Draft Outline for the SPARC CCMVal Report on Evaluation of Chemistry-Climate Models

N.B. This outline has been prepared by the Steering Committee and the Lead Authors with some input from the SPARC SSG.

Steering Committee: **Veronika Eyring, Ted Shepherd & Darryn Waugh**

Chemistry climate models (CCMs) representing the stratospheric ozone layer are key tools for the detection, attribution and, especially, prediction of the response of stratospheric ozone to ozone-depleting substances and other factors (climate change, solar variability, volcanic eruptions, natural variability). It is therefore necessary to quantitatively assess the confidence that can be placed in the CCMs. The present report responds to this need by providing a comprehensive, up-to-date assessment of the ability of CCMs to represent the stratospheric ozone layer, stratospheric climate and climate variability, and the coupled ozone-climate response to natural and anthropogenic forcings. The assessment will be based on the diagnostic metrics developed within the SPARC CCMVal project (see http://www.pa.op.dlr.de/CCMVal/CCMVal_EvaluationTable.html), and will be completed in time to provide useful and timely information for the expected 2010 WMO/UNEP Ozone Assessment, as well as for the expected IPCC AR5. Publication of the material included in the SPARC report in the open literature is encouraged. As SPARC reports are peer-reviewed documents the only requirement is that associated publications need to be submitted before the SPARC report is published. Compared to the individual publications the SPARC report will allow the inclusion of a lot more detail and provide a coherent, integrated assessment of the CCMs based on the CCMVal concept. The report will consider all available runs (i.e. REF1/REF2/SCN2 runs for the 2006 WMO/UNEP Ozone Assessment, new assessment runs, and any other runs as appropriate).

Synthesis Chapter

(Lead Authors: Veronika Eyring, Ted Shepherd, Darryn Waugh)

The executive summary will be divided into overall key findings, key findings per chapter, and key findings for each of the participating models. The ***key findings per chapter*** *in Part A will be based on the models' ability to simulate core processes structured around five major topics (radiation, dynamics, transport, stratospheric chemistry & microphysics, and UTLS). The* ***overall key findings*** *will include a synthesis of the results presented in the five topics to provide a coherent assessment of the current generation of CCMs based on the CCMVal concept. It will also include a summary of the results presented in Part B. The processes that contribute most to uncertainty in current coupled chemistry-climate modeling will be defined and future challenges for model developments summarized. The* ***key findings per model*** *will summarize the performance of each of the participating models relative to the thresholds identified in the individual chapters.*

1 Introduction

Chapter 1 will provide a contextual background to CCMVal and the role of CCMs in previous assessments, and describe the purpose of the report. This will include a very brief discussion of the coupling between stratospheric ozone and climate and the key science questions that are involved. The chapter will also motivate and provide a road map to the structure of the report.

2 Chemistry climate models and scenarios

(Lead Authors: Marco Giorgetta and Kiyotaka Shibata)

Chapter 2 will describe the basic ingredients in CCMs, in terms of theoretical fundamentals, and their key approximations and uncertainties. This discussion will need to address the question of what is required of a CCM, in terms of its basic set-up, in order to be considered for the science topics addressed by this assessment — a topic to be resolved at the 2007 CCMVal Workshop in Leeds. Chapter 2 will also provide a detailed model documentation of the participating CCMs, which can be based on a questionnaire to be sent to all participating CCM groups with detailed questions on, e.g., the underlying AGCM, the chemistry module, the transport scheme, and coupling interfaces. Some of this documentation information is already provided in Eyring et al. (2006, 2007), but will need to be extended and updated. Finally, Chapter 2 will describe the forcing scenarios used for the runs to be analyzed, and why they were chosen.

2.1 Chemistry-climate models

2.1.1 Introduction

The history of CCMs, the current definition of "CCM", the difference between CCMs and ESMs (CCMs simulate the atmospheric circulation and chemistry, but not the climate).

2.1.2 Theoretical fundamentals, key approximations and uncertainties

- Governing equations for circulation and chemistry in CCMs, with referencing to GCMs and CTMs, scale analysis, implied assumptions
- Discretization techniques for dynamics (space, time) and chemistry (families, time)
- Conservation properties (total mass, tracer mass, energy, …)
- Resolution of dynamics, transport, physics, chemistry
- Accuracy and limitation of parameterizations and CCMs themselves
- Persistent problems in chemistry climate modeling (temperature biases, no QBO, diffusive tracer fluxes across tropopause, mass fixers, gravity waves: sources and drag, …)

2.1.3 Initialization and boundary conditions for dynamics and chemistry

- Methodology: state or flux, e.g. chemical abundances or fluxes at surface
- Data sets: uncertainties, implied assumptions
- Model spin-up: time scales

2.1.4 The model documentation questionnaire (MDQ)

- Concept and general structure
- Full MDQ shown in Appendix 2.1

2.1.5 Summary on characteristics of participating CCMs

- Categorizing (or grouping) all the processes and/or parameterizations used in participating CCMs according to the answers to the MDQ
- Model families, resolution, vertical extension, …

2.1.6 Expected future developments of CCMs

- From CCMs to ESMs,

2.2 Scenarios and boundary conditions for CCMVal simulations

2.2.1 CCMVal simulations for WMO 2007 and their uncertainties

(Eyring et al., 2006, 2007)
- GHG scenarios
- ODS scenarios
- Volcanic forcing (radiative and chemical)
- SST/ice
- Solar 11-year cycle
- QBO

2.2.2 CCMVal simulations for the WMO/UNEP Ozone Assessment 2010

- GHG scenarios
- ODS scenarios
- Volcanic forcing (radiative and chemical)
- SST/ice
- Solar 11-year cycle
- QBO

2.3 Appendix Chapter 2

2.3.1 Model Documentation Questionnaire

(To be re-drafted, based on SCOUT-O3 MDQ)

Atmospheric processes
Dynamics
Resolved dynamics
- Spectral transform method
- Finite difference method
- Other methods (finite volume, spectral element, …)
- Turbulence closure

Physical processes
- Radiation

- Cloud microphysics
- Convection
- Turbulent vertical mixing
- Orographic gravity wave drag
- Non-orographic gravity wave drag
- Non-physical internal momentum sources and sinks

Transport

- Advection
- Turbulent (PBL, free atm.)
- Convective

Chemistry, gaseous and particulate

- Photodissociation
- Homogeneous reactions
- Heterogeneous reactions
- Emission
- Deposition
- Mixing
- Aerosols

Coupling of dynamics, transport and chemistry

Land processes

- Surface properties
- Hydrology
- Heat storage

Resolution

Initialization

Boundary conditions

- Lower BCs
- Upper BCs

References

2.3.2 CCM documentation

2.3.2.1 CCM 1
2.3.2.2 CCM 2
2.3.2.3 …
2.3.2.4 n CCM n

Part A

The chapters in Part A will evaluate how well the CCMs do according to the CCMVal diagnostics tables, under present-day conditions. Each process is associated with one or more model diagnostics and with relevant datasets that can be used for model evaluation. This approach provides a coherent framework for the evaluation of CCMs and will be used as a basis for the assessment of long-term changes in Part B. Motivated by Chapter 2, the processes that contribute most to uncertainty in each of the chapters will be defined. The chapters in Part A should include all diagnostics of the CCMVal evaluation table, with the exception of those considered under Chapter 8, as well as any additional diagnostics the authors might wish to include. As there is no separate list of UTLS diagnostics in the diagnostic tables, the UTLS chapter will draw on the relevant diagnostics from the other tables. For the REF1 and REF2 runs performed for the 2006 Ozone Assessment, some, but not all, of these diagnostics have already been produced and assessed in Eyring et al. (2006). In addition the chapters in Part A will include long-term changes of the key processes in the past and future (e.g changes in Brewer-Dobson circulation, PSC frequency, mean age of air, transport barriers, sudden warmings, water vapor budget in the UTLS, etc.).

