GNSS RO pushes forward the detection of volcanic clouds

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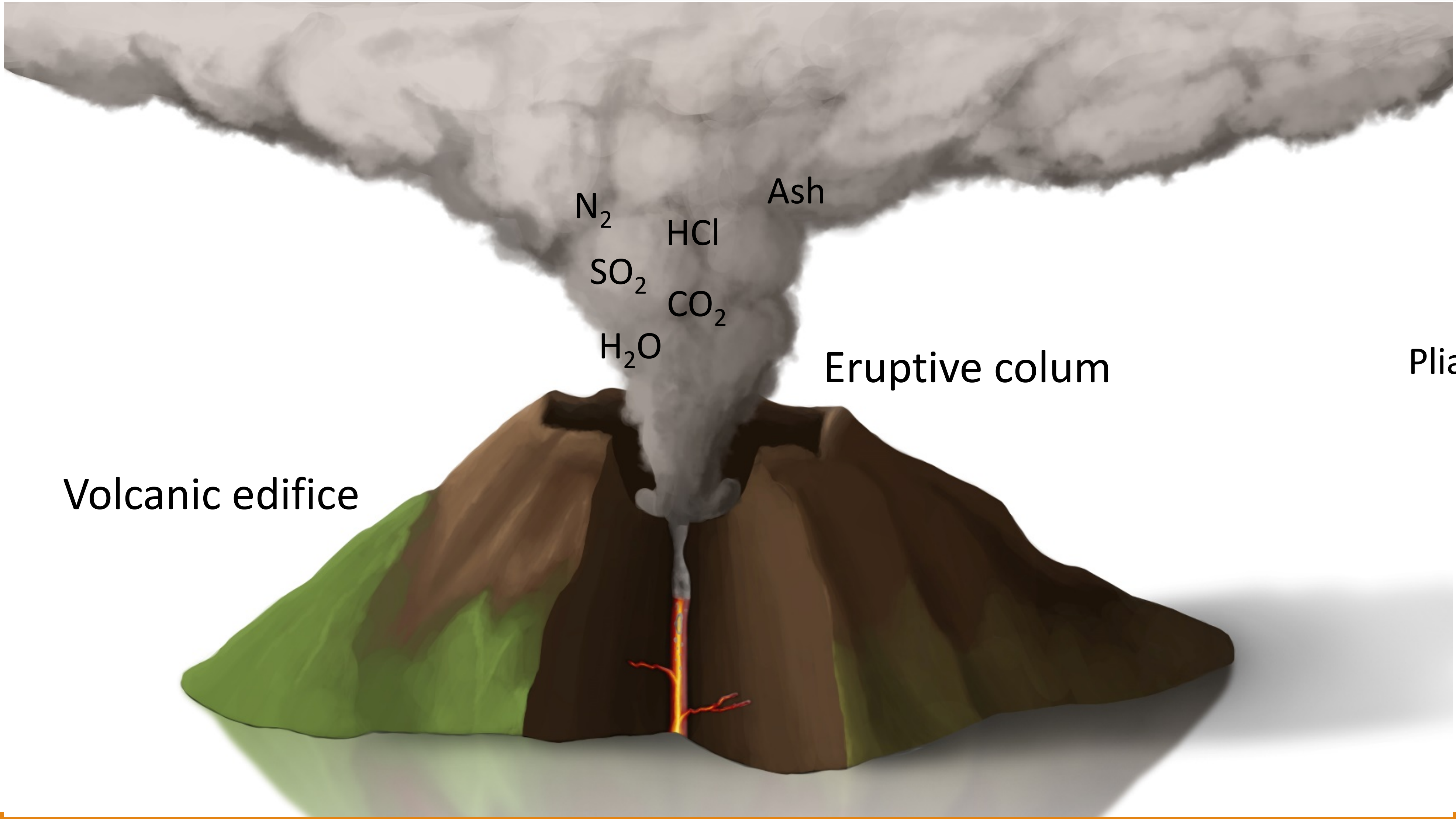
Volcanic eruptions and clouds

