An algorithm for automated cloud pattern recognition and mass eruption rate estimation from umbrella cloud or downwind plume observed via satellite imagery

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WMO 7 International Workshop on Volcanic Ash, Anchorage, AK

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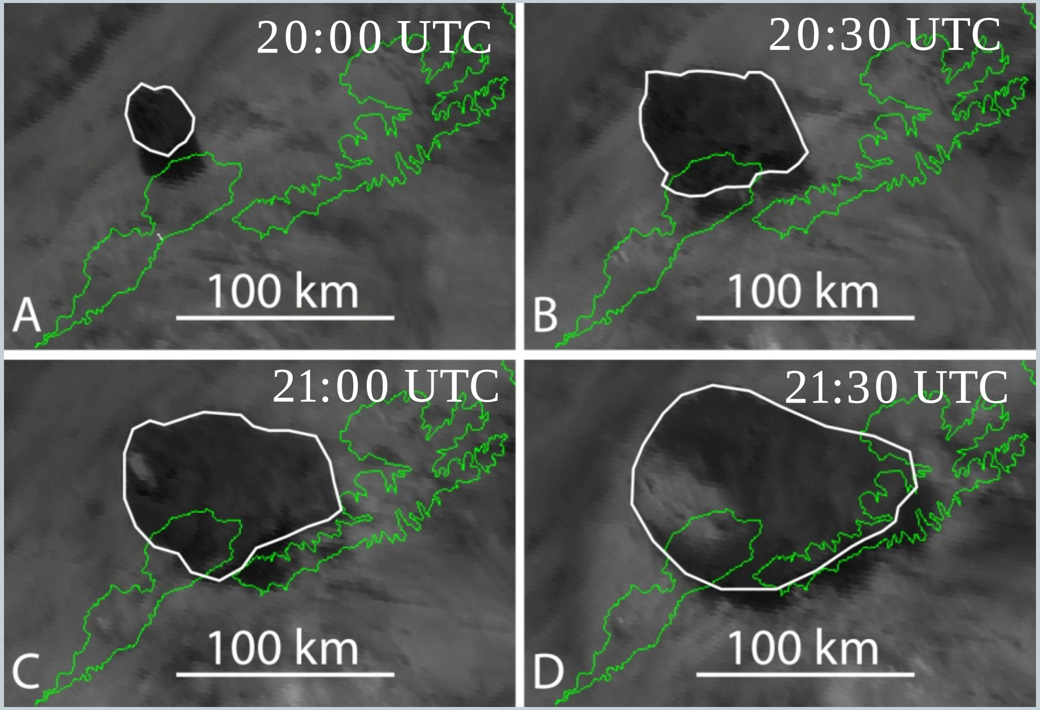
Introduction

- Volcanic ash transport and dispersion models require mass eruption rate (MER)
- Can satellite imagery be used to estimate MER from cloud growth?
- Could this be done in an automated fashion?

