COCCON activities during the La Palma volcano eruption: gases and aerosols observations

N. Taquet, O. García, R. Campion, T. Boulesteix, W. Stremme, C. Rivera, M. Grutter, A. Barreto, O. Álvarez, S. León-Luis, R. Ramos, V. Carreño, F. Almansa, F. Hase, T. Blumenstock, M. Schneider

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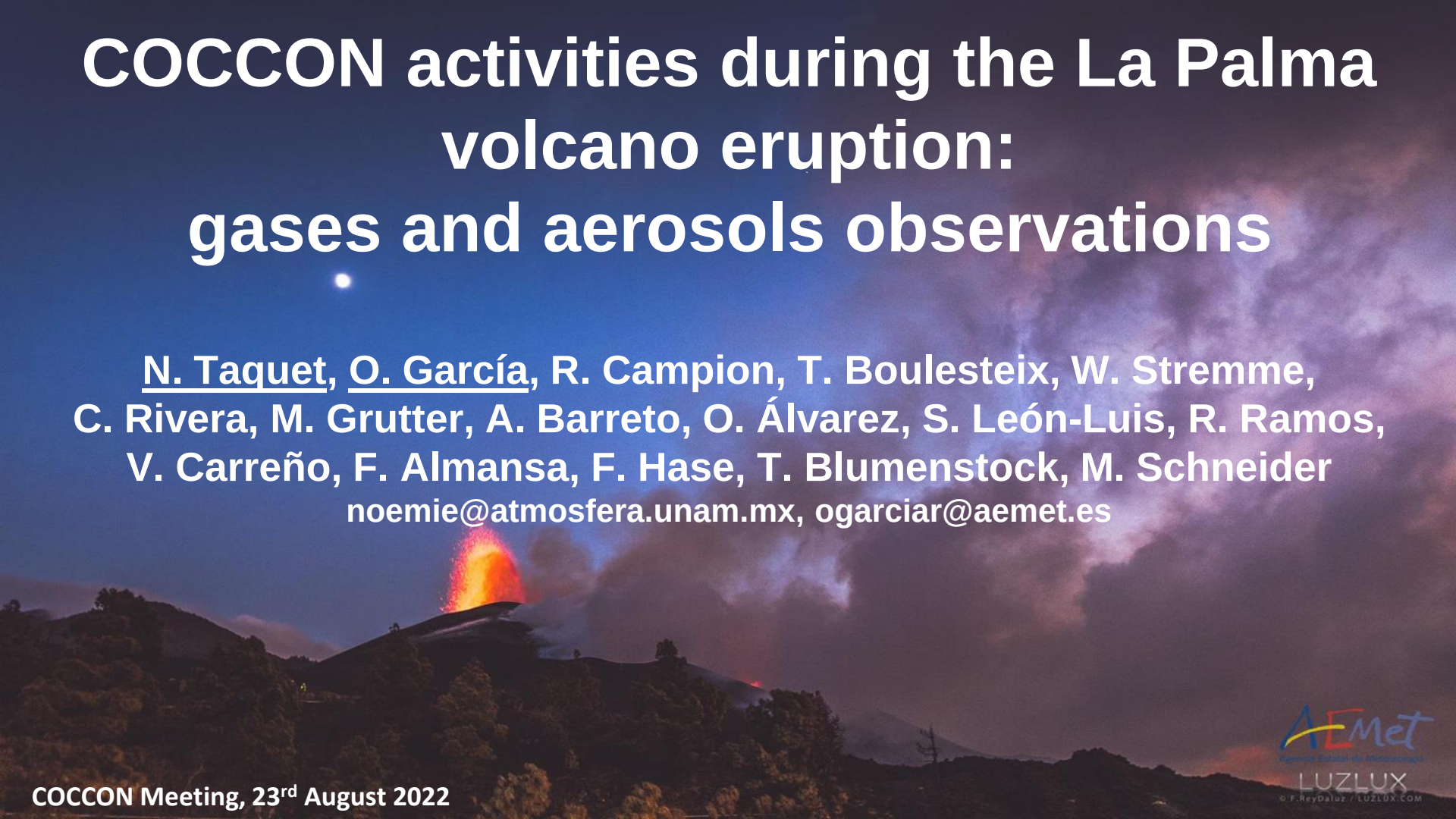
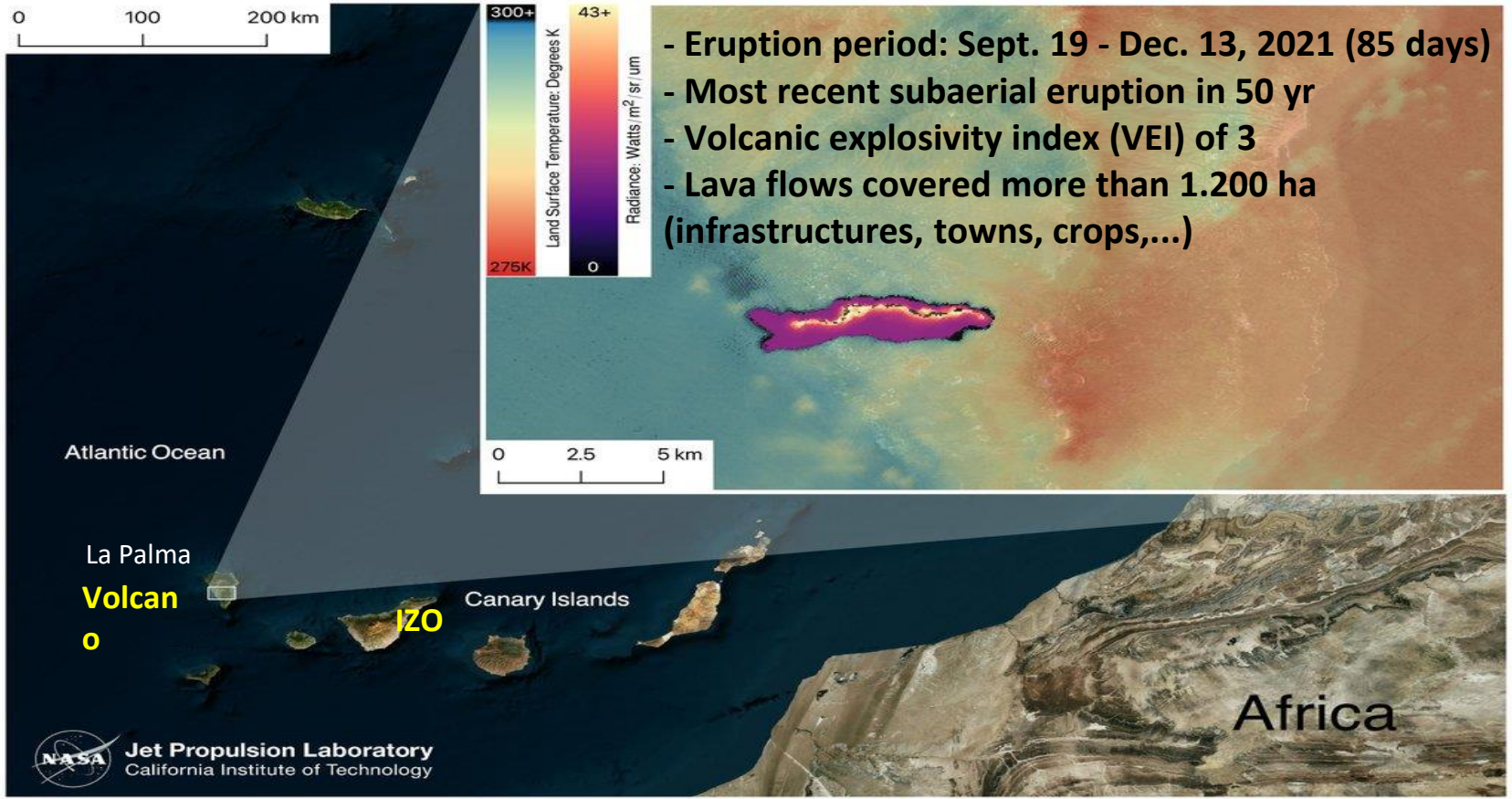


