Atmospheric Science Conference

Frascati, May 10, 2006

SO_2 retrieval from GOME and SCIAMACHY nadir measurements

Andreas Richter F. Wittrock, and J. P. Burrows

Institute of Environmental Physics and
Institute of Remote Sensing
University of Bremen

Introduction

Measurements of SO_2:

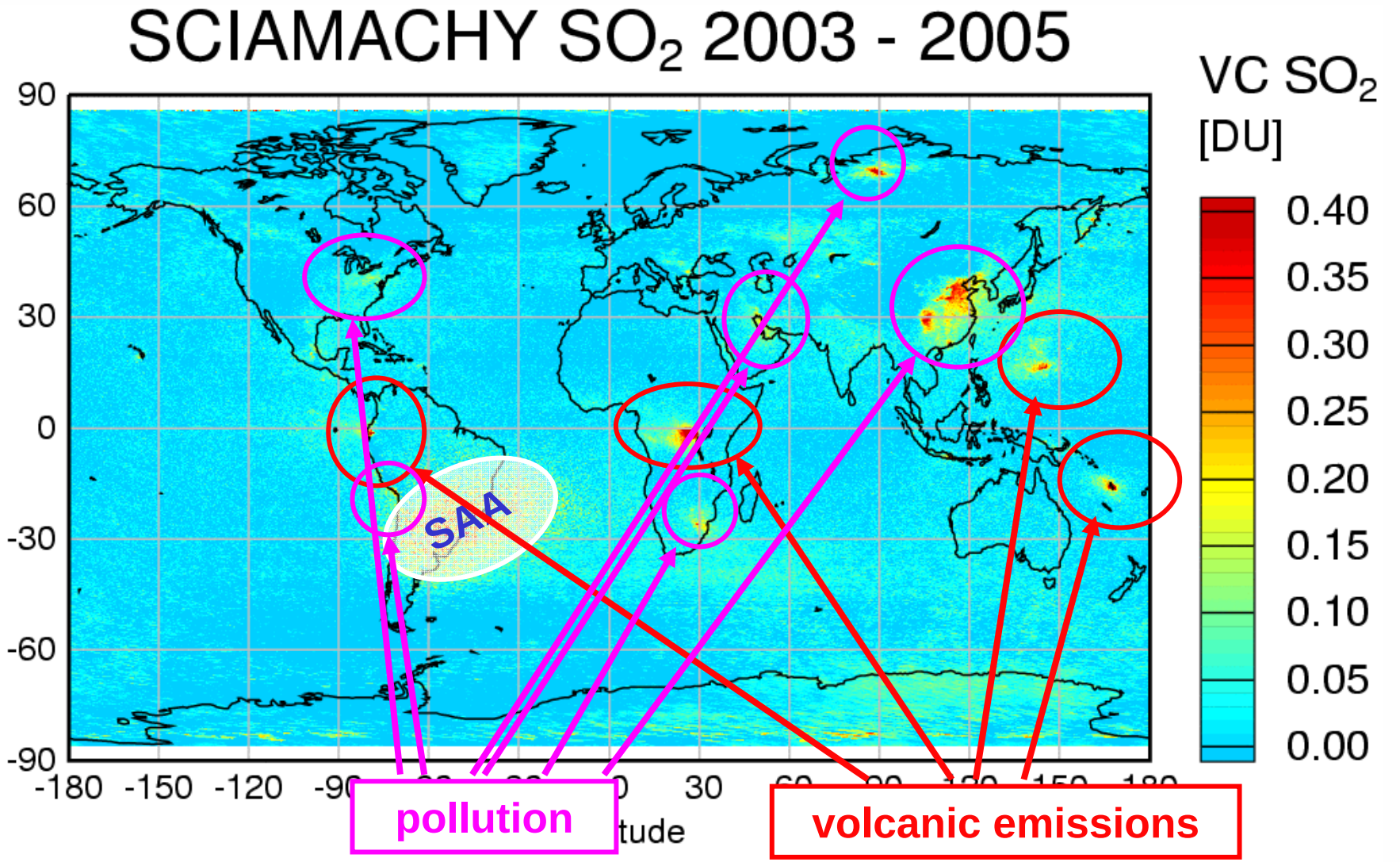
- volcanic emissions (explosive and degassing)
- boundary layer pollution (mainly coal burning, refineries and smeltering)
- biomass burning?

What is special about SO_2 measurements?

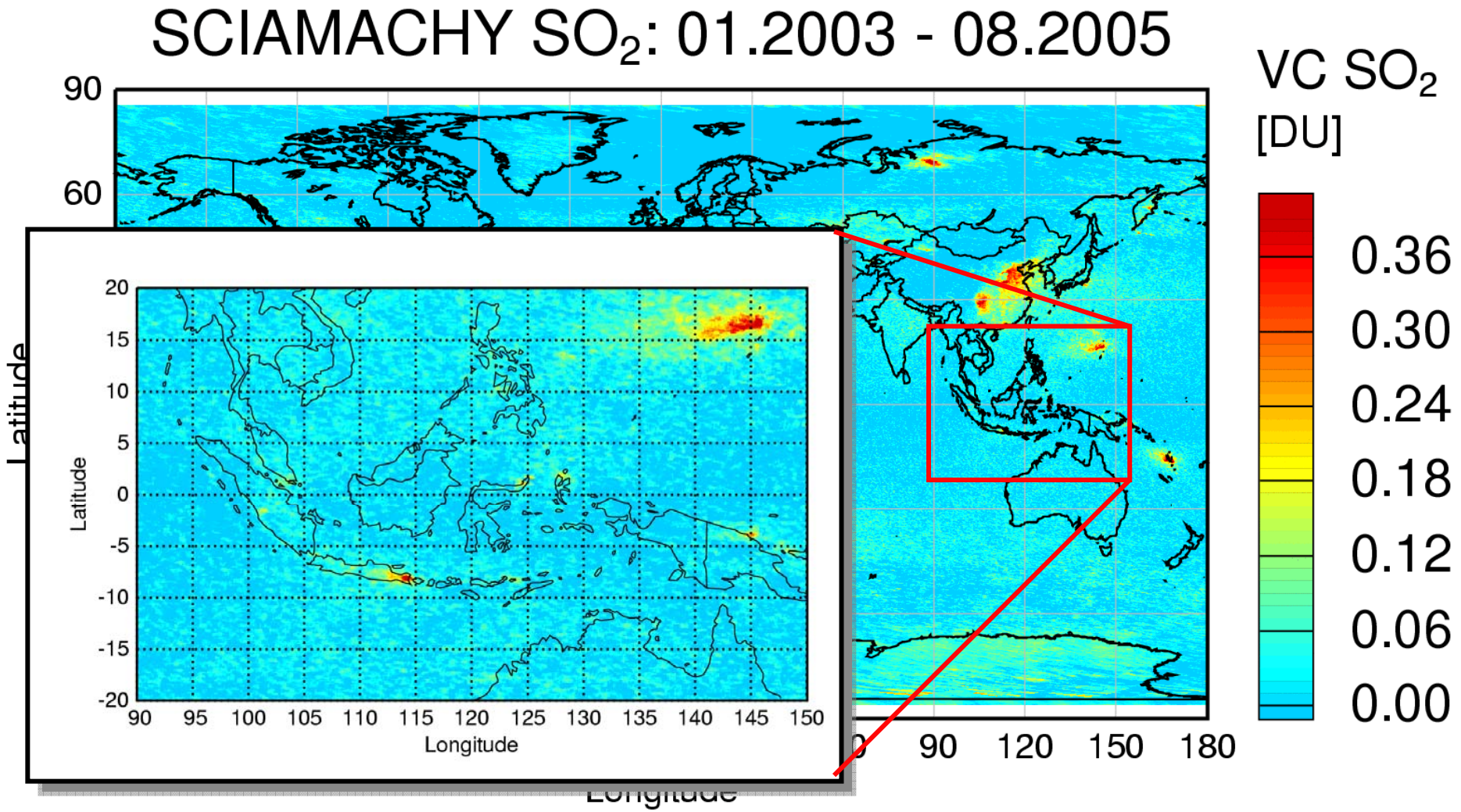
- UV measurements:
  - low intensity
  - strong O_3 absorption
  - strong Rayleigh scattering
- SO_2 can be a strong absorber during volcanic eruptions

