Near real time detection of exceptional events using principal component analysis on IASI atmospheric spectra

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Introduction

- The 3 IASI instruments on-board the Metop satellites have been sounding the atmospheric composition since 2006 allowing the monitoring of atmospheric chemistry (Clerbaux, et al 2009) and the detection of exceptional events such as fires (Coheur et al., 2009; R'Honi et al., 2013), volcanic eruptions (Clarisse et al., 2008) or pollution events (Boynard et al, 2014).
- The early detection of extreme events is key to take appropriate decisions regarding protection of inhabitants and the environment.
- With IASI providing global observations twice a day in near real time, a new way for the systematic and continuous detection of exceptional atmospheric events to support operational decisions is possible.

Objectives

- Using and improving a method for the detection and characterization of extreme events, which relies on the principal component analysis method (Atkinson, N. C., 2010, 2011; Chefdeville S., 2010).
- Creating a record of extreme events (volcanic eruption and fires) based on IASI data.
- Characterizing and classifying fire, volcanic eruption and pollution events.

Method

The Principal Component method

- The reference database is generated using nearly 120 000 spectra randomly selected in 2013 over the entire globe.
- From the reference database, eigenvectors are created to statistically depict the atmospheric variability during a full year, around different conditions of acquisition over the entire globe.
- By projecting raw apodized spectra (y) on the eigenvectors, reconstructed spectra $\tilde{y}$ are obtained, which are supposed to contain only information on the standard atmospheric variability, except for anomalous events.
- The residual normalized by the IASI noise (N) is calculated as follows: $r = N^{-1}(y - \tilde{y})$.

Spectral bands (cm^{-1})	Peaks (Spectroscopic Database)	Molecule ID
667.250 - 667.750	667.5 cm^{-1} (Q-branch CO_2)	CO_2
711.500 - 713.500	713 cm^{-1} (Q-branch of HCN ν_2)	HCN
729.250 - 730.000	729.25 cm^{-1} (C_2H_2 Q-branch ν_5)	C_2H_2
763.000 - 763.750	763 cm^{-1} (ν_8 HNO_3)	HNO_3
821.750 – 822.250	822 cm^{-1} (C_2H_6 Q branch ν_7)	C_2H_6
853.500 - 854.250	854 cm^{-1} (NH_3 Q branch)	NH_3
867.750 - 868.750	868 cm^{-1} (NH_3 Q branch)	NH_3
878.500 - 880.000	879 cm^{-1} (ν_5 HNO_3)	HNO_3
887.250 - 888.250	888 cm^{-1} (NH_3 Q branch)	NH_3
891.750 - 892.250	892 cm^{-1} (NH_3 Q branch)	NH_3
895.500 - 896.750	896 cm^{-1} (ν_6 HNO_3)	HNO_3
908.000 - 909.000	908.3 cm^{-1} (NH_3 Q branch)	NH_3
931.750 - 933.750	930 cm^{-1} (transition NH_3 Q branch)	NH_3
949.000 - 950.500	949 cm^{-1} (ν_7 band vibration liaison CH_2)	C_2H_4
966.000 - 968.000	967 cm^{-1} (transition NH_3 Q branch)	NH_3
991.750 - 993.500	992.8 cm^{-1} (NH_3 Q branch)	NH_3
1007.750 - 1008.250	1008 cm^{-1} (NH_3 Q branch)	NH_3
1034.000 - 1034.750	1034 cm^{-1} (CH_3OH Q branch)	CH_3OH
1046.250 - 1047.250	1047 cm^{-1} (NH_3 Q branch)	NH_3
1065.750 - 1066.250	1066 cm^{-1} (NH_3 Q branch)	NH_3
1075.750 - 1076.250	1076 cm^{-1} (NH_3 Q branch)	NH_3
1084.500 - 1085.750	1085 cm^{-1} (NH_3 Q branch)	NH_3
1103.000 - 1104.250	1104 cm^{-1} (NH_3 Q branch)	NH_3
1104.500 - 1105.750	1105 cm^{-1} (ν_6 band Q branch)	HCOOH
1180.500 - 1184.750	1184 cm^{-1} (ν_8 band Q branch)	CH_3COOH
1121.500 - 1122.750	1122 cm^{-1} (NH_3 Q branch)	NH_3
1325.750 - 1326.250	1326 cm^{-1} (ν_3 HNO_3)	HNO_3
1344.500 - 1346.500	1345 cm^{-1} (SO_2 ν_3 band)	SO_2
1370.500 - 1372.000	1371 cm^{-1} (estimate absorption in the SO_2 ν_3 band)	SO_2
1375.750 - 1377.000	1376 cm^{-1} (absorption in the SO_2 ν_3 band)	SO_2
1710.750 - 1711.500	1711 cm^{-1} (Q branch HNO_3)	HNO_3
1776.750 - 1777.250	1777 cm^{-1} (HCOOH ν_3 band)	HCOOH
2032.500 - 2087.000	2050.2 - 2069.65 cm^{-1} (ν_3 OCS branch)	OCS
2111.000 – 2112.250	2111.50 cm^{-1} (P-branch CO)	CO
2123.000 – 2124.250	2123,75 cm^{-1} (P-branch CO)	CO
2130.000 – 2132.250	2131.75 cm^{-1} (P-branch CO)	CO
2157.750 – 2158.725	2158.00 cm^{-1} (R-branch CO)	CO
2164.750 – 2166.000	2165.75 cm^{-1} (R-branch CO)	CO
Not defined	Unkown	UNKNOWN

