UT/LS Measurements of SO_2 Using a New Airborne Sensor

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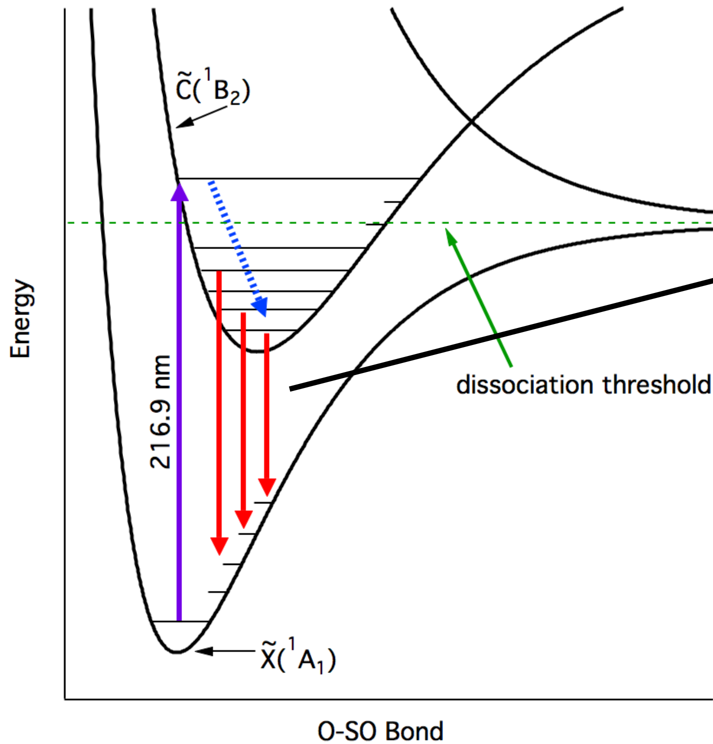
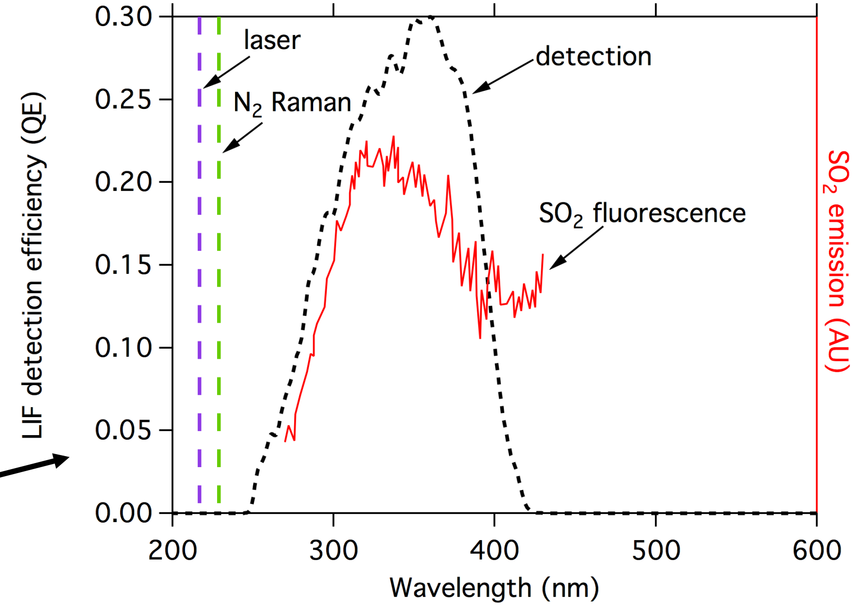
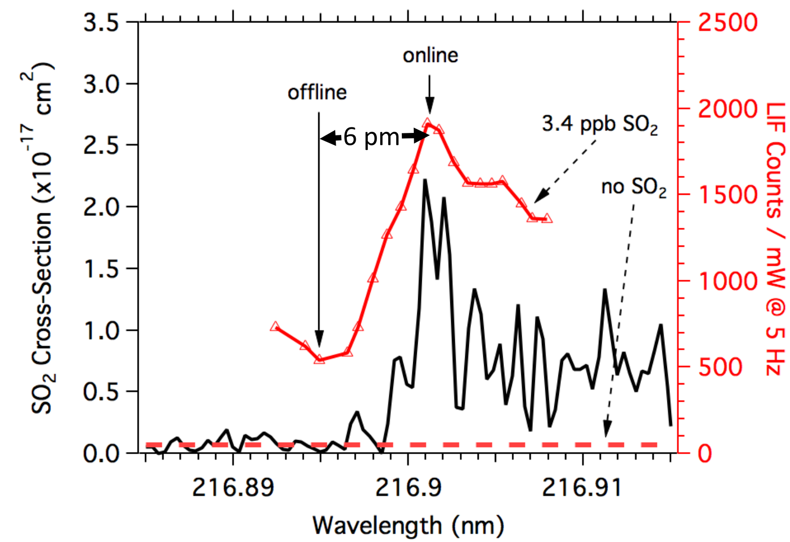
SO_2 Laser Induced Fluorescence (LIF) Spectroscopy

LIF: Observation of fluorescence following laser electronic excitation.
Signal ∝ absorption × fluorescence yield







Fluorescence lifetime ~ 5 ns

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WB-57F LIF Instrument

- Custom fiber-laser produces 2-3 mW at 216.9 nm.
- PFA / PEEK sampling system with minimal surface area – no evidence of inlet artifacts.
- In-situ calibration performed hourly using SO_2 standard addition.
- In-situ background check performed every 15 minutes using zero air addition.

