

Report on the Seventh Meeting of the SPARC Scientific Steering Group

Paris, France, 2-5 November 1999

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This year the SPARC Scientific Steering Group (SSG) met in Paris, at the headquarters of the French Space Agency (Centre National

des Etudes Spatiales, CNES). After a busy and successful initial seven years, this meeting marks the beginning of a critical review, by the SSG

and study group leaders, of the scientific objectives and scope of the project. The agenda of the three and a half day meeting was therefore a very full one.



Participants, from left to right:

1st row: M.-L. Chanin, V. Ramaswamy, Y. Koshelkov, V. Khatatov, P. DeCola, K. Kodera, S. Yoden. 2nd row: M. Geller, W. Randel, C. Granier, G. Amanatidis, A. O'Neill, K. Labitzke, J. Gille. 3rd row: J. Russell, T. Peter, T. Wehr, C. Phillips, R. Newson, M. Baldwin, K. Hamilton, R. Vincent. 4th row: N. Harris, F. Dulac, D. Karoly, P. Canziani, M. Proffitt, U. Schmidt, G. McFadyen, P. Udelhofen, S. Penkett, P. Haynes

M. Geller opened the meeting by thanking F. Dulac (CNES Middle Atmosphere Programme) for his help in the organisation of the meeting and for providing excellent facilities at CNES. He also thanked the numerous funding agency representatives for attending the meeting (European Commission, CNRS, CNES, NASA, European Space Agency (ESA), and the Department of the Environment, Transport and the Regions (UK)). Their contributions to the meeting were very useful and the interactions with them were fruitful.

M.-L. Chanin, M. Geller and R. Newson reviewed the main events of concern to SPARC since the last SSG meeting in October 1998, in particular the meeting of the WCRP Joint Scientific Committee (JSC) that took place in March 1999 (see Newsletter 13) and the opening of the SPARC Data Centre (more information at end of this report).



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The SSG was pleased to learn that the European Commission has recently agreed to fund two projects related to SPARC, EuroSPICE (European project on Stratospheric Processes and their Impact on Climate and the Environment) and SOLICE (Solar Influence on Climate and Environment). The EuroSPICE project (co-ordinated by J. Austin) will study the impact of stratospheric ozone trends on past (1980-2000) and future (2000-2020) climate, updating observations and inter-comparing models. The SOLICE project (co-ordinated by J. Haigh) will attempt to determine the mechanisms by which changes in solar forcing can impact climate, intercompare the results of various models, and extend and improve existing data analyses.

Review of progress in SPARC activities

GCM-reality intercomparison for SPARC (GRIPS)

K. Kodera and T. Shepherd reported on recent progress of the GRIPS initiative. This intercomparison project has grown both in the number of research groups involved and the number of assigned tasks. The 1999 GRIPS meeting is described in detail in Newsletter 13, and only a brief summary of progress and issues is given here.

The first phase of the GRIPS initiative, a simple intercomparison of models, is nearing completion. A summary of the results and their scientific implications will appear in the Bulletin of the American Meteorological Society in March 2000. The second phase of GRIPS, already underway, involves validating the models and carrying out controlled experiments to test the parameterisation schemes. The phase 2 tasks include: intercomparisons of radiation schemes (led by U. Langematz), intercomparisons of model responses to mesospheric drag (led by S. Beagley), and tests of gravity wave parameterisations (led by C. McLandress).

During the third phase of GRIPS, the group plans to clarify understanding of the factors that determined the atmospheric state from 1979 to 1999. The three main issues that will be addressed will be natural variability, lower boundary forcing (i.e. the impact of interannual differences in sea surface temperatures and sea ice) and variations in radiative forcing. The sensitivity of the model climates to interannual variations in radiative forcing will be studied by carrying out a series of perturbation experiments, imposing interannual changes in solar

forcing, ozone and volcanic aerosol. The solar forcing experiments will be co-ordinated by K. Kodera. He presented the plans for this task in detail, as it is one of the scientific issues the WCRP JSC has asked SPARC to study.

A proposal for a fourth phase of GRIPS was described. The fourth phase would involve imposing climate change scenarios in the model runs and comparing the ensemble of transient runs, the aim being to show the impacts of middle atmospheric change on climate.

Stratospheric Reference Climatology

W. Randel presented the reference climatologies and stratospheric circulation statistics that this initiative has produced for the validation of stratospheric models.

The climatologies (monthly) have been created using UARS measurements of:

- temperature
- zonal winds (UKMO/HRDI)
- constituents (N_2O , CH_4 , H_2O , O_3 , NO_2 , HNO_3 , ...)

The stratospheric circulation statistics (monthly, daily) have been calculated using:

- NMC stratospheric analyses
- NCEP reanalyses
- UKMO stratospheric assimilation
- Free University of Berlin analyses
- GSFC assimilation

Other data sets that have been made available include the Singapore QBO winds and tropopause statistics.

This year the main activity of the group has been making the data available for use at the SPARC Data Centre. The climatology group plans to hold a meeting in 2000 and to produce a technical report describing the available data sets, comparing the stratospheric circulation statistics and quantifying uncertainties and interannual variability.

Stratospheric Aspects of Climate Forcing

This initiative has been led by D. Karoly to facilitate the modelling of stratospheric aspects of time-varying climate forcing. Data has been compiled on interannual changes from 1880 (if possible) to present of ozone, volcanic aerosol and solar irradiance. The data sets are now available at the SPARC data centre. The concluding report of this initiative is on page 15 of this issue.

Penetration of UV radiation in the lower stratosphere and troposphere

P. Simon and S. Penkett reviewed the scientific issues related to the penetration of UV radiation in the lower stratosphere and troposphere. They

reminded the SSG that decreases in stratospheric ozone impact the chemical composition of the troposphere, including the concentration of the OH radical that regulates the lifetime of greenhouse gases such as CH_4 , HCFCs and HFCs. Long-term atmospheric observations of methane already show this effect, (see article by C. Granier in Newsletter 13).

They pointed out that there is currently a need for measurements of global photodissociation rate constants (J_s) (climatology as a function of altitude and variations) and of actinic flux (to calculate the J_s) and to improve model calculations of J_s .

A joint SPARC-IGAC activity on UV penetration was proposed which would:

- Evaluate existing data
- Evaluate current J values and actinic flux measurements
- Discuss requirements for possible new instrumentation
- Organise radiative transfer model validation campaigns

The SSG agreed that such an activity would be very useful and could be carried out within the SPARC UT/LS processes initiative. P. Simon and S. Penkett proposed to hold a workshop on measurements and radiative transfer modelling and to work towards a better synergy of ground-based and satellite observations, together with the WMO Global Atmosphere Watch UV Scientific Steering Committee. The results of this work should also benefit the new IGBP Surface Ocean and Lower-Atmosphere Study (SOLAS), as one of the principal scientific objectives is to understand whether changes in the spectrum and intensity of solar radiation affect the production of trace gases in the surface ocean.

Stratospheric temperature trends

V. Ramaswamy reported on the activities of this working group. The original aim of this initiative was to assess observations of stratospheric temperature trends. Modelling studies also carried out by the group have helped improve our understanding of the observations. The results of the data and modelling activities have already been used in the WMO/UNEP 1999 Assessment of ozone trends and will be published in Reviews of Geophysics in 2000. A longer report is in preparation and will appear as a SPARC report. The work of the group is currently being used for the preparation of the IPCC 2001 report, in particular the chapters on radiative forcing, processes and detection-attribution.

In July 1999 the working group met in Birmingham and decided to revisit the data sets, address new scientific issues and plan new model investigations. They plan to update the data sets till the end of 1999, re-calculate trends and uncertainties, resolve discrepancies between satellite and radio-sonde trends, compare reanalyses with "raw" data sets, continue work on the rocket and sonde data and consolidate previous work by carrying out cross-checks. The data will be analysed for seasonal trends and variability and in particular the Northern Hemisphere polar winter-springtime trends will be examined closely. The sensitivity of the trend calculations to the inhomogeneities in the data (spatial and temporal) and to the time period being examined will be tested.

The group also plans new model investigations of the causes of the observed stratospheric seasonal and mean temperature trends, (e.g., the potential effect of interannual changes in water vapour concentrations) and to examine trends over regions and specific locations. To complement the linear trend experiments carried out to-date, sources of disturbances in the stratospheric climate will be examined. Transient GCM simulations will be carried out with appropriate time-varying forcings (e.g. Pinatubo volcanic aerosol) and compared to the observations. For each of these issues the comparisons with the data will be on finer spatial and temporal scales and will be more rigorous. With an increasingly longer data record, the detection-attribution arguments should be more reliable. The model uncertainties will be estimated so that the variability and trends can be compared with observational diagnostics.

The scientific objectives of the working group have become much broader than those set originally, and the group now wishes to address; the analysis of trends above the middle stratosphere in collaboration with ICMA, IAGA and SCOSTEP, as discussed during the LT-ACT conference in Pune in February 1999 (see Newsletter 13), refining the trends near the tropopause including tropopause height, the solar cycle signature in the observations and the models and stratosphere-troposphere coupling. The group plans short "mini-thrusts" focussing on climate variability and long-term change, and research on the major unresolved issues that have appeared during the past 3-4 years. They also hope to work alongside the other SPARC initiatives in a combined "integration" task studying on other stratospheric parameters (e.g. ozone, H₂O, dynamical activity and clouds). They believe that this research activity

should continue to be carried out under the auspices of SPARC, as this is an ideal way of carrying out coherent international research activity.

The working group hopes to meet during the second SPARC General Assembly, then late 2001, or early 2002.

Understanding ozone trends

N. Harris reported that this working group proposes to hold a workshop in the year 2000 on the attribution of past stratospheric ozone trends and the detection of the effect of the Montreal Protocol. Such a workshop would help to identify gaps in our knowledge on the attribution of stratospheric trends, consolidate existing work and hopefully encourage more research in this area by promoting contact between the various research groups. If there is a consensus to do so, the results of the workshop could be published as a set of peer-reviewed papers or in another format. It is hoped that the results would be available for use by the community by the year 2002, and could feed into the future WMO/UNEP Ozone Assessment planned for 2002-03.

It is felt that the SPARC project is the ideal context for such a workshop as it will encourage international co-operation and would hopefully lead to work on attribution of stratospheric trends in general (including temperature), one of the issues the SPARC project hopes to address within the coming years (see section below on the future of SPARC).

Water vapour in the stratosphere and upper troposphere

This working group has been very busy in 1999 preparing the SPARC Water Vapour Assessment (WAVAS). D. Kley presented the plan of the assessment (see Newsletter 13 for details) and its current status. The first draft of the assessment is currently being peer reviewed. A review meeting will be held in Paris, 17th to 20th January 2000, and it is hoped that the final version of the assessment will be ready for printing and publication on the SPARC web site by summer 2000.

Gravity wave processes and their parameterisation

The group constructing the climatology of gravity wave activity using high-resolution radio-sonde data met 15-16 July 1999 in Abingdon, UK. R. Vincent reported on the workshop. The issues discussed included: results from the initial analysis of high-resolution radio-sonde data using the common analysis package; quality control; horizontal drift; height coverage; averaging intervals; intermittency and how to quantify

it; spatial variability; sources of spatial variability and interpretation of the observations aided by theory and modelling. The group has agreed to produce climatologies based on monthly-mean values of kinetic energy, potential energy, horizontal directions of propagation, spectral parameters (m^* , t), axial ratios of hodographs, ratios of upward to downward propagating energy and mean vertical wavelengths. The climatology will cover a 7km interval in the lower stratosphere, the lower boundary of which will be determined by the mean height of the tropopause (using a model based on Hoinka, 1998). The analyses will be produced for as many years as possible in order to study the interannual variability of gravity wave activity.

It is planned to produce the following research products: intrinsic frequencies; horizontal wavelength; phase velocities and maybe momentum fluxes.

The initial collation of the results for hemispheric climatologies will take place early 2000 and will then be distributed to the working group for comment and update. Mid-2000, it is planned to submit for publication a series of articles describing the research efforts that have gone into the creation of this climatology.

K. Hamilton reported on the plans for the international field campaign ETCE (Effects of Tropical Convection Experiment). This approximately 6-week intensive observation period would study the intense diurnal convection that occurs over the Tiwi Islands north of Darwin, Australia. The main scientific objectives are to: characterise the 3D development of tropical deep convection in unprecedented detail; study the generation of stratospheric gravity waves by deep convection; study the effects of the convection on transport and mixing in the upper troposphere and lower stratosphere; the transformation of ozone precursors in the upper troposphere; the injection of water vapour into the stratosphere and the generation and dynamical and microphysical evolution of tropical anvil cirrus. The fourth planning meeting for this field campaign was held in October 1999 in Boulder. The target dates are now late October-early December 2002. A detailed plan of the scientific objectives and the instrumentation to be deployed during the field campaign is available at <http://www.princeton.edu/~kph/EXP2>.

Lower stratospheric/upper tropospheric processes

T. Shepherd and P. Haynes reviewed the scientific driving force for studying transport and mixing in the lower

stratosphere and upper troposphere and presented plans for a workshop on the tropopause to be held in 2001 in France. The workshop will address the following key questions: what is the tropopause, how well is it known, and why does it have its observed structure? How does the tropopause control the distribution of radiatively active species (locally and globally)? How might the tropopause be expected to change in the future?

A.R. Ravishankara and A. Cox reviewed the joint SPARC-IGAC studies of chemical processes in the UT/LS. A.R. Ravishankara presented some results from the group working on the quantum yield of the ozone photolysis reaction. They have reviewed recent laboratory measurements through extensive correspondence, exchange of data and analyses, and held a meeting in Oxford, UK, 23-24 September 1999. The group aims to publish a review paper in 2000 in which the evaluated data will be presented in a form accessible to atmospheric chemists.

A. Cox presented the progress of the group working on the analysis and evaluation of data on the atmospheric chemistry of small organic peroxy radicals (CH_3O_2 , $\text{C}_2\text{H}_5\text{O}_2$, $\text{CH}_3\text{C}(\text{O})\text{O}_2$, $\text{CH}_3\text{C}(\text{O})\text{O}_2$). The members of this group aim to produce critically evaluated data that can be used for atmospheric modelling.

A.R. Ravishankara underlined that these types of joint SPARC-IGAC activity are crucial as they produce an international evaluation of a given process in more detail than that carried out by the data evaluation panels (e.g. De More *et al.*, 97 and Atkinson *et al.*, 92) and bring providers and data users together. The SPARC-IGAC groups will therefore continue to recommend crucial chemical issues that require evaluation efforts.

Other scientific issues discussed during the meeting

The quasi-biennial oscillation and its role in coupling the stratosphere and troposphere

M. Baldwin reported on the activities of the ad hoc working group set up to review this scientific issue. The results of the workshop held in California in March 1998 have now been written up and are accepted for publication by *Reviews of Geophysics*. In 1999 a symposium on the QBO and internal gravity waves was convened by I. Hirota during the IUGG in Birmingham (see report this issue). M. Baldwin also reported on work being carried out

using radio-sondes, rocket-sondes, SSU and the UARS HRDI data to estimate zonal equatorial winds in the stratosphere and mesosphere from 1963 to 1999. The SPARC SSG will continue to follow with interest research on this aspect of the dynamical coupling of the modes of variability of the stratosphere and troposphere (see below).

Stratosphere-troposphere dynamical coupling

Part of the meeting was devoted to discussion of the Arctic Oscillation/North Atlantic Oscillation (AO/NAO) and stratosphere-troposphere dynamical coupling (see article by M. Baldwin on p. 10). M. Baldwin and K. Kodera presented recent research on this theme and stimulated a more general discussion on what we really know about this issue, what the key scientific questions are and whether the scientific community is addressing them. The consensus was that the field has developed rapidly and is likely to continue to do so this coming year, promoted by a special session at the AGU on the AO, a Chapman conference on the NAO during October-November 2000 and the 2nd SPARC General Assembly in November 2000. The SSG will follow with close interest the scientific developments on the connection between stratospheric and tropospheric modes of variability, and discuss during its next meeting whether or not SPARC has a role to play in encouraging research in this area. A report on this issue will be addressed to the WCRP JSC in March 2000 and to the CLIVAR SSG in May.

Data assimilation

A. O'Neill reviewed the role of data assimilation in climate research, pointing out that this technique is ideal for the cross-evaluation of data sets and evaluating the quality of reanalyses, and provides a link between modelling groups, instrumental groups and scientific users. He reminded the SSG that assimilation is used not only in stratospheric and climate research, but also in numerical weather prediction where an expertise has developed in parallel.

A. O'Neill suggested that a SPARC initiative on data assimilation would maintain and promote international co-operation, encourage interdisciplinary exchange within the stratospheric community, and provide a link to the numerical weather prediction community. The SSG agreed that such a new SPARC initiative is indeed timely and asked A. O'Neill to chair it. The working group will hold a workshop, report on current activities to the SSG and

recommend developments in those areas where it is needed. They will work in co-operation with the WCRP Working Group on Numerical Experimentation (WGNE) which monitors the advances in data assimilation and analysis methods and is the focal point in WCRP for encouraging and reviewing the reanalysis projects carried out at various centres.

Solar forcing and climate variability

The SPARC project currently reports annually to the WCRP JSC on advances in research on solar forcing, its variability as a source of variations in climate, and possible underlying mechanisms. (The evidence for past climate variability is reviewed by CLIVAR).

K. Kodera stimulated discussion on this issue by reviewing recent research on the effects of variations in solar activity. Although changes in the solar spectrum are known to impact ozone, temperature and the actinic flux in the middle atmosphere, to date there is no consensus on whether tropospheric climate is affected by these changes. The SSG noted that the data analysis planned in the European project SOLICE and the modelling activities starting up in GRIPS phase 3 and SOLICE should help elucidate this issue.

The SSG have invited SCOSTEP to work jointly with SPARC on encouraging research in solar influences on global change. They also hope that the results of the SCOSTEP International Solar Cycle Studies (ISCS) project that is studying the time-variation of solar UV and total irradiance, will be made available as input for modelling activities.

Monitoring stratospheric change

The SSG continues to follow closely the progress and strategy of measurement programmes such as the WMO Global Atmosphere Watch (GAW), the Network for the Detection of Stratospheric Change (NDSC), the WMO Global Climate Observing System (GCOS), and the Committee on Earth Observation Satellites (CEOS). When invited to do so, the SSG has supplied these programmes with recommendations for both the monitoring of the stratosphere and for process studies.

The issue of monitoring of stratospheric ozone was discussed since, if we are to follow the recovery of stratospheric ozone resulting from the actions of the Montreal Protocol and its subsequent amendments, it is essential to ensure the continuity and quality of the existing monitoring systems.

The SSG noted that it is crucial to continue to operate well-calibrated WMO

Global Atmosphere Watch (GAW) ground-based and sonde ozone measurements and a letter has been sent to WMO/GAW stating this support.

Faced with a potential gap in the continuity of global space-based measurements of total ozone, NASA has implemented Quik TOMS, due to be launched 15 August 2000 (<http://quiktoms.gsfc.nasa.gov>). The SSG has sent a letter to NASA thanking them for their responsiveness and stating that they hope that NASA will be similarly responsive in addressing the looming gap in SAGE measurements for ozone profile trend determination at mid and low latitudes.

Review of overall SPARC strategy and status of implementation

After 7 years of activity, the SSG feels that the SPARC project has successfully completed most of the initial tasks, and now needs to assess and maybe re-organise the scientific initiatives promoted by the project. Discussion on this issue was stimulated by a review by T. Shepherd of the current role of the project and possible future priorities.

To date the initiatives of the project were highly focused and treated separately by distinct working groups. The SSG feels that although some of the scientific issues originally addressed still need a continued focused effort, the time has come to integrate the knowledge acquired and work together towards improving our general understanding of all the aspects of stratospheric variability and change, its coupling with the troposphere and its role in climate.

Stratospheric processes that still need to be addressed through concerted efforts include the gravity wave climatology, UT/LS chemistry and microphysics, the tropopause and solar forcing and climate variability. The SSG would also like to assess atmospheric observations of aerosol (together with IGAC). Specific modelling issues that should be addressed include the parameterisation of gravity waves, assimilation and the issues identified during phase 1 of GRIPS.

The integration/synthesis of our understanding of trends (O_3 , temperature, dynamics, H_2O , aerosol and other constituents) and solar effects would be done through modelling studies aimed at elucidating UT/LS variability and change and its role in the climate system. This would build on the modelling work already carried out by the temperature trends initiative and GRIPS, but would also require the use

of models (e.g. 2D models, Chemical Transport Models) and techniques (e.g. assimilation) which have not yet been used in the project.

It was restated that the role of the project is to continue to facilitate research on stratospheric processes and their role in climate by identifying and supporting activities that would benefit from international co-operation and encouraging interdisciplinary exchange. For example, it was felt that although the number of climate models which include the stratosphere is increasing, currently the SPARC community does not have enough contact with the tropospheric climate community and it is hoped that the new initiatives on data assimilation and UV penetration will help build bridges between them. Finally, it was noted that although the SPARC project is driven by scientific questions and not political motives, it can, and should be providing the best available evidence (on those issues addressed by the project) for international assessments such as the IPCC and WMO/UNEP assessments.

Co-operation with other programmes

The project continues to maintain strong links with other programmes both through the joint working groups and the ex-officio members of the SSG.

As mentioned above, a formal assessment of trends in upper atmospheric indicators of climate change is planned in collaboration with ICMA, IAGA and SCOSTEP. SPARC will also work with SCOSTEP on the issue of solar forcing and climate variability.

The co-operation with IGAC continues, especially through the joint working groups on UT/LS chemical processes and will be extended to the issues of the penetration of UV in the stratosphere and upper troposphere and maybe the climatology of aerosol. S. Penkett's presentation of IGAC is summarised in the insert below.

COSPAR has invited the SPARC community to submit papers to a session of its Scientific Assembly in July 2000 on the "Contribution of Remote Sensing of the Upper Troposphere and Stratosphere to Understanding Climate Change". The session is convened by J. Gille (gille@ncar.ucar.edu).

Finally, within WCRP, SPARC plans to report to the CLIVAR SSG on the AO/NAO and a possible connection between the stratosphere and troposphere.

Planning for the 2nd SPARC General Assembly

Alan O'Neill presented the scientific programme for the 2nd SPARC General Assembly to be held in Mar del Plata, Argentina, 6-10 November 2000. He pointed out that, while they were elaborating the programme, the scientific organising committee spent a lot of time thinking about the role of the project and the direction it is heading in. They hope that the organisation of the Assembly will not only help consolidate the research SPARC has undertaken to date, but will also help identify areas where new initiatives are needed. The meeting will be divided into four sessions on:

- stratospheric processes and their role in climate,
- stratospheric indicators of climate change,
- modelling and diagnosis of stratospheric effects on climate,
- UV observations and modelling.

A description of the focus of each session is available on the conference web site (<http://www.sparc2000.at.fcen.uba.ar/>).

P. Canziani, chair of the local organising committee (LOC), described the local arrangements and reported on the efforts of the LOC to ensure that the meeting is successful.

M.-L. Chanin was pleased to report that the SPARC office has been able to attract many sponsors, and that some travel support for students and young scientists will be available. The requests for support should be made when submitting abstracts.