Table.1 : Definition of molecule indicators using known absorption peaks for the characterisation of PCA detections.

The MIN_MAX_RESIDUALS method

- For a given granule, the extreme values of the residuals are saved for each IASI channel for the entire spectral domain (645cm^{-1} to 2760cm^{-1}) → we obtain an array called « MIN_MAX_RESIDUAL » (*Fig. 1*).
- By analyzing the signal in each IASI channel of the MIN_MAX_RESIDUALS, we compare the strongest peaks to pre-defined micro-windows where specific molecular signatures are expected (*Table.1*).
- The method is applied on a granule basis to allow the detection in real time.

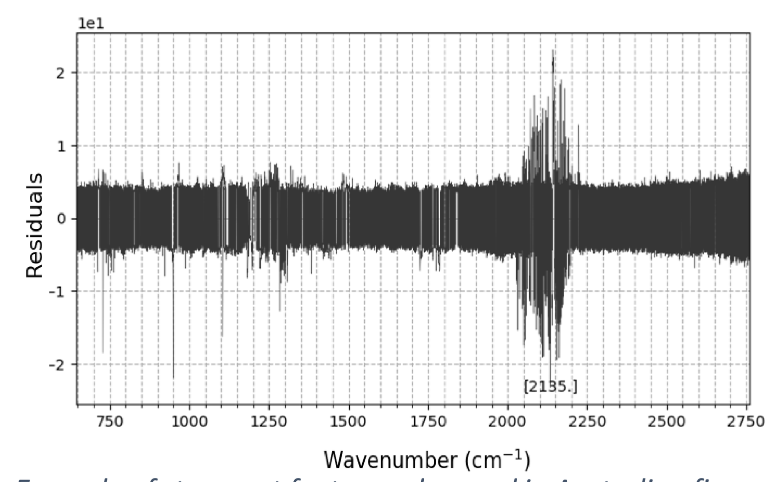

Fig.1 : Example of strongest features observed in Australian fires residuals during the day (2020/01/01) from the MIN_MAX_RESIDUALS.