SO_2 inlet

Typical Performance

- Response time ~ 0.1 s
- Signal: 5 cps / ppt SO_2
- Background: 400 cps (scatter)
- 1-σ noise = 4 ppt at 1Hz
- Linear to ~ 8 ppb
- ± (0.9 ppt + 16%) uncertainty

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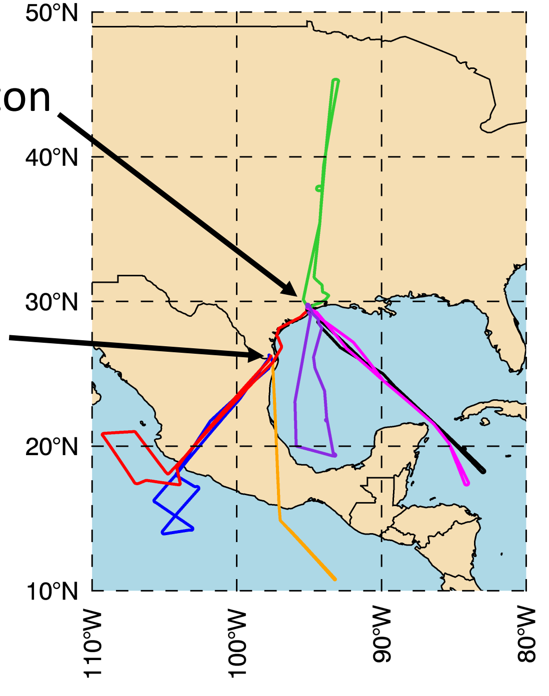
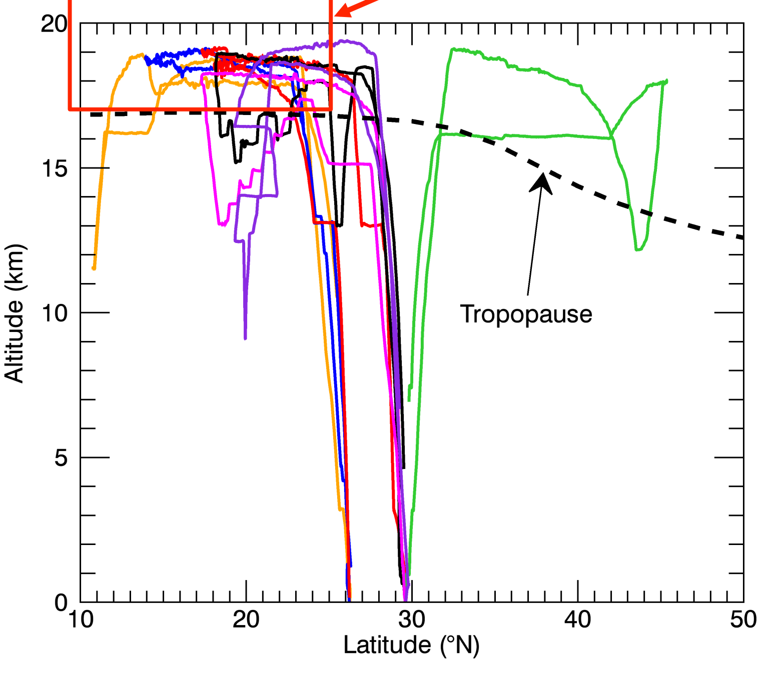
Volcano-Plume Investigation Readiness Gas-Phase and Aerosol Sulfur (VIRGAS)

October 2015, NASA WB-57F, Houston and Harlingen, TX

- Demonstrate Payload
- Test models & satellites
- Quantify SO_2 background at and above tropical tropopause

