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

Summit: 1260 m
Recent eruptions: 1986, 2006
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.

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).
EFFECT OF SIZE ON FALLOUT RATES

Time for a particle to reach the ground:
- 1 micron: ~0.0003 km/hr, 3.3 years
- 10 microns: ~0.01 km/hr, 290 hours
- 50 microns: ~0.8 km/hr, 11.5 hours
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:

\[
R_e = \frac{d \, v_t \, \rho}{\eta}
\]

(where \( d \) = particle diameter, \( v_t \) = terminal velocity, \( \rho \) = density of the atmosphere and \( \eta \) = viscosity of the atmosphere.)

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

\[
C = \frac{24}{R_e}
\]

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

\[
V \, \sigma \, g = \frac{1}{2} \, C \, \rho \, A \, v_t^2
\]

(where \( V \) = particle volume, \( \sigma \) = 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 $7.5 \times 10^{10}$ 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:

$$ H = 236.6 \times Q^{0.25} $$

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

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

- 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

- particle size of 132 microns - way too big!
- fallout time of 3.86 hours - way too fast!
Augustine 1986 Fallout

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).
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