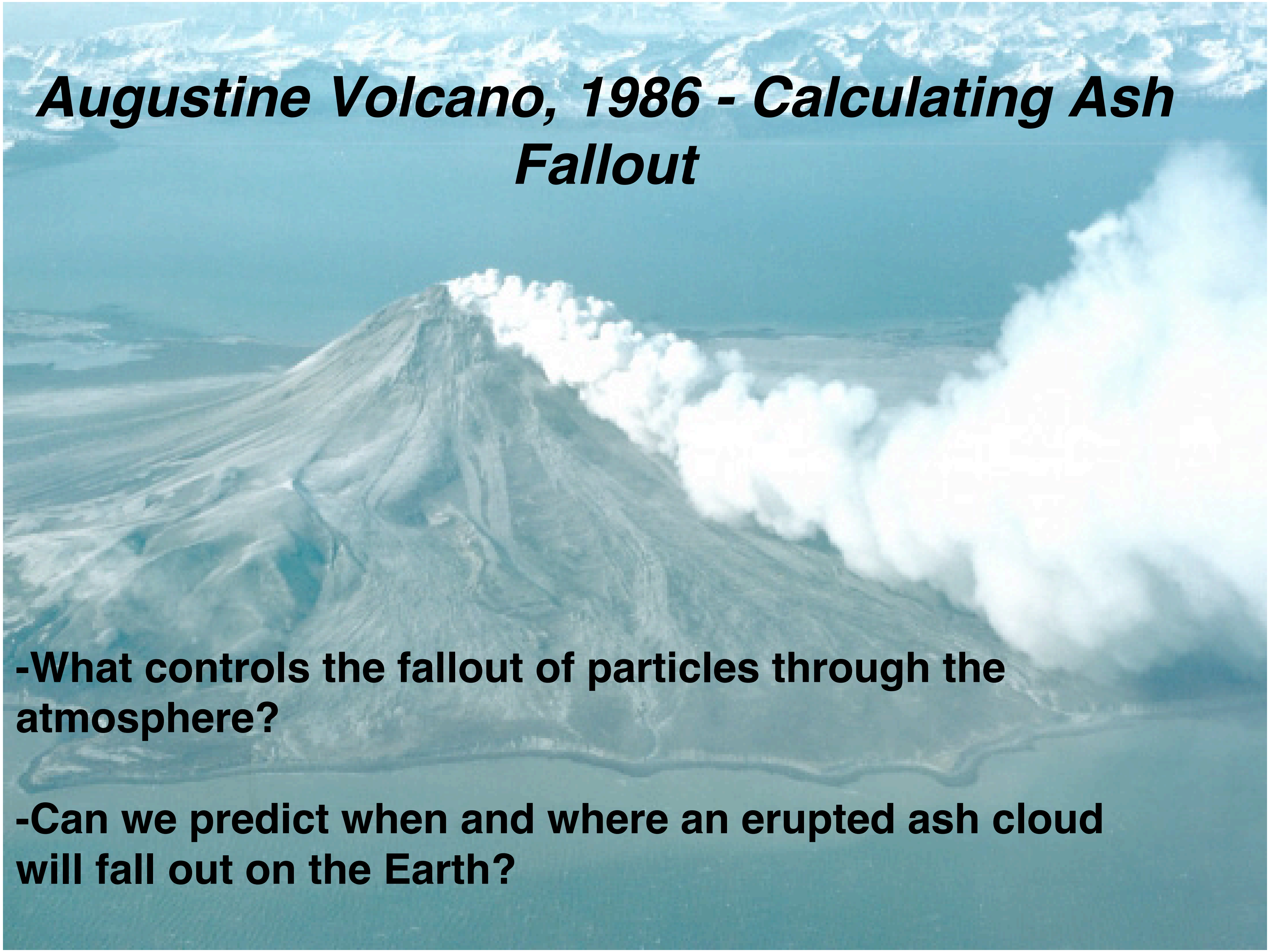
Augustine Volcano, 1986 - Calculating Ash Fallout



