National report The Netherlands

Systematic observations:

Surface networks

- Brewer measurements in the Netherlands

The Brewer measurements at the station “De Bilt” by KNMI with Brewer #189 have been continued into 2017. Brewer #189 has been operated continuously since 1 October 2006. It replaced Brewer #100 which provided observations since 1 January 1994.“De Bilt” had the longest record of ozone measured with an MKIII instrument in the WOUDC database. The Brewer ozone column data from 1994-2015 are presently available from WOUDC.

- Brewer measurements in Surinam

Measurements at the station “Paramaribo” with Brewer #159 have been continued into 2017. After careful cleaning, the ozone column dataset from1999-2013 has been submitted to WOUDC and NDACC. (The variability in de ozone data in this tropical station is low, and interference by clouds is a significant problem at this site.)

- Ozone soundings in the Netherlands

The ozone sounding program at station “De Bilt” by KNMI has been continued up to present, with at least one launch per week, and more when special events or campaigns occurred. The data from 1992-2015 are available from WOUDC.

- Ozone soundings in Surinam

The ozone sounding program in Paramaribo has been continued with one launch per week. Paramaribo station is part of the SHADOZ network. The observations at Paramaribo are performed by staff of the Meteorological Service of Surinam. All Paramaribo ozone soundings have been reprocessed in line with the "O3S-DQA-Guidelines Homogenization-V2-19November2012". However, the suggested background current correction does not work well for this site, hence the pressure dependent correction proposed by Newton and Vaughan (2016) has been used. Reprocessed data from 1999-2016 are available in the SHADOZ archive https://tropo.gsfc.nasa.gov/shadoz/Paramaribo.html.

- UV-monitoring in the Netherlands

RIVM continued the spectral UV-monitoring at Bilthoven in the Netherlands. The overall UV-data record in now spans 23 years (1994-2016). The solar UV-spectrum at the ground is recorded each 12 minutes from sunrise to sunset. More than 20000 spectra are recorded each year. The spectral data are automatically processed with the QC (quality control) and data-analysis software package SHICrivm and the calculated solar UV-index (or zonkracht in Dutch) is presented in real time on the RIVM website (www.rivm.nl/zonkracht (in Dutch) and www.rivm.nl/UVindex (in English)).

- Ozone lidar measurements Lauder, New-Zealand

RIVM has continued the operation of the stratospheric ozone lidar at the NDACC station in Lauder, New-Zealand where first measurements started in 1994. Procedures for lidar ozone profiling have been standardized with contributions by Van Gijsel and Swart from the Netherlands (Leblanc, 2016a,b). On a single measurement night, usually various measurements are done at Lauder. Profiles up to December 2016 have been submitted to international databases, including NDACC (ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/lauder/ames/lidar/).

Concerns:

Driven by the need for budget-reduction, the operational strategy of the lidar was altered in July 2011. Given the limited budget, necessary software (and possibly hardware) adjustments take considerable time to implement. A second worry comes from the aging of the system. The lidar has been in operation in Lauder for more than 20 years. While laser and computer have been replaced once since, most parts are close to 25 years old. Many electronic parts are no longer replaceable (no longer built) and failure of those would require a large system update. This is not feasible with the current funding status. Continuity of the measurements is therefore at stake, and measurements may stop abruptly on a failure. To address these issues, RIVM and NIWA are working towards a transfer of the instrument from RIVM to NIWA. A smooth transfer of knowledge and PI-ship is anticipated.

Satellite networks

The Netherlands was and is involved in satellite ozone measurements from several instruments: GOME, SCIAMACHY, OMI, GOME-2 and TROPOMI. These are UV-visible satellite spectrometers, from which ozone and several other trace gases, like NO2, SO2, HCHO, are determined. The OMI and GOME-2 instruments are operational. The TROPOMI instrument is presently being prepared for launch in 2017.

SCIAMACHY (July 2002-8 April 2012) was contributed by Germany, the Netherlands, and Belgium to ESA's Envisat satellite. OMI (1 October 2004 onward) is a contribution from the Netherlands and Finland to NASA's EOS-Aura satellite. TROPOMI is the successor instrument of OMI and SCIAMACHY. TROPOMI was developed by the Netherlands and ESA, and will fly on the ESA Sentinel-5 Precursor mission, to be launched in 2017. KNMI has the PI-role of OMI as well as TROPOMI.