Results: analysis of the year 2020

Volcanic eruption events

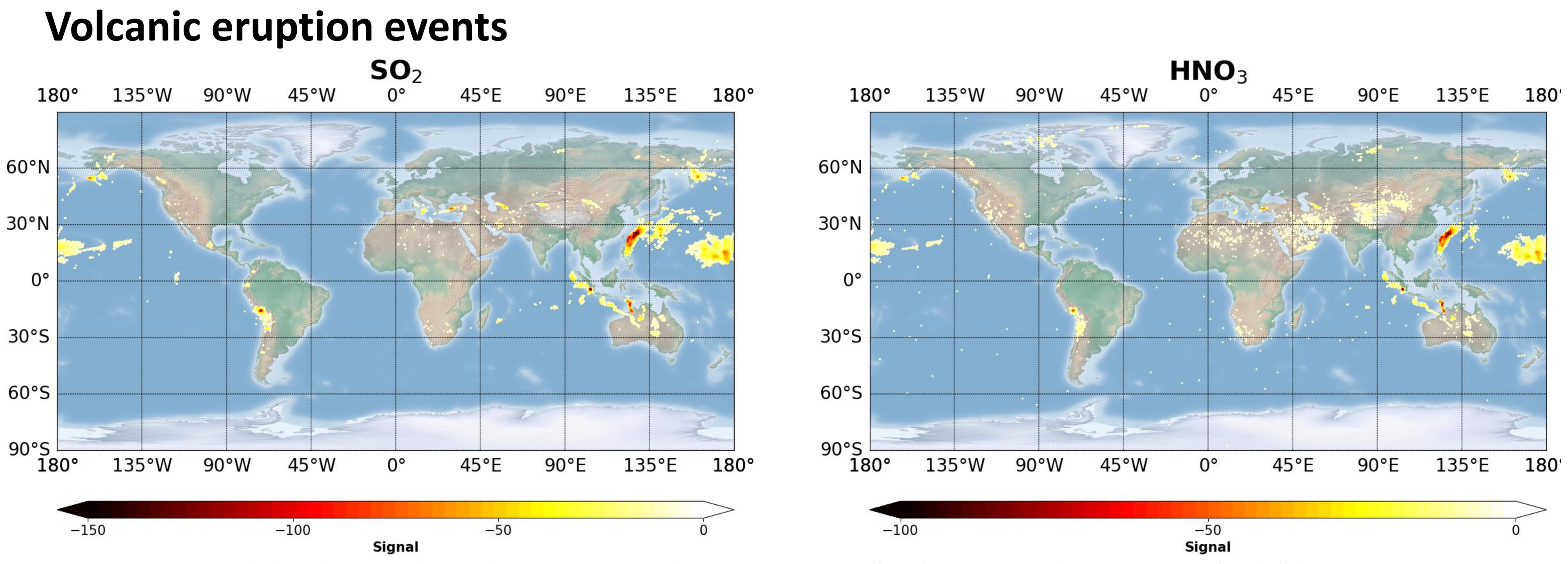

Fig.3 : Spatial distribution of PCA detection pixels for indicators SO_2 (left) and for indicators HNO_3 (right) for the year 2020.

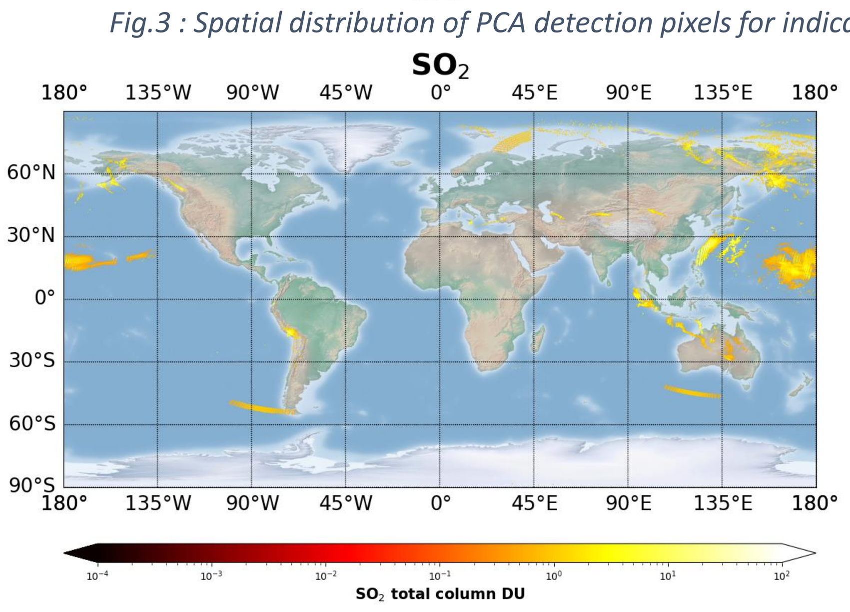

Fig. 4 : Spatial distribution of IASI L2 SO_2 total column for the year 2020.