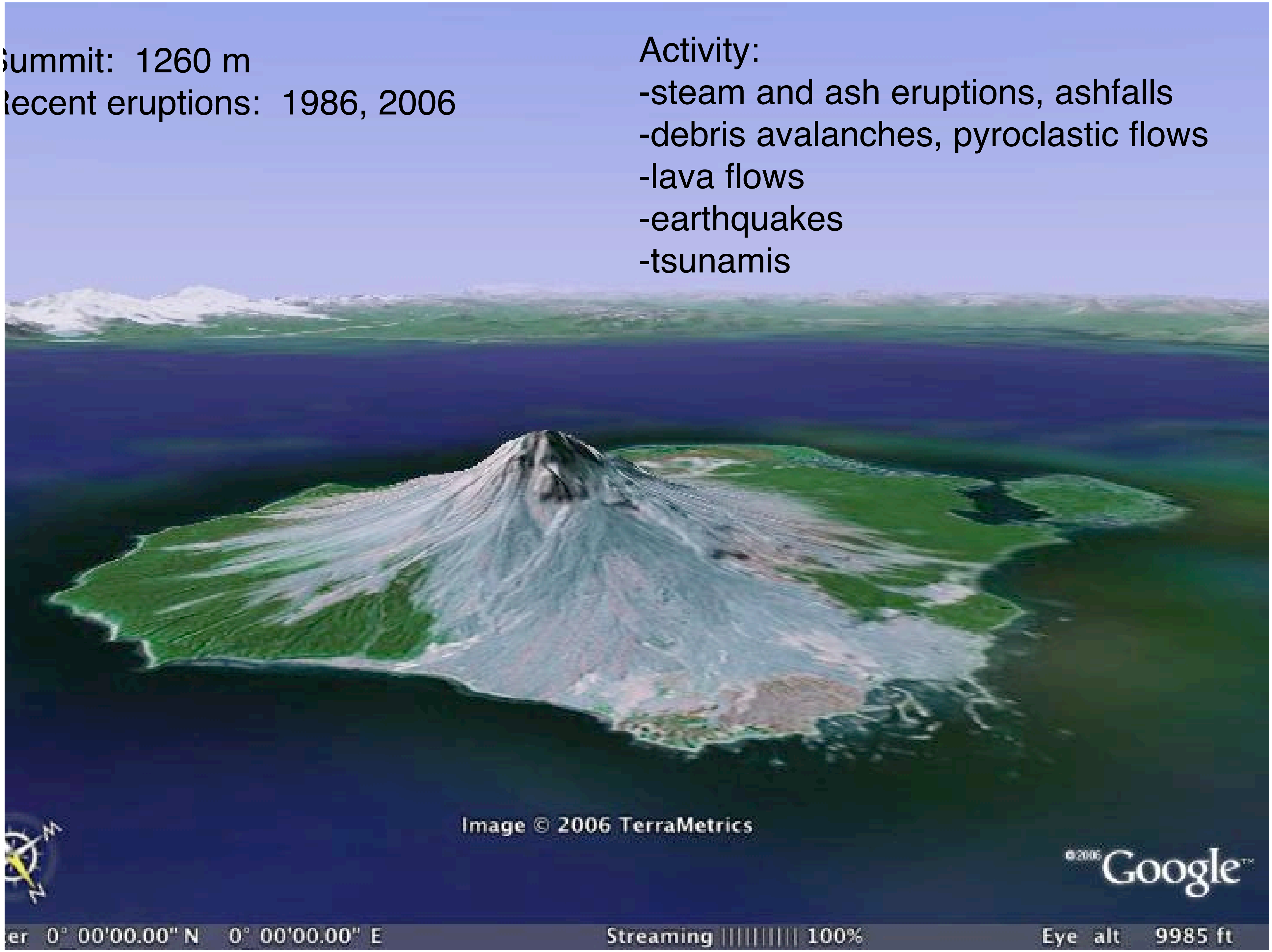
-What controls the fallout of particles through the atmosphere?

-Can we predict when and where an erupted ash cloud will fall out on the Earth?

Alaska
map location
N
S
E
W
Hayes
Spurr
Double Glacier
Redoubt
Iliamna
Augustine
Douglas
Fourpeaked
Susitna River
Wasilla
Houston
Sutton
Palmer
Knik
Eklutna
Anchorage
Tyonek
Hope
Whittier
Nikiski
Salamatof
Cooper Landing
Kenai
Moose Pass
Soldotna
Kasilof
Seward
Clam Gulch
Ninilchik
Nikolaevsk
Anchor Point
Homer
Seldovia
Nanwalek
Port Graham
Cook Inlet
Lake Clark
Port Alsworth
Nondalton
Pedro Bay
Iliamna
Newhalen
Lake Iliamna
Kokhanok
0
50
100
kilometers

Summit: 1260 m
Recent eruptions: 1986, 2006

Activity:
- steam and ash eruptions, ashfalls
- debris avalanches, pyroclastic flows
- lava flows
- earthquakes
- tsunamis



