

# Experimental use of satellite data for automatic detection of volcanic eruptions

TANG Wai-ho, CHAN Ying-wa  
Hong Kong Observatory

The 13th Asia-Oceania Meteorological Satellite Users' Conference  
7 November 2023



# Background

Volcanic ash (VA) may pose dangers to aviation activity, monitoring volcano is crucial

Example of workflow once an eruption is observed:

- Step 1: VA Advisory, issued by Volcanic Ash Advisory Center (VAAC)
- Step 2: VA SIGMET, issued by Meteorological Watch Office (MWO)
- **Is it possible to have an automatic monitor or alert using satellite data?**

# Hotspot

- Determination of hotspots (DOI: [10.1080/01431161.2019.1688887](https://doi.org/10.1080/01431161.2019.1688887))

(1) Normalized Brightness Temperature Difference Index (NBTDI) to find potential hotspots

$$NBTDI = \frac{T(B07) - T(B15)}{T(B07) + T(B15)}$$

(2) Mid-infrared (MIR) criterion for final decision

Potential hotspot?

50 pixels x 50 pixels  
(100 km x 100 km)

Extract a ~~21 pixels x 21 pixels (84 km x 84 km)~~ sub-image centered on target volcano.

Define volcanic and non-volcanic regions.

Calculate the  $\Delta NBTDI_{diff}$  of each pixel.

$\Delta NBTDI_{diff}$  for volcanic > the highest value of  $\Delta NBTDI_{diff}$  ( $\Delta NBTDI_{nat}$ ) for non-volcanic?

NO → STOP

YES

Potential hot spots Detected.

Calculate the  $\Delta T_{MIRdiff}$  of potential hot-spot and non-volcanic pixels.

$\Delta T_{MIRdiff}$  for volcanic > the highest value of  $\Delta T_{MIRdiff}$  ( $\Delta T_{MIRnat}$ ) for non-volcanic?

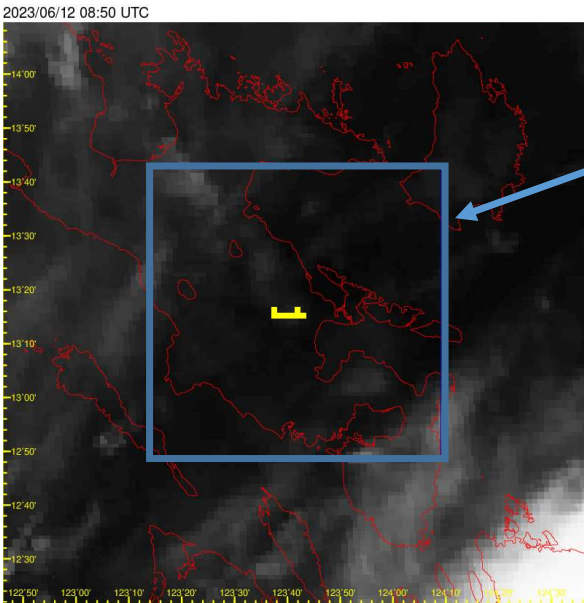
NO → STOP

YES

Hot spots Detected.

Decision

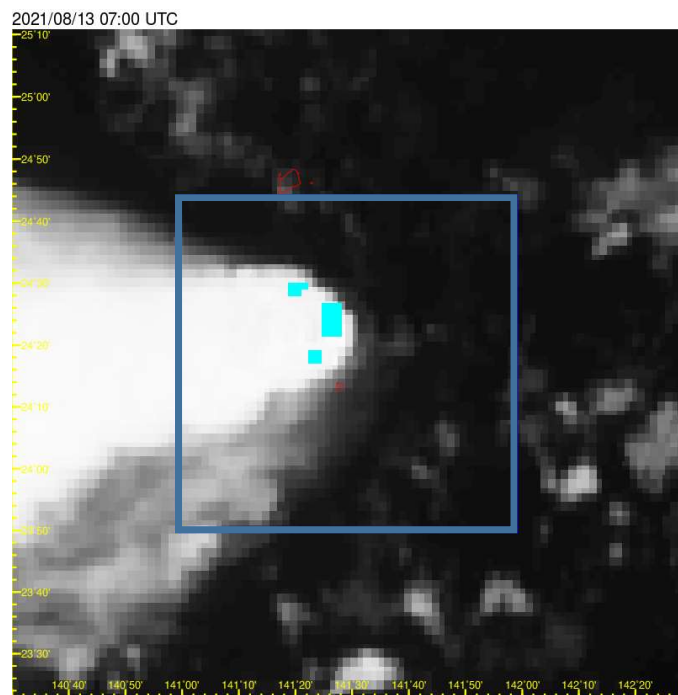
100km\*100km monitoring area centered at the volcano



Hotspot at Mayon  
0850UTC, 12 June 2023

# Ash

- Brightness temperature difference with “ $T(B13) - T(B15) < 0$ ”



Ash at Fukutoku-Okanoba  
0700UTC, 13 Aug 2021

# Alert Mechanism

- Hotspot and ash within the monitoring area could be obtained in every 10 minutes, including both day and night.
- Based on the characteristics of volcanic eruption, alert triggering conditions are set up for real-time monitoring.

