Dust impacts on aviation

Barbara Scherllin-Pirscher

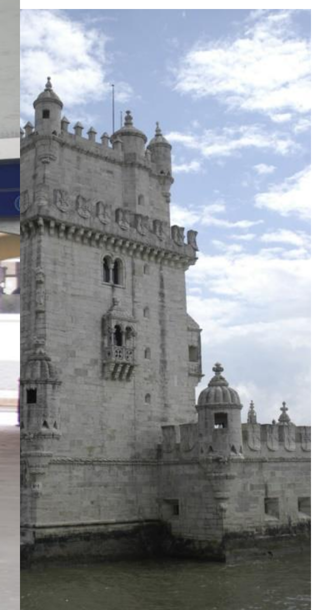
16 June 2021
inDust webinar

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Motivation: April 2010

Lisbon, Portugal

Source: Alasdair McLellan



ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Eruption of the Eyjafjallajökull volcano in Iceland

April 14:

- Increasing volcanic activity
- Explosive eruptions
- Ejection of fine ash

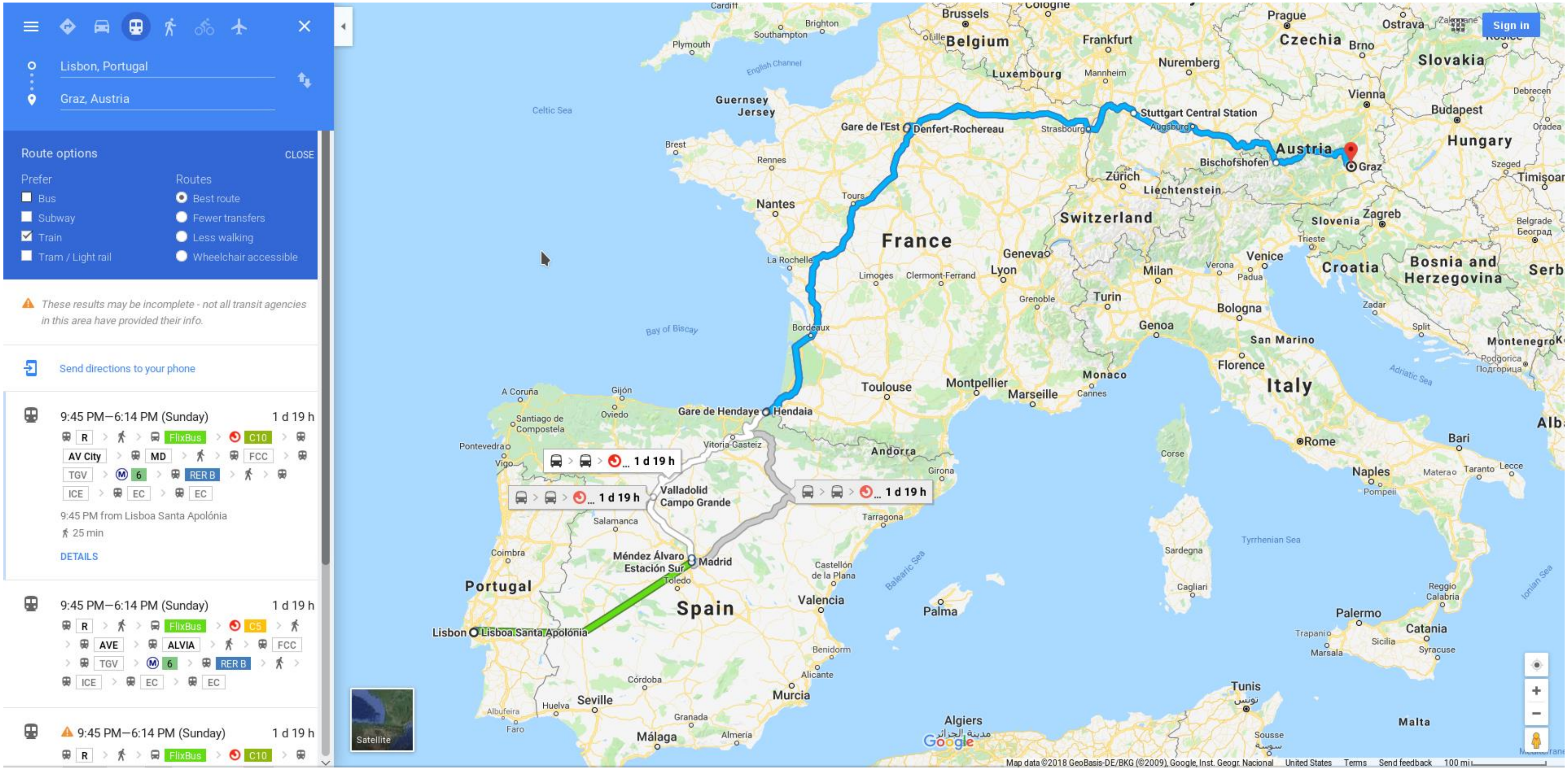
Ash was advected towards continental Europe

