Ozone monitoring mission

Professor Pieternel Levelt works on the satellite-mounted Ozone Monitoring Instrument and the Dutch-European Space Agency Tropospheric Monitoring Instrument. Here, she explains their importance in monitoring emissions for air quality and climate, and discusses her hopes for miniaturised satellite instrumentation.

Could you provide an outline of your objectives for the Ozone Monitoring Instrument (OMI) project?

In 1998, NASA asked The Netherlands to deliver OMI for the Low Earth Orbit (LEO) EOS-Aura satellite. The instrument was developed for measurements of the ozone layer, air quality and climate change. The scientific objectives of OMI are to answer four questions:

- Is the ozone layer recovering as expected?
- What are the sources of aerosols and trace gases that affect global air quality and how are they transported?
- What are the roles of tropospheric ozone and aerosols in climate change?
- What are the causes of surface UV-B change?

The Royal Netherlands Meteorological Institute (KNMI) is Principal Investigator of OMI, and the Finnish Meteorological Institute (FMI) is the co-Principal Investigator.

From what context did the investigation emerge and to what extent is your approach different from prior studies?

The GOME and SCIAMACHY instruments were previously developed to fly on European Space Agency satellites ERS-2 and ENVISAT. From this, KNMI, in cooperation with industry and the Dutch Space Agency NSO, began to think about a new instrument that could measure several trace gases at the same time, like GOME and SCIAMACHY, and also measure the atmosphere with daily global coverage and high spatial resolution like the Total Ozone Mapping Spectrometer (TOMS). This led to the design of OMI, in which, for the first time for ultraviolet-visible (UVVIS) satellite instruments, a two-dimensional detector is used. Due to its high spatial resolution, OMI is able to look ‘in between’ the clouds (that hamper our view of the troposphere), making the instrument suitable for measuring tropospheric trace gas columns for air quality.

In what ways does the Dutch-European Space Agency Tropospheric Monitoring Instrument (TROPOMI), planned for launch in 2015, differ from the OMI launched in 2004?

For TROPOMI, we decided to develop even higher spatial resolution (7 x 7 km²) and a higher sensitivity for low concentrations. We will also measure additional information on clouds and new trace gases (CO and CH₄), which are important for air quality and climate change.

Why does the University of Technology, Delft, together with KNMI, want to develop smaller satellite instrumentation?

Smaller satellite instrumentation would minimise cost, which is an important consideration in these time frames. Smaller instrumentation is also significant for operational monitoring in order to reduce cost and increase launching possibilities. This is of importance for the continuation of the Copernicus programme, and for the monitoring capabilities of countries themselves. Furthermore, for large science missions, smaller instrumentation can increase the number of trace gases and parameters measured by the same platform. This creates the opportunity to add more channels and more instruments with different capabilities. Smaller instrumentation would therefore help us answer complex science questions and improve our understanding of atmospheric chemistry.

What role can the satellite measurements of pollutants play in emission monitoring for air quality and climate?

Measurements of the troposphere have only been made in the last two decades, during which period they have vastly improved. We are now able to calculate emissions from satellite-based concentration maps and can quantify the emission source size and its change. For example, we can measure the change in emission sources over Europe, the US and China. There is often no other means to obtain this information over areas like China and Africa due to lack of ground-based measurements.

KNMI was able to develop an inverse method that is extremely fast and able to detect new emission sources. The current practice of obtaining the information to build these emission maps is based on evidence gathered by the government from industry and agriculture etc., and/or using ground-based measurements (the bottom-up method). Updates to these maps often take at least a year. With our new satellite based (top-down) method, this can be achieved in a few weeks. We are currently working on miniaturised satellite instrumentation that will reveal pixel sizes of 2 x 2 km² (TROPOLITE). This will greatly enhance our capability to measure individual emission sources.

As we obtain longer data records, I expect that satellite data will become an important source of information to check the effectiveness of emission regulation measures. Because it is possible to measure the whole atmosphere with only one instrument, there are no issues with biases in emission maps between countries. Moreover, the satellite data is not only capable of measuring over land, but also over oceans where ground-based measurements are lacking, and can therefore also provide quantified information of ship emissions.
Humankind is under great pressure to better understand and predict global atmospheric changes. The Royal Netherlands Meteorological Institute is coordinating two satellite instruments that will help to face this challenge.

EARTH’S ATMOSPHERE HAS changed dramatically since the Industrial Revolution. Human activities have greatly increased emissions and the resultant changes to the composition of the atmosphere are manifest as climate change, air pollution and ozone depletion. There have been several international agreements in response to these changes, including the Montreal Protocol, a treaty designed to protect the ozone layer.

Many components of the atmosphere need to be monitored for protection of the environment, first of which is the ozone layer. This layer of the atmosphere limits the amount of harmful UV radiation that reaches the surface of the Earth, and its breakdown has been primarily attributed to chlorofluorocarbons (CFCs).

