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Stratospheric Processes and their Role in Climate SPARC

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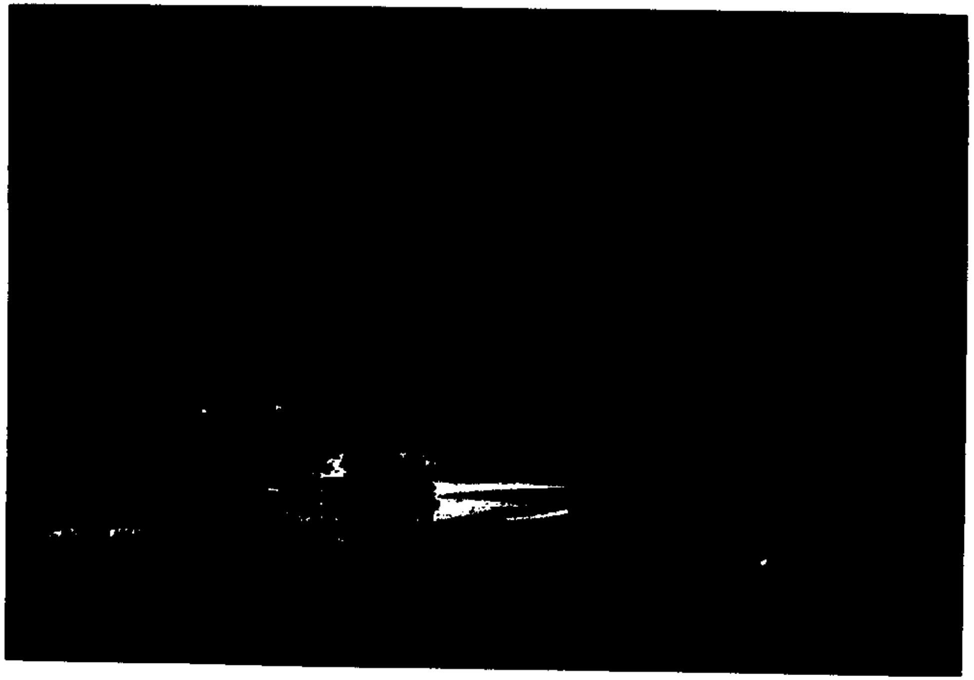
STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE

S P A R C

A PROJECT OF THE WORLD CLIMATE RESEARCH PROGRAMME

INTERNATIONAL IMPLENTATION PLAN



Polar Stratospheric Clouds (PSC's) above KIRUNA - Courtesy: Y. KONDO

SPARC Project Office   Verrières-le-Buisson, FRANCE   October 1992

STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE

(SPARC)

A Project of the World Climate Research Programme

SPARC is a programme that focuses on understanding stratospheric chang and their relation to tropospheric climate. It has been long understood hc important tropospheric processes are in determining the structure of t stratosphere. It is less well understood how stratospheric processes affe tropospheric climate; however, it is becoming increasingly clear that the stratosphe cannot be ignored in considering climate change. Many of the same gases that a responsible for greenhouse warming of the troposphere are important for ozo photochemistry. Since ozone is itself a greenhouse gas, changes in stratospher ozone must be considered in assessing future climates resulting from greenhou warming.

The stratosphere is one of the most fragile parts of the geosphere. An illustration this is the appearance of the Antarctic Ozone Hole in which fully half of t Antarctic Spring column ozone has disappeared during the past decade. Although is now well established that polar stratospheric clouds (PSC$_S$) interacting with m released chlorine and bromine species are causing this depletion, key questio related to global consequences of similar processes occurring at Northern latitud and in connection with stratospheric aerosols are still unanswered. SPARC wi address this question which is important for understanding present and futu ozone changes. SPARC will mainly seek to understand present stratosphe interactions with the climate in order to predict the influences that future states the stratosphere will have on the climate.

The implementation of SPARC involves co-ordinated observatio modelling, and analysis approaches to understand the effects of stratospheric chan on the climate. Process studies of the stratosphere are necessary to gain tl quantitative knowledge of the physics and chemistry underlying the observe changes in the stratosphere. Characterization of the present state of the stratosphe and its changes must be accomplished, and an understanding of which long-ter stratospheric variations are of natural origin and which are of anthropogenic orig must be attained.

Of course, a principle concern about stratospheric ozone has been the conce of what consequences on the biosphere might result from the increased U *radiation reaching the earth's surface through a diminished ozone layer. There is a need for extensive studies of the propagation characteristics of UV radiation in the atmosphere and in the top layers of the ocean and of the direct effects of UV radiation on biota. SPARC will address the physio-chemical aspects of this problem and invites the cooperation of the international biological community to cooperate with SPARC so that the biological consequences of the physio-chemical changes in the stratosphere can be studied in a coordinated manner.*

INTRODUCTION TO SPARC

Natural and anthropogenic variations of the stratosphere could have important consequences on the climate and the biosphere in several ways. Firstly, stratospheric ozone is the major absorber of UV-B radiation in the earth's atmosphere and UV-B is known to have damaging effects on biological systems. Any processes, whether natural or anthropogenic, that cause decreases in stratospheric ozone and therefore cause increases in UV-B radiation are of great concern. Second, biospheric processes are known to affect the concentrations of radiatively active trace gases in the atmosphere. Therefore, consideration must be given to the possibility of indirect effects of the stratosphere on climate that might result from UV-B-produced biospheric effects that could modulate the flux of greenhouse gases into the atmosphere.

Stratospheric change can affect the climate in a quite complex way through radiative and dynamical interactions with the troposphere. On one hand, ozone decreases cause less solar-UV absorption in the atmosphere, thereby allowing more solar radiation to heat the surface. On the other hand, reduced stratospheric ozone leads to a cooler stratosphere which, in turn, radiates less infrared energy downward into the troposphere, resulting in tropospheric cooling. The climate could be changed as a result of alterations in the incoming and outgoing radiative fluxes. There is also the possibility that ozone changes in the stratosphere could lead to changes in the stratospheric distributions of wind and temperature and thus affect the dynamical interactions between the troposphere and stratosphere.

SPARC (Stratospheric Processes And their Role in Climate) is a Project of WCRP that focuses on understanding how stratospheric change can affect the climate. The stratosphere is one of the most fragile parts of the geosphere. An illustration of this is the appearance of the Antarctic Ozone Hole in which fully half of the Antarctic Spring column ozone has disappeared during about one decade. SPARC seeks to understand present stratosphere interactions with the climate and to be able to predict the influences that future states of the stratosphere will have on the climate.

The implementation of SPARC involves coordinated observation, modelling, and analysis approaches to understand the effects of stratospheric changes on the climate. Process studies of the stratosphere are necessary to gain the quantitative knowledge of the physics and chemistry underlying these effects. Another task is to characterize the state of the stratosphere and how it is changing. Furthermore, one must be able to separate long-term stratospheric variations of natural origin from those of anthropogenic origin. Finally, there is a need for extensive studies of the propagation characteristics of UV radiation through the troposphere where it could affect the distribution of greenhouse gases, and in the top layers of the ocean where it may interact with species playing a major role in the sink process of CO_2, as well as the direct effects of UV radiation on the biota. SCOPE has recently published a report setting forth a detailed strategy for investigating the effects of increased UV radiation on biological systems (SCOPE, 1992). SPARC has been implemented as a purely physio-chemical programme; however, it is clear that a comprehensive study of stratospheric ozone behaviour and its effects on climate and biological systems requires a cooperative effort involving both the physio-chemical and biological communities. It is hoped that the IGBP, along with other biologically oriented international organizations, will enable the implementation of the SCOPE programme so that SPARC together with a biologically oriented counterpart can undertake the coordinated study of the stratosphere, climate, and biological interactions.

SPARC RESEARCH THEMES

In the following, the four research themes of SPARC are briefly described.

a) The Role of the Stratosphere in Climate Change

The stratosphere interacts significantly with the troposphere both radiatively and dynamically, as it was shown recently by several GCMs where the stratosphere was represented in more details than in most GCMs. Thus, changes in stratospheric structure, whether produced by natural or anthropogenic effects, can lead to alterations in tropospheric climate.

b) Stratospheric Process Studies

The stratosphere is a region in which radiation, chemistry, and dynamics interact strongly. Thus, all three of these processes must be understood in the stratosphere individually as well as in interaction with one another. The Antarctic Ozone Hole phenomenon is an excellent example of a case in which complex interactions among radiation chemistry and dynamics give rise to startling departures from "normal" climatological behaviour.

c) Global Change of the Stratosphere

The stratosphere is the terrestrial atmospheric region where the largest changes are expected in both ozone concentrations and temperature. Such changes have already been detected. The monitoring of trends and the prediction of future trends due to anthropogenic forcing require a knowledge of natural variability due to volcanic, solar, and interannual circulation variations.

d) Stratospheric Change and the Penetration of UV-B Radiation

The penetration of solar UV-B radiation is determined primarily by the amount of the absorbing ozone in the stratosphere, even though aerosols, tropospheric clouds and tropospheric ozone also play an important role. Modelling and monitoring of UVB through the stratosphere, tropospheric and down to the ground and the upper layer of the ocean will be a major issue of the programme.

The effects of changes in the available UV-B radiation in the troposphere and at the Earth's surface will be studied for different scenarios of ozone depletion.

GLOBAL CHANGE AND THE STRATOSPHERE

The basic motivation for including the role of the stratosphere in Global Change is provided by the influences of stratospheric processes on climate and on the surface environment of the global biosphere system. The stratosphere is coupled to climate and the biosphere in a number of important ways. The most familiar of these ways involves the role of the stratospheric ozone layer in determining the amount of biologically harmful solar radiation reaching the surface. Less familiar, perhaps, is the fact that the downward flux of stratospheric ozone into the troposphere is largely responsible for the chemistry which oxidizes and, consequently, leads to the removal of many of the gases emitted from the surface, from either biogenic or anthropogenic sources.

Some of the gases emitted from the surface, in turn, determine the concentrations of stratospheric ozone. These are the gases which are relatively inert to oxidation in the troposphere and, therefore, have sufficiently long lifetimes to be transported into the stratosphere. They include the biogenic gases, N_2O and CH_4, and the industrial halocarbons. The photochemical breakdown of these gases under the influence of ultraviolet radiation in the stratosphere leads to chemical fragments which catalytically destroy ozone.

Changes in stratospheric composition as a result of changes in surface emissions therefore have a direct impact on the penetration of UV-B radiation to the surface and to the oxidative (cleansing) efficiency of the troposphere/biosphere.

Stratospheric composition also has two important climatic influences.

The first is through the attenuation of solar radiation which affects both tropospheric climate and biological activity at the surface. Again, we should note a two-way coupling. For example, sulphur gases of biogenic origin such as COS, which after transport into the stratosphere, are responsible for the stratospheric aerosol layer. These aerosols reflect incoming solar radiation and thereby influence the climate of both the stratosphere and the troposphere. Direct emission of sulphur gases into the stratosphere by volcanoes also contribute to the aerosol layer in the stratosphere and must be characterized.

The second, less direct, influence of stratospheric composition is through the coupling of stratospheric and tropospheric climate and dynamics. In addition to affecting ozone concentrations, N_2O, CH_4, and the fluorocarbons are powerful infrared absorbers which contribute significantly to the greenhouse effect. CH_4 oxidation in the stratosphere is a major contributor to the H_2O content of the stratosphere which is both an effective greenhouse gas and is implicated in the formation of the Antarctic ozone hole. Increases in emissions of these gases, as well as of CO_2, leads to heating of the troposphere (the familiar greenhouse warming) and also to cooling of the stratosphere. The predicted cooling of the stratosphere is so large that it could serve as an early warning system for the enhanced greenhouse effect. Radiative cooling of the stratosphere affects its climate and circulation. In addition, changes in the stratospheric temperature distribution resulting from increased emissions of greenhouse gases, affect stratospheric ozone concentrations through the temperature dependence of chemical reaction rates which enter into ozone production and loss. It should also be borne in mind that reactions in the stratosphere are the major sinks for N_2O and the halocarbons. Changes in their removal rates will affect their removal rates will affect their steady-state concentrations both in the troposphere and in the stratosphere and, because of their strong radiative properties, the climate in both regions.

Major volcanic eruptions are known to emit very large quantities of material into the troposphere, but only the most powerful eruptions can also inject significant quantities of material directly in the stratosphere. The long residence time of these materials in the stratosphere can influence the global radiation balance. In addition, variations of solar intensity on several time scales modulate atmospheric variability. This natural variability must be characterized distinguish it from the biogeochemical climate changes of concern to IGBP.

A new atmospheric science issue to be considered is the possibility that the stratosphere will be used by extensive aircraft fleets in the near future. These commercial aircraft will fly in a climatically sensitive region where the consequence on ozone may become a serious problem. Major studies are urgently needed for the scientists to be able to influence future commercial policies.

A schematic of coupling processes in the Stratosphere-Troposphere-Biosphere system is illustrated in Fig. 1.

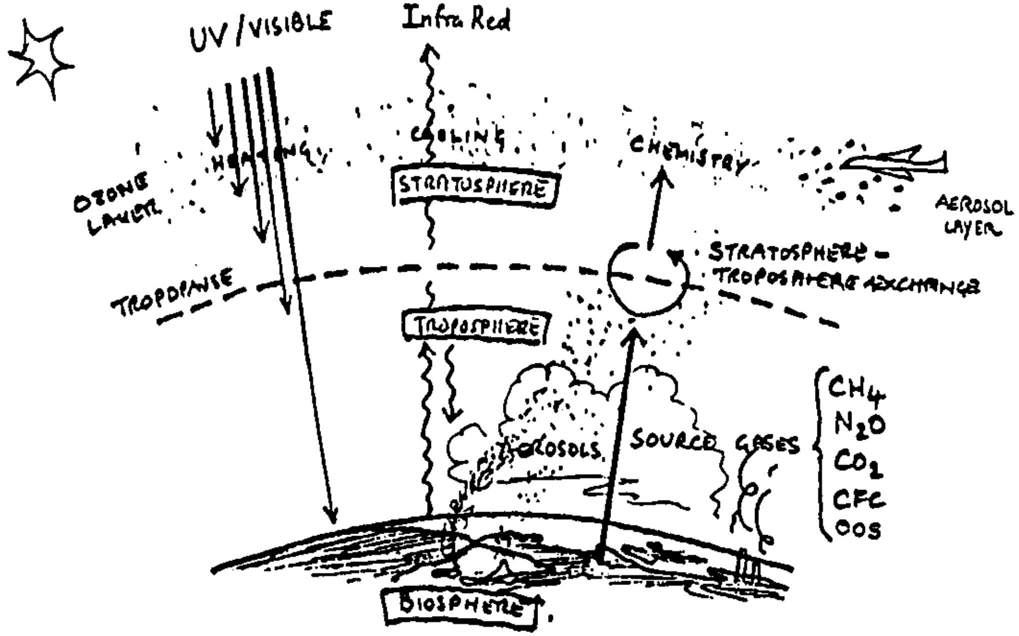


Figure 1. Schematic of coupling processes in the Stratosphere-Troposphere-Biosphere system.

OUTLINE OF SPARC RESEARCH FOCI, OBJECTIVES, AND ACTIVITIES

For each of the four research themes of SPARC, the implementation plans have been organized into a small number of research activities. Under each research focus, a number of activities were developed, and under each research activity, a number of objectives appear. An outline of SPARC's research Foci, Activities, and Objectives follow.

