PERFORMANCE ASSESSMENT OF FUTURE LEO AND GEO SATELLITE INFRARED INSTRUMENT TO MONITOR AIR QUALITY

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Abstract

Efficiently monitoring air quality from space is a valuable step forward towards a more thorough comprehension of pollution processes that can have a relevant impact on the biosphere. Thermal infrared space-borne instruments, like the IASI, have recently demonstrated to have the capability of retrieving useful information on, e.g., the tropospheric ozone, at favourable conditions. However, limitations remain with the current observation systems, in particular to observe ozone in the lowermost troposphere with the sufficient accuracy and with a spatial and temporal resolution relevant for monitoring short-term pollution processes and/or at regional scale. Future low Earth and geostationary Earth orbit missions are expected to overcome these limitations. Here we show a group of simulation exercises to verify and evaluate the added value of these future missions. Four instruments, IASI, IASI-NG, IRS and MAGEAQ, are simulated by means of a general and modular pseudo-observations simulator, for a case study of 3 days characterized by a peculiar pollution phenomenon over Europe. The results show that a dedicated instrument for air quality monitoring in the thermal infrared spectral region, like the MAGEAQ, can be able to effectively retrieve the lowermost tropospheric ozone information from space.

1. INTRODUCTION

Air quality (AQ) pertains to the state on the atmosphere near the Earth’s surface in terms of trace gases concentrations and aerosols characterization. AQ monitoring from satellite platform is crucial to complement with in situ measurements and chemical and transport models (CTMs) to draw a more comprehensive picture of pollution processes that can have a relevant impact on the biosphere. The concentration of the ozone in the lowermost troposphere (LmT) is one of the most important AQ parameters. Thermal infrared (TIR) space-borne instruments are widely regarded as a useful tool to observe targeted AQ parameters like tropospheric ozone concentrations. It has recently been shown that existing low Earth orbit (LEO) satellite missions, like the MetOp-IASI, can provide useful information on the ozone concentrations into the lower troposphere on certain conditions, e.g. with a high thermal contrast (see, for example, Eremenko et al., 2008, or Dufour et al, 2010). However, since resolving ozone concentrations at the lowest layers is not always assured with the present instruments, future missions are required to undergo a thorough design process to maximize the expected sensitivity to the LmT. Finally it can be mentioned that LEO instruments are not the best choice to monitor small scale and short term phenomena involving AQ, owing to their unsatisfactory revisit time. A more satisfactory concept might be based on geostationary Earth orbit (GEO) platforms. However, existing and planned GEO missions to be operating over Europe are not well adapted for LmT ozone retrievals owing to their technical design.

Here we present a group of simulation exercises to evaluate the impact of present and future LEO and GEO satellite TIR observing systems on the monitoring and forecast of AQ over Europe. At this aim, we have developed a general and modular simulator to produce pseudo-observations for different existing, planned or concept observing systems; our simulator is described in section 2. We used this tool to evaluate the improvements brought by a future LEO mission, IASI-NG, and to contribute to the set-up of a future GEO mission, MAGEAQ, which is explicitly designed to monitor AQ over Europe;
the results of the comparisons of the performances of such future missions with IASI and IRS are given in sections 3.1 and 3.2 respectively. Conclusions are drawn in section 4.

2. SET UP OF THE SIMULATIONS

2.1 Pseudo-observations simulator

A basic scheme of our simulator is given in figure 1. The pseudo-reality, in terms of both the meteorological variables and the trace gases concentrations, including the target ozone fields, is produced by means of a combination of the CTMs CHIMERE (see, e.g., Boynard et al., 2011), for the troposphere, and MOZART (see, e.g., Kinnison et al., 2007), for the stratosphere. The KOPRA radiative transfer model (Still et al., 2002) is used to simulate the radiation as viewed by the selected instrument, which is defined by its technical specifications (see section 2.2). Then, the simulated spectra are inverted by means of the KOPRAfit module embedding a dedicated algorithm to obtain pseudo-observations of LmT ozone, which are finally compared with the pseudo-reality to evaluate possibilities and limits of the selected observing system. The inversion algorithm used to derive the pseudo-observations is an altitude-dependent Tikhonov-Phillips regularization method. Its constraint matrix and parameters are optimized to maximize the degrees of freedom (DOFs) and minimize the error in the LmT. This algorithm operates at 7 spectral microwindows, in the region of 975-1100 cm\(^{-1}\). Please refer to Dufour et al., 2010, for more details on the inversion algorithm. Our simulator includes a module to simulate both LEO and GEO observation geometries.

