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World Climate Research Programme

Chapter 10: Effect of the stratosphere on climate
Preferred Presentation: poster

Southern Hemisphere Circulation Change as Simulated by the SPARC/CCMVal-2 Models: The Role of Stratospheric Ozone

Son, Seok-Woo

Chapter 10: Effect of the stratosphere on climate
Preferred Presentation: oral

Annular Mode Time Scales and Stratosphere-Troposphere Coupling in the CCMVal Models

Gerber, Edwin

Stratosphere-troposphere coupling on intraseasonal time scales in the CCMVal models is evaluated by testing their ability to capture the temporal structure of the annular modes patterns of variability. The annular modes connect fluctuations in the strength of the stratospheric polar vortex to variations in the position of the tropospheric westerly jets, and so characterize a significant fraction of stratosphere-troposphere coupling. Baldwin et al. (Science, 2003) and Gerber and Polvani (J. Climate 2009) suggest that this coupling leads to enhanced low frequency variability in the troposphere during the NH winter and SH spring. The CCMVal models vaguely capture key qualitative features of the Northern and Southern Annular Modes. In the troposphere, Northern Hemisphere time scales are shorter than those of the Southern Hemisphere and weakly peak in boreal winter, while Southern Hemisphere time scales peak in austral spring and summer. In the stratosphere, the time scales are generally larger than in the troposphere and appear connected to the active seasons of the polar vortices. Models, however, fail to capture the details of the coupling, particularly in the Northern Hemisphere winter. The CCMVal models are compared against Intergovernmental Panel on Climate Change Fourth Assessment Report models to assess the significance of the stratosphere on a model's ability to capture the tropospheric annular modes.

Chapter 10: Effect of the stratosphere on climate
Preferred Presentation: oral

Effect of the stratosphere on climate: Overview

Gillett, Nathan; Baldwin, Mark

We review the dynamical, radiative, and chemical influence of the stratosphere on the troposphere in simulations of the CCMVal-2 models. We start by validating the simulation of tropospheric climate in the CCMVal-2 models. We assess dynamical

stratosphere-troposphere coupling in the context of high frequency variability in these simulations, and we also examine the effects of past and future changes in stratospheric composition on the troposphere. In the Southern Hemisphere, preliminary results indicate that the CCMVal-2 models simulate larger cooling in the stratospheric vortex in spring than the CMIP3 models, resulting in larger and more realistic tropospheric geopotential height trends, a larger southward shift of the subtropical jet, and more broadening of the Hadley Cell. In the future simulations these changes are reversed as stratospheric ozone recovers. We go on to assess the radiative effects of simulated changes in stratospheric composition on the troposphere, and the effects on the flux of ozone across the tropopause.

Chapter 10: Effect of the stratosphere on climate
Preferred Presentation: oral

Ozone depletion, surface climate and the Annular Modes: A model study

Morgenstern, Olaf; Bodeker, Greg; Braesicke, Peter; Pyle, John

High-latitude climate variability, such as the cooling over the Antarctic interior of recent decades, is often explained in terms of trends in the annular modes. Here we report on CCM experiments suggesting that a recent strengthening of the annular modes of both hemispheres is mainly caused by anthropogenic ozone depletion. A reference simulation covering 1959-2100 exhibits first a strengthening of both annular modes to ~2000, similar to observations, followed by a decline during the period of ozone recovery, before further strengthening after ~2045. A second simulation from 1960 to 2000 excluding anthropogenic ozone depletion exhibits no significant strengthening of either mode. Substantial surface temperature anomalies over the northern continents and Antarctica are associated with the variations of the modes in the reference simulation. For the 20th century they compare well with observations; for the first half of the 21st century we find a weakening or reversal of temperature trends in some large continental areas, for example, the Antarctic Plateau, Central Siberia, and Eastern Canada. Our results corroborate emerging evidence that ozone recovery will dominate climate change in Antarctica in the coming few decades. For the Northern Hemisphere, our results suggest a more dominant role of ozone in driving the Northern Annular Mode than has hitherto been appreciated. We speculate that prescribing zonal-mean ozone, i.e., ignoring zonal asymmetries and the coupled nature of ozone, is responsible for conventional climate models to underestimate the importance of ozone in driving the annular modes.

Chapter 10: Effect of the stratosphere on climate
Preferred Presentation: poster

Influence of lower stratospheric ozone variation on tropospheric temperature and mean meridional circulation in the Northern Hemisphere summer in the recent past

Nakamura, Tetsu; Akiyoshi, Hideharu

The influence of the lower stratospheric ozone variation on the tropospheric temperature and mean meridional circulation in the Northern Hemisphere mid-latitude summer is examined by statistical analyses of observational data. It is found that an increase in the lower stratospheric ozone strengthens static stability at the tropopause, thus the vertical propagation of the planetary wave is trapped there more efficiently. The zonal flow deceleration due to the wave forcing induces the anomalous residual mean circulation, which causes anomalous cooling in the troposphere through the sensible and latent heat transport. Then, the tropospheric temperature decreases associated with the stratospheric ozone increasing.

A sensitivity experiment using chemistry-climate model (CCM) has been carried out to examine the tropospheric responses to the stratospheric ozone increasing. The result shows responses similar to the observations. The consistence between the observation and CCM suggests a climate change in the troposphere induced by stratospheric ozone variation.

Chapter 10: Effect of the stratosphere on climate
Preferred Presentation: oral

Do we need to include the stratosphere for 21st century climate change projections?

Perlwitz, Judith; Pawson, Steven

The stratospheric circulation is to a large degree controlled dynamically by motions that originate in the troposphere. However, there is increasing evidence from observations, theory and modeling studies that the stratosphere has a significant influence on the troposphere. It has been concluded that improvements to stratospheric representation in models might lead to improvements in seasonal predictions and climate-timescale projections.

This talk illustrates how anthropogenic climate forcings can affect the stratosphere and what are subsequent effects on the tropospheric circulation. To address the role of stratosphere in 21st century climate change, simulations with the GEOS CCM and multi-model scenario experiments from the Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change are compared.

Chapter 10: Effect of the stratosphere on climate
Preferred Presentation:

Tropospheric climate in CCMVal-2, CCMVal-1, and CMIP-3

Reichler, Thomas; Kim, Junsu

This work provides an intercomparison of the simulation qualities of tropospheric mean climate and climate variability (inter-annual and day-to-day) from the CCMVal-2, CCMVal-1, and CMIP-3 group of models. The study is based on the period 1979-1999 and on simulations that were forced with observed SSTs and sea ice, meaning that REF-B1 simulations are considered from CCMVal and AMIP-type simulations from CMIP-3. We investigate a wide range of climate quantities from the free troposphere and the surface for which simulation and observation data are available. In most cases, the simulations are compared against multiple observations in order to provide estimates of observational uncertainty. For each model and for the multi-model means of the three model generations we calculate non-dimensional root mean square errors, which are then combined into a single metric of overall model performance. The individual results are broken down in various ways (region, season, type of quantity, mean vs. variability) to allow an objective comparison of the individual models and model generations.

Chapter 10: Effect of the stratosphere on climate
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Response of the CCSR/NIES chemistry-climate model to the solar cycle and volcanic aerosol during 1980-2000

Yamashita, Yousuke; Sakamoto, Kei; Akiyoshi, Hideharu; Takahashi, Masaaki; Nagashima, Tatsuya; Zhou, L. B.

The results of sensitivity experiments using a three-dimensional chemistry climate model (CCM) for 1980-2000 are analyzed to understand the distribution of the 11-year solar cycle component of equatorial ozone and temperature variation. The Center for Climate System Research/National Institute for Environmental Studies (CCSR/NIES) CCM is used in this study. The 11-year solar cycle variability is analyzed by using the CCM outputs for the REF1 scenario of the CCMVal and the multiple regression analysis. The result clearly shows two maxima vertically at 5 hPa and 80 hPa over the equatorial region. Furthermore, sensitivity runs with and without solar variation indicate that the solar term of the regression equation for the upper stratosphere highly comes from the solar variation, in agreement with previous studies. In the lower stratosphere, however, the solar term is affected by aliasing of volcanic eruption, quasi-biennial oscillation (QBO) and sea-surface temperature (SST) variation, leading a fake solar signal on the equation. Thus, an accurate separation of these effects with the multiple regression analysis seems difficult in a short time period. Sensitivity runs are useful to isolate the solar response from these effects. The results show that the solar term in the lower stratosphere is affected mainly by the volcanic forcing which influences 90% in ozone at 80 hPa and 80% in temperature at 70 hPa. The QBO and the inter-annual variability of the SST have only small effects. The real contribution of the solar cycle forcing in the lower stratosphere is about 10% in ozone and 20% in temperature. The overestimation of the volcanic effects on ozone in the CCSR/NIES CCM makes such a large effect on the solar term. An analysis of the solar term for a longer period for 1960-2006 using CCMVal2 outputs from the CCSR/NIES CCM shows a much smaller magnitude of ozone variation at 80 hPa. Thus, the longer period for analysis reduces the aliasing of the volcanic forcing, and then reduces the uncertainty in detecting solar signals in the lower stratosphere.

Chapter 2: Chemistry climate models and scenarios
Preferred Presentation: poster

Blood, sweat and tiers: A vertically resolved ozone database for assessing chemistry-climate models

Bodeker Greg; Hassler Birgit, Dameris Martin

Following the expenditure of much blood and sweat, a new global three dimensional (latitude, pressure, time) zonal mean monthly mean ozone database, from 1979 to 2007, has been created. The database is global with zonal means centered at 87.5S to 87.5N at 5 degree latitude resolution and from 878 hPa to 0.0460 hPa on 70 pressure levels approximately 1 km apart. A complimentary database on altitude levels extends from 1 to 70 km alttitude in exactly 1 km increments. The databases have no missing values and have been constructed by fitting a regression model to monthly mean ozone calculated from ozone observations combined from a number of sources including LIMS, SAGE I, SAGE II, HALOE, POAM II, POAM III and ozonesondes. By expanding the regression model coefficients in Legendre polynomials in latitude, a single regression fit at each pressure/altitude level avoids biasing due to unequal sampling at different latitudes and allows extension to regions where no measurements are available. Four different 'tiers' of database have been constructed by summing the contributions of different regression model basis functions, viz.:

1) Anthropogenic: regression model mean annual cycle plus contributions from the equivalent effective stratospheric chlorine (EESC) and linear trend basis functions. This database just aims to capture long-term secular changes in ozone.

2) Natural: regression model mean annual cycle plus contributions from the quasi-biennial oscillation (QBO), solar cycle and El Niño basis functions.

3) Natural & Volcanoes: The Tier 2 database but now also including contributions from the volcanic eruption basis functions.

4) All: constructed by summing the contributions from all of the basis functions included in the regression model.

NetCDF files of all 4 tiers are available, both in number density and in mixing ratio, and indexed by altitude and by pressure. The databases will be compared against chemistry climate model ozone fields from the CCMVal2 database.

Chapter 2: Chemistry climate models and scenarios
Preferred Presentation: poster

A comparison of CCMVal-1 versus CCMVal-2 model performance

Eyring, Veronika; Waugh, Darryn; Cionni, Irene and CCMVal-2 team

We apply the diagnostics of Eyring et al. (2006) and the performance metrics of Waugh and Eyring (2008) to the CCMVal-1 and CCMVal-2 models in order to perform a quantitative assessment of model improvements. Model improvements will be documented for individual models that participate in both rounds (CCMVal-1 and CCMVal-2), for newly participating CCMs in order to see how they perform against the CCMVal-1 model validation standard and for the different generations of models (CCMVal-1 versus CCMVal-2). The results are produced in support of the synthesis chapter of the SPARC CCMVal report.

