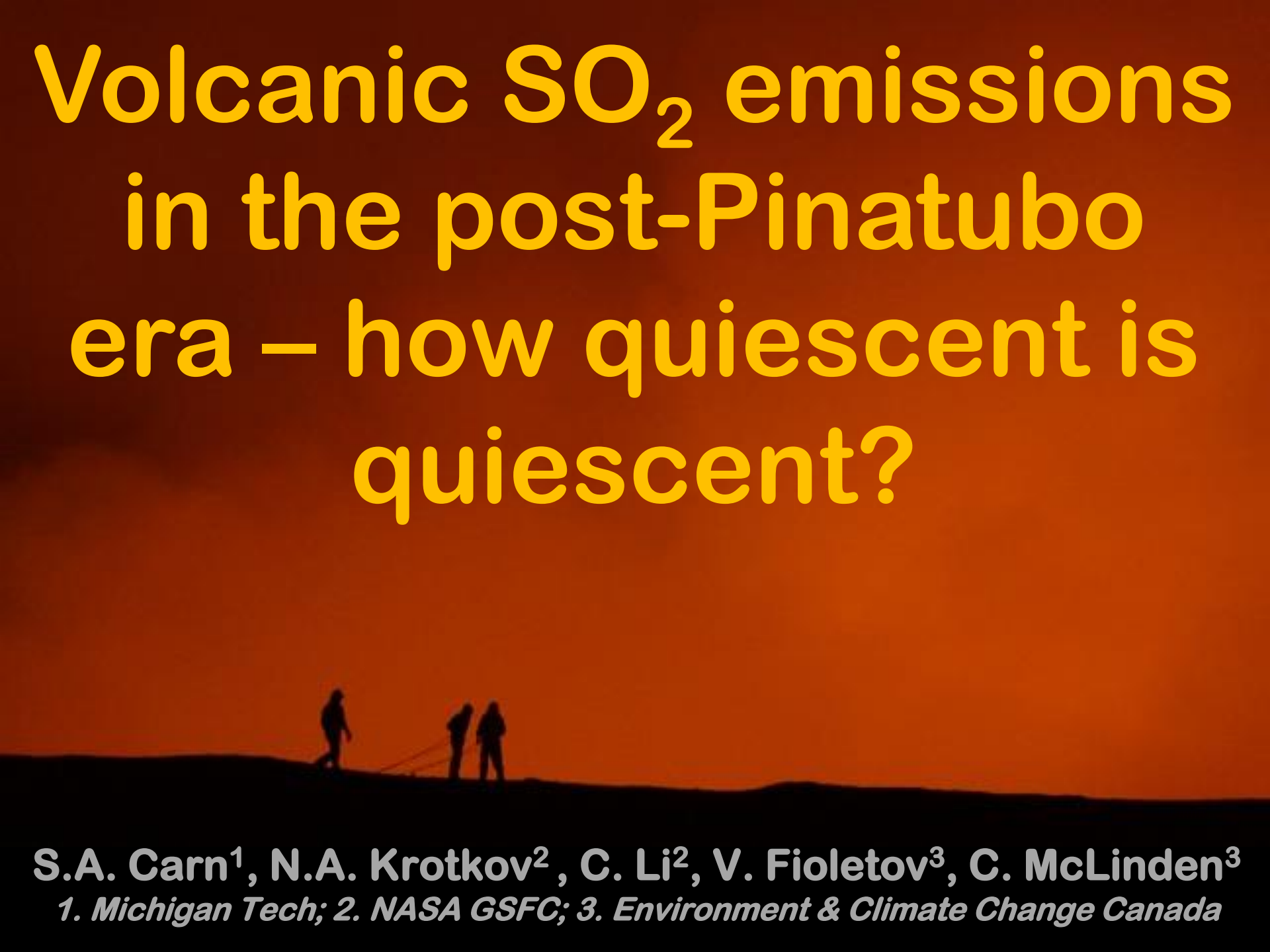
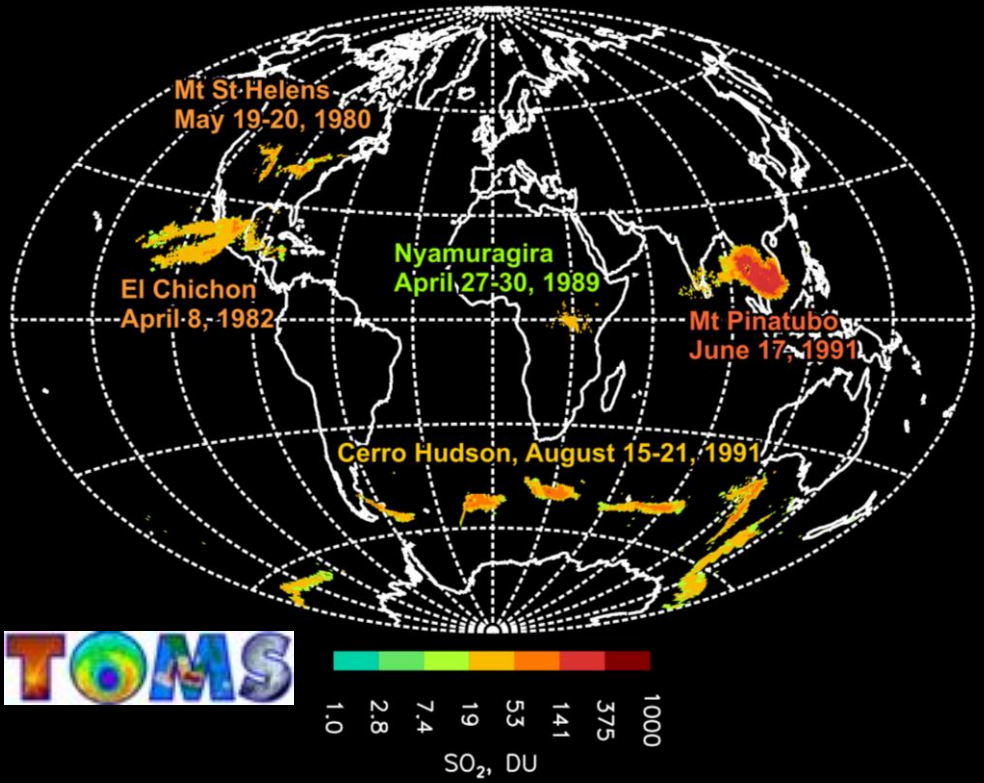
Volcanic SO_2 emissions in the post-Pinatubo era – how quiescent is quiescent?

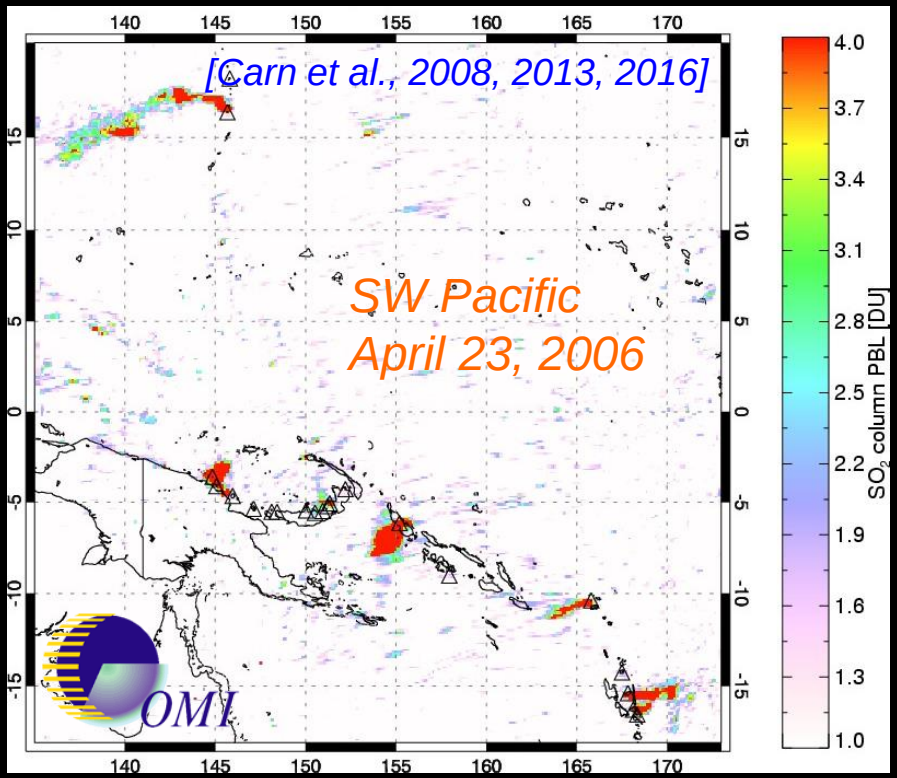


S.A. Carn[1], N.A. Krotkov[2] , C. Li[2], V. Fioletov[3], C. McLinden[3]

