EVALUATION OF THE OZONE AND WATER VAPOUR DATASETS OF THE 40-YEAR EUROPEAN RE-ANALYSIS OF THE GLOBAL ATMOSPHERE (FOR THE PERIOD 1991-1999)

NERC SUMMARY FINAL REPORT WITHIN THE
UPPER TROPOSPHERE / LOWER STRATOSPHERE OZONE PROGRAMME, DECEMBER 2004

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1. THE ERA-40 RE-ANALYSIS ARCHIVE AND PROJECT OBJECTIVES

ERA-40 is the latest re-analysis scheme of the European Centre for Medium-Range Weather Forecast (ECMWF) spanning from September 1957 to August 2002. Nevertheless, the international atmospheric science community is currently lacking a systematic evaluation of the ERA-40 ozone and water vapour data sets in the stratosphere and upper troposphere. Therefore, the present work aims primarily to: (i) evaluate the ozone and the water vapour ERA-40 products in comparison with independent (i.e. non assimilated into the Re-analysis) measurements throughout the 1990s; and (ii) to examine the ability of ERA-40 to accurately describe the state of the stratosphere and the UTLS (Upper Troposphere Lower Stratosphere), as well as to reproduce specific processes, such as the Antarctic and Arctic ozone hole, and the attenuation with height of the tape recorder signal over the tropics. ERA-40 is a 3D-Var data assimilation system which makes use of the Integrated Forecasting System (IFS) developed jointly by ECMWF and Météo-France to represent several physical processes. In ERA-40 the ozone production and loss in the stratosphere are described by Dethof and Holm [2002; 2004]. Regarding the water vapour, ERA-40 adopted a simple parameterization of the upper-stratospheric moisture source due to methane (CH_4) oxidation (more details can be found in the ECMWF IFS documentation http://www.ecmwf.int/research/ifsdocs/). ERA-40 assimilates ozone satellite measurements from TOMS (Total Ozone Mapping Spectrometer) and SBUV (Solar Backscatter Ultra-Violet). In addition, the water vapour data assimilated into ERA-40 are humidity profiles from radiosondes and radiances from a number of satellite instruments.

2. PROJECT METHODOLOGY

In order to validate the ERA-40 archive the independent ozone and water vapour measurements used here are of two types: (i) satellite observations from HALOE (Halogen Occultation Experiment) and MLS (Microwave Limb Sounder) on board NASA's UARS (Upper Atmosphere Research Satellite); and (ii) aircraft *in situ* measurements from the EC MOZAIC programme (Measurement of OZone by Airbus In-service airCraft) that is operational since 01/08/94. The HALOE instrument is considered very stable throughout the entire period of its operation (i.e. 11/10/91 onwards) and no particular future improvements are expected in both the ozone and water vapour products of Version 19 and down to 100hPa used in this work (taken directly from //daac.gsfc.nasa.gov/data/dataset/UARS/HALOE/). On the other hand, as there were several problems and data uncertainties encountered with MLS we consider here MLS Version 5 [Livesey et al., 2002] for ozone data (//daac.gsfc.nasa.gov/data/dataset/UARS/MLS/) and down to 68hPa, and MLS Version 7.02 (kindly provided to us by W. Read, see [Read et al., 2004]) for water vapour data and only in the layers between 56-147hPa. Finally, the MOZAIC programme database (http://www.aero.obs-mip.fr/mozaic/) contains well calibrated, high-resolution observations around tropopause altitudes taken with a 4-second interval along the aircraft route. Following tests with various ERA-40 interpolation time steps, it was decided to consider here the average value of continuous (when available) aircraft observations during 4 minutes.