FOCUS 1: THE INFLUENCE OF THE STRATOSPHERE ON CLIMATE

Objective 1.1 Study the Influence of the Stratosphere on Tropospheric Climate

Activity 1.1.1 Evaluate and improve our current capability of modelling the troposphere-stratosphere system.

Activity 1.1.2 Understand the role of dynamical variability of the stratosphere in the climate system.

Objective 1.2 Assessing the Potential Role of Stratosphere/Troposphere Interactions in Climate Change

Activity 1.2.1 Understand the effects of <u>naturally</u> occurring perturbations on the stratosphere and their influence on the climate system

Activity 1.2.2 Understand the effects of anthropogenically produced perturbations of the stratosphere on the climate system.

FOCUS 2: PROCESS STUDIES ASSOCIATED WITH STRATOSPHERIC OZONE DECREASE

Objective 2.1 Study the Chemical and Aerosol Processes

Activity 2.1.1 Basic stratospheric chemistry

Activity 2.1.2 Heterogeneous chemical reactions

Activity 2.1.3 Appearance and evolution of aerosols and polar stratospheric clouds (PSC's) within the stratosphere.

Objective 2.2 Study the Dynamical Transport of Chemical Constituents

Activity 2.2.1 Quantify stratospheric-tropospheric exchange

Activity 2.2.2 Quantify stratospheric transport and mixing phenomena

Objective 2.3 Study the Radiative Forcing of the Stratosphere

Activity 2.3.1 Measurement of radiative fluxes

Objective 2.4 Study the Radiative-Dynamical-Chemical Interactions

Activity 2.4.1 Improving models of stratospheric processes

FOCUS 3: GLOBAL CHANGE OF THE STRATOSPHERE

Objective 3.1 Understand the Variability and Long-Term Trends in the Stratosphere.

Activity 3.1.1 Monitoring of the stratosphere

Activity 3.1.2 Analysis and interpretation of stratospheric data

Activity 3.1.3 Modelling of stratospheric variability due to both natural (solar, volcanic; internal forcing) and anthropogenic origin and long-term trends

FOCUS 4: MONITORING AND MODELLING OF UV IRRADIATION CHANGES IN THE BIOSPHERE AND THE TROPOSPHERE

Objective 4.1 Modelling and Experimental Validation of UV Penetration

Activity 4.1.1 Understanding the UV radiation environment and the processes which control it, including ozone abundance, full and partial cloud cover, aerosols, urban, regional, and global scale pollutants, and atmosphere-cryosphere-ocean coupling.

Activity 4.1.2 Validating UV radiative transfer models by intensive field measurement campaigns.

Objective 4.2 Establish Global UV Climatology and Prediction

Activity 4.2.1 Establishment of a global observation network to determine the present day baseline of UV climatology, and to detect long term trends.

Activity 4.2.2 Data base management connecting UV observations with supporting data

Activity 4.2.3 Develop practical radiative transfer models for predicting UV climatology on global and regional scales, from ground-based and satellite observations of atmospheric composition; and to validate such models against UV irradiance data from the observational network and from space observations during satellite overpasses.

Activity 4.2.4 Predict future UV radiation changes under natural and anthropogenic perturbation scenarios, and examine the implications of such changes for the biosphere, the troposphere and the overall climate system.

IMPLEMENTATION PLAN FOR SPARC

In the following, implementation plans are presented for each of the foci, objectives and activities that were presented in the previous outline. Under each of the activities, a number of tasks are presented that are needed to advance the objectives. Since each of the tasks are in different stages of development, an assessment is given as to whether the status of the task is active or in the planning phase. International programmes which have related efforts in the task areas are also mentioned.

FOCUS 1 : THE INFLUENCE OF THE STRATOSPHERE ON CLIMATE

This focus of SPARC is directed towards the study of the influence of the stratosphere on the present climate and the potential for the stratosphere to cause or modify changes in the climate system. These changes may be produced by injections of volcanic aerosols, solar variability, trends in stratospheric composition due to anthropogenic emissions of trace gases, or by feedbacks involving the response of the stratosphere to changing tropospheric circulation patterns. However, the coupling of the dynamics and climate of the troposphere with the stratosphere is not well understood. Another important effect linking the troposphere and stratosphere is that the downward emission of longwave radiation by trace gases in the lower stratosphere is a significant component of the greenhouse effect maintaining the current surface temperature. Changes in this emission contributes significantly in predictions of future greenhouse warming.

Objective 1.1 Study the Influence of the Stratosphere on Tropospheric Climate

The stratosphere plays at least two roles in the climate system. The first is the impact of stratospheric trace gases and aerosols on the net radiative balance of the surface-troposphere system. Ozone and aerosols reduce the downward radiative flux at the tropopause by absorbing and reflecting solar radiation while, in addition, ozone, CO_2 and several other trace gases increase the downward radiative flux by emitting longwave radiation. The second role of the stratosphere in the climate system is through the dynamic coupling of the troposphere and stratosphere. The stratospheric circulation influences the vertical propagation of tropospheric waves but the feedback of this process on the tropospheric circulation is not well understood. Finally, stratospheric processes play a major role in determining the chemical composition of the atmosphere. The downward transport of stratospheric ozone across the tropopause is a major source of tropospheric ozone, which alters chemical balance in the troposphere. The stratosphere itself is the major sink region for many greenhouse gases (e.g. CFCs, CH_4, and N_2O).

Activity 1.1.1 Evaluate and improve our current capability of modelling the troposphere-stratosphere system.

Modelling the troposphere and stratosphere as a coupled system is central both to testing our understanding of the physical processes which are involved and to predicting the response to natural or anthropogenic perturbations. The models used may range from highly simplified process models, such as radiative-convective models, to complex three-dimensional models including the transport and chemistry of trace constituents. The evaluation of current models will require both intercomparing different models and testing them against observations in order to isolate deficiencies. Improving current models will require a better theoretical understanding of the coupling between the troposphere and stratosphere.

Task 1.1.1.1

Improved understanding of basic stratosphere-troposphere interaction mechanisms using theory, modelling and observations.

The most important task in evaluating the influence of the stratosphere on the climate system is to improve the current level of understanding of the dynamic coupling processes by which the stratosphere interacts with the tropospheric circulation. The circulation of the stratosphere is determined by a balance between radiative processes and forcing by vertically propagating waves which originate in the troposphere. The radiative processes are themselves affected by the stratospheric composition, which is determined by chemistry and by the transport of constituents by the stratospheric circulation. The propagation of waves in both the vertical and meridional directions, after their generation in the troposphere, is influenced by the refractive properties of the stratospheric flow and by radiative and dynamical dissipative processes. The coupling of all of these processes is still not well understood, nor is the extent to which stratospheric processes affect the generation and structure of waves in the troposphere, and the exchange of constituents between the troposphere and stratosphere.

Task 1.1.1.2

Conduct intercomparisons and validation of troposphere-stratosphere models.

A key task in evaluating the current models of the troposphere-stratosphere system is to intercompare models and their subcomponents and verify them using observations. The current state of modelling of the complete troposphere-stratosphere system is not sufficiently advanced to make a full scale model intercomparison of long term climate integrations appropriate at this time, although WCRP is sponsoring such a project for tropospheric climate models. A specific

comparison of full troposphere-stratosphere models should be started in cooperation with the ICMUA Working Group on Modelling. This project should draw upon the ongoing WGNE Atmospheric Model Intercomparison Project where possible. The performance of the radiation codes should be compared (and validated to the extent possible) up to the stratopause, possibly in the framework of the ICRCCM (the Intercomparison of the Radiation Codes used in Climate Models). A comparison and validation of other major components of the models such as the parameterizations of small scale dissipation and of gravity wave momentum deposition and mixing should also be made. Unfortunately, the performance of these parameterizations is difficult to validate, since observations of the relevant atmospheric processes are difficult to obtain, and comparisons with detailed process models will probably be required.

Task 1.1.1.3

Determine the extent to which a detailed representation of the stratosphere is required in climate models.

Most three-dimensional climate models contain at least a rudimentary representation of the lower stratosphere, but few models resolve the entire stratosphere. Several studies have shown that tropospheric climate simulations are adversely influenced by poor representations of the stratosphere. However, the mechanisms by which the troposphere is affected are still not completely understood. In consequence, it is not yet known whether it is necessary to use complete models of the troposphere-stratosphere system, or whether simplifications are possible. Tropospheric simulations are also sensitive to the parameterizations of gravity wave momentum deposition and dissipation in the stratosphere. The acceptable representation of the stratosphere in various climate models should be determined.

Task 1.1.1.4

Improve stratospheric datasets for diagnostic studies and verification of models.

High quality data sets extending from the surface through the stratosphere are essential for diagnostic studies of the coupling of the troposphere and stratosphere and for the verification of models of the troposphere-stratosphere system. The best data sets, in principle, for these studies would be those routinely produced by the data analysis and assimilation systems of operational weather prediction centers as the initial conditions for numerical forecasting. However, with the exception of the STRATAN system at NASA/GSFC, these analyzed fields are generally not suitable for diagnostic studies of the stratosphere and of stratosphere-troposphere interactions since the models currently used in the assimilation system do not extend above the middle stratosphere. The analyses produced for the lower stratosphere may therefore be distorted and no analyses are produced for the upper stratosphere, even though considerable amounts of satellite data are available and more will be available in the future (e.g. from UARS). Operational analysis and assimilation systems are frequently revised and it has become clear that a reanalysis of many years of data using a uniform, state of the art, analysis system would be invaluable for climate research. Such a reanalysis is currently being planned under the auspices of WCRP but will not extend into the upper stratosphere. The availability of stratospheric data and the need for uniform data sets extending from the troposphere into the upper stratosphere should be taken into account in the plans for future reanalysis efforts. It is unlikely that significant progress can be made in this direction at the operational centers until their standard forecast models include an explicit representation of the upper stratosphere.

Activity 1.1.2 To understand the role of dynamical variability of the stratosphere in the climate system.

The stratospheric circulation undergoes a strong annual cycle in which the zonal winds in each hemisphere change from westerly to easterly between winter and summer. The interannual variability of the stratosphere is also large in winter, because of the occurrence of stratospheric warmings, during which the stratospheric winds reverse temporarily, affecting the circulation for several weeks. Large interannual variability in the tropical stratosphere is associated with the quasi-biennial oscillation (QBO), in which the equatorial zonal winds oscillate between easterly and westerly over an irregular period averaging about 26 months (see Figure 2, which is an updated figure from Naujokat, 1986). Stratospheric warmings and the QBO are now understood to be connected with wave forcing from the troposphere. However, these phenomena dramatically modify the wind and temperature profiles in the stratosphere and hence the propagation characteristics of planetary scale waves, which may then feed back and affect the wave structures in the troposphere. Understanding the role of stratospheric variability in determining variability in the troposphere will require both observational and modelling studies to isolate the effects of specific stratospheric processes and the mechanismes by which they produce tropospheric responses. Determining these processes will be essential for understanding the effect of potential changes in the stratospheric circulation on the climate system.

Task 1.1.2.1

Conduct diagnostic and modelling studies on the interactions between the QBO, stratospheric structure and climate.

Further diagnostic studies should be undertaken to examine whether systematic variations in large-scale tropospheric circulation patterns are associated with the QBO. The current generation of three dimensional models is not able to stimulate the QBO. However, modelling studies are already in progress, in which opposite phases of the QBO are forced in the stratosphere of three-dimensional models and the effect on tropospheric waves is assessed. In coordination with the WGNE, a coordinated modelling study with available atmospheric troposphere-stratosphere models should be mounted, comprising experiments starting from

identical initial conditions, but for differing imposed stratospheric structures corresponding to opposite phases of the QBO. If significant tropospheric effects of the QBO are found, then theoretical and modelling studies will be required to determine precisely why the QBO is not simulated in the current models and how this deficiency may be corrected.

Task 1.1.2.2

Conduct diagnostic and modelling studies of the effect of interannual variability of the stratosphere on the tropospheric state.

There is considerable interannual variability in the winter stratospheric circulation associated with the occurrence of stratospheric warmings. Extensive diagnostic studies of the coupled troposphere-stratosphere system leading up to and following sudden stratospheric warmings both as observed and simulated in models have been carried out for many years. However, the extent to which a sudden stratospheric warming (triggered by tropospheric forcing) can in turn feed back to affect the tropospheric circulation is not clear, and specific attention needs to be focussed on this question.

Stratospheric warmings are not observed in the Southern Hemisphere although planetary waves of fairly large amplitude do occur. Because of the different structure of tropospheric and stratospheric circulation in the northern and southern hemispheres, there are significant differences in the stratosphere-troposphere interactions in the two hemispheres. These differences can be used as a basis to explore the potential influence of the stratosphere on the troposphere as a function of atmospheric structure.

Status: Some work underway but needs coordination
Timetable:

The tasks in this SPARC activity require both modelling and diagnostic studies. Model performance must be validated with observations, but insufficient data exist to assess the extent of stratospheric effect on the troposphere using observations alone.

1993 : SPARC Modelling Working Group meeting. All interested troposphere-stratosphere modelling or diagnostic groups will be invited to plan intercomparisons of simulations for the current climate.

1993 : Plan re-analysis project for stratospheric data sets and assembly of the relevant satellite data sets.

1994 : Finish model intercomparisons and validation for current climate

1995 : Workshop on stratospheric model intercomparisons and validation

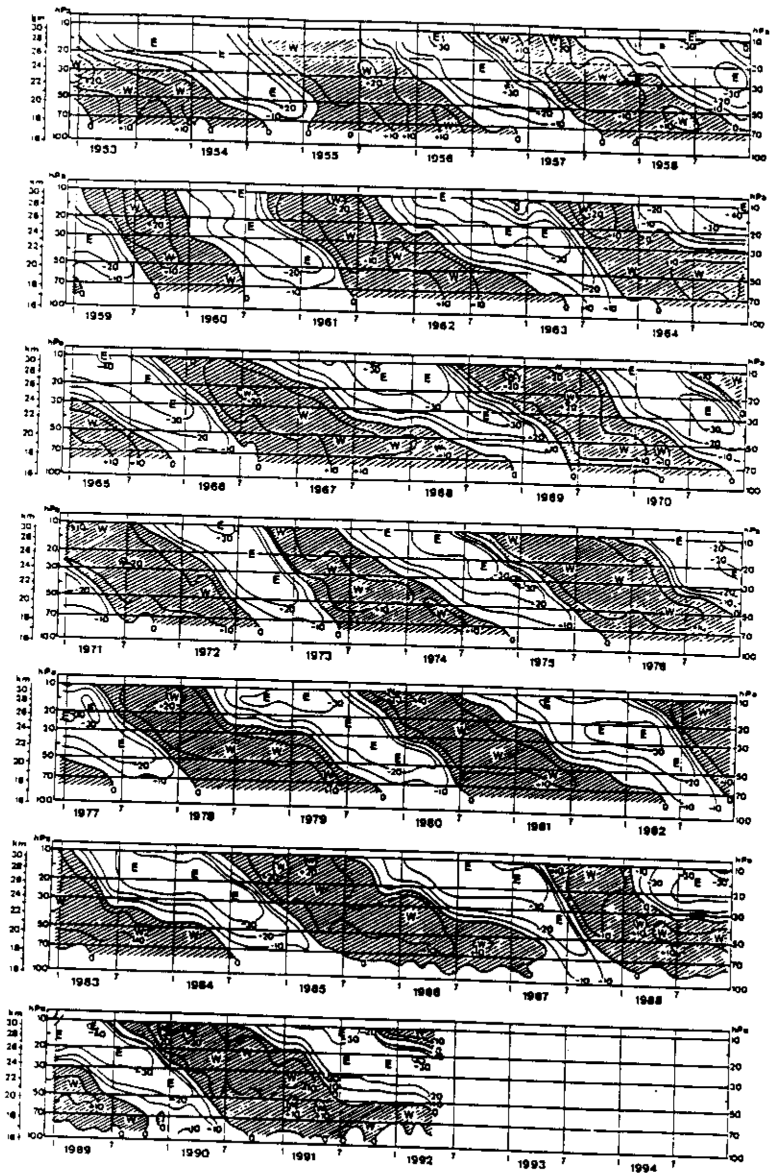


Fig. 2. Monthly mean zonal wind (m/sec) in the stratosphere above the equator. Updated from Naujokat (1986).