3 Radiation (Lead Authors: Victor Fomichev and Piers Forster)

3.1 Introduction

Role of radiative processes in establishing the Earth's climate and in driving climate changes; main components of the radiative energy budget; radiative-equilibrium temperature; what are NLTE and LTE, line-by-line approach and parameterizations.

Cross reference - section 6.4 photolysis
Could move sections 3.4-3.5 to section 9.7. Forster is main contact either way

3.2 Radiation scheme design in CCMval models

spectral resolution, band choices, non-LTE. Table of what each model has - based on modified Q. Fu questionnaire on Forster's home page

3.3 Radiation schemes versus line-by-line calculations

Forster results

Comparison of heating rates, fluxes and FDH temperature changes for a variety of zonally averaged January profiles

Sensitivity to perturbations in radiativly active gases
Perturbing CO_2, CH_4, N_2O, CFCs, Ozone and water vapour

3.4 Radiative forcing of long-term changes

Role of different absorption bands. Likely based on review of IPCC report and output of 3.4

Forster and John Austin study based on existing archive of CCMVal output
(zonal timeseries of ozone, temp, water vapour, GHG fields)
Could update to latest planned runs with staff commitment!

Could move sections 3.4-3.5 to section 9.7. Forster is main contact either way

Radiative Forcings also go into Chapter 10!

3.5 Changes in the radiative energy budget

(occurring due to long-term changes) – based on output of 3.4

3.6 NLTE effects in the middle atmosphere

Importance of NLTE, height regions where NLTE effects start to occur for different absorption bands/gases.

3.7 Solar variability study

UV changes, requirements to spectral resolution
Focus on pure radiation issues
(Watch for overlap with Section 8.1, 8.4)

4 Dynamics (Lead Authors: Neal Butchart and Andrew Charlton)

The chapter will examine dynamical quantities and processes from the underpinning GCMs used in CCMVal. We will investigate the mean, variability and seasonal evolution of these processes. As well as evaluating against observations the chapter will examine how the underlying dynamical processes will change in a future climate. We might also consider to what extent the models exhibit decadal predictability.

4.1 Model Climatology

4.1.1 Zonal mean zonal wind and temperature climatology.

Basic diagnostics of zonal mean zonal winds and temperatures including their vertical structure and seasonal evolution. In addition this section will also include diagnostics of eddy behaviour including heat and momentum fluxes, E-P fluxes and stationary wave components.

4.2 Mean Meridional Circulation

All of the diagnostics in this section require monthly mean data only, which will be provided as standard.

4.2.1 Mean meridional streamfunction

4.2.2 Response of March temperatures to Jan/Feb winds

This will use the Newman et al. diagnostic (recipe available). The relationship between heatflux and temperature in other seasons will also be included.

4.2.3 Planetary wave vs gravity wave drag

These diagnostics should be available from the model and simple to plot. The orographic and non-orographic components will be seperated.

4.2.4 Downward control integral

This is a little more involved and would need a numerical recipe from the Haynes et al. paper.

4.3 Extra-Tropical Dynamics

The diagnostics in this section require data with daily output frequency.

4.3.1 Frequency and Dynamics of Major Stratospheric Sudden Warmings
This will use the Charlton and Polvani diagnostic in the table (recipe available)

4.3.2 Timing of Final Warmings/ Winter-Summer transition

A diagnostic scheme is needed for this section, perhaps based on the Waugh et al. 2001 paper. Examine and match trends in the reanalysis, particularly in the southern hemisphere. Additionally the summer to winter transition could be examined.

4.3.3 Area of polar stratospheric clouds
This would be based on a simple temperature threshold diagnostic. We would focus on 50hPa. If PV fields are available we could compare this diagnostic to the area of the vortex diagnosed from equivalent latitude PV gradients.

4.3.4 Hemispheric Ozone variability indices
This will use the Erbetseeder diagnostic in the table (recipe available). Daily total ozone fields are required.

4.3.5 Leading EOF and its persistence

This is also in the table and will link to chapter 10. It is at present unclear if this diagnostic will be placed here or in chapter 10.

4.4 Tropical Dynamics

The diagnostics in this section could be calculated with monthly mean data.

4.4.1 QBO

4.4.2 SAO

The diagnostics for this section are not firmly determined and would need some discussion. Focus on amplitude and phase of both the QBO and SAO but no explicit method for calculation has been determined.

4.4.3 Strength of tropical upwelling

This diagnostic should be linked to tape recorder and other diagnostics from the transport section. We will examine the mean mass-flux through several pressure surfaces in the tropical pipe region.

Data request priorities CCMVal Chapter 4: Dynamics
07/01/2008
Andrew Charlton-Perez and Neal Butchart
I have divided the diagnostics into three priority categories, essential to our analysis, desirable for our analysis and not needed. The basic analysis needed for our chapter could be done with only the essential fields, further and extended science questions could be answered with the desirable fields.

Essential
Section 1.1, Fields T2Ds or T2Is, 2D daily mean fields (lat, lon)
Section 1.1, Fields T2Dz or T2Iz, 2D daily zonal mean fields (lat, pressure)
Section 1.1, Fields T1Iz, daily mean values (note the second, simpler definition only)
Section 1.2, Fields T2Mz, 2D monthly zonal mean fields (lat, pressure) including TEM and gravity wave diagnostics.
Section 1.2, Fields T1Ms, 1D monthly mean fields (lat)

Desirable
Section 1.2, Fields T2Ms, 2D monthly mean fields (lat,lon)
Section 1.2, Fields T3M, 3D monthly mean data (lat, lon, pressure), Temperature and Geopotential only.

Not needed
Section 1.1, Fields T3D or T3I, 3D instantaneous fields (lat, lon, p)
Section 1.2, Fields T3M, 3D monthly mean data (lat, lon, pressure), U, V, W, H2O and Age of air.

5 Transport (Lead Authors: Jessica Neu and Susan Strahan)

5.1 Introduction

The distribution of long-lived trace gases in the stratospheric overworld is controlled mainly by the balance between the meridional 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 meridional circulation and that of the transport barriers are linked to wave activity in the stratosphere and thus vary with height and season.

In this chapter we will evaluate model representation of stratospheric transport processes using process-oriented diagnostics derived from observations. These diagnostics can provide insight into the strengths and weaknesses of model representation of transport and may also provide feedback for model improvements. One challenge presented by these diagnostics is that they all depend to some extent on the interplay between advective and diffusive processes (e.g. the propagation of the tropical "tape recorder" signal depends on vertical advection, exchange with the extratropics across the subtropical transport barrier, and vertical mixing).

The transport processes in the overworld provide the upper boundary condition for the extratropical UT/LS region. The tracer distributions in this region are a function mainly of rapid poleward transport of very young air to the extratropics and descent of old, photochemically aged air in midlatitudes. We will attempt to provide some diagnostics of the relative importance of these two processes as a link to the UT/LS chapter.

These transport diagnostics will be applied to simulations of present day and future scenarios. They will be used to evaluate any long-term changes in important stratospheric processes such as ascent, descent, and the strength of subtropical and polar transport barriers.

Figure 1. Diagram of stratospheric transport processes indicating regions where tests will be applied.

Note: Jessica and Susan assume overall responsibility for these analyses. Contributing authors have not been assigned tasks.

