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Explosive Volcanic Eruptions: What can Radar do for you?

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U.S. Geological Survey

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Outline

- Explosive volcanic eruptions and ash hazards
- Current radar utility, capabilities, and limitations
- Speculation on improvements in operations and research with a National MPAR system

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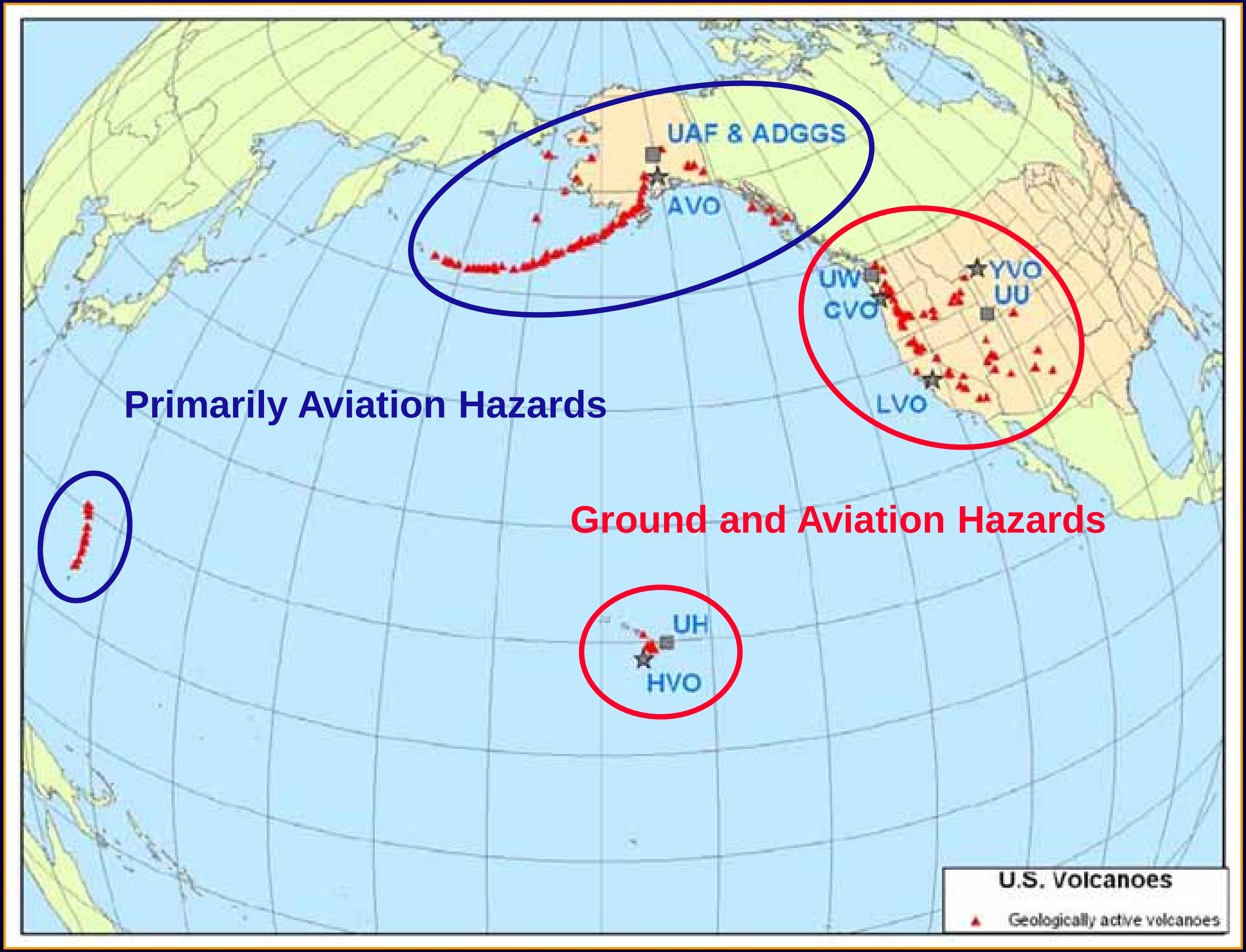
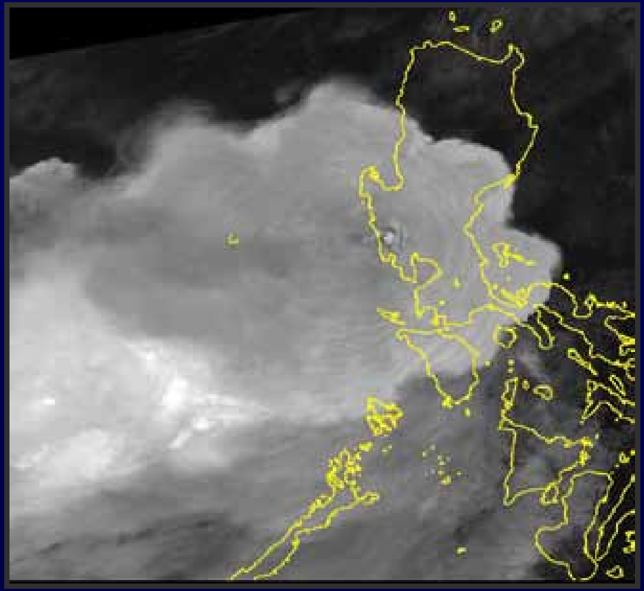
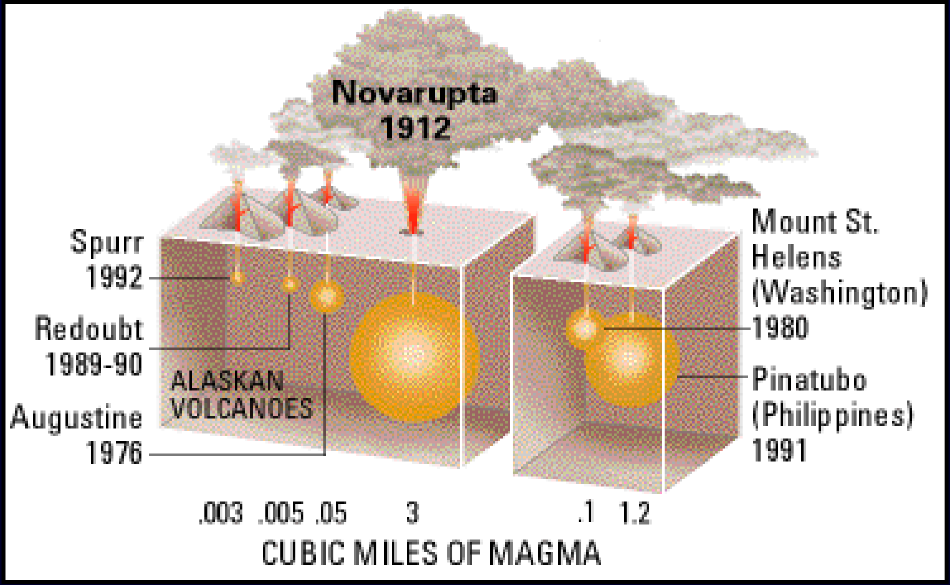
Distribution of U.S. volcanoes and USGS Volcano Observatories



