This work has been partially supported by the EU 7th Framework Program under the grant 603557 (StratoClim)

Sensitivity of TIR nadir satellite instruments to the chemical and micro-physical properties of UTLS sulphate aerosols

Pasquale Sellitto, Geneviève Sèze, Bernard Legras
Laboratoire de Météorologie Dynamique, IPSL, CNRS-École Normale Supérieure, Paris, France

psellitto@lmd.ens.fr

2nd SPARC SSiRC Workshop,
Potsdam, Germany - 25-28 April 2016

SSiRC
Stratospheric Sulfur and its Role in Climate

Introduction and motivation

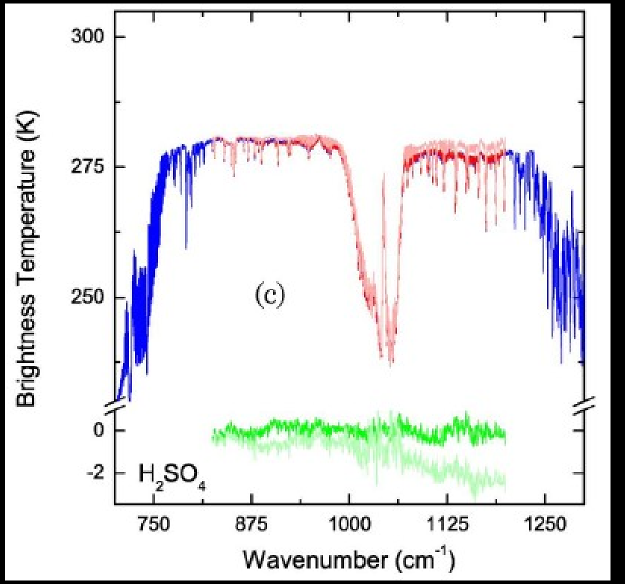
Nadir instruments have better spatio-temporal resolution and coverage than limb → regional scale, process studies

Satellite observation of SSA using nadir instruments is limited

Opportunity: exploit the sensitivity of TIR observations to chemical composition → spectral variability of $\Im(n)$ in the TIR as a function of chemical composition

Connect the SSA TIR signature to composition – $\Im(n)$ – and microphysics – size distribution

Study to connect empirical observations of SSA spectral signatures (Pinatubo observations, IASI recent literature, etc) to SSA optical properties: a better knowledge to better use the observations
Estimate the sensitivity of different instruments



[Clarisse et al., AO, 2010]

SSiRC
Stratospheric Sulfur and its Role in Climate

Data and methodology

Complex refractive indices for binary systems of H_2SO_4 / H_2O solutions, with H_2SO_4 mixing ratios between 10 and 80% and temperatures between 183 et 293 K, taken from *.
Data available at the website: *http://www.pole-ether.fr/geisa/*

* [Biermann et al:, JPCA, 2000]

Refractive indices H_2SO_4 / H_2O

Size Distribution: uni-modal log-normal

Mie code

Mie code *developped by the Earth Observation Data Group, Physics Department, University of Oxford. (www.atm.ox.ac.uk/code/mie/)*

Optical prop. of sulphate aerosols: B_{abs} B_{sca} SSA, phase function, asymmetry par.

Altitude of the aerosol layer: 150 hPa

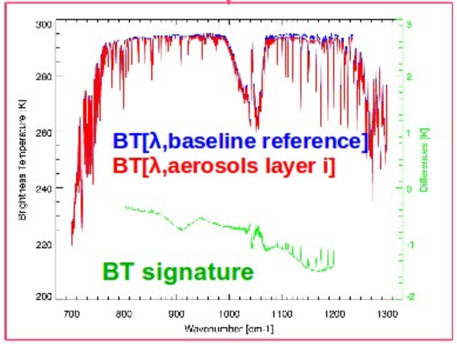
Typical tropical atmosphere: vertical pressure, temperature and gas concentration profiles

4A/OP *developed by LMD and NOVELTIS, with the support of CNES (http://4aop.noveltis.com/)*

Radiative transfer forward model

IASI instr. simulation: ISRF, radiometric noise, nadir observations

Pseudo-observations: IASI BT spectra



$$n(r)=N_0\frac{1}{\sqrt{2\pi}\ln(\sigma_r)\,r}\,e^{-\frac{1}{2}\left(\frac{\ln(r/r_m)}{\ln(\sigma_r)}\right)^2}$$

σ_r=1.86 µm (fixed)

