New discoveries enabled by OMI SO_2 measurements

N. Krotkov [1,2] , K. Yang [1,2] , A.Krueger[3], C. Lee [4], R. Martin [4], S. Carn [5] , J. Witte [6,2], K. Pickering [2] , C. Li [7,2], R. Dickerson [8], C. Wei [9], G. Carmichael [9], D. Streets [10], Q. Zhang [10]

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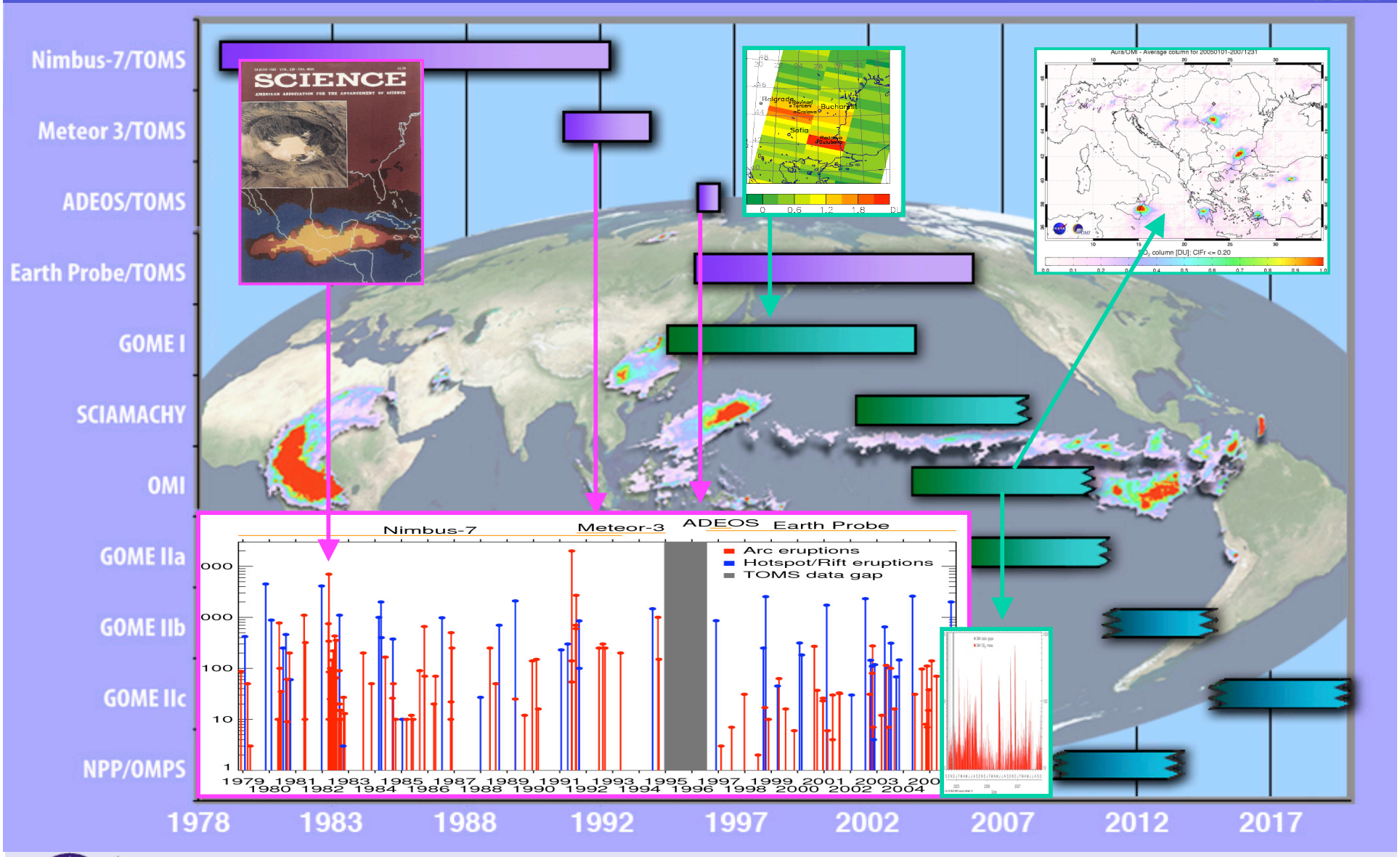
AURA ST meeting, Leiden, Netherlands, September 16, 2009

OMI continues TOMS 25+ years volcanic SO_2 data set with ~100 times enhanced sensitivity



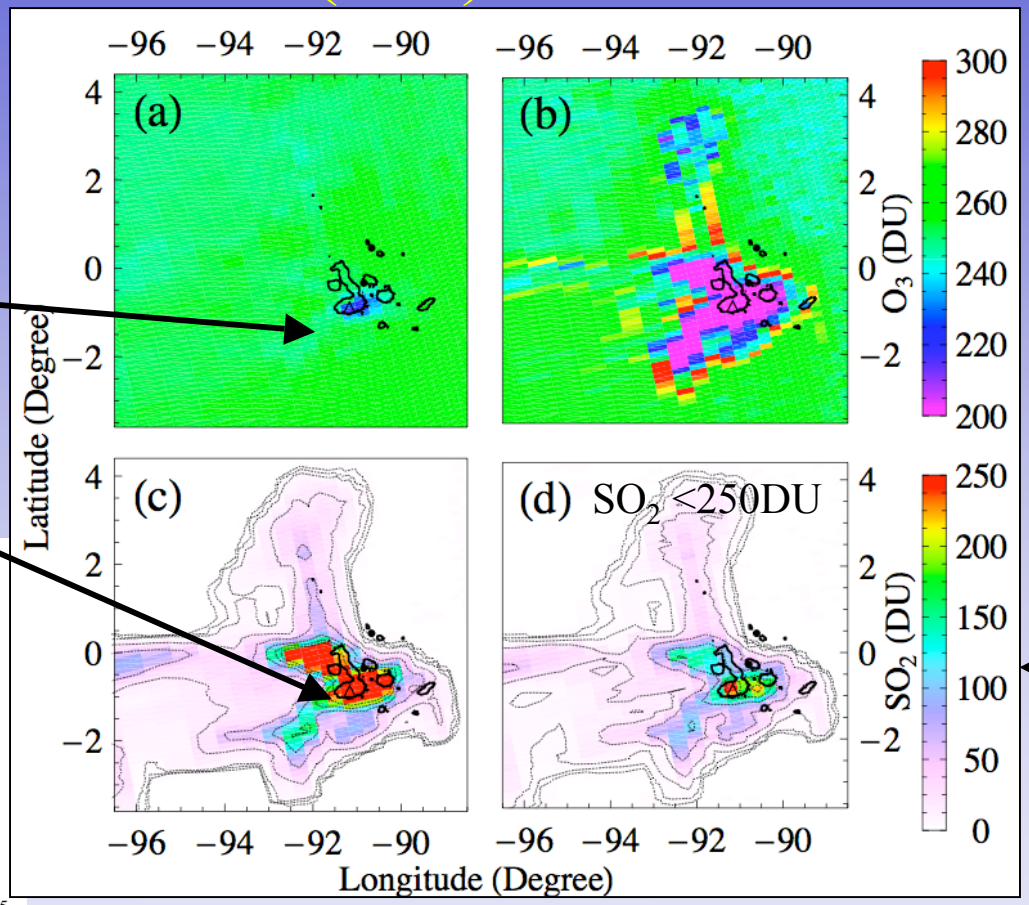
[A. Krueger 1983; 1995; 2005;2009; S. Carn 2003;2008-2009; K. Yang 2007; 2009ab]

NEW Combo SO_2 and O_3 algorithm: Iterative Spectral Fit (ISF) [K. Yang, GRL 2009a]

NEW (ISF) Operational alg

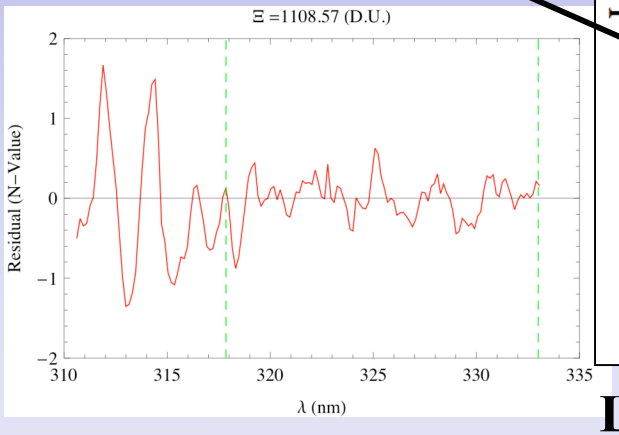
Ozone Consistency: Inside and Outside of the Plume

