Quantification of SO_2 emission rates from the Kīlauea volcano using S5P-TROPOMI satellite measurements

Adrian Jost[1,*], Steffen Beirle[1], Nicole Bobrowski[2,3], Christian Borger[1], Steffen Dörner[1], Christoph Kern[4], Nicolas Theys[5], Simon Warnach[1], and Thomas Wagner[1]

[1]Max Planck Institute for Chemistry, Satellite Remote Sensing, Mainz, Germany
[2]Institute of Environmental Physics, University of Heidelberg, Heidelberg, Germany
[3]Istituto Nazionale Geofisica e Vulcanologia Catania, Italy
[4]U.S. Geological Survey Cascades Volcano Observatory, Vancouver, WA 98683, USA
[5]Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Brussels, Belgium

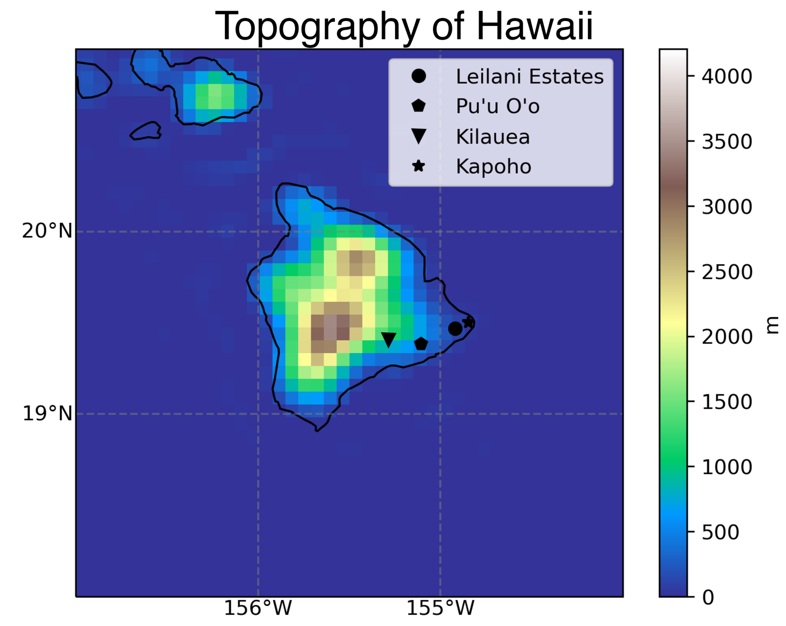
MAX PLANCK INSTITUTE FOR CHEMISTRY

Motivation

- SO_2 affects climate and the environment on regional to global scales as well as atmospheric chemistry
- SO_2 is one of the main components of volcanic gases
- TROPOMI provides high spatial resolution measurements of 3.5 x 7 km² (3.5 x 5.5 km² since August 2019)
- applying the divergence to the SO_2 flux yields information about the source

The location and strength of SO_2 emissions from Kīlauea are determined for the 2018 Lower East Rift Zone eruption (beginning of May to the end of July) by using the divergence method.

Topography of Hawaii



Divergence Method

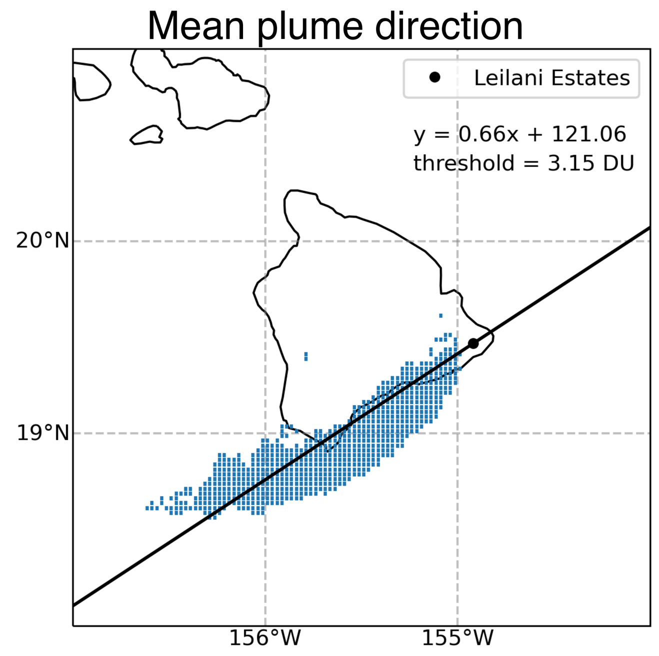
- SO_2 flux is given by: $F = VCD \times w$
- divergence of the horizontal flux yields the sources and sinks of SO_2: $D = \nabla(VCD \times w) = E - S$
- divergence is calculated numerically
- assumption of steady state
- no a priori lifetime is needed

