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STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE
A Project of the World Climate Research Programme

# Report on the 11th Session of the SPARC Scientific Steering Group

## Frankfurt, Germany, 22-25 September, 2003

**Vladimir Ryabinin,** JPS/WCRP, Geneva, Switzerland (VRyabinin@wmo.int)

## Introduction

### Opening of the session, introductory comments

The eleventh session of the SPARC Scientific Steering Group (SSG) was held in a guesthouse of the Johann – Wolfgang Goethe University of Frankfurt am Main, Germany, from 22-25 September 2003, at the kind invitation of **U. Schmidt** of the Institute for Meteorology and Geophysics, University of Frankfurt am Main, and a member of the SPARC SSG.

Opening the session, the SSG co-Chairs, **A. O'Neill** and **A. Ravishankara,** welcomed the new SSG members, **D. Hartmann** and **J. Burrows,** and expressed their expectation that the new SSG members would make an excellent contribution to the project. The chairs noted with appreciation the attendance of all ex-officio members representing WMO/GAW (**M. Proffitt**), COSPAR (represented by **M.L. Chanin**), SCOSTEP (**M. Geller**) and NDSC (**M. Kurylo**), as well as the presence of **D. Parish** for the IGAC project and **T. Wehr** of the European Space Agency. They also thanked **U. Schmidt, M.-L. Chanin** and **C. Michaut** for their work in preparing the meeting, which resulted in excellent local arrangements.

After a round of self-introductions, the chairs briefly introduced the current status of SPARC development. The new directions of SPARC research were discussed at the 10th SSG meeting in Kyoto and presented to the 24th Session of the WCRP Joint Scientific Committee (JSC, 17-22 March 2003, Reading, UK) and the Committee approved them. The JSC session put forward a new initiative on the development of the Climate system Observational and Prediction Experiment (COPE), which was expected to become a major WCRP overarching theme for the coming decade. The chairs called on the SSG members to think how SPARC would fit within COPE and contribute to it. Evaluating the current status of SPARC, the chairs noted that stratosphere was getting more recognition in climate research and numerical weather prediction, as well as in modern observing systems. The general goals of the 11th SSG meeting would be to continue the discussion on how SPARC would evolve as a collective project. SPARC needs a new Implementation Plan that would move forward SPARC research and would also facilitate integration of the project into other WCRP activities.

### WCRP comments

**V. Ryabinin** briefly described the most important activities of the WCRP projects, their recent achievements and main events. CLIVAR (Climate Variability and Predictability) activities are vast and include, among

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others, the continued development of the ARGO array, El Niño forecasting, unfolding monsoon studies in various parts of the world. In 2004, CLIVAR is holding the First CLIVAR Science Conference (Baltimore, USA, June 2004). GEWEX (Global Energy and Water Cycle Experiment) is active in developing the Co-ordinated Enhanced Observing Period (CEOP); it will include a very elaborate data-processing system, which includes specialised centres distributed around the world. The Arctic Climate System Study (ACSYS) is finishing in 2003 with a Final Science Conference held in St. Petersburg, Russia, in November 2003. Dramatic changes are being observed in the Climate and Cryosphere project (CliC), which is defining its main project areas and developing its implementation activities. The First CliC Science Conference will be held in 2005. In 2003, the Global Climate Observing System (GCOS) published its second report on the adequacy of climate observing systems. Stratospheric elements were sufficiently well represented in the report.

The JSC of WCRP, at its 24th session, considered the following outstanding science questions of the programme: hydrological cycle and its changes; modelling of clouds, radiation, and precipitation; sea level rise due to glacier/ice sheet melt; a possibility of an abrupt climate change due to a regime shift in the cryosphere; mechanisms of natural climate variations; effects of atmospheric composition on climate; anthropogenic impacts; inclusion of biosphere in climate models; and studies of the effect of bio-geo-chemical cycles on climate.

The JSC session decided to launch a new WCRP-wide activity called "Climate system Observational and Prediction Experiment" (COPE, 2005-2015). The first focus of COPE is to be the seasonal and interannual prediction, which will constitute the basis for the terms of references for a new task force.

Summarising his WCRP review, **V. Ryabinin** presented the following list of issues of high importance for SPARC in 2004/2005: SPARC Assembly in August 2004, move of the International Project Office from Paris, smaller budget at the Joint Planning Staff (JPS) of the WCRP; new tasks for WCRP as a whole, such as Task Force on Seasonal Prediction, possible changes in the WCRP structure, and the International Polar Year (IPY 2007-2008).

### Report from the Gordon conference

**V. Ramaswamy** continued the introductory session by reporting on a Gordon Research Conference on Solar Radiation and Climate, which was held at the Colby-Sawyer College, New Hampshire, USA, on 13-18 July 2003. SPARC co-financed the conference, which summarised the current research on physical and chemical factors in the observed radiative properties and energy budget of the planet and this led to a consideration of how perturbations of the radiative energy budget affect climate variations at several time scales, from seasonal to interannual and decadal (see full report on page 18).

### Strategic development of SPARC

On behalf of the two SSG co-Chairs, **A. O'Neill** addressed the session presenting new ideas on the strategic development of SPARC (see full paper on page 13).

Recent SPARC activities have been concerned with stratospheric indicators of climate change, study of stratospheric processes, development of modelling, various assessments and development of data assimilation. The recent deliverables have been: an assessment report "Stratospheric temperature trends: observations and model simulations" (paper awarded the WMO Norbert Gerbier-MUMM Award, 2003); a stratospheric reference climatology report, WMO/UNEP Ozone Assessment 2002, Chapter 4 of the publication "Global Ozone: past and future".

**A. O'Neill** summarized the expected future deliverables by SPARC:

- Temperature Trend Assessment Report.
- Aerosol Assessment Report.
- Review on Arctic Oscillation / North Atlantic Oscillation for stratosphere - troposphere system.
- Review of gravity-wave parameterizations.
- Review of scientific issues in the domain of chemistry and climate.
- A review on global circulation models / chemical transport models with focus on ozone and predictions of mid-latitude $O_3$ .
- A contribution to IPCC process.

**A. O'Neill** concluded his presentation by indicating the most important links of SPARC with other WCRP Projects.

In the subsequent discussion, the SSG members agreed that the three main streams of the future research were indeed the issues of highest priority for SPARC. The lack of a dedicated WCRP project addressing chemistry in troposphere was seen as a problem. The group felt that it was very important to move ahead from detection of trends towards their understanding and attribution. The meeting decided to embark on preparations of a new implementation plan for SPARC.

### The stratosphere in the climate system: an overview

The introductory part of the session was concluded by a new SSG member, **D. Hartmann,** who gave an overview of the stratosphere in the climate system focussing mostly on dynamical aspects. His talk presented a list of research topics of importance for SPARC that included stratospheric warmings, mechanisms for the impact of the stratosphere on the troposphere, annular modes of variation and long-term trends, possible slow down of the Brewer – Dobson circulation in a warmer climate, explanation of trends in stratospheric water vapour, studies of radiation, convection and circulation of the tropical tropopause (see full report on page 15)

## The New SPARC Strategies

### Detection, attribution and Prediction of stratospheric changes

**W. Randel** presented this item on behalf of a group of SPARC specialists. He reported on the preparation of a one-day workshop on understanding seasonal temperature trends in the stratosphere, which was held in Silver Spring, USA, on 5 November 2003, following a symposium honouring the career of J.K. Angell. The workshop was being organised by the SPARC Stratospheric Indicators of Climate Change Initiative and addressed observations, model simulations of stratospheric temperature changes and their interpretation, and the effect of stratospheric variability and circulation on trends (see workshop report on page 24).

From the view-point of observations, two important issues were noted by **W. Randel.** They are the continuity of stratospheric temperature data sets and data on stratospheric water vapour changes. Changes in meteorological analysis procedures or in data characteristics strongly influence current stratospheric data sets. There are significant uncertainties in all analyses associated with the change of data source from TOVS to ATOVS Polar

*Participants of the SSG in Frankfurt. From left to right.*
*First row: A. Ravishankara, A. O'Neill, V. Ramaswamy, M. Geller*
*Second row: S. Yoden, M.-L. Chanin, V. Yushkov, J. Burrows, M. Kurylo*
*Third row: K. Kodera, T. Shepherd, V. Ryabinin, M. Baldwin, W. Randel, P. Canziani,*
*Fifth row: T. Peter, F. Lübken, T. Wehr, U. Schmidt, D. Parrish, D. Hartmann, M. Proffitt*

Orbiting Sounding products. This will affect future assessments, and for further studies it is important to recognise the inherent observational uncertainties. SPARC should encourage efforts to improve the observational record in the future. There must be work on a more integrated understanding of past changes, which would involve studies of trends in ozone, temperature and water vapour trends, as well as aerosol assessments. Modelling results should be more widely used to explain and verify the trends. The SPARC workshop following the Angell Symposium and a workshop on coupled climate models in Garmisch-Partenkirchen, November 2003, could be instrumental in finding better ways of studying the trends. Opportunities to link activities with those of GRIPS should be explored. SPARC has to develop other strategies for the attribution of stratospheric trends and this can contribute well to interests of wider communities, such as WMO, IPCC assessments and goals of environmental agencies. **V. Ramaswamy** concurred with points made by **W. Randel** and mentioned that high natural variability in the atmosphere created particular difficulties of water vapour trend analysis in the latitudinal belt from 60° to 90° of winter hemisphere.

According to the views of **S. Pawson,** "understanding the past" could be a new major direction for GRIPS. It could be a natural development of existing level-3 GRIPS activities. This would be a solid contribution to detection and attribution work of SPARC. A "climate – chemistry" component of GRIPS could form as a new level-4 activity, which would fit perfectly the new SPARC research directions. Successful implementation of these tasks would open the way for level-5 activities, which could be devoted to predictive experiments. It will be essential to have credible atmospheric global circulation models with full troposphere, robust radiation codes, parameterizations for hydrological cycle and other physical factors and with upper boundaries in the mesosphere. The SSG agreed with these comments and expressed a view that GRIPS leaders should seek to encourage the GRIPS community to participate fully in these scientific challenges.

The SSG requested **W. Randel, S. Pawson,** and **K. Kodera** to lead further development of SPARC activities in the area of change detection, attribution and prediction. The group felt strongly that GRIPS was able to contribute crucially in the stream of SPARC science.

## Stratospheric chemistry and climate

**A.R. Ravishankara** introduced this item. Significant progress in reviewing the current state of affairs and in planning was achieved at a joint SPARC-IGAC Workshop on Climate-Chemistry Interactions held in Giens, France, on 3-6 April 2003 (see SPARC Newsletter N°21). The discussions at the workshop have highlighted five major topics: aerosols and climate, water vapour and clouds, stratospheric ozone and climate, tropospheric chemically active greenhouse gases (GHGs), stratosphere-troposphere (ST) interactions. A paper summarising the results of the workshop will be written in time for the 3rd SPARC General Assembly. It will be available on the SPARC and IGAC web sites.

Atmospheric measurements alone are not capable of providing reliable information on abundance of short-lived greenhouse species and, therefore, their representation in models requires extensive process studies. The aim of the new programme will be to reduce the uncertainties in chemically dependant climate forcings, for which aerosols are one significant issue. Aerosol forcing is regional, and the proposed approach will be to run high resolution regional models fed by well-defined measurements and then to scale up to global climate models. The aerosol indirect effect is a complex process involving interactions between the aerosols, dynamics, cloud microphysics and the gas phase. The aerosol indirect effect, too, requires a coupled approach of using high resolution models and well defined measurements. For the water vapour, the key question will be the mechanisms that control the humidity in the upper troposphere and stratosphere, as well as its long-term changes. There is a link to aerosols through cloud formation, evolution, their effects on radiation, precipitation and chemical composition of the atmosphere. Important climate-chemistry feedbacks need to be quantified, whilst models representing them need to be systematically compared. Satellite data should help to reduce uncertainties in data on emissions of aerosols and ozone precursors. Careful evaluation of such data as GOME and SCIAMACHY at highest possible resolution is needed to have solid confidence in the products. In order to address ST interactions, one needs to assess the representation in global models of the spatial distribution and temporal variability of constituents (including aerosols) in the lowermost stratosphere and tropical tropopause layer, and to establish metrics based on observations of long-lived stratospheric tracers. Without this it will be difficult to ensure realistic representation in models of the fluxes of mass, ozone and other constituents from the stratosphere to the troposphere.

The scientific problems, presented above, could form the foci of strong collaboration between SPARC and IGAC. The following topics are indicative of priorities:

• The role of UTLS aerosol and clouds in chemistry, in climate, and in their interactions: understanding and representing microphysical, chemical and radiative processes in numerical models.

• The role of convection (both deep and warm) in controlling UTLS water and chemical constituents.

• Tropical tropopause layer and climate-chemistry interactions.

• The extent and role of ST exchange in controlling the abundances of ozone and other species in the UTLS and, specifically, an accurate quantification of the ST exchange contribution to tropospheric and upper-tropospheric ozone budget.

• The use of tracers and their variability in observations and in models to identify and diagnose roles and contributions of processes, an assessment of the role of inter-annual variability in the circulation patterns affecting the distribution of chemical constituents in the stratosphere and troposphere.

• The role of lightning in the production and distribution of nitrogen oxides.

• Determination of the fundamental parameters in kinetics, heterogeneous chemistry (specifically aerosols and ice in upper troposphere), photolytic processes, spectroscopy, and optical properties *via* laboratory studies.

• Satellite observations of trace species and meteorological parameters in the troposphere and lower stratosphere, assimilation of satellite observations, evaluation of models by using satellite data.

**J.P. Burrows** picked up the last theme and tried to further elaborate the SPARC strategy in developing observations for studying climate - chemistry interactions. The classical view on this is that chemistry changing from both natural phenomena (e.g., volcanic emissions) and anthropogenic activity (e.g. pollution, emissions, land use etc.) results in changes in the surface spectral reflectance, the composition of trace gases and aerosol, which are both chemically and radiatively active, radiation, cloud cover, precipitation rates, i.e. weather (short term) and climate (in the medium and long term). However, the system is nonlinear and includes feedbacks.

Important issues are the extent and non-linearity of the coupling and interaction between the chemistry, weather and climate, and the attribution of the natural and anthropogenic contributions to changing and variable atmospheric composition and conditions. Emphasis needs to be focused on regional air quality, long-range transport and transformation of pollutants, the atmospheric lifetime and turnover of GHGs and aerosols.

For the stratosphere the questions are as follows. Will ozone recover from chlorine driven depletion as predicted? What is the role of tropopause height changes in ozone trends, in climate and chemistry interactions? What is the role of bromine? Will the dynamics and circulation remain stable and what will be the impact of a changing circulation on the chemical composition?

Additional scientific questions arise in connection with the mesosphere. Are the mesospheric composition changes a potential early warning signal for climate change? What is the nature of the noctilucent clouds, their cover and frequency? To what extent is the mesosphere an $NO_x$ source for the stratosphere? Do we understand well enough all the processes involved in transformations between $O_2$ and $O_3$ in the mesosphere?

Some of these questions will be addressed by forthcoming satellite missions, which will provide a basis for first sensitivity studies. The goal will be to estimate, based on given instrument performance, the mean noise-induced error on geophysical parameters. The method is based on the radiative transfer simulation, instrument model and retrieval algorithm. It has been already applied in various sensitivity studies in the MIPAS, GOME, GOME-2, GOMOS and SCIAMACHY projects.

The integrated observing strategy, as seen by the current CEOS-IGOS-IGACO activities, comprises high resolution spatial and temporal measurements of key constituents. Three to four geostationary and two low orbit satellites would constitute the space segment, which should be complemented by ground based measurements and aircraft process studies campaigns. Continuity is an absolute requirement for the satellite systems.

Summarising his presentation, **J. Burrows** informed the meeting that a SPARC-IGAC 1$^{st}$ International UV/vis Limb Scattering Workshop took place in Bremen, Germany, on April 14-15, 2003 (see workshop report on page 31). He also named several ongoing European projects, which were presented to the SPARC SSG on 24 September 2003. He concluded by stating that more observations were necessary, that satellites were demonstrating some interesting capabilities, and that there was a true need to move towards an integrated observing system addressing key atmospheric constituents, comprising satellites, ground based measurements and campaigns with aircraft.

Following **J. Burrow**'s presentation a concern has been raised that at the moment the system was unable to provide continuity for trend analysis.

On behalf of **N. Harris, A. Ravishankara** presented the eight-year UK NERC funded thematic programme UTLS OZONE, which started in 1998 to study ozone in the UTLS. The Programme aims to make authoritative statements on chemical, dynamical and radiative processes controlling the distribution of ozone in the UTLS at middle latitudes. Studies related to pollution (from surface sources and from aircraft) and to chemistry/climate interactions will be in scope. In total, within the programme, 45 projects have been funded, which are summarised below.

Stratospheric humidity affects both radiative forcing of climate and stratospheric composition including ozone abundance. Current observational data are unable to tell us whether the humidity of air entering the stratosphere through the tropical tropopause is controlled by slow dehydration in weak mean ascent, or by rapid dehydration in dramatic overshooting cumulus clouds. Experiments performed within the UTLS OZONE Programme using a numerical cloud-resolving model clearly favour the slow-dehydration scenario.

Research within the UTLS OZONE Programme has identified a number of important oxygenated volatile organic compounds released from soot during oxidation by ozone. This is previously unreported in the literature (although water soluble species have previously been observed to be formed and retained under similar conditions). This observation may explain some of the measured complexity of organic species present in urban atmospheres.

Model simulations were used to investigate how the ozone layer will recover, as chlorine concentrations decrease during the next decades, but concentrations of GHGs increase. Results indicate that global ozone would decrease by 1% between 1979 and 2060 when the increases of greenhouse gas concentrations are ignored. When GHGs are included, ozone was found to increase by 0.5%. The work on the causes of observed temperature trends in the stratosphere has input directly into the WMO/UNEP Scientific Assessment of Stratospheric Ozone 2002, which supports the Montreal Protocol process, and which aims to protect the ozone layer.

As part of the UTLS OZONE Programme, the photodissociation quantum yields of acetone were measured over atmospherically relevant ranges of wavelength, pressure and temperature, and the lifetime of acetone in the UTLS is a factor of 2 longer when using the new quantum yields.

The UTLS OZONE discussions are ongoing regarding the possibility of installing equipment to measure trace gases on British commercial aircraft. A workshop "Aerosols in the UTLS" was held at the University of Oxford, 17-18 December 2003, organised jointly with the CWVC Programme. CIRRUS and ITOP campaigns will be held following launch of the new FAAM BAE-146 aircraft.

**T. Peter** then discussed related studies of cirrus clouds and tropical tropopause layer. Analysing the radiative properties of the clouds, he emphasised the need to better understand the nucleation of ice particles. Other issues are whether there is a trend in tropical tropopause layer water vapour concentrations, and/or whether there is a trend in cirrus coverage in the tropical tropopause layer. One needs to understand the relative roles of cirrus and deep convection in the dehydration mechanism. **T. Peter** emphasised the need for an explanation of the stratospheric humidity increase and he presented a number of related findings.

**W. Randel** presented a new initiative called Integrated Study of Dynamics, Chemistry, Clouds and Radiation of the UTLS. The scientific significance in this initiative stems from the importance of the radiative and chemical impacts of UTLS ozone, water vapour, cirrus clouds and aerosols. The initiative is based on active utilisation of new observational capabilities: aircraft HIAPER (2005) (see full report on page 34), the AURA satellite (2004) and other A-train platforms, GPS/COSMIC (2005). A UTLS community workshop was held in October 27-28, 2003 at NCAR, Boulder, USA. A science working group will be formed to plan integrated research using HIAPER and to optimise integration with satellite programs and multi-scale models.

The SSG requested **A. Ravishankara, J. Burrows** and **T. Peter** to lead further development of SPARC activities in the area of climate - chemistry coupling. Some experts outside the SPARC SSG could be invited to further strengthen the transition team.

## ST dynamical coupling

**M. Baldwin** started the discussion of this topic and informed the meeting of a workshop "The Role of the Stratosphere in Tropospheric Climate", which took place in Whistler (BC), Canada, on 29 April-2 May 2003 (see report in SPARC Newsletter N°21 and **www.atm.damtp.cam.ac.uk/shuckburgh/Whistler/**). **M. Baldwin** was one of the workshop organisers. The purpose of the Whistler workshop was to improve the understanding of the role of the stratosphere in tropospheric climate on sub-seasonal to multi-annual timescales. The focus was on understanding the dynamical mechanisms that link the variability in these two regions.

The workshop was very successful. A short perspective and review paper will be prepared in the near future. A summary of the discussions at the workshop contains, *inter alia,* the following conclusions:
• The stratosphere influences the troposphere.
• Together with the tropical troposphere, the stratosphere is a player in determining the memory of the climate system.
• The influence is mainly during northern winter and southern spring.
• The stratosphere may play an important role in climate variations through downward coupling to SSTs, sea ice and the high-latitude oceans.
• The most pressing issue is to better understand the dynamical processes by which the tropospheric circulation responds to changes in the stratosphere.

**M. Baldwin** also presented some observational results depicting ST interactions by using a decomposition of the total atmospheric pressure variability into empirical orthogonal functions and considering the dominant pattern, the Northern Annular Mode (NAM). He showed several examples favouring the concept of the leading role of the stratosphere in variations extending through both stratosphere and troposphere, such as variations triggered by stratospheric warmings.

**M. Baldwin** was able to show that it was possible to develop a statistical approach to Arctic Oscillation (AO) Index Forecasting. Enhanced predictability showed that there was a not yet understood mechanism of ST coupling. An "amplifier" is needed to communicate circulation anomalies in the lowermost stratosphere to the surface and this amplifier likely involves both planetary and synoptic scale waves near the tropopause region.

**M. Baldwin** concluded that:
• Persistence and predictability of the AO depend on the long timescale of large circulation anomalies in the lowermost stratosphere.
• The most pressing issue in ST coupling is to better understand the dynamical processes by which the tropospheric circulation responds to changes in the stratosphere.
• This understanding may help to better predict not only the weather on monthly and seasonal time scales, but also the climatic effects of greenhouse gas increases, stratospheric ozone depletion, solar changes and volcanoes.

**F.-J. Lübken** added to the presentation a comment that mesosphere winds could act as early precursors of changes in stratosphere.

**T. Shepherd** continued the discussion of the ST coupling studies by reviewing the major peculiarities of the ST system. Firstly, the system is open because cooling to space takes place. Secondly, its angular momentum budget is tightly constrained. Apart from seasonal cycle, the short-term variability of the system is driven by variability in the Eliassen - Palm flux divergence, which is generated either by tropospheric wave sources or internally in stratosphere. This results in a stronger or weaker circumpolar vortex. The stratosphere can exhibit downward propagation of wind anomalies and has long-term memory compared with the troposphere. The studies of ST coupling receive considerable attention and are supported by funding agencies. There is need to strengthen the connections of the tropospheric science community, including IPCC.

A targeted workshop as a follow-on from the SPARC Assembly may be required. It could well be organised as a SPARC-WCRP workshop and would cover a range of time scales from seasonal to long-term ones.

**S. Yoden** presented to the SSG a series of experiments with so-called mechanistic circulation models, which contained a simplified physical package in comparison with full climate models but enabled longer time integration (up to millennium) and ensemble experiments. The model included an imposed quasi-biennial oscillation. Seasonal composites of zonal mean temperature were analysed. Statistical analysis of the long series generated significant estimates of distributions, which can form the basis for understanding climate variability and change.

The SSG felt that **M. Baldwin, T. Shepherd** and **S. Yoden** could lead further development of SPARC in the area of ST coupling. It also requested **M. Baldwin** to represent SPARC in the WCRP task force on seasonal prediction.

## Cross-cutting and Supporting Projects

### Data Assimilation

**A. O'Neill** started his analysis with a list of data assimilation requirements for SPARC science. They include:
• Long term, global data sets for the troposphere and stratosphere, free of artificial trends.
• 3-D velocity fields with reduced data assimilation "noise" at an interval of several hours.
• Estimates of mass fluxes associated with sub grid-scale processes.
• Diabatic heating rates.
• Ozone, tracers and aerosols.
• Attention to bromine in the UTLS region.

To fulfil these requirements is the goal of the SPARC Data Assimilation (DA) initiative. A DA working group has been established, which
• Collects information on stratospheric data sets on meteorology and chemistry (quality, availability, software…);
• Undertakes process-focused quality assessments;
• Collects and documents information in DA systems;
• Liaises with space and other agencies on SPARC data needs.

In June 2003 SPARC organised two meetings on stratospheric DA, an ASSET/SPARC workshop in Florence, Italy, and an ECMWF/SPARC workshop in ECMWF, Reading, UK (see report in SPARC Newsletter N°21).

In the work on collecting information on stratospheric data sets, the group objectives are to:
• Overview most used datasets (UK Meteorological Office, ECMWF, NCEP, etc.).
• Prepare a web site with links to information on each dataset and related publications.
• Produce a test dataset for SPARC intercomparisons (a proposal is already available).

The aim of process-focused quality assessments is to compare different analyses using diagnostics tailored to particular problems. The developed diagnostics focus on the following issues:
• Polar processes (Arctic polar stratospheric clouds, chlorine activation, areas of low temperatures);
• Fine-scale structure and filamentation;
• Mixing and transport barriers;
• Wave propagation into stratosphere and effects on modelling studies;
• ST exchange and tropics, $O_3$ mini holes.

The group collects and documents information on stratospheric DA systems for global circulation models (e.g. DARC/UK Meteorological Office, ECMWF, Canadian Meteorological Service), chemical transport models (e.g. KNMI, BIRA-IASB, UPMC, DAO), and coupled systems (e.g., Météo-France). It liaises with space and other agencies on SPARC data needs and tries to anticipate their requirements.

Space agencies mostly require:
• Information on instruments (past, current and future) and how good they are;
• Feedback on observation strategies: what and how to measure;
• Exploitation of datasets: calibration/validation and quality-control, access by earth observation community to achieve best use of investment.

Meteorological services mostly need: stable, high-quality data (good resolution, good error characteristics, good coverage and near real time) with "pedigree"; data that can improve forecast skill (i.e. confront models with observations); to improve and extend services to society (e.g. "chemical weather").

### Stratospheric processes

**T. Shepherd** and **A. Ravishankara** presented this item based on contributions from several scientists including **K. Hamilton** who submitted an analysis of the SPARC Gravity Wave Initiative activities.

*Radiosonde Climatology*
This SPARC-coordinated activity looks at the climatology of wavelike fluctuations in ultrahigh-resolution radiosonde wind and temperature data. It has involved participants from eleven countries and data at over 200 stations worldwide. Some of the individual participants in the project have submitted papers on analysis of their own national data. **R. Vincent** and co-authors are completing a draft of a journal paper discussing the climatology produced by analysis of the entire data set (a preview is available in SPARC Newsletter N°20). There is a question of how much of the original data used in the study can be made available through the SPARC Data Centre and contacts are made with the participants to see if they are willing (and are legally able) to send their data to the SPARC Data Centre. It is believed that the SPARC Data Centre is the only location where a substantial collection of the high-resolution balloon data will be conveniently available to the research community.

*DAWEX Experiment*
The DAWEX experiment (carried out October-December 2001) examined the middle atmospheric gravity wave field in the Northern Australian region and its relation to tropospheric convection. At a small workshop, which was held in Honolulu in December 2002 to discuss analysis of the results, the participants decided to produce coordinated manuscripts for submission to a special issue of a journal (see workshop report in SPARC Newsletter N°20).

*Chapman Conference*
The SPARC Gravity Wave Initiative co-chairs had produced a proposal to American Geophysical Union (AGU) to hold a Chapman Conference on Gravity Wave Processes and Parameterization. This proposal was accepted by AGU and the conference was scheduled for 10-14 January 2004 at Waikoloa, Hawaii. The Conference may be regarded as the sequel meeting to the earlier NATO Advanced Research Workshop on "Gravity Wave Processes and Parameterization in Global Climate Models" held in 1996, which was co-sponsored by SPARC.

*Prospects for the Gravity Wave Initiative*
Over the year 2004 the main projects that the Gravity Wave Initiative has pursued, namely the radiosonde climatology and the field experiment in Northern Australia, should be essentially completed. At the SSG 2004 it should be possible to give final reports on these projects and to review the Hawaii Chapman Conference. Many uncertainties in the gravity wave problem will still remain, and there may still be a useful role for SPARC in

coordinating some research activities. The more "engineering" aspects of the gravity wave parameterisation issue may be passed to the GRIPS initiative (and possibly also the DA initiative). An important remaining issue is possible SPARC involvement with future field experiments that includes studies of convective forcing of gravity waves. The US ARM program is planning a large campaign based in Darwin for January 2006. There is some European funding for a Geophysica/Falcon campaign in the western tropical Pacific region in 2006 or 2007.

The SPARC SSG meeting in Kyoto decided to look into possibilities of organizing an equatorial superpressure balloon campaign. **K. Hamilton** enquired with a few specialists and concluded that there was enthusiasm and interest for a campaign that would, at a minimum, produce a great deal of *in situ* wind data in the equatorial lower stratosphere. Such a campaign should be coordinated with stratospheric DA efforts. The SCOUT project, which was presented to the SSG later in the meeting (see below), is expected to stimulate a long duration balloon campaign at the Equator funded mostly by national sources. The COSPAR meeting of 2004 and the 3rd SPARC Assembly in August 2004 will provide an opportunity to discuss the scope for such a campaign (e.g. whether chemical measurements could be included in it), and find out how a SPARC group could facilitate national efforts.

