UNITED STATES OF AMERICA

1.0 INTRODUCTION AND OVERVIEW

This section describes the contributions of the United States of America to international efforts in atmospheric chemical / dynamical and UV radiation monitoring and research relevant to global changes in atmospheric ozone and its relationship to changes in climate. These research and observational activities provide a set of predictive tools and capabilities that deliver sound scientific information for use by policy and economic decision makers as they consider various options for mitigating or adapting to global change. An attempt has been made to construct a reasonably comprehensive description of the activities supported by the various US Government Agencies that have research programs in these areas, utilizing their FY2002 reports to the US Global Change Research Program (USGCRP) as well as more recent inputs provided specifically for this report. Nevertheless, it is possible that some Agency contributions are not reflected herein.

Relevant atmospheric chemical and UV radiation research within the United States is principally managed under the auspices of the National Aeronautics and Space Administration (NASA), the Department of Commerce (DoC) (primarily the National Oceanic and Atmospheric Administration (NOAA) but also the National Institute of Standards and Technology (NIST)), the National Science Foundation (NSF), the Department of Energy (DoE), the Environmental Protection Agency (EPA), the Department of Health and Human Services / National Institutes of Health (HHS/NIH), the United States Department of Agriculture (USDA), the Department of Defense (DoD), and the Smithsonian Institution (SI). The following is an integrated overview of the central themes and approaches found within these institutional programs:

- Global observations of atmospheric change, including
  - Ground-based flask collection and in-situ measurements of ozone- and climate-related trace gases at a set of globally distributed stations;
  - Ground-based measurements of upper tropospheric and stratospheric parameters, particles, and chemically active compounds using remote sensing instruments;
  - Space-based, balloon-borne, and airborne measurements of ozone and chemicals and parameters related to stratospheric and tropospheric ozone chemistry.

- Elucidation of the processes that cause regional and global atmospheric changes, including
  - Laboratory studies of key atmospheric trace chemical species to determine the kinetic, photochemical, thermodynamic, and spectroscopic properties that are required as inputs to computational models; and
  - Focused airborne/balloon-borne/surface-based field campaigns (integrated with satellite-based measurements) that are designed to probe selected regions of the atmosphere to characterize the controlling chemical and related dynamical processes.

- Development of a predictive capability that includes diagnostic and prognostic models, which incorporate the chemical and dynamical understanding gained, to test the scientific theories, to reveal deficiencies in understanding, and to predict future atmospheric chemical behavior as a result of natural and/or anthropogenic forcings.

- Linkages of atmospheric chemical changes to other environmental changes such as ecological and human health, including
  - Monitoring the exposure of ecosystems to ultraviolet radiation;
  - Characterizing potential human health risks associated with substances that are planned to replace compounds having known risks to the environment, and development of suitable alternatives for those substances; and
  - Measuring and modeling atmospheric species (e.g., sulfur dioxide/sulfate, nitrogen oxides/nitrate) involved in global tropospheric chemistry, particulate formation, and acid deposition.

- Evaluation and assessment of scientific findings and integrating them for use by decision makers, including
    - State-of-science assessments of the ozone layer and climate system, as they relate to atmospheric trace gases and associated human impacts.

The following sections provide a more detailed synopsis of how these research responsibilities are distributed amongst the various US Government Agencies.

2.0 NASA

2.1 *Goals and Objectives*

The mission of NASA's Earth Science Enterprise (ESE) is to develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations. Within this framework, NASA has mapped out a research strategy for the next decade to address questions in the logical scientific progression of variability, forcing, response, consequences, and prediction respectively:

- How is the global Earth system changing?
- What are the primary causes of change in the Earth system?
- How does the Earth system respond to natural and human-induced changes?
- What are the consequences of changes in the Earth system for human civilization?
- How well can we predict future changes to the Earth system?

Under each of the above five categories are more detailed questions that reflect the ESE thematic research areas. Thus, NASA's component of the US program in atmospheric chemistry research lies within the ESE research theme of Atmospheric Chemistry, Aerosols, and Solar Radiation and is designed to address the following more specific questions:

- How is stratospheric ozone changing, as the abundances of ozone-destroying chemicals decrease and those of new substitutes increase?
- What trends in atmospheric constituents and solar radiation are driving global climate?
- How do stratospheric trace constituents respond to changes in climate and atmospheric composition?
- What are the effects of regional pollution on the global atmosphere, and the effects of global chemical and climate changes on regional air quality?
- How well can future atmospheric chemical impacts on ozone and climate be predicted?

Research activities formulated around these questions are designed to increase our understanding of the distribution of ozone and other chemically and radiatively active species in the global troposphere and stratosphere in the context of an atmosphere undergoing both chemical and climatic change from both human-induced and natural processes. Elements of the NASA program are (a) global measurement of trace constituent and aerosol distributions with space-based platforms, (b) focused process-oriented field campaigns utilizing space-, aircraft-, balloon-, and ground-based instruments, (c) long-term measurements of key trace tropospheric and stratospheric constituents with ground-based instruments, (d) computational models for simulating the recent past and long-term future of atmospheric chemical composition, (e) development of new technologies for atmospheric chemistry measurements, (f) laboratory investigations of fundamental kinetic, photochemical, thermodynamic, and spectroscopic processes, and (g) support for national and international assessments and intercomparison activities.

2.2 *Contributing Elements*

2.2.1 Earth Observing System (EOS) and other Space Flight Programs - This element involves the development of new space-based remote sensing instrumentation and associated flight platforms, ground and data systems, algorithms, and data processing. The largest part of this is associated with the EOS Aura mission, a four-instrument mission currently planned for launch in early 2004. The instruments comprising this mission are as follows.

- The High Resolution Dynamics Limb Sounder (HIRDLS) will use infrared emission to measure ozone, water vapor, temperature, and a broad range of trace constituents, including long-lived source gases and most of the important nitrogen-containing species (N_2O, NO_2, HNO_3, N_2O_5, and ClONO2) in the upper troposphere and stratosphere. The long duration and high vertical resolution of HIRDLS measurements will make a unique contribution to knowledge of stratospheric constituents and the transport of trace gases between different regions of the stratosphere and troposphere. HIRDLS is a joint development of the US and United Kingdom.
- The Microwave Limb Sounder (MLS) uses emission in the microwave spectrum to observe the distribution of ozone, water vapor, long-lived tracers like N_2O, halogen compounds and the OH radical. Simultaneous measurements of ClO and HCl will also made. These observations will allow a critical test of current understanding of the partitioning of chlorine between reservoir species. Sulfur dioxide measurements will enable studying the decay of stratospheric SO_2 injected by occasional volcanic eruptions.
- The Tropospheric Emission Spectrometer (TES) will conduct an exploratory survey of tropospheric trace constituents and corresponding chemical processes. The high spectral resolution (~0.025 cm^{-1}) of TES will allow vertically resolved measurements of ozone and other trace constituents, including the important nitrogen oxide family that plays a major role in ozone production in the lower atmosphere. Key tropospheric molecules measured by TES also include carbon monoxide and water vapor. TES will operate in both a nadir- and limb-viewing mode, and is pointable so that interesting regions can be observed more than once per day.
- The Ozone Monitoring Instrument (OMI), supplied by the Netherlands, will measure total column amounts of ozone as well as yield information on ozone profiles. The OMI column ozone record will build on the measurement record obtained from the Total Ozone Mapping Spectrometer (TOMS) and the European Global Ozone Monitoring Experiment (GOME) and will provide similar information with higher spatial resolution. OMI will also measure total column amounts of several other trace gases, notably NO_2.

The EOS flight program also includes the Measurement of Pollution in the Troposphere (MOPITT) instrument aboard the EOS-Terra platform launched in December 1999 and the third Stratospheric Aerosol and Gas Experiment (SAGE III) instrument launched in December 2001. The US space measurements program is closely interconnected with that of our foreign partners - for example, the first SAGE III was launched aboard a Russian Meteor-3M spacecraft, while Canadian and Dutch instruments are being flown aboard EOS-Terra and EOS Aura respectively (with important British contributions to another Aura instrument). NASA supported scientists are involved in algorithm development and data analysis for GOME and there are plans to provide support to US scientists for the analysis of ENVISAT data.

2.2.2 Total Ozone and Aerosol Mapping - Total ozone data have come principally from the series of Total Ozone Mapping Spectrometer (TOMS) flights on NASA spacecraft or cooperative flight missions of opportunity, and Solar Backscatter Ultraviolet (SBUV) measurements on the NOAA polar-orbiting operational environmental satellite series. Both are based on solar ultraviolet backscatter measurements to determine ozone amounts. TOMS is a cross-track scanning instrument that provides daily global mapping of total column ozone with long-term accuracy of the order of 1% per decade. SBUV is a nadir-viewing instrument that provides total column and partial ozone profile data along the sunlit portion of the sub-satellite track, i.e., typically 16 orbits per day.

The TOMS program also provides unique information on the distribution of aerosol and particulate matter in the troposphere, including UV-absorbing particles (mineral dust, volcanic ash, smoke particles from fires and biomass burning) and sulfate aerosol. TOMS aerosol data are of particular interest because they currently constitute the only source of information on large-scale aerosol loading of the atmosphere over land areas.

TOMS instruments were flown on Nimbus 7, Meteor-3, ADEOS, and currently on Earth Probe platforms since 1997. A launch failure of the QuikTOMS instrument occurred in September 2001, placing the continuity of the column ozone record from TOMS instruments in jeopardy. Space-based measurements by other agencies will, thus, be important in filling any ozone observation gap. The European space agency GOME instrument has been operating since 1995 and the successor instrument SCIAMACHY on the European ENVISAT mission is expected to provide more comprehensive data, beginning in 2002. NASA investigators are playing a significant role in the exploitation of GOME data and the development of retrieval algorithms for both GOME and SCIAMACHY. This type of cooperative effort is expected to be pursued in the future, as data from these instruments will be required for the continuity of the column ozone record until the launch of OMI on EOS-Aura.