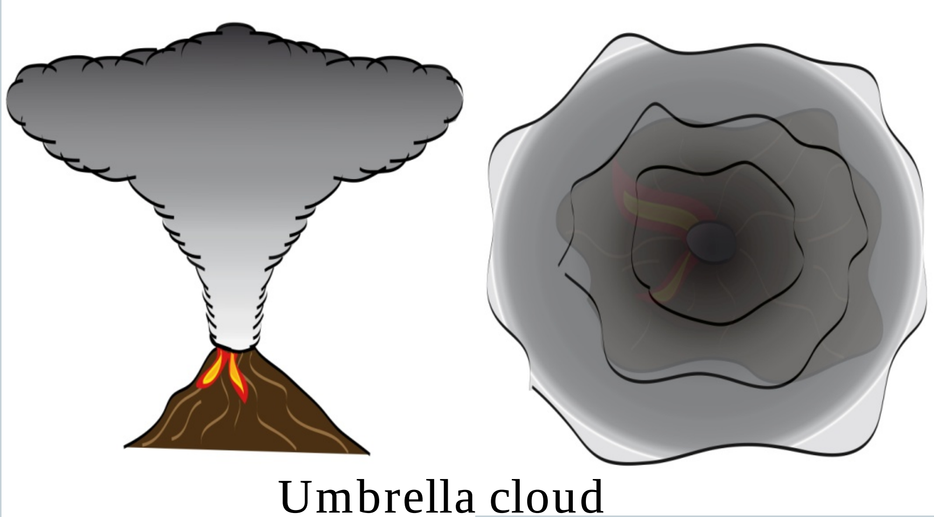


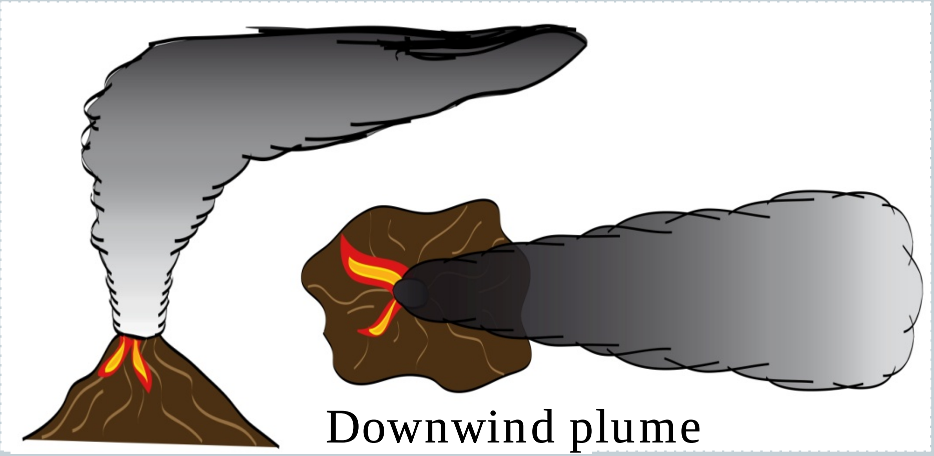
Visible AVHRR images from Okmok eruption on 12 July 2008

Umbrella Cloud and Downwind Plume

- <u>Umbrella Cloud</u>: radially driven intrusion (gravity current) into the atmosphere at neutral buoyancy level

- <u>Downwind Plume</u>: result of downstream spreading by wind and crosswind spreading as gravity current





Case Studies

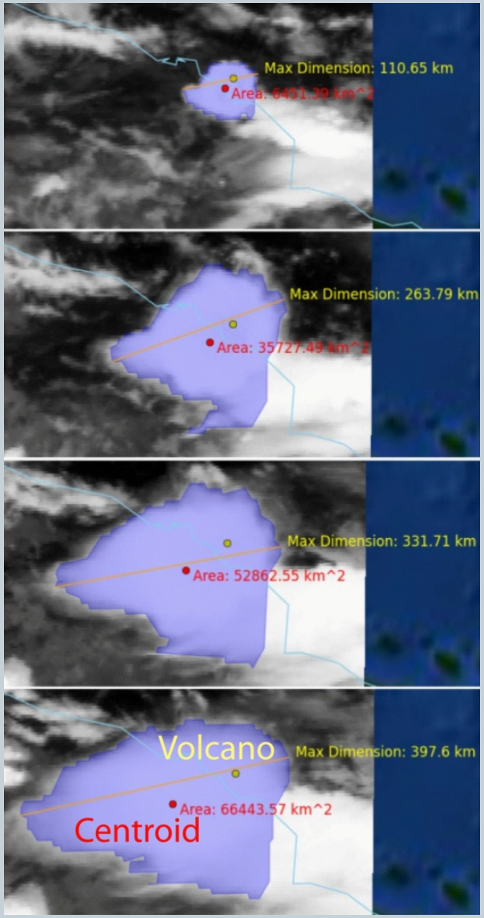
- Manam October 24th 2004 (Papua New Guinea)
- Manam January 27th 2005 (Papua New Guinea)
- Okmok July 12th 2008 (Alaska, USA)
- Kelut February 12th 2014 (Java, Indonesia)

Visible satellite imagery of Manam on October 24th at 04:25 UTC

Pattern recognition – what do we need?

APES - Automated Probabilistic Eruption Surveillance

- IR satellite images in NetCDF format with lat, long and radiance
- Four consecutive images
- Atmospheric temperature and wind profile
- Yields cloud area, centroid, etc.



Umbrella cloud from Manam, 27 January 2005, detected by APES algorithm

Pattern recognition – how does it work?

