SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

CTBTO
PREPARATORY COMMISSION

Use of infrasound data for early notification of Volcanic Ash Advisory Centres

Philippe Héreil[1], Greg Brock[2], Paula Acethorp[3], Andrew Tupper[4], Pierrick Mialle[5], Alexis Le Pichon[6] and Emanuele Marchetti[7]

Invited talk on Risk Mitigation / I07-529

1 *Meteo France, VAAC Toulouse, France*
2 *World Meteorological Organization, Geneva, Switzerland*
3 *Civil Aviation Authority of New Zealand, New Zealand*
4 *Natural Hazards Consulting, Australia*
5 *CTBTO Preparatory Commission, Vienna, Austria*
6 *Commissariat à l'énergie atomique et aux énergies alternatives ,France*
7 *University of Firenze, Department of Earth Sciences, Firenze, Italy*

ORAL PRESENTATION

Volcanic Ash and aviation : background

Numerous incidents due to ash encounters in the 1980's:

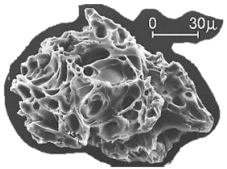
- June 1982 : a Boeing747 (BA9) flew over the Galunggung volcano (Indonesia)
- July 1982: Emergency landing for a B747 Singapore Airlines after ash encounters
- and a lot of other incidents in the 80's….

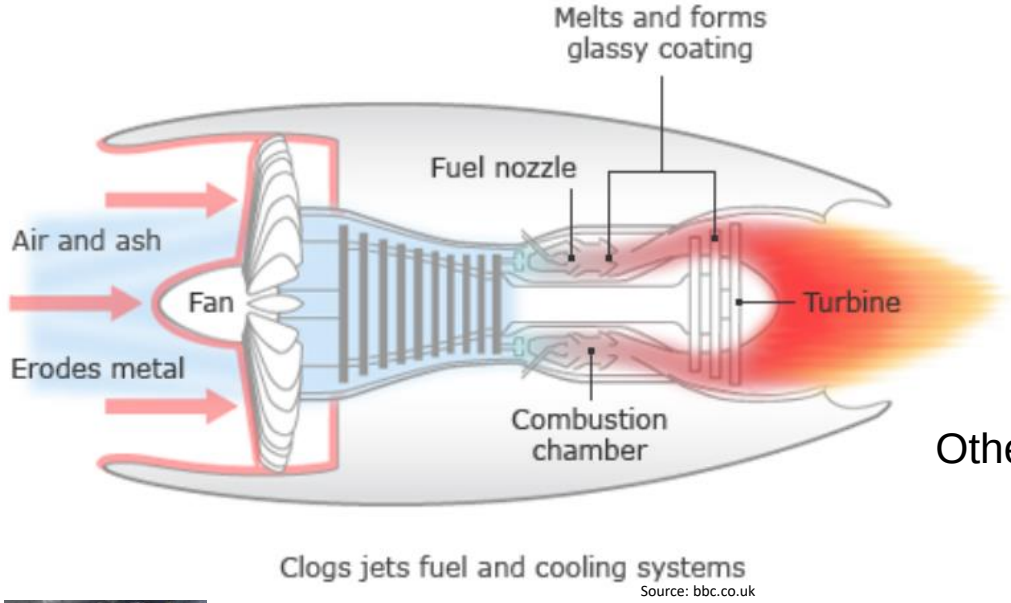
➢ **Volcanic Ash has become a real concern for ICAO* since 1982**

***International Civil Aviation Organization**

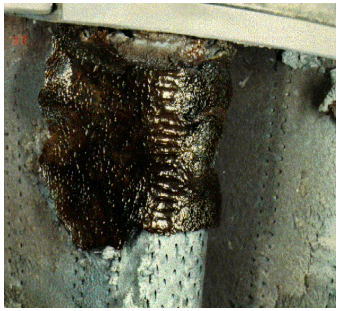
Disclaimer: The views expressed on this presentation are those of the author and do not necessarily reflect the view of the CTBTO

