Long-term changes in stratospheric constituents

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How radiatively active trace species change in time is of interest from a climate perspective. Key species of interest are ozone and water vapor as well as ozone depleting substances. Changes in long-lived species and temperature in the stratosphere can also give information on changes in circulation. Global coverage of stratospheric trace species is relatively limited in time and examination of trends requires stitching together records from multiple platforms. In this presentation I will discuss efforts to produce long-term time series for ozone and water vapor in the stratosphere as well as what changes in circulation can be ascertained from the existing data record. Models suggest that circulation changes will occur in a future climate with increased levels of greenhouse gases. I will also discuss what future measurements I think are needed to continue monitoring the stratosphere in a changing climate.

The Search for Ozone Recovery Using 36 Years of SBUV Satellite Data

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The Montreal Protocol has led to the leveling off and decrease of the chlorine content of the stratosphere. Ozone concentrations decreased and have now leveled off and may be showing signs of increasing. Potential attribution of this behavior to the changes in chlorine content require examination of both the latitude, altitude, and seasonal changes in ozone over the last several decades. We use the newly released Version 8.6 of the data from the SBUV series of satellite instruments to examine the question of ozone recovery. The version 8.6 data retrieves total ozone as the sum of the retrieved layer amounts of ozone in the vertical distribution. The instruments on the Nimbus 7 and NOAA 9, 11, 14, 16, 17, 18, and 19 satellites have been recalibrated to optimize their consistency with one another to provide a continuous data set from late 1978 through the present.

We examine these data using regression analyses to evaluate the contributions of solar cycle, QBO, ENSO, and volcanoes to ozone variability. We look separately at the upper stratosphere, the lower stratosphere, and the total column ozone content. The removal of variability allows us to examine the contribution of chemical loss due to chlorine by several methods; 1) using EESC to test the quality of the fit, 2) using piecewise linear fit to examine the rate of decline of ozone in the 1978-1995 time period compared to the rate of increase of of ozone in the 2000-2012 period, and 3) independently fitting the decline from 1978 to 1995 compared to 2000-2012 without requiring the common point of the piecewise linear fit.

A Re-Evaluated Canadian Ozonesonde Record: Changes in the Vertical Distribution of Ozone Over Canada from 1966 to 2012

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Abstract. In Canada routine ozone soundings have been carried at Resolute Bay since 1966, making this record the longest in the world. Similar measurements started in the 1970s at three other sites (Edmonton, Goose Bay and Churchill). These four sites switched to ECC sondes in 1980, and the network was subsequently expanded with the addition in 1987 of Alert, of Eureka in 1992 and in 2003 of four southern mid-latitude sites, Kelowna, Bratt's Lake, Egbert and Yarmouth.

The global ozonesonde record is increasingly important for understanding long-term changes in both tropospheric and stratospheric ozone, as both may be affected by changes in long-range quasi-horizontal transport, as well as by vertical exchange. Much effort has therefore gone into homogenization and re-evaluation of some of the longer time series from Europe and other parts of the world. As part of the SPARC/IO$_3$C/IGACO-O3/NDACC (SI^{2}N) initiative, Canada's important record has also been re-evaluated. The effect of the corrections, and remaining issues will be discussed.

The overall linear trends are generally quite small, and both positive and negative trends are seen, both in tropospheric and lower stratospheric ozone. However, the time series show a strong decline until about 1993, followed by an increase until 2002 or 2003, with insignificant trends afterward. The time series also show large variations from year to year. Some of these anomalies can be related to cold winters (in the Arctic stratosphere), or changes in the Brewer-Dobson circulation, which may thereby be influencing trends. In the Arctic surface trends appear to be driven by an increase in the frequency of halogen-catalyzed surface ozone depletions.

The trends are also compared with those computed from annually-averaged ozone fields derived from the global ozonesonde sounding record by a trajectory mapping method, using forward and back- trajectories calculated from NCEP reanalysis data using the HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory) model.