1. Convective analysis

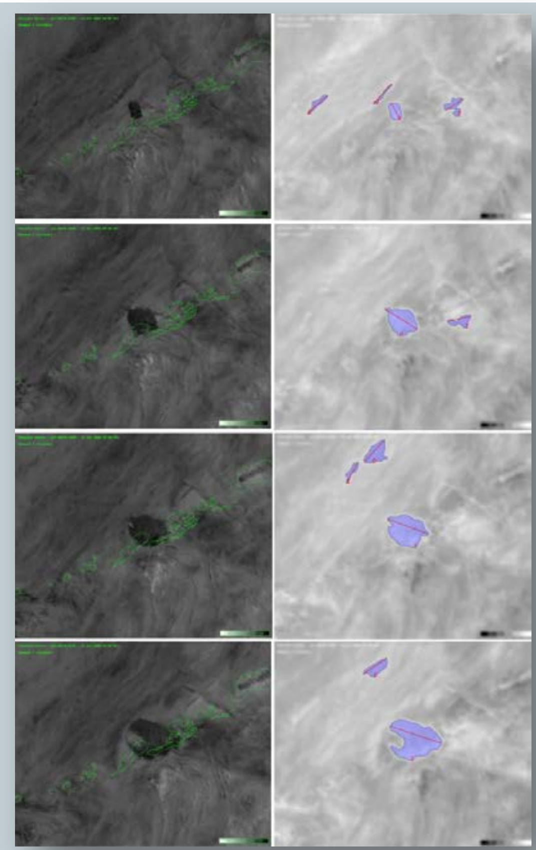
Estimate the convective available potential energy, the number of cloud levels and their respective heights

2. Image analysis

Outline clouds and assign into families of clouds of same type

3. Eruption detection

Identification of the group made up of eruptive clouds by weak correlation with previous cloud families



Umbrella cloud from Okmok July 12 2008 on visible imagery (left) & outlined by algorithm on IR imagery (right)

From area to MER for umbrella cloud

For continuous release

- Assuming the umbrella cloud initially intrudes as inertial gravity current
- Quasisteady growth rate between two times, the MER of the plume at time *i* is

$$Q_{i,Hb} = \frac{2\bar{\rho}}{3\sqrt{\pi}\lambda N} \frac{A_i^{3/2} - A_{i-1}^{3/2}}{(t_i^2 - t_{i-1}^2)}$$

- $A \sim t^{4/3}$

At eruption cessation

- In this case, no more material is added
- Estimate of mass of the cloud at time *i* is expressed as:

$$m_i = \frac{\sqrt{\pi}\bar{\rho}}{3\lambda N} \frac{(A_i^{3/2} - A_{i-1}^{3/2})}{(t_i - t_{i-1})}$$

- $A \sim t^{2/3}$

From area to MER for downwind plume

- The plume is assumed to spread downwind at the windspeed, *u*, and in the crosswind direction as a gravity current

- The MER can be expressed at time *i* as:

$$Q_i = \frac{9\bar{\rho}}{8\lambda' N u} \frac{\left(A_i^2 - A_{i-1}^2\right)}{\left(t_i^3 - t_{i-1}^3\right)}$$

- $A \sim t^{3/2}$

Kliuchevskoi volcanic eruption, Kamchatka, September 30, 1994 (NASA-Johnson Space Center)

From plume MER to particle MER using radiosonde or NWP

$$Q_{i,p} = Q_{i,Hb}\left(1 - \frac{\rho_g}{\bar{\rho}}\right)$$

Where $\bar{\rho}$ is atmospheric density at the mid-height of the intrusion and ρ_g is gas density in the cloud estimated from:

$$\rho_g = P_{\bar{H}} / (R_d T_b)$$

In which the pressure is given from NWP or radiosonde, and temperature is brightness temperature

