SPARC

STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE

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Report on the 29th Session of the JSC of the WCRP

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Introduction

The annual JSC meetings are the occasions where progress in the various WCRP activities are discussed, connections between the different activities are highlighted or stimulated, and where the strategic direction of WCRP is examined, together with its links to other international research programmes.

The 29th session marked a number of changes both in WCRP management and JSC composition. The new director, Ghassem Asrar, was introduced at the meeting by the outgoing Chair, **J. Church**. In a short introductory presentation, **G. Asrar** noted the importance of the overarching aims of the meeting, which were to:

(a) address the future of WCRP and the implementation of the WCRP Strategic Framework (COPES, Coordinated Observation & Prediction of the Earth System),

(b) prepare for the Sponsors'/Funders' review of WCRP and the Earth System Science Partnership (ESSP) during the coming year.

Two key objectives were proposed for the meeting:

(1) to ensure that the WCRP has adequate support (commitment, people, funding) to implement the strategy and engage the sponsors in defining its future path and,

(2) to seek the JSC's guidance on ways for the WCRP to continue providing benefits to scientists and sponsors that would not have accrued if it did not exist.

The agenda for the JSC meeting was very extensive and wide-ranging, with presentations and discussions on the whole range of activities, panels, working groups, and projects that are part of the WCRP. In the interest of brevity, we will report only on decisions and deliberations pertaining to SPARC and related cross-cutting activities, of which "Atmospheric Chemistry and Climate (AC&C)" is currently the most relevant.

The new JSC Chair, Tony Busalacchi of the University of Maryland, and Vice-Chair, David Griggs of Monash University, were elected at the meeting.

The evolution of the WCRP

Last year's JSC report (SPARC Newsletter No. 29) discussed a number of challenges facing the WCRP. While these challenges remain, there was a distinct mood of optimism at this year's JSC meeting, and a vigour to move ahead proactively. Over the past year it seems to have become an accepted consensus that by 2013, current WCRP core projects and working groups — most of which will then have been in existence for 20 years or more — will have wound up, and WCRP activities will have been reconfigured in a way that better serves the mission of the WCRP and the future needs of society. This is not to fault the existing structure, but recognises that the world of climate science has changed dramatically in the last 20 years. In particular, there is a perception by many governments that the science of climate is "done" and that it is now time to move on to applications, such as dealing with the impacts of climate change. We climate scientists know that this is not the case, but clearly the onus is on us to make the link between climate research and the quantification of uncertainties in climate predictions and projections that policy-makers (and all users of climate information) are asking from us. In other words, we need to demonstrate the benefits of climate research in a very tangible way.

The COPES framework which was developed several years ago had already envisaged such an "end to end" approach to climate research, and has been reaffirmed as the operative Strategic Plan for WCRP. However, COPES is really only a framework; the challenge now is to develop, over the next five years, a detailed implementation plan for the next decade or more. Various cross-cutting initiatives (such as AC&C) have been introduced during the last few years with the aim of playing an important evolutionary role, helping to chart out new synergies and directions. The JSC meeting was structured to facilitate this process, with presentations from cross-cutting initiatives, core projects, and panels and working groups.

Report on SPARC and on AC&C

The SPARC co-chairs presented the report on SPARC by first providing some general background on the development of this WCRP core project, which began with an orientation towards stratospheric dynamics, but over time developed an equally strong focus on stratospheric chemistry, including links to the International Global Atmospheric Chemistry Project (IGAC, a core project of IGBP). In this context the important roles of SPARC's Climate-Chemistry Model Validation activity (CCMVal) and of the cross-cutting "Atmospheric Chemistry and Climate" activity (AC&C), were highlighted. The co-chairs briefly addressed the status of the various activities within SPARC: DynVar and its focus on how stratospheric representation in GCMs affects tropospheric climate, variability, and climate responses; the Tropical Tropopause Layer initiative strengthening SPARC/IGAC/GEWEX links, *e.g.* with respect to cloud-resolving modelling and the new water vapour activities such as the AquaVIT campaign in the AIDA cloud chamber; the rejuvenated SPARC Gravity-Wave Activity, which held its kick-off meeting in conjunction with the DynVar workshop earlier this year; the SPARC Tropopause Initiative, fostering work on the tropical and extratropical tropopause layers; and the SPARC Workshop on Ozone Recovery, which took place in May 2008.

The report provided a representative image of our vibrant project. It was also mentioned that while the Fourth IPCC Assessment Report (AR4) had an unprecedented level of "SPARC-friendly" authorship, there was a discrepancy between what the AR4 says in terms of understanding and what is in the models. For the upcoming IPCC activities, we need to show modelling groups that the stratosphere is relevant if they are going to commit resources to it, and we need to provide information in a user friendly way (*e.g.* calculate forcings, give advice on model resolution). Some key gaps are: the necessary update of stratospheric ozone (last update was for the IPCC TAR), the uncertainties in stratospheric water vapour, the lacking evaluation of solar effects on chemistry, and the requirement to relate stratospheric changes to regional surface changes not just in Antarctica, but in other regions as well.

The report on AC&C was given by **A.R. Ravishankara**, coauthored by Phil Rasch and Sarah Doherty from IGAC. AC&C is a cross-cutting initiative run by SPARC and IGAC on behalf of WCRP and IGBP, respectively. Its goal is to improve the understanding and representation of chemical processes in climate. The main objectives of AC&C are: (1) understanding the role of emissions on atmospheric composition, (2) linking the concentrations to radiative forcings and climate change, and (3) improving the representation of related processes in models. AC&C is strongly tied to CCMVal. Furthermore, it builds on existing activities such as AeroCom, HTAP, and ACCENT, adding value to all of these activities. With its topic "TropChem," AC&C will focus on key tropospheric chemistry processes. The emphasis in Phase 1 of the initiative is on modelling of aerosols (formation, transformations, cloud interaction, photolysis, and reactivity), ozone and deposition processes and emissions (the latter mostly with GEIA), with a focus on distributions in the free troposphere, from 5 km up to the tropopause.

Several proposals were made on how AC&C could interact with other groups. Possible candidates were the iLEAPS/IGAC/GEWEX initiative "Aerosols, Clouds, Precipitation and Climate" (ACPC) and the Global Atmosphere Watch (GAW) programme. However, given the limited resources it was also noted that keeping the existing level of commitment of the scientists involved was of primary importance.

The JSC recognised that both SPARC and AC&C are working well. The JSC affirmed SPARC's approach to identify "bite sized" deliverables in a well-defined strategic plan, and endorsed its 2007 results and its plans for 2008, noting especially the valuable contribution to the 2006 WMO/UNEP Scientific Assessment of Stratospheric Ozone Depletion. The increasingly close collaboration between SPARC and IGAC, including coordination of the SPARC General Assembly and the IGAC Conference in 2008, and possible joint SPARC SSG/IGAC SSC meetings in 2009, was welcomed. The general recognition that AC&C was working very well was reinforced by **K. Noone**, Director of the IGBP, who was enthusiastic about AC&C from both a scientific and organisational perspective. The JSC was of the opinion that AC&C provided a good model for a WCRP/ESSP cross-cut.

In the following we highlight a few central discussion points resulting from the reports on SPARC and AC&C during the JSC.

Discussion on Geoengineering Proposals

The SPARC co-chairs reported on the discussion of geoengineering proposals that took place at the last SPARC SSG meeting (SPARC Newsletter No. 30), which was stimulated by an editorial essay by Paul Crutzen (Crutzen, 2006). In a short but intense debate, the SPARC SSG had addressed the potential advantages and the various concerns about harmful side effects that such a measure, if indeed viable, may have. They concluded that this proposal *may* turn out to be an option to ameliorate climate change, but for the moment it remains merely a substantially unexplored idea.

This prompted the JSC to discuss the position of the WCRP with respect to the various geoengineering proposals, and stirred discussion of the pros and cons. Some members wondered whether the whole issue should be considered at all within the WCRP, since research on such proposals could be easily misinterpreted by external parties as an inherent interest in actually pursuing a geoengineering approach. However, others expressed the view that research on geoengineering would proceed whether the WCRP became involved or not, and that therefore the WCRP was better off assessing existing and upcoming work, and forming an authoritative opinion on the topic.

A consensus emerged among JSC members that there was a need to review the subject in a comprehensive way before determining WCRP's approach to it. It was decided to invite leading scientists on this subject to the next JSC session, and to create a small group to collect information, document ideas, and suggest a way forward for WCRP in this area. All WCRP working groups, panels, and projects were asked to put the issue of geoengineering on their agendas and report the outcomes of their discussions to the JSC. Concerning the specific proposal of an albedo enhancement by stratospheric sulphur injections, SPARC and WGCM agreed to consider common possibilities in this respect during the upcoming WGCM annual meeting in September in Paris. CCMVal might be a good platform for investigations on the topic, but existing obligations of the CCMVal modelling groups in supporting the upcoming WMO/UNEP and IPCC assessments on ozone and climate, respectively, need to be considered carefully and must not be jeopardised.

Polar Activities beyond the International Polar Year

In the SPARC presentation, the role of the polar regions in climate was raised as an interesting and important cross-cutting scientific topic. There is currently no consensus from CCMs as to whether climate change will act to warm or cool the polar lower stratosphere in the two hemispheres. Dynamical variability of the stratospheric polar vortex is large and exhibits considerable decadal power, whose mechanisms are poorly understood. This makes the detection and attribution of long-term changes a challenge, certainly in the real atmosphere but even in models. This high degree of dynamical variability seems to be linked to the sensitivity of the stratospheric polar response to climate change.

Yet dynamical variability in the polar vortex represents a key mechanism of stratosphere-troposphere coupling. Because the polar regions also exhibit the largest ozone depletion, chemical-dynamical coupling is highly nonlinear in this region. For the same reasons, the polar regions exhibit the strongest feedback of ozone depletion on climate; indeed, the delay in the breakdown of the Antarctic vortex in late spring represents the one unambiguous example of the impact of ozone depletion on the stratospheric circulation, with surface manifestations. Recent studies have shown that the strengthening of the Southern Annular Mode over the last few decades, with cooling of the Antarctic plateau and warming of the peninsula, can be expected to reverse in response to the recovery of the Antarctic ozone hole.

The rapid melting of Arctic sea ice points to the major differences between the response of the two polar regions to climate change, and has potential ramifications in terms of stratosphere-troposphere coupling. There is strengthening evidence of tropical-polar coupling within the stratosphere, and even evidence of inter-hemispheric coupling. Thus, the polar regions represent key elements within the global climate system, with highly nonlinear aspects involving strong chemistry-climate coupling. For all these reasons, it seems that the role of the poles in global climate would be a valuable focal point of research across WCRP. While there is a lot of polar research being carried out (*e.g.* WCRP CliC and IPY — including significant SPARC IPY activities) it does not necessarily have a global perspective. Thus, the JSC welcomed this suggestion and set up a small *ad hoc* working group, to develop the ideas further and possibly organise a focused WCRP workshop on the topic.

Model Metrics

A final aspect of the SPARC presentation which elicited considerable discussion was that of model metrics, or "grading." It was noted that the issue had come up at the CCMVal workshop in 2007, and that the intention was to try to apply the approach in the CCMVal report. The issue of model metrics has also come up in tropospheric climate modelling, where it is no less controversial, and it was therefore no surprise that a lively discussion ensued. While everybody seems to agree that metrics are needed, there is concern about making sure they are done right, and don't just turn into a "beauty contest."

However, there is no doubt that metrics can quantify and document model improvements, to demonstrate steady progress over time. Furthermore, decision-makers are increasingly asking for climate projections — with uncertainties. The responsibility is on scientists to provide the best possible information. Using the spread of model projections as an estimate of uncertainty, as is the usual current practice, has little (if any) scientific justification. Thus in spite of potential misgivings, the scientific community is obligated to tackle the question of metrics in order to provide the best quality scientific information. In fact the issue should really be viewed as that of quantifying scientific uncertainty, rather than grading models. From this perspective, no model should be excluded from contributing to a community consensus; but likewise, no model should have the right to have an undue influence on the result.

In terms of "doing it right", CCMVal is arguably leading the way with its focus on process-oriented diagnostics as the basis for model metrics, and involving the measurement and process-oriented communities in the model assessment. The upcoming CCMVal report will be an interesting experiment in whether the concept of using diagnostic-based metrics to quantify the uncertainty in model projections can be applied in a way that achieves broad community assent.

Challenges Ahead

The SPARC International Project Office is currently funded from the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS), for which we are very grateful. However, this support will end in 2010 with no current prospect for renewal. We have started to investigate possible new resources. In doing so SPARC also needs to avoid imposing too much overhead on all involved scientists. Independent of its office, SPARC science will likely need a new long-term "home" after the anticipated restructuring of WCRP, while new scientific issues will continue to arise.

Challenges facing AC&C are to establish a timeline by which information will be fed into assessments (*e.g.* the next WMO/UNEP and IPCC reports), the difficulty of dealing with high pollution episodes in global chemistry models, and to establish links with human health issues which may be important. (This would provide an important input into IPCC Working Group II.) Another challenge for AC&C is a need to enhance its visibility through the briefing of national programme coordinators and funding agencies, to ensure the needed attention and support from various countries.

Seasonal and Decadal Scale Prediction

(a) Seasonal Prediction

In 2005, the WCRP commissioned the Task Force on Seasonal Prediction (TFSP) to assess, over a two-year period, current seasonal prediction capabilities in reference to a range of practical applications. As part of the assessment process the TFSP, in collaboration with WCRP core projects and working groups, organised the First WCRP Seasonal Prediction Workshop (Barcelona, June 2007). Outcomes of this workshop were discussed at the JSC meeting and are summarised in the companion article by Kirtman *et al*., in this newsletter, which also highlights the importance of stratospheric processes in seasonal prediction. Within WCRP, the mandate of the TFSP is now being carried forward by the CLIVAR Working Group on Seasonal and Interannual Prediction (WGSIP). The activities of WGSIP complement a wide range of other activities within the WMO dealing with various aspects of seasonal prediction and its applications.

The Coupled Historical Forecast Project, now being carried out under the auspices of WGSIP, is one of the continuing projects initiated by the TFSP. Several modelling groups are undertaking numerical experiments designed to address a number of issues including (a) providing a reference for the skill of today's seasonal forecasts, (b) aiding the development of multi-model forecasting techniques, (c) enabling users to start working with numerical seasonal forecast data, and (d) establishing controls for sensitivity experiments.

T. Palmer, who presented the report on seasonal prediction, called on SPARC to provide input to this project.

(b) Decadal Prediction

The current WCRP activity on decadal predictability is being carried out mostly through a WGCM/WGSIP *ad hoc* group led by Gabriele Hegerl. The current activities of the group include assessing the skill of available decadal predictions. Two main objectives are to achieve useful decadal scale predictions of up to 30 years and to develop the science of multi-decadal prediction in the context of a changing climate.

One of the impressions that emerged from the discussion of this topic is that decadal prediction may well become a key feature of the future WCRP notwithstanding some significant challenges, such as the limitations of coupled models and computing resources, and the (currently) weak involvement of young scientists.

Since stratospheric and tropospheric variability are linked on seasonal and longer time scales through a wide range of mechanisms and modes of variability, seasonal and decadal scale prediction are important topics for SPARC. This perception motivated the discussion of variability at the last SSG meeting (SPARC Newsletter No. 30), and is also addressed in the companion article by Keenlyside *et al*., in the current newsletter.

(c) Climate Extremes

A special session on Climate Extremes was held during the JSC meeting. The session was comprised of a number of presentations and concluded with a panel discussion, chaired by Gordon McBean, on the topic of where WCRP should focus its research efforts. The presentations included discussions of various conceptual and practical issues associated with identifying, quantifying, and predicting extreme events. Reports on recent meetings, workshops and other activities included:

(a) the Forum of the US National Academy of Sciences on Extreme Events in a Changing Climate (held in September, 2007 and discussed by **T. Busalacchi**),
(b) climate extremes and the reinsurance industry (how can weather/climate research be integrated into catastrophe modelling? (discussed by **J. Slingo**),
(c) the Joint CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) facilitating international collaboration on climate change detection and, together with relevant programmes (*e.g*. GCOS/WCRP Atmospheric Observation Panel for Climate) and WMO Technical Commissions, identifying observational needs for climate change detection (discussed by **P. Bessemoulin**),
(d) the new ICSU Programme "Integrated Research on Disaster Risk (IRDR)", which aims at addressing the challenges posed by natural and human induced environmental hazards (discussed by **G. McBean**).

The presentations and panel discussion highlighted many of the challenges that should be addressed by future WCRP activities in identifying, studying, and predicting extremes. Among these are: developing meaningful definitions and indices of extremes; evaluating the ability of current models to represent extremes (very long time series of observations and large ensembles of model predictions are needed to address this question); and translating knowledge, analyses, and predictions into useful products. Future needs to address these challenges include: high-end computing power for addressing the modelling of climate extremes; improvement of climate model physics to make the models capable of capturing the processes involved in the formation of extremes; attracting the attention of governments to the need for developing the science and investing in corresponding services; and accounting for events that are so rare that the current observing system is not suitable for evaluating them, for example, tropical cyclones in the Southern Hemisphere.

All of the above issues are also relevant for extreme events in the stratosphere, where the challenges are perhaps greater than for the troposphere. Characterising stratospheric dynamical variability on seasonal and decadal time scales, a major focus of the SPARC DynVar activity, is a necessary first step toward being able to identify extreme events.

An action item emerging from this discussion was to form a task force on Climate Extremes including representation from all of the WCRP core projects to determine foci and deliverables for this cross-cutting activity, and establish links with the WMO Climate Watch Programme.

Activities of WCRP Panels and Working Groups

As noted in the introduction, there were presentations by all of the WCRP panels and working groups. Here we summarise only those aspects that we deem to be of most interest to SPARC.

The WCRP Modelling Panel (WMP) and the Modelling Summit

Organising the World Modelling Summit for Climate Prediction (May 6-9, 2008, at ECMWF) was a major preoccupation of the WMP during the past year. This meeting was cosponsored by WCRP, the World Weather Research Programme (WWRP), and the International Geosphere Biosphere Program (IGBP). Among the key goals of the Summit were: (a) assessing the capability of current modelling systems to address future climate prediction needs and expectations, and (b) developing a strategy to accelerate progress in modelling and predicting regional climate variations and changes from days to decades.

The discussion on the Summit preparations and expected outcomes was wide ranging and brought forward a number of questions concerning the focus of future model development. For example, how much of the available and future resources for modelling should be devoted to improving representation of the "physical" aspects of the climate system, and how much to enhancing resolution and improving numerical accuracy? There is a perceived need to consider the full Earth System in the development of climate models. A desirable outcome of the Summit is to define a stepwise approach that recognises the need to develop a broad modelling perspective that will include biogeochemical elements, and address economic and social issues in the future. An immediate action following the Summit will be the formation of a team to develop a mission statement based on the Modelling Summit, determine what will need to be done to implement this vision, and use it as input to the Third World Climate Conference (WCC3). This statement will be included in the report of the Summit that will be produced in the coming months and included in a future SPARC Newsletter.