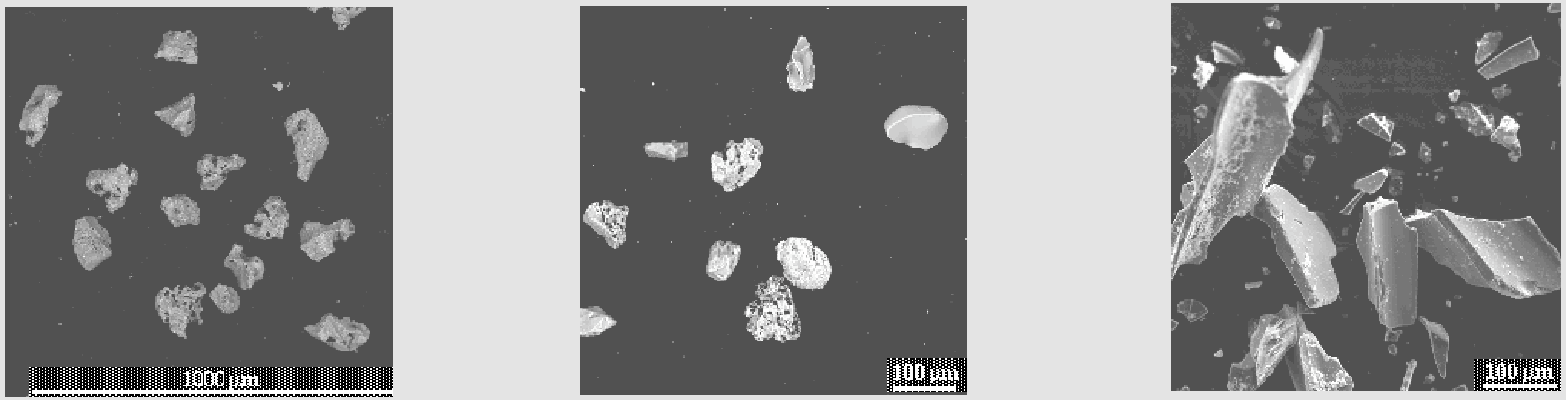
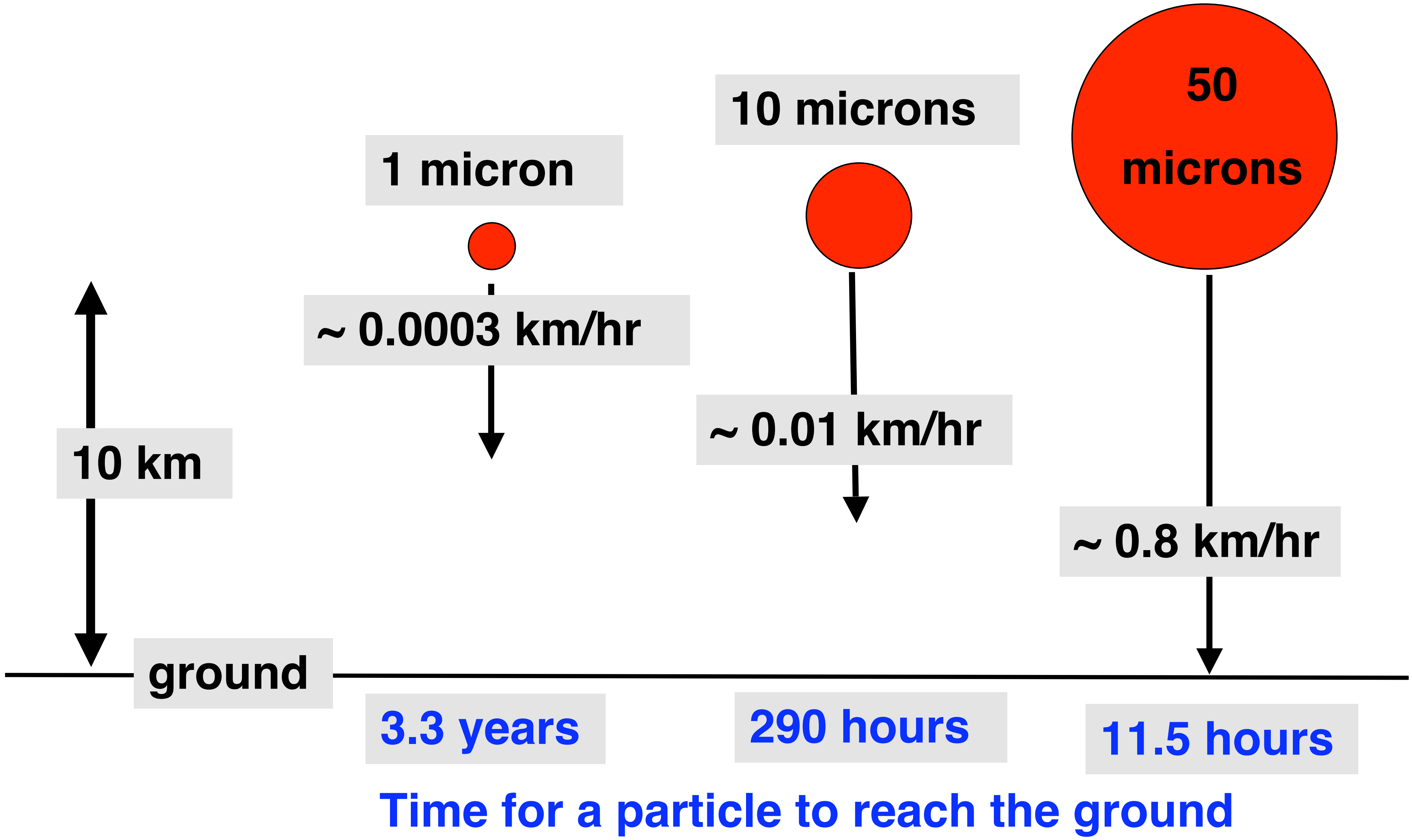


