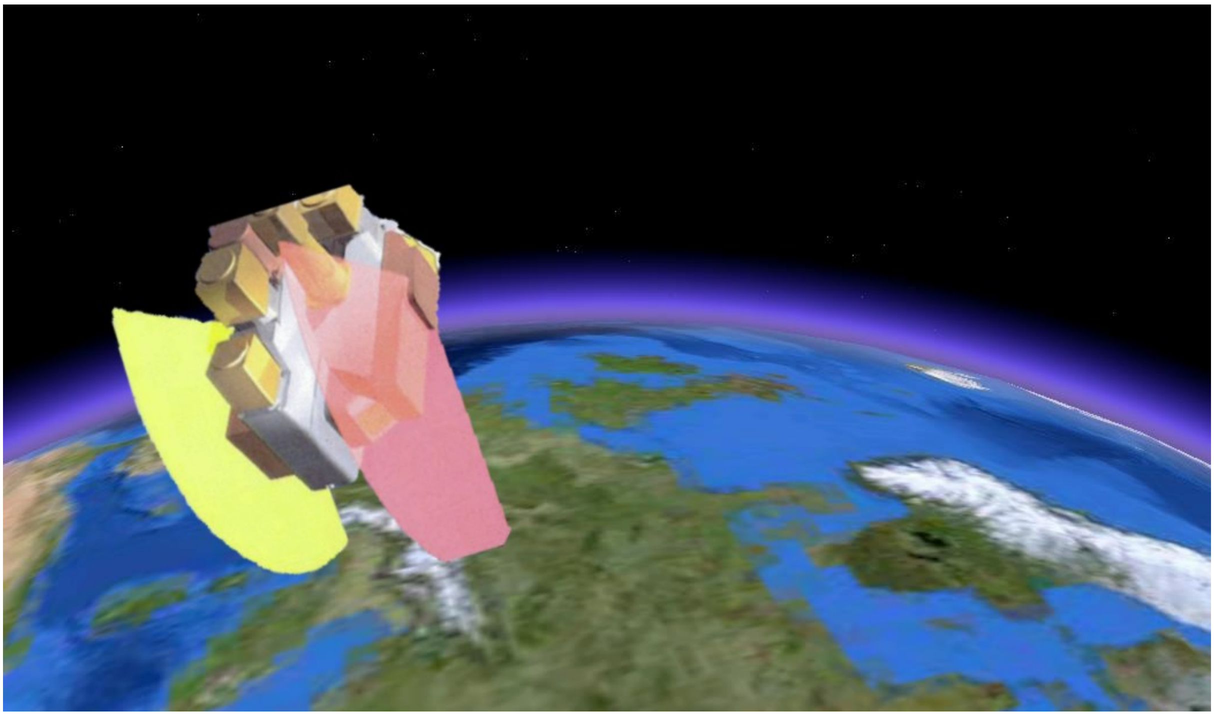
TROPOMI

Report TROPOMI User Workshop

held 5-6 March 2008 at KNMI



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… and all other presenters and participants (see lists in Appendix B & D).

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1 Introduction

The TROPOMI User Workshop took place 5 th and 6 th March at KNMI, de Bilt in The Netherlands. About hundred people were present at the Workshop. The participants came from 7 countries in Europe, and in addition a number of colleagues/interested parties from the United States and Canada participated as well (see Appendix D). It can be said that the interest in the Workshop was overwhelming –particularly considering the Workshop could only be organised at a very late stage- and that the discussions held on TROPOMI User Needs were very lively and fruitful. Overall we can conclude that the Workshop was successful and confirms the high interest in the atmospheric community (and beyond) in the TROPOMI-project.

The objective of the user Workshop was to reach out to a large group of potential users of TROPOMI data and to assess what their specific user needs with respect to TROPOMI data are. To this purpose a large group of potential users was invited to participate to the Workshop. Among the participants and presenters were international representatives of the GMES, GAS, CEOS and GEO initiatives, as well as from the international projects PROMOTE, GEMS, GEOMON, MACC. Also the space agencies ESA, EUMETSAT, NASA and NOAA were represented. From the Netherlands representatives from universities (e.g. Wageningen, TUE, TUD, Vrije Universiteit Amsterdam, …), environmental, climate, weather forecast institutes and companies (RIVM, MNP, KNMI, ARGOSS…), as well as representatives of Dutch user groups such as ROAT were present. Further representatives of many of the leading international scientific institutes in the field of atmospheric chemistry where present and presented their work in climate or air quality research (like . Uni-Leicester, Dalhousie University, BIRA/IASB, MPI-CH, NASA GSFC, EPA etc.)

The Workshop was organised around three main user groups, namely scientific users, institutional operational users, and commercial operational data users. The presentations were grouped according to these user groups where it is noted that the scientific and institutional operational user groups are far more developed in this field and thus constituted the main part of the presentations. Nonetheless, the session on commercial users was certainly inspiring and innovative. The commercial presentations also highlighted how reliant we are on having "clean air" not only as a fundamental need for a healthy environment but also as a pre-requisite in the food product processing industries.

The presenters showed their experience with satellite data, and particular their experience with OMI, SCIAMACHY, GOME-1 and GOME-2. See Appendix B and C for the programme of the Workshop and the abstracts of the (poster) presentations.

It is clear –as one of the presenters put it- that these instruments by far exceeded their expectations and gave us a completely new view and perspective of our own planet's atmosphere. For the first time the global distribution of a number of tropospheric gases was observed with many unexpected findings, new insights were obtained on distribution and characterisation of emission sources, new insights in transport pathways, trend studies, estimates of emissions on global scale through inversions also in combination with groundbased measurements, operational services were developed based on these satellite data (volcanic eruption warnings for aviation control, smog and air quality SMS-warnings for respiratory sensitive people, UV warnings, improvement of the medium range weather forecast).

Based on their experience and on their future needs, the presenters and participants were asked to provide feedback on TROPOMI and indicate their specific needs regarding TROPOMI data and observations. These were then further discussed during the various discussion opportunities at the end of each session. In total four lively discussion sessions were held including a wrap-up session at the end of the Workshop.

In Section 2 an overview is provided of the user requirements for TROPOMI based on the presentations and discussions during the Workshop. The requirements are grouped per user group, but it is noted that a number/many of the requirements from the different groups are quite similar.

Section 3 list the overall user requirements as came forward from the workshop. Also, a number of useful suggestions for fine-tuning the requirements were provided. Those are also given and discussed by the TROPOMI team whether or not they can be accommodated.

Appendix A give a short description the current TROPOMI instrument
Appendices B, C and D contain the programme, the abstracts of presentations and posters and the list of participants.

This report and the presentations given at the workshop can be downloaded from:
http://www.knmi.nl/omi/research/project/meetings/tropomi/workshop2008/

2 User requirements for TROPOMI based on presentations and discussions

Three main User requirements groups are envisaged for TROPOMI, namely the scientific users, the institutional operational users and the commercial operational users. The scientific users can be divided in a climate research group and an air quality research and application group. The institutional operational users provide air quality and meteorological forecasts, while the commercial operational users provide value added products and services.

The **climate research group** will use the TROPOMI data for understanding of processes, which have an impact on the global climate. Another important aspect is the improvement and verification of the climate models. Others will focus on the trends of concentrations of key species relevant for global climate. Additionally, also the sources and sinks of these species are assessed, in order to derive trends therein, or to improve existing emission inventories. Up-to-date emission inventories are key inputs for global climate models. This user group also provides information in support of climate policy regulations and protocol making and verification.

The **air quality research and application group** will use the TROPOMI data for understanding of processes important for both regional and global air quality and to improve the air quality models. Researchers in this group will focus on trends in key chemical species relevant for air quality. While the climate research group will primarily focus on global data sets, the air quality research group will focus on both regional trends, as well as trends in the long range transport of pollutants.

Operational forecast groups will use the TROPOMI data in combination with other observations and chemical transport models to provide analysis and forecasts of aerosols and chemical species relevant for air quality, as well as meteorological applications. A key feature of this user group is that near-real time data is used to generate data products and services operationally.