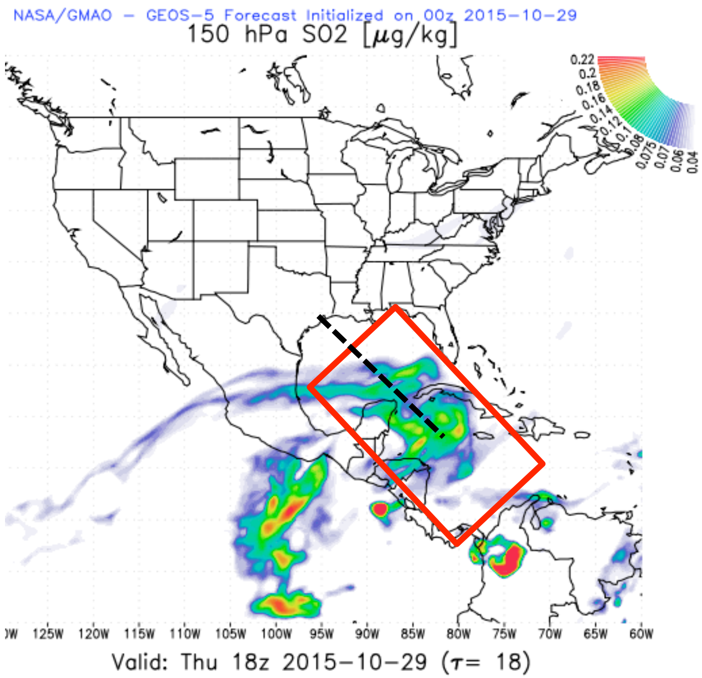
8.6 h SO_2 data in tropical LS

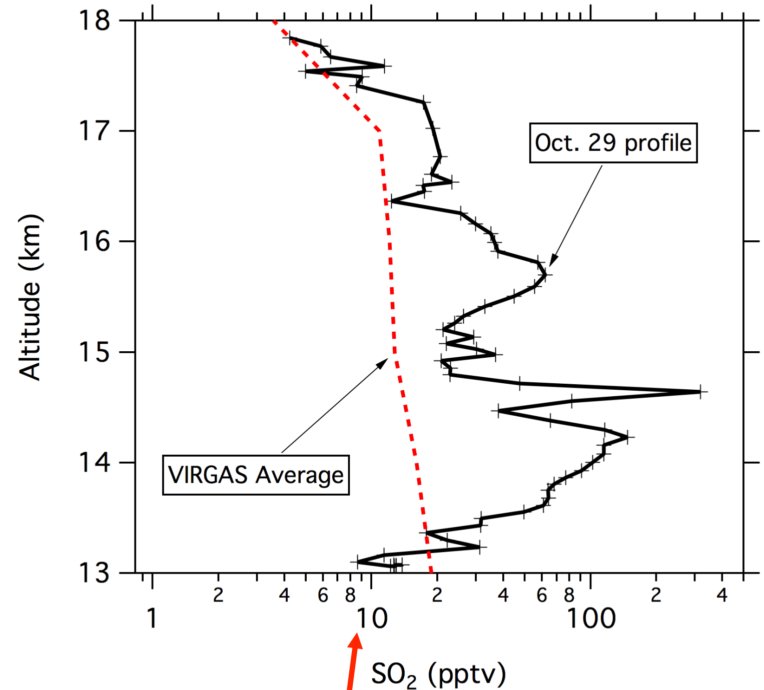


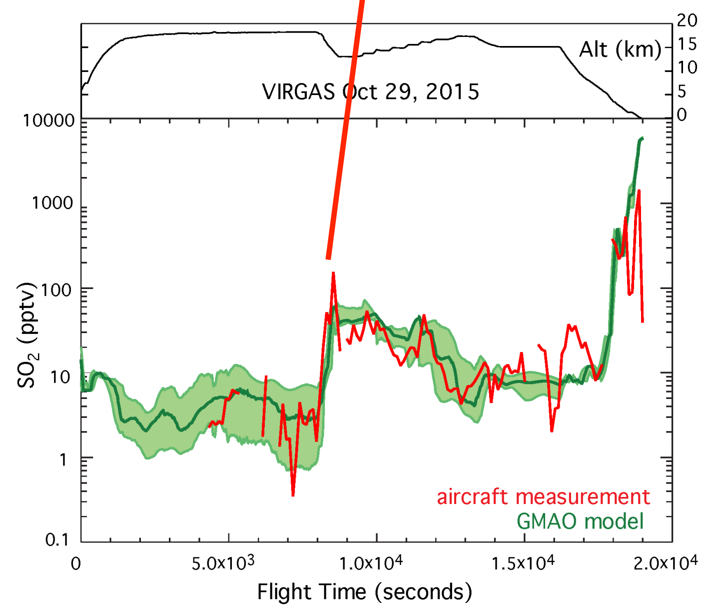


VIRGAS observations

GMAO SO_2 Forecast model used to target areas with potentially elevated SO_2 events in the UT.







