Volcanic eruptions and volcanic ash in the atmosphere

WMO Aviation Meteorology training seminar 2022

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Session Outline

0500 UTC Introduction

0510 UTC Volcanic ash, the hazards to aircraft, and effects on airspace

- session recap
- open discussion

0530UTC VA meteorological and observatory products, VA monitoring

- session recap
- open discussion

0555UTC Tongan eruption case study

- session recap
- open discussion

0620 UTC Wrap-up

Session Outline

1000 UTC Introduction

1010 UTC Volcanic ash, the hazards to aircraft, and effects on airspace

- session recap
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1030UTC VA meteorological and observatory products, VA monitoring

- session recap
- open discussion

1055UTC Tongan eruption case study

- session recap
- open discussion

1120 UTC Wrap-up

Volcanic Ash intro and hazards

- Introduction to VA – history, world volcanoes, volcanic groups, eruption column
- Hazards to aviation of VA – drifting ash cloud, composition of particles (Mt Ruapehu ash demo), jet engine effects, windscreen abrasion, on-ground effects
- Effects on airspace in your region, ash concentration

Introduction

Lava flows, lahars and pyroclastic flows are severe volcanic eruption hazards. But we are concerned with Volcanic Ash (VA), which may or may not be so obvious.

VA:

- has severe effects on aircraft
- affects air quality – may cause problems for those with respiratory diseases
- falls on farmland and can be beneficial or toxic, depending on chemical composition

Historic Events

Mount St. Helens, USA 1980:

- https://en.wikipedia.org/wiki/1980_eruption_of_Mount_St._Helens

British Airways Flight 9, Indonesia 1982 (video):

- https://en.wikipedia.org/wiki/British_Airways_Flight_9

Mount Ruapehu, New Zealand 1995/1996:

- https://en.wikipedia.org/wiki/Mount_Ruapehu#1995%E2%80%931996_eruptions

Eyjafjallajökull, Iceland 2010:

- https://en.wikipedia.org/wiki/2010_eruptions_of_Eyjafjallaj%C3%B6kull

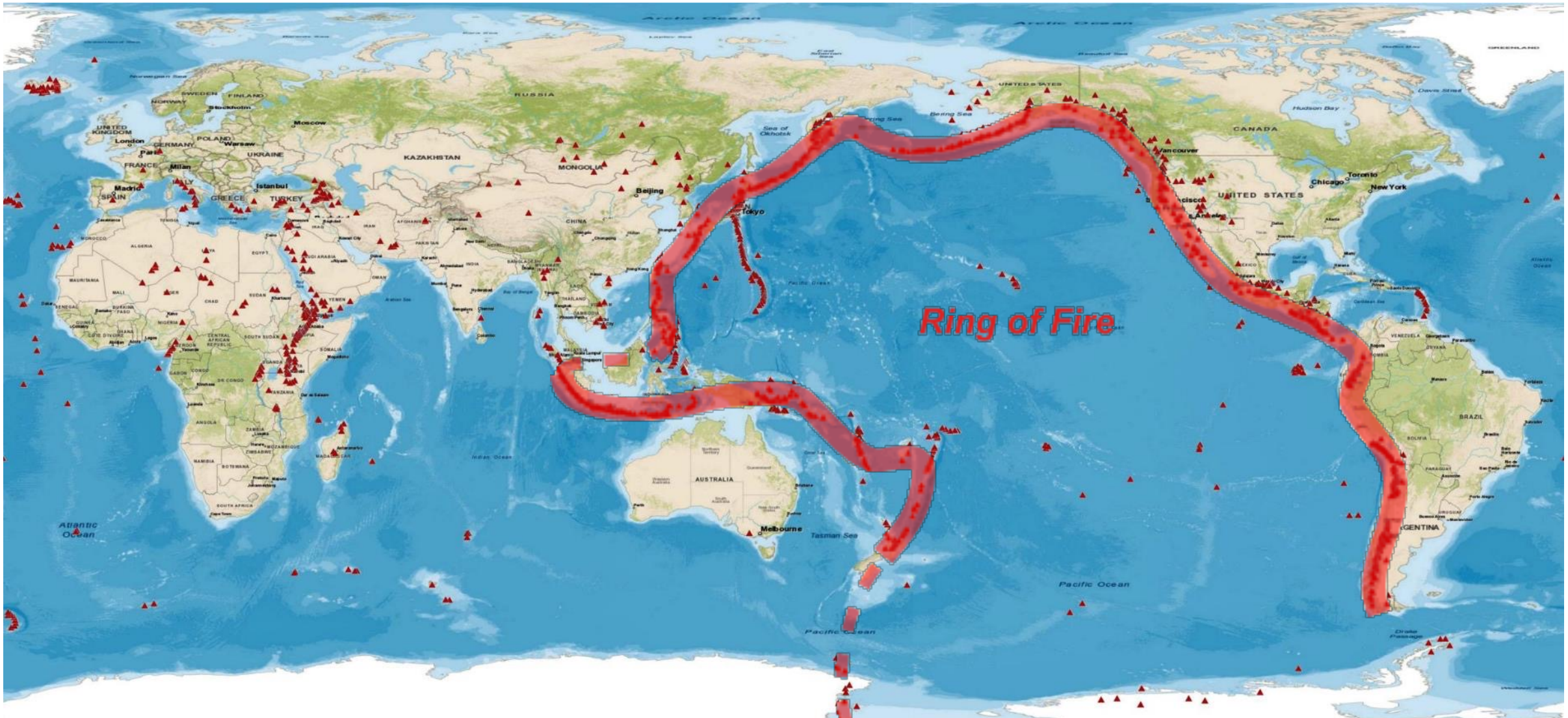
Puyehue-Cordón Caulle, Chile 2011/2012:

- https://en.wikipedia.org/wiki/2011%E2%80%932012_Puyehue-Cord%C3%B3n_Caulle_eruption

Distribution of Volcanoes

Much of the world's volcanic and seismological activity occurs along plate boundaries.

75% of volcanoes lie along the "Ring of Fire".



Volcano Types

Shield Volcanoes

- hot “basalt” magma (1200°C)
- little dissolved gas content (CO_2, H_2O, SO_2)
- eruptions that flow out, and less ash

