

ERTH 456 / GEOL 556
Volcanology

– Lecture 12: Volcanic Plumes –

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hours: TR 3-4PM or appt.

October 03, 2016

Volcanic Explosivity Index

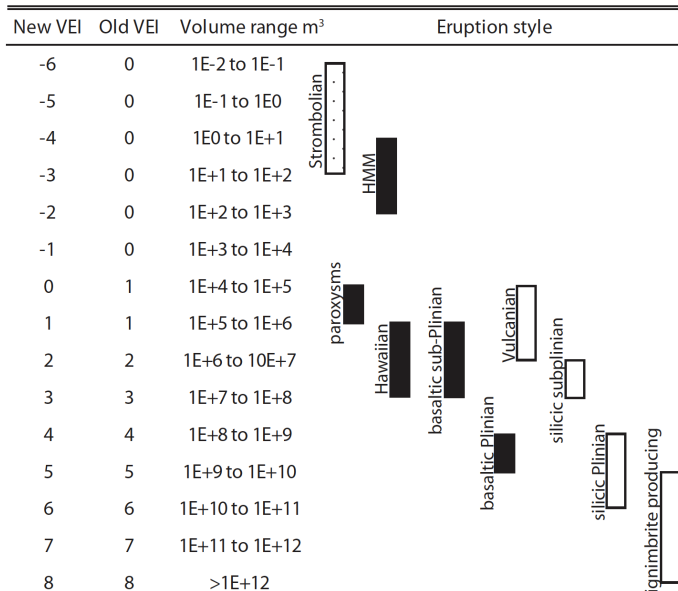
- Devised by Chris Newhall & Stephen Self in 1982
- “Richter scale for eruptions” (note, we don’t use Richter scale anymore)
- based on volume of tephra, plume height
- often criticized / used for things it wasn’t made to do
- recently revised by Houghton and others (2013, *Geology*) to account for small explosive events

Volcanic Explosivity Index

| VEI | 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) | | 1x10 ⁴ | 1x10 ⁶ | 1x10 ⁷ | 1x10 ⁸ | 1x10 ⁹ | 1x10 ¹⁰ | 1x10 ¹¹ | 1x10 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" → | | ← "Cataclysmic," "paroxysmal," "colossal" → | | ← "Severe," "violent," "terrific" → | | | |
| Eruption Type (see fig. 7) | ← Hawaiian → | | ← Strombolian → | | ← Vulcanian → | | ← Plinian → | | | ← Ultra-Plinian → |
| Duration (continuous blast) | ← <1 hr → | | ← 1-6 hrs → | | ← 6-12 hrs → | | ← >12 hrs → | | | |
| Maximum explosivity | Lava flow | ← Phreatic → | | ← Explosion or Nuée ardente → | | ← Dome or mudflow → | | | | |
| Tropospheric Injection | Negligible | Minor | Moderate | Substantial | | | | | | |
| Stratospheric Injection | None | None | None | Possible | Definite | Significant | | | | |
| Eruptions | 976 | 1239 | 3808 | 1083 | 412 | 168 | 50 | 6 | 0 | |

Newhall & Self, 1982; Siebert et al., 2010

Volcanic Explosivity Index+



What's in a plume?



ISS Crew, 2008

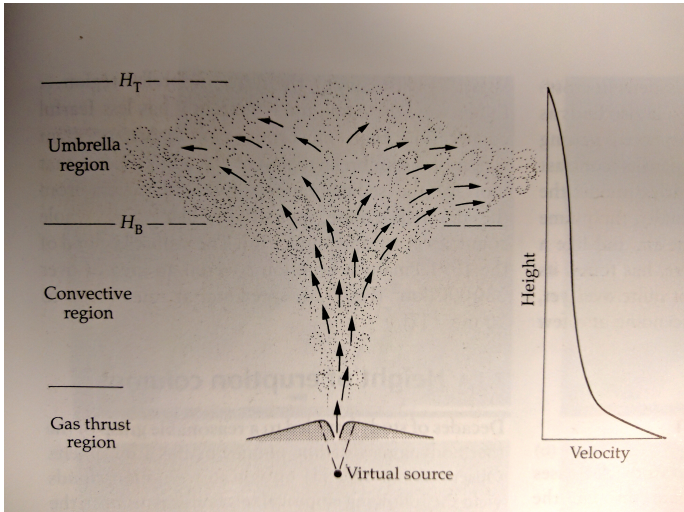
What's in a plume?

