# New Insights into Volcanic Degassing from OMI and the A-Train

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# OMSO2 status

- Provisional OMSO2 data (AVDC) processed using Band Residual Difference (BRD) algorithm [Krotkov *et al.*, 2006; IEEE Aura special issue] - uses OMTO3 residuals.
- BRD algorithm fails for high $SO_2$ loadings (>50 DU).
- New 'linear fit' algorithm [Yang *et al.*, in prep.] implemented for OMSO2 public release (Sept/Oct 2006).
  - Needs *a-priori* $SO_2$ profile (PBL, 5 km, 15 km)
- Open issue: AMF for PBL $SO_2$ retrievals - needs validation
  - Chinese air pollution - comparisons with UMD aircraft profiles (Krotkov, AGU)
  - Volcanic degassing (Carn)
- Spectral fit $SO_2$ algorithm - early 2007?

# Volcanic degassing

- No eruption of magma
- Long-lived (weeks-centuries)
- Low altitude - tropospheric (<5 km)
- Environmental/health hazard
- Climate impacts poorly understood
- Poorly quantified

- Magma erupted (ash)
- Short-lived (hours-days)
- High altitude - stratospheric (<40 km)
- Aviation hazard (ash)
- Global climate effects possible
- Well quantified (TOMS)

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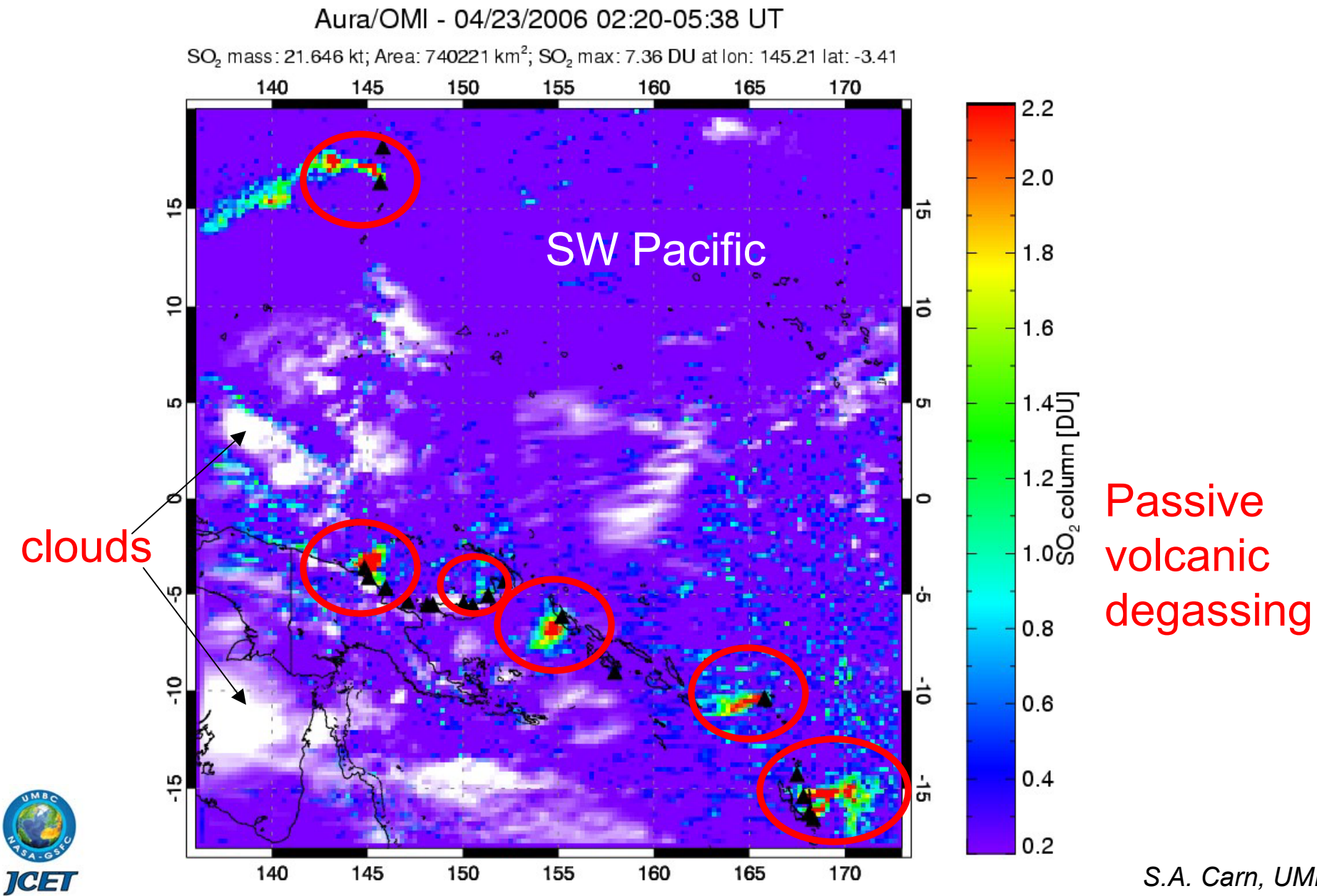
# Daily measurements of volcanic degassing by OMI

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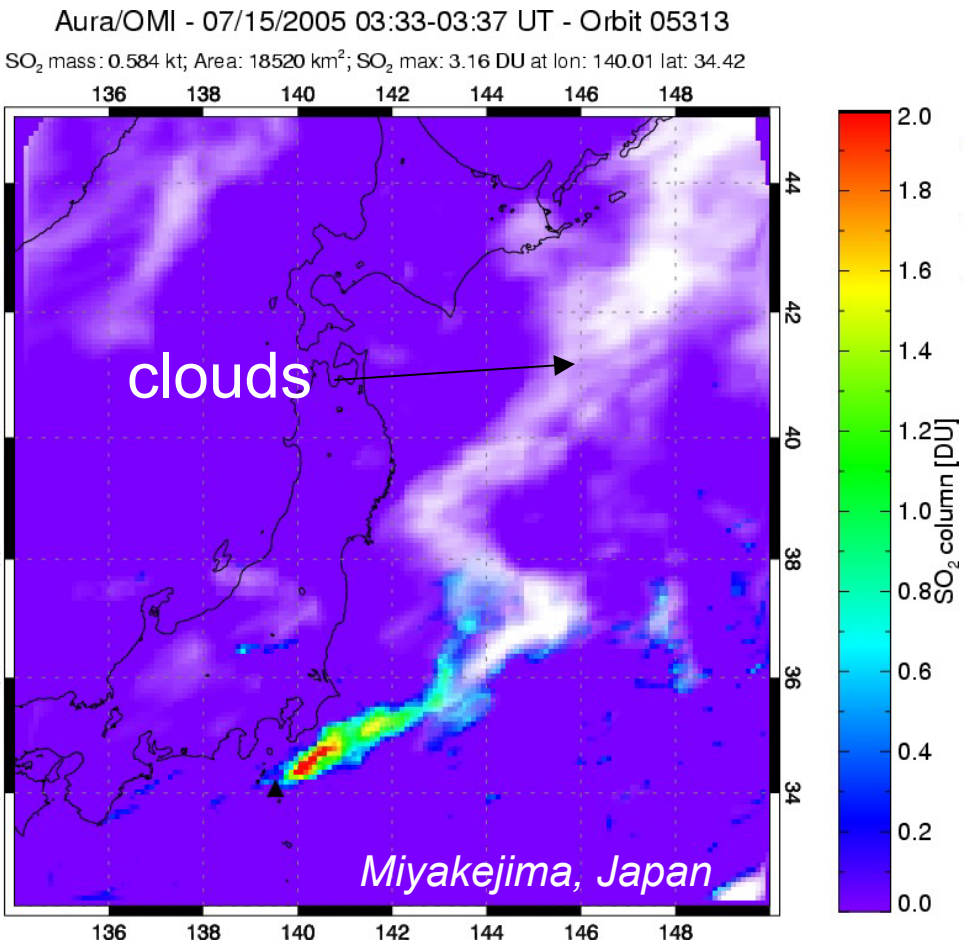
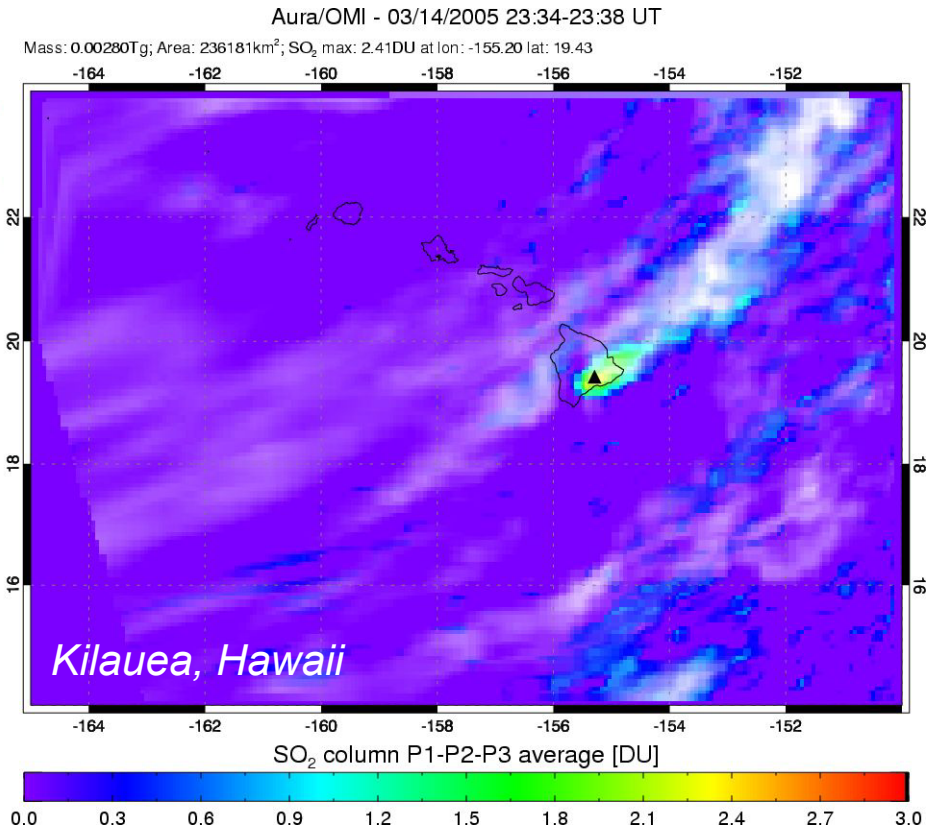
# Cloud seeding/brightening by volcanic aerosol




- OMI $SO_2$ measurements permit quantitative studies of the effects of passive volcanic $SO_2$ degassing on cloud formation and cloud microphysics.

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# Volcanic cloud studies with the A-Train

