Final Report Summary - MARCOPOLO (Monitoring and Assessment of Regional air quality in China using space Observations, Project Of Long-term sino-european co-Operation)

Executive Summary:
Due to the strong economic growth in China in the past decade, air pollution has become a serious issue in many parts of the country. Actual information on the air quality and a forecast for a few days ahead is needed to inform the general public, but also to support for policy makers in their decisions on air quality regulations. Eleven institutes from Europe and four from China combined their efforts in the MarcoPolo project, part of the EU FP7 programme, to provide this information. The objective of MarcoPolo was to provide these air quality information for China using satellite observations and chemical transport models.

Satellite products are derived from a wide range of different satellites (e.g. GOME-2, OMI, MISR, MODIS, CALIPSO) for the tropospheric concentrations of the air pollutants ozone, nitrogen dioxide, sulfur dioxide, formaldehyde, carbon monoxide and for aerosol type and concentrations. China is challenging for satellite derived products because of the various sources and the unusual high concentrations of pollutants. To improve the satellite retrievals for this region special attention was paid to the interference of high aerosol concentration on the trace gas retrievals. To better understand the atmospheric processes, studies on trends and temporal variations have been performed for the pollutants, which have been compared to the national and local air quality regulations in China.

For high quality chemical transport modelling it is essential to have up-to-date information on emissions, especially when the economic situation is changing so fast. Regular bottom-up emission inventories at the start of the project were several years old. Therefore, a strong focus in the MarcoPolo project was placed on the creation of a new up-to-date emission inventory based on satellite observations and new statistical information on the source sector distributions.

From satellite data, emission estimates for aerosol and gaseous species (i.e. nitrous oxides, sulfur dioxide, isoprene and volatile organic compounds) are made for anthropogenic and biogenic sources, using several state-of-the art techniques, such as point source estimation using mass balance, applied trend studies and full inversions using advanced types of data assimilation. By combining these emission data with information on the source sector distribution from the MEIC inventory, a new emission database has been constructed for the year 2014. This new MarcoPolo emission inventory is expected to improve the existing air quality modelling and forecasts considerably. Besides creating a new emission inventory for China a method was developed for source apportionment of the concentrations. In this way the location of various pollutants can be traced back to the location of origin. Also the national bottom-up inventory of China (MEIC) was extended with the year 2012.

Using new inventories the air quality has been modelled on both regional and urban scales. The highest spatial resolution (2.5 km) was applied to the regions of Shanghai, Beijing and the Pearl river delta. The entire region of East China is modelled on a resolution of 0.25 degree. For this region air quality forecasts are calculated for 2 to 3 days ahead. To improve the quality of the forecasts, it was decided to extend this service towards an ensemble forecast system which includes 3 models from MarcoPolo and 4 from the PANDA project (another FP7 project focussing on China). The ensemble model forecasts are operational and accessible via an interactive web page on the web-portal www.marcopolo.eu. For reference, the city time series automatically include the observations of the official Chinese ground observation network.

An uncertainty estimation of these data is very important for the users. Therefore, the quality of all steps involved in the
MarcoPolo system is ensured by detailed validation activities at different locations. Satellite observation, emission estimates and model results are compared to ground observations of the same species in urban, rural and forest environments. To promote our activities and results, many visits have been made to Chinese organisations and companies involved in informing the public or involved in providing information to policy makers. There was especially an interest in the emission inventory and the ensemble forecast. Plans for further exploitation of the MarcoPolo service have been studied and described in reports.

Project Context and Objectives:
1.2 Summary description of the project context and objectives
Improving quality of life and health
Air quality is a serious environmental problem in China. Its fast economic development gives rise to several environmental concerns including severe degradation of the air quality, which has been recognized to have numerous adverse effects on human health and ecosystems. As a corollary to the spectacular progress of the Chinese economy and the quick changes in social welfare, the emissions of air pollutants estimated using the traditional statistical approach become quickly outdated and do not reflect the real air pollution status in many regions. Constraints from space combined with ground-based measurements, air quality modelling, and validation activities have demonstrated in the past to considerably improve our quantitative understanding of the air quality situation in China.
In MarcoPolo we have addressed air quality issues in China around the following activities:
1. Improvement of monitoring methods for space and ground-based observations and cross-validation
2. Derivation of top-down emissions using inverse modelling of relevant trace gases and aerosols, for local, regional and global applications in science and policy-making.
3. Development of a new up-to-date inventory for Chinese anthropogenic and biogenic emissions
4. Regional air quality modelling on various spatial scales
5. Building an operational ensemble forecast system including observations of the ground network.

Capacity building and long-term Sino European co-operation
The connection of ground-based and satellite measurements with state-of-the-art models should be a prototype for regional observation systems on a world-wide scale in order to control international treaties. The political implications for the negotiation of further protocols are likely to be very important.
We anticipated that most aspects of the project required significant innovation and the new approaches and new solutions that has been developed has enhanced not only the capabilities of the participating institutes but also the competitiveness of European and Chinese research as a whole.
For the involved groups, improvement of their expert scientific/technical capabilities was established from the project in terms of model development and improvement of modelling capabilities, observational networking, data analysis tools development, satellite data algorithm improvement and exploitation and increase of the scientific impact of available expertise. Thus the involved teams all gained in terms of interdisciplinary understanding and broadening of their scientific horizon.
Building on the existing co-operation from previous initiatives and strengthened and expanded within the MarcoPolo project, we expect an enduring co-operation between the involved groups from China and Europe.

Project objectives and results
In the MarcoPolo project, data are produced describing the atmospheric composition over China based on satellite observations. These data include concentrations of trace gases such as ozone (O3), nitrogen dioxide (NO2), sulphur dioxide (SO2), formaldehyde (HCHO), glyoxal (CHOCHO), and aerosols. These species are retrieved from different instruments flying on different satellites which together span the time frame from 1995 until present. For each species different techniques may be used. Trace gases are determined using passive spectrometers, i.e. instruments which measure the spectrum of the radiation reflected by the planet Earth (surface + atmosphere) at the top of the atmosphere (TOA) over a range of ultraviolet (UV) and visible (VIS) wavelengths. For aerosol retrieval the spectral resolution is generally less important and the TOA radiation is measured in discrete wavebands which preferably include wavelengths in which gaseous species do not absorb,
spanning a wavelength range from the UV to the thermal infrared (TIR). TIR bands together with shorter wavelengths are also used for cloud detection. High spectral resolution is used to determine aerosol layer height or to detect certain aerosol types (e.g. in the TIR measured by the IASI instrument).

The different techniques used for the retrieval of trace gases and aerosols imply that the spatial resolution, i.e. the sub-instrument pixel size, is very different: large for spectrometers, smaller for radiometers. As the satellites look from, above, the concentrations are retrieved as column properties. In some cases also information on concentrations in the troposphere/stratosphere or on the vertical distributions along the whole column can be obtained. For instance, for aerosols both column information (AOD) and vertical profiles, with indication of the aerosol species, are provided.

During the first year of the Marco Polo project, the focus was on providing the data. In the second year a first analysis was made of the spatial distribution of aerosols and trace gases across China, including yearly and seasonal variations, as well as the temporal variation of the various atmospheric components over the whole period available from the included satellite observations. This analysis showed the temporal variation of trace gas and aerosol properties on different time scales: from year to year, seasonal effects and other time periods such as a weekly cycle for aerosol. The results were summarized in the mid-term report. New work on tropospheric ozone monitoring and work on improvement of the aerosol retrieval from both passive and active sensors has been continued.

Since the 90s, a growing number of Earth-observing satellites has been able to detect air pollution at increasingly high spatial and temporal resolution. We combined a wide range of satellite measurements with state-of-the-art inversion techniques to infer emission estimates of key pollutants from space over Eastern China. The high spatial resolution and global coverage of the satellite retrievals are ideal properties for improving the emission estimates. For this purpose, the retrieved tropospheric column concentrations of a trace gas are confronted with the simulated concentrations from chemistry-transport models, which are using emission information from bottom-up inventories. The difference between observed and modelled concentrations contains information on how to adjust the underlying trace gas emissions. The inverse problem is computationally challenging, due to the large number of emission parameters to be optimised, especially when the non-local relation between emission and concentration has to be accounted for. In MarcoPolo, we used satellite observations of nitrogen dioxide (NO2), sulphur dioxide (SO2), formaldehyde (HCHO), and aerosol/particulate matter (PM) from various satellite sensors to develop updated satellite-based inventories for NOx, SO2, anthropogenic volatile organic compounds (VOCs), biogenic isoprene, and aerosols. The five teams involved in this task employed different advanced inversion approaches (Kalman filter, adjoint method, four-dimensional data assimilation, mass-balance method) implemented in the respective chemistry-transport models.

The space-based emission estimates were made freely available at the MarcoPolo website [http://www.marcopolo-panda.eu/products/toolbox/emission-data]. The space-based inventories are expected to improve the air quality modelling and forecast skills, and to better face the challenge of improving air quality in this rapidly changing region.

Up-to-date and reliable emission inventories are essential for accurate air quality modelling and forecasting on various spatial scales. These inventories are also used by policy makers to evaluate the effectiveness of emission abatement measures, and to decide on future (mitigation) strategies. For this reason, in WP4 of the MarcoPolo project, a bottom-up and a top-down emission inventory with a monthly temporal breakdown have been constructed for East- and Central-China. The impacts of the new inventories on modelled concentrations has been evaluated. Furthermore, we aimed at elucidating the origin of ambient particulate matter over China, both spatially as by source sector, by combining model approaches and earth observation data. The bottom-up MEIC emission inventory for China was extended to include the entire period 2000-2010 and the year 2012 for 11 air pollutants and greenhouse gases using an updated technology-based compiling methodology. Monthly gridded emissions at a 0.25 degree resolution are delivered through an open-accessed, online framework and can be downloaded by users.

