NASA/TM—2020-219042

Laboratory for Atmospheres 1996 Technical Highlights

Goddard Earth Sciences Division - Atmospheres

April 2020

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Goddard Earth Sciences Division - Atmospheres
Goddard Space Flight Center

National Aeronautics and
Space Administration

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LABORATORY FOR

ATMOSPHERES

Section 1

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

1. Introduction

A broad and vigorous science program in NASA is vital for the advancement of knowledge through space research. Scientists at NASA in collaboration with outside scientists play a key role in conceiving new space missions, providing mission requirements, and carrying out research oriented towards explaining the behavior of Earth's and other planetary systems. NASA scientists also supply outside scientists with technical assistance and scientific data.

The Laboratory for Atmospheres serves as the focal point of a broad theoretical and experimental research program. The goal of the program is to study all aspects of the atmospheres of the Earth and other planets, including their structural, dynamical, radiative, and chemical properties.

The Laboratory is one of four science laboratories of the Earth Sciences Directorate at the Goddard Space Flight Center (GSFC). The Laboratory is located in Greenbelt, MD along with the Laboratory for Terrestrial Physics and the Laboratory for Hydrospheric Processes. The Goddard Institute for Space Studies (GISS), located in New York, NY, is the fourth science Laboratory in the Directorate. The Directorate also includes the Global Change Data Center and the Space Data and Computing Division (SDCD). The GSFC is the lead center for science and management of the Mission to Planet Earth (MTPE), which is one of the four NASA enterprises.

This report is a general statement of the purpose and philosophy of the Laboratory and of its role within NASA. It also includes a broad description of the research areas; information on human resources, scientific interactions, and outreach activities with the outside community; and a selection of the major accomplishments achieved in the Laboratory in calendar year 1996.

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LABORATORY FOR

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Section 2

2. Philosophy

The philosophy of the Laboratory is characterized by:

- carrying out high quality research;
- balancing a scientist's research and programmatic responsibilities;
- enhancing interactions with the academic community, other NASA centers, and federal laboratories;
- supporting Project Scientists who represent the scientific interests of the outside community in NASA's mission; and
- reaching out to the general public, thereby nurturing their interests in atmospheric science.

Quality

The Laboratory places high importance on measuring and promoting quality in its scientific research. About 95% of the work in the Laboratory is funded through a peer review process. The overall quality of the scientific efforts of the Laboratory is evaluated periodically by three standing committees of advisors from the external scientific community. Section 9 contains information on the present membership of these committees.

Balance

It is the nature of our Laboratory to have some relatively large programs often focused on sizable satellite missions or observational campaigns with many associated scientists. This environment is unlike that at most universities. A management goal of the Laboratory is to assure a proper balance between the programmatic needs of large projects and the need for individual scientists to maintain an active research agenda. This balance allows each member of the Laboratory to improve their scientific credentials.

Interactions with the Academic Community

The Laboratory depends on support from universities to achieve its goals. Such cooperation makes the best use of the capabilities of Government facilities and those of academic institutions and assists in the education of new generations of scientists and engineers. Education programs include summer programs for faculty and students, graduate research fellowships, and postdoctoral associateships. The Laboratory frequently supports workshops on a wide range of scientific topics of interest to the academic community (see Section 10 for a list of recent workshops). NASA and non-NASA scientists work together on NASA missions, experiments, and instrument and system developments. Likewise, several Laboratory scientists work on programs residing in universities or other federal agencies. The facilities, large data sets, and software developed within the Laboratory are routinely made available to the outside community. The list of refereed publications, Section 7, is an indication of the intense scientific interactions with the outside community: 71% of the publications involve co-authors from other institutions.

Prime examples of collaboration with the academic community in which the Laboratory is involved include these recently established cooperative agreements with universities:

- the Joint Center for Earth System Science (JCESS) with the University of Maryland at College Park;
- the Joint Center for Earth System Technology (JCET) with the University of Maryland at Baltimore County;
- the Joint Center for Geoscience (JCG) with the Massachusetts Institute of Technology;
- the Joint Center for Observation System Science (JCOSS) with the Scripps Institution of Oceanography, University of California; and
- the Center for Earth-Atmosphere Studies (CEAS) with the Colorado State University.

These joint centers are designed to increase the scientific interactions between the Earth Sciences Directorate at Goddard and the faculty and students at participating universities.

University and other outside scientists visit the Laboratory for periods ranging from one day to as long as two years (see Section 11 for list of recent visitors and Section 12 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, and 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. A list of NRC Research Associates, USRA Visiting Scientists, Visiting Fellows and associates of the Joint Institutes during 1996 is given in Section 13.

Interactions with NASA Centers and Federal Laboratories

The Laboratory maintains strong, productive interactions with NASA centers and federal laboratories. The ties with the NASA centers serve to broaden our knowledge base: they allow us to complement each other's strengths thus increasing our competitiveness, while minimizing a duplication of efforts. They also increase our ability to reach the agency's scientific objectives. Interactions with other federal laboratories result in activities that are synergistic with those funded by NASA Headquarters. The interactions are particularly strong in the area of ozone research, radiation and data assimilation studies, water vapor and aerosols measurements, ground truth activities for satellite missions, and operational satellites.

Project Scientists

A special position exists in NASA to help carry out spaceflight missions. The Project Scientist and the Project Manager are the principal leaders of the Project. The Project Scientist must provide continuous scientific guidance to the Project Manager, must lead a science team, and is the interface between the Project and the scientific community at large. In addition, the function of the Project Scientist provides a unique opportunity for scientific management experience. Typically the Laboratory invites candidates from the senior ranks to fill these roles. Project and Deputy Project Scientists are listed in Table 1.

Project Scientists	
Name	**Project**
Pawan K. Bhartia	EOS CHEM
Pawan K. Bhartia	TOMS
Dennis Chesters	GOES
Yoram Kaufman	EOS AM
Mark R. Schoeberl	UARS
Joel Susskind	POES
Warren J. Wiscombe	GSFC/DAAC
Deputy Project Scientists	
Name	**Project**
Anne R. Douglass	UARS
Charles H. Jackman	UARS
Christian D. Kummerow	TRMM
EOS Validation Scientist	
Name	**Project**
David O'C. Starr	EOS
Aircraft Campaign Co-Project/ Mission Scientists	
Name	**Project**

Yoram Kaufman	TARFOX
Paul A. Newman	STRAT
Paul A. Newman	POLARIS
Mark R. Schoeberl	TOTE/VOTE
David O'C. Starr	SUCCESS
Si-Chee Tsay	TARFOX

Table 1

Outreach

Members of the Laboratory interact with the general public to support a wide range of interests in the atmospheric sciences. The Laboratory raises awareness of atmospheric science through public lectures and demonstrations, making available scientific data of general interest, mentoring students and teachers, teaching, etc. A summary of the Laboratory's outreach activities during 1996 is found in Section 6.

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LABORATORY FOR

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Section 3

3. Organization, Staffing, and Facilities

The current Laboratory staff is comprised of 104 civil servants: 75 of these are scientists with 69 holding doctoral degrees and 11 are engineers. In addition, there are 54 visiting scientists (NRC, JCESS, JCET, USRA) and 222 non-civil service specialists supporting the various projects and research programs throughout the Laboratory.

Branches

The present Laboratory organization (see Chart 1) consists of the following units:

Tropical Rainfall Measuring Mission Office (TRMM), Code 910.1
The Office provides the infrastructure for planning and implementing a Global Validation Program (GVP) to support the TRMM and to support the TRMM Science Team. The Office also conducts relevant scientific studies including rain measurement technology research, precipitation processes studies, radar algorithm development, and the development of methodologies for validating satellite measurements of rainfall. Information on the Office activities can be found on the World-Wide Web (http://trmm.gsfc.nasa.gov/).

Data Assimilation Office (DAO), Code 910.3
Data assimilation combines all available meteorologically relevant observations with a prognostic model to produce accurate time series estimates of the complete global atmosphere. This Office 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 MTPE enterprise. Information on the Office activities can be found on the World-Wide Web (http://dao.gsfc.nasa.gov/).

Mesoscale Atmospheric Processes Branch, Code 912
This Branch studies the physics and dynamics of atmospheric processes through the use of satellite, aircraft, and surface-based remote sensing observations and computer-based simulations. It develops advanced remote sensing instrumentation (primarily lidar) and techniques to measure meteorological parameters in the troposphere. Key areas of investigation are cloud and precipitation systems and their environments from the scale of individual cloud systems to the scale of regional and global climates. Information on the Branch activities can be found on the World-Wide Web (http://rsd.gsfc.nasa.gov/912/).

Climate and Radiation Branch, Code 913
This Branch conducts basic and applied research with the goal of improving the fundamental understanding of regional and global climate on a wide range of spatial and temporal scales. Research emphasis is placed on radiative and dynamical processes leading to the formation of clouds and precipitation and their effects 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 modeling seasonal-to-interannual variability of climate. Information on the Branch activities can be found on the World-Wide Web (http://climate.gsfc.nasa.gov/).

Atmospheric Experiment Branch, Code 915
This Branch carries out experimental investigations to further knowledge and understanding of the formation and evolution of various solar system objects such as planets, their satellites, and comets. Investigations of the composition and structure of planetary atmospheres as well as the physical phenomena occurring in the Earth's upper atmosphere are carried out. Neutral, ion, and gas chromatograph mass spectrometers are developed to measure atmospheric gases from entry probes and orbiting satellites. Information on the Branch activities can be found on the World-Wide Web (http://webhost.gsfc.nasa.gov/Code915/).

Atmospheric Chemistry and Dynamics Branch, Code 916
This 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 the ozone layer. Information on the Branch activities can be found on the World-Wide Web (http://hyperion.gsfc.nasa.gov/).

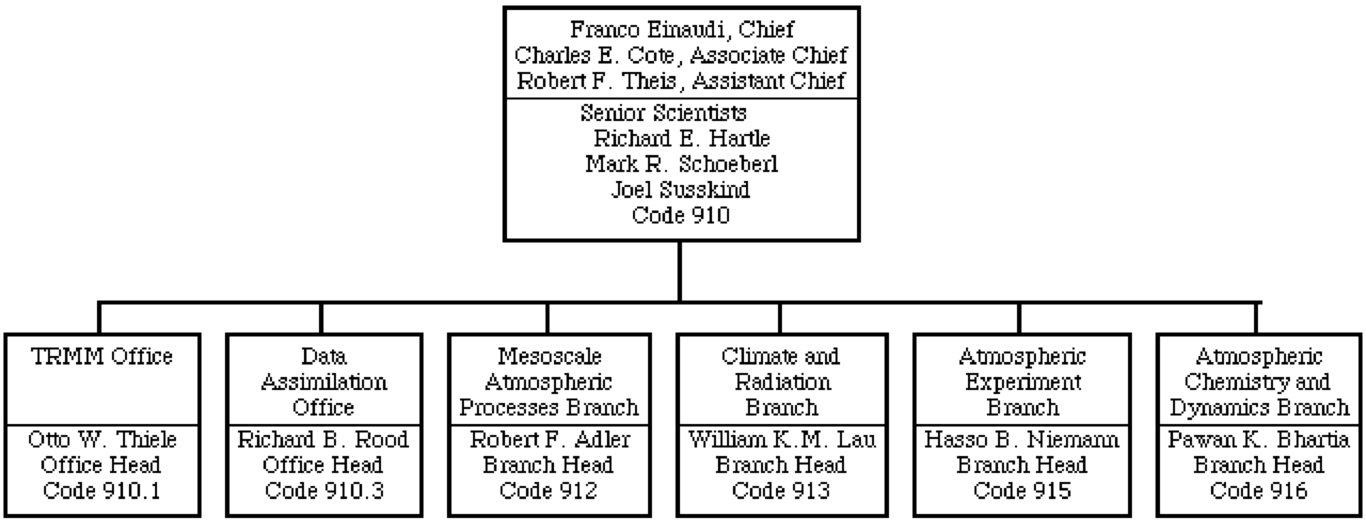

Chart 1. Organization of the Laboratory for Atmospheres

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Facilities

Major Laboratory facilities include:

- Computational Capabilities

The Laboratory computing equipment ranges from high performance supercomputers through scientific workstations to desktop PC and Mac systems. Supercomputers are operated for general use by the NASA Center for Computational Sciences (NCCS). Their flagship machine is a Cray T3D with 512 PE's (DEC 21064 Alpha microprocessor) each with 64 Mbytes of memory. Supercomputer resources are also available through special arrangement from the Ames Research Center at their Numerical Aerospace Simulation (NAS) facility.

Each Branch maintains a distributed system of workstations and desktop personal computers. The following is a sampling of the most capable workstation class machines currently in use within the Laboratory. These machines have been acquired to support particular programs, but may be available on a limited basis for other research.

Code	Machine	Processor	Memory
910.3	DEC Alpha 2100 DEC Alpha 8200 SGI Power Challenge	2 250 MHz 4 300 MHz 8 R10000 194 MHz	2000 MB 500 MB 1000 MB
912	SGI Onyx	2 R10000 194 MHz	1000 MB
916	SGI Power Challenge L	4 R10000 194 MHz	256 MB

- Mass Spectrometry

The Mass Spectrometry Laboratory is equipped with unique facilities for the design, development, fabrication, assembly, calibration and testing of flight mass spectrometers that are used in atmospheric sampling. The equipment includes precision tools and machining, material processing equipment, and calibration systems which are capable of simulating planetary atmospheres. Instruments which have utilized the facility include those for Venus, Saturn and Mars orbiting spacecraft, as well as Jupiter and Titan probes. The Laboratory also has flight instrument assembly and clean rooms, and hazardous gas handling equipment for poisonous and explosive gases.

- Optical Spectroscopy

The Spectroscopy Laboratory is set up to provide data on molecules of atmospheric interest, leading to the design of new scientific instrumentation or to better calibration of existing instruments, primarily in the near ultraviolet (UV). The Laboratory is well-equipped for quantitative spectroscopy and provides moderate spectral (0.03 nm) and temporal (~1 nsec) resolution. The Laboratory also provides a test bed for laser development and various detector technologies. The Laboratory is equipped with tunable and fixed wavelength laser sources, several spectrometers, a gas handling system, and a variety of test equipment.

- 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 200 nm to beyond 10 microns are available as are a range of sensitive photon detectors for use throughout this wavelength region. Telescopes with primaries up to 30 inches in diameter, high speed counting systems for detecting weak signals, and associated hardware are utilized. Lidars developed in the Laboratory include the Airborne Raman Lidar (methane, water vapor and temperature), STROZ LITE (ozone, temperature and aerosols), Large Aperture Scanning Airborne Lidar (clouds and aerosols), Cloud and Aerosol Lidar System (clouds and aerosols), Scanning Raman Lidar (water vapor), and the Edge Technique Wind Lidar System (wind).

- Radiometric Calibration and Development Facility (RCDF)

The RCDF supports the development and calibration of Shuttle demonstration flights for new techniques for ozone measurements operating in the UV, Visible (VIS), and Infrared (IR). 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. The flight Shuttle Solar Backscatter Ultraviolet (SSBUV) instrument, successfully flown on eight shuttle missions, is being reconfigured for ground based measurements so that it can be used as a reference standard for network deployed UV monitors. The RCDF contains state of the art calibration equipment and standards traceable to the National Institutes for Standards and Technology. Calibration capabilities include wavelength, linearity, signal to noise (s/n), Instantaneous Field of View (IFOV), field of regard (FOR), and goniometry. Capabilities also exist to characterize instrument subsystems such as spectral dispersers and detectors. The Facility includes a class 10,000 clean room with a continuous source of N_2 for added contamination control.

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LABORATORY FOR

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Section 4

4. Major Activities

4.1 The Context of Laboratory Research

The research activities of the Laboratory are congruent with the science priorities at NASA Headquarters. Thus, our activities must be seen in the context of NASA programs and goals.

There are four core program areas (or enterprises) in NASA: 1) MTPE, which looks toward our planet to better understand the interactions of its system components and develop a capability to predict its future evolution; 2) Space Science, which explores our star system and beyond to better understand the universe and the origin of life; 3) Human Exploration and Development of Space, which expands the human presence beyond the Earth; and 4) Aeronautics, which develops and transfers innovative flight technologies. The Laboratory's activities are focused mainly on MTPE, with a substantial component directed to Space Science.

Atmospheric Science Activities

MTPE is NASA's contribution to the U.S. Global Change Program. An ambitious program designed to investigate the Earth as an integrated system, MTPE is a program with great scientific challenges and important practical applications. The mission has identified five areas of research as having high priority. From the 1996 "Mission to Planet Earth Strategic Enterprise Plan 1996-2002," these are:

- Atmospheric Ozone

To detect and identify causes of atmospheric ozone changes and evaluate consequences.

- Seasonal-to-Interannual Climate Prediction

To provide global observations and gain scientific understanding to improve forecasts of the timing and geographic extent of transient climate anomalies.

- Long-Term Climate Variability

To provide global observations and gain scientific understanding of the mechanisms and factors which determine long-term climate variations and trends.

- Land Cover Change and Global Productivity

To report and understand the trends and patterns of change in regional land-cover, biodiversity, and global primary production.

- Natural Hazards

To apply MTPE remote sensing science and technologies to disaster characterization and risk reduction from earthquakes, wildfires, volcanoes, floods, and droughts.

The Laboratory atmospheric science activities are outlined in graphic form in Figure 1a with the MTPE science priorities identified at the center. The activities are divided into three groups: measurements and data products, data analysis, and modeling. These groups cut across the MTPE science priorities as well as the organizational structure of the Laboratory. They also correspond to the process of asking the scientific question, identifying the geophysical variable needed to answer it, conceiving the best instrument to measure it, analyzing the data, modeling the results, and asking the next question.

The group activities can be summarized as follows:

Measurements and Data Products

Measurements

The Laboratory has a number of experimental activities distributed throughout the branches. They include:

1) Measurements from Space Laboratory scientists have pioneered the development of space-based ozone measurements since the 60's. This effort involves an active experimental program of measurements from Solar Backscatter Ultraviolet (SBUV) and TOMS, coupled with state of the art UV calibration studies and algorithm development. The resulting 16-year record of TOMS total ozone has played an essential role in understanding the evolution of stratospheric ozone and its trends.

2) Measurements from Ground Based and Aircraft Campaigns

The ER-2 Doppler radar, various ground based and airborne Lidars, and radiometers are conceived to meet numerous objectives: to develop remote sensing capabilities for spaceborne platforms; to help the design and validation of retrieval algorithms; to study cloud properties and the interaction of clouds with aerosol particles and their combined climatic impact; and to measure ozone and trace gases relevant to the chemistry and photochemistry of ozone.

