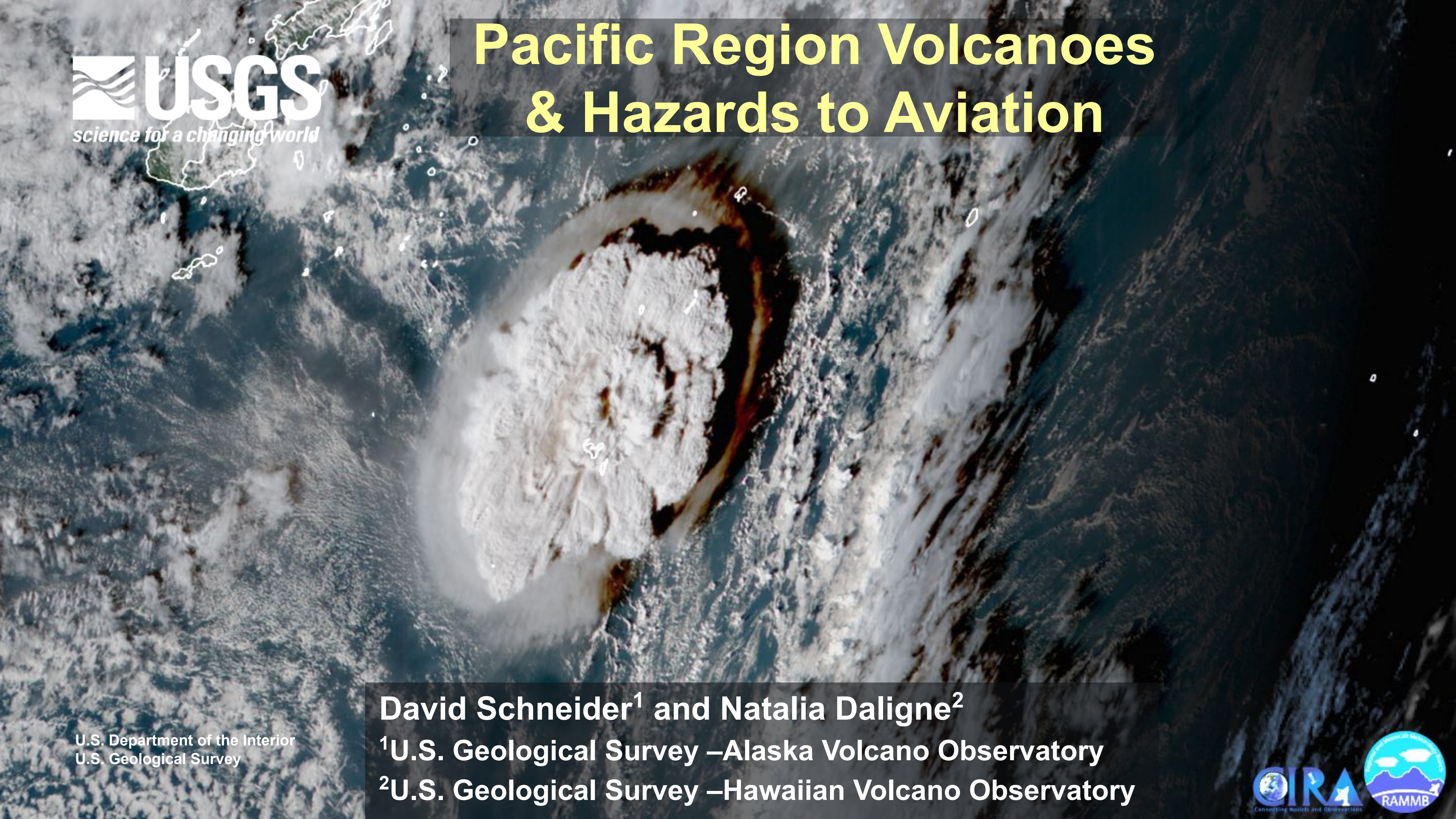
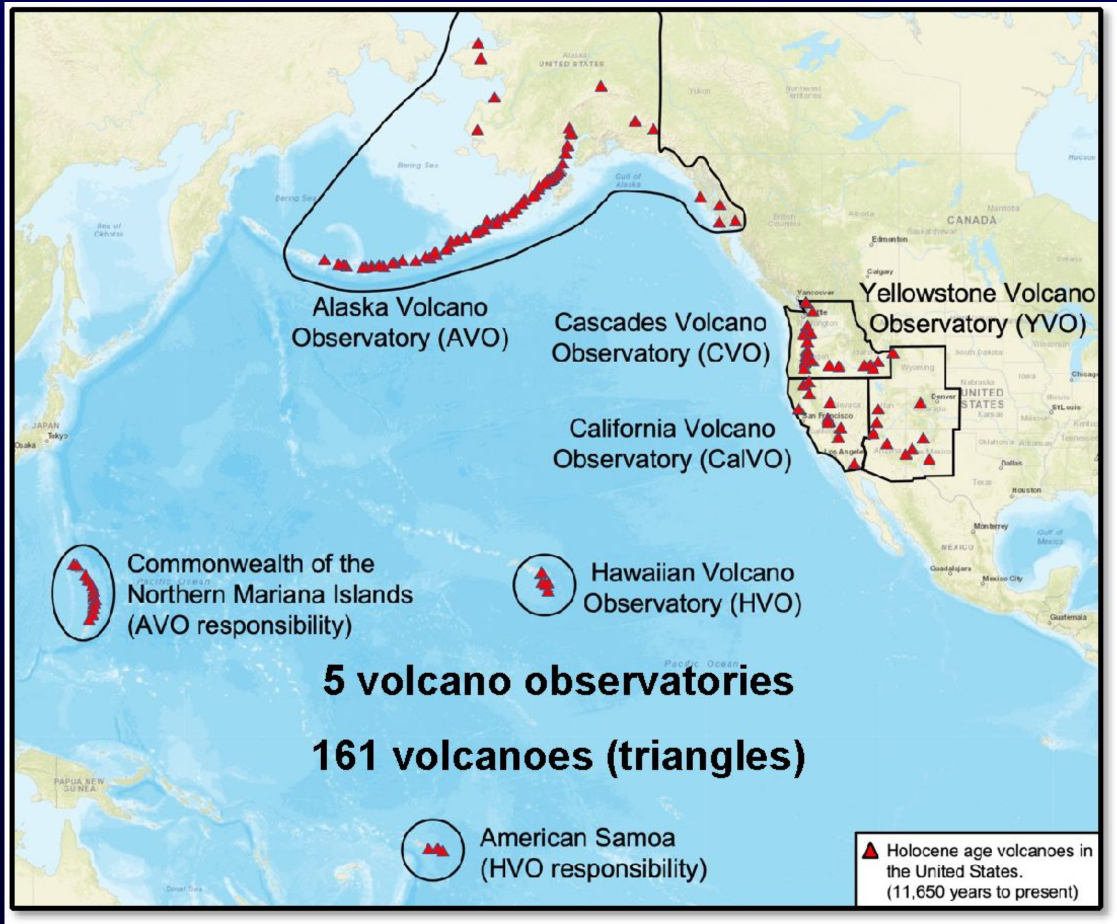
Pacific Region Volcanoes & Hazards to Aviation



David Schneider[1] and Natalia Daligne[2]
[1]U.S. Geological Survey –Alaska Volcano Observatory
[2]U.S. Geological Survey –Hawaiian Volcano Observatory

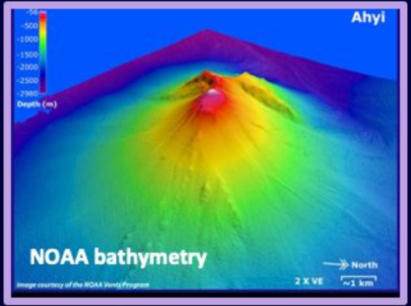
U.S. Department of the Interior
U.S. Geological Survey

