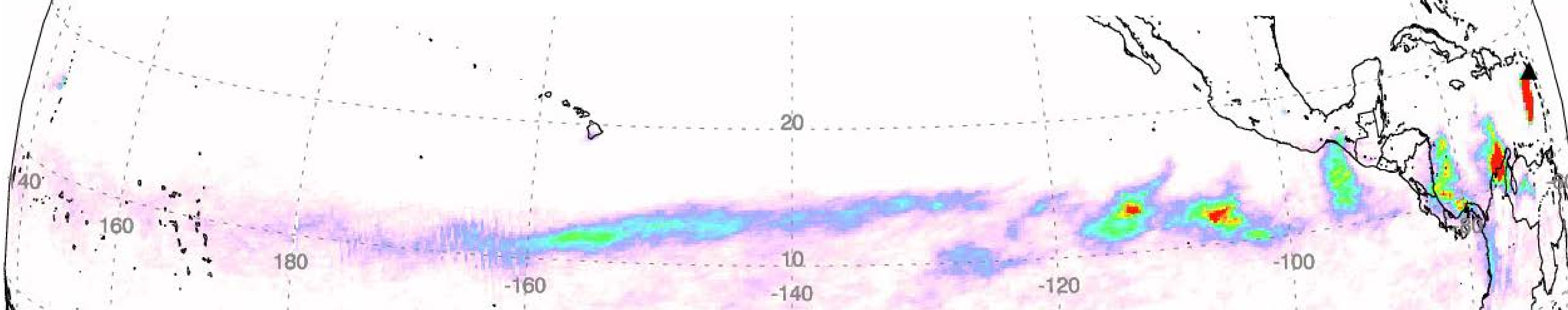
Monitoring trace gas emissions and transport with Aura and the A-Train



Simon Carn

Dept. of Geological and Mining Engineering, Michigan Technological University, Houghton, MI

OMI

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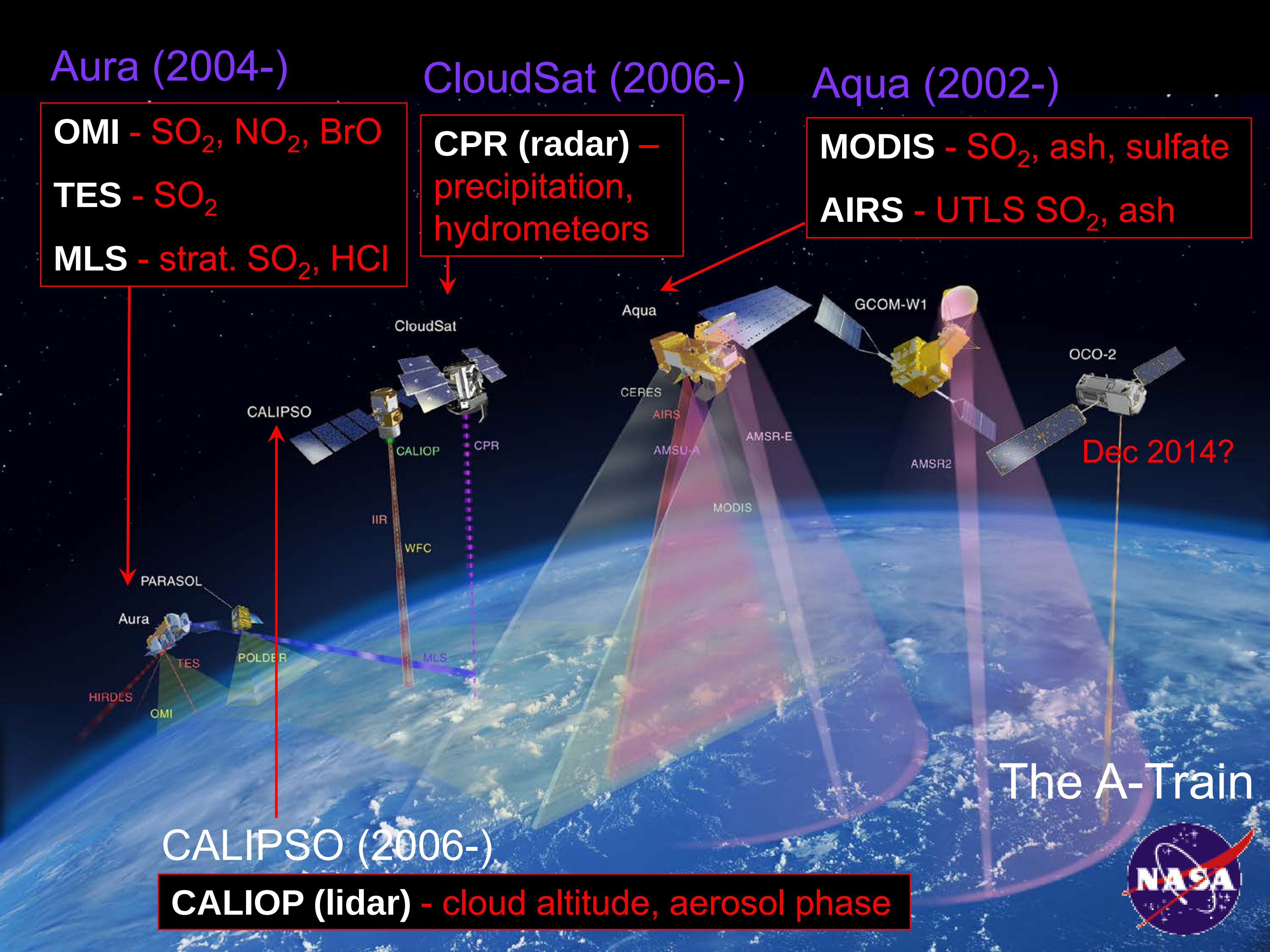
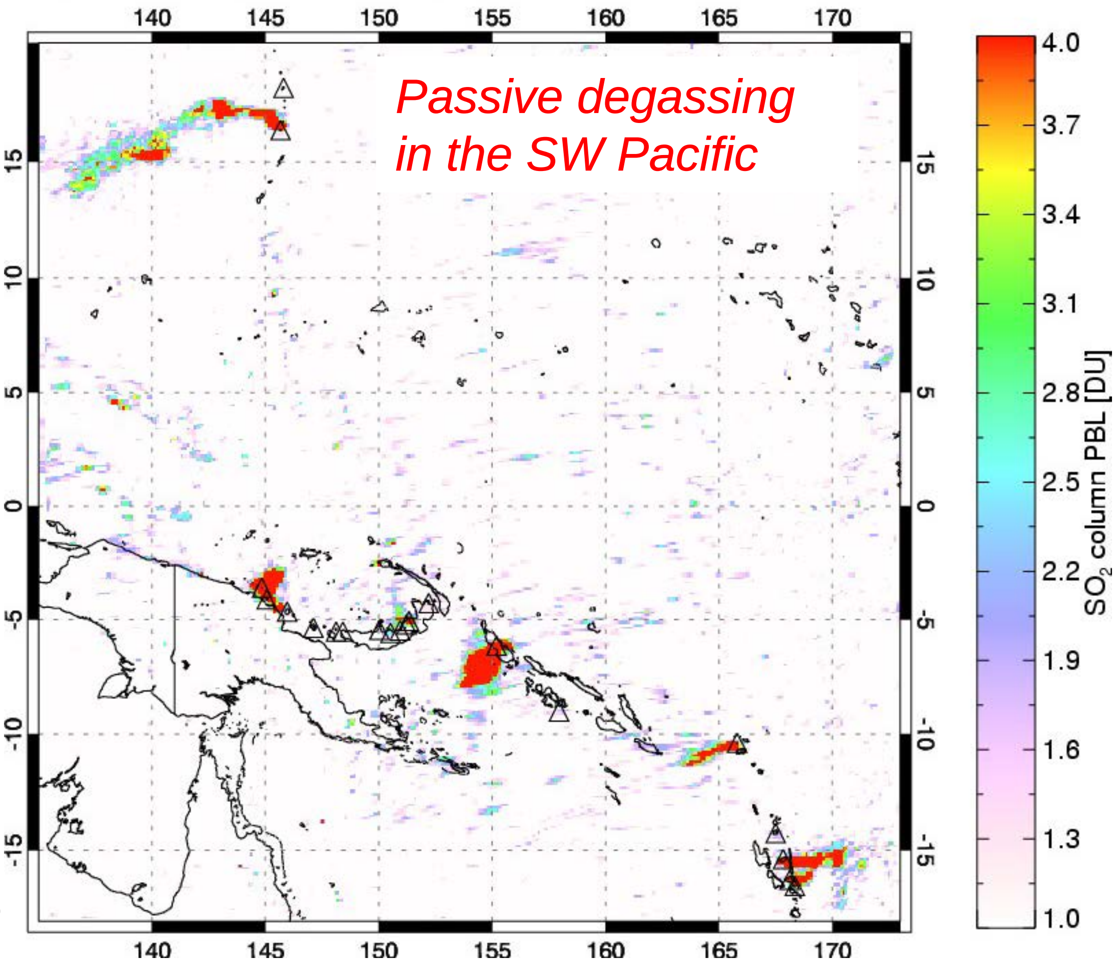

Aura (2004-)
OMI - SO_2, NO_2, BrO
TES - SO_2
MLS - strat. SO_2, HCl
CloudSat (2006-)
CPR (radar) – precipitation, hydrometeors
Aqua (2002-)
MODIS - SO_2, ash, sulfate
AIRS - UTLS SO_2, ash
Aqua
GCOM-W1
CloudSat
OCO-2
CERES
AIRS
AMSR-E
AMSU-A
CALIPSO
CALIOP
CPR
AMSR2
Dec 2014?
MODIS
IIR
WFC
PARASOL
Aura
TES
POLDER
MLS
HIRDLS
OMI
The A-Train
CALIPSO (2006-)
CALIOP (lidar) - cloud altitude, aerosol phase
NASA

Aura - Ozone Monitoring Instrument (OMI)

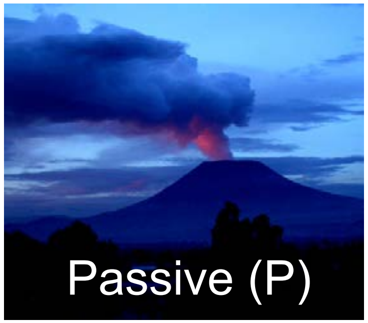
- UV/Visible sensor
- On NASA/Aura satellite
- Launched July 2004
- Daily contiguous global coverage (until 2008)
- 13 x 24 km nadir pixel
- Overpass at 1:30-2:00 pm local time
- Measures SO_2 total column (plus other gases and aerosols)
- Data publicly available and free
- NRT SO_2 data available on web



- First satellite sensor to provide daily, global SO_2 measurements with sensitivity to the lower troposphere (i.e., passive volcanic degassing)

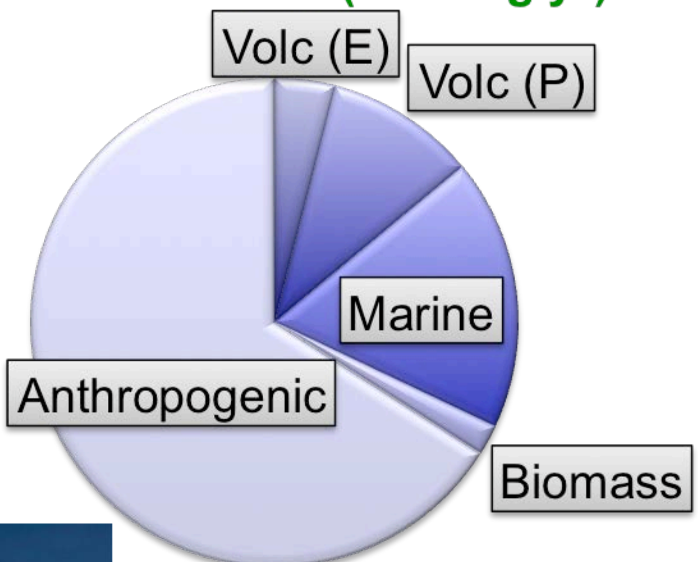
Global sulfur emissions inventory

Volcanic

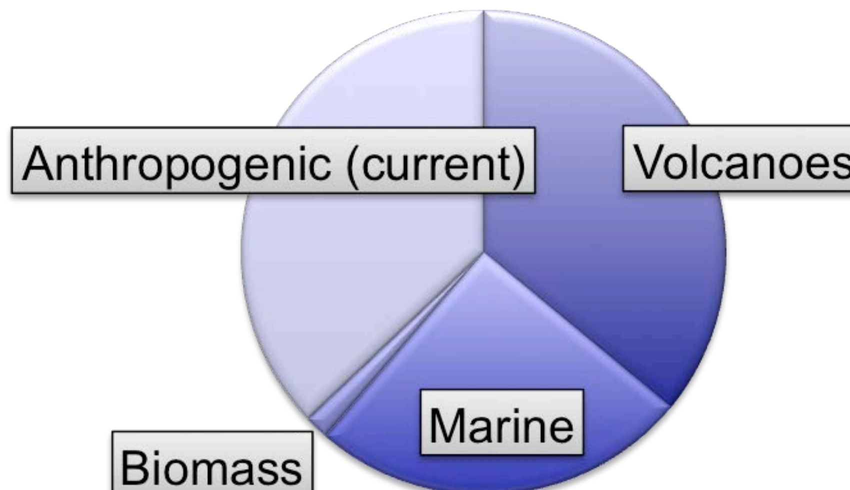


- Climate impact of volcanic sulfate aerosol
- Global fluxes of other volatile species
- *Altitude* of emissions critical

Sulfur emissions (~100 Tg/yr)

