"Ticosounding" Turrialba
Profiling volcanic SO_2 in Costa Rica

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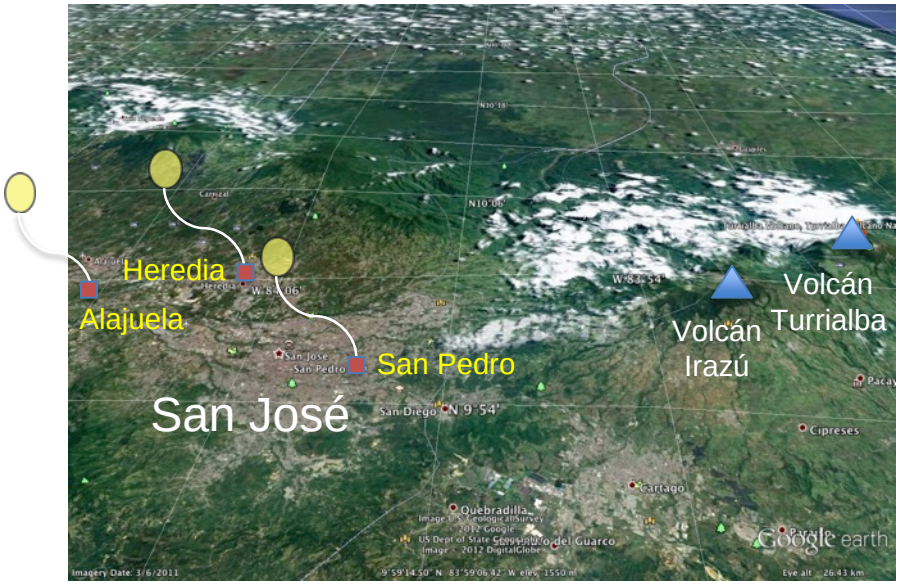
Photo: Simon Carn

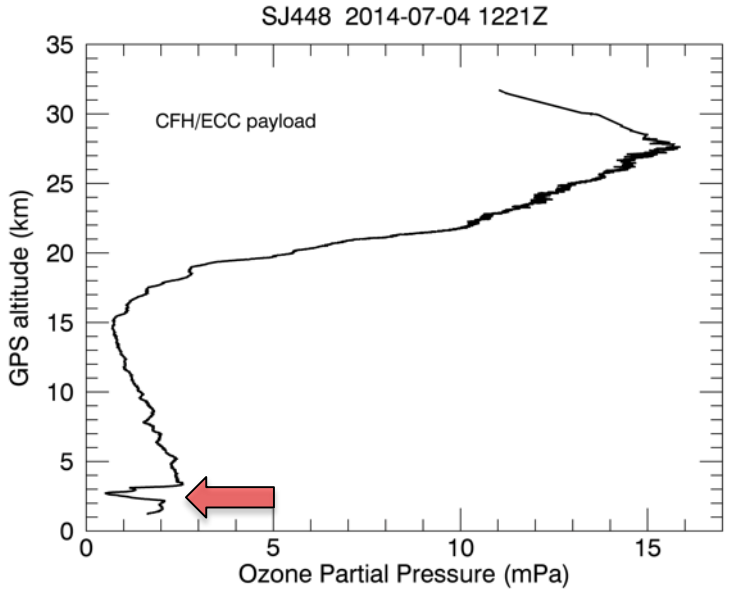
The Ticosonde opportunity

The NASA Ticosonde project has been launching ozone (ECC) and water vapor (CFH) balloon sondes since 2005 at 3 sites around San José, Costa Rica



The San José metro area lies just to the west of Volcán Turrialba (3480 m) which became active again in the mid-1990s.