United States volcanoes

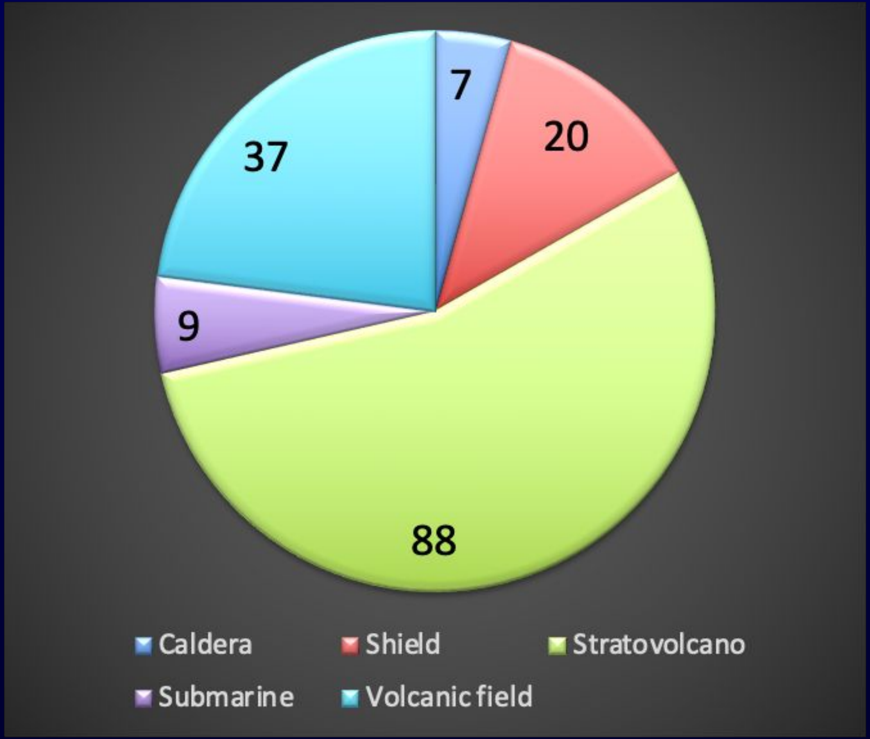


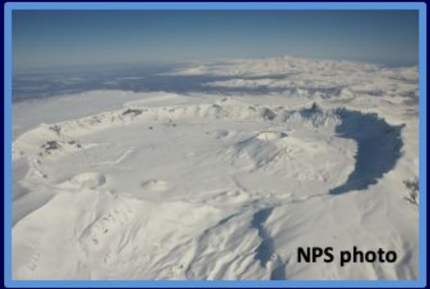
United States volcanoes:
A large (161) diverse assortment