The **commercial application group** consist of private companies and non-governmental organizations that provide value added products or services. These commercial companies develop specific value added operational products for specific requests at regional and local levels for their customers. Customers of commercial users can be governmental organisations, industry and consumers.

During the workshop representatives for all these users groups were present.

User requirements scientific users

Here the high level user requirements for the different user groups are summarized. The requirements are ordered according to the following guidelines: TROPOMI data product needs, accuracy, spatial resolution, coverage, availability of measurements.

Auxiliary data:	clouds, aerosols, surface albedo, and vertical profile to improve accuracy of products.

Climate Research:

Primary constituents:	Methane, aerosols, tropospheric ozone, ozone, volcanic SO_2
Secondary constituents:	NO_2, CO, SO_2:(these are precursors for greenhouse gases CH_4, CO_2), clouds, H2O…
Auxiliary data:	clouds, aerosols, surface albedo, and vertical profile to improve accuracy of products.

- High requirements on accuracy for products to determine long term trends in order to connect measurements with previous measurement series (e.g. TOMS and OMI ozone record) and for reliable trend estimates and estimates of emissions..

- 10×10 km^2 resolution in order to resolve sources and sinks.
- Daily Global coverage
- Availability of measurements: for climate research long term data records are needed for trend analyses.
- Long-term calibration of instruments and mutual calibration between instruments of paramount importance

It is noted that the users expressed an interest in measuring CO_2 for climate applications. CO_2 is not only interesting by itself, but also as normalisation for CH_4. Because of cost and complexity considerations, as well as conflicting observational requirements with other trace gases TROPOMI does not have the capability to measure CO_2. In addition, it is noted that it still needs to be proven that CO_2 measurements from space can be made accurately enough for the purpose of generating useful CO_2 sink estimates. This issue can be revisited based on the experience with the OCO and GOSAT missions (launches end of 2008).

Also N_2O is an important greenhouse gas to consider. However, the requirements to measure N_2O are comparable (if not more demanding) compared to CO_2 because of its long lifetime. In addition, the sensitivity to measure N_2O from space in the optical spectral range is much lower than CO_2 which makes N_2O an even more challenging target than CO_2 and this is therefore not further considered within TROPOMI.

Air Quality Research & Application:

Primary constituents:	trop NO_2, trop O_3, aerosols, CO, SO_2, HCHO (Formaldehyde)
Secondary constituents:	CHOCHO (Glyoxal)
Auxiliary data:	clouds, aerosols, surface albedo, and vertical profile to improve accuracy of products.

- High accuracy and consistency needed for reliable trend estimates and estimates of emissions.
- 10×10 km^2 resolution or smaller in order to resolve sub-urban scale features and more cloud free observations[1].
- Daily global coverage
- Availability of measurements: long-term data records are needed for trend analyses and estimates of emission sources.
- Long-term calibration of instruments and mutual calibration between instruments of paramount importance

Data availability: for AQ research NRT and DB type of data availability is important for performing the research needed for operational systems.

User requirements of operational users:

- Products:
  - O_3 total column and profile for weather forecast
  - Tropospheric NO_2, tropospheric O_3, aerosols, CO for AQ forecast
  - SO_2 for aviation control
- Accuracy of products: requirements for total column O_3 not too demanding, quality NRT products can be relaxed somewhat compared to the non-NRT products as long as a reliable error characterisation is provided

[1] Cloudy observations will be used as well, for example to detect long range transport of CO and NO_2 over the oceans or to study NO_2 production by lightning.

- Accuracy Requirements for AQ and aviation control the same as for scientific users.
- Spatial resolution of 10 × 10 km^2 or better for AQ and aviation control
- Spatial resolution of 20 × 20 km^2 for total O_3 weather forecast
- Global coverage
- Timeliness of availability products: NRT or DB delivery is essential! Operational global NRT data started with GOME and are available now from SCIAMACHY, OMI and GOME-2 as a standard capability. Direct Broadcast has been shown for OMI to deliver O_3 and UV data on the internet within 15 minutes of measurement.
- Long term continuation of measurements is a necessity for operational applications. It was noted that e.g. implementation of OMI data in operational products would be seriously hampered if continuity of high resolution data by TROPOMI is not guaranteed.

User requirements of commercial users:

Have the same requirements as operational users but require a sustainable (continuity of data, meeting well defined quality standards) and robust delivery of data. Commercial user customers will not tolerate intermittent services which will lead to loss of support for using satellite based services and data and most likely to direct financial penalties to the commercial users. Commercial users are interested in resolution 5 × 5 km^2 rather than 10 × 10 km^2.
Commercial customers want products and services that provide answers for now, tomorrow, next year and ten years from now.

A very important point that was raised by the commercial users (voiced by ARGOSS in their presentation), is that data gained from missions funded by public funds should be made available at no cost (free data access) apart from possibly administrative costs for delivery of data. Currently this is not the case where it concerns data from ESA missions. The situation with EUMETSAT data is less restricting. Data from NASA missions is freely available also for commercial purposes with the only restriction that only value-added data can then be sold to third parties. This hampers the use of ESA data and leads to use of data from other sources even where equivalent or better ESA products are available.

3 Discussion summary and conclusions

The users at the Workshop as well as the representatives from GEMS, GAS, WMO and IGACO confirmed during their presentations and in the discussions that the TROPOMI initiative with an envisaged launch date ~2014 is very needed and timely considering the life time of ENVISAT and EOS-Aura. Although MetOp is operational until its follow-on post EPS Sentinel 5 will be launched in ~2020, there is a clear need for OMI and SCIAMACHY-like measurements and these are only partially addressed by GOME-2 and IASI on MetOp, most notably high spatial resolution tropospheric measurements (pixel size) and CO, CH_4 measurements with sensitivity to the ground.

Overall it can be concluded that most of the instrument, observation and data requirements as defined by the TROPOMI team were strongly supported by the users.
The overall high level requirements for TROPOMI are:

High level user requirements

Primary constituents:	Ozone, tropospheric ozone, aerosols, NO_2, methane, HCHO (Formaldehyde, a Volatile Organic Compound (VOC)), SO_2 and CO
Secondary constituents:	Ozone profile, H_2O, OClO, BrO, CHOCHO (also a VOC), clouds
Auxiliary data:	clouds, aerosols, surface albedo and vertical profile to improve accuracy of products.

- High requirements on accuracy for products
- $< 10 \times 10$ km^2 resolution
- Daily Global coverage
- Information on the diurnal cycle (early afternoon orbit preference and use synergy with GOME-2)
- Long term data records are of high importance.
- Near Real Time (NRT) and Direct Broadcast (DB) data delivery

A number of useful suggestions (listed below) for fine-tuning the requirements were provided and the TROPOMI team will investigate if these can be accommodated/try to accommodate those.

Suggestions for extra products

- It was recommended to consider to include a CO_2 channel in TROPOMI as CO_2 is the most important anthropogenic greenhouse gas. Another aspect is that CO_2 observations can be used for the normalisation of CH_4 observations made in the same channel. It was however recognized that measuring CO_2 from space for the purpose of determining its sources and sinks is extremely challenging and therefore costly. For both reasons, the current TROPOMI baseline does not include a CO_2 channel.
- Also N_2O is an important greenhouse gas. However, the requirements to measure N_2O are even more demanding compared to CO_2. In addition, the sensitivity to measure N_2O from space in the optical spectral range is much lower than CO_2 which makes N_2O an even more challenging target than CO_2 and this is therefore not further considered within TROPOMI.

Spatial resolution and coverage requirements, orbit preference

- The users have clearly expressed their need for spatially highly resolved data to observe sub-urban areas and also to obtain more cloud-free observations. A spatial resolution of 5×5 km^2 is preferred for some species (see also instrument recommendations), although 10×10 km^2 was definitely considered good enough.
- Daily global coverage is strongly preferred.

- The users expressed their need for diurnal sampling. An afternoon orbit was clearly expressed as the preferred one, considering both the build-up of (anthropogenic) pollution during the day, chemical diurnal cycles, but also the guaranteed presence of GOME-2 and IASI on MetOp in an early morning orbit (9:30 a.m.), which would result in optimal synergy with respect to diurnal sampling and exploitation of the data.

