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# Citizen Science meets Remote Sensing

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## The Netherlands as Living Lab for Air Quality Technological and Social Developments

Monitoring air pollution is key to a better awareness of the size, seriousness and impacts of the problem. Unfortunately, air quality monitoring stations are expensive. Our pilot project explores the added value of citizen science measurements combined with satellite measurements. This approach can draw attention to the problem of air pollution and empower citizens to address it.

*Air quality measurements by the Dutch national air quality monitoring network (Luchtmeetnet)*

According to the European Environment Agency (EEA), air pollution is the largest single environmental health hazard in Europe. In 2020, particulate matter (fine dust) and nitrogen dioxide caused an estimated 287,000 premature deaths in Europe. These victims remain largely faceless, hidden in statistics. Monitoring air pollution is key to a better local understanding of the size, seriousness and impact of the problem, which is needed to take appropriate measures. Unfortunately, air quality monitoring stations are expensive in purchase and maintenance. Many countries, in particular outside Europe, have only sparse networks of reference stations - or none at all. New technological and social developments provide new complementary ways to monitor the air quality. As an example, we report here on a pilot project that explores whether citizen science measurements using Palmes tubes may help to interpret satellite measurements. This approach has the potential to draw attention to the problem of air pollution and to empower people to do something about it.

Air quality in the Netherlands is monitored with a dense official measurement network, together with advanced modeling tools using detailed emission inventories. In addition, the Netherlands has a strong research community developing and using satellite instruments for observing atmospheric composition. Also, it has one of the densest citizen science air quality networks in the world. This puts us in an excellent position to use the Netherlands as a *living lab* to explore new ways to monitor air quality, and to assess how they complement the existing measurement methods. These methods may then be of added value in particular in countries that cannot afford (many) official measurement stations.

## The TROPOMI satellite instrument

Mounted on the Sentinel-5P satellite, the Dutch instrument TROPOMI has provided global observations of concentrations of pollutants in the atmosphere with unprecedented detail since early 2018 (see Figure 1).

