MONITORING AIR QUALITY: THE ROLE OF OSSES IN DETERMINING THE FUTURE OBSERVING SYSTEM

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Abstract

The need to monitor air quality (AQ) is recognized world-wide. This involves measurements of key pollutants (e.g. ozone and carbon monoxide) in the lowermost troposphere at spatio-temporal scales relevant to policy makers (temporal frequencies less than 1 hour; spatial scales less than ~10 km). We describe the role of Observing System Simulation Experiments (OSSEs) in determining the future observing system to monitor AQ. Caveats associated with setting up and interpreting OSSEs are discussed. OSSEs performed to assess the added value of the proposed geostationary satellite platform MAGEAQ (Monitoring the Atmosphere from Geostationary orbit for European Air Quality) are presented to illustrate the concept.

INTRODUCTION

A fundamental challenge for humankind at the start of the 21st Century is to respond in the most efficient way to global changes, which put increasing pressure on ecosystems, the economy and human society. Atmospheric composition is a key aspect of this challenge, both contributing to processes associated with global change, and reflecting the outcomes of these processes.

Air quality (AQ) is defined by the atmospheric composition of gases and particulates near the Earth’s surface. This composition depends on local contributions (emissions of pollutants), chemistry, and transport processes; it is highly variable in space and time (McNair et al. 1996). Key lower tropospheric pollutants include ozone (O₃), aerosols (e.g. particulate matter; PM), and the O₃ precursors NOₓ (=NO+NO₂) and volatile organic compounds (VOCs) (Brasseur et al. 2003). Tropospheric O₃ controls the oxidation of many tropospheric species through reactions involving the hydroxyl radical (OH) (Brasseur et al. 2003). Owing to its relatively longer lifetime, tropospheric carbon monoxide (CO) observations provide information on sources of pollution and transport processes affecting AQ.

Atmospheric pollution impacts human society, ecosystems and materials; it also can affect climate change and in turn can be affected by climate change (Crutzen 1974; Solomon et al. 2007). High concentrations of O₃, PM, NO₂ and SO₂ near the Earth’s surface cause health problems, in particular pulmonary and cardiovascular diseases (Brunekreef and Holgate 2002), and recognition is growing of the combined health effects of multiple pollutants (Dominici et al. 2010). Photochemical pollution, in particular from O₃, can also affect severely vegetation, forests and crops (Cooper et al. 2010). Tropospheric CO is not regarded as a health concern outdoors, but recent work shows a possible link between exposure to urban CO concentrations and cardiac problems in rats (Lucas et al. 2010; Meyer et al. 2011). Health costs attributable to AQ are significant; weather can affect AQ (Lahoz et al. 2011).

AQ will be a key issue for the 21st Century. Simulations show increases in 21st Century tropospheric O₃ associated with climate change and increased stratospheric O₃ flux into the troposphere (Hegglin and Shepherd 2009; Zeng et al. 2010). An evaluation of the high-emissions IPCC SRES A2 scenario showed global mean surface O₃ increases of ~5 ppbv (parts per billion by volume) by 2030 and 20
ppbv by 2100 (Prather et al. 2003). These increases would be expected to affect human health, ecosystems and climate. Only introduction of stringent abatement technologies involving international cooperation will keep surface O₃ and its impact to acceptable levels (Rypdal et al. 2009).

Throughout the world decision makers are taking action on emissions abatement to monitor, forecast and manage AQ. These activities are based on the monitoring of surface concentrations of key pollutants and on scientific understanding of their impact on human health and the environment. This requires understanding the impact of AQ on human society; health (WHO 2000); ecosystems (WHO 2005); agricultural production and management (Aneja et al. 2008); design and construction of megacities (Molina and Molina 2004); and climate change (Solomon et al. 2007).