Synergetic options

- The value and accuracy of TROPOMI data could significantly be enhanced by combining with thermal infrared instruments, a dedicated aerosol instrument and a high resolution cloud imager.
- Formation flying with NPOESS or A-train in an early afternoon orbit was recommended. This provides, in synergistic combination with MetOp, diurnal sampling for some species and includes synergy with high spatial resolution cloud and aerosol information.

Data delivery & availability

- Development of (assimilation) models for air quality forecasting is a long-term investment. Therefore, continuity of data via operational satellites is preferred. The current (regional air quality) models need a lot of improvement.
- For a number of (operational) users (ECMWF, NOAA, and commercial users offering forecast services) data continuity and Near Real Time (within 3 hours) access to data is crucial.
- For air quality applications, direct broadcast or very fast access (within 15-30 minutes) is an important extension, which will allow for a real-time monitoring and real-time data assimilation of air pollution.
- Easy (and free) data access is strongly recommended
- Early reliable data use is crucial in order to use the data for operational forecast during most of the lifetime of the instrument. A careful and thorough on-ground calibration will be essential to fulfil this requirement.

Recommendations for instrument design optimisation

- It was highly recommended to optimise the 300-320 nm wavelength range in order to make the best emission estimates of tropospheric O_3 and anthropogenic SO_2. This can be achieved by optimising signal-to-noise (S/N) in the UV2 wavelength range, perform accurate radiance calibration, dark-current evaluation, and avoid ‘at all cost’ straylight issues. The TROPOMI team will take this into consideration when optimising the separation of UV1 and UV2, but this is not easy to meet.
- Include an additional (1.6 micron) SWIR channel to improve the CH_4 measurements (by allowing for normalisation to CO_2) and, possibly, to observe CO_2 with this additional channel. However, … (see discussion under “Suggestions for extra products”).
- For OMI, the ground pixel size increases from nadir towards the end of the swath. Users expressed the need to keep the footprint of the observations as regular in size and the spatial resolution close to 10×10 km^2 also in off-nadir. The TROPOMI team will investigate the option to use a variable binning factor across the swath to accommodate this need.
- A way to achieve smaller ground pixel than 10×10 km^2, it was suggested to perform the binning of detector pixels on – ground rather than on-board. The TROPOMI team will investigate the feasibility of this option with respect to S/N requirements, data rates and volume.
- A careful and thorough on-ground calibration, for better products (some calibration parameters can not be determined accurately anymore after launch) and early reliable date use (see also last item under “Data delivery & availability”.
- It was recommended that spectral features should be avoided in the design (e.g. diffuser, polarisation scrambler, ..) as it severely affects the accuracy of retrievals (mostly of a DOAS type) for trace gases.
- It was suggested to have a spectral sampling of 3 or more for the SWIR channel.

Other remarks

- Retrieval algorithms could be improved by improvement of the current radiative transfer modelling (e.g. BiDirectional Reflectance distribution Function (BDRF) surface, ocean properties, …) and spectroscopy.
- There is a clear need to develop models and data assimilation techniques well in time to take full advantage of what the TROPOMI instrument will offer.
- It was noted that the UV part of TROPOMI provides information on detection of smoke and aerosol in cloudy conditions and the possibility to differentiate between absorbing and scattering aerosol not provided by other instruments.
- It was further remarked that the measurements over clouds are also useful (e.g. CO transport, NO_2 production by lightning).

Appendix A: TROPOMI description

Introduction

TROPOMI (TROPospheric Monitoring Instrument) is a satellite instrument for remote sensing of the Earth's atmosphere. Its primary goal is to be sensitive in the troposphere down to the boundary layer/Earth's surface in order to quantify emissions and transport of anthropogenic and natural trace gases and aerosols, which impact air quality and climate.

TROPOMI will measure the main tropospheric pollutants (O_3, NO_2, CO, formaldehyde (HCHO) and SO_2) and two major climate gases (tropospheric O_3 and methane (CH_4)). In addition, it will measure important parameters of aerosols (aerosol scattering, absorption and type identification), which play a key role in climate change as well as in tropospheric pollution. The main instrument requirements for the TROPOMI instrument have been derived to fulfil the user requirements for the above-mentioned species.

TROPOMI is a Dutch initiative building upon the successes of SCIAMACHY and OMI. This new instrument combines all good things of the previous instruments and improves on most specifications. The instrument is designed by TNO and Dutch Space in The Netherlands, who were also involved to great extent in TROPOMI's predecessors (OMI on NASA's EOS-Aura, launched in 2004 [Levelt et al, 2006]; SCIAMACHY on ESA-ENVISAT, launched in 2002 [Bovensmann et al, 1999]; GOME on ESA-ERS-2, launched in 1995 [Burrows et al, 1999]; and EUMETSAT MetOp, launched in 2006 [Callies et al, 2000]).

The design uses a modular approach, in order to be flexible to accommodate different requirements from the various missions it can fly on.

Instrument overall description

TROPOMI is a nadir-viewing grating-based imaging spectrometer similar to OMI, with an additional optical channel based on the SCIAMACHY heritage. The instrument will measure both the Earth radiance and solar irradiance spectra, in combination yielding the reflectance spectrum that contains the information for retrieval of atmospheric trace gases. It has two dimensional detectors, which use one dimension to measure spectral information and the other dimension for the across-flight swath.

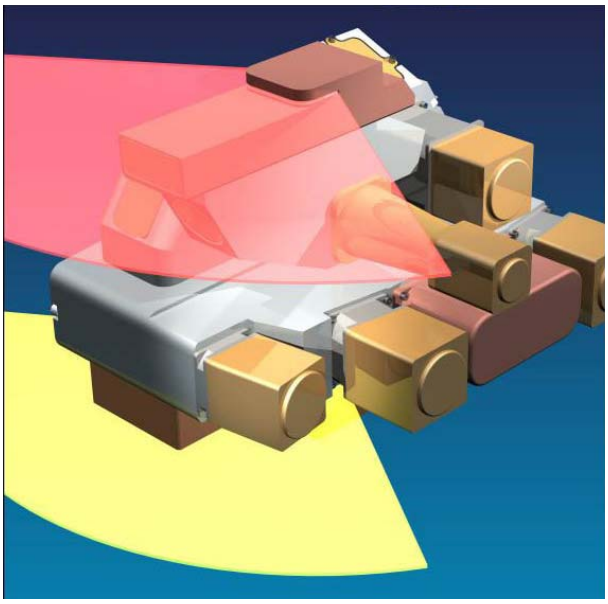

Fig. B1. CAD drawing of TROPOMI. At the bottom the UV-VIS-NIR module, on the top, the SWIR module.

The special OMI-like telescope has a wide viewing angle that enables daily global coverage and that corresponds to a swath width of about 2600 km. The swath allows coverage of the complete globe in one day and at higher latitudes several observations per day as a result of orbit overlap. For a non-sun-synchronous, medium-inclination drifting orbit, the swath width is also about 2600 km and allows near-global daily coverage and unique diurnal time sampling with up to 5 daytime observations over mid-latitude regions (Europe, North- America, China). TROPOMI will have 140 ground pixels/swath, OMI has 60.

TROPOMI covers the OMI wavelengths of 270 – 490 nm to measure O_3, NO_2, HCHO, SO_2, cloud and aerosols parameters in three channels (UV1, UV2 and VIS). Compared to OMI, a NIR channel and a SWIR module are added (heritage from SCIAMACHY). The NIR-channel (710 – 775 nm) is used for improved cloud detection using the oxygen A-band. The SWIR module (2305 – 2385 nm) measures CO and CH_4 and forms a separate module because of its thermal requirements. The spectral resolution will be about 1.1 nm in the UV1 channel, about 0.45 nm in the UV2/VIS/NIR channels and 0.25 nm in the SWIR wavelength range. See Table A1 for the characteristics of the different channels.

Table A1. Characteristics of the TROPOMI optical channels and their products.