Opening of the SPARC Data Centre

An important event this year has been the opening of the SPARC Data Centre (<http://www.sparc.sunysb.edu/>). P. Udelhofen, the Data Centre manager, summarised the work that has been carried out so far and the products that are currently available through it. These include US high-resolution radio-sonde data and reference climatologies (NCEP reanalyses from 1978 to 1998, observed 1979-97 ozone trends, climatologies of stratospheric trace gases derived from UARS observations and a link to NCEP tropopause heights).

The SPARC Office

The SPARC Office continues to support the project by preparing the newsletter, updating the web page and organising meetings. This year the main other activities of the office have

been supporting the preparation of the WAVAS report and finding sponsors for SPARC 2000.

Plans for the next meeting of the SSG

The next SSG meeting is planned 13-16 November 99 in Buenos Aires, Argentina. P. Canziani has kindly

volunteered to organise the local arrangements. In the light of the research presented during the Second SPARC General Assembly the SSG will continue to assess the project, define new objectives and discuss the renewal of its membership.

The full meaning of the acronyms and abbreviations used in this report can be found on the SPARC web site.

References

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IGAC for SPARC in 9 minutes

S.A. Penkett (m.penkett@uea.ac.uk), University of East Anglia, Norwich, UK

- IGAC is concerned with processes which control the trace gas and particulate composition of the troposphere.
- The main components are studies of:
 - biogenic emissions from land and ocean and impact of human emissions
 - photochemistry leading to oxidation processes, particularly with free radicals
 - aerosol physics and chemistry
 - transport processes in the troposphere

The output from many field and laboratory studies is fed into 3D chemical transport models of tropospheric chemistry.

- A recent model intercomparison exercise carried out with support from the European IGAC Project Office (EIPO) revealed substantial differences between the models, which can only be resolved with a much larger data base on tropospheric composition requiring many more in situ experiments and hopefully new observations from satellites which will be launched in the next few years.

- Some current issues are:
 - production of natural and anthropogenic sulphate and organic aerosols over the ocean
 - global transport of emissions from biomass burning and urban/regional pollution, particularly ozone, spread of pollution
- Tropospheric chemistry is very efficient. It has controlled atmospheric composition over geological time.

When it is ineffective, it causes key problems, e.g.

- CO₂: long lifetime due to no photolysis plus no oxidation reactions
- CFC₆: not removed by tropospheric chemistry, contrast with HCs, which are and lead to ozone production in the troposphere.

- One of the prime consequences of tropospheric chemistry is the large in situ production and loss of ozone.

Stratospheric/Tropospheric exchange produces	~ 400 MT in troposphere
Gaseous deposition	~ 1000 MT/yr
Tropospheric chemistry produces	~ 4000 MT/yr
Tropospheric chemistry destroys	~ 3500 MT/yr

Distribution is poorly known because of sparseness of sonde sites, particularly in the tropics.

A new effort to use satellites is being mounted by NASA and ESA including:

- An attempt to use a geostationary satellite for tropospheric ozone.
- A major new programme entitled GTOP (Global Tropospheric Ozone Programme) with the purpose of stimulating measurements of ozone in the troposphere.

- Where is IGAC going?

- Links with SPARC including a new group with A. R. Ravishankara in charge to consider common issues related to atmospheric chemistry.
- IGAC is currently producing a book concerned with findings over the last decade in a process of integration and synthesis. The following 5 Chapters will be produced in the year 2000:
 - Introduction
 - Biosphere/Atmosphere Interactions
 - Photochemistry/Oxidising Capacity
 - Aerosols
 - Synthesis

Report on the SPARC/IGAC working group on ozone photolysis

A. R. Ravishankara (ravi@al.noaa.gov) and R. A. Cox.

The hydroxyl radical is one of the most important reactive species in the atmosphere. It is the agent that leads to the removal of a large number of chemicals in the atmosphere and also transforms many other atmospheric species, hence nick-named Mother Nature's detergent. The primary pathway by which OH is produced in the atmosphere is via the photodissociation of ozone in the ultraviolet region to produce electronically excited oxygen atoms O(¹D) followed by the reaction of this species with water (or other species). Even though this pathway is considered to be well established (it is in all atmospheric chemistry textbooks), the quantum yield for the production of O(¹D) (i.e., the fraction of ozone molecules absorbing light that dissociate to give this species) in ozone photolysis was uncertain. The quantum yield for O(¹D) production as a function of wavelength and temperature is a key input for atmospheric

modelling calculations. In the past few years, a large number of investigators have measured this quantity using diverse methods. The result of these studies have shown that the data currently used in models is erroneous at wavelengths beyond ~310nm. To provide the modelling community with the best possible information, the SPARC/IGAC task on ozone photochemistry under the Laboratory Studies project brought together most of the principal scientists involved in these investigations to carefully analyse the available data and come up with the best possible recommendation for the quantum yields. The working group consists of the following scientists:

- Y. Matsumi, University of Nagoya, Japan (Chair of this group),
- F. J. Comes, Frankfurt University, Germany,
- G. Hancock, Oxford University, UK,
- A. Hofzumahaus, KFA, Germany,

- A. J. Hynes, University of Miami, USA,
- M. Kawasaki, Kyoto University, Japan,
- A. R. Ravishankara, NOAA, USA.

The group did a great deal of work through electronic communication and finally met in Oxford, UK, in September of 1999. The meeting was extremely successful. It led to a lot of checks and inter-comparisons. The finalised recommendation is being derived and is being written up for publication. It will be available to the atmospheric chemistry community in a few months. It will be submitted to a refereed journal for publication. Also, all the supporting material, as well as the final write-up, will be in the SPARC Data Center.



On the role of the stratosphere in the climate system

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The traditional view in climate science has been that the stratosphere, which represents only about 10-20% of the atmosphere in terms of mass, can play only a limited role in climate change. However, there has been increasing evidence in recent years that the stratosphere is a sensitive component of the climate system, which can affect the troposphere through various coupling mechanisms. This article reviews the current state of knowledge, and discusses possible mechanisms for this coupling.

The role of wave driving

The temperature structure of the stratosphere represents a balance between radiative and dynamical heating. To a very large extent, radiative transfer in the stratosphere is a clear-sky process and is well understood (Andrews *et al.* 1987); the only significant exception occurs in the aftermath of a large volcanic eruption. The radiative equilibrium state is dynamically stable nearly everywhere and there are no rapid small-scale adjust-

ments to be considered as there are in the troposphere. The one place where stability is not guaranteed is in the tropics, where the seasonal migration of the solar heating maximum about the equator leads to a process of quasi-horizontal inertial adjustment (Dunkerton 1989). This process has not received much attention, presumably because it is resolved to some extent in climate models, but it is still not well understood in detail. A point of concern in this respect is that the "traditional" form of the hydrostatic primitive equations, widely used in climate models, becomes invalid at the equator (de Verdiere *et al.* 1994).

The dynamical heating is associated with vertical (adiabatic) motion which is partly caused by radiative heating, but is primarily caused by the breaking and dissipation of Rossby waves and gravity waves emanating from the troposphere. The extent to which the wave-induced forcing is the dominant factor increases as one considers longer time scales, reaching a wave-induced "downward control" regime in the steady-state limit (Haynes *et al.* 1991). Thus, on climatolo-

gical time scales one can regard the stratospheric temperature field as being pulled away from radiative (-inertial) equilibrium by wave-induced forces. In the extratropical stratosphere, the wave-induced forces are almost exclusively westward and act to drive air poleward, thus producing a meridional mass circulation that is generally rising in low latitudes and sinking in high latitudes (Holton *et al.* 1995). The resulting dynamical heating is negative in low latitudes and positive in high latitudes.

The dominant wave-induced forcing in the stratosphere is believed to come from tropospherically generated planetary-scale Rossby waves, and this forcing maximises in winter because that is the season of greatest tropospheric baroclinicity and greatest land-sea thermal contrasts. This is reflected in the fact that the meridional mass circulation, although two-celled, is dominantly directed towards the winter pole, and it leads to a significant warming (and weakening) of the polar night vortex relative to its radiatively determined state. This points to a mechanism whereby differences in

wave-induced forcing lead directly to differences in stratospheric polar night temperatures. Such differences are most apparent in the asymmetry between the Northern and Southern Hemispheres: the Southern Hemisphere, with less zonal inhomogeneity, produces less planetary-wave forcing and therefore less dynamical warming of the vortex; in the Northern Hemisphere, the forcing is sometimes strong enough to completely destroy the vortex in a "sudden stratospheric warming". By the same token, interannual variability and long-term trends in wave-induced forcing can lead directly by this mechanism to corresponding changes in stratospheric temperatures. It is important to note that the temperature effect of wave-induced forcing is to a first approximation zero in the global mean, at any pressure level, because rising motion in one place must be compensated by sinking motion elsewhere; thus the signature of such changes is compensating temperature changes in the tropics and extratropics. This compensation has been noted in the annual cycle, with the coldest tropical temperatures occurring in Northern Hemisphere winter when the wave-induced forcing is greatest (Yulaeva *et al.* 1994).

There nevertheless remain significant uncertainties in both qualitative and quantitative aspects of the wave-induced forcing. A qualitative uncertainty is that while the wave-induced forcing is greatest in the winter hemisphere, the maximum radiative imbalance and maximum upwelling in tracer fields are found on the summer side of the equator. Various reasons have been advanced for this discrepancy, but they all require knowledge of the tropical angular momentum budget and thus will be difficult to test for two reasons: first, there is great sensitivity to small errors in this budget, and second, the quality of stratospheric wind analyses in the tropics is very poor.

The role of subgrid scale waves

The principal quantitative uncertainties in wave-induced forcing have to do with the role of gravity waves, which are essentially undetected in stratospheric analyses. Inferences regarding the role of gravity waves have therefore had to come from systematic errors in climate models, most notably the well-documented "cold pole" problem. Based on the arguments presented above, the cold pole problem is most plausibly attributed to insufficient wave drag. On the presumption that the planetary-wave forcing in GCMs is reasonable (since planetary waves are well resolved even by relatively coarse models), attention naturally focuses on

gravity waves. Although some gravity waves will be represented in GCMs, a GRIPS study has shown that their horizontal wavenumber spectra of kinetic energy are shallow (Koshyk *et al.* 1999). Thus for most models, most of the drag will be unrepresented; typical horizontal length scales are believed to be in the range 10–200 km.

It is widely accepted that the drag exerted by breaking and dissipating gravity waves is responsible for the pole-to-pole solstitial circulation in the mesosphere (Andrews *et al.* 1987). The principle of downward control shows how mesospheric wave drag can affect temperatures in the stratosphere, particularly in the polar night where there is strong sensitivity of temperatures to dynamical heating (because of the long radiative time scale). Several middle atmosphere GCMs have eliminated most of the cold pole problem by using a strong Rayleigh friction in the upper stratosphere or mesosphere. Although such "tuning" with Rayleigh drag may be an effective way of obtaining reasonable mean states, it can lead to erroneous meridional circulations in response to climate perturbations because Rayleigh drag is not momentum-conserving (Shepherd *et al.* 1996). More physically based gravity-wave drag parameterisation schemes have been developed, but there is little consensus on the most appropriate framework. More seriously, in all these schemes the amplitude and shape of the gravity-wave spectrum must be determined empirically, but current measurements provide little information on either of these quantities.

As the resolution of climate models increases, more of the gravity-wave spectrum is explicitly resolved and the cold pole bias tends to reduce as more wave drag is explicitly represented (Hamilton *et al.* 1995; Jones *et al.* 1997). However, even calculations performed with the GFDL SKYHI GCM at 0.6° resolution (which can resolve gravity waves longer than about 100 km) reveal a cold bias of up to 20 K in the upper stratosphere. Thus, given the extreme computational cost of ultra-high-resolution simulations, this is not a feasible approach at the present time. Moreover, there is no guarantee that the gravity-wave spectrum will be realistic, since the principal forcing mechanisms will be physical parameterisations such as convective adjustment in the troposphere, acting near the grid scale of the model.

Although most attention with regard to gravity-wave drag has focused on the Southern Hemisphere, it is interesting that gravity-wave drag has been found to be crucial for obtaining realistic simulations of the Northern Hemisphere winter

in some modest-resolution models (Boville 1995; Beagley *et al.* 1997). A major scientific issue in climate change involves possible changes in the Arctic wintertime vortex and the impact of those changes on ozone depletion (WMO 1999, Chapter 12; see further discussion below). The fact that the realism of present-day simulations of the Arctic vortex can depend critically on a parameterisation unconstrained by measurements is therefore a cause for concern.

Until recently, a consistent failing of middle atmosphere GCMs has been their inability to simulate the quasi-biennial oscillation (QBO). Now the situation is changing rapidly. First, QBO-like oscillations were found in highly simplified GCMs with better than 1 km vertical resolution and very little horizontal dissipation (Takahashi 1996; Horinouchi and Yoden 1997). Subsequently they were found in very high resolution versions of some GCMs (although these simulations are typically quite short). Yet more recently, several groups have found such oscillations in moderate resolution GCMs using a parameterised gravity-wave drag that is sensitive to critical lines. It should be noted that a "QBO-like oscillation" simply means a downward propagating oscillation between equatorial easterlies and westerlies with a quasi-regular period. Whether the period is close to biennial is not really a key feature, since the period is expected to depend on the amplitude of the tropical wave-drag forcing (either resolved or parameterised) which is unlikely to be correct. It remains unclear exactly what is required for a model to produce a QBO-like oscillation, and whether the oscillations that have been seen are occurring for the right reasons. Some models exhibit curious parameter dependencies, and some show a tendency for an intriguing seasonal synchronisation.

The role of transport and mixing

The distribution of radiatively active trace gases in the stratosphere is an important component of climate forcing, including the shape of the tropopause itself. This distribution is controlled by dynamics in two ways. First, through the temperature distribution which affects chemical reaction rates; and second (generally more importantly), through transport and mixing by winds. The same meridional mass circulation that produces dynamical heating and cooling also transports chemical species poleward in the stratosphere; this is the so-called Brewer-Dobson circulation (Andrews *et al.* 1987). The balance between this overturning circulation (which on its own has a time scale of about five

years) and quasi-horizontal mixing due to breaking planetary waves produces a characteristic picture for long-lived tracers (such as CH_4 and N_2O) with tropospheric sources and stratospheric sinks of quasi-horizontal tracer distributions having an upward bulge in the tropics. The control of stratospheric chemical distributions by transport and mixing induced by breaking planetary waves points to a possible feedback mechanism between tropospheric dynamics and radiative forcing, via the stratosphere. Thus, it is essential to understand what controls the Brewer-Dobson circulation. In the last several years, there have been significant advances in the understanding and quantification of this process (see WMO 1999, Chapter 7).

A key quantity determining the stratospheric distribution of long-lived trace gases is the length of time it takes to get from the tropical tropopause (the entry point to the stratosphere) to the location in question. Because of mixing, there is no single pathway, but rather a distribution of pathways; an air parcel at a given location is composed of many components with different transport histories and, therefore, different transit times. The distribution of such transit times is known as the "age spectrum", and the mean of the distribution is the "mean age". Although the age spectrum cannot be measured directly, the mean age can be inferred from measurements of long-lived tracers with linear trends, such as SF_6 (e.g. Volk *et al.* 1997); this provides a valuable constraint on models. Generally speaking, model ages are too "young", suggesting that the models mix too rapidly (Vaughan *et al.* 1997). This suggests a potential climate drift problem for simulations with full chemical-radiative interactions, and it can be expected to compromise predictions of stratospheric residence times (e.g. of halogens). These problems may be expected to become more evident in the coming years as groups begin to perform long simulations using full chemical modules.

The picture of a meridional mass circulation modified by quasi-horizontal mixing has been refined in several respects in the last few years. Transport "barriers" have been identified at the edge of the polar vortices as well as in the subtropics. The isolation of tropical upwelling, together with the annual cycle of temperature at the tropical tropopause mentioned earlier, leads to a remarkable phenomenon dubbed the "tropical tape recorder" (Mote *et al.* 1996): since the tropical tropopause is a local temperature minimum, it controls the amount of water vapour entering the stratosphere through "freeze drying". The annual cycle in temperature is therefore imprinted on the water vapour distribution, which gets carried

upward with remarkably little attenuation. From this signal one can infer a vertical transport time scale of about 0.2-0.4 mm/s (greatest in NH winter) – corresponding to only 20-40 m per day – which is consistent with ascent rates derived from diabatic circulation calculations.

Because the tropopause is higher in the tropics than in the extratropics, there is a dynamical distinction to be made between isentropic surfaces lying entirely within the stratosphere and those which intersect the tropopause (lying in the stratosphere only in the extratropics). The former are well isolated from the troposphere, while on the latter, known as the "lowermost stratosphere" (Holton *et al.* 1995), rapid quasi-horizontal isentropic mixing with the troposphere is possible. In this region, evidence of intrusions of tropospheric air is evident from transport studies as well as direct dynamical-chemical signatures. Any air mixed into this region cannot drift upwards into the deep stratosphere and will eventually have to find its way back into the troposphere. Nevertheless, the degree of inmixing is a key factor in radiative forcing of climate through its control of the water vapour and ozone distribution in the lowermost stratosphere, which is the part of the stratosphere most crucial for the radiative balance at the surface.

A key factor affecting tropospheric climate is the height of the tropopause. It is rather remarkable that this question, so basic to climate, remains poorly understood. Considerations of radiative-convective adjustment suggest that the tropopause be identified with the top of the region of moist convection. There are, however, important feedbacks from the stratosphere itself. The dynamical heating associated with the Brewer-Dobson circulation acts to raise the tropopause in the tropics and to lower it in the extratropics. In addition, the radiative equilibrium temperature is determined by trace gas distributions in the stratosphere, particularly ozone and water vapour, and these distributions are controlled by the transport and mixing processes described above. In particular, the poleward and downward transport of ozone in the Brewer-Dobson circulation acts, through radiation, to lower the tropopause in the extratropics. Thus, the latitudinal variation in the height of the tropopause is controlled to a considerable extent by stratospheric processes.

Coupling mechanisms between the stratosphere and troposphere

There are three principal mechanisms by which the stratosphere can affect tropospheric climate. The first is through

radiative transfer, either by changes in the amount of solar radiation that reaches the surface (e.g. after a volcanic eruption), or by changes in the amount of downwelling longwave radiation emitted by the stratosphere (e.g. because of stratospheric ozone depletion). The impact depends very sensitively on the vertical, latitudinal, and seasonal structure of the changes in the radiatively active substances, particularly in the vicinity of the tropopause (Forster *et al.* 1997; Hansen *et al.* 1997).

The fact that the distribution of radiatively active substances is controlled by the Brewer-Dobson circulation together with quasi-horizontal inmixing into the lowermost stratosphere emphasises that climate models need to represent these processes with sufficient fidelity in order to capture this sensitivity.

The second and third mechanisms by which the stratosphere can affect tropospheric climate take account of the basic dynamical fact that tropospherically forced waves propagate up, while zonal-mean anomalies propagate down. Thus, the second mechanism is that the stratosphere can affect the "upper boundary condition" of the troposphere by affecting the propagation characteristics of tropospheric waves. This possibility goes back to the classic work of Charney and Drazin, but there has been remarkably little investigation of this issue in recent years. The possibility of wave reflection at the tropopause has obvious implications for regional climate perturbations.

The third mechanism is then the downward propagation of zonal-mean anomalies, whose mechanism is «downward control». Such downward influence has been seen in model studies (Kodera *et al.* 1996). Since the zonal-mean anomalies are themselves caused by wave-induced forces whose ultimate origin is the troposphere, this provides a purely dynamical troposphere-stratosphere feedback loop, which may account for the well-documented troposphere-stratosphere anomaly correlations seen in observations (Baldwin *et al.* 1994). Indeed, there has been much recent interest in the possibility that the North Atlantic Oscillation could be coupled with the strength of the wintertime Arctic vortex (Thompson and Wallace 1998), thereby accounting for the unusual strength (and coldness) of the Arctic vortex through most of the 1990s and the resulting halogen-induced severe ozone depletion (WMO 1999, Chapter 7). Whether the stratospheric vortex is an essential component in a feedback loop involving the NAO, or simply responds to the NAO, remains unclear: in long-term climate simulations with coupled models, results from different groups differ in

this respect. (However, even a model without a real stratosphere will still have some capacity for this mechanism in its uppermost levels.)

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The Arctic Oscillation and its role in stratosphere-troposphere coupling

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Introduction

In a white paper on the North Atlantic Oscillation (NAO) and tropical Atlantic variability, J. Marshall and Y. Kushnir¹ described climate changes that have taken place during the last few decades:

"Since the mid-1960s there has been a steady increase in wintertime storminess in the northeastern Atlantic and the North Sea. At the same time northern European countries bordering the Atlantic have experienced an upward trend in winter rainfall, while from the Iberian Peninsula to Turkey there has been a steady decline in rainfall. Winter air temperatures over northern Europe and Asia, from Scandinavia to Siberia rose steadily from the mid-1960s. During the same period the Middle East and North

Africa cooled. Over Greenland and the Canadian arctic strong cooling occurred while the eastern half of the United States warmed slightly. In sub-Saharan Africa, rainfall steadily decreased after the wet decade of the 1950s, turning the Sahel into a drought-stricken region. At the same latitude, mid-summer to late autumn tropical storms which were frequent during the 1940s and 50s became less frequent from the 1960s onwards. Some of these climatic trends may have been felt as far south as the semi-arid region of northeast Brazil, where austral summer rainfall, regulated by the annual migration of the Inter-Tropical Convergence Zone (ITCZ), has displayed an upward trend."

Marshall and Kushnir then asked the following questions: "Is there a causal relation between these climatic events?

Do they have a single orchestrating factor, and if so what is it? Can we discern the mechanisms that have governed these fluctuations? If so will we be able to foretell their future evolution?" Many of the answers may come from an understanding of a "mode of climate variability" called the Arctic Oscillation (AO).

The AO was first defined by Thompson and Wallace [1998] as the leading mode of variability of the extratropical Northern Hemisphere. They used an empirical orthogonal function (EOF) analysis of wintertime monthly-mean 1000hPa geopotential anomalies to obtain this leading mode, but it is important to realize that the AO is not just the leading mode of the surface, and not just of the winter months. It is also possible to obtain the AO without EOF analysis. Its strong zonal symmetry led Thompson and Wallace [2000] to call it the northern

1 - <http://geoid.mit.edu/accp/avehtml.html>

"annular mode." The terms "Arctic Oscillation," northern "annular mode," and "leading mode of the Northern Hemisphere" are all used in the literature to describe the same phenomenon.

The Arctic Oscillation "rivals ENSO in terms of its significance for understanding global climate variability and trends" [Wallace, 2000]. The well-known teleconnection pattern known as the North Atlantic Oscillation (NAO) may be regarded as the manifestation of the AO in the Atlantic sector, and maps of the AO and NAO over the Atlantic half of the Northern Hemisphere are nearly identical. Its similarity to the NAO has caused some confusion, and led Wallace to explain how the AO and NAO may be viewed as a single phenomenon viewed through two different paradigms. The AO provides a useful way through which to evaluate and understand climate variability and trends, the occurrence of significant weather events, and the role of stratosphere-troposphere coupling. The AO paradigm provides a framework in which remote linkages, such as between tropical Atlantic climate variability and North Atlantic variability can be better understood.

