Global, Long-term Volcanic SO_2 Measurements from Satellites and the Significance to Climate

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Introduction

There is increasing interest in the gaseous composition of the atmosphere, especially with the recognition that changes are occurring more rapidly than expected and through both anthropogenic and natural causes. Sulphur dioxide (SO_2) has both natural and man-made sources, has a significant effect on the radiative forcing of the atmosphere and significant vertical structure. In recent years several satellite instruments have demonstrated that the total column of SO_2 can be measured well and it has been shown that some limited vertical information can be obtained due to the sensitivity of the kernel functions [1–4]. Retrievals of total or partial column SO_2 can be made using infrared (IR) [2,5] ultra-violet (UV) [3,7], and microwave satellite instruments and here we concentrate on the IR and UV measurements. In the UV, TOMS, SCIAMACHY, GOME, OMI, GOME-2 and OMPS provide global information on SO_2 at differing spatial and time-scales dating back to 1979. In the IR, HIRS, MODIS, AIRS, SEVIRI, GOES and IASI provide similar information, also going back to 1979. Many of these sensors can only detect SO_2 above a certain threshold and the IR sensors mostly detect SO_2 in the upper-troposphere/lower stratosphere (UTLS). The UV sensors have better sensitivity to emissions closer to the surface and are able to measure passively degassing volcanic emissions as well as emissions from anthropogenic sources [1,7]. Thus they are well-suited to assessing the contributions of SO_2 from both strong and weak volcanic eruptions. Combing the IR with the UV measurements offers the possibility to explore the vertical structure of SO_2 emissions and potentially separate out natural from anthropogenic emissions in the upper troposphere. By utilizing the more accurate modern satellite instruments, such as IASI, AIRS, GOME-2 and OMI to post-calibrate older measurements (e.g. from TOMS and HIRS) a long time series of volcanic SO_2 emissions, dating from 1979 is being developed. The data-set has the potential to offer an improved climatology of volcanic SO_2 emissions to the UTLS and will allow models to better constrain the effects of SO_2 on the radiative balance and hence on climate. These data may be considered as a global climatology of volcanic SO_2 emissions and could be used as an SO_2 inventory for climate models or as validation data for hindcast and model sensitivity experiments.

Instrument/ Parameter	OMI	GOME-2	IASI	AIRS	TOMS	HIRS
Spacecraft	Aura	MetOp-A	MetOp-A	Aqua	Nimbus-7 Meteor-3 Earth Probe	NOAA MetOp
Launch date	15/07/2004	19/10/2006	19/10/2006	04/05/2002	24/10/1978	05/11/1978
Data available from	01/10/2004	07/03/2007	30/11/2006	31/08/2002	01/11/1978	01/12/1978
Data-set length (years) (up to 01/06/2012)	8	6	5	10	27	34
Swath width (km)	2600	1920	2200	1650	2800	2230
Pixel size (km x km)	13x24	40x80	12x12	13.5x13.5	50x50	18.5x18.5
Frequency	Daily	Daily	Twice per day	Twice per day	Daily	Up to 4 per day
Measurement	UV	UV	IR	IR	UV	IR
Detection limit (DU)	0.2	0.5	5	6	5	20
Min detectable mass (kt)	0.05	1	0.5	0.7	7	10

Table 1: Characteristics of satellite sensors used to measure global volcanic SO_2 emissions.

Time-series

Initial estimates of SO_2 emissions from OMI, GOME-2, AIRS and IASI are shown in the panels of Figure 1. Detailed inter-comparisons have not yet been completed but will entail careful consideration of sampling differences, timing, spatial resolution and differing vertical sensitivities.