Optical channel	Full spectral range [nm]	Full performance range [nm]	Nadir ground pixel size [km^2]	Achievable S/N for minimum scenario (1)	Spectral resolution [nm] / and sampling ratio	Products (2)
UV1 (3)	270 – 320	270 – 310	40 × 40	100 (at 270 nm) - 1000 (at 310 nm)	1.1 / 4	**O_3**
UV2	295 – 380	310 – 370	10 × 10	1000	0.45 / 4	**O_3**, **SO_2**, **HCHO**, *BrO, OClO*
VIS	360 – 495	370 – 490	10 × 10	1500	0.52 / 4	**NO_2**, **aerosol properties**, O_2-O_2 cloud fraction / pressure, *CHOCHO*
NIR	710 – 775	710 – 775	10 × 10	Absorption 100 Continuum 500	0.45 / 4	**O_2-A cloud fraction, optical thickness and pressure**, H_2O, *aerosol height*
SWIR	2305 – 2385	2314 – 2375	10 × 10	95	0.25 / 2	**CO**, **CH_4**

Notes: (1) *The S/N is specified for a minimum scenario with a surface albedo of 2% (UV-VIS-NIR), and 5% (SWIR).*

(2) *The main products are* **in bold**, *lower priority products are* in italics.

(3) *The UV1 channel is meant for measurements of the stratosphere and upper troposphere and has relaxed spatial and spectral requirements.*

A major improvement with respect to the SCIAMACHY and OMI capabilities is the reduced ground pixel size of TROPOMI. This not only improves the ability to locate sources and sinks of certain gases, but also significantly increases the number of cloud-free observations. The nadir ground pixel of TROPOMI is 10 × 10 km^2. This value is relaxed to 40 × 40 km^2 for the UV1 channel, because the ground and the lower troposphere cannot be observed in this wavelength range and thus larger ground pixels can be used to meet the required signal-to-noise ratio. Using improved optics and detectors, TROPOMI will have signal-to-noise ratios that are typically a factor of two better than OMI. For SWIR the nadir ground pixel improves compared to SCIAMACHY from 120 × 30 km^2 for CO and 60 × 30 km^2 for CH_4 to 10 × 10 km^2. In addition, the sensitivity per individual measurement is much improved (at least a factor 5 for CO).

Development status

TROPOMI is designed to improve significantly on sensitivity and spatial resolution compared to OMI and especially to SCIAMACHY and GOME-2. This will be achieved by, amongst others:

- using improved CCD or CMOS detectors
- having separate UV1 and UV2 detectors instead of combing the UV image on a single CCD detector as in OMI
- using the OMI pushbroom imaging technique (measuring a full swath at the same time) for the SWIR channel instead of the scanning mirror concept of SCIAMACHY and GOME-2 (which performs only one single measurement at the time).

The SWIR channel is one the most challenging technical parts of the TROPOMI design. In order to realise pushbroom imaging technique in the SWIR within an acceptably sized instrument, new technologies are needed, in particular a so-called immersed grating. Therefore, a functionally flight representative breadboard model of the SWIR channel has been designed [Hoogeveen et al, 2007] to test the performance and various critical components. These components are HgCdTe-based 2D CMOS detector, the on-board SWIR calibration LED, and in particular, the SRON/TNO developed silicon-based immersed grating that allows a strongly reduced instrument volume. Preliminary tests have demonstrated the feasibility of extending the OMI pushbroom observation strategy to the SWIR wavelength range.

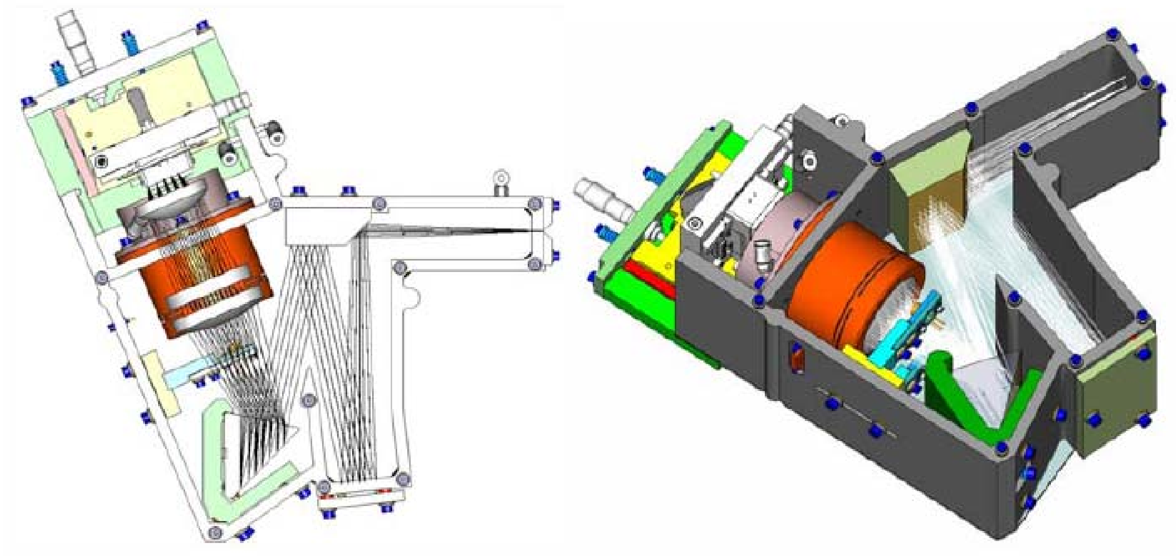

Fig. A2. Design of the TROPOMI-SWIR breadboard model (drawings courtesy of MECON BV)

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Appendix B. Program

Wednesday 5 March 2008

General Session — ***Chair: Hennie Kelder (KNMI)***

9.00-9.10	Frits Brouwer (KNMI)
9.10-9.20	Ger Nieuwpoort (NIVR)
9.20-9.30	Reinout Woittiez (RIVM)
9.30-10.00	Pieternel Levelt (KNMI) "*TROPOMI : Sensing the troposphere from space*"

Scientific Session — ***Chair: Hennie Kelder (KNMI)***

10.00-10.20	Pawan K. Bhartia (NASA-GSFC) "*NASA's experience in using the Aura OMI data for studies of atmospheric composition*"
	Chair: Pawan K. Bhartia (NASA-GSFC)
11.00-11.20	Johanna Tamminen (FMI) "*FMI participation in OMI and plans for TROPOMI*"
11.20-11.40	Folkert Boersma (KNMI) "*Observing NO_x air pollution from space at multiple scales*"
11.40-12.00	Martine De Mazière (BIRA) "*Exploitation of GOME, SCIAMACHY and OMI data for monitoring atmospheric composition and transport, at the Belgian Institute for Space Aeronomy*"
13.20-13.40	Randall Martin (Dalhousie University) "*Interpretation of Satellite Observations of Tropospheric NO_2: Implications for TROPOMI*"
13.40-14.00	John Remedios (Leicester University) "*Regional Air Quality and Climate from Space – A reality?*"
14.00-14.20	Didier Tanré (LOA) "*Aerosol remote sensing from the PARASOL mission and the A-train*"
14.20-14.40	Discussion: User needs for TROPOMI

Commercial Session — ***Chair: Harry Forster (NIVR)***

15.20-15.40	Willem Posthouwer (Friesland Foods Kievit) *"Kievit and the importance of clean air"*
15.40-16.00	Han Wensink (ARGOSS) "*A service Infrastructure for Local Air Quality Services*"
16.00-16.20	Iarla Kilbane-Dawe (AEA Energy & Environment) "*UK applications of remote sensing data for policy and operational applications*"
16.20-16.40	Discussion: User needs for TROPOMI

Thursday 6 March 2008

Operational Session — ***Chair: Rose Munro (EUMETSAT)***

9.00-9.10	Hennie Kelder (University of Technology Eindhoven) "*An Integrated global Atmospheric Chemistry Observations strategy*"
9.10-9.20	Pieternel Levelt (on behalf of Ernest Hilsenrath, NASA HQ) "*Atmospheric Composition Constellation*"
9.20-9.40	Daan Swart (RIVM) "*GMES and SmogProg: towards integrated environmental monitoring of the atmosphere*"