San Francisco Volcanic Field



Ahyi Seamount





Aniakchak Caldera

Mauna Loa

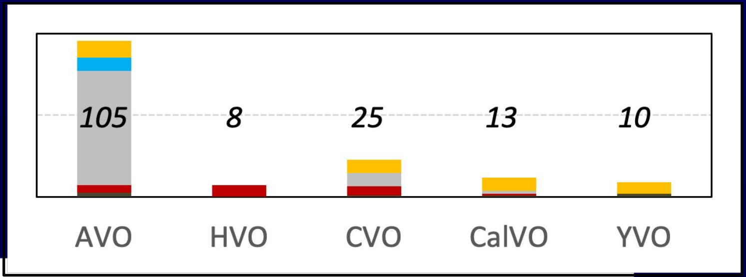
Mount Rainer

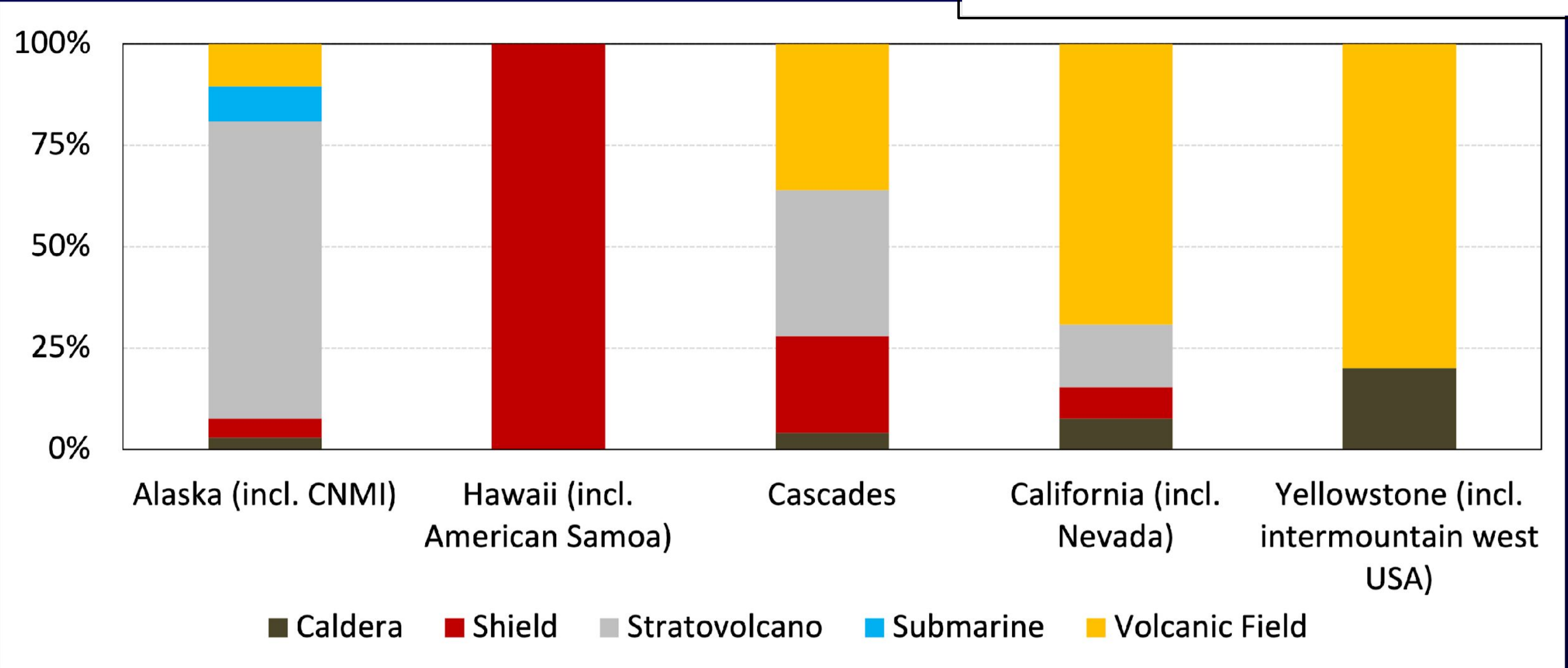
USGS

Data from https://pubs.er.usgs.gov/publication/sir20185140

United States observatories

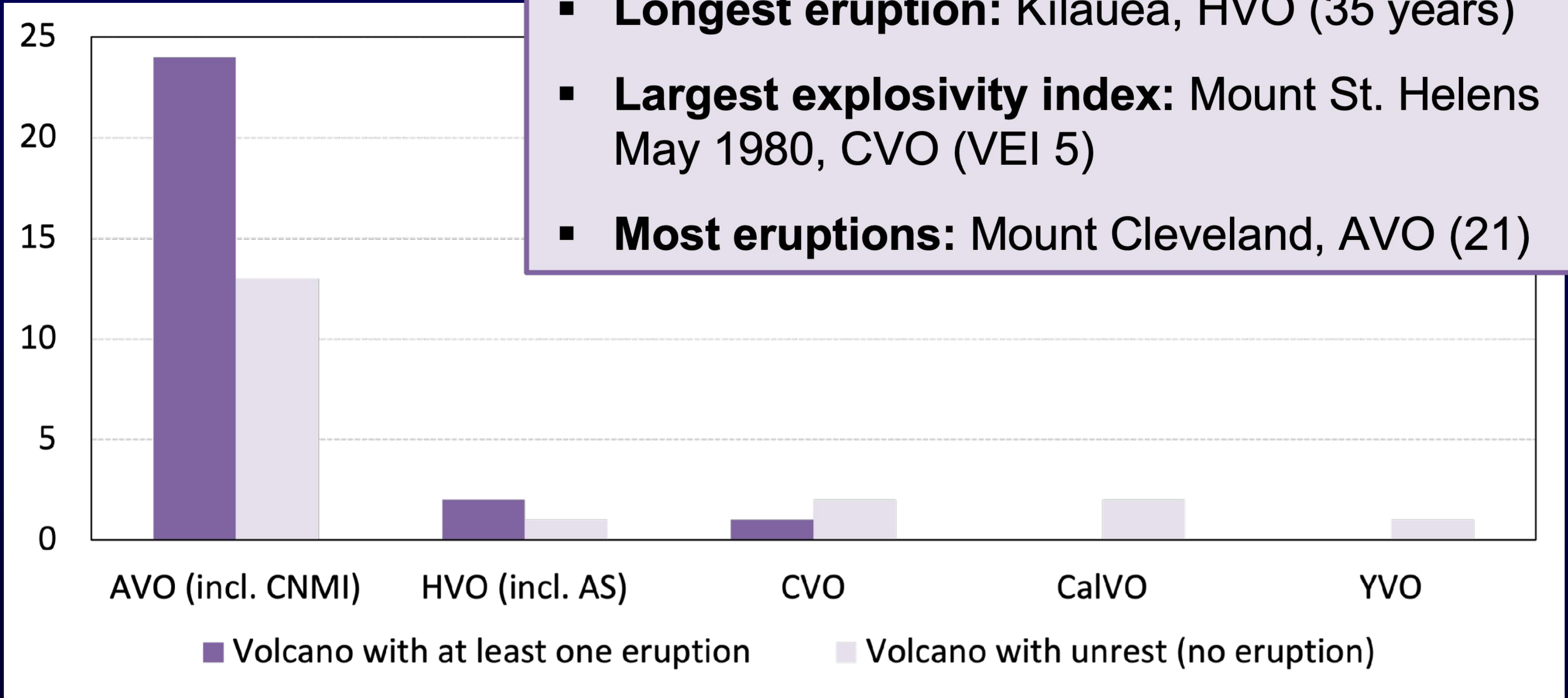
Proportion (▼) of each volcano type and total number (►) monitored by observatory





Data from https://pubs.er.usgs.gov/publication/sir20185140

Eruptions 1980 – present



- **Longest eruption:** Kīlauea, HVO (35 years)
- **Largest explosivity index:** Mount St. Helens May 1980, CVO (VEI 5)
- **Most eruptions:** Mount Cleveland, AVO (21)

USGS

Data through 2017 from https://pubs.er.usgs.gov/publication/sir20185140, supplemented with data from AVO and HVO websites

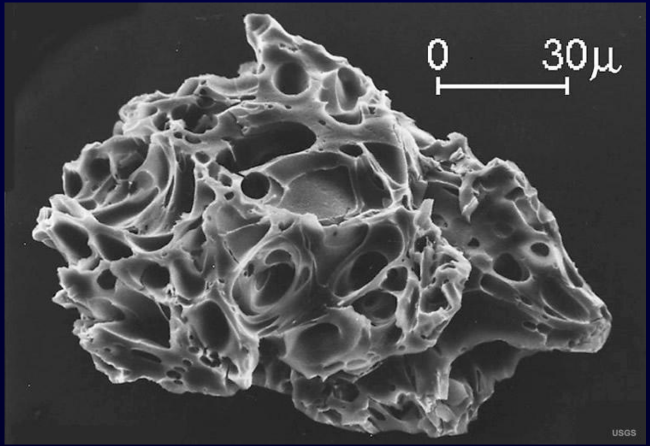
Different styles of eruptions: Stratovolcanoes

- Volcanic Ash
- Volcanic Gases
  - SO_2, CO_2, other
- Acid Aerosols
  - Sulfate: sulfuric acid from the conversion of SO_2
- Water
  - Solid, Liquid, and Vapor
- Amounts of these constituents are highly variable

USGS

Volcanic ash

- Sand (mm) to dust (micron) sized rock and mineral fragments produced during explosive eruptions
- Rock fragments are typically glassy and form as magma quenches following eruption
- Mineral fragments melt at higher temperatures than do the glassy rock fragments
- Ash is hard, sharp, angular, and abrasive



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Different styles of eruptions: Shield Volcanoes

Kilauea: June 7, 2023
USGS Photo

USGS

- Typically erupt lava
- High amounts of volcanic gases, primarily SO_2 and water.
- Vog: A hazy mixture of SO_2 gas and aerosols, primarily sulfuric acid and other sulfate (SO4) compounds.
- Ash emissions are less common but can occur, especially at the onset of eruption.

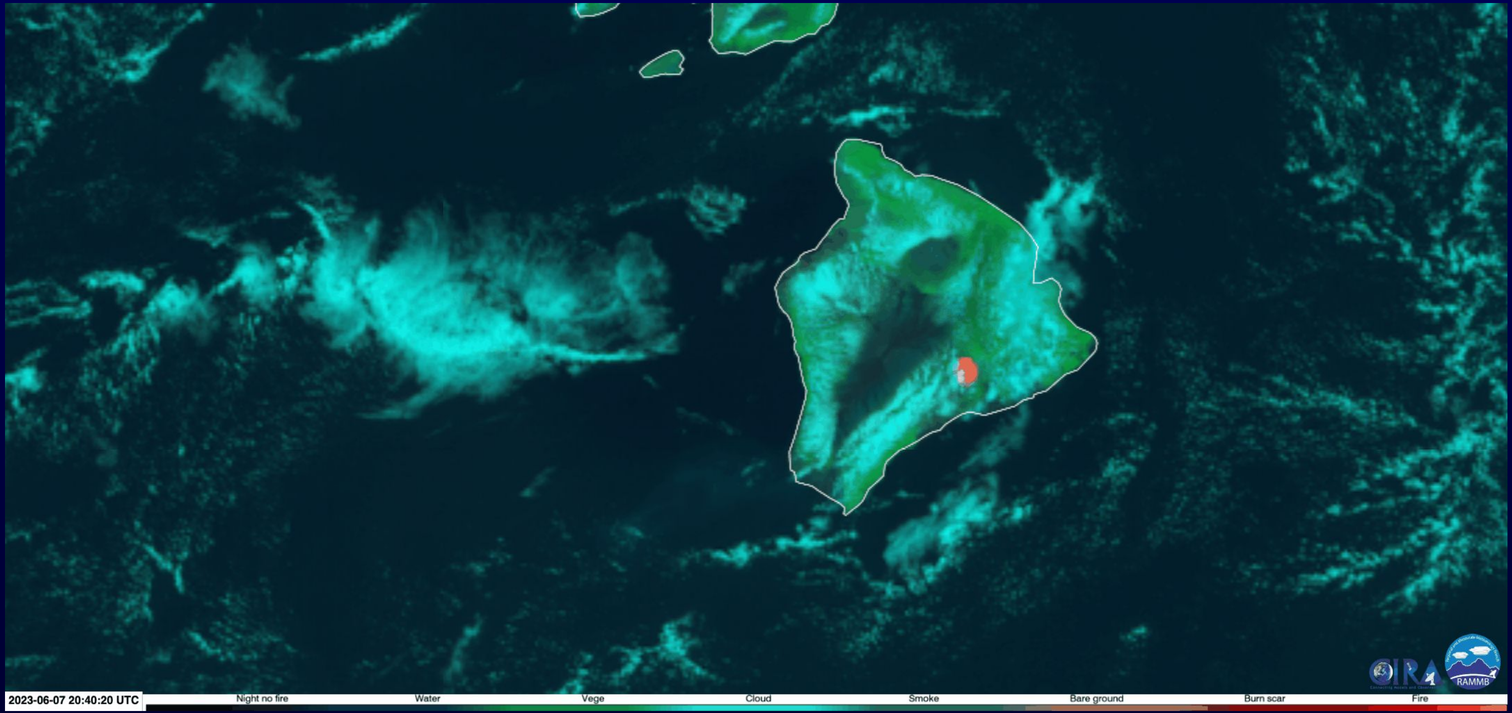
Kilauea volcanic ash

Ash-rich plume rising from a new vent in Halema‘uma‘u Crater in Kīlauea Caldera, March 2008

Pele’s hair and tears, tiny spheres, and shards of volcanic glass, that was erupted from Halema‘uma‘u Crater, Kīlauea Volcano.

