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Assessing the impacts of assimilating SO_2 TROPOMI retrievals with MINNI and DART at the European scale: a case study of the Mount Etna eruption

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The Mount Etna eruptions are not included in the anthropogenic emission inventories used to simulate air quality in Europe. This study examines the potential of using satellite data assimilation techniques for “adding” the volcanic contribution to atmospheric concentrations. Sulfur dioxide (SO□) column data from the Sentinel-5p L2 COBRA retrievals (5.5 km x 3.5 km resolution and 2660 km swath) is incorporating through Data Assimilation in 3D SO_2 concentrations (0.15° x 0.1°, 14 vertical levels) simulated with MINNI, an atmospheric modelling system member of the CAMS regional air quality ensemble (*https://atmosphere.copernicus.eu/charts/packages/cams_air_quality/products/europe-air-quality-forecast-regulated?base_time=202501140000&layer_name=composition_europe_o3_forecast_surface&level=key_0&originating_centre=85_205&projection=opencharts_europe&valid_time=202501140000*) which is based on the Chemical Transport Model FARM. The work is part of the CAMs EvOlution (CAMEO, *https://ww.cameo.project.eu/)* project.

The Data Assimilation framework based on the Ensemble Adjustment Kalman Filter (EnAKF) is for the first time designed and implemented to couple FARM with the Data Assimilation Research Testbed (DART) tool (*http://doi.org/10.5065/D6WQ0202*). The system runs a 20-member ensemble over an hourly assimilation window. The model perturbations are achieved by varying anthropogenic emissions and boundary conditions to estimate model uncertainties. A specific forward operator based on the Copernicus Satellite Operator (CSO, CAMS / CSO · GitLab) is implemented in DART to obtain the simulation of retrieval products from the model state using averaging kernels. Vertical localization was performed using the 5th-order Gaspari-Cohn (GC) rational function, while prior inflation was applied to minimize filter divergence due to insufficient variance. The Quantile Conserving Ensemble Filter Framework Method was applied to preserve the positivity of the trace gas concentrations. Furthermore, it is assumed that the impact of increments due to SO_2 observations only influences the model SO_2states.

The DA experiment has been conducted for August 2023. The comparison of the time series, illustrated in Figure 1, shows the vertical column TROPOMI SO_2, the prior ensemble mean and the posterior ensemble mean averaged on a subdomain including Sicily, Malta and part of the Mediterranean Sea. Both the prior and the posterior exhibit a negative bias, highlighting the necessity of incorporating volcanic emissions to address this discrepancy. During the period influenced by volcanic activity (08/13 – 08/17), the modelled concentrations after assimilation are enhanced in correspondence of the volcanic plume across the Mediterranean Sea, as depicted in Figure 2.

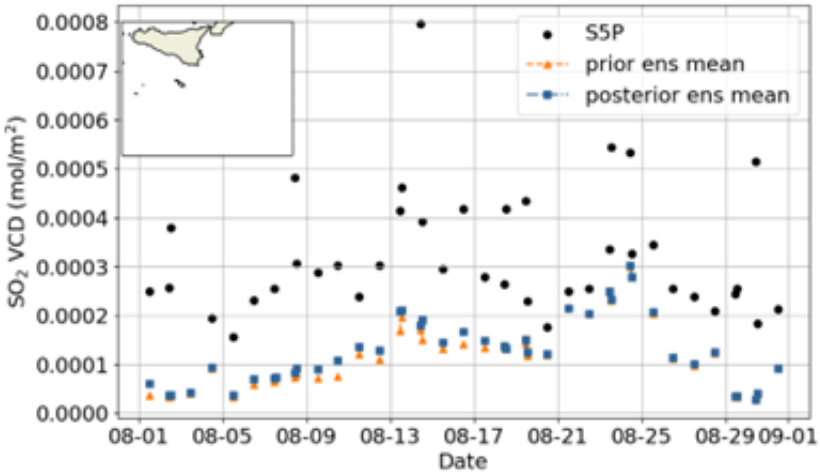

Figure1. Time series of sulphur dioxide (SO□) retrieval over a selected region (inset map) during August 2023. black: S5P_PAL_L2_SO2CBR observations, orange: prior ensemble mean, blue: posterior ensemble mean.

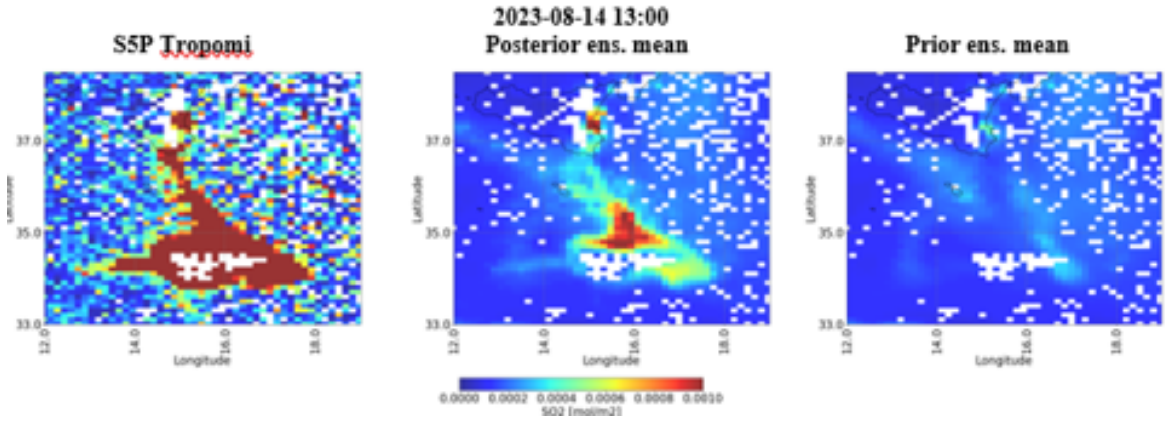

Figure 2. Comparison of S5P (left), prior ensemble mean (centre) and posterior ensemble mean (right) on 2023-08-14 13:00.