Data Products

The Production of high quality data sets is an important function of the Laboratory for its internal research and for use by the scientific community at large. TIROS Operational Vertical Sounder (TOVS) multiyear temperature and water vapor profiles will contribute to the identification and study of atmospheric properties and changes.

The DAO meteorological reanalysis has produced a multiyear gridded global atmospheric data set for use in climate research, including tropospheric chemistry applications. These data have been widely distributed and have contributed to the improvement of the Goddard EOS (GEOS) General Circulation Model (GCM) and to the understanding of atmospheric behavior. The DAO has the responsibility of incorporating into the analysis the new data types which will be available from MTPE space platforms. The large data volumes associated with MTPE observations require new methodologies for the assimilation of the data.

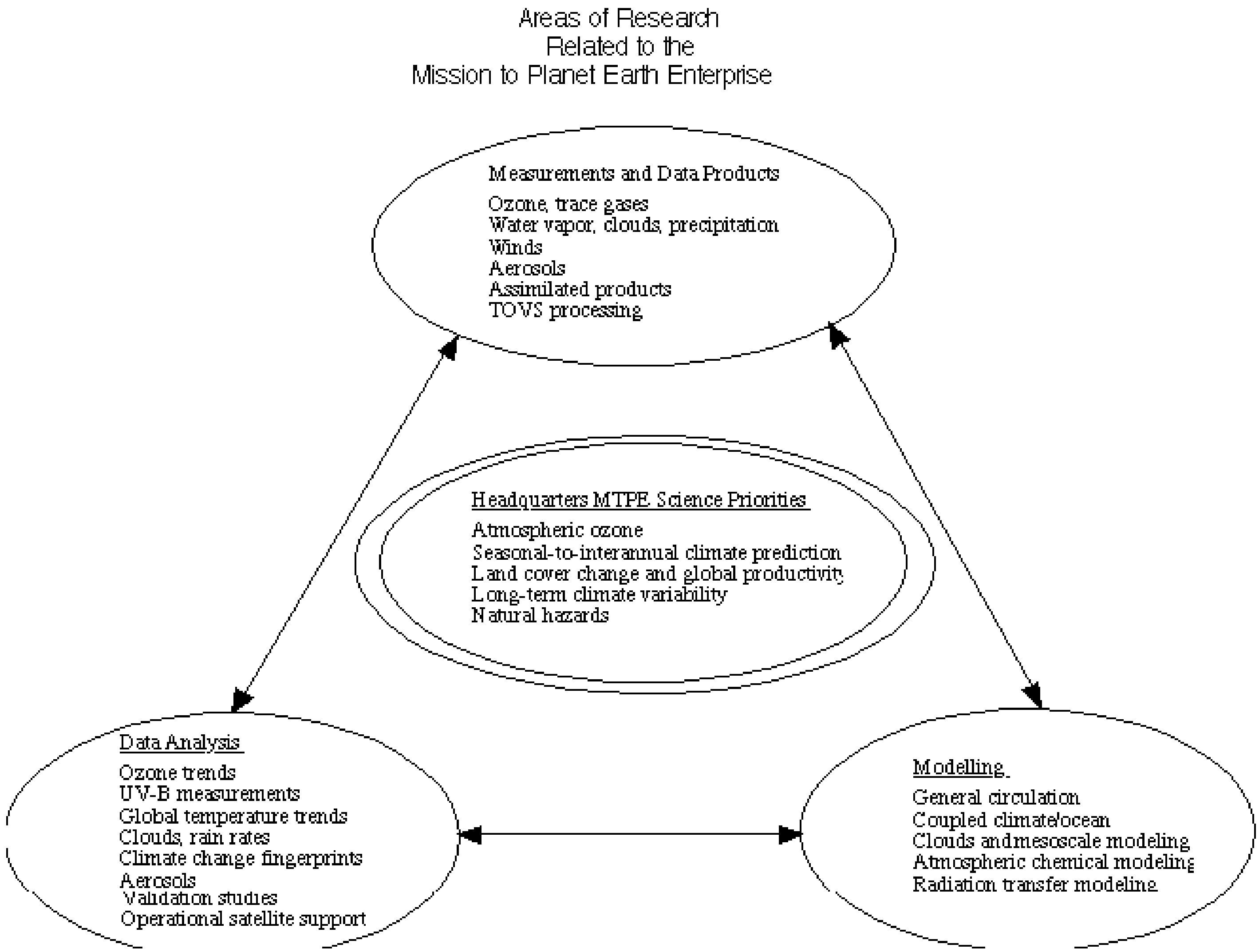

Figure 1a

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Data Analysis

In all research areas substantial efforts are underway in data analysis. The main areas are:

1) Climate Analysis

Advanced analysis techniques are used to identify natural variability on seasonal, inter-annual, and inter-decadal time scales and to isolate it from the anthropogenic signal. The analysis is carried out on a variety of data sets, from satellites, ocean arrays, ground based operational stations, aircraft and other campaigns, validation networks, and data sets from the DAO, the European Center for Medium-Range Weather Forecasting (ECMWF), National Center for Environmental Prediction (NCEP) and other sources.

2) Ozone Trends

Extensive analysis of SBUV, TOMS, aircraft and ground based data on ozone and other trace gases has taken place to identify and explain processes of ozone destruction. Substantial efforts are dedicated to the accuracy of TOMS data, an essential component of ozone trends determination.

3) Aerosols/Cloud Climate Interactions

Extensive studies are underway on the optical properties of aerosols and their effectiveness as condensation nuclei. A variety of data from satellite and experimental campaigns are analyzed to assess the direct and indirect effects of aerosols on climate.

4) Water Vapor and Clouds

Multisensor observations have been utilized to study moisture and water droplet distributions. Analysis of aircraft data shows the potential for contrail cirrus as an anthropogenic factor in climate change. Studies are underway to determine the overall effect of aircraft generated cirrus on climate.

5) Rain Measurements from Space

Laboratory scientists have been involved in algorithm development for measurement of rain rates from space, through the analysis of satellite data, radar and ground based information. This analysis is essential for gaining a better understanding of the hydrologic cycle.

Modeling Studies

The overall goal of the MTPE Program is to determine the causes and the extent of environmental change. A key part of this effort is the development of integrated models which use observations from EOS instruments as well as from standard sources. The ultimate goal is for these models to have predictive capabilities.

Atmospheric models are being developed and used in the following areas:

1) Regional/Cloud Scale Processes

Two- and three-dimensional cloud and regional scale models are used to study classical meteorological problems such as convective systems in the tropics and in mid-latitudes, transport of aerosols and trace gases, stratospheric-tropospheric exchange, air-sea interaction and its cloud-climate feedback. Cloud models are an intrinsic part of the development of retrieval algorithms designed to make maximum use of data that will be produced by the forthcoming TRMM mission. Regional models are also used to develop and test parameterization schemes to be utilized in GCM's.

2) Climate Variability

GCMs are an essential tool to study seasonal, inter-annual, and inter-decadal time scales and to isolate natural variability from the anthropogenic global change signal. In collaboration with the Laboratory for Hydrospheric Processes, substantial efforts are devoted to El Niño Southern Oscillation (ENSO) with the ultimate goal of assessing the role of satellite data on our ability to study and predict the phenomenon. Particular attention is devoted to the development of parameterization codes for radiation and moisture processes which play an essential role in climate sensitivities to cloud microphysics, water vapor, and other trace gases, and in the global water and energy cycles.

3) Trace Gas Modeling

Two- and three-dimensional global models and chemical trajectory models have been developed to interpret the data from various sources including satellites, aircraft, sondes, and ground based stations. They are used to simulate natural and man-made influences on ozone, to study atmospheric motions and transport of trace gases and ultimately to predict quantitative changes in the chemical composition of the atmosphere.

Thus, the activities of the Laboratory relate strongly to the atmospheric ozone, seasonal-to-interannual climate prediction, and long-term variability science priorities of MTPE, and have some connections with the land cover change and global productivity and natural hazards.

Space Science Activities

The Space Science program area seeks to explore and understand the sun, the solar system, the galaxies, and the universe for the benefit of humanity. The programs in the Office of Space

Science are centered around four themes corresponding to fundamental questions.

From the 1995-2000 Strategic Plan "Space Science for the 21st Century" they are:

- The Galaxy and the Universe

What is the Universe? How did it come into being? How does it work? What is its ultimate fate?

- The Connection between the Sun, Earth, and Heliosphere

How does the Sun influence the Earth and the rest of the solar system? What causes solar variability?

- The Origin and Evolution of Planetary Systems

What was the origin of the Sun, the Earth, and the planets, and how did they evolve? Are there worlds around other stars? What are the ultimate fates of planetary systems?

- The Origin and Distribution of Life in the Universe

How did life on Earth arise? Did life arise elsewhere in the universe?

The activities in the Laboratory relate primarily to the second and third theme and are outlined schematically in Figure 1b. The Laboratory has a long history of theoretical and experimental research on the atmosphere of the Earth, beyond the stratosphere, and of other planets. Ion and neutral composition, neutral temperature and wind, and electron temperature and density measurements have been made by Laboratory instruments on the Atmosphere Explorers, Dynamics Explorer, Pioneer Venus Orbiter, and the Galileo missions.

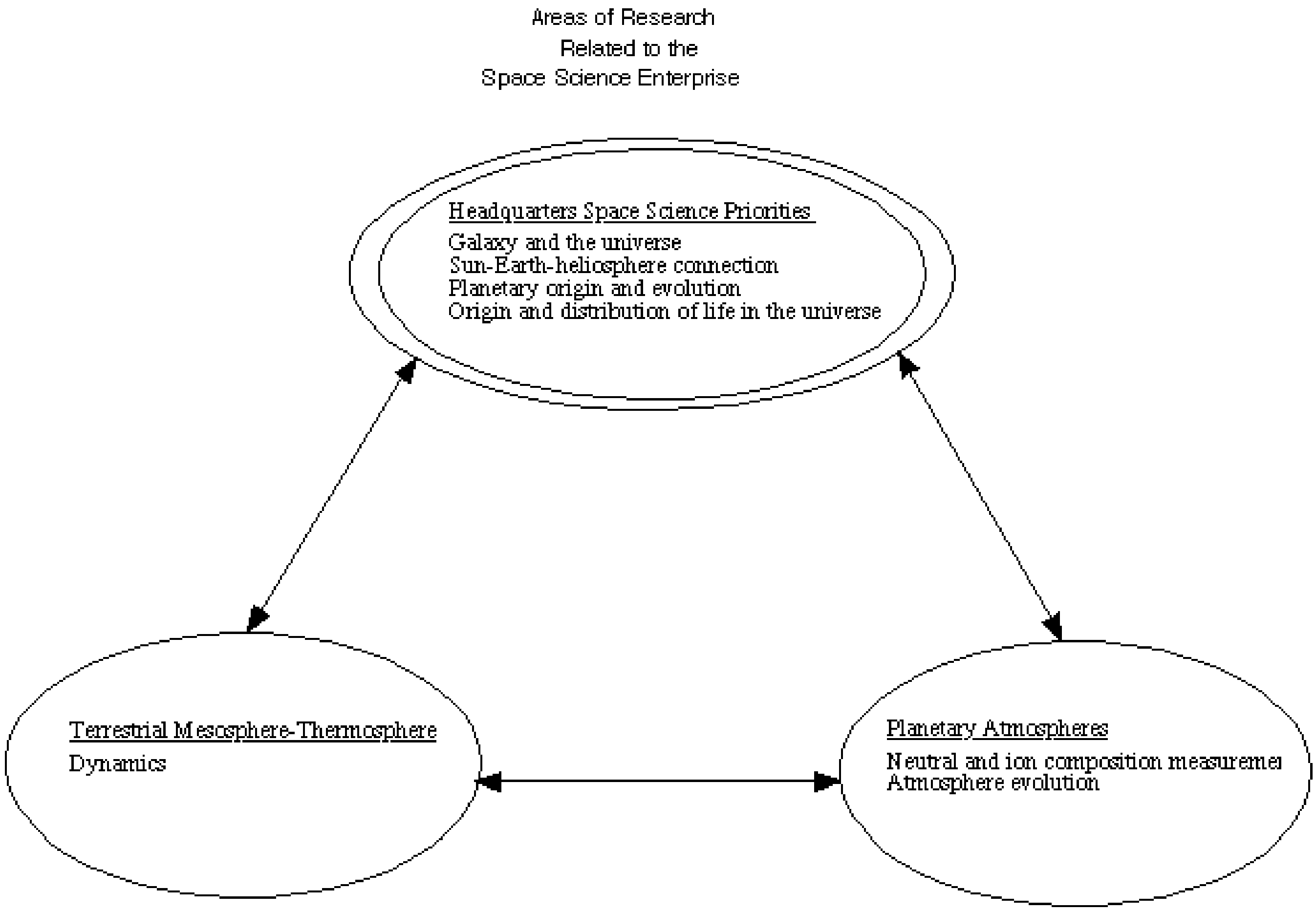

Figure 1b

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Ongoing experimental work includes the Gas Chromatograph Mass Spectrometer (GCMS) to measure the chemical composition of gases and aerosols in the atmosphere of Titan, and the Ion and Neutral Mass Spectrometer (INMS) to measure the chemical composition of positive and negative ions and neutrals in the inner magnetosphere of Saturn and in the vicinity of the icy satellites. Work has just started on a Neutral Mass Spectrometer to measure the neutral atmosphere of Mars, to be flown on a joint mission with Japan.

Major activities in the Laboratory are outlined in this section. Highlights for calendar year 1996 are described in Section 5, which has some overlap with Section 4.

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4.2 Measurements and Data Products

Data Assimilation

The core activities of the DAO are focused on meteorological research, development, and applications of the GEOS Data Assimilation System (DAS). The GEOS DAS is designed to produce research-quality data sets for the MTPE Enterprise. These data sets are derived from diverse sources, are checked for physical and dynamical consistency, and go through a rigorous quality control process. Continuous near real-time production for EOS will start with the launch of the first EOS platform (AM-1). Data sets produced prior to AM-1 will also be an important part of the development effort. The data products of the DAO complement and supplement the EOS observations by providing estimates of unobserved quantities and advanced quality control.

The GEOS-1 DAS is the baseline for later versions of the data assimilation system. It is described in [1]. The GEOS-1 DAS has been used to produce a meteorological data set covering the period from 1980-1993. Other configurations of GEOS-1 DAS are being used to produce stratospheric data sets and forecasts providing real time support for aircraft missions to study ozone chemistry. The GEOS-1 DAS has been used in a wide variety of applications [2], including tropospheric and stratospheric chemistry, interannual variability of climate dynamics, and regional flood and drought cycles. A copy of the GEOS-1 DAS data sets and the DAO tracer transport model has been transferred to Lawrence Livermore National Laboratory for use in atmospheric chemistry assessments of aircraft emissions.

The current version of the DAS is GEOS-2. Its characteristics are highlighted in the major accomplishments section. GEOS-3 DAS will be the operational system for the 1998 launch of the EOS AM-1 platform. Recently, parameterizations for land surface [3] and cloud water [4] were incorporated into the GEOS-2 GCM. These developments provide enhanced surface and lower atmospheric capabilities for the AM-1 platform. Further development of the Physical-space Statistical Analysis System (PSAS), adaptive representation of error covariances, and more sophisticated quality control will provide the basis of the analysis system for GEOS-3. Recent prototypes of marine surface wind and precipitation assimilation techniques show positive impact on the representation of the atmosphere's general circulation by the GEOS DAS. Assimilation of these fundamental climate system quantities will provide significant improvements in the GEOS-3 system. The GEOS-3 DAS is described in the DAO Algorithm Theoretical Basis Document which is available from the DAO at http://dao.gsfc.nasa.gov/subpages/atbd.html. Much of the framework for the GEOS-3 analysis development is given in [5].

1. "An Assimilated Data set for Earth Science Applications," S. D. Schubert, R. B. Rood, J. W. Pfaendtner, *Bull. Amer. Meteor. Soc.*, **74**, 2331-2342, 1993.

2. NASA Technical Memorandum #104606, R. Rood and S. Schubert, **7**, 1995.

3. "Modeling the Land Surface Boundary in Climate Models as a Composite of Independent Vegetation Stands," R. Koster, D. Randal, and M. J. Suarez, *J. Geophys. Res.*, **97**, D3, 2697-2715, 1992.

4. "A Prognostic Cloud Water Parameterization for Global Climate Models," A. D. DelGenio, M.-S. Yao, W. Kovari, and K. K.-W. Lo, *J. Clim.*, **9**, 270-304, 1996.

5. "An Introduction to Estimation Theory," S. E. Cohn, to appear *J. Meteor. Soc.*, Japan, 1997.

Data Sets for Climate Analysis

- TIROS Operational Vertical Sounder (TOVS) Pathfinder

The Pathfinder Projects are joint NOAA/NASA efforts to produce multiyear climate data sets using observations from operational satellites. These include TOVS which is comprised of three atmospheric sounding instruments, the High Resolution Infrared Sounder-2 (HIRS-2), the Microwave Sounding Unit (MSU), and the Special Sensor Unit (SSU) which have flown on the NOAA Operational Polar Orbiting Satellite since 1979. An algorithm developed in the Laboratory to infer temperature and other surface and atmospheric parameters from TOVS observations is being used to reprocess TOVS data from 1979 to 1995. The data are used to study global and regional natural variability and trends between surface and atmospheric anomalies.

Trace Gas Measurements

The Clean Air Act Amendment of 1977 has assigned NASA and NOAA major responsibilities for studying the ozone layer. In the 60's and 70's Laboratory scientists pioneered the development of a space-based ozone measurement system. This group plays a major role in the measurement and modeling of atmospheric trace gases in the middle and upper stratosphere and actively participates in the World Meteorological Organization (WMO) and NASA sponsored assessments of the depletion of the ozone layer. The focus of this group is now shifting towards the lower stratosphere and the upper troposphere, as part of new NASA initiatives to understand the effects of commercial aircraft on this chemically complex region of the atmosphere.

- Long-Term Monitoring of Ozone

Analysis of data from the Backscatter Ultraviolet (BUV) instrument series, begun in 1970, continues to be an active area of research within the Laboratory. The original BUV instrument and its follow-on instruments, Solar BUV (SBUV/SSBUV) and TOMS, played a major role in monitoring anthropogenic effects on ozone. The ozone group works actively with NOAA in producing high quality ozone data from the SBUV/2 instruments on the NOAA polar orbiters. The RCDF previously described is responsible for pre-launch calibration of these instruments. In addition to satellite monitoring, ground-based and aircraft lidar measurements of ozone and other trace gases are being made a part of the Network for Detection of Stratospheric Change.