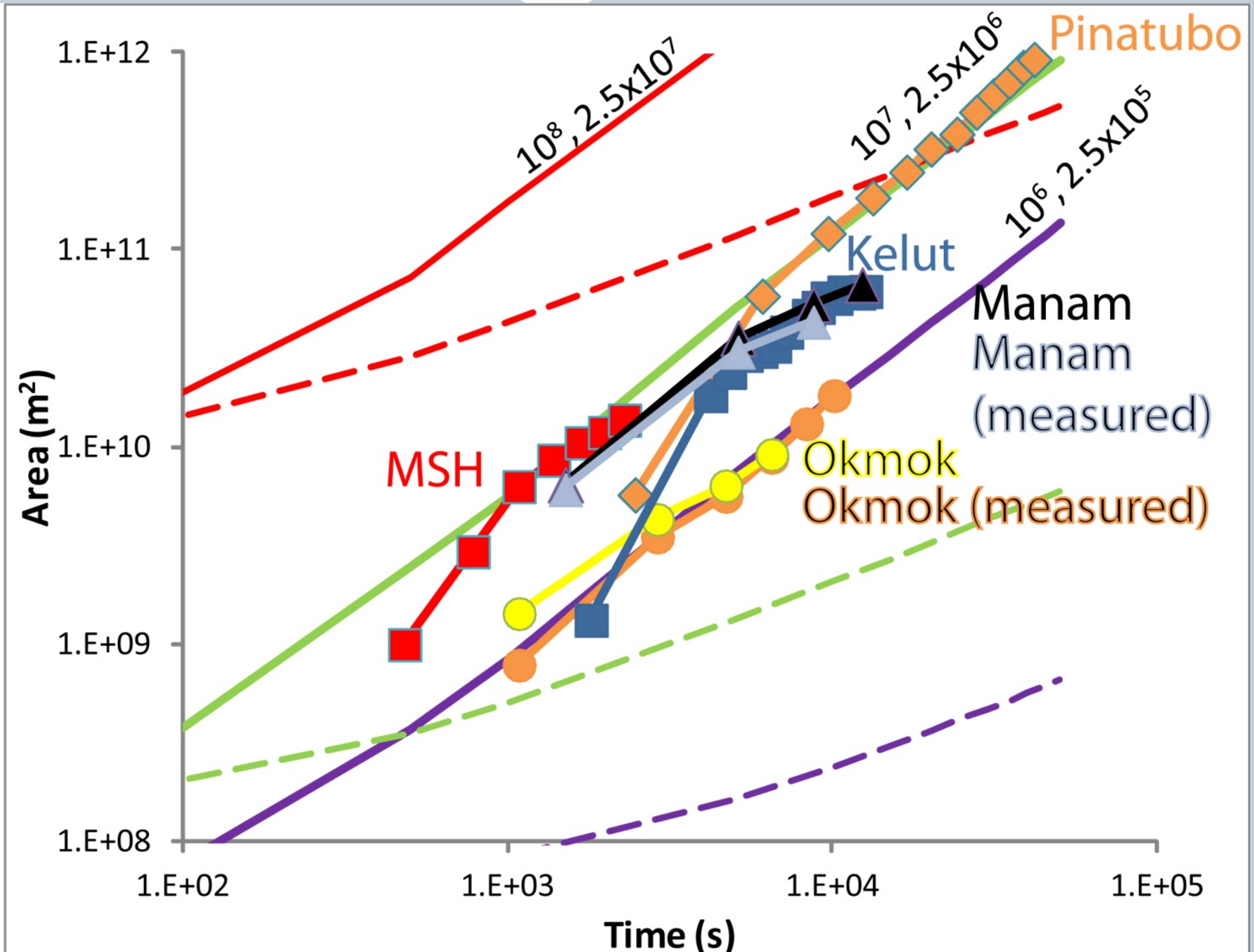
Note: we assume most of the gas in the cloud by volume is air and that the solid particle portion of the cloud is opaque

Results

Estimation of MER of the plume (gas and particles) and of the particles at the level of neutral buoyancy for the eruption of Manam, January 27th 2005

Time (UTC)	Eruption duration (s)	Area detected (m^2)	MER $_{Hb}$ – plume (kg/s)	MER $_{Hb}$ – particles (kg/s)
13h25	-	-	-	-
14h25	1.50E+03	6.45E+09	-	-
15h25	5.10E+03	3.57E+10	9.46E+10	4.32E+06
16h25	8.70E+03	5.29E+10	3.92E+10	1.79E+06
17h25	1.23E+04	6.64E+10	2.37E+10	1.08E+06

