Ozone_cci+

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Executive Summary

This Project Scientific Highlights (PSH) document is intended to inform ESA of key scientific results of the project for use in its communications and outreach. It also includes the list of peer-reviewed publications between July 2022 and January 2025 that relied on the availability of datasets or analyses conducted during the Ozone_cci project.

Table of Contents

1 Scientific Highlights

This section contains a short summary of publications co-funded by Ozone_cci+. These are a subset of the publications listed in the previous section.

1.1 The novel GOME-type Ozone Profile Essential Climate Variable (GOP-ECV) data record covering the past 26 years

Short summary of Coldewey-Egbers, M., Loyola, D. G., Latter, B., Siddans, R., Kerridge, B., Hubert, D., van Roozendael, M., and Eisinger, M.: The novel GOME-type Ozone Profile Essential Climate Variable (GOP-ECV) data record covering the past 26 years, Atmos. Meas. Tech. Discuss. [preprint], https://doi.org/10.5194/amt-2024-196, in review, 2025.

The GOME-type Ozone Profile Essential Climate Variable (GOP-ECV) data record provides monthly mean ozone profiles with global coverage from 1995 to 2021 at a spatial resolution of 5°x5°. Measurements from five nadir-viewing satellite sensors are first harmonized and then merged into a coherent record. The long-term stability of the data record is further improved through scaling of the profiles using as a reference the GOME-type Total Ozone Essential Climate Variable (GTO-ECV) data record.

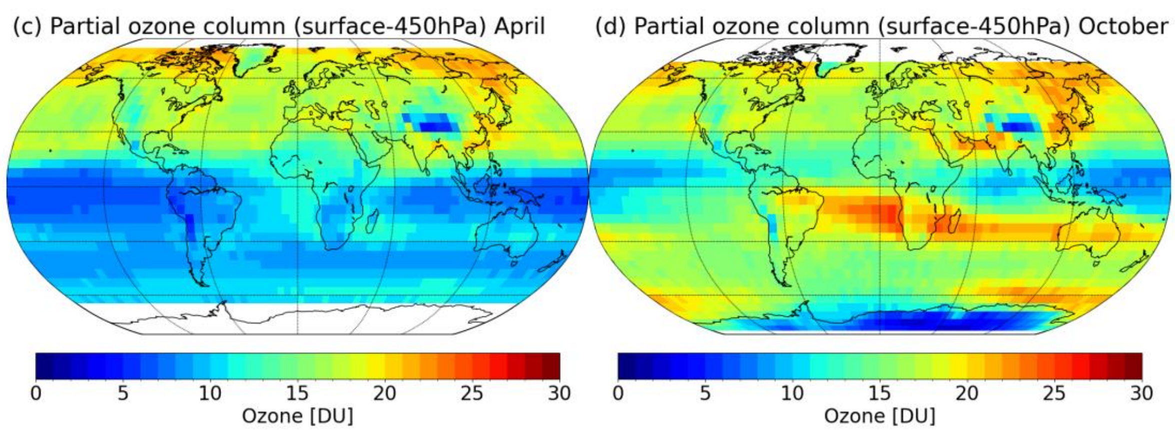

Figure 1.1 - Climatological ozone distribution derived from GOP-ECV 1995-2021 for the integrated total column ((a) and (b)), and the partial column amounts in the layers: surface-450 hPa (0–6 km, (c) and (d)), and 100–50 hPa (16–20 km, (e) and (f)). For the total column and each layer the values for April ((a), (c), (e)) and October ((b), (d), (f)) are shown. White grid cells denote that no data is available, mainly due to polar night conditions.

1.2 Tropospheric ozone column dataset from OMPS-LP/OMPS-NM limb–nadir matching

Short summary of Orfanoz-Cheuquelaf, A., Arosio, C., Rozanov, A., Weber, M., Ladstätter-Weißenmayer, A., Burrows, J. P., Thompson, A. M., Stauffer, R. M., and Kollonige, D. E.: Tropospheric ozone column dataset from OMPS-LP/OMPS-NM limb–nadir matching, Atmos. Meas. Tech., 17, 1791–1809, https://doi.org/10.5194/amt-17-1791-2024, 2024.

