Overview of IGAC-SPARC CCMVal Community Simulations in Support of Upcoming Ozone and Climate Assessments and Process Studies

Coordinating Committee:
Veronika Eyring, DLR-Institut für Physik der Atmosphäre, Germany (veronika.eyring@dlr.de),
Peter Hess, Cornell University, USA (pgh25@cornell.edu),
Jean-Francois Lamarque, National Center for Atmospheric Research, USA (lamar@ucar.edu),
Martyn P. Chipperfield, University of Leeds, UK (martyn@env.leeds.ac.uk),
Bryan Duncan, NASA Goddard Space Flight Center, USA (Bryan.N.Duncan@nasa.gov),
Arlene Fiore, Columbia University, USA (amfiore@ldeo.columbia.edu),
Andrew Gettelman, National Center for Atmospheric Research, USA (andrew@ucar.edu),
Claire Granier, IPSL, Paris, France (cgranier@latmos.ipsl.fr),
Michaela Hegglin, University of Reading, UK (m.i.hegglin@reading.ac.uk),
Doug Kinnison, National Center for Atmospheric Research, USA (dkin@ucar.edu),
Randall Martin, Dalhousie University, Canada (randall.vaughn.martin@gmail.com),
Paul A. Newman, NASA Goddard Space Flight Center, USA (Paul.A.Newman@nasa.gov),
Alan Robock, Rutgers University, USA (robock@envsci.rutgers.edu),
Tom Ryerson, NOAA; USA (Thomas.B.Ryerson@noaa.gov),
Alfonso Saiz-Lopez, Laboratory for Atmospheric and Climate Science, Spain (a.saiz-lopez@ciac.jccm-csic.es),
Martin Schultz, Forschungszentrum Juelich, Germany (m.schultz@fz-juelich.de),
Theodore G. Shepherd, University of Toronto, Canada (tgs@atmosp.physics.utoronto.ca),
Drew Shindell, NASA Goddard Institute for Space Studies, USA (dshindell@giss.nasa.gov),
Johannes Stähelin, ETH Zürich, Schweiz (johannes.staehelin@env.ethz.ch),
Susann Tegtmeier, Helmholtz Centre for Ocean Research Kiel (GEOMAR), Germany (stegtmeier@geomar.de).
Darryn W. Waugh, Johns Hopkins University, Baltimore, USA (waugh@jhu.edu).

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- *Draft sent to all modeling groups on **May 5, 2012**. This will allow discussions at the institutes prior to the workshop. In this way we should be able to more easily reach a consensus at the workshop.*
- *To collect comments on the draft and the questionnaire from modeling groups by **May 16, 2012***
- *To discuss and agree the revised document at the Davos workshop, including prioritization of simulations (could also mean deletion of some of the runs if no group is interested).*
- *To publish a final version in SPARC and IGAC Newsletters mid-2012*
- *To provide the forcings for the simulations by summer-autumn 2012 on a central webpage*

Please return your comments on this document (preferably one coordinated response per model group) to Veronika.Eyring@dlr.de, lamar@ucar.edu, and peter.hess@cornell.edu if possible by **May 16, 2012**. The revised version that considers the comments we have received by that day will be presented at the workshop and will form the basis for discussions at the Davos workshop.

1. Introduction

1.1 Background

The study of chemistry-climate interactions represents an important and, at the same time, difficult focus of global change research. The interacting factors relating chemistry and climate strongly couple the emerging issue of climate, ozone depletion and air quality, from both scientific and policy perspectives. Understanding how the chemistry and composition of the atmosphere may change over the 21st century is essential in preparing adaptive responses or establishing mitigation strategies. The abundance of aerosols and reactive greenhouse gases is controlled by atmospheric chemistry and physics integrated over global scales. A changing atmosphere not only drives climate change but also directly impacts human health, agricultural productivity, and natural ecosystems. Projections of future climate change are coupled with changes in atmospheric composition whose impacts extend to air quality (Prather et al., 2001; Stevenson et al., 2006) and stratospheric ozone (WMO, 2011). Further, chemically active species in the troposphere are more amenable to short-term manipulations through changes in emissions are therefore of major policy relevance to both air quality and climate (Shindell et al., 2012). Provision of high-quality, policy-relevant information on the current state of climate and its possible future states, as well as options for mitigation / control / change / adaptation are strongly dependent on the progress in this area.

Increasingly, the chemistry and dynamics of the stratosphere and troposphere are being modeled as a single entity in global models. For the first time, some of the Earth system models (ESMs) with interactive oceans that participated in the fifth round of the Coupled Model Intercomparison Project (CMIP5) (Taylor et al., 2009) had interactive chemistry. The 2010 WMO/UNEP Scientific Assessment of Ozone Depletion (WMO, 2011) also featured several stratospheric models that included tropospheric chemistry, and one model with a coupled ocean. It was also one of the main recommendation of the SPARC-CCMVal (2010) report, that stratosphere-resolving chemistry-climate models (CCMs) should continue to evolve towards more comprehensive, self-consistent stratosphere-troposphere CCMs. These developments provide a pathway for including a better representation of stratosphere-troposphere and chemistry-climate coupling in CCMs and ESMs used for ozone and climate assessments. There is therefore a need to better coordinate the previously separate activities addressing these two domains and to assess scientific questions in the context of comprehensive stratosphere-troposphere resolving models with chemistry and increasingly a coupled ocean.

1.2 Purpose and scope of the proposed community simulations

To meet these scientific needs, the IGAC and SPARC CCMVal communities are jointly defining new reference and sensitivity simulations as part of the *IGAC / SPARC Global Chemistry-Climate Modeling and Evaluation Workshop (Davos, May 2012)* that are described in this document. These simulations will be carried out in support of upcoming ozone and climate assessments and will help to answer emerging science questions as well as improving process understanding.

In this document community-wide **reference (REF)**, **sensitivity (SCN)** and **process-study (PRO) simulations** for CCMs, ESMs with interactive chemistry, and chemistry-transport models (CTMs) are proposed. The over-riding principle behind the choice of theses simulations is to produce the best possible science.

There are two overall requirements for the **REF** simulations. The first requirement is to see how well the models can reproduce the past behavior (climatology, trends and interannual variability) of tropospheric and stratospheric ozone, other oxidants, and more generally chemistry-climate interactions, as well as to understand processes that govern these interactions. That is the rationale behind the “past” transient hindcast reference simulations in either free-running (**REF-C1**) or nudged (**REF-C3**) mode. These simulations are forced by boundary conditions specified from observations or empirical data (e.g., sea surface temperatures, emissions, greenhouse gas concentrations). One of the goals for the new **REF-C3** simulation is an improved evaluation against observations, in particular new satellite, ground-based, and in situ measurements. The second requirement is to analyze projections of the future evolution of tropospheric and stratospheric ozone. That is the rationale behind the “future” transient reference simulation **(REF-C2)**, which is forced by trace gas projections and either prescribed modeled sea surface temperatures (SSTs) and sea ice concentrations (SICs), or an interactively coupled ocean. Experience gained from the evaluations performed for the SPARC-CCMVal (2010) report shows that it is important to have a continuous time series from the models covering both past and future, in order to avoid inhomogeneity in the data sets (in terms of both absolute values and variability), and also that the simulations extend to 2100 in order to fully capture the process of ozone recovery from the effects of ozone-depleting substances (ODSs). Accordingly, **REF-C2** simulations should cover the period 1960-2100, with a 10-year spinup starting in 1950. It is recommended that groups perform a small ensemble of simulations covering the ‘past’ and ‘future’ periods from 1960-2010 (**REF-C1)** and from 1960-2100 (**REF-C2**), respectively, so as to establish an uncertainty range in the simulations.

The proposed **SCN** simulations are designed to augment, in various ways, the science that can be obtained from the reference simulations. These simulations include investigating the sensitivity to various greenhouse gas (GHG) scenarios, ODSs, and emissions. Simulations for process **(PRO)** studies in the troposphere and stratosphere are additionally proposed to study specific aspects with shorter simulations. Those will be further defined at the workshop.

All simulations are open to a broad range of participating CCMs with or without interactive oceans, as well as to ESMs with interactive stratospheric and/or tropospheric chemistry. A subset of simulations (e.g., **REF-C3**) is also open to CTMs with specified meteorology or to CCMs with nudged meteorology. We propose all models participating use a standard set of specified interannual forcings to drive the models (e.g., emissions and sea-surface temperatures), which are specified in this document and provided on a central website.