Chapter 2: Chemistry climate models and scenarios
Preferred Presentation: poster

Results of a EMAC-long term simulation from 1980 to 2050 in comparison to different sensitivity studies

Kirner, Ole; Ruhnke, Roland

We performed a REF-B2 simulation from 1980 to 2050 with the boundary conditions of IPCC-A1B scenario [IPCC, 2001] and WMO-Ab scenario [WMO, 2007] with the chemistry-climate-model ECHAM/MESSy Atmospheric Chemistry (EMAC) [Joeckel et al. , 2006]. For the present study we used EMAC (version 1.5) with the horizontal resolution T31 and with 39 vertical layers which covers the atmosphere from the surface up to 80 km. We applied the chemistry of the Stratosphere and Mesosphere and a new parameterisation of polar stratospheric clouds (PSC) based on the efficient growth and sedimentation of NAT-particles [Kirner, 2008].

We present the results of this simulation and compare these with sensitivity studies in which we changed some settings in the PSC submodel.

Chapter 2: Chemistry climate models and scenarios
Preferred Presentation: poster

The new UKCA climate-chemistry model: Evaluation of the stratospheric performance

Morgenstern, Olaf; Hurwitz, Margaret; Braesicke, Peter; O'Connor, Fiona; Bushell, Andrew; Johnson, Colin; Osprey, S.; Pyle, John

The UK Chemistry and Aerosols (UKCA) model is a new chemistry module coupled to the Met Office Unified Model capable of simulating composition and climate from the troposphere to the mesosphere. Here we assess its performance in the stratosphere. We present basic and derived dynamical and chemical model results and compare to ERA-40 reanalyses and satellite climatologies. Polar temperatures and the lifetime of the southern polar vortex are well captured, indicating that the model is suitable for assessing the ozone hole; this is partly a consequence of a good representation of meridional heat fluxes in the model. Ozone and long-lived tracers compare favourably to observations. Chemical-dynamical coupling, as evidenced by the anticorrelation between winter-spring northern polar ozone columns and the strength of the polar jet, is also well captured. We discuss remaining weaknesses and ways to improve the model. The simulation presented here forms part of our contribution to the CCMVal-2 model intercomparison.

Chapter 2: Chemistry climate models and scenarios
Preferred Presentation: oral

CCMVal Data at the BADC

Pascoe, Charlotte

There are many good reasons to keep data and here are three of the best... 1. Re-use 2. Re-purposing 3. Citation This presentation is all about why you were asked to provide CCMVal data to the BADC in CF complient NetCDF and how this self-describing standard enables the BADC to fulfill it's role as custodian of the CCMVal data archive.

RE-USE Providing data in CF complient NetCDF allows your data to be shared with other scientist now and in the future. Right now the CF NetCDF common fomat is facilitating the quick verification of data from different CCMVal models with the use of standard diagnositic tools. Twenty years from now the data will still be understood because it uses the self describing CF NetCDF standard.

RE-PURPOSING Using CF standard names to describe the CCMVal variables will enable scientists from other diciplines to make use of the CCMVal data when it is eventually made available to them. The CF standard names facilitate data discovery through vocabulary servers which allow users to find data without needing to know the exact names of variables. Such value added services satisfy the increasing expactation from funders that science data can be used by different research communities.

CITATION CCMVal data is an ideal candidate for publication in the new data journals because it used the CF NetCDF standard. Once the CCMVal data has been verified and moved to the archive at the BADC our data scientists can help with the process of publishing the data so that your data can be cited.

Chapter 2: Chemistry climate models and scenarios
Preferred Presentation: poster

The GEOS-CCM, Versions 1, 2 and 3

Pawson, Steven ; Nielsen, Eric; Duncan, Bryan; Stolarski, Richard; and the GEOS-CCM Team.

This paper examines evolution of key ozone and climate aspects in our range of Goddard Earth Observing System Models, Versions 1-3. Version 1 (Pawson et al., 2008; JGR) used GSFC stratospheric ozone chemistry in GEOS-4 GCM. A chronic high bias in polar ozone at low chlorine loading persisted into Version 2, which used the GEOS-5 GCM and the same chemistry. This is much improved in Version 3, which uses the GMI-COMBO stratosphere-troposphere chemistry. A dynamical problem with Version 1, the overactive nature of the Antarctic polar vortex, is corrected in Versions 2 and 3, when GEOS-5 replaces GEOS-4. Other changes between the various model versions will be documented.

Chapter 2: Chemistry climate models and scenarios
Preferred Presentation: oral

SWIFT – A new fast semi-empirical model for polar ozone loss

Rex, Markus; Huck, Petra E.; Kremser, Stefanie; Bodeker, Greg E.; Santee, Michelle L.; Bernath, Peter

Increasing evidence suggests that a robust representation of all aspects of climate change in global climate models requires the inclusion of stratospheric chemistry. Coupled Chemistry Climate Models (CCMs) are designed to do this. However, they are numerically very demanding and models that include both an ocean and stratospheric chemistry are still under development. Due to the numerical expense of such models they cannot be used to explore a wide range of scenarios. The most prominent chemical signal of stratospheric change is anthropogenic polar ozone loss. We have developed SWIFT (Semi-empirical Weighted Iterative Fit Technique), an extremely fast semi empirical model for polar ozone loss that allows accounting for this process in Atmosphere/Ocean General Circulation Models with hardly any numerical overhead. The model solves the differential equations that describe the vortex average evolution of HCl, ClONO2, HNO3 (gas phase), HNO3 (liquid/solid phase), ClOx, and ozone. It is driven by daily values of the vortex average extent of PSC conditions and solar illumination. The model includes 5 to 8 empirical fit parameters which are trained on vortex averaged observations of HCl and HNO3(gas phase) by the Microwave Limb sounder on Aura, ClONO2 by ACE FTS and ozone loss rates from Match. The training of the model is done with data from one Arctic and one Antarctic winter. We show that the model reproduces both the seasonal variation of the included trace species and the inter-annual variations of ozone loss well.

Chapter 2: Chemistry climate models and scenarios
Preferred Presentation: poster

ATLAS – A new fully langrangian model for stratospheric transport and chemistry

Wohltmann, Ingo; Rex, Markus

In most CCMs chemistry is calculated on grid points and transport of chemical species is carried out with various advection schemes. But all eulerian advection schemes suffer from numerical diffusion that is by far larger than the real atmospheric diffusion, particularly for lower resolutions. This causes a range of problems e.g. excessive flux of species across atmospheric transport barriers like the subtropical barrier or the edges of the polar vortices and often prevents a realistic representation of the Antarctic ozone hole. To overcome these problems we have developed a new fully lagrangian chemistry/transport module that can be coupled to CCMs. The module follows the same concept as CLaMS, the first lagrangian Chemical Transport Model, but is different in a number of aspects. E.g., it is completely free of vertical levels and therefore is the first truly grid less CTM. We show that this architecture further reduces mixing in the model and leads to more realistic results, particularly at the lower resolutions that are required for long integrations. We will present a general description of the new model and a detailed validation of the transport and mixing properties of the model.

Chapter 3: Radiation
Preferred Presentation: oral

On the attribution of stratospheric ozone and temperature changes to changes in ozone-depleting substances and well-mixed greenhouse gases: Update for CCMVal-2 simulations

Jonsson, Andreas; Shepherd, Theodore

The vertical profile of global-mean stratospheric temperature changes has traditionally represented an important diagnostic for the attribution of the cooling effects of stratospheric ozone depletion and CO2 increases. However, CO2-induced cooling alters ozone abundance by perturbing ozone chemistry, thereby coupling the stratospheric ozone and temperature responses to changes in CO2 and ozone-depleting substances (ODSs). In an earlier study we showed that it is possible to untangle the ozone-temperature coupling and that the attribution of global-mean stratospheric temperature changes to CO2 and ODS changes (which are the true anthropogenic forcing agents) can be quite different from the traditional attribution to CO2 and ozone changes. The significance of these effects were quantified empirically using simulations from the CMAM performed for CCMVal-1.

For CCMVal-2 the CMAM has been revised and in particular the middle atmosphere CO2 heating scheme has been corrected to adjust for an underestimated sensitivity to CO2 changes in the past. Analysis based on these new results reveals that about 2/3 of the upper stratospheric cooling over the period 1975-1995 can be attributed to ODS increase while only about 1/3 is caused by CO2 increase. Thus, the current view that CO2 contributes roughly half of the recent upper stratospheric temperature trends is an overestimate.

Upper stratospheric ozone decrease over 1975-1995 is largely due to ODS increases, although the total trend was offset by about 15% by the increase in CO2. When considering ozone recovery, however, the ozone-temperature coupling is a first-order effect; about half of the upper stratospheric ozone increase projected to occur from 2010-2040 is attributable to CO2 increases. Thus, it has now become necessary to base attribution of global-mean stratospheric temperature changes on CO2 and ODS changes rather than on CO2 and ozone changes.

Chapter 3: Radiation
Preferred Presentation: poster

The Influence of Spectral Solar Irradiance Data on the 11-Year Solar Signal

Langematz, U.; Oberländer, S., Matthes, K., Kubin, A.

The effect of solar variability on the atmospheric radiation budget as simulated in chemistry climate models (CCMs) strongly depends on the capability of the broad-band radiation schemes used by the CCMs to account for the spectral variations of solar irradiance. Another aspect influencing the amplitude of the simulated solar signal is the spectral solar fluxes that need to be prescribed at the top of the model atmosphere. Several data sets have recently been compiled from different measurement platforms and the purpose of this study is to examine to which extent the simulated solar signal is affected by the prescribed solar flux data set. We will present results obtained with the FUBRad short-wave radiation parameterization (Nissen et al., 2007) implemented in the ECHAM5-MESSy (EMAC) CCM. Short wave heating rate differences between a minimum (September 1986) and a maximum phase (November 1989) of the 11-year solar cycle will be compared. They are calculated using observed spectral solar flux variations from three different data sets: (a) daily spectral data from UARS/SOLSTICE described in Lean et al. (2005), (b) spectral solar irradiance reconstructed from the SATIRE model based on SOHO MDI imaging (Krivova and Solanki, 2005), and (c) scaled solar variability data derived from SCIAMACHY (Pangaran et al., 2009).

Chapter 4: Dynamics
Preferred Presentation: oral

Impact of SSTs on the stratospheric dynamics

Garny, Hella; Dameris, Martin; Stenke, Andrea

The Brewer-Dobson circulation (BDC) is largely driven by planetary waves which are generated in the troposphere, propagate upward and dissipate in the stratosphere. Most climate and chemistry-climate models predict an increase in the strength of the BDC in future climate with enhanced greenhouse gas concentrations, but so far the cause and effect relationships for the intensified BDC are unclear. While climate models are interactively coupled to an ocean model, in chemistry-climate models (CCMs) sea surface temperature (SST) and sea ice coverage are commonly prescribed as lower boundary condition. Therefore, the results of CCM simulations are dependent on the SST data set used.

In this study, two simulations with the CCM E39C-A are compared, which differ only with respect to the prescribed SSTs, spanning the years from 1960 to 1999. The prescribed SST and sea ice data sets correspond to the suggested boundary conditions for the new multi-decadal CCM simulations for the next WMO ozone assessment. One SST data set is based on observations, the other one is derived from a simulation performed with an AOGCM (coupled atmosphere-ocean general circulation model). Climatologies of temperature and ozone, as well as the BDC itself differ significantly between the two simulations, the latter resulting from different planetary wave driving. The time series of tropical up-welling, as a measure of the strength of the BDC, evolve differently in the simulations, with a reverse from negative to positive trends in one of the simulations and positive trends throughout the other simulation. This indicates that SSTs can act to modify the BDC. Additional simulations have been performed to study the sensitivity of the BDC on SST changes more closely, and their role in affecting the strength of the BDC is confirmed.

