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BAQ Special Issue

Satellite and Local Measurements Based Services for Air Quality Improvement

Johan de Vries*, Edo Loenen[1], Bas Mijling[2], Wencke van der Meulen, Arthur van der Meer

Airbus Defence and Space Netherlands BV, Mendelweg 30, 2333 CS Leiden, The Netherlands
[1]S[&]T, Olof Palmestraat 14, 2616 LR Delft, The Netherlands
[2]Royal Netherlands Meteorological Institute (KNMI), Utrechtseweg 297, 3731 GA De Bilt, The Netherlands

***Corresponding author.**
Tel: +31-71-5245879
E-mail: j.de.vries@airbusds.nl

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ABSTRACT AIRBUS presents a global monitoring service on atmospheric composition and emission allocation. Air composition and meteorological data from satellites and local sensors are combined into a chemical transport model to build up or validate trace gas and particulate matter emission sources and their impact on air quality. The service is using the AIRBUS' developed OMI and TROPOMI satellite sensors to be able to quickly disclose new regions around the globe at low cost, as has been done for eastern Asia and the Indian continent. This yields a database of up-to-date emission sources at a spatial resolution of about 3.5 km (and in the future 1 km) and provides daily observation data on regional and transboundary transport of pollutants. Target constituents are NO_2, particulate matter, CH_4, (tropospheric) ozone and SO_2. The full blown service adds data from several measurement systems (on ground, aircraft, high-altitude solar powered drones or pseudo satelites (HAPS) and nanosatellites) and various data like land-use and traffic information to achieve street level spatial resolution while maintaining accuracy and validation status. The resulting database of emission sources has the same street level spatial resolution and is intended to serve local issues. It has presently been built for several EU cities. This advanced and cost-competitive Air Quality Monitoring service is used for awareness building, policy development and policy evaluation and enforcement. The intent is to realize a commercial global service, based on local cooperation. The paper will describe the service and status.

KEY WORDS Air quality monitoring, TROPOMI, Chemistry transport modeling

1. GLOBAL MONITORING SERVICE

The monitoring service described in this paper is intended to support users from anywhere on the globe in providing data for improving air quality and related atmospheric composition issues. The data is expected to form the solid basis for evaluation of current issues and infrastructure decision making.

The service consists of the following components:

- *Observations*: pollutant measurement data, firstly space based and with spatial resolution down to 1 km
- *Concentrations*: high resolution ($<$100 m) urban Air Quality data with forecast
- *Sources quantification*: attributing pollutants to quantified emission sources or source apportionment
- *Sources*: dynamic emission source data

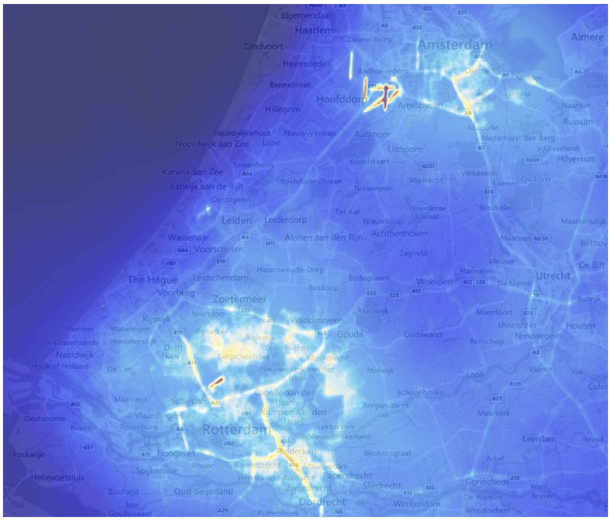

Fig. 1. Example data from the *Concentrations* service component: high resolution NO_2 concentrations for the western part of the Netherlands.

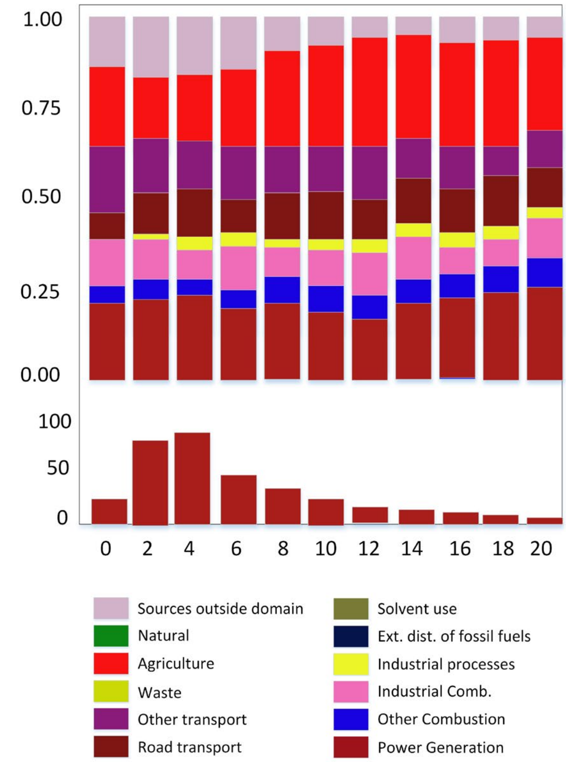

Fig. 2. Labelling or source apportionment example data showing the different contributors for the atmospheric composition at the given location.