In the next sections we discuss the Global Observing System (GOS) for AQ; the concept of Observing System Simulation Experiments (OSSEs); OSSEs for the proposed MAGEAQ (Monitoring the Atmosphere from Geostationary orbit for European Air Quality) AQ satellite mission; and provide conclusions regarding the role of OSSEs in designing the GOS for monitoring AQ.

THE GLOBAL OBSERVING SYSTEM FOR MONITORING AIR QUALITY:

To monitor, forecast and manage AQ, observations are needed at a high spatio-temporal resolution appropriate for capturing variability in the lowermost troposphere (0-3 km height) of pollutants or their proxies, including emission sources and sinks, transformation, and transport from urban to intercontinental scales. Difficulty in discriminating between regional and local pollutants fundamentally limits our current understanding of AQ, and our ability to quantify AQ and establish what level of AQ is beneficial for human society. Appropriate resolutions are (Lahoz et al. 2011): (i) temporal frequencies less than 1 hour (Fig. 1); (ii) spatial scales less than ~10 km (Fig. 2). Although local contributions to AQ are well-sampled by surface networks, there is a lack of height-resolved regional/continental scale space-borne observations of pollutants in the lowermost troposphere, in particular in the planetary boundary layer (PBL) (IGACO 2004).

Figure 1. Spatial variability of O₃ (red), CO (black), NOₓ (blue) and SO₂ (green) measured over the period 5-6 June 2009 at Reims, France (x-axis, hour; y-axis, concentration, µg m⁻³). This shows high frequency variability of these species at the ground, where human activity makes AQ an issue. Observations of trace gases and aerosols must be able to capture this temporal variability. Data obtained from the French reference Air Quality Database (BDQA) and measurements made and validated by the local network of Reims Atmo-Champagne-Ardenne. © Copyright 2011, American Meteorological Society (AMS) Lahoz et al. (2011).

Thousands of stations in Europe and North America continuously survey the ambient levels of atmospheric pollutants to which one might be exposed, chiefly O₃, NO₂, SO₂ and PM. In addition, other important programmes like the WMO Global Atmospheric Watch (GAW, http://www.wmo.int) or MOZAIC (http://mozaic.aero.obs-mip.fr) have compiled years of in situ ground-based and airborne observations to better understand the spatio-temporal variability of tropospheric pollutants. These data (ground stations, WMO GAW, MOZAIC) provide the backbone of the in situ element of the GOS devoted to monitoring AQ. Ground-based in situ observations have the advantage of high spatio-temporal resolution. However, they have various disadvantages that limit their effectiveness: inhomogeneous spatial coverage; and high variability in spatial representativeness, measurement methods and correction factors. A key function of the GOS, which incorporates in situ data as well as
satellite data (see below), is to provide input data for operational numerical weather prediction (NWP) (Thépaut and Andersson 2010).

Large-scale coverage requirements (from the urban scale to the intercontinental scale) to monitor AQ indicate the need to use satellite platforms. These mostly operate either in geostationary orbit or low Earth orbit. Geostationary satellites (GEOs), located at 36,000 km on the equatorial plane, orbit the Earth with the same angular velocity as the Earth’s rotation and, therefore, provide continuous viewing of a selected portion of the Earth. Low Earth Orbit satellites (LEOs) in sun-synchronous orbits, the most common for atmospheric measurements, orbit the Earth at 700-800 km with orbital periods of ~100 minutes. In both cases (GEOs/LEOs), a constellation of satellites is required to provide adequate global coverage in both space and time. This is achieved by current NWP satellite constellations (Thépaut and Andersson 2010).

Figure 2. Map of O₃ partial column (calculated over the height range 0-3 km; height above the model surface) over Europe (x-axis, longitude; y-axis, latitude) for 12 UTC (daytime) on 1 July 2009; units, 10¹⁷ molecules cm⁻². Red-purple-pink colours denote relatively high values of O₃ partial column, indicative of high levels of pollution and a need to monitor AQ; blue colours denote relatively low values of O₃ partial column. Map is derived from a state-of-the-art chemistry transport model (MOCAGE; Bousserez et al. 2007). It shows high spatial variability over local scales in the lowermost troposphere, including the area near the ground (where human activity is of dominant influence). © Copyright 2011, American Meteorological Society (AMS) Lahoz et al. (2011).

