University of Leicester

MIPAS observations of Sarychev Peak: Plume detection and sulphate aerosol formation

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1. MIPAS detection of cloud & aerosol particles

- The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) on ESA's ENVISAT (operational from March 2002 to April 2012) is a limb-sounding Fourier Transform Spectrometer that measured thermal emission spectra from the Earth's limb (figure 1).
- A spectral resolution of 0.0625 cm^{-1} (between 4.15µm – 14.6 µm) and a vertical resolution of ~1.5 km in the upper troposphere and lower stratosphere (UTLS) makes it ideal to study volcanic pollution events reaching the stratosphere.

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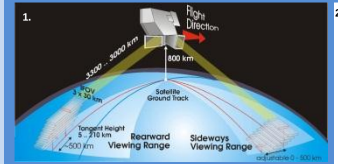

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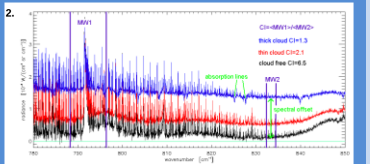

- MIPAS cloud/aerosol detection is based on a cloud index (CI) which is the ratio of 788.20 – 796.25 cm^{-1} ("control") and 832.3 – 834.4 cm^{-1} (cloud/aerosol) spectral regions (figure 2).
- Behaviour of CI modifies with cloud/aerosol influence, i.e. CI values from 1 to 10 describe transition from optically thick cloud/aerosol influence to clear-sky background conditions.
- New cloud/aerosol detection thresholds for the CI have been developed at the University of Leicester specifically to account for the high sensitivity of cloud/aerosol particles in the MIPAS field of view (Sembhi et al, 2012, Spang et al, 2012).
- Cloud and Aerosol top heights (CATH) derived with new detection thresholds show that MIPAS CATH are within 0.5 km to 1 km of those derived from HIRDLS and CALIOP.

2. Sarychev Peak : 11th June to 16th June 2009

- Strato-volcano located at 48ºN, 153ºE on the Kuril Islands, NE Japan
- Injected 1.2 ±0.2Tg of sulphur dioxide (SO_2) into UTLS (Haywood et al, 2010)
- Ash cloud injection estimated at altitudes ~ 8 to 16 km & 21 km (Rybin et al, 2011)
- Aerosols reached the Arctic altitudes < 7 days after the eruptions (O'Neil et al, 2012)
- Aerosol effective radius between 0.1 & 0.3 µm (Doeringer et al, 2012)

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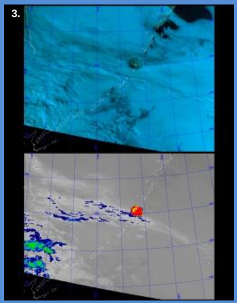

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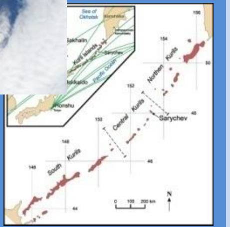
12th June 2009 Sarychev Peak eruption captured by astronauts on the ISS (figure 4).



AVHRR overpass at 2005 UTC on the 14th June 2009 (figure 3) captures Sarychev Peak eruptions (11 µm brightness temperature and pseudo-RGB image are shown). This explosion is thought to have reached > 16 km (Rybin et al, 2011).

3. MIPAS observations of Sarychev Peak

- **Vertical transport:** First Sarychev Peak signals observed by MIPAS from the 17th June 2009. CI profiles along-orbit track (figure 5) shows signatures of volcanic material captured up to 24 km.

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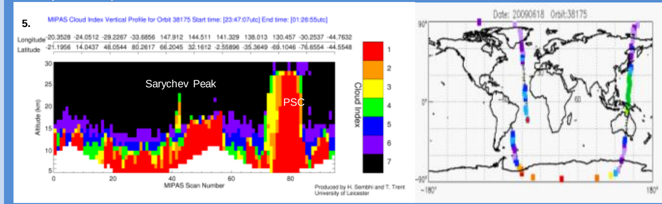

- Inter-comparison of longitude – altitude cross section (50°N to 60°N) of MIPAS CI (figure 6) and CALIOP scattering ratio (figure 7) for 16th July to 31st July 2009 shows good agreement in location of enhanced aerosol in the stratosphere (between 20 km and 24 km) following the eruptions.