- hot pyroclasts
- magmatic gas
- air



ISS Crew, 2008

Plume Basics



Francis & Oppenheimer, 2004

H_B : height of neutral buoyancy; H_T : maximum plume height
($H_T \approx 1.4H_B$)

Examples - Karymsky 2008 R. Grapenthin



Examples - Karymsky 2008 R. Grapenthin



Examples - Karymsky 2008 R. Grapenthin



Examples - Karymsky 2008 R. Grapenthin



Examples - Karymsky 2008 R. Grapenthin



Examples - Karymsky 2008 R. Grapenthin



Examples - Karymsky 2008 R. Grapenthin



Examples - Karymsky 2008 R. Grapenthin

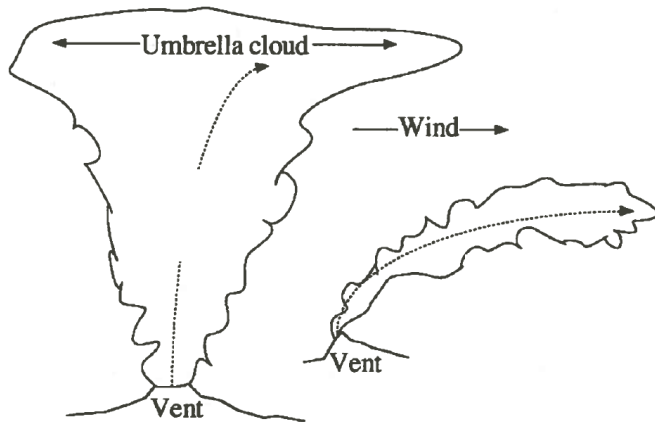


Examples - Karymsky 2008 R. Grapenthin



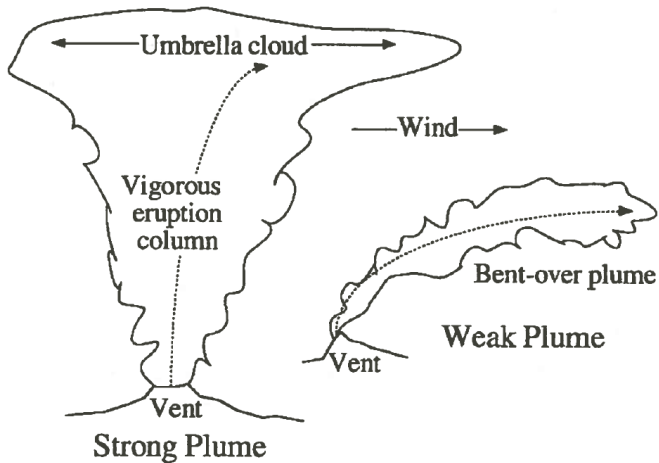


Plume Characteristics



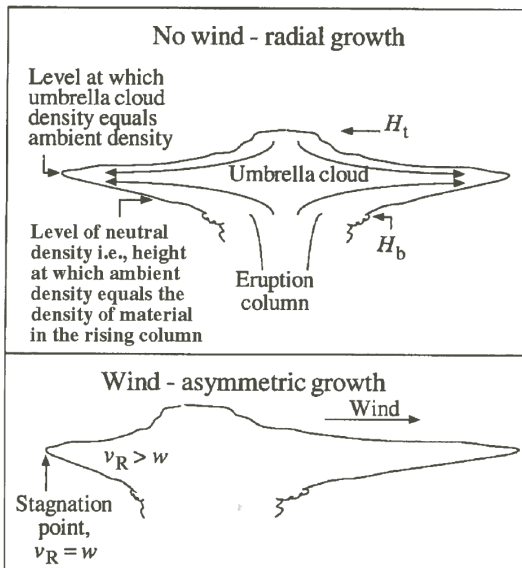
Sparks et al., 1997

Plume Characteristics



Sparks et al., 1997

Plume Characteristics



Examples - Karymsky



S. Serovetnikov (?)

Examples - Grímvötn" 2011

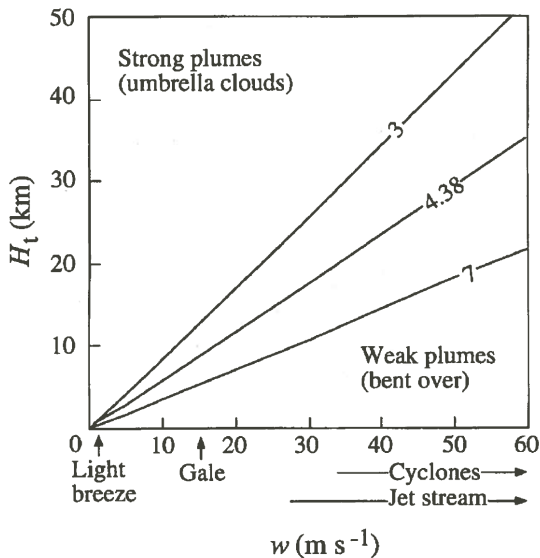


