Towards The Generation Of A Long-term Data Record Of Formaldehyde Tropospheric Columns From Multiple Satellite Sensors

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This work presents a 25-year multi-satellite data record of formaldehyde (HCHO) observations. Within the QA4ECV project, a 20-year level-2 data record of HCHO columns was reprocessed using state of the art European retrieval algorithms applied to four low-earth-orbit UV-VIS spectrometers: GOME, SCIAMACHY, GOME-2A and OMI. Those products are openly distributed via the QA4ECV web-site (www.qa4ecv.eu). In addition, operational retrievals from TROPOMI rely on similar algorithms, which facilitates their inclusion in a climate data record. Retrieval algorithms have been homogenized to ensure optimal consistency between the historical QA4ECV dataset and the new TROPOMI operational products. However, despite these efforts of homogenization, fundamental differences remain between the datasets, such as the spatial resolution, the overpass time, the sampling period, and possible instrumental degradation effects. Auxiliary datasets such as the cloud product, the a priori profiles or the surface reflectivity are also more difficult to harmonize over such a long time period, as shown in recent satellite intercomparison exercise and ground-based validation studies. We present the status of the HCHO long-term data record, with the aim to assess the needs towards the creation of an atmospheric essential climate variable for ozone and aerosols precursors. We also present some examples of scientific applications using this long-term HCHO dataset, in combination with the QA4ECV/TROPOMI NO_2 dataset.

Satellite data record intercomparison

Cloud product impact

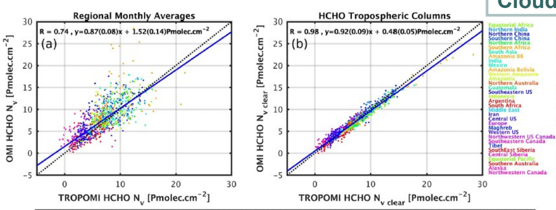


Fig.3: Scatter plots of OMI versus TROPOMI columns for monthly averaged collocated data. Results are shown for N_v (cloud correction, a) and N_{v_clear} (no cloud correction, b). The correlation, slope and intercept are given in each panel and plotted as a blue line.

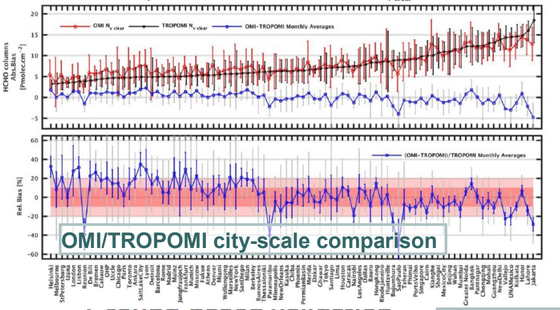


Fig.4: Absolute and relative biases between OMI and TROPOMI HCHO monthly averaged tropospheric columns (N_{v_clear}) within 20 km around selected cities, sorted as a function of the median TROPOMI HCHO column. The median OMI (red) and TROPOMI (black) columns are plotted together with the absolute differences (in blue). Error bars represent the median absolute deviations (MADs) of the columns and of the differences (in grey). Pink areas indicate 10 % and 20 % bias.

Ground-based validation

Vertical smoothing impact

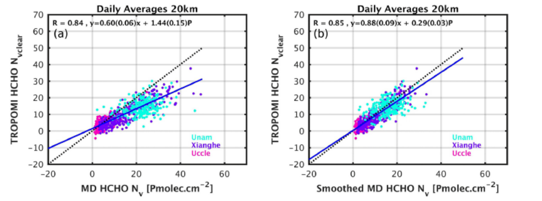


Fig.5: Scatter plots of TROPOMI versus MAX-DOAS data for the daily means of collocated data before (a) and after (b) vertical smoothing of the MAX-DOAS profile in Uccle, Xianghe and UNAM, Mexico. The results of a linear regression is given in each panel.

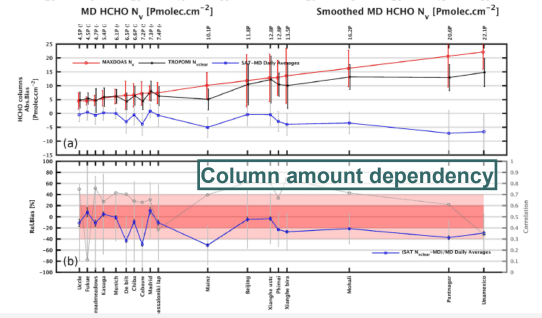


Fig.6: Absolute (**a**, blue line) and relative biases **(b)** between MAX-DOAS and TROPOMI HCHO daily averaged tropospheric columns in a circle of 20 km radius around the stations. Regions are sorted as a function of the median MAX-DOAS HCHO column. In **(a)**, the median MAX-DOAS (red) and TROPOMI (black) columns are plotted together with the differences. Pink areas indicate 20 % and 40 % bias. The correlation between the daily observations is given in **(b)** (grey circles).

25 years HCHO data record [QA4ECV + TROPOMI]

Regional comparisons

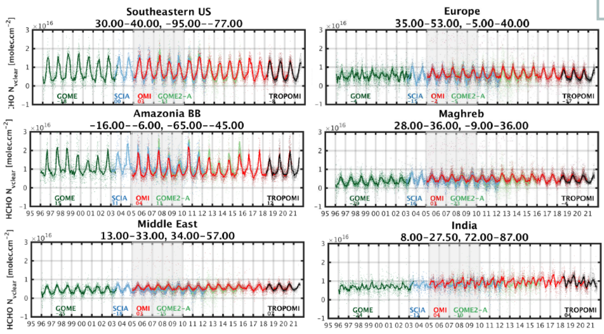


Fig.1: Examples of daily and monthly averaged HCHO columns (N_{v_clear}, no cloud correction) calculated over large emission regions, retrieved from the complete QA4ECV dataset (GOME, SCIAMACHY, GOME-2A, OMI) combined with the TROPOMI dataset. The provided numbers are the mean relative difference of each satellite dataset compared to the OMI 5-years average HCHO between 2005 and 2009.

