Overview of the New CCMVal Reference and Sensitivity Simulations in Support of Upcoming Ozone and Climate Assessments and the Planned SPARC CCMVal Report

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The CCMVal community has defined new reference and sensitivity simulations that will be carried out in support of upcoming ozone and climate assessments and that are tailored to the planned SPARC CCMVal report on the evaluation of coupled Chemistry-Climate Models (CCMs), see http://www.pa.op.dlr.de/CCMVal/SPARC_CCMValReport/SPARC_CCMValReport.html. The three reference simulations that should be run by the various modeling groups with highest priority are described in Section 1. Depending on the computing capacity of the individual groups, it is recommended that in addition to the reference simulations the sensitivity simulations described in Section 2 be performed by as many groups as possible. However, it is most important that groups simulate the full time period specified, to allow a reliable comparison between the different models.

The over-riding principle behind the choice of these reference and sensitivity simulations is to produce the best possible science. Accordingly, the first requirement is to evaluate the models against observations. That is the rationale behind REF-B0, a time-slice experiment performed under 2000 conditions, the period for which we have the most plentiful observations. A long reference run will provide good statistics for the model comparison. The second requirement is to see how well the models can reproduce the past behavior of stratospheric ozone. That is the rationale behind the 'past' transient reference simulation REF-B1, which is forced by observations. Experience in *Eyring et al.* [2006] showed that it is important to establish a good baseline from which to identify the effects of halogens on ozone, and to avoid spin-up problems. Based on this experience, REF-B1 requires around 10-years spin-up prior to a 1960 start. The third requirement is to see what the models predict for the future evolution of stratospheric ozone. That is the rationale behind the 'future' transient reference simulation REF-B2, which is forced by trace gas projections and modeled sea surface temperatures (SSTs). Experience in *Eyring et al.* [2007] showed 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). Based on this experience, REF-B2 also requires around 10-years spin-up prior to a 1960 start, and extension to 2100. To provide continuity with *Eyring et al.* [2007], and track any changes in the models, REF-B2 is based on the same GHG scenario (SRES A1B, medium) as used in *Eyring et al.*

[2007]. For both REF-B1 and REF-B2, it is recommended that groups perform at least a small ensemble (e.g. three simulations) so that an uncertainty range for the model results can be established.

The sensitivity simulations are designed to augment, in various ways, the science that can be obtained from the reference simulations. To rigorously assess the effects of perturbations on a climate simulation, and to quantify internal model variability, it is necessary to have a control run with constant forcings. That is the rationale behind the time-slice experiment CTL-B0 under 1960 conditions. While REF-B0 has constant forcings, it is in a strongly perturbed time period, and the 20-year period of REF-B0 is not sufficient to fully define multi-decadal variability. SCN-B1 is a sensitivity simulation that is consistent with REF-B1 with the exception that an additional source of stratospheric inorganic bromine (Br_y) from very short-lived substances (VSLS) is included, in light of the fact that observations derived from the breakdown of long-lived organic source gases underestimate the Br_y abundance in the stratosphere by about 5 ppt. In SCN-B2a, the GHG scenario is changed from A1B (medium) to A2 (or a new IPCC scenario to be defined in mid-2008). An A2-like scenario has been suggested by the Working Group on Coupled Modelling (WGCM) as one of the benchmark concentration scenarios for the next round of coordinated Atmospheric-Ocean Global Circulation Model (AOGCM) and Earth System Model (ESM) simulations. Thus SCN-B2a will allow us to 'map' the CCMVal REF-B2 results onto the A2 scenario. SCN-B2b (fixed halogens) is designed to address the science question of what is the effect of halogens on stratospheric ozone (and climate) in a changing climate (by comparison with REF-B2). SCN-B2c (no greenhouse-gas induced climate change) is designed to address the nonlinearity of ozone depletion/recovery and climate change (by comparison with REF-B2 and SCN-B2b). SCN-B2d is designed to address the impact of 'realistic' natural variability on the REF-B2 simulations, for which the natural variability is underestimated. Thus, all these sensitivity (and control) simulations are designed to augment, in various ways, the science that can be obtained from the reference simulations.

1. CCMVal Reference Simulations

This section gives an overview of the main characteristics of the new CCMVal reference (REF) simulations. The key characteristics are also summarized in Table 1.

