CGMS-39 EUM-WP-30
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Prepared by EUMETSAT
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Discussed in WGII

EUM REPORT ON CAPABILITIES AND PLANS TO SUPPORT VOLCANIC ASH MONITORING

In response to CGMS action WGII 38.31:

CGMS satellite operators are invited to report on a regular basis on their capabilities and plans to support volcanic ash monitoring, including the development of relevant products and techniques for utilisation, in order to inform the relevant ICAO and WMO bodies: the WMO/IUGG Volcanic Ash Scientific Advisory Group and the ICAO International Volcanic Ash Task Force/International Airways Volcanic Watch Operations Group (IVATF/IAVWOPSWG). Report at CGMS-39.

Following the raised interest in quantitative volcanic information derived from satellite observations after the 2010 Eyjafjalla eruption, EUMETSAT commissioned two science studies with the aim to explore the information content of the Metesoat Second Generation (MSG) observations in this respect. It was shown that total ash loading can be retrieved with good detection capabilities and accuracy, while other parameters need a more sophisticated approach.

This paper provides a short summary of the two studies, including some sample results and presents the EUMETSAT plans with respect to an operational availability of volcanic ash products. The paper also summarises the volcanic ash related activities based on Metop data.

Recommendation proposed: CGMS-39 WGII to take note.

EUM Report on Capabilities and Plans to Support Volcanic Ash Monitoring

1 INTRODUCTION

The April and May 2010 eruption of the Eyjafjalla volcano in southern Iceland rather unexpectedly caused major disruptions to aviation in large parts of Europe, resulting in economic difficulties that were felt around the globe. This event resulted in a sharp increase in interest concerning satellite based volcanic ash products – both qualitatively and quantitatively.

EUMETSAT conducted two science studies in 2010 with the aim to explore the potential of the Meteosat Second Generation (MSG) data to provide quantitative ash (and possibly SO_2) information. This paper summarises the two study concepts and their outcome and the EUMETSAT plans in this area.

2 QUANTITATIVE VOLCANIC ASH AND SO_2 RETRIEVAL STUDIES

2.1 Study with SAVAA-NILU

A first science study was conducted with SAVAA-NILU (Support to Aviation for Volcanic Ash Avoidance – Norwegian Institute for Air Research). The already existing SAVAA-NILU algorithm, as e.g. published in

> Prata, A.J. and J. Kerkmann, 2007: Simultaneous retrieval of volcanic ash and SO2 using MSG-SEVIRI measurements. ***Geophys. Res. Lett.***, **34**, L05813, DOI: 10.1029/2006GL02869.

was applied to the Eyjafjalla eruption and compared to other space and ground based measurements taken during this event.

The volcanic ash detection relies on the so-called reverse absorption effect in the atmospheric window channels between 10 and 12 µm wavelengths, as illustrated in Figure 1. For MSG-SEVIRI, the important channels are IR10.8 and IR12.0 with their measured brightness temperatures BT10.8 and BT12.0.

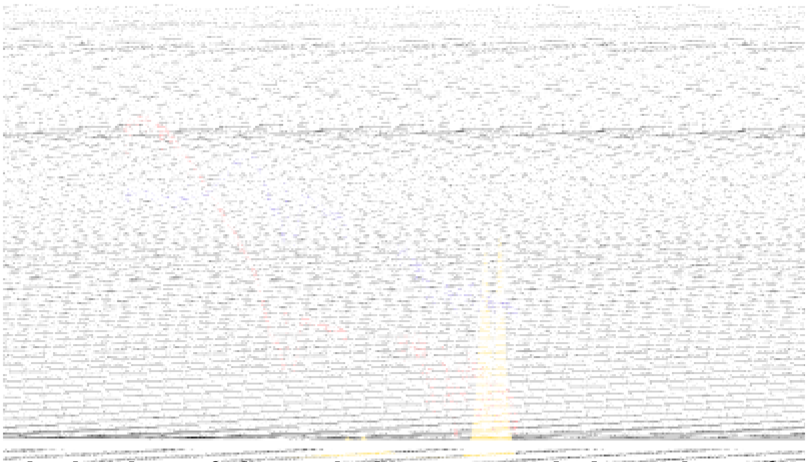

Figure 1: MSG IR filter functions (black), ice and ash absorption strength (red and blue) and SO2 absorption (yellow).