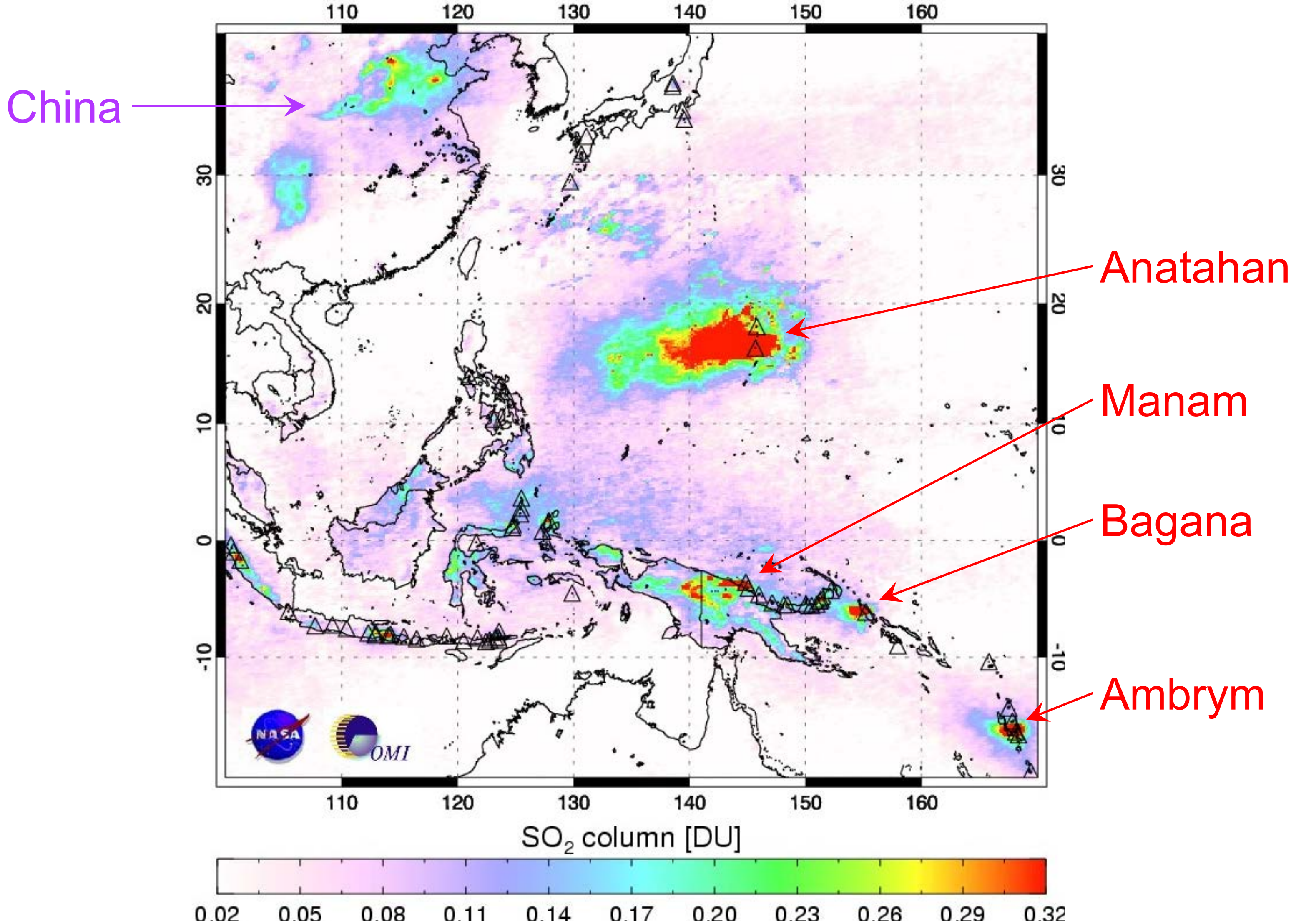


Sulfate burden



[Graf *et al.*, 1997; Andres & Kasgnoc, 1998; Smith *et al.*, 2011]

OMI annual average SO_2 in 2005: W. Pacific/S.E. Asia



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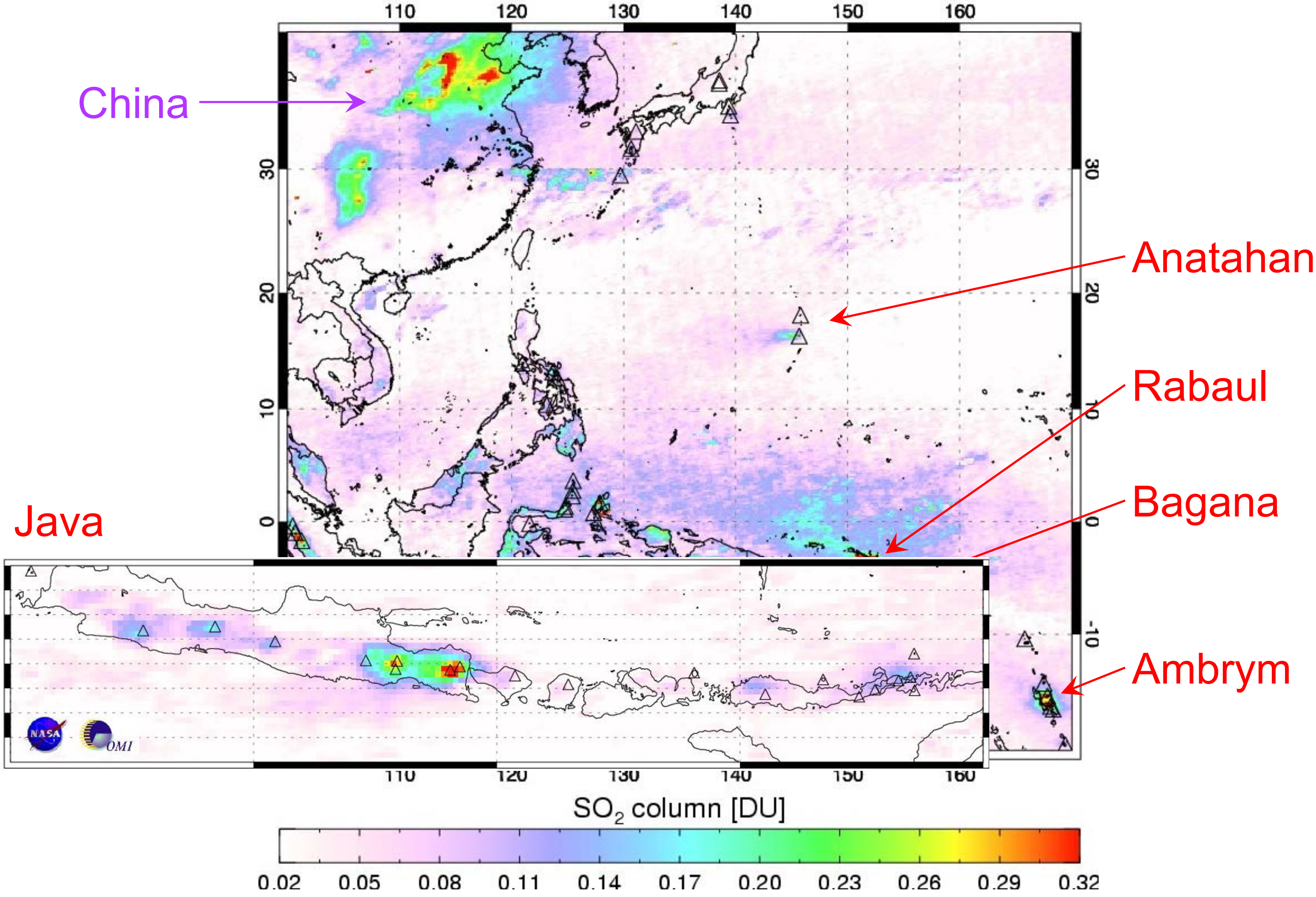
OMI annual average SO_2 in 2006: W. Pacific/S.E. Asia



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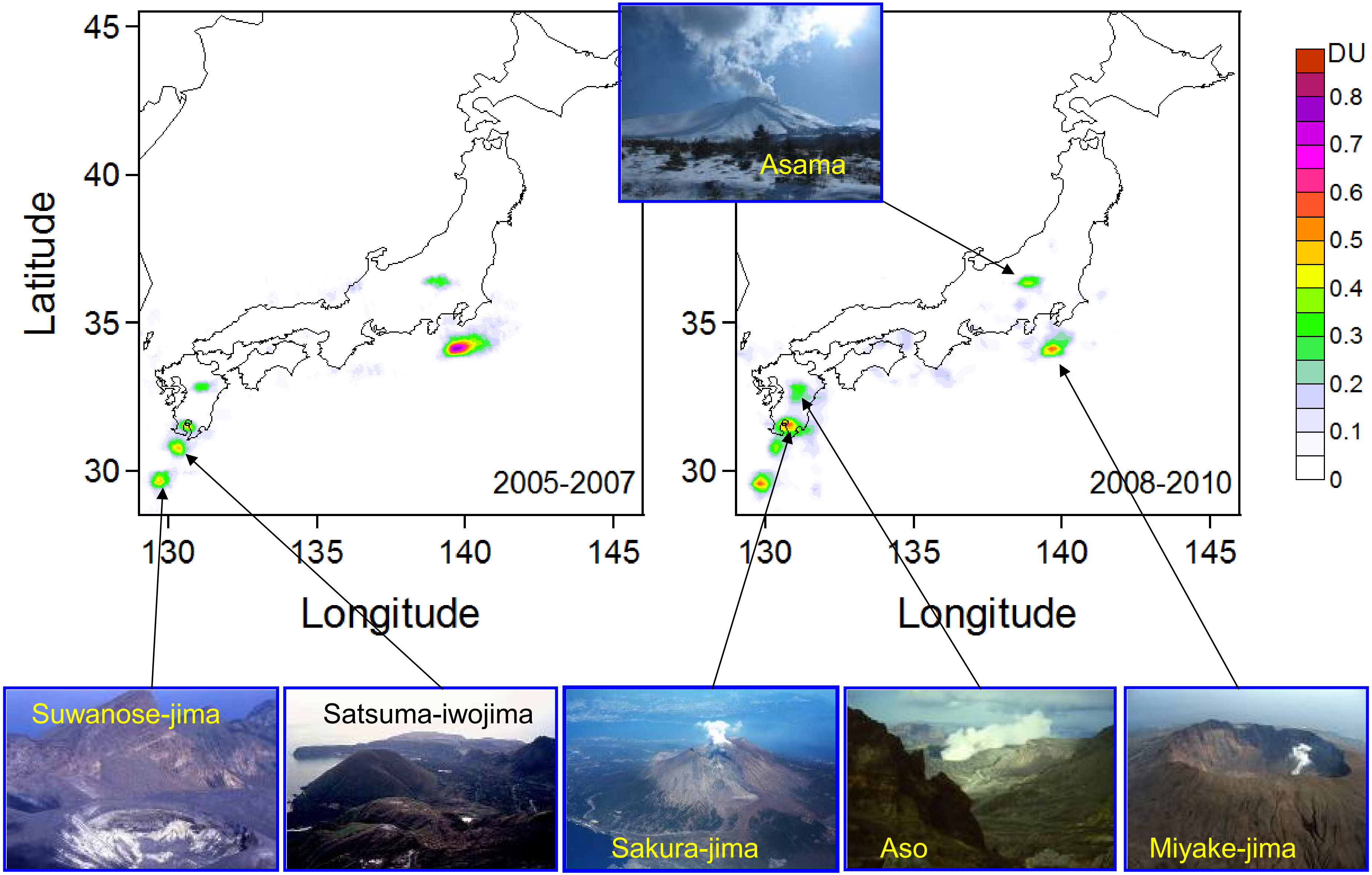
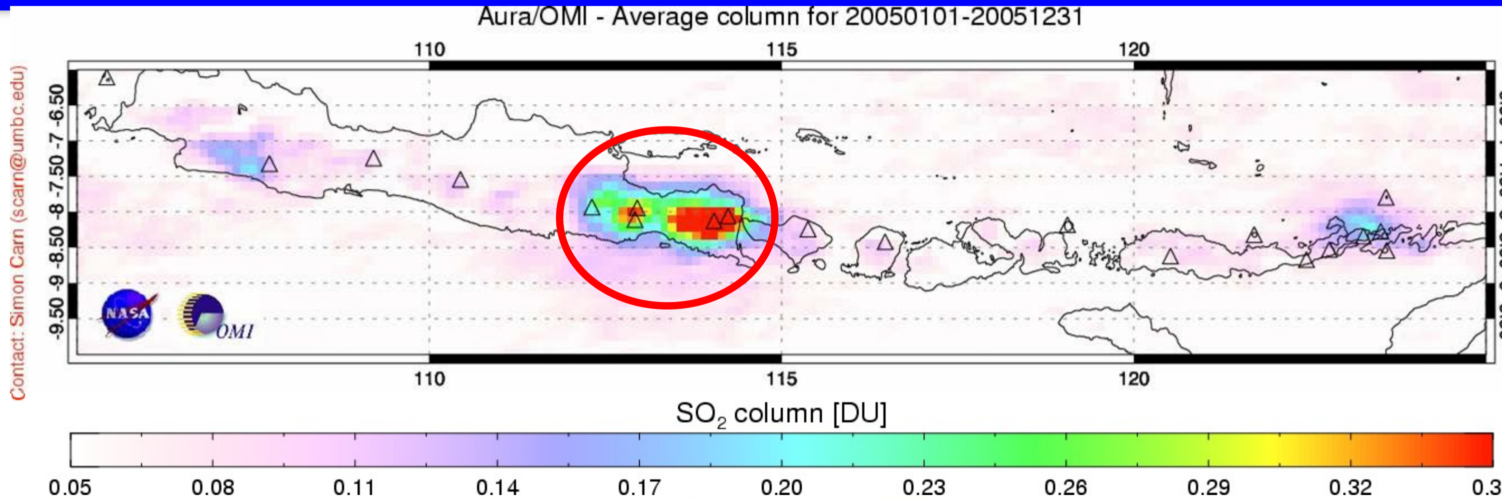
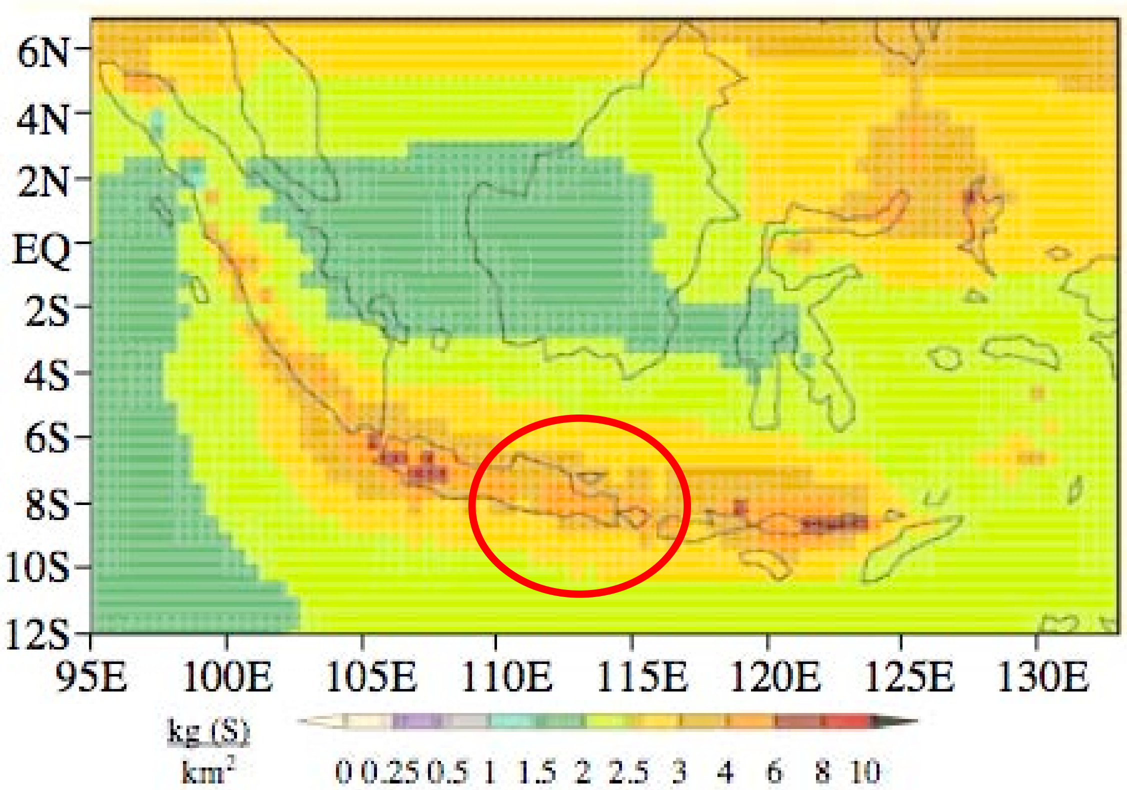
Global SO_2 emission source catalog (*Fioletov et al.*, in prep)