1. Michigan Tech; 2. NASA GSFC; 3. Environment & Climate Change Canada

UV satellite measurements of volcanic SO_2





1978-2005
Total Ozone Mapping Spectrometer (TOMS)

1995-2003
Global Ozone Monitoring Experiment (GOME)

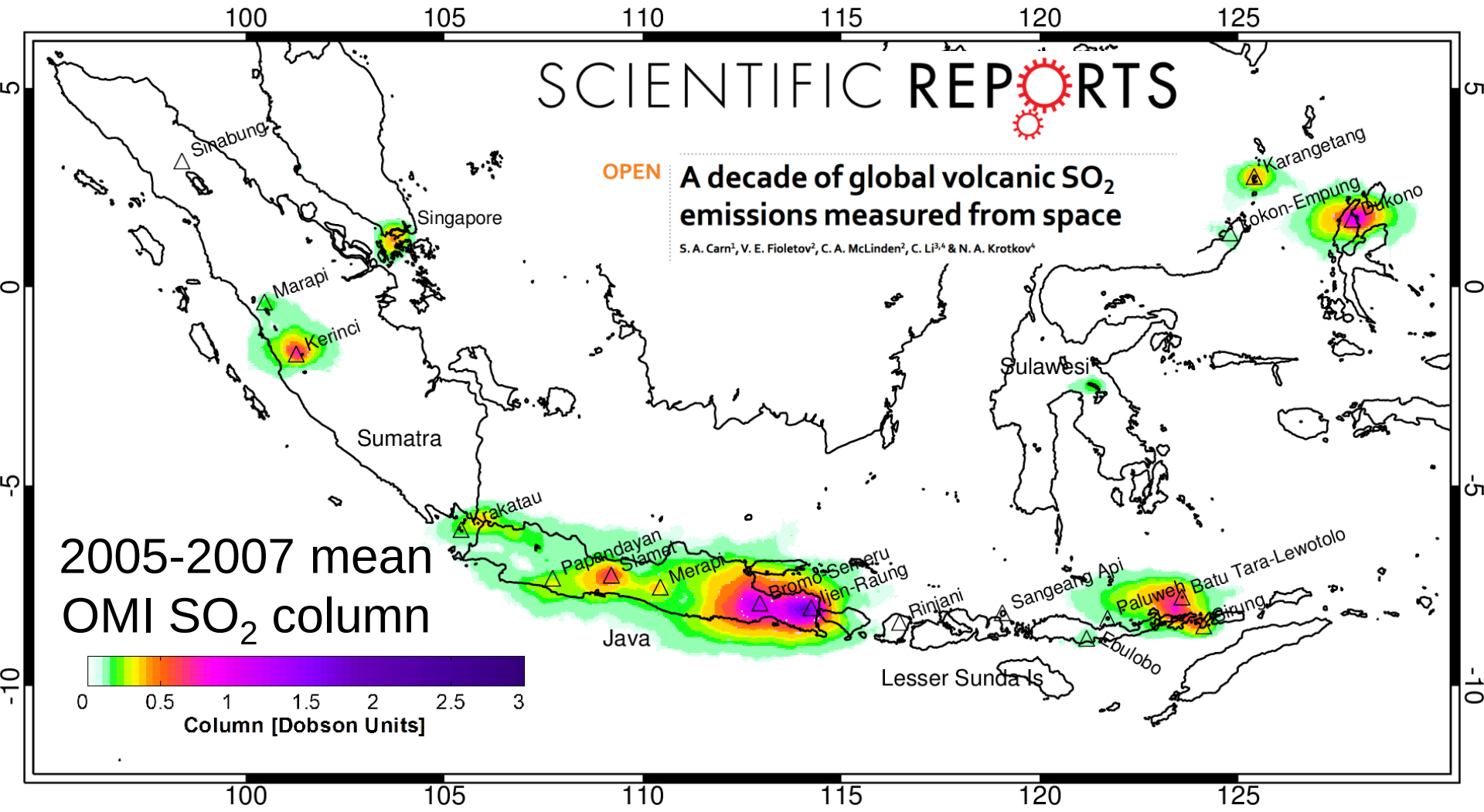
2004-
Ozone Monitoring Instrument (OMI)

2006-
Global Ozone Monitoring Experiment 2 (GOME-2)

2012-
Ozone Mapping and Profiler Suite (OMPS)