The long-term changes in free tropospheric ozone concentrations over Canada appear to correspond with lower stratospheric changes. Interannual variability is also similar: statistically significant (95% confidence) correlations are found for the lowest stratospheric layers with all tropospheric layers. This suggests that ozone levels in the troposphere over Canada are partly controlled by stratospheric ozone. The most evident reason for this is stratosphere-troposphere transport, and this interpretation is supported by Lagrangian dispersion-model studies which suggest that much of the variability of ozone in the free troposphere over midlatitude sites in Canada is due to stratospheric intrusions.

Ozone trends and variability in a changing climate

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Three decades of global satellite observations of ozone show decadal variability related to atmospheric dynamics as well as stratospheric halogen changes following the phasing out of ozone depleting substances (ODS) as a measure of the Montreal Protocol and its Amendments. These low frequency changes are overlaid by inter-annual variability related to circulation changes induced by QBO, ENSO, and the Brewer-Dobson circulation [Chehade et al., 2013]. The effect of the winter Brewer-Dobson circulation (BDC) on the seasonal and decadal evolution of total ozone in both hemispheres have been investigated using total ozone observations and outputs from two chemical climate models (CCM) [Weber et al. 2011]. Combining data from both hemispheres a linear relationship between the winter mean extratropical eddy heat flux and the ozone spring-to-fall ratio exists and is statistically significant for tropical as well as polar ozone. This compact relationship can be exploited to separate the effects from long-term changes in the halogen load (ozone recovery) and the year-to-year variability. This compact linear relationship is also found in chemical climate models suggesting that current models realistically describe the variability in stratospheric circulation and its climate effect on total ozone. Future changes in this compact linear relationship show clear distinct phases of ODS dominated changes (ODS related ozone recovery) and greenhouse gas (GHG) related changes, the latter dominating the second half of this century. From limb satellite observations during the last decade positive ozone trends in the upper stratosphere are observed and could be indicative of ODS related ozone recovery. In contrast negative ozone trends are observed between 30 and 40 km altitude in the tropical region [e.g. Gebhardt et al., 2013]. Possible links to NO_x changes are investigated using NO_2 observations as well as CTM calculations. The NO_x related ozone changes highlight the important role of N_2O in middle stratosphere ozone depletion.

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Developing the 20th Century Reanalysis version 3 (1850-2013)

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The historical reanalysis dataset generated by NOAA ESRL and the CIRES Climate Diagnostics Center, the Twentieth Century Reanalysis version 2 (20CRv2), is a comprehensive global atmospheric circulation dataset spanning 1871-2011, assimilating only surface pressure and using monthly Hadley Centre SST and sea ice distributions (HadISST1.1) as boundary conditions. It has been made possible through collaboration with GCOS, WCRP, and the ACRE initiative. It is chiefly motivated by a need to provide an observational validation dataset, with quantified uncertainties, for assessments of climate model simulations of the 20th century, with emphasis on the statistics of daily weather. It uses, together with an NCEP global numerical weather prediction (NWP) land/atmosphere model to provide background "first guess" fields, an Ensemble Kalman Filter (EnKF) data assimilation method. This yields a global analysis every 6 hours as the most likely state of the atmosphere, and also yields the uncertainty of that analysis.

The 20CRv2 dataset provides the first estimates of global tropospheric variability, and of the dataset's time-varying quality, spanning 1871 to the present at 2 degree spatial resolution. Intercomparisons with independent radiosonde and station temperature data indicate that the reanalyses are of high quality. Overall, the quality is approximately that of current three-day NWP forecasts.

It is anticipated that the 20CRv2 will be useful to the climate research community for both diagnostic studies and model validations. Some surprising results are already evident. For instance, the long-term trends of the tropical Pacific Walker Circulation are weak or non-existent over the full period of record in this dataset.