*Past and future "laboratory" Projects*

As reported by **A. Ravishankara,** this activity started in 1999, when a peer-reviewed paper on small organic peroxy radicals was published in the J. of Geophysical Research (JGR). In 2002 laboratory data evaluation resulted in updated data for quantum yields for production of $O(^1D)$ in the ultraviolet photolysis of ozone, also published in JGR, 2002. **S. Solomon** (co-Chair of the IPCC Working Group 1) requested a SPARC sponsored study of the global warming potential of hydrofluorocarbons (HFC) 134a. Five groups of specialists are currently involved in this activity. Associated radiative forcings and their uncertainties will be estimated, mostly using line-by-line models with account of vertical profile of HFC, clouds, typical temperature profiles inclusive of tropopause. Some preliminary results were presented to the SSG session. There is some discrepancy of the results. Its origin will be investigated and the results will be recalculated. A paper was to be prepared for submission by the end of 2003.

## SPARC Aerosol Assessment

**T. Peter,** also on behalf of **L. Thomason,** presented the status of ASAP, the SPARC Aerosol Assessment. After the kick-off meeting at CNES in November 2001, there have been an informal meeting at Spring AGU Washington, DC, in May 2002, and a lead authors meeting in July 2003.

The scope of the prepared report comprises aerosol processes, precursor gases, aerosol instruments and measurements, aerosol records and climatology, trend analysis, and related modelling. The aerosol record will be presented in the coordinates of equivalent latitude and potential temperature.

The main data sources for ASAP are measurements by SAGE (Stratospheric Aerosol and Gas Experiment), HALOE, optical particle counters and lidar data sets. From primary measurements of extinction, backscatter, size distribution, data sets of Surface Area Density (SAD), effective radius, volume/mass were derived for the period 1979-2003.

The following problems of measurements and analysis were noted. Satellite-based SAD tends to underestimate *in situ* measurements, particularly those including small particle sizes. The scale and ubiquity of the problem is not clear. Size-resolved (≥ 10 nm) aerosol observations in the stratosphere are therefore needed. The importance of meteorites and smoke is uncertain. There is significant uncertainty in trends, which makes it difficult to even detect their sign.

Extinction ratios (size) are inconsistent between models and measurements; modelled lower stratospheric tropical extinctions are too low for the measured SAD. Work is underway on processing data from major volcanic eruptions.

The assessment should be completed in 2004. A lead author meeting is being organised at the Atmospheric and Environmental Research Inc. in Lexington, USA, on 18-21 January 2004. The draft assessment report is expected in February 2004. After a peer-review, the assessment will be printed.

## SPARC Data Centre

The aim of the SPARC data centre is to provide data to the SPARC scientific communities and their major programmes. **M. Geller** reviewed the status of the SPARC Data Centre. The web site is located at **http://www.sparc.sunysb.edu**. **X.L. Zhou** is the centre manager.

The SPARC FTP Server is located at **ftp://atmos.sparc.sunysb.edu/pub/sparc**. There is a link to numerous other data centres. The new acquisitions include: daily mean temperatures, geopotential heights, pressures, and saturation mixing ratio of water vapour at the tropical cold point tropopause, derived from ECMWF reanalysis; a data set of temperature field near the tropical tropopause; the US high resolution radiosonde data set, which includes data from 93 stations for 1998-2001 obtained from NOAA (data for 2002 will be put online when available).

The SPARC grant period is from February 2002 to January 2005 (inclusive) and work is underway to renew the grant and upgrade the data centre computer.

The idea of having a back-up centre was proposed and **S. Yoden** agreed to consider its possible location in Japan. The problem of data certification was raised along with the need to ensure high quality for all data available at the Centre.

## Co-operation with IGAC/IGBP

This SSG session benefited from the participation of two scientists from IGBP, the Chair of the IGBP Scientific Committee **G. Brasseur** and **D. Parrish** of the International Global Atmospheric Chemistry project (IGAC).

**G. Brasseur** gave a broad introduction to the IGBP activities and its co-operation with the WCRP in the framework of the Earth System Science Partnership (ESSP). The goal of IGBP is to describe and understand Earth System dynamics focusing on the interactive biological, chemical and physical processes, the changes that are occurring in the dynamics and the role of human activities in these changes. At present the programme has entered its Phase II and has a new structure built around the three compartments of the environment: atmosphere, land, ocean, their respective boundaries and needed integration activities. **G. Brasseur** introduced all major components of the IGBP II and the four joint projects of the ESSP on water, food, global carbon and human health, as well as the Global Change System for Analysis, Research and Training (START). Areas where interactions occur with WCRP projects were indicated. A new development in the ESSP is the start of the Integrated Regional Studies, which involve all sciences (natural, social, economic).

**G. Brasseur** introduced in more detail the IGAC and its two overarching questions: (1) What is the role of atmospheric chemistry in amplifying or damping climate change? (2) What effects do changing emissions and deposition, long-range transport, and transformations have on the chemical composition of the atmosphere and on air quality? The programme needs to operate across traditional organizational boundaries at regional to global scales, integrating traditional troposphere (IGAC), stratosphere (SPARC) and measurement (GAW, IGOS) programmes. It needs to develop strategies in concert with ocean and terrestrial scientists to quantify the exchange of chemical species between atmosphere/ocean/land/biosphere and to build a common interactive emission database.

**D. Parrish** presented activities of the Intercontinental Transport and Chemical Transformation (ITCT) task team within IGAC and concluded that UTLS and SPARC are of significant interest for IGAC. Possible joint actions of SPARC and IGAC could include coordination of measurements campaigns and development of joint observational strategy. There may be a need in high resolution (~100 m) observations in the tropopause layer as proposed by **G. Brasseur. D. Parrish** also emphasised the high efficiency of using aircraft observations for atmospheric chemistry observations, because the cost of one satellite is comparable to the cost of using tens of aircrafts.

## Co-ordination with other programmes

*European Space Agency (ESA), National Aeronautics and Space Administration of the USA (NASA)*

**T. Wehr** from ESA gave a very comprehensive account of current and future ESA programmes and related activities (for additional information, see **http://www.esa.int/export/esaCP/index.html**).

Selected Earth Explorer Core Missions include GOCE and ADM-Aeolus and Opportunity Missions are Cryosat and SMOS.

Additional information and access to ESA data can be obtained *via* an Open Distributed Information and Services for Earth Observation (ODISSEO) at **http://odisseo.esrin.esa.it/**. **T. Wehr** also presented in more detail the Atmosphere and Climate Explorer Mission (ACE+), which will perform atmospheric profiling using radio occultation; stratospheric wind interferometer for transport studies (SWIFT) onboard GOSAT, which is a European-Japanese-Canadian stratospheric dynamics mission; WALES, which is intended to determine profiles of water vapour accurately and at high vertical resolution from space with global coverage, using Nadir-viewing water vapour Differential Absorption Lidar (DIAL) System.

**T. Wehr** drew attention to the fact that ESA/ESTEC was planning to issue an invitation to tender for a study of advances in the research in atmospheric chemistry and dynamics by development of coupled chemistry-dynamics DA models.

*The Integrated Global Observing Strategy* (IGOS) partnership approved a theme on Integrated Global Atmospheric Chemistry Observations (IGACO). The IGACO team is currently developing a strategy for the evolution of the global atmospheric composition observation system and the integration of data.

**P. DeCola** of NASA was unable to attend the session and **M. Kurylo** presented some of the related activities and especially the extensive program of aircraft atmospheric chemistry measurements, which extends from tropics to the polar regions.

*COSPAR*

**M.-L. Chanin,** Chair of the Scientific Committee of the next COSPAR General Assembly to be held in Paris, France, July 19-24, 2004, gave first hand information about this important event. She mentioned that two interdisciplinary lectures would be of direct interest for the SPARC Community. **P. Crutzen** will present the "First results from ENVISAT" and **C. Fröhlich** will give a talk on "Solar radiation and climate". There will also be a panel on "The role of space in monitoring global change" where the issue of long-term commitment to atmospheric observations will be raised.

Among the disciplinary sessions of COSPAR 2004, four are co-sponsored by SPARC (see **www.COSPAR2004.org**).

*SCOSTEP*

**M. Geller** represented the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP). After a brief reminder of the nature and structure of SCOSTEP (**www.ngdc.noaa.gov/stp/SCOSTEP/scostep.html**), he focussed his talk on the major SCOSTEP project entitled "Climate and Weather of the Sun-Earth System" (CAWSES), a new SCOSTEP Programme for 2004-2008.

There are four CAWSES themes: (1) "Solar Influence on Climate", (2)"Space Weather: Science and Applications", (3)"Atmospheric Coupling Processes", (4) "Space Climatology". The successful implementation of CAWSES will provide an integrated scientific framework for solar-terrestrial research in the future, and produce an informed basis for guiding later programmes under different solar conditions and changing anthropogenic influences.

*NDSC accomplishments and the future*

**M. Kurylo** updated the SSG on the progress in the development and activities of the Network for the Detection of Stratospheric Change (NDSC) of which the goals were defined in the SPARC Newsletter N°19 and at **http://www.ndsc.ws**. NDSC strives to ensure data quality and the investigators subscribe to a protocol designed to ensure that archived data are of as high a quality as possible within the constraints of measurement technology and retrieval theory.

## German and European Research Programmes

A half-day of the meeting was devoted to a joint session with German and European scientists who presented an impressive review of national activities and their research under the framework of European Programmes. **U. Schmidt** opened the session and introduced the German colleagues.

*German Atmospheric Research Programme AFO 2000*

**M. Dameris** presented a very impressive Atmospheric Research Programme 2000, which is a component of the "Research for the Environment" of the German Federal Government. AFO 2000 has been in place since July 2000 (see **http://www.afo2000.de**).

The programme is divided into 4 theme groups: (1) "Surface-Atmosphere Interactions", (2) "Chemistry, Dynamics, Radiation, and their Interactions", (3) "Multiphase Processes", (4) "Atmosphere-System Analysis: Models and Data".

*Mesospheric Research – an overview of German activities*

**F.-J. Lübken** presented the results of several areas of mesospheric research using data from various instruments and stations. Trends in the mesosphere have been obtained for the summer temperature, altitude and occurrence of noctilucent clouds, seasonal heights of polar mesospheric clouds.

*UTLS*
A new concept for atmospheric measurement campaigns for studies of ST exchange was presented by **A. Engel.** It is being implemented by the AFO 2000 project SPURT with the objective to investigate transport, mixing (and chemistry) in the extratropical tropopause region based on regular airborne observations of chemical composition (see full article on page 29).

*Results of a 40-year simulation with ECHAM*
**V. Grewe** presented new simulation results based on the ECHAM climate model, version E39/C, which is a ST fully coupled chemistry-climate model. The physical model package includes parameterizations of radiation, clouds, precipitation, convection, and diffusion. The chemistry module includes 37 species and 107 gas-phase reaction, methane oxidation, polar stratospheric cloud formation with 4 related heterogeneous reactions, parameterization of dry/wet deposition, lightning and surface emissions. Physical and chemical modules are interactively coupled at every time step. The goal of on-going experiments is to realistically simulate the Earth's atmosphere from 1955 to 2000. One out of three transient simulations was just finished and **V. Grewe** presented preliminary results.

*New results from ENVISAT*
ENVISAT has been successfully launched on the night from 28 February to 1 March 2002. German participants in the SSG session reported on their work with several sensors on the satellite.

**H. Fischer** has presented the status of the MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) and described an experiment with its data. The data will be processed to derive global distributions of temperature and more than 25 trace constituents. In addition, the detected broadband spectra will allow determination of polar stratospheric clouds properties and, in case of high load, aerosol amount.

**J. Burrows** presented new results as part of an extensive validation campaign of SCIAMACHY (see ESA Envisat home page at **http://envisat.esa.int** for near-real time and offline data) and some information about GOME on ERS-2. Germany is supporting a major part of the SCIAMACHY Validation Structure and there are 20 national projects involving ground-based and ship-born data from aircraft, balloons and satellites (see the SCIAMACHY homepage **http://www.schiamachy.de** and the SCIAMACHY Operations Support Team's site **http://atmos.af.op.dlr.de/projects/scops**).

The ENVISAT instrument GOMOS (Global Ozone Monitoring by Occultation of Stars) is providing: vertical profiles of ozone, $NO_2$, $NO_3$, $O_2$, $H_2O$, aerosols, temperature, turbulence. **A. Hauchecorne** presented the status of some related calibration/validation activities, which involved intensive intercomparison with independent data sources. The overall conclusions are that after 18 months of flight, GOMOS operates well and validation studies indicate no significant bias in $O_3$. The systematic data processing at ESA and the data distribution to principal investigators are expected to commence after the validation workshop at ESRIN in May 2004.

*Sixth Framework Programme (FP) of the EC*
**M. Dameris** presented SCOUT-$O_3$ (stratosphere-climate links with emphasis on the UTLS) as a new accepted project. The central aim of the project is reliable prediction of future evolution of the ozone layer and surface UV radiation with a focus on the interaction between the Montreal and Kyoto Protocols.

*Process Oriented Validation of Chemistry/Climate Models*
**V. Eyring** presented the preparations for a workshop 17-19 November 2003 in Grainau/ Garmisch-Partenkirchen, Germany on Process oriented validation of Chemistry/Climate Models (see full report on page 27).

## SPARC Project Office and Future Plans

The SPARC office actively pursued its activities in 2003, namely contacts with the JPS of WCRP, WCRP projects, IGBP, other partner programmes, and the SPARC community of scientists; organization of SPARC meetings, compiling and editing SPARC Newsletters (two a year), updating the SPARC mailing list, maintaining the SPARC website, preparation of SPARC reports for publication. A new SPARC brochure will be prepared soon. The session warmly thanked the director and the office staff **M-L Chanin,** as well as **C. Michaut** and **Y. Koshelkov,** for their excellent support. During 2003, **Y. Koshelkov** has retired. A new SPARC scientist was hired for the office. **E. Oikonomou** started his duties on 1 June 2003 using a grant provided by ESA.

In 2004 the SPARC Office is expected to move from Paris. After many years of outstanding service, the director, **M.-L. Chanin,** will pass her duties to a new person in charge of the office. Activities to find a new home for the office were presented to the SSG. A proposal to move the office to the Department of Physics, University of Toronto, was submitted by **T. Shepherd** and **N. McFarlane** to several Canadian organisations. Expectations were high that the proposal would be considered favourably and approved. In that case, there would be a transition period. The operation of the office in Paris would not stop abruptly. **C. Michaut** agreed to visit the new office in Toronto and help to speed up operations there. Full transition to the base would be completed after the SPARC General Assembly 2004.

## Next SSG Meeting and SPARC General Assembly 2004

**T. Shepherd** reviewed the preparations for the 3rd General Assembly of SPARC, 1-6 August 2004, Victoria, Canada. More information is available at **http://sparc.seos.uvic.ca**.

A particular emphasis for this General Assembly will be chemistry-climate coupling.

**T. Shepherd** and **A. Ravishakara** will co-chair the Scientific Committee and **N. McFarlane** will be the chair of the Local Organising Committee.

**T. Shepherd** and **N. McFarlane** proposed to hold the 12th Session of the SPARC SSG in Canada, after the SPARC General Assembly. This offer was accepted with appreciation and the dates for the session were set on 9-12 August 2004.

## Closure of session

Before closing the session, the participants considered and agreed upon a list of follow-up actions. In particular, it was decided that a new Implementation Plan of SPARC should be prepared during the year 2004 and submitted for discussion at the next SPARC SSG session. Some SSG members were asked to lead the preparation of individual chapters.

Closing the session, the co-Chairs, **A. O'Neill** and **A. Ravishankara,** thanked SSG members for their contribution to the discussion. Noting that the next SSG session would be held after the SPARC General Assembly and that the current session might be the last SSG session, which **M.-L. Chanin** and **C. Michaut** organised in the capacity of the project office director and manager, respectively, the co-Chairs, on behalf of the SPARC project and all participants in the meeting, deeply thanked **M.-L. Chanin** for her outstanding leadership of the project for the whole period of its existence. **C. Michaut** was thanked for her excellent work at the office.

A complete version of the WCRP report is available on the SPARC Website **http:.//www.aero.jussieu.fr/~sparc/SSGReports.html**.

◆

**Announcement**

## 3rd SPARC General Assembly

The 3rd SPARC General Assembly is to be held in Victoria (BC), Canada, August 1-6, 2004. The submission deadline has been extended to **March 15, 2004**

Abstracts can be submitted electronically via the SPARC Assembly web site **http://sparc.seos.uvic.ca**

Further details can be found on registration, accommodation, the Scientific Programme and information about Victoria.

Abstracts for oral and poster presentations are invited within the following topics of relevance to the SPARC programme:
- Stratospheric climate and indicators of climate change
- Stratospheric data assimilation
- Transport and mixing in the stratosphere and between stratosphere and troposphere
- Gravity-wave processes and their parameterization
- Stratospheric and upper tropospheric water vapour
- Chemistry, radiation, aerosols and dynamics in the UT/LS
- Chemistry-climate modelling of the stratosphere

Financial Support: if you are a student, young scientist, or scientist from a developing country consider applying for financial support. The SPARC Office will do its best to accommodate requests for financial support.



# A Short History of the Beginning of SPARC and its Early Development

**Marie-Lise Chanin,** SPARC Office, Verrières le Buisson, France (chanin@aerov.jussieu.fr)

The genesis of any project requires years of efforts by a community of scientists, first to formulate the issue and then to have it accepted by the main international scientific organisations. In the process which led to the recognition of SPARC as a project of WCRP, a number of scientists were involved in different ways. It is impossible to mention all of them, without taking risk to be incomplete, but I would like to associate the name of **M. Geller** as a main actor in all of these attempts, which led to the project as it has developed, and to thank all the others for their active support.

## The Recognition of SPARC as a WCRP Project

The issue of ozone depletion had raised an enormous interest in our community since the middle of the 70's, and even more after the discovery of the ozone hole in 1984. Many important national programmes were set-up and there was no need to create new ones on the same issue. However, in the early 90's, the stratosphere was barely mentioned as a region of interest in the thematic of the two main International Global Change Programmes of ICSU: WCRP, which dealt with the physical aspect of the climate, and IGBP, which had just been created in 1986 to study the interactive physical, chemical and biological processes that regulate the total Earth System. The issue of the stratosphere, or to be more precise of stratospheric ozone, was considered as completely separate from the climate issue. As a matter of fact, it has been true for quite a long time that the WMO-UNEP Scientific Assessments on Ozone Depletion were carried out completely independently of the IPCC Assessments. This is no more true today and outputs of the first one are being taken into account in the later.

On the other hand at that time, tropospheric chemistry had received a full recognition within the IGAC Project first created by the International Commission of Atmospheric Chemistry of IAMAP and later in the late 80's accepted as an IGBP Core Project. However, the issues covered by IGAC dealt exclusively with the troposphere and did not include the complex interactions between chemistry, radiation and dynamics, which characterise the tropopause region and the stratosphere.

Two main organisations prepared the way for the recognition of the role of the stratosphere in the climate. First, the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) which, after the very successful Middle Atmosphere Programme (MAP) in the

1980's, included in its following Programme STEP (Solar Terrestrial Energy Programme) a topic entitled "Middle atmosphere response from above and below". The relevant W.P. 4 led by **M. Geller** and myself had a large influence on the scientific content of SPARC. I should also mention that it included the issue of "Solar variability effects on the environment" as the theme of W.G. 5 of STEP under the leadership of **K. Labitzke**; this issue was picked up later on by SPARC and is still a theme of joint interest between SCOSTEP and SPARC.

During the same period, the role that the International Union of Geophysics and Geodesy (IUGG) should play in IGBP was being discussed; a proposal was elaborated at the end of the 80's, mostly by a group of scientists from two of the IUGG Associations, IAGA, IAMAP (now IAMAS), and of its joint Commission on Middle and Upper atmosphere ICMUA, (which later became ICMA). This programme was elaborated and proposed in 1988 to be implemented by IGBP under the name of MARC (Middle Atmosphere Responses to Changes). But it was not accepted as an IGBP Project.

Meanwhile, as a member of the first Scientific Steering Committee (SSC) of IGBP established in 1987, I tried to find a way to include the stratosphere in the IGBP Programme. The Project STIB (Stratosphere-Troposphere Interactions and the Biosphere), which emerged after several workshops (Abington, UK, January 1990 and Stony Brook, USA, June 1991), took into account the specific interest of IGBP and, therefore, placed the emphasis on the impact of ozone depletion on the biosphere. STIB was concerned with the way biogenic and anthropogenic emissions change the composition, radiation and dynamics of the stratosphere and how those changes affect the biosphere. The topic of the biosphere impact of UV radiation essentially disappeared later from SPARC, due to the fact that it concerns actually a quite different community. The other themes in the proposal were very close to what was included in the future SPARC. The refusal of STIB by IGBP in 1991 led to a revision of the proposal and to the acceptance of SPARC by WCRP in March 1992. We were fortunate to have scientists who were themselves distinguished middle atmospheric researchers in the Joint Scientific Committee (JSC) and in the Joint Planning Staff (JPS). Thanks to all of them and to the Executive Director, **P. Morel,** for whom it was surely quite a revolution to introduce Chemistry in the fortress of Physics. The development of SPARC within WCRP has in fact been a wonderful experience and **R. Newson,** who, until his recent retirement, has been our permanent contact with the JPS of WCRP, is to be thanked for his constant support during the first decade of SPARC.

## The Development of SPARC

The first main meeting of the very young SPARC Project took place in September 1992 in Carqueiranne, in the South of France, as a NATO ASI, which I organised with a group of lecturers who played a main role in the definition of SPARC priorities and in the write-up of a WCRP Report entitled "Initial Review of Objectives and Scientific Issues", published in 1993.

The composition of the first SSG was decided at the March 1993 JSC-WCRP meeting and the selection of its members had a strong influence on the development of the project. It included to assist the two co-Chairs, **M. Geller** and myself: **D. Ehhalt, I. Isaksen, V. Khattatov, J. Mahlman, T. Matsuno, J. Pyle, T. Shepherd, S. Solomon, H. Tanaka** and **R. Turco.** Its first meeting took place in 1993 in Corpus Christi College, Cambridge, UK.

I would like to mention some principles, which we kept in mind continuously during the development of the project. A first important rule, which I, with **M. Geller** and the SSG members tried to respect all along, was not to include in SPARC the topics that were ongoing in other existing programmes. That meant essentially that we established strong links and good relationship with the national "ozone depletion" programmes, without walking in their path but rather looking for areas that needed more concerted efforts. This approach worked very well, thanks to a few key people, who recognised that SPARC was not a threat but a complement to their activity. A second rule was to anticipate areas where better knowledge of the stratosphere could contribute; this led to a successful activity of assessments of our current knowledge of key quantities (temperature, ozone vertical profile, water vapour concentration, aerosols as well as the contribution of the stratosphere to radiative forcing), which were and are still needed for the larger enterprises of WMO-UNEP and IPCC assessments. Those exhaustive assessments required the participation of hundreds of scientists and played an important role in the recognition of the role of SPARC. Most of them are published as SPARC Reports.

One main characteristic in running the project and which could not have been able to decide in advance, even though we could have wished it to be, has been a constant feature of SPARC leadership all along those years: it is the wonderful sense of community within the enlarged leading group, which includes, beside the co-Chairs and the SSG members, the ex-officio members of the SSG and the activity leaders, all of them working in a very friendly and cheerful atmosphere. This, I have to admit, is the best reward that one can have when devoting one's energy for the success of any project.

When thinking of the way the role of the stratosphere in the climate issue was perceived 12 years ago compared to the present situation, I feel that a large step has been made during that period. Just to mention a few examples: most GCMs are now including the stratosphere with a more or less sophisticated chemistry, as the demonstration was made that it plays an important role in the way the troposphere behaves. Models are also starting to benefit from a better parameterization of gravity waves, a subject in which SPARC has been intensively involved. The representation of the Quasi-Biennial Oscillation (QBO) in the models has been improved. The connection between the stratospheric Northern and Southern Annular Modes and the surface, which has been recently discovered, is obviously confirming the idea that the coupling between stratosphere and troposphere cannot be ignored. Another very controversial issue a decade ago was the way the solar variability influences the climate: it is now a subject taken without passion and the role of the stratosphere in the process through the UV absorption by ozone starts to be well accepted. The perception of the tropopause, not only as a barrier between two regions of the atmosphere, but also between two scientific communities is now starting to disappear; our newly developed joint-project with IGAC is a symbol of this situation.

## First Phase of SPARC

The first Implementation Plan of SPARC was published in 1998 as a WCRP report. It emphasized three of the foci identified in WCRP 93, taking into consideration the evolution of the field in these first years.

• *Stratospheric indicators of climate change:*
- Detection of stratospheric temperature trends;
- Detection of trends in the vertical distribution of ozone;
- Compilation of a water vapour climatology and detection of long-term changes;
- Stratospheric aerosol climatology and trend;
- Detection of trends in the dynamical activity in the stratosphere.

All but the last one led to SPARC Reports and all led to numerous publications. The paper "Stratospheric temperature trends: observations and model simulations" was awarded the WMO Norbert Gerbier-MUMM Award 2003 and an update of the Temperature Assessment is planned as SPARC Report N°4; the Assessment on Ozone Vertical Profile was published as SPARC Report N°1 in 1998 and was used in WMO/UNEP Ozone Assessment 2002, Chapter 4 of the publication "Global Ozone: past and future". The Water Vapour Assessment was published as SPARC Report N°2 in 2000. The Aerosol Assessment will be published in 2004 as SPARC Report N°5.

• *Stratospheric processes and their relation to climate:*
- Stratosphere-troposphere exchange and dynamics and transport in the lower stratosphere and upper troposphere;
- The QBO and its possible role in coupling the stratosphere and troposphere;
- Gravity wave processes and the parameterization of the effects of unresolved internal gravity waves in global numerical atmospheric models;
- Chemistry and microphysics in the lower stratosphere and upper troposphere.

These issues have been the subjects of several important workshops, (some of them supported by NATO), which led to a few seminal papers that have changed the perception of the dynamical coupling between the two regions (e.g.: Holton *et al.,* Rev Geophys, 1995). This thematic is getting even more emphasis now with the evidence of the Arctic Oscillation (AO) and the presence of Annular Modes connected with the surface. The last issue is getting now more developed in a joint SPARC-IGAC initiative.

• *Modelling stratospheric processes and trends and their effects on climate:*
- The GCM-Reality Intercomparison Project for SPARC: GRIPS and its successive levels. The results of the activities under GRIPS Level 1 (intercomparisons of models) and Level 2 (impacts of different parameterization schemes) have already been the subjects of publications in BAMS and JGR in 2000 and JAS in 2002. Level 3 tasks study mechanisms by which various forcing factors control the atmospheric circulation and how they are represented in models and they should be ready in due time for the next WMO-UNEP and IPCC assessments.
- The compilation of a stratospheric reference climatology against which model results can be compared using global satellite data. The output was published as a SPARC Report N°3, 2003).
- The current best estimates of stratospheric parameters, which play a role in climate forcing. Adequate data were provided to IPCC. A recommended set of key indices is being prepared.

The WCRP has also asked the SPARC project to help define the *solar forcing* to be used in climate models, an activity to be carried out jointly with the SCOSTEP.

It is satisfactory to see that most of the activities decided a decade ago have led to results and that the original goals have been achieved, leaving the place for a new series of initiatives. However, the memory of SPARC past activity should be kept in the SPARC archives. They will be available on the web site and the web version of this SPARC history will direct the reader to the main information which he/she may wish to consult: Implementation Plan; reports of SSGs and working groups, organisation of SPARC Workshops, or related meetings; SPARC general assemblies; SPARC reports and related publications.

## The Transition between the two Phases

In those last two years, SPARC has been going through a transition period between its first phase (under the leadership of **M. Geller** and myself) with the scientific initiatives described above, and a new phase, both due to the change of leadership (**A. O'Neill** since 2001 and **A. Ravishankara** since 2003) and the evolution of the projects as scientific priorities are changing. The new initiatives will be described by the SPARC Co-Chairs in the following paper (page 13). Other changes going to take place in 2004 are those of Director and site of the SPARC Office, which had been in Verrières-le-Buisson (France) under my leadership since January 1993, and is going to be transferred to the University of Toronto under the leadership of **N. Mc Farlane.** The new Office will be operational after the SPARC General Assembly in September 2004. We are very happy that Canada has offered to support the new Office. I would like to take this opportunity to thank the French agencies, CNRS/INSU and CNES, for supporting the operation of the Office in France for the last 12 years, as well as Météo-France for publishing the SPARC Newsletter. They should find here not only the expression of my thanks but also of the whole community. Many thanks are also due to NASA whose constant support led to the creation of the SPARC Data Center in Stony Brook, which has been very instrumental in the success of SPARC. Obviously none of the SPARC achievements will have been possible without the continuous support and encouragements of WCRP.

# The Future Development of SPARC

**Alan O'Neill**[(1)] (alan@met.reading.ac.uk), and **A.R. Ravishankara**[2] (ravi@al.noaa.gov),
SPARC co-Chairs (on behalf of the SPARC SSG)

(1) - Data Assimilation Research Centre, Reading, UK
(2) - NOAA-Aeronomy Laboratory, Boulder CO, USA

In a companion article in this Newsletter, **M.-L. Chanin** summarises the first decade of SPARC as a project in the World Climate Research Programme (WCRP) (see page 10). As the first co-Chairs of SPARC, **M.-L. Chanin** and **M. Geller** played a central role in guiding SPARC's development and encouraging numerous enthusiastic scientists to become involved with it. We have heard members of WCRP's Joint Scientific Steering Committee (JSC) say on several occasions that they were impressed by SPARC's approach and effectiveness.