Ozone data processing and users

At KNMI near-real time and off-line data processing of satellite ozone columns and ozone profiles is taking place; see Table 1. Also data assimilated products are made. Most of the products are being delivered to users via the web portal www.temis.nl. The multi-sensor reanalysis 1 (MSR1) which covered 1978-2008) has recently been extended to 1970-2012 and refined (Van der A, 2015). This version 2 (MSR2) is available at http://www.temis.nl/protocols/O3global.html

The OMI ozone products are being delivered via the GSFC Data and Information Services Center (DISC). GOME-2 data processing at KNMI (January 2007 onward) is performed in the framework of the Ozone and Atmospheric Chemistry Monitoring Satellite Application Facility (O3MSAF) of EUMETSAT. Data delivery of near-real-time ozone profile products is done via EUMETCast broadcasting**.**

There are many users of the satellite ozone data; for example, OMI ozone column data is being delivered in near-real-time to ECMWF for assimilation in the model, amongst others for the Copernicus Atmosphere Monitoring Service (CAMS) forecasts and reanalyses.

Table 1: Near-real-time and offline satellite ozone products made by KNMI.

Instrument	**Product**	**Period**	**Data delivery**
GOME	Ozone column	1995 – 2011 (global until 2003)	http://www.temis.nl
SCIAMACHY	Ozone column	2002 – 2012	http://www.temis.nl
OMI	Ozone column, Ozone profile, Assimilated ozone column	2004 – now	http://www.temis.nl http://disc.sci.gsfc.nasa.gov/Aura
GOME-2	Ozone profile, Assimilated ozone column	2007 – now	http://www.temis.nl http://o3msaf.fmi.fi http://wdc.dlr.de/data_products/SERVICES/GOME2NRT/o3.php EUMETCast
Multi-Sensor Reanalysis2 (MSR2)	Assimilated ozone column	1970-2012	http://www.temis.nl

Assessment contributions, input to negotiations on the amendment of the Montreal protocol, and outreach

Netherlands scientists (Jos de Laat and Ronald van der A from KNMI and Guus Velders from RIVM) have contributed to several chapters of the last UNEP/WMO Scientific assessment report.

Guus Velders has for many years provided important information on the future atmospheric abundances and climate forcings from scenarios of global and regional HFC emissions. The Montreal Protocol has been very successful in phasing out the global production and consumption of ozone-depleting substances (ODSs). In response, the use of HFCs as ODS replacements has increased strongly since the mid-1990s for refrigerants and foam blowing agents, medical aerosol propellants and miscellaneous products. HFCs do not deplete the ozone layer, but are greenhouse gases and therefore contribute to the radiative forcing of climate. Almost all HFCs currently used as CFC and HCFC replacements have high (100-yr time horizon) global warming potentials (GWPs) ranging from about 150 to 8000. Observations show that the abundances of many HFCs are increasing in the atmosphere. Therefore without regulations, HFCs may contribute significantly to future climate forcing.

In 2015 Velders et al. formulated baseline (or business-as-usual) scenarios for 10 HFC compounds, 11 geographic regions, and 13 use categories. The scenarios rely on detailed data reported by countries to the United Nations; projections of gross domestic product and population; and recent observations of HFC atmospheric abundances. In the baseline scenarios, by 2050 China (31%), India and the rest of Asia (23%), Middle East and northern Africa (11%), and USA (10%) are the principal source regions for global HFC emissions; and refrigeration (40-58%) and stationary air conditioning (21-40%) are the major use sectors. The corresponding radiative forcing could reach 0.22-0.25 W m^{-2} in 2050, which would be 12-24% of the increase from business-as-usual CO_2 emissions from 2015 to 2050. Using the climate model MAGICC6 it was calculated that under the baseline scenario HFCs would contribute 0.35 to 0.5 ^{o}C to global surface temperatures in 2100 (Figure 1).

In 2014 and 2015, regional (EU) and national (Japan, USA) regulations have been implemented to limit the use of high-GWP HFCs. In Oct. 2016 an amendment of the Montreal Protocol has been agreed by all Parties to the protocol. With the amendment HFCs are included in the Protocol and their use will be reduced globally by 80-85% from baseline levels before 2050. The contribution from HFCs to global surface temperatures is now expected to be reduced from 0.35-0.50 ^{o}C to about 0.06 ^{o}C in 2100.