Often, traditional bottom-up emission inventories are a few years behind the actual developments, and lack important information such as biogenic emissions related to agricultural burnings. For this reason, the MarcoPolo emission inventory was created based on (a) top-down satellite emission estimates for the year 2014 derived in WP3, and (b) source sector information of the bottom-up inventory constructed by THU. Apart from the standard resolution inventory (0.25 x 0.25 degree resolution), a high resolution inventory (0.01 x 0.01 degree resolution) has been composed for three selected regions: the Beijing-Tianjin area, the Yangtze River delta and the Pearl River delta, by downscaling the standard resolution emissions to a
higher resolution using open source proxy data. The impact of the updated emission inventory on modelled concentrations has been evaluated by comparing results from model runs with either the MEIC or the MarcoPolo inventory as input. Another objective was particulate matter (PM) source attribution, using different source apportionment methods that are either based on modelling or monitoring. The LOTOS-EUROS chemistry transport model was used to study the origin of PM. For this purpose, the model was first adapted and improved to the specific Chinese situation (e.g. development of a wind-blown dust module). Subsequently, some evaluations of models results were performed, followed by source attribution of PM levels over China for 2010. The results have been compared with observations and other results in the literature. On the monitoring side, in-situ PM measurement campaigns were conducted in different regions and for different periods, followed by analysis of the monitored data. Amongst other analysis, daily variations of PM2.5 concentrations and PM2.5 chemical compositions were investigated.

Another goal of MarcoPolo was to provide air quality information for selected industrialized regions and metropolitan areas by running models at different spatial scales. The specific objectives were: (a) to develop an air quality modelling chain (regional-urban-city scale) with setup, testing, and validation using remote sensing and ground-based observations; (b) to downscale the modelling chain as a service for East China (regional), Beijing-Tianjin-Hebei region, Yangtze and Pearl Rivers deltas (urban) and Shanghai, Beijing, Hongkong metropolitan areas (urban/city scales); and (c) to study relationships, interactions and two-way feedbacks between pollution and meteorology/climate for selected Chinese regions.

For validation purposes, many different ground measurements at various sites in China have been done. Trace gases (NO, NO2, O3, SO2, HCHO, CHOCHO), BVOC emissions, particulate matter, AOD, and meteorological parameters (temperature, relative humidity, solar radiation, etc.) were measured at typical sites including big cities, counties, villages and forests, such as Guangzhou, the cities in the region of the Yangzi River Delta, Taihe (Jiangxi province), Xinglong (Hebei province). Good agreements were obtained between the ground measurements and satellite retrievals. Empirical models of BVOC emissions were developed, which are able to simulate isoprene and monoterpene emissions in a subtropical Pinus forest. For this type of forest, BVOC emission factors at standard conditions were determined by this model and the MEGAN model for the period 2013-2016. Empirical models of ozone were also developed for the subtropical Pinus plantation. Ground observations of BVOC emissions, solar radiation, trace gases and particles were provided for some sites. The evaluations of the bottom-up inventory of isoprene emissions and the satellite-based MarcoPolo emission inventory for isoprene derived using inversion of satellite columns of formaldehyde have been done for two representative forests in China. Overall, model simulations were in good agreement with the local measurements.

A comprehensive evaluation of emission estimates for power plants and cities in China have been conducted, based on satellite observations from OMI since 2005. Emission trends and the effectiveness of atmospheric regulations have been assessed.

Overall, project results contain measurement data, emission inventories, and model results, all accompanied by validation results and reports to provide information of the quality of the data. These results have been and will be disseminated during and after the project period. The main dissemination channels for the project results are formed by two websites: a public website (www.marcopolo-panda.eu) for public dissemination of the project results, and an internal password-protected website (www.marcopolo-panda.eu/internal) for project partners to share their results. Both websites combine the results of the MarcoPolo and PANDA project. To attract the target audience, the public pages are bilingual, in English and Chinese. To promote the MarcoPolo project, we designed a leaflet and made a general presentation for scientists and policy makers. Attention to the project and its results was drawn at numerous conferences and meetings.

Project exploitation opportunities have been identified. We found that, when disseminating air quality results as Air Pollution Indices (API), this should be done with great care to avoid confusion with other standards and to ensure compliance with national regulation. The MarcoPolo project benefits from a more political openness towards the air pollution concerns in China, which increases drastically the availability of local ground data (needed for e.g. quality assessment of the data products), and increases the public demand for information on air quality. Several potential commercial companies have been identified and contacted which are interested in one or more data products. According to our market research, the best strategy would be to act as a data provider for local channels (e.g. app or environmental companies). To facilitate further commercial exploitation of the results, a product catalogue has been made with an overview of the data products including their technical description.
Project Results:

1.3 Description of the main S&T results/foregrounds

1.3.1 Monitoring and analysis of air quality (WP2)

An objective of Marco Polo is to provide satellite-derived high-quality data sets providing information on the following atmospheric constituents: ozone (O3), nitrogen dioxide (NO2), sulphur dioxide (SO2), formaldehyde (HCHO), glyoxal (CHOCHO) and aerosols over China and an initial analysis of their spatial and temporal variability.

The satellite-based monitoring of trace gases and aerosols requires different instrument characteristics. In general, the solar radiation reflected by the Earth system (surface and atmosphere) at wavelengths in the UV/VIS/NIR part of the solar spectrum and/or the radiation emitted in the MIR and TIR is measured at the top of the atmosphere by spectrometers and radiometers.

The retrieval of trace gases requires the spectral resolution provided by spectrometers, at the cost of relatively large pixel size (~10 km or more) whereas aerosol optical properties vary little with wavelength and thus the use of a radiometer providing observations in a range of spectral bands suffices. Such observations allow for a spatial resolution of a few hundreds of meters to a few km. The small spatial resolution is particularly important to identify cloud-free areas: cloud reflection is much stronger than aerosol reflection and thus overwhelms the aerosol signal. The larger the retrieval area, the larger the probability of cloud contamination. Cloud masking is also important for trace gases, but also for high aerosol loads a correction is needed.

This correction has been investigated.

Both types of measurements, using spectrometers or radiometers, typically provide trace gas or aerosol properties integrated over the whole atmospheric column and additional analysis or measurements are required to provide vertical information such as ozone concentration in the troposphere or aerosol extinction profiles. The latter are provided by active instruments, i.e. space-borne lidars. Information on aerosol vertical structure may also be obtained from spectrometers by measuring along a molecular absorption band and thus “slicing” the atmosphere into different vertical segments. The use of multiple wavelengths, viewing angles and polarization enhances the information content for aerosol retrieval thus allowing for the retrieval of additional information such as fine/coarse mode fraction, or the contribution of selected aerosol components (e.g. dust or absorbing aerosol) to the total AOD. This information is not used in MarcoPolo, except from lidar (CALIOP) measurements, because of the experimental nature of the spectrometer data. The main purpose of the MarcoPolo data sets is to use them for the inversion of emissions using chemical transport models (CTMs). This requires well-characterized data sets of good quality with an uncertainty estimate.

Table 1.1 shows the satellite-derived observations available from MarcoPolo WP2. It is noted that other instruments and data sets are available as well, such as from IASI for trace gases and dust aerosol, or MISR, POLDER, Chinese satellites, but were not explicitly included in the MarcoPolo project. The ATSR (ATSR-2 and AATSR; 1995-2012) AOD data include per pixel uncertainty estimates. In addition to data sets from individual sensors, also a merged data set has been developed where AOD retrieved from different instruments has been combined to provide better spatial coverage. The spatial variability and its seasonal variation of the AOD has been studied in MarcoPolo.

Table 1.1. Availability of satellite-derived trace gas and aerosol properties in the MarcoPolo project.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Satellite</th>
<th>Years with data available</th>
<th>Parameter</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOME</td>
<td>ERS-2</td>
<td>1996-2003</td>
<td>NO2</td>
<td></td>
</tr>
<tr>
<td>SCHIAMACHY</td>
<td>ENVISAT</td>
<td>2002-2012</td>
<td>NO2; SO2</td>
<td>ENVISAT lost in April 2012</td>
</tr>
<tr>
<td>OMI</td>
<td>AURA</td>
<td>2004-today</td>
<td>NO2; H2CO; CHOCHO; trop-O3</td>
<td>Row anomaly problems since 2007</td>
</tr>
<tr>
<td>GOME-2</td>
<td>METOP-A</td>
<td>2007-today</td>
<td>NO2; SO2; H2CO; CHOCHO; trop-O3</td>
<td>Switched to small swath mode in 2013</td>
</tr>
<tr>
<td>GOME-2</td>
<td>METOP-B</td>
<td>2013-today</td>
<td>NO2; H2CO; CHOCHO; trop-O3</td>
<td></td>
</tr>
<tr>
<td>AATSR</td>
<td>ENVISAT</td>
<td>2002-2012</td>
<td>AOD</td>
<td>ENVISAT lost in April 2012</td>
</tr>
<tr>
<td>MODIS TERRA</td>
<td>1999-today</td>
<td>AOD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MODIS AQUA</td>
<td>2002-today</td>
<td>AOD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CALIOP CALIPSO</td>
<td>2007-today</td>
<td>Dust-AOD; Total-AOD; aerosol layer height</td>
<td></td>
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</tr>
</tbody>
</table>

Table 1.1 shows that for each of the parameters a time series of more than a decade is available and hence have been used to
identify trends. Figure 1.1 shows selected examples of these time series for SO2, NO2 and aerosols, as well as linear trends analyzed for SO2 and HCHO. Figures 1.1a and 1.1b show time series of mean annual SO2 and NO2 (normalized to 2007) columns over ten provinces with the highest concentrations (in light gray) and their envelope (gray area), with the red line the average over these provinces. Clearly the SO2 columns decrease after 2007, in response to remission reductions, except for Ningxia (blue line) where new power plants were responsible for the increases in 2010. The NO2 columns show a plateau between 2011 and 2014 after which the annual concentrations decrease.

