Using glaciers to identify, monitor and predict volcanic activity

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Glaciers and volcanoes


[1]

Eyjafjallajökull eruption 2010

- Dispersal of very fine grained ash

→ Closure of many airports in Northern Europe


[2]

Destroyed village of Armero (Nevado del Ruiz, 1985)

- Generation of disastrous lahars

→ 23000 lives lost

- **Glacio-volcanism**
- **Major threats to infrastructure and human lives**

Glacierized volcanoes worldwide

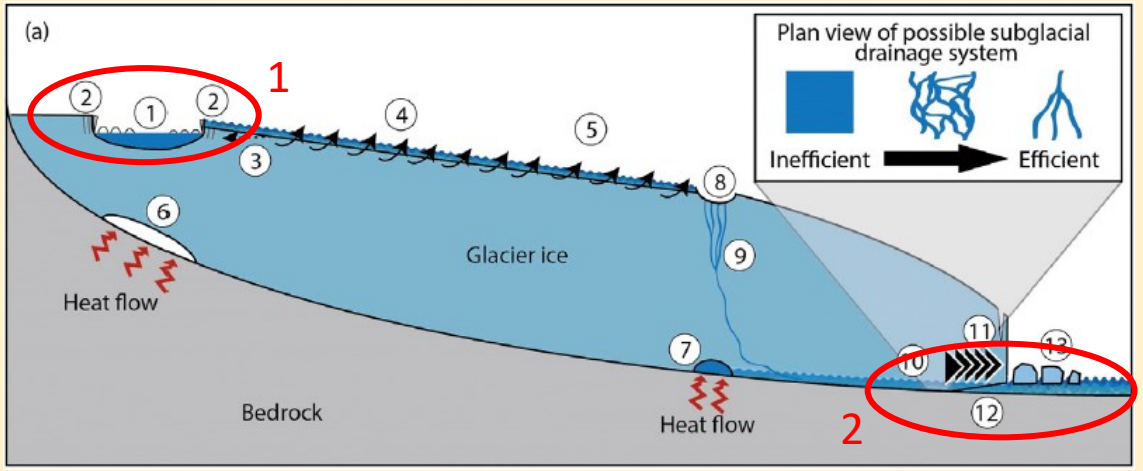
[3]

- 245 glacierized volcanoes worldwide

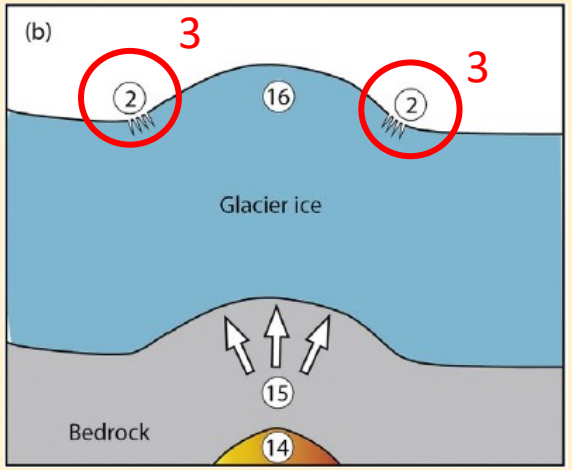
➢ „glacierized volcano“: ice within 5-km buffer (Edwards et al. 2020)

➢ Some of them in remote places on earth

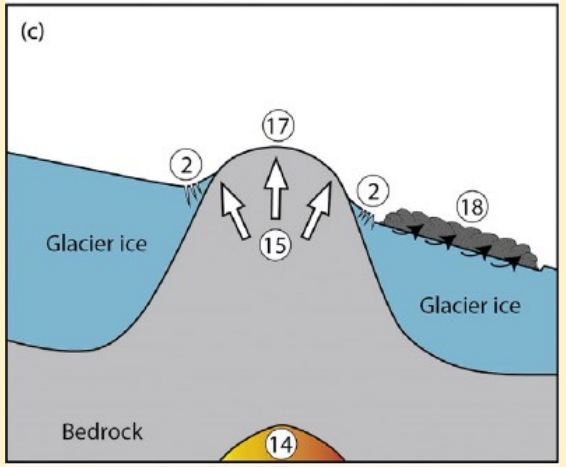
Glacio-volcanic processes



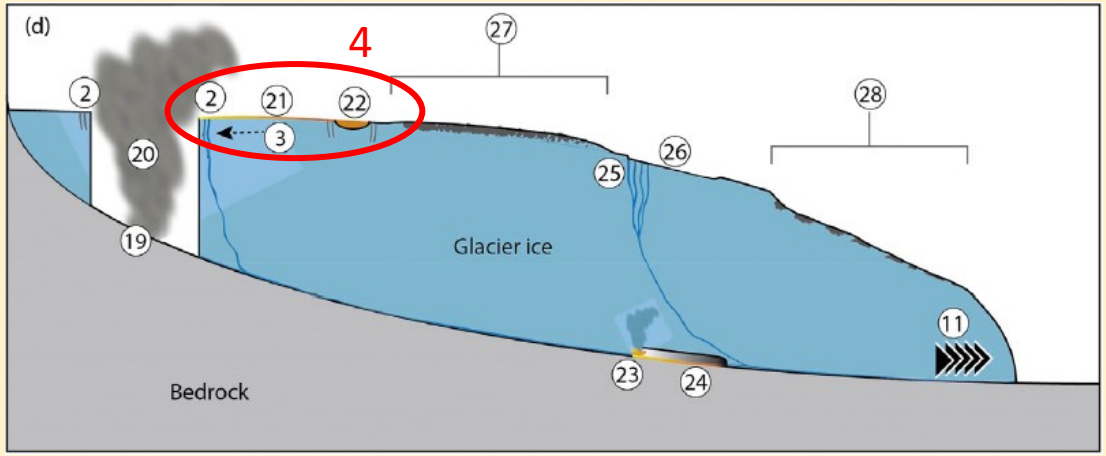
Subglacial heat flow



Subglacial volcanic dome growth



volcanic dome extrusion



Subglacial volcanic eruption

From Barr et al. 2018

<u>Volcanic impacts on glacier morphology</u>

e.g. ice cauldron formation due to subglacial heat flow (1), glacier terminus advance (2), glacier fracturing due to volcanic dome growth (3), glacier crevassing due to supraglacial lava flows (4)…