1.1. TIME-SLICE EXPERIMENT (REF-B0)

REF-B0 is a time-slice experiment for 2000 conditions, proposed to facilitate the comparison of model output against constituent datasets from various high-quality observational data sources and meteorological analyses under a period of high chlorine loading and peak ozone losses. Each simulation is integrated over 20 annual cycles following adequate spin-up (10 years is recommended). The model data of these 20 years are evaluated against contemporary observations (i.e., during the satellite measurement period of UARS, Aura, ENVISAT, Odin, SAGE, SBUV, TOMS, ACE, etc.) and compared to results of other CCMs. The 20 years of output is necessary in order to compare mean quantities with large variability (e.g., polar temperatures). It should be possible for analysis of runs based on REF-B0 to start much earlier than the other scenarios and to collect extended output, which will be useful for developing the diagnostics as well as providing a preliminary evaluation.

- **Trace gas forcings** are characteristic of 2000 levels for both ODSs and greenhouse gases (GHGs). The surface concentrations of GHGs are based on *IPCC* [2001] while the surface halogens are based on Table 8-5 of *WMO* [2007] for the year 2000. Both ODSs and GHGs repeat every year.

- **Background aerosol** is prescribed from the extended *SPARC* [2006] SAD data set (see REF-B1) for the year 2000.
- **Solar irradiance** is averaged over 1-solar cycle to provide a mean solar flux for the year 2000.
- **Sea surface temperatures (SSTs) and sea ice concentrations (SICs)** in this simulation are prescribed from observations by using a climatological mean derived from the years 1995 to 2004 (HadISST1) data set provided by the UK Met Office Hadley Centre [*Rayner et al.*, 2003]. Prescribed SSTs and ice distribution repeat each year in REF-B0 (cf. REF-B1 SSTs/SICs).
- **Quasi-Biennial Oscillation (QBO).** In this run the QBO is not externally forced, but only included by those models that internally generate a QBO.
- **Emissions of ozone and aerosol precursors** (CO, NMVOC, NO_x and SO_2) are averaged over the years 1998 to 2000 and are taken from an extended data set of the REanalysis of the TROpospheric chemical composition (RETRO) project [*Schultz et al.*, 2007, see http://retro.enes.org]. The RETRO emissions inventory is a comprehensive global gridded data set for anthropogenic and wildfire emissions over the past 40 years. The data set comprises a high level of detail in the speciation of NMVOC compounds. The data originates from a large variety of sources, including the TNO TEAM inventory, information on burnt area statistics, the regional fire model Reg-FIRM, and satellite data. In case of SO_2, RETRO only provides biomass burning related emissions. Therefore, this data is combined with an interpolated version of EDGAR-HYDE 1.3 [*Van Aardenne et al.*, 2001] and EDGAR 32FT2000 [*Olivier et al.*, 2005; *Van Aardenne et al.*, 2005].
- **Chemical kinetics** should be taken from *JPL* [2006], as for all other CCMVal simulations described below.

1.2. REPRODUCE THE PAST: Reference Simulation 1 (REF-B1), Core Time Period 1960 to 2006

REF-B1 (1960-2006) is defined as a transient run from 1960 to the present and is designed to reproduce the well-observed period of the last 35 years during which ozone depletion is well recorded. 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. The set-up and forcings are very similar to the REF-B1 simulations that were evaluated in *Eyring et al.* [2006]. A re-assessment of temperatures, trace species and ozone in the CCM simulations will allow documenting progress of individual models and overall progress on the representation of key processes compared to the last CCM assessment. 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. This transient simulation includes all anthropogenic and natural forcings based on changes in trace gases, solar variability, volcanic eruptions, quasi-biennial oscillation (QBO), and SSTs/SICs. REF-B1 covers the time period from at least 1960 to 2006 (with around 10 years spin-up prior to 1960) to examine model variability and to replicate as closely as possible the atmospheric state in this period.

- **Greenhouse Gases** (N_2O, CH_4, and CO_2) between 1950 and 1996 are taken from *IPCC* [2001] and merged with the NOAA observations forward through 2006. NOAA CO_2, CH_4, and N_2O were scaled to agree on January 1996 with the historical IPCC data.
- **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-B1 are taken from Table 8-5 of *WMO* [2007]. The mixing ratios are calculated by a box model using yearly emissions and are given for the middle of the month. The time series does not contain a yearly variation in mixing ratios. Through 2004 the values are as much as possible forced to equal global estimates calculated from observations (for details see Chapter 8 of *WMO* [2007]). For models that do not wish to represent all the brominated and chlorinated species in Table 8-5 of *WMO* [2007], 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.