Briefly put, SPARC's approach has been first, to be responsive to the need for scientific input to international scientific assessments; secondly, to identify manageable projects where co-ordination at international level can make a difference; and thirdly, to have clear deliverables for each project, such as scientific reviews which summarise the state of knowledge, facilitate and stimulate new directions for research.

**M.-L. Chanin**'s article has noted that SPARC organised its activities around particular foci, or themes concerned with observed changes in the stratosphere, atmospheric processes relevant to those changes, and modelling those processes. Our intention is to retain this thematic structure, but to evolve it in response to progress during the first phase of SPARC, and to respond to new issues that have recently emerged about the role of the stratosphere in climate. The main aim of SPARC will continue to be: to bring stratospheric expertise to bear on scientific issues concerned with climate processes and climate prediction, for the benefit of climate science as a whole, and specifically for WCRP, the WMO/UNEP Ozone Assessment exercises, the Intergovernmental Panel on Climate Change (IPCC), and the Space Agencies, which seek guidance on stratospheric issues for mission planning. The effective approach developed by our predecessors will remain: to deal with manageable scientific tasks, with a well-defined outcome, over a relatively short period of time (to bring about closure and to maintain momentum in the project), while seeking to anticipate the needs of the wider community.

We see collaboration with other international projects, both within and outside the current WCRP, as essential for promoting SPARC science. The JSC of the WCRP has recommended the following key objectives for SPARC: to lead a collaboration on chemistry-climate interactions with the IGAC project, a project in the International Geosphere Biosphere Programme (IGBP); to focus on issues raised by recent studies of the Arctic Oscillation (AO); to liaise with SCOSTEP on solar radiative forcing and temperature trends; to work with the WMO's Global Atmospheric Watch (GAW) project on the penetration of ultraviolet radiation; and to contribute to international planning and mission planning. The above list is merely a subset of possible areas of collaboration. We should add, for instance CLIVAR, with which much stronger links are essential on long-term climate variability and predictability.

In response to the stimulus of the JSC, and with the guidance of our colleagues in SPARC (particularly the SSG), we propose the following outline of SPARC's scientific objectives for the next five years. Implicit in each of them is the goal, now being re-emphasised within WCRP's developing strategy, of making better predictions of changes to the climate system. The scientific questions raised under each of the themes set out below give a preliminary view of some of the key questions as seen by SPARC's Scientific Steering Group (SSG). Working groups are being established for each theme to refine the issues, to chart the way forward and to widen the participation of the scientific community.

## SPARC Scientific Themes and Associated Key Questions

The following themes are meant to encapsulate, in brief, SPARC's future programme. The associated questions posed with each theme are certainly not exhaustive; they aim to identify primary foci for our activities, at least in the immediate future.

### 1. Detection, Attribution and Prediction of Stratospheric Changes

- What are the past changes and variations in the stratosphere?
- How well can we explain past changes in terms of natural and anthropogenic effects?
- How do we expect the stratosphere to evolve in the future, and what confidence do we have in those predictions?

This theme is a continuation, synthesis and extension of earlier SPARC themes on long-term variability and trends in the stratosphere. The extension of previous work should be a greater emphasis on attribution and prediction, which will require a concerted, collaborative research programme involving, in many instances, coupled chemistry-climate models. A report, in this Newsletter, on the SPARC Workshop on Understanding Seasonal Temperature Trends in the Stratosphere summarises some essential priorities concerned with the acquisition of observational data and the needs for numerical modelling (see page 24). It is now clear that confidence in attribution and prediction will demand statistically significant results based on large ensembles of integrations with numerical models (or approaches that can be shown to be statistically equivalent). SPARC can play an important role in co-ordinating experimental design by different groups to facilitate meaningful comparison of results.

### 2. Stratospheric Chemistry and Climate

- How will stratospheric ozone and other constituents evolve?
- How will changes in stratospheric composition affect climate?
- What are the links between changes in stratospheric ozone, UV radiation and tropospheric chemistry?

The latest assessment report of the IPCC identifies insufficient knowledge of the coupling and feedbacks between atmospheric chemistry, the biosphere and the climate – and the consequent failure to represent the relevant processes adequately in climate prediction models – as serious scientific limitations. Some of the diverse scientific challenges that must be tackled have been summarised by **A.R. Ravishankara** at the SSG meeting (see the full report on page 1). An interdisciplinary approach must be adopted involving laboratory measurements, field campaigns and numerical modelling. It is proposed that work under this theme will be undertaken as a strong collaboration between SPARC and the IGAC project of the IGBP. The UTLS region is a region of common interest where some of the scientific challenges are most demanding.

### 3. Stratosphere-Troposphere Coupling

- What is the role of dynamical and radiative coupling with the stratosphere in extended range tropospheric weather forecasting?
- What is the role of dynamical and radiative coupling with the stratosphere in determining long-term trends in tropospheric climate?
- By what mechanisms do the stratosphere and troposphere act as a coupled system?

A strong motivation for this theme is that several recent observational studies have proposed that a so-called Arctic Oscillation (or Northern Annular Mode, with an equivalent Southern Annular Mode) is a dominant component of large-scale variability in the atmosphere. The finding that anomalies in an AO index can sometimes span the stratosphere-troposphere (ST) system has revivified the long-stating issue of ST coupling. In particular, the occasional downward propagation of anomalies from the stratosphere into the troposphere implies, with support from statistical analysis of the data, that knowledge of the state of the stratosphere can enhance our ability to predict aspects of the large-scale evolution of the troposphere, which would be of practical value for weather forecasting and climate prediction. Whether the state of the stratosphere influences the evolution of the troposphere in any causal sense, and if so by what mechanisms and on what timescales, are key issues demanding numerical experimentation.

## Underpinning Activities

We anticipate that research to address these scientific questions will highlight the need for underpinning activities, which will require the setting up of (possibly temporary) targeted working groups.

Three such activities are:
- Model Development,
- Process Studies,
- Data support.

SPARC's collaborations on model development have been undertaken within the GCM Reality Inter-comparison Project for SPARC (GRIPS). As **M.-L. Chanin** notes in her article, GRIPS has evolved through successive phases, from undertaking basic comparisons of models, to studies of mechanisms. Since numerical modelling will be an essential component of all the above scientific themes, we envisage that GRIPS will evolve to play a key role in all of them, with more targeted exercises to document and resolve model deficiencies being undertaken by specially created working groups.

We also envisage that targeted working groups will need to be established to resolve a variety of issues concerned with atmospheric processes within the context of the main scientific themes. As one of many possible examples, considerable uncertainties remain about microphysical processes in the atmosphere, in the tropopause transition layer (or tropical tropopause layer) in particular, uncertainties which seriously limit our ability to understand the transport of water vapour from the troposphere to the stratosphere, and to account for apparent long-term variability in water vapour concentrations. SPARC will contribute to resolving these uncertainties through scientific assessments aimed at producing scientific review papers, and by promoting and participating in observational campaigns and associated numerical modelling.

In connection with observational data for the scientific themes, we aim to secure a continuing role for the SPARC Data Centre as a repository of data sets associated with SPARC's research activities. Global, quality-controlled data sets produced by assimilating diverse observations into GCMs are a vital resource for climate research. In recognition of this, a SPARC Data Assimilation Working Group has been established to provide the community with information on data availability, location and documentation; to carry out inter-comparisons of data sets focused on specific atmospheric processes and phenomena; and to consult with the space agencies on data needs. This working group aspires to close links with a related activity in WCRP's Working Group on Numerical Experimentation (WGNE).

During the next few months, SPARC colleagues will be helping us to devise a specific set of actions to implement the scientific programme outlined above. By demanding clear thinking on how an international project like SPARC can make a difference, the very act of creating a new "implementation plan" should in itself be a stimulus to moving the programme forward, as well as to communicating our goals to potential collaborators.

We both feel privileged to be co-Chairs of a well-respected project like SPARC, at a time when the stratosphere is gaining new prominence in climate science. The friendliness and enthusiasm of the growing community involved with SPARC is testimony to the wise leadership and inspiration of the co-Chairs who preceded us, **M.-L Chanin** and **M. Geller.** Our unalloyed enthusiasm for SPARC is tempered only by the thought that we have a lot to live up to.

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# The Stratosphere in the Climate System

**Dennis L. Hartmann,** University of Washington, Seattle WA, USA (dennis@atmos.washington.edu)
**Varavut Limpasuvan,** Coastal Carolina University, Conway SC, USA

## Introduction

Until relatively recently, the stratosphere has been viewed as a passive part of the climate system, with a small mass and relatively minor influence on surface climate. The primary effect of the stratosphere on surface climate was felt to be the radiative effect of the amount and vertical distribution of stratospheric ozone, which was more of concern for its health effects, rather than its effect on surface temperature and precipitation. In recent years, however, the stratosphere has been shown to have a significant influence on surface weather and climate, and this has become a major research topic.

What are the reasons for the enhanced interest in the stratosphere as a player in climate change? First, at the present time changes in stratospheric temperature associated with ozone depletion are large compared to changes thought to be associated with other greenhouse gases (GHGs) (Ramaswamy *et al.,* 2001). Moreover, temperature changes expected in response to increasing GHGs are larger in the stratosphere than in the troposphere, albeit of opposite sign. So the magnitudes of the temperature changes in the stratosphere associated with human activities are much larger than those expected near the surface. The interactions between a warming troposphere and cooling stratosphere are potentially very significant.

Secondly, recent research has shown that changes in the stratosphere can have significant impacts on surface weather and climate (Kodera and Yamazaki, 1994). The most obvious example of this is the sudden stratospheric warming, which has been shown to have a robust and consistent effect on surface weather patterns (Baldwin and Dunkerton, 1999; Baldwin *et al.,* 2003; Kodera *et al.,* 2000). This connection is expressed primarily through the dominant natural structures of variability, which tend to be quasi-zonally symmetric and are often called the annular modes of variability (Thompson and Wallace, 1998; 2000). A similar pattern of events occurs in the Northern Hemisphere (NH) during a midwinter major warming event, and in the Southern Hemisphere (SH) during the Spring warming. Both stratospheric and tropospheric climate appear to have linked secular trends over the past 30 years (Thompson and Solomon, 2002; Thompson *et al.,* 2000).

The effects of the annular mode variability appear to extend into the tropics, both through the effects on the Brewer-Dobson Circulation, that flows upward across the tropical tropopause and toward the winter pole (Holton *et al.,* 1995), and through the connection of the stratosphere to tropospheric modes of variability. The tropospheric annular modes can influence the meridional location of eddy activity and, thereby, influence tropical circulation (Thompson and Lorenz, 2003). The tropical tropopause is a particularly interesting and critical area for stratospheric chemistry and possible climate-chemistry interactions (Mote *et al.,* 1996). Here we focus principally on the extratropical dynamical interactions between the stratosphere and troposphere and the possible influences of global change on those interactions.

## Stratospheric Warmings and Downward Control

Annular modes explain a large fraction of the intraseasonal and interannual variability (Kidson, 1988; Nigam, 1990; Thompson and Wallace, 2000) and appear to arise naturally as a result of internal interactions within the troposphere and stratosphere (Feldstein and Lee, 1998; Limpasuvan and Hartmann, 2000; Lorenz and Hartmann, 2001; Lorenz and Hartmann, 2003; Robinson, 1991; Yu and Hartmann, 1993). In the stratosphere most of the variability is associated with variations in the large-scale wave driving, which is strongly associated with the occurrence of stratospheric warmings. In the troposphere wave driving is also necessary to move the westerly jets in latitude, but this driving is provided by transient baroclinic waves, as well as quasi-stationary planetary waves. Although stratospheric annular variability and tropospheric annular variability are coupled at times, tropospheric annular variations also occur independent of stratospheric annular variations (Kodera and Kuroda, 2000). It appears that low-frequency quasi-barotropic waves are most important for producing changes in the polarity of annular modes of variation in the troposphere, but high-frequency baroclinic waves are most important for maintaining the persistence of these anomalies (Feldstein and Lee, 1998; Lorenz and Hartmann, 2001; Lorenz and Hartmann, 2003).

Limpsuvan *et al.* (2003) have taken the 44 years NH data from the NCEP/NCAR reanalysis and composited the flow relative to stratospheric warming events. The stratospheric warming events are selected as anomalies of the first mode of 50 hPa zonal flow – times when the zonal vortex is especially weak. These dates correspond approximately to major or minor stratospheric warmings. These composites show statistically significant forerunner and follower structures to the NH wintertime warming events.

**Figure 1** (p. I) shows the composite geopotential anomaly height fields at 50, 250 and 1000 hPa at five temporal phases relative to the warming time. The lifecycle of the stratospheric warming was divided into five 15-day periods: *onset* (days -37 to –23), *growth* (days -22 to -8), *mature* (days -7 to +7), *decline* (days +8 to +22) and *decay* (days +23 to +37). The 1000 hPa field has a statistically significant anomaly at the *onset* time, which is not zonally symmetric, but is composed mostly of planetary scale waves. The stratosphere develops a strong anticyclone over the pole in the *growth* phase that continues through the *decline* phase. The near surface signal (1000 hPa) is unclear in the *growth* phase, but persists through to the *decay* phase with a polar structure that is similar to that in the stratosphere (50 hPa). This apparent downward propagation of the polar signal is consistent with the composite analysis of Baldwin and Dunkerton (1999).

The meridional mass movements indicated by the geopotential field must be associated with meridional transport of zonal momentum. **Figure 2** (p. II) shows components of the composite momentum balance from days -40 to +40. Panel (c) shows the zonal mean wind, which is very similar to the plots of Baldwin and Dunkerton (1999). The strongest upward EP flux anomalies occur about day -25, and these are associated with the strongest reduction of zonal wind in the upper stratosphere. This is the preconditioning phase of the warming (Mcintyre, 1982). Later, around day -8 a second burst of upward EP flux occurs, which is associated with a secondary wind reduction that penetrates deeper and eventually reaches the surface around day zero. The composite warming thus seems to have two phases and two time scales. A longer time scale is associated with the preconditioning of the vortex by an earlier wave forcing event, and the shorter time scale is associated with the major warming itself, which penetrates to the surface.

The main warming event is associated with very anomalous meridional EP fluxes and associated mean meridional circulations in the troposphere, shown in panels (a) and (d). This tropospheric meridional EP flux anomaly is associated with synoptic-scale waves with zonal wavenumbers greater than 3 (Limpasuvan *et al.,* 2003). Thus, a response by tropospheric synoptic waves seems to be responsible for the final meridional shift of the tropospheric zonal winds and its associated weather and climate consequences. The important role of tropospheric synoptic scale waves is consistent with previous diagnostic studies of the momentum budget of tropospheric annular modes (Lorenz and Hartmann, 2003).



The downward propagation of the signal from the stratosphere is likely to be closely associated with the concept of downward control in which wave driving effects are projected downward to the flow below the level of wave driving (Haynes *et al.,* 1991). In major warmings the wave driving propagates downward to the lower stratosphere and forces a response in the troposphere. Once a zonal wind anomaly is projected into the troposphere, the resulting changes in wave propagation and baroclinic instability can result in the positive feedback that reinforces the initial signal through the intermediacy of the synoptic scale waves (Robinson, 2000).

The possibility of rather weak forcing from stratospheric changes producing much larger than expected changes in tropospheric climate has been discussed in several places and has occurred in some global model simulations (Hartmann *et al.,* 2000; Shindell *et al.,* 2001). Because of the nonlinearity of the stratospheric warming dynamics, small changes in wind in the stratosphere or troposphere can lead to changes in the probability of major stratospheric warmings, which can have large effects on stratospheric and tropospheric climate.

Consideration of wave propagation effects on stratosphere-troposphere (ST) coupling is facilitated by index of refraction arguments. The index of refraction for stationary waves is defined in (1) for a zonal wavenumber k (Matsuno, 1970).

$$n^2 = \frac{[q]_\phi}{[u]} - \left(\frac{k}{a\cos\phi}\right)^2 - \left(\frac{f}{2NH}\right)^2 \qquad (1)$$

Where $[u]$ is the zonal mean zonal wind, $f$ is the Coriolis parameter, $N$ is the buoyancy frequency, $H$ is the scale height, $a$ is the radius of Earth and $\phi$ is latitude. The meridional gradient of potential vorticity $[q]_\phi$ is given by,

$$[q]_\phi = \frac{2\Omega}{a}\cos\phi - \frac{1}{a^2}\left(\frac{([u]\cos\phi)_\phi}{\cos\phi}\right)_\phi - \frac{f^2}{\rho_0}\left(\rho_0\frac{[u]_z}{N^2}\right)_z \qquad (2)$$

where $\Omega$ is the rotation rate of Earth, z is height and $\rho_0$ is the mean density.

Geometric optics arguments suggest that waves should be refracted toward regions of larger index of refraction. A rearrangement of (2) yields,

$$[q]_\phi = \frac{2\Omega}{a}\cos\phi - \frac{1}{a^2}\left(\frac{([u]\cos\phi)_\phi}{\cos\phi}\right)_\phi - \frac{f^2}{N^2}[u]_z\left((\ln N^2)_z + \frac{1}{H}\right)_z - \frac{f^2}{N^2}[u]_{zz} \qquad (3)$$

which divides the potential vorticity gradient into contributions from planetary and meridional wind shear (first two terms), vertical shear (third term) and vertical curvature (fourth term in (3)). Both positive vertical shear and positive vertical curvature act to decrease the index of refraction from (3), as does increasing the zonal wind in (1). Therefore, waves should be refracted toward regions of weak westerly winds, weak wind shear and weak or negative wind curvature, with a tendency for equatorward propagation that becomes stronger nearer the equator because of the planetary vorticity gradient (2).

From (1-3) we see the potential for a positive feedback between stronger winds and weaker wave forcing, if the stratospheric jet is poleward of the primary source of planetary wave forcing in the troposphere. If the jet is stronger and has stronger shear, then planetary waves are more likely to be refracted toward the equator and less likely to propagate into the vortex and weaken it. This reasoning may explain why planetary waves are more likely to penetrate the vortex when the tropospheric midlatitude jet is displaced equatorward, which may make stratospheric warmings more likely when the Northern Annular Mode is in its negative phase (Limpasuvan and Hartmann, 1999). In contrast, when the tropospheric jet is displaced poleward, planetary waves are more likely to be refracted toward the equator.

The effect of ozone depletion on tropospheric climate through annular modes seems understandable from basic principles, but the effect of greenhouse cooling of the stratosphere on annular mode variability seems less clear. Ozone depletion is larger in high latitudes if the stratosphere there is sufficiently cold and isolated, so that in the springtime an increased gradient in ozone heating can be expected. Also, since the total ozone column is greater in higher latitudes and the effect of ozone heating penetrates deeper into the atmosphere there, depletion of ozone leads to reduced polar lower stratospheric temperatures in springtime. This acts to stabilize the vortex, resulting in reduced probability of major warmings and delayed spring warming. From these considerations a prediction of ozone depletion leading to a stronger vortex emerges, and this seems to be born out both by observations and by modelling experiments. Greater winds and fewer stratospheric warmings seem to result from ozone depletion, and this appears to have a secondary effect on surface climate that is propagated through the annular modes of variability. Gillett and Thompson (2003) were able to simulate realistic changes in SH climate with only the forcing associated with ozone depletion.

The effect of GHGs on stratospheric warming probabilities is less clear. The polar stratosphere will not obviously cool more significantly than the tropical stratosphere. Moreover, a tendency for polar amplification of warming near the surface would seem to work against enhanced meridional temperature gradients in the stratosphere. One might expect that warming of the tropical upper troposphere and cooling of the polar stratosphere by greenhouse gas increases, would lead to increased temperature gradients on constant pressure surfaces in the upper troposphere – lower stratosphere region, and that this would increase the vertical shear and refractive index in mid-latitudes. It is not clear that these changes would be far enough poleward to produce a positive feedback on the stratospheric polar night jet, however. Moreover, many other changes would occur in the troposphere that would produce effects. Gillett *et al.* (2003) found consistent positive annular mode responses (increased winds at high latitudes) in response to $CO_2$ increases, but the magnitudes of these changes were not large. Kushner *et al.* (2001) also found that $CO_2$ increases moved the eddy-driven jet poleward in the SH in a transient coupled model experiment.

In addition to the complications associated with interpreting the sign of refractive index changes, one must consider changes in the wave forcing that may result from changes in zonal wind in the troposphere. Taguchi and Hartmann (2003) found that while increasing the temperature gradient in the stratosphere led to index of refraction changes in the stratosphere that should have lead to a weaker wave drag on the vortex, the increase in high latitude surface winds that resulted from the annular mode shift increased the magnitude of the topographic planetary wave forcing. The increase in wave forcing overwhelmed the effect of the index of fraction, so that the increased upward EP flux compensated for changes in index of refraction that would have ducted waves more toward the equator. The result was a large negative dynamical feedback, in the sense that dynamical heating increased to compensate increased radiative cooling near the pole. A similar enhancement of planetary wave generation was found by Gillett *et al.* (2003).

## Summary and Conclusion

Thermally forced temperature changes in the stratosphere associated with human-induced ozone depletion and greenhouse gas increases are larger than temperature changes nearer the surface of Earth. The dynamical response to these changes can be important and can be translated into changes in surface climate that are larger, or structured differently than those expected from direct forcing in the troposphere. The response to ozone depletion seems to consistently give a stronger and more persistent stratospheric vortex, which expresses itself as a positive anomaly of the Annular mode variability.

The stratospheric warming events in both hemispheres seem particularly important in enforcing a ST connection through the annular modes. Compositing of the NH warmings in a 44-year data set suggests that the synoptic-scale waves are especially important in producing the shift in tropospheric wind patterns, which in the stratosphere is driven primarily by wave forcing from planetary scale waves. This further suggests that the stratospheric wave drag and zonal wind responses are able to induce a transition in the naturally-occurring tropospheric mode of variation.

Despite considerable effort, the response of annular modes to carbon dioxide increase seems more uncertain than the response to ozone decreases. Many additional questions remain concerning the response of the coupled ST system to greenhouse gas increases and the associated climate change. Among the key questions are the following. How will winter and spring planetary wave driving change in response to global warming? How will the Brewer-Dobson circulation respond to climate change? How will climate change affect the temperature of the tropical tropopause? How will stratospheric water vapour change in the future, and how will this interact with the climate? Much of interest and importance remains to be done.


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# A Report of the Gordon Research Conference on "Solar Radiation and Climate"

## New London (NH), USA, July 13-18, 2003

**Venkatachalam Ramaswamy,** NOAA/GFDL, Princeton, USA (V.Ramaswamy@noaa.gov)



The Gordon Research Conference (GRC) on "Solar Radiation and Climate" was held in Colby-Sawyer College, New London (NH), USA, July 13-18, 2003. This was the 3rd in the series, following the first one in 1997 and the second in 2000. The Chair of the Conference was **V. Ramaswamy,** with **J. Kiehl** being the co-Chair. The Gordon Conferences provide an ideal forum for the presentation, communication and discussion of frontier research topics, with this particular one focusing on radiation-climate links and interactions. The Gordon meetings are designed to stimulate ideas at the frontiers of the science and foster creative ideas for its advancement. The format of the present Conference consisted of morning (with 3 talks) and evening (with 2 talks) sessions, with the afternoons kept aside for recreation and freewheeling informal interactions amongst the participants, these being integral components of a Gordon Conference. All the talks were invited presentations only and poster exhibition sessions were scheduled during late afternoon on two of the days. In addition, at the conclusion of the talks every evening, the "social" provided the opportunity to continue the poster discussions, exchange ideas and engage in in-depth conversations on a host of scientific issues raised during the course of the meeting. The younger scientists benefited in particular from a format that promoted lengthy, unhurried interactions with speakers, discussion leaders, and other researchers.

The thematic focus of the 3rd Conference was "radiation and its links with climate, climate variations and change: interpretations from observations and model simulations". The questions sought to be addressed were twofold: (a) How do the various processes (physical, chemical, etc.) interact with and/or determine the observed radiative properties and energy budget of the planet, and how do they affect the general circulation of the atmosphere and explain the observed climate? (b) How does the perturbation of the radiative energy budget, owing to natural and anthropogenic factors, affect or is associated with climate variations and changes, ranging in timescales from seasonal to annual to decadal to centennial (including paleoclimate and future climate changes)?

The sessions were arranged as follows:

| Session Number | Session Title | Speaker and Discussion Leader (DL) |
|---|---|---|
| Session 1 (Keynote) | Radiation and climate change | V. Ramanathan, S. Solomon; J. Kiehl (DL) |
| Session 2 | Radiative interactions in the climate system | Q. Fu, R. Pincus, S. Klein; J. Coakley (DL) |
| Session 3 | Cloud processes in the climate system | C. Bretherton, L. Donner; S. Krueger (DL) |
| Session 4 | Radiative forcing of climate change (tropospheric aerosols) | O. Boucher, U. Lohmann, W. Collins; J. Haywood (DL) |
| Session 5 | Radiative forcing of climate change (stratospheric species, solar irradiance) | J. Haigh, A. Robock; K. Shine (DL) |
| Session 6 | Paleoclimate changes | B. Otto-Bliesner, A. Clement,T. Crowley; C. Covey (DL) |
| Session 7 | Recent climate variations and change | D. Seidel, B. Soden; J. Hack (DL) |
| Session 8 | Climate feedbacks and sensitivity | A. Hall, S. Bony, D. Hartmann; B. Wielicki (DL) |
| Session 9 | Detection and attribution of climate change | B. Santer, P. Stott; D. Karoly (DL) |

There were 50 poster presentations whose contents spanned the breadth indicated by the Conference theme, and whose substance amplified the issues raised in the talks. The posters ranged from discussions of fundamental radiation and climate modelling problems to satellite and other observations to diagnostic interpretations of model simulations and measurements. A distinctive feature of this Conference was the award by the Gordon Research Board of the prestigious Alexander M. Cruickshank Lecture. This year, this Conference was the only one chosen to receive the distinction in the physical sciences, with **V. Ramanathan** selected as the Lecturer.

The mix of speakers, discussion leaders, poster presenters and participants came from universities and national laboratories, and from a number of countries. Particular attention was paid to facilitate qualified young scientists to attend the Conference. The number of persons attending the Conference was 148 (107 US and 41 non-US), a higher-than-usual number, with about one-third being graduate students and post-doctoral researchers. The Conference benefited considerably from funding received from a variety of agencies. Matching funds from GRC for Eastern Europe and minority scientists complemented funds from NASA, NOAA, DOE, NSF, IGAC and WCRP/SPARC. The WCRP/SPARC funds were utilised to provide for the participation of students, post-doctoral researchers and lecturers from developing countries.

In the keynote session, the emerging climatic significance of soot particles, as exemplified by the anthropogenic carbonaceous aerosol emissions from the Indian subcontinent, was discussed. These give rise to a substantial atmosphere and surface radiative forcing, with consequences for changes in the regional climate (including surface temperature and hydrological cycle), effects that merit considerations alongside the global climate change due to greenhouse gas increases. A look ahead to planning for the next Intergovernmental Panel on Climate Change (IPCC) assessments followed, focusing on the climate responses to anthropogenic radiative forcing. In addition to the aerosol effects, other emerging questions were raised, such as changes in circulation, unforced climate variability, stratosphere-troposphere connections, carbon cycle and climate response time scales; these are issues that are likely to be explored in the next IPCC assessment (due in 2007).

Session 2 highlighted unresolved problems in fundamental radiative transfer, including the infrared water vapour continuum, light scattering by ice crystals and 3D radiation effects. The representation of cloud processes and their radiative description in general circulation models continues to pose serious uncertainties, with the need to represent the fields more realistically on the sub-grid scale and consider new approaches in models. The evolution of cloud parameterizations in models was discussed, with a focus on parameterizations that recognise the heterogeneity of the cloud microphysics and radiation fields, and treat radiation-turbulence interactions in an appropriate manner.

Session 3 highlighted the processes that control the global distribution and radiative effects of boundary-layer clouds by synthesizing global observations, field experiment data and numerical model simulations. Feedbacks between the clouds, turbulence and underlying surface properties were emphasised. The role of deep convection in determining the microphysical and radiative properties of high clouds and its evolution was illustrated using cumulus parameterization as a conceptual framework. Cloud-resolving models, together with the use of observations, are enabling the identification of key physical processes associated with deep convection.

Session 4 discussed the basic definitions in aerosol forcing, including the various facets of the indirect effect. A review of satellite observations and model simulations of the direct aerosol effect was presented taking into consideration the question of atmospheric aerosol absorption. Processes that control the aerosol indirect effect were highlighted, and the complexity of the interplay between aerosol forcing, clouds, radiation and hydrologic cycle was elaborated using observations and model results. The radiative role of natural and anthropogenic aerosols was distinguished. Absorbing aerosols can influence the hydrologic cycle considerably in heavily polluted regions, and a way to reduce uncertainties in global aerosol properties description was demonstrated utilising observations and models.