=> Report on ongoing work on SO_2 retrieval at IUP Bremen

SCIAMACHY SO_2 measurements

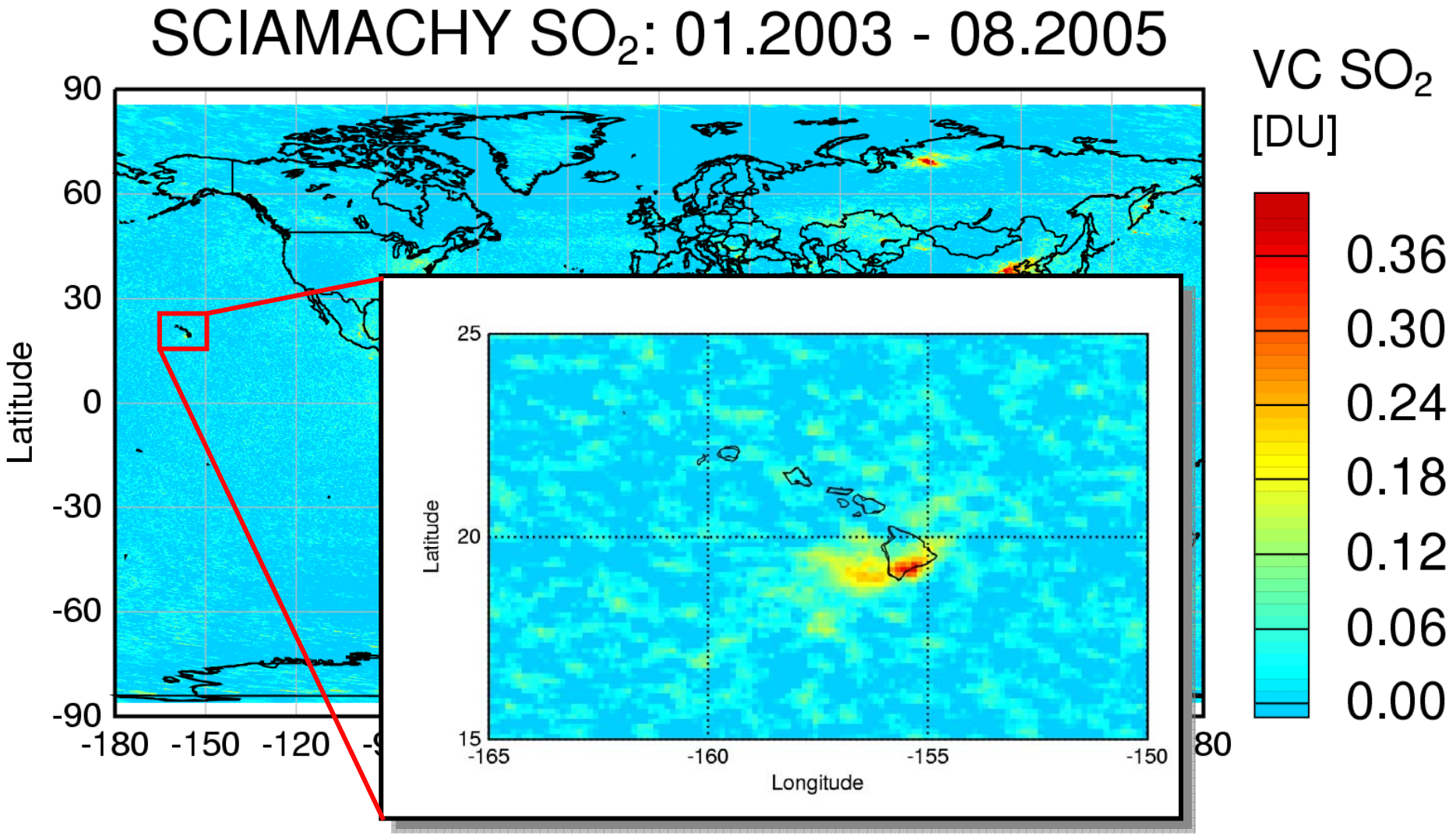


SCIAMACHY SO_2: Volcanic Emissions



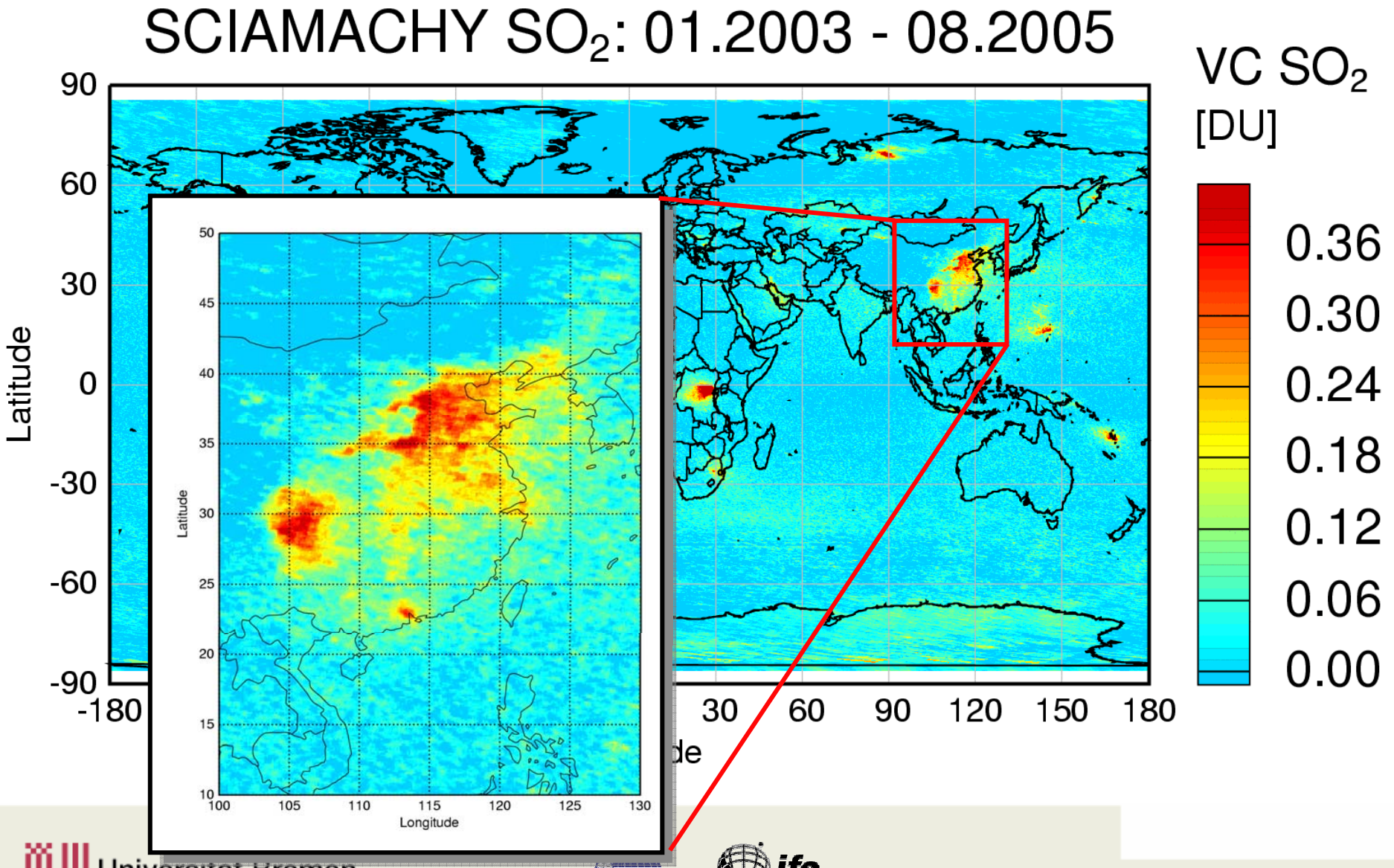
Universität Bremen
Andreas.Richter@iup.physik.uni-bremen.de

SCIAMACHY SO_2 : Volcanic Emissions



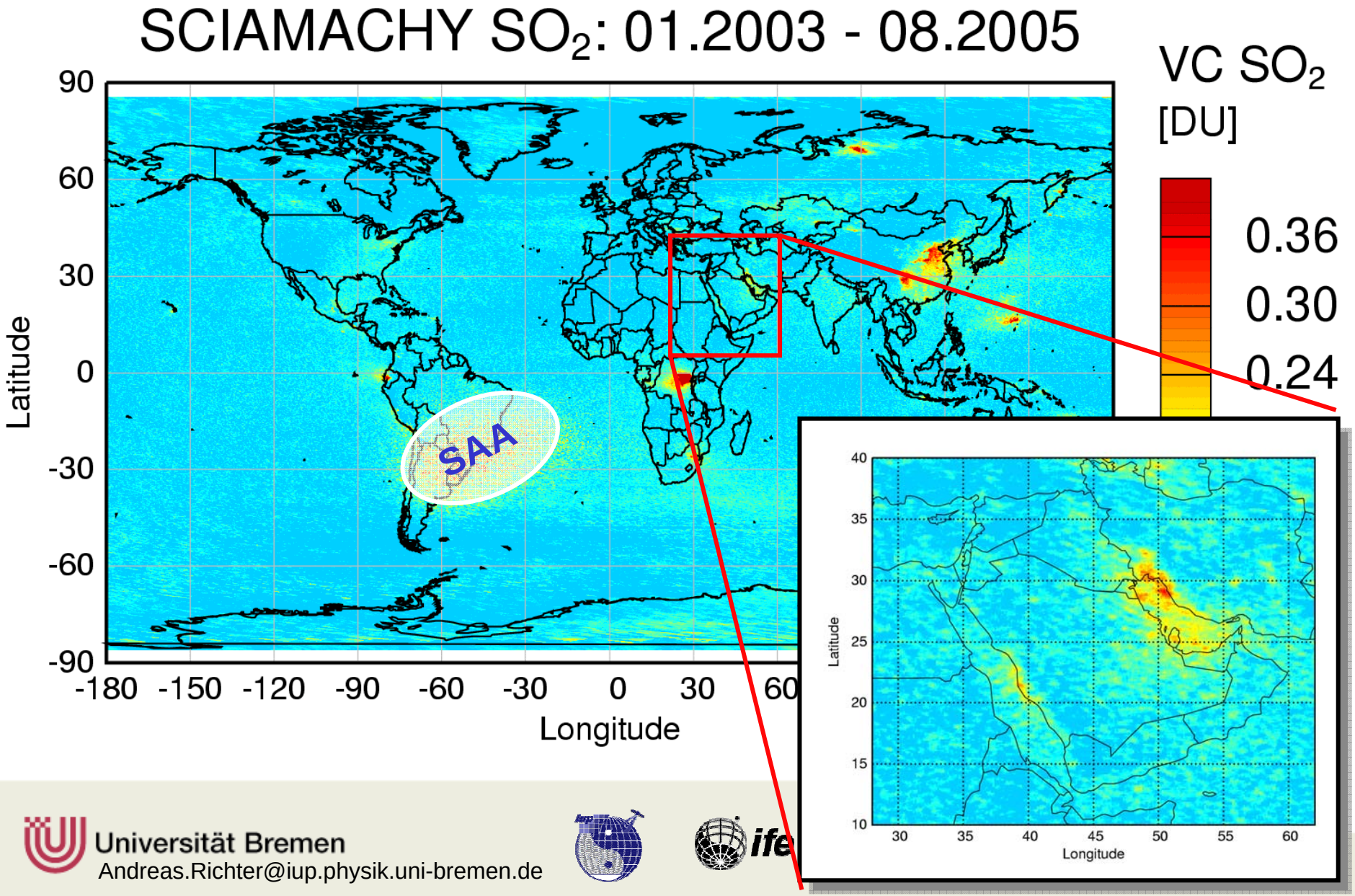
Universität Bremen
Andreas.Richter@iup.physik.uni-bremen.de