Objective 1.2 Assess the Potential Role of Stratosphere-Troposphere Interactions in Climate Change

Changes in stratospheric composition or aerosol loading could affect climate in a number of ways. The increase of greenhouse gases in the stratosphere (CO_2, CH_4, H_2O) will increase infrared energy emission down to the troposphere, adding to its warming. In contrast, the stratosphere will cool and its circulation may change in response, with consequences for tropospheric dynamical processes and troposphere-stratosphere exchanges. Anthropogenically induced changes in stratospheric ozone will likewise have radiative and dynamical effects. On shorter time scales, changes in volcanic aerosol loading and in solar output will induce variability in the stratosphere. This activity has as its goal the assessment of the role of such interactions in climate projections.

Activity 1.2.1 Understanding the effects of naturally occurring perturbations on the stratosphere and their influence on the climate system.

In addition to determining the internal variability of the climate system, it is necessary to understand the effect of naturally occurring on the climate. Only then will it be possible to distinguish anthropogenically-induced climate changes from those which occur naturally. The principal natural perturbations are associated with volcanic aerosols and with solar variations. Both can have direct effects on stratospheric temperatures and radiative fluxes into the troposphere, and may affect tropospheric dynamics in subtle ways. Since the strength of these forcings can be quantified, they provide us the opportunity to increase our understanding of the troposphere-stratosphere climate system, and to test the sensitivity of our models.

Task 1.2.1.1

Develop and utilize stratosphere-troposphere models to simulate the effects of volcanically enhanced stratospheric aerosol loading on the troposphere and compare with known events.

Volcanic aerosols in the stratosphere cause surface cooling by scattering incoming solar radiation. Global mean surface temperatures decreased for several years following the eruption of Mt. Agung in 1963, and a similar effect could be discerned following the eruption of El Chichon in 1982 (Hansen and Lebedeff, 1987). The recent eruption of Mount Pinatubo probably injected more SO_2 into the stratosphere than any previous eruption in the last century resulting in greater stratospheric aerosols concentrations. The resulting effects of the Pinatubo eruption on surface temperatures should be at least as large as those following the earlier volcanic eruptions. In addition, volcanic aerosols can absorb both short and long wave radiation and have been observed to warm the tropical lower stratosphere. Modelling studies should be undertaken to determine the effect of perturbations of this magnitude on the rest of the climate system.

Quantifying the potential impacts of volcanic eruptions will require the continued development of stratosphere-troposphere models with sufficient vertical resolution near the tropopause to allow for a realistic input of volcanic aerosol profiles, and simulation of the response. Such models must allow their sea surface temperatures to change, so as to assess the climate impact of the aerosol.

Continued observations of global stratospheric aerosol concentrations and radiative characteristics will also be required. The SAGE II instrument aboard ERBS is currently monitoring volcanic aerosols, but its replacement is not scheduled prior to EOS-B in the next century. Lidars can provide local profiles of aerosol loading while in-situ observations of aerosol composition and particle size could be provided by balloon or aircraft programmes. There will be close cooperation with the International Global Aerosol Programmeme (IGAP) and International Aerosol Climatology Project (IACP) and SPARC on these efforts.

Task 1.2.1.2

To understand the processes by which variations in solar UV and energetic particle outputs might affect the troposphere, acting through changes in the stratosphere.

The direct impact of solar ultra-violet and high energy particle variations is primarily in the atmosphere above the tropopause, so it is likely that if such variations do affect the troposphere, they will be transmitted via the stratospheric response. Recent correlations between the solar sunspot cycle, the quasi-biennial oscillations (QBO) and atmospheric circulation patterns have observed apparent effects extending from the stratosphere down to the surface (Labitzke and van Loon, 1988). The sunspot cycle is associated with variations in UV radiation which can affect stratospheric ozone concentrations, temperatures and winds, conceivably altering vertical propagation of tropospheric planetary waves. Ozone concentrations may also be affected by high energy particles emitted in solar flares, through the generation of NO_x.

Studying these processes will require stratosphere-troposphere models to be run with altered UV radiation. The effect on stratospheric winds and temperatures should be compared to observations of such changes during the solar cycle. Stratospheric and tropospheric planetary wave responses should be assessed in both models and observations in order to distinguish these influences from natural variability. Further measurements of UV radiation variations will be provided by SUSIM and SOLSTICE on UARS and subsequent instruments on EOS.

Activity 1.2.2 Understanding the effects of anthropogenically produced perturbations of the stratosphere on the climate system.

Anthropogenic increases in CFC's, CO_2, CH_4, and other trace gases are altering the composition of the stratosphere with potential modifications to its structure. Recent observations suggest that cooling may have already begun in the upper

stratosphere and mesosphere (Hauchecorne et al., 1991). The ozone hole apparently causes a delay in the transition from the winter to the summer circulation in the Southern Hemisphere stratosphere. Although many studies have been performed on the radiative changes associated with greenhouse gas increases and ozone decreases, our understanding of their influence on stratosphere-troposphere interactions and the climate system is far from complete.

Task 1.2.2.1

To understand the impact of anthropogenically induced stratospheric ozone changes on climate.

Stratospheric ozone reductions will produce changes in the stratospheric thermal regime, as well as the radiative flux into the troposphere. In particular, radiative cooling of the middle and upper stratosphere may change stratospheric dynamics and the transport of radiatively active substances. Increased UV fluxes into the troposphere could alter tropospheric OH and $O(^1D)$ concentrations and chemical interactions. The impacts of these stratospheric changes on tropospheric chemistry and ozone, on tropospheric radiative fluxes and on dynamics are yet unclear. They will have to be studied by GCMs (general circulation models) of the troposphere, stratosphere and lower mesosphere in combination with two- and three-dimensional photochemical models. Three-dimensional modelling of radiative and dynamical effects of the observed Antarctic ozone hole may be a good example of a start of such studies, which could be coordinated with WGNE activities.

Task 1.2.2.2

To understand the mechanisms by which stratospheric feedbacks may alter the response of the climate system to changing concentrations of greenhouse gases.

Since stratospheric dynamical processes depend on tropospheric wave forcing, climate changes in the troposphere may well alter the circulation of the stratosphere. For example, an increase in planetary wave forcing of the stratosphere, as occurred in one model simulation of the effects of doubled CO_2 (Rind et al., 1990), may significantly reduce the strength of the polar night jet. Such an effect, together with changes in the stratospheric circulation caused by the altered longwave cooling distribution in the stratosphere due to the CO_2 increase could significantly alter the original tropospheric response to the CO_2 incease. The vertical distribution of the radiative heating perturbations caused by CFC's and other greenhouse gases is quite different from that due to CO_2. Therefore, these may be expected to produce significantly different impacts on the circulation of the troposphere and stratosphere. To understand the potential feedbacks requires the use of coupled troposhere/stratosphere models for climate experiments. As some of theses changes are likely to be model-dependent, an organized set of three-dimensional troposphere/stratosphere climate change experiments should be established for canonical climate change forcings, such as 2 x CO_2 and 1 ppb concentration of CFC's 11 and 12.

Task 1.2.2.3

To understand the effects which changing concentrations of greenhouse gases may have on the exchange of constituents between the troposphere and stratosphere

The mechanisms which result in the exchange of air between the troposphere and stratosphere are still poorly understood. However, it is clear that the exchange of air and constituents, and the vertical transport of constituents in the stratosphere is partially controlled by stratospheric dynamical processes. Changes in the behaviour of these processes caused by increasing greenhouse gases may alter the exchange of constituents between the troposphere and the stratosphere, and the transport of constituents within the stratosphere. For example, the increase in planetary wave forcing of the stratosphere found in the double CO_2 simulation by Rind et al. (1990), led to an acceleration of the stratospheric residual circulation of 10-20%. Such an effect could alter the tropospheric residence time of radiatively important tropospheric trace gases (e.g., CFC's) and their forcing of climate change while also altering stratospheric ozone. Greenhouse gas induced changes in tropical tropopause temperatures may modify the stratospheric water vapor concentration with subsequent impact on greenhouse warming, and on the occurence of polar stratospheric clouds and therefore on ozone depletion. The dynamical changes predicted by coupled troposphere/stratosphere models in response to greenhouse gas increases could be used to generate corresponding transport changes in complex two- or three- dimensional transport-chemical models, in order to assess their impact. Ultimately, increasing greenhouse gas experiments will have to be conducted with the new generation of radiative/dynamical/chemical models now being built by several groups.

Task 1.2.2.4

To understand the mechanisms by which stratospheric feedbacks may alter the response of the climate system to other anthropogenic effects.

Other anthropogenic impacts on the stratosphere may produce changes of climatic (or biological) consequence. For example, the stratospheric composition and ozone concentration are likely to be affected by the projected fleet of high flying civil aircraft and space rocket launches. Preliminary model estimates show that the effects of such emissions may produce short term ozone depletion locally (which could also result in enhanced UV fluxes to the ground on the same scale) but that the cumulative effects on ozone and climate are likely to be small on the global scale. However, it is necessary to obtain new chemical data on the efficiency of heterogeneous reactions on the surfaces of the aerosol particles which would be produced in aircraft exhausts. Additional anthropogenic impacts may well occur. This situation implies a great need for monitoring trace gas trends in the upper troposphere and lower stratosphere.

Task 1.2.2.5

To understand the effects of the changing stratosphere on the tropospheric chemistry and composition.

The expected changes in ozone arising from anthropogenic effects and the possible changes in troposphere-stratosphere exchange associated with climate changes are likely to increase the UV flux intensity in the troposphere. For example, 2D model calculations, combining the effects of CFC emissions with CO_2 induced cooling of the upper stratosphere, predict a 4% decrease in column ozone. This decrease should result in an increase in tropospheric OH concentrations. As the climate warms, increased evaporation from the ocean will increase water vapor levels (a 30% increase with a 4 ^{o}C warming), further increasing OH concentration. The combined effects may well change tropospheric chemistry, affecting trace gas concentrations of such radiatively important species as CH_4 and N_2O, as well as biologically important gases (e.g., CO).

The complexity of these processes requires evaluation with combined troposphere/stratosphere chemistry/dynamic models. Construction of three-dimensional versions of these models is still in progress, and many problems exist. Preliminary analysis with lower resolution models should be attempted. Such modelling efforts will need to be augmented by observations of tropospheric trace gas trends which should be performed through IGAC. Close cooperation between SPARC and WGNE is desirable to foster modelling research in this area.

<u>Status</u>: Some activity underway, but needs coordination.

<u>Timetable</u>:

1993 : SPARC Modelling Working Group meeting. Plan climate change experiments to be done by all interested troposphere-stratosphere modelling groups.

1994 : Finish first set of simple climate change experiments.

1995 : Workshop on stratospheric model intercomparisons and validation.

1996 : Finish longer term climate change experiments.

1997 : Workshop on climate change experiment results and implications.

FOCUS 2 : PROCESS STUDIES ASSOCIATED WITH STRATOSPHERIC OZONE DECREASE

One of the principal stratosphere-troposphere-biosphere interactions involves stratospheric ozone loss and the accompanying increase in biologically damaging UV radiation at the Earth's surface. Ozone loss involves coupled dynamical, chemical and radiative processes and feedbacks that occur within the stratosphere. In order to completely understand the roles of these interactions, the processes themselves must be well understood. Recent intensive field and laboratory experiments and theoretical studies have contributed to a partial resolution of some key issues, although many important questions remain. Aircraft and ground-based experiments that have focused on polar stratospheric ozone depletion have provided considerable information defining chemical reaction mechanisms and the participation of stratospheric aerosols, particularly polar stratospheric clouds, in chemical processing. In this regard, the United States and European ozone campaigns (the Airborne Arctic Stratosphere Expeditions, AASE, and the European Arctic Stratospheric Ozone Experiments, EASOE, respectively) provide a fundamental data base. Combined with SAGE and UARS data and a variety of in situ measurements, these data may be integrated and analyzed for evidence on basic processes. The Mount Pinatubo eruption of June, 1991 produced what may be the largest stratospheric perturbation of this century. The aerosol, radiative and chemical changes were large enough to be discernable in numerous instrumental records. These data comprise a unique and important set bearing on the question of global change. Accordingly, Pinatubo offers an opportunity to investigate stratospheric processes and test concepts and models of basic processes. Some of the appropriate activities related to such studies are discussed below. In this regard, the priorities for these studies are set by their relevance to ozone change and its impact on ultraviolet radiation at the surface.

Objective 2.1 Study of the Chemical and Aerosol Processes

The discovery of the ozone hole over Antarctica in the austral spring has led to considerable research on causal processes. Both field and laboratory studies show that heterogeneous reactions which occur on polar stratospheric clouds (PSC's) lead to high concentrations of active chlorine radicals, particularly ClO. These chlorine radicals, in turn, react catalytically to deplete ozone. More recently, it has been suggested that significant heterogeneous chemistry could also occur at other latitudes on sulfate aerosols. Volcanic eruptions provide an important source of stratospheric sulfate aerosols through SO_2 injection, as well as injecting other particulates. Accordingly, volcanic eruptions may be associated with enhanced ozone loss. Some ozone loss was observed following the Pinatubo eruption, but the causes and extent of the ozone effects remain uncertain. Further analyses of the existing data base, including the results of the EASOE and AASE missions, could shed light on the processes leading to ozone depletion. Knowledge of heterogeneous chemical

processes and the distribution of key compounds that participate in the ozone chemistry of the lower stratosphere is incomplete. Hence, studies of the gas-phase and particle chemistry interactions should focus on this region.

Modeling is a key activity in this work, because the observations need to be integrated into a comprehensive theory of stratospheric ozone depletion. Moreover, the chemistry and microphysics of stratospheric trace gases and aerosols must be coupled to the dynamics and radiation of the stratosphere. Hence, the objective of this segment of the research is to increase our understanding of gas-phase and heterogeneous chemical processes and the evolution of stratospheric aerosols in the context of atmospheric dynamical and radiative processes of the lower stratosphere. Although these are all active fields of research, there are currently large uncertainties in heterogeneous chemical reaction processes, and in the generation, evolution and removal of stratospheric aerosols, including sulfate particles and PSCs. In addition, the basic transfer of materials into and out of the stratosphere — stratosphere-troposphere exchange — has never been adequately described, either experimentally or through dynamical process modeling. The injection of anthropogenic pollutants into the stratosphere and their removal from the stratosphere are largely controlled by these dynamical processes. As another example, the mechanism by which water vapor is transported into the stratosphere in tropical regions has not been explained. The radiation processes of the stratosphere also provides significant coupling between the stratosphere and troposphere. Ozone absorption of longwave radiation contributes to the global greenhouse effect. Hence, ozone changes modulate the greenhouse forcing of the troposphere. Stratospheric ozone also controls ultraviolet radiation penetration to the surface. Ozone transported into the troposphere from the stratosphere has a substantial impact on tropospheric chemistry, oxidation potential, and distributions of greenhouse-active gases.