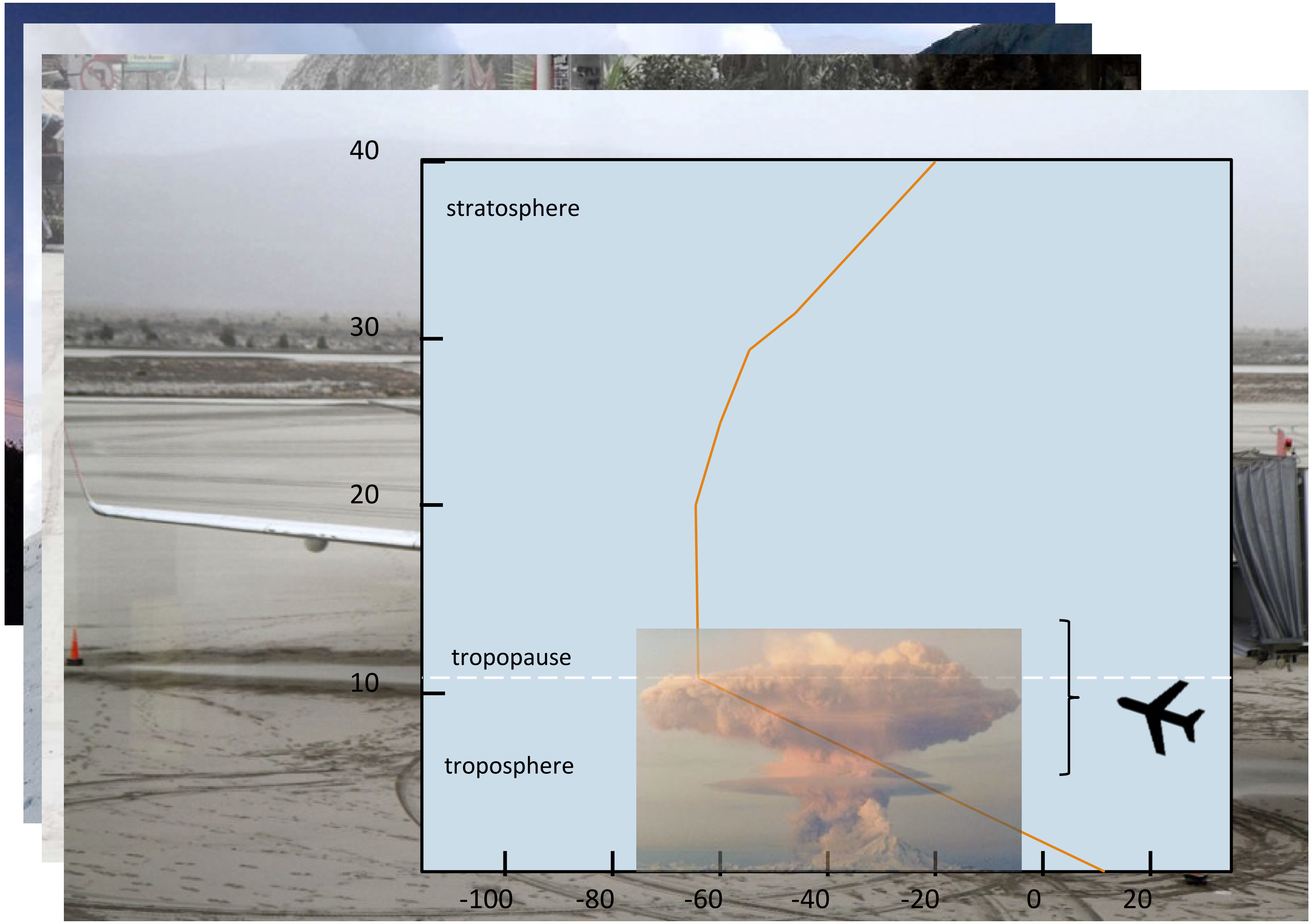


Umbrella cloud

Plianian and Sub-Plinian
Vulcanian

Ejection of
pyroclasts

Hazard related to volcanic clouds



Volcanic ash
<2 mm and as fine as 1 µm

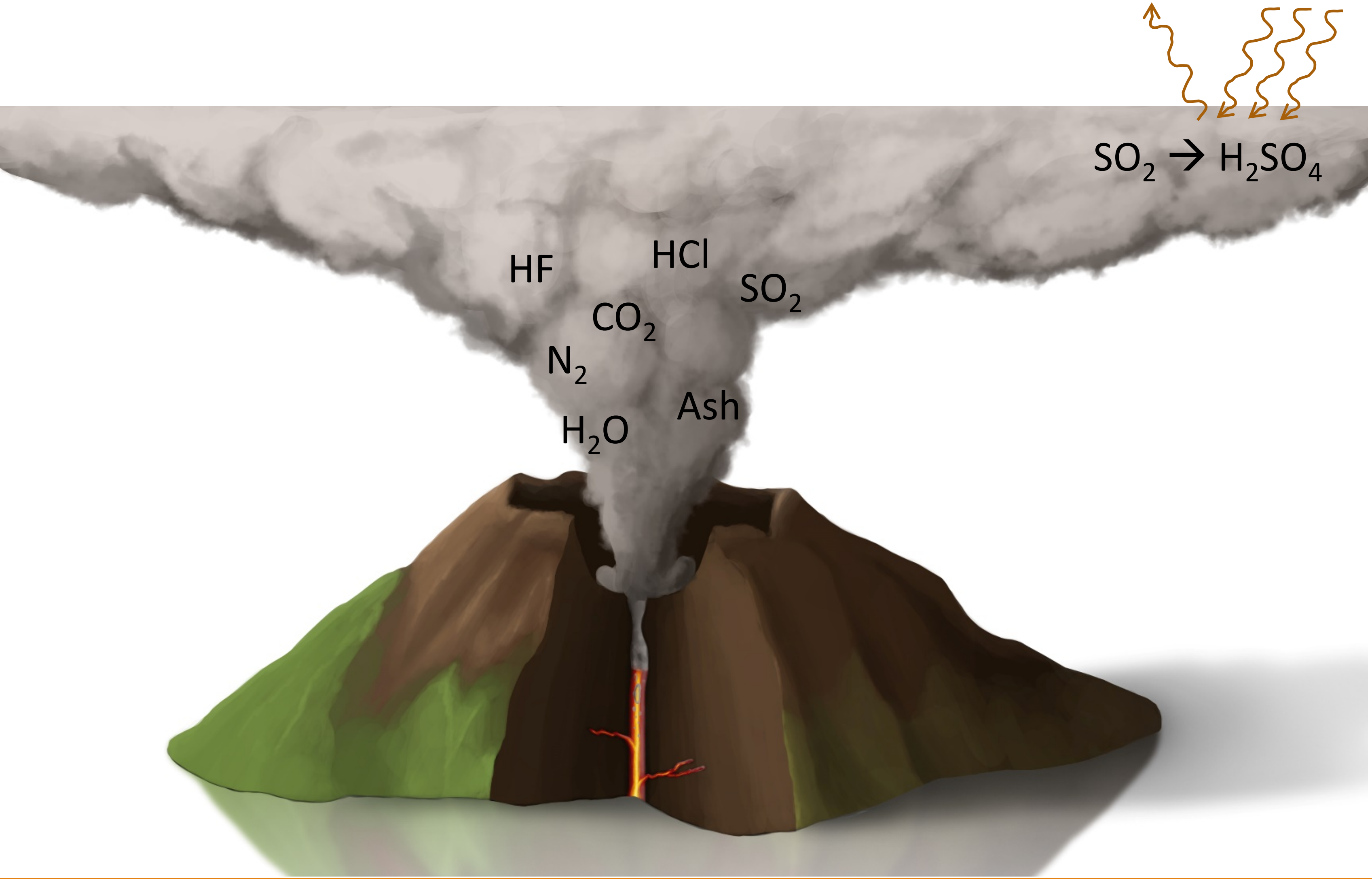
Impact both
the **vicinity** and **far**
from the source

Burial of buildings

Health hazard

Aviation hazard

Hazard related to volcanic clouds



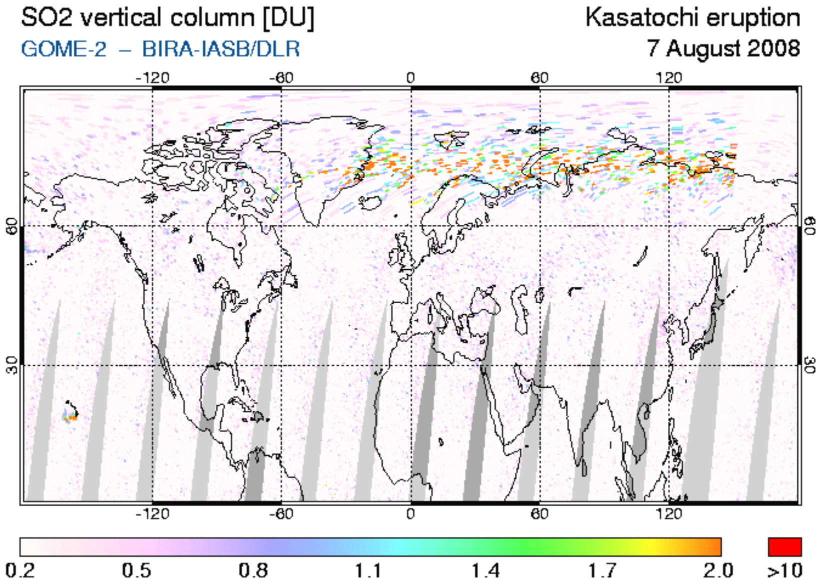
Impact both the **vicinity** and **far** from the source

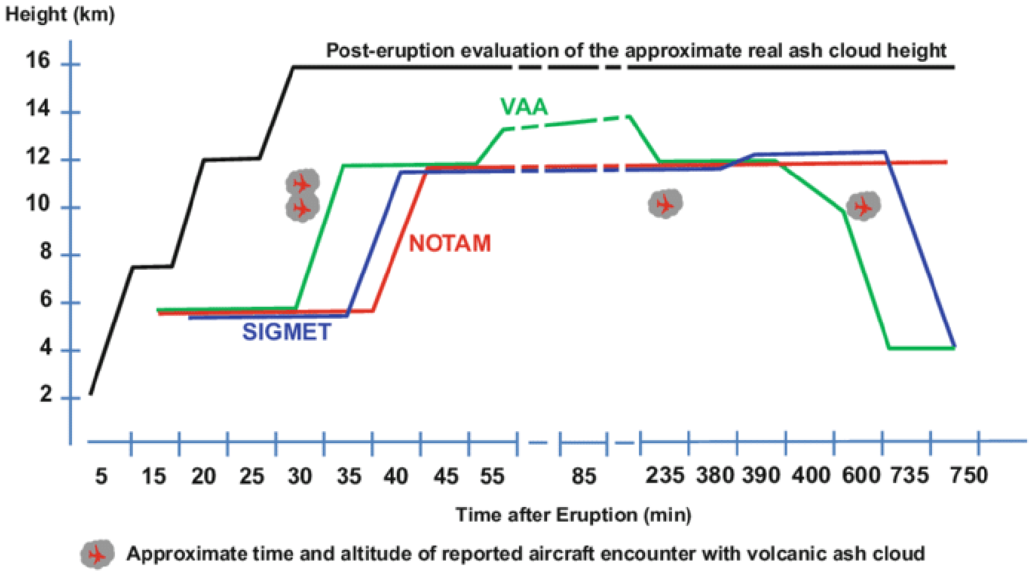
Impact of the atmosphere structure

Climate impact

The suspect profile: what we want to know

DISPERSION



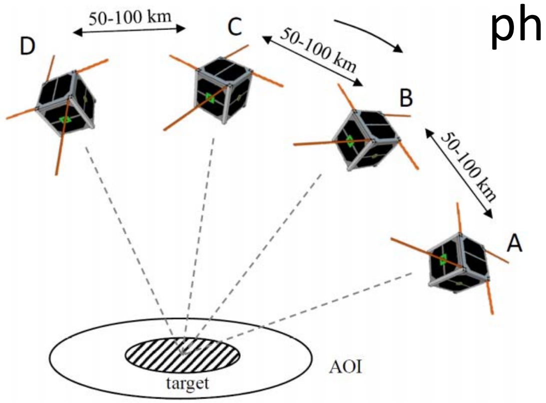


ALTITUDE

Dispersion and altitude estimation

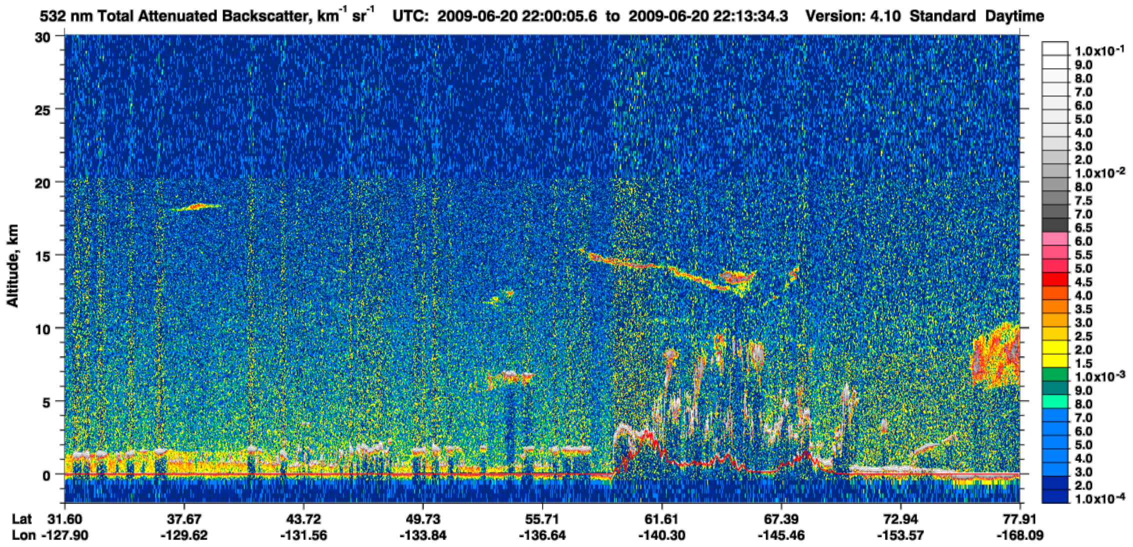
hyperspectral UV and IR sensors

Sensor[a]	Volatile species: H_2O	CO_2	CO	SO_2	H_2S	HCl	BrO	OClO	CH_3Cl	Timespan
TOMS*										1978–2005
SBUV* (P)										1978–present
HIRS*										1978–present
GOME										1995–2003
MODIS*										1999–present
ASTER										1999–present
MOPITT										1999–present
SCIAMACHY (L)										2002–2012
MIPAS (L)										2002–2012
AIRS										2002–present
ACE (L)										2003–present
SEVIRI										2004–present
OMI										2004–present
MLS* (L)										1991–2001; 2004–present
TES (P)										2004–present
GOME–2*										2006–present
IASI*										2006–present
OMPS*										2011–present
VIIRS										2011–present
CrIS										2011–present
AHI										2015–present
GOSAT (P)										2009–present
OCO–2										2014–present



