derstanding of the fundamental processes and feedbacks underlying polar predictability. At the same time, a number of general issues and opportunities were identified which apply to both poles:

(i) A better understanding of seasonal predictability, not only for its societal benefits but also for understanding the seasonality of longer-term variability and changes. The WCRP's Working Group on Seasonal to Interannual Prediction (WGSIP) has the infrastructure to perform prediction studies but needs the expertise of polar scientists to interpret the results of those studies in polar regions and design new experiments.

(ii) A better understanding of decadal variability and its partitioning between internally generated and externally forced components. The WCRP's Working Group on Coupled Modelling (WGCM) has defined a set of coordinated experiments focusing on the near term (*i.e.*, several decade) time horizon within its CMIP5 activity, which will provide a large archive of model simulations that can be analysed from this perspective.

(iii) Improved initial state estimates. Potential improvements in existing observations (or their availability) need to be identified for action by the relevant agencies; coupled assimilation systems including snow and sea ice need to be developed, in collaboration with weather prediction centres who are wrestling with this issue as part of their efforts to improve polar weather prediction; and there needs to be a better understanding of the sensitivity of polar predictability on decadal time scales to initial-state error in the ocean, to guide ocean observational network design.

(iv) A better understanding of potential predictability. The value of a "perfect model" methodology hinges entirely on how realistic the model is. In cases where models have some basic credibility, this approach can be exploited to determine where the predictability lies. In other cases, key model processes that are holding back progress need to be identified for a targeted effort at improvement.

The conclusion of the workshop was that a cross-cutting WCRP initiative was needed in the area of polar predictability, whose first action would be to hold a focused meeting in about six months' time, to develop a detailed implementation plan concerning the above issues. In developing such a plan it will of course be necessary to engage and partner with other relevant research bodies. It was felt that although there were important differences between the Arctic and Antarctic that could lead to differences in priorities, there were also considerable scientific and logistical benefits to be obtained by considering the two poles in parallel. Therefore it was suggested that there should be a single initiative, but with distinct Arctic and Antarctic foci.

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Report on the SPARC DynVar Workshop 2 on Modelling the Dynamics and Variability of the Stratosphere-Troposphere System

3-5 November 2010, Boulder, USA

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The 2nd Workshop of the Stratospheric Process and their Role in Climate (SPARC) DynVar Activity took place in Boulder, Colorado, USA, 3-5 November 2010. The workshop was hosted by the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory's (ESRL) Physical Sciences Division in collaboration with the Cooperative Institute for Research in Environmental Sciences (CIRES) at University of Colorado, and was held at NOAA ESRL David Skaggs Research Center. CIRES, NOAA, including NOAA's Modeling, Analysis, Prediction and Projection (MAPP) Program, the European Commission COMBINE Integrating Project, and the SPARC project of the World Climate Research Programme (WCRP) kindly provided support for the workshop. A special thanks to the many people at NOAA and CIRES involved in the organization of the excellent local arrangements for the Workshop at NOAA ESRL.

The SPARC DynVar Workshop 2 attracted 68 participants from 11 countries: USA (35), Canada (8), United Kingdom (7), Japan (6), Germany (4), France (3), Denmark (1), Israel (1), Italy (1), Norway (1), Spain (1). The workshop consisted of 11 invited and 41 contributed presentations (11 orals and 30 posters) and was opened by a keynote presentation by Susan Solomon. Forty-five abstracts were submitted to the workshop, although submission of abstracts was not compulsory. The relatively large number of submitted abstracts indicates a growing interest in the role of stratospheric dynamics and variability on the climate system. Poster sessions were all well attended. Lunch and coffee breaks held on site were intensively used for informal discussions. A total of 5 hours was dedicated to discussing the core goals of the DynVar Activity, including difficulties and opportunities for those in the SPARC community, with most of the discussion focused on the role of stratospheric dynamical processes in the Earth system.