To extract tropospheric information (including the PBL) from GEO and LEO platforms, it is necessary to separate stratospheric and tropospheric contributions to the signal received by the satellite. Commonly, this is achieved by taking advantage of the different penetration depths into the atmosphere of different spectral regions (ultraviolet (UV); visible (VIS); infrared: thermal infrared (TIR), near infrared (NIR)).

This approach has been used to measure tropospheric trace gases and aerosols from LEO platforms in the UV, VIS and IR. For the UV/VIS these include: (i) tropospheric O₃ column from GOME with mean biases of up to 3 Dobson Units (DU) and standard deviations within 3-8 DU against ozonesondes (Liu et al. 2005); (ii) O₃ profiles from OMI with tropospheric information of up to 1.5 degrees of freedom for signal (DFS; Rodgers 2000), peaking between 500–700 hPa and sensitivity down to ~800-900 hPa, and random errors of ~10% (Liu et al. 2010); (iii) tropospheric columns of NO₂, SO₂, HCHO (formaldehyde), and C₂H₂O₂ (glyoxal) from GOME and/or SCIAMACHY (Chance 2005); and (iv) aerosol products from biomass burning: aerosol optical depth from MODIS and aerosol absorption optical depth and UV aerosol index from OMI (Torres et al. 2010). For the infrared these include: (i) lower troposphere (surface to 700 hPa) CO profile retrievals from MOPITT (Deeter et al. 2007); (ii) near surface (surface to 800 hPa) increased CO information (quantified by the DFS) from TIR+NIR MOPITT retrievals in comparison to TIR only MOPITT retrievals (Worden et al. 2010); (iii) partial O₃ column (0-6 km) and tropospheric O₃ column (0-11 km) from IASI with bias of 5% or less against ozonesondes (Eremenko et al. 2008; Keim et al. 2009); and (iv) a capability for height-resolved tropospheric O₃ information (DFS of 2.4) from TES, and demonstration of sensitivity to CO concentrations between 5 km and 15 km from TES (Worden et al. 2004). As part of this effort, ESA missions have been instrumental in building a picture of pollution over various regions of the globe (Fig. 3).
A GEO platform has much better sampling of diurnal variability than a LEO platform (Fig. 4), and improved likelihood of cloud-free observations (this, however, depends on pixel size) with continuous observations of a particular location during at least part of the day. This “stare” capability from a GEO provides significantly greater measurement integration times compared to a LEO. This feature of the GEO platform makes it very effective for retrieval of lowermost troposphere information for capturing the diurnal cycle in pollutants and emissions, and the import/export of pollutants, or proxies for pollutants. Realistically (given technical, scientific and cost considerations), a GEO is the only satellite platform that can provide this information at the spatio-temporal scales associated with variability of tropospheric pollutants. A single GEO provides AQ information with complete temporal coverage over a key continental area of the globe (e.g. Europe, East Asia, or North America), whereas many LEOs would be required to provide the same information (Fig. 4).

**Figure 3.** NO2 tropospheric densities (representative of the vertical column), averaged for 2009, from the SCIAMACHY instrument onboard the ESA Envisat satellite. (Left): USA; (middle): Europe; (right): China. Units, 10^{15} molecules cm^{-2}. Figure courtesy A. Richter (IUP-IFE, University of Bremen). © Copyright 2011, American Meteorological Society (AMS) Lahoz et al. (2011).

**Figure 4.** The number of LEOs required for one hour revisit time over Europe. (Left): 1° x 1° resolution (~100 km); (right): 0.4° x 0.4° resolution (~40 km). Grey colours indicate no measurements are possible. In both cases, the least number of LEOs required is three (dark blue regions), but this is only for very small regions over Europe. For one hour revisit time and ~10 km (or less) resolution, the least number of LEOs required to cover Europe up to 60°N is more than ten; by contrast, only one GEO is required. © Copyright 2011, American Meteorological Society (AMS) Lahoz et al. (2011).