USGS

Lava seen from GOES-18 : Kilauea 6/7/2023



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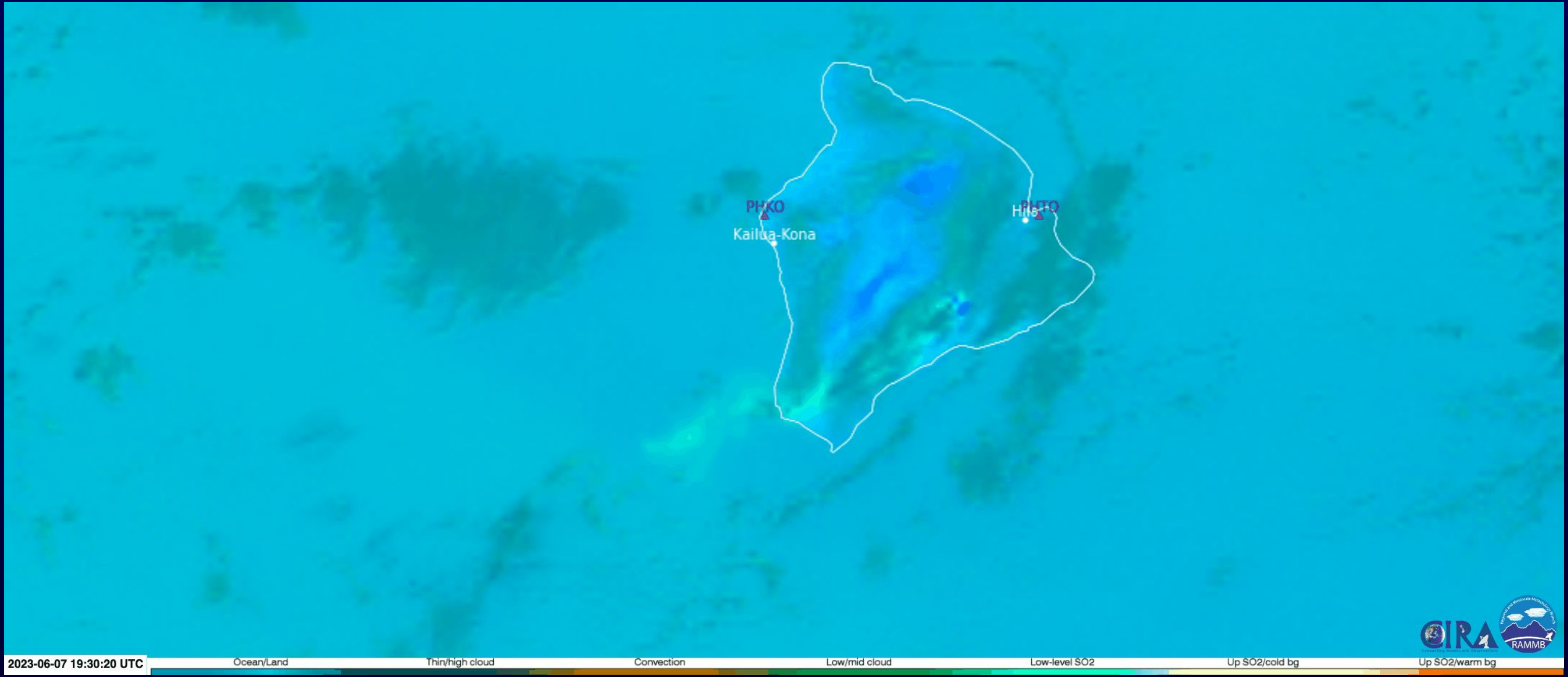
GOES SO_2 from GOES-18 : Kilauea 6/7/2023



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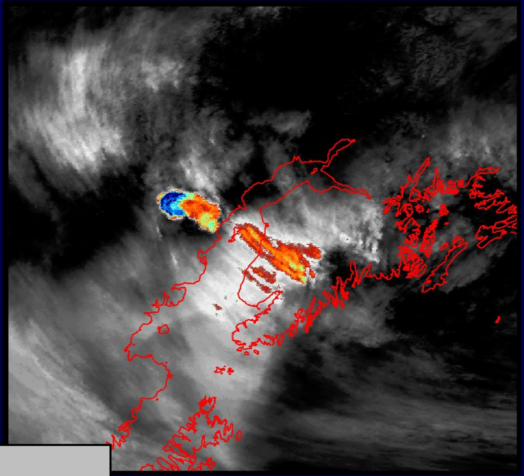
Stages of volcanic cloud evolution from explosive eruptions

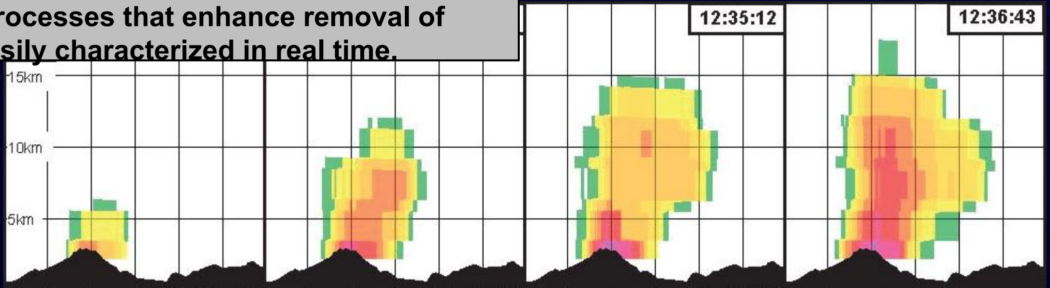
- Stage 1: First several hours of ash in the atmosphere
  - Eruption column processes active (ice, aggregates) and material distributed for 10+ km vertically
  - Ash fallout: particle diameters larger than ~0.5 mm
  - Observation with radar and satellite
  - Potential for acute aircraft damage
- Stage 2: Several hours to several days
  - Volcanic cloud expansion by wind advection and diffusion shears cloud into layers several km thick vertically
  - Particle aggregation and fallout of very fine to fine ash (10-500 microns)
  - Infrared and ultraviolet remote sensing of ash and SO_2
  - Potential for acute or chronic aircraft damage
- Stage 3: Days to weeks
  - Drifting volcanic clouds typically present as very thin layers > km thick
  - Very fine ash present but "low" concentration
  - Visible and UV remote sensing of SO_2 and sulfate aerosol

USGS

Stage 1 volcanic cloud



- Rapid rise to flight altitudes (>5 minutes)
- Characterization of height critical (radar, satellite, PIREP), as is variability over time
- Particle size distribution can be inferred from eruption style, but column processes that enhance removal of very fine ash not easily characterized in real time.



