SO_2 and BrO observation in the plume of the Eyjafjallajökull volcano 2010: CARIBIC and GOME-2 retrievals

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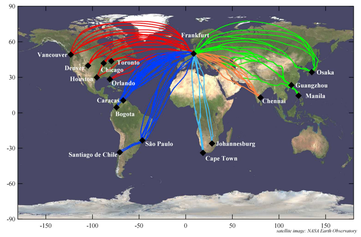
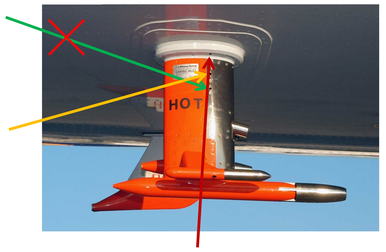
Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container

CARIBIC uses a Lufthansa Airbus A340-600 equipped with a dedicated air inlet system. The monthly deployment of the 1.5 ton measurement container on typically 4 intercontinental flights provides regularly detailed data for the UT/LS and tropical free-troposphere. Since December 2004 ~250 flights were successfully performed.



The inlet system has probes for trace gases, for aerosols, for gaseous water, and for total water. A DOAS system with 3 telescopes (-82°, -10° and +10°) is integrated. The fibre bundle connecting the +10° telescope with its spectrograph was broken and could not be replaced until December 2010. For cloud observation a video camera is installed in the inlet system as well.



Special flights for Eyjafjallafökull ash plume

During the airspace closure Lufthansa offered three special flights to CARIBIC to investigate the volcanic ash plume. During all three flights indications of the volcanic plume were observed.

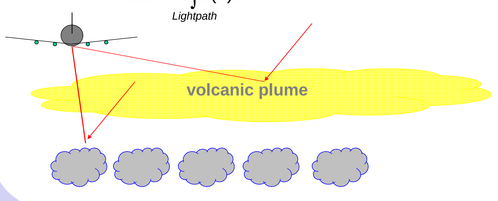
	DOAS	Aerosol Probe	OPC	Other
16.04.2010	SO_2 close to the detection limit	Enhanced concentrations of silicon, potassium, calcium and iron	Aerosol entering the boundary layer	--
16.05.2010	SO_2 and BrO observed		Failed	CO, NMHC
19.05.2010	Failed		Clear enhancement for all aerosol 125nm -1µm	CO, NMHC

The DOAS technique

DOAS is based on Lambert-Beers law, which describes the attenuation of light when crossing through an absorbing medium with the concentration c. Using a wavelength interval allows the retrieval of several trace gases simultaneously.

$$\ln\frac{I(\lambda)}{I_{FR}(\lambda)} = -\sum_{Tracegases}\sigma(\lambda)\cdot DSCD + P(\lambda)$$

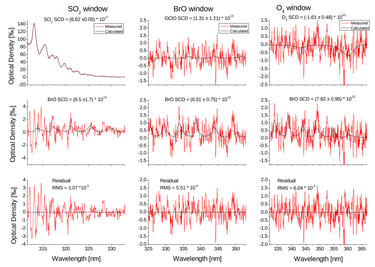
$$SCD = \int_{Lightpath} c(\vec{r})\,dr$$



For the retrieval of local concentrations the length of light path has to estimated. Therefore additional information e.g. cloud cover have to be assumed or estimated, based on other observations.

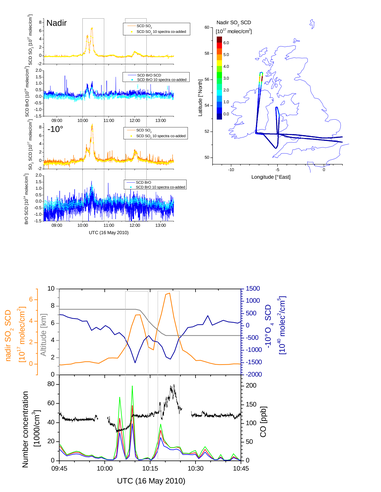
DOAS fit-results

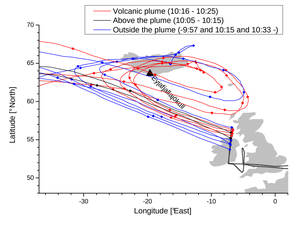
In the DOAS retrieval both SO_2 and BrO were found to be inside the plume. There seems to be a systematic structure in the SO_2 residual which might be caused by an imperfect O_3 fit. The SO_2 absorption however is so strong that the resulting error is small. In the Nadir viewing telescope the changes in the O_4 absorptions are less pronounced than in the -10°degree, however a small decrease is observed here as well. The BrO SCD for three different wavelength intervals agree very well. Other trace gasses like OClO or HCHO were always below the detection limit.