The Working Group on Coupled Models (WGCM)

A major focus of SPARC CCMVal over the past several years has been supporting the 2006 WMO/UNEP Ozone Assessment. In a similar capacity, a major focus of the WGCM has been to support the IPCC AR4. In carrying out these supporting activities, both groups have employed similar modelling strategies and in many cases common model components at the same modelling centres. This has led to increasing interaction and cooperation between WGCM and SPARC in regard to modelling activities. Future WGCM activities will continue to include coordinating climate prediction experiments under the agreed scenarios in support of future IPCC Assessments.

Future WGCM activities aimed at climate model improvements are expected to include cloud feedbacks, the carbon cycle, and development of climate model metrics. It is expected that WGCM will extend its scope to contribute to development and improvement of ice sheet models, regional models, and prediction of air quality (together with AC&C). WGCM serves the community that studies climate change impacts and future emphases will be on decadal time scales, and providing input to climate projection downscaling.

Future directions

In the short term, the COPES framework will represent the Strategic Plan for WCRP. It defines criteria for evaluation of the effectiveness of all WCRP activities. Crosscutting activities will be managed by the core projects, with oversight committees to provide advice and guidance. The new WCRP Director will be putting together an "accomplishments" document with up-to-date examples, to sell the programme to funders. This can also be used to provide input to the WCC3 in 2009. This exercise needs to be used to align all WCRP activities more closely with the COPES framework, and position WCRP for the future.

In the long term (post-2013), there is a consensus that the activities of WCRP will need to be restructured to better serve the needs of society. At the JSC meeting, the U.S. CLIVAR restructuring was presented as a possible model to consider. (This consists of three coordinating panels: (1) process studies and model improvement; (2) predictability, prediction and applications interface; (3) observations and synthesis. Working Groups with limited lifetimes focus on topical issues (*e.g.* salinity, MJO, drought).) All projects are now being asked what functions will need to be maintained post-2013, and what science issues are emerging. All JSC members are being asked to list the three most important functions or capabilities of WCRP, and to suggest a possible new structure with no more than five elements. During the coming year, ideas will ferment. It is of course important that input be received from the grassroots, because to be successful the new WCRP structure must resonate with both scientists and national funding agencies, who actually carry WCRP science forward.

While at this time last year there was much preoccupation with the possibility of a merger between WCRP and IGBP, the sense now is that WCRP's core mission remains valid — to determine and improve the predictability of climate (*i.e.* quantify the uncertainty in climate predictions) and to quantify and mitigate the impact of anthropogenic activity on climate — and that our first priority is to improve WCRP, before considering how WCRP and IGBP might work more closely together.

At the SPARC General Assembly in Bologna, we will have an informal session to help facilitate this discussion about the future of WCRP within the SPARC community. While to a young scientist such "science by committee" may seem boring compared with actually doing science, the existence of international coordinating bodies such as SPARC is enormously helpful to facilitate the best research, and it is in all of our interests to play a role in this discussion. So we look forward to your involvement.

References

Cruzen, P.J., 2006: Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma?, *Climatic Change*, 77, 211-220.

New SPARC Project: Gravity Wave Momentum Budget for Global Circulation Studies

26-27 March 2008, Toronto, Canada

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A new SPARC project has been initiated to take advantage of a number of recent developments in satellite observations, modelling, and data assimilation that begin to quantify the role of gravity waves in the forcing of the global circulation. A small workshop was held at the University of Toronto in Canada March 26-27 to initiate and plan the new project.

Background

Small-scale atmospheric waves, called gravity waves or buoyancy waves, have sources in the troposphere such as flow over topography, convection, and jet imbalance. As these waves propagate upward, they play an important role in the atmospheric circulation at altitudes near the tropopause, and well above in the stratosphere and mesosphere. Global circulation models used for weather and climate forecasting derive the unresolved gravity wave momentum forcing terms for the momentum equations from parameterizations that must make assumptions about the wave properties. These assumptions are effectively tuning parameters, to adjust the circulation and temperature structure in the upper troposphere and middle atmosphere. Different models have different goals and apply different types of parameterizations with unique tunings. For example, ozone forecasting models use non-orographic gravity wave parameterizations to adjust their stratospheric circulation and polar temperatures sufficiently to allow realistic ozone chemistry to occur, while weather forecasting models have traditionally used mountain wave parameterizations to improve the structure of the winter jets and horizontal temperature gradients near the tropopause. The tuning of gravity wave parameterizations can be laborious for modellers since the parameters themselves are poorly constrained, and, for example, different parameter settings are required whenever model resolution is changed.

Recent Developments

The requirements from observations to constrain the tuning parameters in gravity wave parameterization schemes has been impossible to achieve on the global scale until fairly recently. What is needed is characterisation of the vertical flux of horizontal pseudomomentum, and three-dimensional (3-d) characterisation of the wave properties in order to define their vertical propagation. These three-dimensional properties include horizontal and vertical wavelength, as well as wave propagation direction. In the last decade, this has been achieved using high-resolution satellite observations. However, each individual satellite measurement technique can only observe a portion of the full 3-d spectrum of gravity wave properties. Errors in the derived pseudomomentum flux (approximated as momentum flux in these studies) also remain large for global studies, although local case studies can now be quite accurate. Some very high-resolution global modelling studies that include a middle atmosphere are also now resolving much of the gravity wave spectrum and are being used to study the wave sources, propagation and dissipation, and the momentum forcing of the circulation without the use of any gravity wave parameterizations. In recent years, new methods for inferring the missing momentum forcing due to unresolved waves in lower resolution models have also been developed using advanced data assimilation methods.

Scientific Focus

With these recent developments, we can collectively begin to quantify the role of gravity waves in the momentum budget of the global circulation. We have initiated the SPARC Project on the Gravity Wave Momentum Budget for Global Circulation Studies to bring together experts in these areas and to combine information from these various sources to map out the geography and seasonal variations of the gravity wave terms important to the global momentum budget. The project is initially organised into three components:

(I) Direct observational constraints on gravity wave momentum flux from the lower stratosphere;

(II) Direct simulation of gravity waves and their role in the global circulation at middle atmosphere levels; and

(III) Constraints on gravity wave momentum forcing using assimilation methods.

We solicited speakers for the planning workshop to examine the recent developments in these three areas of focus, and we also enlisted participation from a few members of the global modelling community who will likely put the results of the project to use in future global model studies. A portion of the workshop was held in conjunction with the SPARC DynVar Project, which held its own meeting March 27-28, and which involves numerous members of the middle atmosphere modelling community that will be interested in the results of the gravity wave project.

Meeting Summary

The first session invited several members of the global modelling community to give their perspective on the biggest issues involving gravity waves in global circulation studies.

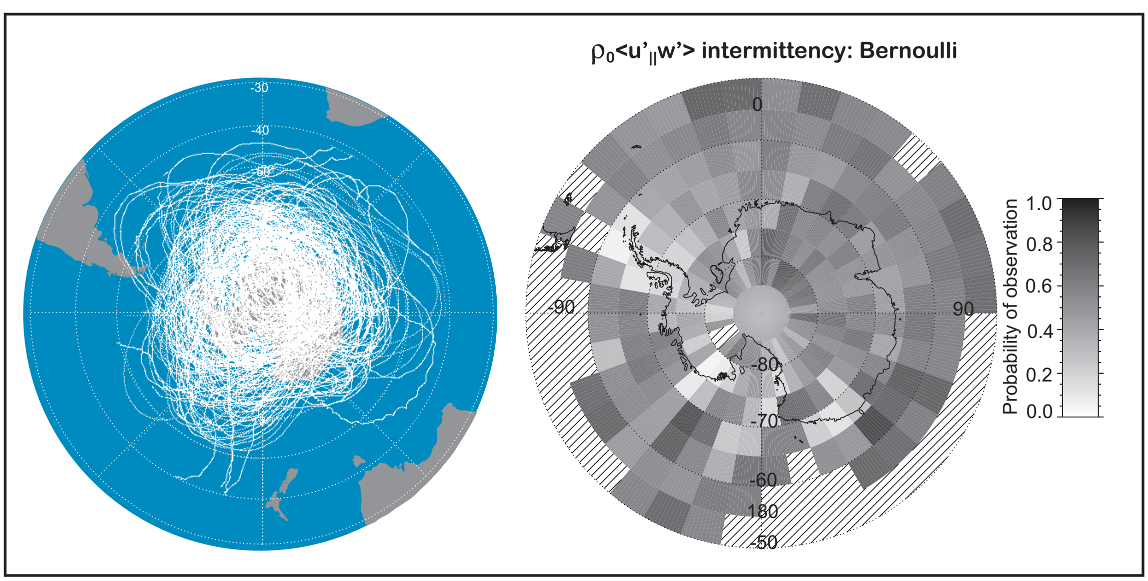
C. McLandress spoke about the role of orographic gravity wave drag in driving the Brewer-Dobson circulation in 140-year climate simulations (CCMVal REF2) performed with the Canadian Middle Atmosphere Model (CMAM). Using the downward mass flux at 70 hPa as an indicator of the strength of the circulation, the simulations showed that orographic gravity wave drag was responsible for 60% of the average 10 kt/yr trend seen in the simulations. The trend in wave drag was not due to changes in wave sources, but was instead associated with changes in the zonal mean circulation near the tropopause. **F. Sassi**

addressed the issue of tuning gravity wave parameterizations in chemistry-climate model studies. He noted that realistic ozone chemistry simulations require not only realistic stratospheric zonal-mean winds and temperatures, but they also require accurate simulation of the timing of the seasonal cycle. He also noted that despite the use of orographic gravity wave schemes in global models for over twenty years, even modest changes in the tuning parameters in these schemes have big effects on model variability. **J. Scinocca** described the tropospheric climate response to doubled CO_2 in models with differing top pressure levels (10 hPa for a low top model and .001 hPa for a high top model). Through carefully controlled experiments, they found that differences in the tuning parameters in the orographic gravity wave drag schemes were responsible for most of the differences in the doubled CO_2 mean sea-level pressure response patterns in models with high tops and low tops. By using identical gravity wave parameters, the high top and low top models gave similar response patterns. **T. Shaw** stressed the importance of conserving momentum and energy in the application of gravity wave parameterizations in global models. In climate change studies, differing portions of the gravity wave momentum flux spectrum may remain at the model upper boundary *(i.e.* the waves are not dissipated before they reach the top of the model atmosphere). These remaining fluxes should be dissipated at or near the upper boundary to conserve momentum and to achieve reliable model responses in climate change studies.

The second session invited presentations on direct observational constraints on gravity wave momentum fluxes in the stratosphere. **J. Alexander** described gravity wave observations from AIRS (Atmospheric Infrared Sounder) and HIRDLS (High Resolution Dynamics Limb Sounder). The different viewing geometry (AIRS using nadir, HIRDLS using limb) make the two measurements sensitive to waves in different parts of the gravity wave spectrum. Global gravity wave momentum fluxes can be inferred from both data sets, but with potentially large errors that make these only reliable lower limit estimates. Case studies using auxilliary information can produce much more accurate momentum flux estimates. **S. Eckermann** discussed AMSU (Advanced Microwave Sounding Unit) observations of gravity waves (see SPARC Newsletter No. 26). These have similar vertical resolution to AIRS, reduced horizontal resolution, and the measurements extend to lower altitudes. AMSU instruments currently fly on 6 satellite platforms that give 12 overpasses per day and much higher temporal resolution than AIRS. AMSU temperature measurements are fully 3-d and allow accurate calculation of gravity wave momentum fluxes. **M. Geller** described constraints for gravity wave parameterizations derived from US high-resolution radiosonde data. These results give information on low-frequency inertia-gravity waves in the lower stratosphere. At mid-latitudes, the zonal momentum flux is negative (roughly 1-3 mPa) with the largest fluxes at mid- to high-latitudes in winter. In summer there are positive zonal momentum fluxes at low- to mid-latitudes. Meridional momentum fluxes are negative at low latitudes (largest in summer) and positive at mid-latitudes (largest in winter). **P. Preusse** described gravity wave momentum fluxes derived from CRISTA (Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere) data and their characterisation of the errors in these estimates. The results showed good agreement with super-pressure long duration balloon estimates of momentum flux. His presentation included general comments on satellite observations of gravity waves with a map of the coverage of the gravity wave spectrum by various satellite instruments. (**Figure 1**, colour plate I)

R. Vincent described gravity wave properties derived from long-duration super-pressure balloon flights near 18-km altitude during the Vorcore campaign at high southern latitudes in spring through late summer. These measurements give reliable vector momentum fluxes versus wave intrinsic phase speed and are very unique in this regard. A momentum flux phase speed spectrum was also derived from this data, although phase speeds tended to be over-estimated. These balloon measurements are sensitive to waves with low to medium frequencies that may have a wide range of horizontal and vertical wavelengths. **A. Hertzog** described information on intermittency in gravity wave momentum fluxes that can be inferred from these balloon measurements. The largest amplitude events exceeded zonal means by a factor of 400. The larger fluxes were associated with flow over the topography of the Antarctic peninsula, but these fluxes also show the highest intermittency. Non-orographic waves over open ocean are associated with weaker fluxes but occur almost nearly continuously. (**Figure 2 and Figure 3**; colour plate I)

Figure 2: The flights of super-pressure balloons from Vorcore (left) and the probability of observation (right), a measure of the intermittent nature of wave events.



S. Eckermann led a focused discussion on constraints for mountain wave parameterizations, noting that major uncertainties remain in the gravity wave momentum flux. Results from recent field campaigns show that surface processes like low-level wind shear, latent heat release, and upstream blocking are all important, however no direct comparisons with parameterized orographic gravity wave fluxes were performed. A proposal to combine satellite observations of mountain wave events with mesoscale model simulations and offline mountain wave parameterization calculations was discussed to better constrain the parameterizations with the newest observations.

A third session focused on high-resolution global model studies of gravity waves and their effects in the middle atmosphere using the Earth Simulator, with horizontal resolution of ~60 km and vertical resolution of 300 m from the surface to 85 km. The presentations described results from a three-year simulation with no parameterized gravity waves. **K. Sato** presented numerous comparisons to observations. The zonal-mean structure and seasonal cycle are very realistic despite the absence of parameterized wave forcing. A QBO-like oscillation with 1.5-yr period appeared in the tropical lower stratosphere with a very realistic semiannual oscillation above in the stratosphere and mesosphere. Wave events from orographic and jet sources show very realistic structure in comparison to observations. Wave momentum fluxes show very similar magnitudes and seasonal cycles compared to radar observations. **S. Watanabe** described the three-dimensional characteristics of the gravity wave drag in the model, and derived the parameters necessary for input to the Hines parameterization. The assumption that waves propagate only in a vertical column (common to all parameterizations) caused significant differences between the high-resolution model drag and the parameterized drag, emphasising the importance of lateral propagation of gravity waves. **Y. Kawatani** described an analysis of the waves that drive the QBO in the model. The equatorially trapped waves in the model show very realistic properties compared to observations. In the westerly shear phase, Kelvin waves dominate the equatorially trapped waves, but wavenumbers 1-11 contribute only 30% of the total QBO forcing. Higher wavenumber gravity waves contribute the remaining 70% with wavenumbers greater than 42 contributing 50%. In the easterly phase, the forcing due to equatorially trapped modes is very small with gravity waves contributing nearly all of the forcing.

The fourth session looked at constraints on gravity wave forcing derived using global data assimilation techniques. **M. Pulido** described the use of 4D-var (four-dimensional variational) assimilation tools with the UK Met Office model. The technique minimises the cost function, described as the mismatch between the observations and the model, using an adjoint model. Using this method, the non-divergent component of the gravity wave drag at stratospheric levels can be estimated with reasonable accuracy. Gravity wave drag versus latitude, longitude, and height at daily time intervals can be derived. **S. Polavarapu** discussed methods to constrain the gravity wave momentum budget using models with a full mesosphere but with observations assimilated only at stratosphere levels and below, noting that the large scales in the mesosphere are predictable due to propagation of information from below. An example using 1D-var at 68°S latitude during the 2002 sudden warming event was shown. Although observations were applied only below 1 hPa, the gravity wave drag in the mesosphere is constrained through its effects on the zonal-mean zonal wind and planetary waves. The momentum flux spectrum input to the chosen gravity wave parameterization can also be constrained with this method.

Results of the Meeting

In the short term, the group decided to prepare a review paper summarising the scientific results presented at the meeting. For 2009, we also plan to hold a focused workshop to assemble observational constraints on the gravity wave momentum flux spectrum from different measurement techniques in the stratosphere. Focus groups on constraints for orographic wave drag and high-resolution global model studies are also planned.

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Report on the Chapman Conference: "The Role of the Stratosphere in Climate and Climate Change"

24-28 September 2007, Santorini, Greece

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Summary

The Chapman Conference was held 24-28 September 2007 on the Greek Island of Santorini. It was a follow-on to a meeting held in Whistler, BC, in spring 2003. Since the Whistler meeting, several aspects of stratosphere-troposphere coupling have become more prominent, most notably 1) stratospheric chemistry-climate coupling, including the effect of ozone changes on climate, and of climate change on the ozone layer; and 2) the role of stratosphere-troposphere coupling in recent climate change. Over the past few years, considerable progress has also been made in understanding the physical mechanisms that underlie stratosphere-troposphere coupling.

The Chapman Conference in Santorini focused on how stratospheric processes affect tropospheric climate and weather. It provided an opportunity to discuss the latest research ideas regarding the mechanisms for stratosphere/troposphere coupling. It also provided a forum for discussing emerging ideas regarding the importance of stratospheric chemical processes, anthropogenic forcing, and even oceanic processes in the observed coupling between the stratospheric and tropospheric circulations.

Overview

To first order, the coupling between the stratosphere and troposphere is mediated by wave dynamics. Planetary-scale Rossby waves, gravity waves, and equatorially trapped Kelvin and mixed Rossby-gravity waves typically originate in the troposphere, propagate upward into the stratosphere, and then dissipate causing variability of the stratospheric flow. The conventional view through the 1990s was that the resulting interactions are principally one way, *i.e.* that tropospheric waves influence the stratospheric circulation, but that stratospheric circulation anomalies did not have significant effects on tropospheric weather and climate. However, in the past ~5-10 years, the prevailing view has changed, and variability in the extratropical atmospheric flow is now recognised to reflect "two-way" interactions between the stratospheric and tropospheric circulations.