Eruptions vary greatly in size





Volcanic Cloud Composition

- Volcanic Ash (rock fragments and glass)
- Volcanic Gases
  - SO_2, CO_2, other
- Water
  - Solid, Liquid, and Vapor (magma, ice melt, atm.)
- Amounts of these constituents are highly variable

Rapid cloud rise: Flight levels within 5 minutes of onset

Volcanic Cloud Drift

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Volcanic Ash Hazards

- Volcanic ash
  - Abrasive and dense (machinery, roof loading)
  - Conductive (electronics and power grids)
  - Small (infiltration, respiratory concern)
- Ash fallout
  - Most of the ash particles (d>500 microns) fall near the volcano (< 25 km) within the first hour
  - Fine grained ash typically falls out within 12-24 hours at distances of hundreds of km
- Drifting volcanic ash clouds
  - Hazardous to aviation

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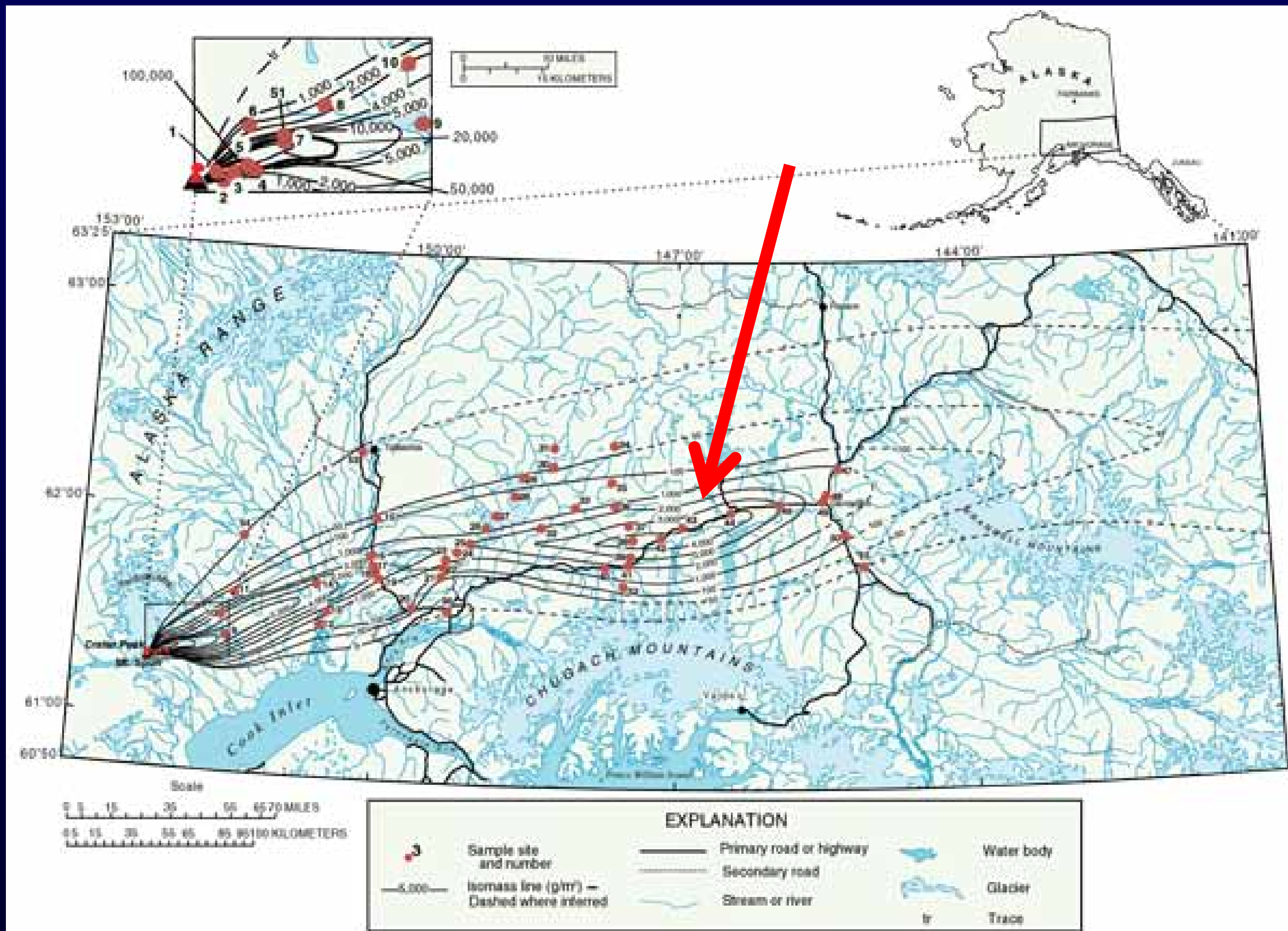
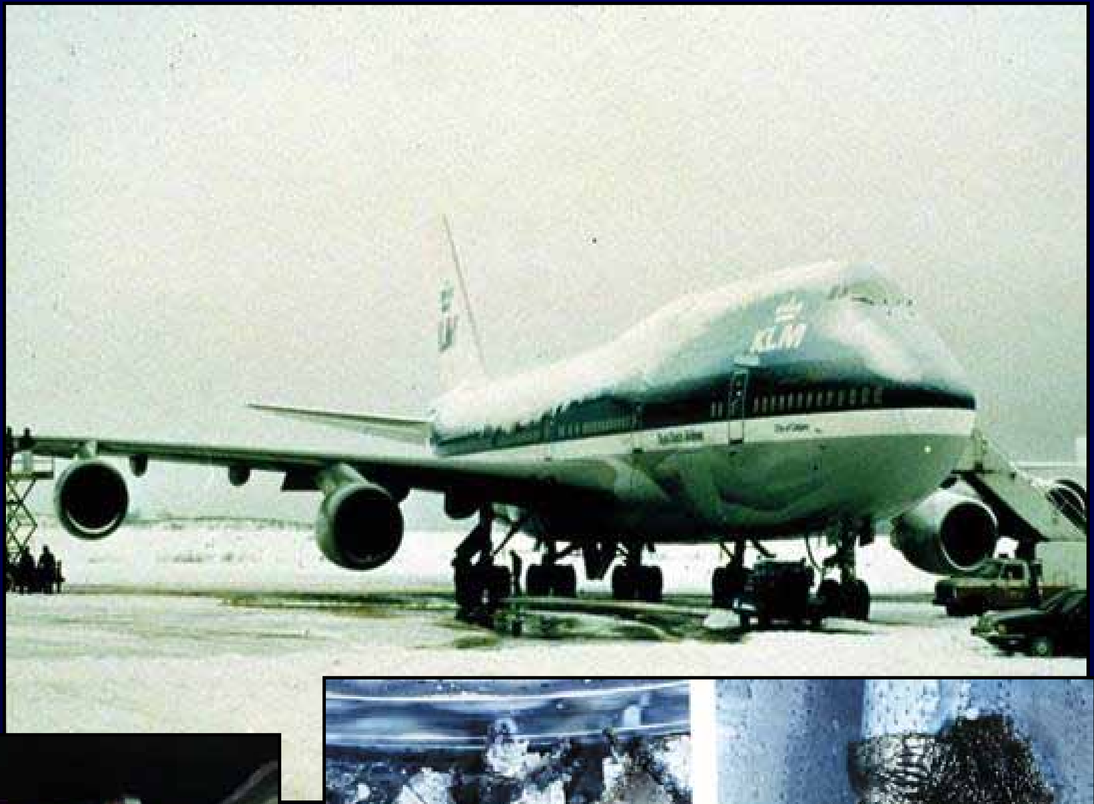
Mt. Spurr ash fall map

