GOME O3 profiles and their application in modelling stratospheric transport

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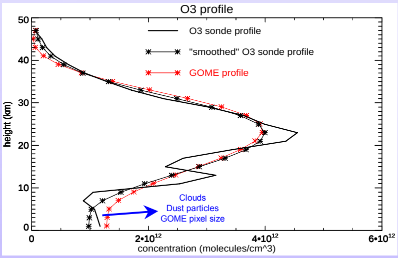
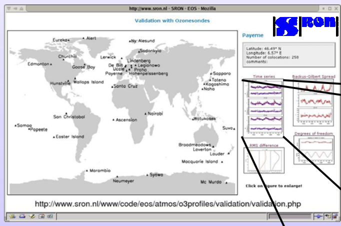
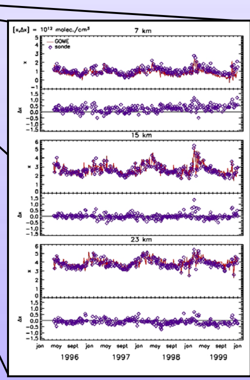






Validation of GOME O_3 retrieval on the SRON website

The SRON algorithm for O_3 profile retrieval from GOME measurements is validated with O_3 sonde measurements at 38 geo-locations over the period 1996-1999. The sonde profiles are provided by the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) and the Network for the Detection of Stratospheric Change (NDSC).

O_3 profiles retrieved from GOME measurements are compared with sonde profile measured at individual stations. Retrieved O_3 concentrations and sonde measurements are shown at 7, 15 and 23 km altitude. (O_3 sonde profiles are smoothed to the vertical resolution of the retrieval, see also box below). Several statistics are given like the root-mean-squares of the differences between both data sets give an estimate of the overall error, the Backus-Gilbert spread function and the degrees of freedom for signal.

This information is available at:
http://www.sron.nl/www/code/eos/atmos/o3profiles/validation/validation.php

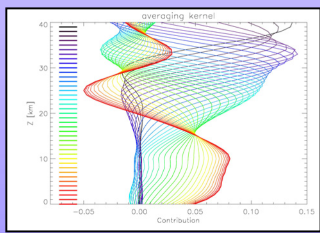
GOME O_3 retrieval at SRON

SRON algorithm to retrieve of ozone profiles from backscattered ultraviolet radiation measured by GOME Retrieval algorithm does not depend on climatological a priori information about O_3.

Limited O_3 "information" in GOME measurement ⇨ "smoothing" of the real O_3 profile.

Retrieved O_3 profile depends only on the information content of the measurement ⇨ easy interpretation.

The figure above shows an example for the validation with one particular O_3 measurement.



What is an averaging kernel ?

The GOME measurement of the spectral range that is used for retrieving O_3 does not contain enough information to resolve the fine scale vertical structures of the O_3 profile. This is a generally occurring phenomenon in retrieval of atmospheric trace gases from satellite measurements. The relation between the retrieved (smoothed) and "real" O_3 profile is described by the "averaging kernel".

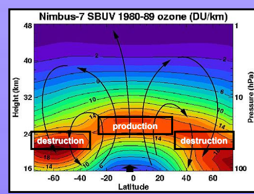
The figure to the left shows an example of an averaging kernel (the colors indicate the altitude for which the a particular element of the averaging kernel is representative). The averaging kernel can be considered as the sensitivity of O3 at a given altitude for changes in O3 at all altitudes. Ideally a single element of the averaging kernel is a delta function at the given altitude. The figure clearly shows that in reality an element represents a particular altitude range.

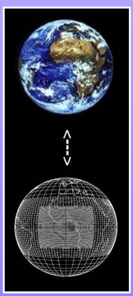
What does the stratospheric circulation look like ?

The stratospheric circulation is dominated by very strong westerly winds in the lower stratosphere (the so called jet-stream) circulating around the earth. A much weaker poleward circulation exists (known as the Brewer-Dobson circulation). This very slow circulation (wind speed of mm/s as opposed to windspeeds of 100 m/s for the zonal circulation) is responsible for the transport of stratospheric air masses from the equator to the poles.

The meridional circulation is also responsible for maintaining the O_3 layer at middle and higher latitudes. O_3 is produced in the tropical stratosphere and destroyed at higher latitudes. The Brewer-Dobson circulation links the O_3 production and destruction regions and has a strong seasonal variation (strong during local winter, weak during local summer)

This so-called "residual" circulation (see panel to the right) is very difficult to model, as even very small disturbances in the zonal circulation strongly affect the meridional circulation (think about it as the residual being the result from subtracting two large numbers).





Chemistry-transport modeling (CTM) with TM5

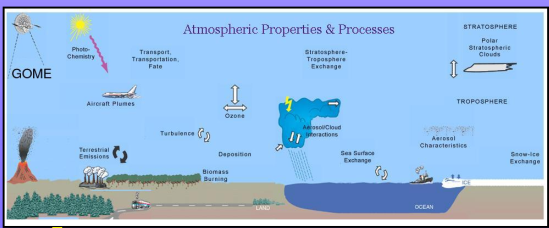
CTM's use wind fields generated by other models (climate models or weather analysis) to simulate transport processes.

Chemical reactions and interactions of gases with particles and cloud-droplets can be included.