SCIAMACHY SO_2: Pollution



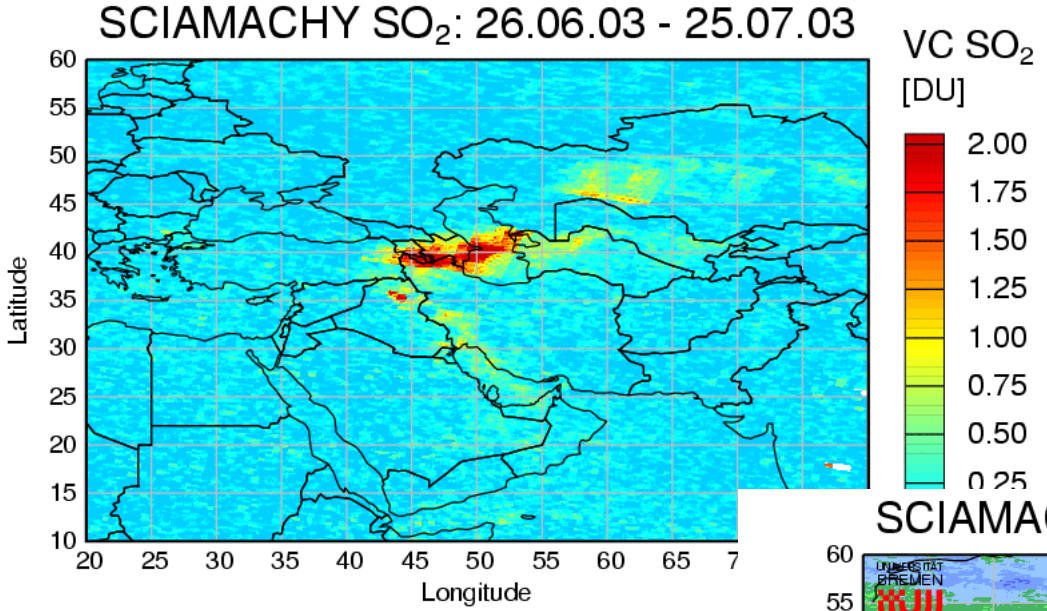
Universität Bremen
Andreas.Richter@iup.physik.uni-bremen.de

SCIAMACHY SO_2:Pollution



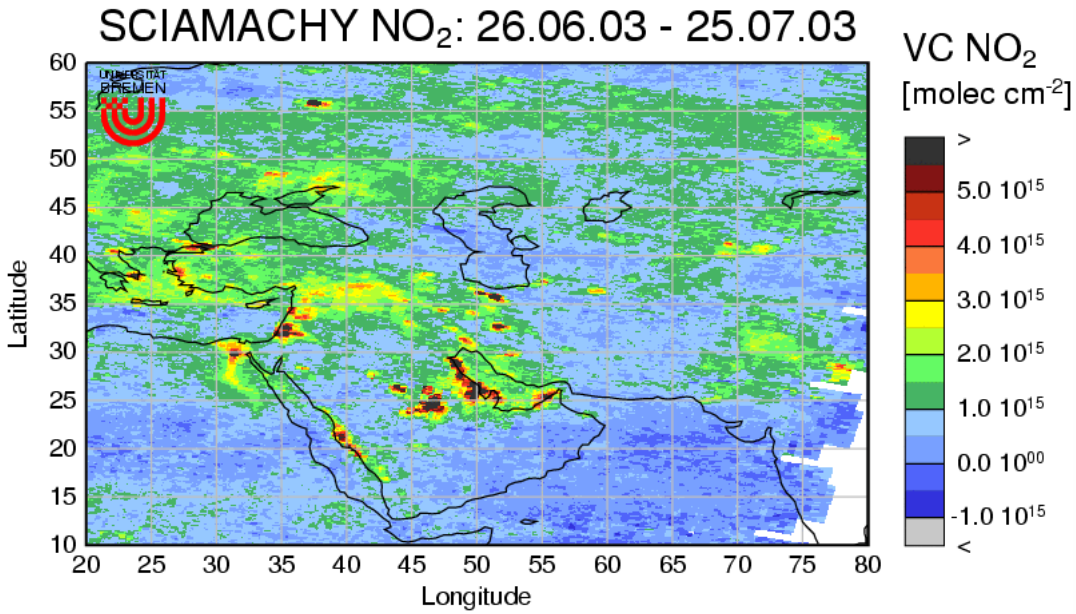
Universität Bremen
Andreas.Richter@iup.physik.uni-bremen.de

SCIAMACHY SO_2: Fire in Sulphur Plant



- **LARGE** SO_2 plume over Middle East in June / July 2003
- Fire in a sulphur plant in Qayyarah, Iraq

No matching NO_2 plume!



Universität Bremen
Andreas.Richter@iup.physik.uni-bremen.de

SO_2 data analysis

DOAS settings:

- standard DOAS
- ASM solar background from December 2002
- uncalibrated spectra
- 315 – 327 nm
- O_3 at 2 temperatures
- Ring effect
- offset & slope
- ETA nadir
- SO_2

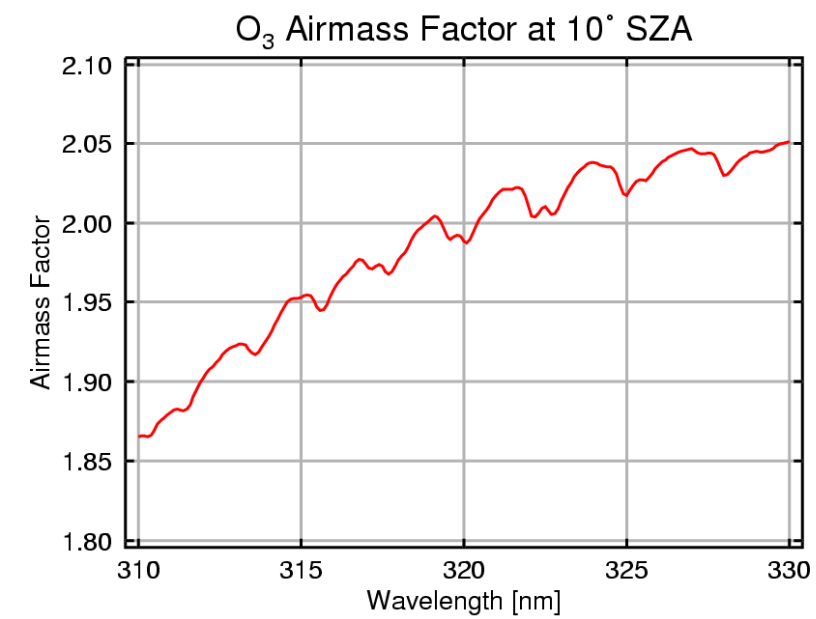
Airmass factor settings:

- two different data versions, one with “volcanic” airmass factor, the other with “urban pollution” airmass factor

Offset correction:

- either “reference sector” to compensate most of the latitudinal offset variation and an global offset
- or subtraction of the values from a localised reference area in the Pacific