Additional SBUV/2 instruments are still planned for launch on the NOAA Polar-orbiting Operational Environmental Satellite series. In the long term, the US National Polar Orbiting Environmental Satellite System (NPOESS) will deploy an Ozone Mapping and Profiling Suite (OMPS) that encompasses the capabilities of TOMS and will maintain backscatter UV measurement of total ozone and stratospheric profiles indefinitely in the future. Likewise, an ozone-profiling sensor (GOME-2) is planned on the European METOP operational polar-orbiting environmental satellite series.

2.2.3 Ozone, Aerosol and Polar Stratospheric Cloud Profiles - The principal source of high resolution stratospheric ozone and aerosol profile data has been the Stratospheric Aerosol and Gas Experiment (SAGE) program, based on the principle of occultation of solar radiation by the limb of the atmosphere. The main limitation of SAGE data is spatial coverage, since solar occultations occur only in two latitudes bands for a given orbit. The SAGE data have been very important in determining long-term trends in ozone vertical profile, especially in the lower stratosphere and SAGE data analysis and science studies continue to be a research priority – in particular, comparison of SAGE ozone profile data with UARS observations. NASA also supports the systematic analysis of high latitude solar occultation data acquired by the Polar Ozone Aerosol Monitor (POAM) instruments on the French SPOT earth observation satellite series (in polar orbit).

Two flight models of an improved instrument SAGE III have been fabricated for deployment on a Russian Meteor-3M spacecraft launched in December of 2001 (sun-synchronous polar orbit) and possibly on the International Space Station in 2007 (51.5° inclination orbit). The nature of solar occultation instruments in polar sun-synchronous orbits restricts observations to high latitudes, although the lunar occultations will help to “fill in” the tropics and mid-latitudes. An third SAGE III instrument is available for another flight opportunity should one arise. It is the intention that this program merge with the NASA systematic measurement program (see below).

Stellar occultation is a promising technique for ozone profiling, as it provides many more occultation opportunities than either solar or lunar occultations and enables greatly expanded spatial coverage. In addition, the small size of stellar sources simplifies the retrieval process. This approach has been successfully demonstrated with the UVISI instrument on the DoD MSX mission, with NASA support for data analysis. The Global Ozone Monitoring by Occultation of Stars (GOMOS) instrument on the European ENVISAT mission (to be launched in early 2002) will also make use of the stellar occultation technique.

2.2.4 Mission Operations and Data Analysis - This element involves spacecraft operation, data transfer and processing, and scientific verification and analysis for presently operating satellites making trace constituent and aerosol measurements of the global atmosphere. Currently, these include the Earth Probe/Total Ozone Mapping Spectrometer (EP/TOMS) and Earth Radiation Budget Satellite/Stratospheric Aerosol and Gas Experiment (ERBS/SAGE II) instruments, as well as the Upper Atmosphere Research Satellite (UARS). Support is also provided to help maintain the accuracy of the long-term record of measurements from the Solar Backscatter Ultraviolet (SBUV/2) instruments flown by the National Oceanic and Atmospheric Administration.

2.2.5 Research and Analysis Programs

Upper Atmosphere Research Program (UARP) – This program uses a combination of laboratory measurements, long-term globally distributed ground-based measurements, process-oriented airborne- and balloon-borne campaigns, and process models to study the distribution of ozone, aerosols, and other atmospheric trace constituents in the global stratosphere and upper troposphere. Laboratory measurements emphasize those of fundamental stratospheric and tropospheric molecular processes (kinetics, photochemistry, thermochemistry) and properties (molecular spectroscopy relevant to remote and *in situ* sensing). Ground-based measurements emphasize accurate long-term knowledge of distributions of stratospheric trace constituents whose concentrations are expected to vary with time, as well as their tropospheric precursors. Process-oriented field campaigns range from studies of high latitude chemistry to transport processes connecting the tropics and mid-latitudes. Balloon-borne missions support both comprehensive studies of atmospheric trace constituent profiles above altitudes reachable by aircraft and validation of satellite measurements. New instrumentation is developed for airborne use, especially to increase the set of constituents amenable to *in situ* measurement.

Tropospheric Chemistry Program (TCP) – This program emphasizes the use of airborne platforms to study the impact of human activity (e.g. fossil fuel combustion, biomass burning) on the composition of the super-regional to global-scale troposphere. Process-oriented field campaigns are carried out with comprehensively instrumented aircraft for these studies. In recent years these have been located in the Pacific Ocean region, including both the western and tropical Pacific, an emphasis that is planned to continue in concert with Atlantic studies. The Pacific region, in particular, is expected to be impacted heavily by the growing industrial activity and growing transportation needs of Asia, but it is still a relatively clean air part of the world. Studies there provide an valuable baseline for studies of the chemistry/climate connection. The Pacific Ocean region is also an excellent laboratory for studies of fundamental tropospheric photochemistry. Process modeling studies and the development of smaller, lighter instrumentation for the airborne measurement are also important elements of the program.

Atmospheric Chemistry Modeling and Analysis Program (ACMAP) – This program uses a combination of data analysis and computational modeling approaches to study the distribution of trace constituents and aerosols in the global atmosphere and the way in which material is transported between different regions of the atmosphere. Both space- and aircraft-based measurements are extensively studied to improve our understanding of chemical and transport processes, as well as the spatial and temporal variability (both short and long term) of atmospheric trace constituents. Computational models are used to simulate both the evolution of the atmosphere in recent times for comparison with observational data and in the future to allow for projections of future changes based on assumed chemical and climatic forcing, as well as to explore the linkages between atmospheric chemical and climate change.

Earth Observing System Interdisciplinary Science Program (EOS/IDS) - This element of the NASA program involves the uses a variety of computational models to study the linkages between atmospheric chemistry and climate change, including the development of computational models that can address the feedback effects between the processes associated with these two issues. Models that can simulate the distribution of radiatively important tropospheric ozone and tropospheric aerosols are the major part of this research element.

Technology Development Program - The implementation of this relatively new focus on technology development for both space- and airborne-based instrumentation continues. This will accelerate the incorporation of new technology into atmospheric chemistry measuring instruments, and may even facilitate the development of whole new observational approaches. The investments made in this program will significantly improve the chances that new technology can be successfully proposed for future space-based missions.

2.3 *Selected Highlights*

- Investigations of the altitude dependence of ozone trends via detailed studies of the altitude dependence of ozone loss have continued using ground-, balloon-, and space-based observations. Results from these studies of the loss rates of ozone in the upper stratosphere, are consistent with computational models. Ozone profile trends studies will continue with data from the SAGE III satellite instrument launched in December 2001. The continuity of NASA's column ozone trends studies was set back by the launch failure of the QuikTOMS instrument in September 2001 and the degradation of the optics of the EP-TOMS instrument. NASA scientists are calibrating the latest EP-TOMS data using SBUV-2 retrievals. They are also playing a significant role in the exploitation of GOME column ozone data and the development of retrieval algorithms for both GOME and SCIAMACHY. This type of cooperative effort is expected to be pursued in the future, as data from these instruments will be required for the continuity of the column ozone record until the launch of OMI on EOS-Aura.

- Based on SAGE I and SAGE II observations, stratospheric sulfate aerosol levels in 2002 are significantly less than those observed in the 1970's, which had been considered the baseline for non-volcanic aerosol levels. In most regions, aerosol levels in 2002 are more than 20% less than those observed in 1979. However, at altitudes near the tropopause, levels are nearly the same in the two periods. This suggests that anthropogenic effects on stratospheric aerosol levels are minimal.

- NASA supported data analysis has succeeded in measuring the tropospheric pollutants and ozone precursors nitrogen dioxide (NO_2) and formaldehyde (HCHO) from space, using the European Space Agency's Global Ozone Monitoring Experiment (GOME) instrument. The NO_2 measurements included global determinations that distinguish between the stratospheric background concentrations and the tropospheric amounts from activities such as biomass burning and industrial activity. Formaldehyde measurements include the burden over North America and the initial studies to relate the measured concentrations to sources of biogenic volatile organic compounds (VOCs).

- NASA and NOAA satellite observations show that the Antarctic ozone thinning in 2001 Austral spring began earlier than usual, exceeded 26 Million km^2, and broke up in the first two weeks of December. The measurements were obtained this past year between mid-August and early October using the Total Ozone Mapping Spectrometer (TOMS) instrument aboard NASA's Earth Probe (TOMS-EP) satellite and the Solar Backscatter Ultraviolet Instrument (SBUV) aboard the NOAA-14 satellite. Data from the satellites show that 2001 ozone depletion reached a an extremely large and persistent ozone hole that exceeded a size of 10.3 million square miles (26.6 million square kilometers) on Sept. 17, 2001. The ozone hole exceeded 25 million km2 for 20 days during the Austral spring of 2001. The ozone level fell to 99 Dobson units on Sept. 26, 2001. These extremely low values are comparable to those observed during the 1990's.

- Unusually low levels of ozone over the Arctic were measured during March 1997 and 2000 by satellite-based monitoring instruments operated by NASA and the National Oceanic and Atmospheric Administration (NOAA). During the winter of 1999-2000, the NASA sponsored SAGE III Ozone Loss and Validation Experiment (SOLVE) was jointly conducted with the European Commission sponsored Third European Stratospheric Experiment on Ozone 2000 (THESEO 2000). This joint measurement campaign employed satellite, aircraft, and ground-based instruments to measure Arctic stratospheric ozone losses, and the factors that control those losses. During the period from mid-January to mid-March, a 60% loss of ozone was observed in a layer near 20 km. This large loss has been tied to halogen catalytic loss processes with direct measurements of chlorine and bromine species. The cold temperatures of that year enhanced the activation of chlorine via the heterogeneous chemistry that occurs on the surfaces of polar stratospheric cloud particles. Recent years, such as the winter of 2000-2001, have been relatively warmer, slowing the ozone loss process. This large interannual variability confounds the direct attribution of ozone loss, and makes difficult the separation of ozone loss resulting from chemistry and dynamics. Further, the impact of climate change on stratospheric ozone remains a paramount challenge.