- **Sea surface temperatures and sea ice concentrations** in REF-B1 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. 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-B1. 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.* [2007]. 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. The NCAR group modified this new 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. Differences in the new modified SPARC SAD data set and the previous CCMVal SAD data set created by *D. Considine* and used in *Eyring et al.* [2006] are briefly described below. The modified SPARC SAD time series shows minor deviations from the previous CCMVal SAD time series in the mid-latitudes and tropics. The most significant changes occur in high latitude regions, specifically during the period influenced by major volcanic eruptions. Here, the previous CCMVal SAD time series is consistent with background values (see description in the header of the previous CCMVal SAD time series input file for details on how this data set was created). The Agung eruption in 1963 is not covered by this data set. As a remedy we follow the method described in *Dameris et al.* [2005]. The well documented years following the eruption of Mt. Pinatubo (1991–1994) have been adopted and associated with the period 1963–1966 with modifications based on published results to account for differences in total mass of sulfate aerosols in the stratosphere, in maximum height of the eruption plumes, and in the volcanoes' geographical location. Above the maximum vertical extent of Agung's eruption plume the annual mean of 1979 has been incorporated. For the time periods 1950–1962 and 1968–1978 the annual mean of 1979 has been adopted. For the new CCMVal simulations, we recommend using the new modified

SPARC SAD time series described above, in particular for those models that have a heterogeneous chemistry halogen activation approach based solely on the occurrence of super cooled ternary (STS) PSCs.

- **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; *G. Stenchikov and L. Oman*, pers. communication, 2007]. In addition to the larger eruption (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 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.
- **Solar variability.** To account for the highly variable and wavelength-dependent changes in solar irradiance, daily spectrally resolved solar irradiance data from 1 Jan 1950 to 31 Dec 2006 (in $W/m^2/nm$) are provided. The data are derived with the method described in Lean et al. [2005] and are available with the following spectral resolution: 1 nm bins from 0 to 750 nm; 5 nm bins from 750 to 5000 nm; 10 nm bins from 5000 to 10000 nm; 50 nm bins from 10000 to 100000 nm. Each modeling group is required to integrate these data over the individual wavelength intervals (a) in their radiation scheme (to adjust the shortwave heating rates) and (b) in their chemistry scheme (to adjust the photolysis rates). It is recommended to use the provided solar flux data directly (integrated over the respective intervals in the radiation and chemistry schemes), rather than a parameterization with the F10.7 cm radio flux previously used. Additional information as well as the data can be found on the SOLARIS website at http://www.geo.fu-berlin.de/en/met/ag/strat/research/SOLARIS/Input_data/index.html.
- **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 GCM 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.

- **Ozone and aerosol precursors** (CO, NMVOC, NO_x and SO_2) from 1960 to 2000 are taken from the extended data set of the RETRO project [*Schultz et al.*, 2007]. For the spin-up period from 1950 to 1959 we recommend using the 1960 values from this data set. The data set will be extended through 2006 by using trend estimates and will be harmonized so that regional totals are the same as in RETRO for the year 2000.

1.3. MAKING PREDICTIONS: Reference simulation 2 (REF-B2), Core time period 1960 to 2100

REF-B2 is an internally consistent simulation from the past into the future. The objective of REF-B2 is to produce best estimates of the future ozone-climate change up to 2100 under specific assumptions about GHG increases (Scenario SRES A1B) and decreases in halogen emissions (adjusted Scenario A1) in this period. REF-B2 only includes anthropogenic forcings. External natural forcings such as solar variability 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 the IPCC [2000] 'A1B' scenario, to provide continuity with *Eyring et al.* [2007].
- **Surface mixing ratios of Ozone Depleting Substances** are based on the halogen scenario A1 from *WMO* [2007]. However, at the 2007 Meeting of the Parties to the Montreal Protocol, the Parties agreed to an earlier phase out of HCFCs, with nearly a full phase out by Article 5 countries in 2030 (http://ozone.unep.org/Meeting_Documents/mop/19mop/Adjustments_on_HCFCs.pdf). The current scenario A1 does not include this phase out. Hence, a new scenario has been developed that includes this phase out (hereafter referred to as adjusted scenario A1). The adjusted scenario A1 will only have HCFCs adjusted; distributions of CFCs, Halons, and other non-HCFC species remain identical to the original scenario A1. The adjusted scenario A1 can be downloaded from the CCMVal website.
- **Background aerosol** is prescribed from the extended *SPARC* [2006] SAD data set (see REF-B1) for the year 2000.
- **Sea surface temperatures and sea ice concentrations in REF-B2.** One of the most critical issues is the design of the future simulation REF-B2. 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-B2 runs use simulated SSTs and SICs for the entire period. There are three alternate approaches, depending on the resources of each modeling group. 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 for IPCC. Second, groups that have a coupled atmosphere-ocean model that does not include chemistry should use their own modeled SSTs/SICs for 1960-2100 in their CCM run. Third, groups that do not have their own coupled ocean-atmosphere model should use SSTs/SICs from an A1B-scenario IPCC AR-4 simulation, for example from CCSM3 [*Collins et al.*, 2007]. The SSTs from HADGEM1 used in the first CCMVal REF-B2 simulation have a cold bias with

