SPARC

STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE

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The WCRP Open Science Conference (OSC) was held in Denver, Colorado from 24-29 October. This was the first time in the 30-year history of the WCRP where all the projects met together to exchange scientific ideas. The conference covered the entire scope of WCRP activities. It featured daily plenary sessions with overarching themes of Climate Research in Service to Society, Climate System Components and their Interactions, Observation and Analysis of the Climate System, Assessing and Improving Model and Predictive Capabilities, Climate Assessments and Future Challenges, Translating scientific understanding of the climate system into climate information for decision makers, and the Future of the WCRP. This final session featured a panel discussion, while each of the preceding ones featured invited talks dealing with facets of the relevant themes. The scientific programme included parallel oral sessions and large, well-attended posters sessions. The pan-WCRP nature of the OSC also encouraged presentations on including the human dimension in Earth systems models, and the impact of climate and climate change on human health and decision-making.

Within the poster sessions, poster clusters encouraged projects of SPARC to present work associated with projects such as SOLARIS, HEPPA, WAVAS-2 and the Data Initiative, along with other WCRP projects. Given the size (over 1900 participants) and scope of the OSC, we confine attention in this summary to high-lights of sessions and presentations that are of particular interest to SPARC. Many of the presentations and posters are available online and we encourage readers to visit the website **http://conference2011.wcrp-climate.org/**. In addition, each plenary session produced draft position papers that are available to download.

Plenary Sessions

There were several talks in each plenary session addressing the main theme, and several of these talks addressed issues that are relevant to SPARC. Within the theme on Climate System Components and Their Interactions, **M. Visbeck** discussed the grand challenges for global climate research by reviewing WCRP achieve-

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WCRP World Climate Research Programme
ICSU International Council for Science

ments against the backdrops of the three World Climate Conferences (WCC) that have been held. The first if these (WCC1, 1979) gave rise to the WCRP. The second (WCC2, 1992) gave rise to the Global Climate Observing System (GCOS) and the United Nations Framework Convention on Climate Change (UNFCC), while the third (WCC3, 2009) has established the Global Framework for Climate Services (GFCS) with the goal of providing timely climate information on global and regional scales. The TOGA (Tropical Ocean, Global Atmosphere), WOCE (World Ocean Circulation Experiment) and ACSYS (Arctic Climate System Study) programmes are notable examples of WCRP achievements. Over the past three decades the four core projects (SPARC, GEWEX, CLIVAR, CLiC) have come into being as the major components of the WCRP programme. There have been notable achievements within each of these core projects as well. Visbeck provided a number of exemplary challenges that fall within the programmes of the current WCRP core projects. Meeting the challenges entails building of scientific capacity - engaging the next generation of scientists and empowering developing countries, utilising opportunities, funding to coordinate international activities, sustaining and enhancing the observing system, continuing to improve models.

The challenges of sustaining a high quality climate observing system were addressed in the plenary talk by **K. Trenberth** within the theme of Observations and Analysis of the Climate System. He noted the imperative of Earth observations to support planning and decisions in regard to climate services and assessing climate change from human activities ("You can't manage what you can't measure"). The changing observing system poses major challenges for maintaining continuity and quality control of observational records. He noted the possibility of major gaps in satellite records in the future as current instruments reach the ends of their lifetimes. There is a need to maintain adequate overlap and duality in observing systems and to establish and maintain key reference observing systems.

C. Jakob discussed the challenges and progress in improving climate models within the theme of Assessing and Improving Model and Predictive Capacities. Modelling capabilities have advanced dramatically over the last two decades especially in regard to numerical weather prediction. Models, particularly those used for climate prediction have also grown in complexity. Current climate models include a wide range of coupled sub-system models that permit, in principle, realistic modelling of the evolution of the Earth system on timescales ranging from days to centuries. However key issues remain and progress in resolving them may require a significant transformation in modelling community. Given their importance as the most effective tools for making weather and climate predictions, improving weather and climate models is now a key requirement for achieving the prediction skill that is required to address future societal needs. Capacity building in this field is important - model developers are increasingly rare. In addition, a concerted international effort to achieve major advances in model improvement in a relatively short time may be needed. Such an effort would draw on the achievements and expertise of major modelling centres around the world.

Within the same theme, **A. Scaife** addressed challenges and progress in prediction for regional spatial scales on a wide range of timescales. The importance of prediction for monthly to decadal timescales in conjunction with understanding the effects of climate changes is underlined by the incidence of large impact events (*e.g.*, floods, droughts, cold periods) that are associated with seasonal to decadal scale variability that accompanies the more slowly varying climate signal. Predictions for months to years must rely on both accurate measures of the initial state and its uncertainty as well as on accurate estimates of changes in climate forcing mechanisms ("boundary values" such as changes in the radiatively active components of atmospheric composition). In recent years considerable progress has been made in understanding key processes that influence monthly and seasonal predictability. These include improved understanding and modelling of the coupling between tropical and extratropical intraseasonal oscillations such as the Madden-Julian Oscillation (MJO) and the North Atlantic Oscillation (NAO), the lagged coupling between stratospheric sudden warmings (SSWs) and tropospheric circulation anomalies, and predictability of El Niño Southern Oscillation (ENSO) events and their effect on weather patterns (rainfall) both in the tropics and the extratropics. There is now evidence that more accurate initialisation improves long-range predictions, particularly in the tropics. However long range predictability of extratropical weather events is generally poor. Some improvements have been achieved in making skilful prediction of the occurrence of high-impact weather events such as the numbers of hurricanes and the frequency of hot days. Further improvements in extended range forecasting are expected to emerge from the results of international activities such as the CMIP5 decadal hindcast activity.

Parallel Sessions

Climate System Observations, Reprocessing, Reanalysis and Climate Data Records

This session addressed progress in producing or reprocessing observational data sets to generate climate data records and monitor changes in the climate system. The session covered a wide range of topics. It included two invited papers that dealt, respectively with developments in climate reanalysis (**D. Dee**, ECMWF) and development of Sparse Input Reanalysis for Climate Applications (SIRCA) (**G. Compo**, CIRES).

The talk by **K. Rosenlof** on the SPARC Water Vapour Assessment focused on water vapour in the upper troposphere-lower stratosphere (UTLS) region. The goal of this SPARC initiative is to assess past trends in stratospheric water vapour and make predictions as to possible future changes and feedbacks. The lack of global measurements over long periods of time for the UTLS is a general impediment. The available observational data are comprised of local measurements from sondes and solar occultation satellite measurements, with some more recent satellite measurements having better spatial coverage. Long-standing differences in these data sets make it difficult to assess measurement uncertainties. There is a need to assess whether different measurement systems are retrieving the same values at the same time/location in order to combine data sets to construct an extended record. There are large vertical gradients in water vapour in the UTLS and large spatial and temporal variability in the upper troposphere. Not all measurement techniques are adequate for covering the entire range. Although constructing a continuous data set remains challenging, a multi-step methodology has been worked out to achieve this goal. This methodology relies on using several data sets that have the longest continuous (overlapping) records and (ideally) global spatial coverage. Adjustments among the data sets are needed to resolve inconsistencies before they can be combined and uncertainties within the resulting time series need to be assessed. Data sets under consideration include SAGE II: 1985-2005, HALOE: 1991-2005, Aura MLS: 2004-present, and ACE (2004-present) to fill in gaps in polar regions. When available, a filled data set can be used in model runs and analysed for trends and variability.

Understanding Atmospheric Processes in Climate: Clouds, Aerosols and Dynamics

The presentations in this session focused on aerosols, cloud-aerosol interactions, boundary layer clouds, deep convection, and stratospheric dynamics. The four invited talks provided a comprehensive picture of several of the key issues regarding cloud-aerosol interactions, the organisation of convection and dynamical responses to anthropogenic forcing. These identified key areas where climate models exhibit the largest uncertainties and biases.

The presentations provided clear evidence that research combining observations, process models, and parameterization development has led to improved GCMs and climate predictions. The representation of boundary layer clouds is a key example where recent research has lead to several new parameterization improvements and demonstrated reduction in climate model errors. Another process study success is the clear identification of stratospheric ozone loss as the leading cause of the observed poleward shift of the Southern Hemisphere jet in the late 20th century. There remain large uncertainties in radiative feedbacks associated with cloud-aerosol interactions in climate models, although progress is being made, *e.g.*, GFDL model results show improvement when parameterizations using multivariate probability density functions.

Significant progress has been made in the understanding of the aerosol-cloud-precipitation interaction in boundary layer clouds. The data sets obtained in dedicated field campaigns combined with LES simulations have greatly improved our understanding of the main factors that are relevant for the evolution of those systems. VOCALS campaign measurements have shown that aerosols are far more interactive with stratocumulus than previously thought. In particular, pervasive drizzle was observed in the clean marine boundary layer stratocumulus, but nearly absent in polluted conditions.

Future work is clearly required on virtually all of the traditional physical parameterizations (*e.g.*, boundary layer, clouds, convection, and gravity waves). Examples highlighted during the session suggest that success will be achieved *via* improvements in our process-level understanding that follows from coordinated observational and model studies.

How Reliable are the CMIP5 Climate Models?

In spite of the yet incomplete subsample of the CMIP5 model ensemble to date, evaluation of these models is underway. Novel diagnostics and analysis methods are being utilised to explore the skill of particular processes, the degree to which models have improved since CMIP3, and particular features of the hindcasts, decadal and centennial projections. These assessments strongly benefit from the increasing availability of state-of-the-art data sets and model output processing techniques. The existence of an increasingly wide ensemble of model simulations re-emphasises the need to carefully consider the implications of model spread. Disparity between projected results implies that model uncertainty exists, but does not necessarily provide the true estimate of this uncertainty. Weighting results from different projections is a viable technique when the purpose of the weighting is clearly identified.

The WCRP can play a major role in further reducing the gap between observations and models. The current project "obs4MIPs" provides satellite data sets specifically tailored for CMIP model evaluation, and should be expanded to include additional observations from other space agencies (*e.g.*, ESA, NOAA, EUMETSAT), observations from in situ and ground-based measurements, and suites of observations for Earth System model evaluation (*e.g.*, aerosol, chemical composition, ecosystem, land processes, carbon cycle, water cycle). It is recommended that guidance and coordination regarding the above could be provided in some formal manner at the direction of the WCRP Data Council. In addition, the WCRP Modelling Council could play a larger role in setting the observational requirements needed to improve model capabilities, including extensions towards biogeochemistry and human interactions. The WCRP can also play a role in promoting the development of process-oriented model evaluation and the application of performance metrics (by continuation of the WGNE/WGCM metrics panel). Given the importance and additional uncertainties that are introduced by biogeochemical processes, WCRP should further expand its research areas to include biogeochemistry in addition to the physical climate, in collaboration with IGBP.

For every observationally oriented panel, an action such as the "obs4MIPs" project should be put forward as an example of pro-active data use for model evaluation. The SPARC Data Initiative could connect to the WCRP Data Council who is hopefully taking on the task of coordinating "obs4MIPs". SPARC should continue to promote process-oriented model evaluation and should help to extend this approach to the troposphere. CCMVal should provide recommendations to the WGNE/WGCM metrics panel for stratospheric performance metrics that are important for climate models. SPARC should establish strong links to IGBP (particularly AIMES) and could consider taking on biogeochemistry in the future.

How Climate Change Impacts Climate Variability

This was a diverse session that covered studies on the identification of mechanisms, modes and regimes of large-scale variability in different climates. Papers covered paleoclimate studies, present day, and future climates with increased carbon dioxide. Three of the talks were of particular interest to SPARC.

L. Polvani showed that CO_2 increases and changes in stratospheric ozone are quite different in the way they drive changes in climate. He concluded that increasing CO_2 affects the climate from the "bottom up", with surface changes producing atmospheric changes. On the other hand, ozone changes act from the top down, where changes in the lower stratosphere impact the entire southern hemisphere atmospheric circulation and surface climate. He noted that stratospheric ozone depletion is quite likely the dominant driver of observed southern hemisphere atmospheric circulation changes in December-January-February for the period from 1960-2000.

Using an investigation of two coupled models with the same forcings, **J. Arblaster** found that SAM trends are strongly correlated with climate sensitivity and upper tropospheric warming in CMIP3 models; the larger the warming, the larger the trend in the SAM.

B. Dong's work was motivated by a change in interannual NAO variability in the late 1970s, which was characterised by an eastward shift of the NAO centre of action. His analysis showed a downstream extension of climate anomalies associated with the NAO. Using Hadley Centre model experiments, he showed that both SST and CO_2 changes independently force an eastward shift in interannual NAO variability, and found that the effects of SST changes could be understood in terms of mean changes in the troposphere while those due to CO_2 could not. The implication is that stratospheric changes may play an important role in the observed eastward shift in interannual NAO variability and related climate anomalies.

Radiative Forcing of Climate and Chemistry-Climate Interactions

This session covered a number of major issues in radiative forcing (RF) and responses, and chemistry-climate interactions. Recently proposed alternative definitions of RF incorporate different components of the climate feedback, so the concept of RF now needs to be linked to atmospheric processes along with a need to determine the "fast" climate feedback mechanisms. Climate models appear to be getting similar responses to historical forcings for differing reasons (*e.g.*, offsets of differing RFs and feedbacks, leading to uncertainty in our understanding of the atmospheric response to climate forcings). There is a need to improve the understanding of the mechanisms and the quantification of the links between RF, especially including that of black carbon, brown aerosols, sulphate aerosols and aerosol-cloud interactions, and observed changes of the surface energy budget and the hydrological cycle (*e.g.*, the Asian monsoonal rainfall). Global monitoring of short-lived trace gases and aerosols needs to be improved, especially since a significant positive aerosol RF trend is expected in the 21st century relative to 2000; this is even more compelling for the Asian, South American and African regions. There is still a large uncertainty in cloud forcing estimates by models and observations. At present, decadal variations of observed radiative fluxes can be assessed with uncertainties on the order of +/-10 W/m^2 at the surface and +/-3 W/m^2 at the top of the atmosphere. Models still overestimate the shortwave downward flux and under-estimate the longwave downward flux, and have problems in simulating the brightening since 1990. Rapid mobilisation of the Arctic carbon store through methane emissions is not seen in observations, but tropical methane emissions are found to be increasing.