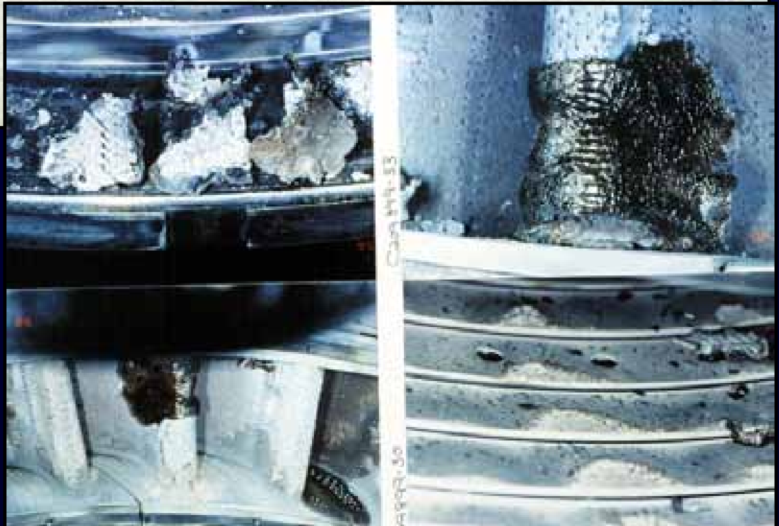


Volcanic ash fall

Redoubt Aircraft Encounter (1989)

- Encountered an ash cloud ca. 250 km from Redoubt Volcano.
- Power from all 4 engines was lost. The aircraft descended to within 1-2 km above the ground before restarting the engines.
- Damage to the aircraft was ca. $US 80M.





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~120 ash/aircraft encounters documented 1973-2008
(*minimum value due to under-reporting*)

ICAO SEVERITY INDEX

Class 0: acrid odor, electrostatic discharge, no damage reported

Class 1: light cabin dust, EGT fluctuations

Class 2: heavy cabin dust, external & int. abrasion damage, window frosting

Class 3: engine vibration, erroneous instrument readings, hydraulic-fluid contamination, damage to engine and electrical system

Class 4: engine failure requiring in-flight restart

Class 5: engine failure or other damage leading to crash

~25% of encounters have resulted in major damage to aircraft.
In 9 encounters, temporary engine failure (flameout) occurred.

** NO CLASS 5 ENCOUNTERS TO DATE **

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Ash hazard mitigation

- Interagency approach:
  - USGS, NWS, FAA, DoD, DHS, State and local agencies
- Eruption onset forecast and detection
- Confirmation of ash emission
- Modeling of ash dispersion and fallout
  - Altitude and movement of ash cloud
  - Vertical mass distribution
  - Eruption duration
  - Ash removal processes
- Radar can be used to constrain model parameters

USGS Volcano Radar Experience

- Mount St. Helens, Washington, 1980
  - (WSR-74C: NWS and FAA: Seattle, Spokane)
- Pinatubo, Philippines, 1991
  - (AN/FPS-77: Clark AFB and AN/FPS-106: Cubi Point NAS).
- Mount Spurr, Alaska, 1992
  - (WR 100-2 C: NWS lease)
- Popocatepetl, Mexico 1997-1999
  - (Kavouras Triton C-band: USGS)
- Augustine, Alaska, 2006
  - (WSR-88D: FAA)
- Fourpeaked, Alaska, 2006
  - (WSR-88D: FAA)
- Redoubt, Alaska, 2009
  - (EEC Minimax C-band: USGS and WSR-88D: FAA)

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Alaska NEXRAD and Volcanoes: 250 km Range

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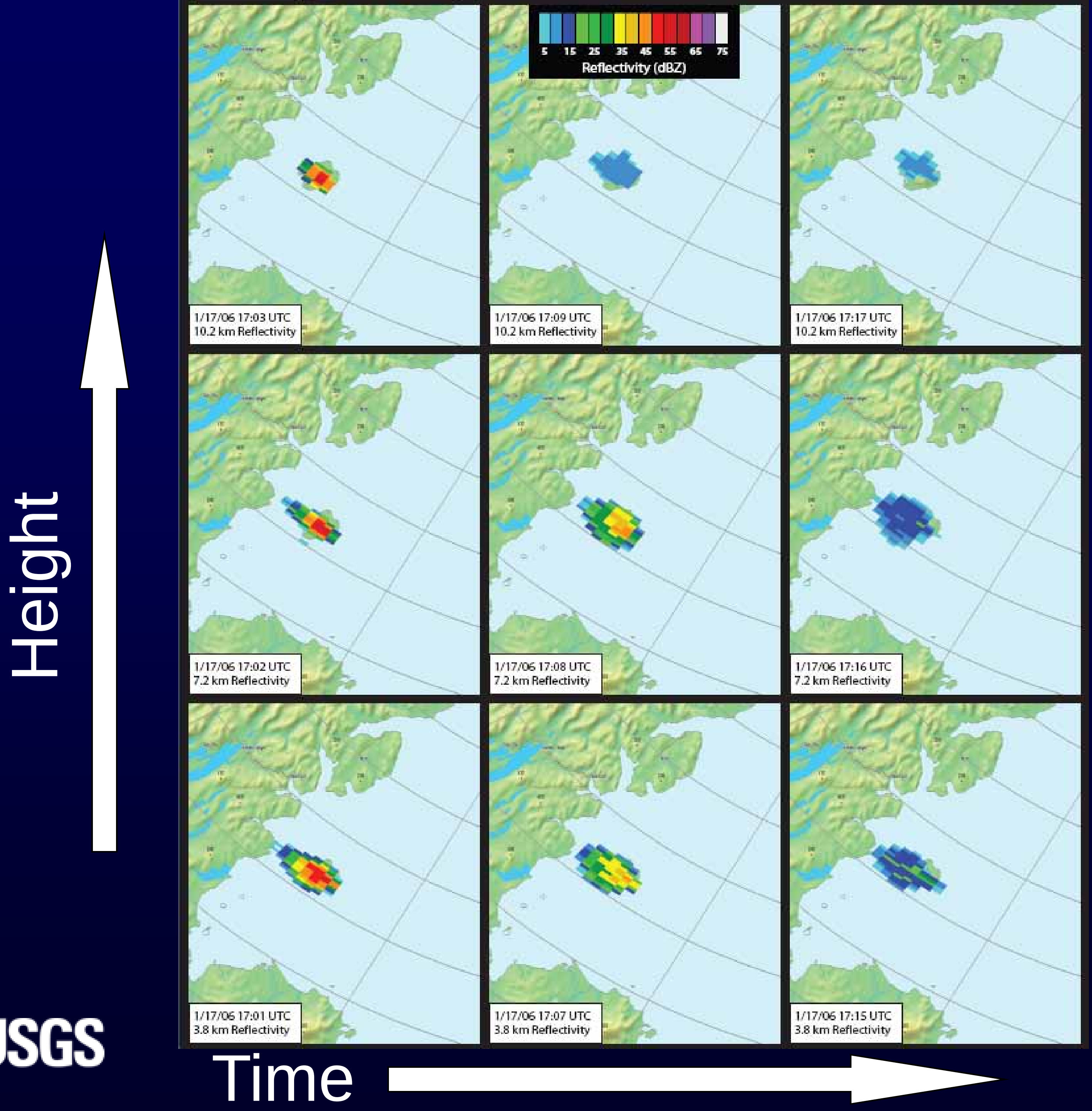
5 15 25 35 45 55 65 75
Reflectivity (dBZ)
1/17/06 17:03 UTC
10.2 km Reflectivity
1/17/06 17:09 UTC
10.2 km Reflectivity
1/17/06 17:17 UTC
10.2 km Reflectivity
1/17/06 17:02 UTC
7.2 km Reflectivity
1/17/06 17:08 UTC
7.2 km Reflectivity
1/17/06 17:16 UTC
7.2 km Reflectivity
1/17/06 17:01 UTC
3.8 km Reflectivity
1/17/06 17:07 UTC
3.8 km Reflectivity
1/17/06 17:15 UTC
3.8 km Reflectivity
Height
Time

