ASAP Volcano Research at Lincoln Laboratory

Earle R. Williams, MIT LL

NASA Applied Sciences Weather Program Review

November 18-19, 2008

NCAR

Outline

- DoD satellite assets with capabilities for volcano surveillance
- Design considerations
- Aviation safety and interest in 5 minute warning time
- Practical measures of hazard: VEI and plume height
- Height detection capability in daytime
- The Hazard Support System
- Sample eruptions – The radiance “spike”
- Plume height vs. peak radiance:
  - Judging the hazard of an eruption based on the first 60 seconds of its behavior
- Suggestions for exploitation by FAA, NOAA VAAC, NRL, NASA etc.

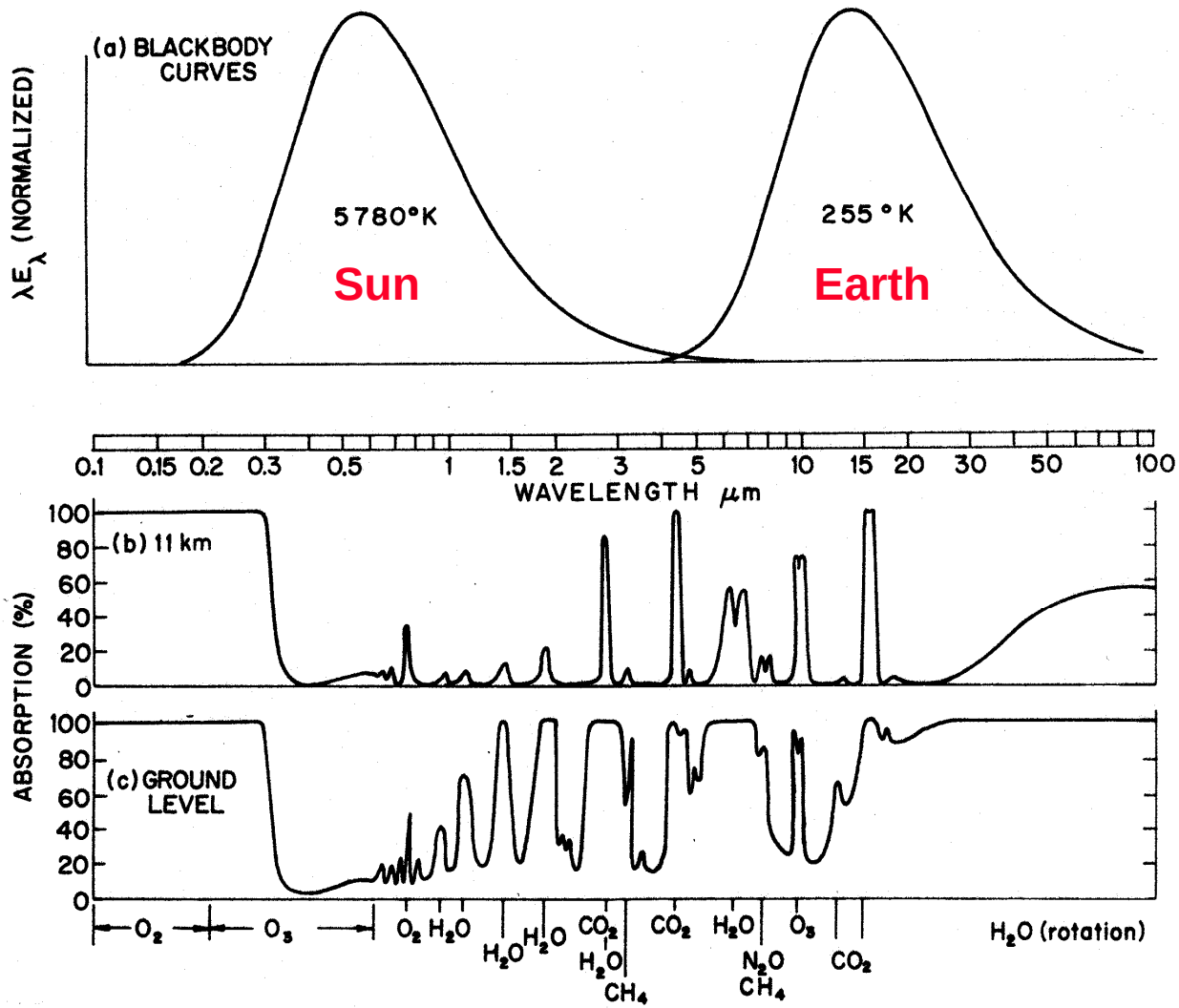
DoD Satellite Infrared Sensors

- **Design objective:**
  - **Detection of hot, water-vapor-laden rocket exhaust**
- **Sub-minute temporal resolution for entire earth**
- **Volcanic eruptions:**
  - **Hot (magma temperature ~1000°C) and water-vapor laden plumes**
- **Most serious limitation: cloud cover and blockage by water-laden eruption cloud**

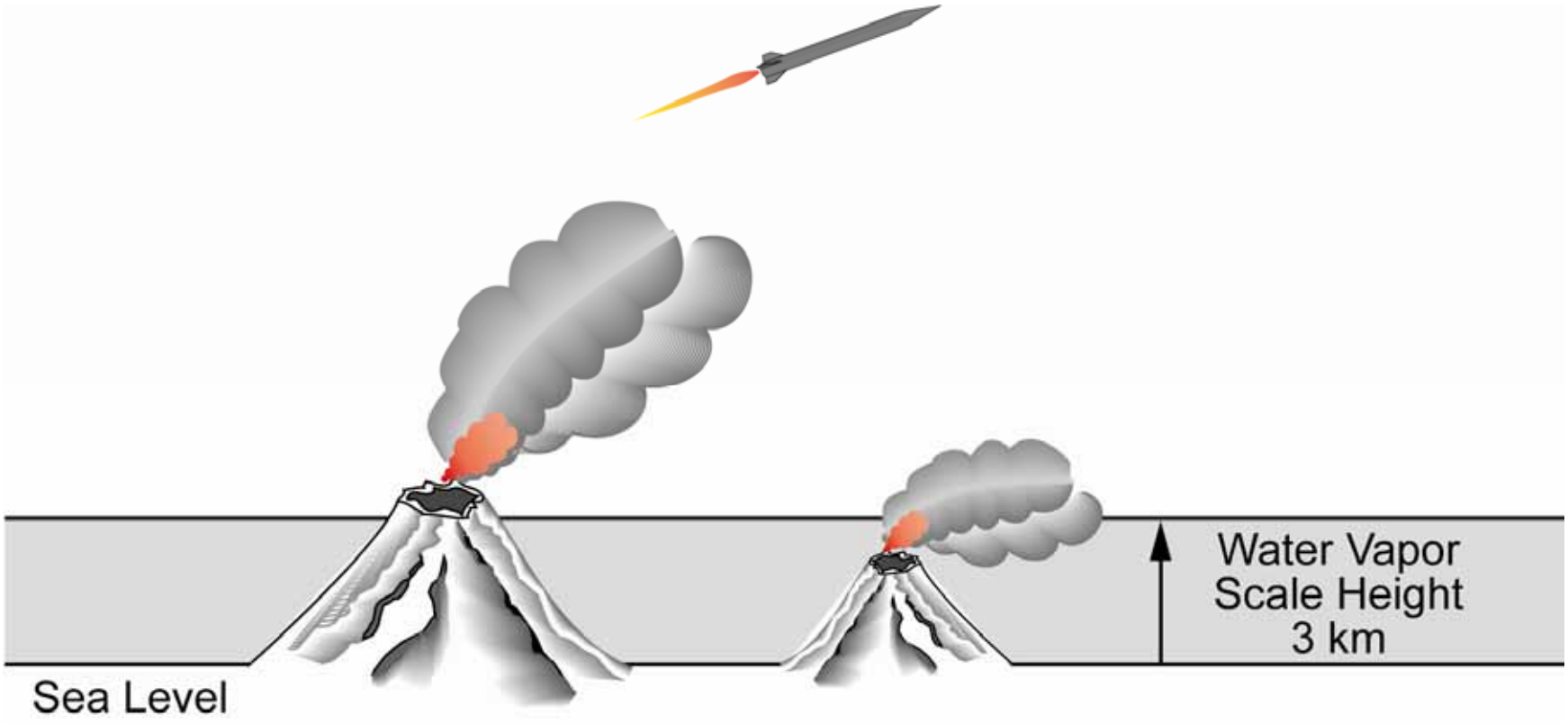
Most Valuable Unclassified Reference to the Capabilities of DoD Satellites

Pack, D.W., C.J. Rice, B.J. Tressel, C.J. Lee-Wagner and E.M. Oshika, Civilian Uses of Surveillance Satellites, Crosslink, The Aerospace Corporation Magazine, January 2000, 2-8, 2000.

Selection of Operating Wavelength



The Influence of Water Vapor on Detectability



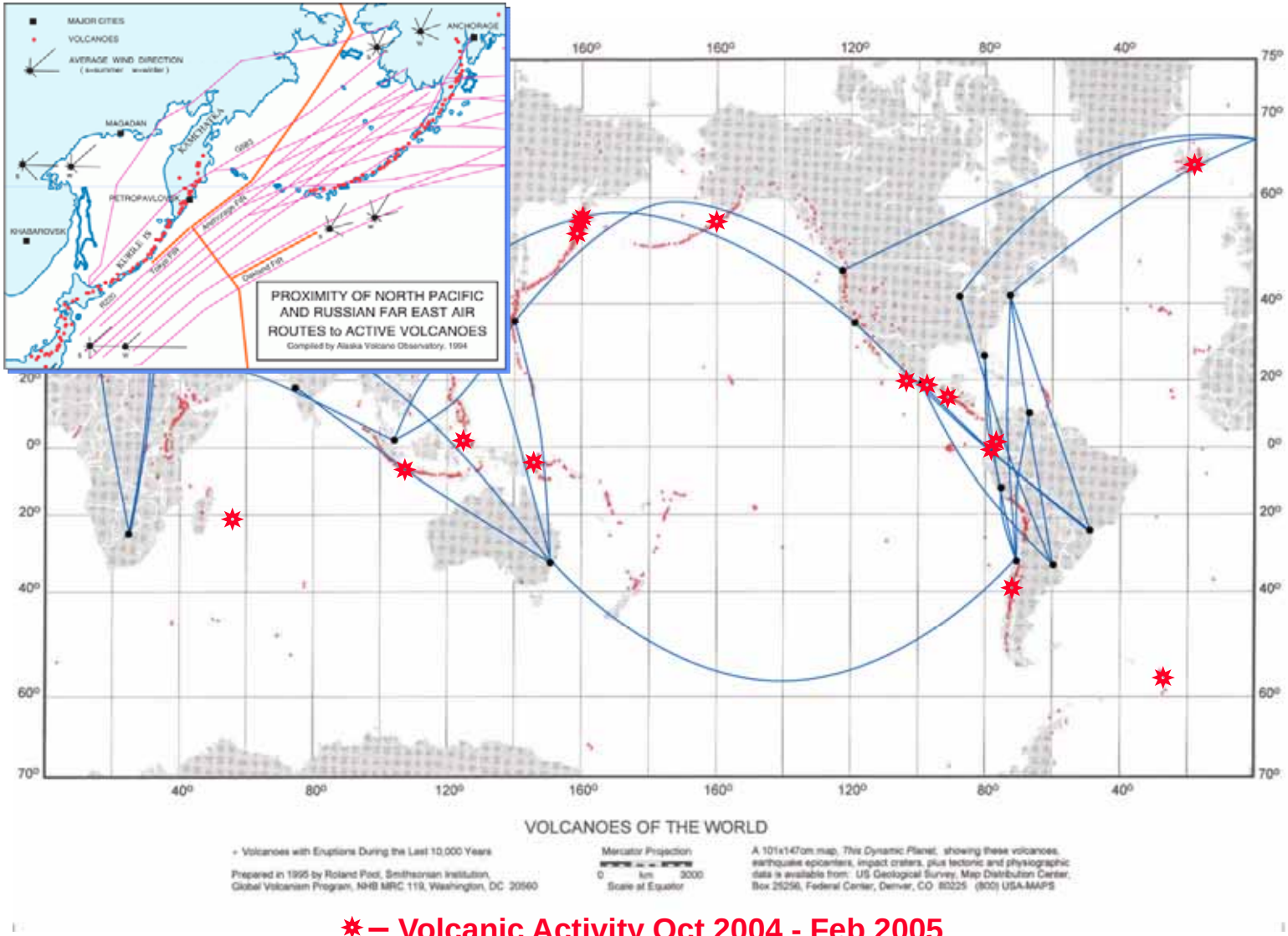
416137_m_3.ai

Volcanic Anvil Cloud

Ascending eruption cloud from Redoubt Volcano and its reflection in the waters of Cook Inlet. View is to the west from the Kenai Peninsula.