photogrammetry

CALIOP lidar



When GNSS RO comes into place

CALIOP lidar

60 m vertical resolution

Low spatial and temporal resolution

GNSS RO

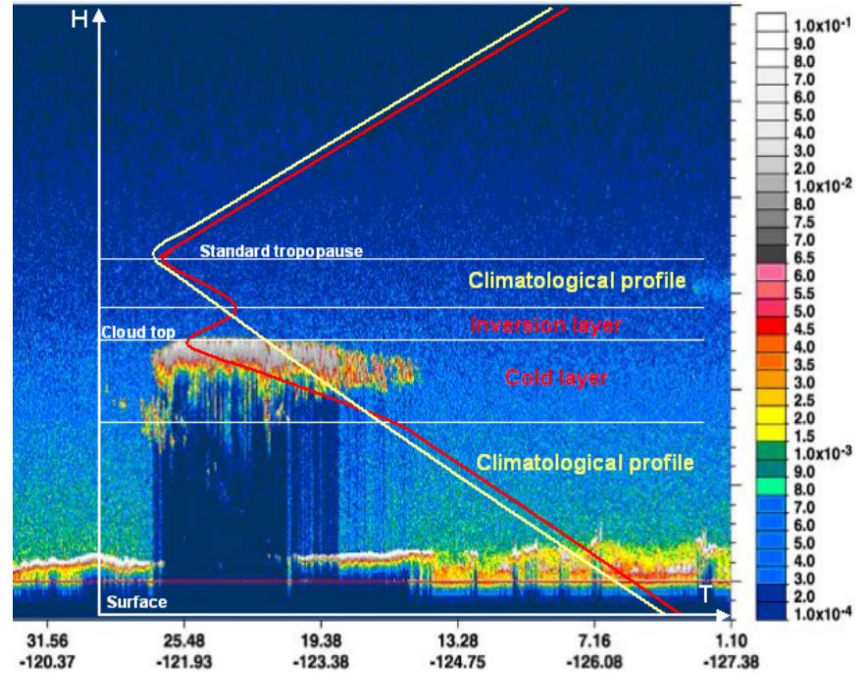
200 m vertical resolution UTLS

Successful on convective clouds’ altitude

And on thermal effect of volcanic eruptions

ALTERNATIVE

June 20, 2018 - ATTENTION: ONGOING
CALIOP is experiencing an elevated frequency of low energy laser shots within and near the South Atlantic Anomaly (SAA) region which has degraded the science quality of affected profiles since September 2016. Please see the Low Laser Energy Advisory page for further information and guidance for identifying affected profiles.



When GNSS RO comes into place

CALIOP lidar

60 m vertical resolution

Low spatial and temporal resolution

GNSS RO

Wide spatial and temporal coverage

Public and private missions

ALTERNATIVE

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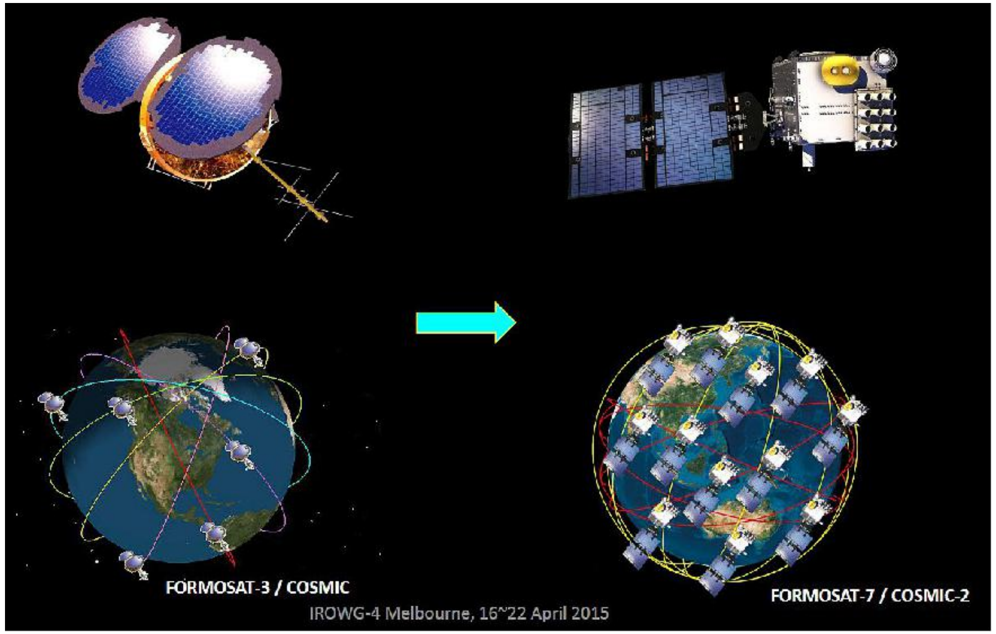


Can GNSS RO be used as an operational tool in volcanic cloud monitoring?