Example: Volcanoes in Japan (multi-year OMI SO_2 averages)



Comparing emission inventories with measurements

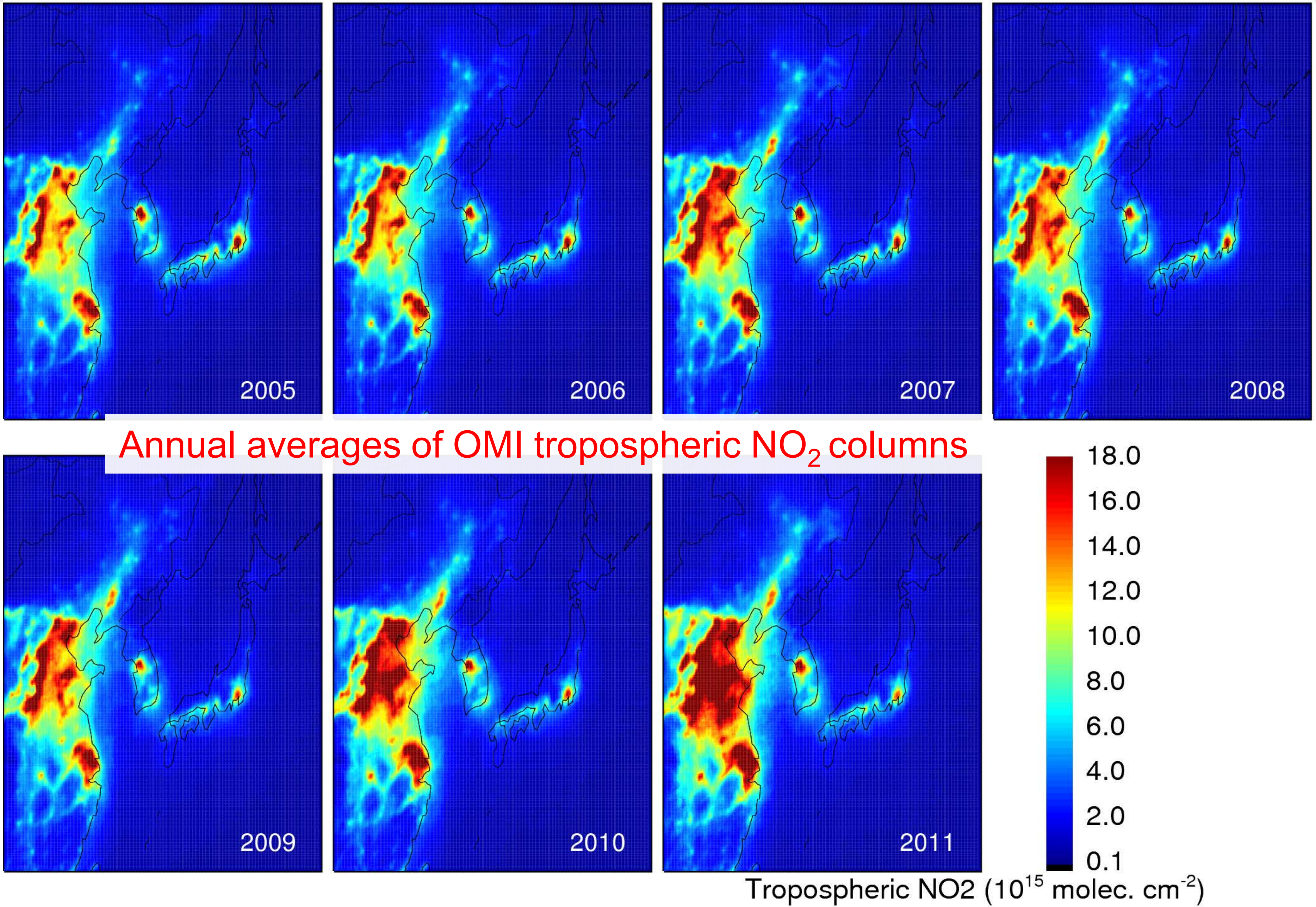




- OMI measurements indicate deficiencies in current volcanic SO_2 emission inventories

REMOTE model simulation of annual mean SO_2 columns over Indonesia [*Pfeffer et al., ACP, 2006*]

Trends in NO_2 emissions in East Asia (*Lok Lamsal, NASA*)

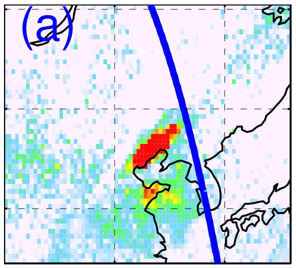


Combine OMI SO2 and AIRS CO to Identify Transpacific Transport Events: One Example in 2006

[Hsu et al., JGR 2012]

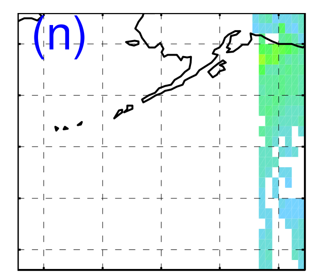
Oct. 8 Oct. 9 Oct. 10 Oct. 11 Oct. 12

OMI SO_2 (DU)



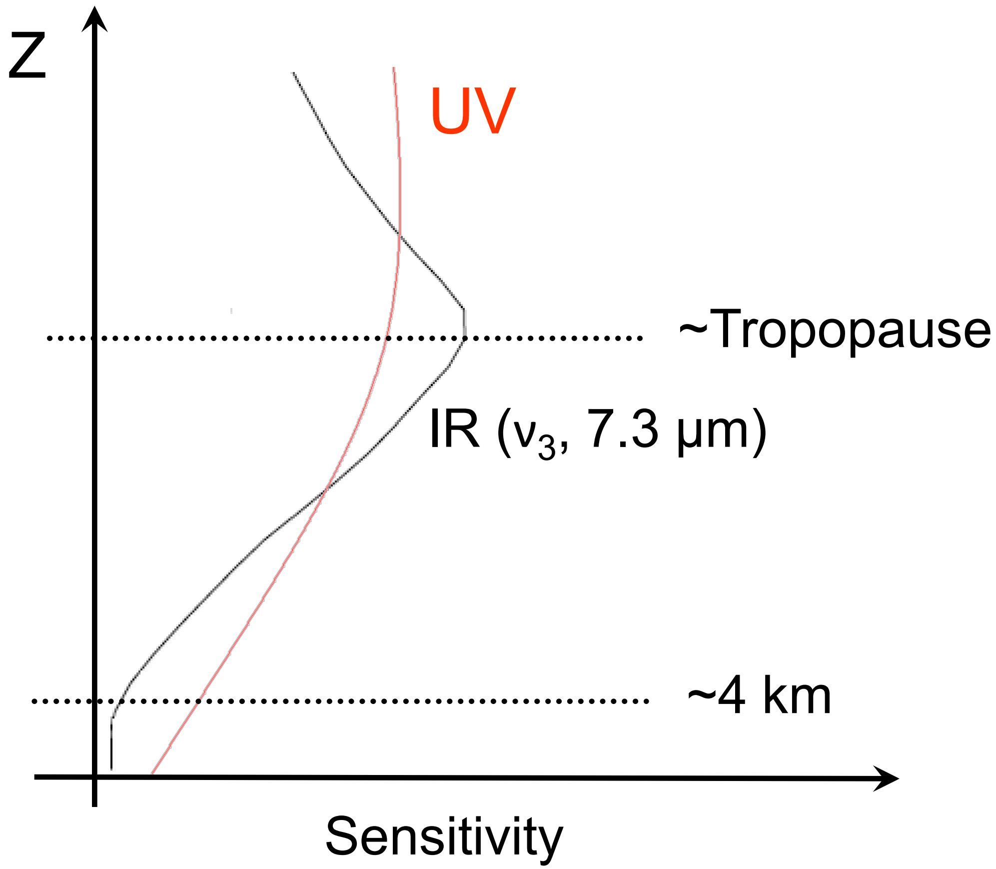
Trajectory SO_2 plume Height (3 km)

AIRS CO (10^{18} mole/cm^3)



Using CALIPSO, the Plume Height can be verified along the transport pathway.

Relative sensitivity of UV and IR measurements



Courtesy of L. Clarisse, ULB

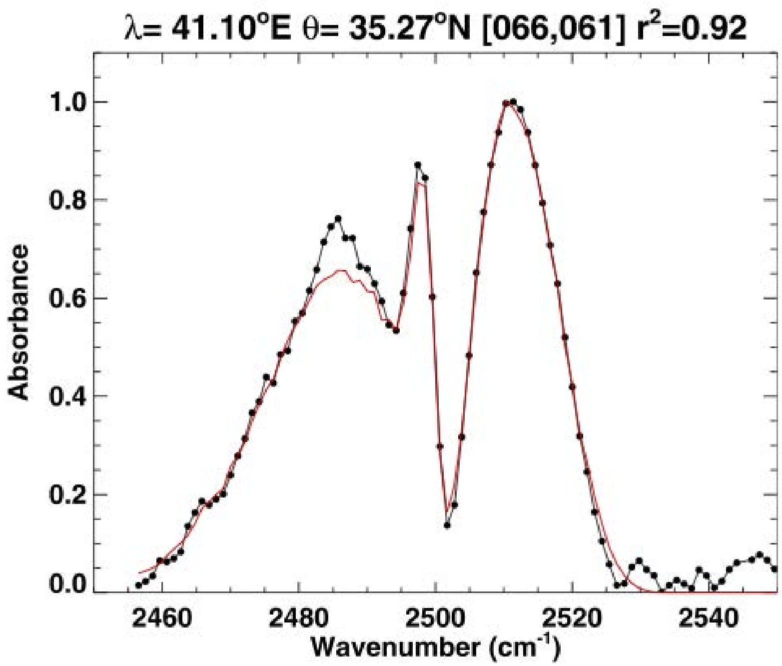


Figure 15. Spectral matching plot for the 4 μm band of SO_2. The red line shows a synthetic absorbance spectrum and the black line shows AIRS measurements. The data are for an AIRS image of the Al-Mishraq (Iraq) SO_2 plume on 25 June 2003.

Prata and Bernardo, 2007

- IR channels at ~4 μm and ~8.6 μm can detect lower tropospheric SO_2

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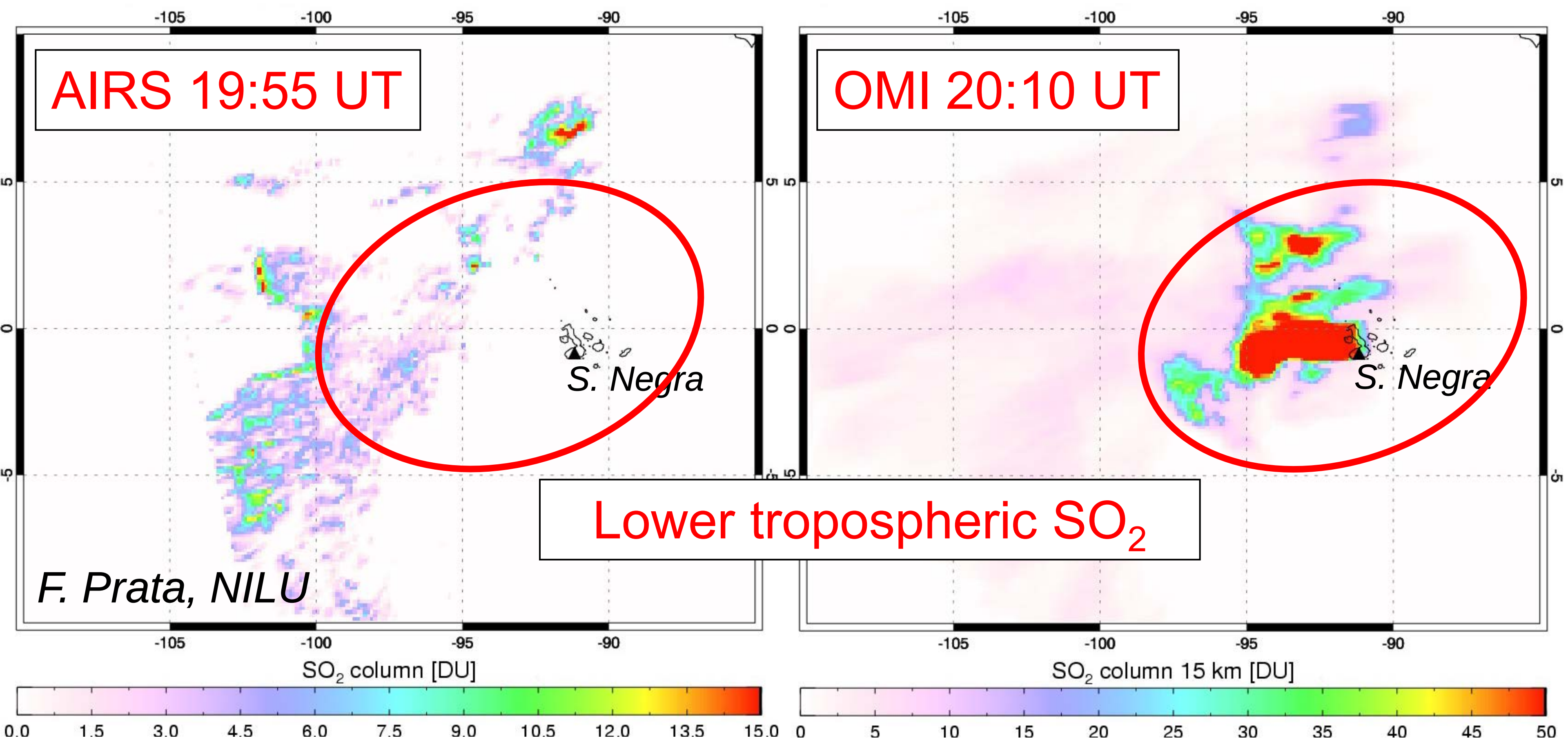
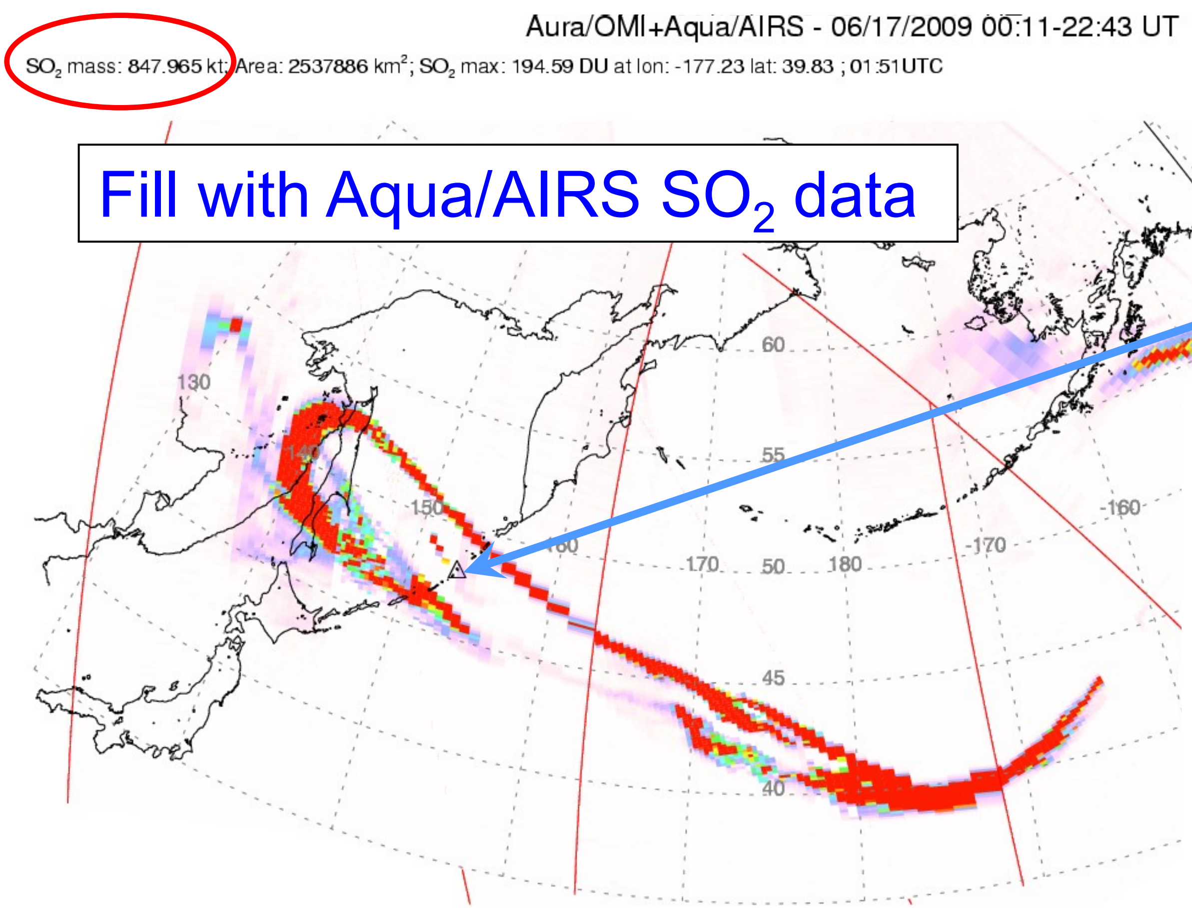
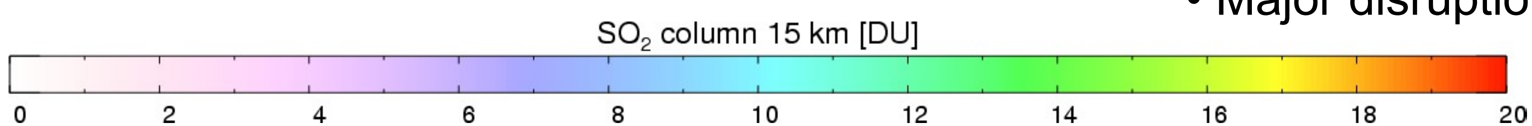
Aura/OMI - Aqua/AIRS: Sierra Negra (Galapagos) 2005