The Netherlands satellite ozone observations are regularly used in the Antarctic and Arctic Ozone Bulletins given out by WMO. Each year for World Ozone Day a national news item is published about the evolution of stratospheric ozone and UV, e.g.:

- in 2014: https://www.knmi.nl/over-het-knmi/nieuws/wereldozondag-begin-herstel-ozonlaag

- in 2015: https://www.knmi.nl/over-het-knmi/nieuws/ozon-meten-nodig-ondanks-stagnatie-ozonafbraak
- in 2016: https://www.knmi.nl/over-het-knmi/nieuws/het-gaat-langzaam-beter-met-de-ozonlaag

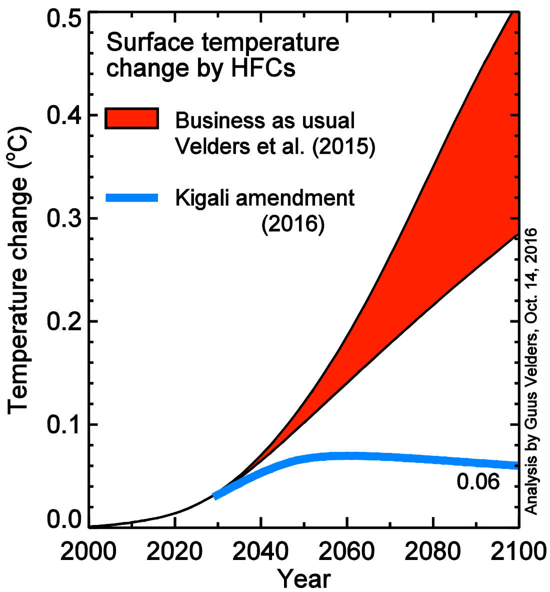

Figure 1. Global surface temperature contribution from HFCs under business-as-usual scenarios and with implementation of the Kigali amendment of 2016.

Selected other contributions

De Laat et al., 2015 performed a sensitivity analysis of multivariate regressions of recent springtime Antarctic vortex ozone trends using a "big data" ensemble approach. The results indicated that the poleward heat flux and the effective chlorine loading respectively explain most of the short-term and long-term variability in different Antarctic springtime total ozone records. The inclusion in the regression of stratospheric volcanic aerosols, solar variability and the quasi-biennial oscillation was shown to increase rather than decrease the overall uncertainty in the attribution of Antarctic springtime ozone because of large uncertainties in their respective records.
When taking fit residuals into account in a piecewise linear trend (PWLT) fit, they found that approximately 30–60% of the regressions in the full ensemble result in a statistically significant positive springtime ozone trend over Antarctica from the late 1990s onwards (Figure 2). De Laat et al. concluded that “Although the results indicate that the use of multivariate regressions is a valid approach for assessing the state of Antarctic ozone hole recovery, and it can be expected that results will move towards more confidence in recovery with increasing record length, uncertainties in choices currently do not yet support formal identification of recovery of the Antarctic ozone hole.”