Figure 1.1 Annual time series for SO2 (a), NO2 (b) and AOD (e); spatial distributions of SO2 trends over China (c) and formaldehyde trends over S Asia (d). See colour scales and legend for further explanation.

Figure 1.1e shows the AOD time series for SE China (over land only), increasing between 2005 and 2015. The AOD time series over all China (also only over land) is much lower and the difference with SE China becomes larger with time, with some large fluctuations to both lower and higher mean annual AOD which may be related to specific weather conditions and/or emission events. Further analysis is needed to determine whether there is a systematic change in the AOD in response to regulations for emissions of either precursor gases (such as SO2, NO2, VOCs) or direct emissions of aerosols (such as desert dust or biomass burning).

Figures 1.1c and 1.1d show the spatial distributions of the trends in SO2 and formaldehyde. Figure 1c clearly shows the decreasing trend in SO2 columns, with one exception where a positive trend is observed. Formaldehyde emissions increase over the whole area shown and the change in intensity of the red colour shows the variability of these trends for different provinces in China and elsewhere.

Figure 1.2 illustrates the use of CALIOP data to determine the contribution of dust aerosol to the total AOD. The top figure shows the total AOD, and the bottom figure shows the dust AOD, identified by using the polarization signal. The two figures show that over the Taklimakan desert the total and dust AOD are similar, i.e. the total AOD is governed by dust. Further east, however, over the Beijing area, the dust AOD is much smaller and contributed about 50% to the total AOD.

Figure 1.2 CALIOP derived AOD (top) and dust-AOD (bottom), averaged for the spring (MAM) for the years 2007-2015.

In conclusion, satellite data have been provided to the MarcoPolo consortium where they are used to invert emissions of trace gases and aerosols which are input to the MarcoPolo emission inventory. The satellite data have been used to describe the spatial distributions of trace gases and aerosols and their seasonal differences. Long term measurements, spanning a period of 10 or more years, were used to determine temporal variations, responses to emission reductions and to identify trends.

1.3.2 Emission estimates using satellite data (WP3)

China’s population has grown by 43% since the eighties, to reach 1.38 billion people as of May 2016. The gross domestic product increase during the last 35 years has been tremendous, with today’s GDP being almost about 60 times higher than in 1980. This fast economic development gave rise to several environmental concerns including a severe degradation of the air quality. As the number of Chinese megacities is steadily increasing, air pollution issues are brought at the forefront of public awareness. In Shanghai and Beijing, ambient PM2.5 concentrations often exceed by many times the upper threshold recommended by the European and US Air Quality Standards, testifying that development in China has come at a serious cost. In the aftermath of the progress of the Chinese economy and social welfare, the emissions of air pollutants estimated using the traditional bottom-up statistical approach become quickly outdated and do not reflect the real air pollution status in
many regions, whereas large discrepancies between national emission estimates for the entire China and the sum of the regional estimates of its provinces underline the need for alternative ways of emission estimation. Complementary to bottom-up methodologies, inverse modelling of fluxes has the potential to improve those estimates through the use of atmospheric observations of trace gas compounds.

To this aim, we combine a wide range of satellite observations with state-of-the-art inversion techniques to infer emission estimates of key pollutants from space. The high spatial resolution and global coverage of the satellite retrievals are ideal properties for improving the emission estimates. The observed tropospheric column abundances of trace gases are confronted with the simulated concentrations from chemistry-transport models, which are using emission information from bottom-up inventories. The difference between observed and modelled concentrations contains information on how to adjust the underlying trace gas emissions. The inverse problem is computationally challenging, due to the large number of emission parameters to be optimised, especially when the non-local relation between emission and concentration has to be accounted for. Here, we use satellite observations of nitrogen dioxide (NO2), sulphur dioxide (SO2), formaldehyde (HCHO), and aerosol/particulate matter (PM) from various satellite sensors to develop updated satellite-based inventories for NOx, SO2, anthropogenic volatile organic compounds (VOCs), biogenic isoprene, and aerosols. The five teams involved in the MarcoPolo inventory (KNMI, FMI, BIRA-IASB, AUTH, and DUTH) employ different advanced inversion approaches (Kalman filter, adjoint method, four-dimensional data assimilation, mass-balance method) implemented in their respective chemistry-transport models. The space-based emission estimates are derived and made publicly available via the MarcoPolo webportal (http://www.marcopolo-panda.eu/products). These estimates are expected to improve the air quality modelling and forecast skills, and guide decision-making. Here we discuss main findings of the MarcoPolo emission inventory.

Space-based NOx emissions
The DECSO Ensemble Kalman filter emission estimation algorithm (Mijling and van der A, 2012, Ding et al., 2017) is used to generate a monthly emission inventory for East China over the period 2005-2015 using tropospheric NO2 columns retrieved by OMI and GOME-2 satellite sensors. Figure 2.1 illustrates the spatial distribution and trends in NOx emissions as derived from space measurements. Emissions over the entire country are found to be stable between 2011 and 2014, and decline in 2015, as a response to air quality regulations related to traffic and NOx filtering at power plants (Liu et al., 2016, van der A et al. 2017). The DECSO algorithm was successfully used for a case study assessing the effectiveness of the air quality measures during the Nanjing Youth Olympic Games in August 2014, showing that the skill to detect short-term emissions changes within a city (Ding et al., 2015).

Figure 2.1 Left: Annual distribution of space-based NOx emissions from the MarcoPolo inventory. Right: The evolution of annual NOx emissions in China from 2007 to 2015 according to the DECSO v5 algorithm applied to OMI observations. The grey lines represent the NOx emissions for the 10 most polluting provinces. The red line shows their average.

Space-based PM emissions
The SILAM data assimilation system is used to derive top-down multi-annual aerosol emission estimates over Asia. The estimates are constrained by the MODIS 550 nm aerosol optical depth (AOD), and cover primary anthropogenic aerosol emission at monthly temporal resolution, whereas emissions from wildfires are included as described by the IS4FIRES inventory (Vira & Sofiev, 2012).

Figure 2.2 Spatial distribution of fine particulate matter averaged over 2000-2015, derived by the SILAM 4d-Var system. High PM loadings are inferred in the North China Plain and South China, as well as over the Indo-Gangetic Plain, and in Southeast Asia during the fire season (March-May).

Space-based anthropogenic and biogenic VOC emissions
The derivation of space-based isoprene fluxes and anthropogenic VOC fluxes is performed using HCHO column densities observed by OMI and source inversion built on the IMAGESv2 CTM and its full adjoint model (Stavrakou et al. 2015, Bauwens
et al. 2016). The satellite observations of HCHO suggest lower isoprene fluxes than the a priori, especially in Southern China. In Figure 2.3 the OMI-based anthropogenic VOC emissions over China are derived and compared with bottom-up inventories. The top-down emissions are generally higher than in REASv2, which is used as a priori in the inversion, with the strongest updates (up to 80%) derived in the Northeast. The satellite observations of HCHO suggest moderate positive emission updates in Beijing (10-30%), and in the Chengdu-Chongqing region (40%). A substantial reduction of the emissions is found in Shanghai (up to 50%), and along the Yangtze River, whereas moderate flux decreases (ca. 20%) are deduced in the Guangzhou region.

Figure 2.3 Top: Monthly isoprene emissions from 3 bottom-up inventories (black, orange and green), and estimated by OMI-based (red) and GOME-2-based inversion (magenta). Bottom left: total anthropogenic VOC emissions over China from 7 bottom-up inventories and estimated using OMI columns. Bottom right: Relative increment between the optimized anthropogenic VOC fluxes and the bottom-up inventory.

Space-based SO2 fluxes
The mass-balance method, based on the MEIC bottom-up inventory for SO2, the CHIMERE CTM fields and OMI SO2 columns, is used to provide updated monthly SO2 emission estimates for the MarcoPolo emission inventory. The implementation of government desulphurization legislation over China is effective in ~90% of the locations studied (Koukouli et al. 2016). The pre- and post-2010 trends in emissions are equal to +0.51±0.38 Tg and -1.64±0.37 Tg, respectively. While the pre-2010 calculation does not deviate from the respective error levels, the post-2010 trend is found to be statistically significant and quite telling for the decline in SO2 levels over China in recent years.

Figure 2.4 The annual 2010 emissions in Gg/annum as provided by the a priori MEIC v1.2 bottom-up inventory (upper left), the a posteriori emissions based on OMI observations (upper right), their percentage and absolute differences (bottom).

1.3.3 Source apportionment and emission inventories (WP4)
Up-to-date and reliable emission inventories are essential for accurate air quality assessment and forecasting on various spatial scales. These inventories are also used by policy makers to evaluate the effectiveness of emission abatement measures, and to decide on future (mitigation) strategies. For this reason, in WP4 of the MarcoPolo project, a bottom-up and a top-down emission inventory with a monthly temporal breakdown have been constructed for East- and Central-China. Secondly, the work package also focussed on elucidating the origin of particulate matter over China.