- Atmospheric Effects of Aviation Project (AEAP)

The Atmospheric Chemistry and Dynamics Branch contains the Project Office of the AEAP which sponsors research to evaluate the impact of the current fleet of subsonic and proposed high-speed civil aircraft on stratospheric and tropospheric ozone and climate. AEAP is a project of the Office of Aeronautics at NASA HQ, run in coordination with observational and theoretical Programs in MTPE. Elements of this program include aircraft campaigns and modeling of photochemistry and transport, and of cloud-radiation interactions. Aircraft campaigns in 1996 included SUbsonic aircraft: Contrails and Cloud Effects Special Study (SUCCESS) (with the DC-8), directed at studying cloud-contrail-cirrus interactions, and partial support for Stratospheric Transport of Atmospheric Tracers (STRAT) (with the ER-2) directed towards understanding transport between different regions of the atmosphere. The Global Modeling Initiative is a multi-institutional effort that is assembling various contributed software modules to create a coupled chemical-transport model, with a shared code resident at Lawrence Livermore National Laboratory.

Rain Measurement Validation for TRMM

The TRMM GVP objective is to provide reliable area/time averaged rainfall data from numerous representative tropical and sub-tropical sites world-wide for comparison with TRMM satellite measurements. Rainfall measurements are made at Ground Validation (GV) sites equipped with weather radar, raingauges, and disdrometers. A range of data products derived from measurements obtained at GV sites will be available at the TRMM Science Data and Information System (TSDIS). The list of 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 meeting mission requirements.

During the pre-mission phase, the emphasis will be on rain measurement research, precipitation physics, development of measurement and procedural techniques for calibrating the mission GV sites, development of algorithms and software for generation of standardized products, provision of operational software to TSDIS, and establishment of procedures to assure a reliable flow of data and products to the TRMM Science Team. Long term, climatological rainfall data bases are also being collected and analyzed for each site. Field campaigns during the flight phase will also be an important element of the validation process.

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4.3 Data Analysis

Climate Analysis

Climate analysis seeks to identify natural variability on seasonal, inter-annual, and inter-decadal time scales, and to isolate the natural variability from the anthropogenic global change signal. Climate diagnostic studies use a combination of remote sensing data, historical climate data, model outputs and assimilated data. The most often used datasets include radiation data from the Earth Radiation Budget Experiment (ERBE), the International Satellite Cloud Climatology Project (ISCCP), the Outgoing Longwave Radiation (OLR) from Advanced Very High Resolution Radiometer (AVHRR), and the water vapor from TOVS; and rainfall data from the Global Precipitation Climatology Project (GPCP), the Comprehensive Ocean Atmospheric Data Set (COADS), the Tropical Ocean Atmosphere (TOA)-Array, and the assimilated data products from the DAO and others. Studies are also conducted to unravel the physics of ENSO, quasi- biennial oscillation, intraseasonal oscillation, and monsoon variability as well as water vapor and cloud feedback processes. Advanced analysis techniques including multivariate singular value decomposition, wavelets, and fractal characterization are used.

Rain Estimation Techniques from Satellites

A number of techniques have been developed to extract rainfall information, a key element in the study of the hydrologic cycle, from current spaceborne sensor data (Special Sensor Microwave/Imager [SSM/I]) and for potential use with data from future space missions (TRMM, EOS/Advaned Microwave Scanning Radiometer [AMSR]). The retrieval techniques belong to four categories: 1) physical/empirical relationships which exist between polar-orbit SSM/I measurements and rain rates; 2) a theoretical, multifrequency technique which relates the complete set of microwave brightness temperatures to rainfall rate at the surface; 3) an empirical relationship which exists between cloud thickness and rain rates, using TOVS sounding retrievals; and 4) an analysis technique which uses low-orbit microwave, geosynchronous infrared and raingauge information to provide a merged, global precipitation analysis.

The multifrequency technique (category 2) also provides information on the vertical structure of hydrometeors and 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. Scientists involved in rainfall algorithm development participate in international rainfall intercomparison studies such as the recent third Precipitation Intercomparison Project (PIP-3) involving satellite-based global rainfall maps and precipitation fields calculated from global models.

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 for producing different drop size distributions in clouds, which in turn will affect the radiative balance of the atmosphere. Algorithms are being developed for routine derivation of aerosol loading optical properties and total precipitable water vapor from the future EOS-Moderate Resolution Imaging Spectrometer (MODIS) data. These algorithms are based on Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), MODIS simulator, AVHRR and Landsat Thematic Mapper (TM) data. Laboratory scientists are actively involved in the analysis of data recently obtained from national and international campaigns of Smoke, Clouds And Radiation-Brazil (SCAR-B), SUCCESS, and Tropospheric Aerosol Radiative Forcing Observational eXperiment (TARFOX). Preliminary results show distinct differences in aerosol characteristics between SCAR-B (biomass burning) and TARFOX (industrial pollution) data. In SCAR-B, diurnal variation in particle concentrations and lognormal size distributions were clearly observed, which was not the case for TARFOX. However, aerosols from both sources serve as cloud condensation nuclei. In SUCCESS, small ice particles formed by jet exhaust frequently remained airborne for a long period of time. Microphysical properties of cirrus clouds observed in contrails differ from those of cirrus observed away from contrails. In turn, their optical and radiative properties were quite different. Extensive studies to assess the climatic impact by the direct and indirect effects of aerosols are underway.

Hydrologic Processes and Radiation Studies

Methods are being developed for the estimation of the atmospheric water and energy budgets, including calculating the radiative effects of absorption, emission and scattering by clouds, water vapor, aerosols, CO_2, and other trace gases. Both observational and modeling approaches are applied to study the interaction of clouds, water vapor, and radiation, and the effect on climate. The observational data include the ERBE radiation budgets, ISCCP clouds, Geostationary Meteorological Satellite (Japan) radiances, NCEP sea surface temperature, as well as Tropical Ocean Global Atmosphere Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) observations, whereas the models include the GEOS GCM and the Goddard Cloud Ensemble model (GCE). The response of radiation budgets to changes in water vapor and clouds are studied during El Niño events in the Pacific basin and during westerly wind-burst episodes in the western tropical Pacific warm pool. The relative importance of large-scale dynamics and local thermodynamics on clouds and radiation budgets and modulating sea surface temperature are investigated.

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4.4 Modeling

Cloud and Mesoscale Modeling

There are two models in this area: a cloud-resolving model (GCE) and a regional/mesoscale model (Penn State/National Center for Atmospheric Research [NCAR] Mesoscale Model Version 5 [MM5]). These models are used for:

1) Classical meteorological applications such as the study of the dynamic and thermodynamic processes associated with frontal rainbands, surface (ocean, land, and soil) effects on atmospheric convection, cloud-chemistry interactions, tropical and midlatitude convective systems, stratospheric-tropospheric interaction, and of the effects of assimilating satellite derived water vapor and precipitation fields on tropical and extra-tropical regional-scale weather simulations.

2) Climate applications involving long-term integrations. These allow the study of air-sea interactions and their application to the cloud-climate feedback mechanisms; and surface energy, radiation, diabatic heating and water budgets associated with the weather systems studied during TOGA-COARE (i.e., Westerly Wind Bursts and super cloud clusters).

3) Applications for retrieval algorithms. The GCE model is providing the TRMM investigators with four dimensional data sets (hydrometeors/latent heating) for the development and improvement of TRMM rainfall and heating retrieval algorithms.

Physical Parameterization in Atmospheric General Circulation Models

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 the development and improvement of physical parameterizations in two major areas: radiative transfer and moisture processes in the atmosphere. Both areas are extremely important for better understanding of the global water and energy cycles. For atmospheric radiation, efficient, accurate and modular longwave and shortwave radiation codes are being developed. The radiation codes allow the efficient computation of climate sensitivities to water vapor, cloud microphysics and optical properties and global warming potentials of carbon dioxide and various trace gases. For atmospheric hydrologic processes, a new prognostic cloud liquid water scheme is being developed 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. Both the radiation and the prognostic water scheme are being tested with *in situ* observations from Atmospheric Radiation Measurement (ARM) and TOGA-COARE. The radiation schemes are being incorporated into the latest version of the GEOS model and the GCE model.

Trace Gas Modeling

In addition to long-term monitoring, a comprehensive research program is underway to understand the chemical and dynamical processes that govern the formation and destruction of ozone. The overall goal of the trace gas modeling program is to understand the trends in ozone and other trace gases, and to predict future changes in the ozone layer as a result of natural and anthropogenic influences. The trace gas modeling effort has four components: (1) Lagrangian models: These chemical 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: These latitude-height models have comprehensive chemistry but use specified, parameterized dynamics. They are used both in data analysis and multidecadal chemical assessment studies. (3) Two-dimensional interactive models: These 2D models have interactive radiation and dynamics and can study the dynamical impact of major chemical changes. (4) Three dimensional (3D) models: These models have a full chemistry package and use the analyzed wind fields for transport. The 3D models are used to interpret observations, assess the impact of aircraft pollution, and determine the accuracy of the two dimensional models.

Trace gas data from sensors on the Upper Atmosphere Research Satellite (UARS) and from various NASA sponsored aircraft and ground based campaigns are used in rigorous testing of the 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. Trace gas simulations in 3D models using winds and temperature from GEOS DAS provide a test of the consistency of the meteorological fields with the trace gas observations and the photochemical model, which is an important step towards constituent assimilation.

Coupled Atmosphere-Ocean-Land Models

To study climate variability and sensitivity, it is necessary to couple the atmospheric GCMs to ocean and land-surface models. Much of the work in this area is conducted in collaboration with the Laboratory for Hydrospheric Processes. 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, snow and ice accumulation sublimation and melt, and groundwater budgets.

Coupled ocean-atmosphere models are used to study inter-annual to inter-decadal time scales, with emphasis on phenomena such as the ENSO. Atmosphere-land coupled models are used to study the physical mechanisms responsible for the maintenance of the global hydrologic cycle and the role of land-surface processes in interannual climate variability. Climate experiments have been carried out with atmosphere-land models on monsoon simulations, deforestation experiments, atmospheric teleconnections, effects of radiation on large scale dynamics, and the interaction of soil moisture and precipitation.

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4.5 Spaceflight Missions

Spaceflight missions are central to NASA's ability to carry out its science programs. Global change studies require a comprehensive set of observations from existing and planned missions. Likewise, planetary sciences will rely on instruments such as gas chromatographs and mass spectrometers to study the atmospheres of planets. A number of research missions are planned for the 90's and beyond to meet these goals.

Members of the Laboratory are Project and Deputy Project Scientists for the following missions (launch dates shown in parenthesis):

1) UARS

To understand the chemistry and dynamics of the stratosphere and mesosphere. (1991)

2) TOMS Missions

To provide daily mapping and long-term trend determination of total ozone and to obtain information on tropospheric ozone, dust, and aerosols. (1996)

3) TRMM

To understand global energy and water cycles by providing distributions of climatological rainfall and inferred heating over the tropics. (1997)

4) EOS AM

To study the terrestrial and oceanic surfaces, clouds, radiation, and aerosols. (1998)

5) EOS/CHEM

To understand the atmospheric chemical species and their transformations. (2002)

Principal Investigators for the following instruments are members of the Laboratory:

1) TOMS on Earth Probe and Advanced Earth Observing System (ADEOS) Missions

úTo provide daily mapping and long-term trend determination of total ozone. (1996)

2) IR Spectrometer Imaging Radiometer (ISIR)

To improve infrared observations of clouds and the surface from the Space Shuttle with greater coverage and temporal sampling in combination with microwave and active optical sensing. It is based on smaller and more reliable infrared imaging using uncooled array detectors. (1997)

3) Huygens Probe: GCMS

To determine the chemical composition of gases and aerosols in the atmosphere of Titan . (1997)

4) Cassini: INMS

To determine the chemical composition of positive and negative ions and neutrals in the inner magnetosphere of Saturn and in the vicinity of the icy satellites. (1997)

5) Planet-B: Neutral Mass Spectrometer

To measure the composition of the neutral atmosphere of Mars to improve knowledge and understanding of energetics, dynamics and evolution of the atmosphere. The mass spectrometer will be flown on a spacecraft developed by the Institute of Space and Astronautical Science, Japan. (1998)

6) Shuttle Ozone Limb Sounding Experiment (SOLSE)/Limb Ozone Retrieval Experiment (LORE)

An experimental payload designed to demonstrate the measurement of the vertical distribution of ozone from the upper stratosphere to the lower troposphere. SOLSE is a photometer which uses a Charge Couple Device (CCD) detector to measure the mid to upper stratosphere limb; LORE is an imaging spectrometer which uses three filters and linear arrays to measure the lower troposphere limb. The first flight experiment is aboard STS 87. (1997)

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4.6 Aircraft, Balloon, and Ground Based Instruments

The experimental programs of the Laboratory involve laboratory, field and space experiments using *in situ* and remote sensing instruments. Instrument systems are conceived, designed and developed for flight on rockets, balloons, and aircraft and for ground based observations. These systems are outlined according to the scientific disciplines they serve (Figure 2). The use of balloon and airborne platforms provides a view of processes such as precipitation and cloud systems from high in the atmosphere. Such platforms serve as a step in the development of space borne instruments. For some instruments, such as the Cloud Lidar and the lidar for measuring winds, plans are underway to propose them for space missions.

Instrument Research and Development Programs				
	Atmospheric Structure and Dynamics	**Atmospheric Chemistry**	**Clouds and Radiation**	**Planetary Atmospheres/ Solar Influences**
Space		Shuttle Ozone Limb Sounding Experiment (SOLSE) Raleigh Scattering Attitude Sensor (RSAS) Limb Ozone Retrieval System (LORE) (Shuttle)	IR Spectrometer Imaging Radiometer (ISIR) (Shuttle)	Solar EUV Flux Monitor Galileo Probe Mass Spectrometer Cassini Gas Chromatograph Mass Spectrometer (GCMS) Cassini Ion Neutral Mass Spectrometer (INMS) Planet B Mass Spectrometer Rosetta Rendezvous and Lander Mass Spectrometer
Aircraft	Large Aperture Scanning Airborne Lidar (LASAL) Holographic Scanner for Lidar ER-2 Doppler Radar (EDOP)	Methane Raman Lidar (DC-8)	Visible and IR Lidar (VIRL)(DC-8) Cloud Lidar System (CLS)(ER-2) Visible and IR Cloud Radiometer (ER-2) Tilt Scan CCD Camera (ER-2)	Solar Disc Sextant(Balloon)
Ground	Water Vapor Raman Lidar Holographic Circle to Line Converter for Lidar Direct Detection Wind Lidar (Edge Technique)	Ozone Lidar Temperature and Aerosol Lidar Tropospheric Ozone Lidar	Micro-Pulse Lidar	

Figure 2

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All instrument systems provide information leading to basic understanding of relations between atmospheric systems and processes, and/or serve as calibration references for satellite instrument validation. Principal instruments and their objectives are:

Aircraft Instruments

1) Cloud Lidar System (CLS)

Measures cloud and aerosol structure from the high altitude ER-2 aircraft for combined integration of multispectral visible, microwave, and infrared imaging radiometers. The data are used in radiation and remote sensing studies.

2) Tilt Scan CCD Camera (TSCC)

Measures bi-directional reflectance of high and low clouds used in cloud radiative transfer studies and remote sensing applications.

3) ER-2 Doppler Radar (EDOP)

Measures vertical rain and wind structure of precipitation systems to improve understanding of mesoscale convective system structure and spaceborne rain measurement algorithm validation.

4) Large Aperture Scanning Airborne Lidar (LASAL)

Measures atmospheric backscatter with emphasis on boundary layer height and structure. Capable of (raster) scanning at up to 90 degrees per second and providing three-dimensional aerosol structure of the lower troposphere and boundary layer.

5) Airborne Raman Lidar (ARL)

Measures the structure and concentration of methane in the troposphere and lower stratosphere to contribute to understanding the chemistry of this region.

Balloon Instrument

Solar Disk Sextant (SDS)

Measures the diameter of the Sun to milli-arc second accuracy to determine the relation between the diameter and the solar constant.

Ground Based Instruments

1) Raman Lidar

Measures light scattered by water vapor, nitrogen, oxygen, and aerosols to determine the water vapor mixing ratio, aerosol backscattering, and aerosol extinction and their structure in the troposphere. These trailer-based measurements are important for studies of radiative transfer, convection, and the hydrological cycle, as well as for assessing the water and aerosol measurement capabilities of surface, aircraft, and satellite-based instruments.

2) Doppler Lidar

Measures winds in the planetary boundary layer, using the Edge Technique. It is expected to be extended to the full troposphere in 1997.

3) Micro Pulse Lidar (MPL)

Makes quantitative measurements of clouds and aerosols. It is a unique "eye-safe" lidar system that operates continuously 24 hours a day in an autonomous fashion,

4) Stratosphere Ozone Lidar Trailer Experiment (STROZ LITE)

Measures the structure and concentration of ozone.

5) TRMM Validation

Doppler and polarimetric radars, supported by specifically developed disdrometers and rainrate gauges are the fundamental components of the TRMM Validation effort.

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4.7 EOS Interdisciplinary Investigations

The overall goal of the 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 for 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. The latter investigations are to improve understanding of the Earth as a system by developing and refining integrated models which will use observations from EOS instruments. The Laboratory is carrying out the following two interdisciplinary science investigations:

1) Global Hydrologic Processes and Climate

The goal is to provide a description and a better understanding of the global hydrologic and energy cycle. The investigation focuses on three scientific objectives aimed at improving understanding of the following: the physical mechanisms of atmospheric hydrologic processes; the role of hydrologic processes in large-scale ocean, atmosphere, and land interactions; and the role of land surface processes in the global hydrologic cycle.

2) Stratospheric Chemistry and Dynamics

The goal is to separate natural from anthropogenic changes in the Earth's atmosphere, to determine their effects on ozone, and to assess radiative and dynamical feedbacks. This will be done by analysis of stratospheric chemical and dynamical observations from EOS instruments and current satellites and aircraft campaigns. This includes a study [1] concerning the processes which produce the Antarctic ozone hole and the interannual differences in the amount of ozone lost. The study combines UARS data, trajectory modeling, and TOMS observations. Reports from this investigation can be found on the World-Wide Web (http://hyperion.gsfc.nasa.gov/EOS/EOS.html).