High SO_2 >1000DU



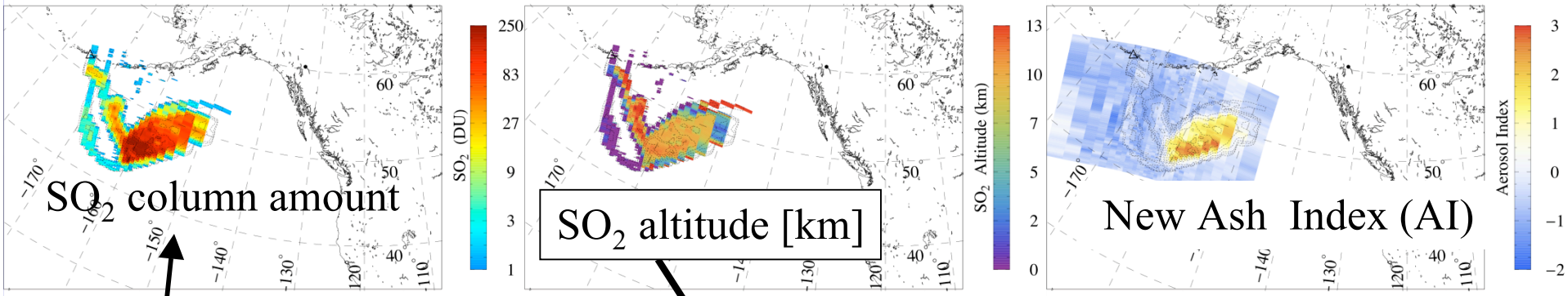
← O_3

← SO_2

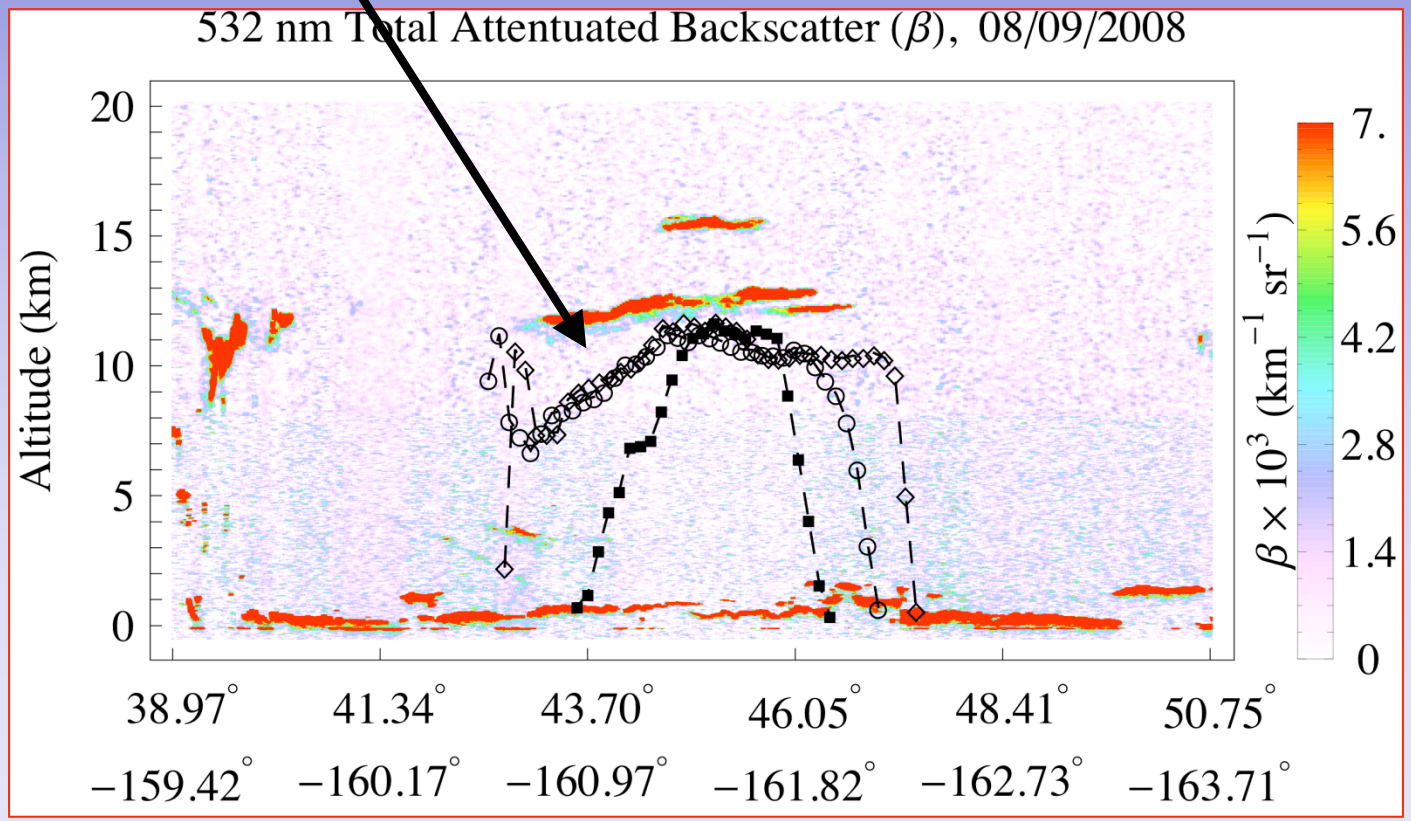


Low altitude effusive eruption of Sierra Negra volcano, Galapagos Islands on October 23 2005

Simultaneous O_3, SO_2 loading and altitude retrieval extended Iterative Spectral Fit (EISF) [K. Yang, GRL 2009b]

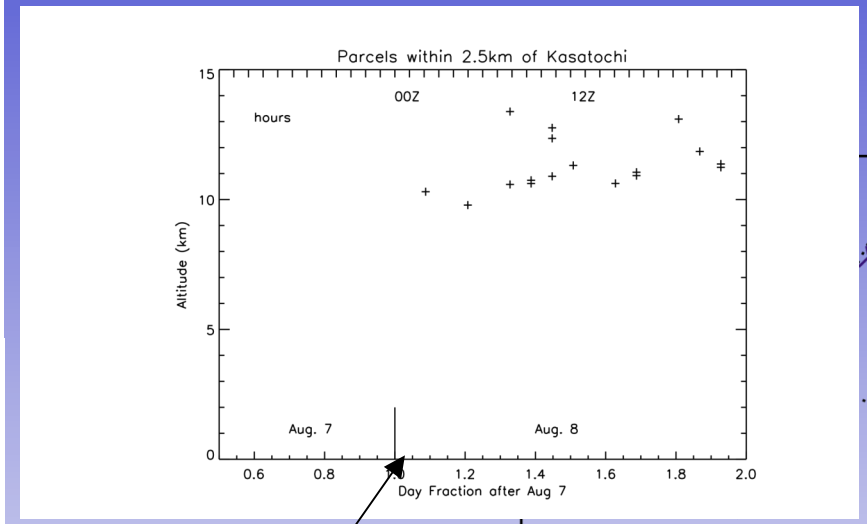


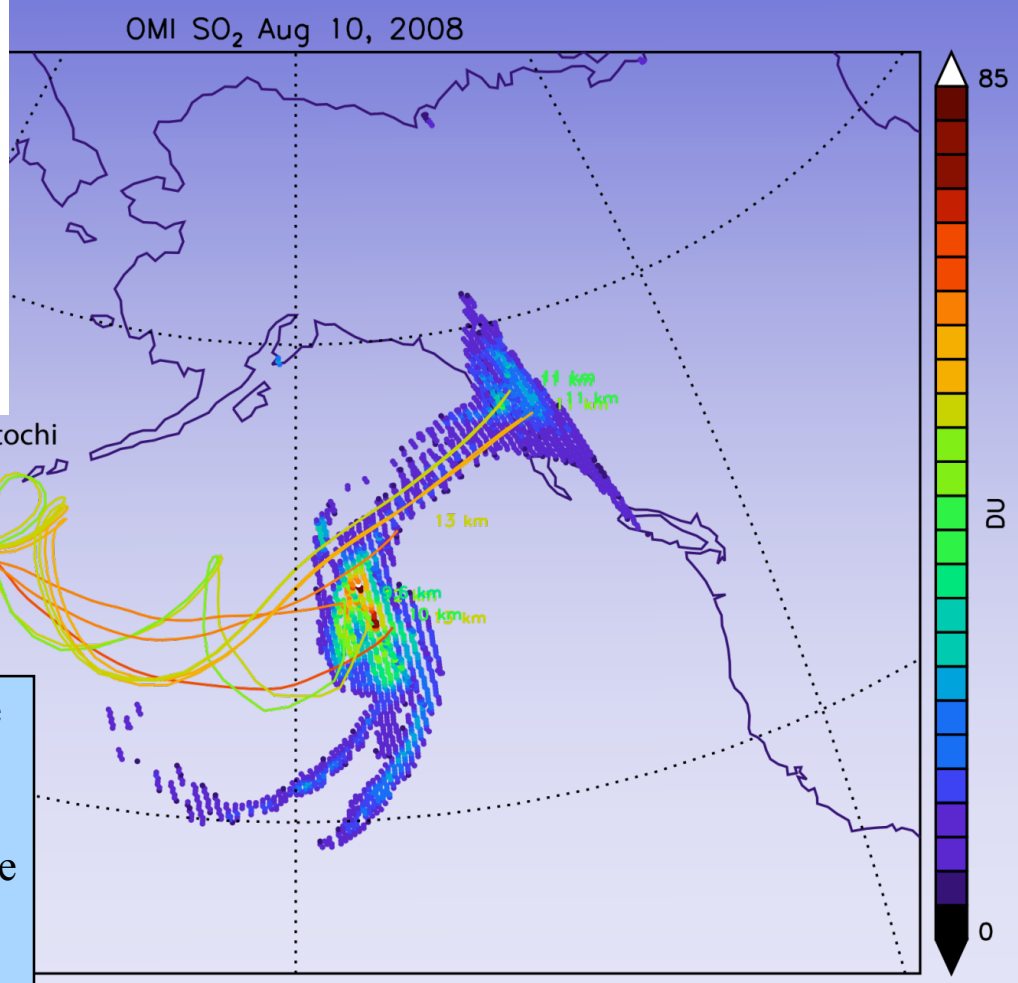
Mt. Kasatochi eruption plume on August 10 2008