**OMI** - $SO_2$, aerosols, BrO

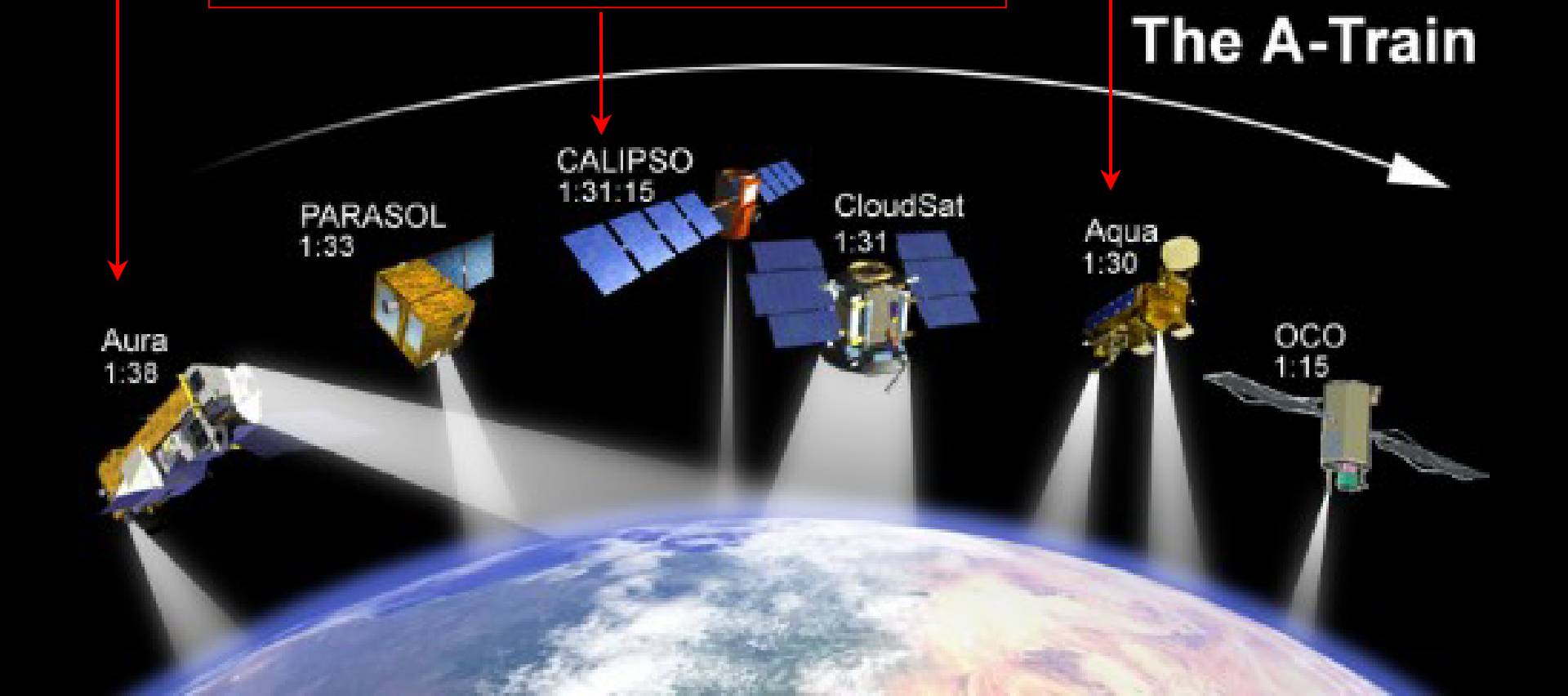
**TES** - $SO_2$, HCl

**MLS** - strat. $SO_2$, HCl

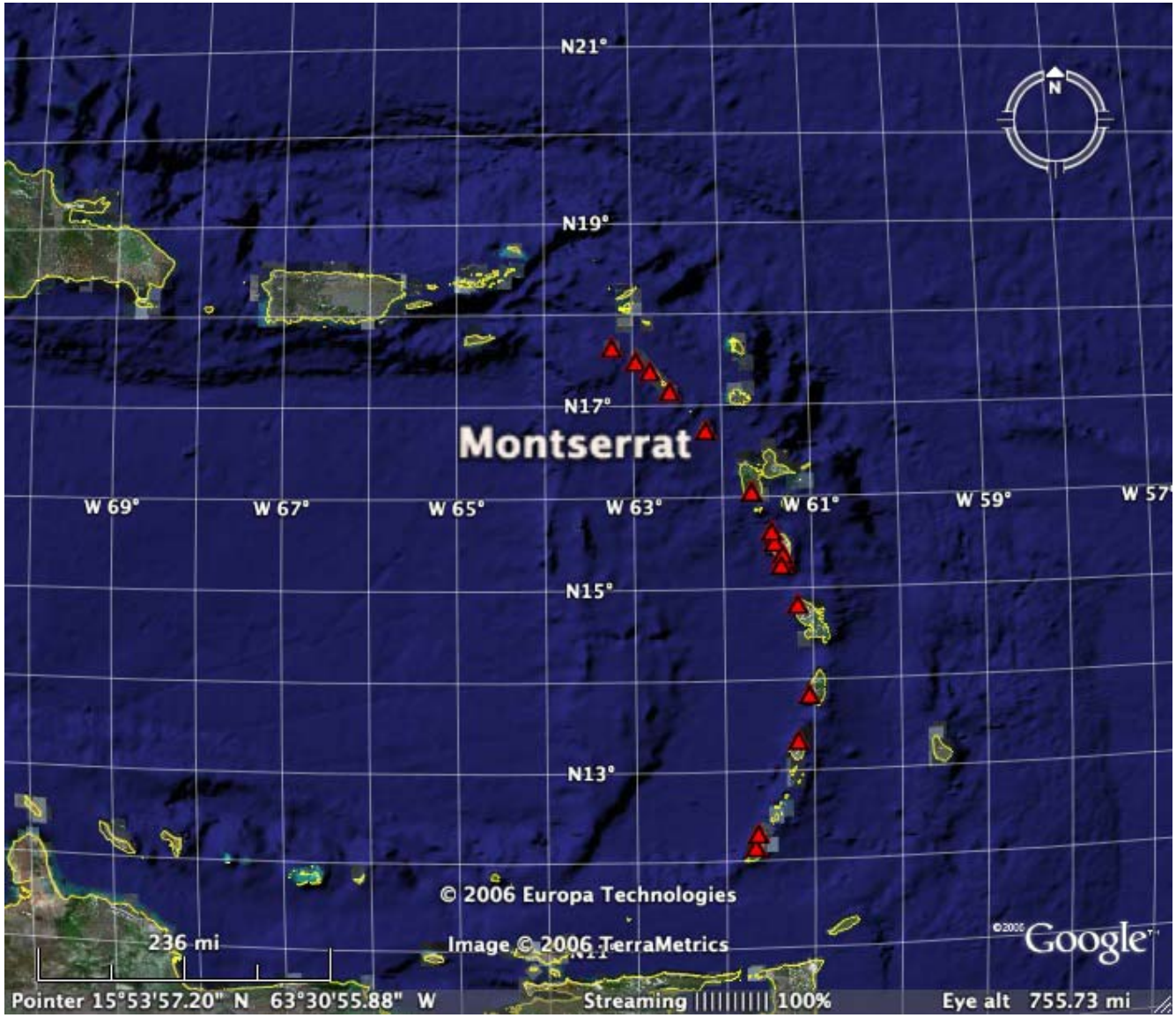
**MODIS** - $SO_2$, ash, sulfate

**AIRS** - UTLS $SO_2$, aerosols, $SO_2$ profile?

**CALIPSO** - cloud height, aerosol type



# Soufriere Hills (Montserrat) eruption - May 20, 2006

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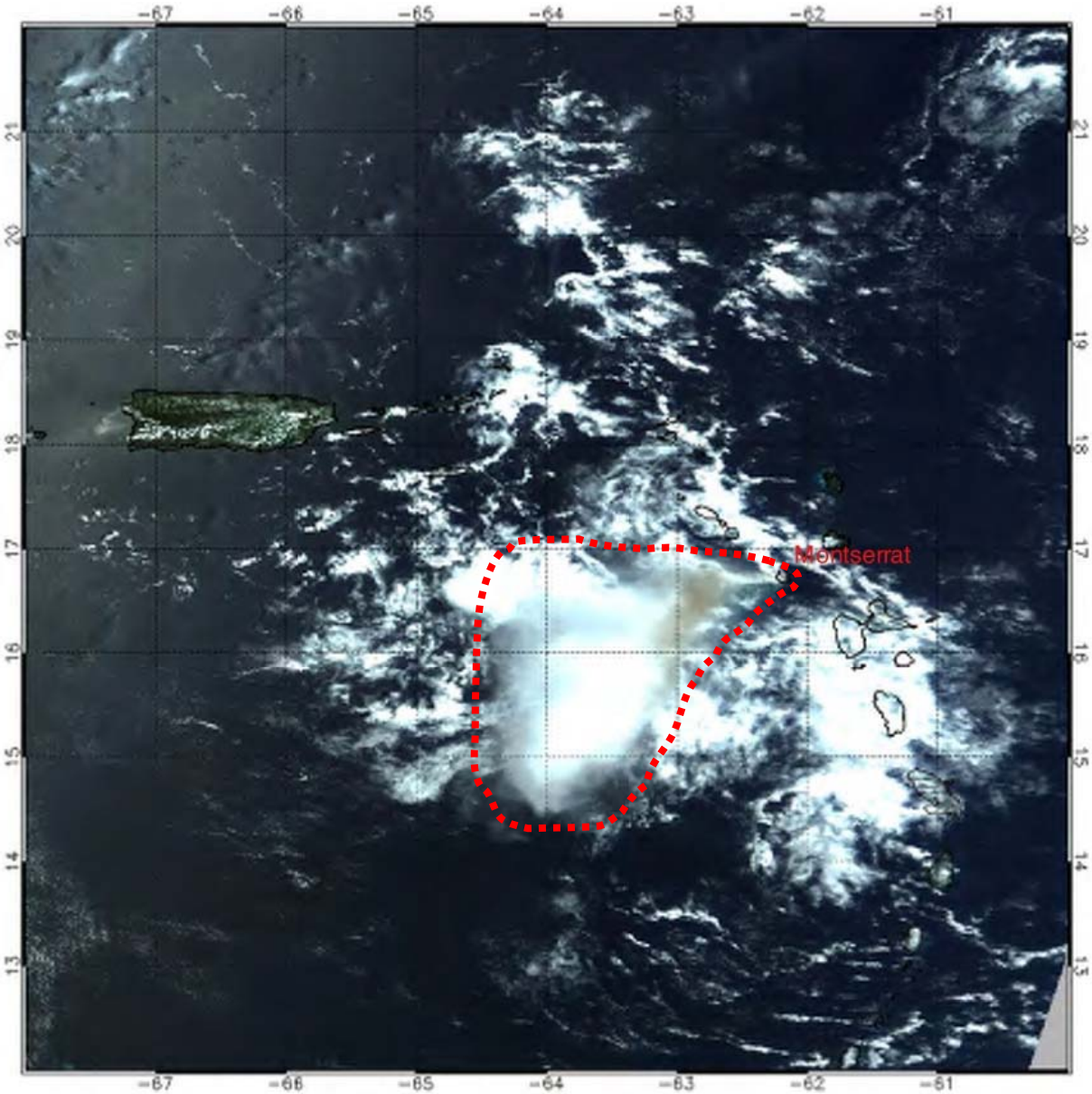
# MODIS (Terra) image of volcanic cloud

20 May
0620UT

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# Long-range transport of $SO_2$ cloud, May-June 2006

QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

http://aura.gsfc.nasa.gov/science/feature-062006.html

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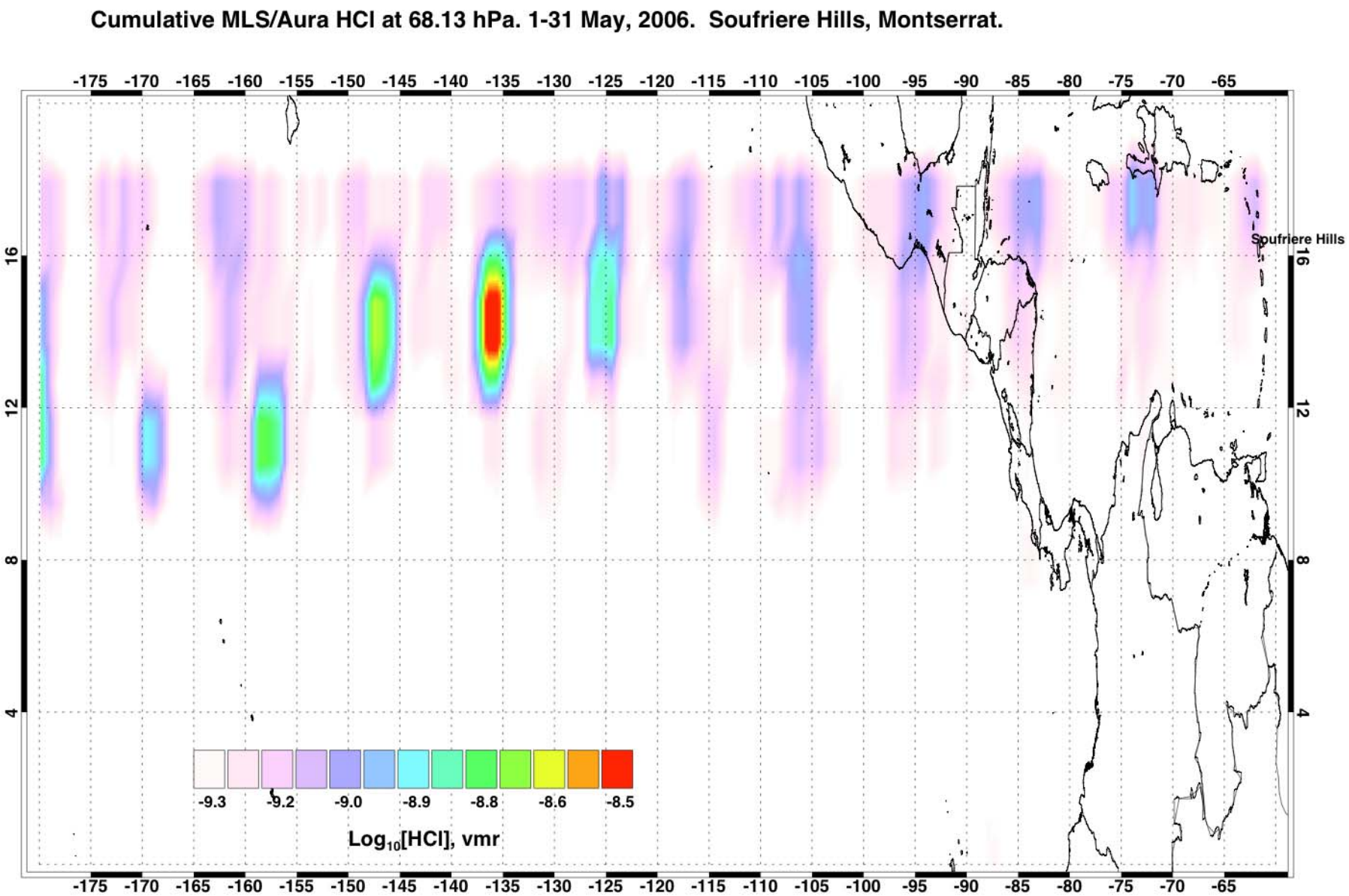
# Combining Aura/OMI and Aqua/AIRS observations of $SO_2$