1. "Development of the Antarctic Ozone Hole," M. R. Schoeberl, A. R. Douglass, S. R. Kawa, A. E. Dessler, P. A. Newman, R. S. Stolarski, A. E. Roche, J. W. Waters, and J. M. Russell, *J. Geophys. Res.-Atmos.*, **101**, 20909-20924, 1996.

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4.8 Support for NOAA Operational Satellites

Goddard supports NOAA remote sensing requirements. Laboratory Project Scientists support the NOAA Polar Orbiting Environmental Satellites (POES), also referred to as Meteorological Satellites (METSAT), 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 which is now operational within NOAA/National Environmental Satellite Data and Information Service (NESDIS), with a series of SBUV/2 instruments flying on POES/METSAT. 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.

GOES

NASA GSFC project engineering and scientific personnel support NOAA for the GOES-I/M satellites for the periods 1994-2004. GOES supplies images and soundings to study atmospheric processes, such as haze, 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, where it is otherwise unobservable. In addition to high quality imagery, the new 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 expected to improve NOAA's numerical weather forecasts of local weather by the late 1990's. Meanwhile, the GOES Project Scientist at GSFC provides free public access to real-time weather images for regions all over the western hemisphere via the World-Wide Web (http://climate.gsfc.nasa.gov/).

POES

Algorithms are being developed and optimized for analysis of data from HIRS-3 and the Advanced Microwave Sounding Unit (AMSU) when launched on NOAA K in 1997. Simulated data for the Atmospheric Infrared Sounder (AIRS) is being analyzed to assess its utility for the next operational meteorological sounding system on NOAA N' in 2007 and the NOAA/DOD/NASA converged platform in 2010. The applicability of the Interferometer Temperature Sounder (ITS), another proposed advanced infrared sounder, is being assessed for potential use as the future operational infrared sounder.

SBUV/2

NASA's responsibility is to monitor the pre-launch and post-launch calibration of the SBUV/2 and to develop new algorithms to process ozone more accurately. Laboratory scientists recently developed an algorithm that was used to reprocess the NOAA 11 SBUV/2 data record, covering the period from January 1989 to the present. The algorithm is designed to increase the accuracy of ozone measurements in the Antarctic ozone hole. The absolute calibration was set through comparison with SSBUV, while the relative calibration was stabilized through January 1993 to within ± 2-5% per decade. This SBUV/2 data set was joined with the NASA SBUV record to produce a continuous 15 year record of ozone. The resulting trends were reported in the 1994 WMO United Nations Environment Program (UNEP) report.

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LABORATORY FOR

ATMOSPHERES

Section 5

5. 1996 Highlights

Laboratory scientists have contributed directly to the advancement of Earth and space science by publishing 176 articles in refereed journals during the past year (listed in Section 7), as well as presenting talks and written articles for public and professional audiences. Other publications by Laboratory scientists include NASA Technical Memoranda, technical books and book chapters, and expositions related to national and international scientific policy issues (listed in Section 8). While it is not possible to mention all of these accomplishments in this report, a few examples illustrate the breadth and quality of Laboratory achievements. These examples correspond to work completed or nearly completed during 1996. The selection was somewhat subjective and time will tell the ultimate impact that these contributions will have.

All the highlights listed below are the achievements not only of civil servants and non-civil servants who work in the Laboratory, but also of many other colleagues at Goddard, at NASA Headquarters, at other NASA centers (Ames, Langley, Jet Propulsion Laboratory (JPL), and Marshall, in particular), at private companies, and at other government laboratories and universities in the United States and abroad.

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5.1 Measurements and Data Products

Planetary Atmospheres

- Cassini Mission to Saturn

The Atmospheric Experiment Branch delivered two instruments which are part of the Cassini Mission to Saturn: the INMS for the Orbiter and the GCMS for the Huygens Probe. The Cassini Mission to Saturn is a joint effort between NASA and the European Space Agency (ESA). The Saturn Orbiter is under development by NASA; the Huygens Probe will investigate the atmosphere of Titan and is under development by ESA.

The GCMS is a very versatile gas chemical analyzer designed to identify and quantify the abundances of various constituents in the atmosphere of Titan, including argon, other noble gases, and isotopes. Its Qualification Model (QM) and Flight Model (FM) were delivered to Daimler-Benz Aerospace in Germany for integration on the Huygens Probe.

The INMS is intended to measure positive ion and neutral species composition and structure in the upper atmosphere of Titan and the ion and neutral environments of Saturn's icy satellites, rings and magnetosphere. The INMS Engineering Model was delivered to the JPL for integration on the Saturn Orbiter.

Launch of the Cassini Spacecraft is scheduled for October 1997 with Saturn encounter in 2004.

Data Assimilation Studies

- GEOS-2 Data Assimilation System (DAS)

Validation tests show that the GEOS-2 DAS provides a significant improvement over GEOS-1 DAS. GEOS-2 DAS is the baseline version of the GEOS DAS system which will become the operational system in support of the EOS AM-1 platform. GEOS-2 DAS is being used to provide support for ADEOS, with a particular focus on marine surface winds from NASA Scatterometer (NSCAT) observations. It will be used to develop precipitation assimilation capabilities from TRMM data.

Characteristics of GEOS-2 DAS which represent advances over GEOS-1 DAS include increasing the vertical resolution to 70 levels, with special attention to the planetary boundary layer and the stratosphere. GEOS-2 DAS is the first implementation of the Physical-space Statistical Analysis System which is the first analysis system that allows completely general representation of error characteristics [1]. The Physical-space Statistical Analysis System also provides the framework to incorporate new data types which will be available from MTPE platforms. The GEOS-2 DAS system is described in the DAO Algorithm Theoretical Basis Document which is available from the DAO at http://dao.gsfc.nasa.gov/subpages/atbd.html.

1. "Assessing the Effects of Data Selection with the DAO Physical-Space Statistical Analysis System," A. M. da Silva, J. Guo, S. E. Cohn, J. Pfaendtner, M. Sienkiewicz, and D. Lamich, to be submitted to *Mon. Wea. Rev.*, 1997.

- Kalman Filter Data Assimilation of Halogen Occulation Experiment (HALOE) Constituent Observations

The DAO has implemented the first global atmospheric Kalman filter data assimilation system [1]. The first implementation was on the INTEL Paragon at JPL and the system is now running on the Cray T3-D at Goddard. The Kalman filter has been used to assimilate methane data from HALOE, an occultation instrument aboard UARS. Even though HALOE provides less than 30 profiles per day, the Kalman filter generates global maps which validate well with the more dense measurements of other instruments on the UARS platform [2]. The success of the HALOE assimilation has motivated further research into using SAGE data with the goal of developing long-term data sets with improved representation of lower stratospheric ozone. These data sets will be used with TOMS data to provide improved estimates of tropospheric ozone.

1. "Parallel Implementation of a Kalman Filter for a Constituent Data Assimilation," P. M. Lyster, S. E. Cohn, R. Menard, L.-P. Chang, S.-J. Lin, and R. G., in press *Mon. Wea. Rev.*, 1996.

2. "Assimilation of Constituent Observations in the Stratosphere," R. Menard, L.-P. Chang, P. M. Lyster, and S. E. Cohn, to be submitted to *J. Geophys. Res.*, 1997.

- Consistent Assimilation of Retrieved Data

The DAO has developed a new methodology which allows assimilation of retrieved data while maintaining the fidelity of error representation thought possible only through the direct use of radiances [1]. The methodology is called the Consistent Assimilation of Retrieved Data (CARD). CARD and associated data reduction algorithms provide an important and necessary advance because of the large data volumes associated with MTPE observations. Instead of having to move and assimilate hundreds of gigabytes of radiance data, the information content can be compressed into files two or more orders of magnitude smaller at the data archive. CARD is a important theoretical advance with tremendous operational consequences.

1. "Efficient Methods to Assimilate Satellite Retrievals Based on Information Content," J. Joiner and A. M. da Silva, submitted to *Q. J. Roy. Meteor. Soc.*, 1996.

Data Sets for Climate Analysis

- Sea Surface Wind Data Set

A multiyear (1987-1995) data set from SSM/I marine surface wind speed observations has been developed and archived at the JPL Distributed Active Archive Center (DAAC) [1]. This data set uses assimilation methods to assign wind direction information to the SSM/I wind speeds and also fills in unobserved regions between satellite swaths. The data have been successfully used to drive ocean circulation models, and have revealed previously unobserved interannual variability of large scale convergence centers [2]. The SSM/I data have been used as a prototype to develop assimilation and analysis techniques to utilize scatterometry observations from NSCAT aboard the ADEOS satellite launched in Summer 1996. The data are currently being used with the GEOS DAS at Goddard in NSCAT validation activities.

1. "A Multiyear Global Surface Wind Velocity Dataset Using SSM/I Wind Observations," R. Atlas, R. N. Hoffman, S. C. Bloom, J. C. Jusem, and J. Ardizzone, *Bull. Amer. Meteor. Soc.*, **77**, 869-882, 1996.

2. A Comparison of Surface Wind Products over the North Pacific Ocean," M. M. Rienecker, R. Atlas, S. D. Schubert, and C. A. Scholz, *J. Geophys. Res.-Oceans*, **101**, 1011-1023, 1995.

Aerosols

- Aerosols Effects on Climate

First measurements were reported of the efficiency of tropospheric aerosol particles to reflect radiation back to space, and thus cool the Earth [1]. Aerosol particles from anthropogenic or natural sources generate a negative radiative forcing of the climate system, by directly reflecting sunlight back to space, and positive forcing by absorbing solar radiation. The efficiency □ of backscattering of incoming radiation by aerosol particles was previously calculated from models of aerosol physical properties or derived from ground based aerosol volumetric measurements. Systematic sky spectral radiance measurements were used to derive the value of □ for smoke aerosol in Brazil and for industrial/urban aerosol in the Mid-Atlantic region of the United States. Since aerosol particles scatter light upward to space and downward towards the Earth, the sky radiance can be used to derive the fraction of solar flux reflected to space. The aerosol measurements are of the ambient aerosol and are integrated on the vertical column.

The average value of □ derived from the measurements varied between 0.20 and 0.28 for both aerosol types, as compared to 0.29 used by other authors [2, 3] in their modeling efforts to calculate radiative forcing by sulfate and smoke aerosol, respectively. They used the average value of □ on all solar illumination directions. But high optical thicknesses occur in the Amazon and Eastern United States during the period of July to September, when the solar elevation is high. For these months and latitude range the actual average value of □ is 25% lower for the same two aerosol types. A combination of these two factors results in values of □, and the corresponding aerosol direct radiative forcing of climate, that are 30-50% lower than the previous estimates.

1. "Hemispherical Backscattering by Biomass Burning And Sulfate Particles Derived from Sky Measurements," Y. J. Kaufman and B. N. Holben, *JGR-Atmospheres*, **101**, 19433-19445, 1996.

2. "Climate Forcing by Anthropogenic Aerosol," R. J. Charlson, S. E. Schwartz, J. M. Hales, R. D. Cess, J. A. Coakley, Jr., J. E. Hansen, and D. J. Hoffman, *Science*, **255**, 423-430, 1992.

3. "Effects of Aerosol from Biomass Burning on the Global Radiation Budget," J. E. Penner, R. E. Dickinson, and C. A. O'Neill, *Science*, **256**, 1432-1434, 1992.

Ozone and Trace Gas Measurements

- New TOMS Satellites Successfully Launched

In July and August 1996, successful launches put new TOMS instruments into orbit, ending the 2-year hiatus following a 16-year data record. Global ozone had been monitored for 16 years by TOMS instruments on Nimbus 7 (11/78-5/93) and on Meteor 3 (8/91-12/94). Earth-Probe TOMS, launched on 2 July on a Pegasus vehicle, was placed into a 500 km orbit for 25 km ground resolution, which aids in the retrieval of lower tropospheric ozone, dust and aerosols. The Japanese ADEOS TOMS was launched on 17 August in an 800 km orbit and provides a 42 km ground resolution. Near-real-time TOMS data from Earth Probe and ADEOS are being distributed via the internet (at: http://jwocky.gsfc.nasa.gov/).

The Flight Projects Directorate, Code 400, at Goddard oversaw the construction of the TOMS instruments and the Earth Probe (EP) spacecraft. The Atmospheric Chemistry and Dynamics Branch scientists contributed to the original scientific motivation for the missions and are the Project and Instrument Scientists.

- Version 7/TOMS Data: A 16-Year Record of Ozone

New self-consistency techniques for calibrating in- orbit instruments have achieved an unprecedented accuracy of 1% over 16 years in the version 7 TOMS data [1, 2] released to the public in April 1996. CD-ROMs of TOMS data (5000 copies) were produced and are being distributed worldwide through the Goddard DAAC. This high accuracy allowed the development of unanticipated new TOMS products such as ground level UV [3] and absorbing aerosols.

The TOMS ozone maps have led to world-wide recognition of the Antarctic "ozone hole" and were critical in developing the understanding of its formation. TOMS data have had a significant influence on international treaties on CFC control.

1. "An Assessment of the Accuracy of 14.5 Years of Nimbus 7 TOMS Version 7 Ozone Data by Comparison with the Dobson Network," R. D. McPeters and G. J. Labow, *Geophys. Res. Lett.*, **23**, 3695-3698, 1996.

2. "Long-Term Trends Derived from the 16-Year Combined Nimbus 7/Meteor 3 TOMS Version 7 Record," R. D. McPeters, S. M Hollandsworth, L. E. Flynn, and J. R. Herman, *Geophys. Res. Lett.*, **23**, 3699-3702, 1996.

3. "UV-B Increases 1979-1992 from Decreases in Total Ozone," J. R. Herman, P. K. Bhartia, J. Ziemke, Z. Ahmad, and D. Larko, *Geophys. Res. Lett.*, **23**, 2117-2120, 1996.

- Stratospheric Transport of Atmospheric Tracers (STRAT)

The STRAT series of ER-2 flights out of NASA Ames and Hawaii made two breakthroughs in 1996. First, by flying in a stacked flight path--something only recently allowed by flight operations, STRAT obtained an unprecedented high-resolution cross-section of trace gas constituents of the upper troposphere/lower stratosphere. Lifetimes of tracers in the "middle world" where potential temperature isopleths enter the upper tropical troposphere have been determined [1]. Mean lifetimes for stratospheric air vary from 1-5 years, which is analogous to exhaust lifetimes from proposed high-altitude stratospheric aircraft. Second, OH measurements on STRAT were the first to be made in the upper troposphere. OH is the key atmospheric oxidant that controls the buildup of greenhouse gases like methane and substituted chlorofluorocarbons.

The STRAT mission was a NASA sponsored mission involving several NASA centers, other government laboratories, and universities. Scientists from the Laboratory for Atmospheres contributed to the conception and planning of the mission, and provided meteorological support, including generation of forecasts and analysis using the GEOS DAS. The mission Co-Project scientist was a member of the Atmospheric Chemistry and Dynamics Branch.

1. "Stratospheric Mean Ages and Transport Rates from Observations of Carbon-Dioxide and Nitrous-Oxide," K. A. Boering, S. C. Wofsy, B. C. Daube, H. R. Schneider, M. Loewenstein, and J. R. Podolske, *Science*, **274**, 1340-1343, 1996.

Remote Sensing of Clouds and Water Vapor

- Inference of Marine Atmospheric Boundary Layer Water Vapor and Temperature Profiles using Airborne Lidar and Radiometer Data

Data gathered during an extended airborne field campaign over the Atlantic Ocean in support of the Lidar In-space Technology Experiment (LITE) has been used to develop a new technique for the retrieval of moisture and temperature profiles throughout the Marine Atmospheric Boundary Layer (MABL). The technique utilizes lidar derived statistics on the height of cumulus clouds which frequently cap the MABL to estimate the Lifting Condensation Level (LCL). Combining this information with radiometer derived SST measurements, an estimate of the near surface moisture can be obtained to an accuracy of about 0.8 grams of water vapor per kg of dry air.

Lidar derived statistics on convective plume height and coverage within the MABL are then used to derive the profiles of potential temperature and moisture with a vertical resolution of 20 meters. The retrieved profiles compare favorably with dropsonde measurements and demonstrate consistently good results. The root-mean-square error of average MABL moisture content and potential temperature obtained from 16 retrieved profiles is less than 1 g/kg and 1 degree Celsius, respectively [1]. The method relies on the presence of a cumulus-capped MABL and relatively small air-sea temperature differences such as that found over the tropical and sub-tropical regions. The technique has also been successfully applied to actual LITE data and the results show promise for the retrieval of MABL moisture and temperature over the tropics and sub-tropics using spaceborne lidar. Future work will combine scatterometer-derived wind speed and moisture retrievals near the surface to estimate latent heat flux over the ocean. Additional work will also be done to assess the applicability of the technique over land areas using LITE data.

1. "Airborne Remote Sensing of Atmospheric Boundary Layer Water Vapor and Temperature Profiles over the Ocean," . S. P. Palm, D. Hagan, G. Schwemmer, S. H. Melfi, submitted to *J. Appl. Meteor.*, 1996.

- The ER-2 Doppler Radar (EDOP)

The complex nature of updrafts, downdrafts, and reflectivities on scales of 1 to 2 km has been observed using the EDOP data [1, 2]. The airborne EDOP provided unique high-altitude observations of extensive storm systems during a second Convection and Moisture Experiment (CAMEX-2) which took place during the summer of 1995 and focused in part on the vertical structure of precipitation in convective systems. The data clearly show the complex nature of up and downdraft couplets within individual convective cells with dimensions of only 1 to 2 km. Another remarkable result from the high resolution EDOP observations is the appearance of strong updrafts/ downdrafts near the cloud top. Individual updraft cells such as those observed by the EDOP radar have significantly smaller dimensions than the footprints of spaceborne instruments. In remote or oceanic areas where no ground-based Doppler radar data exists, observations from EDOP can provide information on the highly detailed vertical structure of precipitation and wind-flow fields needed to better understand and validate precipitation retrievals from spaceborne instruments.

EDOP has had significant impact upon the TRMM validation strategies. EDOP observations have been used to simulate TRMM Precipitation Radar (PR) nadir observations to provide guidance in developing PR algorithms as well as validation strategies. These simulations have focused the emphasis upon the differences that one can expect from intercomparison between spaceborne and ground-based radars. Precipitation bright bands clearly visible with 4 km spatial and 250 m vertical resolution commensurate with the PR, for instance, can be completely missing from a ground-based radar less than 100 km away from the precipitation. Such analyses have a profound impact upon the very nature of the validation experiments that must be planned for the TRMM mission, refocusing attention from a philosophy of belief in ground "truth" to one that seeks to understand the underlying physics of the observations.