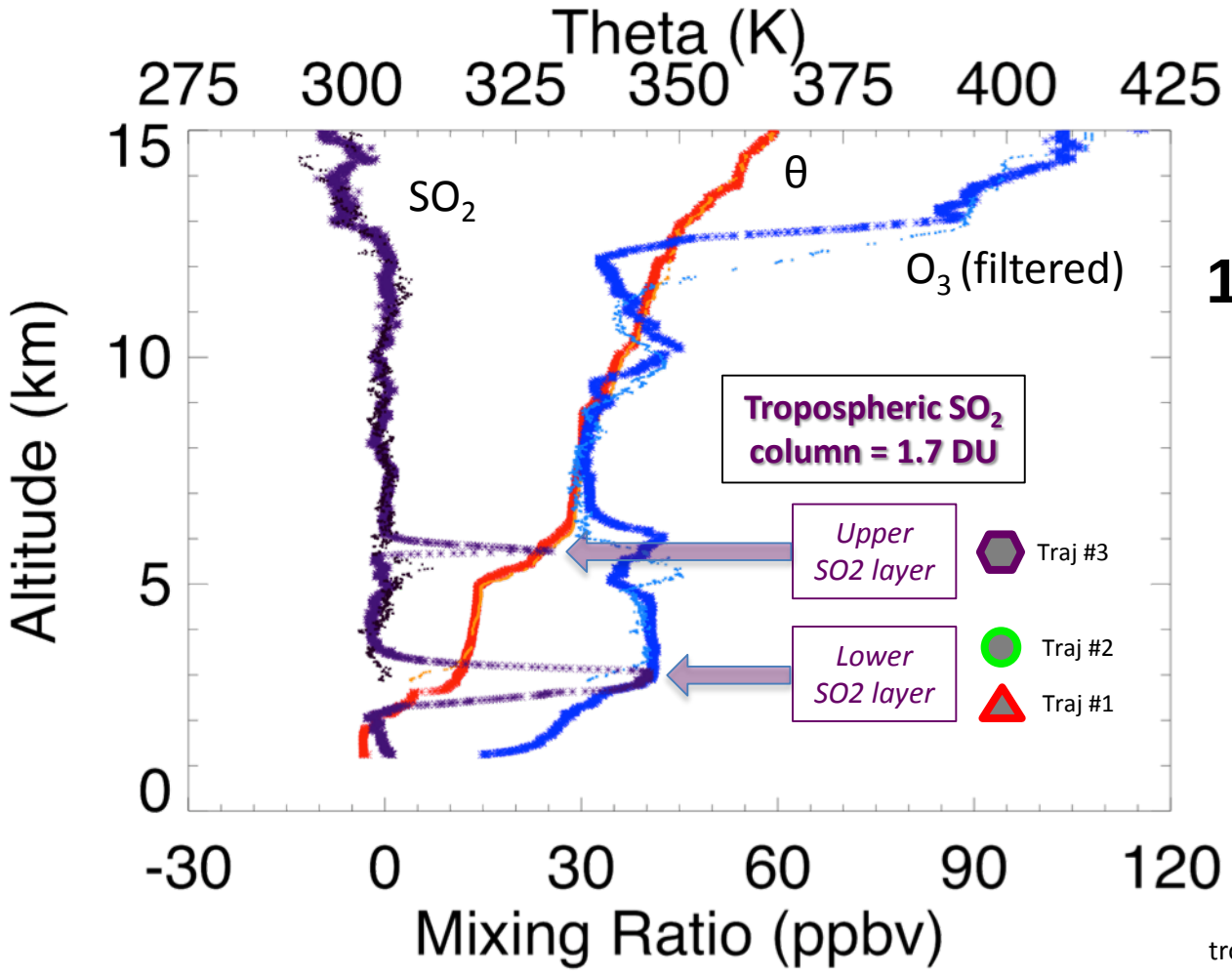
Beginning in 2006, we began to see from time to time ozone profiles with distinct notches, mostly below 5 km



It seemed likely that these notches were caused by volcanic plume SO_2 entering the ozone sonde and causing interference of the O_3 detection

Dual ozone sonde profiling

beginning 2012



SJ470
13 Mar 2015

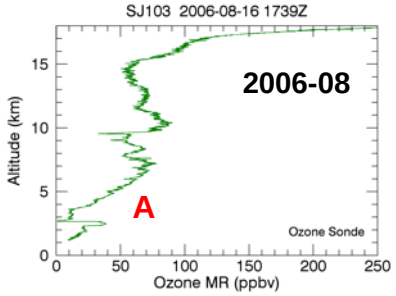
O_3 ascent
O_3 descent
SO_2 ascent
SO_2 descent
Theta ascent
Theta descent