Mt Eden, NZ

Cone/Strato-volcanoes

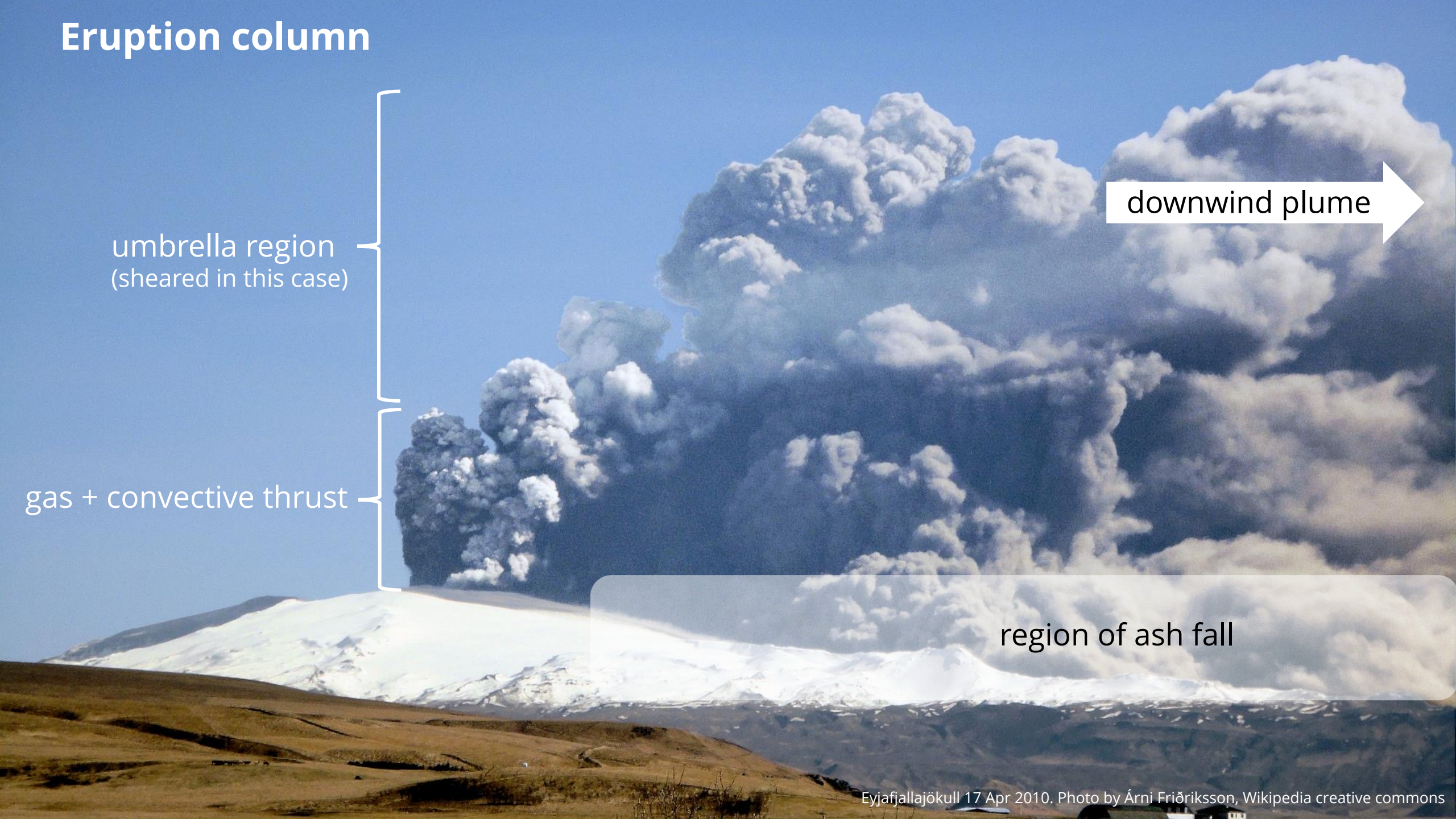
- moderate temperature “andesitic” magma (800 - 1000°C)
- moderate dissolved gas
- flowing + moderate explosive eruptions

Caldera/Super-volcanoes

- lower temperature “rhyolitic” magma (750 - 850°C)
- much dissolved gas
- VERY explosive eruptions

Lake Taupo, NZ

Eruption column



Eyjafjallajökull 17 Apr 2010. Photo by Árni Friðriksson, Wikipedia creative commons

Hazards to Aircraft in flight

Volcanic Ash is composed of sharp, hard particles ranging in size from a fine powder to a few millimetres in diameter (too small for onboard radar to detect).

- Clip of Mt Ruapehu ash, saved from 1995:
  (click on video to play)

Hazards to Aircraft in flight

- In aircraft engines, erosion of moving parts and partial melting of ash can lead to engine surge or stall. Jet engines can have a total breakdown of airflow, leading to engine “flameout”.

- Any forward facing surface, such as windscreens and leading edges, will be scratched.

- Small ash particles can get into openings in aircraft exterior, for example pitot tubes which supply airspeed and altitude (British Airways Flight 9 crew, 1982, did not know their airspeed).

Boeing 747 windscreen damaged in Dec 1989 eruption of Mt Redoubt, Alaska. Right side is very obscured; left side got only glancing blows from ash particles

Image courtesy of U.S. Geological Survey

Drifting VA Cloud

Wind can carry VA thousands of km, for example Cordón Caulle went right around the Southern Hemisphere.

Things to consider:

- Upper wind profile
- Size and height of eruption
- Duration of eruption
- Settling/fall out velocity – depends on height, particle size, wind strength
- Presence of weather systems – VA can be washed out by rain

Concentration Forecast Products

The 2010 eruption of Eyjafjallajökull caused massive air travel disruptions across Europe.

Since then, Rolls-Royce has researched ash concentration and exposure duration on engines. Results show that aircraft can tolerate ash dosages equivalent to one second of exposure to 14.4 grams of ash per cubic metre (although there may be economic impact through reduction on engine life).

- this is equivalent to flying for two hours in ash concentrations of 2 milligrams per cubic metre.

VAACs currently run on an ash/no ash basis, and aim to have ash concentration forecasts by 2026.

- but it is hard to determine ash concentration from satellite imagery without knowledge of the thickness of the ash layer.

- modelling relies on accurate observations of ash concentration.

- observation and modelling of ash concentration are subject to ongoing research.

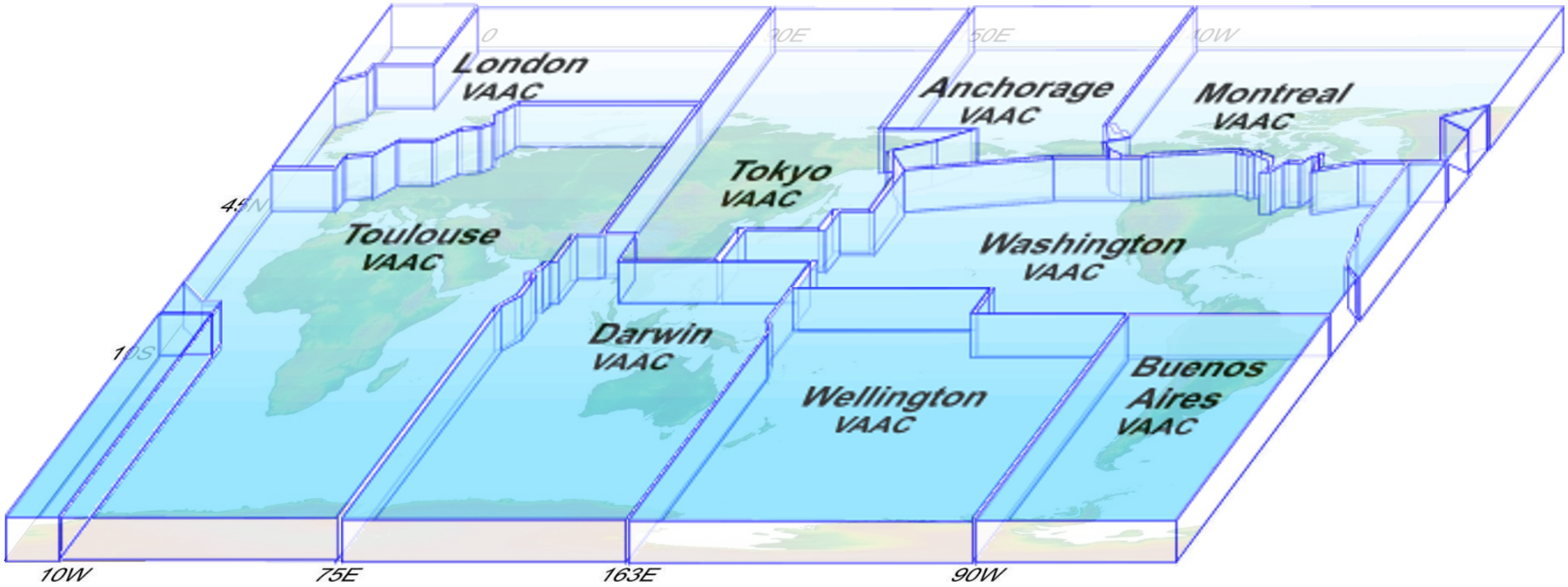
Minor events

Small eruptions may eject gas only, or a small ash plume that rises a few thousand feet into the troposphere.

Whakaari White Island (300m) Feb 2013. Photo by Gérard Nouméa, Wikipedia creative commons

VAAC regional airspaces

- the 9 Volcanic Ash Advisory Centres



Open Discussion!

What is the nearest volcano to your region or country?

Has your country ever been affected by Volcanic Ash? If so, what happened?