Volcanic Ash: a natural hazard for aviation safety and performance



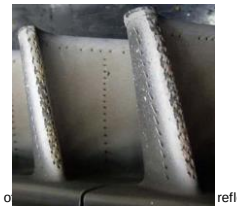


Source: bbc.co.uk



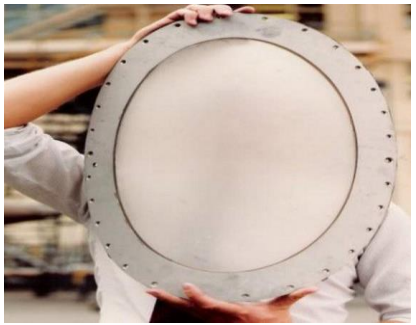
Immediate damages: engine failure

Source: Researchgate.net



Long term damages: erosion

Other effects : opacification



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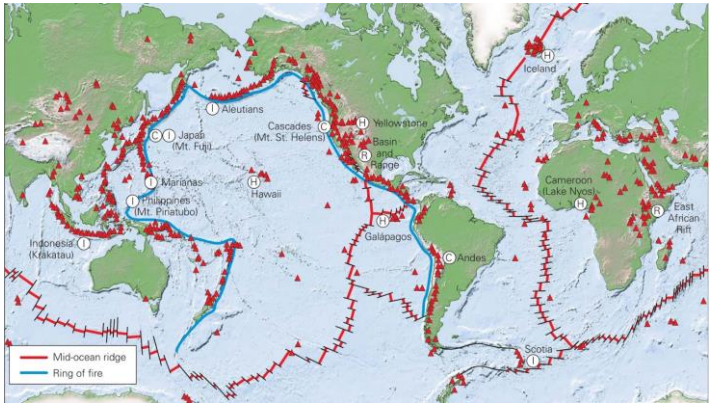
Aircrafts and volcanic ash

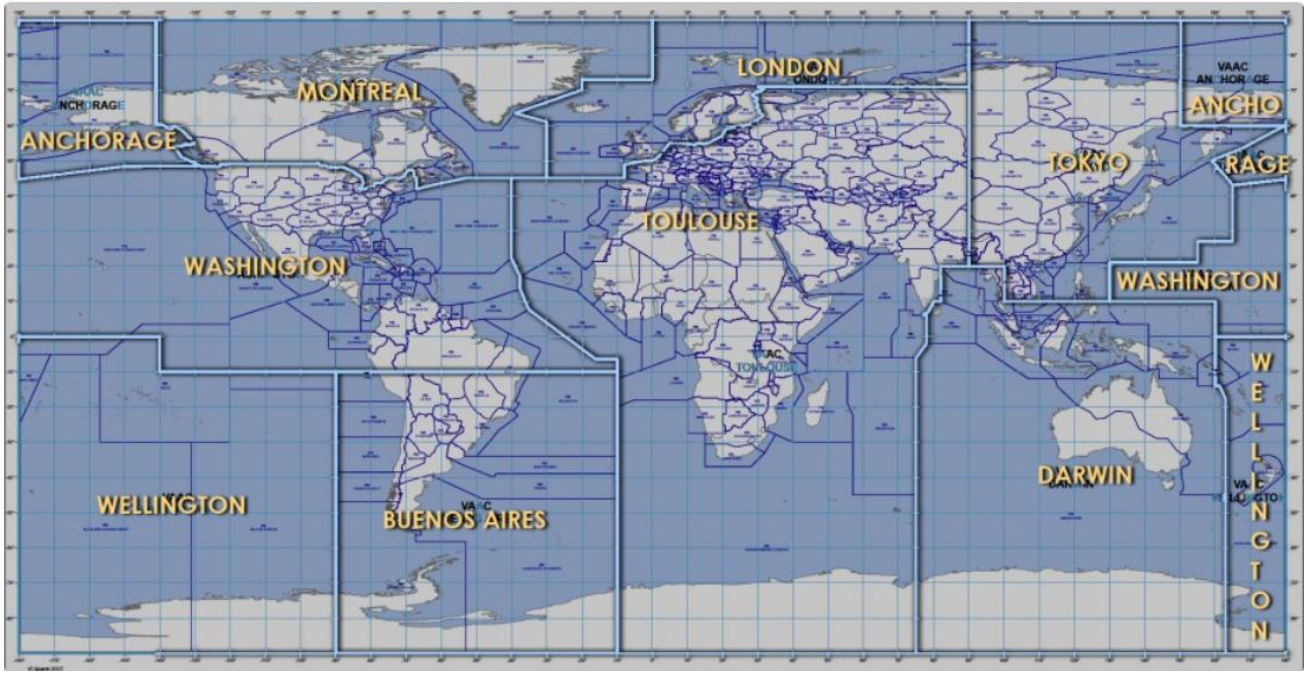


Yearly stats:
- 5700 Volcanic Ash Advisories
- 20 days, airspace contamination is likely to reach FL300

- ~100 ash-aircrafts encounters reported so far
- Impact of ash cloud encounters:
  - on aircraft safety as far as 1000 km from the source
  - on aircraft performances up to 4000 km, 72 h
- Since the 80's, damage cost > 250 M$,
  avoidance cost > many T$, but no victims

Setup of the International Airways Volcano Watch (ICAO)

ICAO: Setup of the International Airways Volcano Watch (IAVW,1987) with the support of WMO*



- Designation of 9 Volcanic Ash Advisory Centres (VAAC)
- VAAC duties:
  - Watch Volcanic Ash 7d/7, 24h/24
  - Issue VA Advisories on aeronautical dedicated communication networks