SO_2 data analysis: O_3 absorption

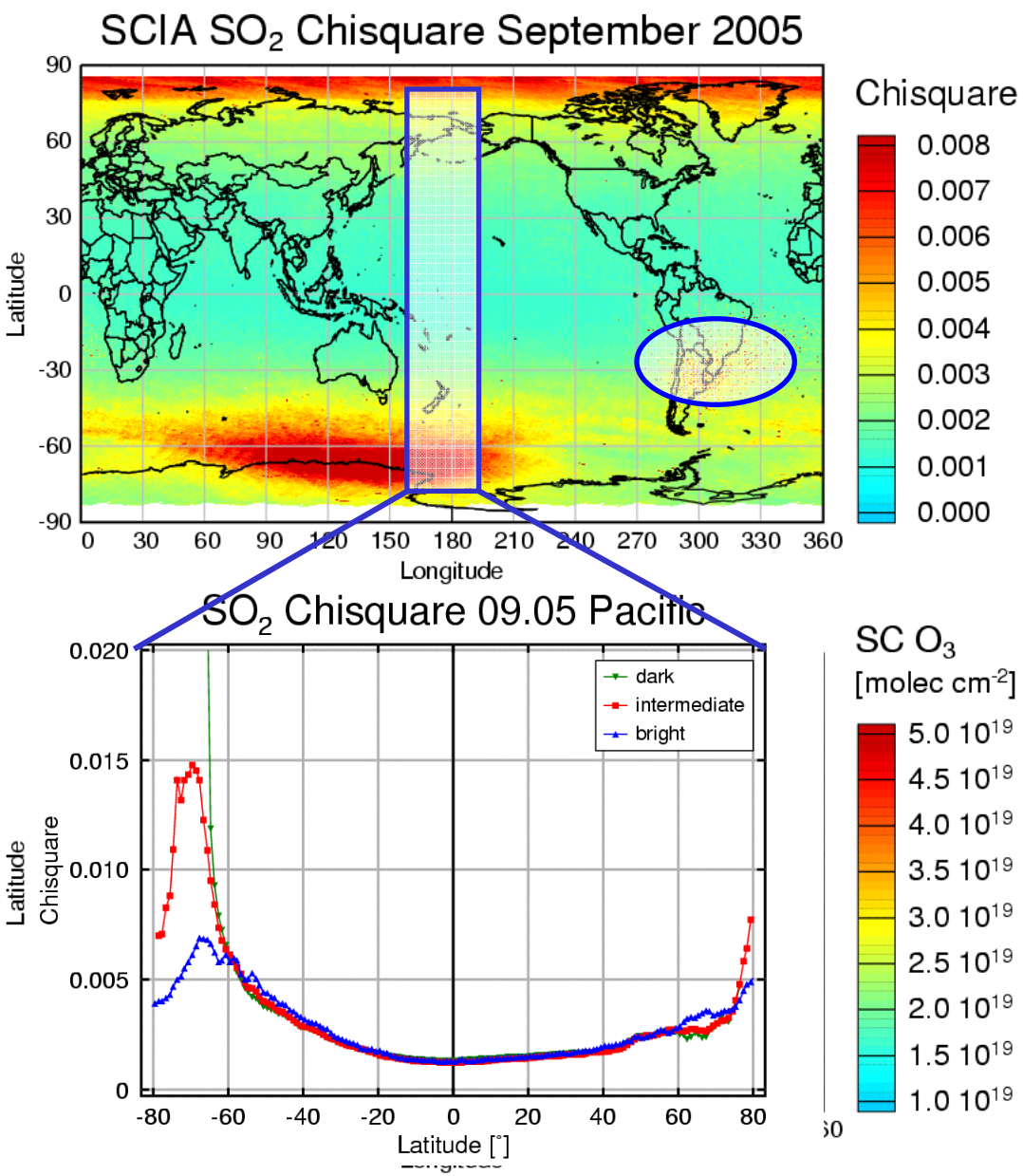


- O_3 absorption is strong in the SO_2 fitting window
- the temperature dependence of the O_3 absorption cross-section is large
- the airmass factor changes significantly with wavelength
- airmass factor changes are correlated with O_3 bands

=> at large SZA (> 75°), the change of O_3 AMF with wavelength has to be accounted for to avoid

- negative offsets
- correlation between apparent SO_2 columns and O_3 amount

SO_2 Fit Quality

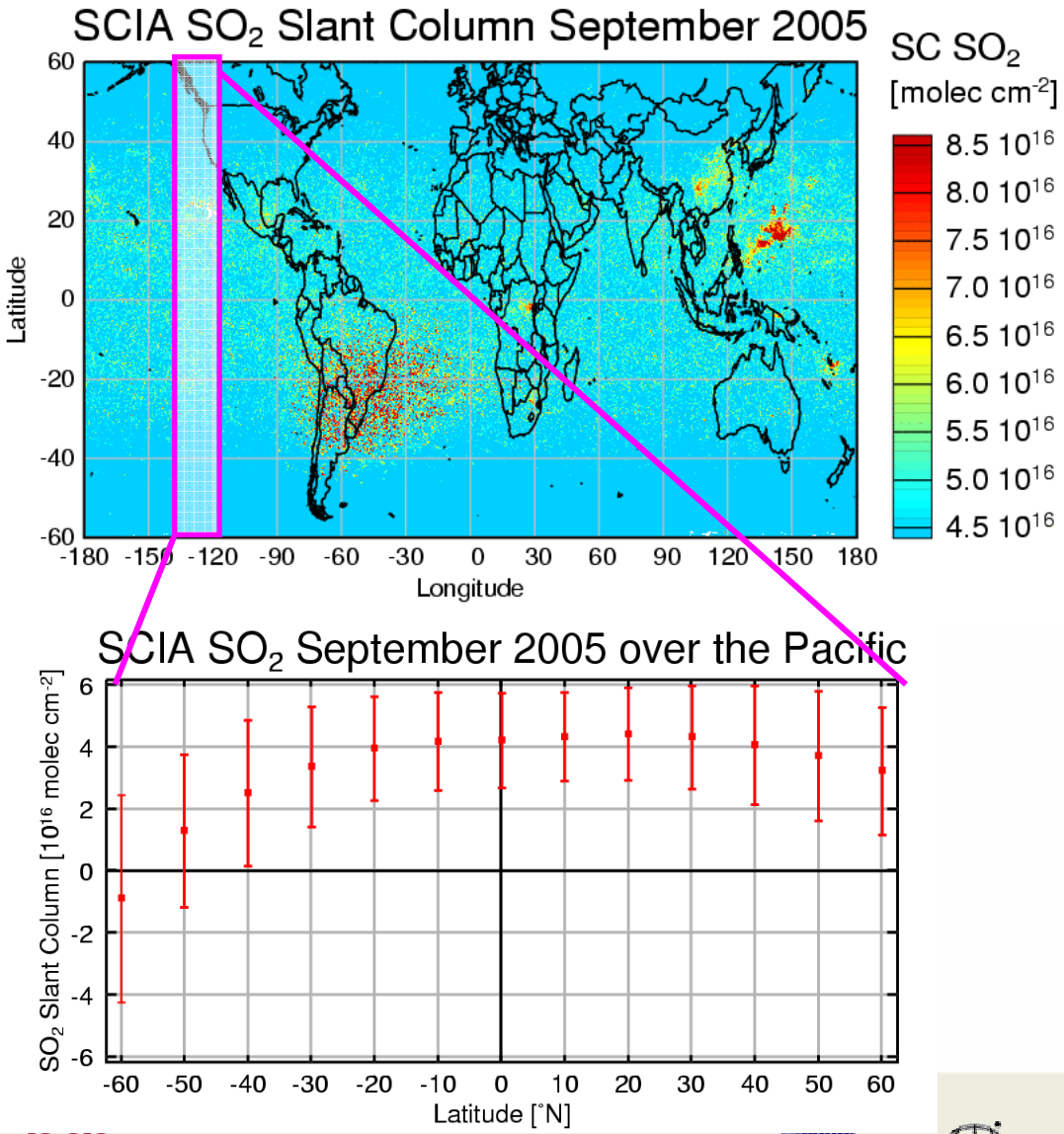


Fit quality dominated by

- SAA
- solar zenith angle
- ozone column
  - slit function?
  - airmass factor?
  - temperature dependence?
- time difference to background spectrum

- brightness seems to be less important
  => not shot noise limited?

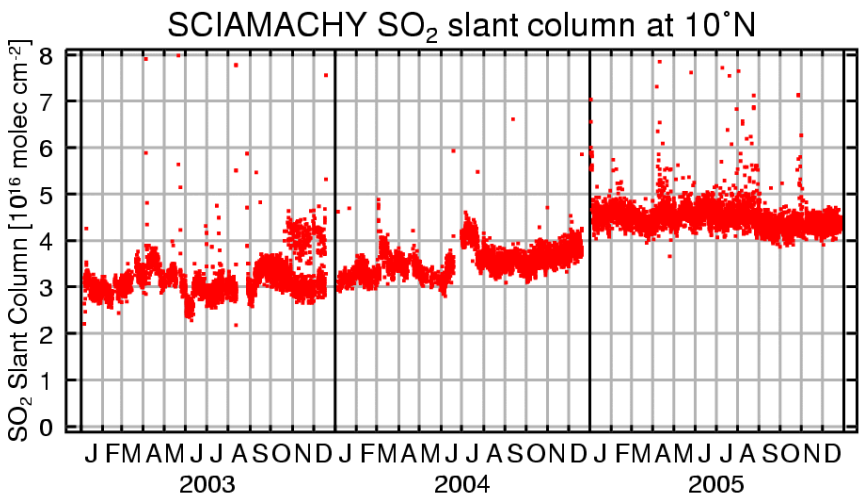
SO_2 Slant Column Scatter

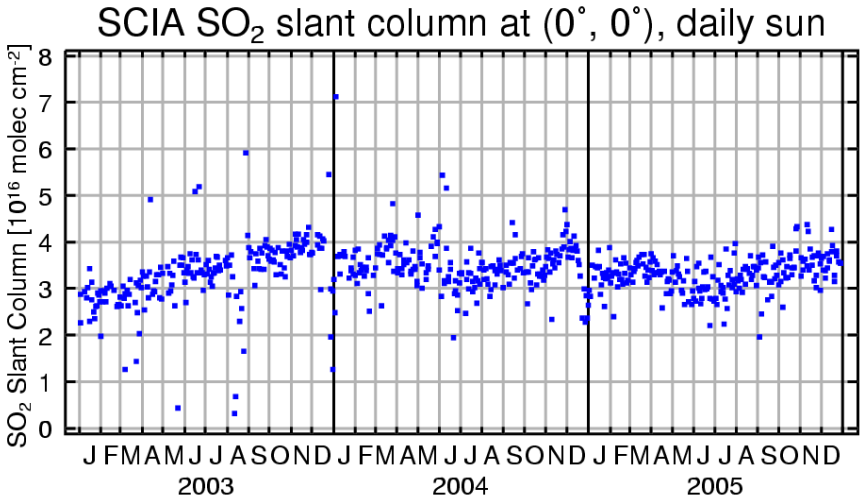


Scatter of SO_2 columns

- larger at high latitudes
- smaller at low latitudes
- of the order of $2x10^{16}$ molec cm^{-2}
- depending on assumed airmassfactor, this corresponds to a standard deviation of 0.3 – 1 DU for individual measurements
- mainly random, but also some scan angle dependency