Despite the advantages for monitoring AQ of a GEO compared to a LEO, a GEO will significantly lose signal and spatial resolution owing to its larger distance from Earth (compared to a LEO). Thus, a GEO platform will be challenged by data accuracy and spatial resolution. This requires the use of larger telescopes by a GEO. However, the continued observation of a given area by a single pixel by a GEO allows integration of signals to recover a satisfactory signal-to-noise ratio while still achieving high temporal resolution and providing improved likelihood of cloud-free observations.

Studies show the potential of multi-spectral observations to extract PBL information, with O3 and CO being the best candidate species at present. Retrieval studies for combining OMI and TES O3 measurements (Landgraf and Hasekamp 2007; Worden et al. 2007) indicate that such combinations are highly promising. This approach requires measurements from at least two O3 bands from among the ultraviolet Hartley-Huggins, the visible Chappuis, and the thermal infrared v3 band (9.6 μm).

The combination of TIR+VIS (other spectral combinations are being considered – see Natraj et al. 2011) measurements for O3 (in a LEO or GEO platform) is desirable because, for clear skies, the visible Chappuis bands view directly to the ground, overcoming the difficulties from UV O3 measurements (limited in near surface sensitivity by Rayleigh scattering) and infrared O3 measurements (limited by low thermal contrast between the Earth’s surface and the lower
air) (Note that the VIS and UV do not provide information at night.). However, the absorption in the Chappuis band is weak and potential aerosol contamination of species retrievals and variations in the surface reflectance as a function of wavelength may present challenges.

Measurement of PBL \( \text{O}_3 \) concentrations to desired precision levels is the major current technical difficulty for GEO platforms. The major missing components of tropospheric \( \text{O}_3 \) measurements are (Lahoz et al. 2011): (i) the ability to make precise \( \text{O}_3 \) measurements from the nadir geometry using the visible Chappuis band; and (ii) the capability to perform multi-spectral retrievals, which improves sensitivity to different atmospheric altitudes (Fig. 5).

Satellite observations and *in situ* observations for AQ monitoring are complementary: the former sample in the vertical, typically as a column; the latter sample the surface. Furthermore, satellite observations rely on ground-based observations for calibration and validation (USGEO 2010). In NWP, data assimilation is used to combine the high accuracy of *in situ* observations with the high spatial coverage of satellite platforms (Andersson and Thépaut 2010).

A recent WMO gap analysis of space missions with respect to Global Climate Observing System (GCOS) requirements (WMO 2011) discusses future plans for various tropospheric species relevant for AQ. The main conclusion is that for \( \text{O}_3 \), \( \text{CO} \), \( \text{NO}_2 \), \( \text{SO}_2 \) and \( \text{HCHO} \) long-term continuation of the observational record seems secured, in particular from LEO Sentinel-5 and post-EPS (EUMETSAT Polar System) platforms. Plans for future operational satellites, although not optimal, are increasingly taking account of the need to measure aerosol properties (aerosol optical depth, aerosol concentration, aerosol effective radius and aerosol type). As of 2011, no observations of trace gases have been made from a GEO platform. By contrast, multi-channel imagers providing information on aerosols and fire-related parameters at high spatio-temporal resolution have been flying on GEO NWP satellites for the past three decades (e.g. NOAA GOES series; EUMETSAT Meteosat series). Both qualitative (smoke plume analysis; dust mask) and quantitative (aerosol optical depth; main fire hot spots; size of unexpected fires and burned area) AQ products are currently available from GEOs.

