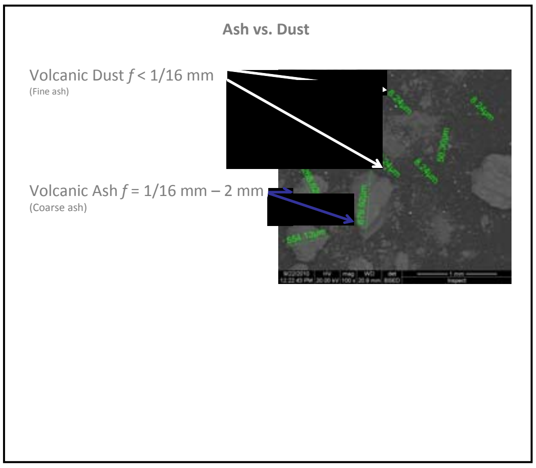
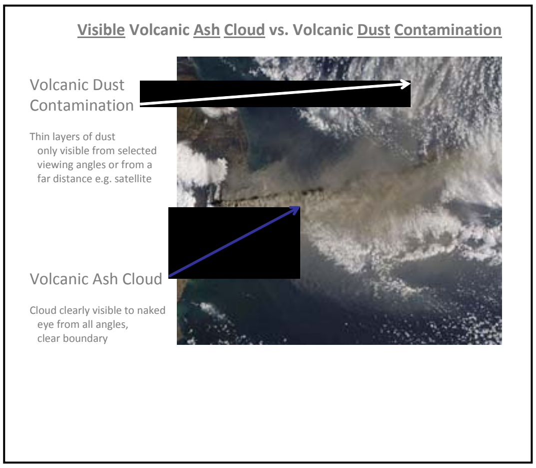
Main conclusions and results from the phase 1 of the EUROCONTROL Volcanic Ash Safety Project

1. Volcanic Ash/Dust Definition

By “volcanic ash” or “volcanic dust” we understand particulate matter ejected in the atmosphere at a certain initial height during a pyroclastic volcanic eruption. The particulate matter remains in suspension for a limited time interval, during which it gets transported by the wind. Volcanic ash/dust are defined by 10 structural parameters, and other 5 positional parameters.





2. Eruption-Ash-Dust Distinction

There is a relevant distinction between *volcanic ash cloud* as per ICAO Doc 9691 and *volcanic dust contamination.*

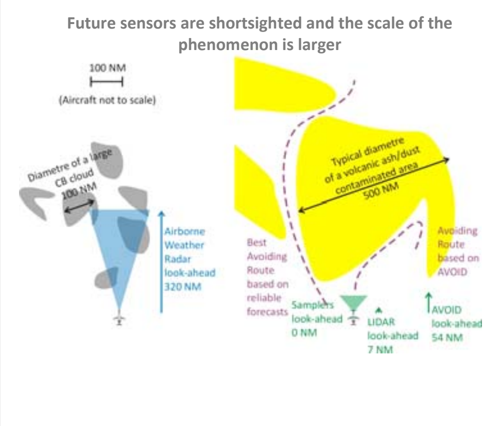
There are three separate *types of threats* to aviation safety in connection with the volcanic activity: (VPE) *Volcanic pyroclastic eruption*, (VAC) *Volcanic ash cloud*, and (VDC) *Volcanic dust contamination*; separate risk assessment, information processing, analysis in the decision making process, and lines of action are appropriate for each of these three types of risks; mixing or failing to de-couple the three types of threats may lead to *economic risk* (excessive measures and unjustified losses for civil aviation stakeholders).

Volcanic dust contamination and *sand aerosols* are similar threats to aviation; this fact is useful because sand aerosols contaminations are much more frequent and fairly usual.

3. Safety-Maintenance Distinction

Safety risks have to be assessed separately from *maintenance issues*, otherwise the *economic risk* increases.

Volcanic dust contamination in concentrations comparable to that current for sand aerosols (4·10—3 g/m3) is not a safety issue (maintenance issue like flying at Ryadh or Cairo); Hence we need a safety risk approach separated from maintenance issues.