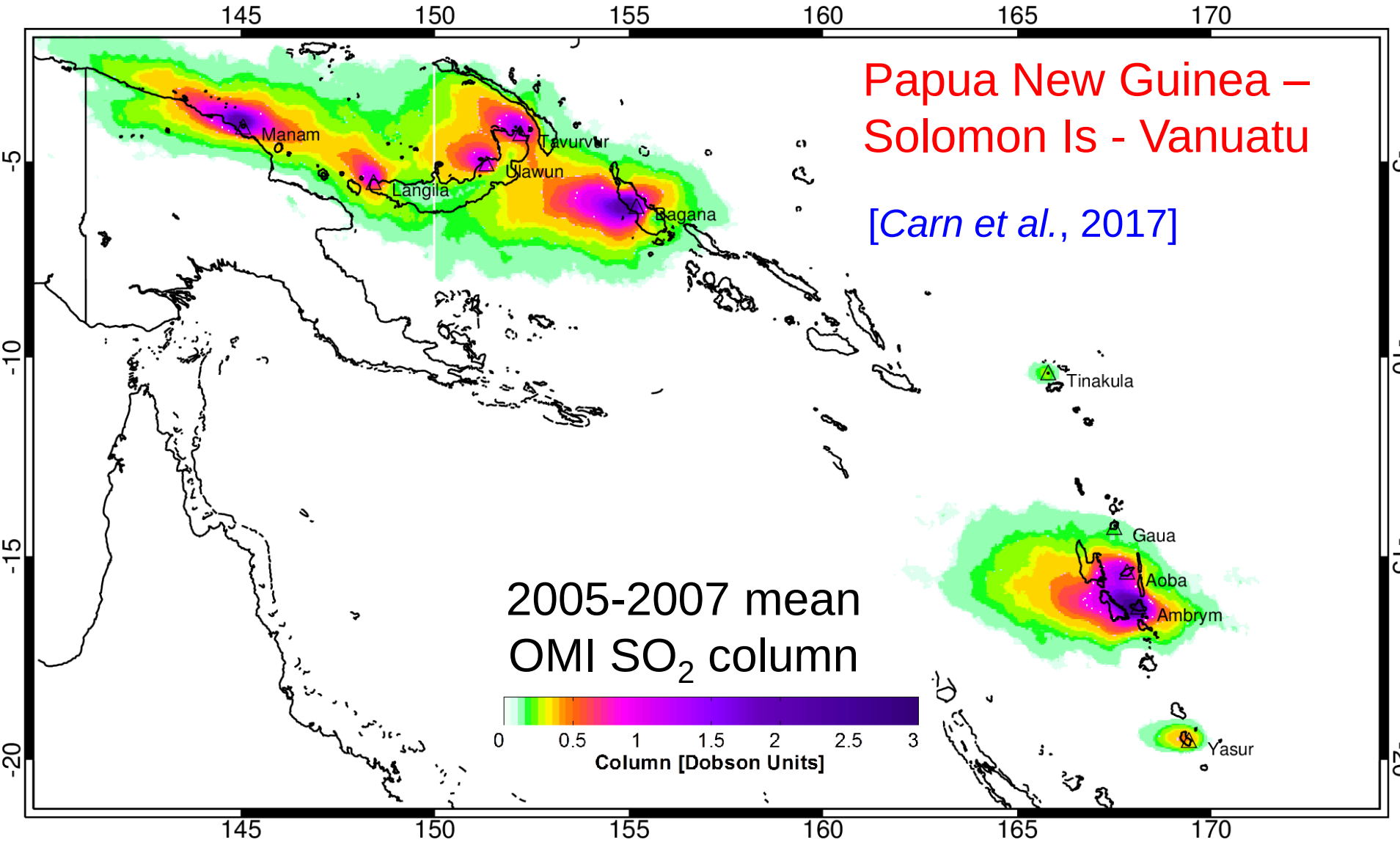
2015-
DSCOVR/ EPIC

Volcanic SO_2 sources in Indonesia



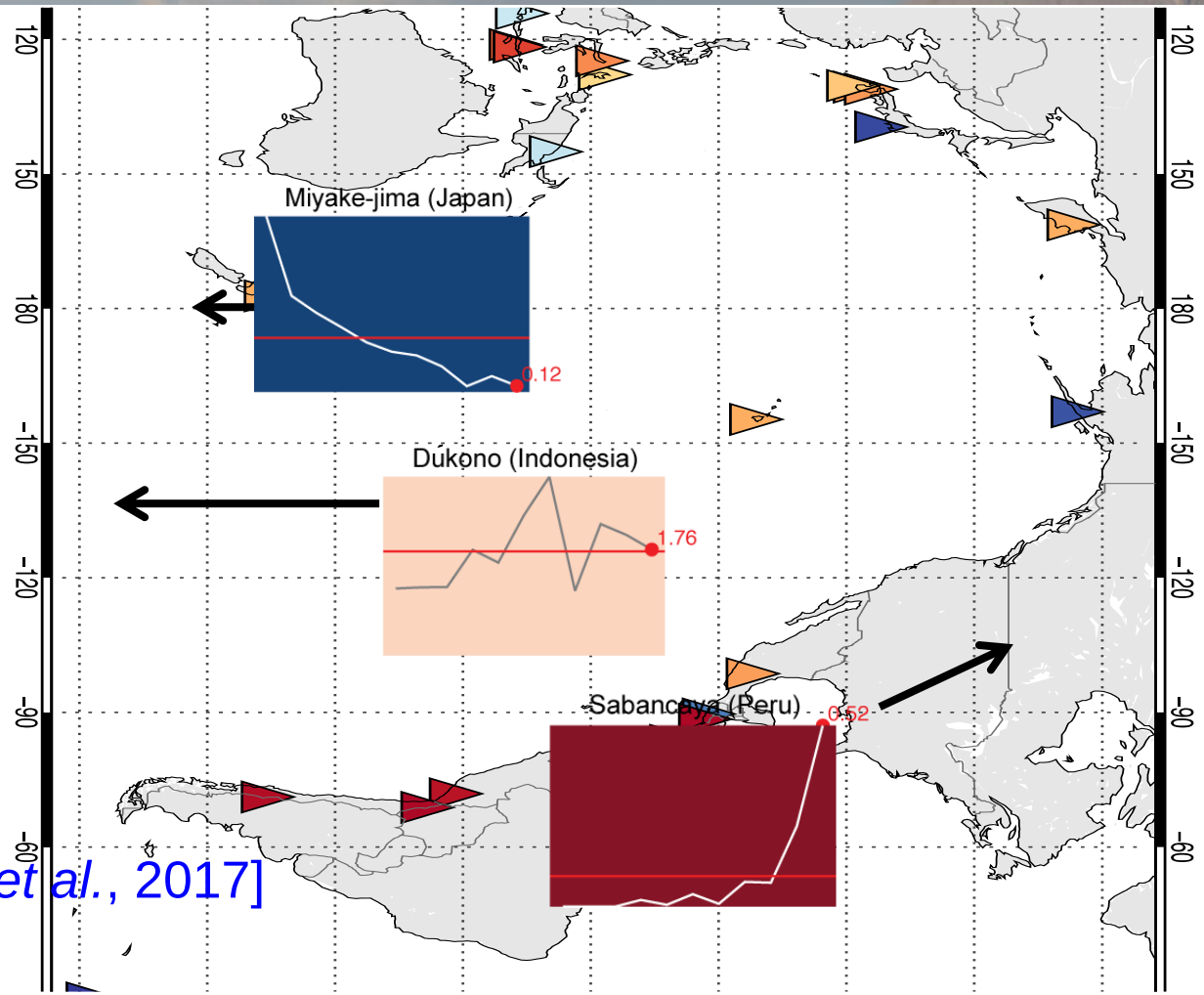
- **Globally, 90-100 volcanic SO_2 sources quantified**
- **Total SO_2 flux of 23+/-2 Tg/yr (~63 kt/day)** [*Carn et al.*, 2017]

First SO_2 emissions data for some remote regions



- **Volcanic emissions dominate in many regions**

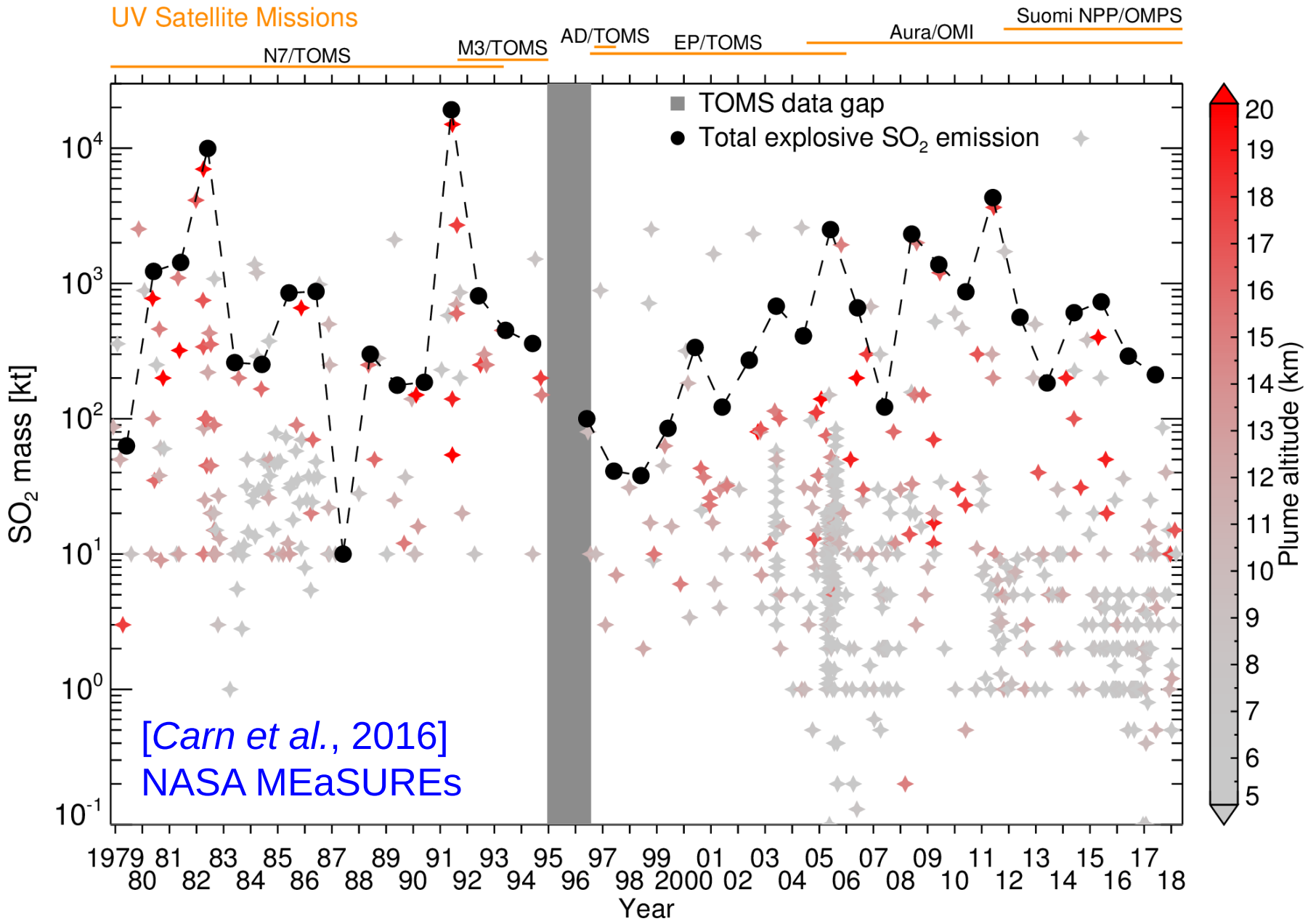
Trends in tropospheric volcanic SO_2 emissions