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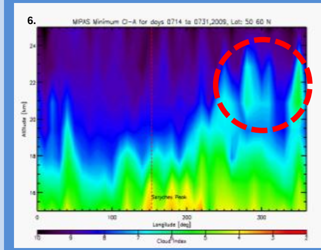

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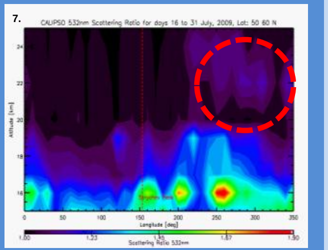

- **Inter-continental transport:** MIPAS initially observed 2 primary modes of plume dispersion followed by the development of a northern hemisphere aerosol layer.
- June & July 2009: CATH show eastwards-moving upper tropospheric layer (16 km to 18 km) over North Atlantic and North America. A westwards-moving stratospheric filament (20 km to 24 km) was observed moving towards Russia and Europe, eventually encircling the globe (figure 8).
- August 2009: CATH across the northern hemisphere increased from 12 km (pre-eruptive) to 16 – 18 km (post-Sarychev Peak eruptions). The CATH returned to pre-eruption levels by December 2009.

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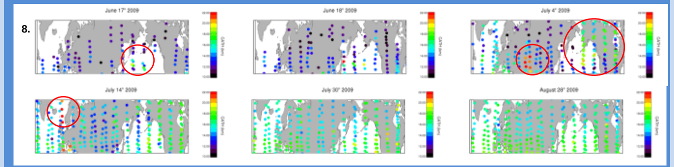

4.Spectral Identification

- Using MIPAS CI and CATH, spectral residuals of SO_2, sulphate aerosol (H_2SO_4) and ash can be separated (figure 9 to 12).
- Residual spectra = individual "plume" spectra – "control spectra"
- Plume spectra = 2< CI <6 and CATH > 15 km
- Control spectra = Averaged (~100) clear sky (CI > 6.5) pre-eruption MIPAS spectra collected from same latitude and same altitudes.

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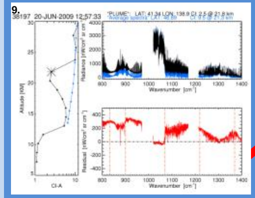

Figure 9. Example of plume (black) and clear sky (blue) CI profiles, MIPAS spectra and resulting residual (red)

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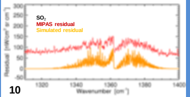

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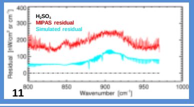

Comparisons of MIPAS spectral residuals and simulated SO_2 and H_2SO_4 residuals (figure 10 and 11) using the Oxford reference forward model (RFM), HITRAN aerosol (Massie et al, 2010) and HITRAN SO_2 cross sections.

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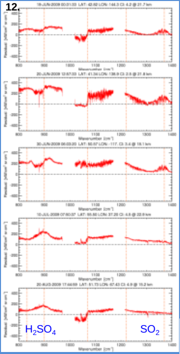

MIPAS residuals from June to August capture the transition of SO_2 to H_2SO_4 conversion with the decline in SO_2 feature centred on 1360 cm^{-1} and the increase in H_2SO_4 peak at 900 cm^{-1} (figure 12).

SO_2 & H_2SO_4 detection

Specific feature detection based on analysis of MIPAS residuals allows calculation of the distribution of SO_2 and H_2SO_4 across northern hemisphere (figures 13 and 14).

SO_2 = mean(1370:1375 cm^{-1}) > mean (1399:1400 cm^{-1})
H_2SO_4 = mean(900cm:903 cm^{-1}) > mean (820:830 cm^{-1}) & mean(955:960 cm^{-1})

MIPAS SO_2

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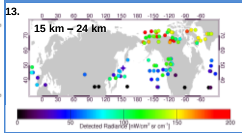

MIPAS H_2SO_4

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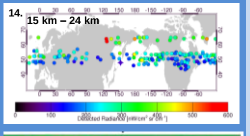

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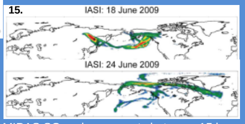

MIPAS SO_2 enhancements between 15 km and 24 km (figure 13) compares well with retrieved SO_2 columns from IASI as shown in Haywood et al, 2010 (figure 15).

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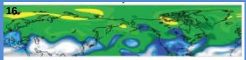

Positions of H_2SO_4 enhancements between 15 km and 24 km (figure 14) compares well with HADGEM2 sulphate aerosol calculations as shown in Haywood et al, 2010 (figure 16).

Summary

- MIPAS spectra provided high resolution vertical information on Sarychev Peak volcanic outflow as well as inter-continental mapping of the plume material.
- Spectral residuals indicate presence of SO_2 up to 22 km several days after the eruptions. H_2SO_4 signals were observed from ~10 days after the eruptions with enhanced CATH until November/December 2009.
- Volcanic ash proves to be more difficult to detect but there is some indication of ash-related spectral enhancements close to 950 – 970 cm^{-1} in MIPAS spectra.
- Results highlight how FTIR limb sounders can resolve the vertical structure of pollution in the UTLS

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