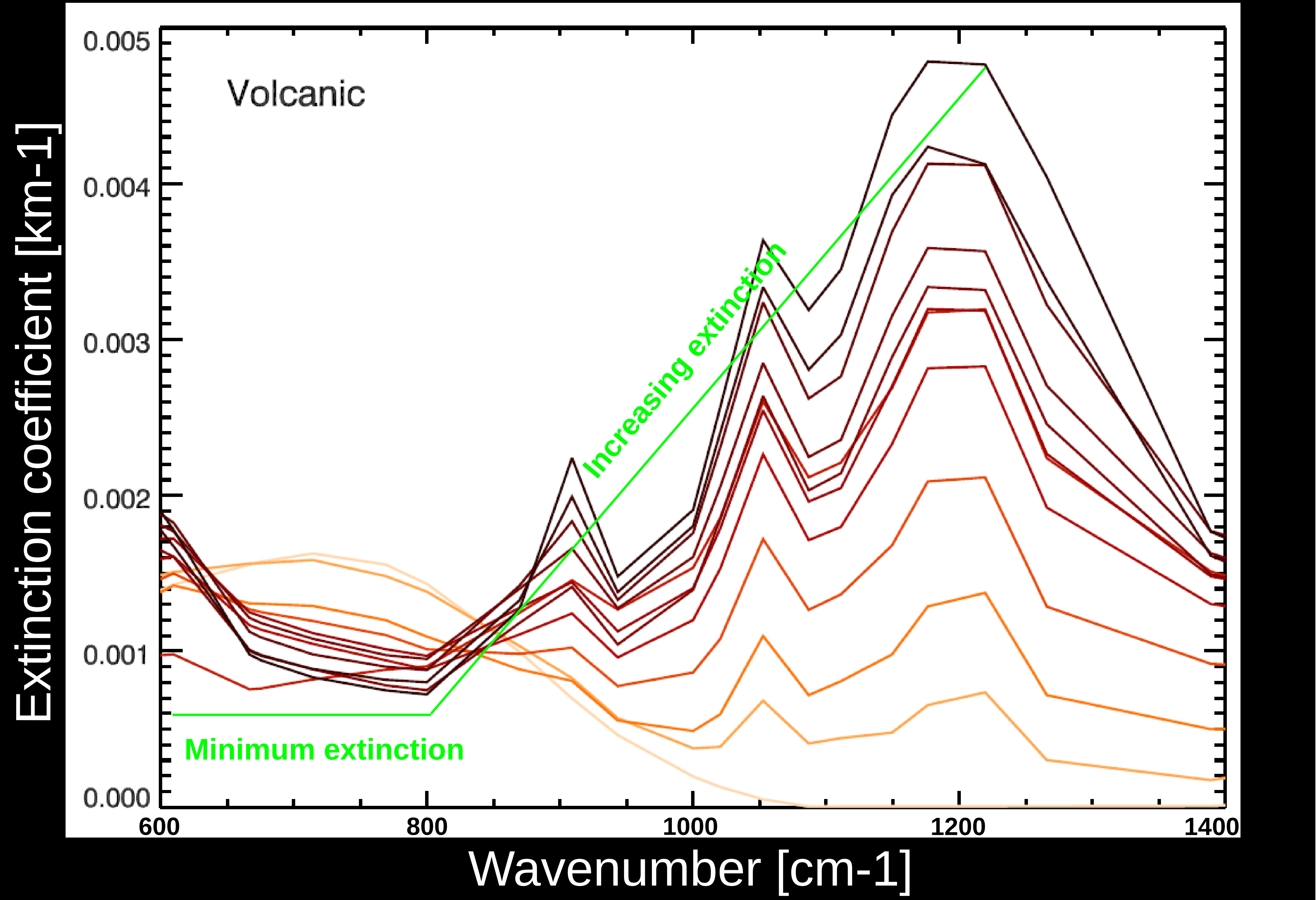
N_0[µm]	N_e[µm]
8	2.52
9	2.83
10	3.15
12	3.78
15	4.72
20	6.30
25	7.87
30	9.45

r_m[µm]	r_e[µm]
0.06	0.16
0.07	0.18
0.08	0.21
0.10	0.26
0.15	0.39
0.20	0.52
0.30	0.79
0.40	1.05