- Sierra Negra (Galapagos) eruption, October 24, 2005
- OMI-AIRS synergy indicates SO_2 concentrated in the lower troposphere
- Altitude determines climate impact of SO_2 and sulfate aerosol

Sarychev Peak (Kurile Is) eruption,



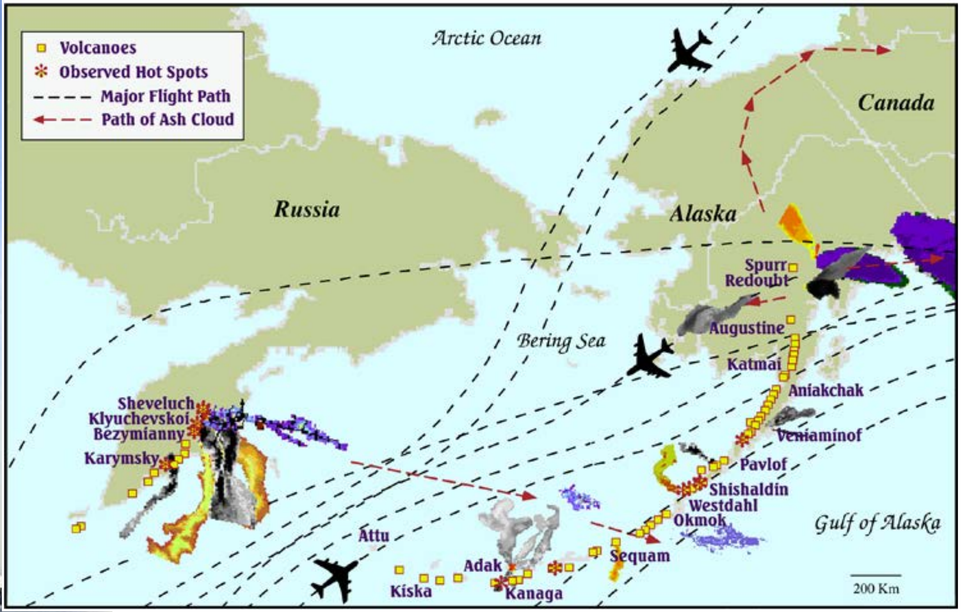


Astronaut photo from ISS, 14 June

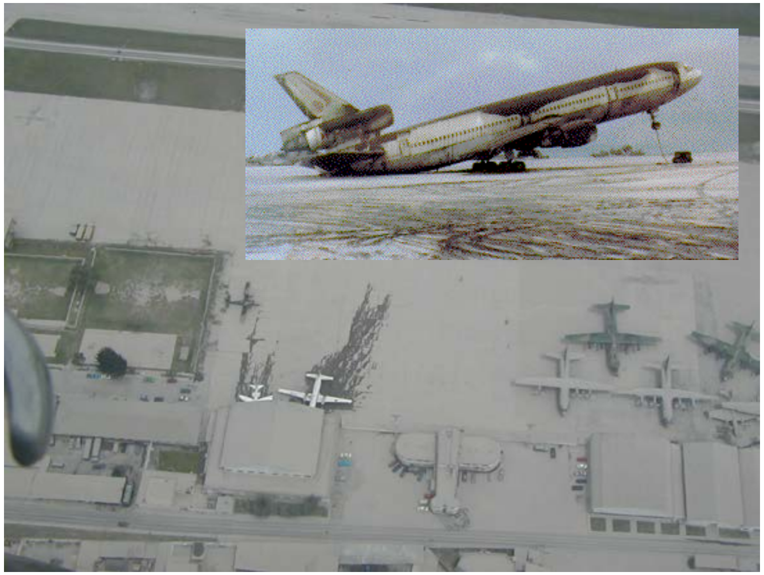
- 11-16 June 2009
- 2nd large NH stratospheric SO_2 injection (≥1 Tg) in a year, after the August 2008 Kasatochi eruption (Aleutian Is)
- Timing near summer solstice increases aerosol radiative (cooling) effect
- Major disruption to aviation

- Current OMI row anomaly creates data gaps in large volcanic eruption clouds
- A-Train synergy compensates for lost data and improves SO_2 loading measurements

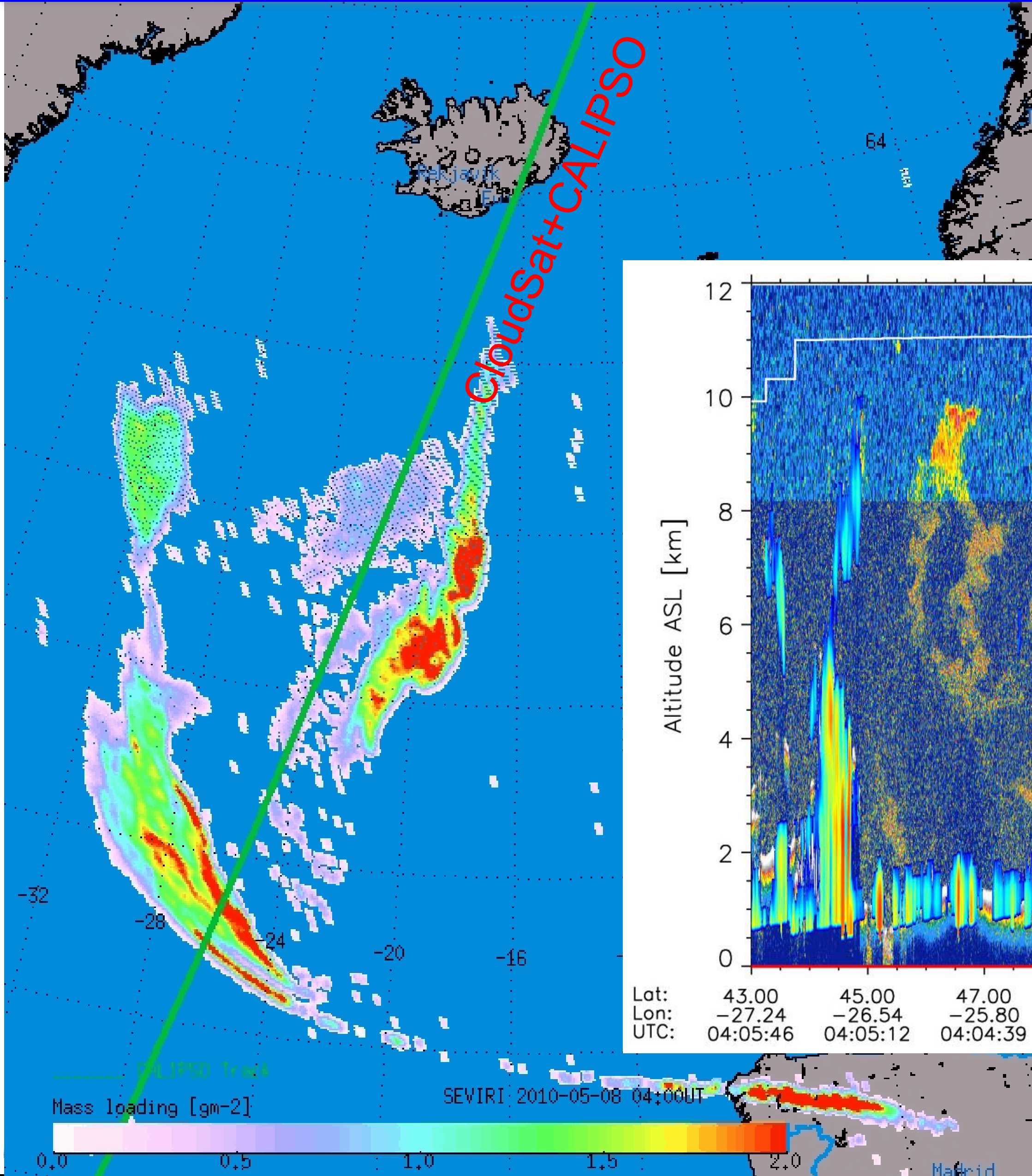
Aviation hazards from volcanic eruption clouds



- Immediate hazards
  - Engine failure due to melted ash
  - Abrasion of windshield
- Secondary hazards
  - Corrosion by ash, sulfuric acid
- Mitigation
  - Immediate detection of fresh volcanic clouds
  - Tracking/forecast of cloud position and altitude – SO_2 valuable for cloud tracking