respect to observations [see Figure 3 of *Johns et al.*, 2006], whereas the tropical SSTs from the CCSM3 are in better agreement with observations [*Large and Danabasoglu*, 2006]. *Oldenborgh et al.* [2005] present a multi-model study of the representation of El Nino in IPCC AR4 models.

- **Ozone and aerosol precursors** in REF-B2 are similar to REF-B1 until 2000 (extended RETRO data set), and use the adjusted IIASA scenario through 2100 [*M. Amann* and *P. Rafai*, pers. communication, 2007]. The data set needs to be harmonized so that regional totals are the same as in RETRO for the year 2000.

Table 1: Summary of proposed CCMVal reference simulations.

Scenario	Period	Greenhouse Gases	ODSs	SSTs/SICs	Background & Volcanic Aerosol	Solar Variability	QBO	Ozone and Aerosol Precursors
REF-B0	Time slice 2000 Appropriate spin up then provide 20 years of output.	OBS Fixed at 2000 concentrations (from IPCC, 2001), repeating each year	OBS Fixed at 2000 concentrations (from Table 8-5 WMO, 2007), repeating each year	OBS 1995-2004 average derived from HadISST1, repeating each year	OBS Background SAD from 2000	OBS Averaged solar irradiance over 1 solar cycle	Only internally generated	OBS RETRO 1998-2000 mean
REF-B1	Transient simulation 1960-2006 Appropriate spin up prior to 1960	OBS GHG used for WMO/UNEP 2002 runs and updated until 2006.	OBS Table 8-5 WMO [2007]	OBS HadISST1	OBS Surface Area Density data (SAD)	OBS Spectrally resolved irradiance data	OBS or internally generated	OBS Extended RETRO data set
REF-B2	Transient simulation 1960-2100 Appropriate spin up prior to 1960	A1B(medium) (from IPCC, 2000)	OBS + adjusted A1 scenario [WMO 2007, Table 8-5]	Modeled SSTs	OBS Background SAD from 2000	NO	Only internally generated	Same as REF-B1 until 2000 + adjusted IIASA scenario through 2100

2. CCMVal Sensitivity and Control Simulations

The following CCMVal sensitivity and control experiments are proposed:

SCN-B1 (1960-2006, REF-B1 with additional organic bromine): Observations suggest that stratospheric inorganic bromine (Br_y) derived from the breakdown of long-lived (>3 years) organic source gases (i.e., CH_3Br, halon-1211, halon-1301, and halon-2402) underestimate the Br_y abundance in the stratosphere by about 5 ppt, with estimates ranging from 3 to 8 pptv. Observations also suggest that very short-lived substances (VSLS) with atmospheric lifetimes of less than 0.5 years make up the missing stratospheric Br_y [Chapter 2 of *WMO* 2003, 2007]. The supply of bromine from VSLS can result in a substantial fractional increase to the amount of bromine in the lowermost stratosphere, with important consequences for ozone trends and the photochemical budget of ozone, particularly during times of high aerosol loading. SCN-B1 was developed to quantify the effect on ozone of bromine from VSLS. This scenario is consistent with REF-B1 with the exception that an additional source of 5 pptv of Br_y from VSLS is included. In SCN-B1, we are proposing to add the species dibromomethane (CH_2Br_2) to the chemical mechanism of participating CCMs. The lifetime of CH_2Br_2 is approximately 120 days at 5 km [Table 2.3, *WMO* 2007] and the reaction with OH is the dominant loss process [Table 2.4, *WMO* 2003]. The estimated fraction of CH_2Br_2 mixing ratio in the tropical upper troposphere relative to the abundance in the marine boundary layer is approximately 0.8 [Table 2.2, *WMO* 2007]. Therefore, if the surface abundance of CH_2Br_2 is set to 3 pptv, the stratospheric Br_y abundance should increase by approximately 5 pptv (i.e., 5 pptv total Br_y / 2 Br per CH_2Br_2 molecule / 0.8 is equal to ~3.0 pptv CH_2Br_2). If modeling groups prefer not to add a new species to their CCM, we propose adding 5 pptv of total bromine to the shortest-lived organic bromine source gas currently included in the chemical mechanism.