- UARP continues to support the operation of the Advanced Global Atmospheric Gases Experiment (AGAGE) network, which aims to further our understanding of a number of important global chemical and climatic phenomena by (1) optimally determining from observations, the rate of emission and/or chemical destruction (i.e., lifetime) of the anthropogenic chemicals that contribute most of the reactive chlorine and bromine released into the stratosphere; (2) accurately documenting the global distributions and temporal behavior of the biogenic/anthropogenic gases N_2O, CH_4, CO, H_2, CH_3Cl, CH_3Br, and $CHCl_3$; (3) optimally determining the average concentrations and trends of OH radicals in the troposphere by calculating the rate of destruction of atmospheric CH_3CCl_3 and other hydrohalocarbons from continuous measurements of their concentrations together with industrial estimates of their emissions; (4) optimally determining, using CH_4 and N_2O data (and theoretical estimates of their rates of destruction), the global magnitude and distribution by semi-hemisphere or region of the surface sources of CH_4 and N_2O; and (5) providing an accurate data base on the rates of accumulation of trace gases over the globe which can be used to test the synoptic-, regional-, and global-scale circulation predicted by three dimensional models and/or to determine characteristics of the sources of these gases near the stations. The continuation of this effort is crucial in order to monitor the chlorine loading of the atmosphere in response to the Montreal Protocol on Substances That Deplete the Ozone Layer (and its Amendments and Adjustments) as well as provide information for climate change studies. These measurements show a decreasing burden of regulated ozone destroying chemicals, and increasing abundances of substitute compounds less destructive to ozone, in the lower atmosphere. As a component of the AGAGE network, *in situ* gas chromatograph-mass spectrometer measurements of a wide range of chlorofluorocarbon replacements and other halocarbons have been initiated at one Northern Hemisphere site (Mace Head, Ireland) and one Southern Hemisphere site (Cape Grim, Tasmania) and this capability will soon be extended to other sites.

- The continued implementation of the international ground-based remote-sensing measurement Network for the Detection of Stratospheric Change (NDSC), championed in the US by NASA and the National Oceanic and Atmospheric Administration (NOAA), remains a high priority. The NDSC was formed to provide a consistent, standardized set of long-term measurements of atmospheric trace gases, particles, and physical parameters via a suite of globally distributed sites. The NDSC is based on a set of high quality, remote-sensing research stations for observing and understanding the physical and chemical state of the stratosphere and for assessing the impact of changes in the stratosphere on the underlying troposphere and on global climate. The measurement priorities include ozone, key parameters such as temperature and aerosols that affect the ozone layer, and tracers of chemistry and of atmospheric motion. The NDSC consists of five Primary Stations (all but one being comprised of multiple sites) so designated because their geographical characteristics and operational infrastructure facilitate measurements with nearly a complete suite of primary NDSC instruments (lidars for ozone, temperature, and aerosols; UV/Visible spectrometers for ozone, NO_2 and OClO; UV spectrometers for ground-level UVB radiation; microwave radiometers for ozone, ClO, and water vapor; FTIR spectrometers for a wide variety of source and reservoir compounds; Dobson and Brewer spectrometers for ozone, and balloon sondes for ozone and aerosols). Additional measurements are conducted at more than 40 Complementary NDSC Sites, at each of which only a subset of the primary NDSC measurements are conducted. Future expansion in low latitude regions of the globe is high NDSC priority whose degree of implementation will depend on funding availability.

- The NASA-sponsored SAGE III Ozone Loss and Validation Experiment (SOLVE) and the Third European Stratospheric Experiment on Ozone (THESEO 2000), collaborated to form the largest field campaign yet mounted to study Arctic ozone loss. This international campaign involved more than 500 scientists from over 20 countries. These scientists made measurements across the high and mid-latitudes of the northern hemisphere to study (a) the processes leading to ozone loss in the Arctic vortex and (b) the effect on ozone amounts over northern mid-latitudes. The campaign included satellites, research balloons, 6 aircraft, ground stations, and scores of ozone-sondes. Campaign activities were principally conducted in 3 intensive measurement phases centered on early December 1999, late January 2000, and early March 2000. Observations made during the campaign showed that temperatures were below normal in the polar lower stratosphere over the course of the 1999-2000 winter. Because of these low temperatures, extensive polar stratospheric clouds (PSCs) formed across the Arctic. Large particles containing nitric acid trihydrate were observed for the first time, showing that denitrification can occur without the formation of ice particles. Heterogeneous chemical reactions on the surfaces of the PSC particles produced high levels of reactive chlorine within the polar vortex by early January. This reactive chlorine catalytically destroyed about 60% of the ozone in a layer near 20 km between late-January and mid-March 2000, with good agreement being found between a number of empirical and modeling studies. The measurements made during SOLVE-THESEO 2000 have improved our understanding of key photochemical parameters and the evolution of ozone-destroying forms of chlorine. SOLVE also had the objective of conducting direct SAGE III intercomparison activities. While these were not accomplished because of a prolonged delay in the launch of the satellite instrument, SOLVE data are being used in conjunction with measurements from several other satellite instruments for validation studies.

- Laboratory studies in spectroscopy, thermodynamics, chemical kinetics, and photochemistry are fundamental to UARP's maintaining the expertise required for interpreting atmospheric measurements and for performing theoretical simulations of the atmosphere (such as the investigation of heterogeneous processes that occur on polar stratospheric cloud particles and sulfate aerosols, photochemical processes that govern the partitioning of active and reservoir species, and atmospheric degradation mechanisms for CFC replacement compounds). Important kinetic and photochemical results from UARP investigations and similar studies conducted nationally and internationally are periodically evaluated and summarized by a panel of scientists organized by NASA's UARP. The reports of this NASA Panel for Data Evaluation, distributed as a NASA Jet Propulsion Laboratory publication, contains entries for more than 700 chemical processes and serves as the standard data set for atmospheric assessment models. A similar assessment process is being formulated for spectroscopic data.

- The Transport and Chemical Evolution Over the Pacific (TRACE-P) field experiment was conducted in March/April 2001, had as it's major objectives to (1) determine the chemical composition of the Asian outflow over the western Pacific in spring in order to understand and quantify the export of chemically and radiatively important gases and aerosols, and their precursors, from the Asian continent and (2) determine the chemical evolution of the Asian outflow over the western Pacific in spring and to understand the ensemble of processes that control the evolution. TRACE-P data is currently undergoing detailed review and analysis.

- Operations of the Southern Hemisphere Additional Ozonesonde (SHADOZ) network continues with additional ozonesondes launched from several locations in the tropics and southern subtropics. This program is developing the first ever climatology of upper tropospheric ozone in the tropical region. Most previous efforts to measure ozone in this region have typically been focused on either the Atlantic or the Pacific but not both. This network is done in collaboration with numerous international partners.

3.0 DOC

3.1 NOAA

3.1.1 Goals and Objectives

NOAA's global change efforts are designed to provide a predictive understanding of the climate system and its modes of variability, and to advance the application of this information in climate-sensitive sectors through a suite of process research, observations and modeling, and application and assessment activities. Specifically, NOAA's research program includes ongoing efforts in operational in situ and satellite observations with an emphasis on oceanic and atmospheric dynamics, circulation, and chemistry; understanding and predicting ocean-land-atmosphere interactions, the global water cycle, and the role of global transfers of carbon dioxide among the atmosphere, ocean and terrestrial biosphere in climate change; improvements in climate modeling, prediction, and information management capabilities; the projection and assessment of variability across multiple timescales; the study of the relationship between the natural climate system and society and the development of methodologies for applying climate information to problems of social and economic consequences; and archiving, management, and dissemination of data and information useful for global change research.

3.1.2 Contributing Elements

Atmospheric Composition – Research activities under this element include:

- Characterizing the "ozone-friendliness" of substitutes for ozone-depleting gases, developing methods for the detection of the recovery of the ozone layer, and characterizing the regional variance of tropospheric ozone and its role in the heat budget.
- Quantifying the trends and sources/sinks of long-lived greenhouse gases, and characterizing the fundamental processes that control the shorter-lived radiative species.
- Advancing efforts to reduce uncertainties in the understanding of direct radiative forcing by tropospheric aerosols through an integrated program focused on targeted in situ measurements of aerosols integrated with model analyses.

To accomplish the above, NOAA employs global monitoring, process-oriented laboratory and field studies, and theoretical modeling to improve predictive understanding of the atmospheric trace gases that influence the earth's chemical and radiative balance, with emphases on stratospheric ozone depletion and greenhouse warming.

Climate Variability and Change – Studies under this element are aimed at

- Increasing understanding of the role in climate variability, and the predictability, of the El Niño-Southern Oscillation, the North Atlantic (or Arctic) Oscillation, Tropical Atlantic Variability, the Pacific Decadal Oscillation, and the Pan-American monsoons.
- Continuing the advancement of the sustained global ocean observing system to support Climate Variability and Predictability (CLIVAR) research, operational and experimental climate forecasting, and the major scientific assessments.
- Advancing the improvement of models and modeling systems for climate prediction at all timescales and the ability to provide regional-scale forecasts and predicted probabilities of extreme weather events.
- Advancing detailed studies of past climate variability on seasonal to centennial time scales using century to millennia-long paleoenvironmental proxy records in order to improve the current understanding of seasonal to decadal variability.
- Developing and applying advanced statistical techniques to detect climate change signals and attribute these to specific causes.

Global Carbon Cycle – This research element focuses on

- Advancing efforts to produce more accurate projections of future atmospheric CO_2 concentrations by better parameterization of transfers of CO_2 between ocean, atmosphere, and terrestrial biosphere, and development of dynamic, coupled carbon cycle models.
- Initiating observations and modeling necessary to quantify the magnitude and variability of the Northern Hemisphere terrestrial sink, with an initial focus on large-scale observations over the North American continent and adjacent ocean basins.
- Continuing to document the inventory of carbon in the ocean as it accumulates, and characterize how that inventory might be affected by changes in ocean circulation in the future.