The 21st Century is expected to see societal challenges that affect AQ: population growth, climate change, increased resource demand and continual development of coastal and urban areas. To monitor, forecast and manage AQ in the 21st Century requires information about the Earth system and how it changes over time. This requires implementation and maintenance of a robust GOS (USGEO 2010). Additional satellite observations (GEO/LEO) are needed to complement, extend and fill gaps in the current GOS for AQ; in particular, high spatio-temporal height-resolved, continental-scale data on pollutants in the PBL and lowermost free troposphere (IGACO 2004). An improved GOS extends the benefit provided by the constraint on AQ forecast models from use of observational data with data assimilation/inverse modelling methods (Elbern et al. 2010). This constraint brings model improvement and increased understanding of processes affecting AQ. Users of these additional satellite data and their derived products include decision makers; governments, local authorities; pollution authorities; health authorities; industry; agriculture; and the meteorological agencies. The main benefit is improved monitoring, forecasting and management of AQ. The main beneficiary is human society.
OSSEs (Masutani et al. 2010) use data assimilation to investigate the potential impacts of prospective observing systems (satellite platforms, ground-based networks), including additions to the GOS. They may also be used to investigate current observational and data assimilation systems by testing the impact of new observations. The information obtained from OSSEs is generally difficult, or in some contexts impossible, to obtain in any other way.

OSSEs are closely related to Observing System Experiments (OSEs; Masutani et al. 2010). OSEs reveal what happens when a data assimilation system is degraded by removing particular subsets of observations and thus measure the impacts of those observations. The structure of an OSSE is formally similar to that of an OSE with one important difference: OSSEs are assessment tools for new data, i.e., data obtained by hypothetical observing systems that do not yet exist. OSSEs are widely used in the meteorological community for assessing the usefulness of new meteorological satellite data. The methodology of an OSSE consists of (see Masutani et al. 2010 for additional details, including information on various OSSE variants):

- Generation of reference system states for the OSSE period under consideration. This is usually done with a realistic atmospheric model in a free-running mode without data assimilation. This is often called the Nature Run, providing the proxy “truth,” from which observations are simulated and against which subsequent OSSE assimilation experiments are verified. One of the challenges for an OSSE is to demonstrate that the Nature Run has the same statistical behaviour as the real atmosphere (or other system under consideration) in every aspect relevant to the observing system under scrutiny;
- The generation of simulated observations, including realistic errors, for all existing observing systems and for the hypothetical future observing system;
- A control run in which all the data representing the current operational observational data stream are included;
- A perturbation run in which the simulated candidate observations under evaluation are added;
- A comparison of analysis and forecast skill between the control and perturbation runs, with evaluation done against the Nature Run.

For consideration of AQ monitoring instruments, the OSSE methodology is modified to account for the fact the GOS is much less developed for AQ instruments than for meteorological instruments. In particular, for AQ applications the observing system simulated from the Nature Run often just includes one observation type, the additional observation under consideration. Because of this, in an OSSE for AQ monitoring instruments, the perturbation run includes the additional observation type and the control run includes no observations, becoming a free model run, i.e., a forecast for the length of the OSSE period. To our knowledge, only a few OSSEs have been performed for AQ purposes, and they all concern a GEO platform (Edwards et al. 2009; Timmermans et al. 2009; Claeyman et al. 2011b).

In OSSEs, it is important to avoid the identical or fraternal twin problem, where the same model is used to produce the Nature Run and perform the assimilation experiments. If the model from which hypothetical observations are extracted is the same as the assimilating model, the OSSE results will show unrealistic observation impact and overly optimistic forecast skill (Masutani et al. 2010). Ideally, the model used for the Nature Run should not be used later for assimilation experiments in the OSSE. However, if different models are used, a significant bias between the models could affect the OSSE results. Care must be taken to eliminate (or at least ameliorate) model dependence of the OSSE results. OSSEs are often expensive to set up - the expense can be comparable to that of setting up an operational NWP system. This expense can be reduced by simplifications to the OSSE. However, the expense of setting up a realistic OSSE is generally worthwhile.