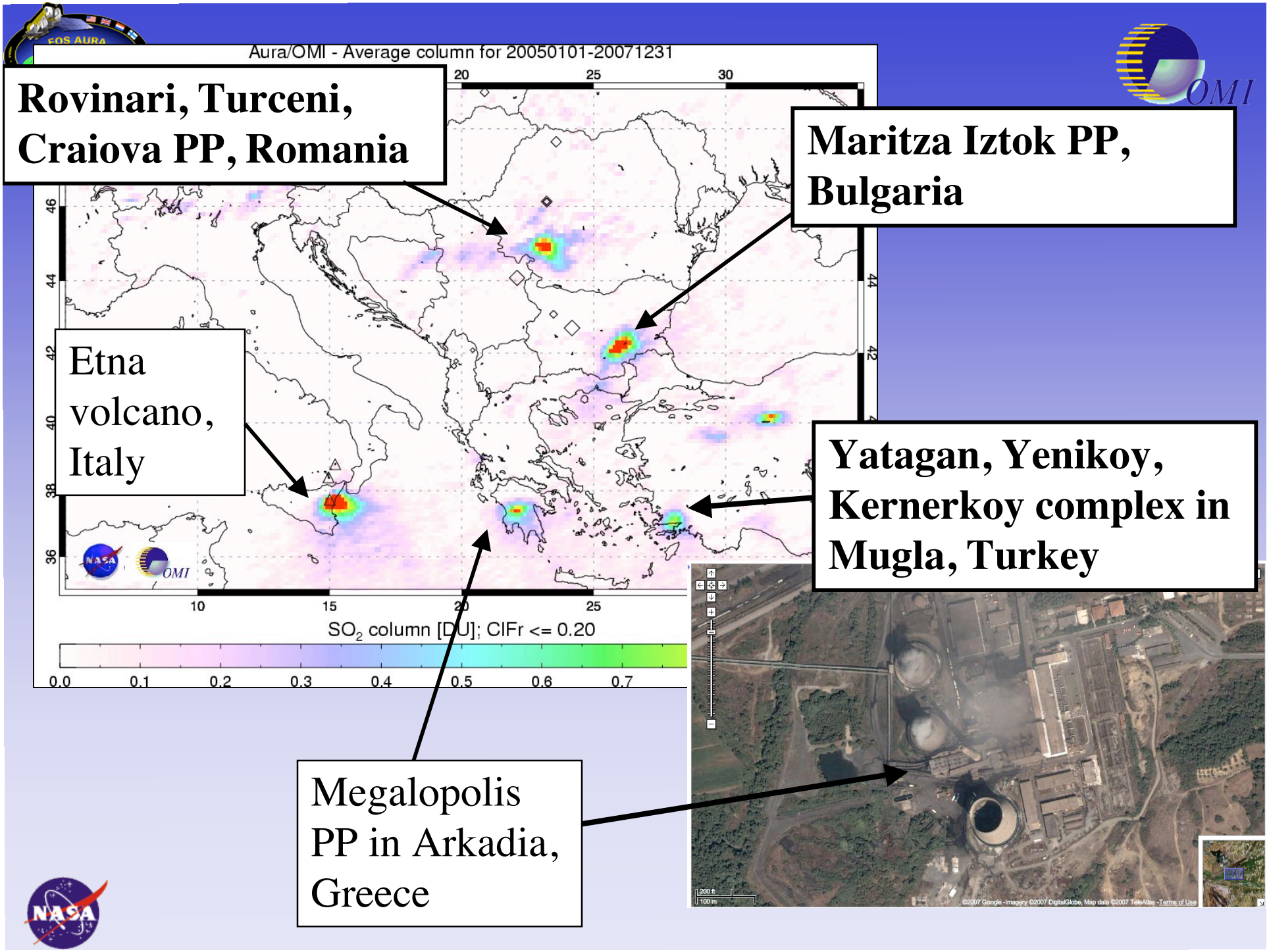
OMI retrievals and inverse modeling of the Kasatochi SO_2 cloud: Implications for accurate transport modeling of volcanic clouds

Mark Schoeberl, et al. see Poster

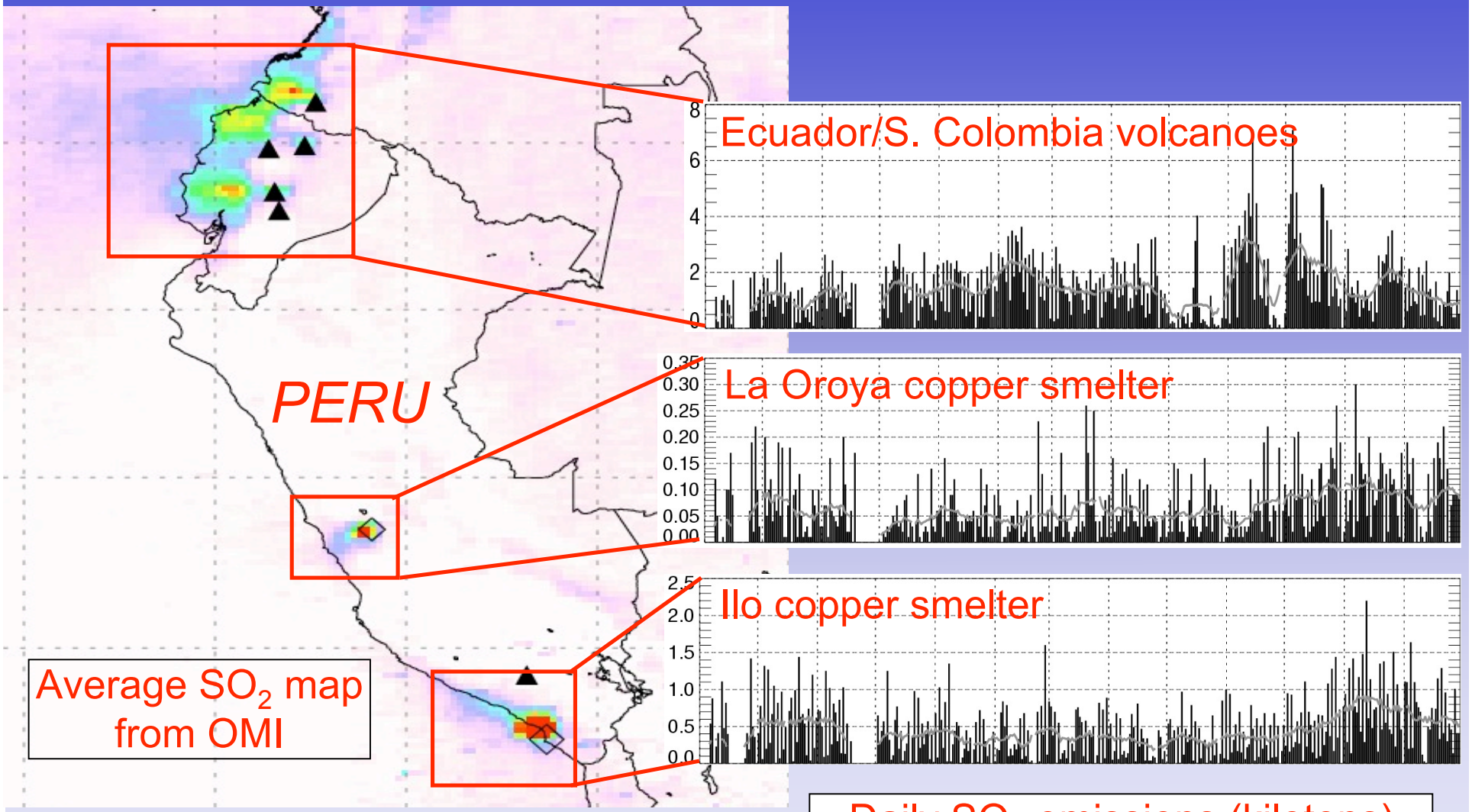




The arrivals time to Kasatochi island vs. altitude from a back trajectories starting on August 10, 2008. UTC times are after August 7 with hours shown at the top. The calculation shows that the ~10 km plume initiated shortly after 1 am on August 8 and a ~13 km plume was initiated about seven hours later,


Aura/OMI - Average column for 20050101-20071231
Rovinari, Turceni, Craiova PP, Romania
Maritza Iztok PP, Bulgaria
Etna volcano, Italy
Yatagan, Yenikoy, Kernerkoy complex in Mugla, Turkey
Megalopolis PP in Arkadia, Greece
SO2 column [DU]; ClFr <= 0.20
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
10 15 20 25
36 38 40 42 44 46
20 25 30
OMI
NASA