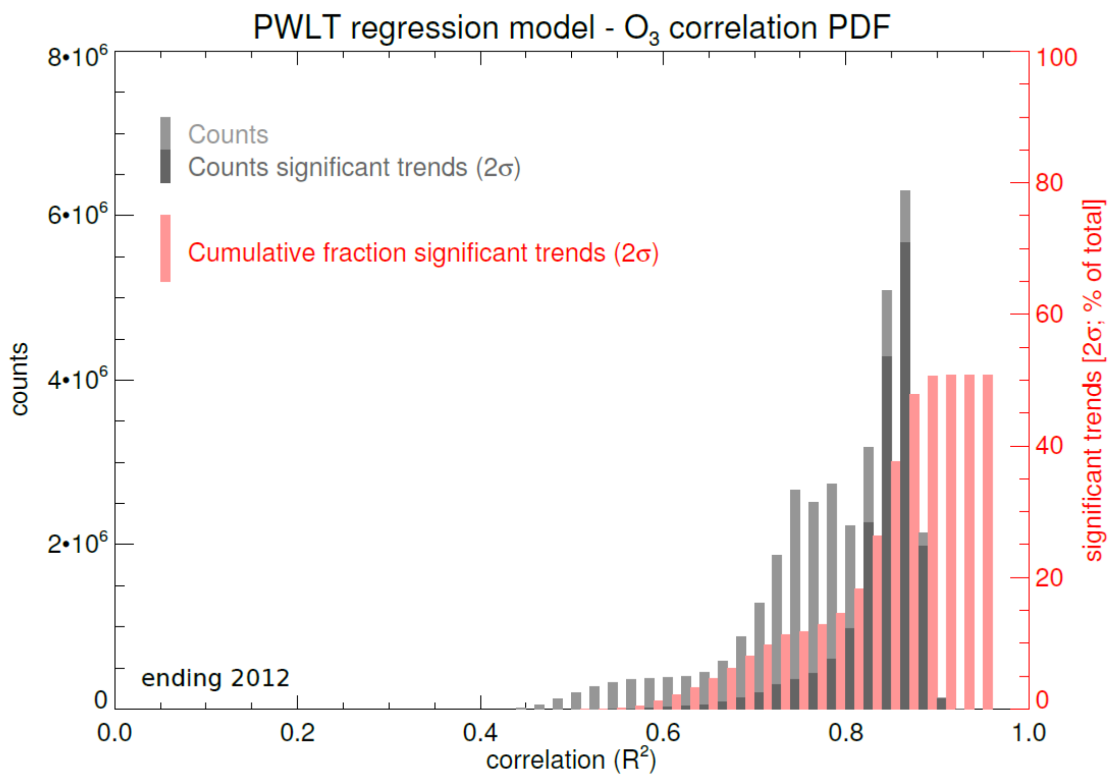

Figure 2
The probability distribution of regression-model–ozone-record-scenario correlations (R^2) for regressions ending in 2012 and the cumulative fraction of statistically significant (2σ) ozone trends for each correlation interval (red, right axis).

Van Peet et al. (2014) have further developed and documented the Ozone ProfilE Retrieval Algorithm (OPERA) version 1.26. This is used for retrieving ozone profiles from UV–VIS observations of most nadir-looking satellite instruments like GOME, SCIAMACHY, OMI and GOME-2.

Van der A et al. (2015) extended the total record of their first version (MSR1) in a second version of the multi sensor reanalysis of total ozone (MSR2) by 13 years. This resulted in an ozone record for the 43-year period 1970–2012.
The chemistry transport model and data assimilation system used in the reanalysis, TMDAM, have been adapted to improve the resolution, error modelling and processing speed. The resolution of the TMDAM model runs, assimilation and output was increased from 2x3 to 1x1 degrees from MSR1 to MSR2. The reanalysis was driven by 3-hourly meteorology from the ERA-Interim reanalysis of the European Centre for Medium-Range Weather Forecasts (ECMWF) starting from 1979, and from ERA-40 before that date. As observations the reanalysis included total ozone retrievals of 15 satellite instruments: BUV-Nimbus4, TOMS- Nimbus7, TOMS-EP, SBUV-7, -9, -11, -14, -16, -17, -18, -19, GOME, SCIAMACHY, OMI and GOME-2. The

performance of the MSR2 analysis was quantified with the help of observation-minus-forecast (OmF) departures from the data assimilation, by comparisons with the individual station observations and with ozone soundings (Figure 3). The OmF statistics show that the mean bias of the MSR2 analyses is less than 1 % with respect to de-biased satellite observations after 1979.

