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FULLY AUTOMATED VOLCANO MONITORING AND TASKING WITH PLANET SKYSAT CONSTELLATION: RESULTS FROM A YEAR OF OPERATIONS

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ABSTRACT

We collect alerts of volcanic activity from space remote sensing, volcano observatories, and meteorological organizations [1, 2]. We use these alerts to autonomously generate $<$1 m/pixel observation requests for Planet SkySat [3] and 70m/pixel thermal infrared data from the ECOSTRESS instrument on the ISS. We also automatically download Dove imagery corresponding to alerts to supplement the SkySat and ECOSTRESS imagery. One new feature is that we can then automatically generate thermal products from the Planet image data using newly-developed band-comparison classifiers.

This system has been running continuously for nearly 1.5 years without a dedicated operations team. It has generated over 650,000 alerts, tasked over 80 SkySat observations, and resulted in more than 6,000 scenes scheduled for ECOSTRESS.

Index Terms— Sensorwebs, volcano monitoring, automated tasking

1. VOLCANO SENSORWEB 2.0 – 1.5 YEARS OF OPERATIONS

The new Volcano SensorWeb (VSW 2.0) has been operating and tasking since 5th January 2022, at an hourly cadence. From 2020-2022 it performed alert generation. As of 15th May 2023, it has executed 11,813 runs, generating 657,147 alerts for 478 volcanoes. Some volcanoes generate more alerts: 27 volcanoes acount for over 90% of alerts. Figure 3 presents the number of alerts generated by each source. We generate the most alerts from the VIIRS Active Fire product distributed by FIRMS [4] and the Volcanological Survey of Indonesia (PVMBG) [5]. The location of the volcanos causing alerts can be seen in figure 2, volcanoes in Iceland and Indonesia triggered the most alerts.

The number of alerts generated by PVMBG is higher than one might expect based on recent eruptions. PVMBG frequently has many volcanoes in a low-level alert category. Additionally, it counts as a new alert every time we pull data from a source. This inflates the number of alerts from PVMBG and other sources that we scrape volcano status from, compared to event-based sources such as the VAACs.

The number of alerts generated from MODVOLC is much lower than expected. This is likely due to web page format update not yet accounted for in our web scraper.

Overall, the new VSW generates many more alerts than the previous one, at least in part due to a less restrictive definition of an alert. VSW 1.0 generated less than 200,000 alerts from 2004-2017 [2] from all sources. In comparison, VSW 2.0 has generated more alerts in 16 months just from the VIIRS Active Fire product (253,555) and a total of 657,142 from all sources. In the same period of time, we extrapolate that VSW 1.0 would have generated approximately 20,000 alerts. This means that VSW 2.0 is generating 30 times the alerts as the original. This does not mean that we are generating better data than VSW 1.0, as some of these alerts are likely lower quality. However, we can still make good observation requests through the use of the priority metric.

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As of 4th January 2023, The VSW has requested 82 SkySat observations with approximately 72 orders resulting in at least one captured scene. 54 of these orders resulted as "expired", meaning the capture did not meet Planet's quality requirements. This is typically due to clouds obscuring the target, though sometimes Planet classifies volcanic plumes as clouds.

Here we describe one example order. On 4th August 2022, the VSW created an alert for Reykjanes based off data from the Icelandic Meteorological office (IMO). VSW autonomously issued a tasking request to Planet Labs on August 4th. Over the next week and a half, Planet made 8 observations of the area until it satisfied its quality requirements on August 15th. Figure 1 shows part of the observation.

VSW alerts have been used to generate low-priority requests for ECOSTRESS since 13th January, 2022 [6]. As of 26th October, 2022, these alerts resulted in approximately 2423 requests to the ECOSTRESS scheduler with 6665 volcanic scenes scheduled.

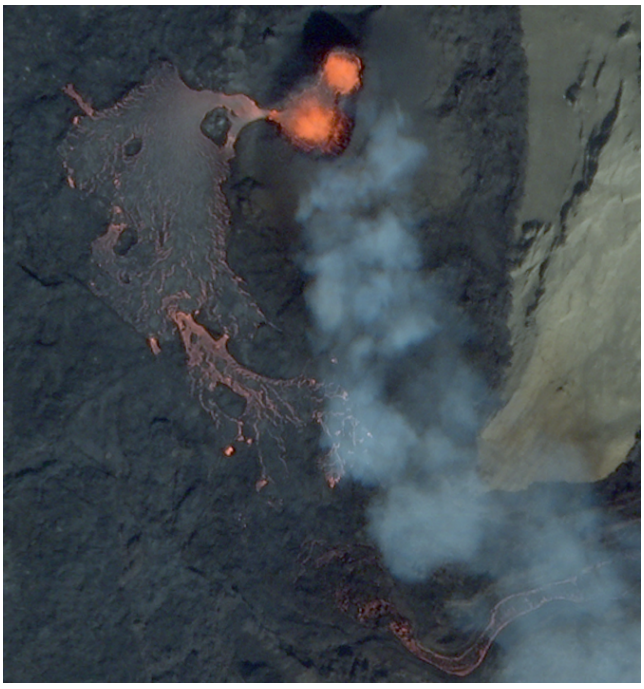


Fig. 1. Planet SkySat observation of Fagradalsfjall tasked by the VSW. Acquired on 15 August 2022. This portion of the image covers ∼340m by 360m, with ∼0.5m/pixel resolution. Image courtesy of Planet Labs.