EDOP was built in collaboration with the Microwave Sensors Branch of the Laboratory for Hydrospheric Processes.

1. "Structure of Florida Thunderstorms Using High-Altitude Aircraft Radiometer and Radar Observations," G. M. Heymsfield, I. J. Caylor, J. M. Shepherd, W. S. Olson, S. W. Bidwell, W. C. Boncyk, and S. Ameen, *J. Appl. Meteor.*, **35**, 1736-1762, 1996.

2. "The EDOP Radar System on the High-Altitude NASA ER-2 Aircraft," G. M. Heymsfield, S. Bidwell, I. J. Caylor, S. Ameen, S. Nicholson, W. Boncyk, L. Miller, D. Vandermark, P. E. Racette, and L. R. Dod, *J. Atmos. Oceanic Tech.*, **13**, 795-809, 1996.

- Investigation of the Effect of Contrail Cirrus on Climate

A NASA remote sensing experiment has provided results which indicate the potential for contrail cirrus as an anthropogenic factor on climate change. Observations of contrail cirrus have been obtained by remote sensing from the NASA ER-2 high altitude aircraft. The observations involve multispectral visible and infrared imagery, high frequency microwave and active lidar sensing. In 1996, the SUCCESS project was specifically directed to the problem of contrail cirrus. Of special importance, remote sensing observations contained contrails verifiable from observations by lower altitude aircraft participating in SUCCESS. There are preliminary conclusions from this and previous experiments [1]. Newly produced contrails are composed of ice crystals with significantly smaller effective size than those found in the ambient cirrus and have significantly different radiative properties. Older contrails suggested microphysics similar to those of the ambient cirrus. Contrail ice/water content retrievals show that contrails are similar in water content to nearby natural cirrus and that jet exhaust vapor is an insignificant component. Estimates from remote sensing data indicate that contrails do not add significantly to cloud radiative forcing effects. But, through their interaction with the ambient cirrus and water, they may increase the radiative forcing of large areas of cloud cover if it can be determined that the contrails influence a large scale perturbation in the cloud fields. In a spectacular experiment on May 15, 1996 the NASA DC-8 aircraft participating in SUCCESS generated an oval shaped contrail cloud that could be seen and tracked in GOES satellite images from off the coast of California through Utah. The completion of studies involving both aircraft and global analysis of satellite data is required to determine the overall climate effect of aircraft generated cirrus.

1. "Contrail Microphysics and Radiative Properties from Aircraft Remote Sensing," C. Drummond and J. D. Spinhirne, submitted to *J. Appl. Meteor.*, 1996.

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5.2 Data Analysis

Planetary Atmospheres

- Analysis of the Jovian Atmosphere

The Atmospheric Experiment Branch's contribution to the Galileo mission to Jupiter was the mass spectrometer on the Galileo Probe. Shortly before arrival at Jupiter, the Probe separated from the Galileo Orbiter, entered the atmosphere, and descended on a parachute December 7, 1995, into the deep Jovian atmosphere. Data were collected by the mass spectrometer for 57 minutes, from an atmospheric pressure of approximately 0.3 to 23 times Earth sea level pressure where the Probe data transmission stopped. The Galileo Probe Mass Spectrometer (GPMS) was the primary Probe instrument to measure chemical composition of the atmosphere of Jupiter which consists primarily of hydrogen and helium, with smaller amounts of water, methane, ammonia, hydrogen sulfide, and lower concentrations of other molecules. The Galileo Probe Mass Spectrometer measured variations in the abundance of all these species as a function of altitude and detected other species in the atmosphere such as the chemically inert noble gases. A comparison of noble gas abundances on other planets and the sun will help distinguish between possible mechanisms of planetary formation and evolution of the atmosphere. Since Jupiter is the most massive planet in the solar system, the noble gas abundances found there are expected to closely reflect the abundances in the solar nebula from which the planets formed.

Atmospheric species with molecular weights from 2 to 150 Atomic Mass Units were analyzed and signals from more that 6000 values of mass to charge were taken during the descent. Preliminary findings [1] indicate that the abundance ratio of helium to hydrogen in the atmosphere is near but slightly lower than the solar value at 0.156 (by volume) while the abundance ratio of methane is higher, and the abundance ratio of water during the early part of the descent is surprisingly lower than those predicted using solar values of carbon and oxygen (i.e., a much dryer atmosphere than expected). However, hydrogen sulfide, water, and other condensable species show a substantial increase in mixing ratio at the highest pressures encountered during the descent. These observations coupled with the observation that the Probe entered Jupiter in a relatively cloud free region and in an infrared hot spot are presently stimulating a reevaluation of prior models and enabling a new understanding of the atmospheric circulation on Jupiter.

1. "The Galileo Probe Mass Spectrometer: Composition of Jupiter's Atmosphere," H. B. Niemann, S. K. Atreya, G. R. Carignan, T. M. Donahue, J. A. Haberman, D. N. Harpold, R. E. Hartle, D. M. Hunten, W. T. Kasprzak, P. R. Mahaffy, T. C. Owen, N. W. Spencer, and S. H. Way, *Science*, **272**, 846-849, 1996.

- Evolution of Water on Mars

In preparation for future Mars missions, analysis of the relation between the present Deuterium/Hydrogen (D/H) ratio and an early water reservoir on the planet was carried out to obtain insight on the liquid environment in which early life may have evolved. It was found that the winds in the upper atmosphere of Mars significantly enhance the Jeans escape flux of D and consequently increase previous estimates of the size of a juvenile water reservoir by factors of three or more [1]. The foundation for this work sprung from the analysis of measurements made of the D/H ratio in the atmosphere of Venus, which led to the identification of the dominant escape mechanism of these constituents and in turn to the conclusion that Venus had a significant reservoir of water more than four billion years ago, equivalent to a range of 125 to 570 m of liquid distributed uniformly on the surface [2].

1. "Effects of Wind-Enhanced Escape on the Evolution of Water on Mars," R. E. Hartle, *EOS Trans. AGU*, Fall Meet. Suppl., **77(46)**, F431, 1996.

2. "Hydrogen and Deuterium in the Thermosphere of Venus: Solar Cycle Variations and Escape," R. E. Hartle, T. M. Donahue, J. M. Grebowsky, and H. G. Mayr, *J. Geophys. Res.*, **101**, 4525, 1996.

Solar Effects

- Detection of Climatic Signals in Mesospheric Water Vapor

This study [1] explores the feasibility of identifying long-term changes in the mesospheric water vapor as a result of the increasing level of methane and the solar cycle modulation of Lyman □. A number of recent studies [2, 3] have suggested that changes in mesospheric water vapor and temperature may be good indicators of changes in carbon dioxide (CO_2) and methane (CH) concentrations on climatic time scales. Water vapor has no significant source in the mesosphere. It is

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produced in the stratosphere by oxidation of methane and is transported into the mesosphere via winds and eddy transport where it is photo dissociated by Lyman □. Since methane is biologically produced and affected by human behavior, long-term changes in mesospheric water can be affected by the increasing level of methane on the surface of Earth due to anthropogenic activity. The variation in water vapor caused by the solar cycle has a modulating influence on the secular increase of water vapor in the mesosphere. The current study is based on recent measurements of water vapor in the mesosphere and the solar Lyman □ flux from the UARS HALOE and Solar Stellar Irradiance Comparison Experiment (SOLSTICE) instruments during the declining phase of solar cycle 22 when solar activity decreased from a near maximum to a near minimum level. The analysis of these data sets, in conjunction with the Goddard two dimensional (latitude and altitude) chemistry and transport model, suggests that the methane-related increase in water vapor at mesopause heights (~80 km) may be of the order of only 2-3% in comparison to a modulation of about 30-40% caused by the solar cycle variation of Lyman □ from 1991 to 1995. This relation changes dramatically with decreasing heights. In the lower mesosphere (60-65 km), the solar cycle related changes in water vapor are comparable to the predicted methane related change. The long term monitoring of the mesospheric water vapor may therefore offer an opportunity for detecting climatic signals in the atmosphere.

1. "The Seasonal and Long Term Changes in the Mesospheric Water," S. Chandra, C. H. Jackman, E. L. Fleming, and J. M. Russell III, *Geophys. Res. Lett.*, 1996.

2. "Global Change in the Mesosphere-Lower Thermosphere, Has it already Arrived?," G. E. Thomas, *J. Atmos. Terr. Phys.*, **58**, 1629-1656, 1996.

3. "Is the Polar Mesosphere the Miner's Canary of Global Change?," G. E. Thomas, *Adv. Space Res.*, **18(3)**, 149-158, 1996.

Climate Analysis

- New Insights into Mechanisms for SST-Convection Interaction over the Tropical Oceans

Using TOGA-COARE data, scientists in the Climate and Radiation Branch [1] have found that the warm pool SST and the overlying atmosphere undergo continuous cycles of alternate cold and warm states on time scales of one to two months. The warm pool region of the tropical western Pacific and Indian Ocean is the largest reservoir of heat and moisture in driving the global general circulation and the global water and energy cycles. This region also represents one of the most stable components of the Earth's climate system. It has been suggested that because of the huge heat capacity and the strong negative feedback processes within the warm pool ocean-atmosphere system, the warm pool may act as a flywheel to moderate major global warming events, delaying and even sequestering warming signals in the tropical ocean surface.

The cycles of cold and warm states found in the TOGA-COARE data occur as mutual dynamical and thermodynamical adjustments of SST and organized large scale convection [1]. This mutual adjustment represents one of the dominant modes of the warm pool-convection system interaction on seasonal to interannual time scales. It may also be responsible for the long-term stability of the warm pool SST. Results indicate that through the large scale teleconnection between the Indian Ocean and the western Pacific, convective growth and SST warming over the warm pool are self-limiting, with quasi-periodic cycles. An inverse relationship in the form of an oscillating dipole is found between convection over the Indian Ocean and the western Pacific. Coupling with SST appears to enhance the amplitude of the dipole.

1. "Mechanisms of Short-Term Sea Surface Temperature Regulation: Observations During TOGA-COARE," K.-M. Lau and C. H. Sui, in press *J. Climate*, 1996.

Aerosols

- A New Method for Detection of Absorbing Aerosols (Dust and Smoke) from TOMS Data

A newly developed TOMS algorithm obtains global distributions of UV-absorbing aerosols from measured 340 nm and 380 nm radiances [1, 2]. The data cover the period 1979 to 1993, and since July 1996 for the new ADEOS and Earth-Probe/TOMS. Time series for the major sources of biomass burning and desert dust show the frequency of occurrence over land and oceans. A key finding has been the identification of the major sources of most atmospheric dust. Sporadic sources of aerosols are also seen (volcanic ash and oil fires, e.g. Kuwait). Year-to-year variability of UV-absorbing aerosol amounts has been determined for the following major aerosol source regions: 1. Central South America (Brazil) near 10_S latitude, 2. Africa near 0_ - 20_S and 0_ to 10_N latitude, 3. Saharan and Desert and sub-Saharan region (Sahel), Arabian Peninsula, and the northern border region of India near 25_N latitude, 4. Indonesia, Eastern China and Indochina, and near the mouth of the Amazon River, due to agricultural burning, and 5. Northeastern China, due to coal burning and dust. The first three of these dominate the injection of UV-absorbing aerosols into the atmosphere each year and cover areas far outside their source regions. Much dust originates from agricultural regions, frequently within arid areas like the Sahel region of Africa and intermittently dry drainage areas and streams. In addition to the drought cycle, this suggests there may be an anthropogenic component to the amount of dust injected into the atmosphere each year.

1. "Detection of Biomass Burning Smoke from TOMS Measurements," N. C. Hsu, J. R. Herman, P. K. Bhartia, C. J. Seftor, O. Torres, A. M. Thompson, J. F. Gleason, T. F. Eck, and B. N. Holben, *Geophys. Res. Lett.*, **23**, 745-748, 1996.

2. "Global Distribution of UV- Absorbing Aerosols From Nimbus-7/TOMS Data," J. R. Herman, P. K. Bhartia, O. Torres, C. Hsu, C. Seftor, E. Celarier, accepted for publication, *J. Geophys. Res.*, 1996.

Validation Networks

- Critical Ocean Rainfall Observations for TRMM Validation

With the acquisition during 1995 of an excessed NOAA/National Science Foundation WSR-88D radar system, Goddard was able to substantially improve weather measurement data recorded from the Kwajalein Atoll/Marshall Islands location. A key feature of the installation was the provision for a suitable tower (~25 meters) to rise above nearby building and palm tree obstructions. An equally important factor in extending the range for radar precipitation estimates is the acquisition of calibration data from rain gauges. To accomplish this, arrangements were made with the Republic of the Marshall Islands to install and operate several additional gauges on a number of other atolls located out to a range of 150 km from the radar. The radar became operational by the end of May 1996. Most of the additional rain gauges have been installed and are operational. Kwajalein will now have the capability to supply the crucial data needed to both verify TRMM instrument algorithms with instantaneous measurements and validate longer term climatological averages over a critical ocean region.

Operational Satellites

- Geosynchronous Advanced Technology Environmental System (GATES)--A Geosynchronous Environmental Observatory

In 1996, GSFC took an initiative to study how modern space technology could be used to create an advanced imager in geosynchronous orbit that would be an observatory for both weather and climate in our hemisphere. The Laboratory for Atmospheres appointed the GOES project scientist, who took the opportunity to combine the requirements from NOAA's National Weather Service (NWS) for a high-performance imager together with NASA's MTPE specifications for MODIS. The resulting system design is called the GATES [1]. GATES is a very compact, visible-infrared radiometer on its own small satellite, capable of beaming full-disk multispectral data within minutes for realtime distribution of high-quality images to weather forecasters, to research scientists, and to the general public. The GATES concept is synergistic with the other weather- and climate-observing systems of the next century, particularly for monitoring clouds and the diurnal cycle between overpasses by the polar-orbiting satellites. GATES goals have been well-received by the head of the NWS, by the NASA Administrator, and by the MODIS science team. A GATES phase-A engineering review was held in 1996. Because GATES is designed to use off-the-shelf components, a flight unit could be built, launched and operated within 3 years of a Phase-B design, much faster than previous GOES satellite development.

1. "GATES, an Advanced Geosynchronous Imaging System,", D. Chesters and D. Jenstrom, SPIE Conf. "GOES-8 and Beyond", Denver CO, August 1996.

Rain Measurements from Space

- TRMM Passive Microwave Algorithm

An operational microwave rainfall algorithm has been developed based upon first principles. The Goddard Profiling Algorithm (GPROF) is a multi-channel, physically-based hydrometeor profiling algorithm developed for SSM/I, TRMM and EOS/AMSR. The algorithm retrieves rainfall and its associated hydrometeor structure based solely upon the physics of precipitation systems without requiring ground calibration data. GPROF begins by constructing large databases of cloud model derived profiles. Radiative transfer computations at cloud model resolution are performed for each sensor frequency. The resulting brightness temperatures (Tb) are then convolved to the observing resolution using appropriate antenna gain functions. Using a Bayesian inversion method (integral form of the minimum variance solution), a solution can be found that is the product of the probability that a certain profile occurs multiplied by the probability that the observed Tb corresponds to a particular profile. The formal solution to the above problem is presented in detail in [1]. Applications of GPROF to high resolution aircraft and SSM/I satellite data are extremely encouraging. Because of the physical basis, additional sensor information such as the TRMM radar can easily be incorporated [2]. The latent heating derived from the cloud model can also be treated like a retrievable geophysical parameter. This has led to encouraging results in which the latent heat in hurricane intensification was studied.

1. "A Simplified Scheme for Obtaining Precipitation and Vertical Hydrometeor Profiles from Passive Microwave Sensors," C. Kummerow, W. S. Olson, and L. Giglio, *IEEE Trans. Geosci. Remote Sensing*, **34**, 1213-1232, 1996.

2. "A Method of Combined Passive/Active Microwave Retrievals of Cloud and Precipitation Profiles," W. S. Olson, C. Kummerow, G. M. Heymsfield, I. J. Caylor and L. Giglio, *J. Appl. Meteor.*, **35**, 1763-1789, 1996.

Ozone Changes

- Recent Estimates of Changes in Atmospheric Ozone and Comparison with Models

Stratospheric ozone is affected by anthropogenically caused chlorine and bromine increases, solar cycle ultraviolet flux variations, and the changing sulfate aerosol abundance due to several volcanic eruptions. A study [1] was recently completed, which included all three of these variations, with a two-dimensional (latitude and altitude) atmospheric chemistry and transport computer model to predict ozone variations over the 1979 to 1994 period. The model captures much of the variability and downward trend in total ozone that was measured by TOMS instruments, on Nimbus 7 and on Meteor 3, over this time period.

The model simulations predict a decrease in total ozone of about 4% from 1979 to 1994 due to the chlorine and bromine increases. The changing sulfate aerosol abundances can also significantly affect total ozone with the Mt. Pinatubo eruption computed to cause a decrease in global ozone by about 3% in 1992. Solar ultraviolet flux variations cause increases and decreases in total ozone with computed changes of about 1% from solar maximum to minimum.

Model predictions for the future indicate that total ozone should start to recover from its lowest levels by the late 1990's. Future measurements of ozone are crucial to verify the recovery process.

1. "Past, Present, and Future Modeled Ozone Trends with Comparisons to Observed Trends," C. H. Jackman, E. L. Fleming, S. Chandra, D. B. Considine, and J. E. Rosenfeld, *J. Geophys. Res.*, **101**, 28753-28767, 1996.

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5.3 Modeling

Cloud and Mesoscale Modeling

- Mesoscale Modeling of Convective Systems and Their Associated Precipitation Processes

The GCE model has been used to quantitatively determine the effects of longwave radiation on squall lines, both tropical and midlatitude. The model results show that longwave radiation enhances precipitation, about 30 percent in the tropics and 8 percent at midlatitudes. The GCE simulations also indicated that the increase in relative humidity caused by longwave radiative cooling (no one has proposed this before) resulted in much more rainfall because of the high moisture contents in the Tropics. The midlatitude cloud system with a higher Convective Available Potential Energy (CAPE) and lower humidity environment was only slightly affected by longwave radiative processes. This strongly suggests that radiative processes could play a significant role in the daytime minimum/nighttime maximum precipitation cycle found over most oceans [1].