OMI measures SO_2 emissions in South America

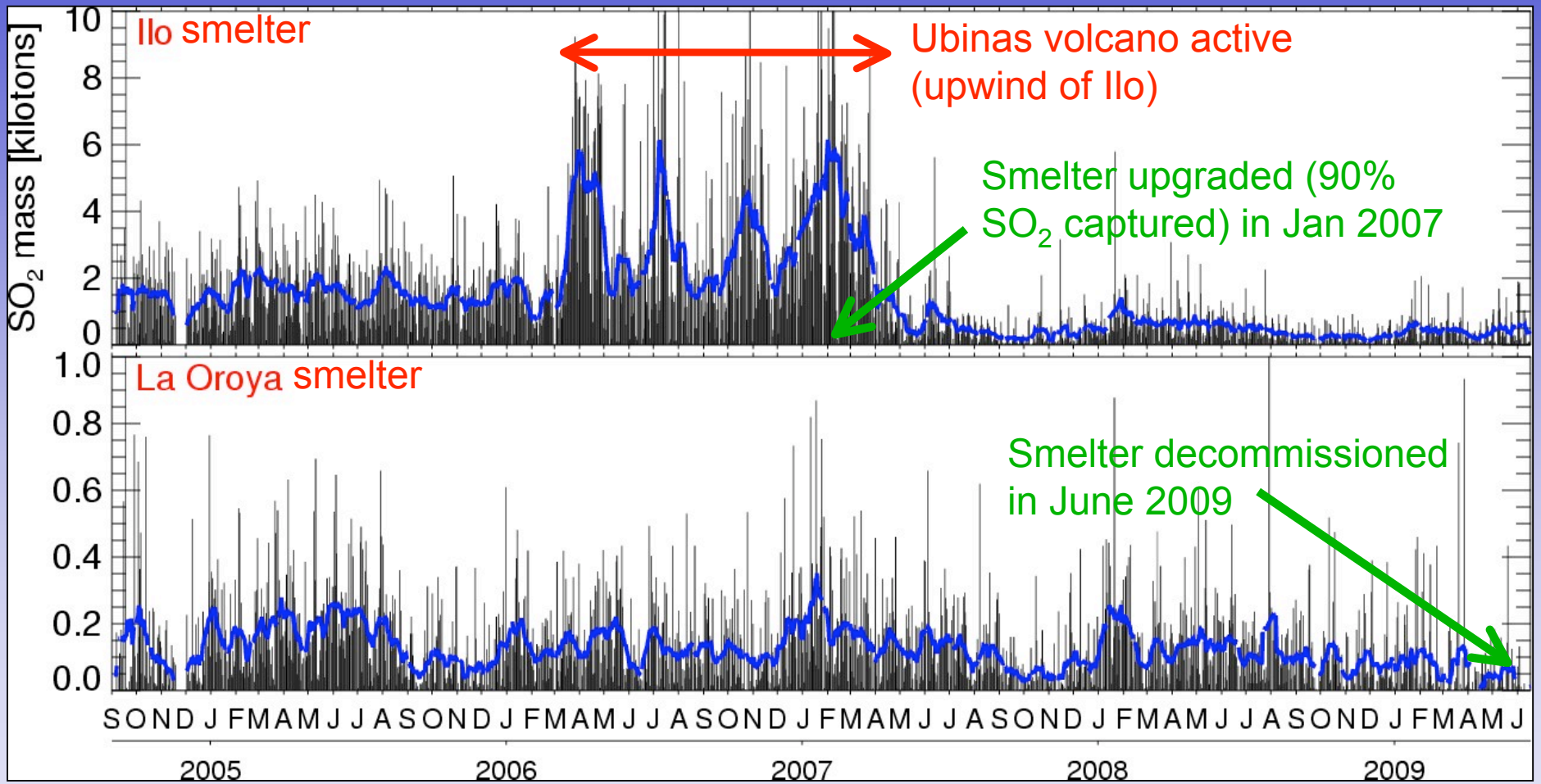


Daily SO_2 emissions (kilotons)
Sept 2004 - Sept 2005

Carn, S.A., N.A. Krotkov, A.J. Krueger, K. Yang, P.F. Levelt, "Sulfur dioxide emissions from Peruvian copper smelters detected by the OMI", GRL, 2007.

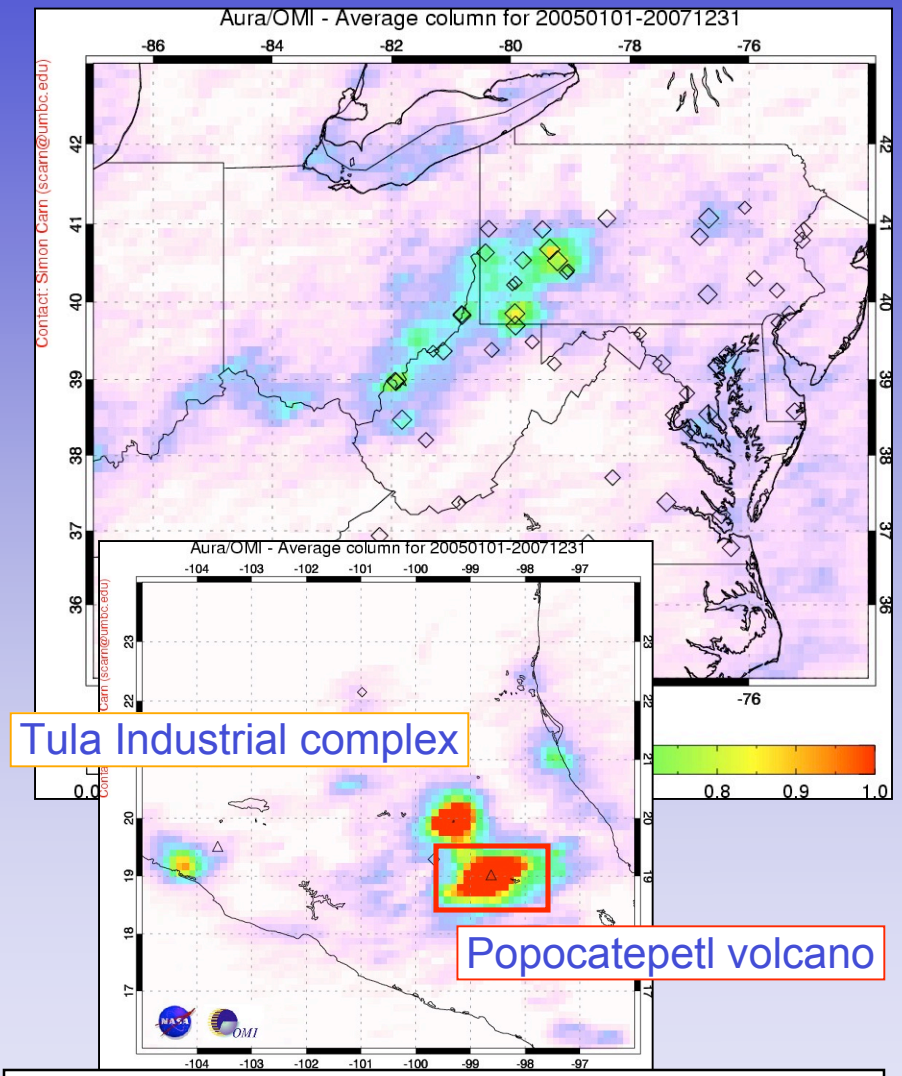
OMI measures decline in Peruvian copper smelter SO_2 emissions,

S. Carn - Aura Brochure

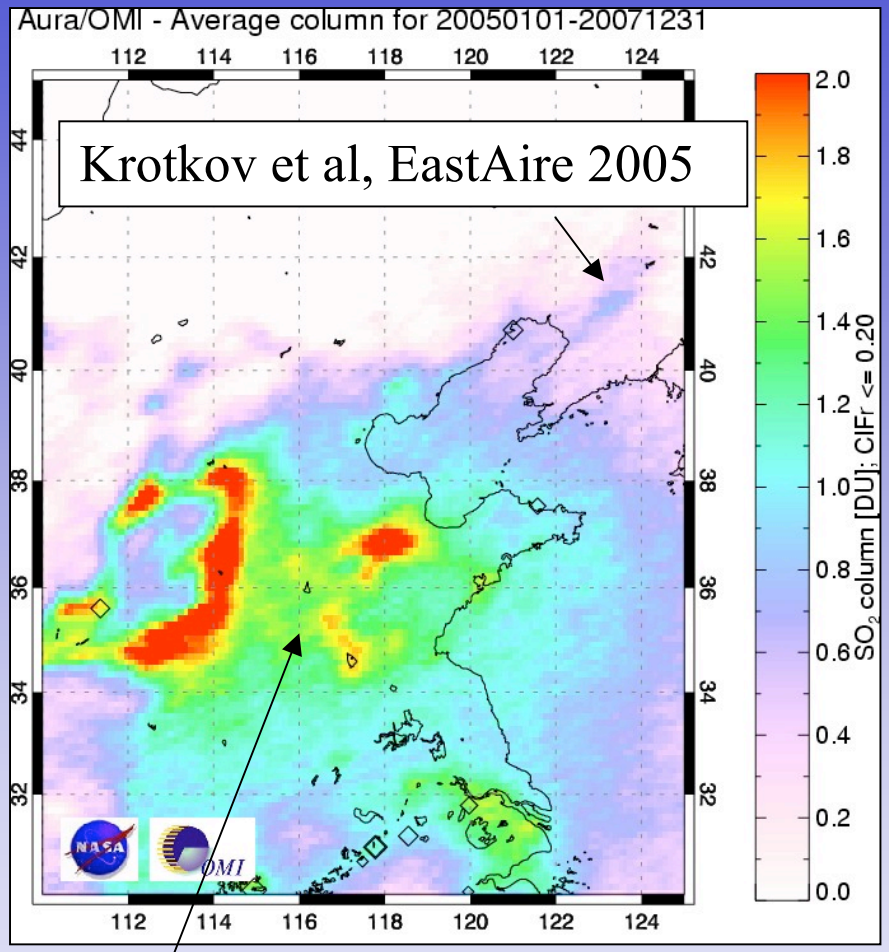


- Volcanic emissions from Ubinas volcano drift over Ilo in 2006-2007
- Upgraded sulfur capture technology at Ilo reduces SO_2 emissions
- Shut-down of La Oroya smelter in mid-2009; reduction expected

Quantitative comparisons of long-term SO_2 burdens in different regions of the world