Since the 1960s the AO has experienced a "trend" toward a positive index, broadly consistent with the climatological changes described by Marshall and Kushnir, and possibly related to climate change. The changes in the AO at the Earth's surface have been paralleled by a tendency for the high-latitude stratospheric polar vortex to be stronger and colder. The AO in the troposphere is strongly coupled to the strength of the stratospheric polar vortex, and stratospheric circulation anomalies are seen to propagate downward to the Earth's surface, where they are reflected as changes in the magnitude and sign of the AO [Baldwin and Dunkerton, 1999]. Since the AO modulates the circulation of the northern troposphere, and even influences low latitudes, such as the strength of the trade winds across the subtropical and tropical Atlantic, intra-seasonal changes in the stratospheric circulation are observed to precede both high-latitude and low latitude Atlantic climate anomalies and significant weather events. On longer timescales, modeling work by Shindell *et al.* [1999] has shown that increasing greenhouse gases, which may be expected to cause a cooling and strengthening of the stratospheric polar vortex, may be linked to a trend toward a positive AO index, with hemispheric implications for surface climate. Also, the phase of the NAO (or AO) may influence the formation and intensity of hurricanes, and NAO-related statistics are used in seasonal hurricane formation¹.

Wallace [2000] noted that the AO paradigm transcends geographic and programmatic classifications, and therefore serves as a cross-cutting theme of interest to the climate prediction, Arctic, stratospheric, anthropogenic climate change, and atmospheric dynamics communities. The AO does not fall entirely within CLIVAR or SPARC, but it provides a framework in which possible significant advances in our understanding of climate variability may be made.

Spatial structure of the AO

Baldwin and Dunkerton [1999] expanded on the AO paradigm of Thompson and Wallace [1998], but calculated the leading mode as the first EOF from a single field consisting of geopotential at five levels (1000, 300, 100, 30, 10hPa), in order to study coupling of the stratosphere and troposphere. Their reasoning was that the leading mode of the lowest 30km of the atmosphere would better capture the relationship between the stratosphere and troposphere. Remarkably, their results were very similar to Thompson and Wallace, who used only the 1000hPa level. Figure 1 illustrates the signatures of the leading mode at nine levels, including the five levels used to define the AO. Each panel is calculated by a regression between the December-February AO index (the principal component time series from the EOF calculation) and geopotential. The panels are contoured in meters per standard deviation of AO index. The signature of the AO at 1000hPa, with the exception of the Pacific region, is nearly identical to SLP projected onto the NAO index (compare with Figure 2.1 of the Atlantic Climate Variability Prospectus²).

The 500hPa panel again captures the same mode as Thompson and Wallace [1998], with one center of action over southern Greenland opposing a broad mid-latitude band. Figure 3a from Baldwin *et al.* [1994] illustrates that the 500hPa pattern resulting from singular value decomposition (SVD) between 50 and 500hPa is essentially similar to that shown in Figure 1 or that shown by Thompson and Wallace. In the stratosphere, the 50hPa pattern is much simpler and is dominated by a center of action displaced slightly off the pole toward Greenland, with a nearly zonally symmetric ring in mid-latitudes. As with the 500hPa pattern, the 50hPa pattern is nearly the same as either the SVD mode of Baldwin *et al.* [1994] or the AO signa-

ture of Thompson and Wallace [1998]. The 10hPa panel shows a pattern centered nearly over the pole, but with less zonal symmetry in mid-latitudes, featuring an opposing center of action over the eastern Pacific.

The above comparisons demonstrate that the AO pattern is extraordinarily robust, in that it may be recovered using a variety of data levels and techniques, and it is not sensitive to the number of months included in the winter season. Other than the seasonal cycle, the AO is the largest mode of variability in the extratropical northern troposphere-stratosphere.

Advantages of the AO Paradigm

Climate variability in the extratropical Atlantic region has been viewed largely through the paradigm of the NAO. The NAO may be described as "a large-scale see-saw in atmospheric mass between the subtropical high located near the Azores and sub-polar low near Iceland³," and its influences are typically illustrated to extend from the east coast of the United States through Europe, and from the Tropical Atlantic through the North Atlantic to the Arctic. Fluctuations in the NAO index are associated with dramatic shifts in weather patterns over the Atlantic basin, and especially over Europe. Winds, storm tracks, rainfall, temperature, ocean circulation, fisheries, and related human impacts are all modulated by the phase of the NAO. Any predictability of the NAO would have immediate application and benefit over the entire Atlantic region.

The temporal variation of the NAO is often defined by an index of normalised, time-averaged pressure differences between stations representing its two centers of action, such as the Azores and Iceland. There is a key advantage to such a definition - the existing weather records allow the NAO index to be extended back in time to at least 1864⁴. Further, by extending such an index through the use of paleo climate indicators such as tree rings⁵ and ocean sediments, proxies for the NAO and the tropical North Atlantic can be extended back several hundred years [e.g., Black *et al.*, 1999]. These indices show that the NAO is apparently robust and has existed for hundreds of years. When the NAO index is correlated or regressed with gridded surface pressure data, the resulting north-south dipole pattern defines the spatial pattern of the NAO.

1 - <http://typhoon.atmos.colostate.edu/forecasts/1999/aug99/index.html>

2 - http://www.ldeo.columbia.edu/~visbeck/acve/report/acve_report.html

3 - The North Atlantic Oscillation, brochure produced by Lamont-Doherty Earth Observatory of Columbia University, 1999. <http://www.ldeo.columbia.edu/NAO/>

4 - http://www.cgd.ucar.edu/cas/climind/nao_winter.html

5 - <http://www.ldeo.columbia.edu/~cullen/Indices.html>

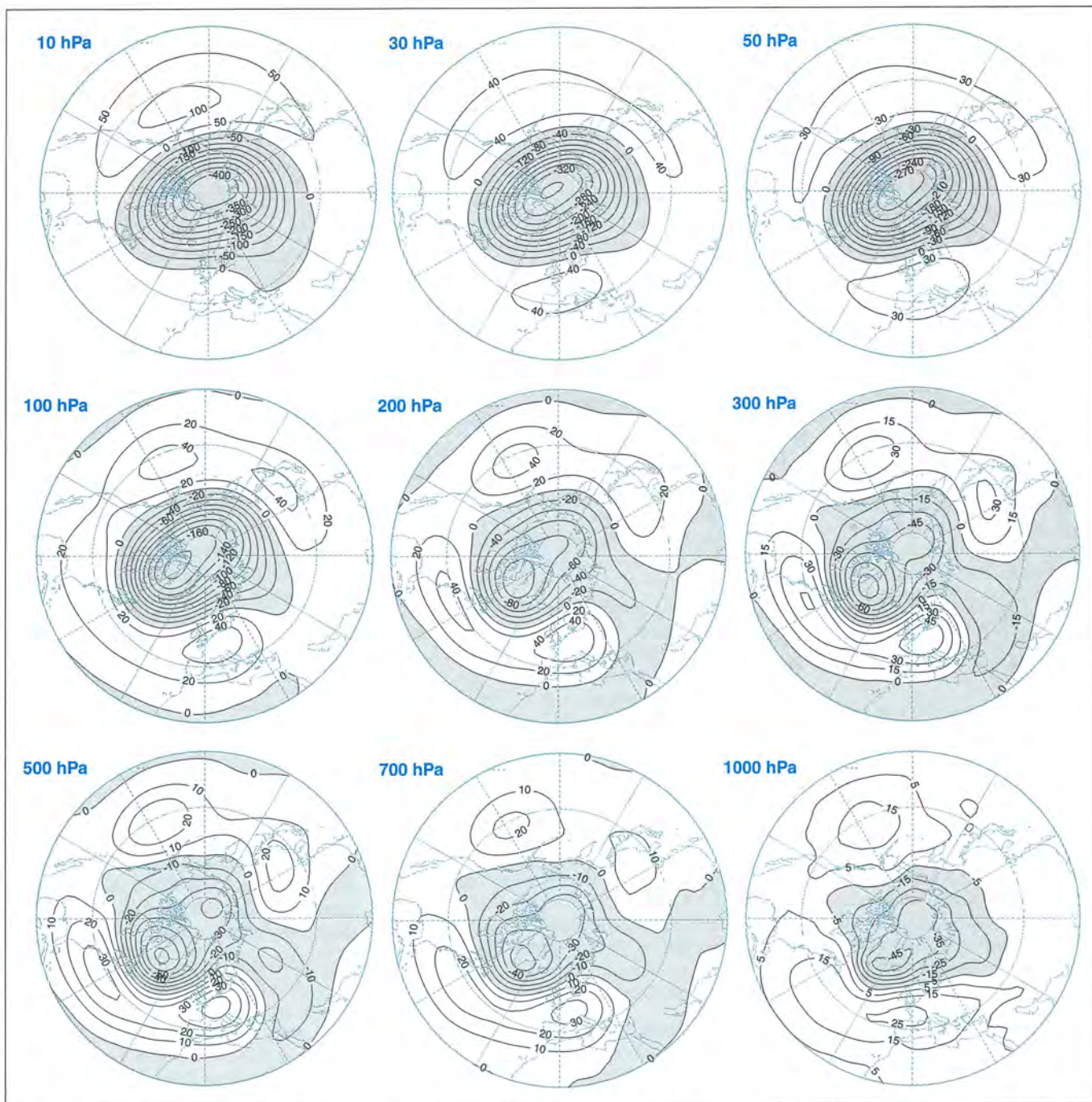


Figure 1. Spatial signatures of the Arctic Oscillation at 10, 30, 50, 100, 200, 300, 500, 700, and 1000hPa. Each panel is produced by regressing the AO index (the time series of the first EOF of geopotential in the 1000–10hPa layer) with geopotential. Contour values are meters, corresponding to a one standard deviation anomaly in the AO Index. The contour interval of the 1000hPa panel is $\pm 5, \pm 15, \dots$ for ease of comparison with Thompson and Wallace [1998]. The 1000hPa panel is very similar to the NAO pattern produced by J. Hurrell (e.g., http://www.ldeo.columbia.edu/~visbeck/acve/report/acve_report.html).

Reliance on only two stations necessitates time-averaging of the data, at least by month and more typically by season. Short-period fluctuations cannot be captured by such an index. Such station-based indices are not very well suited to representing the time-dependent behavior of the NAO [Wallace, 2000]. The spatial pattern of the NAO is very robust and is somewhat insensitive to the details of the index used, so that different time series can produce regression maps in

surface pressure that are nearly identical [e.g. Hall and Visbeck, 2000¹]. This is an important consideration, as it allows a variety of indices to be used to define the spatial structure of the NAO, but it results in uncertainty in interpreting the physical meaning of the indices. A second consideration is that the spatial scale of the NAO is defined, and in effect limited, by the choice of index – the patterns will tend to be localised by the choice of stations.

Wallace [2000] carefully and eloquently explained that the AO and NAO represent a single phenomenon viewed through two paradigms. Wallace showed that the original definition of the NAO [Walker and Bliss, 1932], which is based on a linear combination of data from seven stations, defines a pattern nearly identical to the AO¹. Wallace also demonstrated that the time series of the AO and that of Walker and Bliss's original NAO index display an astounding correlation of 0.99. The AO/annular mode may be thought of as the leading wintertime low-frequency mode

1 - Preprint available: http://rainbow.ldeo.columbia.edu/climategroup/papers/ann_modes_preprint.pdf.

of variability of SLP, while the NAO is the leading mode in the Atlantic basin. Remarkably, maps of the two modes in the Atlantic region are nearly indistinguishable (but their respective indices are different).

None of the names NAO, AO, or northern annular mode, are really adequate to describe the leading mode of variability of the Northern Hemisphere. It is sometimes pointed out that this mode is not confined to the North Atlantic or the Arctic, and that it does not oscillate, at least in the sense of a linear oscillator. Also, the mode is not zonally symmetric, especially in the troposphere, so it is not really annular. Indeed, some authors prefer to avoid all these names, employing terms such as "leading mode" or "leading coupled variability mode" [e.g., Perlwitz *et al.*, 2000].

One key advantage of the AO/annular mode paradigm is conceptual. The AO may be thought of as a "free mode" of the northern troposphere [D. Hartmann, personal communication, 1999] that can be excited by a variety of sources. It may be thought of as a deep, hemispheric mode, with maximum variance over the North Atlantic, corresponding to the NAO centers of action. It is not surprising that such a free mode could act to connect widely separated areas of the troposphere (as opposed to "teleconnecting" specific regions). It is also natural to explore the existence of such a mode in the Southern Hemisphere [Thompson and Wallace, 2000]. Indeed, such "annular modes" are seen in zonal-mean zonal wind in numerical models; their existence does not depend on the Atlantic Ocean, or any ocean at all. In the case of the Earth's Northern Hemisphere, land-sea contrasts (especially warm Atlantic Ocean extending to high northern latitudes [Wallace, 2000]) and mountain ranges produce the mode that we observe.

The concept of the AO superseding or coexisting with the NAO may cause some friction with programs and research focused around the NAO, but this need not be the case. The AO/annular mode paradigm, rather than diminishing the importance of the Atlantic region, inevitably leads to the conclusion that the Atlantic effects are more far-reaching and significant than previously thought. It is the Atlantic region that is profoundly linked to the leading mode of variability of the entire hemisphere.

Thompson and Wallace [personal communication, 1999] projected the surface AO signature map onto daily surface data to obtain a daily AO index. They confined their study to January–March,

when the tropospheric and stratospheric circulations are coupled. They showed that the AO affects the frequency of occurrence of weather events such as blocking, cold air outbreaks, and high wind events throughout the Northern Hemisphere, including North America, Europe, and eastern Asia. They then selected high and low index days and examined a variety of weather events. Even in the Pacific Northwest, well outside the Atlantic basin (and not in a region highly correlated with the AO), they found that the AO index had a significant (at the 99% confidence limit) influence on weather events such as snow in Seattle (favored during low AO index days) and snow in the Cascade Mountains east of Seattle (favored during high AO index days).

Connection to the stratosphere

A strong link between the leading mode in the troposphere and the strength of the stratospheric circulation was shown in Kodera *et al.* [1991], Baldwin *et al.* [1994], and Perlwitz and Graf [1995]. In their white paper on Atlantic Climate Variability, Marshall and Kushnir noted that these studies demonstrated a strong statistical connection between the strength of the stratospheric cyclonic winter vortex and the tropospheric circulation over the North Atlantic. During winters of an anomalously strong stratospheric polar vortex, the NAO (or AO) tends to be in a positive phase with enhanced westerlies across the Atlantic, perhaps associated with changes in vertically propagating planetary waves. The strong vertical coupling may be largely due to the influence of the zonal-mean flow on vertically-propagating planetary waves. Another idea, suggested by Thompson and Wallace [1998] is the vertical coupling is accomplished, not by any particular planetary wave pattern, but by the zonally symmetric component of the flow itself, by interacting with whatever planetary waves happen to be present at the time. By thinking in terms of robust, dominant, hemispheric modes of variability, other fundamental connections to climate variability and the upper atmosphere have been made. Thompson and Wallace [1998] showed that the AO is, to date, the best measure of coupling of the tropospheric circulation to that of the stratosphere.

1 - An occasional criticism of the AO paradigm is that the mode depends on a EOF calculation. The comparison with Walker's original NAO definition demonstrates the EOFs are not necessary to calculate the NAO or AO. Wallace [2000] speculates that Sir Gilbert Walker would have discovered the AO if hemisphere data had been available to him.

The AO index (the principal component time series) is defined only during the time period used in the EOF calculation, and for Figure 1 is based on December–February 75-day lowpass filtered data. A daily AO index for all seasons can be constructed by letting the spatial patterns in Figure 1 define the AO, then projecting these patterns onto daily data to obtain a unique AO index for each of the 17 data levels. By doing this, it can be seen whether the AO pattern in the stratosphere leads or lags the surface signature. Figure 2 illustrates the resulting time-height cross section of the AO, for 40 years of data from 1000 to 10hPa. The strong vertical coherence in Figure 2 shows that during winter, the stratospheric and tropospheric circulations tend to be coupled. It is also clear that the AO, especially outside the winter season, exists independently of the stratosphere. Figure 2 also demonstrates that large anomalies in the stratospheric circulation tend to propagate downward to the Earth's surface, with an average propagation time of approximately three weeks. The downward propagation is variable, and is not apparent during some winters. The mechanism for downward propagation appears to be a result of wave, mean-flow interaction, but the details are not well understood. The downward propagation of the AO has been documented in a control run of the UKMO Unified GCM [P. McClohrrie, Oxford University, personal communication, 1999].

The tight relationship between sudden stratospheric warmings and the AO is easily seen in Figure 2, wherein all major warmings are marked with a broad red tick, and Canadian warmings have a red "C." Within the stratosphere, the weak vortex during warmings is seen as a negative AO index. The multi-level AO index provides a statistic that allows the warming to be traced all the way to the Earth's surface, in most cases. This view is consistent with synoptic studies of sudden warmings [e.g. Sherhag *et al.*, 1970], which showed that some major warmings began as high as 60km, and progressed downward, in some cases, to the Earth's surface.

In Figure 2 the shift over 40 years from predominantly red to predominantly blue reflects a trend toward positive AO index which has been discussed by Thompson and Wallace [1998] and Thompson *et al.* [2000]. This cooling trend in the stratosphere may be related to the observed warming trend in the troposphere, and could be enhanced by increasing greenhouse gas concentrations. Shindell *et al.*, [1999] used several climate models to demonstrate that a trend in the Arctic Oscillation with increasing greenhouse gasses is captured

only in models that have a well-resolved stratosphere. They concluded that the proper representation of stratospheric dynamics appears to be important to the attribution of climate change. Similarly, the phase of the AO can be affected by explosive tropical volcanic eruptions [Robock and Mao 1992].

The possibility that the quasi-biennial oscillation (QBO) [Baldwin *et al.*, 2000] in the equatorial stratosphere acts to force the AO was discussed by Baldwin and Dunkerton [1999]. It appears that the phase and strength of the AO, especially in the stratosphere, are influenced by the QBO in a manner consistent with the QBO's effect on the strength of the polar vortex. The AO tends to be in its negative phase (weak vortex) when the QBO is easterly.

In a series of papers Kodera and colleagues [e.g., Kodera *et al.*, 2000] have shown that within the stratosphere, anomalies in zonal-mean zonal wind tend to propagate northward and downward during the winter season. The results have been confirmed by numerical experiments in which circulation anomalies begin as high as the lower mesosphere, and move slowly northward and downward, over a period of 2–3 months. The propagation is described well in the phase space of the first two EOFs of zonal-mean zonal wind, which tend to trace out a circular path, especially during sudden warmings. A synoptic interpretation of this process is the development of a sudden warming with a reduction in strength of the polar vortex and downward progression of the warming, sometimes to the Earth's surface. The resulting surface signature of this process, which Kodera calls the Polar Jet Oscillation (PJO), is that of the Arctic Oscillation. The relationship between the AO and the PJO is not clear; in the lower stratosphere one could call the leading mode of variability the AO or the PJO.

Questions and Challenges

The introduction of the Arctic Oscillation has resulted in a flurry of new research and a refocusing of other investigations. With climate impacts potentially as important as ENSO, the AO is not yet well understood. Several fundamental questions remain, and there is active debate as to which paradigm is most useful, and even what name to use.

- The stratospheric connection may yield a measure of predictability of the surface AO, especially at times of major warmings. Can this downward propagation be used to improve medium-range weather forecasts?

- We do not know whether the AO propagates into the troposphere or appears to propagate into the troposphere. It is possible that the tropospheric AO is largely independent of the stratosphere, and when the anomalies align they amplify or reinforce each other. This view is consistent with Hartmann's idea that the AO is a free mode of variability in the troposphere and is forced by the stratosphere.

- How can the polar jet oscillation of the stratosphere be reconciled with the AO in the stratosphere and troposphere? Is it possible to have one unifying explanation?

- Why does the AO in the stratosphere propagate downward, and why doesn't it always happen? Why is the time scale for downward propagation variable (1–5 weeks)? All the information needed to diagnose (or predict) downward propagation is not contained in the zonal mean wind field or the AO index in Figure 2.

- Does the QBO act to force the AO? If so, can the predictability of the QBO be exploited to marginally improve seasonal wintertime forecasts?

- If low-latitude zonal wind anomalies in the upper stratosphere are caused by solar/UV influence, does the PJO/AO mechanism amplify these anomalies and cause them to reach the high-latitude troposphere?

- How well do climate models simulate downward propagation? Do climate models have to have a vertically coherent AO structure? Does the model have to exhibit downward propagation?

- Is the AO fundamentally zonally symmetric (as stated by Thompson and Wallace) or asymmetric?

- Can the downward propagation of the AO be understood through the interaction of waves with the mean flow? Or, is the atmosphere during warmings too disturbed for the concept of waves on a zonal-mean flow?

The SPARC Scientific Steering Group has organized an informal study group on stratosphere-troposphere coupling. The group will at first be based on an e-mail list of interested persons. If you would like to be added to the mailing list, please contact mark@nwra.com.

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Stratospheric Aspects of Climate Forcing

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The SPARC Scientific Steering Group agreed at its session in 1997 that it was important and timely to undertake a review of stratospheric aspects of climate forcing aimed at providing, for the use of the climate modelling community, the current best estimates of relevant forcing parameters. This was partly in response to the requirement identified by the Conference on the World Climate Research Programme in August 1997 to assess "the impact of natural and human-produced aerosols on the climate system", "quantifying and clarifying the impact of the major depletions of ozone in the lower stratosphere", and "examination of effects of natural external forcing, in particular solar variability". This activity would complement the efforts of the WCRP Working Group on Coupled Modelling (WGCM) in reviewing standardized forcing scenarios to be used in transient climate model simulations of the climate of the twentieth century.

The SPARC Working Group was established in early 1998. The people involved in the working group at some stage are listed in Table 1. Its objective has been to provide, to the climate modelling community, the current best estimates of appropriate parameters that determine stratospheric aspects of recent time-varying climate forcing. The approach has been to consolidate existing information and provide estimates of time-varying forcings over the period since about 1880 associated with stratospheric ozone, stratospheric volcanic aerosols and solar variations. This is a brief report on the activities of the Working Group, with the forcing data sets now available from the SPARC Data Center (www.sparc.sunysb.edu).

Ozone

It is clear that the changes in stratospheric ozone over the last twenty years have been an important forcing of climate

change. They have led to significant changes in the temperature in the lower stratosphere and the troposphere. These changes have been reviewed recently by the SPARC Ozone Trends Assessment (Harris *et al.*, 1998) and the WMO/UNEP Ozone Assessment (Bojkov and Hudson, 1999; Chanin and Ramaswamy, 1999).