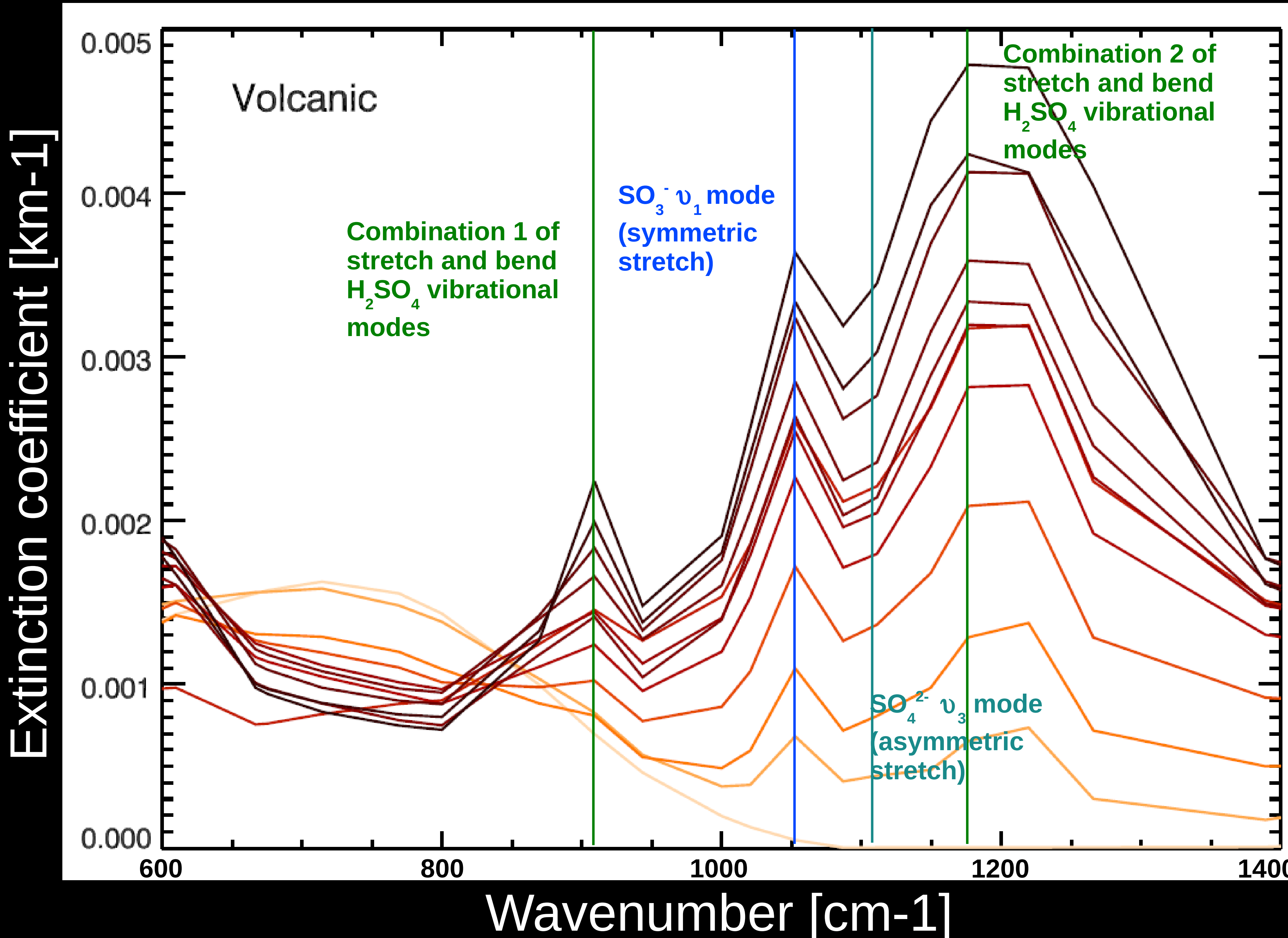
Output: Hundreds of BT IASI (pseudo-observations) → variable [H_2SO_4], T , N_e, r_e

IASI pseudo-observations compared with a baseline simulation (no UTLS aerosols)

