Volcanic cloud remote sensing products at the Met Office for Near Real-Time Applications - Present and Future Outlook

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Met Office, United Kingdom
Overview

• How do we use satellite products?
• Which satellites/instruments do we use?
• Different types of satellite products monitored at the London VAAC
• Ongoing research and development
• Airborne remote sensing
• Ground-based remote sensing
• Summary
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How do we use satellite products?

• Real time monitoring of volcanic plumes to inform VAAC forecasters, and hence improve VA guidance
  • Horizontal extent
  • Trajectory (ash height)
  • Radiative ash height estimate
  • Estimate of column mass loading
• Constraining the initialisation of dispersion model runs:
  • To aid specification of source term
  • As part of data inversion process
• Use satellite datasets for post-event validation of the model predictions (together with other observations)
The London Volcanic Ash Advisory Centre (VAAC)

- An International Civil Aviation Organization (ICAO) designated centre
- Responsible for issuing advisories for volcanic eruptions originating in Iceland and the north-eastern corner of the North Atlantic
- Hosted and run by the Met Office from its Exeter UK headquarters
- Specialist forecasters who produce volcanic ash advisories and guidance products using a combination of:
  - satellite-based, ground-based and aircraft observations
  - weather forecast models and dispersion models

One of 9 VAACs worldwide, London VAAC provides a reciprocal back-up facility with Toulouse VAAC, operated by Meteo-France.
The VAAC process
How do we use satellite products?

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Which satellites/instruments do we use?

**Orbits**
- Geostationary Orbit
  - At an altitude of 35,800 km, satellite rotates once around the Earth in 24 hours.
  - Continuous coverage of one section of the globe
  - Data acquisition straightforward
  - Active systems relatively large, excellent for monitoring systems
  - Poor polar coverage

- Polar Orbit (LEO = Low-Earth Orbiting)
  - Satellite altitudes typically 850 km and pass close to the pole.
  - At a certain inclination to the equator (~98.7°), the satellite's orbital plane will appear to be fixed with respect to the sun (synchronous).
  - Crossing time of the equator is fixed
  - Good polar coverage
  - Good resolution
  - Active systems are visible
  - Large payloads with more instruments
  - Satellite only views a portion of the earth at one time

**Satellites**
- Meteosat Second Generation
- Metop
- NOAA POES
- EOS Terra & Aqua

**Instruments**
- SEVIRI - the European Geostationary Imager
- Advanced Very High Resolution Radiometer (AVHRR)
- MODIS Summary
- GOME-2
- IASI on Metop
Which satellites/instruments do we use?

Orbits
- Geostationary Orbit
- Polar Orbit (LEO = Low-Earth Orbiting)

Satellites
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- Metop
- NOAA POES
- EOS Terra & Aqua
- NOAA SSN
- GOME-2

Instruments
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- Advanced Very High Resolution Radiometer (AVHRR)
- MODIS
- IASI on Metop
SEVIRI - the European Geostationary Imager

- Scans Africa, Europe, Middle East and Atlantic every 15 minutes
- 3/1 km spatial resolution at 0° N, 0° E
- 12 channels (different wavelengths)
- Meteosat-10 operational, Met-9/Met-8 backup
Which satellites/instruments do we use?

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Satellite products used at London VAAC

- Qualitative imagery of ash
- Quantitative ash detection
- Quantitative ash property retrievals
- Simulated satellite imagery
- $\text{SO}_2$ products
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“AVHRR” visible imagery

21st May 2011, 1918Z
NOAA-16

22nd May 2011, 0551Z
FY-1D MVISR
MSG/SEVIRI visible imagery

SEVIRI
23rd May 2011, 1400Z

MODIS
23rd May 2011, 1352Z
Thermal infrared difference imaging

Optical characteristics of ash and water/ice are different in the 8-12 μm atmospheric window

Cloud: BT 10.8 > BT 12.0

Ash: BT 10.8 < BT 12.0

Clouds absorb more at 12.0 than at 10.8

Ash absorbs more at 10.8 than at 12.0

Earth's Surface
Ash plume from Eyjafjallajökull Volcano over the North Atlantic - MODIS true colour composite
Eyjafjallajökull

MSG Dust RGB

Ash

2010/04/15 1330 UTC
Grímsvötn

MSG Dust RGB

2011/05/24 0200 UTC
Volcanic ash images

Yellow/orange/red areas (-ve values) show areas of ash that are:

• Not optically thick (which would look grey)
• Fine ash particles, approx 1-10 µm
Satellite products used at London VAAC

- Qualitative imagery of ash
- Quantitative ash detection
- Quantitative ash property retrievals
- Simulated satellite imagery
- $\text{SO}_2$ products
Improving ash detection

• Although the simple “channel-difference” (BTD) type of product is useful, it is also desirable to have a more sophisticated detection scheme in order to produce the mask on which to apply the volcanic ash retrieval calculations (see later).