Photograph by J. Warren, April 21, 1990

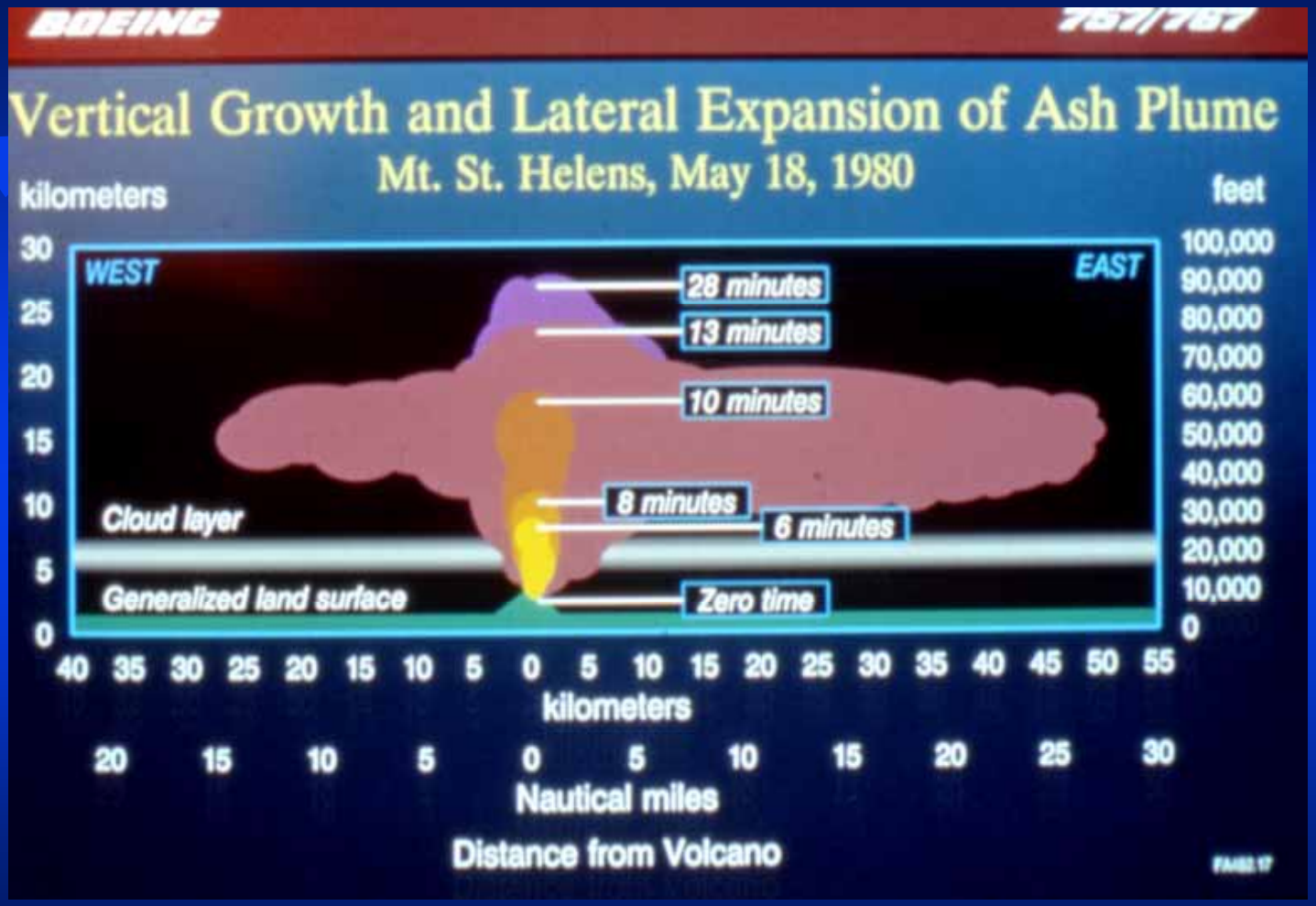
Aviation Routes Subject to Volcanic Ash Hazard



✸ – Volcanic Activity Oct 2004 - Feb 2005

Justification for Need for 5-Minute Warning Time

(Courtesy: Len Salinas, United Airlines)



Advantages Over Civilian Satellites

DoD	Civilian
• 10 Second Updates	• 10 – 30 Minute Updates
• Multiple Satellites	• Single Satellite (GOES)

Prominent Magma Types in Volcanic Eruptions

Increasing Viscosity ↓

Magma	Temperature
Komatiite	1500 C
Basalt	1250 C
Andesite	1150 C
Dacite	1000 C
Rhyolite	900 C

Example of Incandescent Basalt

Volcanic Explosivity Index

	0	1	2	3	4	5	6	7	8
General Description	Non-Explosive	Small	Moderate	Moderate-Large	Large	Very Large			
Volume of Tephra (m^3)		1×10^4	1×10^6	1×10^7	1×10^8	1×10^9	1×10^{10}	1×10^{11}	1×10^{12}
Cloud Column Height (km) Above crater Above sea level	<0.1	0.1-1	1-5	3-15	10-25	>25			
Qualitative Description	"Gentle,"	"Effusive"	"Explosive"	"Severe,"	"Cataclysmic,"	"violent,"	"paroxysmal," "terrific"		"colossal"
Eruption Type (see fig. 6)	Hawaiian	Strombolian		Vulcanian	Plinian		Ultra-Plinian		
Duration (continuous blast)	<1 hour		1-6 hrs	6-12 hrs			>12 hrs		
CAVW max explosivity (most explosive activity listed in CAVW)	Dome or mudflow		Lava flow / Phreatic				Explosion or Nuee ardente		
Tropospheric Injection	Negligible	Minor	Moderate	Substantial					
Stratospheric Injection	None	None	None	Possible	Definite	Significant			

Table 4. Volcanic Explosivity Index (VEI) criteria. [99]

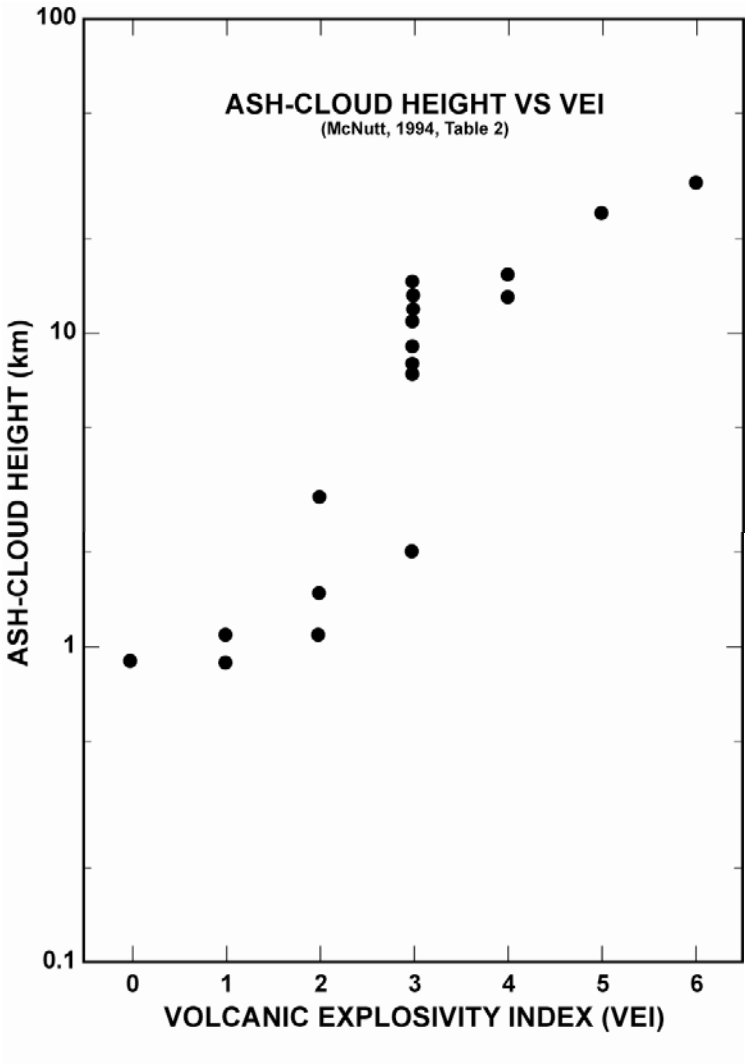
Simkin and Siebert (1994)

Magma Composition for Eruptions with Lightning

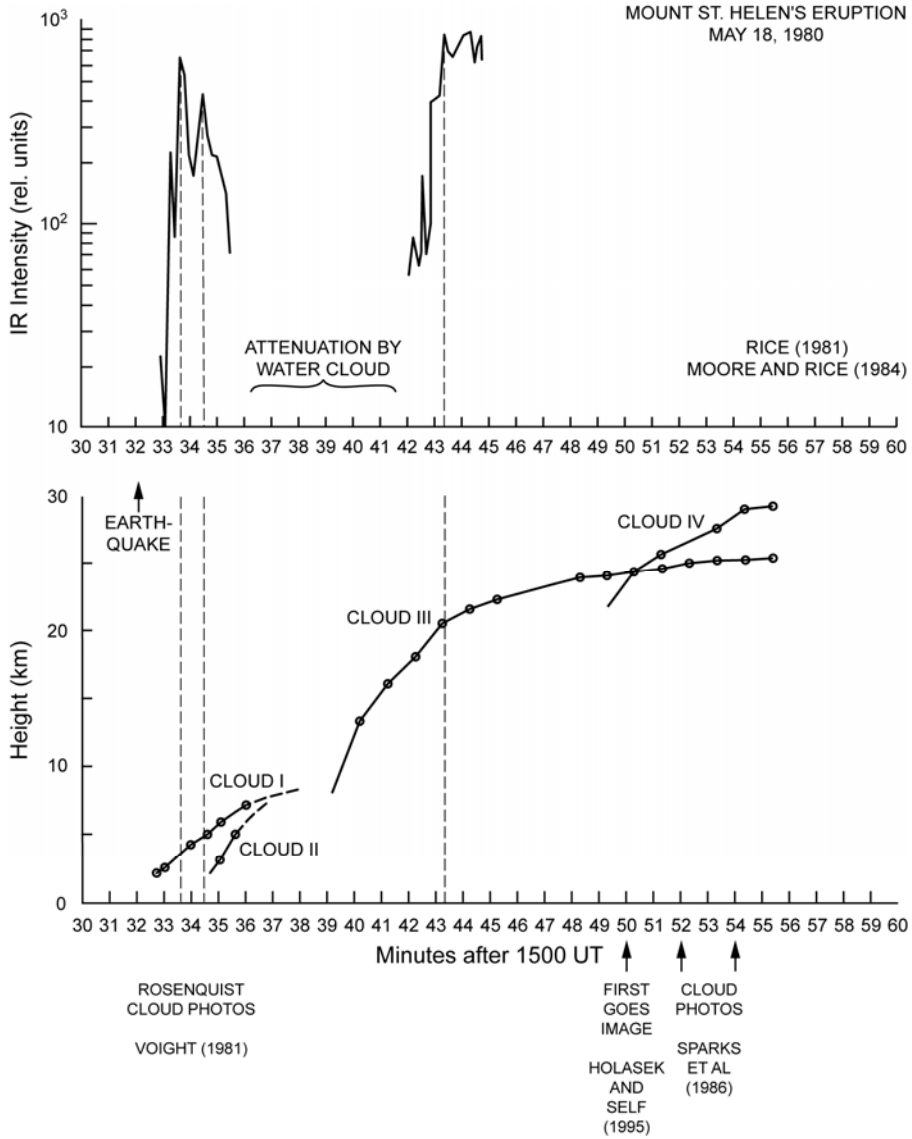
From McNutt and Williams, 2009)