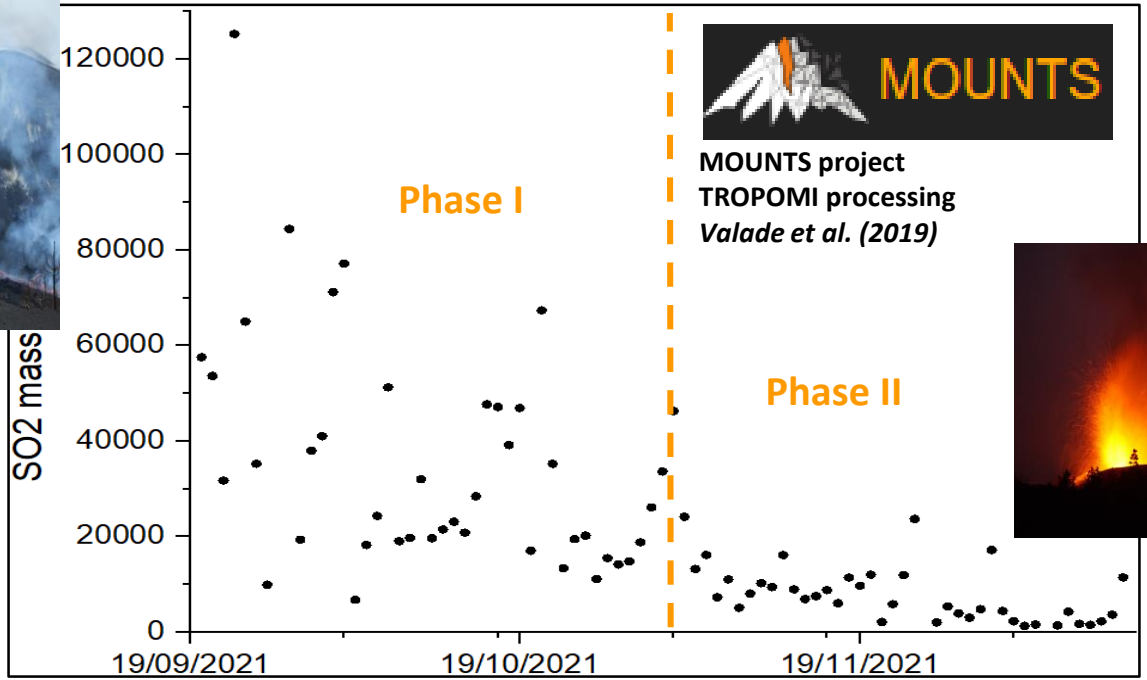
COCCON Meeting, 23rd August 2022

La Palma Volcanic Eruption



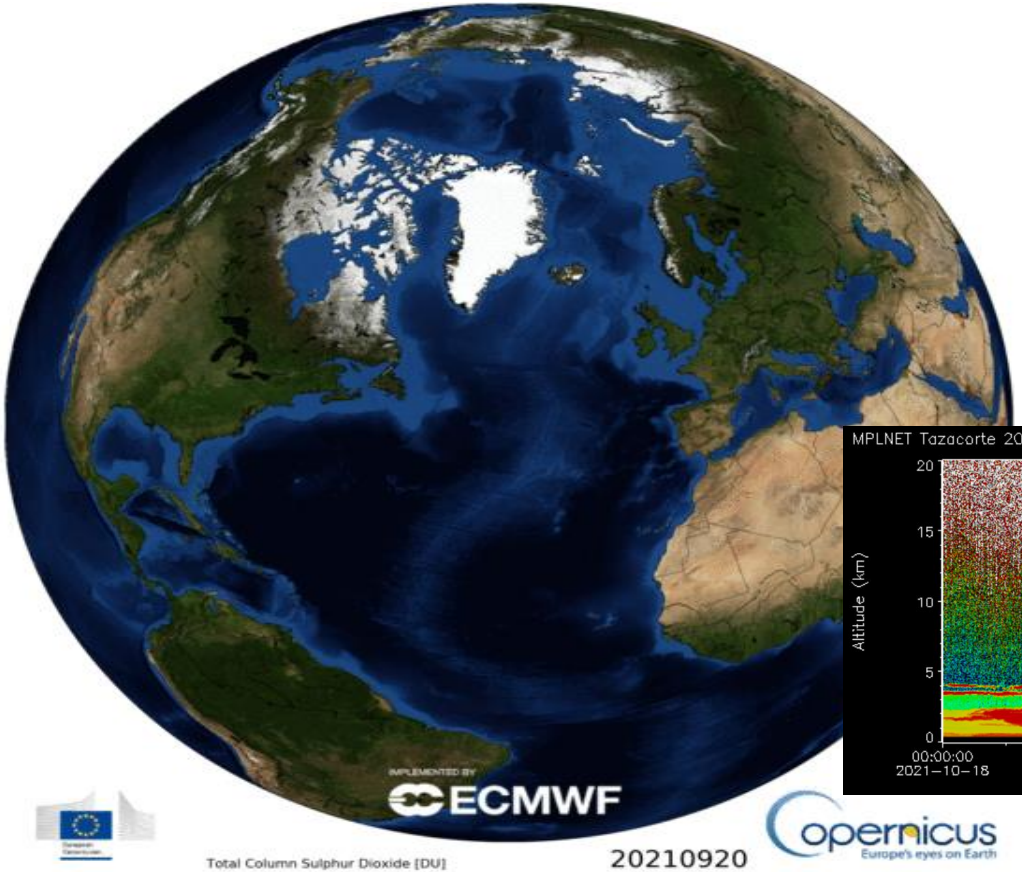
La Palma Volcanic Eruption

Total SO2 amount released: 1,84 Mt

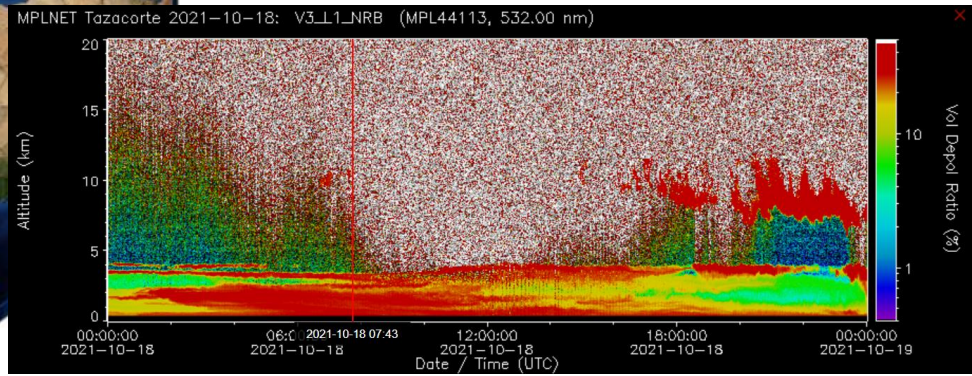


Phase I: alternating **explosive and effusive activity**, emissions at different vents.
Phase II: less energy in the volcanic system, more **effusive** activity (more lava flows, less aerosol and gas emissions)

La Palma Volcanic Eruption



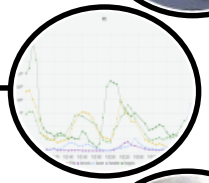
Transport to Europe, America and Africa in the middle troposphere (aerosol and gas injection between 2-6 km)



AEMet Deployment at La Palma

Weather monitoring and forecasting

Aerosol profiling (Transport)



Air Quality

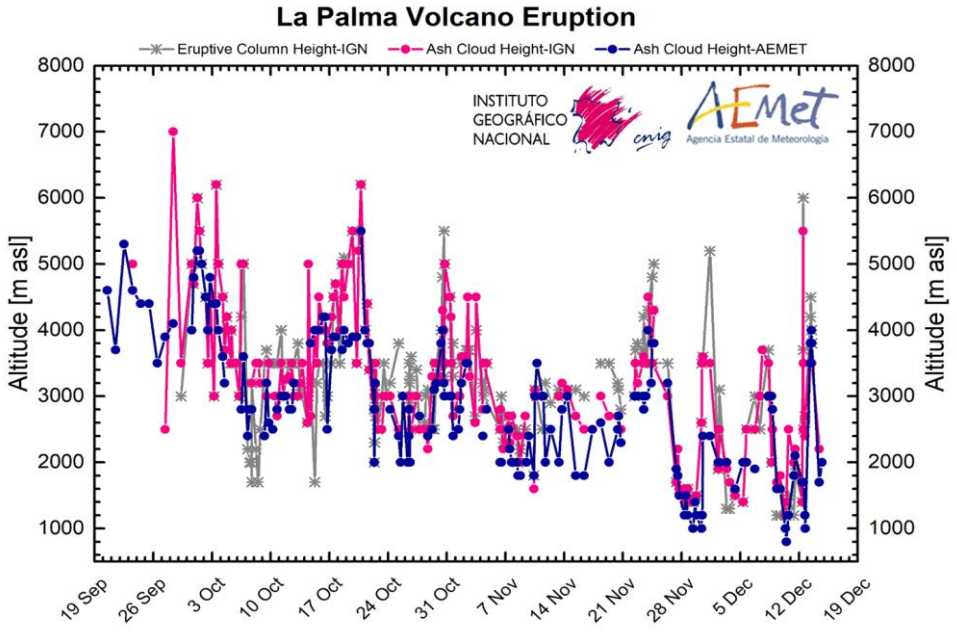
Research (aerosols & gases)

IZO WMO-GAW

AEMet Deployment at La Palma

- **Roque de los Muchachos** (2400 m): ARCADE Raman Lidar at Cherenkov Telecospe Array + Sun-photometer (AERONET)
- **El Paso** (700 m): Prototype Vaisala CL61 ceilometer
- **Tazacorte** (140 m): Surface SO2, O3, aerosols, MPL lidar (MPLNet+e-profile), all-sky cameras, ZEN radiometer, ash deposition, meteo
- **Airport** (60 m): Vaisala CL51 ceilometer (e-profile), meteo
- **Fuencaliente** (680 m): sun-lunar photometer (AERONET), CHM15k Luff ceilometer (e-profile), all-sky camera, EM27/SUN
- **Los Llanos** (295 m): meteorological sondes
- **Angeles Alvariño** (ship): low-cost air quality products

AEMet Deployment at La Palma



Aerosol profiling network (Roque, El Paso, Tazacorte, Airport and Fuencaliente): detect the **height and thickness** of the volcanic plume and the **vertical distribution in real time.**

DOAS & EM27/SUN Measurements at FUE station

Volc. species: **HCl, HF, CO_2, CO and SO_2**

Measurement days:

DOAS: 33 (from 10/10 to 10/12)

EM27/SUN: 59 (from 25/09 to 14/12)

+ 14 (post eruptive)

Days capturing volcanic plume: 21

(At IZO: Days capturing volcanic plume: 9
+ EM27 measurements: 4)

EM27/SUN:

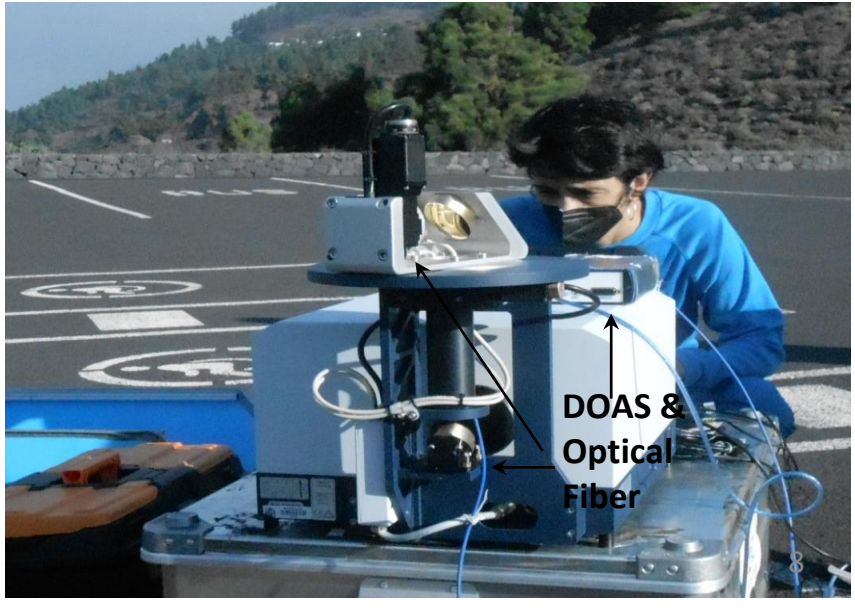
Spectral range: (4000 to 5500 cm^{-1}) & (5500 to 12500 cm^{-1})