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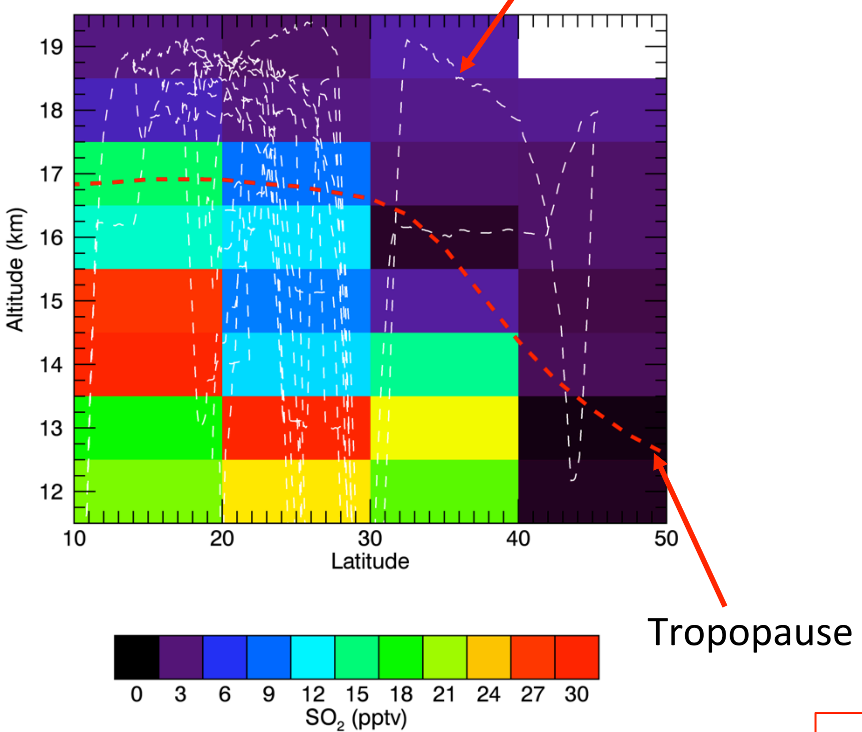
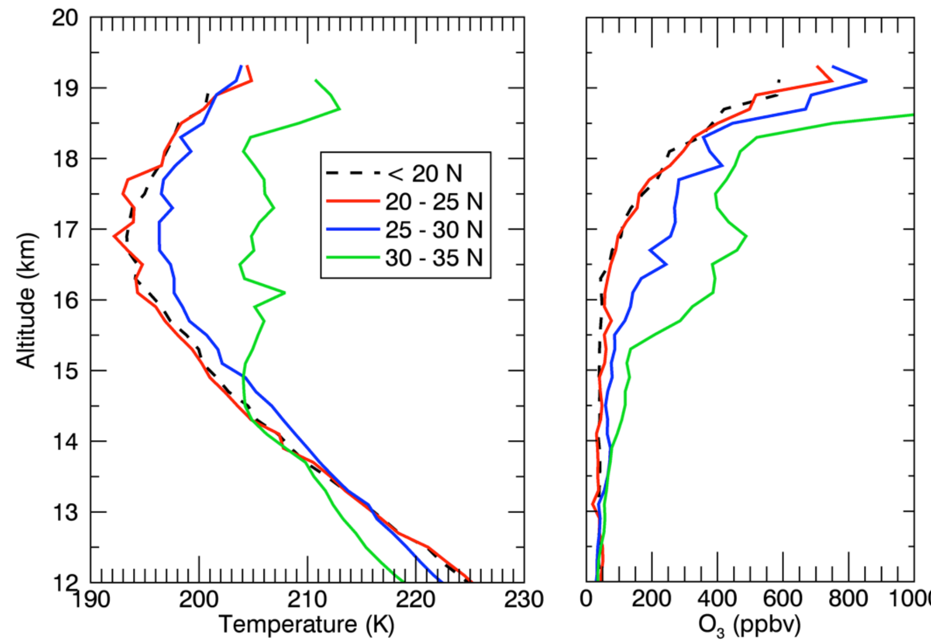
Tropical average SO_2

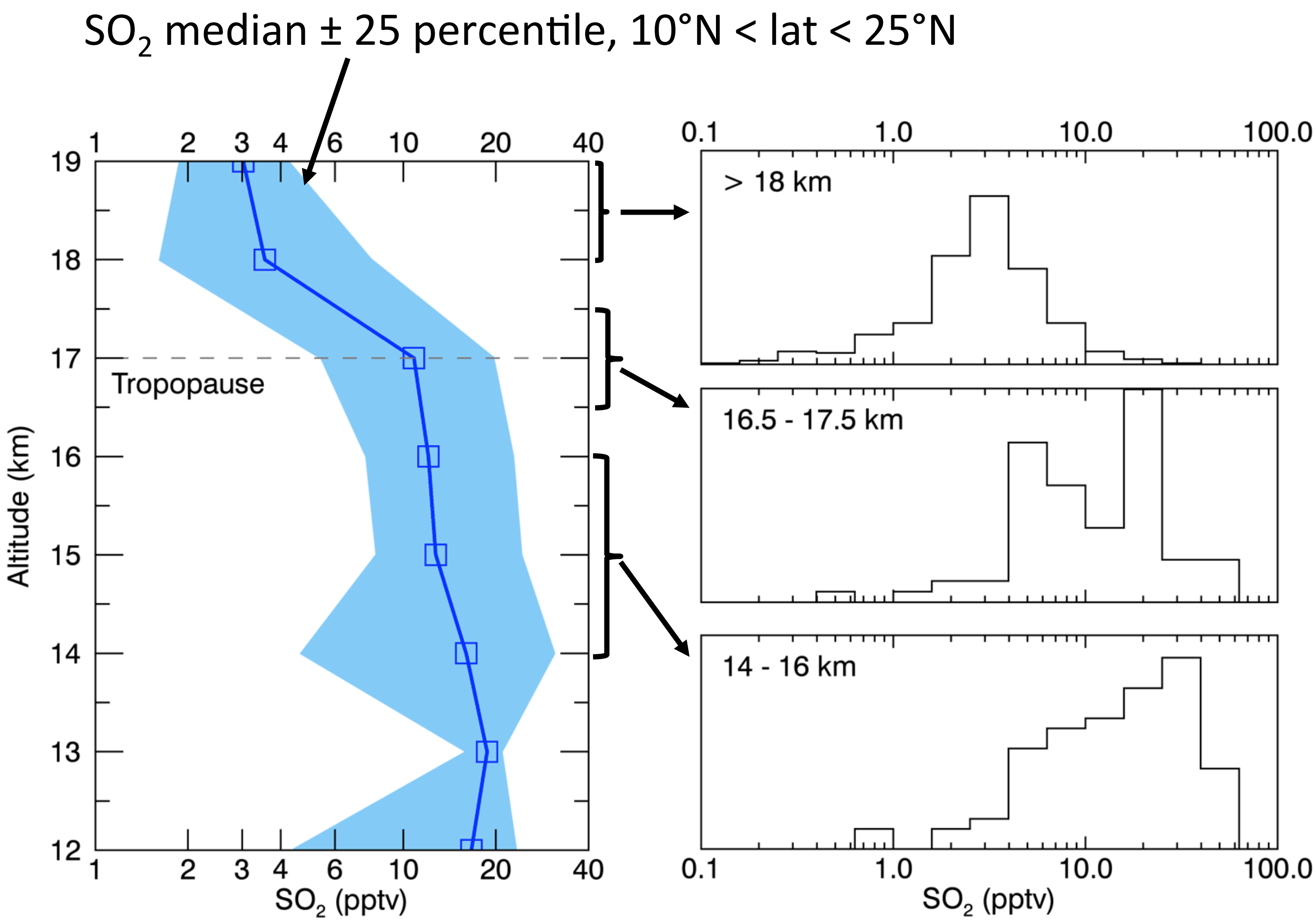
LIF measured Zonal Median SO_2
110°W – 80°W





