Precursors_cci+

ESA Climate Change Initiative (CCI)



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Precursors-cci+ scientific highlights 2024-2025

Started in July 2022, the Precursors_cci+ project focuses on developing, producing and assessing climate data records of NO_2, HCHO, CHOCHO, SO_2, CO and NH_3 derived from multiple satellite sensors. While the first cycle of activities concentrated on user requirements, L2 retrieval algorithms and the generation/validation of preliminary data sets, the second cycle (covering the period from January 2024 until June 2025) concentrated on generating mature L3 data records from all target gases, assessing their accuracy and fitness for purpose and developing use case studies illustrating their usefulness for chemistry-climate applications.

Efforts deployed by the EO Science Team to improve and harmonise the retrieval algorithms used to process a large number of different satellite sensors have resulted in new long-term data records suitable for trend analysis and atmospheric composition variability studies. A particular focus was put on the generation of L3 data sets, with proper error quantification. For the case of NO2, this work resulted in the development of new approaches to better estimate what fraction of the L2 uncertainty cancels when averaging over space or time and what fraction persists despite the averaging, the spatial and temporal error correlations arez evaluated for all sources of uncertainty in the L2 retrieval. Using these estimates, the L3 uncertainty budget was established based on input L2 uncertainties and new methods to estimate spatial and temporal representativeness uncertainties and to propagate measurement uncertainties through space and time. It was found that the total relative uncertainty in the resulting L3 dataset is in the range of 15 %–20 % in polluted areas, which brings the tropospheric NO_2 data to within the Global Climate Observing System (GCOS) “goal” and “breakthrough” requirements (Glissenaar et al., 2025).

Next to product development and data record generation, another strong focus concerned the validation and verification of compliance of the generated data prroducts with user requirements. For each ECV data record, detailed validation results were provided with associated quality indicators enabling the verification of the fitness-for-purpose of the data as well as an assessment of the compliance of the project’s Climate Research Data package (CRDP) with GCOS requirements. For NO_2, validation concluded on a good consistency across the different sensors. It was also found that for most sensors, bias, dispersion, and total uncertainty meet the threshold requirement (≤50%) in clean conditions, while in highly polluted places (≥10 Pmolec/cm2) the total uncertainty exceeds the threshold requirement for most sensors except TROPOMI. Regarding HCHO, the GCOS goal requirement on total uncertainty is met in clean conditions (≤4E15 molec/cm2), while it is at breakthrough level (≤8E15 molec/cm2) in polluted conditions. Drifts, assessed with FTIR observations, are non-significant and meet the GCOS goal requirement (≤8E15 molec cm-2/decade). Concerning SO2, the bias and dispersion of the L3 S5P and OMI products are within the GCOS threshold requirement (max(50%,0.37 DU)), while the OMI bias exceeds it at higher SO2 levels. The total uncertainty, which combines bias and dispersion, meets the threshold requirement (≤0.37 DU) at low SO2 concentrations for both OMI and TROPOMI, but exceeds it (>50%) at higher SO2

concentration. For CO, the uncertainty of merged IASI-MOPITT product exceeds the threshold requirement (<5%), mainly due to the dispersion, while the bias is within the threshold level. The drift is within threshold level (<2%/decade). Finally, for NH_3, it was found that the bias is positive for clean sites and negative for polluted sites. The total uncertainty is around 2.6 Pmolec cm-2 at lower NH_3 levels (<2 Pmolec cm-2) and around 4.5 Pmolec cm-2 at higher NH_3 levels (>4 Pmolec cm-2) and within the threshold requirement of 5 Pmolec cm-2. As for CO, the drift is within threshold level (2 Pmolec cm-2).

To assess the usability of the generated data records, two model-based use case studies were conducted. The first one was based on the GEOS-Chem model and the second on the MAGRITTE chemical-transport model (CTM).

GEOS-Chem simulations with constraints from HCHO and NO2 climate data records
The aim of this study was to investigate the impact of surface emissions on tropospheric ozone in the tropics using GEOS-Chem simulations. Tropospheric columns of NO_2 and HCHO were used as observational constraints. In addition, tropospheric columns of ozone and CO from the IASI sensor served for model evaluation. The model assessment reveals that the combination of Global Fire Assimilation System (GFAS) as BB and Copernicus Atmospheric Monitoring Service (CAMS) as anthropogenic emission inventories provides the best overall agreement with the selected satellite observations. Further results indicate that the GEOS-Chem simulation with this couple of emissions captures the annual spatial distributions of NO_2 and HCHO reasonably well compared with OMI retrievals, and that the ozone and CO columns are also in agreement with IASI data. The modeled and observed ozone columns exhibit similar seasonal variability over the period 2008–2020, but the model produces a positive ozone trend not seen in observations. This modelled trend is related to the increase in anthropogenic emissions of ozone precursors in South and East Asia regions, from the CAMS emission inventory. The difference could be caused by the low sensitivity of IASI to O3 in the boundary layer.

Assessment of the variability and trends of HCHO columns over Africa
This study analysed the variability and trends of tropospheric formaldehyde (HCHO) columns over Africa based on long-term satellite observations from OMI and simulations performed with the regional chemistry-transport model MAGRITTE over 2005-2018. The objective was to evaluate the capacity of the model to reproduce observed HCHO distributions and trends, and to interpret these in terms of changes in emissions, land cover and climate. Overall it was found that the model successfully captures the main spatial and seasonal variability of HCHO across the continent and exhibits high correlations with OMI data. Observations indicate widespread positive HCHO trends across Africa between 2005 and 2018, ranging from +0.4 to +1 $\%yr^{-1}$, with the strongest values in southern African regions. The model succeeds in reproducing the trend patterns but underestimates their magnitude. Methane oxidation is found to be the dominant source of HCHO (50-60% of total columns), except over tropical forests where biogenic emissions prevail. Biogenic emission trends, while having only a modest overall impact, improve the agreement between model and observations. Increasing

anthropogenic activity and declining biomass burning contribute to the observed regional contrasts. This work demonstrates the complementarity of long-term satellite datasets and regional chemistry-transport modelling for quantifying changes in atmospheric composition due to climate, and to changes in emissions and land use over Africa. Future work will extend the analysis to more recent years and explore the joint use of HCHO and NO_2 data within the ESA PIRAMID project framework.

References:

Glissenaar, I., Boersma, K. F., Anglou, I., Rijsdijk, P., Verhoelst, T., Compernolle, S., Pinardi, G., Lambert, J.-C., Van Roozendael, M., and Eskes, H.: TROPOMI Level 3 tropospheric NO_2 dataset with advanced uncertainty analysis from the ESA CCI+ ECV precursor project, Earth Syst. Sci. Data, 17, 4627–4650, https://doi.org/10.5194/essd-17-4627-2025, 2025.