San Cristobal volcano, Nicaragua.

NOVAC

Network for Observation of Volcanic and Atmospheric Change

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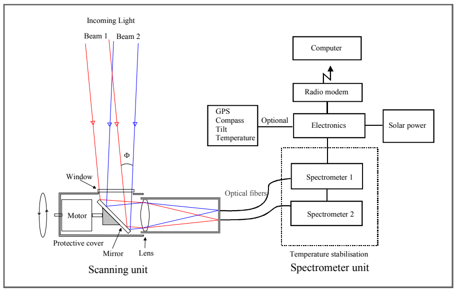

Figure 1. Schematic view of the optical layout of the Dual-Beam scanning mini-DOAS instrument. The prism and the protective cover is rotated around the optical axis of the telescope, thereby scanning the field-of-view of the instrument in a plane perpendicular to the optical axis.

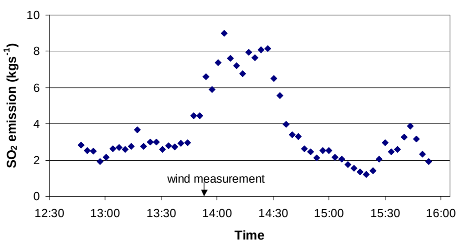

Figure 2. Time-resolved measurement of emissions from San Cristobal 23 November 2002, calculated using plume height and wind speed from Dual Beam mini-DOAS measurements.

Figure 3. Measurement of plume speed during the field campaign at Mt. Etna in May 2005, using a dual-beam mini DOAS system.

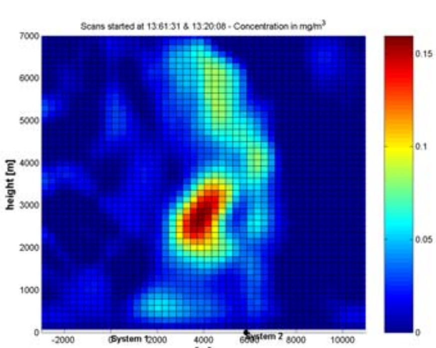

Figure 4. Two-dimensional vertical concentration measurement performed on the plume from Mt Etna on 18 September 2004. The altitude in the figure is relative to the scanning systems, which were situated at 950 m above sea level. From the plot one can conclude that the centre of the plume is at around 4000 meters height above sea level. The concentration is presented in mg/m3.

Introduction

NOVAC is a recently started project, funded by European Union, with the aim to establish a global network of stations for the quantitative measurement of volcanic gas emissions. The network is based on a novel type of instrument, the Scanning Dual-beam mini-DOAS, developed within the EU-project DORSIVA. Primarily the instruments will be used to provide new parameters in the toolbox of the observatories for risk assessment, gas emission estimates and geophysical research on the local scale. In addition to this, data are exploited for other scientific purposes than local volcanic gas emissions, e.g. global estimates of volcanic gas emissions, large scale volcanic correlations, studies of climate change, studies of stratospheric ozone depletion. In particular large scale validation of satellite instruments for observing volcanic gas emissions will be possible for the first time, allowing to bring observation of volcanic gas emissions from space a significant step forward.

The Scanning Dual-beam Mini-DOAS instrument represents a major breakthrough in volcanic gas monitoring; it is capable of real-time automatic, unattended measurement of the total emission fluxes of SO_2 and BrO from a volcano with better then 5 minutes time resolution during daylight. The high time-resolution of the data enables correlations with other geophysical data, e.g. seismic data, thus significantly extending the information available for real-time risk assessment and research at the volcano. By comparing high time resolution gas emission data with emissions from neighbouring volcanoes on different geographical scales, or with other geophysical events (earthquakes, tidal waves) mechanisms of volcanic forcing may be revealed.

The spectra recorded by the instrument will also be used to derive data that complement global observation systems related to climate change and stratospheric ozone depletion research.

The Dual-Beam Scanning mini-DOAS instrument

The basic mini-DOAS system consists of a pointing telescope fiber-coupled to a spectrograph. Ultraviolet light from the Sun, scattered from aerosols and molecules in the atmosphere, is collected by means of a telescope with a quartz lens defining a field-of-view of 12 mrad. Light is transferred from the telescope to the spectrometer by means of a optical quartz fiber. The spectrometer uses a 2400 lines/mm grating combined with a 50 µm slit, providing an optical resolution of ≈ 0.6 nm over a wavelength range of 245-380 nm.

In the Scanning mini-DOAS the telescope is attached to a scanning device consisting of a mirror attached to a computer-controlled stepper-motor, providing a means to scan the field-of view of the instrument over 180º, *Figure 1*.

In a typical measurement the instrument is located under the plume, and scans are made, from horizon to horizon, in a plane perpendicular to the wind-direction. Typically a 3 seconds integration time is used, with 3.6º angular resolution, providing a full emission measurement every 5 minutes. By adding a second spectrometer and fiber, simultaneous measurements can be made in two viewing directions.

In *Figure 2* is shown a time resolved measurement of the gas emissions from San Cristobal volcano in Nicaragua. A 3-fold increase in gas emission is seen over a time scale of 1 hour. Further studies of the gas emission from this volcano using the scanning mini-doas system have revealed cyclic degassing behaviour involving fluctuations of SO_2 fluxes on three superimposed time scales in the course of a day. Correlating these gas data with other geophysical data, e.g. seismic data, is likely to substantially increase our understanding of the status and behavior of this volcano.