Top-down MEIC inventory
Tsinghua University (THU) developed the bottom-up MEIC emission inventory for China for 11 air pollutants and greenhouse gases. The monthly bottom-up emission inventory was developed using a technology-based methodology to calculate emissions for more than 700 anthropogenic emitting sources over China. With the detailed source classification, the inventory can represent emission characteristics from different sectors, fuels, products, combustion/process technologies, and emission control technologies. The major improvements with respect to previous work include a unit-based power plant emission database, a high-resolution vehicle emission modelling approach, and an explicit NMVOC speciation assignment methodology. Initially, an inventory for the first decade of the 21st century (2000 – 2010) was planned, but since both project partners and local policy makers demanded more up-to-date data, also an inventory for 2012 has been developed. Gridded emissions (with 0.25° x 0.25° resolution) are delivered through an open-access, online framework (http://www.meicmodel.org) and can be downloaded by users.

Bottom-up MarcoPolo inventory
Traditional bottom-up emission inventories are often a few years behind the actual developments, and they lack important information such as biogenic emissions related to agricultural burnings. To address these issues, VITO has created the MarcoPolo emission inventory based on (a) top-down satellite emission estimates for the year 2014, and (b) source sector information of existing bottom-up inventories (see Figure 3.1 and the detailed description in Deliverable 4.2). The satellite-
based estimates derived in work package three of the MarcoPolo project provide total anthropogenic and biogenic emissions for PM2.5 NOx, SO2 and VOCs. Emissions for missing pollutant have been based on (local) ratios to PM2.5 contained in bottom-up inventories (for PM10 and BC), or have been copied from these inventories (for CO, NH3). The split of the emissions between the six different sectors is based on the bottom-up MEIC-inventory. For international shipping emissions in ports, the sector contribution relies on existing bottom-up literature data.

Figure 3.1 Schematic overview of the methodology used to compile the MarcoPolo high and low resolution inventory.

A first analysis using chemical transport models (by project partners KNMI, BIRA and TNO) points at realistic outcomes for VOCs, SO2 and NOx, with improvements for modelled total vertical columns and mixed results for ground concentrations. For PM2.5 the MarcoPolo inventory leads to realistic results in summer, but it also leads to an overestimation of modelled PM2.5 concentrations during winter months, especially in the North of China (see Figure 3.2 and detailed results in Deliverable 4.3). These results highlight the difficulties related to the aerosol emission inversion, which is more complicated than the NO2- and SO2-inversion. Further research on these inversion routines and the associated issues will improve the quality of satellite base emission inventories.

Figure 3.2 Time series of observation minus modelled surface PM2.5 in Beijing. In blue and green the model results using the MEIC and MarcoPolo inventory respectively.

Some of the air quality models used in the modelling work package (WP5) require input at a higher resolution than the one of the standard resolution inventory. Therefore, apart from the standard resolution inventory (0.25 x 0.25 degree resolution), a high resolution inventory (0.01 x 0.01 degree resolution) has been composed for three selected regions (the Beijing-Tianjin area, the Yangtze River delta and the Pearl River delta), by downscaling the standard resolution emissions to a higher resolution using open source proxy data (see anew the methodology in Figure 3.1). Both the standard resolution and the high resolution inventory are available on-line on the MarcoPolo website, access is granted after completion of a questionnaire.

Source contribution
TNO and PKU focussed on a second objective, being particulate matter (PM) source attribution, using different source apportionment methods that are either based on modelling or monitoring. TNO applied the LOTOS-EUROS chemistry transport model with its source attribution module to study the origin of PM. Hereto, the model was first adapted and improved to the specific Chinese situation (e.g. development of a wind-blown dust module). Subsequently, some evaluations of model results were performed, followed by source attribution of PM levels over China for 2013. Example results for Beijing are shown in Figure 3.3 and more results are listed in the report of Deliverable 4.3. Peking University, on the other hand, conducted in-situ particulate matter measurement campaigns in different regions and for different periods, followed by analysis of the monitored data. Amongst other analysis, daily variations of PM2.5 concentrations and PM2.5 chemical compositions were investigated.

Figure 3.3 Dominant source categories and regions for PM2.5 for different seasons in Beijing.

1.3.4 Air quality assessment and forecasting (WP5)
The main goal of MarcoPolo WP5 is to provide air quality information for selected Chinese largely industrialized regions and metropolitan areas by running models at different spatial (regional-urban-city) scales. The specific objectives are: 1) to develop a modelling chain (regional-urban-city scale) with setup, testing, and validation using remote sensing and ground-
based observations; 2) to downscale air quality modelling chain as a service for East China (regional), Beijing-Tianjin-Hebei region, Yangtze and Pearl Rivers deltas (urban) and Shanghai, Beijing, Hongkong metropolitan areas (urban/city scales); and 3) to study relationships, interactions and two-way feedbacks between pollution and meteorology/ climate for selected Chinese regions.

Regional air quality forecasting

The air quality (AQ) forecast service, developed by KNMI, consists of an open system where model forecasts from different project members can be easily incorporated and intercompared. For comparison with the ground truth, a web scraping service was built which stores hourly data from more than 1500 ground stations in about 400 Chinese cities. Towards the end of the project 7 models were included. From their data a continuously updated ensemble forecast is created and published on the website at http://www.marcopolo-panda.eu/forecast/. The 48-hour forecast can be interactively browsed on a map, while individual time series of 38 cities (all with more than 3 million inhabitants) can be selected, see Figure 4.1.

Figure 4.1 Screenshot of the MarcoPolo air quality service for Chinese cities, delivering spatio-temporal distribution of concentrations for selected air pollutants.

The time series also indicate the standard deviation of ground measurements and the range of the model predictions. Typically the accuracy will depend on geographical location and chemical species. KNMI's CHIMERE model was validated positively for the year 2015. It was found that the in-situ measurements can serve as a useful dataset for evaluating model simulations. Other ongoing validation studies will further refine the accuracy of the individual models and the ensemble.

During the Project Review Meeting, the ensemble forecast system was indicated as one of the promising project results. Market research by IsardSat has identified various potential clients, and concludes that the consortium should focus on being an AQ data provider to external (commercial) partners, instead of developing e.g. elaborate smart phone apps. As the functionality of the forecast service grew during the project lifetime, the data availability grew accordingly. Table 4.1 lists the included models participating in the ensemble forecast.

Table 4.1 Data availability

<table>
<thead>
<tr>
<th>Model</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHIMERE v2013</td>
<td>24 May 2015 - ...</td>
</tr>
<tr>
<td>C-IFS (ECMWF)</td>
<td>4 Sep 2015 - ...</td>
</tr>
<tr>
<td>WRF-Chem (SCUEM)</td>
<td>9 Nov 2015 - ...</td>
</tr>
<tr>
<td>SILAM (FMI)</td>
<td>20 Jan 2016 - ...</td>
</tr>
<tr>
<td>WRF-Chem (MPI)</td>
<td>1 Mar 2016 - ...</td>
</tr>
<tr>
<td>EMEP (Met.no)</td>
<td>6 Apr 2016 - ...</td>
</tr>
<tr>
<td>LOTOS-EUROS (TNO)</td>
<td>12 May 2016 - ...</td>
</tr>
<tr>
<td>Ensemble (median/mean)</td>
<td>25 Apr 2016 - ...</td>
</tr>
</tbody>
</table>

Urban air quality modelling

The VITO team, at first, identified the needs of local stakeholders regarding urban air quality assessments. In the framework of setting up a close collaboration between VITO, our Chinese partner LiboVITO and Chinese stakeholders, two extensive field trips were organized. During both trips, intense discussions between European and Chinese scientists on one hand and local policy makers on the other hand revealed the urge for high resolution air quality data. Regional authorities are interested in pollution maps at the resolution of a few meters, and require information on the source of the pollution, struggling with questions as “Which sector is causing the pollution in my city?” (sector contribution) and “Where is the pollution (spatially) coming from?” (source attribution).

To bridge the gap between the user needs and the tools that currently are available, VITO has introduced a model chain which combines local Gaussian dispersion modelling with a measurement-based background-estimate. Input emissions stem from the top-down MarcoPolo inventory, complemented with local data, acquired through the local stakeholders involved. For three case study cities, air pollution maps at a resolution of 50m were composed, identifying the hotspots in the city centres. To meet the requirements of the stakeholders regarding pollution sources, VITO has developed a tool which analyses the source attribution and sector contribution at random locations in the domain (see Figure 4.2).
Figure 4.2 Screenshot of the air pollution assessment tool, visualising the air pollution and sector contribution in Shijiazhuang. The map shows the mean NOx-concentration in Shijiazhuang. The pie diagrams show the source sector contribution at the location indicated on the map.

The results of the model chain for particulate matter have been compared with particulate matter measurements. The validation reveals a good comparison between the time series for the measurement stations and those derived by the model, but also indicates large deviations for the spatial pattern across the city, highlighting the need for improved emission inventories, which combine top-down estimates with bottom-up data provided by local authorities.

Urban/ city-scale air quality modelling

The effects of Chinese megacities on the environment were evaluated and modelling technologies developed – on-line integrated Enviro-HIRLAM (Environment – High Resolution Limited Area Model) and off-line SILAM (System for Integrated modelling of Atmospheric composition) models – were advanced and adapted to China.