Beyond ozone destruction, atmospheric gases, including CO₂, CH₄ and O₃, heat the atmosphere and the Earth’s surface by trapping infrared radiation. Alongside this, NOₓ and SO₂ result in acid rain and photochemical smog. The Environmental Protection Agency (EPA) has designated certain pollutants, including tropospheric ozone, NOₓ and aerosols, as serious threats to agricultural productivity and human health. The recent Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5) has also focused on understanding of stratospheric and tropospheric chemistry and is a nadir-viewing imaging spectrometer that gives daily global coverage. It uses a wide-field telescope feeding two image-grating spectrometers to observe Earth’s backscattered radiation. The light entering the telescope is depolarised using a scrambler and split into two channels: UV and Vis.

OMI measures key air quality components such as NOₓ and SO₂. Able to differentiate between aerosol types and measures cloud pressure and coverage, it can provide the necessary data to derive information on tropospheric ozone. The instrument maps pollution products from an urban to super-regional scale and provides measurements which are highly synergistic with the other instruments on the Aura platform. It also extends the 30 year total ozone record measured by the TOMS instruments.

One axis of the detector is used for the spectral information, and the other for spatial information, enabling daily global coverage with high unprecedented spatial resolution. While OMI is based on TOMS and GOME, it is able to measure many more atmospheric constituents than the former and provides much greater resolution than the latter. It can detect volcanic ash and SO₂ produced by volcanic eruptions with sensitivity at least 100 times greater than TOMS, which is hugely important for aircraft safety. The spatial resolution of OMI is 13 km x 24 km² in nadir. Such small pixel size enables OMI to measure ‘in between the clouds’, vastly improving its capacity to sense the troposphere.

TROPOMI

TROPOMI is also a space-borne nadir-viewing spectrometer, with bands in the UV, Vis, near infrared and shortwave infrared. Its data products will be developed to include state-of-the-art methods that will utilise the new instrument...
capabilities, at the same time as extending current
data records from OMI and SCIAMACHY.

The instrument’s scientific objectives expand
on those of OMI and include better estimation
of long-term trends in the troposphere related
to air quality and climate, and developing and
improving air quality forecast models and
emission estimates.

TROPOMI will make daily global observations
of O₃, NOₓ, SOₓ, CO and CH₄ (the second most
important anthropogenic greenhouse gas) as well
as aerosol properties. It uses a two-dimensional
detector, as introduced by OMI, enabling retrieval
of an unprecedented small pixel size of 7 x 7 km²
maintaining daily global coverage and, while it builds
on the solid foundation of its heritage instruments,
it also represents a pioneering advance. The
combination of a high spatial resolution, high signal-
to-noise ratio and improved cloud detection will
provide stimulating new high accuracy information
on the composition of the troposphere.

EMISSION CALCULATIONS
AND TREND MONITORING

In addition to generating satellite data, KNMI
constructs long-term trends in emissions, based
upon the data of several successive instruments.
A study based on data from OMI provided, for the
first time, a space-based NOₓ emission inventory
for shipping offering a framework for future studies
to constrain ship emissions using satellite NO₂
emissions. During 2011, in research published in
Nature, OMI measured exceptionally low ozone on
the North Pole and it was found, using additional
satellite instrumentation on the same Aura
satellite (MLS), that chemical ozone destruction
over the Arctic in early 2011 was comparable to the
Antarctic ozone hole. The finding was surprising,
because temperatures are much milder in the
Arctic and ozone loss in the region had previously
had been far more limited than in the Antarctic.

Inventories of air pollutants provide crucial
information for policy makers and are important
for air quality models. Using satellite observations
for emission estimates has many advantages over
bottom-up inventories: they have global coverage
and allow updates soon after the satellite data
becomes available, whereas bottom-up inventories
are infrequently updated and dependent on local
information of differing quality, limiting their
value. The satellite data ultimately serve as an
independent tool for validating and updating
bottom-up emission maps.

LOOKING TO THE FUTURE

The data provided by OMI and TROPOMI are
invaluable. These satellite instruments enable
monitoring and prediction of atmospheric changes,
both globally and regionally. This will lead
to an ability to anticipate and manage environmental
change, which is strongly needed in this time of radical transformation.

KNMI is also in the process of developing a
device to test NO₂ concentration – known as
a sonde – for satellite validation. In satellite
retrievals, some assumptions must be made,
one of which is the profile of the trace gas
under study. If the assumption is incorrect, it
will affect the quality of the retrieval. The cheap
and easy-to-use NO₂ sonde will solve many of
these problems, as Levelt elaborates: "It will
improve our assumptions of NO₂ by validating
our models and/or by generating an NO₂ climatology profile". The sonde can measure very low concentrations of NO₂, be used under several weather conditions and has garnered a lot of interest from the scientific community.

Moreover, Levelt is working on miniaturised
satellite instrumentation, together with industry,
to further advance understanding of atmospheric
chemistry. Overall, her efforts, and those of
her colleagues, are providing a significant step
forward in atmospheric observations.

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Finland: TEKES • USA: NASA

TROPOMI: The Netherlands: ministries for
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PIETERNEL LEVELT obtained her Master’s
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Investigator of OMI (Launched on NASA’s
EOS-Aura satellite in 2004) and she is still
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She is scientific initiator of the new Dutch/
ESA TROPOMI instrument, to be launched on
ESA’s Sentinel 5 precursor in 2015. She also
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