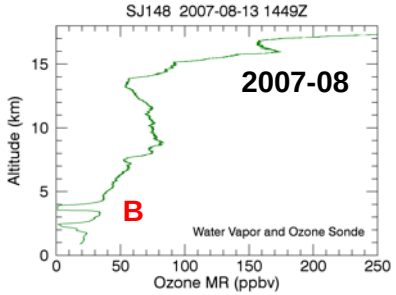
trop_so2_o3mr_2015031312

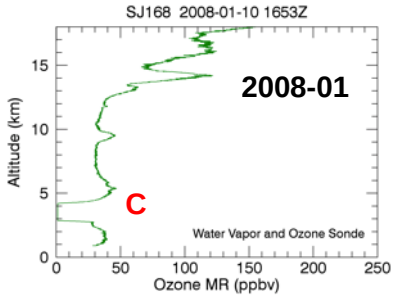
OUTLINE of the TALK

- History of SO_2 notching of Ticosonde ozone profiles
- Dual-sonde profiling technique for SO_2
- The dual-sonde program in Costa Rica since 2013
- Inter-comparison with single-sonde notch interference method
- Sample comparisons to two satellite retrievals
- Validation opportunities and challenges
- Summary and science questions

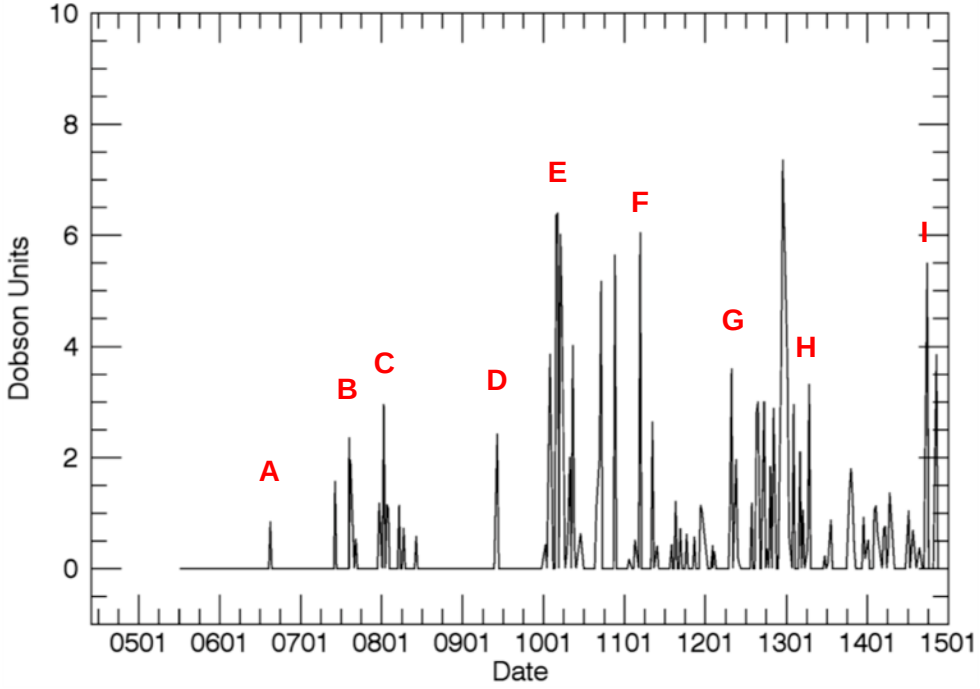
NEARLY A DECADE OF NOTCHING

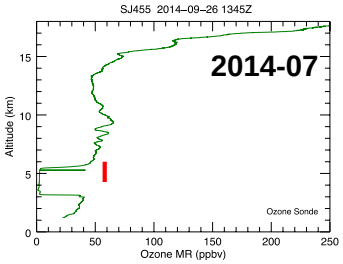


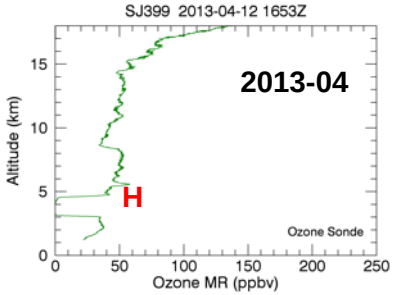


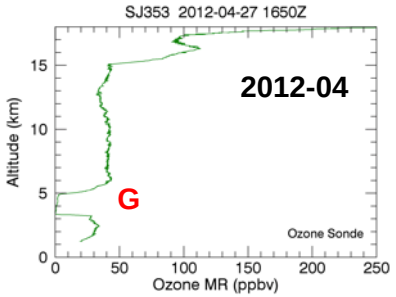


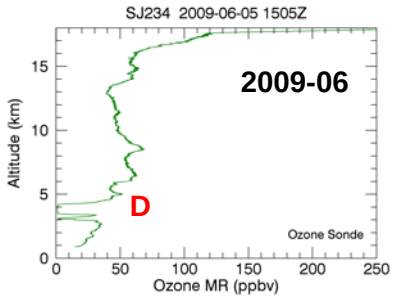
Notch-inferred SO_2 columns

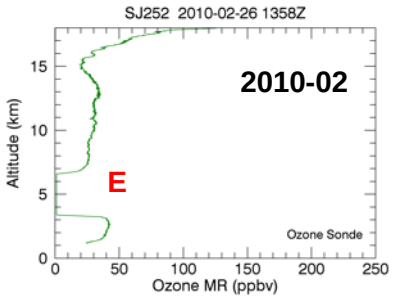


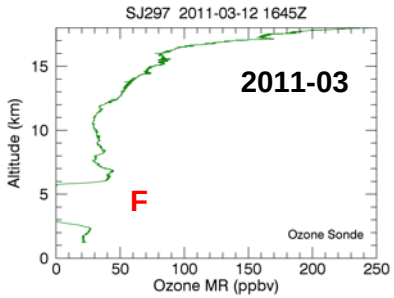












Ticosonde ozone sonde notch history

Year	All ozone sondes (single and dual)	# sondes with notches	Dual ozone sondes
from 7/2005	28	0	
2006	76	1	
2007	43	8	
2008	48	7	
2009	26	3	