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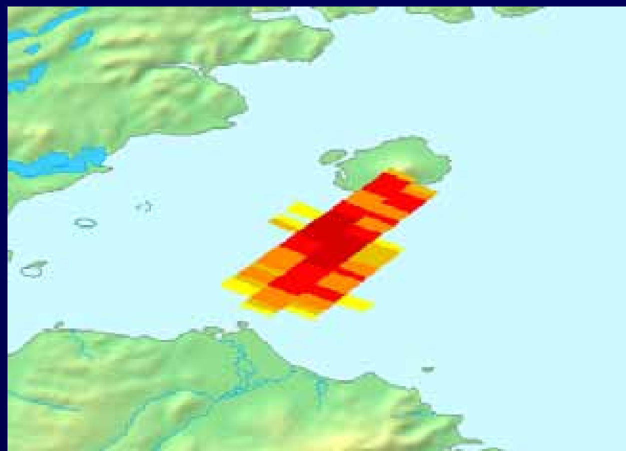
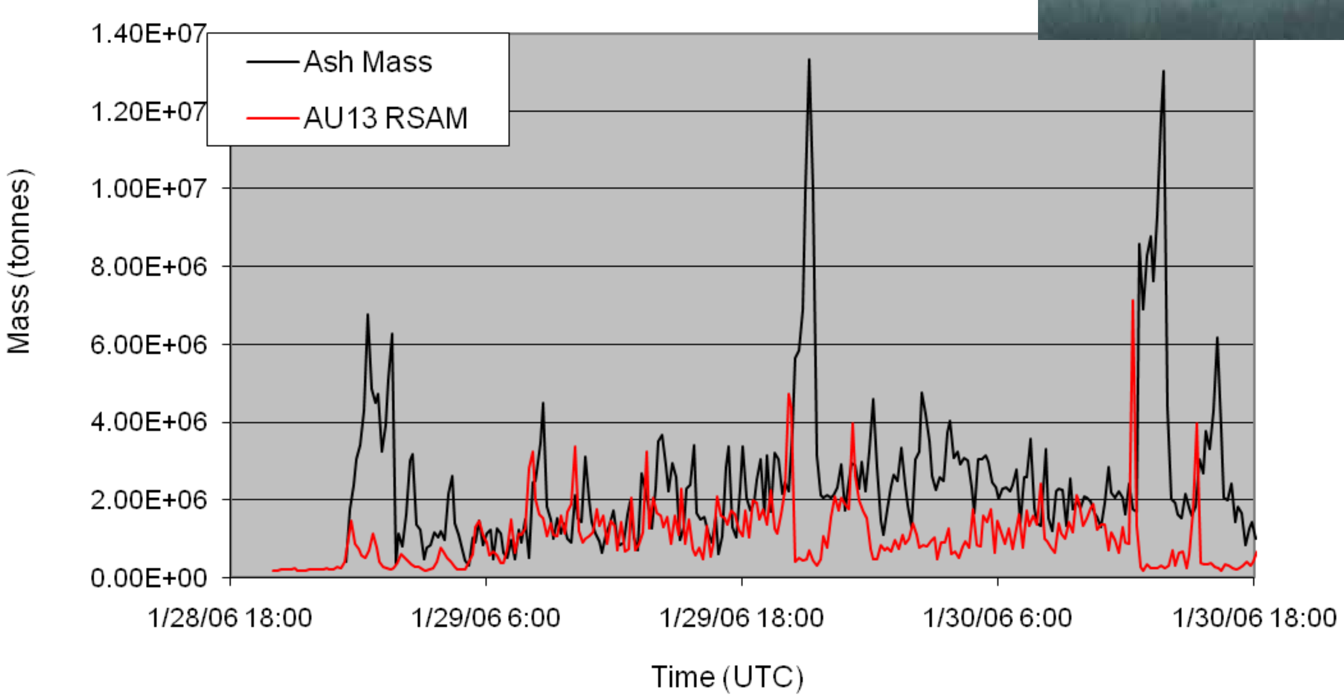
Radar Ash Retrieval