![Figure 1: Scheme of our pseudo-observation simulator](image)

2.2 Instruments specifications

Table 1 shows the technical specifications, in terms of the spectral sampling interval (SSI), the noise equivalent spectral radiance (NESR), the estimated signal to noise ratio (SNR), revisit time and pixel size of the 4 instruments. It is possible to note that the IASI-NG, which is now in phase A and is expected to be launched in the 2018-2020 time frame, has double the radiometric requirements than IASI (Crevoisier et al., 2011), while we considered the same geometry and pixel size of the IASI. As for the two GEO instruments, we compared the performances of the IRS and the MAGEAQ. The primary objective of the IRS, which is in phase B and is expected to be launched in 2019, is to support numerical weather prediction in Europe (Tjemkes et al., 2011). The MAGEAQ has been a candidate for the ESA’s Earth Explorer 8 call for proposals; the proposed SSI and SNR are thought to be adapted for the monitoring of tropospheric ozone and carbon monoxide (Peuch et al, 2010).
<table>
<thead>
<tr>
<th>Instrument</th>
<th>SSI (cm⁻³)</th>
<th>IASI</th>
<th>IASI-NG</th>
<th>IRS</th>
<th>MAGEAQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>NESR (nW/cm²/s·cm⁻³)</td>
<td>20.0</td>
<td>10.0</td>
<td>24.5</td>
<td>6.04</td>
<td></td>
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<tr>
<td>SNR</td>
<td>230</td>
<td>460</td>
<td>180</td>
<td>750</td>
<td></td>
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<tr>
<td>Revisit Time</td>
<td>2 overpasses/day</td>
<td>2 overpasses/day</td>
<td>1 h</td>
<td>1 h</td>
<td></td>
</tr>
<tr>
<td>Pixel Size (km)</td>
<td>12</td>
<td>12</td>
<td>4</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

*Table 1: Technical specifications of the four instruments simulated in this work*

3. RESULTS

Case studies over short time periods have been conducted and performances of each instrument are evaluated. At this aim, we selected 3 days characterized by a peculiar pollution phenomenon and its evolution, August 19-21, 2009. In figure 2 the pseudo-reality for the tropospheric ozone column (TOC) from surface to 6 km is shown. The maps are representative of a IASI-like morning overpass. High values of the TOC 0-6 km over the south of France on the 19th were moving toward north-east, reaching north of France to Netherlands on the 20th, and then Germany, Poland and the Scandinavian peninsula on the 21st. Another peculiar evolution can be seen over the Po Valley, with a marked peak on the 21st. In the following subsections we will show some comparisons of the performances of IASI versus IASI-NG, and then IRS versus MAGEAQ, starting from this pseudo-reality.

![Maps of pseudo-reality for TOC 0-6 km over Europe for the days 19, 20 and 21 August 2009](image)

*Figure 2: Pseudo-reality for the TOC 0-6 km over Europe for the days 19, 20 and 21 August 2009*

3.1 IASI versus IASI-NG

In figures 3, 4 and 5 the pseudo-reality (left plate), the TOC fields smoothed with the averaging kernels (central plate) and the pseudo-observations (right plate), for the two LEO instruments IASI and IASI-NG (top and bottom, respectively) and for the 3 days are shown. In white are cloudy pixels (cloud fraction greater than 0.3). With this comparison it can be clearly seen how most TOC patterns are better discriminated by IASI-NG than IASI pseudo-observations, see, e.g., the low values east of Iceland, which are not caught by the IASI, or the marked overestimation over the whole Mediterranean basin, which is less evident for the IASI-NG.
Figure 3: TOC 0-6 km pseudo-reality (left), pseudo-reality smoothed by the averaging kernels (center), pseudo-observations (right) for the IASI (top) and IASI-NG (bottom), for the 19th August 2009.