The Enviro-HIRLAM model downscaling chain for regional-subregional-urban/city scales (15-5-2.5 km resolutions) was setup and tested for 3 large metropolitan areas (MA) of China (Shanghai as testbed, Beijing, and Pearl-River Delta) on specific case studies. The formation and development of meteorological and chemical fields were evaluated through a chain of control and urbanized runs (taking into account urban effects) runs. The setup includes the urban Building Effects Parameterization module and including Anthropogenic Heat Fluxes, describing different types of urban districts (industrial commercial, city center, high density and residential) with its own morphological and aerodynamical characteristics. A summary of findings on a diurnal cycle is shown (Mahura et al., 2015). These obtained simulation results allowed to take practical steps towards setup and operationalization of the atmospheric chemical composition forecasting. Testing and semi-operational runs (with focus on Shanghai Metropolitan Area, MA) showed good model performance for winter vs. summer months (Jan and Jul 2010) (Mahura et al., 2016). Similar setup was realized for the Beijing and Perl River Delta MAs. The effects of urbanization showed importance for atmospheric transport, dispersion, deposition, and chemical transformations, in addition to better quality emission inventories for China and selected urban areas.

Figure 4.3 Example of the operational Enviro-HIRLAM (a) -C15, (b) -C05 and (c) -C02 downscaling chain models output for PM2.5 concentration field at 12 hour forecast length for the Shanghai metropolitan area.

Starting Fall 2016, the Enviro-HIRLAM system provides meteorology and air quality forecasts at regional-subregional-urban scales (China - East China – Shanghai metropolitan area) at subsequent horizontal resolutions of 15-5-2.5 km (Mahura et al., 2017; see example in Figure 4.3). The atmospheric composition (with focus on aerosols) and meteorology (air temperature, relative humidity, wind speed) forecasts for Air Quality Service are available at http://www.marcopolopanda.eu/products/regional-air-quality-forecasts/enviro-hirlam. For convenience and easier interpretation of changes in the pollutant concentrations the meteorological fields can be directly used (in addition the wind direction and mean sea level pressure are also included in plots).The system is running twice per day at 00 and 12 UTC in a subsequent mode (e.g. output generated from the outer run is used for inner run) with the forecast length up to 48 hours. The system is also run at 06 and 18 UTCs, but at the shorter forecast length of 9 hours and these runs are used in order to keep the assimilation of meteorological data at mid-term for smoother and more continuous fields of meteorological and aerosol patterns. In particular, such forecasting is important for metropolitan areas, where formation and development of meteorological and chemical/aerosol patterns are especially complex. It also provides information for evaluation impact on selected megacities of China as well as for investigation relationship between air pollution and meteorology.

The SILAM model towards better representation of conditions in South-East Asia, first of all, formation of the secondary organic aerosols and emission of wind-blown dust; development and evaluation of the model ability to reproduce the large-scale features of the region, first of all, large-scale effect of the Asian monsoon; and practical steps towards materialising the multi-
scale atmospheric composition forecasting system. The large area, wide altitude range and presence of strong processes reaching up to the stratosphere (Asian monsoon, wild-land fires) prompted a series of the SILAM model refinements and evaluation efforts, aiming at robust representation of the peculiarities of the region. In particular, a refined transport mechanisms and related model adjustments allowed for successful representation of global 3D transport and chemical transformation patterns, including Asian monsoon. The model refinements combined with developments within a scope of other projects, allowed for setting up a multi-scale Asian forecasts.

The operational East Asia forecasting at horizontal resolution of 0.125 deg is done for a forecast length up to 96 hours since Feb 2016. The data availability includes: model hourly output of 2-3 latest forecasts (e.g. boundaries, vertical profiles, station time series etc.) with daily mean/ max for selected chemical species such as SO2, NO, NO2, CO, O3, PM10, PM2.5. The results are available at both http://silam.fmi.fi and http://www.marcopolo-panda.eu websites (see example of the SILAM model operational output in Figure 4.4).

Ongoing validation studies for both models will further refine the accuracy of forecasting for atmospheric composition (for both models) and meteorology (for Enviro-HIRLAM model as online integrated).

Figure 4.4 Example of the output (on the global and China areas scales) generated by the System for Integrated modelling of Atmospheric composition (SILAM).

Study relationship between air pollution and meteorology
The DMI team has been testing and improving of the aerosol-radiation interactions. In the HARMONIE model by default six IFS aerosol types are used: land, sea, desert, urban, stratospheric background and stratospheric volcanic. Sensitivity tests on improving aerosol cloud interactions in the model were performed. The simulations of aerosol effects have been performed with the convection permitting 2.5 km resolution weather model HARMONIE-AROME for an area around Shanghai and the Yangtze River Delta for Jan and Jul 2010. Experiments included the direct, semi-direct and indirect radiative effects of aerosols, and not the aerosol effects on the cloud ice precipitation and cloud drizzle formation. For the direct aerosol experiment average cloud cover changes of about -1% were seen in both months; and the changes in rainfall of -4.2% and -12.1% are seen in Jan and Jul, respectively, relative to the reference. For the total aerosol experiment average changes in rainfall of -3.9 and -11.3% are seen in Jan and Jul, respectively. Thus, most of the rainfall changes are due to the direct aerosol effect in these experiments. Summaries of monthly average net irradiances and other meteorological variables are given in monthly tables. The main findings are the following: a general reduction of the net short-wave surface flux of approx. 20% is found; precipitation reductions of 4% and 11% are found in Jan and Jul 2010, respectively; and the Twomey effect is found to have relatively little influence compared to the direct aerosol effects (perhaps due to the high carbon content).

The DUTH team has used decade (2003-2013, instead of originally planned 7 year period) of aerosol and cloud parameters (daily at 1x1 deg resolution) from the MODIS TERRA and AQUA satellites instruments to investigate the aerosol-cloud interactions over 3 major urban clusters of China (e.g. Beijing-Tianjin-Hebei region, Yangtze river delta and Pearl river delta) which are representative of 3 different climatic regions. The results of this study are published in Kourtidis et al. (ACP, 2015). DUTH team investigated the aerosol optical depth (at 550 nm) – total cloud cover (AOD-CC) relationship under different synoptic conditions using sea level pressure (SLP) data from NCAR/NCEP and under different clear sky water vapour (WV) contents. Over all urban clusters, and for all SLP regimes, CC is found to increase with AOD, thus pointing out that the CC dependence on AOD is not driven by synoptic co-variability. It is found that at AOD>0.2 the AOD impact on CC at low SLP conditions is about two times higher than its impact at high SLP conditions. Further, at its largest part this difference is due to water vapour differences between low and high SLP conditions rather than arising from differences in horizontal transport patterns. In general, WV has a strong impact on CC and thus, studies of aerosol-cloud interactions based on satellite data that do not account for this parameter, may result in erroneous quantitative and qualitative results. Namely, studies of AOD-CC relationships based on satellite data, might greatly overestimate the AOD impact on CC in regions where AOD and WV have similar seasonal variations, while they might greatly underestimate the AOD impact on CC in regions where AOD and WV have opposite seasonal variations. In the three areas of study, where AOD and WV have similar seasonal variations, if the water vapor effect is taken into account the slopes of the CC/AOD relationship for
AOD>0.2 might be reduced up to 90%. Further, this WV impact on AOD-CC relationships shows that the hydrological cycle interferes with the aerosol climatic impact and we need to improve our understanding of this interference. The work has been extended to include apart from CC also Cloud Optical Depth (COD) and study the impact of AOD on CC and COD under different WV conditions for cloud systems of different heights (Stathopoulos et al., 2017).

1.3.5 Validation of air quality monitoring methods (WP6)

New and existing observational data of trace gases, aerosols at various typical sites (e.g. big cities, counties, village and forests) in China for air quality study have been acquired. The column densities of NO2, HCHO and CHOCHO using MAX-DOAS, BVOC emissions above the canopy, trace gases (NO, NO2, O3, SO2), particulate matter (PM2.5) AOD, and solar radiation have been measured at Guangzhou, the cities in the region of the Yangzi River Delta, Taihe (jiangxi province), Xinglong (Hebei province). Validation of NO2, HCHO, CHOCHO using MAX-DOAS, validation of BVOC (Biogenic Volatile Organic Compound) emissions, trace gases (NO2, O3, SO2), particulate matter (PM2.5) AOD have been done by all WP6 partners, and good agreements (e.g. NO2, O3, AOD and BVOC emissions) were obtained between the ground measurements and satellite retrievals.

MAX-DOAS validation

Several MAX-DOAS instruments are employed for the validation of air quality data. The university of Thessaloniki has installed a new MAX-DOAS instrument in Guangzhou for the validation of tropospheric NO2 columns in MarcoPolo. The instrument had been operating at the Guangzhou Institute of Geochemistry of Chinese Academy of Sciences from March 31st 2015 through mid-March 2016 performing both direct solar irradiance and sky radiance measurements at different elevation angles (zenith and off-axis). The MAX_DOAS data recorded in Guangzhou are compared with corresponding OMI/Aura, GOME-2/MetOp-A and GOME-2/MetOp-B overpass data and good agreement was found.

Ground-based MAX-DOAS measurements in three locations are used by the Hefei Institute of Physical sciences to validate satellite and model data. These instruments are located in three cities of the Yangtze River delta (YRD) region, Wu Xi, Hefei and Shanghai. YRD is the largest metropolitan area in Asia with the population of 150 million. One Mini MAX-DOAS developed by AIOFM is located in WuXi city which is located about 130 km north-west of Shanghai. WuXi is an important industrial city and has about six million inhabitants. NO2, SO2, HCHO and aerosols were measured in this station. The other Mini MAX-DOAS is located in Shanghai which is the largest city in China. Shanghai is an important economic, financial and cultural center of China, which has a population of about 24 million. NO2 SO2 were measured in this station. And a 2D MAX-DOAS developed by AIOFM is located in Hefei city which is located about 450 km north-west of Shanghai. Hefei is the deputy center city of the Yangtze River delta (YRD) region and has about seven million inhabitants. NO2, SO2, HCHO and aerosols were measured in this station.