Major disruptions in air traffic

Source: Patrick Nielsen

Motivation: April 2010

Eruption of the Eyjafjallajökull volcano in Iceland



Motivation: April 16, 2010

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Motivation: April 17, 2010

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Motivation: April 18, 2010

Motivation: April 19, 2010

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Motivation: April 20, 2010

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Motivation: April 21, 2010

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

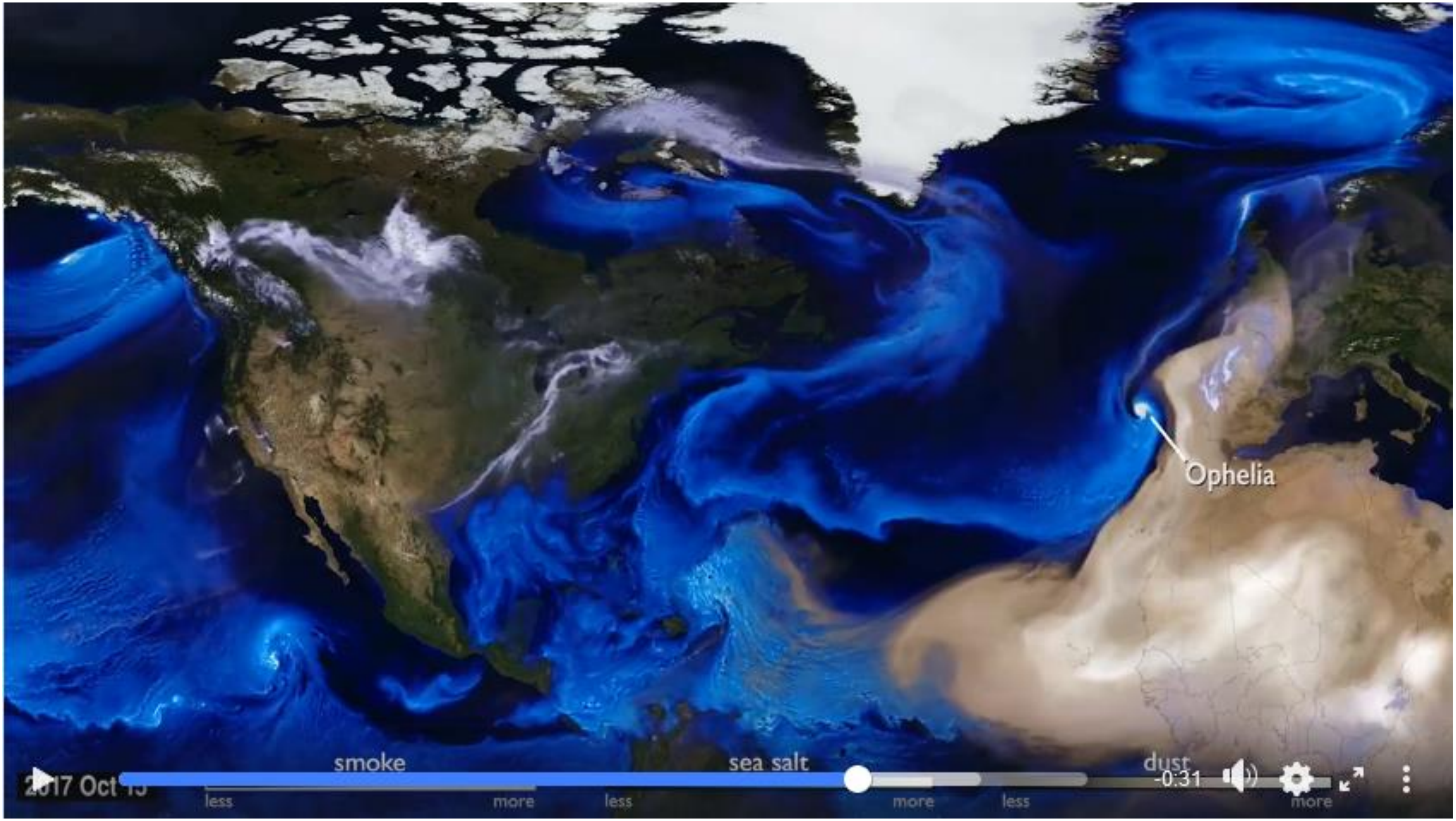
Eruption of the Eyjafjallajökull volcano in Iceland