OSSES FOR THE PROPOSED MAGEAQ AIR QUALITY SATELLITE MISSION:

To address shortcomings in the GOS, a number of initiatives in Europe are planning GEOs capable of monitoring chemical species. The GMES Sentinel-4 Ultraviolet-Visible-Near infrared (UVN) platform (ESA 2007) will measure tropospheric O$_3$, NO$_2$, HCHO, SO$_2$ and aerosol properties (column averaged optical thickness, aerosol type). The Meteosat Third Generation-InfraRed Sounder (MTG-IRS)
platform (Munro 2010) will measure tropospheric $O_3$ and CO (although as a NWP sounder, it is not optimized for these species). Sentinel-4 UVN and MTG-IRS instruments are due for launch from 2017-2018 onwards. The POGEQA and MAGEAQ initiatives (Peuch et al. 2009, 2010; Table 1) focus on tropospheric $O_3$ and CO.

A number of projects outside Europe are developing GEOs for monitoring chemical species. These include the NASA GEO-CAPE mission, with launch proposed for 2020 (GEO-CAPE 2008); the Korea mission MP-GEOSAT, with launch planned in 2017-2018 (Lee et al. 2010); and the Japan JAXA AQ-Climate mission, with launch proposed for 2020 (Akimoto et al. 2008). These developments focus on tropospheric aerosols and trace gases such as $O_3$. Synergies between European, US and Asian GEO satellite platforms would be of great benefit for quasi-global monitoring of AQ. Synergy between GEO and LEO satellite platforms and surface observations would provide further benefits.

<table>
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<tr>
<th>Observation requirements and geometry</th>
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<tr>
<td><strong>Domain covered</strong></td>
<td>15° E – 35° E; 35° N – 65° N</td>
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<tr>
<td><strong>Spatial resolution</strong></td>
<td>10 km x 10 km at 45° (target); 15 km x 15 km (threshold)</td>
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<tr>
<td><strong>Temporal resolution</strong></td>
<td>1 hr (target); 2 hr (threshold)</td>
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<tr>
<td><strong>Duty cycle</strong></td>
<td>Higher than 90% of observational time</td>
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**Ozone sensor**

- **Objectives**: 2 (target) to 3 (threshold) pieces of information in the troposphere. Accuracy: 10% (target) for 0-6 km column; 20% (threshold) for height-resolved information in the lower troposphere
- **Channel 1 (TIR)**: Centred 1060 cm$^{-1}$, 40 cm$^{-1}$ wide
- **Channels 2-9 (VIS)**: 8 broadband channels from 450 nm to 690 nm

**CO sensor**

- **Objectives**: 2 pieces of information separating lower and upper free troposphere. Accuracy: 5% (target) for 0-6 km column; 15% (threshold)
- **Channel 10 (MIR)**: Centred 2130 cm$^{-1}$, 40 cm$^{-1}$ wide

**Table 1: Summary of MAGEAQ mission requirements.**

The relative merit of surface networks and satellite platforms (impact on the GOS, observing system versus cost), as well as the combination of ground network and satellite observations for AQ monitoring, is being studied in the POGEQA project using OSSEs (Claeyman et al. 2011a, b). The added value of the MAQEAQ-TIR configuration (Table 1) has been compared against that from a configuration similar to that of MTG-IRS. Figures 6-7 show sample results from these OSSEs.

**Figure 6.** Longitude-latitude difference plots for $O_3$, 0-3 km column (% of the Truth) over a period of 2 months (July-August 2008). Left: absolute value of (Truth - Free run) minus absolute value of (Truth – MAQEAQ-TIR); right: absolute value of (Truth – MTG-IRS) minus absolute value of (Truth – MAQEAQ-TIR). Red/blue colours indicate the MAQEAQ-TIR configuration is closer to/further from the Truth than either the Free run (left plot) or the MTG-IRS configuration (right plot). The assimilation runs were set up with changes in the emissions. Figure based on Claeyman et al. (2011b).

