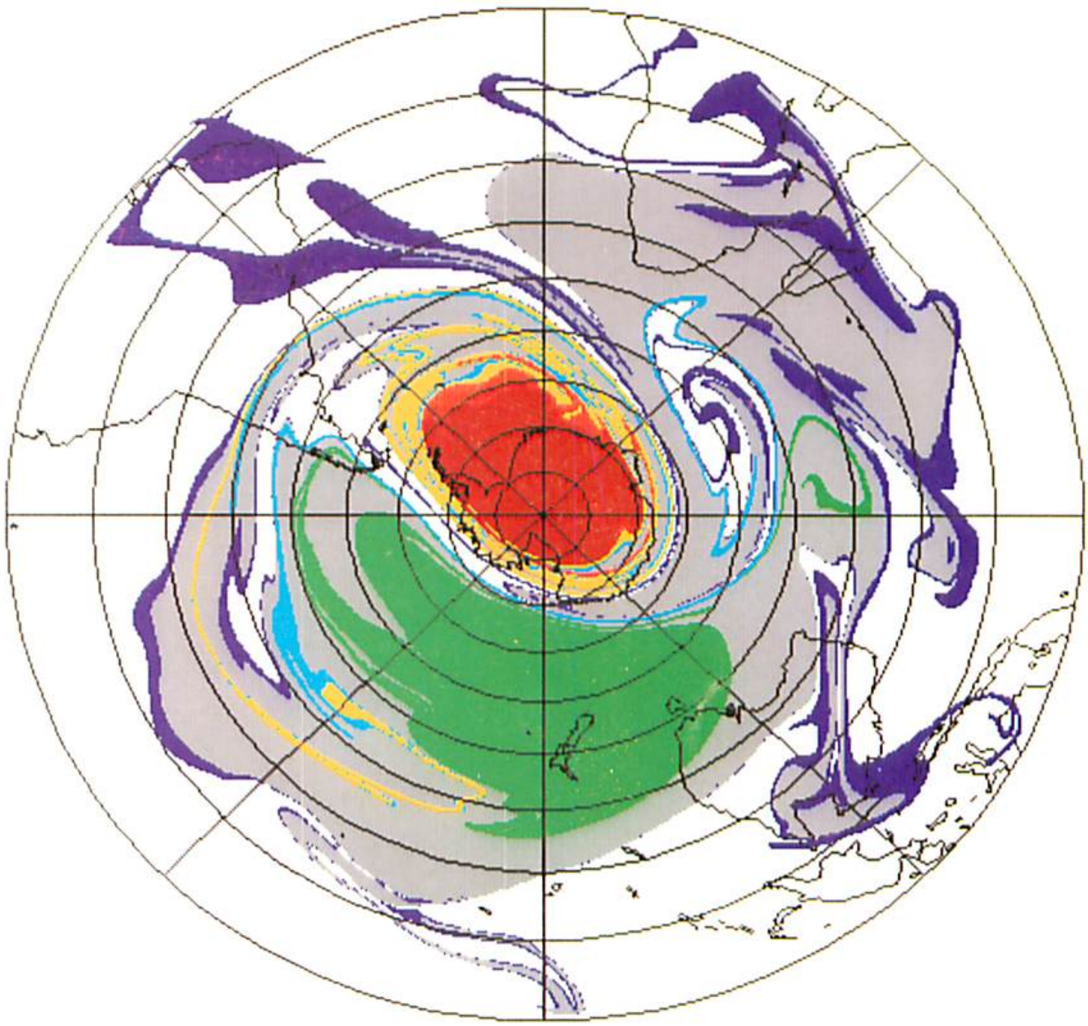
Coordinated U.K. Studies of the Atmosphere using UARS Data

Proposal in response to the

Upper Atmosphere Research Satellite Guest Investigator Program

NASA RESEARCH ANNOUNCEMENT (NRA 94-MTPE-03)



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Cover

Polar projection of the Southern Hemisphere illustrating the evolution of material contours on the 850 K potential temperature surface in the vicinity of the polar vortex. A selection of material contours have been advected by the wind field using a technique known as 'contour dynamics' (Norton 1994). The winds were taken from a UK Meteorological Office model run in which the temperatures are continually relaxed towards observations - this product has been developed and supplied as part of the UK committment to the UARS project (Swinbank and O'Neill 1994). The contours were initialised along selected isolines of potential vorticity (PV) on October 3rd 1992 and the plot shows the contours 7 days later (11th October).

The inner core of the vortex (red) remains essentially intact, indicating little horizontal mixing with lower latitude air. Note, however, the region of contour filaments around the edge of the vortex (mainly yellow), which are in the region of the strong westerly winds. The formation of filaments such as these enables efficient horizontal mixing between air parcels whose origins were at substantially different latitudes. For example, subtropical air (white) close to the Greenwich meridian has penetrated as far poleward as 75°S (at 225°E) in a tongue of air which has then been caught up in the jet and wrapped around the vortex. Notice also that part of it is then transported back into mid-latitudes in a tongue of air that has been stripped off the edge of the vortex (230-300°E; 30-40°S) and is being wrapped around a region of high pressure denoted by the green contour. This feature is believed to be a signature of planetary wave breaking, leading to irreversible mixing and the formation of a 'surf zone' in the mid-latitudes (McIntyre and Palmer 1983).

A more detailed description of this contour plot and its use in the interpretation of HALOE measurements is provided by Bithell, Gray, Harries, Russell and Tuck (1994).

Contents

1 Abstract

The proposal describes research of the dynamical, radiative and chemical balance of the middle atmosphere to be carried out in the UK, utilising data from the Upper Atmosphere Research Satellite (UARS). The studies are aimed at improving the understanding of atmospheric processes that control the distribution of ozone in the Earth's atmosphere. The work will be carried out jointly by eleven groups in the UK who are actively involved in research of the middle atmosphere. Extensive use will be made of the hierarchy of computer models that have been developed as part of the Natural Environment Research Council's 'UK Universities Global Atmospheric Modelling Programme' (UGAMP). The proposed dynamical studies include examination of the evolution of the polar vortex, transport in and around the vortex, the role of gravity wave forcing, interactions of vortex and mid-latitude air and possible causes of mid-latitude ozone depletion. Proposed chemical studies include mechanisms for the activation and deactivation of chlorine, the nitrogen budget, the water vapour and total hydrogen budgets and studies of the roles of polar stratospheric clouds and aerosols. Finally, studies of inter-annual variability and solar terrestrial interactions are proposed and also the development of an ozone climatology.

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3 Introduction

The U.K. has a long standing record of atmospheric research that covers virtually the entire range of atmospheric studies, including instrument design and development, data analysis, computer modelling, atmospheric radiation, dynamics and chemistry. In this proposal, we outline studies to be carried out in the U.K. that will utilise the recent data acquired by the various instruments flown on the Upper Atmosphere Research Satellite (UARS). Several UK researchers already have a recognised status as Principal or Collaborative Investigator (Co-I) on one of the UARS instruments and therefore do not appear specifically as a Co-I on this proposal (specifically, Prof. A. O'Neill of Reading University, Prof. F. Taylor, Drs. C. Rodgers and D. Andrews of Oxford University and Dr. R. Harwood of Edinburgh University). The studies proposed involve collaboration with those groups already affiliated with UARS and have the full support of them. The studies described in this proposal are those proposed to be conducted *over and above* those which are already planned by the affiliated UK groups.

The studies will involve the interpretation of the data in order to further our understanding of the radiative, dynamical and chemical processes that affect the abundance and distribution of ozone in the atmosphere. A hierarchy of computer models has already been developed as part of the U.K. Universities Global Atmospheric Modelling Programme (UGAMP) and substantial use of these will be employed in the studies. The British Atmospheric Data Centre (formerly the Geophysical Data Centre - GDF), of which the PI is Project Scientist, will be extensively involved in facilitating the UK distribution of the data and of software to manipulate it.

A brief description of the UGAMP project and the tools that are available to this project is provided in the next section. A description of the planned work, the methods to be used and the importance of the anticipated results of each of the proposed studies is provided in section 5. A description of the management structure and funding of the project is provided in sections 6 and 7. A brief CV of each of the investigators is also provided in Appendix A.

4 The U.K. Universities Global Atmospheric Modelling Programme

The UK Universities Global Atmospheric Research Programme was initiated in 1987 as a coordinated modelling activity involving five university departments and the Rutherford Appleton Laboratory. In 1990 it was adopted by the UK Natural Environment Research Council (NERC) as a Community Research Programme. The programme has a Director, Professor Alan O'Neill (who is already actively involved in the UARS mission) and the active participation of nine research groups: the Centre for Global Atmospheric Modelling (CGAM), Reading University, the Meteorology Department, Reading University, the Chemistry Department, Cambridge University, the Rutherford Appleton Laboratory, the Department of Atmospheric, Oceanic and Planetary Physics, Oxford University, the Department of Applied Mathematics and Theoretical Physics, Cambridge University, the Centre for Remote Sensing, Imperial College London, the Meteorology Department, Edinburgh University and the Climate Research Unit, University of East Anglia.

The overall aim of UGAMP is to improve our basic understanding of the large-scale atmospheric phenomena and processes that affect our environment. The two main goals are to investigate the dynamical and photochemical processes that govern the amount and distribution of ozone and to advance our understanding of the natural internal variability of the atmosphere on time-scales from days to decades. Progress in these areas will increase our ability to simulate natural and man-made changes in the atmosphere, and will allow us to make more informed judgements of the reliability of long-term numerical predictions.

The approach of UGAMP is to use a hierarchy of numerical models as research tools to interpret observations of the atmosphere and hence to further basic understanding of atmospheric processes. The models range from simple hypothesis-testing models to sophisticated general circulation models (GCMs). The GCMs represent many of the atmospheric processes involved in the ozone balance and climate change, and incorporate advanced photochemical schemes to predict the distribution of ozone and other trace gases.

The main GCM available to UGAMP has been adapted from the forecast model developed at the European Centre for Medium Range Weather Forecasting (ECMWF). This may be run on the original (19) vertical levels extending from the ground to approximately 30 km or on an extended (47) vertical level grid that reaches to approximately 90 km (0.0001 mb) in order to model middle atmosphere processes (Gray et al., 1993, Jackson 1993,1994, Jackson and Gray 1994). The models use a spectral formulation in the horizontal and may be run at a variety of different resolutions. In both versions of the model, photochemical reactions involved in determining the distribution of ozone have been included.

In addition to the full GCMs UGAMP has available a number of other simpler models and tools such as

- a contour advection scheme (e.g. Norton 1994),
- an analysis scheme for chemistry along trajectories (Chipperfield et al., 1994a)

- two dimensional models (height latitude) using both pressure coordinates (Harwood and Pyle, 1975) and isentropic coordinates (Kinnersley and Harwood, 1993) with extensive chemistry included,
- two dimensional models (latitude - longitude) of extremely high resolution for fluid dynamical experiments and high resolution chemistry (e.g. Juckes and McIntyre, 1987)
- simpler 3-d models with fewer parametrizations than the GCM (e.g. Hoskins and Simmons, 1975).

Two important new versions of the model have recently been developed to complement the hierarchy of models already available. The first is an 'off-line' chemistry and transport model for case studies of ozone depletion (Chipperfield et al., 1994b). This enables much more detailed chemical studies to be undertaken using observed winds from, for example, the UKMO assimilated model runs. It incorporates a detailed representation of photochemistry, including a representation of heterogeneous reactions on polar stratospheric clouds. It is allowing detailed simulations to be made of periods when ozone destruction is thought to have taken place in the stratosphere; its use is considerably enhancing our understanding of the interaction between transport, chemistry and dynamics. This model has been used extensively in the interpretation of data from the European Stratosphere Ozone Experiment (EASOE). A novel method has also been developed for initialising the chemical distributions to ensure conformity between the initial chemical and meteorological distributions (Lary et al., 1994).