The SPARC programme focussing on stratospheric processes complements the International Global Atmospheric Chemistry (IGAC) programme of the IGBP, which focuses on the troposphere. Indeed, as noted above, tropospheric and stratospherc chemistry are closely related through dynamical (transport) and radiation processes. A potentially strong interaction between IGAC and SPARC is envisaged. The SPARC programme can contribute information on the ultraviolet radiative fields impinging on the troposphere, which drives tropospheric chemistry, and on the source of tropospheric ozone from stratosphere-troposphere exchange. The combined IGAC/SPARC studies can also define the sources of chemically active trace gases — such as methane, nitrous oxide and the chlorofluorocarbons — for the stratosphere. The chemical and dynamical forcing of the stratosphere from below is an important aspect of ozone depletion that is coupled to tropospheric tracer transport and chemistry, which will be investigated in the IGAC programme.

New questions have been raised about the expansion of commercial aviation and the prospect of a new supersonic stratospheric aircraft in the near future. Emissions of nitrogen oxides, water vapor and sulfate particles are the primary concern for a large fleet of aircraft. The water vapor and NOx emitted in the stratosphere can attack ozone through homogeneous chemical processes. In addition, accumulated water vapor and nitric acid derived from the nitrogen oxides may significantly increase the frequency of PSC formation in the northern high latitudes. The enhanced PSCs could lead to unusual heterogeneous chlorine activation and ozone depletion. The sulfate aerosols from the engine exhaust could catalyze heterogeneous reactions that further exacerbate the ozone loss. Before significant headway can be made on this problem, the coupled processes of aerosol formation and evolution, and heterogeneous chemical processing on these aerosols, must be defined more precisely through detailed measurements and analyses. Specifically, data bases and modeling treatments that accurately represent the physical and chemical mechanisms must be developed. These must be incorporated in models and tested against field observations. Eventually a predictive scientifically based model can be built through efforts coordinated by SPARC.

Activity 2.1.1 Basic stratospheric chemistry.

Our understanding of stratospheric chemistry in terms of the gas phase chemical cycles was thought to be relatively complete until heterogeneous chemical reactions on PSC particles were shown to cause the ozone hole. Outside the polar regions, chemical reactions on sulfate and volcanic aerosol particles may provide another important ozone loss process beyond the normal homogeneous chemistry. Studies of the reactions that occur on stratospheric particles must be extended. The effects of such reactions on the distributions of gaseous species, particularly members of the ClO_x, NO_x and HO_x families, remain to be defined in a sufficiently detailed manner to allow accurate predictions with stratospheric chemical models. The existing empirical approaches to the problem of heterogeneous chemistry neglect many of the fundamental processes, and thus may not be reliable for conditions differing from the present state of the stratosphere. The reliable forecasting of ozone loss in the future depends on a thorough scientific understanding of the entire stratospheric chemical system, including coupled homogeneous and heterogeneous processes.

Task 2.1.1.1

Observation of key chemical components.

In order to understand chemical processes in the lower stratosphere, observations of key chemical compounds are essential. For example, the hydroxyl radical, OH, has never been measured in the lower stratosphere, where its role is crucial to the photochemistry. Additional data is needed for the CFC's and HCFC's; N_2O, CH_4, CO, and H_2O; as well as key NO_x, NO_y, HO_x, ClO_x, ClO_y and BrO_y species. The need is particularly acute for the nitrogen compounds. The amount of NOx and of Clx present in the lower stratosphere determines to a large extent the impact of particles on the ozone chemistry. Observations of chlorine compounds, first of all, ClO and also ClONO2 and HCl will give important information on the role of chlorine in the ozone chemistry as well as give information on the impact of particles on the ozone chemistry. Aircraft observations of the type performed in the

two US polar campaigns are best suited for this type of study. Measurements can also be made from balloons.

Ozone observations in the lower stratosphere are also needed. These observations should both be of campaign type and long term studies.

Task 2.1.1.2

Modelling of the gas-phase and particle reactions.

A chemical modelling programme operating in close collaboration with the above activities is necessary for identifying the main chemical processes and what the impact on the ozone chemistry is. The model should be able to give the detailed interactions between gas phase and particle chemistry (Turco et al., 1989; Hanson and Ravishankara, 1991). Of particular importance is that these model studies will provide the necessary input for parameterization in the large scale models which look at long term ozone depletion.

Activity 2.1.2 Heterogeneous chemical reactions.

There are three basic types of aerosols upon which heterogeneous reactions are thought to take place: nitric acid trihydrate (NAT), ice crystals and stratospheric sulfate particles. Improvement of our knowledge of heterogeneous reactions on these particle surfaces is critical to our understanding of global ozone changes.

Task 2.1.2.1

Laboratory studies of heterogeneous chemical reactions.

The main focus of this task is to quantify the heterogeneous chemical reactions which can take place on aerosol surfaces using laboratory measurements. This task is currently active in USA institutions and should be promoted in other countries.

Task 2.1.2.2

Field studies of heterogeneous chemical reactions.

In-situ stratospheric measurements should be made in the presence of aerosols of different types to validate the laboratory data and to determine whether new types of heterogeneous reactions may be occurring. Intensive field measurement campaigns have to be planned and carried out.

Activity 2.1.3 Appearance and evolution of aerosols and PSC's within the stratosphere.

The climatology and physical morphology of aerosols and PSC's is a new and important area of stratospheric research. The research scope includes aerosol and PSC production and loss, the size distribution of aerosols, the surface area of aerosols, the chemical composition under a variety of conditions, and the distribution of PSC's and aerosols.

Task 2.1.3.1

Laboratory studies of aerosol and PSC formation.

Laboratory studies of sulfate, NAT and ice particles will yield important information on the conditions necessary for aerosol and PSC formation (Hanson and Mauersberger, 1988). This task is currently active in only few laboratories and has to be carried out more extensively. Conditions appropriate to the stratosphere need to be better evaluated in the experiments.

Task 2.1.3.2

Field studies of aerosol and PSC formation.

Studies of sulfate, NAT and ice particles using aircraft and balloon instrumentation will yield important information on the conditions necessary for aerosol and PSC formation (Hofmann and Deshler, 1991). Chemical thin-film testing is useful for the detection of nitric acid. Lidar studies of PSC layers when accompanied by appropriate column nitric acid, and lidar temperature information will be very useful for process studies. Satellite sensing of aerosols and PSC's are also very important (see Figure 3, for example).

Task 2.1.3.3

Volcanic debris studies.

The occasional injection of volcanic aerosols into the stratosphere provides a unique opportunity for studying the impact of aerosols on stratospheric chemistry (Hofmann and Solomon, 1989). Because these phenomena are intermittent, plans should be drawn up to mobilize stratospheric in-situ (aircraft, balloon, rocket), ground-based, and satellite observations to take advantage of this phenomenon. In the meantime, the data from the more recent globally significant eruptions (e.g., El Chichon and Pinatubo) will provide possible data set for analysis. This is an appropriate task for SPARC to sponsor and provide international coordination.

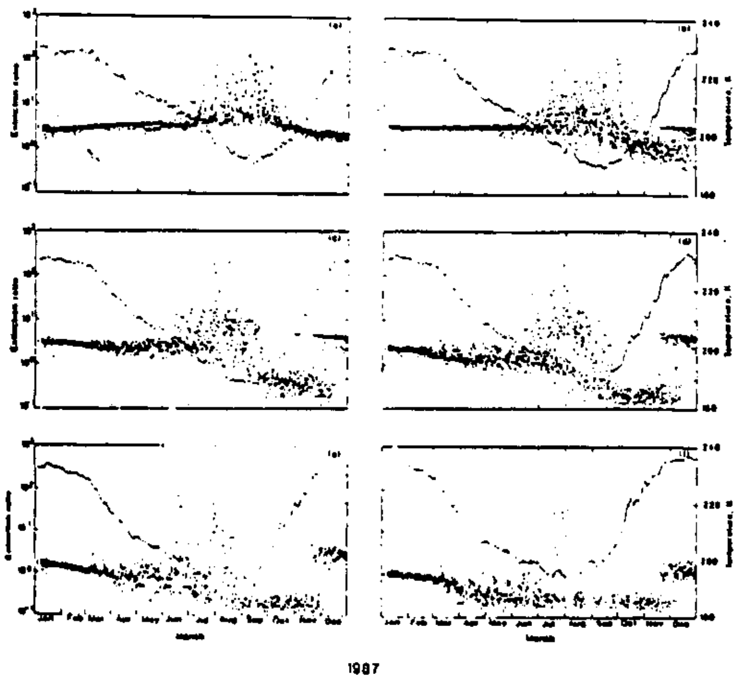


Figure 3. Seasonal variations of PSC's (dots) and temperature (solid curves) in 1987 over Antarctica. Extinction ratios of PSC's measured by the NIMBUS 7 SAM II instrument are shown at altitudes of (a) 14 km, (b) 6 km, (c) 18 km, (d) 20 km, (e) 22 km, (f) 24 km. (Adapted from McCormick et al., 1989).

Task 2.1.3.4

Tropical cirrus studies.

Aside from PSC's in the polar region, the tropopause dehydration cycle associated with tropical cumulonimbus anvils may provide a sufficient amount of ice particles so that heterogeneous reactions may be taking place in the tropical lower stratosphere. These reactions may not have been detected yet because of the lack of reservoir species in the upwelling zone. Nonetheless the role of tropical lower stratospheric cirrus should be investigated along with in situ measurements of many chemical species. This is is an appropriate task for SPARC to encourage and provide international coordination. A close connection with WCRP-ISCCP and IGAC will be very helpful.

Status: Some activity, but needs encouragement and coordination mainly with IGAP / IAMAP programme

Timetable:

1993 : Establish the coordination of the activity.
1992-1995 : Arctic and Antarctic ground-based and aircraft campaigns.
1992-1995 : Development of models with heterogeneous chemistry.
1993 : IAMAP conference session on stratospheric chemical processes.
1996 : Synthesis workshop.

Objective 2.2 Study the Dynamical Transport of Chemical Constituents

This activity concerns the transport of ozone catalytic source gases from the troposphere into the stratosphere, the transport of stratospheric species back into the troposphere, the transport or mixing of chemicals within the stratosphere, and the transport of material from the mesosphere into the stratosphere. All of these processes are critical to understanding ozone changes.

The transport of CFC's, HCFC's, N_2O, CH_4 and H_2O by the Hadley circulation into the stratosphere, and the return of reservoir gases and radicals by tropopause folds determines the total content of chlorine, nitrogen and hydrogen radicals in the stratosphere. The transport of NO_x in the upper troposphere - lower stratosphere is important for understanding ozone chemistry. A similar process governs sulphur compounds.

Ozone is produced mainly in the equatorial stratosphere by photochemical processes and then transported poleward by dynamical processes. The principal transport of ozone is through the Brewer-Dobson circulation. Secondary transport (or mixing) is associated with the transient planetary waves. Irreversible chemical eddy effects are likely to be associated with stationary planetary waves. Arctic mini ozone holes are also important in the sense that they are caused by mesoscale

dynamical effects and then chemical and aerosol processes follow (see Kondo et al., 1990).

Ozone loss in the Antarctic polar stratosphere occurs within the cold polar vortex through heterogeneous chemical processes. Associated with PSC formation is the solid phase transport of trace species by gravitational settling of ice and NAT particles. This process has an obvious impact on the chemical budgets of the stratosphere.

As the Antarctic ozone hole breaks up, ozone loss is spread throughout the entire Southern Hemisphere. The phenomenon of ozone hole dilution and its impact on the ozone budget in the Southern hemisphere is still uncertain.

Activity 2.2.1 Quantify stratospheric-tropospheric exchange.

Quantifying the exchange of trace gases and water across the tropopause is crucial for understanding and predicting the long term changes of the stratospheric ozone layer. Most of the tropospheric air enters the stratosphere through the tropical Hadley cell (Holton, 1984; Remsberg et al., 1984). The most intense upwelling, called the stratospheric fountain (Newell and Gould-Stewart, 1981), appears to be near the Indonesian maritime continent. Source gases for stratospheric chlorine (CFC's), nitrogen (N_2O), hydrogen compounds (CH_4, H_2O) and background sulfate (COS) are carried into the stratosphere in this region. Air returns to the troposphere primarily through tropopause folds associated with midlatitude baroclinic instability (Hoskins, 1972). Reservoirs for the catalytic species are presumably removed from the stratosphere through folds.

The overall exchange process between the stratosphere and the troposphere is not well understood (e. g., Holton, 1990). The tasks outlined below are indicated as important research areas.

Task 2.2.1.1

Tropical transport.

Intensive observational studies are needed to quantify and characterize tropical tropopause transport. These studies not only examine cloud cluster dynamics, but make measurements near the tops of anvils in the Indonesian, Amazon and equatorial African regions. These studies should also examine the interannual and intraseasonal changes in the Hadley circulation. This is an appropriate task for SPARC to encourage and to provide international coordination for. Network observation systems are being planned around the Indonesian maritime continent and across the tropical Pacific Ocean.

Task 2.2.1.2

Tropopause folds.

The fold phenomenon has been studied by many investigators, but the frequency and actual chemical and aerosol transport associated with folds remains uncertain (e. g., Danielsen, 1968; Shapiro, 1980). Observational programmes are needed in this area as are correlative modelling programmes. This is an appropriate task for SPARC to encourage and to provide international coordination for.

Task 2.2.1.3

Solid-phase transport.

Materials can be removed from the stratosphere through settling of PSC particles. Intense denitrification and dehydration of the Antarctic stratosphere appears to be due to this phenomena. It is not clear, however, that this material actually is removed from the stratosphere since particles may evaporate at lower and warmer levels. Chemical measurements of the tropopause region could be made to determine if nitric acid is accumulated in that region.

Activity 2.2.2. Quantify stratospheric transport and mixing phenomena.

Quantifying the dynamical transport and mixing of ozone, chemical species, aerosols and water is crucially important in understanding the formation of the Antarctic ozone hole and Arctic mini ozone holes, the dilution of the Antarctic ozone hole as well as predicting the global distribution of materials (Solomon, 1990). The Brewer-Dobson circulation in the lower stratosphere transports ozone poleward where the ozone lifetime is sufficiently long that it can accumulate. This circulation is dependent on the climatology of lower stratospheric planetary waves and internal gravity waves and thus exhibits seasonal and interannual variabilities.

The fully developed polar vortex provides a barrier to poleward transport. Trace species are trapped in the polar vortex when it forms. If PSC's also appear, significant chemical perturbations of polar stratospheric air occur and ozone depletion results (see Figure 4 from Anderson et al., 1991).

The springtime breakup of the polar vortex allows for the spread of the perturbed trace gases to midlatitudes. This process is sometimes called dilution of the polar vortex and leads to a significant increase of the UV flux in the Southern Hemispheric high latitudes.

Task 2.2.2.1

Transport processes associated with the polar vortex and its springtime dilution.

The spread of ozone depleted, denitrified and dehydrated air to midlatitudes due to the breakup of the polar vortex is an especially important problem for quantifying global ozone loss (Sze et al., 1989). This process shows considerable interannual variability associated with similar variations in lower stratospheric

planetary wave activity. Global measurements of column ozone and specific in situ chemical measurements are needed to quantify the chemical evolution of trace species as they emerge from the vortex.

Task 2.2.2.2

Transport processes associated with the Brewer-Dobson circulation.

The Brewer-Dobson circulation system is the main mechanism for transport of trace gases from the Hadley region to midlatitudes (Holton, 1986). This circulation cannot be directly observed, and is only detectable through its effect on long-lived trace species. World-wide cooperative observations are required by ground-based facilities such as ozone lidar and ozonesondes, and satellite systems such as UARS, ADEOS and EOS to diagnose this circulation.