Res: 0.5 cm^{-1}

DOAS Model: Avantes ULS 2048

Spectral range: 270-425 nm

Res: 0.4 nm



DOAS Measurements and processing

Measurements performed with **MobileDOAS software** (developed by BIRA-IASB)

Exposition Time: Manually adjusted

Integration time: ~30 sec

QDOAS processing:

- **Reference**: 1 Measured spectrum without volcanic signature & SZA close to 0.0
- **Settings: Based on Butz et al. (2017)**

Target Gas	Spectral windows (nm)	Interfering gases
SO_2	312.0-326.8	O_3

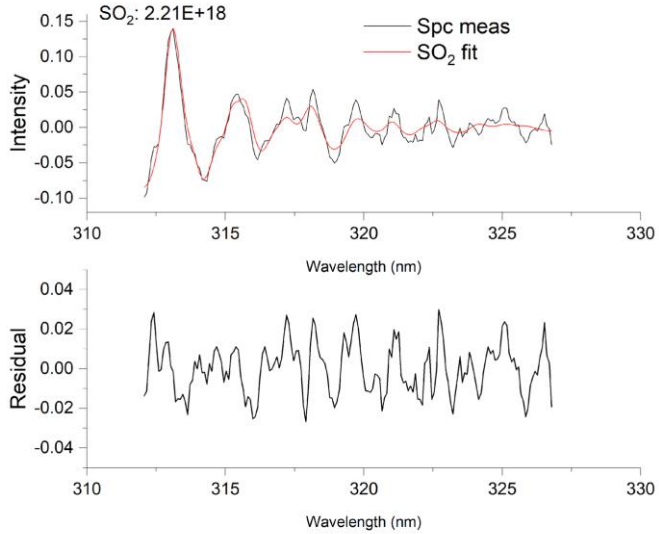
OClO, BrO (330.6–356.2) nm: too much noise

Conversion of Slant Col. to Vert. Col:

$VC\_SO_2 = SlC\_SO_2 / airmass$

with airmass= 1/cos (SZA)

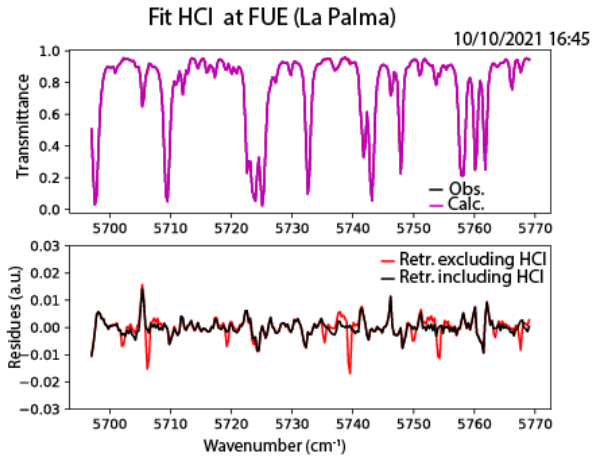
Example of SO_2 fit from FUE DOAS solar absorption measurements



EM27/SUN data processing: HCl, HF, CO_2, CO

Using PROFFAST v2.0

Gas	Spectral windows (cm^{-1})	Interfering gases
HCl (HIT2012)	(5697.0 - 5769.0) *(5684.0 – 5795.0) (*1)*	H_2O (HIT2020), CH_4 (HIT2020)
HF (HIT2012)	(7765.0 - 8005.0)	H_2O (HIT2020), CO_2 (HIT2020), O_2 (HIT2020)
CO_2 (HIT2020)	(6173.00,6390.00)	H_2O, CH_4 (HIT2020)
CO (HIT2020)	(4208.7,4318.8)	H_2O, HDO, CH_4 (HIT2020)

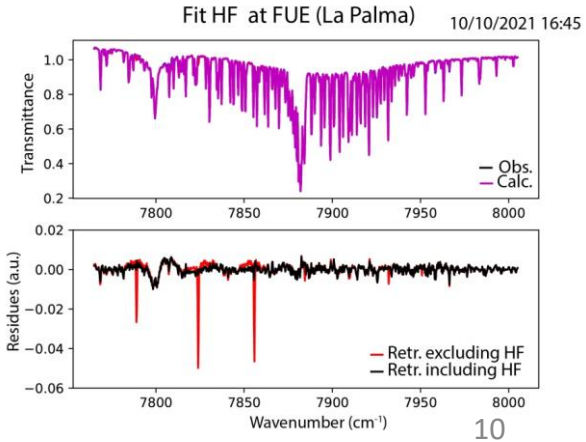


Retrieval Strategies

HCl & HF:

- Scaling of the lower troposphere (0.630 - 2.7 km) & atmospheric contribution neglected
- pT files and VMR a priori from MAPs files GGG2014

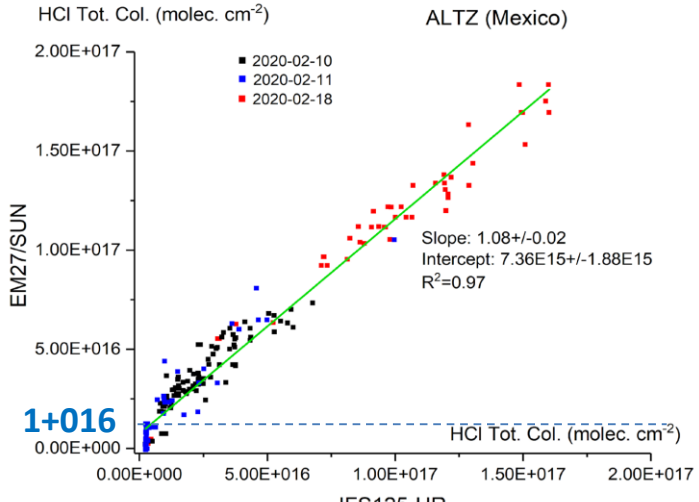
(factor of 1.00065 with GGG2020)



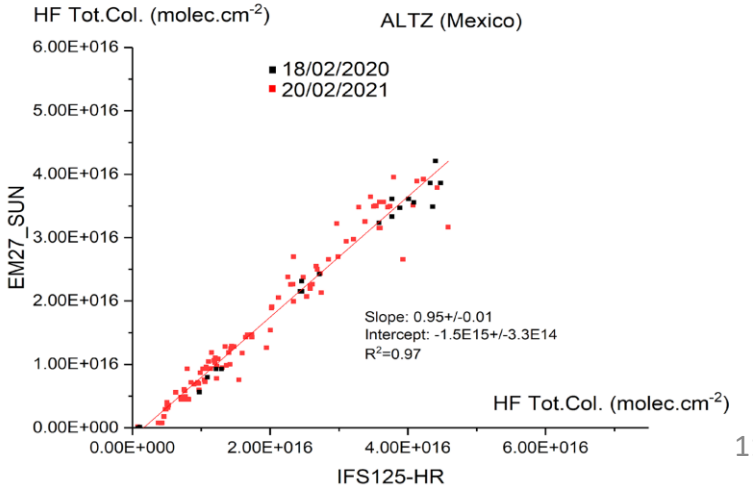
Based on (*1) Butz et al. (2017) & Mexico's settings

Validation HF & HCl at Popocatépetl: EM27-SUN vs IFS 125HR

HCl EM27/SUN (5697.0 - 5769.0) cm^{-1}
HCl IFS 125HR : 12 independent windows in (2727.0 – 2796.5) cm^{-1}
(Taquet et al., 2019)



HF EM27/SUN (7765.0 - 8005.0) cm^{-1}
HF IFS 125HR : (3999.0 – 4003.5) & (4036.5-4041.0) cm^{-1}
(Taquet et al., 2019)



EM27/SUN Measurements and processing: HCl, HF, CO_2, CO

Using PROFFAST v2.0

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CO (HIT2020)	(4208.7,4318.8)	H_2O, HDO, CH_4 (HIT2020)

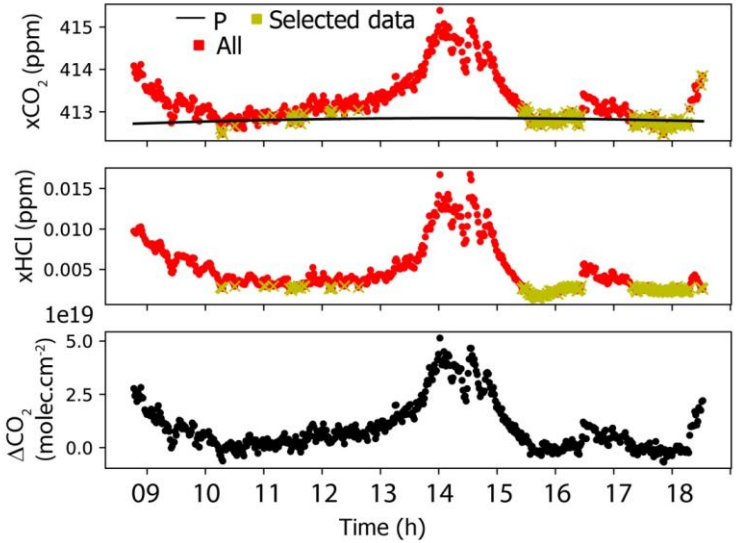
Retrieval Strategies

Volcanic CO_2 & CO :
Retr. with COCCON settings + post-correction to remove the atmospheric contribution

Determination of Volcanic CO_2 columns

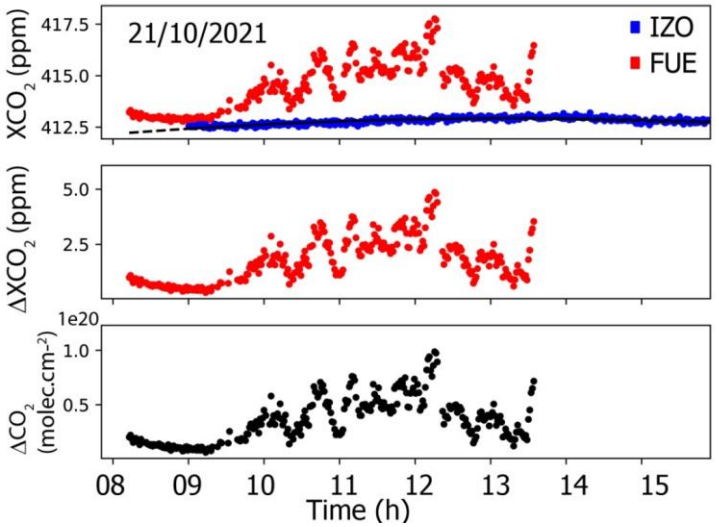
(1) Daily selection of XCO_2 data without volcanic contribution (XHCl < 0.002 ppm)