The second recent model addition has been the development of a stratosphere mesosphere model in which the model is forced from below at approximately 100 mb using geopotential height fields that have been derived from observations. This model, therefore, also enables case studies of particular events in the atmosphere to be carried out and may also be used to study the effect of the troposphere on the middle atmosphere.

For further details of the UGAMP Programme and a description of some of the areas of science that it has addressed, a brochure has been produced by the Natural Environment Research Project entitled 'Modelling the Atmosphere' (see enclosures).

5 Description of Proposed Work

The proposed work has been organised into a series of scientific topics. There will inevitably be substantial areas of overlap between the projects due to strong interactions between different regions of the atmosphere and the different processes that are present.

5.1 The Stratospheric Winter Vortex.

Work to be carried out by : READ, OX, RAL, CAMB, ED.

The recent discoveries of severe Antarctic ozone depletion (Farman et al. 1985) and the potential for depletion in the northern hemisphere (e.g., Waters et al. 1993) have highlighted the need to understand the morphology, evolution and transport processes of the middle atmosphere as well as the chemistry. The existence of a wealth of global three-dimensional and contemporaneous data sets, such as UARS observations (Geophys. Res. Lett. UARS special issue, volume 20) and UK Meteorological Office analyses (Swinbank and O'Neill 1993), provides an unprecedented opportunity to carry out diagnostic studies of the middle atmosphere.

The stratospheric winter vortex is particularly interesting and important in terms of its dynamics, the associated transport of air and chemical species, and its potential for anomalous chemistry. We propose to use UARS observations and UK Meteorological Office analyses, firstly, to document and, as far as possible, understand the seasonal evolution of the three-dimensional structure of the stratospheric winter vortex, and secondly, to investigate the transport of material in and around the vortex.

For much of the work described below, three dimensional gridded fields will be used. Accordingly, we are investigating ways and means of producing optimal synoptic analyses from the along-track profiles produced by various instruments. In addition to the Kalman filtering and asynoptic gridding techniques being used at NCAR, JPL and elsewhere, we have developed an objective analysis scheme. Evaluation of such gridding techniques is being carried out under the aegis of the UARS Science Team by intercomparing the gridded products and data fields which have been assimilated into numerical models. These studies will be continued and will benefit the various specific studies proposed below.

5.1.1 Dynamical Evolution of the Vortex

Data required: UK Meteorological Office analyses; temperatures and long-lived tracers from MLS, ISAMS, CLAES and HALOE.

Our understanding of the seasonal evolution of the stratospheric winter vortex is still far from complete. Some of the processes involved are radiative forcing, upward propagation of disturbances from the troposphere, wave breaking and irreversible quasi-horizontal mixing leading to a 'surf zone' outside the main vortex (McIntyre and Palmer 1983), 'peeling off' of vortex edge air leading to sharpening of the vortex edge (Juckes and McIntyre 1987), interaction of the vortex with mid-latitude anticyclones (e.g., Mechoso et al. 1988), and minor and major warming events. Diagnostics of the stratospheric vortex will be calculated using UARS temperature measurements and UK Meteorological Office analyses. In particular, the three-dimensional nature of the flow will be emphasized in order to study phenomena which are obscured in the traditional zonal mean / wave picture, such as the interaction of the main vortex with eastward travelling and / or quasi-stationary mid-latitude anticyclones.

One recent area of interest has been the use of coordinate independent diagnostics such as area integrals (Butchart and Remsberg 1986, Lahoz, work in progress) and circulation integrals (O'Neill and Pope 1993a, 1993b) to study the evolution of the vortex, though the studies so far appear to disagree over the relative importance of the role of radiation. These new techniques will be developed further and applied to observations and model simulations in order to gain experience in interpreting them and relating them to more familiar concepts such as wave-mean flow interaction and isentropic mixing of potential vorticity. One particular aim will be to disentangle the effects of finite resolution (in the model and observations) and numerical dissipation (in the model) from the radiative and dynamical processes controlling the evolution of the vortex.

Selected periods will be simulated using the recently developed middle atmosphere model, with forcing from analysed 100hPa geopotential fields and the full middle atmosphere model. The results will be compared with the observations and analyses to validate the model and to test its sensitivity to resolution and to the details of the parameterized physics. In particular, differences between the model and the observations will give insight into the role of processes in the middle atmosphere such as gravity wave drag, planetary wave propagation and stratospheric warmings.

5.1.2 Transport in and around the Vortex

Data required: MLS, ISAMS, HALOE, CLAES, UK Meteorological Office Analyses.

Recent analysis of global measurements of ozone distributions using satellites have revealed a widespread decline in column ozone, with regional reductions approaching approximately 1% per annum. Downward trends in ozone are present in both hemispheres, throughout the year, and are not limited to polar regions. The existence of a middle-latitude ozone loss has prompted much debate over whether and how perturbations to the chemical composition at high latitudes within the polar vortex may lead to reduced ozone amounts at lower latitudes. There are two extreme hypotheses about the transport of air through polar regions and its export to middle latitudes. One hypotheses is that containment of air within the polar vortex is complete during winter, and that all transport occurs as the polar vortex breaks down during spring. During this process, air from within the polar vortex, in which ozone may have been depleted, mixes with low-latitude air and reduces the mid-latitude ozone column purely by dilution. It is also possible that further chemical ozone loss could occur in this air after it reaches middle latitudes. In either case there is a clear limitation on ozone loss: no more ozone can be destroyed than the amount contained within the polar vortex when it first forms in early winter.

The opposite extreme is that expressed as the 'flowing processor hypothesis' (Tuck

1989, Proffit et al., 1989), namely that the air in polar regions is not well contained, and that a substantial volume of air passes through those regions to middle latitudes throughout the winter months. If vortex temperatures are low enough, then polar stratospheric clouds (PSCs) will form within the vortex and heterogeneous chemistry will cause reactive chlorine concentrations to rise. Denitrification, which allows active chlorine compounds to persist for longer, may also occur (as may dehydration). Large amounts of air passing through the vortex to middle latitudes could thus be chemically primed for ozone loss. Although, in such a situation, temperatures in middle latitudes may never have reached the threshold for PSC formation, the effects of heterogeneous PSC chemistry (and dehydration) would still be apparent. Mid-latitude ozone loss could then proceed, initiated by the polar air. In such a situation the potential for middle latitude ozone loss would be significantly enhanced over simple dilution, because the volume of lower-stratospheric air exposed to PSC chemistry could be substantially greater than the instantaneous volume of the polar vortex. These different scenarios have very different implications for understanding and predicting mid-latitude ozone loss. Furthermore, such processes could be major factors in determining the chemical structure of the middle latitude lower stratosphere.

In order to address this very important uncertainty concerning the interaction of polar and mid-latitude air, the morphology and evolution of the winter stratosphere will be studied using chemical and dynamical tracers from the MLS, CLAES, ISAMS and HALOE instruments and isentropic distributions of potential vorticity calculated from UK Meteorological Office analyses. Chemical studies which complement these dynamical studies will also be carried out and are described in section 5.2. Again, the vortex centred viewpoint and the three-dimensional nature of the flow will be emphasized. Some progress has already been made studying the northern winter of 1991/1992 (Lahoz et al. 1993, Ruth et al., 1994, Rosier et al., 1994) and the southern winters of 1991 and 1992 (Harwood et al. 1993, Bithell et al., 1994). Correlations between the different tracers will be used to assess the data quality. Mean slopes of tracer isopleths will be used to estimate the relative strengths of vertical (cross-isentrope) motion and quasi-horizontal mixing (Mahlman et al. 1986). Also, extending the ideas of Plumb and Ko (1992), we will examine the feasibility of using spatial and temporal variations in the correlations between different species to identify regions of significant horizontal mixing and regions of little horizontal mixing. One key question is the extent to which some part of the vortex remains isolated from lower latitude air at different altitudes and different stages of the winter. The techniques of parcel trajectories and contour advection (Norton 1994) have already been employed to study periods in the Antarctic spring-time during which the vortex is gradually breaking up (Bithell et al., 1994) and are being used to quantify the transport of air that has been chemically activated by PSCs, out of the northern hemisphere vortex (Norton and Chipperfield, work in progress). These studies will be extended to examine the different stages of winter.

Descent of air in and around the vortex can be diagnosed or calculated in a variety of ways and so provides a way of comparing different data sets, as well as providing a robust test of the processes driving the meridional circulation in numerical models. There is evidence that air of mesospheric origin can reach the middle stratosphere on a time scale of 3-4 months (Russell et al. 1993, Lahoz et al. 1993). However, currently there appears to be disagreement between different estimates of descent rates within the vortex in the lower and middle stratosphere, for example, using observed descent rates of tracer isopleths (Hartmann et al. 1989, Lowenstein et al. 1989, Harwood et al. 1993, Lahoz et al. 1993), radiative transfer calculations (Rosenfield et al. 1987, Shine 1989), observations of dehydrated air outside the vortex (Tuck et al. 1993) and air parcel trajectory calculations using model generated winds (Fisher et al. 1993) and analyses. Estimated descent rates range from a fraction of a K/day to about 2K/day in terms of potential temperature in the lower to middle stratosphere. It is crucial to our understanding of the wintertime stratosphere to be able to reconcile the observed tracer distributions, calculated radiative heating rates and dynamical ideas of what controls the circulation. Furthermore, the descent rate is one factor determining how much air can experience the extreme cold within the vortex during the course of one winter (the other factor being the amount of lateral transport) and hence be subject to anomalous chemical processing (e.g., Randel 1993). This has an important bearing on the question of mid-latitude ozone depletion. Diabatic descent rates will be calculated using temperature and data from MLS as input to the radiative transfer model of Haigh (1984) and possibly other radiative transfer models. These will be compared with descent rates estimated from tracer distributions.

Simple chemical tracer schemes in the middle atmosphere model will be used as an indicator of the ability of the model to simulate the dynamics of the atmosphere. Water vapour, methane and nitrous oxide are all tracers of atmospheric motion in the middle atmosphere and a basic parametrization of their chemical source and sink terms has been included in the UGAMP middle atmosphere model in a simplified version of the chemical scheme that enables runs of many months duration. Various model simulations will be run to study the evolution of the winters of both hemispheres. The model will be initialised with measured distributions of water vapour from MLS and CH_4 and N_2O from ISAMS and CLAES. Comparisons will be carried between the model evolution and the observations. Estimates will be made of the descent rates from different methods, using e.g., diabatic heating rates, the residual circulation or air parcel trajectories. The aim will be to examine the variations of the descent rate on synoptic space and time scales in relation to the detailed dynamical evolution of the vortex and the sensitivity to the gravity wave parametrization. These runs will be compared with shorter model runs in which the full chemistry scheme is included (see section 5.2.4).

5.1.3 The Role of Gravity Wave Drag

Work to be carried out by : CAMB, UW, RAL.

Data required : ISAMS, MLS, CLAES, HALOE, HRDI, WINDII.

One present concern is the role of gravity wave drag in the general circulation of the atmosphere. The extent and rate of the descent at polar latitudes in winter is an important factor in understanding the depletion of ozone in that region which is not fully understood. The importance of gravity wave forcing of the atmosphere on the mean circulation and hence on the downwelling at polar regions is generally accepted, although other factors such as radiative effects are also important. However, there are no climatological data on gravity wave drag against which to test models. One approach to the gravity wave drag problem has been to calculate residuals of the known force terms in the momentum equations. In the past, such calculations have been carried out for the zonal mean, but data at sufficiently high resolution has not been available to examine zonal asymmetries. The ISAMS instrument on board UARS provides temperature data throughout the mesosphere and it is hoped that sophisticated numerical techniques involving new methods of calculating winds from temperature data will allow us to evaluate the influence of gravity wave drag upon the descent rate into the polar vortex (as discussed earlier).