B. Oddsson

Examples - Kliuchevskoy Group 2010 s. Serovetnikov



Plumes vs. Wind



Plumes vs. Wind

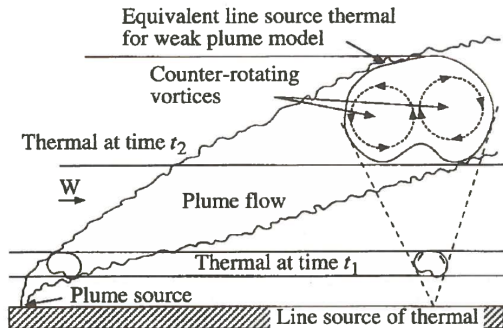


Figure 11.9 Schematic diagram showing the local features of the interaction of a plume with the wind (after Figure 5a of Ernst *et al.* 1994). When the plume is bent over into a subhorizontal orientation, it resembles a thermal in cross-section

Sparks *et al.*, 1997

Plumes vs. Wind

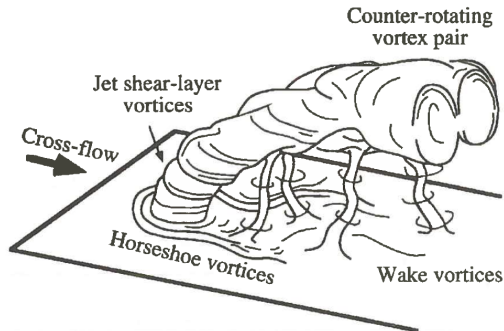


Figure 11.10 Diagram showing four types of vertical vortical structures developed by interaction of a plume or jet with a cross-flow (after Fric and Roshko 1994)

Sparks et al., 1997

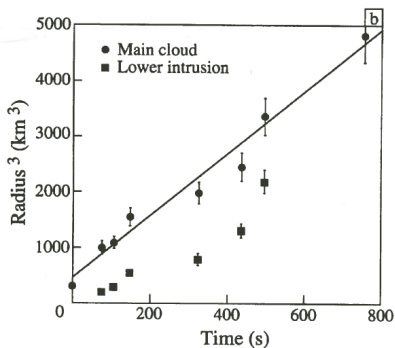
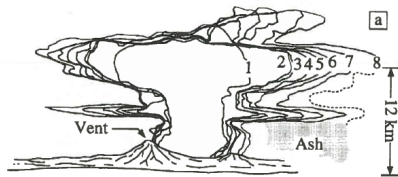
Plumes vs. Wind vs. Topography



Figure 11.11 A Landsat image showing the plume of April 3, 1986 issuing from the crater of Augustine volcano, Alaska. (Photograph provided by W. I. Rose.)