Session 5 presented the radiative forcing due to solar irradiance variations considering the measurements available over the past two decades, the reconstructions going back to late 19$^{th}$ century, and the influence due to changes in stratospheric ozone chemistry. The radiative role of stratospheric water vapour and ozone changes, and the response of the troposphere to a stratospheric radiative perturbation, were also discussed. Both observational and modelling knowledge have advanced concerning the climatic effects of stratospheric aerosols from explosive volcanic eruptions, following studies of the 1991 Pinatubo eruption and its aftermath. These include: the radiatively induced cooling of the troposphere and a warming of the tropical lower stratosphere; potential feedback effects in the column water vapour due to the tropical cooling; and the high-latitude warming during the winter following the eruption possibly arising as a result of stratospheric-tropospheric dynamical coupling.

In Session 6, the simulated global climate change during past warm periods in the Earth's history owing to the Milankovitch orbital variations of insolation and the manner in which this modulates the modes of climate variability were discussed, along with the issue of feedbacks in the Arctic and implications for global warming in the future. Paleoclimate records reveal that there are fluctuations in the global ice volume on the same timescale as the orbital insolation forcing, but the linkages are not fully understood. In addition, abrupt shifts in climate occur on millennial timescales that may be due to internal instabilities in the climate system. Correlations of solar irradiance variations and climate on the decadal-millenial timescales suggests a relatively minor role for solar variability on hemispheric scale climate change; however, lower frequency millennial-scale oscillations of solar variability have a greater correlation with some millennial-scale climate oscillations, suggesting a frequency-dependent role to the Sun-climate link.

Session 7 discussed upper-air temperature changes in satellite and radiosonde datasets. Care is required in the analyses of these data since the platforms were not originally intended for climate monitoring; however, several problems involving time-varying biases, inhomogeneity of station records, and satellite data problems have been addressed, the datasets have been intercompared, and reasonably reliable estimates of temperature variation (and less reliable trend estimates) have been obtained. Uncertainty of changes in the distribution of water vapour and clouds leads to a significant uncertainty in the quantification of climate feedback. Observations of the variations in water vapour, clouds, precipitation and radiative fluxes from satellite observations over the past two decades were analysed to focus on the documented discrepancies between observations and climate model results, and explore hypotheses for their explanations.

Session 8 discussed climate sensitivity and feedbacks. The relevance of variations in the shortwave optical properties of the Earth's surface for climate variability and change was presented, with ice/snow albedo and vegetation albedo feedbacks as examples. Results from models and satellite observations show that water vapour and cloud responses to a radiative forcing can be forced by large-scale circulation changes, as well as by changes in the atmospheric thermodynamical structure. A framework to unravel the components in the tropics was proposed. The behaviour of tropical convection-cloud interactions, including the net radiative effect of the clouds and their implication for climate sensitivity, and the feedback uncertainties regarding planetary boundary layer in the tropics and subtropics, were also highlighted.

Session 9 presented recent developments in detection and attribution research consisting of improved characterization of satellite data uncertainties leading to improved analyses of model simulations with observations, and introduction of new fingerprints in identifying anthropogenic effects on climate e.g., ocean heat content and tropopause height changes. Climate model simulations are enabling the estimation of contributions by the different natural and anthropogenic radiative forcing agents to the observed climate changes in the 20th century. Trends in global-mean and continental-scale surface temperature are becoming detectable above the noise of the unforced internal variability in the climate system, while evidence is also beginning to emerge of trends in other climatic indicators.

Each of the talks dwelt on state-of-the-art research, starting with a brief review of current knowledge and relevance of the topic, followed by a balanced presentation of the latest research results, and concluding with views on the future course of research including the outstanding issues and challenges. The discussion leaders, chosen for their expertise and experience, helped in emphasizing the key points, steered the discussions by providing additional thoughts and introduced related ideas. A particularly gratifying feature was that the younger scientists (especially students) energetically participated in the discussions period. Substantive points were raised on all three fronts - observations, modelling and diagnostic interpretations concerning present-day climate and climate change – during the course of the discussions.

As is customary at every Gordon Conference, all participants were invited to respond to a questionnaire distributed by GRC. About 85% responded, an unusually high return that is indicative of the high degree of interest stirred up by the meeting. The evaluation comprised 5 categories: science/ideas, discussion, management/organization, atmosphere and overall Conference suitability. The results of the evaluation were highly complimentary in all categories, with significant improvements compared to the prior two Conferences. The participants' ranking places this Conference in the upper echelons of the meetings held by GRC in the physical, chemical and biological sciences and technology. At the conclusion of the meeting, the Conference participants voted to elect **W. Collins** as Chair of the Conference in 2007, with **P. Russell** as the co-Chair. The Chair and co-Chair of the next Conference in 2005, who were elected during the 2000 meeting, are **H. Barker** and **R. Ellingson,** respectively.

♦



## Brief Report on the START Young Scientists Conference on Global Change

### Trieste, Italy, 17-19 November, 2003

The conference and its aims were to stimulate competition, encourage excellence, reward outstanding performance, encourage the development of personal and institutional networks, and at the same time indulge in high-level capacity building among young scientists from both developed and developing countries.

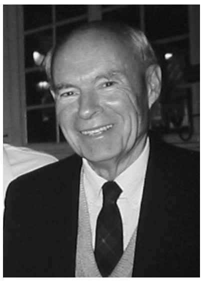
In every way the conference was a resounding success. The endeavour stemmed from the Earth System Science Partnership (ESSP) Open Science Conference on Global Change held in Amsterdam in July 2001, when the ESSP, comprising the IGBP, WCRP, IHDP and DIVERSITAS, asked START to organize a high-level international conference for young scientists of 35 years old and younger. An organizing committee comprising three young scientists, **K. Ross** of South Africa, **R. Pongracz** of Hungary and **A. Freise** of START, planned the conference under the Chairmanship of **P. Tyson.** Over 1000 submissions were received and finally, 51 young scientists were selected for 15-minute oral paper presentations and 31 for 2-minute oral poster presentations, the standards of content and presentation being outstanding.

The winner of the Crutzen Award for the Best Paper was G. Pineiro of Universiy of Buenos Aires, Argentina, for his paper "Long term grazing impact on soil carbon and nitrogen pools in South American grassland" co-authored by **J.M. Paruelo, E.G. Jobbagy, M. Oesterheld** and **R.B. Jackson.**

The award of Best Poster went to **S. Marquart** of DLR Oberpfaffenhofen, Germany, for her poster "Future development of contrail cover, optical depth and radiative forcing: impact on increasing air traffic, alternative fuels and climate change" co-authored by **M. Ponater, R. Sausen** and funded by the International START Secretariat.

The conference met all its aims, making it an outstanding success and generated great enthusiasm and camaraderie. The fact that so many young global change scientists from developing countries were able to compete on merit alone for places at the conference is testimony to the success of more than a decade of research-driven capacity building by START, its sponsors and conference partners. WCRP can well be satisfied with the state of global change science among young scientists and leaders of the future in the WCRP family.

# Symposium Honours Jim Angell on his 80th Birthday



## Silver Spring (MD), USA, November 4, 2003

**Dian Seidel,** NOAA (R/ARL), Silver Spring, MD, USA (Dian.Seidel@noaa.gov)
with contributions from **B. Hicks, K. Labitzke, J. Lanzante, J. Logan, J. Mahlman, V. Ramaswamy, W. Randel, G. Rasmusson, A. Robock, B. Ross, and S.F. Singer.**

Before the establishment of the WCRP in 1980, and well before the organisation of the SPARC in 1992, ***Jim Angell*** was making pioneering contributions to our understanding of the climate system and the role of stratospheric processes in climate variability. On November 4, 2003, more than 50 colleagues and friends gathered at the NOAA Science Center in Silver Spring (MD), USA, for a one-day symposium reviewing and honouring ***Jim***'s career achievements and celebrating his 80th birthday (November 2). This article highlights some of ***Jim***'s contributions, both as reviewed during the symposium, and as captured in poems composed in his honour and recited at a birthday dinner celebration. More information about ***Jim Angell*** and the Angell Symposium, including photos, some presentations, his publications list and more poems, is online at **www.arl.noaa.gov/ss/climate/Angell Symposium.html**.

***Jim*** received his Ph.D. in meteorology in 1956 from the University of California, Los Angeles, where he worked as a lab instructor for J. Bjerknes. His dissertation research, under advisor M. Neiberger, addressed atmospheric transport using data from constant level balloons developed by J. Mastenbrook. After graduation, ***Jim*** was offered a position in the Special Projects Branch of the U.S. Weather Bureau (now NOAA's National Weather Service) by L. Machta. That branch evolved into the NOAA Air Resources Laboratory (ARL), where ***Jim*** has spent his entire career. Having retired from Federal service in Spring 2000, ***Jim*** continues to work on climate and ozone research at NOAA/ARL in Silver Spring, Maryland.

### Grounded in Observations, Taken aloft by Balloons

*There once was a fine lad named James*
*Who found that balloons weren't just games*
*He pulled out their data*
*'Cause sooner or lata*
*They would bring him his multiple fames.*

*Jerry Mahlman*

"The work being done in climate today rests on the early efforts of scientists such as ***Jim***," said **R.D. Rosen**, in remarks welcoming participants to NOAA. **J. Mahlman** gave an overview of ***Jim***'s career, noting his strong focus on analysis of observations, particularly from balloon-borne instruments, to address emerging scientific challenges, ranging from the transport and dispersion of air pollution to long-term climate change and stratospheric ozone depletion. **J. Mahlman** noted ***Jim***'s "passion for observations with a purpose," remarking that "he carefully examined the data, acknowledged its flaws and decided whether or not he was seeing new physical insights into atmospheric behaviour."

### Global Temperature Monitoring and Research

*Jim with his network of sites, 63,*
*studies temperature change in the atmosphere-free.*
*He calmly considers (without any panic)*
*effects on the change of eruptions volcanic.*
*His ongoing study of T trends, decadal,*
*will continue no doubt as long as he's able.*
*His service to science is quite an example*
*so lets give him credit and* LOUD APPLAUSE *ample.*

*Becky Ross*

***Jim*** set out to monitor the variability and trends of atmospheric temperature three decades ago, when he identified a global network of 63 radiosonde stations, and a methodology of analysis of seasonal anomalies of zonal, hemispheric and global temperature at the surface and in different atmospheric layers, in a seminal paper [Angell and Korshover 1975]. The datasets he developed covered the period from the 1958 expansion of the radiosonde network for the International Geophysical Year to near-present. ***Jim*** extended and analysed data from this network to identify numerous climate signals, from short-term seasonal and interannual variations to long-term trends. The network continues to provide meaningful results, although in his most recent paper [Angell 2003], ***Jim*** removed nine stations with anomalous trends from the record.

In addition to his work with radiosonde data, ***Jim*** was among the first to use data from meteorological rocketsondes to explore temperature variations at higher stratospheric altitudes. His comprehensive explorations of temperature observations often made insightful and original connections with related parameters, including early stratospheric water vapour data, sea surface temperature and pressure observations, Indian monsoon rainfall data, sunshine duration and cloudiness observations, atmospheric carbon dioxide concentrations and, most notably, stratospheric ozone and ozone profile data.

Dubbing ***Jim*** "The Monitoring Expert," ***V. Ramaswamy*** noted five hallmarks of his career: incessant research, breadth of exploration, meticulous analyses, prompt reports, and exemplary collegiality. ***V. Ramaswamy*** congratulated and thanked him for his contributions to several major assessment activities, including the SPARC Temperature Trends and Ozone Assessment Panels, the WMO/ UNEP Scientific Assessments of the Ozone Layer, and the Intergovernmental Panel on Climate Change assessment reports.

### Ozone Studies

*Jim measured the polar vortex as it would grow,*
*Though his pencil and calculator made him a little slow,*
*A true pioneer in the field,*
*Such insights his statistics would yield,*
*And he took us where no one else knew where to go.*
*Jim studied volcanoes, the vortex and* QBO*,*
*He put on quite a scientific show,*
*A gentlemen is he,*
*A most pleasant person with which to be,*
*And from his friends, a gracious thanks, we now bestow!*

*John Lanzante*

**J. Logan** traced the course of ***Jim***'s ozone investigations. His pioneering analyses documented three dominant influences on interannual variability of stratospheric ozone: the quasi-biennial oscillation (QBO), the solar cycle, and major volcanic eruptions. ***Jim*** conducted the first comprehensive analysis of the QBO in column ozone [Angell and Korshover 1964]. He turned his attention back to ozone in the early 1970s when concerns were first raised about ozone depletion. In a landmark paper [Angell and Korshover 1973], he: (1) showed the "quasibiennial fluctuations" in ozone as a function of latitude and their relationship to the winds, (2) provided a careful analysis of the relationship between ozone and sunspot number, a controversial subject at the time, (3) analysed long-term trends in column ozone, which was increasing in the 1960s, and (4) found no evidence for a reduction in ozone resulting from nitric oxide produced by nuclear bomb tests.

***Jim***'s search for trends in ozone later expanded to include the first analyses of trends in the Umkehr and ozonesonde data, after models predicted the vertical profile of ozone loss. Recurring themes in his analyses of ozone over a 35-year period are examination of the relationship of ozone to the QBO, solar cycle and volcanic eruptions. His concern over data quality is another constant, as is his search for consistency among the various ozone records from Dobson, Umkehr and sondes. He laid the groundwork for later work on ozone trends as statisticians entered the field, and as satellite data became available: the QBO and solar cycle are now included as explanatory variables in all regression estimates of ozone trends.

*"It is hoped that this discussion has directed the reader's attention to the complex nature of the total-ozone variation, both in time and space. Because of uncertainty concerning the raison-d'être of much of the variation, it is extremely difficult at this time to evaluate accurately man-made influences on ozone amount. Consequently, when considering the possible effects of the supersonic transport on stratospheric ozone, for example, we must be very careful that any changes noted reflect the human influence and would not have occurred naturally. For conscientious scientists, this may be the most difficult determination of all."* [Angell and Korshover, 1973].

## Discovery and Characterization of the QBO

*Our friend Jim has a strong reputation,*
*For analysis of data and not speculation,*
*East winds changing to west,*
*Were the ones he knew best,*
*He called it the quasi-biennial oscillation*

*William Randel*

**W. Randel** reviewed **Jim**'s contributions to understanding the stratospheric QBO and noted that he was one of the first scientists to recognise its importance in global climate variability. His careful work with sparse data sets documented the global dynamical structure of the QBO and quantified its influence on a variety of meteorological fields and trace constituents. Publications by Angell and Korshover (1962, 1963) quickly followed the 1961 discovery of the biennial oscillation and characterized the propagation characteristics and global structure (including extension into middle latitudes).

In 1964 Angell and Korshover coined the term "Quasi-Biennial Oscillation" and documented correlated variations in global temperatures, ozone and tropopause height. Further original work included quantifying QBO variations in equatorial Kelvin waves and the QBO influence on global ozone variability, and documenting effects on tropical tropopause temperatures and associations with stratospheric water vapour, both topics of current stratospheric water vapour investigations. ***Jim*** also documented QBO effects on tropospheric circulation patterns, in particular surface pressure variations in the 'centers of action' (the North Atlantic and North Pacific subtropical high pressure systems); his pioneering results agree well with recent estimates of surface QBO effects. Over the past 40 years, ***Jim*** has contributed over 20 publications on the structure and global influence of the QBO.

## Volcanic Effects on Climate

**A. Robock** reviewed the fundamentally new understanding of the effects of volcanic eruptions on climate that resulted from ***Jim***'s observational studies of temperature, winds and ozone concentration in the atmosphere. During the past 50 years, which ***Jim*** studied, there were three major volcanic eruptions that produced massive stratospheric sulfate aerosol clouds: Agung in 1963; El Chichón in 1982; and Pinatubo in 1991. ***Jim*** used radiosonde and rocketsonde data to study the stratospheric temperature response following these large eruptions, accounting for the effects of the stratospheric QBO [Angell and Korshover 1983]. In addition, ***Jim*** showed that six major eruptions, starting in 1780, produced a significant surface cooling for a couple of years.

***Jim*** was also a pioneer in using the mid-tropospheric thickness (850-300 mb) obtained from radiosondes to measure tropospheric temperature changes. He was the first to notice that volcanic and El Niño influences have about the same amplitude and time scale, and that to delineate the volcanic influence, the El Niño influence needed to be removed. He showed that after doing this, a clear volcanic cooling influence is evident [Angell 1988]. Finally, ***Jim*** recognised the impacts of volcanic eruptions on stratospheric ozone, associated with the increasing effect of heterogeneous chemistry on volcanic aerosols to liberate anthropogenic chlorine, which catalyzes ozone destruction [Angell 1997].

## Solar Signals in Climate

**K. Labitzke** reviewed ***Jim***'s contributions to the identification of solar signals in ozone and climate, noting the controversies surrounding this topic. Recognizing the difficulty of separating solar, volcanic and anthropogenic influences, all of which have comparable time scales of variability, Angell and Korshover (1973) noted with characteristic caution and care that "...evidence for a nearly 11-yr periodicity in total ozone directs one's attention toward the possibility of a relationship with sunspot number.... we plan to re-open this particular Pandora's box....". As the length of data record grew, ***Jim*** confirmed and explored the details of the solar signal in ozone in subsequent publications in the 1970s, 1980s, and 1990s, in which he stressed the need to consider (and remove) the solar signal in evaluating long-term ozone trends. More recently, ***Jim*** identified a possible solar influence in atmospheric circulation patterns, showing that the size of the North Polar vortex varies in association both with El Niño and with sunspot number.

*"The rationale for this paper is the belief, nay certainty, that knowledge of past 'natural' variations is a prerequisite to detection and comprehension of possible future effects."* [Angell 1980].

## El Niño-Southern Oscillation Signals in Climate

**G. Rasmusson** provided a comprehensive summary of ***Jim***'s El Niño-Southern Oscillation (ENSO) research, initiated during a 1979-80 sabbatical year at CSIRO in Aspendale. His contributions are in three general areas of inquiry: (1) ENSO effects on NH extra-tropical circulation, (2) the nature and stability of tropical Pacific - monsoon sector relationships, and (3) the impacts of ENSO warm events and volcanic eruptions on interannual tropospheric temperature variability and long-term temperature trends.

***Jim***'s work in collaboration with B. Elliott: (1) confirmed a high correlation between the Southern Oscillation Index (SOI) and equatorial Pacific Sea Surface Temperature (SST), (2) identified a two-season lag of tropical tropospheric temperature relative to equatorial Pacific SST, (3) identified a two-season lag of tropical Pacific SST relative to monsoon rainfall, and (4) identified a lag of the atmospheric carbon dioxide decrease relative to tropical Pacific SST, which increased from one season in the tropics to three seasons in the polar regions [Angell 1981; Elliott and Angell 1987, 1988]. The team also identified secular changes in the correlation of SST with SOI over the course of the twentieth century. As ***Jim*** often notes with irony "You need to know when to stop in correlation studies, because just when the correlations seem to be convincing, a longer data record results in the correlations falling to pieces."

***Jim*** identified ENSO effects on the NH extratropical circulation, addressing both the four centres of action [Angell and Korshover 1984] and the 300 mb North Polar vortex [Angell 2001], suggesting a link between ENSO and the Arctic Oscillation. ***Jim*** also identified and quantified the atmospheric thermal pulse associated with an equatorial Pacific warming and its poleward spread, which allowed him to "back out" the ENSO warming and obtain the volcanic cooling contribution in cases where the two signals overlapped, *i.e.* Agung (1963) and El Chichón (1982). Using this information, he later evaluated the contribution of ENSO warming to the long-term tropospheric temperature trend [Angell 2000].

## Atmospheric Transport and Boundary Layer Research

**B. Hicks** discussed some of ***Jim'*** s early contributions to the understanding of atmospheric dispersion and transport, noting how relevant those studies remain today. ***Jim***'s dissertation research with constant-pressure balloon (transosonde) data and his later work, with constant-volume balloons (the tetrahedral-shaped tetroons) shed light on the long-range transport of air within the United States, and across the Pacific Ocean from Japan. ***Jim*** conducted flights to study mesoscale urban and sea-breeze influences on atmospheric circulation, inertial oscillations in the atmosphere, vertical velocities in the atmospheric boundary layer, jet stream velocities and lateral dispersion. ***Jim*** spent a sabbatical year in 1961-62 working with F. Pasquill at the British Meteorological Office in Bracknell, and tells of a rather harrowing experience in the field, launching tetroons from open wicker basket suspended below a barrage balloon at 1000 m altitude, in 30 knot winds and near-freezing temperatures.

In addition to all the topics mentioned above, ***Jim*** also made significant contributions to the study of climate and air quality in the United States. He developed climatologies of air stagnation, cloudiness and sunshine duration, each of which plays a role as meteorological controls on the formation and duration of air pollution episodes. For many years, he monitored variations and trends in cloudiness and sunshine, until changes in observing systems made continuation of the analyses impossible. With the availability of reanalysis data products, and in collaboration with J. Wang, ***Jim***'s stagnation datasets have been updated and used by NOAA's National Weather Service as part of its suite of forecast products.

## Summary

As J. Mercer wrote, "Fools rush in where angels fear to tread." But as the symposium made clear, ***Jim*** fearlessly treads just about everywhere in the atmospheric sciences. Carried along largely by data from balloons, he has analysed everything from the Earth's surface to the stratosphere, examining atmospheric variations on hourly to centennial scales, drawing connections among elements as wide-ranging as volcanoes and sunshine, temperature and ozone, cloudiness and water vapour. ***Jim*** remains an active contributor to atmospheric science. As the icing on his 80th birthday cake proclaimed, "Long may the time series continue!"

The day after the Angell Symposium, SPARC sponsored a Workshop on "Understanding Seasonal Temperature Trends in the Stratosphere" (see page 24). The workshop co-chairs, **W. Randel** and **V. Ramaswamy,** noted that, "Many of the details of the workshop trace their origin to ***Jim***'s pioneering sonde analyses right from the early days."

*Figure 1: Participants at the Jim Angell 80th Birthday Symposium, November 4, 2003, at the NOAA Science Center in Silver Spring, Maryland.*


*Clickety Clac, kety*
*Hail* NOAA *'s Angell.*
*Troposphere's guardian,*
*Stratosphere's knight.*
*Environmentally*
*Data collecting, but*
*Always concerned about*
*Getting it right.*

*S. Fred Singer*

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# The SPARC Workshop on Understanding Seasonal Temperature Trends in the Stratosphere

## Silver Spring (MD), USA, November 5, 2003


**William Randel** (co-Chair), NCAR, Boulder, USA (randel@ucar.edu)
with input from the Organizing Committee: **V. Ramaswamy** (co-Chair), **D. Karoly, D. Seidel, S. Yoden** and Workshop Participants.


Previous SPARC activities organised under the Stratospheric Indicators of Climate Change initiative have included several highly successful projects, including assessments of the vertical distribution of ozone trends, stratospheric temperature trends, upper tropospheric and stratospheric water vapour, middle atmosphere climatologies, and stratospheric aerosols. These independent studies were aimed at assessing and consolidating our understanding of specific aspects of stratospheric climate change, with a focus on analyses and critical appraisal of existing observations and datasets. But it was also recognized that the topics are inter-related (such as ozone, water vapour and temperature changes), and as the SPARC programme matures, a natural evolution is to try to understand past and future stratospheric changes in a more coupled manner, combining a range of both observational and modelling studies. This evolving project has been labelled the **SPARC Initiative on Detection, Attribution and Prediction of Stratospheric Changes.**

To assess the state of the science and understand emerging research areas, a one-day workshop was held in Silver Spring, MD on November 5, 2003 (in conjunction with the Jim Angell 80th Birthday Symposium). This workshop focused on the outstanding scientific questions related to understanding stratospheric temperature trends, and discussing the community's plans for understanding past and future stratosphere climate change. The workshop was organised into three sessions focusing on: 1) observations, 2) model simulations, and 3) additional relevant topics, such as the effects of circulation changes and predictability of stratospheric climate. Each session had a set of invited presentations only, and time was allocated for extensive discussions among the 40 workshop participants, aimed at articulating key points and framing the current outstanding questions.

### Observations

The morning session focused on observational issues related to stratospheric climate change. **W. Randel** gave an overview of the current global temperature data sets used to assess stratospheric temperature changes, including meteorological analyses and reanalyses, and direct satellite measurements. There are substantial differences among the data sets, and there are often discontinuities associated with changes in analysis systems or changes between operational satellites (**Figure 1**). One important observational priority will be to produce long-term stratospheric temperature records where such artificial changes are minimised. **J. Miller** presented new analyses of Stratospheric Sounding Unit (SSU) and Advanced Microwave Sounding Unit (AMSU) satellite radiance data sets to understand long-term temperature changes. The SSU data cover 1979-2002, and provide much of our current

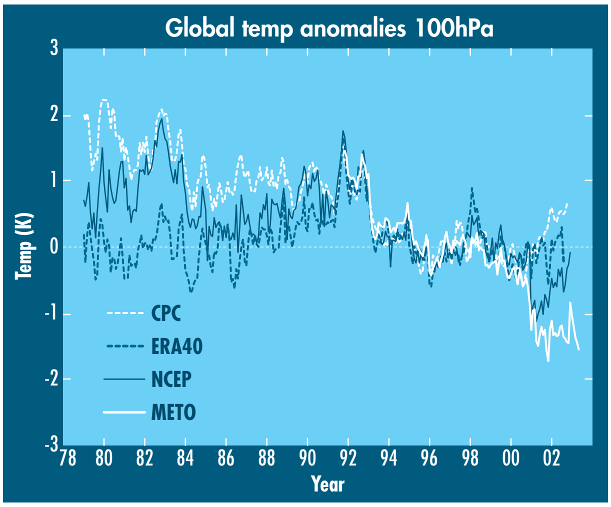



*Figure 1. Time series of global mean 100 hPa temperature anomalies, derived from four different meteorological data sets (ERA40 reanalyses, NCEP reanalyses, METO stratospheric analyses, and NCEP CPC analyses). Each data set has been deseasonalized and the anomalies are normalized to zero for the period 1992-1999. Note the substantial differences in estimates of global temperature changes among the different data sets.*

understanding of stratospheric temperature trends (especially in the middle and upper stratosphere) for this period; the AMSU data begin in 1998 and it will be incorporated on future operational satellites. While details of the SSU and AMSU instruments and weighting functions are very different, the substantial overlap period between the two instruments (1998-2002) allows continuous temperature data sets to be derived from regression analyses. This ongoing work will be of high value to the SPARC community.

**J. Angell** presented updated observations of lower stratospheric temperatures from radiosonde measurements, and highlighted the complexity of obtaining homogeneous time series from historical data (there are large disparities among different methods that are currently used). An unresolved point is the difference in trends in the lower stratosphere, and in the tropopause region, derived from radiosonde and satellite data since 1979, and among different radiosonde datasets since 1958, especially in the SH and Tropics. He also highlighted the non-linear nature of temperature changes, focusing on the abrupt changes associated with volcanic eruptions. **J. Haigh** presented a discussion of the effects of the 11-year solar cycle on global temperatures, zonal winds and ozone. Overall there is reasonable agreement between observations and model simulations for effects in temperature, whereas there are substantial uncertainties regarding the vertical structure of the ozone response. Mechanistic models are providing new insights into the mechanisms of solar influence. Improved characterization of the solar cycle is important for understanding temperature variability in stratospheric observational records that span only a few decades.