Improved gravity wave parametrization schemes for use in computer models are currently under development within UGAMP. For example the Fritts-Lu parametrization has recently been introduced into the middle atmosphere model and diagnosis of the results is underway. The model runs with various gravity wave forcing will be tested against the observations of the atmosphere from UARS. Additionally, theories of stratospheric clear-air turbulence both from the viewpoint of wave drag and from that of vertical mixing will be studied. UARS data will provide invaluable clues, and tests of developing concepts, during the course of this work. The tests will involve both studies of local behaviour in the lower stratosphere and global-scale tracer transport, both of which are affected by the gravity wave phenomenon in question.

In a separate study, orographically generated gravity wave stress will be investigated using experimental information from a limited number of aircraft and balloon measurements and estimates from short periods of radar observations. The primary objective of the proposed research in this area is to observe the characteristics of gravity waves associated with different sources and to estimate the corresponding momentum fluxes, using the UK MST radar facility at Aberystwyth. It has previously been demonstrated that such radar systems can provide information on the momentum flux at tropospheric, stratospheric and mesospheric heights (Fritts et al., 1990, Thomas et al., 1992, Fritts and Vincent, 1987). Recent observations at Aberystwyth have compared the fluxes for periods greater and less than 6 hours in both the troposphere and lower stratosphere (Prichard and Thomas, 1993) and have shown substantially larger fluxes associated with orographic waves than with other short-period waves. A related study, which will make use of both the radar facility and lidar systems at Aberystwyth to make measurements over the whole height range up to about 80 km will be concerned with the saturation of atmospheric gravity waves (Marshel et al., 1991). A third area of investigation employing the radar system is concerned with the incidence of turbulence in the troposphere, lower stratosphere and mesosphere (Thomas and Astin 1994), its association with gravity waves and its role in vertical mixing.

The restrictions of these measurements to a single site limits their direct comparison with relevant UARS data. However, the continuous measurements of the vertical structure of waves, the associated momentum flux and turbulence intensity could identify day-to-day and seasonal changes for corresponding studies of UARS data. Furthermore, the parameters derived from the radar measurements could be compared with those inferred from comparison of theoretical models and UARS observations.

5.2 Chemical Studies of the Middle Atmosphere

Work to be carried out by : CAMB, BAS, ED, IMP, RAL.

Data required : HALOE, ISAMS, MLS, CLAES, UKMO Meteorological Analyses.

5.2.1 Chlorine Activation and Deactivation

Chlorine is activated when reservoirs react on the cold surfaces of polar stratospheric clouds and sulphate aerosol. Chlorine remains activated as long as temperatures remain low; the subsequent deactivation depends on, inter alia, the availability of nitrogen oxides. The rate of deactivation can be expected to be different in the two hemispheres. Understanding the deactivation stage is vital if we are correctly to predict future ozone loss. For example, if vortex air mixes into middle latitudes the ozone loss will depend critically on the rate of chlorine deactivation.

We will carry out a quantitative study of the rate of chlorine activation and deactivation, using a combination of MLS, CLAES and, possibly, HALOE data. The study will build on a current investigation (Chipperfield et al., 1994a) of the $ClONO_2$ data from the MIPAS FTIR on the TRANSALL aircraft. In this study our off-line chemical transport model, with transport forced by the daily analysis from the ECMWF, has been used to study the Arctic vortices of 1991/92 and 1992/93 (Chipperfield et al., 1993, Chipperfield et al., 1994b, Chipperfield, 1994). These studies have shown remarkable agreement with the structure seen in the TRANSALL measurements of column $ClONO_2$. Thus the model reproduces a $ClONO_2$ collar around the vortex in mid-winter and a vortex filled with high $ClONO_2$ in the early spring. A particularly interesting result is that the model reproduces the large variations seen in the $ClONO_2$ amount around a PV contour. These variations are due to photolysis of HNO_3 leading to a recovery of active chlorine back to $ClONO_2$. It would be our intention to look for similar structure in both ClO and $ClONO_2$ in and around the polar vortices of both hemispheres and to compare quantitatively the expected and observed rates of change.

5.2.2 The Nitrogen Budget

We propose to study in detail the nitrogen oxide budget of the stratosphere and mesosphere, using data from ISAMS, HALOE and CLAES. We will concentrate on two specific problems. Firstly, the partitioning in the winter polar lower stratosphere. Ground based data taken during the EASOE campaign (see, for example, Special EASOE Issue of Geophys. Res. Letts, 1994, to appear) showed an interesting temperature dependence in NO_2 which could have important implications for our understanding of heterogeneous chemistry on sulphate aerosol. We will look for evidence of similar behaviour in the UARS data.

Secondly, we will continue our present studies of nitrogen oxides in the winter polar upper stratosphere. ISAMS data shows some extremely interesting structures during the mid-winter of 1991/92 when, during certain periods, high HNO_3 is found both inside the polar vortex (i.e. high HNO_3 correlates well with high PV) and outside the polar vortex (i.e. high HNO_3 also correlates well with low PV in high latitudes). Our 3-D model studies reproduce the latter feature. Air high in NOy is advected polewards; the ratio of HNO_3/NOx increases polewards. However, the basic model does not reproduce the high HNO_3/high PV correlation. It may be related to heterogeneous chemistry in the upper stratosphere or perhaps transport of NOy from a mesospheric source play an important role. We propose a number of studies to investigate this feature.

Thirdly, the consistency between measured and theoretical values of the $NO:NO_2$ ratio will be examined as a function of physical variables such as pressure, temperature, solar zenith angle and overhead ozone column. While this ratio has been investigated previously in the middle and lower stratosphere at mid-latitudes with balloon-borne measurements, the UARS IR emission sensors have provided simultaneous global data on NO and NO_2, together with critical quantities which govern their steady-state balance. The statistics afforded by UARS data should permit a quantitative test of this aspect of photochemical theory to be performed over a wider range of atmospheric conditions than has hitherto been possible.

5.2.3 Studies of Ozone Loss.

In addition to the UGAMP GCMs which include chemistry, we have developed a detailed chemistry/trajectory model (Lutman et al., 1994a,b). This model has been used to study EASOE data by running large numbers of long-duration 3-D trajectories to cover the entire domain of interest. In this way, a 3-D picture of atmospheric chemistry evolution can be developed. This picture complements that provided by the GCM. It is possible by comparing the two models to isolate model dependent features. For example, spatial variations revealed in the trajectory studies cannot be due to diffusion, which is not included in that model.

We have carried out studies of the ozone loss in the winter of 1991/92 using the large number of ozone sondes launched during EASOE and these two models. One study (Lucic et al., 1994) used the GCM model to estimate descent rates within the polar vortex while the second (Von der Gathen et al, in prep.) attempted to match ozone observations taken at increasing times along calculated air parcel trajectories. We propose to repeat these two studies using UARS data from MLS and ISAMS. UARS data obviously provides many more data points, over a much wider area, than the ozone sondes, which have superior vertical resolution. A comparison of the time behaviour along the trajectories of species other than ozone will also be performed.

5.2.4 Studies of the Water Vapour and Total Hydrogen Budgets.

The aims of this study are

1. To combine data from the HALOE, MLS, CLAES and ISAMS instruments in order to

    - develop a climatology of H_2O,
    - analyse the $H_2O + CH_4$ budget of the atmosphere,
    - derive the H_2 content of the mesosphere,
    - evaluate the accuracy of the measured upper troposphere H_2O fields.

2. To compare the H_2O, CH_4 and H_2 fields measured and combined in this way with model calculations from the UGAMP 3-d model with full chemistry.
3. To study the fields in the stratosphere in terms of dynamical effects, using the UKMO analyses.

The justification for this study lies in the importance of water vapour and other hydrogen species in both the chemistry and radiation balance of the middle atmosphere. H_2O is the source of the active radical OH in the stratosphere (for example, through oxidation by atomic oxygen in the ^1D state), which is a dominating influence on stratospheric chemistry through many important reactions (see Brasseur and Solomon, 1984, pp245-250) and along with CH_4, H_2O gives rise to molecular hydrogen in the mesosphere and above (Le Texier et al., 1988). Moreover, water is implied in vortex ozone-destroying reactions through the central role of ice crystals. In radiation terms, water vapour accounts for a large fraction of the tropospheric long-wave radiative cooling to space, and much of this cooling is controlled by water vapour in the middle and upper parts of the troposphere. Also, in the stratosphere, water vapour contributes significantly to the local radiation balance, both through long-wave cooling and, to a lesser extent, short-wave absorption. Clouds, as a manifestation of water, are also of great importance to the radiative balance of the atmosphere, although one of currently great uncertainty.

The UARS data derived from a number of the composition-sounding experiments on board (HALOE, CLAES, ISAMS and MLS) represent a unique set of measurements of the water vapour in the atmosphere, and it is important firstly to derive the best 'climatology' of H_2O and related species such as CH_4 and (proxy) H_2 that we can from them. The different instruments have their characteristic advantages and disadvantages. HALOE can make very high precision measurements, on account of the high signal-to-noise ratio obtained with a solar-occultation measurement, but the coverage obtained with such a sounder is not perfect; the ISAMS instrument provides much better coverage, but the pressure-modulation technique used seems to have calibration problems, and the short life of ISAMS (less than one year) is a limitation; the MLS data covers a long time base, and provide good coverage, etc. A second aspect of the study is that we can now ensure that we fully understand the details of the relationship between H_2O and CH_4 in the stratosphere, as the latter is converted to the former: never before have we had such complete datasets with which to test our models, as a function of time, season, latitude and longitude.

Another issue that can be addressed with the new data is the H_2 budget of the mesosphere: previously, measurements were very limited in time and/or space; now we can test our model simulations, and therefore our understanding, over a wide range of conditions. One other important feature of the data which we must address is to establish just how deeply into the troposphere we can make useful measurements: the great importance of the middle and upper troposphere to the radiation balance makes this a vital question, which will be addressed in this work.

With the data properly analysed and understood as a data set, a principal aim of this work is to test the predictions of 3-d GCM models against the measured composition fields, and their variation in time and place. Of special interest will be two important regions: first, the equatorial tropopause region, where exchange processes between the troposphere and the stratosphere badly need new measurements if they are to be fully understood. The second is the winter/spring polar vortex regions, where studies have already shown that the interplay of dynamics, radiative effects and chemistry is intense (e.g. Tuck et al., 1993). The new data provide one of the best views of these interacting processes that we have available, and will be used in this work to test the models which, in such a complex system as the atmosphere, is the only way to properly test our theoretical understanding of the atmosphere. In this area, the chemical studies will be carried out in conjunction with the work proposed on dynamical studies of the vortex described in section 5.1.2.

5.2.5 Correlative Antarctic Ozone and NO_2 Studies.

Measurements of O_3 and NO_2 by the BAS UV-visible spectrometer (SAOZ) at Faraday, Antarctica have identified several features of interest which will be interpreted in conjunction with co-located UARS data. The features include:

- Within the vortex, ozone appears to increase during early winter and decrease during late winter, possibly signifying descent followed by earlier depletion than previously observed. However, the measurements have a small dependence on profiles of both ozone and temperature which needs to be investigated further.
- At the breakdown of the vortex in 1991, O_3 and NO_2 did not recover simultaneously. Again, the measurements have a small profile dependence and a significant dependence on aerosol in December 1991, when Mount Pinatubo aerosol arrived.
- During late spring, the change in NO_2 between morning and evening is much less inside the vortex than outside, despite the NO_2 abundance being comparable. This change in NO_2 should equal the amount of ($2^*N_2O_5$+$ClONO_2$) photolysed during the day. Again, the measurements have a profile dependence and the explanation might simply be the temperature dependence of photolysis of N_2O_5.

Each of these features would benefit from examination of UARS profiles of O_3, NO_2 and aerosol, even if the profiles are not complete. The possible explanation of each feature, if confirmed after excluding profile and other dependencies, are also of great interest to the UARS community: descent within the vortex, early ozone depletion, reduced NO_2 in pockets outside the vortex and low N_2O_5 within the vortex despite plentiful NO_2 are all areas of interest. Each would open the possibility of wider collaborative science with both UARS measurement groups (MLS measurements of high ClO in the early winter, measurements of HNO_3 within the vortex) as well as with modelling groups.