A global stratospheric ozone trends data set, which makes use of the results from the SPARC Ozone Trends Assessment, has been prepared by Randel and Wu (1999). This provides monthly ozone profile trend estimates above the tropopause for the period 1979-97. SAGE I/II profile trends have been used above 20km outside of the polar regions, and results between the tropopause and 20km were derived by differencing SAGE and TOMS column ozone trends. In polar regions, trends have been derived from ozone sonde data up to 27km, using the near-complete records at Syowa (69°S) and Resolute (75°N). While these polar ozone sonde trends agree well with TOMS outside of polar night, the Arctic data indicate significant ozone losses beginning in midwinter that are not observable in TOMS data. This construction of the ozone profile trends is shown schematically in Fig. 1, together with the zonal mean ozone trends in April and October from Randel and Wu (1999) in Figure 2. The ozone profile trends have been assessed further by Randel *et al.* (1999) and compared with NH midlatitude ozonesonde profiles. These monthly ozone trends are available at 1km vertical resolution and 5 degree latitude resolution, with further details at the SPARC Data Center.

In addition to the recent decreases in stratospheric ozone, there have been significant increases in tropospheric ozone over the last hundred years. While the observational network is sufficient to identify these increases, it is not adequate

to describe the horizontal distribution of these changes in tropospheric ozone. Kiehl *et al.* (1999) have used an atmospheric chemical transport model, together with satellite and ozonesonde data, to produce a hybrid monthly ozone data set from 1870 to 1990 for the troposphere and stratosphere. In the troposphere, the chemical model provides most of the information on the ozone distribution and its changes. In the stratosphere, the ozone trends are very similar to those developed by Randel and Wu (1999). For the data set available through the SPARC Data Center, the Randel and Wu ozone data set in the stratosphere have been merged with the Kiehl *et al.* (1999) data set, to ensure consistency between the two data sets.

Stratospheric volcanic aerosols

Major volcanic eruptions lead to increases in the stratospheric aerosol load, which affect the radiative forcing of climate through scattering and absorption of solar radiation. Direct measurements of stratospheric aerosol optical depth exist only for about the last twenty years with reasonable global coverage through satellite observations. The radiative forcing associated with historic eruptions before the satellite era is more uncertain. Sato *et al.* (1993) estimated aerosol optical depth from ground-based observations over the last century, and this has been used in a number of modelling studies. This estimate has been updated and adjusted recently by Andronova *et al.* (1999).

The eruption of Mt Pinatubo in 1991 caused the most recent major increase in volcanic aerosols. Alan Robock and Georgiy Stenchikov have produced a 2-year stratospheric aerosol data set (June 1991 - May 1993) suitable for use in forcing climate models (Stenchikov *et al.*, 1998). This includes monthly latitude-height information on aerosol optical thickness and size distributions. This Pinatubo aerosol forcing data set has been used for simulations in a number of climate models (Andronova *et al.*, 1999; Bengtsson *et al.*, 1999; Kirchner *et al.*, 1999) and is being used in the Pinatubo Simulation activity of the GCM-Reality Intercomparison Project for SPARC (GRIPS). This involves the comparison of climate model results to learn about the sensitivity of models to the forcing and the robustness of the climate response. Robock and Stenchikov can produce forcing data compatible in both spectral

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L. Poole	NASA Langley Research Center, USA
V. Ramaswamy	NOAA GFDL, USA
W. Randel	NCAR, USA
A. Robock	Rutgers State Univ., USA
S. Solomon	NOAA Aeronomy Lab., USA
G. Stenchikov	Rutgers State Univ., USA

Table 1. Members of the SPARC Working Group

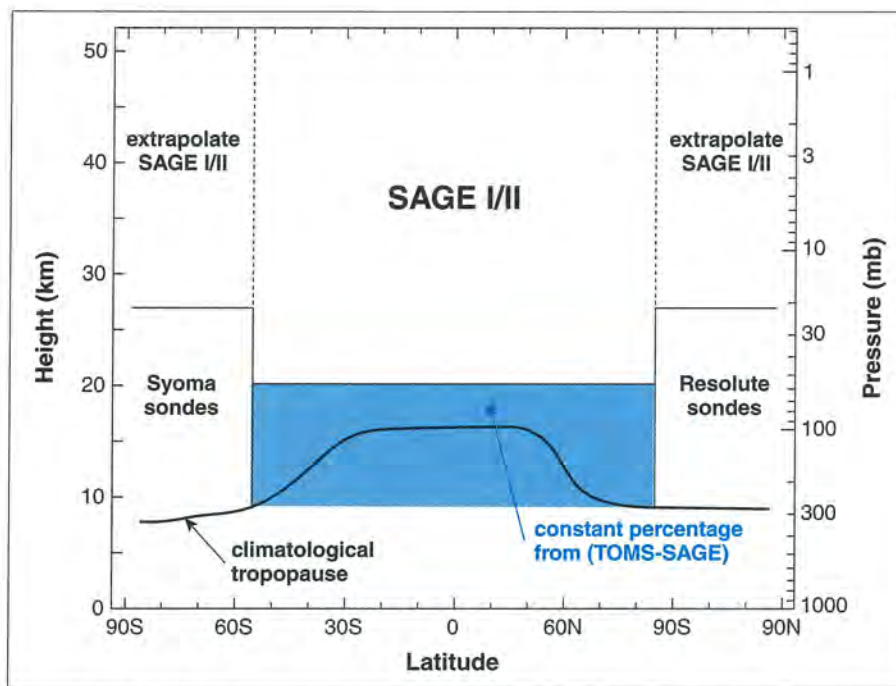


Figure 1. Schematic diagram showing the sources of data for the global ozone trend estimates of Randel and Wu (1999).

and spatial resolution with the climate models that will use them. Further information is available from the SPARC Data Center.

Solar irradiance variations

The variations of total solar irradiance associated with the 11-year sunspot cycle have been assessed with some accuracy using satellite data for more than 20 years. However, measurements of the absolute magnitude of total solar irradiance and of the magnitude of modulations of solar irradiance between solar cycles are less certain due to problems with the absolute calibration of satellite instruments and comparisons between measurements from different instruments.

The estimation of earlier solar irradiance fluctuations is indirect. Several recent reconstructions estimate variations in solar irradiance of about 0.24% to 0.30% on decadal to centennial timescales (Lean *et al.*, 1995; Lean, 1997; Hoyt and Schatten, 1993), compared with a 0.1% modulation during the 11-year solar cycle measured from satellite. The reconstructions of Lean *et al.* (1995) and Hoyt and Schatten (1993), which have been used in climate modelling studies, vary not only in amplitude but also show a considerable phase lag at times. These two estimates of total solar irradiance variations are available from the SPARC Data Center.

Satellite measurements show that there are variations in the solar spectrum, particularly at short wavelengths, during the

11-year solar cycle. These variations in solar UV irradiance during the solar cycle are proportionally much larger than in total solar irradiance. They could affect the photochemistry of ozone in the stratosphere, leading to an indirect climate forcing through changes in the ozone distribution. Lean *et al.* (1997) provides high resolution spectral estimates of solar irradiance from 120 nm to 1000 nm during solar maximum and solar minimum based on satellite measurements. These are available from the SPARC Data Center.

Summary

Recent estimates of parameters relevant to stratospheric aspects of climate forcing have been reviewed and numerical data sets collated at the SPARC Data Center. These include:

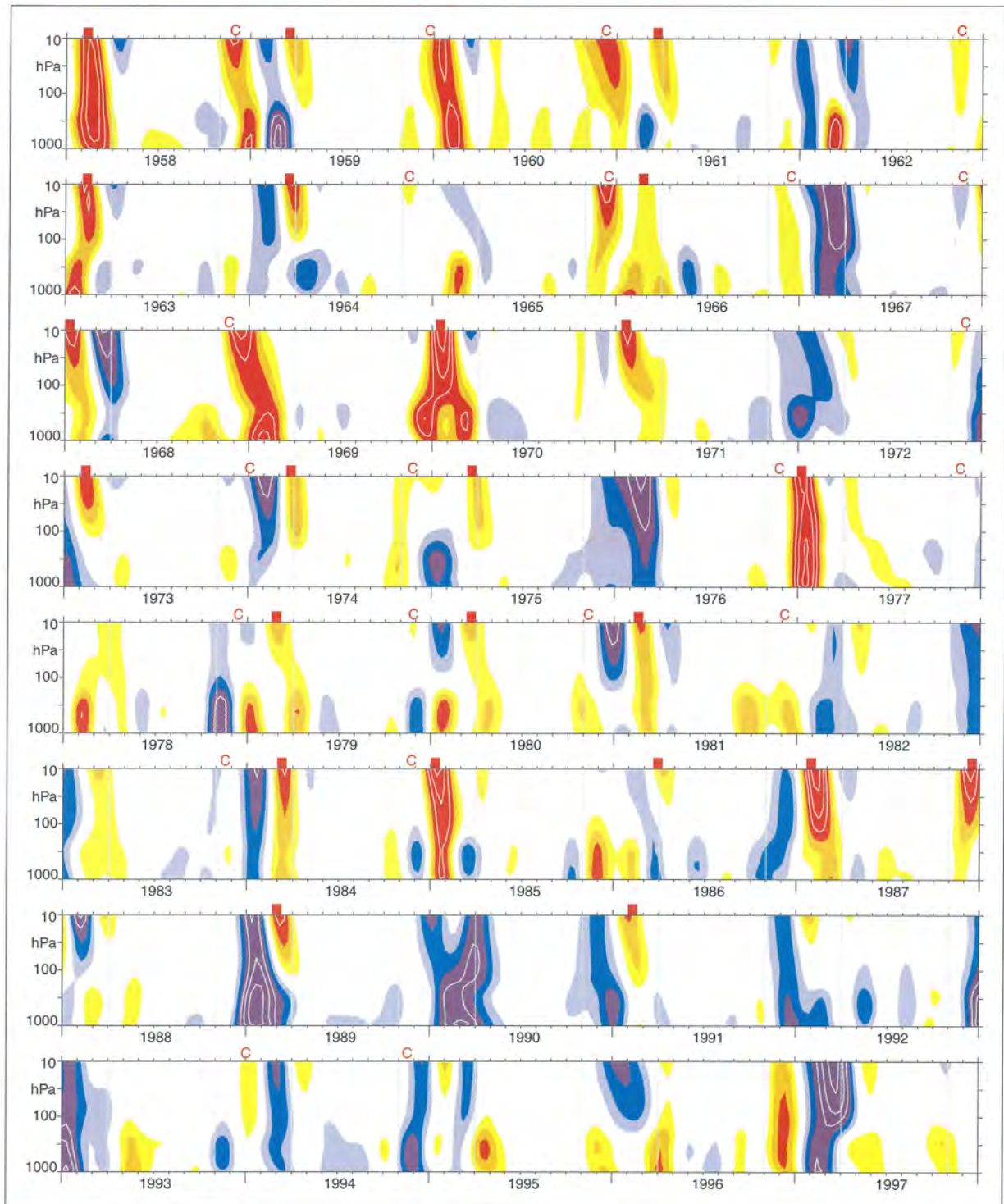
- 1 - changes in the ozone distribution in the stratosphere over 1979-1997,
- 2 - estimated changes in the ozone distribution in the troposphere since 1870,
- 3 - estimated variations in stratospheric volcanic aerosol optical depth since 1850,
- 4 - stratospheric volcanic aerosol distributions during 1991-93 associated with the eruption of Mt Pinatubo,
- 5 - estimated variations in total solar irradiance since 1700, and
- 6 - spectral solar irradiance at solar cycle maximum and minimum.

Further information about these climate forcing data is available in the relevant references below and from the SPARC Data Center.

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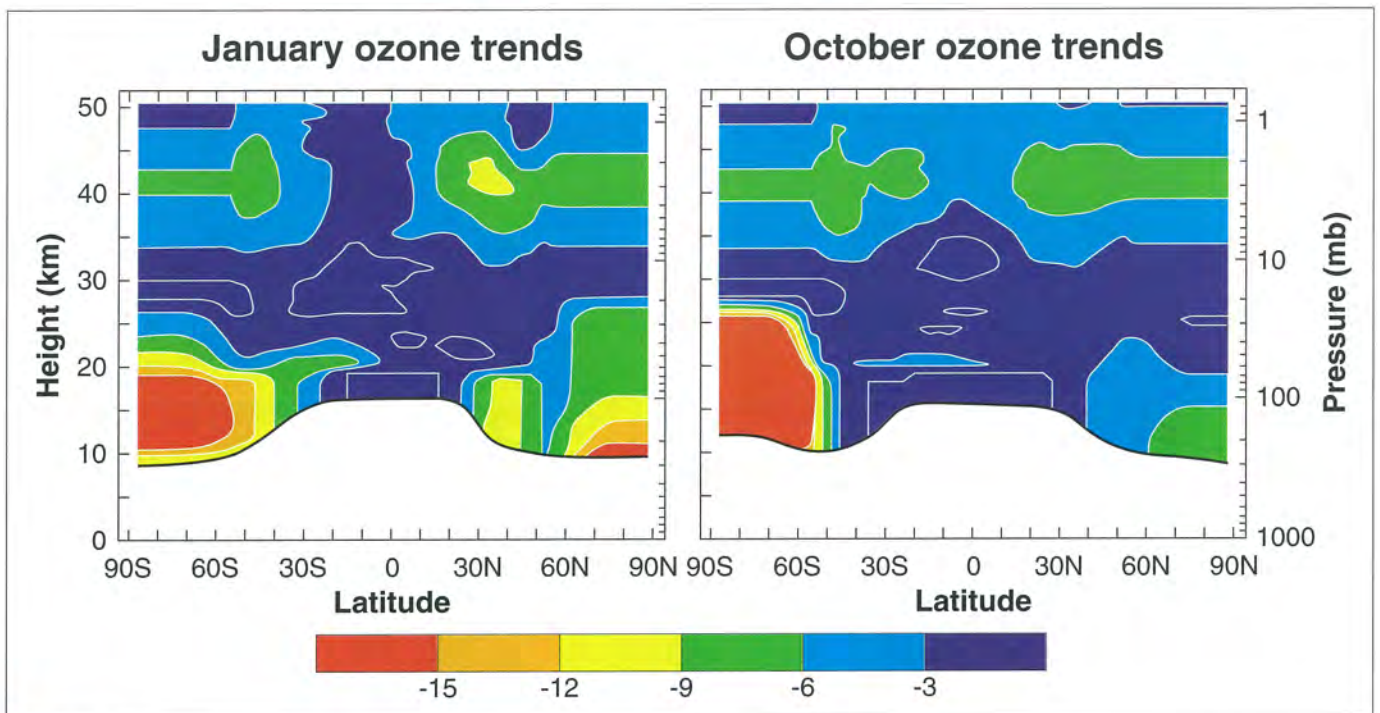
The Arctic Oscillation and its role in stratosphere-troposphere coupling



▲ **Figure 2**

Time-height cross-section of the Arctic Oscillation, 1958-1997. The Arctic Oscillation is defined as the leading EOF of Northern Hemisphere 75-day low pass filtered geopotential anomalies in the 1000-10hPa layer. The EOF defines a spatial pattern of geopotential anomalies at each level from 1000 to 10hPa. The diagram shows a nondimensional measure of the magnitude of the patterns in Figure 1 as a function of height and time, in 75-day lowpass filtered data. Blue corresponds to a strong, cold polar vortex, while red indicates a warm, weak polar vortex. Red ticks indicate all major stratospheric warmings, while each red "C" indicates a less severe "Canadian" warming. The diagram illustrates that the characteristic Arctic Oscillation pattern in the middle stratosphere tends to occur before the corresponding pattern in the troposphere, with a variable downward propagation time averaging about three weeks. The downward propagation occurs for either positive or negative anomalies, but does not always occur.

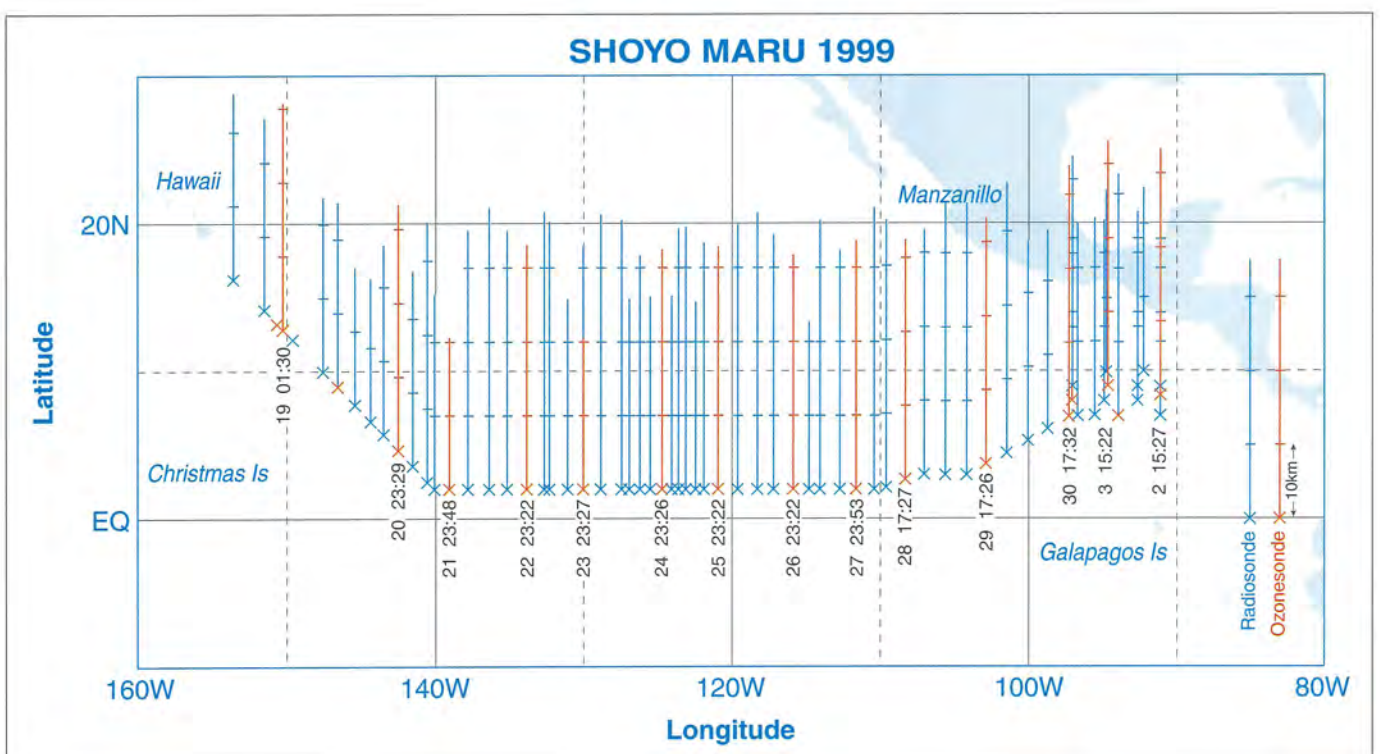
Stratospheric Aspects of Climate Forcing



▲ Figure 2

Global ozone trends for January (left) and October (right), shown in units of percent per decade, from Randel and Wu (1999). The local 95% statistical significance levels are trends on the order of 3-5% per decade.

SOWER/Pacific - the Shoyo-maru Pacific Ocean-Atmospheric Survey



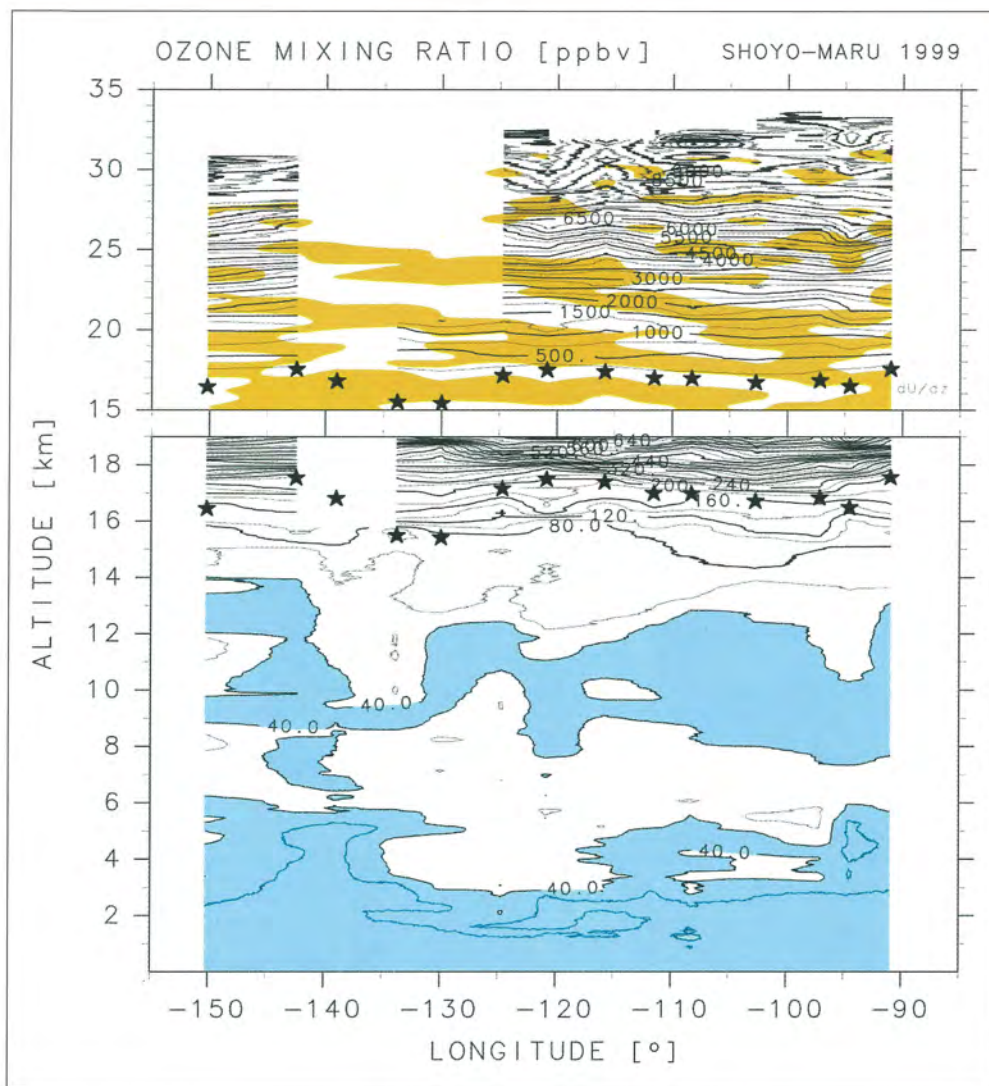


Figure 2

Longitude-altitude distributions of ozone mixing ratio between 15km and 35km (top) and between surface and 19km (bottom) obtained from the SHOYO MARU 1999 cruise. The contour intervals are 250ppbv for the top panel and 20ppbv for the bottom panel. The tropopause positions defined by the temperature minimum for each sounding are indicated by stars in both panels. The coloured regions in the top panel correspond to those of positive vertical gradient of zonal wind, and those in the bottom panel correspond to those of less than 40ppbv.

