Using NO_2 Satellite Observations to Support Satellite-based CO_2 Emission Estimates of Cities and Power Plants

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Abstract: We created synthetic CO_2 and NO_2 satellite observations and compared various methods for estimating anthropogenic CO_2 emissions. The NO_2 observations increased the number of detected CO_2 plumes and reduced mean bias and scatter of the emission estimates making an NO_2 instrument a valuable addition.

OCIS codes: (280.0280) Remote sensing and sensors; (280.1120) Air pollution monitoring; (100.3008) Image recognition, algorithms and filters

1. Introduction

Under the Paris climate agreement, the signatory countries have set ambitious goals to reduce CO_2 emissions and limit global warming to below 2°C. The ability to implement long-term policies and manage them effectively will require consistent, reliable, and timely information on CO_2 emissions [1, 2]. The majority of anthropogenic CO_2 is emitted on a tiny fraction of the globe by cities and large power plants. Cities often take more aggressive mitigation measures to reduce CO_2 emissions compared to the country average, but are lacking reliable means to monitor the success of their policies. The European Space Agency (ESA) and the European Commission are therefore proposing a constellation of imaging CO_2 satellites to support the quantification of CO_2 emissions and to assist greenhouse gas mitigation policies at the national, city and facility level. Previous studies have shown that such satellites will have the potential to quantify emissions from strong point sources during a single overpass [3].

We present the results of a detailed study conducted on behalf of ESA, which aims (i) to investigate the capabilities of such a CO_2 satellite mission for estimating emissions, (ii) to analyze the benefit of auxiliary NO_2 measurements as a tracer of anthropogenic emissions, and (iii) to specify the requirements in terms of observation strategy and measurement accuracy.

2. Methods

We set up a highly optimized version of the COSMO-GHG model [4] for the simulation of CO_2 and NO_x for a domain centered over the city of Berlin and covering a large number of power plants in Germany and neighbouring countries. The simulations covered the year 2015 with very high resolution (1 km × 1 km) and accounted for anthropogenic and biospheric fluxes as realistically as possible. Synthetic satellite observations were generated by sampling the XCO_2 and NO_2 model fields with 2×2 km^2 spatial resolution along the 250-km wide swaths of constellations of one to six satellites (Figure 1). Parametrized instrument noise was applied to the CO_2 instrument at three different levels (σ_{VEG50} = 0.5 ppm, 0.7 ppm and 1.0 ppm) and to the NO_2 instrument at two levels ($\sigma_{ref} = 1\times10^{15}$ cm^{-2} and 2×10^{15} cm^{-2}).

The CO_2 emissions of the city of Berlin and the Jänschwalde power station were quantified by different methods to assess the range of uncertainties associated with the approaches. Emissions from Berlin were quantified (i) by scaling the simulated XCO_2 tracer representing only emissions from Berlin to match the synthetic XCO_2 observations minus simulated background, and (ii) by applying an image processing algorithm determining the extent of Berlin's emission plume directly from the noisy synthetic observations and estimating the flux of CO_2 through vertical control surfaces perpendicular to the plume. The first method assumes perfect knowledge of atmospheric transport and background XCO_2 levels, while the second method is a simple mass balance approach requiring only an estimate of the mean wind speed within the plume. Emissions from Jänschwalde were quantified by matching a Gaussian plume model to the individual plumes detected by the image processing algorithm, again requiring only an estimate of mean wind speed.

