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Satellite observations and modelling of hydrogen cyanide in the Earth's atmosphere

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Summary. — Hydrogen cyanide (HCN) is one of the most abundant cyanides present in the global atmosphere, and is a tracer of biomass burning, especially for peatland wildfires. In this work we present observations of HCN during the 2015 Indonesian peatland fires from the IASI (Infrared Atmospheric Sounding Interferometer) satellite instrument. We also investigate HCN variability using an updated version of the TOMCAT three-dimensional (3-D) chemical transport model (CTM), which is evaluated using HCN profiles measured by the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) and FTIR ground-based instruments in the NDACC (Network for the Detection of Atmospheric Composition Change) network. Here, we compare model simulations with the IASI measurements over Indonesia.

1. – Introduction

Hydrogen cyanide (HCN) is emitted into the atmosphere mainly by biomass burning and its main removal process is oceanic deposition [1-3]. Due to its low chemical reactivity and its lifetime of about 5 months in the troposphere and about 4–5 years in the stratosphere [1, 2], HCN is a good atmospheric tracer of biomass burning. HCN is able to interfere with the nitrogen cycle [1,2] but, despite its importance, the reactions in the atmosphere driving its variability are still not completely understood [2].

This study focuses mainly on the emissions of HCN during the 2015 Indonesia wildfire season, which was strongly influenced by the 2015 El Niño event. In Indonesia, fires are commonly used for agricultural land clearance for management and in preparation for the

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sowing season. The native moist forests and peatlands are cleared and drained, making them a prime fuel source and enhancing the potential risk for burning. Once burned, peats are able to emit a large quantity of a complex mixture of carbon dioxide, particulate matter (PM) and other trace gases, including HCN, which is thus an atmospheric tracer for peat fires [4]. During the intense 2015–2016 El Niño event, comparable to the 1997-1998 El Niño which was one of the strongest recorded, severe effects were observed in Indonesia, such as warmer temperatures and a reduction in rainfall [5]. The large and very diffuse Indonesia peatland wildfires produced significant quantities of HCN, with a detrimental effect on air quality.

This work presents the HCN satellite measurements during the 2015 Indonesian peatland fires from the Infrared Atmospheric Sounding Interferometer (IASI) instrument. Here we also use the TOMCAT 3-dimensional chemical transport model (CTM), which includes the chemical processes driving the HCN variability, to investigate the atmospheric response to the Indonesia 2015 peat fire season with a focus on HCN. The preliminary results of the comparison between the model and the IASI satellite measurements over Indonesia are presented.

2. – IASI satellite observations

HCN is retrieved from IASI radiance spectra with an optimal estimation method [6] developed at the University of Leicester and adapted to that purpose (University of Leicester IASI retrieval scheme, ULIRS) [7]. HCN columns are calculated on an 8-layer equidistant altitude grid, with 3 km spacing, from 0 to 21 km. The optimal estimation approach uses 16 channels in the range 710–717 cm^{-1}, with a 0.25 cm^{-1} spacing, to include the strong HCN Q-branch at 712.5 cm^{-1}.

During El Niño years, a strong peak in global HCN emissions has generally been observed, due mainly to the extreme increase in biomass burning in the equatorial Asia region [4]. Our IASI observations of HCN total columns over Indonesia (fig. 1) retrieved between September and November 2015 clearly show the expected large enhancement of HCN total column over Indonesia which extends over the Indian Ocean.

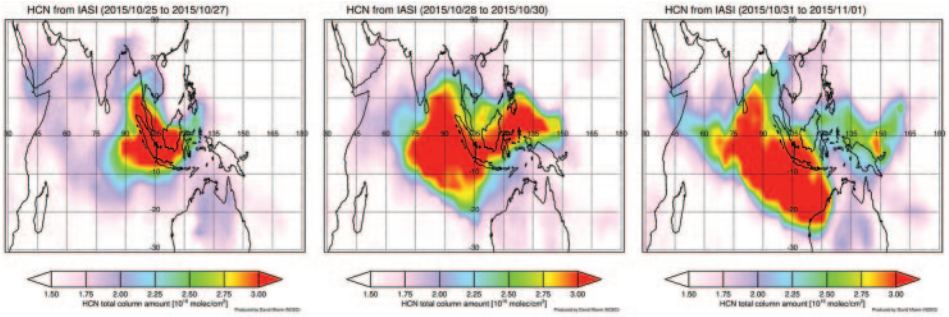

Fig. 1. – Three-day rolling average of HCN total column over Indonesia retrieved using ULIRS between October 25 and November 1, 2015.

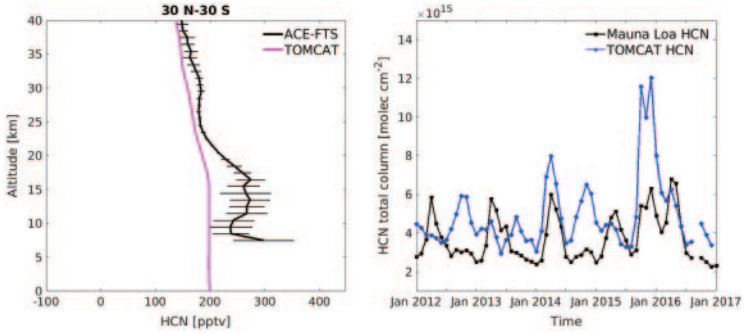

Fig. 2. – Average September 2009 HCN profiles modelled by TOMCAT compared with the profiles measured by ACE-FTS with $\pm 1\sigma$ standard deviation for latitude bands 30°N-30°S (left panel). HCN total column time series (molecules cm^{-2}) measured at Mauna Loa NDACC station (19.4°N, 155.6°W) and modelled at the same location (right panel).