Following 20CRv2, with GCOS, WCRP, and ACRE, we are investigating 20CR version 3: an improved version of the historical reanalysis dataset. Results illustrating the effects of higher spatial resolution and increased observational density compared to 20CRv2 will be presented. 20CRv3 will have a companion ocean reanalysis generated by Texas A&M University using the Simple Ocean Data Assimilation system. The effects of using SODA boundary conditions compared to HadISST in 20CRv3 will be investigated. Together 20CRv3 and SODA will provide global states of the atmosphere, land, and ocean back to 1850.

Global Response to the Major Volcanic Eruptions in 9 Reanalysis Datasets

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The global climate response to the eruptions of El Chichón in 1982 and Pinatubo in 1991 is investigated using 9 reanalysis datasets (ERA-40, ERA-Interim, JRA-25/JCDAS, JRA-55 Evaluation Data, MERRA, NCEP/NCAR, NCEP/DOE, NCEP-CFSR, and 20CR) during the period from 1979 to 2009 (2001 for ERA-40). Multiple linear regression is applied to the zonal and monthly mean time series of key dynamical variables by considering the components of seasonal variations, linear trends, Quasi-Biennial Oscillation (QBO), solar activity, and El Niño Southern Oscillation (ENSO). The residuals are used to define the volcanic signals. Latitude-altitude distributions of the volcanic signals and of the regression coefficients are compared and discussed among the different reanalyses. In response to the Pinatubo eruption most reanalyses show statistically significant negative and positive temperature anomalies in the tropical troposphere and in the tropical lower stratosphere, respectively. The signals are similar for the El Chichón eruption, with a statistically insignificant tropospheric response. This work is a contribution to the SPARC Reanalysis Intercomparison Project (S-RIP).

The SPARC Water Vapor Assessment II – Quality assessment of water vapor data records from satellites

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The past decade has been a "golden age" for observations of middle atmospheric trace gas distributions from space since numerous satellite instruments have been in orbit. One of the most important trace species with respect to its impact on global climate and stratospheric chemistry is water vapor. The SPARC Water Vapor Assessment II (WAVAS-II) initiative will provide an intercomparison and quality assessment of the recent satellite instruments and newly available data versions of previous instruments. Within the presentation, we will provide an overview on the currently available data base, and on climatologies derived from the satellite data sets covering the altitude range from the upper troposphere to the lower mesosphere. The status of the WAVAS-II Satellite Data Quality Assessment initiative will be presented, with some focus on the difficulties that we are facing on the way to a consistent multi-instrument long-term data set covering the last 30 years. We will also discuss and intercompare the available satellite data sets of water vapor isotopologues, mainly HDO, and what can be learned from those about the transport of water vapor from the troposphere into the stratosphere, including phase transition processes (convective processes, freeze-drying, and overshooting of ice particles). Finally, future perspectives for the continuation of middle atmosphere water vapor observations from space will be discussed.

Detection and Attribution Studies of the Role of the Stratosphere in Recent Climate Changes

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Detection and attribution studies seek to detect significant observed climate changes outside the range of natural internal variability and to attribute those changes to known forcing factors. Such studies require high quality and lengthy observational data sets, reliable estimates of natural internal climate variations from models and observations, model estimates of the expected climate responses to a range of different known forcing factors, and appropriate statistical methods to maximize the signal to noise ratio and enhance the prospects for detection and attribution.

This review will discuss some of the reasons why there have been fewer detection and attribution studies applied to the role of the stratosphere, compared with surface and tropospheric climate changes. Examples of detection and attribution studies applied to changes in the thermal structure of the stratosphere and in tropopause height will be presented. In addition, examples of the attribution of some surface climate changes to stratospheric forcing, particularly linked to Antarctic ozone depletion, will be described. The relationships between detection and attribution studies and evaluation of both observational data sets and climate model simulations will be discussed, with specific application to the stratosphere.