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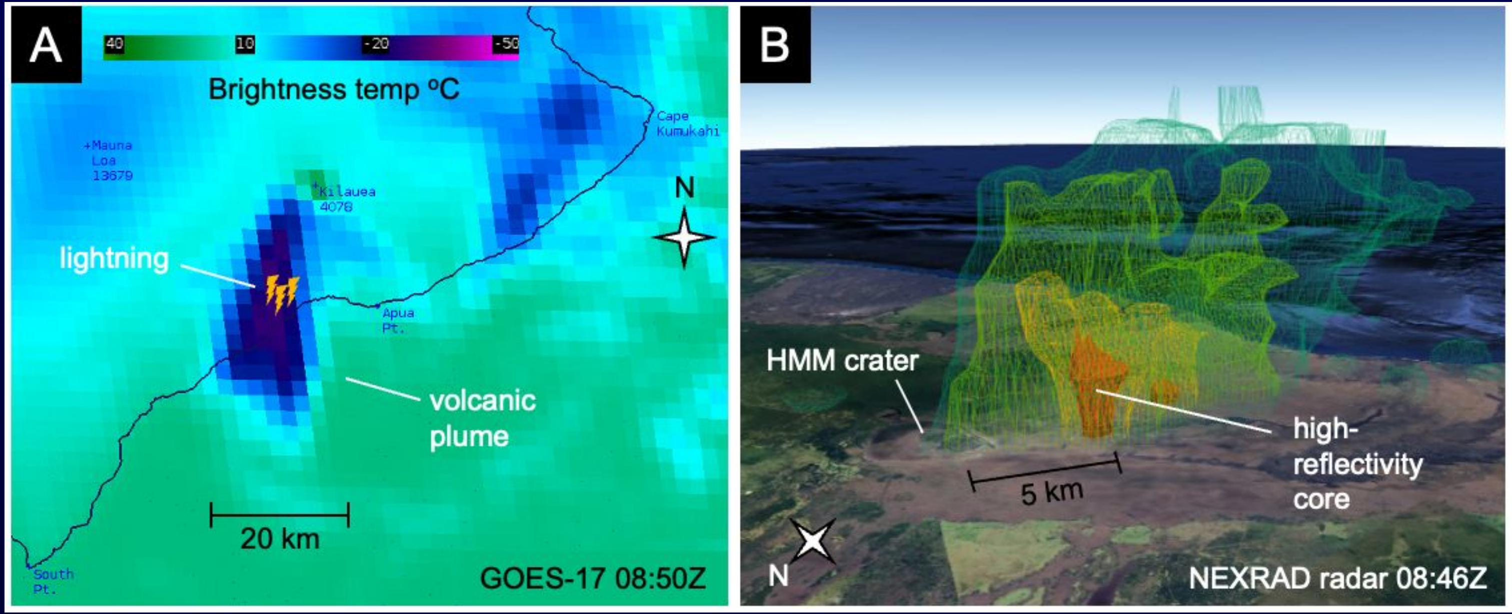
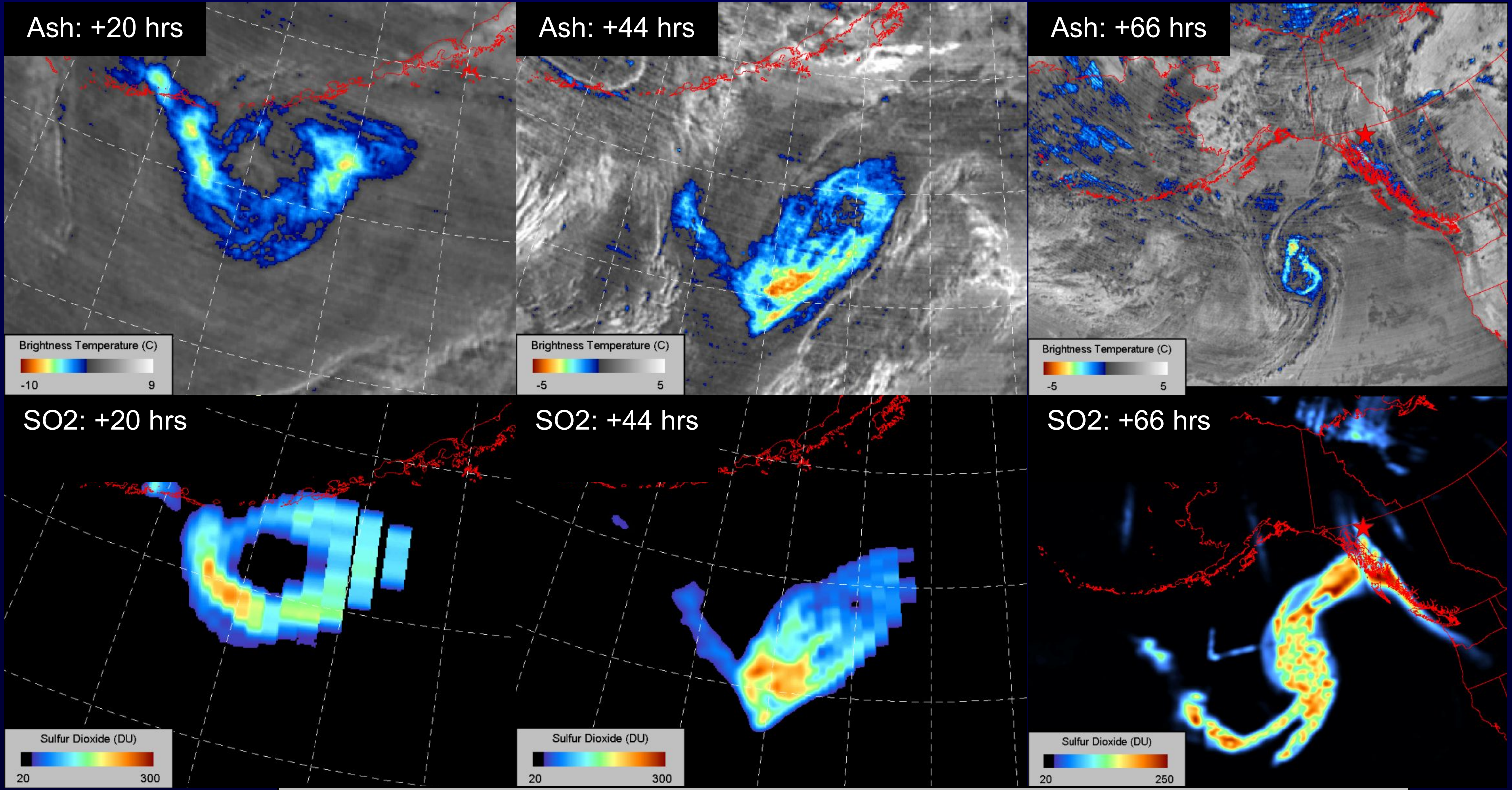
Satellite IR, lightning and NEXRAD: Kilauea 12/21/2020



Cahalan and others (2023) interpreted the high-reflectivity core as a region of large particles—likely water droplets—descending from the volcanic cloud.

USGS

Stage 2 volcanic cloud



The ash signal that is observed in infrared satellite data decreases over the first several days of atmospheric residence time, while the SO_2 signal remains more easily observed.