How were your airlines affected?

Do airlines in your country ever discuss with your organisation the risk of VA occurring, and how to deal with it?

What communications do you have with the Volcanic Ash Advisory Centre responsible for the airspace that includes your country?

What do you know about how this VAAC operates? Have you or a colleague ever visited this VAAC?

Volcanic Ash products and monitoring

- VA meteorological products – VA SIGMET, VAA and the nine VA Advisory Centres, Pilot reports, TAF, Metar
- Volcano observatory products – VONA, VAB
- Responding to VAA, with examples of how you deal with VA in your agency
- VA monitoring – manual observations, satellite imagery (including RGB, SO_2 products), soundings, upper wind data, webcams

VA SIGMET

VA SIGMETs are valid for 6 hours rather than the standard 4 hours.

VA SIGMET contains:

- Volcano name and location
- Observed (OBS) or forecast (FCST) height and extent of VA
- Forecast position of VA at the end of the SIGMET validity period (no height is included here, it is assumed to be the same)

VA SIGMET Examples

Initial VA SIGMET:

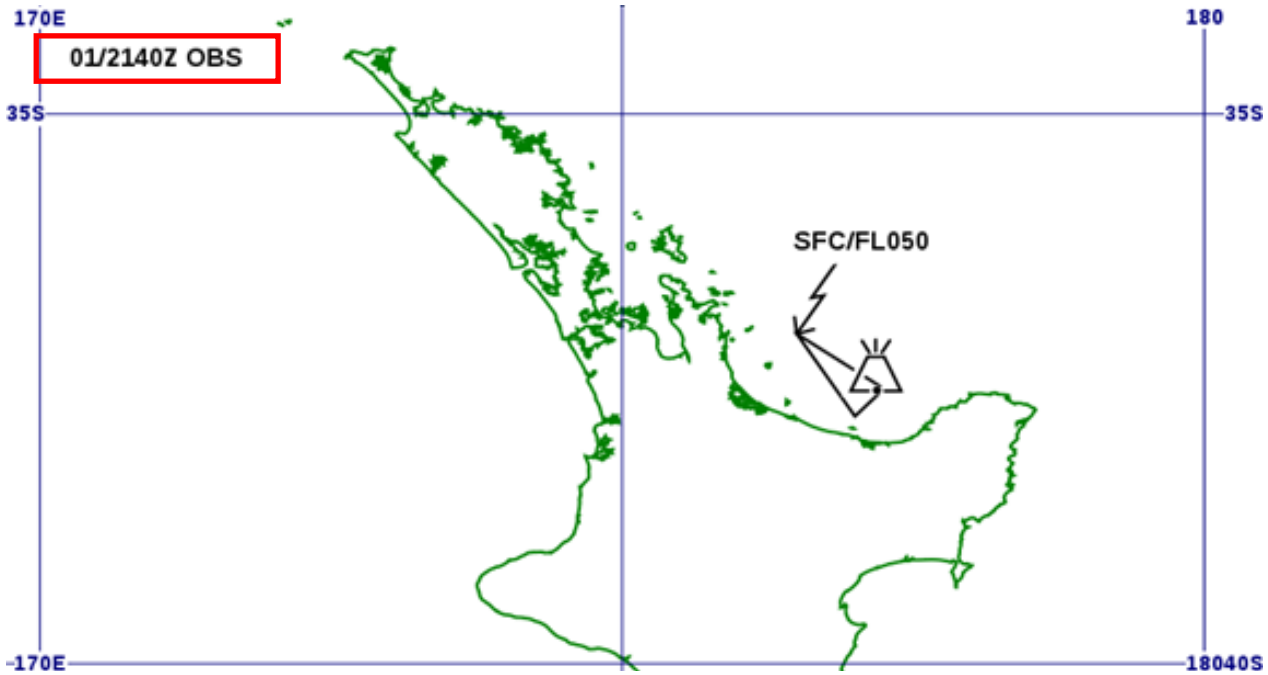
```
WVNZ21 NZKL 012232
NZZC SIGMET 15 VALID 012237/020437 NZKL -
NZZC NEW ZEALAND FIR MT WHAKAARI - WHITE ISLAND PSN
S3731 E17711 VA CLD OBS AT 2231Z =
```

Full VA SIGMET:

```
WVNZ21 NZKL 012232
NZZC SIGMET 15 VALID 012237/020437 NZKL -
NZZC NEW ZEALAND FIR MT WHAKAARI - WHITE ISLAND PSN
S3731 E17711 VA CLD OBS AT 2231Z WI S3730 E17715 -
S3745 E17700 - S3700 E17630 - S3730 E17715 SFC/FL040
FCST AT 0437Z WI S3730 E17715 - S3745 E17700 - S3700
E17630 - S3730 E17715 =
```

Initial VAA & VAG example

```
FVPS01 NZKL 012140
VA ADVISORY
DTG: 20210901/2140Z
VAAC: WELLINGTON
VOLCANO: WHAKAARI - WHITE ISLAND 241040
PSN: S3731 E17711
AREA: NEW ZEALAND
SUMMIT ELEV: 294M
ADVISORY NR: 2021/1
INFO SOURCE: SATELLITE IMAGERY, WEBCAM
AVIATION COLOUR CODE: UNKNOWN
ERUPTION DETAILS: POSSIBLE LOW LEVEL ERUPTION
OBS VA DTG: 01/2140Z
OBS VA CLD: SFC/FL050 S3730 E17715 - S3730 E17715 - S3745
        E17700 - S3700 E17630 MOV S 05KT
FCST VA CLD +6 HR: 02/0340Z NOT AVBL
FCST VA CLD +12 HR: 02/0940Z NOT AVBL
FCST VA CLD +18 HR: 02/1540Z NOT AVBL
RMK: MORE INFORMATION TO FOLLOW
NXT ADVISORY: NO LATER THAN 20210902/0340Z=
```



VA in TAF and METAR/SPECI

TAF

- VA is included in a TAF when fallout is expected at the aerodrome
- not every aerodrome within the VA SIGMET area needs VA in the TAF, only those expecting ashfall
- may or may not lead to significant visibility reduction

METAR

- VA should be included in a METAR if ash is falling within 8km of aerodrome
- if VA is observed within 8-16km, then VCVA should be added
- VA beyond 16km may be added to the RMK

Examples of ash in TAF and METAR/SPECI

TAF

```
TAF NZGS 172154Z 1721/1812 33005KT 20KM VA FEW020 SCT030
BECMG 1722/1801 18010KT
PROB30 TEMPO 1722/1801 8000 VA
2000FT WIND 24020KT
BECMG 1803/1806 18010KT
QNH MNM 1028 MAX 1037 =
```

(the 20KM visibility is a local variation for domestic TAFs)

```
TAF NZRO 172218Z 1721/1812 VRB02KT 20KM VA FEW040
TEMPO 1721/1812 5000 VA
2000FT WIND VRB02KT
QNH MNM 1030 MAX 1039 =
```

METAR

```
SPECI NZRO 170100Z 20007KT 5000 VA BKN030 06/M05 Q1024 =
```

```
SPECI NZTG 170100Z 22014KT 8000 VA BKN030 12/05 Q1024 RMK EXTENSIVE VA S AND E SPREADING
N TOWARDS FIELD =
```

VONA example

Item No	Element	Content
1	**Message title**	**VOLCANO OBSERVATORY NOTICE FOR AVIATION**
2	**Issued**:	20191209/0100Z
3	**Volcano:**	White Island 241040
4	**Current Aviation Color Code**:	Orange
5	**Previous Aviation Color Code**:	Yellow
6	**Source**:	GNS Science, New Zealand
7	**Notice Number**:	NZ VONA 01/20
8	**Volcano Location**:	3752S17718E
9	**Area**:	White Island
10	**Summit Elevation**:	1053FT
11	**Volcanic Activity Summary**:	Eruption has just occurred at ~1410.
12	**Volcanic Cloud Height**:	5,000 to 6,000 ft
13	**Other Volcanic Cloud information:**	NIL
14	**Remarks**:	More information to follow
15	**Contacts**:	Duty Volcanologist, +6472761784ph,+6473748199fax
16	**Next Notice**:	Will be issued if there is a change in aviation color code or when a significant volcanic event happens within the current color code.