## Modelling

The next session focused on model simulations of stratospheric temperature changes over the past two decades. **K. Shine** discussed a recent intercomparison of annual mean stratospheric temperature changes between several current models and observations. While there is reasonable agreement between the vertical profile of global mean observations and model results (**Figure 2**), there are uncertainties in some details, including the cause of observed northern midlatitude lower stratosphere cooling. There are also substantial differences in model results for identical imposed changes, suggesting that further model intercomparisons are needed. **D. Rind** discussed the effects of changing dynamical coupling between the stratosphere and troposphere, and chemical coupling effects, using results from the GISS model. He stressed the importance of temperature changes in the tropical upper-troposphere in influencing the residual circulation in the stratosphere and in determining the nature of the response of Arctic Oscillation to changes in well-mixed greenhouse gases, water vapour and ozone. **J. Austin** analysed stratospheric ozone and temperature trends simulated in coupled chemistry-climate models, presenting results from the EuroSPICE intercomparisons. Key points are that model temperature biases have an important leverage on polar ozone losses, and that dynamical variability and coupling with the troposphere are important contributors to decadal-scale changes. **R. Garcia** showed simulations of stratospheric temperature and water vapour trends using the NCAR Whole Atmosphere Community Climate Model (WACCM). The model results show water vapour increases of ~0.2-0.4 %/year for 1980-

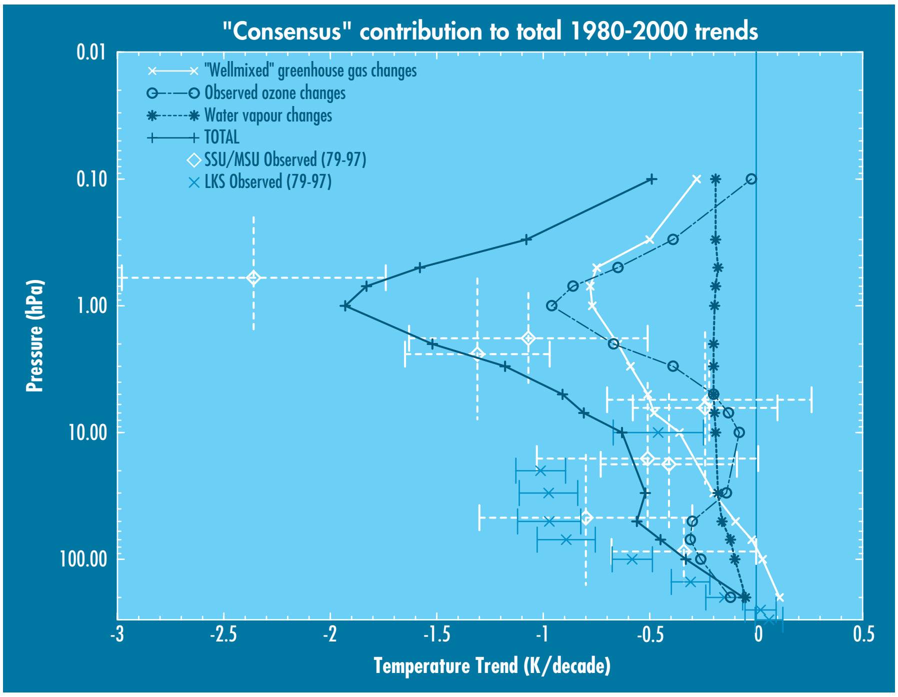
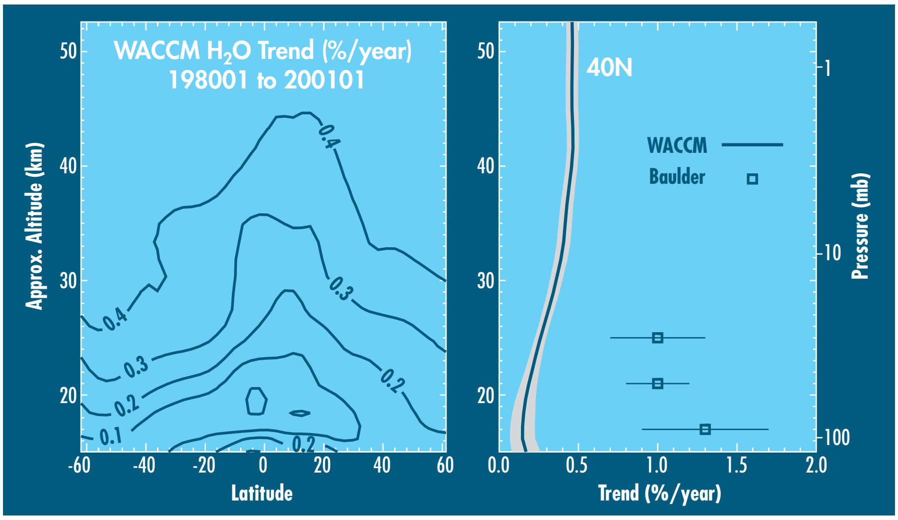



*Figure 2. Global and annual mean temperature trends for the period approximately 1980-2000, from an average of model results using observed changes in ozone and greenhouse gases, and idealized water vapour trends. Observed temperature trends derived from satellite and radiosonde data sets are indicated by the symbols, and the error bars give the two-sigma trend uncertainties [from K. Shine et al., 2003].*

*Figure 3. Left panel shows linear trends in water vapour (in % per year) during 1980-2001 as simulated by the NCAR WACCM. Right panel compares the WACCM results at 40°N with water vapour trends derived from balloon measurements at Boulder, Colorado (40°N) during 1980-2000 (from S. Oltmans et al., 2000). [Courtesy of D. Marsh].*




2000 (see **Figure 3**). There are also very different rates of increase for the two decades 1980-1990 and 1990-2000, illustrating substantial variability on decadal time scales.

## Additional Relevant Topics

The afternoon session featured discussions on circulation effects, outstanding uncertainties in general circulation models, and prospects for stratospheric climate prediction. **U. Langematz** discussed the effects of changes in stratospheric circulation, including strengthened polar vortices and reductions in planetary wave forcing from the troposphere. The mechanisms that control tropospheric planetary wave forcing of the stratosphere, and how they will evolve under a changing climate, are key factors for understanding stratospheric climate change. The presence of significant internal dynamical variability also highlights the need to perform large ensembles of climate simulation experiments (to separate climate noise from forced signals). The important role of parameterized gravity wave forcing in middle atmosphere GCM's was highlighted by **T. Shepherd,** who showed that details of the schemes are very important for understanding dynamical feedbacks to radiative perturbations. **S. Pawson** presented an update of outstanding issues related to stratospheric climate models from the SPARC GRIPS programme. While, overall, models have substantially improved their climate simulations with time, there are still chronic problems in many models, including persistent temperature and zonal wind biases, and a lack of realistic tropical oscillations. These mean climate biases are probably associated with details of the resolved and parameterized wave forcings. The understanding of dynamical coupling between the stratosphere and troposphere and agreement with observations are especially challenging in light of such chronic model biases. **A. O'Neill** discussed a probabilistic approach to understanding decadal-scale changes in stratospheric climate. This includes the use of large ensemble simulations to properly distinguish signal and (climate) noise (illustrated in **Figure 4**). It also involves the use of multiple models, given current uncertainties in model formulations and dynamical feedbacks. Because large community resources are needed for such work, SPARC has an important role to play in planning effective research strategies.



## Summary

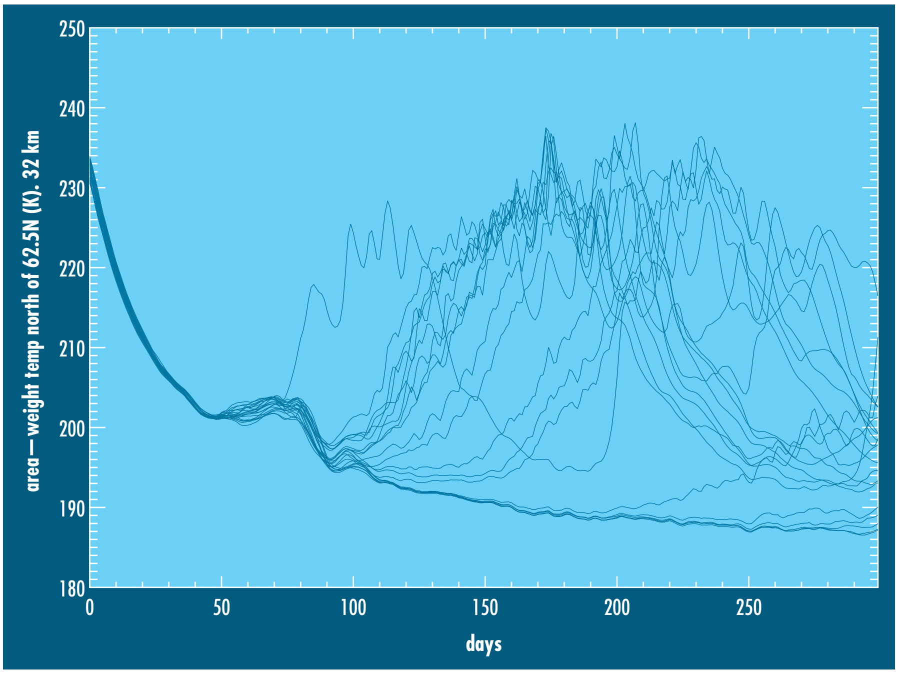
The workshop ended with a group discussion of some of the outstanding key issues raised during the day. The following is a list of topics and key points derived from that discussion (not in any particular order). Together with further community input, these topics can help SPARC in identifying future research priorities.

## Observations

*Operational and climate data sets*

(1) Ensure the availability of long-term high quality 'climate' temperature data sets for the stratosphere and mesosphere; (2) Identify problems and quantify uncertainties in current satellite data and reanalyses; (3) Optimise continuity in data sets across the TOVS-ATOVS satellite boundary, and in future satellite datasets; (4) Include SPARC input into future reanalyses and 'climate network' designs.

*Figure 4. An ensemble of time series of temperature in the middle stratosphere over the polar cap, as simulated by a numerical model of the stratosphere and mesosphere, starting from slightly different initial conditions in August. [Courtesy of L. Gray].*



*Process and experimental data sets*
(1) Include multiple sources of data and specific UTLS measurements; (2) Ensure quality of radiative forcing data sets, including ozone, water vapour and aerosols.

## Models

*Consistency of model simulations*
(1) Intercomparison of radiation codes; (2) Compare inter-model responses to specified forcings (GRIPS Level 3+4 activities - this includes both model vs. model and model vs. observations).

*Model processes and parameterizations*
(1) Evaluate the role of interactive chemistry in model variability; (2) Improved quantification of gravity wave parameterization effects, sensitivities and uncertainties; (3) Better understanding of dynamical coupling of the troposphere and stratosphere, especially EP flux coupling and annular modes; (4) Evaluate model uncertainties in the face of interannual variability, especially in winter polar regions; (5) Improve UTLS physics, especially aerosol and cloud microphysics; (6) Identify robust indicators for model sensitivity studies.

## Detection, Attribution and Prediction

(1) Estimate signal vs. noise using ensemble runs and long control simulations; need to use a probabilistic approach for attribution and prediction. (2) Understand sensitivity of past and future predictions to uncertainties in forcings. (3) Test consistency across different indicators (*e.g.* temperature and radiative gases). (4) Develop and use fingerprint techniques based on space-time patterns of signal responses and noise. (5) Understand the differences between equilibrium runs (time slices) vs. transient response experiments. (6) Quantify the role of tropospheric forcing of the stratosphere, including the impact of observed vs. climatological vs. simulated SST's. (7) Develop improved diagnostics to distinguish radiative vs. dynamical responses.

♦

# Brief Report on the Workshop on Process-Oriented Validation of Coupled Chemistry-Climate Models



### Garmisch-Partenkirchen/Grainau, Germany, November 17-19, 2003

**Veronika Eyring,** DLR-Institiut für Physik der Atmosphäre, Germany (Veronika.Eyring@dlr.de)
**Neil Harris,** European Ozone Research Coordinating Unit, UK (Neil.Harris@ozone-sec.ch.cam.ac.uk)
**Markus Rex,** Alfred-Wegener Institut-Potsdam, Germany (mrex@awi-potsdam.de)
**Theodore G. Shepherd,** University of Toronto, Canada (tgs@atmosp.physics.utoronto.ca)
With contributions from **D. Fahey, J. Austin, M. Dameris, H. Graf, T. Nagashima, and B. Santer**

A workshop was held on "Process-oriented validation of coupled chemistry-climate models" on November 17-19, 2003 in Garmisch-Partenkirchen/Grainau, Germany. Approximately 80 participants attended from Europe, the United States, Canada, Japan, and New Zealand. The workshop was held under the auspices of the Institute for Atmospheric Physics of the German Aerospace Center (DLR), the EU research cluster OCLI (Ozone CLimate Interactions), and SPARC.

The workshop was motivated by the need to evaluate the skill of coupled chemistry-climate models (CCMs) to predict the future state of the ozone layer. Providing accurate and reliable predictions of future changes in stratospheric ozone is of central importance in climate studies. Simulating the interaction between chemistry and climate is of particular importance, because continued increases in greenhouse gases and a slow decrease in halogen loading are expected, which both influence the abundance of stratospheric ozone. In recent years CCMs with different levels of complexity have been developed. They produce a wide range of results concerning the timing and extent of ozone layer recovery [WMO, 2003]. This outcome has created a need to identify the main dynamical, chemical and physical processes that determine the long term behaviour of ozone in the models and to validate these processes by comparison with observations and other models.

Unlike chemical transport models (CTMs), which are constrained to follow the meteorology of a particular year and can, therefore, be directly compared with measurements on a day-today basis, CCMs simulate a climate that at best only bears a statistical relationship to the real atmosphere. As a result, validation of stratospheric CCMs presents particular challenges. Firstly, it is important to separate errors in model chemistry from errors in model dynamics and radiation. For example, a temperature bias would lead to an incorrect prediction of polar ozone, even if a model's chemistry were correct. Secondly, natural dynamical variability means that a comparison of model results with measurements must be performed in a statistical manner. This is problematic, because it appears to take many decades to define a robust stratospheric climatology, especially in the

Arctic winter. While tropospheric climate models can be validated, in part, by their ability to reproduce the climate record over the 20th century, the paucity of stratospheric climate data prior to the satellite era (before 1979) severely restricts such possibilities for validating stratospheric ozone.

For these reasons, validation of CCMs needs a process-oriented basis to complement the standard comparisons of model and observed climatologies. By focussing on processes, models can be more directly compared with measurements. Furthermore, natural variability becomes an aid rather than an obstacle because it allows one to explore parameter space and, thereby, more readily identify cause and effect within a model. In the context of stratospheric GCMs (i.e. without chemistry), process-oriented validation represents the level II tasks within the GCM-Reality Intercomparison Project for SPARC (GRIPS) [Pawson *et al.,* 2000]. The recent WMO/UNEP Assessment contained a first attempt at process-oriented validation of CCMs [Austin *et al.,* 2003]. The purpose of this workshop was to build on this foundation and develop a systematic, long-term approach.



The workshop brought together members of the CCM and CTM communities, as well as various measurement groups, to develop a list of key processes and to identify specific diagnostics and datasets that could be used to validate those processes. The group also included those experienced with model validation activities, such as GRIPS, EU-TRADE-OFF, NASA Models and Measurements-II initiative, and the Program for Climate Model Diagnosis and Intercomparison (PCMDI). The workshop was structured around six major topics: (1) Transport Characteristics, (2) Stratospheric Dynamics, (3) Stratospheric Chemistry and Aerosols, (4) Tropical Tropopause Layer including the Upper Troposphere and Lower Stratosphere, (5) Tropospheric Forcing, (6) Radiative Transfer and Balance. Presentations in each topic began with an overview talk, were followed by two to four solicited shorter oral presentations highlighting certain specific issues, and then were completed with extended discussion. Each topic included contributed poster presentations.

The lasting impact and the full benefit from the workshop will come from the concerted validation activity that will be based on the results of the meeting. This activity will unfold over the next couple of years and needs the support of a broad community. It is important that the validation procedures defined for this activity are accepted and valued by all participants in this joint exercise. With the help of the theme speakers and the rapporteurs, the program committee has compiled a list of key validation processes, associated diagnostics, and relevant datasets, based on the contributions and discussions at the workshop. For the next few months this list will be open for discussion by the whole community, including all interested parties unable to attend the workshop. During this process the list of diagnostics and datasets will fully evolve. The list in its final form, a more comprehensive report of the workshop and the plans for the coming years will be published in the next SPARC Newsletter. We invite all interested parties to actively contribute to the discussion process and to the joint activity that will be defined as a result of it. The evolving list with diagnostics, developing ideas and a list of contacts for individual aspects of the validation activity can be found on the website of the workshop at:
**www.pa.op.dlr.de/workshops/ccm2003/.**

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*Participants at the Workshop on Process-Oriented Validation of Coupled Chemistry-Climate Models*

# New Insights into Upward Transport across the Extratropical Tropopause derived from Extensive *in situ* Measurements during the SPURT Project

**Peter Hoor,** MPI for Chemistry, Mainz, Germany (hoor@iac.umnw.ethz.ch)
**H. Bönisch**[3], **D. Brunner**[2], **A. Engel**[3], **H. Fischer**[1], **C. Gurk**[1], **G. Günther**[4], **M. Hegglin**[2], **M. Krebsbach**[4], **R. Maser**[5], **Th. Peter**[2], **C. Schiller**[4], **U. Schmidt**[3], **N. Spelten**[4], and **H. Wernli**[2,6], **V. Wirth**[6]

(1) - Max Planck - Institute for Chemistry, Dept. of Air Chemistry, Mainz, Germany
(2) - Institute for Atmospheric and Climate Science, Swiss Federal Institute of Technology, Zürich, Switzerland
(3) - Institute for Meteorology and Geophysics, Johann Wolfgang Goethe - University, Frankfurt am Main, Germany
(4) - Institute of Chemistry and Dynamics of the Geosphere, ICG-1, Research Center Jülich, Germany
(5) - Enviscope GmbH, Frankfurt am Main, Germany
(6) - Institute for Atmospheric Physics, University of Mainz, Germany

## Introduction

Long-term observations from 1970 to 2000 indicate a substantial ozone decrease in the northern mid latitude stratosphere accompanied by a negative temperature trend [WMO, 2003]. Changes in ozone in the lowermost stratosphere where it acts as an efficient greenhouse gas and participates in local chemistry are of particular importance, but difficult to detect due to the high degree of dynamical and chemical variability in this region. In particular, troposphere-to-stratosphere transport (TST) in the extratropics involving diabatic processes (e.g. radiative processes associated with the decay of anticyclones, turbulent mixing in the vicinity of the jets, convection) perturb local chemistry with feedbacks on temperature or ozone budget.

Model studies indicate that TST occurs throughout the year below the isentropic surface defined by a potential temperature of $\Theta$ = 345 K, predominantly to the north of 50°N with a relatively weak zonal variability [Sprenger and Wernli, 2003]. During summer a secondary maximum of TST occurs at low latitudes at $\Theta$ = 360 K, which is partly associated with weaker PV gradients at the subtropical tropopause in summer [Haynes and Shuckburgh, 2000].

The effect of TST and subsequent mixing was identified by *in situ* trace gas measurements [e.g. Danielsen, 1968; Dessler *et al.* 1995; Fischer *et al.*, 2000; Ray *et al.*, 1999], which, however, were too limited to allow conclusions about the overall effect of these individual processes on the lowermost stratosphere. In particular, relatively little is known about the spatial extent, which is affected by extratropical TST and subsequent mixing within the lowermost stratosphere.

## The SPURT Measurement Strategy

To address these issues an improved measurement strategy was developed for the project SPURT (SPURenstofftransport in der Tropopausenregion, Trace Gas Transport in the Tropopause Region), which has been conducted as part of the German atmospheric research program AFO 2000 funded by BMBF (German Federal Ministry of Education and Research). During SPURT airborne *in situ* measurements of dynamical trace gases were performed on a regular basis to obtain an overview on their spatial distribution in the UT/LS-region in all four seasons and over a broad latitude range. A Lear Jet 35 based in Hohn (Germany, 52°N/6°E) was used as the measurement platform. The area investigated covered the tropopause region up to 13.7 km from the southwestern tip of Europe to polar latitudes (**Figure 1**, p. II). In total, 160 flight hours were spent on eight measurement campaigns over a time period of three years.

A highly modular set of *in situ* instruments was developed to keep preparation time for each individual campaign short and to maximize a high reliability for all the instruments. The whole set of observed species is given in **Table 1.** The trace gas measurements were supplemented by measurements of several meteorological parameters, such as temperature, pressure and horizontal wind components.

Typically, a campaign was performed over five days including three days for technical integration of the combined payload and for ground tests, and two successive days for the measurements, of which one day was dedicated to the lowermost stratosphere over southern Europe followed by a day with flights heading to polar latitudes (Fig. 1). Each individual flight ideally consisted of two long flight legs, one at tropopause altitude level and one leg high above the tropopause. At the end of each flight a climb to maximum altitude was performed to sample undisturbed stratospheric air, followed by a slow descent to obtain a high resolution vertical profile. The return flight to Germany on the same day mirrored this flight pattern. Flight planning was based on meteorological forecast products provided by the ETH Zürich using operational ECMWF forecasts (60 levels). From the

*Table 1: In situ techniques combined in the payload employed during the SPURT missions*

| Species | Technique | Time resolution | Total uncertainties, 1 $\sigma$-level | Institute |
|---|---|---|---|---|
| CO, $N_2O$, $CH_4$ | TDLAS | 5s | 1.5%, 1.5%, 2.5% | MPI-Mainz |
| $CO_2$ | NDIR | 1s | 0.2 ppm | MPI-Mainz |
| $O_3$ | UV-absorption | 9s | 5% | FZ Jülich |
| $H_2O$ | Lyman-$\alpha$ fluorescence | 1s | 6% | FZ Jülich |
| $N_2O$,F12,$SF_6$,$H_2$ | *in situ* GC | 75 s | 1%, 1%, 1%, 2% | University Frankfurt/Main |
| $O_3$, NO, $NO_y$ | CLD, gold catalyst ($NO_y$) | 1s | 5%, 8%, 13% | ETH-Zürich |

predicted potential vorticity (PV)-fields the location of the tropopause (PV = 2 PVU) was deduced to select the flight levels. Itineraries and flight levels were chosen to cover different tropopause altitudes associated with various meteorological conditions and different types of air masses.

Meteorological post-flight analyses included the calculation of ten-day backward trajectories, which were initialised every ten seconds along the flight track at the exact location and time of the aircraft.

## Measurements and Results

During SPURT the influence of extratropical cross tropopause mixing was investigated using *in situ* measurements of different species and subsequent model studies. In this article we focus on the spatial distribution of carbon monoxide, CO. Tropospheric sources of CO are mainly combustion processes and the oxidation of hydrocarbons leading to average tropospheric mixing ratios ranging from 70 ppbv in the tropics to 130 ppbv in the Northern Hemisphere extratropics. In the stratosphere the major photochemical source is oxidation of methane ($CH_4$), which is rather slow compared to CO degradation. The photochemical lifetime of CO in the lowermost stratosphere is of the order of three months. Thus, in the stratosphere CO mixing ratios of 10 - 15 ppbv would be expected for photochemical steady state, if no additional transport and subsequent mixing of tropospheric air occurs. Therefore, CO is an ideal tracer to investigate TST and subsequent mixing on time scales of days to weeks in the lowermost stratosphere, as any excess above the equilibrium value must stem from the troposphere.

Meridional advection of (sub-)tropical tropospheric air or southward excursions of stratospheric air lead to strong displacements of the local tropopause from its climatological mean. Equivalent latitude, $\varphi_{eq}$ accounts for these deviations as long as PV is conserved, *i.e.* under adiabatic conditions [Strahan *et al.,* 1999]. It transforms the undulating PV-contours on a given isentropic surface to the arc of the equal area circle resulting in a tropopause-following coordinate system. Thus, lower stratospheric trace gas distributions in $\varphi_{eq}$-$\Theta$ coordinates are displayed according to the distance from the local tropopause. Note that no averaging has to be applied for calculating $\varphi_{eq}$ and that the transition from PV to equivalent latitude on a given isentrope is unique. Extratropical TST requires an air parcel to increase its PV or $\varphi_{eq}$, conserved quantities unless diabatic processes occur, such as mixing, radiative heating or the release of latent heat.

As evident in **Figure 2** (p. II), measured CO distributions in $\varphi_{eq}$-$\Theta$ coordinates appear to be rather similar for the whole set of campaigns during SPURT. Highest mixing ratios are found in the troposphere ranging from 75 ppbv to more than 130 ppbv. During winter the tropospheric latitudinal gradient becomes evident, being maximum at high latitudes. Patchy tropospheric structures illustrate the variability of CO and its sources in the troposphere. The lowest CO values between 20 and 30 ppbv were encounered above $\Theta$ = 370 K and PV-levels exceeding 8 PVU.

The gradient of CO at the tropopause, as well as intermediate CO mixing ratios between upper tropospheric and lowest stratospheric values, indicate that the tropopause is a barrier against TST and subsequent mixing but it is not totally impermeable. In case of rapid mixing of tropospheric air along isentropes within the lowermost stratosphere, one should expect a homogenous isentropic CO distribution (e.g. SPURT 6, $\Theta$ = 335 K) for the whole lowermost stratosphere. Instead, CO-gradients on isentropic surfaces extend further into the lowermost stratosphere resulting in isopleths of CO that are not parallel to isentropes. The region of the strongest CO decline from upper tropospheric CO values down to 50 ppbv forms a band roughly following the local tropopause, indicating that mixing of tropospheric air across the extratropical tropopause is too weak to balance photochemical CO degradation and the diabatic descent of CO-depleted stratospheric background air. Note that this observation is independent of the choice of the PV threshold for the tropopause as a higher PV-value would not affect isentropic CO-gradients (PV = 4 PVU in Fig. 2).

Obviously, a transition region, which is strongly affected by TST and subsequent mixing, becomes established close to the tropopause, exhibiting chemical characteristics both of the troposphere and stratosphere. The isentropic gradient of CO in the lowermost stratosphere indicates that the influence of TST and subsequent mixing decreases with distance from the local tropopause.

However, even at the largest distances from the tropopause ($\Theta$ > 45 K above the local tropopause) the air cannot be regarded as purely stratospheric. The lowest CO values range from 20 ppbv to 30 ppbv, well above the CO equilibrium value and still indicate a significant tropospheric contribution. A detailed analysis of long-lived trace gases (e.g. $CO_2$ and $N_2O$) reveals that air originating from the tropics may contribute significantly to the trace gas budget of the lowermost stratosphere [Hoor *et al.,* 2003].

## Summary

The new operational SPURT measurement strategy facilitated a broad overview of the seasonal and latitudinal trace gas distribution in the tropopause region and lowermost stratosphere over Europe. The results of the airborne *in situ* observations during the SPURT project illustrate that TST and subsequent mixing significantly alter the chemical composition in a narrow band above the local tropopause. Isentropic CO gradients mark a transition region, which follows the tropopause and indicate that the influence of extratropical tropospheric air is a function of distance from the local tropopause rather than potential temperature $\Theta$.

The new seasonally resolved SPURT dataset furthermore provides the possibility to perform detailed process-oriented case studies on TST [*e.g.* Hegglin *et al.,* 2003]. Ongoing work investigates TST on global scales, including the determination of lag times (using $SF_6$ and $CO_2$ measurements) and condensation processes occurring at the tropopause (based on the observations of $H_2O$) in combination with related models and theoretical studies.

## Acknowledgements

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# Report on the 1st International UV/vis Limb Scattering Workshop,

## Bremen, Germany, April 14-15, 2003

**Christian von Savigny** (csavigny@iup.physik.uni-bremen.de),
**Kai-Uwe Eichmann** (eichmann@iup.physik.uni-bremen.de),
**Heinrich Bovensmann** (heinrich.bovensmann@iup.physik.uni-bremen.de)
**John P. Burrows** (burrows@iup.physik.uni-bremen.de),
Institute of Environmental Physics, University of Bremen, Bremen, Germany



### Introduction

Satellite-borne remote sensing instruments operating in the UV/visible spectral range to study the chemical composition of the Earth's atmosphere have traditionally been of two types: (a) Nadir viewing spectrometers (*e.g.,* TOMS (Total Ozone Mapping Spectrometer) [McPeters *et al.,* 1998] and GOME (Global Ozone Monitoring Experiment) [Burrows *et al.,* 1999]) providing almost global observations of total column amounts of ozone and other minor constituents on a daily basis, and (b) solar occultation instruments (*e.g.,* SAGE (Stratospheric Aerosol and Gas Experiment) [McCormick *et al.,* 1989] and POAM (Polar Ozone and Aerosol Measurement) [Lucke *et al.,* 1999]) capable of providing vertical profiles of typically $O_3$, $NO_2$, $H_2O$ and aerosol extinction with high vertical resolution (1-2 km). Each of these observation techniques has its disadvantages. The nadir viewing instruments cannot provide vertical profiles with a vertical resolution better than about 8 km and the occultation instruments only measure 15 - 30 profiles per day and for a limited range of latitudes only. The limb scattering observation technique, where the instrument line of sight follows a slant path tangent through the atmosphere and limb-scattered solar radiation is measured, allows to retrieve vertical profiles of several minor constituents with high vertical resolution as long as the sunlit of the Earth is observed. Thus, global coverage is combined with high vertical resolution.

In recent years several space-borne limb scattering instruments were launched to remotely sense the Earth's atmosphere. These include the SOLSE/LORE (Shuttle Ozone Limb Sounding Experiment/Limb Ozone Retrieval Experiment) [McPeters *et al.,* 2000] flown on the space shuttle mission STS-87 in 1997, its re-flight SOLSE - 2 on the shuttle Columbia that was tragically lost in January 2003, OSIRIS (Optical Spectrograph and InfraRed Imaging System) [Llewellyn *et al.,* 1997] on the Swedish-led Odin satellite launched in February 2001, SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY) [Bovensmann *et al.,* 1999] on ESA's ENVISAT launched in March 2002, as well as NASA's SAGE III on the Russian Meteor-3M satellite.

It should be noted that the limb-scattering technique has also been applied by several satellite-borne spectrometers in the past. For instance, limb scattering measurements with the UV spectrometer on SME (Solar Mesosphere Explorer) were used to retrieve mesospheric ozone profiles [Rusch *et al.,* 1984] and $NO_2$ profiles [Mount *et al.,* 1984] in the upper stratosphere since the early 80s. Yet, the greatly enhanced computing power makes profile retrievals possible for extended altitude ranges and other minor constituents, since spherical radiative transfer models - taking multiple scattering into account - can be employed.

A total of 48 scientists from 7 countries attended the workshop that was dedicated to the STS-107 shuttle crew, whose responsibilities also included the operation of the SOLSE - 2 limb-scattering experiment. The workshop consisted of three sessions: (1) Instruments, (2) Inversion algorithms and radiative transfer, and (3) Retrievals and first scientific results.

### Instruments

All of the recently launched Earth orbiting instruments capable of performing limb scattering observations were represented at the workshop. Overviews were given on the SOLSE/LORE and SOLSE-2 (**R. McPeters**), OSIRIS

(**E. Llewellyn**), SAGE III (**D. Rault**), SCIAMACHY (**J. Burrows, S. Noel**), as well as the future OMPS mission (Ozone Mapping and Profiles Suite) (**J. Larsen**) on a NPOESS satellite (National Polar-Orbiting Operational Environmental Satellite) - scheduled for launch in 2008. The main technical features of the these instruments are listed in **Table 1.**

There was a general consensus that the two most important problems all limb scattering instruments have to deal with to a certain extent are external straylight and the limb pointing accuracy. External straylight is an issue mainly in the visible and NIR spectral ranges where the limb scattered radiance decreases by up to 5 orders of magnitude when going from 10 km tangent height to 90 km tangent height. Thus, only a minute amount of straylight from the lower atmosphere may significantly contaminate the limb measurements at higher tangent heights. Pointing is a potential problem, since very precise knowledge of the satellite attitude and mirror positions etc. are required. For example, an error in the knowledge of the satellite's orientation of only 1/100 degree translates to a tangent height error of about 0.5 km. The experiences from the existing limb scattering instruments will hopefully lead to significant improvements of the next generation limb scattering instruments.