Summary

***Required* model outputs:**

1. **T2Mz:** 2D zonal monthly mean N_2O, CH_4, H_2O, age, CH3Cl, CH3Br, CFCl3 (F11), CF2Cl2 (F12), CH3CCl3 (methyl chloroform), and CHClF2 (HCFC-22).
2. **T3D or T3I:** Instantaneous or daily averaged CH_4 and N_2O, at least 3 days per month.
3. **T0As:** Year 2000 Global annual average loss rates above and below 100 hPa for N2O, CH4, CH3Cl, CH3Br, CFCl3 (F11), CF2Cl2 (F12), CH3CCl3 (methyl chloroform), and CHClF2 (HCFC-22).

We would strongly prefer to have all outputs (daily, monthly, etc) on a set of standard vertical levels so as to reduce the possibility of misusing a model's vertical coordinate. Output every third year will work fine for us.

5.2 Description of Diagnostics and Data Requirements

5.2.1 Ascent and isolation in the tropical lower stratosphere – the Tape Recorder

Air entering the stratosphere through the tropics slowly ascends with limited horizontal mixing. The observed 'H2O vapor tape recorder' signal has a change in amplitude with height that 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 the ascent rate. Grading may be based on models' ability to match the observed phase and amplitude at several heights between 18-26 km.

Fields T2Mz: 2D monthly zonal mean fields (CH4 and H2O)

5.2.2 Mean Age and Age Spectra at 20 km

Grading may be based on 1) tropical age, 2) polar ages, and/or 3) the tropical-extratropical age difference. Monthly mean age of air is preferred although CO_2 can be used.

Fields T2Mz: 2D monthly zonal mean Age tracer

5.2.3 Middle stratospheric tropical isolation

Tropical isolation in the middle stratosphere can be assessed using pdfs of N_2O at 10, 20, and 30 mb, from ~46S-10N and from 10S-~46N (similar to 'Test 3' in Douglass et al., 1999). The observations used are 3 years of AURA MLS N_2O (2004-2007). Bimodal pdfs from 10-30 mb in the southern hemisphere (and 20-30 mb in the northern hemisphere) indicate tropical isolation.

Fields T2Mz: 2D monthly zonal mean N_2O

5.2.4 Mean meridional circulation in the middle/upper stratosphere

Slope of summer subtropical tracer gradients - CH_4 or N_2O. Compare to HALOE CH_4, MLS N_2O. In the middle and upper stratosphere, the slope of the summer gradients should be largely controlled by the circulation (in the absence of strong wave-driving). This diagnostic is under development.

Fields T2Mz: 2D monthly zonal mean N_2O and CH_4

5.2.5 Polar transport/Vortex Isolation

This diagnostic uses 9 years of high latitude HALOE CH_4 profiles in late winter/early spring to examine the descent and the degree of isolation during descent in each hemisphere. Some key features in the Antarctic observations that will be used to develop a grading scheme include 1) near zero vertical gradient from 20 mb – 1 mb (isolated descent), and 2) clear separation (bimodal behavior) of mid and high latitude profiles between 5-70 mb. [This could augment and take the place of the HALOE CH_4 vortex isolation test in the CCMVal webpage.] Slightly different criteria would be necessary for the NH. This diagnostic requires instantaneous, not monthly averaged model output on pressure levels

Fields T3D or T3I: 3D instantaneous or daily averaged CH_4

5.2.6 Upper boundary for the UT/LS

Does the mid and high latitude lower stratosphere (downward branch of the Brewer-Dobson circulation) provide realistic input for the lowermost stratosphere? Use 3 years of MLS N2O data on the 100 mb surface. This is often considered the bottom of the overworld, so these data alone might be simple and appropriate. Examine the distribution (pdfs) of N2O mixing ratios in winter/spring (FMAM) and summer (JASO) from 50-80N (downward branch of the BD circulation). Grading might be based on the ratio of mean winter N2O at 100mb to the tropospheric value (e.g. 250/320), and of the mean summer N2O at 100 mb to the tropospheric value (e.g. 290/320), and on the summer pdf width being ~half of the winter pdf width.

Fields T3D or T3I: 3D instantaneous or daily averaged N_2O

5.2.7 Integrated circulation: Chemical Lifetimes

To calculate whole atmosphere lifetimes and separate the effects of having (or lacking) tropospheric losses, we require global, annually-averaged loss rates above 100 hPa and below 100 hPa (with units of #molecules/s) for the following species:

N2O, CH4, CH3Cl, CH3Br, CFCl3 (F11), CF2Cl2 (F12), CH3CCl3 (methyl chloroform), and CHClF2 (HCFC-22). 2D zonal mean monthly mean fields are also required for these species. Only 1 year of output is needed.

Fields T0As: Global annual average Loss Rates for Year 2000
Fields T2Mz: 2D monthly zonal mean chemical fields

6 Stratospheric Chemistry and Microphysics

(Lead Authors: Martyn Chipperfield and Doug Kinnison)

6.1 Introduction

Goals:

- Describe chemical formulism in CCMs. (Some of this has been discussed in earlier sections. The focus here will be to discuss how chemical formulisms affect model performance).
- Document performance of CCMs with respect to chemistry and microphysics (i.e., evaluate with observations).

6.2 Formulation of Chemical / Microphysical Schemes

6.2.1 Summarize components of chemical schemes
6.2.1.1 Numerical solution approaches
6.2.1.2 Chemical mechanisms
6.2.1.3 Photochemical data sources and uncertainties
6.2.1.4 Heterogeneous chemistry approaches (PSC, aerosol, cirrus?)

6.2.2 Discuss how formulation of chemistry will affect CCM performance

6.3 Evaluation of CCMs

Chapter 6 will first evaluate the chemistry schemes of the CCMs. For this the core model datasets are the 3D instantaneous fields (T3D / T3I) for the period 1990-2005 from the REF1 runs. This data will allow comparison with the most important recent observations and allow model-model comparisons under different aerosol and meteorological conditions. Chapter 6 will also evaluate the model chemistry over longer timescales and link into scientific studies which will exploit CCMVal output. For these studies 3D instantaneous output at a reduced frequency (every 3 years) or 2D monthly mean zonal mean output will be used.

6.3.1 Evaluation of CCM Fast Photochemistry

Analysis will be performed by: Ross Salawitch

Abstract: Evaluation of the calculation of radical species and the representation of the radical precursors in CCMs. Each CCM will be evaluated by comparing radical species in the O_x, HO_x, NO_x, ClO_x, and BrO_x families to results from a comprehensive photochemical box model, constrained by values of radical precursors specific to each CCM. The CCM results will also be compared to satellite, balloon, and aircraft measurements of radical species. The model to be used has been compared exhaustively to observed abundances of radicals and radical precursors (e.g., Salawitch *et al*., 1994a,b, 2002; Wennberg *et al*., 1994, 1998; Osterman *et al*., 1997, 1999; Sen *et al*., 1998, 1999; Jucks *et al*., 1998, 1999, Christensen *et al*., 2002; Kovalenko *et al*., 2007). This model will serve as means to quantify whether differences between the abundance of radicals found by various CCMs are due to details of the implementation of the chemical mechanism within specific models and/or are due to details of how the radical precursors are being calculated. This analysis approach has been previously applied to the evaluation of 2D and 3D models sponsored by the NASA Models and Measurements Intercomparison II (NASA/TM-1999-209554). The lead has ready access to several decades of observed radical and radical precursor data, which will enable incorporation of a wealth of observations into the evaluation process.

Model Output Request: 3D instantaneous profiles **(T3D / T3I)** for a simulation that uses *observed aerosol loading*, of p, T, aerosol surface area, solar zenith angle, J_{O2}, J_{Cl2O2}, H_2O, CH_4, CO, N_2O, CFC-11, CFC-12, total NO_y, total Cl_y, total Br_y, $O(^3P)$, $O(^1D)$, OH, HO_2, H_2O_2, all of species that constitute NO_y, all of species that constitute Cl_y, and all of the species that constitute Br_y, at all model latitudes and longitudes, three times per month at a specific time (0UT or as close as possible), for ***model year 1993*** (high aerosol loading) and ***model year 2000*** (near background aerosol loading). Output should be reported on the native latitude/longitude grid.