3.1.3 Specific Laboratory Contributions

3.1.3.1 Aeronomy Laboratory

SOLVE Field Mission - scientists in two NOAA Laboratories, the Aeronomy Laboratory and the Climate Monitoring and Diagnostics Laboratory, participated in a NASA-sponsored experiment to study Arctic springtime ozone loss. The field campaigns of the SAGE III Ozone Loss and Validation Experiment (SOLVE) were conducted from November 1999 to March of 2000, and included several flights of the NASA ER-2 high-altitude research aircraft and the NASA DC-8 medium altitude flying laboratory. Onboard the ER-2 were NOAA instruments that measured ozone, reactive nitrogen compounds, water vapor, and tracer species such as halocarbons and nitrous oxide. The Observations of the Middle Stratosphere (OMS) balloon gondola was also deployed and carried NOAA instruments to measure vertical profiles of trace gases and meteorological parameters. Scientists from NOAA, NASA, academia, and other agencies participated in the experiment. Significant findings from the study were:

- In one of the Arctic stratosphere's coldest winters on record, scientists, during February and March of 2000, measured ozone losses as great as 50 percent at about 60,000 feet altitude in the ozone layer. *Payoff:* The findings may be an indication that future cold winters in the Arctic could prolong the depletion of ozone by manmade chlorine compounds, despite the fact that chlorine is now diminishing in the atmosphere in response to international agreements.
- An unusual class of large PSC particles was observed for the first time, using a NOAA instrument that measures reactive nitrogen compounds in the atmosphere. *Payoff:* The newly discovered class of particles has given scientists a better understanding of the processes that "set the stage" for chlorine-caused ozone depletion in the stratosphere above the Arctic, and will enable scientists to make better predictions of ozone loss in the Northern Hemisphere in the future.

International Ozone-Layer Assessment - NOAA scientists are playing prominent roles in the 2002 international scientific assessment of the ozone layer, in preparation during 2001-2002. The document, World Meteorological Organization/United Nations Environment Programme Scientific Assessment of Ozone Depletion: 2002, will be completed in December 2002 in accordance with the Montreal Protocol on Substances that Deplete the Ozone Layer and available in printed form in spring 2003. Hundreds of scientists worldwide are contributing to the planning, preparation, reviewing, and publication of this document. NOAA scientists are participating as Co-chair, chapter lead authors, chapter authors, chapter contributors, reviewers, and coordinating editor. Payoff: The assessment will give "state-of-scientific-understanding" information regarding the Earth's ozone layer.

Laboratory Studies of Reactions Important To the Stratospheric Ozone Layer - The NOAA Aeronomy Laboratory conducts laboratory studies to elucidate the reaction rates and product pathways of reactions that are important to the stratospheric ozone layer. In 2000/2001, for example, research showed that a degradation product of methyl chloroform was, itself, a chlorine-containing compound (phosgene) that can still transport some chlorine to the stratosphere. This study demonstrates the importance of a complete study of the chemical degradation of an ozone-depleting substance in the troposphere. The Aeronomy Lab's research includes studies that help identify the "ozone-friendliness" of new industry-proposed substitutes for ozone-depleting compounds. A recent emphasis is the study of new proposed compounds that are relatively short-lived in the atmosphere, but which might (through either the initial compound or its degradation products) deliver reactive halogens to the stratosphere. *Payoff:* The complete "chemical picture" is information that is valuable to have in advance of the costly investments that are involved in gearing up to produce and market a new compound.

Advancing the Understanding of Ozone Changes In the Stratosphere - NOAA Aeronomy Laboratory scientists and their colleagues have completed analyses of the data series from ozone stations in Europe, correlating the ozone observations with the North Atlantic Oscillation over the time period since the 1960s. A significant part of the variance in the ozone records is explained by the phase of the NAO. During the NAO "positive" phase, deep intrusions of naturally low-ozone air from the upper tropical troposphere into the mid-latitude lower stratosphere may be an important process in the observed ozone changes. *Payoff:* The combination of long-term dynamical changes and chemical processes will provide a better understanding of the observed ozone behavior and hence a better predictive capability of the future ozone layer.

NOAA researchers and their colleagues have studied the trends, radiation, and chemistry of a key player in stratospheric ozone-layer processes: water vapor. The trends of water vapor over the past half century have been newly characterized in an international study conducted under the auspices of SPARC. Further, a comprehensive study has examined the effects of observed trends of stratospheric water vapor on both ozone depletion and temperature. The work has shown that water vapor trends have likely made significant contributions to the decline in mid-latitude ozone observed over the past twenty years, and that they played a substantial role in the cooling of the stratosphere. *Payoff:* The efforts help to quantify the role of a key player in the stratosphere, thus advancing understanding of the factors contributing to the observed ozone trends.

Measuring the Chemical Composition Of Individual Atmospheric Particles - This NOAA research elucidated the role of atmospheric particles in sequestering reactive halogen atoms (fluorine, chlorine, bromine, iodine) in the critical tropopause boundary region at the interface of Earth's troposphere and stratosphere. If tightly bound in particles, the halogen atoms are effectively removed from chemical reaction cycles that influence stratospheric ozone depletion processes. Scientists at the Aeronomy Laboratory carried out state-of-the-art airborne measurements of aerosol particles in the hard-to-access tropopause region, characterizing the chemical composition of individual particles in real time. The measurements were made by use of a highly sophisticated instrument developed at the Aeronomy Laboratory, the Particle Analysis by Laser Mass Spectrometry (PALMS) instrument. Particles are sampled into the PALMS instrument during flight and characterized "on the fly", that is, without requiring that samples be collected or stored. The instrument was flown aboard a NASA WB-57F research aircraft during field missions in 1998, 1999, and 2000. Latitudinal transects were completed, and data were also gathered in the exhaust plumes of a rocket and the space shuttle. The resulting powerful dataset has thousands of individual particle mass spectra and contains the most detailed information to date on aerosol chemical composition near the tropopause. *Payoff:* The research has contributed to a better understanding of the role of aerosols in the depletion of ozone in the stratosphere, which will ultimately contribute to an improvement in the predictive capability of models of stratospheric ozone.

3.1.3.2 Climate Monitoring and Diagnostics Laboratory

Ozone Monitoring -

- Dobson Cooperative Observing Network: This consists of16 stations around the world measuring total column ozone with 15 to 40 year records - 9 in continental North America, 2 in Pacific island locations (Hawaii and American Samoa), 1 in South America (Peru),1 in New Zealand (Lauder),1 in Australia (Perth),1 in Europe (France), and1 in Antarctica (South Pole). There are 6 stations measuring ozone vertical profiles using the Umkehr method (Alaska, France, Colorado, Hawaii, Australia, and New Zealand).

- Ozonesonde Network: There are 8 stations making ozone vertical profile measurements (0 – 35 km). Three of these have been operating for15 or more years (Colorado, Hawaii, and South Pole), while the remaining 5 have 3-10 years of data (California, Alabama, Galapagos, Samoa, and Fiji).

- Surface Ozone Network: There are 4 long-term sites (25+ years) and 4 shorter record sites.

Water Vapor Profiles at Boulder, Colorado - Monthly profiles have been obtained from 1980 to present covering the altitude range 5 - 28 km.

Measurements of Ozone Depleting Source Gases (N_2O, Halocarbons, Halons, Halogen Solvents, SF_6) – This network consists of 8 stations equipped with in situ instruments and 14

stations that employ flask sampling
Greenhouse Gases (CO_2, CH_4, N_2O, SF_6, CO) – These measurements are obtained at 6 stations using in situ instruments, and at 47 stations and on 1 ship using flask sampling techniques.

Radiation Measurements – There are 15 stations at which solar and thermal radiation are recorded and 5 stations recording UV radiation.

3.1.3.3 Air Resources Laboratory

Quality is an ongoing and critical concern in any attempt to monitor and explore changes in ozone and UV, and is the major focus of NOAA's Air Resources Laboratory Surface Radiation Research Branch. Understanding the biological effects of UV radiation and determining whether the Montreal Protocol and its amendments are successful depend on measurements that are as accurate as possible. NOAA's Air Resources Laboratory personnel invest substantial effort to attain and ensure high quality UV measurements, and are internationally recognized as the world's leaders in this area. This focus on quality is emphasized by both the Central UV Calibration Facility, which characterizes and calibrates several types of UV instruments used in monitoring network worldwide, and by the Surface Radiation Budget Network (SURFRAD), providing accurate, consistent measurements at sites across the U.S.

UVB monitoring by NOAA's Surface Radiation Budget Network - Broadband erythemal UVB measurements are made by the Surface Radiation Budget Network (SURFRAD), established in 1993 by NOAA's Air Resources Laboratory through the support of NOAA's Office of Global Programs. The network was designed to measure the surface radiation budget, and also provides information on surface erythemal UVB amounts and basic meteorological parameters. Monochromatic solar data, which can be used to recover aerosol loading, have also been archived since operational monitoring began. Currently, six stations are operating in climatologically diverse regions of the United States and are located in regions where the landform and ground cover are nearly homogeneous over an extended region. This homogeneity allows point measurements from the stations to be representative of a larger area for satellite validation work. The SURFRAD stations are located in northeastern Montana (since March 1, 1995), central Illinois (since Jan. 1, 1995), northwestern Mississippi (since January 1, 1995), Boulder, CO (since August 1, 1995), the Nevada Test Site northwest of Las Vegas (since March 16, 1998), and near Penn State in central Pennsylvania (since June 29, 1998). SURFRAD and the Department of Energy ARM/SGP site in Kansas and Oklahoma (which also began in 1995) are the first long-term surface radiation budget networks to exist in the United States.

All SURFRAD instruments are exchanged annually with freshly calibrated units; their calibrations are all traceable to recognized world standards. Daily files of three-minute averaged data from each station are quality controlled and distributed in near real time via anonymous FTP and the world wide web (http://www.srrb.noaa.gov). To further support satellite and model validation activities, an imaging system that records the hemispheric sky and computes the cloud fraction once each minute has been deployed at each station. To bolster the network's utility to radiative transfer research, rawinsonde-type soundings are interpolated to the SURFRAD site locations for 0000 and 1200 UTC each day. Assurances are made that the interpolated soundings are hydrostatically consistent.

SURFRAD data are submitted regularly to the BSRN archive in Zurich, Switzerland. Observations from SURFRAD have been used for validating hydrologic, weather prediction, and climate models, and for satellite determinations of surface UVB and solar irradiance. For example, data from several UV instruments over a three-year period at the Mississippi station were used to demonstrate an 18% bias in TOMS-based clear-sky surface UVB estimates (DeLuisi et al., 2002). Work is continuing to determine the cause of the bias, and whether the method is useful for evaluating UV instrument performance.