Figure 1. SEM photos of (l-r) Fuego, Guatemala basaltic ash; Mt. Spurr, Alaska andesitic ash; bubble wall shards from the rhyolitic ash of the Ash Hollow Member, Nebraska (Riley et al., 2003).

Particles (ice, silicates, mixtures and aggregates) that fall from volcanic clouds can be collectively classified as fallout. The prediction of ash fallout (from calculating fall velocities and knowing local meteorological conditions) forms an important part of volcanic hazard mitigation, from the airline industry, meteorologists, and volcano observatories. Recently, more attention has been paid to the shape of particles and how they interact as they drift through the atmosphere, to help improve our understanding of fallout patterns.

EFFECT OF SIZE ON FALLOUT RATES



Terminal Velocity

The fallout velocity of a particle is dependent upon the terminal velocity (v_t) at which a particle can fall. Terminal velocity, defined as the maximum velocity a particle can fall at in the Earth's atmosphere, can be calculated using three formulas.

These equations describe how a particle moves through a fluid, and are used in many earth science applications, such as contaminant transport in groundwater, particle settling in riverine systems, precipitation and settling of minerals in magma chambers (~Stoke’s Law).

In our case the “fluid” is the atmosphere. Think about how a particle would fall through a column of syrup, versus through a column of water - would it tumble? slide?

(1) The **Reynolds number (R_e)** describes how a particle moves through a fluid:

$$R_e = d\ v_t\ \rho\ /\ \eta$$

(where d = particle diameter, v_t = terminal velocity, ρ = density of the atmosphere and η = viscosity of the atmosphere.)

(2) The **Drag Coefficient (C)** is a measure of the air resistance acting on a falling particle:

$$C = 24/\ R_e$$

(3) **Gravitational Settling** describes the falling of objects through the Earth's atmosphere:

$$V\ \sigma\ g = 1/2\ C\ \rho\ A\ v_t^2$$

(where V = particle volume, σ = particle density, g = gravitational acceleration, A = particle cross-sectional area, and all other variables are defined as before.)

For volcanic ash clouds, the actual distance that fallout occurs is not only a function of terminal velocity, but also of wind velocity. Material ejected into the atmosphere during an eruption is carried from the vent by the prevailing winds. As the particle falls it is carried horizontally until it impacts the ground.

Augustine's peak eruption rate Q was estimated to be $7.5 * 10^{10}$ kg/day based on measurements of emitted materials and the timing of the eruption.

To calculate the maximum column height above the vent we use Wilson's equation:

$$H = 236.6 * Q^{0.25}$$

Where Q is in kg/s, and H is in meters.

Cloud H = 7221 m (above summit) = 8421 m (above sea level)

-Particle fallout began in Anchorage approximately 22 hours after the eruption began.

-The mean particle size was 22 microns.