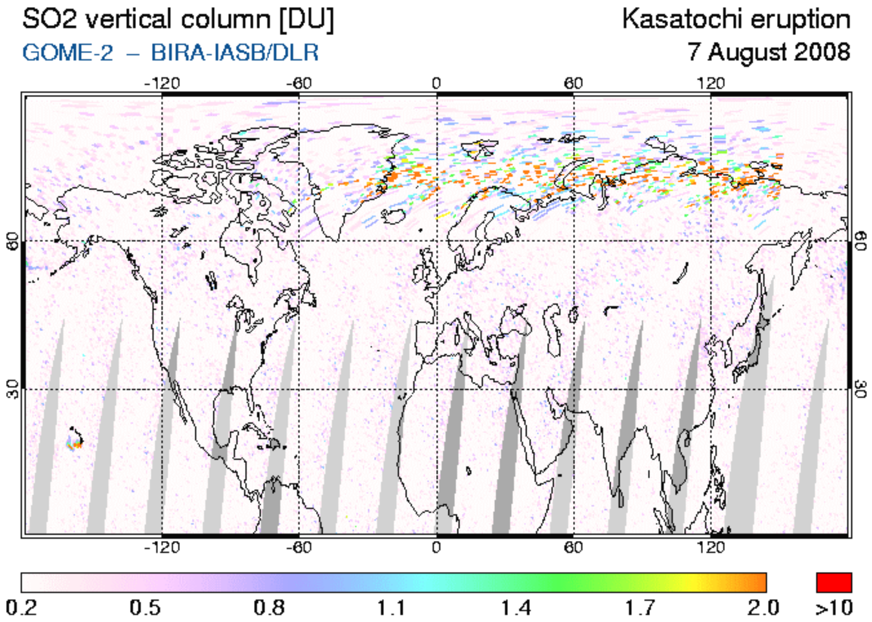
Kasatochi eruption 2008 – Case study

Aleutian arc

314 m above sea level

07 August 2008

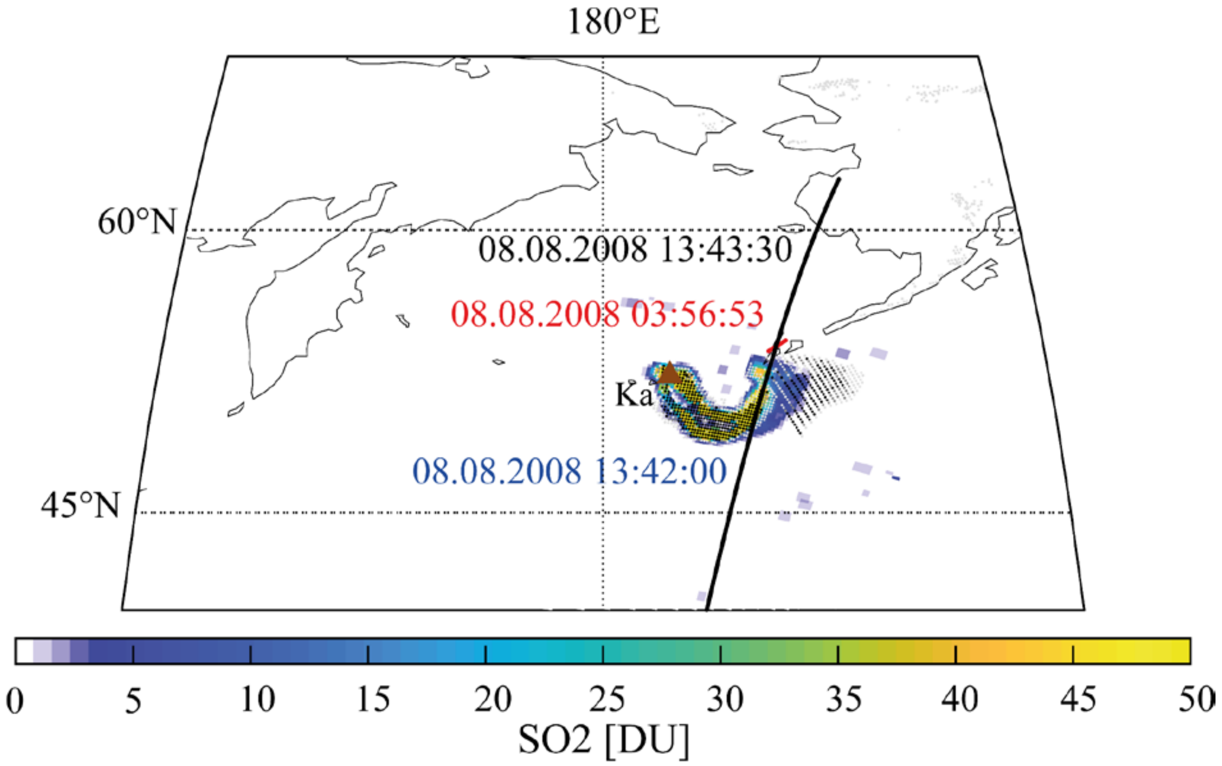
3 large explosions within 6 hours



Eruptive column up to 14 km

0.3-2.7 Tg SO_2 & 0.3-0.5 Tg ash

detected for 4 months



A team effort: AIRS IASI GOME CALIOP RO

Maps of the volcanic cloud

- AIRS, IASI and GOME IR & UV acquisitions
  - Different times and locations

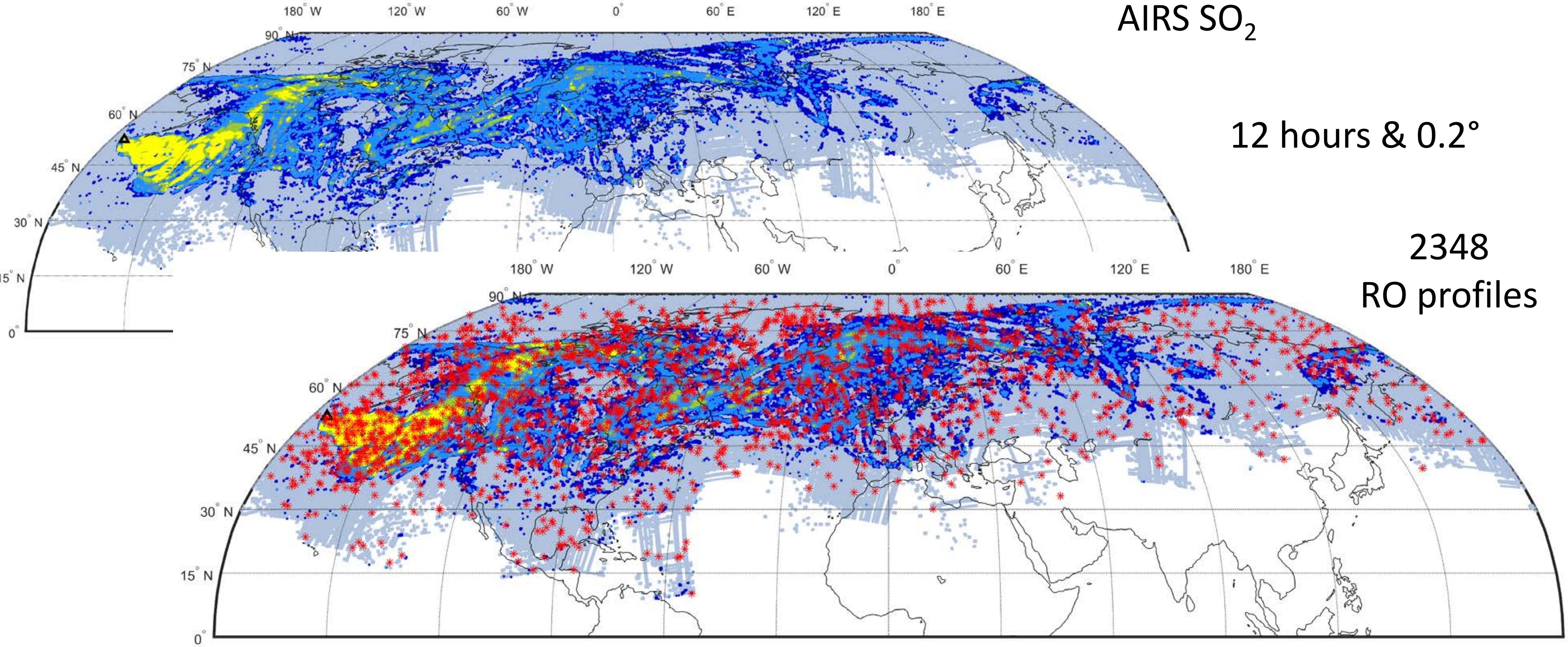
Cloud altitude estimation

- RO bending angle anomaly

Cloud altitude validation

- CALIOP lidar backscatter acquisitions