Plume Height km	Basalt	BA	Andesite	AD	Dacite	Rhyolite
0-1		BA	A,A			R,R
1-2	B,B	BA	A,A,A,A			R,R
2-3	B		A,A,A,A,A			
3-4	B,B		A,A			
4-5		BA			D	
5-6	B		A			
6-7		BA,BA				
7-8		BA	A,A,A	AD	D	
8-9	B	BA		AD		
9-10			A,A,A	AD,AD,AD		
10-11	B		A,A,A,A	AD,AD,AD,AD	D	
11-12	B		A,A			
12-13				AD,AD	D,D	
13-14	B	BA,BA	A			
14-15		BA				
15-16			A			
16-17	B					
17-18						
18-19		BA,BA				
19-20						
20-21	B		A		D,D	
21-22						
22-23					D	
33					D	

Plume Height vs. Magnitude of Eruption

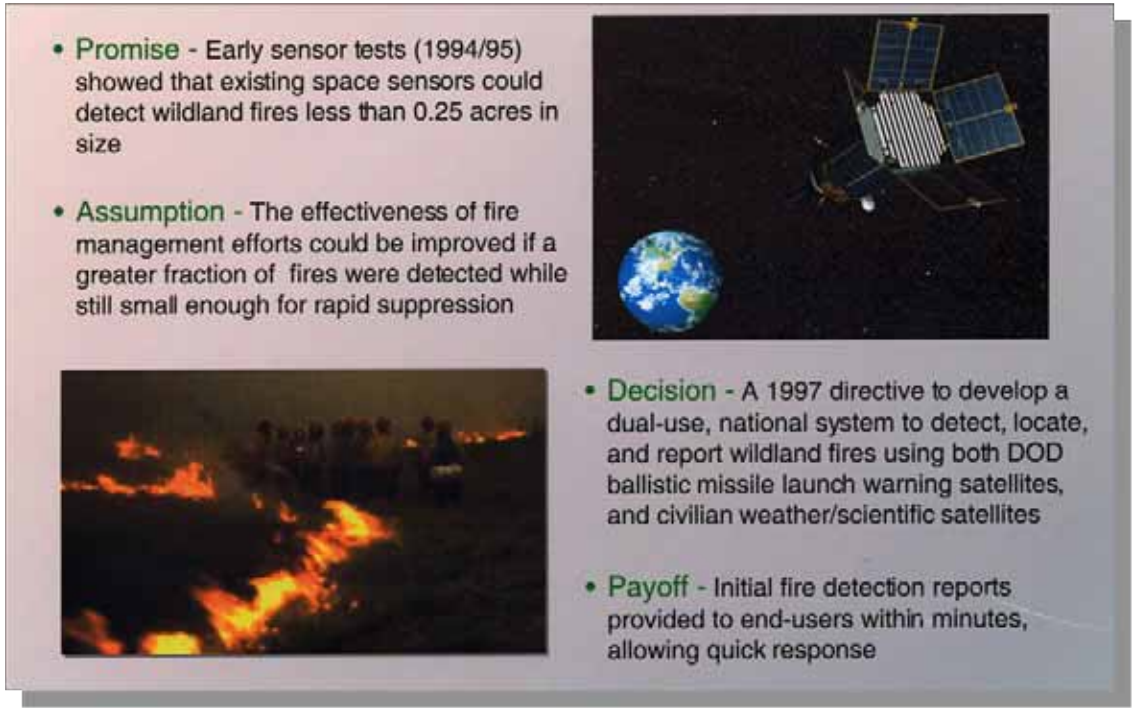


Integrated DoD Satellite Analysis on Mt St Helens- May 18, 1980



Hazard Support System (HSS)

- **Utilization of DoD and civilian satellite assets to identify natural hazards in two categories**
  - **Fires**
  - **Volcanic eruptions**



- **Period of operation:**
  - **1997-1999**

- **Information on times and locations of volcanic eruptions were supplied to the Washington VAAC for a short time**

Information on Global Detection Efficiency (Sparse)

Although there is a large degree of uncertainty in our analysis, it is fair to say that, during late January-early February, the HSS eruption-detection algorithm was reliably detecting less than half of all known eruptions, and was spuriously detecting as many non-volcanic events as volcanic events. Since then, some obvious improvements to the detection algorithm have been implemented and more are planned in coming months.

In our opinion, it is much too early to assess the value of HSS to the Volcano Hazards Program.

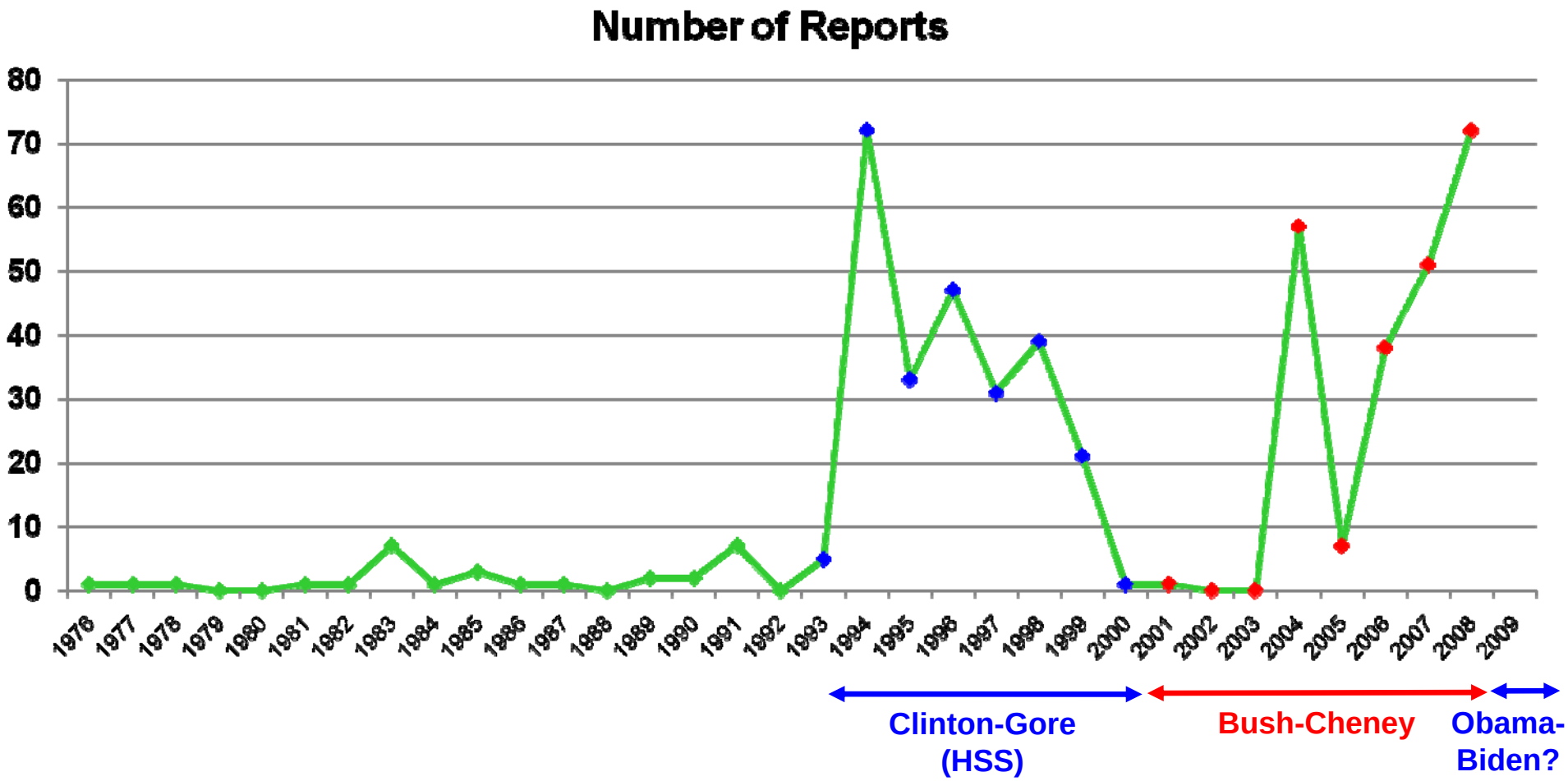
From: Memorandum dated April 19, 1999 from the Hazard Support System

Authors: Dan Dzurisin and Chris Newhall

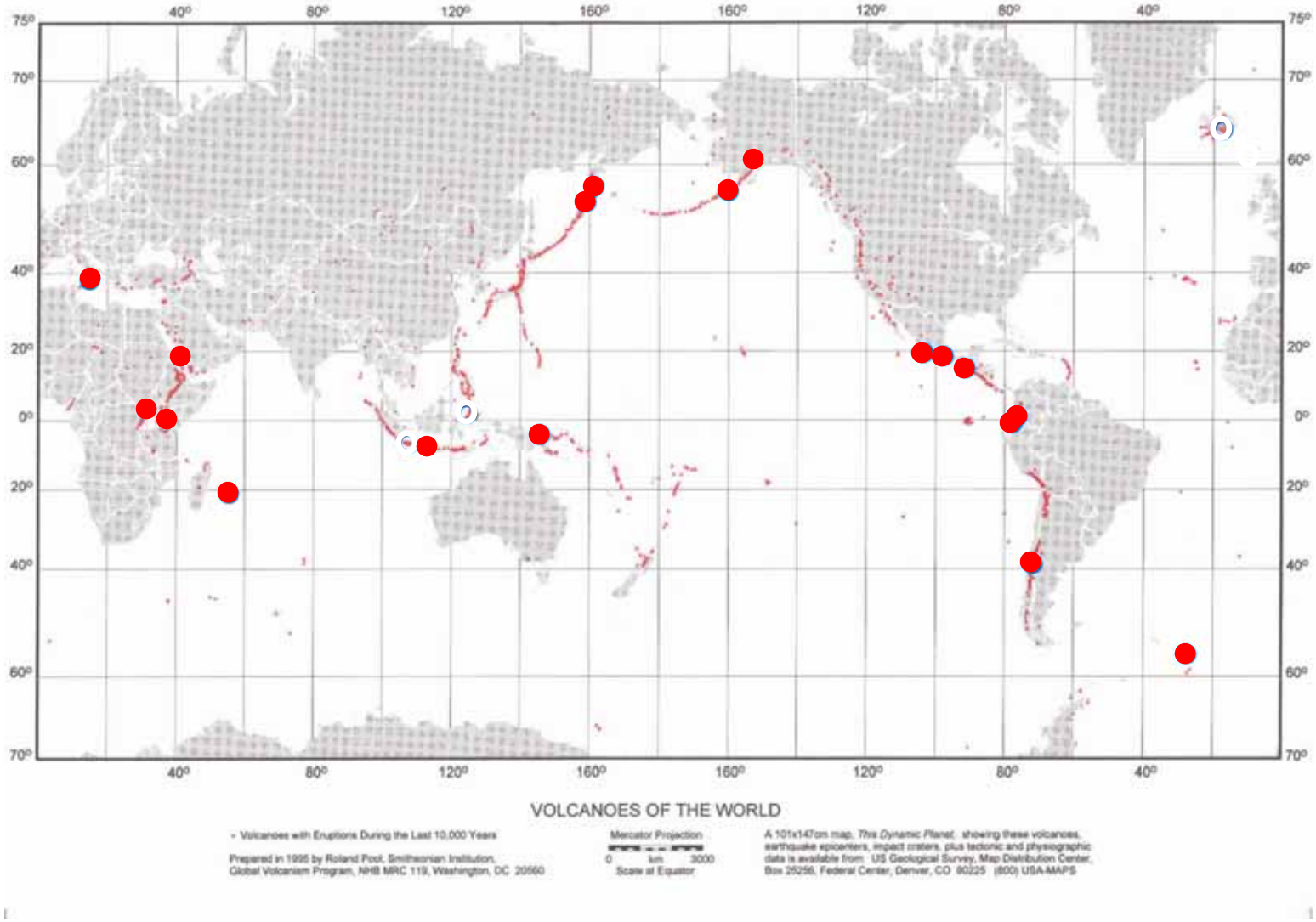
Comparisons between Smithsonian Catalog and DoD Archive during the Hazard Support System

