EUMETSAT

AC SAF

ATMOSPHERIC COMPOSITION MONITORING

AC SAF PILOT PROJECT:

NEW TAILORED AIR QUALITY PRODUCTS FOR WEATHER FORECASTERS

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DOCUMENT STATUS SHEET

Issue	Date	Modified items / Reason for change
1.0	07/05/2025	First version

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1. Aim and scope of the work

Operational meteorologists are frequently required to provide assessments of the current air quality conditions, as they are the only operational people working with atmospheric data. Although a wide range of satellite-based products exists that could provide valuable insights into air quality, these tools are often underutilized due to a lack of specialized training. Forecasters typically focus on meteorological phenomena and therefore may not possess the expertise required to interpret complex aerosol-related satellite data.

The objective of this study was to develop novel, fused satellite-derived products tailored to the operational needs of weather forecasters. These products are intended to be intuitive and easily interpretable, enabling even non-expert users to quickly identify whether significant air quality events are occurring within a specific region. Additionally, accessibility was a key design criterion: the products should be readily available through the forecasters' existing workstation interfaces to ensure seamless integration into daily workflows.

The initial plan for this pilot project was to create a single easy-to-use satellite-based air quality indicator product for weather forecasters. However, early-stage interviews with several meteorologists at the Finnish Meteorological Institute (FMI) revealed a broader operational need — specifically the ability to distinguish between different types of aerosols that influence air quality. Thus, the scope of this work was adjusted, and we decided to start developing three different easily interpretable satellite-based air quality products for detection of wildfire smoke, desert dust and volcanic ash.

2. Outline of the work

2.1. Finding out forecasters' needs

We chose a user-centric approach developing the products for the forecasters. Forecasters were involved in the development from the beginning. We wanted to know for example what kind of new satellite-based air quality products the forecasters would actually want to use and what kind of visualizations they would prefer. We made a questionnaire to FMI forecasters and got answers from 13 of them. We also interviewed a couple of forecasters personally. The results can be seen in Figures 1-3.

When asked about which variables should be included in the product the most important parameter for the forecasters was wildfire smoke, closely followed by desert dust and volcanic ash (Fig 1). Separate trace gas products like NO2 and SO2 were also interesting to some respondents.

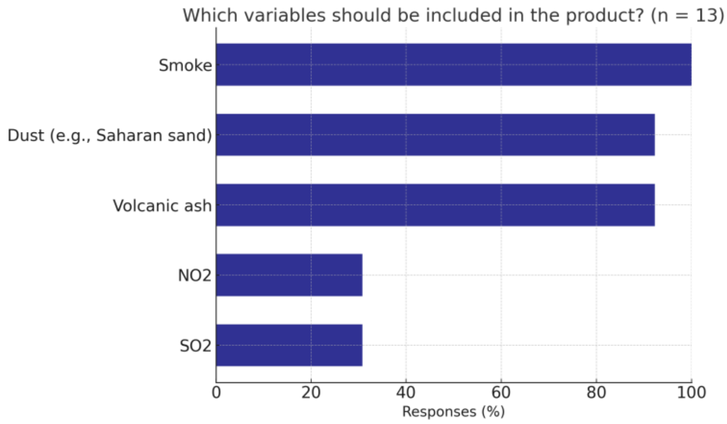


Figure 1: Answers of 13 FMI forecasters to the question which variables should be included in the new satellite-based air quality product.

We also wanted to ask about visualization, especially if the forecasters would rather like to use a "traffic light" air quality indicator product or see sliding values from low to high. Most of them answered that they would prefer the latter (Fig. 2). In the open answers several people answered that they wanted to see concentrations on a map marked with different colours meaning low to high. One of the respondents also wrote that "ppm values are not usually very clear for forecasters" and thus they would prefer to also have an indicator whether a specific value is low or high.