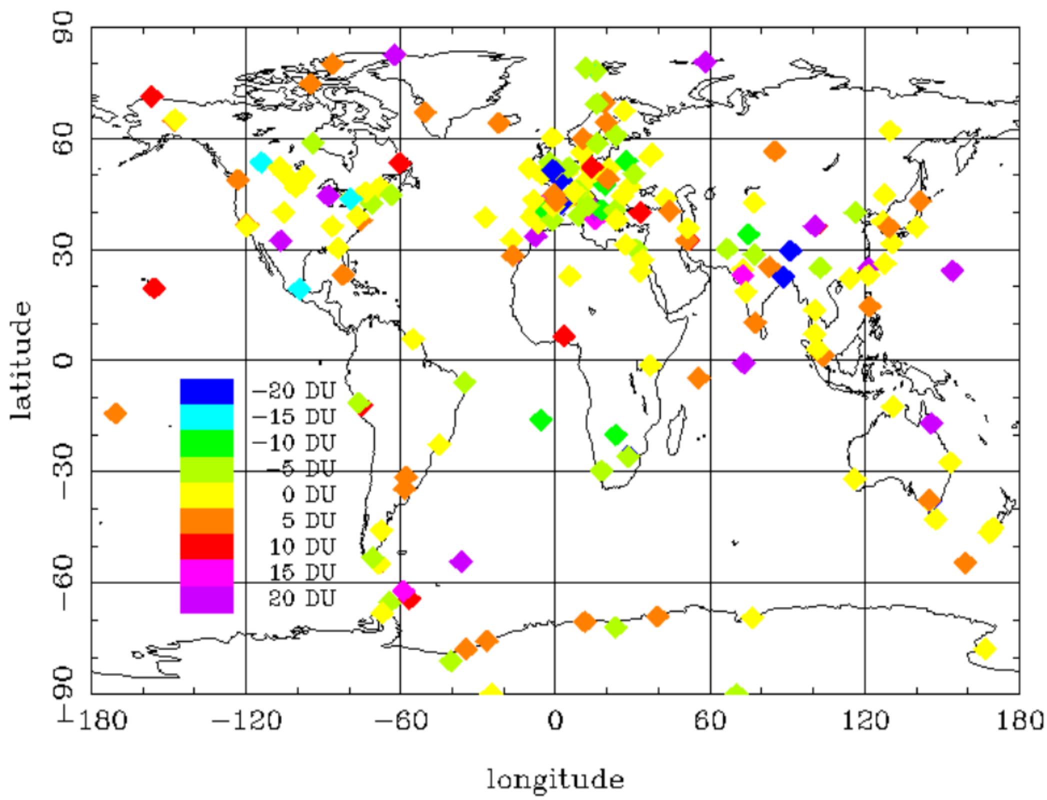

Figure 3
Mean offset (MSR2 minus observations) between the MSR2 reanalysis data and all selected Dobson and Brewer ground-based measurements during the period 1970–2012

As mentioned above, RIVM/VLH (Harry Slaper, Peter den Outer, and Arjan van Dijk) continued the spectral UV-monitoring in Bilthoven in the Netherlands. All measured data are used to calculate yearly sums of UV-radiation, skin cancer weighted doses, received on a horizontal plane. A standard procedure is used to correct for differences in cloud effects. Thus, one obtains the measured yearly sum of UV-radiation received at ground level and in addition derive a cloud-corrected yearly sum (see Figure 4 lower and upper panel) for the observed trends. The procedure enables a separation of trends caused by ozone, and trends and changes caused by combined effects of ozone and clouds.