Additional GCE model results include the following: 1. latent heat flux from the ocean and subsidence induced by deep convection (not the convective downdrafts as suggested by theoretical studies) are the two major processes acting against each other that keep the CAPE in the tropics nearly constant; 2. higher CAPE is co-located with areas of higher equivalent potential temperature (caused by larger latent heat fluxes); 3. cloud updrafts are mainly initiated by dynamic forcing - strong convergence in the lower troposphere below the 1.5 km level. These results could be used to improve the representation of convective processes (i.e., the triggering function in cumulus parameterization schemes) in GCMs and climate models [2, 3].

1. "Mechanisms of Cloud-radiation Interaction in the Tropics and Midlatitudes," W.-K. Tao, S. Lang, J. Simpson, C.-H. Sui, B. Ferrier, and M.-D. Chou, *J. Atmos. Sci.*, 53, 2624-2651, 1996.

2. "The Impact of Ocean Surface Fluxes on a TOGA-COARE Convective System," Y. Wang, W.-K. Tao, and J. Simpson, *Mon. Wea. Rev.*, **124**, 2753-2763, 1996.

3. "Factors Responsible for Different Precipitation Efficiencies Between Midlatitude and Tropical Squall Simulations," B. S. Ferrier, J. Simpson, and W.-K. Tao, *Mon. Wea. Rev.*, 124, 2100-2125, 1996.

General Circulation Modeling

- Including Cloud Fractal Structure Improves Climate Simulations

Use of an "effective" cloud thickness which depends on the cloud fractal structure has been found to improve model simulations by the climate model of the ECMWF. The fractal structure of clouds helps explain how the liquid water content of clouds determines their albedo, which controls the amount of solar energy available to drive the Earth's climate system. Practical computing constraints require climate models to treat clouds as uniform. But uniform clouds are invariably too reflective, so that models must artificially reduce the cloud liquid water content, typically by a factor of three, in order to obtain a reasonable albedo. Recent work by scientists in the Climate and Radiation Branch has related the cloud liquid reduction factor to the fractal properties of clouds, through an "effective cloud thickness" [1, 2]. The model's absorbed solar radiation produces a more realistic climate simulation when observed fractal properties are used to compute cloud thicknesses. Fractal analysis is also being applied to clouds produced by high-resolution cloud resolving models in order to evaluate the realism of such model's convective parameterization schemes [3, 4]. If convective schemes can be found which produce realistic cloud fractal structures, which change appropriately when boundary conditions change, then global climate models might safely rely on cloud resolving models to determine changes in cloud albedo when the climate changes.

1. "Bounded Cascade Clouds: Albedo and Effective Thickness," R. F. Cahalan, *Nonlinear Proc. Geophys*, **1**, 156-167, 1994.

2. "The Albedo of Fractal Stratocumulus Clouds," R. F. Cahalan, *J. Atmos. Sci.*, **51**, 2434-2455, 1994.

3. "An Extension of Cloud-Radiation Parameterization in the ECMWF Model: The Representation of Subgrid-Scale Variations in Optical Depth," M. Tiedke, *Mon. Wea. Rev.*, **124**, 745-750, 1995.

4. "Fractality in Idealized Simulations of Large-Scale Tropical Cloud Systems," J.-I. Yano, J. C. McWilliams, and M. Moncrieff, *Mon. Wea. Rev.*, **124**, 838-848, 1996.

- New Prognostic Cloud Water Parameterization

The new cloud scheme called Microphysics of Cloud with Relaxed Arakawa-Schubert (RAS) cumulus parameterization (McRAS) has been completed and tested. McRAS is designed for simulating more realistic clouds and cloud-radiation interactions. It uses several new design concepts introduced in [1]. Its major novel features are prognostic clouds that advect in the horizontal and vertical directions and have a physically based cloud life-cycle. McRAS uses downdrafts [2];

full cloud-microphysics within convective towers and anvils; cloud-radiation interactions [3]; cloud microphysics [4, 5]; cloudiness inhomogeneity correction [6]; and several other tunable parameters from observations and sensitivity studies with the field data and/or GEOS-1 GCM.

McRAS features prognostic equations for the cloud water substance and cloud mass fraction. These equations are coupled to all the other prognostic equations of the GCM. In cumulus convection, RAS provides the mass flux. The new cloud-buoyancy equation (cloud-scale vertical momentum equation) yields fractional areas and ascent velocity of the cumulus mass flux. These form the key inputs for the cloud microphysics. Large-scale cloud parameterization is an integral part of the new cloud microphysics. The generation of large-scale (LS) clouds is linked to the growth of relative humidity above a threshold value (derived from observations). Boundary layer (BL) clouds are produced if supersaturation is reached within the BL eddies that rise toward the inversion layer. These clouds detrain beneath/into the inversion layer. For all clouds, the condensate-to-precipitation conversion is obtained from the growth of hydrometeors by accretion, collection, and Bergeron-Fiendsen processes. Clouds dissipate by entrainment of dry ambient air and/or drying through geophysical interactions and subsidence. The problem of advecting a discontinuous cloud-field is solved by appropriately combining diffusion and advection schemes.

McRAS has been tested with GATE, Atmosphere Radiation Measurement-Cloud and Radiation Testbed (ARM-CART), and TOGA-COARE datasets. It has shown promise in the 17-layer GOES-1 GCM that is being prepared for climate studies with an emphasis on more realistic cloud processes [7].

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LABORATORY FOR

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Section 6

6. Outreach Activities

The Laboratory for Atmospheres continues to support Goddard's role in NASA's efforts to serve the scientific community, inspire the nation, and foster education. The Laboratory's outreach activities include joint ventures with universities, as discussed in Section 2, outreach lectures, mentoring programs, increased public affairs, visualization software development, data archival and distribution programs (i.e. Global Learning and Observations to Benefit the Environment [GLOBE]), and multicultural outreach activities.

- Interaction with Howard University

The Laboratory has entered joint research and educational activities with the Center for the Study of Terrestrial and Extraterrestrial Atmospheres (CSTEA) at Howard University. The Center is entering its second five-year funding cycle as part of the NASA University Research Centers at Minority Institutions Program. The program is designed, among other things, to increase participation by faculty and students of Historically Black Colleges and Universities (HBCU) in mainstream research. CSTEA has designated Goddard Space Flight Center as its lead installation. The Laboratory for Atmospheres has been chosen as the primary technical monitor.

Ongoing collaborative research exist between Laboratory scientists and CSTEA researchers. These efforts take advantage of the Laboratory's expertise in remote sensing, climate modeling, atmospheric chemistry, and laser technology. A series of nine lectures was presented this year by Laboratory scientists as a part of the CSTEA lecture series. The Laboratory also plays a key role in the ongoing curriculum development of the atmospheric sciences program at Howard.

The Laboratory participates in ongoing student programs with CSTEA. The Summer Institute and Research Traineeship in Atmospheric Sciences (SIRTAS) continues to present 20-30 minority undergraduate students the opportunity to tour Laboratory research facilities at GSFC. Laboratory scientists have given lectures and participated on panels during this 8-week summer program.

- Interaction with Western Maryland College (WMC)

GSFC has a Memorandum of Agreement with WMC to promote the use and development of a new lidar technology--a scanning holographic telescope developed with the participation of the University of Maryland. GSFC is providing lidar system components, related test equipment, guidance, and collaboration. WMC has constructed a lidar observatory on their Westminister, Maryland campus as a permanent facility to house and further develop this technology and its applications. Together, Laboratory and WMC scientists have built the Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing (PHASERS). Science applications for such a system include measurements and characterization of clouds, aerosols, and winds. Development of this technology will allow significant weight savings over conventional technology for earth observing lidar telescopes. The PHASERS facility will be the basis for many student projects and serve as a testbed for new developments in this field.

- Lectures

Laboratory personnel continue to lecture about atmospheric science to a wide range of audiences, including those in local community organizations, various interest groups visiting GSFC, industrial employees, students in K-12 education programs, and students and faculty at colleges and universities. The CSTEA lecture series and the Science Engineering Education (SEE) Day at Prince George's Community College are just two of many programs in which Laboratory personnel lecture.

- Mentoring

Scientists in the Laboratory serve as mentors to students at the high school, undergraduate, and graduate levels in various programs sponsored by the Laboratory, GSFC and NASA.

Programs at the high school level include the Summer Student Assistantship Program, a cooperative program of the Laboratory with Caelum Research Corporation. The aim of this program is to introduce qualified high school students, especially students traditionally under-represented in the Earth sciences, to atmospheric sciences and related disciplines. In only three years, this program has introduced six students into atmospheric science research. Other high school programs include partnerships with the Eleanor Roosevelt High School Science and Technology Magnet program and will eventually include other schools in the area.

Programs at the undergraduate level include the Summer Institute on Atmospheric and Hydrospheric Sciences and the NASA Academy. Graduate level programs include the USRA/GSFC Graduate Students Program in the Earth Sciences and the Graduate Student Researcher's Program. Postgraduate programs include NRC Resident Research Associateships and NASA/University Joint Venture (JOVE) appointments. Laboratory scientists and engineers also mentor high school and university level teachers in such programs as the Maryland Initiative and the Summer Faculty Fellows program.

- Public Affairs and Demonstrations

Laboratory scientists were interviewed in popular media outlets (newspapers, magazines, and television) about results of recent research and vital information on weather and climate. The work of Laboratory personnel has been prominently featured this year in major outlets such as Time, Life, and Encyclopedia Britannica. Laboratory personnel have also been featured on major network newscasts and in the PBS Educational Series "Real Science."

Personnel from the Laboratory continue to prepare and present demonstrations of scientific instruments constructed, numerical models developed, and results of scientific investigations at national meetings, local visitor centers, science fairs, and the Smithsonian Institution.

- Public Use of Remote Sensing Data (RSD)

The RSD Program was established to encourage the development of innovative applications of earth and space science remotely sensed data maintained by NASA and other agencies for use by schools, businesses and the general public. Laboratory scientists in collaboration with personnel of the Visualization Studio of the Space Data and Computing Division (SDCD) are participating in this program supported by the NASA Information Infrastructure Technology and Applications (IITA) initiative. Progress of the activities in the program can be followed by watching the RSD server at http://rsd.gsfc.nasa.gov/rsd/.

- Global Learning and Observations to Benefit the Environment (GLOBE) Visualization Project

Scientists in the Laboratory, in conjunction with personnel in the Visualization Studio of the SDCD, support GLOBE, a White House program directed by Vice President Gore, which is a worldwide science and education program coordinating the work of K-12 students, teachers, and scientists to monitor the global environment. Daily visualizations of student observations and of reference data are created and the images distributed via World-Wide Web. Locally, Laboratory scientists work with the Prince George's County (MD) school system and the Owens Science Center in bringing GLOBE into all classrooms. The GLOBE visualization efforts have received the NASA group achievement award (1996). The award-winning GSFC GLOBE internet web page serves over 3000 schools in 45 countries and the general public. The GLOBE Visualization server is on the World Wide Web at http://globe.gsfc.nasa.gov/globe/.

- Visualization for Science and Public Outreach

Laboratory scientists have played an instrumental role along with the Visualization Studio of the SDCD in the Goddard scientific visualization effort in support of the Smithsonian Institution HoloGlobe Project. A variety of high-resolution color animations of global datasets produced at GSFC are displayed on the HoloGlobe. Other visualizations produced by the group are on display at the National Museum of Natural History and the National Air and Space Museum.

- GOES Weather Satellite Images On-Line

The Laboratory operates two realtime antennas for receiving GOES weather satellite imager and sounder data. These are placed in 24-hour deep data pools that are web-accessible. Scientists at NASA and university sites use these calibrated and Earth-located radiances during field campaigns. The general public also makes considerable use of these images, especially during hurricane season. Under a cooperative agreement with a Washington, DC television station (NBC 4) large GOES images are supplied for their use in their daily weather broadcasts. Digital scrapbooks of enhanced GOES pictures and movies are also kept on-line, and are one of the most popular services in the Laboratory. For more information, http://climate.gsfc.nasa.gov/~chesters/goesproject.html.

- Multicultural Outreach

The Laboratory continues to foster NASA's advocacy of Multicultural Diversity and Outreach. Many of the mentoring and lecture programs reach diverse groups in local, state, and national institutions. Laboratory personnel also serve on both the GSFC and Earth Science Directorate Multicultural Advisory Teams. Nationally, the American Meteorological Society's (AMS) Board on Women and Minorities is chaired by a member of the Laboratory.

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Section 7

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"A Five-Year Simulation of Supersonic Aircraft Emission Transport Using a Three-Dimensional Model," C. J. Weaver, A. R. Douglass, D. B. Considine, *J. Geophys. Res.-Atmos.*, **101**, 20975-20984, 1996.

"Validation of the UARS Solar Ultraviolet Irradiances - Comparison with the ATLAS-1 and ATLAS-2 Measurements," T. N. Woods, D. K. Prinz, G. J. Rottman, J. London, P. C. Crane, R. P. Cebula, E. Hilsenrath, G. E. Brueckner, M. D. Andrews, O. R. White, M. E. Vanhoosier, L. E. Floyd, L. C. Herring, B. G. Knapp, C. K. Pankratz, P. A. Reiser, *J. Geophys. Res.-Atmos.*, **101**, 9541-9569, 1996.

"Atmospheric Sulfur Cycling in the Tropical Pacific Marine Boundary-Layer (12-Degrees-S, 135-Degrees-W) - A Comparison of Field Data and Model Results .1. Dimethylsulfide," S. A. Yvon, E. S. Saltzman, D. J. Cooper, T. S. Bates, A. M. Thompson, *J. Geophys. Res.-Atmos.*, **101**, 6899-6909, 1996.

"Zonal Asymmetries in Southern-Hemisphere Column Ozone-Implications of Biomass Burning," J. R. Ziemke, S. Chandra, A. M. Thompson, D. P. McNamara, *J. Geophys. Res.-Atmos.*, **101**, 14421-14427, 1996.

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Section 8

8. NASA Technical Memoranda and Other Publications

"Technical Report Series on Global Modeling and Data Assimilation, Volume 10: Dynamical Aspects of Climate Simulations Using the GEOS General Circulation Model," L. L. Takacs, M. J. Suarez, NASA Technical Memoradum, 1996.

"FIRE Phase III: Cirrus Implementation Plan," T. Ackerman, W. Cotton, S. Cox, T. Del Genio, L. Donner, A. Heymsfield, M. King, K.-N. Liou, P. Minnis, W. Rossow, D. Starr, and G. Stephens, FIRE Project Office, NASA Langley Research Center, Hampton, VA, 111 pp., 1996.

GOES Project Science, D. Chesters, (http://climate.gsfc. nasa.gov/~chesters/goesproject.html).

"Report of the EOS Test Site Meetings," D. O. C. Starr, C. O. Justice, D. E. Wickland, J. T. Suttles, NASA EOS Project Science Office, (http://eospso.gsfc.nasa.gov/), 53 pp., 1996.

Public Use of Remote Sensing Data, J. F. de La Beaujardiere, F. Hasler, A. Nelson (http://rsd.gsfc.nasa. gov/rsd/). GLOBE Visualizations, J. F. de La Beaujardiere, F. Hasler, H. Mitchell, D. Batchelor, P. Jackson, P. Keegstra, C. O'Handley, S. Stemwedel, T. Williams, (http://globe.gsfc. nasa.gov/globe/).

MTPE Research Accomplishments Database, J.-F. de La Beaujardiere, J. Dodge, F. Hasler, (http://globe2.gsfc. nasa.gov/ MTPE/).

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LABORATORY FOR

ATMOSPHERES

Section 9

9. The 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 (December 1992, December 1993, February 1995, June 1996)

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

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

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

Phillippe Courtier
Centre Nationale des Etudes Spatiales (CNES)
(served Advisory Panel 1995, 1996)

Robert E. Dickinson

Department of Atmospheric Science
University of Arizona, Tucson, AZ
(served Advisory Panel 1995, 1996)

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 1996)

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

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)

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

**No longer on the committee*

Data Assimilation Computer Advisory Panel (May 1996)

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

Atmospheric Chemistry and Dynamics Branch Advisory Panel (Scheduled for April 1997)

Susan Solomon, Chairperson
Atmospheric Chemistry Division
NOAA/Aeronomy Laboratory, Boulder, CO

Bill Chameides
School of Earth and Atmospheric Sciences
Georgia Institute of Technology, Atlanta, GA

Doug Davis
School of Geophysical Sciences
Georgia Institute of Technology, Atlanta, GA

Matt Hitchman
Department of Atmospheric and Oceanic Sciences
University of Wisconsin, Madison, WI

Dave Hofmann
Climate Monitoring and Diagnostics Laboratory
NOAA/Oceanic and Atmospheric Research, Boulder, CO

Joe Waters
Microwave Atmospheric Science Team
Earth and Space Sciences Division
Jet Propulsion Laboratory, Pasadena, CA

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LABORATORY FOR

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Section 10

10. 1996 Workshops

Tropical Rainfall Measuring Mission Office

TRMM Field Campaign Workshop, NASA Goddard Space Flight Center, March 1-2, 1996, 10 attendees, Edward Zipser, Chair.

Mesoscale Atmospheric Processes Branch

Information Infrastructure Technology Applications (IITA) Meeting "NASA Communicating Science - A Celebration of Accomplishments," NASA Goddard Space Flight Center, September 16-18, 1996, 114 attendees, Alan Nelson, Chair.

Airborne Rain Radar Workshop, NASA GSFC, October 21-22, 1996, 50 attendees, Toshiaki Kozu, Chair.

First Global Energy and Water-Cycle Experiment Cloud Systen Study Workshop on Precipitating Convective Cloud Systems, Historic Inns of Annapolis, October 21-23, 1996, 25 attendees, Wei-Kuo Tao, Chair.

Third Precipitation Intercomparison Project (PIP-3), University of Maryland Conference Center, November 18-20, 1996, 60 attendees, Robert Adler, Chair.

Climate and Radiation Branch

FIRE-III Science Team Cirrus Meeting, Williamsburg, VA, February 12-13, 1996, 50 attendees, Steve Cox, Chair.

Final SUCCESS Operations Planning Meeting, NASA Langley Research Center, February 14-16, 1996, 30 attendees, David O'C. Starr, Chair.

SCAR-B Workshop, NASA Goddard Space Flight Center, March 1996, 20 attendees, Yoram Kaufman, Chair.

EOS Land Test Site Workshop, NASA Goddard Space Flight Center, March 18-19, 1996, 60 attendees, Chris Justice, Chair.

EOS Science Data Validation Workshop, NASA Goddard Space Flight Center, March 8-10, 1996, 120 attendees, David O'C. Starr, Chair.