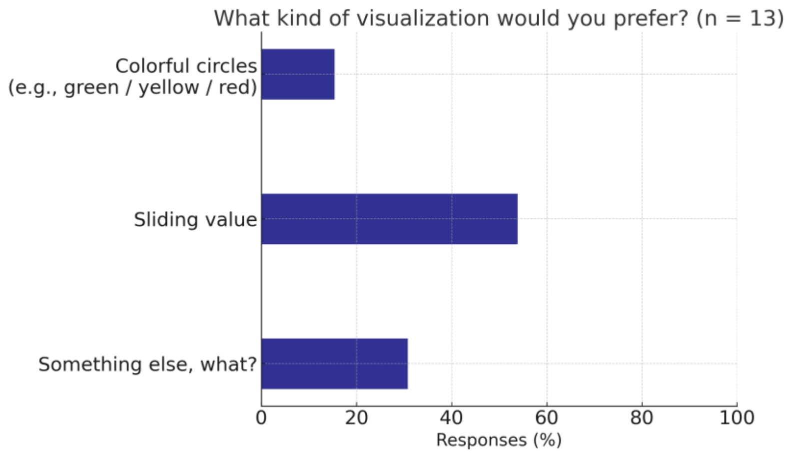


Figure 2: Answers of 13 FMI forecasters to the question what kind or visualization they would prefer.

Last we asked whether the forecasters would see themselves actually using such new satellite-based air quality products if they were available. Out of the 13 respondents 11 answered that they would very likely or quite likely use the product (Fig. 3). Two people answered in an open answer. One of them wrote that it depends on whether the product will be good and whether it adds value to the information available on public sites. The other wrote that they would use the product especially in more prolonged situations of poor air quality (e.g. forest fire smoke situations).

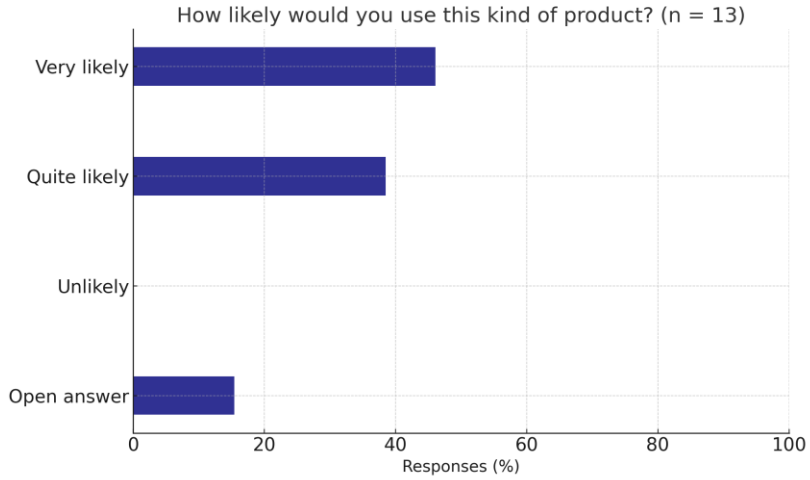


Figure 3: Answers of 13 FMI forecasters to the question how likely they would use this kind of product.

2.2. Identifying the most useful input datasets

Forecasters wanted products that would easily indicate the presence of wildfire smoke, volcanic ash or desert dust in the atmosphere. We explored various types of satellite products as input data sources for our combined product, aiming to effectively separate the three variables. These data sources needed to be operational and available in near-real-time. To broadly represent the presence of aerosols in the atmosphere, we used the Absorbing Aerosol Index (AAI). To differentiate between dust, smoke, and ash, we relied on the dust flag product, total column carbon monoxide (CO), and total column sulphur dioxide (SO2) (Table 1).

These were the initial data sources we began working with. However, the final product may incorporate additional inputs. The source code for the product has been designed to allow easy integration of new data sources.

Product(s)	Instrument (Satellites)	Data provider
Near Real-Time Absorbing Aerosol Index	GOME-2 PMD (Metop)	EUMETSAT / AC SAF
Absorbing Aerosol Index, total column CO	TROPOMI (Sentinel-5P)	Copernicus
IASI combined sounding product (FORLI-CO, SO2 total column and dust flag)	IASI (Metop)	EUMETSAT

Table 1: Used input data sources

2.3. Test events

Products were tested during past air quality events in Europe. Test events are listed in table 2. For testing we chose several major wildfire smoke, volcanic ash and Sahara dust events from recent years. Products were also produced for time periods and/or regions with no major aerosols in the atmosphere to test them for false alarms.

Event	Used time period
Multiple wildfires in Greece	16-20/7/2023
Volcanic eruption in Iceland	12-21/12/2023
Sahara dust in northern Europe	26-30/3/2024
Large amount of Sahara dust in Greece	18-26/4/2024
Wildfires in Portugal	17-19/9/2024

Table 2: Test events

2.4. Algorithm development

Python-based file readers were developed to handle various input data sources. These readers utilize Python libraries such as xarray, h5py, and satpy from the pytroll suite. Initially, the input data undergoes a cleaning process where incorrect values and those falling below or above defined thresholds are filtered out. Once the data is cleaned, it is re-projected onto a common grid using satpy's bucket resampler.