Sparks et al., 1997

Plume Dispersal – Redoubt 1990



Plume Dispersal – Mt. St. Helens 1980

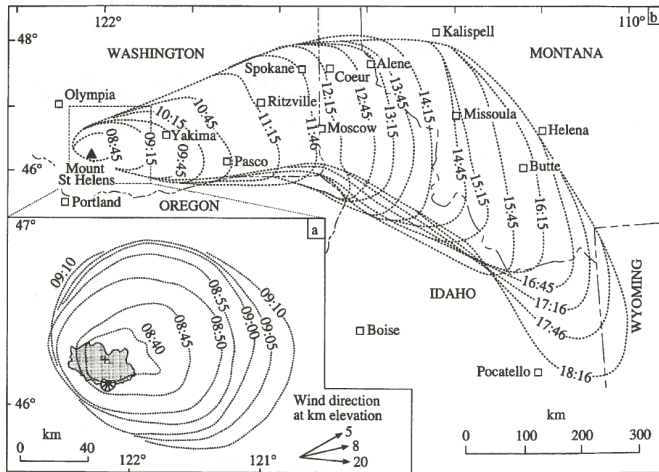
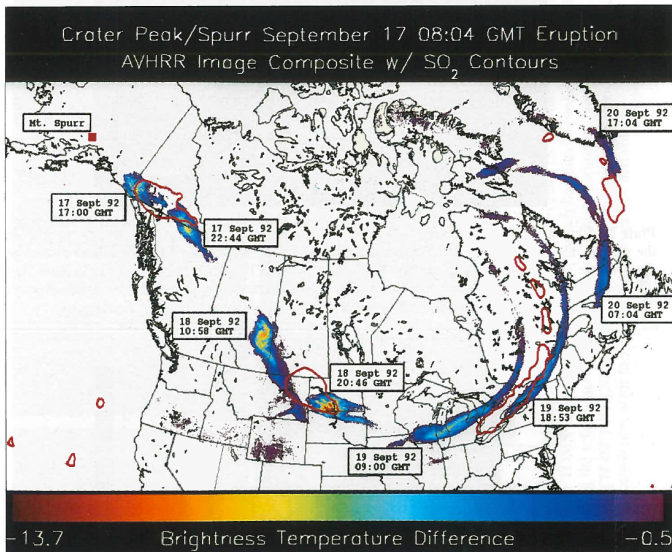


Figure 11.20 (a) Map traced from satellite imagery showing the initial growth of the giant umbrella cloud of Mount St Helens (from Sparks *et al.* 1986). Contours are in five minute intervals labelled with local time in hours and minutes. (b) Map traced from satellite imagery showing the later growth of the May 18, 1980 Mount St Helens plume (redrawn from Sarna-Wojcicki *et al.* 1981)

Plume Dispersal – Spurr 1992 (4 days)



Sparks et al., 1997

Plume Dispersal – Pinatubo 1991 (3 months)

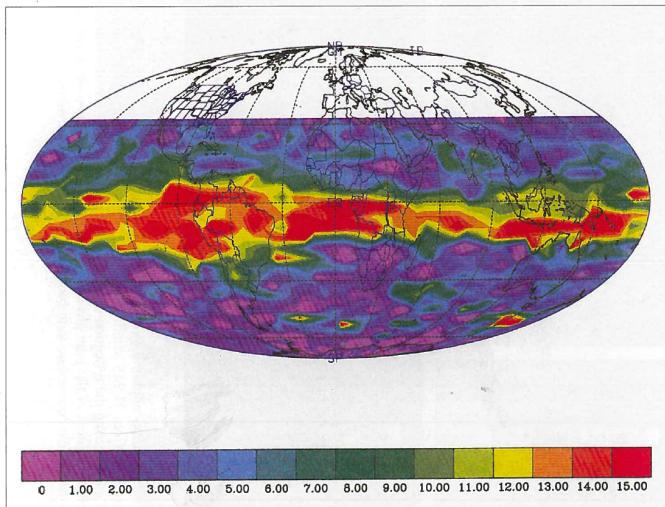


Plate VI Figure 18.10 The global distribution of sulphur dioxide at the 26 km level on September 21, 1991, approximately three months after the Pinatubo eruption (Read *et al.* 1993). The colour bar units are in parts per billion by volume