Passive Remote Sensing of Tropospheric Aerosol and Atmospheric Corrections, Washington, DC, April 1996, 50 attendees, Yoram Kaufman, Chair.

International Planning Meeting for South China Sea Monsoon Experiment (SCSMEX), Chungli, Taiwan, May 15-18, 1996, 40-50 attendees, William Lau, Chair.

US South China Sea Monsoon Experiment (SCSMEX) Implementation Meeting, Boulder, CO, September 5-6, 1996, 20 attendees, William Lau, Chair.

SCAR-B Workshop, Fortaleza, Brazil, November 1996, 50 attendees, Volker Kirchhoff, Chair.

CLIVAR Monsoon Panel Workshop, GOA, India, November 19-22, 1996, 40-50 attendees, William Lau, Chair.

Atmospheric Experiment Branch

Galileo Probe Science Group Meeting, NASA Goddard Space Flight Center, February 26, 1996, 34 attendees, Richard Young, Chair.

Atmospheric Chemistry and Dynamics Branch

Global Modeling Initiative (GMI) SASS Interim Assessment Meeting, Irvine, CA, January 15-16, 1996, 23 attendees, Jose Rodriguez, Chair.

UARS Science Team Meeting, NASA Langley Research Center, March 26-28, 1996, 123 attendees, Charles Jackman/Anne Douglass/Mark Schoeberl, Chair.

TOMS Sulfur Dioxide Validation Workshop, NASA Goddard Space Flight Center, April 10-11, 1996, 24 attendees, Arlin Krueger, Chair.

GMI Science Team Meeting, Boulder, CO, June 4-7, 1996, 44 attendees, Jose Rodriguez, Chair.

TOTE/VOTE Science Team, Boulder, CO, June 11-12, 1996, 34 attendees, Brian Toon/Mark Schoeberl, Chair.

STRAT Science Team Meeting, NASA Ames Research Center, July 20-21, 1996, 81 attendees, Paul Newman/Steve Wofsey, Chair.

TOMS UVB Validation Workshop, NASA Goddard Space Flight Center, October 8-9, 1996, 25 attendees, Prof. John Frederick, Chair.

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LABORATORY FOR

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Section 11

11. 1996 Short-Term Visitors

Tropical Rainfall Measuring Mission Office

Thomas Seliga
University of Washington
February 28, 1996

Robert A. Houze, Jr.
University of Washington
March 1-2, 1996

Steven A. Rutledge
Colorado State University
March 1-2, 1996

Edward Zipser
Texas A&M University
March 1-2, 1996

Mark Morrissey
University of Oklahoma
March 19, 1996

Kenneth Gage
NOAA/ERL
April 9, 1996

Emmanouil Anagnostou
University of Iowa
May 23-25, 1996

Milim Oh
Korean Meteorological Research Institute
May 6-29, 1996

Frank Bradley
CSIRO
June 13-14, 1996

Rikie Suzuki
University of Tsukuba
June 21, 1996

Akiyo Yatagai
National Space Development Agency of Japan
June 21, 1996

Benjamin Kedem
University of Maryland
June - July 1996

Ayako Abe-Ouchi
The University of Tokyo
July 3, 1996

Akiome Yamane
Nihon University
September 6, 1996

Shinsuke Satoh
Communications Research Laboratory
October 23, 1996

Ali Tokay
Saint Louis University
December 16-31, 1996

Tom Rickenbach
University of Colorado
December 1996

Tatsuo Endoh
Hokkaido University
August 9, 1996

Data Assimilation Office

Peter Houtekar
Atmospheric Environment Service
March 16-19, 1996

Reagan Moore
San Diego Supercomputer Center
March 19-20, 1996

John Sloan
NCAR
March 19-20, 1996

Bill Dannevik
Lawrence Livermore National Laboratory
March 19-20, 1996

Alan Davis
The Florida State University
March 19-20, 1996

Menas Kafatos
Institute for Computational Sciences and Informatics
March 19-20, 1996

William Farrell
SAIC
March 19-20, 1996

Richard Swinbank
British Meteorology Office
March 29, 1996

Arnold Heemink
Delft University of Technology
March 30 - April 3, 1996

Roger Daley
NRL
April 1-4, 1996

Bhoris Khattatov
NCAR
April 2-4, 1996

Claire Granier
NCAR
April 2-4, 1996

John Gille
NCAR
April 2-4, 1996

John Caron
NCAR
April 2-4, 1996

Monique Robalo Moura
Instituto Superior Tecnico
April 15 - May 5, 1996

Pinhas Alpert
Tel Aviv University
May 5-10, 1996

Michael Ghil
UCLA at Los Angeles
May 14 and August 12-16, 1996

Minfang Ting
University of Illinois
May 17, 1996

Ian Watterson
CSIRO (Melbourne)
June 14, 1996

David W. Tarasick
AES/Environment Canada
June 27, 1996

Yuval Shay-El
Tel-Aviv University
June 30 - August 4, 1996

Michael Tippett
Centre de Provisao de Tempo Estudios Climaticos
July 6 - August 16, 1996

Son Hoang
CNES-National Centre for Space Studies
July 7-10, 1996

Richard Lindzen
Massachusetts Institute of Technology
July 8-9, 1996

Nataly Perlyn
Tel-Aviv University
July 17-26, 1996

Dan Marchesin
Institute de Matequa Parne Appliqua
July 18-24, 1996

William Sawyer
ELCA Informatique
August 22-25 and October 26 - November 1, 1996

Jay Larson
Purdue University
September 28 - October 6, 1996

Chris Ding
National Energy Research Supercomputer Center
October 1-4, 1996

Mesoscale Processes Branch

Alexandre Y. Fong
SESI Inc.
January 29, 1996

Craig Bishop
Penn State University
February 9, 1996.

Masataka Shiobara
Meteorological Research Institute
February 15-16, 1996

Shosi Asano
Meteorological Research Institute
February 15-16, 1996

Matthias Steiner
Princeton University
February 16, 1996

Nelson Seaman
Penn State University
March 18-19, 1996

Reinout Boers
CSIRO
June 12-13, 1996

Udo Schnieder
Global Precipitation Climatology Centre
June 24-25, 1996

Thoshiro Inoue
Meteorological Research Institute
July 19, 1996

Laura Roberti
Politechnico di Torino
July 26, 1996

Graziela Scofield
INPE
October 7-11, 1996

Da-Lin Zhang
University of Maryland-College Park
October 10, 1996

Dom Kniveton
University of Bristol
November 18-22, 1996

Henri Dautet
EG&G
November 20, 1996

Tom Doyle
EG&G
November 20, 1996

Peter Bauer
German Aerospace Research Establishment
November 22, 1996

Lars Schanz
German Aerospace Research Establishment
November 22, 1996

Dimitris Tsintikidis
Hyrdologic Research Center
December 2-6, 1996

Climate and Radiation Branch

Didier Tanre
Laboratoire d'Optique
January 16-23, 1996

Dr. Kyu-Tae Lee
Kangnung National University
January 16 - February 27, 1996

Jung Yoo
Ewha Womans University
January 17 - February 29, 1996

In-Sik Kang
Seoul Atmospheric University
January 18 - February 28, 1996

Keiji Nakai
Japan Weather Association
February 1-2, 1996

Masafumi Shiratori
Japan Weather Association
February 1-2, 1996

Tadayuki Iwaya
Japan Weather Association
February 1-2, 1996

Seiichi Sugawara
Japan Weather Association
February 1-2, 1996

Nobuhiro Ishida
Japan Weather Association
February 1-2, 1996

Georgiy Stechikov
University of Maryland
February 2, 1996

Atusi Numaguchi
Environmental Studies National Institute
February 13, 1996

Wen-Shung Kao
National Taiwan University
February 26 - March 8, 1996

Jaya Ramaprasad
Department of Earth and Atmospheric Sciences
March 3-8, 1996

Gopal Iyengar
National Center for Medium Range Forecasting
March 12, 1996

Samuel Shen
NOAA Climate Prediction Center
March 12, 1996

Heike Schmidt
Ben Gurion University
March 13-31, 1996

Alberto Setzer
CEC-JRC-IRSA
March 17-21, 1996

Carlos Nobre
INPE
March 20-21, 1996

Tatiana Tarassova
Institute of Atmospheric Physics
March 20-21, 1996

Volker Kirchoff
INPE
March 20-21, 1996

Jose Vanderlei Martins
University of Sao Paulo
March 20-27, 1996

Karla Longo de Freitas
Universidade de Sao Paulo Instituto de Fisica
March 20-27, 1996

Marcia Yamasoe
Universidade de Sao Paulo Instituto de Fisica
March 20-27, 1996

Yanwei Ge
University of Maryland
April 1 - June 30, 1996

Denghua Wu
NOAA/NCEP
April 8, 1996

Katia Laval
Laboratoire de Meteorologie
April 8-11, 1996

Wanru Wu
SUNY at Stony Brook
April 9, 1996

Sally McFarland
student, Mt. Holyoke College
June 1 - August 30, 1996

Kelly Ray
student, Whitman College
June 1 - August 30, 1996

Wendy Parker
student, North Illinois University
June 1 - August 30, 1996

Anthony Vega
University of Pennsylvania
June 3 - August 23, 1996

Anatoli Gitelson
Ben Gurion University
June 11-18, 1996

Shinjiro Kanae
University of Tokyo
June 17-21, 1996

Toshi Yasunari
University of Isukuba
June 21, 1996

Mong-Ming Lu
Central Weather Bureau
June 26, 1996

Jen-Cheng Chang
Central Weather Bureau
June 26, 1996

Yuri Mekler
Tel-Aviv University
June 28 - August 31, 1996

Santiago Gasso
University of Washington
June 28, 1996 - June 22, 1997

Pierre Flamant
Lab. De Met. Dynamique
July 1, 1996

Jaques Pelon
Service D'Aeronomie University
July 1, 1996

Jung-Yoo
Ewha Womans University
July 1 - August 25, 1996

Yasuhiro Yamanaka
University of Tokyo
July 3, 1996

Ayako Abe
University of Tokyo
July 3, 1996

Prof. Shixiong Li
July 25-27, 1996

Giuseppe Dalu
Consiglio Nazionale Delle Ricerche
August 1 - September 30, 1996

Michel Verstrate
Joint Research Center
August 15-16, 1996

Alberto Setzer
CEC-JRC-IRSA
September 2 - October 31, 1996

Joachim Joseph
University of Tel-Aviv
September 2 - October 31, 1996

Arnon Karnieli
Ben Gurion University
September 16-30, 1996

Cornelia Glaesser
Martin Luther University
September 23-October 2, 1996

Risha Singh
Center for Math. Modeling and Computer
September 25, 1996

Harshvardhan
Purdue University
October 7-8, 1996

Shuyi Chen
University of Washington
October 23, 1996

Alberto Mugnai
Istituto di Fisica dell'atmosfera
November 21-22, 1996

Carlos Mechoso
University of California, Los Angeles
December 3-5, 1996

Panxing Wang
University of Maryland
December 9-13, 1996

Atmospheric Experiment Branch

Wesley T. Huntress
NASA Headquarters
February 14, 1996

Sushil K. Atreya
University of Michigan
February 23-26, 1996

Thomas M. Donahue
University of Michigan
February 26, 1996

Konrad Mauersberger
Max-Planck Institut
June 26, 1996

Michel Brisson
Division des Systemes Spatiaux
September 6-9

Koichiro Tsuruda
Institute of Space and Astronautical Science
September 11, 1996

Peter Casely
ESTEC/ESA
October 29, 1996

Michel Verdant
ESTEC/ESA
October 29 - November 1, 1996

Siegfried J. Bauer
University of Graz
November 5, 1996

Masaki Adachi
NEC Corporation
November 25-27, 1996

Hajime Hayakawa
Institute of Space and Aeronautical Science
November 25-27, 1996

Tobias C. Owen
University of Hawaii
December 11, 1996

Atmospheric Chemistry and Dynamics Branch

Yona Ettinger
Israeli Embassy
January 19, 1996

Aidan Roche
Lockheed-Martin Palo Alto Research Laboratory
March 12, 1996

Jack Kaye
NASA HQ
April 4, 1996

Paul Wennberg
Harvard University
April 4, 1996

Dimitri Manin
Rockefeller University
April 11, 1996

Richard Evanson
SUNY/Mt. Sinai Campus
April 11, 1996

Gerd Tomascheck
European Space Agency
May 2, 1996

Carleton Mateer
Retired Canadian Government Scientist
Atmospheric Environmental Service
May 16-17, 1996

Charles Blankenship
NASA Langley
May 29, 1996

Colin Hines
York University
May 29, 1996

Randy Friedl
NASA HQ
June 1 - December 1, 1996

Weixing Shen
SUNY Stony Brook
June 19, 1996

James Crawford
Georgia Tech
June 20, 1996

K. K. Mahajan
National Physical Laboratory
June 22-July 13, 1996

Don Grainger
Oxford University
July 1, 1996

Alyn Lambert
Oxford University
July 1, 1996

Kwing L. Chan
Hong Kong University of Science & Technology
July 5, 1996

Ruben Piacentini
Observatorio Astronomico de Rosario
July 5, 1996

Phillipe Peeter
Belgium Institute for Space Aeronomy
July 8-15, 1996

Michael Praether
University of California
July 15, 1996

Franz Geiger
Georgetown University
July 30, 1996

Estelle Condon
NASA Ames
August 5, 1996

John Burrows
University of Brennen
August 19 - September 2, 1996

Joe McConnell
University of Arizona
August 20, 1996

Rudy Frahm
Southwest Research Institute
October 1, 1996

Jose Rodriguez
AER Inc.
October 4, 1996

Hai-Tien Lee
Research and Data Systems Corporation
October 8-9, 1996

Mario Molina
Massachusetts Institute of Technology
October 15 and November 15, 1996

Wendy Richardson
Colorado State
October 16, 1996

Jose Rodriguez
Atmospheric and Environmental Research
October 16, 1996

Igor Geogdzhaev
Central Aerological Observatory
October 30, 1996

Donald Anderson
Johns Hopkins Applied Physics Laboratory
November 1, 1996

Doug Rotman
Lawrence Livermore National Laboratory
November 5, 1996

Ruth Reck
Argonne National Laboratories
November 7, 1996

Upendra Singh
NASA Langley Research Center
November 11, 1996

Richard Miake-Lye
Aerodyne Research Inc.
November 20, 1996

Donald Anderson
Johns Hopkins Applied Physics Laboratory
November 21, 1996

Joe She
Colorado State University
December 4, 1996

Adam DeVir
Technion University
December 9-13, 1996

Ralif Muller
Laser Analytical Systems
December 9-10, 1996

Uri Timofeyev
St. Petersburg State University
December 12, 1996

Valier Ivanov
St. Petersburg State University
December 12, 1996

George Galezan
Lebedov Institute
December 12, 1996

Caterina Maria Tassone
Ph.D. graduate, Univ. Copenhagen
December 18, 1996

Jaya Ramaprasad
Student, Purdue University
December 20, 1996

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LABORATORY FOR

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Section 12

12. 1996 Seminars

Laboratory for Atmospheres Seminar Series

Timothy DelSole, NRC Postdoctoral Fellow, NASA Goddard Space Flight Center, "Principal Oscillation Pattern (POP) Analysis for Extracting Dynamical Information from a Climate Time Series," January 23, 1996.

Ming Dah Chou, NASA Goddard Space Flight Center, "Effects of Clouds, Water Vapor, and Sea Surface Temperature on Radiation Budgets in the Tropical Pacific During an El Niño," February 13, 1996.

Kerry A. Emanuel, Massachusetts Institute of Technology, "Adaptive Observations," February 27, 1996.

Andrew Dessler, USRA, "Chlorine Partitioning Between 20 and 30 km: The UARS Perspective," March 5, 1996.

Prashant Sardeshmukh, University of Colorado, "Organization of Extratropical Synoptic and Lower-Frequency Variability by Climatological Stationary Waves," March 12, 1996.

Gerald M. Heymsfield, NASA Goddard Space Flight Center, "Precipitation Studies System Using ER-2 Doppler Radar (EDOP) Observations," March 26, 1996.

Katia Laval, Laboratorie de Meteorologie Dynamique, "The Effect of Land Surface Processes on Climate," April 9, 1996.

Peter H. Stone, Massachusetts Institute of Technology, "Coupled Atmosphere-Ocean Process Models," April 22, 1996.

Arlindo da Silva, NASA Goddard Space Flight Center, "The Data Assimilation Office's Physical-Space Statistical Analysis System (PSAS)," April 23, 1996.

Ngar-Cheung Lau, Princeton University, "The Role of the 'Atmospheric Bridge' in Linking Tropical Pacific Enso Events to Extratropical SST Anomalies," May 14, 1996.

Wayne T. Kasprzak, NASA Goddard Space Flight Center, "Measurements of the Chemical Composition of Jupiter's Atmosphere by the Galileo Probe Mass Spectrometer," May 28, 1996.

Keith S. Noll, Space Telescope Science Institute, "Ozone in an Unusual Environment: Detection on Jupiter's Satellite Ganymede," October 8, 1996.

Melvyn A. Shapiro, NOAA/Environmental Research Laboratory, "The Differences Between Classical Norwegian and Contemporary Conceptualizations of the Life Cycles of Extratropical Cyclones and the Potential of Space-based Remote Sensing for Advances in Cyclone Research and Forecasting," October 30, 1996.

Robert F. Cahalan, NASA Goddard Space Flight Center, "Cloud Macrostructure and Radiation," November 12, 1996.

Edward J. Zipser, USRA Visiting Scientist, Texas A&M University, "Why are Cumulonimbus Clouds Over Land Stronger than Those Over Oceans?," November 26, 1996.

Heidi L. K. Manning, USRA, "Two Approaches to the Measurement of the Composition of a Neutral Atmosphere by Means of Energy Separation," December 10, 1996

Tropical Rainfall Measuring Mission Office

Emmanouil Anagnostou, University of Iowa, "Assessment of Systematic and Random Errors in Radar Rainfall Estimation," May 24, 1996.

Benjamin Kedem, University of Maryland, "Bayesian Prediction of Non-Gaussian Rainfall Fields," June 20, 1996.

Benjamin Kedem, University of Maryland, "On Combining Instruments," November 21, 1996.

Data Assimilation Office

Tadashi Tsuyuki, Florida State University, "4-DVAR Rainfall Assimilation," February 16, 1996

Richard Swenbank, British Meteorology Office, "Stratospheric Data Assimilation," March 29, 1996.