Figure 3

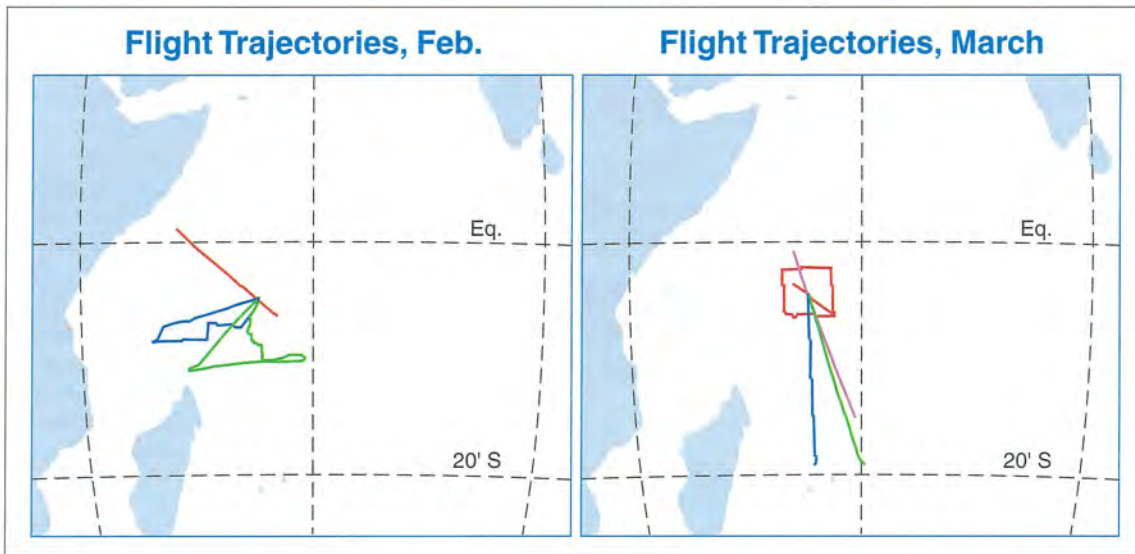
Preparation of a GPS-radiosonde launch which has been conducted within a U-shaped windscreen made of strong vinyl sheet in the backside of the observation deck of the Shoyo-maru.



Figure 1

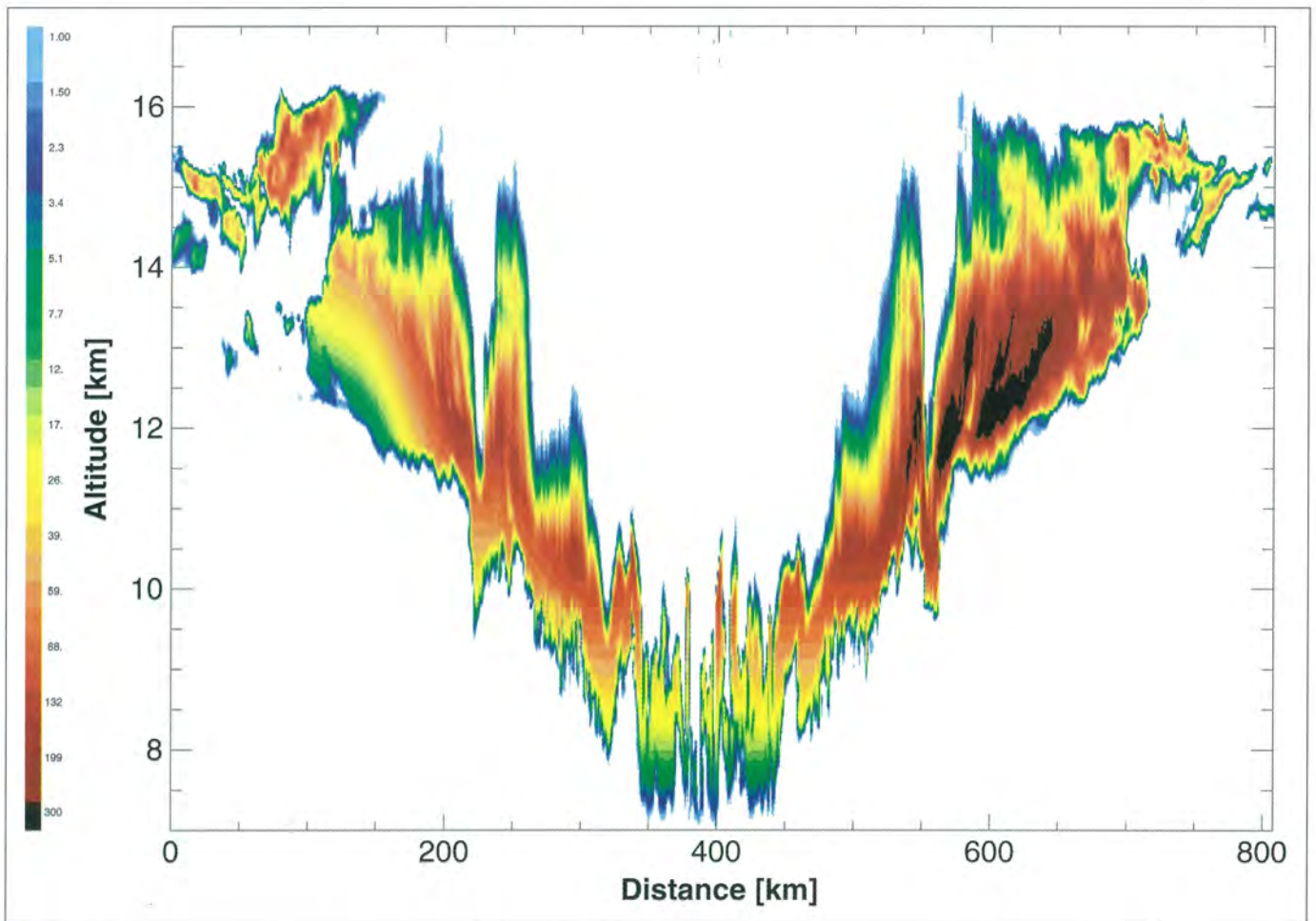
Observation points of GPS radiosondes and ozonesondes with ceiling altitude indicated by blue bars (radiosonde) and red bars (ozonesonde).

APE-THESEO: Clouds, dehydration, and transport at the tropical tropopause



▲ **Figure 1**

Flight paths of the Geophysica during APE-THESEO. Falcon flight paths are very similar, but the Geophysica flight of 4th March was flown alone.



▲ **Figure 5**

OLEX lidar data for the sortie on 9 March 1999, into the cyclone, "Davina". The base of the anvil cirrus descends from 14km to 7km over the 400km traverse of the system. When at the mid-point of the traverse (400km on the x-axis scale in the figure), the Falcon's radar recorded a concave wall of cumulonimbus around the aircraft, although no convection was encountered en route to the mid-point.

SOWER/Pacific the Shoyo-maru Pacific Ocean-Atmospheric Survey

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Introduction

The Soundings of Ozone and Water in the Equatorial Region (SOWER)/Pacific mission has been conducted on a campaign basis at San Cristobal, Galapagos and Christmas Island, Republic of Kiribati supplementing the on-going program in Watukosek, Indonesia (SPARC Newsletter No. 10 and 12). During September to October 1999, we were given the opportunity to join the ship cruise of Shoyo-maru, a research vessel of Fisheries Agency of Japan, investigating the fishery resources in the central and eastern tropical Pacific. This is a brief report on the scientific results from the atmospheric research group.

The scientific target of this cruise widely spreads from ocean and atmospheric sciences and from their dynamics and chemistry. In this report a general overview of the Shoyo-maru survey will be described.

The main fields of interest are as follows:
1 - Ozone distribution in the troposphere and stratosphere

2 - Atmosphere-ocean dynamical coupling associated with the tropical instability waves

3 - Marine boundary layer chemistry

We have made regular GPS radiosonde observations four times a day and ozone-sonde observations once a day. The geographical locations of the sonde release together with the ceiling altitude are displayed in Figure 1; you may see the cruise track from this figure. In addition, several types of on-board observations about such as surface ozone, radiation, air and water samples were made along this track.

Corresponding to this cruise, at the two SOWER bases, San Cristobal (the Galapagos Islands) and Christmas Island (see Figure 1), other SOWER team members also performed usual campaign observations.

The following is a description of each scientific field of the research.

Ozonesonde sounding

A VAISALA ozonesonde system (a Science Pump ECC ozonesonde

connected with a VAISALA GPS radiosonde) was used for measuring the vertical distributions of ozone and meteorological parameters. Figure 2 summarises the results of ozonesonde observations in longitude-altitude panels. There are 14 successful soundings between 19 September and 3 October.

In the equatorial stratosphere the quasi-biennial oscillation (QBO) is one of the remarkable phenomena. During our cruise an altitude of 25km was nearly the boundary of westerly (lower) and easterly (upper) phases of QBO. As a source of momentum equatorial waves and gravity waves are supposed to play a central role in driving the QBO. However, studies of such waves are rather limited to the western Pacific region. Our soundings of meteorological variables over the central-eastern Pacific will contribute to the investigation of the global wave activities.

In the upper troposphere, above 12km, the average ozone concentration was about 60ppbv with a positive vertical gradient (the bottom panel of Figure 2). These characteristics are not common to those in Indonesia during the December-March period where the concentration is nearly constant at 25ppbv throughout the troposphere, but is consistent with the results in Brazil, over Atlantic Ocean, and in Congo (Fujiwara *et al.*, 1999b). This would be explained primarily by the longitudinal dependence of convective activity which transports ozone-deficit air mass in non-biomass-burning season and by that of ozone-rich air mass transport from the stratosphere.

Fujiwara *et al.* (1998) investigated a case of the upper tropospheric ozone enhancement by intensive observation with ozonesondes and radiosondes in Indonesia, and concluded that the equatorial Kelvin waves around the tropopause took part in the ozone transport from the tropical stratosphere. The Shoyo-maru 1999 result shows ozone variations near the tropopause probably related to the equatorial wave activity (the bottom panel of Figure 2). In relation to these variations, we observed about 5K change of the tropopause temperature.

In the troposphere the ozone concentration was about 40ppbv on average but had large variability especially in the vertical direction. As in Figure 2, we usually see layered structure in ozone and humidity profiles. Low (high) relative humidity corresponds to high (low) ozone concentration in several kilometre down to several-hundred-meter vertical scales. Because the ozone mixing ratio of more than 40ppbv could be interpreted as a mid-latitude origin or a biomass-burning origin (cf. Fujiwara *et al.*, 1999a; Fujiwara *et al.*, 1999b), the tropical troposphere over the cruise should be viewed as the pile of atmospheric layers originated from either the inter-tropical convergence zone (wet and low ozone) or the mid-latitudes (dry and high ozone) (cf. Johnson *et al.*, 1999).

Atmosphere-ocean dynamical coupling

In the eastern tropical Pacific, from June to December, the strong SST front develops along about 2°N due to the equatorial upwelling. The SST front meanders meridionally with the typical zonal wavelength of 1000km and a period of 20-30 days. It propagates westward with the phase speed of about 0.4m/s. The meridional displacement of the SST front is about 5 degrees. Since Legeckis (1977) first discovered the wave from satellite infrared images, many studies have been done on this phenomenon to show that it is caused by the ocean dynamical instability (Philander, 1976; Cox, 1980). It is now called Tropical Instability Waves (TIWs).

Although TIWs are oceanic waves, it may affect the atmosphere above through the strong influence on SST spatial pattern. We examined the relation between the surface wind and the SST perturbations using the satellite scatterometer data, showing that surface wind convergence has relation with the SST perturbation (Xie *et al.*, 1998). Our additional numerical experiment using the AGCM (Xie *et al.*, 1998) showed the result consistent with the satellite data analysis. This surface wind convergence may carry the

vapour in the MBL to the upper layer, and hence affect the cloudiness over the TIWs.

Because the SST variation related to the TIWs is largest along 2°N, cruising latitude was chosen exactly on it. The vertical structure of the atmosphere was observed by radio sondes over TIWs. With our cruise from 140°W to 110°W, we crossed 2.5 wavelengths of this SST waves making sonde observations at the rates of 4 times a day in usual and 8 times a day in an intensive period with the cruising speed of about 6 m/sec.

From the sonde data, we can see that the influence of TIWs on the atmosphere appears mostly in temperature and relative humidity at the MBL top. It is related to the vertical displacement of an inverse layer; the existence of this layer is characteristic of the lower atmosphere in the eastern equatorial Pacific. We are analysing the results of the observation further.

Marine boundary layer chemistry

In the marine boundary layer (MBL), halogen atoms derived from biogenic halocarbons in the ocean as well as sea-salt particles may be of considerable importance in controlling the ozone distribution (e.g., Dickerson *et al.*, 1999). Biomass burning has been suggested to be another controlling factor of the

ozone-mixing ratio over the eastern equatorial Pacific (Schultz *et al.*, 1999).

To investigate the distributions of halo-carbons in the equatorial Pacific, sea water samples were collected. Air samples were also collected to determine the concentration of non-methane hydrocarbons and their isotopic compositions which may be valuable tracers of continental airmass. Detailed studies are being conducted for better understanding of ozone and halogen chemistry in the MBL. Along the course of these studies, concentrations of surface ozone and NO_x simultaneously measured on the ship will be used.

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APE-THESEO: Clouds, dehydration, and transport at the tropical tropopause

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Introduction

APE-THESEO, the contribution of the Airborne Platform for Earth observation to the Third European Stratospheric Experiment on Ozone (THESEO), was performed from the island of Mahé in the Seychelles (4°S, 55° 30'E) in February and March 1999. The mission was the primary tropical component of the European Commission's THESEO programme, which aims to understand

the processes affecting stratospheric ozone, particularly its decline over the middle latitudes in the last two decades. APE-THESEO contributes to THESEO by studying the way in which the composition of air changes as it moves from troposphere to stratosphere.

Two aircraft were used in APE-THESEO: the M-55 Geophysica high-altitude research aircraft and the DLR Falcon, which is an executive jet

converted to research use. The mission's objectives and goals were to study the transport, chemistry, and cloud physics of the tropopause region (MacKenzie *et al.*, 1999). An important secondary objective was to provide top-of-troposphere measurements for INDOEX, the Indian Ocean Experiment, which focused on the direct and indirect aerosol effects on climate. In this article we describe general aspects of the tropopause region during the mission.

Readers of the SPARC Newsletter do not need to be reminded of the general arguments for making measurements at the tropical tropopause: see, for instance, the articles by Kley and Russell (1999), and Reid (1998). The particular rationale for using aircraft in APE-THESEO was to study tropical processes with greater spatial resolution than possible from space, and with the ability to fly to areas of interest, which is not possible using balloons. Both of these considerations turned out to be important.

The payloads, described in more detail below, were selected to measure particles, long-lived trace gases, water vapour, ozone, and radiative fluxes. Particular care was taken to have redundancy in measurements of the key species, water vapour and ozone. We are now in the process of careful cross-validation and analysis of all the data, but some preliminary results are already becoming clear.

Instrumentation

The instrument payload for the Geophysica is given in Table 1. The Falcon was equipped with the OLEX ozone-and-aerosol lidar system. Given the relative youth of most instruments, data capture was very good. Flying in the tropics is one of the most stringent tests of instrument reliability. Temperatures at the surface are above 30°C, with humidities near 100 % (≈ 45 mbar); whilst, at the tropopause, temperatures are less than -80°C and water vapour pressures are extremely small ($\approx 10^{-4}$ mbar). Several instruments experienced problems with frosting on optical parts, or other faults

related to environmental stress, but only the two COPAS instruments, the newest instruments on board, gave no data.

Flight paths and flight strategies

The flights performed are shown in Figure 1. Six of the seven Geophysica flights were conducted in tandem with the Falcon. The real-time data display on board the Falcon enabled the Falcon to path-find for the Geophysica, as demonstrated first in APE-POLECAT (Stefanutti *et al.*, 1999). A "Hauptexperimentator" for each sortie was chosen to travel on the Falcon. Armed with the latest Meteosat-5 images, forecast data from the UK Meteorological Office, and the real-time lidar display, the Hauptexperimentator passed instructions to the pilot of the Geophysica via the Falcon's pilots. Only with this level of support was the Geophysica pilot able to intercept the tenuous cloud features that are described below. Amongst the manoeuvres performed were quasi-Lagrangian flight-legs in sub-visible cirrus (cf. Peter *et al.*, 1999). We believe that this is the first time that sub-visible cirrus has been sampled in this way. Quasi-Lagrangian flight-legs take instruments along a path similar to that followed by the cloud particles, and so provide observational data that is more readily comparable with model output. This airborne guidance operation also enabled the Geophysica to 'step' through shallow cloud features, taking horizontal measurements every 200 m in altitude, and enabled the Geophysica to fly safely into the centre of cyclone "Davina".

Temperature and water vapour structure

The mean and extreme vertical profiles of temperature and saturated water vapour mixing ratio are shown in Figure 2. Minimum temperatures near -90°C were measured, at heights around 18 km. At these altitudes, air at such cold temperatures has a saturated water vapour mixing ratio of 1-2 ppmv. The water vapour measurements made during APE-THESEO show that such dry air was indeed present (Figure 3). The likely sources of dry air at the tropical tropopause are: (1) slow upwelling that dries air through large-scale sub-visible cirrus formation (Newell and Gould-Stewart, 1981); (2) convective overturning in cirrus anvils (Danielson, 1982); or (3) drying by gravity-wave-induced cirrus clouds (Potter and Holton, 1995). Analysis of infrared Meteosat-5 images has established that local convection did not penetrate the tropopause where these low water vapour mixing ratios were measured, so the cause of the dryness must be sought elsewhere. One obvious possibility is recent drying in intense convection, or large-scale cirrus, upwind (i.e. east) of the measurements. We are studying radiosonde data from across the Indian Ocean, as well as trace gas measurements made on board Geophysica, to identify the source(s) of air to the tropopause region of the western Indian Ocean during this period.

Clouds

As explained above, installing the Hauptexperimentator on the Falcon provided the opportunity for very closely coordinated flights of the Falcon and Geophysica. In particular, the Geophysica was guided to the precise altitudes of extremely shallow layers of cirrus (Figure 4). The existence of the shallow layer shown in figure 4 is verified by independent measurements using the OLEX lidar. Using cloud-top brightness temperatures from Meteosat-5, which was re-positioned over the Indian Ocean as part of INDOEX, and which provided valuable half-hourly data to APE-THESEO, it is clear that convection in the region of the Seychelles reached only 16 km or less for most of the mission. The cirrus observed at 17 km and above cannot, therefore, be outflow from an existing convective system. It is possible that, like in the case of the cold, dry air, these cirrus layers are the remnants of vigorous convection upwind. On the flight to "Davina" on the 9 March 1999, data from the OLEX lidar shows one of these ultra-thin clouds apparently connected to a cirrus anvil. It is also possible that the cirrus is formed on the

Investigator	Acronym	Description
Fiocco	ABLE	zenith/nadir millijoule lidar, 532nm
Mitev	MAL	zenith microjoule lidar, 532nm
Adriani	MAS	side-looking scatterometer, 532nm
Ström	CVI	counterflow impactor inlet and Lyman- α spectrometer for condensed water.
Mazzinghi	CVI-TDL	tunable diode laser for water and HNO ₃ , with CVI inlet.
Borrmann	COPAS	condensation nuclei counter. One connected to the CVI inlet, one sampling ambient air.
Borrmann	FSSP	particle size-spectrometer.
Khattatov	SORAD	integrating pyranometer.
Giovanelli	GASCOD	DOAS and spectral radiometer.
Yushkov	FLASH	Lyman- α water vapour.
Schiller	FISH	Lyman- α water vapour.
Mezrin	ACH	frost-point hygrometer.
Yushkov Ravegnani	FOZAN	solid-phase Chemiluminescence for ozone.
Rudakov	ECOC	electrochemical cell for ozone.
Volk	HAGAR	gas chromatograph for N ₂ O, F12, F11, H 1211, and SF ₆ IR-Analyzer for CO ₂

Table 1: Instrument payload for the Geophysica during APE-THESEO.

crests of gravity waves produced by local convection. There is evidence for gravity-wave-induced clouds from the Meteosat-5 images (Santacesaria *et al.*, 1999), but these may not account for the thinnest clouds that were detected by the lidars. These ultra-thin clouds extend horizontally for hundreds of kilometres, but extend vertically only a few hundred metres. It seems unlikely that the atmosphere remains at saturation relative to water ice over these vast distances, and in the presence of intense, wave-inducing, tropical convection, so we speculate that the composition of these ultra-thin cloud layers is not pure water ice (Luo *et al.*, 1999). From even these early stages of the analysis, it seems clear that the variety of tropical tropopause clouds is greater than hitherto assumed. The implications of this for water vapour transport, and for upper-troposphere/lower-stratosphere chemistry are intriguing (e.g. Borrmann *et al.*, 1996).

Cyclone "Davina"

On 9 March 1999, the Falcon and the Geophysica intercepted the ageing cyclone "Davina". Although ageing, Davina was still responsible for considerable damage and the closure of the airport when it struck Mauritius the next day. On the 9th, the Falcon penetrated deep into the cyclone. At one point the on-board radar and lidar recorded a concave wall of cloud in front of the aircraft, and a steep decrease in the altitude of the cirrus anvil above (Figure 5). From this point deep in the cyclone, the Falcon guided the Geophysica through the anvil. The Geophysica also performed a vertical profile at the point nearest the cyclone centre. Data from the in situ profiling shows a local ozone minimum at the tropopause, indicative of vigorous convection from a clean marine boundary layer. The implications of the radar, lidar, and in-situ measurements for anvil cloud formation and cyclone dynamics are being studied.

Final Remarks

APE-THESEO is the second scientific mission, outside of Russia, of the Geophysica aircraft. We have again demonstrated the significant added value to be got from using a high-altitude platform, such as the Geophysica, with a pathfinder aircraft, such as the Falcon. A great deal of data has been collected: (1) on the structure of the tropical tropopause far from local sources of tropopause-breaking convection; (2) and on the existence of ultra-thin cirrus clouds far above, or far from, cumulonimbus anvils.

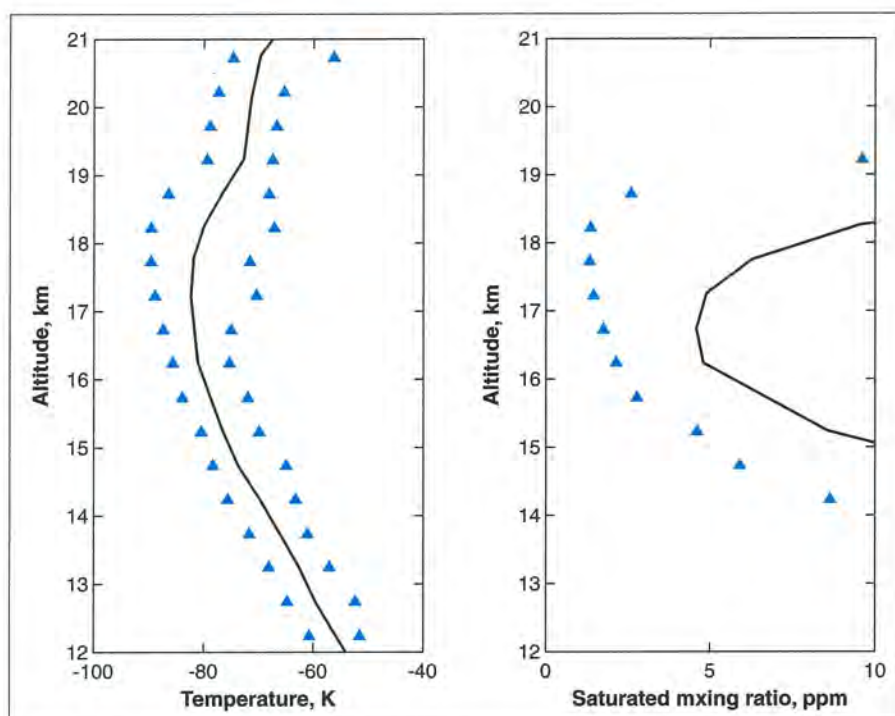


Figure 2. Mean and extreme vertical profiles of temperature, as measured by the Geophysica during APE-THESEO, and calculated mean and extreme saturated water vapour mixing ratios.