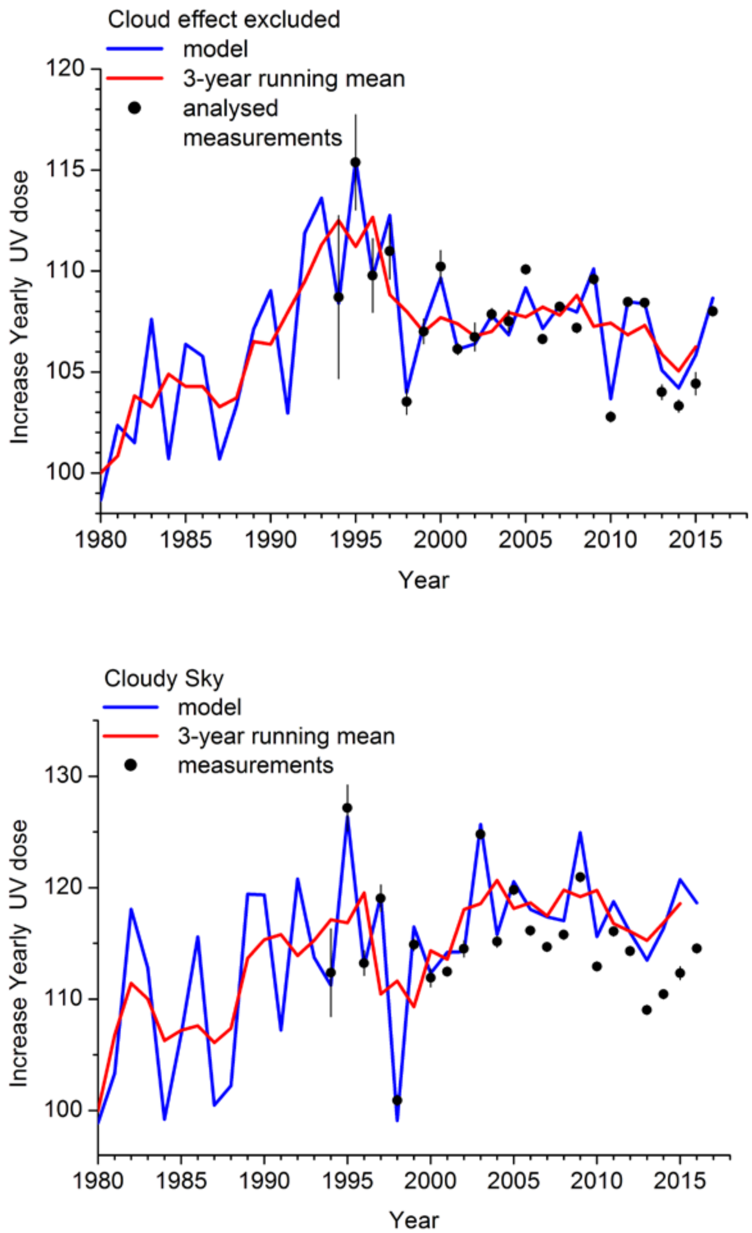

Figure 4.
Observed UV-trends and variations in the Netherlands (Bilthoven) in the past decades. The values are compared to the average over the periode 1979-1981 and thus 100% is given as the yearly dose in 1980. Trends are based on RIVM's UV-monitoring data (circles) and a comparison with modelled UV-radiation levels using a combination of ozone sources (techniques described by Den Outer et al., 2010). The upper panel is corrected for cloud effects and thus shows the ozone related changes in UV at ground level and the lower panel shows the relative doses received at the ground including changes and variations caused by clouds and ozone. Data for the recent period are preliminary.

Maximum clear sky UV-sums are found in the mid-nineties of the last century, with the highest yearly sum in 1995 (see Figure 4). Since that period ozone values slightly increased and consequently clear sky UV-radiation levels decreased slightly. When looking at the yearly UV-sum received at the ground, including ozone and cloud variations (Figure 4 lower panel), the highest yearly sum was also found in 1995. However, 2003 and 2009 closely follow 1995, and we see that for these years a lower reduction by clouds compensated the slightly higher ozone values.
The red line in the upper panel indicate the three year running averages and follows the curve estimated for the amendments of the Montreal Protocol (not shown here) as was previously calculated using the AMOUR-model (van Dijk et al 2013). Thus, the ozone layer appears to follow the expected recovery and this is reflected in the cloud-corrected UV-dataset. However, the cloud effects partly compensate the decrease in UV due to increased ozone (figure 4 lower panel).
Looking at the skin cancer incidence in the Netherlands it is noted that the increase in the incidence is much stronger than expected based on ageing of the population and the increased UV-radiation levels shown here. This implies that behavioral increases in UV-exposure at present dominate the effects of ozone and clouds on the skin cancer risks. However, future risks might further increase due to the presently observed increases in UV-radiation levels. Furthermore, climate change might indirectly, through higher summer temperatures, add to behavioral changes that further increase UV-exposure and subsequent future skin cancer risks.

Publications

A, R.J. van der, M.A.F. Allaart and H.J. Eskes, Extended and refined multi sensor reanalysis of total ozone for the period 1970-2012. Atmospheric Measurement Techniques, 2015, 8, 3021-3035, doi:10.5194/amt-8-3021-2015.

Den Outer PN, Slaper H, Lindfors A, Kaurola J, Bais A, Kazantzidis A, Feister U, Junk J, Janouch M, Josefsson W., Reconstructing of erythemal ultraviolet radiation levels in Europe for the past 4 decades, (2010) *J. Geophys. Res.,* **115**, D10102, doi:10.1029/2009JD012827.