5.2.6 PSC / Aerosol Studies.

Polar Stratospheric Clouds (PSCs) and sulphuric acid aerosols (SA) provide surfaces for heterogeneous reactions in the lower stratosphere. The overall chemical effect of PSCs and SA is a strong function of aerosol loading and particle composition (and hence temperature). Data from various UARS instruments will provide valuable information on the spatial and temporal variability of SA and PSCs and on their correlation with other factors such as temperature and tracer concentrations. Optical extinction data from ISAMS, CLAES and HALOE, along with temperature data, will be used to test the consistency between theoretical predictions of PSC formation, as simulated by a full microphysical model, and observed aerosol properties. Whilst the theoretical predictions are being tested, the actual observations of PSCs will be used to constrain off-line chemistry and transport simulations. These simulations will themselves be compared to UARS data as described in previous sections.

The eruption of the volcano Mt. Pinatubo introduced about 20 Mtonne of SO_2 into the stratosphere. The SO_2 converted to SA in the space of a few months. The transport and oxidation of volcanic SO_2 has been monitored by MLS. The transport and decay of the subsequent aerosol cloud has been monitored by ISAMS, CLAES and HALOE. A 2-D model, containing a detailed treatment of SA microphysics and sulphur chemistry, and MLS data have already been used to confirm sulphur oxidation mechanisms in the stratosphere (Bekki and Pyle, 1994). Simplified schemes are being developed from the full microphysics and included in the GCM and off-line transport models. 3-D simulations, in conjunction with UARS data, will be used to investigate the interaction of heterogeneous processes and transport, and quantify the potential for ozone depletion.

5.3 Ozone Climatologies for General Circulation Models

Work to be carried out by : READ.

UARS data required : HALOE, ISAMS, MLS.

General circulation modelling of the troposphere and middle atmosphere requires three-dimensional and time varying fields of ozone for radiative calculations in either of two ways: (i) in models which do not have ozone as a prognostic variable, the ozone must be specified as an input climatology; (ii) in models which do carry ozone as a prognostic variable, datasets are required to verify model output. Historically, relatively little attention has been paid to such climatologies for GCM use. Producing an ozone climatology for either of these purposes is not a simple task. Although there are a large number of surface-based and satellite-based measurement techniques, no single technique can provide data which meets the requirements of having good horizontal and spatial resolution over the whole globe from the surface to the mesopause. In addition, there is considerable intrinsic natural variability in ozone, particularly that associated the stratospheric quasi-biennial oscillation; this means that short-period observations, even if producing high quality data, have to be incorporated in to climatologies with some care, to ensure that they are not biased to one phase or the other of oscillations.

Work is in progress to combine a number of different data sets to produce a single climatology for the surface - this has entailed using data from 5 different satellite instruments as well as ozonesonde measurements. Merging such data sets into a single climatology is a considerable challenge. Once these climatologies have been produced they will be used to examine the sensitivity of the atmosphere to this specification; preliminary integrations indicated that switching from a simplified climatology used in the ECMWF model to a more recent (but still zonal mean) satellite climatology had substantial effects in the upper troposphere and lower stratosphere.

These climatologies will need to be updated as more data becomes available. Ozone data from a number of UARS instruments (HALOE, ISAMS, MLS) will provide an additional source of data. Particularly important would be height resolved data in the lower stratosphere which is both diabatically important and presently rather poorly sampled.

Finally, long-term trends in ozone have implications for both tropospheric and stratospheric climate. The imposition on models of ozone changes deduced from available data sets, of which UARS instruments will be an important component, will allow an investigation of the effects of the change and comparison with, for example, observed temperature changes.

5.4 Interannual Variability of the Atmosphere

Work to be carried out by : RAL, READ.

Data required: UK Meteorological Office analyses, HALOE, CLAES, MLS.

It has been known since the early 1960's (Reed et al. 1961, Veryard and Ebdon 1961) that the zonal wind in the tropical lower stratosphere reverses sign with period of about 22-34 months, giving rise to the so-called Quasi Biennial Oscillation (QBO). There is also a well defined QBO in ozone that is not confined to the equatorial latitudes; it extends over all latitudes and is largest at high latitudes (Lait et al., 1989). 2-d Modelling studies carried out by Gray and Pyle (1989), Gray and Dunkerton (1990), Gray and Chipperfield (1990) and Chipperfield and Gray (1992) reproduced the ozone QBO and also predicted the existence of a QBO signal in a number of other trace gas abundances such as NO_2, HNO_3, N_2O and $ClONO_2$. In a subsequent study, Zawodny and McCormick (1991) detected a QBO signal in NO_2 as well as ozone from measurements made by the SAGE II instrument, hence confirming the model predictions (see also Chipperfield et al., 1994). In a further study, Gray and Ruth (1992, 1993) showed that the phase of the QBO during the LIMS period of measurements was opposite to that of the first year of UARS and suggested that care should be taken in the use of LIMS observations for UARS validation purposes due to the likelihood of variations in the equatorial abundance of, for example, NO_2 and HNO_3 associated with the QBO.

Although the time-series of data from UARS is insufficient for a rigorous analysis of a QBO signal (which would require at least two QBO cycles and hence possibly five years of measurements) nevertheless some comparisons may be possible with model predictions and previous data now that one complete QBO cycle has been sampled. For example, recent analysis of MLS data has invoked QBO effects as possible mechanisms influencing the measured abundance and distribution of ozone in equatorial regions (Froidevaux et al., 1994). The aim of the proposed study is to examine the UARS data for evidence of the QBO and to extend previous modelling studies of the QBO signal in trace gases by validation with the available UARS data.

In addition, a QBO signal has been detected in the UK Meteorological Office analyses (Swinbank and O'Neill, 1994) with clearly defined descending bands of equatorial easterlies and westerlies. It is generally accepted that the QBO is driven mainly by equatorially trapped, upward propagating Kelvin waves and Rossby-gravity waves (e.g., Holton and Lindzen 1972). Some uncertainties remain over the possible role of planetary waves propagating from the winter hemisphere (Dunkerton 1983), the role of gravity wave drag and the possible coupling with the annual cycle. The work of Swinbank and O'Neill will be extended by further diagnosing the UK Meteorological office analyses in order to more fully characterize the structure of the QBO, including the associated meridional circulation. It is not yet clear to what extent the waves driving the QBO are present in the analyses. Diagnostic studies will be carried out to identify and quantify the waves that are present. The residual in the angular momentum budget will be calculated to quantify the effect of motions that are not captured in the analyses, either through lack of resolution or lack of raw observations.

5.5 Solar Terrestrial Interactions

Work to be carried out by : IMP, LEIC.

Data required : PEM, ISAMS, HALOE, CLAES.

It is well established that the middle and upper atmospheres respond to solar energetic particle events; in particular, solar proton events (SPEs), associated with solar flare activity, impact the atmosphere at high latitudes and produce odd nitrogen, through the dissociation and ionisation of N_2, which can then take part in the catalytic destruction of ozone (Crutzen et al., 1975, Solomon and Crutzen, 1981). Two dimensional model studies (Jackman et al., 1990, Reid et al., 1991) suggest ozone depletions following SPEs of more than 20% lasting perhaps 2 months in the upper stratosphere at polar latitudes. In the lower stratosphere predicted ozone changes are small but depend sensitively on the penetration depths, and thus the energy spectra, of the protons.

Lower stratospheric ozone plays a crucial part in the radiative balance of the lower and middle atmospheres and is important in determining the downward flux of infrared and solar radiation across the tropopause. Any changes in lower stratospheric ozone, therefore, may have an impact on the radiative forcing of climate. In this proposal, we seek to investigate the potential effects of SPEs on climate through the modification of stratospheric ozone.

The photochemistry scheme in the UGAMP 2-d model will be extended to include the appropriate ion chemistry and its response to the SPEs of February, June and October 1992 will be assessed using proton flux data from the PEM. The accuracy of the model results will be assessed by comparison with ISAMS, HALOE and CLAES observations of temperature, ozone and the nitrogen family species. The changes in net radiative flux at the tropopause predicted by the model will then be analysed in the context of changes due to other mechanisms e.g. increasing concentrations of greenhouse gases, using existing detailed radiative transfer schemes. The 2-d model predictions of ozone change will also be used in the middle atmosphere model so that the full climatic response (including, for example, wave activity) to variations in lower stratospheric ozone might be investigated.

At a later stage it is anticipated that the appropriate photochemical schemes will also be implemented in the GCM and the 2-d experiments described above repeated in

3-D. In this way the inevitable approximations in the representation of the transport of heat, momentum and mass (especially trace gases) of the 2-d model will be avoided and a full 3-d simulation of the effects of solar variability directly on the atmosphere.

In a further study of Middle / Upper Atmosphere coupling, the role of the thermosphere will be examined. Significant changes to both the neutral and the ionised media occur in the upper atmosphere above approximately sixty kilometres altitude. The mechanisms by which coupling with the rest of the atmosphere takes place are not well understood. The Leicester ionospheric physics group has long experience of using ground-based radars to study the upper atmosphere and is actively engaged in a program to investigate the coupling between neutral gravity waves and the ionosphere. It is intended to extend the work to look at sources in the lower atmosphere and wave propagation into the mesosphere and thermosphere.

Idealised radiative / chemical / dynamical studies of the global atmosphere are already being carried out. It is proposed to extend an existing middle atmosphere model into the lower thermosphere and to introduce a number of mechanisms which are affected by solar variability directly. In addition, studies of wave instabilities and damping involving modulated heat and momentum sources and their role in coupling different atmospheric layers will be continued: these have been studied analytically and numerically and there is now a need to examine these processes from an experimental standpoint. Both of the above topics would benefit greatly from the use of thermal composition and dynamical data from most of the UARS instruments at low, middle and upper atmospheric heights.

6 Management of the Project.

The project will be managed as a community project, with regular meetings in the UK in order that the progress of research studies be reported and discussed. Some of these meetings will be part of the regular meetings of the middle atmosphere UGAMP community, where appropriate. The majority of the proposed studies involve collaboration between two or more research groups. These collaborations will be organised locally by the Co-Investigators involved. Additionally, regular meetings between the Scientific Co-Investigators and the British Atmospheric Science Datacentre (BADC) Team (who will facilitate access to the data - see next section) will be held to ensure that the access routes to the data are adequate and that sharing of software tools is facilitated. The Principal Investigator is in an excellent position to ensure the smooth running of this project and that good communication is maintained between the scientific co-investigators and the data centres: she is a Principal Scientist of UGAMP and the Project Scientist of the BADC.

6.1 The UK Universities Global Atmospheric Modelling Programme.

As already described in section 4, UGAMP is a community programme consisting of the active involvement of nine research groups in the UK. It is coordinated by Prof. Alan O'Neill, its Director, from the Centre for Global Atmospheric Modelling at Reading University. In addition to the twelve Principal Scientists (which includes Dr. Gray) there are four full-time coordinators with designated areas of responsibility (the troposphere, the middle atmosphere, chemical studies and supercomputing topics). Three of the coordinators are also based at CGAM, the fourth (the chemistry coordinator) is based at the Chemistry Department, Cambridge University. The research conducted under the auspices of UGAMP is carried out in the various research departments of the Principal Scientists in collaboration with personnel at the CGAM. Many of these are postdoctoral and postgraduate researchers funded specifically by UGAMP.

Regular UGAMP meetings are held in order that the work carried out be properly informed and coordinated where appropriate. One major (2-3 day) meeting is held each summer which covers the whole programme and many smaller meetings are held throughout the year on specific topics. The middle atmosphere group of UGAMP meets regularly 3-4 times each year. Similar regular meetings will be held to discuss data interpretation issues and discussion of the progress of the UARS Guest Investigator Program will naturally fall into these sessions. The meetings will be widened specifically to involve those participants of this programme who are not already involved in UGAMP.