1.3 Scientific questions and timelines

These newly proposed community simulations come at a critical but inopportune time between various international assessments.

The CMIP5 simulations are now being studied in great detail in support of the IPCC Fifth Assessment Report (AR5), along with analysis of simulations performed under the Atmospheric Chemistry & Climate Model Intercomparison Project (ACCMIP) and Aerosol Comparisons project (AeroCom). For example, a set of simulations to be performed by the chemistry/aerosol modeling community has been defined by ACCMIP to characterize the radiative forcing from individual species in the CMIP5 simulations, and to diagnose causes of intermodel differences. In addition, simulations are being performed for the Geoengineering Model Intercomparison Project (GeoMIP). Here, the effects of stratospheric geoengineering with sulphate aerosols are studied under standard forcing scenarios applied to multiple climate models to compare their results and determine the robustness of their responses (Kravitz et al., 2011). Overall, this represents a huge community investment that has not been fully analyzed and explored. It also represents a significant time investment by modeling groups in preparing and executing these models, and contributing data. Many of the models participating in these projects do not have a fully developed stratosphere. We fully encourage the participation of these models in the current project while recognizing they may not be able to participate in all the proposed simulations.

At the same time, the next WMO/UNEP Scientific Assessment of Ozone Depletion (due in 2014) should be supported by updated simulations of stratospheric ozone. It is envisaged that the new simulations broadly follow the recommendations of the SPARC-CCMVal (2010) report, in particular:

- CCM simulations of ozone depletion/recovery should be performed seamlessly over the entire 1950-2100 period, with consistent forcings, and with data produced in a standard format to allow for multi-model intercomparison.
- A range of different scenarios should be simulated, e.g., fixed GHG, fixed ODSs, and different GHG projections. To be consistent with CMIP5, these scenarios should follow the four Representative Concentration Pathways (RCPs, Moss et al. (2010), van Vuuren et al. (2011a)). These simulations will allow correct attribution of the predicted changes and an understanding of the sensitivity to the GHG scenario employed.
- Development should continue towards comprehensive troposphere-stratosphere CCMs, which include an interactive ocean, tropospheric chemistry, a naturally occurring QBO, spectrally resolved solar irradiance, and a fully resolved stratosphere.
- The next generation of CCMs should also include a better representation of tropospheric chemical processes (e.g., non-methane hydrocarbons; lighting NO_x production; detail inclusion of dry and wet deposition processes). This is certainly important for science studies in the troposphere and Upper Troposphere Lower Stratosphere (UTLS) region, but also may be important in better representing the overall climate system.
- The coupling of CCMs to interactive oceans is recommended in the future, in order to make the representation of climate change in the models more physically self-consistent.
- The community should address the issue of how to include very short-lived (VSL) organic bromine species into the boundary condition and chemical mechanisms of CCMs.
- An accurate knowledge of the atmospheric lifetime of gases is essential for predicting the ozone-depletion and climate effects of emissions. A re-evaluation of the lifetimes of important halogen source gases (e.g., CFC-11, CCl4, Halons, HFCs, HCFCs, and related species) is currently underway as part of the SPARC activity on ‘Lifetime of halogen source gases’ (see http://www.sparc-climate.org/activities/lifetime-halogen-gases/), since evidence has emerged that in many cases the actual lifetimes may be considerably longer than those currently assumed in the 2010 WMO/UNEP Ozone Assessment (2010), and in the scenarios used to drive the CCMs. This represents a major uncertainty in reconciling top-down and bottom-up emission estimates, and in model projections. New model estimates of lifetimes, will require new CCM simulations.

Some of the above mentioned points are already considered in existing simulations. For example, a subset of models participating in CMIP5 has interactive chemistry and a coupled ocean. These runs can be included in studies that analyze the ozone evolution under different GHG scenarios. On the other hand, some of the model groups that did not participate in any of the above mentioned model intercomparison projects (MIPs) might want to additionally run simulations that extend the science beyond what was possible for WMO (2011).

In addition, the scientific questions that can be addressed through a new hindcast simulation with models including interactive chemistry are diverse. An incomplete list of questions includes: (i) How well does the current generation of global chemistry models capture the interannual variability in tropospheric and stratospheric constituents? (ii) How have changes in atmospheric forcings impacted chemical composition and chemistry over the last 30 through 50 years? These forcings include: a) changes in climate forcing with resulting impacts on temperature, water vapor and meteorology possibly extending to stratosphere-troposphere exchange, b) changes in ozone and aerosol precursor emissions; c) changes in land cover, and d) changes in ODSs. (iii) How have changes in aerosol loading impacted oxidative capacity of the troposphere over the last 30 to 50 years? (iv) To what extent do the increased satellite retrievals of tropospheric and stratospheric constituents constrain constituent variability over the last 10-15 years? (v) To what extent can CCMs forced with observed SSTs capture the observed interannual variability of the hindcast simulations? (vi) What is the role of very short-lived halogen species (VSLS)? The proposed hindcast simulations will address these questions through observationally based simulations and sensitivity tests. Additionally, a re-assessment of temperatures, trace species and ozone in the simulations will allow documenting progress of individual models and overall progress on the representation of key processes compared to the last CCM assessments. The comparison of CCM results with observations will also allow some groups to identify and correct previously unrecognized model errors and will help to indicate a range of model uncertainties.

Overall, there are two competing timescales for performing these simulations: the short term ozone assessment timescale including the need to perform a new hindcast simulation for improved understanding, and the longer time timescale for integrated climate and chemistry assessment for both the troposphere and stratosphere. These competing timescales have been recognized, and a key aspect of this document is to detail a long-term strategic plan for simulations that can meet the complex needs of simulating chemistry-climate interactions, while also seeking to prioritize simulations for near term (~next 3 year) needs. The result is that these simulations are envisaged to occur in two main phases over the next few years, see further details in Section 7.

1.4 Outline

The three reference simulations that should be run by the various modeling groups with highest priority are described in Section 2. Depending on the computing capacity of the individual groups, it is recommended that in addition to the reference simulations the sensitivity simulations and process studies described in Section 3 and 4, respectively, are performed by as many groups as possible. It is important that groups simulate the full time period specified, to allow a reliable comparison between the different models and to observations. In Section 5 and 6 the output format and requests are specified, and Section 7 outlines a timeline. Section 8 closes with a summary and outlook.

2. IGAC-SPARC CCMVal Reference Simulations

This section gives an overview of the main characteristics of the new IGAC-SPARC CCMVal REF simulations. Where possible, the forcings follow the recommendations of CMIP5 (http://cmip-pcmdi.llnl.gov/cmip5/forcing.html). The key characteristics are also summarized in Table 1.

2.1 HINDCAST: Reference Simulation 1 (REF-C1), Core Time Period 1960-2010

REF-C1 (1960-2010) covers the time period from 1960 to 2010 (with a 10-year spin-up prior to 1960) to examine model variability and to replicate as closely as possible the atmospheric state in this period for which ozone and other atmospheric constituents have been measured. This simulation is designed for CCMs. It allows a more detailed investigation of the role of natural variability and other atmospheric changes important for ozone balance and trends. All forcings in this simulation are taken from observations or empirical data, including anthropogenic and natural forcings based on changes in trace gases, solar variability, volcanic eruptions, quasi-biennial oscillation (QBO), SSTs, and SICs (see details below). Note, that many of these forcings are not necessary for models without explicit representation of stratospheric chemistry or alternatively, without explicit tropospheric chemistry. The primary focus of the proposed hindcast simulation is the evolution and variability of tropospheric and/or stratospheric ozone over the last 40-50 years. The proposed hindcasts will include a number of new aspects not previously examined in multi-model chemical hindcast simulations, including detailed evaluations of tropospheric oxidants and chemistry in addition to stratospheric chemistry, interactions between stratospheric and tropospheric chemistry, chemistry-aerosol interactions, the inclusion of very short-lived species, and more generally the impact of using stratospheric-tropospheric CCMs versus primarily tropospheric or stratospheric CCMs.

It should be noted that this simulation is similar to the historical simulation of the CMIP5 protocol (Taylor et al., 2009), but covers a shorter time period. Therefore, multi-model analysis could include the historical simulations from the CMIP5 archive that are carried out with an ESM with interactive chemistry.