Gaudel, A., H. Clark, V. Thouret, L. Jones, A. Inness, J. Flemming, O. Stein, V. Huijnen, H. Eskes, P. Nedelec and D. Boulanger, On the use of MOZAIC-IAGOS data to assess the ability of the MACC reanalysis to reproduce the distribution of ozone and CO in the UTLS over Europe. Tellus, 67, 2016, 27955, doi:10.3402/tellusb.v67.27955.

Huijnen, V., J. Flemming, S. Chabrillat, Q. Errera, Y. Christophe, A.M. Blechschmidt, A. Richter and H. Eskes, C-IFS-CB05-BASCOE: stratospheric chemistry in the Integrated Forecasting System of ECMWF. Geoscientific Model Development, 2016, 9, 3071-3091, doi:10.5194/gmd-9-3071-2016.

Laat, A.T.J. de, R.J. van der A and M. van Weele, Tracing the second stage of Antarctic ozone hole recovery with a “big data” approach to multi-variate regressions. Atm. Chem. Phys., 15, 2015, 79-97, doi:10.5194/acp-15-79-2015.

Leblanc, T., Sica, R. J., van Gijsel, J. A. E., Godin-Beekmann, S., Haefele, A., Trickl, T., Payen, G., and Gabarrot, F.: Proposed standardized definitions for vertical resolution and uncertainty in the NDACC lidar ozone and temperature algorithms – Part 1:

Vertical resolution, Atmos. Meas. Tech., 9, 4029-4049, doi:10.5194/amt-9-4029-2016, 2016a.
Leblanc, T., Sica, R. J., van Gijsel, J. A. E., Haefele, A., Payen, G., and Liberti, G.: Proposed standardized definitions for vertical resolution and uncertainty in the NDACC lidar ozone and temperature algorithms – Part 3: Temperature uncertainty budget, Atmos. Meas. Tech., 9, 4079-4101, doi:10.5194/amt-9-4079-2016, 2016b.
Van Dijk A., H. Slaper, P.N. den Outer, O. Morgenstern, P.Braesicke, J.A. Pyle, H.Garny, A.Stenke, M.Dameris, A.Kazantzidis, K.Tourpali and A.F. Bais, Skin Cancer Risks Avoided by the Montreal Protocol—Worldwide Modeling Integrating CoupledClimate-Chemistry Models with a Risk Model for UV, *Photochemistry and Photobiology*, **89**: 234–246, 2013.
Van Peet, J. C. A., van der A, R. J., Tuinder, O. N. E., Wolfram, E., Salvador, J., Levelt, P. F., and Kelder, H. M.: Ozone ProfilE Retrieval Algorithm (OPERA) for nadir-looking satellite instruments in the UV–VIS, Atmos. Meas. Tech., 7, 859-876, doi:10.5194/amt-7-859-2014, 2014.
Velders, G.J.M., S. Solomon, J.S. Daniel, Growth of climate change commitments from HFC banks and emissions, Atmospheric Chemistry and Physics, 14, 4563–4572, doi:10.5194/acp-14-4563-2014, 2014.
Velders, G.J.M., D.W. Fahey, J.S. Daniel, S.O. Andersen, M. McFarland, Future atmospheric abundances and climate forcings from scenarios of global and regional hydrofluorocarbon (HFC) emissions, Atmos. Env., 123, 200-209, doi: 10.1016/j.atmosenv.2015.10.071, 2015.
Williams, J.E., O. Hodnebrug, P.F.J. van Velthoven, T.K. Berntsen, O. Dessens, M. Gauss, V. Grewe, I.S.A. Isaksen, D. Olivie, M.J. Prather and Q. Tang, The influence of future non-mitigated road transport emissions on regional ozone exceedences at global scale. Atmos. Environm., 2014, 89, 633-641, doi:10.1016/j.atmosenv.2014.02.041.
Xu, Y., D. Zaelke, G.J.M. Velders, V. Ramanathan, The role of HFCs in mitigating 21st century climate change, Atmospheric Chemistry and Physics, 13, 6083-6089, doi: 10.5194/acp-13-6083-2013, 2013.

Other references

Newton, R., Vaughan, G., Ricketts, H. M. A., Pan, L. L., Weinheimer, A. J., and Chemel, C.: Ozonesonde profiles from the West Pacific Warm Pool: measurements and validation, Atmos. Chem. Phys., 16, 619-634, doi:10.5194/acp-16-619-2016, 2016.