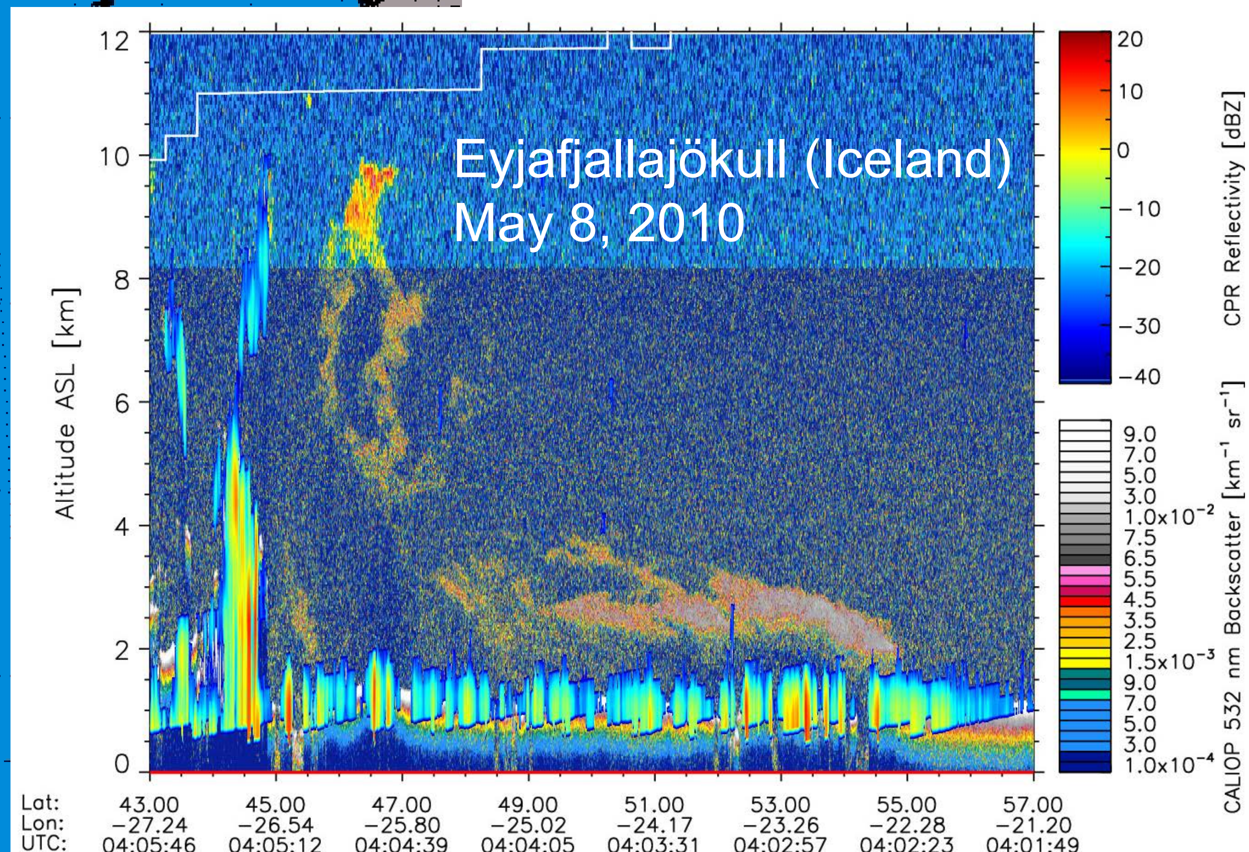


A-Train measurements of volcanic ash concentrations



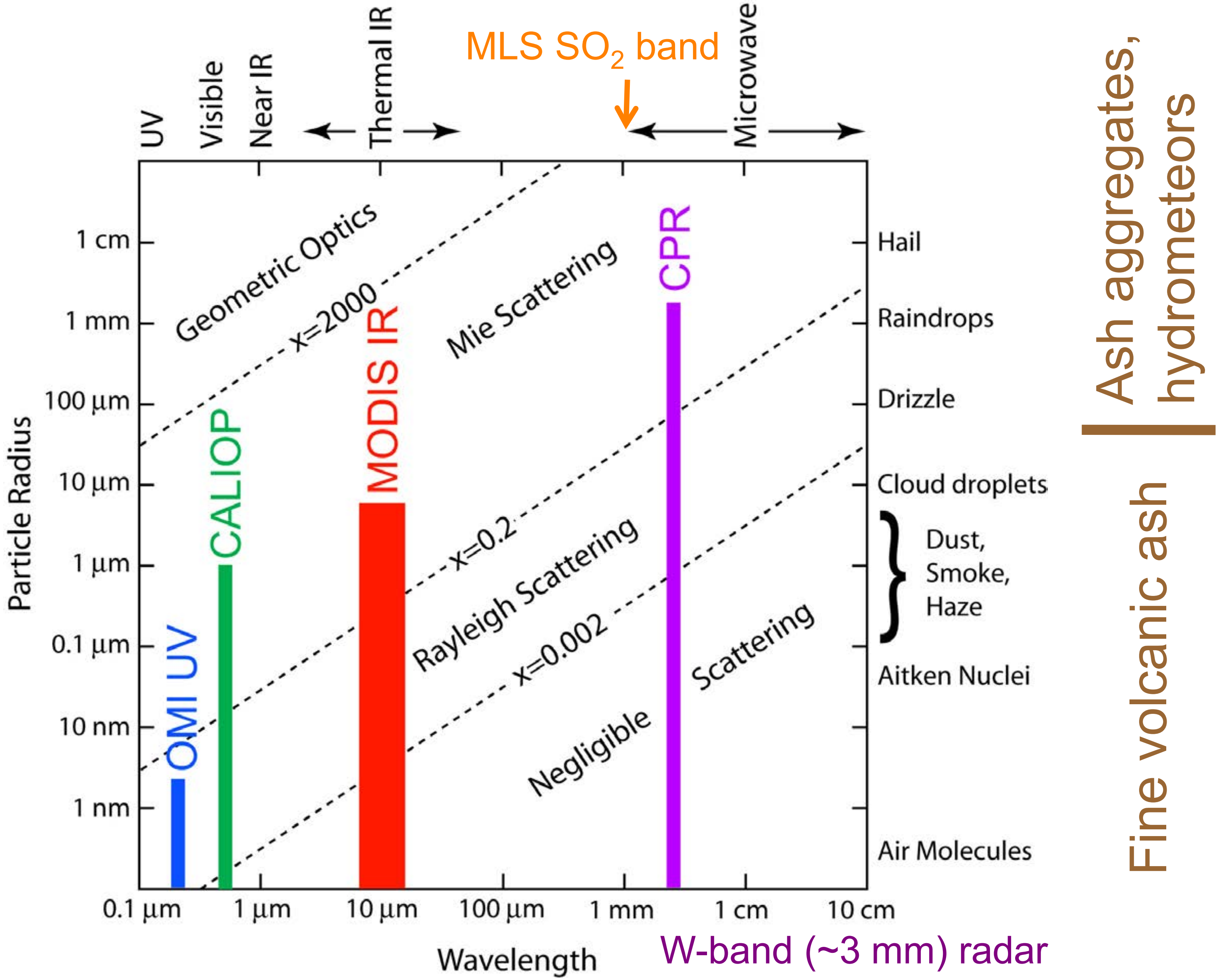
- Ash concentration =
  mass loading/thickness

- Thickness from CALIOP

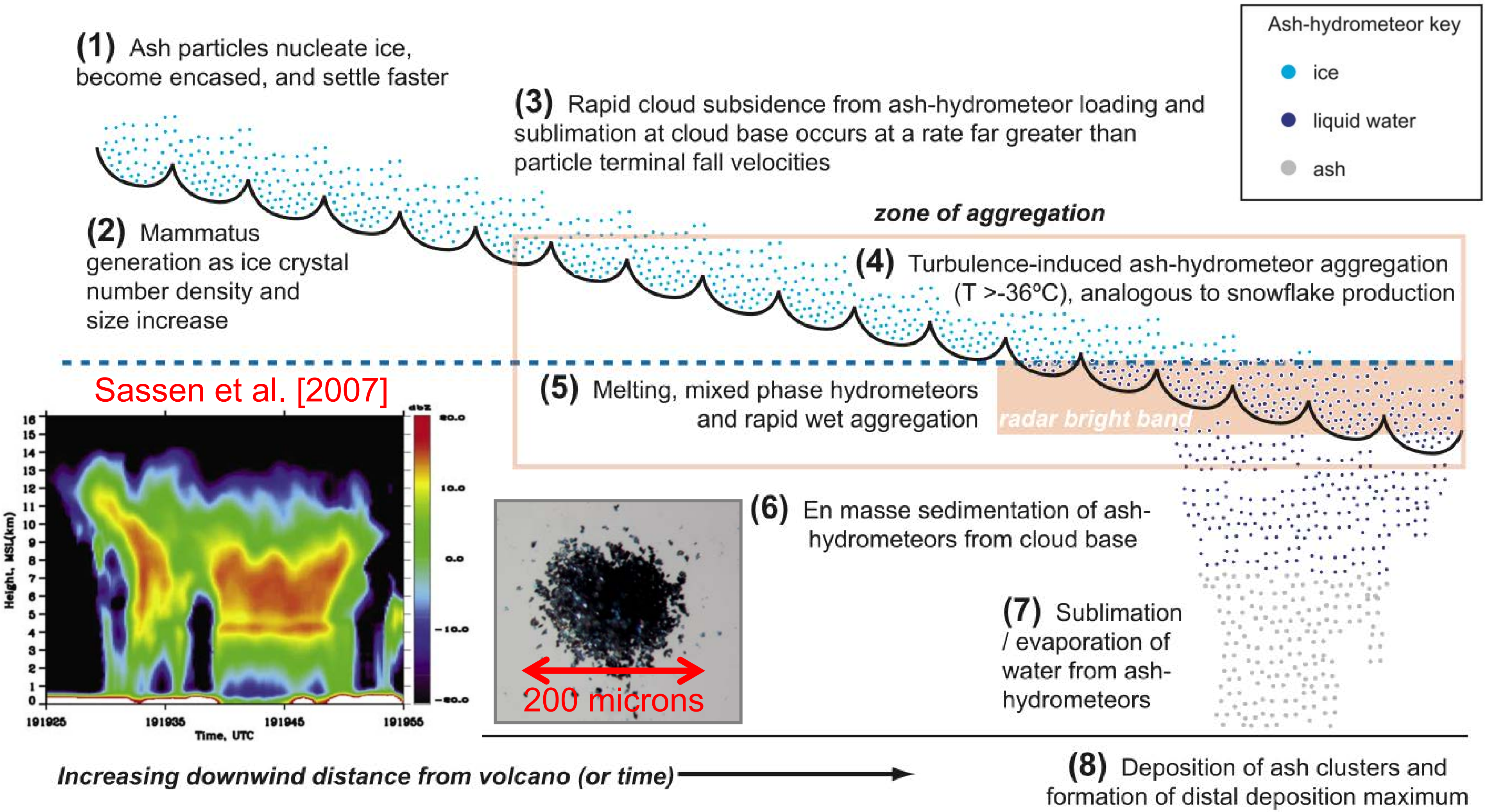


- Typical concentrations were ~2-4 mg m^{-3}

A-Train sensor synergy in volcanic clouds



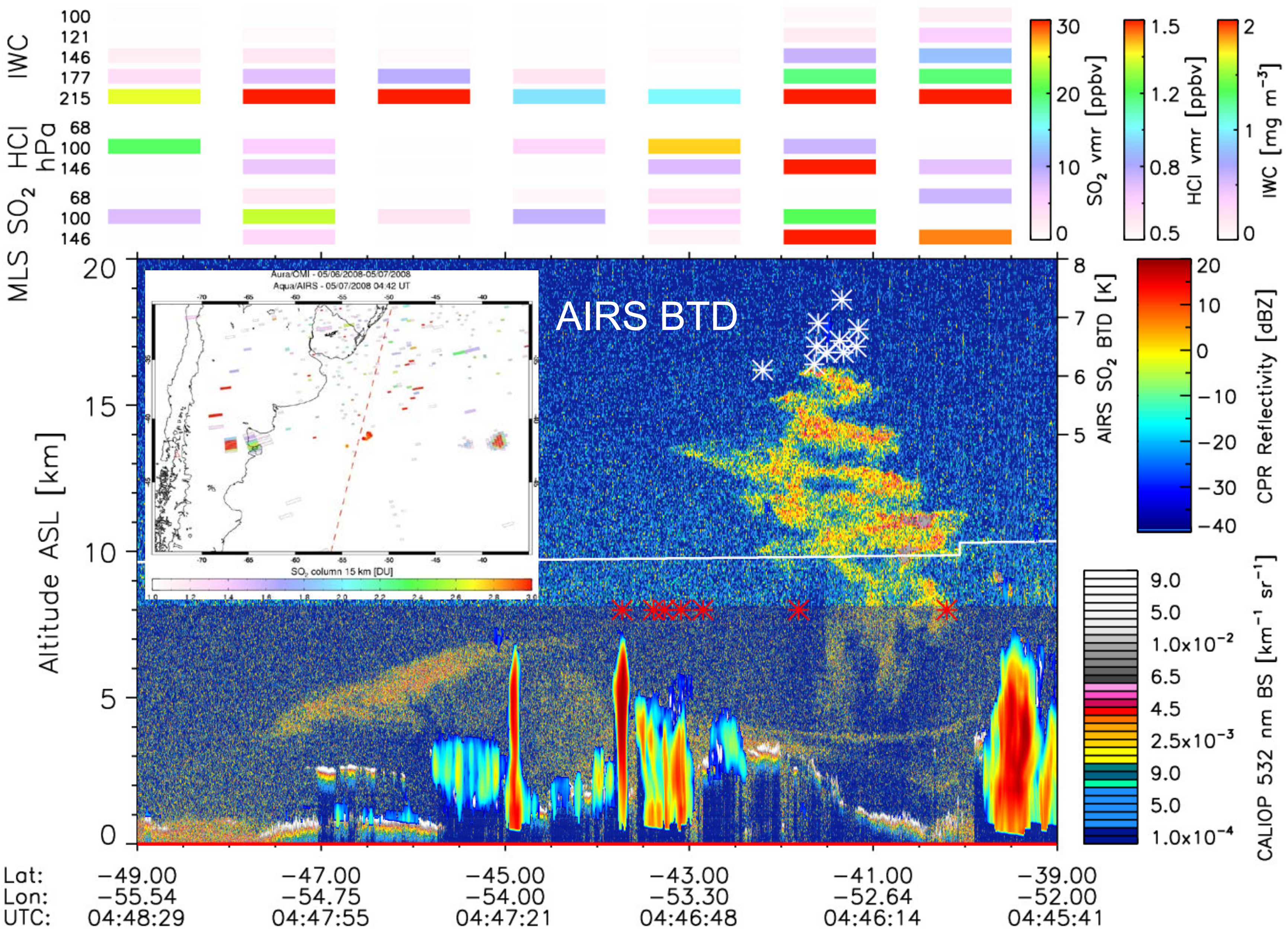
Hydrometeor-enhanced sedimentation of volcanic ash



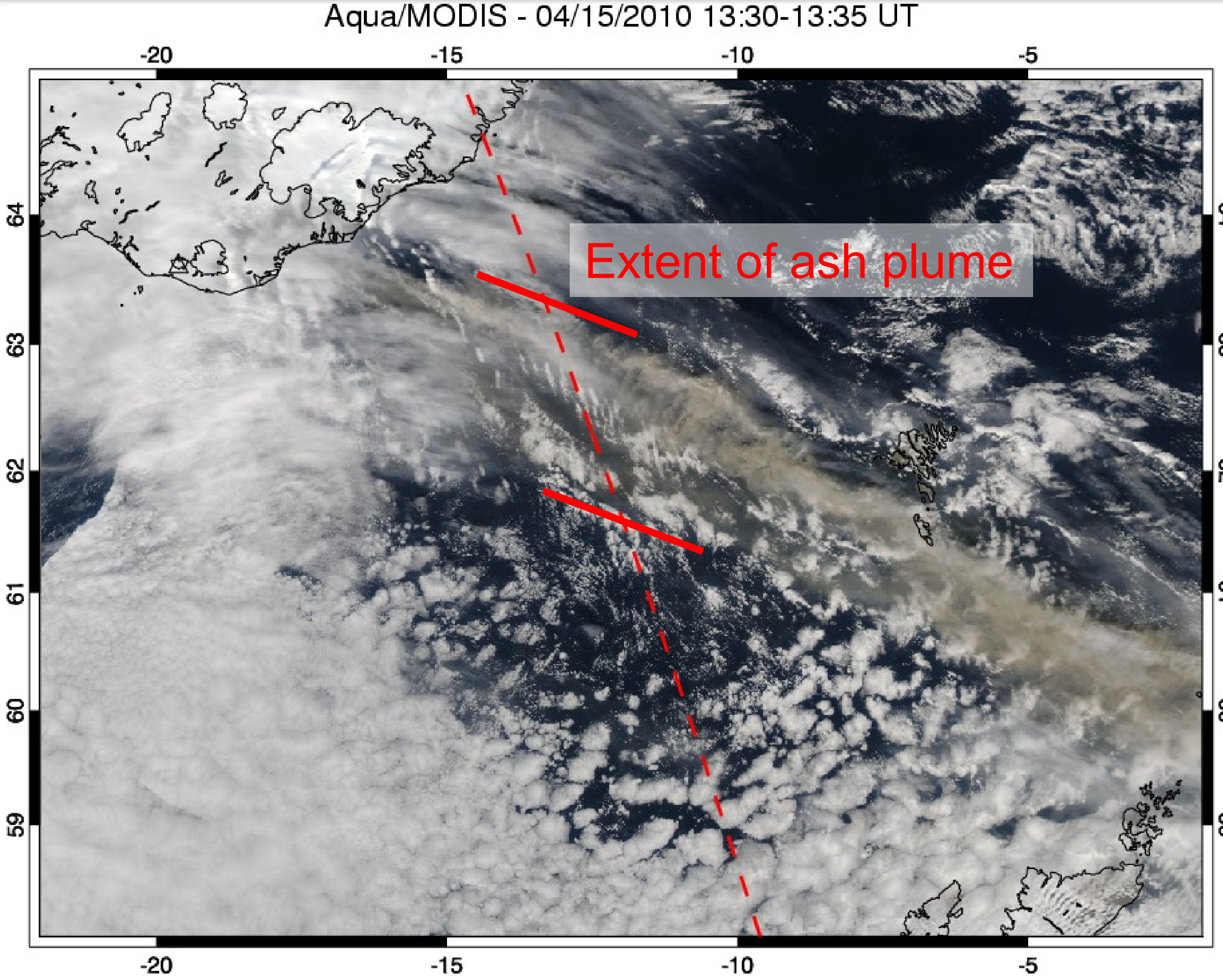
- Ash aggregation prematurely removes fine ash that would be an aviation hazard
- How do we explain secondary ash thickness maxima and ash aggregate fallout?
- Can CloudSat W-band radar detect the bright band?