Chapter 4: Dynamics
Preferred Presentation: poster

Low Polar temperature extremes in the Canadian Middle Atmosphere Model

Hitchcock, Peter; Shepherd, Theodore G. and McLandress, Charles

Observations over the past half-century suggest that low temperature extremes have become increasingly widespread in the lower stratosphere during the coldest Arctic winters. Diagnostic measures of these extremes are strongly correlated with chemical ozone loss in the Northern Hemisphere, suggesting the potential risk of severe Arctic ozone loss if the trend continues in the near future (Rex et al. 2004, 2006). An analysis of the ensemble of CMAM runs submitted for the first CCMVal project found only a weak signal of such a trend, which could be associated with the ozone loss itself rather than climate change (Hitchcock et al. 2009). We present an updated analysis of the new ensemble of runs to be submitted for the upcoming round of CCMVal inter-comparison.

Chapter 4: Dynamics
Preferred Presentation: oral

Breakup of the Antarctic Polar Vortex in two new CCMs

Hurwitz, Margaret; Newman, Paul; Li, Feng; Morgenstern, Olaf; Braesicke, Peter; Pyle, John

The ability of two new chemistry–climate models (CCMs) to simulate the breakup of the Antarctic polar vortex in assessed. The stratospheric version of the UK Chemistry and Aerosols model (UKCA) is able to reproduce the observed timing of the transition to easterlies at 60ºS. In version 2 of the Goddard Earth Observing System (GEOS V2) CCM, insufficient planetary wave driving during the October–November period delays the transition to easterlies by two to three weeks at 10 hPa. The consequences of the delayed breakup of the Antarctic polar vortex in the GEOS V2 CCM are evaluated by examining differences in the response in years when the modeled eddy heat flux at 100 hPa is particularly weak or particularly strong. The delayed breakup of the Antarctic vortex biases temperature, circulation and trace gas concentrations in the polar upper stratosphere in November and December.

Chapter 4: Dynamics
Preferred Presentation:

Stratopause Evolution: Climatology, Influence of Stratospheric Sudden Warmings, and Implications for Climate Model Evaluation

Manney, Gloria; Krueger, K.; Schwartz, M; Pawson, S; McKee, N; Sienkiewicz, M; Daffer, W; Hoppel, K; Livesey, N; Polavarapu, S; Mlynczak, M; Remsberg, E; Russell III, J

The region around the stratopause, in the upper stratosphere/lower mesosphere (USLM) is important to climate change: E.g., Temperatures in this region are expected to be sensitive, early indicators of climate change, and changes in wave propagation and radiative heating in the USLM are linked to changes in the Brewer-Dobson circulation. Global daily temperature datasets extending through the mesosphere from the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) and

the Aura Microwave Limb Sounder (MLS) instruments are the first to allow comprehensive evaluation of the performance of models and data assimilation systems in the USLM. Recent work with these data sets has shown that operational analyses from European Center for Medium-Range Weather Forecasting (ECMWF) and NASA's Global Modelling and Assimilation Office (GMAO) show serious deficiencies in reproducing extreme events such as the prolonged stratospheric sudden warmings in the 2005-2006 and 2008-2009 Arctic winters, and show substantial biases in global stratopause structure and evolution under more typical conditions. We show improvements in stratopause structure and evolution in analyses from several research assimlations, including some from GMAO, the Canadian Middle Atmosphere Model Data Assimilation System (CMAM-DAS) and from the Naval Research Laboratory (NRL) NOGAPS-ALPHA DAS. These improvements result from changes such as raising model tops, using more sophisticated gravity-wave drag parameterizations, and/or assimilating of MLS and SABER data. The implications of stratopause evolution and response to stratospheric sudden warmings for evaluation and improvement of climate models are discussed.

Chapter 4: Dynamics
Preferred Presentation: oral

Impact of climate change on stratospheric sudden warmings as simulated by the Canadian Middle Atmosphere Model

McLandress, Charles; Shepherd, Ted

The dynamics of northern hemisphere major midwinter stratospheric sudden warmings (SSWs) are examined using transient simulations extending from 1950 to 2100 from the Canadian Middle Atmosphere Model (CMAM). The simulated SSWs show good overall agreement with reanalysis data regarding composite structure, statistics, and frequency. Using observed or model sea-surface temperatures (SSTs) is found to make no significant difference to the SSWs, indicating that the use of model SSTs in the simulations extending into the future is not an issue. When SSWs are defined by the standard (wind based) definition, their frequency is found to increase by ~60% by the end

of this century, in conjunction with a ~25% decrease in their temperature amplitude. However, when the northern annular mode index is used to define the SSWs, no future increase in frequency is found.

This latter result is consistent with the fact that the variance of 100-hPa daily heat flux anomalies is unaffected by climate change.

The future increase in frequency of SSWs found using the standard method is a result of the weakened climatological mean winds due to climate change, which make it easier for the SSW criterion to be met.

A comparison of winters with and without SSWs reveals that the weakening of the climatological westerlies is not a result of SSWs.

The Brewer-Dobson circulation is stronger by ~10% during winters with SSWs, a value which does not change significantly in the future.

Chapter 4: Dynamics
Preferred Presentation: oral

The effects of prescribing tropical variability in CCMVal Models

Osprey, Scott; Butchart, N; Charlton-Perez, Andrew

The ability of coupled chemistry-climate models to reproduce past variability and confidently predict future ozone levels/recovery, is a goal of the SPARC Ozone Report. The ability of a model to predict future ozone is dependant on a number of different factors: constraints provided by future forcing scenarios, initial conditions uncertainty and model uncertainty. A relevant question for the SPARC Report is how much of the future ozone recovery is down to prescribed scenarios and variability. Concerning the former, it is assumed that existing and future concentrations of ozone depleting substances are known. For the latter, dynamically relevant phenomena like the QBO are either prescribed, internally/spontaneously generated or even left out of future ozone predication simulations. In this study, we will examine the effect of tropical variability, in particular the QBO, on extratropical variability in the CCMVal models.

Chapter 4: Dynamics
Preferred Presentation:

Leading EOFs of Stratospheric Zonal Mean Zonal Wind and Climate Change

Perlwitz, Judith

In Reanalysis data, EOF 1 and EOF 2 of stratospheric zonal mean zonal wind represent the variation of the strength of the polar night jet and the north-south excursions in the polar vortex position respectively. We evaluate CCMs in representing the structure of these leading EOFs. We also investigate whether changes in stratospheric circulation project onto these modes of variability.

Chapter 4: Dynamics
Preferred Presentation: oral

Comparison of zonal asymmetries in midlatitudes between reanalysis of ERA-40 and CCMVal-model data sets

Peters, Dieter H.W.; Gabriel, Axel

The column integrated heating differs from winter to summer very strongly in midlatitudes of the Northern Hemisphere. It shows a high zonal variability reflecting mainly the radiative effects of continent-ocean distribution, but includes also heating rates resulting from zonal asymmetries of trace gases. At surface thermal heating anomalies together with topography and transient eddies are forcing quasi-stationary planetary Rossby waves which could propagate upwards into the middle atmosphere in a basic stream of mean westerlies. For instance zonal asymmetries of total ozone are significantly anti-correlated to the quasi-stationary 300 hPa geopotential height structure due to the induced large-scale ozone transport in the lower stratosphere. We use data sets of monthly mean zonal dependent geopotential as indicator for the zonal variation of mean circulation as given by ERA-40, and compare these patterns with results of some CCMVal model experiments. Data for a 20 year-period from 1980-1999 are mainly used which include the assimilation of radiances from satellites. By applying a pattern correlation method we found that all models underestimated the upper tropospheric geopotential by about 15% in January. For the lower stratosphere, three model groups have been classified, showing an overestimation, a relatively medium and strong underestimation which continues into the middle and upper stratosphere. The winter variance increases from 10 % in the troposphere up to 20% in the stratosphere as the MRI ensembles runs are showing. Further, the seasonal cycle shows in nearly all used model results an underestimation in the upper tropospheric structure, but a high variability in the stratosphere, with a very strong overestimation increasing in time during spring. By examining the decadal structure change, we found that the performance of all models is insufficient in comparison with ERA-40 data set. Some more details are shown and possible causes of this deficiency will be discussed.

Chapter 4: Dynamics
Preferred Presentation: oral

Influences of the equatorial QBO on the winter stratospheric circulation: Comparison between ERA-40 and MRI-CCM REF1 simulation

Shibata, Kiyotaka; Naoe Hiroaki

The effects of the equatorial quasi-biennial oscillation (QBO) on the extratropical winter stratosphere are investigated with statistical methods, focusing on winter season in the Northern Hemisphere, based on both 44-year of the ERA-40 reanalysis dataset (1958-2001) and 125-year of the MRI-CCM simulation data set (5 members times recent past 25 years from 1980 to 2004) of the REF1 scenario. MRI-CCM reproduced realistically the QBO of about 27-month period, albeit smaller (~20%) amplitude than observed one. The influences of the QBO on the wintertime stratosphere are well captured in the simulation such that colder and stronger polar vortices appear during the westerly QBO phase with statistical significance.

Chapter 4: Dynamics
Preferred Presentation: poster

Building a Stratosphere-Troposphere Stationary Wave Model

Wang, Lei; Kushner, Paul

Stationary wave, the climatological mean zonally asymmetric circulation, extends from the surface throughout the atmosphere above and is likely to play a significant role in understanding the dynamical coupling between the stratosphere and the troposphere. Stationary wave models are simplified general circulation models that are able to capture the dynamics of stationary waves fairly well, although have been occasionally questioned about the crude treatment of the complicated nonlinear processes. In such models, the diabatic heatings, transient eddy fluxes and stationary nonlinearity are treated as zonally asymmetric forcings besides topography, based on the diagnoses of the underlying dynamics. On the other hand, Rayleigh friction, Newtonian cooling and enhanced diffusion are employed in order to obtain steady state solution and/or avoid singularity, where the magnitudes of these dampings are often determined arbitrarily and thus vary among different models or experiments. The diabatic heating and transient eddy fluxes have been found having equivalent damping effects on zonally asymmetric circulations since late 1970s, while their impacts are difficult to quantify. ECMWF reanalysis data have been used to study the sensitivity of stationary wave solution on the dampings and its possible physical and dynamical connection with the forcings mentioned above in a stationary wave model which is developed to study the stratosphere-troposphere dynamical coupling issues. It is revealed that the radiative component of diabatic heating undermines the quality of the stationary wave solution and therefore should be excluded in the forcing of stationary wave models, while negligible impacts on stationary wave solution have been found from transient eddy fluxes.

Chapter 5: Transport
Preferred Presentation: oral

On the QBO modulation of the stratospheric tropical upwelling as evidenced by N2O distributions

Braesicke, Peter; Strahan, Susan; Stiller, Gabriele; Morgenstern, Olaf; Pyle, John and CCMVal2 Contributors

In the lower stratosphere tropical probability density functions (PDFs) of N2O have a distinct two peak structure evidencing the existence of a surf-zone around a region of upwelling. The separation of the two peaks is more pronounced in the winter season than in the summer season. The general morphology of N2O PDFs has been used for model validation purposes in the past. Here, we will focus on the summer time variability of N2O PDFs and how it is influenced by the phase of the quasi-biennial oscillation (QBO).We will construct observational evidence of the modulation stratifying MIPAS and MLS N2O observations. Recent chemistry-climate model integrations will be treated in the same way and will be confronted with the observational results. A special focus will be on the new UK chemistry and aerosol community model (UKCA) and its ability to simulate an internal QBO, which in its periodicity is highly dependent on the simulated chemistry and in turn impacts the tropical upwelling during summer time. This process oriented validation will help to support further model development to improve existing CCMs.