Figure 4: Same as figure 3 but for the 20th August 2009
3.2 IRS versus MAGEAQ

Our second exercise is a comparison of the pseudo-observations from 2 GEO instruments, IRS and MAGEAQ. For this case we considered only one image corresponding to the morning overpass of the IASI for the 20th August 2009. Please note that, while we have considered here the overpass time of the IASI, the geometry of observation and the pixel sizes/positions are calculated for a geostationary orbit and for the subsatellite point and horizontal resolution of the MAGEAQ (Peuch et al., 2010). The IRS geometrical characterization, in this exercise, has been considered the same as for MAGEAQ. In the future we plan to fully characterize the simulations of the GEO instruments, e.g. by consider a revisit time of 1 hour. For the time being, we can see how the IRS pseudo-observations are not completely satisfactory. Indeed, even only smoothing the pseudo-reality with the IRS averaging kernels, TOC patterns are lost. This result suggests that the radiometric characteristics of the IRS, in terms of both the SSI and the NESR (or the SNR) are not sufficient to retrieve the required information about the LmT ozone. Here we want to stress how atmospheric composition monitoring is not the primary objective of the IRS mission (Tjemkes et al., 2011). On the contrary, MAGEAQ pseudo-observations seem capable of giving valuable information on the TOC 0-6 km.
Figure 6: TOC 0-6 km pseudo-reality (left), pseudo-reality smoothed by the averaging kernels (center), pseudo-observations (right) for the IRS (top) and MAGEAQ (bottom), for the 20th August 2009.

We had the chance to compare the 4 instruments, regardless the acquisition geometry, on the same image, i.e. for the morning overpass of the IASI for the 20th August 2009. To have a more sound statistical characterization of the pseudo-observations we analysed the distributions of both the DOFs up to 6 km, figure 7, and the altitude of the maximum of the averaging kernel for the TOC 0-6 km, figure 8, for the 4 instruments on the said image. The DOFs represent the pieces of independent information into the considered vertical interval. We obtained, for the 4 instruments, a mean value of 0.35 (IRS), 0.40 (IASI), 0.62 (IASI-NG), 0.86 (MAGEAQ). The maximum of the averaging kernel of the TOC represents the altitude of the maximum sensitivity of the observations. We obtained, for the 4 instruments, a mean value of 5.3 km (IRS), 4.1 km (IASI), 3.6 km (IASI-NG), 2.9 km (MAGEAQ). The MAGEAQ reaches values close to 1 for the DOFs, meaning a full resolved TOC 0-6 km, and 3 km for the peak altitude of the averaging kernel, meaning a maximum sensitivity at the centre of the column. These results give an indication on how a dedicated instrument to monitor AQ from space can be important. The improvements brought by a GEO over a LEO instrument, as well as the role of the target 1 hour revisit time is not here discussed but it is expected to be relevant.
Figure 7: Degrees of freedom for the 4 simulated instruments, for the 20th August 2009

Figure 8: Altitude of the maximum of the averaging kernel for the TOC 0-6 km for the 4 instruments, for the 20th August 2009
4. CONCLUSIONS

In this paper we presented some simulation exercises, starting from CHIMERE/MOZART CTMs pseudo-reality. The exercises have involved the comparison of IASI with IASI-NG and IRS with MAGEAQ pseudo-observations by means of case studies of 3 and 1 images, respectively. The results have shown that, for the two LEO instruments, as expected, an instrument with the technical characteristics of IASI-NG offers a significant added value for LmT ozone retrieval. For the GEO part, for our simulations IRS seemed weakly sensitive to LmT ozone. The MAGEAQ, on the contrary, had very satisfactory performances on the TOC 0-6 km, i.e. DOFs of almost 1.0 and averaging kernels peaking at about 3 km, on average. This means that MAGEAQ pseudo-observations have been able to retrieve the TOC 0-6 km, within our case study.

REFERENCES