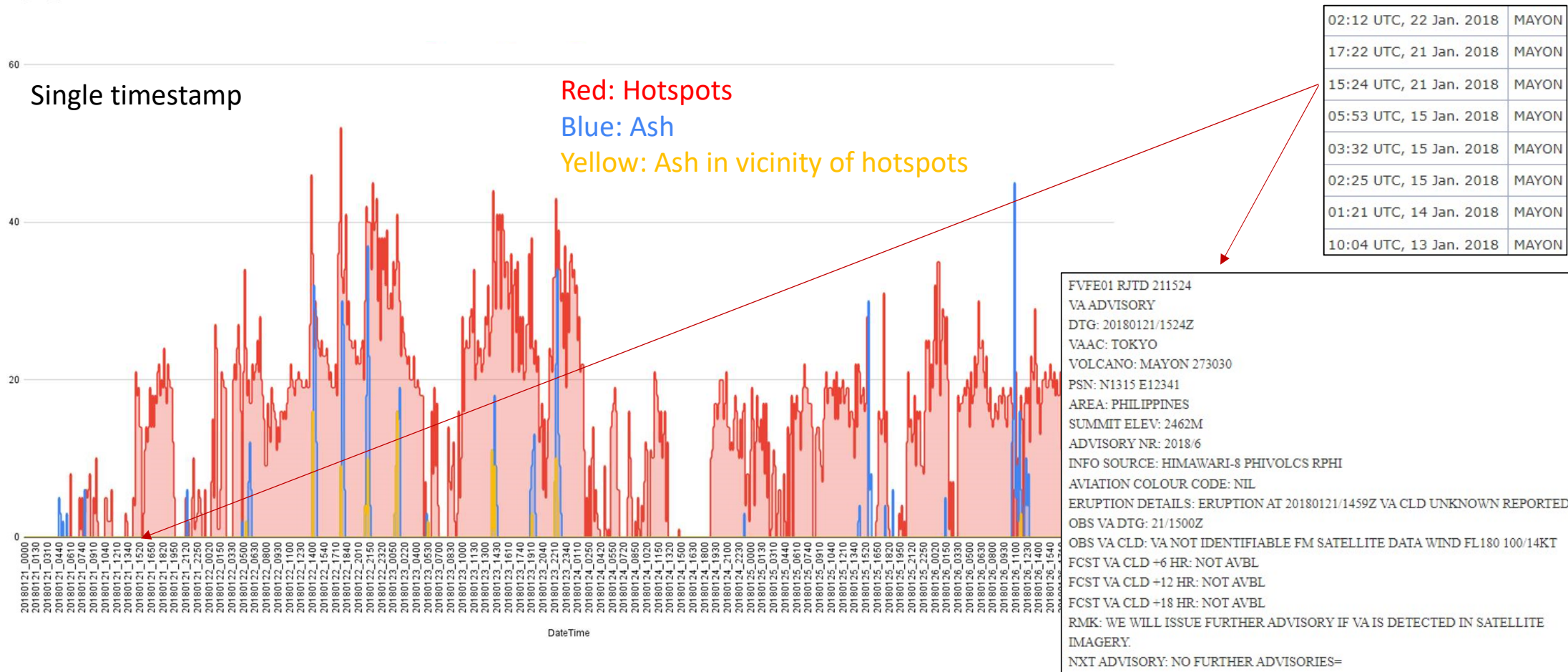
# Characteristics

Case 1: Mayon (21 Jan 2018)

(1) **Discontinuity**

(2) Number of **Hotspots** >> Number of **Ash**

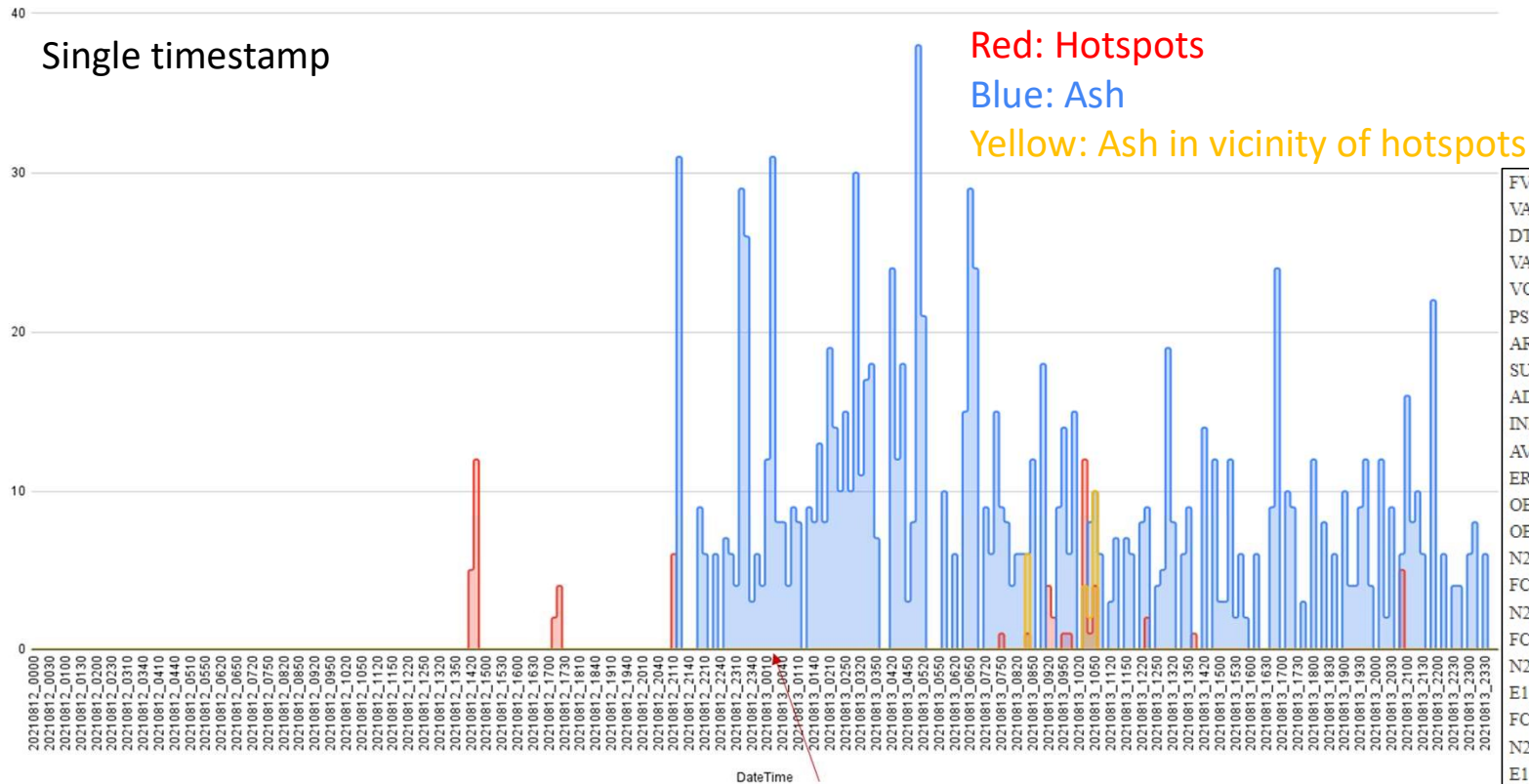
Mayon\_20180121-20180126



# Characteristics

Case 2: Fukutoku-Okanoba (13 Aug 2021)  
**(1) Discontinuity**  
**(2) Number of Hotspots << Number of Ash**