	Volcanic Ash Cloud	Volcanic Dust Contamination	Sand Aerosol Contamination
Visibility	Clearly visible from all angles, easily identifiable by dark colour, distinct boundary	Visible only from selected angles, hard to distinguish, visible in satellite imagery	Visible sometimes from selected angles, visible in satellite imagery
Where?	Within 1-200 NM of the eruption	Very large areas (>1000 NM in size)	Large areas
Typical Concentrations (1 $kg/hm^3 = 10^{-3}$ g/m^3)	1000 kg/hm^3	1-100 kg/hm^3	1-100 kg/hm^3
Particle size range (µm)	1-2000	1-40	1-50
Floatability in atmosphere (age)	1-2 Days (due to ash-dust differentiated sedimentation)	6 Days (traces remain for years)	3 Days
	Volcanic Ash Cloud	**Volcanic Dust Contamination**	**Sand Aerosol Contamination**
Aviation Safety Risk	Serious incidents, no injury accidents	None on record	Very low (windshield cracks)
Impact on aviation	Local	Global due to misinterpretation	Maintenance issues

4. Forecasted vs. Actual Concentrations

Forecasted concentrations are needed for the flight operations and for ATM-related decisions and not *actual (historical) concentrations.* IFR flight operations and air traffic management decisions need information many hours in advance, and the contamination is rapidly changing, due to the winds which move the dust around.

Reliable *forecasted concentrations* are deliverable using a *modern tandem dispersion model* with daily *relevant data assimilation* of *actual (historic) concentrations*, measured systematically, following a predetermined scheme.

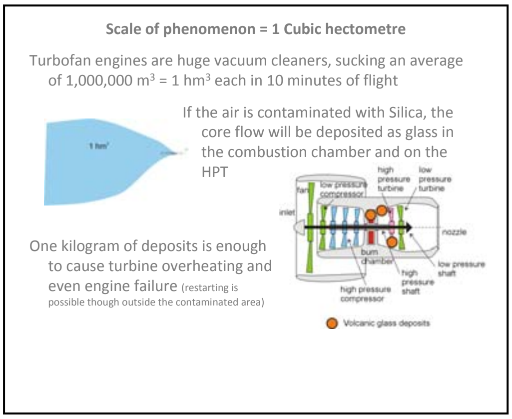
5. Hectometric Principle for Actual Concentration Measurement

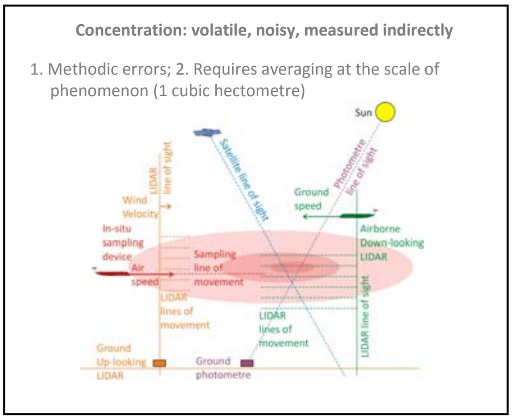
Concentration is a very noisy *random* variable; its actual *average* and *variance* (not the peak value) should be determined over a volume of air of the order of one *cubic hectometre* to be useful for *relevant data assimilation. In-situ hectometric concentration measurement* of volumes of air of the order of one cubic hectometer (1,000,000 m^3) is needed for relevant data assimilation; *in-situ sampling* of volumes of air of the order of one cubic metre are useful for scientific purposes, but not for operational concentration measuring, due to the noise they induce.

Actual (historic) concentrations are best measured by a *volcanic ash and dust hectometric concentration measurement unit* (VADHCMU), which is a combination of three instruments operating together, in the same area:

1. Airborne 6 channel (3 wavelenghts plus polarizations) backscattering infrared *LIDAR*,
2. Ground based (mobile) optical *photometre*, and
3. Airborne *in-situ hectometric concentration measurement unit.*

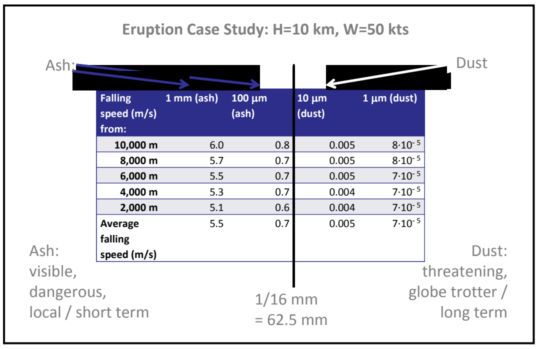
Volcanic ash and volcanic dust are visible on *satellite images* in multiple wavelength infrared pictures, but these images have no information of height, and they integrate the concentrations on each vision axis; based on the values of these integrals, no feedback is directly usable in the dispersion model data assimilation; satellite images may however be used to supplement or to extrapolate the VADHCMU measurements; they are also useful in an open-loop validation of the model, but for that, the model has to compute the integrals from given points of vision, providing direct comparison images.