PIREP Examples

```
QU SYDAXQF
.QXSXMXS 160424
[1]A87
FI QF0004/AN VH-QPC
DT QXS NOU1 160424 M02A
- PIREP
AT TIME 0330 AOBA WAS OBSERVED
TO GROW FROM A VERY LOW LEVEL
CLOUD TO A LARGE CLOUD IN EXCE
OF 30000FT AND THEN FORM A
MUSHROOM TOP RAIN OR ASH OBS ON
EAST SIDE FROM APPROX 15-20000FT
```

```
UAXX33 NZZC 280400
(ARS-NZM22-NZNR-NZAA-AT76
-NOBAR135074
-0359
-F170
-PRE-ERUPTION VOLCANIC ACTIVITY AT
WHITE ISLAND. INCREASED SMOKE NOT
PENETRATING THE INVERSION LAYER)
```

Satellite Imagery

- In clear skies VA is easy to detect, but things become tricky when meteorological cloud is about.

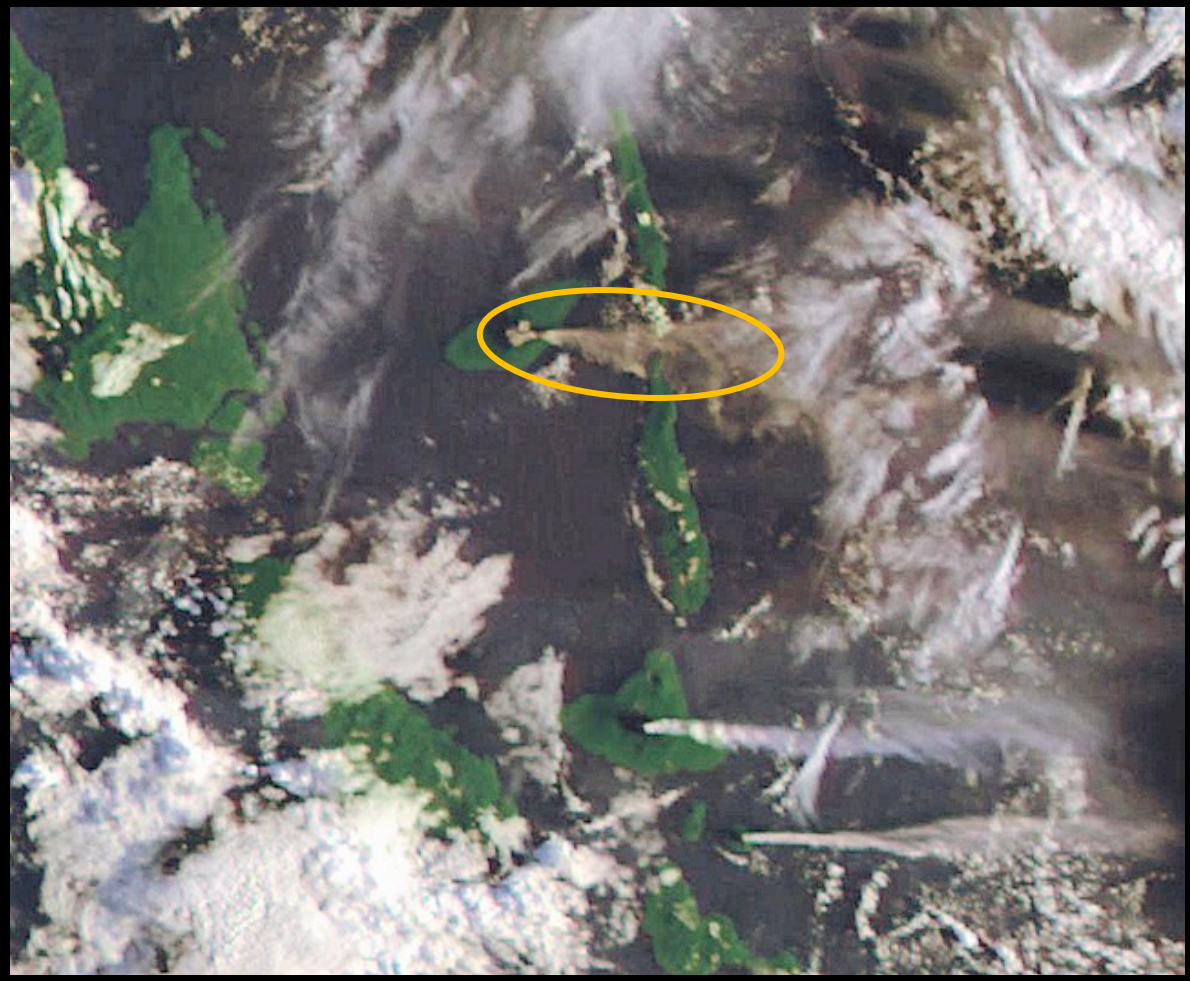
- VA clouds are often thin, so therefore show up better on visible imagery than IR.

  IR will give a brightness temperature from a combination of cloud top and Earth's surface, so weak contrast.

- True colour imagery allows distinguishing between ash (brown) and steam (white/grey) – however both types of visible imagery are only available during the day.

True Colour RGB

Aoba/Ambae eruption and ash cloud, Vanuatu 9 Feb 2018



Ash/Dust RGB: Himawari-8 example

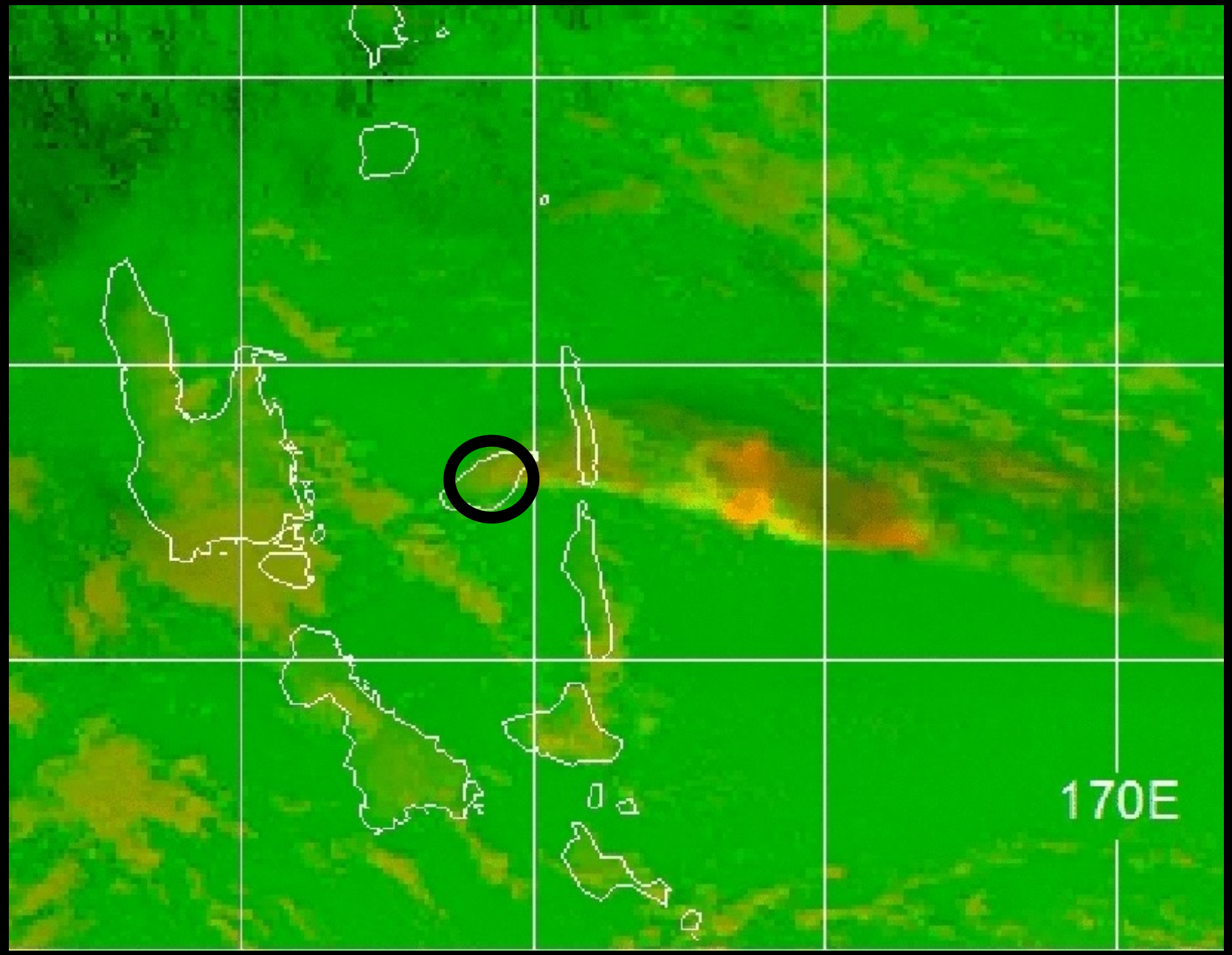
Uses 12.4μm (micron, Band 15), 10.4μm (Band 13) and 8.6μm (Band 11), and combines them using primary colours.