The *Observations* service component provides user friendly access to a measurement archive with firstly OMI and TROPOMI atmospheric composition measurements. OMI (Levelt *et al.*, 2006) is the sun backscatter instrument providing air quality measurement data since 2004. It is launched on NASA's AURA satellite and has to today's standards a somewhat coarse spatial resolution of $13 \times 24\,km^2$. OMI's follow-on is the TROPOMI instrument on ESA's Sentinel 5p satellite (Veefkind *et al.*, 2012). It has an order of magnitude better sensitivity, about an order of magnitude better spatial resolution ($3.5 \times 3.5\,km^2$ to $7 \times 7\,km^2$, depending on the gas) and it has more spectral bands allowing for additional trace gas products.

Although both instruments are state of the art, the spatial resolution is still somewhat coarse and several sources may end up in the same single pixel. To be able to discriminate between sources within an observed area, we have two approaches:

- We plan for a dedicated nanosatellite system with 1 km resolution;
- In the *Concentrations* service component we combine observations with a modelling layer which creates data products down to 100 m resolution.

S[&]T, TNO, and Airbus D&S NL are setting up the *Concentrations* service component to obtain constituent concentrations at this very high spatial resolution. First it assimilates high quality satellite data into a chemistry transport model (CTM). In the second step it is combined with local information on traffic streams, the location of specific polluting facilities, orography, in-situ measurements and meteorological data. The traffic and topography/orography data has high spatial resolution and is used to redistribute the constituent data to the higher spatial resolution. Fig. 1 shows example data. Preliminary validation shows good agreement of this data with ground measurements. Validation in other regions in the world (in particular more polluted Asian cities) is being planned for the coming year.

Input to the CTM model is a database of emission sources, with emission strengths attached to the sources. Assimilating measured concentrations, emission source strengths are adjusted to match the modelled and observed constituent concentrations. The CTM used is LOTOS-EUROS (Manders *et al.*, 2017). LOTOS-EUROS has the possibility to label constituents based on their emission sources and this is used in the service component *Sources quantification* (see example in Fig. 2).

The labelling used in source apportionment is started at the emission of the constituent and is followed during transport and chemical transformations. The example in Fig. 2 shows how the labels refer to the emission sources or emission source systems, as initialized. This allows the number of labels to be far larger than the number of pollutants considered.

This labelling together with assimilation of various measurement data forms the basis of the *Sources quantification* service component. This component also allows scenario computations, adding e.g. a new source and showing the impact of such new source on the overall situation. This service component is instance valuable tool for e.g. government officials to make informed decisions on planned infrastructure adaptions.

The final (currently foreseen) service component is *Sources*. This is the *Sources quantification* service component running in a continuous and automated mode, with continuously assimilating new measurement data and continuously updating emission source strengths as a means to observe changes in time for each of the sources.

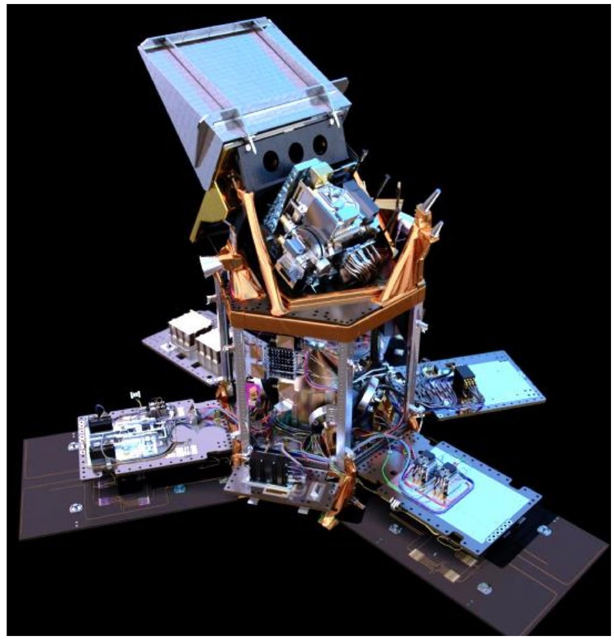

Fig. 3. TROPOMI instrument on top of the deployed Sentinel 5 precursor satellite, just before launch.