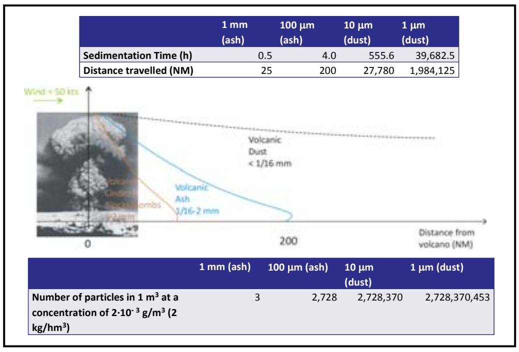


Particle *sedimentation speed* (and consequently the *age* of the volcanic ash or dust particles) depends on the *size* of the particles, and this is the principle by which the *size distribution* changes in time. Also, this observation is useful to understand for how long the particles need to be followed from the moment of the eruption.

The shape of particles is of less importance and generates less variance as initially thought.



Falling speed (m/s) from:	1 mm (ash)	100 µm (ash)	10 µm (dust)	1 µm (dust)
10,000 m	6.0	0.8	0.005	8·10⁻⁵
8,000 m	5.7	0.7	0.005	8·10⁻⁵
6,000 m	5.5	0.7	0.005	7·10⁻⁵
4,000 m	5.3	0.7	0.004	7·10⁻⁵
2,000 m	5.1	0.6	0.004	7·10⁻⁵
Average falling speed (m/s)	5.5	0.7	0.005	7·10⁻⁵



	1 mm (ash)	100 µm (ash)	10 µm (dust)	1 µm (dust)
Sedimentation Time (h)	0.5	4.0	555.6	39,682.5
Distance travelled (NM)	25	200	27,780	1,984,125

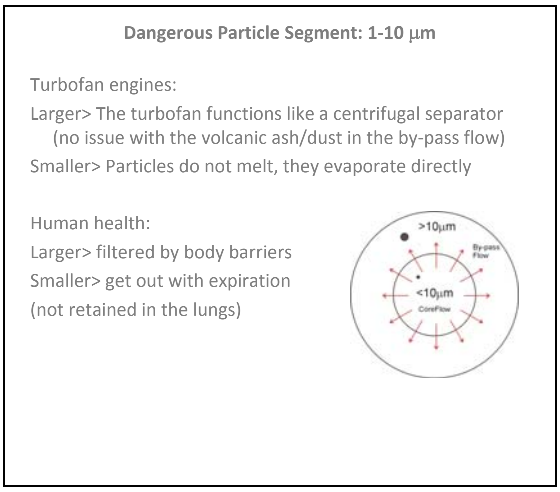
	1 mm (ash)	100 µm (ash)	10 µm (dust)	1 µm (dust)
Number of particles in 1 m^3 at a concentration of $2 \cdot 10^{-3}$ g/m^3 (2 kg/hm^3)	3	2,728	2,728,370	2,728,370,453

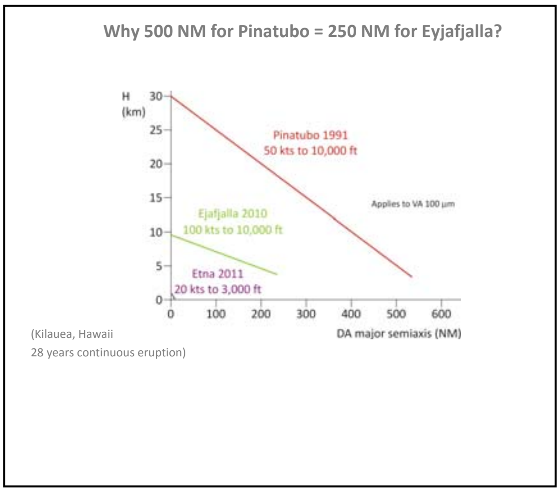
7. Size Segmentation

Not all sizes of particles are equally dangerous to turbine engines and human health; it is worth doing a risk segmentation based of particle size, to provide a criterion for targeting those segments which are aggressive.