*World Meteorological Organization

The ICAO MET PANEL and the VAACs

International Civil Aviation Organization (ICAO) MET PANEL

MRI - Requirements and Integration

MISD - Information and Service Development →

- Volcanic Ash (VA)/Sulphur Dioxyde
- Space weather
- Radioactive material
- Hazardous Weather Information Service (HWIS)
- WAFS

MIE - Information Exchange

MCRG - Cost Recovery Guidance and Governance

MOG - Operations Group →

- Volcanic Ash (VA)
- SADIS
- WAFS

The World Meteorological Organization (WMO)

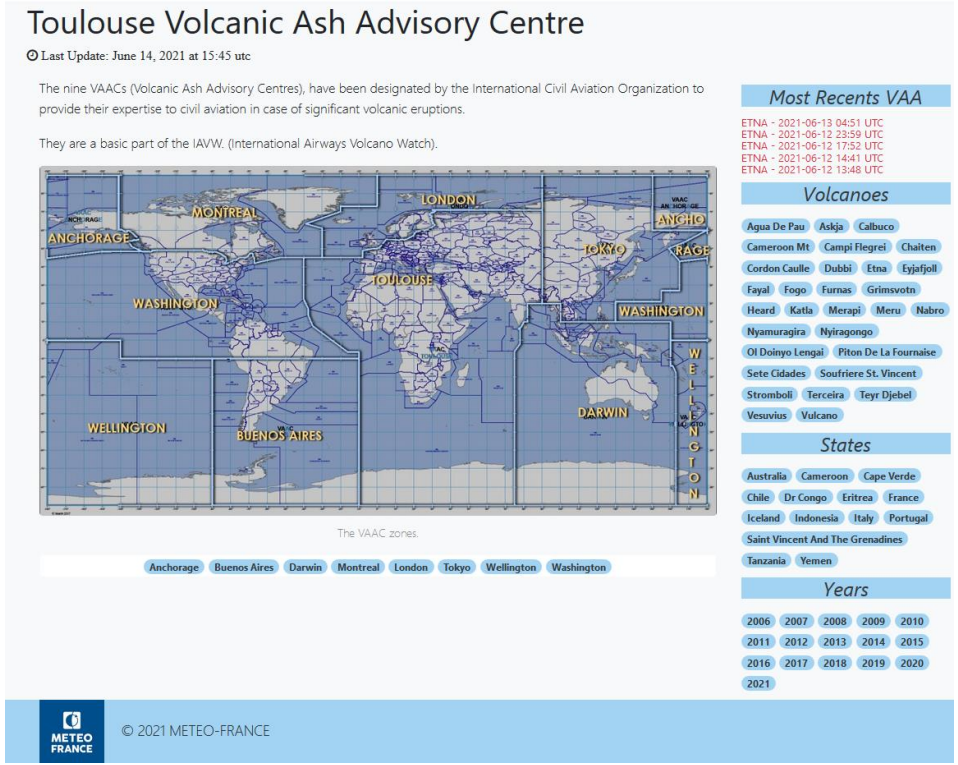
WMO OMM

VAAC Best Practices

The WMO:

- Defines standards for VAAC forecasters skills and competencies
- Promotes the sharing of experience and methods between the VAACs
- Uses scientific progress for improving observation and transport prediction of VA
- Strengthens links between volcano observatories and VAAC communities
- Contributes to VA product evolution (e.g. quantitative products)

The Toulouse VAAC, a piece of the International Airways Volcano Watch



- VAAC Toulouse hosted by Météo-France
- One forecaster on duty, 7/7d 24/24h watch
- In 2021, 253 VA Advisories issued so far:
  - 197 Etna (Italy)
  - 54 Nyiragongo (RDC)
  - 2 Stromboli (Italy)

> Active Volcanic Year in the VAAC Toulouse Area of Responsibility

http://vaac.meteo.fr/

How to detect the presence of volcanic ash in the atmosphere?

- Observations from State Volcano Observatories / on-site monitoring : Webcams, seismic sensors, radars

  e.g. INGV* issues Volcano Observatory Notice for Aviation (VONA) for Etna
  (*Istituto Nazionale di Geofisica e Vulcanologia)

- Satellite / remote sensing : geostationary or low polar orbiting
- Pilot reports
- Aerosol Lidars (from ground or from satellite)

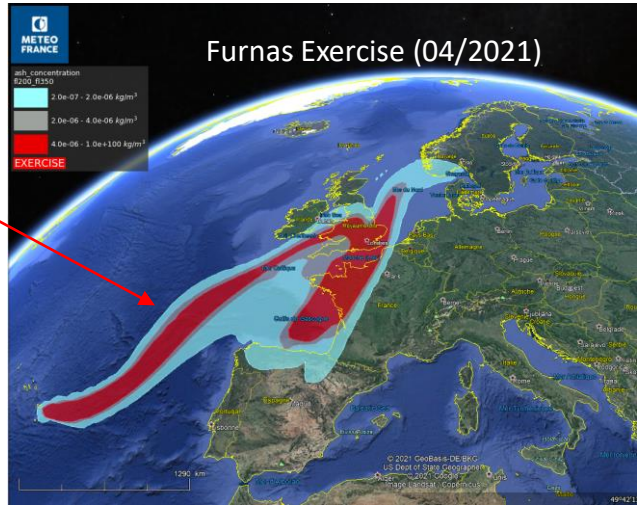
- Use of SO2 measurement as a proxy for VA (e.g. SACS)
- Instrumented aircrafts (field campaigns)
- Other observing systems or diagnosis (e.g. Hotvolc platform, IPGC)

Prediction of the ash transport for the next hours
A challenge!

