A33I-3307

Profiling the SO_2 Plume from Volcan Turrialba:
Ticosonde Balloon Measurements Compared with OMI and OMPS Retrievals

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MOTIVATION and APPROACH

Unlike many other atmospheric trace species, the large-scale distribution of SO_2 is affected by episodic , spatially inhomogeneous and occasionally large-magnitude emissions events. Both of these represent a challenge for remote sensing of SO_2 from space, and it is thus important to take advantage of every opportunity to obtain ground truth measurements of SO_2.

We have been using indirect and more recently a direct dual ozone sonde techniques to estimate volcanic SO_2 over San José, Costa Rica. We compare these two *in situ* approaches and then compare these to SO_2 column observations obtained from two satellite instruments: the Ozone Monitoring Instrument (OMI) on Aura and the Ozone Mapping and Profiler Suite (OMPS) on Suomi-NPP.

Photo: Simon Carn

Photo: Smithsonian Global Volcanism Program

Two recent views of Turrialba

A UNIQUE VALIDATION OPPORTUNITY

Turrialba [10.0°N, 83.8°W, elev. 3440 m] is a large stratovolcano located ~35 km east of the San José, Costa Rica. Activity re-commenced in 1996 and has led up to a series of five eruptions, four of them explosive, in the last five years. These have occurred during an **extended period of fumarolic activity and emission of SO_2**.

The NASA Ticosonde program began making **ozone sonde measurements** in the San José metropolitan area in 2005. The following year, we began to see notches in the ozone profiles that were consistent with interference from SO_2 in the ECC ozone sonde. We determined that **the most likely source of the SO_2 was fumarolic emissions from the summit craters of Turrialba**.

In February 2012 we showed **that a dual-ozone sonde technique could successfully detect the Turrialba plume** at San Jose. In July 2013, we began flying dual ozonesondes on a regular basis, and we now have a data base of 24 dual sonde launches along with over 80 regular ozone sondes with notched profiles in the lower troposphere.

DUAL-SONDE DIFFERENCE METHOD vs. NOTCH INFERENCE METHOD

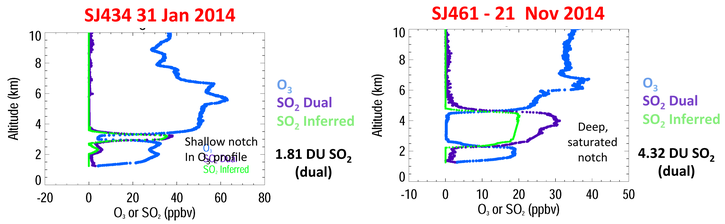

Figure 1: For dual sonde flights, we compare the SO_2 derived using the technique of *Morris et al.* [2010] (dual sonde, filtered minus unfiltered ozone measurements, VIOLET) with that a notch-inferred (GREEN) value estimated from the unfiltered ozone profile only. The case on the left shows a very good result for the inferred vs. "direct' measurement, while the case on the right shows the limitation of the inferred approach in plumes with very high SO_2 concentrations.

Mixing ratio comparison

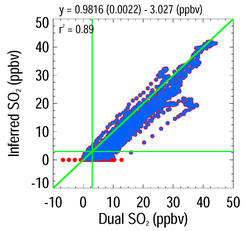

Figure 2: Comparison of 100-m resolution SO_2 mixing ratios derived from direct method (abscissa) and notch-inference method for our set of 24 dual sondes. Red are all points, while blue are comparisons only where the inferred approach identifies a notch.

Column SO_2 comparison

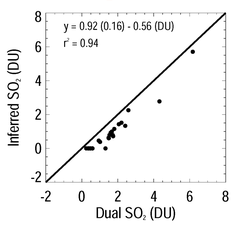

Figure 3: As in Fig. 2, but for tropospheric column SO_2.

Figs. 2 and 3 show that the **inferred SO_2 profile concentrations and column estimates arevery useful but represent lower limits** due to the ozonesonde instrument design (which does not permit negative values) and in layers, as seen in Figure 1 at right, in which both an O_3 and an SO_2 feature exist.