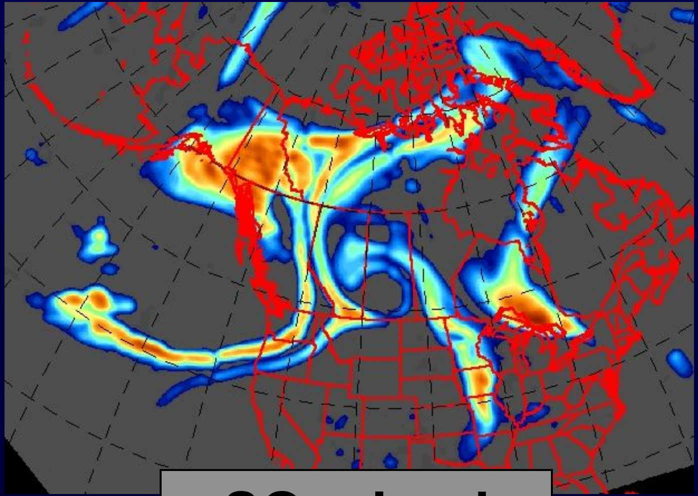
USGS

Type 3 volcanic clouds

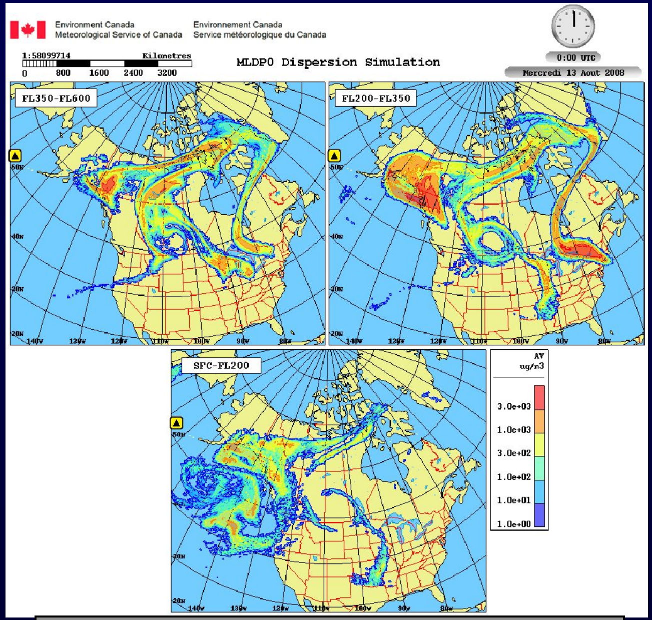
- Typically observable as SO_2 and sulfate aerosols in ultraviolet remote sensing, lidar, and visually under favorable viewing circumstances
- These clouds likely contain minor amounts of very fine ash, but ash is seldom detected using traditional satellite techniques
- Transport and dispersion models can forecast cloud position quite accurately, but the ash concentrations are overestimated due to the lack of realistic ash removal processes

USGS

Kasatochi volcanic cloud at +1 week



SO_2 cloud

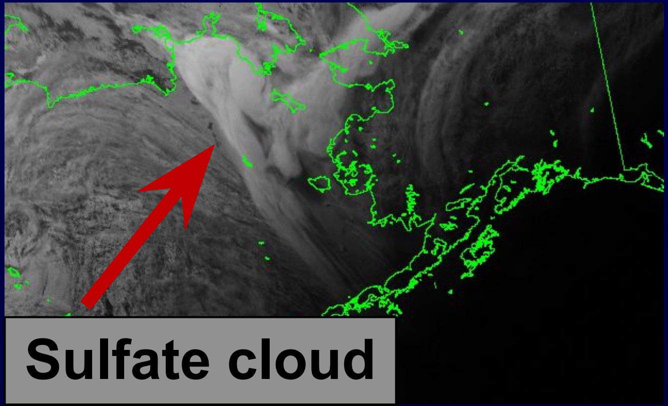


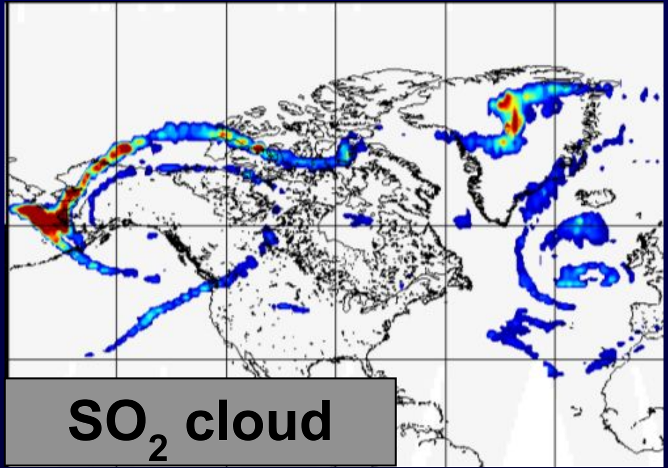
Dispersion model results at 3 altitudes

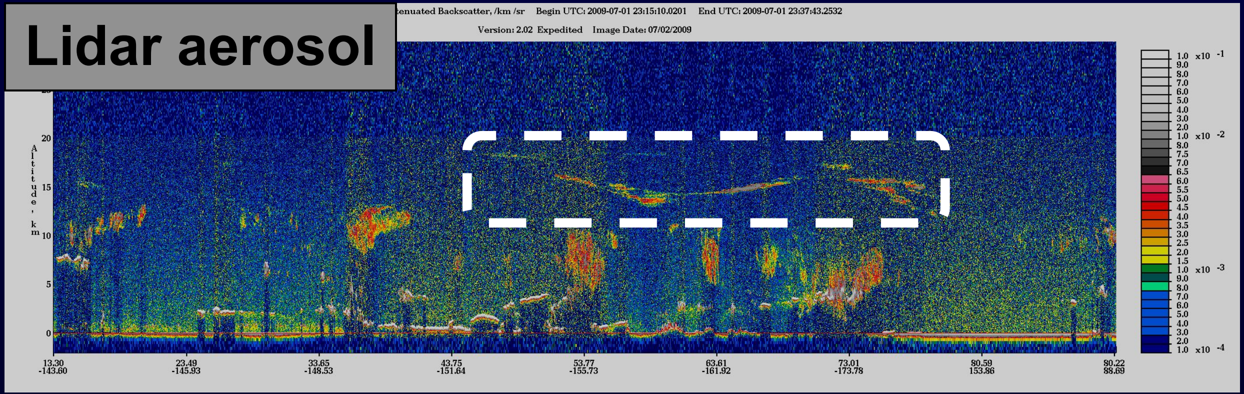
USGS

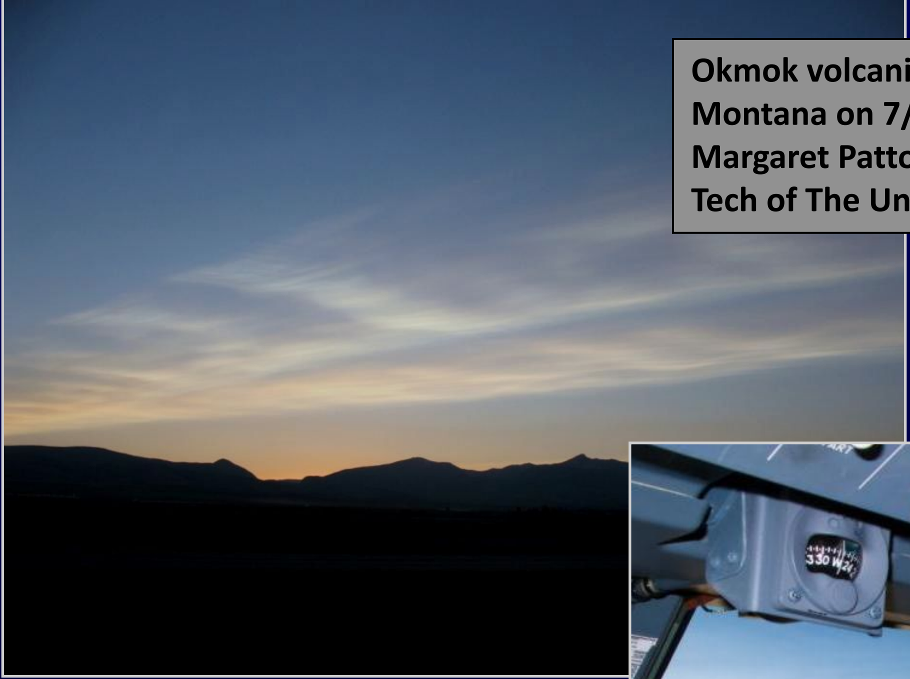
Type 3 volcanic clouds:

Sarychev volcanic cloud at +2 weeks









Okmok volcanic cloud over western Montana on 7/18/2008 (photo by Margaret Patton, Research Office, Montana Tech of The University of Montana)

Okmok volcanic cloud seen from 28,000 ft over Billings, Montana on the evening of 7/19/2008. (Image courtesy of Bradley Johnson and Alaska Airlines)

Color can be deceiving:

Plume between Sun and Observer
Forward Scatter

USGS

Color can be deceiving:

Observer between Sun and Plume

Back Scatter

Plume contains no volcanic ash

USGS

Volcanic Hazards to Aircraft
Redoubt: December 1989

USGS

Redoubt ash encounter

- 150 miles downwind of Redoubt, this B747 flew into what crew thought was a normal cloud but actually was an ash cloud from the eruption.
- All 4 engines failed in 59 seconds
- False warning of cargo-compartment fire displayed
- Airspeed indicators failed
- Aircraft descended without power for 4 minutes over mountainous terrain
- 2 engines restarted with <2 minutes before impact
- Crew managed safe landing in Anchorage, but >$80 million in damage incurred

