Ash Dispersal Forecast and Civil Aviation Workshop

Geneva, Switzerland, 18-20 November 2013

Data Acquisition Document

Introduction

The definition of the source term (mainly plume height, erupted mass, particle size distribution) required by VATDM relies on remote sensing and ground-based observations. All data acquisition techniques have advantages and limitations. Optimized strategies for ash-dispersal forecasting should involve integrated data acquisition resulting from the combination of different techniques that could cover a wide spectrum of conditions. As part of the Ash dispersal forecast and civil aviation workshop this document has been compiled that summarizes the main characteristics of selected available techniques in order to facilitate such integration (appendices 1 to ??).

Appendix 1: AVHRR
Appendix 2: GOES-11 Imagery
Appendix 3: Grimm EDM 107
Appendix 4: Grimm Sky OPC
Appendix 5: Weather-Radar (C band and X band)
Appendix 6: Infrasonic Array
Appendix 7: IR-SO2
Appendix 8: LIDAR
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Appendix 10: MODIS
Appendix 11: MTSAT
Appendix 12: OMI
Appendix 13: PLUDIX
Appendix 14: SEVIRI
Appendix 15: Thermal Camera
Appendix 16: UV Camera
Appendix 17: VOLDORAD

1. System (platform) overview

Instrument Name	**AVHRR**		
Spectral range	0.65, 3.75, 11, and 12 μm channels are needed by ash detection algorithm; 11, and 12 μm channels are needed by retrieval algorithm. Wen and Rose (1994) method can use just the 11 and 12 μm channels for ash detection and to retrieve volcanic ash mass and effective particle size. Method known since Prata (1989 a, b) and used for ash detection at AVO (Webley et al, 2009). Prata and Grant (2001) provide a good detailed description of how to obtain the cloud retrievals from AVHRR data.		
Record frequency	Twice per day per satellite		
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Automated ash detection, ash cloud height (temperature and pressure), ash mass loading (mass/area), ash effective radius, and ash optical depth (wavelength dependent)		
Scale of acquisition			Tick
	Proximal (order of a few km)		X
	Medial (order of 100s of km)		X
	Distal (order of 1000s of km)		X
	Other		
		YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?		X	
If yes, where?	Nearly all VAACs. Alaska Volcano Observatory has been using the 11 and 12 μm channels for ash detection for 15 years (Webley et al, 2009)		

2. Technical requirements

	YES	NO	Comments
Is it ground based?		X	
Is it satellite based?	X		LEO
Does it require dedicated instrumentation?	X		Data can be acquired through ground receiving stations
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)	X		The retrieval technique requires global NWP data (GFS), global snow maps (IMS), global SST data (OISST). With the Wen and Rose (1994) method, then only channels at 11 and 12 μm (AVHRR channels 4 and 5) are needed

Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	X		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?		X

If yes, please complete the following:	
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	Satellite must be in range of ground receiving station
Delivery time (e.g., real-time, days, weeks, months)	Near real-time
Uncertainties	Depend on uncertainty in clear sky radiances, calibration, pixel heterogeneity, microphysical model (composition - index of refraction, particle habit, particle distribution type, etc…).
Type of output	Quantitative ash cloud properties in HDF4 format. Can be readily available as jpeg/png or KML/KMZ, as used by AVO.

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	
Assumptions required for data processing (e.g., complex refractive index data)	
Delivery time of additional processing (e.g., real-time, days, weeks, months)	
Software requirements	
Uncertainties	
Type of output	

	YES	NO
Is data freely available?	X	

If yes, please specify where it can be downloaded:	Via direct broadcast (real-time) or NOAA (not real-time)

4. Limitations

	Comments
Detection limits	> 0.5 tons/km^2
Saturation	~100 tons/km^2
Particle size	Effective radius sensitivity: 0.5 – 15.0 μm
Weather conditions	Ash layer must be colder than surface
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	Ash must be highest cloud layer
Vertical resolution (i.e., 1D, 2D , 3D)	Cloud layer integrated properties of highest ash cloud layer
Units	Mass loading (tons/km^2), Ash Height (km), Ash effective radius (μm)
Other	

5. Other

References

Pavolonis, M. J., 2010: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures Part I: Theory, *J. Applied Meteorol. And Climatology*, **49(9)**, 1992-2012.

Pavolonis, M. J. and J. Sieglaff, 2010: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Volcanic Ash: Detection and Height, Version 2.0., 72 pp.

Pavolonis, Michael J.; Feltz, Wayne F.; Heidinger, Andrew K. and Gallina, Gregory M. A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash. Journal of Atmospheric and Oceanic Technology, Volume 23, Issue 11, 2006, pp.1422-1444.

Prata, A. J., 1989a. Infrared radiative transfer calculations for volcanic ash clouds, *Geophysical Research Letters*, **16**, 1293-1296.

Prata, A. J., 1989b. Observations of volcanic ash clouds in the 10-12 μm window using AVHRR/2 data, *International Journal of Remote Sensing*, **10**, 751-761.

Prata, A. J., and Grant, I. F., 2001. Retrieval of microphysical and morphological properties of volcanic ash plumes from satellite data: Application to Mt. Ruapehu, New Zealand, *Q. J. R. Meteorol.,* 127.

Heidinger, A. K. and M. J. Pavolonis, 2009: Nearly 30 years of gazing at cirrus clouds through a split-window. Part I: Methodology. *J.Appl.Meteorol. and Climatology*, **48(6)**, 110-1116.

Heidinger, A.K., M.J. Pavolonis, R. E. Holz, B. A. Baum, and S. Berthier, 2010: A comparison of the sensitivity to cloud pressure offered by the NPOESS/VIRRS and GOES-R/ABI Infrared observations for cirrus cloud remote sensing, *J. Geophys. Research*, **115**, Doi:10.1029/2009JD012152.

Webley, P.W., Dehn, J., Lovick, J., Dean, K.G., Bailey, J.E. and Valcic, L., 2009. Near Real Time Volcanic Ash Cloud Detection: Experiences from the Alaska Volcano Observatory. *Journal of Vol. and Geo. Research: SI on Volcanic Ash Clouds, eds. Larry Mastin and Peter Webley,* **186** (1 – 2), 79 - 90. doi:10.1016/j.jvolgeores.2009.02.010

Wen, S and Rose, W. I., 1994, Retrieval of Particle sizes and masses in volcanic clouds using AVHRR bands 4 and 5, *Journal of Geophysical Research*, **99,** 5421-5431.