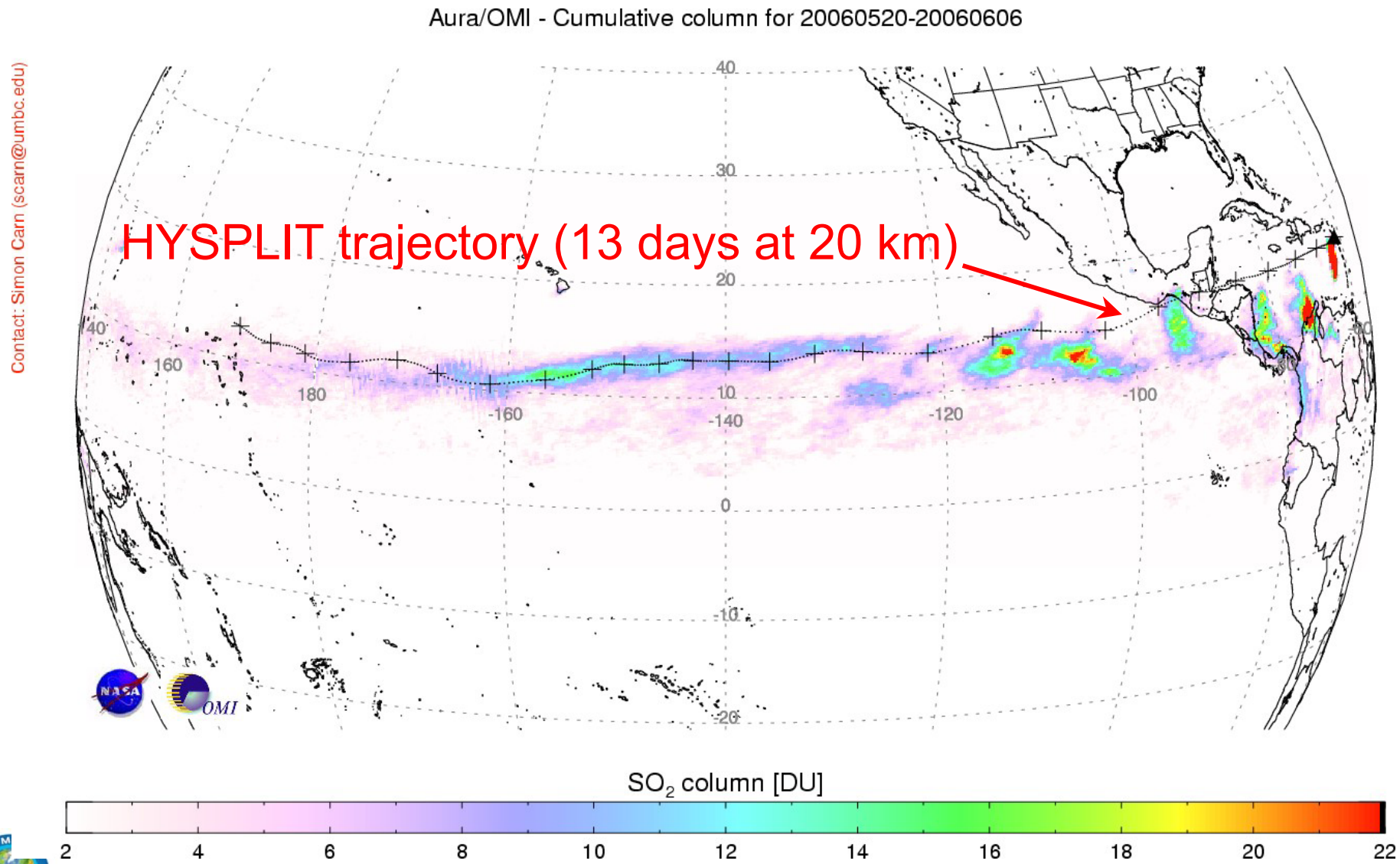
QuickTime™ and a
Photo - JPEG decompressor
are needed to see this picture.

[AIRS $SO_2$ retrievals by F. Prata, NILU]

# Stratospheric HCl from MLS



# Long-range transport of $SO_2$ cloud, May-June 2006

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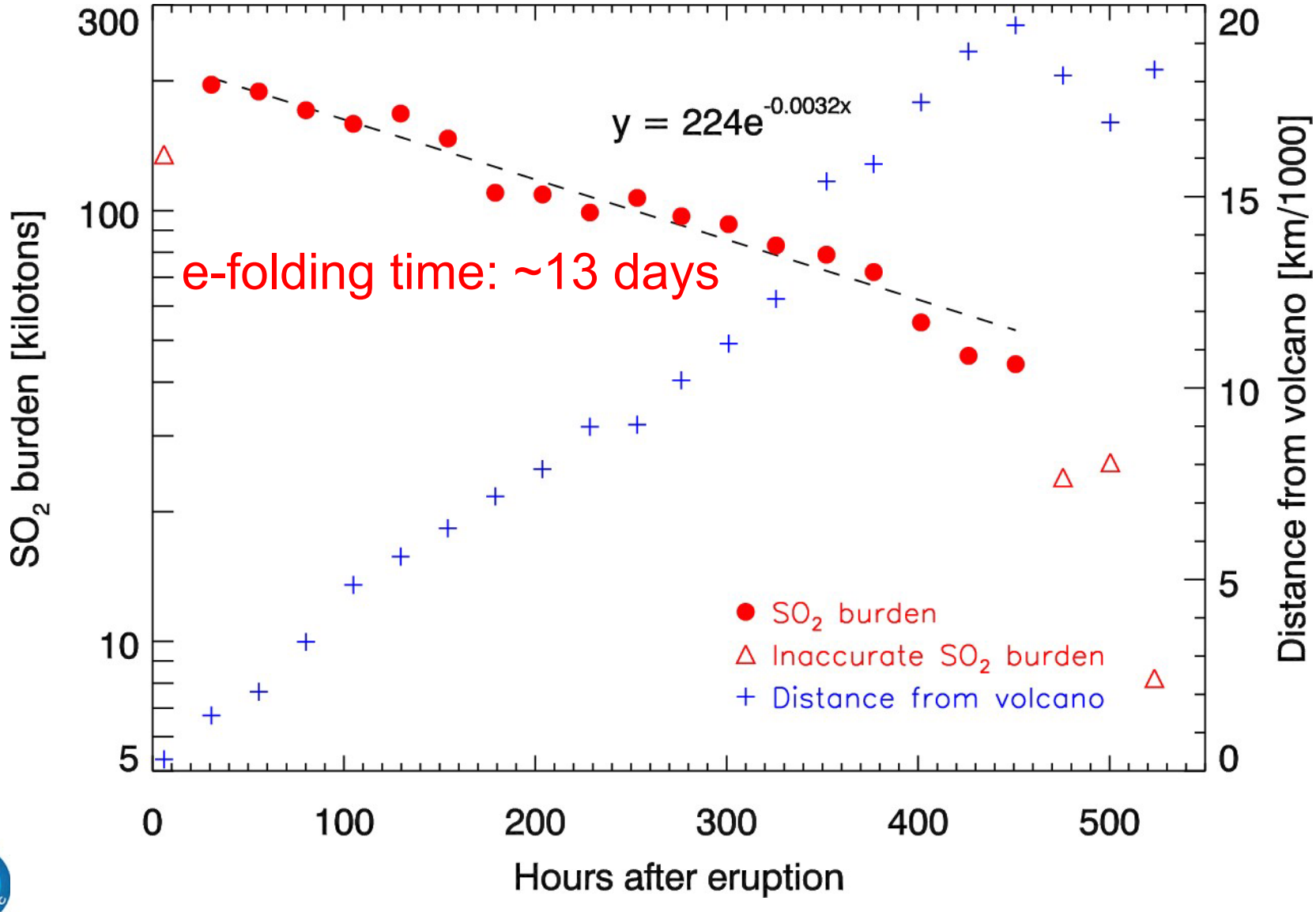
# Evolution of stratospheric $SO_2$ cloud

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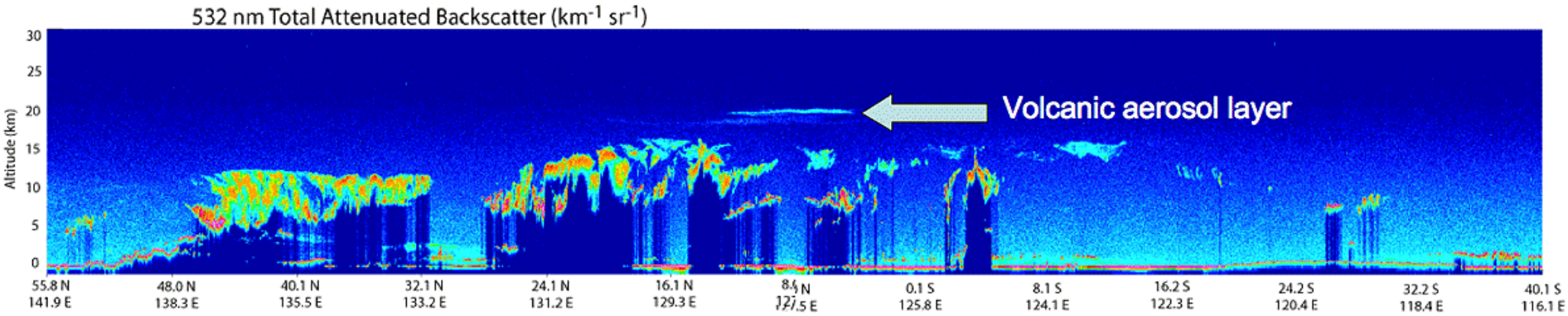
# FLEXPART modeling of $SO_2$ cloud

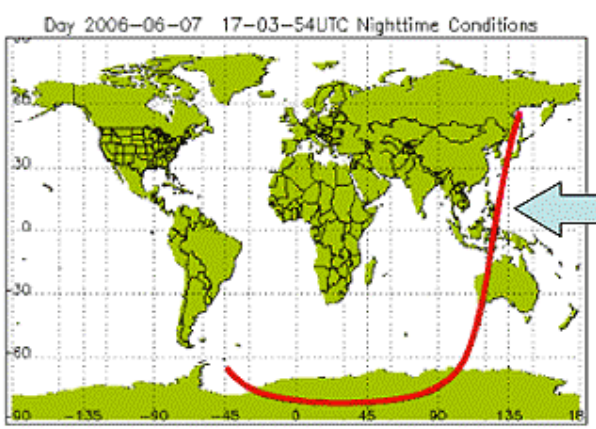
- Peak $SO_2$ burdens:
  - OMI (UV): 0.22 Tg
  - AIRS (IR): 0.18 Tg
  - MSG-SEVIRI (IR): 0.18 Tg
- FLEXPART dispersion model used to simulate $SO_2$ cloud (purely transport). Driven by ECMWF data.
- 'Best-fit' model initialized by injecting 0.027, 0.044, 0.108 Tg $SO_2$ into altitude bins of 17.5-18, 18-18.5, and 18.5-19.5 km.

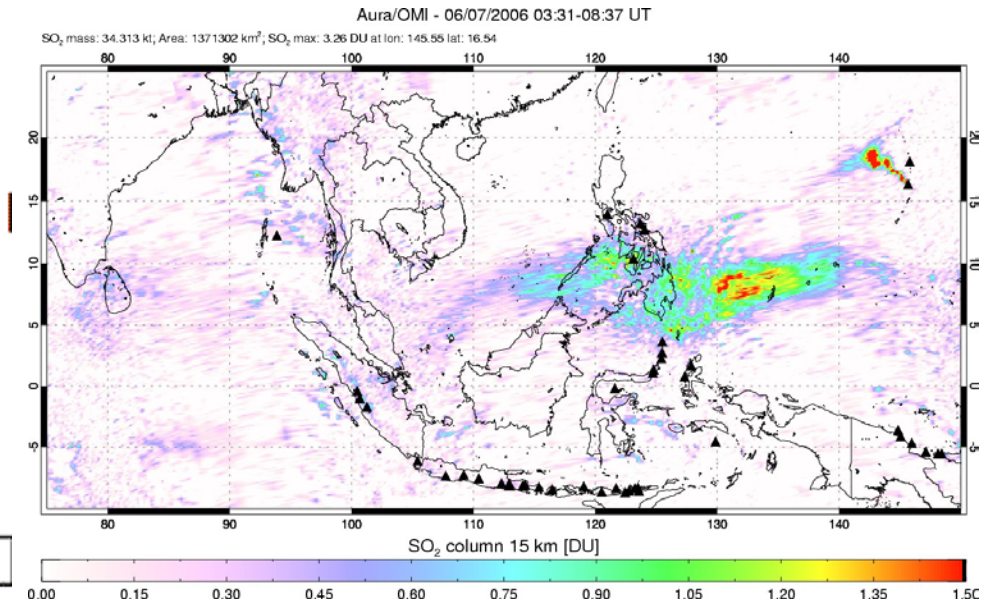
QuickTime™ and a
GIF decompressor
are needed to see this picture.