Optical satellite remote sensing

- **Large increase** in number of operational **land imaging satellites** from 1972 to 2013 (see right) and trend ongoing → many of them available for free
- Increase in spatial resolution

➢ freely available sources: 10-30-m

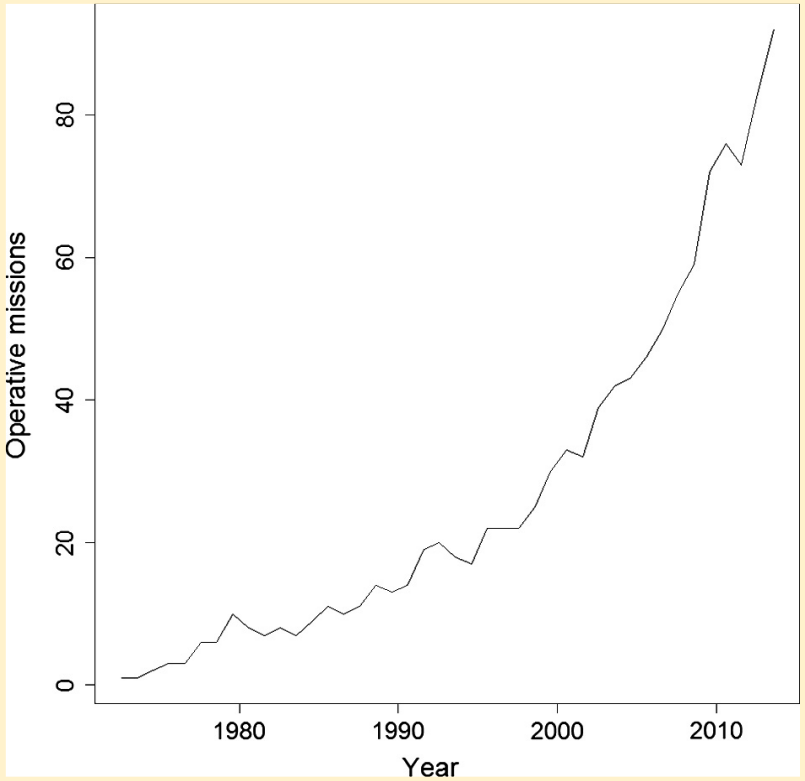
➢ Commercial sources: less than half a meter

→ however expensive!

- Increase in revisit times (temporal resolution)

[4]

Example: Landsat 8 satellite (illustration)



From Belward et al. 2015

→ Can we use <u>optical satellite images</u> to monitor volcanically triggered changes in glacier surface morphology?

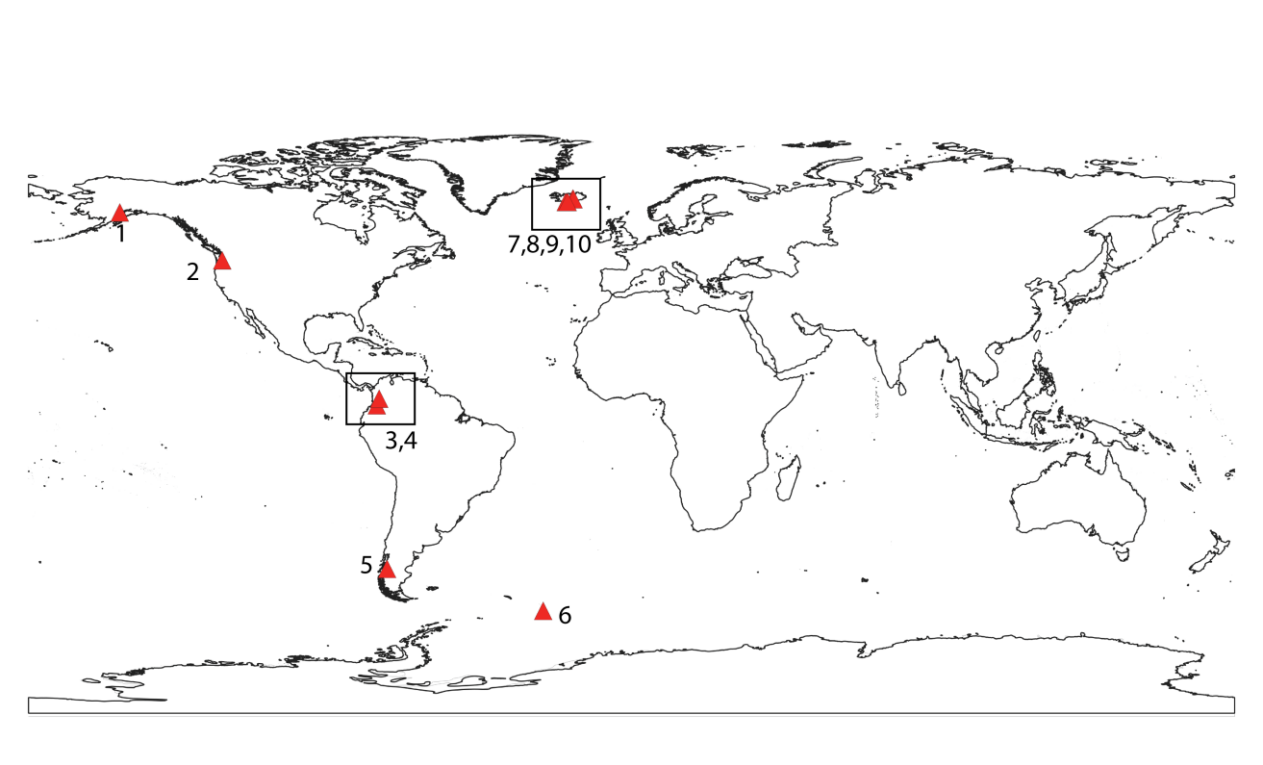
Overall scientific aim of the project

- Development of automated monitoring techniques for the activity of glacier-clad volcanoes worldwide (mostly) based on freely available satellite data and provide a new predictive tool for the activity on glacier-clad volcanoes