Other comments

1. System (platform) overview

Instrument Name	**GOES-11 Imager**		
Spectral range	0.65, 3.9, 6.7, 11, and 12 µm channels are needed by ash detection algorithm; 11 and 12 µm channels are needed by retrieval algorithm. Wen and Rose (1994) method can use just the 11 and 12 µm channels for ash detection and to retrieve volcanic ash mass and effective particle size. Method known since Prata (1989 a, b) and used for ash detection at AVO (Webley et al, 2009).		
Record frequency	Varies depending on location from every 15 minutes to 3 hours		
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Automated ash detection, ash cloud height (temperature and pressure), ash mass loading (mass/area), ash effective radius, and ash optical depth (wavelength dependent)		
Scale of acquisition			Tick
	Proximal (order of a few km)		X
	Medial (order of 100s of km)		X
	Distal (order of 1000s of km)		X
	Other		
		YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?		X	
If yes, where?	Washington and Anchorage VAACs (maybe Darwin as well)		

2. Technical requirements

	YES	NO	Comments
Is it ground based?		X	
Is it satellite based?	X		GEO
Does it require dedicated instrumentation?	X		Data can be acquired through GVAR
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)	X		The retrieval technique requires global NWP data (GFS), global snow maps (IMS), global SST data (OISST). With the Wen and Rose (1994) method, then only channels at 11 and 12 µm (GOES channels 4 and 5) are needed.
Can data be easily automatically transferred? (e.g., wire, radio, GSM)	X		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?		X

If yes, please complete the following:	
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	GVAR access
Delivery time (e.g., real-time, days, weeks, months)	Real-time
Uncertainties	Depend on uncertainty in clear sky radiances, calibration, pixel heterogeneity, microphysical model (composition - index of refraction, particle habit, particle distribution type, etc…)
Type of output	Quantitative ash cloud properties in HDF4 format. Can be readily available as jpeg/png or KML/KMZ, as used by AVO.

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	
Assumptions required for data processing (e.g., complex refractive index data)	
Delivery time of additional processing (e.g., real-time, days, weeks, months)	
Software requirements	
Uncertainties	
Type of output	

	YES	NO
Is data freely available?	X	
If yes, please specify where it can be downloaded:	Via GVAR in real-time	

4. Limitations

	Comments
Detection limits	> 0.5 tons/km^2
Saturation	~100 tons/km^2
Particle size	Effective radius sensitivity: 0.5 – 15.0 µm
Weather conditions	Ash layer must be colder than surface
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	Ash must be highest cloud layer
Vertical resolution (i.e., 1D, 2D , 3D)	Cloud layer integrated properties of highest ash cloud layer
Units	Mass loading (tons/km^2), Ash Height (km), Ash effective radius (µm)
Other	

5. Other

References

Pavolonis, M. J., 2010: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures Part I: Theory, *J. Applied Meteorol. And Climatology*, **49(9)**, 1992-2012.

Pavolonis, M. J. and J. Sieglaff, 2010: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Volcanic Ash: Detection and Height, Version 2.0., 72 pp.

Pavolonis, Michael J.; Feltz, Wayne F.; Heidinger, Andrew K. and Gallina, Gregory M. A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash. Journal of Atmospheric and Oceanic Technology, Volume 23, Issue 11, 2006, pp.1422-1444.

Prata, A. J., 1989a. Infrared radiative transfer calculations for volcanic ash clouds, *Geophysical Research Letters*, **16**, 1293-1296.

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Prata, A. J., and Grant, I. F., 2001. Retrieval of microphysical and morphological properties of volcanic ash plumes from satellite data: Application to Mt. Ruapehu, New Zealand*, Q. J. R. Meteorol.,* 127.

Heidinger, A. K. and M. J. Pavolonis, 2009: Nearly 30 years of gazing at cirrus clouds through a split-window. Part I: Methodology. *J.Appl.Meteorol. and Climatology*, **48(6)**, 110-1116.

Heidinger, A.K., M.J. Pavolonis, R. E. Holz, B. A. Baum, and S. Berthier, 2010: A comparison of the sensitivity to cloud pressure offered by the NPOESS/VIRRS and GOES-R/ABI Infrared observations for cirrus cloud remote sensing, *J. Geophys. Research*, **115**, Doi:10.1029/2009JD012152.

Webley, P.W., Dehn, J., Lovick, J., Dean, K.G., Bailey, J.E. and Valcic, L., 2009. Near Real Time Volcanic Ash Cloud Detection: Experiences from the Alaska Volcano Observatory. *Journal of Vol. and Geo. Research: SI on Volcanic Ash Clouds, eds. Larry Mastin and Peter Webley,* **186** (1 – 2), 79 - 90. doi:10.1016/j.jvolgeores.2009.02.010

Wen, S and Rose, W. I., 1994, Retrieval of Particle sizes and masses in volcanic clouds using AVHRR bands 4 and 5, *Journal of Geophysical Research*, **99,** 5421-5431.

Other comments

1. System (platform) overview

Instrument Name	**Grimm EDM 107**	
Spectral range	Laser wavelength 660 nm	
Record frequency	Max. 10 samples per minute	
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Particle mass per volume Number of particles per volume	
Scale of acquisition		Tick
	Proximal (order of a few km)	
	Medial (order of 100s of km)	
	Distal (order of 1000s of km)	
	Other	**X**

	YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?	**X**	
If yes, where? on request		

2. Technical requirements

	YES	NO	Comments
Is it ground based?	**X**		Can be used groundbased and airborne
Is it satellite based?		**X**	
Does it require dedicated instrumentation?		**X**	
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)		**X**	
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)			It could be upgraded to automatical transfer

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?	X	

If yes, please complete the following:	
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	
Delivery time (e.g., real-time, days, weeks, months)	
Uncertainties	
Type of output	

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	refractive index, ash particles density
Assumptions required for data processing (e.g., complex refractive index data)	refractive index, ash particles density
Delivery time of additional processing (e.g., real-time, days, weeks, months)	Near real time possible
Software requirements	
Uncertainties	
Type of output	

		YES	NO
Is data freely available?			
If yes, please specify where it can be downloaded:			

4. Limitations

	Comments
Detection limits	Number: 1 particle/liter; mass: 0.1 μg/m^3;
Saturation	Number: 2,000,000 particle/liter Mass: PM10: 10,000 μg/m^3; PM2.5: 6,500 μg/m^3 PM1: 1,500 μg/m^3
Particle size	0.25 to 32 μm, bigger particle size with appropriate sampling inlet
Weather conditions	0 to 40 °C; RH< 95%
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	No
Vertical resolution (i.e., 1D, 2D , 3D)	1D
Units	Number of particles; μg/m^3
Other	

5. Other

References
[1] Weber K., Weber S., and Kuttler W., "Flow characteristics and particle mass and number concentration variability within a bus urban street canyon" Atmospheric Environment, vol. 40, pp. 7565-7578, July 2006. [2] Weber K., Weber S., and Kuttler W., "Coupling of urban street canyon and backyard particle concentrations" Metrologische Zeitschrift, vo3, no. 17, pp. 251-261, June 2008.