[Durant et al., JGR, 2009]

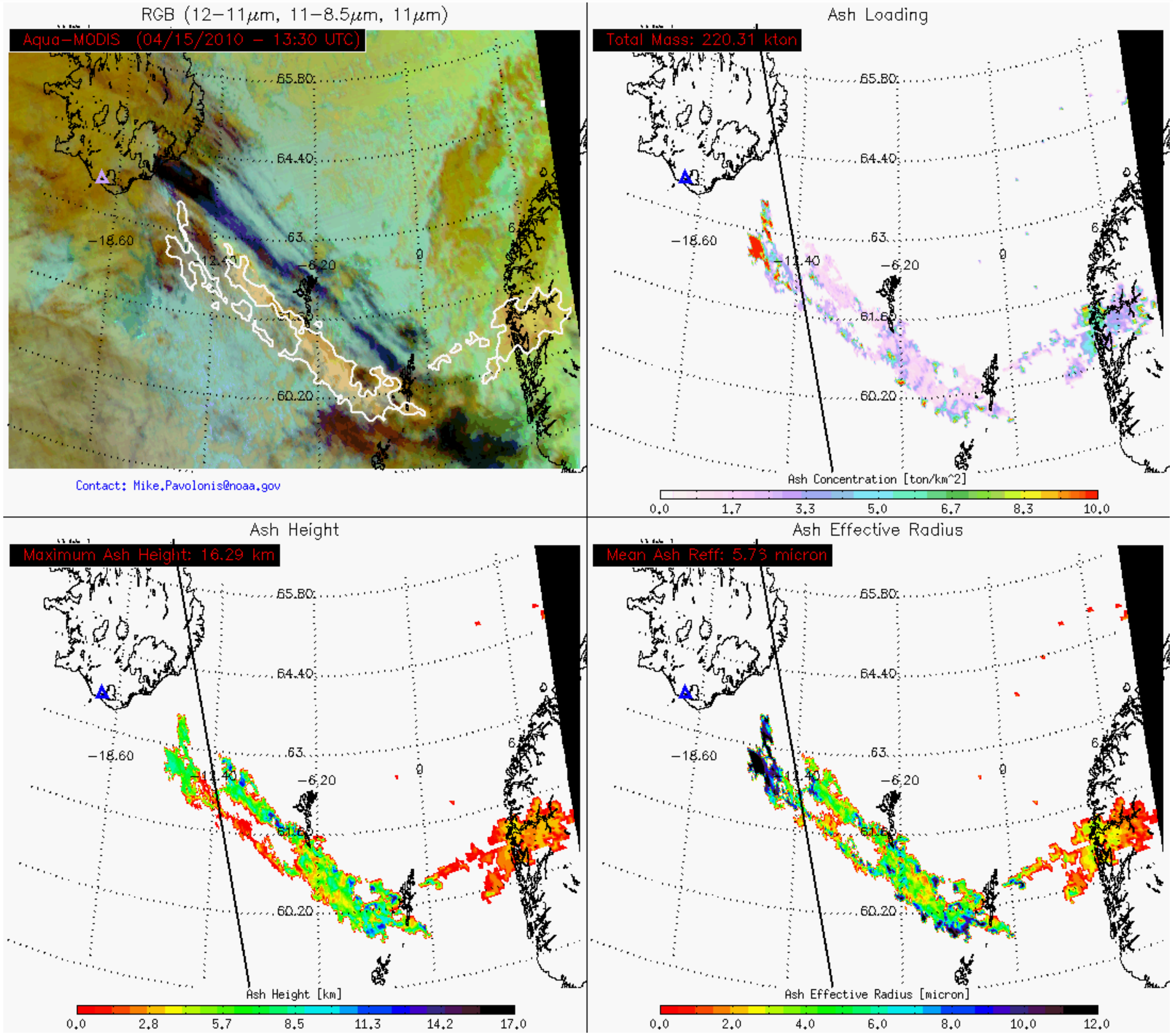
A-Train observations: Chaitén (Chile) eruption (May 7, 2008)



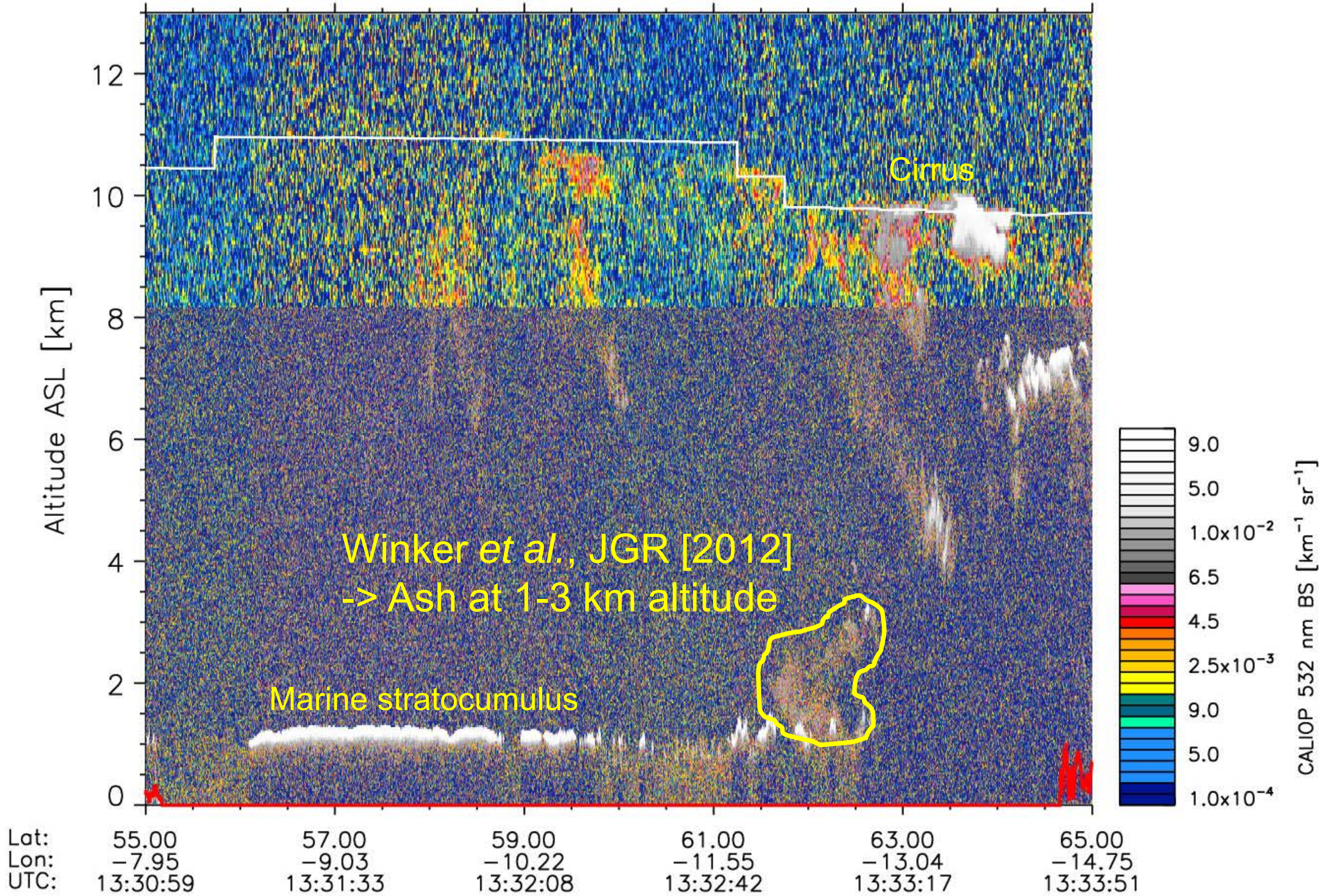
Eyjafjallajökull eruption plume (April 15, 2010) – Aqua/MODIS



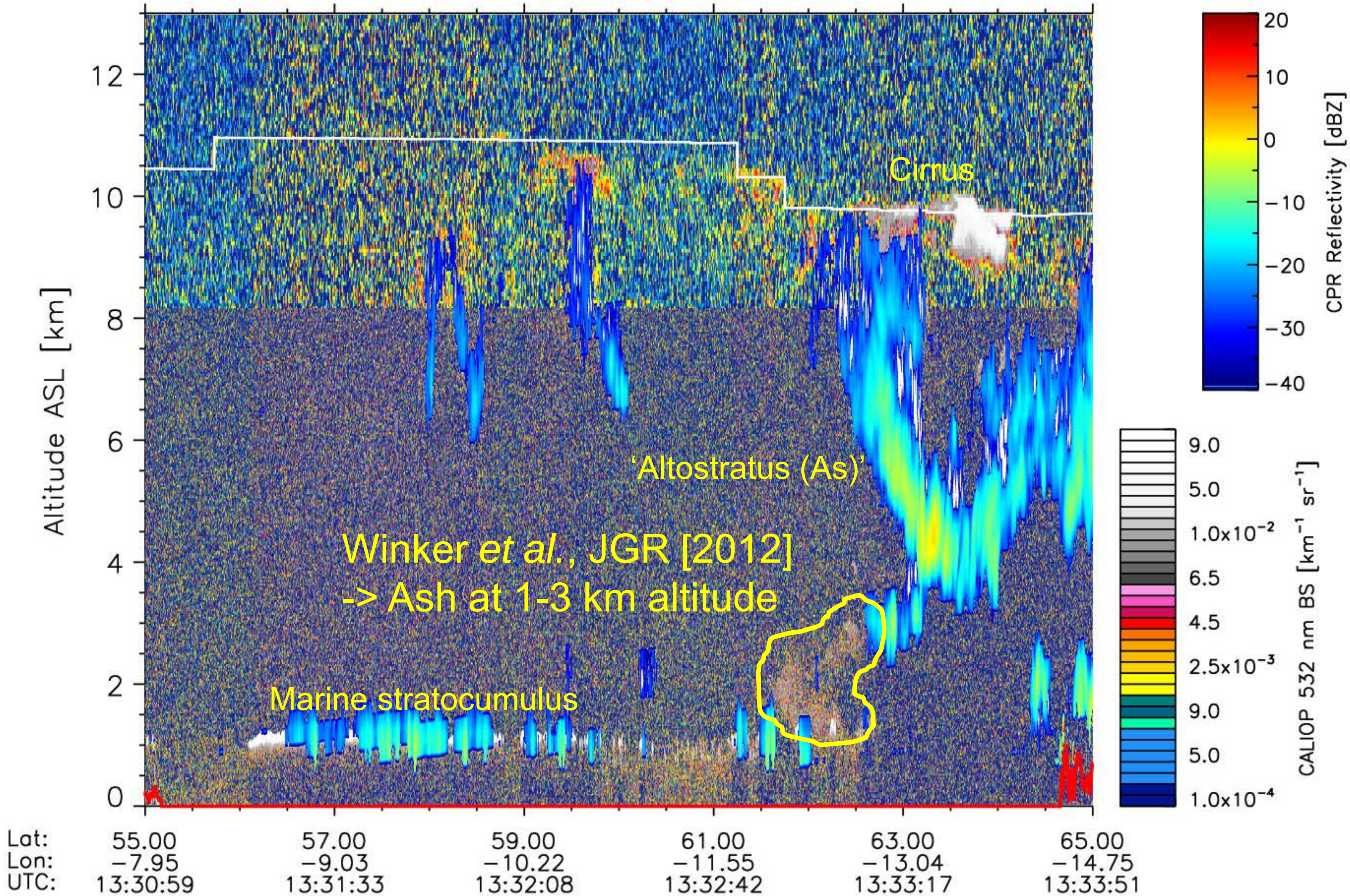
Aqua/MODIS ash retrievals (*M. Pavolonis, NOAA/NESDIS*)