The goals of the DynVar Activity are to determine the dependence of the mean climate, climate variability, and climate change on stratospheric dynamics as represented in climate and Earth system models. Since the first DynVar Workshop (held in Toronto, Canada, 27-28 March 2008), a number of new studies contributing to our knowledge on how stratospheric representation affects climate simulated by models have appeared in the literature. In part, because of these advancements, a number of climate modelling groups are now planning to undertake the Coupled Model Intercomparison Project Phase 5 (CMIP5) experiments with models that include a well-resolved stratosphere. The interest in models with a well-resolved stratosphere has also led to the Stratosphere resolving Historical Forecast Project (SHFP), part of the WCRP's Working group on Seasonal to Interannual Prediction (WGSIP) cross cutting activity with the Climate Variability and Predictability project (CLIVAR), aimed at quantifying improvements in actual predictability by initializing and resolving the stratosphere in seasonal forecast systems.

The 2.5 day workshop provided a forum for:

- Presenting new works on key areas central to the Activity such as the influence of the stratosphere on the tropospheric circulation, the ocean circulation *via* air-sea interactions, and on snow and sea-ice fields; the role of the stratosphere in the tropospheric circulation response to climate change; and the mechanisms for two-way stratosphere-troposphere coupling;
- Assessing the status of the SHFP and CMIP5 runs with models with a well-resolved stratosphere.
- Discussing how to best analyse, make full use, and exchange knowledge from the data generated by the SHFP and CMIP5 runs, with the role of the stratosphere as the focus.

The workshop agenda was organised based based on time scales: Presentations on interannual and shorter time scales, including discussion on the SHFP, occupied the first day, while the second and third days were dedicated to decadal and centennial time scales, and CMIP5 models and experiments.

The first day of the workshop started with a welcome by **J. Perlwitz** and an introduction of the DynVar activity and workshop goals by **E. Manzini**. In her opening keynote presentation, **S. Solomon** reviewed a number of challenges that the climate community is facing, such as understanding the reasons for decadal variations in stratospheric water vapour, modelling the chain of processes in the tropical atmosphere that may bring meteorological signals originating in the lower atmosphere to the stratosphere, the importance of the location of the lid of a model, and the accurate representation of stratospheric processes in models. She acknowledged the role of variability, reviewed the role of the stratosphere in connecting changes occurring in the Antarctic region to global climate change, and presented new results on temperature trends in the UTLS. J. Perlwitz reported on the WRCP Workshop on Seasonal to Multi-decadal Predictability of Polar Climate held in Bergen, the week prior (25-29 October 2010). Topics of relevance to DynVar were the sources of potential predictability reviewed during the workshop, especially those associated with stratospheric processes, and the establishment of both an Arctic and an Antarctic Initiative. She also presented the SHFP-WGSIP activity on behalf of A. Sciafe, and called for leadership from the DynVar group in the analysis of the SHFP runs. The SHFP runs are seasonal hindcast experiments, generally carried out with coupled atmosphere-ocean-sea-ice models, which are also high-top models. **J. Scinocca** presented the CCCma contribution to SHFP, although in this case, the high-top seasonal hindcasts were performed with imposed sea surface temperatures (SSTs) and sea-ice concentrations (SICs).

M. Baldwin reviewed methodologies to diagnose stratosphere-troposphere coupling in both observations and simulations. A key issue is how to define a climatology in a changing climate. By defining a slowly varying climatology with specific statistical properties, the resulting Annular Mode (AM) indices have no trend by definition – meaning that the climatology will change but the annular mode of variability will not. Baldwin suggested using daily zonal-mean geopotential to define the AM from climate model outputs, after removing its daily global-mean, a slowly varying trend and the seasonal cycle to define the anomalies. **D. Waugh** reported that CCMVal-1 and CCMVal-2 have demonstrated the advantage of the multi-model evaluation strategy, combined with model grading, over a range of diagnostics for the identification of deficiencies and systematic biases in chemistry-climate models. These activities have also led to quantifiable improvements in some particular models in the subjects of transport, Cl_y abundance and tropical tropopause temperatures. However, the methodology of model grading has its own limitations, such as the robustness of the metrics and the determination of the uncertainties in the observations used for comparison. Of particular relevance to DynVar are the results of Chapter 10 of the SPARC CCMVal-2 report (Baldwin *et al*., 2010), which demonstrates that the CCMVal-2 models, which generally have a better-resolved stratosphere, perform better than AMIP CMIP-3 models in the stratosphere and perform equally well, if not better, in the troposphere. The reported CCMVal diagnostic tool appeared to be of interest to many analysts and model developers.

