IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium | 978-1-7281-6374-1/20/$31.00 ©2020 IEEE | DOI: 10.1109/IGARSS39084.2020.9324335

PROTOTYPING OF A MULTI-HAZARD EARLY WARNING SYSTEM FOR AVIATION AND DEVELOPMENT OF NRT ALERT PRODUCTS WITHIN THE EUNADICS-AV AND OPAS PROJECTS

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ABSTRACT

The eruption of the Eyjafjöll volcano in 2010 has shown that aviation can be very vulnerable to natural disasters. Although such events are rare, the consequences for aviation can be enormous, on both the economic and human scale. Nowadays many techniques are available to measure hazards to aviation, yet there is still no Europe wide warning system for this kind of disasters. The EUNADICS-AV project aimed at filling this gap, by providing fast information to the aviation community. In addition, the ongoing Engage-KTN OPAS projects involves the development of an algorithm for the retrieval of the height of sulfur dioxide (SO_2) plumes, a proxy for the presence of volcanic ash.

This paper reports on the major contributions to these two projects: the development of an early warning system, the SO_2 layer height developments, and the creation of standardized alert products.

***Index Terms*—** volcanic plume, ash, sulfur dioxide, dust, smoke, radionuclide cloud

1. INTRODUCTION

In the 21st century, aviation belongs to the most critical types of infrastructure. Relatively short disruptions in air traffic, even when only on a regional scale, can already have a large impact on the economic or human scale. This is illustrated by the 2010 volcanic eruption of Eyjafjöll in Iceland, when large sections of European airspace were closed for days on end. Natural hazards to aviation include volcanic eruptions (presence of ash and SO_2 in the atmosphere), desert dust storms, smoke from wild forest fire and nuclear accidents causing the emission of clouds of radionuclides. Even though such events are rare, their impact can be extremely high.

Technological developments over the last decades assure that measurements and monitoring of potential sources of natural threats to aviation are widespread. However, as was also shown during the 2010 events, a system for the real time measurement and monitoring of natural threads on the full European scale does not yet exist. In response to this gap, the H2020 EU-funded project EUNADICS-AV (European Natural Airborne Disaster Information and Coordination System for Aviation; grant agreement no. 723986) was launched in October 2016 and finalized in September 2019. This project includes the assessment of the needs of the aviation stakeholders, the inventory of existing measurement and monitoring networks and the development of new products that can fulfill the needs. The final goal was to provide the mechanisms for European wide real-time measurement and monitoring information on airborne hazards, combined with a near real-time (NRT) data analysis and assimilation system. In the event of a natural disaster, this would allow a prompt and effective response on the level of air traffic monitoring and control.

BIRA-IASB has contributed to several tasks within EUNADICS-AV and was leading the development of an early warning system for high amounts of aerosols, sulfur dioxide (SO_2) and radionuclides in the atmosphere. This also involved a

Sensor/Product	SO_2 VCD	SO_2 height	Aerosol detection	Ash height	Aerosol optical depth	Ash mass loading	Clouds
MetOp/GOME-2 1)	×		×				×
EOS-Aura/OMI	×		×				×
NOAA-20/OMPS	×		×				×
S5-P/TROPOMI	×	×	×				×
MetOp/IASI 1)	×	×	×		×		
EOS-Aqua/AIRS	×		×				
Meteosat/SEVIRI			×	×		×	
Sentinel-3/SLSTR			×	×		×	

1) for all three MetOp platforms: A, B, and C.

Table 1: The satellite sensors and their products in the new SACS system. Whether a specific product is available for a certain sensor (and used by the early warning system) is indicated by ×.

mechanism to send out standardized alerts to stakeholders, containing detailed information about the event.

Building on the EUNADICS experience, the Engage-KTN-funded OPAS project (Operational alert Products for ATM via SWIM) took place from June 2019 to June 2020 and involves the development of an algorithm for near real-time retrieval of the effective altitude of volcanic SO_2 clouds from measurements by the ESA Sentinel 5P satellite instrument TROPOMI. The final goal is to transfer standardized SO_2 layer height alerts to the SESAR SWIM interface for air traffic management (ATM) stakeholders.

This paper focuses on the developments related to the EUNADICS-AV early warning system, the OPAS SO_2 layer height product, and the standardized alerts.

2. EARLY WARNING SYSTEM

In the case of a natural disaster, fast, coherent and consistent information on the event is of crucial importance for a quick response. Within EUNADICS-AV a pilot study has been performed where available sources of aerosols and radionuclides is applied in an operational environment. The result is a prototype global monitoring and alert system for 4 types of airborne hazards: extreme atmospheric quantities (clouds) of sulfur dioxide (SO_2) due to volcanic activity), aerosol (volcanoes and bio-mass burning), desert dust, and radionuclides (nuclear events). The early warning system comprises data sets from a wide range of UV and IR satellite sensors (TROPOMI, IASI, SEVIRI,…), retrievals from ground-based networks (EARLINET, E-PROFILE and OPERA) and, in addition, relays data from existing services, such as SACS, NASA/FIRMS, EFFIS, CAMS, SDS-WAS, EURDEP, ESA CCI, and Land Cover). In the case of an extreme cloud event, the ensemble of data sets assures the quick detection of the cloud. Based on pre-defined thresholds, the detection can lead to the creation of a tailored alert product that is made available to the stakeholders.