Fukutoku-Okanoba\_20210812



First VA advisory at 0027Z, 13 Aug 2021

```

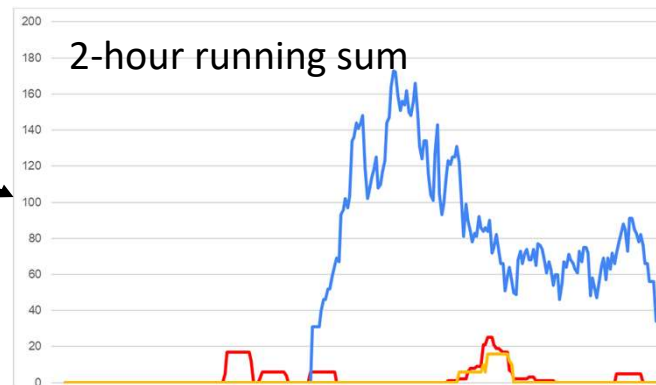
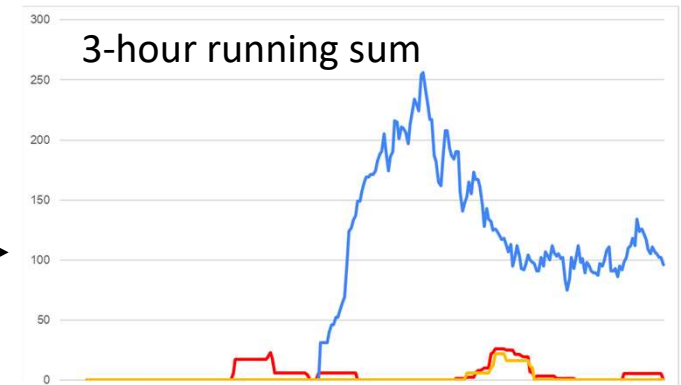
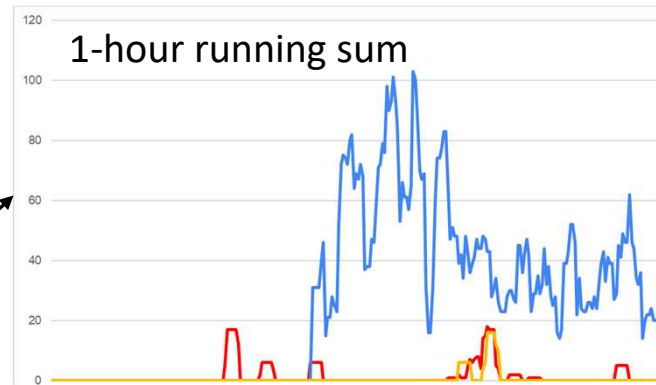
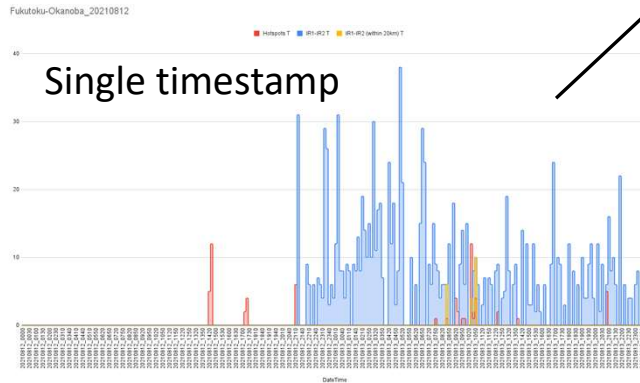
FVFE01 RJTD 130027
VA ADVISORY
DTG: 20210813/0027Z
VAAC: TOKYO
VOLCANO: FUKUTOKU-OKA-NO-BA 284130
PSN: N2417 E14129
AREA: JAPAN
SUMMIT ELEV: -29M
ADVISORY NR: 2021/1
INFO SOURCE: HIMAWARI-8
AVIATION COLOUR CODE: NIL
ERUPTION DETAILS: POSS ERUPTION OBS AT 20210812/2120Z FL540 EXTD W
OBS VA DTG: 12/2350Z
OBS VA CLD: SFC/FL540 N2434 E14137 - N2411 E14138 - N2336 E13907 -
N2426 E13847 - N2454 E13946 MOV W 50KT
FCST VA CLD +6 HR: 13/0550Z SFC/FL560 N2548 E13950 - N2506 E14047 -
N2233 E13843 - N2137 E13532 - N2318 E13404 - N2502 E13720
FCST VA CLD +12 HR: 13/1150Z SFC/FL560 N2740 E13843 - N2539 E14031 -
N2340 E13354 - N2112 E13420 - N2029 E13048 - N2137 E12915 - N2455
E13313
FCST VA CLD +18 HR: 13/1750Z SFC/FL560 N2844 E13937 - N2602 E13948 -
N2520 E13451 - N2340 E12919 - N2046 E13016 - N1908 E12640 - N1937
E12351 - N2615 E12945
RMK: NIL
NXT ADVISORY: 20210813/0300Z=
    
```

# Characteristics

Case 2: Fukutoku-Okanoba (13 Aug 2021)

(1) **Discontinuity**

(2) Number of **Hotspots**  $\ll$  Number of **Ash**



Red: Hotspots

Blue: Ash

Yellow: Ash in vicinity of hotspots

**Discontinuity** become more obvious in N-hour running sum time-series!



# Alert triggering conditions

## Characteristics of volcanic eruption

- (1) Discontinuity in hotspot or ash number before and after eruption
- (2) Large increase in number of **Hotspot** or **Ash**

## Summary of alert triggering conditions:

The following quantity has passed **###%**-tile of past data in past 24 hours:

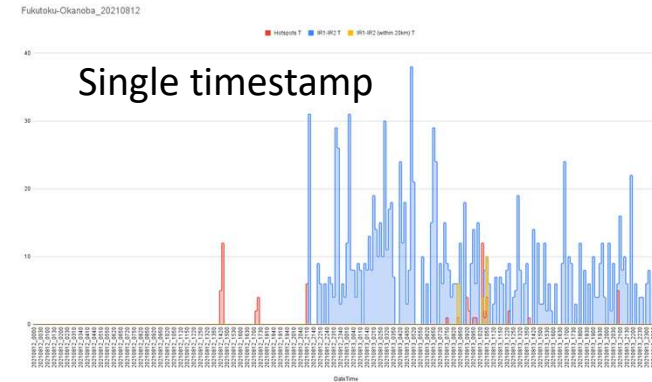
- (i) **3-hour sum** of hotspot; or
  - (ii) 3-hour sum of ash; or
  - (iii) **3-hour sum** of ash in the vicinity of hotspots.
- Avoid flip-flopping alert**

Looking for the discontinuity  
Filtering the noise out

Alert level  
99.9%: **RED** level  
99.7%: **AMBER** level

Apr to Sep in 2020-2022

Red: Hotspots  
Blue: Ash  
Yellow: Ash in vicinity of hotspots



VA Advisory at 20210813, 0027UTC  
(Eruption obs. at 20210812, 2120UTC)  
**AMBER Alert level at 20210813, 0040UTC**

# Volcano: Fukutoku-Okanoba

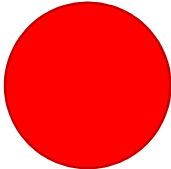
**Based on 2020-2022 (Apr to Sep) data**

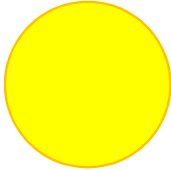
Percentile (3-hr sum)	Hotspots	Ash	Ash in vicinity of hotspots
<b>0.999</b>	<b>138</b>	<b>456</b>	<b>36</b>
<b>0.998</b>	103	186	25
<b>0.997</b>	<b>91</b>	<b>158</b>	<b>19</b>
<b>0.996</b>	78	131	16
<b>0.995</b>	70	118	13
<b>0.994</b>	63	109	11
<b>0.993</b>	60	102	10
<b>0.992</b>	54	93	10
<b>0.991</b>	49	87	9
<b>0.99</b>	46	82	8
<b>0.98</b>	30	46	5
<b>0.97</b>	21	33	0
<b>0.96</b>	17	25	0

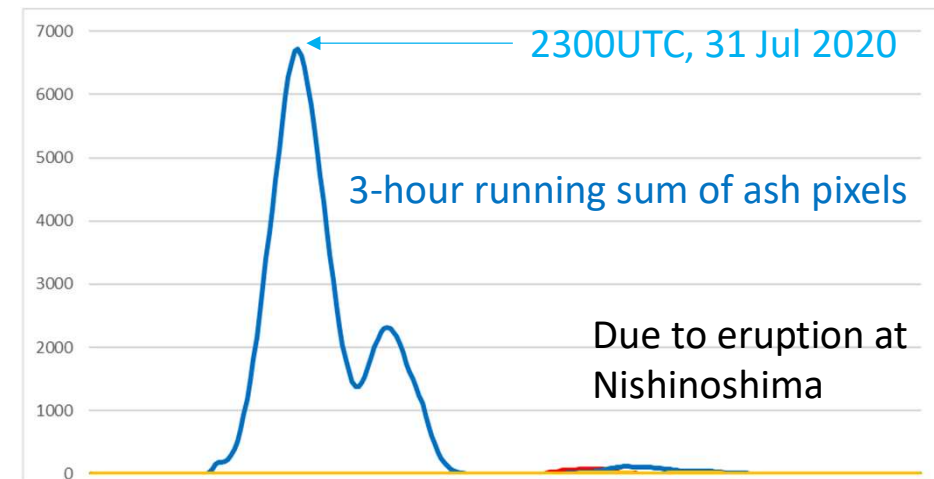
RED level

AMBER level

## Alert triggering time (UTC)

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
<b>0.999</b>	<b>138</b>	<b>456</b>	<b>36</b>
 <b>RED level</b>	20200719_1050	20200716_0040	20200719_1320
	20200915_1120	<b>20200731_1950</b>	20200901_1710
	20210620_1340		20210816_2020
	20210621_1640		20220428_1800
	20210819_1640		20220527_1000
	20210916_1030		20220725_1850
	20220719_1510		20220814_0940