SO_2 Fit Stability





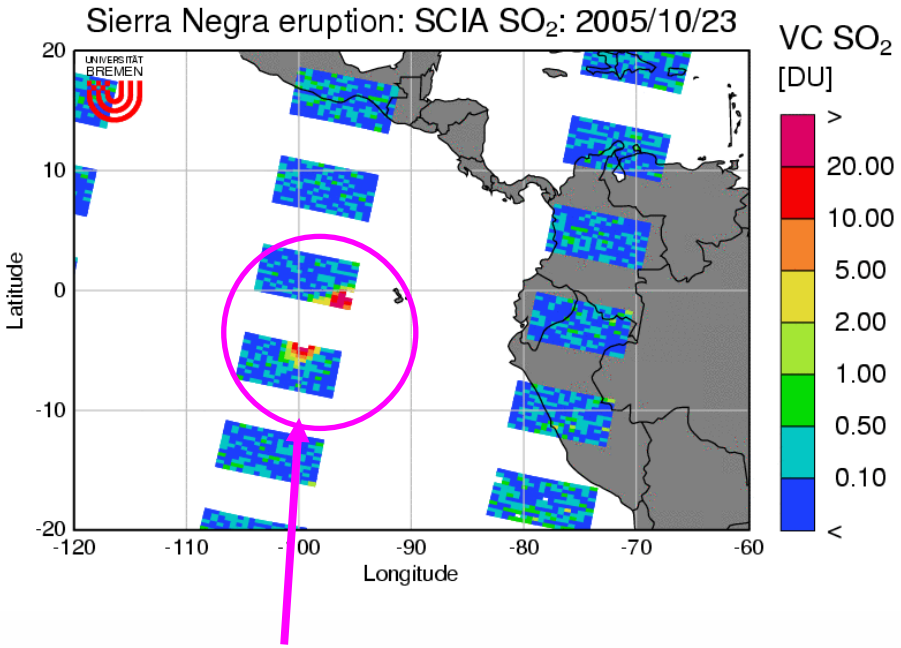
Fixed Background Spectrum:

- test for instrument stability
- avoids “jumps”
- sensitive to instrument changes
- => apparent drift

Daily Background Spectrum:

- uncalibrated ASM spectrum
- improves fits for warm detectors
- no drift but also varying

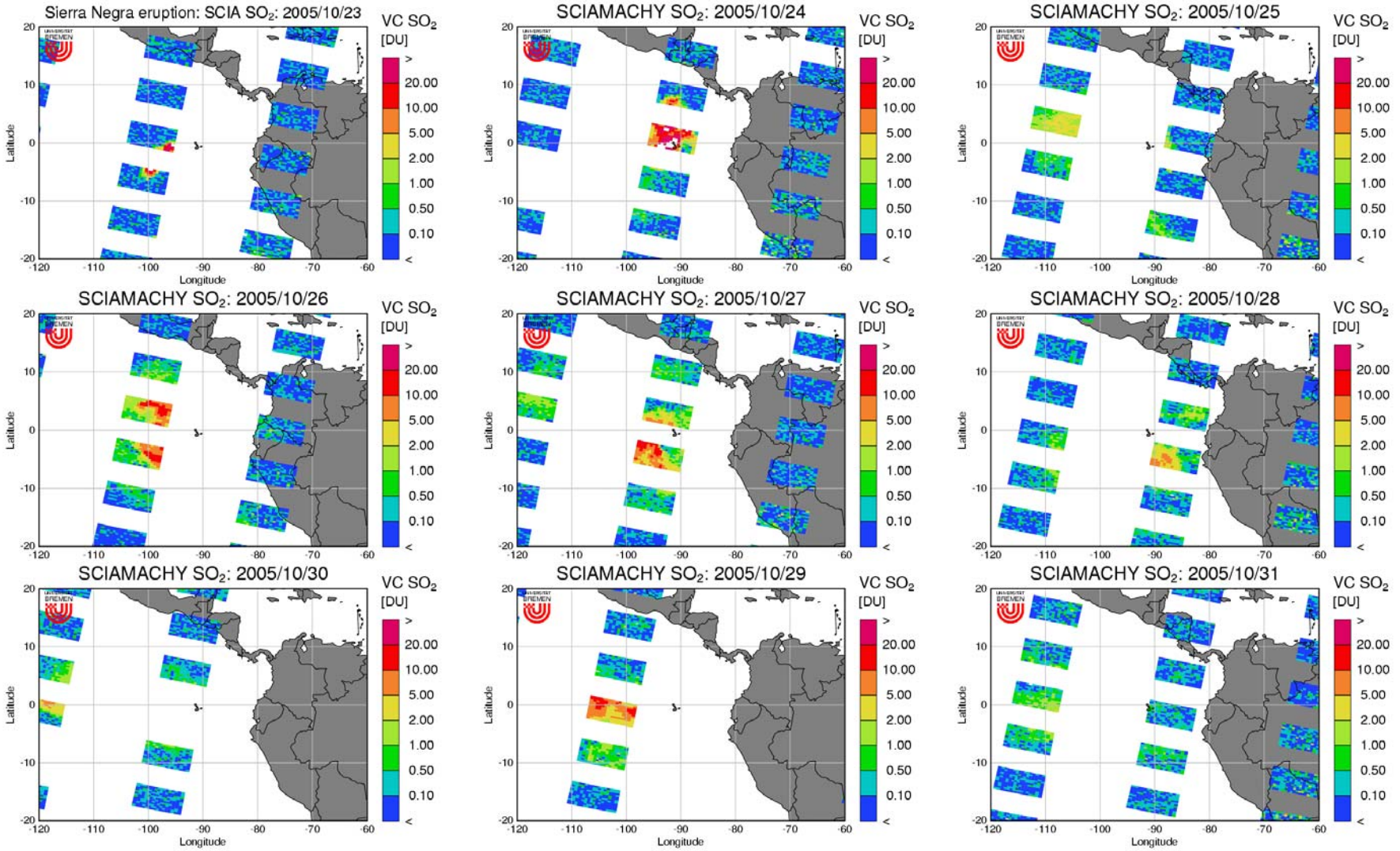
Sierra Negra Eruption



missing values result from poor SO_2 fits over areas with largest SO_2 columns

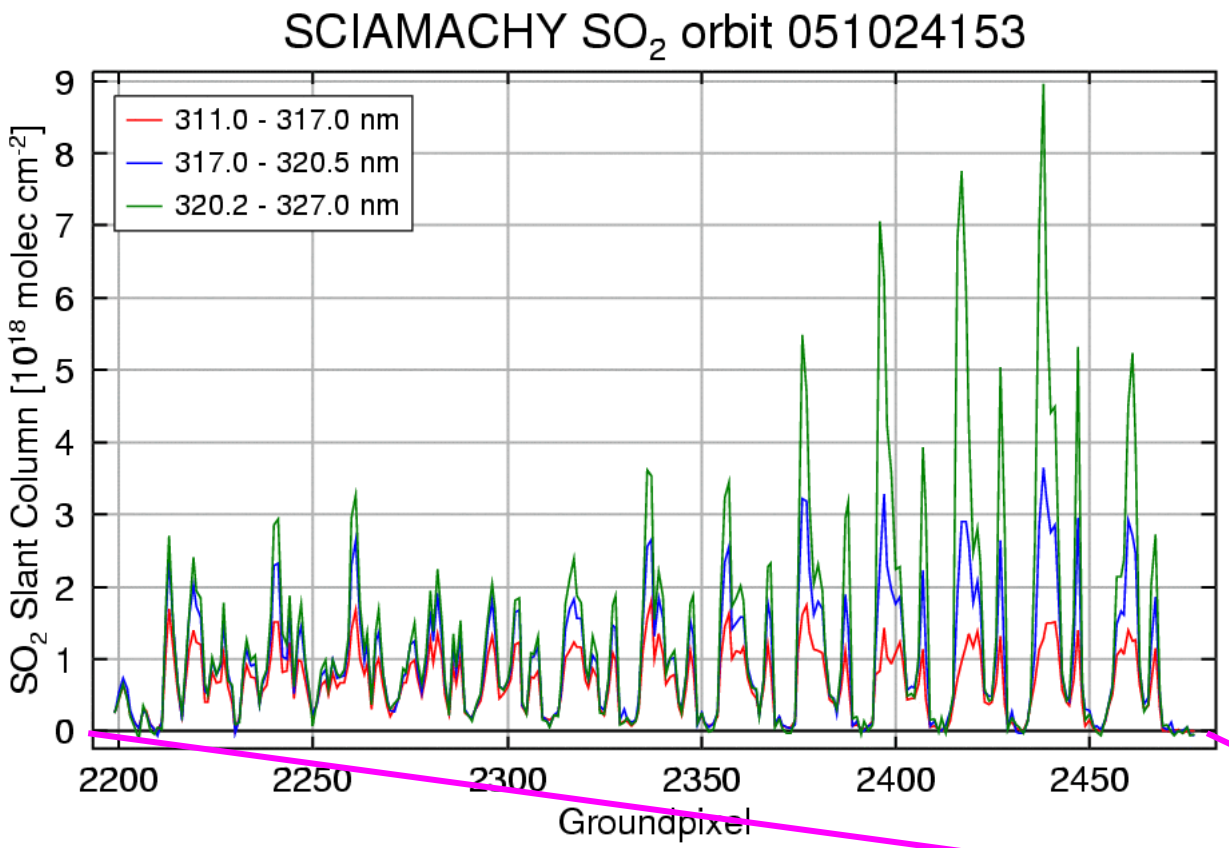
- Volcano on Galapagos Islands
- Eruption October 22 – 31, 2005
- very large amount of SO_2 emitted

SCIAMACHY SO_2 standard evaluation



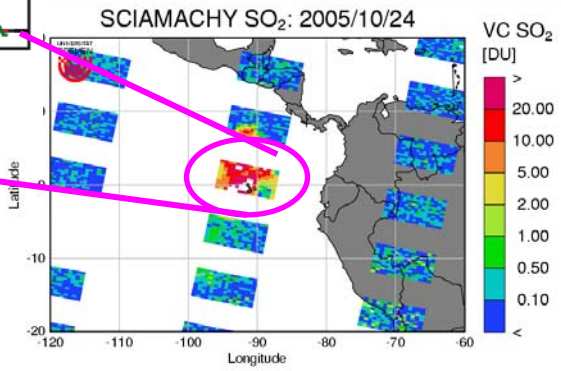
Universität Bremen
Andreas.Richter@iup.physik.uni-bremen.de

What is the wavelength dependence of the SO_2 signal?