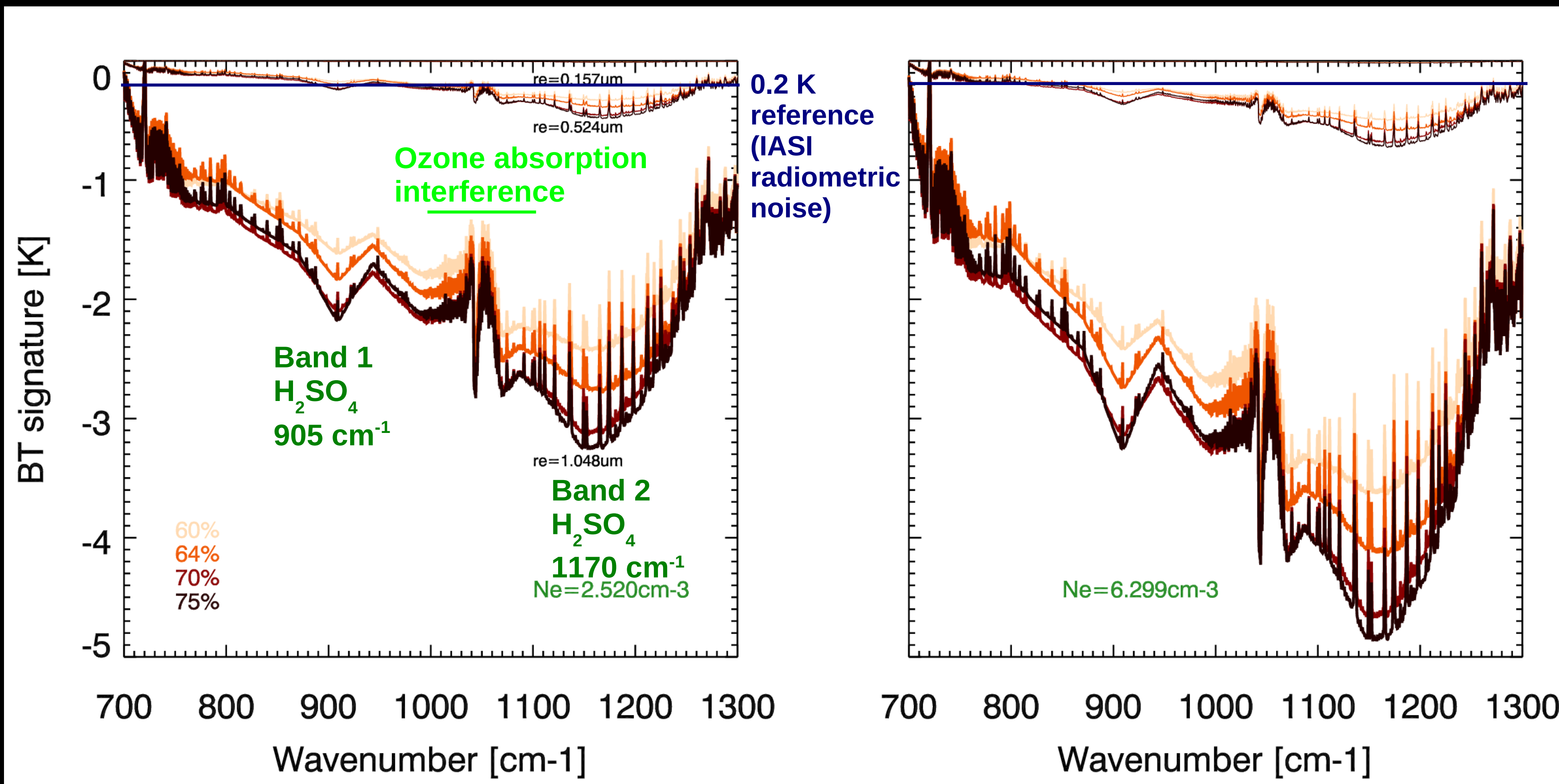
SSA spectral signature



SSA spectral signature



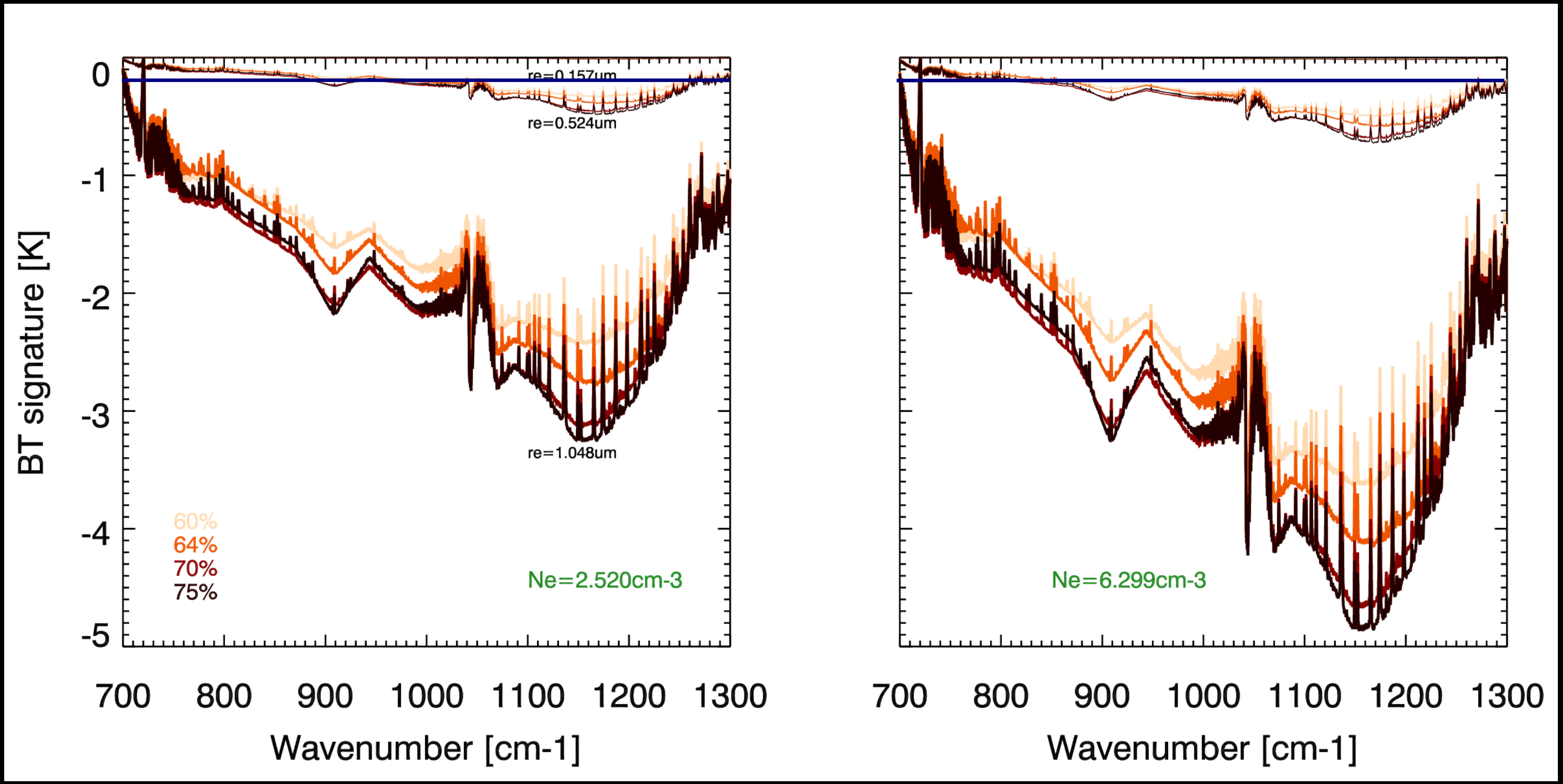
BT HR pseudo-observations variability wrt chemical and micro-physical properties of SSA



BT signature$_i$ (λ) = BT (λ, aerosol layer i ($[H_2SO_4]^i$, N_e^i, r_e^i)) – BT(λ, baseline)

Molecular/ionic bands → decreasing signature (increasing extinction) in the spectral range: 700 et 1200 cm^{-1}