- VAACs run sophisticated numerical dispersion models to predict the transport of VA in the atmosphere for the next 18 hours
- Physical processes: wet deposition, sedimentation, turbulent mixing
- Coupling with Numerical Weather Prediction models
- Sophisticated Source term: plume shape, top, emission rate…

- Model outputs: forecasts of ash concentration charts for the next 18 hours (Toulouse VAAC example with Mocage Accident)
Trend towards quantitative product (ICAO request)

- **Given the source term uncertainty,**
every additional observation is worthwhile!



Timeliness: a real concern for VAACs

Some Timeliness criteria (KPI*) have been defined by the ICAO for VA advisories.

- KPI#1 : VA Advisory #1 shall be issued within 20 minutes after the confirmation of ash evidence in the atmosphere
- KPI#2: VA Advisory #2 shall be issued within 55 minutes after the VAA#1

KPI are generally met: for monitored volcanoes, Volcano Observatories issue VONA and VAACs issue VAA#1 within 20 min

But for poorly monitored regions, VONA is often missing and the detection relies on satellite imagery, when available (cloud cover limitations)

- Sometimes the issuance of the VAAC advisory is delayed

- **Infrasound detection has appeared as an additional mean to collect timely data on eruptions (Synergy CTBTO/ARISE project)**

*Key Performance Index

Official support from ICAO and WMO to use IS detection

Since 2010, continuous interest of ICAO and WMO for the use of IS detection for VAAC notifications

Official Action (2020) : VAAC Toulouse was tasked by ICAO to lead a WG on the use of IS data in support of IAVW

"ICAO MET Panel Working Group on Meteorological Operations Group MOG /Volcanic Ash Action Agreed 11/6: Use of infrasound data in support of IAVW (Dec. 2020)

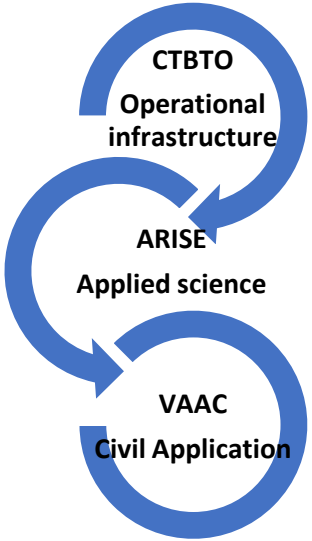
That, an ad-hoc group consisting of VAAC managers be tasked to:

a) Pursue, in collaboration with CTBTO and the ARISE (Atmospheric Dynamics Research Infra-Structure in Europe) community, the further development and testing of the volcanic information system (VIS), with the objective to establish a real-time operational system for use by all VAACs; and

b) Report the results back to the next meeting of the WG-MOG IAVW Work Stream."

Development of a Volcanic Information System (VIS)

The synergy CTBTO / ARISE* has offered a unique opportunity for the VIS establishment using infrasound data from a global station network



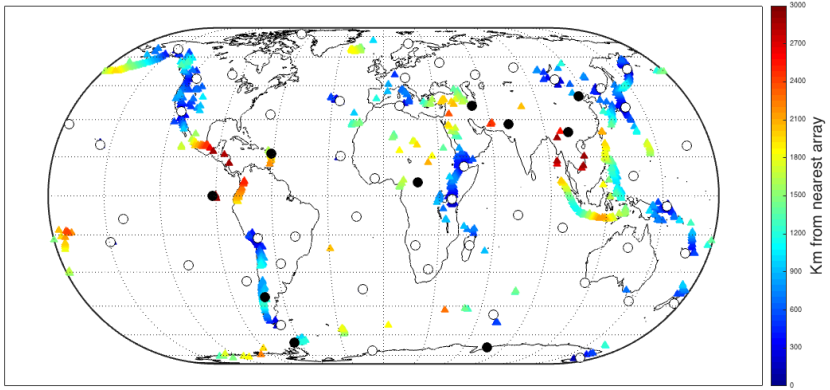
- ARISE advanced products provide valuable parametric inputs on the atmosphere dynamics that drive the infrasound wave propagation
- CTBTO brings its operational infrastructure to support dissemination of information to VAACs through the VIS – Prototype deployed within ARISE2
- The proposed approached has been tested with **VAAC Toulouse**, mandated by the ICAO, to demonstrate the usefulness of infrasonic data to IAVW

➢ Prototype system (VIDEC) has been developed within ARISE-2 project (2018) See LePichon et al. (2019) and e-poster P1.1-133

*(**A**tmospheric dynamics **R**esearch **I**nfra **S**tructure in **E**urope, H2020 EU project)

Using the IMS* infrasound network for VAAC notifications

Distribution of IMS infrasound arrays and volcanoes (triangles) that had activity during the last 10,000 years. For each volcano, the distance to the nearest IMS infrasound station is colour-coded.