- The eruption was relatively small but…
- …the volcano‘s ash spread unusually far and stayed for a long time in the atmosphere

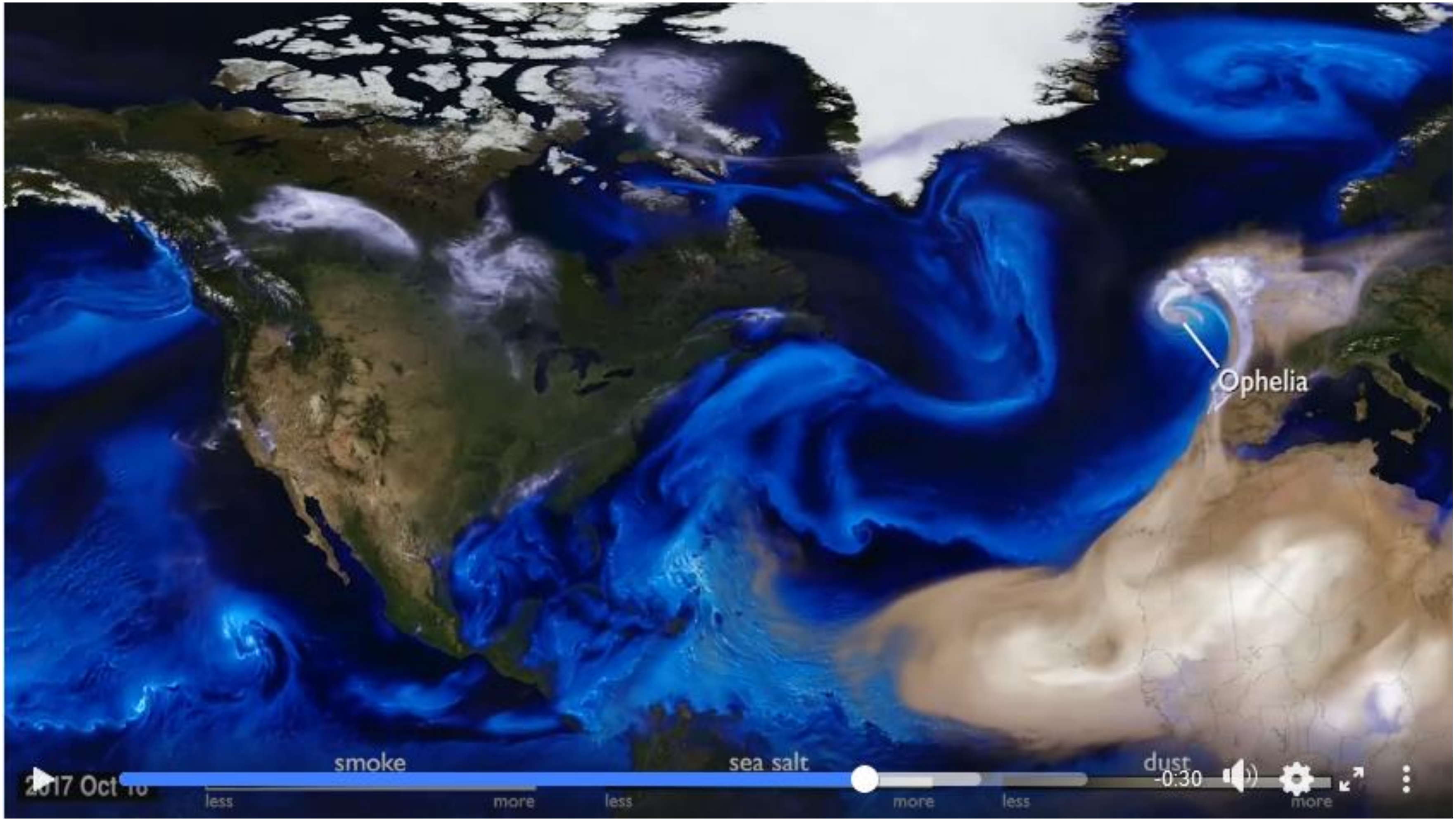
Impact:

- Over 100 000 flights were canceled from April 15 to 21, 2010
- 7 million passengers were affected
- 1.7 billion USD in lost revenue to airlines

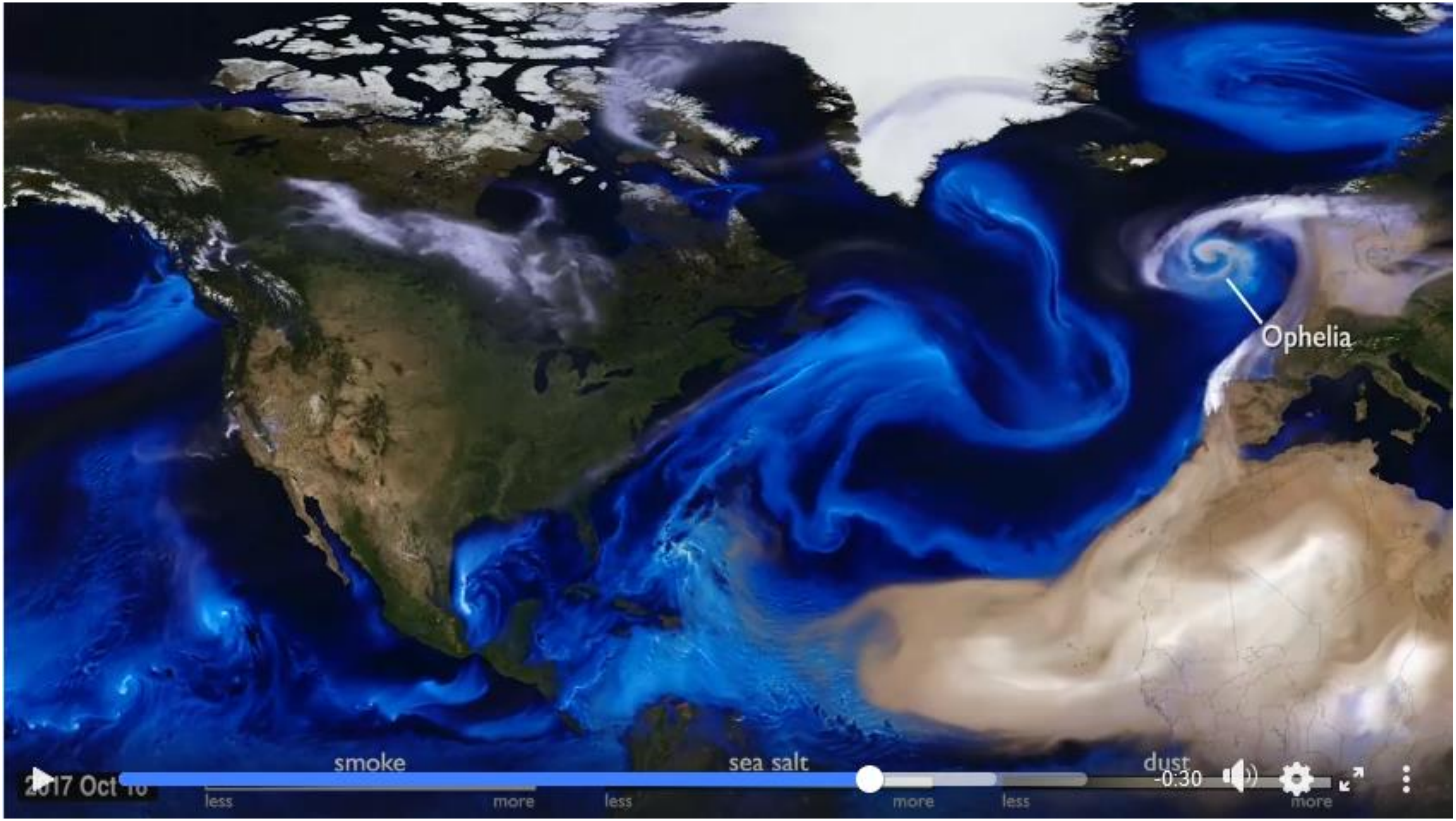
Saharan dust and Iberian wildfires: October 2017