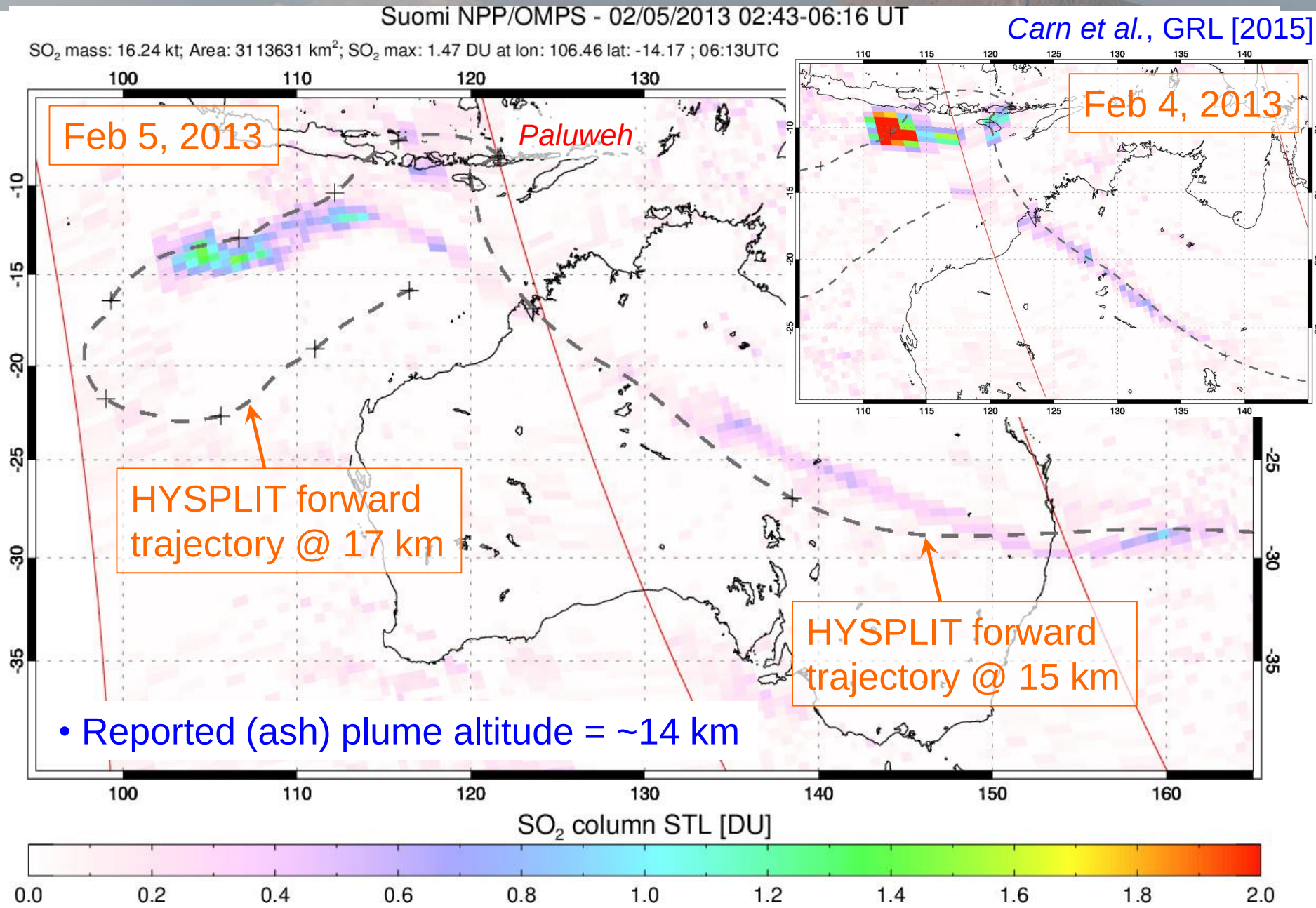
[*Carn et al.*, 2017]

- **~30% of volcanic SO_2 sources show significant decadal trends in emissions**
- **Improvement over Andres and Kasgnoc (1998) database**

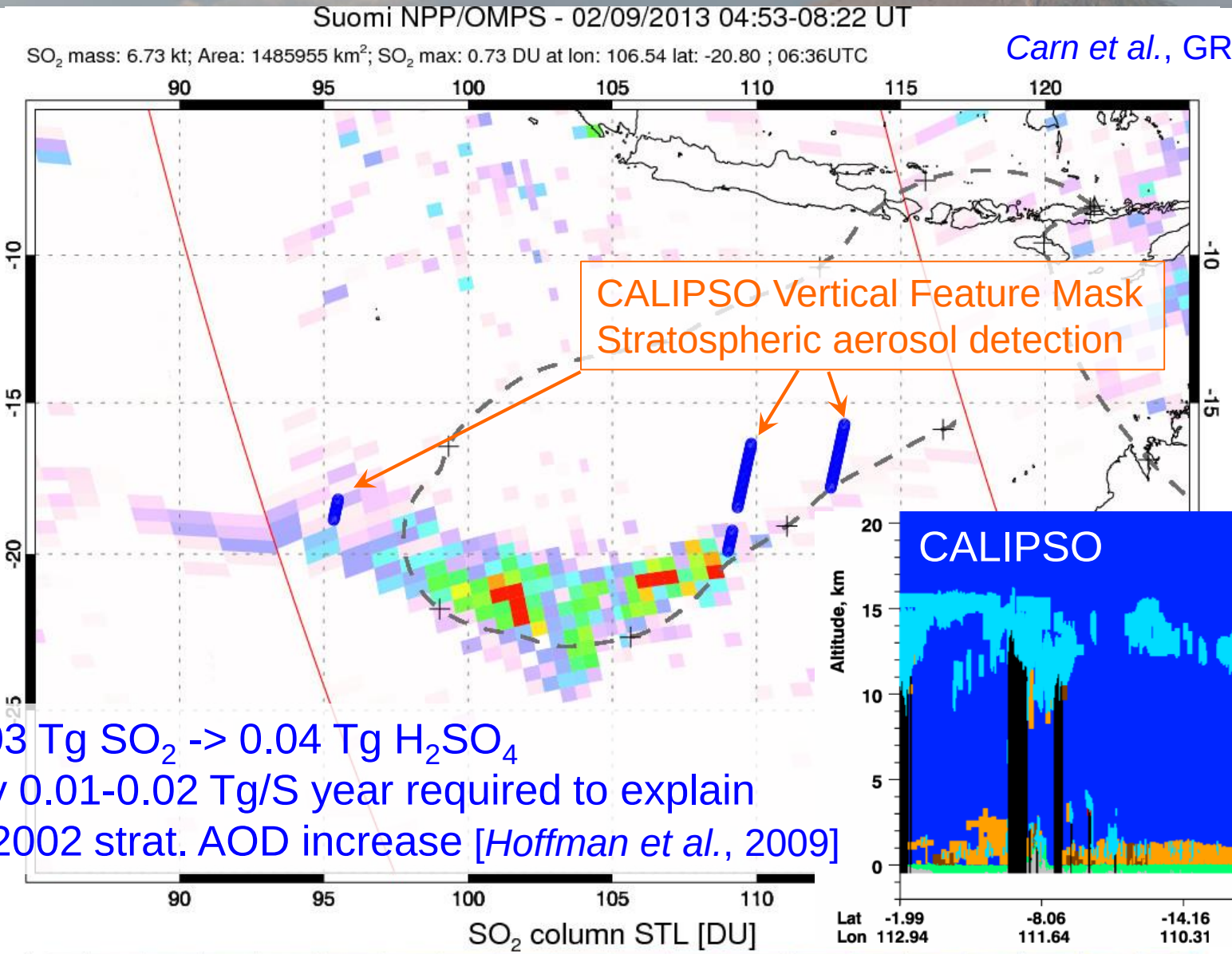
Multi-decadal volcanic SO_2 emissions



Suomi NPP/OMPS NM SO_2 data for Paluweh (Indonesia)