Ceranna et al, 2018

*International Monitoring System operated by CTBTO IS network 90% complete

- Multi-year continuous quality recordings
- Global coverage : median distance from any volcano to the nearest IMS infrasound array was ~980 km

➔ **mean travel time of ~55 min** assuming an isotropic propagation with a celerity of 0.3 km/s

Assessment of VIS on a set of historical data

Presentation at ICAO and WMO meetings (2019)

Volcano name	Country	Year	VAA emitted by	Start Date (VIS)	End Date (VIS)	Stations detecting
Eyjafjallajokull	Iceland	2010	VAAC London	30/04/2010	11/05/2010	I18DK, I26DE
Dubbi	Eritrea	2011	VAAC Toulouse	12/06/2011*	*	A notification is triggered for Dubbi in the same time with Nabro because I32KE (1700km) cannot differenciate the two volcanoes. I19DJ(260km) provides data only since Sept. 2011
Nabro	Eritrea	2011	VAAC Toulouse	12/06/2011	11/07/2011	I32KE, several eruptions over this period
Nyamuragira	RD Congo	2011	VAAC Toulouse	07/11/2011	27/11/2011	I32KE, impossible to differeciate with Nyiragongo.Volcanoes are too close.
Nyiragongo	RD Congo	2011	VAAC Toulouse	11/03/2011	04/04/2011	I32KE, several eruptions over this period
Grimsvotn	Iceland	2011	VAAC London	21/05/2011	22/05/2011	I18DK
Puyehue-Cordon Caulle	Chile	2011	VAAC Buenos Aires	04/06/2011	10/06/2011	I02AR, I41PY, I08BO
Fogo	Cape Verde	2014	VAAC Toulouse	27/11/2014	04/12/2014	I11CV
Cabulco	Chile	2015	VAAC Buenos Aires	22/04/2015	23/04/2015	I14CL, I02AR, I08BO, I09BR
Meru	Tanzania	2015	VAAC Toulouse			No detection and no confirmed eruption
Etna	Italy	2016	VAAC Toulouse	16/05/2016	25/05/2016	I48TN, (OHP), I26DE

- VIS was able to **detect all the major eruptions** (VEI > 3) associated with the VAAs
- Systematic comparison with UNIFI Early Warning results (2008-2016)

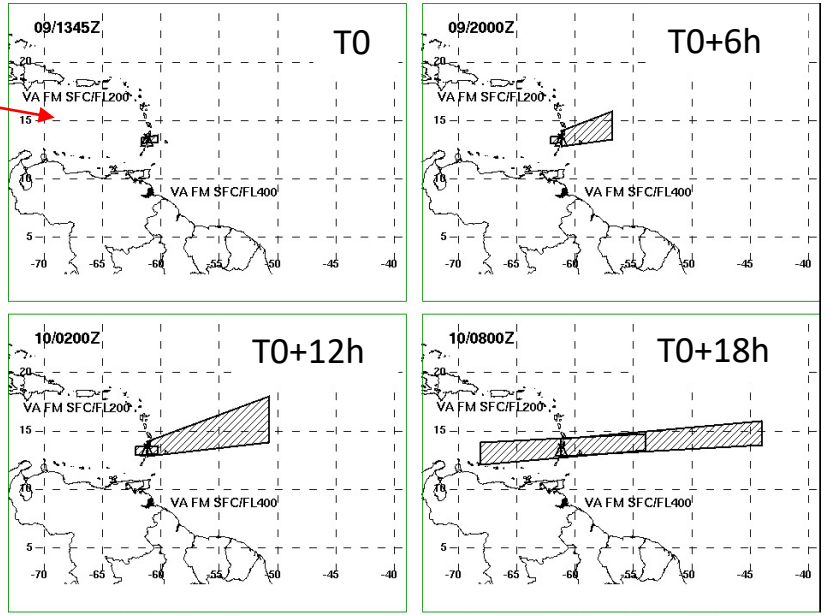
-> The most significant episodes of lava fountaining and ash eruptions are well identified

-> For smaller events, **system performances highly depend on favorable propagation conditions**

April 2021 Case Study: La Soufrière (St Vincent Island)