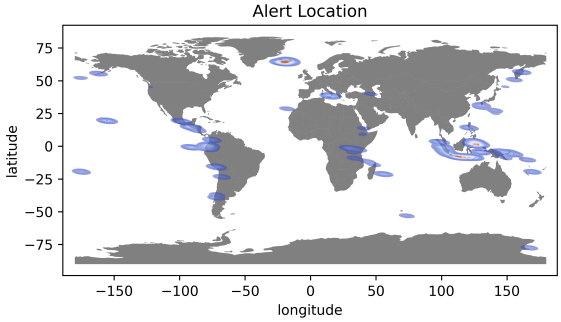


Fig. 2. Location of alerts shown with a kernel density estimate plot. Warmer colors mean more alerts. Data from Jan 5 2022 to May 15 2023.

2. THERMAL CLASSIFIERS FOR PLANET DOVE & SKYSAT

We created hand-derived thermal classifiers for Dove Classic, SuperDove, and SkySat imagery to detect pixels with anomalous thermal emission. The algorithms were tested on a sample of images of volcanoes. The image set consisted of 25 SuperDove (plus 2 expert labeled), 15 Dove Classic (plus 1 expert labeled), and 15 SkySat (plus 1 expert labeled).

Pixels were classified into four categories: Saturated, Extreme, Hot, and nonthermal. Saturation is almost always caused by a thermal source. Extreme pixels are defined as pixels which are, with a very high degree of certainty($> 99\%$), active, hot lava. Hot pixels are qualified as flags which are most likely to be active, hot lava. It is much more likely to see false positives within the Hot pixel set, due to the less strict classifier for Hot pixels.

We are interested in Planet's SuperDove and SkySat constellations. Each SuperDove is a 5.8 kg, 3U cubesat that carries an 8-band instrument with 3m/pixel resolution. Each SkySat is an 110 kg, 60 cm x 60 cm x 90cm smallsat that carries a 4-band instrument with 0.5m/pixel resolution.

The hand-derived classifiers are decision trees created by examining spectral shape, which is affected by temperature distribution within a pixel. The classifiers

Source	Count
VIIRS Active Fire [4]	253,555
Volcanological Survey of Indonesia (PVMBG)	215,344
Iceland Met Office	100,642
Instituto Geofísico, Ecuador (IGEPN)	50,229
VAAC Washington	16,667
VAAC Buenos Aires	11,123
USGS Earthquake	3602
National Geology and Mining Service, Chile (SERNAGEOMIN)	3183
VAAC Tokyo	1654
MODVOLC [7]	891
VAAC Montreal	252
Total	657,142

Fig. 3. Number of Alerts by data source. Data from Jan 5 2022 to May 15 2023.

for Dove Classic and SkySat used all four spectral bands in the wavelength range 0.4 to 0.9 microns. The classifier for SuperDove used all bands except bands 1 and 2 (coastal blue and blue). A particular focus was to avoid the "red edge", a spectral effect that can generate false positives from vegetation, coastlines, red roofs, et al. that are similar in reddish color to fresh lava. The hand-derived classifiers had accuracies greater than 99% at classifying pixels as hot or extreme when compared to the expert set. The small expert set is a limitation – further testing could improve the certainty of the results.

The hand-derived SkySat classifier is as follows. Note that $b1$ is Blue (450 – 515nm), $b2$ is Green (515 – 595nm), $b3$ is Red (605 – 695nm), and $b4$ is NIR (740 – 900nm).

$$\begin{cases} \text{saturated} & b4 = 1, b4 < b3 > b2 > b1 \\ \text{extreme} & b4 > b3 > b2 < b1, \frac{b4}{b3} > 5, b4 > 10,000 \\ \text{hot} & b4 > b3 > b2 < b1, \frac{b4}{b3} > 3, b4 > 8,000 \\ \text{non-thermal} & \text{otherwise} \end{cases}$$