Persistent tails of stratospheric aerosol and non-zero aerosol optical thickness lead to uncertainty in stratospheric aerosol RF, which is equivalent to that of stratospheric water vapour over the last decade, and the roles of small volcanic eruptions and possible anthropogenic sources need clarification in this respect. The spectral distribution of solar variability is uncertain and requires clarification, as this affects the partitioning between solar effects on climate *via* stratospheric ozone and direct tropospheric impacts. Changes in stratospheric ozone are reasonably well simulated by models. The ozone hole has been a primary driver of the recent observed changes in summertime Southern Hemisphere (SH) high-latitude circulation, and ozone recovery is expected to approximately offset future GHG-induced changes in summertime SH high-latitude circulation over the next half century. Yet the dynamical mechanisms by which stratospheric ozone changes induce changes in tropospheric circulation have yet to be clarified, and more work is needed to quantify the expected effect of ozone recovery on SH surface climate, ocean circulation, and Antarctic sea-ice distribution.

SPARC-related Poster Sessions

Atmospheric Composition and Forcings

This session featured a broad range of subjects on the changing composition of the atmosphere and climate, from processes and mechanisms relating natural or anthropogenic composition changes to climate forcing to stratospheric ozone depletion and recovery. In particular, the presentations included discussions of forcings due to emissions of greenhouse gases, ozone depleting substances, and aerosol or aerosol precursors. The SPARC SOLARIS and HEPPA poster cluster presented several studies on the effect of solar variations on climate, and on interactions between the solar forcing and climate variability such as caused by the ENSO or the QBO. The poster cluster also highlighted how the choice of observational data sets on solar irradiance (*i.e.*, the new SORCE/SIM data set in contrast to the standard Lean model) and particular treatment of the solar forcing term in chemistry-climate models affects the response of the atmosphere. A few poster presentations studied the role of energetic particle precipitation events and their impact on stratospheric ozone. Finally, some posters investigated the linkages between climate change and ozone from a process-oriented perspective, including the effect of climate change on Arctic ozone loss, the impact of deep convection and dehydration on the stratospheric bromine loading, and the effect of stratospheric temperature changes on ozone chemistry.

Atmospheric Dynamics and Climate

This poster session covered atmospheric dynamical processes on a broad range of time and spatial scales from local turbulence, mesoscale processes to global scale circulations. A number of posters dealt with topics that are directly related to aspects of current SPARC activities.

Stratosphere-troposphere coupling was a major theme amongst SPARC related posters, with a total of seven posters dealing with different aspects of this broad topic, including both observational and modelling studies. These included observational studies of the coupling between tropospheric and near surface conditions and stratospheric circulation variability. A poster by ***Bracegirdle*** examined the linkage between variability of the SH semi-annual oscillation (SAO) in surface pressure and that of the mid-stratospheric circulation in austral summer/early autumn. A poster by ***Ren et al***. examined the temporal correlation between stratospheric polar vortex variability and ENSO SST anomalies.

There were also posters that dealt with analysing and predicting stratospheric polar vortex anomalies in the northern hemisphere (NH) winter and (***Charleton-Perez et al.***, ***Taguchi et al.***), the linkage between stratospheric polar vortex variability and tropospheric circulation features (***Nakamura et al***.) and anomalous weather such as cold European winter extremes (***Tomassini et al***.), and mesoscale features of the tropopause inversion layer in extratropical cyclones (***Yoden et al***.). Aspects of the coupling between stratospheric and tropospheric climate change responses were addressed in posters by ***Mitchell et al***. and ***Winter***. ***Weber et al***. addressed the observed and modelled coupling between the Brewer Dobson circulation and total ozone on seasonal and longer timescales.

Atmospheric Observations Including Upper Troposphere and Stratosphere

This poster session included clusters focused on the SPARC Data Initiative, which is expected to be completed next year, and the Water Vapour Assessment, and about the observational networks SOWER (tropical water vapour measurements), SHADOZ (tropical ozonesondes) and the GCOS Reference Upper Air Network.

The tropical tropopause is an important area of study since is determines the entry point for the stratosphere. Constraining climate trends at the tropical tropopause is therefore equally important. ***Wang et al***. showed that recent tropical cold point temperature (CPT) trends are less certain than previously implied. Possible causes of inconsistency between temperature and water vapour trends before 2000 include changes in the location of water vapour transport, changes in small-scale processes, and remaining biases in adjusted temperature data. ***Son et al***. examined the spatio-temporal structure of the lapse-rate tropopause using COSMIC GPS radio occulation measurements. The seasonal cycle of the tropopause is significantly influenced by stratospheric processes such as the Brewer Dobson circulation, the polar vortex, and the water vapour concentration around the tropopause. On intraseasonal timescales, tropopause pressure and temperature exhibit significant variability over the Asian summer monsoon and the subtropical regions where double tropopauses frequently occur.

Read et al. presented results from MLS and CALIPSO, measuring convection, thin cirrus, and dehydration in the tropical tropopause layer (TTL). The measurement tracks of CALIPSO and the MLS lidar for cloud profiling have been nearly aligned since May 2008, providing additional insight into the processes by which dehydration is occurring. They found that during Boreal winter a high percentage of the driest and coldest air occurs in convective and thick layered cirrus clouds situated above the nominal level of zero clear-sky radiative heating. The Boreal summer shows fewer such events and hence the height-of-convection shows a strong annual cycle. ***Ray et al***. looked for evidence for changes in stratospheric transport and mixing using SF_6 and CO_2 trace gases to calculate the age of air. Currently, the observations disagree with models on the changes to the BDC, but this study found that the discrepancy may be due to inadequate mixing in the models.

Deep stratospheric intrusions have been regularly observed in field campaigns, suggesting a "fast injection" mechanism of stratosphere-troposphere exchange (STE). A Lagrangian STE forecast developed at Environment Canada was found to have excellent predictive skills for stratospheric intrusions above 500 hPa, with statistical skill below these levels. ***Bourqui et al***. derived the first global one-year climatology of deep stratospheric intrusions from this Lagrangian STE diagnosis system, showing that the fast injection is 10 times larger that previously believed. Clear seasonal cycles were found, with a minimum in the summer and a maximum in the winter. The SH also shows the same behaviour but with a less pronounced seasonal cycle.

Integrating Regional Data Sets into Global Products

A new database of trace gases and aerosols with near global coverage derived from profile measurements with high vertical resolution, the "Binary DataBase of Profiles (BDBP)" version 2.0 was to be released in October 2011. It includes measurements from different satellite and ground-based measurement systems. Using this data set, ***Hassler et al***. presented techniques to homogenize data from multiple sources. Combining the data from different sources requires careful treatment of drifts in time series, offsets between data sources and differences in temporal and spatial sampling.

Wood et al. presented an effort to recover historical data of weather records and environmental conditions from scientists and sailors buried in handwritten logbooks and weather journals. Such a project would enable the reconstruction of long climate time series at the sub-daily resolution required for dynamical reanalysis. The project, using volunteers to transcribe ship logbooks, can be found at **http://www.met-acre.org** and is a collaboration with the US National Archive with ACRE.

Reprocessed Data sets and Climate Data Records

Ozone is an important atmospheric parameter both because it is the key absorber of UV radiation, which affects the Earth's biosphere and because it is a climate parameter, affecting the heating and dynamics of the stratosphere. Of particular relevance to SPARC in this poster session were reconstructions of ozone. ***Bodeker et al***. used ozone measurements from eight different satellites with high vertical resolution measurements to create a merged, gap-free, global data set. These databases, extending from 1978 to 2006 and spanning the ozone field from the surface to 70 km with no missing data, are suitable for assessing ozone fields from chemistry-climate model simulations or for providing the ozone boundary conditions for global climate model simulations that do not treat stratospheric chemistry interactively. ***McPeters et al***. presented a new 40-year global ozone data set from reprocessed NASA and NOAA satellite measurements. New ozone cross-sections were also used, along with a cloud-height climatology derived from the Aura OMI retrievals. The result is a more accurate ozone time series for both total column ozone and the ozone vertical distribution. ***Tilmes et al***. presented a 15-year ozonesonde climatology for model evaluation of the troposphere and lower stratosphere using profiles from 42 stations from 1995 to 2009.

Schneider et al. presented a new web-based community tool to facilitate the discussion and selection of appropriate data sets for Earth system model evaluation; the Informed Guide to Climate Data sets. This tool, funded by NSF, aims to (1) Evaluate and assess selected climate data sets and (2) Provide "expert user" guidance on the strengths and limitations of selected climate data sets. The Informed Guide is based at NCAR's Climate and Global Dynamics Division. The vision of the Informed Guide is to provide an interactive and updatable resource that grows with the participation of the community. ***Robert et al***. presented the reprocessing of the GOMOS aerosol data set. This data set makes possible the computation of suitable corrections to take into account the perturbations of tropospheric remote measurements by the stratospheric compound.

Satellite Observations and their Assimilation: Prospects for the Future

Barre used high-resolution assimilation of ozone data from MLS observations to constrain the MOCAGE model in the UTLS and free troposphere in order to study tropospheric ozone, stratosphere-troposphere exchange and improve estimates of ozone fluxes across the tropopause. The study focused on a stratospheric intrusion event and was compared with MOZAIC data and ozonesondes. It was found that model performance was increased using the assimilation of ozone and with higher resolution, arguing that studies using low resolution may have wrong ozone flux estimates.

Manney et al., looked at improvement in modelling stratopause evolution and transport in advanced data assimilation system. Recent satellite data, including temperature and trace gas fields from the Aura Microwave Limb Sounder (MLS), and data assimilation system (DAS) products, were used to detail the evolution of the stratopause and transport in the stratopause region, focusing on the 2005/2006, 2008/2009 and 2009/2010 Arctic winters that had prolonged major SSWs (and in 2009/2010, an unusual lower mesospheric mixing event). Models with higher tops proved to have better representations of the stratosphere than operational systems due to the assimilation of stratospheric data and/or improved representations of the physics in this region.

The assimilation of satellite data at ECMWF (***Thepaut et al.***) and in WACCM-GEOS5 (***Yudin***) were presented. The ultimate goal is a fully coupled Earth System Model for seamless prediction of timescales from weather to seasonal prediction (in the case of ECMWF) and longer term in the case of WACCM. Data assimilation is a crucial component for constraining and initialising models. Areas of research and development include efforts to better exploit the current satellite observations, introduction of instruments for model validation, data monitoring and assimilation, and development of new assimilation techniques. Using data assimilation in models can help to correct systematic model errors, but also identify data-data biases.

The stratosphere is a region of the atmosphere where chemical data assimilation could greatly benefit our representation of the winds since observations in this region are scarce. Previous studies have looked at the possibility of constraining the forecasted/analysed winds by assimilating atmospheric tracer observations. ***Milewski and Bourqui*** extended these studies by using a more realistic setting with an interactive chemistry-climate model, the IGCM-FASTOC. This advanced data assimilation technique uses ensemble statistics to produce along-the-flow, including cross-variable, background error-covariances allowing for propagation of information from the observed variable to all other model variables.

Improving Climate Models, Including their Components and Parameterizations

This session featured a large poster cluster on how knowledge of stratosphere-troposphere coupling can be used to improve model performance. ***Gerber and Reichler*** characterised intraseasonal variability and coupling between the stratosphere and troposphere with the annular modes in three multi-model data sets (CMIP3, CMIP5 and CCMVal-2). Comparison between models with well-resolved stratospheres and those without helps determine the role of the stratospheric processes in the annular mode coupling.

Climate models tend to exhibit a much too persistent Southern Annular Mode (SAM) circulation anomalies in summer compared to observations, due to a too-late breakdown of the polar vortex and enhanced summertime persistence of the SAM from the troposphere (***Simpson et al.***). This bias may lead to an overly strong model response to anthropogenic forcing during this season. NAM trends account for a significant part of the inter-model differences in future temperature and precipitation trends in some NH regions across the models participated in the latest IPCC assessment report. Understanding the reasons for different NAM responses to the same forcing across the models may help to reduce the uncertainty in future climate prediction. ***Karpechko*** used high-top and low-top versions of ECHAM5 to study the sensitivity of the NAM response to different prescribed SST and sea ice concentration anomalies under doubling CO_2 concentration, finding differences between the high-top and low-top models due to different responses of atmospheric eddy fluxes.

Yoden et al. presented results on the predictability associated with SSWs using one-month forecasts produced by the Japan Meteorological Agency (JMA). During the seven winters studied, they found that some SSWs could be predicted with a lead-time of one week, and that ensemble spread after an SSW was reduced, meaning that predictability after an SSW should be improved.

Recent studies illustrate that stratospheric ozone changes affect the vertical coupling of planetary waves between the troposphere and stratosphere in the Southern Hemisphere. ***Perlwitz et al.*** compared this coupling process between GEOS chemistry climate model simulations with interactive ozone chemistry and a simulation with prescribed zonal mean ozone changes, and illustrate the subsequent impact on tropospheric wave structure. This shows the importance of including interactive ozone chemistry for simulating the impact of stratospheric ozone changes on SH circulation in the troposphere.

Gravity waves are parameterized in climate models and are important for controlling winds, temperature, ozone chemistry and Rossby wave propagation, which impact seasonal, interannual and regional climate predictions. Using new measures of gravity wave momentum flux, ***Alexander et al.*** compared the observations to several climate model parameterizations, and found that non-orographic wave fluxes in the lower stratosphere are surprisingly similar among different models and observations. Preliminary results suggest the possibility that observations decay more rapidly, however, limitations in the gravity wave horizontal wavelengths that can be observed leave significant uncertainly in the interpretation of these changes.

Global Model Evaluation and Projections: CMIP5 and Other Model Intercomparisons

Stratospheric major mid-winter warmings are linked to climate variability in the stratosphere and troposphere. However, studies of both standard climate resolution models and models with a well-resolved stratosphere often reveal deficiencies in the simulation of frequency, climatology and structure of stratospheric major mid-winter warmings. ***Charlton-Perez and Polvani*** studied stratospheric major mid-winter warmings in the CMIP5 models, and assessed the impact of biases in the simulation of major warmings on predictions of future stratospheric climate and stratosphere-troposphere coupling. ***Black and McDaniel*** studied the impact of a well-resolved stratosphere in the CMIP5 models on a detailed diagnostic analysis of the seasonal cycle of the stratospheric circulation, with an emphasis on final warmings, and comparing high-top and low-top models in the CMIP5 database.