The observed coupling between the stratospheric and tropospheric circulations is most clearly evident as deep vertical coupling in the "annular modes" of extratropical climate variability (Thompson and Wallace, 2000). The annular modes extend from the surface to the stratosphere in both hemispheres, and are characterised by meridional vacillations in the geopotential height field between the polar regions and surrounding middle latitudes. During the cold season in the stratosphere, the annular modes correspond to fluctuations in the strength of the polar vortex, while at the surface the annular modes correspond to meridional shifts in the extratropical storm track. The stratospheric and tropospheric components of the annular modes are closely coupled in both hemispheres, but the reasons for this coupling are still not understood.

On intra-seasonal time scales, observations show that large amplitude anomalies in the strength of the Northern Hemisphere wintertime stratospheric polar vortex frequently precede long-lived (up to ~2 months) changes to the tropospheric circulation (Baldwin and Dunkerton, 1999; 2001). These changes modulate not only average weather, but also the likelihood of extreme events on time scales longer than the limit of deterministic weather prediction (Thompson *et al*., 2002).

Another example of the vertical coupling inherent in the annular modes is evident in recent trends in the Southern Hemisphere circulation. Ozone-induced trends in the temperature and geopotential height field in the Southern Hemisphere lower stratosphere are reflected in surface climate over Antarctica. The associated tropospheric circulation trends during austral summer strongly resemble the pattern of the Southern Annual Mode (SAM). That a similar seasonally varying pattern of trends is found in climate models run with prescribed stratospheric ozone losses (Gillett and Thompson, 2003) lends credence to the hypothesis that the observed trends in the Southern Hemisphere tropospheric flow during austral summer reflect a remote response to the Antarctic ozone hole.

On longer time scales, several stratospheric processes affect the troposphere. The stratospheric quasi-biennial oscillation (QBO) has been found to exhibit a signature in surface climate (Coughlin and Tung, 2001; Thompson *et al*., 2002). On time scales of several years, volcanic eruptions that inject sulphate aerosols into the stratosphere also noticeably influence tropospheric climate both radiatively and dynamically (Robock and Mao, 1992; Graf *et al*., 1994; Kodera and Yamazaki, 1994; Stenchikov *et al*., 1998; 2004). On decadal to century time scales up to centuries, stratospheric mechanisms have been proposed to explain a larger than expected impact of solar variability at the surface.

Despite widespread observational evidence that stratospheric processes impact surface climate, many key aspects of stratosphere/troposphere coupling have proven remarkably difficult to understand. For example, we still do not fully understand the processes whereby changes in the stratospheric flow influence the troposphere, nor do we fully grasp how changes in the stratospheric flow influence the vertical propagation of waves (and thus the source of stratospheric variability) in the first place. We hence do not fully understand how the stratospheric circulation will respond to anthropogenic climate change; consequently, our confidence in model simulations of stratospheric climate change remains low. The latter is of particular concern, since it is expected that future changes in the climate of the stratosphere will affect future changes in the troposphere, and will also affect ozone and ozone recovery.

The overall motivation for the Chapman Conference was to better understand the mechanisms whereby stratospheric processes impact surface climate. This is a topic of considerable interest to international organisations such as the World Climate Research Programme through two of its projects: Stratospheric Processes and their Role in Climate (SPARC, **www.atmosp.physics.utoronto.ca/SPARC/**) and Climate Variability and Predictability (CLIVAR, **www.clivar.org/**); and through the WCRP's overarching framework, Coordinated Observation and Prediction of the Earth System (COPES, **copes.ipsl.jussieu.fr/**), as well as International Polar Year (**IPY, www.ipy.org/**).

Meeting Summary

Dynamical understanding

We still do not fully understand what processes drive stratospheric variability. And we also do not fully understand how the resulting stratospheric variability is communicated to tropospheric levels. A wide variety of dynamical topics was covered at the meeting. Stratospheric effects on the troposphere may be (at least in part) explained by geostrophic and hydrostatic adjustment of the tropospheric flow to anomalous wave drag (Haynes *et al*., 1991). **P. Haynes** summarised and clarified our current understanding of downward "influence" on the troposphere, and he explained how apparent downward influence may not involve the downward propagation of "information," as in the QBO. **A. Plumb** provided a theoretical viewpoint of the dynamical response to stratospheric perturbations. **D. Thompson** summarised modelling work which shows that long-lasting thermal perturbations to the lowermost stratosphere can act to decelerate tropospheric winds during that period. (Thompson *et al*., 2006).

The stratosphere-troposphere system is arguably viewed as a single dynamical entity, rather than a troposphere coupled to a stratosphere (**A. O'Neill**). **C. Fletcher** showed evidence that the state of the stratosphere can, in effect, alter the seasonal cycle. Siberian snow cover anomalies during autumn appear to affect the state of the polar vortex later in the winter, which can then feed back to affect the troposphere. In the spring, when the Northern polar vortex breaks down, **L. Sun** showed that the timing of the breakdown affects the troposphere, in effect imposing a seasonal transition from the stratosphere.

G. Vallis examined the NAO and annular patterns, and concluded that although these patterns would occur in the absence of an active stratosphere, stratospheric variability does contribute a lot toward their tropospheric character (*e.g*. the long time scale of the NAM in winter). **C. Chan** discussed results from idealised simple GCM models with unrealistically long decorrelation time scales, and found then to be overly sensitive to external forcing. Therefore, such models may be exaggerating responses from forcings. **A. Charlton-Perez** and **T. Kunz** investigated annular mode time scales in models. Changing the stratospheric radiative time scale in the model changes the dynamical time scale throughout the lower stratosphere and troposphere. **R. Black** discussed vertical high-latitude coupling of the "polar annular mode," the second EOF of zonally-averaged zonal wind. It appears to play an important role in final warmings.

R. Scott described the existence of a deep barotropic mode. Recent research suggests the existence of an external or barotropic mode whose potential impact on the stratospheric circulation can be significantly larger than that of upward propagating waves. Esler and Scott (2005) and Esler *et al.,* (2006) demonstrated the relevance of this mode in wavenumber-2 major warmings in which the vortex is split throughout the full depth of the stratosphere.

Stratospheric variability has long been viewed as being caused by the configuration of tropospheric waves (*e.g*. Quiroz, 1986), which determine the flux of wave activity into the stratosphere. But stratospheric vacillations can exhibit internal variability even if the source of the tropospheric waves remains constant. The current understanding is that the configuration of the stratosphere itself plays an important role in determining the vertical flux of wave activity from the troposphere. R. Scott also concluded that the wave flux through the tropopause is mainly controlled by the stratosphere. But **A. Haklander** pointed out that the troposphere is important, *e.g*. in where geographically the wave flux originates.

How will climate change affect the stratospheric circulation, and how will stratospheric changes affect surface climate?

There is evidence that stratospheric variability will change in response to anthropogenic forcing. For example, tropospheric climate change may alter the generation of planetary-scale waves which, in turn, may alter the strength of the stratospheric large-scale Brewer-Dobson circulation (**M. Dameris**, **M. Giorgetta**), and therefore the net mass exchange between the troposphere and stratosphere. There is growing evidence from models that the Brewer-Dobson circulation will increase in strength (**N. Butchart**). If the Brewer-Dobson circulation were to increase, some simulations show the resulting changes in the descent and adiabatic heating in the polar stratosphere may partly compensate for the greenhouse-gas induced radiative cooling of the Northern polar stratosphere during winter and spring (Schnadt *et al*., 2002; Schnadt and Dameris, 2003; Butchart *et al*., 2006). **W. Randel** presented observations and modelling results suggesting that waves in the tropics, forced by convection, contribute to the forcing, while **Y. Kawatani** described results of a GCM simulation of tropical gravity waves. **D. Siedel** discussed observational evidence that the global tropopause has risen and cooled since 1980, and that the tropical belt has expanded.

The climate models used by the IPCC to understand past and future climate change allow the coupled atmosphere-ocean system to evolve, but they generally do not have substantial interactive chemistry or even well-represented stratospheres. The current models are simply not designed to predict changes to the ozone layer or the dynamics of stratosphere/troposphere coupling. While the radiative effects of ozone-destroying substances (ODSs) and ozone depletion have generally been included to some extent, this has not been done consistently among the models. In fact, many of the models used for the recent IPCC report held stratospheric ozone forcing constant during the 21st century. And without a well-represented stratosphere, it is unlikely that the dynamical response to the stratospheric radiative changes would be realistically captured (Baldwin *et al*., 2007). **E. Cordero** and **J. Perlwitz** discussed systematic differences in stratospheric temperature and circulation trends between CCMs and the AOGCMs used in the IPCC Assessment. These studies provide addition evidence that both full ocean models and stratospheric chemistry will be desirable in future IPCC Assessments.

Additionally, any changes in the large scale stratospheric overturning will influence the temperature profile of the tropical stratosphere, and also the global distribution of stratospheric ozone. But despite the evident importance of any predicted changes in the stratospheric flow, **M. Baldwin** pointed out that our confidence in the model simulations is limited. In fact, even the sign of polar stratospheric temperature change during winter and spring is unclear.

How has ozone depletion affected tropospheric climate and how will climate change affect ozone recovery?

Ozone depletion, especially in the Southern Hemisphere (**A. Agosta**), has affected surface climate (**N. Gillett**, **K. Sato**) and the extratropical circulation (**K. Grise**), but our understanding is incomplete. We still do not fully understand the roles of radiation *vs*. dynamics, or the extent to which zonal asymmetries in the ozone distribution are important (**T. Nathan**).

During the past 25+ years the composition of the stratosphere has changed significantly, with higher abundances of anthropogenic greenhouse gases and ODSs, together with a concomitant thinning of the ozone layer. **T. Shepherd** pointed out that with the recent stabilisation of stratospheric ODSs following the Montreal Protocol we are near the turnaround point in ozone depletion, so that the past climate impacts of ODSs and ozone depletion are about to change sign against a background of continued increase in most greenhouse gases (Baldwin *et al*., 2007). **A.R. Ravishankara** provided an overview of past and future changes to the ozone layer, emphasising the difficulties in defining ozone "recovery."

Because these changes in the lower stratosphere over the last 25+ years appear to have been mainly driven by changes in ODSs and ozone depletion, they can be expected to begin to reverse as the ozone layer begins to recover. These future changes may obscure, or even alter, the climate-change signal from non-ODS greenhouse gases. Therefore, it is important for both attribution and prediction of climate change to properly account for the combined effects of climate change and ozone recovery.

2D models, as well as 3-D Chemistry-Climate Models (CCMs), consistently show that the global amount of total ozone will recover more quickly if stratospheric temperatures decrease in the future. CCM simulations up to 2050, which compare climate change scenarios to a constant level of well-mixed greenhouse gases (*i.e*. CO_2, CH_4, and N_2O), indicate that a full recovery of total ozone, *i.e*. a return to 1980 values, will be reached approximately 15 years sooner due to human-induced climate change (Chapter 5 in WMO, 2007).

To what extent do volcanoes, the QBO, and the solar cycle affect surface climate via stratosphere/troposphere coupling?

Volcanic eruptions have strong impacts on the lower stratospheric thermal structure because volcanic aerosols absorb infrared radiation (*e.g.* Stenchikov *et al*., 1998; 2004). Heterogeneous chemistry occurring on aerosol surfaces affects ozone concentration, producing an additional indirect radiative impact depending on the concentration of atmospheric chlorine. The 11-year solar cycle modulates UV radiation, and therefore ozone concentrations, with implications for tropospheric climate (Gleisner and Thejll, 2003). **L. Hood** presented observational evidence for 11-year solar cycle changes to the stratospheric circulation, and **K. Labitzke** discussed the role of the 11-year solar cycle on teleconnections between the tropics and the Arctic. **I. Simpson** discussed the modelled tropospheric response to stratospheric heating, and how eddy momentum fluxes and winds could be affected. The QBO modulates the distribution of both volcanic aerosols and ozone. These effects are seen in both observations and models (*e.g.* Shindell *et al*., 2001; Steinbrecht *et al*., 2006). **S. Yoden** discussed a parameter sweep experiment, which combined the effects of the QBO and the solar cycle. He found a systematic effect of the phase of the QBO, and a solar effect consistent with observations.

How will the tropopause layer change?

The tropical tropopause layer is the body of air extending from the level of the lapse rate minimum at 11-13 km to the level of highest convective overshoot, at ~17 km (Gettelman and Forster, 2002). The tropical tropopause layer appears to have changed within the last few decades but future changes are uncertain. Such changes are important because concentrations of stratospheric water vapour may change. The situation regarding transport of water vapour into the stratosphere is complex (**S. Fueglistaler**), but our understanding may be aided by studying isotopes. The height of the extratropical tropopause has been identified as a climate-change fingerprint (Santer *et al*., 2003), and D. Seidel presented observational evidence that the height has been increasing. **T. Birner** discussed the dynamics of the stratospheric residual circulation and tropopause structure. Changes to both the tropical and extratropical tropopause layers have implications for coupled-chemistry-climate effects, but our ability to predict these effects is limited. **K. Krüger** pointed out that ENSO, volcanoes and the solar cycle have zonally asymmetric effects on the TTL, while the QBO is more zonally symmetric.

Will a well-represented stratosphere improve weather and climate forecasts? What is necessary in models to include stratospheric effects?

A key question is to consider is whether improving the stratosphere will improve simulations of past changes in surface climate, and in particular the NAO/AO. Although the exact answer depends on the choice of variable and time frame, there is a broader question of how future increases in computational power should be used (*e.g.* add interactive chemistry, give better representation of boundary layer processes, or give better representation of the stratosphere).

How much improvement in forecast skill can we expect by improving the stratosphere in models for extended-range, seasonal, and decadal forecasts? Observations (*e.g.* Baldwin *et al*., 2003b) show statistical skill, and modelling studies (*e.g.* Charlton *et al*., 2003; 2004; Mukougawa *et al*., 2005) have demonstrated that changes to initial conditions in the stratosphere have a significant effect on medium to extended range forecasts. Christiansen (2005) showed that a simple statistical forecast based on stratospheric information performs as well as a state-of-the-art dynamical seasonal forecast model when forecasting the surface zonal mean zonal wind at 60°N and the temperature in Northern Europe.

Improvements in weather forecasting skill were discussed by **T. Reichler** and **K. Kodera**, while seasonal forecasting improvements were discussed by **Y. Kuroda** and B. Christiansen. T. Hirooka pointed out that improved tropospheric forecasts first require models that can simulate stratospheric sudden warmings. **S. Ineson** discussed the role of the stratosphere in communicating the effects of ENSO to Europe. A good representation of the stratospheric polar vortex appears to be necessary to communicate the ENSO signal.

P. Kushner gave an overview of the SPARC DynVar project (**www.sparcdynvar.org**), which is an international climate modelling project that studies the influence of the stratospheric circulation on the global climate system. **M. Sigmond** detailed the effects of removing a well-resolved stratosphere on tropospheric climate and on climate change. **E. Manzini** discussed the differences between high-top and low-top simulations. Although there are clear differences in simulations with altered stratospheres, it is not yet clear precisely what is required of models to do a realistic job of simulating stratosphere-troposphere coupling.

A final note

Although the topic is not specific to stratosphere-troposhere coupling, **M. McIntyre** demonstrated repeatedly throughout the conference that the attendees (and presumably scientists in general) are easily duped by elementary statistical/probability tricks. If effect, we lack good critical thinking skills. He made the case that the problem is rooted in how probability is taught, and it may be wise to be skeptical of statistical significance tests. But, by realising that all probabilities are conditional, and by using careful reasoning, there may be some hope for us. A brief essay on the topic can be found at **www.atm.damtp.cam.ac.uk/people/mem/mcintyre-thinking-probabilistically.pdf**

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References

Baldwin, M.P. and T.J. Dunkerton, Downward propagation of the Arctic Oscillation from the stratosphere to the troposphere, *J. Geophys. Res*., 104, 30,937-30,946, 1999.

Baldwin, M.P., and T.J. Dunkerton, Stratospheric harbingers of anomalous weather regimes, *Science*, 294, 581–584, 2001.

Baldwin, M.P., D.W.J. Thompson, E.F. Shuckburgh, W.A. Norton, and N.P. Gillett, Weather from the Stratosphere?, *Science*, 301, 317-318, 2003a.

Baldwin, M.P., D.B. Stephenson, D.W.J. Thompson, T.J. Dunkerton, A.J. Charlton, A. O'Neill, Stratospheric memory and extended-range weather forecasts, *Science*, 301, 636-640, 2003b.

Baldwin, M.P., M. Dameris, and T.G. Shepherd, How will the stratosphere affect climate change?, *Science*, 316, 1576-1577, 2007.

Butchart N., A.A. Scaife, M. Bourqui, J. de Grandpre, S.H.E. Hare, J. Kettlebororough, U. Langematz, E. Manzini F. Saasi, K. Shibata, D. Shindell, M. Sigmond, A multi-model study of climate change in the Brewer-Dobson circulation, *Clim. Dyn*., submitted, 2006.

Castanheira, J.M. and H.-F. Graf, 2003: North Pacific - North Atlantic relationships under stratospheric control? *J. Geophys. Res*., Vol.108, D1, 4036, doi: 10.1029/2002JD002754, 2003.

Charlton A.J., O'Neill A., Stephenson, D.B., Lahoz, W.A., and Baldwin M.P., Can knowledge of the state of the stratosphere be used to improve statistical forecasts of the troposphere?, *QJRMS*, 129, 3202-3225, 2003.

Charlton A.J., O'Neill A., Lahoz W.A. and Massacand A.C., Sensitivity of tropospheric forecasts to stratospheric initial conditions, *QJRMS*, 130, 1771-1792, 2004.

Chen, P., and W.A. Robinson, Propagation of planetary waves between the troposphere and stratosphere, *J. Atmos. Sci*., 49, 2533-2545, 1992.

Christiansen, B., Stratospheric vacillations in a general circulation model, *J. Atmos. Sci*., 56, 1858-1872, 1999.

Christiansen, B., Downward propagation of zonal mean zonal wind anomalies from the stratosphere to the troposphere: Model and reanalysis, *J. Geophys. Res*., 106, 27307-27322, 2001.

Christiansen, B., Evidence for nonlinear climate change: Two stratospheric regimes and a regime shift, *J. Climate*, 16, 3681-3689, 2003.

Christiansen, B., Downward propagation and statistical forecast of the near surface weather. *J. Geophys. Res*., 110, D14104, doi:10.1029/2004JD005431, 2005.

Coughlin, K., and K.-K. Tung, QBO Signal found at the extratropical surface through Northern Annular Modes, *Geophys. Res. Lett*., 28, 4563-4566, 2001.

Dameris, M., K. Matthes, R. Deckert, V. Grewe, and M. Ponater, Solar cycle effect delays onset of ozone recovery, *Geophys. Res. Lett.*, 33, L03806, 10.1029/2005GL024741, 2006.

Esler, J. G. and R.K. Scott, On the excitation of transient Rossby waves on the polar stratospheric vortex and the barotropic sudden warming, *J. Atmos. Sci.*, 62, 3661-3682, 2005.