Sub-aim

- Assessing the use of optical remote sensing images to detect volcanic impacts on glacier morphology

Choice of well-known eruptions



[5]

- Choice of suitable examples of well-known eruptions

➢ **Search for optical satellite images in databases showing volcanic-glacier interactions**

- Work based on Barr et al. 2018:

→ Literature review on volcanic impacts on glaciers based on the literature

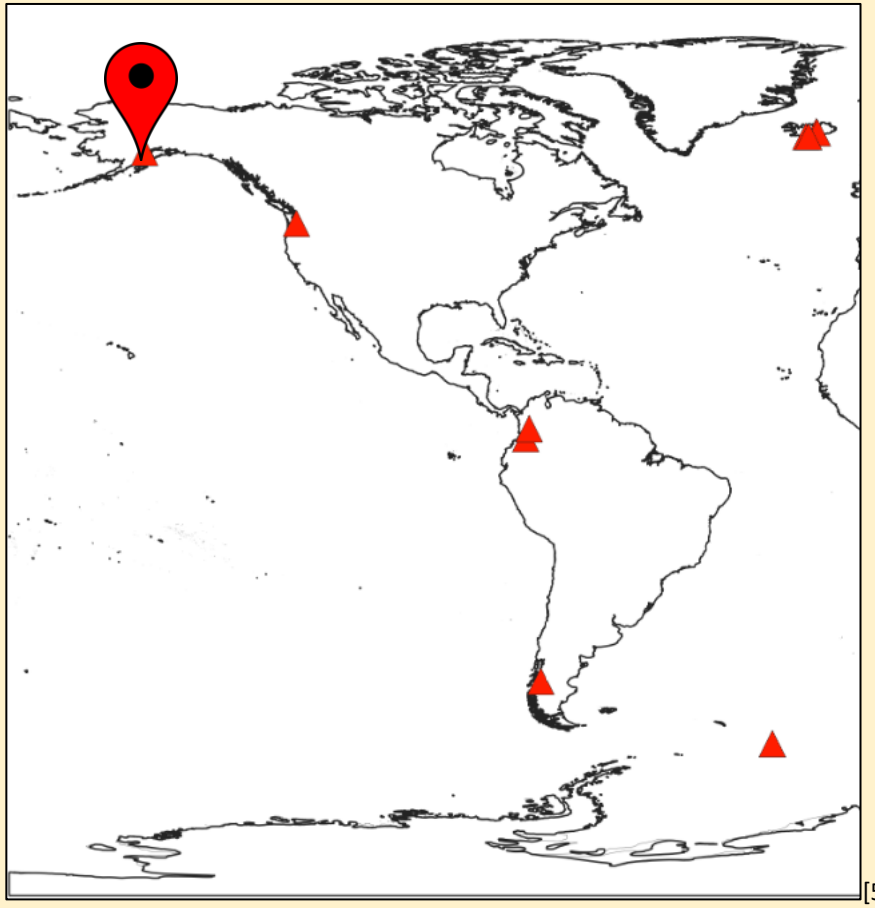
Methods

- Search for evidence of volcanic impacts on glacier morphology in satellite image databases (e.g. GoogleEarth Engine Code Editor, earthexplorer, planet, geocento)
- Viewing of several 100s (mostly freely available) optical satellite images and small number of commercial images
- Image viewing mostly in GoogleEarth Engine Code Editor or QGIS (including histogram stretch/contrast enhancement)

1. Example: Ice cauldrons within thin ice (Mount Redoubt, Alaska)

- ice-clad stratovolcano
- ~150 m thick ice
- eruption with major changes to summit glacier

Mount Redoubt (Alaska), 2009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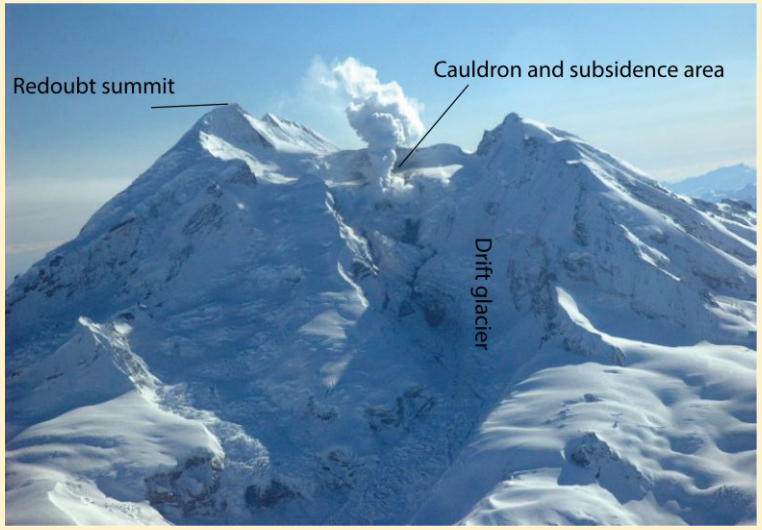
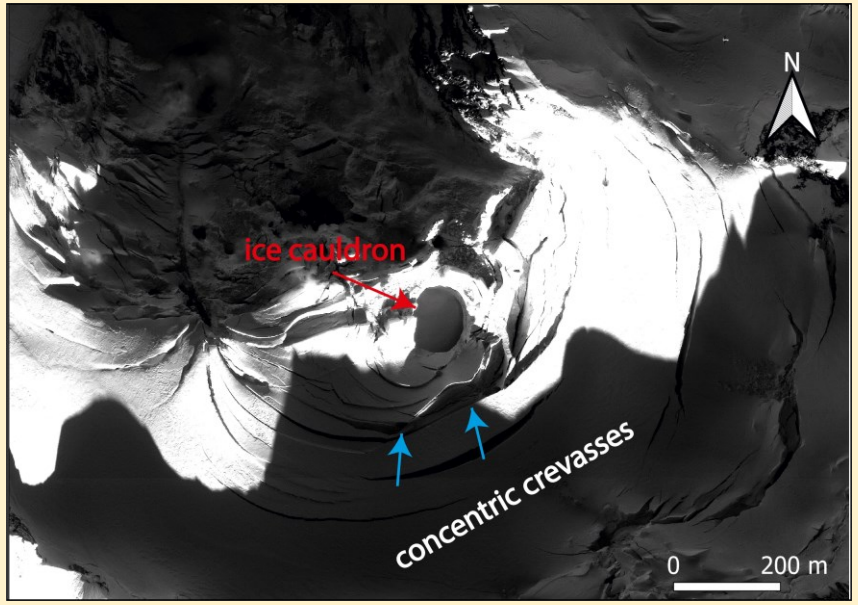