Volcano		Eruption	
Montague Island (South Atlantic Ocean)		Quasi-steady emission	
Kilauea (Hawaii, USA)		Quasi-steady emission	
Mt Etna (Italy)		October 28, 2002 November 22, 2002 Quasi-steady emission	
Fuego (Guatemala)		February 2002	
Lopevi (Vanatu, SW Pacific Ocean)		March 21, 2000	
Nyamuragira (Africa)		July 25, 2002	
Rinjani (Lesser Sunda Is., Indonesia)		Sept. 15-17, 2001	
Piton de la Fornaise (Reunion Island, Africa)		May 1998 January 5-6, 2002 November 6, 2002	
Reventador (Ecuador)	NO DETECTION	November 3, 2002	VEI =4
Shiveluch (Kamchatka)	NO DETECTION	August 15, 1999	VEI=4
Ulawan (New Britain)	NO DETECTION	September 28, 2000	VEI=4
Suwanose-jima	NO DETECTION	December 30, 2001	VEI=3?
Shiveluch (Kamchatka, Russia)		February 15, 2002	

Archived Volcano Reports by DoD Satellite Assets

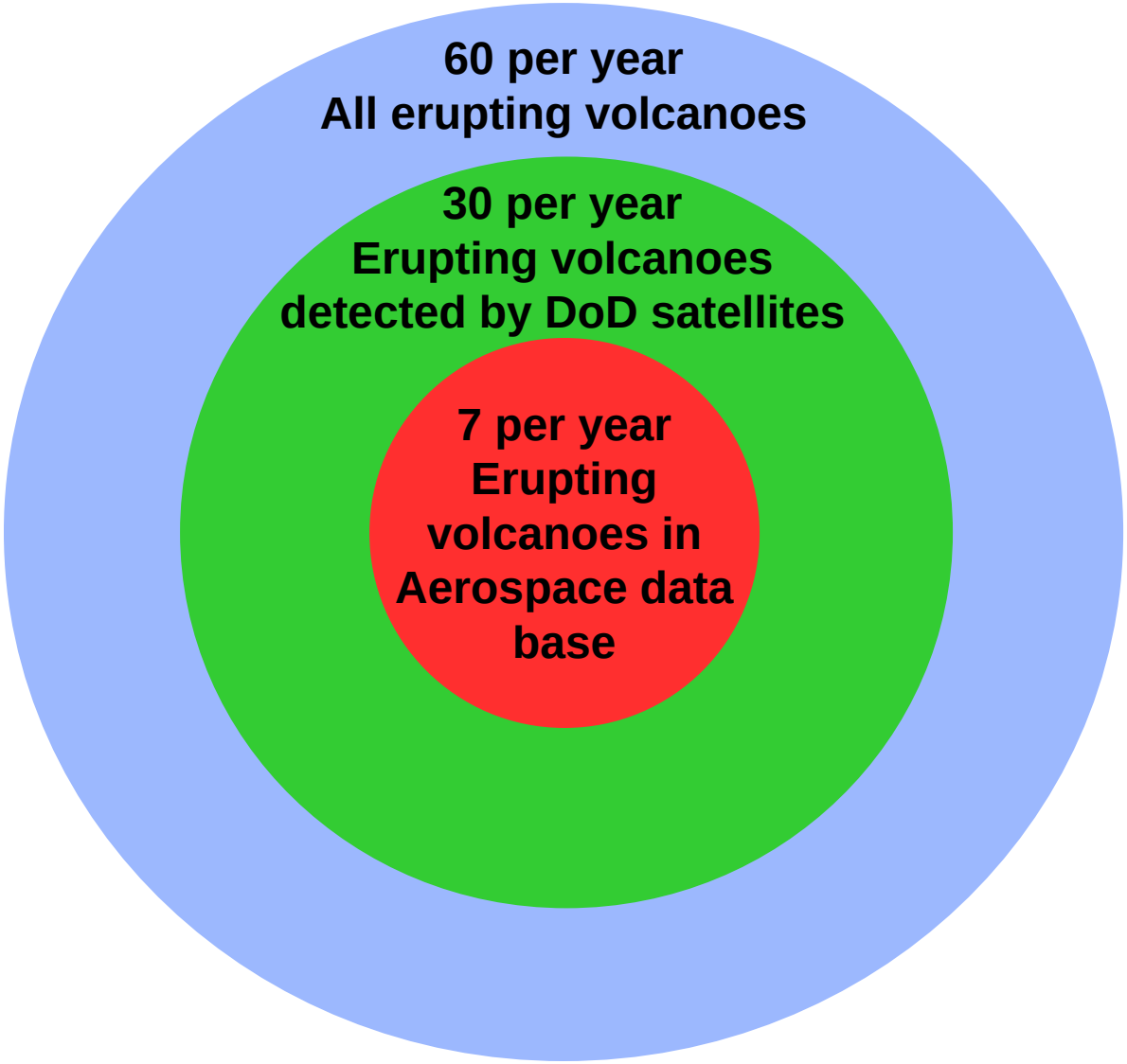


Ongoing Volcanic Activity in Recent Months (2005-2008)



Venn Diagram for Global Eruptions

(By Volcano Count)

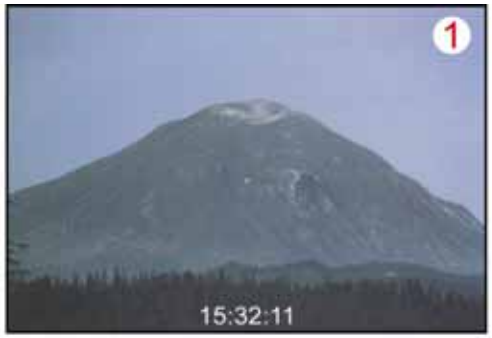


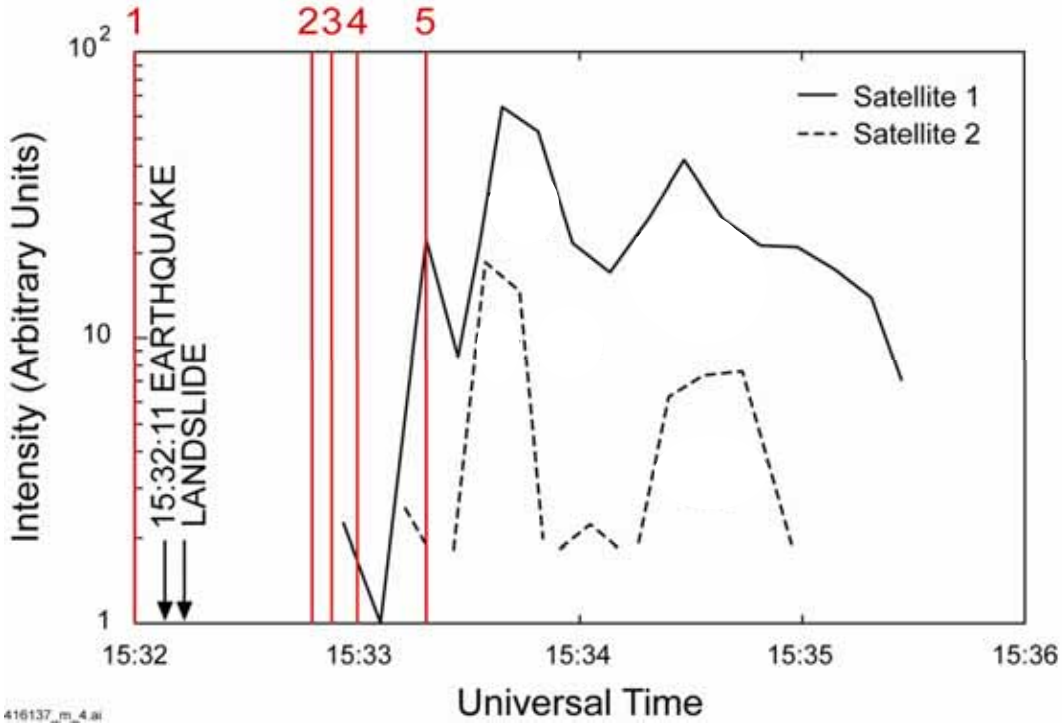
False Alarms on Eruption Detections

- **General behavior of short wave IR radiation in sunlight:**
  - **Reflections from the ocean surface: NOT DETECTABLE**
  - **Reflections from the Antarctica ice pack : DETECTABLE**
  - **Reflections from upper level cirrus cloud: ABUNDANT (Sun 'glints')**
    (and from volcanic ash cloud!)

- **Can do much to filter out glints:**
  - **Spatially known locations of volcanoes**
  - **Temporal behavior of Sun glints compared to radiance signatures of eruptions**
  - **Use of multiple satellites**