Esler, G., L. Polvani, and R.K. Scott, The Antarctic stratospheric sudden warming of 2002: A self-tuned resonance?, *Geophys. Res. Lett.* submitted, 2006.

Gettelman, A. and P. M. d. F. Forster, Definition and climatology of the tropical tropopause layer, *J. Met. Soc. Japan*, 80, 911-924, 2002.

Gillett, N.P. and D.W.J. Thompson, Simulation of recent Southern Hemisphere climate change, *Science*, 302, 273-275, 2003.

Gleisner H., and P. Thejll, Patterns of tropospheric response to solar variability, *Geophysical Research Letters*, 30, doi:10.129/2003GL017129, 2003.

Graf, H. -F., J. Perlwitz and I. Kirchner, Northern Hemisphere tropospheric midlatitude circulation after violent volcanic eruptions, *Contr. Atm. Phys*., 67, 3-13, 1994.

Haynes, P.H., C.J. Marks, M.E. McIntyre, T.G. Shepherd, and K.P. Shine, On the “downward control” of extratropical diabatic circulations by eddy-induced mean zonal forces, *J. Atmos. Sci*., 48, 651–679, 1991.

Holton, J.R., and C. Mass, Stratospheric vacillation cycles, *J. Atmos. Sci*., 33, 2218–2225, 1976.

Kodera, K., K. Yamazaki, M., Chiba, and K. Shibata, Downward propagation of the upper stratospheric mean zonal wind perturbation to the troposphere, *Geophys. Res. Lett*., 17, 1263-1266, 1990.

Kodera, K., and K. Yamazaki, A possible influence of recent polar stratospheric coolings on the troposphere in the northern hemisphere winter, *Geophys. Res. Lett*., 21, 809-812, 1994.

Kushner, P. J. and L. M. Polvani, Stratosphere-troposphere coupling in a relatively simple AGCM: The role of eddies, *J. Climate*, 17, 629-639, 2004.

McIntyre, M. E., How well do we understand the dynamics of stratospheric warming?, *J. Meteor. Soc. Japan*, 60, 37-65, 1982.

Mukougawa H., H. Sakai, and T. Hirooka, *Geophys Res. Lett*., 32 (17), L17806, 2005.

Perlwitz, J. and H.-F. Graf, Troposphere-stratosphere dynamic coupling under strong and weak polar vortex conditions, *Geophys. Res. Lett*., 28(2), 271-274, 10.1029/2000GL012405, 2001.

Perlwitz, J. and N. Harnik, Downward coupling between the stratosphere and troposphere: The relative roles of wave and zonal mean processes, *J. Climate*, 17, 4902-4909, 2004.

Quiroz, R., The association of stratospheric warmings with tropospheric blocking, *J. Geophys. Res*., 91, 5277-5285, 1986.

Rind, D., J. Perlwitz, and P. Lonergan, AO/NAO response to climate change: Respective influences of stratospheric and tropospheric climate changes, *J. Geophys. Res.* 110, D12107, doi:10.1029/2004JD005103, 2005.

Robock, A., and J. Mao, Winter warming from large volcanic eruptions, *Geophys. Res. Lett*., 12, 2405-2408, 1992.

Santer, B.D., *et al*., Behavior of tropopause height and atmospheric temperature in models, reanalyses, and observations: Decadal changes, *J. Geophys. Res*., 108(D1), 4002, doi:10.1029/2002JD002258, 2003.

Schnadt, C., M. Dameris, M. Ponater, R. Hein, V. Grewe and B. Steil, Interaction of atmospheric chemistry and climate and its impact on stratospheric ozone, *Climate Dynamics*, 18, 501–517, 2002.

Schnadt, C. and M. Dameris, Relationship between North Atlantic Oscillation changes and an accelerated recovery of stratospheric ozone in the northern hemisphere, *Geophys. Res. Lett.*, 30, 1487, doi:10.1029/2003GL017006, 2003.

Scott, R.K., and P.H. Haynes, Internal interannual variability of the extratropical stratospheric circulation: the low-latitude flywheel, *Quart. J. Roy. Met. Soc*., 124, 2149-2173., 1998.

Scott, R.K. and L.M. Polvani, Stratospheric control of upward wave flux near the tropopause, *Geophys. Res. Lett.*, 31, L02115, doi:10.1029/2003GL017965, 2004.

Scott, R.K. and L.M. Polvani, Internal variability of the winter stratosphere. Part I: Time independent forcing, *J. Atmos. Sci*., submitted, 2005.

Shepherd, T., Issues in stratosphere-troposphere coupling, *J. Meteorol. Soc. Japan*, 80, 769–792, 2002.

Shepherd, T.G. & Shaw, T.A. The angular momentum constraint on climate sensitivity and downward influence in the middle atmosphere, *J.Atmos.Sci.* 61 2899-2908, 2004.

Shindell, D.T., R.L. Miller, G.A. Schmidt, and L. Pandalfo, Simulation of recent northern winter climate trends by greenhouse-gas forcing, *Nature*, 399, 452–455, 1999.

Shindell, D.T., Climate and ozone response to increased stratospheric water vapor, *Geophys. Res. Lett.,* 28, 1551-1554, 2001.

Smith A.K., An investigation of resonant waves in a numerical model of an observed sudden stratospheric warming, *J. Atmos. Sc*i., 46 3038- 3054, 1989.

Song, Y. and W.A. Robinson, Dynamical mechanisms for stratospheric influences on the troposphere, *J. Atmos. Sci*., 61, 1711-1725, 2004.

Steinbrecht, W., B. Haßler, C. Brühl, M. Dameris, M. A. Giorgetta, V. Grewe, E. Manzini, S. Matthes, C. Schnadt, B. Steil, and P. Winkler, Interannual variation patterns of total ozone and temperature in observations and model simulations, *Atmos. Chem. Phys*., 6, 349-374, 2006.

Stenchikov, G. L., I. Kirchner, A. Robock, H.-F. Graf, J. C. Artuna, R. G. Grainger, A. Lambert, and L. Thomason, Radiative forcing from the 1991 Mount Pinatubo volcanic eruption, *J. Geophys. Res*., 103, 13,837-13,857, 1998.

Stenchikov, G., K. Hamilton, A. Robock, V. Ramaswamy, and M. D. Schwarzkopf, Arctic oscillation response to the 1991 Pinatubo eruption in the SKYHI general circulation model with a realistic quasi-biennial oscillation, *J. Geophys. Res*., 109, D03112, doi:10.1029/2003JD003699, 2004.

Taguchi M., Hartmann D.L., Change in Occurrence Frequency of Stratospheric Sudden Warmings with ENSO-like SST Forcing as Simulated WACCM, *J. Climate* 19 (3), 324-332, 2006.

Thompson, and J. M. Wallace, Annular modes in the extratropical circulation. Part I: Month-to-month variability, *J. Climate,* 13, 1000-1016, 2000.

Thompson, D.W.J, S. Lee, and M.P. Baldwin, Atmospheric processes governing the Northern Hemisphere annular mode/North Atlantic Oscillation, from the book *The North Atlantic Oscillation*, 2002.

Thompson, D.W.J. and S. Solomon, Interpretation of recent Southern Hemisphere climate change, *Science*, 296, 895-899, 2002.

Thompson, D.W.J., J.C. Furtado, and T.G. Shepherd, On the tropospheric response to anomalous stratospheric wave drag and radiative heating, *J. Atmos. Sci*., in press, 2006.

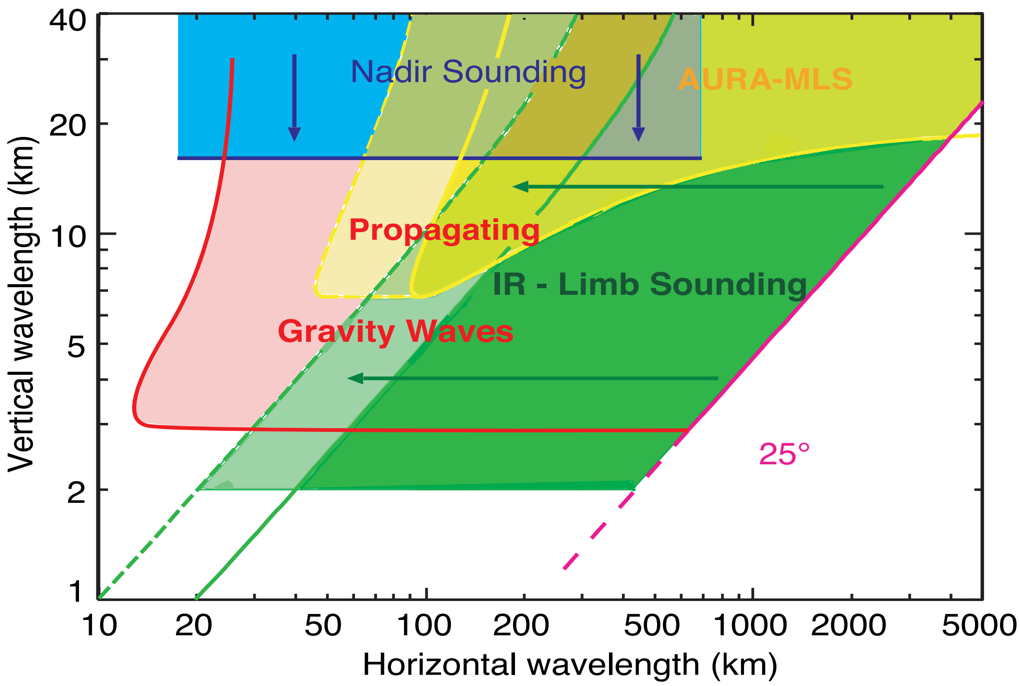
Walter, K. and H.-F. Graf, The North Atlantic variability structure, storm tracks, and precipitation depending on the polar vortex strength, *Atmos. Chem. Physics*, 5, 239-248, SRef-ID:1680-7324/acp/2005-5-239, 2005.

Wittman, M.A.H., L.M. Polvani, R.K. Scott, and A. J. Charlton, Stratospheric influence on baroclinic lifecycles: connection to the Arctic Oscillation, *Geophys. Rev. Lett*., 31, 10.1029/2004GL020503, 2004.

Wittman, M.A.H., A.J. Charlton, and L.M. Polvani, The effect of lower stratospheric shear on baroclinic instability, *J. Atmos. Sci*., submitted, 2006.

WMO (World Meteorological Organization), Scientific Assessment of Ozone depletion: 2006, Global Ozone Research and Monitoring Project, Report in preparation, 2007.

New SPARC Project: Gravity Wave Momentum Budget for Global Circulation Studies



^ Figure 1

Summary of the different satellite instruments showing which part of the gravity wave spectrum can be observed by each.

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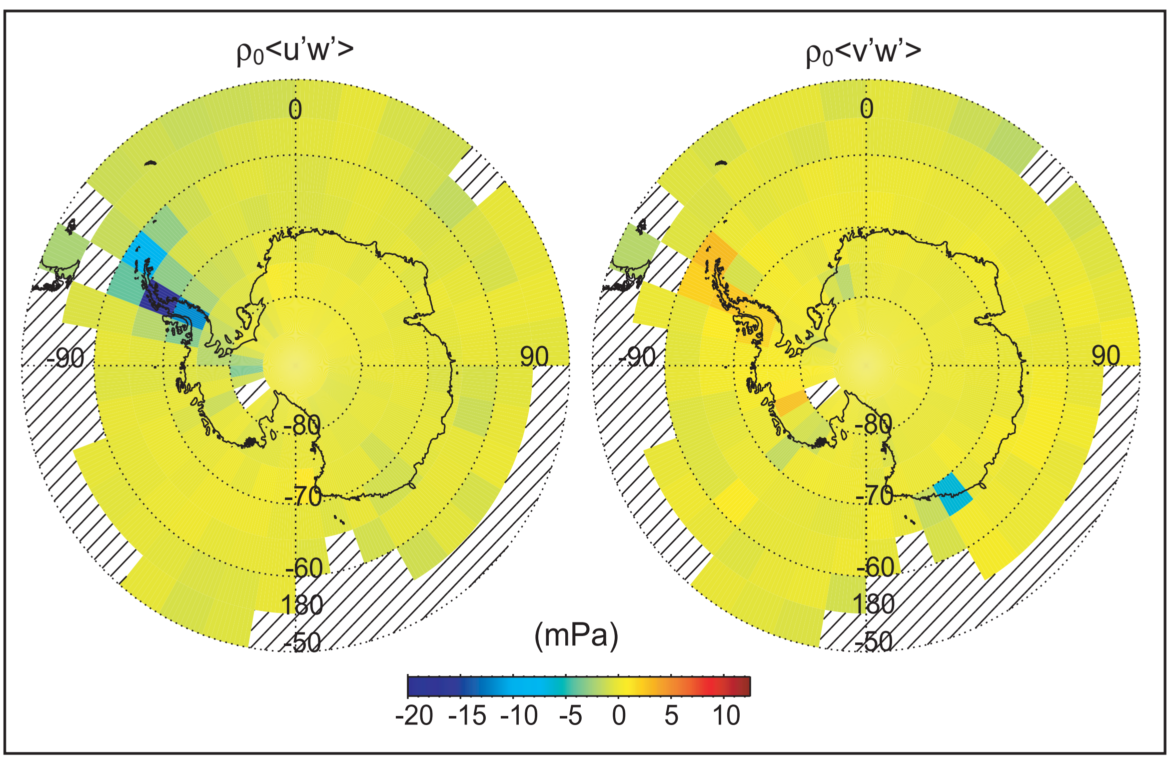
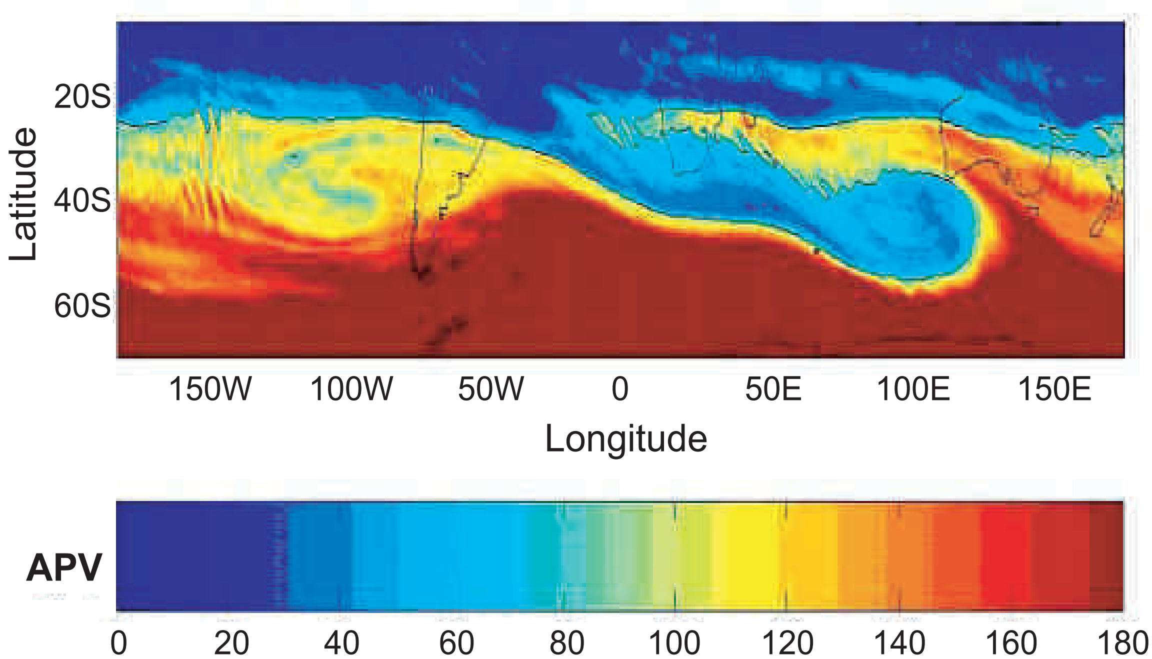


^ Figure 3

The wave momentum fluxes from Vorcore: Zonal (left) and meridional (right).