Algorithm

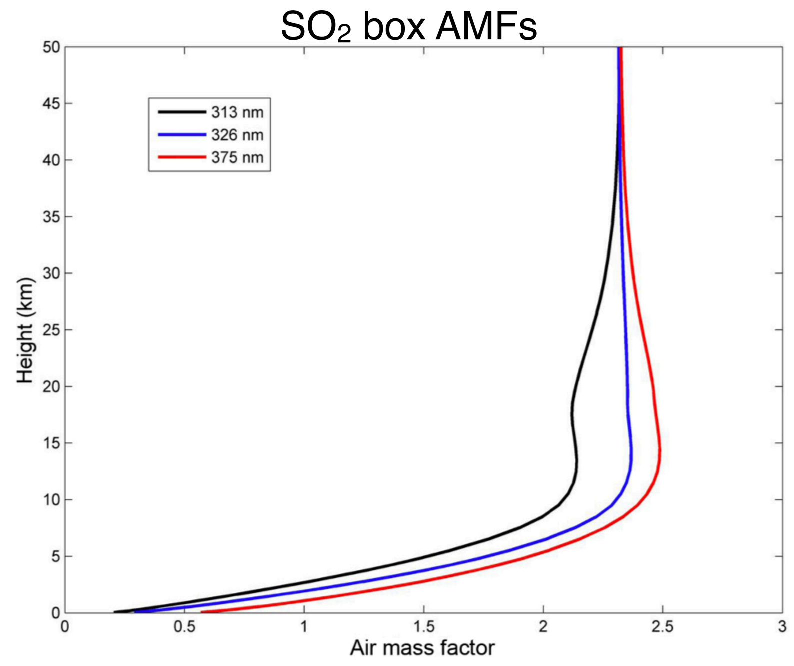
- selection of two different SO_2 datasets:
  - SCDs for the final selected fitting window from the multiple windows algorithm (NORMAL)
    - fitting window selection is based on the measured SO_2 slant columns
  - SCDs analysed around 375 nm only, suitable for high SO_2 columns (WIN3)
- destriping and conversion of slant column densities to vertical column densities using SO_2 box AMFs (N. Theys, 2017)
- filtering of the TROPOMI SO_2 data by omitting high shielding clouds
- gridding of the data to a fine grid with 0.025° horizontal resolution
- interpolation of wind fields to constant heights above sea level
- comparing plume direction with wind direction at different altitudes to find an approximate plume height (plume at approximately 2 km)
- application of the divergence method (S. Beirle, 2019)
- calculation of emission rates for each individual pixel and subsequent summation of pixels around Leilani Estates (source of emissions); the considered area is approximately 300 km²

Results have been obtained for single day observations taking only one orbit into account, as well as for the temporal mean SO_2 columns combining three months worth of TROPOMI observations.