Initial Stage of Mt St Helens from the Ground and from DoD Satellites in Space

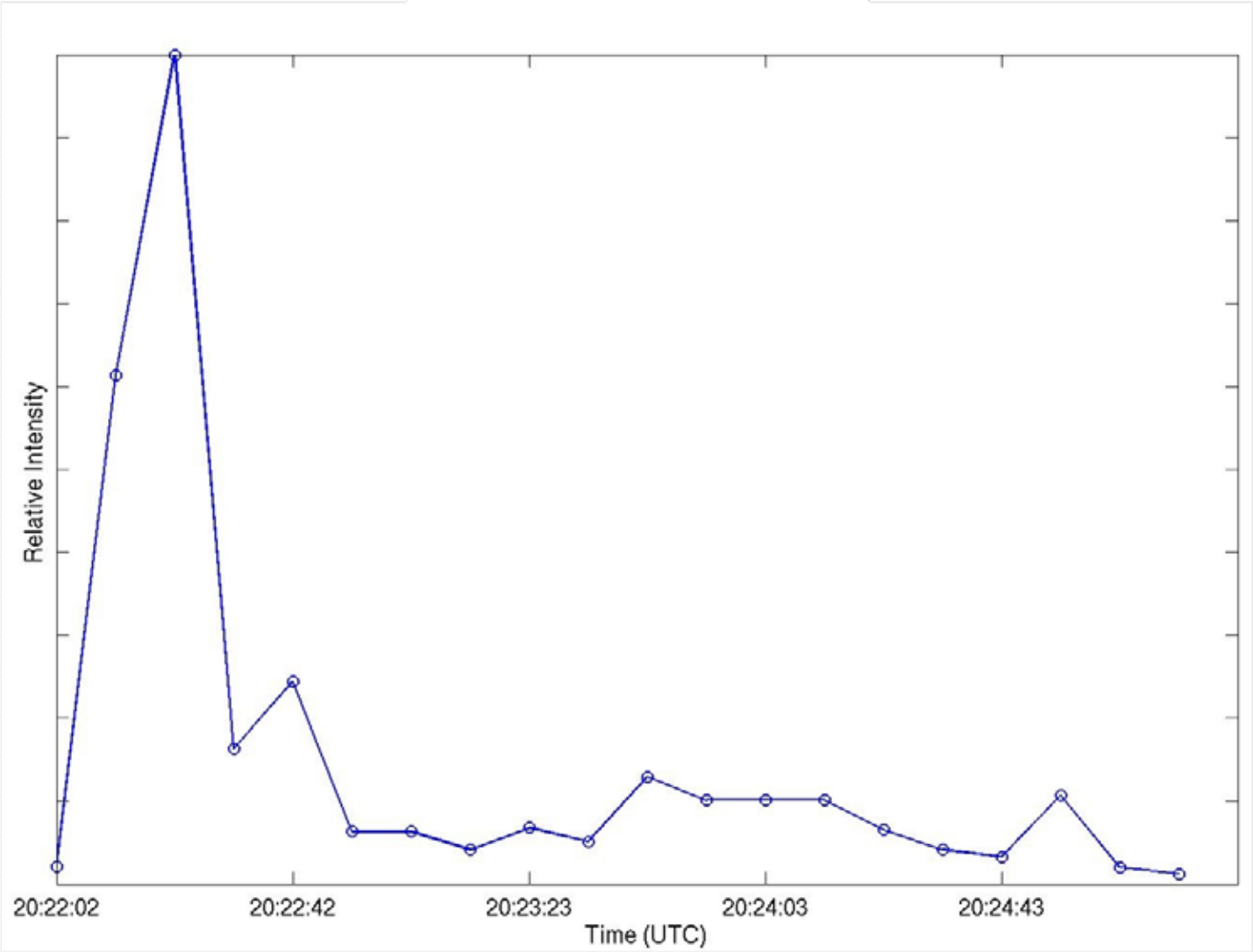




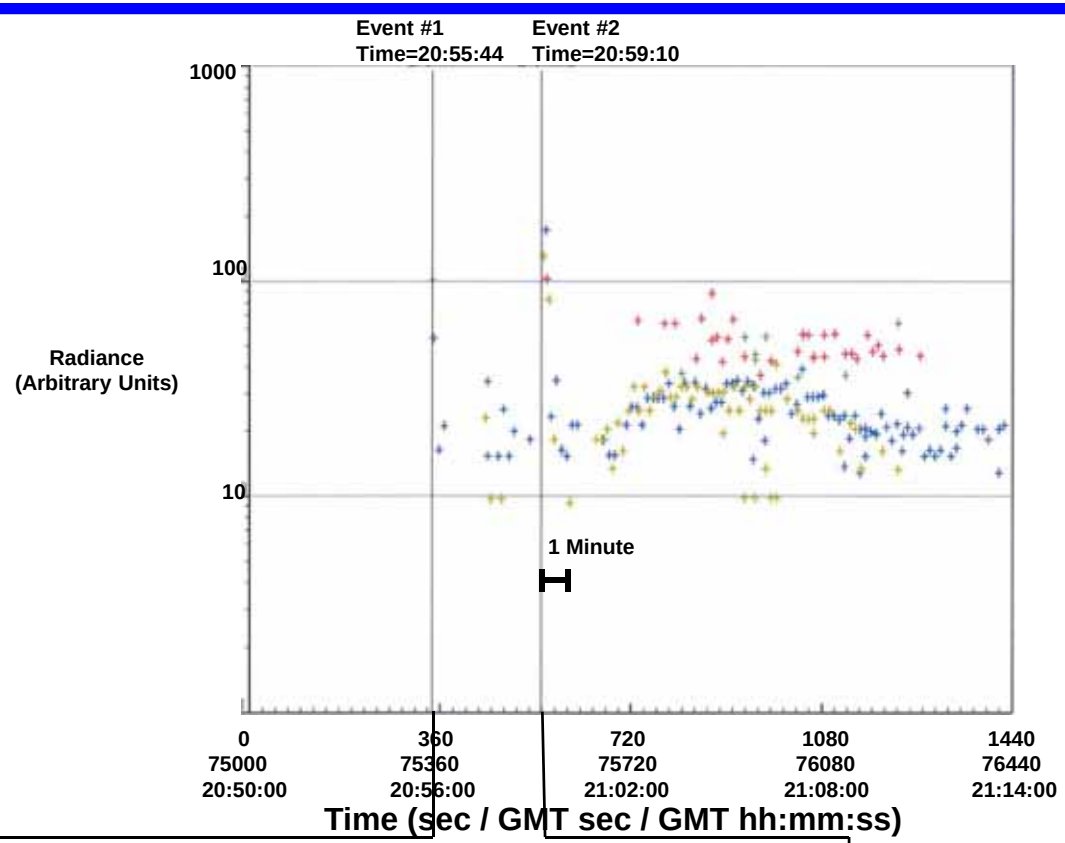
Mt St Helens Eruptions

Date	Plume Height	Satellite Identification
May 18, 1980	95,000ft (29 km)	Detected
October 1, 2004	10,000ft (3km)	Not detected operationally
March 8, 2005	36,000ft (11km)	Detected

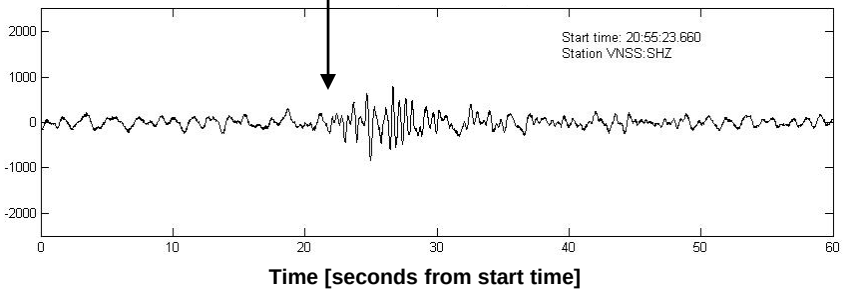
Eruption of Mt. Augustine, Alaska January 2006