Wang and Waugh looked at CCM simulations of recent trends in lower stratospheric temperatures and stratospheric residual circulation. Observed recent temperature trends show significant seasonal variations and SH warming in late winter-spring, linked to a strengthening in the stratospheric meridional circulation. Stratospheric-resolving CCMs can produce these aspects of temperature trends, but there is a large spread among models, which is related to differences in trends of wave activity in the stratosphere. The results of Wang and Waugh suggest: (1) The observed temperature trends may not be a robust response to external forcing; (2) Comparison with these trends may not be a good test of climate models.

Stratospheric sulphate aerosols produced by major volcanic eruptions modify the radiative and dynamical properties of the troposphere and stratosphere through their reflection of solar radiation and absorption of infrared radiation, producing cooling at the Earth's surface. However, major tropical eruptions tend to be followed by warmer than usual winters over the NH continents. This volcanic "winter-warming" effect is understood to be the result aerosol heating in the tropical stratosphere, which produces a positive NAM anomaly. ***Toohey et al.*** studied the influence of volcanic eruptions using an aerosol-GCM and found that the season of eruption has a significant impact on the response of stratospheric annular modes. The annular mode response increases logarithmically with increasing eruption magnitude, and that models tend to underestimate the response, perhaps because of weak stratosphere-troposphere coupling in the models.

Furtado et al. studied the connection between variability in Eurasian snow cover and wintertime stratosphere-troposphere coupling in the CMIP5 models. In previous work, autumnal Eurasian snow cover has been used to predict the phase of the AO, which strongly tied to stratosphere-troposphere coupling. The objectives in this work were to (1) Assess the ability of the models to capture Eurasian snow cover variability; (2) Diagnose the relationships between snow cover variability in the models and the wintertime stratospheric and tropospheric circulation; and (3) Compare results to observations and evaluate model performance.

Stratospheric Ozone and Other Trace Gases

Although ODSs are now regulated under the Montreal Protocol and are observed to be declining in both the troposphere and stratosphere, little improvement has been seen in the recovery of the ozone layer. In fact, the first-ever Arctic ozone hole was observed in 2010. The Antarctic ozone hole now covers an extensive area, reaches very low values in early October (< 150 Dobson Units), and shows virtually zero ozone in the altitude range from about 12-20 km by early October. Models and parametric studies have projected that the ozone hole will recover to 1980 ozone levels in the 2050-2070 period. These same studies have predicted that the first signs of recovery should appear in about 2020. However, recent work by suggests that the ozone hole is already showing signs of recovery. ***Newman et al***. reviewed the observations and techniques used to estimate the recovery of the ozone hole, and will presented evidence on the uncertainties in Antarctic ozone trends over the last decade. ***Braesicke et al***. made a study of the changing transport due to climate change using N_2O and the response by the ozone layer.

Other phenomena effecting Antarctic ozone levels were also addressed. For example, the impact of El Niño events on Antarctic ozone, presented by ***Hurwitz et al***., were isolated in the GEOS V2 CCM using time-slice simulations, by comparing one sets of runs with a warm-pool El Niño and one without. The phase of the QBO was also taken into account. ***Sturges et al***. examined the potential threat to ozone recovery from short (lifetimes of about 1 year) and very short lived (lifetimes of about 0.5 years or less) halocarbons. These ODSs are not regulated by the Montreal Protocol but have the potential to have a significant impact on the ozone layer in the future.

Many climate models do not include interactive ozone. ***Young et al***. looked at whether using different ozone data sets in these models results in significantly different climate impacts. They found that attribution of the climate impacts in the 20th century depends on the ozone data set used. A more realistic data set (the BDBP) gives a stronger climate impact, which extends into the troposphere in the Southern Hemisphere.

Large-scale Climate Variability and Change

Uncertainty in future climate change presents a key challenge for adaptation and mitigation planning. An overlooked source of climate change uncertainty is natural variability due to processes internal to the atmosphere, ocean, and coupled system. ***Deser*** investigated the role of natural variability to address the questions to determine minimum ensemble size, when change first becomes detectable and determine the relative contributions of the atmosphere and ocean to the uncertainty. ***Baldwin*** looked at how the stratospheric variability can affect the troposphere. The primary mechanism involves modulation of the residual circulation, which creates anomalous downwelling and deep polar temperature anomalies, which extend through the polar tropopause. This directly affects the height of the tropopause, and therefore the thickness of the troposphere.

Waugh et al. studied the connection between the formation of the Antarctic ozone hole and upper tropospheric Rossby-wave breaking (RWB). Reanalyses show an increase in the occurrence of RWB in middle latitudes during southern summer over the last thirty years, which is connected to the movement of the tropospheric jet (and southern annular mode). ***Smith and Kushner*** studied the role of linear interference in troposphere-stratosphere interactions in limiting vertical fluxes of Rossby wave activity to propagate upwards.

Hitchcock and Shepherd presented a study on the Arctic polar-night jet oscillation (PJO). They showed that highly coherent, large amplitude and long-time scale recoveries occur following roughly half of all major stratospheric sudden warmings. The robustness of the circulation anomalies during PJO events and the dominance of radiative processes during the recovery phase suggests that they are highly predictable, and their impact on the troposphere suggests this may in turn be a source of skill in seasonal forecasting. ***Son et al***. looked at the impact of stratospheric QBO on tropical deep convections, tropical cyclone tracks, and extratropical circulations during the Northern Hemisphere warm season using various observational and reanalysis data sets. Although QBO-induced circulation change is relatively weak, it affects the tropical cyclone tracks, particularly the typhoon tracks over the western North Pacific. However, no sensitivity is found in the intensity and frequency of tropical cyclones.

Observations and model studies suggest that anthropogenic emissions result in a poleward contraction of the mid-latitude jets in both hemispheres. ***Thompson and Butler*** examined the physical mechanisms that underlie the trends in the mid-latitude circulations using simple atmospheric model, and suggested that the response of the mid-latitude jets to climate change can be interpreted in the context of 1) the projection of anthropogenic forcing onto the meridional slope of the extratropical isentropic surfaces; and 2) a diffusive model of the eddy fluxes. ***Polvani et al***. looked at abrupt circulation changes in response to climate change in an idealised, whole-atmosphere model, noting that the circulation response is similar to the one found in comprehensive models for weak forcing. However, when the warming of the upper tropical troposphere exceeds approximately 5 K, as projected by the end of the 21^{st} century, an abrupt change of the whole atmosphere circulation is observed. This abrupt transition is found to be robust to a doubling of either the horizontal or vertical resolution.

The low-frequency nature of stratospheric events might be effective in driving and enhancing intrinsic oceanic variability. Being able to detect such an influence would have important implications for climate predictability on both decadal and climate time scales. A study by ***Reichler et al***. found clear evidence for impacts of long-lived stratospheric circulation anomalies on the Atlantic Meridional Overturning Circulation (AMOC), and determined that the intrinsic low frequency variability persists for many decades. ***Manzini et al***. also studied long lasting anomalies of the polar vortex in an atmosphere-ocean-sea-ice coupled model with a well-resolved stratosphere and found that these variations are due to a change in the frequency of SSW events. Interannual variations are also responsible for the stratosphere/troposphere connections at the multi-decadal scale. The connection to the mean sea level pressure, SST and sea-ice cover is indication of the atmosphere forcing of the AMOC.

Air Quality and Effects of Aerosols and Pollution

This poster session included the most important aspects of modern tropospheric chemistry. In some posters a direct link between air pollutant (trace gases) and climate change was made. Laboratory studies were represented in a poster related to hygroscopicity and evaporation of ammonium chloride and ammonium nitrate. Anthropogenic emission modelling of air pollutants is a crucial issue in tropospheric chemistry and this topic was presented in two posters. One described a recent global emission inventory of ozone precursors and black carbon, and related global CTM simulations (1996-2008); another addressed the international research collaboration required to obtain such an emission inventory (GEIA: Global Emissions inventory Activity). Other posters described air pollutant concentrations and analysis by statistical modelling in regional areas (*e.g*., ozone, nitrogen oxides and total organic compounds) and at a high mountain site (focusing on the trace gas Peroxyacetylnitrate (PAN) and other trace gases). One poster described the modelling of air pollutants in a large city (New Dehli). Several contributions addressed modelling and data analysis on regional and hemispheric scales, in one the meteorological factors important for ambient air concentrations in Spain were studied in detail; this study is also important in the context of air pollutant concentrations to be expected in a changing climate. Still other studies presented results related to human health and environmental factors. A remarkable poster described isocyanic acid (HNCO), a compound that could be harmful for human health and which was identified in several recent studies in ambient air. Isocyanic acid is emitted by biomass burning, low temperature coal combustion and emissions of some vehicle types. The most important tropospheric removal path is washout by rainwater with a characteristic dependence on pH of the rain water which complicates (global) numerical modelling; at the present time it seems difficult to judge the risk of this compound for human health in ambient air.

Geoengineering to Counteract Global Warming

Geoengineering is a relatively new topic to the SPARC community, but is an important component of the response to climate change mitigation. Whether the application of geoengineering techniques is necessary, effective and desirable depends crucially on the method and expected outcomes. The Geoengineering Model Intercomparison Project (GeoMIP) project, which has recently come under the umbrella of SPARC, was highlighted in several posters. GeoMIP is a CMIP Coordinated Experiment to study the climate response to solar radiation management (SRM) *via* introduction of artificial stratosphere aerosol. Thirteen modelling groups are taking part and will examine a number of climate responses including the response of the ozone layer. Posters ranged from studying the effectiveness of inserting an artificial layer of aerosol into the stratosphere, to the impact such a layer would have on crop production (***Xia and Robock***). Several outstanding issues in the models were highlighted, including the lack of proper treatment of coagulation of larger particles (***Sheng et al***.). Alumina (Al_2O_3) and black carbon were studied as alternatives to sulphur, since they have smaller particle sizes and are more effective at scattering light, however, both black carbon and alumina demonstrate adverse effects on the stratosphere including ozone loss (***Kravitz and Robock***).

Geoengineering is at best a partial solution to climate change, with many unintended adverse impacts. Associated with the reductions in temperature and precipitation would be significant conversion of direct radiation to diffuse radiation, a possible weakening of the hydrological cycle and summer monsoons, and a possible slowing of the recovery of the stratospheric ozone layer. Several studies looked into minimising the known negative side-effects of geoengineering. ***MacCracken et al***. studied the effect of reducing only the solar radiation incident on the Earth's polar regions. This would alleviate unwanted responses by tropical circulations such as the monsoons, which are important sources of precipitation. Both the northern and southern polar shielding simulations tended to cool middle and lower latitude regions by drawing additional heat to the poles from these regions. ***MacMynowski et al***. studied the possibility of optimising the solution such that the minimal harm could be done while maximising the benefits. Their results suggest the potential for using spatial and temporal forcing variations to reduce a few of the undesired consequences of SRM.

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Report on the 8th SPARC Data Assimilation Workshop

20-22 June 2011, Brussels, Belgium

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Introduction

The eighth Stratospheric Processes And their Role in Climate (SPARC) Data Assimilation (SPARC-DA8) workshop was held in Brussels, Belgium during 20-22 June 2011. This workshop was one of a series of regular meetings held since 2002, but had the lowest participation (21 participants and 17 presentations) of a dedicated SPARC data assimilation workshop since 2005. Despite this dubious distinction, the workshop was arguably one of the most successful of the series in that a number of activities of relevance to SPARC were proposed for initiation. This workshop also marked the debut of David Jackson (Met Office) as a co-lead of the SPARC data assimilation working group. Saroja Polavarapu now shares the lead as she transitions from research in middle atmosphere data assimilation to research in carbon flux estimation. The workshop presentations will be briefly discussed, along with a description of the new activities.

Reanalyses

Reanalyses are assimilated data sets in which the model and assimilation scheme is held fixed. They provide four-dimensional gridded representations of the state of the atmosphere and are frequently used as proxies for the real atmosphere in process studies and model assessments (*e.g.*, SPARC CCMVal, 2010), and for driving chemistry-transport models. The appeal of reanalyses lies in their spatial and temporal completeness. However, the challenge of reanalyses is these very processes of filling in data gaps and managing biases (due to both model and observations). **D. Dee** noted that in this respect the latest ECMWF product (ERA-Interim or ERA-I, Dee *et al*., 2011) offers improvement over ERA-40 due to the use of variational bias correction (Derber and Wu, 1998, Dee 2004, Dee and Uppala 2009). While ERA-40 biases were handled manually in a pre-processing step, with ERA-I, parameters used to adjust for observation biases are determined simultaneously with the analyses and by fitting all observations. This has led to greater time consistency of analyses through a consistent handling of biases from a myriad of satellite instruments and platforms. The calculated bias corrections are hoped to reflect observation bias but could also reflect model bias. **Figure 1** shows time series of bias corrections for MSU radiances with a distinctive wavy pattern from 2001-2003 (most pronounced for channel 2, top panel). This pattern was also seen in a record of on-board warm-target temperature changes for NOAA-14 resulting from orbital drift (Grody *et al*., 2004) thus verifying that the bias was indeed due to the observations in this case. However, near the model top where model biases are known, the observations would be corrected to compensate for model bias. A solution was to keep the instruments with sensitivity at the highest altitudes (SSU ch. 3 and AMSU-A ch. 14) uncorrected. A consequence is an unavoidable shift in temperature time series in the upper stratosphere due to the transition from SSU to AMSU-A in 1998. Thus, issues in time series from reanalyses remain. Nevertheless, a testament to the progress made in temporal consistency of reanalyses is seen in **Figure 2** which demonstrates that some trend estimates from ERA-I now approach those derived from observations. Here, the trend due to ERA-I is slightly higher due to the warm bias of aircraft data.