- **Greenhouse Gases** (N_2O, CH_4, and CO_2) between 1950 and 2000 are taken from Meinshausen et al. (2011) and continued to 2010 from the RCP 8.5 scenario (Riahi et al., 2011).
- **Surface mixing ratios of Ozone Depleting Substances** (CFC-11, CFC-12, CFC-113, CFC-114, CFC-115, CCl4, CH3CCl3, HCFC-22, HCFC-141b, HCFC-142b, Halon1211, Halon1202, Halon1301, and Halon2402) in **REF-C1** are taken from WMO (2011). For models that do not wish to represent all the brominated and chlorinated species, the halogen content of species that are considered should be adjusted such that model inputs for total chlorine and total bromine match the time series of total chlorine and bromine given in this table. The missing species can lumped in with existing model tracers with similar lifetimes. If not explicitly included, very long lived CFCs (CFC-114, CFC-115) can be ignored.
- **Sea surface temperatures and sea ice concentrations** in **REF-C1** are prescribed as monthly mean boundary conditions following the global sea ice concentration and sea surface temperature (HadISST1) data set provided by the UK Met Office Hadley Centre (Rayner et al., 2003). This data set is based on blended satellite and in situ observations and can be downloaded from http://www.metoffice.gov.uk/hadobs/hadisst/data/download.html. To prepare the data for use in forcing a model, and in particular to correct for the loss of variance due to time-interpolation of monthly mean data, it is recommended that each group follows the procedures described on the C20C project web (see http://grads.iges.org/c20c/c20c_forcing/karling_instruct.html). This describes how to apply the AMIP II variance correction method (see http://www-pcmdi.llnl.gov/projects/amip/AMIP2EXPDSN/BCS/amip2bcs.php for details) to the HadISST1 data.
- **Surface Area Densities (SADs)** from observations are considered in **REF-C1**. A monthly zonal mean time series for SADs from 1979 to 2005 was created using data from the SAGE I, SAGE II, SAM II, and SME instruments (units square microns per cubic centimeter). This time series was published in (SPARC, 2006). In addition, uncertainties of the SAGE II data set are described in detail in Thomason et al. (2008). The altitude and latitude range of this data set is 12 - 40 km and 80°S – 80°N respectively. The SPARC SAD data set does have data gaps, which occur mainly in lower tropical altitudes (below 16 km) and during the El Chichón period. Above 26 km there are large data gaps in the mid-to-high latitude region. There are also missing data at all altitudes in the high latitude polar regions. For CCMVal-2, the NCAR group modified the SPARC SAD data set for CCM applications by filling the missing data using a linear interpolation approach in altitude and latitude. Large gaps of data above 26 km were filled with background values of 0.01 square microns per cubic centimeter. In the upper

troposphere, tropical latitudes, data gaps were filled without scientific considerations. Update dataset to 2010 and update this paragraph.

- **Stratospheric warming and tropospheric-surface cooling due to volcanic eruptions** are either calculated on line by using aerosol data or by prescribing heating rates and surface forcing. For those models that don't calculate this effect online, **pre-calculated zonal mean aerosol heating rates** (K/day) and **net surface radiative forcing** (W/m^2) monthly means from January 1950 to December 1999 for all-sky condition are available on the CCMVal website. They were calculated using volcanic aerosol parameters from Sato et al. (1993), Hansen et al. (2002) and GISS ModelE radiative routines and climatology (Schmidt et al., 2006). In addition to the larger eruptions (Agung, 1963; El Chichón, 1982; Pinatubo, 1991), smaller ones like Fernandina (1968 in Galapagos) and Fuego (1974 in Guatemala) are included. Surface radiative forcing is negative corresponding to cooling caused by volcanic aerosols. The right way to use these data sets to mimic the effect of volcanic eruptions would be to apply heating rates to the atmosphere and cooling flux to the surface. Heating rates and surface forcing would characterize the entire volcanic effect that is: stratospheric warming and tropospheric-surface cooling. If the focus is on stratospheric processes only aerosol heating rates could be used without causing any problem. Update beyond December 1999. There have been a number of small eruptions that have been well-characterized.
- **Solar variability.** For the solar forcing data, we follow the recommendations for CMIP5, see http://sparcsolaris.gfz-potsdam.de/cmip5.php.
- **Quasi-Biennial Oscillation.** The QBO is generally described by zonal wind profiles measured at the equator. The QBO is an internal mode of variability of the atmosphere that dominates the interannual variability in wind in the tropical stratosphere and contributes to the variability in the extratropical dynamics. It is recognized that the QBO is important for understanding interannual variability in ozone and other constituents of the middle atmosphere, in the tropics and extratropics. Currently only a few atmospheric GCMs or CCMs simulate a realistic QBO and hence QBO related influences. Simulated QBOs are generally independent of observed time series because their phase evolutions are not bound by external boundary conditions. Realistic simulated QBOs, however, have similar periods, amplitudes and composite structures in observations. The assimilation of the QBO, for example by a relaxation of zonal winds in the QBO domain ("nudging"), hence may be useful for two reasons: First to obtain a QBO in GCMs that do not simulate the QBO internally, so that for example QBO effects on the general circulation are present; and second to synchronize the QBO simulated in a CCM with a given QBO time series, so that simulated QBO effects, for example on ozone, can be compared to observed signals. Datasets for this purpose and examples for the "nudging" of the QBO in a GCM are discussed on the CCMVal web site. To be updated.
- **Very short lived species (VSLS):** Draft for discussion: In order for the models to have a realistic stratospheric bromine loading, and thereby be able to reproduce past ozone depletion, they will need to account for the transport of bromine to stratosphere by VSLS. We recommend that models explicitly include the two major VSLS species CHBr3 and CH2Br2, Time independent surface mixing ratios of these will be specified. The tracers will decompose to inorganic Bry. Based on past experience we expect that imposing a surface vmr of 1.2 pptv of each (6 pptv bromine) should lead to about the required 4.5 – 5.0 pptv Bry reaching the stratosphere. For models who do not wish to include these VSLS and model tropospheric loss, the model CH3Br tracer can be increased by a constant 5 pptv.

- **Natural biogenic emissions and lightning NO_x emissions**. These emissions are sensitive to meteorological variability and climate change. It is preferable that models diagnose these emissions online through parameterizations sensitive to changes in meteorology and climate. However, we recognize that all groups may not have the capacity to specify internally interactive emissions. We recommend that those groups obtain biogenic emissions, preferably consistent with their meteorology, from a group with the capability of diagnosing these emissions online (the PEGASOS project may provide biogenic emissions). Climatological emissions may provide an acceptable solution for those models with an upper tropospheric emphasis. Lightning emissions are more difficult to specify in an externally consistent manner, but are important to upper tropospheric variability and the tropospheric oxidant balance.
- **Anthropogenic, biofuel and biomass burning emissions**. The MACCity emission dataset (Granier et al., 2011) are proposed for anthropogenic, biofuel and biomass emissions. This emission inventory provides a strong link to the ACCMIP and CMIP5 simulations. MACCity extends the ACCMIP dataset (Lamarque et al., 2010) covering the historical period from 1960 to 2010. This dataset provides an extension of the ACCMIP historical emissions dataset (Lamarque et al., 2010) to the year 2010. Since no global database existed which provided emissions of the main tropospheric gases for each year during the 1960–2010 period, a dataset was created, based on the 1960 and 2000 ACCMIP emissions, and the 2005 and 2010 emissions provided by RCP 8.5. This scenario includes some information on recent emissions at the regional scale in Europe and North America. The emissions for each compound were linearly interpolated, for each sector and each year between 2000 and 2005, and for each year between 2005 and 2010, using the ACCMIP and RCP 8.5 emissions. For anthropogenic emissions, a seasonal cycle was first applied sector by sector, species were then lumped to MOZART-4 species (21 species), and finally emissions were interpolated on a yearly basis between the base years 1990, 2000, 2005 and 2010. Prior to 2005 the emissions are interpolated from decadal time slices. In 2005 and 2010 the emissions are extrapolated using the RCP 8.5 emissions scenario. There is also a version of this inventory that uses the reported 2000-2008 emissions in EMEP, but will not capture the 2008-2009 downturn. More work needs to be done to compare and document differences between the MACCity inventory and other available inventories. Volatile organic carbon (VOC) emissions are always problematical due to the use of lumped VOC species and the different emitted species in different chemical mechanisms. The MACCity emission inventory translates from the ACC-MIP VOC emissions to those appropriate for the MOZART mechanism. Stevenson et al. (2006) recommends using the global speciation given in Prather et al. (2001) with species not included either lumped into others or ignored. Regionally there is likely to be more information for lumping VOCs, but to gather and incorporate this information would need some work. The simulated VOC emissions, speciation and chemistry (Stevenson et al., 2006) likely leads to important differences in the chemistry and needs to be clearly documented in the output. In addition sensitivity studies will likely to be needed to document the impact of different emission inventories. The MACCity emissions can be downloaded from the Emissions of atmospheric Compounds & Compilation of Ancillary Data (ECCAD) database website at http://eccad.sedoo.fr after registration as a user.
- **Aerosol concentrations:** Models that do not simulate aerosols interactively will need to specify a time varying aerosol climatology. A subset of models for CMIP5 have used decadal averages from Lamarque et al. (2010) which can be provided. Alternatively, it might be possible to use results from ACCMIP (tbd). Care needs to be taken to specify the radiative characteristics of these aerosols so as to be compatible with the model's radiation scheme. Common datasets can be shared through web access.