2. SATELLITE DATA

Our primary sources for satellite data are the OMI on NASA's AURA satellite (launch 2004) and TROPOMI on ESA's Sentinel 5p (launch 2017), which provide every day global atmospheric composition data on a series of constituents. Both sensors have been developed and are maintained by members of our consortium (1,2) which gives us in-depth knowledge about their data products and applicability. Data from other sources are also used where they contribute to the overall results.

We are also developing the SpectroLITE sensors, providing from cubesats firstly NO_2 data at a 1 km spatial resolution (launch early 2021) and in a later phase adding other gases. The SpectroLITE instrument will provide per cubesat a daily measurement point next to the already launched sensors and this will gradually grow towards about 8 measurements per day.

Both the SpectroLITE consortium as well as the OMI and TROPOMI developments are led by Airbus DS Netherlands. However, data from OMI and TROPOMI are made available via NASA and the EU Copernicus system whereas the SpectroLITE data will be provided via the consortium.

In particular, the EU is commited to provide continuing data via Copernicus at about 10 km resolution whereas the SpectroLITE will provide 1 km resolution.

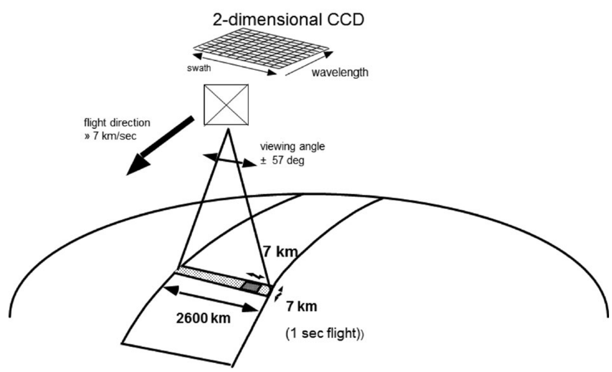

Fig. 4. Sun backscatter trace gas instrument measurement principle as used for TROPOMI.

OMI remains important for the historical record and TROPOMI is these days the work horse for providing satellite atmospheric composition data.

TROPOMI (Fig. 3) is a sun backscatter instrument in the line of (a.o.) SCIAMACHY (Bovensmann *et al.*, 1999), launched on ESA's ENVISAT in 2002 and OMI.

Fig. 4. shows a sketch of the TROPOMI's push-broom measurement principle, showing how the Earth is scanned by a passive sensor with 2 dimensional detector used

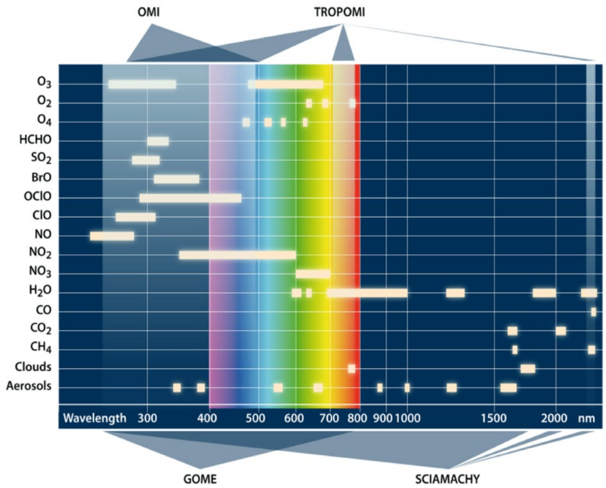

Fig. 5. Spectral ranges of various sun backscatter instruments with trace gas absorption spectral ranges and showing the gases measured with each instrument.

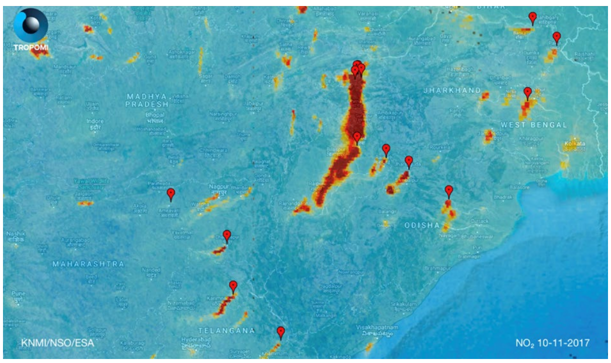

Fig. 6. TROPOMI measurement overviewing central India and showing NO_2 emission plumes used to identify sources (red marks). Figure courtesy KNMI/NSO/ESA.

to register wavelength in one direction and the across-flight distance in the other. The along-track pixel size is determined by the exposure time in combination with the satellite ground velocity.

Fig. 5. shows the wavelengths where the different trace gas products absorb light and are used to detect them independently.

Fig. 6. shows TROPOMI NO_2 measurements showing plumes originating from emitting sources, together with the location of energy facilities. It clearly demonstrates the plume data is very useful for determining the quantitative emissions from the sources and also identifying unknown sources.