9.40-10.00	Rossana Dragani (ECMWF) “*Assimilation of atmospheric composition at ECMWF”*
10.00-10.20	Henk Eskes (KNMI) “*Air Quality Forecasting in Europe”*

Chair: Daan Swart (RIVM)

11.00- 11.20	Dominik Brunner (EMPA) “*Satellite based versus traditional air pollution monitoring: Requirements, limitations, and chances”*
11.20-11.40	Shobha Kondragunta (NOAA-NESDIS) “*Current and Future Applications of Satellite-derived Air Quality Products“*
11.40-12.00	Rose Munro (EUMETSAT) “*GOME-2 on Metop”*
13.20-13.40	Rob Pinder (EPA) “*Use of space-based tropospheric* NO_2 *observations in regional air quality modeling”*
13.40-14.00	Robert Koelemeijer (MNP) “*Atmospheric composition from space: its role in environmental assessment”*
14.00-14.20	Discussion: User needs for TROPOMI

Scientific Session #2 ***Chair: Pieternel Levelt (KNMI)***

15.00-15.20	Ilse Aben (SRON) “*Methane source estimation using space-borne observations”*
15.20-15.40	Thomas Wagner (MPCH) “*Tropospheric data (trace gases, aerosols, clouds) analysed in the satellite group Mainz-Heidelberg from GOME, SCIAMACHY and GOME-2: Critical summary and recommendations for TROPOMI”*
15.40-16.00	Maarten Krol (U. Wageningen) “*Applications of space-borne Carbon-monoxide measurements in Atmospheric Chemistry and Air Quality”*
16.00-16.20	Discussion / Wrap-up

<u>Posters</u>

P-001	DutchSpace, KNMI, SRON, TNO, and NIVR *“TROPOMI: The Best of Both Worlds”*
P-002	DutchSpace, KNMI, SRON, TNO, and NIVR *“TROPOMI Technology”*
P-003	DutchSpace, KNMI, SRON, TNO, and NIVR *“TROPOMI Data Products”*
P-004	Annmarie Eldering (JPL) “*Quantifying the Science Impact of Instrument and Mission Designs: the Ozone Case”*
P-005	Nathaniel Livesey (JPL) “*The Scanning Microwave Limb Sounder (SMLS)”*
P-006	Robert Chatfield (NASA/ARC) “*Robust Remote Sensing of Smog Ozone and Its Production using TIMS 3-micron Full-Column Sensing”*
P-007	Robert Chatfield (NASA/ARC) “*Lower Tropospheric Ozone Signals Contribute Significantly (if Oddly) to OMI Tropospheric Column Estimates”*
P-008	Martijn Schaap (TNO) “*An Observing System Simulation Experiment (OSSE) for aerosols’*
P-009	Martijn Schaap (TNO) “*On the relation between AOD and PM2.5 at Cabauw, the Netherlands”*

Appendix C. Abstracts

TROPOMI : Sensing the troposphere from space
Pieternel Levelt
KNMI, De Bilt, The Netherlands

Sensing the troposphere from space is a recent development in satellite remote sensing. Measurements from GOME and SCIAMACHY revealed the first averaged tropospheric nitrogen dioxide maps. OMI performed unprecedented measurements from space by measuring tropospheric pollution NO_2 maps on a daily basis with urban scale resolution. The greenhouse gas methane was measured by SCIAMACHY and presented in a Science paper which led to a lively debate about methane sources in the tropical rain forest. TOMS measurements were used for the first tropospheric ozone and aerosol index maps. Similar techniques were later applied to GOME, SCIAMACHY and OMI data. In this presentation the challenges and future developments for sensing the troposphere from space will be discussed, resulting in the presentation of a new satellite instrument (TROPOMI). The science questions in terms of contribution to climate and air quality research, potential operational and commercial use, data products and potential mission options of TROPOMI will be presented.

NASA's experience in using the Aura OMI data for studies of atmospheric composition
Pawan K. Bhartia
Laboratory for Atmospheres
NASA Goddard Space Flight Center
Greenbelt, Maryland, USA

The OMI instrument was launched on NASA's EOS Aura satellite in July 2004. NASA funds a team of about 10 US scientists to analyze OMI data. Most members of this team have worked on similar instruments before that include TOMS, SBUV, GOME and SCIAMACHY. In my talk I will discuss NASA's experience in using the OMI data to study atmospheric composition globally and how these data are being utilized by US operational agencies such as NOAA, EPA, USGS, and FAA for monitoring volcanic eruptions and air quality over the US continent. A key advantage in favor of OMI, compared to previous instruments of this type, is that it is flying on a spacecraft that consists of three other state-of-the-art atmospheric composition instruments and the Aura spacecraft is part of a constellation of 5 satellites with several advanced instruments to measure atmospheric composition, clouds, and aerosols. This has allowed us to understand in much greater detail than before how best to utilize data collected by instruments such as OMI for scientific studies. This experience will help greatly in designing future instruments such as TROPOMI.

FMI participation in OMI and plans for TROPOMI
Johanna Tamminen

The strong involvement of Finnish Meteorological Institute (FMI) in Dutch-Finnish OMI project is demonstrated by showing results of the global UVB data and the Very Fast Delivery (VFD) processing system. Our future plans for further utilizing the OMI data are discussed. In addition, we present our preliminary ideas related to using the TROPOMI data.

Observing NO_x air pollution from space at multiple scales
Folkert Boersma and co-authors at Harvard University, NASA GSFC, Weizmann Institute, and KNMI

Since September 2004, it is possible to observe NOx air pollution from space at a range of scales by using measurements from OMI on board NASA's EOS-Aura satellite, SCIAMACHY on board ESA's ENVISAT, and GOME-2 on EUMETSAT's METOP. In this presentation, I will show that it is possible with OMI to detect day-to-day reductions in NOx pollution resulting from traffic restrictions. Then I will discuss the interplay between the diurnal cycle in photochemistry and NOx emissions to explain differences in NO2 columns observed at 10:00 hrs from SCIAMACHY and at 13:40 hrs by OMI. The sensitivity of satellite measurements for NO2

concentrations at the surface is demonstrated through a comparison of near-surface NO2 concentrations and tropospheric NO2 columns observed from the ground and from space. This comparison shows consistency between the seasonal, weekly and diurnal variation observed with the surface-based and space-borne techniques.

Exploitation of GOME, SCIAMACHY and OMI data for monitoring atmospheric composition and transport, at the Belgian Institute for Space Aeronomy

M. De Mazière[1], I. Desmedt[1], B. Dils[1], J.C. Lambert[1], C. Lerot[1], J.F. Müller[1], G. Pinardi[1], T. Stavrakou[1], J. van Geffen[1], J. van Gent[1], M. Van Roozendael[1], B. Mijling[2], R. van der A[2]
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[2] *Royal Netherlands Meteorological Institute (KNMI), De Bilt, the Netherlands*

The GOME, SCIAMACHY and OMI satellite data have been used in many different scientific research activities at the Belgian Institute for Space Aeronomy, often in collaboration with the KNMI. Among these activities are the development and validation of level-2 products and the optimization of retrieval algorithms, data assimilation in numerical modeling, and geophysical analyses. This presentation will highlight four applications that use these satellite data and that would greatly benefit from similar products from a future TROPOMI mission. .

New information about the global distribution of H_2CO and NO_2 has been derived. The H_2CO and NO_2 data sets have been used, among others, for an improved top-down determination of the anthropogenic sources of NO_x and biogenic emissions of non-methane volatile organic compounds (NMVOC). OMI data for NO_2 supported by FLEXPART simulations are also used to identify and monitor long-range transport processes of NO_x, e.g., over the Atlantic Ocean.

The last application deals with the use of satellite aerosol and SO_2 data for a Support to Aviation Control Service.

Interpretation of satellite observations of tropospheric NO_2: Implications for TROPOMI

Randall Martin

Major outstanding issues in surface air quality are accurate estimates of ozone precursor concentrations and emissions, and measurements of surface air quality over an entire domain. Here we explore the potential to achieve these goals through satellite remote sensing. We examine the relationship of tropospheric NO_2 columns with NO_x emissions and surface NO_2 concentrations. Validation needs and areas for further algorithmic development will be identified. Accuracy objectives will be proposed for the retrieval of tropospheric NO_2 with respect to the goal of emissions constraints. Implications for instrument design will be noted.