6.2 The British Atmospheric Data Centre (BADC).

The UARS data required for the studies described in this proposal will be acquired by the individual research groups with aid from the British Atmospheric Data Centre (the BADC - formerly the Geophysical Data Facility), which is funded by the UK Natural Environment Research Council (NERC) as its prime atmospheric data centre. Where the same dataset is required by more than one UK research group, the data will be transferred from the Goddard Distributed Active Archiving Centre (DAAC) to the

BADC and thence distributed within the UK. This will ensure efficient usage of the network links across the Atlantic. Good coordination will hence be achieved between the UK users of the data and the source of the data in the U.S. Dr. Gray is also a member of the Goddard DAAC User Group and is therefore able to represent the interests of the UK users of the data in that forum.

6.3 The UK Meteorological Office.

The UK Meteorological Office (UKMO) middle atmosphere group is responsible for producing the synoptic analyses which underpin many of the proposed studies. The UKMO group will continue to produce and diagnose these analyses as part of their own commitments to the UARS project. The assimilation system will continue to be developed to analyse UARS measurements of trace chemical species and stratospheric winds. UKMO will also collaborate with the groups proposing to use the UKMO data for studies of stratospheric circulation dynamics, in particular studies of the winter vortex and interannual variability.

7 Funding.

There are a number of different sources of funding for the proposed studies. Much of the proposed modelling work will fall naturally within the UGAMP programme (see section 4) which is funded by the Natural Environment Research Council (NERC). As part of the infrastructure of UGAMP, the NERC funds the Centre for Global Atmospheric Modelling (CGAM), 4 coordinator posts, a number of central unit staff and a number of research topic staff. Currently, the total number of personnel funded through the UGAMP project is approximately 30. In addition, approx. £1M per annum. is allocated for supercomputing costs in this area. Where proposed studies do not directly involve modelling, funds may also be bid for via the NERC 'responsive mode' route for grants and studentships. In addition to funding by the NERC in this area, there are a number of other bodies that fund university research in this area, for example the Commission for European Communities and the UK Department of the Environment.

In the proposed areas of study which involve the upper atmosphere (above about 100 km) the relevant funding agency is the newly established 'Particle Physics and Astronomy Research Council' (PPARC). The UK Science and Engineering Research Council (SERC) which formerly funded the work in this region has been superceded by a number of smaller research councils, of which PPARC is the one designated to cover this research area.

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- Zawodny, J.M. and M.P. McCormick, 1991. Stratospheric Aerosol and Gas Experiment II measurements of the quasi biennial oscillation of ozone and nitrogen dioxide. J. Geophys. Res., 96, 9371-9377.

APPENDIX A
Curriculum Vitae
Lesley J. Gray

Date of Birth: 5 August 1956.

Address: Rutherford Appleton Laboratory, Chilton, Didcot, Oxon., OX11 0QX.

Qualifications

1980: B.Sc. (Hons) 1st class (Geophysical Sciences) Southampton University.

1983: Ph.D. Meteorology Dept. Reading University. Thesis title : Regime Studies of Atmospheric Flow.

Employment

1983–1985: Research Assistant, Oxford University (on secondment to the Rutherford Appleton Laboratory and supported by the Chemical Manufacturers Association).

1985–1989: Senior Research Associate, Rutherford Appleton Laboratory (RAL).

1989–: Senior Scientific Officer, progressing to Principal Scientific Officer (Grade 7), Rutherford Appleton Laboratory.

Relevant Experience

Project Scientist, British Atmospheric Data Centre (BADC) providing scientific direction and supervision of the development of a database for atmospheric data, including data from satellites, meteorological radars and models.

Visiting lecturer at the Centre for Remote Sensing, Imperial College, London, U.K.

Principal Scientist on the UK Universities Global Atmospheric Modelling Project.

Member of the U.K. Stratospheric Ozone Review Group, a panel set up at the request of the U.K. Department of the Environment and the U.K. Meteorological Office to advise the U.K. government on matters concerning the ozone layer.

Member of the International Commission on the Meteorology of the Upper Atmosphere (ICMUA).

Prime Coordinator on an EEC funded project to study the transport of ozone and stratosphere troposphere exchange. The project involves nine groups from four EEC countries.

Co-Investigator on an EOS inter-disciplinary theoretical study (CHEDAR).

Co-Investigator on a NASA study of the Quasi Biennial Oscillation: modelling and data studies.

Member of the User Working Group for the NASA Goddard Space Flight Center Distributed Active Archive Center.

Invited reviews on the semi annual oscillation and the quasi biennial oscillation at the American Meteorological Society (A.M.S.) meeting in San Francisco, 1989 and Atlanta, Georgia in January 1991.

Member, SAGE II Science Team.

Co-Convenor of session on Chemistry, Radiation and Transport in the Middle Atmosphere at the 1995 IUGG Meeting.

Recent Publications

Gray, L.J. and J.A. Pyle, 1986. The semi-annual oscillation and equatorial tracer distributions. Q. J. Roy. Met. Soc., 112, 387-407.

Roscoe, H.K. et al., 1986. Simultaneous measurements of stratospheric NO and NO_2 and their comparison with model predictions. J. Geophys. Res., 91, 5405-5419.

James, I.N. and L.J. Gray, 1986. Concerning the effect of surface drag on the circulation of a baroclinic atmosphere. Q. J. Roy. Met. Soc., 112, 1231-1250.

Gray, L.J. and J.A. Pyle, 1987. Two dimensional model studies of equatorial dynamics and tracer distributions. Q. J. Roy. Met. Soc., 113, 635-651.

Gray, L.J. and J.A. Pyle, 1987. The influence of the semi-annual and quasi-biennial oscillations on equatorial tracer distributions, in Transport Processes in the Middle Atmosphere. eds. G. Visconti and R.R. Garcia, p.b. Reidel.

Brasseur, G. et al., 1987. Odd nitrogen during the MAP/GLOBUS 1983 campaign: theoretical considerations. Planet. Space Sci., 35, 637-645.

Pyle, J.A., A.M. Zavody and L.J. Gray, 1987. Tests of photochemical and dynamical theories from satellite data. Phil. Trans. R. Soc. Lond. A323, 667-678.

Gray, L.J. and J.A.Pyle, 1989. A two dimensional model of the quasi-biennial oscillation of ozone. J. Atmos. Sci., 46, 203-220.

Gray, L.J. and M.P. Chipperfield, 1990. On the Inter-Annual Variability of Trace Gases in the Stratosphere. Geophysical Research Letters, 17, 933-936.

Gray, L.J. and T.J. Dunkerton, 1990. Seasonal Cycle Modulations of the Equatorial QBO.

J. Atmos, Sci., 47, 2431-2451.

Chipperfield, M.P. and L.J. Gray, 1992. Two dimensional model studies of the interannual variability of trace gases in the Middle Atmosphere. J. Geophys. Res., 97, 5963-5980.

Gray, L.J. and S. Ruth, 1992. The interannual variability of trace gases in the stratosphere : a comparative study of the LIMS and UARS measurement periods. Geophys. Res. Letts., 19, 673-676.

Gray, L.J. et al., 1993. First results from a 3-dimensional middle atmosphere model. Adv. Space Sci., 13, 363-373.

Gray, L.J. and S. Ruth, 1993. The modelled latitudinal distribution of the ozone QBO using observed equatorial winds. J. Atmos. Sci., 50, 1033-1046.

Jackson, D.J. and L.J. Gray, 1994. Simulation of the semiannual oscillation of the equatorial middle atmosphere using the extended UGAMP general circulation model. to appear in Quart. J. Roy. Met. Soc.

Gray, L.J., M. Bithell and B.D. Cox, 1994. The role of specific humidity fields in the diagnosis of stratosphere troposphere exchange. to appear in Geophys. Res. Lett.

Chipperfield, M.P., L.J. Gray, J. Kinnersley and J. Zawodny, 1994. A 2-d model study of the QBO signal in SAGE data. To appear in Geophys. Res. Lett.

Cox, B.D., M. Bithell and L.J. Gray, 1994. A general circulation model study of the transfer of air between the stratosphere and troposphere at mid-latitudes. submitted to Quart. J. Roy. Met. Soc.

Bithell, M., L.J. Gray, J.E. Harries, J.M. Russell and A. Tuck, 1994. On the synoptic interpretation of HALOE measurements using PV analyses. submitted to J. Atmos. Sci.

Curriculum Vitae
Joanna D. Haigh.

Date of Birth: 7th May 1954

Address: Space and Atmospheric Physics, Blackett Laboratory, Imperial College, London SW7 2BZ

Qualifications

1975: B.A. Physics, Oxford University.

1977: M.Sc. Meteorology. Imperial College, London.

1980: D.Phil Department of Atmospheric Physics, Oxford University. 'Satellite Measurements of Atmospheric Structure'.

Employment

1980–1984: Postdoctoral Research Assistant, Department of Atmospheric Physics, Oxford University.

1984–: Lecturer in Atmospheric Physics and Remote Sensing, Imperial College, University of London.

Other relevant experience.

1971 : B.A.A.S. Young Scientists Travel Award.

1979–80 : Graduate Scholarship, St. Cross College, Oxford.

1981–84 : Junior Research Fellowship, St. Cross College, Oxford.

1993–96 : SERC Advanced Fellowship.

1982–84 : Member of Editorial Board of Weather.

1984–87 : Editor of Weather.

1986–88 : Member of University of London Inter-Collegiate Coordinating Committee on Remote Sensing.

1988– : Co-Investigator on NASA EOS Interdisciplinary Research Project (CHEDAR).

1990– : Principal Scientist on NERC UGAMP Project.

1991– : Member of NERC Scientific Steering Group for Special Topic in Clouds and Radiation.

1992– : Member of ATSR Science Team

1992–95 : Member of Council of Royal Meteorological Society.

1993–96 : Member of NERC Atmospheric Sciences Committee.

Recent Publications.

Pawson, S., R.S. Harwood, and D. Haigh, 1992. A study of the radiative dissipation of planetary waves. J.Atmos.Sci., 49, 1304-1317.

Gray, L.J., M.Blackburn, M.Chipperfield, J.D. Haigh, D.R. Jackson, K.P. Shine, J.T.

Thuburn and W. Zhong, 1993. First results from a 3-d middle atmosphere model. Adv. Space. Res., 13, 363-372.

Zhong, W., J.D. Haigh and .A. Pyle, 1993. Greenhouse gases in the stratosphere. J.Geophys.Re: 98, 2995-3004.

Haigh, J.D., 1994. Solar radiative forcing of climate - the importance of stratospheric ozone. submitted to Nature.

Curriculum Vitae
John E. Harries

Address: Imperial College, London.

Qualifications

B.Sc. (Hons) University of Birmingham.

Ph.D., King's College, London.

Employment

1967–1980: National Physical Laboratory. Began career as Scientific Officer; rose to become Principal SO and Head of Environmental Standards Group by 1975.

1980–1993: Rutherford Appleton Laboratory. Senior Principal SO; became Deputy Chief SO in 1984 and appointed Director and Head of Space Science Department. Also, Deputy Director, Technology at the British National Space Centre.

1994–: Professor of Earth Observation at Imperial College, University of London.

Other Relevant Experience

President of the International Radiation Commission.

Vice-President of the Royal Meteorological Society.

Publications

Over 100 articles, papers and books, including 60 or so in refereed literature and the book 'Earthwatch : the Climate from Space'.

Curriculum Vitae
Rod. L. Jones

Address: Cambridge Centre for Atmospheric Science, University of Cambridge, Department of Chemistry, Lensfield Road, Cambridge CB2 1EW.

Qualifications

1976: B.A. B.A. (Physics and Theoretical Physics), University of Oxford.

1984: M.A.; D.Phil., Atmospheric Physics: Measurement of CH4 and N2O from satellites, University of Oxford.