2010	40	17	
2011	46	12	
2012	43	16	1
2013	42	18	6
2014	34	15	18
2015 (to present)	14	10	5
TOTAL	**439**	**107**	**30**

Data Access

Ozonesondes (SHADOZ) at Aura Validation Data Center: http://avdc.gsfc.nasa.gov

Dual ozonesondes at Valparaiso : http://physics.valpo.edu/ozone/ticosonde_so2.html

Dual ozone sonde SO_2 profiling

Measurement principle of the ECC ozonesonde

Ozone flowing through cathode upsets equilbrium between negative iodide ions and molecular iodine,

$$2KI + O_3 + H_2O \rightarrow 2KOH + I_2 + O_2$$

To re-establish equilibrium, 2 electrons must flow from anode to cathode, *viz.*,

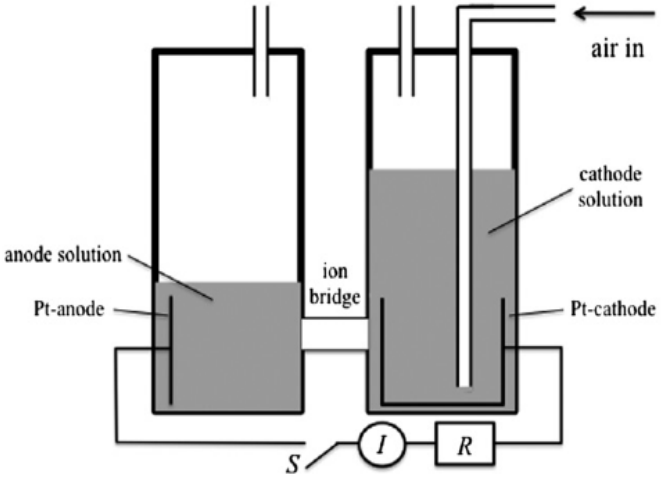
$$3I^- \rightarrow I_3^- + 2e^- \,(anode)$$

$$I_2 + 2e^- \rightarrow 2I^- \,(cathode)$$

Interference by SO_2

SO_2 short-circuits the anode current by reacting with water to yield a sulfate ion and two electrons, *viz.*,

$$SO_2 + 2H_2O \rightarrow SO_4^{2-} + 4H^+ + 2e^-$$



Dual ozone sonde setup as used by *Morris et al.*, 2010. Note SO_2 filter on RH sonde.