Task 2.2.2.3

Exchange of trace gases between the mesosphere and the stratosphere :

The exchange of trace species between the mesosphere and the stratosphere is not well understood. It is known that nitric oxide (NO) from the mesosphere can penetrate into the polar stratosphere during winter. NO is produced by energetic particle precipitation into the atmosphere. Less well understood is the exchange of hydrogen species between the two regions.

Status: Active but would benefit from better coordination

Timetable:

1993 :	Establish the coordination of the activity.
1993-1996 :	Settle observation networks in the tropical, midlatitude and polar regions and measure the transport processes (ST and MST radars, Doppler lidars, CADRE).
1993-1996 :	Model development of stratospheric transport processes.
1993 :	IAMAP conference session on dynamical transport processes.
1996 :	Synthesis workshop.

Objective 2.3 Study the Radiative Forcing of the Stratosphere

The objective of this activity is to quantify several phenomena associated with radiative processes. The lower stratosphere is a region where the cooling timescale is relatively long. Thus, there will be a large thermal response to any radiative change in that region. This includes changes in the surface temperature, cloud top temperature, and heating through UV absorption by ozone. In addition the changing amount of radiatively active trace gases such as CO_2, N_2O and CFC's may alter the tropopause temperature. These feedbacks have been discussed in Focus 1, but basic radiative transfer measurements are needed to quantify all the feedbacks. These

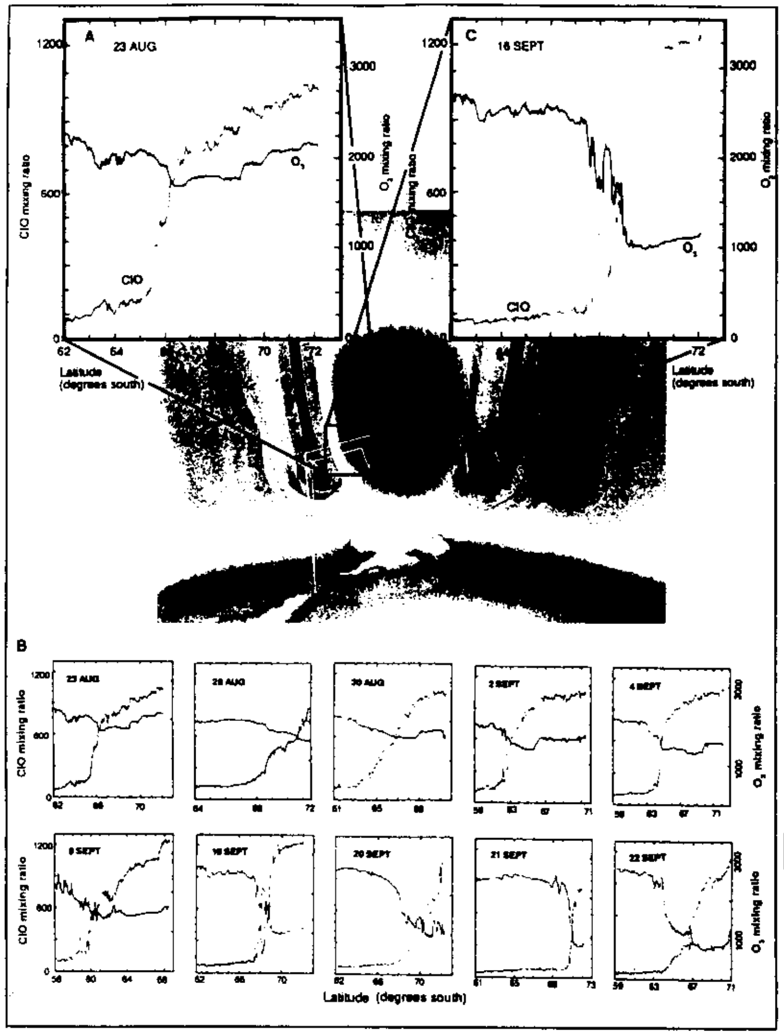


Figure 4. A rendering of the containment provided by the circumpolar jet that isolates the region of highly enhanced ClO (shown in green) over the Antarctic continent taken from the results of the Airborne Antarctic Ozone Experiment that was undertaken in the austral spring of 1987. Evolution of the anticorrelation between ClO and O_3 across the vortex transition is traced from (A) the initial condition observed on 23 August 1987 on the southbound leg of the flight. (B) Summary of the sequence over the ten-flight series; (C) imprint on O_3 resulting from 3 weeks of exposure to elevated levels of ClO. ClO mixing ratios are in parts per trillion by volume; O_3 mixing ratios are in parts per billion by volume. (Figure taken from Anderson et al., 1991)

basic measurements include validating the results of line-by-line calculations at several atmospheric levels.

Directly affecting the biosphere is the surface UV flux attenuated by the ozone layer. An extremely important component of that measurement is the UV flux at the top of the atmosphere. Because Focus 4 put emphasis on the measurement of UV, the measurement of IR fluxes will be emphasized here.

Activity 2.3.1 Measurement of radiative fluxes.

Since the stratospheric circulation is ultimately determined by the net radiative cooling and heating rates in the stratosphere, it is important that computation of these rates be validated against line-by-line calculations and the parameterization schemes used in radiative/dynamical/chemical models.

Task 2.3.1.1

Measurement of IR at high spectral resolution.

Despite the advances that have taken place in IR radiative transfer computations throughout the atmosphere, relatively little effort has gone into the validation of the computation methods for these fluxes. It would be useful to make high spectral resolution measurements at several stratospheric levels under a variety of conditions to validate line-by-line computations of the IR flux.

Task 2.3.1.2

Measurement of broadband IR fluxes at cloud top levels.

Clouds absorb surface IR fluxes, and this tends to cool the lower stratosphere. In effect, the lower stratosphere "sees" the cold cloud top rather than the warm earth surface. The overall role of clouds and their effect on the lower stratospheric circulation are unknown. Extremely cold high clouds are formed in the polar regions, and sub-visible cirrus is common in the tropics. Broadband IR measurements are needed to quantify the effect of clouds on the radiative budget of the lower stratosphere. These measurements could significantly improve the treatment of aerosols and multiple cloud layers with partial opacity in radiative transfer models.

Status: Some activity but needs encouragement and coordination.
Timetable:

1993 : Establish the coordination of the activity.
1993-1996 : IR flux measurement programme.
1993 : IAMAP conference session on radiation in the stratosphere.
1995 : IUGG/ IAMAP Special Session.
1996 : Synthesis workshop.

Objective 2.4 Radiative-Dynamical-Chemical Interactions

Almost all important ozone depleting phenomena involve a combination of radiative/dynamical/chemical (R/D/C) interactions. The basic circulation in the stratosphere is driven by the meridional gradient in ozone solar absorption combined with forcing from the troposphere. Thus, changes in ozone will produce a response in the basic circulation, mixing processes, and thus the distribution of stratospheric trace gases including ozone.

R/D/C feedbacks have an important impact on the Antarctic ozone hole as far as the lifetime of the polar vortex is concerned. Once the ozone is lost in the Antarctic region, the temperatures remain colder than normal throughout the late spring due to the decrease in ozone solar heating. Thus the austral polar vortex is often maintained well into December. Prior to the ozone hole's appearance, the polar vortex typically survived only until late October. From the viewpoint of the biosphere, this kind of interaction is very important since very low ozone values are maintained over the Antarctic region into early summer thus increasing the total UV exposure.

Activity 2.4.1 Improve models of stratospheric processes.

Stratospheric models are currently being used to assess the impact of increasing CFCs and to estimate the depletion of ozone. There are several areas where models can be improved. For zonal mean, 2-D chemical models (height - latitude), heterogeneous processes are not realistically included. Part of the difficulty comes from lack of basic chemical information about the heterogeneous reactions (see Activity 2.1.2). Another problem is the fact that the zonal averaging in 2-D models produces warmer temperatures than those required for extensive PSC formation.

With the advent of faster computer systems, some 3-D chemical computations have recently been performed. However, only limited chemical packages can be used with these models since over a hundred reactions are involved in a full ozone chemistry computation. Doubtless, the 2-D models will continue to be used in the near future as the workhorse for assessment calculations, but the 3-D models will play an increasingly important role in the investigation of polar vortex and ozone hole dilution phenomena. They will also be used to evaluate the performance of 2-D models.

The tasks outlined below are intended to address some of the shortcomings of current models.

Task 2.4.1.1

Parameterize heterogeneous reactions.

Improvement of the parameterization of heterogeneous processes should be a goal of the research community. Research in this area will have an impact on both 2-D and 3-D modelling efforts.

Task 2.4.1.2

Improve radiative transfer models for both short- and long-wave radiations.

The radiative transfer algorithm is an important factor for estimating the UV flux near the surface. With most models, the UV heating rate computation is done separately from the photolysis calculation, and they may not be done consistently. It is not clear if this is a problem, but this kind of model inconsistency should be checked.

The IR radiative transfer algorithm is used to compute the circulation of the stratosphere. Yet most of these computations ignore the effects of tropospheric clouds and stratospheric aerosols. These deficiencies should be corrected.

Task 2.4.1.3

Assess the impact of ozone depletion events to validate models.

Natural and some anthropogenic phenomena provide good tests of our understanding of processes within the stratosphere and can help validate models. Thus studies of R/D/C interactions should be phenomenologically tested. A partial list of investigation opportunities are listed below:

(a) Volcanic eruptions
(b) Ozone hole formation and dilution
(c) Tropical ozone changes during QBO or ENSO events
(d) Solar flares and solar cycle changes

Status: Active but would benefit from results of activities 4/1-2-3

Timetable:

1993 : Establish the coordination of the activity.
1993-1996 : Model development of R/D/C feedback processes in cooperation with WGNE/WCRP.
1993 : IAMAP Session on R/D/C model.
1996 : Synthesis workshop.

FOCUS 3 : GLOBAL CHANGE OF THE STRATOSPHERE

The impact of the stratosphere on the terrestrial climate is expected to be determined by the amounts and distributions of ozone and aerosols in the stratosphere, and by the wind structure in the stratosphere, which controls the vertical propagation of waves from below. While much has been learned in recent years about the factors that determine the behaviour of the stratosphere, there are still major uncertainties in our understanding of its variability and long-term trends. In particular, there is an urgent need to distinguish the trend that results from human activities from the long-term variability due to natural causes, including solar variations, aerosol loading by volcanic eruptions, and variations in the forcing from the troposphere.

Accomplishing this objective requires monitoring of the stratosphere, using both ground-based techniques and satellite remote sensing. Analysis, interpretation, and modelling activities must be pursued as integral parts of the project.

The scientific rationale for studying variability and trends in the stratosphere within the framework of WCRP lies in the need to understand, and ultimately to predict, the variations that will have an effect on the climate in the troposphere. The increasing impact of man's activities has lent urgency to this objective.

There are several possible natural causes for variation in stratospheric composition in addition to those deriving from man's activities. If we are ever to have a solid basis for predicting future stratospheric change, these natural effects must be understood, and every effort must be made to identify unique characteristics, or "fingerprints", that will enable us to take them into account in interpreting current and future stratospheric behaviour. It may never be possible to separate anthropogenic and natural effects cleanly, especially when both have long-term slowly varying features, but the cyclic or event-like nature of some of the natural sources should enable us to learn much about their properties, and to assess their importance in relation to the anthropogenic variations that are anticipated.

Objective 3.1 Understand the variability and long-term trends in the stratosphere

Identification of the natural causes of stratospheric variability, and quantitative evaluation of their magnitude, is one of the most basic aspects of atmospheric research. While it has been a major objective of stratospheric research for many years, only recently have the necessary instrumentation and measurements been available with sufficient precision to make it a realizable goal. The overall task is a long-range one, and encompasses three separate components: monitoring of stratospheric parameters, analysis and diagnosis, and modelling of variability and trends. To a large extent these goals are already being addressed as part of an overall research effort aimed at understanding and ultimately predicting

the climatology of the stratosphere (WMO, 1988). The approach at present is somewhat piecemeal, however, and SPARC can serve as a central focus for coordinating these activities under the overall aegis of WCRP.

Stratospheric variability is driven by solar variations, by aerosol loading, and by tropospheric influences, as well as by anthropogenic chemical forcing. In addition to these identifiable sources, the nonlinear nature of the atmospheric system makes it vulnerable to random stochastic forcing, whose influence must also be considered.

Solar Forcing

Solar ultraviolet radiation exerts a dominating influence on the stratosphere, since it both creates and destroys ozone and other species. Solar UV variability exists on time-scales ranging from the 27-day rotation period of the sun to the 11-year activity cycle, but the magnitude of the associated variation in spectral irradiance is not yet well established, particularly at the longer UV wavelengths that are absorbed by the Hartley band system of ozone. While the 13.5 and 27-day variations of ozone have been clearly seen, the existence and magnitude of the 11-year cycle has not been conclusively established, partly because of the long data base needed, and partly because of the difficulty in separating it from the slowly increasing anthropogenic effects. Recent analysis of spacecraft data, however, suggests that the globally averaged peak-to-peak variation in total ozone is of the order of 1.5 to 2% (figure 5).

Solar UV variability also influences the stratosphere less directly through the changes in temperature that result from ozone changes. Temperature variations directly affect the rates of several of the key photochemical reactions that determine the ozone concentration, and they have an indirect effect through modification of stratospheric winds, and thus of ozone transport.

A possible form of long-term solar influence on the stratosphere has been suggested by the discovery that the stratosphere in subtropical latitudes shows remarkably high correlations between geopotential heights and the 11-year solar cycle (Labitzke and van Loon, 1991). These correlations are highest from April to October, but when the winter data are divided according to the phase of the equatorial quasi-biennial zonal wind oscillation (QBO), the east years are especially highly correlated with the solar cycle. To date, no credible mechanism has been proposed to account for these correlations, and the interpretation of the winter correlations is still a matter of controversy. Further effort aimed toward resolving whether the correlation originates in a real solar-climate connection, or whether it is a result of some unknown cyclic response of the ocean-atmosphere system that happens to have a period near 11 years is clearly needed, since its potential value in predicting variations in stratospheric ozone is great. Also, similar solar / QBO influences are found to exist in the troposphere.

Solar variability exerts a more sporadic influence on the stratosphere through the chemical changes brought about by large-scale ionization events associated with individual major solar flares and with enhanced solar activity. Energetic particles originating from the sun, or accelerated by processes occurring in the earth's magnetosphere as a result of solar activity, can frequently penetrate to the level of the stratosphere, where they efficiently dissociate nitrogen molecules, leading to the formation of substantial concentrations of odd-nitrogen compounds, and hence to the catalytic destruction of ozone. These effects appear to be largely confined to the high-latitude upper stratosphere, above the levels of maximum ozone concentration, so that their impact on the total ozone column concentration is likely to be relatively minor. Since the amount of odd nitrogen produced by these events is fairly easily calculated, however, they provide unique tests of our understanding of stratospheric chemistry and dynamics through comparisons of the calculated and observed ozone depletions.

Study of the solar forcing may contribute to the understanding of past global change, and cooperation with PAGES/IGBP will be pursued.

Aerosol Forcing

The discovery of the Antarctic springtime ozone hole, and its subsequent interpretation as a consequence of heterogeneous chemical reactions occurring in the presence of polar stratospheric cloud particles, has led to a new realization of the major importance of aerosols in the chemistry of the stratosphere. The ozone hole is an example of an anthropogenic effect and a natural effect acting in cooperation to produce a catastrophic result that is much larger than that produced by either effect working alone. The fact that it was totally unexpected despite the major effort that had been devoted to investigating the chemistry of the stratosphere provides a timely warning that the atmosphere can still produce unwelcome surprises.

