EUROCONTROL – Univ. Politehnica of Bucharest & ROMATSA Project Volcanic Ash Safety

EUROCONTROL

The European Organisation for the Safety of Air Navigation

POLITEHNICA

romatsa

Ash Safety

Studies on the Measurement and the Effects
of the Volcanic Origin Particles in Suspension in the Atmosphere
on the Safety of Aircraft

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Ash Safety	
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Presentation Overview

1. Project, Work Packages, Tasks

2. Outcome and Deliverables

3. Key Questions and Answers

Ash Safety Project

- **Research Subject**

  „Studies on the Measurement and the Effects of the Volcanic Origin Particles in Suspension in the Atmosphere on the Safety of Aircraft”

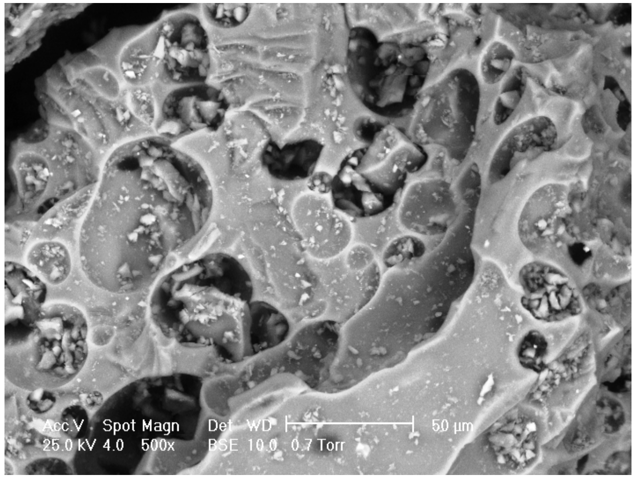
- **Research Objectives:** to provide objective, relevant, and scientifically validated information for the future decisions on the air traffic in volcanic ash contaminated atmosphere, for the best trade-off for the most fluent air traffic under the circumstances, with uncompromised flight safety.

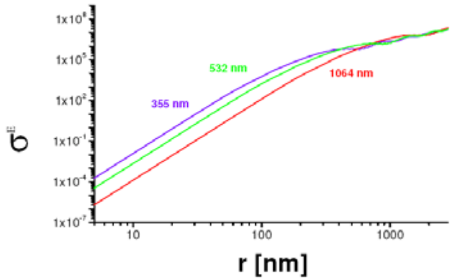
Work Plan and Expected Results

- 8 work packages => research report => software application
- multidisciplinary research teams with experts in: flight operations, avionics integrated systems, aircraft propulsion systems, maintenance and repair operations, chemistry, atmosphere physics, meteorology, geology and volcanic research, aerodynamics, thermodynamics, medicine, mechanics, abrasion, air traffic management, computer based modeling and simulations
- 1st phase ended in 2010, beneficiary: EUROCONTROL
- 2nd phase due to start in 2011, beneficiaries: EUROCONTROL and ROMATSA

Work Package 1

- Composition and physiochemical properties of the particles of volcanic origin – basic elements for ATM air airline operations safety risk assessment





Work Package 2

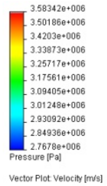
- Methods and techniques of determining the concentration of volcanic ash particles in suspension in the atmosphere; errors, limitations, and how these methods could be used by ANSPs, Authorities and Airlines to decide on operations within airspace potentially contaminated with volcanic ash

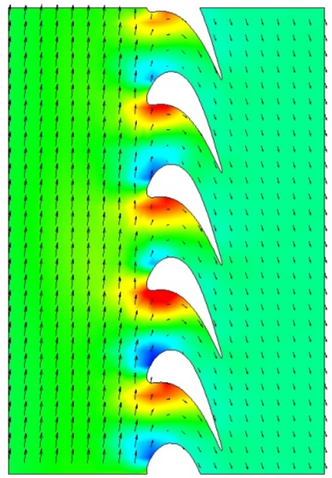
- Optical methods (photometre, LIDAR, infrared sensing)
- Methods of sampling “in situ”
- Abrasion based methods
- Chemical methods (including the use of SO_2 as a proxy)

Work Package 3

Study of the possible effects of the volcanic ash particles in suspension on the aircraft in flight

- Turbine engines contamination effects
  - Compressor blades abrasion
  - Burn chamber abrasion
  - Turbine blades abrasion
  - Melting and solidifying particles in the burning chamber
  - Solidifying of the melted particles on the turbine blades
  - Contaminant impact on the gas flow inside turbine engines
  - Particles influence on the engine combustion
  - Blocking the turbine blades cooling ventilation
- Pitot tubes and static pressure inlets contamination
- Abrasion effects on the body of the aircraft
- Contamination of aircraft piston engines
- Contamination of the fresh air inflow in a pressurized cabin
- Impact on visibility for VFR flights
- Effects of electrostatic nature on avionics
- Impact on Air Traffic Control





Overall effects and combination of impact will provide input for ANSPs in deciding how many flights can be allowed in which airspace contaminated with which type of volcanic ash and in which concentrations.

Work Package 4

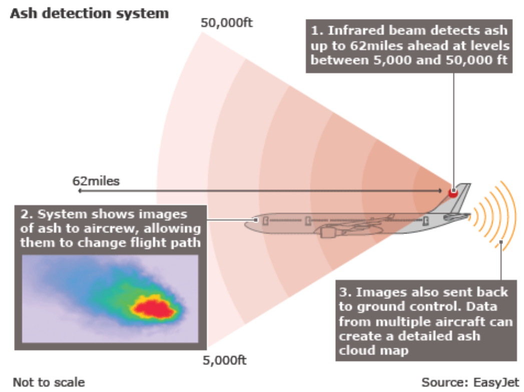
Preventive action and mitigation measures in the volcanic ash contaminated atmosphere:

- Best practice in case of turbine engines flame out due to contamination
- What an ATC controller could expect from a flight in case of volcanic ash encounter

Work Package 5

Impact of contamination on the Air Traffic Management

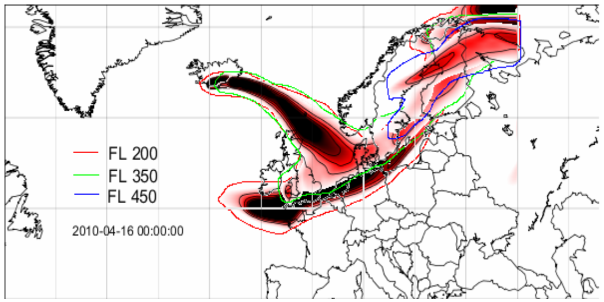
- How to manage overall ATM safety aspects and criteria for ATM safety decision making of senior management of ANSPs as well for ATCOs and flow management