USGS

ICAO Ash Severity Index

Class	Criteria
0	+ sulphur odour noted in cockpit and/or cabin + anomalous atmospheric haze observed + electrostatic discharge (St. Elmo's fire) on windshield, nose, or engine cowl + volcanic ash reported or suspected by flight crew, but no other effects or damage noted
1	+ volcanic ash deposited on exterior of aircraft + fluctuations in exhaust gas temperature (EGT) with return to normal values + volcanic ash observed in cockpit and/or cabin
2	+ abrasion damage to exterior surfaces (wind screens, engine inlet and/or engine fan blades) + volcanic ash deposited in engine + volcanic ash deposited in cockpit, cabin, and/or air systems + volcanic ash deposited in pitot-static system, insufficient to affect instrument readings
3	+ vibration or surging of engine(s) + plugging of pitot-static system to give erroneous instrument readings + contamination of engine oil and/or hydraulic system + damage to electrical and/or computer systems + engine damage affecting engine performance + interference of navigation and/or communication systems
4	+ engine failure requiring in-flight restart or permanent shutdown of engine(s)
5	+ engine failure or other damage resulting in loss of aircraft

USGS

Number of reports for each severity class: 1953-2016

Severity	Criteria	Number of reports	Percentage of encounters
Class 0	Sulphur odour noted in cockpit and/or cabin	85	36.6
	Anomalous atmospheric haze observed	26	11.2
	Electrostatic discharge (St. Elmo's fire) on windshield, nose, or engine cowl	24	10.3
	Volcanic ash reported or suspected by flight crew, but no other effects or damage noted	28	12.1
Class 1	Volcanic ash deposited on exterior of aircraft	42	18.1
	Fluctuations in exhaust gas temperature (EGT) with return to normal values	2	0.9
	Volcanic ash observed in cockpit and/or cabin	18	7.8
Class 2	Abrasion damage to exterior surfaces (wind screens, engine inlet and/or engine fan blades)	70	30.2
	Volcanic ash deposited in engine	29	12.5
	Volcanic ash deposited in cockpit, cabin, and/or air systems	11	4.7
	Volcanic ash deposited in pitot-static system, insufficient to affect instrument readings	4	1.7
Class 3	Vibration or surging of engine(s)	6	2.6
	Plugging of pitot-static system to give erroneous instrument readings	5	2.2
	Contamination of engine oil and/or hydraulic system fluids	7	3.0
	Damage to electrical and/or computer systems	3	1.3
	Engine damage affecting engine performance	23	9.9
	Interference of navigation and/or communication systems	1	0.4
Class 4	Engine failure requiring in-flight restart or permanent shutdown of engine(s)	9	3.9
Class 5	Engine failure or other damage resulting in loss of aircraft	0	0.0

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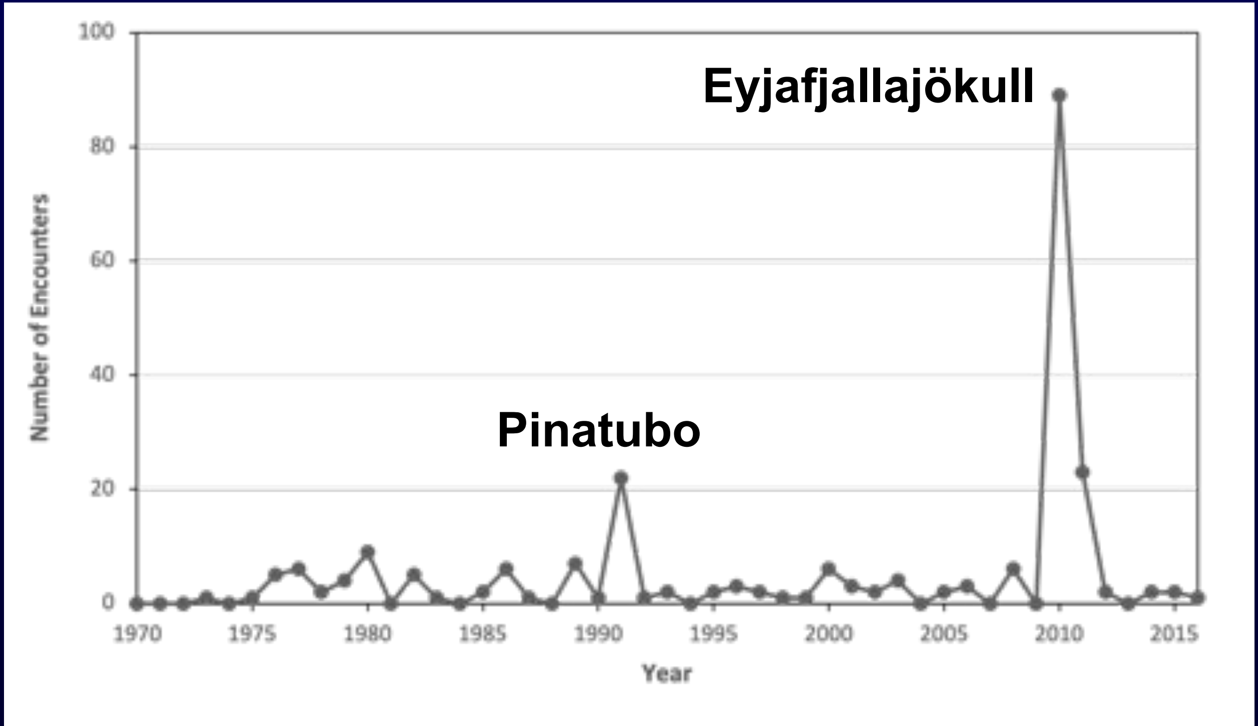
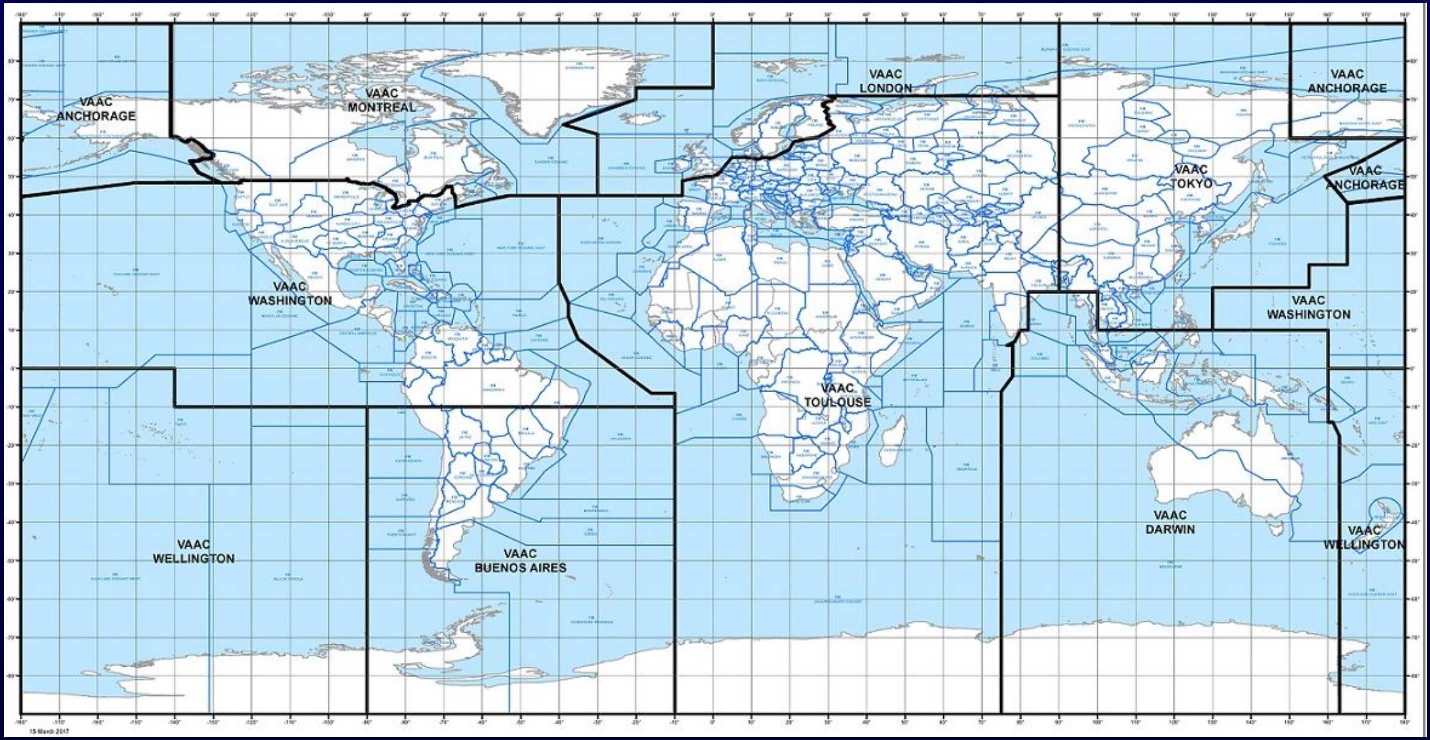
Annual frequency of encounters, 1970 to 2016.