Distance and time for a 22 micron particle to hit the ground

2b. Calculate distance and time for 22 micron particle fallout

	Diameter	Diameter	Part density	Gravity	Atm viscosity	Constant	Term vel	Vert dist	fall time	Windspeed	hor dist	Cum dist
	cm	cm^2	g/cm^3	cm/s^2	g/cm s		cm/s	cm	hrs	km/hr	km	km
Level	**d**	**d^2**	**σ**	**G**	**η**	**18**	**T**				x	
8-9 km	2.20E-003	4.84E-006	2.50E+000	980	1.48E-004	18	**4.45**	4.20E+004	**2.6**	93.53	**245**	245
7-8 km	2.20E-003	4.84E-006	2.50E+000	980	1.49E-004	18	**4.42**	1.00E+005	**6.3**	107.42	**675**	920
6-7 km	2.20E-003	4.84E-006	2.50E+000	980	1.50E-004	18	**4.39**	1.00E+005	**6.3**	108.34	**685**	1605
5-6 km	2.20E-003	4.84E-006	2.50E+000	980	1.53E-004	18	**4.31**	1.00E+005	**6.5**	100.93	**651**	2256
4-5 km	2.20E-003	4.84E-006	2.50E+000	980	1.55E-004	18	**4.25**	1.00E+005	**6.5**	94.45	**617**	2874
3-4 km	2.20E-003	4.84E-006	2.50E+000	980	1.58E-004	18	**4.17**	1.00E+005	**6.7**	66.67	**444**	3318
2-3 km	2.20E-003	4.84E-006	2.50E+000	980	1.61E-004	18	**4.09**	1.00E+005	**6.8**	51.86	**352**	3670
1-2 km	2.20E-003	4.84E-006	2.50E+000	980	1.63E-004	18	**4.04**	1.00E+005	**6.9**	32.41	**223**	3893
0-1 km	2.20E-003	4.84E-006	2.50E+000	980	1.66E-004	18	**3.97**	1.00E+005	**7.0**	20.37	**143**	4035
TOTALS									**55.5**		**4035**	

55.5 hours - way too long! (Anchorage ashfall ~22 hours after eruption)

4035 km - way too far! (Anchorage about 280 km from Augustine)

Adjust the particle size so the particle will hit the ground in 22 hours

4. Change particle size to make fall out in 22 hours

	Diameter cm	Diameter cm^2	Part density g/cm^3	Gravity cm/s^2	Atm visc g/cm s	Constant	Term vel cm/s	Vert dist cm	fall time hrs	Windspeed km/hr	hor dist km
Level	**d**	**d^2**	**σ**	**G**	**η**	**18**	**T**				
8-9 km	3.50E-003	1.23E-005	2.50E+000	980	1.48E-004	18	**11.27**	4.20E+004	**1.0**	93.53	**96.9**
7-8 km	3.50E-003	1.23E-005	2.50E+000	980	1.49E-004	18	**11.19**	1.00E+005	**2.5**	107.42	**266.6**
6-7 km	3.50E-003	1.23E-005	2.50E+000	980	1.50E-004	18	**11.12**	1.00E+005	**2.5**	108.34	**270.7**
5-6 km	3.50E-003	1.23E-005	2.50E+000	980	1.53E-004	18	**10.90**	1.00E+005	**2.5**	100.93	**257.3**
4-5 km	3.50E-003	1.23E-005	2.50E+000	980	1.55E-004	18	**10.76**	1.00E+005	**2.6**	94.45	**243.9**
3-4 km	3.50E-003	1.23E-005	2.50E+000	980	1.58E-004	18	**10.55**	1.00E+005	**2.6**	66.67	**175.5**
2-3 km	3.50E-003	1.23E-005	2.50E+000	980	1.61E-004	18	**10.36**	1.00E+005	**2.7**	51.86	**139.1**
1-2 km	3.50E-003	1.23E-005	2.50E+000	980	1.63E-004	18	**10.23**	1.00E+005	**2.7**	32.41	**88.0**
0-1 km	3.50E-003	1.23E-005	2.50E+000	980	1.66E-004	18	**10.04**	1.00E+005	**2.8**	20.37	**56.3**
TOTALS									**21.94**		**1594.3**

-particle size of 35 microns - too big!