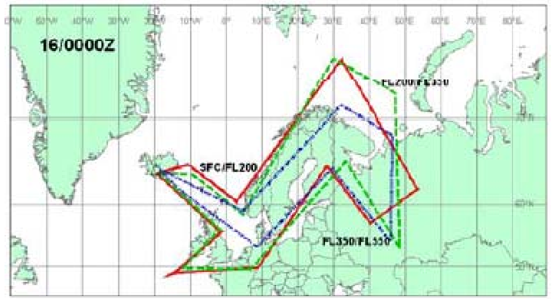


Work Package 6

Estimating thresholds of volcanic ash particles concentration for air traffic, by computer modeling and simulations

- Forecasting dispersion of volcanic ash/dust by computer modeling – ATM relevant aspects

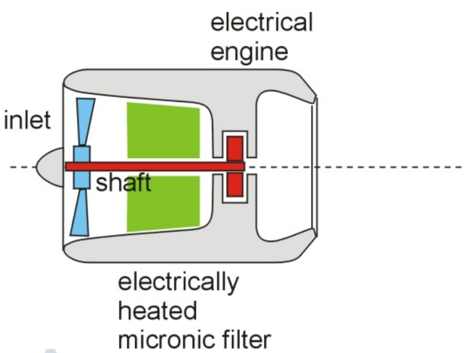




Work Package 7*

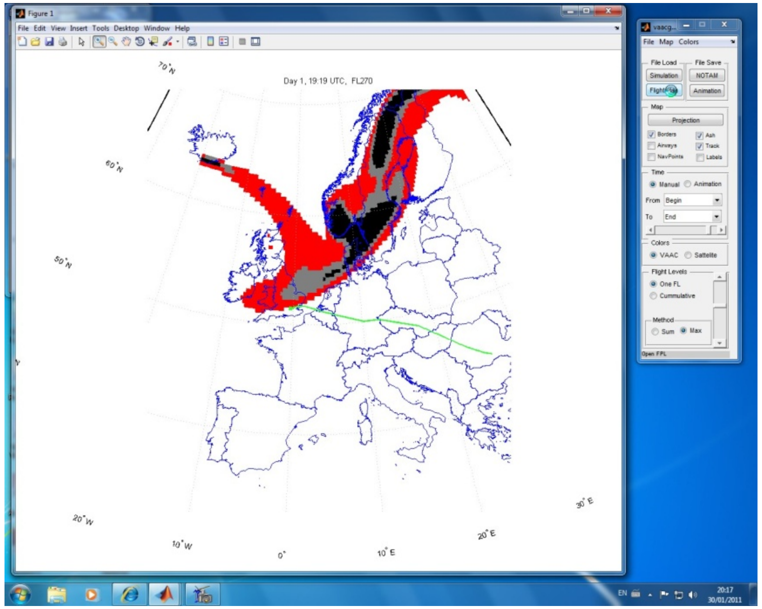
Specifications for an operative unit to measure the concentration of volcanic ash particles in a given airspace

Determining the volcanic ash particles concentration in atmosphere in a defined airspace (for cost efficiency reasons, we propose FAB Danube as a case study)



Work Package 8

Alert system for any given airspace from the moment of a new eruption: Ash4D Software



Tasks decomposition

1. Particles Diffusion in Atmosphere
2. Thermo-Chemistry and Corrosion (Thermo-Chemical reactions), and Physics (Phase changes)
3. Risk Functions / Scenarios Risk Analysis
4. Wear Effects – Abrasion Studies
5. Turbine Engines Cycle and Air Breathing Simulator
6. ATM Capacity / Complexity Simulator / Mapping Engine
7. Volcanic Ash/Dust Particles Model (Distribution, Dimensions, Density, Shapes, Concentration)
8. Human Health and Safety Impact
9. Flight Dynamics
10. Air Polution with Sand
11. Measurement Techniques (other than LIDAR)
12. LIDAR Technology
13. Legal and regulatory aspects

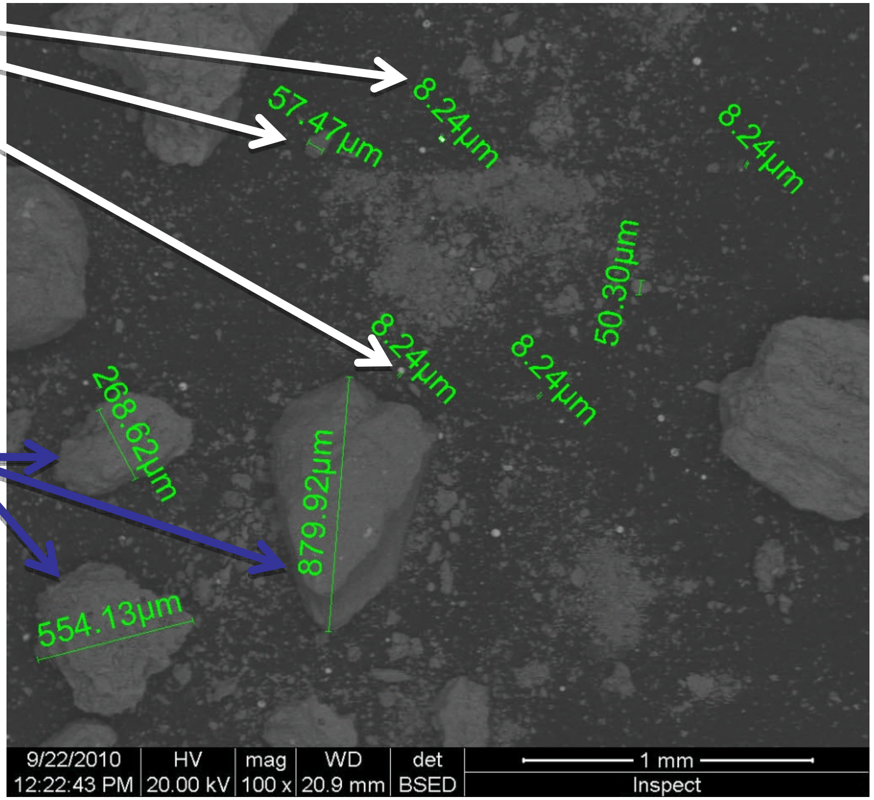
Key Questions

Issues	Key Questions to be Answered
Volcanic ash vs. volcanic dust	What is the influence of the particle sizes on the aircraft parts exposed?
Accurate simulations of volcanic ash encounters for various types of aircraft and engines	Increased wear or safety hazard? Where does the safety hazard begin?
Similarity between volcanic ash/dust and sand atmospheric pollutant	There is much flying experience in sand contaminated atmosphere; is it worth using it for volcanic ash?
Volcanic ash longevity in the atmosphere	Is it fair to demand total avoidance of the volcanic ash, since it floats up in the atmosphere for years?
Operators risks vs. ATM risks	If operators decide they could fly through a contaminated area, is the ATM system able to cope with the increased emergency probability?
Impact of volcanic ash/dust on the human body	Do aircraft occupants risk anything by breathing dust-contaminated air?
Risk functions	Does the risk function depend on concentration threshold, or time of exposure, or both in certain proportions? Does the risk depend on the particles dimension distribution?
Reporting system optimization for relevance	How should pilot reports and objective measurements be consistently used in an information system used by decision makers?