The baseline of the method is to pre-calculate values of BT10.8 and BT12.0 for various combinations of ash cloud optical depth and effective particle size and to store these results in large lookup tables. Any measured pair (BT10.8, BT12.0) can then find a solution for optical depth and particle size in these tables. Figure 2 illustrates the concept.

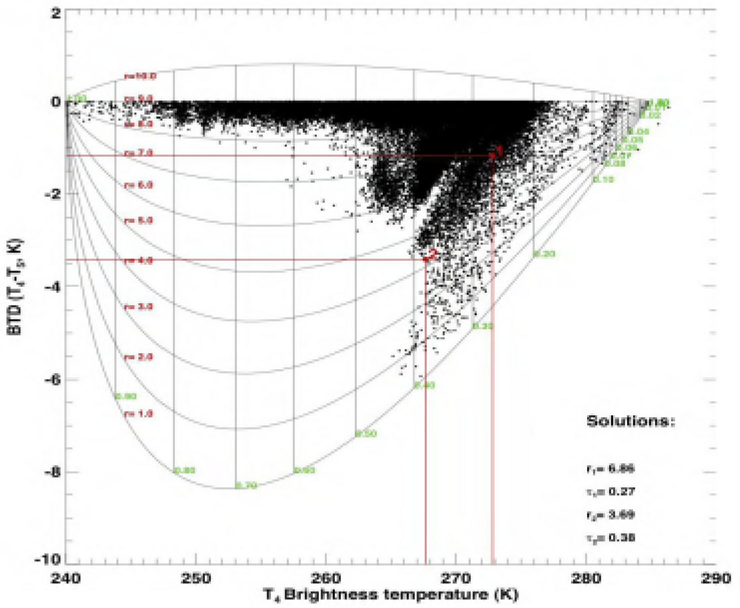

Figure 2: Observations of the brightness temperature difference (BT10.8 – BT12.) vs.BT10.8 together with pre-calculated values for different optical depths and effective particle sizes.

Retrieval of optical depth and particle size allows the computation of total ash mass loading. Figure 3 shows an example.

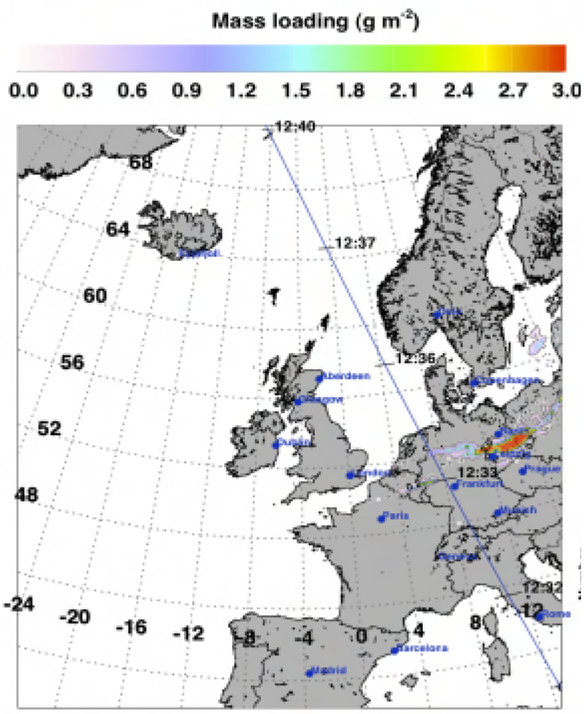

Figure 3: Retrieved total mass loading for the Eyjafjalla eruption (16 April 2010, 1230 UTC), a day where Europe experienced major airspace restrictions. The straight line shows the collocated overpass of the Calypso instrument which was used as a validation data source in this study.

Together with other (independent) measurements, e.g. by ground based Lidars or ceilometers, the total mass loading can be converted into ash concentrations, which is the most important parameter for aircraft security.

The study also touched upon the possible retrieval of SO_2 (from MSG) and comparing that to other retrievals (e.g. from GOME-2 or IASI onboard Metop): Any quantitative comparison here showed poor quality of the MSG result, either because the SO_2 cloud was optically too thick and thus violating some underlying assumptions in the retrieval process, or the cloud was too thin so thermal contrast was lost. Preliminary results suggested that it is possible that the MSG results can be used to fill in times when GOME-2/IASI (or AIRS) overpasses are not available, but this method would need some further refinement.

The algorithm as developed through this study was coded up in Fortran and is running in EUMETSAT's prototyping environment.