• Specifically, the background NWP model’s temperature and humidity profiles are useful pieces of additional information which do not get used in the simple BTD products described thus far – these can, to some extent, allow for the effects of the intervening atmosphere on the top-of-atmosphere radiances.
A series of 5 tests to arrive at final ash mask

- Test 1: (strict 2-chan BTD)
- Test 2: (3-chan BTD)
- Test 3: (2-chan BTD with NWP)
- Test 4: (β-ratio false alarm removal with NWP)
- Test 5: (noise)
Satellite products used at London VAAC

- Qualitative imagery of ash
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1D-Var scheme developed to retrieve quantitative volcanic ash information from SEVIRI data

Uses channels at 10.8 µm, 12.0 µm and 13.4 µm
Ash height retrievals – effect of different refractive indices, and their solution costs

2010/05/13 0800 UTC

Pollack (andesite)  Pollack (obsidian)  Balkanski  Volz

1D-Var final cost gives a measure of how well the solution has managed to fit the observations
Ash detection and retrieval products also monitored from other Near-Real-Time sources during eruptions.
Satellite products used at London VAAC

- Qualitative imagery of ash
- Quantitative ash detection
- Quantitative ash property retrievals
- Simulated satellite imagery
- $\text{SO}_2$ products
Why simulate imagery?

7 May 2010 1200 UTC

BT10.8 – BT12.0

Raw NAME concentration for FL000-FL200

Dust RGB

BT10.8 – BT12.0

Raw NAME concentration for FL200-FL350

Dust RGB
• Ash correct over Iceland, but needs ash further east and south over North Sea
Satellite products used at London VAAC

- Qualitative imagery of ash
- Quantitative ash detection
- Quantitative ash property retrievals
- Simulated satellite imagery
- $\text{SO}_2$ products
Ash index and SO$_2$ column
23$^{rd}$ May 2011
Detection of the Grímsvötn 2011 volcanic eruption plumes using infrared satellite measurements. Cooke et al., 2014, ASL.
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Further Developments

• Further improvements to operational ash detection?

• Comparisons between different quantitative ash retrievals?

• Multi-layer retrievals?

• Greater use of hyper-spectral sounding data?

• Towards a global geostationary capability
A series of 5 tests to arrive at final ash mask

Test 1 (strict 2-chan BTD)

Test 2 (3-chan BTD)

Test 3 (2-chan BTD with NWP)

Test 4 (β-ratio false alarm removal with NWP)

Test 5 (noise)
Volcanic Cloud Detection

The VOLCAT detection approach is multi-faceted and employs several different conceptual models to identify volcanic clouds across the spectrum of eruption cloud types.

- Spectral cloud objects [spectral signature]
- Plume [spectral signature + geometric properties]
- Puff [spectral signature + cloud growth]
- Major Explosion [cloud growth]
- Tracking in time [spectral signature + feature tracking]
Further Developments

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Important for agreement to take points observed in common
But ash detections quite different...
SEVIRI, all Eyja cases, v NOAA
Further Developments

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Two-Layer Retrievals

Recent research:
Watts et al. (2011)
Siddans & Poulsen (2011)
Further Developments

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- Comparisons between different quantitative ash retrievals?
- Multi-layer retrievals?
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Calbuco SO$_2$ plume from IASI

10hr after 2$^{nd}$ eruption

5hr after 1$^{st}$ eruption

26-27 April

25 April 00UTC

25 April 12UTC

25-26 April

24 April 12UTC

23 April 02UTC

25 April 12UTC

25-26 April

24 April 12UTC

23 April 02UTC

25 April 00UTC

26-27 April

8 May

3 May

1 May

5hr after 1$^{st}$ eruption

5hr after 2$^{nd}$ eruption

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SO$_2$ – Calbuco plume heights (early days)