Ash vs. Dust

Volcanic Dust $f < 1/16$ mm
(Fine ash)

Volcanic Ash $f = 1/16$ mm – 2 mm
(Coarse ash)



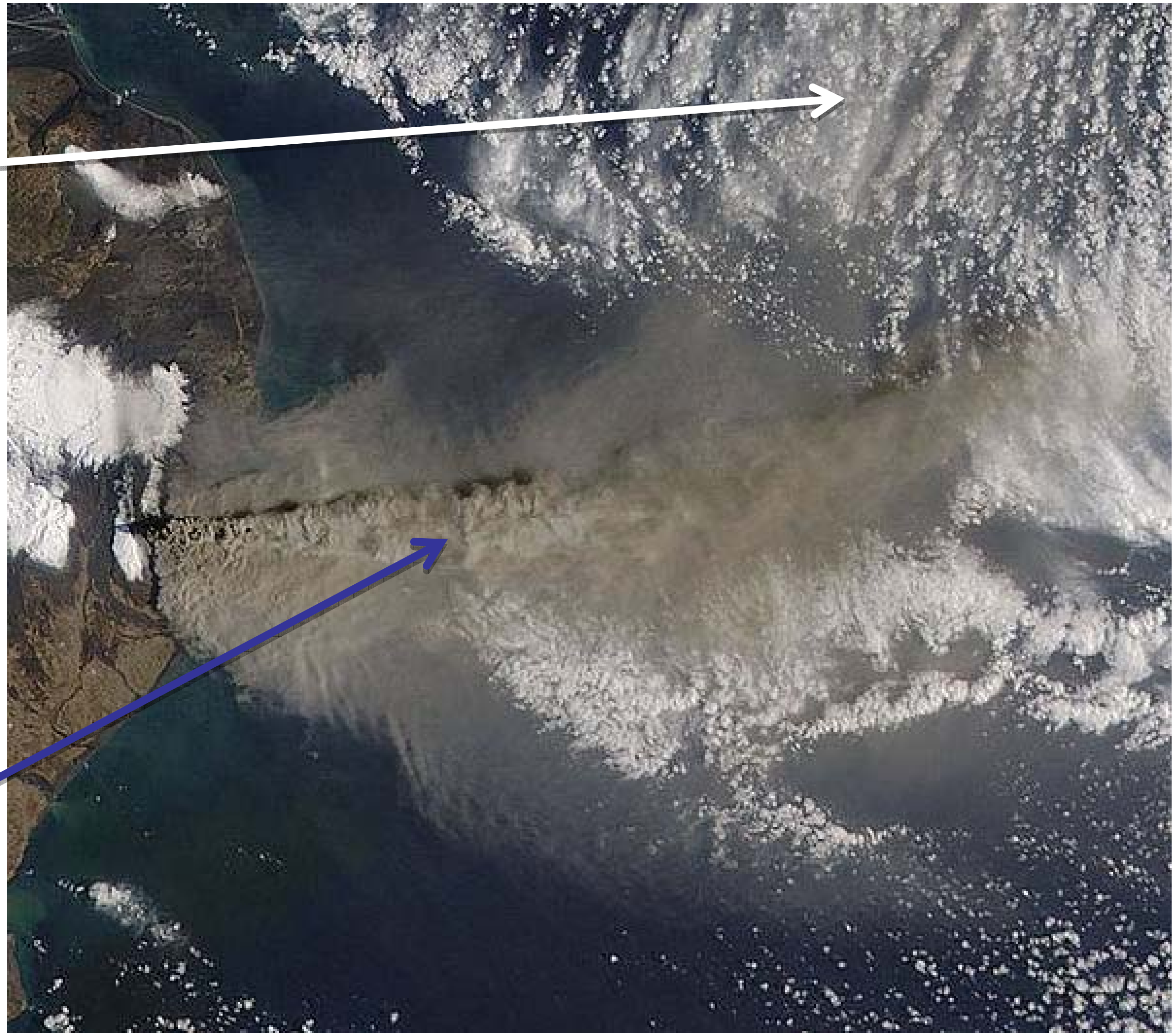
Visible Volcanic Ash Cloud vs. Volcanic Dust Contamination

Volcanic Dust Contamination

Thin layers of dust
only visible from selected viewing angles or from a far distance e.g. satellite

Volcanic Ash Cloud

Cloud clearly visible to naked eye from all angles, clear boundary

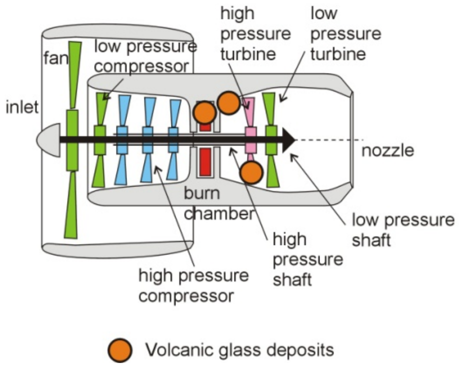


What can go wrong in a VA encounter

Parts / Occupants	Cause	Effect	Response
Turbine engines	fuel injection and combustor deposits of melted ash (glassy coatings)	surge, shut-down, difficult restart in flight	idle thrust, evasive maneuver
Turbine engines	clogging the turbine cooling vents	overheating	idle thrust, evasive maneuver
Pitot-static	clogging the sensors	unreliable air speed indications	attitude-based flying, indicated air speed deducted from ground speed and wind velocity
Turbine engines	abrasion with hard particles	wear of fan, compressor, turbine, transmission	idle thrust, evasive maneuver
Pneumatic controls	clogging the vents	failure	evasive maneuver
Windshield, body, wings, empennage	cracks, abrasion with hard particles	wear, opaqueness	evasive maneuver
Avionics, on-board instruments	clogging air-cooling vents, electrostatic discharges	overheating, malfunction	evasive maneuver
Human occupants	breathing contaminated air, eye cornea contact with ash/dust particles	respiratory problems, eye damage	nose breathing, replace contact lenses with eyeglasses
Turbine engines, body and instruments metallic parts	acidity, exposure to associated SO_2 and sulfuric acid	corrosion (in time)	maintenance check and replacement

