

Monitoring volcanic SO₂ emissions with the Infrared Atmospheric Sounding Interferometer

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Study Aims:

- To investigate how the IASI instrument and University of Oxford linear SO₂ retrieval can be used to assess ongoing emissions of SO₂ at volcanoes across the globe
- To explore the strengths and weakness of a new emission rotation algorithm which is used to isolate and enhance the SO₂ signal. It is then used to assess ongoing changes.
- To create a dataset that is complementary to existing methods for assessing long term volcanic activity.



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**ENVIRONMENTAL
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Summary of the IASI instrument

Satellites	MetOp-A, B and C
Launch	2006, 2012, 2018
Spectral Range	645 – 2760 cm ⁻¹ (3.62 – 15.5 μm) – covering three SO ₂ absorption bands
Spectral Resolution	0.5 cm ⁻¹
Swath Width	2200 km
Spatial resolution	Circular pixels - 12 km diameter
Temporal resolution	Global coverage twice a day

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Methods

Linear Retrieval

Developed by Walker *et al.* (2011; doi:[10.5194/amt-4-1567-2011](https://doi.org/10.5194/amt-4-1567-2011)).

Purpose: Detects elevated levels of SO₂

Method:

- spectral background represented within covariance matrix

Advantages:

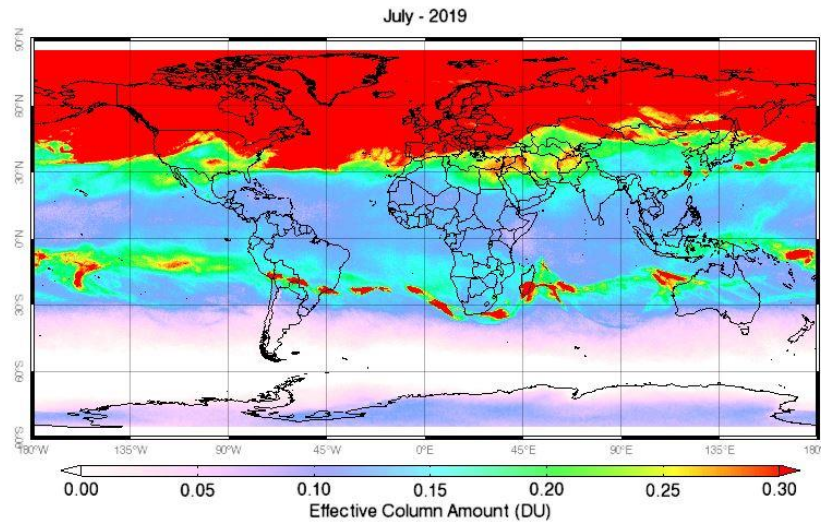
- Fast
- Using full spectrum in ν_3 absorption band = increased sensitivity

Assumptions:

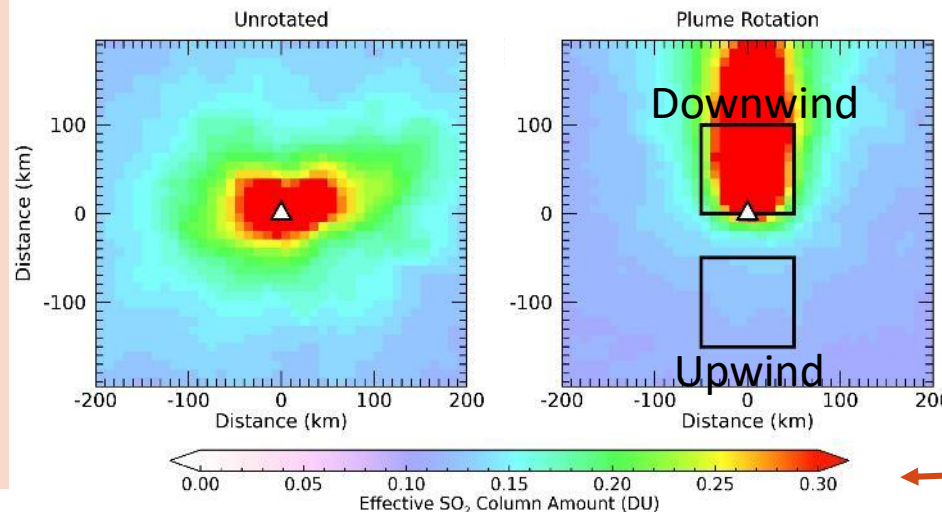
- Background covariance matrix
- Plume altitude

Application in this study:

Applied globally to IASI-A data from 2007 to 2017



↑ Example of the linear retrieval averaged for July 2019. It is possible to see plumes from Raikoke (Kamchatka) and Ulawun (Papua New Guinea)



Emission Rotations

To investigate how the retrieval performs at volcanoes across the globe we developed an emission rotation algorithm.