The Central UV Calibration Facility (CUCF) - The Central UV Calibration Facility (CUCF) was set up in the mid-1990s to meet the needs of the U.S. Interagency UV Monitoring Program. The internationally recognized facility, located in the Surface Radiation Research Branch of NOAA's Air Resources Laboratory, has developed instrumentation and other laboratory assets worth an estimated $2.5-3.0 million. The WMO recently designated it as the UV calibration facility of North and South America. The CUCF's services, research, and responsibilities continue to grow as the importance of UV science is being increasingly recognized by scientific organizations worldwide. The facility has hosted four spectroradiometer intercomparisons and has provided calibration and installation assistance to foreign countries, including Argentina, Greece, Italy, and New Zealand. Dr. Kathleen Lantz, one of the facility's staff members, serves on a WMO panel for UV instrumentation and has made significant contributions concerning UV measurement technology and calibration.

Assessing Signs of Recovery in Total Column and Vertical Ozone Distributions - With the Montreal Protocol in place, we are currently looking forward to slow, gradual recovery of the ozone layer over coming decades. One critical question for research planning, policy and communication with the public is, "How long will it take until we can see an improvement in the ozone layer?" We have made some of the first steps toward addressing that question using data from the Total Ozone Mapping Spectrometer (TOMS) and predictions from NASA's Goddard Space Flight Center two-dimensional chemical model. These data were used to estimate the length of time needed to detect the expected recovery of the ozone layer (Weatherhead et al., 2000). Because of the variability and autocorrelation associated with the total column ozone data, between 15 and 45 years will be needed to detect recovery in most regions of the world. This recovery is likely to be most readily detected in the Southern Hemisphere near New Zealand, southern Africa, and southern South America. Work is in progress to explore signs of recovery in ozone profile data from the Solar Backscattering UV (SBUV) series of instruments and from the Umkehr record.

Different processes dominate ozone depletion at different altitudes of the atmosphere. Vertical ozone profile measurements therefore play an important role in identifying the influences of these processes, and in detecting signs of recovery. The historical Dobson Umkehr record began in 1956 and provides retrievals of the vertical ozone profile. Improvements to the Umkehr ozone profile retrieval algorithm have been developed and are now being implemented. One of the changes in the algorithm (Petropavlovskikh et al.) eliminates the bias due to total ozone trends, which is known to affect the existing Umkehr ozone profile record. The updated algorithm is able to simulate observations more accurately and provides data output that is easier to analyze. The updated retrievals are being compared with ozonesonde, lidar, and other highly resolved vertical profile data and can provide high quality information for identifying signs of ozone recovery at altitudes where decreases in ozone-depleting substances would influence the first signs of a turn-around. For instance, the earliest signs of recovery may be expected to occur at around 40 km altitude where CFC chemistry is the prevailing factor in ozone destruction. Questions about the effect of human activities on chemical ozone destruction and recovery will likely be most easily answered by examining ozone variability at the 40-km altitude. The Umkehr measurements have very solid information about ozone variability, and loss and recovery rates at this level. The long historical record can also provide additional information for separating the dynamic and chemical mechanisms of depletion, and can help the community better understand climate change effects.

Analysis of UV Network Data - Scientists in NOAA's Air Resources Laboratory have worked on quality assurance and data analysis issues using Brewer Mark IV observations from the Environmental Protection Agency/University of Georgia's UV monitoring network. The network is operated collaboratively with the National Park Service and includes instruments at 14 national parks and in 7 urban areas. Weatherhead et al. (2001) have completed work to characterize the temperature dependence of the Brewer Mark IVs, which are used for ground-based UV and ozone monitoring worldwide. Additional work is in progress to explore latitudinal and seasonal relationships between noontime UV dose rate and daily-integrated UV amounts. Improved understanding of UV levels, changes, and effects requires good estimates from satellite, well-maintained ground-based monitoring, and robust models. Only by combining and utilizing all three of these elements can the links between UV and biological effects be understood.

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3.2 *NIST*

3.2.1 Goals and Objectives

NIST activities pertinent to stratospheric ozone chemistry and ground level UV radiation are in the areas of (1) laboratory and computational studies of the kinetics, thermodynamics, photochemistry, and spectroscopy of ozone-related and climate-related trace gases, (2) data evaluation activities aimed at providing a reliable kinetic and photochemical database for use in atmospheric modeling, (3) participation in international ozone assessment activities as reviewers and authors, and (4) research to provide for more accurate measurements ground-level changes in damaging ultraviolet radiation.

3.2.2 Contributing Elements

Laboratory and Computational Studies - NIST researchers conduct laboratory studies that emphasize photochemical and kinetic measurements contributing to the general understanding of the chemistry of the stratosphere and upper troposphere, with a specific emphasis on stratospheric ozone. In particular, these laboratory experimental activities focus on measurements of the gas-phase rate constants for the reactions of hydroxyl radicals with anthropogenic and naturally occurring ozone-related and climate-related trace gases. These include partially halogenated hydrocarbons, other species under consideration as replacements for the fully halogenated chlorofluorocarbons (CFCs), and other naturally occurring or anthropogenically produced compounds important in determining the chemical and/or radiative balance of the Earth's atmosphere. The results of these determinations are used together with measurements of ultraviolet absorption cross-sections (also measured in the NIST laboratories) to estimate the atmospheric (tropospheric) lifetimes of such compounds. These atmospheric lifetimes are critical modeling input parameters for the estimation of Ozone Depletion Potentials (ODPs) and Greenhouse Warming Potentials (GWPs) upon which decisions are made regarding the environmental acceptability of such chemicals. These photochemical kinetic studies emphasize areas of moderate uncertainty and sensitivity identified by the NASA Data Panel as well as through interactive discussions with the international atmospheric experimental and modeling communities and members of the technical communities interested in environmentally same industrial chemicals and fire suppressants. In addition, infrared band strengths are measured for selected chemicals to provide estimates of their GWPs. A program of ab initio rate constant calculations augments the experimental program by providing reactivity and lifetime estimates beyond those that are derived from the experimental kinetic data base for OH reactions. In addition to developing and applying computational methods for calculating the chemical and physical properties of selected species and systems, this activity is aimed at establishing the accuracy and reliability of computational methods and developing resources to provide guidance to non-experts on methods, reliability, and resource requirements for such computations.

Data Evaluation - NIST maintains a Chemical Kinetics Database that includes essentially all reported kinetics results for thermal gas-phase chemical reactions. The database is designed to be searched for kinetics data based on the specific reactants involved, for reactions resulting in specified products, for all the reactions of a particular species, or for various combinations of these. In addition, the bibliography can be searched by author name or combination of names. The database contains in excess of 38,000 separate reaction records for over 11,700 distinct reactant pairs. These data have been abstracted from over 12,000 papers with literature coverage through early 2000. NIST researchers also serve as members of NASA's Panel for Data Evaluation. This Panel meets up to twice yearly to prepare published evaluations of photochemical, thermodynamic, and kinetic data for use in atmospheric modeling. These reports have been issued as both NASA Reference Publications and as publications of the Jet Propulsion Laboratory (via both printed and electronic media).

Ozone Assessment Activities - NIST scientists played prominent roles as authors and reviewers for various chapters in the 1998 scientific and technology assessments conducted under the auspices of WMO and UNEP for the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer. Similar participation exists for the current WMO/UNEP assessments in preparation during 2001-2002 and targeted for completion in December 2002.

UV Standards and Calibration Research - NIST scientists engage in activities to specify, standardize and categorize UV instruments (spectral, narrow band, and broadband) in order to provide for more accurate measurements of ground-level changes in damaging ultraviolet radiation from the sun. Such measurements are crucial in assessing effects of ozone depletion in the upper atmosphere on human health, agriculture, fisheries and materials such as concrete, plastics and paints. In partnership with NOAA NIST maintains an intercomparison and research site at Table Mt., CO. The goal of such research to help the various UV monitoring agencies achieve high levels of accuracy in UV measurements so that readings from different networks in different locales will be reliable in calculating global trends. Continuous calibration will be needed to ensure the long-term data quality. To do this, routine intercomparison of spectral instruments will be an integral part of each network's operations. As a non-regulatory agency of the Commerce Department's Technology Administration, NIST promotes U.S. economic growth by working with industry to develop and apply technology, measurements and standards.

4.0 NSF

4.1 *Goals and Objectives*

NSF programs address global change issues through investments in challenging ideas, creative people, and effective tools. In particular, NSF global change research programs support research and related activities to advance the fundamental understanding of dynamic physical, biological, and human systems and the interactions among them. The programs encourage interdisciplinary activities with particular focus on Earth system processes and the consequences of change. NSF programs facilitate data acquisition and information management activities necessary for fundamental research on global change, and promote the enhancement of models designed to improve our understanding of Earth system processes and interactions and to develop advanced analytic methods to facilitate basic research. NSF also supports fundamental research on the general processes used by organizations to identify and evaluate policies for mitigation, adaptation, and other responses to the challenge of varying environmental conditions

4.2 *Contributing Elements*

NSF will continue to invest in collaborative international programs such as the World Climate Research Programme, the International Geosphere-Biosphere Programme, and the International Human Dimensions Programme. A major focus on atmospheric composition and chemistry will continue through programs in tropospheric chemistry. Studies of atmospheric transport of aerosols will provide insights into how aerosols affect the radiative and cloud nucleating properties of the atmosphere, and ultimately the climate. In concert with its agency partners, NSF will continue its emphasis on climate variability and change. This is a major activity for the Agency and consists of support for observational campaigns and numerous analytical and modeling activities, as well as paleoclimate studies.