International Airways Volcano Watch (IAVW)

- Formed by ICAO in conjunction with the World Meteorological Organization (WMO) and in consultation with IUGG.
- State Volcano Observatories (SVOs) – provide pre-eruptive and eruptive volcanic information via VONAs.
- Regional Volcanic Ash Advisory Centres (VAACs) – issue warning guidance material via VAAs.
- Meteorological Watch Offices (MWOs) in each State – provide warnings to aviation via SIGMETs.
- Air-Traffic Control Centers (ACC) in each State – provide information about hazardous volcanic activity via NOTAMs.
- Pilots and aircraft operators – provide reports of eruptions and volcanic clouds via PIREPs.

Volcanic Ash Advisory Centers:
Established following 1992 eruption of Pinatubo



Blue polygons show the areas covered by Met Watch Offices (MWOs)

Eyjafjallajökull 2010

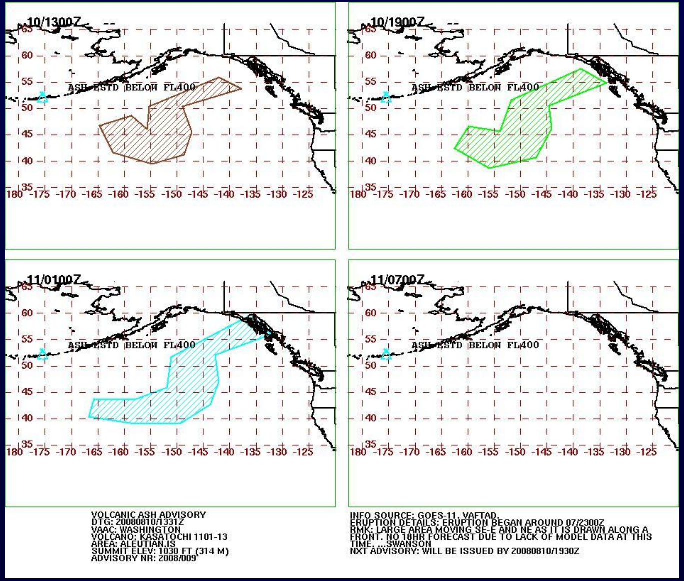
AVOID! AVOID! AVOID!

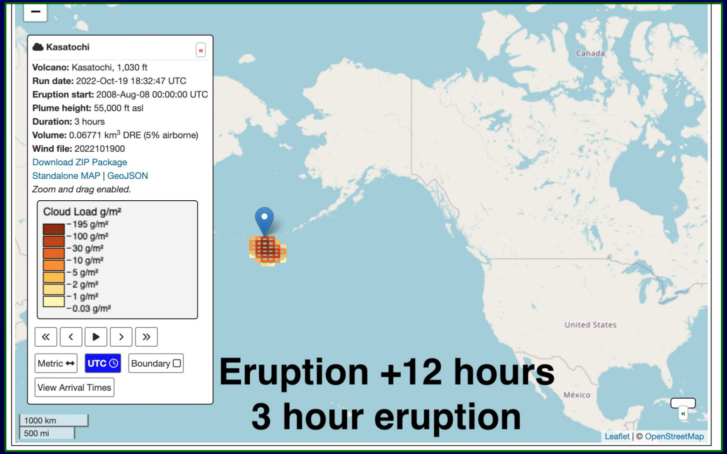
- The 2010 eruption of Eyjafjallajökull caused huge disruption to aviation, highlighting a need to identify volcanic ash concentration thresholds that could improve route efficiency without posing a safety concern for aircraft.
- In response, the International Civil Aviation Organization (ICAO) developed standards for quantitative volcanic ash (QVA) information, to be provided by Volcanic Ash Advisory Centers (VAACs).

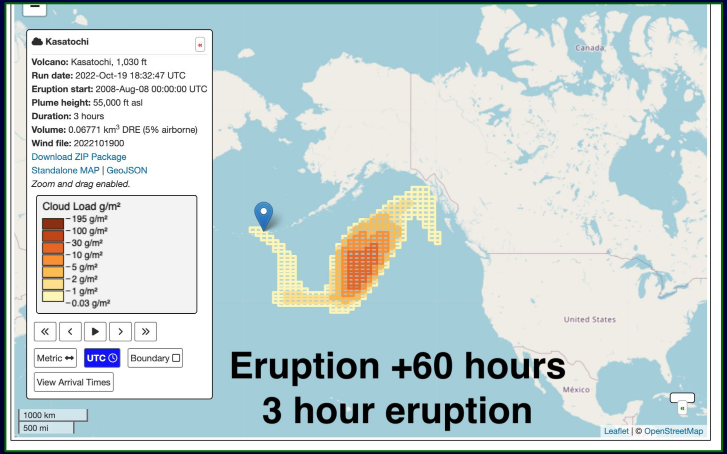
*These are not travelers to IAVCEI 2023

USGS

From polygons to data







USGS

Consistently applying the ICAO Aviation Color Code

AVIATION COLOR CODES	
When the volcano color code changes, a Volcano Observatory Notification for Aviation (VONA) is issued.	
GREEN	Volcano is in typical background, non-eruptive state or, *after a change from a higher level,* volcanic activity has ceased and volcano has returned to noneruptive background state.
YELLOW	Volcano is exhibiting signs of elevated unrest above known background level or, *after a change from a higher level,* volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
ORANGE	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, **OR** eruption is underway with no or minor volcanic-ash emissions [ash-plume height specified, if possible].
RED	Eruption is imminent with significant emission of volcanic ash into the atmosphere likely **OR** eruption is underway or suspected with significant emission of volcanic ash into the atmosphere [ash-plume height specified, if possible].

Aviation Color Code: Developed by USGS and adapted by ICAO as a recommended practice (2024).

- Ideally Aviation Color Code would be consistently applied across all volcano observatories of the world
- Some challenges:
  - Wording can be interpreted in different ways (e.g. minor, significant, typical background)
  - Public intuitively understand colors, but Aviation Color Code not reflective of hazards on the ground
  - Choice at times to couple Aviation Color Code with ground-based systems

Volcano Observatory Notice for Aviation (VONA)

- Use of the VONA for communicating volcanic unrest is in the process of becoming a recommended practice by ICAO.
- A State volcano observatory should issue a VONA under the following circumstances:
  - when volcano level of alert color code is changed; or
  - within a color-code level when an ash-producing event or other significant change in volcanic behavior occurs;
  - for episodes of observed re-suspended ash that could pose a hazard to aviation
- VONAs are to be part of the international aviation communications network


Mahalo and thank you.