Detecting and Tracking Airborne Volcanic Ash with WSR-88 Radars

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Why Track Volcanic Ash?

- It is a hazardous substance for human health
- It is especially dangerous for modern aviation
  - small ash particles go through filters & damage airplane engines and electronic equipment
  - ash from Iceland’s Eyjafjoll Volcano (2010) caused major disruptions of European aviation operations for more than a month
- It affects weather and climate
  - Injected into the upper troposphere/stratosphere, ash particles can reside there for years with weather & climate repercussions

What Do We Know about Radar-Sensing of Ash?

- Most of what we know comes from sensing by radars other than WSR-88Ds
- Fragments of magma, burned material, and other particles thrown into the air are called **tephra**, together with gases they form a plume
- Plumes from even weak eruptions (concentrations as low as 0.2 g m^{-3}, and particle sizes of 2 mm diameter and smaller) can pose aviation and other hazards
- Plumes from stronger eruptions emit large ash and other particles in greater concentrations
- Based on size and concentration, plumes over and nearby the vent can produce reflectivities > 70 dBZ
- Because larger particles fall out quickly, at ranges >50 km from the vent, plume reflectivity magnitudes usually lower to <30 dBZ
- However, a secondary peak in reflectivity at longer range from the vent can occur when condensation of volcano water vapor on ash particles and quick freezing produces ice particles and snowflakes

Volcanic Ash Radar Data from Abroad

Eruption	Type of radar, frequency band	Distance to volcano, km	Intensity of eruption, maximal echo height
1. Mt Hekla, Iceland, 26-27 February, 2000	Keflavik, **C-band,** single pol,	144	Moderate, H_{max} = 12 km
2. Grimsvotn, Iceland, November 2004	Keflavik, **C-band**, single pol.	260	Moderate, H_{max}= 15 km.
3. Eyjafjöll, Iceland, April-May 2010	Keflavik**, C-band**, single pol.	156	Moderate. H_{max} = 10 km.
4. Mt Etna, Sicily, Italy, April 2010	DPX4, **X band**, **dual-pol**	30	Weak, H_{max} = 6 km.
5. Grimsvotn, Iceland, May 2011	DPX1, **X-band**, **dual-pol**	70	Moderate, H_{max}= 18 km
6. Kelud, Indonesia, February 2013	**C-band**, single-pol	75	Intense, Hmax = 22 km
7. Calbuco, Chili, April 2015	RMA, **C-band**, **dual-pol**	124	Intense, H_{max}= 24 km