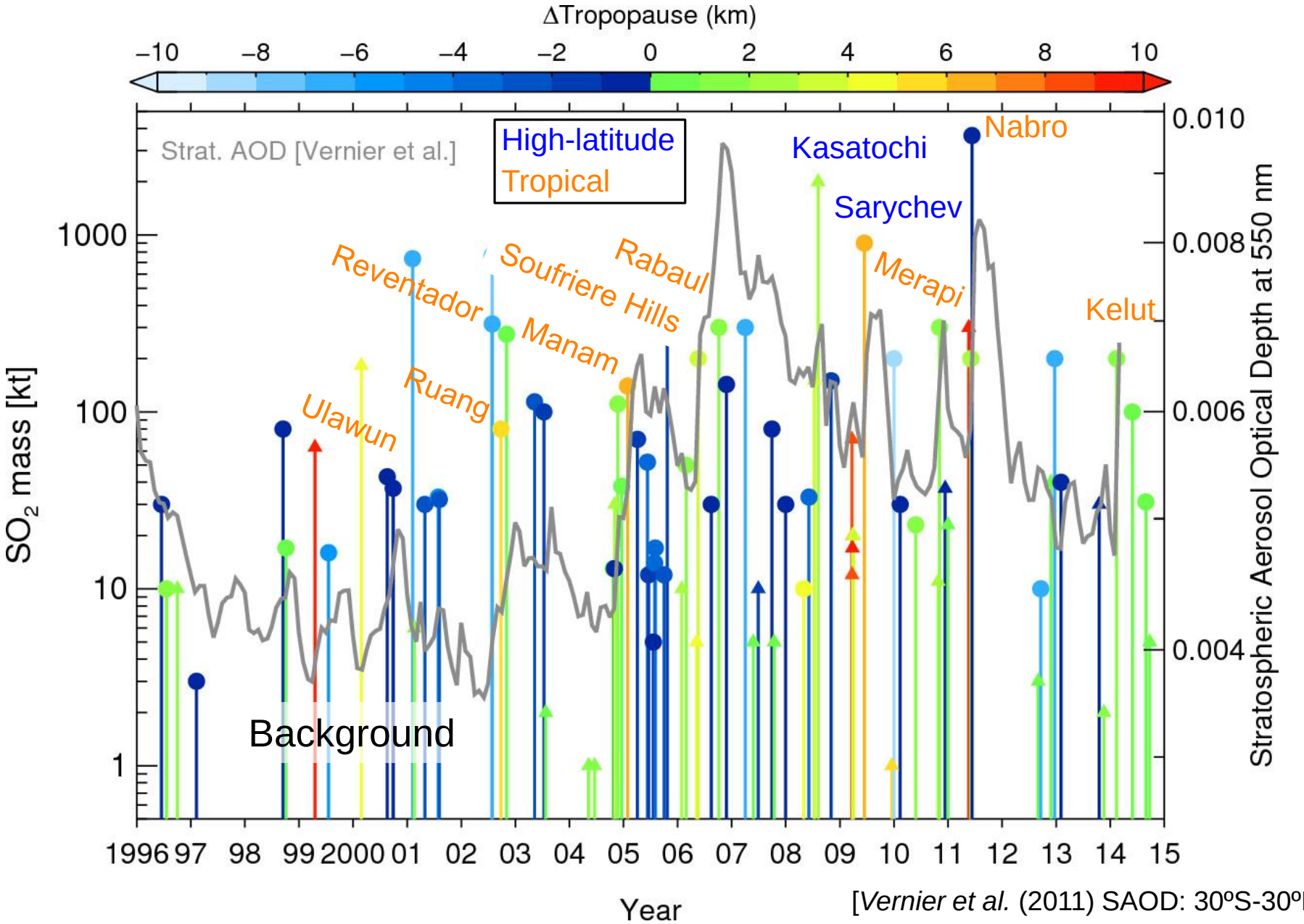
Suomi NPP/OMPS SO_2 data for Paluweh



Carn et al., GRL [2015]

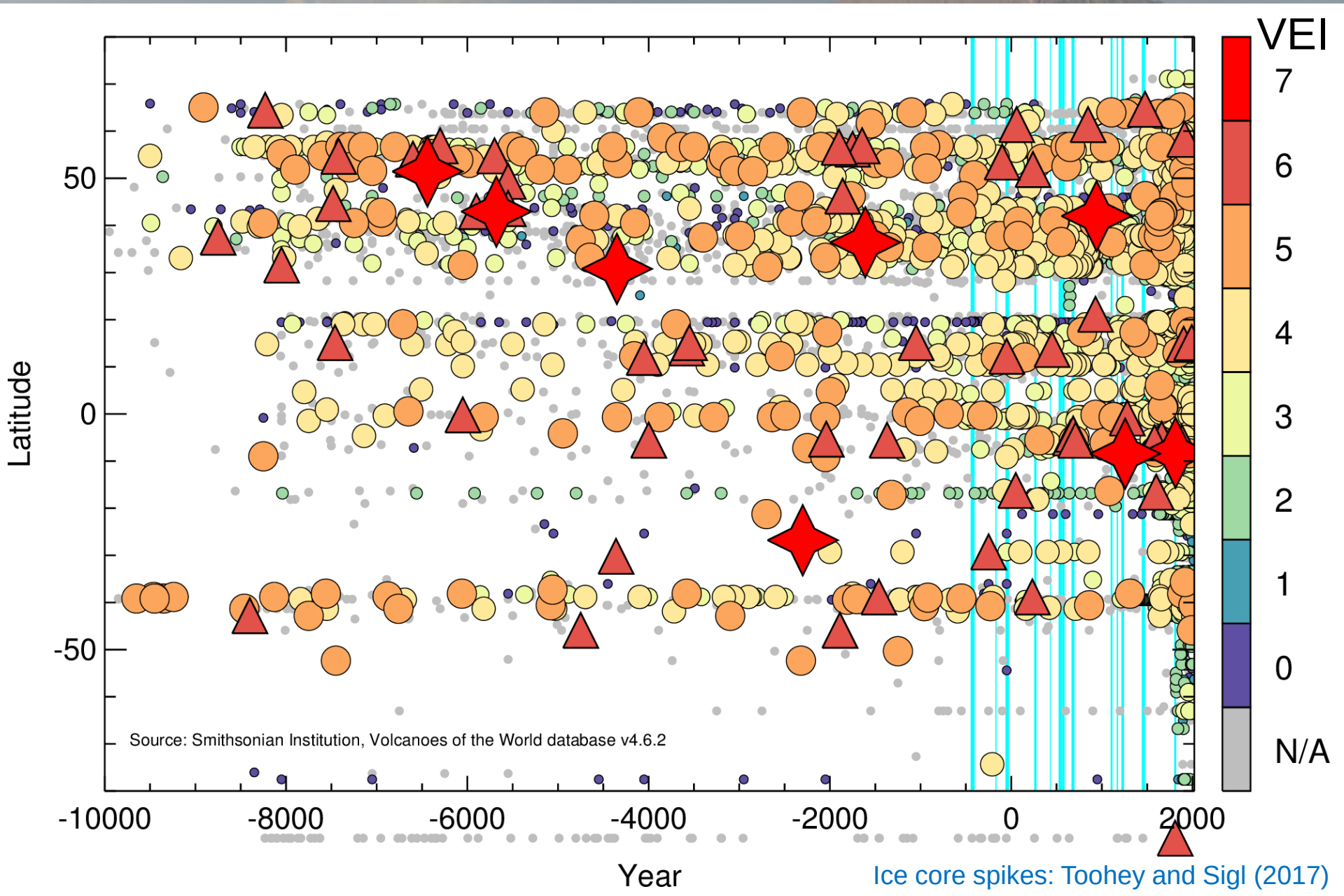
- ~0.03 Tg SO_2 -> 0.04 Tg H_2SO_4
- Only 0.01-0.02 Tg/S year required to explain post-2002 strat. AOD increase [*Hoffman et al.*, 2009]

Volcanic SO_2 and stratospheric aerosol since 1998



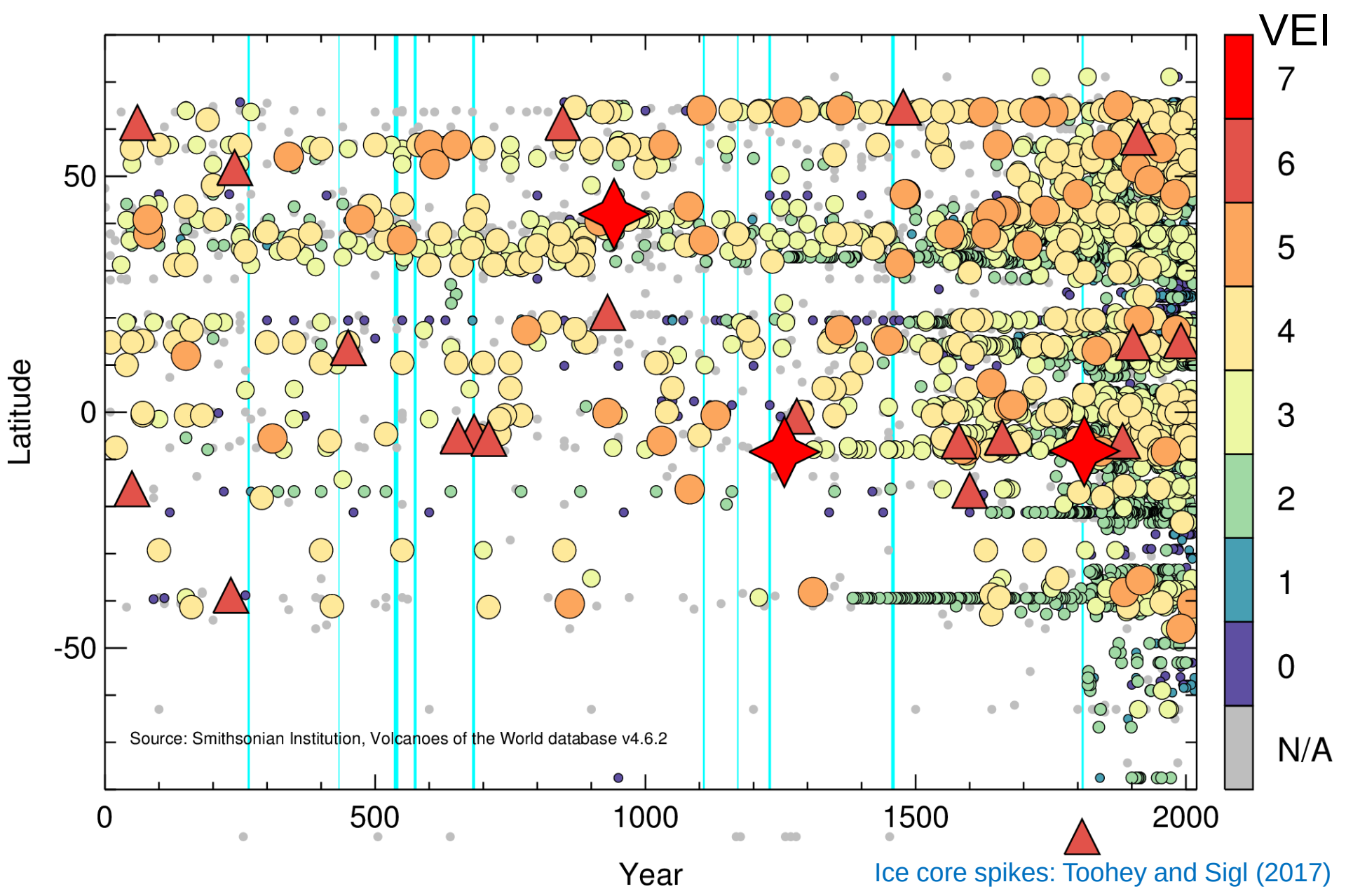
[*Vernier et al.* (2011) SAOD: 30ºS-30ºN]