Specific activities in the area of stratospheric chemistry include:

- Balloon-borne measurements of ozone and aerosol profiles: Antarctica, SH and NH mid-latitudes; ClO and BrO in mid-latitude cirrus and Arctic PSCs
- Instrument development and participation in airborne stratospheric measurement campaigns
- Ground-based measurements of OH column abundance
- Sample analysis, laboratory and theoretical studies aimed at an improved understanding of the isotopic composition of major stratospheric constituents
- Laboratory and theoretical spectroscopy studies of trace gases relevant to the stratosphere
- Laboratory and *ab initio* modeling studies of gas phase reactions and heterogeneous processes on surfaces representing polar stratospheric cloud particles
- Development and application of chemical transport models describing stratospheric chemistry, near-tropopause transport, and chemistry/climate interactions
- Studies of the budget of halogenated hydrocarbons and fate of CFC-substitute compounds

In the area of ground-based UV monitoring, NSF has an active program within the polar regions. Pertinent details of this activity include the following:

- Established in 1987: sites at McMurdo, Palmer and South Pole (Antarctica), Ushuaia (Argentina) Barrow (AK), San Diego (CA). Site to be established at Summit Greenland
- Instrument: SUV-100 scanning spectroradiometer (Biospherical Instruments)
- Data Products: Full-resolution spectra from 280-600 nm, measured quarter hourly
- Databases with spectral integrals and biologically weighted irradiance for various action spectra and with spectral measurements at selected wavelengths
- Databases with daily doses
- Preliminary data available weekly via the website <www.biospherical.com/nsf>
- Final data available on CD-ROM or via website

5.0 DOE

5.1 *Goals and Objectives*

Research supported by DoE's Office of Biological and Environmental Research (BER) addresses the effects of energy production and use on the global Earth system, primarily through studies of climate response. It includes research in climate modeling, atmospheric chemistry and transport, atmospheric properties and processes affecting the Earth's radiation balance, and sources and sinks of energy-related greenhouse gases (primarily CO_2). It also includes research on the consequences of atmospheric and climatic changes on ecological systems and resources, critical data needs for the detection and attribution of climate change, and tools and methods needed to conduct scientific assessments of climate change, and education and training of scientists and researchers in global change.

5.2 *Contributing Elements*

5.2.1 Atmospheric Chemistry and Carbon Cycle - DoE will continue the support of field, laboratory, and modeling studies to improve our understanding of the atmospheric processes associated with transport, transformation, and dispersion of energy-related emissions and their effects on air quality and climate, including studies of oxidants, aerosols, and the heterogeneous chemistry of these materials. It will also include studies of the dispersion of energy-related materials through the lower troposphere to help understand the fundamental processes that control vertical transport for stable and transition boundary layers and how pollutants move through these layers in the lower atmosphere.

Research in both terrestrial and marine environments will be continued to improve understanding of the global carbon cycle. DoE will continue field CO_2 enrichment experiments (FACE), observations of net CO_2 exchange between the atmosphere and biosphere (AmeriFlux), and dynamic modeling of the carbon cycle and its relationship to climate influences. This research will focus on biophysical controls, biogeochemical mechanisms and climate-related feedbacks of terrestrial carbon cycling. Data from experiments and tested carbon cycle models will be used for predictions of future atmospheric CO_2 change and for estimating quantity and longevity of carbon sequestration by terrestrial ecosystems. Support for experiments and AmeriFlux measurements continues to be a high priority. DoE also will continue to fund the development and application of new molecular biological probes to carbon and nitrogen cycles in near shore marine environments. A field experiment combining a range of new probes with biogeochemical rate measurements and satellite imagery will be planned for a well-characterized near-shore site.

5.2.2 Climate and Hydrology - DoE will continue the development of advanced diagnostics and an on-line diagnostic library to evaluate the ability of climate models to simulate and predict climate variability and change. To better connect observational and modeling research programs, DoE will implement a parameterization test bed that will facilitate the development and implementation of improved physics modules into climate models. Additionally, extensive effort will be directed toward advancing the computational, numerical, and software engineering aspect of climate models as part of the Scientific Discovery through Advanced Computing Program in DoE's Office of Science.

Using data collected at the Atmospheric Radiation Measurement (ARM) Cloud and Radiation Testbed sites, DoE's ARM Program will continue measurement and modeling efforts to improve the radiative flux calculations and associated heating rates in climate models.

5.2.3 Related Research - DoE plays a major role in carbon sequestration research to slow the increase in atmospheric concentrations of energy-related greenhouse gases, especially carbon dioxide, and their emissions to the atmosphere. The research builds on but is not part of the USGCRP. It focuses on developing the understanding needed both to enhance the net carbon sequestration of excess CO_2 from the atmosphere in terrestrial and ocean systems and to assess the potential environmental consequences and ancillary benefits. DoE (in collaboration with NSF) will support an iron-fertilization experiment in the Southern Ocean, the largest high nutrient-low chlorophyll region in the world's oceans, focusing on quantifying the amount of carbon that is exported to the deep ocean - a prerequisite for carbon sequestration.

6.0 EPA

6.1 *Goals and Objectives*

EPA's Global Change Research Program is an assessment-oriented program with primary emphasis on understanding the potential consequences of climate variability and change on human health, ecosystems, and socioeconomic systems in the United States. This entails: (1) improving the scientific basis for evaluating effects of global change in the context of other stressors and human dimensions (as humans are catalysts of and respond to global change); (2) conducting assessments of the risks and opportunities presented by global change; and (3) assessing adaptation options to improve society's ability to respond effectively to the risks and opportunities presented by global change as they emerge.

6.2 Contributing Elements

Few studies have investigated the effect of global change on air quality. Given EPA's legal mandates with respect to air pollution and substantial capability and expertise in modeling air quality and evaluating integrated response actions, examining the effects of global change on air quality is a logical focus of the Global Program. Assessments are planned that will examine the potential consequences of global change on tropospheric ozone and particulate matter. The air quality assessments will provide input to related human health assessments.

7.0 DHHS / NIH

7.1 *Goals and Objectives*

Three NIH institutes support research on the health effects of UV and near-UV radiation. Their principal objectives include an increased understanding of the effects of UV and near-UV radiation exposure on target organs (e.g., eyes, skin, immune system) and of the molecular changes that lead to these effects, and the development of strategies to prevent the initiation or promotion of disease before it is clinically defined. In addition, the National Institute of Environmental Health Sciences (NIEHS) supports research on the health effects of CFC replacement chemicals, including studies on the metabolism and toxicity of HCFCs and halogenated hydrocarbons.

7.2 *Contributing Elements*

The NIEHS program supports grants and intramural projects that investigate the effects of UV exposure on the immune system, aging process, sensitive tissues such as the retina and skin, and methods to reduce these harmful effects. Other projects involve the comparison of mutagenic potential in bacteria of UV and near-UV radiation at levels found in natural sunlight and at levels anticipated with a 15 percent depletion of stratospheric ozone. Several projects supported by NIEHS are investigating molecular changes in DNA that lead to aberrations and mutations in human tissue, rodents, fruit flies, and bacteria, and the variety of ways these organisms repair damage to DNA resulting from UV exposure.

The National Eye Institute (NEI) supports studies on the impacts of UV radiation on the eye (retinal damage as well as corneal capacity). A major initiative is underway to determine how and why eye cataract develops and to search for ways to prevent or slow the progression of cataract, an age-related eye disease that affects 17-20 million people globally. This project is investigating the role of UVB radiation, which has been implicated as a specific risk factor in cataract development. Another important area of research is the understanding of certain detoxification systems in the eye and how they combat damage from UVB radiation. The goal of this effort is to identify drugs that might have therapeutic or preventative applications.

The National Cancer Institute (NCI) is supporting a wide range of studies to characterize the etiology, biology, immunology, and pathology of a variety of changes in the skin (morphological effects that might precede skin cancer), including photoaging, non-melanoma skin cancers, and melanoma caused by exposure to UV radiation. Other research is exploring UV-induced immunosuppression, which is critical to the development of UV-induced skin tumors, and the cellular and molecular basis for the genetic predisposition to UVB-induced skin cancer in people with Basal Cell Nevus Syndrome.

The National Institute of Arthritis and Muscoloskeletal and Skin Diseases (NIAMS) supports basic and clinical research on the effect of UVA and UVB radiation on skin.

8.0 USDA

8.1 *Goals and Objectives*

USDA-sponsored research focuses on understanding terrestrial systems and the effects of global change (including water balance, atmospheric deposition, vegetative quality, and UV-B radiation) on food, fiber, and forestry production in agricultural, forest, and range ecosystems, examining the role of managed and unmanaged terrestrial systems in the global carbon cycle, and assessing how agricultural and forestry activities can contribute to a reduction in greenhouse gas concentrations.

8.2 *Contributing Elements*

As part of the collaborative interagency Carbon Cycle Science Program, USDA conducts research on how land management practices affect the net carbon balance and develop methods to assist farmers, ranchers, and forest landowners in increasing carbon sequestration and better managing other greenhouse gas emissions. USDA will continue to quantify carbon sources and sinks from land management activities, including fluxes for all U.S. forest and agricultural lands and other land uses. The implications of changes in water quality and availability on agricultural and forestland productivity will be assessed. USDA research will examine the economic implications of alternative greenhouse gas offset strategies. In addition, USDA will continue to assess how resilient managed agricultural, rangeland, and forest ecosystems are to climate change and what adaptation strategies will be needed to adjust to a changing climate.

The Agricultural Research Service (ARS) will focus on four broad research areas: 1) studies of the carbon cycle and carbon storage, emphasizing identification and quantification of the current and potential roles of agriculture in the global carbon cycle with sufficient accuracy to inform policy and aid producers in making decisions that are both economically and environmentally sound; 2) managing non-carbon dioxide trace gases, such as methane and nitrous oxide, which are produced by certain processes in some crop and animal production systems; 3) determining the impacts of increased atmospheric carbon dioxide, rising temperatures, and altered water availability on crops and their interactions with other biological components of agricultural ecosystems; and 4) characterizing and measuring changes in weather and the water cycles at local and regional scales, and determining how to manage agricultural production systems facing such changes.

The Economic Research Service (ERS) will continue to focus on two broad research areas: 1) the long-run impacts of the accumulation of greenhouse gases on agriculture, including effects resulting from changes in temperature and precipitation, and from carbon dioxide fertilization; and 2) the economic implications of alternative net greenhouse gas emission reduction and carbon sequestration options for U.S. agriculture.

The Cooperative State Research, Education, and Extension Service (CSREES) will continue to support the USDA UV-B Monitoring Network. Information from this research network is combined with satellite-based measurements to provide an accurate climatological UV-B irradiance database. This database documents long-term trends and supports research and assessment of the potential for damage to ecosystems. Global change research in CSREES's National Research Initiative (NRI) Competitive Grants Program and formula-funded programs aims to increase understanding of the possible impacts of global environmental change on the sustainability of agriculture and forestry.