Employment

1985–1990: U.K. Meteorological Office, Atmospheric Chemistry research group. Senior Scientific Officer, rising to Principal Scientific Officer (Grade 7). Head of research group in Atmospheric Chemistry.

1990– University Lecturer, Department of Chemistry, University of Cambridge. Fellow, Queens' College, Cambridge.

Relevant Experience

1985/6: Panel member of the NOx and HOx chapters in the 1986 WMO report 'Stratospheric Ozone 1985'.

1986 to present: Member of the United Kingdom Stratospheric Ozone Review Group.

1986 Eurosense Award of the Remote Sensing Society for the best paper by a European author, jointly with Dr. J.A. Pyle.

1987: Principal Investigator for the 1987 Airborne Antarctic Ozone Experiment.

1988 NASA group Achievement Award for the Airborne Antarctic Ozone Experiment.

1988/9: Principal Investigator for the 1988/9 Airborne Arctic Stratospheric Expedition.

1988/9: Co-chairman of the 'Polar Ozone' chapter for the 1989 UNEP ozone assessment.

1990 to present: Co-principal investigator for the Meteorological Office UARS theory project.

1991 NASA group Achievement Award for the Airborne Arctic Stratospheric Expedition.

1991 The Macelwane Award of the American Geophysical Union.

1991/2: Contributor to the 'Heterogeneous Processes' chapter for the 1992 UNEP ozone assessment.

1993/4: Chapter Chairman of the 'Mid-latitude Ozone Loss' chapter for the 1994 UNEP/WMO ozone assessment.

1993 to present: Member of the NERC Atmospheric and Aquatic Physical Sciences Committee.

Recent Publications

Jones R.L. and Pyle J.A. Observations of CH4 and N2O by the Nimbus 7 SAMS, a Comparison with In Situ Data and Two Dimensional Model Calculations. J. Geophys. Res. 89, D4 (1984), 5263-79.

Rodgers C.D., Jones R.L. and Barnett J.J. Retrieval of Temperature and Composition from Nimbus 7 SAMS Measurements. J. Geophys. Res. 89, D4 (1984), 5280-86.

Jones R.L. et al., The Water Vapour Budget of the Stratosphere Studied using LIMS and SAMS Satellite Data. Quart. J. Roy. Met. Soc. 112 (1986), 1127-43.

Jones R.L. et al., Lagrangian Photochemical Modelling Studies of the 1987 Antarctic Spring Vortex: Comparison with Observations. J. Geophys. Res. 94, D9 (1989), 11529-58.

Jones R.L. et al., Polar Stratospheric Cloud Event of January 24. Part 2: Photochemistry. Geophys. Res. Lett. 17, 4 (1990), 541-44.

Jones R.L. et al., Simulating the Evolution of the Chemical Composition of the 1988/89 Winter Vortex. Geophys. Res. Lett. 17, 4 (1990), 549-52.

Jones R.L. et al., On the Influence of Polar Stratospheric Cloud Formation on Chemical Composition during the 1988/89 Arctic Winter. Geophys. Res. Lett. 17, 4 (1990), 545-48.

Brune, W.H. et al., 1991. The potential for ozone depletion in the Arctic polar stratosphere. Science, 252, 1260-1266.

Toumi R., Jones R.L. and Pyle J.A., Stratospheric ozone depletion by Chlorine nitrate photolysis. Nature, 365, 37-39, (1993).

Fish D.J. et al., Total Ozone Measured during EASOE by a UV-visible Spectrometer which observes stars. Geophys. Res. Lett, in press (1994).

Lutman E. et al., Box model studies of CLox deactivation and winter ozone loss during the 1991/92 northern hemispheric winter. Geophys. Res. Lett, in press (1994).

Mackenzie A.R. et al., The spatial and temporal extent of chlorine activation by polar

stratospheric clouds in the northern hemisphere winters of 1988/89 and 1991/92. Geophys. Res. Lett, in press (1994).

Curriculum Vitae
William A. Lahoz

Date of Birth: 29 December 1960.

Address: Centre for Global Atmospheric Modelling, Reading University, UK.

Qualifications

1981: B.Sc. (Hons) 1st class Mathematics. University of Manchester (UMIST).

1986: Ph. D. Theoretical Physics, University of Manchester, (UMIST).

Employment

1986–1993 : Research Fellow in Department of Meteorology, University of Edinburgh. Responsible for data validation of water vapour data from Microwave Limb Sounder (MLS) aboard the Upper Atmosphere Research Satellite (UARS) and analysis of tracer data from UARS.

1993–: Research Fellow in Centre for Global Atmospheric Modelling (CGAM) in Department of Meteorology, University of Reading. Responsible for interpretation of atmospheric data using observations, high resolution trajectory studies, and a hierarchy of numerical models.

Awards

Overseas Research Student Award awarded by the Committee of Vice-Chancellors and Principals of the United Kingdom (1982-85).

Recent Publications

Harwood, R.S. et al., 1993: Springtime stratospheric water vapour in the southern hemisphere as measured by MLS. Geophys. Res. Lett. 20, 1235-1238.

Manney, G.L. et al., 1993: The evolution of ozone observed by UARS MLS in the 1992 late winter southern polar vortex. Geophys. Res. Lett. 20, 1279-1282.

Randel, W.J. et al., 1993: Stratospheric transport from the tropics to middle latitudes by planetary-wave mixing. Nature 365, 533-535.

Lahoz, W.A. et al., 1993: Northern hemisphere mid-stratosphere vortex processes diagnosed from H2O, N2O and potential vorticity. Geophys. Res. Lett. 20, 2671-2674.

Massie, S.T. et al., 1994: Spectral signatures of polar stratospheric clouds and sulfate aerosol. Submitted to J. Atmos. Sci.

Lahoz, W.A. et al., 1994: Three-dimensional evolution of water vapour distributions in the northern hemisphere stratosphere as observed by MLS. Submitted to J. Atmos. Sci.

Manney, G.L. et al., 1994: Lagrangian transport calculations using UARS data. Part I: passive tracers. Submitted to J. Atmos. Sci.

Carr, E.S. et al., 1994: MLS stratospheric water vapour at the tropics. Submitted to Geophys. Res. Lett.

Manney, G.L. et al., 1994: Stratospheric warmings during early winter in the northern and southern hemisphere. Submitted to Quart. J. Roy. Met. Soc.

Lahoz, W.A. et al., 1994: Data validation of 183 GHz UARS MLS H2O measurements. In preparation, to be submitted to J. Geophys. Res.

Curriculum Vitae
Michael E. McIntyre

Date of Birth: 28 July 1941.

Address: Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Silver St, Cambridge, UK.

Qualifications

1963: B.Sc. (Hons) 1st class Mathematics, University of Otago, New Zealand.

1967: Ph.D. Geophysical fluid dynamics, University of Cambridge. Thesis title: Convection and baroclinic instability in rotating fluids.

Employment

1963 : Assistant Lecturer in Mathematics, University of Otago, New Zealand.

1967–69 : Postdoctoral research associate, Dept. of Meteorology, Massachusetts Institute of Technology.

1969– : Assistant Director of Research in Dynamical Meteorology, Dept. of Applied Mathematics & Theoretical Physics, University of Cambridge, rising to Professor of Atmospheric Dynamics and Co-Director of the Cambridge Centre for Atmospheric Science.

Relevant Experience

1981 Adams Prize, University of Cambridge.

1987 Carl-Gustaf Rossby Research Medal of the American Meteorological Society.

1989– Member of the Academia Europaea.

1990– Fellow of the Royal Society.

1990– Fellow of the American Meteorological Society.

1992–97 Science and Engineering Research Council Senior Research Fellow.

1979–89 Member International Commission for Meteorology of the Upper Atmosphere (IUGG/IAMAP).

1988– Co-investigator, Interdisciplinary Proposal for NASA Earth Observing System, on Chemical, Dynamical and Radiative Interactions through the Middle Atmosphere and Thermosphere.

1988–90 Member Theory Team, Airborne Arctic Stratospheric Expedition (NASA/NOAA/DoE

1989– Member Atmospheric Sciences Committee, Natural Environment Research Council.

1991– Senior Consultant, Jet Propulsion Laboratory, Pasadena, California.

Recent Publications

McIntyre, M.E., 1982: How well do we understand the dynamics of stratospheric warmings? J. Meteorol. Soc. Japan **60**, 37–65. [Invited paper for Special Centennial Issue. Still poses challenges!]

McIntyre, M.E., Palmer, T. N., 1983: Breaking planetary waves in the stratosphere. Nature, **305**, 593–600.

McIntyre, M.E., Palmer, T. N., 1984: The 'surf zone' in the stratosphere J. Atmos. Terrest. Phys. **46**, 825–849.

McIntyre, M.E., Palmer, T. N., 1985: A note on the general concept of wave breaking for Rossby and gravity waves. Pure Appl. Geophys. **123**, 964–975.

Killworth, P. D., McIntyre, M.E., 1985: Do Rossby-wave critical layers absorb, reflect, or over-reflect? J. Fluid Mech. **161**, 449–492.

Hoskins, B.J., McIntyre, M.E., Robertson, A.W., 1985: On the use and significance of isentropic potential-vorticity maps. Q. J. Roy. Met. Soc., **111**, 877–946. (Also **113**, 402–404).

Haynes, P. H., McIntyre, M. E., 1987: On the representation of Rossby-wave critical layers and wave breaking in zonally truncated models J. Atmos. Sci. **44**, 2359–2382.

Juckes, M. N., McIntyre, M.E., 1987: A high-resolution, one-layer model of breaking planetary waves in the stratosphere. Nature, **328**, 590–596.

McIntyre, M. E., 1989: On the Antarctic ozone hole. J. Atmos. Terrest. Phys., **51**, 29–43.

McIntyre, M. E., Norton, W.A., 1990: Dissipative wave-mean interactions and the transport of vorticity or potential vorticity. J. Fluid Mech. **212**, 403–435.

Haynes, P. H., McIntyre, M. E., 1990: On the conservation and impermeability theorems for potential vorticity. J. Atmos. Sci., **47**, 2021–2031.

Dritschel, D. G., McIntyre, M. E., 1990: Does contour dynamics go singular? Phys. Fluids **A 2**, 748–753.

Haynes, P. H., Marks, C.J., McIntyre, M. E., Shine, K. P., Shepherd, T.G., 1991: On the downward control of extratropical diabatic circulations by eddy-induced mean zonal forces J.Atmos. Sci., **48**, 651–678.

McIntyre, M. E., 1992: Atmospheric dynamics: some fundamentals, with observational implications. Proc. Internat. School Phys. "Enrico Fermi", CXV Course, *The Use of EOS for Studies of Atmospheric Physics*, ed. J.C. Gille and G. Visconti. Amsterdam, North Holland [Invited review], 313–386.

Thorncroft, C. D., Hoskins, B. J., McIntyre, M. E., 1993: Two paradigms for baroclinic-wave life cycle behaviour Q. J. Roy. Meteorol. Soc., **119**, 17–55.

McIntyre, M.E. and W. Norton, 1994. Potential vorticity inversion on a hemisphere. J.Atmos. Sci. (To appear).

McIntyre, M. E., 1994: Stratospheric fluid dynamics and the ozone-layer problem. Sci. Prog. Oxf. [Invited review], to appear. A first, shorter version has appeared, also by invitation, under the title What will it take to model stratospheric ozone depletion? Bull. Inst. Maths. Applics., **26**, 214–224 (1990).

Curriculum Vitae

Warwick Alexander Norton

Date of Birth: 15 September 1962, Christchurch, New Zealand.

Address: Department of Atmospheric, Oceanic and Planetary Physics, Clarendon Laboratory, Parks Road, Oxford OX1 3PU, U.K.

Qualifications

1984: B.Sc. (Hons) 1st class (Physics), University of Canterbury, Christchurch, New Zealand.