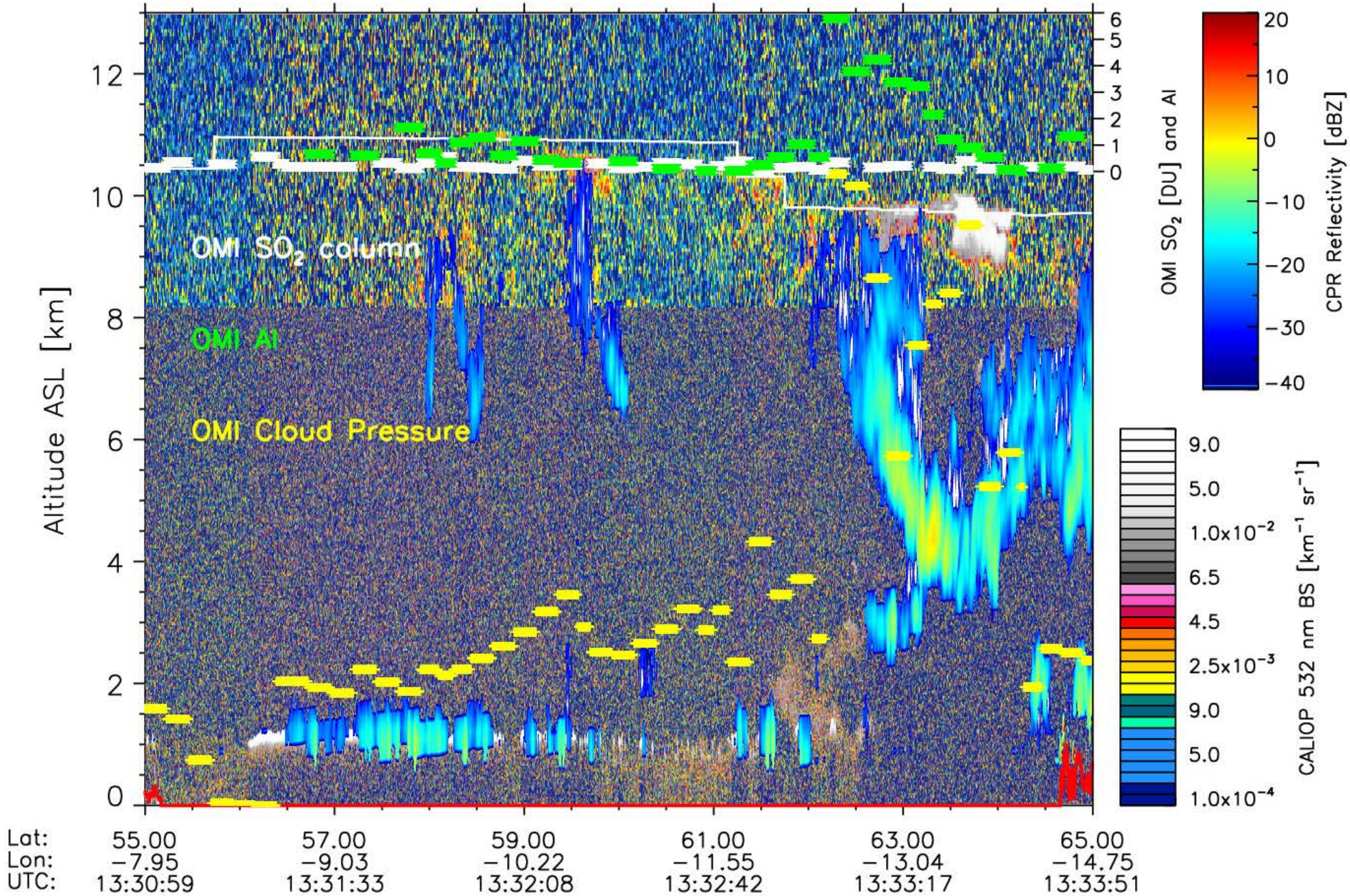
CALIPSO: April 15, 2010



CALIPSO + CloudSat: April 15, 2010



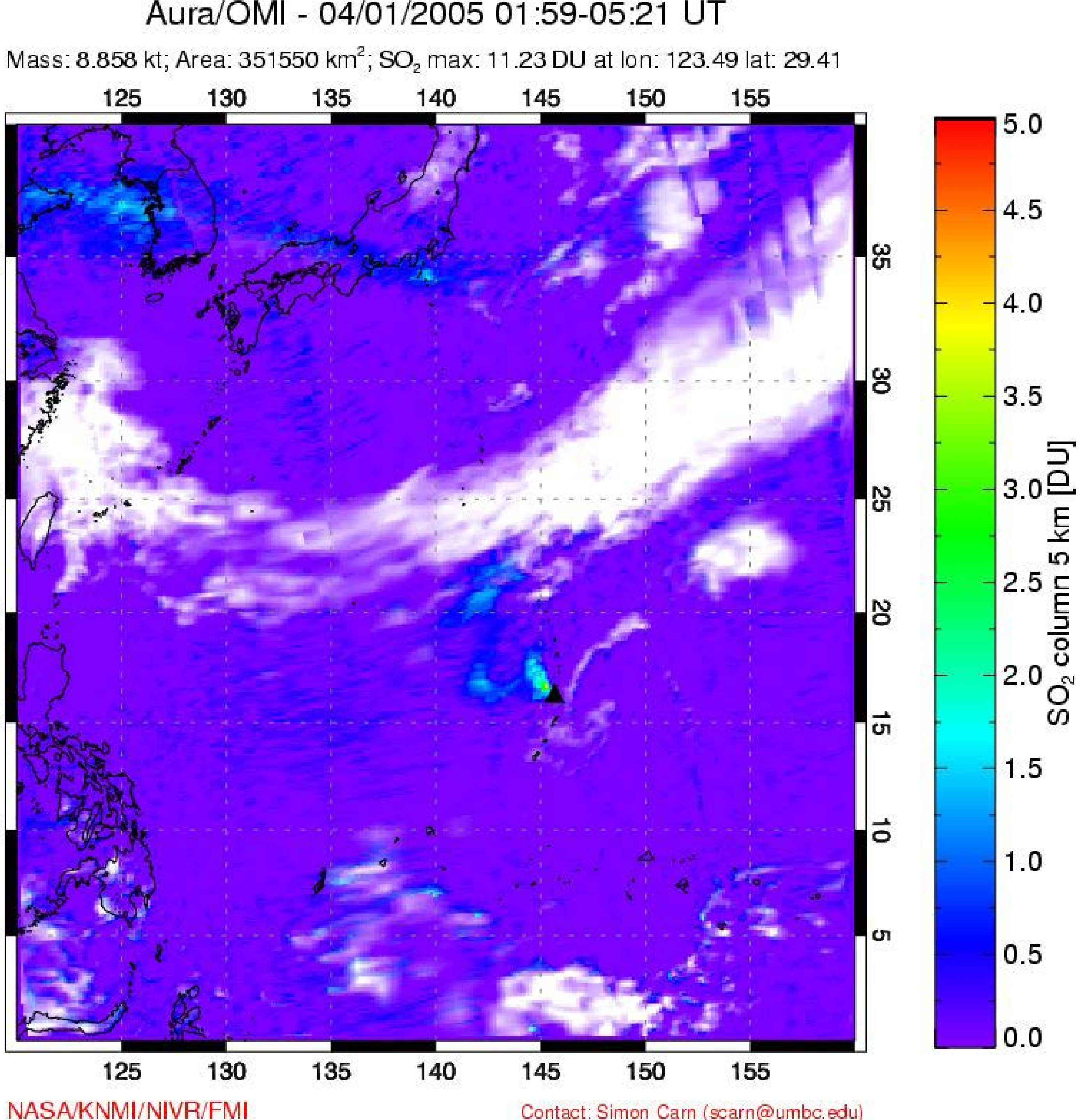
CALIPSO + CloudSat + OMI: April 15, 2010



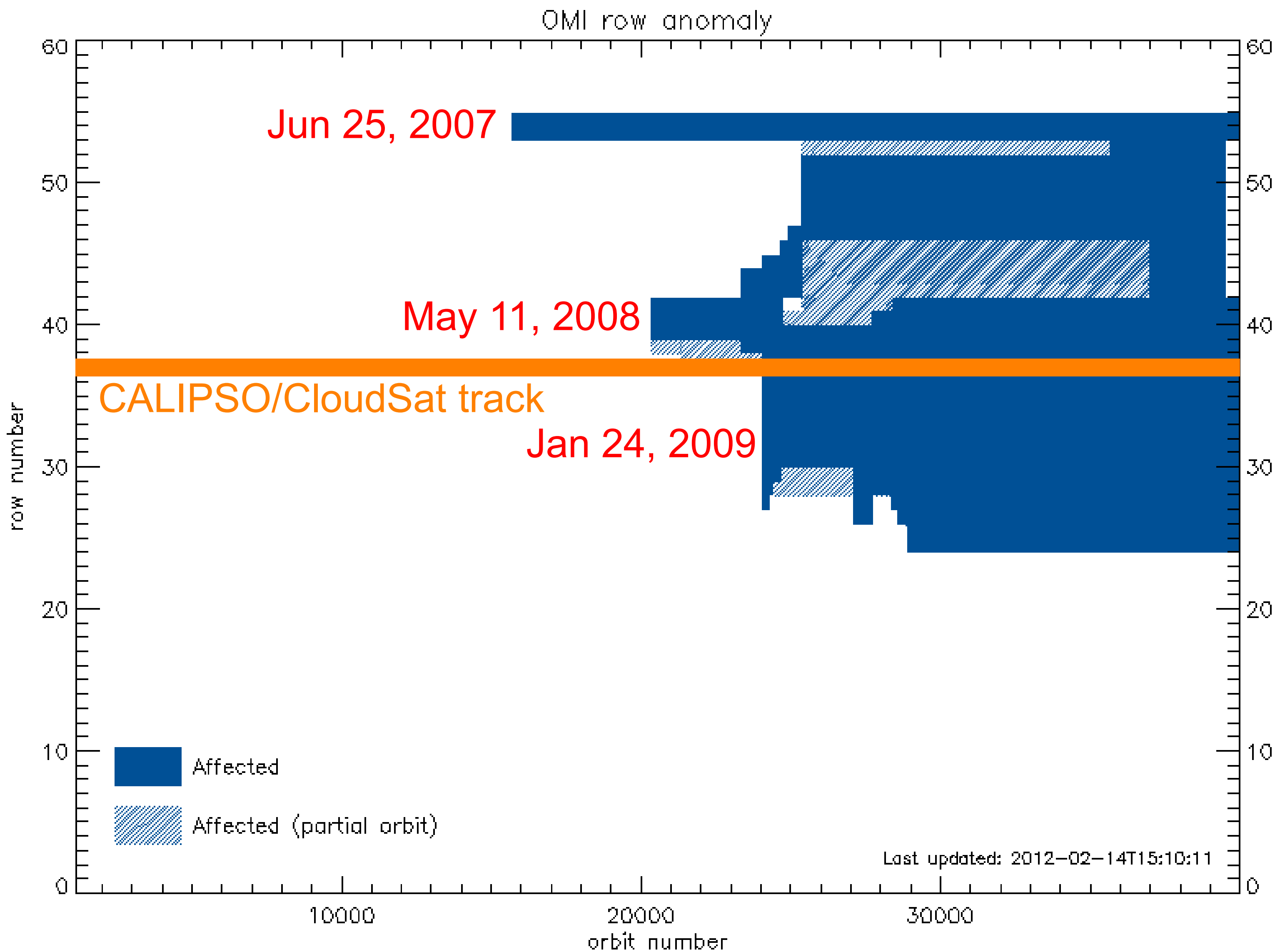
Summary

- Aura/OMI measurements of trace gases (SO_2, NO_2) are improving volcanic and anthropogenic emissions inventories
- A-Train synergy is providing unprecedented observations of the vertical distribution of trace gases, aerosols and hydrometeors in volcanic clouds and pollution outflow
- Measurements of ash cloud altitude and thickness (e.g., by CALIPSO) are of prime importance for aviation hazard mitigation
- Data latency of most A-Train products (and spatial coverage of the active sensors) is the main impediment to operational use for aviation hazard mitigation and other applications
- The A-Train greatly facilitates validation/intercomparison of satellite data products (e.g., SO_2 column measurements)

Acknowledgments:

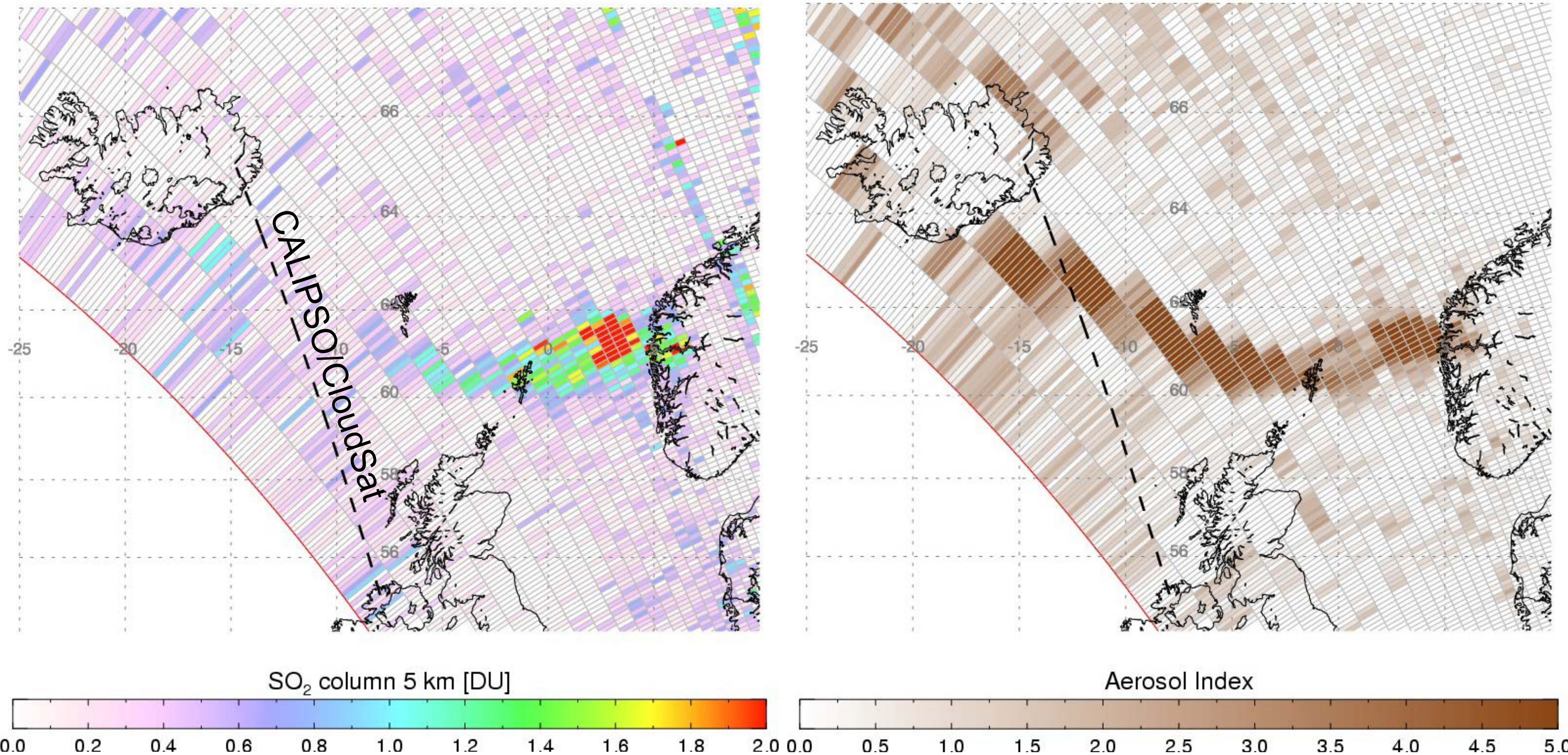

Aura/OMI - 04/01/2005 01:59-05:21 UT
Mass: 8.858 kt; Area: 351550 km²; SO₂ max: 11.23 DU at lon: 123.49 lat: 29.41
125 130 135 140 145 150 155
35 30 25 20 15 10 5
5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
SO₂ column 5 km [DU]
NASA/KNMI/NIVR/FMI
Contact: Simon Carn (scarn@umbc.edu)