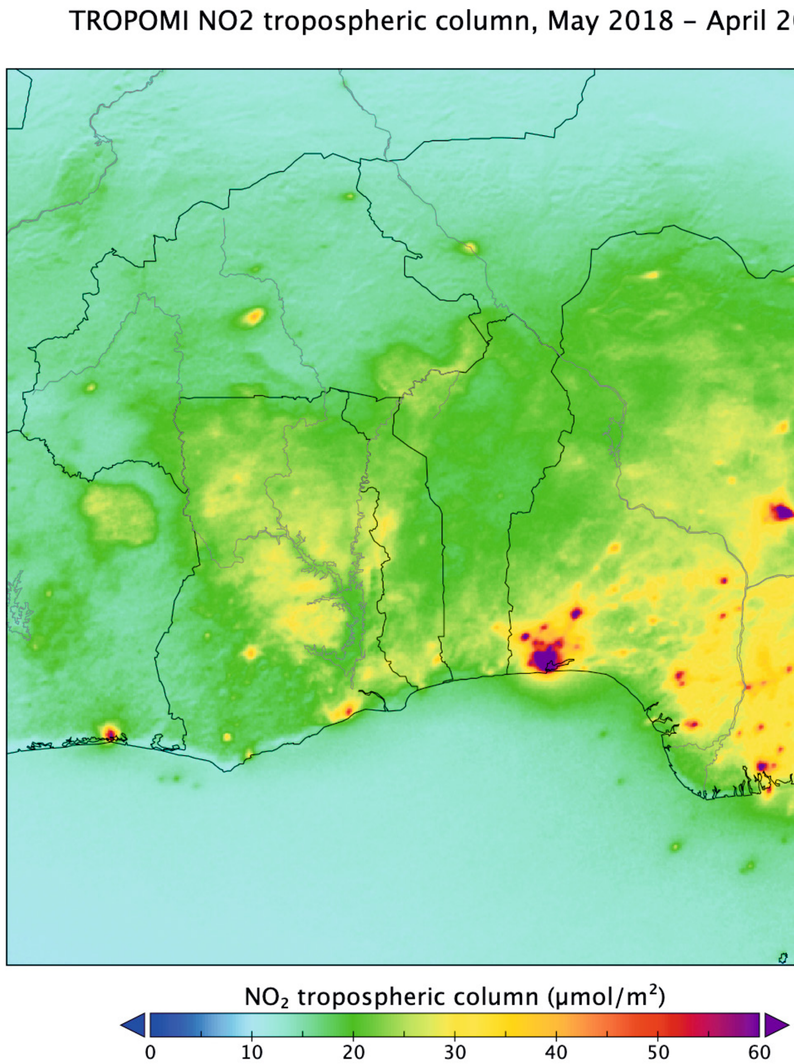


*Figure 1. Observations from space: an example of $NO_2$ column concentrations over West Africa observed by TROPOMI.*

Since its launch in late 2017, it has scanned Earth's atmosphere from a distance of 800 km. It measures the absorption spectrum of sunlight which has travelled through the atmosphere and backscatters upward towards the instrument. From this spectrum the chemical composition of the atmosphere in the light path can be determined. Using advanced algorithms, the $NO_2$ concentration in the troposphere can be derived. The height distribution of the air pollution, however, remains unknown. Without additional modeling or ground measurements it is impossible to translate these column measurements to surface concentrations.

## Low-cost sensors and Palmes tubes

New sensor technologies enable air quality measurements at affordable costs, which inspires many communities to start measuring for themselves. For instance, the manual offered by Sensor.Community[1] for building a low-cost particulate matter (PM) sensor has resulted in a global network of thousands of new measuring sites.

Trace gases such as $NO_2$ are harder to measure with cheap electronic sensors. Alternatively, Palmes tubes are well suited for citizen science measurements of $NO_2$. These plastic tubes are open at one end. Based on molecular diffusion, $NO_2$ then reacts with an absorbing agent (triethanolamine) at the closed end of the tube. The tubes are mounted at a fixed location – usually attached to a pole – for a period of 4 weeks (see Figure 2), after which they are sent to a laboratory for analysis. Using colorimetry, the average concentration of $NO_2$ during the measurement period can then be determined.

## Remote sensing meets citizen science

At first glance, high-tech remote sensing and low-tech citizen science are very different. Where satellite remote sensing offers global coverage by a single instrument, with a relatively large footprint and over a column, citizen science offers thousands of very local point measurements at ground level. From a budgetary perspective, they are also at different scales. A satellite mission costs millions of euros to cover its development, launch, and maintenance. A citizen can buy an air quality sensor kit or a year's supply of $NO_2$ Palmes tubes for around 100 euros.

On the other hand, high-tech remote sensing and low-tech citizen science also have important features in common. Both tend to attract a lot of publicity and attention for air pollution and what can be done about it. Also, even though both do not comply with the standards for air quality monitoring in the EU and elsewhere, they provide useful complementary data. For example, satellites can spot sources of pollution in remote areas. $NO_2$ Palmes tube data may be used to calibrate model calculations. In the campaign described below we explored how $NO_2$ tubes may be used to interpret TROPOMI satellite data.

## The GLOBE campaign

In spring 2023, KNMI and GLOBE Netherlands[2] organised a measurement campaign in which ten secondary schools participated. This initiative was supported by the national Clean Air Agreement and the Netherlands Space Office.[3] Students were asked to mount Palmes tubes at different locations in their surroundings and leave them for a month. After analysis of the tubes, the measurements were published on the RIVM national citizen science data portal[4] (see Figure 3). The campaign provided valuable insight into air pollution levels at the surroundings of the school, and how these relate to levels found at other schools. In the process, the school children learned about air quality and were challenged to think about possible solutions. From a science perspective, the measurements


*Figure 2. Palmes tube mounted on a lamp post (right). Photos: GLOBE*

*School children mounting Palmes tubes on a fence near their school. Photo: RIVM*

turned out to correlate reasonably well with collocated satellite measurements (Figure 4). We did not expect a perfect match, as measurement locations near strong sources are not representative for the larger area sensed by the satellite instrument. Also, the campaign period was quite cloudy, such that more than half of the satellite measurements could not be used. The satellite passes over daily around 13:00, whereas the Palmes tubes are measuring continuously. Nevertheless, the found correlation could be used to improve the translation of satellite column data to a national map of surface concentrations for the campaign period (Figure 5).