The contributed talks of the first day included oral and poster presentations on a variety of topics, including the role of the stratospheric ozone on the medium-range weather forecast (**M. Deushi**), the role of linear interference in the annular mode response to tropical forcing (**P. Kushner**), wave forcing of the QBO (**J. Anstey**), the evaluation of the stratosphere in seasonal forecast models (**A. Butler** and **A. Maycock**) and on the factors controlling decorrelation time scales in the lower stratosphere (**P. Hitchcock**).

N. Butchart opened the second day with a talk on climate change and stratosphere-troposphere interactions, and pointed out that the effect of stratospheric changes on surface may not be limited to the impact of Antarctic ozone depletion and recovery. According to the multi-model study reported, the inter-comparison of the atmospheric response to 4xCO_2 in low- and high-top models showed that stratospheric climate changes may contribute substantially to changes in storm tracks, sea level pressure and precipitation in the Northern Hemisphere during winter. The fact that the impact of a well-resolved stratosphere stands out in the reported multi-model comparison suggests that results are robust, despite widely differing parameter settings and schemes in the high- and low-top models. However, a limitation of the reported work is the specification of the SSTs and SICs, disabling any air-sea interactions in the high top models, such that the climate is slaved to the imposed SSTs and SICs. It is therefore paramount to call for a similar analysis, with high- and low-top atmosphere-ocean general circulation models (AOGCMs).

Discussion of the status of the development of AOGCMs with a well-resolved stratosphere followed. In most cases, these models are high-top versions of low-top models. **C. Cagnazzo** reported results from the CMCC, IPSL-CM5, and MPI models. These three modelling systems, together with EC-Earth presented by **S. Yang,** and the METO&UK Universities presented by **S. Hardiman**, participate in the COMBINE European Integrating Project that aims to develop the next generation of Earth System Models by including components such as a dynamical stratosphere. The model descriptions and status of the CMIP5 simulations were given for the GFDL CM3 model (**J. Austin**), MIROC-ESM (**S. Watanabe**), WACCM (**D. Marsh**), GEOS-5 (**S. Pawson**), and MRI (**K. Shibata**). There were therefore 10 high-top model systems present at the DynVar workshop, with at least three models (EC-Earth, METO&UK Universities and WACCM) that have low-top counterparts. At the time of the workshop, pre-industrial control simulations were completed (or close to completion) for all the models. Some centres (*e.g.*, GFDL) were finishing the majority of the core CMIP5 long-term experiments (pre-industrial control run, 1850-2005 historical run, RCP4.5 and RCP8.5 runs). GEOS-5 and the MPI model were the only high top AOGCMs planning to run the CMIP5 decadal prediction experiments. At least three model systems (GFDL CM3, MPI and MIROC-ESM) will also run with CO_2 emissions, requiring modules for the land and ocean carbon cycle. Interactive atmospheric chemistry was included in at least three model systems (GFDL CM3, MIROC–ESM and WACCM). Different modelling groups were using similar types of diagnostics to analyse some of the most current topics of research in the troposphere-stratosphere region. These topics include ENSO signals in the tropics, ENSO teleconnections in the Northern Hemisphere, the Atlantic meridional overturning circulation (AMOC), simulation of the QBO and its forcing, and changes in tropical upwelling due to climate change, and decadal variability in water vapour. This potential for collaborative studies is precisely what initiatives such as DynVar are meant to address.