- **Stratospheric boundary conditions for models without interactive stratospheric chemistry.** As recommended for CMIP5 simulations without interactive chemistry, ozone can be prescribed from the AC&C/SPARC ozone database (Cionni et al., 2011). Other stratospheric boundary conditions need to be specified. Common datasets can be shared through the web access. These boundary conditions should include the impact of Pinatubo, solar forcing and aerosol loading in the stratosphere. To be further specified.

2.2 HINDCAST: Reference simulation nudged 3 (REF-C3), Core time period 1980 to 2010

REF-C3 is a transient simulation from 1980 to 2010 that is either nudged towards observed meteorology in a CCM or simulated with a CTM, where the meteorology is prescribed. Otherwise, the forcings are similar to those of **REF-C1**. Compared to **REF-C1**, this simulation can be more directly compared to observations. In free-running mode CCMs simulate a statistical relationship to the real atmosphere, and so a comparison of model results with measurements must be performed in a statistical manner. This is problematic, because it takes many decades of observations to define a robust climatology. To allow a more direct comparison of the model output with observations in CCMs, **REF-C3** complements **REF-C1**. In **REF-C3**, meteorological parameters (e.g., temperature, surface pressure, vorticity and divergence) are “nudged” towards meteorological analysis. Alternatively CTMs can be used for **REF-C3** where the meteorology is specified by the meteorological analysis. These setups make comparisons of the simulation period to observations of a specific year possible. This is particularly beneficial as some observational data often only cover short time periods. There is a discontinuity in reanalysis datasets near 1979 with the incorporation of satellite data into the reanalysis product, making the interpretation of these simulations prior to 1980 problematic.

2.3 FUTURE PROJECTIONS: Reference simulation 2 (REF-C2), Core time period 1960 to 2100

REF-C2 is an internally consistent simulation from the past into the future between 1960 and 2100. This simulation is designed for CCMs. The objective of **REF-C2** is to produce best estimates of the future ozone-climate change up to 2100 under specific assumptions about GHG as well as tropospheric ozone and aerosol precursors that follow RCP 4.5 (Thomson et al., 2011) and a specified ODS scenario that follows the halogen scenario A1 from WMO (2011). **REF-C2** only includes anthropogenic forcings. External natural forcings such as solar variability (tbd; not compliant with CMIP5) and volcanic eruptions are not considered, as they cannot be known in advance, and the QBO is not externally forced (also as it cannot be known in advance; furthermore it represents the internal dynamics of the model). To avoid introducing inhomogeneity into the time series, these natural forcings are not applied in the past either.

- **Greenhouse gas concentrations** (N_2O, CH_4, and CO_2) are taken from Meinshausen et al. (2011), but extended so that they cover annual concentrations and the period from 1950 to 2100 from the RCP 4.5 scenario (Thomson et al., 2011).

- **Surface mixing ratios of Ozone Depleting Substances** are based on the halogen scenario A1 from WMO (2011). The new lifetimes from the SPARC Lifetime Assessment will be released in early 2013. The report will include new lifetime estimates along with uncertainties for those lifetimes. After the release of these new lifetimes, the production of a new scenario A1 will be start. In addition to a new A1, a "high" ODS scenario and a "low" ODS scenario based upon the uncertainties of the lifetimes will be produced.

- **Background aerosol** is prescribed from the extended *SPARC* [2006] SAD data set (see **REF-C1**) for the year 2000. Update this paragraph?

- **Sea surface temperatures and sea ice concentrations in REF-C2.** One of the most critical issues is the design of the future simulation **REF-C2**. Discrepancies between observed and simulated SST and SICs complicate the selection of these fields for runs that span the past and the future. Because of potential discontinuities between the observed and modeled data record, the **REF-C2** simulations use simulated SSTs and SICs for the entire period. There are three alternate approaches, depending on the resources of each modeling group.
    1. First, groups that have fully coupled atmosphere-ocean models with coupled chemistry and a middle atmosphere should perform a fully coupled run that calculates the SSTs/SICs internally. Due to the inertia of the coupled atmosphere ocean system, such integrations should be started from equilibrated control simulations for preindustrial conditions, as it is standard for the 20th century integrations in CMIP5 (i.e., from 1850-2100).
    2. Second, groups that have a coupled atmosphere-ocean model that does not include chemistry should use their own modeled SSTs/SICs to prescribe those in the CCM integration during the period 1960-2100.
    3. Third, groups that do not have their own coupled ocean-atmosphere model should use SSTs/SICs from an RCP 4.5-CMIP5 simulation.
- **Solar variability.** For the solar forcing data, we follow the recommendations for CMIP5, see http://sparcsolaris.gfz-potsdam.de/cmip5.php. The recommendation is to repeat the last cycle (cycle 23), with values from 1996 to 2008 inclusive mapping to 2009-2021, 2022-2034 etc. Please note that cycle 23 starts in 1996.4 and ends in 2008.6. To be discussed.
- **Very short lived species (VSLS):** Same methodology as **REF-C1** with constant surface vmr of VSLS species through to 2100. To be discussed.
- **Natural biogenic emissions, lightning NO_x emissions and biomass burning emissions**. The magnitude and variability of these emissions depends on climate. Recently the capability to simulate interactive biomass burning has been added to ESMs. Models without the capability to explicitly simulating these emission types are advised to use constant climatological emissions. Common datasets can be shared through web access.
- **Anthropogenic, biofuel and biomass burning emissions** in **REF-C2** are similar to **REF-C1** until 2010. After 2010 they follow RCP 4.5 (Lamarque et al., 2011).
- **Aerosol concentrations:** These can be specified as in **REF-C1**.
- **Stratospheric boundary conditions for models without interactive stratospheric.** As recommended for CMIP5 simulations without interactive chemistry, ozone can be prescribed from the AC&C/SPARC ozone database (Cionni et al., 2011). Other stratospheric boundary conditions need to be specified. Common datasets can be shared through the web access. These boundary conditions should include the impact of Pinatubo, solar forcing and aerosol loading in the stratosphere. To be further specified.

Table 1: Summary of proposed IGAC-SPARC CCMVal reference simulations.

Scenario	Period	Greenhouse Gases	ODSs	SSTs/SICs	Background & Volcanic Aerosol	Solar Variability	VSLS	QBO	Ozone and Aerosol Precursors
REF-C1	Transient simulation 1960-2010	OBS GHG used for CMIP5	OBS (WMO, 2011)	OBS HadISST1	OBS Surface Area Density data	OBS Spectrally resolved	YES	OBS or internally generated	OBS Based on Lamarque

	Appropriate spin up prior to 1960	simulations, updated until 2010.			(SAD)	irradiance data			et al. (2010), but annual emissions
REF-C2	Transient simulation 1960-2100 10-year spin up prior to 1960	RCP 4.5 (Thomson et al., 2011)	OBS + A1 scenario from WMO (2011)	Modeled SSTs	OBS Background SAD from 2000	YES Spectrally resolved irradiance data	YES	Only internally generated	Same as REF-C1 until 2005 + RCP 4.5 scenario in the future
REF-C3 (nudged for CCMs, or CTMs)	Transient simulation 1980-2010	OBS GHG used for CMIP5 simulations, updated until 2010.	OBS (WMO, 2011)	OBS Consistent with met. reanalysis (ERA-Interim)	OBS Surface Area Density data (SAD)	OBS Spectrally resolved irradiance data	YES	OBS or internally generated	OBS Based on Lamarque et al. (2010), but annual emissions

3. IGAC-SPARC CCMVal Sensitivity Simulations (additional sensitivity simulations from ACCMIP as well as possibly other suggestions from the community will be added; to be determined at the workshop)

The following IGAC-SPARC CCMVal sensitivity simulations are proposed (to be prioritized at the workshop):

SCN-C1-Emis / SCN-C3-Emis is a sensitivity study that involves that individual groups specify their own emission inventory that is different to that in **REF-C1** and **REF-C3**. Otherwise the specification of forcing is as in **REF-C1** or **REF-C3**. This simulation will assess the importance of using different emission inventories in tropospheric chemical variability.