[6]

1. Example: Ice cauldrons within thin ice Mount Redoubt (Alaska)

- **Summit region of Mount Redoubt**
- Both satellite images acquired on same day

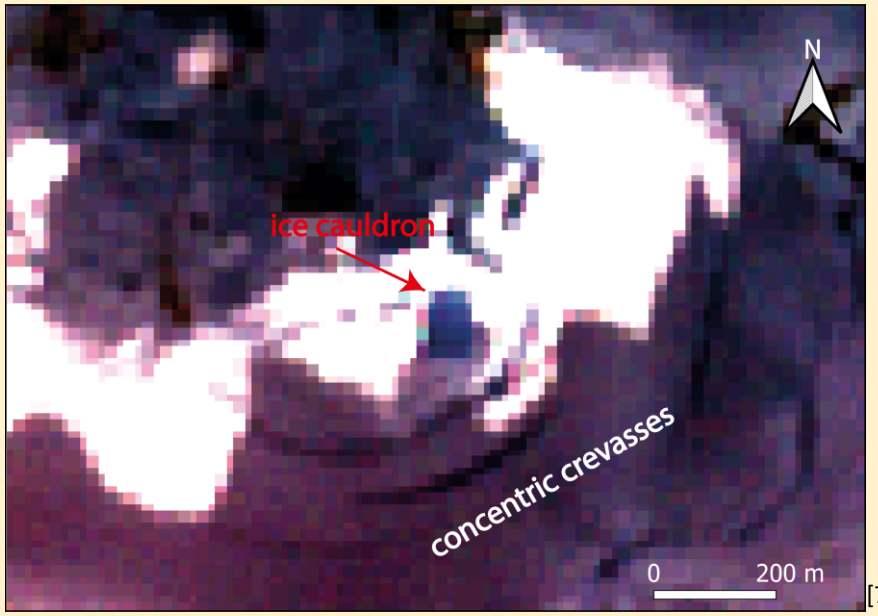
IKONOS-2 (commercial) image (0.8 m)



[*]

- High spatial resolution with many details
- Commercial image: expensive!

ASTER (freely available) visible image (15 m)



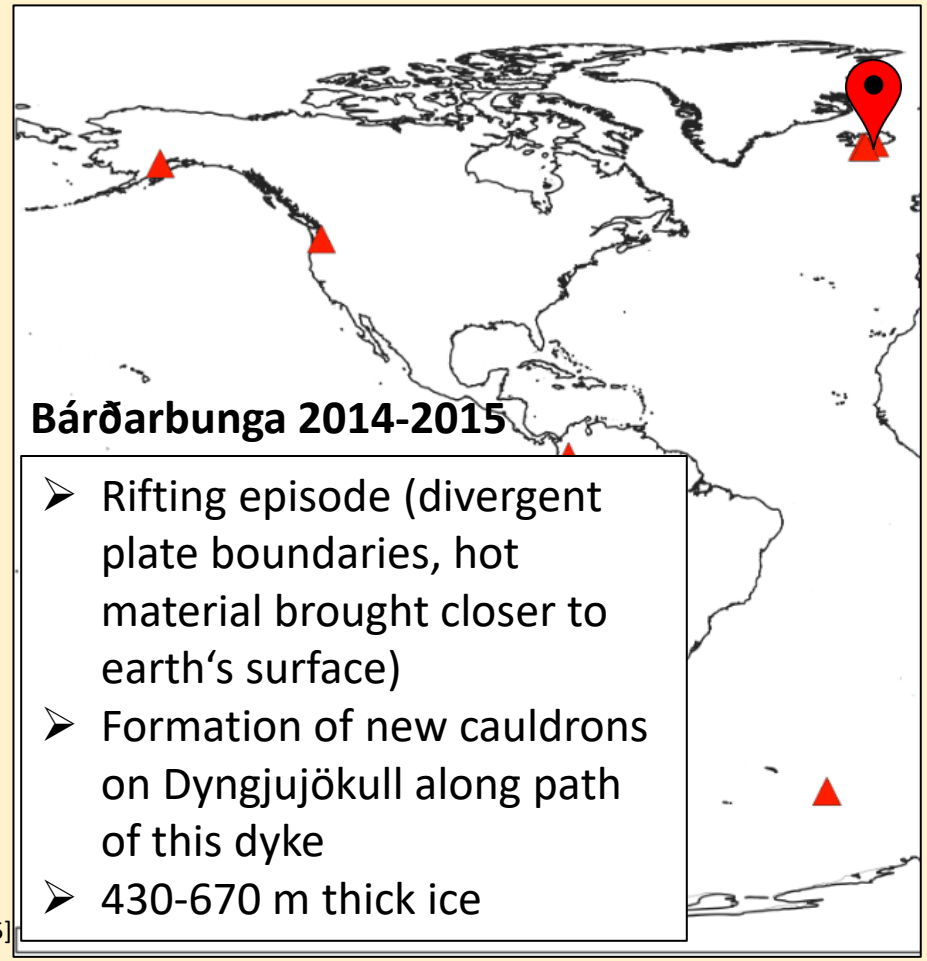
[7]

- Unclear features (low resolution image)
- Freely available image

→ Detection of ice cauldron before start of eruption 20 days later

[*] DigitalGlobe Products. IKONOS-2 © 2009 DigitalGlobe, Inc., a Maxar company.