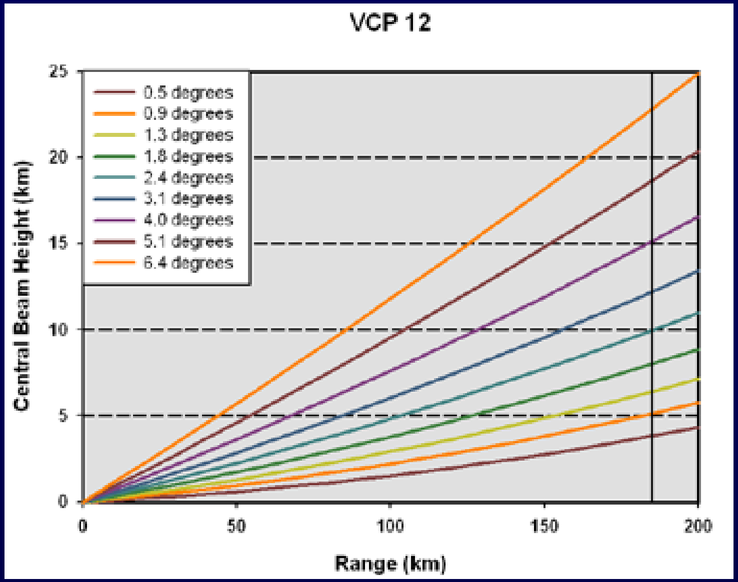


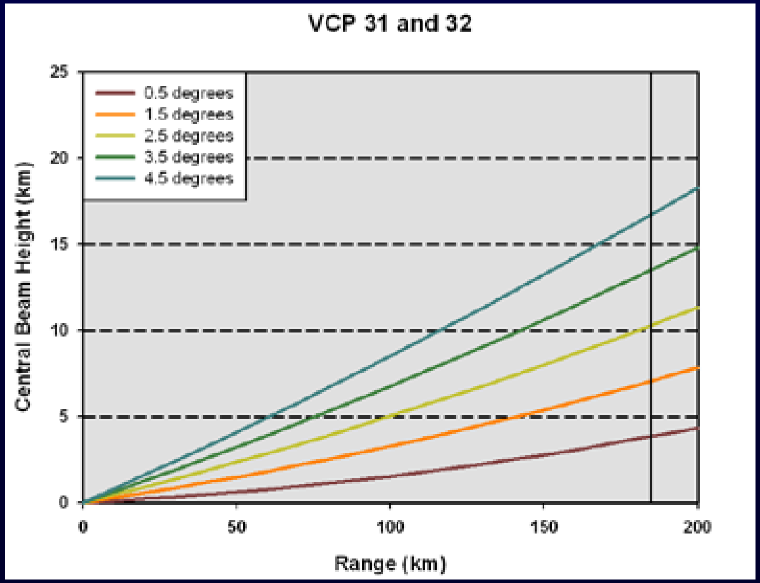


Technique of
Marzano et al., 2006

NEXRAD Limitations

- Temporal resolution
  - 4-10 minutes
- Geographical constraints
  - Many volcanoes have limited or no coverage
- Scan strategy limitations
  - Too close or too far away
- No Level II data for Alaska





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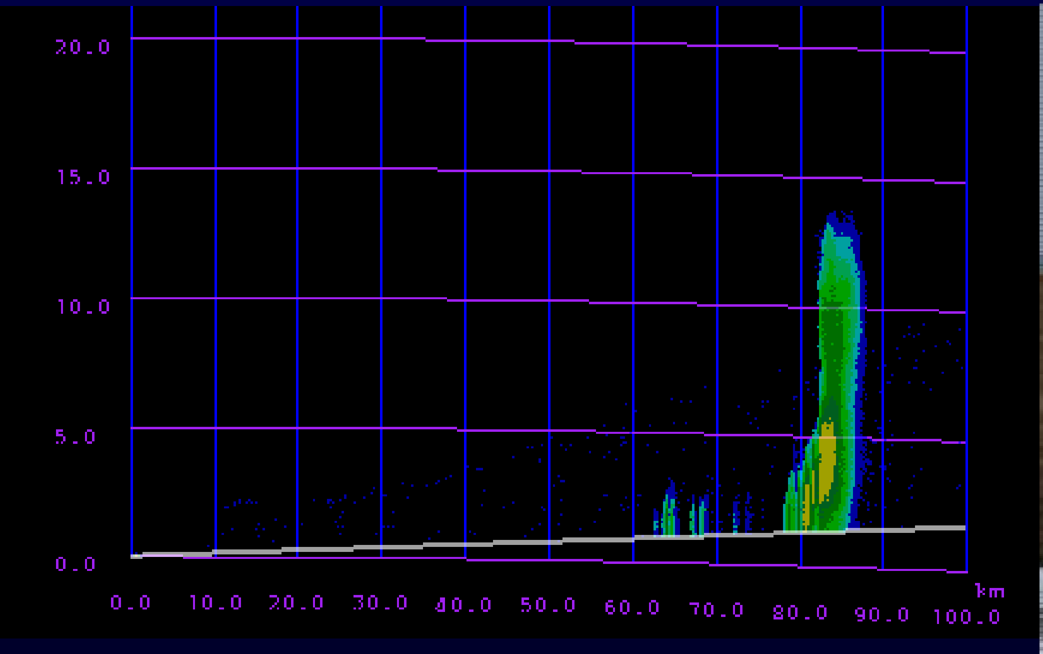
USGS Volcanic Ash Radar
EEC MiniMax 100C

- C-band Doppler; 8’ dish; 250 watts.
- For tactical deployment at restless volcanoes.
- Rapid sector volume scans (60 s) due to limited geographical area.
- RHI mode (15 s).
- Ability to merge radar data with other geophysical data streams