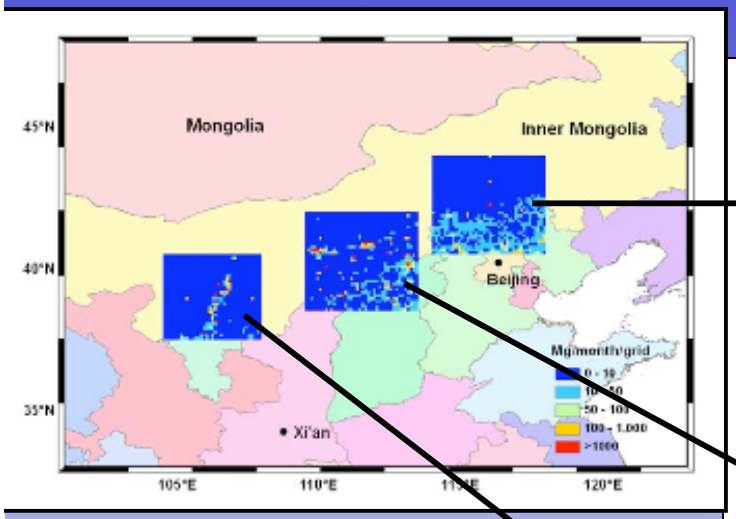


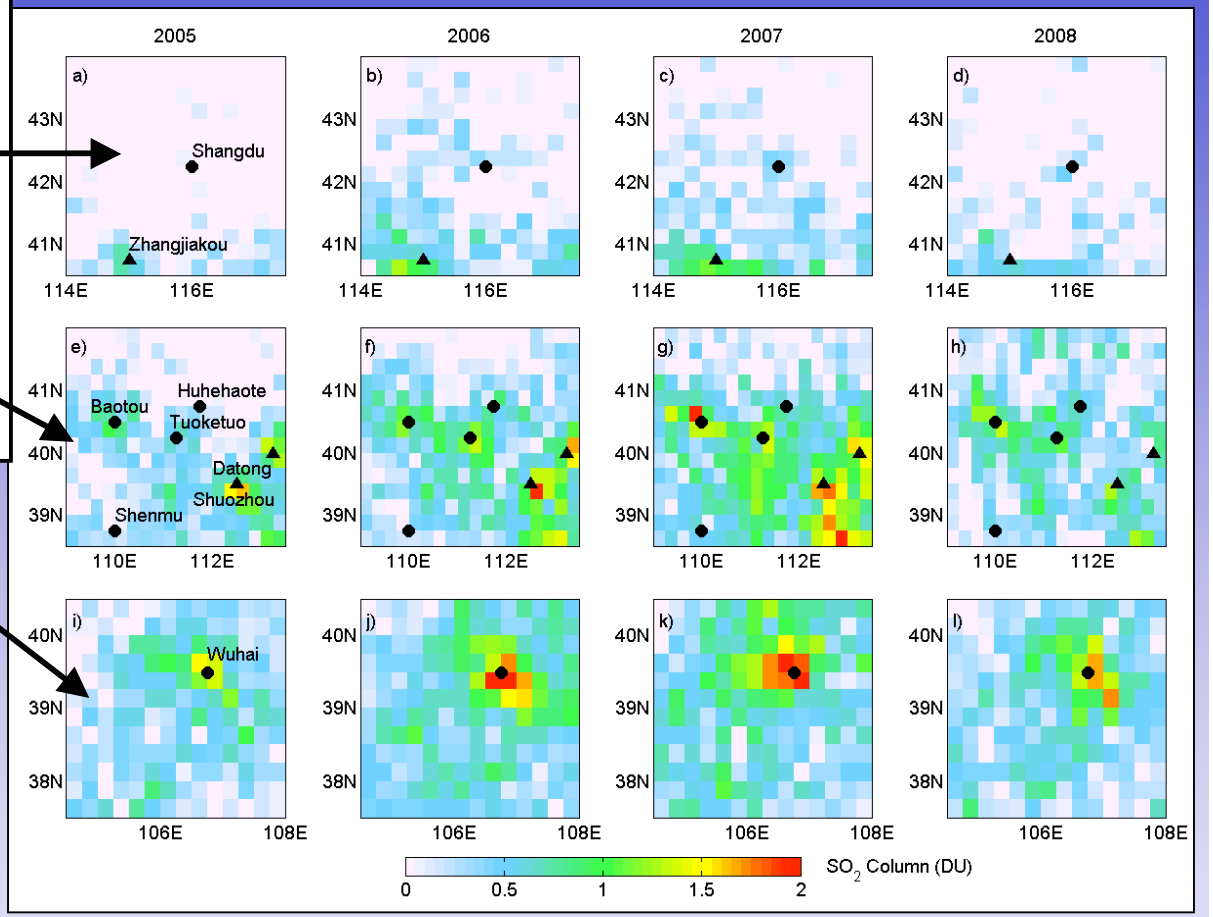
B. De Foy, et al., "Hit from both sides: tracking Industrial and volcanic plumes in Mexico city …", ACP, 9, 2009



New aircraft in-situ SO_2 validation campaign in Henan province March 2008

OMI observed SO_2 pollution from new Power Plants in Inner Mongolia province [Can Li, in prep. 2009]





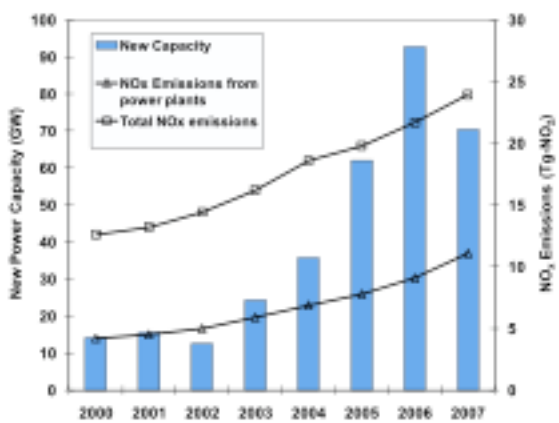


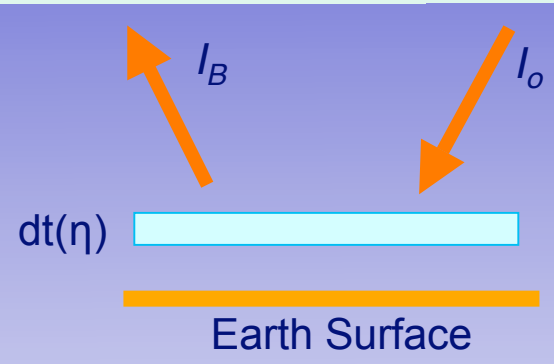
Figure 1. NO_x emissions in China. Emissions for 2000–2004 are adapted from *Zhang et al.* [2007], and emissions after 2004 are estimated from updated data, using the same method.

Summertime average OMI SO_2 column amount over areas in eastern (a-d), central (e-h), and western (i-l) Inner Mongolia from 2005 to 2008 (L-R). Solid dots and triangle represent areas with and without newly built power plants during the period of 2005-07 according to *Zhang et al.* [2009].

Improvement of Pollution SO_2 Data from OMI
C. Lee, R. Martin, et al, JGR 2009 in press

$$AMF = \frac{Slant\ Columns}{Vertical\ Columns} = AMF_G \int_{\eta_T}^{1} \omega(\eta) S(\eta) d\eta$$

LIDORT Radiative Transfer Model [R. Spurr]



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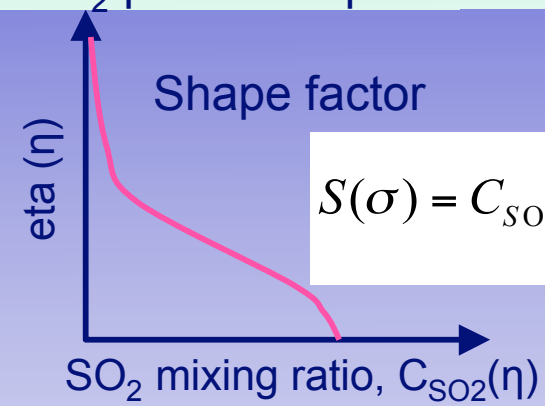
Using GEOS-CHEM model for SO_2 profile shape correction



$$S(\sigma) = C_{SO_2}(\sigma) \frac{\Omega_{air}}{\Omega_{SO_2}}$$

Local Scattering weight $\omega(\sigma) = -\frac{1}{AMF_G} \frac{\alpha(\sigma)}{\alpha_e} \frac{\partial(\ln I_B)}{\partial \tau}$

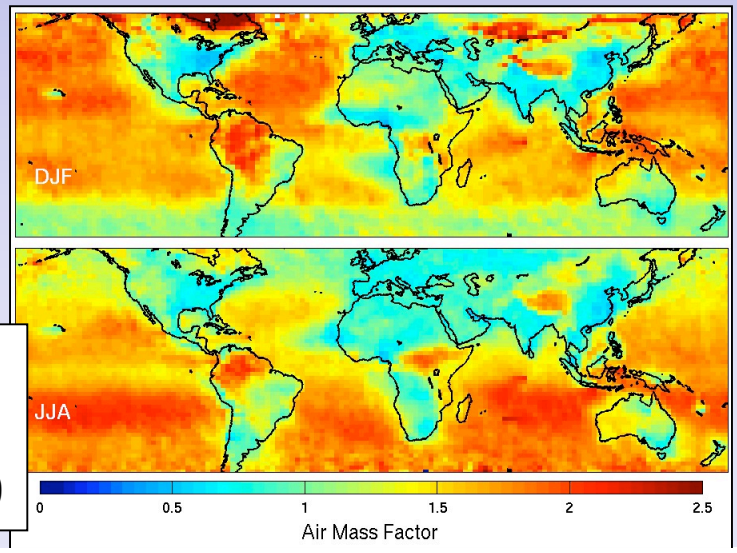
$\alpha(\eta)$ is temperature-dependent cross-section

Calculate $\omega(\eta)$ as function of:

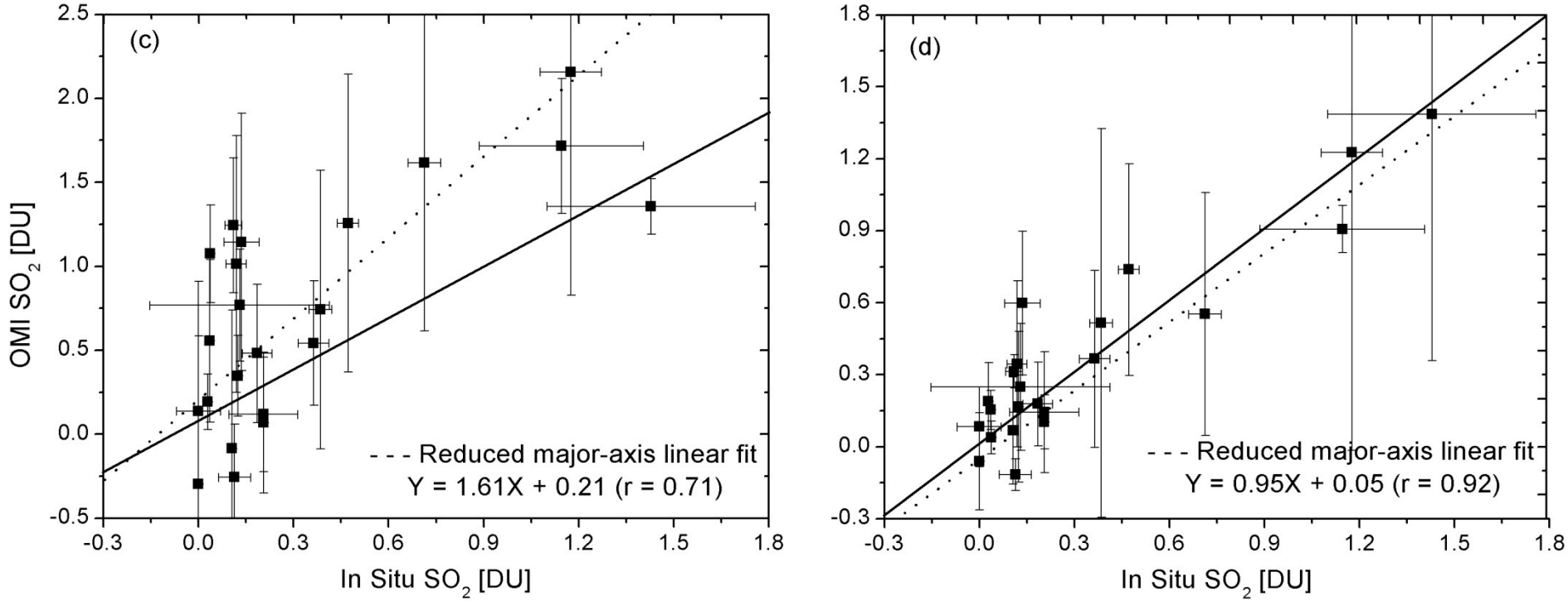
- solar and viewing zenith angle (θ_s, θ_v)
- surface reflectivity, pressure
- aerosol
- O_3 column