Report on the Chapman Conference: "The Role of the Stratosphere in Climate and Climate Change"

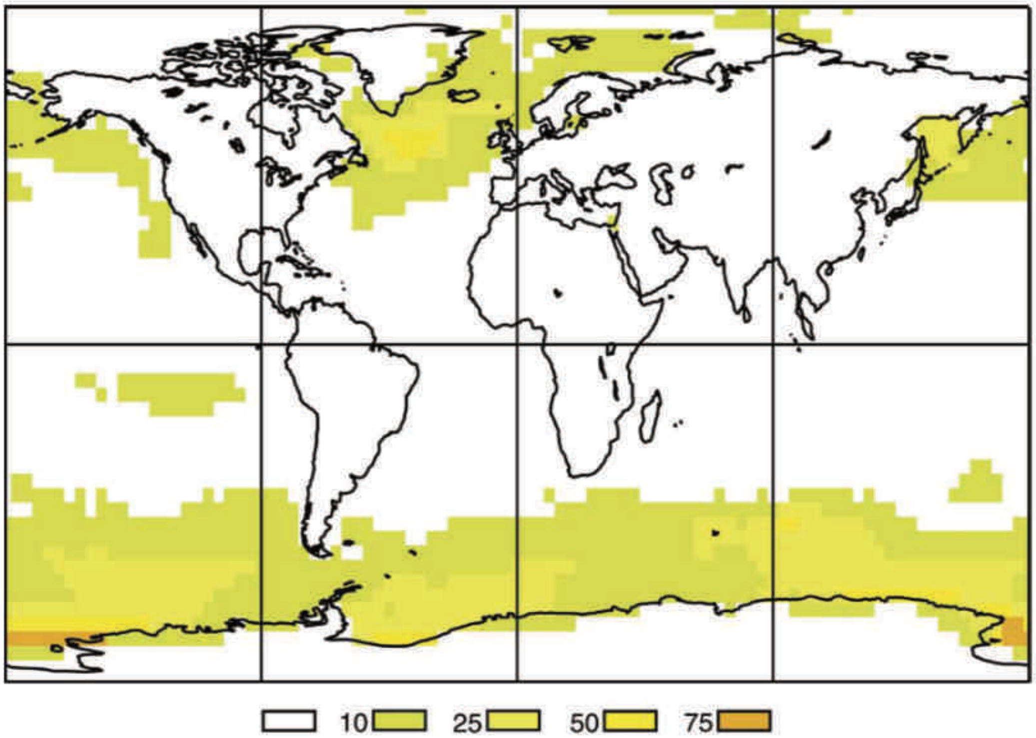
Reunion Island International Symposium on Tropical Stratosphere and Upper Troposphere



^ Figure 1

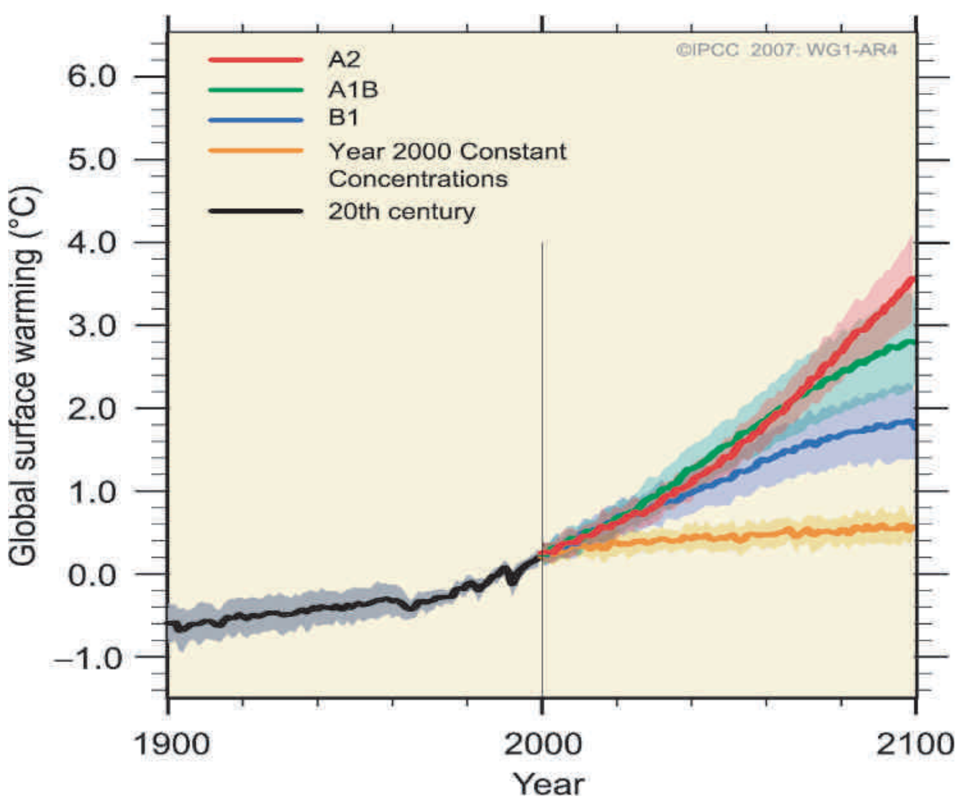
Map of absolute Potential Vorticity advected by the high-resolution MIMOSA model (Hauchecorne et al., 2002) using ECMWF ERA40 reanalysis on the 700K potential temperature surface, for 5 July 2003. Low-PV values (in blue) depict air-masses originating from the tropical pipe, while high-PV values (in red) correspond to polar air-masses. The superimposed black line shows the subtropical barrier location as discussed by Guillaume Kirgis based on the Nakamura criterion (high PV gradient and low effective diffusivity). From the figure, one can see a large-scale isentropic exchange event in the Southern Hemisphere and locations of copper smelters. (Simon et al., 2007.)

Decadal predictability: How might the stratosphere be involved?



^ Figure 3

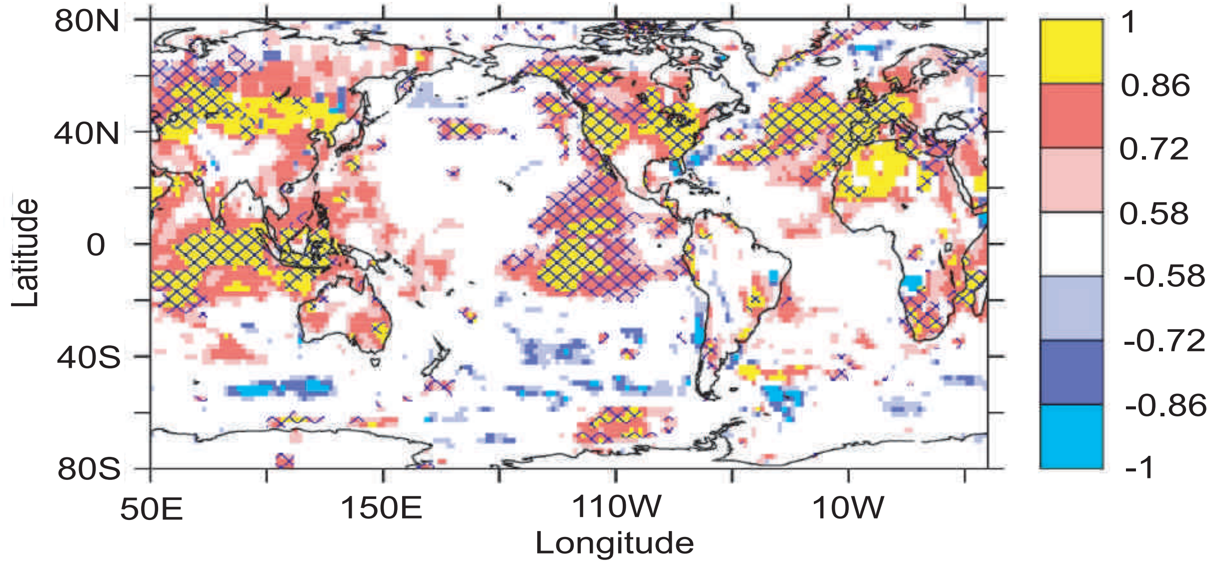
Potential decadal predictability for decadal means as derived from extended-range control integrations with 11 coupled ocean–atmosphere general circulation models. Potential decadal predictability is defined here as the ratio of the decadal variance to the total variance. Figure from Boer, (2001).



< Figure 4

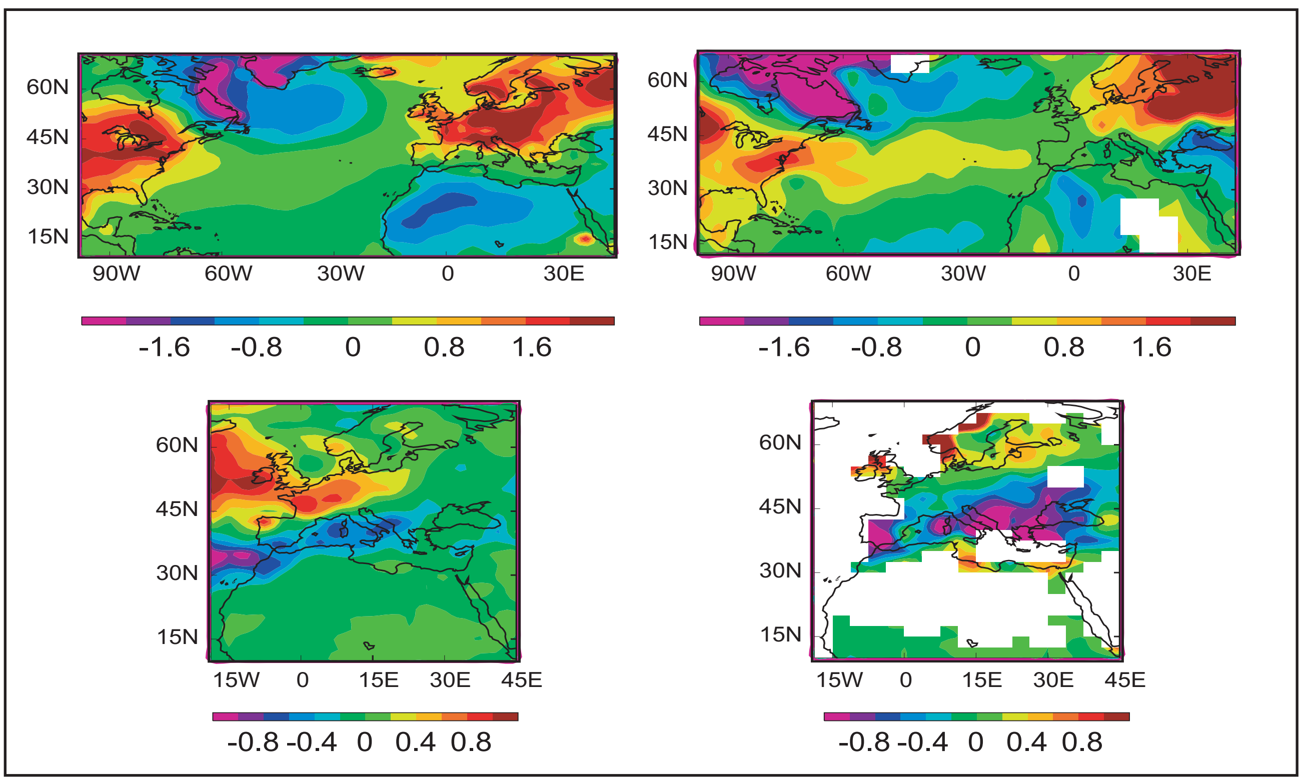
Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages (IPCC, 2007).

Decadal predictability: How might the stratosphere be involved?



^ Figure 6

IV *Correlation between observed and predicted decadal mean temperature for nine retrospective predictions performed over the period 1955-2005. The predictions were ten years long, consisted of three ensemble members, and were performed with the ECHAM5/MPIOM coupled model. Blue hashing indicates regions where the SST initialisation scheme leads to a significant enhancement in skill over predictions made only with varying radiative forcing (Keenlyside et al., 2008).*



^ Figure 7

Surface climate response to a stratospheric circulation trend similar to the observed stratospheric westerly trend between 1965 and 1995. Upper left: modelled winter surface temperature change (K). Upper right: observed winter surface temperature change (K). Lower left: modelled winter precipitation change over land (mm/day). Lower right: observed winter precipitation change over land (mm/day). Reproduced from (Scaife et al., 2005).

Report on the 4th International Limb Workshop

October 29-November 2 2007, Virginia Beach, Virginia, USA,

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The Limb Workshop series began in April 2003, when the University of Bremen hosted three days of meetings and discussions in Bremen, Germany. Subsequent meetings have occurred at 18 month intervals, with the University of Stockholm hosting the next meeting in Stockholm, Sweden (October 2004), followed by the University of Saskatchewan acting as hosts for the April 2006 meeting in Montreal, Canada. The 4th International Limb Workshop recently continued this series, hosted by the limb scattering team at National Aeronautics and Space Administration (NASA) Langley Research Center in Virginia Beach, USA. The meeting was sponsored jointly by NASA Headquarters and the World Climate Research Programme (WCRP) / Stratospheric Processes And their Role in Climate (SPARC). The workshop programme, schedule and presentations are available online at **http://limb-scatter.larc.nasa.gov/**.

The 4th International Limb Workshop brought together more than 70 scientists representing 8 countries to discuss the use of atmospheric limb measurements (including occultation, scattering, and emission techniques) to study the Earth's atmosphere. An effort was also made to invite presentations from outside the community of scientists directly engaged with limb measurements, to allow discussion of correlative measurements that might be used to validate limb measurements, as well as to consider the perspectives of data users from the atmospheric modelling and trend-studies communities. This meeting placed a special emphasis on demonstrating the progress made with the limb scattering technique towards providing products (particularly ozone profiles) of sufficient quality for long-term trend analysis, and extending the existing record obtained predominantly from occultation measurements.

The meeting was composed of two parts. The first three and a half days were devoted to oral presentations (20-25 minutes in length), with a brief period included for questions after each talk. The presentations were organised into seven half-day sessions, with several invited talks included to anchor the sessions and provide a broader perspective on the various topics. Fifty presentations were made, in addition to five posters displayed throughout the meeting and highlighted in a poster session. The remaining one and a half days were divided into six workshop sessions. These sessions featured less formal presentations of work-in-progress, and allowed more time for dialogue than was possible during the preceding oral presentation sessions.

The Past, Present and Future of Limb Measurements

The limb viewing geometry allows one to measure atmospheric profiles of unparalleled vertical resolution above tropospheric cloud tops. For this reason, limb observations have played a key role in previous investigations of the composition and dynamics of the stratosphere and mesosphere. The Limb Workshop series was initiated at a transitional time in the history of limb measurements, when several prominent solar occultation measurement series were approaching end-of-life, and while several relatively new limb scattering instruments were beginning their years of service. The growing maturity of the limb scattering measurement technique has been a key theme of this workshop series, but the workshops continue to feature recent innovations in other measurement methods (particularly occultation and emission).

The 4th Limb Workshop began with several invited talks that described the state of the art for the solar occultation (**J. Zawodny**), limb scattering (**D. Flittner**), and limb emission (**J. Urban**) techniques. **B. Weatherhead** followed those talks with a presentation describing the challenges associated with designing a measurement system to detect long-term trends in a noisy, inhomogenous data set.

A series of talks followed, detailing the current status of several ongoing space-borne limb measurement campaigns, including the Atmospheric Chemistry Experiment (ACE – **P. Bernath**), Microwave Limb Sounder (MLS – **B. Read**), Optical Spectrograph and Infrared Imaging System (OSIRIS – **D. Degenstein** and **N. Lloyd**), and SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY – **J. Burrows** and **C. von Savigny**) instruments. Balloon-borne limb scanning miniDOAS observations of trace gases and aerosols were also represented (**C. Prados**, **L. Kritten**). The future Atmospheric Limb Tracker for Investigation of the Upcoming Stratosphere (ALTIUS) limb mission was also described by **D. Fussen**, in a talk featuring several novel characteristics, including 2D limb imaging and the use of acousto-optical filters. A set of talks discussing plans for the Ozone Mapping and Profiler Suite Limb Profiler (OMPS LP) instrument design (**S. Asbury**, **Q. Remund**) and data processing (**D. Rault**, **J. Bergman**) rounded out the session.

Aerosols and Clouds

Several sessions focused on the study of clouds and aerosols in the upper atmosphere, headlined by several presentations describing the instrument design and remarkable first results from the Aeronomy of Ice in the Mesosphere (AIM) instrument (**J. Russell**, **L. Gordley**, **M. McHugh**). Observations of polar mesospheric clouds (PMCs) by the SCIAMACHY (C. von Savigny) and Polar Ozone and Aerosol Measurement (POAM – **E. Shettle**) instruments were also presented, as well as polar stratospheric cloud (PSC) observations from solar occultation and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) measurements (**L. Poole**) and the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) measurements (**D. Flittner**). **P. McCormick** also presented an overview of the global observations of PSCs and cirrus clouds now available from the CALIPSO instrument.

On the aerosol side, L. Poole surveyed the 25-year record of solar occultation stratospheric aerosol measurements, and **G. Yue** then described aerosol properties derived from the Stratospheric Aerosol and Gas Experiment (SAGE II and SAGE III) measurements from 2002-2005. **T. Deshler** discussed the *in-situ* aerosol record obtained from balloon flights into the stratosphere. E. Shettle and **M. Fromm** then presented complementary papers discussing observations of smoke in the upper troposphere / lower stratosphere (UTLS) region by the POAM and Halogen Occultation Experiment (HALOE) instruments, documenting global transport of the smoke. Retrievals of stratospheric aerosol extinction and microphysical properties from OSIRIS (**A. Bourassa**) and SAGE III (**R. Loughman**) limb scattering measurements were also presented.

Atmospheric Trace Gases

Given the importance of monitoring the predicted stratospheric ozone recovery, we devoted a session to discussions of limb ozone retrievals. Limb scattering ozone retrievals from GOMOS (**E. Kyrölä**), SCIAMACHY (**B. Ovigneur**), and both (**G. Taha**) were featured, as well as a valuable description of the SHADOZ ozonesonde network by **S. Oltmans**. **B. Pierce** represented the data user community by showing the dramatic analysis improvements achieved in the Regional Air Quality Monitoring System (RAQMS) model when solar occultation and limb scattering ozone profile data were assimilated, particularly in the crucial UTLS region.

Retrievals of water vapour from limb observations were another hot topic. Several talks focused on mesospheric retrievals, with results presented from SABER (**A. Feofilov**), OSIRIS (**M. Stevens**), and the Odin/Sub-Millimeter Radiometer (SMR – **S. Lossow**). The problem of extracting stratospheric and upper tropospheric water vapour information from SCIAMACHY was addressed by **A. Piters**. Climatologies and retrievals of other trace gases obtained from limb observations also received attention. OSIRIS data was used to retrieve NO_x (**C. Sioris**) and BrO (**C. McLinden**), while **S. Brohede** discussed NO_x and HNO_3 retrievals from Odin measurements (SMR and OSIRIS).

Algorithm Improvements

The oral presentations concluded with several algorithm-related talks, to transition us toward the more technical workshop presentations to follow. A series of presentations from the group at the University of Saskatchewan focused on radiative transfer for limb scattering radiance calculation and its influence on retrievals. The effects of refraction (**T. Wiensz**) and the curvature of the model atmosphere (**C. Roth**) were discussed, and an overview of the allowable approximations in the diffuse radiation field calculation was given (**D. Degenstein**). **J. Pukite** applied the 3D Monte Carlo radiative transfer model "Tracy-II" to SCIAMACHY limb measurements, while **S. Tukiainen** demonstrated the modified onion peel (MOP) retrieval method for ozone, NO_2, aerosol and neutral density retrievals. **T. Sonkaew** addressed the sensitivity of limb scattering ozone retrievals to clouds, and **L. Flynn** discussed research plans for the OMPS LP retrieval algorithms.

Workshop

The workshop sessions focused on the topics most relevant for continued improvement of limb scattering retrievals, and the format provided a useful forum for the necessary detailed technical exchanges. Six sessions were defined, with two sessions running concurrently throughout the workshop period. Two 3-hour sessions (Instrument Effects and Retrievals) were complemented by four 1.5-hour sessions (Inhomogeneity Effects, Aerosols, Radiative Transfer, and Tangent Height Registration).

The Instrument Effects session was a healthy exchange highlighting the work that too often occurs "behind the scenes," as several groups discussed the steps required to refine the raw measurements into useful inputs for retrieval algorithms. Contributions came from the OMPS (**Q. Remund**, **G. Jaross**, **J. Bergman**), OSIRIS (**N. Lloyd**), SAGE III (**D. Rault**), GOMOS (D. Fussen), and SCIAMACHY (C. von Savigny) groups.

The Retrieval session included an examination of the impact of water vapour on NO_2 retrievals (C. Sioris), as well as G. Taha's work on the possibility of NO_2 retrievals from OMPS data. D. Degenstein and D. Rault then led a lively discussion on the proper way to combine ozone profile information obtained from the visible and ultraviolet spectral regions.

The Inhomogeneity Effects session featured a discussion of the impact of cloud distribution on NO_2 profile retrievals by C. Sioris. J. Pukite also contributed a discussion on the sensitivity of limb observations to the distribution of scatterers within the atmosphere.

In the Aerosol session, T. Deshler gave a more detailed overview of the instrumentation used in balloon-borne *in-situ* aerosol measurements, while **F. van Hellemont** discussed the aerosol and PSC products derived from GOMOS data.