1988: Ph.D., Department of Applied Mathematics and Theoretical Physics, University of Cambridge.

Awards

1980: Junior Scholarship, BP Bursary.

1983: Senior Scholarship.

1984: Prince of Wales Scholarship, Commonwealth Scholarship, Edward and Isabel Kidson Scholarship.

Employment

1988–1989: Research associate in Department of Applied Mathematics and Theoretical Physics, University of Cambridge

1989–1992: Research associate in Department of Applied Mathematics and Theoretical Physics, University of Cambridge on British Antarctic Survey special topic 'Model studies of dynamics, chemistry and transport in the Antarctic stratosphere'.

1993–: UGAMP Research associate in Department of Atmospheric, Oceanic and Planetary Physics, University of Oxford.

Recent Publications

McIntyre M.E. and W.A. Norton, 1990: Nonlinear vorticity or potential-vorticity inversion. In *Topological fluid mechanics*, eds. H.K. Moffatt and A. Tsinober, Cambridge University Press, 355-358.

McIntyre M.E. and W.A. Norton, 1990: Dissipative wave-mean interactions and the transport of vorticity or potential vorticity. *J. Fluid Mech.*, **212**, 403-435.

Cooper, S.P., and W.A. Norton, 1990: Towards an improved person-machine interface in atmospheric modelling. In *Computer modelling in the environmental sciences*, eds. D.G. Farmer and M.J. Rycroft, Oxford University Press, 189-197.

Haynes, P.H., and W.A. Norton, 1992: Quantification of scale cascades in the stratosphere using wavelet analysis. In *Wavelets, Fractals and Fourier Transforms: New Developments and New Applications*, eds. M. Farge, J.C.R. Hunt and J.C. Vassilicos, Oxford University Press, 229-234.

Norton, W.A., 1994: Breaking Rossby waves in a model stratosphere diagnosed by a vortex-following coordinate system and a technique for advecting material contours. *J. Atmos. Sci.*, **51**, 654-673.

Norton, W.A. and G. D. Carver, 1994: Visualizing the evolution of the polar vortex in January 1992. *Geophys. Res. Lett.* (EASOE special issue), to appear.

Carver, G.D., W.A. Norton and J.A. Pyle, 1994: A case study in forecasting the stratospheric vortex during EASOE. *Geophys. Res. Lett.* (EASOE special issue), to appear.

McIntyre M.E. and W.A. Norton, 1994: Potential vorticity inversion on a hemisphere. *J. Atmos. Sci.*., to appear.

Lary D.J., M.P. Chipperfield, J.A. Pyle, W.A. Norton, and L.P. Riishojgaard, 1994: Three-dimensional tracer initialisation and general diagnostics using Equivalent PV latitude - Potential Temperature coordinates. *Quart. J. Roy. Met. Soc.*, submitted.

Curriculum Vitae
John A. Pyle

Date of Birth: 4th April 1951.

Address: Department of Chemistry, University of Cambridge, Lensfield Road, Cambridge, CB2 1EW.

Qualifications

1972: B.Sc. (Hons) 1st class (Physics), University of Durham.

1976: D.Phil Department of Atmospheric Physics, Oxford University. 'Some problems in the numerical modelling of the atmosphere'.

Employment

1976–1982: Research Officer, Department of Atmospheric Physics, Oxford University.

1982–1985: Higher Scientific Officer, Rutherford Appleton Laboratory. Promoted to Senior Scientific Officer, 1984.

1985–: Lecturer in Physical Chemistry, Department of Chemistry, University of Cambridge.

1986, Fellow of St. Catherine's College. From 1990, Head of European Stratospheric Ozone Research Coordinating Unit, based at Cambridge.

From 1992, Director of Centre for Atmospheric Science, a joint initiative of the Departments of Chemistry and Applied Mathematics and Theoretical Physics.

From 1992, Principal Scientist, Atmospheric Chemistry Modelling Support Unit, a five-year NERC funded programme and part of the UGAMP Programme.

Other relevant experience.

1985: Eurotrac award of the Remote Sensing Society for the best paper by a European author (jointly with R.L. Jones).

1991: Winner of the Royal Society of Chemistry's 1991 Interdisciplinary Award.

1991-92: Coordinator, European Stratospheric Ozone Experiment (EASOE).

1994-95 : Coordinator, Second European Stratospheric Arctic and Mid-latitude Experiment (SESAME).

1993: Elected Member of Academia Europaea.

Chairman of the World Climate Research Programme working group on the modelling of greenhouse gases; member of the SPARC Working Group for WCRP.

1979–84: Secretary of the Royal Meteorological Society with responsibility for the scientific meetings programme.

1986–92: Chairman of the Royal Meteorological Society specialist group on atmospheric chemistry.

1986–92: Member of the International Ozone Commission.

1986–: Member of the Council of the European Geophysical Society.

Member, British National Space Centre, Earth Observation Programme Board.

Member, EEC Task Group on Stratospheric Ozone.

Prime author of modelling chapter of the 1986 NASA/WMO ozone report.

Joint author of a chapter for the 1992 NASA/WMO report on ozone.

Recent Publications.

Harwood, R.S. and J.A. Pyle, 1975. A two dimensional mean circulation model for the atmosphere below 80 km. Quart. J. Roy. Met. Soc., 101,723-748.

Jones R.L. and Pyle J.A. Observations of CH4 and N2O by the Nimbus 7 SAMS, a Comparison with In Situ Data and Two Dimensional Model Calculations. J. Geophys. Res. 89, D4 (1984), 5263-79.

Jones R.L., Pyle J.A., Harries J.E., Zavody A.M., Russell J.M. and Gille J.C. The Water Vapour Budget of the Stratosphere Studied using LIMS and SAMS Satellite Data. Quart. J. Roy. Met. Soc. 112 (1986), 1127-43.

Gray, L.J. and J.A. Pyle, 1987. Two dimensional model studies of equatorial dynamics and tracer distributions. Q. J. Roy. Met. Soc., 113, 635-651.

Pyle, J.A., A.M. Zavody and L.J. Gray, 1987. Tests of photochemical and dynamical theories from satellite data. Phil. Trans. R. Soc. Lond. A323, 667-678.

Gray, L.J. and J.A.Pyle, 1989. A two dimensional model of the quasi-biennial oscillation of ozone. J. Atmos. Sci., 46, 203-220.

Zhong, W., J.D. Haigh and .A. Pyle, 1993. Greenhouse gases in the stratosphere. J.Geophys.Res 98, 2995-3004.

Toumi R., Jones R.L. and Pyle J.A., Stratospheric ozone depletion by Chlorine nitrate photolysis. Nature, 365, 37-39, (1993).

Lary, D. J. et al., 1994: Three-dimensional tracer initialisation and general diagnostics using Equivalent PV latitude - Potential Temperature coordinates. (Submitted to Quart. J. Roy. Meteor. Soc.)

Chipperfield, M.P. et al., 1994. The variability of $ClONO_2$ in the Arctic polar vortex : Comparison of Transall MIPAS measurements and 2D model results. J.Geophys.Res. (submitted).

Lucic, D., N.R. Harris, J.A. Pyle and R.L. Jones, 1994. Diagnosing ozone loss in the Northern hemisphere for the 1991/92 winter. (In preparation).

Lutman, E.R. et al., 1994. Trajectory model studies of ClOx activation during the 1991/92 northern hemisphere winters. Geophys. Res. Letts. (In press).

Lutman, E.R., R.Toumi, R.L.Jones, D.J.Lary, J.A.Pyle, 1994. Box model studies of

ClOx deactivation and ozone loss during the 1991/92 northern hemisphere winter. Geophys.Res.Letts. (In press).

Carver, G.D., W.A. Norton and J.A. Pyle, 1994: A case study in forecasting the stratospheric vortex during EASOE. Geophys. Res. Lett. (EASOE special issue), to appear.

Kettleborough, J. A. et al., 1994. Three dimensional modelling of chlorine activation in the Arctic stratosphere, submitted to Geophys. Res. Lett.

Curriculum Vitae
Terry Robinson

Date of Birth: 29 July 1947.

Address: University of Leicester, Department of Physics and Astronomy, University Road, Leicester, LE1 7RH, UK.

Qualifications

1968: B.Sc. Physics, Birmingham University

1969: Cert. Ed. Oxford University.

1977: M.Sc. (Space Physics (Distinction) Leicester University.

1983: Ph.D. Ionospheric Physics, Leicester University.

Employment

1969–1976:Teacher in UK and Tanzania (with VSO).

1977–1979: Lecturer in Department of Physics, University of Dar-es-Salaam, Tanzania.

1982–: Lecturer in Department of Physics and Astronomy, Leicester University.

Research Activities

(i) Space plasma theory applied to plasma irregularities, waves, instabilities and turbulence, in the auroral ionosphere, with particular emphasis on the interaction of high power radio waves with the ionosphere (heating). I also have a strong interest in radar backscatter from natural and artificial turbulence and the interpretation of data obtained from major facilities such as the EISCAT and SABRE radars.

(ii) Generation and propagation of atmospheric waves, especially in the upper atmosphere.

(iii) Effects of the atmosphere on satellite borne remote sensing altimeters such as those on board the ERS-1 and TOPEX satellites.

Other Relevant Experience.

1992–95: Principal Investigator of 'Studies of the effects of ionospheric variability on the accuracy of the ERS-1 radar altimeter.

Co-Investigator on the NASA Space Shuttle mission SIR-B (1984).

Co-Investigator in the international ERRRIS programme studying E-region turbulence with radars and rockets.

1985–87: Chairman, EISCAT Plasma Physics Working Group.

1985–87: Member, SUNDIAL Working Group.

1987–90: Member, Institute of Physics Plasma Physics Committee.

1989–: Member, EISCAT Heating Working Group.

1991–: Member, SERC Geophysical Data Facility Panel.

Recent Publications Approx. 70 scientific papers, of which the following are samples of the most recent work :

Robinson, T.R., 1993. A generalisation of the Rayleigh criterion for atmospheres with both energy and momentum sources : Implications for atmospheric wave propagation through convecting plasmas. J. Geophys. Res., 98, 19235-19241.

Robinson, T.R., 1994. A note on the Klein-Gordon equation and its solutions with applications to certain boundary value problems involving waves in plasma and in the atmosphere. in press, Ann. Geophys.

Arnold, N.F. and T.R. Robinson, 1994. A mechanism for generating nonlinear electron density distributions when forced by large amplitude monochromatic gravity waves. submitted to Ann. Geophys.

Robinson, T.R., F. Honary, A.J. Stocker, T.B. Jones and P. Stubbe, 1994. First EISCAT observations of the modification of F-region electron temperature during heating at harmonics of the electron gyrofrequency. submitted to J. Atm. Terr. Phys.

Jones, T.B. and T.R. Robinson, 1994. Coherent radar studies of dynamical processes in the auroral E-region. submitted to J. Atm. Terr. Phys.

Eglitis, P., I.W. McCrea, T.R. Robinson, T.B. Jones, K. Schlegal and T. Nygren, 1994.

Flow dependence of COSCAT spectral characteristics. submitted to J. Atm. Terr. Phys.

Curriculum Vitae
Howard K. Roscoe.

Date of Birth: 27th July 1948.

Address: British Antarctic Survey, High Cross, Madingley, Cambridge.

Qualifications

1969: B.A. Physics, Oxford University.

1972: D.Phil Department of Atmospheric Physics, Oxford University. 'Satellite Measurements of Atmospheric Structure'.

Employment

1972–1975: Department of Atmospheric Physics, Oxford University. Headed a team to develop measurements of the changes in NO and NO_2 across sunrise.

1975–1978: Jet Propulsion Laboratory, California, working with Dr. J. Waters' group making airborne microwave measurements.

1978–1987: Department of Atmospheric Physics, Oxford, measuring stratospheric constituents from balloons. Joint flights with CNRS, JPL, NPL and Denver University. First measurements of N_2O_5.