SUMMARY AND FUTURE WORK

With over two dozen dual sonde launches to date and a growing record regular ozone sondes showing evidence of volcanic SO_2 plumes, we have assembled a unique data set to validate both past and forthcoming retrievals of column SO_2 from both OMI and OMPS as well as future instruments such as TROPOMI. This initial effort demonstrates the advantages and the challenges inherent in validating satellite measurements of small-scale and intrinsically dynamic feature in the atmosphere. Further progress will require consideration of plume trajectories as well as a better understanding of the near-field evolution of the plume.

COMPARISONS TO OMI LF RETRIEVALS: NOTCH-INFERENCE MEASUREMENTS, 2006-present

Ozone sonde inferred SO2

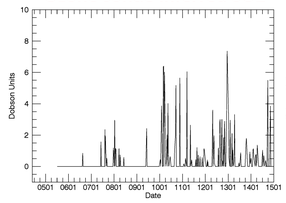

Figure 4: Balloon sonde SO_2 columns inferred from notches in O3 profiles.

OMI LF TRL – overpass max

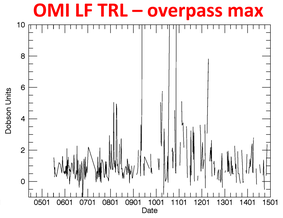

Figure 5: Overpass maximum of OMI TRL (lower troposphere) linear-fit (LF) product, sonde dates.

Screened cloud fraction

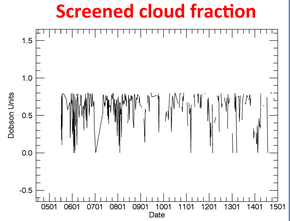

Figure 6: Retrievals with CLD_F > 0.8 screened out.

Figs. 4 and 5 demonstrate that the OMI LF product is capturing the major episodes of SO2 "notching" in the sondes since 2006. After screening out high cloud fraction retrievals (Fig.6) – but not for plume trajectory – **we find a positive relationship between the in situ and remote sensing measurements**, with the retrieval dynamic range ~60% of the range of the sondes.

Sonde/OMI LF comparison

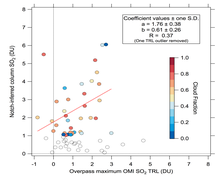

Figure 7: Inferred SO2 column (>1 DU) vs overpass max TRL

SAMPLE COMPARISONS TO OMI LF and OMPS PCA SATELLITE RETRIEVALS: DUAL SONDE MEASUREMENTS since 2013

SJ423
18 Oct 2013
Dual sonde
2.59 DU

SJ435
7 Feb 2014
Dual sonde
1.60 DU

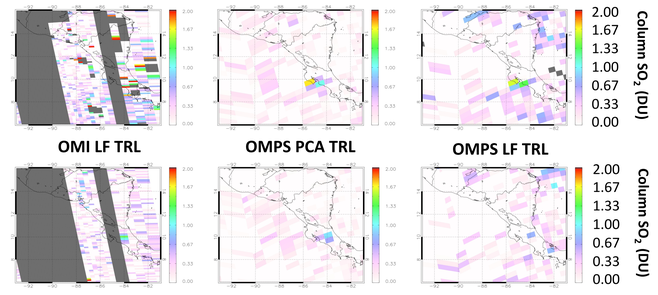

Figure 8: Columns of lower tropospheric SO_2 from OMI LF, OMPS PCA and LF TRL on two days with dual sondes.

Shown in the a above figure are maps for two dual sonde launch days of the OMI standard LF product along with the OMPS LF and the OMPS Principal Components Analysis (PCA) retrievals. **The PCA retrieval shows a lower noise level than its counterpart**. However, because of **the higher resolution of OMI, the standard product permits a closer match to the sonde measurements than OMPS** at sites such as San Jose where the plume may not have undergone substantial spreading.

Acknowledgements: This work has been supported in by the NASA Aura Science, Upper Atmosphere Compostion Observations and MEaSUREs programs.