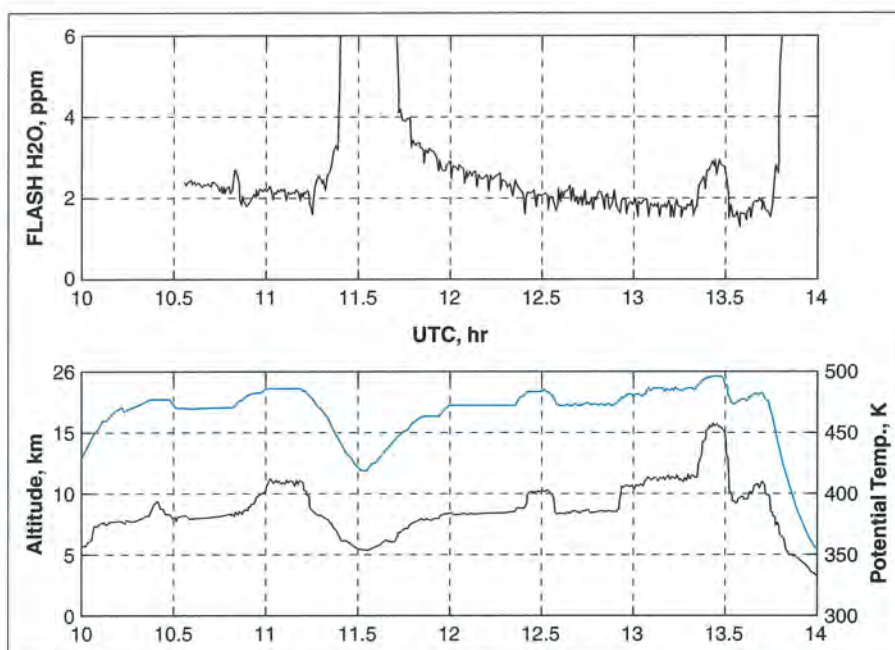


Figure 3. Water vapour measurements for 19 February 1999, from the FLASH instrument as a function of UTC hour. The altitude and potential temperature of the Geophysica are also shown. FLASH data from the first part of the flight are missing.

In addition, we have made a number of meridional transects, including dives to 10km altitude, for the study of the distribution of trace gases. Radiative flux measurements were made on all flights, for comparison with INDOEX measurements. Vertical profiles in the stratosphere, from the lidars, scatterometers, and in situ instruments, confirm the very low background aerosol concentrations reported from APE-POLECAT (Borrmann *et al.*, 1999) and elsewhere.

Although it is premature to draw any fixed conclusions from the mission, it seems certain that it will provide much needed clues to the behaviour of the tropical tropopause that will improve our analyses and forecasts of this climatically important region. More details of our preliminary results will be reported in the proceedings of the EC-sponsored Fifth European Workshop on Stratospheric Ozone, held in St. Jean de Luz in October 1999.

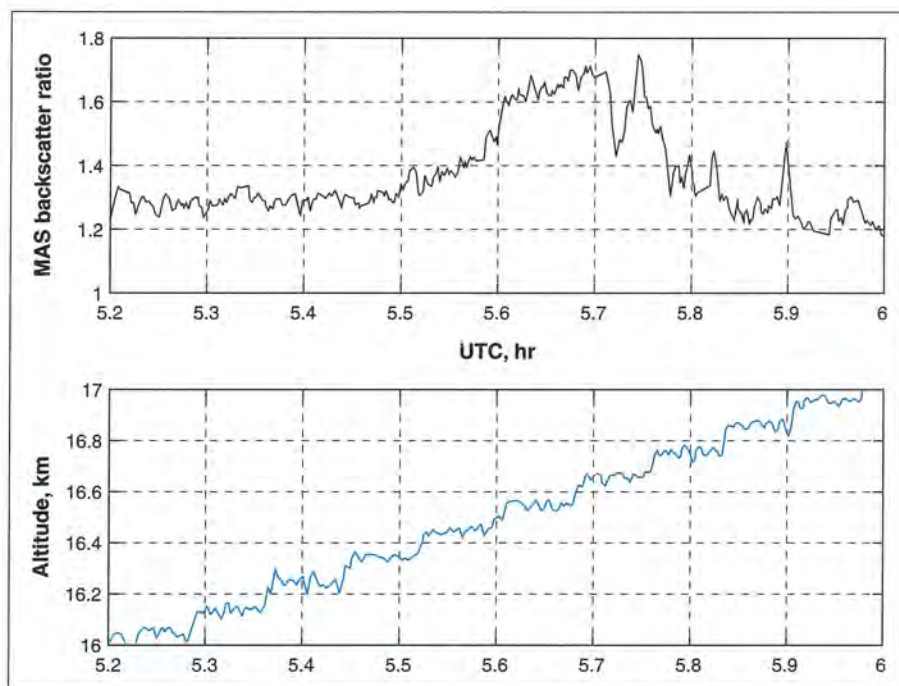


Figure 4. MAS backscatter data and Geophysica altitude, for 27 February 1999. The figure demonstrates the Geophysica being guided through a high-altitude cirrus layer in altitude steps of roughly 200m. The MAS backscatter signal is yet to be finally calibrated. From satellite and visual observations, it is clear that no local convection reached 17km on this day.

Acknowledgements

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Meteorological Office, aided by a grant from the UK UTLS Ozone programme, from Eumetsat and the INDOEX Steering Committee, through their repositioning of the METEOSAT-5 satellite, and from the Seychelles Meteorological Bureau.

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APE-GAIA Campaign

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The APE-GAIA Campaign (Airborne Polar Experiment, Geophysica Aircraft in Antarctica) was performed in September-October 1999 from Ushuaia (Argentina), with the main objectives to

study the chemistry and dynamics of the Antarctic polar vortex. The project was sponsored by the Italian Programme for Research in Antarctica, and 11 countries participated.

The data analysis is in progress, and results are planned to be provided for *SPARC Newsletter* 15.



The Chapman Water Vapour Conference

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Introduction

There are still many aspects of water vapour properties, distribution, and roles in the atmosphere and the climate system that are not well understood. On

October 12-15, 1999 the American Geophysical Union convened a Chapman Conference on Water Vapour in the Climate System to review the present status of knowledge of the distribution of water vapour in the atmosphere

and its role in atmospheric processes. About 100 scientists gathered at the Bolger Center in Potomac, MD, for in-depth discussions and exploration of new ideas and data. The center, on extensive grounds, provided an excellent

venue for people to interact in and out of the sessions. A previous conference of the same title was held in 1994 (Elliott and Gaffen, 1995). It focused on tropospheric water vapour, and emphasised the difficulties in measuring water vapour with sufficient accuracy and resolution to allow observational tests of theory. Recent discussions, including some led by SPARC, have emphasised the importance of Upper-Troposphere/Lower-Stratosphere (UT/LS) water vapour. This second Chapman Conference was broadened to include discussion of this topic.

This review selectively (and subjectively) notes some of the highlights of interest to the SPARC audience, with emphasis on the UT/LS. More complete information, the program and abstracts may be found at <http://www.agu.org/meetings/cc99bcall.html>.

Measurements

For all its prevalence and importance, water vapour is very hard to measure accurately, even in the lower atmosphere. The best current capacitive radiosondes were stated to be very good sensors if not contaminated, but they have a dry bias at low levels, and are too moist at low humidities, where a temperature-dependent correction factor may reach a factor of 2 at -70°C . Measurement programs by the US Atmospheric Radiation Measurement (ARM) program have sought to use the advanced instrumentation of ARM to quantify the water vapour measurement uncertainty of the sondes, and find ways of improving the accuracy, with a goal of order 2%. At present, using sondes, ground based microwave, GPS, Raman lidar normalisation and solar radiometer comparisons, the full range of differences is still at least 12%.

The discussion of measurement capabilities and difficulties in the UT/LS at the conference paid considerable attention to the work done within the SPARC Water Vapour Assessment (WAVAS) activity (cf. SPARC Newsletter 13). The wide variety of sensors that can operate in the UT/LS were summarised; no single technique or instrument covers all latitudes. Individual instruments reach an accuracy on the order of 5%, although intercomparisons between different instrumental techniques showed even larger discrepancies. It was concluded that no technique available today has proven to be an absolute standard, and future calibration and characterisation will be required for high-quality measurements. Inexpensive balloon-borne frost-point hygrometer were suggested as a way to overcome some of these difficulties.

Results from the MOZAIC program, in which capacitive sensors are flown on commercial aircraft to obtain measurements over long tracks in the UT/LS were presented, with emphasis on the need for frequent calibration of the sensors in this demanding regime. Another aircraft measurement program noted the need for large corrections when operating near the speed of sound, and mentioned plans to develop a tunable diode sensor to alleviate some of these problems.

Satellite data are characterised by a variety of different spectral bands and viewing geometries, but all in general have good coverage and precision, making them suitable for studies of relative variations. WAVAS is using different techniques to make intercomparisons among them, allowing the errors to be estimated. The quality of nine data sets being evaluated will be described in the WAVAS final report. The utility of the high vertical and horizontal resolution of a future satellite instrument was also illustrated. Recent progress in determining the total column of water vapour under all weather conditions from GPS signals, and from GOME data under clear skies, was also described. Airborne DIAL systems have been successful in seeing vertical distributions and small horizontal scale variations in the UT/LS.

Water Vapour and Atmospheric Radiation and Chemistry

Several presentations dealt with the role of water vapour in radiative transfer in the Earth's atmosphere. For studies of radiative balance or remote sensing, a spectral perspective was felt to be essential in disclosing processes, as well as for calculation purposes. One theme was the importance of the pure rotation spectrum of water vapour (wavelengths longer than about 20 micrometers), which dominates cooling in the UT. The SHEBA experiment in the cold, dry Arctic has provided unique information on these features, and the continuum created by broadening of the spectral lines of water by other kinds of molecules (foreign broadening), which is inextricably linked with the lines in the band. Uncertainty in this quantity results in an uncertainty in UT cooling of order 0.2K/day . (By contrast, the continuum created by water molecules (self-broadening) dominates transfer between bands (e.g. in the 10-micrometer window region), which is effective near the surface.) Cavity ringdown spectroscopy was described as a new approach to measure continuum absorption.

Water vapour has many roles in atmospheric chemistry. It is the major source

of the hydroxyl radical (OH), which is the major oxidising agent and cleanser in the atmosphere. Additionally, ice provides absorbent sites for polar molecules, and a matrix for chemical reactions, while liquid water provides sites for aqueous chemistry. Finally, liquid water is a solvent, resulting in wet removal processes and acid rain. In the stratosphere water is created by the oxidation of methane and is responsible for ozone destruction in the upper stratosphere, while water vapour chemistry is responsible for processes that cool the mesopause by 9K/day . These strong links between the hydrological cycle and atmospheric chemistry mean that future climate changes are tightly linked with atmospheric chemistry.

Upper Troposphere-Lower Stratosphere.

Fifty years ago Brewer used airborne measurements of water vapour in the UT/LS to infer that the Lagrangian mean transport in the stratosphere, later termed the Brewer-Dobson circulation, consists of rising motion through the tropical tropopause, poleward drift, and sinking at high latitudes. Recent measurements, which have again illustrated the importance of water vapour as a tracer of atmospheric motions, have added detail to this picture. Reviews pointed out that measurements by HALOE, MLS, and aircraft have illustrated the upward propagation of the effects of the seasonal cycle in tropical tropopause temperatures on water vapour values in the tropical stratosphere, the so-called "tape recorder" effect. The reduction of this signal up to $\sim 30\text{hPa}$ indicates mixing with extra-tropical air, while from the relatively unattenuated signal above this level one can deduce an isolated "tropical pipe" in the tropical stratosphere, and also estimate mean upwelling rates that have been used to confirm estimates from radiative calculations.

Trends in UT/LS water were a subject of much discussion. Analysis of roughly 40 years of LS Northern mid-latitude data from numerous in situ and more recently satellite sources indicated that there has been an increase of $\sim 0.05\text{ppmv/year}$ since the late 1950's. This is larger than can be explained by the measured increase in methane or measured changes in tropical tropopause temperatures, and may indicate a change in the circulation.

Speakers pointed out that the vertical resolution of current climate models is not adequate to resolve the important processes controlling UT water vapour

and temperature, or changes in tropopause height. Water vapour is a particularly challenging problem because it decreases by 4 orders of magnitude between the surface and tropical tropopause, while current models typically use less than 15 tropospheric layers. In response to CO₂ increases, all current climate models predict a larger temperature increase in the upper tropical troposphere than at the surface, and an increase in UT specific humidity of ~40%. The stratospheric temperature decreases in response to increased radiative cooling. Much greater vertical resolution is needed to have confidence in model predictions of UT/LS water vapour.

Processes in the Tropical UT

Several speakers discussed the injection of water into the stratosphere through the tropical tropopause. One proposed mechanism suggested that convective overshooting inserted water vapour and cirrus into a tropopause layer, suggested to lie between roughly 150-50hPa. Entry into the stratosphere occurs away from the overshooting region, where radiative heating leads to upward motions greater than those of the Brewer-Dobson circulation. However, an attempt to model this process, including detailed cloud microphysics, indicated that the process is more complicated than suggested. Cloud crystal growth and sedimentation can short circuit the apparent water vapour transport, while the vertical pumping of water vapour depends very strongly on the horizontal scale of the cloud. Another participant concluded that the water vapour depends sensitively on cloud microphysics that present GCMs neglect. However, he suggested that this

sensitivity was probably masked by inadequate vertical resolution. Clouds appear to be a source of moistening in the UT in the tropics. A 3D model study indicated downward motion in the stratosphere over Indonesia, inconsistent with a fountain in this region.

Processes in the Extratropical UT

New measurements are also providing more insight into distributions and processes in the extratropical middleworld, the UT and stratosphere. Four years of data from the MOZAIC program over the Atlantic between Europe and North America at altitudes of 9-12km found about 30% of the cases where the air was supersaturated by as much as 150% with respect to ice. (This can have a significant impact on the formation and lifetime of aircraft contrails in this altitude region.) They also showed strong seasonal variations, with higher specific humidity in the summer than the winter, but with relative humidities about 10% lower in the summer than the winter, and about 30% lower in the subtropics than in mid-latitudes. These changes are associated with the seasonal march of the subtropical and polar jet streams, where strong latitudinal boundaries occurred. Measurements obtained by the RB57 high altitude research aircraft flying along the tropopause also saw such boundaries, with highly variable regions on the poleward edge of the subtropical jet, consistent with recent mixing of air into the extratropical and providing insights into the dynamics of STE in this region. A related study using MLS retrievals of water vapour at 215hPa found

strong evidence for mixing by Rossby wave breaking in the North Atlantic region, although this effect was weak in the central and eastern Pacific region. Finally, a study using NVAP data, based on nadir viewing operational satellites, indicated a dependence of UT water vapour on SST anomalies south of the jet, where deep convection and meridional fluxes dominate. North of the jet stronger upper level cyclonic flow dries the UT when the baroclinicity of the storm tracks is enhanced.

The Global Water Vapour Program of GEWEX

GEWEX (The Global Energy and Water Cycle Experiment), a sister program to SPARC under the World Climate Research Program, has as one of its components a subprogram called the Global Water Vapour Program (GvAP). Taking advantage of the conference, the US GEWEX Panel and the GvAP Science Working Group held a "town meeting" to discuss the GvAP Science and Implementation Plan. SPARC has been encouraged to work closely with GvAP.

Convenors for the Conference were Dian Gaffen (NOAA), John Gille (NCAR & U. of Colorado), and Becky Ross (NOAA). The conference was sponsored by the American Meteorological Organization, EUMETSAT, NASA, NOAA, NSF, and SPARC.

Reference

Elliott, W.P. and D.J. Gaffen, 1995: Chapman conference probes water vapour in the climate system, EOS, 76,67.

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22nd IUGG GENERAL ASSEMBLY

Birmingham, UK, 18-30 July 1999, Sessions relevant to SPARC

MC06 Quasi-biennial Oscillation and Internal Gravity Waves

Convener: Isamu Hirota. Report by Mark Baldwin (mark@nwra.com)

This session on the quasi-biennial oscillation (QBO) was held over an entire day, with two invited review talks and nine contributed presentations, covering the basics of equatorial dynamics, and extratropical dynamical effects, observations using rawinsondes, observations of QBO modulation of trace gases, modelling of the QBO, and modelling of its extratropical effects on circulation and chemical constituents such as ozone.

One current problem is the vertical coupling of the stratospheric QBO, both to the troposphere below and the mesosphere above. In the upper stratosphere, the amplitude of the QBO is much smaller than the semi-annual oscillation (SAO), but the stratospheric QBO wind regimes affect the vertically propagating waves that reach the mesosphere, and seem to cause a strong QBO near the mesopause. The upper equatorial stratosphere is also a region of ozone heating, which varies with the 11-year solar cycle. The possible role of the QBO in communicating variability of the QBO, the SAO, and the solar cycle to the extratropics is not yet understood, and is made more difficult by a lack of data above

the highest (10hPa) radiosonde level. Rocketsonde wind data, which began in the early 1960s, is available at stations at 8°N and 8°S. These data extend well into the mesosphere, and may help to solve this problem.

The role of the QBO in stratosphere/troposphere coupling may take two forms. The QBO modulates the strength of the northern stratospheric vortex (and the timing of the break-up of the southern vortex), and high-latitude stratosphere-troposphere coupling (through the Arctic Oscillation) appears to communicate some effect from the QBO to the Earth's surface. Although the QBO has only a very small amplitude in the equatorial

upper troposphere, it may have an important effect on Atlantic hurricanes. This possible connection is not yet understood, and is based on a statistical relationship between the QBO phase and hurricane formation and intensity. Several mechanisms have been proposed to explain the effect of the QBO on Atlantic hurricanes, but the most promising mechanism may involve the QBO modulating vertically-propagating waves during hurricane formation.

Several GCMs have successfully simulated the QBO, or a "QBO-like oscillation." The QBO is generated spontaneously in these models, and it is challenging and time consuming to adjust the models to improve the QBO simulations. In general, high vertical resolution, as close as 500m, allows an improved simulation of gravity waves, which force the QBO. Small horizontal diffusion is also necessary. The simulation of the QBO in GCMs is a particularly challenging problem, but it is potentially an important one. It is becoming clear that realistic climate (and climate change) simulations require a realistic stratosphere. It is not yet known how important the global circulation changes associated with the QBO are to these simulations. Modelling studies have shown that increasing greenhouse gases may cause the northern polar vortex to become stronger and colder, and the presence of a QBO would tend to increase the variability of the vortex.

There have been many observational studies, using reanalysed data sets such as NCEP and ECMWF, as well as with satellite observations (e.g. HALOE) of trace constituents. These data sets allow the analysis of the QBO's global effects on the zonally-averaged circulation, including the details of how the phase of the QBO interacts with the annual cycle in the tropics and subtropics, as well as ascent rates in the tropics. The analysis of zonally averaged trace constituent fields help to deduce the mean meridional circulation of the stratosphere. UARS/HRDI wind measurements provide a lower resolution replacement for rocketsonde measurements, which tapered off near the time that HRDI measurements began. Satellite observations of chemical constituents also allow analysis of both ozone feedback mechanisms and long-term variations.

In October the SPARC QBO Working Group submitted a paper, "The Quasi-biennial Oscillation," to *Reviews of Geophysics*.

JSM26. Chemistry and Transport in the Upper Troposphere and Lower Stratosphere (UT/LS)

Conveners: M. Shiotani (shiotani@ees.hokudai.ac.jp), T. Shepherd and A. Ravishankara

This 2 1/2-day symposium focused on space-time variations in minor species and chemical-dynamical processes in the UT/LS. Special attention was given to stratosphere-troposphere exchange (STE) and to the recent ozone decrease in Arctic spring. **A. Plumb** (invited) opened the symposium with discussion mainly on the meridional circulation which controls STE. Factors controlling the circulation largely depend on the tropical angular momentum distribution and budget in the LS. A puzzle is why models, which are presumably too viscous, do not tend to have too strong diabatic circulations. Another topic was the «age» of air, especially how the age of mid-latitude air may change substantially in relation to the relative strengths of the meridional circulation and horizontal mixing. **W. Sturges** reported that C_2F_6 measured at Cape Grim seems to be an ideal age-of-air tracer in the stratosphere. On the basis of the Lightweight Airborne Chromatograph Experiment (LACE) observations, **E. Ray** investigated transport and mixing in the lowermost stratosphere. **W. Grose** showed results from a 3D GCM (IMPACT) including gas-phase and heterogeneous chemical reactions, with a focus on transport and mixing across the vortex-edge and subtropical barriers. **L. Bruhwiler** presented results obtained using the GFDL SKYHI on the effects of an imposed stratospheric QBO. The QBO was found to systematically modulate the eddy transport of ozone during the NH winter. **P. Haynes** (invited) focused on the extratropical tropopause in analogy with the edge of the stratospheric polar vortex. This analogy has two aspects. One is based on the fact that numerical simulations show that a quasi-realistic, statistical equilibrium tropopause may form in a simplified numerical model. Another aspect is based on transport properties of the isentropic velocity field obtained from observational data using the effective diffusivity diagnostics. **T. Horinouchi** used the NCAR CCM3 to investigate signatures of synoptic-scale Rossby waves in the UT/LS in connection with the Pacific westerly duct. **J. Thuburn** examined the tropopause height by taking into account the solar heating and dynamical warming or cooling, comparing results from simple models with GCMs. **A. Gettelman** compared several methods to diagnose STE from GEOS-1 assimilation data, and found that the instantaneous two-way

exchange may be significantly exaggerated by Wei's method. **R. Rood** used conditional probability distribution functions and showed that the GEOS model maintains a mix of air in the lowermost stratosphere similar to observations.