The hand-derived SuperDove classifier is as follows. Note that $b1$ is Coastal Blue (431 - 452 nm), $b1$ is Blue (465 - 515 nm), $b1$ is Green I (513 - 549 nm), $b1$ is Green (547 - 583 nm), $b1$ is Yellow (600 - 620 nm), $b1$ is Red (650 - 680 nm), $b1$ is Red Edge (697 - 713 nm), and $b1$ is NIR (845 - 885 nm).

$$\begin{cases} \text{saturated} & b8 = 1, b8 < b7 > b6 > b5 > b4, b7 > 3000 \\ \text{extreme} & b8 > b7 > b6 < b5, \frac{b8}{b3} > 8, b8 > 10000 \\ \text{hot} & b8 > b7 > b6 > b5, \frac{b8}{b3} > 5, b8 > 8000 \\ \text{non-thermal} & \text{otherwise} \end{cases}$$

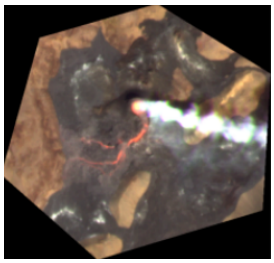
Figure 4 shows the results of the hand-derived Planet SuperDove classifier on an example from the 2021 Fagradalsfjall Eruption.

We also generated random forest classifiers from the expert set. These performed similarly to the hand-derived classifiers, but performed worse at discriminating red edge pixels. The ML classifier results could potentially be improved with further work.

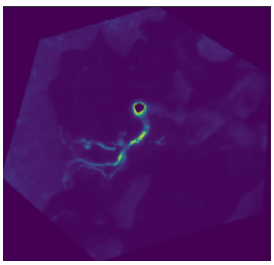
3. RELATED WORK

The VSW represents the state of the art in terms of autonomous acquisition and processing of data. While other applications address parts of the request-observe-process-request cycle - notably MODVOLC [7] for processing and posting MODIS data analysis; and the ASTER Urgent Request Protocol [8] for automatic observation request - no other application (e.g. MOUNTS [9]) has automated the entire process cycle, including identification of thermal anomalies and assessment of thermal emission to the level the VSW has.

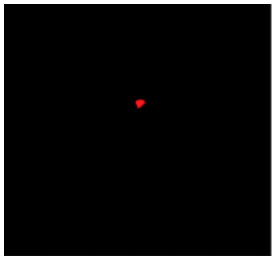
Using data from several sources to autonomously task additional observations is the cornerstone of the



(a) RGB Composite



(b) Band 8 (NIR, 865nm) with cloud mask applied



(c) Extreme Oversaturated Values

(d) Hot and Extreme Pixels

Fig. 4. Example product from a hand-created thermal classifier for Planet SuperDove (8-bands). Data from Planet SuperDove, Fagradalsfjall Eruption, 26th June 2021.

sensorweb concept. The Thailand Flood Sensorweb, operating from 2010 to 2012, automatically tasked the Earth Observing-1 (EO-1) satellite by automatically detecting flooding in MODIS imagery [10]. The previous iteration of the Volcano SensorWeb, operating from 2004 to 2017, led to 9050 observations from EO-1 [2].

4. CONCLUSION

We have demonstrated the ability to autonomously observe and analyze volcanic activity. The next-generation Volcano Sensorweb has completed a year of operations. There are many avenues for future work including increasing our partnerships with volcanologists, improving or creating additional thermal classifiers, and improving the priority scoring system.