Chapter 5: Transport
Preferred Presentation: oral

Simulated Lifetimes for CFCs

Douglass, Anne; Strahan, Susan

Endeavors such as CCMval establish a means for comparisons of different models and interpretation of their results, but caution must be used when interpreting results for a single diagnostic. For example, the WMO 2006 model distributions of the mean age of air (WMO 2006, Figure 6-7) are much more similar to those derived from observations of CO2 and SF6 than the 2002 model

distributions (WMO 2002, Figure 4-28). Even though the mean ages are similar to observed, the simulated transport and mixing differs among models, as evidenced comparisons with other measurements. For example, compared with mean age there is much greater variance in the simulated values of Cly in the south polar vortex (WMO 2006, Figure 6-8) and in the variance in simulated lower stratospheric HCl. From these differences we infer differences in simulated age spectra (the distribution of ages for all of the elements that characterize a parcel composition at a given location) and/or differences in the pathway and maximum height encountered by the various elements of the age spectrum.

CFC destruction increases rapidly with altitude. If a significant fraction of the CFC in a parcel has been destroyed relative to the amount that would be in the parcel based on its mean age, then some of the elements of the age spectrum must have experienced altitudes high enough for rapid CFC destruction. For example, in the tropics the local lifetime of CFC-11 is less than 2 years at pressures lower than about 50 hPa but the local lifetime CFC-12 is longer than 2 years until reaching pressures lower than 30 hPa. Comparisons of measurements of CFCs in the lower stratosphere with observations from aircraft and satellite and investigation of the relationship between the simulated CFC distributions with the mean age provide information about the credibility of the simulated age spectra and may also explain the inter-model differences in simulated Cly even for models with similar mean age.

The altitude dependence of the loss processes also controls the simulated lifetime. Mixing ratio boundary conditions control the evolution of CFCs in the models and, in a perfect model, the simulated loss will match that inferred from surface observations. These relationships will be investigated in the various models participating in CCMval to take a step beyond comparison of mean age to understand the differences in the model predictions for stratospheric ozone.

Chapter 5: Transport
Preferred Presentation: poster

Transport characteristics of CCMs evaluated with amplitude and phase of the water vapour tape recorder signal

Huck, Petra; Strahan, Susan; Waugh, Darryn; CCMVal Modelling Teams

Amplitude and phase of the water vapour tape recorder signal are metrics to evaluate the ascent rate of air entering the stratosphere through the tropics. The change in amplitude with height gauges the degree of isolation of the tropical pipe in the lower stratosphere (~18-26 km), while the phase, with respect to the phase at the tropical tropopause, assesses net vertical transport rate (ascent + vertical mixing). In this study, amplitude and phase of the water vapour tape recorder signal were calculated for chemistry-climate models participating in CCMVal-1 and CCMVal-2. The results of the tape recorder diagnostics are compared with other diagnostics for tropical transport in order to develop a consistent picture of tropical transport characteristics for each model.

Chapter 5: Transport
Preferred Presentation:

Evaluation of CMAM in the lower stratosphere using motnhly averages of O3 and N2O derived from Odin/SMR and ILAS/ILAS-II observations

Khosrawi, Farahnaz; R. Mueller, M. H. Proffitt, J. J. Jin, K. Semeniuk, J. McConnell, J. Urban, D. Murtagh, H. Nakajima

Data sets of monthly averaged nitrous oxide (N2O) and ozone (O3) derived from satellite measurements are used as a tool for the evaluation of atmospheric photochemical models. The N2O and O3 monthly averages are thereby derived by binning the data by potential temperature and then averaging over a fixed interval of N2O (20~ppv).

The advantage of this method is, that it reduces the variability of ozone due to latitudinal transport from photochemical changes. Thus, applying this method helps to separate between photochemical and dynamical processes and thus allows to evaluate photochemical models concerning polar winter ozone loss, polar summer ozone loss and descent. A 4-year data set has been derived from the Odin Sub-Millimetre Radiometer (Odin/SMR) observations and is used to evaluate a 4-year simulation from the Canadian Middle Atmosphere Model (CMAM). The avluation was performed for the entire Northern and Southern Hemisphere as well as separated into latitude regimes (polar, midlatitude and tropics). To inlcude an additional satellite data set we use

observations from the Improved Limb Atmospheric Spectrometer (ILAS and ILAS-II). However, ILAS and ILAS-II measurements are only available for the polar regions. A good agreement between Odin/SMR and CMAM is found with differences generally in the range of +/-20%. Differences exceeding +/-20% occur e.g. in the polar regions where an overestimation of ozone loss was found in the Southern Hemisphere.

Chapter 5: Transport
Preferred Presentation: oral

Overview of Chapter 5: Transport Diagnostics

Strahan, Susan; Neu, Jessica

The distribution of long-lived trace gases in the stratospheric overworld is controlled mainly by the balance between the diabatic circulation, which acts to create equator-to-pole gradients in tracer isopleths, and quasi-horizontal mixing, which acts to flatten tracer isopleths in mixing regions while sharpening gradients at the locations of mixing barriers. Three important barriers to transport are the subtropical barrier (i.e., the tropical pipe), the polar vortex, and the extratropical tropopause. Both the strength of the diabatic circulation and that of the transport barriers are linked to wave activity in the stratosphere and thus vary with height and season.

We have assembled a suite of diagnostics that attempts to assess many of the transport processes controlling trace gas distributions, from entry in the tropical lower stratospheric to exit through the extratropical 100 hPa surface. Some of the diagnostics were previously used in the Eyring et al. [2006] evaluation of CCMVal-1 models. The processes diagnosed include tropical ascent rate, isolation of the tropics (i.e., subtropical barriers), isolation of the polar vortices, and meridional circulation in the upper stratosphere. The transport processes affecting the 100 hPa surface (descent at high latitudes and horizontal transport from low latitudes) provide the upper boundary condition for the extratropical UT/LS region, and will also be evaluated. Some of the diagnostics are overlapping, that is, they evaluate, at least in part, a process also evaluated by another diagnostic. Because of this redundancy, consistency of results between different diagnostics may give us increased confidence in the transport evaluations that we make.

In this presentation we will show the results of the application of the transport diagnostics to all chemistry climate models submitting output to the CCMVal-2 project. For each model, the results from all the diagnostics will be combined in order to characterize the representation of important aspects of stratospheric transport, such as tropical ascent and recirculation, and descent and isolation at polar latitudes.

Chapter 5: Transport
Preferred Presentation:

Seasonal persistence of anomalies of ozone and other trace gases in the stratosphere

Tegtmeier, Susann; Fioletov, Vitali E. and Shepherd, Theodore G.

Analysis of observed ozone profiles in the tropics, subtropics and midlatitudes of both hemispheres reveals a strong persistence of ozone anomalies throughout the year in the middle/upper stratosphere. In the tropical region the ozone anomalies persist from late summer to spring of the following year, while ozone profiles in the subtropical region show persistence from autumn to summer of the following year. Overall, the time window of persistence of ozone anomalies depends strongly on the latitude band and we find a later time window for higher latitude bands. This shift of the time window of persistence is continuous through tropics, subtropics and midlatitudes of both hemispheres. The persistence of ozone anomalies can be used to improve the performance of regression models (e.g., for trend detection) particularly during summer and autumn months when the correlation between equatorial wind and ozone is small. The strong persistence in the upper stratospheric ozone anomalies is surprising, given the short lifetime of Ox at these altitudes. It is hypothesized that this "seasonal memory" in the upper stratospheric ozone anomalies arises from the persistence of transport-induced wintertime NOy anomalies, which perturb the ozone chemistry throughout the rest of the year. This hypothesis is confirmed by analysis of observations of NO2 and NOx, which are found to exhibit the same seasonal persistence and a similar time shift in persistence. The time shift in persistence is presumably related to the effect of stratospheric transport times on trace gas anomalies.

Chapter 5: Transport
Preferred Presentation: oral

Diagnostic of ozone laminas in the UTLS: evaluating model predictions in the HIRDLS space

Yudin Valery; Kinnison Douglas, Simone Tilmes, John Gille

In the lower stratosphere (LS) ozone profiles measured by sondes and High Resolution Dynamics Limb Sounder (HIRDLS, on board NASA Aura satellite) frequently display thin vertical layers of substantially enhanced or decreased mixing ratios, which are called laminas. The 2005-2007 HIRDLS O3 dataset and model simulations are used to evaluate the statistics of monthly frequencies of these events in the LS. In this region data and models demonstrate similar annual variations of the monthly frequencies of O3 laminas including the seasonal movements of their preferential locations. In the extra-tropics of the Northern Hemisphere (NH) a strong annual cycle of laminas is diagnosed with both HIRDLS and simulations with the most frequent counts during March-April and rare counts between August and October. In the Southern Hemisphere (SH) O3 lamina events are less frequent compared to the NH. This study provides the global multi-year examination of ozone laminas in the LS with space-borne data, chemistry-climate and chemistry-transport models and reported ozone analyses. The global statistics of O3 laminas observed by HIRDLS is considered here as an attractive metric for evaluations of simulated and analyzed ozone vertical structures in the UTLS.

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation: oral

Comparison and evaluation of the photolysis rates used in stratospheric chemistry models -- PhotoComp 2008

Bian, Huisheng; Kinnison, Douglas; Chipperfield, Martyn ; Prather, Michael

A photolysis benchmark (PhotoComp-2008), a component of the SPARC CCMVal Chapter 6, has been designed to evaluate how models calculate photolysis rates (and indirectly heating rates) in the stratosphere and troposphere. The three parts of PhotoComp are designed to test (1) high-sun J-values in clear sky, and optionally with stratus clouds and with a volcano-enhanced stratospheric sulfate layer; (2) low-sun and polar twilight conditions, including 24-hour averages; and (3) wavelength integration of the J-values for O3 =>O(1D) and NO2=>NO+O. While there is no "correct answer" for these cases, there is a convergence of several independent photolysis codes that adopt the same physics (e.g., recommended cross sections) and there are outliers, where we will try to ascertain if this due to different assumed physics or the numerical methods. Differences in the models become greater at low sun and twilight, indicating potentially large differences in polar photochemistry. The error in averaging over wavelength bins appears to be small, <3%, in the troposphere and lower stratosphere.

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation: poster

An approach for evaluating long-term changes in the chemical cycles affecting the ozone budget

Bodeker Greg; Struthers Hamish, Smale Dan

A method has been developed to disaggregate the contributions of 15 chemical destruction cycles, as well as the odd-oxygen Chapman cycle, to the ozone budget. The contributions of these cycles to ozone are accumulated into monthly means within each model grid cell. By examining how the relative contributions of these cycles to the ozone budget change with time, the cycles likely to play a larger role in determining ozone concentrations in the future can be identified. Changes in the contributions as a function latitude and altitude can also be evaluated. If a particular reaction set is identified as likely to become more important in determining ozone in the future, any anthropogenic enhancement of that set of reactions should in turn attract greater attention. This may help to identify where stratospheric ozone chemistry might be more sensitive to anthropogenic interference in the future. To explore some of the salient features of this technique, it has been applied to a REF-B1 simulation of Niwa-SOCOL. Examples of the contributions of various reaction cycles to ozone through the year and across the multiple years of the simulations, for different latitude and altitude regions, will be shown and discussed. In future we will also apply this diagnostic to a REF-B2 simulation. In addition to the diagnosing the ozone tendencies due to chemical processing, the contribution of dynamics can be evaluated and as a result long-term dynamically induced ozone changes can be assessed. However, in this presentation, only chemically induced changes in ozone will be presented and discussed.