(2) Determination of a P function fitting the selected spectra



When IZO data exists:

Use of $XCO_{2\ IZO}$ to refine the P function



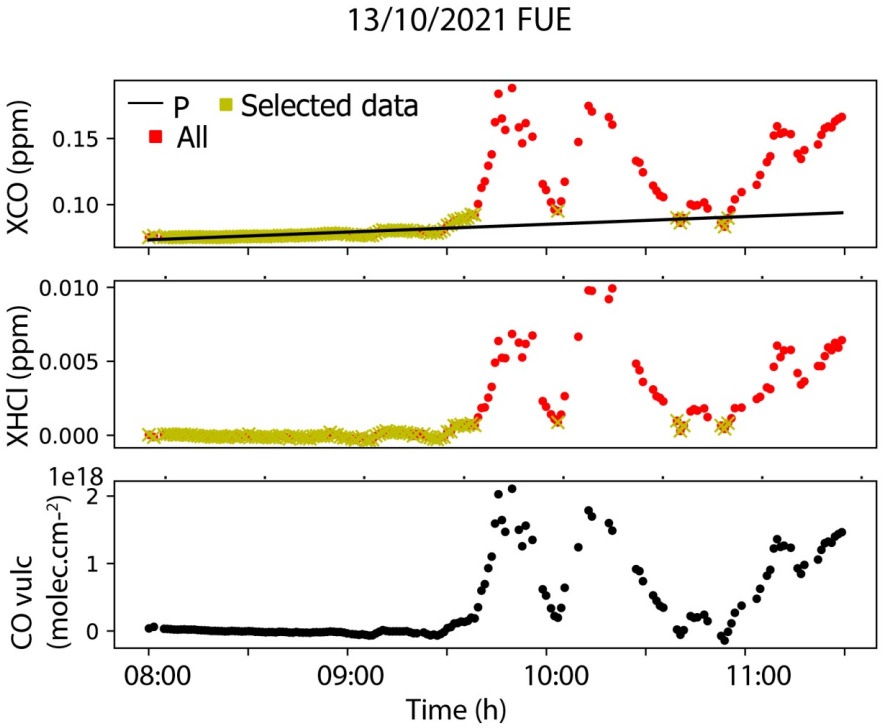
(3) Determination of Volcanic CO_2 VCD:

$\Delta XCO_2 = XCO_2 - P$

$CO_{2VOLC} = \Delta XCO_2 \cdot [O_2]/0.20942$

Based on Butz et al. (2017)

Determination of Volcanic CO columns

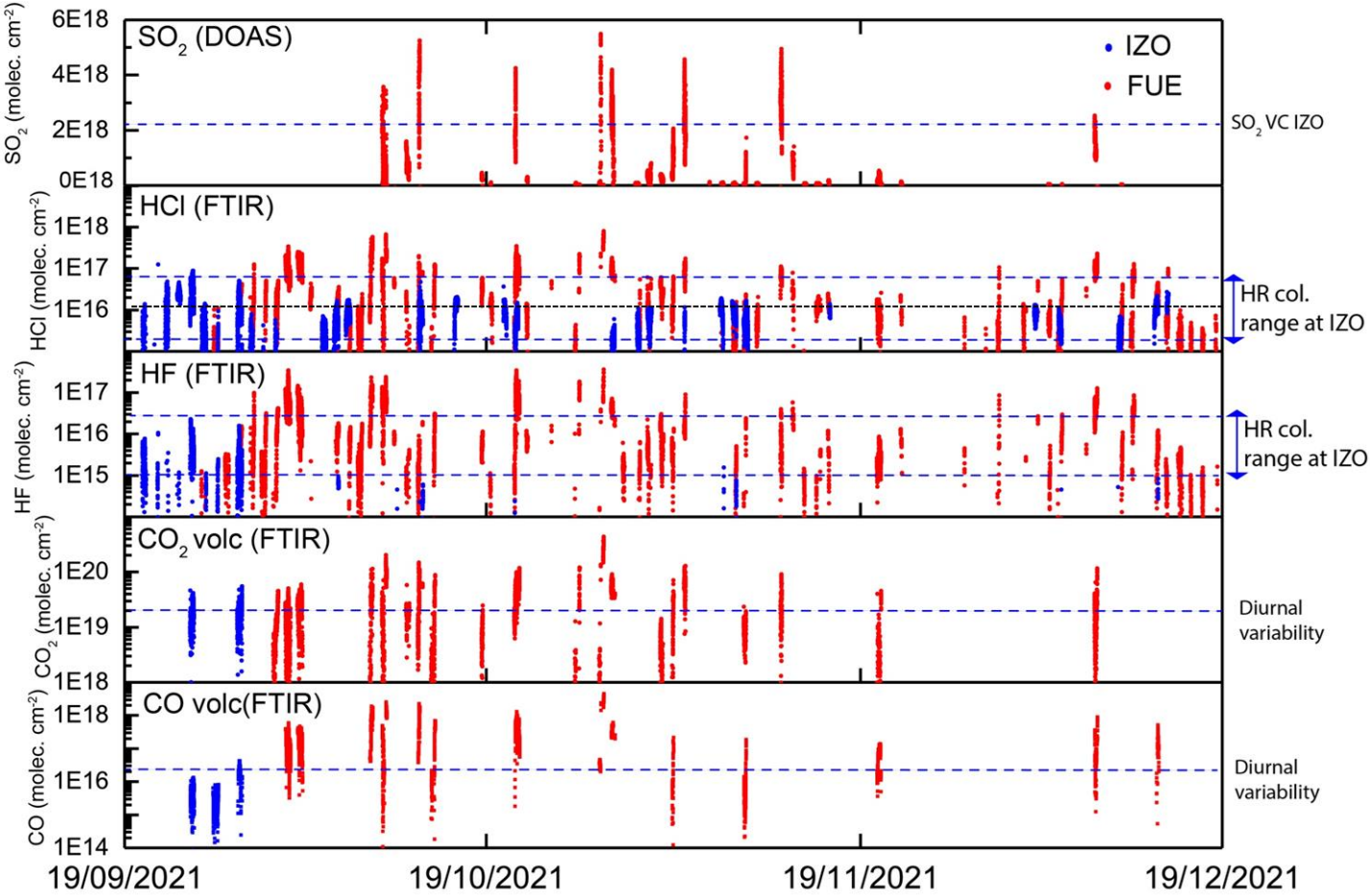


$\Delta XCO = XCO_{FUE} - P$

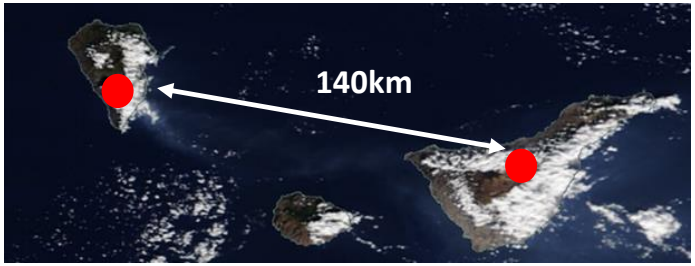
Volcanic CO VCD:

$CO_{VOLC} = \Delta XCO . O_2 / 0.20942$

Volcanic columns at FUE and IZO: SO_2, HCl, HF, CO_2, CO

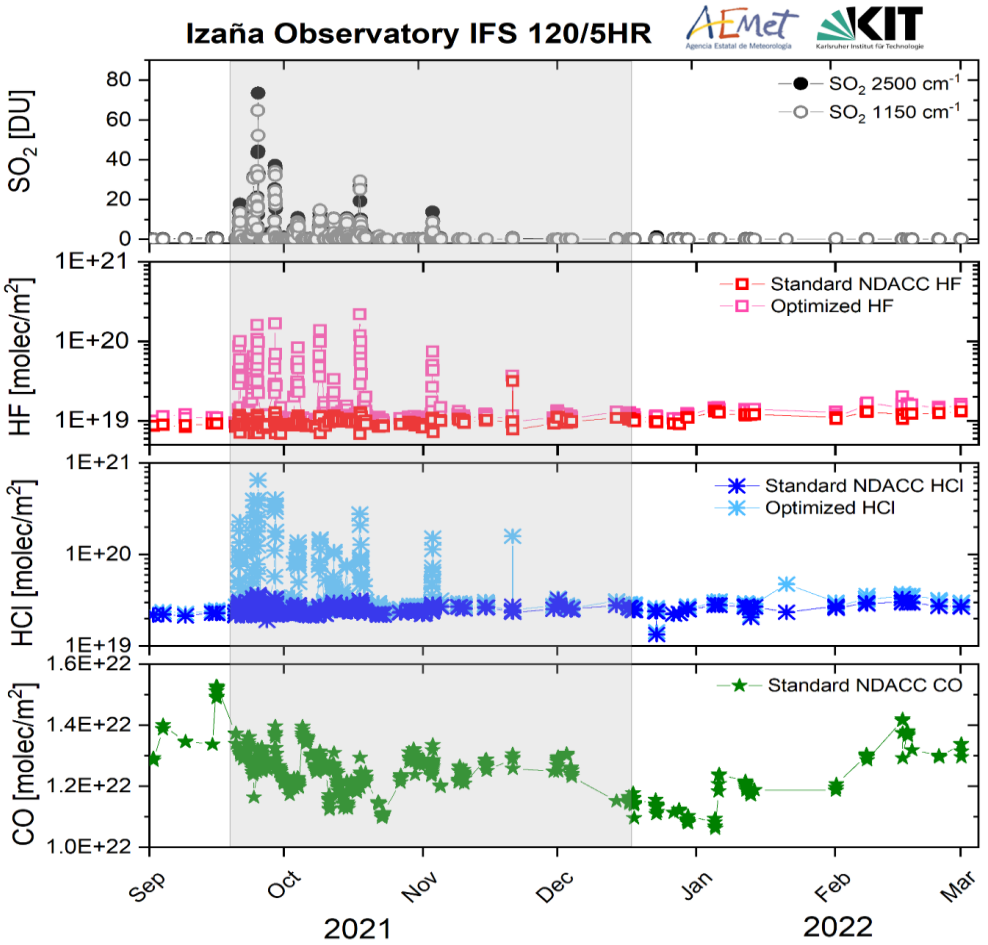


Volcanic IFS 125HR columns at IZO: SO_2, HF, HCl, CO

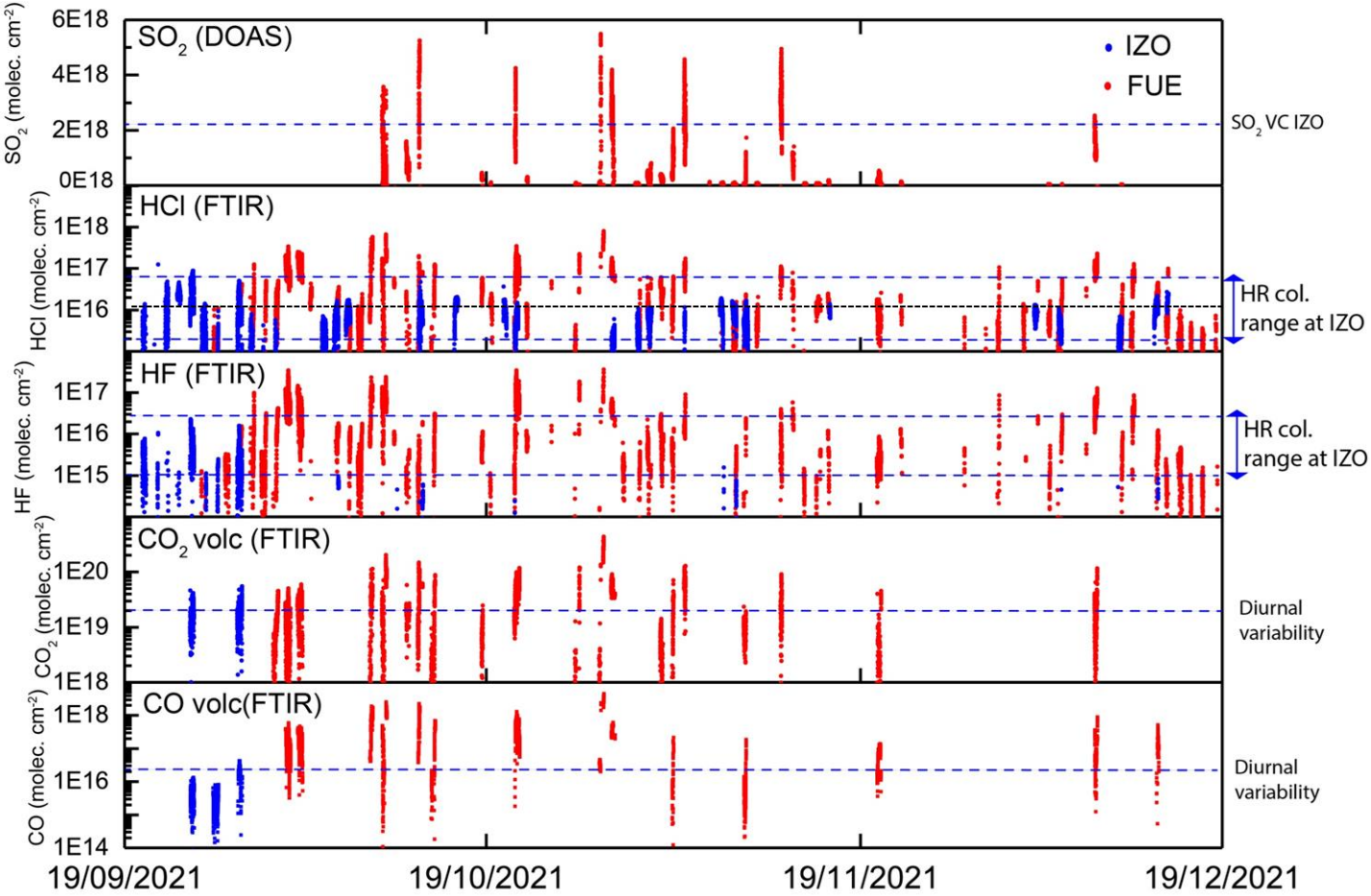


PROFFIT – 2022
(Standard NDACC and optimized products)

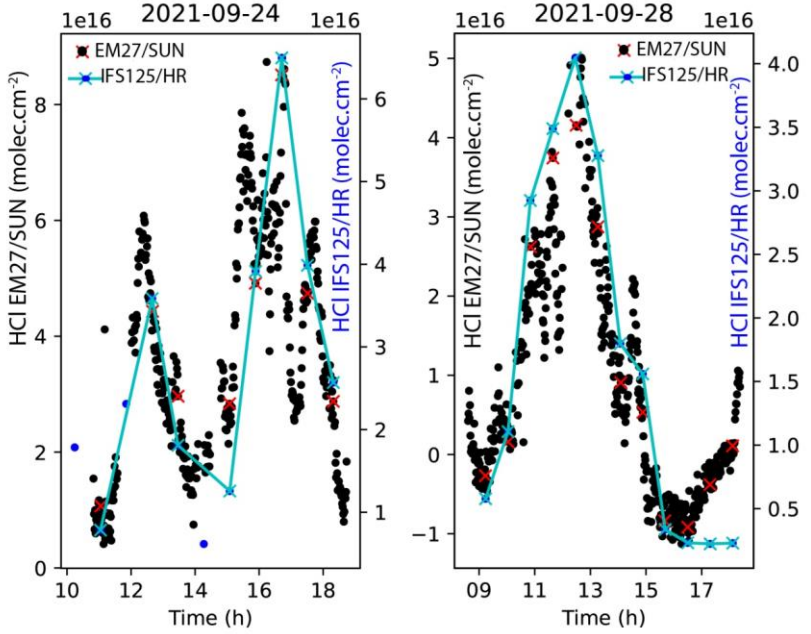
Days capturing volcanic plume: 9

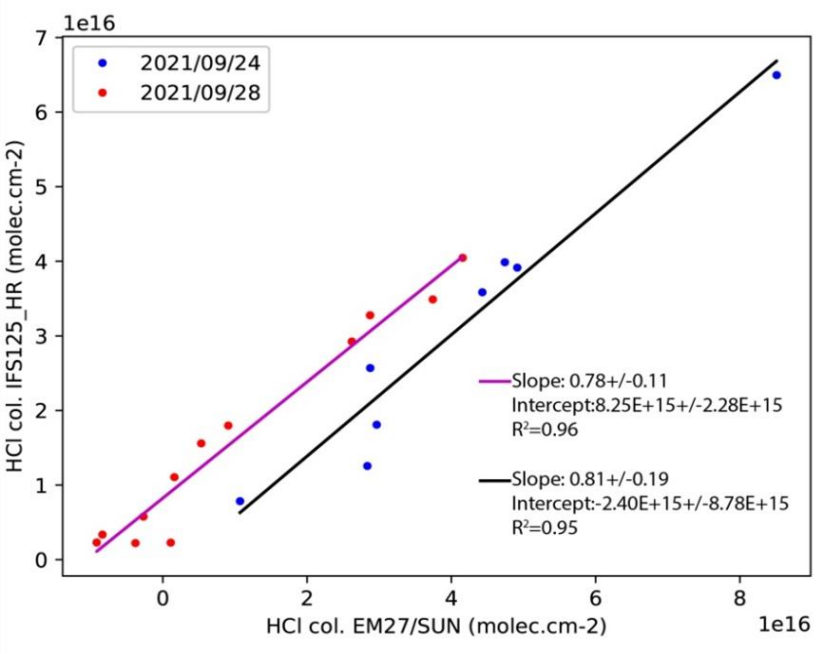


Volcanic columns at FUE and IZO: SO_2, HCl, HF, CO_2, CO



Preliminary intercomparison EM27/SUN & IFS 125HR at IZO: HCl Columns

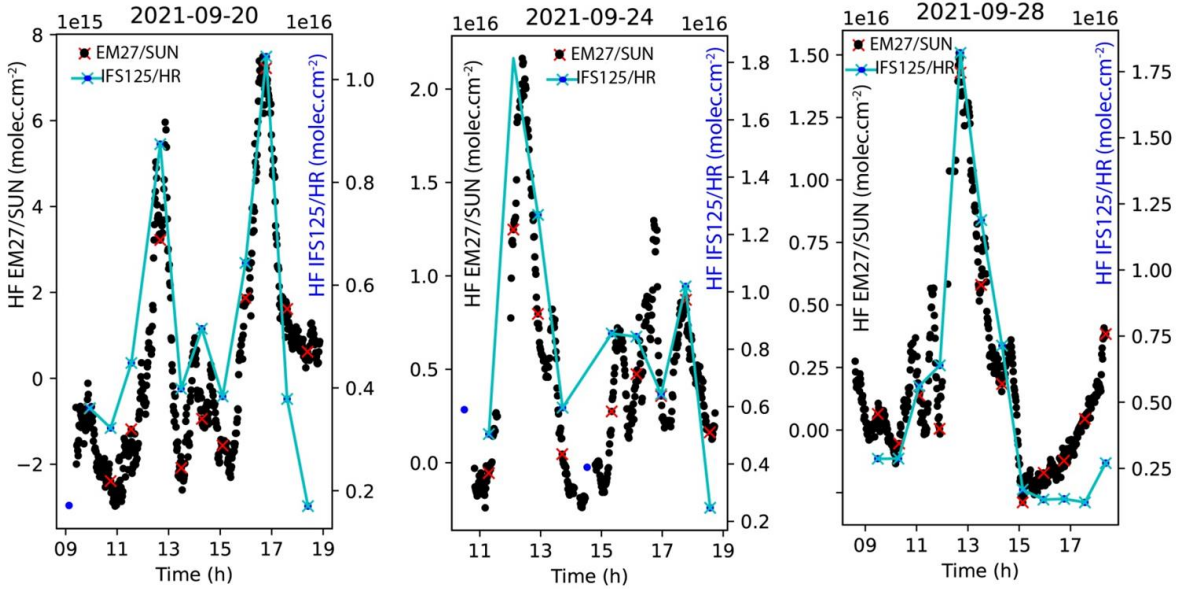




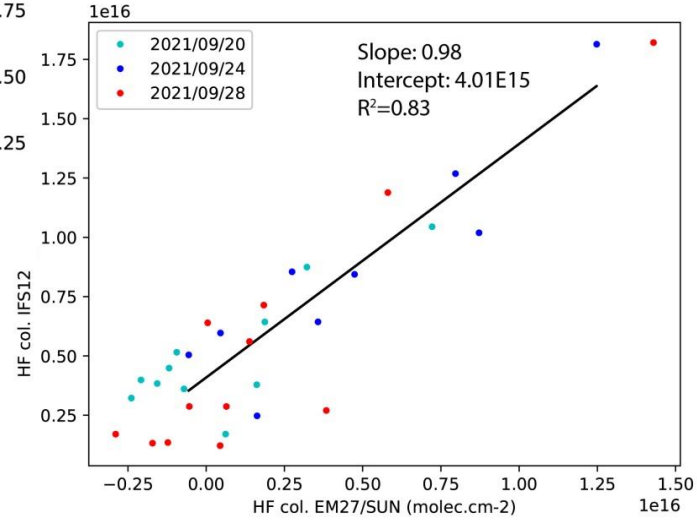
Different vertical sensitivities have not been considered (next step)