This study: the transport model version 5 (TM5)

Developed by the Institute for Marine and Atmospheric Research at the Utrecht University (IMAU), the Royal Dutch Meteorological Institute (KNMI) and the Centre for Mathematics and Informatics (CWI) in Amsterdam.

For TM5 wind fields from the ECMWF are used.



Results from TM5

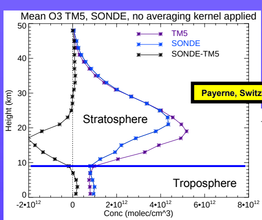
TM5 simulation of stratospheric O_3 (parameterized).

Panel below: comparison of TM5 results and GOME measurements at Payerne (46.5°N, 6.7°E).

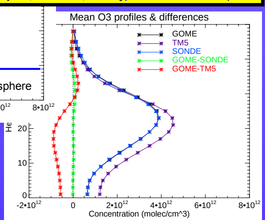
⇨GOME and O_3 sondes agree very well

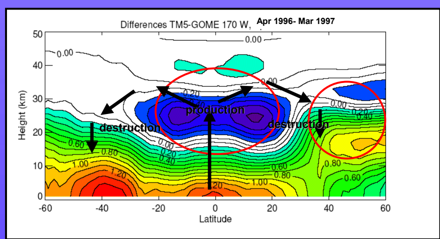
⇨Positive TM5 bias below 25 km altitude.

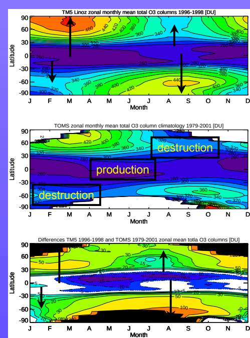
Left panel left: comparison without the "smoothing" [see the box on the averaging kernel for an explanation].



Payerne, Switzerland, mean O_3 profile for the 1996-1998 period





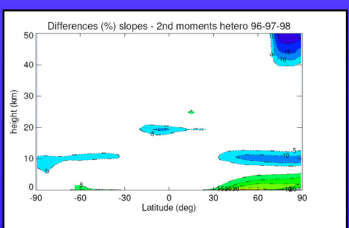


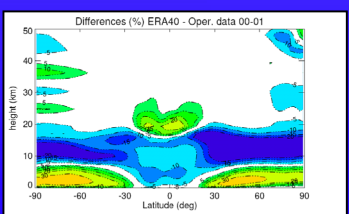
The too fast poleward transport in TM5

Panel above, left: mean difference between TM5 and measured O_3 concentrations [10^{12} molecules/cm^2] along 170°W for one year. Other studies have shown that for stratospheric photochemical O_3 production and destruction are simulated correctly.

Explanation: stratospheric circulation is too fast from tropics to mid-latitudes. O_3 is transported away too fast from the production region (tropics) leading to too low tropical stratospheric O_3. At mid-latitudes, O_3 that is produced at tropical latitudes is transport too fast from the tropics leading to accumulation of additional O_3.

Panel above, right: comparison of TM5 and TOMS total O3 column measurements. A strong seasonal variation in the differences is found: the largest differences occur during local winter (strong poleward transport) and the smallest differences during local summer (weak poleward transport).





The too fast poleward transport in TM5: solutions

Several solutions for the too fast poleward transport have been suggested.

The upper panel, left: differences between the "slopes" and "second moments" advection schemes. A slight improvement (10 %) for lower stratospheric ozone is found, not sufficient to resolve model bias (up to 100 %). The advection scheme describes modeled transport processes.

Lower panel, left: different wind fields which are more physically consistent (see box to the right for more information).

The bias is reduced by up to 30 %, which is a considerable improvement upon the original simulation but also cannot fully reduce the bias.

Other solutions are currently being investigated.

What is the ECMWF ?

ECMWF is a research institute in Reading (UK) which makes analyses and weather forecasts based on numerous observations around the globe. The observations are put into a numerical weather forecast model (the so-called data assimilation) based upon which an analysis of the current atmospheric circulation is made. This analysis is then used as the starting point for a numerical weather forecast. This is the basic principle for making numerical weather forecasts. Note that the procedures for the data assimilation is quite complicated.

What products does ECMWF deliver ?

Originally ECMWF provided weather forecast data. It was then recognized that these observations used for making weather forecasts could also be used for making a re-analyses of the atmospheric circulation for longer periods of time (typically a weather forecast used to cover 10 days). The first re-analysis provided by ECMWF covered the period 1979-1993. To satisfy the growing the demand for better and longer analyses more recently produced a second generation analysis, called the ERA40 re-analysis dataset which covers the period 1957-2001 and which is currently used in a wide variety of applications.

What are the differences between the ERA40 and operational ECMWF wind fields ?

The application of weather forecast and re-analysis data in CTM's to study the stratospheric circulation turns out to be somewhat problematic. Because of the continuous assimilation of observations in the ECMWF model, the delicate balance in the stratospheric circulation that determines the poleward transport is continuously disturbed. Although the disturbances are small, they have a considerable impact on the slow poleward transport. It was therefore suggested to used the operational data (that is, the data that has been used to make weather forecasts) rather than the re-analysis data. The reanalysis data is continuously disturbed while the operational data is only disturbed up to a certain point in time and must be physically consistent because after this point no observations are available to "steer" the model in the right direction. Several studies have shown that this is indeed the case, and this study also confirms this hypothesis.