The main conclusions from the OSSEs regarding MAGEAQ are:

- MAGEAQ-TIR is generally closer to the "Truth" than MTG-IRS for both $O_3$ and CO. This improvement is over large areas of Europe but is height dependent. Improvement over the height range 0-1 km would be expected from a TIR+VIS configuration (see Fig. 5);
- MAGEAQ-TIR can have a significant impact on the GOS and improve on the $O_3$ and CO information provided by MTG-IRS (see Claeyman et al. 2011b).

Building from these initial results, POGEQA is designing OSSEs to test various observing configurations (Lahoz et al. 2011); various GEO platforms (MAGEAQ-TIR+VIS, MTG-IRS); a constellation of GEOS; GEOS versus LEOs; ground-based in situ data versus satellite data (GEOS/LEOs). As a first step, a Nature Run is being designed (R. Pommrich, Pers. Comm., 2011).
Thus, OSSEs are an integral part of the POGEQA and MAGEAQ efforts. This approach is in line with that at ESA (ADM-Aeolus and CarbonSat missions) and NASA (GEO-CAPE mission), and with developments at the National Centers for Environmental Prediction (NCEP) (Masutani et al. 2010).

Figure 7. Correlation (left), absolute relative difference in % (middle) and root-mean-square (RMS) difference in % (right) between the Nature Run and the control run (black); between the Nature Run and the assimilation run of $O_3$ data from MTG-IRS (red) and between the Nature Run and the assimilation run of $O_3$ data from MAGEAQ-TIR (green). The height range considered is 0-5 km. Percentages are with respect to the Nature Run. The assimilation runs were set up with changes in the meteorology, the emissions and the initial conditions. Note improvement provided by MAGEAQ-TIR, but that this is less significant over the height range 0-1 km. Figure based on Claeyman et al. (2011b).

CONCLUSIONS:

The final word on OSSEs is provided by a quote from Masutani et al. (2010):

“NCEP’s experience with OSSEs demonstrates that they often produce unexpected results. Theoretical predictions of the data impact and theoretical backup of the OSSE results are very important as they provide guidance on what to expect. On the other hand, unexpected OSSE results will stimulate further theoretical investigations. When all efforts come together, OSSEs will help with timely and reliable recommendations for future observing systems.”

This applies to the design of the Global Observing System to monitor Air Quality.

REFERENCES


List of acronyms

ESA: European Space Agency
ELMETSAT: European organisation for the exploitation of METeorological SATellites
GEO-CAPE: GEOstationary Coastal and Air Pollution Events mission
GMES: Global Monitoring for Environment and Security
GOES: Geostationary Operational Environmental Satellite
GOME: Global Ozone Monitoring Experiment
IASI: Infrared Atmospheric Sounding Interferometer
IGACO: Integrated Global Atmospheric Chemistry Observations
IPCC: Intergovernmental Panel on Climate Change
JAXA: Japan Aerospace space eXploration Agency
MAGEAQ: Monitoring the Atmosphere from Geostationary orbit for European Air Quality
MOCA: MOdélisation de Chimie Atmosphérique à Grande Echelle (Model of Atmospheric Chemistry at Large Scales)
MODIS: MODerate resolution Imaging Spectroradiometer
MOPITT: Measurements Of Pollution In The Troposphere
MOZAIc: Measurement of OZone and water vapor by Airbus In-service airCraft
MP-GEOSAT: Multi Purpose GEostationary SATellite
NASA: National Aeronautics and Space Administration
NOAA: National Oceanic and Atmospheric Administration
OMI: Ozone Monitoring Instrument
POGEQA: Plateforme d’Observation GÉostationnaire pour la mesure de la Qualité de l’Air (Observation of Air Quality from a Geostationary Platform)
SAGE: Stratospheric Aerosol and Gas Experiment
SCIAMACHY: Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY
TES: Tropospheric Emission Spectrometer
WHO: World Health Organization
WMO: World Meteorological Organization