In WuXi, generally the best consistencies of NO2 and SO2 VCDs with MAX-DOAS results are found for OMI, however GOME-2B HCHO VCD shows the best consistency among the three satellite instruments. The cloud effects become significant for cloud fractions > 40% for the OMI DOMINO NO2 product, >30% for the GOME-2A/B NO2 products, > 10% for the OMI BIRA SO2 product, >20% for the OMI NASA SO2 product, >30% for the GOME-2/A/B BIRA SO2 products and >30% for all HCHO products. For the model comparison, the systematic underestimations of about 60% and 50% compared to MAX-DOAS observations are found for model runs with Edgar and MEIC, respectively. The slope indicates an underestimation by about 18% in the high value range. The high NO2 values in winter are well represented by CHIMERE model, however the low values in summer are overestimated by up to 10 ppb. A similar seasonality of HCHO with MAX-DOAS results is found for the simulations, but the simulations systematically underestimate the HCHO values.

In Hefei, systematically higher correlation coefficients R2 for OMI than for GOME-2A are found of NO2. But the better consistency for the GOME-2B product of HCHO probably because of the weaker degradation of the instrument during the short time at noon. However the standard simulations systematically overestimate the HCHO values obviously especially in winter. The month variation of NO2 and SO2 is rising first then falling from January to December. The peak of concentration is in July and August, and the lowest density is in January and February. However, the month variation of NO2 and SO2 is falling first then increasing, and the highest value of HCHO is in August. For the model comparison, the CHIMERE model strongly
overestimates the NO2 near-surface VMRs in the morning in all the seasons. In Shanghai, the best consistencies of NO2 VCDs with MAX-DOAS results are found for OMI and GOME-2B from 2012 to 2015 on average with the cloud fraction <10%. Systematic differences between the GOME2-A and GOME-2B VCDs are found. For OMI, R2 decreases with increasing cloud fraction; the slopes keep stable with different fractions. For GOME-2A, a generally lower R2 is found with a stable change. For GOME-2B R2 decrease with increasing cloud fraction similar to OMI. The results show that the cloud effect on OMI and GOME-2B for NO2 data becomes critical for cloud fractions over 30%. For model comparison, the high NO2 values in winter are underestimated up to 15 ppb by CHIMERE model than MAX-DOAS, however the low values from May to June are overestimated by up to 10 ppb.

Biogenic flux validations

The surface concentrations of trace gases (i.e. O3, NO, NO2, SO2), solar radiation (solar global, direct and scattered radiation, UV, PAR, etc.), aerosols (PM2.5) AOD, and meteorological parameters (temperature, relative humidity) were measured routinely at some sites (i.e. Xinglong and Xianghe stations, Hebei province) during 2013-2016 in China. 10-year variations of PM2.5 and trace gases at Xinglong station implied that anthropogenic volatile organic compound emission control is the most important action in air pollution control in North China. BVOC emission fluxes, O3 concentration and solar radiation were measured at a subtropical Pinus plantation (Taihe county, Jiangxi province) during 2013-2016. BOVC emissions and concentrations, O3 concentrations and other parameters have been acquired, the relations between BVOC emissions and O3 were analyzed. Monoterpenes were the dominant BVOCs contributing 71.6% of total terpenoid emissions. PAR (photosynthetically active radiation) and temperature are important factors in controlling BVOC emissions, and biomass burning smoke and phenology may also play a role. Compared to 2013, annual BVOC emissions decreased in 2015, associated with decreases of PAR, temperature and water vapor. The uncertainty of BVOC emissions from measurement and analysis techniques is about ±25 %. An empirical model of BVOC emissions (EMBE) was developed for this subtropical Pinus plantation. The simulated emissions were in agreement with the observed and the estimates of MEGAN (Model of Emissions of Gases and Aerosols from Nature) model. The mean emission factors at standard conditions for the entire campaign (2013-2016) calculated by MEGAN and EMBE models were 0.71 and 1.19 mg m-2 h-1 for isoprene and 1.39 and 1.65 mg m-2 h-1 for total monoterpenes, respectively. There were no strong correlations between O3 concentrations and either BVOC emissions or BVOC concentrations. The evident influences of biomass burning and florescence on BVOC emissions, as well as O3 were observed. The relations between O3 concentrations and BVOC emissions are likely complicated and dependent on atmospheric conditions. We have summarized our measured BVOC emissions in some typical ecosystems (e.g. grassland, temperate forest, subtropical forests) in China. Isoprene emission was the lowest and monoterpenes emissions were the highest in a subtropical Pinus plantation. BVOC emissions from January, 2013 to December, 2016 were estimated using EMBE model. The annual total emissions were 2333 mg m-2 for isoprene and 2626 mg m-2 for monoterpenes during 2013-2016. The decreasing trends were found for isoprene and monoterpenes emissions from 2013 to 2016. An empirical model of O3 concentration was also developed based on PAR energy balance and EMBE. We have done the sensitivity analysis, O3 increased with the increase of isoprene emissions in most conditions was found. The evaluations of the bottom-up inventory of isoprene emissions and the satellite-based MarcoPolo emission inventory for isoprene derived using inversion of satellite columns of formaldehyde have been done for two representative subtropical forests in China. Overall, model simulations were in good agreement with the local measurements.

Aerosol validation

The MODIS and CALIOP products used in MarcoPolo are available from public websites. These products have been extensively validated elsewhere. The retrieval of AOD from ATSR has been continuously improved in the course of the MarcoPolo project with a focus on China with the strong spatial variation across the country. Very high AOD values occur over, e.g. the North China plain and other areas in SE and SW China and very low AOD over other areas such as the Tibetan Plateau. The latest version of the algorithm (ver2.30_plume) has been described by Sogacheva et al. In particular the cloud post-processing described in Sogacheva et al. (2017) was aimed at reducing cloud contamination in the retrieval results (Kolmonen et al., 2016) while at the same time retaining areas with very high AOD (Sogacheva et al., 2017). Validation of these latest results, i.e. the comparison with reference data sets obtained by independent measurements, is essential to evaluate their reliability.
as indicated by statistical measures provided by this comparison. In addition, uncertainties are provided with the ATSR data on a per pixel basis and these uncertainties are validated independently. We have done validation of the ATSR-retrieved AOD, using FMI's ATSR Dual View algorithm and therefore referred to as ADV, version Ver2.30_plume. We also use MODIS data to extend the ATSR time to 2016 which allows for evaluating the most recent trends, and use AOD from MODIS-Terra which flies in a morning orbit with an equator passing time difference with ATSR of ca.60 minutes which allows for collocation of the MODIS and ATSR AOD in space with an acceptable time difference. The necessity for good time collocation was summarized. One of the AERONET time series was collocated with AATSR overpass time and the comparison was very good, and the other AERONET time series showed an average over all data available, resulting in very large deviations.

Three algorithms (the SU algorithm, the ADV algorithm, and the ORAC algorithm) display different performances in estimating AOD over mainland China in 2007, 2008, and 2010. None of the these algorithms show an explicitly better performance than the other two. All of these algorithms tend to underestimate AOD to some degree. The underestimation becomes more severe with increasing AOD or aerosol loading. The precision of the SU and ADV algorithms is at the same level over different surfaces. However, the SU product has stricter quality control than the ADV product, and it eliminates AODs to make the MBE less than 0.10 over different sites (de Leeuw et al., 2013). All of these algorithms underestimated AOD at a high level, perhaps because these algorithms are not sensitive to absorptive aerosols. ADV AOT time series follow the shape of AERONET AOD time series. Best agreement between ADV AOD and AERONET AOD is observed during the high AOD loading periods, which are spring or summer, depending on the region.

Validating emission estimates from satellites
The comprehensive evaluations on emission estimates for power plants and cities in China, emissions trend since 2005, and effectiveness of atmospheric regulations have been conducted, based on satellite observations from OMI. In more detail, the derived NOx emissions show generally good agreement with bottom-up inventories for power plants and cities. Regional inventory shows better agreement with top-down estimates for Chinese cities compared to global inventory. We detected the peak of NO2 column densities at a national level in the year 2011, with average NO2 column densities deceasing by 32% from 2011 to 2015. Power plants are the primary contributor to the NO2 decline, which is further supported by the emission reduction of 56% from the power sector in the bottom-up emission inventory associated with the penetration of selective catalytic reduction (SCR) increasing from 18% to 86% during 2011-2015. Meanwhile, regulations for vehicles also make a significant contribution to NOx emission reductions, in particular for a few urbanized regions (e.g. Beijing and Shanghai) where strict regulations for vehicle emissions were implemented years ahead. We also estimated the SO2 emission burdens surrounding 26 isolated power plants before and after the effective operation of their flue gas desulfurization (FGD) facilities. The OMI estimated average SO2 removal equivalence (56.0%) was substantially lower than the official report (74.6%). It has been concluded that the real reductions of SO2 emissions in China associated with the FGD facilities at coal-fired power plants were considerably diminished.