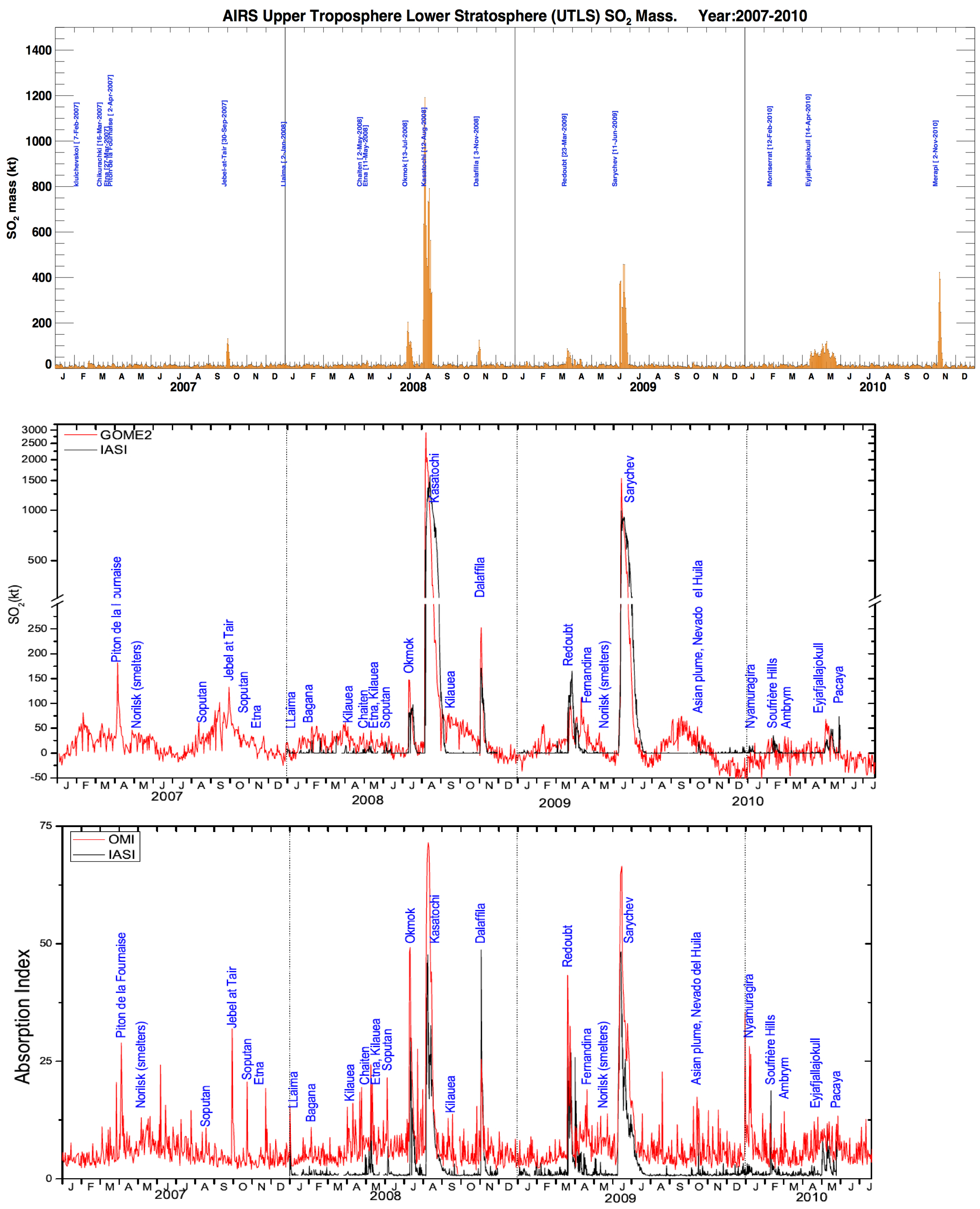

Figure 1. Time-series of total SO_2 mass estimated by different sensors. ***Top-panel:*** **AIRS SO_2 mass,** ***Middle-panel:*** **IASI and GOME-2, and** ***Bottom-panel:*** **SO_2 absorption index for IASI and OMI.**