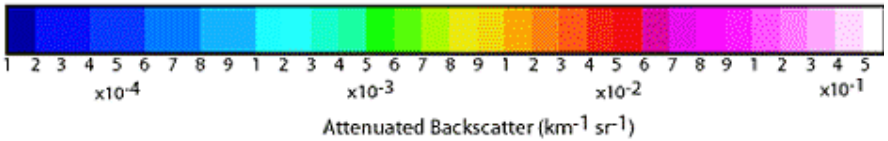
FLEXPART Lagrangian particle dispersion model
[Courtesy of A. Stohl, NILU]

# CALIPSO lidar 'first light' - 7 June 2006




[Credit: *CALIPSO Team, NASA Langley*]

- Aerosol layer non-depolarizing
- Sulfate dominant, not ash

http://www.nasa.gov/mission_pages/calipso/news/First_Light.html

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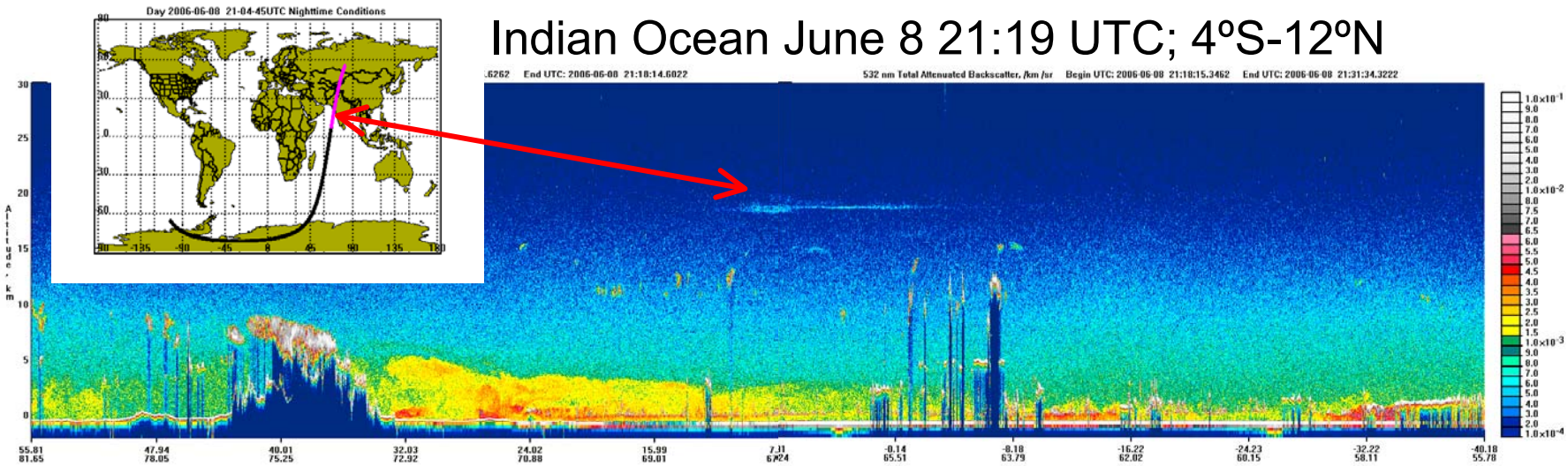
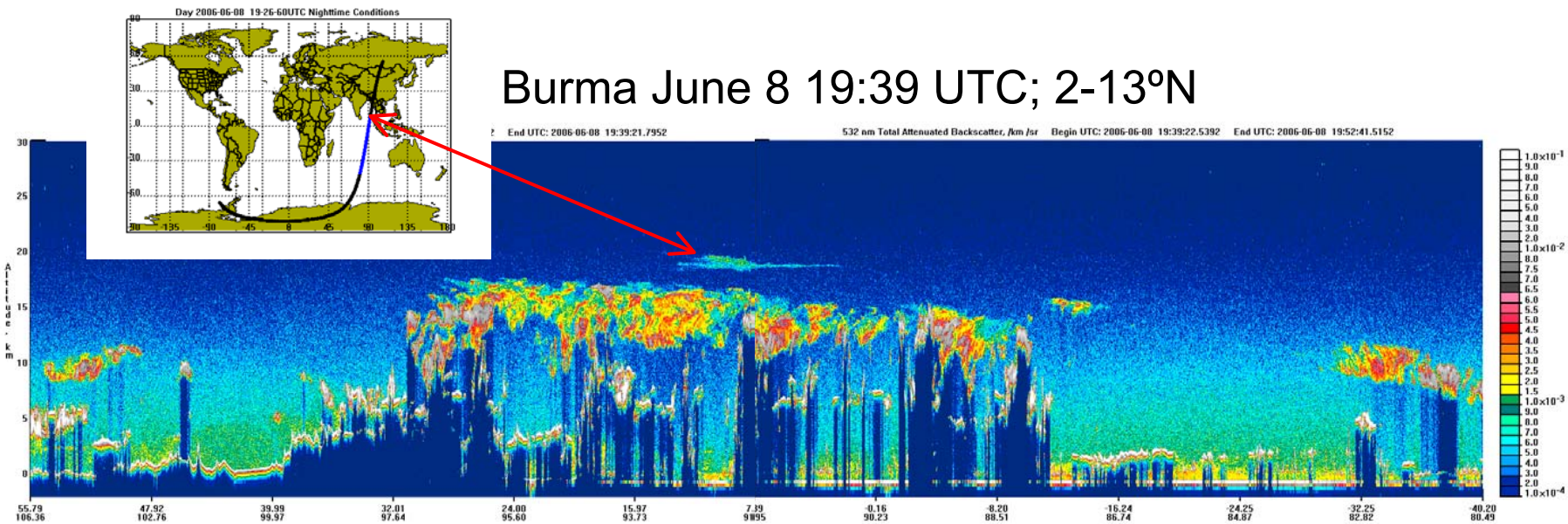
# CALIPSO lidar curtains - June 8, 2006 (eruption +19 days)




Indian Ocean June 8 21:19 UTC; 4ºS-12ºN




Burma June 8 19:39 UTC; 2-13ºN

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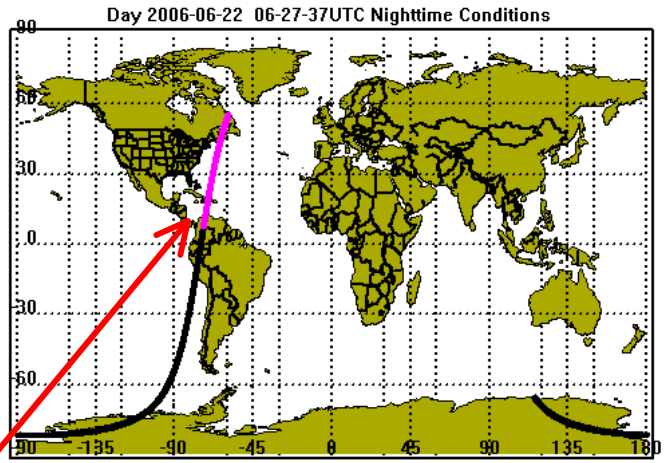
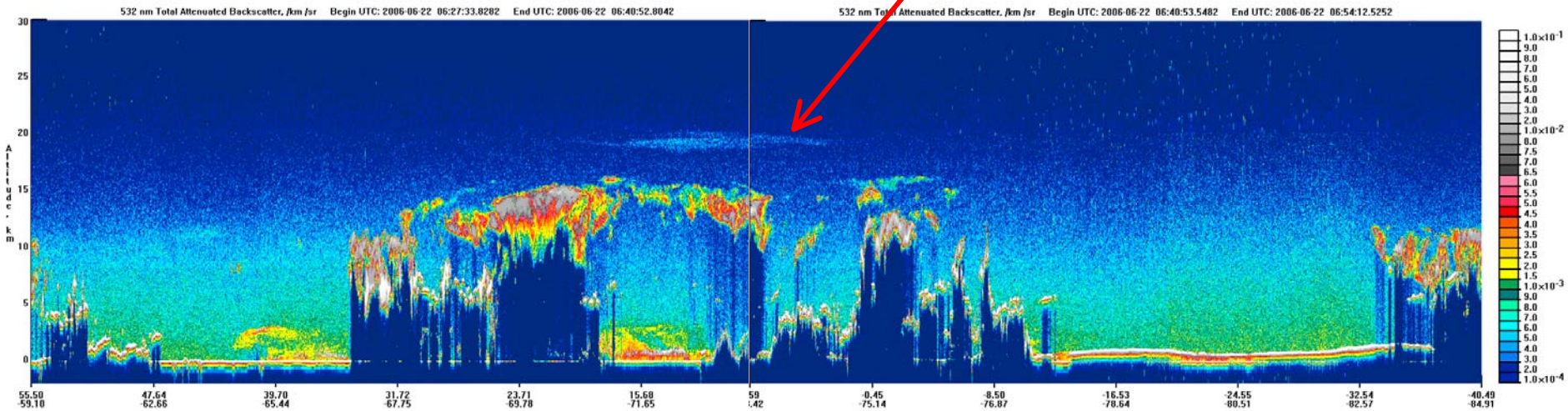
# Volcanic cloud returns home

June 22, 2006 (eruption +33 days)
6:40 UTC

Back in the Caribbean after 1 loop
Latitude range: 3-20ºN

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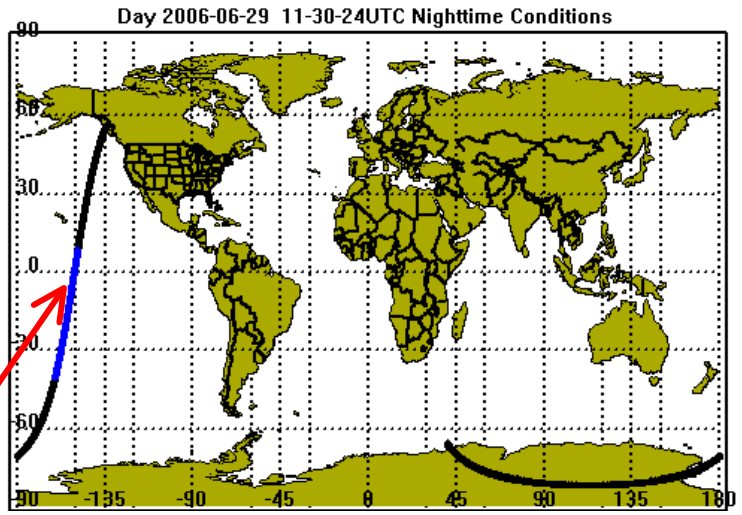
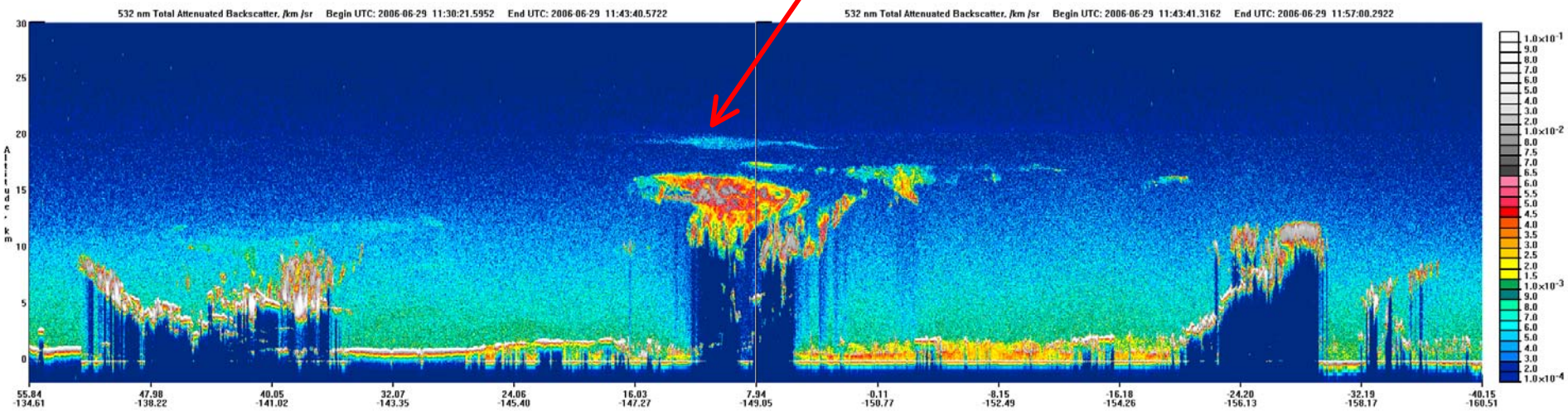
# Once more across the Pacific

