The NASA Applied Sciences Program: Volcanic Ash Observations and Applications

John J. Murray
Associate Program Manager
Atmospheric and Hydrological Disasters

Applied Sciences Program
Earth Science Division
Science Mission Directorate
NASA
Washington, DC USA

john.j.murray@nasa.gov

96th AMS Annual Meeting
New Orleans, LA
January 10 – 14, 2016
Co-authors (alphabetically by surname):

- Duncan Fairlie\(^1\)
- David Green\(^2\)
- John Haynes\(^2\)
- Nickolay Krotkov\(^3\)
- Franz Meyer\(^4\)
- Mike Pavolonis\(^5\)
- Charles Trepte\(^1\)
- Jean-Paul Vernier\(^1\)

1 NASA Langley Research Center, Hampton, VA, 2 NASA Headquarters, Washington, DC, 3 NASA Goddard Space Flight Center, Greenbelt, MD, 4 University of Alaska, Fairbanks, 5 UW/NOAA Cooperative Institute for Meteorological Satellite Studies, Madison, WI,
NASA Applied Science Program
Disasters Focus Area

Associate Administrator (AA) (John Grunsfeld)
Deputy AA (Geoff Yoder)

Deputy AA for Programs (Greg Robinson)
Deputy AA for Mgt (Roy Maizel)
Deputy AA for Research (David Pierce - Act)

Planetary Protection Officer (C. Conley)

JWST Program Office Dir. (E. Smith)

Sci. Engagement & Partnerships Dir. (K. Erickson)
Chief Technologist (M. Seablon)

Resource Management Division
Dir. (C. Tupper) Dep. (K. Wolf)

Strategic Integration & Management Division
Dir. (D. Woods) Dep. (J. Feeley)

Earth Science Division
Dir. (M. Freilich) Dep. (Vacant)

Joint Agency Satellite Division
Dir. (S. Smalley) Dep. (Vacant)

Heliophysics Division
Dir. (S. Clarke) Dep. (M. Luce)

Planetary Science Division
Dir. (J. Green) Dep. (D. Schurr)

Astrophysics Division
Dir. (P. Hertz) Dep. (A. Razzaghi)

Disasters, David Green
Ecological Forecasting, Woody Turner
Air Quality and Public Health, John Haynes
Water Resources, Brad Doorn

Embeds/POCs
Chief Engineer (J. Pellicciotti)
Safety & Msn Assurance (P. Panetta)
General Counsel (M. Harrington)
Legislative & Intergvt Affairs (G. Adler)
Public Affairs (D. Brown)
Intl & Interagency Relations (D. McSweeney)
NASA Earth Science: Current Operating Missions

- OSTM/Jason 2 (NOAA)
- QuikSCAT
- Terra
- ISS: RapidScat, CATS
- Landsat 7 (USGS)
- EO-1
- Aqua
- NISTAR, EPIC (NOAA's DSCOVR)
- SORCE, TCTE (NOAA)
- Aura
- GRACE (2)
- CALIPSO
- CloudSat
- GPM
- OCO-2
- Landsat 8 (USGS)
- Suomi NPP (NOAA)
NASA Earth Science: Current and Upcoming Missions
Satellite imagers provide the best source of information concerning the location of volcanic ash. When one thinks of imager data, typically this is what typically comes to mind.
**Multi-spectral Imaging: Making Full Use of Space-based Imagers for Volcanic Cloud Monitoring**

<table>
<thead>
<tr>
<th>LEO</th>
<th>GEO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NOAA and MetOp AVHRR</strong></td>
<td><strong>Terra and Aqua MODIS</strong></td>
</tr>
<tr>
<td><img src="image1.jpg" alt="Image" /></td>
<td><img src="image2.jpg" alt="Image" /></td>
</tr>
<tr>
<td><img src="image4.jpg" alt="Image" /></td>
<td><img src="image5.jpg" alt="Image" /></td>
</tr>
</tbody>
</table>

**GOES-13-15** | **MTSAT-(1r and 2)** | **Met-(8,9,10) SEVIRI** |
| ![Image](image7.jpg) | ![Image](image8.jpg) | ![Image](image9.jpg) |

*Courtesy UW NOAA CIMSS, Madison WI*
Horizontal Mapping Of Volcanic Ash: SNPP/OMPS NRT SO₂ & Ash Index

Eruption of Sangeang Api

NPP/OMPS  May 31 2014 (04:35-06:25 UT)
**Imager and UV Sun-photometer Complementarity**

- **IR ash detection:**
  - Plume must be transparent
  - Water hides ash
  - Plume temperature contrast with underlying surface
  - Detectable day and night
  - Low concentration not detectable

- **Fresh ash clouds:**
  - Dense, must wait until sheared to thin layer
  - Full of water, ice which masks detection

- **UV ash (AI) detection:**
  - Scattering by ash differs from Rayleigh scattering
  - Sunlight necessary
  - Low concentrations are detectable

**Fresh ash clouds:**
- Detected upon eruption
- Independent of water content
- Not detectable at night
NASA Direct Readout data processing at FMI and UAF/GINA

Direct Broadcast from Aura and S-NPP satellites

Receiving station in Sodankylä, Finland (FMI)

OMI and OMPS DR processing in Sodankylä

NASA/GSFC Direct Readout Laboratory and NPP ozone PEATE create software package for local processing of NPP DR data

OMPS DR Processing at UAF/GINA

Receiving station at GINA/UAF in Fairbanks Alaska

OMPS Volcanic SO₂

OMI Volcanic SO₂

FMI’s WWW and FTP services. Available within 20 min after data reception.