- VA appears as **red/magenta/orange**
- SO_2 appears as **bright green** (10.4μm – 8.6μm)
- Mix of VA/SO_2 appears in **yellow**

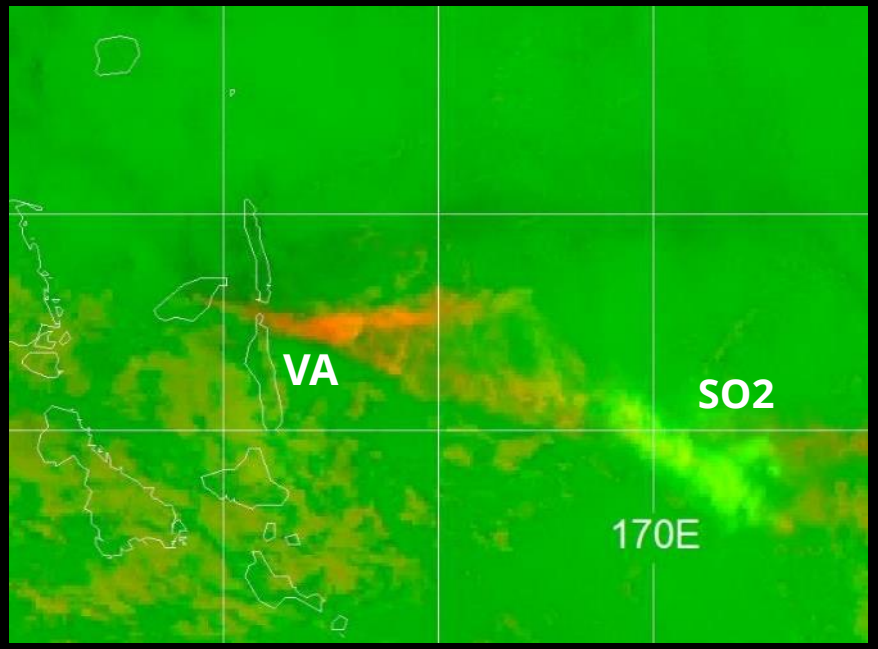
Aoba, 11 April 2018

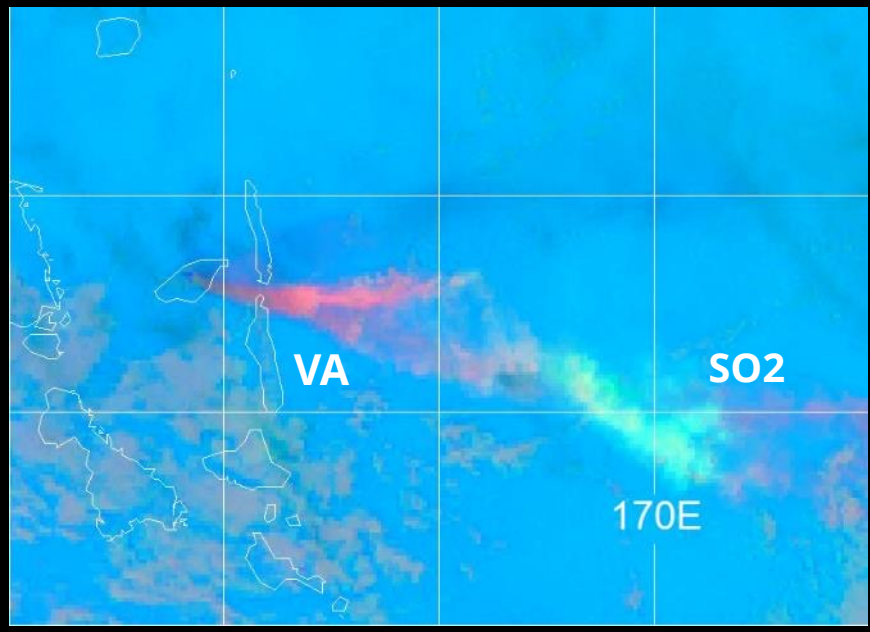
Bright green SO_2
Orange VA
Yellow mix of above

Limited detection when ash mixed with ice; black cirrus cloud may or may not be volcanic.



Ash RGB imagery for ash and SO_2 detection, Aoba April 2018





JMA scheme

Colour	Channel/Channel Difference	Temperature Ranges
Red	12.4μm - 10.4μm	-4 to +2K
Green	10.4μm - 8.6μm	-4 to +5K
Blue	10.4μm	243 to 208K (-30 to -65C)

EUMETSAT scheme

Colour	Channel/Channel Difference	Temperature Ranges
Red	12.4μm - 10.4μm	-4 to +2K
Green	10.4μm - IR8.6μm	-4 to +5K
Blue	10.4μm	243 to 303K (-30 to 30C)

NOAA CIMSS

(National Oceanic & Atmospheric Administration & Cooperative Institute for Meteorological Satellite Studies)

A volcanic cloud monitoring website that uses a number of geostationary and polar orbiting satellites to cover much of the world.

Satellite imagery is analysed using a collection of algorithms to identify volcanic ash, volcanic Cb, SO_2 and thermal anomalies.

https://volcano.ssec.wisc.edu/

Ash Dispersion Modelling

e.g. HYSPLIT - Hybrid Single-Particle Lagrangian Integrated Trajectory

Uses wind data from NWP and a set of eruption details to create a volcanic ash dispersion prediction.