The existence and comparison of multiple reanalysis products is invaluable for providing insight into deficiencies of assimilation schemes and models (*e.g.*, model lid height, resolution, *etc*.). This leads to improved reanalyses for the next generation of products. **C. Long** compared various reanalyses (ERA-40, ERA-I, JRA-25, MERRA, CFSR) and found improved consistency of the latest generation of

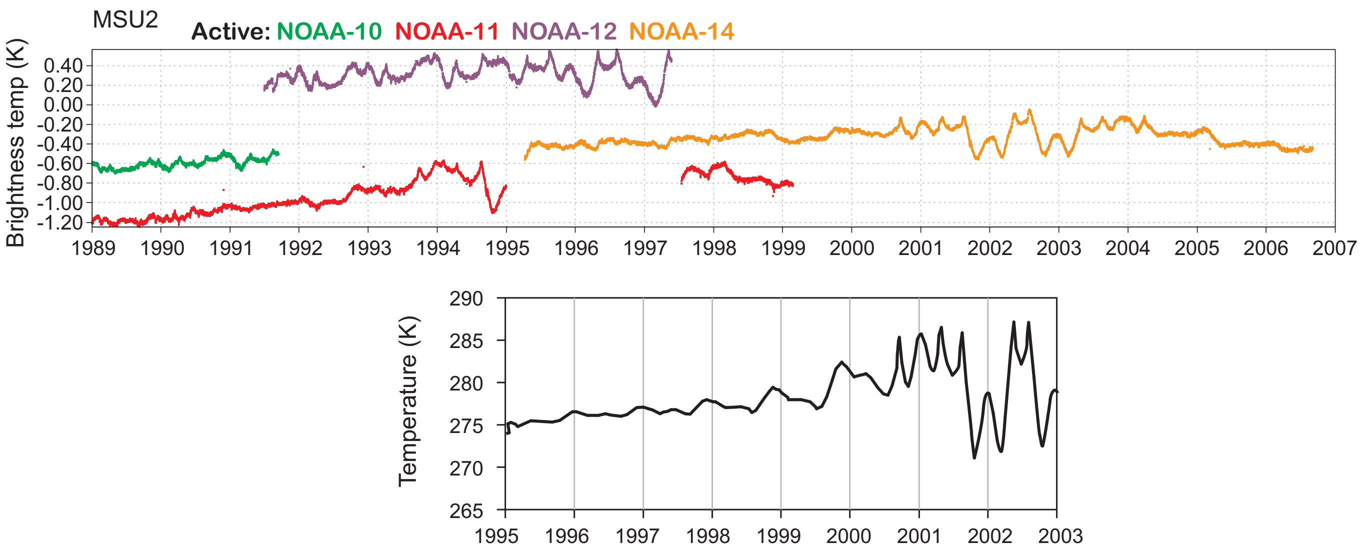

Figure 1: Top panel: Time series of globally averaged radiance bias corrections for MSU channels 2. Bottom panel: Independently obtained record of on-board warm-target temperature changes for NOAA-14, due to orbital drift (Grody et al., 2004). Figure courtesy of Dick Dee, ECMWF.

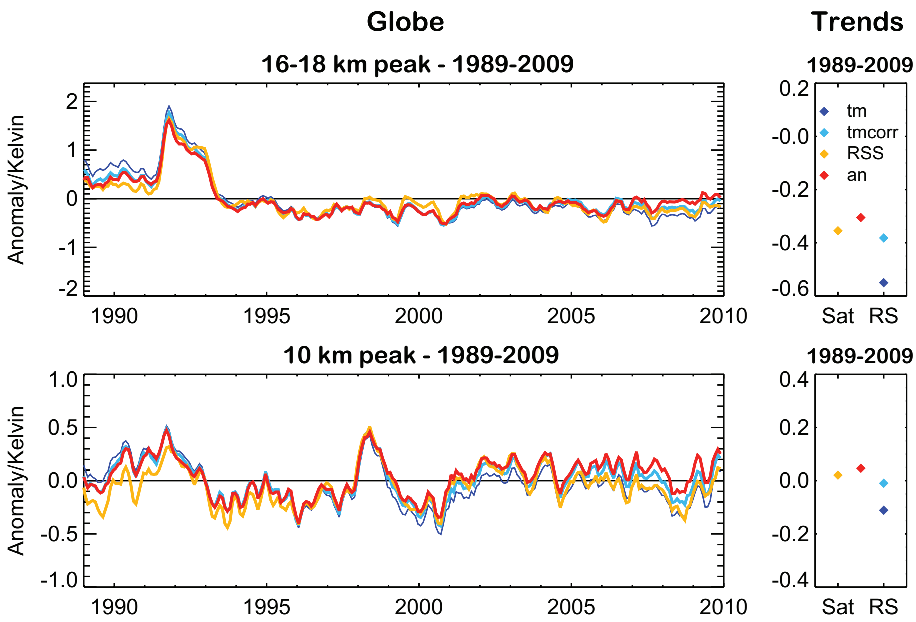

Figure 2: Global mean temperatures for MSU equivalent vertical averages estimated from ERA-Interim (red), from MSU observations (orange: provided by Remote Sensing Systems), from radiosondes (dark blue: uncorrected; light blue: bias-corrected). Time series (left column) and trends (right column) are shown for 1989-2009 for the MSU channel with a Jacobian peak near 16-18 km (top row) and for the channel with a Jacobian peak near 10 km (bottom row). Panels on the right show average decadal trends according to each data set. Figure courtesy of Dick Dee, ECMWF.

products with each other. The regions of largest discrepancy however remain the upper stratosphere and the tropics. **Figure 3** shows a comparison of the seasonal cycles of tropical temperatures at 1 and 10 hPa. The amplitude of the cycle is generally similar but an offset of 4 K between the warmest and coldest data sets is seen at 1 hPa. Long also showed that reanalyses differed most from Singapore radiosondes during the transition of the quasi-biennial oscillation (QBO) from easterly to westerly phase. In addition, correlations with Singapore radiosondes differ if the early period of 1979-2009 is considered instead of a later period of 1989-2009 (**Figure 4**) with correlations being lower in the former case. Tropical large-scale wave activity deviated by 10-40% in variance even among the most recent reanalyses (ERA-40, JRA-25, ERA-I, MERRA, and CFSR) considered by M. Fujiwara and, interestingly, the newer reanalyses tend to have greater wave activity. Even the climatology of the 100 hPa temperature differed among these five reanalyses by up to 1 K, which corresponds to a saturation water vapour mixing ratio of 1 ppmv at this level.

The continued discrepancy of reanalyses in the tropics is at least partly related to inadequacies of the present observing system. **E. Andersson** noted that major gaps in the observing system for global weather forecasting remain and include (1) wind profiles at all levels; (2) temperature and moisture profiles of adequate vertical resolution in cloudy areas and over land in tropics; (3) precipitation; (4) vertically resolved ozone; and (5) snow mass. Thus, additional wind measurements such as from the proposed ADM instrument (measuring line of sight winds) could significantly benefit tropical analyses, if the promising results of observing system simulation experiments are realised.

Aside from the tropics, the upper stratosphere and mesosphere remain regions where reanalyses are less consistent with each other. While **M. Fujiwara** noted a qualitative realism in the amplitude and phase of the migrating diurnal tide among the six reanalyses he considered, amplitudes in and above the upper stratosphere were 50% lower than those derived from SABER measurements. **S. Polavarapu** noted that nonorographic gravity wave drag can play a role in obtaining realistic mesospheric analyses, and to some extent compensate for the absence of mesospheric observations in a data assimilation cycle. Thus, gravity wave drag schemes are valuable not only for forecasts but within a data assimilation cycle. New measurements from the Concordiasi experiment (Rabier *et al*., 2010) conducted over Antarctica over three autumns are able to resolve almost the entire gravity wave spectrum and may thus provide valuable information needed to constrain parameters in gravity wave drag schemes. **F. Rabier** indicated that data from Concordiasi is freely available at **http://www.cnrm.meteo.fr/concordiasi/**. In addition to dynamical variables measured from drop sondes and stratospheric balloons, measurements from a balloon-borne ozone photometer are available.

Ozone in reanalyses remains a challenging area. While total column ozone values may be useful, the vertical distribution is generally unreliable because of the dearth of vertical profile measurements. Therefore, prognostic ozone is not used in radiation calculations (neither during the model forecast nor for temperature assimilation). Given the benefit of reanalyses to users, and the feedback to providers

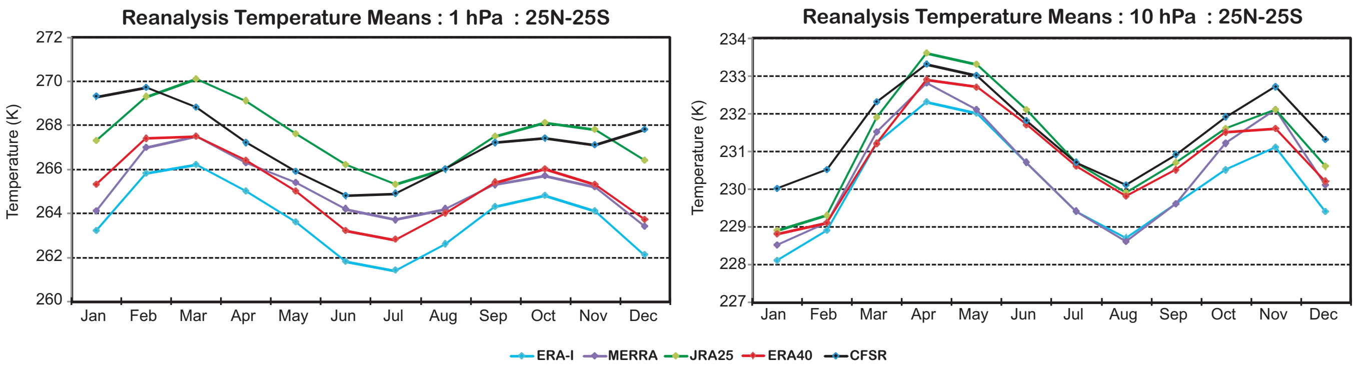

Figure 3: Mean monthly temperatures from five recent reanalyses at 1 hPa (left) and 10 hPa (right) for the 25°N to 25°S zone for the period 1979-2009. The reanalyses include ERA-Interim (mean period from 1989-2009), MERRA, JRA-25, ERA-40 (mean period 1979-2002), and the CFSR. Figure courtesy of Craig Long, NCEP.

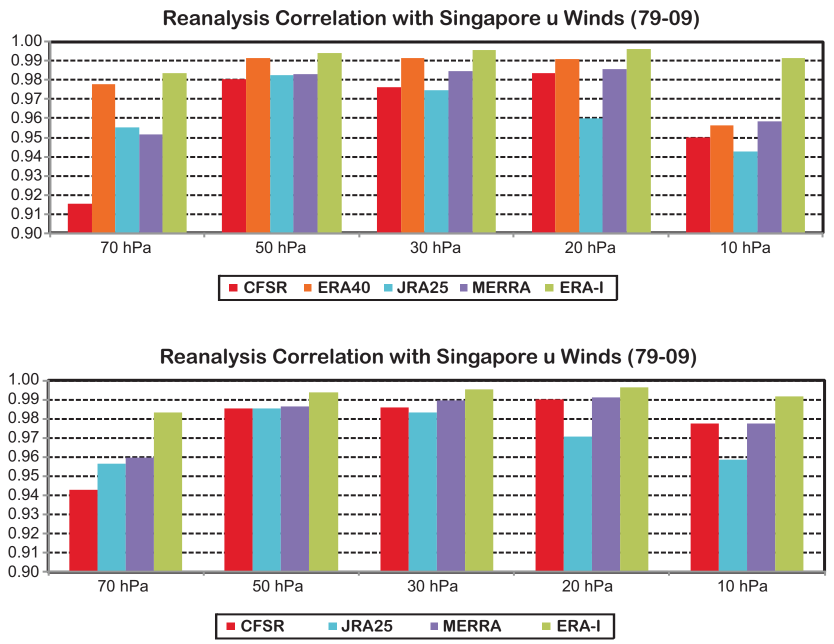

Figure 4: Correlation of the zonal wind component from recent reanalyses at (1°N, 104°E) with Singapore radiosonde zonal wind values at 70, 50, 30, 20 and 10 hPa for the period 1979-2009 (top) and 1989-2009 (bottom). The top figure includes complete period coverage of CFSR, MERRA, and JRA-25 and partial period coverage of ERA-40 (1979-2002) and ERA-Interim (1989-2009). The bottom figure covers just the ERA-Interim period (1989-2009). The performance of the reanalyses is better during the more recent period (1989-2009). Figure courtesy of Craig Long, NCEP.

and subsequent improvement in assimilation systems, expansion of the products to include chemical constituents is inevitable. To this end, **H. Eskes** described a new 30-year total ozone reanalysis effort involving the TM5 chemistry-transport model driven by ECMWF analyses. The model uses a Cariolle-type parameterized ozone chemistry with an Kalman-type assimilation system in which forecast error variances are advected but correlations are fixed in time. Data access will be provided through **http://www.temis.nl** and **http://www.gmes-amosphere.eu**. Because constituent reanalyses efforts are still in their infancy, their value for climate science remains to be seen. Nevertheless, the exercise of performing reanalyses is extremely valuable for the feedback that climate scientists provide to data producers. In fact, ECMWF user feedback helps to set priorities for changes to the next product release. Thus, to improve the vital interaction between users and data providers, ECMWF is developing a data server to facilitate feedback and to provide users with more detailed information about the reanalyses. For example, in order to interpret trends, users need to know if the reanalysis used an instrument measuring a particular variable and height. The new data server should help users identify the raw observations used, which will in turn help them interpret results.

Chemical data assimilation

S. Chabrillat presented results showing that the high water vapour values (between 7 and 8 ppmv) seen at ~3 hPa in analyses of MIPAS observations by the BASCOE assimilation system (Thornton *et al*., 2009) were not seen in unconstrained results of the BASCOE CTM (**Figure 5**). This suggests that there is another source for water vapour other than the methane oxidation included in the BASCOE CTM (and other models). The extra source is an open research question. **F. Baier** compared analyses made during 2003 with a chemical transport model and with a) all available MIPAS constituent data assimilated and b) only ozone assimilated, in order to investigate the impact of the source gases H_2O and CH_4 on reactive species. In the upper stratosphere, when the assimilation of non-ozone species is stopped, H_2O rapidly changes with increasing mixing ratios (as large as those noted by Chabrillat) in the Southern Hemisphere. In the same area, HCl values also increase compared to the reference run where all MIPAS species are assimilated. These results show that non-assimilated species are strongly influenced by the assimilated species, and it is therefore important to compare all chemical related model species when evaluating model results. **D. Jackson** also focused on water vapour. He presented results using the new Met Office humidity control variable, which includes a normalisation designed to limit under- (over-) estimates of humidity near zero (saturation), and to make the control variable probability density function more Gaussian. Most benefits are seen in the troposphere, but comparison with MLS data shows there is a small improvement in the analyses near the tropopause, too.