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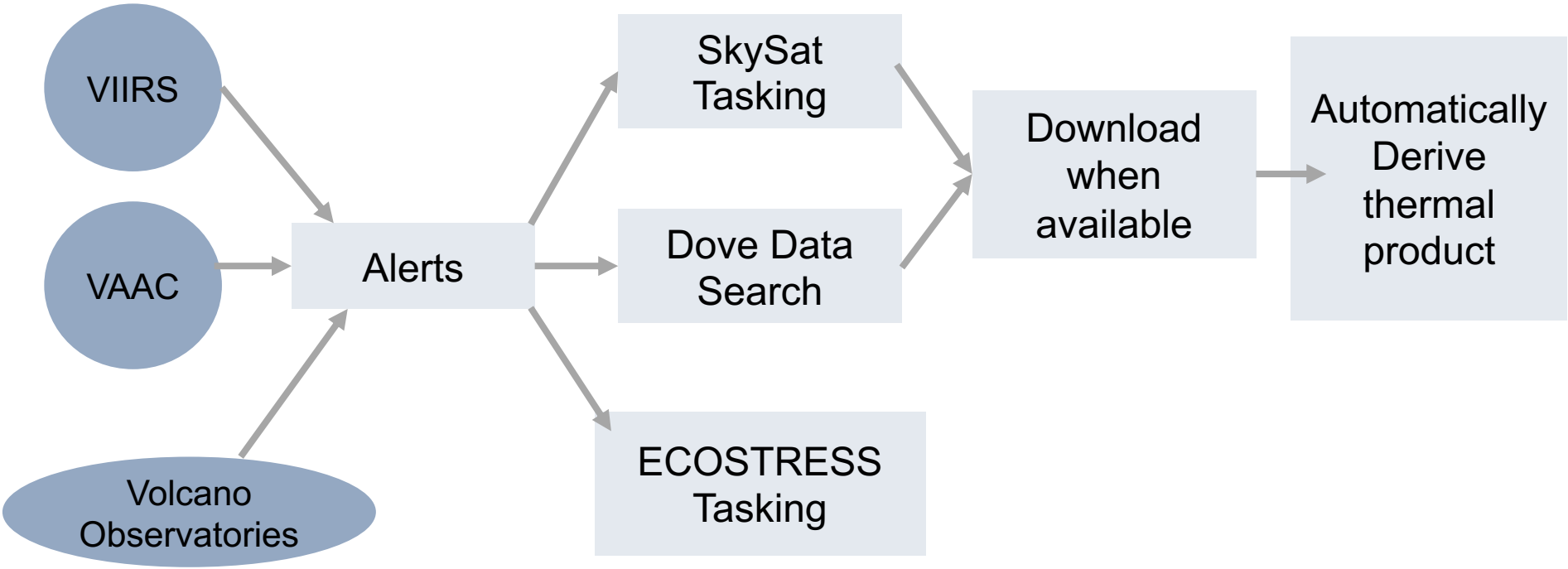
Sensorweb Background

- Aggregate data from satellite and in-situ sensors to detect and track phenomena
- Task observations for detected events
- The Volcano Sensorweb (VSW 1.0) operated from 2004 to 2017, led to 9050 observations from EO-1 (~700 observations/year)

- VSW 2.0 extends to commercial constellations
- VSW 2.0 expands the alert generation
- Created thermal classifiers for Planet data

VSW 2.0: Overview Diagram



Number of Alerts by Source

Jan 5, 2022 – May 15, 2023

Source	Count
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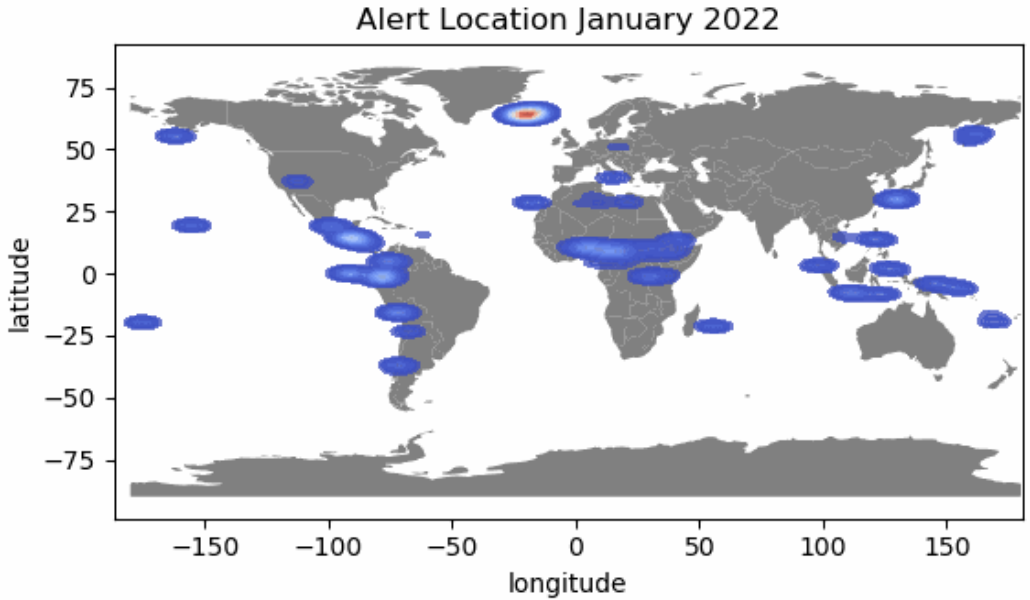
Iceland Met Office	100,642
Instituto Geofísico, Ecuador (IGEPN)	50,229
VAAC Washington	16,667
VAAC Buenos Aires	11,123