Frequency: three times per month (1st, 11th, 21st), for model year 1993 and for model year 2000, for one specific Universal Time (0UT, i.e. the same UT at all model grid points)

Spatial Density: Global profiles (from the surface to the highest level considered)

6.3.2 Evaluation of Reservoir and Long-Lived Chemistry.

Analysis will be performed by: Martyn Chipperfield *[C. Bruehl?]*

Abstract: Compare model climatology between models and with observations (e.g. satellite climatology from 1990, groundbased time series (NDACC) from e.g. 1980). Also, compare model v observations via e.g. tracer-tracer correlations using instantaneous fields. For example compare NOy v N_2O plots for information on model production of NOy. Climatologies will be based on 3D instantaneous fields (or in some cases 2D monthly mean fields T2Mz if 3D fields not available). The study will cover 1990-2005 at least (e.g. for time-varying species or analysis under different aerosol loading), but output from 1980 would allow for longer comparison of e.g. HCl, ClONO2 which increased during this period. Output from REF1 is sufficient (but REF2 results for same period could be used if REF1 not available).

Data needed: 3D instantaneous output **(T3D / T3I)** for 1990-2005 for N_2O, CH_4, $CFCl_3$, CF_2Cl_2, CH_3Cl, CH_3Br, (+ other source gases), NOy, HNO_3, N_2O_5, HO_2NO_2, $ClONO_2$, HCl, H_2O_2, CH_2O, CH_3OOH, CO.
For longer comparisons (e.g. HCl, ClONO2 trends) data from zonal mean monthly fields **(T2Mz)** will be used.

Frequency
REF1: 1990-2005, each year, every 10-days.
Can use REF2 if REF1 not available

6.3.3 Polar Chemistry

6.3.3.1 Denitrification and Dehydration

Analysis will be performed by: M. Chipperfield, *R. Mueller??*

Abstract. Analyse extent/duration of modelled denitrification and dehydration. Construct tracer-tracer plots of NOy v N_2O, total hydrogen ($2CH_4 + H_2O$)

Data needed: 3D instantaneous output **(T3D / T3I)** for T, PV, NOy, HNO_3, N_2O, H_2O, CH_4, H_2 (if applicable), and aerosol/PSC surface area densities.

Frequency
REF1: 1980-1989 every 3 years / 1990-2005 each year, every 10-days.
REF2: 1980-2100, every 3-years, every 10-days.
(One could argue that we only need periods which cover NH and SH winter/spring but that is most of the year anyway, so these fields should be saved globally all the time)

6.3.3.2 Chlorine Activation

Analysis will be performed by: *Cora Randall??*

Abstract. Analyse extent/duration of modelled chlorine activation as a function of temperature, PSC occurrence. Compare with observed climatologies (e.g. MLS ClO). Also, compare abundances of reactive bromine, especially BrO.

Data needed: 3D instantaneous output **(T3D / T3I)** for T, PV, All model chlorine species (Cl, ClO, Cl_2O_2, HOCl, HCl, $ClONO_2$, OClO, BrCl,..) and Cl-containing source gases. All model bromine species (Br, BrO, HOBr, HBr, $BrONO_2$...) and Br-containing source gases. Also aerosol/PSC surface area densities.

Frequency
REF1: 1980-1989 every 3 years / 1990-2005 each year, every 10-days.
REF2: 1980-2100, every 3-years, every 10-days.
(One could argue that we only need periods which cover NH and SH winter/spring but that is

most of the year anyway, so these fields should be saved globally all the time)

6.3.3.3 Evaluation of Chemical Ozone Loss in Polar Lower Stratosphere.

Analysis will be performed by: Simone Tilmes

Abstract: Chemical ozone loss is derived via the tracer-tracer correlation method (using N_2O and O_3). Each CCM will be evaluated by looking at the vortex temperature, sharpness of the vortex edge, and the potential of activated chlorine (PACl). Meteorological and chemical information about the polar vortex, temperature, vortex size, and activation time, and level of equivalent effective stratospheric chlorine are necessary to derive PACl. PV, equivalent latitude, and potential temperature will be derived from requested meteorological variables. Model chemical ozone loss versus PACl in both the Arctic and Antarctic will be compared with available satellite observations. This analysis approach has been previously applied to WACCM3 REF1 simulations (*Tilmes et al*., 112, D24301, doi:10.1029/2006JD008334, 2007). The consistency of chlorine activation across CCMs will also be evaluated by looking at ClOx and Cly abundances.

Data needed: 3D instantaneous output **(T3D / T3I)** for U, V, T, z (Geopot. Height), O_3, N_2O, H_2O, HNO_3, ClOx (all inorganic chlorine except HCl and $ClONO_2$), Cly (total inorganic chlorine). Also passive O3 for comparison of diagnosed loss.

Frequency
REF1: 1980-1989 every 3 years / 1990-2005, each year, every 10-days.
REF2: 1980-2100, every 3-years, every 10-days.

6.4 Summary

7 UTLS (Lead Authors: Andrew Gettelman and Michaela Hegglin)

Justification of daily data requests from the UTLS LAs:
From a perspective of the UT/LS, and thinking about using the runs for strat-trop coupling, the LAs of the UTLS chapter strongly advise that we keep all the tropospheric levels for all the species requested. For both the UTLS and strat-trop coupling we will want all available levels in the troposphere. A core of SPARC is to understand the role of the stratosphere in Climate, and this implies being able to look at the troposphere and its climate.

The data will get divided into one file per species, so people can only work with what they need, and the data volumes will not be significantly reduced by eliminating some levels in the troposphere. For the instantaneous data the point is to estimate the self consistency of the models and for the high latitude UT/LS (especially in the Antarctic) we will need levels close to the surface.

Instantaneous data is necessary to calculate the tropopause, stability and PV, tropical edge, and to examine tracer-tracer correlations for long and short lived species and the relationship to cloud fields.

If we start varying the vertical resolution for different species the LAs of the UTLS chapter see problems and complexities with (1) analysis/diagnostic codes and (2) code needed to produce the files by each modeling group.

Note that we do not ask for derived fields (tropopause, PV), but will ask diagnostic developers to do this themselves.

If for the instantaneous output, modelers still would like to eliminate some tropospheric levels, that's their choice. The data specification asks for "model levels". Groups need not supply ALL model levels, but some if they wish. This will make the models less suitable for certain diagnostics, and they may be then eliminated from these analyses. Therefore we strongly recommend that modelers submit ALL model levels for instantaneous output. We require that the levels be consistent across all 3D instantaneous species. Monthly mean output is sill requested on CCMVal standard pressure levels, which do include a complete description of the troposphere.

7.1 Executive Summary

7.2 Introduction

7.3 Description of observational data sets used for CCM validation

7.4 The tropical UTLS

7.4.1 Overview and description (background)

7.4.2 TTL Structure [Gettelman & Birner, 2007, Gettelman et al 2008]

7.4.2.1 General diagnostics TTL structure

- Tropopause height and temperature (C)
- Temperature profiles (C)
- Edge of the tropics (definition)
- Level of zero heating (C)
- Lapse rate min pressure
- Clouds: Top of convection, Cloud Fraction, Convection (C)

Analysis performed by: Gettelman, Son, Birner

Abstract: The structure of the TTL will be analyzed using monthly mean and daily mean data for temperature, ozone, heating rates, clouds and short-lived species. Stability and the subtropical jet will also be examined. Several different definitions of the edge of the tropics will be used involving the tropopause, heating rates and zonal wind. Water vapor in the TTL will be examined. The distribution of clouds and convection will be compared to newly available satellite data in the TTL to examine the vertical structure of cloud fraction. Instantaneous data is necessary to calculate the tropopause, stability and tropical edge, and to examine tracer-tracer correlations for long and short lived species and the relationship to cloud fields.