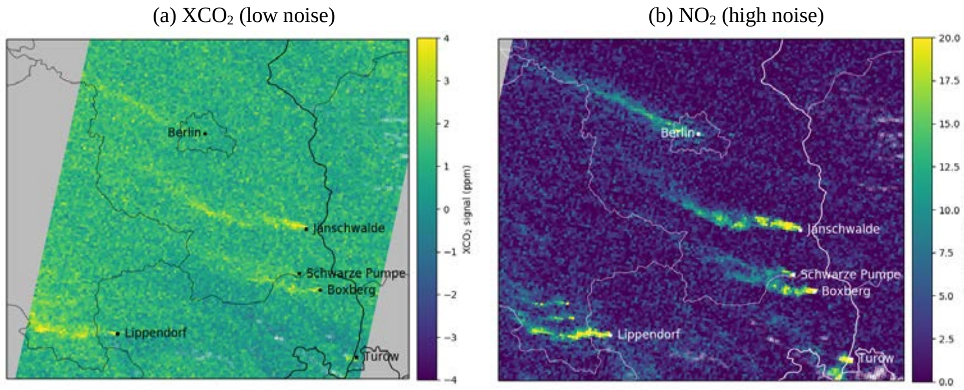

Figure 1: Synthetic satellite observations of (a) XCO_2 and (b) NO_2 with low noise ($\sigma_{VEG50} = 0.5$ ppm) and high noise ($\sigma_{ref} = 2\times10^{15}$ cm^{-2}), respectively, on 2 July 2015 (11 UTC).

3. Results and discussions

Although a constellation of six satellites was sufficient to cover Berlin on a daily basis, only about 60 out of 365 plumes per year could be observed due to frequent cloud cover. CO_2 emissions were estimated for these plumes with a perfect model tracer, i.e. a tracer including only measurement noise but assuming perfect knowledge of atmospheric transport. The mean bias was close to zero and the root mean square deviation (RMSD) of the mean of all plumes was in the order of 0.4 Mt yr^{-1} for the low-noise ($\sigma_{VEG50} = 0.5$ ppm) and 0.6 Mt yr^{-1} for the high-noise ($\sigma_{VEG50} = 1.0$ ppm) CO_2 instrument.

The uncertainties in the individual emission estimates were much larger when the emissions were estimated by the second approach. The detection of Berlin's CO_2 plume was difficult in many cases, because even under cloud free conditions the plumes were often too weak to be easily seen by the CO_2 instruments. The number of plumes useful for estimating CO_2 emissions in this way (i.e. with more than 100 detectable pixels) was reduced to 6 to 14 per year for six satellites with an instrument with high ($\sigma_{VEG50} = 1.0$ ppm) and low noise ($\sigma_{VEG50} = 0.5$ ppm), respectively. This number could be significantly increased to 39 plumes per year with an additional NO_2 instrument for the detection of the location of the CO_2 plume. The NO_2 instrument did not only enhance the potential for plume detection but also greatly helped to quantify the XCO_2 background. The CO_2 instrument alone could only detect a reduced fraction of the real plume, so that the background, estimated from the values surrounding the plume, actually contained significant amounts of XCO_2 emitted from Berlin. This resulted in an overestimation of background XCO_2 within the plume and a corresponding underestimation of Berlin's emissions by about 15-25%. The NO_2 instrument, conversely, detected a much larger portion of the plume and therefore enabled an almost unbiased estimation of the background and the emissions of the city (<10%). The uncertainties of estimated emissions for a single overpass were about 5-10 Mt yr^{-1} (30%-60%) and, for a constellation of six satellites, the RMSDs of the mean emission estimate were 4-7 Mt yr^{-1} for the CO_2 instruments and about 2 Mt yr^{-1} when also adding information from the NO_2 instrument.

For the power plant Jänschwalde, the CO_2 instrument could detect 30-40 plumes per year with 6 satellites. The NO_2 instrument increased this number to about 55 plumes. Using a Gaussian plume model, the uncertainties of the estimated emissions were quite high (10-20 Mt yr^{-1}), because the meandering plumes could often not be described well by a Gaussian plume. The RMSDs of the mean emissions were 2-6 Mt yr^{-1} for the CO_2 and NO_2 and 8-9 Mt yr^{-1} for the CO_2 instrument.

4. Conclusions

A constellation of CO_2 satellites is capable to estimate CO_2 emissions of cities and large power plants. An additional NO_2 instrument on the same platform significantly improves the emission estimates by increasing the number of plumes that can be detected by the constellation and by reducing biases and scatter of the estimated emissions.

5. References

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