Vulnerability ~ Air Breathing Flow

Air Breathing Order of Magnitude	Description	Affected Hardware or Liveware
1,000 m^3/s	High flow non-filtered air breathing	turbine engines
100 m^3/s	Directly exposed to airflow	windshield, empennage, body and wing
0.01 m^3/s	Low flow non-filtered air breathing	human occupants, Pitot-static sensors, computers, electrical engines and other air-cooled parts
Irrelevant	Air breathing through filters	piston engines, air-cooled parts with air filters

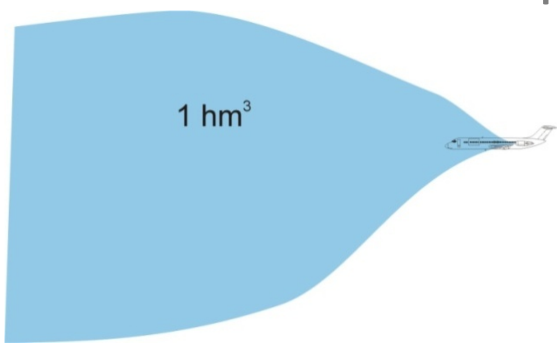


Example of quantity of contaminant accumulated in 10 minutes of flight in a concentration of $2 \cdot 10^{-3}$ g/m^3

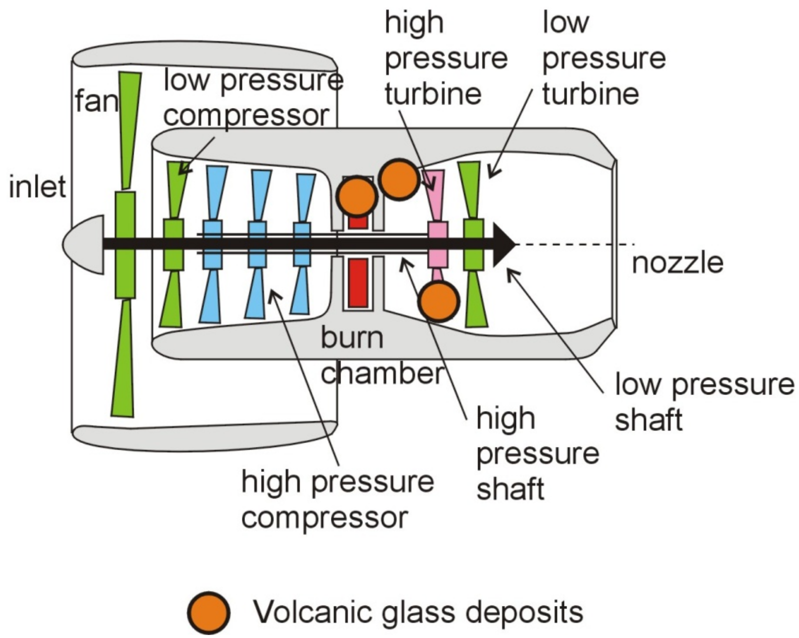
Air Breathing Order of Magnitude	Quantity of contaminant accumulated in 10 minutes flight at a concentration of $2 \cdot 10^{-3}$ g/m^3	Affected Hardware or Liveware
1,000 m^3/s	1.2 kg	turbine engines
100 m^3/s	120 g	windshield, empennage, body and wing
0.01 m^3/s	12 mg	human occupants, Pitot-static sensors, computers, electrical engines and other air-cooled parts
Irrelevant	0 g	piston engines, air-cooled parts with air filters

Scale of phenomenon = 1 Cubic hectometre

Turbofan engines are huge vacuum cleaners, sucking an average of 1,000,000 m^3 = 1 hm^3 each in 10 minutes of flight



If the air is contaminated with Silica, the core flow will be deposited as glass in the combustion chamber and on the HPT



One kilogram of deposits is enough to cause turbine overheating and even engine failure (restarting is possible though outside the contaminated area)

Dangerous Particle Segment: 1-10 μm

Turbofan engines:

Larger> The turbofan functions like a centrifugal separator (no issue with the volcanic ash/dust in the by-pass flow)

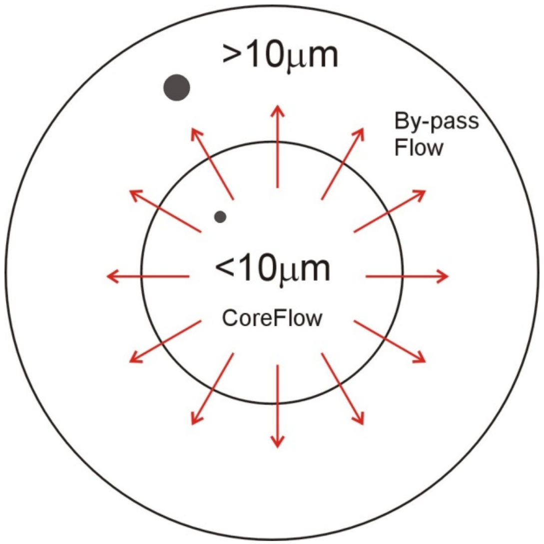
Smaller> Particles do not melt, they evaporate directly

Human health:

Larger> filtered by body barriers

Smaller> get out with expiration

(not retained in the lungs)



Eruption Case Study: H=10 km, W=50 kts

Ash:

Dust

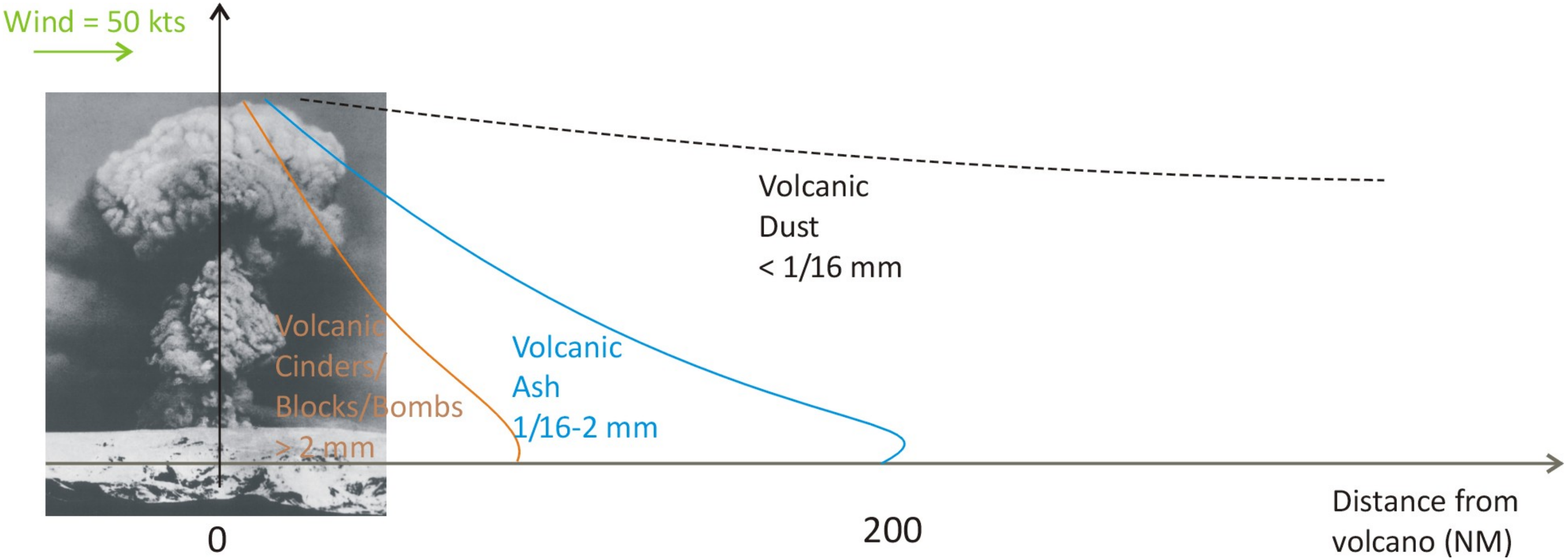
Falling speed (m/s) from:	1 mm (ash)	100 μm (ash)	10 μm (dust)	1 μm (dust)
10,000 m	6.0	0.8	0.005	$8 \cdot 10^{-5}$
8,000 m	5.7	0.7	0.005	$8 \cdot 10^{-5}$
6,000 m	5.5	0.7	0.005	$7 \cdot 10^{-5}$
4,000 m	5.3	0.7	0.004	$7 \cdot 10^{-5}$
2,000 m	5.1	0.6	0.004	$7 \cdot 10^{-5}$
Average falling speed (m/s)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

Ash: visible, dangerous, local / short term

1/16 mm = 62.5 mm

Dust: threatening, globe trotter / long term

	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

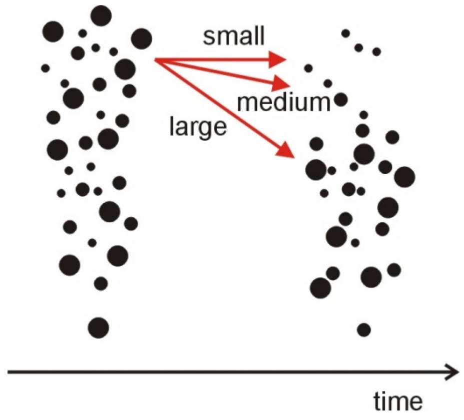


	1 mm (ash)	100 μm (ash)	10 μm (dust)	1 μm (dust)
Number of particles in 1 m^3 at a concentration of $2 \cdot 10^{-3}$ g/m^3 (2 kg/hm^3)	3	2,728	2,728,370	2,728,370,453

Terminology discriminator:

Volcanic Ash = 1/16 mm – 2 mm
(Coarse ash)

Volcanic Dust < 1/16 mm
(Fine ash)

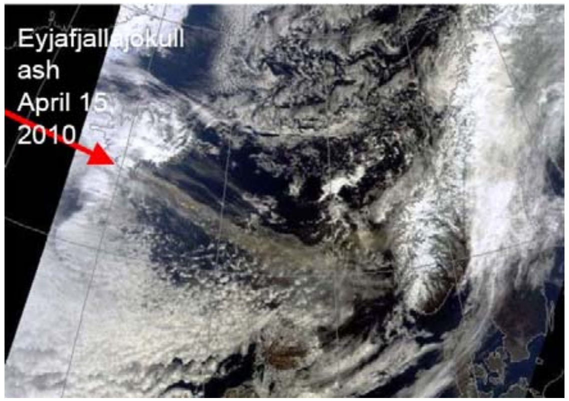


	Volcanic Ash	Volcanic Dust
Particle size (µm)	63 - 2000	< 63
Location	1-200 NM around the volcano	Floats around the world
Sedimentation time ≈	1/2 hour (for 1 mm)	23 Days (for 10µm)

Volcanic Ash / Dust / Sand Aerosols

	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 ($1\ kg/hm^3 = 10^{-3}\ g/m^3$)	$1000\ kg/hm^3$	$1\text{-}100\ kg/hm^3$	$1\text{-}100\ kg/hm^3$
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

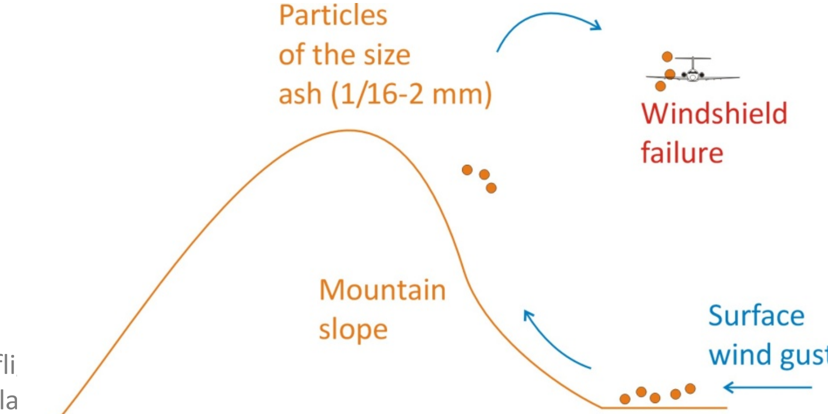
	Volcanic Ash Cloud	Volcanic Dust Contamination	Sand Aerosol Contamination
Aviation Safety Risk	Serious incidents, no injury accidents	None on record	Very low (windshield cracks)
Impact on aviation	Local	Global due to misinterpretation	Maintenance issues