Using 10 – 25 °N for Tropical analysis

Tropical SO_2 statistics



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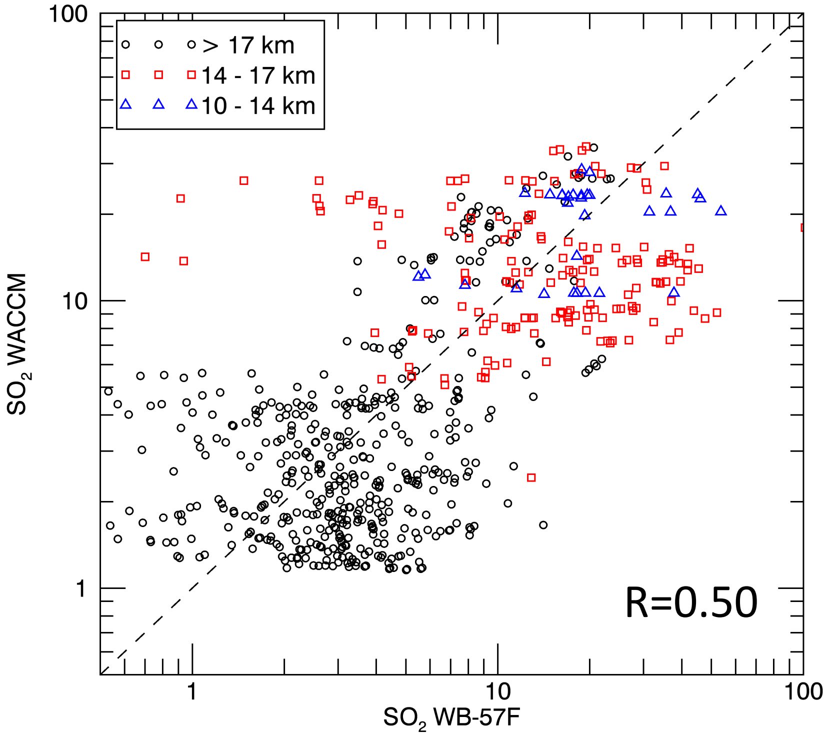
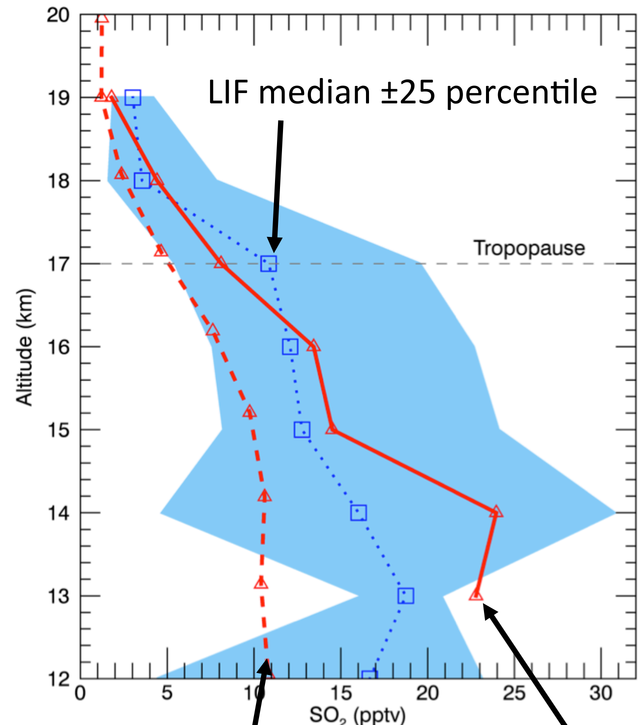
WACCM comparison