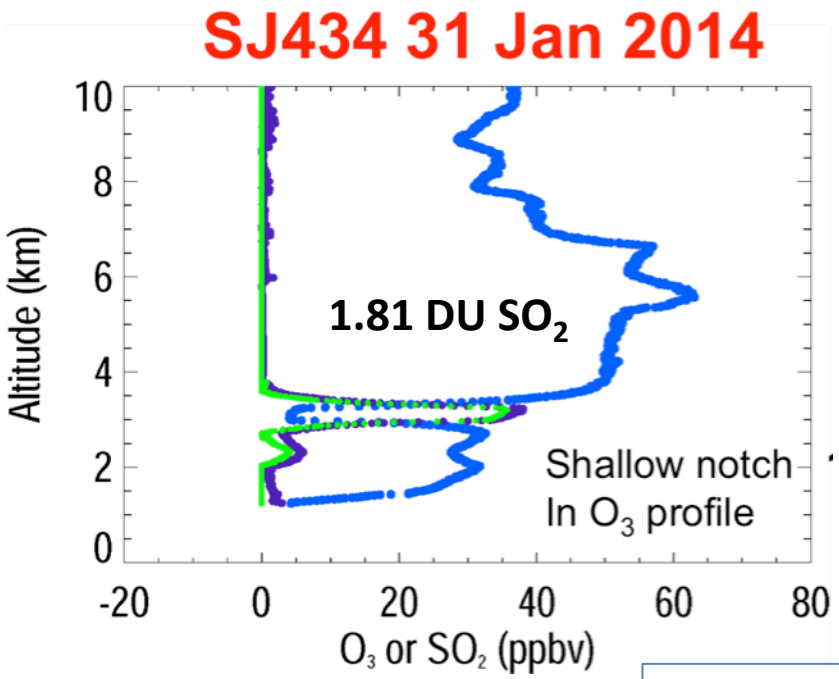
SO_2 measurement principle

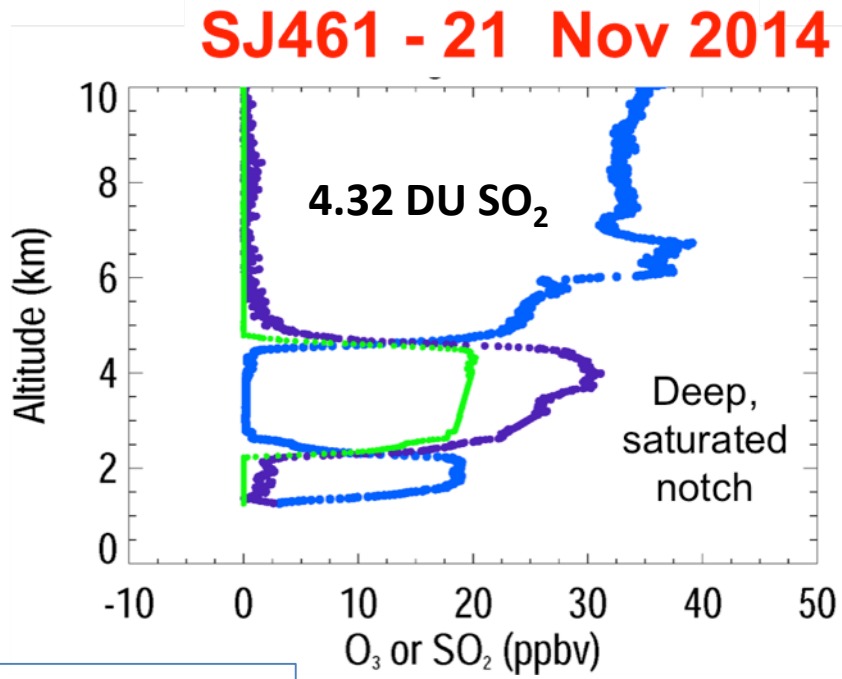
SO_2 interferes with the O_3 measurement on a one-to-one basis. One approach then is to fly two ozone sondes side by side, one with an SO_2 scrubber filter on intake, and the second unfiltered. In simple terms (and as long as $[O_3] > [SO_2]$),