Since the ice particles that are essential for the development of the ozone hole can only grow in the extreme cold of the Antarctic winter and spring stratosphere, and more sporadically in the Arctic stratosphere, the depleted ozone, with enhanced UV flux at the surface will have its major effects at polar latitudes. When the polar vortex breaks up in late spring, however, ozone-depleted air is transported to lower latitudes, and could have a significant impact on global tropospheric climate as well as surface UV fluxes. (See Figure 6.)

Sources of stratospheric aerosols other than polar stratospheric clouds exist, but their influence on the chemistry of the stratosphere remains uncertain. In particular, volcanic eruptions can provide large injections of dust and sulfur compounds that form long-lasting clouds of sulfuric acid droplets in the stratosphere. The influence of these volcanic clouds on the chemistry and dynamics of the stratosphere is under intense study at this time, and may well be quite significant.

In addition to the natural sources of aerosols in the stratosphere, there is likely to be increased loading as a result of anthropogenic activities, linked in particular to increased sulfur emissions. A major monitoring effort is clearly needed in order to investigate the influence of both natural and anthropogenic aerosols on

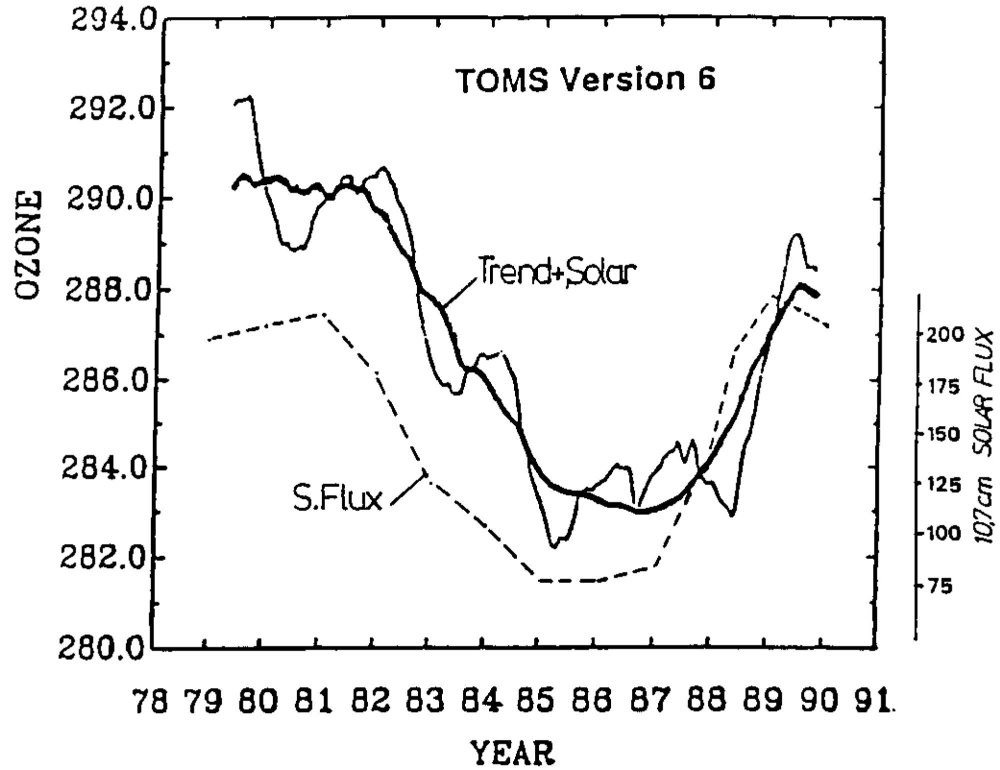


Fig. 5. Time Series of Toms Ozone Column Density 40S - 40N using 365 - day running mean. Solar Flux at 10.7 cm in dashed line (private communication Keating 1992)

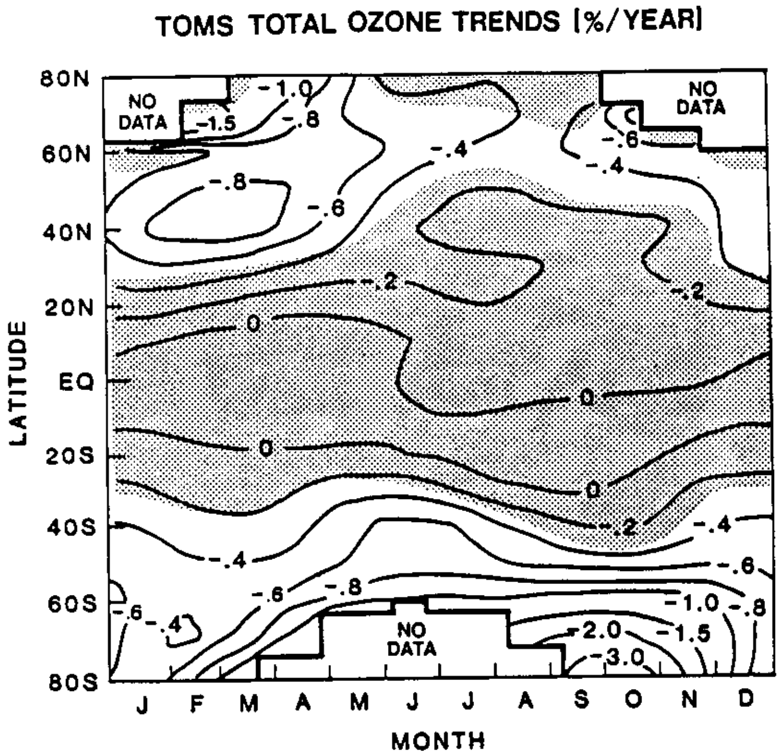


Figure 6. Trend in total ozone, as measured by TOMS, as a function of latitude and season as determined by Stolarski et al. (1991). Seasonal variation is fit with the annual and semi-annual harmonics only. The shaded area indicates where the trends are not statistically different from zero at the 2σ level. Significance was determined by the root sum of squares sum of the absolute and statistical error estimates. Poleward of the heavy solid line is polar night where no TOMS measurements are possible.

the global stratosphere, and to take advantage of future individual volcanic eruptions to study the decay and transport of aerosols.

Close cooperation will be undertaken with the WMO/GAW and the IGAP/IACP (the International Global Aerosol Programmes which is an output of the International Aerosol Climatology Project) in these pursuits.

Tropospheric Forcing

The dynamics and chemistry of the stratosphere are strongly influenced by processes taking place in the troposphere. For example, the injection of trace species into the stratosphere occurs largely in conjunction with deep tropospheric convection, particularly in the humid tropical atmosphere, and the removal of trace species is greatly enhanced in the tropopause folding events that accompany cyclogenesis at middle latitudes. These processes are discussed elsewhere in the report, and our concern here is with the long-term monitoring aspects, since changes in the tropospheric concentrations of any of these trace gases, or in their vertical transport, resulting from natural or anthropogenic causes, will lead to changes in stratospheric ozone content, and hence in radiative fluxes at the surface. Monitoring of the tropospheric concentrations themselves is a component of the WMO/GAW and the IGBP/ IGAC programme.

Goals

In summary, a few specific goals of the programme are as follows:

(a) determine the impact of human activities (e.g., halocarbon and high-flying aircraft exhaust emissions) on the stratosphere;
(b) establish the magnitude and properties of the 11-year solar cycle variation of stratospheric composition and dynamics;
(c) characterize the interannual variability of the stratosphere;
(d) assess the long-term impact of energetic particle fluxes on ozone and other trace species in the stratosphere;
(e) determine the underlying causes of the apparent link between stratospheric temperatures, the solar cycle, and the quasi-biennial oscillation; and
(f) determine the importance of aerosols in stratospheric chemistry and dynamics;
(g) determine the importance of stratospheric (and upper tropospheric) ozone for the radiative budget of the troposphere;
(h) determine the importance of stratospheric aerosols for the radiative budget of the troposphere;
(i) determine how changes in middle atmosphere structure that change the ability of planetary waves to propagate through it affect the tropospheric climate.

Three major activities will be pursued to meet these goals.

Activity 3.1.1 Monitoring of the stratosphere.

The basic measurement activity is one of long-term monitoring, using well-established techniques and ensuring the highest degree of precision possible. The objective is to provide the observational basis for studying variability and long term trends in stratospheric properties.

Task 3.1.1.1

Utilization of continuing data sets.

Although many current measurement programmes have a considerable history, several extending back to the 1950s, in many cases these have developed within their own research or operational environments rather than as part of a long-term monitoring programme. As the objectives of the stratospheric monitoring programme can require very high precision for trend detection (e.g., about 1.5 °K in temperature per decade in the middle stratosphere and about 2 percent per decade for total ozone) a major examination of the historical data bases needs to be undertaken to ensure that a data set of uniformly high quality exists. As we will note below, this will allow analysis of the variations of these parameters through several solar cycles, and will thus provide robust results.

Just as in the case of the ground-based and in-situ measurements, a large body of satellite data exists on stratospheric ozone and trace-gas composition. Every effort should be made to ensure that the data obtained from existing satellites and ground-based programmes, and from those that are planned for the future, are treated in a coordinated way, and that they are made available to the scientific community in a readily usable format. In order to be useful for trend determination, they should be processed using similar input spectral data and retrieval methods.

While current plans for stratospheric remote-sensing measurements have been made by several countries, there is no coordinated approach to data analysis. The WCRP/SPARC project could play a vitally important coordinating role that could be implemented on a relatively short time scale.

Task 3.1.1.2

Endorse and encourage developing monitoring systems.

We take recognizance of the recent development of several observing networks and of several ongoing and planned satellite missions that are of importance to the SPARC programme. Among the ground-based networks are the Network for Detection of Stratospheric Change (NDSC) and the U.S. Atmospheric Radiation Measurements (ARM) programme. Satellite programmes include continued operational measurement of stratospheric temperatures, and monitoring of the total ozone content with the TOMS instrument as an international effort. It is extremely important that this be fully implemented, and that more attention be paid

to deriving vertical ozone profiles of stratospheric structure on a global basis by means of satellite measurements.

The NDSC is an evolving network presently comprised of about five stations dedicated to long-term measurements of parameters and chemical species of importance to the detection of stratospheric change and the validation of satellite observations. ARM, on the other hand is dedicated to the measurement of the surface radiation at a wide range of wavelengths.

Plans for establishing the networks are well in hand, but consideration should be given to the possibility of establishing additional stations, perhaps measuring only a few of the parameters. While it is clear that the siting of such networks is highly dependent on individual instrument requirements and availability of resources, from the perspective of SPARC we recognize obvious synergisms that can be achieved if the sites can be coordinated. We recommend that SPARC coordinate such complementary programmes and their data management procedures.

Several ongoing operational and research programmes will provide measurements of great use to SPARC. These include the operational temperature sounders and SBUV II measurements of column ozone and its vertical profile by the U.S. National Oceanic and Atmospheric Administration (NOAA). The temperature data already extend over 13 years, and after the upcoming reprocessing will form an extremely important data base for looking at long term changes. Similarly, the SBUV II's now overlap with the original research SBUV, providing an ozone record of 14 years duration.

Present and future satellite programmes will provide some of the needed data on trace species. These include the instruments on the U.S. Upper Atmosphere Research Satellite (UARS), and the Japanese ADEOS spacecraft. Later in the decade, international collaboration among Canada, Europe, Japan and the United States will lead to the implementation of the Earth Observing System (EOS). The committment to 15 years of continuous data makes this especially relevant to SPARC's long term monitoring activities. While present plans are now being formulated, it is clear that SPARC needs these data that should be accurate, stable, and precise, will have greater coverage as well as higher vertical and horizontal resolution than their predecessors, and will provide information on more species of importance.

Activity 3.1.2 Analysis and interpretation of stratospheric data.

Analysis and interpretation form the second activity, and should take place on a continuing basis as the data become available from the networks and from satellite remote sensing. Its objective is to integrate the observations and to explore the physical causes of stratospheric variability.

Task 3.1.2.1

Determine variability and long-term trends in ozone.

A substantial number of estimations of long-term trends of ozone and temperature have been carried out within the framework of the Middle Atmosphere Program (MAP) and other programmes, and the latest results have been reviewed, for example, in the report of the International Ozone Trends Panel. Further efforts should be made to work jointly with WMO in order to refine the estimates.

Despite the investigations that have already been carried out, some characteristics of the long-term trends of ozone and temperature have remained unclear. As a first priority, investigation should be directed toward distinguishing between natural and anthropogenic effects in the stratosphere. Additional studies are required of the properties of the 11-year solar cycle in ozone, the relationship between ozone variations and such features as aerosol content and stratospheric circulation, and the regional and seasonal features of long-term variability. Achieving a comprehensive estimate of trends and cyclic variations will require analysis of all the available observational data.

This is a currently active task. Integrated analysis of data from the established Dobson and Umkehr networks as well as those that are in the development stage, together with the satellite data, should lead to resolution of many of the current uncertainties. New approaches to the statistical evaluation of the data should be explored.

Task 3.1.2.2

Determine variability and long-term trends in stratospheric trace gas composition.

The situation with regard to stratospheric trace constituents other than ozone is less satisfactory. The need for an improved long-term data base formed a major part of the rationale behind the NDSC development. Of particular importance are the source gases that give rise to the ozone-destroying radicals, such as H_2O, N_2O, CH_4, and CFC's (and their substitutes), while the ratios of radicals to reservoir species, such as ClO/HCl, provide useful information on the chemistry that is taking place. As NDSC becomes fully operational, data on these constituents will become available, and analysis of the long-term variability and trends will gradually become possible.

This task is active and ongoing. The analysis should be carried out for key locations in each of the principal geographical regions of the earth, i.e., polar and midlatitude locations of each hemisphere and in the equatorial regions, and extension to the global scale should be carried out to the extent possible.

Task 3.1.2.3

Determine variability and long-term trends in stratospheric temperatures and winds.

Some analyses of trends in stratospheric temperatures on a global basis have been carried out using the worldwide radiosonde network, and more recently using the microwave sounding technique from satellites. The global radiosonde network has been in operation roughly since the early 1950's, so that four decades of data exist from many locations, though the global coverage has been variable. Coverage of the stratosphere is much less satisfactory than that of the troposphere, but since about 1965 temperatures and geopotential heights have been routinely reported up to the 10 millibar level (about 30 km altitude) by many stations. The quality and reliability of the data are questionable at the upper levels, but are probably reasonably good at the lower stratospheric levels, at and below about 30 millibars (23 km altitude, near the level of maximum ozone concentration). Above 30 km and since 1979, Lidars have monitored the upper stratosphere and mesosphere (Hauchecorne et al., 1991) and the long term survey will be insured through the NDSC network.

This task is in an active status, but an increased effort is highly recommended. An important motive is provided by the possibility of isolating the signal of increasing greenhouse-gas concentrations together with ozone changes.

Activity 3.1.3 Modelling of stratospheric variability and long-term trends.

Modelling is an activity that should proceed hand in hand with the data gathering and analysis activities. Modelling is necessary in order to determine the parameters that should be monitored, and to set the results in the framework of our knowledge of the stratosphere. The objective is to simulate stratospheric variability and long term trends and, ultimately, to develop a predictive capability.

Task 3.1.3.1

Develop the capability to model variability and long-term trends in the stratosphere.