Regional Air Quality and Climate from Space – A reality?

Paul Monks, John Remedios
Leicester University

The talk will overview the application of space-based measurements to the determination of regional air quality and greenhouse gas concentrations. A requirement for future missions will be a consideration of the linkages of spatial and temporal scales. Examples will be given from current measurements from OMI and SCIAMACHY as a pointer for future requirements. Finally, some technology gaps will be highlighted with respect to future missions of the likely TROPOMI class.

Aerosol remote sensing from the PARASOL mission and the A-train.

D. Tanré[1], A. Lifermann[2], F-M.Bréon[3,4], J.L. Deuzé[1], F. Ducos[1], B. Gérard[1], Ph. Goloub[1], N. Henriot[4], M. Herman[1], J.F. Léon[1], J. Pelon[5], L. Remer[6], F. Thieuleux[1]
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Since December 2004, the CNES Parasol (Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar) mission is flying in the A-train with Aqua and Aura (NASA), further completed in April 2006 by Calipso (NASA/CNES) and CloudSat (NASA/CSA). Parasol carries a wide-field imaging radiometer/polarimeter designed to improve the knowledge of the radiative and microphysical properties of clouds and aerosols.

Advantages of each instrument are described. For instance, by measuring the directionality and polarization of light reflected by the Earth-atmosphere system, PARASOL can detect non-spherical particles within the coarse mode, which is not the case of MODIS or OMI. OMI is sensitive to altitude and aerosol absorption; it can be combined with PARASOL measurements in the blue which are also affected by the same parameters. CALIOP can then be used for validation. Joint inversion scheme can be proposed.

The lessons learned from this exercise can be used to show the benefit from the synergy between sensors of the TRAQ mission, which will carry instrument with similar capabilities, lidar excepted.

Kievit and the importance of clean air

Willem Posthouwer
Friesland Foods Kievit

Friesland Foods Kievit -operating company of FrieslandFoods- is a global market player on the production spray-dried, encapsulated ingredients meeting all food industry standards. Kievit has major plants in Europe as well as Asia.

As part of its production process, Kievit imports clean air, roughly about 400.000kg of air every hour. In order to encapsulate ingredients this air is used as a transportmedium for access humidity. The importance of clean air for manufacturing of food grade ingredients must therefore not be underestimated.

In this presentation, background on Kievit as well as the importance of clean air for the production process will be given.

A service Infrastructure for Local Air Quality Services

Han Wensink, Leslie Gale Agnes Mika, Hein Zelle, Peter Bange
ARGOSS

Detailed information on air quality is important for many applications ranging from life sciences to recreation. Hereto, in Europe, large research projects are being performed to develop a basic service for air quality data, using in-situ measurements, satellite data, meteorological models and air quality models. Although very advanced, these basic data services are often focused on the scientific users and provide information on a very coarse scale.

At ARGOSS, we have started developing a global infrastructure for air quality products and services focused on applications on a local to regional scale. The infrastructure we are developing uses global (nested) meteorological models, regional and local models, integrated with air quality models. Where possible local measurements and satellite observations are integrated with the models. The services are being developed in such a way that they can directly be linked to the EU Atmospheric Core on a European Scale. Whether this will be done will depend upon availability and the (favourable) access conditions.

The presentation will present the background on the different type of products and services we are providing for air quality, the different group of clients we are serving, the infrastructure we are developing, the business models we are using and the role and needs we have on satellite data.

UK applications of remote sensing data for policy and operational applications

I. Kilbane-Dawe[1], P. Willis[1], S. Christiansen[1], J. Targa[1], R. Toumi[2]
[1] *AEA*
[2] *Imperial College*

AEA is responsible for operation of the UK stratospheric ozone and spectral UV monitoring programme, and for monitoring transboundary air pollution over Gibraltar. As part of the UK programme OMI ozone measurements were compared with ground based Brewer-Dobson spectrophotometer total column ozone measurements at three sites over the UK. A significant improvement in the correlation with groundbased measurements was found in the NASA reprocessed Collection-3 OMI data. Remote sensing data also proved useful in estimating transboundary air pollution over Gibraltar. Future applications of remote sensing data for UK and EU policy are extensive and a number of avenues for this development are outlined, including implications of the SEIS for the remote sensing and air quality community.

An Integrated global Atmospheric Chemistry Observations strategy

Hennie Kelder
University of Technology, Eindhoven

In the last two decades the atmospheric chemistry community has put a lot of effort in developing a view on an integrated observation strategy. The elements for this strategy are ground-based and in situ measurements, measurements from satellites, models and chemical data assimilation. One of the mile stones is the IGACO report on the Integrated Global Atmospheric Chemistry Observation System published in 2004. The requirements and recommendations have been used in several studies afterwards. An important step was that WMO has adopted IGACO and integrated the strategy in the GAW philosophy. in the last two years the WMO CAS has developed an implementation plan. In parallel the initiatives for global monitoring of the environment, weather and climate, GMES in Europe and the global effort GEOSS have also led to developments of elements for an integrated approach for observations. In the Cape Town GEOSS summit, end 2007, a further step was taken by the GEOSS community by mapping the IGACO/GAW atmospheric chemistry theme on the GEO tasks. It will be illustrated that the TROPOMI concept is in line with the developments indicated above.

Atmospheric Composition Constellation

Ernest Hilsenrath[1], J. Langen[2], C. Zehner[2]
[1] *NASA Headquarters*
[2] *ESA*

GMES and SmogProg: towards integrated environmental monitoring of the atmosphere
Daan Swart
RIVM, Bilthoven, The Netherlands

The European Union and the European Space Agency have started a large initiative : Global Monitoring for Environment and Security (GMES). In the GMES framework, ground based and space borne monitoring is combined and integrated into an information system that aims to assess and understand the state of the Environment worldwide. GMES encompasses the themes land, water, atmosphere and security. Within GMES, the GMES Atmosphere Service is currently a pilot service for the theme atmosphere, that will be further developed in the coming years. In this presentation, we will outline the concept and some of the recent developments, and touch on the possible role of TROPOMI in this context.

More on the concrete side, we will show some first results of a Dutch project named SmogProg. SmogProg aims to improve the Dutch ozone smog forecast with a combination of groundbased and satellite measurements assimilated in the atmospheric chemistry and transport model LOTOS-EUROS.

Assimilation of atmospheric composition at ECMWF
Rossana Dragani
European Centre for Medium-Range Weather Forecasts

This talk will present a number of results obtained at ECMWF from the active assimilation of remotely sensed atmospheric composition products.

The first part of the talk will discuss the benefits of assimilating ozone products retrieved from SCIAMACHY, GOME-1, and OMI, that can be regarded as the TROPOMI predecessors. The results that will be presented here are based on the experience gained either within the ECMWF operational activities or in the ECMWF reanalysis projects.

In the second part of the talk, the potential use of other-than-ozone level-2 products - which are anticipated to be provided by the TROPOMI instrument - will be discussed. ECMWF coordinates the EC-funded project GEMS (Global and regional Earth-system Monitoring using Satellite and in-situ data) that aims at developing:
- global modelling and data assimilation for greenhouse gases, reactive gases and aerosols,
- a validated global production system for the above, including surface-flux estimation,
- collaborative regional modelling, analysis and forecasting of air quality for Europe.

The GEMS community has already been identified as one of the potential users of the TROPOMI products, and most of these gases can already be used in the GEMS system (for example CO, O_3, HCHO, NO_2, and CH_4). The GEMS system capability of forecasting and assimilating a number of greenhouse and reactive gases, such as those that will be delivered by TROPOMI, will be discussed.

Air Quality Forecasting in Europe
Henk Eskes
KNMI, De Bilt, The Netherlands

In my presentation I will discuss recent air quality forecasting, modelling and data assimilation initiatives in Europe. Especially in the context of the GMES project there is a major effort to provide detailed and high-quality air pollution information to the citizens.

