Geophysical Research Abstracts
Vol. 13, EGU2011-10515, 2011
EGU General Assembly 2011

Early in-flight detection of SO_2 via Differential Optical Absorption Spectroscopy: A feasible aviation safety measure to prevent potential encounters with volcanic plumes

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Volcanic ash is a threat to aviation, mainly to jet engines with the risk of total engine failure. Other risks include abrasion of windshields and damage to avionic systems. These threats have been widely recognized since the early 1980s, when volcanic ashes provoked several near fatal incidents of engine failure of jet aircrafts (e.g. Mt. St. Helens, USA, 1980; Mt. Galunggung, Indonesia, 1982 and Redoubt volcano, USA, 1989). In addition to volcanic ash, also volcanic gases pose a threat. Prolonged and/or cumulative exposure of sulfur dioxide (SO_2) or sulfuric acid (H_2SO_4) aerosols potentially affects e.g. windows and airframes, and damage to engines has been recorded. SO_2 receives most attention because its presence above the lower atmosphere is a clear proxy for a volcanic plume and indicates that fine ash could also be present. One of the most recent examples of volcanic ash impairing aviation is the eruption of Eyjafjallajökull, Iceland, between March and May 2010, which led to temporal closure of the European air space. Although no severe incidents were reported, it affected an unprecedented number of people and economic losses are estimated to amount up to U.S. $1.7 billion.

Up to now, remote sensing of SO_2 via Differential Optical Absorption Spectroscopy (DOAS) in the ultraviolet spectral region has primarily been used to measure volcanic clouds from satellites and ground-based platforms. Here we present a set of experimental and modelled data showing the feasibility of DOAS to be used as an airborne early detection system of SO_2 distributions in two spatial dimensions. In order to prove the concept, simultaneous airborne and ground-based measurements were conducted at Popocatépetl volcano, Mexico, in April 2010. Popocatépetl is especially suited because its summit is at 5426m above sea level, thus volcanic gases are emitted above the boundary layer and at altitudes which allow extracting significant conclusions from the measurements because of its proximity to typical traffic airspace.

Ground based observations consisted of stationary instruments and traverse measurements, allowing to obtain plume height and wind direction relative to the source. The plume of Popocatépetl extended at an altitude around 5250m a.s.l., and was approached and passed through at the same flight level with forward looking DOAS systems aboard an airplane. These DOAS systems measured SO_2 in the flight direction and at 40mrad angles in both horizontal and vertical directions relative to it. The approaches started at distances up to 25 km from the plume and SO_2 was measured at all times well above the detection limit. The observations are combined with radiative transfer studies modelling the conditions at hand. The experimental data validate the radiative transfer modelling results. They indicate that, depending on flight height, an extended volcanic plume with a SO_2 concentration of 10^{12} molec/cm^2 can be detected at distances up to 80km away, providing a tool of early warning to pilots in order to avoid potentially dangerous approaches to aircraft-threatening volcanic plumes.