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation:

Reactive nitrogen, hydrogen and chlorine species and stratospheric ozone in the CCMVal2-models and constraints by satellite data

Bruehl, Christoph; Baumgaertner, A., Austin, J., Lamarque, J.F., Aikiyoshi, H., Plummer, D., Michou, M., Frith, S., Bekki, S., Shibata, K., Rozanov, E., Mancini, E., Chipperfield, M., Dhomse, S., Butchart, N., Fischer, C.

NO and NO2 as the most important species for (mostly natural) catalytic ozone loss in the CCMVal2-REF-B1 simulations are compared with HALOE satellite data and checked for consistency with ozone and total NOy with focus on the tropical and midlatitude stratosphere. The contributions of the nitrogen, hydrogen and chlorine catalytic cycles in the models to the chemical ozone budget will be estimated and compared with constraints given by HALOE data. It is shown that ignoring water vapor formation from methane oxidation causes a severe underestimate of HO2 and OH in the upper stratosphere and an overestimate of ozone already in the altitude of the ozone maximum around 10hPa.

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation: oral

Satellite stratospheric measurements from the 1990's to now: Data and models

Froidevaux, Lucien; Santee, Michelle; Kinnison, Doug; Garcia, Rolando; Fuller, Ryan; Lambert, Alyn; Schwartz, Michael; Manney, Gloria; Daffer, William; Livesey, Nathaniel

Measurements of stratospheric species from the Aura satellite's Microwave Limb Sounder (MLS) during the past 4 years are compared to models and results from the earlier (1990's) Upper Atmosphere Research Satellite (UARS) MLS instrument. We focus here on chlorine species measured by Aura MLS (ClO and HCl in particular), along with HNO3 and H2O; data from the UARS Halogen Experiment (HALOE) are considered as well. Emphasis is given to polar processing issues (extent, timing, and variability of denitrification, dehydration, and chlorine activation). We discuss data/model comparisons, with an initial focus on the WACCM3 climate chemistry model(CCM).

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation: poster

ACE-FTS climatological dataset for model comparisons

Jones, Ashley; Jin, JianJun; Walker, Kaley A.

The Atmospheric Chemistry Experiment - Fourier Transform Spectrometer (ACE-FTS) aboard the Canadian satellite SCISAT measures the composition of the upper troposphere, stratosphere, and mesosphere. By using the solar occultation technique, it has produced high precision observations since February 2004. ACE-FTS measurements include pressure, temperature and over thirty chemical species such as ozone (O3), water vapor (H2O), methane (CH4), nitrous oxide (N2O), carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO2), dinitrogen pentoxide (N2O5), nitric acid (HNO3), hydrogen chloride (HCl), chlorine nitride (ClONO2), chlorofluorocarbons (e.g., CFC-11 and CFC-12), and hydrogen fluoride (HF). The vertical sampling of the profiles is 3-4 km. Although the ACE-FTS measurements focus on the polar atmosphere, observations are also made at middle and lower latitudes and, over the course of one year, global coverage is obtained. In this poster, the new ACE-FTS climatological dataset will be introduced and preliminary comparisons will be shown.

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation: oral

Evaluation of stratospheric chemical and microphysical processes used in CCMs: A Chapter 6 overview.

Kinnison, Douglas; Chipperfield, Martyn; Bekki, Slimane; Bian, Huisheng; Bruhl, Christoph; Canty, Tim; Dhomse, Sandip; Froidevaux, Lucien; Harvey, Lynn; Muller, Rolf; Prather, Michael; Randall, Cora; Salawitch, Ross; Santee, Michelle; Tian, Wenshou; and Tilmes, Simone

The SPARC CCMVal Chapter 6 goals are to document and evaluate the stratospheric chemical and microphysical processes used in CCMs - this presentation will summarize the current status of this effort. The focus here will be to discuss how chemical formalisms affect model performance. Two benchmarks will be used: 1) A photolysis benchmark to evaluate the accuracy of the photolysis code used in CCMs; and 2) a fast chemistry benchmark to examine chemical partitioning compared to a reference photostationary state (PSS) box model. The PSS model will be constrained by the temperature and long-lived (reservoir) fields from each CCM REFB1 simulation. The PSS model will act as a benchmark to inter compare the fast chemistry calculations in the CCMs. This chapter will also evaluate reservoir species abundances and long-lived distributions. Global comparisons will be made with satellite observations and climatologies from in-situ aircraft data. Polar chemical process in CCMs will also be extensively evaluated (e.g., ozone loss, dehydration, denitrification, and chlorine activation processes). These comparisons will be primarily done with the REFB1 simulations.

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation: poster

Present-day climatology of a new coupled chemistry-climate model CNRM-ACM : sensitivity to horizontal resolution, meteorological parameters and coupling

Michou Martine; Olivié D., Teyssèdre H., Borchi F., Saint-Martin D., Karcher F., Peuch V.-H, Cariolle D., Chéroux F.

We present results of simulations from our new coupled chemistry-climate model (CCM) CNRM-ACM.

This CCM is composed of the GCM ARPEGE-Climat (Déqué et al., 1994) and the CTM MOCAGE-Climat (Teyssèdre et al., 2007), both developed at the Centre National de Recherches Météorologiques (CNRM, Météo-France/CNRS, Toulouse). We have performed several multi-year simulations in order to evaluate the present-day climatology of our model in the stratosphere and its variability.

Our baseline simulation is the 20-year time-slice experiment for conditions equivalent to the year 2000, designed in the framework of CCMVal-2. Four other simulations have been completed: (1) no coupling, ECMWF operational analyses forcing the CTM; (2) no coupling, the GCM ARPEGE-Climat forcing the CTM; (3) coupling of ozone, as in the baseline simulation, but with a higher horizontal resolution of the chemical fields; and (4) coupling of both ozone and water wapor.

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation: poster

A global inventory of stratospheric NOy from ACE-FTS measurements

Qin, G; Strong, K.; Toohey, M.; Kerzenmacher, T.; Walker, K. A.; Bernath, P. F.; Boone, C. D.; McLinden, C. A.

The total odd nitrogen (NOy) budget in the stratosphere and lower mesosphere has been determined using the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) measurements of NO, NO2, N2O5, HNO3, ClONO2, and HNO4. ACE-FTS has been measuring these six major NOy species from orbit since February 2004 using infrared solar occultation. A global NOy climatology of monthly mean volume mixing ratio profiles and their standard deviations as a function of latitude has been constructed using the first four years of ACE-FTS data. The effect of diurnal variation was minimized by grouping the measurements into those taken at local sunset and at local sunrise. Additional annual zonal means of NOy and its partitioning have been generated for five latitude bands (60-90N, 30-60N, 30S-30N, 30-60S, and 60-90S) for each year of data.

The resulting annual inventories of NOy show differences that can be attributed to solar activity, descent, and denitrification. Seasonal variations have also been assessed, taking into account the spatial and temporal sampling of the ACE occultation geometry. This ACE-FTS NOy data set will be useful for model validation and atmospheric studies.

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation:

Upper stratospheric ozone temperature correlations; impact of changing chlorine

Stolarski, Richard; Strahan, Susan; Douglass, Anne R.; plus representatives from models submitted to BADC

The seasonal cycle of upper stratospheric ozone is driven by the seasonal cycle in the temperature. High (low) temperatures result in high (low) ozone loss rates due to the catalytic cycles of Cly, Bry, NOy, HOx, and Ox. The temperature dependence of Cly reactions is smaller than the overall temperature dependence so that addition of chlorine results in a weaker dependence of ozone on temperature. The REF1 and REF2 scenarios thus show a time dependence of the slope of the ozone-temperature relationship that minimizes in about the year 2000 and then begins to recover. We show the results from the models submitted to the CCMVal data base and compare them to values derived from several satellite instruments (LIMS on Nimbus 7; MLS on UARS; and MLS on Aura).

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation: oral

CCMVal Model Evaluation of Heterogeneous Processes in the Polar Lower Stratosphere

Tilmes, Simone; R.Mueller, J. Austin, H. Akiyoshi, Y. Yamashita, D. Plummer, M. Hegglin, M. Dameris, V. Eyring, S. Pawson, R. Stolarski, S. Bekki, C. Bruehl, M. Giorgetta, E. Manzini, K. Shibata, M. Deushi, E. Rozanov, E. Mancini, G. Pitari, N. Butchart, M. Chipperfield, S. Dhomse,W. Tian, R Garcia, D. Kinnison.

The relationship between chemical ozone loss and the potential for activated chlorine (PACl) is proposed as a diagnostic to quantify heterogeneous processes in the lower stratosphere (Tilmes et al., 2007). To identify differences in this diagnostic between results derived from Chemistry Climate Models (CCMs) and observations, simulated polar vortex temperatures and the vortex volume need to be investigated. In addition, the evolution of different species (e.g., ClOx, BrOx) during the ozone loss season in the Arctic and Antarctic gives further insight in possible shortcomings of the models. Here, we present a comparison of the described diagnostics derived from the available CCMVal-2 REF-B1 model output. Chemical ozone depletion will be derived using tracer-tracer correlations and, if available, passive ozone data. Model results are compared to results from HALOE satellite observations and UK Met Office analysis between 1960-2006. The accuracy of simulated chemical ozone depletion was shown to be strongly dependent on the precise simulation of the dynamics of the polar vortex. Earlier WACCM model results have shown a good agreement for Antarctica between 1960-2003, however discrepancies in the Arctic polar vortex, because of a too small and too warm polar vortex.

Tilmes, S., E. D. Kinnisen, R. R. Garcia, R. Mueller, B. A. Boville, F. Sassi, and D. R. Marsh, Evaluation of heterogeneous processes in the polar lower stratosphere in WACCM3, J. Geophys. Res., 112 , 2007.

Chapter 6: Stratospheric Chemistry & Microphysics
Preferred Presentation: poster

Halogen emissions of major volcanic eruptions: a new approach using the petrologic method and CCMs

Toohey, Matthew; Hansteen, Thor, Kutterolf, Steffen, Niemeier, Ulrike, Timmreck, Claudia, Krueger, Kirstin

Volcanic eruptions play a significant role on the global climate of the Earth system and led to significant ozone loss in mid-latitudes observed after the El Chichon and Mt. Pinatubo eruptions. Major volcanic eruptions, which directly inject gases, aerosols and volcanic ash into the stratosphere, have a strong and long lasting impact on the global climate and atmospheric tracer concentration depending on their geographical latitude and their SO2 and halogen (Cl, Br, I) release.

We will use a CCM including aerosol microphysics, along with new experimental data, to study the potential impact of halogen emissions from large volcanic eruptions on the stratospheric ozone layer. Halogen emissions for each eruption are estimated from volcanic material through the petrologic method, using the concentration differences between glass inclusions and matrix glasses. Reliable estimates of heavy halogen emissions are only possible using SYXRF microprobe for the glass inclusions followed by pyrohydrolysis and ICP-MS analysis for matrix glasses. First results from melt inclusions and degassed matrix glasses of Nicaraguan volcanics show tens of ppm bromine as well as several ppm iodine.

This poster will introduce the strategy how to implement the volcanically released volatile fluxes into the CCM experiments. For the planned simulations special emphasis will be placed on the global role of volcanically released halogen species on atmospheric chemistry and the possibility of a volcanically induced pre-industrial ozone hole. Different halogen and sulphur scenarios will be simulated, investigating their effect on past and present day climate, but also to assess their possible effect in a future climate scenario.

Chapter 7: UTLS
Preferred Presentation: oral

Transport characteristics in the UTLS in models and observations

Hoor, Peter; Austin, J.; Akiyoshi, H.; Baumgärtner, A.; Bekki, S; Bodeker,G.; Braesicke, P.; Brühl, C.; Butchart, N.; Chipperfield, M.; Dameris, D.; Deushi, M.; Eyring, V.; Gettelman, A. ; Giorgetta, M.; Hegglin, M.I. ; Kinnison, D. ; Lamarque, J.-F.; Mancini, E.; Michou, M. ; Nagashima, T. ; Pawson, S.; Pitari, G.; Plummer, D.;Rozanov, E.; Shibata, K.; Stolarski, R.