Data needed:

T3I (Daily Instant 3D) Temperature, Pressure, Surface Pressure, H2O, O3, CO, Cloud Fraction, zonal wind (U), HCl, Acetylene (C2H2), Ethane (C2H6), Methyl Chloride (CH3Cl)
T3M (Mon Mean 3D) Temperature, Pressure, Surface Pressure, H2O, O3, HCl, CO, Cloud Fraction, Zonal Wind (U) heating rates, Acetylene (C2H2), Ethane (C2H6), Methyl Chloride (CH3Cl)

7.4.2.2 Tropical Waves (Kelvin Waves)

Analysis performed by: Fujiwara

Abstract: The organization is one of the most important characteristics of tropical convection. Organized convection generates equatorial Kelvin and Rossby, which dissipate around the tropopause and thus greatly affect this region. These waves cause the zonal asymmetry of tropical tropopause temperature [Highwood and Hoskins, 1998] and may even control the annual cycle of the tropical tropopause temperature [Norton, 2006]. Equatorial Kelvin waves cause great temperature purturbation at the equatorial tropopause [Tsuda et al., 1994], dehydration [Fujiwara et al., 2001], and cirrus variation [Bohem and Verlinde, 2000]. These waves also cause irreversible ozone transport [Fujiwara et al., 1998], and turbulence generation [Fujiwara et al., 2003]. Equatorial Rossby waves, on the other hand, set up the horizontal transport pathway to and from the off-equatorial region [Hatsushika and Yamazaki, 2003]. (The monsoon circulation may be viewed as a Rossby wave response to the tropical convections.) Therefore, appropriate representation of tropical convection and organization and of large-scale equatorial waves is crucial even for stratospheric models. In this section, the tropical activity of convections and large-scale waves are investigated for some of the CCMs [cf., Fujiwara and Takahashi, 2001]. (Monsoon circulations will also be included in the investigation.) Global reanalysis data and radiosonde data are used for validation.

Data needed:

Daily Instantaneous 3D:
T, (Pressure, Surface Pressure,) Geopotential, U, V, W (or Omega), H2O, Cloud Fraction, O3, (HCl, CO)

Daily Instant 2D:
OLR, Rain/Precipitation

7.4.3 Transport/TTL Chemistry

7.4.3.1 H2O and Ozone profiles (C)

Analysis performed by: Kunze, Langematz, Birner
Abstract: H2O and Ozone profiles and structure in the TTL will be examined and compared to observations (SHADOZ radiosondes, Satellite data). Instantaneous data is necessary to calculate the tropopause and stability. Instantaneous data will also be used to examine tracer-tracer correlations for long and short lived species and the relationship to cloud fields, and check statistics and relations in monthly means.

Data needed:
T3I (Daily Instant 3D) Temperature, Pressure, H2O, O3, CO, HCl, cloud fraction
T3M (Mon Mean 3D) Temperature, Pressure, H2O, O3, HCl, CO, Cloud Fraction

7.4.3.2 Vertical gradient of $H2O$, CO, and O3

Analysis performed by: Hegglin
Abstract: (see description longterm variability/trends in extratropical UTLS)
Data needed: **T3I (Daily Instant 3D)** H2O, CO, H2O, temperature, pressure, surface pressure

7.4.3.3 Short lived species & tropical convection

Analysis performed by: Gettelman, Park
Abstract: Vertical structure of short-lived species (lifetime < 6 months) will be examined and compared to observations (ACE, MLS). Focus will be on the Asian Monsoon, Western Pacific, and Tropical Continental Convective regions.Convective relationships, the tropopause calculations, and tracer-tracer correlations require instantaneous data. Winds are needed instantaneously for calculating PV and the streamfunction.

Data needed:
T3I (Daily Instant 3D) Temperature, Pressure, Surface Pressure, H2O, O3, CO, Cloud Fraction, HCl, Acetylene (C2H2), Ethane (C2H6), Methyl Chloride (CH3Cl), U, V
T3M (Mon Mean 3D) Temperature, Pressure, Surface Pressure, H2O, O3, HCl, CO, Cloud Fraction, heating rates, Acetylene (C2H2), Ethane (C2H6), Methyl Chloride (CH3Cl), U,V

7.4.3.4 Lightning impact

Analysis performed by: Hegglin, Plummer
Abstract: The impact of lightning on NOx and O3 distributions will be analyzed using model runs with/without lightning parameterization, comparison of different model parameterizations, and comparison to observations. Diagnostics will include NOx/NOy and NOy/O3 vertical profiles. Instantaneous data is needed to understand NOx partitioning and NOx/NOy ratios, as well as the relationships to clouds.

Data needed:
T3I (Daily Instant 3D) NO, NO2, O3, NOy, temperature, pressure, surface pressure, cloud fraction
T3M (Mon Mean 3D) NO, NO2, O3, NOy, temperature, pressure, surface pressure, cloud fraction

7.4.3.5 Residence and transport time scales

Analysis performed by: Rex, Kremser
Abstract: Case studies will be performed using Lagrangian trajectories [Berthet, Haynes et al. JGR, Levine et al. JGR 2007; Fueglistaler et al., 2004]
Data needed: winds, temperatures, heating rates (daily or 6 hrly) Do we have this data? May have to ask for these in a separate data request for interested modelers only.

Analysis performed by: Park, Gettelman, Haynes, Pyle, Morgenstern
Abstract: [RESEARCH] Project to look at the lifetime of short lived species using tropospheric chemistry calculations for some models. Goal is to understand transport

pathways. Will use same data as short lived species above for multi-model ensemble, and use detailed information from other models. Requires data similar to that above, but for other species as well.

Data needed:
T3I (Daily Instant 3D) CO, O3, HCL, H2O, C2H2 (Acetylene), C2H6 (Ethane), CH3Cl (Methyl Chloride), Cloud Fraction

T3M (Mon Mean 3D) NO, NO2, O3, NOy, temperature, pressure, surface pressure, cloud fraction, age of air, heating rates, U, V

7.4.4 Long-term variability/trends

7.4.4.1 General diagnostics TTL structure

- Validate trends v. Past (REF1)
- Tropical Tropopause Pressure
- Cold point temperature
- Tropical Edge: Tropical extratropical UTLS/trop coupling

Analysis performed by: Gettelman, Birner
Abstract: Structure of the TTL will be evaluated over time from both instantaneous and monthly mean fields of temperature, water vapor, ozone, short lived species, cloud fraction. Similar to analysis done for 7 .4.2.1 (1.4.2.1). Analysis has shown that the monthly mean fields may not give a full picture of trends. Instantaneous data is needed for checking some of the basic trends with monthly mean data.