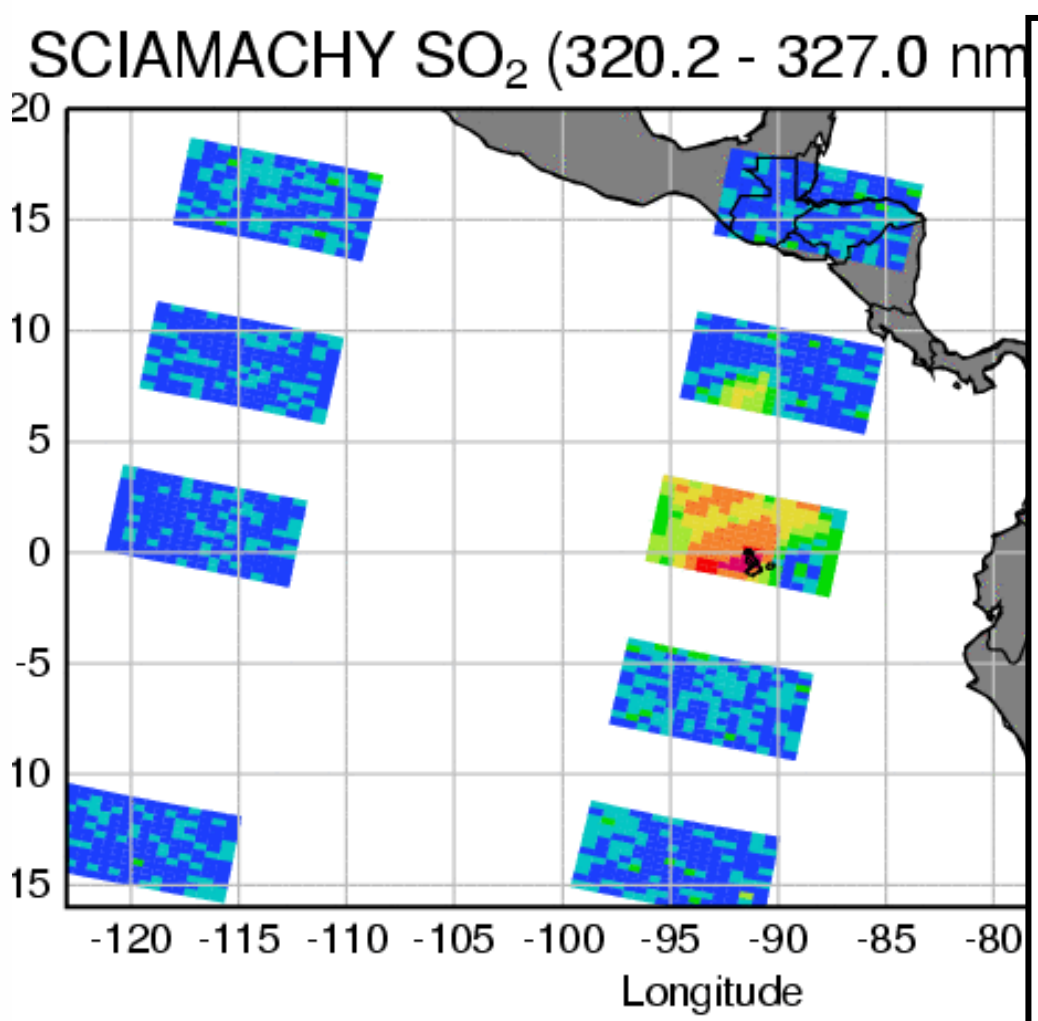


Observation:

- SO_2 slant column depends strongly on wavelength region
- effect of vertical sensitivity or saturation?



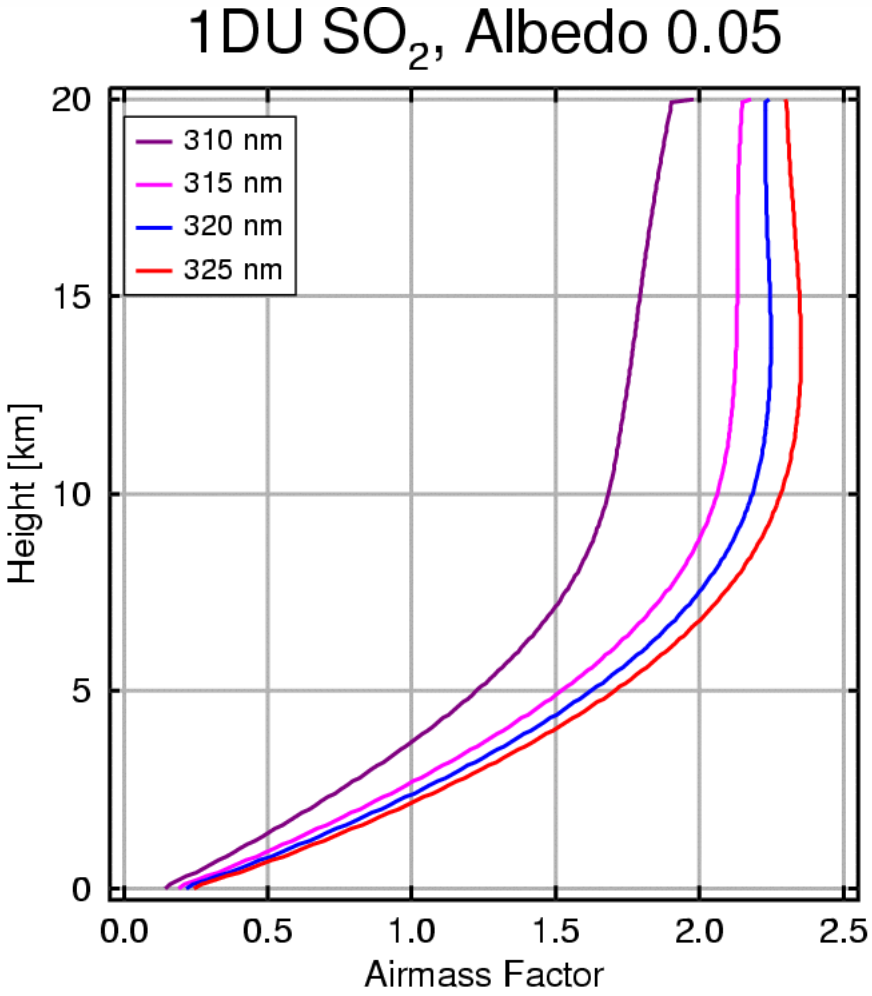
What is the wavelength dependence of the SO_2 signal?



Observation:

- standard AMF for 12 km layer, optically thin atmosphere used
- the shape of the plume looks different in the 320 – 327 nm window compared to the 311 – 317 nm and 317 – 320 nm regions
- largest columns (up to 120 DU!) only observed at longer wavelengths
- is this profile information or are we just getting “blind” at shorter wavelengths?

Wavelength Dependence of Airmass Factor



Settings:

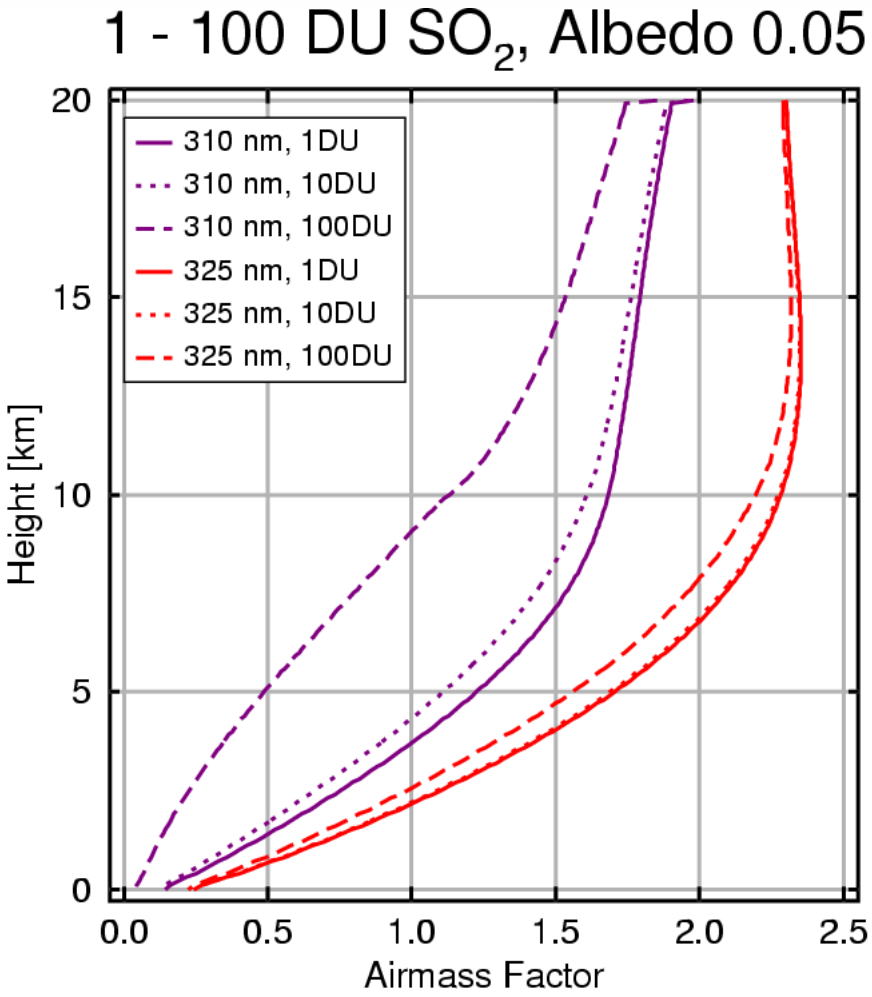
- 1 DU SO_2 well mixed in lowest 10 km
- no aerosols
- surface albedo 5%
- 40° SZA

Results:

- low sensitivity close to surface
- moderate wavelength effect

=> can not explain observations!