In the Tangent Height Registration session, G. Taha demonstrated how GOMOS data could be used to assess several tangent height registration methods using the observations of diffuse radiance above and below the stellar occultation window, given the ground-truth attitude information available from the simultaneous occultation. C. Sioris briefly described one such method (the "ozone knee" method), while D. Rault presented his recent work to expand another established tangent height registration method (the "Rayleigh-Scattering Attitude Sensor" or "RSAS" method) to a larger wavelength range.

The Radiative Transfer session featured an introduction to the Tracy-II Monte Carlo method by J. Pukite. R. Loughman then described a past comparison of existing limb scattering radiative transfer models, which stimulated a discussion of possible future work to compare and test the variety of radiative transfer models currently in use.

Conclusions

This meeting served several purposes in the evolving world of limb measurements. The impressive contributions made by occultation measurements (the first widely used limb technique) were highlighted, stressing that serious consideration should be given to reviving this technique in future missions. It also opened the door that too often separates practitioners of infrared/microwave emission measurements from their colleagues working at the optical wavelengths more commonly used in limb scattering and occultation measurements. The impressive array of atmospheric products that can be obtained from the emission spectrum serves as an essential complement to the climate-related investigations possible at the wavelengths for which solar radiation dominates.

The meeting also featured strong contributions from scientists focused on mesospheric phenomena, particularly in the area of improved understanding of PMCs. The stratosphere continued to receive a great deal of attention as well, with special focus on the continued need to monitor the stratospheric ozone layer. The meeting was also enriched by contributions related to atmospheric modelling, trend studies and direct measurement methods. This broader perspective was essential for the meeting, to place the more narrowly focused technical work in its proper context.

One striking aspect of the meeting was the growing maturity demonstrated in a variety of areas for limb scattering retrievals. These efforts were in their early stages just four and a half years ago in Bremen, but retrievals presented in this meeting showed ozone, aerosol, PMC and PSC retrievals of sufficient quality for scientific applications. Ongoing work in the area of NO_2, H_2O and BrO retrievals adds another dimension to the continued growth of this field. Tangent height registration and stray light issues both posed serious problems for early limb scattering platforms, limiting the success of early retrievals. But these problems have been gradually overcome through diligent work by the instrument characterisation teams, and the demonstrated success of these efforts (and the free exchange of information contained in these Limb Workshops) augurs well for the success of future limb scattering missions such as ALTIUS and OMPS LP.

More work remains to be done, as we try to apply limb measurements to the most challenging scientific problems of the day, such as maintaining trend-quality data sets and characterizing the critical UTLS atmospheric region. The lines of communication opened with outside experts at this meeting will benefit the scientific community, and we hope to continue in this direction for future meetings. Thanks to everyone who contributed to the success of this meeting, and we hope to see you again next time. E. Kyrölä has volunteered to host the next Limb Workshop in Helsinki, Finland, which is tentatively scheduled for April-May 2009.

Acknowledgements

We would like to recognise Tracey Silcox and Kim Keith for their invaluable and enthusiastic work throughout the preparation for and execution of the 4th International Limb Workshop.

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Reunion Island International Symposium on Tropical Stratosphere and Upper Troposphere

4-9 November 2007, Reunion Island, France

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The tropical "Stratosphere – Upper Troposphere" is a region where significant changes are expected to occur. Since dynamical activity in this region is closely linked to chemical composition, including ozone and other trace gases, any chemical or/and dynamical change may have a significant effect on mass and energy transport, including both stratosphere-troposphere exchange, as well as tropic / mid-latitude exchange.

The Reunion Island International Symposium (RiiS) was held at Reunion Island to discuss issues related to:

- transport processes near dynamical barriers, *i.e.* the tropical tropopause and the subtropical barriers,
- collection, validation and distribution of reliable data from ground-based and satellite measurements and networking with other data communities, and
- recent developments in the fields of data assimilation and modelling.

The RiiS was hosted by the Reunion University (*Université de La Réunion*) under SPARC, SCOUT-O3, NDACC, WRCP and INSU/CNRS sponsorship. A total of 84 scientists from 15 countries participated. The symposium included 13 invited papers among more than 40 oral presentations, and 25 posters.

Reunion Island Observatory

Reunion Island (20.8°S, 55.5°E) is an overseas French island. The observatory has been making atmospheric measurements continuously as part of the NDACC (Network for Detection of Atmospheric Composition Change) since 1994, and as part of the SHADOZ (Southern Hemisphere ADditional OZonesondes) projects since 1998. Depending on the season, Reunion can be influenced by the ITCZ, convective cells and cyclones, the jet-stream, and subtropical barriers. This makes it an interesting site to survey tropospheric and stratospheric ozone and related components, and to investigate dynamical processes involved in vertical and meridional exchanges through the dynamical barriers such as the tropical tropopause and southern subtropical barrier (**Figure 1**, colour plate II).

Moreover, in spite of the sparseness of ground-based measurements in the Southern Hemisphere, Reunion offers the international community an exceptional variety of qualified atmospheric data sets, and presents opportunities to international research groups (see **Table 1**). Indeed, the local CNRS Research unit, *i.e.* the Laboratory of Atmosphere and Cyclones, and OPAR (Reunion Island Observatory of Atmospheric Research) have been monitoring atmospheric parameters continuously since 1993.

Operating Instruments				
Instruments		Associated Network	Date	Parameters
Spectrometers	SOAZ UV-vis	SOAZ-NDACC	1993	Total column O_3,NO_2
	FTIR		campaigns 2002-2004-2007	CO, NO, OCS, HF, HCl, HNO_3, HCHO…
	MAXDOAS UV-vis		campaigns 2004-2005	NO_2, BrO, HCHO, O_3, SO_2,O_4
Radiosondes		SHADOZ-NDACC	1992	P, T, Rh, O_3
Rawindsondes	by GPS			winds
Sun photometer	CIMEL CE 318	AERONET	2004	Aerosols
µ-wave Radiometer			campaigns 2007-2008	Stratospheric H_2O
IR Radiometer	CIMEL CE 312		2006	Cirrus
LIDARs	Tropospheric DIAL		1998	Tropospheric O_3
	Stratospheric DIAL	NDACC	2000	Stratospheric O_3
	Rayleigh-Mie	NDACC	1994	Temperature Aerosols/cirrus
	Raman N_2	NDACC	1999	Temperature
	Raman H_2O		2001-2005	H_2O
	Doppler		2008	Trop and Strat wind components

Table 1: Summary of ground-based instruments operating at Reunion Island (http://opar.univ-reunion.fr/).

Clouds, cirrus and dehydration processes

Jean-Pierre Pommereau opened the session as one of the invited speakers. He gave an overview of troposphere-stratosphere exchange and transport in the tropical tropopause layer (TTL). He underlined that the mechanisms and time scales governing transport in this region remain uncertain. He summarised the traditional view of transport: convection up to the base of the TTL followed by slow uplift due to the radiative heating of the TTL, the formation of a "mixing layer" after convective overshooting deep into the TTL followed by an irreversible mixing, detrainment, and subsequent slow ascent in the lower stratosphere, in comparison with fast convective ascent and deep overshooting penetration in the lower stratosphere. Using recent observations of temperature, water vapour, ice particles and long-lived tropospheric species from the HIBISCUS, TROCCINOX and SCOUT-O3 campaigns, he showed that injection of tropospheric air and ice particles across the tropopause (up to 19-20 km) resulting in the hydration of the tropical stratosphere, occurs in convective regions over land. **Stephan Borrmann** (invited speaker) discussed results of ultra-fine particle measurements with a specialised COndensation PArticle measurement System (COPAS), including relevant data from other *in-situ* instruments from the TROCCINOX, SCOUT-O3 and AMMA campaigns. **Slimane Bekki** presented an analysis of MLS water vapour observations in the tropical lower stratosphere. He discussed features in the data with respect to the theory of the "stratospheric fountain". **Rong Fu** presented a paper about transport of water vapour into the lower stratosphere over the Tibetan Plateau using observational data from Aura/MLS and other A-Train observations. These observations suggest that water vapour transport by summer convection over the Tibetan Plateau is a main contributor to the observed lower stratopshere moisture content over the Asian monsoon/Tibetan region.

By contrast, Sergey Khaykin (talk given by J.P. Pommereau) showed observations from the AMMA campaign indicating lower stratospheric hydration by convective overshooting of ice particles over Western Africa. **Franz Immler** investigated the occurrence of clouds in the TTL with a trajectory model and found that ice particles form in slow ascent and efficiently dehydrate the air. He showed a correlation between temperature anomalies and occurrence of thin cirrus due to Kelvin wave propagation. **Philippe Keckhut** showed a cirrus climatology at mid-latitude from LiDAR observations. He also shows that water vapour and cirrus cloud occurrences are linked to isentropic exchange between the tropical pipe and mid-latitudes.

Composition, dynamics and subtropical barriers

A major focus of the symposium was the mechanisms by which air is exchanged between the tropics and mid-latitudes, and the relationship to the stratospheric circulation (Brewer-Dobson circulation) and wave forcing from the troposphere. In fact, exchange between the tropical pipe and mid-latitude depends on the state of the subtropical barrier. Similar to the polar vortex, the subtropical barrier may be weakened or strengthened depending on wave activity anomalies and modulations of the state of the stratosphere due to the quasi-biennial oscilliation (QBO). Our understanding of this processes still need to be improved.

Group photograph during the Reunion Island International Symposium on "Tropical Stratosphere and Upper Troposphere".

Two sessions were devoted to this topic with two invited speakers.

Using v2.2 Aura/MLS data **Michelle Santee** (invited speaker) explored a number of issues related to extra-tropical stratosphere-troposphere exchange, such as mixing of stratospheric and tropospheric air in the upper troposphere/lower stratosphere (UTLS), quasi-isentropic troposphere-to-stratosphere and stratosphere-to-troposphere exchange events, dispersal of chemically-processed air from the sub-vortex, and the seasonal evolution and inter-annual and inter-hemispheric variability in trace gases in the UTLS.

Based on the CATO data set (Candidoz Assimilated Three Dimensional Ozone), **Johannes Staehelin** presented new results regarding transport processes from the tropics to the extra-tropics caused by the QBO and Brewer Dobson circulation. The results focus on stratospheric ozone and water vapour trends, and discuss whether the increasing stratospheric water vapour trends are explicable with the present knowledge. Using LiDAR temperature observations over three northern hemisphere stations, **Vidyaranyana Charyulu** investigated statistical characteristics of stratospheric sudden warming occurrences and showed a relationship with variability of planetary wave activity and QBO phase. **Philippe Ricaud** examined the time variations of N_2O in relation with mechanisms of transport in the equatorial stratosphere, from Odin/SMR, UARS/CLAES, Nimbus7/SAMS, and Aura/MLS instruments, while **Joachim Urban** addressed upward transport in the tropical lowermost stratosphere and its seasonal and multi-annual variability from Odin/SMR, and **Alain Hauchecorne** presented a study on the tropical stratospheric ozone and NO_2 response to the QBO from ENVISAT/GOMOS data set. **Bernard Legras** (invited talk) presented a study on the age of air in the stratosphere using 5 years of heating rates from the ERA-40 reanalysis and a recent reanalysis made with 4D-Var assimilation. The study showed that heating rates alone predict much too large age of air due to insufficient heating in the lower tropical stratosphere and trapping of parcels. An optimal correction combining heating rates and a filtered version of the assimilation increment to be used for vertical transport in the stratosphere was proposed.

Isentropic transport and associated diffusion nearby the subtropical barrier was examined by two complimentary approaches: **Guillaume Kirgis** gave an evaluation of transport by multivariate analysis and **Francesco d'Ovidio** used the Lyapunov diffusion to retrieve the mixing structures of the large-scale circulation and determine the variability of the tropical pipe.

Troposphere-stratosphere exchange in the tropical UTLS

Theodore Shepherd opened this session and gave an overview talk about transport and mixing in the tropical stratosphere and upper troposphere. The talk reviewed current understanding of transport processes in this region, and their representation in models and analyses. Reported results showed evidence of strong coupling between the tropics and extra-tropics, highlighted the promising role of satellite measurements in quantifying this connection, and summarised the significant improvement of CCMs regarding their representation. **Philippe Ricaud** examined the impact of convection over land on troposphere-stratosphere exchange in the tropics using data sets from Odin/SMR, UARS/HALOE, Terra/MOPITT and Aura/MLS instruments, together with outputs from the MOCAGE Chemistry Transport Model. **Panuganty Devara** examined processes involved in stratosphere-troposphere exchange using simultaneous observations by LiDAR and Radar experiments in the tropical UTLS. **Markus Rex** showed a new approach to quantify vertical transport rates from meteorological fields and from ozone profile data. His results indicated that the use of NCEP or ECMWF ERA40 vertical winds in the TTL should be avoided, since quantification of ascent rates from assimilation data usually suffers from excessive noise in the vertical wind fields. **Jean-Pierre Chaboureau** presented mesoscale modelling results from two case studies over Brazil and Western Africa to study troposphere-stratosphere exchange and discussed existence of hydratation by convective overshoots in the tropical stratosphere. **Carine Homan** presented recent results obtained from the M55 Geophysica aircraft during the SCOUT-O3 Tropical Aircraft Campaign and from the AMMA/SCOUT-O3 campaign. She discussed vertical mixing of air in the TTL that occurs in association with convection and wind shear along the subtropical jet.

Trends and chemistry-climate interactions

John Pyle was invited to open the session. He gave an overview of recent work on chemistry and transport models developed in the UK, and described calculations with a number of chemistry-climate models, with a focus on the lower stratosphere. He looked at the role of climate change on lower stratospheric processes and how this could affect stratospheric ozone depletion and the tropospheric oxidising capacity. **Anne Thompson** reported on ten years of tropical stratosphere-troposphere profiles from the SHADOZ project. She underlined the role of sondes in global observations and reviewed results from different SHADOZ sites about tropospheric climatology, global and regional trends, convection, wave and QBO impact on ozone distributions in the tropical UTLS. Reunion Island has been operating as part of the SHADOZ project since 1998. A comparative study between Reunion Island and Irene, South Africa on long-term tropospheric ozone trends was presented by **Jean-Luc Baray**. Reported results showed significant differences in ozone behaviour in the upper troposphere from one site to another, and discussed possible effects of dynamics and anthropogenic changes, *i.e.* STE and biomass burning impact. **Karen Rosenlof** (invited speaker) discussed long-term trends in temperature in the tropical lower stratosphere, emphasising recent anomalous variations and important implications for the minor constituent compositions of the stratosphere, in particular water vapour. Results from ground-based and satellite observations show a drop in temperatures near the tropopause in the tropics by the end of 2000, and a concomitant drop in stratosphere water vapour.

Francis Schmidlin gave a useful talk on evaluation of performance and dependability of the ECC (Electro-concentration cell) ozonesonde. In fact, ozonesondes are widely contributing in numerous issues such as satellite validation, ozone variability, the study of dynamical and/or chemical processes, *etc*. Therefore, it is worthwhile maintaining their performance, stability, and consistency over time. It was shown in the talk that there is a large number of parameters in ECC preparation that require extreme care, such as back-ground current, flow rate, and pump correction.

References

Hauchecorne, A., Godin, S., Marchand, M., Heese, B., and Souprayen, C.: Quantification of the tansport of chemical constituents from the polar vortex to middle latitudes in the lower stratosphere using the high-resolution advection model MIMOSA and effective diffusivity, *J. Geophys. Res*., 107, 8289–8302, 2002.

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Report on the First WCRP Workshop on Seasonal Prediction

4-7 June 2007, Barcelona, Spain

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Introduction

The First WCRP Seasonal Prediction Workshop was held on 4-7 June 2007 in Barcelona Spain, bringing together climate researchers, forecast providers and application experts. The workshop was organised by the WCRP Task Force on Seasonal Prediction in collaboration with the core projects of the WCRP (CLIVAR, CliC, SPARC and GEWEX) and the WCP (through its WCASP/CLIPS project). The workshop's ambitious agenda addressed the current status and main limitations of seasonal forecast skill, how seasonal forecasts are being applied by users, and sought to make recommendations to improve both of these aspects. It is clear that there is substantial scope for improving skill by reducing model biases and including a wider range of climate processes.

The recommendations and overarching consensus statements that have resulted from this workshop bear the weight of the diverse seasonal prediction community that this workshop brought together. This included researchers of the physical climate system and forecast methodology, operational forecast providers and forecast application experts. Representatives from all the major operational seasonal prediction centres were in attendance. There were approximately 180 attendees, with over 30 countries from the WMO Regions I-IV (Africa, Asia, South America, North and Central America, Southwest Pacific and Europe) represented.

The workshop focused on two questions:

(i) What factors are limiting our ability to improve seasonal predictions for societal benefit?
(ii) What factors are limiting the application of our seasonal predictions for societal benefit?

In addition to addressing these questions, the workshop participants proposed recommendations spanning both the physical and application sciences for how to overcome these limiting factors. The workshop participants also developed a roadmap for improving skill and setting priorities on the development and application of dynamical models for seasonal prediction. The main outcomes of the workshop are contained in the WCRP Seasonal Prediction Position Paper, available at **http://www.clivar.org/organization/wgsip/references/WCRP_SeasonalPrediction_PositionPaper_Feb2008.pdf**. To see a full list of talks, posters, please refer to the workshop website: **http://www.clivar.org/organization/wgsip/spw/spw_main.php**. A longer version of this meeting summary has been submitted to the Bulletin of the American Meteorological Society.

Background

Our ability to predict the seasonal variations of the Earth's tropical climate dramatically improved from the early 1980s to the late 1990s. This period was bracketed by two of the largest El Niño events on record: the 1982-83 event, whose existence was unrecognised until many months after its onset; and the 1997-98 event, which was well monitored from the earliest stages, and predicted to a moderate degree by a number of models several months in advance. This improvement in forecast skill was due to the convergence of multiple factors, including a concerted international effort to observe, understand and predict tropical climate variability, the application of theoretical understanding of coupled ocean-atmosphere dynamics, and the development and application of models that simulate the observed variability.

After the late 1990s, our ability to predict tropical climate fluctuations reached a plateau with little subsequent improvement in quality. Was this a result of a fundamental change in the predictability of the climate system due to either natural or anthropogenic forcing, or the emergence of a critical failing in the models used to make predictions, or merely a sampling effect? Have we accounted for all the critical interactions among all the elements of the climate system (ocean-atmosphere-biosphere-cryosphere)? Are the observations adequately blended with the models to make the best possible forecasts? A large portion of the world's population lives in countries influenced significantly by climate anomalies. Many of these countries have economies that are largely dependent upon their agricultural and fishery sectors. The climate forecast successes of the 1980s and 1990s brought great promise for societal benefit in the use and application of seasonal forecast information. However, this promise has not been fully realised, partly because there have not been adequate interactions between the physical scientists involved in seasonal prediction research and production, applications scientists, decision makers and operational seasonal prediction providers.