With more $NO_2$ data points we expect the correlation to increase, especially when we include more surface measurements that are representative for the averaging effect of the 3,5 x 5,5 $km^2$ satellite measurements.

This GLOBE campaign indicated how low-cost citizen science measurements can help to add value to satellite measurements. The schools were very enthusiastic to partici-

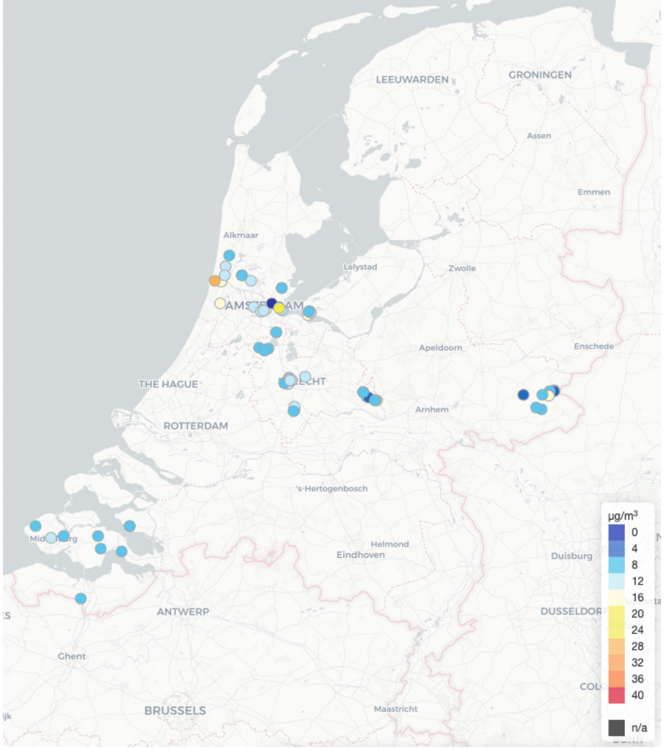


*Figure 3. Locations of the $NO_2$ tubes during the GLOBE spring campaign.*

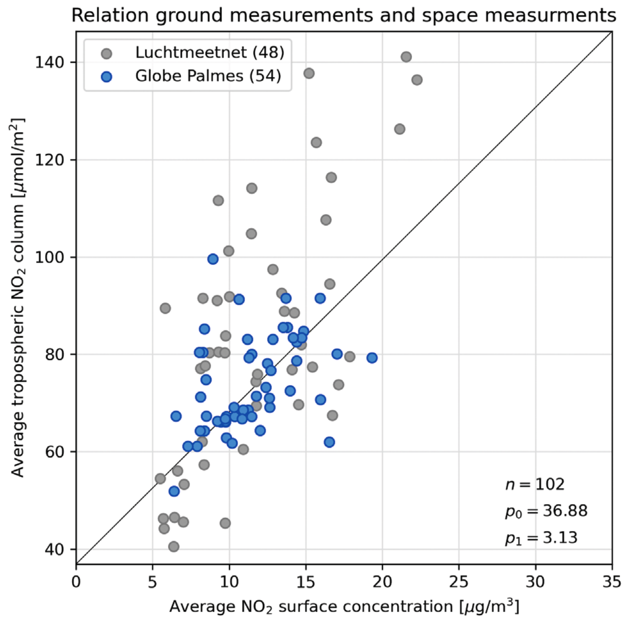


*Figure 4. Relation between surface measurements of $NO_2$ with Palmes tubes (x-axis) and column measurements from space by TROPOMI (y-axis). The data has been enriched by including averaged surface measurements of the national monitoring network (grey dots).[5] Note that a zero ground concentration does not correspond to a zero column concentration from space, as the satellite always observes an additional amount of $NO_2$ higher up in the atmosphere.*