Radar construction: March 6-22

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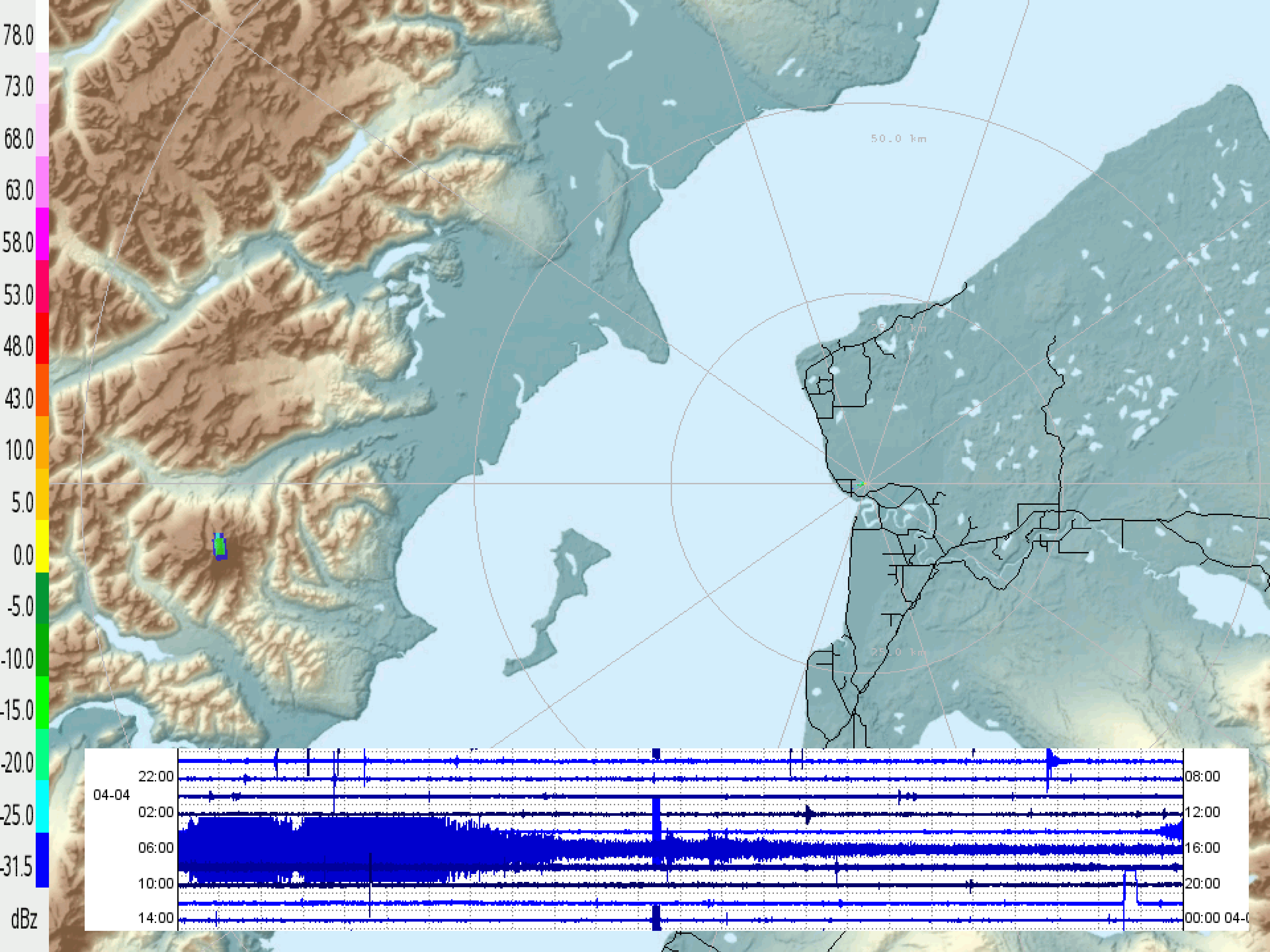
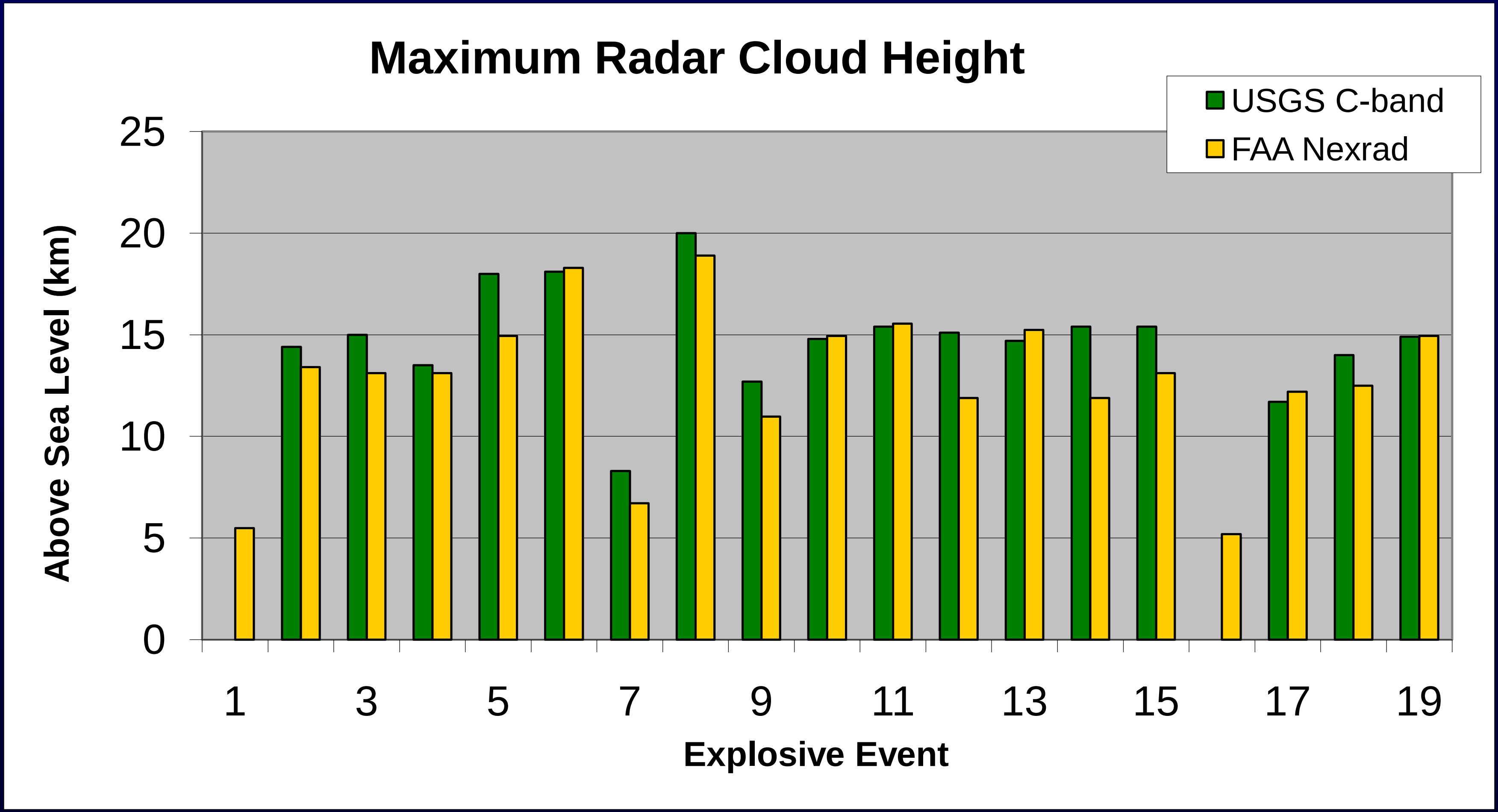

78.0
73.0
68.0
63.0
58.0
53.0
48.0
43.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-31.5
dBz
50.0 km
25.0 km
25.0 km
04-04
22:00
02:00
06:00
10:00
14:00
08:00
12:00
16:00
20:00
00:00


Maximum Radar Cloud Height
USGS C-band
FAA Nexrad
Above Sea Level (km)
0
5
10
15
20
25
1
3
5
7
9
11
13
15
17
19
Explosive Event

MPAR Speculation:
What can be improved?

