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DIFFERING REGIONAL CAPABILITIES IN SATELLITE-BASED VOLCANIC ASH CLOUD DETECTION

The GOES-R AWG is responsible for the developing the algorithms that will address the official GOES-R Level 1 and Level 2 product requirements.

In recognition of the need for quantitative information on volcanic ash clouds, the GOES-R requirements include volcanic ash cloud height and mass loading (mass of ash per unit area) products, which are needed to nowcast and forecast volcanic ash clouds. Unlike traditional aerosol products, the volcanic ash products are required day and night. As such, the AWG developed an infrared-based approach to retrieve information on ash cloud height, mass loading, and particle size.

Action/Recommendation proposed: None

Differing Regional Capabilities in Satellite-based Volcanic Ash Cloud Detection

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Introduction

Satellite capabilities relevant to volcanic ash cloud tracking are not globally uniform, and thus vary across (or even within) areas of responsibility of the Volcanic Ash Advisory Centres (VAACs). The figure below depicts the area of responsibility for each of the nine VAAC's. This paper describes how regional variations in satellite-based ash cloud tracking capabilities impact VAAC operations and summarizes how regional satellite capabilities will change as new satellites are placed into operations over the next 10 years. In order to ensure that volcanic clouds have a chance to be skilfully tracked regardless of location, the global satellite constellation must continue to evolve as currently planned.

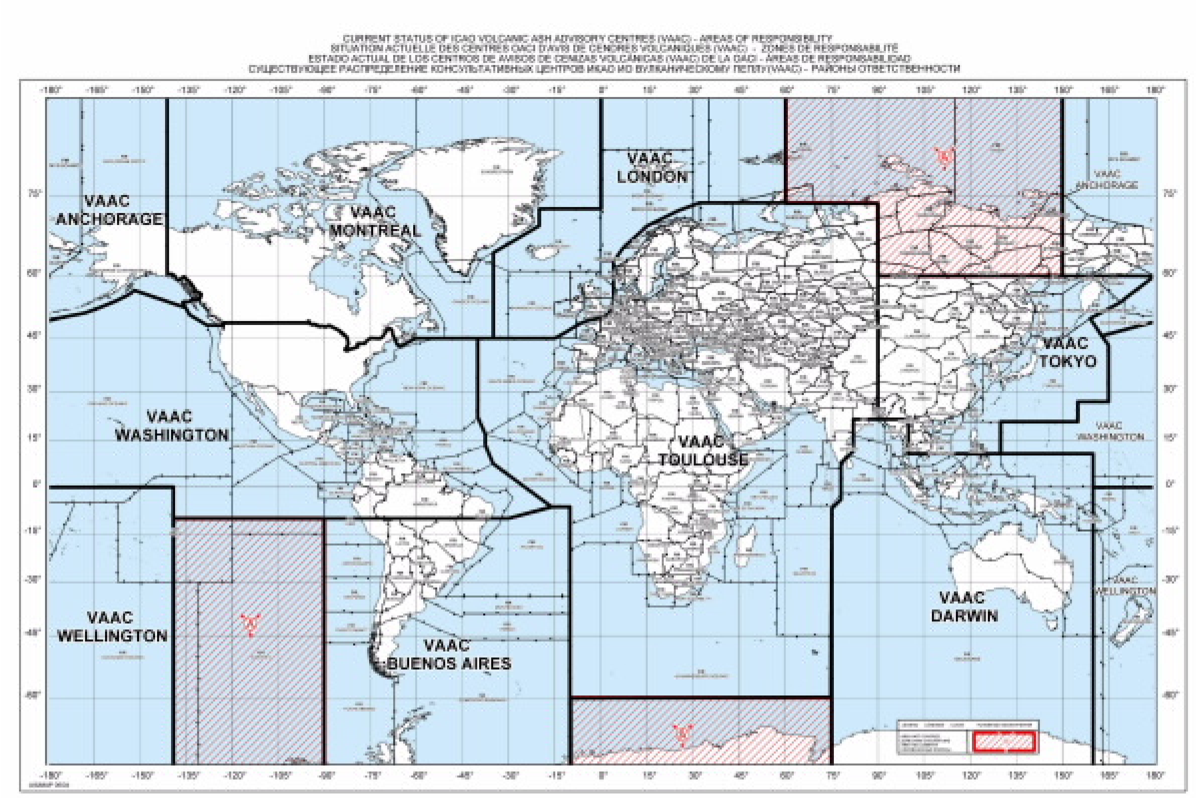

Figure 1: The area of responsibility for each of the nine Volcanic Ash Advisory Centres (VAAC's)

