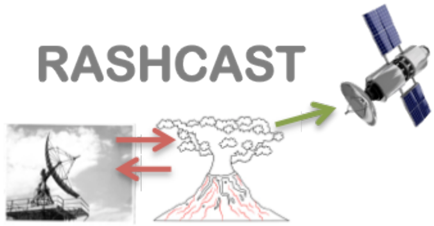
1. PUBLISHABLE SUMMARY



Summary description

The explosive ***eruptions of active volcanoes*** with consequent formation of ash clouds represent a severe threat in several regions of the urbanized world. The injection of large amounts of fine and coarse ash and rock fragments and corrosive gases into the troposphere is usually followed by a long-lasting ash-fall that can cause a variety of damages. Given the significance of the hazards posed by volcanic ash, timely detection and tracking of the erupted ash cloud is essential to a successful warning process, particularly during and immediately following an eruptive event.

Nowadays, the increasing availability of ***remote sensing observations*** from ground and space-based platforms allows monitoring the volcanic activity on regional and global scales in real or near-real time. ***Forecasts of volcanic ash paths*** in the atmosphere are also routinely accomplished after eruptions with the use of Volcanic Ash Transport and Dispersion Models (VATDMs), which make use of numerical weather prediction (NWP) models to describe the evolution of the spatial and temporal state of the atmosphere. These models require input parameters of meteorological type (e.g. outputs of weather forecasts) and ***volcanic near-source parameters*** (e.g. Ash concentration, mass eruption total gain size distribution etc.). These parameters should be known accurately and continuously; otherwise, strong hypothesis are usually needed, leading to large uncertainty in the dispersion forecast.

A two-year research study has been accomplished under the ***Marie Curie IEF FP7-RASHCAST project*** *(RADAR-based ASH monitoring and foreCASTing by integrating remote sensing techniques and volcanic plume models)* trying to increase the joint quantitative use of satellites and ground observations and volcanic plume models for producing ash estimates during a volcanic eruption event.

Description of the work

This work has addressed on the use of remote sensing observations and volcanic plume models to extract volcanic near-source parameters. The sensors used are the ground-based microwave weather radar operating at C (SPC at wavelength: 5.4 cm) and X band dual polarization radar (DPX at wavelength: 3.2 cm) and the SSMIS space-borne microwave radiometer operating in several channels at wavelengths from 0.16 to 1.6 cm.

Observations are used together with forward-model simulations to establish simulated relationships between near source parameters and sensor's outputs. Model simulations are based on the two-dimension version from the numerical plume model Active Tracer High-Resolution Atmospheric Model (ATHAM), in conjunction with the radiative transfer model Satellite Data Simulator Unit (SDSU) that is based on the delta- Eddington approximation which includes Mie scattering. The study area is the Icelandic subglacial volcanic region and the analyzed case study is that of the Grímsvötn eruption in May 2011. **Figure 1** shows the data set used for this study. It includes radar and satellite observations and ATHAM model simulations of the Grímsvötn eruption in 2011 as reported in the figure's caption. All the data synthetically shown in figure 1 are used to derive quantitative estimation of ash concentration within the volcanic plume. It is worth to note that, with respect to other studies, in this work instruments working at microwaves are used. This aspect implies that the microwave optical depth of the ash cloud is relatively low compared to that at visible and/or infrared wavelengths, allowing to the ash estimates to be sensible to layers inside the volcanic cloud instead that at its edges.

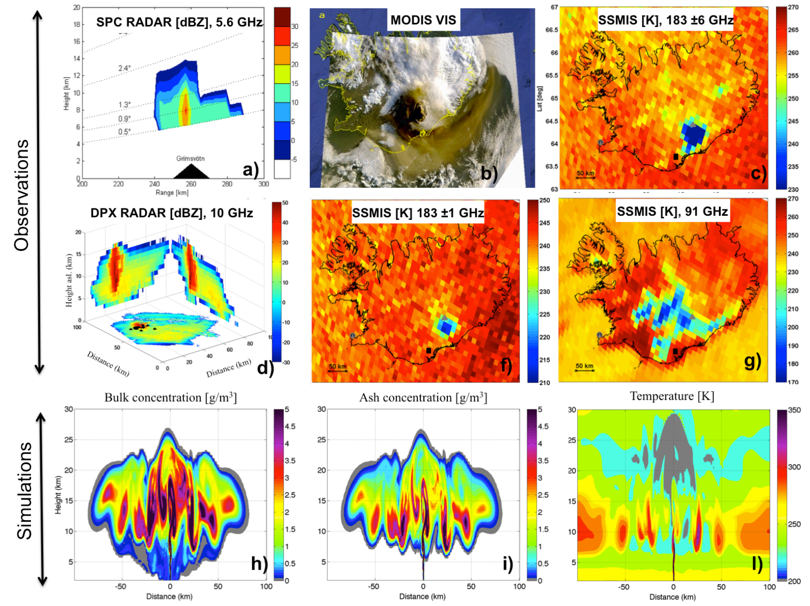


Figure 1: Observations of the Grímsvötn eruption on May 22, 2011. (b) Geolocated image taken over Iceland, acquired from the MODIS aboard the Aqua satellite, at 1-km resolution on 05:15 UTC (courtesy of Jeff Schmaltz of MODIS Rapid Response Team). (a) and (d) Vertical cross section showing the Keflavík single polarization C-band (SPC) and mobile dual polarization X band (DPX) radar reflectivity (in decibels of Z_{HH}) at 08:35 UTC. (c)–(f)-(g) Brightness temperature (BTs, in Kelvin) images at 08:34 UTC and frequency (in GHz) per-polarization-state values of (183 ± 6)/H, (183 ± 1)/H, 91/V, respectively, acquired by SSMIS aboard the F-16 DMSP satellite. (c)–(g)-(f) Position of the Grímsvötn volcano the Keflavík C-band and the mobile X band radar are indicated with the gray symbols " Δ" and "◦," and "□", respectively.