Other comments

1. System (platform) overview

Instrument Name	**Grimm Sky OPC**		
Spectral range	Laser wavelength 660 nm		
Record frequency	Max. 10 samples per minute		
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Particle mass per volume Number of particles per volume		
Scale of acquisition			Tick
	Proximal (order of a few km)		
	Medial (order of 100s of km)		
	Distal (order of 1000s of km)		
	Other		**X**
		YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?		**X**	
If yes, where?	on request		

2. Technical requirements

	YES	NO	Comments
Is it ground based?			Can be used groundbased and airborne (pressure correction), especially designed for aircraft measurements
Is it satellite based?		**X**	
Does it require dedicated instrumentation?		**X**	
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)		**X**	
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)			It could be upgraded to automatical transfer

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?	x	

If yes, please complete the following:	
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	
Delivery time (e.g., real-time, days, weeks, months)	
Uncertainties	
Type of output	

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	refractive index, ash particles density
Assumptions required for data processing (e.g., complex refractive index data)	refractive index, ash particles density
Delivery time of additional processing (e.g., real-time, days, weeks, months)	Near real time possible
Software requirements	
Uncertainties	
Type of output	

	YES	NO
Is data freely available?		
If yes, please specify where it can be downloaded:		

4. Limitations

	Comments
Detection limits	Number: 1 particle/liter; mass: 0.1 μg/m^3;
Saturation	Number: 2,000,000 particle/liter Mass: PM10: 10,000 μg/m^3; PM2.5: 6,500 μg/m^3 PM1: 1,500 μg/m^3
Particle size	0.25 to 32 μm, bigger particle size with appropriate sampling inlet
Weather conditions	0 to 40 °C; RH< 95%
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	No
Vertical resolution (i.e., 1D, 2D , 3D)	1D
Units	Number of particles; μg/m^3
Other	

5. Other

References

Other comments

1. System (platform) overview

Instrument Name	**Doppler weather radar** at C band with horizontal single polarization (WR-C) **Mobile Doppler weather radar** at X band with dual polarization capability (WR-X)	
Spectral range	WR-C: Regular 240 km, but can be put to max 480 km. WR-X: Regular 60 km, but can be put to max 120 km.	
Record frequency	5 min frequency during volcanic eruption, otherwise 15 min frequency.	
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	WR-C: Horizontally-polarized reflectivity (dBZ) of particles (hydrometeors, ash and others). WR-X: Horizontally-polarized reflectivity (dBZ) of particles (hydrometeors, ash and others); differential reflectivity (dB); differential-polarization phase shift; copolar correlation coefficient; linear cross-polarization ratio (dB)	
Scale of acquisition		Tick
	Proximal (order of a few km)	x
	Medial (order of 100s of km)	x
	Distal (order of 1000s of km)	
	Other	

	YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?	x	
If yes, where?	IMO uses radar data and it is VO, AVO has used for volcanic eruptions, Anchorage VAAC for Alaska	

2. Technical requirements

	YES	NO	Comments
Is it ground based?	x		
Is it satellite based?			
Does it require dedicated instrumentation?	x		
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)		X	Depends on the retrieved product; thermal state of the atmosphere may be a useful information.
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	x		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?		x

If yes, please complete the following:	
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	
Delivery time (e.g., real-time, days, weeks, months)	
Uncertainties	
Type of output	

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	Commercial and research software packages are available for data processing or equivalent (e.g., Selex-Gematronic Rainbow software or VARR software).
Assumptions required for data processing (e.g., complex refractive index data)	Particle refractive index at C or X band together with particle density and fallout velocity.
Delivery time of additional processing (e.g., real-time, days, weeks, months)	Near real-time (few minutes after volume scan completition).
Software requirements	For example: Rainbow5.
Uncertainties	Ambiguity between ash clouds and rain clouds in mixed weather
Type of output	Graphical output, volume data.

	YES	NO
Is data freely available?		x
If yes, please specify where it can be downloaded:		

4. Limitations

	Comments
Detection limits	Topographical blocking, range/height (Earth curvature), particle size distribution, refractive index and density uncertainties.
Saturation	
Particle size	Particle less than 100 microns may be not detectable, but it depends on signal-to-noise

	level. WR-X may be more sensitive with respect to WR-C, since its radar-plume distance may be reduced thanks to its mobility.
Weather conditions	Rain/Snow/Ice conditions might alter the ash signal.
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	No
Vertical resolution (i.e., 1D, 2D , 3D)	3D.
Units	WR-C: dBZ and height; range. WR-X: dBZ and height; range; dB, degrees, dB.
Other	

5. Other

References

Harris, D.M. and W.I. Rose, Estimating particle sizes, concentrations and total mass of ash in volcanic clouds using weather radar. J. Geophys. Res., 88, pp. 10969-10983, 1983.

Lacasse, C., Karlsdóttir, S., Larsen, G., Soosalu, H., Rose, W.I., Ernst, G.G.J., Weather radar observations of the Hekla 2000 eruption cloud, Iceland. Bull. Volcanol. 66, pp. 457-473, 2004.

Marzano F.S., S. Barbieri, G. Vulpiani and W.I. Rose, Volcanic cloud retrieval by ground-based microwave weather radar, IEEE Trans. Geosci. Rem. Sens., ISSN: 0196-2892, vol. 44, n.11, pp. 3235-3246, 2006.

Marzano F.S., S. Barbieri, E. Picciotti and S. Karlsdóttir, Monitoring sub-glacial volcanic eruption using C-band radar imagery. IEEE Trans. Geosci. Rem. Sensing, 58, pp. 403-414, 2010.

Marzano F.S., M. Lamantea, M. Montopoli, S. Di Fabio and E. Picciotti, The Eyjafjöll explosive volcanic eruption from a microwave weather radar perspective. Atmosph. Chemistry and Physics, 11, pp. 9503–9518, 2011.

Marzano F.S., M. Lamantea, M. Montopoli, B. Oddsson and M.T. Gudmundsson, Validating sub-glacial volcanic eruption using ground-based C-band radar imagery. IEEE Trans. Geosci. Rem. Sens., ISSN: 0196-2892, 50, pp. 1266-1282, 2012.

Other comments
Information about the C-band doppler radar located close to Keflavík airport, Iceland (adapted from Lacasse et al., 2004):

Type	C-band Ericsson radar system EWIS. Updated to doppler radar, first week of April 2010. Software from Selex-Gematronic.
Location	64º01’35”N, 22º38’09”W
Operational since	January 1991
Height of antenna	47 m above sea level
Peak transmitted power	245.2 kW
Beam width	0.9º
Elevation angle	0.5º
Pulse duration	2.15 µm
Wavelength	5 cm
Pulse repetition rate	250 ± 2 Hz
Maximum range	480 km
Actual gain of antenna	44.9 dB

Information about X-band dual-polarization Doppler weather radars and their potential for ash plume monitoring can be obtained from:

Marzano F.S., E. Picciotti, G. Vulpiani and M. Montopoli, Synthetic Signatures of Volcanic Ash Cloud Particles from X-band Dual-Polarization Radar. IEEE Trans. Geosci. Rem. Sens., ISSN: 0196-2892, 50, 193-211, 2012.

1. System (platform) overview

Instrument Name	**INFRASONIC ARRAY**	
Spectral range	0.001 Hz – 50 Hz	
Record frequency	100 sps	
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Acoustic pressure of infrasonic waves Infrasonic waves back-azimuth	
Scale of acquisition		Tick
	Proximal (order of a few km)	X
	Medial (order of 100s of km)	X
	Distal (order of 1000s of km)	
	Other	

	YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?		X
If yes, where?		