Factor $HCl_{HighRes}$/ HCl_{LowRes}: 0.8

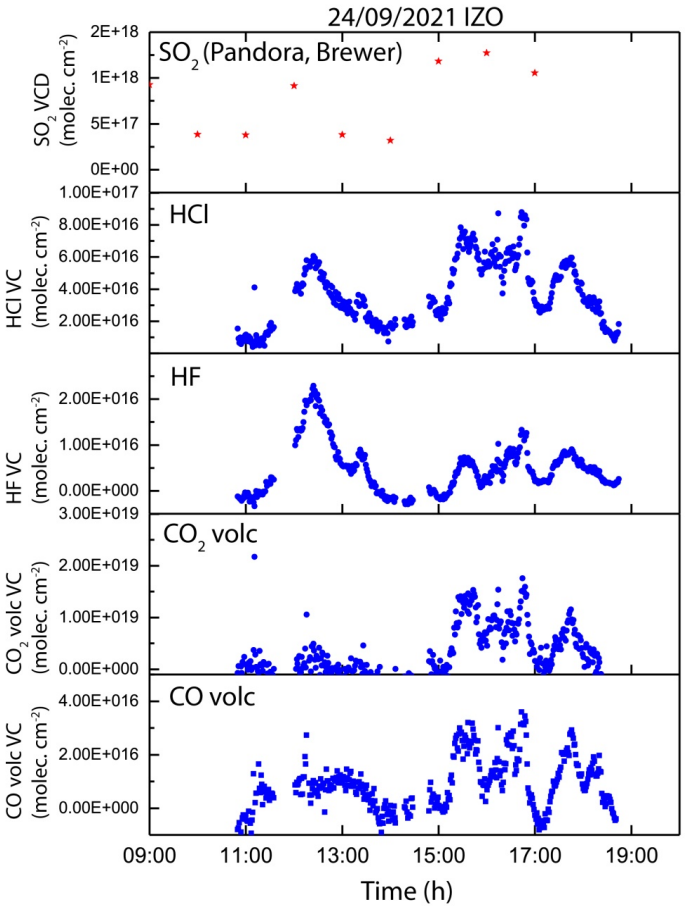
Preliminary intercomparison EM27/SUN & IFS 125HR at IZO: HF Columns

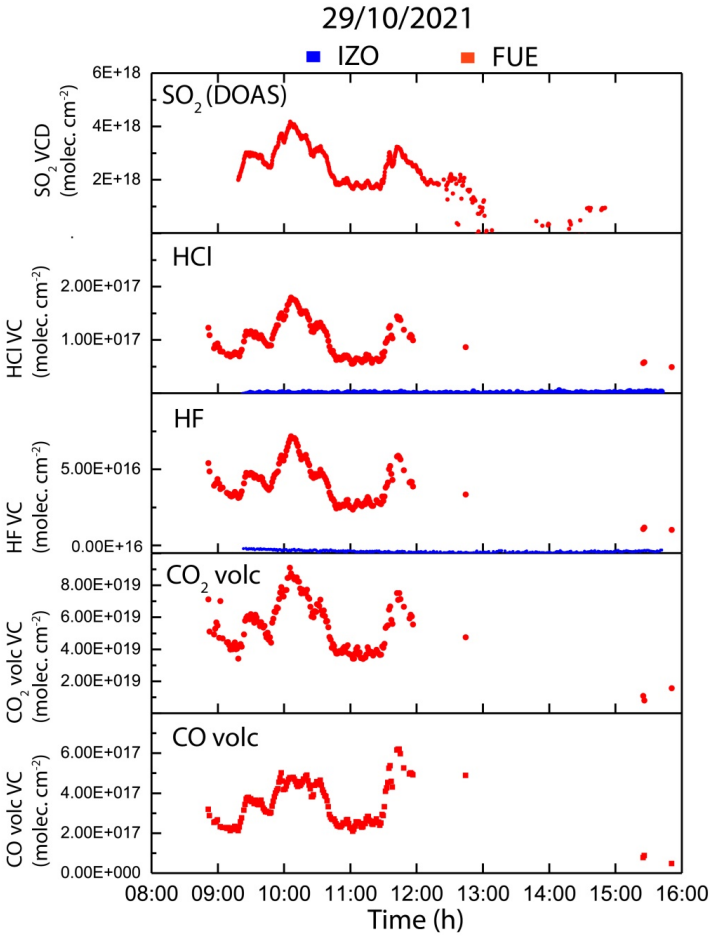


Factor $HF_{HighRes}$/ HF_{LowRes}: 0.98



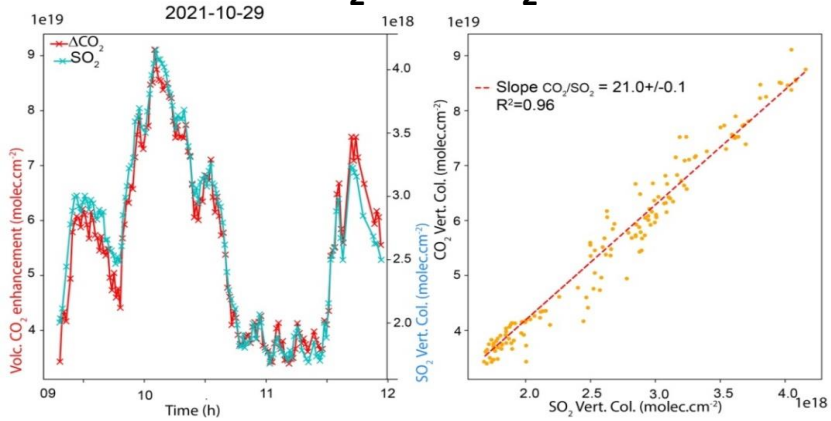
Examples of Volcanic plume detection at FUE and IZO