All 1 – min. data, 10 - 25°N



10 - 25°N



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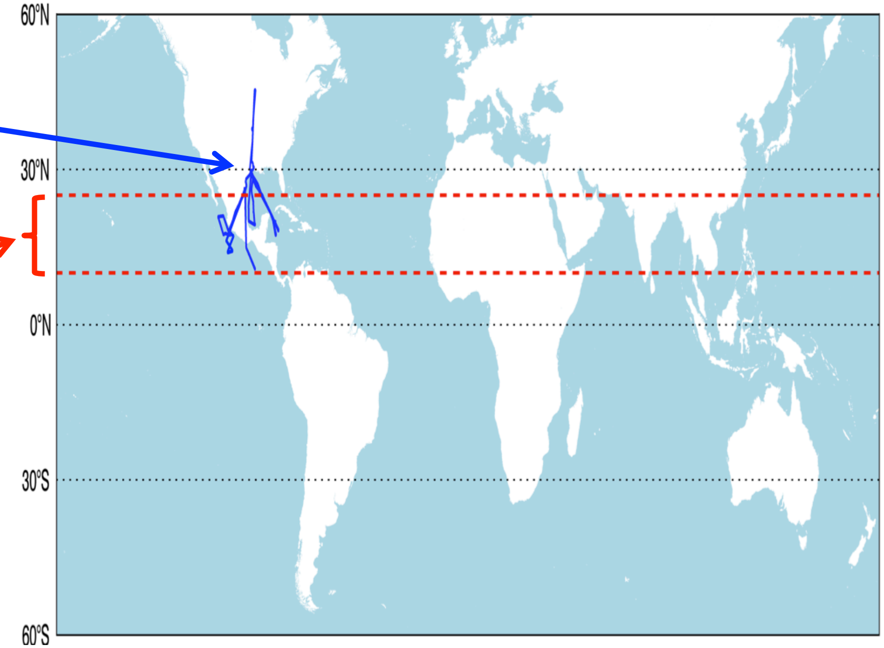
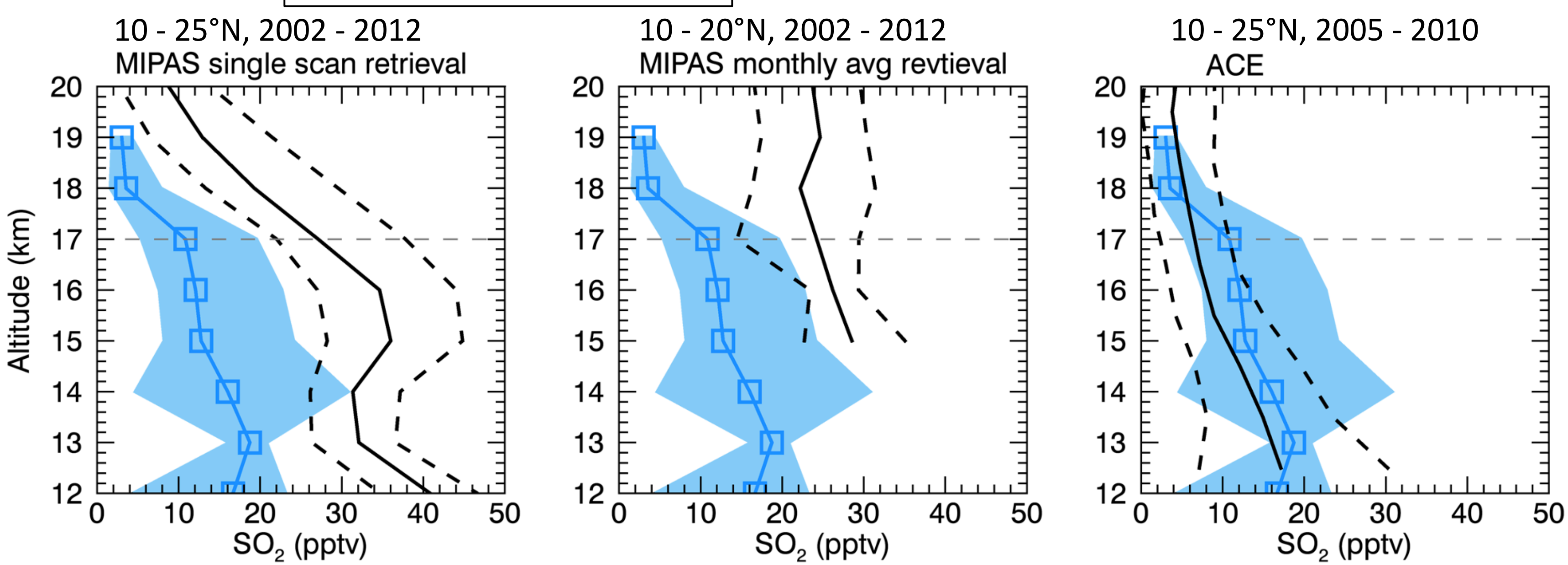
Satellite tropical average SO_2 comparison