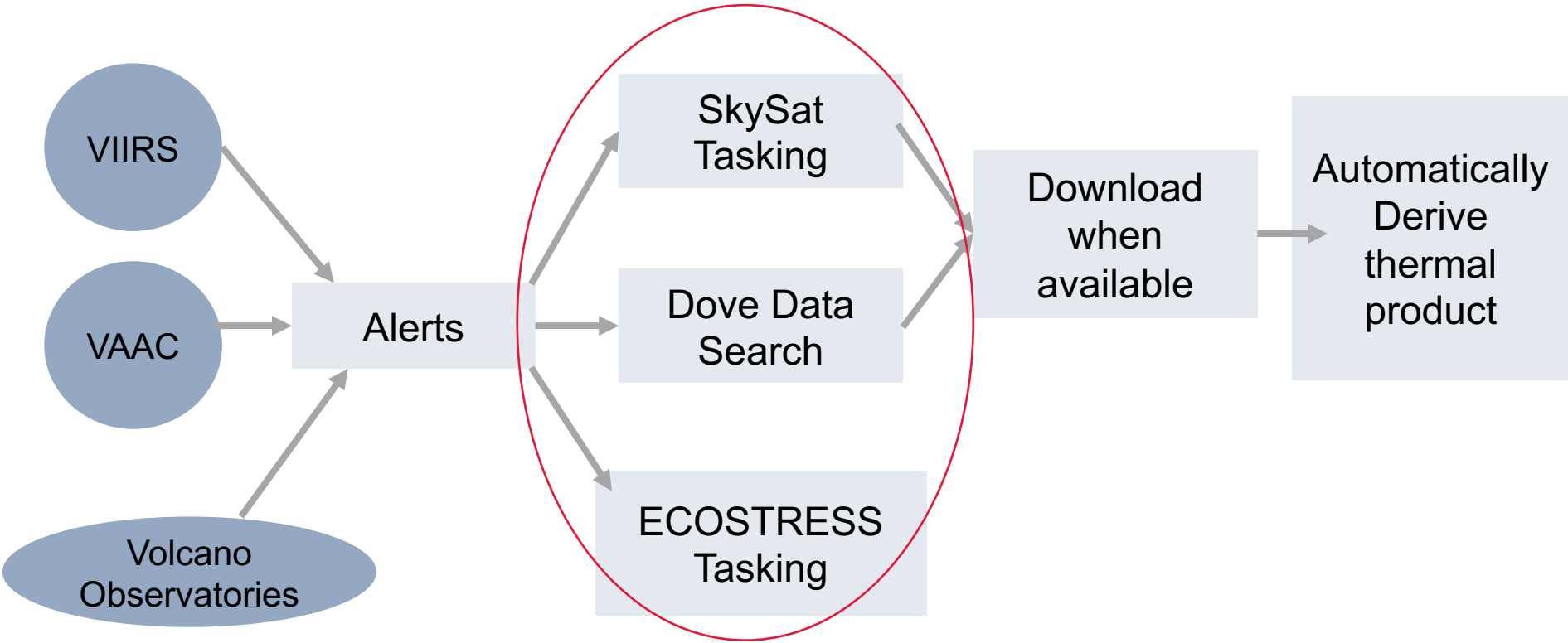
Source	Count
USGS Earthquake	3602
National Geology and Mining Service, Chile (SERNAGEOMIN)	3183
VAAC Tokyo	1654
MODVOLC	891
VAAC Montreal	252
Total	657,142

* - PVMBG creates many alerts because they classify many volcanoes in a low-level alert category, and we create a new alert every time we pull data from a source. This makes sources that report a color status give a higher alert count compared to most event-based sources