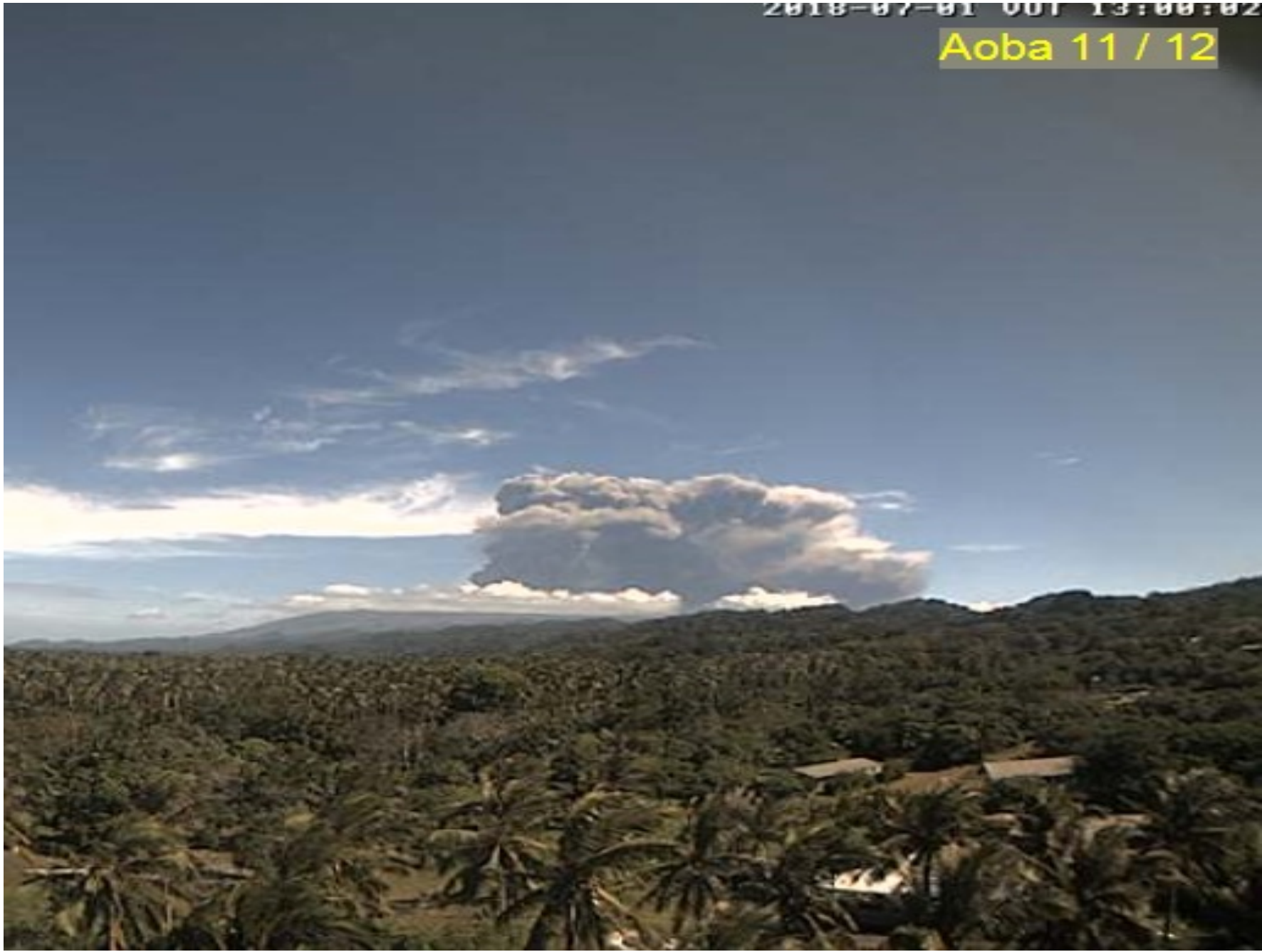
Eruption details include time of eruption, duration, rate and height. Some of these may not be known, so there are three default scenarios for each volcano: small, medium and large.

Webcams

Used in conjunction with satellite imagery to help confirm a possible eruption.

Particularly helpful for low level eruptions.

May have seismographs that you can view.



Open Discussion!

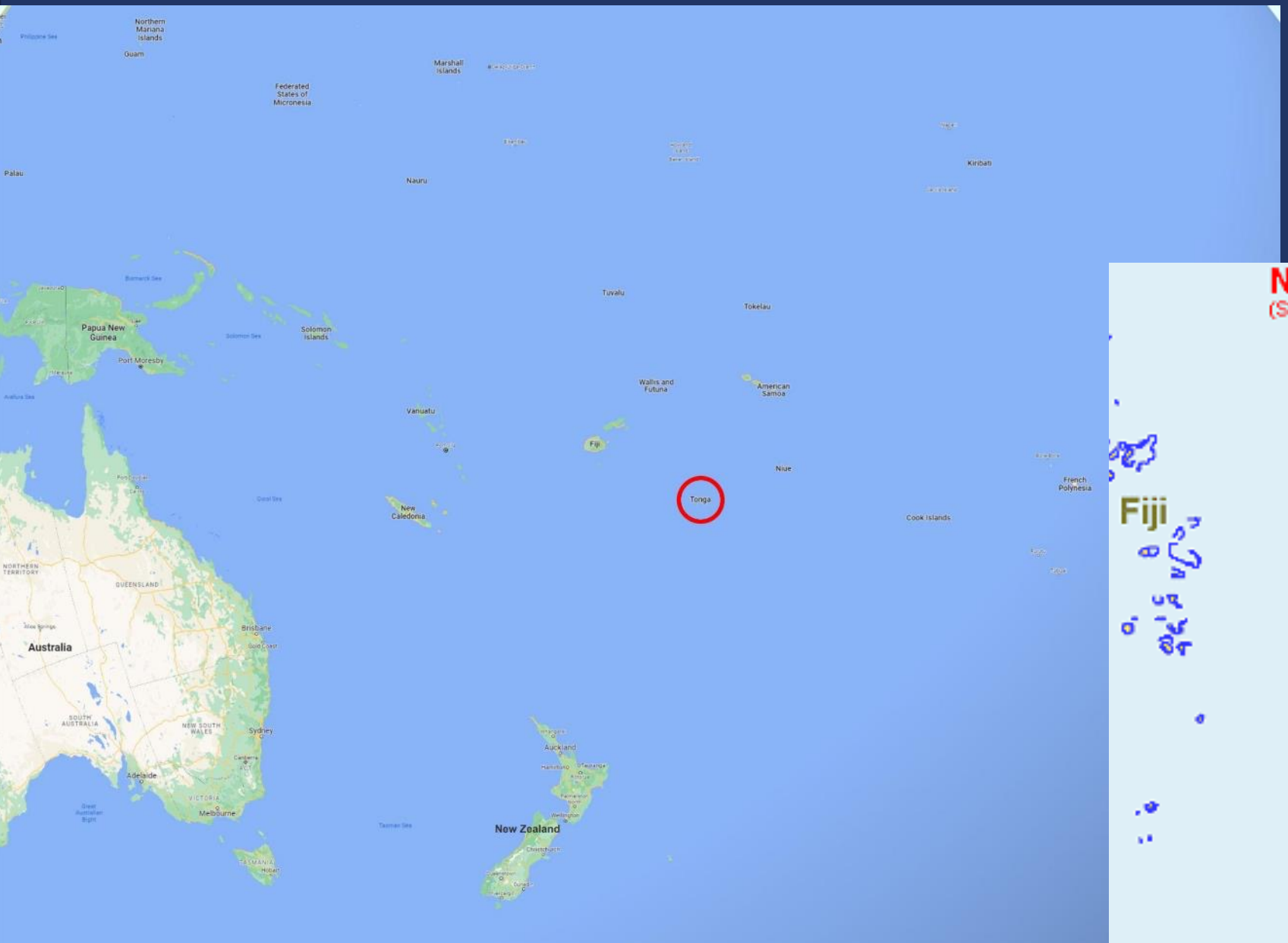
Does your organisation have procedures for handling VA SIGMETs or Advisories, issued either from your country or a neighbouring country?