1987–1988: Rutherford Appleton Laboratory. Ground-based microwave radiometer proposal.

1988–: Research Scientist (Grade 7) at the British Antarctic Survey, Cambridge. Current responsibilities are deploying instruments to measure constituents in the ozone hole. Deployed a UV-visible spectrometer to Faraday, and built an instrument to observe UV-visible spectra of stars to measure constituents in the polar night (deployed in N. Sweden in winter). Constructed a star-pointing UV-visible spectrometer for installation at Halley in 1994.

Other relevant experience.

1989–92 : Associate Editor of J. Quant. Spectrosc. Radiat. Trans.

1979–85; 1989–92 : Research Affiliate at JPL.

Member of ESA's GOMOS (Global Ozone Monitoring by Occultation of Stars) Science

Advisory Group and Calibration Working Group.

Member of the Department of Environment's Stratospheric Ozone Review Group.

Correlative Measurements Investigator for NASA's Upper Atmosphere Research Satellite.

Recent Publications.

Roscoe, H.K., R.A. Freshwater, R. Wolfendon, R.L. Jones, D.J. Fish, J.E. Harries, D.J. Oldham, 1994. Using stars for remote sensing of the Earth's stratosphere, in press.

Fish, D.J., R.L. Jones, R.A. Freshwater, H.K. Roscoe, D.J. Oldham, J.E. Harries, 1993. Total ozone measured during EASOE by a UV-visible spectrometer which observes stars. Geophys. Res. Letts (EASOE Special Issue) in press.

Roscoe, H.K. et al., 1993. Year-round measurements of ozone at 66°S with a visible spectrometer, Proc. Quad. Ozone Symp., Charlottesville.

Roscoe, H.K. 1991. Review and revision of measurements of stratospheric N_2O_5. J. Geophys.Res., 96, 10879-10884.

Roscoe, H.K. et al., 1990. Intercomparison of remote measurements of stratospheric NO_2. J. Atmos. Chem., 10, 111-144.

Roscoe, H.K., J.R. Drummond, R.F.Jarnot, 1981. Infrared measurements of stratospheric composition III The daytime changes of NO and NO_2. Proc. Roy. Soc. Lond. A 375, 507-528.

Curriculum Vitae
Keith P. Shine

Date of Birth: 19 April, 1958.

Address: Department of Meteorology, Reading University.

Qualifications

1978: B.Sc. (Hons) Physics. Imperial College of Science and Technology.

1981: Ph.D., Department of Meteorology, Edinburgh University. Thesis title : Some development of a zonally averaged climate model'.

Employment

1981–1983: Senior Research Assistant, Department of Geography, University of Liverpool.

1983–1988: Postdoctoral Research Assistant, Department of Atmospheric, Oceanic and Planetary Physics, Oxford University.

1988–1990: CEGB Research Fellow, Department of Meteorology, University of Reading.

1990–: Lecturer, Department of Meteorology, University of Reading.

Other Relevant Experience.

1987–1990: Editor of the Royal Meteorological Society monthly journal Weather.

1987–: Member of the Department of Environment / UK Meteorological Office Stratospheric Ozone Review Group.

1987–1988: Co-author of the temperature trends chapter of the NASA / WMO Ozone Trends Panel Report.

1988–1989: Co-author of Polar Ozone chapter of WMO/UNEP report on Scientific Assessment of Stratospheric Ozone.

1989–1990: Lead author of section 2 (radiative forcing of climate) of the Intergovernmental Panel on Climate Change Working Group 1 report Scientific Assessment of Climate Change.

1990–1991: Co-author of Radiative Forcing chapter of WMO/UNEP report on Scientific Assessment of Stratospheric Ozone.

1991 : Awarded the L.F. Richardson Prize by the Royal Meteorological Society for most meritorious paper published in its Quarterly Journal by an author under the age of 35.

1992–: Member of Radiation Commission of the International Association of Meteorology and Atmospheric Physics.

1993–: Member of Steering Committee of WMO/UNEP Ozone Assessment 1994.

1993–: Convening lead author of Radiative Forcing chapter of the 1994 and 1995 Intergovernmental Panel on Climate Change Working Group 1 Climate Change Assessments.

Recent Publications

Shine, K.P., 1986. On the modelled response of the Antarctic stratosphere to a depletion of ozone. Geophys. Res. Lett., 13, 1331-1334.

Shine, K.P., 1987. The middle atmosphere in the absence of dynamical heat fluxes. Quart. J. Roy. Met. Soc., 113, 603-633.

Shine, K.P., 1989. Sources and sinks of zonal momentum in the middle atmosphere diagnosed from the diabatic circulation. Quart. J. Roy. Met. Soc., 115, 265-292.

Haynes, P.H., C.J. Marks, M.E. McIntyre, T.G. Shepherd and K.P. Shine, 1991. On the 'downward control' of extratropical diabatic circulations by eddy induced mean zonal forces. J.Atmos. Sci., 48, 651-678.

Pawson, S. and K.P. Shine, 1991. the effect on the modelled middle atmosphere of degrading radiation calculations. Ann. Geophys., 9, 654-660.

Shine, K.P., 1991. On the cause of the relative greenhouse strength of gases such as the halocarbons. J.Atmos. Sci., 48, 1513-1518.

Austin, J., N. Butchart and K.P. Shine, 1992. Possible Arctic ozone hole in an idealised doubled CO_2 climate. Nature, 360, 221-225.

Ramaswamy, V., M.D. Schwarzkopf and K.P. Shine, 1992. Radiative forcing of climate from halocarbon-induced global stratospheric ozone loss. Nature, 355, 810-812.

Gray, L.J. et al., 1993. First results from a 3-dimensional middle atmosphere model. Adv. Space Res., 13, 363-372.

Shine, K.P. 1993. The greenhouse effect and stratospheric change. in The Role of the Stratosphere in Global Change. Springer Verlag.

Curriculum Vitae
Peter Alister Stott

Date of birth: 15. 8. 1962

Address: Meteorology Department, Edinburgh University, James Clerk Maxwell Bldgs., King's Building, Mayfield Road, Edinburgh EH9 3JZ.

Qualifications

1983: BSc (Hons) 1st class (Mathematics) Durham University Certificate of Advanced Study in Mathematics

1984: Part III Mathematics Tripos, Cambridge University, Department of Applied Maths and Theoretical Physics

1988: PhD Imperial College of Science, Technology and Medicine "Effects of physical and chemical processes in storms on reactor accident consequences"

Employment

Sep 1984–Sep 1985 : Computer Programmer, Central Electricity Generating Board Computer Centre

Oct 1989–Mar 1993 : Post Doctoral Research Fellow Meteorology Department, University of Edinburgh, (United Kingdom Global Atmospheric Modelling Program core funding).

Apr 1993–Sep 1993 : French course, University of Geneva

Oct 1993 - present : Post Doctoral Research Fellow, Meteorology Department, University of Edinburgh, (United Kingdom Global Atmospheric Modelling Program special topic funding).

Recent Publications

Stott, P.A. and R. S. Harwood, An implicit time-stepping scheme for chemical species in a global atmospheric circulation model, Ann. Geophysicae, 11, 377-388, 1993.

Kettleborough, J. A., G.D. Carver, D.J. Lary, J.A. Pyle and P.A. Stott, Three dimensional modelling of chlorine activation in the Arctic stratosphere, submitted to Geophys. Res. Lett.

ApSimon, H.M. and P. A. Stott, Assessing the wet deposition of radionuclides, Meteorologie und Geophysik, 1, 1989.

ApSimon, H.M., J. J. N. Wilson, S. Guirguis and P. A. Stott, Assessment of the Chernobyl release in the immediate aftermath of the accident, Nucl. Energy, 26, 295-301, 1987.

Curriculum Vitae
Richard Swinbank

Address: Meteorological Office, London Road, Bracknell, RG12 2SZ.

Qualifications

1978: B.A. 1st class (Physics), University of Cambridge.

1982: M.A. University of Cambridge.

Employment

1978–: Meteorological Office. Worked on FGGE experimental data assimilation project during 1979, using the results to study the global circulation of the atmosphere. A particular area studied was the global angular momentum budget of the atmosphere. This led on to the development of a gravity wave drag scheme (now used by, or adapted for, many different weather prediction models). Other topics studied include the Madden and Julian Tropical Intraseasonal Oscillation. Transferred in 1987 to working on the operational data assimilation system, wit particular emphasis on the use of satellite sounding data. Also involved in re-writing the data assimilation scheme for use in conjunction with the 'Unified Model', adapting the scheme to use hybrid (sigma / pressure) vertical coordinates. Developed the stratosphere / troposphere assimilation scheme from the operational assimilation scheme for the UARS project.

1993–: Head of the Middle Atmosphere Group, UK Meteorological Office.

Recent Publications

Lyne, W.H., R. Swinbank, N.T. Birch, 1982. A data assimilation experiment with results showing the atmospheric circulation during the FGGE special observing periods. Quart. J. Roy. Met. Soc., 108, 575-594.

Lorenc, A.C. and R. Swinbank, 1984. On the comparison of general circulation statistics calculated from FGGE data - a comparison of results from two sets of analyses. Quart. J. Roy. Met. Soc., 110, 915-942.

Swinbank, R., 1985. The global atmospheric angular momentum balance inferred from analyses made during the FGGE. Quart. J. Roy. Met. Soc., 111, 977-992.

Palmer, T.J., G.J. Shutts and R. Swinbank, 1986. Alleviation of a systematic westerly bias in general circulation and numerical weather prediction models through an orographic gravity wave parametrization. Quart. J. Roy. Met. Soc., 112, 1001-1039.

Swinbank, R., T.N. Palmer and M.K. Davies, 1988. Numerical simulations of the Madden and Julian Oscillation. J. Atmos. Sci., 45, 774-788.

Miller, M.J., T.N. Palmer and R. Swinbank, 1989. Parametrization and influence of subgridscale orography in general circulation and numerical weather prediction models. Met. and Atmos. Physics, 40, 84-109.

Swinbank, R., A. O'Neill (1994). A stratosphere troposphere data assimilation system. Monthly Weather Review, 122, 686-702.

Farman, J.C., A. O'Neill and R. Swinbank, 1994. The dynamics of the polar vortex during the EASOE campaign. Geophys. Res. Letts. (in press).

Manney, G.L., R.W. Zurek, A. O'Neill, R. Swinbank, J.B. Kumer, J.L. Mergenthaler and A.E. Roche, 1994. Stratospheric warmings during February and March 1993. Geophys. Res. Letts., (in press).

Curriculum Vitae
Lance Thomas

Address: Physics Department, University of Wales at Aberystwyth.

Qualifications

1950: B.Sc. (Hons) University of Wales, Aberystwyth.

1953: Ph.D., University of Wales, Aberystwyth.

1972: D.Sc., University of Wales, Aberystwyth.

Employment

1959–1981: Senior, Principal and Senior Principal Scientific Officer, Appleton Laboratory.

1965–1966: Guest Worker, NOAA Environmental Research Laboratories, Boulder, Colorado, USA.

1981–: Professor and Head of Department of Physics, University of Wales, Aberystwyth.

Other Relevant Experience.

1975–77: Member of NASA Working Group for Scientific Definition of Spacelab Missions.

1982–87 : Chairman, Royal Society British National Committee for Solar Terrestrial Physics.

1987–88: Member, Earth Observation Programme Board of British National Space Centre.

1981–: Principal Investigator, SERC national MST radar facility.

1989–93: Member, SERC Astronomy and Planetary Science Board.

Publications

About 120 publications concerned with

(a) Analysis and interpretation of ionospheric data

(b) Theoretical models of ionospheric regions

(c) Theoretical studies of ionospheric radio-wave propagation

(d) Distribution of neutral constituents in mesosphere and lower thermosphere

(e) Airglow excitation processes

(f) Lidar probing of middle atmosphere

(g) Theoretical and radar studies of atmospheric waves and turbulence in middle atmosphere.