Q. Errera revised calculations of constituent background error covariances in the BASCOE system. To date, this matrix has been diagonal, but a new approach calculates the covariances using the Hollingsworth and Lonnberg methods. After bootstrapping, it was demonstrated that the overall effect was to decrease assimilation errors, especially below 100

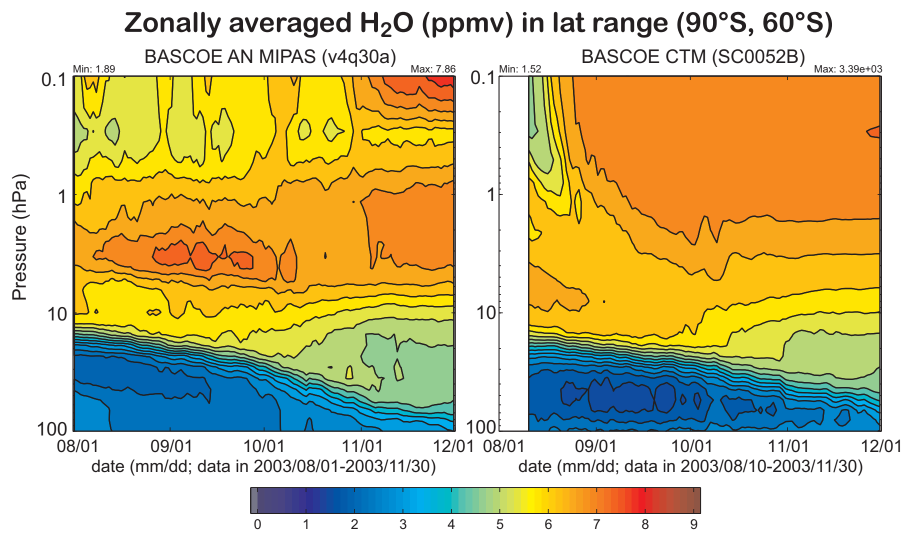

Figure 5: Zonally averaged volume mixing ratio of water vapour in the 90°S-60°S latitude band, August to November 2003. Left: analyses of MIPAS observations by BASCOE; right: unconstrained simulation by the BASCOE CTM. Figure courtesy of Q. Errera and S. Chabrillat, BIRA.

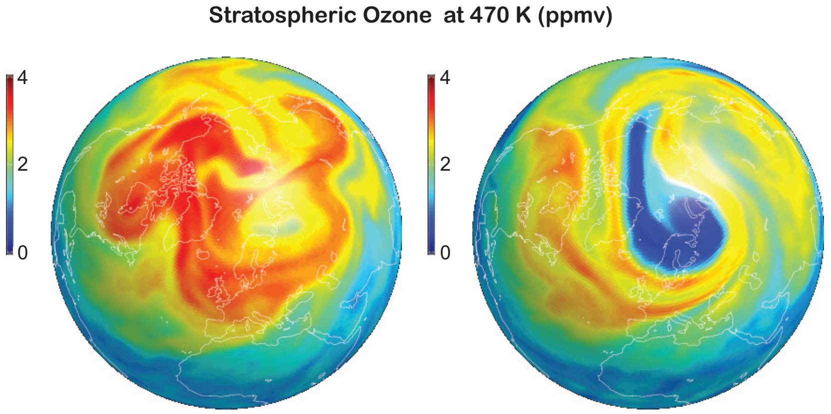

Figure 6: Ozone analysis by IFS-MOZART, the main NRT Forecast System of MACC, at the 470 K isentropic level, showing ozone depletion on the 27th of March 2011 (right) compared to the same day in 2010 (left). At this level, the ozone analysis simulated ozone volume mixing ratios as low as 0.5 ppmv above Scandinavia and Northwest Russia. The data comes from ECMWF and is generated for the EU FP7 project MACC (http://www.gmes-atmosphere.eu/), in which BIRA-IASB is in charge of the stratospheric ozone service (http://www.gmes-stratosphere.eu/). Figure courtesy of Karolien Lefever, BIRA.

hPa. **K. Lefever** used the BASCOE system to examine the Arctic ozone hole of 2010/11 with the goal of understanding the processes that led to this event. **Figure 6** shows just how low stratospheric ozone was in late March 2011 compared to the same day in 2010. She found that while simulations that included assimilation represented the ozone loss well, those that used no assimilation did not. This is likely due to the fact that the model's PSC scheme was tuned for the Antarctic and does not well represent the PSC production for this unusually deep Arctic ozone hole. **K. Shibata** evaluated the separate effects of stratospheric ozone assimilation and total ozone assimilation, and their impacts on the predictability of stratospheric and tropospheric ozone. This was done by assimilating or nudging to analysed atmospheric fields, total ozone and stratospheric ozone profile observations. The best performance was when all fields were used, while the worst performance was the analyses-only case. Under non-negligible biases of model atmospheric fields, assimilation or nudging to the analysed atmospheric fields is preferable and produces better ozone prediction in the transport-dominant domain below the middle stratosphere, such as the region of Antarctic ozone hole.

T. Milewski described work aimed at assimilating synthetic ozone and temperature observations in a chemistry-climate model using both an ensemble Kalman filter and an ensemble Kalman smoother. The ozone and temperature assimilation experiments yielded approximately the same constraint on the dynamical state of the system. Temperature assimilation however has more problems in constraining the chemical state. Assimilating future ozone observations using the Kalman smoother seems to improve the dynamical forecast, but the associated medium-range forecasts do not beat the corresponding forecasts produced by the Kalman filter. **K. Miyazaki** presented a summary of assimilation work in a number of areas – ozone, aerosols and surface CO_2 flux – in Japan. The assimilation systems developed for these applications all use the same scheme, a localised ensemble transform Kalman filter. Use of ozone assimilation was shown to reduce stratospheric temperature biases in the analyses, while the aerosol analyses are planned to be used operationally in the near future to initialise aerosol forecasts, and for other NWP (numerical weather prediction) and climate applications. The high resolution surface CO_2 flux estimates have been developed using OSSEs, and this knowledge will be used to interpret the results now being produced using real observations from GOSAT and CONTRAIL.

J.-C. Lambert focused on improved observation operators for assimilation. An ideal operator perfectly reproduces the smoothing and sampling characteristics of the observation, but in reality the choice of operators is more pragmatic. Examples of operators from a number of instruments (*e.g.*, MIPAS, GOME2) were shown. Consideration of smoothing/sampling issues has demonstrated value for: optimising co-location criteria; assessing smoothing errors of an individual observation system; and assessing discrepancies due to differences in smoothing and sampling. Clearly in this area, feedback from the assimilation community, which uses the observations, is very important and this topic was covered in the talk by **V. Yudin**. He performed assimilation of ozone and other tracers in the WACCM/GEOS5 system. His results show the need for resolution dependent analysis (RDA) in which only observable structures are constrained by assimilation, and scales unresolved by the observations are preserved. For example, ozone analysis schemes should properly acknowledge separation of visible and data-null scales. He currently is implementing RDA for both nadir and limb data with resolution kernels (OMI, MLS, and HIRDLS), but future applications to radiance data (*e.g.*, AMSU-A channels in the upper stratosphere) are possible.

Discussion and Future Directions

Extensive and lively discussions were held on reanalyses, improving SPARC / NWP linkages and on future directions of the SPARC DA Working Group (DAWG). As a result, six target areas for future activity were identified.

Three of the goals are relatively short-term and can probably be achieved with little additional resources: The first is to produce a summary document of how the stratosphere is represented in global NWP systems around the world. Many, if not all, NWP systems now resolve the whole stratosphere, but it is important to intercompare the various stratospheric parameterization schemes used, the impact of the model stratosphere on tropospheric analyses and forecasts, and the ongoing research challenges. The second goal follows largely from the talks of Lambert and Yudin, and this is to develop a greater interaction between the satellite retrieval and data assimilation communities, possibly *via* a specialist workshop. The third is to update a WMO/SPARC Rolling Requirements document, which is maintained by the Expert Team on the evolution of global observing systems. E. Andersson noted that the section regarding SPARC expresses requirements for aerosol, ozone, temperature, horizontal wind and specific humidity profiles, as well as long and short-wave radiation. While this WMO review is normally updated every 15 months, the SPARC section was last updated on 28 October 1998. Thus, SPARC-DAWG will take on the task of fielding information from the SPARC community to provide updates for this report. A question raised by Andersson (but not answered) was whether this section should be merged with the section on global NWP, GCOS or atmospheric chemistry requirements.

The three longer term activities proposed were: a new reanalysis intercomparison project, an intercomparison effort to identify the impact of the stratosphere on tropospheric medium range weather forecasts, and a possible intercomparison of the missing body force due to subgrid scale gravity wave drag. These activities are described below.

CCMVal has become a key SPARC activity and it relies on observations and reanalyses to assess climate models. However, reanalyses still have deficiencies that data providers would like to resolve in future releases. Thus a comparison of reanalysis products focusing on the middle atmosphere could be of great value to SPARC, as well as to reanalysis providers. M. Fujiwara proposed (and was asked to lead) a new SPARC reanalysis/analysis intercomparison project focusing on the middle atmosphere (see article in this newsletter). The goal of the project is to better understand reanalysis products, as well as the process, technology and science of reanalysis, and to contribute to future reanalysis improvements. This would be accomplished by performing diagnostics not done by data providers. Such diagnostics could be process-oriented (following the lead of CCMVal) and might include: the tropical pipe, quasi-biennial oscillation, semi-annual oscillation, waves, variability related to climate indices and solar cycle, mass and other budgets, *etc*. Diagnostics of analysis increments could also be envisioned. Involvement of the wider SPARC community, which has the expertise in these types of diagnostics, is required. At the same time, involvement of the NWP centres is needed to provide technical information, interpretation and feedback. The SPARC-DAWG will coordinate the effort in connecting the SPARC data users and the reanalysis data centres. Although the focus will be on reanalyses and analyses, CTM results could also be considered in the future. Since reanalyses are now viewed as an ongoing activity with a roughly seven-year cycle between product generations, this activity could also be ongoing.

A topic of interest to NWP centres is the quantification of the impact of the stratosphere on tropospheric medium range weather forecasts. While ECMWF, GMAO and the Met Office model lids were raised to around 80 km a few years ago, only recently have the CMC and the Met Office tried to quantify this impact. However, results from an individual centre are likely model dependent, thus a multi-centre experiment may be needed to assess the generality of results. The idea will be to start with case studies (such as stratospheric sudden warmings) in which stratospheric influence is expected to be observed (at least on the 10-15 day scale) before considering statistical analyses. The SPARC-DAWG will connect with the SPARC community to identify events for case studies and will contact the NWP community through the WGNE (Working Group on Numerical Experimentation) to assess interest in launching such an intercomparison activity (to be led by Andrew Charlton-Perez).

Representatives of NWP centres at the workshop indicated an interest in an assessment of missing drag due to subgrid scale gravity waves. Thus, a study could be undertaken to compare the missing drag from various analyses, along the lines of Pulido and Thuburn (2008). This work could be done by a small group of interested researchers since only analysis data sets are required of the NWP centres.

Outlook

The SPARC-DAWG was initially envisioned (by Alan O'Neill in 2002) to serve as a link between SPARC and NWP centres. With the newly proposed activities, the SPARC-DAWG is poised to assume this role, connecting SPARC with reanalysis centres through the reanalysis intercomparison project, and with NWP centres through the stratosphere-troposphere coupling project and the gravity wave drag morphology project. At the same time, the need for constituent analyses/reanalyses is increasing so there is a pressing need to understand and solve issues with constituent analyses. Thus middle atmosphere constituent assimilation will continue to play a key role in the SPARC-DAWG. Finally, parameter estimations (such as those done in gravity wave drag studies) may become more common in the near future as their value for air quality and climate simulations is assessed.

Next meeting

The next meeting is likely to take place in June 2012 in the USA, possibly in New Mexico.

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A proposal of the SPARC Reanalysis/Analysis Intercomparison Project

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Introduction

Meteorological analysis data sets are constructed as a best estimate of the state of the atmosphere using atmospheric observations with an assimilation scheme and a global forecast model. The assimilation schemes and forecast models used for operational weather forecasts are routinely updated as improvements are made, and the changes in the system produce artificial changes in the analysed fields. The term "reanalysis" is used for an analysis data set that is produced using a single version of a model and assimilation scheme for a long-term (typically multi-decadal) period in the past (*e.g.*, Trenberth *et al.*, 2008). Note, however, that the observational data inputs still vary over the period of the reanalysis. The SPARC community has used reanalysis and analysis data sets to understand atmospheric processes, variability of the stratosphere and upper troposphere, and to validate chemistry-climate models (*e.g.*, SPARC CCMVal, 2010).

There are currently eight global reanalysis data sets available worldwide (see **Table 1**). In the near future, at least three new global reanalysis data sets will be available; namely ERA-20C, CFSR-Lite, and JRA-55. Some analysis data sets are also available and used for middle atmosphere science (*e.g.*, UKMO stratospheric assimilated data originally prepared for the Upper Air Research Satellite project, operational ECMWF analyses, and NASA's GEOS-5) and for mesosphere and lower thermosphere science (*e.g.*, Navy Operational Global Atmospheric Prediction System - Advanced Level Physics and High Altitude (NOGAPS-ALPHA; Eckermann *et al.*, 2009). Studies comparing some of these reanalysis/analysis products have shown that different data sets give different results for the same diagnostic, such as the global energy budget and hydrological cycle (Trenberth *et al.*, 2011), the Brewer-Dobson circulation (Iwasaki *et al.*, 2009), the stratospheric vortex weakening and intensification events (Martineau and Son, 2010), large-scale wave activity at the tropical tropopause (Fujiwara *et al.*, 2011), diurnal migrating tides (Sakazaki et al., 2011), and temperature trends (Randel *et al.*, 2009; Xu and Powell, 2011a, 2011b), as well as the climatology of the middle atmosphere (*e.g.*, Randel *et al.*, 2002; Kishore *et al.*, 2009). Depending on the diagnostic, the different results may be due to differences either in the observational data assimilated, the assimilation scheme or forecast model, or any combination of these.