The last 2 sessions of contributed oral and posters presentations featured, the relative role of ozone and dynamical trends (and their model biases) in the southern polar stratospheric temperature trends (**N. Calvo**), the relationship between stratospheric ozone and Antarctic sea-ice trends (**M. Sigmond**), changes in the reflective downward coupling associated with ozone depletion (**N. Harnik**), evidence of coupling between the North Annular Mode and low frequency AMOC variability, suggesting a connection between stratospheric variability and variation in deep ocean temperature variations (**J. Kim**), and the dynamical enhancement of the equator to pole contrast in tropopause height, by more than a factor 2 compared to the radiative equilibrium solution (**T. Birner**). Posters also covered a wide range of topics that were both directly relevant to DynVar, or indicate fruitful interactions between DynVar and other SPARC activities. For example, the connection with gravity waves was highlighted as a prerequisite to calculate accurate momentum budgets in the stratosphere, which is a focus of the SPARC Gravity Wave Activity and is also relevant to some of the DynVar topics. Different studies on changes in atmospheric composition, in particular water vapour and ozone also indicated that DynVar could exploit interactions with CCMVal. Similarly, the role of dynamics in mediating the solar cycle signal from the stratosphere to the surface indicates an interaction with SOLARIS. Other posters were more specific to the DynVar objectives, covering for example the role of resolved planetary waves generated in association with tropical warm pools of SSTs.

Presentation sessions were complemented by discussion sessions dedicated to addressing how the SPARC community could make use of the opportunities generated by international activities such SHFP and CMIP5. The final session on Friday was dedicated to consolidating future efforts and plans. A number of activities were proposed and are summarised here:

1. Evaluate the feasibility of writing "news and views" papers on the role of stratospheric dynamics on tropospheric climate (Edwin Gerber, Natalia Calvo and Tiffany Shaw)
2. Evaluate the feasibility of writing a review paper on the changes occurring in the Antarctica region, focusing on the effects of ozone depletion on the climate system, including the ocean carbon fluxes (Judith Perlwitz)
3. Coordinate two synthesis papers on the CMIP5 runs: (i) Multi-model high-top model comparison of stratospheric climate, variability and change (Andrew Charlton-Perez) and (ii) Multi-model high-top / low-top comparison focused on surface climate, variability and change (Elisa Manzini)
4. Establish research groups to foster analysis of the SHFP and CMIP5 archives, towards a workshop in mid-2012, to be proposed to SPARC at the next Scientific Steering Group (SSG) meeting.

While each modelling centre has planned its own papers on the validation and/or novel applications of the new high-top AOGCMs, it is envisaged that a number of studies may explore the simulations that will become available through the SHFP and CMIP5 archives. DynVar is seen in this respect as a facilitator, fostering collaborative analysis on the role of stratospheric dynamics in the climate system, and on the implications of stratosphere-troposphere dynamical coupling for the prediction of variability and change of the climate system at all time scales. This stage of DynVar is foreseen to last at least for the next two years. To this end, DynVar "Research Groups" are being established on a number of topics raised at the workshop. Proposed research groups proposed include: Antarctica: From Ozone to Carbon; Surface climate, variability and change; Sudden Stratospheric Warming; ENSO and QBO; AMOC and PDO; Water vapour; Annular Modes / Stratospheric memory; QBO and tropical waves; Tropopause and External forcing (volcanic). Concerning the solar external forcing and gravity waves topics, we note that the SPARC SOLARIS and Gravity Wave activities already exist to study these areas. Collaboration with CCMVal on a variety of issues is also envisioned. To foster the collaboration with CLIVAR, Amy Butler and Adam Scaife have volunteered to be the DynVar contacts on the SHPF project. Research Groups and their contacts will be posted on the DynVar web site (**http://www.sparcdynvar.org/**).