Total Climate System Seasonal Prediction

The feasibility of seasonal prediction rests on the existence of slow, and predictable, variations in the Earth's boundary conditions. Within the paradigm of atmospheric predictability due to external forcing, the potential for skillful forecasts depends on the ratio of the externally forced signal relative to the atmospheric generated internal noise. The majority of external variance is known to originate from sea surface temperature variations. Less is known about the seasonal signals due to other external forcings of the total climate system, such as soil moisture, land use, sea ice, atmospheric chemical composition and aerosols. Additional skill due to atmospheric initial conditions is expected for certain slow modes of the atmosphere (for instance, annular modes), but there is little evidence that atmospheric initial conditions contribute to skill for lead times beyond a few weeks. Sessions were organised at the Barcelona workshop to address if and how seasonal forecast quality can be improved by taking into account processes in the cryosphere, land surface and stratosphere. The following factors have the potential of improving the predictability of variability at seasonal time scales:

- Sea ice is highly coupled to the ocean-atmosphere system from synoptic to decadal time scales, with large sea ice anomalies tending to persist due to positive feedback in the ocean-atmosphere-ice system. Sea ice anomalies in the Southern Hemisphere can be predicted statistically at seasonal time scales by a linear Markov model, and cross-validation with observed estimates can yield correlations of 0.5 even at 12 month lead times. Land ice and snow cover in the Northern Hemisphere is a highly variable surface condition, both spatially and temporally, and can be related to atmospheric variability.

- Soil moisture anomalies, which can persist from weeks to months, can generate rainfall and air temperature anomalies in transitional zones between wet and dry regions. Other potential land-based sources of predictive skill, in addition to snow cover, are sub-surface heat reservoirs and vegetation health (leafiness).

- The stratosphere in many ways acts as a boundary condition for the troposphere, with a highly variable circulation at time scales that are much longer than those of the troposphere. In particularly sensitive areas, such as Europe in winter, model results suggest that the influence of stratospheric variability on land surface temperature can exceed the local effect of SST.

The impact of the different components of the climate system on seasonal prediction quality remains an area in need of active research, both in terms of initialisation and in terms of model development (*e.g.* resolution of stratospheric processes, stratosphere-troposphere coupling).

Summary of the SPARC session

M. Baldwin and **A. Charlton** (a.k.a. A. Charlton-Perez) discussed how the circulation of the stratosphere affects the troposphere, on time scales relevant for seasonal forecasting. In many ways the stratosphere acts as a boundary condition for the troposphere. The stratospheric circulation can be highly variable, with a time scale much longer than that of the troposphere. The variability of the stratospheric circulation can be characterised mainly by the strength of the polar vortex, or equivalently the high-latitude westerly winds. During Northern winter and Southern late spring, stratospheric variability peaks. When the flow just above the tropopause is anomalous, the tropospheric flow tends to be disturbed in the same manner, with the anomalous tropospheric flow lasting up to ~2 months. The surface pressure signature looks very much like the North Atlantic Oscillation (NAO) or Northern Annular Mode (NAM).

The stratospheric aspects of seasonal prediction can only be captured by models that properly simulate stratospheric variability. Thus far, the stratosphere's potential to improve seasonal forecasts is largely untapped. It is essential that seasonal forecast models simulate the intense, rapid shifts in the stratospheric circulation, as well as the downward propagation of circulation anomalies through the stratosphere. In addition, models must be able to simulate the poorly understood connections between the lower stratosphere and the tropospheric circulation.

In the cold seasons, the intra-annual variability in the stratosphere features downward propagation of circulation anomalies. **B. Christiansen** discussed the physical mechanisms that could lead to seasonal prediction capability. Zonal-mean zonal wind anomalies are born in the mesosphere and propagate down through the stratosphere and into the troposphere on a time scale of weeks to months. The mechanism is a consequence of nonlinear interactions between the zonal-mean and large scale waves, and shows that even simple models can represent the basic features. Considering the near surface zonal-mean zonal wind at 60°N as a predictand he showed that the inclusion of stratospheric information improves the daily forecast on lead times larger than 5 days. The best forecasts are obtained for predictors in the lower stratosphere. Similar predictions can not be obtained if the statistical forecast only includes tropospheric information. The simple statistical forecast based on stratospheric winds compares favourably to the forecasts of a state-of-the-art dynamical ensemble prediction system.

H. Mukogawa reasoned that it is first necessary to be able to predict events within the stratosphere, such as sudden warmings. He described a model study in which the predictability of stratosphere-troposphere dynamical coupling during stratospheric sudden warming (SSW) events was examined using an AGCM and an operational 1-month ensemble forecast data set provided by the Japan Meteorological Agency (JMA). December 2001 served as a case study. He found that the SSW was predictable from at least 2 weeks in advance, and was highly sensitive to the initial conditions. This emphasises the need for accurate

data assimilation, if tropospheric events are to be predicted.

SSWs are a typical example of the stratosphere-troposphere coupled system, in which planetary wave driving gives rise to its rapid time evolution. **T. Hirooka** discussed how planetary waves play an important role in their development. Accurate prediction of the details of warming events, such as vortex splitting, is ultimately important for tropospheric prediction. Such a difference in the course of time evolution would make a difference in predictable periods of the sudden warmings. He examined five warming events occurring in five recent Northern Hemisphere winters using the JMA ensemble one-month forecast data. The predictability of certain periods crucially depended on the time evolution of the warmings; the lead time for the prediction of the wavenumber-1 warmings was relatively long, say, 2-3 weeks in advance, compared with that of the warmings contributed to by wavenumber-2 and/or 3, say, 7-10 days. The short predictability of the latter might be connected to the difficulty in the prediction of wavenumber-2 and 3 evolution compared with that of wavenumber-1 evolution. Even though the time change of zonal-mean temperatures is successfully predicted, that of zonal-mean zonal winds is often difficult to predict.

GloSea4 is the new UK Met Office Seasonal Forecasting System, expected to become operational in 2009. **A. Scaife** and **M. Keil** discussed the plans for GloSea4. A commonly held view is that the stratosphere is primarily important on seasonal and climate time scales, but not so important at shorter time scales. However, recent upgrades to the UK Met Office operational global NWP model have shown a strong relationship between an improved stratospheric analysis and more accurate tropospheric weather forecasts on the 0-5 days time scales. In general, studies have shown that stratospheric changes appear to be important for the very rapid warming of European winters between the 1960s and 1990s and associated changes in the frequency of climate extremes. The stratosphere also appears to play a key role in transmitting ENSO signals to Europe in winter. The winter of 2005/6 was used as a case study to illustrate how stratospheric influence occurs in an individual year. These results indicate that an improved vertical domain leads to improved forecasts.

W. Norton discussed specific aspects of using a new high resolution coupled model (HiGEM) model for prediction of European weather. Statistical analysis shows that for non-ENSO years Atlantic SSTs can provide a useful predictor of wintertime anomalies over Europe (an example being the winter of 2005/6). However, dynamical seasonal forecast models have so far failed to reproduce this predictive capability. HiGEM is now being tested to see if it produces the connection between the Atlantic SSTs and wintertime anomalies over Europe. It will be examined to see if the NAO has added persistence in the 10-25 day range, which potentially could arise from stratospheric anomalies.

The WCRP Position Paper

The following is the summary of the stratospheric outcomes, as published in the WCRP Position Paper **http://www.clivar.org/organization/wgsip/references/WCRP_SeasonalPrediction_PositionPaper_Feb2008.pdf.**

In many ways the stratosphere acts as a boundary condition for the troposphere. The stratospheric circulation can be highly variable, with a time scale much longer than that of the troposphere. The variability of the stratospheric circulation can be characterised mainly by the strength of the polar vortex, or equivalently the high latitude westerly winds. Stratospheric variability peaks during Northern winter and Southern late spring. When the flow just above the tropopause is anomalous, the tropospheric flow tends to be disturbed in the same manner, with the anomalous tropospheric flow lasting up to about two months. The surface pressure signature looks very much like the North Atlantic Oscillation (NAO) or Northern Annular Mode (NAM). Surface temperature signals are also similar to those from the NAO and Southern Annual Mode (SAM) and there are associated effects on extremes. In particularly sensitive areas, such as Europe in winter, experiments suggest that the influence of stratospheric variability on land surface temperatures can exceed the local effect of sea surface temperature.

The stratospheric aspects of seasonal prediction can only be captured by models that properly simulate stratospheric variability. Thus far, the stratosphere´s potential to improve seasonal forecasts is largely untapped. It is essential that seasonal forecast models simulate the intense, rapid shifts in the stratospheric circulation, as well as the downward propagation of circulation anomalies through the stratosphere. In addition, models must be able to simulate the poorly understood connections between the lower stratosphere and the tropospheric circulation.

To maximise predictability from the stratosphere, forecasting systems also need to predict stratospheric warmings and other variability at as long a lead time as possible. Recent experiments suggest this is typically 1 to 2 weeks but it can be longer in some cases.

Recommendations:

1) To exploit predictability from stratospheric processes, seasonal forecast models must have accurate representations of stratospheric processes. Our current understanding suggests that a model would be required to have a model top significantly above the stratopause (or the order of 0.01hPa) and to have a high vertical resolution (of the order of 30 levels in the stratosphere) to have a good simulation of the stratosphere.

2) It will also be necessary to diagnose stratosphere-troposphere coupling in seasonal forecast models. This can be done by *producing diagnostics based on multi-level annular mode indices. To do this, daily, zonal-mean geopotential is required at all model (or pressure) levels. If these zonal-mean geopotential data are available, then diagnostics such as variance of the annular modes, and time scale of the annular modes can be examined and compared to observations. Such analyses are necessary to know if the model's representation of stratosphere-troposphere coupling is realistic.*

Acknowledgements

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Acronyms:

CliC: Climate Cryosphere
CLIVAR: Climate Variability
GEWEX: Global Energy Water Experiment
NWP: Numerical Weather Prediction
WCASP/CLIPS: World Climate Applications and Services Programme /Climate Information and Prediction Services
WCP: World Climate Programme
WCRP: World Climate Research Programme

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Decadal predictability: How might the stratosphere be involved?

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How warm, wet, and stormy will the next decade be? This question and how to answer it – decadal climate prediction – is currently generating a large amount of interest in the research community. The interest stems from the growing awareness that climate varies naturally on decadal time scales, both regionally and globally, with large socio-economic consequences, and has the potential to temporarily offset or exacerbate anthropogenic global warming. The aim here is to discuss the current status of decadal prediction and highlight areas where the stratosphere may play an important role.

Natural decadal variability

Where does natural decadal variability occur? What are the mechanisms? Is it predictable? These are important questions in the context of decadal prediction. Only a few key points are discussed here; Latif *et al.,* (2006a) give a recent review of some of these issues.

During the last century, there was an increase in global mean temperature of around 1°C (**Figure 1**). Superimposed on the slow increase, there were also fluctuations on multi-decadal time scales. A good example is the warming early last century, which peaked around 1940. Multi-decadal climate variations are not only seen at a global scale, but occur regionally. For example, the early century warming had a strong expression in the North Atlantic Sector (**Figure 2**), which was associated with Atlantic Multi-decadal Variability (AMV, Delworth and Knutson, 2000). AMV is an internal mode of the climate system involving large-scale air-sea interaction in the Atlantic (Bjerknes, 1964; Kushnir, 1994; Schlesinger and Ramankutty, 1994; Knight *et al.,* 2005). Its impacts include hurricane activity (Figure 2 from Goldenberg *et al.*, 2001), and surface temperature and rainfall variations in Northern Africa (Figure 2 from Folland *et al.,* 2001), and Europe (Sutton and Hodson, 2005). Modelling studies indicate that AMV also influences global mean temperature (Knight *et al.,* 2006; Zhang *et al.,* 2007).

In addition to the North Atlantic, pronounced decadal variability is observed in the North Pacific, the Tropical Pacific and the Southern Ocean. Modelling studies suggest that these four regions have high potential decadal predictability, with the North Atlantic and Southern Ocean showing the highest levels (**Figure 3**, colour plate III). Interestingly, both are regions with a possibly strong stratospheric influence (*e.g*. Thompson and Wallace, 2000). The mechanisms for decadal variability remain largely controversial, due to lack of observations and disagreement among models. Despite this, perfect model predictability studies show that the North Atlantic and Southern Ocean variability is predictable on decadal time scales. The level of predictability and extension over land, however, vary among models.

Although there have been several mechanisms proposed for AMV, the importance of the Atlantic Meridional Overturning Circulation (MOC) is common to most. The MOC transports a significant amount of heat from the equator to the Northern Hemisphere, contributing to the relatively mild climates of Europe and eastern North America. Results from coupled models and

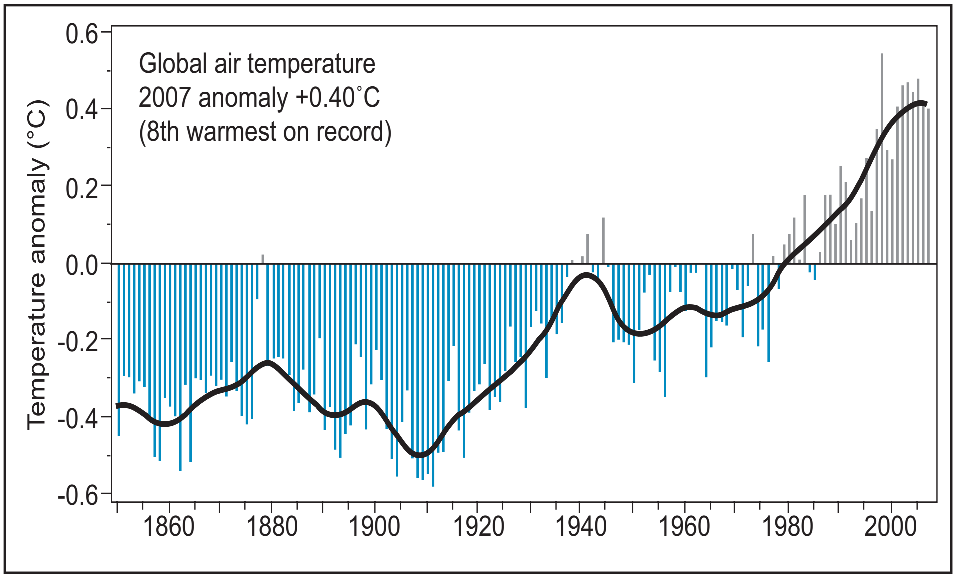
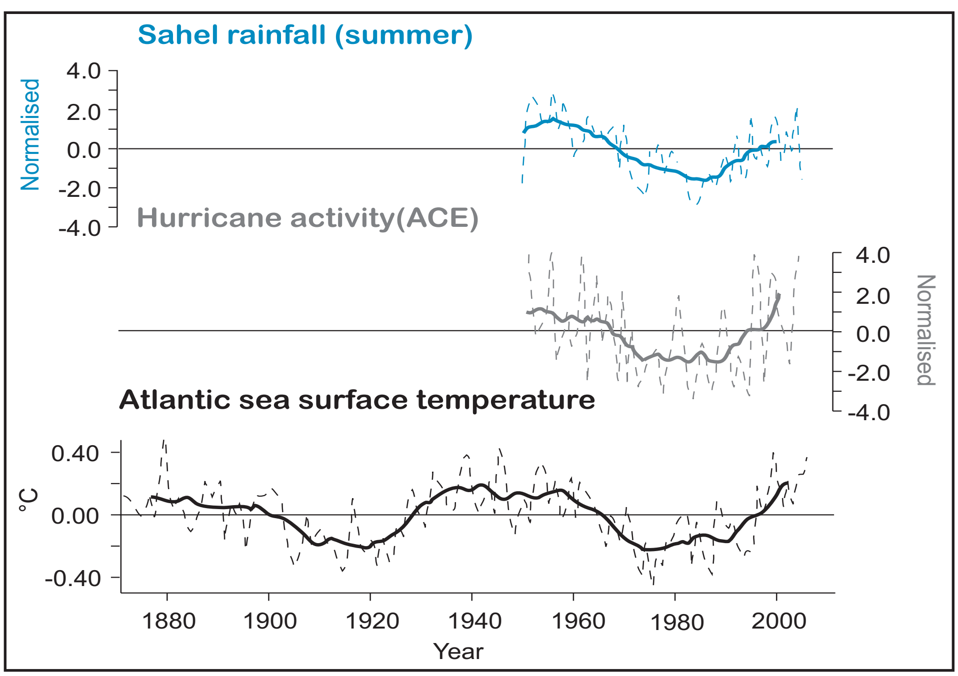


Figure 1: Observed temperature anomalies (Brohan et al., 2006), from the Climate Research Unit, University of East Anglia, UK.

uncoupled ocean models show a close relationship between multi-decadal fluctuations of the MOC and Atlantic sea surface temperature (SST). Although the origin of the multi-decadal fluctuations of the MOC remains controversial, there is evidence that the North Atlantic Oscillation (NAO) plays an important role. Specifically, variations in the NAO drive changes in the Labrador Sea convection, and in this way influence the amount of dense water formed and the strength of the MOC (Eden and Jung, 2001; Latif *et al.,* 2006b). Similarly, variations in the Southern Annular Mode may drive changes in the Southern Ocean circulation (Cai *et al.,* 2005), and possibly the Atlantic MOC (*e.g.* Vallis, 2006).

A joint initial value/boundary value problem

Climate prediction has been mostly considered on two different time scales: seasonal and centennial. Seasonal prediction is primarily an initial value problem, *i.e*. the evolution of the system depends on the initial state (Palmer *et al.,* 2004). Whereas centennial scale prediction is normally considered a boundary value problem, *i.e.* the evolution of climate depends on external changes in radiative forcing, such as anthropogenic changes in atmospheric composition or solar forcing (IPCC, 2007). What class of problem is decadal prediction: initial value or boundary value?



As described above, observations and models indicate that decadal climate variations – global and regional – may arise from internal modes of the climate system and be potentially predictable (*i.e.* an initial value problem). On the other hand, climate predictions indicate a rise in global mean temperature of between 2 and 4°C by 2100, dependant on emission scenario and model (**Figure 4**, colour plate III). This translates to an average rise in global mean temperature of order 0.3°C per decade. This is large compared with observed increase of around 1°C during the last century (Figure 1), and argues that decadal prediction is also a boundary value problem. Twentieth century climate simulations that include both natural and anthropogenic forcing further support this picture, as they reproduce the observed increase in global mean temperature (IPCC, 2007). Consistent with decadal prediction also being an initial value problem, these simulations poorly reproduce the early century warming, with the largest discrepancy over the ocean (Figure 5 from Summary for Policy Makers, IPCC, 2007)). Two other reasons for this discrepancy are the impact of external forcing in the models is too weak and the observed time series is partly erroneous (David Thompson, private communication).