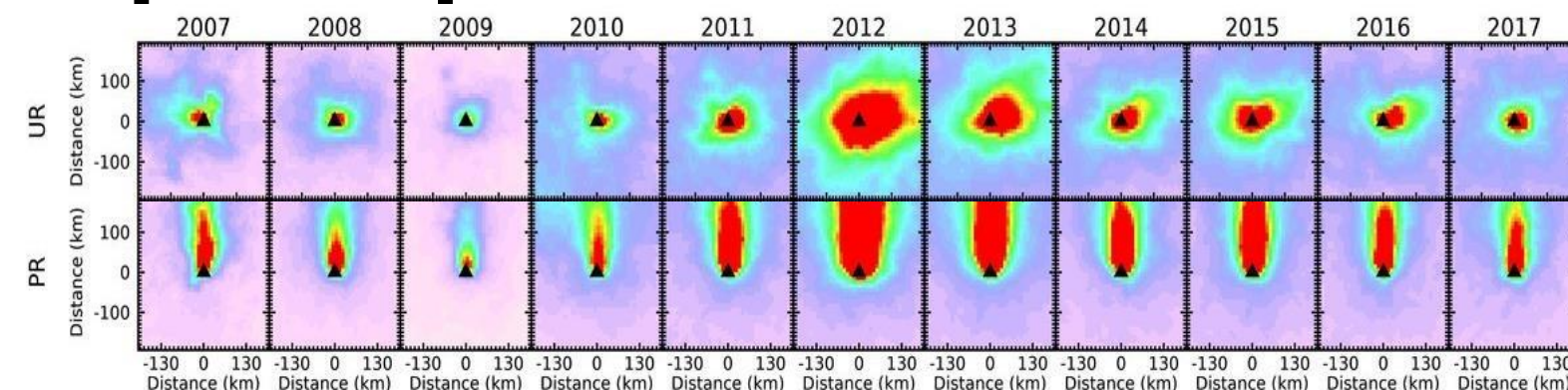
- At each volcano, if a plume is identified in an IASI orbit, the linear retrieval output is rotated so that it appears that the plume is travelling to the north of the volcano
- If no plume is identified then the linear retrieval output for that orbit is rotated with the wind direction at the volcano's vent (using ECMWF data)
- The unrotated and rotated data are then averaged over different time periods: monthly, annual and multi-annual

This helps to **isolate and enhance the SO₂ signal**.

To evaluate the long term emission changes we compute an **emission index** which is the difference between the mean column amount in the downwind (signal) and upwind (noise)

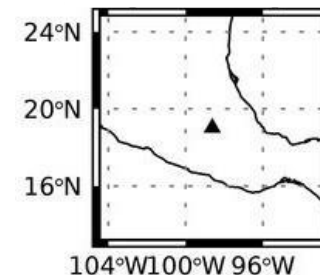
Examples of annual averages – before and after rotations at Popocatepetl (2015)

Popocatepetl



Annual averages
(unrotated)

Annual averages
(rotated)