Valuable information on the tropospheric ozone column (TrOC) can be obtained globally by combining space-borne limb and nadir measurements (limb–nadir matching, LNM). This study describes the retrieval of TrOC from the OMPS instrument (since 2012) using the LNM technique. The OMPS-LNM TrOC was compared with ozonesondes and other satellite measurements, showing a good agreement with a negative bias within 1 to 4 DU. This new dataset is suitable for pollution studies.

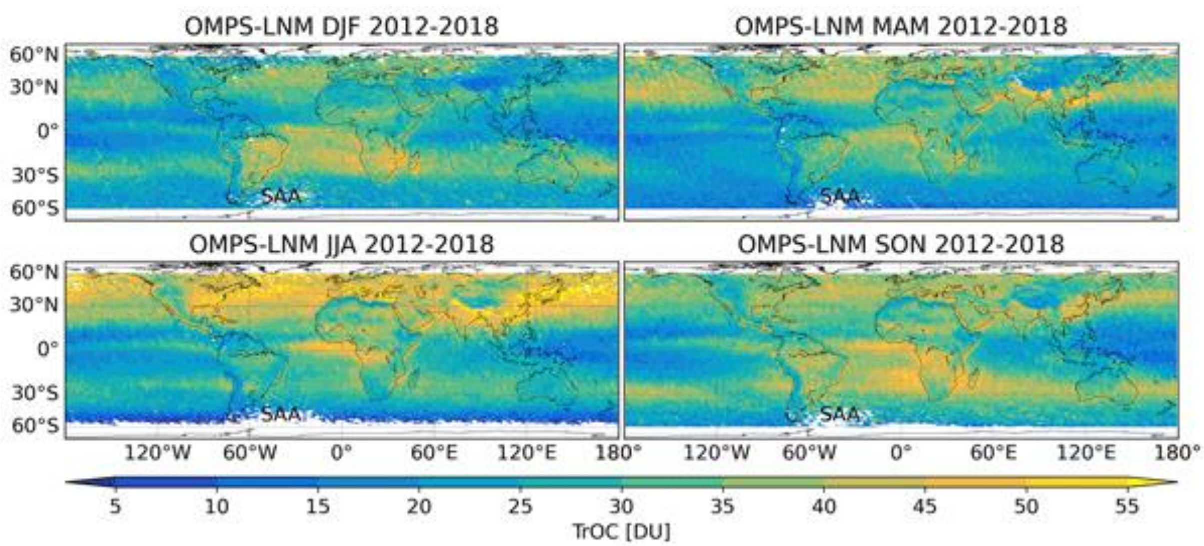

Figure 1.2 - Seasonal maps of OMPS-LNM TrOC averaged from 2012 to 2018.

1.3 Updated merged SAGE-CCI-OMPS+ dataset for the evaluation of ozone trends in the stratosphere

Short summary of Sofieva, V. F., Szelag, M., Tamminen, J., Arosio, C., Rozanov, A., Weber, M., Degenstein, D., Bourassa, A., Zawada, D., Kiefer, M., Laeng, A., Walker, K. A., Sheese, P., Hubert, D., van Roozendael, M., Retscher, C., Damadeo, R., and Lumpe, J. D.: Updated merged SAGE-CCI-OMPS+ dataset for the evaluation of ozone trends in the stratosphere, Atmos. Meas. Tech., 16, 1881–1899, https://doi.org/10.5194/amt-16-1881-2023, 2023.

The paper presents the updated SAGE-CCI-OMPS+ climate data record of monthly zonal mean ozone profiles. This dataset covers the stratosphere and combines measurements by nine limb and occultation satellite instruments (SAGE II, OSIRIS, MIPAS, SCIAMACHY, GOMOS, ACE-FTS, OMPS-LP, POAM III, and SAGE III/ISS). The update includes new versions of MIPAS, ACE-FTS, and OSIRIS datasets and introduces data from additional sensors (POAM III and SAGE III/ISS) and retrieval processors (OMPS-LP).