Source: Prof. Ulrich Schumann, DLR Institute of Atmospheric Physics, NASA Earth Observatory

Sand Aerosols – a New Safety Concern (Denver – Colorado)

16/02/2007 = 14 aircraft: windshield failures within 3½h
19/01/2011 = 3 aircraft: windshield failures within a 30’



Delta Airlines Boeing 757-200, fli
DL-1916 from Denver, CO to Atla
GA (USA), during initial climb out
runway 34L reported a cracked
windshield and returned to Denver

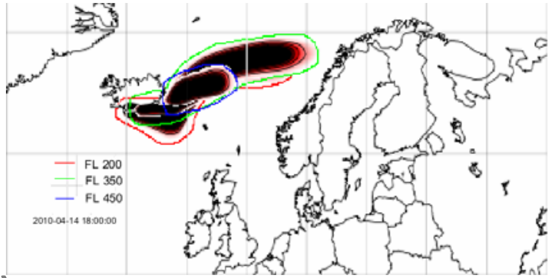
windshield cracked during initial climb out of
runway 34L and returned to Denver

ywest Canadair CRJ-700 on behalf of
nited Airlines, flight OO-6761/UA-
761 from Denver, CO to Cleveland, OH
JSA), reported a cracked windshield
during initial climb out of runway 34R
and returned to Denver

Source for photos: www.airliners.net

Future Eruption First Reaction Checklist

✓ Location of the eruption / time: LAT, LONG, HHMMz, DDMMYY



{repeat until eruption ends}

✓ How tall is the eruption column? H (m AMSL)

✓ Download wind profile in the area from NOAA: WD/WV

✓ Calculate how far will the volcanic ash cloud go: VA_{MAX}

✓ Draw an ellipse with VA_{MAX} as major axis on the map: DA

Ash4D

Volcanic Ash Danger Area

How far does the VA travel?

Function of: H (height of eruption column), FL (flight level), and WV (wind velocity)

Pinatubo 1991

Eruption column	H (m)	30000
Flight Level	(100 ft)	100
Wind Velocity	(kts)	50
Danger area	(NM)	535

Eyjafjalla 2010

Eruption column	H (m)	9000
Flight Level	(100 ft)	100
Wind Velocity	(kts)	100
Danger area	(NM)	236

Etna 2011

Eruption column	H (m)	1000
Flight Level	(100 ft)	30
Wind Velocity	(kts)	20
Danger area	(NM)	1

Why 500 NM for Pinatubo = 250 NM for Eyjafjalla?

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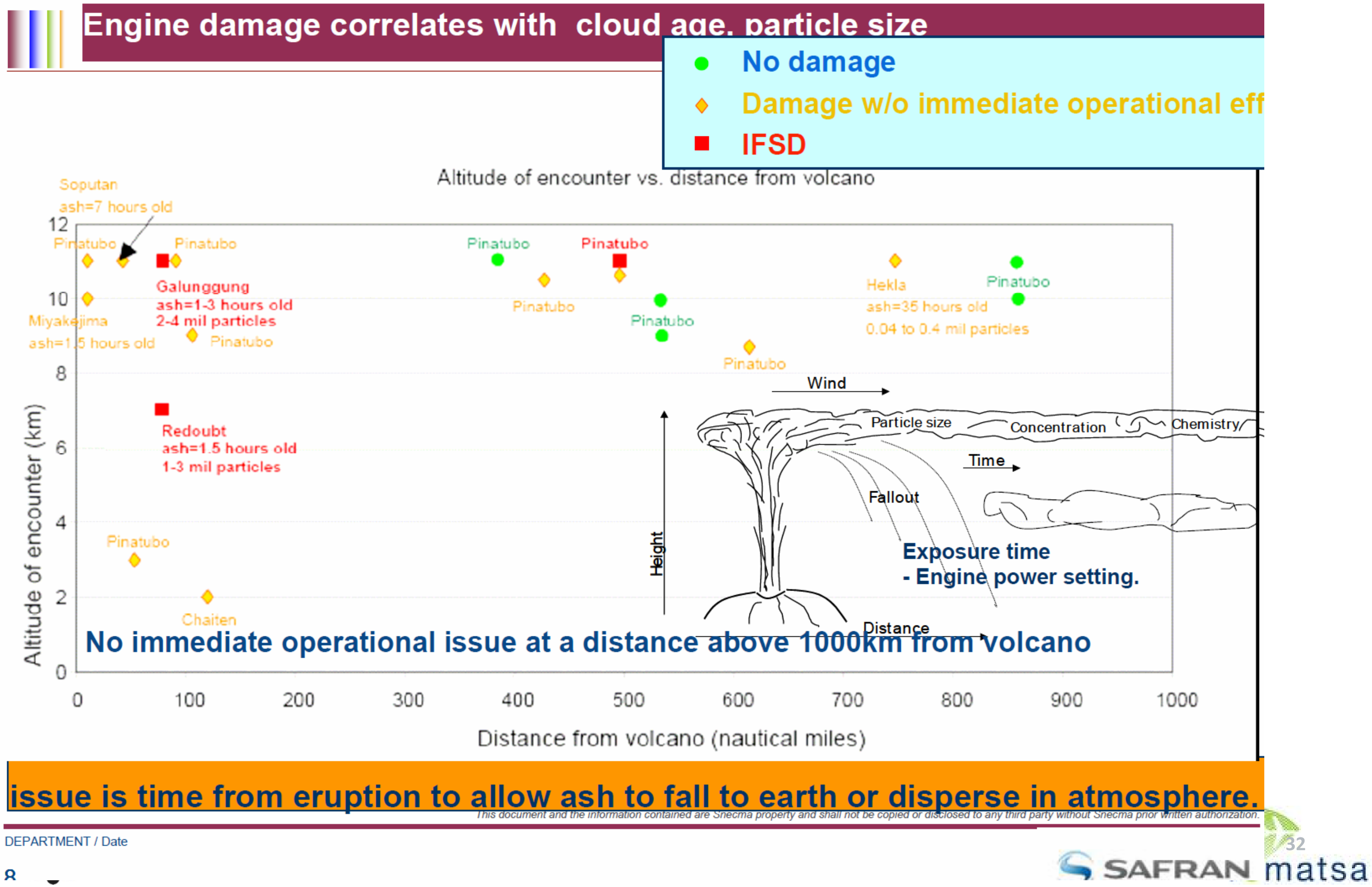
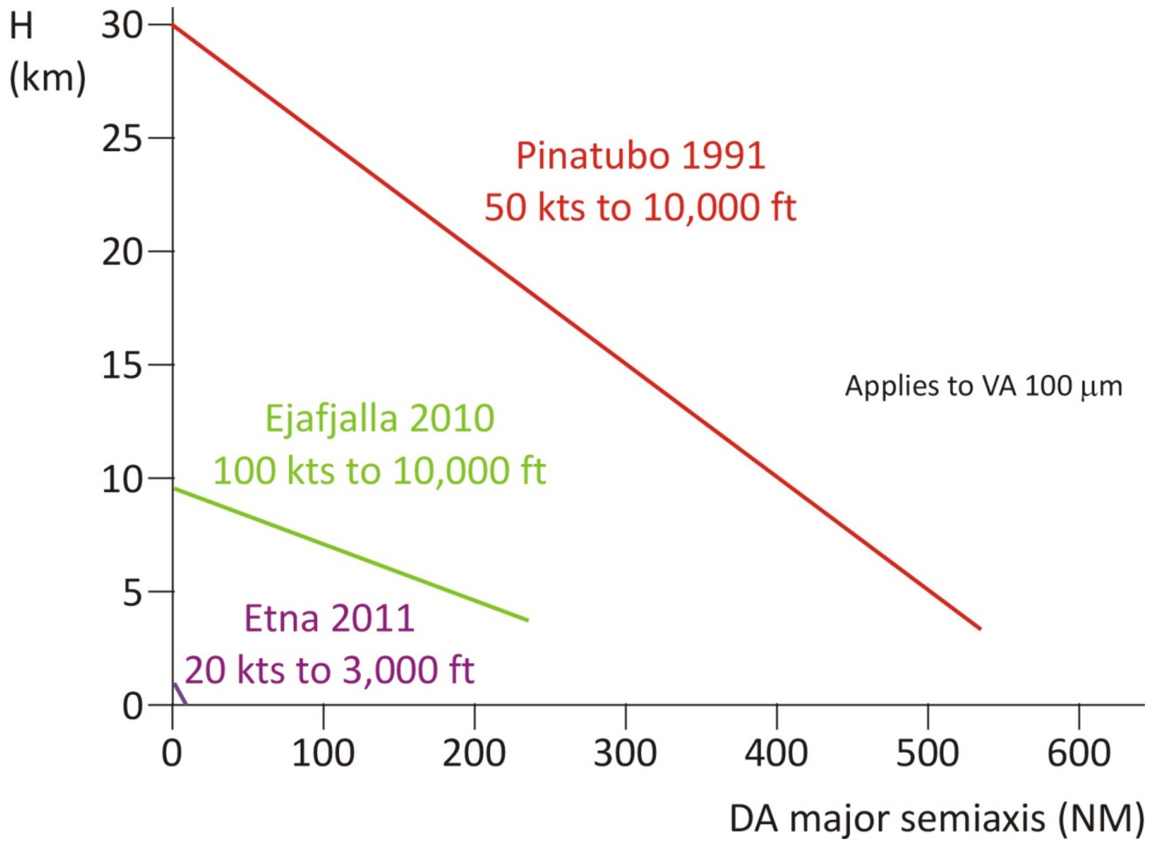
Slide from Jacques Renvier, CFM/SNECMA, Atlantic Conference on Eyjafjallajokull, Keflavik 2010