1.3.6 Data dissemination and public outreach (WP7)
The goal of this work package is the dissemination of the MarcoPolo results during and after the project period, and the identification of exploitation opportunities. Dissemination takes place of monitoring results, emission inventories and model results, accompanied by the validation results to provide information of the quality/uncertainty. In accordance with WP 8 (Cooperation with PANDA), the project web site is the main dissemination channel for both the MarcoPolo and the PANDA project.

We found out that, when disseminating air quality results such as Air Quality Indicators (AQI), this should be done with great care to avoid confusion with other standards and to ensure compliance with national regulation. The MarcoPolo project profits from a more political openness towards the air pollution concerns in China, which increases drastically the availability of local ground data (needed for e.g. quality assessment of the data products), and increases the public demand for information on air quality. Several potential commercial companies have been identified and contacted which are interested to pay for one or more data products. According to our market research, the best strategy would be to act as a data provider for local channels (e.g. app or environmental companies). To facilitate further commercial exploitation of the results, a product catalogue has...
been made with an overview of the data products including their technical description. Please note that the identification of exploitation opportunities (task 7.2, 7.3 and 7.4) are described in other sections of this report.

MarcoPolo web-site
The project websites take a central position in the communication between the project members and the dissemination of the project results. Two separate project websites are online: a public website (www.marcopolo-panda.eu) for public dissemination of the project results, and an internal password-protected website (www.marcopolo-panda.eu/internal) for project partners to share their results. A content management system enables contributions of different contributors through a user-friendly interface, and offers an infrastructure for translation to Chinese.

During the project lifetime the website attracts an increasing amount of unique visitors (around 2000/month). Most visitors consult the site during the winter months, which coincides with the occurrence of extreme air pollution in most Chinese megacities. In these months the air quality forecast page (http://www.marcopolo-panda.eu/forecast/) ranks high, and most unique visitors are from China.

Public website (www.marcopolo-panda.eu)
The public website shows results from the MarcoPolo and PANDA project. Having the visitor in mind, the content is not strictly divided by project, but rather by topic. The website is maintained by the administrator (Bas Mijling, KNMI), and an appointed content editor for each project. It is bilingual in English and Chinese, and is built in such a way that a Chinese translator can easily translate content from English to Chinese.

Figure 6.1 Home page of the bilingual combined MarcoPolo-PANDA public portal.

The home page (see Figure 6.1) contains a prominent link to the air quality forecasts. During the first Project Review Meeting, the ensemble forecast system was indicated as one of the promising project results. It consists of an open system where model forecasts of different project members can be easily incorporated and intercompared. The forecast information is delivered for today and two days in advance, and is updated whenever new model information becomes available. Apart from interactive maps, time series can be selected for the 37 largest cities in China. Figure 6.2 shows an example of the forecast. Simulations are compared with ground data, which is web scraped from more than 1500 ground stations in about 360 Chinese cities.

Figure 6.2 (Left) Forecasted time series for Shanghai on 29 April 2016. The red line shows the average concentration of this air pollutant taken from the available stations for this city.

At the Products section, different emission products can be downloaded:
• MarcoPolo emission inventory, combined from bottom-up inventories and satellite-derived inventories. To track the users interested in this product, the MarcoPolo inventory can only be downloaded after registration.
• Satellite-derived emission inventories
• Bottom-up emission inventories

Also at the Products section, one can find satellite data and in-situ data from WP 2. The satellite observations can be browsed by a user-friendly interface. Data are previewed when an image is available, and the corresponding data can be downloaded by following the Download-link.

The Publication section lists the relevant results of the AirInform project, and the scientific publications from the MarcoPolo/PANDA consortia.

Internal website (www.marcopolo-panda.eu/internal)
The internal website is primarily designed to facilitate communication between the project members. It contains project information, results, documentation and links. The website is maintained by the administrator (Bas Mijling, KNMI), though content can be edited by all project partners. The internal page opens with the latest news items relevant to the projects, see Figure 6.3.
At the Meetings section, information about the project meetings can be found. Agenda, minutes, and presentations can be downloaded.

The Conferences section lists conferences and other scientific meetings, relevant to the projects.

The Documents section contains a list of all MarcoPolo documents, such as the project proposal, legal documents, periodic reports, presentations, and deliverables.

The Data section is relevant for the validation activities of WP 6. It contains contact information for Chinese ground data, and publishes overpass series for selected Chinese locations of several satellite products. It also provides access to the database of ensemble forecast time series. This data is useful for validation purposes and model intercomparison. Queries to the database are done by filling in an electronic form.

Finally, the Contact section lists the contact information of all project members. At the end of the project there are 89 registered users, 46 users related to MarcoPolo and 45 users to PANDA. The members are listed in a sortable table, accompanied with a photo. There is also a download option for an up-to-date email list, intended for sending mass mails to project members.

Consideration of the AirINFORM project Results

The aim of this task is to summarize all information gained from the AirINFORM project that might be relevant to the dissemination objectives of the MarcoPolo project. In the EU-China AirINFORM project (contract no. DCI-ASIE/2012/299-560) an evaluation of a new Chinese Air Quality Indicator (AQI) was undertaken to assess how it performs technically and as a communication tool. The reports can be downloaded in the Publications section of the public web site, and the main highlights have been summarised and presented in deliverable D7.2.

Given the current level of air pollution, the new Chinese AQI daily calculation grid is suitable for reporting on the air quality in China. However, some improvements were recommended that are important to note for dissemination of the air quality, particularly when PM is the dominant pollutant:

- Hourly PM10 and PM2.5 values can be used. According to the regulation, both the hourly and 24h moving average concentrations for the PM pollutants are used in the daily AQI calculation. This can result in very high AQI values which are unnecessarily disturbing. Thus it was highly recommended to change this. In 2014 a notice was issued by CNEMC to the local environment protection agencies advising them to use hourly PM values in the AQI. However, an hourly PM grid still has to be developed.
- The Chinese AQI is aimed at providing behavioural and health recommendations in case of pollution episodes (risk communication). The problem with this is that a severe episode can last for weeks, even months. So that the behavioural adaption advice provided in the AQI technical guideline (e.g. to stay indoors) becomes almost redundant after the first few days.
- The Chinese AQI is ‘too’ similar yet different to the US-EPA AQI. This is still a source of confusion and controversy.
- The PM2.5/PM10 ratio proposed in the AQI calculation grid does not match the actual ratio found within an observation sample set. The PM2.5/PM10 ratio that should be used for China is 0.56.

Within AirINFORM it was observed that significant technical support is required for local Environment Protection Bureaus at provincial and city level to understand and implement complex air quality information systems for providing forecasts and undertaking source apportionment studies. The MarcoPolo team needs to investigate ways to ensure that the emission inventories generated are also made available to the lower levels, the provinces and key cities that are responsible for setting up these air quality systems.

1.3.7 Cooperation with PANDA (WP 8)
Data exchange
The projects Panda and MarcoPolo work together by exchanging data and information. The data dissemination of both projects is combined by a common web-portal. Data of the satellites and models is freely exchanged between the two projects as has been discussed at the first annual meeting. Most data is exchanged by providing the data on the internal web-sites which is accessible by partners of both projects.

Joint training sessions
Summer schools were organised to enhance the knowledge transfer and the cooperation among the project partners. Within these summer schools, universities arrange training courses with interdisciplinary lectures, practical work and field excursions. The summer schools were offered to PhD students/Post docs/Young Scientists who are interested in the topics of the school and have a background in atmospheric chemistry or meteorology. The first European summer school on “Remote Sensing of the Atmosphere, Emissions and Modeling” was held from 23 August to 29 August 2015 hosted by the Institute of Environmental Physics (IUP), University of Bremen, Bremen, Germany. The second summer school took place from 4 to 8 July 2016 at the School of Atmospheric Sciences (SAS), Sun Yat-sen University in Guangzhou, China.

Common web portal
For a seamless dissemination of the MarcoPolo and PANDA project results, a joint public and an internal website have been developed. The public website is bilingual, in English and Chinese. The password-protected internal website is primarily designed to facilitate communication between the project members. It contains project information, results, documentation and links. Also contact information of all members can be found. At mid-term there are 87 registered users, 44 users related to MarcoPolo and 45 users to PANDA. The content can be edited by all project partners, and can be chosen to made available to one specific project or to both projects.

Potential Impact:
Potential Impact
The management of air quality episodes in China is becoming an important challenge for Chinese authorities due to its large economical and societal impact. In 2012, a report from the World Bank estimated the environmental depletion and degradation in China in 2009 as 9% of the Gross Net Income (Table 1). Air quality pollution is one of the main sources of these damages due to the health, material and CO2 damages that accounted for 4.4% of the GNI in 2009. This report also showed the trend for 2030 where these environmental damages were expected to be reduced to 2.7% of the GNI.

Table 1 Environmental depletion and degradation (% of GNI). Source: World Bank.
Source 2009 2030 forecast
Energy depletion 2.9 1.9
Mineral depletion 0.2 0.2
PM10 health damages 2.8 0.1
Air Pollution material damage 0.5 0.1
Water pollution material damage 0.5 0.1
Soil nutrient depletion 1.0 0.1
Carbon dioxide damage 1.1 0.2
TOTAL 9.0 2.7

Pew Research Center survey showed that air quality pollution was the second top concern in China after officials corruption (Figure 1).