Fig. 7. shows aerosol desert dust clouds measured by TROPOMI over the north of India and Pakistan.

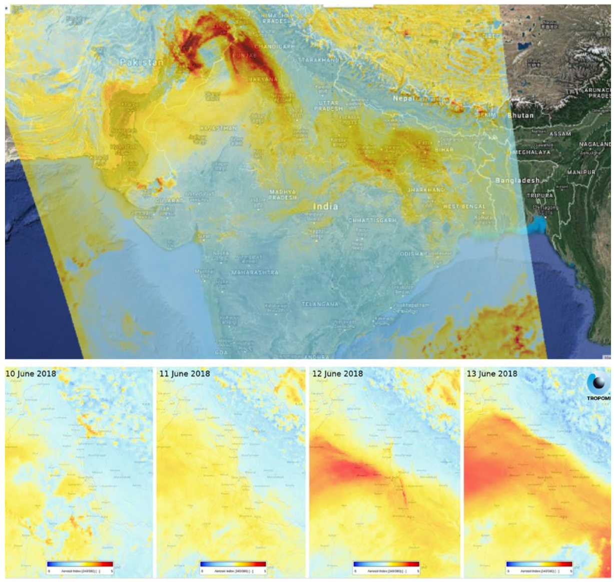

Fig. 7. TROPOMI desert dust aerosol measurements over India. The top graph shows an overview and the bottom a series of 4 subsequent days. Figure courtesy KNMI/NSO/ESA.

The example data shows cloudless regions as the instrument cannot measure under a cloud cover. Sources may still be observed when averaging over a time period including no or few clouds and otherwise a model (section 3) as used for the Concentrations service is used to estimate pollution levels under the clouds.

3. LOTOS-EUROS

LOTOS-EUROS (Manders *et al.*, 2017) is a Chemistry Transport Model with a long history in the Netherlands. It has been developed by a consortium of institutes, by combining two independent predecessors in 2005. The model has been extensively used for smog and air quality assessments in the Netherlands and Europe, and it has been used for many emission scenarios, source apportionment and long-term hindcast and climate change scenarios. The model has been applied to regions outside Europe, e.g. in China. Lotos-Euros makes use of state of the art and proven knowledge and maintains a good balance between the level of detail in models and accuracy of input and output and sufficient effort is spend on validation.

Especially the source apportionment and assimilation capabilities and developments make the model

Table 1. Comparing air pollution and climate change.

	Air pollution	Climate
Gases	PM, NO_x, SO_2, O_3, VOC	CO_2, CH_4, O_3 (GHG)
Effects	Local / regional	Global
Human health effects	Direct	Indirect
Time scale of effects	Short-term, now	Long-term, future
Major sources		CH_4 from wetlands, permafrost
	Mostly from burning of fossil fuels (vehicles, industry)	

suitable for the current service.

The Chemistry Transport Model is also the tool used to combine, via data assimilation, measurement data from different sources such as ground monitoring stations, satellites and occasional aircraft campaigns. Data assimilation allows the model parameters to be adjusted such that the results form a better match to the measurements.

In particular, ground stations are useful as they provide continuous point observations and satellites provide the overview and inflow and outflow of atmospheric constituents.

4. AIR QUALITY MANAGEMENT AND CLIMATE CHANGE

There is considerable interaction between air pollution and climate change, as both are closely related to the chemical composition of the atmosphere. Climate change focusses on the longer time scales whereas air pollution is firstly interested in the short-term effects, as can be seen from the comparison in Table 1.

There is some different interest in specific gases because some of them (e.g. CO_2 and CH_4) are important for climate change but not directly unhealthy to humans and therefore not considered an air pollutant. Ozone has a double role in the sense that it helps to protect the Earth from UV radiation (the ozone layer at 10 km altitude, the 'good' ozone) and it is poisonous to humans (at the surface, the bad ozone).

It is important to realise that our services are relevant for both air quality and climate change as the same tool can be used for both purposes as long as the relevant gases are included. Satellite products for some gases (e.g. CO_2) are currently in an experimental stage, but their quality is likely to improve in the coming years with new algorithms and new satellite instruments.

5. URBAN PLANNING AND CITY SOLUTIONS FOR CLEAN AIR

We expect that the service components described so far significantly contribute to both reporting air quality for in principle every city or region on the globe and for development purposes. It will provide valuable planning and evaluation information which can be used officials working on improvement of local conditions. The up-to-date emission information is crucial to assess the effect of current policy and make better future decisions.

We realize however that the local situation may be different from what we anticipate and therefore we are welcoming discussions and also co-development activities with local parties to further improve the tools.

Development is anyhow needed because the service components are today not fully operational but rather this is expected between now (*observations*) and in about two years' time (*sources*).

The service contributes to achieving the UN's Sustainable Development Goals and helps for public education and awareness on air quality.

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