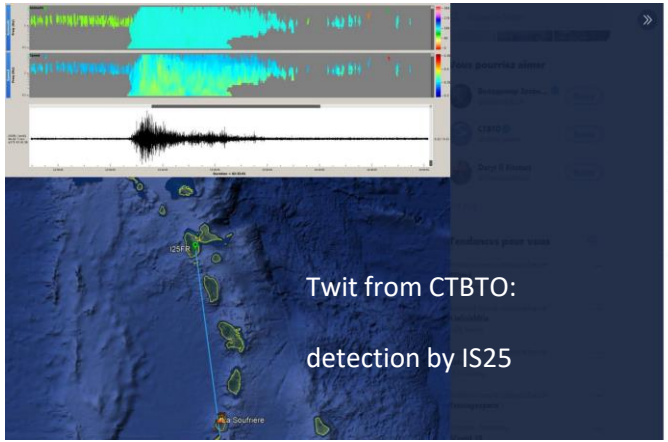
La Soufrière dramatic eruption on 9th April 2021: an ash plume rose up to 10 km, a series of puffs in the days after, 2000 residents evacuated

The first VA Advisory was issued at 1303Z by the Washington VAAC



April 2021 VIS Case Study: La Soufrière (St Vincent Island)

Infrasound Parameter (IP) is derived from IS detections at IS25 (Guadeloupe Island, 300 km distance)

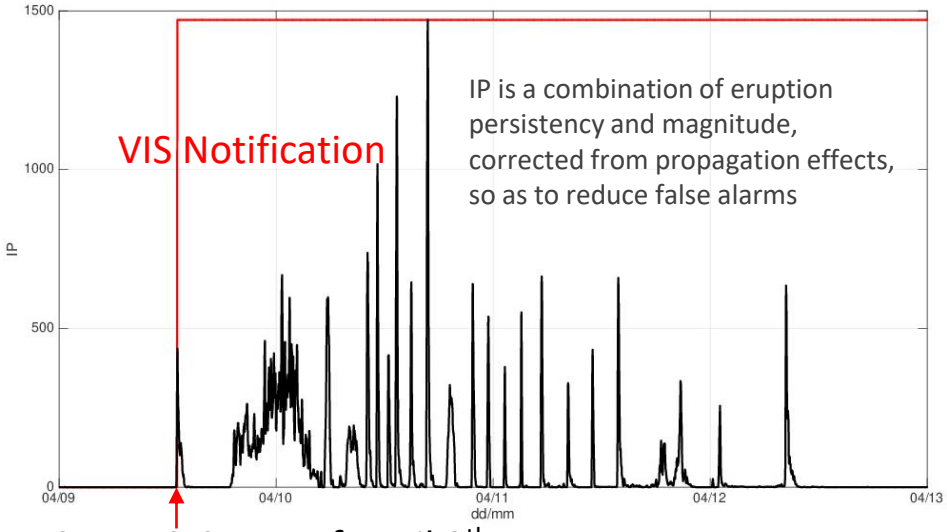


Lasina Zerbo
@SinaZerbo

#IMS infrasound station IS25 (#Guadeloupe) detected a signal around 13:00 UTC on 9 April 2021, from the eruption at #LaSoufrière #@MSZeinavolcano St Vincent. Over 16000 residents evacuated from the exposed zone

9:56 PM · 9 avr. 2021 · Twitter for iPhone

27 Retweets 1 Citer le Tweet 44 J'aime



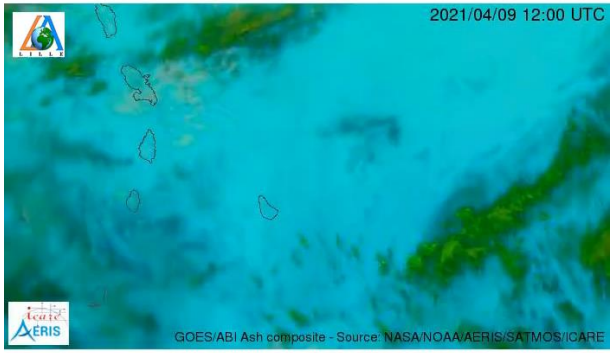
- VIS notification would have been issued to VAACs at 13:04 UT of April 9th
- In addition, it is possible from VIS sequence to reconstruct the chronology of the eruption (source term information for dispersion models)

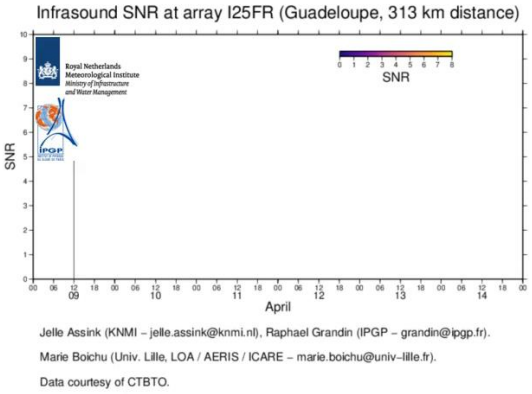
April 2021 Case Study: La Soufrière (St Vincent Island)