Collocation round 1 – cloud maps



AIRS SO_2

12 hours & 0.2°

2348
RO profiles

Collocation round 2 – altitude validation

CALIOP tracks

12 hours & 0.2°

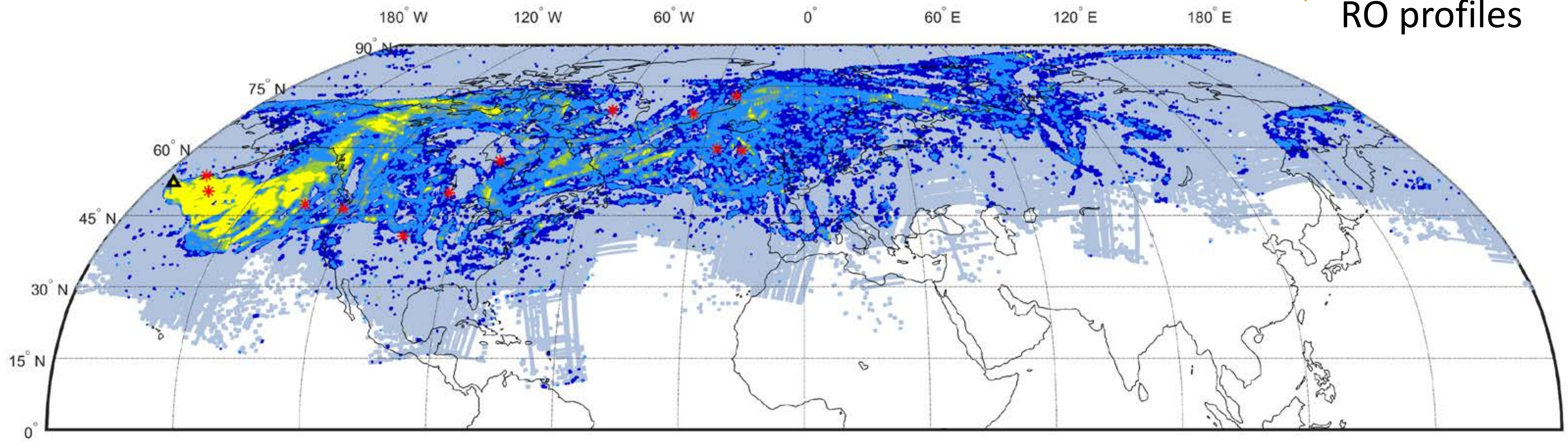
12
RO profiles

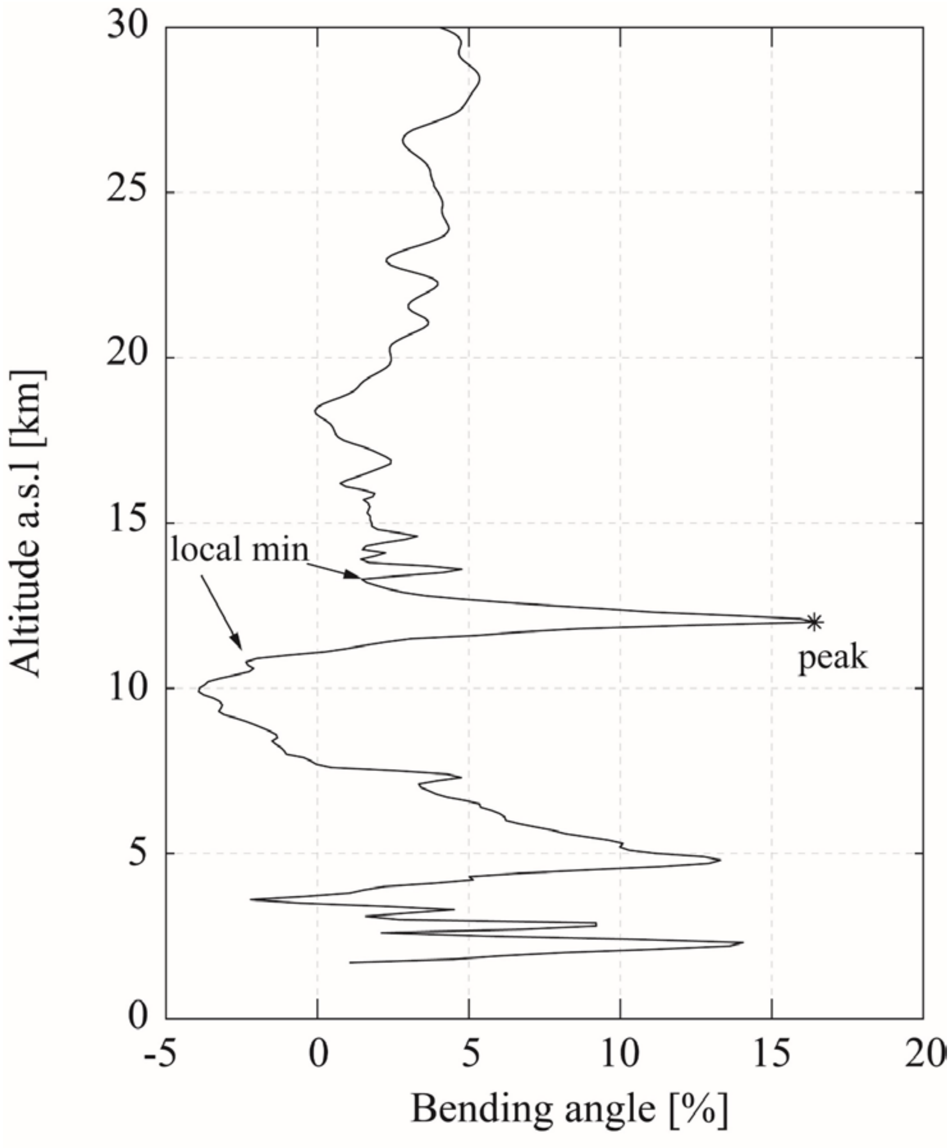
AIRS IASI GOME

3700 collocated
RO profiles

CALIOP tracks

28 collocated
RO profiles



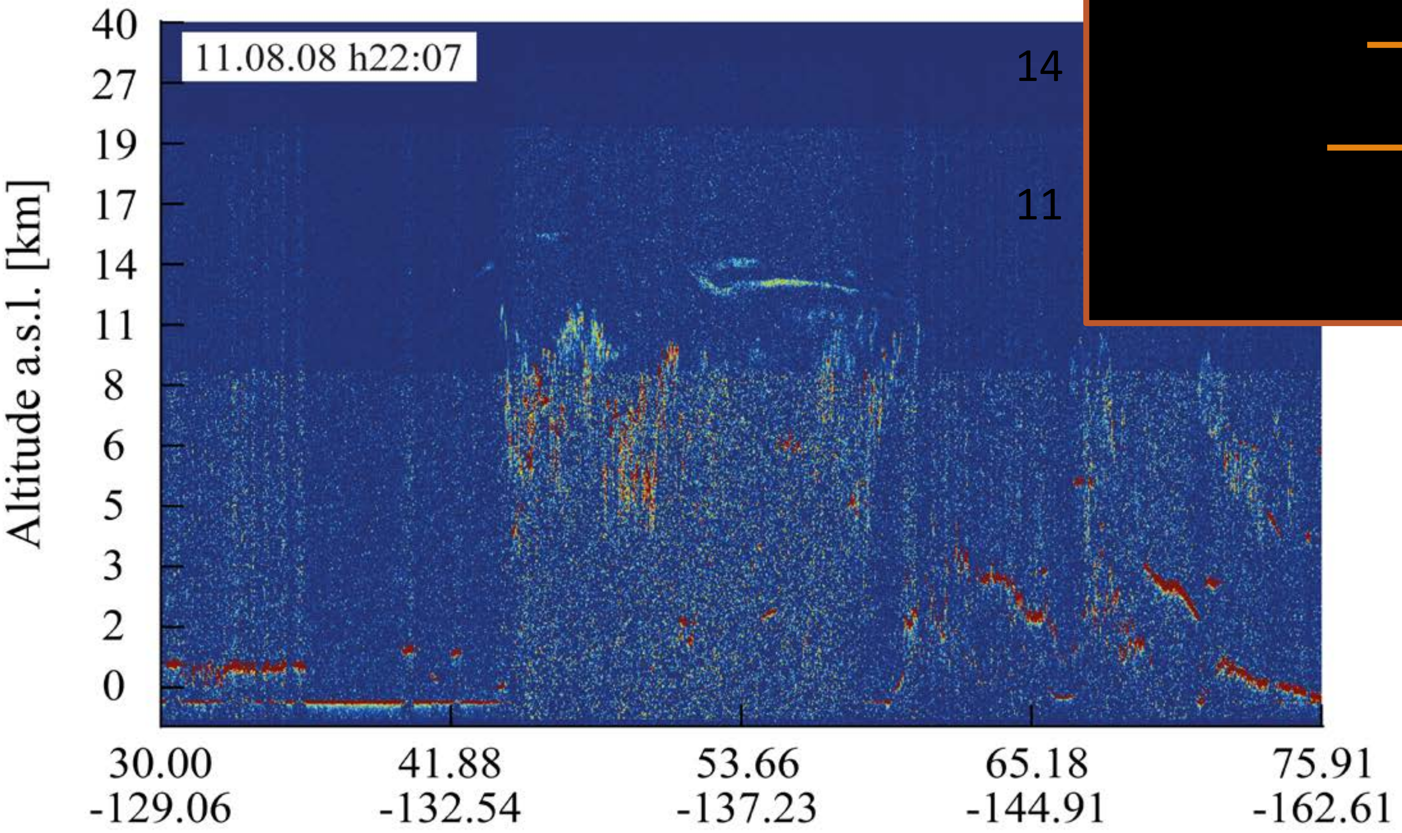


Estimating the volcanic cloud altitude

Total climatology on 10° latitude bands

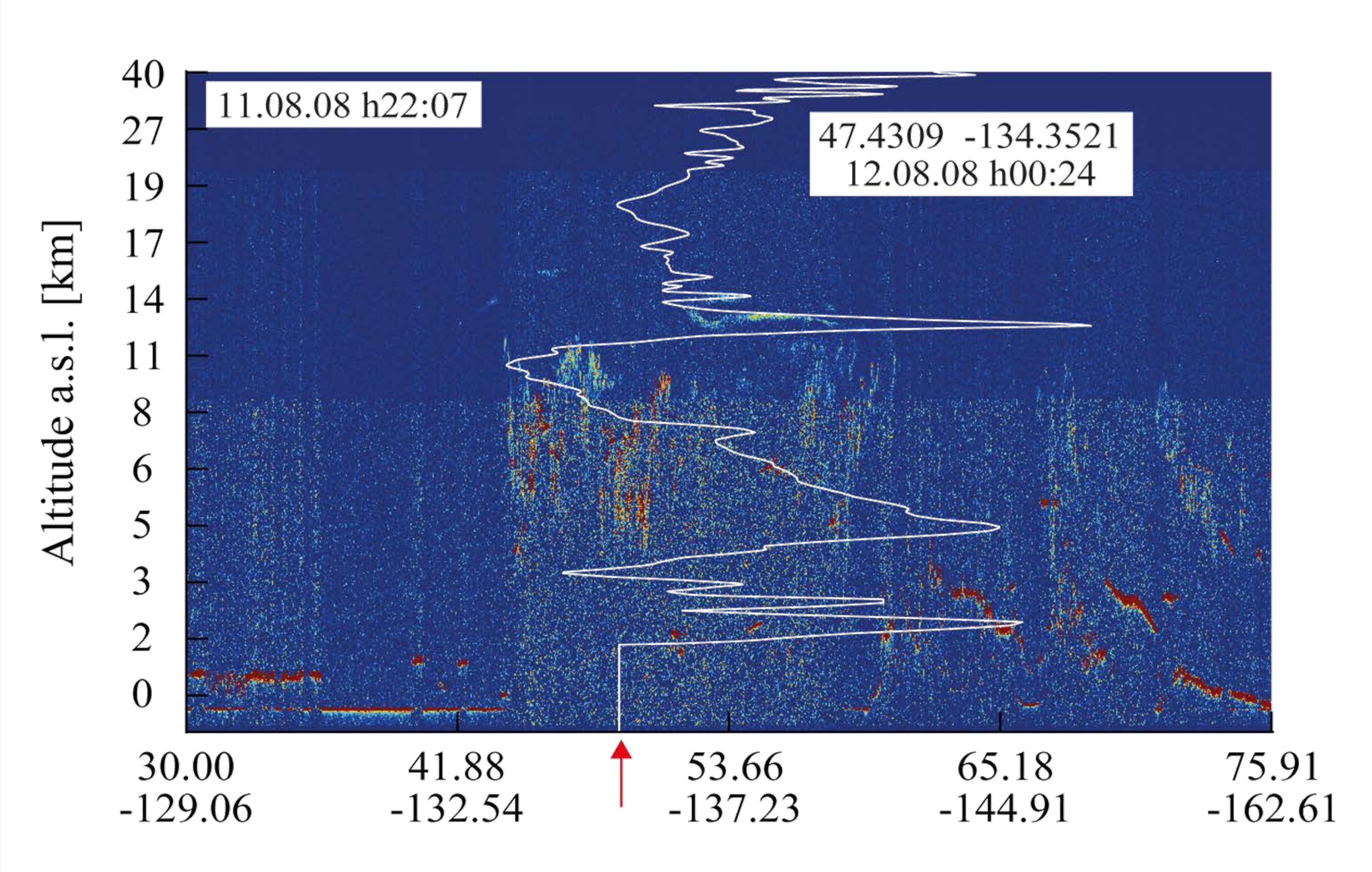
- Calculate the banding angle anomaly
- Select peaks with prominence > 5% above 10km