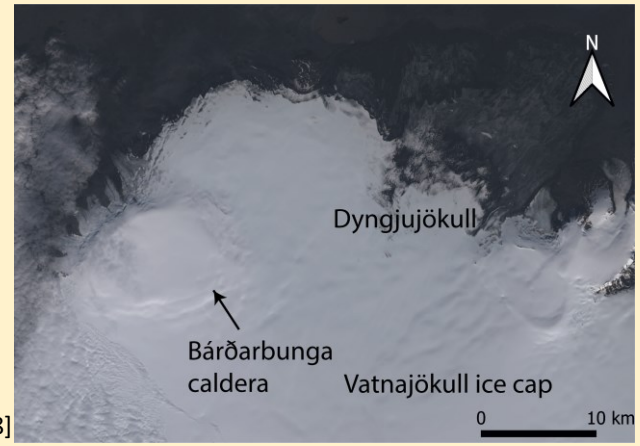
2. Example: Ice cauldrons within thick ice (Bárðarbunga, Iceland)



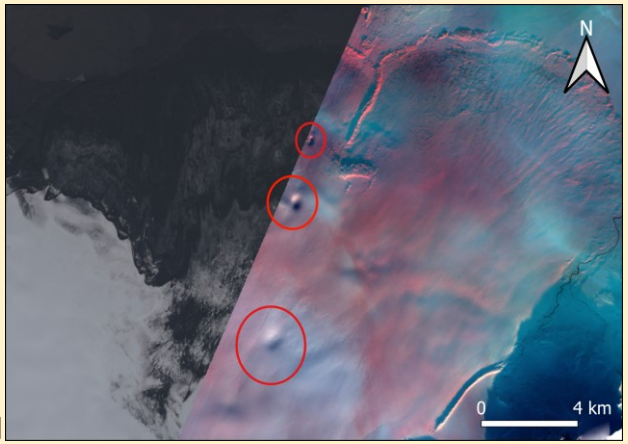
Bárðarbunga 2014-2015

- Rifting episode (divergent plate boundaries, hot material brought closer to earth‘s surface)
- Formation of new cauldrons on Dyngjujökull along path of this dyke
- 430-670 m thick ice

[5]



[8] Landsat 8 overview image of Vatnajoekull ice cap (Iceland)

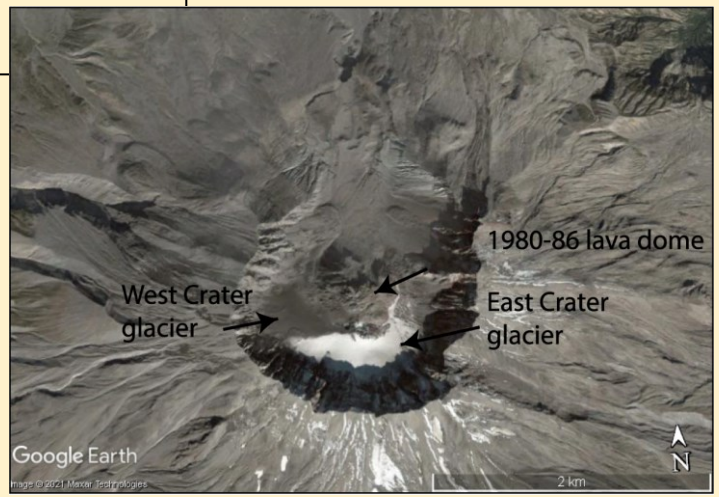


[8] EO-1 ALI false colour image (30 m)

- Cauldrons on glacier surface along dyke path (encircled) detectable in low resolution images

3. Example: Volcanic dome growth on Mount St Helens

- Stratovolcano with ‘amphitheater’-like crater
- Ice thickness: 200 m
- volcanic dome extrusion from 2004-06
- squeezing of crater glacier and heavy crevassing



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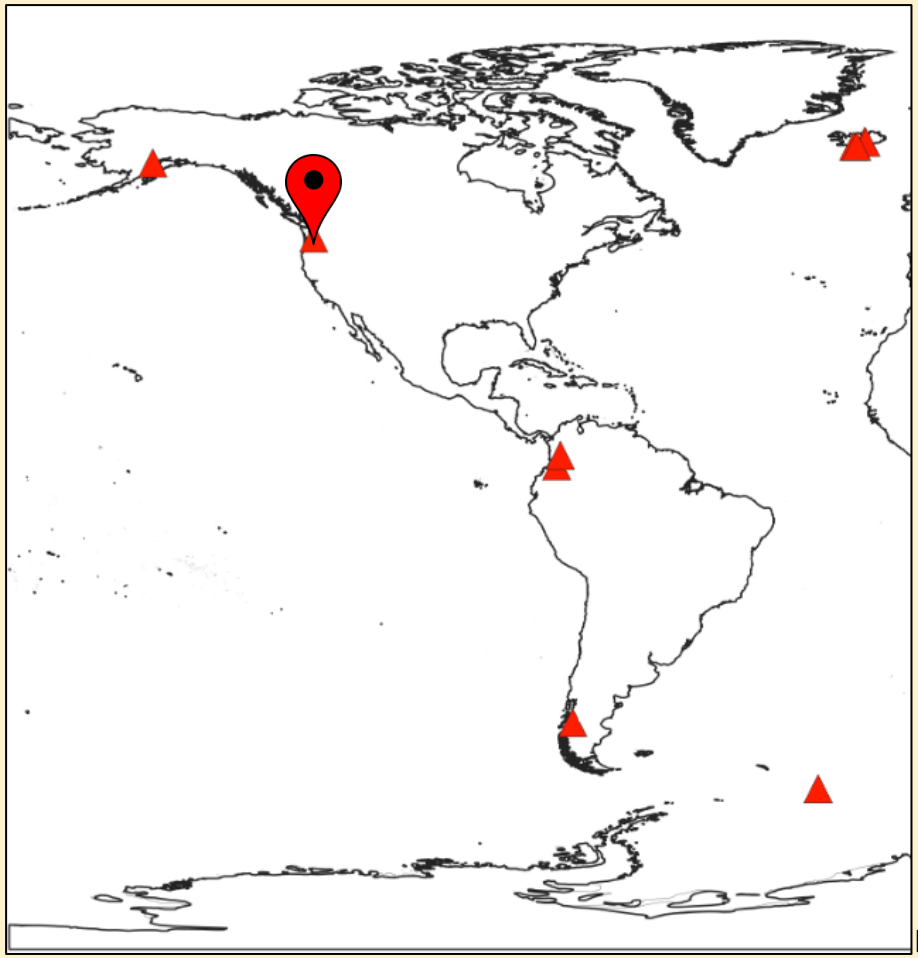
GoogleEarth image of Mount St Helens summit