Data needed:
T3I (Daily Instant 3D) Temperature, Pressure, Surface Pressure, H2O, O3, CO, Cloud Fraction, zonal wind (U), HCl, Acetylene (C2H2), Ethane (C2H6), Methyl Chloride (CH3Cl)
T3M (Mon Mean 3D) Temperature, Pressure, Surface Pressure, H2O, O3, HCl, CO, Cloud Fraction, Zonal Wind (U) heating rates, Acetylene (C2H2), Ethane (C2H6), Methyl Chloride (CH3Cl)

7.4.4.2 Transport/TTL Chemistry

- Past and future ozone and water vapor trends
- Past and future lightning NOx

Analysis performed by: Hegglin, Plummer
Abstract: *(see description longterm variability/trends in extratropical UTLS)*
Data needed:
T3I (Daily Instant 3D) O3, H2O, NO, NO2, NOy, temperature, pressure, surface pressure, cloud fraction
T3M (Mon Mean 3D) O3, H2O, NO, NO2, NOy, temperature, pressure, surface pressure, cloud fraction

7.5 The extratropical UTLS

7.5.1 Overview and Description

7.5.2 Key diagnostics dynamical structure

7.5.2.1 Tropopause height and temperature [Santer et al., 2003, Son et al 2008] (C)

Analysis performed by: Son, Polvani
Abstract:
Data needed:

7.5.2.2 Tropopause inversion layer (TIL) [Birner, 2006] (C)

Analysis performed by: Birner
Abstract:
Data needed:

7.5.2.3 Mass of the lowermost stratosphere [Appenzeller et al., 1996]

Analysis performed by:
Abstract:
Data needed:
T3I (Daily Instant 3D) and/or T3M (Month Mean 3D) : Pressure, Temperature, O3, H2O

7.5.3 Key diagnostics chemical composition and transport

7.5.3.1 Extent, sharpness, location, separation, and seasonality of the extratropical transition layer (ExTL)

Analysis performed by: Pan, Hoor (C)
Abstract: O3-H2O and O3-CO [Pan et al., 2004, 2007]

Analysis performed by: Hoor?, Hegglin?
Abstract: O3-HCl [Marcy et al. 2004]

Analysis performed by: Hoor
Abstract: CO PDFs [Strahan et al., 2007]

Analysis performed by: Hoor (C)
Abstract: CO vertical profiles relative to the dynamical tropopause [Hoor et al., 2004]

Analysis performed by: Pan (C)
Abstract: CO, H2O, and O3 vertical profiles relative to the thermal tropopause [Pan et al., 2004, 2007]

The above analyses need instantaneous data for thermal and dynamical tropopause estimates, as well as tracer-tracer correlations.

Data needed:

T3I (Daily Instant 3D) H2O, O3, CO, HCl, pressure, temperature, U, V (for PV).

7.5.3.2 Lowermost stratospheric 'background' tracer distributions

- Seasonal cycles of tracers at different altitudes (O3, N2O, age of air) [Logan et al., 1999; Strahan et al., 2007] (C)
- Vertical tracer profiles of N2O and O3 relative to the TP height and their seasonal cycle [Hegglin et al., 2006]

Analysis performed by: Hegglin
Abstract: The impact of the large-scale Brewer Dobson circulation on UTLS tracer distributions will be validated using the seasonal cycle observed in O3, N2O, and age of air on different potential temperature or pressure levels. Need instantaneous data for tracer-tracer correlations and the tropopause (thermal and dynamical) definition.

Data needed:
T3I (Daily Instant 3D) N2O, O3, age of air, pressure, temperature, surface pressure, U,V (for PV)

7.5.3.3 Troposphere-stratosphere chemical-dynamical coupling

Analysis performed by: Hoor (C)
Abstract: CO2-seasonal cycles at different levels in the LMS [Strahan et al., 2007]
Data needed:

Analysis performed by: Hoor
Abstract: CO vertical profiles relative to the tropopause height to separate and quantify tropical/extratropical influence [Hoor et al., 2004]
Data needed:
T3I (Daily Instant 3D) CO, temperature, pressure, surface pressure, U, V (for PV)

Analysis performed by: Hegglin (C)

Abstract: The vertical gradient in H2O is used as an alternative method to tracer-tracer correlations in order to investigate the representation of the ExTL and to investigate the role of H2O in forcing and maintaining the tropopause inversion layer [Hegglin et al., 2008].
Data needed:
T3I (Daily Instant 3D) H2O, temperature, pressure, surface pressure

7.5.3.4 Lightning impact

Analysis performed by: Hegglin, Plummer
Abstract: (see description 7.3.4.3)
Data needed:
T3I (Daily Instant 3D) NO, NO2, NOy, O3, temperature, pressure surface pressure, cloud fraction, U,V (for PV)
T3M (Month Mean 3D) NOx, NOy, O3, temperature, pressure, surface pressure

7.5.3.5 Ozone fluxes (STE)

Analysis performed by: Gettelman, Hegglin
Abstract: [RESEARCH] Ozone fluxes will be calculated with some models that have the capability to do so. This is a research product and will not be done across all models. Some monthy mean output is desired to examine ozone around the tropopause.

Data needed:
T3M (Monthly Mean 3D) O3, temperature, pressure, surface pressure

7.5.4 Long-term variability/trends

7.5.4.1 General diagnostics extratropical UTLS structure

Analysis performed by: Polvani, Son, Birner
Abstract: Trends in the extratropical tropopause height/pressure will be investigated along the lines of Son et al 2008. Instantaneous data is desired to check results from monthly means, and to focus on tropopause inversion layer stability structure

Data needed:
T3I (Daily Instant 3D) Temperature, Pressure, Surface Pressure, H2O, O3, CO, U,V (for PV)

T3M (Mon Mean 3D) Temperature, Pressure, Surface Pressure, H2O, O3, U, V (for PV)

7.5.4.2 Past and future trends of O3 and H2O in relative coordinates to the tropopause height

Analysis performed by: Hegglin, Birner
Abstract: Trends in water vapour and ozone in the UTLS will be analyzed using tropopause-based diagnostics applied to the 150 year climate simulations. The radiative feedback of changes in ozone and water vapour on the strength of the tropopause inversion layer [Birner, 2006; Randel et al., 2007] and the causes for changes in stratosphere-troposphere exchange processes will be investigated.
Data needed:
T3I (Daily Instant 3D) H2O, O3, temperature, pressure, surface pressure, U, V (for PV)

7.5.4.3 Transport characteristics

- Trends in the ExTL extent
- Trends in the background LMS distributions / age of air

Analysis performed by: Hegglin, Hoor?, Pan?
Abstract: Trends in the ExTL and the background LMS are being investigated using the diagnostics described in the previous section such as seasonal cycles in tracer distributions at different altitudes, tracer-tracer correlations, PDFs, and analyses of vertical tracer gradients.
Data needed:
T3I (Daily Instant 3D) H2O, CO, O3, N2O, age of air, temperature, pressure, surface pressure

7.5.4.4 Trends in O3 mass flux across given pressure level

Analysis performed by: Gettelman, Hegglin
Abstract: [RESEARCH] Given the calculations of O3 mass fluxes in 7.5.3.5 yield reasonable results in comparison with published values using different methods, the trends in the O3 mass flux across given pressure level will be calculated using a subset of the CCMVal models which allow the required calculations.
Data needed:
T3M (Monthly Mean 3D) O3, temperature, pressure, surface pressure

7.6 Conclusions/Findings

Key References for Diagnostics:

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Gettelman, A and T. Birner, 2007: Insights on Tropical Tropopause Layer Processes using Global Models submitted to J. Geophys. Res., 2007

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Hegglin, et al. , 2006: Measurements of NO, NOy, N2O, and O3 during SPURT: implications for transport and chemistry in the lowermost stratosphere, Atmos. Chem. Phys., 6, 1331--1350, SRef-ID: 1680-7324/acp/2006-6-1331.

Hegglin, et al., 2008: The extratropical tropopause transition layer (ExTL) as seen from ACE O3, CO, and H2O measurements, to be submitted to J. Geophys. Res.

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Pan L. L., W. J. Randel, B. L. Gary, M. J. Mahoney, E. J. Hintsa, 2004: Definitions and sharpness of the extratropical tropopause: A trace gas perspective, J. Geophys. Res., 109, D23103, doi:10.1029/2004JD004982.

Pan L. L., J. C. Wei, D. E. Kinnison, R. R. Garcia, D. J. Wuebbles, 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.