8.2.1 UVB Monitoring and Research Program

Langley Calibrations - Accurate calibration of UV ground-based radiometers is crucial in identifying trends in UV radiation, developing UV climatologies, and quantifying the amount of short-wave radiation absorbed by clouds and aerosols. The Langley method of calibrating UV multi-filter shadow-band radiometers (UV-MFRSR) is explored by Slusser et al. (2000). This method has several advantages over the traditional standard lamp calibrations: radiometer signal level is optimal during the Langley event, the Sun is a free, universally available and very constant source (to within <0.5% between 300 nm and 400 nm over the 11-year solar cycle) and nearly continual automated field calibrations can be made for each Langley event. Difficulties arise as a result of changing ozone optical depth during the Langley event and the breakdown of the Beer-Lambert law over the finite filter band-pass since optical depth changes rapidly with wavelength. The Langley calibration of the radiometers depends critically upon the spectral characterization of each channel and on the wavelength and absolute calibration of the extraterrestrial spectrum used.

Results of Langley calibrations made over a period from January 1 through September 30, 1998 for two UV-MFRSRs at Mauna Loa HI (3.4 km elevation) were compared to calibrations made at CUCF using two National Institute of Standards and Technology (NIST) traceable lamps. The objectives of this study were to compare Langley calibration factors with those from standard lamps and to compare field-of-view effects. The two radiometers were run simultaneously: one on a Sun tracker with a collimated full field of view of about 2.0 degrees and the other in the conventional shadow-band configuration. After 2 months the positions of the radiometers were switched. After another 2 months the radiometers were left in place but the field-of-view for the tracker radiometer was narrowed to 1.5 degrees. Both radiometers were calibrated May 15, 1998 at the CUCF with two secondary 1000-W lamps. The spectral response functions of the channels were measured at the CUCF on October 15, 1998. Over a 9-month period the ratio of Langley to lamp calibration factors for the 7 channels from 300 nm to 368 nm using the shadow-band configuration ranged from 0.948 to 1.025. The estimated uncertainty in the Langley calibrations ranged from ±5.5 % at 300 nm to ±2.4% at 368 nm. For all channels calibrated with CUCF lamps the estimated uncertainty was ±1.6%. Thus for each channel of the two radiometers the agreement between the two methods was within the combined uncertainties of the two methods. Differences between the Langley and lamp calibration factors were much larger at shorter wavelengths using the Langley tracker results, probably due to changing ozone during the Langley event.

Aerosol Properties - Aerosols are suspended atmospheric particles in the solid or liquid phase excluding cloud droplets or precipitation. These particles are of critical importance to the hydrological cycle because they provide condensation sites upon which cloud droplets form in slightly supersaturated air. In addition aerosols scatter and absorb solar radiation, changing the amount of UV reaching the earth's surface as well as modifying the heating of the atmosphere. The USDA UV-B Monitoring Network has the capability to report optical depths, a measure of the total aerosol loading, at 30 sites across the continental U.S. Each of the sites of the UV-B Monitoring Network is equipped with both a UV-MFRSR and a Visible-MFRSR which by measuring the direct beam return the total optical depths on clear days at a total of 13 wavelengths from 300 nm to 940 nm. This constitutes the largest U.S. network of ground-based aerosol optical depths and thus provides atmospheric scientists with a unique data set with which to constrain their models that quantify precipitation processes, aerosol and cloud formation, and global warming.

The Southern California Ozone Study (SCOS97) involved a whole suite of chemical, optical, and meteorological measurements taken in an effort to understand the causes of urban tropospheric pollution in the Los Angeles basin. Two USDA UV-MFRSRs were loaned to the experiment to determine UV irradiances, as well as total and aerosol optical depths (Vuilleumeir et al. 2001). One was placed atop Mt. Wilson and the other in urban Riverside. It was determined that the total optical depths are a necessary input into air quality pollution models.

Ozone Retrievals - Column ozone has been retrieved by Slusser et al. (1999) under all sky conditions at Table Mountain, Colorado (40.177N, 105.276W) from global irradiances of the UV-MFRSR 332 nm and 305 nm channels (2 nm FWHM) using lookup tables generated from a multiple scattering radiative transfer code suitable for solar zenith angles up to 90 degrees. For five months in 1996-97 the mean ratio of column ozone retrieved by the UV-MFRSR divided by that retrieved by the collocated Brewer was 1.024 and for the UV-MFRSR divided by those from a nearby Dobson was 1.025. The accuracy of the retrieval becomes unreliable at large SZA > 75 degrees as the detection limit of the 305 nm channel is reached and due to overall angular response errors.

Direct Sun column ozone has been retrieved under all sky conditions in Mauna Loa HI and the Canadian sites of Bratt's Lake and Toronto (Gao et al., 2000). The mean ratio of column ozone retrieved by the UV-MFRSR divided by that retrieved by the collocated Dobson was 0.969 in Mauna Loa between Julian date 150 and 270 in 1999. Comparisons were also made with Brewers in Canada. The ratio of column ozone retrieved by the UV-MFRSR divided by that of a Brewer was 1.022 in Toronto between Julian date 120 and 240 in 1999, and 1.001 in Regina between Julian date 160 and 250. The UV-MFRSR advantages of relatively low cost, unattended operation, automated calibration stability checks using Langley plots, and minimal maintenance make it a unique instrument for column ozone measurement.

Synthetic Spectra - Plant, animal, and materials effects researchers often want to multiply their particular action spectrum by the spectra measured to estimate damage due to UV. Because of this a study was initiated to use a model to "fill in the pieces" from the 7 channel UV radiometer measurements and construct the entire spectrum. We retrieved a number of synthetic spectra from the 7 channel UV-MFRSR data and made comparisons of these spectra with spectral measured from collocated spectrometers at Boulder CO (Gao et al., 2002). Erythemal doses are generally within ±5% for all SZA < 75 degrees. The study was presented at the Society of Photo-Optical Instrumentation Engineers UV Meeting in San Diego in July 2001.

Radiometric Stability - Bigelow and Slusser (2000) evaluate the stability of the Ion-Assisted-Deposition (IAD) filters used in both prototype and production models of the UV-MFRSR. Based upon an initial examination of a few prototype and production instruments it appeared that there was an approximate 1% per year decline in each instruments' I_o values due to filter instability. The IAD filters are much more stable than the filters in VIS-MFRSRs as reported by Bigelow et al. (1998).

Comparisons of UV-MFRSRs with TOMS and Radiative Transfer Model - Slusser et al. (2002) compared irradiances from a UV-MFRSR with those from a radiative transfer model (TUV) (Madronich, 1993) and NASA TOMS retrievals. Sensitivity tests of the modeled ratio of direct to diffuse irradiances for different aerosol absorption were made for Big Bend of Texas. Clear sky retrievals at New Mexico and Oklahoma generally agreed to within ±4% of the TUV model and the satellite retrievals.

Spectrometer Research Network - Six high-resolution U-1000 1.0 m double spectrometers have been developed by Dr. Lee Harrison of SUNY Albany (Harrison et al., 2002). The first has been completed and installed at the NIST / NOAA research site at Table Mountain CO. This instrument has been operating since December 1998 and the performance has been good although there has been a steady decline in responsivity. The instrument resolution (0.1 nm), out-of-band rejection (10^{-10}), wavelength accuracy and repeatability (±0.02 nm), and cosine response exceed the specifications of any spectrometer in the world. Unlike the Brewer, the instrument is tightly temperature controlled, making it extremely reliable for periods of time directly following a calibration. Data from the instrument are being used to calibrate the triad of UVB-1 broadbands, which in turn are used to calibrate the 44 UVB-1 broadbands (Lantz et al., 1998). The second instrument was installed at the DoE Central Plains ARM CART site near Billings, Oklahoma in September 1999. Currently only the Table Mountain CO instrument has been calibrated. Three automated portable calibrators have been completed and during 2002 will be cycled through the three sites to establish calibration. NASA has expressed interest in the data to validate their retrievals, in particular at wavelengths shorter than 305 nm. NASA is also interested in the magnitude of Raman scattering, which can be studied with U-1000 due to its very fine resolution.

Long Term UVB Broadband Time Series - Frederick et al. (2000) analyzed a four-year time series at 10 USDA sites to determine the influence of solar zenith angle, column ozone, and clouds on seasonal and year-to-year variability in UV irradiances. One conclusion is that variations in cloud cover contribute more than variations in column ozone in the observed year-to-year changes in UV irradiances. The UVMRP collected the broadband monthly sums for all of its 31 sites. These sums show a maximum yearly total at New Mexico and a minimum at Maine.

Other Cooperative Research - Funding was secured from NOAA for a full climatological site at Poker Flat, Alaska. This new site will be an integral part of NOAA's effort to study the effects of ozone and aerosols on Arctic UV It was installed in September 2000. This is the first use of a UV-MFRSR in the Arctic. A new site was installed in September in Starkville, MS. Data from the site in MS will be used in collaboration with the research of Dr. K. R. Reddy of Mississippi State University who is studying UV effects on cotton. This data will also be used by Remote Sensing Technology Center at MSU to provide accurate information to support Precision Farming.

Details of Monitoring Activities - All 2000 and 2001 7 channel UV-MFRSR data (Bigelow et al., 1998) is archived at the WOUDC. The instruments are calibrated at the NOAA Central UV Calibration Facility in Boulder, CO. Data for most sites extends back to January 1, 1999.