Plume speed and plume height

The main source of error in both mobile and scanning mini-doas measurements, is determination of wind-speed at plume height. In the scanning measurements, also knowledge of the plume height is crucial in order to correctly calculate the number of gas molecules in a cross-section of the volcanic gas plume. For the wind measurements the dual spectrometers of the instrument are used to make simultaneous total column measurements of SO_2 in two different viewing directions, one beam pointing upwind and the other downwind the plume. A time series of total column variations are registered in both directions, and from the temporal delay in variations in the total column, the wind speed can be calculated, *Figure 3*. For the plume height measurement the plume is simultaneously monitored by 2 scanning mini-DOAS instruments separated by some distance, and a vertical cross section of the gas concentration is derived using tomography, *Figure 4*. Besides giving the plume height, these data can be used to study the plume dynamics and in combination with a dispersion model assess the impact of the gas emissions on the local environment.

Measurement of additional molecules

As the mini-DOAS instrument registers a broad band spectrum it is possible to expand the measurements to more compounds. An example of this is our recently demonstrated possibility to simultaneously measure SO_2 and BrO from volcanic gas spectra, *Figure 5*. This opens up the possibility to make time resolved measurements of the ratio BrO/SO_2, another parameter that may be used to understand volcanic degassing and eruptive style. An important problem when using scattered Sunlight to study volcanic gas emissions is multiple scattering of the Solar light in aerosols and clouds. Depending on the conditions this effect may result in serious over- or underestimation of the emissions/concentrations. During the past decade significant improvements in radiative transfer modelling and understanding of multiple scattering processes in clouds have been achieved. In combination with the measurement of O_4 column densities by the mini-DOAS, precise correction of errors due to multiple scattering may be made.

Studies of stratospheric and tropospheric composition

The instrument is recording spectra of the sky in a wavelength band that is also used for studies of atmospheric gas composition. Examples of this are studies of stratospheric gas composition (O_3, NO_2, BrO) and the recently developed technique of MAX-DOAS for studies of tropospheric gases (SO_2, O_3, NO_2, CH_2O). Several global networks using these techniques for global atmospheric studies related to stratospheric ozone depletion (NDSC), and climate change (IANABIS) are already established or presently under development. NOVAC will make a valuable complement to these networks, especially in remote areas where active volcanoes are frequently found, *Figure 6*.

Satellite Validation

Many volcanoes with strong gas emission are located in remote places with no regular gas measurements, *Figure 7*. Also in the initial phase of a new major eruption it may take time before any ground-based measurements may be undertaken. In these situations satellites may provide the only way to obtain estimates of the gas emissions. This project will provide an excellent opportunity to validate both the total column data derived from the satellites and the algorithms used to estimate the emissions.

The Consortium

The consortium encompasses observatories of 15 volcanoes from five continents, including some of the most active and strongest degassing volcanoes in the world, *Table 1*. As our ambitions are to expand the network, additional observatories are invited to join. Contact: bo.galle@rss.chalmers.se

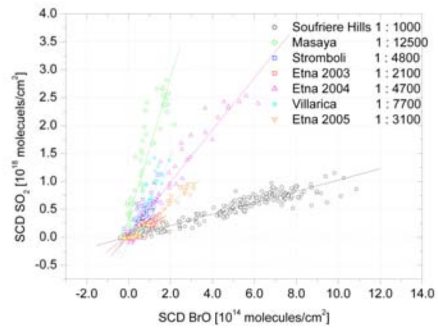

Figure 5. The relationship between SO_2 and BrO measured on 5 different volcanoes measured with a scanning mini-DOAS instrument [Bobrowski *et al* 2003].

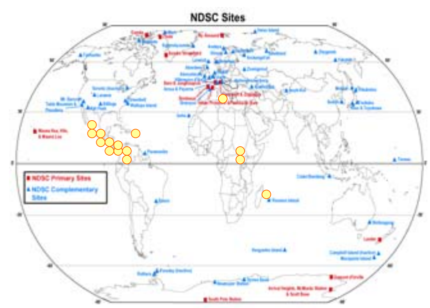

Figure 6. Map showing the 15 volcanoes involved in NOVAC (circles). Also shown are the current coverage of the Network for the Detection of Stratospheric Change. Note that very few NDSC stations are located near the equator.

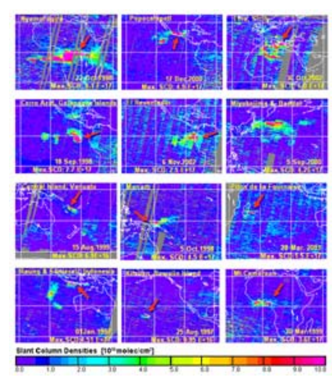

Figure 7. Examples of SO_2 plumes of various volcanoes measured by satellite during the period 1996-2002. Note that 4 of these volcanoes are part of the NOVAC network. [Khokar *et al* 2004]

Institute	Volcanoes
Institut de Physique de Globe de Paris	Piton de Fournaise La Soufrière, Guadeloupe
Istituto Nazionale di Geofisica e Vulcanologia, Italy	Mount Etna
Universidad Nacional Autonoma de Mexico	Popocatepetl Fuego de Colima
Instituto Nicaragüense de Estudios Territoriales	San Cristobal Masaya
Observatorio Volcanologico y Sismologico de Costa Rica	Arenal Poas
Instituto Colombiano de Geologia y Mineria	Galeras Nevado del Ruiz
Servicio Nacional de Estudios Territoriales, El Salvador	Santa Ana San Miguel
Goma Volcano Observatory, Dem Rep. Congo	Nyiragongo Nyiamuragira

Table 1. Institutes and volcanoes presently constituting the NOVAC network.

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