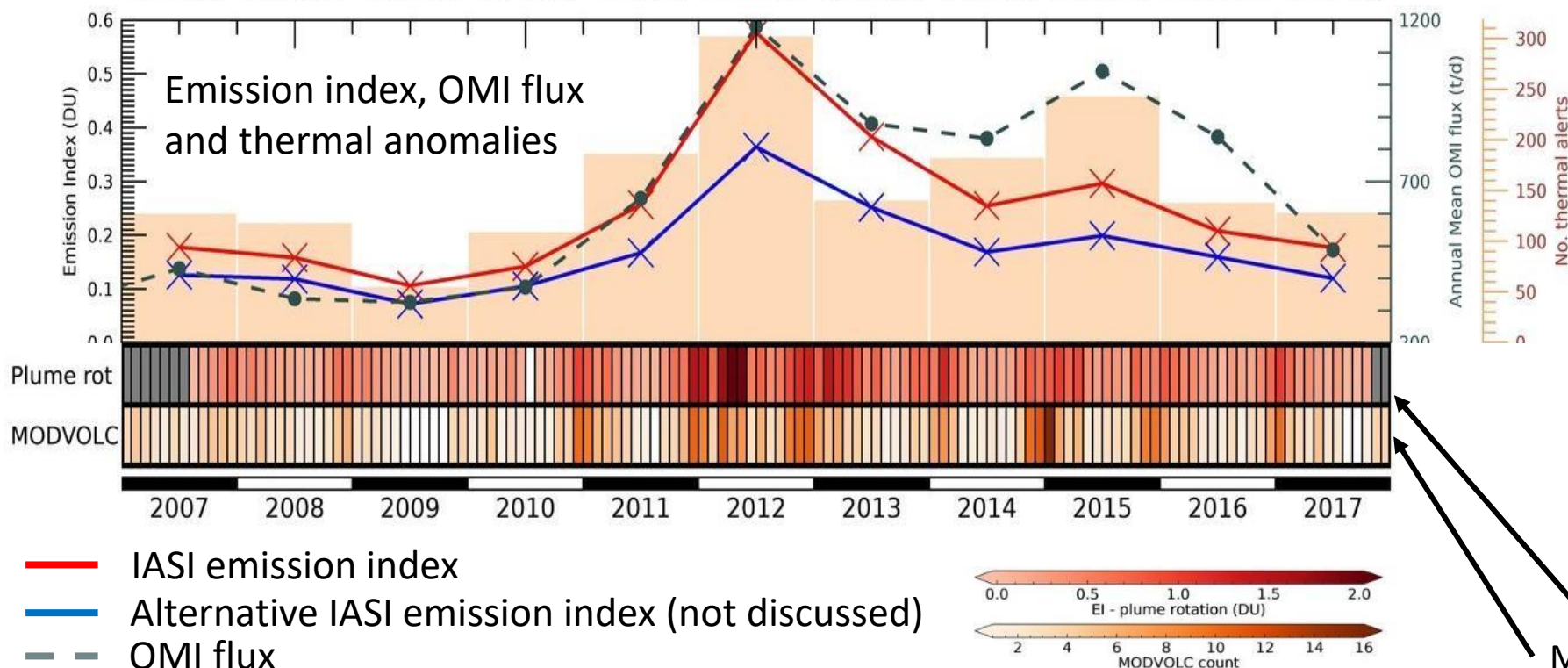


Example of the rotation scheme applied at Popocatepetl.

The emission index has been compared to fluxes generated by Carn *et al.* (2017; doi: [10.1038/srep44095](https://doi.org/10.1038/srep44095)) and the frequency of thermal anomalies detected with MODVOLC (Wright *et al.* 2004;

[doi:10.1016/j.jvolgeores.2003.12.008](https://doi.org/10.1016/j.jvolgeores.2003.12.008))

There is good agreement between these.



MODVOLC data was downloaded from: <http://modis.higp.hawaii.edu/> (April 2019)

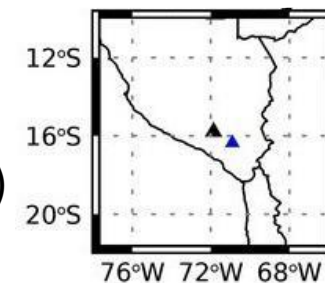
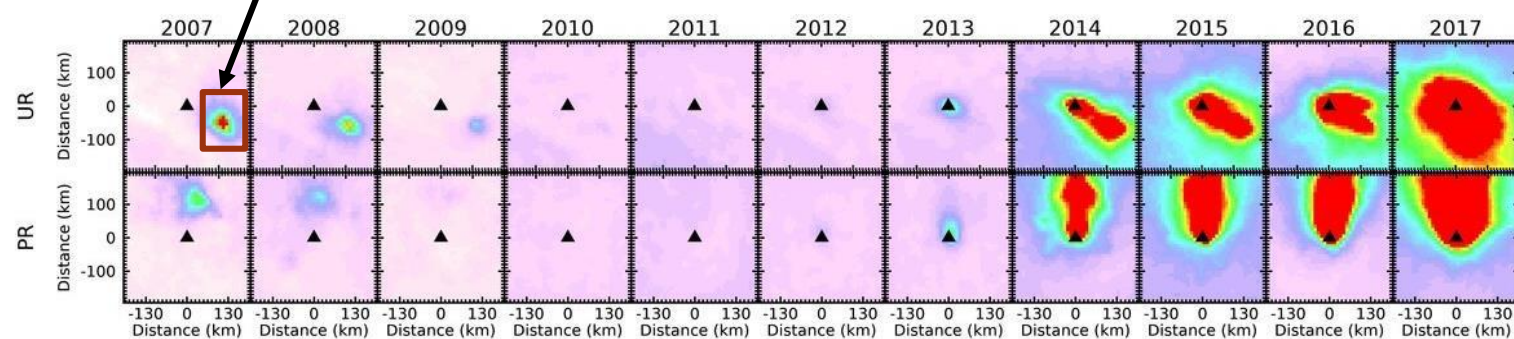
MEaSURES SO₂ flux dataset was downloaded from <https://so2.gsfc.nasa.gov/measures.html> (March 2019)