Satellite imagery (GOES Ash composite, NOAA)

Vs

IS detection at IS25 (Guadeloupe, CTBTO)





Courtesy of CTBTO, IPGP (R. Grandin), KNMI (J. Assink), LOA/ICARE (M. Boichu)

Comparison on the period 9th – 14th April 2021

- Good correlation between IS and satellite data
- IS detection provides realistic description of the time sequence of the puffs

May 2021 Case Study: Nyiragongo

Nyiragongo dramatic eruption (Democratic Republic of the Congo) – 22nd May 2021

- Around1630Z Nyiragongo erupted, with significant ash emission

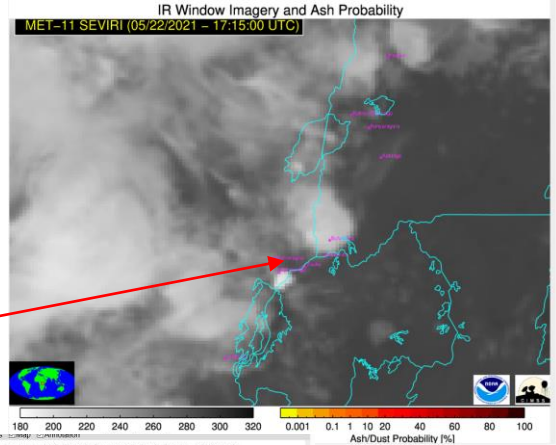
- 30 people killed by lava flows and gases
- Threat on Goma city : evacuation order in the following days

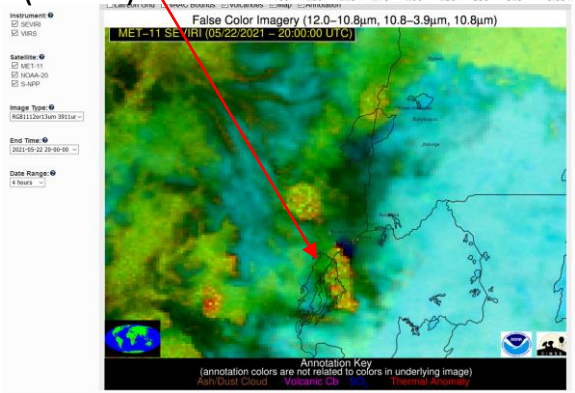
- Poorly monitored volcano : The Toulouse VAAC was informed on May 22nd in the late evening (2030Z) :

➢ VA Advisory#1 was issued at 2102Z, 4h30 after the eruption start

Case Study: Nyiragongo (May 2021)

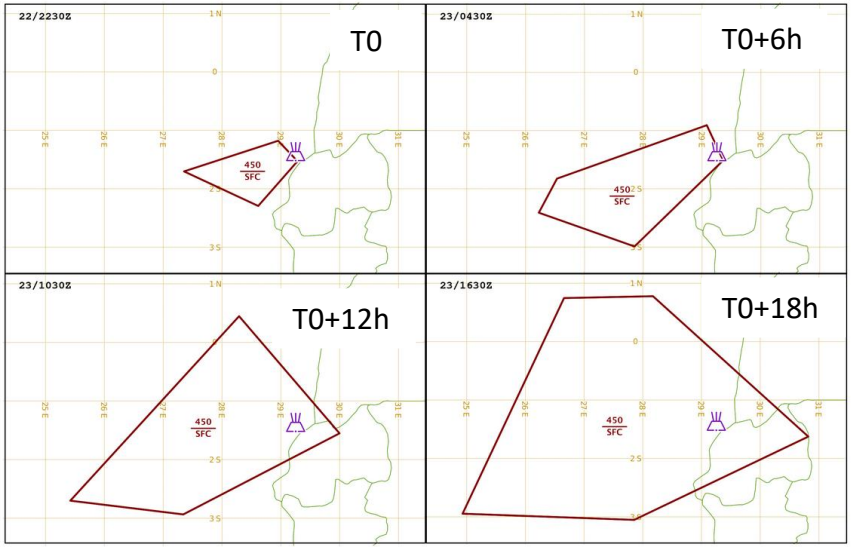
Ash cloud Observed by MSG Imager (NOAA)





Satellite observations are used for describing initial conditions in VAA and for checking VA model predictions