Strahan, S. E., B. N. Duncan and P. Hoor, 2007: Observationally derived transport diagnostics for the lowermost stratosphere and their application to the GMI chemistry and transport model, ACPD, 7, 1449-1477, 2007

Son, S-W, L. M. Polvani, D. W. Waugh.,T. Birner, R.R. Garcia, A. Gettelman, D. A. Plummer, The tropopause in the 21st century as simulated by stratosphere-resolving Chemistry Climate Models, submitted to J. Climate, 2008

Part B

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8 Natural Variability (Lead Authors: Elisa Manzini and Katja Matthes)

Chapter 8 will evaluate how well CCMs represent the effects of various sources of coherent forced and unforced natural variability (internal including tropical oscillations, solar, ENSO and volcanoes) on stratospheric ozone by means of stratospheric dynamics, radiation, chemistry and transport. Some relevant diagnostics are included in the CCMVal evaluation table, and many CCMVal Collaborator projects will contribute to this chapter.

8.0 Introduction

Link to Part A results. For instance, mean behavior of ozone (seasonal cycle, etc) to be used as a background on the signals that we are aiming to identify. Thereafter, for each of the sources, there will be more specific links again to Part A.

8.1 Multiple Linear Regression Analysis

Assessment of existing results from multiple regression analysis.
Perfom a systematic multiple linear regression analysis from available simulations. The purpose being to have a first guess of how the different variability sources contribute to variations in ozone.

8.1.1 Methodology

Discussion needed on what to include in the regression model (also depends on the different model setups, processes included, etc.)

8.1.2 Results

- Apply same regression analysis to observations and CCMs
- Start with existing REF1 simulations, later take new REF simulations and all other appropriate runs

8.1.3 Synthesis

8.2 Internal Variability and Tropical Oscillations

- This section links to Chapter 4 Dynamics and may extend some of their analysis if not done there and provide the background before starting to investigate the response of ozone to external natural forcing.
- For this section, it would be ideal to have a REF simulation of few decades without any external forcing and no ozone depleting substances, say 1960 conditions, in order to clearly quantify the internal variability of the CCMs in absence of perturbations. This is the REF

simulation that Elisa has discussed with Ted and Veronika at IUGG in Perugia and would substitute the time-slice under 2000 conditions.
- Possibly address also low frequency variations.

8.2.1 Daily and Monthly Variance

Quantify the internal variability of the models in general terms (maps of monthly and daily variances). Temperature, Zonal Winds and Ozone. Zonal means of monthly and daily data. Comparison with re-analysis data.

8.2.2 Tropical Oscillations

Evaluate the representation of tropical oscillations and their high-latitude effect in temperature, zonal winds and ozone. Monthly zonal means. Comparison with re-analysis data.

8.2.3 Process Oriented Evaluation

- Evaluate the role of chemical, transport and radiative processes in the variations in the ozone distribution on the time scale considered. Links to Part A Chapters.
- Assess mechanistic model studies for the interpretation of the CCM behavior, especially for the low frequency aspect.
-

8.2.4 Synthesis

8.3 Solar cycle

Impact on ozone via radiation and chemistry directly in the upper atmosphere, indirect effects on dynamics, transport and chemistry throughout the atmosphere. Discuss interactions with tropical oscillations. Short review of observational evidence.

8.3.1 Process Oriented Studies

- Quantify the direct response in the upper stratosphere: (max-min) differences in shortwave heating rate (link to radiation chapter) and temperature.
- Investigate indirect effects throughout the stratosphere (focus on NH and SH winter) and down to the troposphere (link to chapter 10). What are the processes involved in transferring the signal from the sources to the effects? Are these processes represented in the models?
- What is the role of the QBO in modulating the solar cycle response? Is the QBO itself modulated by the solar cycle?
- Explain the results of multiple linear regression analysis with process oriented studies, take additional model experiments into account (also mechanistic model studies)

8.3.2 Synthesis

8.4 ENSO

Impact on ozone via tropical and extra-tropical dynamics, temperature, transport and indirectly chemistry. Short review of observational evidence.

8.4.1 Process Oriented Studies

- Quantify the local tropical response: Surface air temperature in the NINO3.4 for diagnosing if the external forcing of the SST is properly transmitted to the lower tropical atmosphere of the CCMs.
- Temperature in the polar winter stratosphere: Northern Hemisphere. What are the processes involved in transferring the signal from the sources to the effects? Are these processes represented in the models?

8.4.2 Synthesis

8.5 Volcanoes and Stratospheric Aerosols

Direct effect on radiation and chemistry in the stratosphere, indirect effects on dynamics. Links to Chapter 3 (Radiation). Short review of observational evidence.

8.5.1 Process Oriented Evaluation

- Quantify the local radiative and chemical response (heating rates, temperature, chemical reactions)
- Impact of thermal and dynamics in the stratosphere, impact on stratospheric circulation and wave propagation
- Understanding the impact of radiative and chemical induced changes in the ozone concentration due to volcanic aerosols (separation of chemical and radiative effects).
- Investigation the Arctic Oscillation response to volcanic eruptions in the CCMVal model simulations
- What is the role of the QBO in modulating the volcanic response? Is the QBO itself modulated by the volcanic cycle?
- Volcano and EL Nino interactions: How is the volcanic signal influenced by the ongoing El Nino events and how is the ENSO signal modulated by the volcanic eruptions?

8.5.2 Synthesis

8.6 Impacts of inter-connections/Summary

The possible connections between the different sources and their effects will be discussed here.

<u>Data Request:</u>

A lot of the fields requested for this chapter are already on the "standard list".

Daily Data

1. Internal variability, daily variances [Zonal daily means for temperature, zonal wind and ozone on selected pressure levels.]

Monthly Data

2. Internal variability, monthly variances and ENSO [Monthly means for temperature, zonal wind and ozone, on standard pressure levels]

3. Processes studies: Tropical Oscillations, Solar Cycle and Volcanos [Zonal monthly mean for temperature, zonal wind, ozone, and shortwave and longwave heating rates on standard pressure levels]

We need especially the short- and longwave heating rates to assess the ability of the CCMs to simulate the solar cycle. In the radiation chapter (chapter 2) only offline max/min radiation tests are performed whereas we want to look at the specific fields from the REF1 simulations and compare e.g. the signal in the heating rates with the temperature signal.

9 Long-term projections of stratospheric ozone

(Lead Authors: John Austin and John Scinocca)

Chapter 9 will focus on long-term changes (past and future) in ozone and ozone indices and on the cause of these changes (i.e. relate to changes in chemistry, dynamics, radiation, transport and UTLS discussed in Part A chapters). For the REF1 and REF2 runs performed for the 2006 Ozone Assessment, this has already been done by Eyring et al. (2006, 2007), though some more details concerning those results could be usefully provided here. The main work for this chapter will involve evaluating the behavior of ozone recovery in the new runs that will be performed for the 2010 Ozone Assessment.

9.1 Introduction

A wide variety of factors influence the long-term evolution of ozone:

- evolution and composition of halogen loading
- temperature (GHG-induced climate change)
- dynamics (realistic resolved and parameterized wave forcing and its influence on polar vortex variability as well as GHG induced changes to the BD circulation)
- water vapour
- volcanic eruptions
- solar cycle
- others?

The degree to which each of these factors influence the future evolution of ozone broadly depends on latitudinal location and it is most natural to address this issue separately for mid-latitude, tropical, and polar regions. For each of these regions the goal will be to:

- present the projected ozone change from the new CCM simulations performed for this report. Ozone evolution could be documented by plots of total column ozone, vertical profile differences, ozone mass deficit, and hole size.
- review and update our understanding of the dominant factors that affect ozone recovery in that region
- pull together "future-change" information for these factors from the relevant chapters of this report to understand the evolution of ozone and to determine the relative importance of any competing factors
- review modelling deficiencies related to these processes from the last WMO assessment and any model improvements that have occurred in the interim from Part A chapters. This could include improved chemistry, dynamics, or model configuration (e.g. quality and variety of surface forcing, including coupling to an ocean GCM)
- identify outstanding modelling issues that are central to the accurate prediction of long term ozone in that region

9.2 Mid-Latitude Ozone

Dominant factors that affect ozone evolution in this region are the evolution of halogen loading and the slowing of gas-phase ozone depletion due to GHG cooling of the stratosphere.