BT HR pseudo-observations variability wrt chemical and micro-physical properties of SSA



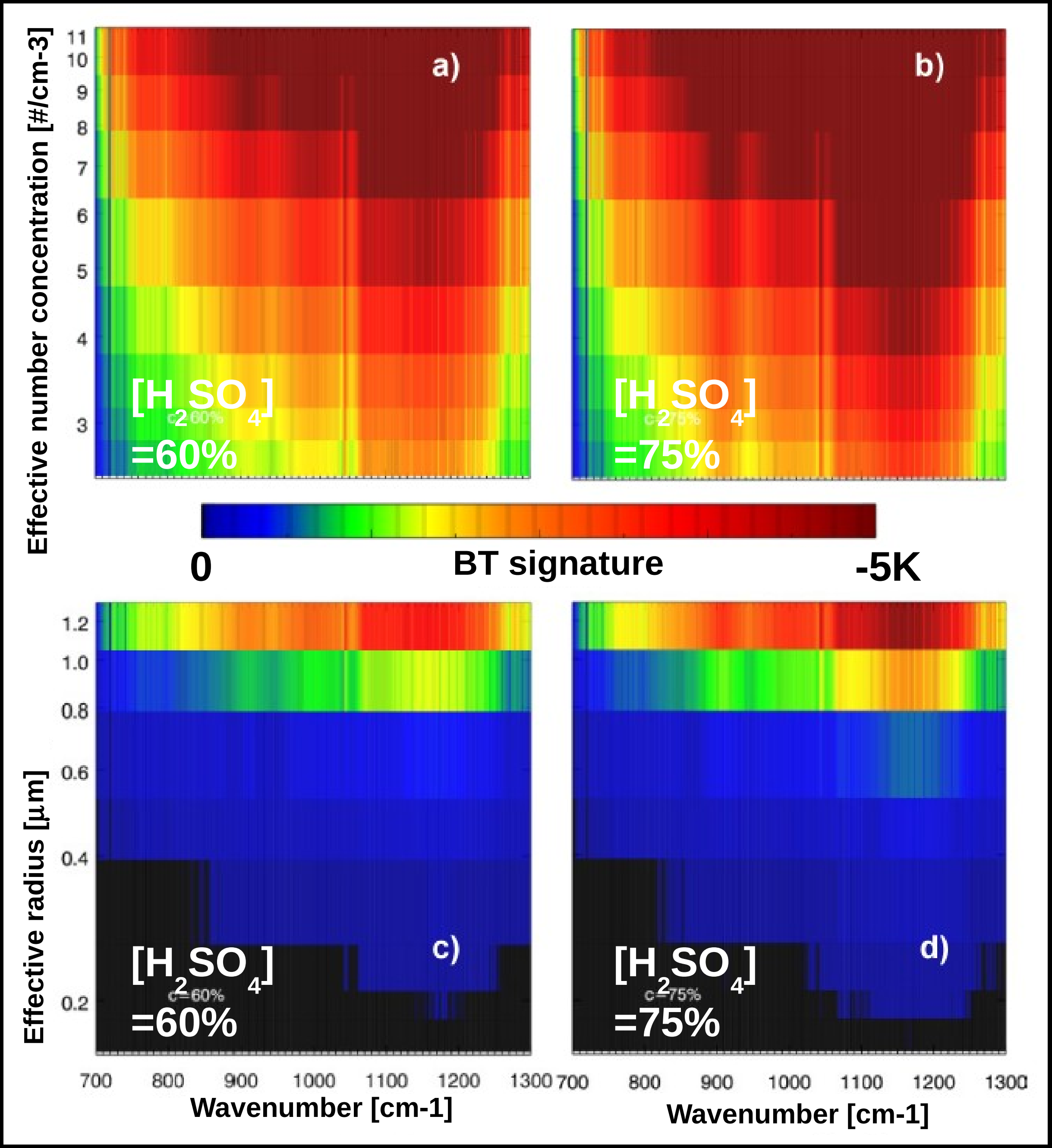
Ionic absorption bands - υ_1 SO_3^- (1050 cm^{-1}) and υ_3 SO_4^{2-} (1110 cm^{-1}) – hardly usable because of the interference with the ozone band @ 9.6 µm (1042 cm^{-1}) → fundamental limitation for the SSA observation in background condition (ionic signature dominant)

Weaker water vapour bands affect the signature → spectral micro-window selection to limit uncertainties

Small signature for background conditions → comparable to radiometric noise

Condition to have strong spectral signatures: bigger r_e → BT signature up to 3 to 5 K