Smithsonian VOTW eruptions - Holocene



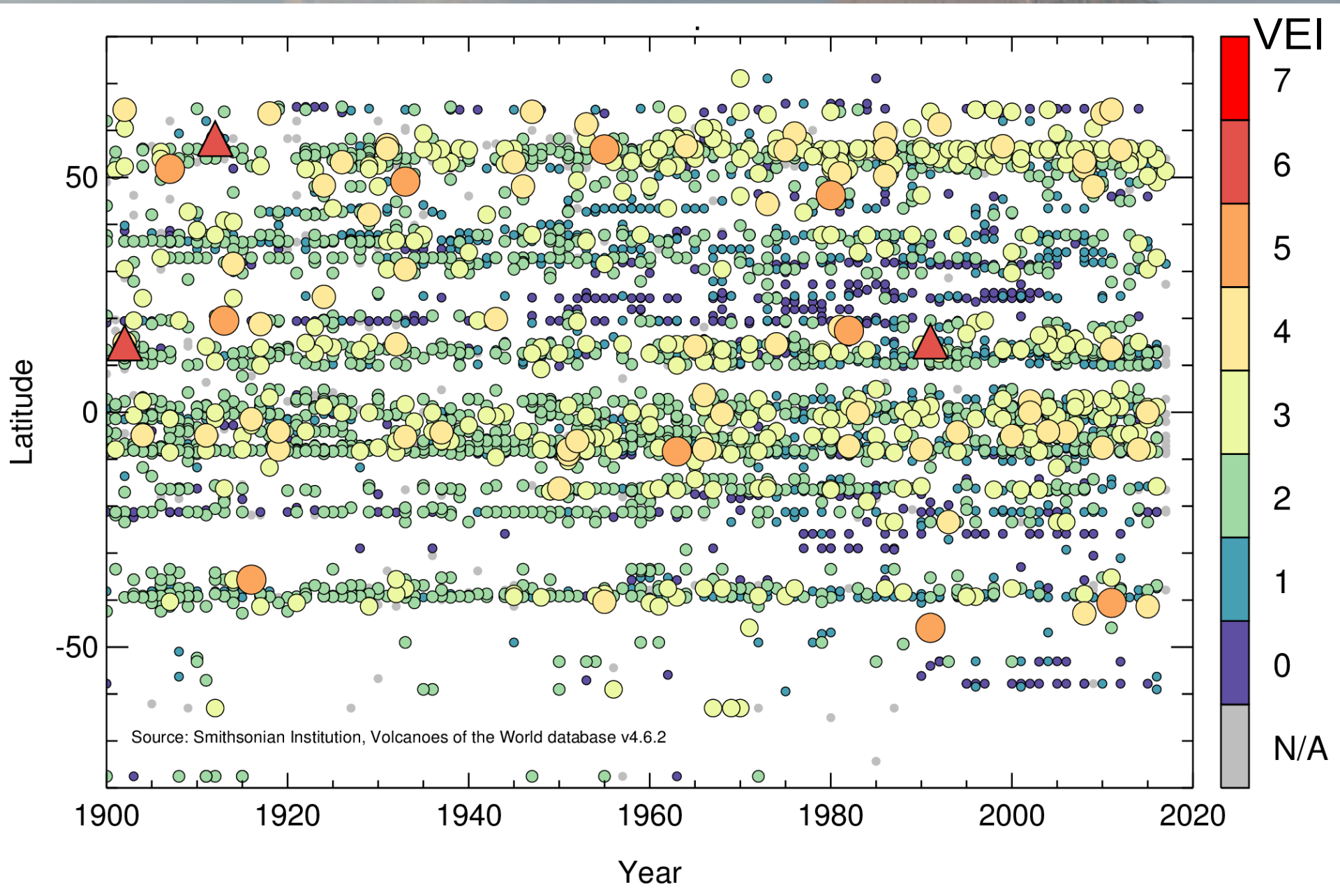
Ice core spikes: Toohey and Sigl (2017)

Smithsonian VOTW eruptions – Common Era

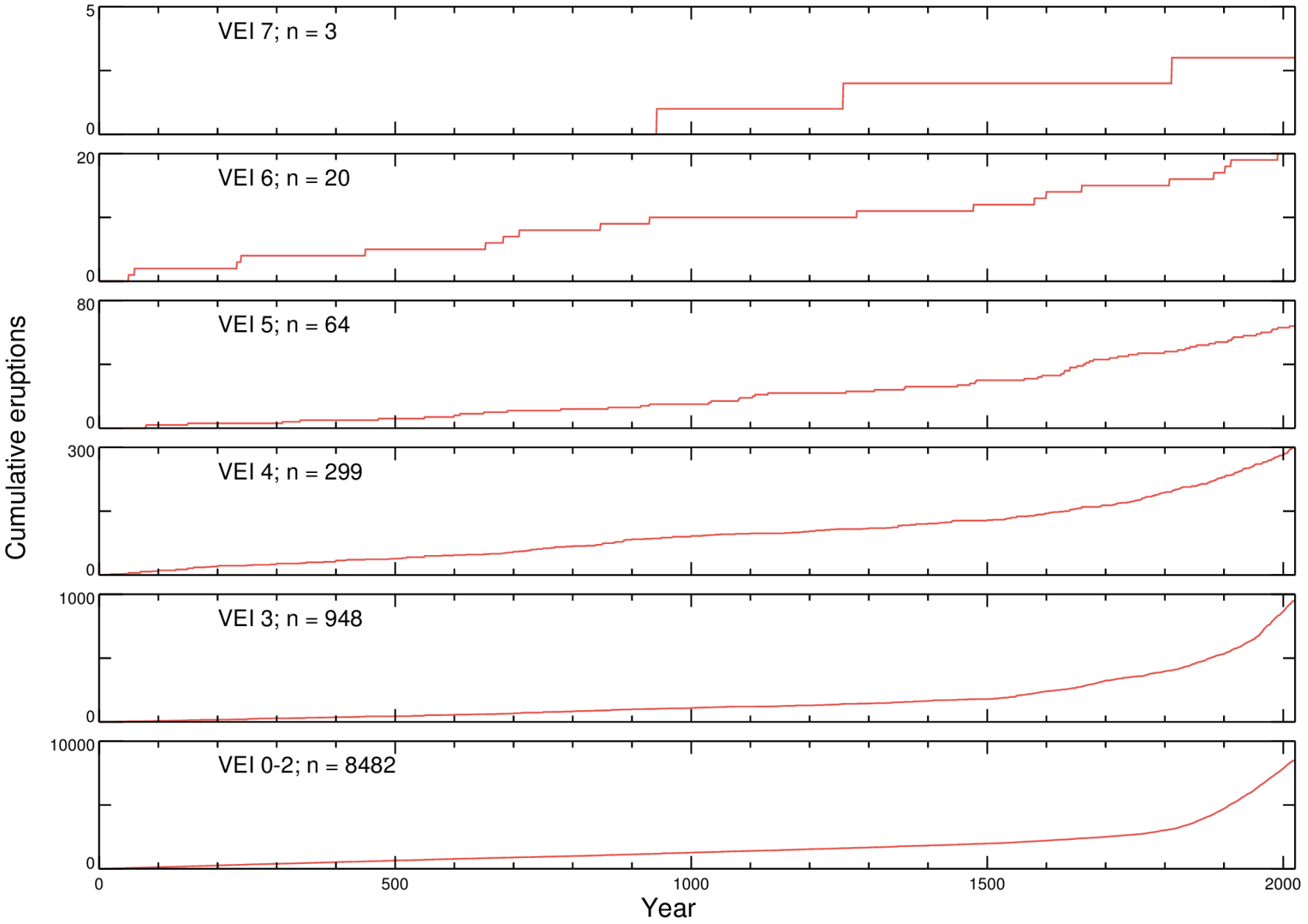


Ice core spikes: Toohey and Sigl (2017)