Volcanic ash particles (over 62.5 µm) are probably dangerous and flying into a visible volcanic ash cloud is not recommended. However, the volcanic ash particles have a high sedimentation speed, falling to the ground in several hours from the eruption. Thus, the affected area is limited around the volcano, in principle within a maximum 200 NM radius.

Volcanic dust particles (under 62.5 µm) are safe to fly into in concentrations of or below $2 \cdot 10^{-3}$ g/m^3 (2 kg/hm^3), much like the sand aerosols. They could be found many days after an eruption, and at large distances from the volcano.
At concentrations higher than $2 \cdot 10^{-3}$ g/m^3 (2 kg/hm^3), the particles which are aggressive both to the turbine engines and to the human health are those between 1 and 10 µm. Consequently, this size range was targeted in measurement strategy and tactics, and if a single size of particle is to be chosen for simplicity, the authors decided for the 5 µm as a representative prototype.





8. Health Hazard from Volcanic Ash/Dust

Reviewing the scientific data, authors concluded that it is reasonable to anticipate that airplane passengers exposed to silicon dioxide by inhalation during flights through volcanic dust clouds are in no danger to develop silicosis. Level of exposure (in terms of concentration and duration) is far from those admitted as capable of inducing pneumoconiosis in the occupational settings. Level of exposure is even smaller than those measured in ambient air in some US cities.

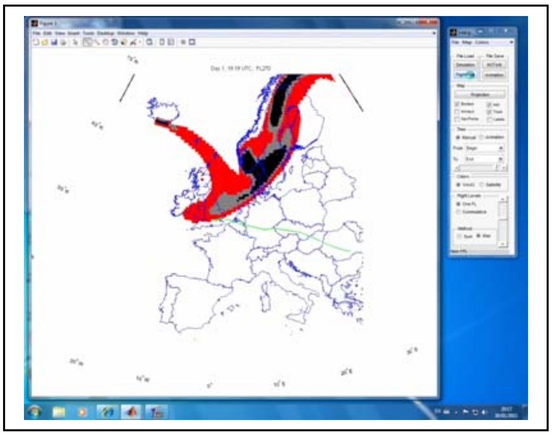
Particles MMAD (mass median aerodynamic diameter) is in the range of fine particles, thus penetrating the airways all the way to the alveoli. Therefore, it is possible an inflammatory reaction as studies on laboratory animals showed, but these experimental studies were conducted using doses much higher than those experienced by airplane passengers or crew.

Software Applications

Volcanic ash/dust simulation software was developed. The volcanic ash/dust parameters presented in WP1 define the essential object of the application.
A turbine engine simulator served to test the impact of volcanic ash/dust. Additionally, CFD software was used to study the effect of the glassy coating of the turbine blades by volcanic ash/dust.

A dispersion model engine (DISP2) has been implemented. This powers two applications FALL4D and ASH4D. The applications could be used in a number of ways, to forecast the shape and movement of contamination, and to allow flight track analysis, pilot reports, and other uses. As it could predict the situation 180 hours in advance, the tool is an early warning system.

ASH4D is a map postprocessor and allows visualizing contamination maps in various formats, interpolating through the maps in 4D (location, time and vertical), using its own dispersion engine FALL4D to extrapolate or forecast more days in advance, export contamination maps and various formats, calculate and export artificial satellite images ready to be compared to the real satellite images for an open-loop validation of the model, superimpose concentration measurements, pilot reports, flight plans, 4D trajectories to the maps. Additionally it will allow superimposing airports, navigation aids, navigation points, airways, FIRs and sector boundaries on the concentration maps.



BRIEF CONCLUSIONS

- Visible volcanic ash cloud is a danger to aviation, but it does not travel very far (1-200 NM, max. 500 NM in the greatest eruption in history, Pinatubo 1991);
- Volcanic dust contamination in concentrations comparable to that current for sand aerosols (4·10—3 g/m3) is not a safety issue (maintenance issue like flying at Ryadh or Cairo);
- Volcanic dust size segment which could affect aircraft and by coincidence the human respiratory system is 1 μm – 10 μm: this range limits our search (because tiny particles of volcanic dust never come down from the atmosphere!)
- It is feasible to provide ANSPs and airlines with a risk approach through a safety case of which elements are supported by tools and data simulations and assimilations.