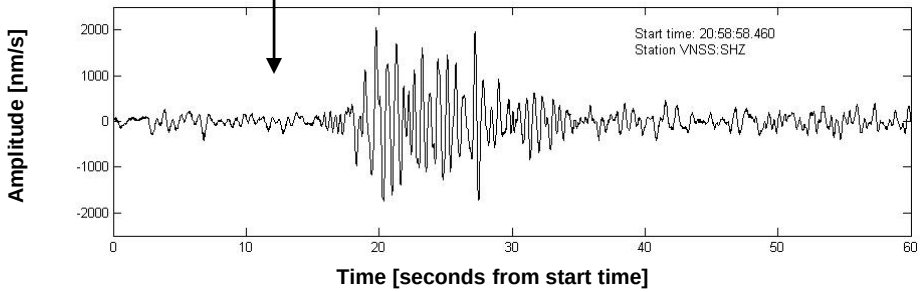


Veniaminof Eruptions
Simultaneous Satellite and Seismic Detection

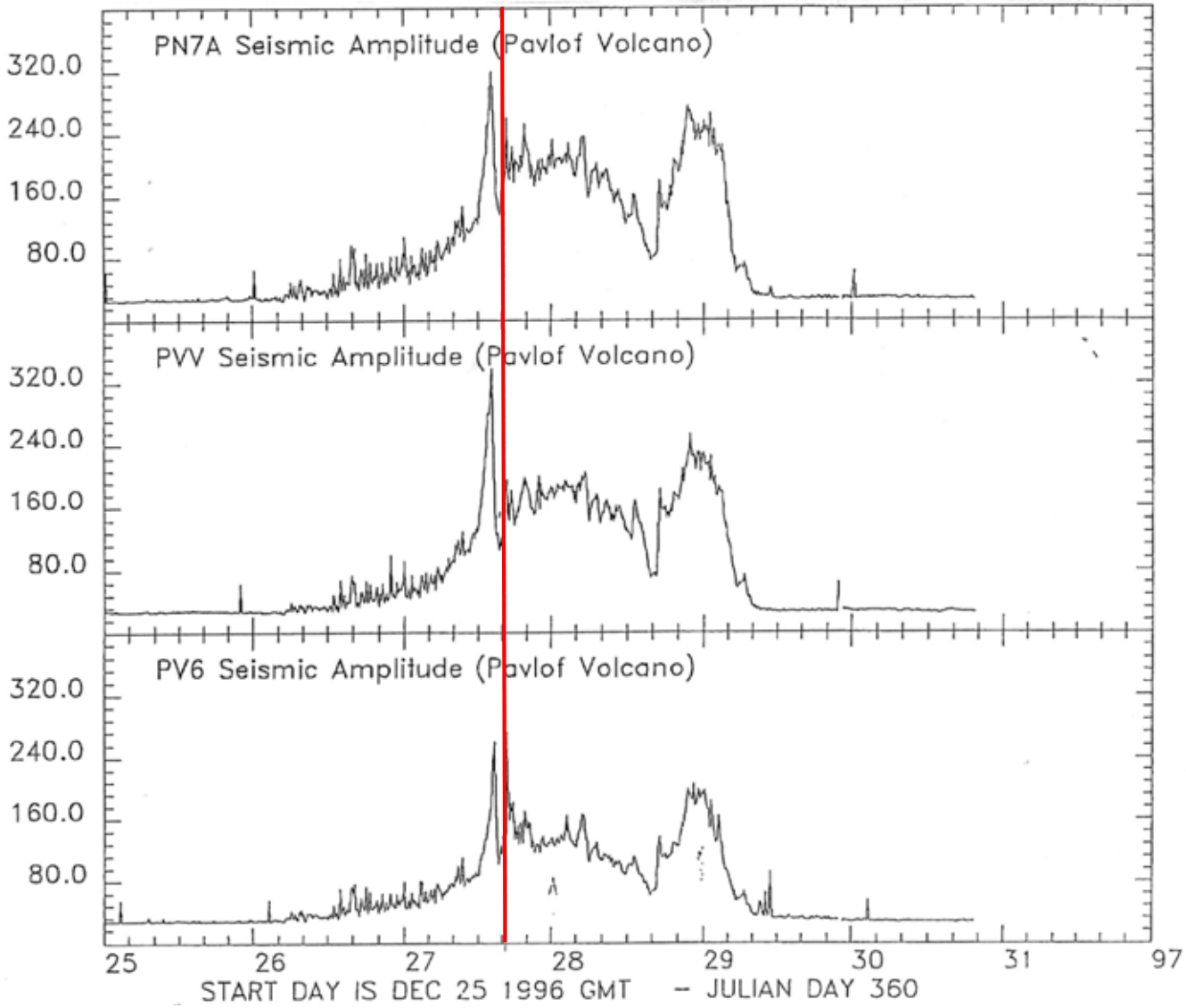


Seismic data courtesy S.R. McNutt

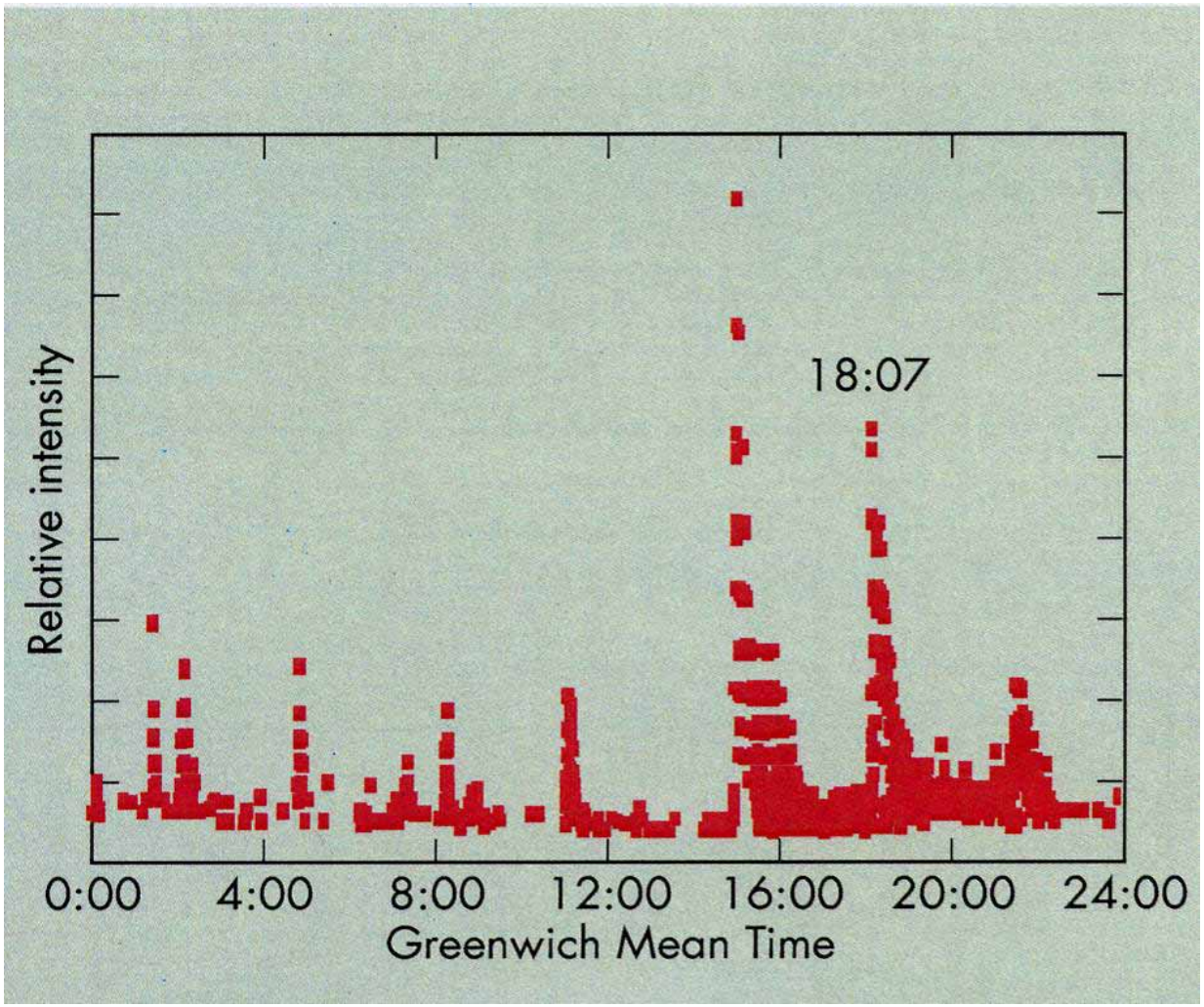




Pavlof Eruption
Seismicity and IR Radiance

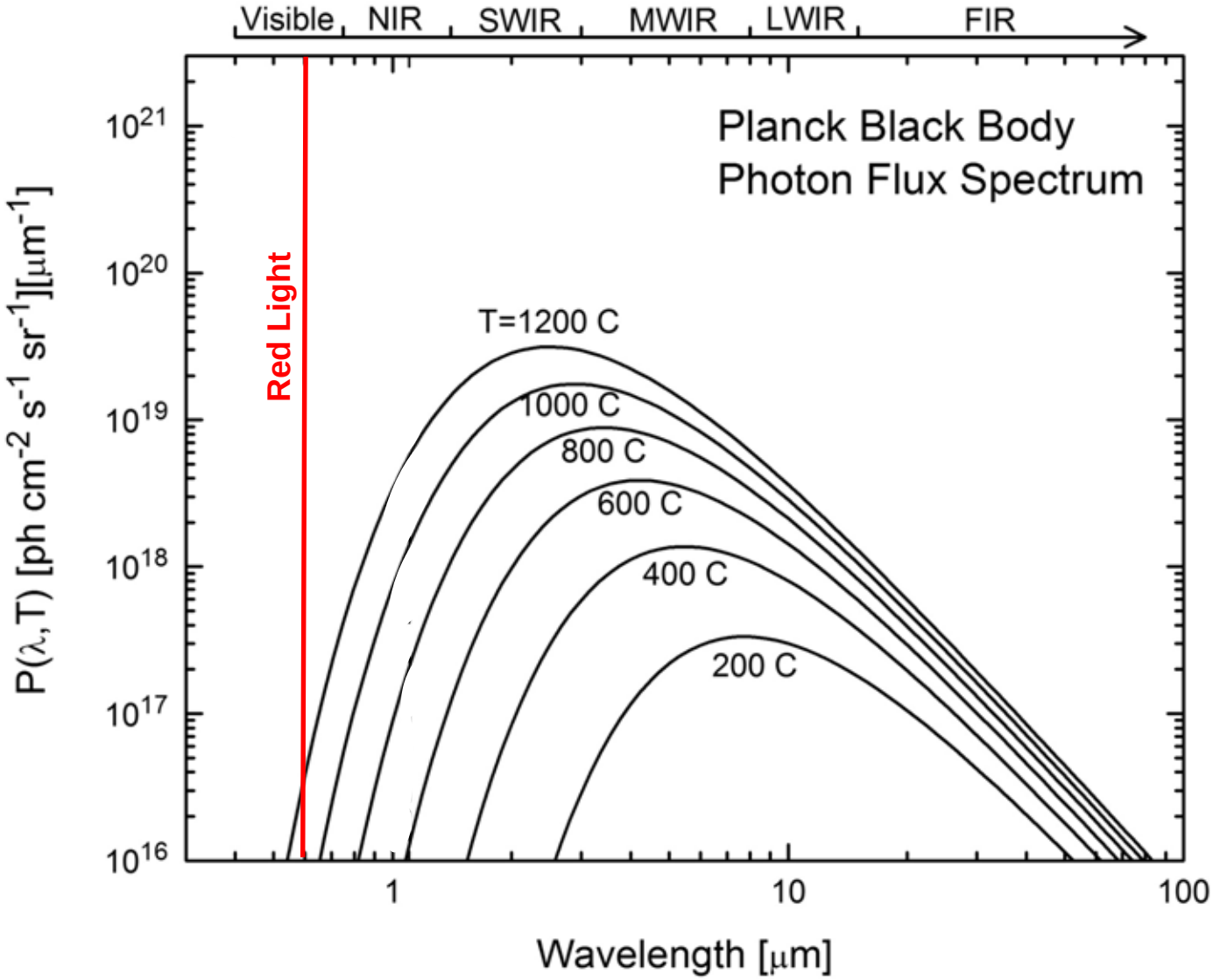


Popocatapétl, Mexico Eruption Data
(VEI = 3)

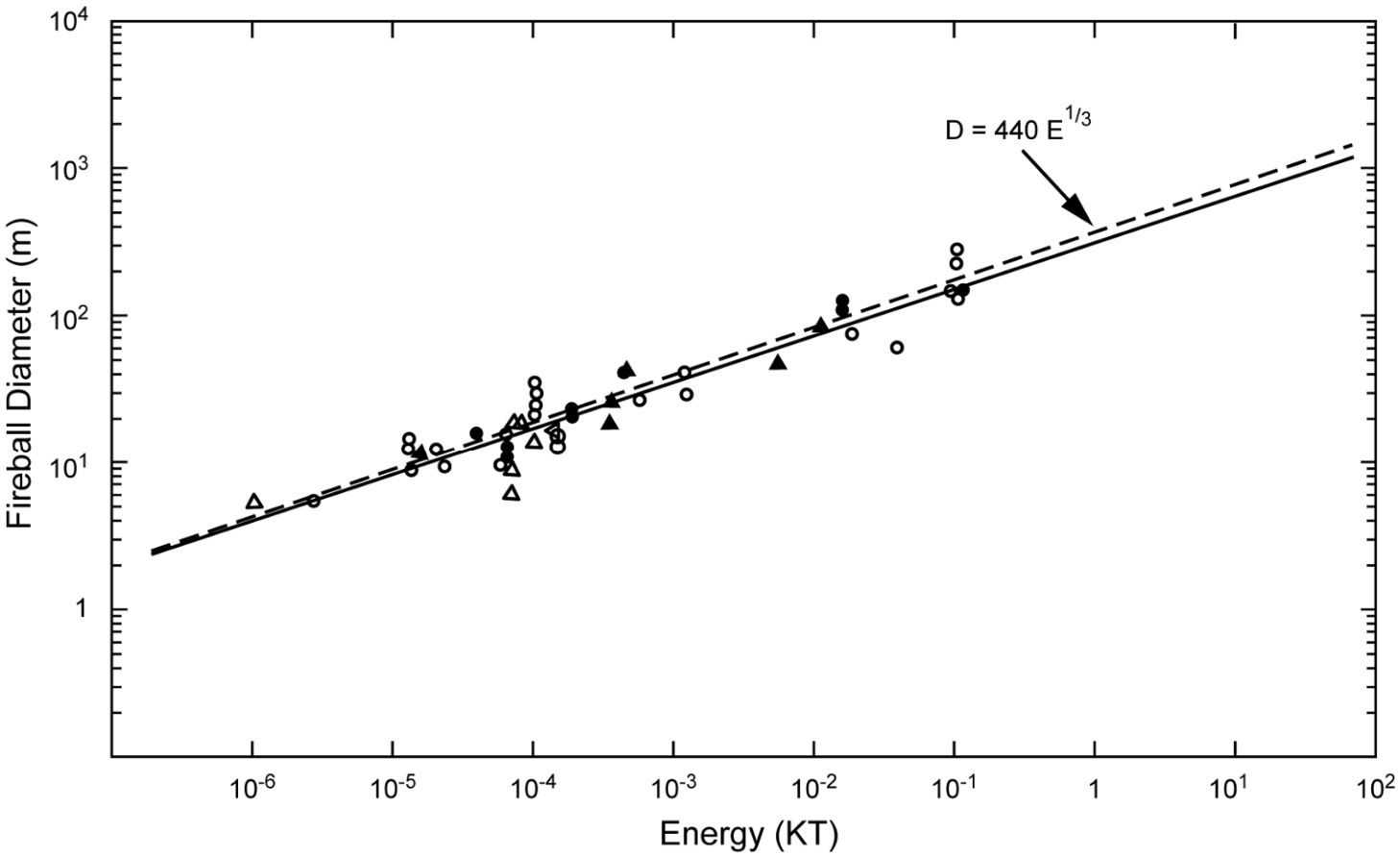


Pack et al (2000)