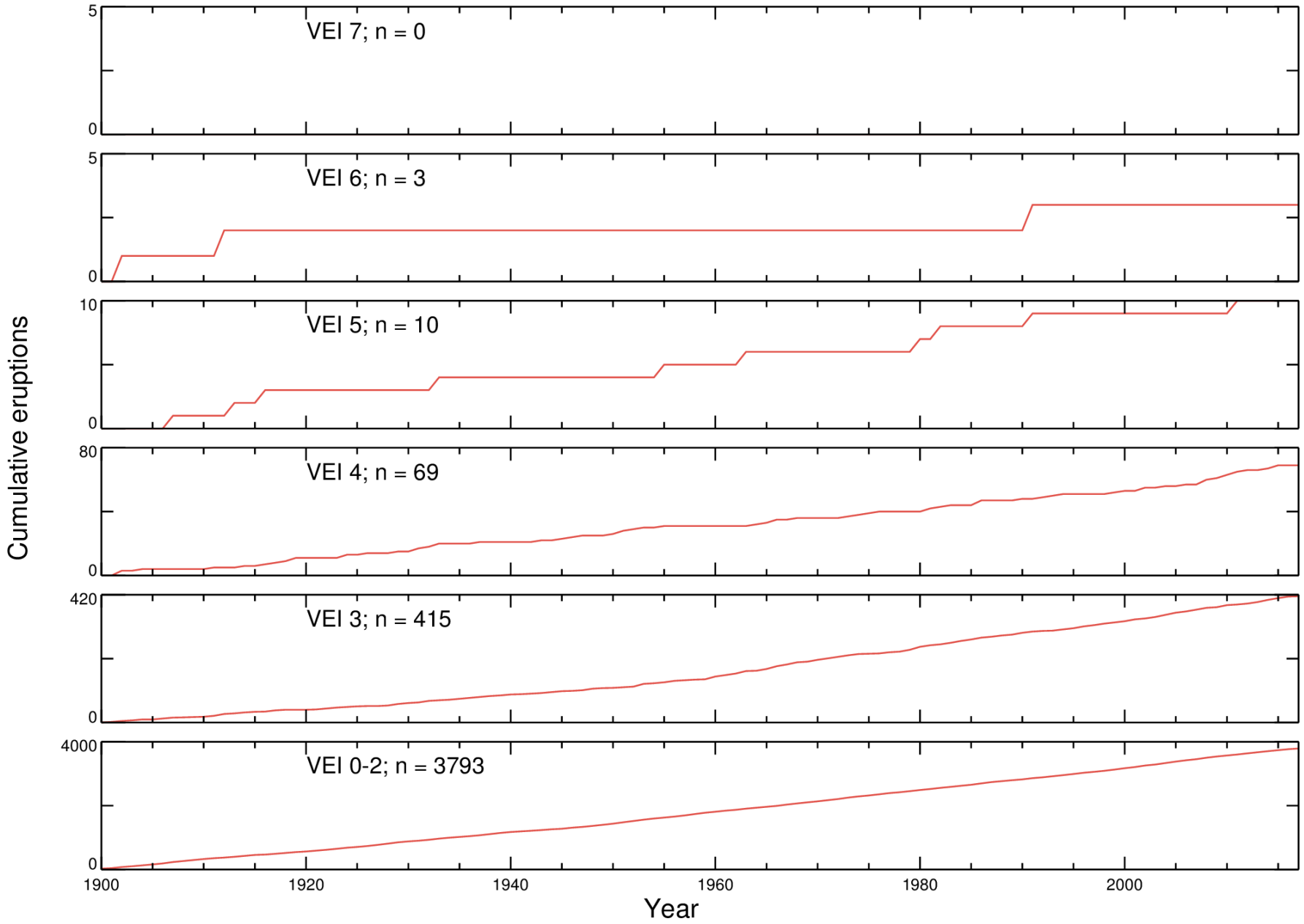
Smithsonian VOTW eruptions – C20-21



VOTW eruptions vs. time – Common Era



VOTW eruptions vs. time – C20-21



Stratospheric sulfate aerosol box model

- Only VEI 3+ eruptions in VOTW db included.
- SO_2 mass (VEI 3-5) estimated from TOMS/OMI record.
- Only 50% of VEI 3 eruptions included.
- Major SO_2 emissions (VEI 5-6+) from ice core or petrological data.
- All SO_2 assumed to reach stratosphere.
- SO_2 loss e-folding time (tropics, high latitude): 30, 15 days.
- Sulfate aerosol removal e-folding: 12, 6 months.

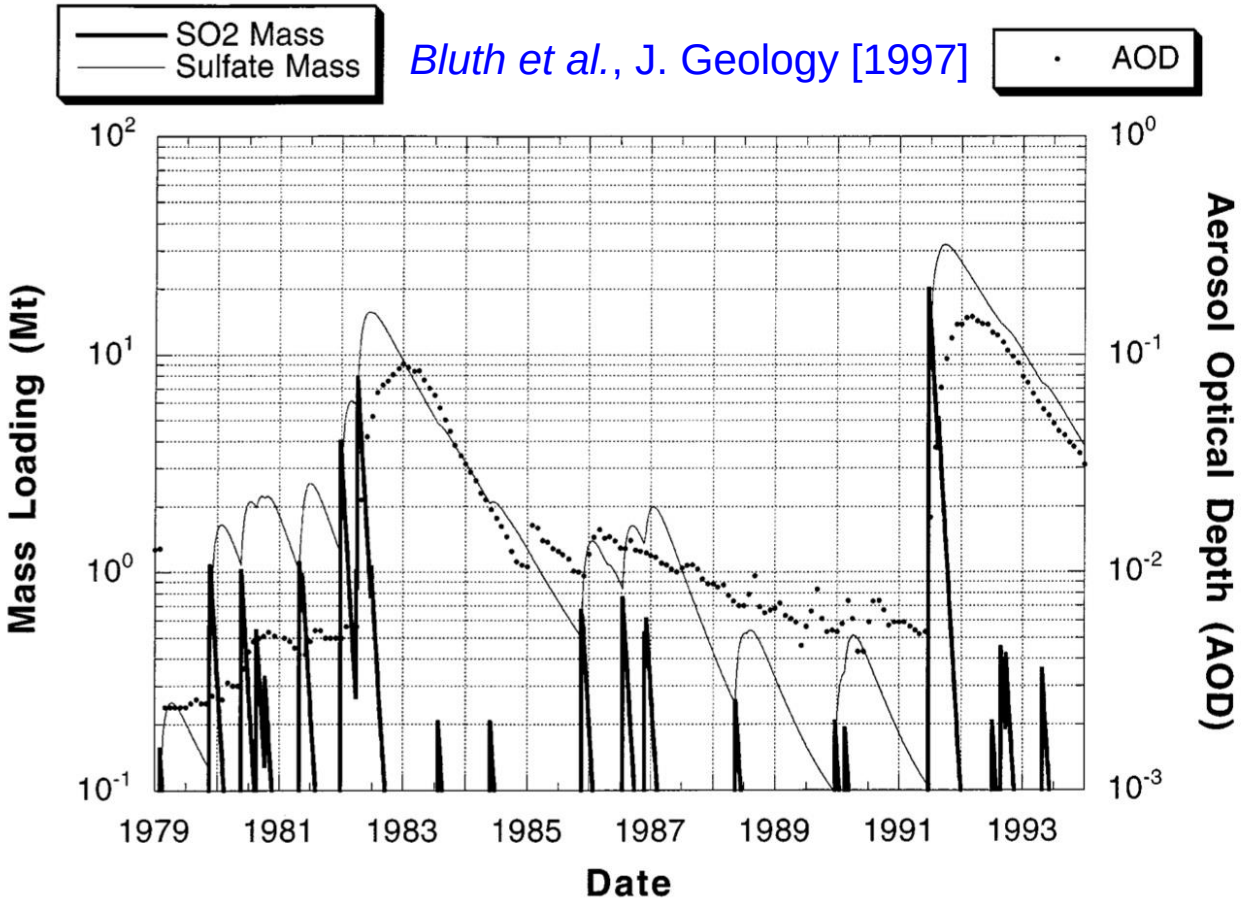
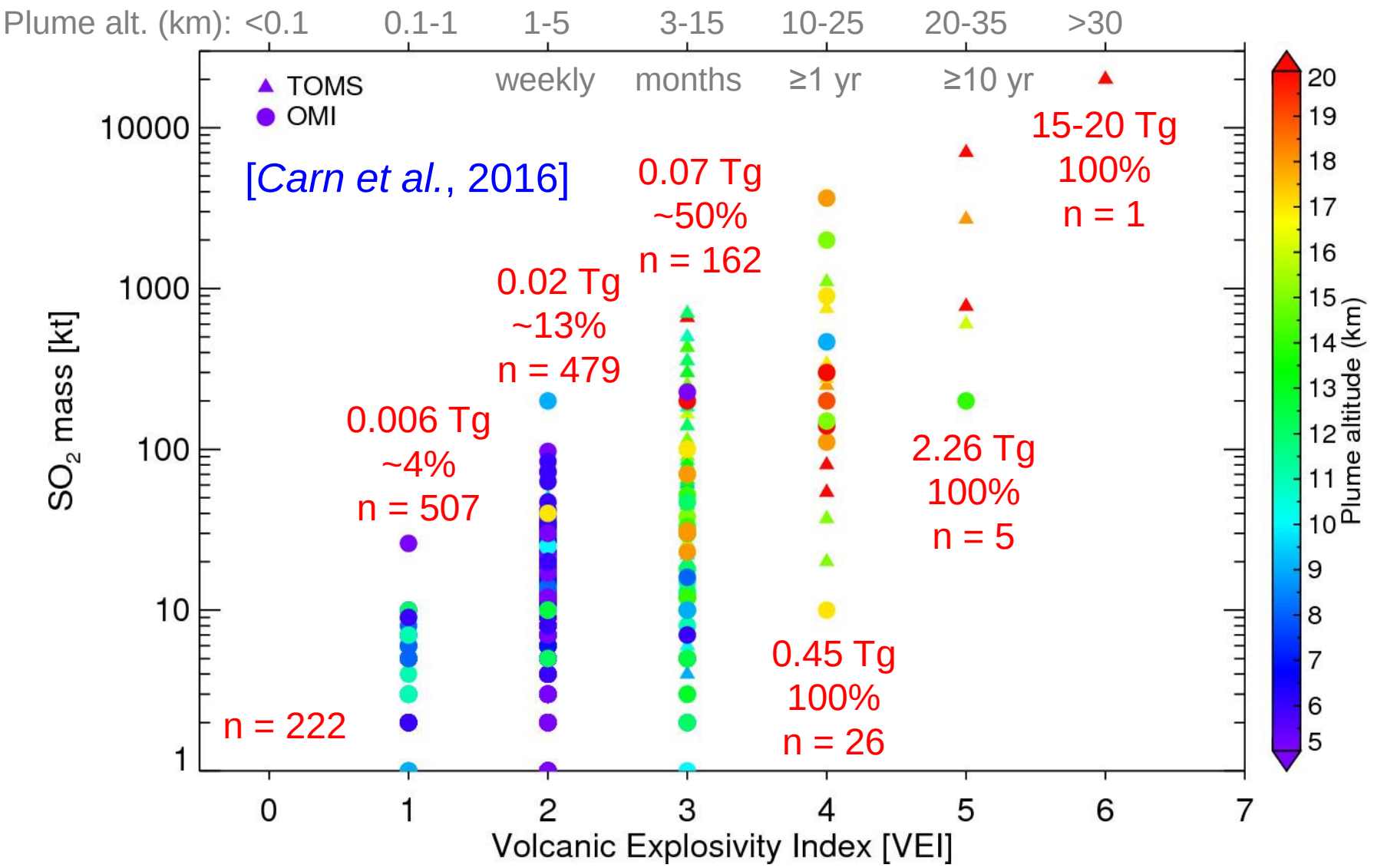