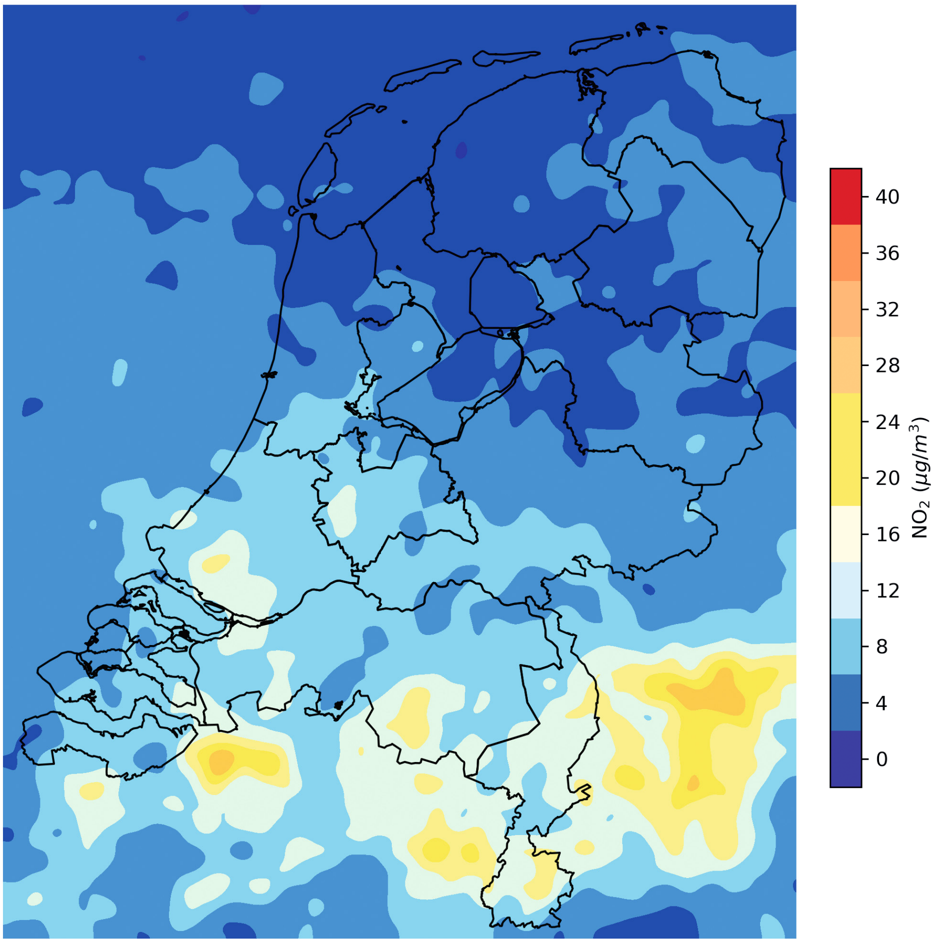


*Figure 5. Average surface NO2 concentrations during the measurement campaign (17 March to 14 April 2023) derived from TROPOMI observations using the $NO_2$ Palmes tube data.*

pate in such relevant research. Due to its success, this national campaign will be extended and students can participate annually during fall and spring. Currently, we are looking for ways to initiate similar campaigns in different countries, with a special focus on cities in developing countries where hardly any surface measurements are done. The GLOBE network of schools offers a great possibility to create local networks of Palmes tubes measurements. This creates local awareness and knowledge among the younger generation, while at the same time it generates monthly measurements of $NO_2$ concentrations which are valuable for the interpretation of satellite measurements. These in turn can be used to fill in the gaps and create surface concentration maps. In the "living lab The Netherlands", these maps can be validated using official maps, increasing their value for countries where such official measurements are scarce. Making the invisible visible will create more awareness of local air pollution problems, while at the same time providing better insight into them.

References for this article can be found at bit.ly/milieumagazine