Medium+High Priority Alert Location over time



VSW 2.0: Tasking stage



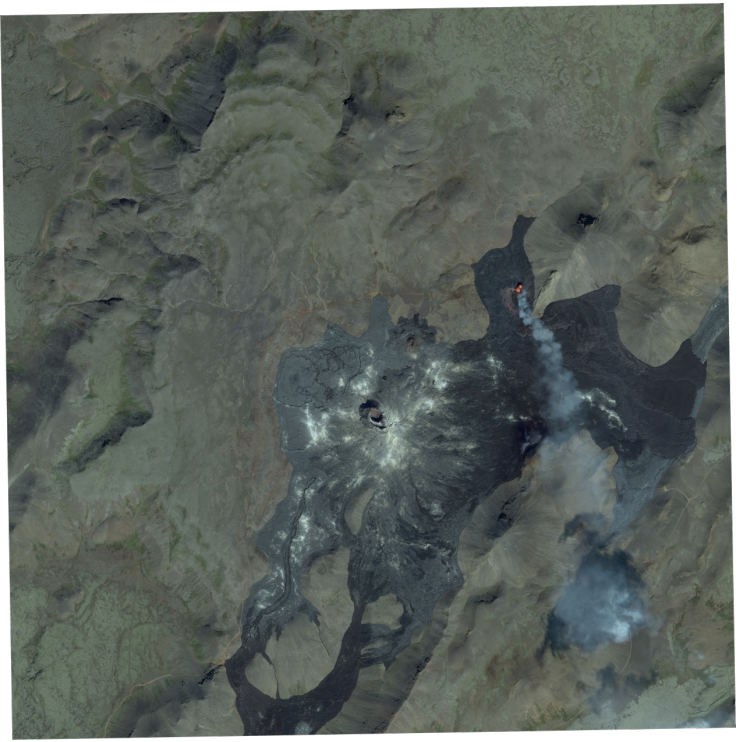
Planet constellation info

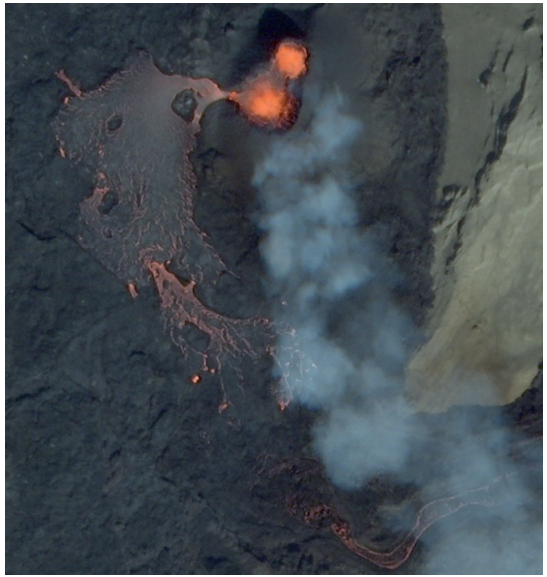
- SkySat
  - 21 targetable satellites
  - 4 band instrument (0.45-0.9 microns)
  - 0.5m/pixel resolution
  - SkySat data available to VSW 2.0 as part of a JPL-Planet collaboration
- SuperDove
  - 200+ satellites. Covers the earth’s surface daily
  - 8 band instrument (0.43-0.9 microns)
  - 3m/pixel resolution
  - Data is free to NASA projects after 30 days through CSDA

Tasking

- SkySat:
  - Task the highest priority observation approximately once per week
  - 92 requests between Jan 2022 and June 2023
  - 82 of these requests resulted in at least one captured scene
- ECOSTRESS
  - Add alerts as low-priority requests when scheduling
  - Scheduled 6665 volcanic scenes from Jan-Oct 2022
  - Due to the nature of ECOSTRESS operations, it is unclear how many captures and downlinks occurred
- Dove:
  - Search for coincidental observations after 30 days
  - VSW has found >600,000 coincidental Dove scenes

SkySat – Fagradalsfjall – 15 August 2022



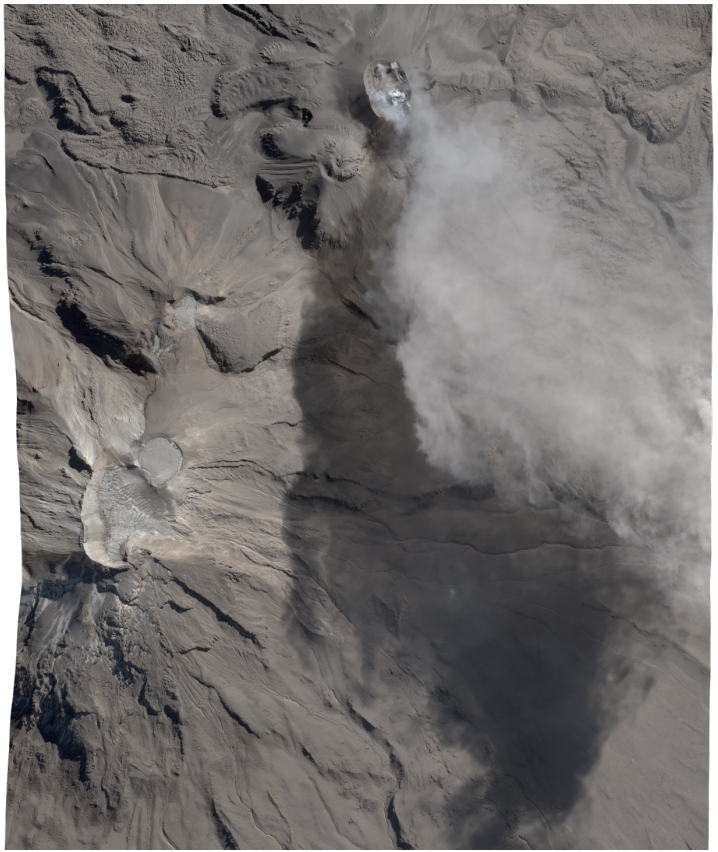


Alert created for Reykjanes on 4th August 2022 from IMO.

SkySat Tasking request to Planet on August 4th.