BT HR pseudo-observations variability wrt chemical and micro-physical properties of SSA



r_e=0.79 µm

(r_m=0.30 µm)

r_e dominant parameter

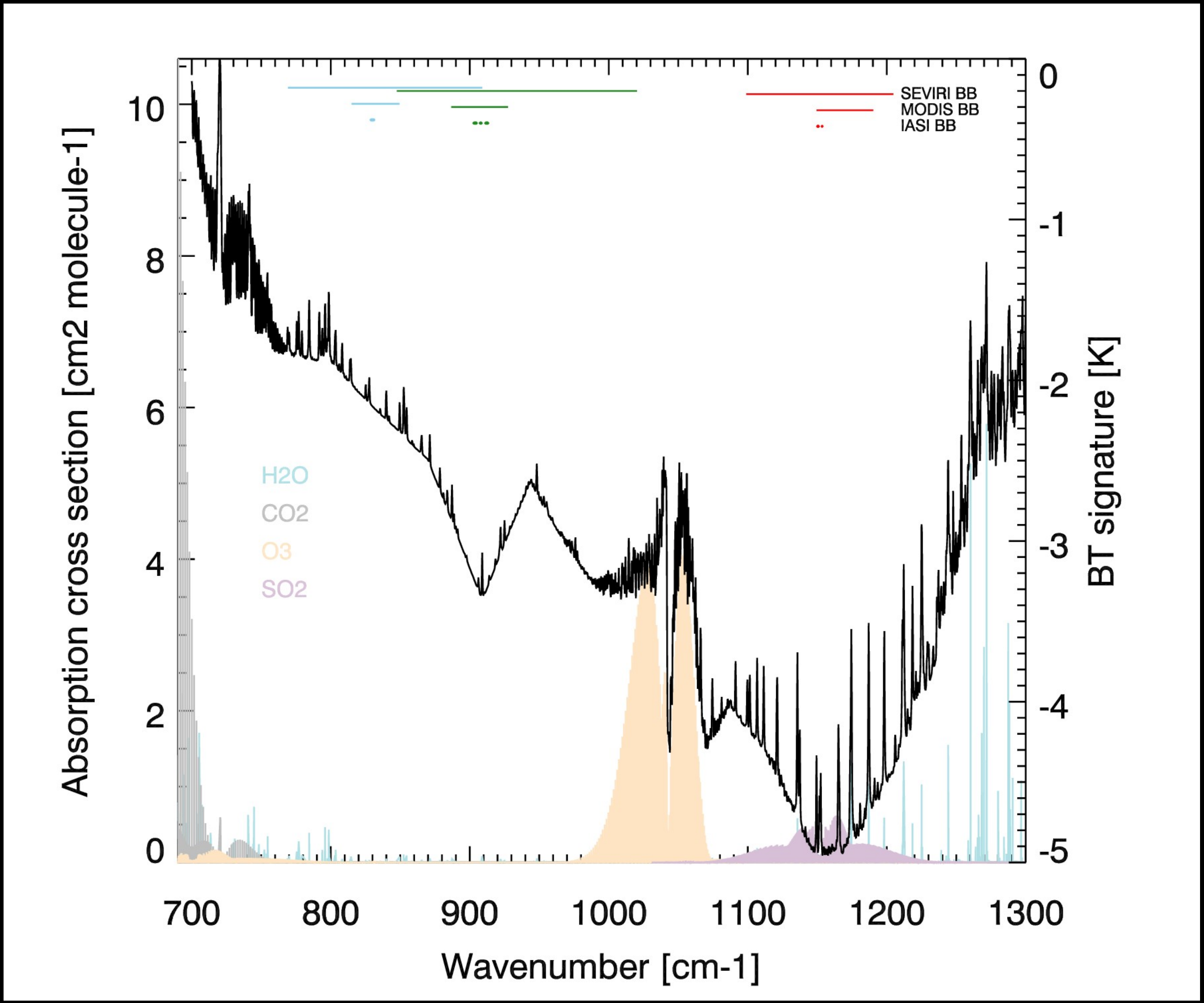
stronger variability,

BT signature (~1150 cm^{-1}) > 0.5 K only for r_e >~0.6 µm (moderate to severe volcanic conditions)

N_e=7.87 #/cm^3

(N_0=25 #/cm^3)

Interfering parameters



O_3: limiting factor in using ionic bands

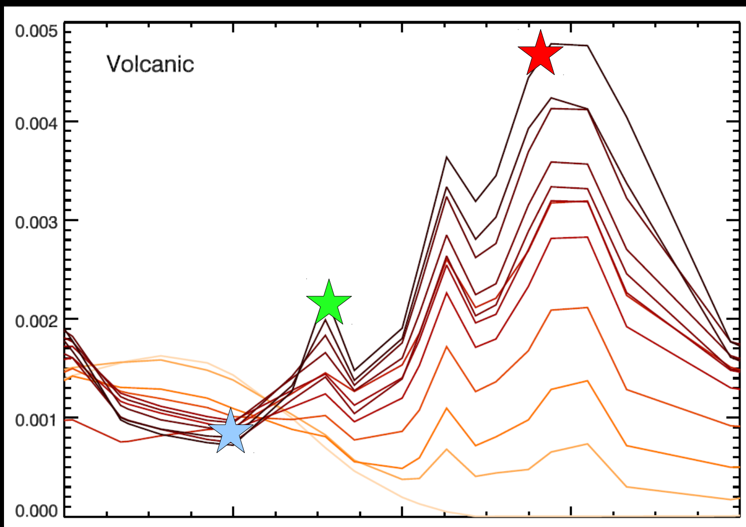
H_2O: careful selection of spectral micro-windows

SO_2: interference @ maximum SSA signature

CO_2: not important

Ash (not shown here): different signature, similar magnitude as volcanic SSA

Broad-band features



ME = B_{ext} (1170 cm^{-1})