The mapping of chemical tracer on potential temperature levels relative to the dynamical tropopause (Delta Theta) as decribed in Hoor et al.(2004) allows to differentiate between different transport regimes in the extratropical lowermost stratosphere. The vertical gradient of CO and the CO2 seasonal cycle on different DeltaTheta levels allows to distinguish between transport across the local tropopause on short time scales and transport from the (sub-)tropics

on longer time scales (Hoor et al., 2005).

We evaluated instantaneous and monthly mean output from simulations as decribed in Strahan et al.(2007) (see also Hoor, 2007: http://www.pa.op.dlr.de/CCMVal/EvaluationTable/HOOR CCMVAL07.pdf). We focussed on the REF-B1 simulations of CO, ozone and CO2 and investigated their relation relative to the dynamical tropopause.

The shape and broadness of the probability density functions of CO on

DeltaTheta-levels show large intermodel variations. The chemical distinctness of the DeltaTheta levels is rather different between the models. Whereas most models simulate a rather smooth transition from the extratropical tropopause to the stratosphere above Theta = 380K, some models are able to differentiate between transport across the local tropopause and transport from the (sub-)tropics. These models show a clear separation between both regimes within the UTLS. This indicates that the proper representation of transport timescales and

pathways and the UTLS is possible on global scales with state of the art CCM's.

Chapter 7: UTLS
Preferred Presentation: oral

Water vapour transport in the tropical tropopause region in Coupled Chemistry-Climate Models

and ERA-40 reanalysis data

Kremser, Stefanie; Wohltmann, Ingo; Rex, Markus; Stenke, Andrea; Dameris, Martin; Hegglin, Michaela; Langematz, Ulrike

The interaction of horizontal and vertical transport in the tropical tropopause layer (TTL) determines the distribution of points where individual air masses encounter their minimum temperature and thus minimum water vapour mixing ratio (referred to as dehydration points) during their ascent through the TTL into the stratosphere. The geographical distribution of these dehydration points and the local conditions there determine the overall water vapour flux from the TTL into the stratosphere.

Lagrangian trajectory-based studies are established tools for studying transport processes in the tropical tropopause region and in particular the transport from the troposphere to the stratosphere. In this study we therefore use Lagrangian trajectories to evaluate how realistic the water vapour transport from the TTL into the stratosphere is represented in coupled Chemistry-Climate Models (CCMs). Representing those mechanisms well in a model is crucial for a correct representation of potential long-term changes of water vapour transport into the stratosphere due to climate change.

This work provides a framework for the evaluation of key transport processes in the tropical tropopause region in CCMs. Results from two different CCMVal-2 models will be presented.

Chapter 7: UTLS
Preferred Presentation: poster

Diagnostic tools for evaluating the quasi-horizontal transport process in the upper troposphere and lower stratosphere

Lee, Huikyo; Wuebbles, Donald J.

Planetary waves in the upper troposphere may play an important role in the stratosphere-troposphere exchange, and the exchange along the waves can be a key process for evaluating the effect of aircraft emissions at cruise altitude. We have found observational evidences of this cross-tropopause exchange from satellite data. Based on the observation, effective methods for testing capabilities of models were developed and applied to chemistry climate models. We adopted the thermal tropopause-relative altitude system as a vertical coordinate which gives finer vertical resolution to satellite data in the UT/LS region. As effective methods for diagnosing this transport process in chemistry climate models, we examined probability density functions in chemical tracer profiles in the upper troposphere and lower stratosphere region and compared the results with MLS satellite WOUDC ozonesonde observations. Using the broad coverage of satellite data, seasonal variation and latitudinal characteristics of chemicals near the tropopause were derived. To minimize the difference between the model meteorological fields and the real atmosphere, we classified data by the tropopause height. To verify the origin of an air parcel, we utilized two different tracer-tracer correlation maps. Also through a case study, we found favorable synoptic conditions for air mass exchange between the tropics and mid-latitudes, and calculated the cross-tropopause flux and trajectories of chemical tracers. Dependence of tracer concentrations on tropopause heights in the UTLS was used as an effective tool to test impacts of the transport of tropical air parcel on the distributions of chemicals on isobaric surfaces.

Chapter 7: UTLS
Preferred Presentation: oral

Model Evaluation of Tracer Behavior in the Upper Troposphere Lower Stratosphere (UTLS)

Tilmes, Simone; L. Pan, J. Austin, H. Akiyoshi, Y. Yamashita, D. Plummer, M. Hegglin, M. Dameris, V. Eyring, S. Pawson, R. Stolarski, S. Bekki, C. Bruehl, M. Giorgetta, E. Manzini, K. Shibata, M. Deushi, E. Rozanov, E. Mancini, G. Pitari, N. Butchart, M. Chipperfield, S. Dhomse, W. Tian, R Garcia, D. Kinnison

The gradient of tracers across the tropopause, especially of ozone and water vapor, is an important component of chemistry-climate interaction. The representation of these tracers in Chemistry Climate Models (CCMs) is controlled by both the chemistry and transport schemes in the models. We use a novel aircraft based climatology to evaluate the behavior of simulated tracers (Ozone, CO and water vapor) in the Upper Troposphere Upper Stratosphere (UTLS) region (Tilmes et al., 2009). This

climatology, using measurements between 1995 and 2008, provides a statistical representation of three regimes, the Tropics, Sub-Tropics and Extra-Tropics/Polar, and four seasons. The three regimes are identified using the thermal tropopause height. Using a set of diagnostics, we examine how well the models represent the distinct characteristics for each regime and the seasonal variations shown in the aircraft observations. Tropopause referenced tracer profiles and tracer-tracer correlations from the available CCMVal-2 outputs will be presented. We also evaluate the sharpness of the chemical transition and the extent of mixing between troposphere and lowermost stratosphere. Earlier studies by Pan et al., 2007, have shown significant discrepancies of the chemical gradient across the TP between models and observations.

S. Tilmes, L. L. Pan, P. Hoor, G. W. Sachse, M. Loewenstein, J. Lopez, C. Webster, L. E. Cristensen, M. Proffitt, R.-S. Gao, G. S. Diskin, M. A. Avery, J. R. Podolske, R. L. Herman, N. Spelten, A. Weinheimer, T. Campus, E. J. Hintsa, E. M. Weinstock, J. Pittman, M. A. Zondlo, M. E. Paige, E. Atlas (2009) An Aircraft based Upper Troposphere Lower Stratosphere O3 , CO and H2O Climatology for the Northern Hemisphere, J. Geophys. Res., to be submitted

Pan, L. L., J. C. Wei, D. E. Kinnison, R. R. Garcia, D. J. Wuebbles, and G. P. Brasseur (2007), A set of diagnostics for evaluating chemistry-climate models in the extratropical tropopause region, J. Geophys. Res., 112 (D09316), doi:10.1029/2006JD007792.

Chapter 8: Natural variability
Preferred Presentation: poster

Northern winter stratospheric temperature and ozone responses to ENSO inferred from an ensemble of Chemistry Climate Models

Cagnazzo Chiara; Manzini Elisa

The connection between the El Niño Southern Oscillation (ENSO) and the Northern polar stratosphere has been established from observations and atmospheric modeling. Here a systematic inter-comparison of the sensitivity of the modeled stratosphere to ENSO in Chemistry Climate Models (CCMs) is reported. This work uses results from a number of the CCMs included in the 2006 ozone assessment. In the lower stratosphere,the multi-model mean reports a warming of the polar vortex during strong ENSO events in February-March, consistent with but smaller than the estimate from satellite observations and ERA40 reanalysis. This anomalous warming is associated with an anomalous dynamical increase of total ozone north of 70°N that is accompanied by coherent total ozone decrease in the Tropics, in agreement with that deduced from the NIWA total ozone database, implying an increased residual circulation in the multi-model mean behaviour, during ENSO. The spread in the model responses is partly due to the large internal stratospheric variability but it is shown that it crucially depends on the representation of the tropospheric ENSO teleconnection in the models.

Chapter 8: Natural variability
Preferred Presentation: oral

Ozone QBO signal in CCMVal-2 models

Calvo, Natalia; Pena-Ortiz, C., Gray, L., Manzini, E., Matthes, K., Randel, W., Lamarque, J.F., Akiyoshi, H., Scinocca, J., Michou, M., Bruehl, C., Frith, S., Slimane, B., Shibata, K., Rozanov, E., Mancini, E., Dhomse, S.

The signature of the Quasi Biennial Oscillation in stratospheric ozone has been analyzed in most of the model simulations part of CCMVal-2. The analysis shows that some of these modes do not reproduce a QBO in the zonal mean zonal winds and thus, no QBO-related ozone signature is observed. Most of the models that do represent the QBO, either by assimilating the zonal winds or by spontaneous occurrence, simulate adequately the QBO variability in the tropics. The temporal evolution of the ozone QBO and its downward propagation have been analyzed and compared to observations. The main mechanisms involved in the QBO-related ozone anomalies in both lower-middle stratosphere and upper stratosphere have been studied: changes in ozone related to changes in advection, upwelling, transport of ozone or its precursors and temperature.

Chapter 8: Natural variability
Preferred Presentation: poster

Quantifying the Influence of 11-year Solar Flux Variability Using 3D CTM (SLIMCAT)

Dhomse Sandip; Chipperfield Martyn

We use 3D CTM (Chemical Transport Model) SLIMCAT and CCM (Climate Chemistry Model) to quantify the influence of 11-year solar cycle on the long term ozone changes. Composite and regression analysis shows that SLIMCAT simulations forced with ERA40 (1979-2001) and operational analysis (2002-2006), reproduces general features of the solar response in ozone fields. In total ozone fields, model simulations show up to 8-10 DU solar response at higher latitudes and up to 4-6 DU solar response at lower latitudes, which is in agreement with the satellite data sets (e.g. TOMS/SBUV merged data).

In order to investigate the cause of differences between modeled and observed solar response in ozone fields (especially in 80s), we performed model simulations under various chemical (e.g. constant/transient aerosol loading and/or solar fluxes) and dynamical (e.g. constant/transient dynamics) conditions. We show that the inconsistencies in ERA40 dynamical fields due to changes in assimilated data sets lead to up to 4 DU changes in total ozone at higher latitudes, underlining that estimated solar response in earlier studies (in both chemical and dynamical fields) using ERA40 data must be treated carefully.

Chapter 8: Natural variability
Preferred Presentation: oral

Changes of the Brewer Dobson Circulation due to natural forcing

Krueger, Kirstin; Thomas, Manu, Giorgetta, Marco, Timmreck, Claudia

Monitoring and understanding the observed changes of the Brewer Dobson Circulation (BDC) is a major activity in CCMVal. To better distinguish anthropogenic versus natural forcing components of the BDC, coupled chemistry climate models are a helpful tool to better interpret them. Here in this study we want to concentrate on the period of the Mt. Pinatubo eruption as a natural forcing experiment in the present climate.

Major volcanic eruptions have a significant impact on stratospheric and tropospheric climate, chemical composition and the atmospheric circulation. As the last three major volcanic eruptions (1963 Mt. Agung, 1982 El Chichon and 1991 Mt. Pinatubo) occurred during strong El Nino events and different Quasi Biennial Oscillation (QBO) phases, no stratospheric observations are available since the 1950s demonstrating a “pure” volcanic signal without a simultaneous El Nino event.