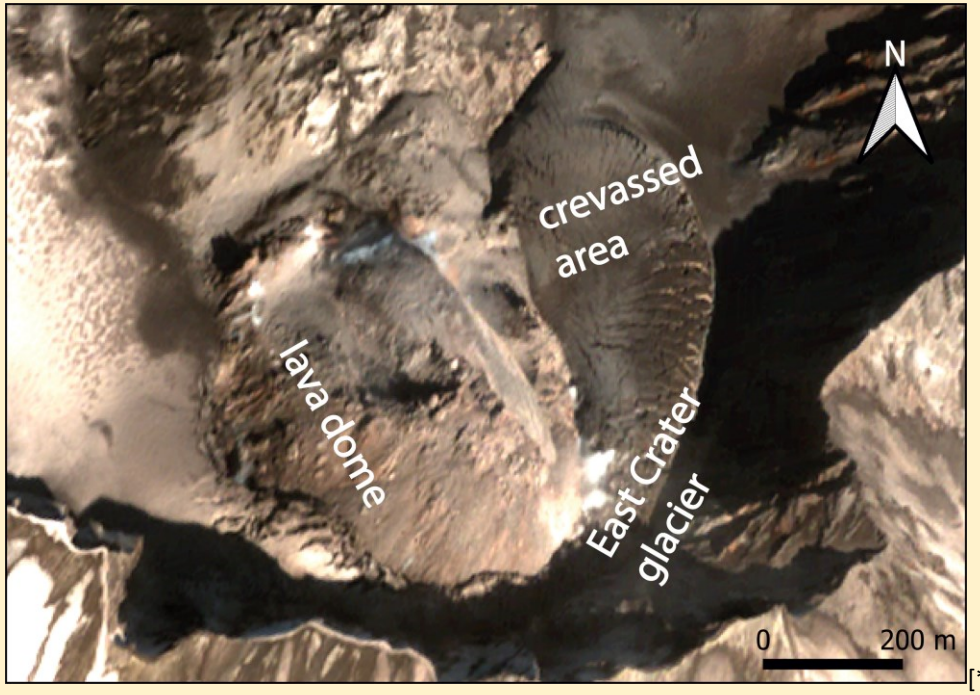
Mount St Helens (United States), 2004-06


[5]

[*] image from 03/10/2004 © 2021 Maxar Technologies

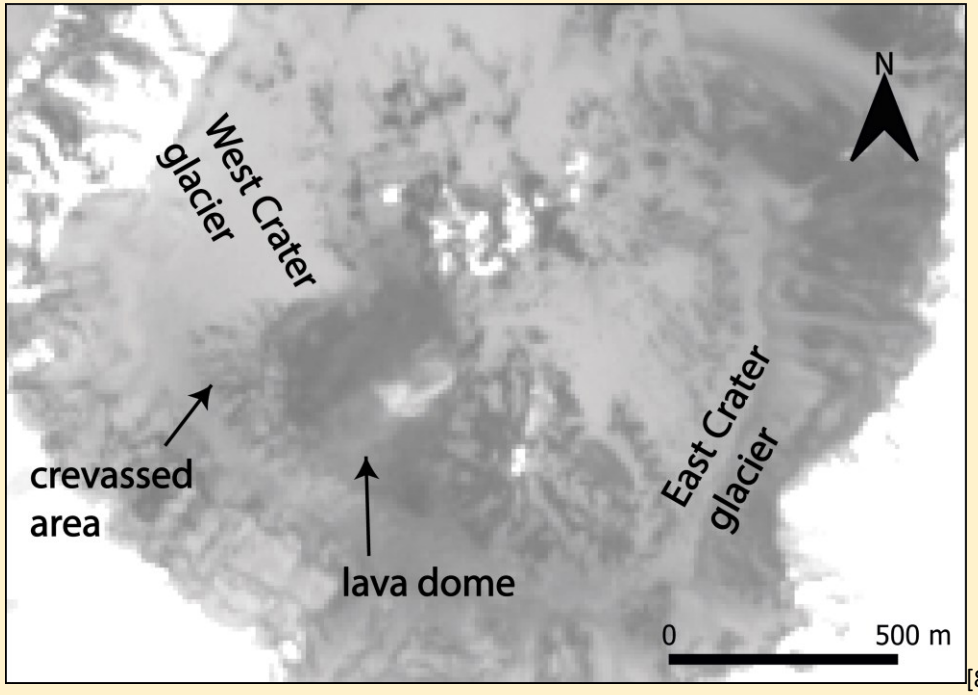
3. Example: Volcanic dome growth on Mount St Helens

QuickBird-2 multispectral image (2.4 m)



[*]

EO-1 ALI panchromatic image (10 m)