With the availability of several global reanalysis data sets, we think that now is the time to start a coordinated activity to compare all (or some of the newer) reanalysis data sets for various key diagnostics, to understand the causes of the differences, to use the results to provide guidance on appropriate usage of various reanalysis products in scientific studies, and to connect such activities with future improvements of the reanalysis products. The data assimilation community, including reanalysis centres, will benefit from coordinated user feedback. Such feedback can lead to improvements in the next generation of reanalysis products. The "key" diagnostics include both those for the middle atmosphere science and those with large impact on the reanalysis improvements. For these purposes, it is critical to have a close collaboration between the data users and the reanalysis centres. The SPARC community consists of many active scientists who study the full range of middle atmosphere science, and has produced several successful, coordinated studies such as the SPARC Intercomparison of Middle Atmosphere Climatologies (Randel *et al.*, 2002) and the Chemistry-Climate Model Validation project (SPARC CCMVal, 2010). Although the reanalysis data sets extend to the surface (and even the subsurface for some data sets), a project focusing on the middle atmosphere (including the Upper Troposphere Lower Stratosphere (UTLS), stratosphere, and mesosphere) by the SPARC community would be able to produce a rather concise but very meaningful summary for the reanalysis intercomparison. Therefore, we here propose the SPARC Reanalysis/Analysis Intercomparison Project (S-RIP). (The idea of S-RIP was first discussed at the 8th SPARC Data Assimilation Workshop in June 2011; see the report in this issue.)

S-RIP will be in part an update of the previous climatology intercomparison by SPARC (Randel *et al.*, 2002) but with a much wider perspective, covering all the major middle atmosphere diagnostics. Also, some of the aspects of S-RIP would be quite similar to those of CCMVal project and SPARC DynVar project (**http://www.sparcdynvar.org/**). We can thus utilise the experience and knowledge obtained from these previous activities. One clear difference from CCMVal is the fact that the reanalysis centres are largely independent of the SPARC community, having connections with other weather prediction, climate and atmospheric-science communities. We thus need to establish a collaborative link between the reanalysis centres and the SPARC community. The collaboration will include the discussion and interpretation of the analysis results, and the preparation of the final report.

Possible Diagnostics Focusing on the Middle Atmosphere

Possible "key" diagnostics are discussed here. Our current thinking is that the scientific working group will discuss and suggest the "key" diagnostics and that individual researchers will determine the actual diagnostics and data sets to be analysed (see the next section for our current ideas on the project organisation).

Firstly, the "key" diagnostics addressed in the intercomparison should include all the major diagnostics for the middle atmosphere sciences (*e.g.*, those covered by the CCMVal). Intercomparison between different reanalysis/analysis data sets would give us information on the current technological level of the reanalyses. Where possible, evaluations will be made using independent or original observational data sets. Second, in order to gain a deeper understanding of the reanalysis system and to contribute to future improvements in the reanalysis products, we may need further data analyses. For example, it would be useful to clarify how each part of the reanalysis system (*e.g.*, satellite observations, radiosonde observations, resolved wave drag, parameterized wave drag) contributes to each of the diagnostics. In other words, we want to understand how much the observations constrain a specific diagnostic and how much the model components and the assimilation scheme control that diagnostic. Third, there could be some diagnostics or data analyses that are directly relevant to finding flaws in the reanalysis system or improving the system, especially from the reanalysis-centre perspective.

Examples of possible areas of interest are listed below:

- Middle atmosphere climatology (*e.g.*, Randel *et al.*, 2002; Kishore *et al.*, 2009): These diagnostics can be calculated using the CCMVal diagnostic tool (Gettelman *et al.*, 2012, manuscript in preparation)
- Brewer-Dobson circulation (*e.g.*, Iwasaki *et al.*, 2009; Okamoto *et al.*, 2011; Butchart *et al.*, 2010, 2011): More emphasis should be placed on contributions of sub-grid scale momentum fluxes and momentum deposition, and of orographic and non-orographic gravity wave drag.
- Heat budget of the middle atmosphere (*e.g.*, Fueglistaler *et al.*, 2009)
- Atmospheric energetics and balance by using the normal-mode function expansion - the role of large-scale inertio-gravity waves in the tropics (Žagar *et al.*, 2009a, 2009b)
- Quasi-Biennial Oscillation including its influence on the extratropics, and Semi-Annual Oscillation
- Polar stratosphere issues including lower-stratospheric wintertime temperature evolution (which determines the degree of polar processing and chemical ozone loss) (*e.g.*, Manney *et al.*, 2003, 2005), Sudden Stratospheric Warmings (SSWs) (*e.g.*, Charlton and Polvani, 2007) and stratosphere-troposphere dynamical coupling (*e.g.*, Martineau and Son, 2010; Nishii *et al.*, 2011).
- Upper troposphere and lower stratosphere (UTLS) issues (Gettelman *et al.*, 2010; Hegglin *et al.*, 2010) including the tropical width (*e.g.*, Davis and Rosenlof, 2011), advection dehydration calculations (*e.g.*, Liu *et al.*, 2010; Schoeberl and Dessler, 2011), effective diffusivity (*e.g.*, Shuckburgh *et al.*, 2009), and wave activity (*e.g.*, Suzuki *et al.*, 2010; Fujiwara *et al.*, 2011)
- Dynamics of the upper stratosphere and lower mesosphere/stratopause region where observations are limited (*e.g.*, Sakazaki *et al.*, 2011). This may be helpful in assessing differences in the underlying forecast models.
- Various trajectory calculations such as, *e.g.*, age of air, and UTLS transport for ozone and water vapour budget (*e.g.*, Liu *et al.*, 2010; Schoeberl and Dessler, 2011)
- Tracer distributions (ozone and water vapour; *cf.* SPARC Data Initiative by Hegglin and Tegtmeier, 2011)
- The mass conservation (by comparing with free-running model simulations)
- Radiative flux and heating/cooling rate profiles
- Variability at various interannual time scales in association with, *e.g.*, the Annular Modes, El Niño Southern Oscillation (*e.g.*, Trenberth and Smith, 2006, 2009), solar cycle (*e.g.*, Powell and Xu, 2010), and volcanoes eruptions
- Trends (*e.g.*, Randel *et al.*, 2009; Xu and Powell, 2011b; SPARC Stratospheric Temperature Trends Working Group)
- Other diagnostics that can answer the question, "how can we use operational polar orbiting satellite data better in future reanalyses?" If additional resources are available at the reanalysis centres, investigating the analysis increment data and Observation minus Forecast (OmF) data, and performing an Observing System Experiment (OSE) may be very useful. Note that the analysis increment data can be a good proxy for the gravity wave drag.

Finally, note that some basic diagnostics have already been investigated at the reanalysis centres. See, for example:

- Dee, ERA-Interim data products and plans for future ECMWF reanalyses, presented at the 8th SPARC Data Assimilation Workshop, 2011
- Long *et al.*, Evaluation of the stratosphere in recent reanalyses, presented at the 8th SPARC Data Assimilation Workshop, 2011

The electronic files for the above two presentations are available at **http://www.atmosp.physics.utoronto.ca/SPARC/sparc_daworkshop/scientificprogram.html**. Therefore, the SPARC community needs to contribute to the investigation of advanced and unique diagnostics.

Organisation of the Project

The project will have three major components: (1) the management team which will deal with the overall coordination including the SPARC-reanalysis centre

Table 1: Summary of available global reanalysis data sets. For further information on these reanalyses, see, e.g., http://reanalyses.org/ prepared by the reanalysis centres and http://www.cgd.ucar.edu/cas/catalog/ and http://climatedataguide.ucar.edu/ prepared by National Center for Atmospheric Research.

Product	Centre	Period	Resolution and Lid Height of the Forecast Model
NCEP-1	NCEP and NCAR	1948-present	T62, L28, 3 hPa
NCEP-2	NCEP and DOE AMIP-II	1979-present	T62, L28, 3 hPa
ERA-40	ECMWF	1958-2001	TL159 and N80 reduced Gausiian, L60, 0.1 hPa
ERA-Interim	ECMWF	1979-present	TL255 and N128 reduced Gausiian, L60, 0.1 hPa
JRA-25/JCDAS	JMA and CRIEPI	1979-present	T106, L40, 0.4 hPa
MERRA	NASA	1979-present	(2/3)x(1/2) deg., L72, 0.01 hPa
NCEP-CFSR	NCEP	1979-present	T382 (T574 for post 2010), L64, 0.266 hPa
NOAA-CIRES 20th Century Reanalysis (20CR)*	NOAA/ESRL PSD	1871-2008	T62, L28, 2.511 hPa

(*) NOAA-CIRES 20CR assimilates only surface pressure reports and uses observed monthly sea-surface temperature and sea-ice distributions as boundary conditions (Compo et al., 2011).

connection and with the data archiving, (2) the scientific working group which will suggest the diagnostics covered and has the responsibility for editing and writing the final report, and (3) all SPARC-related researchers who will perform the data analysis, write journal papers, and contribute to the final report.

More specifically, the management team, which will include Masatomo Fujiwara and David Jackson and representatives from the reanalysis centres, will be responsible for making the arrangements with the reanalysis/analysis centres, forming the scientific working group, and making the data archiving arrangements including website management. The scientific working group would be made up of 7 to 10 dedicated members and would include the management team. It would be responsible for determining the relevant diagnostics, providing guidance on specific approaches to data analyses, recruiting the researchers to contribute to the final report and work on each of the diagnostics, and editing the final report. SPARC-related researchers would perform the data analysis, write journal papers, and contribute to the S-RIP workshops and the final report.

The reanalysis data sets shown in **Table 1** are freely available from the websites prepared by individual reanalysis centres and from **http://dss.ucar.edu/**. As archiving processed data such as climatologies, diagnostics of SSWs, vortex breakdown date, *etc*., would also be useful for the community, the management team will consider this. The scientific working group would also make summary tables showing/comparing detailed and relevant technical information of the reanalyses (*e.g*., observational data usage and corrections, specifications of assimilation scheme and forecast model, *etc*.) for the interpretation of the comparison results. The project will hold two or three dedicated workshops where analysis results are discussed with the SPARC community and the reanalysis centres, and produce the final report as a SPARC report, which reviews the then past and near-future publications. The project duration is expected to be 3-5 years for the first phase. Since reanalysis centres envision a 7-year period between new generations of reanalysis products, there is scope for additional phases of this project depending upon the success of the first phase.

S-RIP will be officially proposed at the SPARC SSG meeting in February 2012. If you are interested in becoming involved, and/or if you have any sugestions, please contact Masamoto Fujiwara.

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Update on the SPARC Temperature Trends Working Group

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The SPARC Stratospheric Temperature Trends group focuses on improved understanding of long-term variability and trends in stratospheric temperatures, based on various observational data sets and model-data comparisons. The group has been relatively dormant for the past several years, but has recently been revived with the addition of a new co-chair (David Thompson, Colorado State University) (together with co-chair William Randel, NCAR), in addition to adding several new members. Details of the group membership and past activities can be found on the group website: **http://www.sparc-climate.org/activities/temperature-trends/**.

The temperature trends working group held a 2-day workshop September 20-21 in Paris, hosted by Philippe Keckhut and Chantal Claud. This meeting focused on setting group priorities and plans for the near future, and provided an opportunity for detailed discussions on revised and updated data sets (including radiosonde-based data, satellites, lidars and reanalysis data). The discussion leaders and topics are briefly highlighted below.

S. Bronniman led a discussion of long-term radiosonde data and reanalysis data sets, focusing on historical data prior to 1960 (a focus of the Comprehensive Historical Upper Air Network, CHUAN; Stickler *et al.*, 2010). **D. Seidel** discussed analysis of the seasonal and latitudinal patterns in temperature trends, and also highlighted the growing GCOS Reference Upper Air Network (GRUAN) network for climate-quality upper-air measurements. **C. Claud** showed new analysis of stratospheric temperature variations (focused on polar-tropical differences) derived from satellite and reanalysis data sets, interpreted as possible evidence for long-term changes in the Brewer-Dobson circulation. Evaluation of stratospheric temperatures in various reanalysis data sets was presented by **C. Long**. While the current generation of reanalysis products is improving compared those of the past, there are still discontinuities and unrealistic structures evident in that caution their use in evaluating trends.

Several talks focused on new analysis of operational satellite data from the series of Microwave Sounding Unit (MSU), Stratospheric Sounding Unit (SSU) and Advanced Microwave Sounding Unit (AMSU) instruments. The SSU data are the primary tool for assessing long-term temperature variability in the middle and upper stratosphere. **C.-Z. Zou** presented a new merged data set derived from the SSU data record (1979-2005), as described in Wang *et al*., 2011 and these important new data are available to the community on the STAR web site (**ftp://ftp.orbit.nesdis.noaa.gov/pub/smcd/emb/mscat/data/SSU_v1.0/**). **C. Mears** discussed combining the SSU data with AMSU (using the overlap period during 1998-2005) to generate middle and upper stratospheric time series extended to 2011 (an independent analysis was also discussed by C. Long). This work will soon provide carefully constructed and evaluated data sets for quantifying stratospheric temperatures to 2011 and beyond.

Figure 1 summarises our current understanding of the evolution of global-mean temperatures since 1979 based on the most recent update of the SSU and MSU/AMSU data, as presented at the meeting. Global mean temperatures at the lowest level shown (middle troposphere, TMT) have risen over the past few decades; global mean temperatures at and above the lower stratosphere (TLS and above) have cooled since 1979 but have not changed notably since the mid 1990s.

The application of Global Positioning System (GPS) radio occultation measurements to monitoring stratospheric temperatures was discussed by **A. Steiner** and **B. Ho**. While the GPS data record is still relatively short (beginning in 2001), it is valuable for understanding recent variability and quantifying uncertainties in overlapping radiosonde and operational satellite data sets. **V. Sofieva** discussed several other satellite temperature data sets that have received less attention, including GOMOS and MIPAS (both beginning in 2002); these data sets will soon be available to the wider community.