2. Technical requirements

	YES	NO	Comments
Is it ground based?	X		
Is it satellite based?		X	
Does it require dedicated instrumentation?	X		Small aperture (<500m) infrasonic array
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)	X		Weather station
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	X		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?		X

If yes, please complete the following:	
	Comments
Assumptions required for data	

acquisition (e.g., geometry of observations)	
Delivery time (e.g., real-time, days, weeks, months)	
Uncertainties	
Type of output	

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	Progressive Multi-Channel Correlation (PMCC) algorithm
Assumptions required for data processing (e.g., complex refractive index data)	Plane wavefront propagation
Delivery time of additional processing (e.g., real-time, days, weeks, months)	Real-time
Software requirements	Matlab
Uncertainties	Source distance
Type of output	Acoustic pressure, source backazimuth

	YES	NO
Is data freely available?		X
If yes, please specify where it can be downloaded:		

4. Limitations

	Comments
Detection limits	From mPa to MPa, depending on the sensors and the distance from the source
Saturation	Depending on the sensors
Particle size	---
Weather conditions	Wind noise can affect and reduce the array sensitivity
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	No
Vertical resolution (i.e., 1D, 2D , 3D)	---
Units	Pressure [Pa], Back-azimuth [deg]
Other	---

5. Other

References
Ripepe, M., E. Marchetti, (2002). Array tracking of infrasonic sources at Stromboli volcano, Geophys. Res. Lett. 29, 2076. Ripepe, M., S. De Angelis, G. Lacanna and B. Voight, (2010). Observation of infrasonic and gravity waves at Soufrière Hills Volcano, Montserrat, Geophys. Res. Lett., 37.

Other comments

1. System (platform) overview

Instrument Name	**Broadband IR SO_2 sensors – MODIS, ASTER, SEVIRI**		
Spectral range	8-12 microns.		
Record frequency	Varies from 15 mins (SEVIRI) to at least several days (ASTER)		
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	SO_2 burden, vertical distribution (experimental for everything but ASTER)		
Scale of acquisition			Tick
	Proximal (order of a few km)		X
	Medial (order of 100s of km)		X
	Distal (order of 1000s of km)		X
	Other		
		YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?		X	
If yes, where?	Through EUMETSAT and NASA portals/db		

2. Technical requirements

	YES	NO	Comments
Is it ground based?		X	
Is it satellite based?	X		
Does it require dedicated instrumentation?		X	
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)	X		
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)		X	Direct broadcasting requires specialist equipment (London VAAC has, obviously) as data volumes are considerable

3. Data acquisition and delivery

		YES	NO
Can raw data be used with no additional processing?			X
If yes, please complete the following:			
	Comments		

Assumptions required for data acquisition (e.g., geometry of observations)	Need met. data (sometimes) and some a priori information (typically height)
Delivery time (e.g., real-time, days, weeks, months)	NRT
Uncertainties	Multispecies interference, clouds, met. data.
Type of output	SO_2 maps

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	
Assumptions required for data processing (e.g., complex refractive index data)	
Delivery time of additional processing (e.g., real-time, days, weeks, months)	
Software requirements	
Uncertainties	
Type of output	

	YES	NO
Is data freely available?	X	
If yes, please specify where it can be downloaded:	NASA portals, e.g. WIST, geonetcast	

4. Limitations

	Comments
Detection limits	Ca. 1 gm^{-2} (typical for a 3km plume)
Saturation	1000 gm^{-2}
Particle size	NA
Weather conditions	Clouds prevent retrieval
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	Day/night
Vertical resolution (i.e., 1D, 2D , 3D)	At best, +/- 1 km for height.
Units	gm^{-2}
Other	

5. Other

References
Prata, A.J., G.J.S. Bluth, C. Werner, V.J. Realmuto, S.A. Carn, and I.M. Watson, 2010, Gas Emissions from Volcanoes, in *Monitoring Volcanoes in the North Pacific: Observations from Space*, eds. K.G. Dean and J. Dehn, ISBN: 978-3-540-24125-6, Springer-Praxis Books (in press). Thomas, H.E., Watson, I.M., 2010, Observations of volcanic emissions from space: current and future perspectives. Natural Hazards, doi: 10.1007/s11069-009-9471-3 Watson, I.M., Schneider, D.J., Saunders, R., Thoradson, T., Thomas, H.E., Zehner, C., Rose, W.I.,and Prata A.J., 2010, Chapter 1. Are we making best use of existing observing systems to adress the problems created by the Eyjafjöll eruption?, in 'Monitoring volcanic ash from space, ESA-EUMETSAT workshop on the 14th April to 23rd May eruption of Eyjafjöll volcano, South Icelend', ed. Kluas Zehner, STM-280: 10-25

Other comments

1. System (platform) overview

Instrument Name	**LIDAR**	
Spectral range	UV-VIS-nearIR	
Record frequency	Variable	
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Aerosol layer geometrical properties Aerosol extinction coefficient Aerosol backscatter Optical depth PBL height Linear particle and volume depolarization ratio Possible (but not in all cases): mass concentration profile and microphysical properties	
Scale of acquisition		Tick
	Proximal (order of a few km)	
	Medial (order of 100s of km)	
	Distal (order of 1000s of km)	
	Other	X

	YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?		X
If yes, where?		

2. Technical requirements

	YES	NO	Comments
Is it ground based?	X		
Is it satellite based?	X		CALIPSO at moment ADM-Aeolus and EarthCARE in the future
Does it require dedicated instrumentation?	X		
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)	X		Ancillary data (such as radiosoundings) are useful but not necessary
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	X		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?	X	

If yes, please complete the following:	Raw data (actually with just a simple processing) can provide information about the distribution in space and time of the aerosol/cloud fields. This is what we call quicklook data
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	Geometry could be important depending on the specific lidar technique
Delivery time (e.g., real-time, days, weeks, months)	Real-time (possible, to be implemented and probably not for final QA products)
Uncertainties	Depending on lidar experimental setup
Type of output	Profile data (typically netcdf format)

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	Elastic Backscatter (Klett, Iterative) Extinction (Raman signal 1st derivative) Raman backscatter (Combined Raman/elastic method)
Assumptions required for data processing (e.g., complex refractive index data)	Elastic backscatter (lidar ratio profile) Atmospheric standard model when no correlative radiosounding is available
Delivery time of additional processing (e.g., real-time, days, weeks, months)	Hours (possible but it taks some effort to be implemented); Days (possible in most of the cases); Months (complete QA products)
Software requirements	Dedicated software
Uncertainties	Depending on lidar experimental setup, integration time and vertical resolution. Typically below 5% for backscatter and below 10% for extinction
Type of output	Profile data (NetCDF typically)

		YES	NO
Is data freely available?		X	X
If yes, please specify where it can be downloaded:	Data access depend on the different systems. Regarding lidar networks, mainly yes EARLINET data are available at www.earlinet.org		