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
<b>0.997</b>	<b>91</b>	<b>158</b>	<b>19</b>
 <b>AMBER level</b>	20200604_1900	20200612_1120	20200707_1320
	20200719_1040	20200704_2000	20200719_1100
	20200915_1100	20200716_0010	20200816_1320
	20210620_1230	<b>20200731_1850</b>	20200901_1700
	20210819_1630	20200804_0700	20200929_0410
	20210916_1010	20200816_1210	20210527_1650
	20220527_1000	<b>20210813_0040</b>	20210813_1050
	20220529_1940	20220603_0410	20210816_2010
	20220621_1510	20220604_2150	20210819_1630
	20220719_1450	20220725_1900	20220428_1750
	20220725_1930	20220807_2310	20220527_0940
	20220830_1500		20220725_1840
			20220814_0800
			20220901_1540



Red: Hotspots    Blue: Ash    Yellow: Ash in vicinity of hotspots

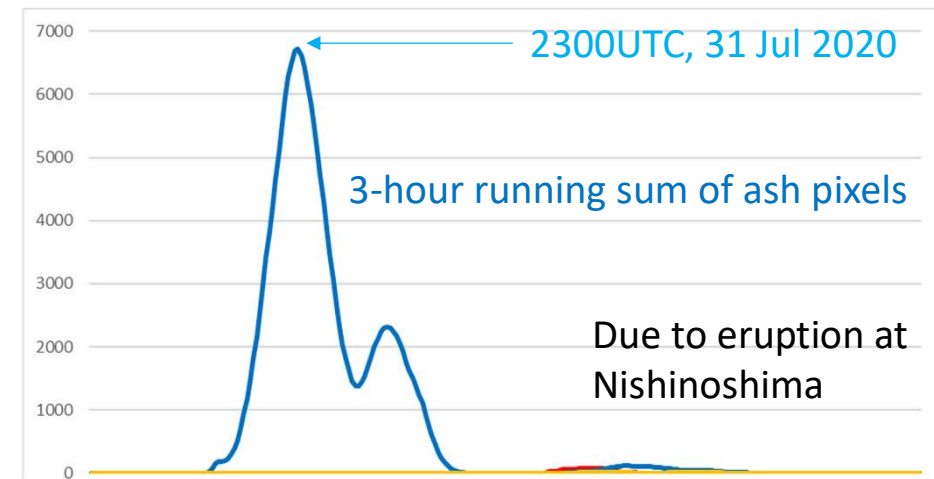
# Volcano: Fukutoku-Okanoba

## Based on 2020-2022 (Apr to Sep) data

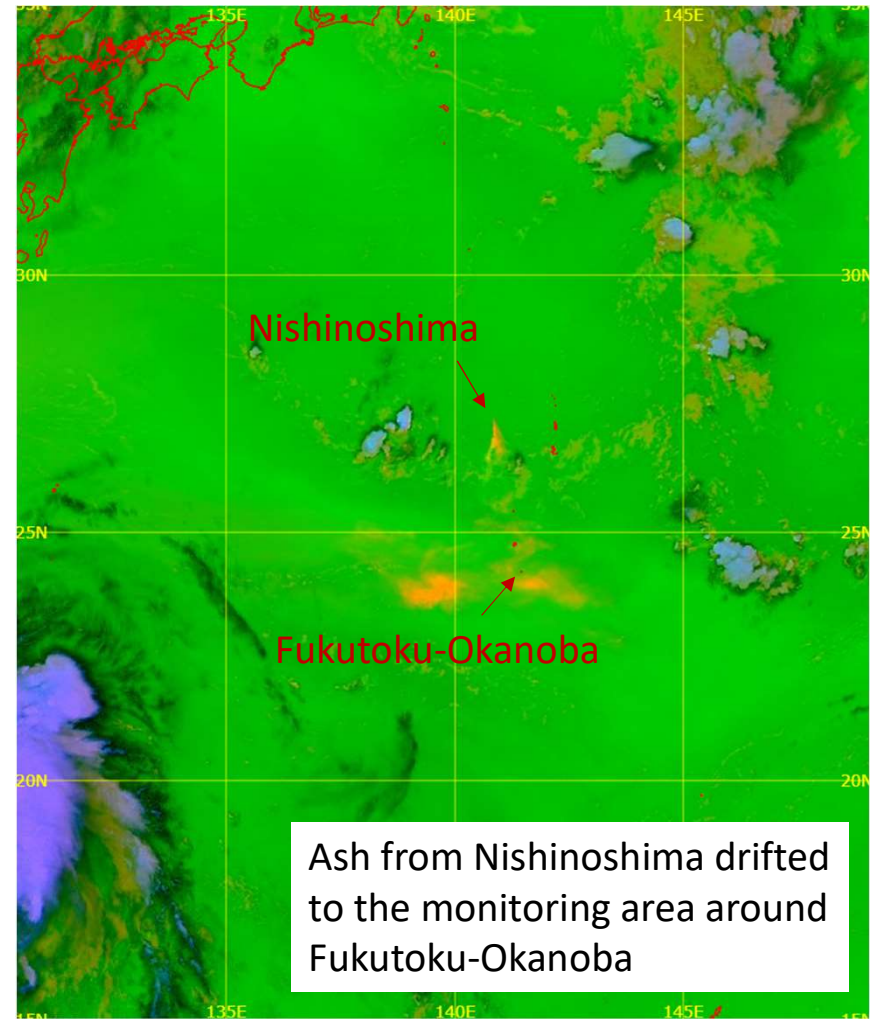
Percentile (3-hr sum)	Hotspots	Ash	Ash in vicinity of hotspots
0.999	138	456	36
0.998	103	186	25
0.997	91	158	19
0.996	78	131	16
0.995	70	118	13
0.994	63	109	11
0.993	60	102	10
0.992	54	93	10
0.991	49	87	9
0.99	46	82	8
0.98	30	46	5
0.97	21	33	0
0.96	17	25	0