Brian Wong, Pennsylvania State University, "Acoustic Tomography in the Northeast Pacific Ocean," May 23, 1996.

Son Hoang, CNES, France, "Assimilation of the Altimetric Data into the PE Model (MICOM) by the Adaptive Filter," July 9, 1996.

Roni Avissar, Rutgers University, "Which Type of Observations are Needed to Evaluate High Resolution Atmospheric Models: A FIFE Case Study," July 30, 1996.

Evan Fishbein, Jet Propulsion Laboratory, "MLS Instrument and Validation of the Stratospheric Temperatures Retrieved with MLS," July 31, 1996.

Jame K. Luers, University of Dayton, "Temperature Correction Models for the World's Major Radiosondes," August 12, 1996.

Gail Skofronick Jackson, Georgia Institute of Technology, "The Retrieval of Precipitation Parameters Using Passive Microwave Brightness Temperature Imagery," October 3, 1996.

Keith S. Noll, Space Telescope Science Institute, "Detection of Ozone on Ganymede," October 8, 1996.

Eric Ray and James Holton, Department of Atmospheric Sciences, University of Washington, "Some Features of the Semiannual and Quasi-Biennial Oscillations of the Tropical Stratosphere as Observed by UARS," October 22, 1996.

Laurie Rokke, NCAR, " The Measurement of Pollution in the Troposphere (MOPITT) Simulation and Cloud Detection," October 28, 1996.

Weiyu Yang, "Development of the Adjoint Model of the RAS Parameterization Package and Error Analysis on Approximation Adjoint Calculations," November 7, 1996.

Lydie Lavanant, P. Brunel, Guy Brochard, Centre de Meteorologie Spatiale, "TOVS Sounding Products at CMS," November 14, 1996.

Gerald Potter, Lawrence Livermore National Lab, "Systematic Model Errors Uncovered During the Atmospheric Model Intercomparison Project," November 14, 1996.

Shawn Turner, Atmospheric Environment Service, "Forward Modelling for TOVS/GEOS at the Atmospheric Environment Service," December 3, 1996.

Wayne Higgins, National Meteorological Center, "Influence of the North American monsoon on the United States Summer Precipitation Regime," December 6, 1996.

Richard Menard, JCET, "Kalman Filter Data Assimilation of HALOE Observations," December 9, 1996.

Lars Peter Riishojgaard, USRA, "Potential Vorticity Modeling and Assimilation," December 10, 1996.

Yong Li, General Sciences Corporation, "Potential Vorticity Modeling and Assimilation," December 10, 1996. Shian-Jiann Lin, General Sciences Corporation, "Physically-Based Modeling of Geophysical Fluids, December 13, 1996.

Mesoscale Atmospheric Processes Branch

Kazumasa Aonashi, Meteorological Research Institute, "Assimilating Microwave Radiometer Data into a Regional NWP Model," January 2, 1996.

David Kingsmill, University of Washington, "Inflow and Outflow Characteristics of Convection in TOGA-COARE," February 8, 1996.

Stefano Grivet-Talocia, SSAI, "Wavelet Analysis of a Microbarograph Network," February 20, 1996.

Kuan-Man Xu, Colorado State University, "Applications of Cloud Ensemble Simulation to Cloud Parameterizations," February 20, 1996.

Bill Kuo, NCAR/NMM, "Impact of GPS Data on the Prediction of an Extratropical Cyclone: An Observing System Simulation Study," February 21, 1996.

Anthony Giullory, Marshall Space Flight Center, "Variability of Integrated Water Content (IWC) from GOES Pathfinder Data," March 25, 1996.

Govindasamy Balasubramanian, Princeton University, "The Role of Eddy Momentum Fluxes in Shaping the Lifecycle of a Baroclinic Wave," April 5, 1996.

Henry Juang, EMC/NCEP, "Regional Climate Simulations Over Asia by the NCEP Regional Spectral Model," April 8, 1996.

Tom Rickenback, Colorado State University, "Convection in TOGA-COARE: Horizontal Scale, Morphology, and Rainfall Production," April 25, 1996.

Jeffrey B. Halverson, Universities Space Research Association, "Two Dimensional Modeling Investigations of a TOGA-COARE Mesoscale Convection System," May 28, 1996.

Joseph M. Prospero, University of Miami, "The Temporal and Spatial Variability of Aerosols in the Marine Boundary Layer Over the World's Oceans: Comparisons with AVHRR Aerosol Optical Thickness Measurements," June 10, 1996.

Peter G. Black, NOAA/AOML, "Eyewall Meso-vortices in Hurricanes Hugo and Andrew," June 19, 1996.

Xiaoqing Wu, National Center for Atmospheric Research, "Long Term Cloud Resolving Modeling of Cloud Systems Observed During TOGA-COARE," June 24, 1996.

Matthew McGill, University of Michigan, "Multi-Channel Incoherent Doppler Lidar Technique for Wind and Aerosol Measurements," July 15, 1996.

Leo Donner, Princeton University, "Elements of Cumulus Parameterization for Microphysics, Radiation and Initialization in Large-Scale Models," July 17, 1996.

Steve Koch, North Carolina State University, "Mesoscale Predictability Studies with the MM4 and MM5 Models in STORMFEST," September 27, 1996.

Konstatine Georgakakos, Scripps Institute of Oceanography, "Modeling Oceanic Tropical Rainfall Variability," October 11, 1996.

Brian Mapes, University of Colorado, "Hand in Glove: Deep Convection and its Stratified Environment," October 31, 1996.

Biao (Ben) Chen, The Ohio State University, "Simulated Global Atmospheric Response to Antarctic Forcing," November 21, 1996.

Anthony Davis, Science Systems and Applications, Inc., "Green's Functions Open New Horizons in Cloud Remote Sensing with Diffusing Solar and Lidar Photons," December 5, 1996.

Brad Ferrier, JCET, "Importance of Updraft Tilt in Two-Dimensional Simulations of Deep Convection," December 9, 1996.

J.-F. de La Beaujardiere, Universities Space Research Association, "Web Site Architecture," December 17, 1996.

Paul J. Roebber, University of Wisconsin at Milwaukee, "The Sensitivity of Precipitation to Circulation Details: An Analysis of Regional Analogues," December 17, 1996.

Climate and Radiation Branch

Scott Power, BMRC, "Stability and Variability of the Thermohaline Circulation," January 24, 1996.

Gerry Mace, Pennsylvania State University, "The Relationship Between Composite Cirrus Morphology and Large-Scale Meteorology Derived from 94 GHZ Cloud Radar Data," February 7, 1996.

Hengyi Weng, General Sciences Corporation, "A Possible Source of Nonstationary Interannual Variability: Nonlinearity due to Frequency Modulation," February 14, 1996.

George Kilades, NOAA, "Characteristics of Observed Equatorial Rossby Waves Over the Pacific Sector," February 21, 1996.

Si-Chee Tsay, NASA Goddard Space Flight Center, "Spectral Reflectance and Atmospheric Energetics in Cirrus-like Clouds," February 28, 1996.

Winston Chao, NASA Goddard Space Flight Center, "Super Cloud Clusters, Twin Cyclones and All That," March 6, 1996.

De-Zheng Sun, NCAR, "Dynamic Ocean-Atmosphere Coupling: A Thermostat for the Tropics," March 20, 1996.

Judit Pap, UCLA, "Solar Total and Spectral Irradiance Variations," March 28, 1996.

Andrew Ackerman, NASA Ames Research Center, "Interactions Between Aerosols and Clouds in the Marine Boundary Layer," April 3, 1996.

Joel Susskind, NASA Goddard Space Flight Center, "ENSO Signals Seen in the TOVS Pathfinder A Data Set," April 17, 1996.

Rosana Ferreira, USRA Visiting Fellow, "TUTTs: Their Formation, Evolution, and Role in the General Circulation," April 25, 1996.

Chung-Hsiung Sui, NASA Goddard Space Flight Center, "Multiscale Air-Sea Interaction During TOGA-COARE," May 1, 1996.

Allen H. L. Huang, U. Wisconsin-Madison, "The Prospects of Advanced Infrared Sounders," May 8, 1996.

Robert Cahalan, NASA Goddard Space Flight Center, "Retrieval and Simulation of Fractal Clouds," May 15, 1996.

Thomas Bell, NASA Goddard Space Flight Center, "Sampling Error for Monthly Gridded Satellite Rainfall Estimates," June 5, 1996.

Stephen Klein, Princeton University, "ENSO Teleconnections in Tropical SSTs and their Causes," August 5, 1996.

Gabriele Hegerl, Max-Planck Institut fuer Meteorologie, "Multi-fingerprint Detection and Attribution of Anthropogenic Climate Change," September 16, 1996.

Michael King, NASA Goddard Space Flight Center, "Earth Observing System-Science Objectives and Challenges," September 18, 1996.

Bo-Cai Gao, Naval Research Laboratory, "Imaging Spectrometry and Applications to EOS/MODIS," October 2, 1996.

Dennis Chesters, NASA Goddard Space Flight Center, "Results and Opportunities on the Present and Future Geosynchronous Weather Climate and Observing Systems," October 16, 1996.

V. Krishnakumar, Applied Research Corporation, "Possible Role of Symmetric Instability in Asian Monsoon Transition," November 6, 1996.

Steve Esbensen, Oregon State University, "Enhancement of Tropical Ocean Evaporation and Sensible Heat Flux by Atmospheric Mesoscale Systems," November 7-8, 1996.

Guyla Molnar, Universities Space Research Association, "Variability of Marine Stratiform Cloud Systems Using Multispectral GOES Imagery," December 2, 1996.

Robert Cess, State University of New York, "Absorption of Solar Radiation by Clouds: Observations Versus Models," December 2, 1996.

Dan Imre, Brookhaven National Laboratory, "Quantifying Cloud-Induced Shortwave Absorption: An Examination of Uncertainties and of Recent Arguments for Large Excess Absorption," December 2, 1996.

Peter Pilewsie, NASA Ames Research Center, "Direct Observations of Excess Solar Absorption by Clouds," December 2, 1996.

Carlos R. Mechoso, UCLA, "Links Between the Pacific and Atlantic Climates," December 4, 1996.

Robert Ellingson, University of Maryland, "The ARM-UAV Program: Project Description and First Results," December 18, 1996.

Atmospheric Chemistry and Dynamics Branch

James Crawford, Georgia Tech, "An Assessment of O3 Photochemistry in the Extratropical Western, North Pacific based on PEM-West B Observations," June 20, 1996.

Lloyd Currie, NIST, "Tracing Biomass Burning Aerosol from the Combustion Laboratory to Summit, Greenland," July 18, 1996.

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Responsible NASA official: Bob Theis

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13. 1996 Visiting Scientists and Associates of Joint Centers

Distinguished Visiting Scientists

David Atlas
Robert Fraser

National Research Council

Keith Cole
Timothy M. DelSole
Colin Hines
Kyu-Myong Kim
Gary Morris
Robert Pincus
Tom Rickenbach
Andrew Wald
Jerald Ziemke

USRA Visiting Fellows

David J. Brown
Ph.D. from:
Australian National University

Someshwar Das
on leave from:
National Center for Medium-Range Weather Forecasting
India

Rosana Ferreira
Ph.D. from:
Colorado State University

Richard Lindzen
on leave from:
Massachusetts Institute of Technology

Lars Riishojgaard
Ph.D. from:
University of Copenhagen

Naihui Song
Ph.D. from:
Penn State University

Edward Zipser
on leave from:
Texas A&M University

USRA Visiting Scientists

Eyal Amitai
Ebby Anyamba
Jeff de La Beaujardiere
Maria Cadeddu
Mian Chin
Eugene Cordero
David Duda
Gregory Gaspari
Jeffrey Haferman
Jeffrey Halverson
Chang-Hoi Ho
Dan Johnson
Chandra Kambhamettu
Chris Kidd
Barry Lynn
Heidi Manning
Richard Menard
Wei Min
Gyula Molnar
Riko Oki
Taikan Oki
Ivanka Stajner
Nobuhiro Takahashi
Ricardo Todling
Bryan Zhou

JCESS

Andrew Dessler
Michael Fox-Rabinovitz
Jay Larson
Peter Lyster
Vikram Mehta
Chung-Kyu Park
Kenneth Pickering

JCET

Scott J. Janz
Xu Liang
Harvey Melfi
Steven Platnick
Peter Soulen
Menghua Wang

University of Michigan

Larry Brace
Matthew McGill

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14. Acronym List

ADEOS Advanced Earth Observing Satellite

AEAP Atmospheric Effects of Aviation Project

AIRS Atmospheric Infrared Sounder

AMIP Atmospheric Model Intercomparison Project

AMS American Meteorological Society

AMSR Advanced Microwave Scanning Radiometer

AMSU Advanced Microwave Sounding Unit

ARL Airborne Raman Lidar

ARM Atmospheric Radiation Measurement

AVHRR Advanced Very High Resolution Radiometer

AVIRIS Airborne Visible/infrared Imaging Spectrometer

BL boundary layer

BUV Backscatter Ultraviolet

CAMEX-2 Convection and Atmospheric Moisture Experiment-2

CAPE Convective Available Potential Energy

CARD Consistent Assimilation of Retrieved Data

CART Cloud and Radiation Testbed

CCD Charge Coupled Device

CEAS Center for Earth-Atmosphere Studies

CLS Cloud Lidar System

COADS Comprehensive Ocean Atmosphere Data Set

CSTEA Center for the Study of Terrestrial and Extraterrestrial Atmospheres

D/H Deuterium/Hydrogen

DAAC Distributed Active Archive Center

DAO Data Assimilation Office

DAS Data Assimilation System

DOD Department of Defense

ECMWF European Center for Medium-Range Weather Forecasting

EDOP ER-2 Doppler Radar

ENSO El Niño Southern Oscillation

EOS Earth Observing System

EP Earth Probe

ERBE Earth Radiation Budget Experiment

ESA European Space Agency

FIRE First ISCCP Regional Experiment

FM Flight Model

FOR field of regard

GATES Geosynchronous Advanced Technology Environmental System

GCE Goddard Cumulus Ensemble (model)

GCIP GEWEX Continental-scale International Project

GCM General Circulation Model

GCMS Gas Chromatograph Mass Spectrometer

GEOS Goddard EOS (model)

GEWEX Global Energy and Water Experiment

GISS Goddard Institute for Space Studies

GLOBE Global Learning and Observations to Benefit the Environment

GOES Geostationary Operational Environmental Satellite

GPCP Global Precipitation Climatology Project

GPMS Galileo Probe Mass Spectrometer

GPROF Goddard Profiling Algorithm

GSFC Goddard Space Flight Center

GV Ground Validation

GVP Global Validation Program

HALOE HALogen Occulation Experiment

HBCU Historically Black Colleges and Universities

HIRS High Resolution Infrared Sounder

IFOV Instantaneous Field of View

IITA Information Infrastructure Technology and Applications

INMS Ion and Neutral Mass Spectrometer

IR Infrared

ISCCP International Satellite Cloud Climatology Project

ISIR IR Spectrometer Imaging Radiometer

ITS Interferometer Temperature Sounder

JCESS Joint Center for Earth System Science

JCET Joint Center for Earth Systems Technology

JCG Joint Center for Geoscience

JCOSS Joint Center for Observation System Science

JOVE Joint Venture

JPL Jet Propulsion Laboratory

KMR Kwajalein Missile Range

LASAL Large Aperture Scanning Airborne Lidar

LCL Lifting Condensation Level

LITE Lidar In-Space Technology Experiment

LORE Limb Ozone Retrieval Experiment

LS large-scale

MABL Marine Atmospheric Boundary Layer

McRAS Microphysics of Cloud with Relaxed Arakawa-Schubert cumulus parameterization

METSAT Meteorological Satellite

MM5 Mesoscale Model Version 5

MODIS Moderate Resolution Imaging Spectroradiometer

MPL Micro Pulse Lidar

MSU Microwave Sounding Unit

MTPE Mission to Planet Earth

NAS Numerical Aerospace Simulation

NASA National Aeronautics and Space Administration

NCAR National Center for Atmospheric Research

NCCS NASA Center for Computational Sciences

NCEP National Center for Environmental Prediction

NESDIS National Environmental, Satellite, Data and Information Service

NOAA National Oceanic and Atmospheric Administration

NRC National Research Council

NWS National Weather Service

NSCAT NASA Scatterometer

OLR Outgoing Longwave Radiation

PHASERS Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing

PIP Precipitation Intercomparison Project

POES Polar Orbiting Environmental Satellite

PSAS Physical-space Statistical Analysis System

QM Qualification Model

RAS Relaxed Arakawa-Schubert

RCDF Radiometric Calibration and Development Facility

RSD Remote Sensing Data

s/n signal to noise

SAFARI Southern African Fire Atmospheric Research Initiative

SBUV Solar Backscatter Ultraviolet

SBUV/2 Solar Backscatter Ultraviolet

SCAR-B Smoke Cloud And Radiation-Brazil

SDCD Space Data and Computing Division

SDS Solar Disk Sextant

SEE Science Engineering Education

SIRTAS Summer Institute and Research Traineeship in Atmospheric Sciences

SOLSE Shuttle Ozone Limb Sounding Experiment

SOLSTICE Solar Stellar Irradiance Comparison Experiment

SSBUV Shuttle Solar Backscatter Ultraviolet

SSM/I Special Sensor Microwave/Imager

SST Sea Surface Temperature

SSU Special Sensor Unit

STRAT Stratospheric Transport of Atmospheric Tracers

STROZ LITE Stratosphere Ozone Lidar Trailer Experiment

SUCCESS Subsonic Aircraft: Contrails and Cloud Effects Special Study

TARFOX Tropospheric Aerosol Radiative Forcing Observational Experiment

Tb brightness temperatures

TIROS Television Infrared Operational Satellite

TM Thematic Mapper

TOA Tropical Ocean Atmosphere

TOGA-COARE Tropical Ocean Global Atmosphere/Coupled Ocean-Atmosphere Response Experiment

TOMS Total Ozone Mapping Spectrometer

TOVS TIROS Operational Vertical Sounder

TRACE-A TRansport and Atmospheric Chemistry near the Equator-Atlantic

TRMM Tropical Rainfall Measuring Mission

TSCC Tilt Scan CCD Camera

TSDIS TRMM Science Data and Information System

UARS Upper Atmosphere Research Satellite

UNEP United Nations Environment Program

USRA Universities Space Research Association

UV ultraviolet

VIS Visible

WMC Western Maryland College

WMO World Meteorological Organization

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