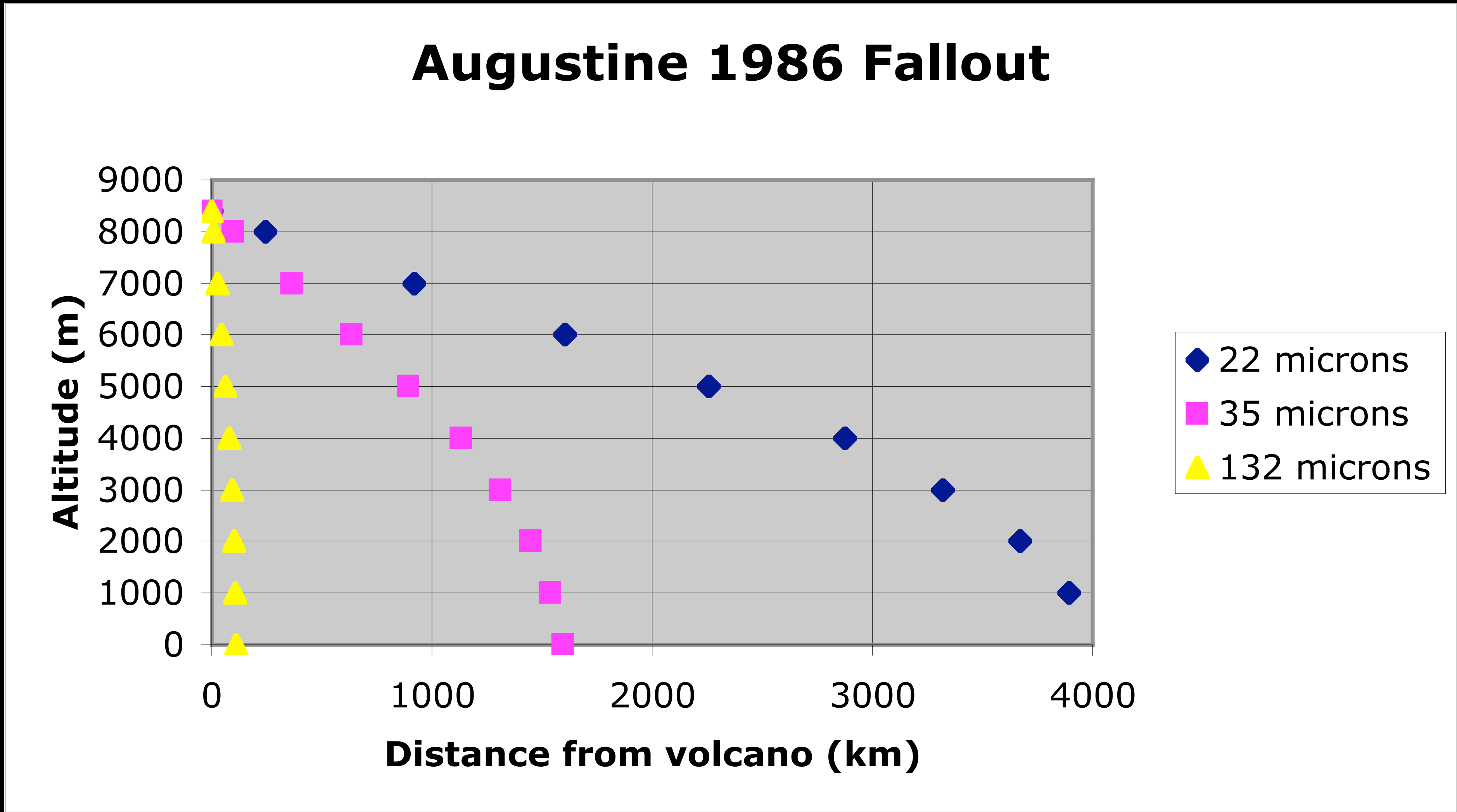
-fallout distance at 1600 km still too far

Adjust the particle size so the particle will hit the ground 280 km from volcano

Change particle size to make fall out 280 km from volcano								
	Diameter	Part density	Atm visc	Term vel	Vertical d	fall time	Windspeed	horizontal d
	cm	g/cm^3	g/cm s	cm/s	cm	hrs	km/hr	km
Level	**D**	**σ**	**η**	**T**				
8-9 km	1.32E-002	2.50E+000	1.48E-004	**64.10**	4.20E+004	0.18	93.53	**17.0**
7-8 km	1.32E-002	2.50E+000	1.49E-004	**63.67**	1.00E+005	0.44	107.42	**46.9**
6-7 km	1.32E-002	2.50E+000	1.50E-004	**63.24**	1.00E+005	0.44	108.34	**47.6**
5-6 km	1.32E-002	2.50E+000	1.53E-004	**62.00**	1.00E+005	0.45	100.93	**45.2**
4-5 km	1.32E-002	2.50E+000	1.55E-004	**61.20**	1.00E+005	0.45	94.45	**42.9**
3-4 km	1.32E-002	2.50E+000	1.58E-004	**60.04**	1.00E+005	0.46	66.67	**30.8**
2-3 km	1.32E-002	2.50E+000	1.61E-004	**58.92**	1.00E+005	0.47	51.86	**24.4**
1-2 km	1.32E-002	2.50E+000	1.63E-004	**58.20**	1.00E+005	0.48	32.41	**15.5**
0-1 km	1.32E-002	2.50E+000	1.66E-004	**57.15**	1.00E+005	0.49	20.37	**9.9**
TOTALS						**3.86**		**280.2**

-particle size of 132 microns - way too big!