Validating the altitude estimations

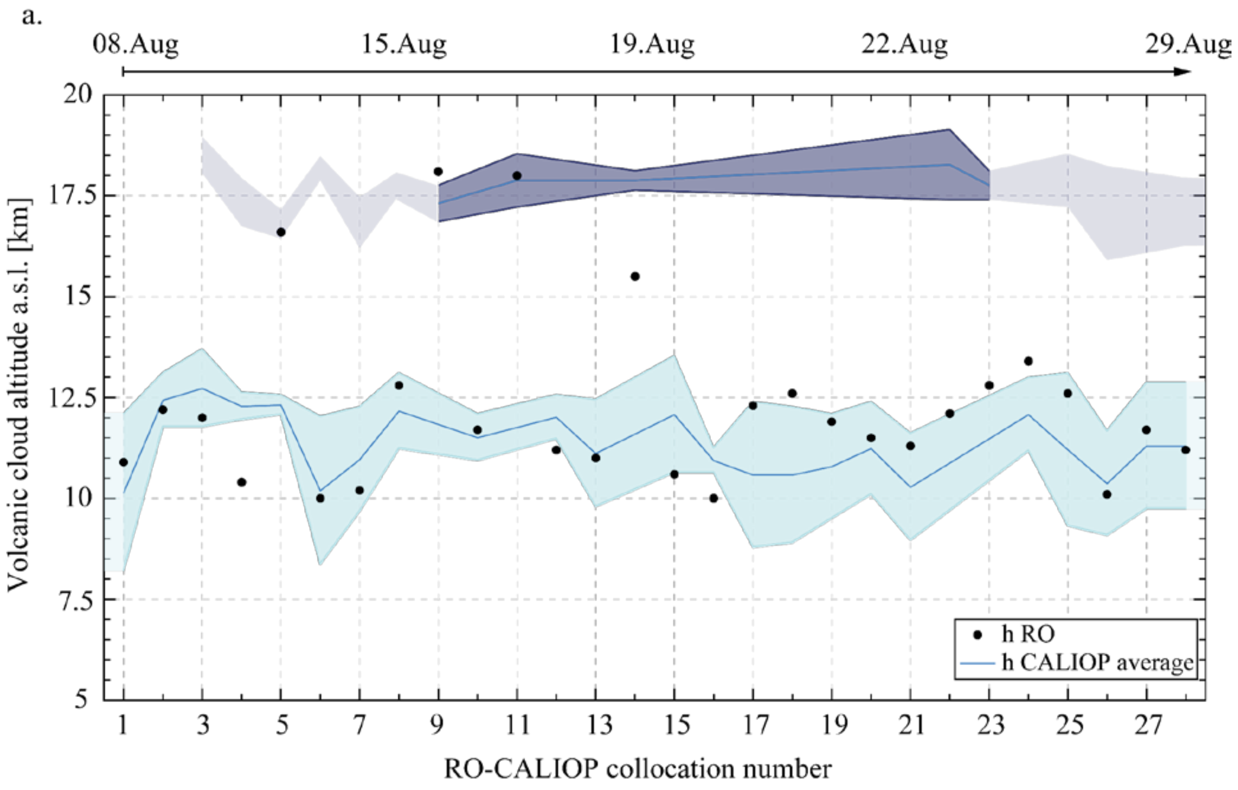


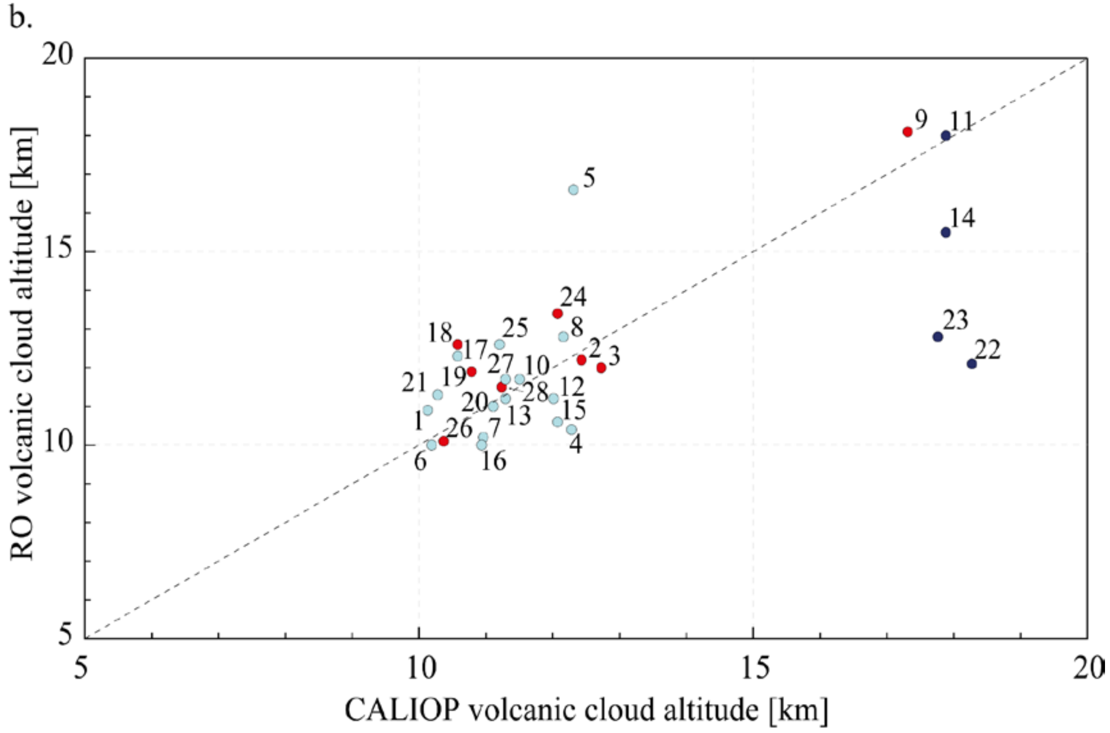
Measuring top and bottom based on pixel backscatter values

Validating the altitude estimations

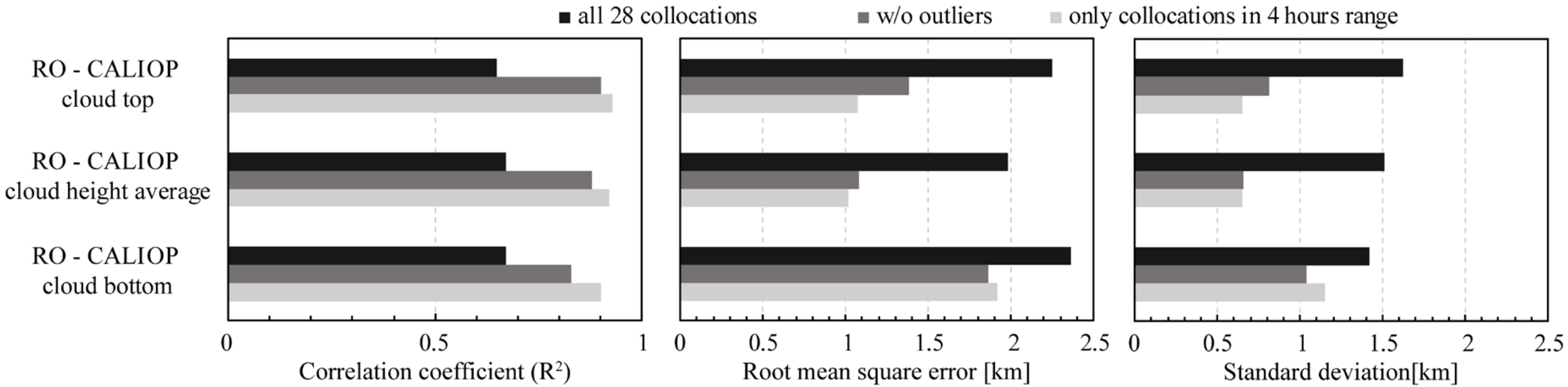


RO vs. CALIOP


a.
08.Aug
15.Aug
19.Aug
22.Aug
29.Aug
Volcanic cloud altitude a.s.l. [km]
RO-CALIOP collocation number
h RO
h CALIOP average


b.
RO volcanic cloud altitude [km]
CALIOP volcanic cloud altitude [km]

RO vs. CALIOP error analysis



Advantages and limits

Large potential spatial and temporal coverage

Increasing the collocation precision

- Increases the estimation accuracy
- Decreases the number of observations

It's a blind technique

- Volcanic or meteo-cloud?

Validation from only ONE available lidar

- small number of observations

Future work

The launch of new missions will provide wider coverage

- Potential for detecting smaller eruptive clouds

Volcanic clouds database

Within the WMO SCOPE

- Potential for training a neural network for top cloud estimation
- Comparison and validation with other different available algorithms

Take home message

GNSS RO potential operational tool

Complementary to current volcanic cloud imagery methodologies

Thank you!

Cigala, V., Biondi, R., Prata, A.J., Steiner, A.K., Kirchengast, G., and Brenot, H., (2019).
GNSS radio occultation advances the monitoring of volcanic clouds: the case of the 2008 Kasatochi eruption.
Remote Sensing, 11(19), 2199;
https://doi.org/10.3390/rs11192199