Mean plume direction



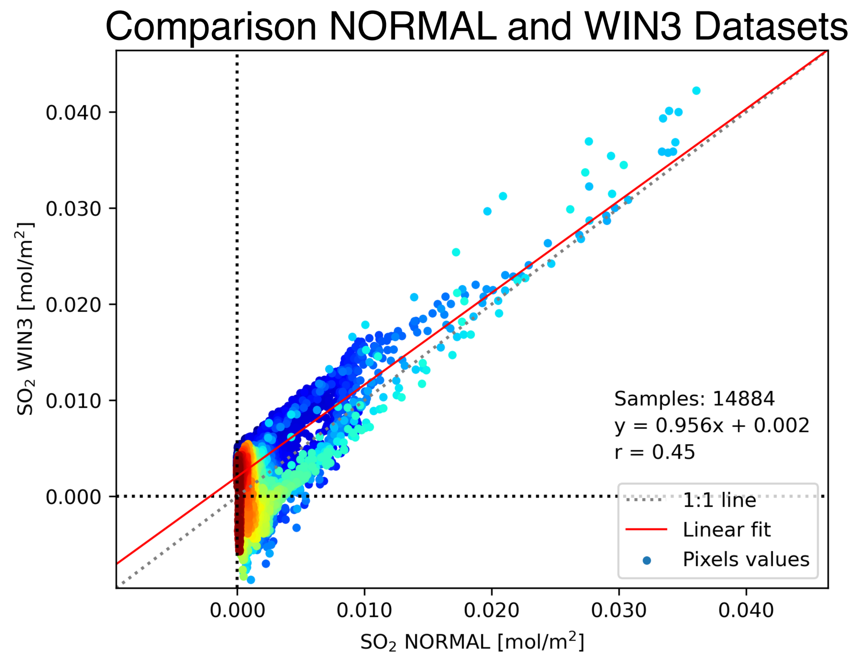
SO_2 box AMFs



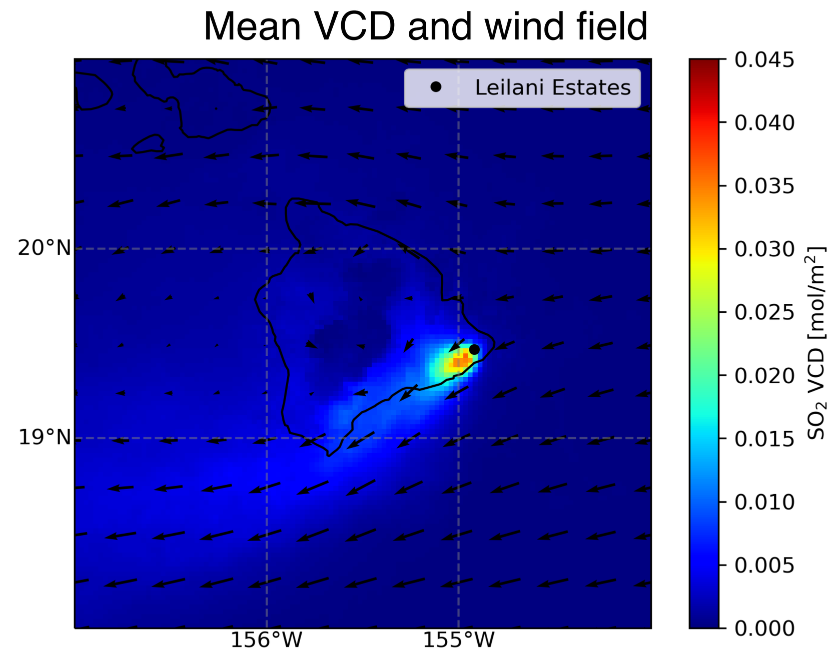
Results

- daily emission rates of up to 44.5 kt/d (June) have been observed
- total SO_2 amount emitted from May to August: 1386 kt
- emission site can be determined clearly
- varying the assumed plume height and associated wind fields by 1 km changes the derived emission rates by a factor of 0.5 (3 km altitude) and a factor of 2 (1 km altitude)
- daily emission rates showing low values are likely to be caused by noise and omitted pixels due to clouds