RE1 = B_{ext} (1170 cm^{-1}) / B_{ext} (800 cm^{-1})

RE2 = B_{ext} (905 cm^{-1}) / B_{ext} (800 cm^{-1})

ME function of r_e, N_e, [H_2SO_4]

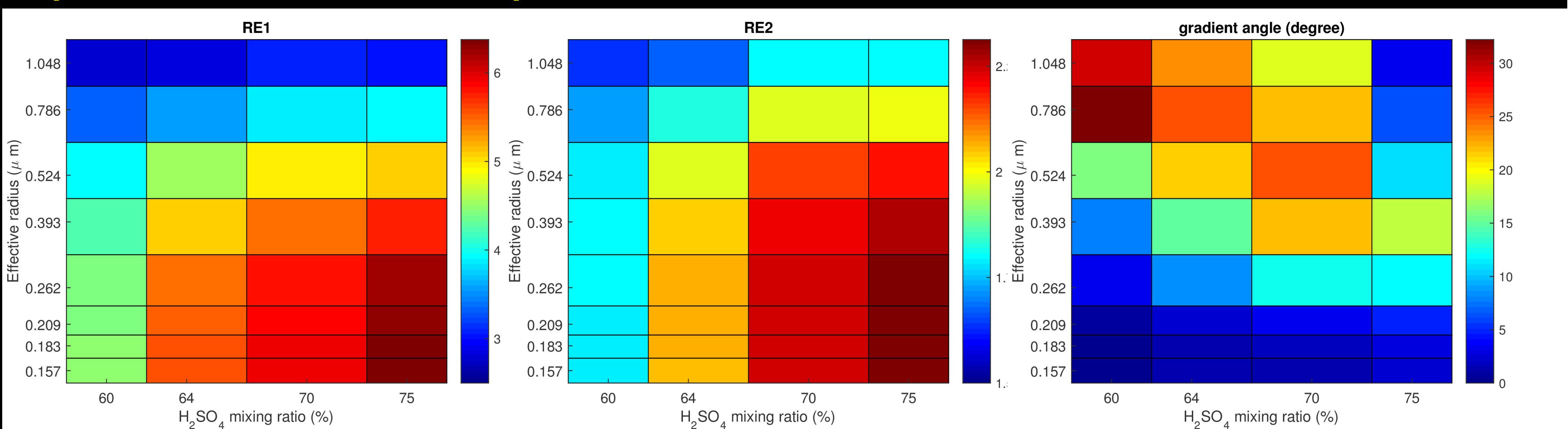
RE1 and RE2 independent on Ne

ME larger for larger r_e, N_e, [H_2SO_4]