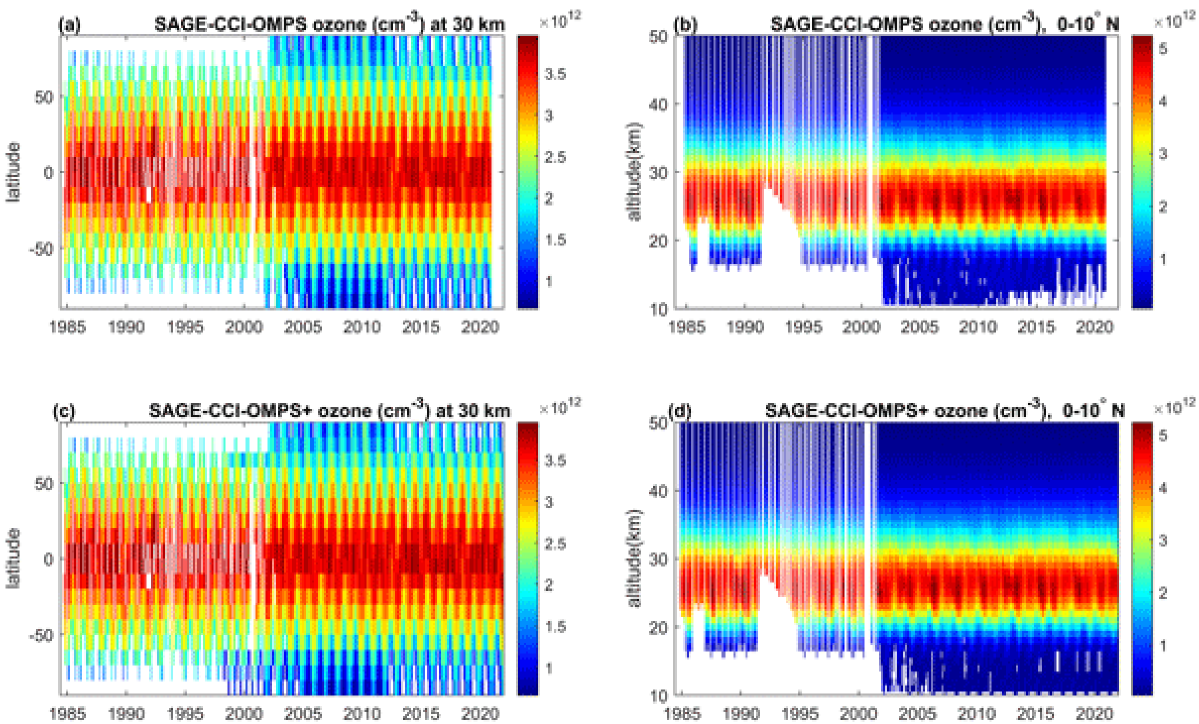

Figure 1.3 - Time series of ozone at 30 km in the merged SAGE-CCI-OMPS (a) and SAGE-CCI-OMPS+ (c) datasets. Time series of ozone profiles at 0–10°N in SAGE-CCI-OMPS (b) and SAGE-CCI-OMPS+ (d).

1.4 Removing Prior Information from Remotely Sensed Atmospheric Profiles by Wiener Deconvolution Based on the Complete Data Fusion Framework

Short summary of Keppens, A.; Compernolle, S.; Hubert, D.; Verhoelst, T.; Granville, J.; Lambert, J.-C. Removing Prior Information from Remotely Sensed Atmospheric Profiles by Wiener Deconvolution Based on the Complete Data Fusion Framework, Remote Sens., 14, 2197, https://doi.org/10.3390/rs1409219, 2022.

A method is developed that removes a priori information from remotely sensed atmospheric state profiles. This consists of a Wiener deconvolution, whereby the required cost function is obtained from the complete data fusion framework. Asserting that the deconvoluted averaging kernel matrix has to equal the unit matrix, results in an iterative process for determining a profile-specific deconvolution matrix. In contrast with previous deconvolution approaches, only the dimensions of this matrix have to be fixed beforehand, while the iteration process optimizes the vertical grid. This method is applied to ozone profile retrievals from simulated and real measurements co-located with the Izaña ground station. Individual profile deconvolutions yield strong outliers, including negative ozone concentration values, but their spatiotemporal averaging results in prior-free atmospheric state representations that correspond to the initial retrievals within their uncertainty. Averaging deconvoluted profiles thus looks like a viable alternative in the creation of harmonized Level-3 data, avoiding vertical smoothing difference errors and the difficulties that arise with averaged averaging kernels.