Updated studies of lidar temperature measurements (over 30-80 km) were discussed by **P. Keckhut**, including improved quantification of uncertainties in long-term records from several stations (due to differences in lidars, plus sampling and tidal

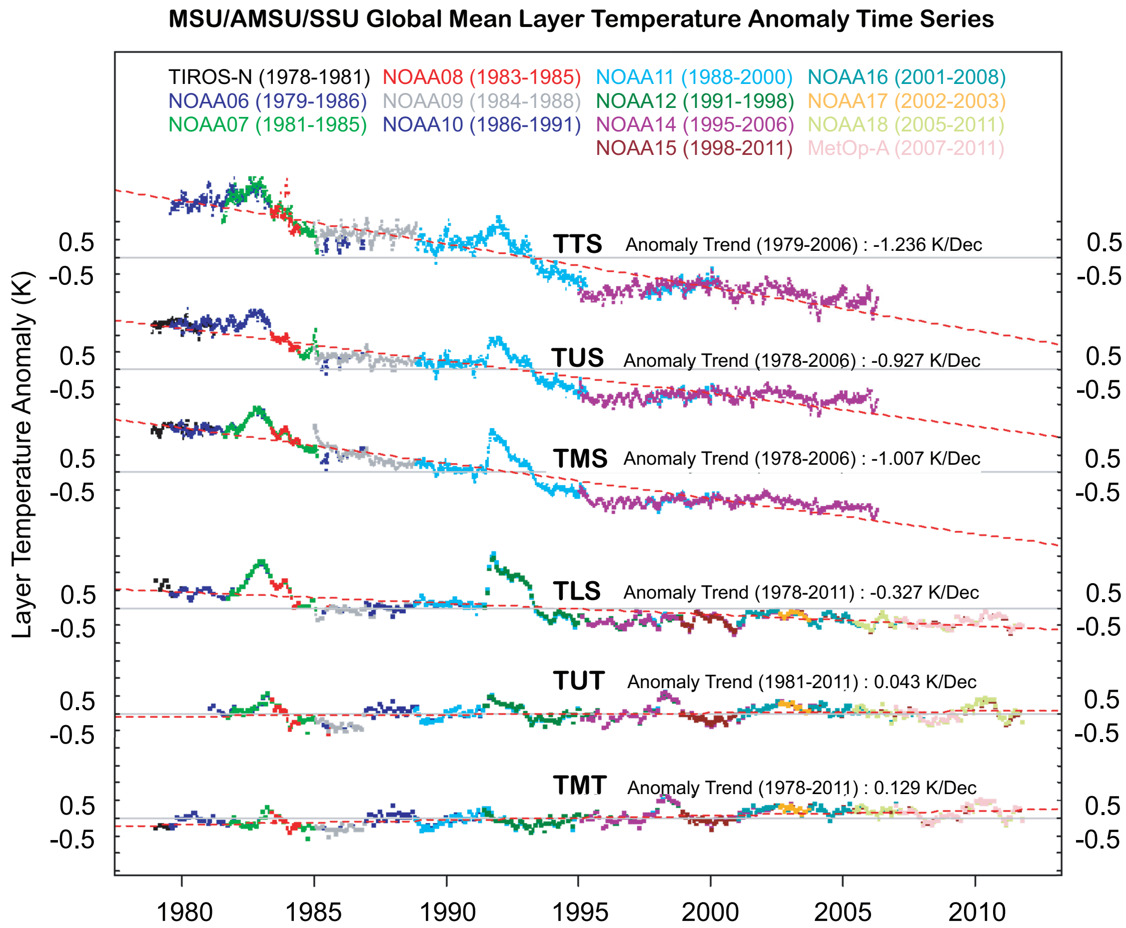

Figure 1: Time series of monthly global temperature anomalies and trends derived from satellites (thick layer measurements from the Microwave Sounding Unit, MSU, and Stratospheric Sounding Unit, SSU). The lower three curves are for MSU channels 2, 3, and 4, termed Middle Troposphere, Upper Troposphere and Lower Stratosphere (centred near altitudes 5, 10 and 18 km), and the three upper curves are for SSU channels 1, 2 and 3 (Middle Stratosphere, Upper Stratosphere and Top Stratosphere, centred near 30, 38 and 44 km). The different colours represent measurements from separate operational instruments, which have been merged to generate continuous timeseries. Details of these data are described at http://www.star.nesdis.noaa.gov/smcd/emb/mscat/mscatmain.htm.

effects; Keckhut *et al*., 2011). **B. Funatsu** extended this work by making detailed comparisons between lidar measurements and AMSU satellite data.

T. Shepherd also attended the workshop on behalf of SPARC, and led a discussion of outstanding issues regarding models and measurements of stratospheric temperatures. Key issues for the community include attributing past and future changes, including separating the influences of ozone depleting substances versus greenhouse gas forcings; this is particularly difficult in polar regions, due to enhanced dynamical variability. Improved understanding of the quality of reanalysis in the stratosphere is also of substantial interest, spanning the range from diurnal tides (important for interpreting satellite observations with drifting orbits) to decadal temperature variations.

The workshop concluded with discussions on future group activities and priorities within SPARC and WCRP. One likely future activity will be an updated comparison of temperature changes in models (*e.g*., CCMVal2 models) with new and updated observational data sets (to 2011 and beyond) discussed at this workshop.

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Superconducting Sub-millimeter-Wave Limb-Emission Sounder - Middle Atmospheric Observations from the International Space Station

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and the SMILES Mission Team

Introduction

The Superconducting Sub-millimeter-Wave Limb-Emission Sounder (SMILES) was developed to operate on board the Japanese Experiment Module (JEM) on the International Space Station (ISS). It is a cooperative project of the Japan Aerospace Exploration Agency (JAXA) and the National Institute of Information and Communications Technology (NICT) of Japan. The key concept of SMILES is to obtain high-sensitivity measurements of minor species in the middle atmosphere using a receiver that employs superconductor-insulator-superconductor (SIS) mixers, which are cooled to 4.5 K by a mechanical cryo-cooler.

SMILES was successfully launched by the H-IIB rocket with the H-II Transfer Vehicle (HTV) on September 11, 2009, was attached to the JEM on September 25, and started atmospheric observations on October 12 (see **Photo**). Unfortunately, SMILES observations have been suspended since April 21, 2010 due to the failure of a critical component in the sub-millimeter local oscillator. Furthermore, the cooler stopped its operation due to the failure of the JEM thermal control system on June 5, 2010. Finally, JAXA officially announced termination of normal operation on January 19, 2011, although data processing is still continuing. (Note: All dates in JST.)

The mission objectives are as follows: i) To demonstrate a 4-K mechanical cooler and superconducting mixers in an outer space environment for sub-millimeter limb-emission soundings in the frequency bands of 624.32-626.32 GHz and 649.12-650.32 GHz; and ii) To globally measure atmospheric minor constituents in the middle atmosphere (O_3, HCl, ClO, HO_2, HOCl, BrO, O_3 isotopes, HNO_3, CH_3CN, *etc*.) in order to get a better understanding of factors and processes controlling stratospheric ozone amounts and those related to climate change.

There are several scientific targets of the SMILES mission. The most important one is a study of the recovery and stability of the stratospheric ozone layer. Although possible future states of the ozone layer have been investigated using coupled chemistry-climate models (CCMs), there are still considerable uncertainties in the factors that affect ozone levels, especially bromine and inorganic chlorine chemistry. The SMILES mission can contribute to the knowledge of detailed halogen chemistry related to ozone destruction by providing useful constraints regarding these issues.

Photo: A picture taken from the Pressurized Module (PM), a part of the Japanese Experiment Module (JEM). SMILES is attached to the Exposed Facility (EF), and sits on the second slot from the front. (Photo courtesy of NASA.)

One recent topic related to such uncertainty is regarding BrO measurements, which suggest that in addition to long-lived source gases, very short-lived source gases likely also contribute to stratospheric total inorganic bromine (Br_y) by about 5 pptv (Salawitch *et al*., 2005; WMO, 2007). As to the enhanced total column BrO observed by satellites, results from the recent field campaigns, ARCTAS and ARCPAC, have suggested that there is significant contribution to BrO hotspot regions of a stratospheric origin during Arctic spring (Salawitch *et al*., 2011). Thus, BrO measurements by SMILES could be expected to provide important information on the bromine-related issues. This is also the case for SMILES measurements of HCl concentrations near the stratopause and above, which are essential for determining Cl_y levels in the middle atmosphere. Because of its high sensitivity, SMILES could provide important information that would be essential to future scenarios for the model study investigating a recovery of the ozone layer.

In this report, we will give a brief description of the SMILES observations, and present some results based on Version 2.0 of the SMILES level 2 operational product provided by JAXA. These results demonstrate SMILES' ability to observe minor atmospheric constituents in the middle atmosphere. For details about the SMILES instrument and the ground data processing system including the initial results, see Kikuchi *et al*. (2010).

SMILES Observations

Within the sub-millimeter-wave region from 625 GHz to 650 GHz, SMILES measures three specified detection bands: 624.32–625.52 GHz (Band A), 625.12–626.32 GHz (Band B), and 649.12–650.32 GHz (Band C). Since the SMILES instrument contains only two AOS spectrometers, observations of Bands A, B, and C are made on a time-sharing basis. **Table 1** lists the specifications of the SMILES instrument. Details about the SMILES performance and the retrieval algorithm can be found in Kikuchi *et al*. (2010).

Since the ISS orbit is circular, with an inclination of 51.6 degrees to the equator, the highest latitude reached by the ISS orbit is 52º north and south. To measure northern high-latitude regions the antenna is tilted 45 degrees to the left of the direction of orbital motion, enabling SMILES to observe latitudes from 38°S to 65°N. Along one 91-minute orbit, SMILES takes approximately 100 measurements; the total number per day is about 1600. Unfortunately, the rotating ISS solar paddles intersect the SMILES field of view twice each orbit. Occurrence of the solar paddle interference is estimated to be a few percent, depending on the latitude range, but it is not negligible.

Another important aspect of the SMILES instrument is that it can measure the atmosphere at different local times because of the non-sun-synchronous orbit of the ISS. This is unique in the sense that most satellite observations for the upper atmosphere are usually done using a sun-synchronous orbit. Measurements of diurnal variation of the minor species are expected to provide further insights into middle atmosphere chemistry.

Data and Some Results

In the following we will show results based on Version 2.0 of the SMILES level 2 operational product provided by JAXA, which was released to internal researchers in October, 2011, and will be open to general users around the end of 2011. For information on the operational data processing algorithm see Takahashi *et al*. (2010), and for descriptions of the improvement for the version 2.0 data see Mitsuda *et al*. (2011). Since the new product uses the latest level 1 data (L1B 007), which include the gain nonlinearity effect of the receivers, biases in retrieved temperatures in the upper stratosphere are suppressed, and consequently the profiles for other minor species show reasonable results.

Table 1: Specifications of the SMILES instrument.

Frequency coverage	Band A (624.32 - 625.52 GHz) Band B (625.12-626.32 GHz) Band C (649.12-650.32 GHz)
Frequency sampling	0.8 MHz
Frequency resolution	~1.1-1.2 MHz (FWHM)
System noise temperature	~350 K
Integration time	0.5 s for each observation tangent point
Noise level in brightness temperature	< 0.7 K (for 0.5 s integration time)
Calibration accuracy	< 1.0 K (for 0.5 s integration time)
Observation cycle	53 s
Observation altitude range	10-60 km (nominal)
Vertical sampling	~2 km (nominal)
Instrumental height resolution (IFOV)	3.5-4.1 km (nominal)
Observation latitudes	38ºS-65ºN (nominal)
Observation azimuth angle	~10-95 degree (0=north)
Power consumption	~ 320 W (at beginning of life)
Payload weight	476 kg
Payload size	0.8 m (W) x 1 m (H) x 1.85 m (L)

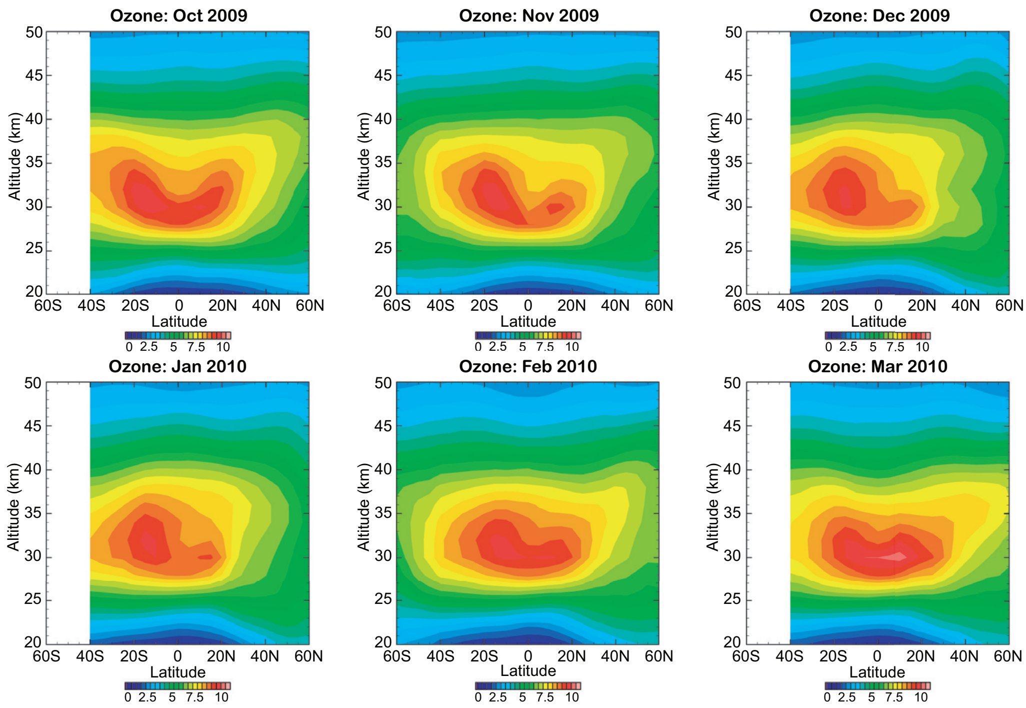

Figure 1: Monthly and zonal mean latitude-height cross-sections of ozone from October 2009 to March 2010.

To view the general make-up of the SMILES data, we first show the monthly mean and zonal mean ozone profiles in latitude-height cross-sections for the SMILES observation period from October 2009 to March 2010 in **Figure 1**. The ozone maxima around 30 km over the equator are clearly seen with some modulation over the observation period. In October 2009, the maxima in the subtropics (around 15°S and 15°N) are separated by a local minimum over the equator. The peak in the northern hemisphere fades away in November, and consequently there is only one peak in the southern hemisphere by December. The double maxima structure then develops again from January to March.