To recognize the engagement of a number of new people at the core of the SPARC DynVar Activity, the DynVar Committee has been restructured: Amy Butler, Natalia Calvo, Andrew Charlton-Perez, Edwin Gerber, Tiffany Shaw and Shingo Watanabe are welcomed as new members; while Judith Perlwitz, Lorenzo Polvani and Fabrizio Sassi will remain involved as ex-officio members.

We would like to note in closing that the larger than expected participation in the workshop clearly highlights the need for a forum of discussion on stratospheric dynamics in the interim period between the last SPARC General Assembly in 2008 and the next one in 2014, possibly reaching out to CLIVAR and CliC (The Climate and Cryosphere project). Given the above and the proposed 2-year time scale for the fostering the analysis of the SHFP and CMIP5 runs, we propose to hold a one week Workshop in spring/summer 2012 with SPARC DynVar and CLIVAR/SHFP, and possibly CliC.

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The SPARC Data Initiative

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The SPARC Data Initiative is the newest SPARC activity and was launched during the 2009 SPARC SSG meeting in Kyoto, Japan. Its aim is to compare data sets of vertically resolved chemical trace gas observations obtained from different satellite instruments, and to provide a "user's guide" for the use of such data in different applications, such as model-measurement comparisons or empirical studies of stratospheric climate and variability.

About 10 years ago, the GCM-Reality Inter-comparison Project for SPARC (GRIPS) found that there was considerable uncertainty in its model inter-comparison of dynamics and radiation arising from the fact that different observed data sets often delivered conflicting results. Accordingly, a middle atmosphere climatology study was initiated by SPARC, which compared the available meteorological data products in terms of various aspects including mean biases, seasonal cycle, variability, and long-term changes. No data set was problem-free, and all data sets were found to have both strengths and weaknesses. The findings were published in the SPARC Report No. 3 (2002), which provided something of a user's guide to the data.

The same sort of situation was faced in the SPARC CCMVal (Chemistry-Climate Model Validation) project (Eyring *et al*., 2005) for chemical trace gas measurements. While ozone and water vapour measurements are the subject of specific SPARC activities, there is no equivalent activity for other chemical trace gases. Yet these gases play an essential role in the ozone budget, and, together with age of air (a derived product), provide tracer information on atmospheric transport; a topic extensively analysed in the recent CCMVal Report. There are a variety of trace gas data sets available and a user cannot easily determine which is the most reliable for any particular application. While comparison of different measurements is often done as part of instrument validation studies, this information is not readily available to users. Moreover, the data sets are not always available in a standard data format, or with appropriate documentation. The result was that for the CCMVal inter-comparison, different observational data sets were used by different people, and scores based on model metrics were highly dependent on the data set employed. The SPARC CCMVal report therefore identified the need for an assessment of the available data sets of chemical trace gases analogous to what was done in SPARC Report No. 3 for the meteorological data sets. A specific recommendation states 'A systematic comparison of existing observations is required in order to underpin future model evaluation efforts, by providing a more accurate assessment of measurement uncertainties'.

Responding to this recommendation, the SPARC Data Initiative aims at assessing and consolidating our knowledge of current and past space-based observations of chemical trace gas species in the upper troposphere, the stratosphere, and the lower mesosphere. Both long-lived (O_3, H_2O, N_2O, CH_4, CFCs, SF_6, HF, NO_y, Br_y, HCl and CO) and short-lived trace gas species (NO, NO_2, NO_x, HNO_3, HNO_4, N_2O_5, $ClONO_2$, $BrONO_2$, ClO, HOCl, BrO, OH, HO_2, CH_2O), as well as aerosols will be assessed. The goal of the project is to assemble and compare climatologies derived from observations, to identify differences between the data sets, and to provide expert judgment on the source of those differences. The results will be documented in a new SPARC report, which will also provide essential knowledge of the measurement and retrieval techniques used. The report will compare quantities including zonal mean climatologies, seasonal evolution, and interannual variability of the chemical species.