#1; Lacasse, et al, 2004


#3; Marzano, et al, 2013

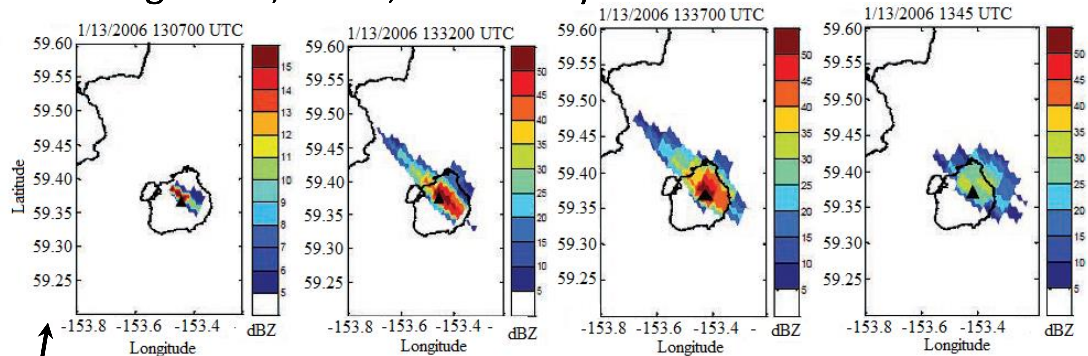

#7; Vidal, et al, 2015

Volcanic Ash Radar Data from the U.S. & Territories

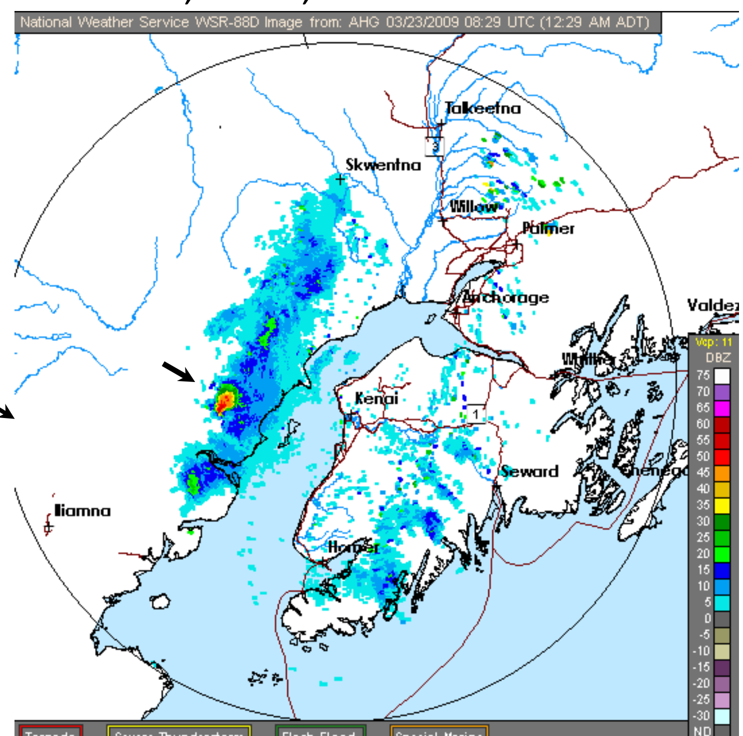
Year	Volcano	Location	Radar, frequency band	Distance between volcano and radar, km	Max Z (dBZ) / Hmax (km)	Reference
1976	Augustine	Alaska	WSR-75 C-band	188	N/A	Sawada 2004
March 1982	Mt St. Helens	Washington	WSR-75 C-band	82	25 / 11	Harris and Rose 1983
August 1992	Spurr	Alaska	WSR-75 C-band	81	35 / 16	Rose et al. 1995b
April 2005	Anatahan	Mariana Islands	**WSR-88D** S-band Guam,PGUA	320	>50 / ?	UCAR COMET METED Pg 4.1.3
January 2006	Augustine	Alaska	**WSR-88D** S-band Kenai,PAHG	190	55 / 13.3	Marzano et al. (2010b)
March 2009	Redoubt	Alaska	**WSR-88D** S-band Kenai,PAHG	80	>75/ 16	This Study

WSR-88D Precip (Clear-Air) Modes ~5 (~15) dB more sensitive than previous radars

Mt Augustine, PAHG, 13 January 2006



Mt Redoubt, PAHG, 23 March 2009



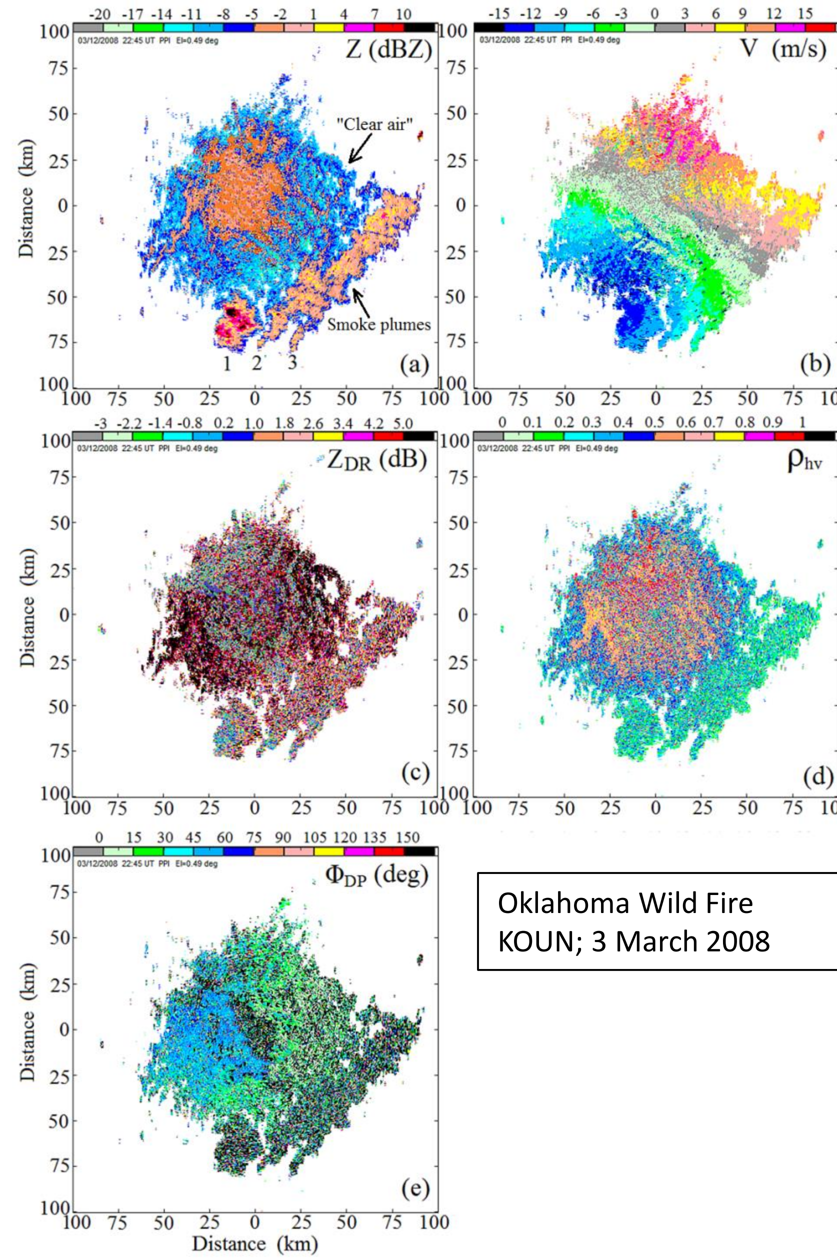
Augustine: Note short duration of eruption, plume weakening