RED level

AMBER level

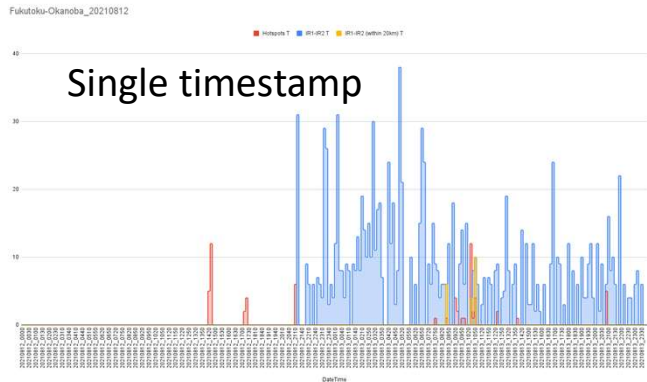


Red: Hotspots    Blue: Ash    Yellow: Ash in vicinity of hotspots



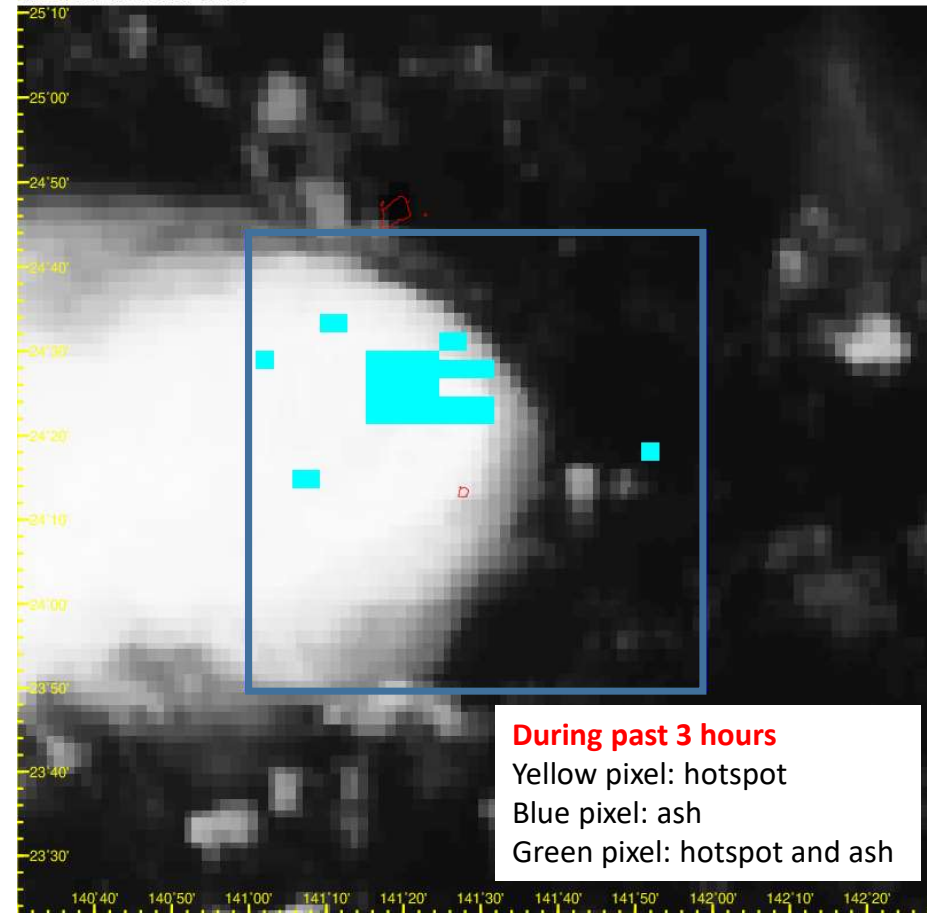
H8/9 Ash 2020/07/31 23:00 UTC

# Volcano: Fukutoku-Okanoba (13 Aug 2021)



VA Advisory at 20210813, 0027UTC  
(Eruption obs. at 20210812, 2120UTC)  
**AMBER Alert level at 20210813, 0040UTC**

2021/08/13 06:00 UTC

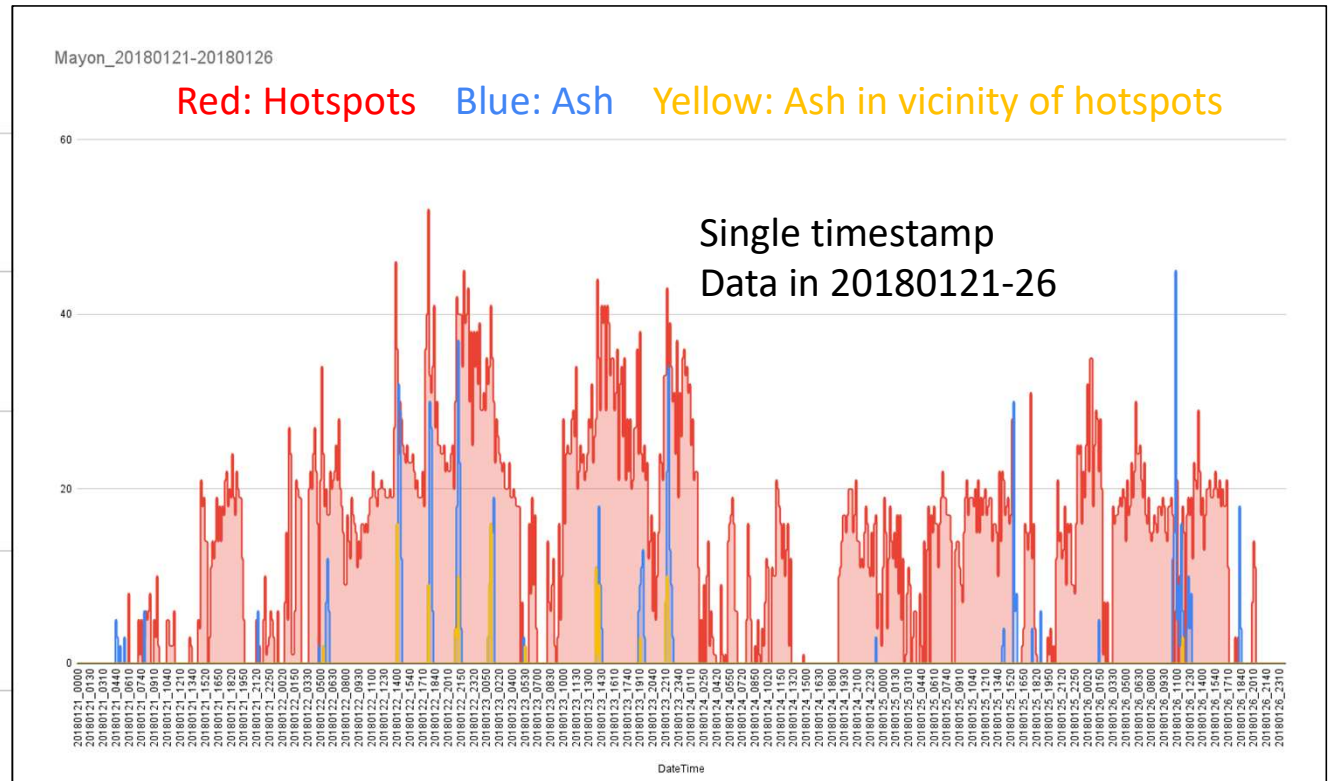
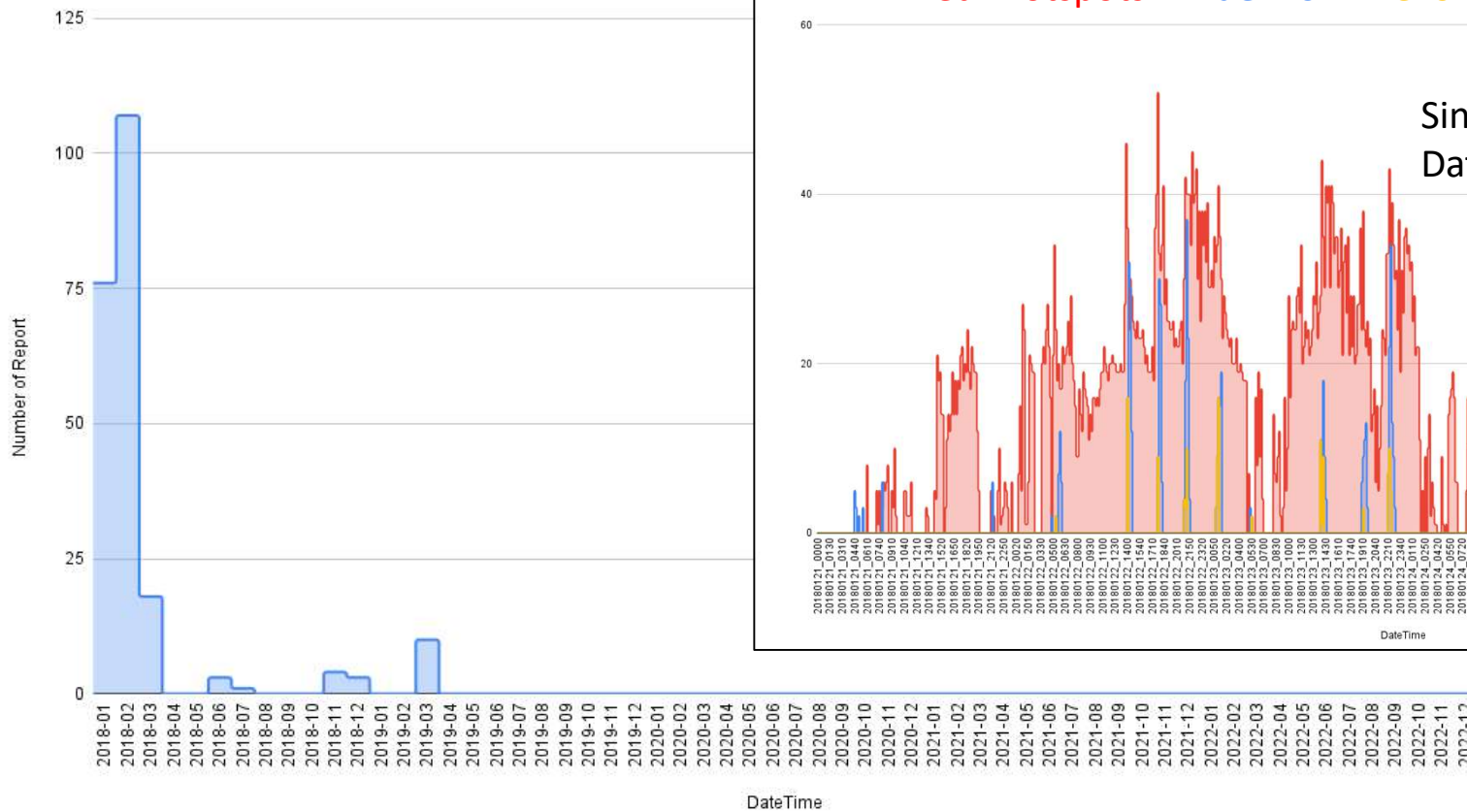