Following the re-gridding step, anomaly detection is applied to carbon monoxide and dust flag datasets. For this task, the Isolation Forest algorithm from scikit-learn (a machine learning module within scipy) is employed. The model is trained using a rolling archive of one week's worth of data. Anomaly detection was also tested on absorbing aerosol index (AAI) and sulphur dioxide (SO_2) datasets. However, it was found that simply setting a sufficiently high lower threshold for AAI effectively identifies its plumes. Meanwhile, SO_2 data typically appears in distinct plumes, making dedicated anomaly detection in this case also unnecessary.

Once only plume-related data remains, the values are normalized to a scale from 0 to 1. These normalized datasets are then merged to produce final output products. Currently, three such products are generated: wildfire smoke, desert dust, and volcanic ash.

- Wildfire smoke is identified by combining total column CO with AAI data, selecting AAI plumes that overlap with areas of elevated CO values.
- Desert dust detection uses both the dust flag and AAI datasets. The final product combines AAI plumes coinciding with high dust flag values and all detected dust flag anomalies. For grid points with values in both datasets, the average is computed.
- The volcanic ash product currently relies solely on the normalized SO_2 data.

A simplified data flow chart is visualized in Figure 4.

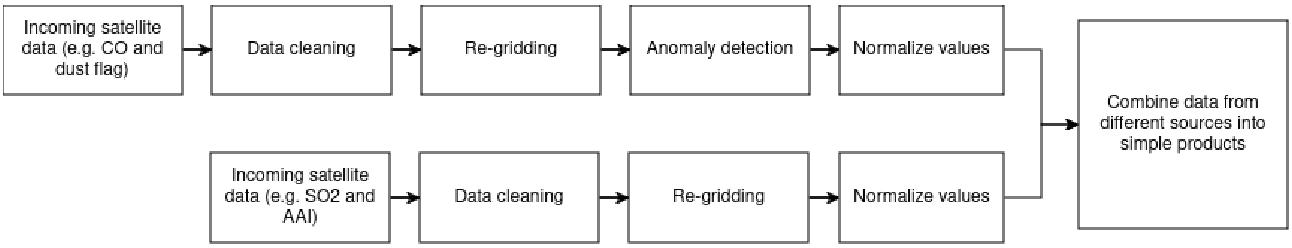


Figure 4: Data flow from incoming satellite data to combined data products.

3. Key results

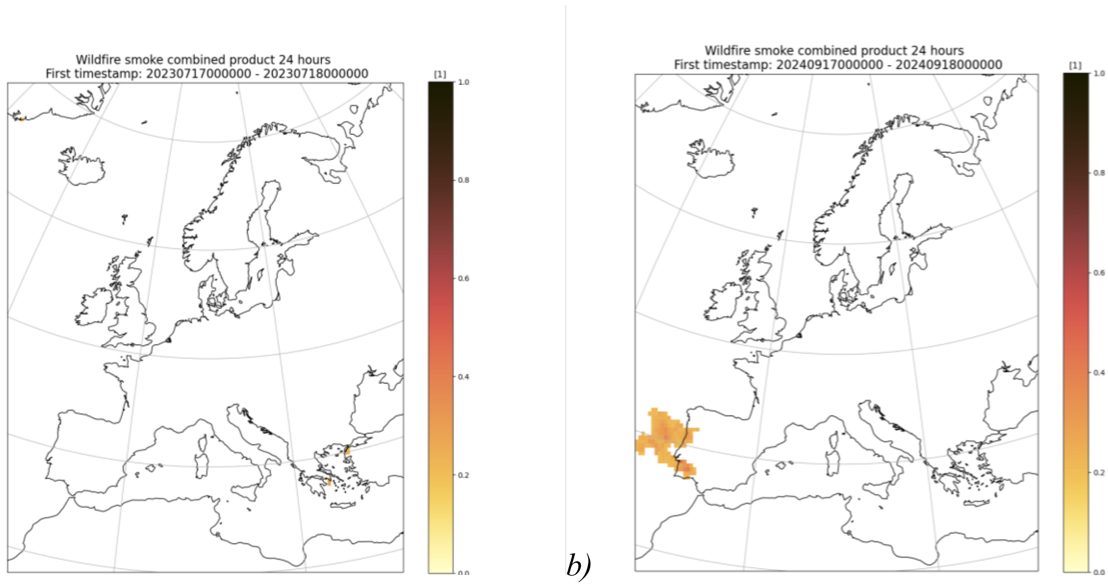
We developed an automated production system that ingests selected satellite data and generates three types of output products: wildfire smoke, desert dust, and volcanic ash. These products are produced in both NetCDF and GeoTIFF formats, enabling direct visualization on forecasters' workstations.