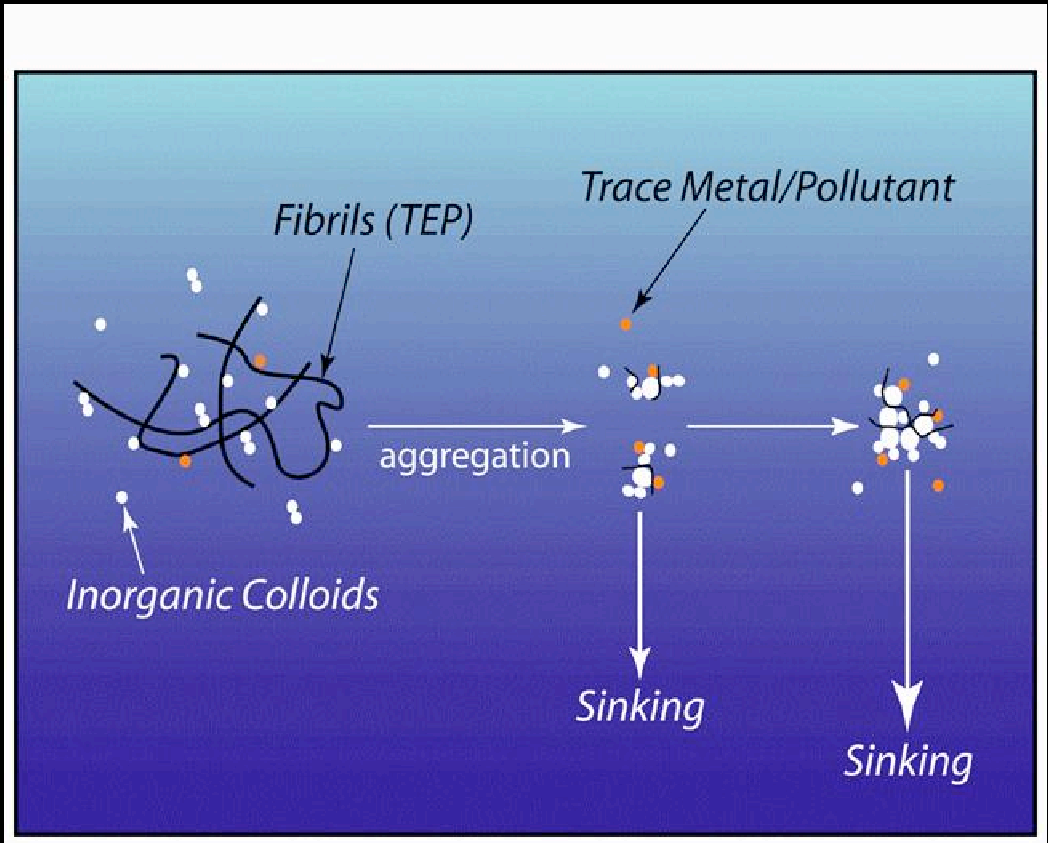
-fallout time of 3.86 hours - way too fast!



Particles do not fall out as modeled - so what is happening?

Aggregation

Individual particles cannot match observed fallout patterns.



But, ash cloud particles collide and stick together with fluid/ice cements; as hydrometeors; or dry, with electrostatic attraction, and therefore can fall out much faster yet leave few traces of aggregation. Also, very small particles can fall with large ones, which explains many fallout deposits.