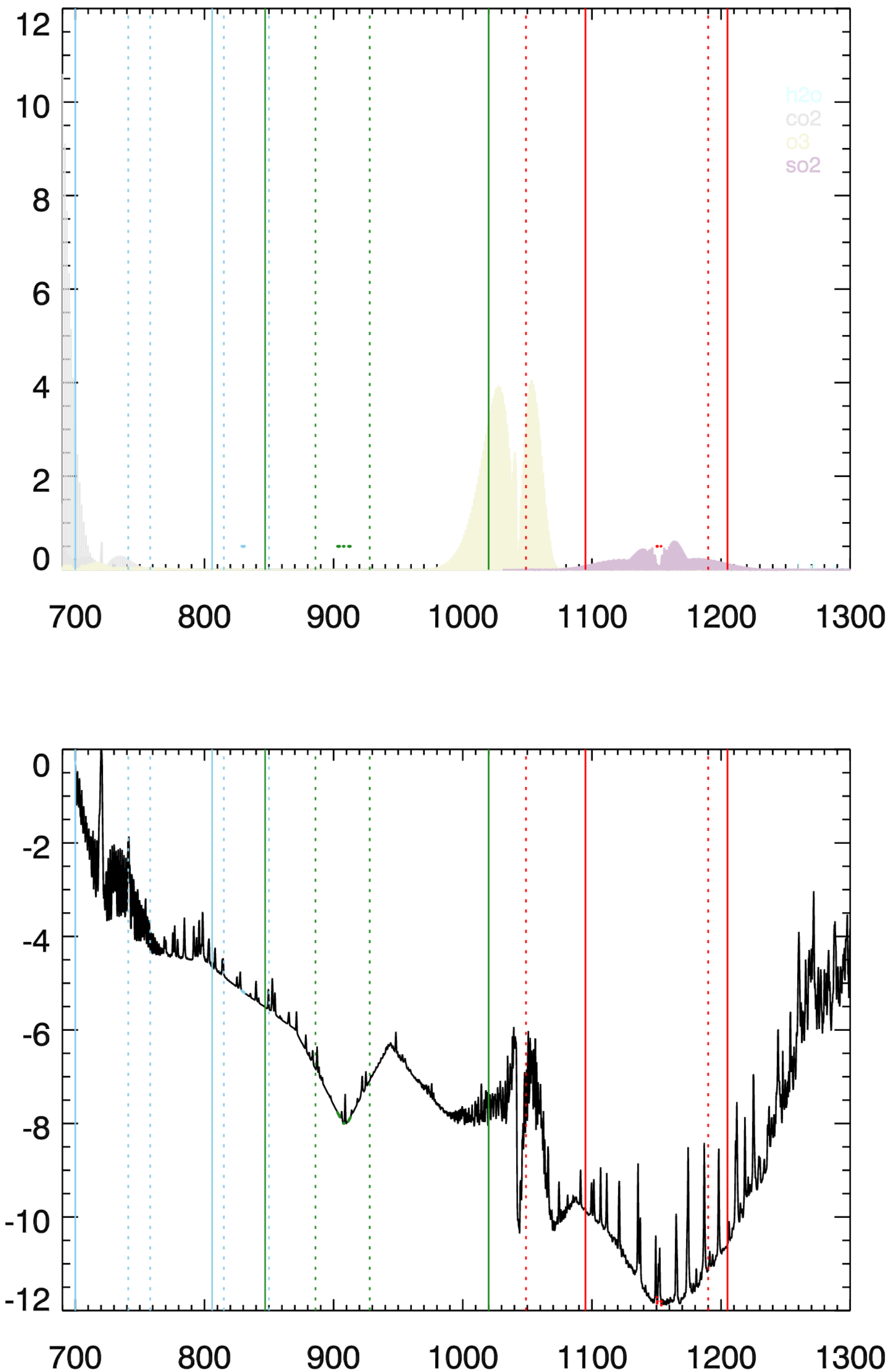
RE1 and RE2 smaller for larger r_e

RE1 and RE2 IC (∇RE1,2) strongly correlated for extreme r_e and [H_2SO_4]

The 3 BB features exploitable for SSA characterization but constraints are necessary (also in volcanic conditions)



Interference in BB and HR approaches



SEVIRI Ch10 (12 µm)
SEVIRI Ch9 (10.8 µm)
SEVIRI Ch7 (8.7 µm)

MODIS Ch32
MODIS Ch31
MODIS Ch29

SEVIRI and MODIS have channels to construct BB features (ME, RE1 and RE2) but may suffer contamination by interfering absorbing species

IASI allows dedicated spectral micro-windows selection or HR spectral fitting approaches

Information content

for high spectral resolution and broad-band features approaches

DOF and total error for the retrieved vector [N_e, r_e, c] (based on Rodger's optimal estimation theory)

HR=high spectral resolution
BB=broad-band spectral features

Bg=background conditions
Volc=volcanic conditions

	IASI HR	IASI BB	MODIS BB	SEVIRI BB
Bg	1.34	0.24	0.22	0.01
Volc	2.70	2.41	2.11	1.48

	IASI HR			IASI BB			MODIS BB			SEVIRI BB		
	N_e	r_e	c	N_e	r_e	c	N_e	r_e	c	N_e	r_e	c
Bg	> 100	37.1	35.9	> 100	> 100	81.0	> 100	> 100	> 100	> 100	> 100	> 100
Volc	30.4	17.6	10.8	80.2	28.1	11.5	81.6	28.2	19.5	87.5	53.5	32.4

- **HR IASI-like pseudo-observations have sensitivity to partially characterize SSA, also in background conditions → IASI Bg+Volc observations feasible**
- **For volcanically-enhanced conditions, the added value of HR vs BB, is smaller than at background conditions.**
- **BB features are reasonably well adapted to characterise chemical and microphysical properties of sulfate aerosols in volcanic conditions → SEVIRI, MODIS Volc observations possible**

Conclusions

Characteristic SSA BT spectral signature between 700 and 1200 cm^{-1} → sulphate and bi-sulphite ionic absorption bands, sulphuric acid molecular absorption bands: increasing extinction + peaks at 1170 and 905 cm^{-1}

Spectral signatures weakly dependent on temperature (not shown)

Spectral signature up to -5.0 K (@1170 cm^{-1}) in volcanic-enhanced conditions: dependent on r_e, N_e, and [H_2SO_4]

Sensitivity dominated by the r_e

Background SSA hardly observable: small signatures, ozone band interference → partly uncorrelated IC on r_e, N_e, and [H_2SO_4] only with HR (IASI)

Broad-band perspective (SEVIRI, MODIS):
BB features: ME, RE1, RE2 – Volcanically-enhanced SSA characterisation feasible

High spectral resolution perspective (IASI):
BB features: Spectral micro-windows selection to avoid gas interference,
HR: spectral fitting approaches to partially characterise
volcanically-enhanced and background SSA

Thank you for your attention!

Atmos. Meas. Tech., 9, 115–132, 2016
www.atmos-meas-tech.net/9/115/2016/
doi:10.5194/amt-9-115-2016

Atmospheric Measurement Techniques
Open Access
EGU

Sensitivity of thermal infrared nadir instruments to the chemical and microphysical properties of UTLS secondary sulfate aerosols

P. Sellitto and B. Legras

Laboratoire de Météorologie Dynamique (LMD), CNRS-UMR8539, Institut Pierre Simon Laplace, École Normale Supérieure, École Polytechnique, Université Pierre et Marie Curie, Paris, France

For more details:

P. Sellitto and B. Legras, Sensitivity of thermal infrared sounders to the chemical and micro-physical properties of UTLS secondary sulphate aerosols, AMT 9, 115-132, 2016

http://www.atmos-meas-tech.net/9/115/2016/amt-9-115-2016.pdf

StratoClim

CNRS

ENS

LMD

SSiRC
Stratospheric Sulfur and its Role in Climate