Monthly emission index

Monthly frequency of thermal anomalies

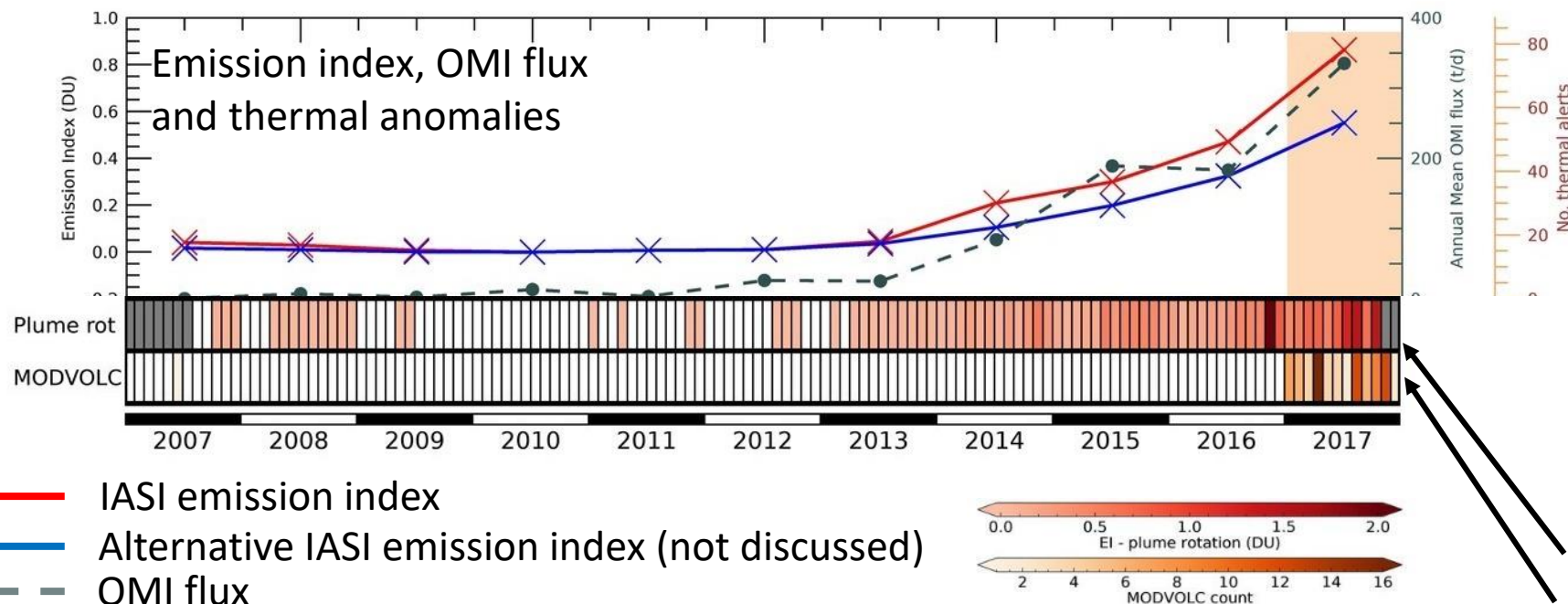
Sabancaya

Sometimes results can be affected by neighbouring volcanoes. In this case Ubinas.



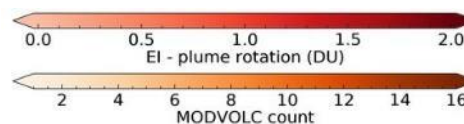
Example of the emission index at Sabancaya volcano in Peru. Here an increase in the IASI emission index and OMI flux can be seen 3 years before the onset of an eruption, marked by the emergence of the thermal anomalies.

Occasionally, there are false detections due to the neighbouring Ubinas volcano.