Contrast in Temperature Dependence Between Visible and IR

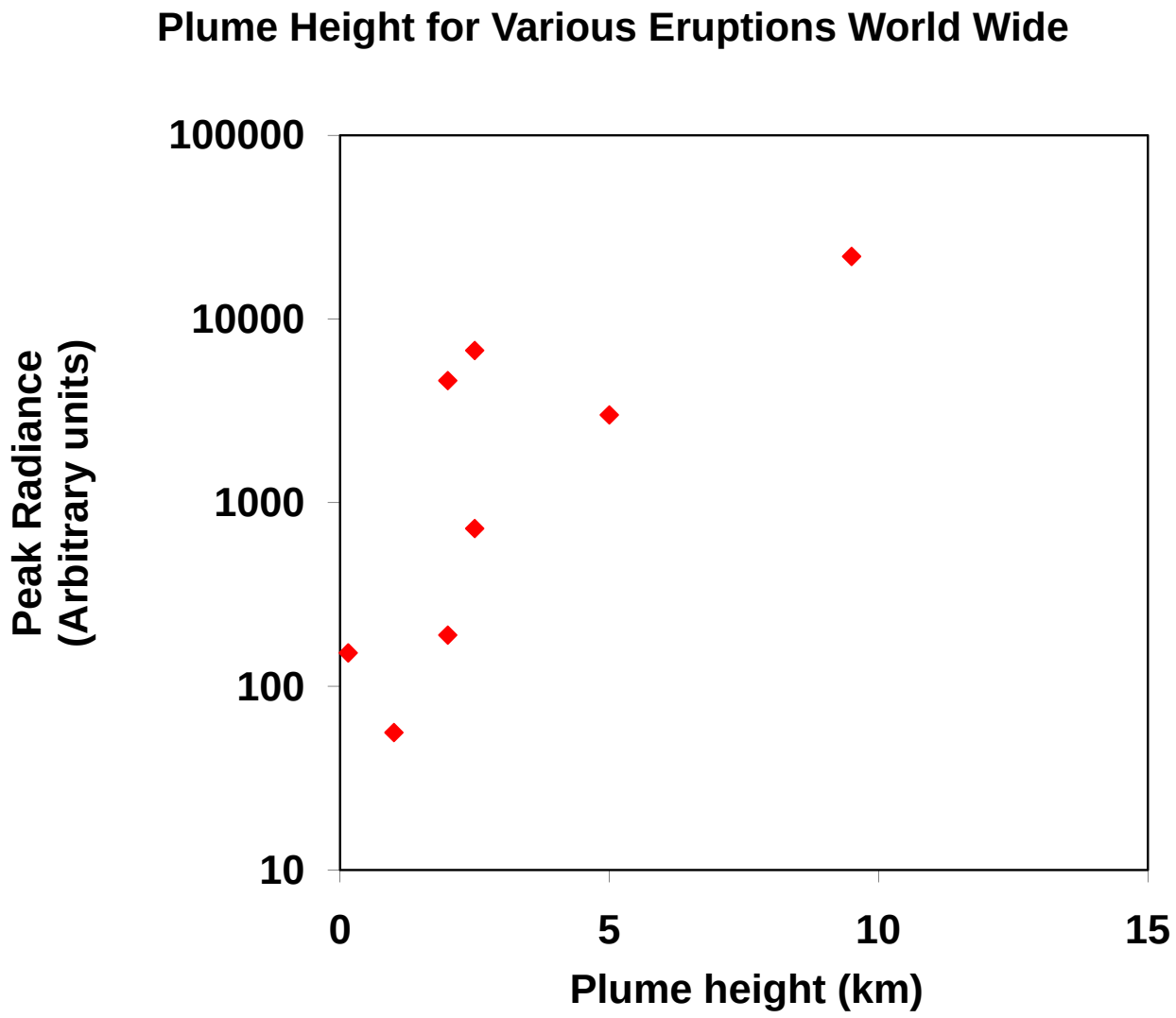


Fireball Diameter vs. Total Energy

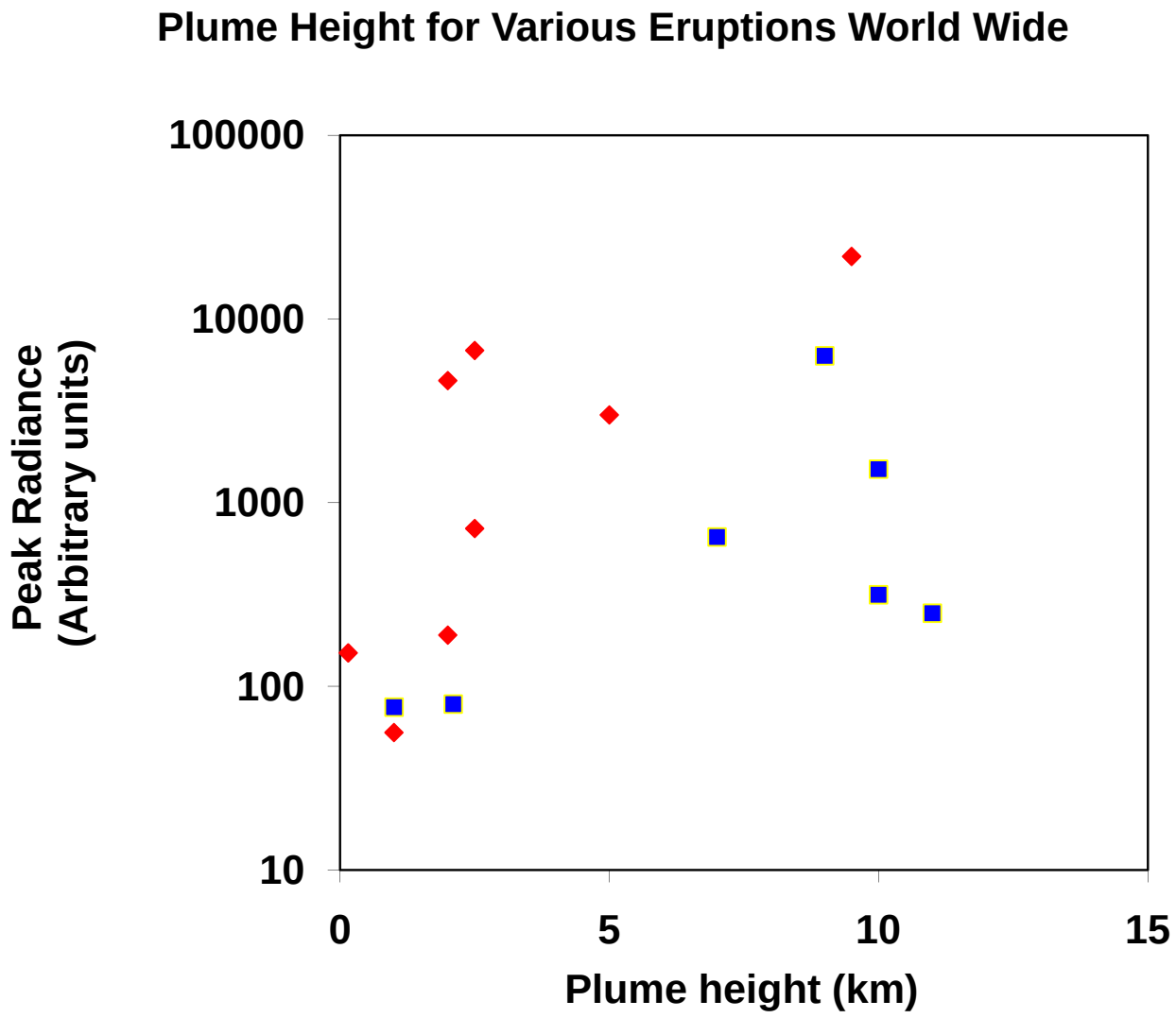


Gayle and Bransford (1965) and High (1968)

Basaltic Eruptions with Known Plume Heights



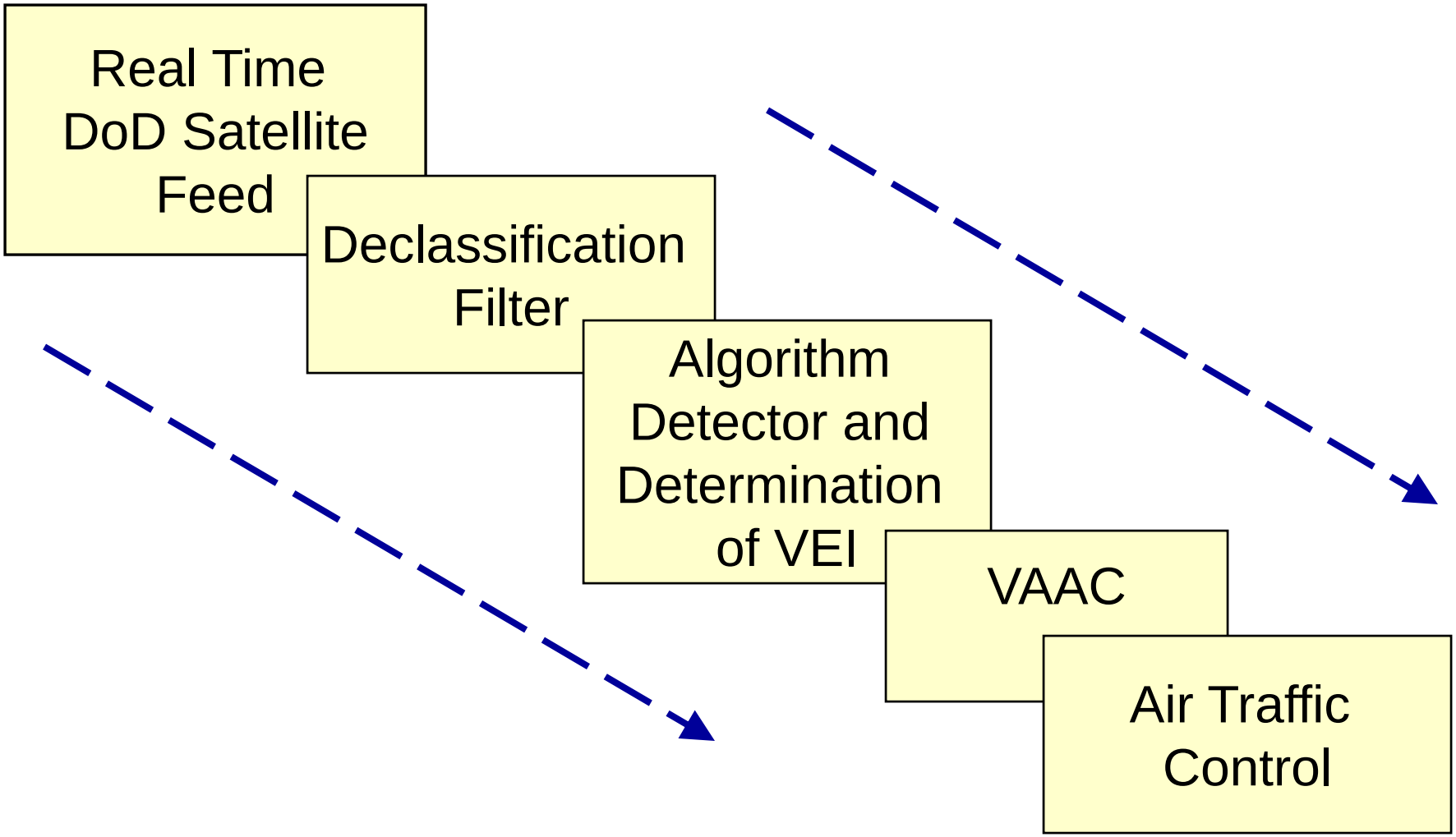
All Eruptions with Known Plume Heights



The Case for Declassification

- The surveillance satellite technology is > than 35 years old
- A precedent exists for (partial) declassification in the Hazard Support System (1997 – 1999)
- Energetic volcanic eruptions produce satellite signals well above the instrument sensitivity
- Eruptions occur at well known locations on the globe, where missile launches are unlikely
- All eruption events are currently identified in near real time and discarded from the operational data stream
- Volcanic ash is a national problem with clear benefits from national satellite assets

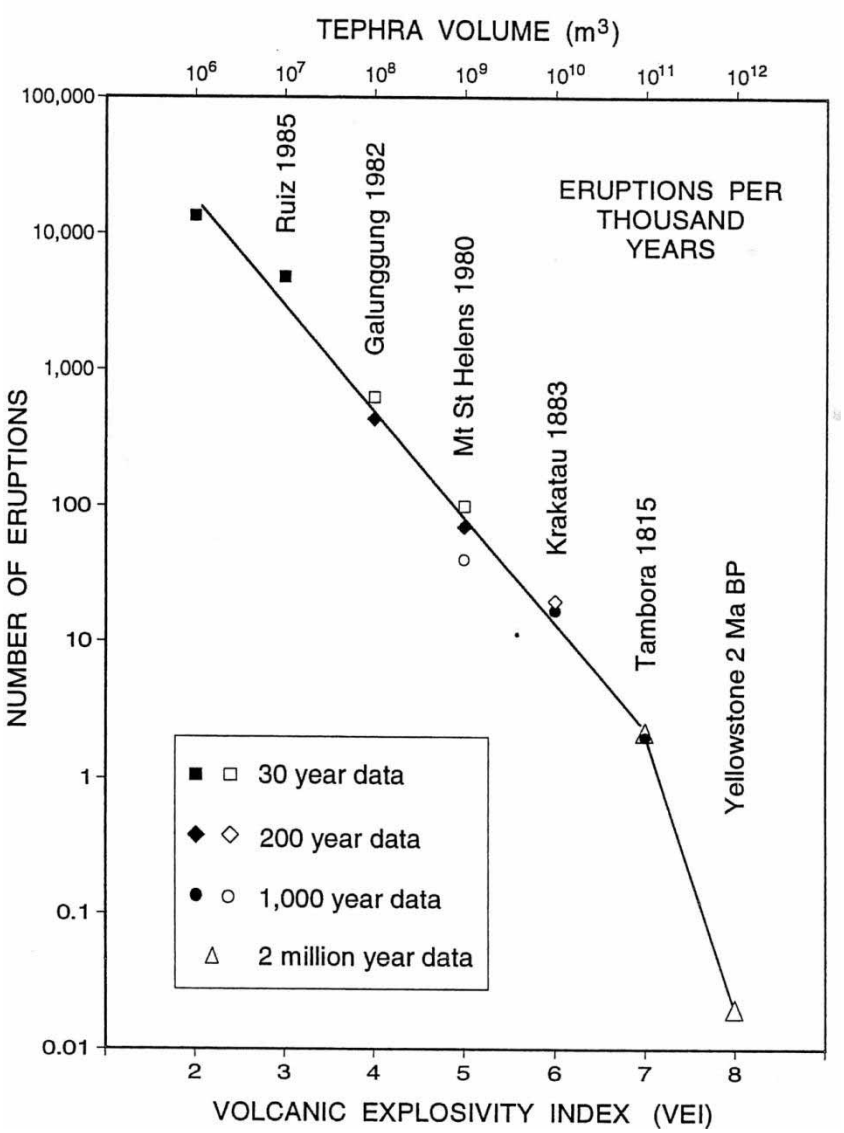
Suggested Operational Implementation



Conclusions

- Volcanoes and their plumes are serious threats to Air Traffic
- Early detection is needed to effectively route flights around eruptions
- Space-based assets are most practical means of detection
- DoD satellite capabilities are well suited to the detection of eruptions that can affect commercial aviation
- Explosive eruptions are characterized by a radiance “spike” of short duration
- Basaltic eruptions show larger peak radiance than andesite/dacite eruptions
- More data (particularly unfiltered data) need to be gathered and studied