June 29, 2006 (eruption +40 days
6:23 UTC

South of Hawaii
Latitude range: 3-16ºN

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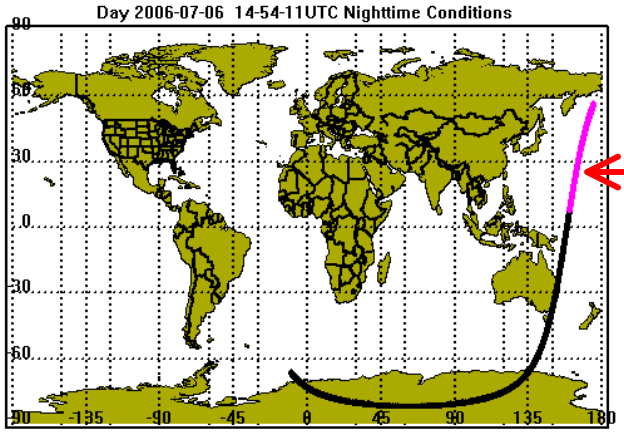
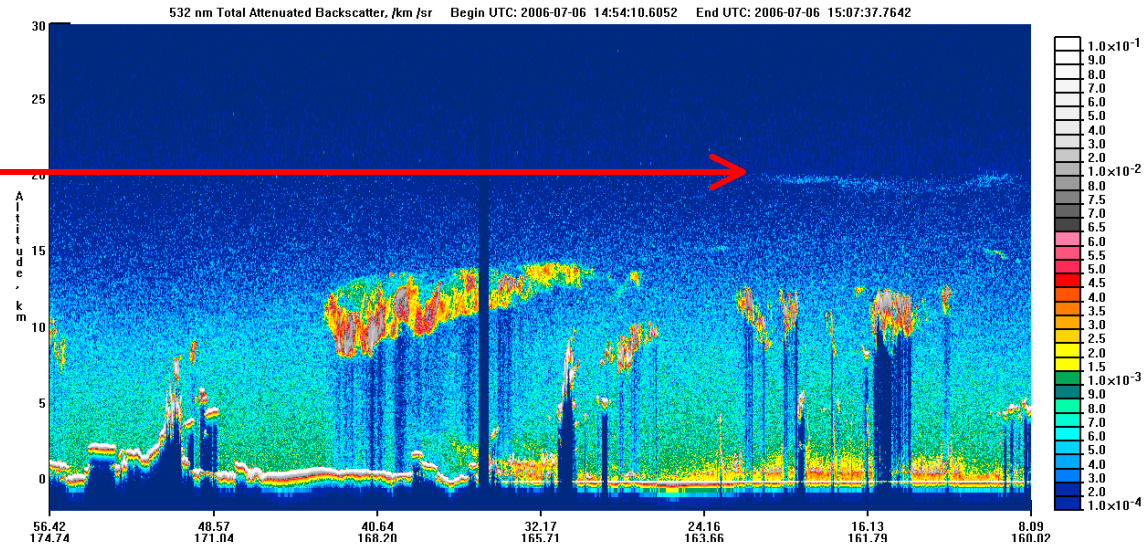
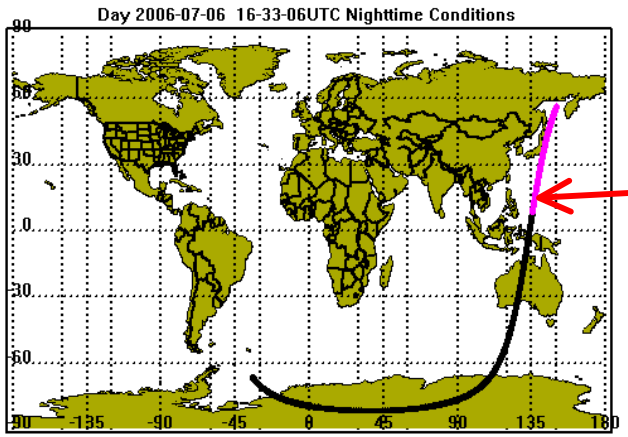
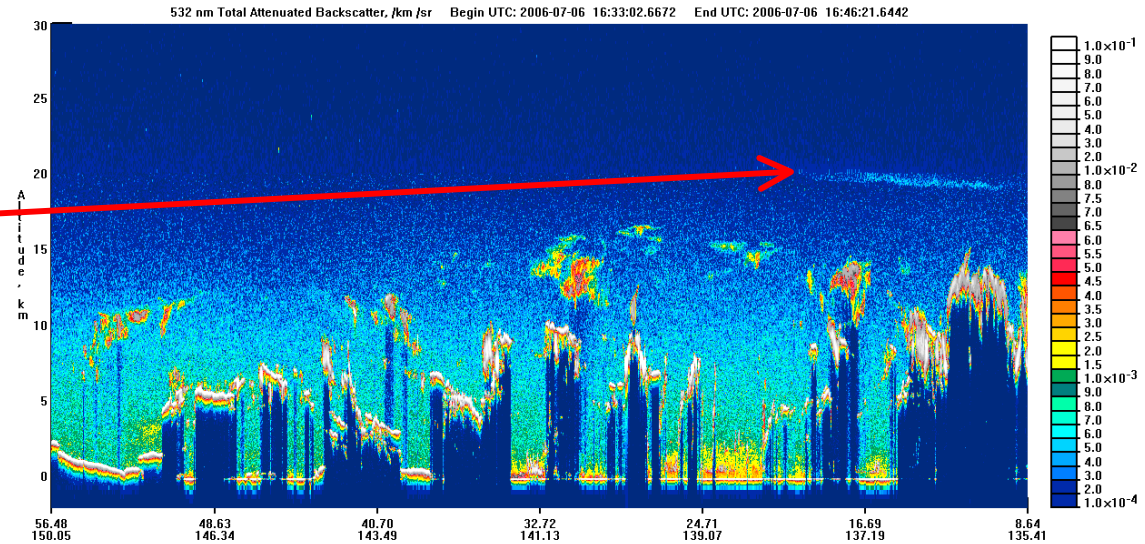
# Sulfate aerosol layer - 47 days after eruption




July 6, 2006 14:54 UT
Lat range: 8-20ºN




July 6, 2006 16:33 UT

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# Lower tropospheric residual $SO_2$ columns using OMI and AIRS

- OMI measures total column $SO_2$
- MLS has inadequate horizontal resolution for $SO_2$ cloud mapping
- Aqua/AIRS sensitive to $SO_2$ above ~3-5 km (using 7.3 μm $SO_2$ band) - 'blind' in lower troposphere due to water vapor.

⇒ OMI - AIRS = lower tropospheric $SO_2$ column

- NRT AIRS data flow already available at NOAA - NRT AIRS $SO_2$ algorithm in development
- NRT OMI $SO_2$ product in development for NASA CAN aviation hazard project

⇒ Derivation of NRT lower tropospheric $SO_2$ product possible

- Aviation hazard and air quality applications
- Issues: cloud filtering, temporal difference, AIRS coverage

# Sierra Negra (Galapagos Is) eruption - October, 2005

CORTESÍA DE GREG ARANEA

- Effusive eruption
- Oct 22 - Nov 1, 2005

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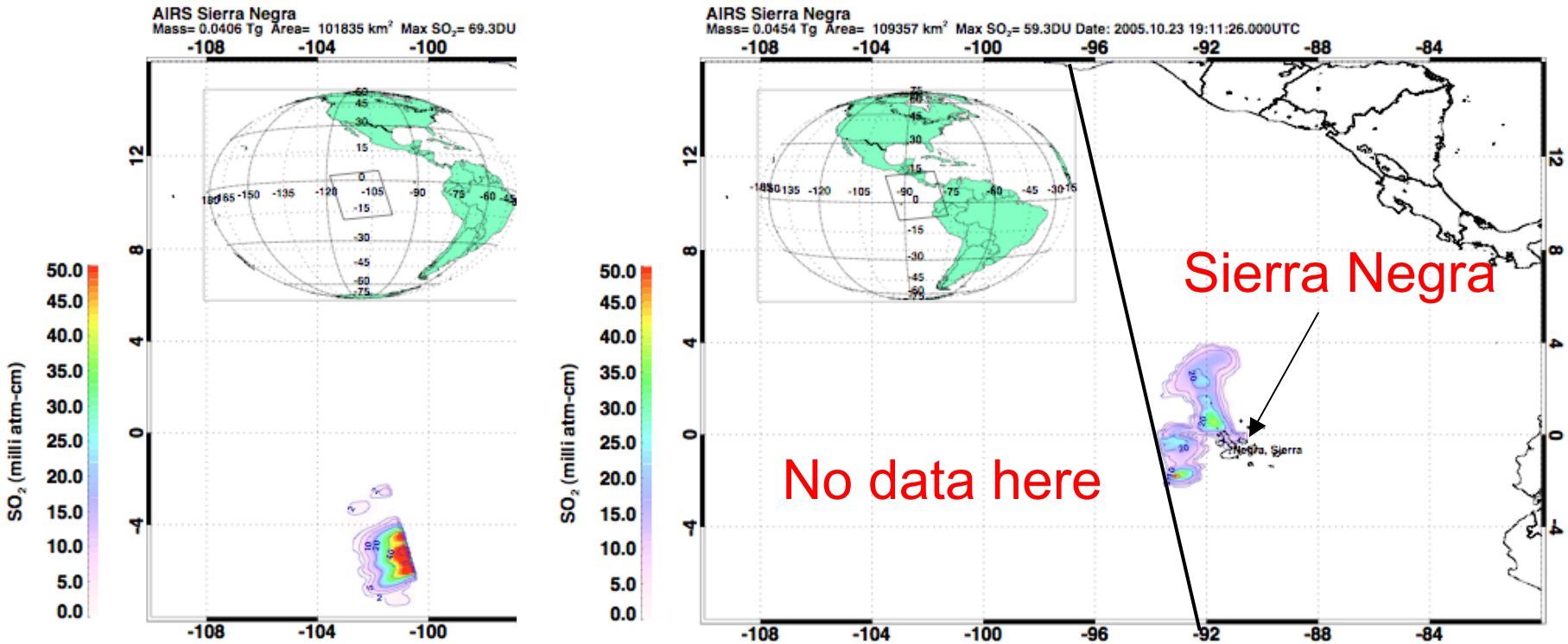
# Sierra Negra - AIRS $SO_2$ - Oct 23, 2005




[AIRS retrievals by F. Prata, NILU]

- AIRS sensitive to $SO_2$ above 3-5 km [*Prata et al., 2003*]
- OMI measures $SO_2$ total column
- OMI-AIRS = lower tropospheric $SO_2$ column