Recent years have seen the development of a hierarchy of stratospheric models of varying degrees of complexity, from simple one-dimensional photochemical and radiative models to full three-dimensional versions coupled to general circulation models. Modelling is an essential component of atmospheric research, bridging the gap between theory and observation, and allowing us to determine the critical parameters that need to be monitored.

Stratospheric processes, in general, tend to have larger spatial scale sizes than those occurring in the troposphere, where mesoscale and synoptic-scale events are often dominant. As a result, the parameterization of sub-grid-scale processes is less critical than in the troposphere. The parameterization of gravity-wave properties is important, however, since they make a significant contribution to the dynamics of the stratosphere.

The approach to modelling of long-term trends and variability does not differ, in essence, from that used in current stratospheric models. Models of the solar-cycle variability in ozone have been developed using the best current estimates of the solar UV flux variation. They have shown that it probably had a comparable magnitude to that of the anthropogenic variation due to CFC's, but the calculations have not included the uncertain, but probably large, effect of ozone-hole dilution. As better data become available from the NDSC and from other sources, the intrinsic uncertainties of the current model predictions will presumably be reduced in size.

Besides the response to ultraviolet variations, the long-term influence of changes in the troposphere brought about by possible variations in solar total irradiance needs to be established, as do the variations in stratospheric composition and dynamics caused by energetic-particle fluxes.

Stratospheric modelling is in an active status, and model improvements are being carried out in an ongoing fashion as new knowledge and increased computer power become available. Model development needs to be continued, however, with increased emphasis on the problems of long-term variability.

Status: Active

Timetable:

Many international meetings have addressed the issue of global change of the stratosphere, and this activity is expected to continue. SPARC will ensure that regular surveys of the state of our knowledge are held in connection with these general meetings through the medium of special sessions and workshops. SPARC Special Sessions are already planned in the near future:

1993: EGS Assembly - Wiesbaden (FRG)
1993: IAMAP Assembly - Yokohama (Japan)
1994: STEP Symposium - Sendai (Japan)

FOCUS 4 : MONITORING AND MODELLING OF UV IRRADIATION CHANGES IN THE BIOSPHERE AND THE TROPOSPHERE

The penetration of solar UV radiation through the stratosphere is greatly influenced by ozone and, to a lesser extent, by light scattering by air molecules and aerosols. In the troposphere, other minor species play a non-trivial role and the scattering by particulates, smokes and hazes can be important. In addition, the scattering and extinction by clouds is the main atmospheric parameter which induces the natural variations of solar UV radiation in the troposphere and also is the most difficult process to be accurately calculated in radiative transfer models.

This focus is aimed at determining the global three-dimensional distribution of solar spectral UV irradiance in the troposphere and its temporal variations. This will require the establishment of a monitoring network and the validation of radiative transfer (RT) model of UV penetration in the atmosphere and ocean. It is also urgent to accurately define the present day baseline of UV irradiance levels at the Earth's surface.

As the long term monitoring of UV irradiance will be made from a limited number of stations, the global distribution of UV irradiance will rely upon complementary accurate RT modelling. Such distribution as a function of latitude and season was modeled by Madronich (1992) and is given in terms of DNA daily effective UV dose in figure 7. The trends computed from the change in total ozone column observed by TOMS over the 11 year period 1979-1989 are given in figure 8. (Madronich, 1992) and indicate changes substancially larger than previously believed (e.g. WMO, 1988).

Such modelling activity should in the future be based upon input data on atmospheric composition, clouds and aerosol characteristics provided by co-located measurements, other tropospheric and stratospheric networks and satellite observations. Consequently, it is essential to validate the radiative transfer models with respect to various natural atmospheric optical parameters such as clouds, at different altitudes, by comparison with extensive measurements obtained during dedicated campaigns. This activity will also be of fundamental importance for tropospheric photochemistry which requires an accurate knowledge of the vertical distribution of the photochemically active solar irradiance.

Therefore, a close interaction between modelling and monitoring activities is essential to fulfil the goals of this focus. These aspects are detailed in the next two activities.

Objective 4.1 Modelling and Experimental Validation of UV Penetration

The basic equations of radiative transfer (RT) theory are well established, but experimental verification of UV radiation models for real atmospheric conditions is largely lacking. Such verification must take into account the temporal and spatial variability of optical properties of the atmosphere, including ozone abundance and to a lesser extent its vertical distribution, the presence of ice or liquid water clouds (which may be multilayered, broken, and irregular), particulate and gaseous constituents, and local surface reflections. Many of these factors, especially those related to clouds and particulates, are difficult to model and are currently poorly characterized. Yet, their impact on the UV radiation environment is substantial.

Activity 4.1.1

To understand the UV radiation environment and the processes which control it (e. g., ozone abundance, full and partial cloud cover, aerosols, urban, regional, and global scale pollutants, and atmosphere-cryosphere-ocean coupling).

Task 4.1.1.1

Development and refinement of radiative transfer models for realistic conditions:

There are several important research topics which will be advanced under this programme. These include the treatment of broken clouds through the development of fully three-dimensional UV radiation models; transmission and scattering at low sun angles via inclusion of spherical geometry; and modelling of the penetration of UV radiation throughout the atmosphere/cryosphere/ocean system requiring a proper treatment of the coupling of the radiation field between these subsystems.

Status: active but need coordination

RT modelling activities are currently going on in different countries and in various existing projects. An inventory of ongoing activities needs to be done and a coordinating panel has to be appointed. A workshop on RT model results should be organized in 1993 for evaluation and definition of further actions.

Related projects and organizations: IRC (IAMAP), IACP/IGAP, GCOS,(WCRP), IGAC.

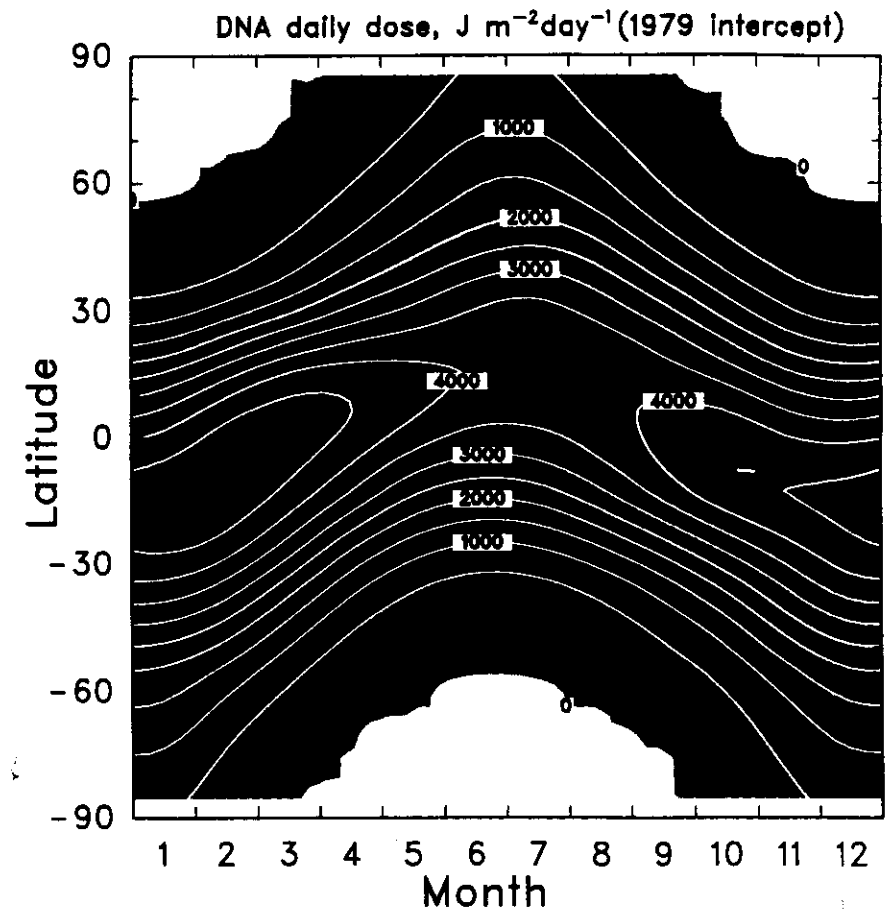


Fig. 7. Distribution of daily effective UV dose for generalized DNA damage as a function of latitude and season (from Madronich,1992)

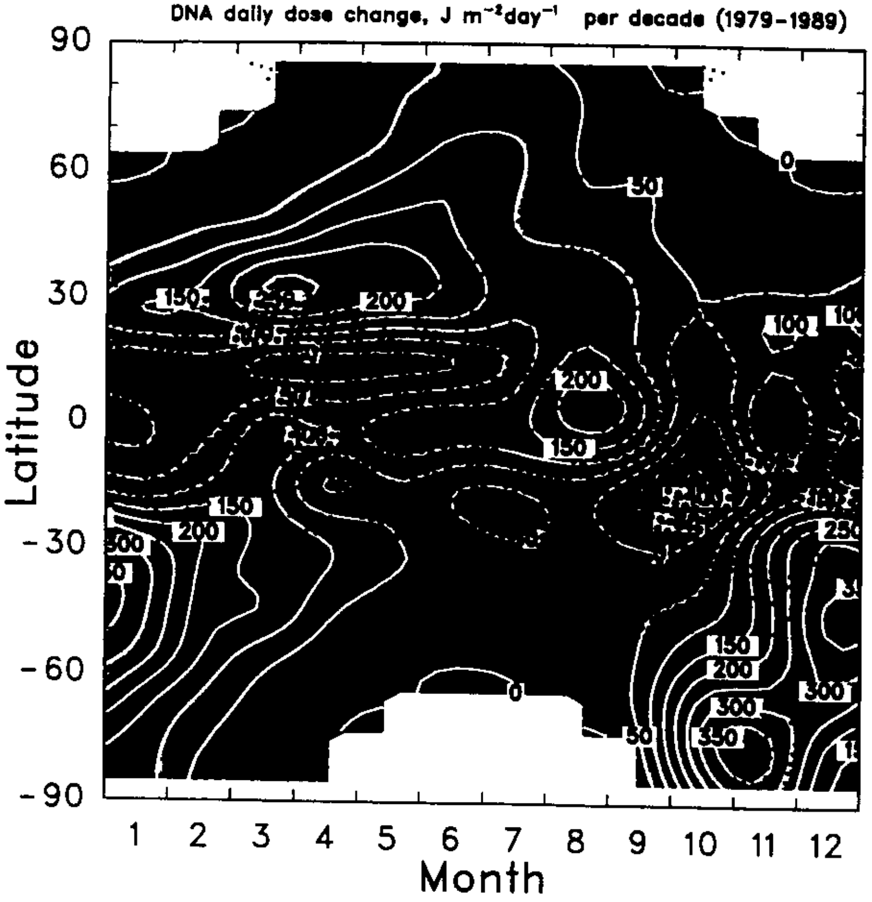


Fig. 8. Trends in daily effective UV dose in absolute units of J m2 per decade, computed using TOMS version 6 ozone column data over the 11-year period 1979-1989. Dark shading indicates regions where trends differ from zero by less than 1 σ, light shading by less than 2 σ. White areas denote no radiation (Winter poles) (from Madronich, 1992)

Activity 4.1.2 Validate UV radiative transfer models by intensive field measurement campaigns.

Task 4.1.2.1

Intensive field campaign for radiation transfer model testing.

UV radiation models should be tested against comprehensive atmospheric measurements under a variety of environmental conditions. Radiation measurements will be made at different wavelengths, altitude, and possibly angular direction. Supporting measurements, to be used as inputs to the RT models, will include total ozone column, ozone vertical distribution, cloud liquid water content, vertical distribution of clouds and aerosols and their particle size distributions, cloud morphology, and surface reflection. Such model-measurement comparisons will focus on the more difficult problems of clouds, especially multi-layer and broken clouds, aerosols, and gaseous pollutants. Measurements will be carried out over a long enough period to encompass a reasonable range of natural variability in cloud cover, haze, ozone, etc. Measurements over the ocean should be complemented by underwater measurements.

Status: planning

Timetable:

1993-1994: Workshop to define the campaign (measurements, time, location,...) ,the logistic support for ground-based measurements, aircraft observations, balloon (tethered?) facilities. Appointment of a scientific coordinating committee.

1994: Preparation of the campaign.

1995: Carrying out the campaign.

1996: Evaluation of results and definition of further actions.

Related projects and organization: SCOPE, IRC (IAMAP), IACP/IGAP, WCRP, IGAC, EUROTRAC, national agencies.

Objective 4.2 Global UV Climatology and Prediction

A knowledge of the actual UV radiation environment in the biosphere is urgently needed for the establishment of a baseline (present day) for the detection of changes in the next decades. Although a number of UV measuring stations are currently in operation in some countries, there is a need for a coordinated activity to document the global (worldwide) UV climatology. Because the number of observing sites will be limited for practical reasons, such a programmeme should rely upon model interpolation between the stations. The results of Objective 4.1 will be of primary importance to improve the quality and the reliability of the global UV climatology. In that context, the deployment of the network should cover a wide variety of realistic environments and should encompass a number of co-located supporting measurements needed to understand the causes in UV changes in the biosphere and the troposphere. A strategy for the methodologies and procedures at the various locations of the network should be defined with regard to accuracy and long term precision. Continuity in the data base should be insured by ongoing instrument intercomparisons and calibration. This monitoring activity should evolve with improvements in measurements and modelling.

Activity 4.2.1 Establishment of a global observation network to determine the present day baseline of UV climatology, and to detect long term trends.

The objectives of a long-term measurements programme focussed on ultraviolet solar radiation at the earth's surface include the development of a long-term (decadal) climatology of UV radiation at a set of sites selected to span a wide range of different environmental conditions. This should provide a data set of sufficient accuracy and precision to define the current day UV irradiance on a global scale, and to allow the recognition and quantification of variations and future trends.

Task 4.2.1.1

Standardization of protocol for calibration.

Any change in UV radiation beyond the natural background variability needs to be identified at an early stage, thus any source of uncertainty in the data must be minimized. To achieve this, consistent and accurate calibration over a long period is essential. There is a need for a widely recognized standard to which all systems are traceable. Each instrument must be characterized, calibrated and standardized with the rest of the network. For that purpose local calibrations should be performed according to a protocol defining methodologies and procedures.

Task 4.2.1.2

Intercomparison of instruments.

There is an increasing number of instruments available that may be adequate for this network. However, few of them have a proven record of field operation and a major task is to evaluate the relative performance of the various instruments, and to assess their applicability as long-term monitoring tools. Instruments currently in use should remain active to provide continuity in the data base and new instrumentation should be phased into the network through detailed field intercomparison.

Task 4.2.1.3

Supporting measurements.

To interpret variability shown by measured irradiances in terms of cause and effect, it is necessary to obtain a set of supporting measurements which define the optical properties of the atmosphere. Ideally this would include total column ozone, cloud type, amount and optical thickness, vertical distribution of absorbing gases and particulates in the lowest few kilometers, plus further parameters as defined by Objective 1.1. In that respect, a close coordination with the WMO's GAW programme (BAPMON Network, GO_3OS), GCOS (WCRP), IACP/IGAP, the NDSC, EUROTRAC and other national and international projects is essential.

Task 4.2.1.4

Definition of measurement strategy and network deployment.

A set of monitoring sites should be selected to encompass a range of realistic atmospheric/radiation environments. Major distinctions should be made between clean and polluted areas, and between clear and partially cloudy regions. There are also obvious arguments for distributing the sites over a wide range of latitudes. Because of the limitation of monitoring instruments, two categories of sites should be considered. with respect to the availability of co-located measurements related to the optical properties of the local atmosphere. The primary sites should have sophisticated instruments with enough supporting measurements to be used for modelling diagnosis. Additional, secondary sites are needed to augment the geographic coverage of the network. They could include only the UV radiation measurements.