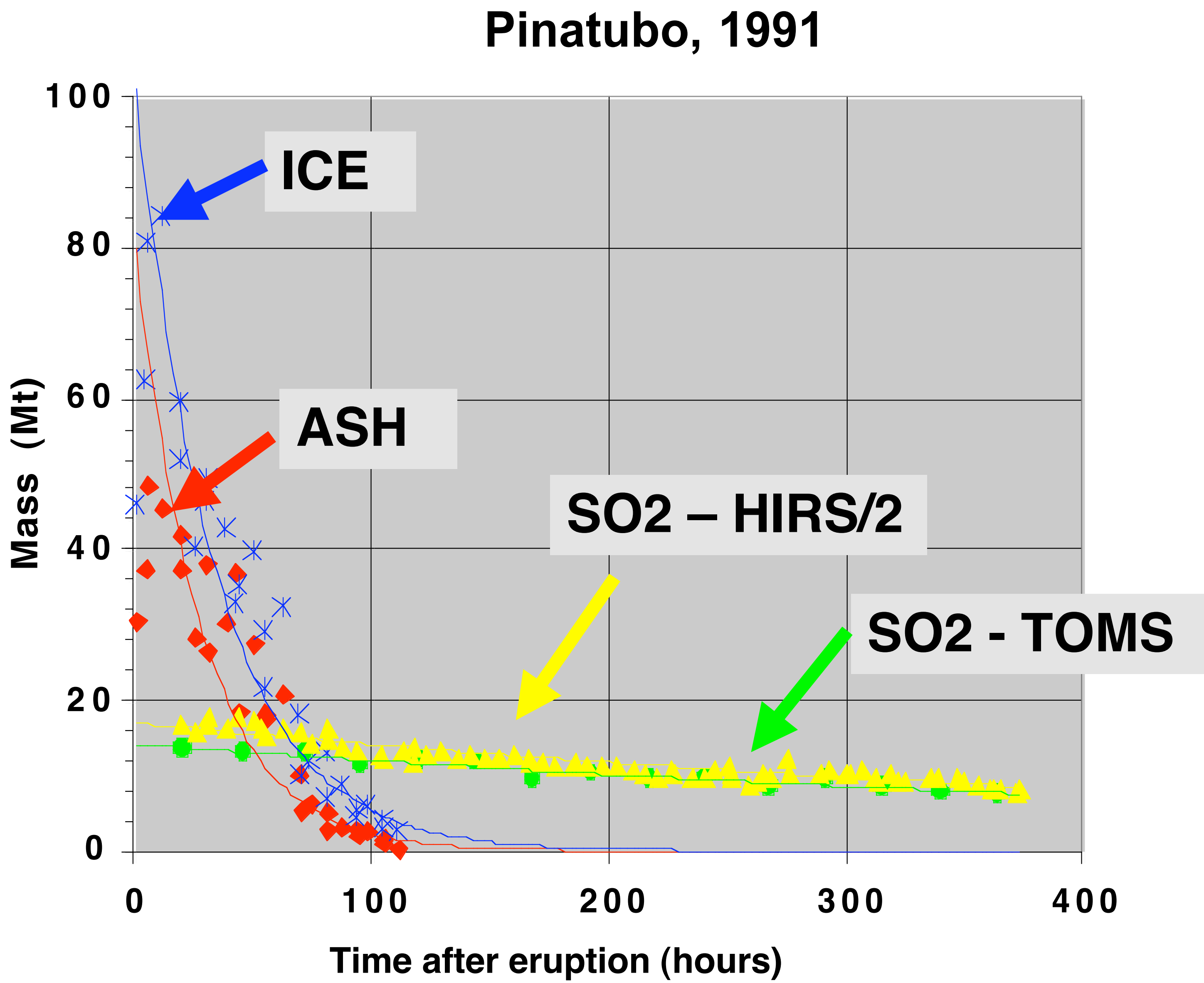


Figure 3. Mass removal patterns of ash, ice and sulfur dioxide in the 1991 Pinatubo volcanic cloud (Guo et al., 2004a; 2004b).

Volcano	Measurement Period (hours after eruption)	Particle type	Mean Removal Rate (kt/hour)	E-folding (hours)	Retrieval Method	Reference
El Chichón, Mexico (1982a)	5 - 68	Ash	34	13	AVHRR	Schneider et al., 1999
El Chichón, Mexico (1982b)	7 – 70	Ash	99	15	AVHRR	Schneider et al., 1999
Pinatubo, Philippines (1991)	5 - 111	Ash	482	24	HIRS/2	Guo et al., 2004b
Pinatubo, Philippines (1991)	5 - 111	Ice	819	30	HIRS/2	Guo et al., 2004b
Pinatubo, Phillipines (1991)	6 - 104	Ash	363	27	AVHRR	Guo et al., 2004b
Pinatubo, Philippines (1991)	6 - 104	Ice	648	27	AVHRR	Guo et al., 2004b
Hudson, Chile (1991)	2 – 132	Ash	21.8	30	AVHRR	Constantine et al., 2000
Spurr, USA (Jun 1992)	13 – 152	Ash	2.3	143	AVHRR	Rose et al., 2001
Spurr, USA (Aug 1992)	14 – 84	Ash	3.7	43	AVHRR	Rose et al., 2001
Spurr, USA (Sept 1992)	8 – 70	Ash	4.9	52	AVHRR	Rose et al., 2001
Hekla, Iceland (2000)	6 – 24	Ice	48	8	AVHRR	Rose et al., 2003
Cleveland, USA (2001)	6 – 20	Ash	1.6	10	GOES + MODIS	Gu, 2004