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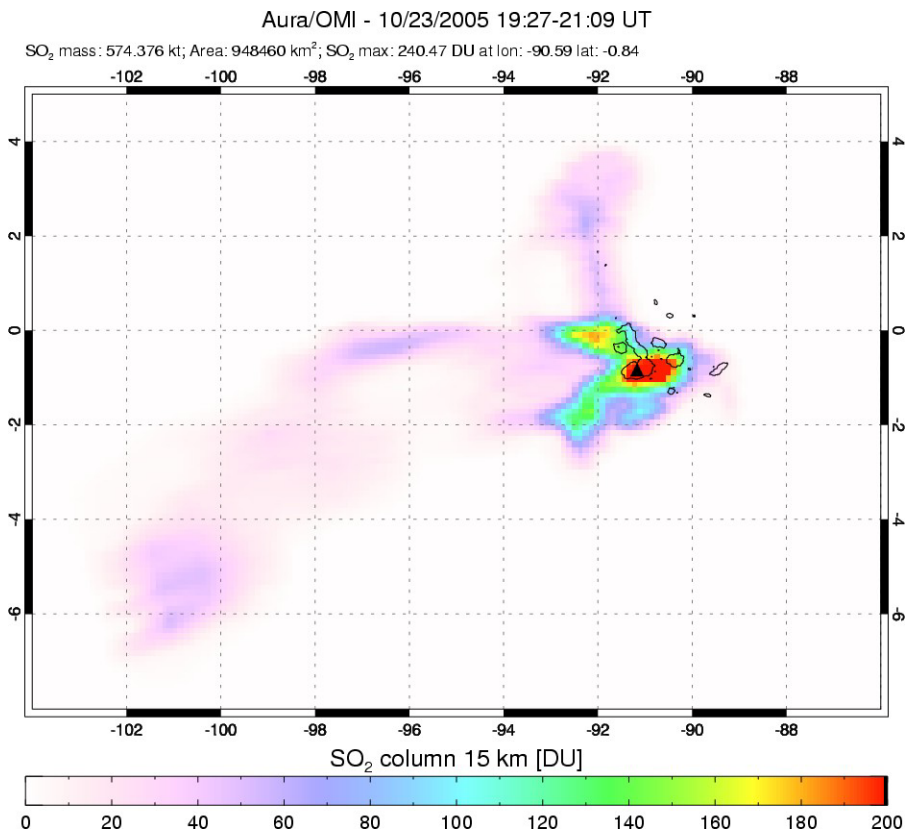
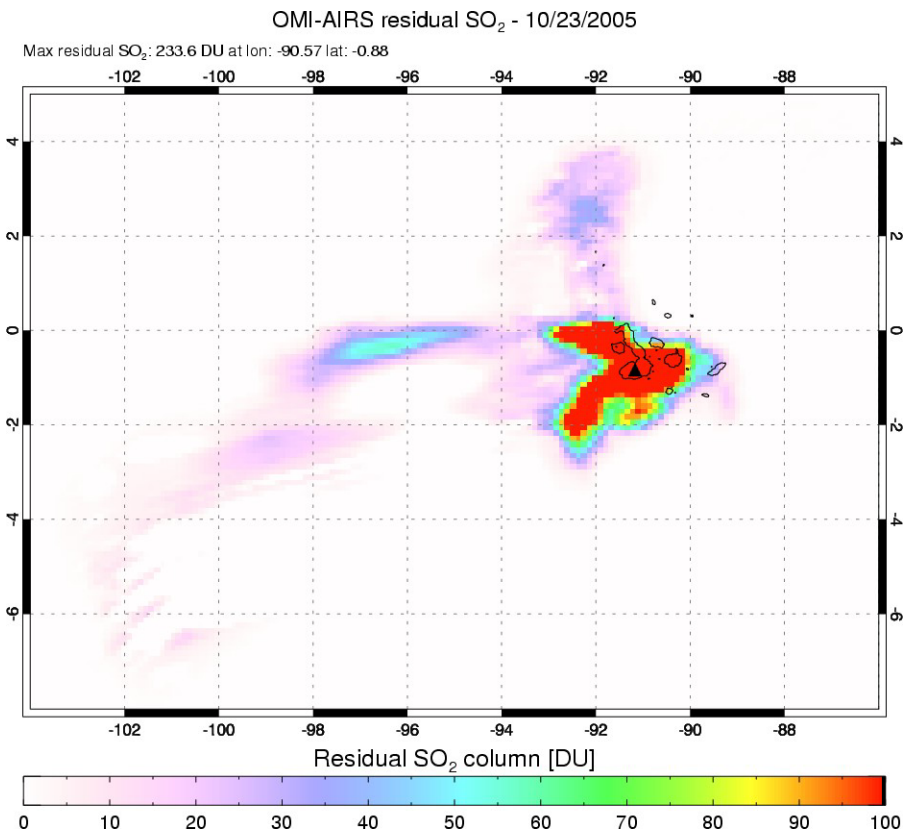
# Sierra Negra - OMI-AIRS residual - Oct 23, 2005




OMI $SO_2$ total column

OMI-AIRS: lower tropospheric $SO_2$

- Most of the $SO_2$ was released into the lower troposphere (<5 km)
- Maximum lower tropospheric $SO_2$ column: 234 DU
- Large $SO_2$ amounts in the lower troposphere are typical of effusive eruptions. Hence eruption style can be distinguished.

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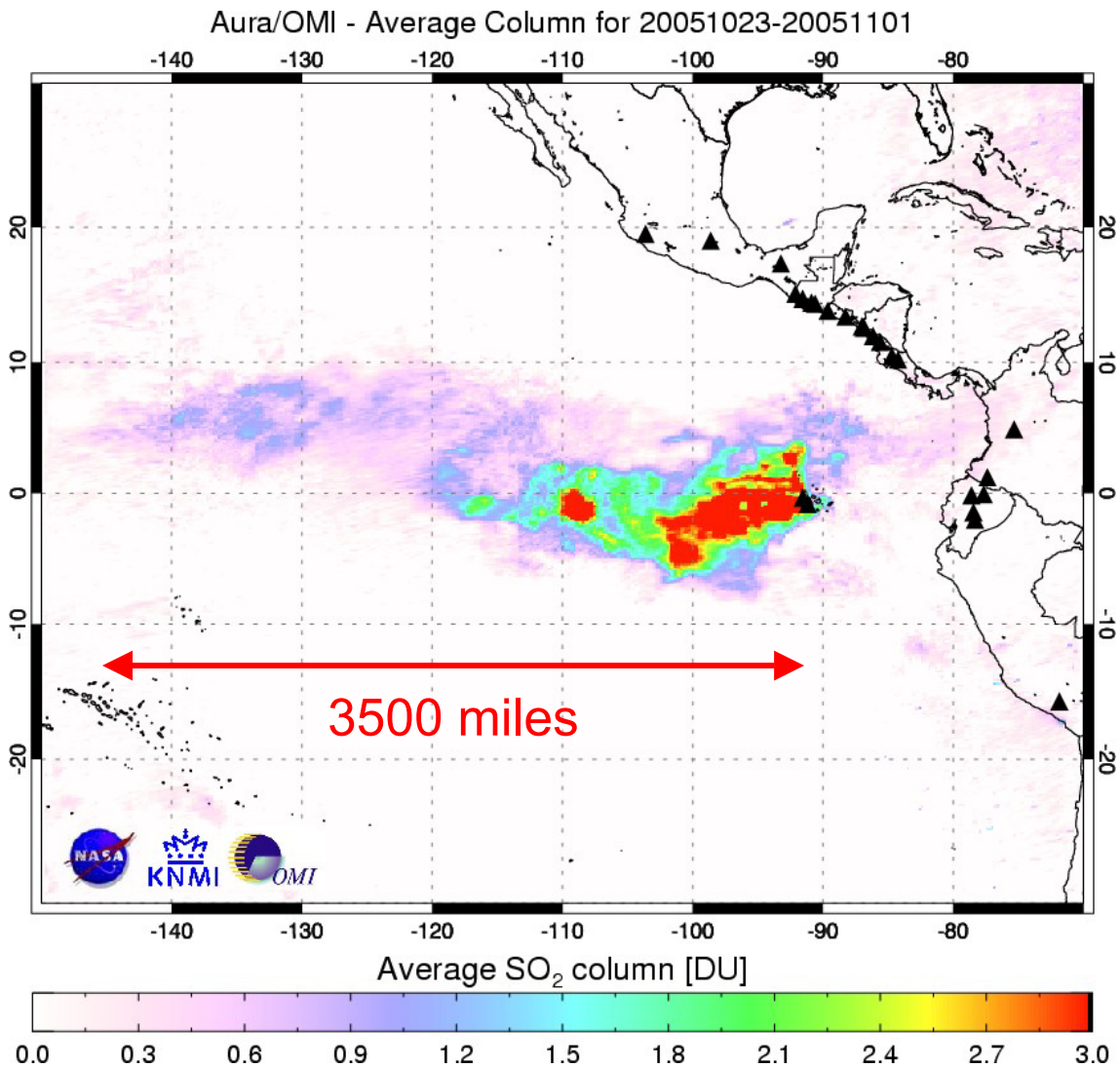
# Sierra Negra - average $SO_2$ - Oct 23-Nov 1, 2005




http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php3?img_id=13253

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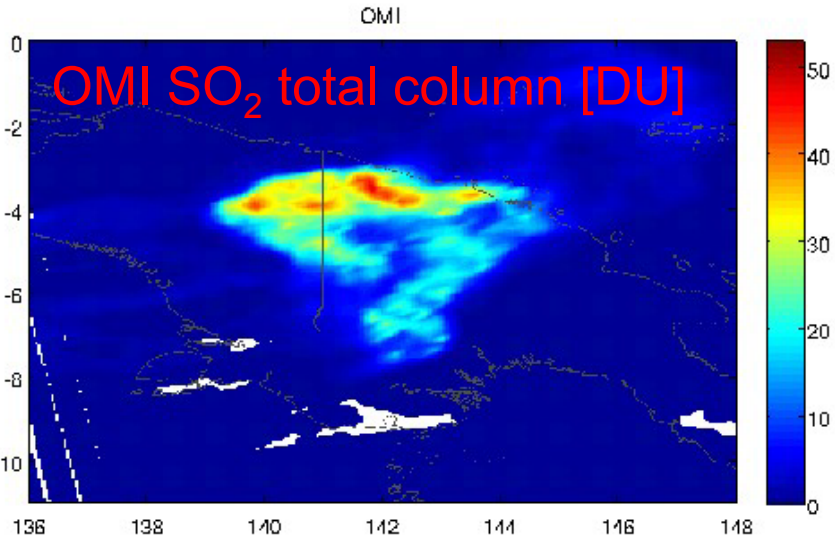
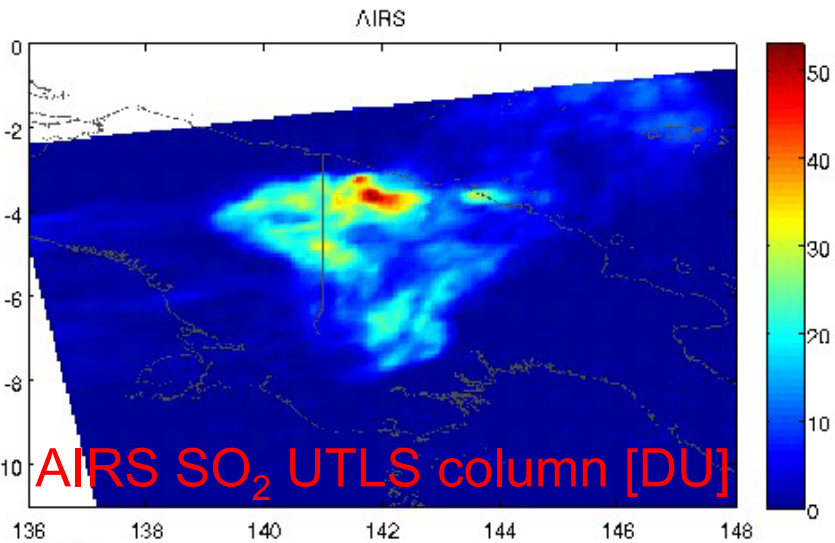
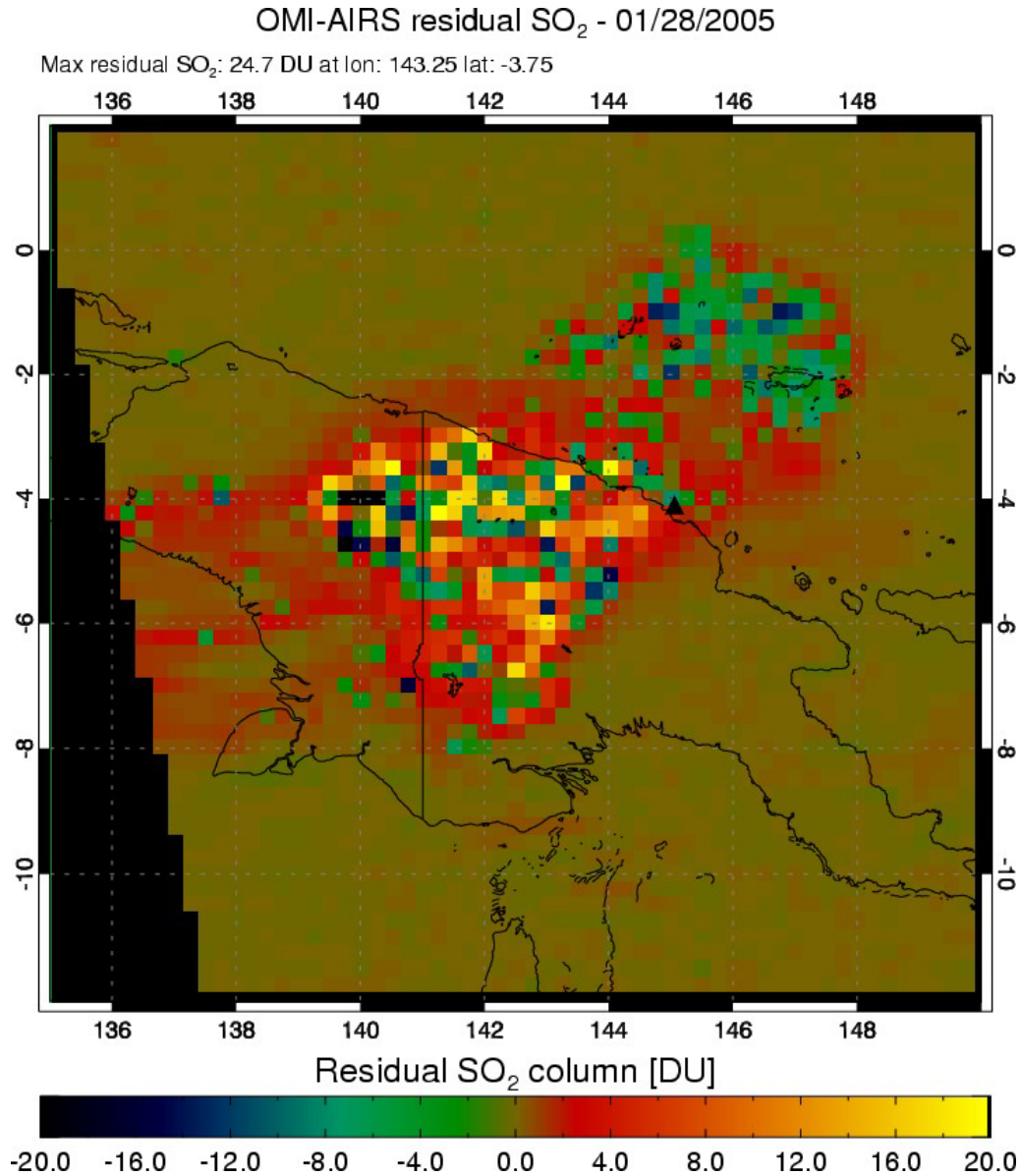
# Manam (PNG) - OMI-AIRS residual - Jan 28, 2005

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# Summary

- Using OMI on Aura we are making unprecedented observations of volcanic $SO_2$ emissions from all types of volcanic activity, including the first daily space-based measurements of passive degassing.
- By combining OMI observations with those from other A-Train sensors, we can gain insight into the vertical distribution and composition of volcanic cloud constituents, and validate trajectory/dispersion models.
- Such information is critical for accurate retrieval of $SO_2$, aviation hazard mitigation, assessment of climate impacts, and evaluation of volcanic eruption style.