25 years NO2 data record [QA4ECV + TROPOMI]

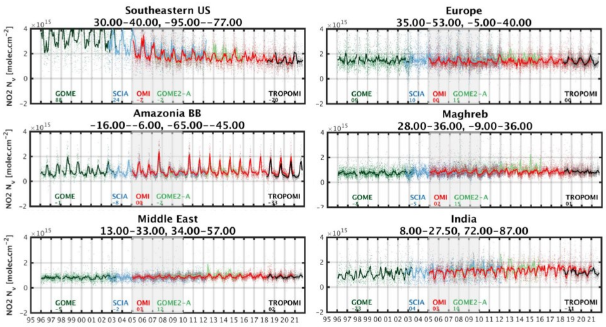


Fig.2: Examples of daily and monthly averaged NO2 columns (N_v, cloud correction) calculated over large emission regions, retrieved from the complete QA4ECV dataset (GOME, SCIAMACHY, GOME-2A, OMI) combined with the TROPOMI dataset. The provided numbers are the mean relative difference of each satellite dataset compared to the OMI 5-years average HCHO between 2005 and 2009.

Scientific applications using QA4ECV data record

Fig.7: "Increases in surface ozone pollution in China from 2013 to 2019: anthropogenic and meteorological influences, Li et al. 2020". Panel (a) shows time series of monthly mean ozone (ppb) anomalies relative to the 2013–2019 summer mean. Observed trends are compared to the trends diagnosed by the MLR model. Panel (b) shows time series of observed JJA mean quantities averaged over the NCP: PM2.5 and NO2 concentrations from the MEE sites, tropospheric NO2 and HCHO column densities from the OMI satellite instrument, and HCHO column density from the TROPOMI satellite instrument. Values are presented as ratios relative to 2013. The TROPOMI HCHO data for 2018 have been scaled to the OMI data.

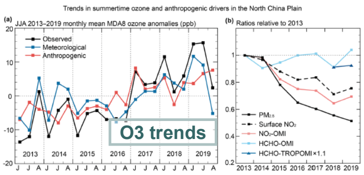
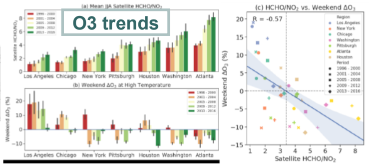


Fig.8: "Inferring Changes in Summertime Surface Ozone–NOx–VOC Chemistry over U.S. Urban Areas from Two Decades of Satellite and Ground-Based Observations, Jin et al. 2020". (a) Satellite-based summertime average HCHO/NO2 in seven cities during five periods. (b)Weekday-to-weekend difference in average summertime O3 within each city at high temperature observed at AQS sites during five periods. Satellite-based HCHO/NO2 is sampled over ground-based AQS O3 sites. (c) Scatter plot between summertime average satellite-based HCHO/NO2 and the weekend ΔO3. The blue line is the fitted linear regression line with 95% confidence interval shaded.



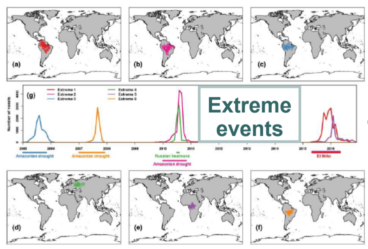


Fig.9: "Vegetation responses to climate extremes recorded by remotely sensed atmospheric formaldehyde, Morfopoulos et al. 2021": Location and timing of the first 6 positive extreme events in the observed OMI HCHO column. Panels a–f show all pixels involved in the identified extreme event for at least 1 month, while panel g shows, for each of these six extremes, the time evolution of the number of voxels involved. Lines underneath the *x*-axis of panel g show the timing of major climatic events as discussed in this study i.e. 2005 (blue), 2007 (orange) and 2010 (pink) Amazonian droughts, 2010 Russian heatwave (green), and 2015 El Niño event (red-magenta).

Conclusions and outlook

- **The QA4ECV and TROPOMI datasets have been developed in parallel and form the longer HCHO data records (Level 2 data).**
- **The OMI and TROPOMI data records have been intercompared and validated at different time and spatial scales. The historical data record needs to be assessed.**
- **Up to now, product users need to generate their own level-3 and handle differences such as spatial resolution [Jin et al., 2020], and many other differences and uncertainties.**
- **It has been shown that the use of different cloud products increase the discrepancy between HCHO datasets from different satellite instruments [De Smedt et al. 2021].**
- **MAX-DOAS validation results show the importance of vertical smoothing and a priori profiles on the tropospheric VCD comparisons. They also show a underestimation of the satellite HCHO over large columns [Vigouroux et al. 2020].**
- **HCHO long-term observations are used in climate studies related to vegetation extreme events [ex: Morfopoulos et al. 2021].**
- **Observed trends in HCHO and NO_2 long-term data records can significantly differ, such as in the Eastern US, Maghreb or the NCP. There is a clear need to study NMVOC emission in combination with NOx trends.**
- **HCHO and NO_2 satellite data records need to be designed with the aim to be used together in tropospheric ozone studies [Li et al. 2020, Jin et al., 2020].**

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