Using monthly mean satellite data, Randel and Wu (1996) also reported a local minimum in ozone concentrations over the equator with corresponding maxima at subtropical latitudes. This spatial structure was associated with the quasi-biennial oscillation (QBO) in the equatorial stratosphere. In the SMILES observations, the vertical wind shear in the zonal wind is westerly around this height over the six month period, and it is thus expected that vertical motion should be dominated by sinking over the equator, similar to the analysis by Trepte and Hitchman (1992) using satellite aerosol data. Because of this downward displacement, in conjunction with warm anomalies, ozone variations related to the QBO around 30 km show minima at the equator when the QBO is in the westerly phase (*e.g.*, Shiotani and Hasebe, 1994). We have further found that the vertical shear is modulated by interaction with the semi-annual oscillation (SAO) the equatorial upper stratosphere, resulting in a stronger shear around the equinoctial month and a weaker one around the solstitial month. Also there may exist an asymmetry in the SAO with respect to the equator that is due the stronger wave activity in the winter hemisphere.

We have also done extensive comparisons with other existing data sources such as satellite observations and results from a chemistry-transport model. **Figure 2** is an example of such comparisons for HCl. Coincidence profiles are chosen from Aura MLS, ACE-FTS and SD (specified dynamics)-WACCM. SD-WACCM is a chemistry-climate model developed at NCAR, and nudged with the GEOS-5 assimilation fields. Agreements between SMILES observations and these data sources are generally good for the height range of 25-45 km. Above that height, however, the results from MLS and ACE-FTS deviate from those of SMILES and SD-WACCM, which show almost constant values of around 3.0-3.1 ppb.

One of the important aspects of SMILES is that it can measure the atmosphere at different local times due to the non-sun-synchronous orbit of the ISS. Since the

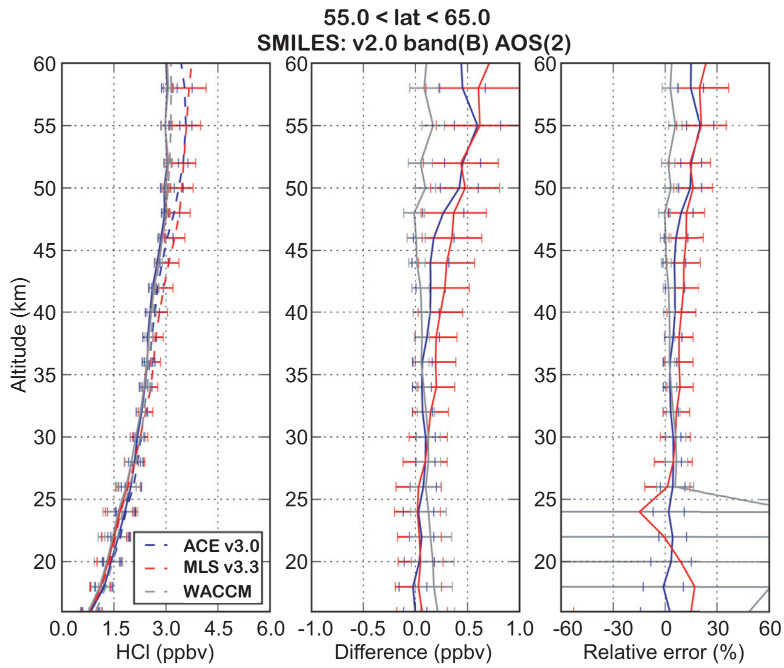

Figure 2: Statistical comparisons of SMILES HCl profiles coincident with those measured from MLS, ACE-FTS and SD-WACCM. Left panel: Mean profiles for SMILES are drawn in solid lines with different colours (but almost overlapped) and others are in dashed lines with corresponding colours (see key). Centre panel: The differences between SMILES and the corresponding profiles are indicated by solid lines for the valid data range with horizontal bars indicating one standard deviation. Right panel: The percentage differences (relative error) from the centre figure.

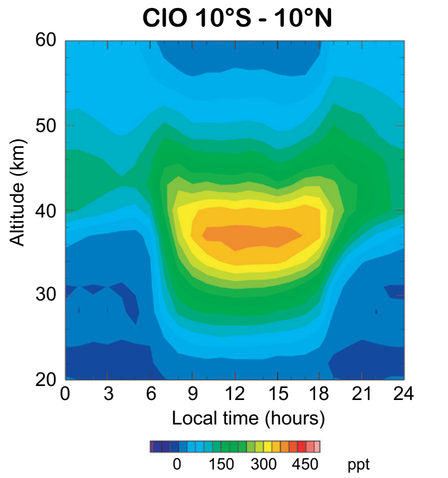

Figure 3: Local time and height section of ClO averaged over 10°S and 10°N. Data was binned into 1 hour increments and 5° latitudes using data for three months from February to April 2010.

local time only changes about 22 minutes a day due to ISS orbit characteristics, diurnal variations of these minor constituents can be seen using a month of data and by combining the ascending and descending measurements. This can provide unique observations of diurnal variation for minor species, such as O_3, ClO, HO_2 and BrO.

Figure 3 is such an example for ClO in a local-time and height section over the equator (averages over 10°S to 10°N). To make this analysis, we first calculated zonal mean values for each day by assuming that the local time is almost constant for those observations, thus we put these values into 1 hour and 5-degree latitude bins. In Figure 3 we clearly see daytime enhancement of ClO with a peak around 38 km. We also see some asymmetry between the sunrise and sunset conditions with a sharp increase at sunrise and rather slower decrease at sunset. Based on these results, we expect that SMILES measurements will give further insight into middle atmosphere chemistry.

Summary

The Superconducting Sub-millimeter-Wave Limb-Emission Sounder (SMILES) was successfully launched on September 11, 2009, started atmospheric observations on October 12, and has been performing global observations at about 100 points per ISS orbit, except for some restrictions due to ISS operation. Though the operation period was limited for about a half year, SMILES provided high-sensitivity measurements of middle atmosphere minor constituents. This is an outstanding experiment that is retrieving unique data with lower noise than other instruments because it employs a 4-K mechanical cooler and superconducting mixers for limb-emission sounding in the submillimeter-wave range. The spectra are used to retrieve vertical profiles of minor atmospheric constituents in the middle atmosphere (O_3, HCL, ClO, HO_2, HOCl, BrO O_3 isotopes, HNO_3, CH_3CN, *etc*.) with their diurnal variations, which will contribute to various issues of atmospheric science.

We have presented some preliminary results. In doing extensive comparisons with other data sources, we have acquired confidence in the SMILES data quality, which can be used for quantitative arguments. For example, the concentrations of HCl above and around the stratopause are almost constant (~ 3.0-3.1 ppb). Accurate levels of HCl at the stratopause are essential in determining Cl_y levels in the middle atmosphere. In addition, BrO measurements taken by SMILES could provide an important constraint on Br_y level as well. Derived profiles such as ozone show interesting seasonality over the equator, suggesting interaction between the QBO and the SAO.

We have shown the capability of obtaining high-quality scientific data that will be important to addressing scientific issues such as the ozone trend problem, middle atmosphere chemistry with a special focus on the diurnal cycle, and the transport process of minor species. These outcomes from SMILES will demonstrate its high potential to observe atmosphere minor constituents in the middle atmosphere. There are several studies in progress that will develop the analysis further from the viewpoint of extensive comparisons for the validation and new scientific achievements, particularly on the diurnal variation of some minor species.

The data will be open to the scientific community around the end of 2011. For further information please visit the following web page: **http://smiles.tksc.jaxa.jp/indexe.shtml.**

Acknowledgements

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Announcement

MACC stratospheric ozone service

The European project MACC (Monitoring Atmospheric Composition and Climate) is the atmospheric component of the European initiative for the Global Monitoring for Environment and Security (GMES). In this framework, the Belgian Institute for Space Aeronomy has developed a website for the MACC stratospheric ozone service: **http://www.gmes-stratosphere.eu/ (Figure 1)**.

MACC takes as its input comprehensive sets of satellite data from many different satellite instruments supplying information on atmospheric dynamics, thermodynamics and composition. The data are made available by the space agencies and institutions collaborating with the agencies to produce retrieved data products. The satellite data are supplemented by *in situ* data from meteorological networks and measurements measuring atmospheric composition. Data are processed to provide a range of products related to climate forcing, air quality, stratospheric ozone, UV radiation at the Earth's surface and resources for solar power generation. Additional *in situ* data are used for validating the processing systems and the products they supply. MACC operates a value-adding chain which extracts information from as wide a range of observing systems as possible and combines the information in a set of data and graphical products that have more complete spatial and temporal coverage and are more readily applicable than the data provided directly by the observing systems.

The MACC stratospheric ozone website displays near-real time (NRT) satellite data, global chemical analyses and reanalyses of historic data sets. The NRT analyses of ozone and ozone-related chemical species are computed by four different chemical data assimilation systems (IFS-MOZART, BASCOE, SACADA, and TM3DAM). They are shown as continuously updated snapshot maps, time series at constant pressure levels (1, 50, and 100 hPa) and as total columns. The ozone abundances are derived in near-real time from observations by several satellite instruments, and are used as input for a data assimilation program that provides global ozone fields for today and a forecast for the coming days. In addition to ozone, several species of interest for stratospheric composition are displayed (currently NO_X, HCl, HOCl, HNO_3, H_2O, N_2O - depending on the system). A snapshot comparison tool is at the user's disposal to allow for an easy comparison of up to 4 different systems, species, levels, map projections and/or dates.

Besides the NRT service, the website also delivers several chemical reanalyses realised for MACC or its predecessor ESA project PROMOTE. Currently the website display ozone by the Multi Sensor Reanalysis (1979-2009) and by IFS-MOZART (2003-2010). Several data sets are available for download.

The website also provides an evaluation of these products by comparing with independent data, and animations of recent ozone hole depletion events (*e.g.*, for communication to the media).

As we are continuously working on improving and extending this service, feedback is highly appreciated. Contact: **macc@aeronomie.be.**

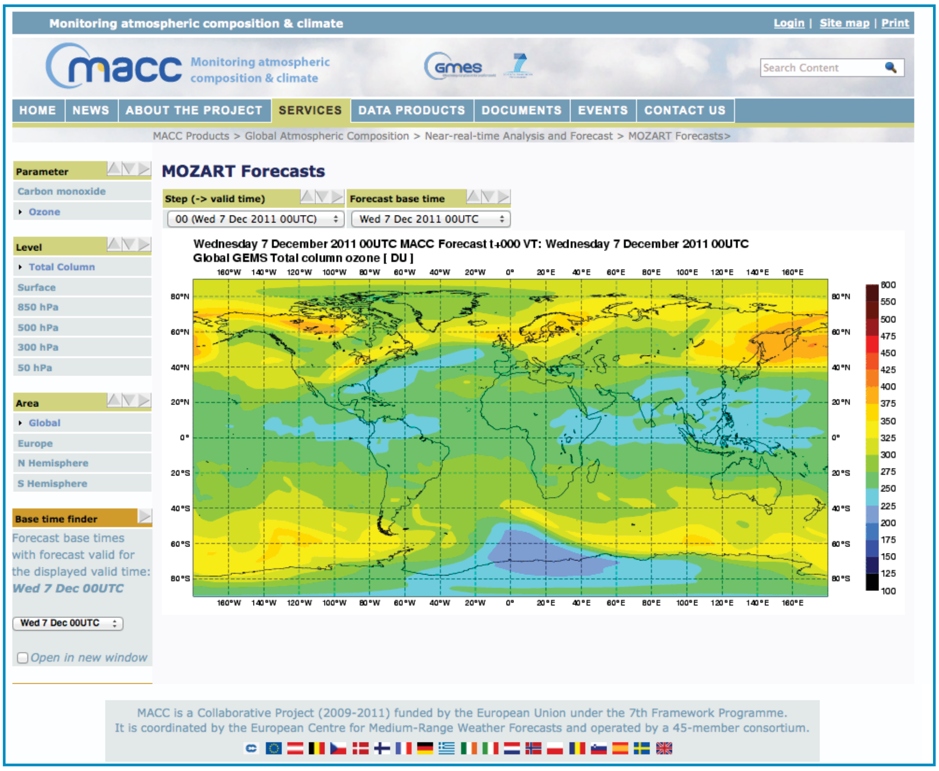

Figure 1: A screenshot of the MACC website showing the GEMS total column ozone for the previous day. Plots are available every 6 hours at 00, 06, 12 and 18 UTC, on 5 pressure levels and the surface, for ozone and carbon monoxide.

Future SPARC and SPARC-related Meetings

2012

22-26 January	Annual American Meteorological Society (AMS) Meeting, New Orleans, USA, http://annual.ametsoc.org/2012/index.cfm/call-for-papers/
22-24 February	Workshop on Stratospheric Sudden Warming and its Role in Weather and Climate Variations, Kyoto, Japan; http://www-mete.kugi.kyoto-u.ac.jp/Kyoto2012/
5-9 March	CMIP5 Analysis Workshop, Honolulu, USA, http://www.wcrp-climate.org/cmip5/workshop/index.shtml
22-27 April	European Geosciences Union General Assembly 2012, Vienna, Austria http://meetings.copernicus.org/egu2012/
7-11 May	4th WCRP International Conference on Reanalysis, Silver Springs, Maryland, USA, http://icr4.org/
22-24 May	SPARC CCMVal 2012 Workshop, Davos Switzerland http://www.pa.op.dlr.de/CCMVal/CCMVal_Workshops.html
27 May - 1 June	Modes of Variability in the Climate System: Past-Present-Future, Obergurgi, Austria http://www.esf.org/activities/esf-conferences/details/2012/confdetail381/381-preliminary-programme.html
29 May - 1 June	AMS 25th Conference on Weather Analysis and Forecasing (WAF), 21st Conference on Numerical Weather Prediction, 46th Canadian Meteorological and Oceanographical Society (CMOS) Congress, Montreal, Quebec, Canada, http://www.cmos.ca/congress2012/en/index.shtml
25-29 June	SPARC Workshop on the Brewer-Dobson Circulation, Grindelwald, Switzerland
17-21 September	3rd International Conference on Earth System Modelling, Hamburg, Germany http://www.meetings.copernicus.org/3icesm/

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