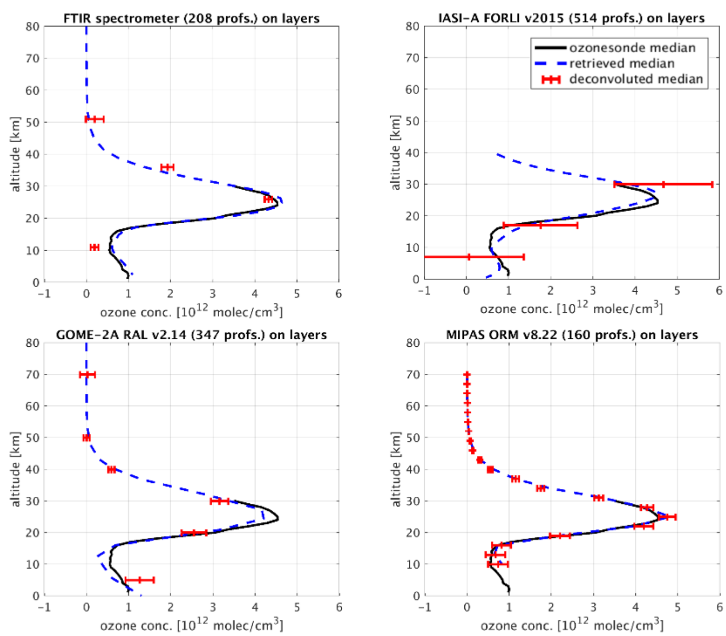

Figure 1.4 - Yearly median ozone profile retrievals (blue dashes) and deconvoluted profiles (red crosses) from the NDACC FTIR, IASI-A, GOME-2A, and MIPAS instruments (left to right and top to bottom) for 2010 at Izaña Deconvolutions are performed for $d-$ layers. Horizontal error bars represent two ex-ante standard deviations, as calculated from the median deconvoluted covariance matrix diagonal. Black lines show the median of the ozone profiles measured by ozonesonde at Izaña.

1.5 Synergy of Using Nadir and Limb Instruments for Tropospheric Ozone Monitoring (SUNLIT)

Short summary of Sofieva, V. F., Hänninen, R., Sofiev, M., Szeląg, M., Lee, H. S., Tamminen, J., and Retscher, C.: Synergy of Using Nadir and Limb Instruments for Tropospheric Ozone Monitoring (SUNLIT), Atmos. Meas. Tech., 15, 3193–3212, https://doi.org/10.5194/amt-15-3193-2022, 2022.

We present tropospheric ozone column datasets that have been created using combinations of total ozone column from OMI and TROPOMI with stratospheric ozone column datasets from several available limb-viewing instruments (MLS, OSIRIS, MIPAS, SCIAMACHY, OMPS-LP, GOMOS). The main results are (i) several methodological developments, (ii) new tropospheric ozone column datasets from OMI and TROPOMI, and (iii) a new high-resolution dataset of ozone profiles from limb satellite instruments.