4. Limitations

	Comments
Detection limits	Depending on the measured parameter (typically AOD ≤ 0.01)
Saturation	Very rare, depending on experimental setup
Particle size	Variable depending on laser wavelengths (typically 100 nm – 2 micron)
Weather conditions	No measurements in case of rain, fog, low clouds
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	Daytime measurements are usually with a worse SNR
Vertical resolution (i.e., 1D, 2D , 3D)	From 1D to 3D, depending on the lidar system. The most common is 1D with variable vertical resolution (typically from 3.75m to 60m raw data vertical resolution)
Units	Depend on the parameter: Geometrical properties (i.e. base, top) [m] Extinction [m-1] Backscatter [m-1 sr-1] Lidar ratio [sr] Optical depth Angstrom exponent Depolarization ratio PBL height [m]
Other	Covered altitude range depends on the system design

5. Other

References
www.earlinet.org (see Publication) www-calipso.larc.nasa.gov/resources/publications.php

Other comments

1. System (platform) overview

Instrument Name	Multiangle Imaging Spectroradiometer (**MISR**)		
Spectral range	4 bands (blue, green, red, and near-infrared)		
Record frequency	Global coverage time: every 9 days, with repeat coverage between 2 and 9 days depending on latitude		
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Plume height, Wind Speed, Optical Depth, Angstrom exponent, Single-Scattering Albedo, Tau Fraction by Particle-Type.		
Scale of acquisition			Tick
	Proximal (order of a few km)		
	Medial (order of 100s of km)		X
	Distal (order of 1000s of km)		
	Other		
		YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?			X
If yes, where?			

2. Technical requirements

	YES	NO	Comments
Is it ground based?		X	
Is it satellite based?	X		
Does it require dedicated instrumentation?		X	
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)		X	
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)		X	

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?		X
If yes, please complete the following:		

	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	
Delivery time (e.g., real-time, days, weeks, months)	
Uncertainties	
Type of output	

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	The stereo height retrieval technique used in the MINX (MISR INteractive eXplorer) software depends on the identification or matching in non-nadir cameras of a scene viewed by the nadir camera. This is accomplished by performing many cross-correlations between the pairs of camera views as the scenes are shifted relative to each other.
Assumptions required for data processing (e.g., complex refractive index data)	MINX assumes that the motion of ash particles in a plume is in a horizontal plane and in the direction specified by the user when digitizing.
Delivery time of additional processing (e.g., real-time, days, weeks, months)	Days
Software requirements	The MINX software
Uncertainties	About 0.5 km for the plume height
Type of output	From MINX - *.txt; *.jpg; *.png

	YES	NO
Is data freely available?	X	
If yes, please specify where it can be downloaded:	http://l0dup05.larc.nasa.gov/MISR/cgi-bin/MISR/main.cgi	

4. Limitations

	Comments
Detection limits	If the dominant visual components of the scene are features on the ground, the correlation process used in MINX will match to the ground rather than to ash in the atmosphere. Further, vertical particle motion and local changes in wind direction can produce a large scatter in

	height and wind values or can prevent MINX from finding a solution.
Saturation	
Particle size	< 10 µm
Weather conditions	Clouds may prevent volcanic ash detection
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	No low optical density of the plume; absence of bright scenes.
Vertical resolution (i.e., 1D, 2D , 3D)	Stereoscopic height retrieval
Units	m
Other	

5. Other

References
http://www-misr.jpl.nasa.gov/index.cfm; Nelson, D. L., Y. Chen, R. A. Kahn, D. J. Diner, , and D. Mazzoni (2008), Example applications of the MISR INteractive explorer (MINX) software tool to wildfire smoke plume applications, Proc. SPIE Vol. 7089, 708908 (Aug. 27, 2008). http://www.openchannelfoundation.org/orders/index.php?group_id=366.

Other comments

1. System (platform) overview

Instrument Name	**MODIS**	
Spectral range	0.65, 3.75, 7.3, 8.5, 11, and 12 μm channels are needed by ash detection algorithm; 11, 12, and 13.3 μm channels are needed by retrieval algorithm. Wen and Rose (1994) method can use just the 11 and 12 μm channels for ash detection and to retrieve volcanic ash mass and effective particle size. Method known since Prata (1989 a, b) and used for ash detection at AVO (Webley et al, 2009).	
Record frequency	Twice daily per satellite	
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Automated ash detection, ash cloud height (temperature and pressure), ash mass loading (mass/area), ash effective radius, and ash optical depth (wavelength dependent)	
Scale of acquisition		Tick
	Proximal (order of a few km)	X
	Medial (order of 100s of km)	X
	Distal (order of 1000s of km)	X
	Other	

	YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?	X	

If yes, where?	Direct broadcast MODIS data are available at the Anchorage VAAC and will be available at the Darwin VAAC (MODIS is also likely available at other VAAC's and VO's). Alaska Volcano Observatory has been using the 11 and 12 μm channels for ash detection since 2001 (Webley et al, 2009).

2. Technical requirements

	YES	NO	Comments
Is it ground based?		X	
Is it satellite based?	X		LEO
Does it require dedicated instrumentation?	X		An X-band receiver is needed to download direct broadcast data
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)	X		The retrieval technique requires global NWP data (GFS), global snow maps (IMS), global SST data (OISST). With the Wen and Rose (1994) method, then only channels at 11 and 12 μm (MODIS channels 31 and 32) are needed.

Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	X		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?		X

If yes, please complete the following:	
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	Satellite must be in range of direct broadcast receiving station
Delivery time (e.g., real-time, days, weeks, months)	MODIS direct broadcast data are available in near real-time
Uncertainties	Depend on uncertainty in clear sky radiances, calibration, pixel heterogeneity, microphysical model (composition - index of refraction, particle habit, particle distribution type, etc…)
Type of output	Quantitative ash cloud properties in HDF4 format. Can be readily available as jpeg/png or KML/KMZ, as used by AVO.

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	
Assumptions required for data processing (e.g., complex refractive index data)	
Delivery time of additional processing (e.g., real-time, days, weeks, months)	
Software requirements	
Uncertainties	
Type of output	

	YES	NO
Is data freely available?	X	
If yes, please specify where it can be downloaded:	Via direct broadcast (real-time) or NASA (not real-time)	

4. Limitations

	Comments
Detection limits	> 0.5 tons/km^2
Saturation	~100 tons/km^2
Particle size	Effective radius sensitivity: 0.5 – 15.0 µm
Weather conditions	Ash layer must be colder than surface
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	Ash must be highest cloud layer
Vertical resolution (i.e., 1D, 2D , 3D)	Cloud layer integrated properties of highest ash cloud layer
Units	Mass loading (tons/km^2), Ash Height (km), Ash effective radius (µm)
Other	

5. Other

References

Pavolonis, M. J., 2010: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures Part I: Theory, *J. Applied Meteorol. And Climatology*, **49(9)**, 1992-2012.

Pavolonis, M. J. and J. Sieglaff, 2010: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Volcanic Ash: Detection and Height, Version 2.0., 72 pp.

Pavolonis, Michael J.; Feltz, Wayne F.; Heidinger, Andrew K. and Gallina, Gregory M. A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash. Journal of Atmospheric and Oceanic Technology, Volume 23, Issue 11, 2006, pp.1422-1444.

Prata, A. J., 1989a. Infrared radiative transfer calculations for volcanic ash clouds, *Geophysical Research Letters*, **16**, 1293-1296.