Ozone Monitoring Instrument (OMI) row anomaly



http://www.knmi.nl/omi/research/product/rowanomaly-background.php

Eyjafjallajökull eruption plume – April 15, 2010

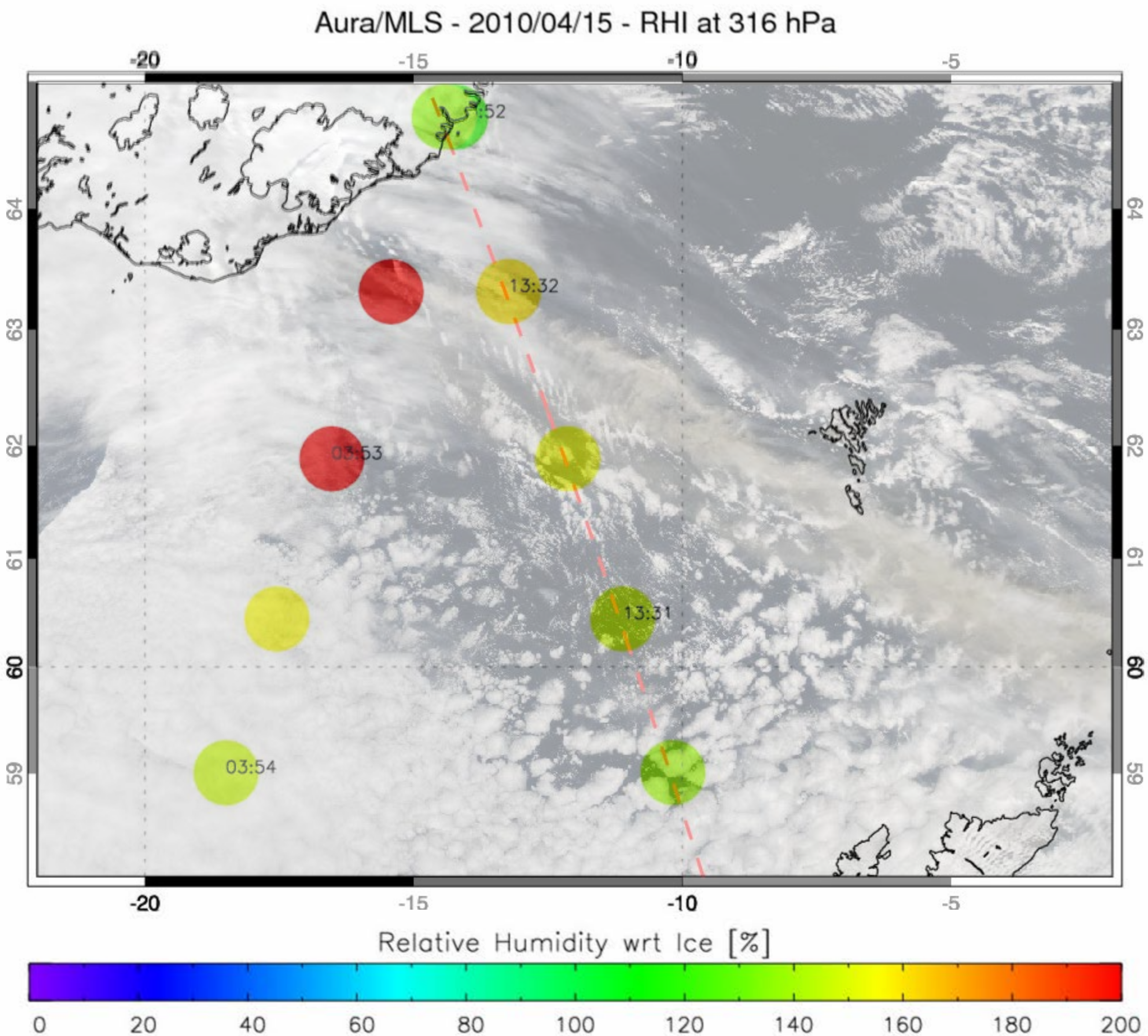


OMI SO_2 column

OMI Aerosol Index

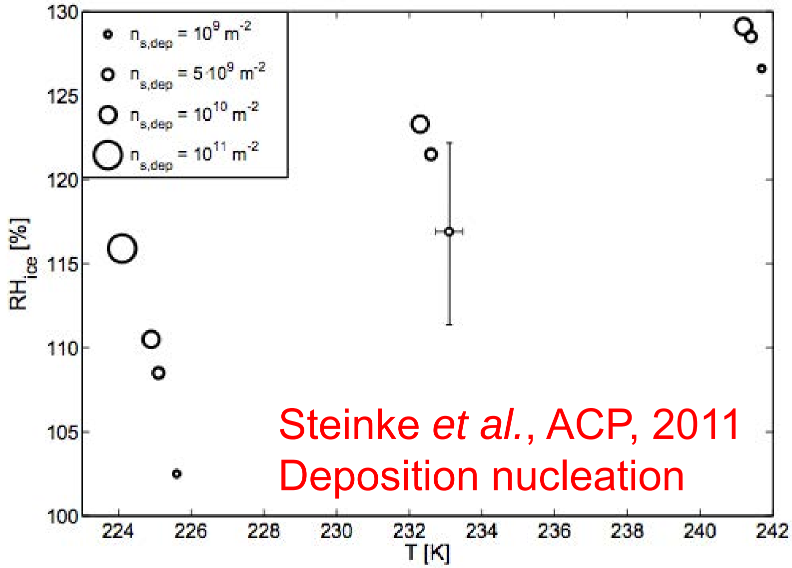
- NB: OMI row anomaly coincides with CALIPSO/CloudSat track

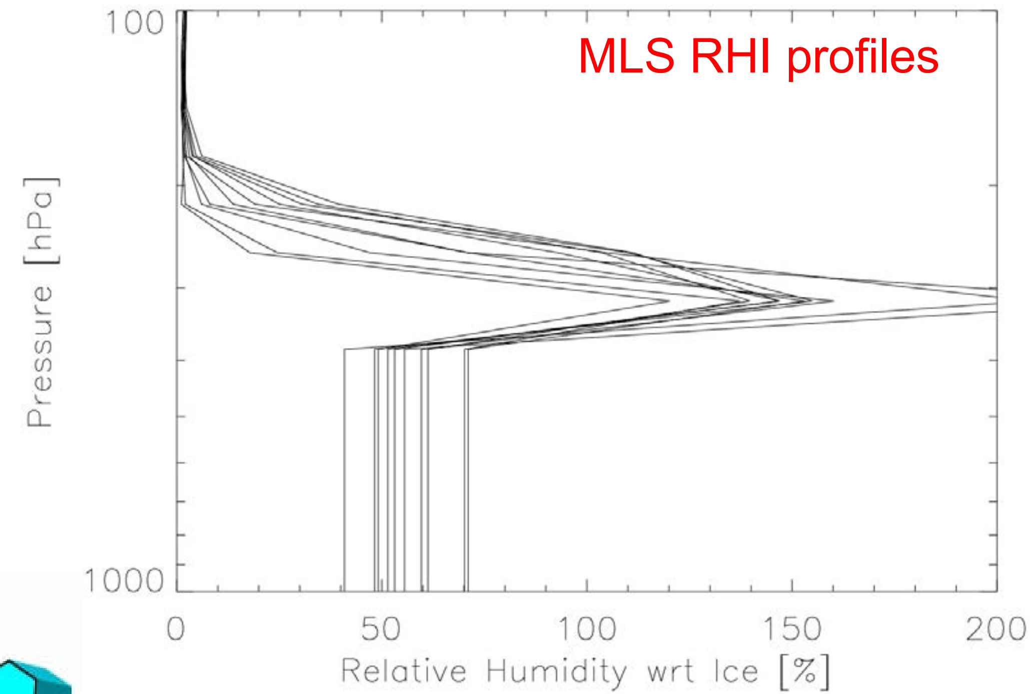
Relative humidity wrt ice (RH_{ice}) from Aura/MLS

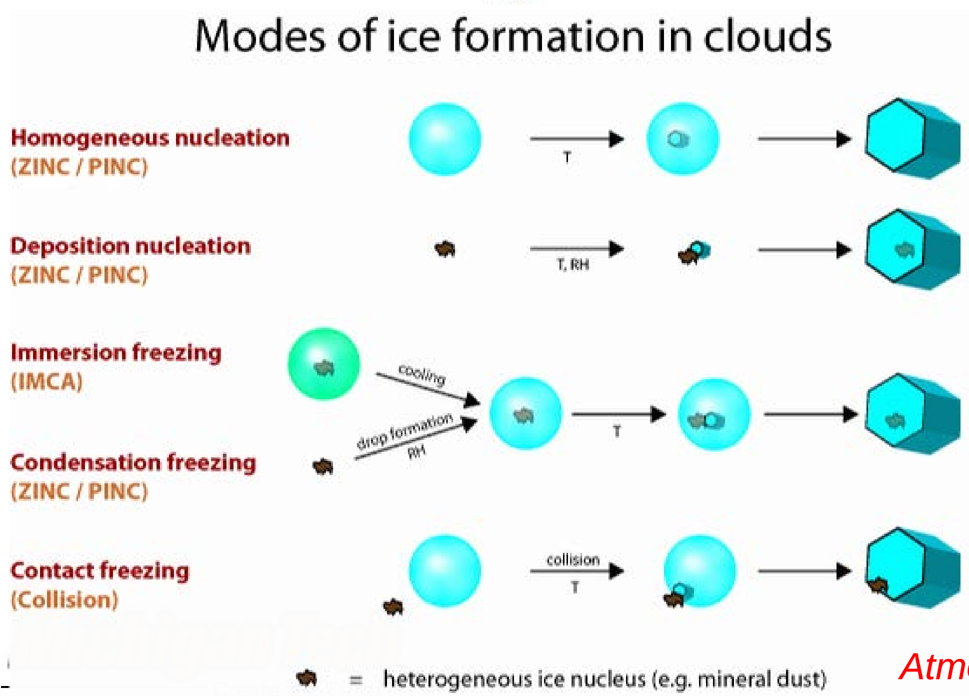


MLS RH_{ice} is derived from Temperature and H_2O data and the Goff-Gratch equation

Conditions for ice nucleation



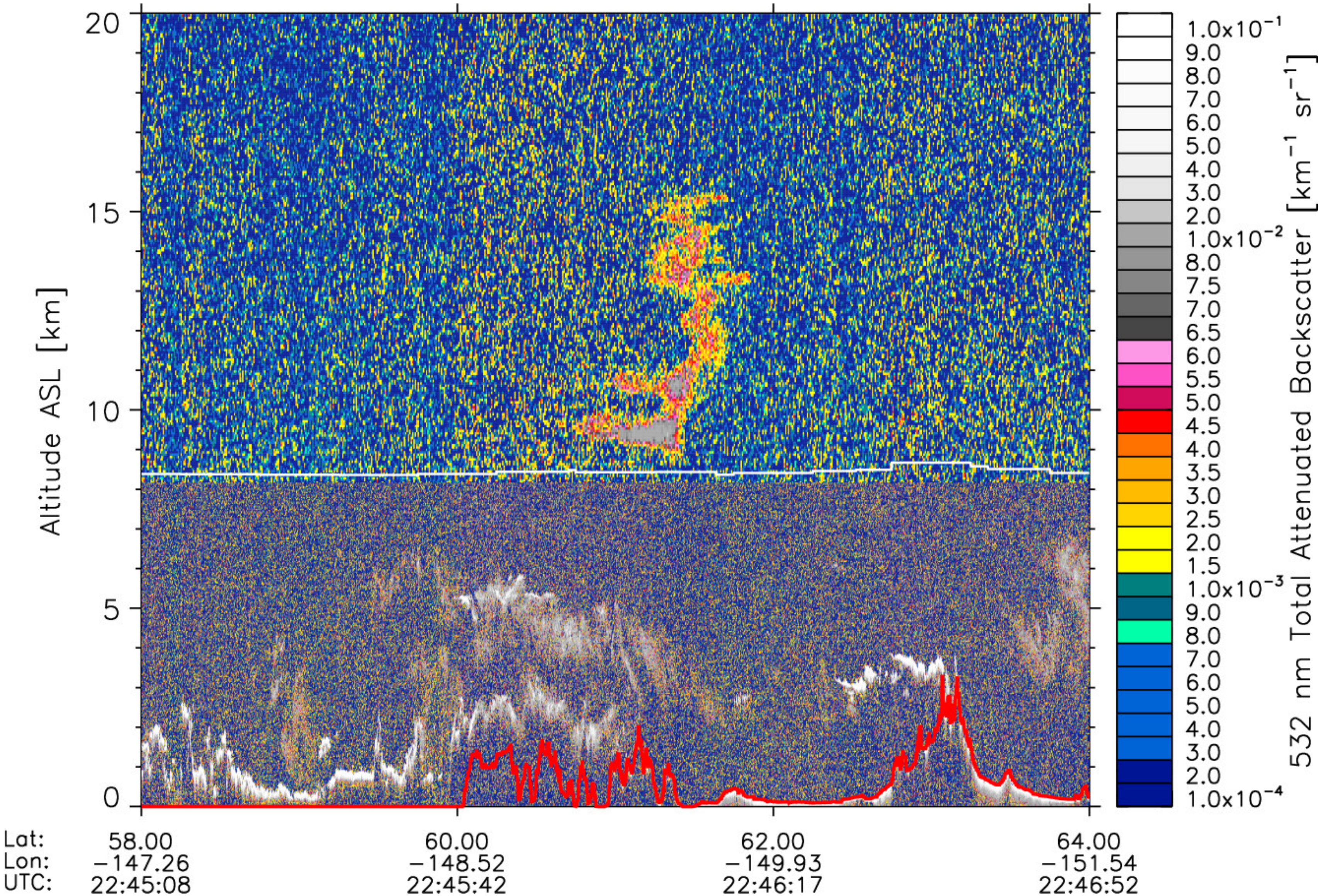




- Conditions in CPR feature:
  - T = ~210-260 K
  - RH_{ice} = 150-160% at 316 hPa (~8-9 km altitude)

Atmospheric Physics Lab, ETH, Zurich

Redoubt volcanic cloud ~5 hours after eruption (CALIOP)



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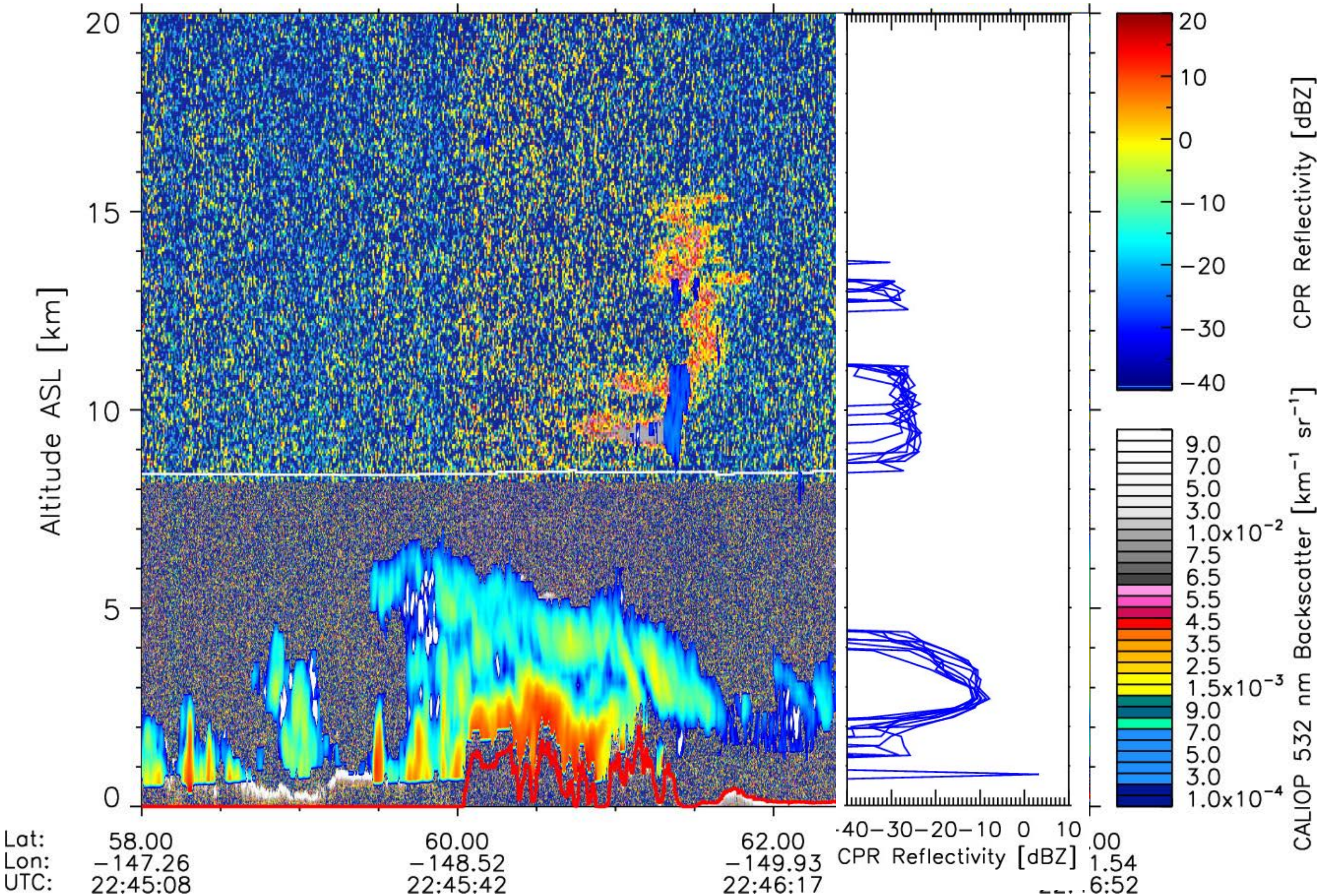
March 26, 2009, 22:45 UTC

Redoubt volcanic cloud ~5 hours after eruption (CALIOP+CPR)



March 26, 2009, 22:45 UTC

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CALIPSO first light – Soufriere Hills volcanic cloud