SCN-B2a (2000-2100, REF-B2 with GHG scenario different than SRES A1B) is a transient simulation similar to REF-B2, but with the GHG and ozone precursor scenario changed from SRES A1B (medium) to A2 (or a new IPCC scenario to be defined in mid-2008). 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. SCN-B2a is designed to be consistent with one of the new coordinated Climate Change Stabilization Experiments proposed for AOGCMs and ESMs [*Meehl et al.*, 2007]. Ideally AOGCMs and ESMs will include their own atmospheric chemistry schemes, but many models do not have this option. For this category of models ozone fields have to be prescribed in the simulations. There are therefore two motivations for this run. One is to assess the future evolution of the ozone-climate change under a different GHG scenario than the A1B scenario used in REF-B2, and the second is to compute a best estimate of ozone fields consistent with the GHG scenario for community use in IPCC AR5 models. Ozone precursors in SCN-B2a are similar to REF-B1 and REF-B2 until 2000, and use the adjusted IIASA A2 scenario through 2100 [*M. Amann* and *P. Rafai*, pers. communication, 2007] or a new IPCC scenario to be defined in mid-2008.

SCN-B2b (1960-2100, REF-B2 with halogens fixed at 1960 levels) is a transient simulation similar to REF-B2, but with halogens fixed at 1960 levels throughout the simulation, whereas GHGs and SSTs/SICs are the same as in REF-B2. 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. By comparing SCN-B2b with REF-B2, 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 advanced in *WMO* [2007].

SCN-B2c (1960-2100, REF-B2 with GHGs fixed at 1960 levels) is a transient simulation similar to REF-B2, but with GHGs fixed at 1960 levels throughout the simulation, whereas the adjusted scenario A1 halogens are the same as in REF-B2. It is designed to address the science question of how nonlinear are the atmospheric responses to ozone depletion/recovery and climate change. 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-B2. By comparing the sum of SCN-B2b and SCN-B2c (each relative to the 1960 baseline) with REF-B2, the nonlinearity of the responses can be assessed. SCN-B2c 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-B2d (1960-2100, REF-B2 with natural forcings and QBO) is designed to address the impact of ‘realistic’ natural variability on the REF-B2 simulations, for which the natural variability is underestimated. This sensitivity simulation is defined similar to REF-B1, with the inclusion of solar variability, volcanic activity, and the QBO in the past. Future forcings include a repeating solar cycle and QBO, under volcanically clean aerosol conditions. SSTs/SICs are simulated or prescribed as in REF-B2. GHGs and halogens will be the same as in REF-B2. We recommend using a repeating solar cycle based on the observed daily spectra described in *Lean et al.* [2005]. It is proposed to repeat the solar cycles 20 to 23 (1962-2004) and therefore neglect the extreme solar cycle 19 (peaking in 1957/58).

CTL-B0 (min. 20 years, REF-B0 but for 1960 conditions) is a time-slice simulation under 1960 conditions designed to establish a baseline control simulation for the reference and sensitivity simulations. The objective is to provide a statistical characterization of the internal variability of the CCMs prior to major perturbations of the ozone layer. The control 1960 simulation has ODSs, GHGs, and solar irradiance held fixed. SSTs/SICs in this simulation are (analogous to REF-B0) prescribed from observations by using a climatological mean derived from years 1955 to 1964 of the HadISST1 data set, repeating every year. Given these design constraints, the only source of variability is the internal dynamics of the atmosphere (and land properties like snow cover and soil moisture), while natural variability arising from solar variability and volcanic eruptions is excluded. Moreover, there are no secular changes in greenhouse gases and halogens, hence no long-term trends, which will allow a statistical characterization of random short-term trends. This is important for assessing the statistical significance of trends in the reference and sensitivity simulations. After a spin-up period of about 10 years, each simulation is integrated over at least 20 annual cycles for analysis. However, the goal of a 46-year control simulation is strongly encouraged, 46 years being the length of the REF-B1 simulation. Some of the reference and sensitivity simulations could branch off from CTL-B0, thereby reducing their respective spin-up periods to a few years.