Prata, A. J., 1989b. Observations of volcanic ash clouds in the 10-12 µm window using AVHRR/2 data, *International Journal of Remote Sensing*, **10**, 751-761.

Prata, A. J., and Grant, I. F., 2001. Retrieval of microphysical and morphological properties of volcanic ash plumes from satellite data: Application to Mt. Ruapehu, New Zealand*, Q. J. R. Meteorol.,* 127.

Heidinger, A. K. and M. J. Pavolonis, 2009: Nearly 30 years of gazing at cirrus clouds through a split-window. Part I: Methodology. *J.Appl.Meteorol. and Climatology*, **48(6)**, 110-1116.

Heidinger, A.K., M.J. Pavolonis, R. E. Holz, B. A. Baum, and S. Berthier, 2010: A comparison of the sensitivity to cloud pressure offered by the NPOESS/VIRRS and GOES-R/ABI Infrared observations for cirrus cloud remote sensing, *J. Geophys. Research*, **115**, Doi:10.1029/2009JD012152.

Webley, P.W., Dehn, J., Lovick, J., Dean, K.G., Bailey, J.E. and Valcic, L., 2009. Near Real Time Volcanic Ash Cloud Detection: Experiences from the Alaska Volcano Observatory. *Journal of Vol. and Geo. Research: SI on Volcanic Ash Clouds, eds. Larry Mastin and Peter Webley,* **186** (1 – 2), 79 - 90. doi:10.1016/j.jvolgeores.2009.02.010

Wen, S and Rose, W. I., 1994, Retrieval of Particle sizes and masses in volcanic clouds using AVHRR bands 4 and 5, *Journal of Geophysical Research*, **99,** 5421-5431.

Other comments

1. System (platform) overview

Instrument Name	**MTSAT**	
Spectral range	0.65, 3.9, 6.7, 11, and 12 µm channels are needed by ash detection algorithm; 11 and 12 µm channels are needed by retrieval algorithm. Wen and Rose (1994) method can use just the 11 and 12 µm channels for ash detection and to retrieve volcanic ash mass and effective particle size. Method known since Prata (1989 a, b) and used for ash detection at AVO (Webley et al, 2009).	
Record frequency	Varies depending on location from every 15 minutes to every 3 hours	
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Automated ash detection, ash cloud height (temperature and pressure), ash mass loading (mass/area), ash effective radius, and ash optical depth (wavelength dependent)	
Scale of acquisition		Tick
	Proximal (order of a few km)	X
	Medial (order of 100s of km)	X
	Distal (order of 1000s of km)	X
	Other	

	YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?	X	
If yes, where? Tokyo, Darwin, and Washington VAACs. Alaska Volcano Observatory and Kamchatka Volcano Emergency Response Team (KVERT) has been using the 11 and 12 µm channels for ash detection (Webley et al, 2009).		

2. Technical requirements

	YES	NO	Comments
Is it ground based?		X	
Is it satellite based?	X		GEO
Does it require dedicated instrumentation?	X		Data can be acquired through direct dissemination from JMA or through JDDS
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)	X		The retrieval technique requires global NWP data (GFS), global snow maps (IMS), global SST data (OISST). With the Wen and Rose (1994) method, then only channels at 11 and 12 µm (MTSAT channels IR1 and IR2) are needed.

Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	X		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?		X

If yes, please complete the following:	
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	Direct dissemination or JDDS access
Delivery time (e.g., real-time, days, weeks, months)	Real-time
Uncertainties	Depend on uncertainty in clear sky radiances, calibration, pixel heterogeneity, microphysical model (composition - index of refraction, particle habit, particle distribution type, etc…)
Type of output	Quantitative ash cloud properties in HDF4 format. Can be readily available as jpeg/png or KML/KMZ, as used by AVO.

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	
Assumptions required for data processing (e.g., complex refractive index data)	
Delivery time of additional processing (e.g., real-time, days, weeks, months)	
Software requirements	
Uncertainties	
Type of output	

	YES	NO
Is data freely available?	X	
If yes, please specify where it can be downloaded:	Via direct dissemination in real-time	

4. Limitations

	Comments
Detection limits	> 0.5 tons/km^2
Saturation	~100 tons/km^2
Particle size	Effective radius sensitivity: 0.5 – 15.0 µm
Weather conditions	Ash layer must be colder than surface
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	Ash must be highest cloud layer
Vertical resolution (i.e., 1D, 2D , 3D)	Cloud layer integrated properties of highest ash cloud layer
Units	Mass loading (tons/km^2), Ash Height (km), Ash effective radius (µm)
Other	

5. Other

References
Pavolonis, M. J., 2010: Advances in extracting cloud composition information from spaceborne infrared radiances: A robust alternative to brightness temperatures Part I: Theory, *J. Applied Meteorol. And Climatology*, **49(9)**, 1992-2012. Pavolonis, M. J. and J. Sieglaff, 2010: GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Volcanic Ash: Detection and Height, Version 2.0., 72 pp. Pavolonis, Michael J.; Feltz, Wayne F.; Heidinger, Andrew K. and Gallina, Gregory M. A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash. Journal of Atmospheric and Oceanic Technology, Volume 23, Issue 11, 2006, pp.1422-1444. Prata, A. J., 1989a. Infrared radiative transfer calculations for volcanic ash clouds, *Geophysical Research Letters*, **16**, 1293-1296. Prata, A. J., 1989b. Observations of volcanic ash clouds in the 10-12 µm window using AVHRR/2 data, *International Journal of Remote Sensing*, **10**, 751-761. Prata, A. J., and Grant, I. F., 2001. Retrieval of microphysical and morphological properties of volcanic ash plumes from satellite data: Application to Mt. Ruapehu, New Zealand, *Q. J. R. Meteorol.,* 127.

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Wen, S and Rose, W. I., 1994, Retrieval of Particle sizes and masses in volcanic clouds using AVHRR bands 4 and 5, *Journal of Geophysical Research*, **99,** 5421-5431.

Other comments

1. System (platform) overview

Instrument Name	**OMI**	
Spectral range	0.30-0.35 microns	
Record frequency	Daily at low latitudes; ~3x daily at high latitudes	
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	SO_2 burden, SO_2 altitude, Aerosol Index (indicates presence of ash and relative abundance), ash mass loading (under development)	
Scale of acquisition		Tick
	Proximal (order of a few km)	
	Medial (order of 100s of km)	X
	Distal (order of 1000s of km)	X
	Other	

	YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?	X	
If yes, where? NOAA process near real-time SO_2 data; Finnish Meteorological Institute (FMI) receives direct broadcast OMI data and process in Very Fast Delivery (VFD) system within 15 minutes of overpass.		