Volcanic data removed

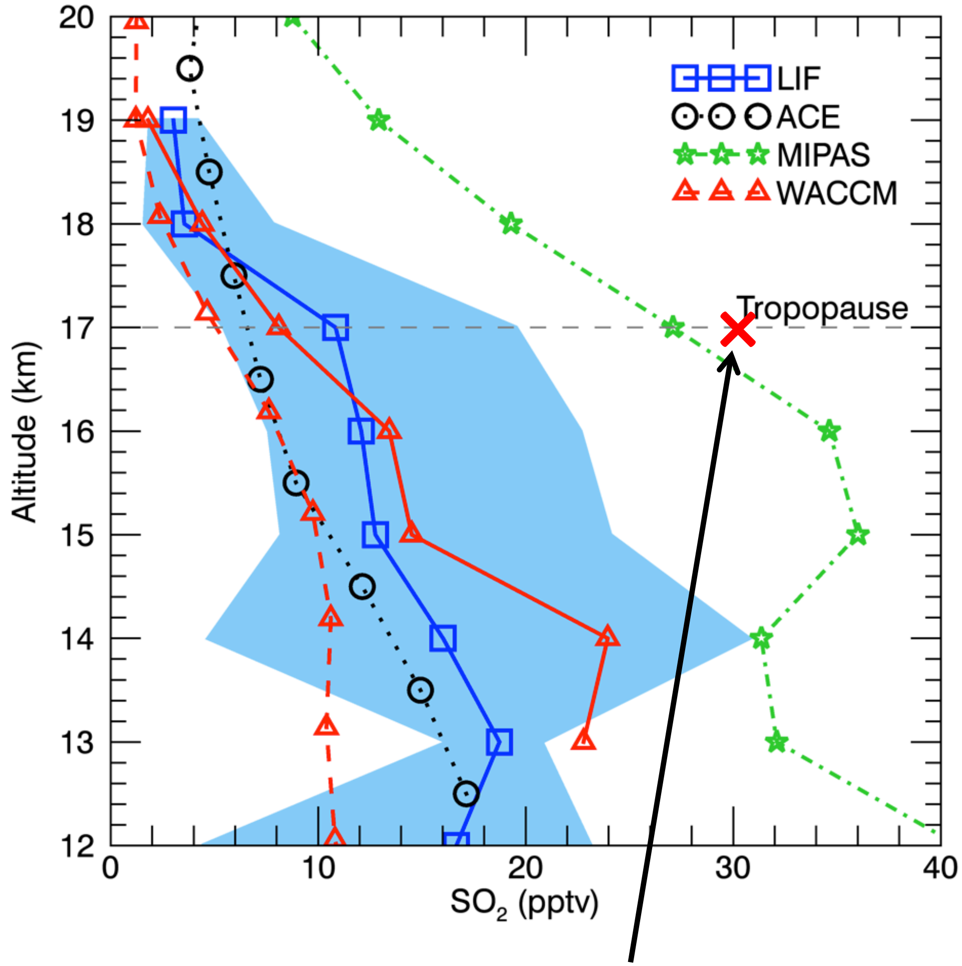


Rollins et al. SSIRC, April 2016

Höpfner et al., ACP, 2013, 2015

Conclusions

- LIF successfully deployed in UT/LS on aircraft to quantify background SO_2.
- Measurements support generally low typical values at the tropopause (10 ppt) and agree reasonably well with ACE retrievals and WACCM and GMAO models.
- 5 – 10 pptv average tropical tropopause mixing ratio would support a relatively small source of S in terms of the background stratospheric budget: 8.5 – 17 Gg S yr^{-1} by scaling Sheng et al.



Sheng et al., 2015
51 Gg S yr^{-1}

SO_2 Laser Induced Fluorescence (LIF) Spectroscopy

LIF: Observation of fluorescence following laser electronic excitation.
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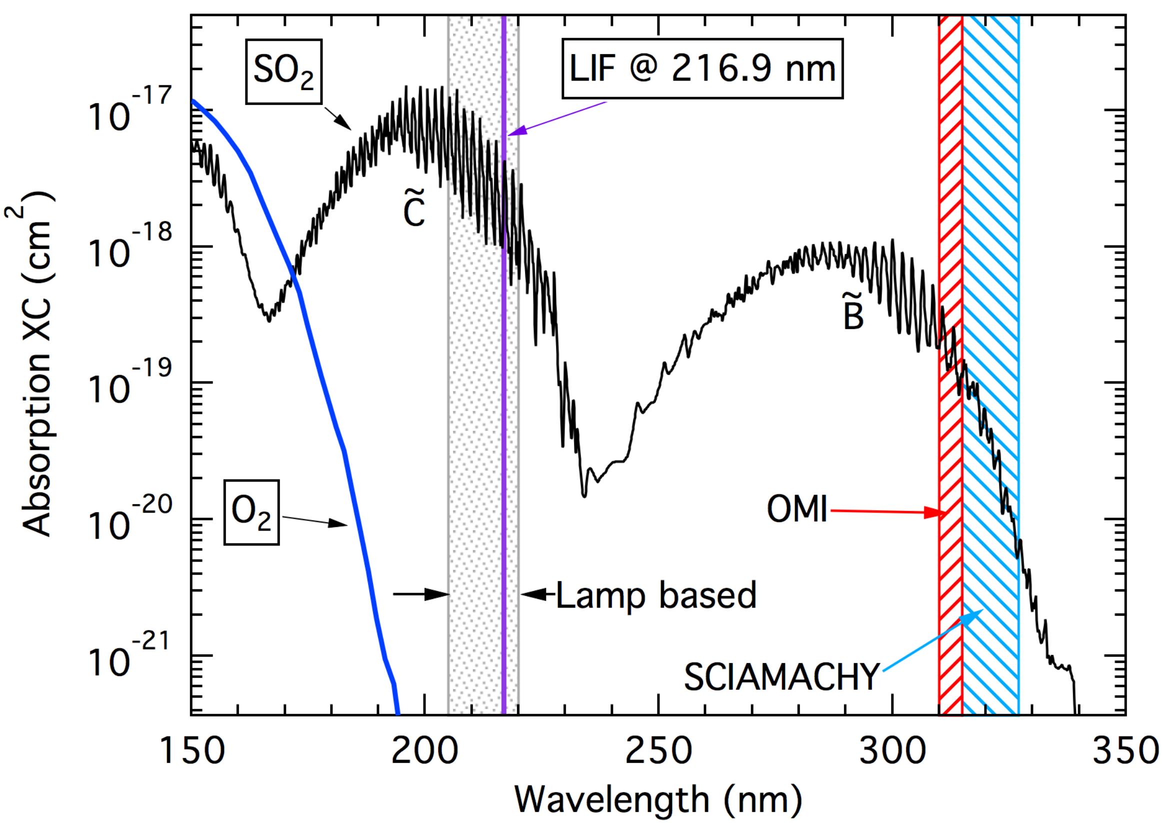