# Mayon Eruption

June 2023

# No eruption in recent years

Advisory Volcanic Ash: Mayon 2018 - 2022



Mayon (updated on 26 May 2023)

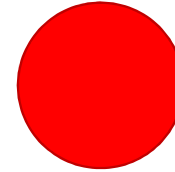
Alert triggering time (UTC)

Based on 2020-2022 (Apr to Sep) data			
Percentile (3-hr sum)	Hotspots	Ash	Ash in vicinity of hotspots
0.999	150	409	37
0.998	89	319	27
0.997	75	245	23
0.996	66	208	21
0.995	58	183	18
0.994	52	159	17
0.993	48	145	16
0.992	46	130	15
0.991	42	120	14
0.99	40	111	14
0.98	26	73	8
0.97	20	57	6
0.96	17	46	4

RED level

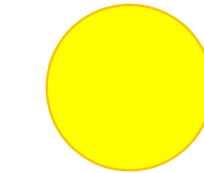
AMBER level

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.999	150	409	37
	20200714_1800	20210611_0610	20200814_1030
	20200915_1220	20210823_1200	20220404_2020
	20210708_1750	20220518_0840	20220411_2110
	20220421_1640	20220520_1120	20220520_1010
	20220822_1800	20220527_2310	20220613_1740
		20220602_0750	20220720_1520
		20220720_1810	20220930_1500



RED level

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.997	75	245	23
	20200404_1320	20200618_0840	20200814_1020
	20200714_1750	20200814_1110	20210708_1800
	20200915_1210	20210609_0620	20210827_1320
	20210525_1540	20210611_0540	20210831_2100
	20210708_1740	20210823_1150	20210902_1200
	20210716_1750	20210913_0630	20210923_1010
	20210913_2140	20220514_1050	20220404_2020
	20220411_2100	20220518_0810	20220411_2100
	20220418_1150	20220520_1040	20220421_1750
	20220421_1430	20220527_2140	20220514_1140
	20220505_1650	20220602_0650	20220519_1850
	20220608_1910	20220707_0700	20220613_1710
	20220618_1820	20220720_1600	20220619_1840
	20220822_1720		20220626_1530
	20220917_1950		20220718_1130
	20220930_1540		20220720_1520
			20220930_1450



AMBER level

Note: No VA advisory was issued during the period

# Eruption in June 2023

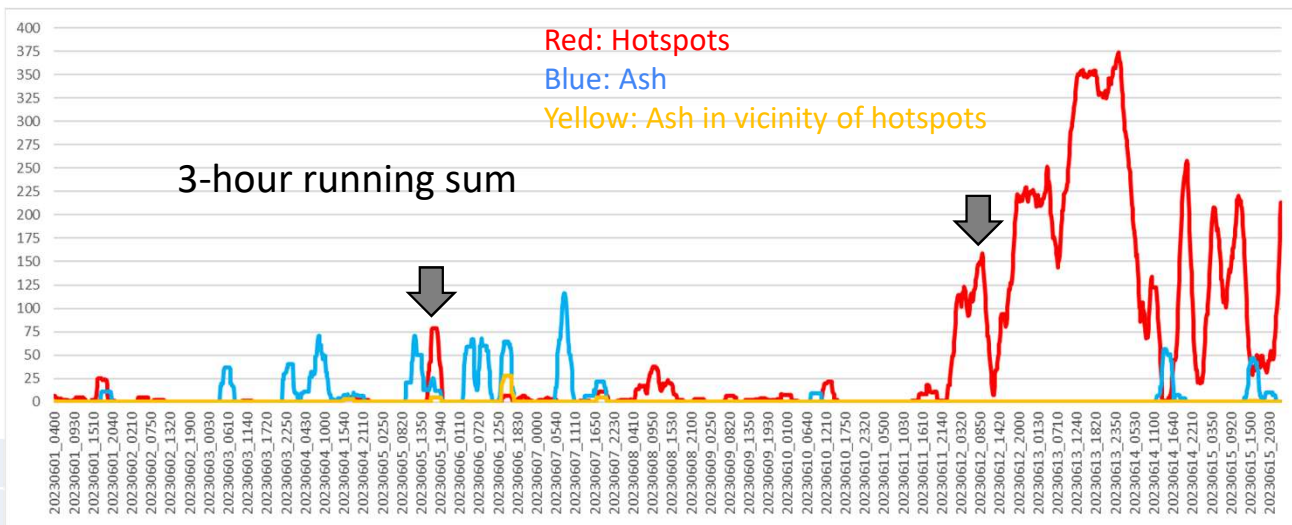
## RED level:

(1) 2023/06/12 08:50UTC – [beyond 15 Jun]

## AMBER level:

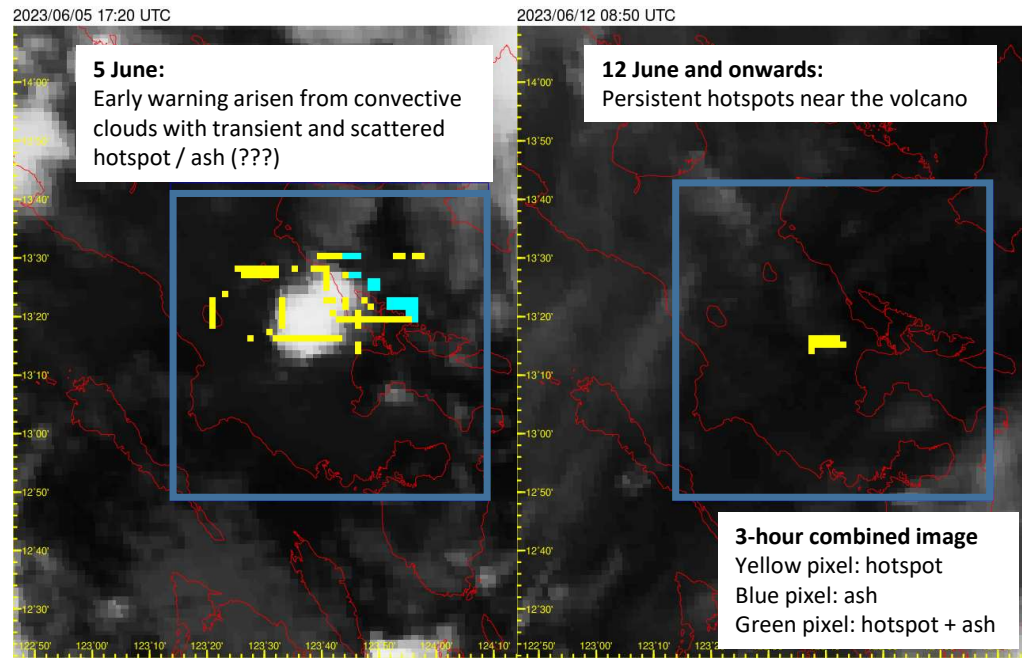
(1) 2023/06/05 17:20UTC – 2023/06/07 16:40UTC

(2) 2023/06/12 01:40UTC – [beyond 15 Jun]



VA Advisory Date Time	ERUPTION DETAILS
...	...
04:42 UTC, 13 Jun. 2023	ERUPTION AT 20230613/0420Z FL090 EXTD ENE REPORTED
01:24 UTC, 13 Jun. 2023	ERUPTION AT 20230613/0105Z FL090 EXTD ESE REPORTED
21:24 UTC, 12 Jun. 2023	ERUPTION AT 20230612/2055Z FL090 EXTD ESE REPORTED
21:06 UTC, 11 Jun. 2023	ERUPTION AT 20230611/2019Z VA CLD UNKNOWN REPORTED
19:09 UTC, 11 Jun. 2023	ERUPTION AT 20230611/1147Z VA CLD UNKNOWN REPORTED
11:39 UTC, 11 Jun. 2023	ERUPTION AT 20230611/1053Z VA CLD UNKNOWN REPORTED
04:04 UTC, 11 Jun. 2023	ERUPTION AT 20230611/0309Z VA CLD UNKNOWN REPORTED
01:28 UTC, 10 Jun. 2023	ERUPTION AT 20230610/0105Z FL100 EXTD E-SE REPORTED
07:29 UTC, 08 Jun. 2023	ERUPTION AT 20230608/0709Z FL100 EXTD E-SE REPORTED
03:31 UTC, 08 Jun. 2023	ERUPTION AT 20230608/0300Z VA CLD UNKNOWN REPORTED
<b>23:41 UTC, 07 Jun. 2023</b>	<b>ERUPTION AT 20230607/2218Z FL110 EXTD S-SE REPORTED</b>

**Alert Level 2 (Increasing Unrest)** on 5 June 2023  
**Alert Level 3 (Increased Tendency Towards Hazardous Eruption)** was raised on 12:00 noon of 8 June 2023  
 Source: <https://www.phivolcs.dost.gov.ph/index.php/volcano-advisory-menu/18239-volcanic-activity-report-mayon-volcano-albay-province-1-10-june-2023>  
 Reference: <https://www.phivolcs.dost.gov.ph/index.php/volcano-hazard/volcano-alert-level>

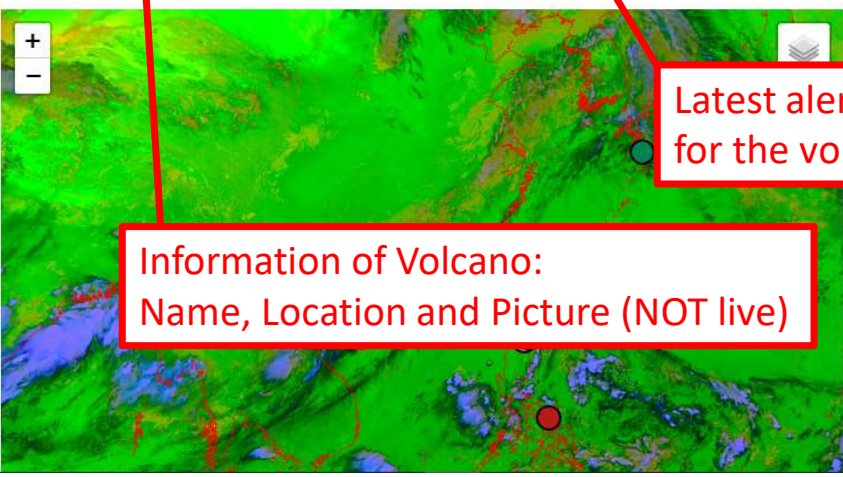




Monitoring Webpage

<p><b>Agung</b> lat/long: -8.34, 115.5 Last RED in UTC : N/A Last AMBER in UTC : N/A</p>	<p><b>Babuyan-Claro-Volcano</b> lat/long: 19.52, 121.94 Last RED in UTC : N/A Last AMBER in UTC : N/A</p>	<p><b>Camiguin-de-Babuyanes</b> lat/long: 18.83, 121.86 Last RED in UTC : N/A Last AMBER in UTC : N/A</p>	<p><b>Didicas-Volcano</b> lat/long: 19.08, 122.2 Last RED in UTC : N/A Last AMBER in UTC : N/A</p>
<p><b>Fukutoku-Okanoba</b> lat/long: 24.28, 141.49 Last RED in UTC : 2023/06/19 15:10 - 2023/06/20 18:00 Last AMBER in UTC : 2023/06/23 20:50 - 2023/06/24 23:20</p>	<p><b>Alert summary for the volcanoes under monitoring</b></p>		<p><b>Ibugos</b> lat/long: 20.33, 121.75 Last RED in UTC : N/A Last AMBER in UTC : N/A</p>
<p><b>Mayon</b> lat/long: 13.26, 123.69 Last RED in UTC : 2023/06/24 11:30 - [IN FORCE] Last AMBER in UTC : 2023/06/12 01:40 - [IN FORCE]</p>	<p><b>Sakurajima</b> lat/long: 31.58, 130.66 Last RED in UTC : N/A Last AMBER in UTC : N/A</p>	<p><b>Semeru</b> lat/long: 8.11, 112.92 Last RED in UTC : 2023/06/21 09:40 - [IN FORCE] Last AMBER in UTC : 2023/06/09 11:20 - [IN FORCE]</p>	<p><b>Tatun-Volcano-Group</b> lat/long: 25.17, 121.56 Last RED in UTC : N/A Last AMBER in UTC : N/A</p>