# Soufriere Hills (Montserrat) eruption - May 20, 2006

18 May 2006

Lava dome collapse, 20 May 2006

- Triggered by heavy rainfall on May 20
- 90 million $m^3$ of lava removed

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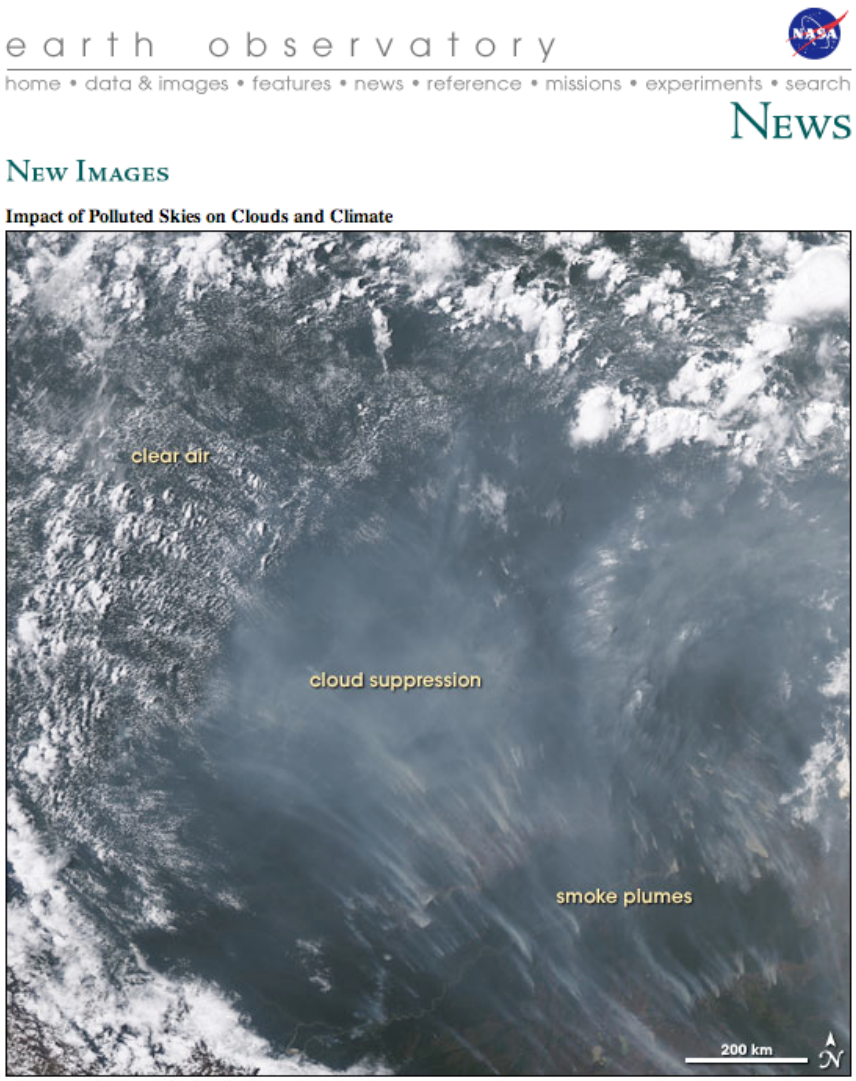
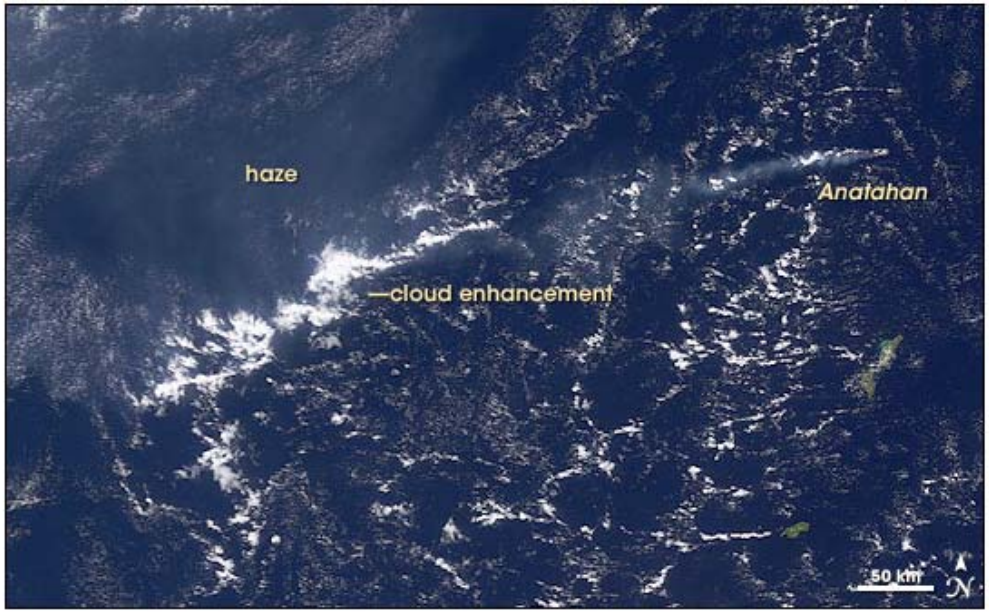
# Impact of aerosols on clouds and climate



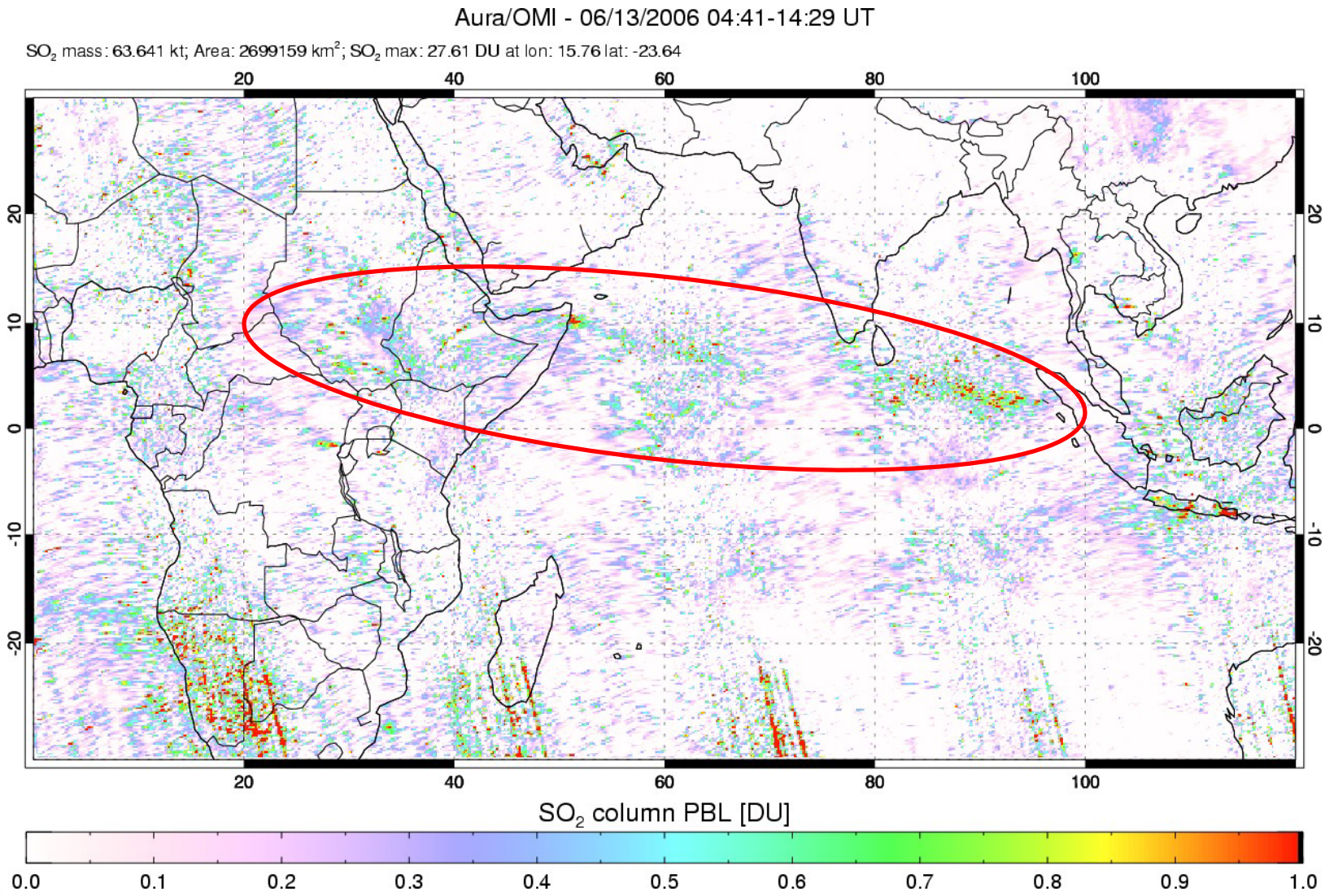

Smoke from forest fires in the Amazon




Volcanic plume from Anatahan

- Impact of aerosols on cloud formation, cloud particle size, cloud albedo and precipitation onset is significant [e.g., *Kaufman and Koren, Science, 2006*]
- Depends on aerosol type (absorbing or non-absorbing)