In the present study, we use ERA-40 products on pressure levels and at full temporal resolution (i.e. at 6-hour intervals: 00, 06, 12, and 18 UTC each day). The ERA-40 data are then interpolated to the positions and times of the satellite/ aircraft measurements by using a cubic scheme in the horizontal (http://www.ecmwf.int/research/ifsdocs/CY25r1/Technical/Technical-3-04.html#wp961293), a logarithmic spline interpolation in the vertical, and a simple linear interpolation in time. All necessary computer software has been developed in-house to read the ERA40, UARS and MOZAIC files and to then compare them to the ERA-40 archive. These programmes along with the validation results are stored on the BADC (British Atmospheric Data Centre) web side and they are accessible to users after registration (see http://badc.nerc.ac.uk/cgi-bin/data_browser/data_browser/badc/utls/).

3. SUMMARY OF RESULTS

The overall conclusion is that since the ozone distribution is primarily driven by the dynamical circulation in the atmosphere, and since the wind field of the re-analysis scheme is considered accurate enough, ERA-40 seems to convincingly reproduce the large scale ozone features detected by satellite measurements, despite the rather simplified chemistry parameterization implemented into the re-analysis. Phenomena such as the Antarctic and Artic ozone hole, the tropical stratospheric ozone maximum, the tropical LS (Lower Stratosphere) water vapour minimum, and the tape-recorder signal are reproduced by the re-analysis. The greatest discrepancies, however, in both the ozone and water vapour between ERA-40 and the UARS and MOZAIC observations occur primarily over the tropics and the high-latitudes. For water vapour, ERA-40 is drier than HALOE in the upper and middle stratosphere by 10-15% and this discrepancy is likely to be due to inadequacies in the methane oxidation scheme used in the re-analysis.

In the upper stratosphere ERA-40 overestimates the ozone concentrations by typically up to 10% over the tropics and the mid-latitudes, and by 10-20% over the high-latitudes, with a strong seasonal dependence in the way ERA-40 captures the actual value of the tropical ozone maximum. In the middle and lower stratosphere, ERA-40 seems to underestimate ozone by typically 5%, a tendency that persists over the tropics throughout the year, but is highly variable with season, and may even change sign over the mid- and high-latitudes. In general, ERA-40 underestimates the ozone concentration within the core of the Antarctic ozone hole by 10-20%, though this situation may be the opposite for same years during the 1990s, but ERA-40 consistently overestimates ozone values by 10% at levels above the Antarctic ozone hole. By contrast, ERA-40 seems to significantly overestimate ozone during Arctic ozone hole events (primarily in January), and especially during the coldest winters throughout the 1990s. In the UTLS ERA-40 tends to consistently underestimate ozone in the LS over the high-latitudes, and overestimate it in the tropical UT (Upper Troposphere). In the UTLS over the mid-latitudes, the ERA-40 ozone performance has a strong seasonal variation. Because of an improvement in the data assimilation system introduced in October 1996, post this date ERA-40 ozone is subsequently closer to MOZAIC data in the UTLS over the mid- and high-latitudes. In view of these results, care should be taken when calculating ERA-40 ozone trends in the UTLS during the 1990s over the mid- and high-latitudes.

The water vapour cycle in ERA-40 appears to be problematic. ERA-40 is too dry by about 10-20% above about 70hPa. Although within the core of the Antarctic vortex, ERA-40 is wetter than HALOE in the LS by a few percent, above about 50hPa ERA-40 is significantly drier within the vortex. This ERA-40 dry bias in the upper and middle stratosphere is not confined to the region of the Antarctic polar vortex but is essentially global. This dry bias seems to increase with time during the 1990s. In the upper stratosphere, ERA-40 does not capture realistically the seasonal cycle in water vapour as observed by HALOE. At tropopause levels and into the UT, ERA-40 values are wetter than those of MOZAIC, typically by about 20%. Finally, in the LS over the high-latitudes the re-analysis is >60% wetter than MOZAIC at and below cruise altitudes of 11.2km (223-215hPa).

A detailed report of the project along with key figures can be found in the publication:
E. K. Oikonomou and A. O'Neill. The evaluation of ozone and water vapour fields from the ECMWF re-analysis ERA-40 during 1991-1999 in comparison with UARS satellite and MOZAIC aircraft observations. Manuscript submitted to *J. Geopys. Res., Atmospheres*, 2005.

4. REFERENCES

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