Planet executed 8 SkySat observations over the next week and a half before meeting quality requirements (clouds)

SkySat – Sabancaya – 11 June 2023

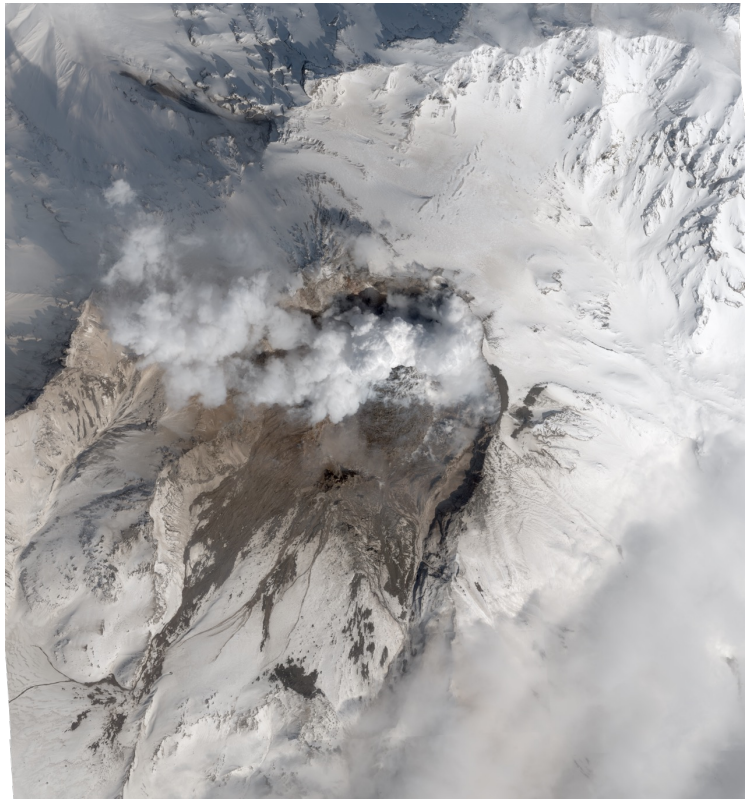


Alert created for Sabancaya on 10th August 2023 from VAAC Buenos Aires.

SkySat Tasking request to Planet on June 10.

SkySat observed on June 11

SkySat – Sheveluch – 27 April 2023



Alert created for Sheveluch on April 20, 2023.

SkySat Tasking request to Planet on April 20.

SkySat made 8 observations until meeting their quality standards on April 29th.

This was one of the invalid observations.