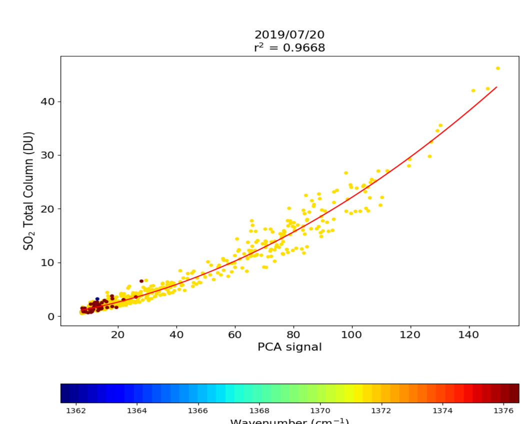

Fig.5 : Scatterplot between the SO_2 PCA detection and L2 data for the Ubinas volcanic eruption 2019/07/20.

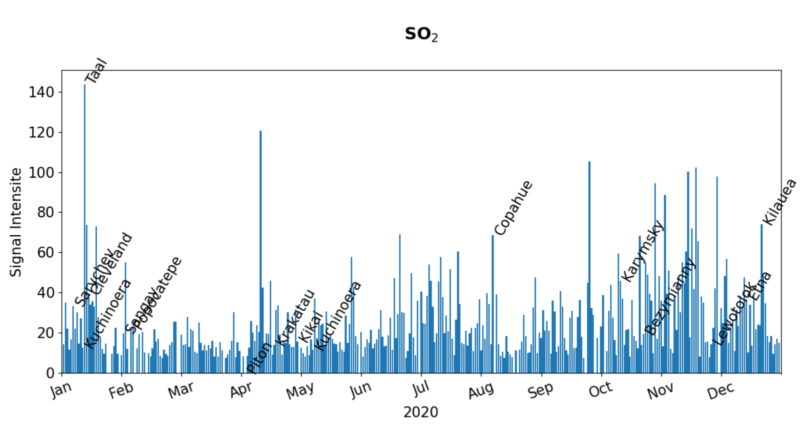

Fig.6 : Maximum absolute intensity of PCA signal for the 2020 year with referenced eruptions in black.

- The PCA method is able to detect volcanic eruptions with the indicators for HNO_3 and SO_2 (*Fig. 3*).
- The PCA method detect more volcanic eruptions than the L2 data (*Fig. 4*).
- An excellent agreement is found between SO_2 PCA and L2 data. This allow potentially a fast quantification of this molecule (*Fig. 5*).
- Record of volcanic eruption events for 2020 with PCA (*Fig. 6*).