## Inversion Algorithms Radiative Transfer

The existing inversion algorithms for retrievals of vertical minor constituent profiles from measurements of limb scattered radiation can be roughly classified into two categories, although all of them rely on differential absorption signatures between spectral regions where the absorption cross-sections of the species of interest differ.

The first type of algorithm follows a DOAS (Differential Optical Absorption Spectroscopy) approach and exploits the high frequency structure of absorption cross sections, while removing the slowly varying component of the cross sections and the measured limb spectra. These algorithms are well suited for weakly absorbing species, such as $NO_2$ [Sioris *et al.,* 2003], BrO and OClO, but they can also be applied to stronger absorbers, such as $O_3$. Retrievals of stratospheric $O_3$ and $NO_2$ density profiles from OSIRIS limb scattering observations (**C. Haley**) and from SCIAMACHY measurements (**A. Rozanov, C. Sioris**) using DOAS type algorithms were presented at the workshop.

The second type of retrieval algorithm exploits the absolute absorption of solar radiation in strong absorption features of atmospheric constituents, *e.g.,* the differential absorption between the center and the wings of the Chappuis, Huggins or Hartley bands of $O_3$. These algorithms usually require only several narrow spectral windows and they are, therefore, computationally more efficient and well suited for operational mass data processing. Yet, their applicability is limited to strongly absorbing species. A first algorithm was designed by Flittner *et al.* [2000] for $O_3$ profile retrievals from SOLSE/LORE observations, and it is now employed in a slightly modified way for operational analysis of OSIRIS observations [von Savigny *et al.,* 2003].

The determination of minor constituent profiles from limb scattering observations requires radiative transfer (RT) modeling. RT models that accurately account for all relevant physical processes are, therefore, a necessary prerequisite of profile retrievals from limb scattering observations. Several pseudo-spherical and spherical RT models were presented at the workshop (**C. McLinden, A. Rozanov, J. van Gent**), including a 3D Monte Carlo model (**C. von Friedeburg**).

Limb scattering retrievals are generally based on different homogeneity assumptions. Two presentations addressed the retrieval errors associated with violations of these homogeneity assumptions: (a) the impact of inhomogeneous surface reflectance on ozone profile retrievals from limb scattering observations (**D. Flittner**), and (b) the impact of horizontal inhomogeneities of atmospheric trace constituent fields on the retrieval of vertical profiles (**C. McLinden**).

As mentioned above, inaccurate pointing knowledge is one of the most important sources of retrieval errors all limb scattering instruments are affected by. Fortunately, tangent heights can also be retrieved from the limb measurements themselves with an accuracy of at least ± 2 km. All of the employed pointing retrieval algorithms are based on the so-called "knee", *i.e.* a maximum in UV limb radiance profiles due to absorption by $O_3$ occurring in the upper stratosphere/lower mesosphere depending on wavelength. Different generalisations of the standard "knee" method using a continuous wavelength range rather than a single UV wavelength are presently employed for tangent height retrievals (**J. Kaiser, C. Sioris**). Unfortunately, tangent height information and the ozone density profile cannot be retrieved reliably at the same time.

*Table 1: Earth orbiting limb scattering sensors*

| Instrument | Platform | Launch date | Spectral range | Spectral resolution | Tangent height range | Vertical resolution |
|---|---|---|---|---|---|---|
| LORE | Space shuttle | 1997 & 2003 | 322, 350, 603, 675, 760 nm | filter radiometer | 0 - 75 km | ≈ 1 km |
| SOLSE | Space shuttle | 1997 & 2003 | 530 - 850 nm<br>270 - 423 nm | 0.7 nm<br>0.35 nm | 0 - 75 km | ≈ 1 km |
| OSIRIS | Odin | Feb 2001 | 280 - 800 nm | 1 nm | 7 - 70 km | ≈ 2 km |
| SAGE III | Meteor-3M | Dec 2001 | 290 - 1020 nm | 1.4 - 2.5 nm | | ≈ 1 km |
| SCIAMACHY | ENVISAT | Feb 2002 | 20 - 2380 nm | 0.2 - 1.5 nm | 0 - 100 km | ≈ 3 km |
| OMPS | NPOESS | 2008 | 290 - 1000 nm | 1.5 - 40 nm | 0 - 60 km | ≈ 3 km |

## Retrievals and First Scientific Results

The second day of the workshop was almost entirely spent on first scientific results and validation of limb scattering retrievals. The majority of the contributions dealt with minor constituent profile retrievals. Examples of minor constituent profile retrievals are shown in **Figure 1** (p. IV). Successful stratospheric $O_3$ profile retrievals were performed from OSIRIS (**C. Haley, S. Brohede**), SOLSE/LORE (**R. Loughman**), SAGE III (**D. Rault**), and SCIAMACHY (**A. Rozanov, C. von Savigny**). The 2002 SH ozone hole split event received special attention, and stratospheric profiles of $O_3$, $NO_2$, BrO and OClO within and outside the polar vortex were shown (**A. Rozanov, C. Sioris, C. von Savigny**) highlighting the capability of limb instruments to globally observe the vertical structure of atmospheric trace constituents on a daily basis. Furthermore, the retrieval of $CH_4$ and $H_2O$ profiles in the UTLS region from SCIAMACHY measurements is presently under development (**K.-U. Eichmann**).

Apart from minor constituent profile retrievals another important application of UV/vis/NIR limb scattering measurements are aerosols and clouds. Due to the long slant paths through the atmosphere in limb geometry, several atmospheric phenomena can be studied, which cannot be observed with nadir viewing instruments. These comprise tropospheric, stratospheric, as well as mesospheric aerosols. Tropospheric water and ice clouds are easily discernible in the vis/NIR spectral range (**D. Degenstein**), where the additional scatterers lead to an enhanced limb radiance signal. Also presented were retrievals of stratospheric aerosol extinction profiles and aerosol particle size estimates from OSIRIS limb scattering observations (**D. Gattinger**). This is a particularly difficult task, since the limb radiance contribution from stratospheric sulphate aerosols is generally quite small, especially under the very clean stratospheric conditions of the past years. Furthermore, accurate retrievals of stratospheric aerosol information requires accurate characterization of the external straylight contamination.

Apart from stratospheric background aerosol, Polar Stratospheric Clouds (PSCs) can be detected and their particle sizes can be estimated. Information of the chemical composition of PSCs can most likely not be inferred from UV/vis/NIR limb scattering observations, since the characteristic spectral absorption features of PSC constituents only occur at longer wavelengths.

In the mesosphere Polar Mesospheric Clouds (PMCs) are accessible by limb scattering experiments and first qualitative and quantitative results are available from both OSIRIS and SCIAMACHY. The observations also allow the estimation of PMC particle sizes.

## Conclusions

Considering the fact that the limb scattering instruments have been orbiting the Earth only for a few years at the most, the variety and quality of available data products is extremely promising. They include minor constituents, whose profiles can be measured from the UTLS region partly up to the middle and upper mesosphere, aerosols, such as stratospheric sulphate aerosols, PSCs, PMCs and cirrus clouds. Yet, it must be recognised that for many data products algorithm refinement and data product validation is still in progress.

In conclusion, the limb scattering instruments have the potential to greatly contribute to our understanding of a variety of atmospheric processes and to provide a long-term archive or a continuation thereof of the atmospheric composition.

The International Limb Scattering Workshop held at Bremen was the first of a hopefully long-lasting series of workshops. **J. Stegman** volunteered to organise the second limb scattering workshop tentatively scheduled to take place at MISU on October 10-13, 2004 in Stockholm, Sweden.

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# Planning for UTLS science using the new HIAPER Aircraft

**William Randel** (randel@ucar.edu) and **Laura Pan** (liwen@ucar.edu), NCAR, Boulder (CO, USA)

A new high altitude research aircraft called the High-Performance Instrumented Airborne Platform for Environmental Research (HIAPER), acquired by the United States National Science Foundation (NSF), will soon become available to the atmospheric research community. The aircraft will be operated for the NSF by the National Center for Atmospheric Research (NCAR) in Boulder (CO), USA. HIAPER is a Gulfstream V aircraft, with high altitude and long-range capability (maximum altitude ~ 50,000 feet or ~15 km, maximum range ~11,000 km) making it a unique platform for sampling the upper troposphere and lower stratosphere (UTLS) using both *in situ* and remote sensing instruments. The aircraft is currently undergoing modification and is scheduled to become available for science applications in summer 2005. Details of the capabilities of the aircraft and its modifications for research can be found at **http://www.hiaper.ucar.edu/**.



With the acquisition of this new research platform, NCAR is developing a UTLS research initiative with the following goals: (1) to plan integrated UTLS research using HIAPER, and optimise integration with satellite programmes and multi-scale models; (2) to formulate detailed science plans that can guide the instrument development for HIAPER and the protocol for field experiments; and (3) to enhance collaborations with national and international partners and within NCAR. Two recent developments of this programme are a draft White Paper describing some of the key issues and potential studies using HIAPER, and a 2-day workshop held at NCAR (October 27-28, 2003) to discuss these plans with the wider community. These topics are discussed briefly here, more detail can be found at **http://www.acd.ucar.edu/UTLS/**.

## The NCAR Initiative on Integrated Study of Dynamics, Chemistry, Clouds and Radiation of the UTLS

The NCAR UTLS initiative is motivated by a renewed appreciation for the importance of the UTLS region for understanding climate change and the evolving chemical composition of the atmosphere. Identifying and understanding the dynamical, chemical and physical processes that control water vapour, ozone, radical constituents, aerosols and clouds in the UTLS are critical for advancing the reliability of predictions of climate change or of trends in global air quality. The UTLS is a highly coupled region: dynamics, chemistry, microphysics and radiation are fundamentally interconnected. For example, the distribution of water vapour and ozone (two radiatively important gases) is controlled by the details of stratosphere-troposphere exchange (STE) and deep convection, chemical processing including multiphase chemistry, and cloud microphysics. These processes are in turn influenced by temperature and aerosol distributions. The coupling of UTLS processes is highlighted in **Figure 1** (p. V).

The initiative is also motivated by the unprecedented observational opportunity provided by new or soon-to-be new satellite instruments. Currently, the UTLS is a relatively under-sampled region compared to the lower troposphere or stratosphere. The altitude range has typically been below the detection range of spaceborne instruments, and there are only a few high altitude airborne observing platforms available to the community. The strong gradients in stability and chemical structure near the tropopause are a challenge to current global and regional models. Future advancements will require coordinated use of high altitude aircraft for small-scale measurements and detailed process studies, combined with satellite data for the larger scale perspective, plus appropriately sophisticated large and small-scale models. The addition of the HIAPER aircraft to the available high altitude platforms, combined with the data from NASA A-train and European and Japanese satellite platforms, present an exciting new opportunity for UTLS studies. Of particular interest in planning for new aircraft measurements is the development of improved *in situ* techniques for measuring a suite of chemical and aerosol/cloud particles.

At the current stage of planning, key UTLS issues are grouped into four inter-related themes. Each theme will potentially involve integrated use of field experiments, satellite measurements and state-of-the-art modelling tools. Models will also be used to help design the field experiments.

*(1) Tropical UTLS water vapour, clouds, microphysics, and radiation.*
The focus is to improve our ability to simulate the tropical UTLS region, which requires detailed understanding of the processes that maintain the observed distributions of water vapour and clouds, and their links with the large- and small -scale temperature structure. This includes observing and simulating the microphysics of cirrus formation and evaporation, and the role of deep convection and its effects on the radiation and chemical budgets. Water vapour is a major source of OH and is, thus, strongly coupled to chemical processing and composition in the tropical UTLS.

*(2) Two-way stratosphere-troposphere exchange (STE) processes.*
The overall objective is to better quantify the contribution of STE to the budgets of ozone and water vapour in the UTLS. There is a need to better characterize the role of multiple scale dynamical processes, from the large-scale planetary wave breaking, to synoptic scale baroclinic systems, and to small scales associated with convection and turbulence. Investigation of the effect of gravity wave breaking and turbulent mixing processes near the extratropical tropopause is an important component.

*(3) Chemistry that controls the budgets of ozone and radical species in the UTLS.*
One focus of this theme is to assess the impact of rapid convective upward transport of near-surface biogenic and anthropogenic emissions or oxidation products on radical budgets in the UTLS. Gaseous and multiphase processes in the UTLS control the sources and sinks of radical constituents ($HO_x$, $NO_x$, $RO_x$, $ClO_x$, $BrO_x$…), and hence the processes that control the budget of $O_3$ and removal of many chemical pollutants.

*(4) Composition of aerosol and cloud particles in the UTLS.*
The processes that control the formation of aerosols and cloud particles in the UTLS are poorly understood at present. Key topics include the chemical composition of aerosols and how the composition might influence the generation of cirrus particles. Identification and refined understanding of multiphase processing of chemical constituents on liquid and ice particles is of particular importance both for detailed microphysical/chemical models and for sub-grid scale parameterizations in global models.

## NCAR Community Workshop

Inviting the wider community's input and participation to the UTLS initiative was the impetus for holding a workshop at NCAR on October 27-28, 2003. Approximately 120 participants attended the two-day workshop, with ~ 55 NCAR scientists and ~ 65 others from ~ 20 universities, NOAA and NASA Laboratories and other research organisations. The objectives of the workshop were to: 1) identify and discuss key issues of UTLS research and to begin to define achievable goals; 2) form a science user community for the use of HIAPER in UTLS research, optimising the synergy with NASA satellites (AURA and A-train in particular); 3) work on a science plan and airborne experiment design and to form working groups to implement the plan; 4) form community consensus on instrumentation strategy. The workshop included a series of presentations and discussions on the four UTLS science themes discussed above. Additional topics included concepts for airborne experiments using HIAPER, the use of multi-scale models to help define the science objectives and strategy of the field campaigns, and required instrumentation that is critical for potential studies.

**J. Holton** and **W. Randel** led the opening session and gave brief overviews of UTLS science issues. The overviews emphasized the importance of convective transport into the UTLS, as illustrated by a simulation of midlatitude convection in **Figure 2** (p. VI), plus the interconnection of transport, chemical, microphysical and radiative processes. **A. Ravishankara** (co-Chair of SPARC) presented an overview of SPARC perspectives, emphasizing the link of UTLS processes to climate change issues. **D. Fahey** presented NASA plans and activities for UTLS research (on behalf of **D. Anderson** and **M. Kurylo** of NASA Headquarter). This presentation focused on the common scientific objectives of the UTLS initiative and AURA satellite measurements, and potential links to HIAPER deployment with the planned airborne AURA validation missions. This was followed by a series of brief discussions on new generations of satellite data in the UTLS region, given by team members from AURA/HIRDLS (**A. Lambert**), AURA/MLS (**G. Manney**), AURA/TES (**H. Worden**), and AQUA/AIRS (**A.-M. Eldering**).

An overview of HIAPER status, funding opportunities for HIAPER instrumentation, and the plan for initial science missions were given by **D. Carlson** (HIAPER PI). He told the community that HIAPER will be ready for initial science payload by the summer of 2005. An initial testing period of six months (July to December 2005) has been designated as the "Progressive Science" period. Solicitation for Letters of Intent will soon be released, and additionally NSF will soon announce the funding opportunity for HIAPER Aircraft Instrumentation.

Following these overview discussions, sessions discussed the following specific topics:
*(1) Mechanisms controlling tropical UT humidity* (by **I. Folkins, A. Dessler, E. Jensen, Q. Fu** and **A. Gettelman**)
The common thread of the discussions was that the "deep convection detrainment layer", spanning altitudes of 10-14 km in the tropics, is a critical region for understanding the processes that control the UT humidity, cirrus formation and their radiative impact. There is good progress in simulating ice crystal formation associated with tropical deep convection, as shown in comparisons with recent tropical measurements (**Figure 3,** p. VII). A better understanding of how dynamical, microphysical and radiative processes couple in this region is required to reduce the uncertainty in climate models. HIAPER, with its altitude capability, is well suited to contribute to investigations of this region.

*(2) Multi-scale dynamics and STE* (by **A. Stohl, L. Pan, T. Lane, J. Sun,** for **D. Lenschow, O. Cooper, J. Moody, P. Wang, T. Marcy** and **J. Gille**)
The discussions recognised recent progresses in STE climatology using Lagrangian models, but pointed out the need to verify these model results by observations. Stratospheric intrusions and mixing between the stratosphere and troposphere are frequently observed but poorly modelled. Characterization of mixing between the stratosphere and troposphere is facilitated by use of chemical tracers (**Figure 4,** p. VII), and global characterization will require multiscale observations from aircraft and spaceborne instruments, coupled with multi-scale models. Better characterization of gravity wave breaking and turbulent mixing was emphasized; an example of mixing from a high resolution simulation is shown in **Figure 5** (p. VIII). It was also recognized that there is increasing observational evidence on the importance of vertical transport by mid- to high-latitude deep convection. The relative contribution of these processes to the lowermost stratospheric composition, compared to that produced by isentropic mixing, needs to be quantified.

*(3) UTLS radical budgets, ozone and convective influence* (by **B. Brune, J. Logan, M. Barth, D. Toohey** and **R. Cohen**)
Discussions focused on ozone and radical budget issues in the tropical and extra-tropical UTLS regions, and the possible impacts of deep convective redistribution, production, or multiphase uptake of constituents. Specific topics included the behaviour of $HO_x$ at high $NO_x$ mixing ratios, multiphase interactions of $HO_x$, identifying the role of OVOCs as $HO_x$ precursors, the sources and sinks of halogen radicals, and the impact of deep convection, cloud processing and lightning $NO_x$ on the ozone budget. Simulations of lightning-generated $NO_x$ in high resolution models show reasonable agreement with aircraft observations (**Figure 6,** p. 36), while global model comparisons with satellite data show some interesting differences (**Figure 7,** p. VIII).

*(4) Interaction of chemistry and particle/cirrus formation* (by **S. Massie, J. Wilson, D. Murphy, A. Heymsfield, R. Gao, M. Fromm** and **T. Clarke**).
The composition of UTLS aerosol has an organic content (~ 50%) that is higher than previously realised. It is known that organic aerosol is produced at the Earth's surface by urban pollution and biomass fires. Boreal forest fires are a (recently recognised) source of particles in the UTLS. Aerosol is potentially a controlling factor for humidity and the cirrus formation criteria near the tropopause. There is observational evidence (INCA) that Northern Hemisphere (NH) cirrus

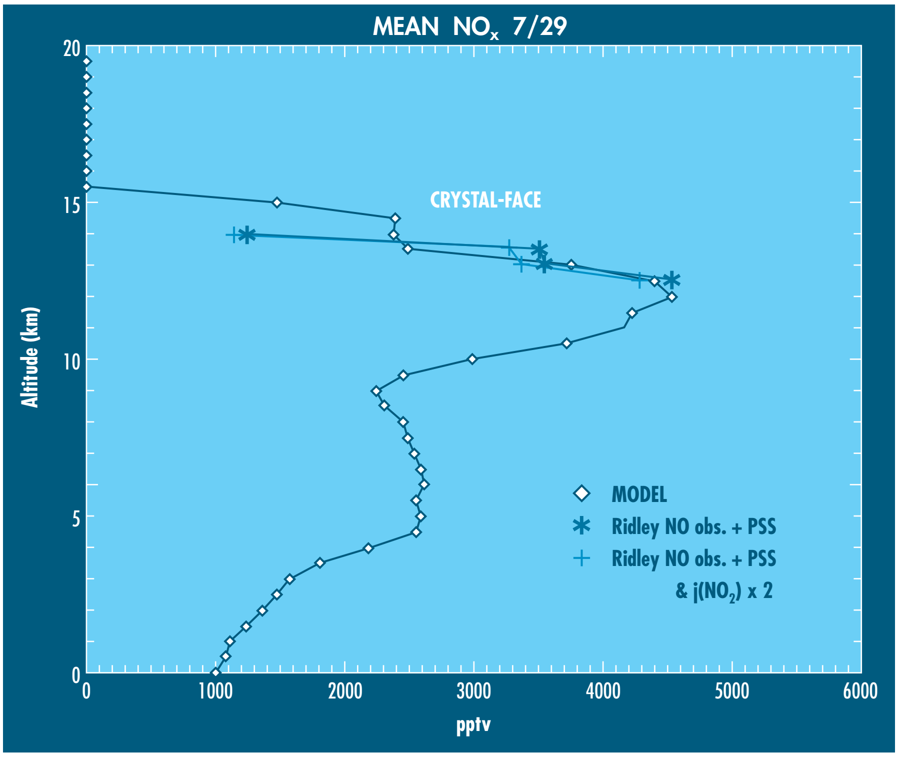


*Figure 6. Comparison of $NO_x$ from the University of Maryland Cloud-Scale Chemical Transport Model (UMD CS-CTM) with measurements for the July 29, 2002, CRYSTAL-FACE storm in South Florida. Model is driven by cloud-resolved MM5 fields in this case and contains a parameterization for lightning $NO_x$. Production of NO by lightning is assumed to be 490 moles/flash for both intracloud and cloud-to-ground flashes. Anvil NO measurements were performed aboard the NASA WB-57 aircraft by B. Ridley of NCAR. $NO_2$ was estimated from photostationary state (PSS) calculations using observed $O_3$ data and assumptions of $NO_2$ photolysis rates (j($NO_2$) for clear sky and for enhancement due to cloud reflections (j($NO_2$) x 2). (Ott et al., 2003). [Figure courtesy K. Pickering].*



formation nucleates at relative humidities lower than those in the Southern Hemisphere (SH), a result attributed to the presence of more ice nuclei in the NH, leading to heterogeneous nucleation of cirrus. Furthermore, recent observations from the NASA CRYSTAL-FACE program were interpreted (**R-S. Gao, D. Fahey**) to show that a nitric acid "coating" on ice near the tropopause interferes with $H_2O$ uptake.

*(5) Airborne experiment strategy* (by **R. Cohen, P. Wennberg, B. Ridley, A. Fried, J. Kuettner, J. Whiteway, A. Heymsfield** and **M. Coffey**)
Initial concepts of several categories of HIAPER-led airborne experiments were discussed, including: (1) Tropical experiments: it is recognised that HIAPER has capability for sampling the 10-14 km altitude range, which is the region of main convective outflow in the tropical UT. A plan for a tropical mission using HIAPER in early 2007 as part of the NASA-led TC4 experiment was presented by **P. Wennberg**. (2) Mid- to high latitude experiments: a number of mid- to high latitude experimental themes were discussed that can potentially be combined into joint campaigns. These are considered to be multi-aircraft campaigns, including HIAPER and other platforms. The prospective experiments covered: (a) STE in the extratropics, characterization of the tropopause transition in the region of the subtropical jet and the coupling of the tropics and the extratropics across the jet; (b) Vertical redistribution of chemical species *via* deep convection, the production and distribution of lightning-produced $NO_x$, and investigation of the downwind impact on ozone production over several days; (c) Detailed process studies of the role of convection on the UTLS radical budgets, particularly the role of peroxides, aldehydes and OVOCs; (d) Characterization of UT aerosol composition, distribution and cirrus formation processes near the tropopause; (e) airborne studies of Polar Stratospheric Clouds (PSCs) in the Arctic.

*(6) Roles of multi-scale models* (by **D. McKenna, K. Pickering, J. Powers, M. Olson, P. Hess** and **A. Gettelman**).
Discussions focused on the range of relevant models, from detailed microphysical/aerosol models, 3-D cloud models, to local and global-scale chemistry transport models. Detailed process studies in the UTLS will be required to quantify dynamical, chemical and aerosol behaviour in models. Models can in-turn be used to focus potential field studies and provide input for the design of aircraft missions.

*(7) Instrumentation issues* (by **P. Wennberg, J. Stith, T. Campos, L. Avalone, C. Gerbig,** for **S. Wofsy, J. Hair,** for **E. Browel, C. Senf, D. Rogers, R. Shetter,** and **E. Apel**).
It is recognised that the success of the HIAPER related science missions critically depends on a strategy for the progressive development of basic instruments to a more complex suite for aerosol and radical studies. Following a review of HIAPER Advisory Committee (HAC)'s recommendation on instrument development, discussions of critical needs and the status of instrument development were given, including 1) fast sampling *in situ* $O_3$ and CO instruments; 2) water vapour and total water instruments; 3) long-lived tracer instruments; 4) cloud microphysics instruments; 5) small lightweight LIDARs for aerosol, ozone, water vapour and wind measurements; 6) radiation instruments; and 7) instrumentation for a variety of VOC measurements.

Over the next few months, working groups are to be identified and organised to begin the more difficult task of formulating detailed plans for field studies and their links with satellite and modelling partners. The NCAR UTLS project welcomes comments or suggestions on possible experiments or research strategies.

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# A New Release of Data from the Total Ozone Mapping Spectrometer (TOMS)

**Charles G. Wellemeyer,** BUV Algorithm Development, Lanham (MD),USA,
(charles_wellemeyer@ssaihq.com)
**P. K. Bhartia, R. D. McPeters, S. L. Taylor, Ch. Ahn,** and the Ozone Processing Team

## Introduction

The Total Ozone Mapping Spectrometer (TOMS) data series extends from November 1978 through the present as shown in **Figure 1.** TOMS provides daily global maps of total column ozone over the sunlit portions of the globe by measuring backscattered ultraviolet radiances at discrete wavelengths in the 310 – 380 nm region. The TOMS algorithm has evolved over the years, with the previous Version 7 data processing being released in 1996 [McPeters *et al.,* 1996]. A new Version 8 of the algorithm has been developed by NASA Goddard's Ozone Processing Team to address a number of issues that have accumulated since then. Broadly speaking, the enhancements in the new algorithm target errors that occur under extreme conditions. Definite improvements are apparent for conditions like high tropospheric aerosol loading, sun-glint, persistent snow/ice, and very high solar zenith angles. The bulk properties of the new Version 8 TOMS dataset do not differ significantly from the previous Version 7, though a calibration shift for the Earth Probe instrument changes the long term ozone trend somewhat. These improvements are most important for applications like derivation of tropospheric ozone or aerosol loading calculations that push the limits for TOMS accuracy.

The TOMS production system will be converted to Version 8 in early 2004, and the reprocessed Version 8 data for the Nimbus 7 and Earth Probe TOMS instruments will be placed in the Distributed Active Archive Center (DAAC) at NASA/GSFC.

## Algorithmic Enhancements

The Version 8 TOMS Algorithm has a number of enhancements that are designed to reduce errors under extreme conditions. We have used corrections calculated using regression studies based on modelling of errors due to tropospheric aerosols, sun-glint, and ozone profile shape dependence at very high solar zenith angles. A season and latitude dependent ozone climatology has been used to reduce errors due to limited sensitivity of the backscattered ultraviolet radiance to ozone in the lower troposphere. Climatological temperature variability is taken into account explicitly using season and latitude dependent temperature profiles, and the forward model has been improved to account for the presence of persistent snow cover and/or high terrain. For a more detailed description of the V8 TOMS Algorithm, see the Algorithm Theoretical Basis Document (ATBD) and Data User's Guides available at: **http://toms.gsfc.nasa.gov**.

## Impact and Validation of Algorithm Changes



Some of the primary features of changes in the V8 TOMS dataset are illustrated by the monthly zonal mean comparisons shown in **Figure 2** (p. 38). The changes at high latitude are the result a combination of effects including: hemisphere and month dependent tropospheric ozone and temperature climatology, improved cloud model for snowy scenes, and the new correction for profile shape errors. In the summer hemispheres, the changes are validated by comparison with measurements from the network of Dobson and Brewer instruments, which are fairly accurate out to ozone path lengths (total column ozone multiplied by the geometric optical path) of up to 1000 D.U. In the winter hemispheres, however, the impact of V8 modifications is primarily occurring at ozone optical paths considerably larger than 1000 D.U. We have addressed the need for validation of TOMS at higher path lengths by comparing V8 TOMS

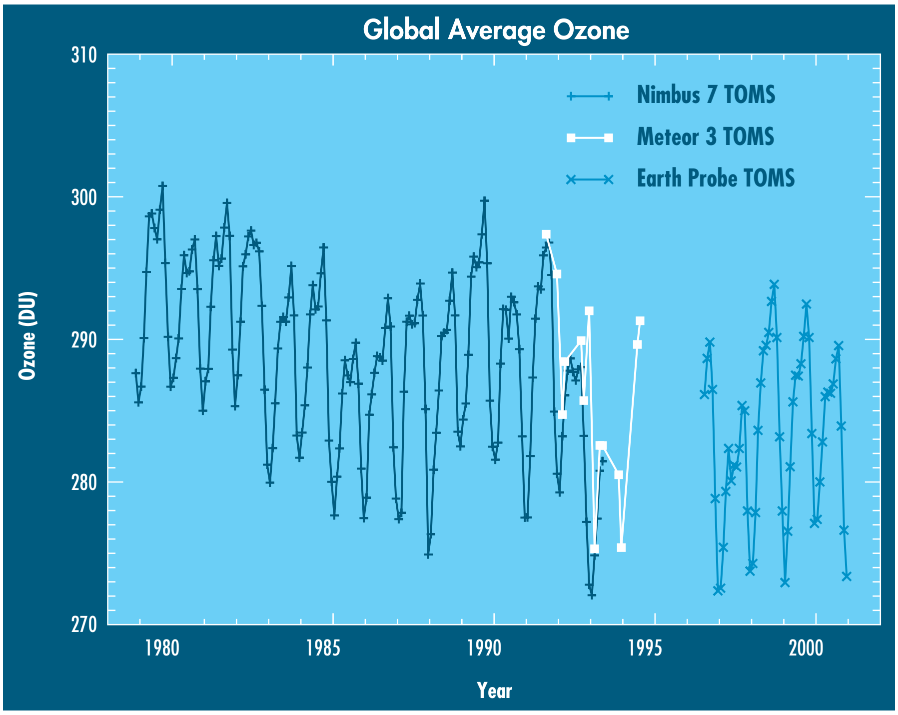


*Figure 1. Global average total ozone from the Version 8 Algorithm applied to Nimbus 7, Meteor 3, and Earth Probe TOMS calculated from 60° S to 60° N latitude. This new dataset will bereleased in early 2004.*

with integrated profiles from Solar Backscatter Ultraviolet (SBUV). These comparisons show good agreement, but a more complete validation is needed for the high path length data from V8 TOMS.