Density Variations in Eruptive Mix

Density of mixture (β) given by:

$$\frac{1}{\beta} = \frac{1-n}{\sigma} + \frac{n}{\rho}$$

n, ρ : mass fraction & density of gas

σ : density of pyroclasts

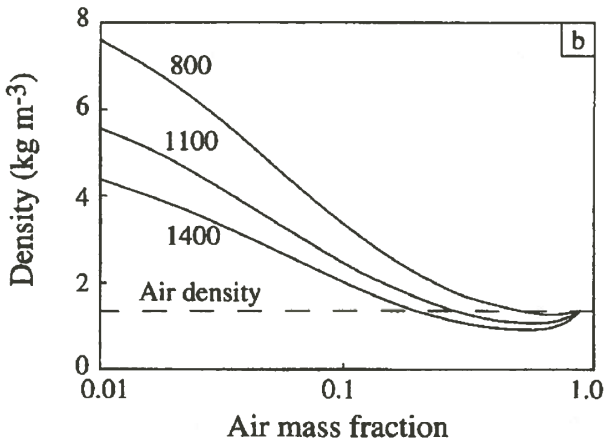
assume gas phase behaves as perfect gas:

$$\rho = \frac{P}{RT}$$

P, T : pressure & Temperature of mixture

R : gas constant, average if gaseous components: air= $285 \text{ Jkg}^{-1} \text{ K}^{-1}$,
 $\text{CO}_2 = 185 \text{ Jkg}^{-1} \text{ K}^{-1}$, water vapor= $460 \text{ Jkg}^{-1} \text{ K}^{-1}$

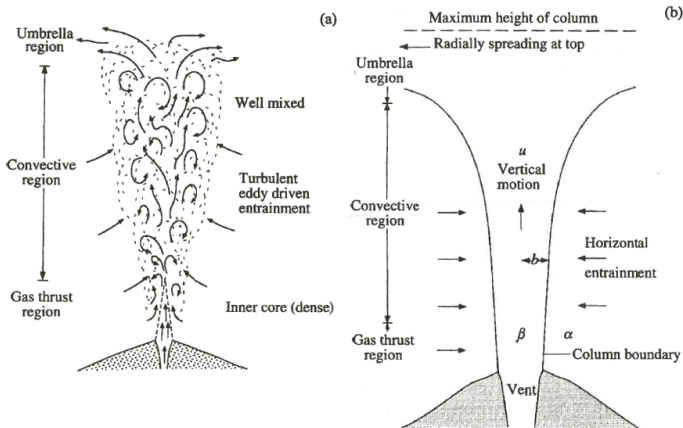
Density Variations in Eruptive Mix



Sparks et al., 1997

Density of mixture (entrained air, pyroclasts, volatiles) function of entrained air; three eruption temperatures given in Kelvin & constant water 3%

Density Variations in Eruptive Mix

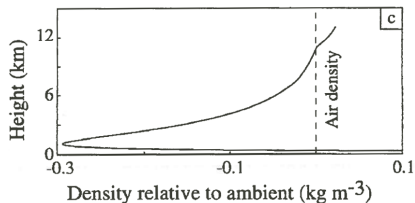
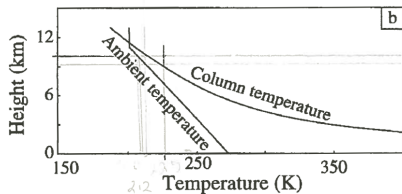
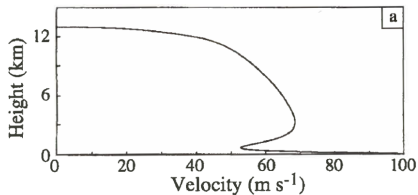


Sparks et al., 1997

entrainment coefficients: jet ≈ 0.06 ; buoyant plume ≈ 0.09 (more efficient; other models exist)

Density & Temperature Variations

- initial radius: 50 m
- initial velocity: 100 m /s
- eruption temperature: 1000 K
- initial mixtures 3% water (mass fraction)



Velocities vs. Vent Radii

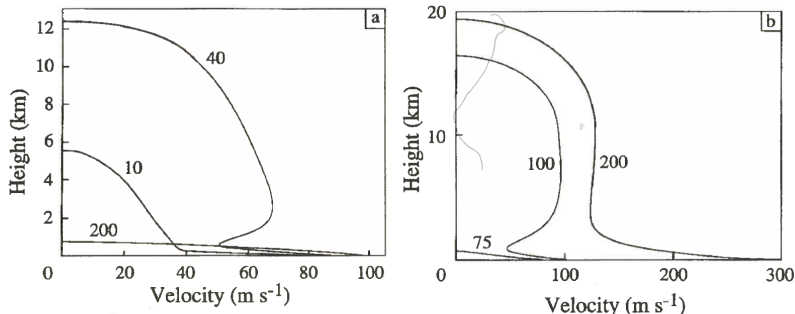
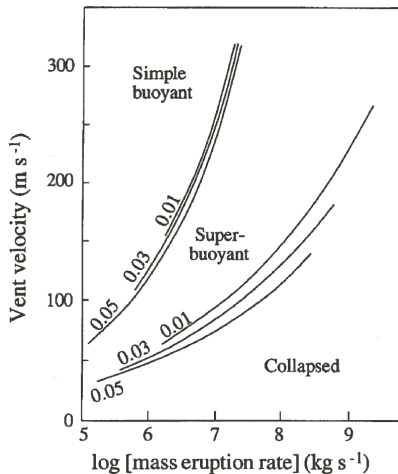