There are two relevant projects. Within PROMOTE an “Integrated Air Quality Platform for Europe” has been set up, an ensemble forecast based on the output from four different air quality models. Within GEMS this model ensemble approach is further developed. The “GMES Atmosphere Service” precursor project MACC (starting 2009) will build on the PROMOTE and GEMS work, and will set up an operational air pollution forecasting system. Advanced assimilation approaches will be developed to exploited the available near-real time observations from surface networks and from satellites.

The available of air quality satellite data which provides reliable information on the composition of the atmospheric boundary layer is limited. In the future - when missions like ENVISAT and EOS-Aura will end - the situation will become even worse. The TROPOMI instrument - when launched - will play a unique role to fill this gap and to provide high-resolution data on CO, O_3, HCHO, NO_2 and absorbing aerosols. Especially the detailed NO_2 data is foreseen to have a considerable impact on the regional air quality models and on a better quantification of the distribution and strength of (incidental and long-term) emissions.

Satellite based versus traditional air pollution monitoring: Requirements, limitations, and chances

Dominik Brunner, Christoph Hueglin, Christoph Zellweger, and Brigitte Buchmann
Laboratory for air pollution and environmental technology, Empa, Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Switzerland

Traditionally, air pollution is monitored using networks of stations equipped with a suite of in situ instruments. The networks are typically designed to cover a wide range of air quality levels from polluted urban sites to remote rural locations. By categorizing the population (or e.g. croplands) according to these different environments and combining this information with air pollutant concentrations measured for each category, representative exposure levels (or loads) can be assessed. Depending on the specific air pollutant, either maximum or mean concentrations, or both, are relevant for human health or vegegation damage assessments. For nitrogen dioxide, for example, limit values exist in Switzerland for annual mean values (30 $\mu g/m^3$), for daily mean values (80 $\mu g/m^3 \leq$ once a year), and for extreme values (95% of 1/2h means <100 $\mu g/m^3$). Furthermore, long-term monitoring provides invaluable information for political bodies to evaluate the success of reduction measures and to develop effective abatement strategies.

Current satellite observations are too limited to fulfil the requirements of continuous air pollution monitoring for several reasons: (i) Satellite pixels are too coarse to resolve the full range air pollution levels. (ii) Satellite overpasses are limited to specific times of the day (not covering for instance peak traffic hours). (iii) Observations can only be obtained under clear sky conditions. (iv) UV/VIS instruments are not very sensitive to air pollution near the ground. However, satellite observations can complement ground based networks as they can fill in gaps in the geographical coverage, they can be more readily used for assimilation into models than in situ observations, and, due to their global coverage, they greatly facilitate the intercomparison of air quality levels between different countries and regions.

In this presentation, we evaluate the potential and limitations of satellite observations for air pollution monitoring over Switzerland by addressing questions such as: How well do satellite and in situ measurements agree? How well are differences between urban and rural sites represented? How well are air pollution episodes seen? Can satellites be used, despite their limitations, to estimate meaningful annual means, number of exceedance days, or other quantities relevant in classical air pollution monitoring? Can satellite observations be used to determine long-term trends and hence to monitor the success of reduction measures?

Current and Future Applications of Satellite-derived Air Quality Products

Shobha Kondragunta
NOAA/NESDIS Center for Satellite Applications and Research

Several air quality products derived from NOAA and NASA satellite sensors are currently being used by air quality community, including the Environmental Protection Agency (EPA) and the NOAA National Weather Service (NWS), to monitor and forecast air quality. These include aerosol optical depth, smoke concentration, fire, and emissions products. Other products under development for operational deployment in 2009 include MetOP-A GOME-2 trace gas products such as NO_2, HCHO, BrO, SO_2, CHO-CHO and absorbing/scattering aerosol optical depth. Most of these trace gases are criteria pollutants that are mandated by the EPA to be in attainment and forecast by the NWS for air quality guidance to the public. Because satellites provide a spatial look that cannot be matched by *in situ* measurements, there is an increase in the use of satellite-derived data by the air quality community. NOAA/NESDIS has been supporting its customers with its operational air quality products but would like to expand the support to include other available satellite data from current and future missions. This presentation will provide information on NOAA air quality mandates, and highlight some of the decision support systems that we are developing and deploying in support to support these mandates.

GOME-2 on Metop – An Overview
Rosemary Munro
EUMETSAT, Darmstadt, Germany

The Second Global Ozone Monitoring Experiment (GOME-2) performs operational global monitoring of ozone column densities and ozone profiles, and column densities of other atmospheric trace gases such as NO_2, BrO, OClO, HCHO, and SO_2. GOME-2 is an improved version of the Global Ozone Monitoring Experiment (GOME-1) launched 1995 onboard the second European Remote Sensing Satellite (ERS-2). It was launched on the first of the METOP series of polar-orbiting operational meteorological satellites on 19th October 2006. The remaining two satellites in the series will be launched in 2010 and 2014.

GOME-2 Level-1b products are produced centrally at EUMETSAT in the Core Ground Segment and are expected to be declared operational in March 2008. GOME-2 Level-2 products are produced by the Ozone Monitoring and Atmospheric Chemistry Satellite Application Facility, part of the EUMETSAT Distributed Ground Segment, and hosted by the Finnish Meteorological Institute. Near-Real Time products are disseminated via the EUMETCast, EUMETSAT's Broadcast System for Environmental Data, and are available within three hours of sensing.

An overview of the GOME-2 instrument, its products and their validation status and product availability and access will be presented.

Use of space-based tropospheric NO_2 observations in regional air quality modeling
Robert W. Pinder, Sergey L. Napelenok, Alice B. Gilliland

Environmental policy makers employ regional air quality models to estimate the impacts of regulated reductions in emitted pollutants. Evaluating and improving these models is challenging, because air quality measurements are spatially disparate and temporally infrequent. Space-based observations can provide nearly global coverage; however, it can be difficult to interpret these data for the troposphere and surface layer. The relationship between local NO_x emissions and the observed NO_2 column density varies based on chemical and meteorological conditions. Using a photochemical model, direct sensitivity calculation, and inverse modeling technique, we have developed a method for re-estimating the NO_x emissions based on the observed NO_2 column. We have applied this technique using SCIAMACHY data over the southeast United States. This presentation will include an evaluation of this technique using surface and aircraft measurements and its use for tracking year to year trends in emission changes. Finally, we will discuss some key improvements to satellite datasets that could be especially helpful to regional air quality modeling: finer horizontal and vertical resolution, consistency in retrieval algorithms to assess multi-year trends, harmonizing the use of fine-scale air quality models in the retrieval processes, and the value of multiple observations per day.

Atmospheric composition from space: its role in environmental assessment
Robert Koelemeijer

Satellite measurements have a proven track-record in the monitoring of the stratospheric ozone layer. Since the 1990s, the application of satellite data for air quality monitoring has been growing.

While air quality in Europe has improved substantially over the past decades, it still poses threats to public health and ecosystems. Therefore, air quality is still high on the political agenda of the EU. EU-policies have been developed along 3 main lines: (1) sectoral source-oriented policies (emission limits for products or production processes, such as cars, industrial plants, limits to sulphur content of fuels, et cetera), (2) national emission ceilings, (3) setting air quality standards.

The impact of policies on the environment is traditionally assessed using a combination of models and measurements. Satellite measurements can play a role in this, through validation of models and emissions (e.g., hemispheric transport), and deliver independent information on air pollutant concentrations. Among the strong points of satellite measurements are that information can be obtained about countries where ground-based measurements are not made available or about areas where ground based measurements are not performed (e.g., oceans), and that satellite information is not influenced by country borders, where ground-based measurements may be systematically different between countries because of differences in measurement methodology.

While the backbone of air quality monitoring is formed by the legally obliged national air quality networks, satellite measurements can be used to improve the mapping of air pollutants, and to improve short-term forecasts of air pollutant concentrations in addition to these ground-based measurements and modeling. In this presentation we will show results of studies by MNP, TNO and RIVM to improve the mapping of particulate matter concentrations using a combination of modeling and ground-based and satellite measurements by MODIS.