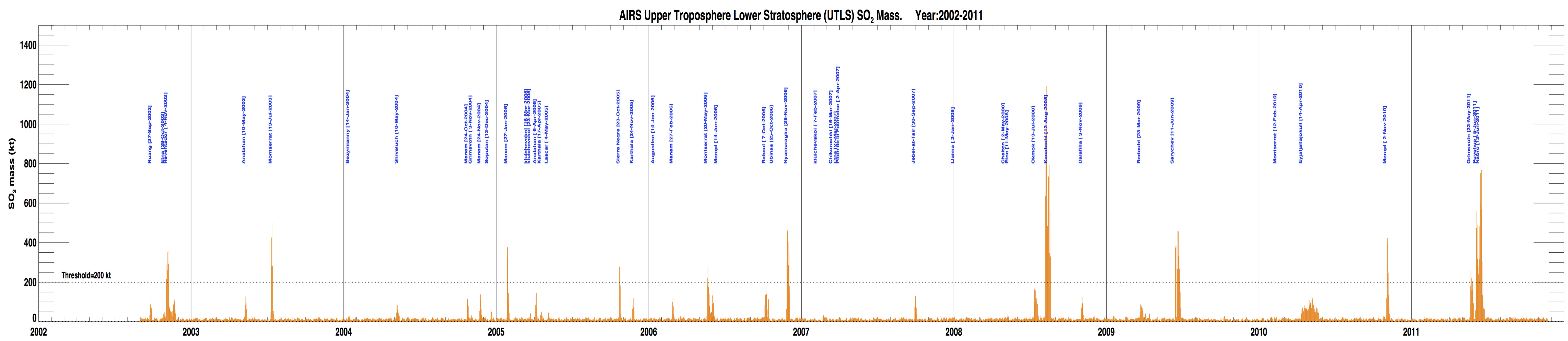

Figure 2. Time-series of total SO_2 mass (kt) estimated from AIRS 7.3 μm measurements for the years 2002–2011. Note that AIRS detects SO_2 in the UTLS and therefore is an excellent monitor for emissions that potentially have a climate impact.

SO_2-retrievals from Satellites

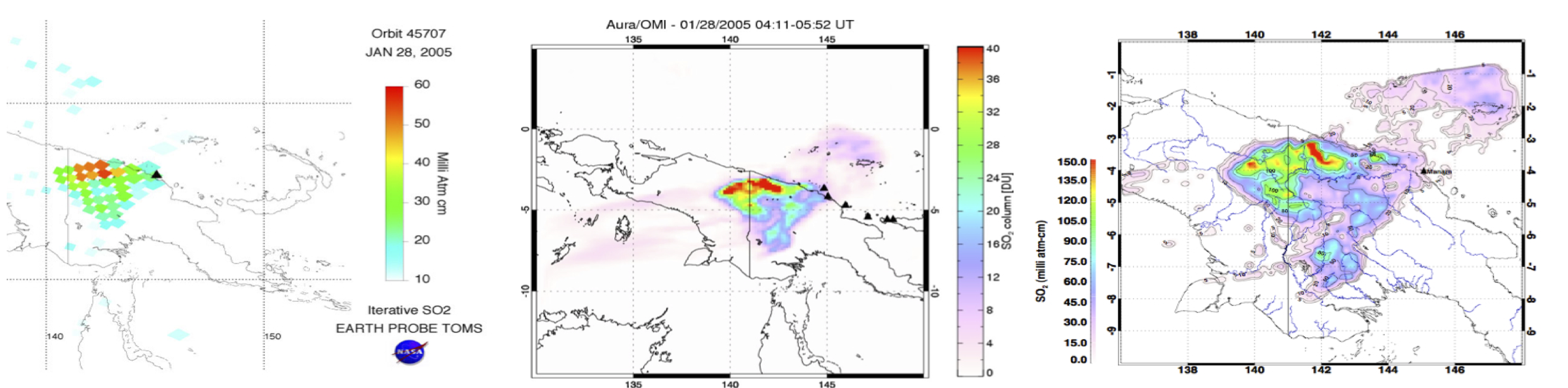

Figure 3. TOMS (*left*), OMI (*middle*), and AIRS (*right*) SO_2 total column retrievals (in Dobson Units, DU) for an eruption of Manam volcano, PNG in 2002.