A4 GIS Danrin VAAC Tokyo VAAC



















Information of Volcano:  
Name, Location and Picture (NOT live)

Latest alert level  
for the volcano

Alert Status	Description
	The following quantity has passed <b>99.9%</b> -tile of past data in past 24 hours: (3) 3-hour sum of ash pixels in the vicinity of hotspots. Alarm will be triggered.
	The following quantity has passed <b>99.7%</b> -tile of past data in past 24 hours: (1) 3-hour sum of hotspot pixels, OR; (2) 3-hour sum of ash pixels, OR; (3) 3-hour sum of ash pixels in the vicinity of hotspots.
	AMBER or RED alert is not triggered for the volcano under monitoring.

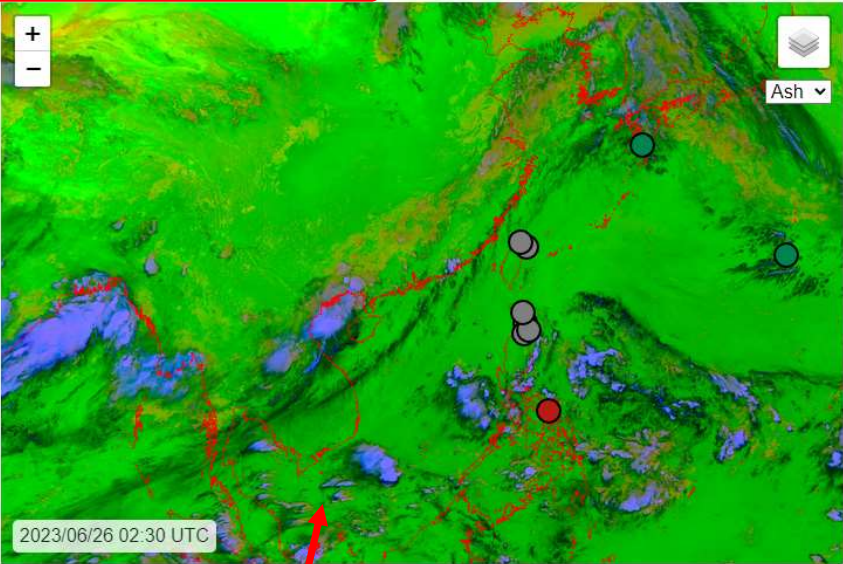
Period of the current or previous episode

 <p><b>Fukutoku-Okanoba</b> lat/long: 24.28, 141.49 Last RED in UTC : 2023/06/19 15:10 - 2023/06/19 15:10 Last AMBER in UTC : 2023/06/23 20:50 - 2023/06/23 20:50</p>		 <p><b>Guishan-Island-(Yilan)</b> lat/long: 24.84, 121.95 Last RED in UTC :</p>		 <p><b>Ibugos</b> lat/long: 20.33, 121.75 Last RED in UTC : N/A Last AMBER in UTC : N/A</p>		 <p><b>Krakatoa</b> lat/long: -6.1, 105.42 Last RED in UTC : 2023/06/24 15:10 - 2023/06/25 18:00 Last AMBER in UTC : 2023/06/24 15:10 - 2023/06/25 18:00</p>	
 <p><b>Mayon</b> lat/long: 13.26, 123.69 Last RED in UTC : 2023/06/24 11:30 - [IN FORCE] Last AMBER in UTC : 2023/06/12 01:40 - [IN FORCE]</p>		 <p><b>Sakurajima</b> lat/long: 31.58, 130.66 Last RED in UTC : N/A Last AMBER in UTC : N/A</p>		 <p><b>Semeru</b> lat/long: -8.11, 112.92 Last RED in UTC : 2023/06/21 09:40 - [IN FORCE] Last AMBER in UTC : 2023/06/09 11:20 - [IN FORCE]</p>		 <p><b>Tatun-Volcano-Group</b> lat/long: 25.17, 121.56 Last RED in UTC : N/A Last AMBER in UTC :</p>	



Useful links, including regional VAAC for latest VA advisories

Rule of alert mechanism

A4 GIS Darwin VAAC Tokyo VAAC



GIS displaying the latest satellite products (Ash, Dust, SO2, IR1 and False Color) with overlay of alert status.

Alert Status	Description
	The following quantity has passed <b>99.9%</b> -tile of past data in past 24 hours: (1) 3-hour sum of hotspot pixels, OR; (2) 3-hour sum of ash pixels, OR; (3) 3-hour sum of ash pixels in the vicinity of hotspots.  Alarm will be triggered.
	The following quantity has passed <b>99.7%</b> -tile of past data in past 24 hours: (1) 3-hour sum of hotspot pixels, OR; (2) 3-hour sum of ash pixels, OR; (3) 3-hour sum of ash pixels in the vicinity of hotspots.
	AMBER or RED alert is not triggered for the volcano under monitoring.
	The volcano is <b>NOT</b> under monitoring.

— Remarks  
 [1] Past data: April to September between 2020 and 2022.  
 [2] Monitoring area: 100km\*100km (i.e. 50pixels\*50pixels) area centered at the volcano.  
 [3] Ash pixel: pixel with IR1 - IR2 < 0.  
 [4] Vicinity: 20km\*20km (i.e. 10pixels\*10pixels) searching area.

# Conclusion

- Characteristic of volcanic eruption is presented, in terms of hotspots and ash
- Design of alert mechanism is explained:
  - 3-hour running sum of hotspot or ash
  - 99.7%-tile (Amber level) or 99.9%-tile (Red level)
  - False alarm are unavoidable in this method (based on percentile in statistics)
- Warning with lead time is demonstrated based on the event of Mayon eruption (June 2023)

## Future directions:

- Altitude or concentration of volcanic ash?
- Making use of GK2B GEMS products?

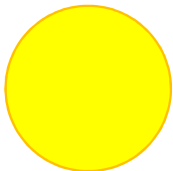
# Thanks!

Appendices:

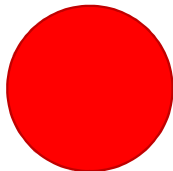
Current threshold values

Characteristics of Krakatoa (20181222)

Based on data in Apr to Sep in 2020-2022



AMBER level



RED level

Fukutoku-Okanoba

Percentile (3-hr sum)	Hotspots	Ash	Ash in vicinity of hotspots
0.997	91	158	19

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.999	138	456	36

Mayon

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.997	75	245	23

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.999	150	409	37

Krakatau

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.997	156	364	36

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.999	245	715	53

Semeru

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.997	147	695	30

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.999	170	969	44

Sakurajima

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.997	102	2715	15

Percentile	Hotspots	Ash	Ash in vicinity of hotspots
0.999	120	5752	49

Krakatoa\_20181222

Red: Hotspots    Blue: Ash    Yellow: Ash in vicinity of hotspots