WMO assessment:

- NH recovery occurs over the period 2005-2035, which is well ahead of the return of halogen loading to 1980 values (2035-2050), while the SH recovery occurs over the period 2025-2040.
- wide spread in peak Cly values (2000) - has this spread narrowed with model improvements (connection with chemistry Chapter 6). Does this translate into more consistent estimates of recovery dates?

New Runs:

- update the WMO estimates of trends, recovery dates, and the 2100 ozone levels in the stratosphere

9.3 Tropical Ozone

Dominant factors that affect ozone evolution in this region are the evolution of halogen loading, increased Brewer-Dobson (BD) circulation and GHG cooling (also water vapour induced tropopause temperature changes).

WMO assessment:

- small (2%) increase in column ozone (2000 to 2020)
- 2050 column ozone slightly lower than 1980 values
- decreased ozone occurs in lower stratosphere - enhancement of BD circulation expected to bring up ozone-poor air from troposphere - can the new set of runs better verify this effect?
- suggestion of “reverse self healing” - do the new runs provide evidence for this?

New Runs:

- update the WMO estimates of trends, recovery dates, and the 2100 ozone levels in the stratosphere
- can we better define water vapour induced temperature changes to the tropical tropopause and its impact on ozone evolution in the stratosphere (connection to TTL Chapter 7)

9.4 Polar Ozone

Dominant factors that affect ozone evolution in this region are the halogen loading and GHG cooling of the stratosphere, which acts oppositely to mid-latitudes in that it promotes ozone loss through enhanced PSC formation . Dynamics are more important to Arctic ozone evolution.

WMO assessment:

- most models have Antarctic Cly that is too low which implies a too early return to 1980 values and a too early ozone recovery. How has this bias improved? (connection with chemistry Chapter 6)
- Arctic ozone evolution not as closely correlated to Cly evolution. Arctic ozone recovers before halogens return to 1980 values and ahead of Antarctic recovery. Influences thought to include enhancement of BD circulation and slowing of gas-phase ozone loss in stratosphere by GHG cooling. Is there evidence for these influences in new runs? (connection to dynamics and chemistry Chapters 4 and 6)

- New Runs:

- update the WMO estimates of trends, recovery dates, and ozone levels in the stratosphere
- explore new more unbiased metrics defining the evolution of ozone loss (e.g. Huck et al. 2007)
- treatment of bromine chemistry not uniform among WMO models. Model improvements will include better treatment of bromine. This should lead to enhanced polar ozone loss and Br should be dominant as Cly loading decreases toward the end of the 21st century. Can this effect be quantified in the new set of runs? (connection with chemistry Chapter 6).
- increased BD down welling in polar vortex can counteract GHG cooling. Is there any evidence for more rapid recovery due to this effect (connection with dynamics Chapter 4).

9.5 Global Ozone

Here we present projections for long-term changes in global ozone from the current set of runs. These changes are discussed and understood in terms of the material presented in Sections 9.2-9.4.

WMO assessment:

- Total column global mean ozone projected to increase 1% to 2.5% 2000->2020
- 2050 to 2100 - slow global drift to increasing ozone due to GHG cooling except in tropics where it is roughly unchanged.
- Global upper and lower stratosphere cooling trend (1980-1999) > (2000-2049). 50hPa cooling 2050-2100 not well defined.

- New Runs:

- update the WMO estimates of trends, recovery dates, and ozone levels in the stratosphere

9.6 Discussion

- how has our understanding of issues related to long-term ozone change improved/changed since the WMO assessment
- what are the big issues related to credible long-term ozone change predictions (e.g. should resources be directed toward coupling to an ocean GCM, improved chemical mechanisms, improved dynamics, or improvements to the underlying models employed for climate-change studies).

- at some point the leading-order response to the inclusion of stratospheric chemistry will be essentially accomplished. The next-order responses will be more subtle and possibly require the inclusion of other essential physics such as tropospheric chemistry and the carbon cycle. Are we at this point yet?

10 Effect of the stratosphere on climate

(Lead Authors: Mark Baldwin and Nathan Gillett)

Chapter 10 will evaluate the impact of stratospheric changes on the troposphere. This will include the radiative forcing from ozone changes, tropospheric effects of polar ozone depletion, and changes in the flux of ozone to the troposphere over long timescales (past and future). Many of the CCMVal diagnostics can be used to address these questions, and many CCMVal Collaborator projects will contribute to this chapter. This chapter should specifically target the needs of the next IPCC report.

10.1 Introduction

10.2 Observations

Review observational evidence for stratospheric influence on the troposphere due to: 1) dynamical coupling (ref ch 4), 2) radiative effects (ref ch 3), 3) chemical effects (ref ch 6).

10.3 Critical evaluation of stratosphere-troposphere coupling in CCMs.

- What can CCMs do better than CMIP3 climate models? What do they do less well? Consider dynamics, radiation and chemistry.
- Are ozone distributions more or less realistic than those specified in CMIP3 models?
- How realistic is the surface climate in CCMs?
- What are the limitations on tropospheric climate imposed by prescribed SSTs in CCMs?
- What does it take to simulate effects on the troposphere? Diagnostics like NAM timescale, AO predictability (ref 4.3.5) in models.

10.4 Simulations of stratospheric influence on the troposphere in the past and future.

10.4.1 Dynamical effects

- How well do CCMs simulate the stratosphere-troposphere coupling and associated climate changes during recent decades? How do these simulations compare to those of the CMIP3 models? Include tropospheric effects of polar ozone depletion.
- How important is a good stratosphere for simulating future climate change?

10.4.2 Radiative effects

- Radiative forcing due to past ozone changes, calculated from CCMVal models (cross-ref section 3.4). Is this more or less realistic than estimates based on ozone observations? Consider also radiative forcing effects of other stratospheric composition and temperature changes. How will this evolve in the future?

10.4.3 Chemical effects

- Impact of stratospheric composition (ozone, aerosol) on tropospheric UV (and hence tropospheric photolysis rates, chemistry and composition).
- Impact of stratospheric composition (ozone, NO_y) on the influx of stratospheric constituents to the troposphere.
- Impact of dynamics on stratosphere to troposphere mass (and hence O_3, NO_y) fluxes.
- Include diagnosis of changes in strat-trop ozone fluxes.

10.5 Data request Chapter 10

- We would like **daily mean** (not instantaneous) zonal mean fields. This is definitely the best for annular mode diagnoses. I imagine we could do the analysis with instantaneous zbar, but this would have additional noise, so daily mean is best if we can get it. Other than daily zonal mean dynamical fields, I think that our data needs are modest.

- We have had discussions with Andrew Gettelman, and he is probably not going to do the ozone fluxes.

- We have not associated names with specific analyses, but of course we are taking full responsibility that Chapter 10 analysis is performed. The details of our analysis will evolve as we proceed. For example, we will be calculating daily annular mode indices from daily zonal-mean geopotential, and comparing model runs with observations (e.g., NAM timescale). Since we have not seen these results, it is difficult to be precise about what we will emphasize. We are trying to understand what is required of models to obtain realistic stratosphere-troposphere coupling.

- For Chapter 10 dynamical/radiative analysis, we would potentially use items 1-18, 20-31, 34-35, and 88-99.

- We may have some comments on chemical fields, after our co-authors get back to us.