Also various weaknesses of satellite measurements can be identified: the methods used to infer (column-integrated) tropospheric concentrations rely often rather critically on assumptions about the atmospheric state and the surface (vertical distribution of pollutants, clouds); air pollutants in the boundary layer can only be measured during cloud-free conditions, and this introduces a bias to fair whether meteorological conditions when calculating long-term averages of measurements; more and more, exceedances of limit values are confined to streets. Satellite measurements do not capture spatial variations at that scale.

Methane source estimation using space-borne observations

Christian Frankenberg[1], Sander Houweling[1,2], Jan-Fokke Meirink [2,4], Maarten Krol [1,2,3], Ilse Aben[1]
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[3] *WUR, Wageningen University, Wageningen*
[4] *KNMI, Royal Dutch Meteorological Institute, de Bilt, NL*

Methane is the second most important antropogenic greenhouse gas. Methane is measured accurately at the surface at various stations as part of the global surface network and as such its global atmospheric concentration is quite well known. However, the observed concentration variations are not well understood, because the sources of methane are poorly quantified. Traditionally a bottom-up approach is used source specific estimates, but top-down approaches starting from atmospheric concentration measurements can be used as well. So far mostly measurements from the surface network are used in top-down approaches, but there are clear limitations as the surface network is too scarce. This thus provides a clear perspective to use satellite measurements which are really covering the entire (or most of the) globe contrary to the surface network which is clearly not sensitive to all different areas of the Earth. For methane the ultimate goal is to estimate the main sources and quantify them as a function of climatic parameters.

SCIAMACHY is the first and only space-based instrument so far measuring methane in the short wave infrared with sensitivity down to the Earth's surface where most of the methane sources are located (wetlands, fossil fuel, rice fields, cattle,..). It is therefore very well suited to use in top-down approaches to better quantify individual sources. This presentation will highlight the SCIAMACHY methane measurements and findings, our latest activities and results on methane retrievals from SCIAMACHY, some results on quantification of methane sources using SCIAMACHY data and give an outlook for TROPOMI data use.

Tropospheric data (trace gases, aerosols, clouds) analysed in the satellite group Mainz-Heidelberg from GOME, SCIAMACHY and GOME-2. Critical summary and recommendations for TROPOMI

Thomas Wagner

An overview is given on various tropospheric data products derived from the satellite instruments GOME, SCIAMACHY and GOME-2. The products include various trace gases, aerosols, clouds and surface properties (e.g. vegetation). In the first part the main retrieval steps (spectroscopy, strat./trop. seprataion, post-processing, and radiative tranfer modelling) are discussed. In the second part examples for various scientific applications (e.g. for NO_2, HCHO, BrO, H_2O and CO) are presented. Finally recommendations for TROPOMI are provided.

Applications of space-borne Carbon-monoxide measurements in Atmospheric Chemistry and Air Quality.

Maarten Krol[1,2,3], Annemieke Gloudemans[2], Jos de Laat[4], Ilse Aben[2], Guido van der Werf[5], Jan Fokke Meirink[3,4]
[1] *Wageningen University and Research Centre (WUR)*
[2] *Netherlands Institute for Space Research (SRON)*
[3] *Institute for Marine and Atmospheric Research Utrecht (IMAU)*
[4] *Royal Netherlands Meteorological Institute (KNMI)*
[5] *Earth and Life Sciences, Free University, Amsterdam (VU)*

Carbon Monoxide (CO) is an atmospheric pollutant that is emitted during incomplete combustion. As such, it is an excellent tracer for air pollution. High CO concentrations are encountered over densely populated areas due to emissions from traffic and industry. Moreover, the process of biomass burning adds large amounts of CO to the atmosphere. This latter process has a strong seasonal variation, following the tropical wet and dry seasons. The clear advantage of satellite measurements compared to surface observations is the global sampling. For instance, emissions from biomass burning are often not well captured by surface observations.

Satellite measurements of atmospheric CO can be made in the thermal and near infrared spectral range. Whereas thermal infrared measurements (e.g. MOPITT) are mostly sensitive to upper tropospheric CO, the near infrared measurements of SCIAMACHY have additional sensitivity to surface CO. Surface sensitivity is important when satellite measurements are used to derive the emission magnitude.

In this presentation the focus will be on the use of atmospheric transport modeling for the interpretation of space-borne CO measurements. By using techniques like data-assimilation, current and future satellite measurements of CO can help us to learn more about the emissions, transport and transformation of air pollutants.

Quantifying the Science Impact of Instrument and Mission Designs: the Ozone Case

Annmarie Eldering
JPL

In an era of fewer space-based earth science missions, the selection process is expected to become more competitive, involving complex interdisciplinary and multi-instrument mission concepts. The success of proposals will not rely solely on text, historical data and past success, but proposed engineering designs and science return will increasingly need to be justified quantitatively. We are developing the capability to quantitatively model (and "virtually" test whenever possible) end-to-end mission objectives, to flow science requirements into observational requirements in a manner that can be justified by using verified and validated models.

The Scanning Microwave Limb Sounder (SMLS)

Nathaniel Livesey, Michelle Santee, Paul Stek
Jet Propulsion Laboratory
California Institute of Technology

The Scanning Microwave Limb Sounder (SMLS) addresses critical outstanding issues in atmospheric science in the areas of climate and climate stability, long range transport of air pollution and its implications for global air quality, and the links between atmospheric composition and climate. SMLS also provides measurements needed to improve the accuracy of climate and weather forecasting models, and continues crucial long-term global records of atmospheric composition. SMLS is a successor to the Microwave Limb Sounder (MLS) instruments flown on NASA's UARS and Aura spacecraft. SMLS adds an azimuth scanning capability, enabling the 50x50 km horizontal resolution and improved temporal resolution needed to quantify poorly-understood 'fast' processes in the atmosphere (such as convection) that are critical for studies of climate, air quality, and ozone layer stability. SMLS can serve as the “Advanced Microwave Limb Sounder” for the “Global Atmospheric Composition Mission” (GACM), identified as one of the priority NASA missions in the recent National Academy of Sciences earth science decadal survey. We present a review of the scientific questions SMLS is designed to address, along with a description of the SMLS observations and their spatial/temporal resolution. A general review of the SMLS instrument concept is given, and synergies with other planned atmospheric composition instruments and missions are discussed.

Robust Remote Sensing of Smog Ozone and Its Production using TIMS 3-micron Full-Column Sensing

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Remote sensing can be used to improve ozone weather forecasts, by spotlighting difficulties in transport and emissions of lowermost tropospheric smog at the approx. 25-km horizontal scale or finer.

O_3 differences of approx. 5 ppb for the 0-2 km region may detectable in special regions. Several techniques will need to be combined, but the total number and complexity of instruments need not be high: two, a column measurement (3.2 and 3.5 µm) and an accurate measurement above 2-3 km (e.g., UV 0.3-0.5 µm) suffice.

IR thermal retrieval may substitute for UV if the accuracy using 9.6 µm and 4.6 µm in the lower troposphere be improved; in any case they only inform to approx. 2.5 km. UV techniques alone or UV+thermal IR techniques are unlikely to provide sensitivity to the smog problem. Reflective IR plus UV-blue sampling give not only O_3 but also vital precursor information, viz: HCHO, NO_2, and photolysis. Other instruments can improve precision and reduce risk.

Limb sounding is not required for the study of smog. The large stratospheric O_3 column may be cleared by an ongoing empirical stratospherie-dynamics fitting or by assimilation. The two techniques are related. In either case, empirical geophysical correlations should be used to aid O_3 estimation even more actively, but these correlations will also require periodic rechecking.

This abstract alludes to means of clearing stratospheric ozone *not* involving limb sampling, but I doubt there will be time or space for that discussion. The technique can likely be further improved by work we would like to do. The following poster, presented at AGU, probably needs some updating, and maybe to lose the material in the green oval.

Appendix D. List of participants

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Gerrit Burgers	KNMI
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Sander Houweling	SRON/IMAU
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Martijn Schaap	TNO
Renske Timmermans	TNO
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