Calculated AMF at 313.2 nm =>

Cloud Radiance Fraction <0.2; SZA<70



Improvement of Pollution SO_2 Data from OMI
C. Lee, R. Martin, et al, JGR 2009 in press



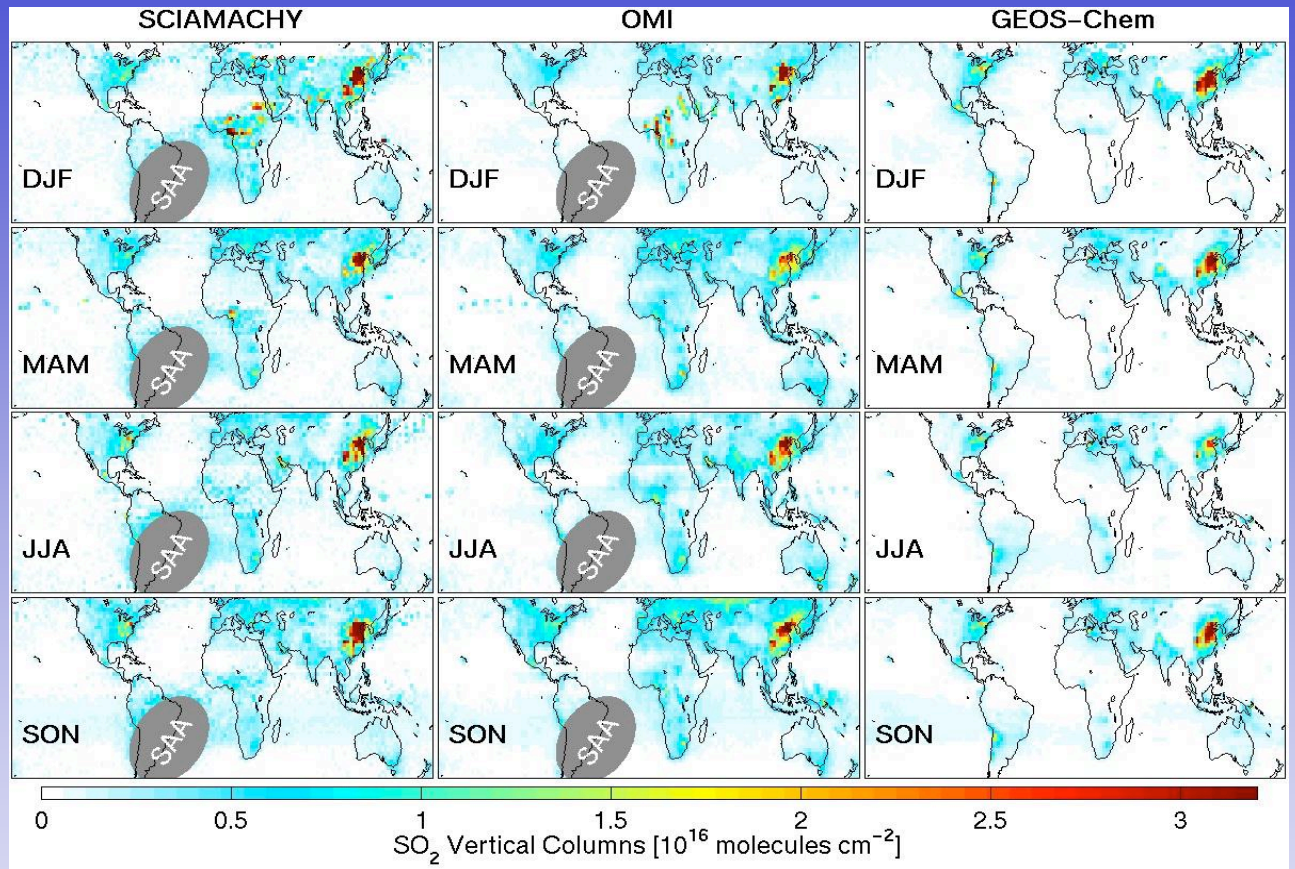
Operational OMI PBL SO_2 data corrected with local air mass factor improves agreement of OMI SO_2 versus aircraft observations (INTEX A & B)

Left: The constant AMF=0.36 refers to the OMI operational PBL product.

Right: The local AMF is developed in Lee et al., [2009] and applied to correct operational PBL data.

Error bars indicate the standard deviations of in situ measurements and the OMI retrieval error. Solid line represents 1:1 line.

Improvement of Pollution SO_2 Data from OMI
C. Lee, R. Martin, et al, JGR 2009 in press



Local AMF improves Correlation with GEOS-Chem (GC)

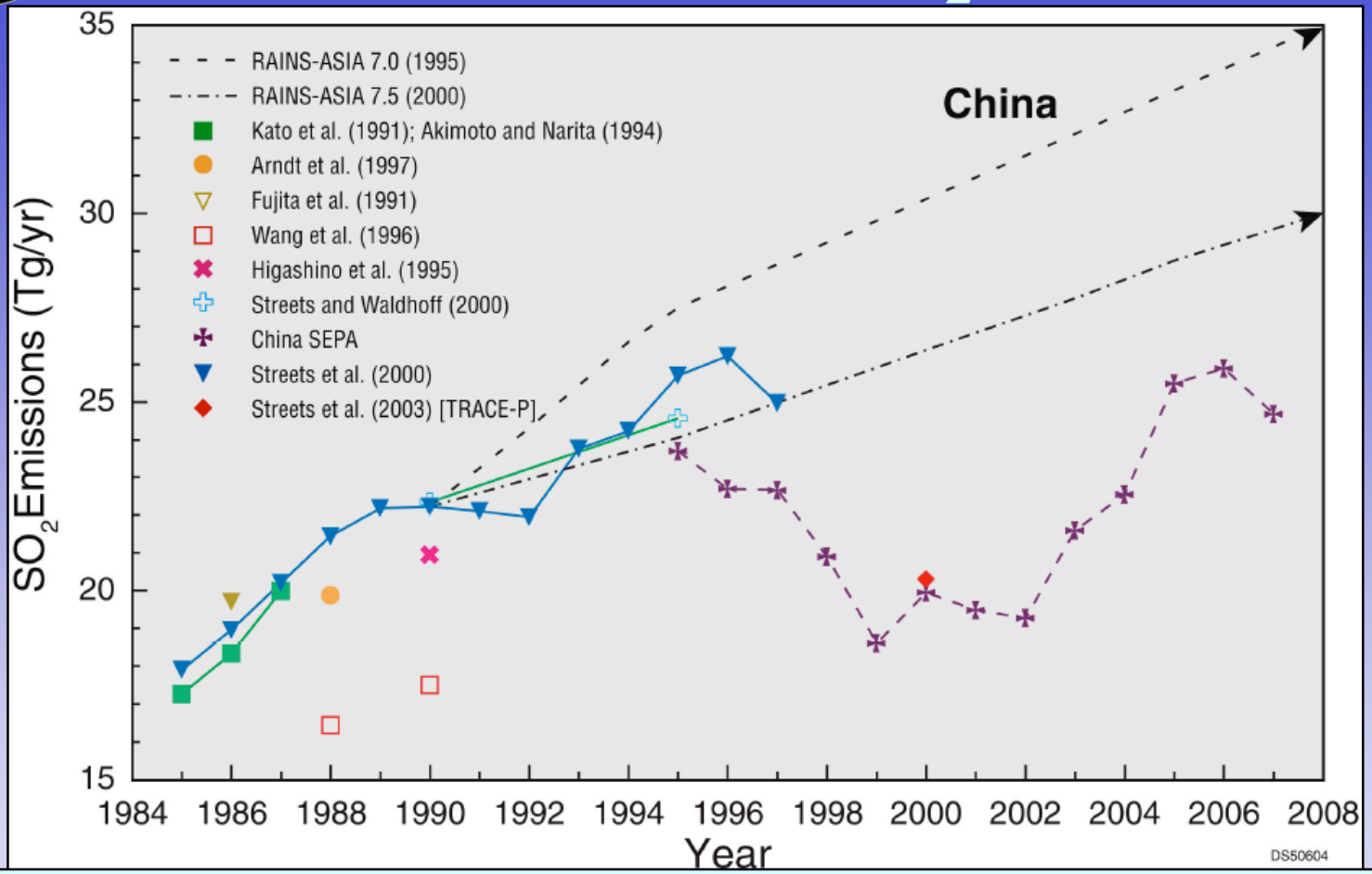
: Globally r ~0.78

: ~0.84 over US

: ~0.83 over China

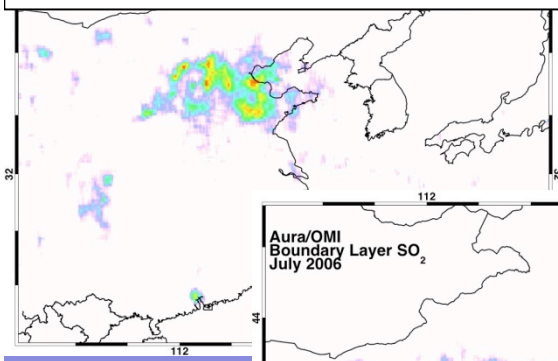
Seasonal mean tropospheric vertical columns of SO_2 for cloud-free (cloud radiance fraction < 0.2) conditions determined from SCIAMACHY,OMI and the GEOS-Chem CTM. The model outputs were sampled coincidently with the observations. The gray oval labeled SAA on the OMI map is the area of South Atlantic Anomaly, where energetic particles of the Van Allen radiation belt bombard the orbiting instrument, drastically increasing the uncertainty of UV measurements [Lee et al JGR, in print]