Results achieved

One of the main results achieved in the RASHAST project is shown in figure 2. It shows a quantitative comparison between the brightness temperature BT_H in [K] from SSMIS space radiometer and ash Total Columnar Concentration (*TCC*) in [kg/m^2] from DPX and SPC radars.

TCC is a radar product derived by the ***Volcanic Ash Radar Retrieval*** (***VARR***) algorithm. In the case of SPC, the version of VARR for single polarization radar systems, VARR-SP, is used considering only the radar reflectivity: Z_{HH}. On the other hand, for the dual polarization radar, labeled DPX, VARR-PX version is used together with additional polarimetry radar variables namely, differential signal phase shift K_{DP} and cross correlation coefficient ρ_{HV}. To allow a better evaluation of the results, *TCCs* are averaged on the same reference grid of SSMIS to match its coarser grid resolution (of the order od 12.5 km instead of a radial spacing of 200 m and 2 km for the DPX and SPC radar, respectively). The SSMIS channel used for the comparison is that at 183 ± 6 GHz. An inverse relationship to convert BT_H [K] into *TCC* [kg/m^2] is evident in the upper left panel of figure 2, even though strong differences exists for SPC and DPX comparisons. This is due to the different geometry of view of the two radars that implies a different sampling strategy of the scene. Overall, figure 2 highlights as a measure of satellite brightness temperature can in principle provide a quantitative estimate of columnar ash concentration. The *TCC* estimate's validation is a difficult task that is planned for a future work subjected to validation data availability.

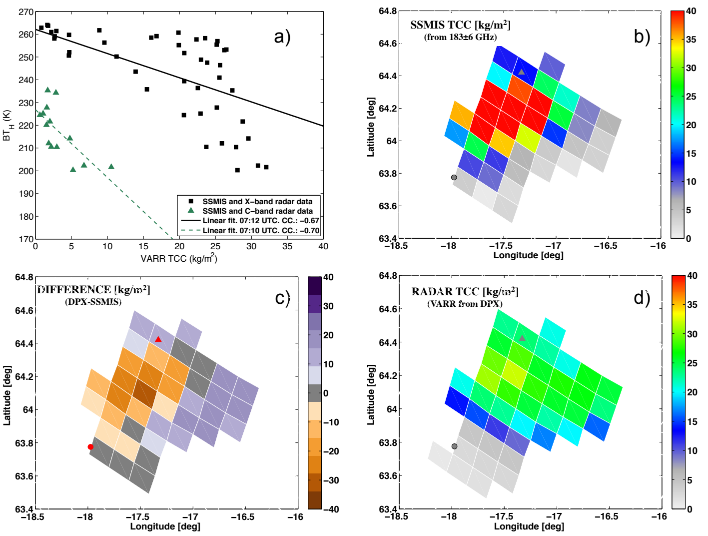


Figure 2: Panel a): brightness temperature re at horizontal polarization (BT_H) [K] from SSMIS versus the Total Columnar Content (*TCC*) [kg/m^2]. *TCC* is estimated through the Volcanic Ash Radar Retrieval (VARR-PX) technique using X-band Dual Polarization (DPX) and C-band Single Polarization (SPC) radar. DPX and SPC data are acquired at 07:12 UTC and 07:10 UTC, respectively on May 22nd 2011 at the Grímsvötn site. Panel b): Retrieval of *TCC* from SSMIS using the channel at 183± 6 [GHz] and the linear relation shown by solid red line in panel a). Panel c): Retrieval of *TCC* from DPX data using the VARR and Z_{HH}, K_{DP} and ρ_{HV} radar variables. Panel d) Difference map: estimates in panel c) minus that in panel b).

Potential impact and use

Scientific impact. While satellites are providing an ideal way of monitoring the volcanic cloud sweeping across Europe recently, ground-based measurements such those performed by LIDARs and RADARs have also been providing a valuable source of information to help scientist and experts to assess ash cloud processes and their monitoring. In this respect, relevant scientific impacts of RASHCAST are represented by the opportunity to estimate, with a given degree of accuracy, the main characteristics of the ash cloud (e.g. ash particle shape and size distribution) and the quantification of the ash cloud content and its thickness with high spatial and temporal resolutions (e.g. using in synergy the ground based microwave RADAR and the satellite radiometers). These achievements, even though at an early stage and with large uncertainty, provide a significant step forward to the comprehension of the dynamic processes of the ash clouds as well as, in a long-term perspective, a better understanding of the volcanic and geological processes.

Socio-economical impact. Volcanic eruptions are responsible for great social losses in the sense of human life, property and economy. The RASHCAST project aimed to bring a significant benefit to: i) air traffic related economy through new methodologies that fully exploit the observations (e.g. VARR) and models providing inputs to quantitatively predict ash cloud paths in the atmosphere; ii) help the diagnosis of health effects due to ash aspiration, through a better characterization of the emitted ash particles and the areas mainly affected by ash-falls. Risk mitigation and improved resilience is implicitly covered by the achievements of this project, which provided a demonstration tool, which integrates models (e.g. ATHAM) and observations (RADARS and RADIOMETERS) for helping decision-making activities during periods of ongoing volcanic crisis.