# Last OMI observation of $SO_2$ cloud?




June 13, 2006

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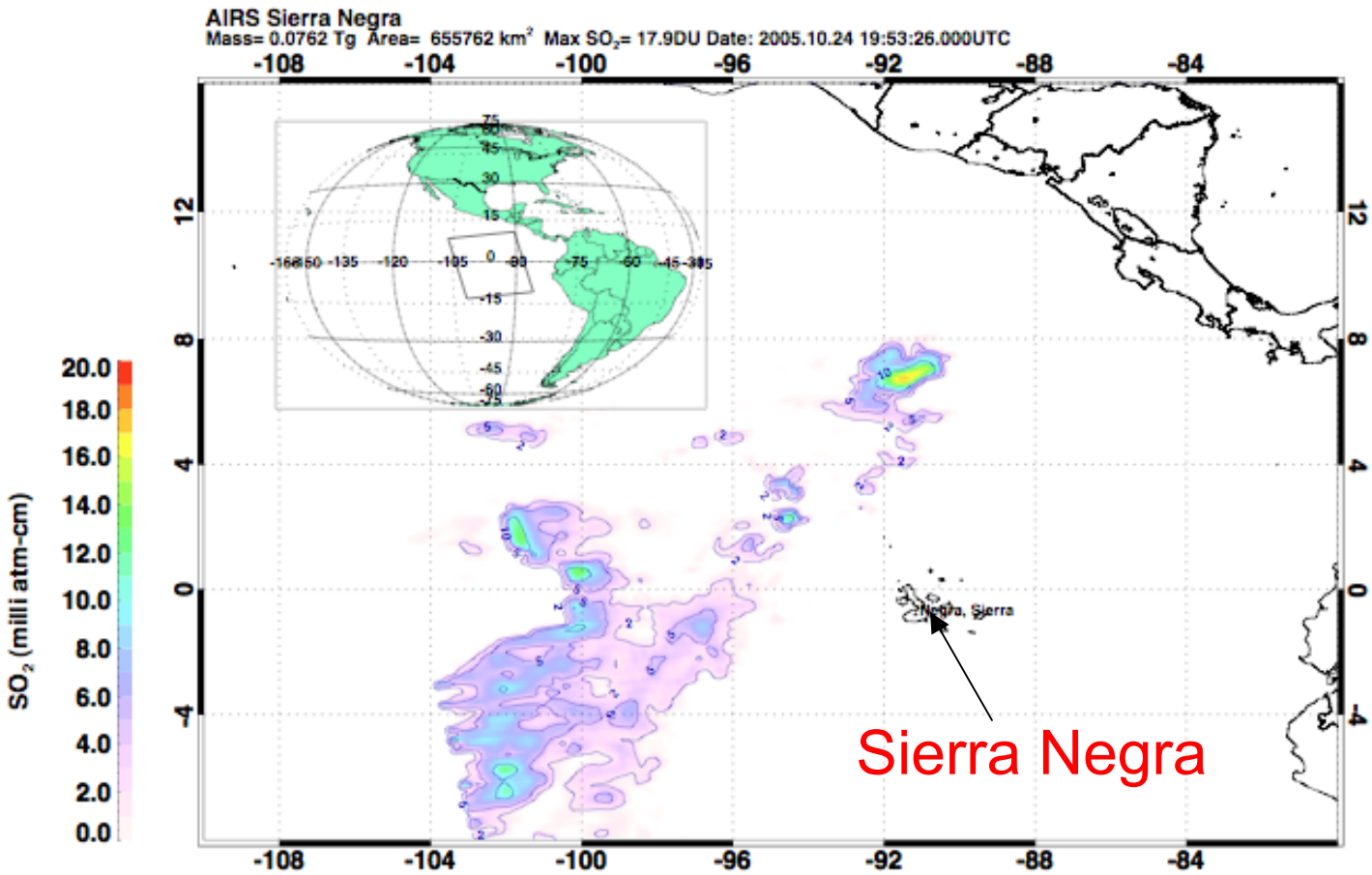
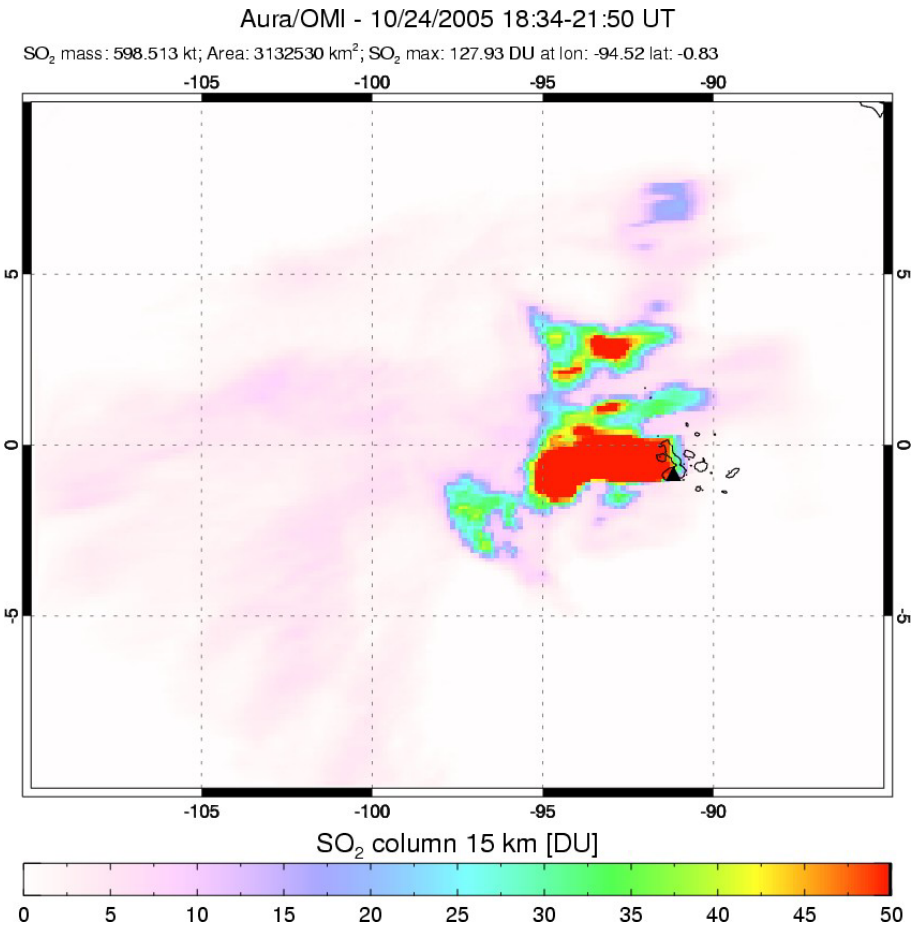
# Sierra Negra - AIRS $SO_2$ - Oct 24, 2005

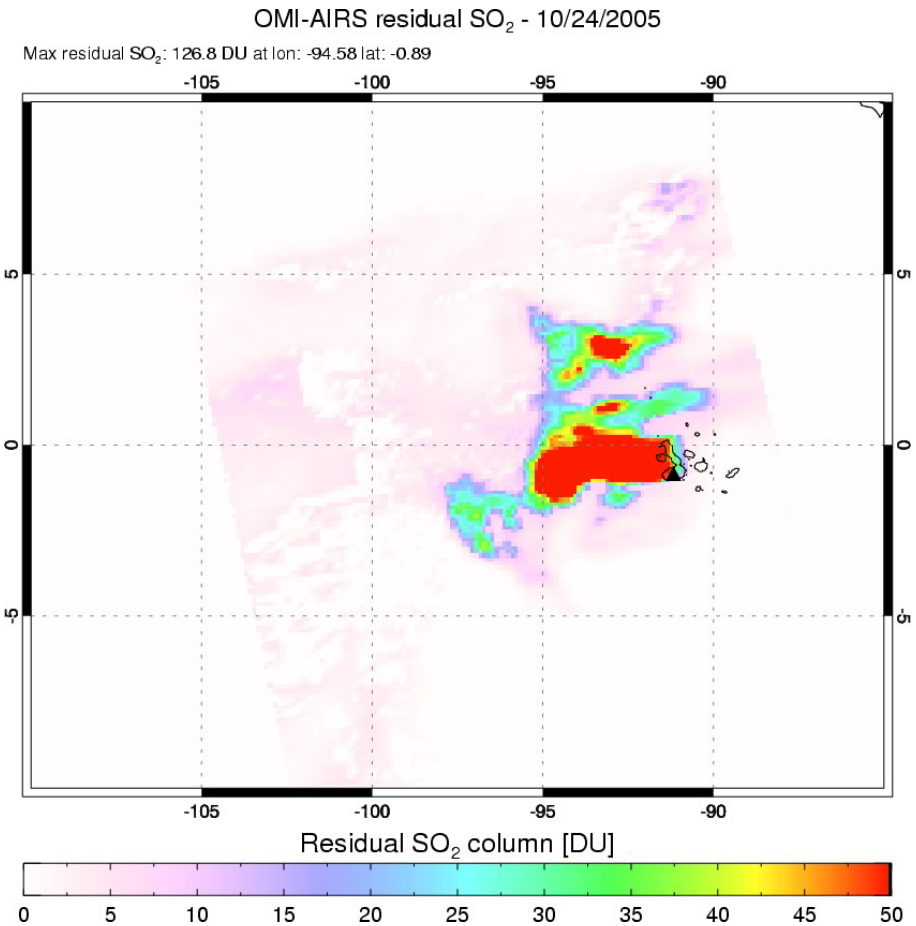



[AIRS retrievals by F. Prata, NILU]

# Sierra Negra - OMI-AIRS residual - Oct 24, 2005




OMI $SO_2$ total column




OMI-AIRS: lower tropospheric $SO_2$

- Large $SO_2$ amounts in the lower troposphere are typical of effusive eruptions. Hence eruption style can be distinguished.

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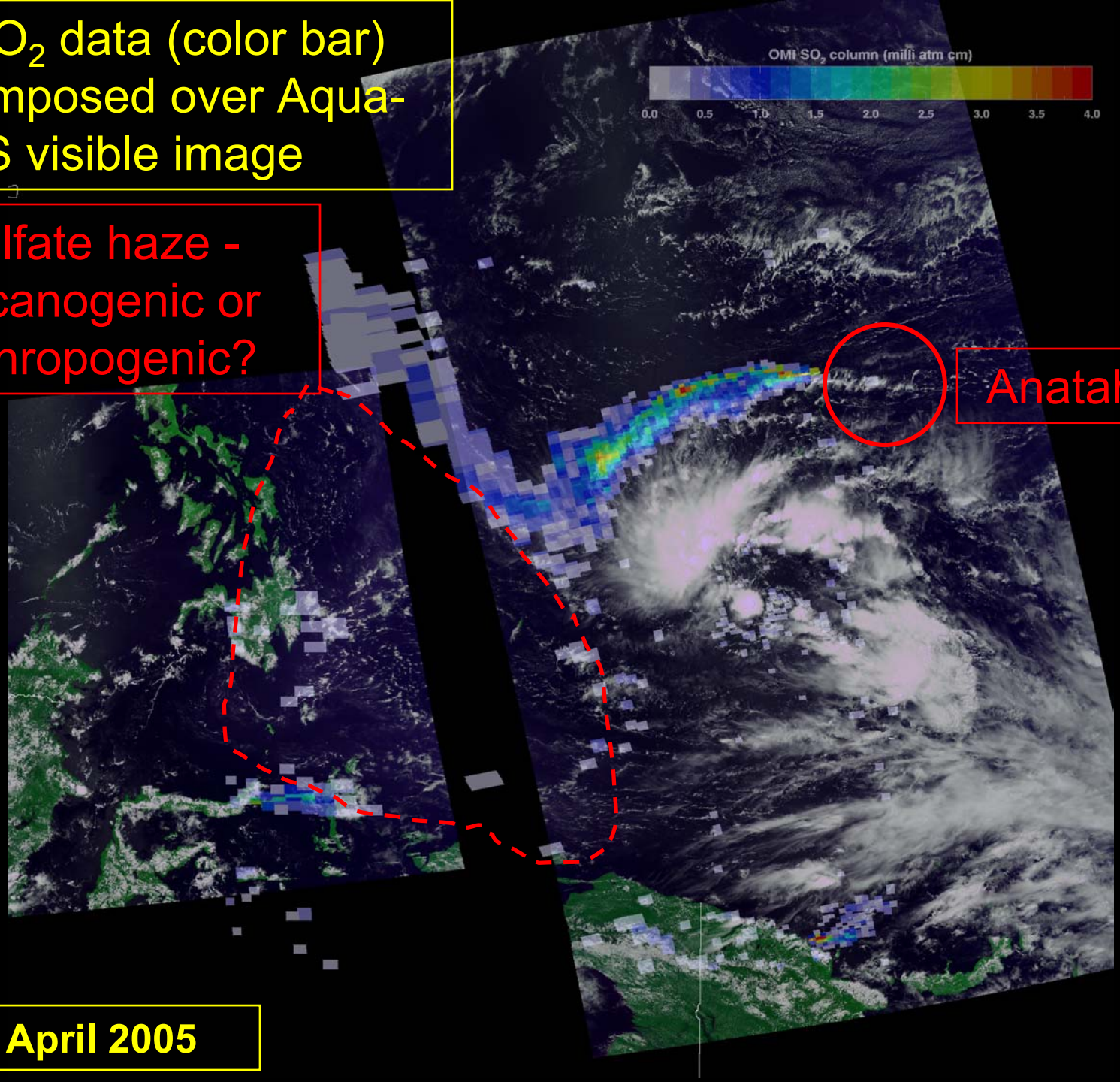
OMI $SO_2$ data (color bar) superimposed over Aqua-MODIS visible image

Sulfate haze - volcanogenic or anthropogenic?




**20 April 2005**

# Volcanic gas compositions

| mol% | Nyiragongo (DR Congo) RIFT | Kilauea* (Hawaii) HOTSPOT | Merapi* (Indonesia) SUBDUCTION | Etna* (Sicily) SUBDUCTION |
|---|---|---|---|---|
| $H_2O$ | 70 | 37 | 91 | 48 |
| $CO_2$ | 24 | 49 | 5 | 20 |
| $SO_2$ | 5 | 12 | 1 | 31 |
| CO | 1 | 2 | 0.1 | 0.4 |
| HCl | 0.3 | 0.08 | 0.6 | - |
| HF | 0.1 | - | 0.04 | - |

*Symonds *et al.* [1994]

Trace constituents: $CH_4$, $N_2$, BrO, Zn, Cu, Hg, Au, As, Re, He, Ne, Ar…..