- **System Improvement**
  - **Greater geographic coverage (put Alaska on the map)**
  - **Faster vertical cross sections**
  - **Polarization**
- **Scientific and operation improvements**
  - **Role of water and ice in eruption column**
  - **Identification of secondary maxima in fall deposits**
  - **Time series of mass loading to constrain eruption source parameters**
  - **Test models of eruption column development**
  - **Spin off development of portable tactical phased-array units.**

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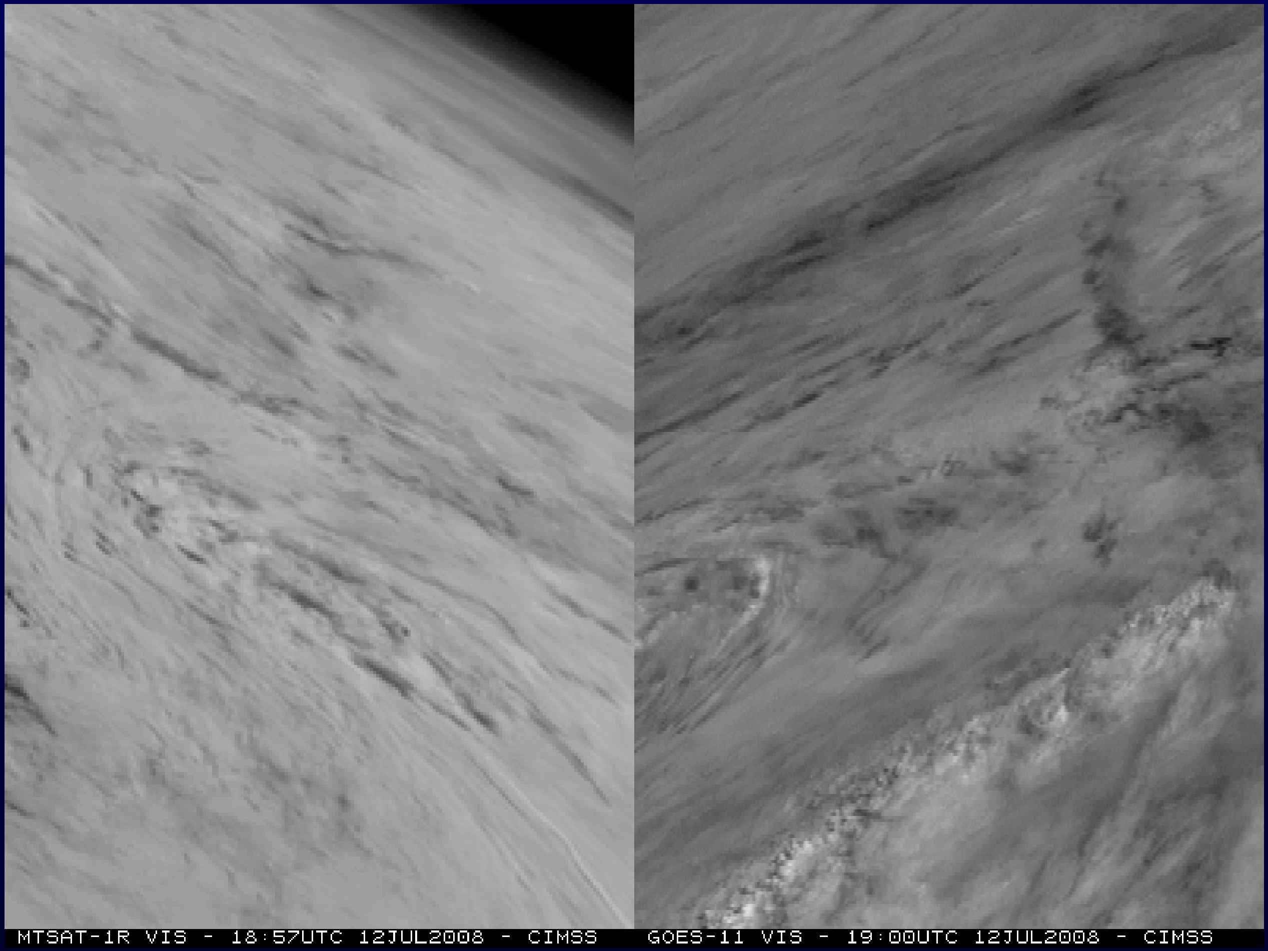
Water in eruption clouds: Okmok 2008



Accretionary lapilli

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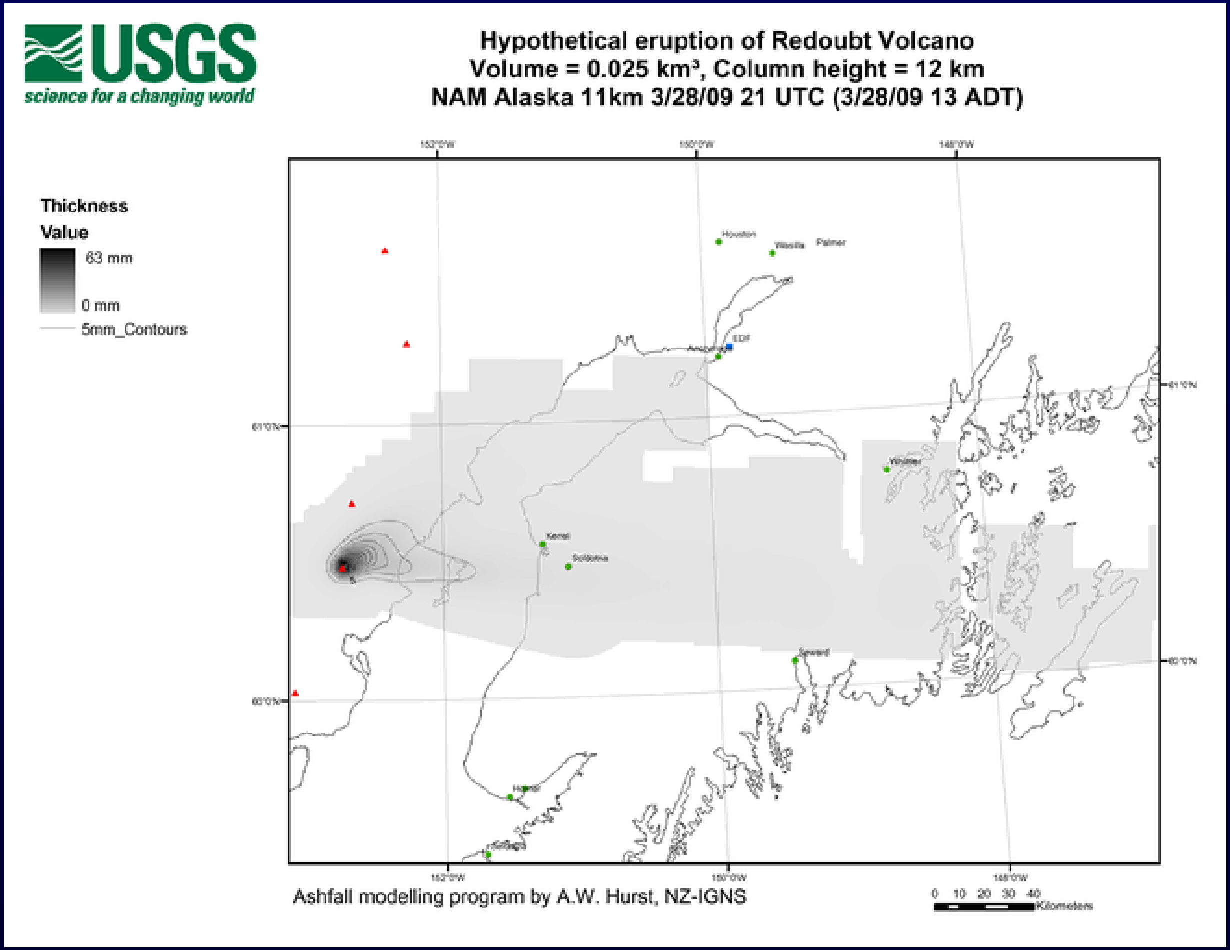
Ash fall modeling