GINA’s WWW and FTP services to Alaska Volcano Observatory. Available within 20 min after data reception.

http://sampo.fmi.fi/volcanic.html
Aura/OMI SO$_2$ data integrated into NOAA/NESDIS volcanic alert system and web site

Latest OMI SO$_2$ Column 5Km - 24-Hour Composite Images

Important Information for OMI Data Users

Current OMI SO$_2$ Composites

- Tropics
- Northern Hemisphere
- Southern Hemisphere

Current & Previous Digital Images

- GeoTIFF, NetCDF, HgIDAS, GIF

Latest OMI SO$_2$ Column 5Km by Volcano

- Alaska, USA
- Aleutian Islands, Alaska, USA
- Anatahan, Mariana Islands
- Cascade
- Central America
- Canary Islands
- Eastern China
- Ecuador
- Etna, Sicily, Italy
- Galapagos Islands, Ecuador
- Hawaii, USA
- Iceland
- Japan
- Java, Indonesia
- Kamchatka, Russia
- Mexico
- Montserrat, West Indies
- New Zealand
- North Western Europe
- Northern Atlantic
- Northern Chile
- Nyiragongo, DR Congo
- Peru
- Philippines
- Papua New Guinea
- Red Sea
- Reunion Island
- Southern Chile
- Sulawesi Sangihe, Indonesia
- Sumatra, Indonesia
- Tanzania
- Vanuatu, South Pacific

For OMI and AIRS SO$_2$ Alerts check the [OMI SO$_2$ Alert Site](http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html) and the [AIRS SO$_2$ Alert Site](http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html)

For science quality products check with [NASA GES DISC](http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html) and with the NASA Global Sulfur Dioxide Monitoring

NOAA/NESDIS distributes NASA volcanic SO$_2$ data from Aura/OMI to operational users via Washington Volcanic Ash Advisory Center. NOAA issues automatic e-mail alerts notifications
The European Support to Aviation Control Service (SACS) is using the operational volcanic SO$_2$ column and Ash Index data from Aura/OMI and SNPP/OMPS as well as volcanic SO$_2$ data from Aqua/AIRS produced by NASA to complement the information already available from the morning instruments (GOME-2A/B, and IASI-A/B). The project is supported by NASA applied Sciences Disaster Program: [http://so2.gsfc.nasa.gov](http://so2.gsfc.nasa.gov)
NASA NRT data are of utmost importance for Support to Aviation Control Service (SACS)

SACS = global alerting system for volcanic SO₂ and ash

SACS is used by 278 subscribed users for many applications:

- Volcanological observatories
- VAACs/metOffices
- Pilots
- Airlines, private companies related to aviation sector
- National civil protection agencies
- Scientists
- Students, Professors
- Journalists
- Citizens

Enhanced Characterization: Assimilating Series of CALIPSO Curtains Into Dispersion Forecast Models

New Zealand

Volcanic ash cloud

Ensemble of trajectories

Australia
Result: Improving VAAC Advisories

CALIPSO-trajectory mapping

- Ash cloud masked by ash in MTSAT data over SE Australia (Sydney)
- Ash Advisory misses area over Tasman Sea
- CALIPSO-trajectory map captured the head of the plume on time as validated by a subsequent independent daytime overpass
- n.b. The plume depiction above is 2-D, whereas the model output is 4-D.
Caliop - The CALIPSO lidar

- Operating since 2006
- Polar Orbit
- Equatorial Crossing-time at 0130 and 1330 LET
- Repeat cycle of 16 days

- Total Backscatter at 532 nm (density)
- Depolarization at 532 nm (geometry)
  - Color Ratio (1064/532) (size)

- High vertical resolution (60 m) of backscatter profiles
- Optical parameters provide unique capability to detect volcanic ash and its vertical structure
Cordon ash clouds over New Zealand observed by CALIPSO several weeks after the eruption

- Multi laminar layers with low color ratio (0.5) and high depolarization (0.3-0.4) indicative of ash as opposed to ice
- Negative BT from IIR on board CALIPSO
- Consistent with small volcanic ash from Cordon
- Similar features observed most of June 2011
Plume 1