VA Advisory#2 2217Z



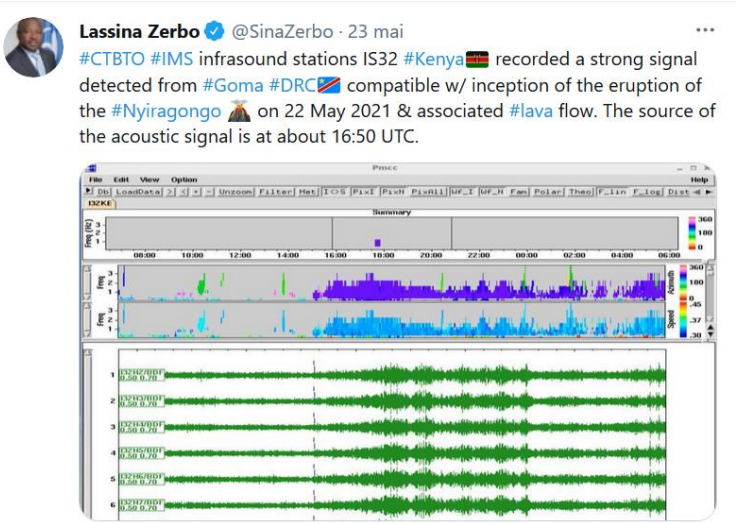
VOLCANIC ASH ADVISORY
DTG:20210522/2217Z
VAAC:TOULOUSE
VOLCANO: NYIRAGONGO 223030
AREA: AFRICA (CENTRAL)
SUMMIT ELEV: 3470M

METEO FRANCE

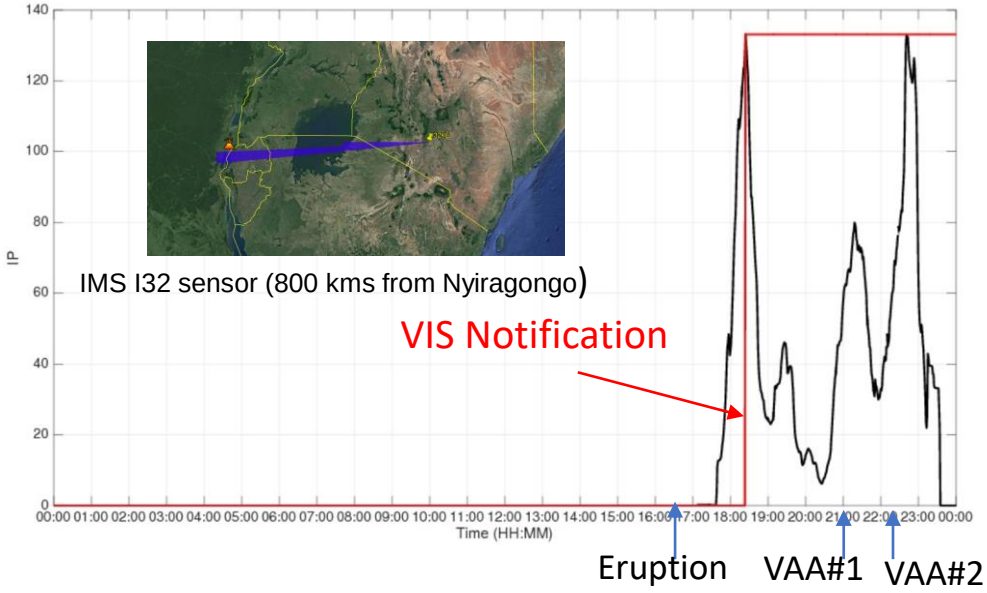
ADVISORY NR: 2021/2
INFO SOURCE:SAT IMAGERY, TWITTER
AVIATION COLOUR CODE:RED
ERUPTION DETAILS: ERUPTION AT 20210522/1800Z ONGOING ERUPTION
RMK: ASH CLOUD ESTIMATED UNDER FL450
NXT ADVISORY:NO LATER THAN 20210523/0430Z.

Case Study: Nyiragongo (May 2021)

Twit from CTBTO : IS32 detection



Use of the VIS method for the Nyiragongo 2021 eruption



- By applying standard parameters, VIS notification would have been issued at 18:23Z May 22nd
- In addition, VIS provides time information on eruption kinetic (puffs) (source term information for dispersion models)

Summary and Perspectives

- Scientific collaboration on VIS is an asset for CTBTO and ICAO/WMO communities
- IS technology has demonstrated its maturity in possibly providing timely notification:

- Draw the attention of the VAAC forecasters on the occurrence of an eruptive event
- Reconstruction of the time sequence of the eruption (source term for dispersion models)

- Results are promising, especially in the case of major eruptions, and for poorly monitored regions

Future work

- Improve the reliability of the notification results, reduce the false alarms rate. Further evaluation of VIS is required, with an extension to other VAACs with poorly monitored volcanoes in their AoR
- Calculate the source amplitude from long range infrasound measurements to estimate the occurrence, and possibly the height of the ash plume: key parameters for ash dispersion models
- Integrate data from regional infrasound array to lower response time and improve reliability
- Evolve from data reanalysis tool to near real-time alert system: use of real time data

➢ **Collaboration on IS detection between CTBTO and ICAO-OACI-IKAO and WMO OMM should be strengthened!**

Use of infrasound data for early notification of Volcanic Ash Advisory Centres (VAAC)

Philippe Héreil et al. (Toulouse VAAC) philippe.hereil@meteo.fr