SCN-C1-fEmis / **SCN-C3-fEmis** is a sensitivity study that involves using constant anthropogenic, biofuel, biogenic and biomass burning emissions. Otherwise the specification of forcings is as in **REF-C1** or **REF-C3**. This simulation will assess the importance of meteorology in tropospheric chemical variability.

SCN-C1-fLC / **SCN-C3-fLC** is a sensitivity study that assesses the impact of changing land-cover on tropospheric chemistry. In **REF-C1** and **REF-C3** changing land cover is included. In these sensitivity studies land cover would assumed to remain fixed. These simulations will be run as **SCN-C1-fEmis** or **SCN-C3-fEmis**, except biogenic emissions will vary. As biomass burning emissions depend crucially on land cover some thought must be given as how to specify these in **SCN-C1-fLC** / **SCN-C3-fLC**.

SCN-C2-RCP (2000-2100, REF-C2 with GHG scenario different than RCP 4.5) is a transient simulation similar to **REF-C2**, but with the GHG and ozone precursor scenario changed from RCP 4.5 (Thomson et al., 2011) to RCP 2.6 (van Vuuren et al., 2011b), RCP 6.0, and RCP 8.5 (Riahi et al., 2011). Accordingly, if the model does not include an interactive ocean, SSTs and SICs are prescribed from an AOGCM simulation that is consistent with the GHGs scenario. The ODS scenario in all these simulations remains as in **REF-C2**. The sensitivity of stratospheric ozone has been studied in Eyring et al. (2010b), but with a limited number of scenarios performed by only a small number of models. These sensitivity simulations will allow assessing the future evolution of the ozone-climate change under a different GHG scenario than the RCP 4.5 scenario used in **REF-C2**.

SCN-C2-fODS (1960-2100, REF-C2 with halogens fixed at 1960 levels) is a transient simulation similar to **REF-C2**, but with halogens fixed at 1960 levels throughout the simulation, whereas GHGs and SSTs/SICs are the same as in **REF-C2**. It is designed to address the science question of what are the effects of halogens on stratospheric ozone and climate, in the presence of climate change (Eyring et al., 2010a). By comparing **SCN-C2-fODS** with **REF-C2**, the impact of halogens can be identified and it can be assessed at what point in the future the halogen impact is undetectable, i.e., within climate variability. This was the definition of full recovery of stratospheric ozone from the effects of ODSs that was applied in WMO (2011)

SCN-C2-fGHG (1960-2100, REF-C2 with GHGs fixed at 1960 levels) is a transient simulation similar to **REF-C2**, but with GHGs fixed at 1960 levels throughout the simulation, whereas the adjusted scenario A1 halogens are the same as in **REF-C2**. It is designed to address the science question of how nonlinear are the atmospheric responses to ozone depletion/recovery and climate change (Eyring et al., 2010a). To that end, GHGs are fixed at 1960 levels throughout the simulation. SSTs/SICs will be a 1955-1964 average of the values used in **REF-C2**. By comparing the sum of **SCN-C2-fODS** and **SCN-C2-fGHG** (each relative to the 1960 baseline) with **REF-C2**, the nonlinearity of the responses can be assessed. **SCN-C2-fGHG** also addresses the policy-relevant (if academic) question of what would be the impact of halogens on the atmosphere in the absence of climate change.

SCN-C2-fEmis (1960-2100, REF-C2 with emissions fixed at 1960 levels) is designed to address the impact of climate change (Stevenson et al., 2006). To be updated.

SCN-C2-GeoMIP is a set of transient simulations to test the climate system response to solar radiation management with stratospheric aerosols, as part of GeoMIP. Kravitz et al. (2011) describe four sets of standardized experiments using solar constant reduction or stratospheric aerosol clouds to either balance anthropogenic radiative forcing or reduce it quickly. Many of these runs have been completed and are now being analyzed, but there are still many interesting questions that can be addressed by CCMs. The G1 and G2 experiments involve reducing the total solar irradiance to balance either an instantaneous quadrupling of CO_2 or a 1%/year increase of CO_2, and would be most appropriate for models with interactive oceans. G3 and G4 involve balancing an RCP4.5 forcing with sulfate aerosols in the stratosphere or a continuous 5 Tg/year stratospheric sulfate injection, and all CCMs could simulate the stratospheric chemical and dynamical responses, in addition to the other climate changes. Models without oceans will need to have SSTs provided from other GCM runs. SADs and net radiative flux changes will be needed for models that do not create their own stratospheric aerosols and the radiative response from SO_2 or sulfate injections.

SCN-C2-Vol Should we have a couple volcanic eruption experiments starting in 2020, one the same as 1991 Pinatubo and one the same as (or larger than) 1912 Katmai (Novarupta), that is a large tropical and a large high-latitude eruption? Please indicate in the questionnaire if you are interested in such a simulation.

Table 2: Summary of proposed IGAC-SPARC CCMVal sensitivity simulations.

Scenario	Period	GHGs	ODSs	SSTs/SICs	Background & Volcanic Aerosol	Solar Variability	VSLS	QBO	Ozone and Aerosol Precursors
SCN-C1-Emis	1960-2010	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Different from REF-C1
SCN-C3-Emis	1980 2010	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Different from REF-C3
SCN-C1-fEmis	1960-2010	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Fixed at 1960 levels
SCN-C3-fEmis	1980-2010	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Fixed at 1980 levels
SCN-C1-fLC	1960-2010	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	Same as in REF-C1	OBS or internally generated	Same as in REF-C1, but non-changing land-cover
SCN-C3-fLC	1980-2010	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	Same as in REF-C3	OBS or internally generated	Same as in REF-C3, but non-changing land-cover
SCN-C2-RCP2.6	2000-2100	OBS + RCP 2.6	Same as in REF-C2	SSTs/SICs distribution consistent with RCP 2.6 GHG scenario	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as REF-C1 until 2010 + scenario consistent with GHGs
SCN-C2-RCP6.0	2000-2100	OBS + RCP 6.0	Same as in REF-C2	SSTs/SICs distribution consistent with RCP 6.0 GHG scenario	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as REF-C1 until 2010 + scenario consistent with GHGs
SCN-C2-RCP8.5	2000-2100	OBS + RCP 8.5	Same as in REF-C2	SSTs/SICs distribution consistent with RCP 8.5 GHG scenario	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as REF-C1 until 2010 + scenario consistent with GHGs
SCN-C2-fODS	1960-2100	Same as in REF-C2	Fixed halogens at 1960	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-	Same as in REF-C2	Same as in REF-C2

			level				C2		
SCN-C2-fGHG	1960-2100	Fixed GHG at 1960 levels	Same as in REF-C2	1955-1964 average of values used in REF-C2, repeating each year	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2
SCN-C2-fEmis	1960-2100	Fixed ozone and aerosol precursors	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Fixed at 1960 levels
SCN-C2-GeoMIP	2020-various	4xCO_2, 1%/year CO_2 or RCP4.5	Same as in REF-C2	Modeled or specified SSTs	Specified by GeoMIP experiment	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2
SCN-C2-Vol	2020-2100	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Volcanic eruptions in the future	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2

4 Simulations for Process Studies

In contrast to the sensitivity simulations, that cover similar long time periods that the reference simulations, shorter simulations for process studies in the troposphere and stratosphere might be additionally proposed to study specific aspects (to be determined at the workshop).

Table 3: Summary of proposed IGAC-SPARC CCMVal simulations for specific process studies.