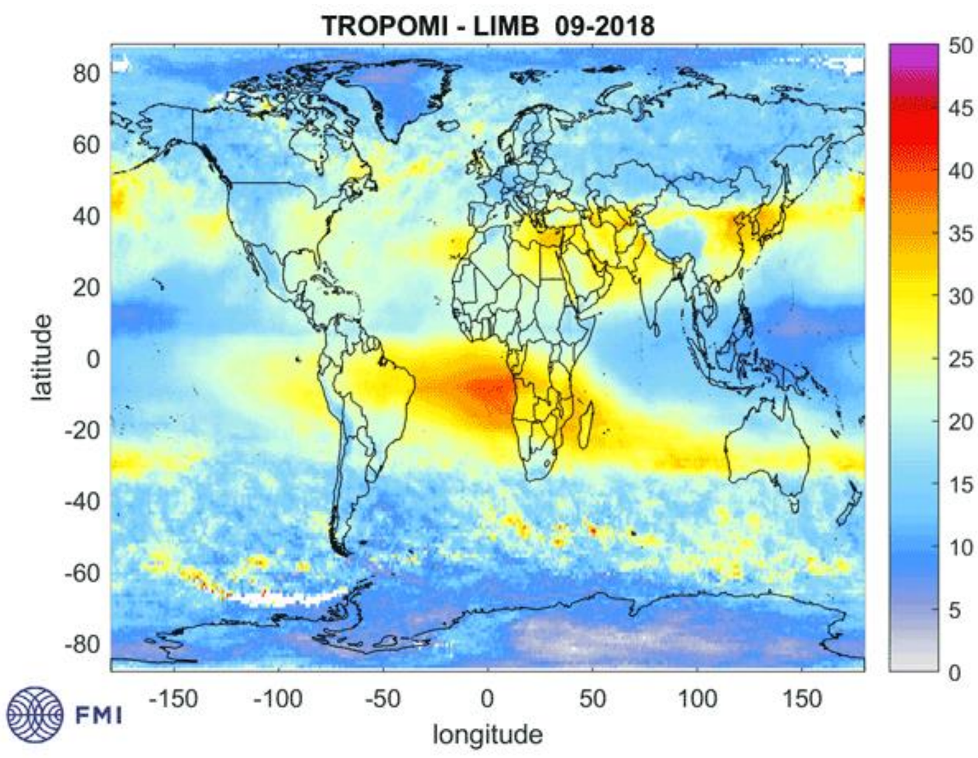

Figure 1.5 - Tropospheric ozone distributions (DU, color) for September 2018 from TROPOMI.

1.6 Global total ozone recovery trends attributed to ozone-depleting substance (ODS) changes derived from five merged ozone datasets

Short summary of Weber, M., Arosio, C., Coldewey-Egbers, M., Fioletov, V. E., Frith, S. M., Wild, J. D., Tourpali, K., Burrows, J. P., and Loyola, D.: Global total ozone recovery trends attributed to ozone-depleting substance (ODS) changes derived from five merged ozone datasets, Atmos. Chem. Phys., 22, 6843–6859, https://doi.org/10.5194/acp-22-6843-2022, 2022.

Long-term trends in column ozone have been determined from five merged total ozone datasets spanning the period 1978–2020. We show that ozone recovery due to the decline in stratospheric halogens after the 1990s (as regulated by the Montreal Protocol) is evident outside the tropical region and amounts to half a percent per decade. The ozone recovery in the Northern Hemisphere is however compensated for by the negative long-term trend contribution from atmospheric dynamics since the year 2000.