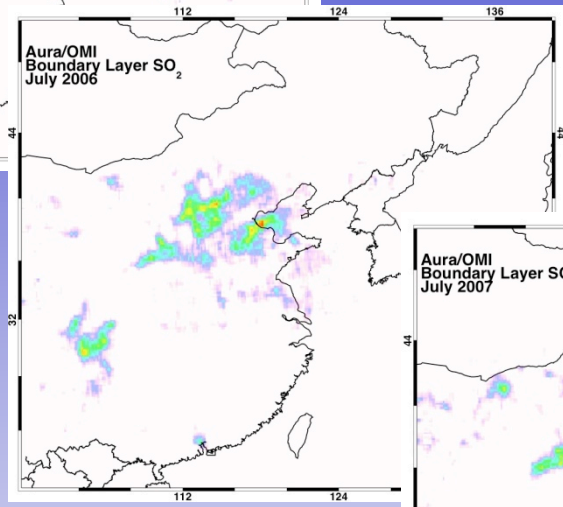
Trends in Chinese SO_2 emissions

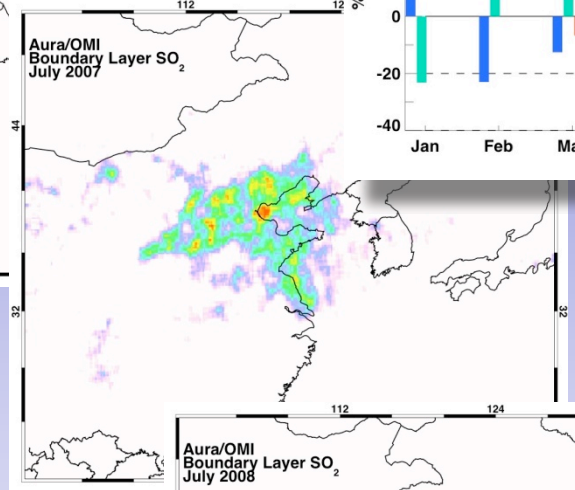


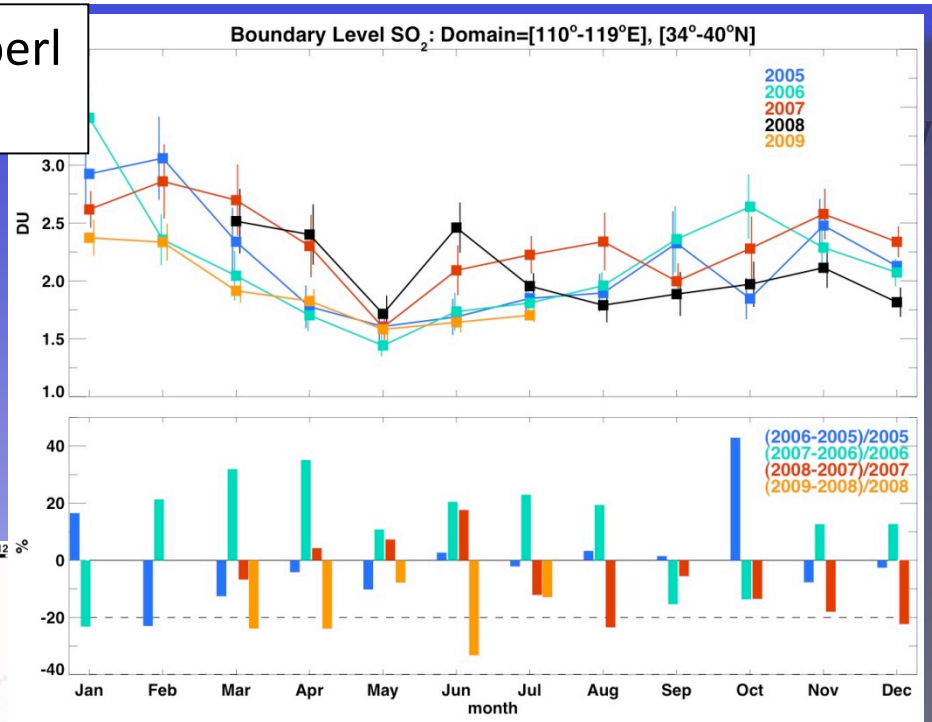
SO_2 emission controls were given a major strengthening in the 11th Five-Year-Plan, with flue-gas desulfurization technology (FGD) required on all new plants and some old ones, and much better inspection and enforcement. Thus we expect the rapid growth that occurred between 2002 and 2006 to be halted.

J. Witte, N. Krotkov, K. Pickering, M. Schoeberl
NASA/GSFC/Code 613.3, see Poster



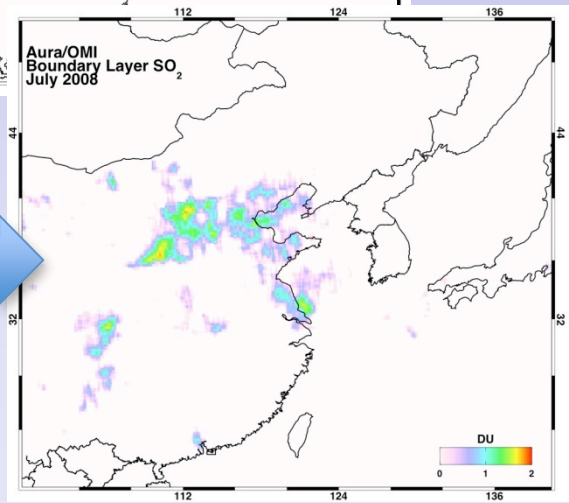


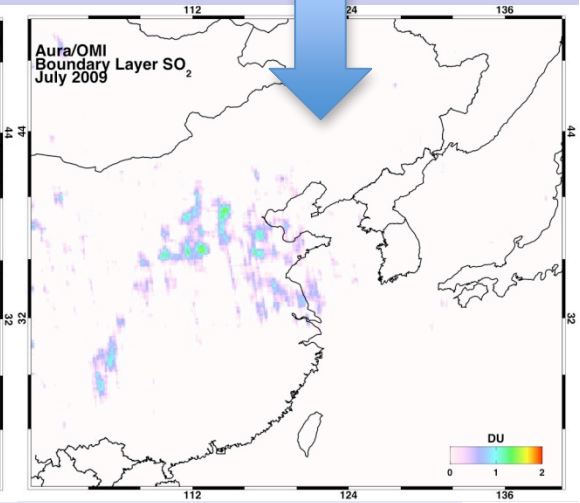




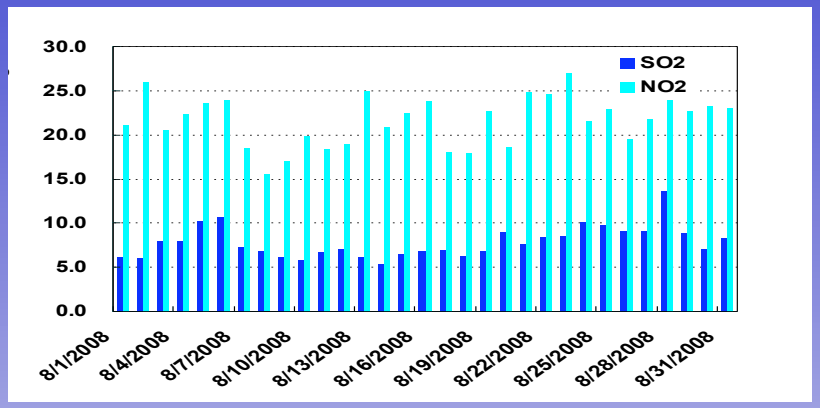
Global Economic Crisis
- Industries close/reduce output

Beijing 2008 Olympics
-Stringent emission control measures were enforced through September 2008

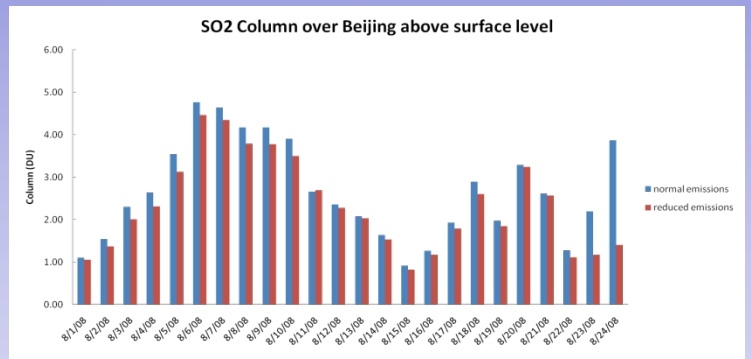




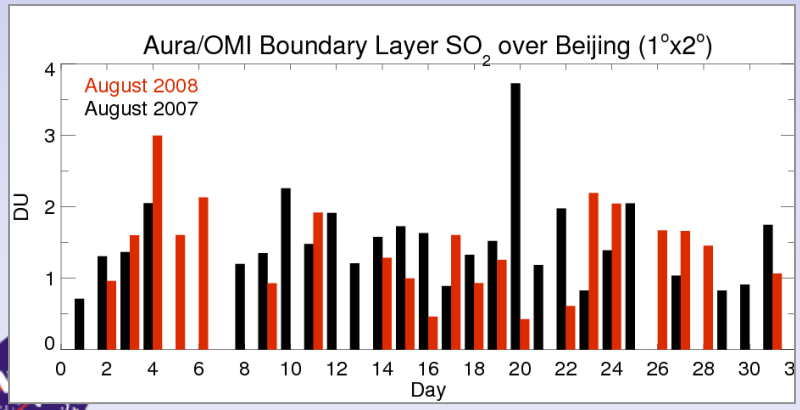
OMI daily data comparisons with University of Iowa STEM model in Beijing area during Olympic games



Surface concentration measurements http://www.bjepb.gov.cn), average daily concentrations from 27 monitoring stations around Beijing



Daily model SO_2 columns from STEM model: Spatial resolution: 60 km x 60 km, 21 sigma layers (0~23km); Meteorology model: WRF 60 km x 60 km.
Constant emissions for Olympic period.