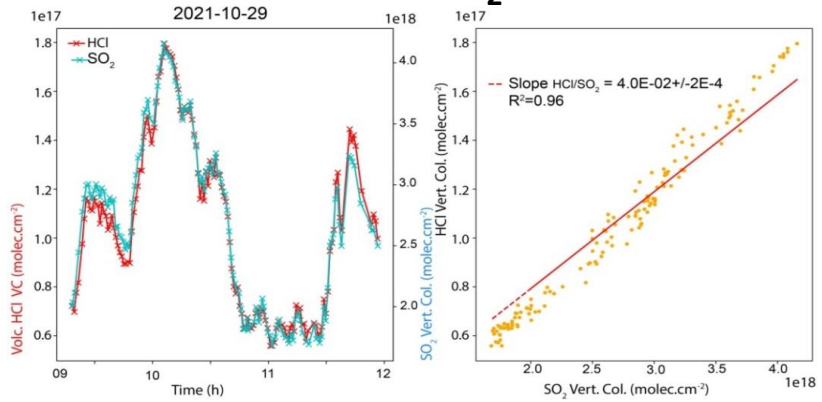


Calculation of ratios from daily correlation plots

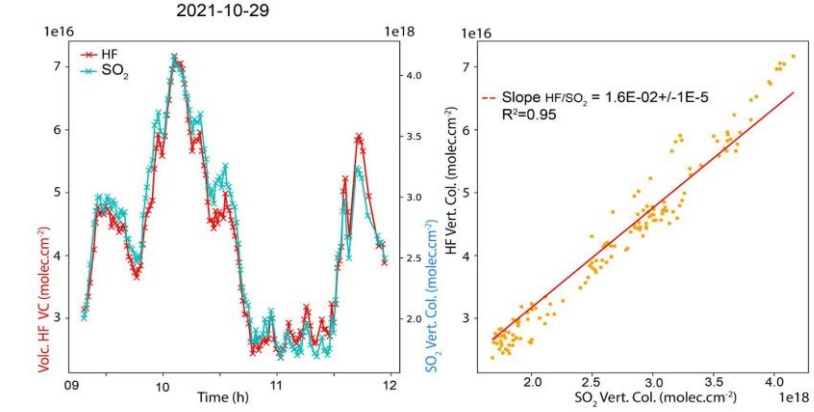
CO_2volc/SO_2



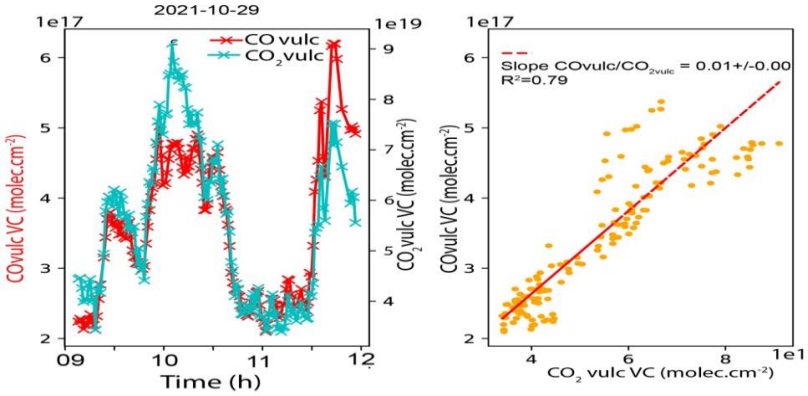
HCl/SO_2



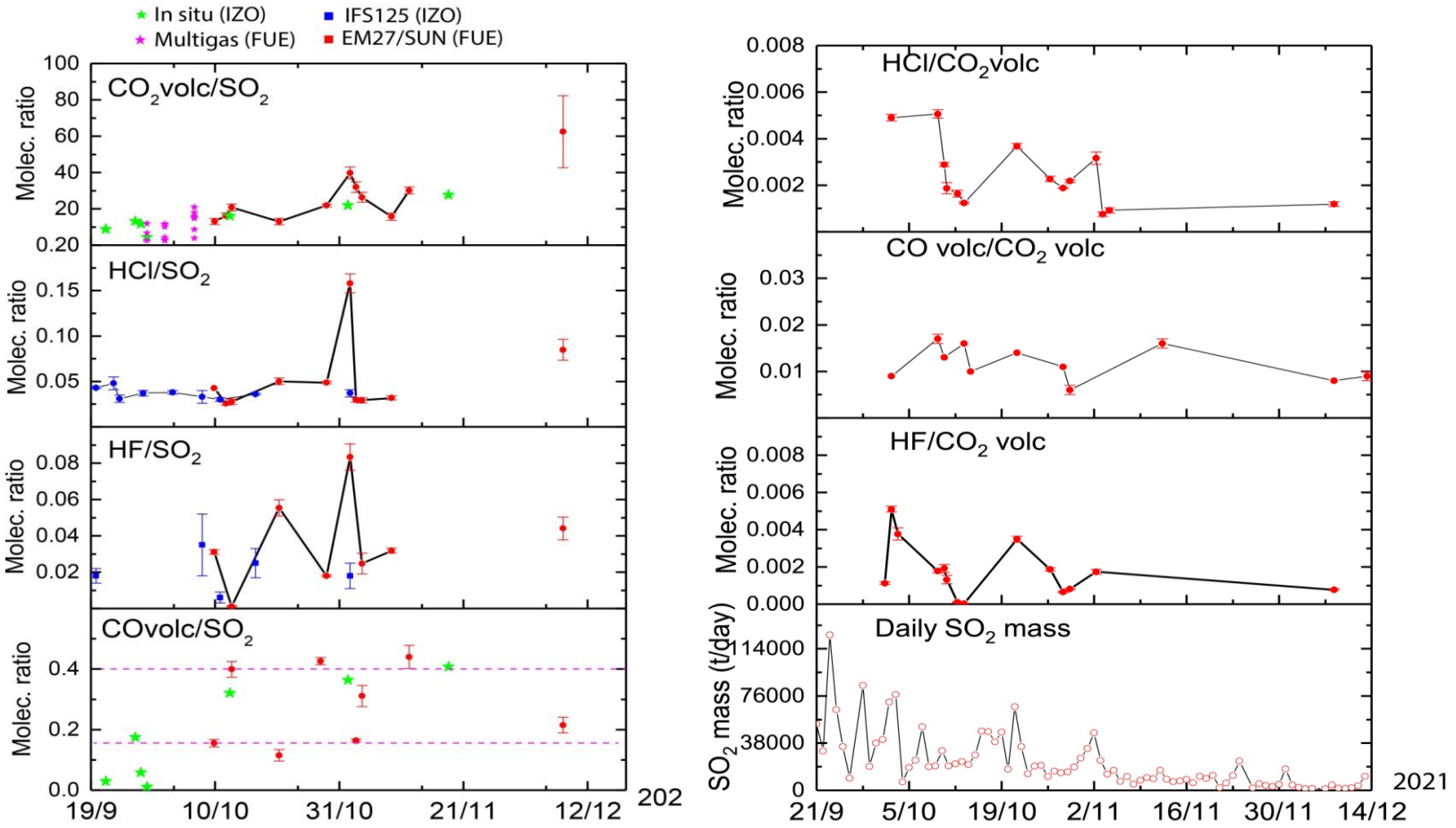
HF/SO_2



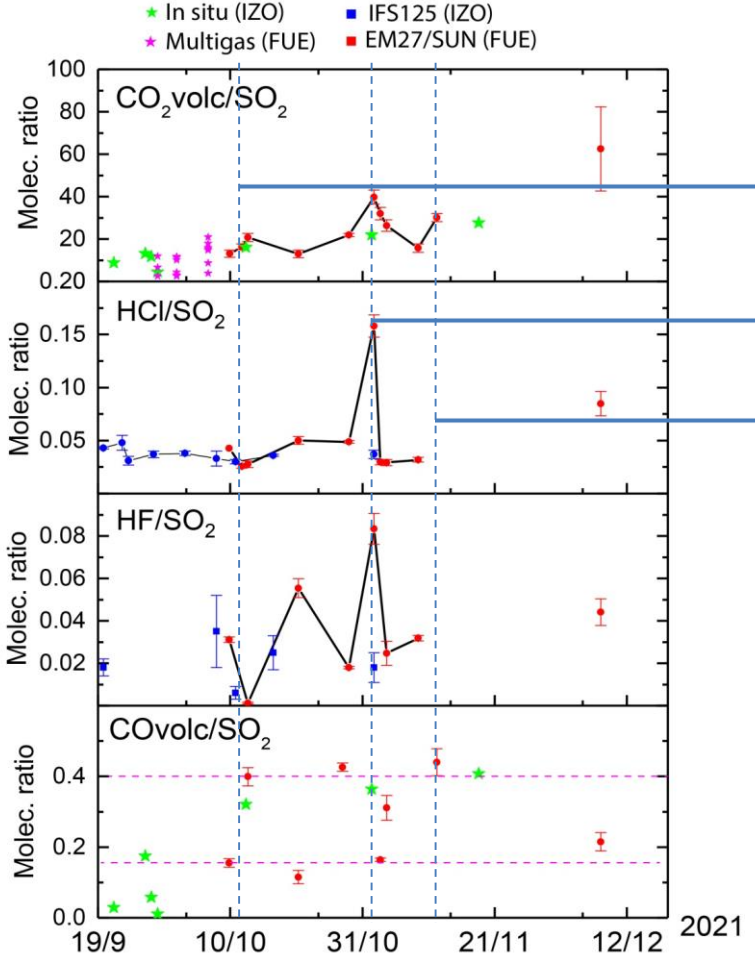
$COvolc/CO_2volc$



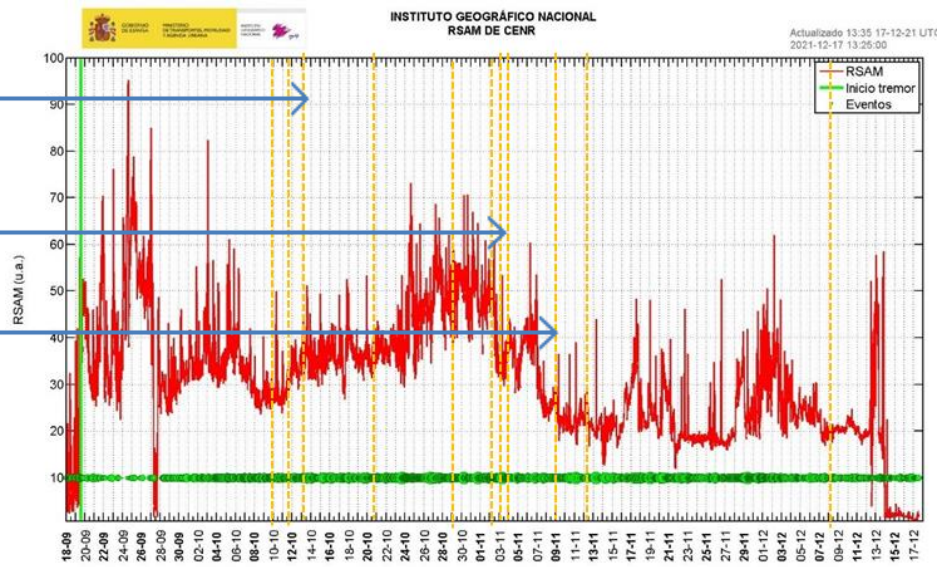
Variability of the volcanic gas ratios during the eruption



Variability of the volcanic gas ratios during the eruption



02/11/2021 RSAM (IGN)

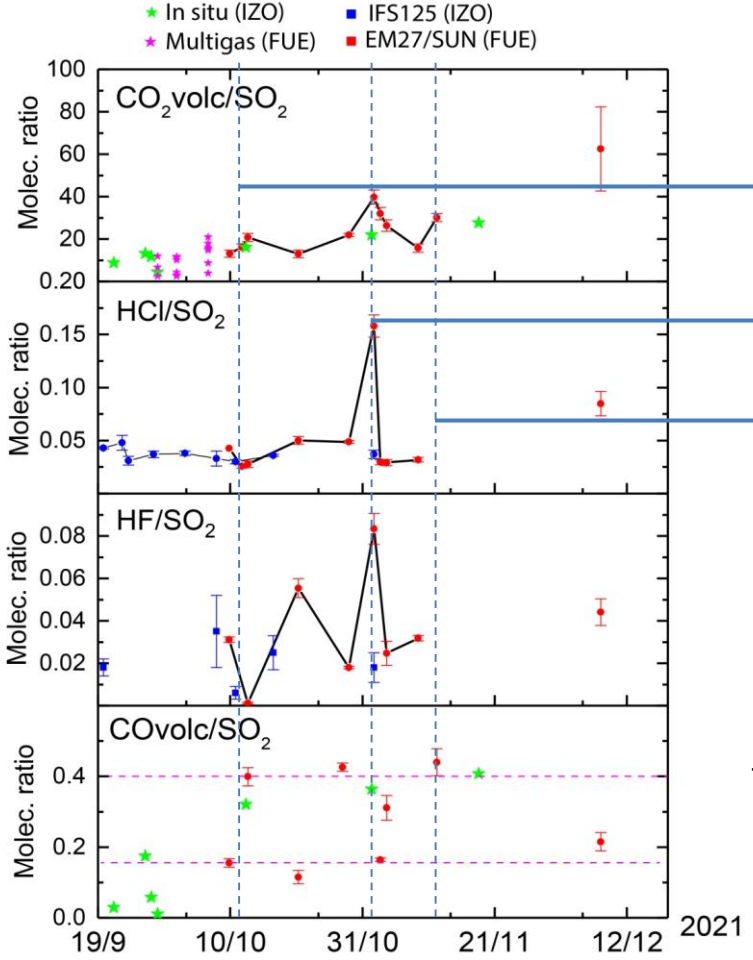


Variation of CO_2/SO_2 & HCl/SO_2 with the seismic signal

CO/SO_2: 2 ranges = 2 different sources?