Based on the atmospheric general circulation model (GCM) MAECHAM5 we want to investigate the changes of the BDC following major volcanic eruptions and other natural forcing components as the El Nino Southern Oscillation (ENSO) and the QBO. For this purpose a set of single GCM forcings will be used to distinguish the effects of volcanic aerosols from ENSO, QBO and the ozone forcing on the BDC during the time period of the Mt. Pinatubo eruption. Deficiencies of the different model simulations and agreements with observations will be used to derive a better understanding of the natural driving processes of the BDC changes, which will help to better understand volcanic forcing experminets with CCMs.

Chapter 8: Natural variability
Preferred Presentation: oral

How do chemistry-climate models capture the Indian summer Monsoon anticyclone?

Kunze, Markus; Braesicke, Peter; Langematz, Ulrike; Stiller, Gabriele and CCMVal1 Contributors

We assess the representation of the Indian summer Monsoon (ISM) circulation in some current chemistry-climate models (CCMs). The main assessment focuses on the anticyclone that forms in the upper troposphere and lower stratosphere and the related changes in water vapour and ozone during July and August for the recent past. We describe the synoptic structures and compare between CCMs and reanalysis models. Multiannual means and weak versus strong Monsoon cases as classified by the Monsoon-Hadley index (MHI) are discussed. We find that current chemistry-climate models capture the averaged synoptic

structure of the ISM anticyclone well as compared to ERA-40 and NCEP reanalyses data. The associated impact on water vapour and ozone in the upper troposphere and lower stratosphere as observed with MIPAS on ENVISAT is captured by most models to some degree. The similarities for the strong versus weak Monsoon cases are limited, but some features emerge in reanalyses data and more than one CCM, e.g. ozone increases at 380K eastwards of the ISM. With the available data base for this study future change of the ISM are hard to assess. Even though the used Monsoon activity index weakens slightly in a future climate as modelled with some CCMs, the area coverage of the ISM widens and some of the modelled water vapour increase seems to be contained in the anticyclone at 360K and sometimes above. We conclude that current CCMs capture the averaged large scale synoptic structure of the ISM well during July and August, but large differences for the interannual variability make assessments of likely future changes of the ISM highly uncertain.

Chapter 8: Natural variability
Preferred Presentation: oral

Overview of Chapter 8 – Natural Variability of Stratospheric Ozone

Manzini, Elisa; Matthes, Katja and the CCMVAl Report Chapter 8 Author Team

Ozone is known to vary in response to a number of natural variability factors, such as the seasonal cycle in solar irradiance, the 11-year solar irradiance and variations in transport associated with large-scale circulations (e.g., the QBO and annular modes) as well as small-scale motions (e.g., gravity waves). Ozone observations have demonstrated variations in ozone on a large number of spatial and temporal scales. To quantify the impact of anthropogenic perturbations of the ozone layer, it is necessary to understand and to quantify the underlying natural ozone variations. The goal of this Chapter is to evaluate how well the CCMs simulate natural stratospheric ozone variability based on current knowledge about links between natural forcing and ozone and especially with respect to their overall performance (done in part A).

We will show first results from observations and compare it to results from the REF-B1 simulations of the CCMs which includes the assessment of modeled ozone variations associated with the seasonal cycle, annular modes, the solar cycle, QBO, ENSO, and volcanos.

Chapter 8: Natural variability
Preferred Presentation: poster

The aerosol cloud of major volcanic eruptions: Sensitivity studies with respect to the geographical latitude

Niemeier, Ulrike; Giorgetta, Marco; Graf Hans. F. and Timmreck Claudia

Volcanic aerosols are an active component of the climate system and play multiple roles in physical and biogeochemical exchanges between the atmosphere, land, surface and ocean. The impact of sulfuric aerosols on atmospheric chemistry and climate after a volcanic eruption is comprehensively studied, but in CCMs mainly with prescribed aerosol distributions for the last three major tropical eruptions (Agung, El Chichon and Mt. Pinatubo). The climate impact of a volcanic eruption depends, however, strongly on the geographical location, as volcanos in the tropics have a global effect and high latitude volcanos show more regional to hemispheric effects.

To study the influence of volcanic aerosol on atmospheric dynamics and composition, dependent on the geographical latitude, interactive simulations of major volcanic eruptions are required. The interactive simulation of the formation, dispersal and temporal development of a large volcanic cloud is a challenging simulation task for every aerosol climate model. For our studies we use the middle atmosphere general circulation model MAECHAM5 including the global aerosol module HAM. HAM calculates the aerosol microphysics of sulfate and other species and their source and sink processes. The model setup has been validated for the Pinatubo eruption, showing good agreement with satellite data. Model studies have been performed for different major volcanic eruptions in the tropics and mid and high Northern latitudes. The impact of the volcanic cloud differs not only to different large scale transport conditions at the locations, also due to exchange between radiative heating processes and local wind systems. Therefore, also the strength of the volcano influences the transport and dispersion of the volcanic cloud. The discussion includes the evolution of the sulfate aerosol, the radiative forcing and changes in atmospheric transport and circulation.

Chapter 8: Natural variability
Preferred Presentation: oral

ENSO influence on zonal mean temperature and ozone in the tropical lower stratosphere

Randel, William; Calvo, Natalia and Garcia, Rolando R.

Analyses of the WACCM Ref1 simulations for 1960-2006 show that tropospheric ENSO events are linked to coherent variations of zonal mean temperature and ozone in the tropical lower stratosphere, tied to fluctuations in tropical upwelling. ENSO temperature variations in the lower stratosphere are out of phase with tropospheric variations, and stratospheric ozone and temperatures are in phase. These model results motivated revisiting observational data sets for both temperature and ozone, and the observational data reveal results very similar to the model. The stratospheric ENSO variability has been masked in the observational data to some degree by the volcanic eruptions of El Chichon (1982) and Pinatubo (1991), which both occurred during ENSO warm events.

Chapter 8: Natural variability
Preferred Presentation: oral

Assessing global atmospheric models using trace gas climatologies from the Odin satellite (2001-2009): Overview, quality, methodology.

Urban, J.; Brohede, S., Murtagh, D., Sanchez, C., Eriksson, P., McLinden, C., Jin, J., Semeniuk, K., McConnel, J., Jegou, F., Khosrawi, F., Lossow, S.

The Odin satellite, launched in February 2001, provides near-global fields of various atmospheric constituents with high vertical resolution in the region between the upper troposphere and the lower thermosphere, based on measurements of two co-aligned instruments, the Sub-Millimetre Radiometer (SMR) and the Optical Spectrograph and Infra-Red Imager System (OSIRIS). The global data sets for species such as O3, N2O, HNO3, NO2, H2O, CO, ClO, among others, span so far the period 2001-2009.

Trace gas climatologies have been derived from the Odin data and evaluated against other satellite data sets in order to allow efficient evaluation of the quality of global atmospheric models such as chemistry-climate models (CCM's) in terms of their representativeness with respect to atmospheric transport and chemistry. The Odin climatologies are in particular useful to assess whether global transport patterns in the middle atmosphere related to the Brewer-Dobson and global overturning circulation are realistically represented by the models using the information from longer-lived tracers such as CO (mesosphere), N2O (stratosphere), and H2O (tropical tape-recorder, high-latitude descent, mesosphere). The Odin climatologies also provide information on several chemically important stratospheric species such as O3, ClO, NO2, and HNO3, among others. Derived products which may be used to diagnose global atmospheric photochemical models include so far an Odin proxy NOy climatology which has been constructed by merging data from OSIRIS and SMR using a chemical box model as well as a climatology of monthly averaged N2O-O3 distributions (to assess ozone photo-chemistry vs transport).

The presentation will give an overview of the relevant Odin climatological data sets and provide examples of comparisons to state-of-the-art chemistry climate models such as the Canadian Middle Atmosphere Model (CMAM) and the Whole Atmosphere Climate Community Model (WACCM).

Chapter 9: Long-term projections of stratospheric ozone
Preferred Presentation: poster

Ozone and halogen recovery times in the future stratosphere calculated by the CCSR/NIES CCM under the CCMVal-REF2 scenario and a no-climate-change run

Akiyoshi Hideharu; Yamashita Yousuke, Sakamoto Kei, Zhou Libo, Imamura Takashi

Recovery times of ozone and halogen concentrations are examined using the outputs of the CCSR/NIES Chemistry-Climate Model (CCM). The CCM calculation for the future atmosphere was performed for the period 1975-2100 under the CCMVal-

REF2 scenario. A sensitivity test of a no-climate-change run for the future atmosphere is also performed, where the concentrations of CO2, CH4, and N2O are fixed to those for 1975 and the sea surface temperature is fixed to that for the 1970-1979 mean while the halogen concentrations are changed following the REF2 scenario. A comparison of the recovery times is made of these two runs. The recovery time of the total ozone in the no-climate-change run corresponds to that of Cly+60Bry at 50 hPa within 5 years in the Southern Hemisphere and tropics. In the Northern Hemisphere, however, the recovery time of the total ozone occurs quite differently more than 15 years earlier than that of Cly+60Bry at 50 hPa and a little differently from that of Cly at 50, 30, and 10 hPa. In the REF2 run, the recovery times of Cly and Cly+60Bry occur a little earlier than those in the no-climate-change run and the recovery time of the total ozone occurs much earlier than those of Cly+60Bry and Cly. These are consistent with the strengthening of the residual circulation and stratospheric cooling in the CCM for the future atmosphere, respectivly. The recovery times of ozone and Cly+60Bry mixing ratios are compared between the Northern Hemisphere and the Southern Hemisphere at a few specified pressure levels in the lower and middle stratosphere. The results at high latitudes are consistent with a hemispheric difference in the strength of annual-mean vertical velocity of the meridional circulation and the effectiveness of chlorine, bromine, and NOx catalytic ozone destruction cycles at these pressure levels.

Chapter 9: Long-term projections of stratospheric ozone
Preferred Presentation: oral

Improved simulations of the GFDL coupled chemistry climate model

Austin, John; Wilson, John

AMTRAC3 (Atmospheric Model 3 with TRansport And Chemistry) is presented and described. The model is an improved version of AMTRAC with an updated climate core, retuned gravity wave forcing and improved photolysis rates. The halogen parameterisation has also been retuned to reproduce chlorine observations more accurately. Results from the simulation of AMTRAC3 for the period 1951-2007 are compared with the previous simulations and with observations.

Overall, there is considerably smaller ozone bias, due to the increase in the photolysis rates of oxygen in the lower stratosphere. The model simulates lower chlorine amounts in the lower stratosphere, particularly in the low and middle latitudes, while in high latitudes the previous values are reproduced, in agreement with observations. Consequently, past ozone trends are a considerable improvement on the previous results and agree much better with observations. The ozone hole and its relationship with the extent of polar stratospheric clouds is also much improved in comparison with measurements, although the ozone hole remains slightly too small in area (10%) and too deep

(typical minimum 70DU). The influence of the gravity wave tuning has been to simulate improved polar stratospheric cloud areas, especially in the Arctic, where there were none in AMTRAC simulations. Due to improvements in the climate model convection scheme, water vapour amounts in AMTRAC3 are higher and much closer to observations, although the tropopause remains too cold. There has been one prominent regression: it is thought that due to the cubed sphere architecture, the age of air is reduced in AMTRAC3 simulations, and is now

significantly lower than observed.

Results are also briefly presented for a simulation forced with model SSTs for the period 1951-2100. The presentation will focus on polar ozone where the results are very similar to that obtained previously using AMTRAC.