For nuclear events, emitting radionuclides in the atmosphere, it relays data from the specific alert system developed by the colleagues from STUK in Finland and ZAMG in Austria. The other existing systems considered, are the forest-fire systems of FIRMS-NASA and EFFIS/EU and the desert dust detection from CAMS/EU/Copernicus and SDS-WAS/WMO.

2.1 SACS

For events related to atmospheric aerosol (volcanic ash, desert dust, forest fires), the early warning system builds upon the existing Support to Aviation Control Service (SACS, [1, 2]) platform. SACS visualizes satellite measurements of SO_2, aerosol index and cloud cover from a series of satellite sensors. In the framework of EUNADICS-AV, the user interface to SACS is undergoing a complete overhaul in order to accommodate for an increased number of satellite data sets and to provide a more personalized user experience, with options to see only the data relevant to a specific user. The full list of satellite products and sensors after its upgrade is given in Table 1.

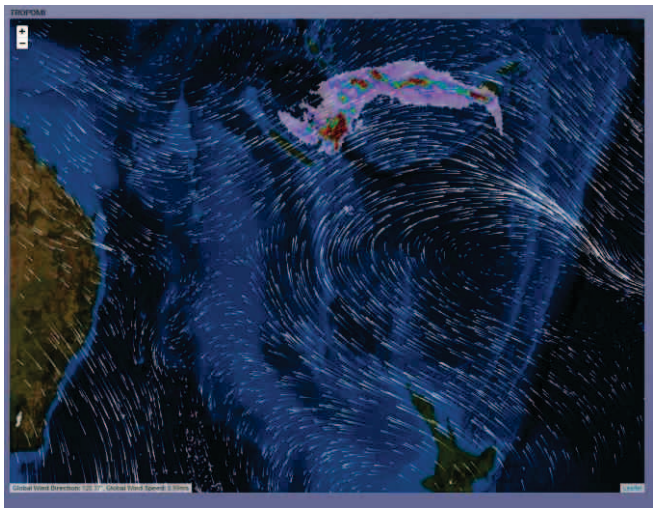

Figure 1. SO_2 cloud originating from Ambrym as seen by S5P/TROPOMI on 16 December 2018. An overlay of wind forecast vectors at 500 hPa was added to facilitate the estimate of the displacement direction of the plume.

The images with satellite data in SACS typically represent a static representation of the SO_2 or aerosol amounts at the time of measurement. Only by checking subsequent measurements the user would get an idea of where the observed plume is heading to, which often requires waiting about 24h until the next measurements are available. To facilitate the estimation of the plume's displacement, the user interface will allow to overlay an animated field of wind vectors on top of the satellite data. The wind data is based on ECMWF forecasts and the user can request the data at a flight level of interest. As an example, Figure 1 shows the SO_2 cloud from the Ambrym volcano in Vanuatu, as measured by the S5-P/TROPOMI instrument on 16 December 2018, together with a wind field overlay.

2.2 Alerts

In addition to displaying satellite data, the SACS is capable of sending out alerts to subscribed users in the case an elevated SO_2 or aerosol amount is detected. Within the EUNADICS-AV early warning system an alert mechanism has been devised that creates standardized alert information files. The alerts are tailored per event type and containing as much information as possible derived from the available measurements. The criteria for those alerts have been determined empirically and based on previous research regarding the concerned type of event. As an example, Figure 2 shows selected information that was part of an issued SACS alert during the 2011 Nabro eruption, derived from a single orbit of MetOp-A/GOME-2 data. When clusters of SO_2 vertical column values (VCD) above a certain threshold are encountered in the orbit data, pixel filtering mechanisms are activated to extract as much information as possible about the encountered cloud. A detailed description of the alert criteria and their information content can be found in [1].

For each type of natural hazard event, the alert information is send out in a standardized netCDF file format, containing a specified hierarchical data structure. An example for the 2011 eruption of Grímsvötn is shown in Figure 3. As part of future