- Dots represent the position of the min DBT (~ max concentration)
- In Blue: from first eruption
- In Red: from second eruption
- Numbers in parentheses are the plume height
- Numbers to the front of the parenthesis are the min DBTs observed in each pass
- Green triangle is the volcano
- Times between each dot ~ 12 hrs
Calbuco clouds & ash plume in 3 methods – 2 instruments

Left panel:
- 3 channel detection scheme
  Francis et al., 2012
- SEVIRI

Middle panel:
- RGB image
- SEVIRI
- Yellow ~ ash and SO\(_2\)
  *Very good agreement with SO\(_2\)* plume from IASI
- Pinky Red ~ Ash

Right panel:
- IASI ash & cloud
- IASI
- Dark red black → ash
- Yellow-White → clouds

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Further Developments

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• Comparisons between different quantitative ash retrievals?
• Multi-layer retrievals?
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Polar orbiter imagery outside the London VAAC Area

Kelut
14th Feb 2014, 0335 UTC

MODIS/TERRA
Geo v LEO, Kelut, 2014/02/14

MTSAT – 0400 UTC

MODIS/TERRA – 0335 UTC
Towards Global Geostationary Coverage

SEVIRI Full Disc

GOES-R launches 2016/17

SEVIRI

Himawari-8 launched 2014
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Use of satellite retrievals in model data inversion – development work

From model

\textit{a priori}

Satellite total column retrieval

From model after data inversion, \textit{i.e.} a new modelled plume closer to the satellite observations

New fine ash source term profile
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FAAM BAe–146–301
Atmospheric Research Aircraft

5 port turbulence probe
FAGE Inlet CVI on other side
Total water probe JW Liq water Nevzerov total/liq water probe Rosemount temp probes
Air sample inlets
BBRs SHIMS
Deimos or IR Camera
TAFTS ARIES
Cloud Physics Probes
MARSS
Lidar
ADAM on other side
SWS on other side
Upward and Forward Video Cameras
Cloud Physics Probes
Dropsonde on other side
BBRs
Rearward and Downward Video Cameras

NERC Centres for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

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Due to safety restrictions, targeted areas had forecasted concentrations < 2000 μg/m³.

Early flights (20-22 April): no significant ash.
17 May

IASI Infrared Spectrometer on board the Metop-A satellite

courtesy of L. Clarisse (ULB, Belgium)
SEVIRI multichannel imager on board Meteosat-9

17 May

17 May 2010
Airborne lidar vs. NAME model

- reasonable overall magnitude
- positional errors sometimes
- model uncertainties: source term, meteorology, sub-scale processes

*courtesy of H. Webster (Atmospheric Dispersion Group)*
Outlook – MOCCA
Met Office Civil Contingencies Aircraft

Cessna 421C with piston engines

- SO$_2$ Analyser
- Nephelometer (optical properties)
- Leosphere ALS450 Lidar
- CAPS probe (size distribution)

courtesy of Joss Kent

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Towards an operational lidar & sun photometer network

• **Purpose:** volcanic ash detection (customer: CAA - Hazard Centre/London VAAC)

• **Infrastructure:** network (9 fixed sites) + mobile platform

• **Products:**
  - **NRT:** range-corrected signal and volume depolarization ratio (lidar) + AOD and Ångström coefficient (sunphotometer).
  - **Post-processed:** aerosol backscatter and extinction coefficients, lidar ratio and linear particle depolarisation ratio (lidar) + Aeronet retrievals including polarisation (sunphotometer)

*courtesy of M. Adam and J. Buxman*
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Summary

- Satellite data represent the most important observations of volcanic emissions away from the source.
- They are crucial in constraining the results from dispersion models such as NAME.
- The additional channels of the SEVIRI and MODIS imagers give important additional information on ash amount, height, etc.
- The availability of these channels on future geostationary imagers in the near future (Himawari-8/-9, GOES-R) will allow the development of consistent high-quality volcanic ash products over much of the globe.
- The spectral coverage and resolution of hyperspectral infrared sounders such as IASI potentially allows for the retrieval of more quantitative information on detection and characterisation of volcanic ash and SO2.
Thank you for your attention – any questions?