Chapter 9: Long-term projections of stratospheric ozone
Preferred Presentation: oral

Mutli-model mean ozone time series in support of CMIP5 simulations

Cionni Irene; Bodeker Greg, Hassler Birgit, Eyring Veronika, Shepherd Ted, Waugh Darryn

SPARC is producing a new consensus observational stratospheric ozone database covering the 1979-2006 period, for CMIP5. This database will be provided together with regression coefficients for EESC and various known natural forcings (volcanic aerosol, solar, ENSO, QBO). The EESC regression coefficients will be used to extrapolate that data back in time, and form an ozone time series backward to cover the entire time period 1850-2006 (SPARC Newsletter 32, Report on SPARC Ozone Database Workshop, Bodeker et al., 2009). While a similar procedure could be used to extrapolate into the future, coupled chemistry climate model (CCM) simulations (Eyring et al., 2007) indicate that future stratospheric ozone abundance is likely to be significantly affected by climate change, and it is not yet possible to estimate this contribution statistically from observations. Therefore, the SPARC CCMVal activity is proposing to provide a dataset for CMIP5 that extends the Tier 1 observational database (SPARC Newsletter 32, Report on SPARC Ozone Database Workshop, Bodeker et al., 2009) into the future based on CCM simulations that include the effects of climate change as well as EESC changes. We propose to construct a reference time series based on CCM simulations for 1979-2100 using exactly the same methodology as for the consensus observational data base; namely using a regression model to isolate the long-term changes, to produce an analogue to the Tier 1 database which would be based on the model simulations but scaled to be consistent with the consensus observational database during the overlap period (1979 2006). The regression model will then allow this data set to be projected out from 2100 to 2150. The above CCM-based time series can then be combined with the observationally-based time series to form a database that will cover the entire time period 1850-2150. The CCM-based time series will be made available through the SPARC Data Center, and would provide stratospheric ozone boundary conditions suitable for long-term global climate model simulations such as the mandatory CMIP5 experiments 1.2 and 2.1-2.4.

Chapter 9: Long-term projections of stratospheric ozone
Preferred Presentation: oral

The effect of climate change on ozone recovery

Hardiman, Steven; Butchart, N, Collins, W, Morgenstern, O, Pyle, J, and Braesicke, P

Results from the CCMVal REF2 simulation carried out using the MetUM coupled to the stratospheric chemistry component of the new UKCA composition model are presented. The results are compared to those from a 'No Climate Change' (NCC) simulation, identical to REF2 except for using constant 2000 CO2 emissions and periodic SSTs and sea ice.

It is found that climate change speeds up ozone recovery by at least 10 years at all latitudes, and by considerably more in the Southern Hemisphere extratropics. A global super recovery in ozone concentrations is observed in REF2, dominated by enhanced ozone at the poles as compared with NCC.

A decreasing stratospheric temperature, leading to decreased rates of homogeneous ozone destruction, and an increased Brewer Dobson Circulation, leading to greater transport of ozone to the extratropics, are the main reasons for this increased rate of ozone recovery.

Age of stratospheric air decreases throughout the 21st century in both integrations, by about 0.25 years/decade in REF2 and about half that rate in NCC. Stratospheric temperatures are seen to decrease in REF2 at around 1.2 K/decade during the period of ozone depletion, and at around half that rate during the period of ozone recovery. It is therefore suggested that ozone concentrations play a role through feedbacks on stratospheric circulation and climate change. The implications of these feedbacks will be considered and are the subject of ongoing work.

Chapter 9: Long-term projections of stratospheric ozone
Preferred Presentation: oral

Objective assessment of ozone in chemistry-climate model simulations

Karpechko, Alexey; Gillett, Nathan, Hassler, Birgit and Rosenlof, Karen

Changes in stratospheric ozone have significantly influenced the tropospheric circulation and climate of the Southern Hemisphere (SH) over recent decades and will continue to influence climate during the 21st century when ozone recovery is expected. Therefore, in order to obtain reliable projections of SH climate, it is important to have reliable estimates of future ozone changes. Chemistry-climate models (CCMs) which include interactions between stratospheric ozone chemistry and greenhouse-gas-induced climate change are the most appropriate tool to obtain future ozone estimates. However projections of ozone recovery differ between models even when the same GHG emissions scenario is assumed. In order to choose those models with the most reliable simulations of future ozone, we compare simulations of 20th century ozone by the same models to available observations and quantify agreement between models and observations, making the assumption that correct simulation of past ozone gives more confidence in future projections. The focus of this study is on SH climate and hence we consider the ability of CCMs participating in the CCMVal project to simulate the global distribution of total ozone and the vertical distribution of ozone over the Antarctic as well as changes in these diagnostics over the last two decades of the 20th century. According to our analysis no one model performs better than the others in all the diagnostics; however, combining errors in individual diagnostics into one metric of model performance allows us to objectively rank the models. The multi-model average shows better overall agreement with the observations than any individual model, although it does not perform better in all the diagnostics. Our approach also allows us to explicitly evaluate improvements in ozone simulations between CCMVal 1 and CCMVal 2 models. Results of this comparative study are presented.

Chapter 9: Long-term projections of stratospheric ozone
Preferred Presentation:

Pre-1980 Antarctic ozone depletion evaluated in chemistry-climate models

Langematz Ulrike; Huck Petra, Bodeker Greg, Shepherd Ted

A regression model describing ozone depletion over Antarctica (63S to 90S) as a function of Cly, Bry and South Pole temperature anomalies has been applied to REF1 simulations from a number of chemistry-climate models (CCMs). The regression model accounts for linear and quadratic dependence of ozone depletion on equivalent effective stratospheric chlorine (Cly + 60*Bry) and explains much of the variability in Antarctic ozone depletion seen in the CCMs (R^2 typically larger than 0.9). By evaluating the regression model using only the terms related to Cly and Bry, the contribution of halogen loading alone to ozone depletion can be quantified. This has been done for the period 1960-1980 to evaluate what fraction of the maximum ozone depletion that had occurred by the late 1990s had taken place during this 20 year period. The same regression model was applied to an observational data set (1960-2005) constructed from combined satellite and ground-based total column ozone observations. The consistency of the CCM simulations of 1960-1980 Antarctic ozone depletion with each other, and against the observational database, is explored. Understanding how much ozone depletion occurred over Antarctic before 1980 is necessary for understanding projections of the recovery of the ozone hole.

Chapter 9: Long-term projections of stratospheric ozone
Preferred Presentation: oral

Quantifying mechanisms and feedbacks to changes in upper stratospheric ozone using multiple linear regression

Oman, Luke; Waugh, Darryn; Lang, Chang; Kawa, Randy; Stolarski, Rich; Douglass, Anne; Newman, Paul

The contributions of different mechanisms to changes in upper stratospheric ozone are quantified using multiple linear regression (MLR) analysis applied to CCM output. We focus first on Goddard Earth Observing System Chemistry-Climate Model (GEOS CCM) simulations using either A1b or A2 greenhouse gas (GHG) scenarios. In these scenarios extra-polar ozone has a very similar secular increase over the 21st century even though there are significant differences in the GHG concentrations. For the simulation using the A1b GHG scenario, this increase is determined by the decrease in halogen amounts and the greenhouse gas induced cooling, with roughly equal contributions from each mechanism. There is a larger cooling in the simulation using the A2 GHG scenario, but also enhanced loss from higher NOy and HOx concentrations, which nearly offset the increase due to cooler temperatures. As a result the ozone trends are similar in the A2 and A1b simulations. The response of ozone due to feedbacks from temperature and HOx changes, related to changing halogen concentrations, are also quantified using simulations with fixed halogen concentrations. The analysis is repeated for A1b simulations from other CCMVal models to evaluate the response across a suite of CCMs and to understand differences in ozone projections.

Chapter 9: Long-term projections of stratospheric ozone
Preferred Presentation: poster

Untangling the effects of chemistry and climate change on the projected evolution of stratospheric ozone

Plummer, David; Scinocca, John; Reader, Cathy; Beagley, Stephen; Shepherd, Ted

The decreasing trend in stratospheric chlorine loading projected to occur over the rest of the 21st Century will take place concurrently with a changing physical climate driven by increases in greenhouse gases. As a result, future changes in stratospheric ozone will not result purely from decreasing halogen concentrations but will also reflect, notably, projected changes

in the Brewer-Dobson circulation and CO2-driven cooling in the upper stratosphere. Here, REF-2 simulations from the Canadian Middle Atmosphere Model (CMAM) for CCMVal-1 and CCMVal-2 are analyzed and linear regression is used to quantitatively separate out the effects of different influences on different regions of the stratosphere and their contribution to changes in the total ozone column. The contribution of different effects derived from regression analysis of the REF2 simulations can then be compared with the evolution of ozone in the CMAM SCN-B2b and SCN-B2c simulations, where the halogen loading and GHG-forcing were, respectively, held constant at 1960 levels.

Chapter 9: Long-term projections of stratospheric ozone
Preferred Presentation: poster

Ozone recovery and super-recovery in 21st century

Rozanov, E.; Brönnimann, S.; Egorova, T.; Fischer, A.; Kenzelmann, P.; Peter, T.; Schmutz, W.; Schraner, M.; Smale, D.; Stenke, A.; Zubov, V.

We analyze the results of the 120-year long transient ensemble run simulation with the CCM SOCOL ver. 2.0 spanning years 1960-2080, driven by the time evolving SST/SI, GHG, ODS, sources of CO and NOx, prescribed according to CCMVal-2 REF-B2 scenario. The goals of our study are to characterize time and space features of the atmospheric ozone evolution during the 21st century and define the total ozone recovery time and the magnitude of the super-recovery. Recovery time is estimated from the comparison of monthly/annually and ensemble mean quantities averaged over consecutive 5-year long intervals. The recovery time is defined as the year after 2000 when the considered quantity reaches its value in 1976-1980 and does not drop below this value for the rest of the time series. If it does the recovery time is not defined. The future changes are defined as the difference between the considered quantities averaged over the years 2076-2080 and reference period (1976-1980). Super-recovery means increase of the ozone in the future above reference level. We demonstrated that the ozone recovery time is very inhomogeneous. It follows the recovery time of inorganic halogens (~2040) where they play a major role (middle-to-upper stratosphere, lower southern stratosphere). In the other regions stratospheric cooling and acceleration of the BD circulation caused by the greenhouse gases works more efficient providing faster ozone recovery (2010-2020). The greenhouse effect causes the ozone super-recovery in the end of 21st century, which consists of the total ozone increase in the middle-to-high latitudes of both hemispheres up to 20% and decrease of tropical ozone by ~4%. The geographical distribution of the total ozone changes reveals intensification of the dynamical total ozone build up, weaker polar vortices and more intensive downward transport of the stratospheric ozone to the regions of natural ozone maximums. Some contribution to the total ozone super-recovery can be caused by the increase of anthropogenic emissions of ozone precursors.

Chapter 9: Long-term projections of stratospheric ozone
Preferred Presentation: oral

Chapter 9 Overview: Long-term projections of stratospheric ozone

Scinocca, John; Stephenson, David Austin, John Plummer, David

This talk will summarize future projections of stratospheric ozone from the recent CCMVal-2 REFB2 experiments. The analysis employs a General Additive Model (GAM) to define smooth multi-model trends in ozone and chlorine over the period 1960-2100. One of the primary advantages of the GAM approach is that it can fit a smooth trend to a multi-model ensemble data set in which the ensemble number and period of each model varies. The GAM is applied to the the full data (e.g. no pre-smoothing by arbitrary filters) to produce a smooth trend for the multi-model average and individual smooth trends for each model. The GAM provides both confidence and "prediction" intervals for these trends.

The GAM analysis is applied to the REF2 experiments from both the current CCMVal-2 and previous CCMVal-1 intercomparison projects. In this way we are able to quantitatively compare changes in the tropical, mid-latitude and polar ozone projections produced from each of these projects and, where possible associate these changes with improvements in the chemistry climate models. The GAM also facilitates a comparison of the CCMVal-1 and CCMVal-2 predictions for ozone and chlorine recovery and these will also be discussed.

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