- Volcanic CO
- Greenhouses & biomass burning (due to lava flows)

Variability of the volcanic gas ratios during the eruption



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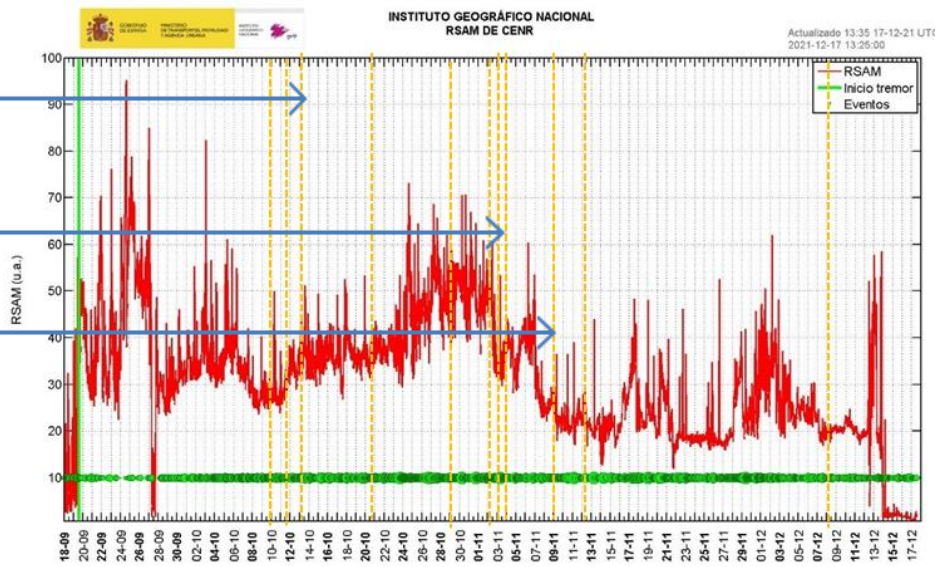


Preliminary Estimation of Halogen & CO_2 Emissions

Total SO_2 amount released: 1.84 Mt

HCl/SO_2 mean = 0.03 (mass ratio)

CO_2/SO_2 mean= 26 (mass ratio)

Estimated HCl emissions: ~ 40 kt

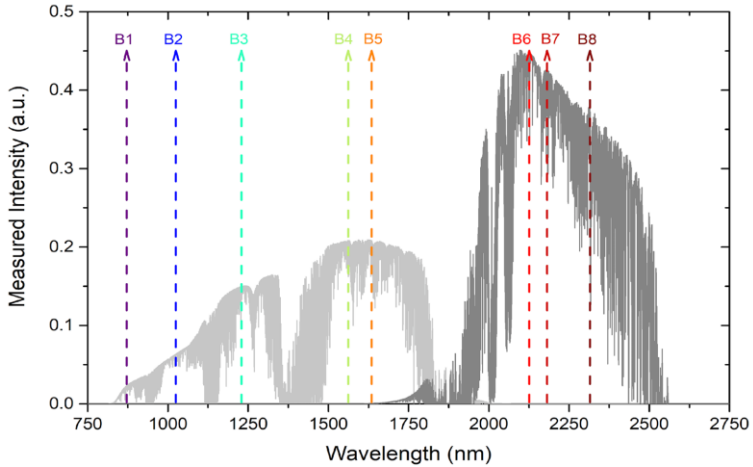
Estimated CO_2 emissions :
~from 11 to 30 Mt

Aerosol Retrievals from EM27/SUN

Aerosol products can be used as **proxy for atmospheric chemistry** (CO/SO_2: 2 ranges = 2 different sources Volcanic CO or GHG/biomass burning (due to lava flows))

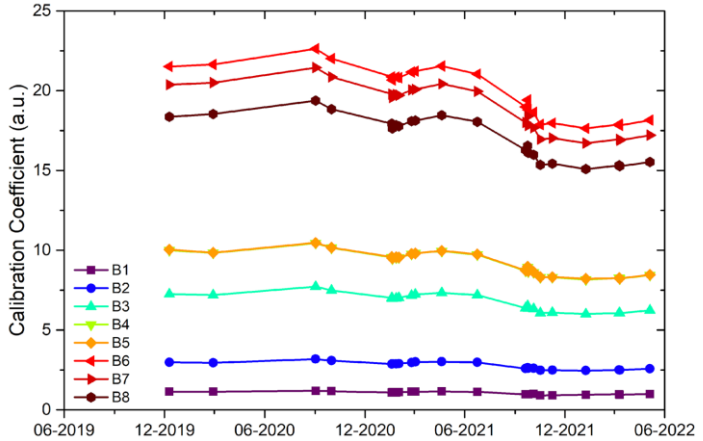
Spectral Aerosol Opticl Depth (AOD)

8 Micro-Windows (very high solar transmission)



- 872.55 nm
- 1020.90 nm
- 1238.25 nm
- 1558.25 nm
- 1636.00 nm
- 2133.40 nm
- 2192.00 nm
- 2314.20 nm

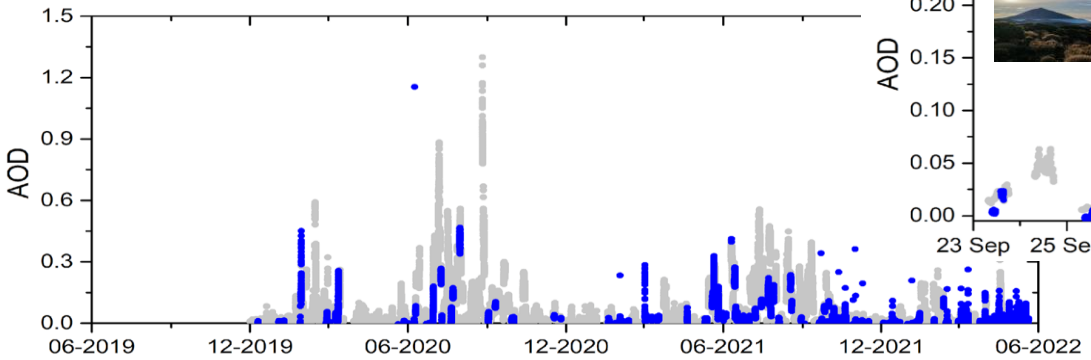
Absolute calibration: continuous Langley-Plot (IZO)

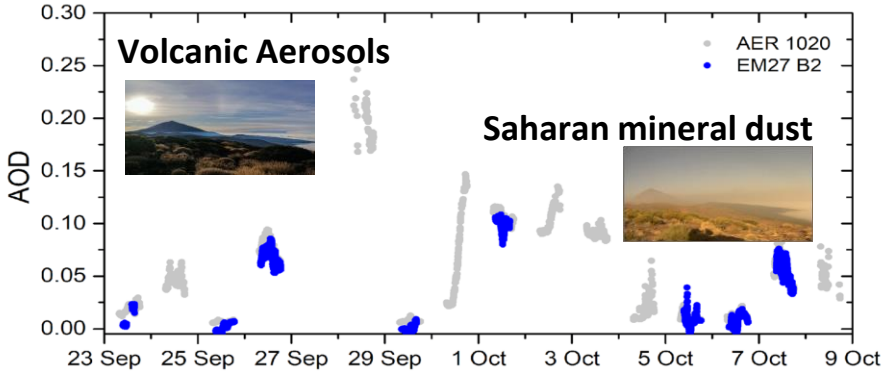


Linear degradation rate of ~0.5%month^{-1}!
(exposed parts of the EM27/SUN solar tracker)

Aerosol Retrievals from EM27/SUN

Long (2.5 years) Spectral AOD retrievals at IZO

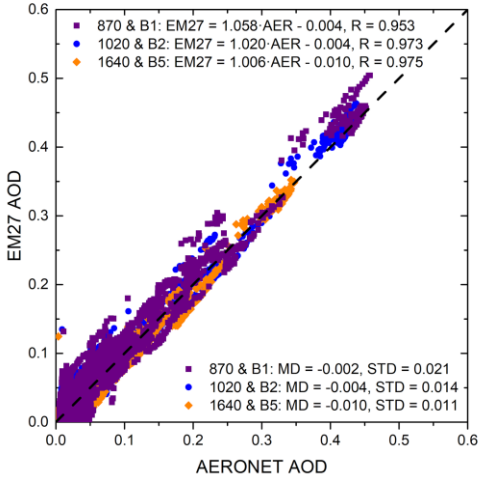




Validation with Co-located AERONET AOD

Excellent correlation for all the AOD range and three common channels

EM27/SUN AOD shows a positive bias of 6% and 2% for 870 and 1020 nm (calibration, gases correction, detector?)



Summary and Outlook

(1) Different tests are still pending, however the **excellent agreement** between DOAS, EM27/SUN, IFS 125HR points to reliable volcanic SO2, HCl, HF, CO, CO2 measurements!!

(2) **Volcanic gas ratios** (CO2/SO2, HCl/SO2, HF/SO2, CO/SO2) allow the evolution of the **volcanic process** to be characterized and estimate the **total gas emissions**:

Variation of CO_2/SO_2 & HCl/SO_2 with the seismic signal

CO/SO_2: 2 ranges = 2 different sources (volcanic CO or GHG & biomass burning due to lava flows)?

Total SO_2 amount released: 1.84 Mt

HCl/SO_2 mean = 0.03 (mass ratio)

CO_2/SO_2 mean= 26 (mass ratio)

Estimated HCl emissions: ~ 40 kt

Estimated CO_2 emissions : ~ from 11 to 30 Mt (maximum estimation)

(3) Low-resolution **COCCON instruments** are suitable for detecting the **aerosol** NIR broadband signal and for retrieving **precise gas concentrations** (multi-parameter capability)

Many thanks!!!!


AEMet
Agencia Estatal de Meteorología
UPC
INTA
Sieltec Canarias
Tragsa
MeteoSwiss
INFN
VAISALA
GIMEL
CSIC
PALAS
UNIVERSIDADE BEIRA INTERIOR
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