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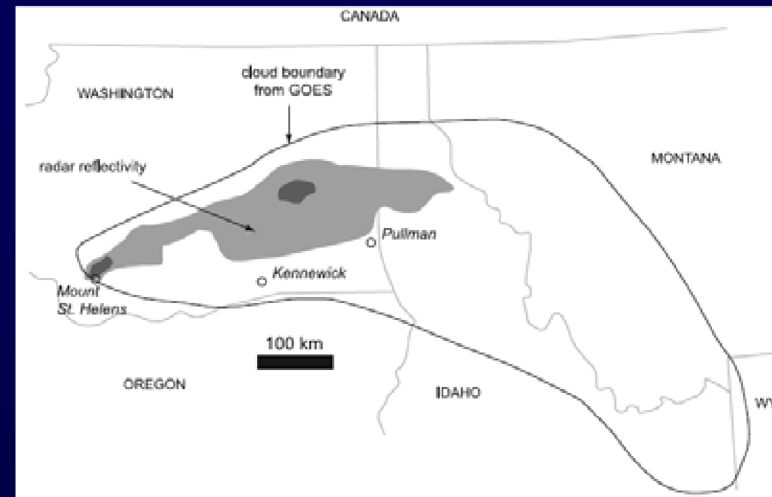
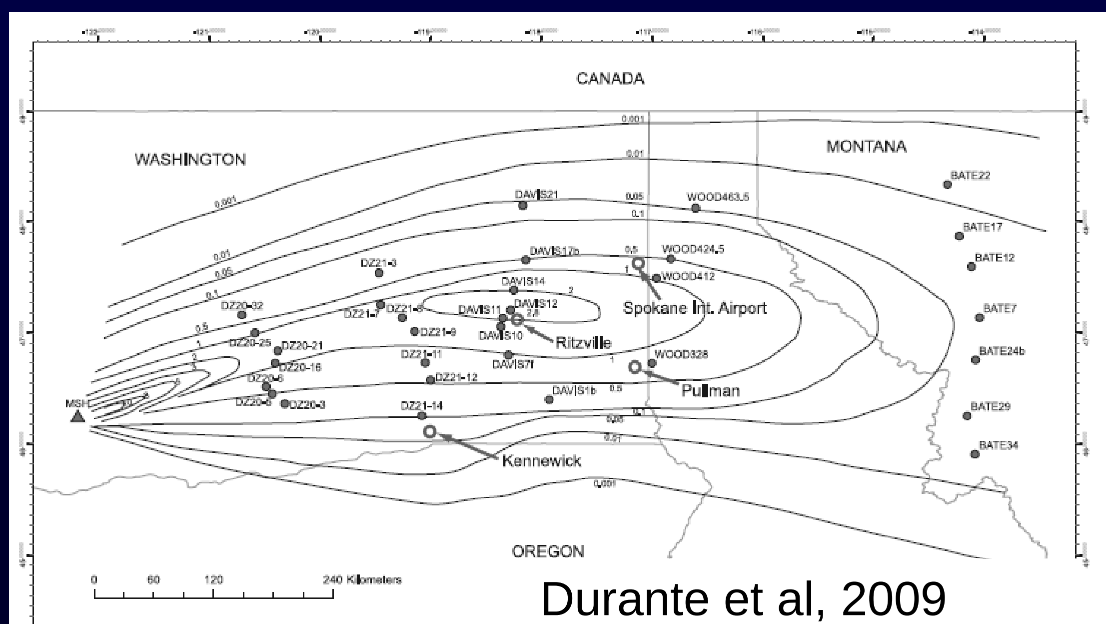
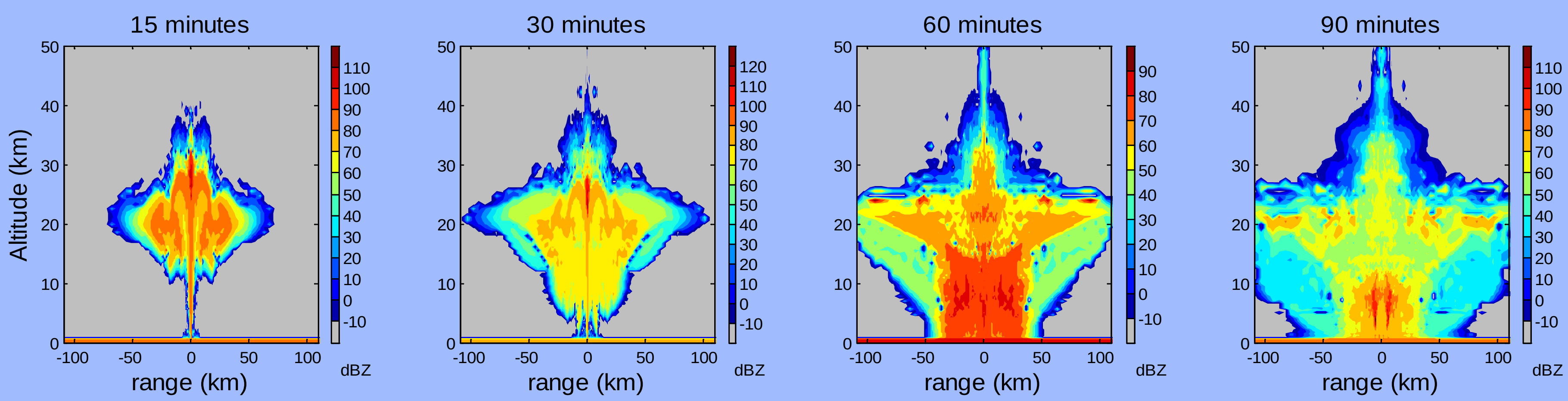
Secondary ash fall maxima





Durante et al, 2009

Validation of eruption models



Marzano et al, in review

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USGS Volcano needs under MPAR (B=baseline, O=optimal)

- Radar
  - Temporal resolution: 1 min (B); 10 sec (O) for short bursts.
  - Beam resolution: 2 km (B); 250 m (O).
  - “Sensitivity”: Ability to image eruption columns (+65 dBz) and drifting fine-grained ash clouds (-10 dBz) without changing modes (O).
  - Dual-polarization to differentiate ash from hydrometeors (B).
- Geographical Coverage
  - WSR-88D sites (B); Eliminate gaps in Aleutians and Northern Marianas (O).
- Data Availability
  - Reflectivity, velocity, spectrum width
  - Delivery to volcano observatories: 5 min (B); near real-time (O).
  - Complete archive of US and it territories (B).

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Thank You

Photo courtesy Nikolay Ushakov