M. Nishida showed the tropopause statistics using the GPS/MET measurements. The tropopause altitude was found to be higher than the level of minimum temperature, especially in winter. **A. Langford** presented evidence from the Fritz Peak ozone DIAL (lidar) on the intrusion of stratospheric air into the troposphere in a fold. The intrusion itself contained tropospheric air, suggesting a return of tropospheric air back into the troposphere (reversible transport). **C. Timmis** addressed the question of the cause of low-ozone layers in the lowermost stratosphere over Aberystwyth, arguing that the layers already exist in the subtropics and are advected over Europe in NH winter. **H. Teyssedre** examined age of air with the Cambridge SLIMCAT and found it produces too old ages. **P. Haynes**, substituting for **J.-R. Alisse**, presented a combination of theory and balloon measurements to address the question of vertical diffusivity in the stratosphere finding values consistent with tracer-based estimates from aircraft measurements, but an order of magnitude smaller than estimates from radars. **D. Jackson** studied cross-tropopause transport in low latitudes using ERA analyses to drive off-line particle trajectories. **D. Fahey** gave an invited talk on photochemistry and transport in the high-latitude summer hemisphere based on the 1997 Polaris campaign. The summer is the time of the largest seasonal decrease in ozone due to increased sunlight and reduced transport. This period is relatively simple, because sulphate aerosol reactions are cut off and the chemistry is purely gas phase. The NO_2/NO ratio exhibits far greater dynamic range than in winter; departures from theory are greatest for high solar exposure, for reasons that are not completely understood. **S. Li** studied the break-up of the Antarctic vortex using the CRC CTM and suggested that the vortex loses mass rapidly during October. **S. Pawson** examined the transport properties of assimilated data sets, using the GEOS-DAS, from the viewpoint of errors which can arise from deficiencies in the observations or in the assimilating GCM. **S. Yoden** studied chaotic mixing in the stratosphere with the flow generated by barotropic instability of a polar night jet.

D. Kley's invited review on water vapour started with the earliest measurements by Brewer and the inference of tropical dehydration. The trends in water vapour abundance were most clearly shown by the data of CMDL over

Boulder. The difference between the tropopause and hygropause was reviewed. The "tape recorder" picture semi-quantitatively explains the observed water vapour concentration and its temporal evolution in the LS. Some data from the recent CEPEX experiments were shown. **I. Keramitsoglou** examined the discrepancy between the Lyman-alpha and the frost point hygrometers, which might be due to the presence of extraneous vacuum UV radiation in the Lyman-alpha hygrometer. **A. Dethof** studied the isentropic transport of water vapour in the lowermost stratosphere and found that the cross-tropopause transport far exceeded descent from the overworld. **S. Borrmann** (invited) reviewed the role of condensed matter in the LS/UT. He showed evidence for potential halogen activation on so-called cirrus clouds. The repeated exposure of inactive halogen species to the "cirrus" leads to activation of chlorine. Since the deactivation is not very rapid, episodic repeated exposure leads to a higher level of active chlorine. He concluded that cirrus activation and its contribution to the ozone trend has to be considered unproven but likely. **V. Dvortsov** described how short-lived bromine containing species, such as bromoform, can provide a significant amount of bromine to the stratosphere via rapid convective transport in the tropics. **L. Steffanutti**, substituting for **R. McKenzie**, depicted the aims and preliminary results of the APE-THESIO. One of the findings was the presence of thin clouds almost continuously around 18km.

R. Cox (invited) examined the laboratory studies of some key reactions: $\text{ClO} + \text{HO}_2$, $\text{BrO} + \text{HO}_2$, $\text{IO} + \text{HO}_2$, $\text{BrO} + \text{ClO}$, $\text{IO} + \text{BrO}$. The possible production of a hitherto-unreported species, OBrO , in the laboratory was described. It has been also reported to be present in the upper stratosphere. If true, it will require a complete alteration of our understanding of bromine chemistry. The recommended values of some of these reaction rate coefficients were presented. **H. Grafts** modelling aimed at investigating the relative role of ozone changes, greenhouse-gas changes, and natural variability in accounting for the observed changes in stratospheric climate. Tropospheric circulation changes resulting from a combination of greenhouse gas forcing and natural variability were argued to be responsible for the changes in stratospheric circulation. On the basis of results from the SOWER/Pacific mission over the Galapagos, **M. Shiotani** showed, contrary to expectations, clear evidence of freeze drying over a deep layer in March. **H. Singh** (invited) presented a summary of the findings of the SONEX mission over the north Atlantic;

(1) the measured NO_y abundance agrees with that deduced from individual components of NO_y . (2) Enhanced nitrogen oxides in the aircraft corridor is clearly visible. (3) The measured ratio of HO_2 to OH agrees very well with the computed value. The measured abundance of HO_x is larger than predicted, the observed HO_2 abundance increases linearly with the abundance of NO , and the measured abundances of CH_2O are much larger than predictions. This mission is expected to yield a much better understanding of the chemistry of the UT.

Y. Orsolini used the SLIMCAT CTM to diagnose isentropic tracer transport in the LS, paying attention to the occurrence of laminae in N_2O . **C. Marquart** examined quasi-isentropic transport in the LS by using high-resolution reverse domain filling calculations. **M. Bourqui** used one-year data from the ECMWF analysis and ozone measurements from the MOZAIC and NOXAR projects to infer the STE flux of air. **D. Karoly** focused on the zonally symmetric oscillation of the total column ozone and its variability in the Antarctic UT/LS, noting the contrast with the behaviour in the Arctic. **W. Norton** with the SLIMCAT CTM investigated interannual variability in isentropic transport and mixing in connection with the QBO, finding reduced mixing during the westerly phase. **A. Iwi** compared several UK models in view of the age of air, the tape recorder signal in the equatorial LS and its modulation by the QBO. **O. Morgenstern** investigated filamentation activity in the NH tropopause region using PV fields. **R. Worthington** presented results based on the MST radar at Aberystwyth and ozonesonde data. **D. Fonteyn** conducted 4D-VAR assimilation including stratospheric chemical species using the CRISTA observations.

JSM32. Small-scale and Layered Phenomena around the Summer Mesopause

Conveners: F.-J. Lubken and G. E. Thomas (Thomas@iap-kborn.de)

A total of 17 oral papers were presented and 50-60 scientists attended the meeting. The main topic was the appearance of small scale layered phenomena, such as noctilucent clouds (NLC), polar mesosphere clouds (PMC), and polar mesosphere summer echoes (PMSE). Recent observations from modern rocket-borne and ground-based instruments, for example by steerable and multicolour lidars, were presented as well as new results from sophisticated modelling of fine structures in the neutrals and in the plasma.

A 22-year database derived from the MeteoSat revealed the presence of PMC over the sunlit polar regions. This data set opens up the possibility of determining solar cycle and longer-term changes of PMC. Southern hemisphere observations of PMC from the MSX spacecraft, of NLC from the ground at Davis, of PMSE from Peru's King George Station and of density/temperature from rocket soundings at Rothra provide further inter-hemispheric comparisons. Seasonal, diurnal and planetary-wave effects were reviewed, and indicated a strong causal connection between ice saturation and the various layered phenomena. Modelling of the relationship of turbulence, mixing, electric fields, and metallic species suggests that a complex combination of physical processes is responsible for the observed layered structures. Observations of PMSE at Svalbard help determine layered phenomena in the deep polar region.

Several papers depicted hemispheric differences of these layers and their dependence on the background thermal structure. It is not clear yet how the obvious lack and weakness of PMSE echoes at southern latitudes is related to the thermal and dynamical structure of the background atmosphere. It seems as if differences in other geophysical processes (e.g. particle charging mechanisms) must be taken into account too.

The potential role of small scale layers in the upper mesosphere as indicators for long term trends was addressed. Although there seems to be no conclusive picture about the relationship between the obvious increase of NLC occurrence frequency and the thermal structure, there was general agreement that the high latitude mesosphere during summer is possibly the best place in the atmosphere to unambiguously detect the influence of anthropogenic activities.

The Layered Phenomena Working Group agreed to have the workshops every two years (the next in October 2000, possible venue Embury-Riddle Univ. at Daytona Beach, Florida; another possibility is Boulder, CO). At the next IAMAS meeting in Innsbruck (July 2001), layered phenomena will be covered at such sessions as MA chemistry, dynamics, long-term trends, etc.

MW01. Intercomparison of Troposphere-Stratosphere GCMs

Conveners: Steven Pawson (pawson@polska.gsfc.nasa.gov), E. Drysdale and K. Krueger

Many of the invited presentations reported results from the SPARC-GRIPS

initiative. The theme of the workshop was on the ability of climate-middle atmosphere models to simulate different aspects of the climate system and on their sensitivity to parameterisations and numerical schemes.

J. Koshyk's paper "The kinetic energy spectrum of horizontal motions of middle atmosphere GCMs" examined the simulated eddy kinetic energy spectra. All the models produced the familiar -3 gradient in the tropospheric wave energy spectra, where the flow is dominated by Rossby waves. In the stratosphere the lower wavenumbers had larger amplitude but the higher wavenumbers are smaller because of filtering. The mesosphere was dominated by gravity waves (GW), which form at ever smaller scales as resolution increases in the SKYHI model. **K. Hamilton** ("Sensitivity of model simulation of the middle atmospheric circulation to vertical and horizontal resolution") ran SKYHI at a variety of resolutions. Increasing the horizontal resolution (in the range N30-N270) improved many aspects of the simulation, especially the polar vortex structure. At high resolution, tropical cyclones were well modeled, having realistic depth, rainfall patterns and trajectories. With moderately high horizontal resolution, increased vertical resolution enabled the model to generate a QBO-like oscillation in the lower stratosphere (LS). Vertical resolution changes had little impact on the extra-tropics. In "Physically-derived dynamical cores in AGCMs," **R. Rood and Shian-Jiann Lin** presented a next-generation, flux-conserving dynamical core which has been coupled to a version of the CCM3 physics. The model is to be used for data assimilation, climate assessment and weather forecasting. As well as good climatologies, the model produces realistic frontal systems, manages a good simulation of a Gulf of Mexico hurricane and is numerically efficient. Overall, although limitations still exist (e.g. the model is hydrostatic), the new generation dynamical core is a feasible candidate for the next version of the NCAR CCM. **T. Horinouchi** ("Vertically propagating waves and the mean flow in the equatorial LS of GRIPS and other GCMs") examined the impact of vertically propagating waves in the tropics on simulating a realistic QBO and SAO. Compared were MRI, FUB, SKYHI N30L40/N45L80, and CCM3MA, along with the AGCM5-HY98 model. The main differences between the tropical waves simulated in the models were found to be due to the space-time variability of cumulus convection influencing the excitation of waves, the model vertical resolution impacting the propagation mechanisms and the horizontal resolu-

tion affecting the oscillation mechanisms of these waves. The importance of GW for climate simulation was addressed by **J. Alexander** ("Parameterization of mean-flow forcing due to GW") with several key areas highlighted: observations typically do not give the most useful parameters of the waves (the momentum flux) and, crucially, the nature of the wave sources is poorly known. Issues such as the source variability and uncertainty of the breaking processes can not be resolved without further observations.

In the poster presentations, **R. Bannister et al.** showed the impacts of upper boundary height on the simulation of tropospheric features. **S. Pawson et al.** presented a summary of the first model intercomparison performed for GRIPS. **V. West and R. Harwood** examined the transport properties of the unified model with a variety of advection schemes implemented, showing that choice of vertical advection scheme can severely impact the transport of trace gases. **Wenyi Zhong et al.** examined the sensitivity of the UGAMP model to the choice of radiation schemes, including a new version of the ECMWF scheme which includes a line-by-line LW transmission table (for CO₂, O₃ and H₂O), an updated parameterisation for the water vapour continuum and a representation of oxygen absorption.

In "Selecting meteorological input for the Global Modelling Initiative (GMI) assessments," **S. Strahan** discussed the requirement to select an optimal meteorological data set for a GMI study of the impact of a stratospheric aircraft fleet. A set of objective criteria were established to test the quality of the data sets available (NCAR-CCM2 and GISS models and the GEOS-DAS assimilations). The criteria addressed the meteorological state and the transport characteristics of the data. Based on the results, the NCAR-CCM2 data set was chosen for the GMI assessment. **G. Stenchikov and A. Robock** split the presentation "Intercomparison of climate model simulations of the response to the 1991 Pinatubo volcanic eruption". The impact of the eruption on climate was simulated in several GCMs, using an ensemble of two-year integrations designed to study sensitivity to volcanic eruptions and SSTs. The largest response arises from radiative forcing due to the volcanic aerosol. This result is found to be insensitive to the SSTs used. The temperature increase of the tropical LS was larger than observations, apparently because they do not simulate a QBO. **J. De Grandpre et al.** ("Ozone study with the Canadian Middle Atmosphere Model") presented

simulations of the pre-ozone hole SH column ozone performed with the Canadian MAM coupled to a fairly complex photochemistry scheme using a choice of semi-Lagrangian (SL) and spectral transport schemes. The spectral scheme proved to be numerically stable, non-dispersive, and produced a realistic climatology with no drift in trace gas concentrations. The present implementation of the SL transport remains diffusive, non-conservative and numerically unstable, making it unsuitable for interactive ozone-climate studies. **U. Langematz et al.** (presentation made by S. Pawson) discussed "First results from the radiation-intercomparison project for GRIPS." This study is motivated by the cold bias in most models. Offline calculations with identical input data revealed a considerable difference between the radiative codes investigated. In "The impact of two decades of ozone change on the stratosphere" **S. Rosier et al.** used an 'Intermediate' GCM to study the effect of observed ozone changes on the stratosphere. The ozone changes were implemented in two ways. Initially, seasonal changes in ozone were applied to the column, and little signature was seen. Applying monthly mean ozone changes in the 150-35hPa layer led to a more realistic impact. The LS cooling reached -5K at 70°N and -15K at 86°S, rather stronger than values of -3K and -9K obtained from a FDH model experiment performed to isolate the radiative and dynamical contributions. **J. Knight et al.** ("The response of the stratospheric climate to changes in greenhouse gas concentrations from 1992-2051") examined two 70 year model runs with slightly different initial conditions, performed to study the impact of double CO₂ concentrations with fixed SSTs on stratospheric climate. They found a linear cooling trend of -1.4K/dec at 10hPa, increasing PSC amounts, and a 2-day/dec delay in the timing of the SH vortex breakdown. The two simulations showed different responses, which might mean that climate models should be used to address the range of possible atmospheric changes, so that ensembles of predictions are needed.

MW-04. Atmospheric Tides in Global Models

Conveners: K. Hamilton (kph@princeton.edu) and C. McLandress (mcland@stpl.cress.yorku.ca)

A one-day workshop was organised by ICMA to discuss the current state of tidal simulation in global models that include the middle atmosphere (MA). The workshop began with a number of talks summarising tidal observations, and, in many

cases, comparing the observations to results from the Global Scale Wave Model (GSWM) developed by **J. Forbes** (U. Colorado) and **M. Hagan** (NCAR). The GSWM is a linear model of the tidal response to a prescribed diurnal or semi-diurnal heating. It allows the inclusion of arbitrary mean wind and temperature structure. **R. Vincent** (U. Adelaide) reviewed tidal wind observations around 86km altitude from MF radars at 5 sites from Kauaii (22°N) to Davis (68°S). He noted significant seasonal and interannual variations in the diurnal tide. At Adelaide (35°S) the phase of the diurnal wind oscillation varies by 4 hours throughout the year, and the amplitudes have large year-to-year variability apparently related to the stratospheric QBO. Two radars very near the equator and separated by about 90 degrees longitude showed similar diurnal variations in the meridional wind, but a factor of two differences in the diurnal zonal wind variation. **A. Manson** (U. Saskatchewan) discussed MF observations from 7 stations from Christmas Is. (2°N) to Tromsø (70°N) and compared them with results from two versions of the GSWM model, one (GSWM95) with mean winds based on CIRA and one (GSWM98) on UARS HRDI. Observed diurnal tides were generally better modelled by the GSWM than semidiurnal. Both the diurnal and semidiurnal tidal observations are in better agreement with the GSWM95 predictions than those from GSWM98. **C. Jacobi** (U. Leipzig) discussed semidiurnal tides observed from radars (MF, low frequency and meteor radars, all within 52°N-56°N). Significant longitudinal asymmetries were noted dependent on season. In January the semidiurnal wind amplitudes near 90km vary by a factor of 4 among the stations, with some success in relating variations in the longitudinal tidal asymmetries to patterns of stratospheric geopotential height. **M. Riese** (Wuppertal U.) discussed the diurnal temperature oscillation determined from CRISTA on the Space Shuttle in 1994 and 1997. The results were compared to the GSWM when run with mean winds computed with gradient wind balance from the CRISTA observed temperatures, and with winds from earlier HRDI observations. There was quite good agreement when the CRISTA-based winds, but much poorer when the HRDI winds were used.

C. McLandress (York U.) reviewed migrating tide observations from the UARS. Winds from WINDII and HRDI, and temperatures from MLS all exhibit a strong semi-annual variation in the propagating diurnal tide in the mesosphere. Interannual variations, which

appear to be linked to the phase of the stratospheric wind QBO, are also evident in the HRDI data. Simulations of the diurnal tide using the Canadian MA GCM were also discussed. These were shown to exhibit a semi-annual variation of amplitude in the mesosphere, in good qualitative agreement with the observations. Resolved large-scale planetary waves were thought to be responsible for the amplitude modulation of the diurnal tide. These simulations did not employ a non-orographic GW drag parameterisation and so such drag was not involved in the seasonal tide variation. **H. Mayr** (GSFC) using a 3D non-linear mechanistic model with the Hines Doppler spread GW drag parameterisation found that the migrating diurnal tide exhibited a semi-annual variation in amplitude like that seen in observations. This was attributed to GW filtering by seasonally-varying zonal winds. Results showed that the GW scheme acted to increase the amplitude and modify the phase of the diurnal tide. **J. Forbes** (U. Colorado) discussed experiments with the GSWM incorporating parameterised GW effects. This incorporation produced major changes in the predicted tides, and both the parameterised momentum drag and eddy diffusion made important contributions to this effect. An attempt was further made to include geographical variability of the tropospheric latent heating excitation for the diurnal tide; this forcing results in predicted non migrating components of the diurnal and semidiurnal wind oscillations at 94km of order 10m/s. **K. Hamilton** (GFDL/Princeton U.) discussed the wind oscillations appearing in control simulations with a version of the GFDL SKYHI GCM with 54 levels up to about 130km. The model produces a realistic tidal surface pressure oscillation, but diurnal wind amplitudes in the lower thermosphere are somewhat weaker than indicated by UARS. The semidiurnal wind oscillation in the MA is quite strong and displays a pronounced seasonal cycle with largest amplitudes in the winter extratropics.

W. Norton (Oxford U.) used a 52-level version of the UGAMP spectral GCM, with an emphasis on seasonal variations in the mesopause-lower thermosphere (MLT) region. In low latitudes there is a strong semi-annual modulation of the diurnal tidal amplitude which is attributed to the interaction of the tide with planetary waves. **S. Miyahara's** (Kyushu U.) 55-level spectral GCM produced a tidal simulation with quite significant non-migrating components in the lower

thermosphere. Miyahara went on to show that in the MLT region the eddy stresses associated with the tide in the model significantly perturb the gradient wind balance normally expected for the zonal-mean zonal wind and zonal-mean pressure fields. This effect should be borne in mind when observed temperatures are used to infer zonal-mean wind at high altitudes. **S. Oliver** (Oxford U.) discussed simulations in a mechanistic version of the UKMO Unified Model (UM) with 36 levels up to about 96km. The diurnal thermal forcing for the experiment was taken from a run with the full UM. The mechanistic model produced a tidal simulation in the MLT region with higher amplitude and weaker zonal asymmetries than the full model. The diurnal wind variations in the mechanistic model at high latitudes were significantly stronger than those in radar observations. **M. Geller** (State U. of NY at Stony Brook) showed linear model calculations of the seasonal and interannual variations in the diurnal tide. These used mean winds taken from HRDI above 55km and from unrelated GCM simulations below. The model included a GW drag parameterisation, and the variation of the GW-induced dissipation could account for the observed semi-annual modulation of the diurnal tide in the lower thermosphere. The model could also explain at least part of the interannual variability of the tides seen in the HRDI data. **R. Swinbank** (USRA/NASA Goddard) discussed the diurnal tide in the Goddard GEOS data assimilation scheme. The GEOS GCM, when run in control simulation mode, produced a reasonable representation of the tide in the stratosphere, but the assimilation products significantly misrepresented the tide. The problem was traced to inadequacies in the operational satellite temperature retrievals that are inserted into the model during the assimilation.

MW05. Radiative processes in the mesosphere and lower thermosphere

Conveners: G.M. Shved (shved@lmupa.phys.spbu.ru) and V.I. Fomichev (victor@nimbus.yorku.ca)

There were 10 presentations (including 3 invited and 2 poster) during this half-day workshop. Half of the papers were devoted to aspects of the energy budget of the mesosphere and lower thermosphere (MLT) region. **V. Fomichev** presented a summary of the current status of our understanding of the MLT energy balance and overviewed radiative

parameterisations used in dynamical models. The main uncertainties in understanding the MLT energetics are primarily related to our knowledge of the quenching processes (especially for CO_2 -O collisions). In addition, important mechanisms such as the solar heating due to the absorption by the near IR CO_2 bands and the thermal effects of the $9.6\mu\text{m}$ O_3 band in the presence of chemical pumping, still need to be parameterised. **V. Ogibalov** presented first ever estimates of the effect of the two- and more v_2 -quanta transitions during CO_2 -O collision on the $15\mu\text{m}$ CO_2 band cooling and showed that the potential increase in the cooling rate could be as high as $15\text{--}25\text{K/day}$ near 130km . **K. Koutoulaki et al.** presented estimates of changes induced by non-thermal emission in the $9.6\mu\text{m}$ O_3 band cooling. **X. Zhu and C. Fu et al.** emphasised that in order to have a more realistic energy balance and atmospheric circulation, dynamical models should include fully-coupled chemical schemes.

K. Grossmann presented first results from the CRISTA measurements which showed longitudinal variations in O in the lower thermosphere and surprisingly small values of CO_2 in the mesosphere. Ground-based nightglow measurements were used by **S. Melo et al.** to obtain variations in the vertical distribution of O.

Ogibalov and Shved considered the non-LTE CO_2 problem and suggested some criteria allowing for the simplification of the CO_2 vibrational level system, depending upon the accuracy required for the calculation. **Kostcov et al.** used the CRISTA measurements to retrieve the vibrational temperature of the $\text{CO}_2(0110)$ state for different CO_2 isotopes in the $60\text{--}130\text{km}$ region. **Ogibalov and Shved** also demonstrated the possibility for the existence of an inversion population of the $\text{CO}_2(00^01)$ and $\text{CO}_2(10^00)$ vibrational states near $95\text{--}100\text{km}$.

MW08. Quasi-Decadal Oscillation

Convener: Lon Hood
(lon@pl.arizona.edu)

Recent observational studies of the quasi-decadal oscillation (QDO) in the middle and upper stratosphere (US) were discussed by **L. Hood**. Analyses of SBUV/SBUV2 and SAGE I/II data showed evidence for a decadal oscillation in upper stratospheric ozone ($1\text{--}2\text{hPa}$) that has been approximately in phase with the solar cycle during the 1979 to 1998 period. The amplitude of the observed US oscillation from solar minimum to maximum is roughly twice as large as is predicted by models that account for the observed solar cycle variation of solar UV spectral irradiance. A mechanism involving solar-induced changes in tropical upwelling, which affects the concentration of key trace constituents such as methane in the US, was proposed to explain the disagreement.