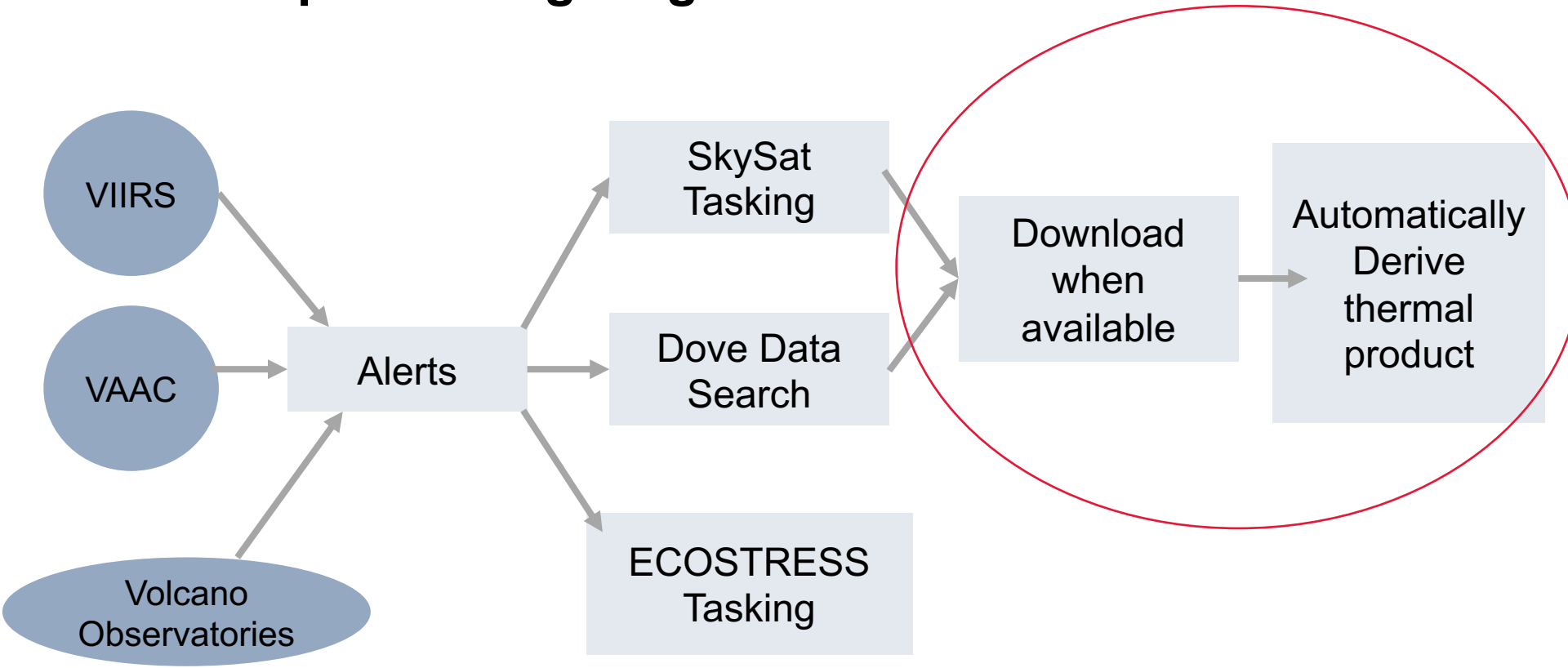
SkySat – Yasur – 20 June 2023

Alert created for Yasur on 17th June 2023 from VIIRS.

SkySat Tasking request to Planet on June 17.

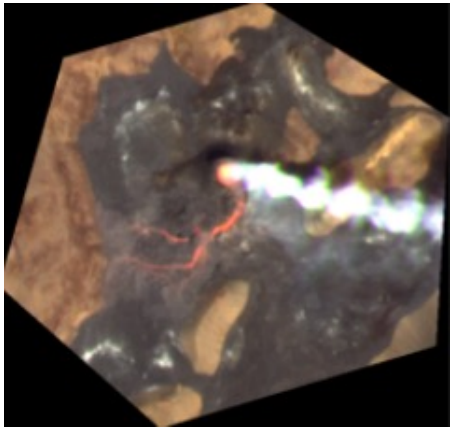
There have been 3 captures, none meeting quality standards

VSW 2.0: processing stage

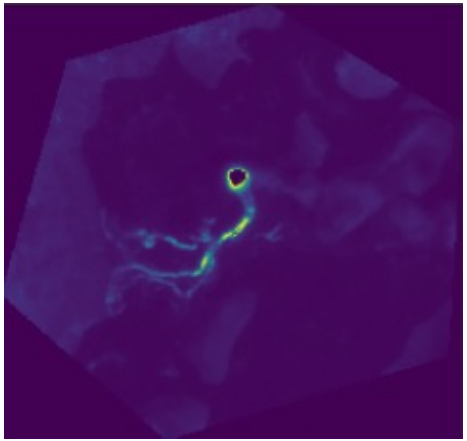


Thermal Classifiers for SkySat, SuperDove

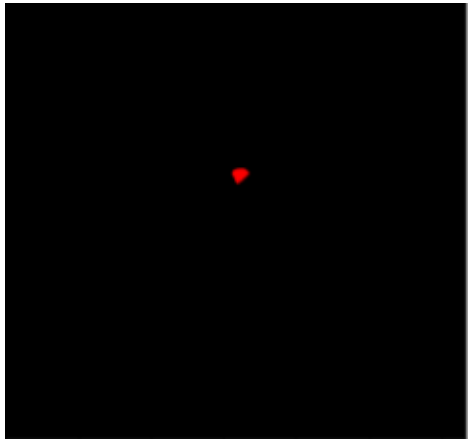
Example product from expert derived classifier for Superdove



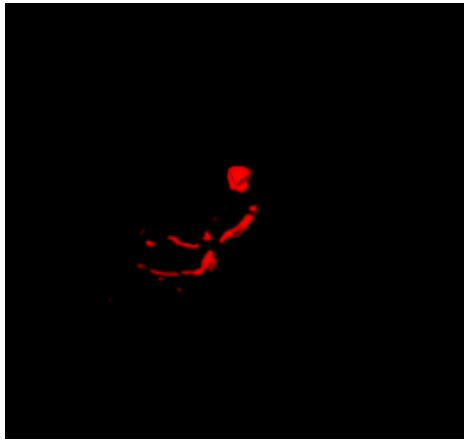
RGB Composite



Band 8 (865nm) with cloud mask applied



Saturated values



Hot and Extreme Pixels

Fagradsalsfjall, June 26, 2021. Data Courtesy Planet Labs

Takeaway

- VSW 2.0 has generated >250,000 alerts from Jan 2022 to June 2023
- VSW 2.0 has acquired:
  - >82 SkySat scenes
  - >600,000 coincidental Dove scenes
  - Scheduled >6,665 ECOSTRESS Scenes
- VSW 2.0 has no operations staff.
- Once configured by the science team, VSW 2.0 operates with no human input and minimal oversight
- We can autonomously monitor volcanoes at low cost

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