Column Dependence of Airmass Factor



Settings:

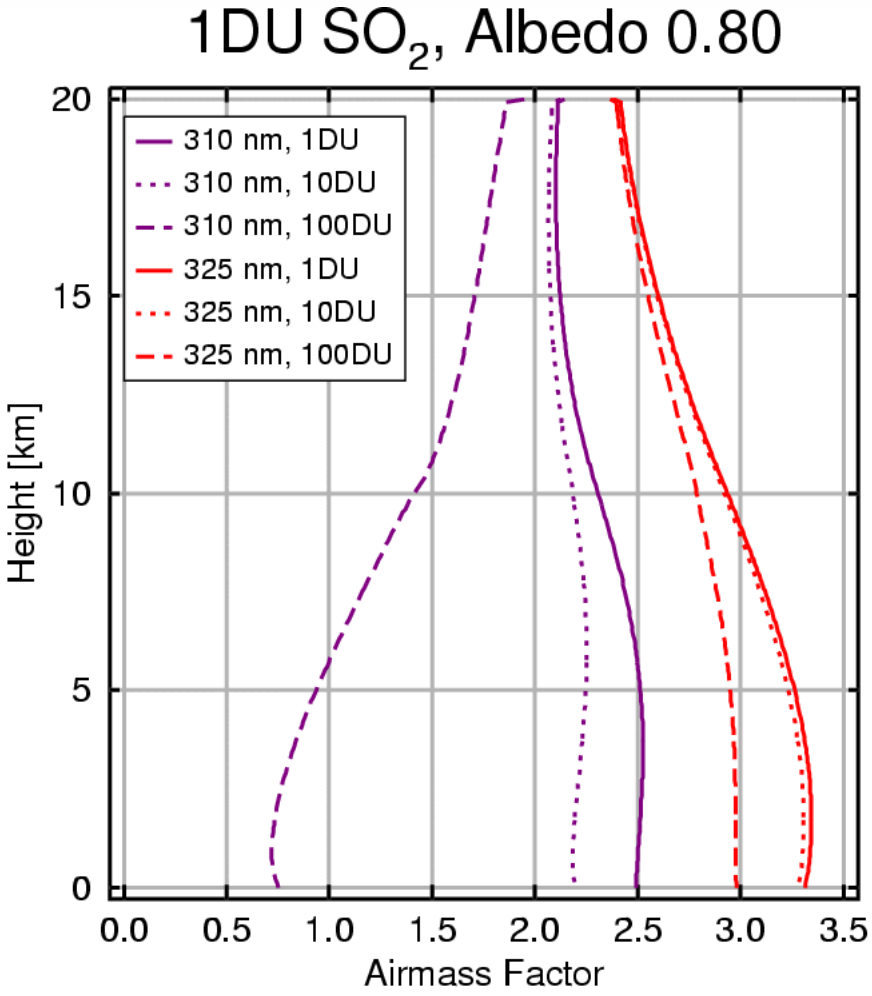
- 1 / 10 / 100 DU SO_2 well mixed in lowest 10 km
- no aerosols
- surface albedo 5%
- 40° SZA

Results:

- low sensitivity close to surface
- wavelength effect increases with SO_2 column

=> qualitatively consistent with observations!

Albedo Dependence of Airmass Factor



Settings:

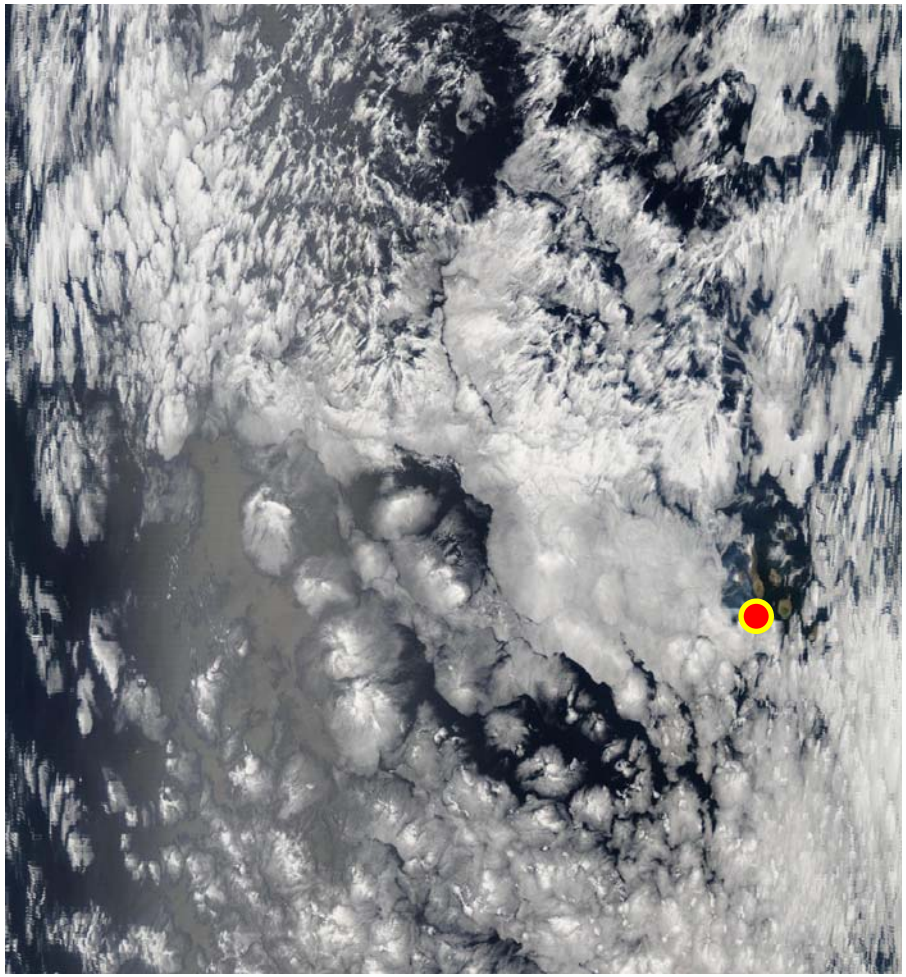
- 1 / 10 / 100 DU SO_2 well mixed in lowest 10 km
- no aerosols
- surface albedo 80%
- 40° SZA

Results:

- sensitivity close to surface high for large albedo
- wavelength effect increases again with SO_2 column

=> also qualitatively consistent with observations!

Cloud Contamination on October 24, 2005

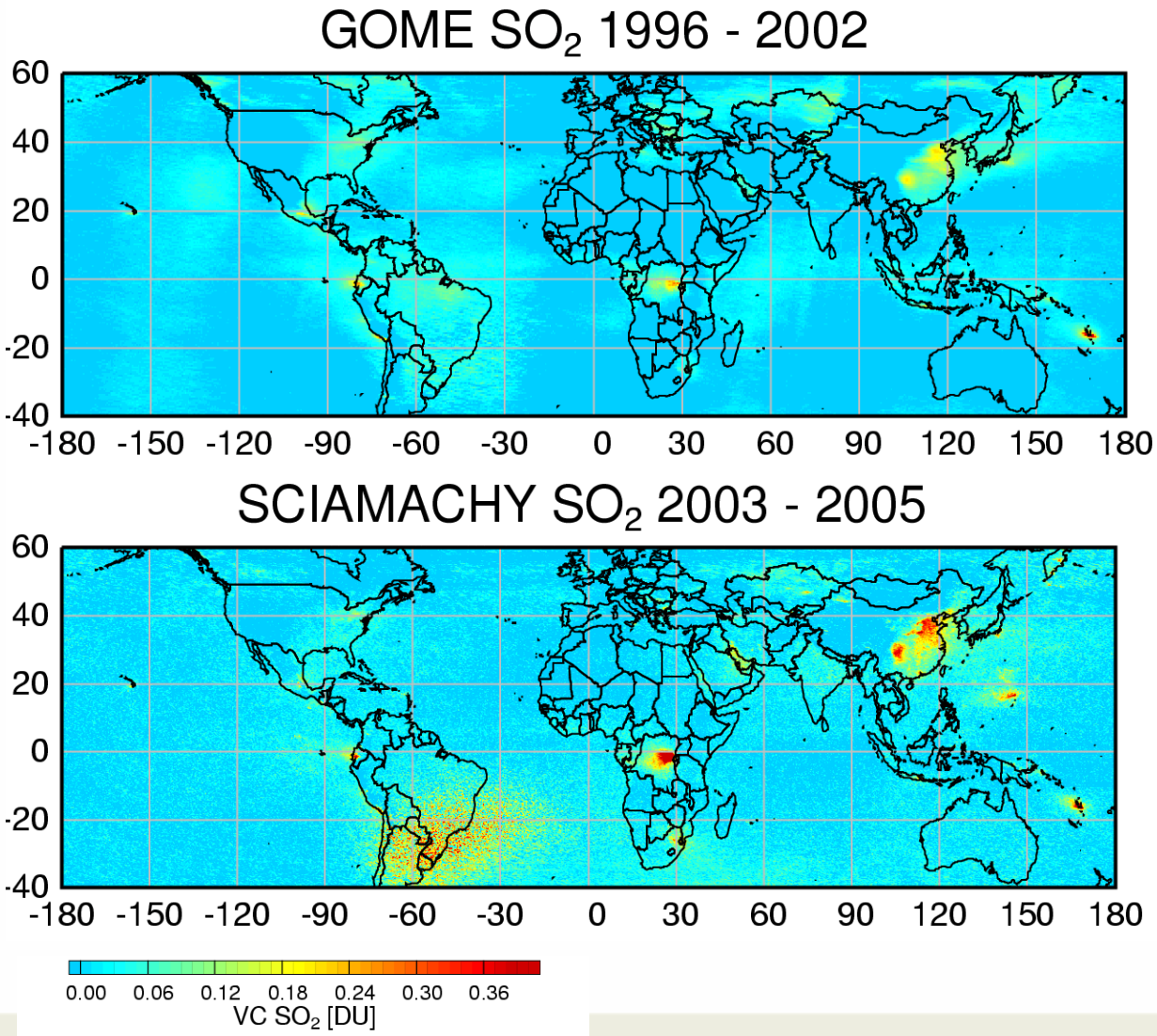


The Moderate Resolution Imaging Spectroradiometer (MODIS) flying onboard the AQUA satellite took this picture on October 24.