Figure 4. Photograph of SO_2 emissions from Turrialba volcano, Costa Rica.

Difficulties arise when combining and comparing SO_2 retrievals from different satellite seniors because each sensor has specific measurement characteristic (see Table 1). Comparisons can be made between retrievals when the sensors are able to view the same SO_2 cloud at similar times and when the whole cloud lies within instruments' the field-of-view. Figure 3 shows one such comparison between TOMS, OMI and AIRS–in this case the comparison is favourable. Another difficulty to overcome is due to the differences in vertical sensitivity of the UV and IR sensors. Generally, UV sensors "see" emissions closer to the surface. SO_2 emissions from Turrialba volcano, Costa Rica (Figure 4) can be detected by OMI but are rarely seen by AIRS.

Conclusions

Some progress has been made in utilising current satellite instruments to infer total SO_2 mass injections into the UTLS. By compositing and comparing these data a methodology is being developed to establish a long-term global data-set of SO_2 mass for use in climate sensitivity studies, for input to dispersion models [4,6] and for investigating the fate of volcanic SO_2 in the atmosphere (see Figure 5). The eventual goal is to use the improved precision and accuracy of the current instruments to calibrate retrievals from older, less precise measurements to establish a data-set spanning more than 30 years.

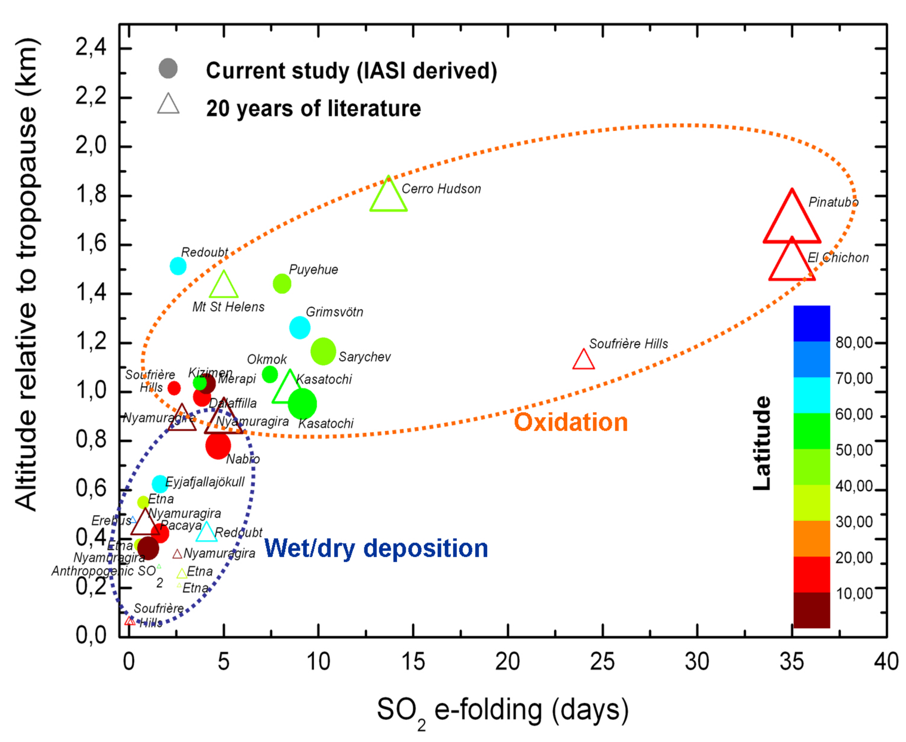

Figure 5. SO_2 e-Folding times (days) for significant volcanic eruptions determined from IASI and other historical data. Two pathways for conversion can be identified. (*Analyses by L. Clarisse.*)

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