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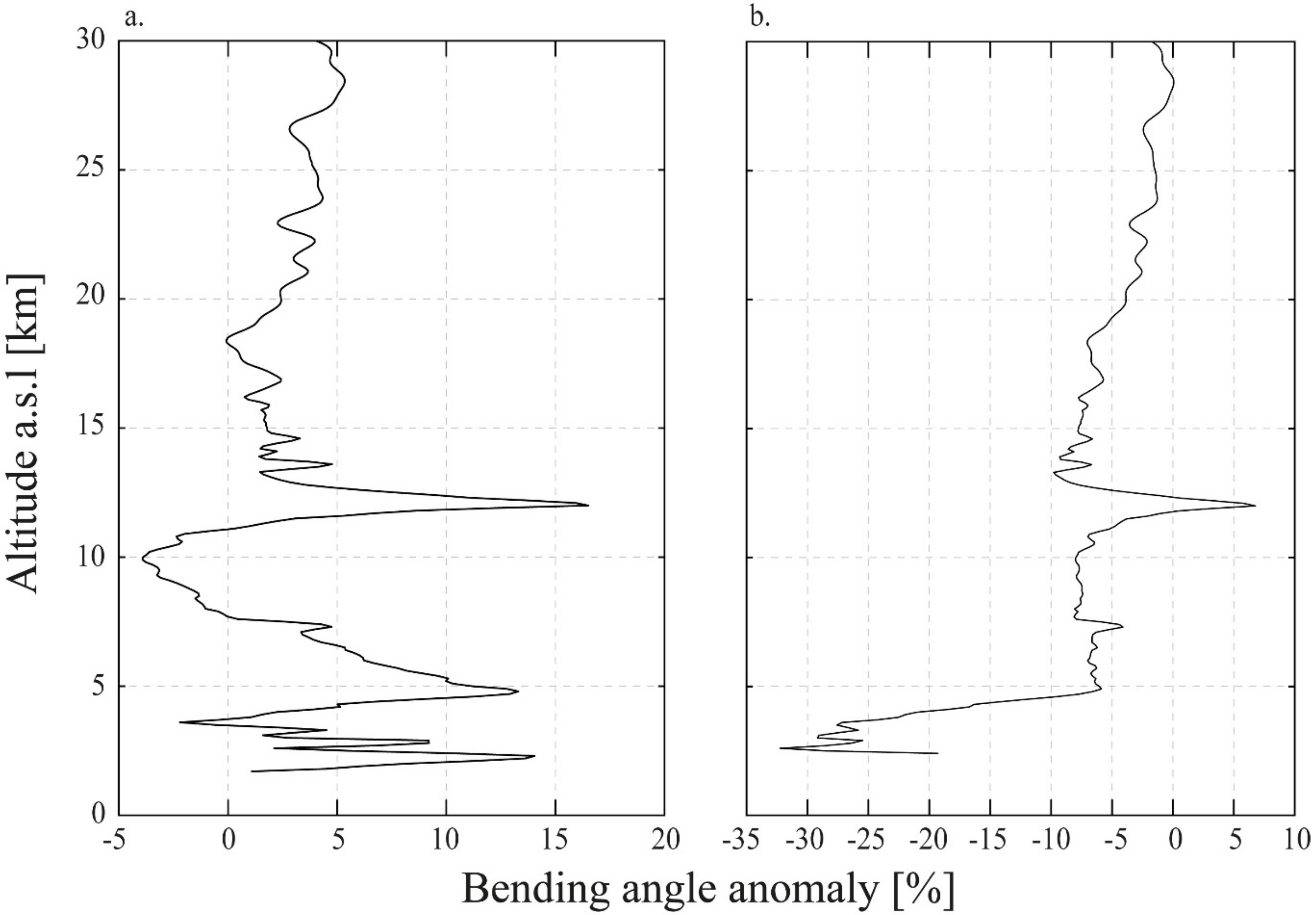
Lechner, P., Tupper, A., Guffanti, M., Loughlin, S., & Casadevall, T. (2017). Volcanic Ash and Aviation—The Challenges of Real-Time, Global Communication of a Natural Hazard. In Observing the Volcano World (pp. 51-64). Springer, Cham.

Nogueira, T., Dombrovski, S., Busch, S., Schilling, K., Zakšek, K., & Hort, M. (2016, June). Photogrammetric ash cloud observations by small satellite formations. In *2016 IEEE Metrology for Aerospace (MetroAeroSpace)* (pp. 450-455). IEEE.

Tupper, A., Carn, S., Davey, J., Kamada, Y., Potts, R., Prata, F., & Tokuno, M. (2004). An evaluation of volcanic cloud detection techniques during recent significant eruptions in the western "Ring of Fire." *Remote Sensing of Environment*, *91*(1), 27–46. https://doi.org/10.1016/j.rse.2004.02.004

Extra slide – climatology



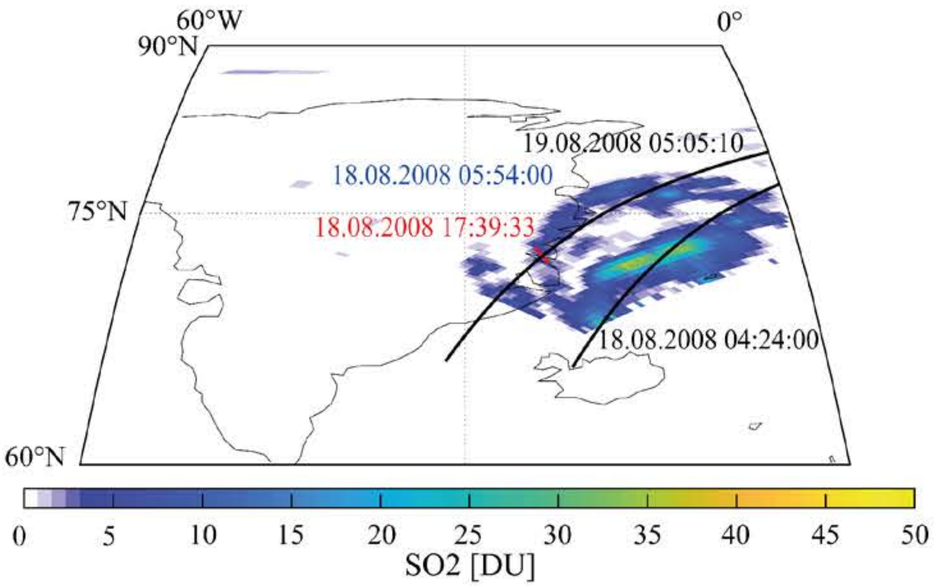
10° latitude bands

vs.

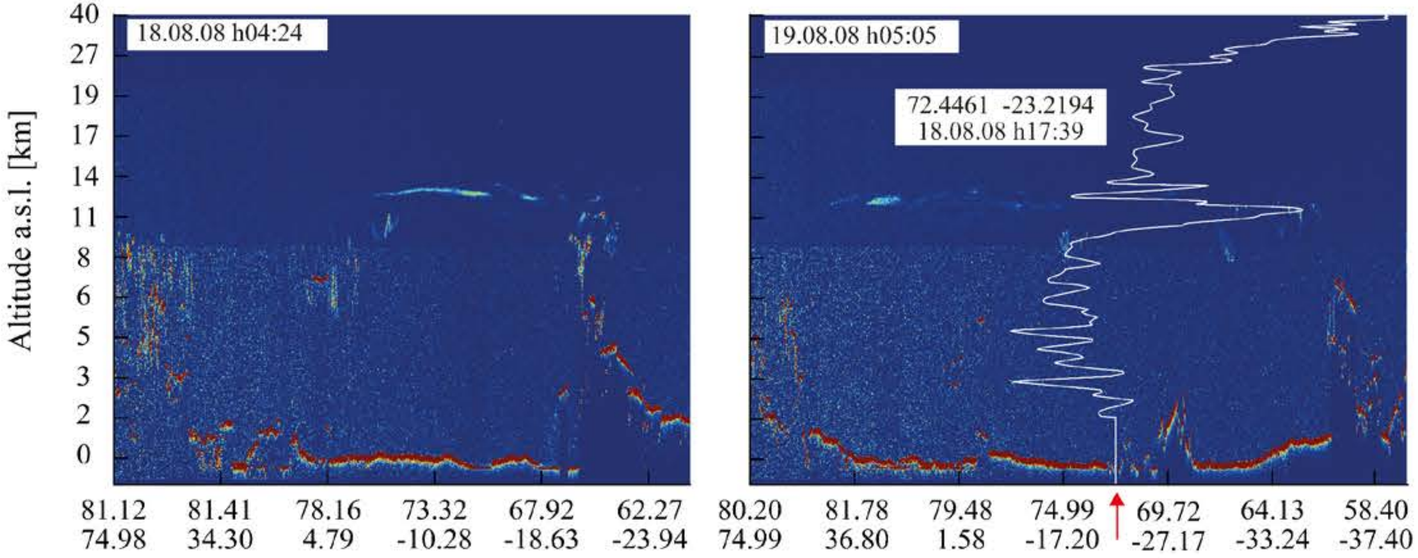
2.5 ° x2.5 ° grid

Extra – double passage of CALIOP

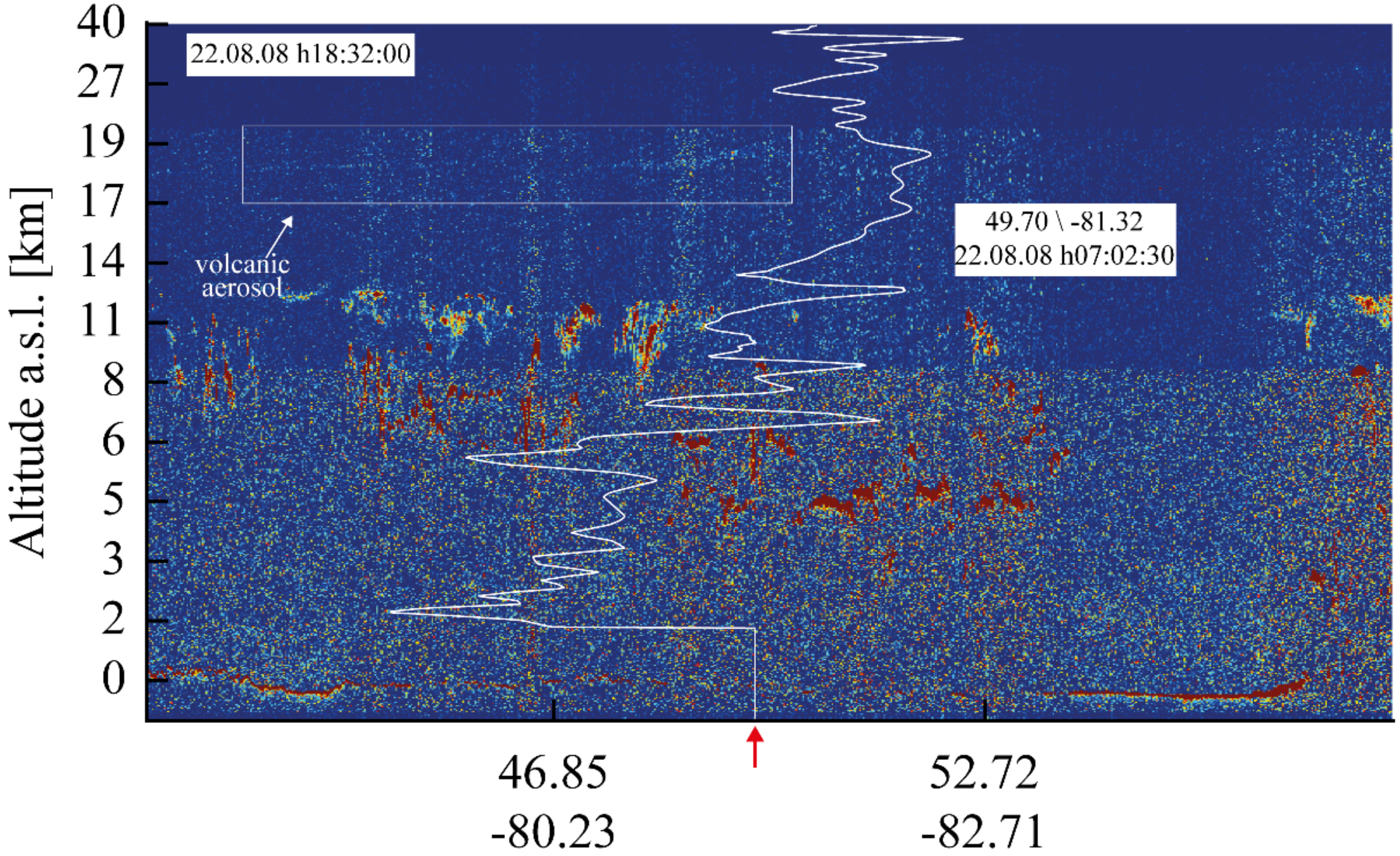
a.



b.