2.2 Study with RAL

A second study was placed with RAL (Rutherford Appleton Laboratories in the UK) with the aim to demonstrate quantitative retrieval of ash properties (altitude, optical depth and particle size) using an optimal estimation approach. The optimal estimation framework is in principle available for the EUMETSAT Optimal Cloud Analysis (OCA) product, which uses the combined information of all MSG channels to simultaneously retrieve cloud microphysical and bulk parameters. The basic algorithmic principle is the fitting of the observed MSG measurements to values predicted by a radiative forward model by adjusting the cloud property values, taking into account error levels in the measurements and the prior information.

Scattering and absorption of radiation by clouds is simulated offline, and the results are used within OCA through lookup tables. For the application to volcanic ash, respective lookup tables were generated using ash optical properties produced by the University of Oxford.

The scheme was also applied to the May 2010 Eyjafjalla eruption, where most of the ash was over the ocean. Land would not necessarily present a fundamental problem to the OCA scheme, but the applied OCA version was not fully optimised for use over land.

Within the OCA retrieval, all MSG channels were fitted, except IR3.9 and IR9.7. Single layer retrievals were performed for liquid water, ice and ash; the cloud type that provided the minimum cost within the retrieval was selected. As only very few scenes contain only volcanic ash (mostly ash is found over thick water clouds), the single layer OCA retrieval is less appropriate. A two-layer scheme was applied, using only the IR channels and retrieving optical depth, particle size and height of the upper layer together with the altitude of an underlying liquid cloud (which is assumed to be opaque).

Figure 4 shows a typical result of the single layer retrieval, while Figure 5 illustrates the distinct advantage of the two-layer scheme, especially with respect to the altitude of the ash cloud.

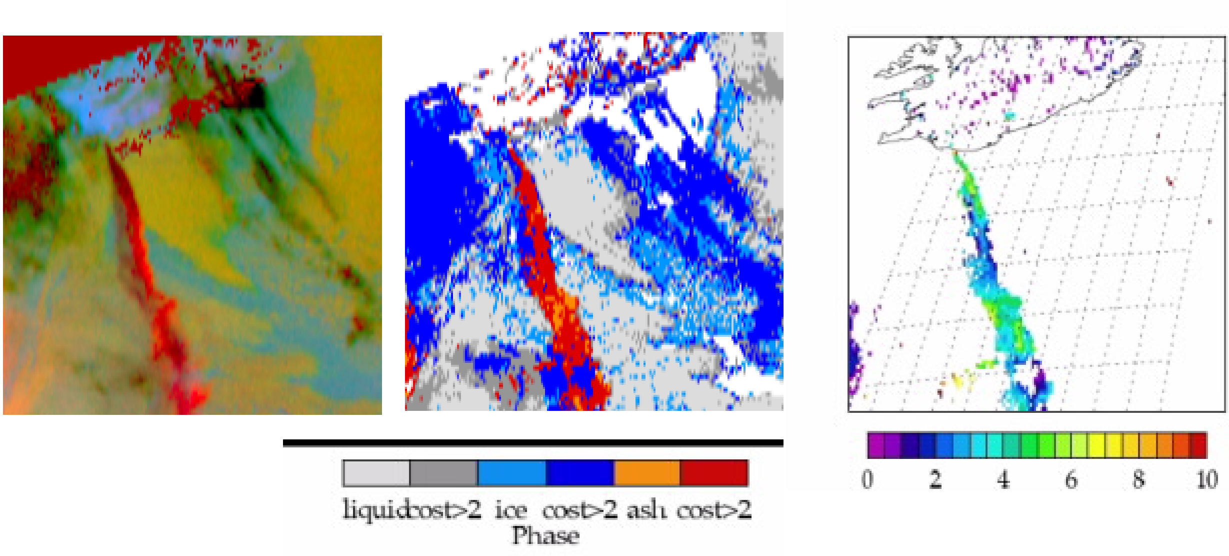

Figure 4: Results of the single layer retrieval.