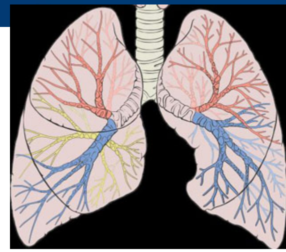


Why 500 NM for Pinatubo = 250 NM for Eyjafjalla?



(Kilauea, Hawaii
28 years continuous eruption)

Conclusions on Human Health Effects



What was studied: passengers (short-term) and crew (long-term) exposure to volcanic dust concentrations of $4 \cdot 10^{-3}$ g/m^3

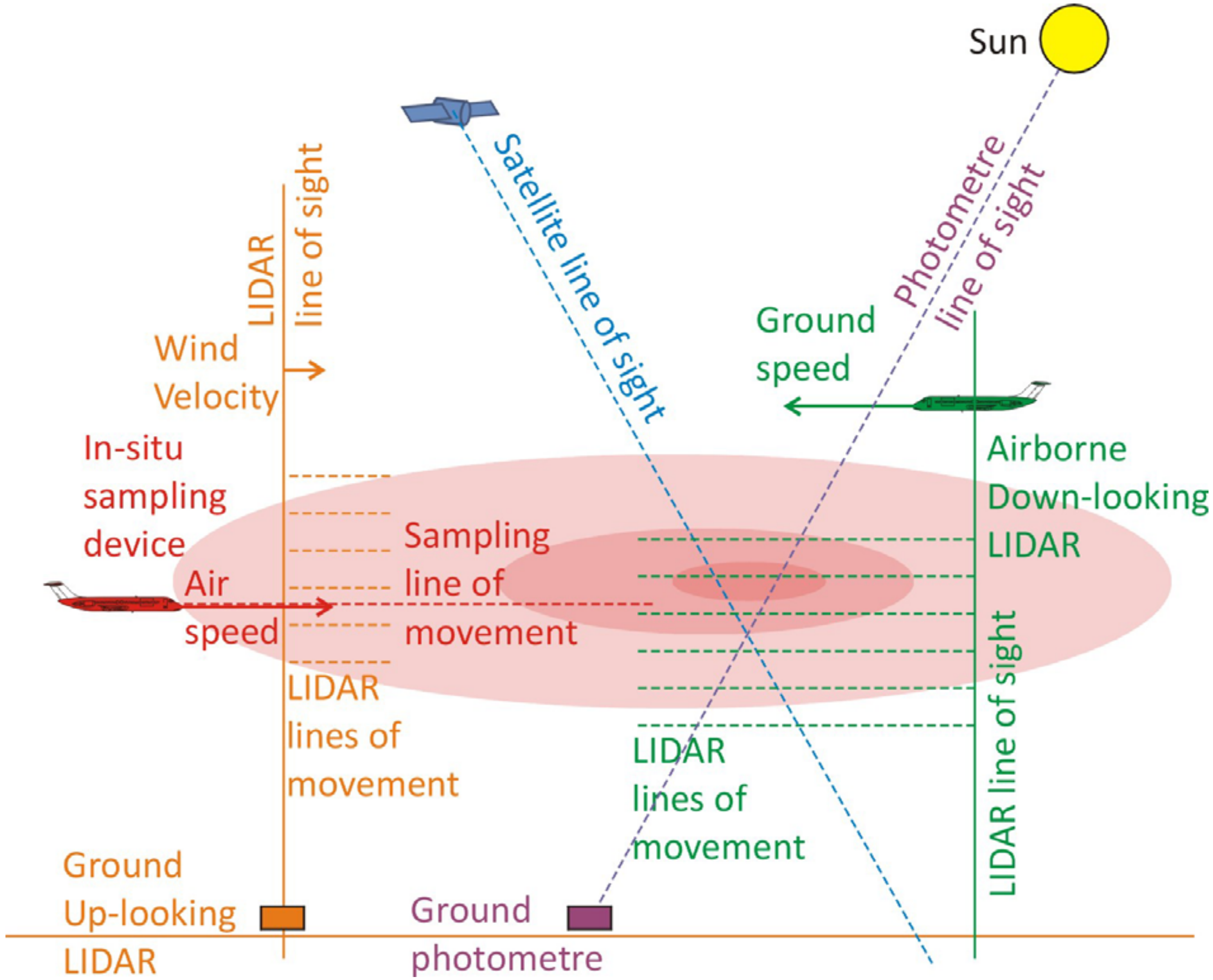
"Well under limits for short time exposure and even lower than those for chronic exposure"