Discussion

Measurements from geostationary (GEO) and low earth orbit (LEO) satellites are vital for tracking and characterizing volcanic ash clouds. From an operational perspective, a high measurement refresh rate is desired. As such, GEO instruments are well suited for operationally monitoring volcanic ash, especially in the tropics and mid-latitudes. At high latitudes, GEO measurements are still valuable though spatial resolution diminishes rapidly toward the poles. For instance, the European Meteosat Second Generation (MSG) geostationary satellite was utilized extensively to monitor the Eyjafjallajökull volcanic ash clouds, which originated north of 60ºN latitude. While GEO satellites offer measurements with high temporal resolution, LEO satellites are needed to obtain high spatial resolution measurements of ash clouds, especially at high latitudes. LEO satellite instruments also generally offer a wider range of spectral measurements that characterize volcanic clouds with greater detail compared to GEO instruments. Thus, VAACs should have easy access to both GEO and LEO products in a manner that is sensitive to infrastructure limitations.

The spectral and temporal capabilities of geostationary satellites vary considerably. The Spinning Enhanced Visible/InfRared Imager (SEVIRI) instrument on the MSG satellites offers superior spectral, spatial, and temporal capabilities compared to the other geostationary instruments currently in orbit. SEVIRI provides imagery of a large area centered on 0° longitude every 15 minutes and the spectral measurements can be used to more accurately detect volcanic ash, retrieve the ash cloud height, mass loading, and ash cloud microphysics, and detect SO_2. Unfortunately, the SEVIRI spatial domain does not include the circum-Pacific "ring of fire" but it does offer coverage of volcanoes in Iceland (London VAAC), Sicily (Toulouse VAAC), Africa (Toulouse VAAC), Madagascar (Toulouse VAAC), the Eastern Caribbean (Washington VAAC), and to some degree South America (Buenos Aires VAAC).

Three Geostationary Operational Environmental Satellite (GOES) satellites (GOES-11, GOES-12, and GOES-13) operated by the U.S. National Oceanic and Atmospheric Administration (NOAA) currently provide coverage that roughly extends from the central Pacific (Anchorage and Washington VAACs) to the eastern Atlantic (Washington VAAC). While the GOES satellites provide coverage for much of the western hemisphere, the temporal and spectral capabilities vary between satellites and regions. Beginning in 2003 with GOES-12, the 12 m channel was replaced with the 13.3 m channel. This substitution limits the effectiveness of the reverse absorption brightness temperature difference method of ash detection, often referred to as "split-window" (Prata, 1989; Ellrod, 2004). More complicated and less accurate methodologies must be used to detect volcanic ash with the GOES-12, GOES-13, GOES-14, and GOES-15 satellites. The 13.3/12 m channel substitution already impacts operations at the Washington, Buenos Aires, and Montreal VAACs and will impact operations at the Anchorage VAAC when GOES-11 reaches the end of its operational lifetime (late in 2011). GOES-11 provides coverage of the North Pacific (Anchorage, Tokyo, and Washington VAACs) from the Kamchatka Peninsula eastward to the western part of the United States (including Alaska) every 30 minutes. In the traditional operational configuration, the GOES satellites provide coverage of the Southern Hemisphere only every 30 minutes, at best (the refresh rate can be as high as 3 hours). In recognition of the operational satellite needs of South American countries, (NOAA began operating the GOES-12 satellite at 60°W longitude in June 2010. The GOES-12 stationed at 60°W provides imagery of South America every 15 minutes, which has been beneficial during the June 2011 eruption of Cordon Caulle in Chile.