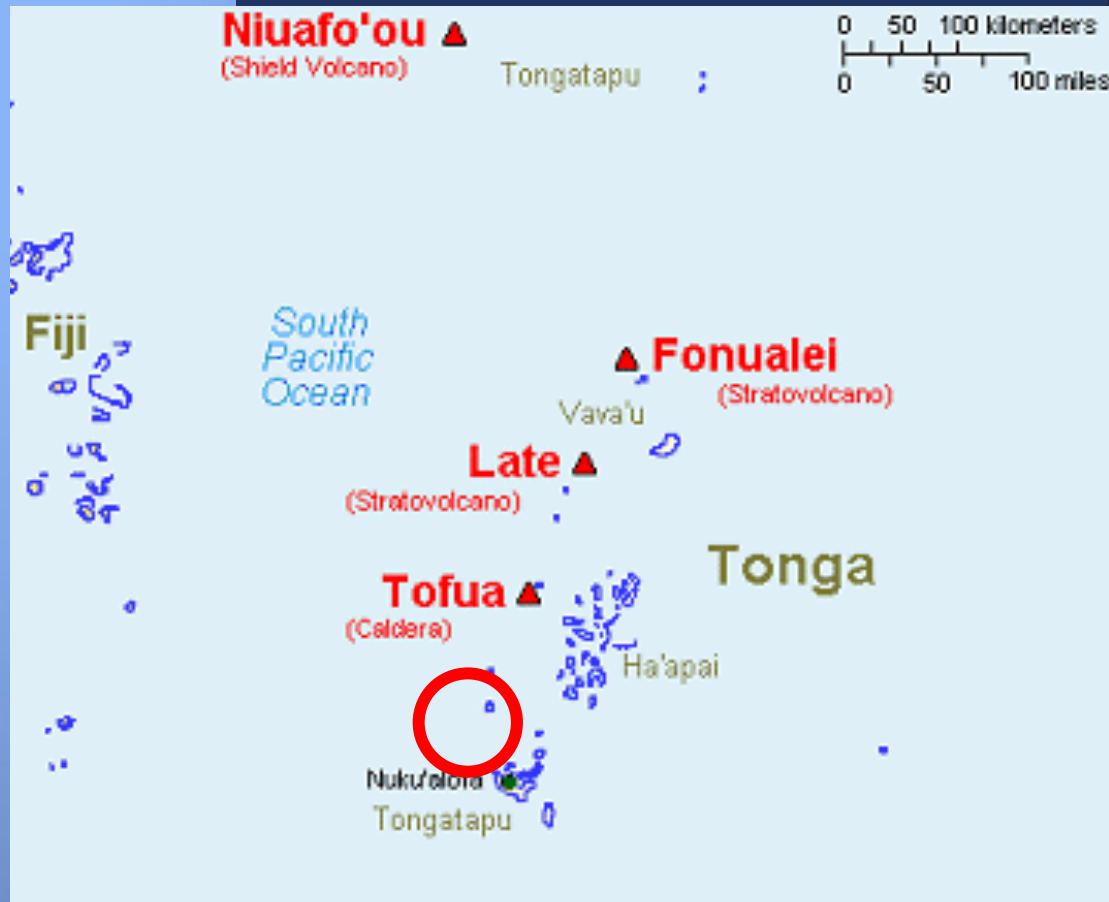
Describe a time when your organisation received a VA SIGMET or Advisory and had to act on it.

What would your organisation do if an eruption were to occur tomorrow and ash was expected to drift into your country's airspace?

Which team or which forecaster(s) would handle this? Would they be prepared?

Tongan eruption case study (15 January 2022)





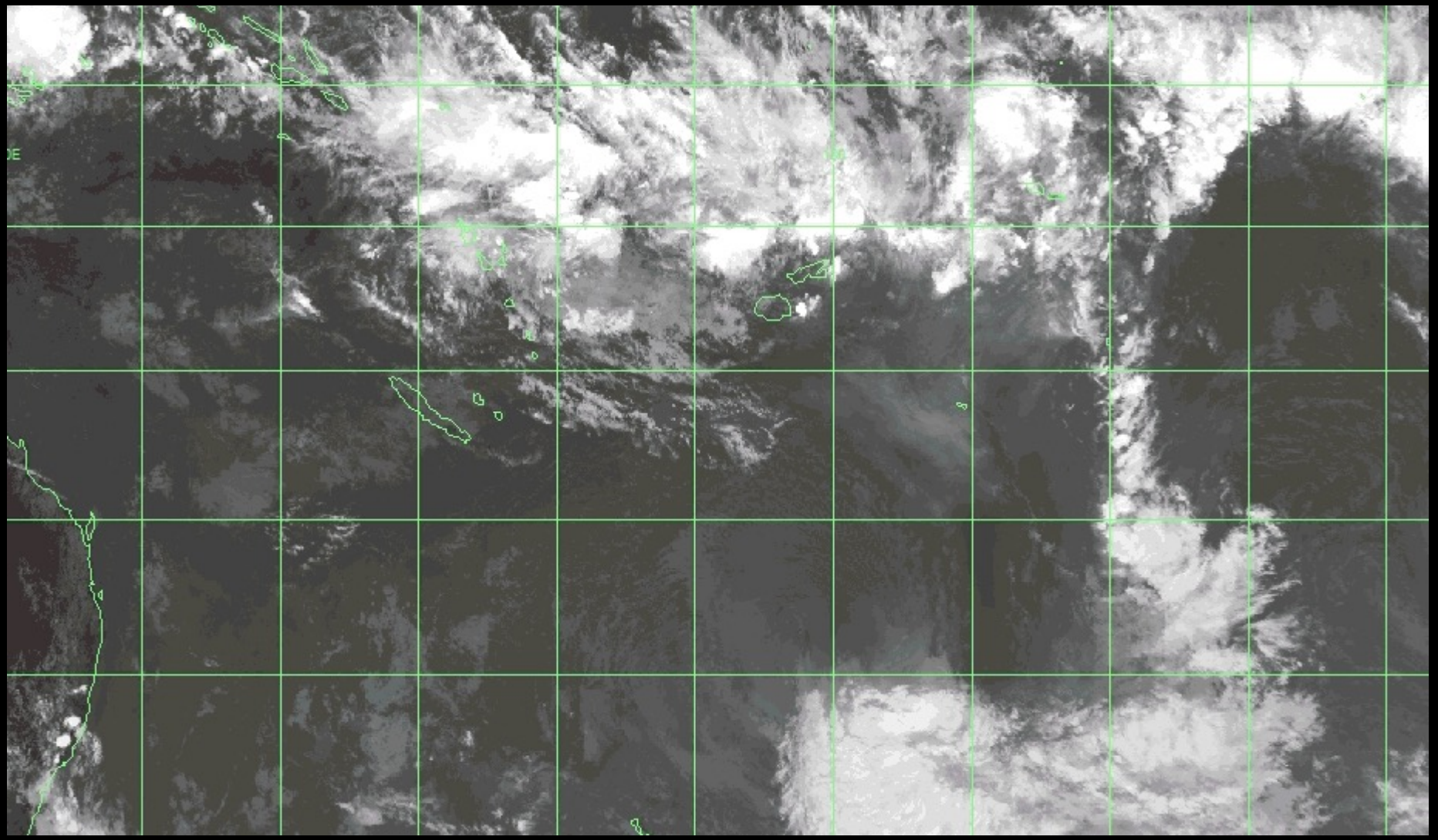
About the Hunga Tonga – Hunga Ha'apai eruption

- erupted just after 0400 UTC
- an underwater eruption: sea water entered a magma reservoir generating a very explosive reaction
- eruption column formed within minutes, reached 58 km above Earth's surface (mesosphere)
- much H_2O vapour, not much SO_2 (and not much pumice)
- umbrella region at 30km (stratosphere)
- shockwave propagated around the planet (see YouTube)
- sonic boom
- intense lightning
- sea retreated over Pacific Islands, then tsunami waves
- after 12 hours, neighbouring islands covered in 100mm of ashfall

Main eruption
15 January 2022

InfraRed imagery
Band-13 Himawari-8

0300 – 2300 UTC
15 Jan 2022
every 10 minutes



enhancement (Brightness temperature °C)