H. van Loon described global correlative studies of NCEP/NCAR reanalysis data below 10hPa at middle and lower latitudes with the solar 10.7 cm radio flux. The correlation patterns in each hemisphere are similar with maximum annual mean correlations at 30hPa in the subtropics. The correlations in the northern hemisphere (NH) confirm those derived from the 40-year Berlin data record. **K. Labitzke** discussed the influence of the equatorial wind QBO on the solar signal in the NH winter. Correlations between the solar 10.7 cm flux and geopotential heights below 10hPa are strong and positive in the Arctic when only QBO west phase years are considered. When only QBO east phase years are analysed, correlations are negative in the Arctic and are positive at lower latitudes. **D. Shindell** applied the GISS GCM to show how US ozone changes can induce circulation changes at lower levels extending into the

troposphere. The model simulates several aspects of the observed QDO in the LS. **M. Baldwin** presented an overview of the dynamical effects of the equatorial QBO on the stratospheric extratropical circulation. Observed effects can be explained mechanistically by changes in the tropical zonal wind field which modifies the effective wave guide for upward and equatorward propagating planetary waves. During NH winter, the west QBO phase tends to excite the Arctic oscillation (AO), a deep, mostly zonally symmetric mode that couples the stratosphere and the troposphere. Downward propagation of the AO may be a general mechanism for downward communication of stratospheric circulation anomalies associated with the QBO or other (solar). **Ch. Marquardt** discussed possible mechanisms for the modulation of the extratropical winter LS by both the QBO and the QDO. During early and middle winter, modulation by the QBO alone dominates while during late winter, modulation by both the QBO and the QDO dominates. The occurrence of an additional biennial oscillation in the extratropical winter was also noted and was suggested to originate as a consequence of the interaction between the annual cycle, the tropical QBO, and the QDO. **N. Balachandran** and co-workers described further comparisons between the predictions of the GISS GCM and the observed LS oscillation. Using a version of the model in which ozone is held fixed but the solar UV flux is varied by large amounts, it was found that the subtropical maximum of geopotential height variation from solar minimum to maximum could be reasonably well simulated. Mechanisms involving downward propagation of changes in stratospheric circulation were discussed. The talk was presented by D. Shindell.

Report on the Fifth European Workshop on Stratospheric Ozone

27 September - 01 October 1999, Saint-Jean-de-Luz, France

Marielle Guirlet and Neil Harris, European Ozone Research Coordinating Unit (EORCU), and Georgios Amanatidis (DG XII-E-1) (Marielle.Guirlet@ozone-sec.ch.cam.ac.uk.).

The Fifth European Workshop on Stratospheric Ozone was held in late September 1999 in Saint-Jean-de-Luz, France and was the successor of the ones held in Schliersee, Germany. The meeting was convened

by CNRS, INSU, CNES and the European Commission (EC) Research DG-XII. It was attended by over 250 participants from across Europe, and in all 221 posters were presented. The European stratospheric research

programme is supported by the EC Environment and Climate programme and by national agencies. Research results from the whole European stratospheric programme were presented and discussed at St-Jean-de-Luz,

except for UV-B, aviation impact and climate/chemistry interaction for which overviews were presented based on recent results, assessments and meetings.

Each session comprised overview talks, talks on individual studies and posters. An important part of the meeting was the presentation and discussion of the results of the Third European Stratospheric Experiment on Ozone (THESEO), whose main field activities took place during the winter 1998/1999 and the first part of 1999 (see articles in SPARC newsletters 10 and 13). We discuss here some of the topics in which significant progress was reported. A complete account of the meeting will be presented in the Workshop proceedings which will be published in EC Air Pollution Research Report series in 2000 and which will contain extended abstracts from the work presented at St-Jean-de-Luz as well as a summary of results from THESEO. The abstracts of the posters and talks presented during the Workshop are available on the European Ozone Research Coordinating Unit Web site (<http://www.ozone-sec.ch.cam.ac.uk/>). The authors wish to acknowledge the efforts and assistance of all involved scientists in the preparation of this article, particularly the THESEO core group and the individual project coordinators.

The stratosphere in 1998-99

The two Arctic winters covered by THESEO offered the opportunity to extend the series of studies of ozone loss in the Arctic lower stratosphere (LS), which started in the late 1980s and continued throughout the 1990s. Since the first large-scale European campaign focussing on the ozone evolution in the Arctic regions (EASOE in 1991-1992, followed by SESAME in 1994-1995), eight Arctic winters have now been well investigated.

The two THESEO winters, 1997-1998 and 1998-1999, were two of the warmest winters in the 1990s and followed a series of winters which were unusually cold. The 1997-98 winter was the colder of the two with several periods of low temperatures between December and February when polar stratospheric clouds (PSCs) formed. There were only two cold periods in the 1998-99 winter, one at the start of December when PSCs were observed over northern Scandinavia and one in February where no observations of PSCs were made by the

available instruments. In both winters the stratosphere was disturbed with no strong isolated vortex existing after December.

In conjunction with the more disturbed stratosphere and higher temperatures, ozone values over the Arctic were higher than in the previous few years. For example high latitude total ozone in March were comparable to the amounts seen in the 1980s, in contrast to the record low values seen in the previous two years. A similar, though less marked picture was observed over northern mid-latitudes.

Analyses of various stratospheric parameters (minimum T, possible area of PSC formation, frequency of stratospheric warmings, etc.) from the long term meteorological records which exist since the 1950s provide a good perspective on the better studied winters of the last decade. This long-term view is also important in understanding the evolution of each individual winter. For example, the first major mid-winter warming since 1990/91 occurred in December 1998, the longest gap between such events in the existing 41-year record (a four-year gap was the previous record). The significance of this longer gap remains unclear; is it a natural fluctuation or part of long-term trend?

Now that the main qualitative features of chemical depletion of ozone in the Arctic regions are understood and reproduced by the models, studies concentrate on interannual variability and respective roles of the dynamics and of the chemistry in ozone depletion in the Northern hemisphere. These studies will help to provide a better quantitative understanding of ozone loss. Stratospheric models currently tend to calculate too little loss in comparison to the ozone loss derived from measurements, though in some winters (notably 1998/99) the models calculate larger losses than determined empirically. Only a correct understanding of the interplay between dynamics and chemistry will allow more accurate calculations of the chemical ozone loss to be made in the models.

Ozone loss at high latitudes

During the two THESEO winters, 1997-1998 and 1998-1999, there were only short episodes of temperatures about or lower than the PSC formation temperatures in the Northern hemisphere. However there was some ozone loss calculated at the end of each winter in the

Northern hemisphere by the different methods, based on ground-based, balloon, satellite measurements and 3D CTM outputs, or using a combination of those techniques. These several independent methods are now well validated and show a good qualitative agreement. Another, purely modelling approach presented is based on tracer experiments made with SLIMCAT. A series of tracers is initialised in several latitude bands. These model experiments can separate the calculated in-situ ozone loss from the influence of air transport from other latitude regions. They confirm that a lot of mixing and transport of activated and/or ozone-depleted air occurred during the two THESEO winters.

The chemical ozone loss occurred under threshold conditions (temperatures around those at which fast chemical loss can take place) which have not been extensively studied before in the 1990s. One notable example which will be a good test of our understanding of cold aerosol chemistry was the period in early February 1999 temperatures hovered around the PSC existence temperature. No PSCs were observed by the available instruments and a number of measurements of active halogen species such as BrO, ClO, OClO, NO₂ and NO₃ were made in this period. These should provide good constraints to calculations and this event offers a good opportunity to investigate the reactions on cold aerosol and PSCs in marginal temperature conditions. This is important as the 3D models calculated that appreciable ozone loss occurred after this cold period.

Ozone loss at mid-latitudes

The causes of middle latitude ozone decline remain controversial and their study was the major aim within THESEO. It has been argued by some that much of the loss occurs in-situ while others have suggested that polar processes have a significant influence on the decline of ozone in mid-latitudes. A number of studies within THESEO, both observational and modelling, are making an important contribution to the debate.

A major effort has been made to develop empirical techniques capable of measuring chemically induced changes in ozone over mid-latitudes. These changes are hard to detect as they usually occur at much slower rates than in the Arctic, and distinguishing the effects of chemistry and dynamics is much trickier. However promising starts have been made with a couple of approaches whose preliminary results show that chemical ozone changes did take place over mid-

latitudes, apparently unrelated to vortex processes, and that the ozone loss occurs faster at lower temperatures in qualitative agreement with current chemical understanding. When confirmed these studies will represent the first direct observational evidence of in-situ chemical ozone changes outside the vortex.

Chemical transport models have been used to examine the connection between polar and middle latitude loss. The winter of 1998/99, the second THESEO winter, has proved to be especially interesting. Temperatures in the LS were higher than average. There was, however, some activation of chlorine inside the polar vortex although outside the vortex synoptic scale temperatures were too high for activation. There were major dynamical disturbances to the vortex in mid-December and in late February. Model calculations show that there was a considerable exchange of air between the polar vortex and middle latitudes associated with these events. There was only a relatively small amount of chlorine-induced loss but this was manifested in the model throughout middle and high latitudes. Model calculated ozone losses did not show a large latitudinal gradient. Clearly, in this winter at least there was a considerable connection between ozone loss in middle and high latitudes.

Interesting comparisons can be made with the modelled ozone losses in earlier winters, including the first THESEO winter, 1997/98. For example, the vortex of 1996/97 was stable and long-lasting with low temperatures again confined inside the vortex. Model calculations indicate that while there was substantial ozone loss inside the vortex there was only a modest decline of ozone outside the vortex. This is in contrast to the model results for more dynamically disturbed winters which show a larger loss outside the vortex, and less contrast with the in-vortex depletion. Thus modelling in THESEO, including studies of earlier winters in the 1990s, has shown that there is a significant and important connection between polar and middle latitude ozone loss. A cold, stable vortex favours large polar loss with little connection with middle latitudes but in more disturbed winters polar loss, and polar processing, contribute to middle latitude decline.

The results from THESEO thus confirm that both in-situ and polar processes contribute to the halogen-induced ozone loss over mid-latitudes. The relative contributions vary from year to year and depend on factors such as the stratospheric temperatures over mid-latitudes and the strength and temperatures of the Arctic vortex.

Chemical studies

A number of chemical studies were presented at the meeting, based on laboratory and modelling studies as well as field observations. One issue, which has received particular attention in the last couple of years, is the role of bromine in the chemical destruction of ozone.

Bromine monoxide was extensively monitored during THESEO by means of UV-visible spectrometers operated from the ground, balloon and satellite (ERS-2/GOME). Altogether these observations form a data set of unprecedented completeness, which have been used to test our current understanding of the stratospheric bromine chemistry at various latitudes, seasons, and time of the day. Comparisons with calculations by 3D chemical transport models reveal a good overall degree of agreement between modelled and observed stratospheric BrO amounts, and their variations. For example, the latitudinal and seasonal variability of BrO columns and profiles are well reproduced. Balloon profile measurements have shown that bromine is activated (about 60% in BrO during daytime) at all latitudes and seasons. Most column changes previously reported from ground or satellite observations are therefore due to transport (vertical displacement of the stratosphere) and not to chemistry. The variability is well reproduced by 3D CTM models, as well as signatures of chlorine activation occasionally observed in twilight BrO columns and explained in the model by the formation of the photolabile BrCl. Finally there is now agreement with respect to the total amount of bromine derived from source gas measurements and the value inferred from BrO measurements, with the inclusion of short-lived compounds such as bromoform give a total of about 20pptv.

The good overall agreement gives us confidence that current models can be used for an assessment of the role of bromine in mid-latitude ozone loss. However some discrepancies between model and observations still exist which require further study, e.g. the behaviour of morning to evening column amounts ratios not well reproduced at all ground-based stations, and the partitioning between bromine species is controlled by NO₂ which is largely underestimated by the models in the LS.

The observed NO_x concentrations in the LS are still significantly larger than those modelled. Recent revisions of laboratory data of chemical reaction rates have reduced the differences in modelled and measured concentrations as well as in the delay in the NO_x recovery at spring, but there are still significant disagree-

ments. Models still fail to capture the presence of NO_x at spring in the lowermost stratosphere as in the model there is fast conversion of HNO₃ on cold aerosol in contrast to observations. Since the discrepancy is similar every year in the long series of profiles started in 1992 when the aerosol loading was 10 times larger, the likely explanation would be in the NO_x gas phase chemistry at lower temperature which requires to be revisited.

Indirect evidence of chlorine activation has been obtained from aircraft measurements in the lowermost stratosphere by the observation of anomalously enhanced CO/C₂H₆ ratios. The measurements also confirmed the presence of subvisible cirrus above the tropopause, suggesting that local chlorine activation has taken place on cirrus crystals. Furthermore, a chemistry box-model and a three-dimensional chemistry-transport model were used to investigate the photochemical effects of enhanced ice particle surface areas in the lowermost stratosphere. It appears that ice particles in the lowermost stratosphere can cause chlorine activation and chemical O₃ loss during most of the year, not only limited to the cold seasons (winter and early spring). Low temperatures thus do not seem to be a prerequisite for chlorine activation, as long as a significant reactive particle surface is present. The combination of heterogeneous chlorine activation with UV light intensity may play a significant role in local chemical O₃ loss in the (sub-) tropical lowermost stratosphere.

Transport and mixing

The relatively high temperatures in the Arctic regions during the 1997/98 and 1998/99 winters were associated with a very disturbed vortex, unstable and often displaced from the high latitudes. These disturbed conditions resulted in extensive exchange of air between the vortex and mid-latitudes throughout the two winters. Specific studies investigated mixing processes between the different latitude regions (and in the UT/LS region) and their impact on mid-latitude ozone evolution. Results and analyses from studies of polar erosion, mixing of air from the sub-tropical UT/LS were presented. They were based on a combination of aircraft measurements in the LS and ground-based and ozonesonde measurements made on alert inside the filamented airmasses. New numerical tools were developed in parallel, efficiently supporting the analysis of the data. A good set of case studies during the two THESEO winters has been assembled as well as the results from the STREAM 98 campaign in Canada in summer 1998.

In-situ tracer measurements with balloon-borne samplers were made in winter and spring 1998/99 in order to investigate the extent of mixing between polar vortex air and mid-latitude air. The tracer data are being compared with similar measurements which were carried out in winter and spring 1996/97, when the polar vortex was extraordinarily robust in March and April persisting through early May. Inside the winter Arctic polar vortex "old" air masses (in terms of mean age and photochemical exposure time) descended from the upper stratosphere/lower mesosphere along with diabatic cooling. After the break-up of the polar vortex, blobs of vortex air can maintain their integrity for up to one or two months and can be advected to lower latitudes, as observed in measurements made at the end of June in 1997 over Gap (Southern France, 44°N).

The results of studies on large-scale transport and stratospheric ozone as calculated by CTMs were presented. The use of tracer relations allowed to investigate the age of air and how well the mixing is simulated by the models. Comparisons with measurements (long-lived tracers) provide a good test of model transport (e.g. descent). New theoretical approaches are being developed (such as effective diffusivity to investigate mixing processes).

Tropical studies

Several studies have concentrated on the processes specific to the tropical regions. The results of a large-field campaign (APE-THESEO) involving the high-flying M55 Geophysica and the DLR Falcon revealed the existence of a very cold tropopause and of a very broad ozone tropopause over the west Indian Ocean. A report of activities within APE-THESEO is presented elsewhere in this Newsletter (p. 18).

Satellite cloud data and real-time aerosol lidar data from the DLR Falcon aircraft were used to guide the M55 Geophysica aircraft, which thus was able to penetrate the thunder cloud anvils and sub-visible cirrus so the in-situ trace gas and particle measurements were made to complement the remote measurements from the lidar. Measurements from both aircraft showed the existence of very thin sub-

visible cirrus which extended over considerable distances. This was something of a puzzle as the observed clouds existed across too large a temperature range for the cirrus to consist of ice particles. Preliminary analyses of measurements from a new instrument indicate the presence of HNO_3 in the condensed phase. Model calculations based on measurements from several instruments and on laboratory data indicate that the particles are made of nitric acid trihydrate, the normally polar particles.

For the first time a large amount of in-situ tracer observations was obtained in the tropical UT/LS between the equator and 20°S during the deployment of the M55 Geophysica aircraft in February/March 1999 from the Seychelles (5°S). A newly developed in-situ gas chromatograph provided measurements of a variety of long-lived tracers (N_2O , F12, F11, H-1211, SF_6) along with high resolution CO_2 measurements by an integrated infrared analyser. The vertical profiles and tracer correlations with ozone in the tropical LS reveal that most of the air sampled has slowly ascended from the tropical tropopause largely, though not completely, in isolation from midlatitude air. In one flight, however, a recent intrusion of southern mid-latitude air to 11°S at 19km altitude is apparent. In the upper troposphere (UT) a weak north-south gradient is observed for tracers with significant inter-hemispheric differences at the surface, suggesting that air masses from the two hemispheres ascending within the Inter-Tropical Convergence Zone (ITCZ) have not completely mixed by the time they reach the stratosphere.

Climate change and the stratosphere

A field of growing importance is the interaction between climate change and the stratosphere with a number of chemical and dynamic factors coming into play. Several long-term changes in the stratosphere have been detected, associated (though possibly not uniquely) with the ozone changes. A long-term negative trend in the temperatures has been calculated at high latitudes. A consequently stronger vortex would then extend longer in spring. Clearly the variability of the Arctic stratosphere (as evidenced in the last few years) makes it hard to distinguish trends from natural variability.

However a colder vortex would lead to greater ozone loss for a given halogen loading and so delay the anticipated ozone recovery as halogen levels fall. This effect may be enhanced by micro-physical processes such as greater sedimentation with consequently longer periods of ozone loss.

Changes in N_2O columns measured over the Jungfraujoch since the 1950s coupled with in-situ N_2O measurements indicate an increase in tropopause height consistent with the increase measured since the late 1960s at Hohenpeissenberg. This increase in tropopause height has occurred over much of Europe and has affected ozone amounts over Europe. An analysis of total ozone measurements at Hohenpeissenberg indicates that part of the ozone trend observed there is related to changes in tropospheric circulation related to the Polar-Eurasia teleconnection pattern; and an analysis of ozone measurements from Switzerland also reveals a significant dynamic contribution to the observed ozone trend, although in this case the dynamic connection is ascribed to the North Atlantic Oscillation. Further work is needed to understand whether this is a regional phenomenon or whether there are implications at the hemispheric and global scales and whether it results from natural variability or climate change.

THESEO 2000

The results from THESEO presented here are the product of on-going research and further analysis is being made, particularly of the results at mid-latitudes where the interplay of chemistry and dynamics is subtle, yet important. A number of the projects in THESEO have been extended to include the 1999/2000 winter. Some of the research in THESEO required cold conditions (e.g. the measurements of the chemical composition of PSCs) and the extension means that these can be addressed further. A new project is also being supported through the EC FP5 programme. These projects comprise THESEO 2000. A close collaboration has been forged between THESEO 2000 and the NASA SOLVE campaign which is studying Arctic ozone loss in this winter. The results from these two campaigns and the further results from THESEO will greatly add to our understanding of ozone loss at mid and high latitudes in the northern hemisphere.

New on the SPARC web site

The full meaning of the acronyms and abbreviations used in this newsletter can be found on the SPARC web page : <http://www.aero.jussieu.fr/~sparc/Acronyms.html>

Future SPARC and SPARC-Related Meetings

25-29 April 2000: EGS General Assembly, Nice, France. (<http://www.copernicus.org/EGS/egsga/nice00/nice00.htm>).

ST2. Open Session on the Middle Atmosphere. Convener: M. Dameris.

ST6. Processes and Issues of the UT and LS. **01.** New chemistry of the upper troposphere. Convener: J.N. Crowley.

02. Stratosphere-Troposphere Exchange. Convener: V. Wirth. **03.** The Impact of Aviation upon the Atmosphere. Convener: R. Sausen.

ST7. Atmospheric Chemistry-Climate Interaction. Convener: M. Dameris.

ST8. Atmospheric Ozone (global, polar, tropospheric, urban, related constituents). Convener: M.-M. Hirschberg.

ST9. 02. New Chemistry of the Atmosphere (Middle Atmosphere). Convener: S.S. Prasad.

OA28. Tropospheric Aerosols: Formation and Heterogeneous Chemistry. Convener: C. George.

3-8 July 2000: Quadriennial Ozone Symposium "Sapporo 2000", Hokkaido University, Sapporo, Japan (<http://www.eorc.nasda.go.jp/AtmChem/O3symp/>).

16-23 July 2000: 33rd COSPAR Scientific Assembly, Warsaw, Poland. (<http://www.cospar2000.pl/>).

A1.3/C2.8. Contribution of Remote Sensing of the UT and Stratosphere to Understanding Climate Change. J. Gille (gille@ncar.ucar.edu), 19-20 July 2000.

C2.1. Ozone Variations of Solar Origin (J. Lastovicka).

C2.3/A1.4. Middle Atmosphere Spatial Structures (K.U. Grossmann).

C2.4. Spatial and Temporal Variations in Gravity Waves (G.R. Swenson).

C2.5. Aerosols, Dust and Layers in the Middle Atmosphere (T.A. Blix).

C4.2. CIRA Part III: Supplements: Additional Reference Atmospheres for Trace Constituents (G.M. Keating).

2-6 October 2000: First S-Ramp Conference, Sapporo, Japan (<http://www.kurasc.kyoto-u.ac.jp/s-ramp/>).

S17. Middle Atmosphere Including Response to Forcing from Above and Below (M. Geller and T. Tsuda). (dynamics, chemistry, tropospheric wave forcing, response to Sun and energetic particle effects, observations, modelling, laboratory results, chemistry/radiation/dynamics coupling).

S18. Solar Variability Effects Upon the Lower Atmosphere and Climate (L. Hood and J. Austin).

(External energy flux variability, its effects on middle and lower atmosphere, models to simulate these effects and identify mechanisms, 27-day and 11-year period effects, interaction with QBO).

6-10 November 2000: 2nd SPARC General Assembly "SPARC 2000", Mar del Plata, Argentina.

Chair of the SOC: Alan O'Neill. Chair of the LOC: Pablo Canziani. (<http://www.sparc2000.at.fcen.uba.ar/>).

1. Stratospheric Processes and Their Role in Climate.

2. Stratospheric Indicators of Climate Change.

3. Modelling and Diagnosis of Stratospheric Effects on Climate.

4. UV Observations and Modelling.

10-18 July, 2001: IAMAS 2001, Innsbruck, Austria (<http://iamas.org>).

- Symposium "Middle Atmosphere Dynamics", 7 days, Lead Convener: K. Hamilton, Co-conveners: T. Hirooka, B. Lawrence, F.-J. Luebken, L. Hood (turbulence, GW, planetary waves, tides, forcing of mean circulation, long-term variability, mesospheric layered phenomena, MA aspects of climate change).

- Symposium "MA Chemistry, Transport and Radiation", 6 days, Lead Convener: A.R. Ravishankara, Co-conveners: N. Harris, V. Fomichev, D.W. Waugh (observations, models, transport relevant to understanding chemistry, aerosol microphysics, MA climate-chemistry interactions, energy budget of the MLT-layer).

- Workshop "Solar Cycle Forcing of the Stratosphere and Troposphere", 1 day. Convener: L. Hood (possible mechanisms: solar UV variability, energetic particle precipitation, etc.).

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