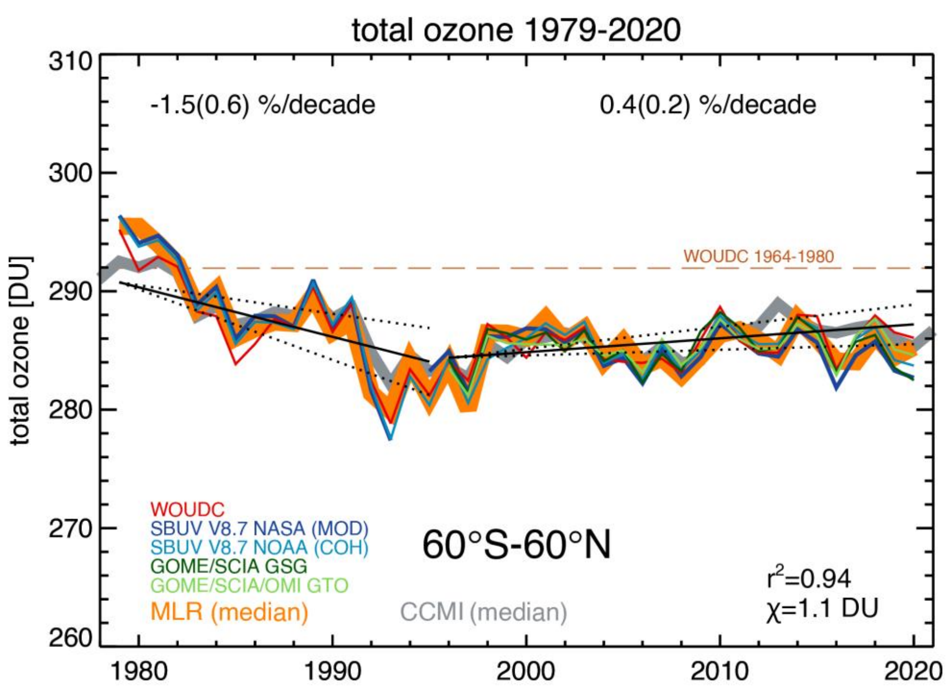

Figure 1.6 - Near-global (60° S–60° N) total ozone time series of five bias-corrected merged datasets. The thick orange line is the result from applying the full MLR to the median time series. The solid lines indicate the linear trends before and after the ODS peak, respectively. The dotted lines indicate the 2σ uncertainty of the MLR trend estimates. Trend numbers are indicated for the pre- and post-ODS peak period in the top part of the plot. Numbers in parentheses are the 2σ trend uncertainty. The dashed orange line shows the mean ozone level from 1964 until 1980 from the WOUDC data. The thick grey line is the median of 17 chemistry–climate models from the CCMI.

2 Complete list of publications

This section lists the publications (co-)authored by Ozone_cci+ team members during Phase 2 of the project (2022-2025). This list also includes work by non-CCI researchers using ozone data products developed as part of ESA's CCI.

2.1 2025

Coldewey-Egbers, M., Loyola, D. G., Latter, B., Siddans, R., Kerridge, B., Hubert, D., van Roozendael, M., and Eisinger, M.: The novel GOME-type Ozone Profile Essential Climate Variable (GOP-ECV) data record covering the past 26 years, Atmos. Meas. Tech. Discuss. [preprint], https://doi.org/10.5194/amt-2024-196, in review, 2025.

Keppens, A., Hubert, D., Granville, J., Nath, O., Lambert, J.-C., Wespes, C., Coheur, P.-F., Clerbaux, C., Boynard, A., Siddans, R., Latter, B., Kerridge, B., Di Pede, S., Veefkind, P., Cuesta, J., Dufour, G., Heue, K.-P., Coldewey-Egbers, M., Loyola, D., Orfanoz-Cheuquelaf, A., Maratt Satheesan, S., Eichmann, K.-U., Rozanov, A., Sofieva, V. F., Ziemke, J. R., Inness, A., Van Malderen, R., and Hoffmann, L.: Harmonisation of sixteen tropospheric ozone satellite data records, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-3746, 2025.

2.2 2024

Arosio, C., Sofieva, V., Orfanoz-Cheuquelaf, A., Rozanov, A., Heue, K.-P., Malina, E., Stauffer, R. M., Tarasick, D., Van Malderen, R., Ziemke, J. R., and Weber, M.: Inter-comparison of tropospheric ozone column datasets from combined nadir and limb satellite observations, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-3737, 2024.

Gaudel, A., Bourgeois, I., Li, M., Chang, K.-L., Ziemke, J., Sauvage, B., Stauffer, R. M., Thompson, A. M., Kollonige, D. E., Smith, N., Hubert, D., Keppens, A., Cuesta, J., Heue, K.-P., Veefkind, P., Aikin, K., Peischl, J., Thompson, C. R., Ryerson, T. B., Frost, G. J., McDonald, B. C., and Cooper, O. R.: Tropical tropospheric ozone distribution and trends from in situ and satellite data, Atmos. Chem. Phys., 24, 9975–10000, https://doi.org/10.5194/acp-24-9975-2024, 2024.

Maratt Satheesan, S., Eichmann, K.-U., Burrows, J. P., Weber, M., Stauffer, R., Thompson, A. M., and Kollonige, D.: Improved convective cloud differential (CCD) tropospheric ozone from S5P-TROPOMI satellite data using local cloud fields, Atmos. Meas. Tech., 17, 6459–6484, https://doi.org/10.5194/amt-17-6459-2024, 2024.