Scenario	Period	GHGs	ODSs	SSTs/SICs	Background & Volcanic Aerosol	Solar Variability	VSLS	QBO	Ozone and Aerosol Precursors
PRO-C1a									
PRO-C1b									
PRO-C1c									
PRO-C1d									
PRO-C1e									

PRO-C1f									

5 Output Format

Output from this new set of simulations will be collected in Climate and Forecast (CF) standard compliant netCDF format from all models in the central CCMVal database at the British Atmospheric Data Centre (BADC). In addition, we anticipate obtaining observational datasets for the core diagnostics. The specified forcings for the new reference simulations and the new data request will be made available for download at the CCMVal website.

6 Output Requests (to be updated based on discussions at the workshop and outcome of the expert teams and working groups)

Output requests will broadly follow the requests made by the ACCMIP and CCMVal activities in their previous rounds. As noted, it is recognized that the runs and output are a significant burden on modeling groups, and significant effort will be placed on prioritizing output requests for simulations that are needed in the near term (for the next WMO/UNEP Scientific Assessment of Ozone Depletion and within three years). For the stratosphere the request will be a reduced set compared to the request in support of the SPARC-CCMVal (2010) report, for example mostly focusing on monthly means.

6.1 Key output for stratospheric processes

6.1.1 *Monthly outputs*

Monthly means: 3D monthly means of state variables (T, U, V, geopotenital height) and chemical fields (from CCMVal-request: H_2O, O_3, Halogens, etc), key stratospheric chemistry diagnostics. Also 3D fields of cloud fractions and heating rates. 2D fields of tropospheric climate parameters (top of atmosphere radiative fluxes, cloud forcing, surface temperature, surface precipitation). As noted, this will be a REDUCED subset of the CCMVal-2 request: with more focus on monthly means. The only additional fields will be a strong request for 2D climate parameters in the troposphere, and radiative fluxes.

6.1.1 Sub-monthly output:

Wave fluxes and transport diagnostics: a limited set of fields (daily total ozone for example) will be requested.

6.2 Key output for tropospheric processes:

6.2.1 *Monthly outputs of chemical variables:*

(i) Species concentrations of: O_3, CO, NO, NO_2, HNO_3, PAN, OH, SO_2, anthropogenic NMVOC, biogenic NMVOC including explicit concentrations of isoprene and terpene, DMS, long-lived NMVOC, medium-lived NMVOC, and short lived NMVOC.

(ii) CFCs, SF_6 and CH_3CCl_3: CFCs were used in the earliest to test and calibrate global transport and mixing. It was suggested that the year-to-year variations in Samoa represented large changes in the inter-hemispheric mixing as opposed to merely a shift in the southern ITCZ. The modeling analysis by Nevison et al. (2007) supports the latter view, but leaves open uncertainties in stratosphere-troposphere exchange as a source of variability. Extending the Nevison et al. (2007) work to stratospheric-tropospheric models might allow resolution of this question. In addition, CH3CCl3 is used to diagnose OH and was used (with given OH concentrations) in TRANSCOM-CH_4. We encourage additional models to follow the TRANSCOM-CH_4 (Patra et al., 2011) protocol in simulating SF_6 and CH_3CCl_3, but with variable interannual variability in OH. The results may possible augment the TRANSCOM-CH_4 archive.

(iii) Mass fraction aerosol concentrations of: PM_{10}, $PM_{2.5}$ and PM_1 at 35% and 50% relative humidity; mass fraction concentrations of nitrate, sulfate, ammonium, black carbon, particulate organic matter, secondary aerosols, sea-salt, dust and aerosol water

(iv) Chemical budget terms: chemical gross production of ozone [to be precisely defined], chemical loss of ozone [to be precisely defined], rate of CH_4 oxidation, and the rate of CO oxidation. CO from methane oxidation, and in NMVOC oxidation (including biogenic oxidation) can be tracked as in HTAP using simple assumptions concerning the yields of CO. The formation rate of nitrates and PAN, production of NO_x from nitrates and PAN, and impact of aerosols on chemical species will also be tracked. Nitrate production and loss should be integrated over all nitrates with perhaps some individual speciation.

(v) Surface Dry Deposition of all species. This should include O_3 and O_3 in stomata, HNO_3, Nitrogen oxides, ammonia, ammonium, SO_2, and all aerosol types

(vi) Surface Wet Deposition of all species. This should include HNO_3, ammonium, ammonia, SO_2, and all aerosol types

(vii) Emission fluxes of: all emitted species (together with the output dry deposition rates calculated above this will allow for a comparison with dry deposition networks).

(viii) Meteorological variables: Temperature, specific humidity, convective mass flux, surface pressure and precipitation. GCM simulations should output additional monthly averaged meteorological variables.

6.2.2 Hourly output:

(i) Surface O_3, CO and NO_2 (hourly averaged or instantaneous). Perhaps better would be to output these variables at a reference height. We might also want to include select locations above the model surface (e.g., Jungfraujoch, Mt Batchelor) that correspond to mountain top measurement stations.

(ii) Boundary Layer Height

6.2.3 Daily output:

(i) Ozone at ozonesonde stations (also perhaps CO, NO and NO_2).

(ii) Meteorological output including winds, temperature, pressure, specific humidity, convective mass flux, precipitation and potential vorticity (due help diagnose stratospheric air). Output of meteorological variables is particularly important for GCMs as the CTMs meteorological fields can be obtained from the reanalysis.

(iii) Ozone and CO (to allow a better look at O_3-CO correlations).

(iv) Mean optical thickness of all aerosol types at 550 nm (daily averaged)

(v) Other relevant surface air quality air pollutants: $PM_{2.5}$, PM_{10}.

6.2.4 *Diagnostic tracer output:*

(i) Stratospheric ozone tracer (specified to ozone values in the stratosphere with a fixed loss rate of 3 days (?) in the troposphere). This species also can help track interannual variability in SST.

(ii) HTAP tracers: CO tracers with 50 day lifetime: CO emitted from anthropogenic VOC, biogenic VOC and methane.

(iii) Methane tracer: CH4_t + OH → OH plus stratospheric loss rate. (This should be in coordination with TRANSCOM-CH4)

(iv) Tropopause tracer as suggested by Prather et al. (2011)

6.2.5 *Output for Diagnostics of OH budget (monthly):*

(i) O_3 + h ν-> O1D + O_2 photoloysis
It would be good to also know the impact of aerosols, clouds and o3 column on this. Thus aerosol optical depth, cloud distribution, cloud optical depths, surface albedo should be calculated.

(ii) O1D production

(iii) HO_x production (through ozone and water vapor)

(iv) HO_x loss through HNO_3, H_2O_2 deposition + other

(v) OH loss (total loss) and the following specific losses:
   a. Oxidation of CH_4
   b. Oxidation of other hydrocarbons
   c. Loss through oxidation of ozone
   d. Oxidation of isoprene and terpene
   e. Sulfate oxidation

(vi) non-primary HO production –e.g., HO_2 + NO

(vii) HO_2 production rate

(viii) HO_2 loss rate

(ix) Explicit calculation of the impact of aerosols on oxidant budget

6.2.6 *Other diagnostic output:*

(i) PAN diagnostics. Suggested output includes: PAN production and loss; ratios with other species including PAN/HNO_3, PAN/CO and PAN/O_3. High frequency output at selected stations would probably be most beneficial. (Because ozone is a highly buffered system it is very possible to get the approximately correct concentration for the wrong reason. Arlene Fiore (personal communication) suggests PAN might more accurately reflect tropospheric chemical processes than ozone.) PAN appears to be highly sensitive to VOCs in addition to NOx (Fiore et al., 2011) and is sensitive to transport processes (Fischer et al., 2011). Required PAN diagnostics and output frequency would ideally be tested prior to the hindcast simulations.

(ii) NO_2 photolysis clear and cloudy sky. (NO_2 is relatively insensitive to the ozone column and thus is a good indicator of the impact of clouds and aerosols on the photolysis rate).