List of USDA UVB Climate Sites

Site	Lat.	Long.	Elev.	Town	State
AK02	65.119	147.430	510	Fairbanks	Alaska
AZ02	36.058	112.183	2073	Flagstaff	Arizona
CA02	38.529	121.761	18	Davis	California
CA22	32.806	115.444	-18	Holtville	California
CO02	40.792	104.755	1641	Nunn	Colorado
CO12	40.450	106.734	3220	Steamboat Sp.	Colorado
CO99	40.177	105.276	1524	Longmont	Colorado
FL02	25.383	80.683	0	Homestead	Florida
GA02	33.175	84.407	270	Griffin	Georgia
HI02	19.539	155.578	3397	Hilo	Hawaii
IL02	40.045	88.368	213	Bondville	Illinois
IN02	40.475	86.992	216	W. Lafayette	Indiana
LA02	30.358	91.166	7	Baton Rouge	Louisiana
MD02	38.916	76.149	7	Queenstown	Maryland
MD12	39.015	76.950	34	Beltsville	Maryland
ME12	46.681	68.038	144	Presque Isle	Maine
MI02	45.555	84.666	238	Pellston	Michigan
MN02	47.181	93.533	390	Grand Rapids	Minnesota
MS02	33.469	88.782	85	Starkville	Mississippi
MT02	48.310	105.100	634	Poplar	Montana
NE02	41.133	96.483	353	Mead	Nebraska
NM02	32.617	106.742	1317	Las Cruces	New Mexico
NY02	42.876	77.029	218	Geneva	New York
NZ02	-45.038	-169.684	370	Alexandra	New Zealand
OK02	36.617	97.500	317	Billings	Oklahoma
ON02	43.780	79.470	198	Toronto	Ontario
SK02	50.197	104.700	580	Regina	Saskatchewan
TX02	29.133	103.517	670	Panther Jnct.	Texas
UT02	41.666	111.900	1368	Logan	Utah
VT02	44.533	72.856	408	Burlington	Vermont
WA02	46.750	117.183	804	Pullman	Washington
WI02	44.708	89.766	381	Dancy	Wisconsin

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9.0 DOD

9.1 *Goals and Objectives*

The Department of Defense does not support dedicated Global Change Research, but continues a history of participation in the USGCRP through sponsored research that concurrently satisfies National Security requirements and stated Goals of the USGCRP.

9.2 *Contributing Elements*

9.2.1 Atmospheric Composition - The Naval Research Laboratory's (NRL's) Special Sensor Ultraviolet Limb Imager, presently awaiting a launch vehicle, will provide long-term baseline data for investigations of global change in the upper atmosphere. Analysis and prediction of world-wide aerosol concentrations, including desert dust, biomass smoke, marine and anthropogenic aerosols, and a radiative transfer algorithm yielding atmospheric transmission coefficients is generated by the Navy Aerosol Analysis and Prediction System (NAAPS).

Other DoD research associated with the US atmospheric chemistry focuses on space and ground-based measurements of ozone, aerosols, water vapor and other trace species. DoD investments in new and novel sensors include the third generation Polar Ozone and Aerosol Measurement (POAM III) sensor system aboard the French SPOT satellite, which is providing high-resolution stratospheric ozone measurements to complement data from NOAA and NASA satellite sensors (TOMS/SBUV). A Ballistic Missile Defense Organization satellite instrument, the Ultraviolet and Visible Imager and Spectrographic Imager (UVISI) aboard the MSX satellite, with NASA support for data analysis has been used to obtain atmospheric ozone profiles using stellar occultation. This is a promising new technique for ozone profiling, as it provides many more occultation opportunities than either solar or lunar occultations and enables greatly expanded spatial coverage. The Naval Research Laboratory is responsible for operation of ground-based microwave instruments at a number of NDSC stations.

The US Defense department is a partner with NASA and NOAA in the US National Polar Orbiting Environmental Satellite System (NPOESS), which will deploy an Ozone Mapping and Profiling Suite (OMPS) that encompasses the capabilities of TOMS and will maintain backscatter UV measurement of total ozone and stratospheric profiles indefinitely in the future.

9.2.2 The POAM Measurement Program - The POAM measurement program was originally supported by the Ballistic Missile Defense Organization with the objective of characterizing atmospheric propagation at laser wavelengths over the poles, for laser weapon and surveillance system applications. Emphasis on stratospheric ozone was added by NRL. POAM is an example of a DoD duel use program, having relevance to the military and also to basic science. POAM is currently supported by NRL and NASA (through the Data Buy Program).

Unique Valuable Measurements: POAM II was in operation from October 1993 – November 1996, and POAM III from March 1998 – present. During the large majority of this time (the only exception being November 1996 - May 1997 when ILAS I was in operation) POAM has been the only operational instrument providing measurements of ozone and related constituents in the polar regions on a continuous basis and has supplied the only satellite-based PSC climatology.

Ozone Depletion: POAM was an important contributor to the SOLVE/THESEO-2000 campaign, providing measurements to the SOLVE data base within 24 hours of acquisition. In addition, the POAM team provided a proxy global ozone product (from potential vorticity / ozone correlations) on a daily basis to provide overhead ozone for computation of J values in photochemical model calculations. POAM has now monitored the formation and dissipation of the ozone hole in unprecedented detail for 8 years and has also provided the first detailed satellite measurements of the dehydration of the Antarctic stratosphere, which is critical phenomenon for ozone hole formation and also plays a role in the middle atmospheric water vapor budget.

UT/LS Processes: POAM measurements and subsequent analysis have provided the first evidence that tropospheric smoke generated in forest fires can reach the lower stratosphere. The mechanism for this cross tropospheric transport appears to be intense thunderstorm activity generated by a combination of severe mesoscale / synoptic scale meteorological forcing and the intense heat generated by the fires. The extent and ramifications, regarding perturbations in the radiation field, of this aerosol source are under investigation. The climatological impact may be significant. Both the POAM ozone and water vapor measurements have now been pushed into the upper troposphere. Validation efforts show that the UT/LS ozone and water vapor products are clearly of sufficient quality for scientific research. These measurements have been used to diagnose the roles of horizontal, isentropic transport from the low latitude upper troposphere and diabatic descent from the mid-stratosphere in establishing the distribution of ozone and water vapor in the high latitude lowermost stratosphere.

Mesosphere / Stratosphere Coupling: On two occasions POAM observed enhanced NO_2 in the lower stratosphere, which has been traced to enhanced NO_x from the mesosphere and lower thermosphere that descended into the vortex during polar night. The effect of the enhanced NO_x on ozone loss in the mid-stratosphere has also been documented (resulting in localized ozone reductions of up to 40%). POAM has provided the first measurements and climatology of polar mesospheric clouds (PMCs) in extinction. The advantage of making these measurements in extinction is that this simple geometry allows properties of the PMC particle size distribution to be readily deduced. For example, the determination that the upper limit to the PMC modal particle radii is about 70 nm is consistent with SME particle size inferences. The POAM PMC climatology has been compared with that obtained 10 years earlier by the SME satellite. A significant increase in the cloud brightness between SME and POAM has been found. The increased cloud brightness may be an indicator of global change resulting from increased water vapor and decreased temperatures in the middle atmosphere.

10.0 SI

10.1 *Goals and Objectives*

Within the Smithsonian Institution, global change research is conducted at the Smithsonian Astrophysical Observatory (SAO), the National Air and Space Museum, the Smithsonian Environmental Research Center (SERC), National Museum of Natural History, Smithsonian Tropical Research Institute (STRI), and National Zoological Park. Research is organized around themes of atmospheric processes, ecosystem dynamics, observing natural and anthropogenic environmental change on daily to decadal time scales, and defining longer-term climate proxies present in the historical artifacts and records of the museums as well as in the geologic record at field sites. The Smithsonian Institution program strives to improve knowledge of the natural processes involved in global climate change, provide a long-term repository of climate-relevant research materials for present and future studies, and to bring this knowledge to various audiences, ranging from scholarly to lay public. The unique contribution of the Smithsonian Institution is a long-term perspective, e.g., undertaking investigations that may require extended study before producing useful results and conducting observations on sufficiently long (e.g., decadal) timescales to resolve human-caused modification of natural variability.

10.2 Contributing Elements

10.2.1 Atmospheric Composition - Researchers at SAO study stratospheric trace species that play an important role in ozone photochemical cycles using balloons, airplanes, and satellites. Solar activity and irradiance are being studied to understand better the climatic effects of solar variability. At SERC, measurements will be made of spectral UV-B in Maryland (>25-year record), Florida, Arizona, and other sites in the United States. These data will be disseminated electronically to meet the needs for assessing the biological and chemical impact of varying UV exposure.

10.2.2 UV Radiation Monitoring - The Smithsonian Institution is a participant in the US Interagency Ultraviolet Radiation Monitoring Network, with the overall goals of defining short- and long-term variation in spectral UV-B; studying the variation of UV-B over latitudinal gradients as well as the effects of clouds and other factors, such as aerosols, on UV-B. The program also supports SERC's program of UV-B effects research, which is conducted by SERC's Photobiology/Solar Research Laboratory (SRL). A priority in the SRL research program has been the development of an instrument that provides sufficient spectral resolution for evaluation of wavelength-dependent UV-B responses, yet is less complicated and easier to operate than the available high-resolution scanning instruments. A basic objective is to design simple and rugged instruments that are serviceable for continuous monitoring under a wide range of temperature and weather conditions. To this end, SRL has designed, built, calibrated and operated multi-filter spectral UV-B radiometers. Measurements have been made continuously in the Washington, DC metro region since the mid-1970's, at present time the series is 25+ years in length, which is unrivaled for spectral measurements (Figure 1 shows map of instrument location and a picture of the tower at SERC where the instrument is mounted). The current instrument design (SR18) incorporates 18, 2 nm bandwidth filters, with center wavelengths at nominal 2-nm intervals between 290 and 324 nm. Spectra are recorded through rotation of a filter wheel, 14 times per minute. Instrument measurements of solar radiation have been extensively validated in a series of intercomparisons with grating based instruments conducted by NOAA. In the last several years, SR18 operation has been expanded to eight sites as part of ongoing collaboration with NIST and USDA. Site locations include SERC, USDA Beltsville, Atlas-Miami, Purdue University, University of Nebraska, Forest Products Laboratory in Madison, WI, Table Mountain in Boulder, CO, and Atlas-Phoenix. SERC/SRL is responsible for maintenance, calibration and data analysis to insure high data quality. This network provides data on incident solar UV spectral irradiance as needed for evaluating effects of varying UV-B on marine ecosystems (SERC), agricultural products (USDA) and materials coatings (NIST).

10.2.3 Changes in Ecosystems - Several SI programs examine biological responses to global change. At SERC, research is being conducted on the responses of global ecosystems to increasing CO_2, exotic species introductions, and solar UV. At STRI, research is being conducted on the effects of climate change (including CO_2 increase) on tropical ecosystems.

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