From area to MER of particles using numerical simulations – umbrella cloud

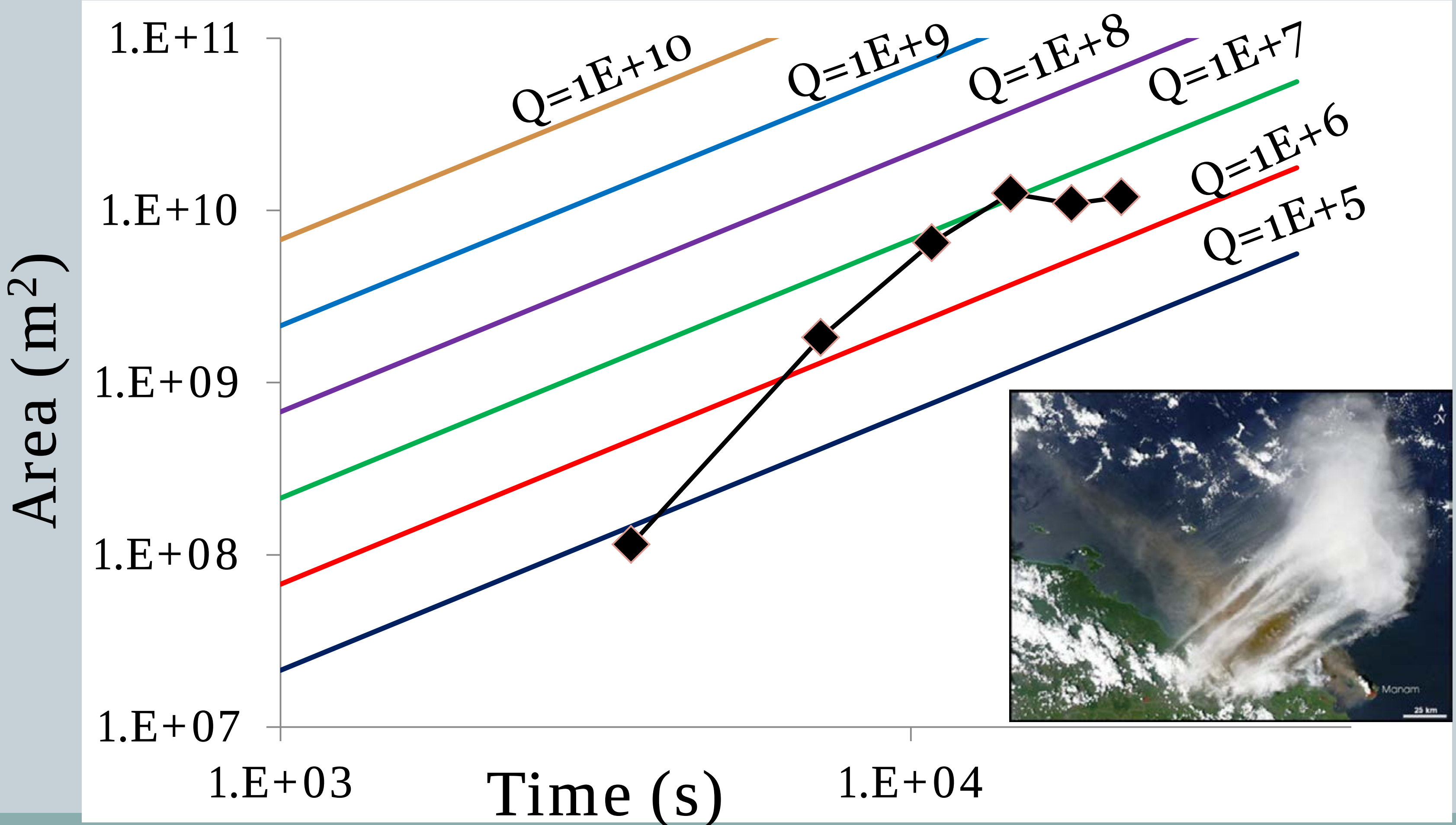


Note: for the curves, 10^x is the MER at the source, and ~2.5×10^x is the MER injected into the umbrella cloud

From area to MER of particles using numerical simulations – downwind plume

Manam October 24 2004

Windspeed of 5.4 m/s



Conclusions

- Pattern recognition can be used to identify volcanic plumes on a satellite image
- Combined with a gravity current model using the area of the plume, the MER and plume shape can be automatically estimated as a function of time on satellite imagery
- Continuing work: implement in an operational mode

Publications

- Pouget *et al.*, in preparation. Automated detection of volcanic clouds and estimation of mass eruption rate from umbrella cloud or downwind plume growth rate. *Geophysical Research Letters.*

- Pouget *et al.*, 2013. Estimation of eruption source parameters from umbrella cloud or downwind plume growth rate. *Journal of Volcanology and Geothermal Research*, 258: 100-112