(iii) High frequency output at special locations. High frequency output of key variables might be desirable at key locations such as field campaigns, or sites where the data needs to be filtered to isolate the clean air sector. In addition to chemical variables, meteorological output should be output at these sites including temperature, relative humidity and selected photolysis rates. (A model output tool developed by J. Staehelin (http://www.megdb.ethz.ch/index.php) and used in Brunner et al. (2003) would be available to reduce high frequency output rather efficiently. Each group would produce high frequency output, sample any particular measurements locations, then delete the high frequency output if desired and keep the sampled output. Alternatively there is a tool available through NCAR of outputting at specific locations. In either case it is important to decide on the special output locations in advance.)

(iv) Ozone flux across 300 hPa or surface.

(v) Monthly lightning flash rates from the simulations for comparison with the OTD-LIS satellite instruments. This will serve as a test of the model's ability to represent the spatial and temporal variation in lightning NOx emissions, and in turn its effect on free tropospheric ozone.

(vi) Vertical profiles of aerosol extinction at 1:30 AM and PM from 2006 onward for comparison with the CALIPSO satellite. Daily profiles are best. Monthly means may be ok.

6.2.7 *Output for key variables in coordination with HTAP and PEGASOS*

-To be coordinated with these groups.

6.3 Satellite output and online diagnostics

Draft from satellite expert groups (Tegtmeier, Hegglin et al.; Duncan et al.); to be further discussed at the workshop

6.3.1 Column data sets:

- Total ozone column information from TOMS, GOME, OMI
- Other important total column observations include NO_2 and CH_2O from GOME (1995-2003), SCIAMACHY (2002 - present), OMI (2004 - present) and GOME-2 (2006 - present).

6.3.2 Partial-column data sets

- CO information from TES, IASI, AIRS and MOPITT
- O_3 and H_2O information from TES

6.3.3 Profile data sets:

i. Single profile measurements: Single profile measurements are available from a large set of long-lived and short-lived trace gases available from various satellite instruments on measurement grid. In particular the high-precision observations of short-lived trace gases from the ACE-FTS satellite instrument have been proven helpful to evaluate stratospheric chemistry of CCMs within the last CCMVal report (2010). Further short-lived species are available from Aura-MLS, MIPAS, and SMILES. The later in particular would be useful for comparison of daily cycles in short-lived species in the REF-C3 simulations.

ii. Climatological data sets: Monthly zonal mean time series of 25 different trace gas species (CH_4, N_2O, HNO_3, N_2O_5, NO_x, HCl, ClO, OClO, HOCl, HF, BrO, SF_6, CO, …) and aerosol are available on the CCMVal pressure grid from the SPARC Data Initiative data archive which will be made available on the SPARC data center http://www.sparc.sunysb.edu/). The available data sets stem from more than 15 instruments (e.g., ACE-FTS, Aura-MLS, SCIAMACHY, SAGE-series, POAM-series, SMR, OSIRIS, MIPAS). Chemical families currently available are NO_x and NO_y, but no Cl_y or Br_y yet. The monthly zonal mean time series of the longer-lived trace gases are especially important to evaluate different transport processes in the stratosphere and associated variability.

6.3.4 Model output required for comparison

Sampling patterns from the satellite instruments that are included in the SPARC Data Initiative are provided on the SPARC Data Initiative archive. These should be considered in the model output and the model output be sampled in the same way as the satellite data to avoid differences due to inhomogeneous sampling or diurnal variations

In addition, satellite output requires outputting at specific local times, see examples in Table 4. Ideally we would request output of NO_2, CH_2O, SO_2, CO and O_3 at a few local times (10:00, 1:45 tbd). Also mean optical thickness of all aerosol types at 550 nm would be valuable. For the IR and microwave instruments, AIRS, IASI, MLS, TES, night time measurements from the descending modes are appropriate. Aura is around 2am, IASI around 9:30pm. While daily sampling would be optimal, monthly averaged profiles may be sufficient. In the case of TES O_3 and CO monthly means are sufficient to compare with satellite data (Aghedo et al., 2011).
In addition, output model profiles at the observational tangent points for SABER, Aura-MLS, HIRDLS, ACE-FTS, and SMILES instruments are very important in particular for the evaluation of species with large diurnal variation (e.g., ClO) in the **REF-C3** simulations.

Other sampling requirements need to be detailed for other satellite instruments, satellite simulators etc. To be completed by expert groups on satellite data.

Table 4: Orbit and sampling characteristics important for instrument-specific climatology construction. Examples are extracted from a preliminary version of *Table 3.1* of the SPARC-DataInitiative (2012) report (in preparation).

	Latitudinal coverage	Local time[1]	Local time measurement time[2]	Inclination[3]	Data density[8]
SAGE I on AEM-2	75°S–75°N (~over one season)	N/A	N/A	57°	30
SAGE II on ERBS	75°S–75°N (~over one season)	N/A	N/A	57°	30
HALOE on UARS	75°S–75°N (~over one season)	N/A	N/A	57°	30
MLS on UARS	80°S–80°N (~over two months)	N/A	N/A	57°	1300
OSIRIS on Odin	82°S–82°N (daily, no winter hemisphere)	a: 6:30 pm d: 6:30 am	a: 6:30 pm d: 6:30 am	97.8°	300 - 975
SMR on Odin	83°S–83°N (daily)	a: 6:30 pm d: 6:30 am	a: 6:30 pm d: 6:30 am	97.8°	600 - 975
GOMOS on ENVISAT	90°S–90°N (daily, no summer poles for night measurements)	a: 10 pm d: 10 am	a: 10-12 pm d: 8-10.30 am	98.55°	100-300 (night measurements)

MIPAS on ENVISAT	90°S–90°N (daily)	a: 10 pm d: 10 am	TBA	98.55°	1000 (1300 since 2005)
SCIAMACHY on ENVISAT	85°S–85°N (65° for winter hemisphere)	a: 10 pm d: 10 am	d: 10 am	98.55°	364 - 1456
ACE-FTS on SCISAT-1	85°S–85°N (~over one season)	N/A	N/A	74°	30
HIRDLS on Aura	65°S–82°N (daily)	a: 1:43 pm d: 1:43 am	a: 2:57 pm d: 0:30 am	98.21°	5600
MLS on Aura	82°S–82°N (daily)	a: 1:43 pm d: 1:43 am	TBA	98.21°	3500
TES on Aura	82°S–82°N (daily) (50°S-70°N for 2008/09; 30°S-50°N for 2010)	a: 1:43 pm d: 1:43 am	a: 1:43 pm d: 1:43 am	98.21°	3145 (2126 for 2008/09; 1890 for 2010)
SMILES on ISS	38°S–65°N (daily)	N/A	N/A	51.6°	1620

[1] Local time of equator crossing for satellites with sun-synchronous orbit (a=ascending, d= descending)
[2] Local time of measurement made at equator crossing for satellites with sun-synchronous orbit (a=ascending, d= descending)
[3] Inclination of the orbital plane

6.4 Output along specific flight paths

Draft from in situ expert group (Ryerson et al.), to be further discussed at the workshop

6.4.1 Charge for in situ-expert team

Identify methodology to meaningfully evaluate CCM simulations against in-situ observations via analyses that bridge these disparate temporal and spatial scales. Following the successful CCMVal exercise, carry out observation/model comparisons by improving access to vetted in-situ data sets to facilitate validation of model input inventories, to assess simulations of atmospheric processes, and to evaluate simulations of longer-term trends.

6.4.2 Topics for consideration

- Improve access to a database of vetted in-situ airborne aerosol/gas-phase observations
    - extension of the Emmons (1997, 2000) compilations
    - formatted and averaged to facilitate comparisons
    - generate metadata that include a campaign overview, time and location (latitude / longitude / height), observed vertical levels, measured species and their uncertainties, meteorological situation, targeted at specific events?
    - divide database into background and specific events?
    - Sample relative to tropopause height?
    - collect aircraft flight tracks into an international database to allow sampling of the model output at the times and locations of the measurements and the interpolation of the model data to the observed vertical levels
- Validate input inventories

  - compare simulated vs. observed tropospheric source area enhancement ratios (ERs) (e.g., BC/CO, halocarbons/CO, CO_2/CO)
  - compare ERs from different sectors (biogenic, developed and developing urban, industrial, shipping…)
  - compare simulated vs. observed biogenic emissions
  - compare emissions of very-short-lived species (VSLS)
  - permafrost?
- Assess chemical process simulations (this connects to other expert teams at the workshop)
  - sulfate formation in presence and absence of clouds (source term for scattering aerosol)
  - NOy budget following long-range transport (integrated effects of wet and dry processing)
  - Specific processes in the UTLS
- Evaluate simulations of longer-term trends
  - compare simulated to observed GHG/CO ERs over time

6.4.3 Suggestions for new simulations and measurements?

- Suggest nudged simulations, in addition to free-running simulations, for a more direct comparison to in-situ data and for process studies. => see REF-C3

7 Timeline

As outlined in Section 1.3, a key aspect of this document is to detail a long-term strategic plan for simulations that can meet the complex needs of simulating chemistry-climate interactions, while also seeking to prioritize simulations for near term (next 3 year) needs. The result is that these simulations are envisaged to occur in two main phases over the next few years. The timeline is summarized in Figure 1.