Early activity: VAA on 19 Dec 2021

DTG: 20211219/2141Z
VAAC: WELLINGTON
VOLCANO: HUNGA TONGA-HUNGA HA'APAI 243040
PSN: S2032 W17523
AREA: TONGA
SUMMIT ELEV: 114M
ADVISORY NR: 2021/1
INFO SOURCE: TONGA MET SERVICES AND SAT IMAGE
AVIATION COLOUR CODE: RED
ERUPTION DETAILS: CONTINUOUS PLUME OF SMOKE/STEAM. TOPS CONTINUING TO RISE
EST VA DTG: 19/2141Z
EST VA CLD: SFC/FL200 S2045 W17530 - S2015 W17530 - S2015 W17500 - S2045 W17500 MOV E 10KT
FCST VA CLD +6 HR: 20/0341Z NOT AVBL
FCST VA CLD +12 HR: 20/0941Z NOT AVBL
FCST VA CLD +18 HR: 20/1541Z NOT AVBL
RMK: MORE INFORMATION TO FOLLOW SHORTLY
NXT ADVISORY: NO LATER THAN 20211220/0341Z

15 January 2022: initial VAA for main eruption

DTG: 20220115/0439Z
VAAC: WELLINGTON
VOLCANO: HUNGA TONGA-HUNGA HA'APAI 243040
PSN: S2032 W17523
AREA: TONGA
SUMMIT ELEV: 114M
ADVISORY NR: 2022/17
INFO SOURCE: HIMAWARI 8 SATELLITE IMAGE
AVIATION COLOUR CODE: ORANGE
ERUPTION DETAILS: NEW ERUPTION SEEN IN SATELLITE IMAGERY
OBS VA DTG: 15/0439Z
OBS VA CLD: SFC/FL520 S2015 W17545 - S2015 W17430 - S2100 W17445 - S2100 W17545 MOV N 05KT
FCST VA CLD +6 HR: 15/1039Z NO VA EXP
FCST VA CLD +12 HR: 15/1639Z NO VA EXP
FCST VA CLD +18 HR: 15/2239Z NO VA EXP
RMK: MORE INFORMATION TO FOLLOW SHORTLY
NXT ADVISORY: NO LATER THAN 20220115/1039Z=

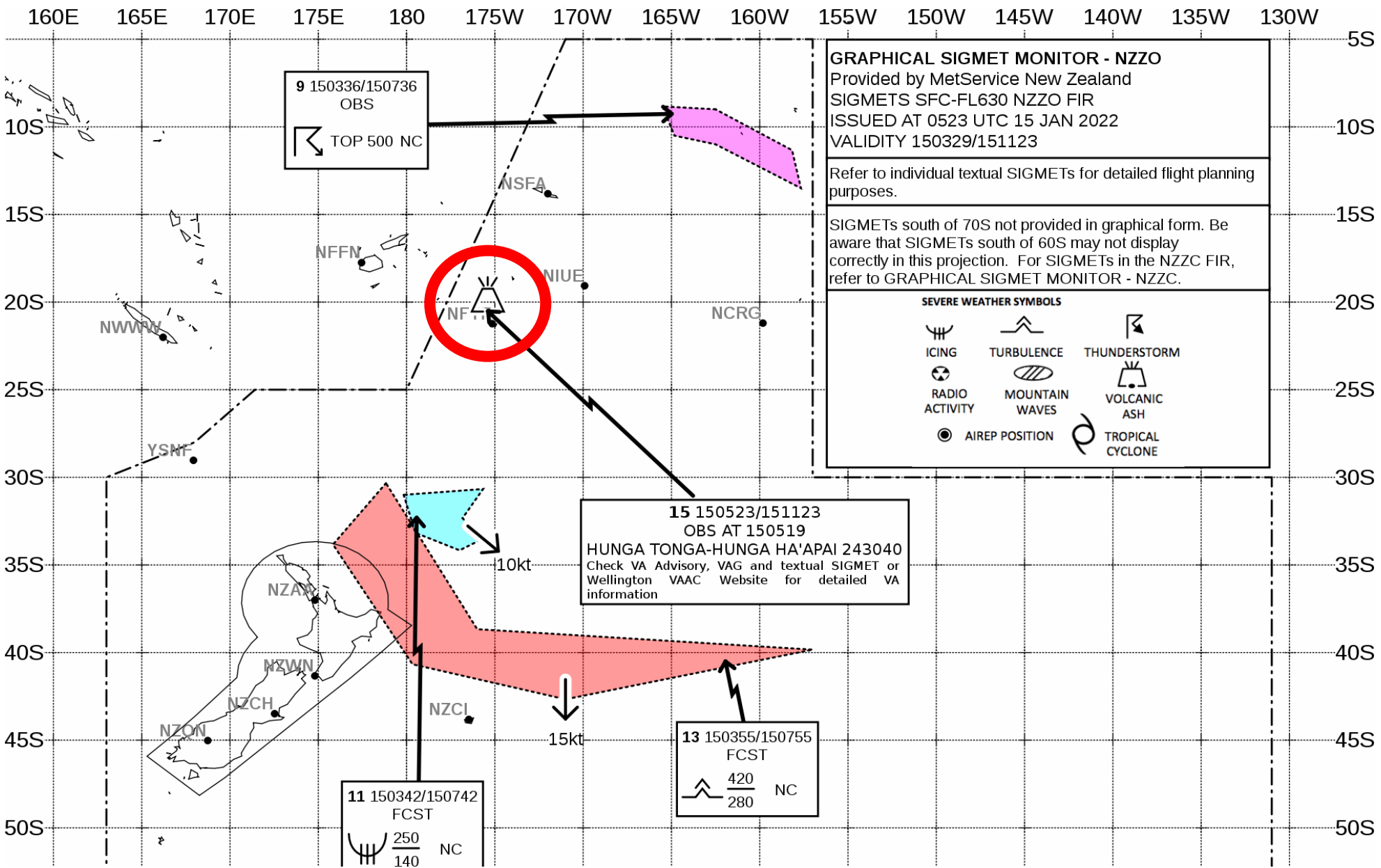
15 January 2022: full VAA

DTG: 20220115/0519Z
VAAC: WELLINGTON
VOLCANO: HUNGA TONGA-HUNGA HA'APAI 243040
PSN: S2032 W17523
AREA: TONGA
SUMMIT ELEV: 114M
ADVISORY NR: 2022/18
INFO SOURCE: HIMAWARI 8 SATELLITE IMAGERY
AVIATION COLOUR CODE: ORANGE
ERUPTION DETAILS: ERUPTION AT 20220115/0400Z LARGE ERUPTION OBSERVED
OBS VA DTG: 15/0519Z
OBS VA CLD: SFC/FL500 S2115 W17615 - S1945 W17615 - S1900 W17330 - S2130 W17345 - S2145 W17445 MOV NE 20KT
FCST VA CLD +6 HR: 15/1119Z SFC/FL500 S2115 W17615 - S1945 W17615 - S1900 W17330 - S2130 W17345 - S2145 W17445 ... *and +12 HR ... and +18 HR*
RMK: LARGE ERUPTION CLEARLY IDENTIFIABLE ON SATELLITE IMAGERY. HEIGHTS AND MOVEMENT ESTIMATED USING MODEL GUIDANCE.
NXT ADVISORY: NO LATER THAN 20220115/1119Z

15 January 2022: VA SIGMET

```
WVPS21 NZKL 150521
NZZO SIGMET 15 VALID 150523/151123 NZKL-
NZZO AUCKLAND OCEANIC FIR
VA ERUPTION MT HUNGA TONGA-HUNGA HA'APAI
PSN S2032 W17523
VA CLD OBS AT 0519Z WI S2115 W17615 - S1945 W17615
- S1900 W17330 - S2130 W17345 - S2145 W17445 - S2115 W17615
SFC/FL500
FCST AT 1123Z WI S2115 W17615 - S1945 W17615 - S1900
W17330 - S2130 W17345 - S2145 W17445 - S2115 W17615
```

15 January 2022: graphical SIGMET, NZZO FIR



Open Discussion!

Do you have any questions about this case study?

Do you know of any other volcanic events that were “felt” around much of the world?

Has your country ever been affected by an eruption in a different VAAC airspace from yours?

Questions or comments about any of today’s material on Volcanic Ash?


Thank you!
MetService
TE RATONGA TIRORANGI
Mt Ngauruhoe, New Zealand