The major change in the tropical regions is the correction for the effects of tropospheric aerosol and sunglint. These effects are not apparent in Figure 2 because the impact of these corrections on the zonal mean is small. During extreme events of dust, smoke from biomass burning, or sun-glint, however, this correction may be as large as 20 D.U. or more, but these events are sporadic and spatially limited. We should point out that in the event of a very large volcanic eruption that injects aerosol into the stratosphere, the V8 TOMS is still subject to errors similar to those for the previous Version 7.

## EP/TOMS Performance Issues

Beginning in mid-2000 it became clear that the EP/TOMS was exhibiting unanticipated changes in performance that manifested as a cross-track dependence in instrument sensitivity. Ozone measured when looking to the right of the orbit track was significantly lower than that measured when looking to the left. The physical mechanism causing this dependence is not understood at this time, though we suspect it results from some asymmetric degradation of the scanning mirror. We have developed a relative correction to remove the cross-track bias, but in addition we have found it necessary to normalize the overall EP/TOMS ozone trend to the SBUV/2 after 2000. EP/TOMS data from launch through June 2003 with the corrections applied after June 2000 will be placed in the GSFC/DAAC in early 2004.

These corrections are difficult to make in near real-time, but we will update them from time to time to keep the ozone errors less than about 5% in the NRT data available through the TOMS Web Site. However, as we are able to do so we will also extend the corrected dataset beyond June 2003.

## Data Products and Availability

In order to make the V8 TOMS Data Products compatible with Earth Observing System (EOS), we are archiving them in Hierarchical Data Format Version EOS-5 (or HE-5). We will place the TOMS Level-2 orbital data product for Nimbus 7, Meteor 3, and Earth Probe TOMS (Figure 1) into the GSFC/DAAC in early 2004.

The V8 TOMS Web Site **(http://toms.gsfc.nasa.gov)** will have a new look, but the format of the data provided there will not change. All of the same products available on the Version 7 web site will be available on the V8 web site in identical format. This will include the native Level-3 products and images, monthly average grids and images, zonal means, and ground station overpasses. The ATBD, Data User's Guides, and the new ozone climatology used in the V8 Algorithm will also be available at the web site.

We also plan to provide the V8 TOMS native Level-3 and images for the entire N7 TOMS and EP/TOMS through June 2003 on DVD, which will be made available through the GSFC/DAAC and will be distributed at scientific meetings as appropriate.

## Acknowledgements

We gratefully acknowledge the support of NASA/GSFC's Ozone Processing Team in providing the TOMS data presented here. The SBUV/2 data were obtained from NOAA/NESDIS with support from the NOAA Climate and Global Change Atmospheric Chemistry Element.

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McPeters, R.D., *et al.,* 1996, "Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) Data Product's User's Guide," *NASA Reference Publication 1384,* National Aeronautics and Space Administration, Washington, DC.

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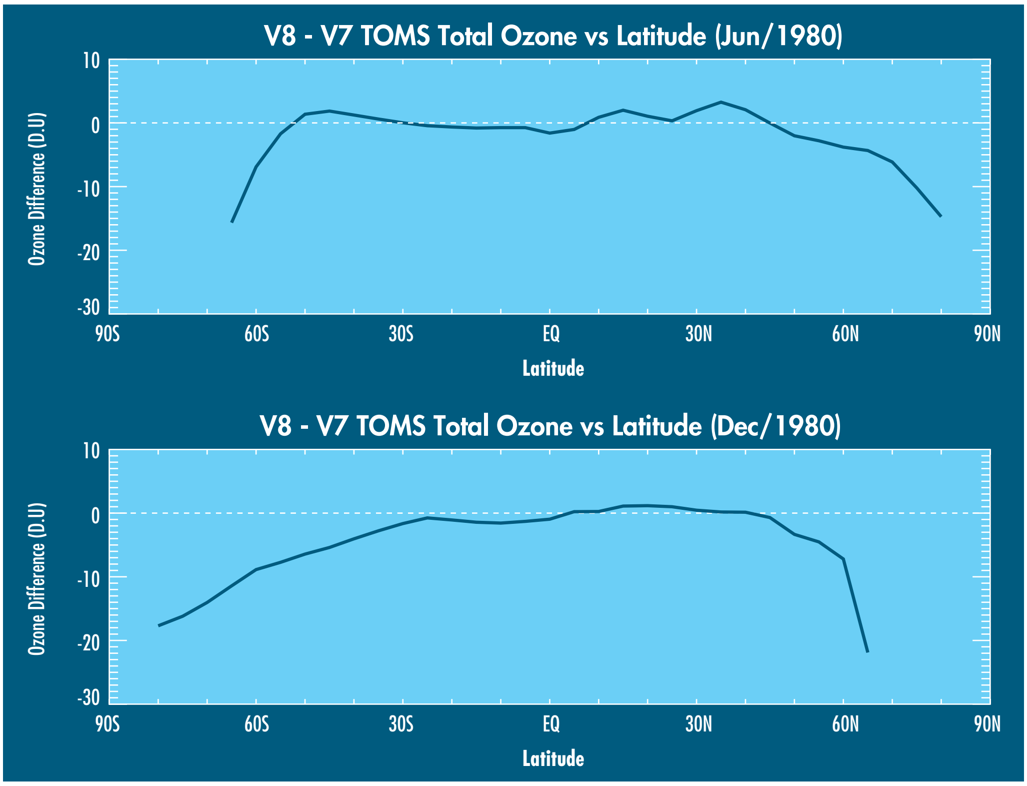



*Figure 2. Version 8 – Version 7 differences of Nimbus 7 TOMS monthly zonal mean total ozone for June and December of 1980 illustrating the impact of the Version 8 Algorithm.*

# Future SPARC and SPARC-related Meetings

## 2004

**24-26** **March: GRIPS workshop,** Bologna, Italy
(http://userpages.umbc.edu/~pawson/grips/html_files/grips_wksh.htm)
Chair: S.Pawson (pawson@gmao.gsfc.nasa.gov)

**25-30** **April: EGU 1st General Assembly,** Nice, France (http://www.copernicus.org/egu2004)
- **AS0:** Open Session on the lower, middle, and upper atmosphere - Convener: M. Juckes
- **AS3.01:** Microphysics and heterogeneous chemistry of aerosols - Convener: C. George
- **AS3.06:** Polar Ozone - Convener: G. Braathen
- **AS3.08:** Processes controlling the chemical composition of the upper troposphere and lower stratosphere - Convener: V. Grewe
- **AS3.09:** Results from Odin and ENVISAT - Convener: G. Stiller
- **AS3.10:** SPARC-IGAC Symposium on climate-Chemistry Interactions (co-sponsored by CL) - Convener: A. Ravishankara
- **AS3.11:** Chemical data assimilation - Convener: B. Khattatov
- **AS3.12:** Impact of traffic emissions on climate and atmospheric chemistry (co-sponsored by CL & ST) - Convener: V. Grewe

**Deadline for receipt of abstracts: 11 January 2004**

**17-21** **May:** AGU/CGU Spring Meeting, Montreal, Canada (www.agu.org/meetings/sm04/index.shtml)
- **A08:** Forcing of the high-latitude climate system by the stratosphere.

**23-28** **May:** 16th Rencontres de Blois “Challenges in the Climate Sciences”, Château de Blois, France
(http://opserv.obspm.fr/confs/climates.html)

**24-29** **May: II Latin-American Congress on Ultraviolet Radiation Measurements and biological effects in high altitude locations,** La Paz, Bolivia
(http://www.conservation.org.bo/claruv/claruv_ingles.htm)

**01-08** **June: Quadrennial Ozone Symposium “Kos 2004”,** Kos, Greece
(http://lap.physics.auth.gr/ozone2004/) Chair: C. S. Zerefos (ozone2004@geol.uoa.gr)

**09-14** **June: 3rd Workshop on Long-term trends in the atmosphere,** Sozopol, Bulgaria
(http://www.stil.acad.bg:80/STIL/ws2004/) Chair: K. Georgieva (kgeorg@bas.bg)

**16-18** **June: The 8th biennial HITRAN Conference,** Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, USA

**6-8** **July: 6th UTLS Ozone Science Meeting,** Lancaster University; UK (http://utls.nerc.ac.uk/)

**18-25** **July: 35th COSPAR Scientific Assembly,** Paris, France
(http://www.cospar2004.org/gb_welcome.htm) Chair: M.-L. Chanin (chanin@aerov.jussieu.fr)
• Interdisciplinary lectures (relevant of SPARC): 21 July: P. Crutzen “First ENVISAT Results”; 23 July: C. Fröhlich “Solar Radiation and Climate”
• SPARC co-sponsored sessions:
- **A 1.1:** Atmospheric Remote Sensing: Earth’s Surface, Troposphere, Stratosphere and Mesosphere. Chair: J. Burrows
- **C.2.3:** Long-term Changes of Greenhouse Gases and Ozone and their Influence on the Middle Atmosphere. Chair: D. Chakrabarty
- **C.2.5:** Structure and Dynamics of the Arctic and Antarctic of the Middle Atmosphere. Chair: M. Rapp
- **D 2.1/C2.2/E 3/I:** Influence of the Sun’s Radiation and Particles on the Earth’s Atmosphere and Climate. Chair: J. Pap

**Deadline for abstract submission: February 29, 2004**

**01-06** **August: 3rd SPARC General Assembly 2004,** Victoria Conference Centre, Victoria (BC), Canada.
(http://sparc.seos.uvic.ca/) Co-Chairs: A. Ravishankara (ravi@al.noaa.gov)
and T. Shepherd (tgs@atmosp.physics.utoronto.ca) (see the announcement in this Newsletter on page 10)
A particular emphasis for this General Assembly will be chemistry-climate coupling.

**Deadline for abstract submission as been extended to March 15, 2004**

# Availability of ERA-40 Re-Analysis Products

The European Centre for Medium-Range Weather Forecasts (ECMWF) has announced the completion of their latest Re-Analysis scheme ERA-40 that spans a period of over 40 years, from September 1957 to August 2002. The ERA-40 six-hourly and monthly mean products at 2.5° resolution are publically available on **http://data.ecmwf.int/data/**.

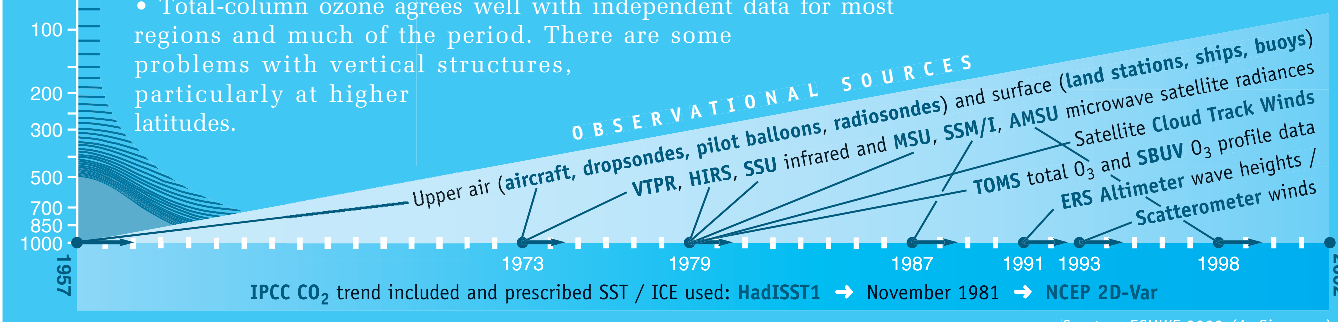
These products consist of 11 parameters, such as Ozone and Relative Humidity fields, given on 23 pressure levels ranging from 1000 to 1 hPa. A wider variety of 54 parameters in total is available on surface level. Users with further requirements and wishing to have access to the full resolution of the ERA-40 archive may submit their enquiries directly to ECMWF (data.services@ecmwf.int).

Assessments on the quality of the ERA-40 products have been carried out and more detailed information is available in the project reports and the ERA-40 website. ECMWF have summarized the following results (as of November 2003) of the ERA-40 quality assessment on issues related to the SPARC interests and activities:

- The general quality of the analyses improves over time.
- Quality is most uniform in time for the Northern Hemisphere (NH) troposphere and lower stratosphere (LS). Quality of the Southern Hemisphere (SH) is substantially better after 1978 and approaches that of the NH later in period.
- Trends and interannual variability in global-mean temperature from the surface to the LS are in reasonable agreement with a number of specialised data studies.

Long-term temperature time series for particular regions, and for the upper stratosphere in general, require careful interpretation due to model biases and variations in observational coverage.

- Stratospheric sudden warmings and the quasi-biennial oscillation of stratospheric winds are well captured. The Brewer Dobson circulation is too strong.
- Total-column water vapour validates quite well against independent data for the satellite era. Tropical analyses are much drier in the pre-satellite period.
- The clear-sky outgoing long-wave radiation is of quite high quality, but there are some evident deficiencies in the all-sky radiation budget.
- Total-column ozone agrees well with independent data for most regions and much of the period. There are some problems with vertical structures, particularly at higher latitudes.



*Courtesy ECMWF 2002 (A. Simmons)*






## Edited by the SPARC Office

Service d'Aéronomie, CNRS, BP 3
91371 Verrières-le-Buisson cedex, France
Tel: +33- 1 64 47 43 15
Fax: +33- 1 64 47 43 16
Email: sparc.office@aerov. jussieu.fr
http://www.aero.jussieu.fr/~sparc/

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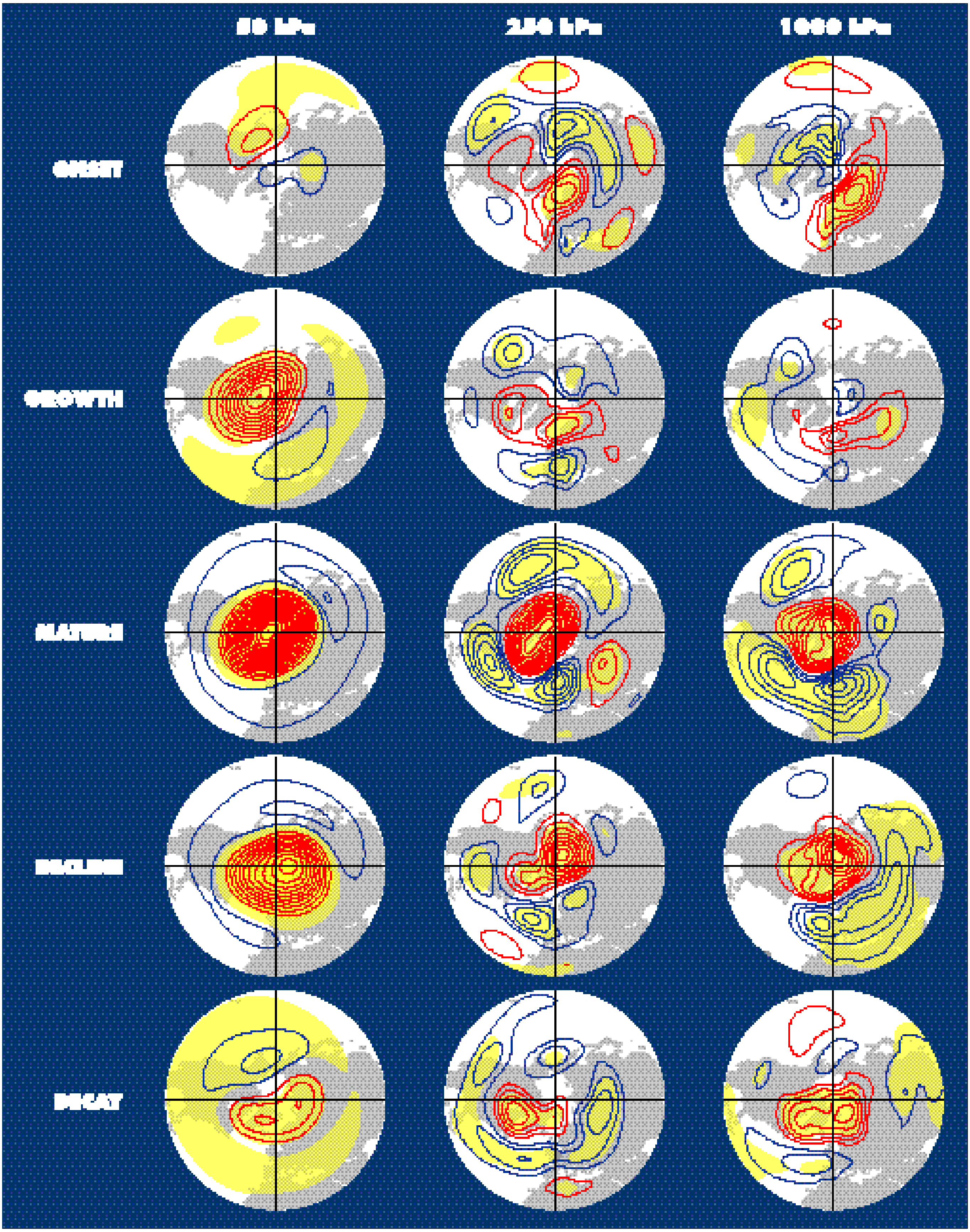
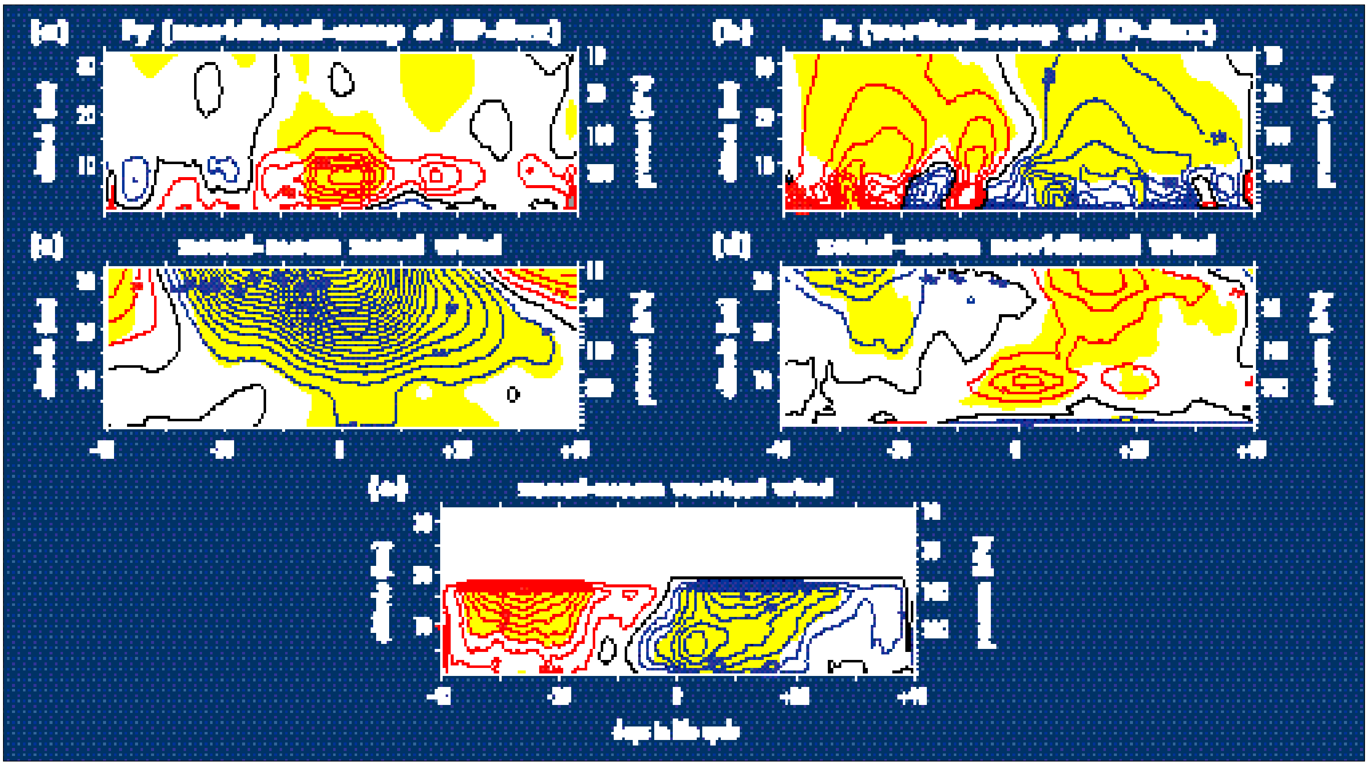


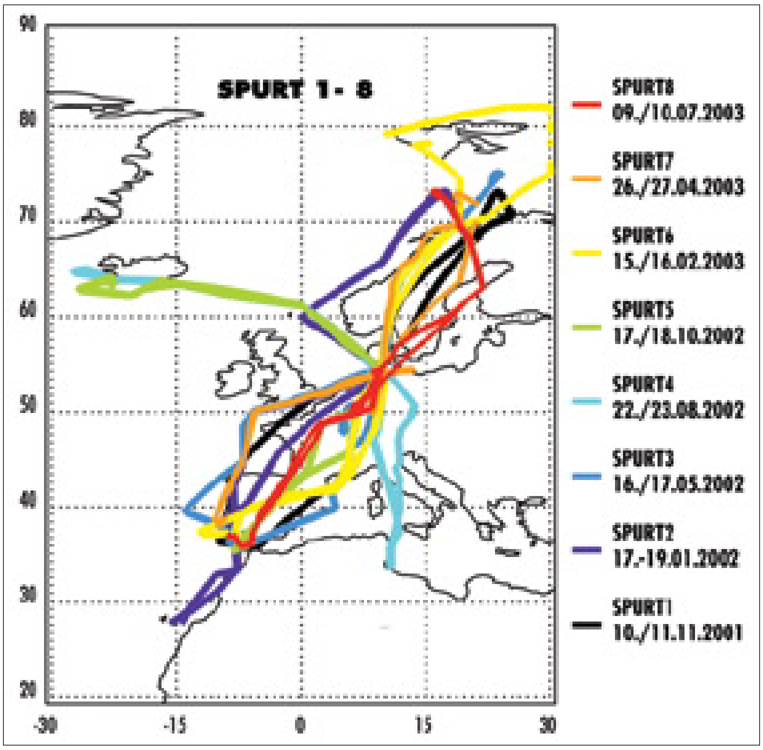

▲ **Figure 1**

Composite geopotential height anomalies at 50, 250 and 1000 hPa for five phases of stratospheric warmings for 39 warming events from NCEP/NCAR Reanalysis during the period 1958-2001. Contour intervals are 3, 1 and 0.5 decameters. Negative contours are blue, positive red. Zero contours are omitted for clarity and 95% confidence limits are shown as yellow shading.

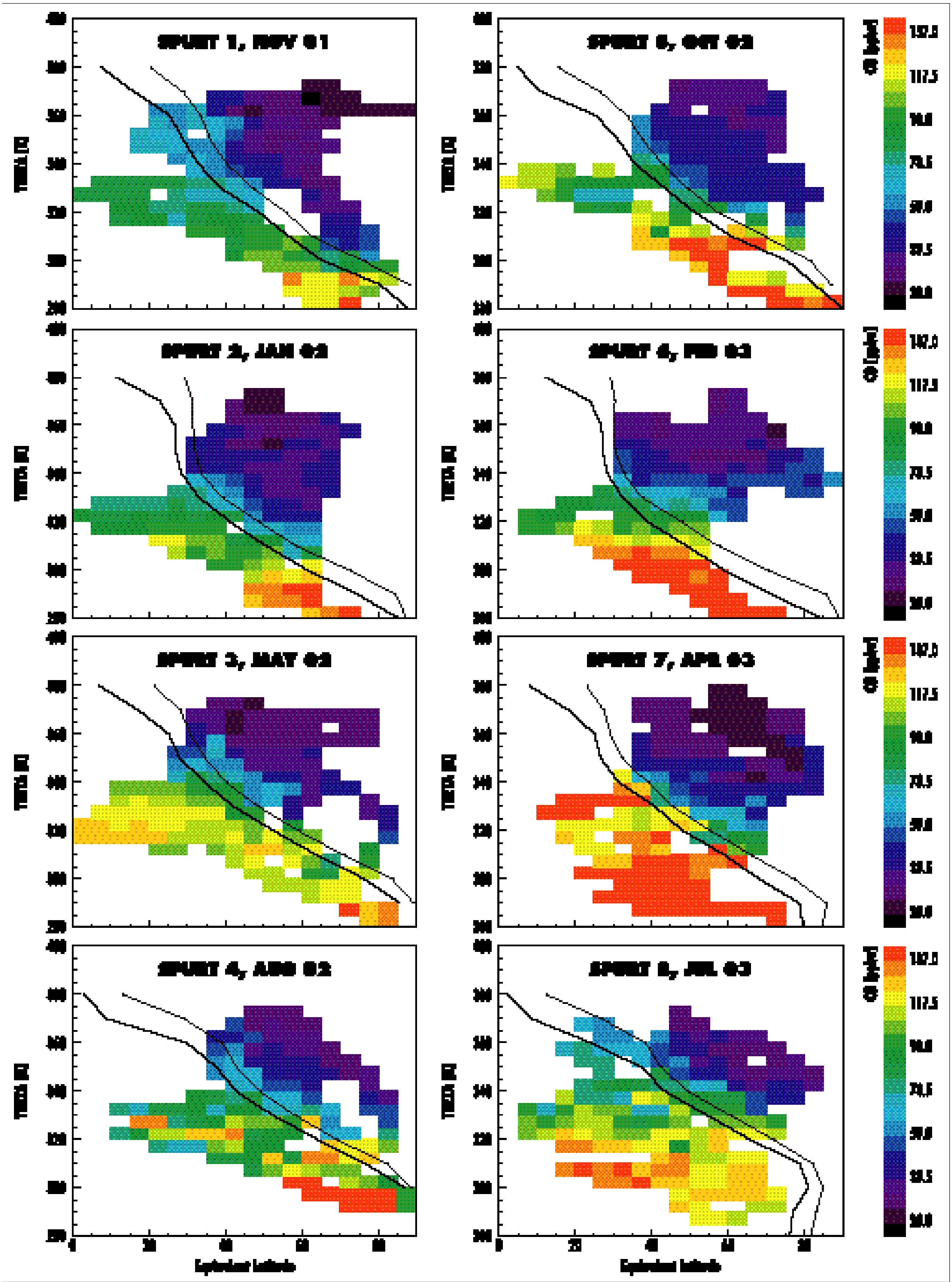


▲ **Figure 2**
Anomalies of various dynamical quantities averaged poleward of 50˚N (except vertical wind, which is averaged poleward of 65˚N). Negative contours are blue, positive contours are red and zero contour is black. a) meridional component of EP flux, c.i. 2 x$10^7$ kg $s^{-2}$, b) vertical component of EP flux, c.i. 1 x$10^7$ kg $s^{-2}$, c) zonal mean wind, c.i. 5 m $s^{-1}$, d) mean meridional wind, c.i. 2 $ms^{-1}$, e) vertical wind, c.i. 2 mm $s^{-1}$. The 95 % confidence limits are shown as yellow shading.

# New Insights into Upward Transport across the Extratropical Tropopause derived from Extensive **in situ** Measurements during the SPURT Project

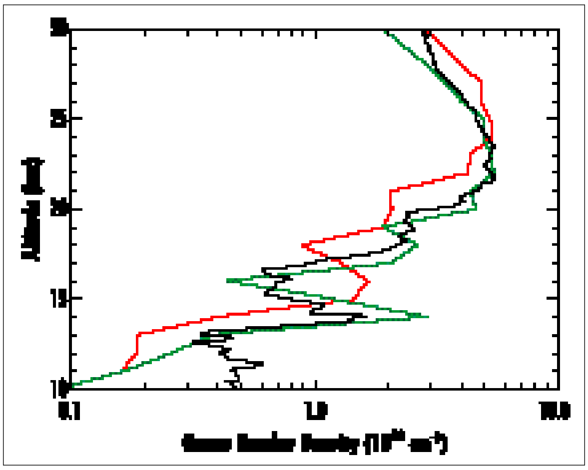



▶ **Figure 1**
Flight itineraries and dates for the eight missions performed during the SPURT-project.