2. Technical requirements

	YES	NO	Comments
Is it ground based?		X	
Is it satellite based?	X		
Does it require dedicated instrumentation?		X	Direct broadcast (DB) Aura data can be accessed via receiving station
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)		X	
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	X		FTP

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?	X	

If yes, please complete the following:	
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	OMI has several SO_2 retrievals as a function of cloud height
Delivery time (e.g., real-time, days, weeks, months)	DB data can be processed in ~15 mins; near real time (NRT) data available within 1-3 hours
Uncertainties	Instrument issues/low light levels
Type of output	SO_2 maps, Aerosol Index maps

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	Complex refractive index at UV wavelengths required for ash retrievals
Assumptions required for data processing (e.g., complex refractive index data)	
Delivery time of additional processing (e.g., real-time, days, weeks, months)	SO_2 altitude currently available next day; operational implementation planned
Software requirements	
Uncertainties	
Type of output	

	YES	NO
Is data freely available?	X	
If yes, please specify where it can be downloaded:	http://so2.gsfc.nasa.gov http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omso2_v003.shtml	

4. Limitations

	Comments
Detection limits	0.4 DU SO_2 (latitude dependent)
Saturation	100-200 DU for operational SO_2 retrievals; offline SO_2 retrievals produce unsaturated data
Particle size	
Weather conditions	Broadly weather independent
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	Day time only
Vertical resolution (i.e., 1D, 2D , 3D)	2D only (SO_2 altitude retrievals currently a research product)

Units	DU (SO_2), g m^{-2} (ash loading)
Other	Note that most of the above information also applies to the UV Suomi NPP OMPS instrument, operational since 2011.

5. Other

References
Carn, S.A., A.J. Krueger, N.A. Krotkov, K. Yang, and K. Evans, 2009, Tracking volcanic sulfur dioxide clouds for aviation hazard mitigation. *Natural Hazards,* 51(2), 325-343, doi:10.1007/s11069-008-9228-4. Krotkov, N.A., Carn, S.A., Krueger, A.J., Bhartia, P.K., and Yang, K., 2006, Band Residual Difference algorithm for retrieval of SO_2 from the Aura Ozone Monitoring Instrument (OMI). *IEEE Trans. Geosci. Remote Sensing*, *AURA Special Issue*, 44(5), 1259-1266, doi:10.1109/TGRS.2005.861932. Yang, K., X. Liu, N.A. Krotkov, A.J. Krueger and S.A. Carn, 2009, Estimating the altitude of volcanic sulfur dioxide plumes from space-borne hyper-spectral UV measurements, *Geophys. Res. Lett.*, 36, L10803, doi:10.1029/2009GL038025.

Other comments

1. System (platform) overview

Instrument Name	**PLUDIX**		
Spectral range	X-band microwave (9.5 GHz)		
Record frequency	Up to 1 sample per minute		
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Settling velocities of ash particles (raw data) Particle size Number of particles		
Scale of acquisition			Tick
	Proximal (order of a few km)		
	Medial (order of 100s of km)		
	Distal (order of 1000s of km)		
	Other		Point
		YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?			X
If yes, where?			

2. Technical requirements

	YES	NO	Comments
Is it ground based?	X		
Is it satellite based?		X	
Does it require dedicated instrumentation?	X		Pludix + PC + Power supply
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)		X	
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	X		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?	X	

If yes, please complete the following:	
	Comments
Assumptions required for data	Terminal velocity model

acquisition (e.g., geometry of observations)	Density of the particles
Delivery time (e.g., real-time, days, weeks, months)	Real-time
Uncertainties	
Type of output	Doppler spectra, particle settling velocity, Particle size

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	Terminal velocity model Mie backscattering coefficients algorithm
Assumptions required for data processing (e.g., complex refractive index data)	Ash refractive index particles density and spherical shape terminal velocity model
Delivery time of additional processing (e.g., real-time, days, weeks, months)	Near-real-time
Software requirements	Matlab
Uncertainties	Real density of particles
Type of output	Particle size vs particle number

		YES	NO
Is data freely available?			X
If yes, please specify where it can be downloaded:			

4. Limitations

	Comments
Detection limits	Variable threshold concentration depending on the size of particles
Saturation	No
Particle size	From 0.5 to 10 mm
Weather conditions	Absence of precipitations (meteorological)
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	No
Vertical resolution (i.e., 1D, 2D , 3D)	1D
Units	Velocity of the particles Power Spectral density
Other	

5. Other

References
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Other comments

1. System (platform) overview

Instrument Name	**SEVIRI**		
Spectral range	0.65, 3.75, 7.3, 8.5, 11, and 12 μm channels are needed by ash detection algorithm; 11, 12, and 13.3 μm channels are needed by retrieval algorithm. Wen and Rose (1994) method can use just the 11 and 12 μm channels for ash detection and to retrieve volcanic ash mass and effective particle size. Method known since Prata (1989 a, b).		
Record frequency	Every 15 minutes		
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Automated ash detection, ash cloud height (temperature and pressure), ash mass loading (mass/area), ash effective radius, and ash optical depth (wavelength dependent)		
Scale of acquisition			Tick
	Proximal (order of a few km)		X
	Medial (order of 100s of km)		X
	Distal (order of 1000s of km)		X
	Other		
		YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?		X	
If yes, where?	London and Toulouse VAACs		

2. Technical requirements

	YES	NO	Comments
Is it ground based?		X	
Is it satellite based?	X		GEO
Does it require dedicated instrumentation?	X		Data can be acquired through EUMETCast
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)	X		The retrieval technique requires global NWP data (GFS), global snow maps (IMS), global SST data (OISST). With the Wen and Rose (1994) method, then only channels at 11 and 12 μm (SEVIRI channels 9 and 10) are needed.
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	X		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?		X

If yes, please complete the following:	
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	EUMETCast access
Delivery time (e.g., real-time, days, weeks, months)	Real-time
Uncertainties	Depend on uncertainty in clear sky radiances, calibration, pixel heterogeneity, microphysical model (composition - index of refraction, particle habit, particle distribution type, etc…)
Type of output	Quantitative ash cloud properties in HDF4 format. Can be readily available as jpeg/png or KML/KMZ.

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	
Assumptions required for data processing (e.g., complex refractive index data)	
Delivery time of additional processing (e.g., real-time, days, weeks, months)	
Software requirements	
Uncertainties	
Type of output	

		YES	NO
Is data freely available?		X	
If yes, please specify where it can be downloaded:	Via EUMETCast		

4. Limitations

	Comments
Detection limits	> 0.5 tons/km^2
Saturation	~100 tons/km^2
Particle size	Effective radius sensitivity: 0.5 – 15.0 μm
Weather conditions	Ash layer must be colder than surface
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	Ash must be highest cloud layer
Vertical resolution (i.e., 1D, 2D , 3D)	Cloud layer integrated properties of highest ash cloud layer
Units	Mass loading (tons/km^2), Ash Height (km), Ash effective radius (μm)
Other	

5. Other

References

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Wen, S and Rose, W. I., 1994, Retrieval of Particle sizes and masses in volcanic clouds using AVHRR bands 4 and 5, *Journal of Geophysical Research*, **99,** 5421-5431.