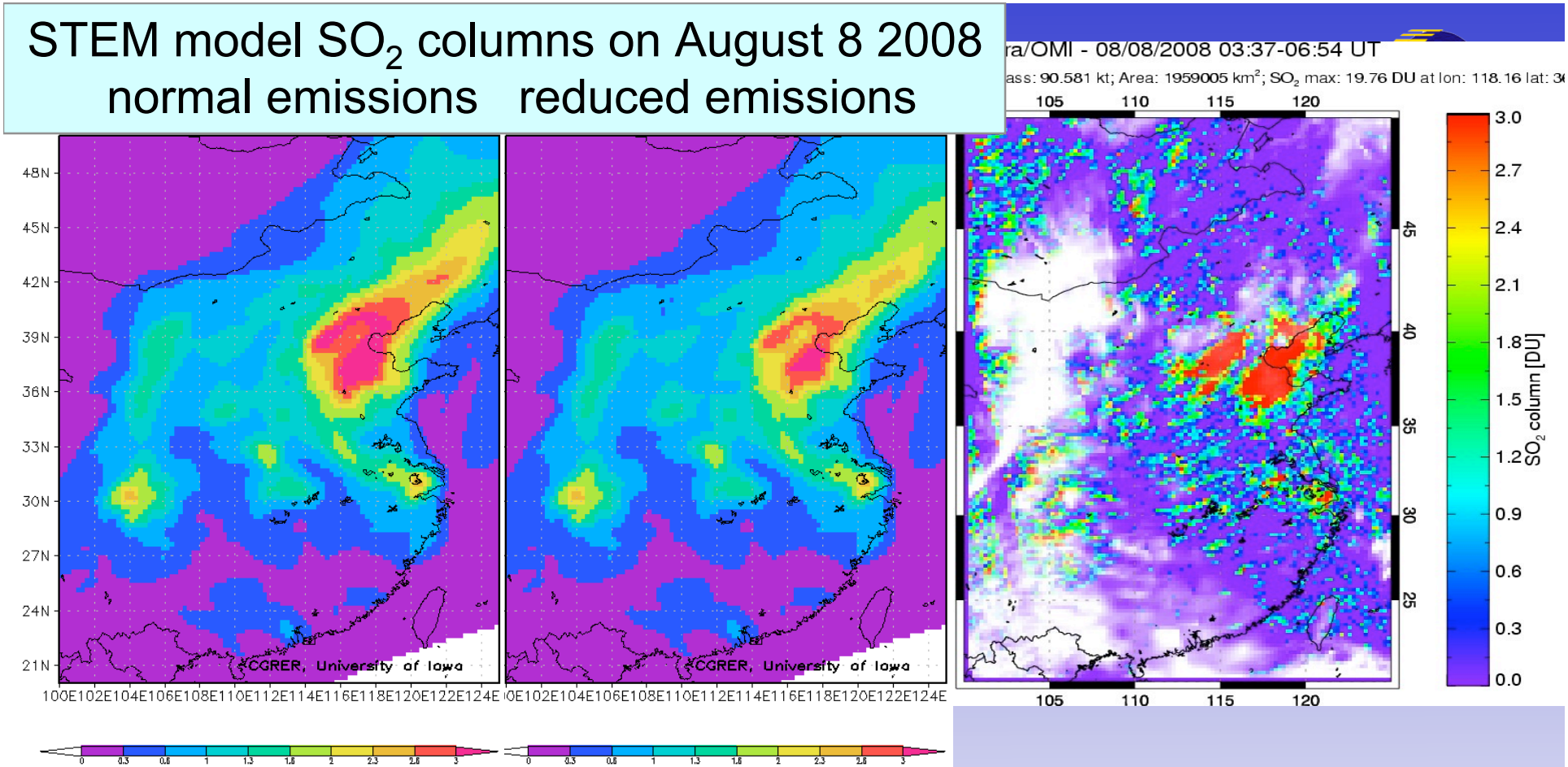


OMI daily PBL SO_2 daily burdens filtered by cloudiness (radiative cloud fraction < 0.3) and using constant AMF=0.36.

- Missing OMI values are due to cloud filtering.

STEM model SO_2 columns on August 8 2008

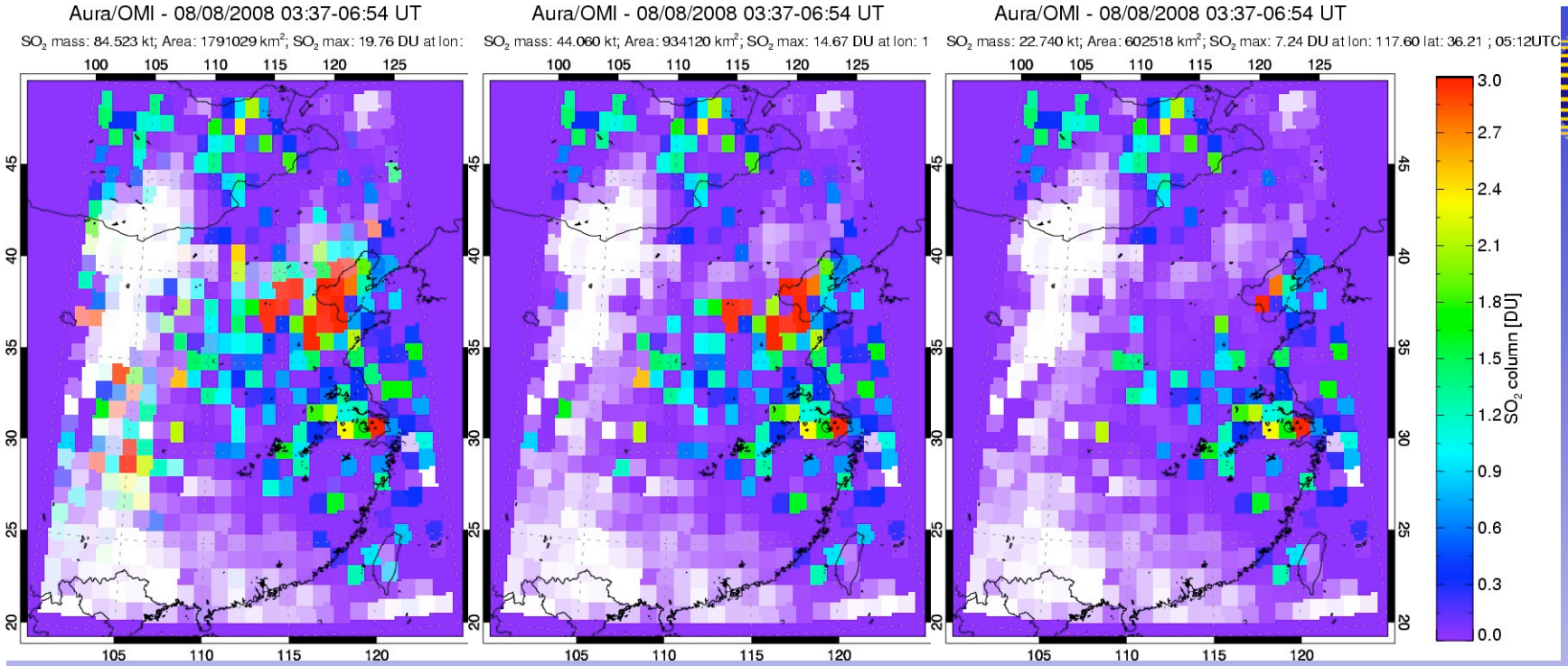
normal emissions reduced emissions



OMI SO_2 columns need to be corrected for clouds.

- The model provides SO_2 vertical distributions as well as aerosol vertical profiles that are needed to correct OMI operational SO_2 retrievals.

- Cloud heights are estimated from OMI measurements

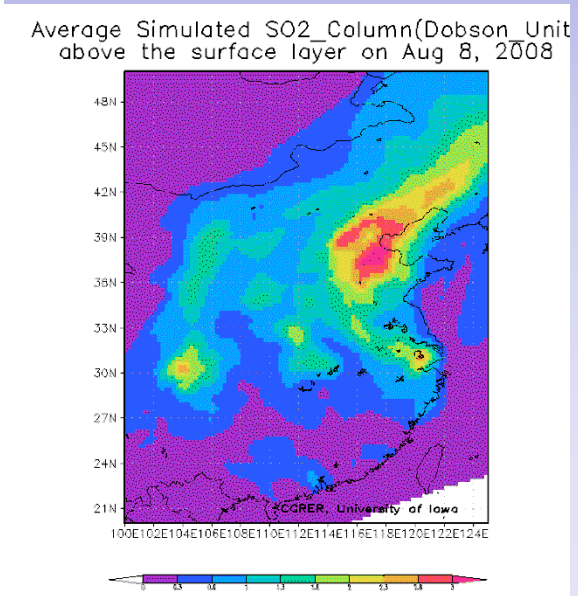


No OMI CldFrac filter

OMI CldFrac <0.5

OMI CldFrac <0.3

(used in monthly OMI maps)



-Satellite data should provide better corrections for partly cloudy scenes: filtering cloud pixels removes useful information;

- A-priori information is needed on cloud effective height, aerosols and SO_2 profile shapes

- Model fields should be re-sampled consistently with satellite measurements (applying the same cloud filter)

Summary

- OMI operational SO_2 data require further improvements:
  - Reanalyze Volcanic data with new algorithms, corrections for ash, clouds and aerosols
  - NRT Volcanic plumes forecasts using trajectory model
  - Apply local AMFs to pollution data, corrections for snow
  - Direct spectral fitting reduces retrieval noise and biases in pollution data
  - Advanced Cloud/aerosol AMF corrections require information on radiative cloud fraction, cloud heights and aerosols.