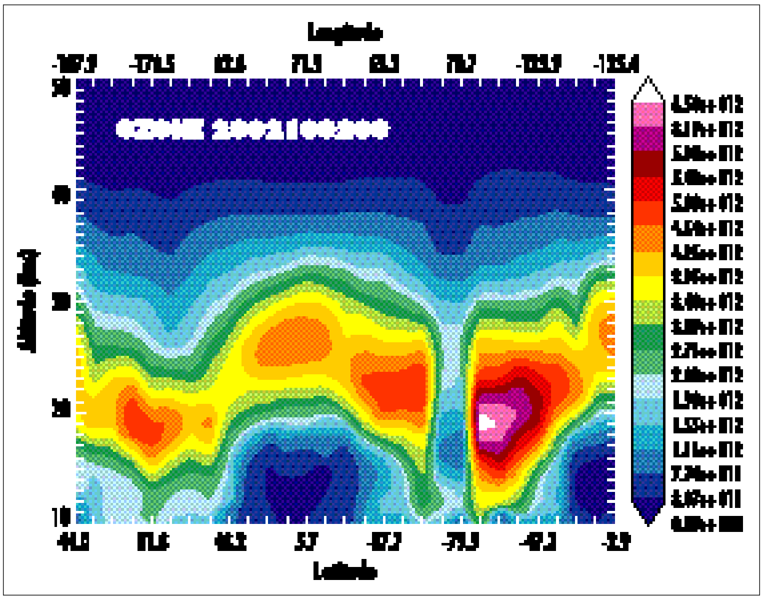



▲ **Figures 2**

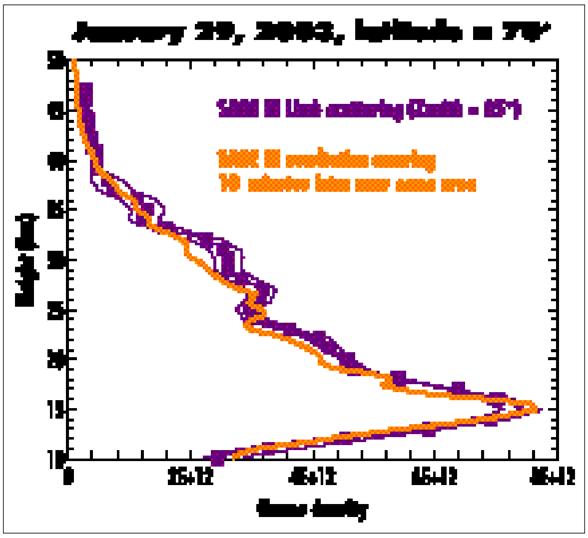
CO as a function of equivalent latitude and potential temperature for all SPURT missions. Also given is the location of the tropopause (PV = 2PVU, thick black line) and the PV = 4PVU surface (thin line). Note that CO isopleths just above the tropopause rather follow the tropopause than isentropes, indicating that the influence of extratropical TST is mainly related to the local tropopause than to isentropic surfaces.



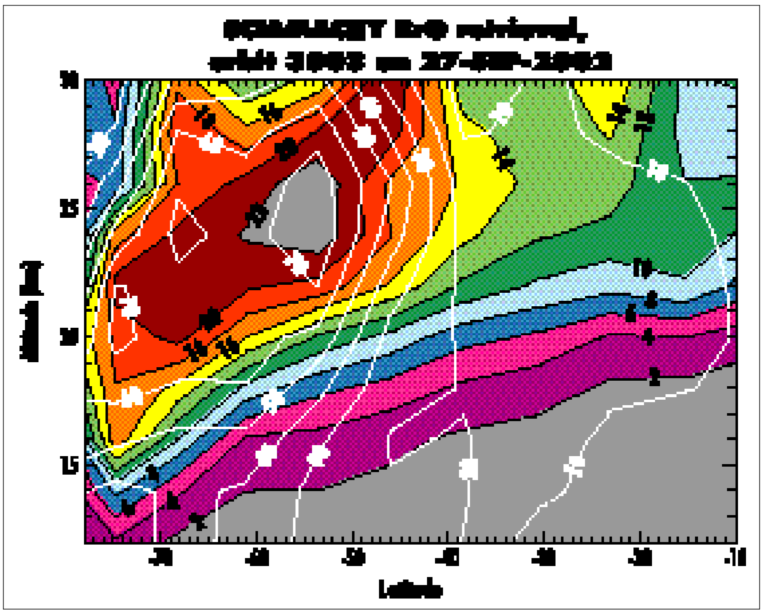
◀ **Figure 1a**
Ozone profile retrieval from SOLSE-2 limb scattering observations on Jan. 23, 2003 (green line with corrected tangent height registration), and comparison with a co-located ECC sonde launched from Santa Cruz/Teneriffe [Courtesy R. Loughman].



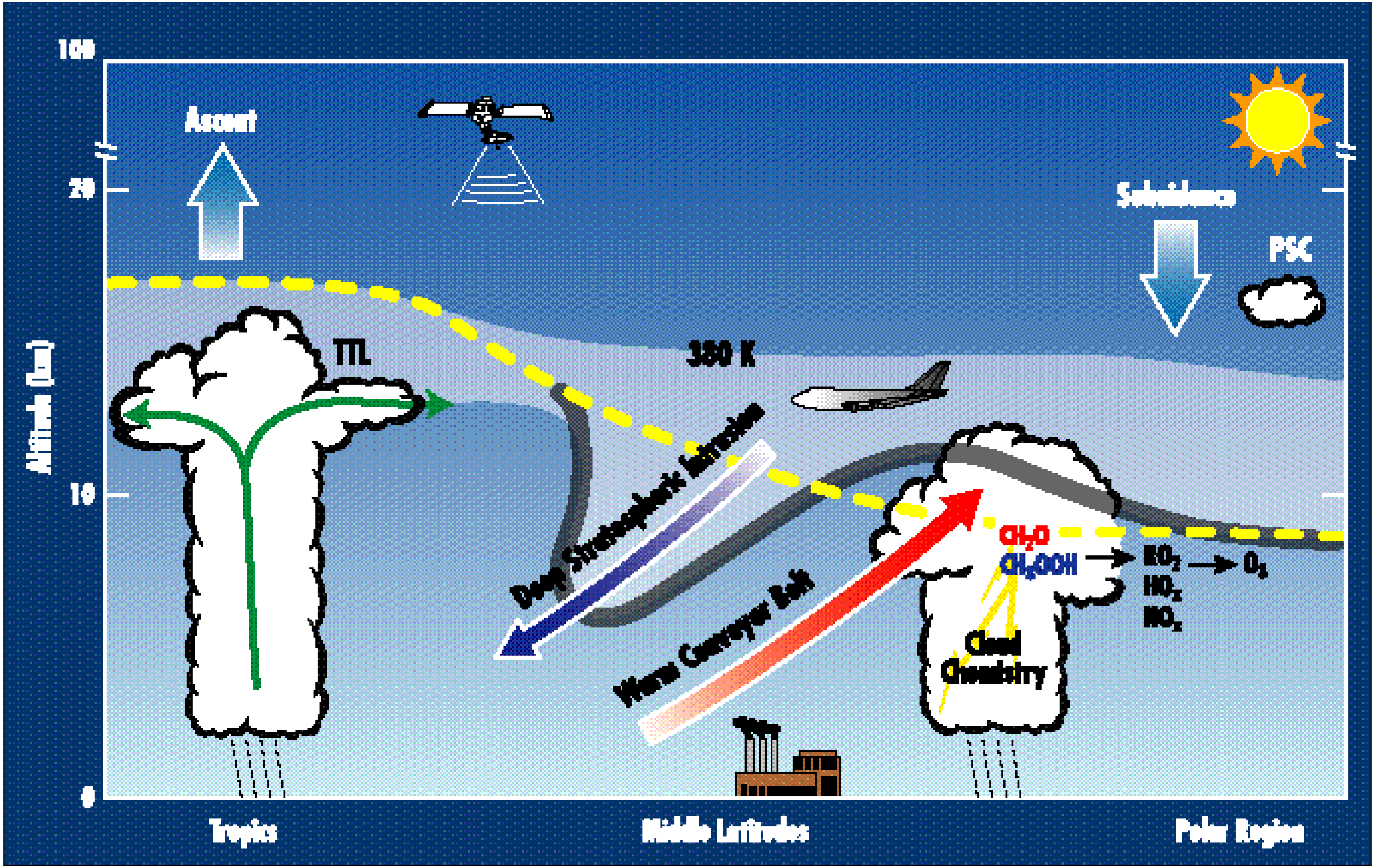
▶ **Figure 1b**
Stratospheric ozone number density (in molecules / cm³) field along an entire orbit retrieved from OSIRIS limb measurements on Oct. 2, 2002 (Courtesy E. Llewellyn]. Note that this is about one week after the Antarctic vortex split into two parts in late September 2002; the secondary ozone hole has already almost disappeared.



◀ **Figure 1c**
Stratospheric ozone number density (in molecules/cm³) profile retrieved from SAGE III limb measurement on January 29, 2003 (Latitude: 70º N, longitude: 2º W) and comparison with co-located SAGE III occultation measurement [Courtesy D. Rault].



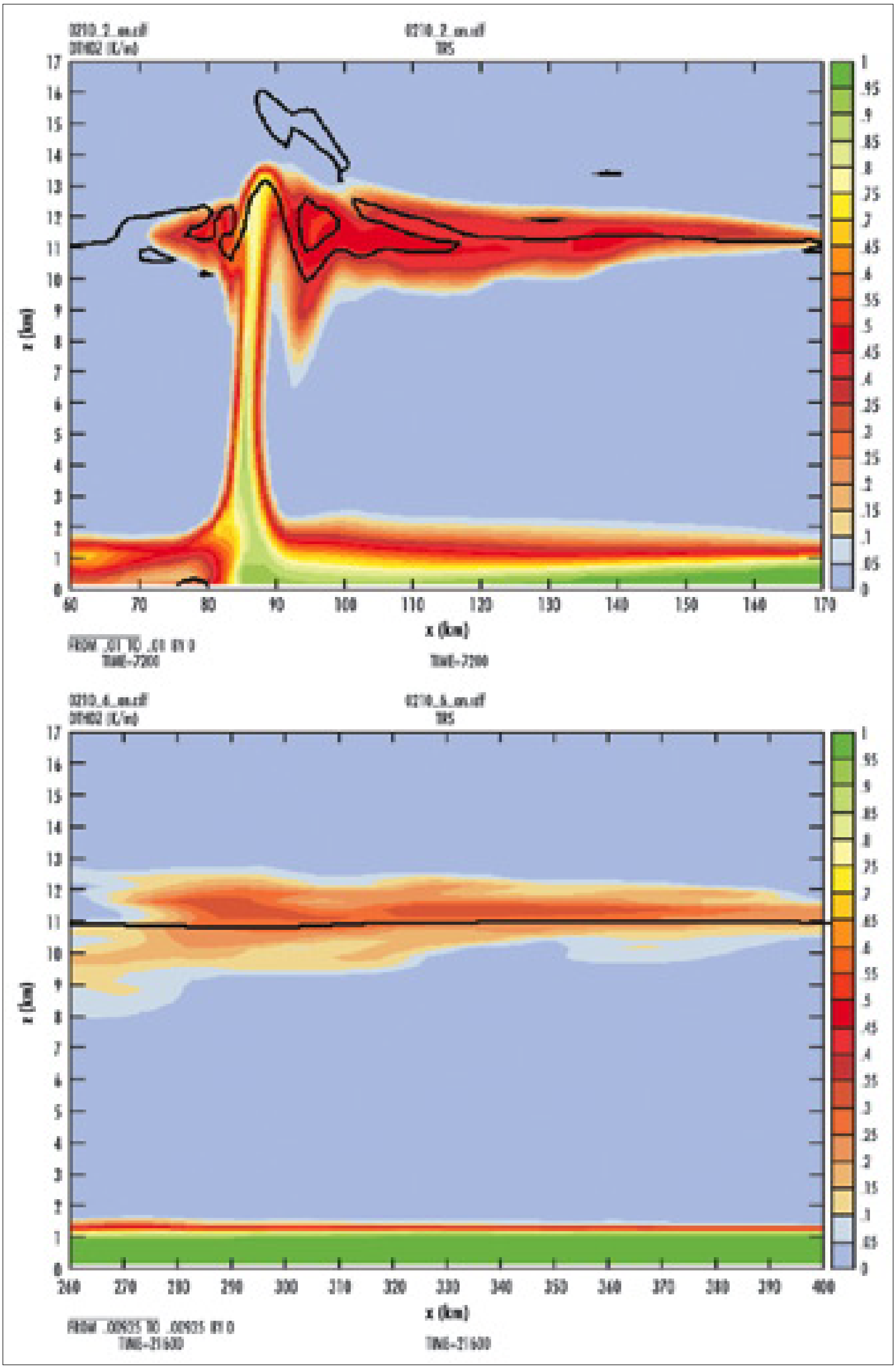
▶ **Figure 1d**
BrO volume mixing ratio field (in ppt, black lines) retrieved from SCIAMACHY limb measurements inside and outside the Antarctic polar vortex [Courtesy A. Rozanov]. The white solid lines are contours of modified potential vorticity.




▲ **Figure 1**
This schematic highlights important processes coupling dynamics, chemistry and cloud microphysics in the UTLS region (adapted from Figure 3 of Stohl *et al.* 2003). The yellow line denotes the time average tropopause. In the tropics, maximum outflow from deep convection occurs near ~12-14 km, while the cold point tropopause occurs near 17 km. The intervening region has characteristics intermediate between the troposphere and stratosphere, and is termed the tropical transition layer (TTL). Extratropical stratosphere-troposphere exchange occurs in tropopause folds and intrusions linked with synoptic weather systems; these events transport stratospheric ozone into the troposphere. In addition, synoptic scale uplift ('warm conveyor belts') and deep convection brings near-surface pollutants (from biomass burning or anthropogenic emissions) into the upper troposphere, strongly influencing global-scale chemistry.

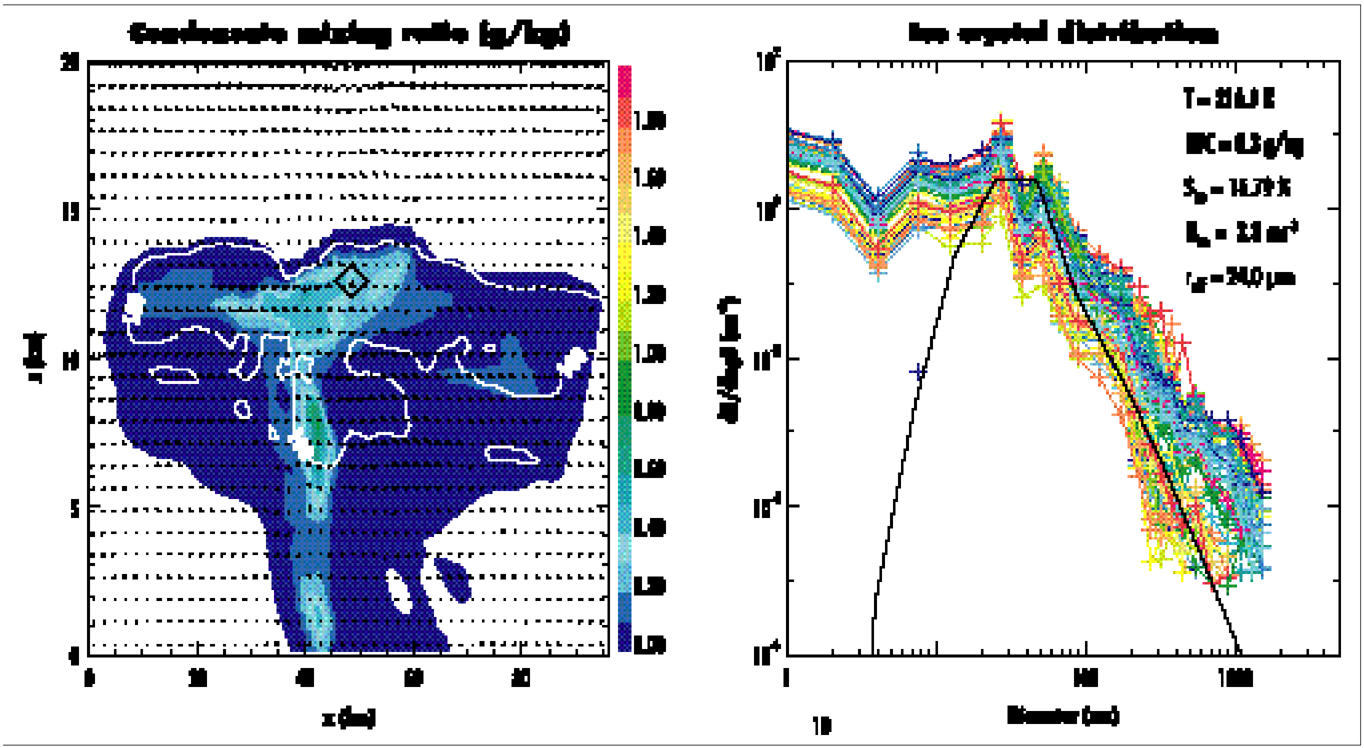
**Figure 3 ▶**

Results of a 3-D cloud model simulation of a deep cumulonimbus cloud sampled on July 29, 2002. The simulation was initialised with aircraft aerosol measurements and with mesoscale meteorological fields provided by D. Wang. The left panel shows a cross section of condensate mixing ratio (ice + water, colour shading) and 100% relative humidity with respect to ice (white contours) in a mature anvil. The right panel shows the ice crystal size distributions measured (coloured lines) by a combination of instruments on the WB-57 [unpublished data courtesy of D. Baumgardner] and simulated (black line) at the location indicated by the black diamond in the left panel. [Unpublished model results courtesy of A. Fridlind and A. Ackerman]. The discrepancy in the 1-10 micrometer region is unresolved at this time. Problems with the particle size distribution retrieval and possible model shortcomings are being explored.




**▶ Figure 2**

Vertical cross-section through an idealised supercell anvil at 2 hours (top panel) and 6 hours (bottom panel). The coloured contours show the concentration of a boundary layer tracer, initialised with a mixing ratio of 1 kg/kg in the lowest 1 km at model time zero. The thick black line shows the location of the tropopause, defined as a surface of constant gradient in potential temperature. [Simulation and figure are courtesy of G. Mullendore]



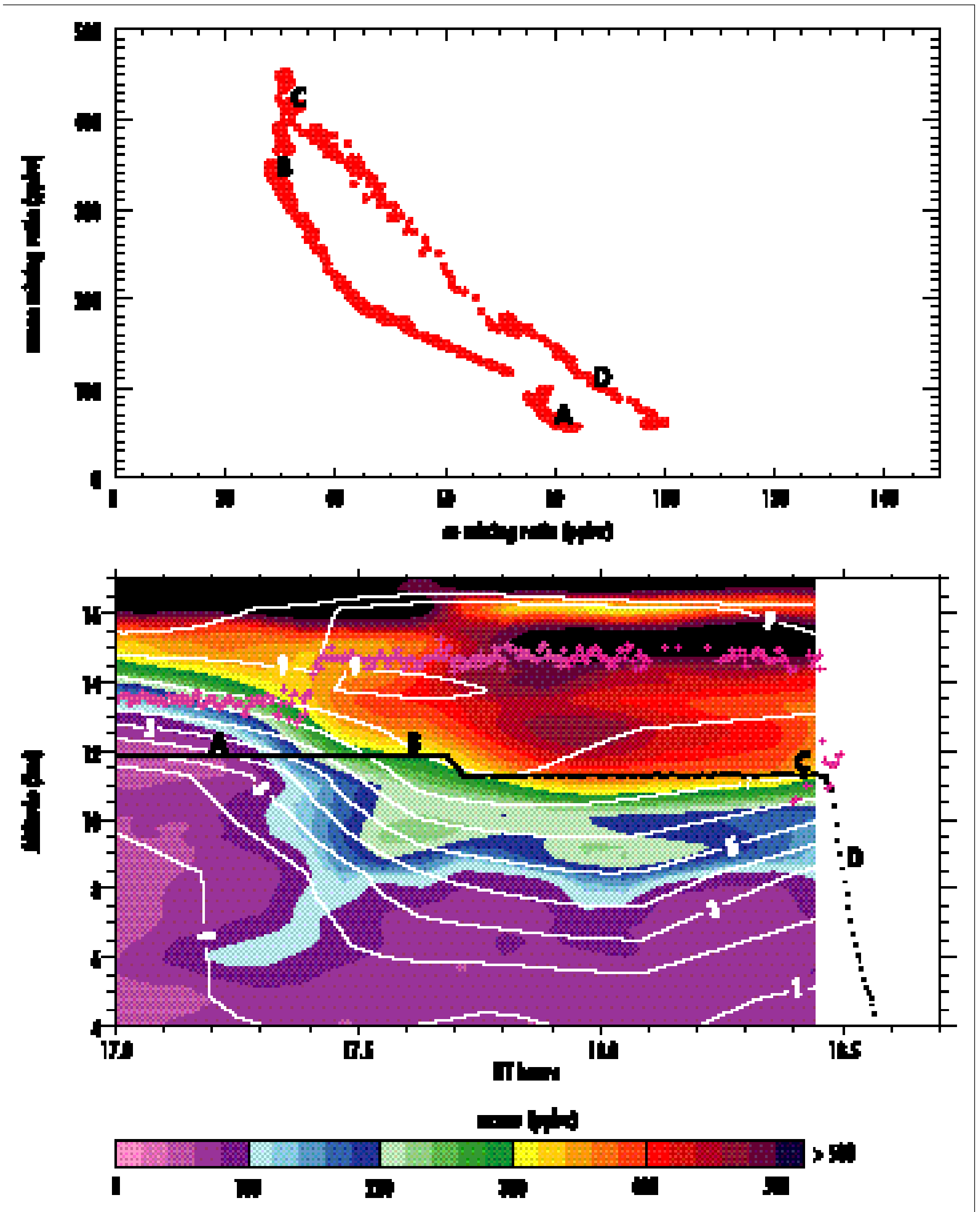



**Figure 4**
Diagnosis of mixing of stratospheric and tropospheric air observed in the vicinity of a tropopause fold. The tracers and temperature measurements are made onboard the DC-8 on October 29, 1997 during SONEX. Lower panel shows an ozone curtain measured by lidar, together with analysed potential vorticity (white lines) and the aircraft flight track (black dotes). Top panel shows a scatter plot of $O_3$ vs. CO along the flight track (from in situ measurements). In both panels, letters A, B, C, and D help identify the segment of flight where the tracer mixing ratios form “mixing lines”. Purple crosses represent the location of the thermal tropopause calculated from MTP measurements. [from Pan et al., 2003]

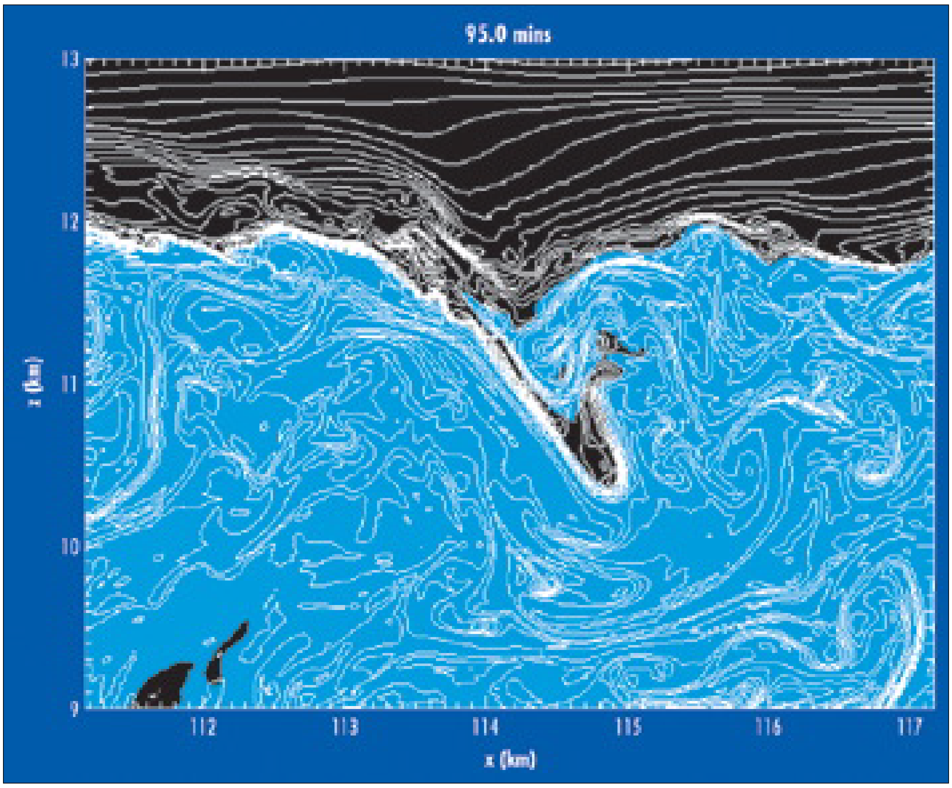



**Figure 5**
High resolution simulation of transport and mixing associated with deep midlatitude convection [from the work of Lane et al., 2003]. Contours show potential temperature at 2K intervals, and blue indicates cloudy air. This close-up view of turbulence near the cloud top highlights a small-scale intrusion of stratospheric air downwards, which is subsequently irreversibly mixed. [Figure courtesy T. Lane].

II

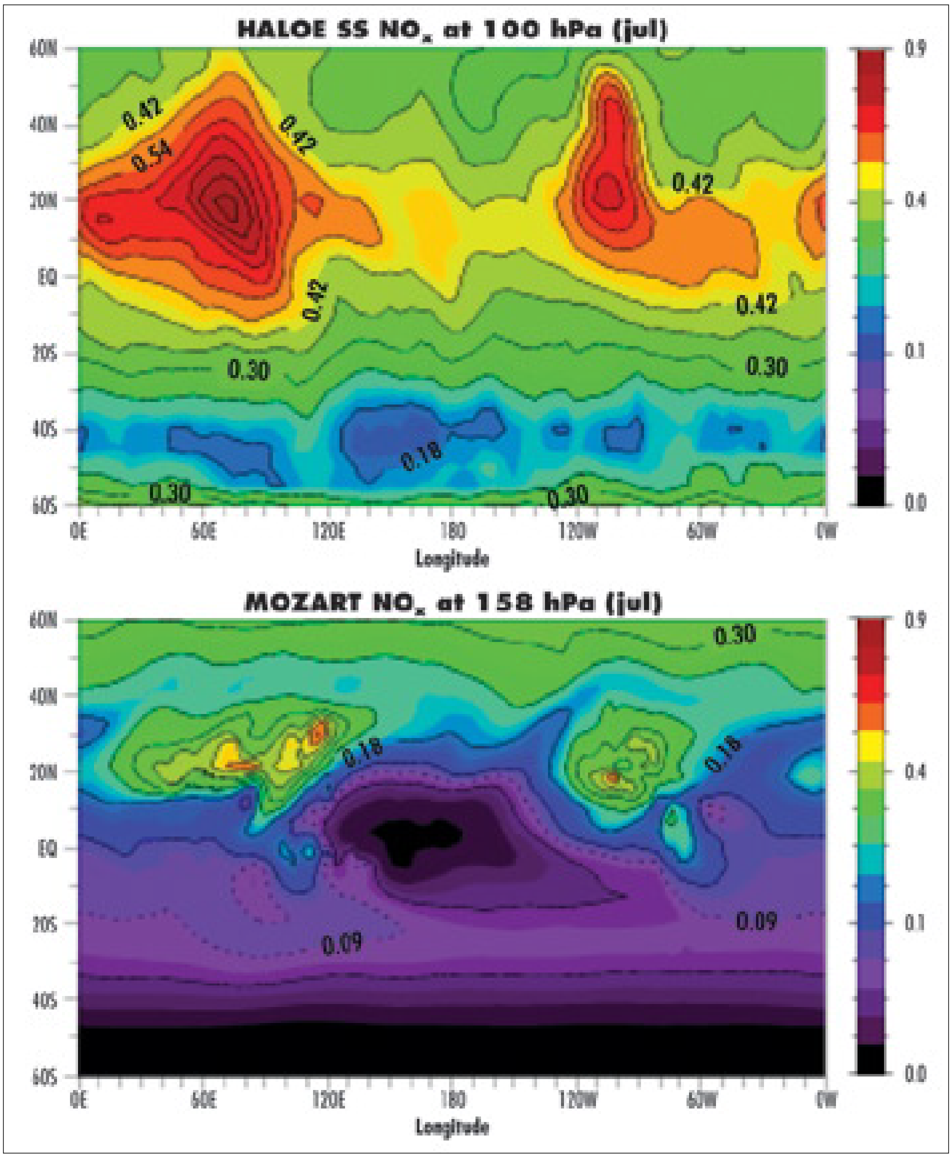



**Figure 7**
(top) Climatology of $NO_x$ (ppbv) at 100 hPa in July, derived from HALOE satellite measurements. (bottom) Simulation of July $NO_x$ at 158 hPa, derived from a MOZART chemical transport model simulation. Both figures show localized maxima in $NO_x$ near the tropopause, associated with the Northern Hemisphere summer monsoons over South Asia and North America. Note the somewhat larger values inferred from the HALOE measurements. (Figure from Park et al., 2003).