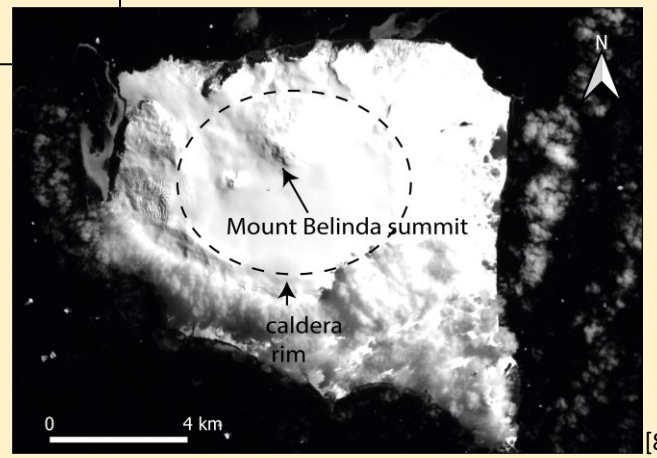
[8]

- Lava dome growth results in heavy crevassing on East Crater glacier (left)
- Ongoing growth results in crevassing on West Crater glacier (right)

[*] DigitalGlobe Products. QuickBird-2 © 2005 DigitalGlobe, Inc., a Maxar company

4. Example: Supraglacial lava flows and (widespread) crevassing on Mount Belinda (Montagu Island)

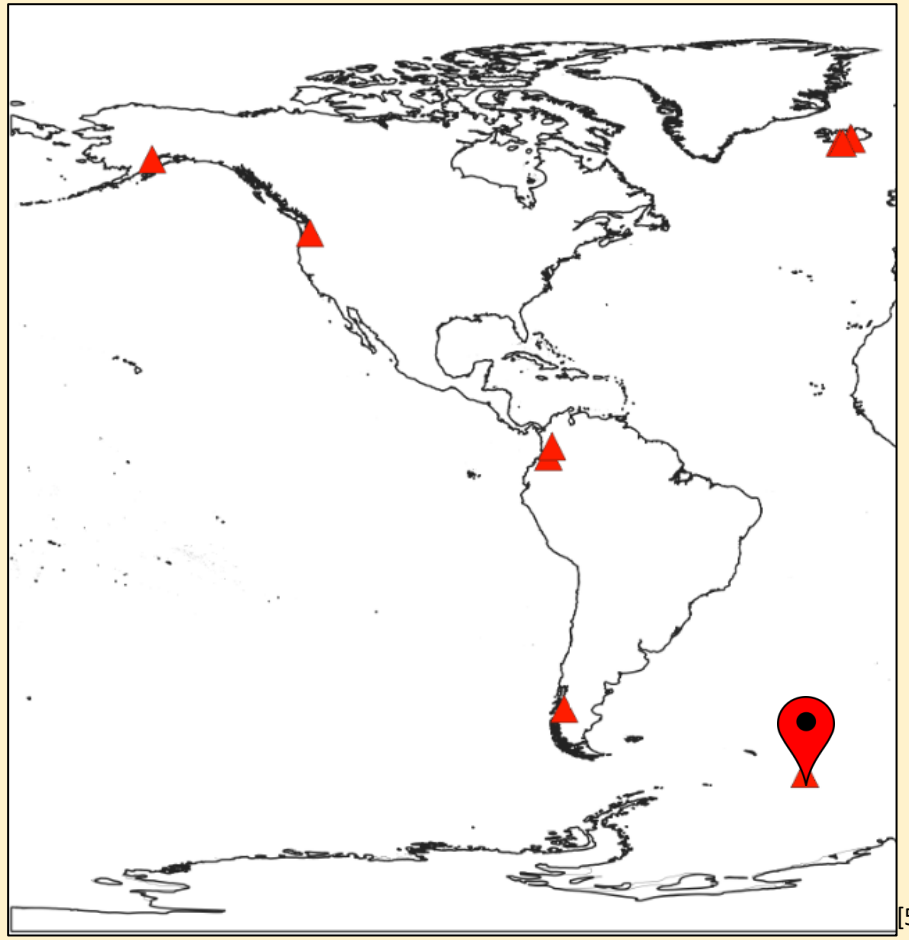
- Mount Belinda: small summit cone on larger shield volcano
- Low-intensity explosive activity and several effusive events
- Active lava flows and subglacial melt



[8]

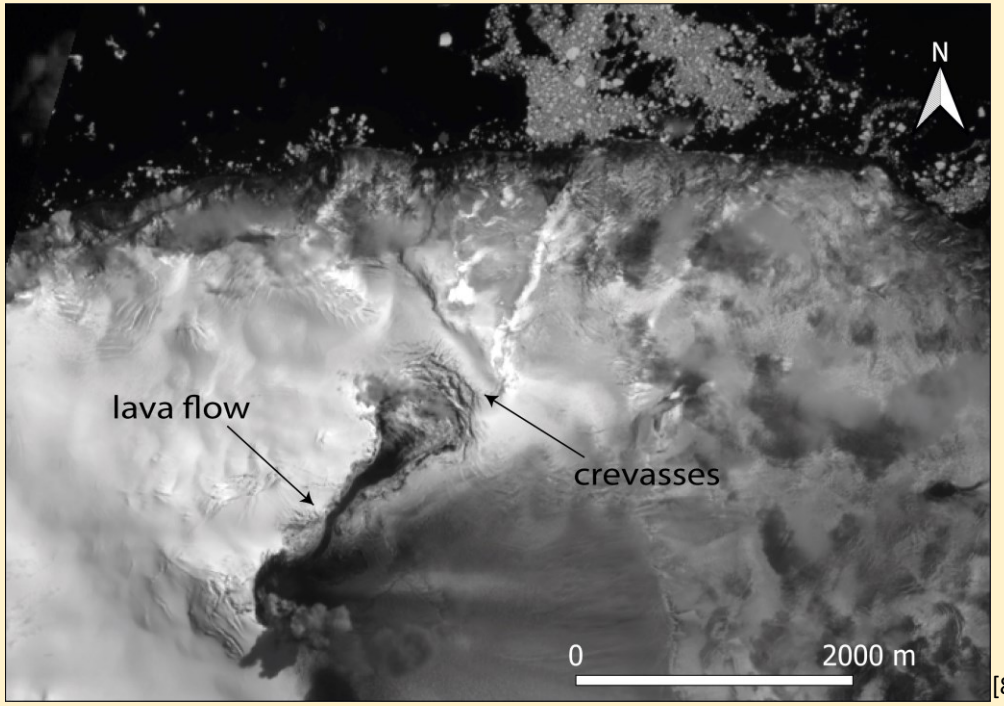
Landsat 7 image of Montagu Island

Montagu Island (South Sandwich Islands), 2001-07


[5]