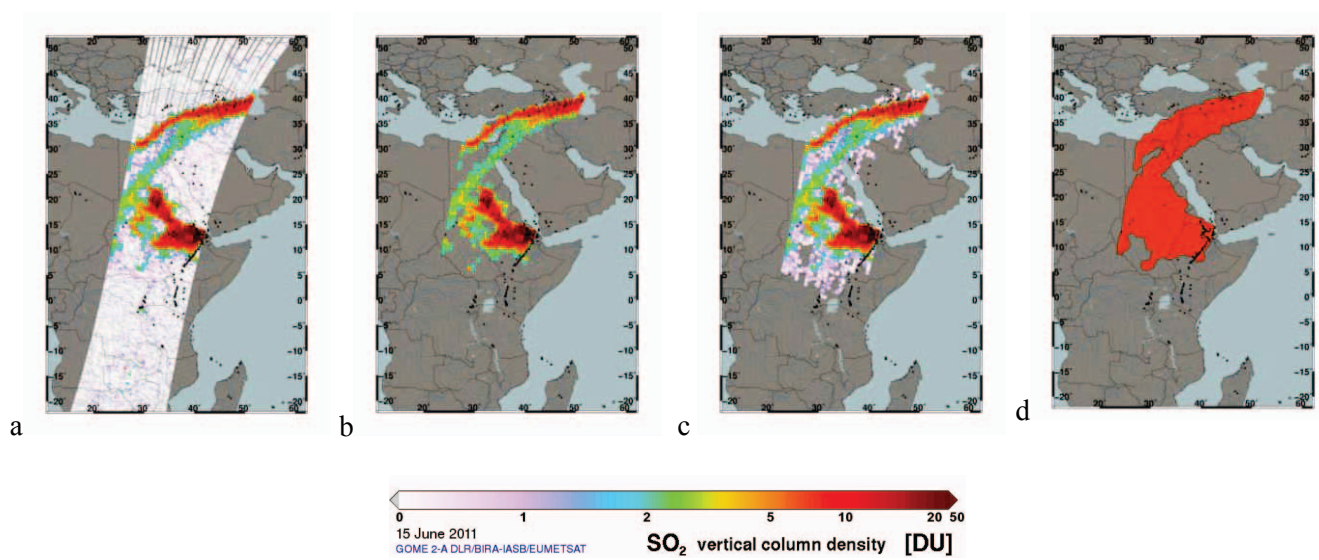

Figure 2. An orbit of MetOp-A/GOME-2 data (a), showing elevated SO_2 columns due to the eruption of Nabro in 2011. Panels b,c,d show the pixels exceeding the alert criteria, mass loading and mean value/area, respectively.

work, the EUNADICS-AV alert products may be further refined and be implemented as a so-called yellow service of SESAR [3] SWIM [4], with information in json format.

2.3 SO_2 layer height

In addition to the products developed within EUNADICS-AV, knowledge around the altitude of volcanic plumes is of high value for air traffic management (ATM). Because of the potential thread to engine conditions, knowledge of ash layer height aids in avoiding the encounter of such layers by air traffic. So far the direct determination of ash layer height has proven difficult and measurements of SO_2 layer height are performed instead, as the presence of SO_2 may serve as a proxy for ash emission.

Within the OPAS project, BIRA-IASB is developing an SO_2 layer height derivation algorithm for the Copernicus Sentinel-5 Precursor (S5P) instrument TROPOMI. In its class, TROPOMI provides and unprecedented spatial resolution as fine as 3.5x5.5 km^2, allowing for the resolution of fine details in the properties of volcanic emissions.

Once mature, the S5P layer height product will be added to the SACS NRT system and its alert mechanism. As a final step, it will be transferred to the SESAR SWIM standard and implemented in the interface for ATM stakeholders.

3. SUMMARY

In the framework of the EUNADICS-AV project, BIRA-IASB has contributed to the creation of a prototype early warning system for 4 types of natural events that are potentially harmful to aviation: volcanic plumes, desert dust, smoke from forest fires, and radionuclide clouds. The system makes use of a wide range of ground-based and satellite data sources and where possible, existing systems have been integrated in the new environment. In particular, the existing SACS visualization and warning system has been revised and extended, providing a more extensive and personalized user experience.

The homogenized alerts resulting from both EUNADICS-AV and OPAS provide valuable data to stakeholders such as weather centers and Volcanic Ash Advisory Centers (VAACS), involved in ATM and natural hazard response.

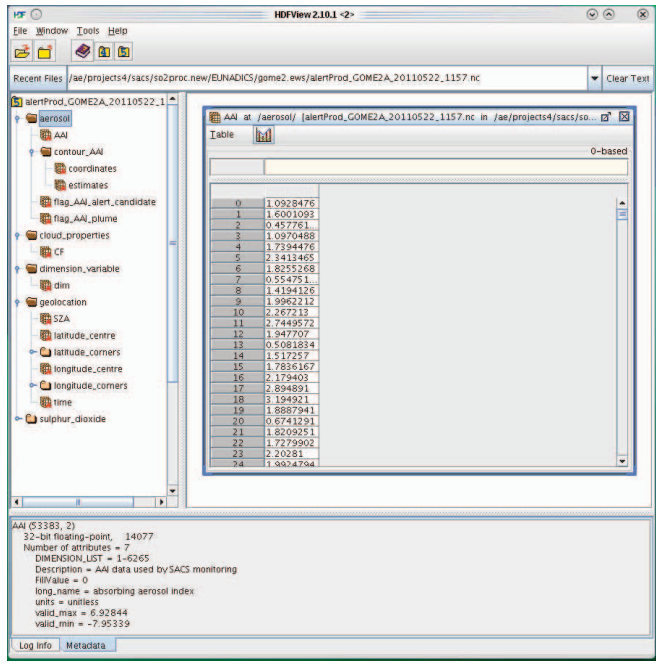

Figure 3 Example of a netCDF alert file showing the data structure used in case of a volcanic eruption.

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