The Japanese Multi-Functional Transport Satellite (MTSAT) series provides coverage of the volcanically and meteorologically active western Pacific, which is monitored by the Darwin, Tokyo, Washington, and Wellington VAACs. MTSAT provides imagery (including "reverse absorption information), every 30 minutes over the Northern Hemisphere and hourly in the Southern Hemisphere. While MTSAT does allow for traditional reverse absorption ash detection, the hourly refresh rate for the Southern Hemisphere is not optimal for operational volcanic cloud monitoring. In addition, the interpretation of MTSAT imagery is complicated by instrument calibration uncertainties. The Feng Yun 2 (FY2) geostationary satellites, operated by the China Meteorological Administration (CMA), also provide coverage of the western Pacific and have similar spectral and spatial capabilities as MTSAT, but also suffer from calibration uncertainties. In January 2011, Russia launched the ELECTRO-L satellite,

which is positioned at 76°E, and thus provides coverage of Africa (Toulouse VAAC), Madagascar (Toulouse VAAC), and Indonesia (Darwin VAAC). Unlike MTSAT, ELECTRO-L will be capable of tracking SO_2 clouds and will allow for improved ash detection. Hopefully, once operational, ELECTRO-L data will be made available to the Darwin, Toulouse, Tokyo, and Wellington VAACs.

This overview has shown that current geostationary satellite capabilities vary from VAAC to VAAC and within VAAC areas of responsibility. However, based on current plans, the United States, Europe, Japan, and China will be upgrading their geostationary capabilities in the 2015–2020 timeframe. The next generation of satellite instruments will offer spatial, spectral, and temporal capabilities equivalent to or better that SEVIRI, resulting in more homogeneous operational capabilities for monitoring volcanic clouds. Finally, volcanic-cloud monitoring would greatly benefit from high spectral resolution infrared measurements in geostationary orbit. High spectral resolution measurements offer increased sensitivity to the presence of ash (e.g., Gangale et al., 2010; Clarisse et al., 2010).

A single LEO satellite is capable of providing twice-daily near-global sampling (the degree of global sampling depends on the width of the overpass swath). While VAACs with high-latitude areas of responsibility theoretically benefit most from LEO satellites (the number of overpasses increases towards the poles), all VAACs benefit from the LEO satellite constellation. The main issues VAACs face in regards to LEO data are data access and latency. For instance, some VAAC's (e.g. Anchorage and Darwin) have timely access to LEO satellite overpasses that are relevant to their area of responsibility via local satellite data downlink stations, while others (e.g. Washington) currently do not. In addition, several LEO sensors that are extremely valuable for tracking volcanic clouds are research sensors (e.g. the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)) and do not have an operational mandate. Thus, the data are not always available in an operationally timely manner (i.e., have latency of hours or even days).

Overall, the LEO volcanic cloud remote sensing capabilities are spectrally and/or spatially more advanced compared to GEO, and, as such, should be used to supplement GEO observations. In particular, infrared and UV/Visible hyperspectral instruments provide an enhanced ability to monitor SO_2 clouds (e.g. Yang et al., 2010) and detect smaller concentrations of volcanic ash. Hyperspectral measurements may also provide some information about the vertical distribution of volcanic ash and SO_2 and the dominant mineral composition of volcanic ash clouds (e.g. Clarisse et al., 2008; Clarisse et al., 2010). Lidar measurements, which provide very detailed information on the vertical structure of clouds and aerosols, are also available on a LEO platform. Thus, it is important that LEO data be made available to all VAACs in a timely manner.

In order to increase the temporal coverage of high spatial resolution measurements at latitudes poleward of 50^o, a third satellite orbit is needed. The highly elliptic orbit (HEO) allows for quasi-geostationary observations over the high latitudes with much greater spatial resolution than a GEO satellite can provide. In recognition of the need to better observe the Arctic from space, the Canadian Space Agency, in partnership with Environment Canada, are planning the Polar Communications and Weather (PCW) mission. PCW will consist of two satellites in a HEO orbit over the North Pole. The PCW spacecrafts will include a GOES-R-like visible/near-infrared/infrared sensor that is capable of providing 15-minute coverage (in the two satellite configuration) of the Arctic, which includes all areas north of 50^o latitude, with a spatial resolution of at least 3 km. Given that many volcanoes in the North Pacific and on Iceland reside north of 50^o latitude, these satellites will be extremely valuable to all northern

hemisphere VAAC's. Currently, the first satellite of the PCW mission is scheduled to be launched in 2017.

Conclusions

In order to ensure that volcanic clouds have a chance to be skilfully tracked regardless of location, the global satellite constellation must continue to evolve as currently planned.

VAACs need easy access to both GEO and LEO products in a manner that is sensitive to infrastructure limitations.

Volcanic cloud monitoring would greatly benefit from high-spectral-resolution infrared measurements in geostationary orbit and highly elliptical orbits that provide improved coverage of high latitude regions.

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