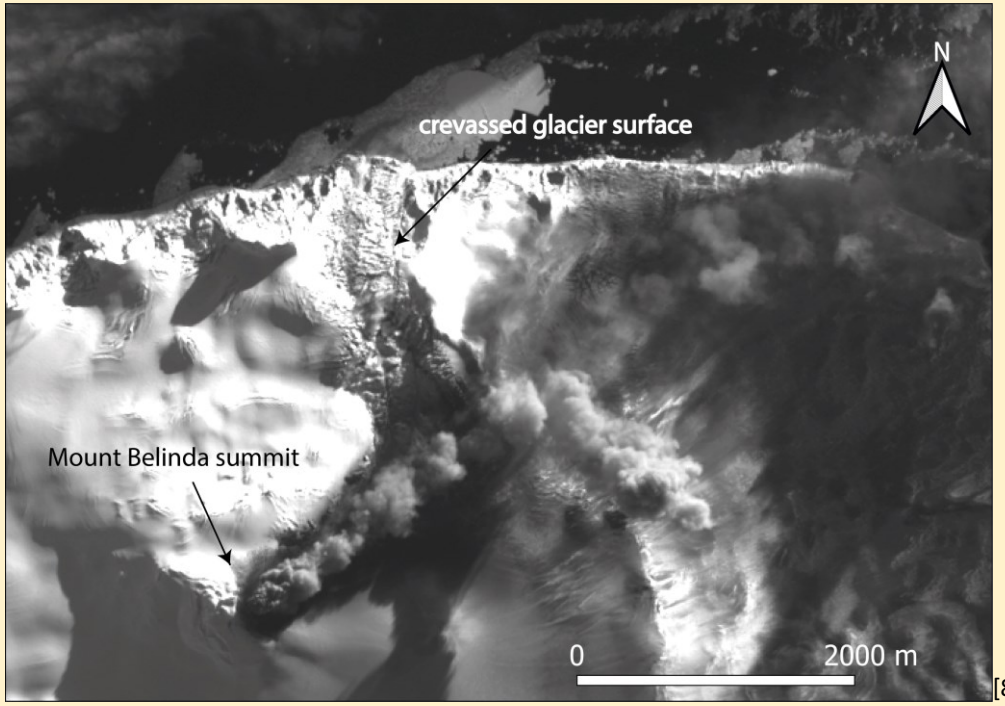
4. Example: Supraglacial lava flows and (widespread) crevassing on Mount Belinda (Montagu Island)

EO-1 ALI panchromatic image (10 m)



[8]

EO-1 ALI panchromatic image (10 m)



[8]

- Crevasses radiating out from a supraglacial lava flow (left)
- Completely crevassed glacier surface (potentially) due to subglacial melting (right)

→ Crevasses well visible in medium resolution images

Discussion

- Ice cauldrons: most common volcanic impact on glaciers observable from optical satellite images both within thick and thin ice

➢ observable due to shadowing (areas distinct from usually bright glacier surface)

- All volcanic impacts investigated here (e.g. subglacial melt, volcanic dome growth, supraglacial lava flow, ice cauldron formation) associated with glacier crevassing visible as dark stripes

Challenges/Outlook

Challenges

- Cloud-cover/eruption plumes tremendously reduces availability of suitable optical images
- Spatial resolution often too low (esp. for events before launch of ASTER/Landsat 7 in 1999)
- Highly variable surface texture and topography (esp. for only partially ice-covered volcanoes with thin ice cover) makes it difficult to spot changes on glacier morphology

➢ requires high-resolution imagery (however expensive!)

- Lack of quantitative information on changing surface elevations

➢ **Yes, we can use land imaging satellites to study impacts on ice-clad volcanoes** (with limitations)

Outlook

- Combined study with low-resolution optical images and judiciously selected high-resolution images
- Increasing (often free) availability of relatively high spatially and temporally resolved optical satellite images in the future

➢ Availability of more cloud/plume-free scenes

- Increasing availability of easy-to-use satellite image platforms (e.g. Sentinel Hub Playground)
- Best use in combination with DEMs, radar data, aerial images and ground-based measurements

Conclusion/Take home message

- Investigation of glacio-volcanism with help of optical satellite images
- ~245 glacierized volcanoes on earth

➢ search for images on a choice of well-known case examples

- Most commonly observable volcanic impact on glacier: Ice cauldrons
- Use of optical images in combination with other techniques (DEMs, radar, ground based measurements…) to obtain best monitoring/prediction results

Sources

- [1] https://www.usgs.gov/media/images/eyjafjallaj-kull-eruption (Credit: Oddur Sigurðsson, Iceland Meteorological Office. Public domain)
- [2] https://www.usgs.gov/media/images/damage-nevado-del-ruiz-lahar (Credit: U.S. Geological Survey, Department of the Interior/USGS, U.S. Geological Survey)
- [3] https://services.arcgisonline.com/arcgis/rest/services/World_Imagery/MapServer/tile/%7Bz%7D/%7By%7D/%7Bx%7D&zmax=22&zmin=0 (Credits: Esri, Maxar, Earthstar Geographics, USDA FSA, USGS, Aerogrid, IGN, IGP, and the GIS User Community)
- [4] https://www.usgs.gov/media/images/landsat-8-illustration-above-earth (Credit: U.S. Geological Survey, Department of the Interior/USGS, U.S. Geological Survey)
- [5] Basemap: "World Continents". Source: depremarc
- [6] Photo by H. Bleick AVO/USGS, taken March 15, 2009; https://avo.alaska.edu/images/dbimages/display/1237246300_ak231.jpg
- [7] **ASTER** data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. *http://lpdaac.usgs.gov;*
- [8] **Landsat and EO-1 data** available from the USGS Earth Resources Observation and Science (EROS) Center
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