$$[SO_2] = [O3]_{filtered} - [O3]_{unfiltered}$$

Reference: Morris, et al., 2010, A balloon sounding technique for measuring SO2 plumes, J. Atmos. Ocean. Tech, 27, 1318-1330, doi: 10.1175/2010JTECHA1436.1

Dual-sonde difference vs. single-sonde notch inference method





Legend: O_3 SO_2 DUAL SO_2 Inferred

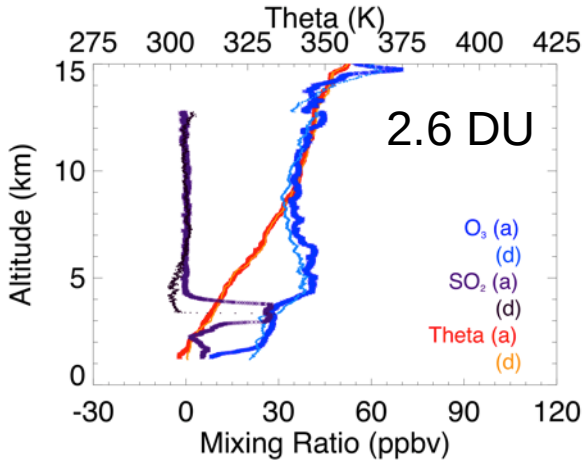
Estimate of column SO_2 from shallow, unsaturated notch close to dual-sonde estimate

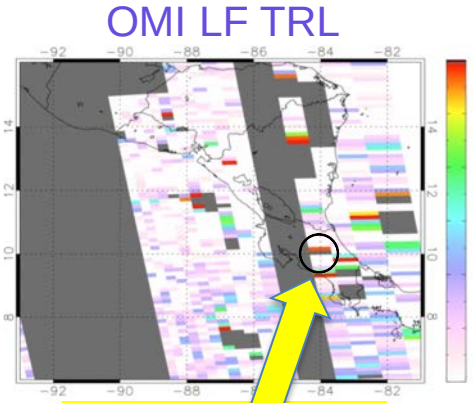
Unusual notch depth and its saturation lead to significant underestimates using both methods

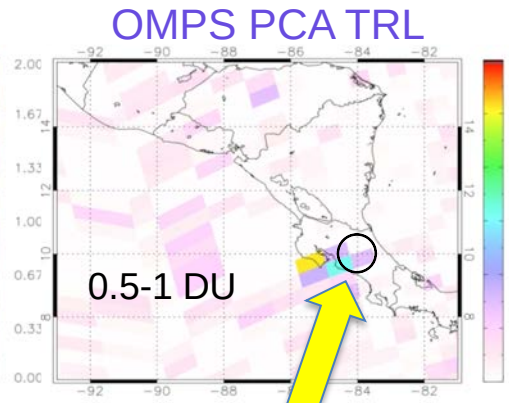
NOAA GMD is developing a modified ECC board that will enable measurement of negative voltage excursions – eliminate zero truncation when $[SO_2] > [O_{\Uparrow}]$

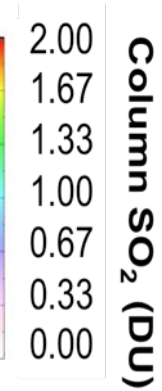
Sample Comparisons of Dual Sonde columns to OMI LF and OMPS PCA lower trop (TRL) retrievals