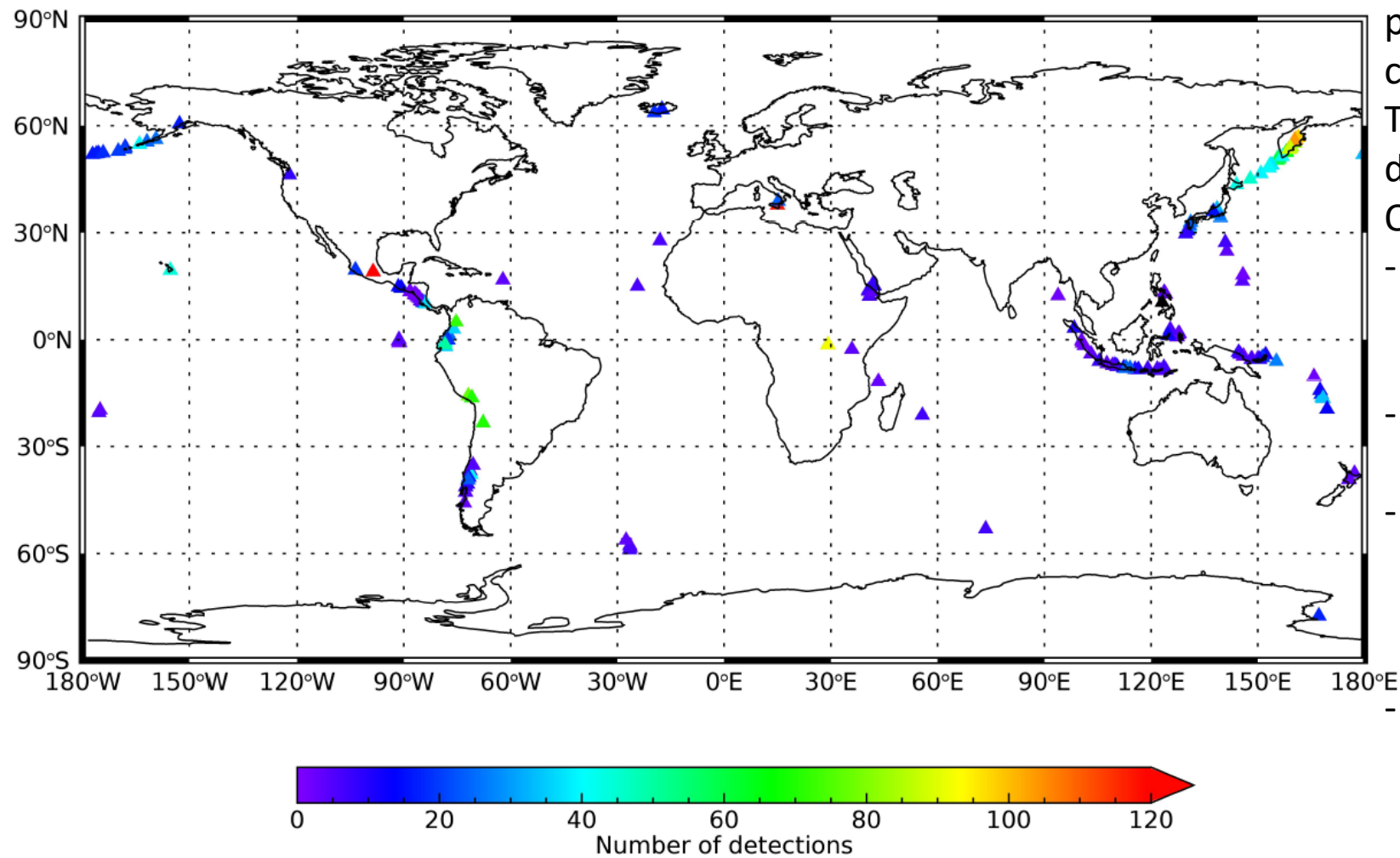


MODVOLC data was downloaded from:
<http://modis.higp.hawaii.edu/> (April 2019)
 MEaSUREs SO₂ flux dataset was downloaded from
<https://so2.gsfc.nasa.gov/measures.html> (March 2019)

— IASI emission index
 — Alternative IASI emission index (not discussed)
 — OMI flux



Global Picture



The rotation scheme was applied to 166 volcanoes worldwide. Where the downwind signal was greater than the upwind signal plus two standard deviations of the upwind is classed as a detection.

The plot of the left shows the frequency of detections worldwide.

Observations:

- Greatest number of detections are at high altitude volcanoes (e.g. those in Central and South America)
- Less detections at lower altitude volcanoes (e.g. those in Asia)
- Numerous detections in Kamchatka – here volcanoes are in close proximity leading to plumes spanning multiple volcanic centres and false detections.
- A number of detections occur in high latitude winters making this a valuable resource which is complementary to UV datasets