Orfanoz-Cheuquelaf, A., Arosio, C., Rozanov, A., Weber, M., Ladstätter-Weißenmayer, A., Burrows, J. P., Thompson, A. M., Stauffer, R. M., and Kollonige, D. E.: Tropospheric ozone column dataset from OMPS-LP/OMPS-NM limb–nadir matching, Atmos. Meas. Tech., 17, 1791–1809, https://doi.org/10.5194/amt-17-1791-2024, 2024.

Pimlott, M. A., Pope, R. J., Kerridge, B. J., Siddans, R., Latter, B. G., Ventress, L. J., Feng, W., and Chipperfield, M. P.: Large Reductions in Satellite-Derived and Modelled European Lower

Tropospheric Ozone During and After the COVID-19 Pandemic (2020–2022), EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-2736, 2024.

Pimlott, M. A., Pope, R. J., Kerridge, B. J., Siddans, R., Latter, B. G., Feng, W., and Chipperfield, M. P.: Long-term satellite trends of European lower-tropospheric ozone from 1996–2017, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2024-3717, 2024.

Pope, R. J., O'Connor, F. M., Dalvi, M., Kerridge, B. J., Siddans, R., Latter, B. G., Barret, B., Le Flochmoen, E., Boynard, A., Chipperfield, M. P., Feng, W., Pimlott, M. A., Dhomse, S. S., Retscher, C., Wespes, C., and Rigby, R.: Investigation of the impact of satellite vertical sensitivity on long-term retrieved lower-tropospheric ozone trends, Atmos. Chem. Phys., 24, 9177–9195, https://doi.org/10.5194/acp-24-9177-2024, 2024.

Pope, R. J., Rap, A., Pimlott, M. A., Barret, B., Le Flochmoen, E., Kerridge, B. J., Siddans, R., Latter, B. G., Ventress, L. J., Boynard, A., Retscher, C., Feng, W., Rigby, R., Dhomse, S. S., Wespes, C., and Chipperfield, M. P.: Quantifying the tropospheric ozone radiative effect and its temporal evolution in the satellite era, Atmos. Chem. Phys., 24, 3613–3626, https://doi.org/10.5194/acp-24-3613-2024, 2024.

Weber, M., Steinbrecht, W., Arosio, C., van der A, R., Frith, S. M., Anderson, J., Ciasto, L. M., Coldewey-Egbers, M., Davis, S., Degenstein, D., Fioletov, V. E., Froidevaux, L., Hubert, D., Loyola, D., Rozanov, A., Sofieva, V., Tourpali, K., Wang, R., Warnock, T. and Wild, J. D.: Stratospheric ozone [in “State of the Climate in 2023”]. Bull. Amer. Meteor. Soc., 105 (8), S99-S100, https://doi.org/10.1175/2024BAMSStateoftheClimate.1, 2024.

2.3 2023

Pope, R. J., Kerridge, B. J., Siddans, R., Latter, B. G., Chipperfield, M. P., Feng, W., Pimlott, M. A., Dhomse, S. S., Retscher, C., and Rigby, R.: Investigation of spatial and temporal variability in lower tropospheric ozone from RAL Space UV–Vis satellite products, Atmos. Chem. Phys., 23, 14933–14947, https://doi.org/10.5194/acp-23-14933-2023, 2023.

Sofieva, V. F., Szelag, M., Tamminen, J., Arosio, C., Rozanov, A., Weber, M., Degenstein, D., Bourassa, A., Zawada, D., Kiefer, M., Laeng, A., Walker, K. A., Sheese, P., Hubert, D., van Roozendael, M., Retscher, C., Damadeo, R., and Lumpe, J. D.: Updated merged SAGE-CCI-OMPS+ dataset for the evaluation of ozone trends in the stratosphere, Atmos. Meas. Tech., 16, 1881–1899, https://doi.org/10.5194/amt-16-1881-2023, 2023.

Weber, M., Steinbrecht, W., Arosio, C., van der A, R., Frith, S. M., Anderson, J., Ciasto, L. M., Coldewey-Egbers, M., Davis, S., Degenstein, D., Fioletov, V. E., Froidevaux, L., Loyola, D., Rozanov, A., Sofieva, V., Tourpali, K., Wang, R., Warnock, T. and Wild, J. D.: Stratospheric ozone [in “State of the Climate in 2022”]. Bull. Amer. Meteor. Soc., 104 (9), S94-S96, https://doi.org/10.1175/BAMS-D-23-0090.1, 2023.