LIF considerations:

- Fluorescence quantum yield from B̃ state is near zero.
- In C̃ band at wavelengths less than 220 nm, fluorescence quantum yield rapidly drops towards zero.
- Tunable lasers are not easy to come by in this region.
- We are using 216.9 nm. Signal might be ~ 2x higher if pumping at 220.6 nm.

Rollins et al. SSIRC, April 2016

WB-57F LIF Instrument

Fiber laser scheme

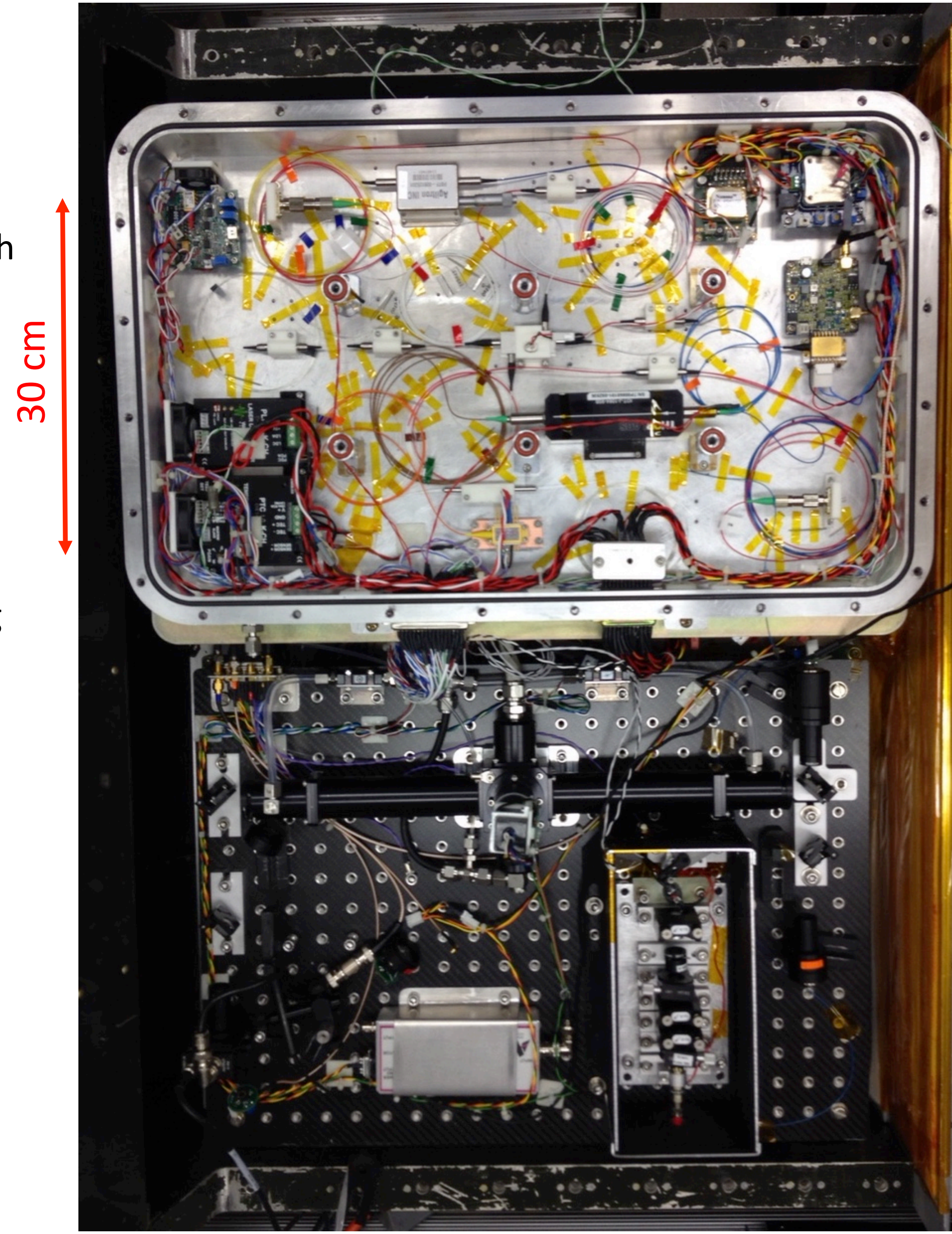
- Pulsed tunable diode laser at 1085.4 nm is amplified ~ 10^6 using rare-earth (Yb^{3+}) doped fibers pumped with diode lasers at 976 nm.*

- Fifth harmonic at 216.9 nm is generated with ~ 1% efficiency using 3 nonlinear crystals.

- 20 W power consumption (excluding computer). Passively cooled.

- Relatively stable in flight environment. We operated for 8 flights with no need to make adjustments.

- Typical output of 2-3 mW @ 216.9 nm



* Collaboration with USA National Institute of Standards and Technology

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