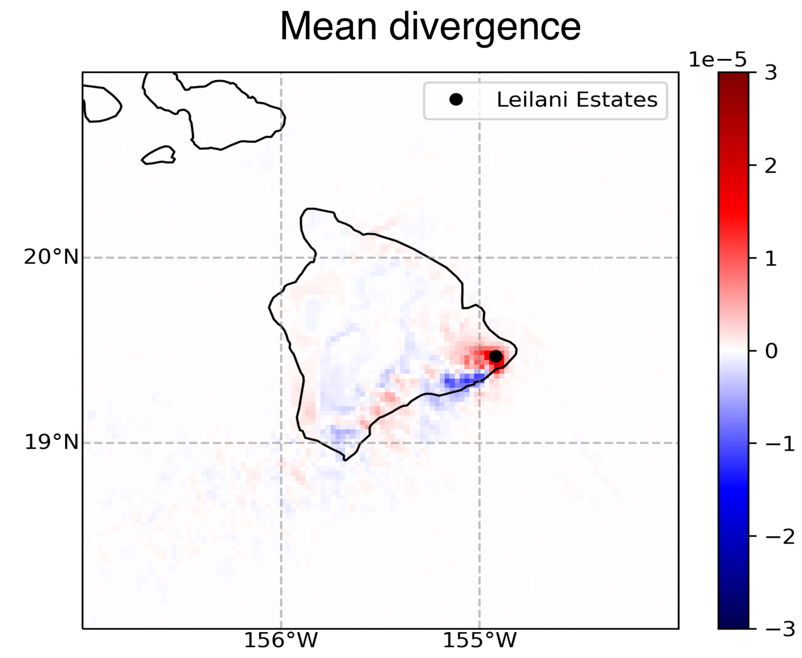
Comparison NORMAL and WIN3 Datasets



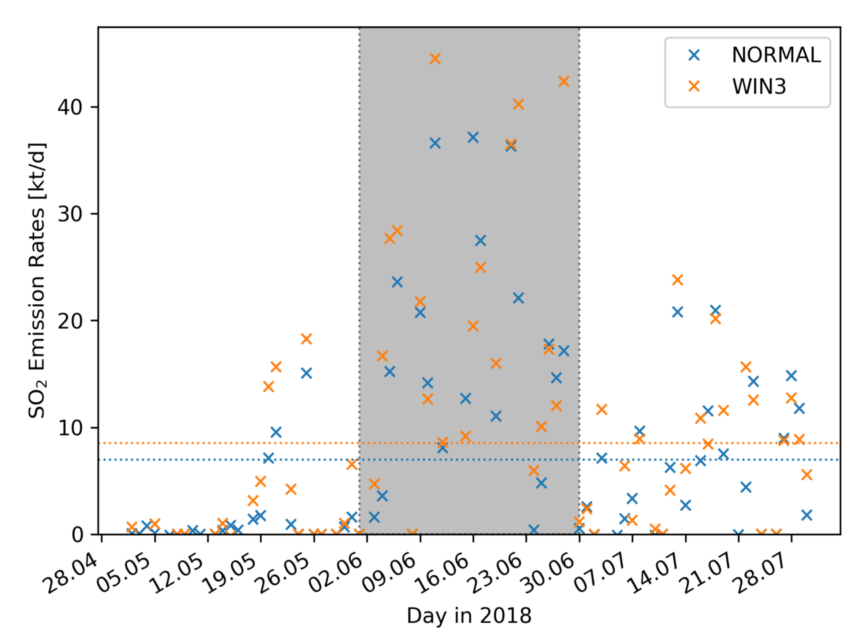
Mean VCD and wind field



Mean divergence



Time series of emission rates

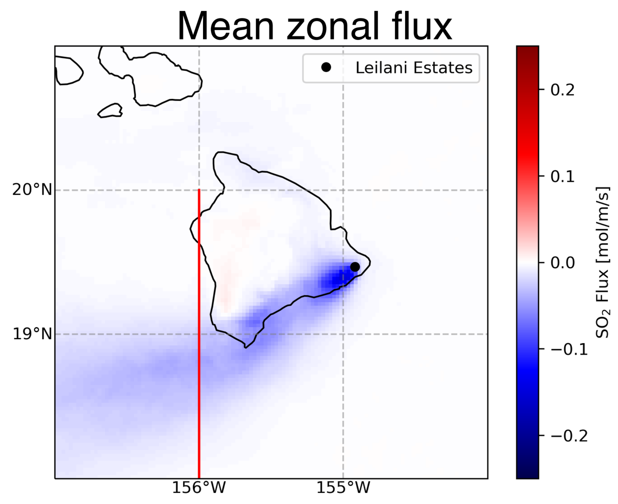


Alternative Approach

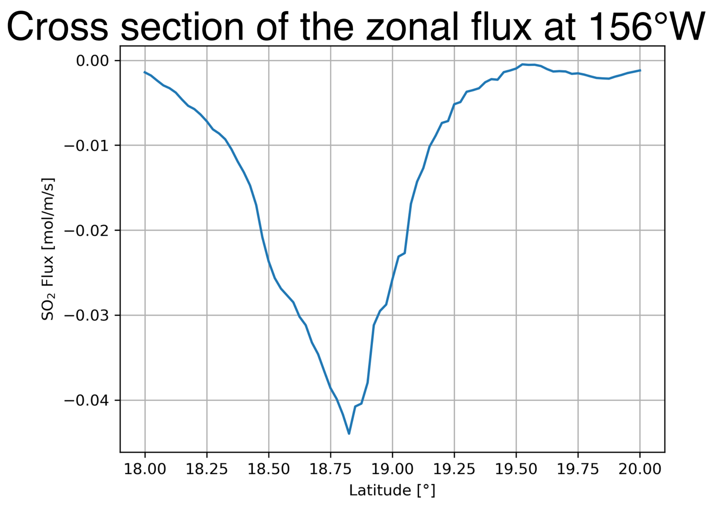
- SO_2 retrieval for dense plumes can be very challenging and uncertain
- diluted plume for cloud-free conditions can be investigated over the Pacific (uncertainties in the radiative transfer are much smaller than directly at the volcano)
- calculation of the mean flux for a sequence of flux cross sections and subsequent multiplication by the distance from the emission site yields the integrated flux
- the divergence method yields slightly lower values for the mean emission rates

Results obtained by the divergence method can be verified by examining the evolution of the SO_2 flux with increasing distance.

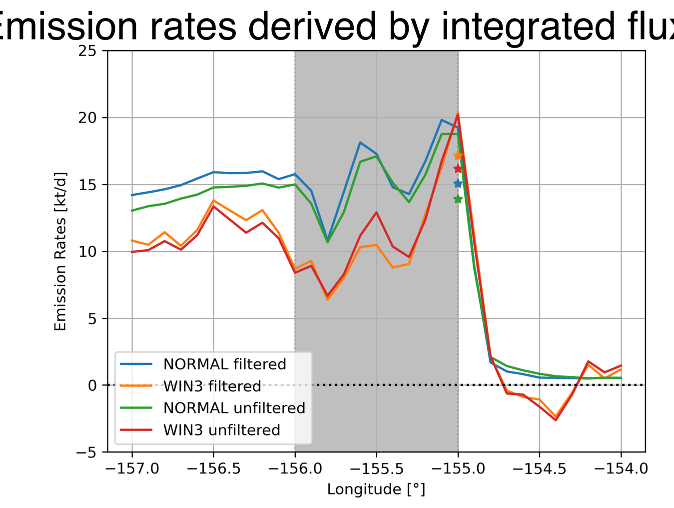
Mean zonal flux



Cross section of the zonal flux at 156°W



Emission rates derived by integrated fluxes



Discussion

- location and strength of SO_2 emissions can be determined for a high spatial resolution and the results are verified by the alternative approach
- obtained emission rates are much lower compared to ground-based observations possibly due to uncertainties of the AMF (C. Kern, 2020)
- poor statistics for individual orbits makes multi-day averaging necessary

- further investigation of the variables leading to high uncertainties
- application of the divergence method on a global scale

REFERENCES:
- S. Beirle: Pinpointing nitrogen emissions from space; Science Advance, 2019
- C. Kern: Quantifying gas emissions associated with the 2018 rift eruption of Kīlauea Volcano using ground-based DOAS measurements; Bulletin of Volcanology, 2020
- N. Theys: sulfur dioxide retrievals from TROPOMI onboard Sentinel-5 Precursor: algorithm theoretical basis; Atmospheric Measurement Techniques, 2017

* Contact: adrian.jost@mpic.de