2.4 2022

Coldewey-Egbers, M., Loyola, D. G., Lerot, C., and Van Roozendael, M.: Global, regional and seasonal analysis of total ozone trends derived from the 1995–2020 GTO-ECV climate data record, Atmos. Chem. Phys., 22, 6861–6878, https://doi.org/10.5194/acp-22-6861-2022, 2022.

Godin-Beekmann, S., Azouz, N., Sofieva, V. F., Hubert, D., Petropavlovskikh, I., Effertz, P., Ancellet, G., Degenstein, D. A., Zawada, D., Froidevaux, L., Frith, S., Wild, J., Davis, S., Steinbrecht, W., Leblanc, T., Querel, R., Tourpali, K., Damadeo, R., Maillard Barras, E., Stübi, R., Vigouroux, C., Arosio, C., Nedoluha, G., Boyd, I., Van Malderen, R., Mahieu, E., Smale, D., and Sussmann, R.: Updated trends of the stratospheric ozone vertical distribution in the 60° S–60° N latitude range based on the LOTUS regression model, Atmos. Chem. Phys., 22, 11657–11673, https://doi.org/10.5194/acp-22-11657-2022, 2022.

Hassler, B. and P. J. Young (Lead Authors), W. T. Ball, R. Damadeo, J. Keeble, E. Maillard Barras, V. Sofieva and G. Zeng, Update on Global Ozone: Past, Present, and Future, Chapter 3 in Scientific Assessment of Ozone Depletion: 2022, GAW Report No. 278, 509 pp., https://csl.noaa.gov/assessments/ozone/2022, WMO, Geneva, 2022.

Keppens, A., Compernolle, S., Hubert, D., Verhoelst, T., Granville, J., and Lambert, J.-C.: Removing Prior Information from Remotely Sensed Atmospheric Profiles by Wiener Deconvolution Based on the Complete Data Fusion Framework, Remote Sens., 14, 2197, https://doi.org/10.3390/rs14092197, 2022.

Mettig, N., Weber, M., Rozanov, A., Burrows, J. P., Veefkind, P., Thompson, A. M., Stauffer, R. M., Leblanc, T., Ancellet, G., Newchurch, M. J., Kuang, S., Kivi, R., Tully, M. B., Van Malderen, R., Piters, A., Kois, B., Stübi, R., and Skrivankova, P.: Combined UV and IR ozone profile retrieval from TROPOMI and CrIS measurements, Atmos. Meas. Tech., 15, 2955-2978, https://doi.org/10.5194/amt-15-2955-2022, 2022.

Sofieva, V. F., Hänninen, R., Sofiev, M., Szeląg, M., Lee, H. S., Tamminen, J., and Retscher, C.: Synergy of Using Nadir and Limb Instruments for Tropospheric Ozone Monitoring (SUNLIT), Atmos. Meas. Tech., 15, 3193–3212, https://doi.org/10.5194/amt-15-3193-2022, 2022.

Weber, M., Arosio, C., Coldewey-Egbers, M., Fioletov, V. E., Frith, S. M., Wild, J. D., Tourpali, K., Burrows, J. P., and Loyola, D.: Global total ozone recovery trends attributed to ozone-depleting substance (ODS) changes derived from five merged ozone datasets, Atmos. Chem. Phys., 22, 6843-6859, https://doi.org/10.5194/acp-22-6843-2022, 2022.

Weber, M., Steinbrecht, W., Arosio, C., van der A, R., Frith, S. M., Anderson, J., Ciasto, L. M., Coldewey-Egbers, M., Davis, S., Degenstein, D., Fioletov, V. E., Froidevaux, L., Hubert, D., Loyola, D., Roth, C., Rozanov, A., Sofieva, V., Tourpali, K., Wang, R., and Wild, J. D.: Stratospheric ozone [in “State of the Climate in 2021”], Bull. Amer. Meteor. Soc., 103 (8), S90-S92, https://doi.org/10.1175/2022BAMSStateoftheClimate.1, August 2022.