Near-term efforts in Phase 1 focus on the hindcast and on simulations supporting the 2014 WMO/UNEP Scientific Assessment of Ozone Depletion with currently existing models. A comprehensive hindcast and future projections will be repeated in Phase 2 with improved models that likely are also more complex and run at higher resolution than today. The long-term target of the IGAC-SPARC CCMVal initiative is 2017/2018, when chemistry-climate could be addressed in a much more comprehensive way than now, e.g. with interactive stratospheric chemistry, aerosols, tropospheric chemistry, biosphere and an ocean. It could be envisaged that the simulations of Phase 2 be part of the sixth phase of CMIP (CMIP6) to also bridge the gap with the climate community at that stage. Phase 2 simulations are therefore proposed to be delivered only in several years and are not defined in this document. The goal is to specify and detail the Phase 2 simulations in a follow-up document around 2016.

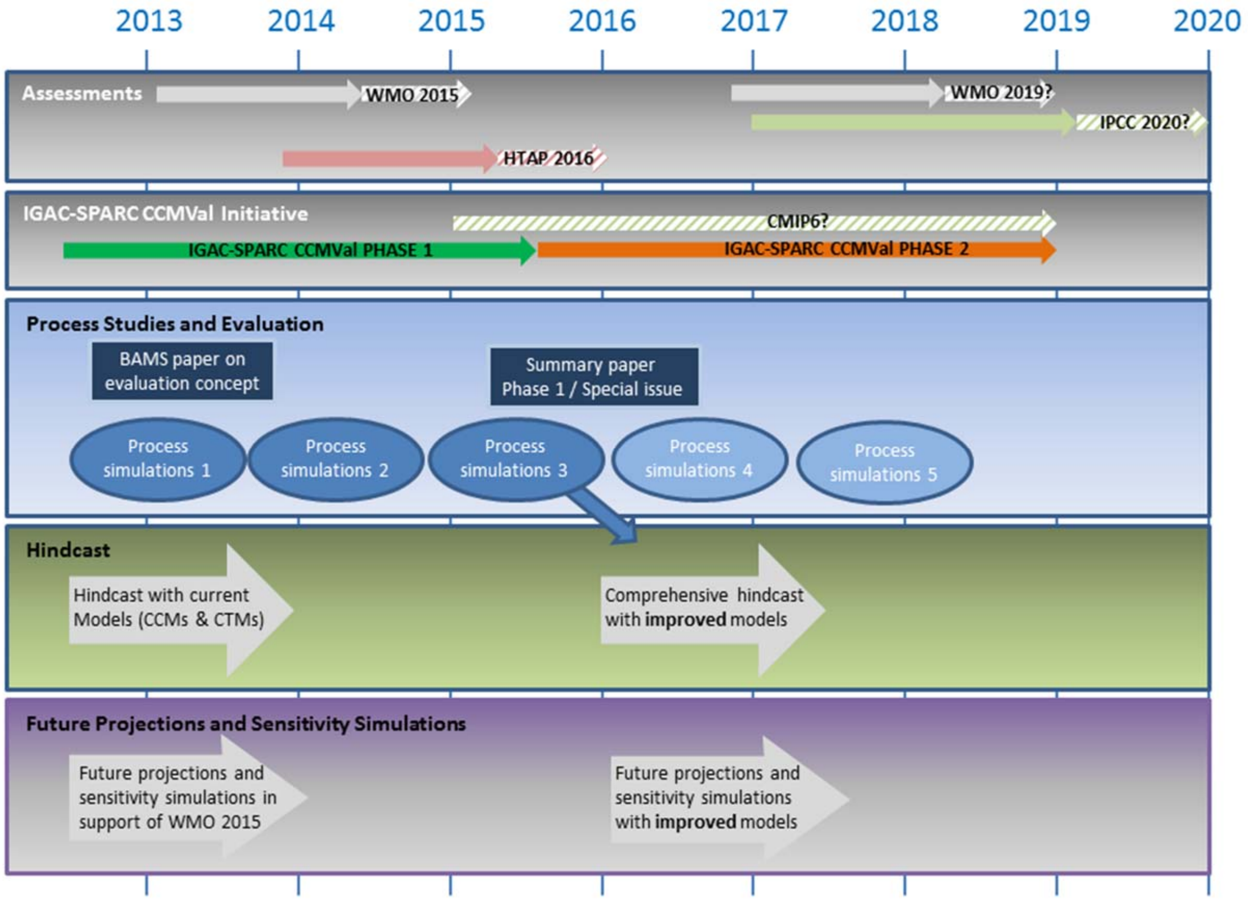

Figure 1. Proposed timeline for IGAC-SPARC CCMVal community wide simulations.

PHASE 1 (near-term, ~next 3 years):

The focus of PHASE 1 is on the hindcast simulation and simulations in support of the 2014 WMO/UNEP Scientific Assessment of Ozone Depletion (Phase 1). The new community wide hindcast simulations are **REF-C1** and **REF-C2**, which are also used in several projects currently underway and thus fulfill multiple purposes (to be specified). It also includes **REF-C2** which will be run in support of the 2014 WMO/UNEP Scientific Assessment of Ozone Depletion plus possibly additional sensitivity simulations (to be defined in Davos based on feedback from modeling groups), with results that can also be taken from existing similar simulations performed for CMIP5 and the SPARC lifetime assessment.

The timeline for the 2014 Ozone Assessment is predicated on several specific milestones: The co-chairs will start working on a draft outline in fall 2012, and an author team will be assembled in spring 2013. The 1st draft will have to be complete around October 2013, the 2nd draft around February 2014, and the 3rd draft in May 2014. The chapters would be finalized by July-August 2014. Therefore, results from the simulations would be required by around mid-2013. Given the computational complexity of the requests for **REF-C1** and **REF-C2** in particular (full chemistry and possibly coupled oceans) this would seem to require that scenario plans and data be set in the summer of 2012. To be updated.

PHASE 2 (long-term, until ~2017/2018):

One of the overall recommendations of the SPARC-CCMVal (2010) report was that the CCMVal assessment and projection process should be synchronized with that of CMIP to make the maximum use of human and computer resources, and to allow time for model improvements. Assuming that there will be another IPCC and WMO/UNEP assessment, they would be much better in phase than today and would open the opportunity to define chemistry-climate simulations as part of the CMIP6 protocol. Hence, as a community 2017/2018 could be considered as a major target where things could come together in a much more comprehensive way than now: stratospheric change, aerosols, tropospheric chemistry, biosphere and ocean. So, there is a long-term vision for this IGAC / SPARC CCMVal initiative. To be updated.

8. Summary and Outlook

CCM groups are encouraged to run the proposed reference simulations with the specified forcings. In order to facilitate the set-up of the reference simulations, SPARC CCMVal and IGAC have established a website where the forcings for the simulations can be downloaded (http://www.pa.op.dlr.de/CCMVal/Forcings/CCMVal_Forcings.html). This web site was developed to serve the needs of the CCM and CTM community, and encourage consistency of anthropogenic and natural forcings in future model/model and model/observation inter-comparisons. Any updates as well as detailed explanation and further discussion will be placed on this website. In addition to the reference runs the groups are encouraged to run as many as possible sensitivity and process simulations, but these will be prioritized for phase 1. The hope is that these additional runs will be available in time to provide useful input for the anticipated UNEP/WMO Ozone Assessment in 2014, so that the ozone projections from the CCMs can be assessed for different halogen and GHG scenarios.

The data will be collected in CF compliant netCDF format at BADC. For the collection of the data, a data policy similar to the one used in previous CCMVal and ACCMIP intercomparison will apply. It is expected that the groups submitting model output to BADC will organize to disseminate the results to the scientific community through a series of publications.

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