Other comments

1. System (platform) overview

Instrument Name	**THERMAL CAMERA**	
Spectral range	7.5 – 13 µm wavelength spectral radiation	
Record frequency	up to 200 fps	
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	Spectral radiation Temperature	
Scale of acquisition		Tick
	Proximal (order of a few km)	X
	Medial (order of 100s of km)	
	Distal (order of 1000s of km)	
	Other	

	YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?	X	
If yes, where? INGV Catania (Etna), LGS Firenze (Montserrat, Stromboli), HVO (Kilauea) to name a few		

2. Technical requirements

	YES	NO	Comments
Is it ground based?	X		
Is it satellite based?		X	
Does it require dedicated instrumentation?	X		Thermal camera + PC + Power supply
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)		X	
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	X		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?	X	

If yes, please complete the following:	
	Comments

Assumptions required for data acquisition (e.g., geometry of observations)	Target emissivity and atmospheric correction, if we want temperature data; and pixel size if we want dimensional data".
Delivery time (e.g., real-time, days, weeks, months)	Real-time
Uncertainties	---
Type of output	Thermal images

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	Multiple-temperature-thresholds image analysis for plume time evolution analysis, particle velocimetry
Assumptions required for data processing (e.g., complex refractive index data)	Field of view and distance from the target, target emissivity. camera pointing and tilt angle, difference in height between camera and target; atmospheric conditions (T and humidity)
Delivery time of additional processing (e.g., real-time, days, weeks, months)	Hours
Software requirements	Matlab
Uncertainties	Size of thermal feature (depending on the distance)
Type of output	Temperature, Plume 2D size, Plume exit velocity

	YES	NO
Is data freely available?		X
If yes, please specify where it can be downloaded:		

4. Limitations

	Comments
Detection limits	Depends on the emissivity and depends no thermal contrast between target and background, distance to target, size of the target, and viewing conditions.
Saturation	Depends on the camera (250 – 2000 °C)
Particle size	ash-to-bombs/blocks
Weather conditions	Good visibility
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	No

Vertical resolution (i.e., 1D, 2D , 3D)	2D
Units	Temperature, Size, Exit velocity W, K, m2, m/s, m3/s, kg, kg/s
Other	

5. Other

References
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Other comments

1. System (platform) overview

Instrument Name	UV camera	
Spectral range	0.3-0.34 microns	
Record frequency	0.5-1 Hz	
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	SO_2 line of sight burden, ash opacity	
Scale of acquisition		Tick
	Proximal (order of a few km)	X
	Medial (order of 100s of km)	
	Distal (order of 1000s of km)	
	Other	

	YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?		X
If yes, where?		

2. Technical requirements

	YES	NO	Comments
Is it ground based?	X		
Is it satellite based?		X	
Does it require dedicated instrumentation?	X		The camera, plus peripherals (ca. 20,000 euros)
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)		X	The instrument does require regular calibration
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)		X	Data volumes are considerable (2.2 Mb per measurement). It's possible to operate remotely, but probably not at full spatiotemporal resolution

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?		X

If yes, please complete the following:	
	Comments
Assumptions required for data	Geometry required, distance to target –

acquisition (e.g., geometry of observations)	some information on visibility is required too.
Delivery time (e.g., real-time, days, weeks, months)	Can be NRT
Uncertainties	Interference from ash, distance correction
Type of output	SO_2 image

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	Yes, although the algorithm is very simple
Assumptions required for data processing (e.g., complex refractive index data)	Gas cell calibration
Delivery time of additional processing (e.g., real-time, days, weeks, months)	Can be NRT, most often used in research mode.
Software requirements	Matlab/IDL
Uncertainties	Distance correction is challenging, ash interference makes the retrieval much more involved.
Type of output	SO_2 image

	YES	NO
Is data freely available?		X
If yes, please specify where it can be downloaded:		

4. Limitations

	Comments
Detection limits	Very dependent on conditions, probably on the order of 10-50 ppm.m
Saturation	1500 ppm.m
Particle size	NA
Weather conditions	Clouds are OK, as long as they are broadly heterogeneous and behind the plume. Anything between plume and instrument prevents the retrieval functioning
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	Day time only. Rain is not good (from both an instrument and radiative transfer point of view)
Vertical resolution (i.e., 1D, 2D , 3D)	2D
Units	Typically reported in ppm.m or kg s^{-1} (if

	converted to emission rate)
Other	

5. Other

References
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Other comments

1. System (platform) overview

Instrument Name	**VOLDORAD (Volcano Doppler Radar)**	
Spectral range	λ = 23.5 cm	
Record frequency	~5-15 Hz	
Parameter(s) detected (e.g., particle/gas concentration, mass, temperature)	- Particle velocities - Particles mass/flux, volume and concentration	
Scale of acquisition		Tick
	Proximal (order of a few km)	0.3-12km
	Medial (order of 100s of km)	
	Distal (order of 1000s of km)	
	Other	

	YES	NO
Is it operational for data acquisition at some Institution/VAAC/VO?	yes	
If yes, where?	OPGC Clermont-Ferrand (3 Doppler radars): 1 radar operating on Etna (collab. Istituto Nazionale di Geosifica e Vulcanologia – Catania)	

2. Technical requirements

	YES	NO	Comments
Is it ground based?	YES		VOLDORAD is a transportable ground based radar system (radar+antenna=70kg)
Is it satellite based?		NO	
Does it require dedicated instrumentation?	YES		Radar + antenna + PC + AC or generator
Does it require additional technologies for data acquisition/retrieval (e.g., atmospheric data)		NO	- Kinetic parameters obtained directly. - Loading parameters need inversion models (available).
Can data be easily automatically transferred? (e.g., wire, radio, GSM telemetry)	YES		

3. Data acquisition and delivery

	YES	NO
Can raw data be used with no additional processing?	YES	

If yes, please complete the following:	
	Comments
Assumptions required for data acquisition (e.g., geometry of observations)	Geometry of the radar sounding and of the target. Particle Size Distribution (for ash load estimates)
Delivery time (e.g., real-time, days, weeks, months)	Near-Real-Time
Uncertainties	Depends on our knowledge of the geometry of observations.
Type of output	Doppler spectra, Particles velocity

If additional data processing is necessary, please complete the following:	
	Comments
Algorithm required for data processing (e.g., complex refractive index data)	Mie scattering algorithm, radar equations.
Assumptions required for data processing (e.g., complex refractive index data)	Complex refractive index, particle density and sphericity.
Delivery time of additional processing (e.g., real-time, days, weeks, months)	Days
Software requirements	Matlab
Uncertainties	Depends on particle size distribution
Type of output	Particles mass and derived parameters

	YES	NO
Is data freely available?		No
If yes, please specify where it can be downloaded:		

4. Limitations

	Comments
Detection limits	Distance (<12 km), cannot see the gas phase
Saturation	No limitation
Particle size	Fine particles are detected above a concentration threshold (low) depending on size.

Weather conditions	No limitation
Are there other detection conditions? (e.g., day/night, clear sky/clouds)	The acquisition can be made day and night, and during clear or cloudy/rainy conditions.
Vertical resolution (i.e., 1D, 2D , 3D)	Probed volumes aligned along radar beam (1D). Along-beam resolution = 60-225m. Horizontal and vertical resolution (=70 m to 2000m)depends on distance
Units	Raw : Power spectral density (dBW) Raw : Particles velocity (m/s)
Other	

5. Other

References
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Other comments
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