Figure 1 China Top Concerns (Source: Pew Research Center).
Since last decade, Chinese Government is aware of this big challenge therefore it has implemented several new policies to
cope with the air quality pollution reduction. In the 12th Five Year Plan (2011-2015), Chinese Government set up the following objectives to reduce air pollutants in China:

- Increase of non-fossil fuel usage in primary energy consumption: 11.4%
- Decrease in energy consumption per unit of GDP: 16%
- Decrease in CO2 emissions per unit of GDP: 17%
- Chemical Oxygen Demand (COD): 8%
- Sulphur Dioxide (SO2): 8%
- Ammonia Nitrogen: 10%
- Nitrous Oxides (NO2): 10%

In order to accomplish these objectives, 12th Five Year Plan estimated that RMB3.4 trillion were about to be invested in pollution control and treatment between 2011 and 2015. In 2013, when Marco Polo project started, the investment in pollution control and treatment reached RMB951.7 which was 15% more than 2012 and 1.67% of the annual GDP.

One consequence of this new political paradigm was the expansion and development of the national and regional systems which monitor and forecast air quality in China. The Ministry of Environment Protection (MEP), through the China National Environment Monitoring Centre (CNEMC), established new regulations and objectives to be accomplished by existing and new provincial and municipal Environmental Protection Bureaus (EPB) and Environmental Monitoring Centres (EMC). The development of these new monitoring networks expanded the number of monitoring sites providing a large amount of new local data (see Figure 2 and Figure 3).

Figure 2 Real-time Air Quality Index based on on-ground monitoring stations. China. (Source: AQICN, 17 May 2016 16:00h)

Figure 3 Real-time Air Quality Index based on on-ground monitoring stations. Beijing city. (Source: AQICN, 17 May 2016 16:00h)

Legal Framework
In September 2013, a new legal and regulatory framework was established through the Air Pollution Action Plan. This plan included 10 actions (see Table 2) and action number 9 was “establish a monitoring and early warning system to tackle highly polluted weather”.

Table 2 Environmental depletion and degradation (% of GNI). Source: World Bank.

In January 2015, a new Environment Protection Law introduced new targets and rules such as total emission control system, penalties, legal liabilities, incentives for emissions reductions and promotion of information disclosure to the public. This new regulatory and legal framework impacted Marco Polo project position because Air quality data became publicly available and new monitoring and forecasting systems were developed in parallel to the Marco Polo project.

Monitoring and Forecasting Systems
During 2014-2016, each Environmental Monitoring Centre (EMC) implemented and maintained new monitoring and forecasting systems at local and provincial level. The data collected and processed were subsequently published and distributed through their own websites and apps. In addition to these official websites, new channels for air quality communication were open through the rapid development of new mobile apps (Figure 4 and Figure 5). Citizens use these new apps to receive information about the air quality status in almost near-real time. Most of the sources of these apps are the official data published by EMCs so they are just merging and improving the communication channel with mobile phone users. Some of these Apps also provide health assessments and warnings to populations based on the standards published by both Chinese health authorities and international organisations (e.g. World Health Organisation).
Figure 4 Sample of Air Quality Index Apps search in Google Play market. (Source: Google Play, 17 October 2016 12:00h)

Figure 5 Examples of Air Quality Index Apps for China. (Sources: AQICN App, Fresh Ideas Apps and CastStudio Apps)
The Chinese National Monitoring Environmental Centre (CNMEC) of the Ministry of Environmental Protection (MEP) also collects the information published and collected at provincial level and national level. CNMEC publishes monthly, quarterly and yearly reports showing the evolution of the main pollutants at National level per classes (Figure 6).

Figure 6 Distribution of the 6 main pollutants according to their classes. 2015. China (Source: CNEMC)

CNMEC also produces an official Air Quality Index combining different levels of individual pollutants into different classes (Table 1.3). These AQI are also classified according to their health impact (Table 3).

Table 3 Chinese Air Quality Index and their classes associated (Source: AirInform)

<table>
<thead>
<tr>
<th>Classes</th>
<th>SO2</th>
<th>NO2</th>
<th>PM10</th>
<th>CO</th>
<th>O3</th>
<th>PM2.5</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>50</td>
<td>0.050</td>
<td>0.050</td>
<td>2.0</td>
<td>0.100</td>
<td>0.035</td>
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<tr>
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<td>0.075</td>
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<tr>
<td>3</td>
<td>150</td>
<td>0.475</td>
<td>0.180</td>
<td>14.0</td>
<td>0.215</td>
<td>0.115</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>0.800</td>
<td>0.350</td>
<td>24.0</td>
<td>0.265</td>
<td>0.150</td>
</tr>
<tr>
<td>5/6</td>
<td>300</td>
<td>1.600</td>
<td>0.75</td>
<td>36.0</td>
<td>1.000</td>
<td>0.350</td>
</tr>
<tr>
<td>7</td>
<td>400</td>
<td>2.100</td>
<td>0.500</td>
<td>48.0</td>
<td>1.200</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Table 4 Chinese Air Quality Index and health implications (Source: MEP)

Following Air Quality Action Plan, the “National Center for Environmental Quality Forecasting”, was established at CNEMC in the summer of 2013. This center was organized at four levels: national, regional, provincial and city level. Its mission was to provide air quality forecasts for all these levels within existing seven regions, thirty-one provinces and major cities. This centre reused four existing forecasting models developed by the Institute of Atmospheric Physics from the Chinese Academy of Sciences: NAQPMS, CMAQ, CAMx and WRF-Chem. This system became operational in 2015. Some of the outputs of this system are shown in Figure 7.

Figure 7 CNMEC Regional Forecast Operating System (Source: CNEMC)

Main dissemination activities
MarcoPolo project activities are organised on seven work packages delivering 34 deliverables. Among these deliverables, we identified two information services that could be commercially exploited after H2020 project funding period:
- Emission bottom-up estimates based on satellite data sets.
- Operational models providing validated forecast results on regional, urban and city scales.
The ensemble of these products information is used to better monitor and predicts any air quality event in China. A plan for exploitation of the project results has been written (deliverable 7.3) with more details about the exploitation, including IPR issues.
The project achievements (including scientific results are disseminated via the following methods:
1 General project presentation (ppt) has been made to present the project in overview talks at scientific meetings or to inform
policy makers.

2 A brochure has been made about MarcoPolo to promote the project. The brochure is bilingual.

3 General information about the project is presented on the public web-portal. The information is bilingual.

4 All data resulting from the project has been made available on the public web-portal.

5 Air quality model results and forecasts, including actual ground observations are presented on the public web-portal, including visualisation on the web.

6 An open User Workshop has been organised at the end of the project to inform (potential) users in detail about the results of the project.

7 A trainings course has been organised by a combined team of Panda and MarcoPolo members. In the training course young scientists has been trained for future work on air quality research.

8 MarcoPolo has communicated to the scientific community with several scientific publications about all topics covered by the project. In addition, the results have been presented at relevant conferences: eg. GEIA workshop, IAAF, EGU, AGU, iLEAPS, etc. (see section 2).

9 A special session has been organised at the AGU about research in PANDA and MarcoPolo

10 The newly developed MarcoPolo inventory will be presented at the GEIA community in September 2017 and presented for inclusion in the ECCAD-GEIA database.

Exploitation of results

A Business Plan has been made following the CANVAS business model (deliverable D7.4). The initial estimation of our 3-years business plan after project closure is based on our initial dialogues with some of the key target customers. The first conclusion from these dialogues is that the value and price of our services depends on each customer benefit so they cannot be easily standardised. The second conclusion is that the pricing strategy only based on the surface covered and the timespan of the data cannot fulfil the business models of some actors. For instance, Environmental Agencies could be comfortable with this pricing model but Apps developers not. Apps developer would like to tie the price of our data to the number of apps users using it. Third, the value (and price) of the data decrease with time. For instance, an emission inventory for February 2017 in March 2017 is precious but its value and price in 2018 could dramatically decrease.

In order to solve this problem, we have simplified our finance plan and we have estimated all the figures taking into account 3 scenarios. Each contract average revenue will be 500Keuros (average of 1, 2 or 3 services included).

List of Websites:
The public project site can be found at http://www.marcopolo.eu see Section 1.3.6.

The list of all 15 project partners can be found in the following table:

<table>
<thead>
<tr>
<th>No.</th>
<th>Organisation name</th>
<th>Name</th>
<th>PI</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Royal Netherlands Meteorological Institute (KNMI)</td>
<td>Ronald van der A</td>
<td>The Netherlands</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Aristotle University of Thessaloniki (AUTH)</td>
<td>Dimitris Balis</td>
<td>Greece</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Belgian Institute for Space Aeronomy (BIRA-IASB)</td>
<td>Trissevgeni Stavrakou</td>
<td>Belgium</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Danish Meteorological Institute (DMI)</td>
<td>Alexander Mahura</td>
<td>Denmark</td>
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<td>5</td>
<td>Democritus University of Thrace (DUTH)</td>
<td>Konstantinos Kourtidis</td>
<td>Greece</td>
<td></td>
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<tr>
<td>6</td>
<td>Finnish Meteorological Institute (FMI)</td>
<td>Gerrit de Leeuw</td>
<td>Finland</td>
<td></td>
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<tr>
<td>7</td>
<td>Institute of Atmospheric Physics (IAP)</td>
<td>Jianhui Bai</td>
<td>P.R. China</td>
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</tr>
<tr>
<td>8</td>
<td>IsardSAT (ISAT)</td>
<td>Bernat Martinez</td>
<td>Spain</td>
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<tr>
<td>9</td>
<td>National Observatory of Athens (NOA)</td>
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<td>Greece</td>
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<tr>
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<td>Hefei Institute of Physical Sciences (HIPs)</td>
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<td>P.R. China</td>
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<tr>
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<tr>
<td>15</td>
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<td>Yong Xue</td>
<td>U.K.</td>
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