In this study, we tested the system offline using selected test cases (see Table 2). The output products were qualitatively validated against other satellite datasets, such as RGB composites. The test cases involved significant aerosol events, and we also compared our results with media reports to assess whether the products indicated aerosol presence in the same locations as reported in the news. We used this validation to develop the products further, including significantly reducing the occurrence of false alarms.

3.1. Wildfire smoke product

The wildfire smoke product uses CO and AAI data as input. The AAI plumes overlapping with high CO anomalies are categorized as smoke. In the development phase, one of the main sources of false alarms in the wildfire smoke product was industrial sources of CO. To avoid them being interpreted as wildfires, we chose to omit all the single pixel CO anomalies.

Examples of wildfire smoke products are shown in Figure 5.



a) b)

Figure 5: Examples of wildfire smoke product during a) wildfires in Greece in July 2023 and b) wildfires in Portugal in September 2024.

3.2. Desert dust product

The desert dust product utilizes AAI and dust flag datasets as inputs. The final output combines areas where AAI plumes are co-located with high dust flag anomalies, along with the original dust flag anomalies. During the development phase, we initially tested a version of the product that included only AAI plumes co-located with dust flag anomalies. However, some dust events were not captured in the AAI data—despite media reports confirming dust transport in those regions. As a result, we decided to include additional dust flag observations in the final product.

Examples of desert dust product are shown in Figure 6.

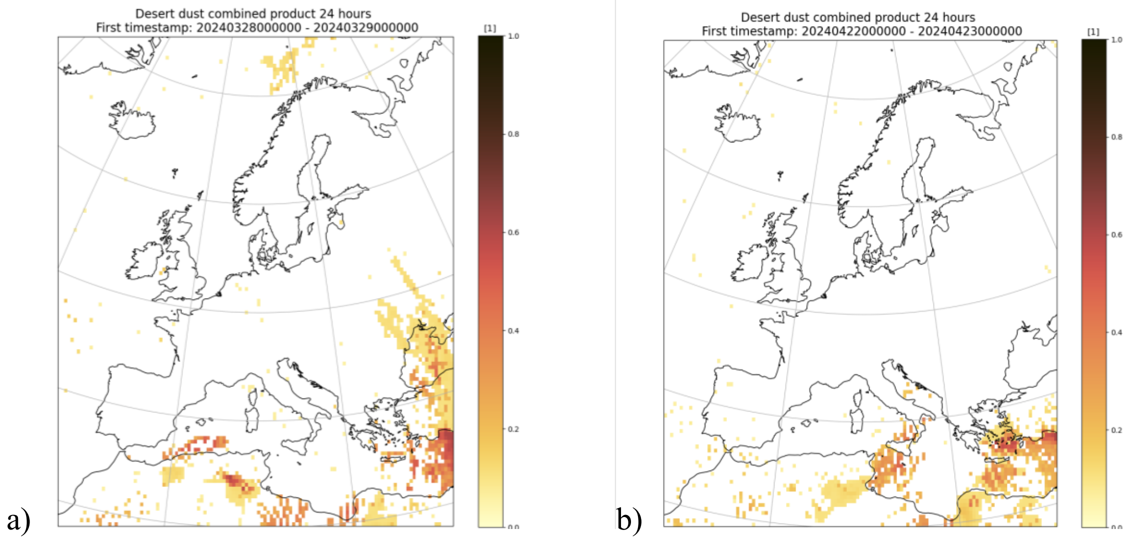


Figure 6: Examples of desert dust product during dust episodes in a) Northern Europe in March 2024 and b) in Greece in April 2024.

3.3. Volcanic ash product

In this first version of the volcanic ash product, we ended up using SO2 observations by themselves. We also did not use any anomaly detection because SO2 observations are point-like by nature.