- **Trace gas forcings** are characteristic of 1960 levels for both ODSs and GHGs. The surface concentrations of GHGs are based on *IPCC* [2001] while the surface halogens are based on Table 8-5 of *WMO* [2007] for the year 1960. Both ODSs and GHGs repeat every year.
- **Background aerosol** is prescribed from the extended *SPARC* [2006] SAD climatology (see REF-B1) for the year 1979.
- **Solar irradiance** is averaged over 1-solar cycle to provide a mean solar flux for the year 1960.
- **Emissions of ozone and aerosol precursors** (CO, NMVOC, NO_x and SO_2) for 1960 conditions are taken from the extended RETRO data set and averaged over the period 1960 to 1962.
- **Sea surface temperatures and sea ice concentrations** in this simulation are prescribed from observations by using a climatological mean derived from the years 1955 to 1964 (HadISST1) data set provided by the UK Met Office Hadley Centre [*Rayner et al.*, 2003]. Prescribed SSTs and ice distribution repeat each year in CTL-B0.
- **Quasi-Biennial Oscillation**. In this run the QBO is not externally forced, but only included by those models that internally generate a QBO.

Table 2: Summary of proposed CCMVal control and sensitivity simulations.

Scenario	Period	GHGs	ODSs	SSTs/SICs	Background & Volcanic Aerosol	Solar Variability	QBO	Ozone and Aerosol Precursors
CTL-B0 1960	Time slice 1960 Appropriate spin-up then provide a minimum of 20 years of output.	OBS Fixed at 1960 concentrations (from IPCC, 2001), repeating each year	OBS Fixed at 1960 concentrations (from Table 8-5 WMO, 2007), repeating each year	OBS 1955-1964 average derived from HadISST1, repeating each year	OBS Background SAD from 1979	OBS Averaged solar irradiance over 1 solar cycle	Only internally generated	OBS RETRO 1960-1962 mean
SCN-B1 (additional bromine)	Transient simulation 1960-2006	Same as in REF-B1	Same as in REF-B1 but with additional bromine	Same as in REF-B1	Same as in REF-B1	Same as in REF-B1	Same as in REF-B1	Same as in REF-B1
SCN-B2a GHGs	2000-2100	OBS + GHG scenario different from A1b	Same as in REF-B2	SSTs/SICs distribution consistent with GHG scenario	Same as in REF-B2	Same as in REF-B2	Same as in REF-B2	Same as REF-B1 until 2000 + scenario consistent with GHGs
SCN-B2b Fixed Halogens	1960-2100	Same as in REF-B2	Fixed halogen scenario	Same as in REF-B2	Same as in REF-B2	Same as in REF-B2	Same as in REF-B2	Same as in REF-B2
SCN-B2c NCC	1960-2100	Fixed GHG	Same as in REF-B2	1955-1964 average of values used in REF-B2, repeating each year	Same as in REF-B2	Same as in REF-B2	Same as in REF-B2	Same as in REF-B2
SCN-B2d Natforcing QBO	1960-2100	Same as in REF-B2	Same as in REF-B2	Same as in REF-B2	OBS in the past and background aerosol in the future	OBS repeating in future	OBS / repeating in future or internally generated	Same as in REF-B2

3. 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, CCMVal has 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 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 simulations. The hope is that these additional runs will be available in time to provide useful input for the anticipated UNEP/WMO

Ozone Assessment in 2010, so that the ozone projections from the CCMs can be assessed for different halogen and GHG scenarios, and not just from one scenario as in *WMO* [2003, 2007].

The proposed simulations will be evaluated as part of the planned SPARC CCMVal Report by 2009 in time for consideration in the anticipated UNEP/WMO Ozone Assessment in 2010. The SPARC CCMVal report itself has two major aims: 1) provide valuable base material for that Assessment, and 2) improve the understanding of the strengths and weaknesses of CCMs and thus increase their integrity and credibility. Regarding mechanisms for model evaluation, a set of standard diagnostics has been agreed at the first CCMVal workshop (Grainau, Germany, November 2003) and further refined at the second workshop (NCAR, Boulder, USA, October 2005). Output for these standard diagnostics [*Eyring et al.*, 2005] and possible additional diagnostics needed for the individual chapters of the SPARC CCMVal report will be collected in Climate and Forecast (CF) standard compliant netCDF format from all models in the central database at the British Atmospheric Data Centre (BADC). In addition it is anticipated to obtain 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. The proposed timeline for the SPARC CCMVal report can be found at http://www.pa.op.dlr.de/CCMVal/SPARC_CCMValReport/SPARC_CCMValReport_Timeline.html.

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