18 Oct 2013





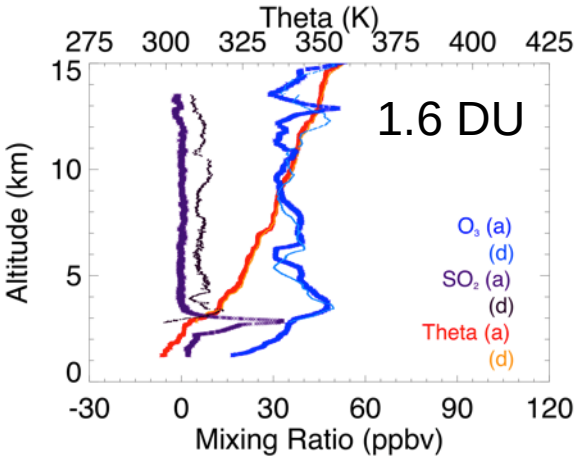


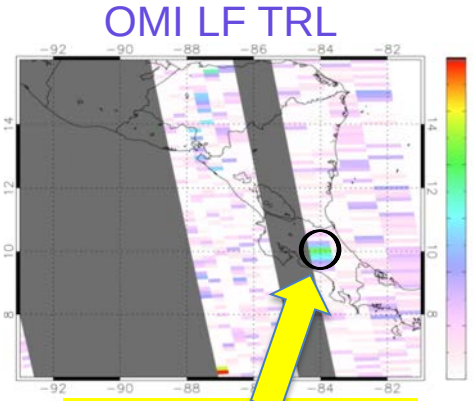


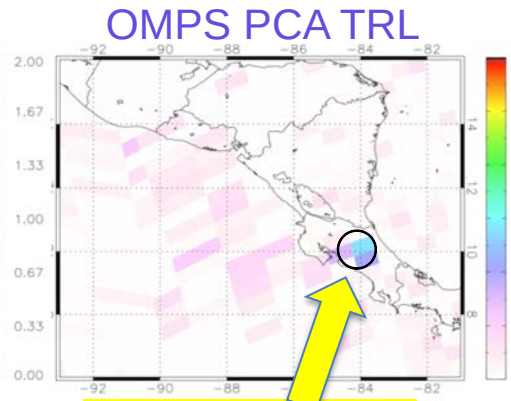
max TRL: >2 DU

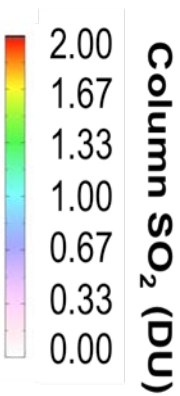
max TRL ≈ 1 DU

7 Feb 2014









max TRL: ~1.3 DU

max TRL ≈ 1 DU

OMI LF TRL: approaches dual sonde column; noisy and data loss in row anomaly

OMPS PCA TRL: less noise, but lower resolution and significant underestimate

SATELLITE VALIDATION
Opportunities and Challenges

- Notch-inference SO_2 column measurements
  - validate Aura OMI LF and PCA retrievals, 2006-present
- Dual sonde SO_2 column measurements
  - validate OMI and OMPS (on Suomi-NPP) retrievals, 2013 – present
    - 22 remaining dual sondes
    - Hope to validate TropOMI (summer 2016 launch)
- Challenges/Questions:
  - **Saturated notches:** Standard ECC cannot measure negative voltages, so restricted to [SO2] ≤ [O3] (testing new sonde from GMD)
  - **Overcast:** Reduces sample size, particularly in rainy season (June-October) (tighten up launch protocols; focus on dry season)
  - **Sampling scale differences, sonde vs FOV:** How representative are sonde samples? (plume dispersion modeling)

SUMMARY

- Frequent observations of SO_2 interference in ozone sondes at San José, Costa Rica, downwind of Volcán Turrialba
  - Notches in 107 of over 400 ozone profiles since July 2005
- Dual sondes unequivocally demonstrate that notches are due to SO_2
  - Notches in 19 of 30 dual sonde profiles since February 2012
- ONGOING and FUTURE WORK:
  - ✓ Continue single- and dual-sonde observations at Costa Rica
  - ✓ Test GMD experimental board to extend range of SO_2 measurement
  - ✓ Complete validation of SO_2 retrievals with single- and dual-sonde observations
    - OMI – 2006 to present
    - Suomi NPP – 2012 to present
    - TropOMI in 2016?
- SCIENCE QUESTIONS:
  - How is plume dispersed and diluted between emission and sonde measurement several hours downstream?
  - Can we exclude the possibility that there is formation of sulfate particles in this time frame?