<u>Status:</u> planning with some active components.

<u>Timetable:</u>

1993 : Appointment of a coordinating scientific committee. Meeting for the initialization and planning of the various tasks, the implementation of the coordination with the existing networks, the definition of supporting measurements and network strategy, ...

1993 : Selection of sites for the extension of the existing networks. Implementation of calibration standardization.

1994 and following: network activities and coordination.

Related projects and Organizations: WMO, WCRP, IGAC, IAGA, IAMAP, EUROTRAC, European Communities, national agencies,...

Activity 4.2.2 Data base management connecting UV observations with supporting data.

Data bases of surface UV radiation measurements are currently non- existent. Data base management has to be defined and implemented in connection with existing data bases of supporting measurements including satellite data on relevant trace species, cloud cover, and local measurements needed for data analysis purposes. Release of the data should follow a consensus protocol.

Task 4.2.2.1

Define the kind of data to be collected, the timing and the processing level of data archiving, data format, and calibration information.

<u>Status:</u> planning.

<u>Timetable:</u>

1993: Meeting for data base implementation. Coordination with existing data bases (NDSC, GO_3OS, GCOS, UARS,...).

Activity 4.2.3

Develop practical radiative transfer models for predicting UV climatology on global and regional scales, from ground-based and satellite observations of atmospheric composition; and to validate such models against UV irradiance data from the observational network and from space observations during satellite overpasses.

Task 4.2.3.1

Optimization of UV radiative transfer models.

Efficient, yet accurate, RT models are necessary for applications which cover large time-space domains (as will likely be the case in global climatological studies), to avoid the prohibitive computational cost of more rigorous RT models. These models should be optimized for UV applications. More work is required to minimize the number of required wavelength and altitude intervals, and to develop effective ways of computing diurnal averages.

Task 4.2.3.2

Data assimilation and climatological model development.

Data assimilation methods must be developed to integrate large amounts of input data required in the global climatological radiation models. For example,

satellite imagery of cloud cover and ocean color will be available with increasing frequency. Existing information on cloud climatology (including data such as fractional area coverage and approximate optical depth) and oceanic opacity will need to be assimilated and used in the RT models, to produce detailed climatological maps of UV radiation at the surface and at various levels in the atmosphere and ocean. Similar information on visibility ranges should be assimilated and used in models to provide estimates of the effect of aerosols on the UV radiation environment.

<u>Status</u>: planning

<u>Timetable</u>:

1993 : Meeting for the definition and the development of data assimilation methods (with activity 4.2.2).

1994 : Development of optimized RT models for UV applications.

1995 : First assessment of RT model results by comparison with monitoring observations and related campaigns (activity1.1.2).

Activity 4.2.4.

Predict future UV radiation changes under natural and anthropogenic perturbation scenarios, and examine the implications of such changes for the biosphere, the troposphere and the overall climate system.

Perturbation scenarios may include depletion of stratospheric ozone, changes in tropospheric ozone and aerosols, and changes in cloud cover associated with climate changes. As longer term data become available from the UV monitoring network, testing and validation of model predictions will become possible.

Task 4.2.4.1

Develop coupled models linking atmospheric changes to UV-B irradiance in the troposphere and the biosphere.

<u>Status</u>: planning

<u>Timetable</u>:

1994: Comparison of existing models for prediction purposes. Definition of scenarios in coordination with projects on stratospheric and tropospheric global change.
1995: Improvement of models
1995-2000 : Model validation with existing data.

General Timetable for SPARC Meetings

1992 : NATO Advanced Study Institute on the Impact of the Stratosphere on Climate and the Biosphere (Carqueiranne, France).
1993 : EGS Wiesbaden(Germany).Special Session on SPARC
1993 : IAMAP Yokohama(Japan). Special Session on SPARC
1994 : SCOSTEP Symposium Sendai, (Japan).
1995 : IUGG, Boulder (USA).

In addition to these meetings, NATO Advanced Research Workshop (ARW) and NATO Advanced Study Institute (ASI) are being proposed at the rhythm of one meeting a year. Furthermore the semi-annual AGU meetings provide an opportunity for special sessions devoted to topics of interest to the SPARC community.

APPENDIX 1

INTERACTIONS AMONG SPARC, WCRP, IGBP, SCOPE, THE WMO GLOBAL ATMOSPHERE WATCH AND STEP

There is great synergism between the SPARC activities and those being pursued within WCRP and in other ICSU programmes, namely IGBP and STEP. Some of the interactions between SPARC and WCRP, WMO/GAW, IGBP, SCOPE and STEP are briefly described here.

SPARC and WCRP

The scientific issues raised in the SPARC Focus "The Influence of the Stratosphere on Tropospheric Climate" concern the role of the stratosphere in the physical climate system, which clearly is of interest to the World Climate Research Programme (WCRP). The WMO/ICSU Joint Scientific Committee for the WCRP recognizes the need to guide and support SPARC to study stratospheric influences on tropospheric climate, as this question has not been explored in detail in the WCRP.

In practice, there will be interaction between SPARC and a number of WCRP activities. In particular, SPARC will be closely coordinated with dynamical studies undertaken by WGNE. There will also be valuable interactions between SPARC and other projects in the WCRP, including studies of radiative transfer in the atmosphere and the effects of clouds, undertaken by the WCRP Working Group on Radiative Fluxes (formed jointly by the IAMAP Radiation Commission and JSC). This same group is overseeing the implementation of the Baseline Surface Radiation Network (BSRN) which will collect state-of-the-art measurements of surface radiation fluxes in a variety of contrasting climatic zones (polar regions, mid-latitude, plain and forested areas, the tropical belt). The WCRP/NASA International Satellite Cloud Climatology Project (ISCCP) will provide needed data on the distribution of clouds necessary in estimating the penetration of UV flux to the surface of the Earth. The WCRP Working Group on Atmospheric Transport and Chemistry (previously the Working Group on Greenhouse Gases) will now be incorporated into SPARC and continue the study of atmospheric tracer transport modelling problems, including global-scale transport, parameterization of sub-grid scale transport, exchange between stratosphere and troposphere and chemical processes. This activity is very important to SPARC, and consequently a Working Group on the modelling activity has been formed at the first SPARC SSG meeting.

The WMO Global Atmosphere Watch

The WMO Global Atmosphere Watch (GAW) is aiming to monitor systematically on a global and regional basis, the chemical composition and related physical characteristics of the background atmosphere. The data gathered will contribute to understanding the impact of global change on the chemical composition of the atmosphere, long-range atmospheric transport and deposition, and the natural cycling of chemical elements in the global atmosphere/ocean/ biosphere system and potential anthropogenic impacts.

GAW includes three main components:

(i) A set of approximately 20 global observatory type stations measuring climate-change and ozone-change related variables,

(ii) 200-300 regional stations with ad hoc measurement programmes, to meet regional national needs,

(iii) A mechanism for coordination with several other atmospheric composition measurement networks.

The variables considered in the basic GAW measurement programme are concentrations of greenhouse gases and ozone (surface, total column, vertical profile), radiation-related parameters (atmospheric turbidity, solar radiation, ultraviolet flux, visibility, aerosol loading), chemical composition of precipitation, reactive gas species (sulphur dioxide, nitrogen oxides, carbon monoxide), radionuclides, cloud condensation and ice nuclei.

The Global Atmosphere Watch should therefore provide systematically an essential range of background data for use by SPARC.

GCOS

The Global Climate Observing System (GCOS) has recently been founded by WMO and IOC to coordinate the scientific initiatives aiming to collect and archive the different parameters that characterise the global climate. Within the stratospheric community several initiatives already exist to monitor many of the relevant parameters, as described in 3-1-1-2.

The NDSC is viewed as a network of 5 to 6 high quality ground-based stations for long term measurement of physical parameters (T) and chemical species (O3, NO2, ClO..etc..) known to have already varied by large amount. The SPARC SSG will discuss the desire of expanding the number of parameters and/or the number of sites to survey the changes in the circulation, and in the chemical and radiative state of the stratosphere which may impact on stratosphere-troposphere exchange processes; the monitoring of aerosols, their composition and their optical thickness may require more than the NDSC selected stations. The monitoring of the UV B at the surface which will be organized through SCOPE and SPARC is another exemple of the type of activity which relates clearly to GCOS.

The archiving of such parameters observed from satellite, as incoming solar flux, total ozone, aerosols, is now under the responsability of NOAA and NASA. The subject of quality control and archiving of these data may be discussed as part of GCOS activity.

SPARC and STEP

The SPARC programme seeks to bring together stratospheric research with stratospheric influences on the climate and a close connection with the impact on the biosphere. The physical and chemical aspects of stratospheric research have until now been coordinated on the international scene by the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP). Major international projects were carried out during the seventies and the eighties under SCOSTEP's Middle Atmosphere Programme (MAP) and its follow-ons. At the present time, SCOSTEP's major activity, the Solar-Terrestrial Energy Programme (STEP) includes a variety of projects that will be a synergistic complement to several of the activities proposed for SPARC.

As a scientific committee of ICSU, SCOSTEP carries out its interunion mandate under the guidance of its adhering bodies, IAGA, IAMAP, URSI, IAU, IUPAP, COSPAR and SCAR. This also applies to STEP which received explicit ICSU endorsement in 1987. The main scientific goal of STEP is to advance the quantitative understanding of the coupling mechanisms responsible for the transfer of energy and mass from one region of the solar-terrestrial system to another. The main practical goal is to improve the predictability of the effects of the variable components of solar energy and disturbance on the terrestrial environment, or technological systems in space and on Earth, and possibly, on the biosphere (see Solar-Terrestrial Energy Programme 1990-1995: Initial Research Projects). STEP involves coordinated ground-based, aircraft, balloon, rocket and satellite measurements. It is organized into six Working Groups of which two include projects of specific relevance to SPARC. They are listed as follows:

STEP Working Group 4 : Middle Atmosphere Response to Forcing from Above and Below

STEP Working Group 5 : Solar Variability Effects in the Human Environment

A close coordination of these STEP projects with SPARC, ensured by the fact that many scientists participating in the research are involved in both programmes, will be of considerable benefit for WCRP and SCOSTEP. Joint planning and research coordination meetings will be one efficient venue.

Of particular use to SPARC could be the activities and services of the STEP Working Group of Informatics. Important satellite and ground-based "Situation Centers" are being established with the principal functions of disseminating real-time information on who, or which observational systems, is measuring what, where, and when. Electronic communications, handling of standard geophysical data, and identifying periods for enhanced data acquisition are important functions of the Working Group which also could be of service to SPARC.

IGBP

The SC-IGBP had seriously considered the possibility of establishing the STIB project (Stratosphere-Troposphere Interactions and the Biosphere) which involved research on the themes included into SPARC, as described here, as well as on the impact of stratospheric changes on the biosphere, with a priority on the biospheric aspect. Even though such a project did not become an IGBP Core Project, the connection with IGBP remains a major preoccupation of the community involved in SPARC.

Within the IGBP Core Projects, GCTE (Global change and Terrestrial Ecosystems) has already included in its plans the study of UV-B effects on the terrestrial biosphere and JGOFS (Joint Ocean Flux Study) is considering the issue. A potential IGBP Core Project LOICZ (Land -Ocean Interaction and Coastal Zone) is clearly very concerned with the UV-B effects on shallow waters and, when established, should be very concerned with the output of the fourth theme of SPARC.

SCOPE

A Scientific Advisory Committee on the " Effects of Increased UV Radiation on Biological Systems" was created by SCOPE in 1990, under the chairmanship of Ed de Fabo, with the task to formulate the recommendations for the development of an innovative research programme in this field, where data are either lacking or inadequate and therefore where large uncertainties still exist. Two workshops were already organized to synthesize existing knowledge on the effects of increased UV on biological systems and the report issued from these workshops clearly concludes to the need of such a programme. Its scientific plans are well defined, but its implementation is still to be elaborated. (SCOPE-UNEP Report 1992)

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ACRONYMS

ADEOS	Advanced Earth Observing Satellite
ARM	Atmospheric Radiation Measurement
ASE	Air Sea Experiment
BAPMON	Background Air Pollution Monitoring Network
BSRN	Baseline Surface Radiation Network
CHEOPS	Chemistry Experiment on Polar Stratosphere
CAS	WMO Commission for Atmospheric Science
COSPAR	Committee on Space Research
DMS	Dimethyl Sulfide
EASOE	European Arctic Stratospheric Ozone Experiment
ENSO	El Nino Southern Oscillation
EOS	Earth Observing System
ERBS	Earth Radiation Budget Satellite
EUROTRAC	European Experiment on Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere over Europe
GAW	Global Atmospheric Watch
GCM	General Circulation Model
GCOS	Global Climate Observing System
GO$_3$OS	Global Ozone Observing System
GFSC	Goddard Space Flight Center
HSRP	High Speed Research Programme
IACP	International Aerosol Climatology Project
IAGA	International Association of Geomagnetism and Aeronomy
ICEAR	International Center for Equatorial Atmosphere Research
IAMAP	International Association of Meteorology and Atmospheric Physics
IAU	International Astronomical Union
ICMUA	International Commission on Meteorology of the Upper Atmosphere
ICRCCM	Intercomparison of the Radiation Codes used in Climate Models
IGAC	International Global Atmospheric Chemistry
IGAP	International Global Aerosol Programme
IGBP	International Geosphere Biosphere Programme
IR	Infrared
IRS	International Radiation Commission
ISCCP	International Satellite Cloud Climatology Programme
IUGG	International Union of Geodesy and Geophysics
IUPAP	International Union of Pure and Applied Physics
JSC	Joint Scientific Committee
MAP	Middle Atmosphere Programme
NASA	National Aeronautical and Space Administration
NAT	Nitric Acid Trihydrate
NDSC	Network for Detection of Stratospheric Change

NMHC	Non-methane Hydrocarbons
NOAA	National Oceanographic and Atmospheric Administration
NSF	National Science Foundation
PAR	Photosynthetically Active Radiation
PSC	Polar Stratospheric Cloud
QBO	Quasi-Biennial Oscillation
R/C/D	Radiative/Chemical/Dynamical
RT	Radiative Transfer
SAGE	Stratospheric Aerosol and Gas Experiment
SAM	Stratospheric Aerosol Measurement
SCAR	Scientific Committee on Antarctic Research
SCOPE	Scientific Committee on Problems of Environment
SCOSTEP	Scientific Committee for Solar Terrestrial Physics
SPADE	Stratospheric Photochemistry, Aerosols & Dynamics Expedition
SPARC	Stratosphere-Troposphere Interaction and Biosphere
STEP	Solar-Terrestrial Energy Programme
STRATAN	Stratospheric Analysis by Data Assimilation
TOMS	Total Ozone Mapping Spectrometer
UARS	Upper Atmosphere Research Satellite
URSI	Union Radio Scientifique Internationale
UV	Ultraviolet
UV-A	280-320 nm UV Wavelength Interval
UV-B	320-400 nm UV Wavelength Interval
WCRP	World Climate Research Programme
WGNE	World Group on Numerical Experiment (Joint Working Group of the WMO Commission for Atmospheric Sciences and WMO/ICSU, Joint Scientific Committee for the WCRP)
WGATC	Working Group on Atmospheric Transport and Chemistry (WCRP)
WGRF	Working Group on Radiation Fluxes (WCRP)

ACTIVITIES IN PREPARATION FOR THIS SPARC PLAN

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