Intertropical Convergence Zone
GLOW	Goddard Lidar Observatory for Winds	JARG	Joint Agency Requirements Group
GMI	Global Modeling Initiative	JASON	name of a mythical character the project is named for
GMS	Geostationary Meteorological Satellite	JCET	Joint Center for Earth Systems Technology
GOES	Geostationary Operational Environmental Satellite	JCG	Joint Center for Geoscience
GoHFAS	Goddard Howard University Fellowship in Atmospheric Sciences	JCOSS	Joint Center for Observation System Science
GPCP	Global Precipitation Climatology Project	JPL	Jet Propulsion Laboratory
GPMS	Galileo Probe Neutral Mass Spectrometer	K	Kelvin
GPS	Global Positioning Satellite	KCO	Kaashidhoo Island Observatory
GSFC	Goddard Space Flight Center	km	kilometers
GUV	Ground-based Ultraviolet Radiometer	KWAJEX	Kwajalein Experiment
GV	Ground Validation	LARS	Lidar Atmospheric Raman Spectrometer
GVP	Ground Validation Program	LAS	Leonardo Airborne Simulator
h	hours	LASAL	Large Aperture Scanning Airborne Lidar
HARLIE	Holographic Airborne Rotating Lidar Instrument Experiment	LI	La Niña Index
HBCUs	Historically Black Colleges and Universities	LSM	Land Surface Model
HDTV	High Definition TV	m	meters
HIRS	High Resolution Infrared Sounder	mb	millibar
HOTS	Holographic Optical Telescope and Scanner	MBA	microbolometer array
HSB	Humidity Sounder Brazil	MEIDEX	Mediterranean Israeli Dust Experiment
HSCT	High-Speed Civil Transport	mid-IR	mid-Infrared
HUPAS	Howard University Program in Atmospheric Sciences	MIT	Massachusetts Institute of Technology
IAP	Independent Activity Period course	mm	micrometer
IFOV	instantaneous field of view	MM5	Mesoscale Model 5
IGS	Internal Government Studies	MODIS	Moderate Resolution Imaging Spectroradiometer
IIP	Instrument Incubator Program	MPL	Micro Pulse Lidar
INDOEX	Indian Ocean Experiment	MRF	Medium-Range Forecast

MSU	Microwave Sounding Unit	PAUR	Photochemical Activity and Ultraviolet Radiation Modulation Factors
NAS	Numerical Aerospace Simulation	PI	Principal Investigator
NASA	National Aeronautics and Space Administration	PLACE	Parameterization for Land Atmosphere Cloud Exchange
NASDA	National Space Development Agency	POES	Polar Orbiting Environmental Satellite
NCAR	National Center for Atmospheric Research	ppbv	parts per billion volume
NCCS	NASA Center for Computational Sciences	PSAS	Physical-space Statistical Analysis System
NCEP	National Center for Environmental Prediction	QuikSCAT	scatterometer satellite
NDSC	Network for the Detection of Stratospheric Change	RCDF	Radiometric Calibration and Development Facility
NESDIS	National Environmental Satellite Data and Information Service	RSAS	Rayleigh Scattering Altitude Sensor
NEWMAS	"NASA Educational Workshop for Secondary Math, Science, and Technology Teachers"	s/n	signal to noise
NGI	Next Generation Internet	SAFARI	Southern Africa Fire-Atmosphere Research Initiative
NGIMS	Neutral Gas and Ion Mass Spectrometer	SAGE	Stratospheric Aerosol and Gas Experiment
NIIEM	Russian Scientific Research Institute of Electromechanics	SASS	Subsonic Assessment
NIST	National Institutes of Standards and Technology	SBIR	Small Business Innovative Research
nm	nanometer	SBUV/2	Solar Backscatter Ultraviolet/version 2
NMNH	National Museum of Natural History	SCAR-B	Smoke Cloud And Radiation -Brazil
NMS	Neutral Mass Spectrometer	SCHIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
NO	nitric oxide	SCO	stratospheric column ozone
NOAA	National Oceanic Atmospheric Administration	SCSMEX	South China Sea Monsoon Experiment
NPOESS	National Polar Orbiting Environmental Satellite System	SeaWiFS	Sea-viewing Wide Field-of-View Sensor
NPP	NPOESS Preparatory Project	SHARP	Summer High School Apprenticeship Research Program
NRC	National Research Council	SMiR	Scanning Microwave Radiometer
NSES	National Science Education Standards	SOLSE/LORE	Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment
NSIPP	NASA Seasonal-to-Interannual Prediction Project	SOLVE	SAGE Ozone Loss and Validation Experiment
NTSC	National Television Standards Committee	SONEX	Sass Ozone and Nitrogen oxides EXperiment
OAT	Operation Algorithm Team	SPARCLE	South Pole Atmospheric Radiation and Cloud Lidar Experiment
ODIN	a Swedish small satellite project for astronomical and atmospheric research	SRL	Scanning Raman Lidar
OLR	Outgoing Longwave Radiation	SSM/I	Special Sensor Microwave Imager
OMPS	Ozone Mapper and Profiler System	SST	sea surface temperature
OSIRIS	ODIN Spectrometer and IR Imager System	SSU	Spectral Sensor Unit
OSR	outgoing shortwave radiation	STAAC	"Systems, Technology, and Advanced Concepts Directorate"
OSSE	Observing System Simulation Experiment		

STROZ LITE	Stratospheric Ozone Lidar Trailer Experiment
SUCCESS	Subsonic aircraft: Contrails and Clouds Effects Special Study
SUNBEAMS	Students United with NASA Becoming Enthusiastic About Math and Science
TARFOX	Tropospheric Aerosol Radiative Forcing Observational eXperiment
TCO	tropospheric column ozone
THESO	Third European Stratospheric Experiment on Ozone
THOR	cloud THickness from Offbeam Returns
TIROS	Televised Infrared Operational Satellite
TM	Thematic Mapper
TMI	TRMM Microwave Imager
TOGA-COARE	Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment
TOMS	Total Ozone Mapping Spectrometer
TOMS-CAM	Total Ozone Mapping Spectrometer Camera
TOMS-EP	Total Ozone Mapping Spectrometer-Earth Probes
TOVS	TIROS Operational Vertical Sounder
TPW	total precipitable water
TRMM	Tropical Rainfall Measuring Mission
TSDIS	TRMM Science Data and Information System
UARS	Upper Atmosphere Research Satellite
UCLA	University of California - Los Angeles
USGCRP	US Global Change Research Program
USRA	Universities Space Research Association
UV	ultraviolet
VAL/912	Visualization and Analysis Laboratory
VIS	Visible
VOLCAM	Volcanic Ash Monitor
WCRP	World Climate Research Programme