Global Eruption Rate



Development of Eruption Conditions

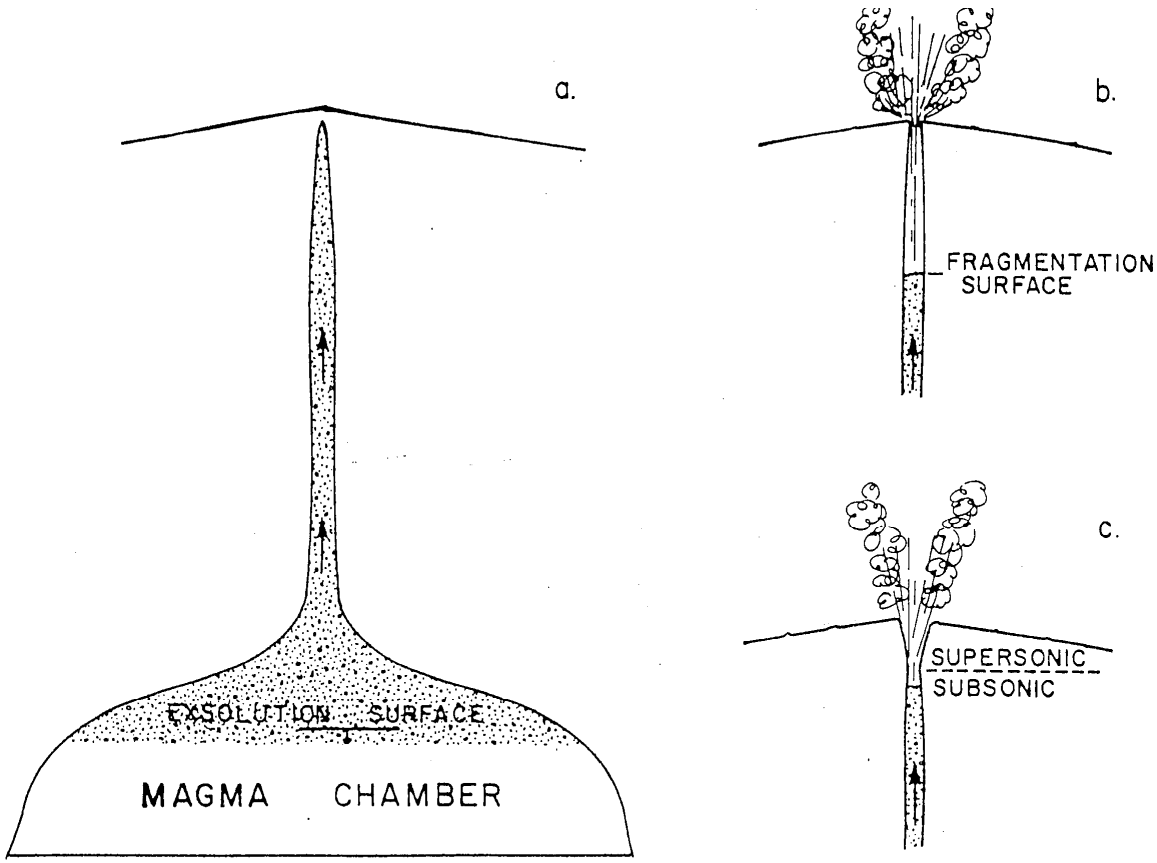
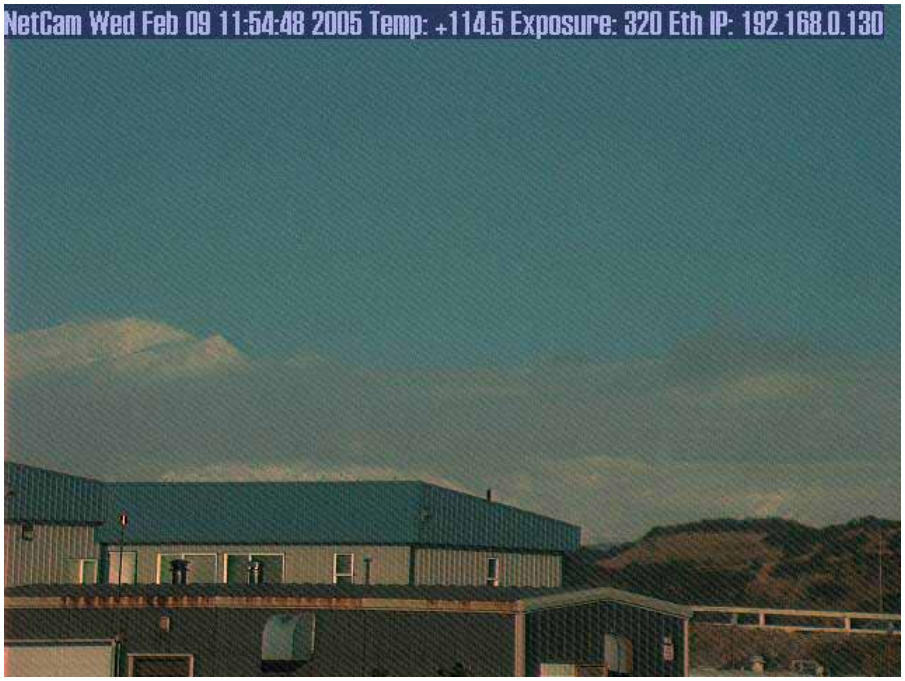


Figure 1. Development of eruption conditions. (a) Fracture propagating toward surface with gas exsolution beginning in upper part of magma; (b) fissure open to surface, magma fragmenting into gas and clasts in upper part of conduit, flow subsonic everywhere and exit pressure greater than atmospheric; (c) Development of upper conduit and vent shape into flared structure permitting supersonic flow and exit pressure close to atmospheric.

(Wilson et al 1980)

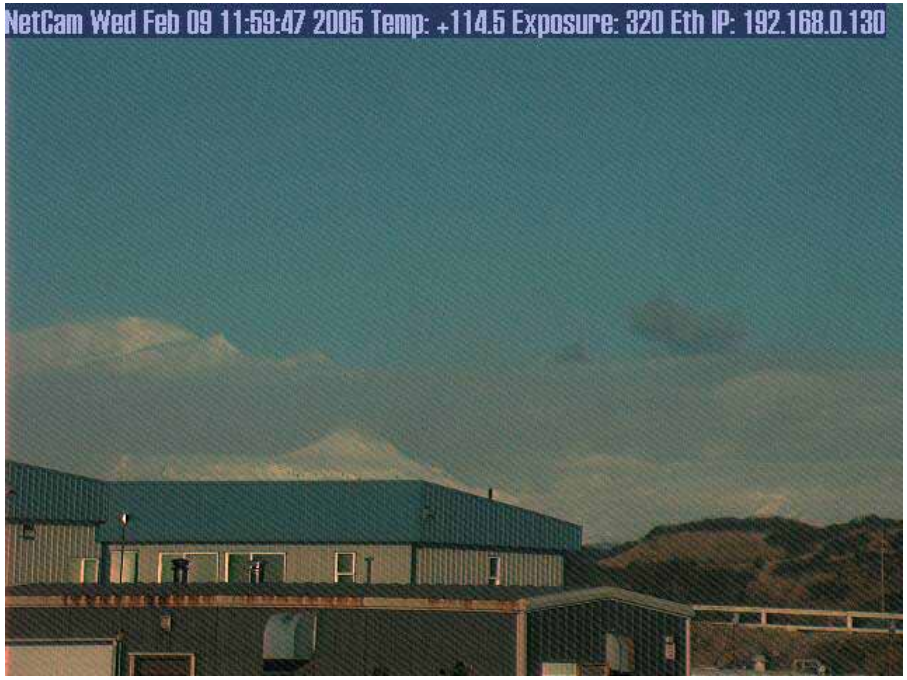
Veniaminof Eruption – Feb 9, 2005

Web cam observations closest in time to DoD satellite observations



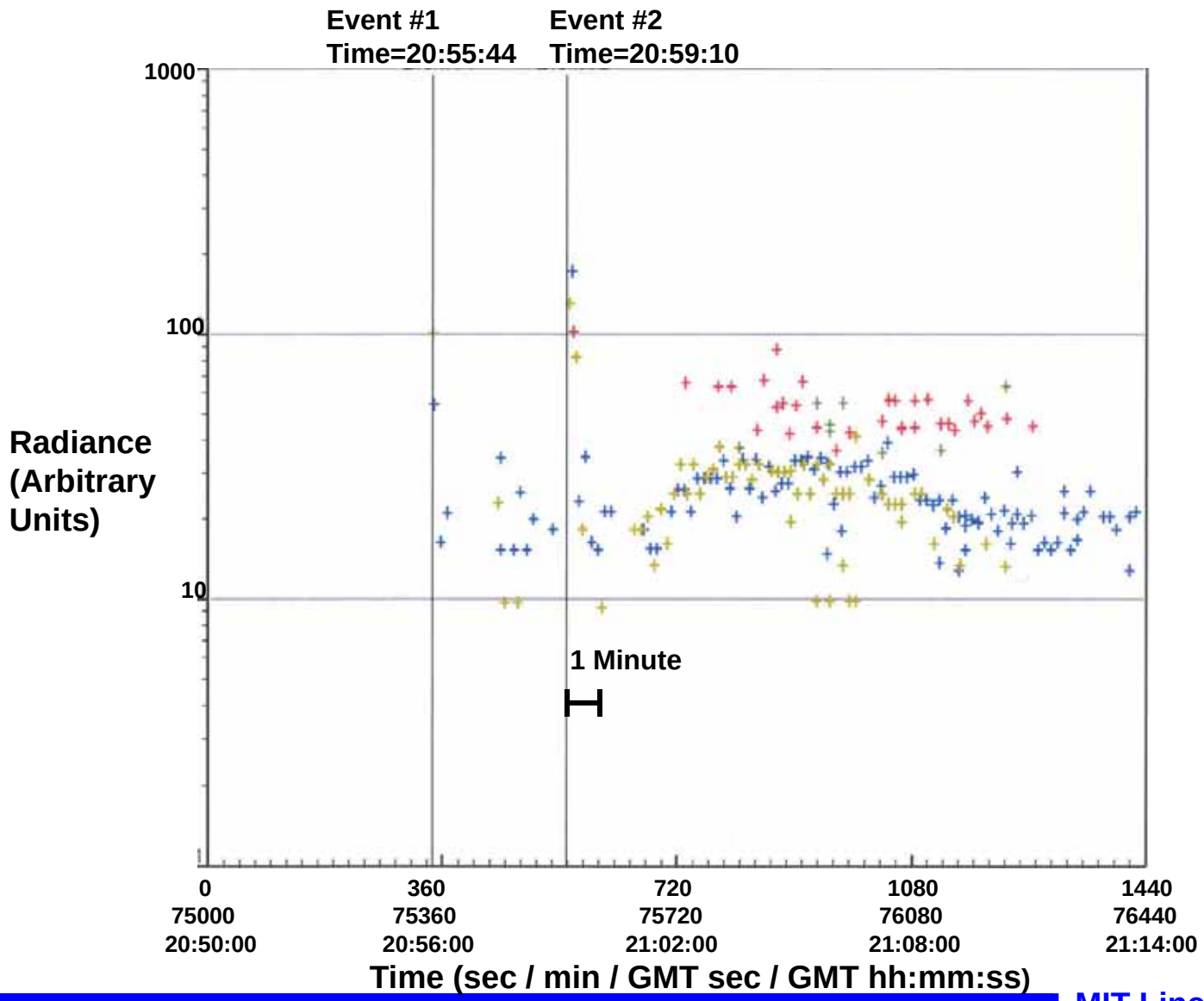
20:54:48 UT
(56 seconds prior to first explosion)

20:59:47 UT
(37 seconds prior to second explosion)



Courtesy S.R. McNutt (UAF)

Veniaminof Eruptions – Feb 9, 2005 (VEI = 0,1)



Sheveluch Eruption (Kamchatka) November 7, 2004

1. **23:03:40 UT**

Strong ramp up in DoD satellite-measured radiance.

Courtesy of Sergey Senyukov