Fire events

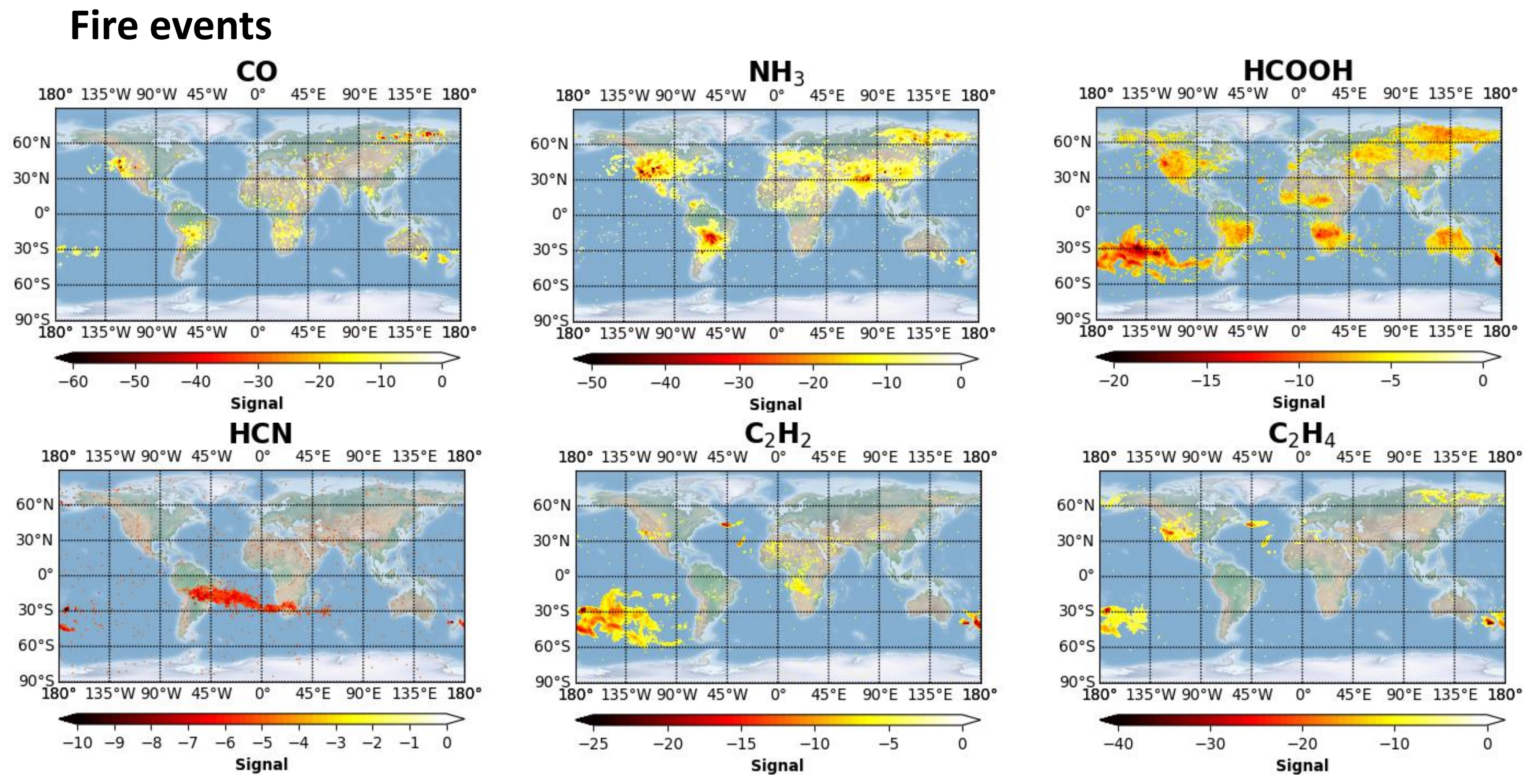

Fig.7 : Spatial distribution of PCA detection pixels for indicators CO, NH_3, HCOOH, HCN, C_2H_2 and C_2H_4 for the year 2020.

- Indicators for CO, NH_3, HCOOH, HCN, C_2H_2 and C_2H_4 are used for the detection of fires and show different molecular species emitted by fires in Australia, Siberia, Brazil, Africa and California (*Fig.7*).
- The method allows to detect extreme events, especially in case of the presence of large concentrations.
- Multiple indicators can detect same events, allowing a characterization and a classification of an extreme event.

Future work

- Extending the record of volcanic eruption events based on IASI L1 data for the entire IASI period.
- Validating the method for fire events (comparison with Level 2 data).
- Characterizing and classifying the events.

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Acknowldgements

IASI is a joint mission of EUMETSAT and the Centre National d'Etudes Spatiales (CNES, France). This study was supported by a CIFRE grant. The AERIS data infrastructure provides access to the Level 2 IASI data.