Figure 4.5 Variation of the velocity in the column as a function of the height. Curves are shown for (a) three initial radii, 10, 40 and 200 m with eruption velocity of 100 m s^{-1} , and (b) three eruption velocities 200, 100 and 75 m s^{-1} with a radius of 100 m. The mass fraction of water is 0.03 and the eruption temperature 1000 K. With the larger initial radius (a) or smaller eruption velocity (b) the material takes longer to entrain sufficient fluid to become buoyant, eventually leading to collapse in the case of the 200 m initial radius (a) and 75 m s^{-1} initial velocity (b). The 10 m vent radius (a) and 200 m s^{-1} eruption velocity (b) lead to a monotonically decaying velocity profile, since the material becomes buoyant rapidly. However, the 40 m vent radius (a) leads to a non-monotonic velocity profile, because the column entrains ambient air more slowly, and so the velocity falls off dramatically before the material becomes buoyant. A column with this non-linear velocity profile is referred to as superbuoyant. After Bursik and Woods (1991)

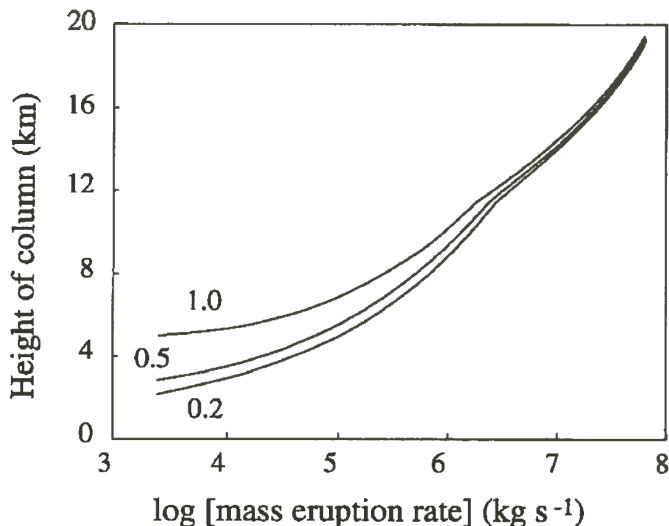
Eruption Regimes: Velocities vs. Vent Radii



Sparks et al., 1997

Solid curves are labeled with initial mass fraction of water

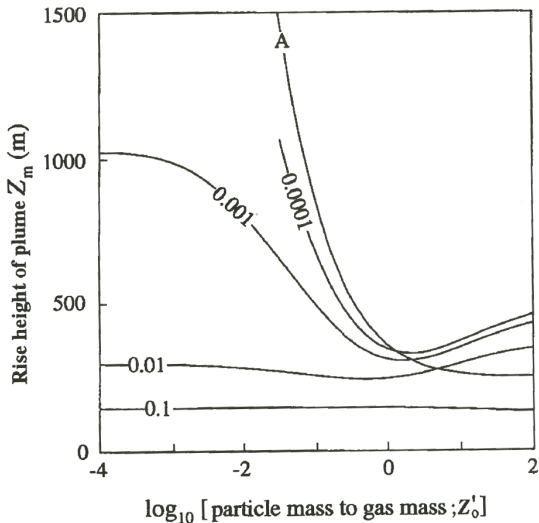
Humidity - Vapor entrainment



Sparks et al., 1997

Solid curves are labeled with different relative humidities

Jet Rise Heights - Vapor entrainment



Sparks et al., 1997

10 m vent diameter with 100 m/s initial velocity, curves for different particle radii in meters