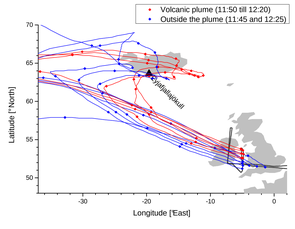


Plume observation

Enhanced SO_2 and BrO slant columns were found north of Ireland. The analysis of the aerosols samples (sample times indicated by the black boxes) showed clear evidence of volcanic aerosol and agreed well with the elemental composition reported for the ash of the Eyjafjallajökull.
However while around 10:00 UTC in the DOAS SO_2 and BrO data two peaks were observed the insitu data (CO and CPC) showed evidence for only one plume observation. Therefore we conclude that the Airbus first flew over the plume (7600m), before descending to the plume's altitude (4500m). This conclusion is also supplemented by the backward trajectory calculation, the air-masses of the first DOAS observation of the plume passed too far south of Iceland to be contaminated with volcanic tracers. There is also a second period of plume observation over the Irish sea south of the Isle of Man. A slight increase in SO_2 is found here as well as a similar aerosol elemental composition as for the first plume observation. As the airspace further north was blocked, the pilots were not allowed to fly deeper into this part of the plume.







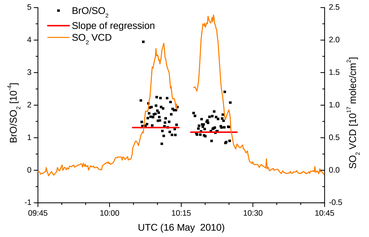
Results (mixing ratio)

For the simulation of the AMF we assumed certain cloud parameters (CTA =1.5 km and COT = 10) partly based on the CARIBIC video camera and or MODIS observations. The optical properties of the volcanic ash plume (SSA =0.95 and k=0.8km^{-1}) was retrieved from the DOAS O_4 measurements. For the volcanic plume an average concentration of ~5 ± 1.8 ppt BrO and 40 ± 1.2 ppb SO_2 between 3 and 6 km.

	BrO [ppt]		SO_2 [ppb]		BrO/SO_2 [10^{-4}]	
	-10°	Nadir	-10°	Nadir	-10°	Nadir
1st peak	4.9	4.3	29.3	35.3	1.69	1.22
2nd peak	6.0	4.5	49.7	45.7	1.21	0.98

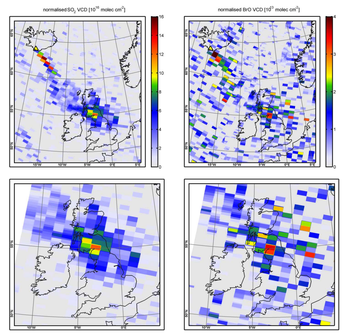
Results (BrO to SO_2 ratio)

The BrO to SO_2 ratio is around 1.3·10^{-4} and hence in the typical range observed for other volcanoes, although those observations were typically performed "close" to the crater (a few hours downwind). The difference between the ratios observed for the two peaks is not significant and therefore it does not contradict the increase in the ratio as observed or simulated by other studies.



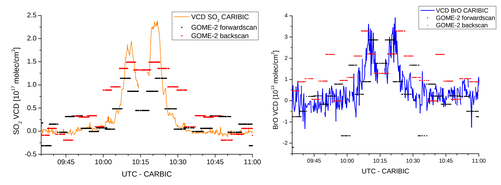
Satellite observation

Satellites instruments like GOME-2 or OMI observed the plume for a longer period and larger areas compared to CARIBIC. The plume north of Ireland is part of an old plume with its centre situated over northern England. A new plume approaches the British Isles from Iceland. The enhancements in SO_2 and BrO as observed by CARIBIC is also visible in the GOME-2 images.



CARIBIC GOME-2 comparison

For the direct comparison of CARIBIC and GOME-2 for each CARIBIC DOAS data point the surrounding GOME-2 pixels are shown. This results in the observed symmetry of the GOME-2 data in the respective "time series" as before and after the u-turn CARIBIC crossed the same GOME-2 pixels.



New Air Mass Factors were simulated for the GOME-2 observations which are based on the same settings as for CARIBIC DOAS for cloud properties, the volcanic aerosol layer and the altitude profile of the trace gases SO_2 and BrO. Both data-sets agree qualitative i.e. the position of the plume and the minimum north of the plume is observed in both data-sets. Also the maximum vertical column densities agree. However while for CARIBIC DOAS observations the BrO and SO_2 maximum are collocated, the maximum in BrO is shifted further north compared to the SO_2 in the GOME-2 data.
Due to the relatively high noise in the BrO data the calculation of the BrO to SO_2 ratio for GOME-2 data and the specific region did not result in a reasonable result. Therefore no comparison to CARIBIC and no spatial variability of these data are shown.

Conclusions

BrO and SO_2 were observed with the CARIBIC DOAS Instrument inside the plume of the Eyjafjallajökull on 16. May 2010. The average mixing ratio between 3 and 6 km altitude was 5 ppt BrO or 40 ppb SO_2 and a BrO to SO_2 mixing ratio of 1.3·10^{-4} was found. The vertical column densities agree well with collocated GOME-2 satellite observations, although the measurement error in the BrO data is quite high for both CARIBIC and GOME-2 observation.
More details are found in Heue et al. "**SO_2 and BrO observation in the plume of the Eyjafjallajökull volcano 2010: CARIBIC and GOME-2 retrievals", ACPD 2011 accepted for ACP.**
Please also visit our CARIBIC overview poster XY 164 **„The CARIBIC aircraft as a versatile tool for measuring Eyjafjallajökull's volcanic plumes in April/May 2010"** by Armin Rauthe-Schöch in the session **AS3.12 (Thursday 7 April 2011).**

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Please inspect the CARIBIC website (www.caribic.de) for more information and to see all the people behind the work.