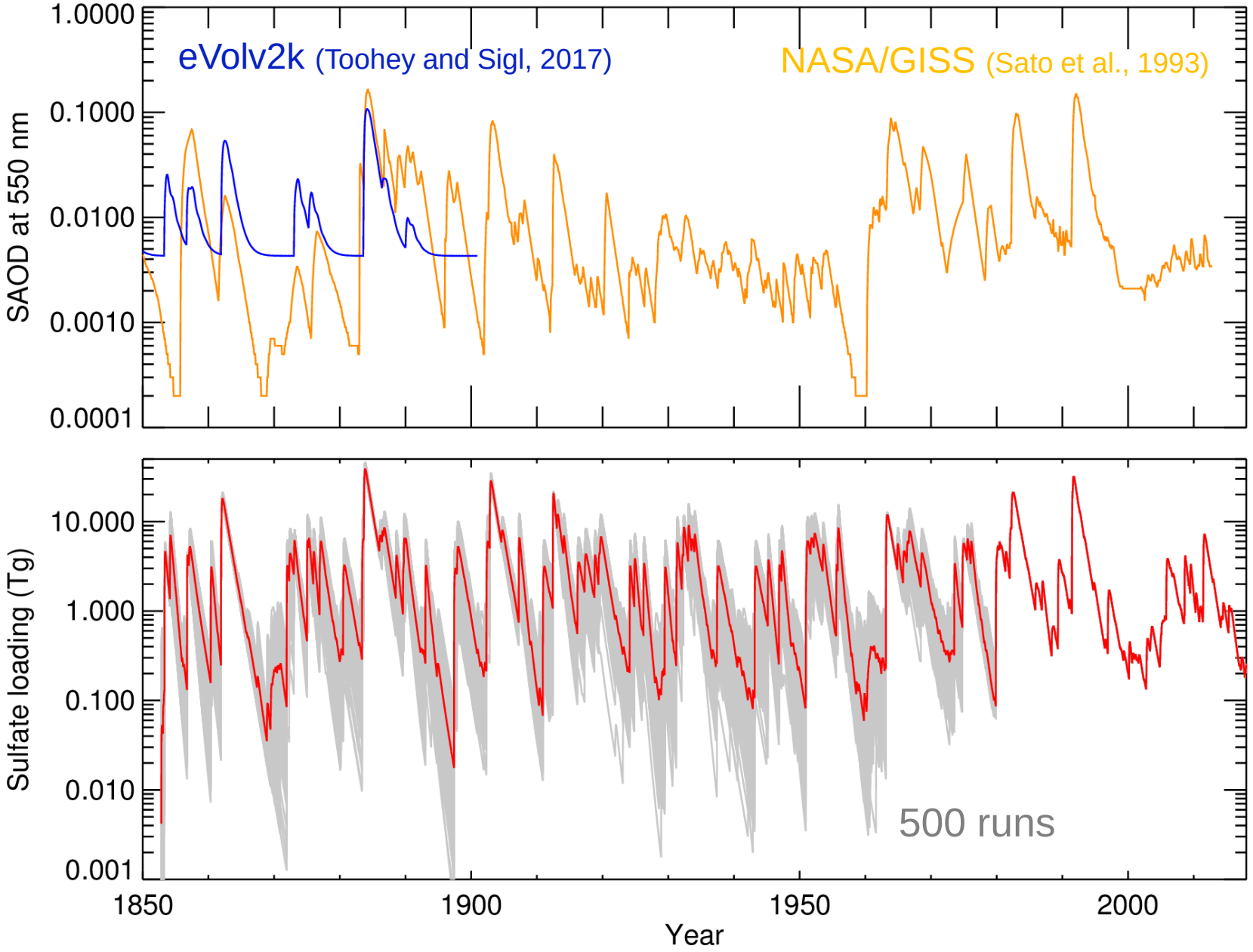
Figure 2. Model results of emitted masses of SO_2 (bold lines) from TOMS data and potential sulfate aerosol mass loading (thin line). This plot was generated by using the TOMS database from 1979 to 1994 of SO_2 emissions and applying rates of SO_2 to H_2SO_4 conversion and aerosol removal to produce a potential aerosol load. Individual eruptions are listed in table 1. The stratospheric aerosol optical depth (AOD, plotted as individual points) data at $\lambda = 0.55$ μm are determined from satellite measurements (Sato et al. 1993); the AOD is not equated with mass loading in this figure. Note the lag between the post-eruption model aerosol production versus the AOD peaks, and the differences between modeled and observed aerosol decay rates.

SO_2 emissions vs. VEI (1978-present)



- **Eruption VEIs from Smithsonian Global Volcanism Program database (VOTW 4.0)**
- **SO_2 data from TOMS, OMI, OMPS, AIRS, HIRS (UV & IR) satellite measurements**

Stratospheric sulfate aerosol box model - results



Summary

- **Multi-decadal record of volcanic SO_2 emissions based on UV and IR satellite measurements continues**
  - **VEI ≥ 3 eruptions well characterized; uncertainty on smaller explosive eruptions and fluxes of other S-gases (H_2S, OCS)**
  - **Volcanic SO_2 flux into the UTLS well-constrained**
- **SO_2 emissions from ~90-100 degassing volcanoes quantified using OMI data, many for the first time**
- **Volcanic SO_2 DB released as NASA MEaSUREs products**
  - **MSVOLSO2L4 – eruptive SO_2 emissions**
  - **MSDEGSO2L4 – passive SO_2 emissions**
- **A simple box model of volcanogenic stratospheric sulfate aerosol provides some insight into the frequency of 'quiescent' volcanic conditions**
  - **Minimum sulfate loading maintained by frequent VEI 3-4 events**

Acknowledgments: NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) and Atmospheric Composition programs