Examples of volcanic ash product can be seen in Figure 7.

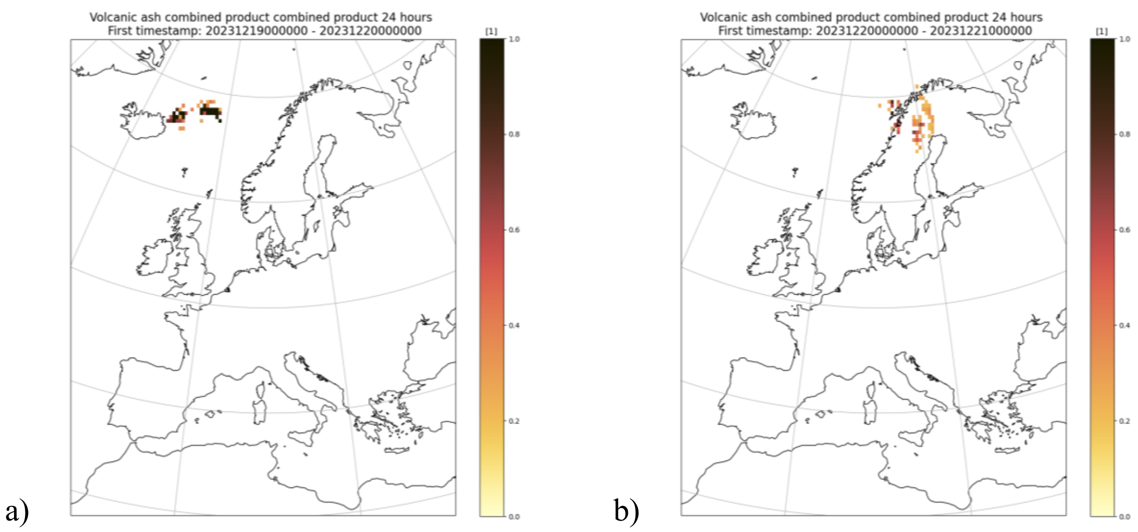


Figure 7: Examples of volcanic ash product during volcanic eruption in Iceland in a) 19th and b) 20th of December 2023.

4. Conclusions

New satellite-based air quality products have been developed to support operational weather forecasting. Before starting the development, forecasters at FMI were asked for feedback on what kinds of satellite products would be most useful in their daily work. Based on this input we created three new products for detection of wildfire smoke, desert dust, and volcanic ash. These products were tested using past events involving wildfire smoke, Saharan dust, and volcanic ash transported into Europe. The products performed well during these test cases.

As part of the testing, the products were also checked for false alarms — for example, situations where wildfire smoke was detected even though no wildfires were occurring. In some cases, high levels of carbon monoxide from industrial emissions, when combined with other types of aerosols, were mistakenly identified as wildfire smoke. Similarly, it can be difficult to tell the difference between dust and smoke when both are present in the same area. Another source of error is the timing differences between satellite overpasses, which can create inconsistencies when combining data from multiple satellites into one product.

The combined products also carry the same limitations as the individual satellite observations they are based on. For instance, the Absorbing Aerosol Index is useful for detecting high-altitude layers of light-absorbing aerosols, like smoke or dust, especially when clouds are present. However, it may miss low-level smoke that stays close to the surface. To improve detection, we are now looking into adding more input data — such as Aerosol Optical Depth and other indicators that help identify aerosol type and height — to increase the accuracy of plume detection.

The objectives of this pilot study have been fully achieved: The approach has been developed together with the end users and the service and products have been demonstrated to FMI operational weather service. The development has continued beyond the initial pilot objectives.

5. Outlook

This pilot study focused on evaluating the products using historical air quality events. The next step is to move toward a pre-operational system that can deliver near-real-time data to forecasters. The system has been built from the beginning with real-time use in mind, and the only remaining step is to add live satellite data streams. In addition to the visual outputs shown in this study, the data are also saved as GeoTIFF files. These files can be opened directly in the forecasters' workstation software, like GeoWeb, which is the goal of the planned pre-operational setup.

As input to our products, we have so far used data only from polar-orbiting satellites. In the future these methods could also be applied for Sentinel – 4 and MTG-IRS geostationary instruments.

The development of the service and products for internal use will continue with FMI resources. The mature system will be proposed to be part of the AC SAF CDOP 5 portfolio and available for other potential NMS users in future.