=> measurements are strongly cloud contaminated

http://rapidfire.sci.gsfc.nasa.gov/realtime/single.php?2005297/crefl2_143.A2005297195500-2005297200001.2km.jpg

Comparison of GOME and SCIAMACHY SO_2 I

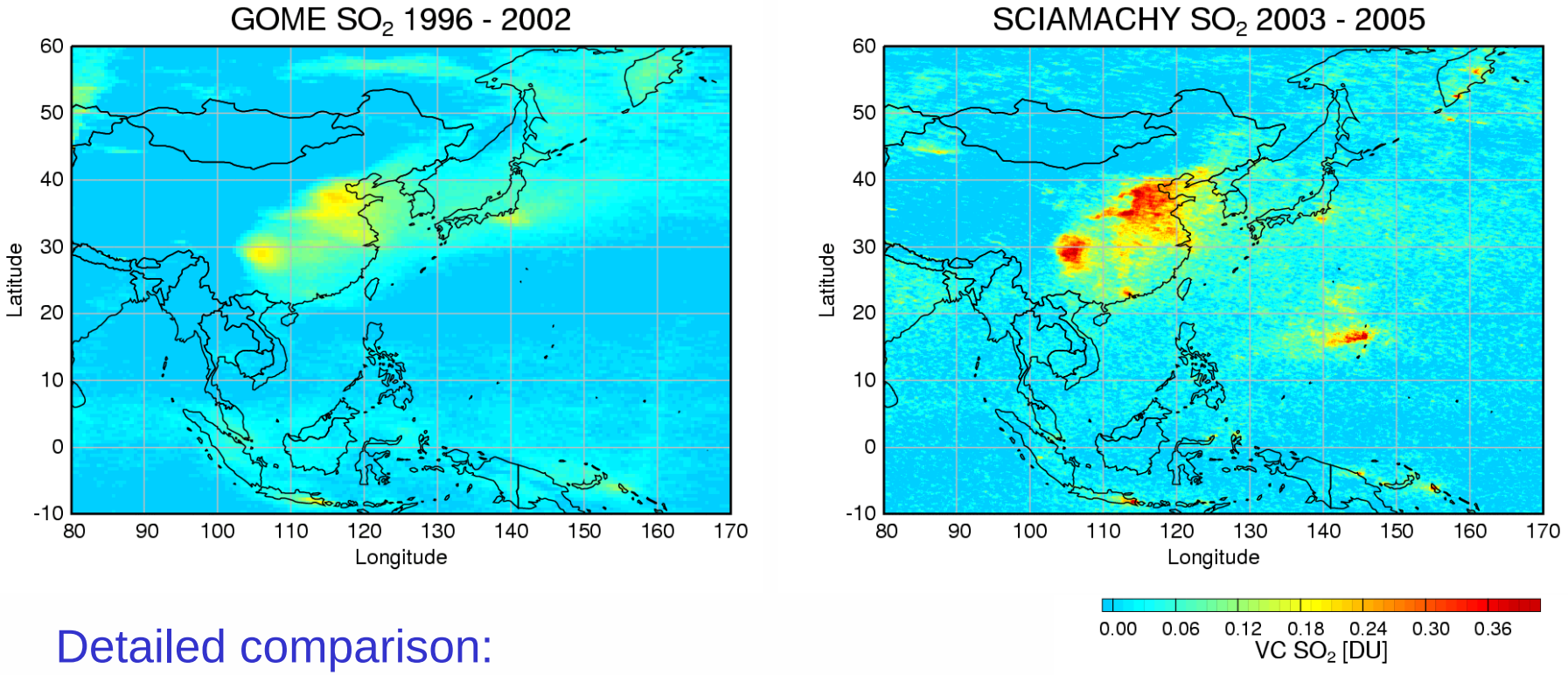


SCIAMACHY SO_2 has

- overall similar values
- less “stripes”
- more scatter (SAA)
- much more detail
- higher values over China
- slightly reduced columns over Europe and the US? (=> work by M. Khokar at IUP Heidelberg)

Universität Bremen
Andreas.Richter@iup.physik.uni-bremen.de

Comparison of GOME and SCIAMACHY SO_2 II



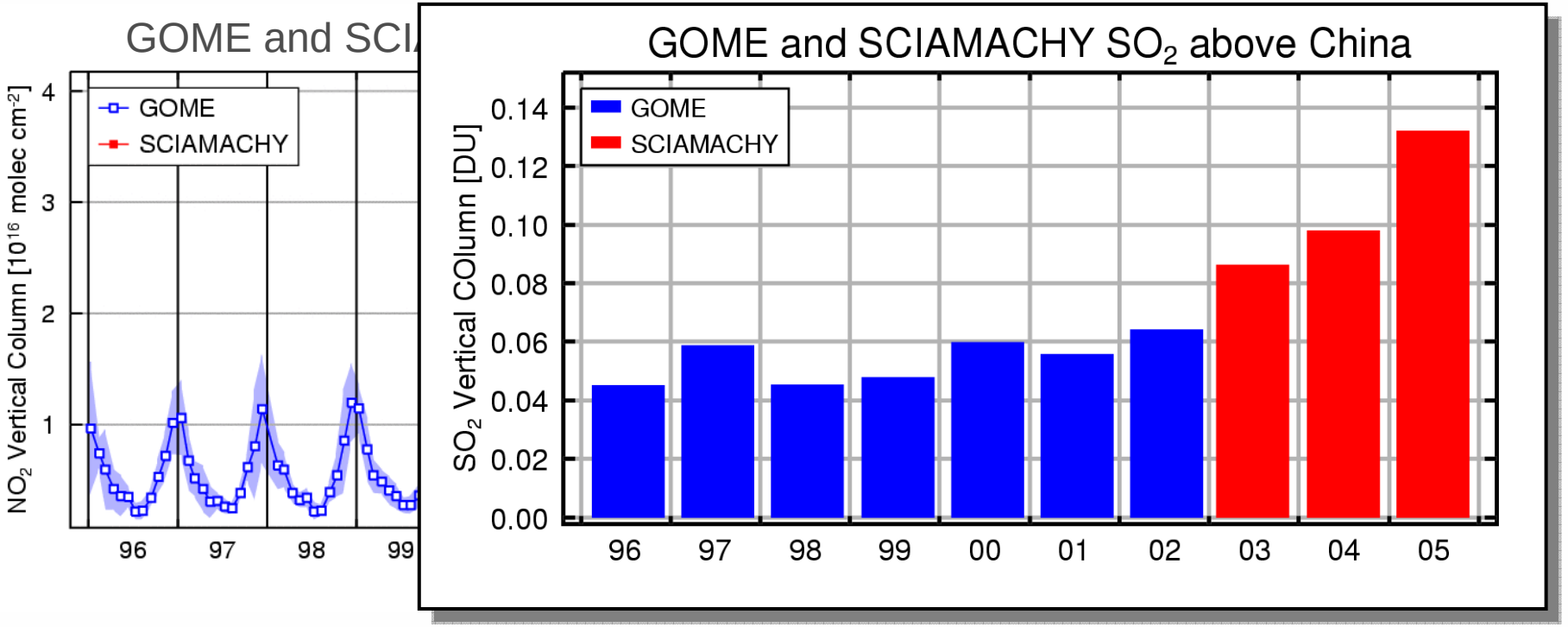
Detailed comparison:

- good overall agreement in pattern
- more fine structure
- more individual source discernible
- increase in values over China

all values still based on "volcanic profile"!

=> underestimation of up to a factor of 2 possible!

Changes of SO_2 above China



=> there is indication for an increase in SO_2 columns above China

but:

- there is much more scatter in the data than for NO_2
- there is much more interannual variability than for NO_2
- this is not yet a quantitative result!

Summary

- SCIAMACHY SO_2 maps show many clear signatures from volcanoes and different large pollution sources
- the improved spatial resolution is a significant step forward compared to GOME measurements
- at large SO_2 columns, the airmass factors become strongly wavelength dependent but as a complex function of albedo, altitude and vertical SO_2 distribution => potential for profile retrieval
- GOME and SCIAMACHY SO_2 columns show good qualitative agreement
- over China, the combined data set indicates a strong increase in emissions, but with large uncertainties
- for air quality and hazard monitoring applications, much higher measurement frequency is needed than once every 6 days

More on SO_2 at the Conference:

Check the posters on SO_2 retrieval:

- **Muhammad Fahim Khokhar (IUP Heidelberg)**: Spatial analysis of anthropogenic SO_2 emissions monitored by GOME on ERS-2
- **Jos van Geffen (IASB/BIRA)**: Monitoring of sulphur dioxide emissions from satellite as part of GSE PROMOTE
- **Werner Thomas (DLR)**: Monitoring volcanic activity from space: Retrieval of sulphur dioxide plumes from ERS2/GOME backscatter data