Initial efforts at decadal prediction

There have been two recent efforts at decadal prediction, and both follow a similar strategy: a global climate model is initialised from observations and run forward ten years, at the same time accounting for changes in external forcing (natural and anthropogenic). In the first work (Smith *et al.,* 2007), the Hadley Centre model was initialised using surface and subsurface ocean observations and the ECMWF atmospheric reanalysis. The results showed that global mean temperature could be predicted out to a decade in advance, with more skill than that obtained by only accounting for external radiative forcing (boundary condition) changes (**Figure 5**). This skill enhance-

Figure 2: Time series of Atlantic (0-60ºN) averaged seas surface temperature (Rayner et al., 2003), hurricane activity (Accumulated Cyclone Energy (ACE); http://www.aoml.noaa.gov/hrd/tcfaq/E11.html), and June-October averaged Sahel rainfall (http://jisao.washington.edu/data_sets/sahel/). The mean trend is removed from all time series. Eleven year running mean and annual values are shown by solid and dashed lines, respectively.

ment resulted from initialisation of the upper ocean heat content. There was skill enhancement also in particular regions, including the Indian Ocean and parts of the Southern Ocean.

In the second study (Keenlyside *et al.,* 2008), the Max-Planck-Institute for Meteorology climate model was initialised using only SST observations, by simply restoring coupled model SST anomalies towards observations. Although simple, the scheme was able to initialise low frequency variations in the ocean circulation, particularly the Atlantic MOC. This forecast system showed skill in predicting ten year mean surface temperature variations a decade in advance over parts of the North Atlantic Sector, including Europe and North America, and the Tropical Pacific (**Figure 6**, colour plate IV). In these regions, skill was again greater than that obtained from only external radiative (boundary condition) forcing. Ten year averaged global surface temperature variations were also predictable, but with marginally less skill than obtained from radiative forcing only.

In both studies forecasts were made for the next ten years, and in both cases, natural internal variability was found to temporarily offset anthropogenic global warming. The offset was largest in Keenlyside *et al.,* (2008), whose results suggest a temporary lull in global warming for the next decade. Keeping in mind the simplicity of the scheme employed by Keenlyside *et al.*, (2008), the results nevertheless highlight the impact of internal variability on the evolution of surface temperature, globally and regionally, over the next decade and warrant further investigation.

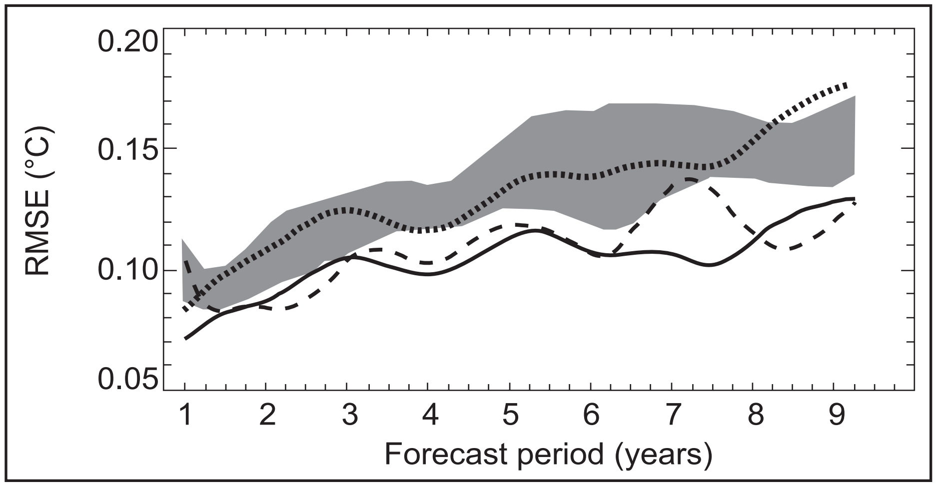


Figure 5: Hindcast skill (root mean square error) in predicting globally averaged annual mean surface temperature anomalies as a function of forecast lead-time of initialised (solid) and uninitialised radiative forcing only (shaded region) forecasts. Shading shows the 5 to 95% confidence interval. Figure from Smith et al., (2007); see article for description of other curves.

How might the stratosphere be involved?

Stratospheric and tropospheric variability are linked on seasonal time scales, as shown by observational (*e.g.* Kodera *et al.,* 1990; Baldwin and Dunkerton, 1999) and modelling studies (*e.g.* Boville, 1984; Christiansen, 2001; Polvani and Kushner, 2002). It follows that low-frequency stratospheric change, of either natural or anthropogenic origin, can influence tropospheric circulation. This was recently highlighted in experiments that showed that the observed strengthening of the stratospheric jet from 1965-1995 could reproduce the observed changes in the NAO and North Atlantic Sector climate (Scaife *et al.,*2005). Both the pattern and amplitude of the winter land surface temperature and precipitation over this multidecadal period were well reproduced once the stratospheric change was imposed in the model (**Figure 7**, colour plate IV). It is thus important to understand the nature of low-frequency stratospheric variability and to simulate it correctly.

Boundary condition forcing from anthropogenic ozone depletion and greenhouse gas increases are an important source of low-frequency stratospheric variations. Both have cooled the polar stratosphere (*e.g.* Ramaswamy *et al.,* 2001). Given the link between stratospheric and tropospheric changes, the response to the continuing expected increase in greenhouse gases may also be modulated by the stratosphere (*e.g.* Huebener *et al.,* 2007). The depletion of ozone in the polar stratosphere is associated with both dynamical and radiative cooling that enhances the polar vortex and makes the ozone depletion even stronger. Because of this feedback, the simulation of the ozone impact on the climate requires a coupled chemistry climate model (CCM) that includes both a troposphere and a stratosphere. The ozone depletion is associated with Annular-Mode-like structures in both hemispheres, which can penetrate into the troposphere (*e.g.* Volodin and Galin, 1998; Kindem and Christiansen, 2001; Thompson and Solomon, 2002; Gillett and Thompson, 2003). In this respect, the recovery of ozone, which is expected to occur over the next 40-50 years (*e.g.* WMO, 2007), may give rise to predictable changes at the surface on decadal time scales.

Solar variations are another potential source of low-frequency stratospheric variability. Depending on the Quasi Biennial Oscillation (QBO) phase, the extra-tropical stratospheric circulation appears to be strongly affected by the 11-year solar cycle (*e.g.* Labitzke, 2005). The signature of the solar cycle appears to be present not only in the stratosphere, but also in the troposphere (*e.g.* Labitzke and van Loon, 1988; Kodera, 2002), and possibly also in the upper ocean temperatures (*e.g.* White *et al.,* 1997). The three most common methods to simulate solar cycle variations are to vary (1) total solar irradiance (as typically done in IPCC class 'low top' models), (2) UV radiation by prescribing ozone climatologies, and (3) to use a CCM, which explicitly captures the ozone feedbacks. All reproduce a significant response at the surface (Matthes *et al.,* 2007, SPARC Newsletter No. 28). However, it needs to be clarified how much of this effect comes from tropical dynamics and the QBO, spectrally resolving short wave radiation, the role played by fully representing the stratosphere, and a good representation of the ozone feedbacks to the solar cycle.

A third way that the stratosphere may play an important role in low-frequency tropospheric variability is by providing teleconnection pathways. In particular, the stratosphere bridges the tropics with the extra-tropics on seasonal time scales (*e.g.* Brönnimann, 2007). A stratospheric bridge between the North Pacific and Atlantic has also been identified (*e.g.* Castanheira and Graf, 2003). Finally, in addition to the ocean circulation, the natural internal variability of the stratosphere itself could lead to decadal time scale variations (*e.g.*

Butchart *et al.,* 2000; Taguchi and Yoden, 2002).

Summary

Decadal climate prediction is of socio-economic importance and has a potentially important role to play in policy making. In contrast to seasonal prediction and centennial climate projections, it is a joint initial value/boundary value problem. Thus, both accurate projections of changes in radiative forcing and initialisation of the climate state, particularly the ocean, are required. Although the first promising steps towards decadal prediction have been made, much more work is required. Understanding of the mechanisms and predictability of decadal-to-multidecadal variability is lacking, and is a key area where stratospheric research should contribute. In particular, the stratosphere may have an important role in correctly capturing the response of climate to changes (natural and anthropogenic) in external radiative forcing, and also by providing a teleconnection pathway to the annular modes and extratropical storm tracks.

References

Baldwin, M. P. and T. J. Dunkerton, 1999: Downward propagation of the Arctic Oscillation from the stratosphere to the troposphere. *J. Geophys. Res*., 104, 30937–30946.

Bjerknes, J., 1964: Atlantic air-sea interaction. *Adv. Geophys*., 10, 1-82.

Boer, G., 2001:Decadal potential predictability in coupled models, *CLIVAR Exchanges*, Vol. 19, No. 3, International CLIVAR Project Office, Southampton, United Kingdom, 3 pp.

Boville, B. A., 1984: The influence of the polar night jet on the tropospheric circulation in a GCM. *J. Atmos. Sci*., 41, 1132–1142.

Brohan, P., J. J. Kennedy, I. Harris, S. F. B. Tett, and P. D. Jones, 2006: Uncertainty estimates in regional and global observed temperature changes: new dataset from 1850. *J. Geophys. Res*., 111, D12106.

Brönnimann, S., 2007: The impact of El Niño/Southern Oscillation on European climate. *Rev. Geophys*., 45, RG3003.

Butchart, N., J. Austin, J. Knight, A. A. Scaife, and M. L. Gallani, 2000: Response of the stratospheric climate to projected changes in the concentrations of well mixed greenhouse-gases from 1992 to 2051. *J. Climate*, 13, 2142-2159.

Cai, W., G. Shi, T. Cowan, D. Bi, and J. Ribbe, 2005: The response of the Southern Annular Mode, the East Australian Current, and the southern mid-latitude ocean circulation to global warming. *Geophys. Res. Lett*., 32, L23706.

Castanheira, J. M. and H.-F. Graf, 2003: North Pacific–North Atlantic relationships under stratospheric control? *J. Geophys. Res*., 108, 4036.

Christiansen, B., 2001: Downward propagation from the stratosphere to the troposphere: Model and reanalysis. *J. Geophys. Res*., 106, 27307–27322.

Delworth, T. L. and T. R. Knutson, 2000: Simulation of early 20th century global warming. *Science*, 287, 2246-2250.

Eden, C. and T. Jung, 2001: North Atlantic Interdecadal variability: Oceanic response to the North Atlantic Oscillation (1865-1997). *J. Climate*, 14, 676-691.

Enfield, D. B., A. M. Mestas-Nuñez, and P. J. Trimble, 2001: The Atlantic Multidecadal Oscillation and its relation to rainfall and river flows in the continental U. S. *Geophys. Res. Lett*., 28, 2077-2080.

Folland, C. K., T. N. Palmer, and D. E. Parker, 1986: Sahel rainfall and worldwide sea temperatures, 1901-85. *Nature*, 320, 602-607.

Gillett, N. P. and D. W. J. Thompson, 2003: Simulation of recent southern hemisphere climate change. *Science*, 302, 273-275.

Goldenberg, S. B., C. W. Landsea, A. M. Mestas-Nuñez, and W. M. Gray, 2001: The recent increase in Atlantic hurricane activity: Causes and implications. *Science*, 293, 474-479.

Huebener, H., U. Cubasch, U. Langematz, T. Spangehl, F. Niehörster, et al., 2007: Ensemble climate simulations using a fully coupled ocean–troposphere–stratosphere general circulation model. *Phil. Trans. R. Soc. A*., 365, 2089-2101.

IPCC, 2007: Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. 996 pp.

Keenlyside, N. S., M. Latif, J. Jungclaus, L. Kornblueh, and E. Roeckner, 2008: Advancing decadal-scale climate prediction in the North Atlantic Sector. *Nature*, 453, 84–88.

Kindem, I. T. and B. Christiansen, 2001: Tropospheric response to stratospheric ozone loss. *Geophys. Res. Lett*., 28, 1547-1550.

Knight, J. R., C. K. Folland, and A. A. Scaife, 2006: Climate impacts of the Atlantic multidecadal oscillation. *Geophys. Res. Lett*., 33, L17706.

Knight, J. R., R. J. Allan, C. K. Folland, M. Vellinga, and M. E. Mann, 2005: A signature of persistent natural thermohaline circulation cycles in observed climate. *Geophys. Res. Lett.*, 32, L20708.

Kodera, K., 2002: Solar cycle modulation of the North Atlantic Oscillation: implication for the spatial structure of the NAO. *Geophys. Res. Lett*., 29, 1218.

Kodera, K., K. Yamazaki, M. Chiba, and K. Shibata, 1990: Downward propagation of upper stratospheric mean zonal wind perturbation to the troposphere. *J. Meteorol. Soc. Jpn*., 9, 1263–1266.

Kushnir, Y., 1994: Interdecadal variations in North Atlantic sea surface temperature and associated atmospheric conditions. *J. Climate*, 7, 141-157.

Labitzke, K., 2005: On the solar cycle QBO relationship: a summary. *J. Atmos.* Sol.-Terr. Phy., 67, 45-54.

Labitzke, K. and H. van Loon, 1988: Associations between the 11-year solar cycle, the QBO (quasi-biennial-oscillation) and the atmosphere. Part I: the troposphere and stratosphere in the northern hemisphere in winter. *J. Atmos.* Terr. Phys., 50, 197-206.

Latif, M., M. Collins, H. Pohlmann, and N. Keenlyside, 2006a: A review of predictability studies of Atlantic sector climate on decadal time scales. *J. Climate*, 19, 5971-5987.

Latif, M., C. Böning, J. Willebrand, A. Biastoch, J. Dengg, *et al*., 2006b: Is the thermohaline circulation changing? *J. Climate*, 19, 4631-4637.

Palmer, T. N., A. Alessandri, U. Andersen, P. Cantelaube, M. Davey, *et al*., 2004: Development of a European multimodel ensemble for seasonal-to-interannual prediction (DEMETER). *Bull. Amer. Meteor. Soc*., 85, 853-872.

Polvani, L. M. and P. Kushner, 2002: Tropospheric response to stratospheric perturbations in a relatively simple general circulation model. *Geophys. Res. Lett*., 29, 1114.

Ramaswamy, V., M.-L. Chanin, J. Angell, J. Barnett, D. Gaffen, et al., 2001: Stratospheric temperature trends: Observations and model simulations. *Rev. Geophys*., 39, 71–122.

Rayner, N. A., D. E. Parker, E. B. Horton, C. K. Folland, L. V. Alexander, et al., 2003: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *J. Geophys. Res*., 108, 4407.

Scaife, A. A., J. R. Knight, G. K. Vallis, and C. K. Folland, 2005: A stratospheric influence on the winter NAO and North Atlantic surface climate. *Geophys. Res. Lett*., 32, L18715.

Schlesinger, M. E. and N. Ramankutty, 1994: An oscillation in the global climate system of period 65-70 years. *Nature*, 367, 723-726.

Smith, D. M., S. Cusack, A. W. Colman, C. K. Folland, G. R. Harris, et al., 2007: Improved surface temperature prediction for the coming decade from a global climate model. *Science*, 317, 796-799.

Sutton, R. T. and D. L. R. Hodson, 2005: Atlantic Ocean forcing of North American and European summer climate. *Science*, 309, 115-118.

Taguchi, M. and S. Yoden, 2002: Internal interannual variability of the troposphere--stratosphere coupled system in a simple global circulation model. Part II: Millennium integrations. *J. Atmos. Sci*., 59, 3037--3050.

Thompson, D. W. J. and J. M. Wallace, 2000: Annular modes in the extratropical circulation. Part I: Month-to-month variability. *J. Climate*, 13, 1000-1016.

Thompson, D. W. J. and S. Solomon, 2002: Interpretation of recent Southern Hemisphere climate change. *Science*, 296, 895-899.

Vallis, G. K., 2006: *Atmospheric and Oceanic Fluids Dynamics: Fundamentals and Large-scale Circulation*. Cambridge Uni. Press.

Volodin, E. M. and V. Y. Galin, 1998: Sensitivity of midlatitude northern hemisphere winter circulation to ozone depletion in the lower stratosphere. *Russ. Meteor. Hydrol*., 8, 23-32.

White, W. B., J. Lean, D. R. Cayan, and M. D. Dettinger, 1997: Response of global upper ocean temperature to changing solar irradiance. *J. Geophys. Res*., 102, 3255–3266.

WMO, 2007: Scientific Assessment of Ozone Depletion: Report of the 2006 Assessment of the Scientific Assessment-Panel. **http://www.ozone.unep.org/Assessment_Panels/SAP/ Scientific_Assessment_2006/index.shtml Rep.**

Zhang, R., T. L. Delworth, and I. M. Held, 2007: Can the Atlantic Ocean drive the observed multidecadal variability in Northern Hemisphere mean temperature? *Geophys. Res. Lett*., 34, L02709.

Announcement

A workshop on “The Role of Halogen Chemistry in Polar Stratospheric Ozone Depletion” was held at the University of Cambridge from June 15-17, 2008. A detailed workshop report is in preparation and information regarding its availability will be posted on the SPARC web site. Publications in each of the focus areas Laboratory/Theory, Atmospheric Measurements and Modelling/Analysis will be assembled in one or two special journal issues on a time scale suitable for use in the 2010 UNEP/WMO Ozone Assessment. A workshop summary will follow in the January 2009 issue of the SPARC Newsletter (no. 32).

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Future SPARC and SPARC-related Meetings

2008

8-11 July	**SCAR/IASC IPY Open Science Conference and Polar Research – Arctic and Antarctic Perspectives in the International Polar Year,** St. Petersburg, Russia, www.scar-iasc-ipy2008.org/
8-11 July	**PAGES 3rd Open Science Meeting,** Corvallis, OR, USA, www.pages.unibe.ch/
13-20 July	**37th Scientific Assembly of the Committee on Space Research and Associated Events - COSPAR 2008 "50th Anniversary Assembly",** Montreal, Canada, http://www.cospar2008.org/ or http://www.cospar-assembly.org
31 August-5 September	**SPARC 4th General Assembly,** Bologna, Italy, www.cmcc.it/web/public/sparc-ga2008
7-12 September	**10th IGAC 2008 Conference: Bridging the Scales in Atmospheric Chemistry: Local to Global** Annecy-le-Vieux, France, http://www.igacfrance2008.fr/
21-23 October	**Ibero American Workshop on Seasonal Prediction: The Modeling science and its contribution to development,** Guayaquil, Ecuador, www.ciifen-int.org
5-10 November	**ESF-FMSH Entre-Sciences International Conference on New Methodologies and Interdisciplinary Approaches in Global Change Research,** Porquerolles, France, www.esf.org/conferences/08284
15–19 December	**2008 Fall AGU Meeting,** San Francisco, CA, USA, http://www.agu.org/meetings/fm08/

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