- Zero-Wind Height
- Wind-Corrected Height
- Terrain Height

Plume 2

- Zero-Wind Height
- Wind-Corrected Height
- Terrain Height

Height: Blue = Wind-corrected

Distance From Plume Source (Km)

R. Kahn, D. Nelson, and the MISR Team, NASA JPL and GSFC

Adding Stereo-Derived plume heights, May 7, 12:39 UT

O~1.1 km spatial resolution curtain has limited utility
OMI and OMPS provide information on the horizontal distribution of total column SO$_2$ and volcanic ash index while Caliop provides critical height distribution data of the volcanic aerosols.
LaRC Airborne HSRL-2: World’s First Airborne Multi-wavelength HSRL

07/17/2012 TCAP flight on B200 aircraft

- High Spectral Resolution Lidar (HSRL) provides independent retrievals of aerosol extinction and backscatter
  - HSRL-2 Capabilities
    - Backscatter at 355, 532, and 1064 nm
    - Extinction at 355 and 532 nm (HSRL)
    - Depolarization at 355, 532, 1064 nm
<table>
<thead>
<tr>
<th>Caliop and HSRL*</th>
<th>HSRL-2 and ACE**</th>
</tr>
</thead>
<tbody>
<tr>
<td>532 and 1024 nm*</td>
<td>355, 532, and 1064 nm</td>
</tr>
<tr>
<td>Backscatter</td>
<td>Backscatter</td>
</tr>
<tr>
<td>Depolarization</td>
<td>Depolarization</td>
</tr>
<tr>
<td>Color ratio</td>
<td>Color ratio</td>
</tr>
<tr>
<td>Extinction at 532 nm</td>
<td>Extinction at 355 and 532 nm</td>
</tr>
<tr>
<td>Effective radius</td>
<td>Effective radius</td>
</tr>
<tr>
<td>Index of refraction</td>
<td>Index of refraction</td>
</tr>
<tr>
<td>Scattering &amp; Absorption Coefficients</td>
<td>Scattering &amp; Absorption Coefficients</td>
</tr>
<tr>
<td>Single Scattering Albedo</td>
<td>Single Scattering Albedo</td>
</tr>
</tbody>
</table>

* 2 channel lidar are a minimum requirement to characterize volcanic ash. HSRL is the Calipso airborne equivalent. 

Eg. ESA EarthCare mission with a single 355 nm channel will provide improved signal to noise performance for plume heights, limited microphysics, and model trajectory validation. It will also provide greater observation frequency with multiple platforms, but it will not be a sufficiently capable, primary volcanic ash assessment tool.

** 3 channel lidar are required to directly retrieve volumetric concentration without secondary cal/val.
UW/NOAA CIMSS Automated Alerts

Primary Application: Initial Detection, Characterization and Alerting

Potential Secondary Application: Automated cuing of higher resolution observations such as Clip
Application of SAR-integrated system to historic eruption of Okmok
- Conventional AVO data showed hazard signals only 20 minutes before eruption!

- SAR showed changing deformation pattern 25 days prior to eruption!

Δt = 350 days

Automatic SAR product shows deformation ~25 days before eruption

Jun 12, 19:40: First seismic signals (only 20 minutes before eruption)

Jun 12, 20:00: Start of eruption

Jun 12, 20:20: First thermal signal in remote sensing data

SAR-VIEWS: SAR Volcano Integrated Early Warning System
NASA ASP Disasters Project, PI: FJ Meyer & University of Alaska Fairbanks
Accomplishment/Result

• While project is aimed at volcanic hazards, we have applied SARVIEWS to disasters of opportunity including:
  – Nepal earthquake (Apr/May 2015)
  – Wolf Volcano (May 2015)
  – Northwest China Earthquake (Jul 2015)
  – Chile Earthquake (Sep 2015)

• Chile Earthquake (9/16/15; mag. 8.3):
  – SARVIEWS team completed event-capturing SAR interferogram within 24 hours of the earthquake!
  – Image on right shows up to 1.5 meters of surface deformation across an area of 130 miles radius
SAR-VIEWS: SAR Volcano Integrated Early Warning System

Additional Examples

- Earthquake Northwest China 7/3/2015
- Wolf Volcano Eruption 5/25/2015
- Nepal Earthquake Apr. 2015

Hazard products for recent disasters: GIS-Ready Surface Deformation maps
KIAsh deployment after Mt Kelud eruption

KIAsh campaign

10-day balloon field experiment in Darwin (Australia) May, 2014 to sample volcanic aerosol from the Mt Kelud eruption. Rapid Response, with critical support from NASA HQ (Considine, Kaye), CALIPSO (Trepte), SAGE (Thomason), Australian BOM (Atkinson), CASA.

Accumulated CALIPSO observations (14-24 May 2014)

- 3 months after the Mt Kelud eruption, the KIAsh campaign has revealed the persistence of volcanic ash in the lower stratosphere. Current models do not account for the climate impact of volcanic ash.
Questions?