3. – Model simulations

The global HCN distribution is studied using the TOMCAT 3-D CTM [8, 9]. The model was run at a spatial resolution of $2.8° \times 2.8°$ on a 60-level altitude grid (surface to approx. 60 km) using the 6-hourly European Centre for Medium-Range Weather Forecasts (ECMWF) meteorological reanalysis data. Natural and anthropogenic HCN emissions used in the model are extracted i) from the Coupled Model Intercomparison Project Phase 6 (CMIP6) for anthropogenic and ocean emissions, ii) from the Chemistry-Climate Model Initiative (CCMI) for a fixed annual biogenic emission dataset and iii) from the Global Fire Emissions Database Version 4 (GFED4) for the biomass burning emissions.

The stratospheric HCN loss reactions are modelled using the rate coefficients for the HCN oxidation by OH radicals and by $O(^1D)$ from [3]. The ocean uptake removal process was included in our model using the flux from [2] scaled by a factor 2 to improve agreement between model and observations. The model was evaluated using atmospheric HCN profiles measured by the Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) and HCN columns from ground-based Fourier Transform Infrared Spectroscopy (FTIR) measurements of the Network for the Detection of Atmospheric

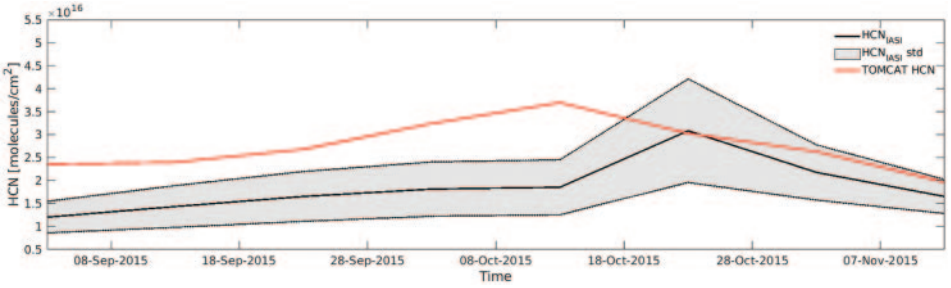

Fig. 3. – Time series of HCN averaged total column (molecules cm^{-2}) measured by IASI and modelled using TOMCAT over Indonesia for September–November 2015. The shaded area shows the standard deviation of the IASI observation.

Composition Change (NDACC) (fig. 2). A more detailed description of the model and its evaluation will be presented in a publication in preparation.

The model data are smoothed by applying the IASI averaging kernels (AKs) to account for the different instrument vertical resolution. The model averaged HCN total column time series over Indonesia during the period September–November 2015 generally agrees with the magnitude of the total column measured by IASI (fig. 3). However, the main peak in the modelled HCN time series is about 10 days earlier than that measured by IASI. The discrepancy observed could likely be partly addressed by managing the HCN monthly emission database used for the global model.

4. – Conclusions

We have presented the IASI HCN measurements during the 2015 Indonesian peatland fires. Using the TOMCAT 3-D CTM, we reproduced the atmospheric HCN variability over Indonesia during this time period. Despite the discrepancy in the peak time, that will be addressed with further investigation using a different setup of the emission database, the preliminary results of the comparison between the model and the IASI satellite measurements over Indonesia show a good agreement in terms of HCN amount. This is an encouraging result in the overall process of developing a model able to reproduce atmospheric HCN variability taking into account extreme events like the 2015 Indonesia peat fire season driven by El Niño.

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REFERENCES

[1] Li Q., Jacob D. J., Bey I., Yantosca R. M., Zhao Y. Kondo, Yutaka and Notholt J., *Geophys. Res. Lett.*, **27** (2000) 357.
[2] Li Q., Jacob D. J., Yantosca R. M., Heald C. L., Singh H. B., Koike M., Zhao Y., Sachse, Glen W. and Streets D. G., *J. Geophys. Res.: Atmos.*, **108** (2003) 8827.
[3] Kleinböhl A., Toon G. C., Sen B., Blavier J.-F. L., Weisenstein D. K., Strekowski R. S., Nicovich J. M., Wine, Paul H. and Wennberg P. O., *Geophys. Res. Lett.*, **33** (2006) L11806.
[4] Sheese P. E., Walker, Kaley A. and Boone C. D., *Geophys. Res. Lett.*, **44** (2017) 5791.
[5] Parker R. J., Boesch H., Wooster M. J., Moore D. P., Webb A. J., Gaveau, D. and Murdiyarso D., *Atmos. Chem. Phys.*, **16** (2016) 10111.
[6] Rodgers C. D., *Inverse Methods for Atmospheric Sounding* (World Scientific) 2000.
[7] Illingworth S. M., Remedios J. J., Boesch H., Moore D. P., Sembhi H., Dudhia A. and Walker J. C., *Atmos. Meas. Tech.*, **4** (2011) 269.
[8] Chipperfield M. P., Cariolle D., Simon P., Ramaroson R. and Lary D. J., *J. Geophys. Res.: Atmos.*, **98** (1993) 537.
[9] Chipperfield M. P., *Q. J. R. Meteorol. Soc.*, **132** (2006) 1179.