"Reasonable to anticipate no risk for silicosis or lung cancer in passengers and crew members"

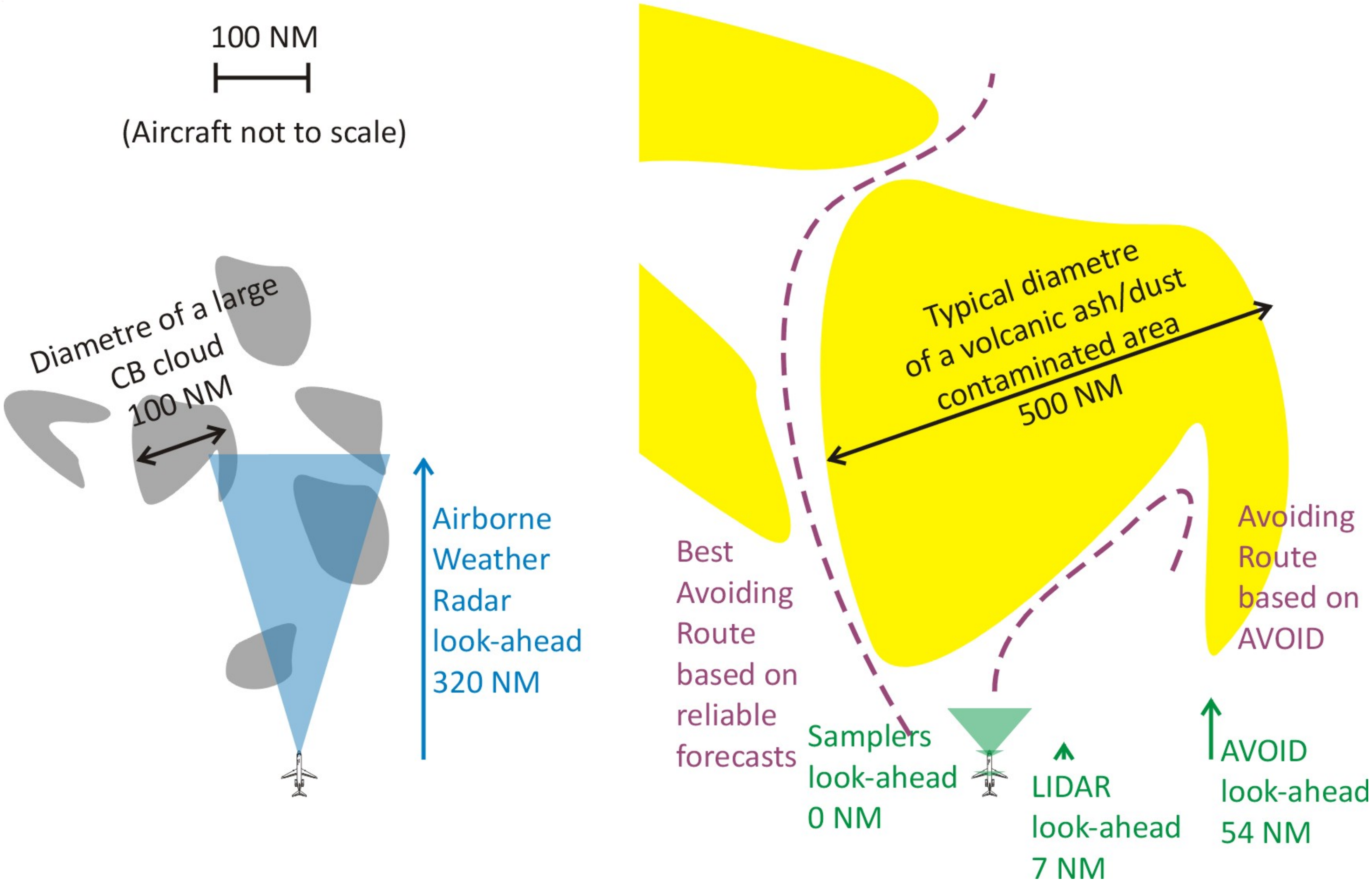
"Concentration lower than environmental Silica aerosols in some parts of the world (e.g. Ryadh, Cairo)"

Concentration: volatile, noisy, measured indirectly

1. Methodic errors; 2. Requires averaging at the scale of phenomenon (1 cubic hectometre)



Future sensors are shortsighted and the scale of the phenomenon is larger



Types of concentrations	Actual	Measured	Forecasted with Data Assimilation	Forecasted Blindly (open-loop)
When they are available (hours)	never	T+2H	T−18H (up to T−180H)	T−18H (up to T−180H)
Uncertainty due to initial data of the eruption (orders of magnitude)	-	-	0.2 - 1	2 - 3
Uncertainty due to the Eulerian diffusion model (orders of magnitude)	-	-	0.1 - 0.4	+1 every 24 hours
Uncertainty due to the measurement techniques	-	0.1 – 1	-	
Area coverage	-	Very local[1]	Global	
Overall errors	0	Significant	Large	Very large and rapidly increasing in time
Relevance to IFR flight operations	-	Tactical avoidance	Flight planning	
Relevance to ATM	-	Forecasts Validation	Airspace management, Flow management	

[1] Except the satellite images, which provide a global view

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 ($4 \cdot 10^{-3}$ g/m^3) 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!)
- --- etc. (read the scientific report for more at each WP)

Thanks for your attention