Redoubt: Note NNE-SSW band of precip overlaying eruption and masking plume; <u>this is a problem for automated detection and tracking</u>

Dual-Pol Properties of Volcanic Ash

Parameter	X-band radar	C-band radar	wild fire S-band
Max reflectivity, dBZ	40	65	>28
Differential reflectivity, dB	-0.5 to +1.5	-1.5…1.5 (Grimsvotn) -1…3 (Calbuco)	1…3
Correlation coefficient	0.980 … 0.992	0.8…1 (Grimsvotn) 0.5…1 (Calbuco)	0.3…0.7
Differential phase, deg	Not available	Not available	-8
Specific differential phase, deg/km	-0.1 … 3	0 … 1.5 (Grimsvotn)	~0

- No WSR-88D (S-band) Dual-Pol data in volcanoes have been collected
- X- & C-band data have scattering properties different from S-band
- Oklahoma wild fire data have been used (for now) as a proxy for S-band
- <u>There is great need for WSR-88D volcanic Dual-Pol data to be collected</u>



Oklahoma Wild Fire
KOUN; 3 March 2008

Likely Places to Collect WSR-88D Volcano Data

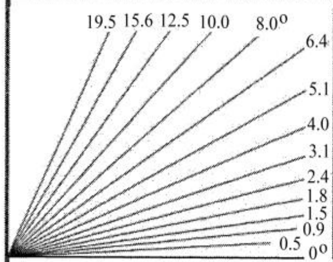
Data from U.S. Geological Survey (USGS)

	Volcano	State	Recent activity	Nearest WSR-88D distance (km)
1	Mt St. Helens	Washington	1980, 1982	KRTX, 80 KATX, 133
2	Mt Rainier	Washington	Dormancy	KATX, 71 KRTX, 156
3	Crater Lake	Oregon	Dormancy	KMAX, 97
4	South Sister	Oregon	Dormancy	KRTX, 171 KMAX, 214
5	Mt Hood	Oregon	Early 1800s	KRTX, 71
6	Mt Shasta	California	Dormancy	KMAX, 114 KBHX, 174
7	Lassen Volcanic Center	California	1917	KBBX, 153 KRGX, 169
8	Mauna Loa	Hawaii	1984	PHKN, 58 PHWA, 32
9	Kilauea	Hawaii	1983	PHKN, 74 PHWA, 42
10	Redoubt	Alaska	2009	PAHG, 80

- Of the 169 geologically active volcanoes in the U.S., 54 have threat levels of “High”
- Listed are the 10 most dangerous volcanoes
- Note that the top 6 volcanoes are in more-populated states of WA, OR, and CA

Likely Places to Collect WSR-88D Volcano Data

Recommended Scan Strategies for WSR-88 Volcano Data Collection

Quick Reference VCP Comparison Table for RPG Operators as of RPG Build 18						July 2016
Slices	Tilts	VCP	Time*	Algs.	Usage	Limitations
	14	12	4.3 mins	AVSET SAILS MRLE	Fastest VCP. Rapidly evolving, severe convective events (e.g. squall line, MCS).	High antenna rotation rate decreases the effectiveness of clutter filtering and decreases the accuracy of the base data estimates.
		212	4.6† mins		Rapidly evolving, severe convective events (e.g. supercells, squall line, MCS). Uses SZ-2 to significantly reduce range-obscured V/SW data compared to VCP 12.	All Bins clutter suppression is not recommended. High antenna rotation rate decreases the effectiveness of clutter filtering and decreases the accuracy of the base data estimates. PRF sectors not allowed.

- **VCPs 212** is recommended for data collection even though it doesn't have the best sensitivity or accuracy of the estimates. The deciding factors are faster update time and better vertical coverage.
- It is recommended that **AVSET** (faster VCP termination once plume has been topped) and **SAILS** (more 0.5° updates) both be turned on
- **VCP 31** is recommended for weak-reflectivity ash clouds, and those at longer distances from radars (>230 km range)

Techniques to Increase Detectability of Volcanic Eruption Radar Echoes

- **Increase the Number of Samples in Spectral Processing**
  - Increase the SNR of weak signals
  - Perhaps modify VCP 31 to have more samples per estimate, and terminate at a lower top elev angle, with decrease in total VCP time period
- **Use Coherent Summation**
  - Use the sum of return from H and V channels to increase SNR of weak signals
- **De-speckle Radar Fields**
  - De-speckling allows use of a lower SNR threshold

Final Thoughts

- WSR-88D radars have the sensitivity and other favorable attributes to detect volcanic eruptions (strong-reflectivity) and track ash plumes (weak-reflectivity) as they travel downwind of the eruption

- Automated WSR-88D algorithms to detect and track volcanic ash can be developed

- However, further algorithm development awaits collection of WSR-88D Dual-Pol data that will allow for proper separation of ash from precipitation particles and other non-precipitation particles