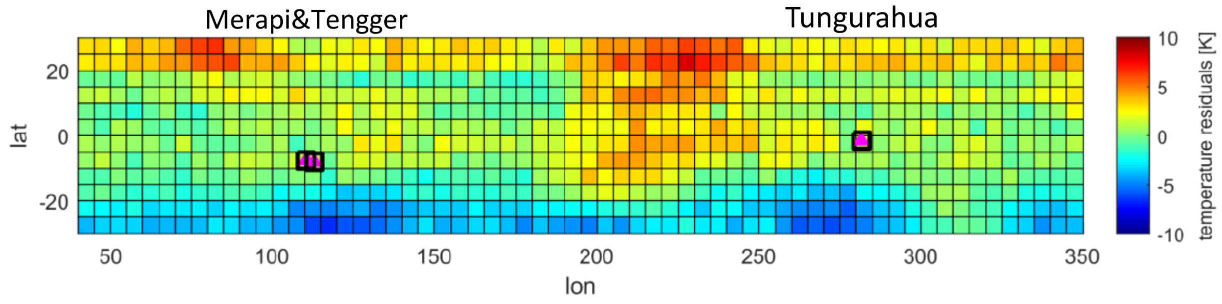
Extra slide – outliers



Analysis of the impact on climate

Credit: Elżbieta Lasota

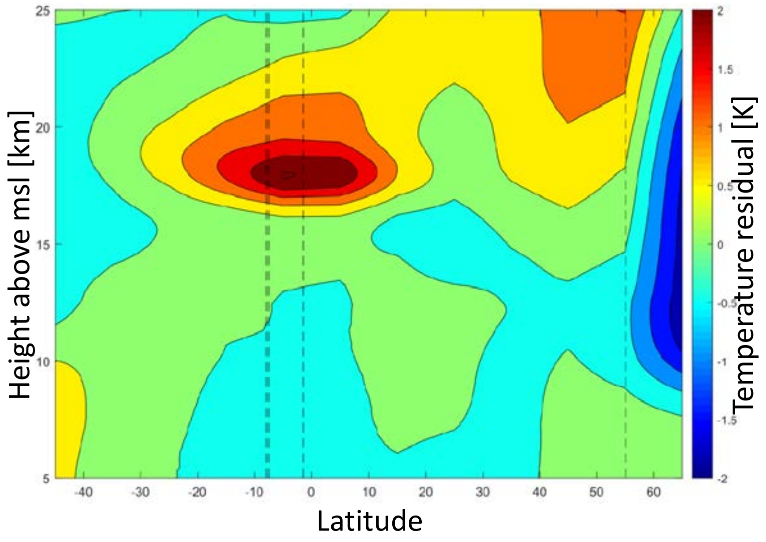
Analysis of the thermal structure of the atmosphere after eruptions of at least VEI >3 via the residuals's analysis.

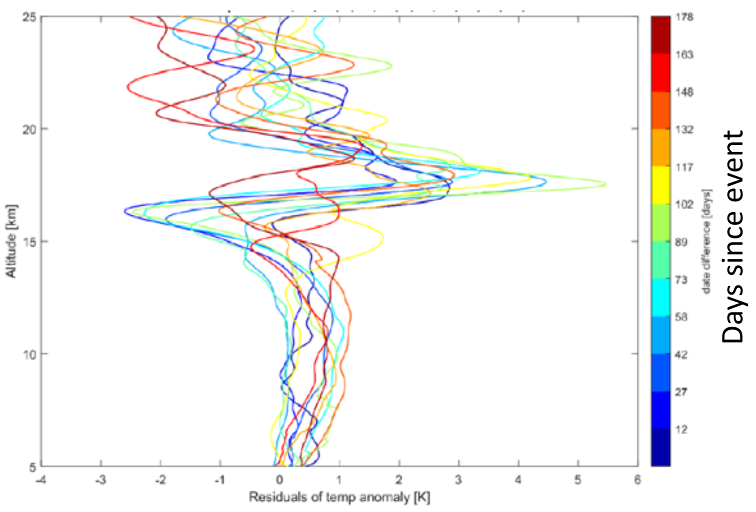


Merapi, Tengger and Tungurahua erupted in November 2010 within 15 days.

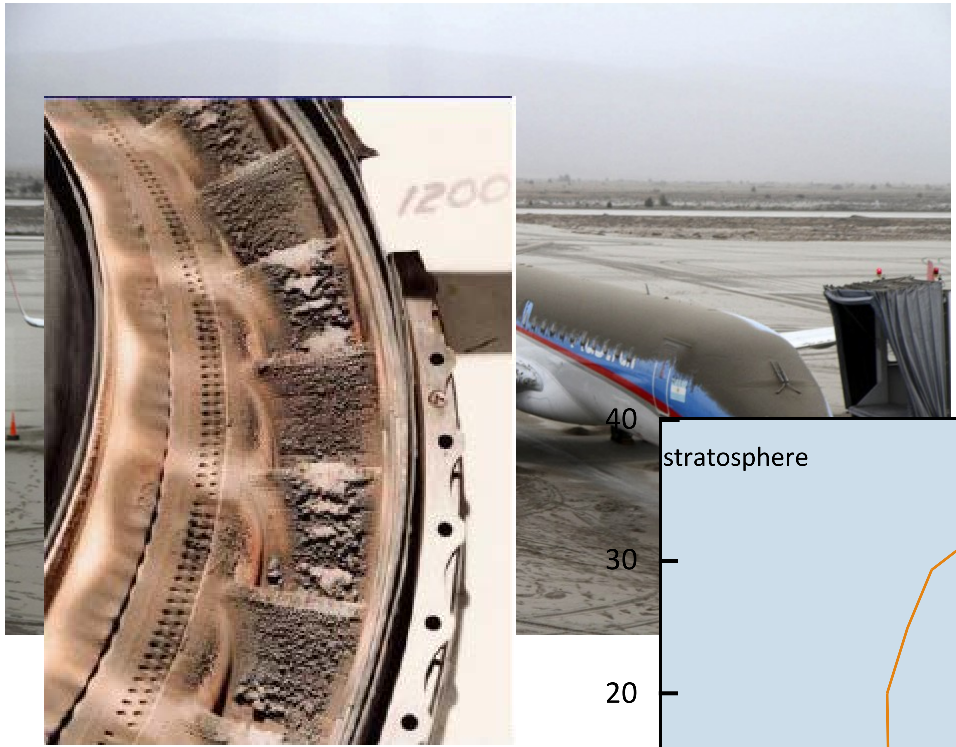
For 7 months → observable warming of the low stratosphere at low latitude

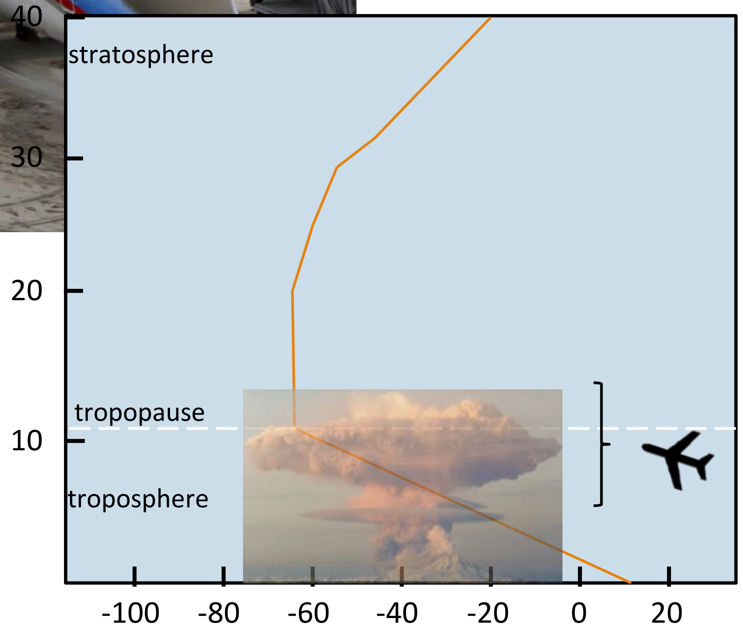
- Peak warming after 4 months





Hazard related to volcanic clouds





Volcanic ash
<2 mm and as fine as 1 µm

Impact both
the **vicinity** and **far**
from the source

Aviation hazard

6 – 13 km