Left: False colour MSG image, qualitatively depicting the ash plume in bright red

Centre: Minimum cost within the retrieval, leading to liquid/ice/ash as the resulting cloud type

Right: Retrieved ash loading in g/m^2

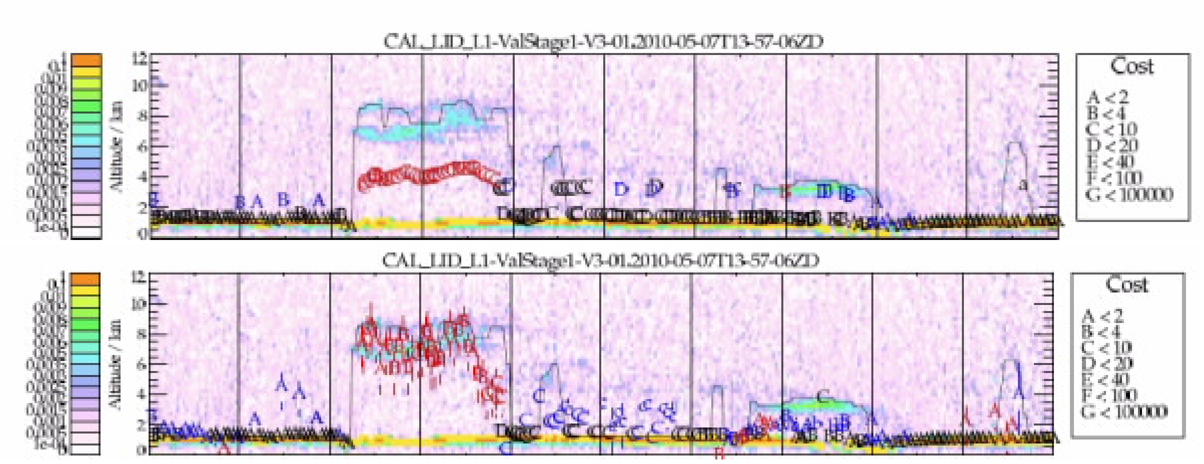

Figure 5: Comparison of single layer and two layer retreival

Top: Single layer ash cloud altitude (letters A-G) on top of a Calypso overpass. Ash layer retrieved at too low heights (red letters)

3 EUMETSAT PLANS

The RAL study has clearly shown the added potential of a full optimal estimation scheme. Further quantitative products can be retrieved, including ash cloud height. For a correct height estimate, the concept of the two-layer retrieval is especially important.

However, as a full (two-layer) optimal estimation scheme is conceptually difficult and extremely CPU expensive, EUMETSAT will first focus on the SAVAA-NILU scheme and plans to make products, based on this algorithm, available in early 2012. The quantitative product will be an ash detection flag and the total ash mass loading. Full implementation of the RAL scheme is currently seen as a future activity which can be addressed through the operational implementation of the (in house developed) OCA scheme for water and ice clouds.

In addition to the volcanic ash product development activities focussed on MSG SEVIRI data, EUMETSAT is also exploring the potential for the development of multi-mission aerosol and potentially volcanic ash products based on Metop GOME-2, IASI and AVHRR data. A review of algorithms for aerosol property retrieval has been carried out and the applicability to Metop data evaluated. In general three to four different techniques have been established to retrieve aerosol optical properties. Measurements of the radiance at different wavelengths can be combined to exploit the wavelength-dependency of the scattering effects. Observations of the same scene using different observation geometries may also be used because the angle-dependency of the measured signal is connected with the phase function. Scattering also affects the state of polarisation and – in addition – the surface reflectance of polarised light show a smaller wavelength-dependency than un-polarised light. Finally, LIDAR measurements can be used to receive information about aerosol top height. An ideal aerosol instrument would be able to combine these methods. None of the current satellite instruments is able to make use of all the four methods. Only two of these approaches can be used with the instruments of the Metop-A satellite; the combination of a wide range of wavelength channels (from the UV to the TIR) and the measurement of the polarization state which is available from GOME-2. The approach to be taken is to start the development with a focus on use of GOME-2 polarisation data for measurement of AOD over sea with subsequent extension to land. A next step would be to take advantage of the fact that GOME-2 is primarily sensitive to fine mode particles and IASI to coarse mode particles. The development is currently in early stages with a first prototype algorithm expected to be available by end 2011.

4 CONCLUSIONS

The two science studies clearly demonstrated the capability of MSG to retrieve quantitative volcanic ash information. Total ash mass loading can be obtained through a relatively simple concept, while other parameters need a more sophisticated approach, especially when looking at multi-layer cloud situations. Development of retrieval algorithms for aerosol products from the Metop instruments has been started with the expectation that a first prototype algorithm will be available by the end of 2011.

It should also be noted that actual ash concentrations cannot be directly obtained from the satellite data, i.e. for actual warning purposes, the satellite products must always be used in combination with other data or model fields.