Saharan dust and Iberian wildfires: October 2017



Saharan dust and Iberian wildfires: October 2017



Saharan dust and Iberian wildfires: October 2017

Wildfires and dust:

- Fires already started in September 2017
- Peak in mid-October (more than 7900 forest fires between October 13 and 18, 2017)
- Saharan dust due to strong wind from the south from October 14 to 17, 2017 (associated with Hurricane Ophelia)

Airplanes:

- Reports of smoke smells on several flights
- Number of flights have been forced to land or divert
- Precautionary landings following repots of smells in the cockpit of airplanes

Volcanic ash vs. dust

Volcanic eruptions

- Rare
- Episodic character
- Volcanic explosions are unpredictable

Dust emissions

- Continuous process with seasonal features
- Depend on meteorological conditions
- Dust storms are predictable

Volcanic ash versus dust:

Different physical and chemical characteristics

Impact on aviation:

- Mainly at cruise levels

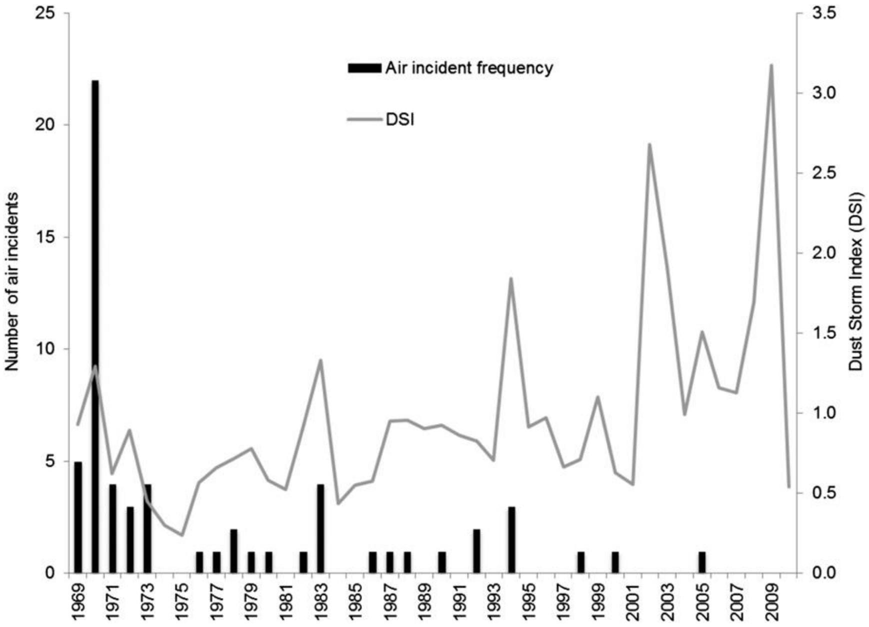
Impact on aviation:

- Mainly at the airport
- During takeoff and landing

Air traffic incident reports in Australia

Baddock et al. (2013)

- Data from 1969 to 2010
- 61 incidents
- Very few occurrences of injury or damage-causing accidents
- Most incidents before 1975
- Increasing aerosol levels

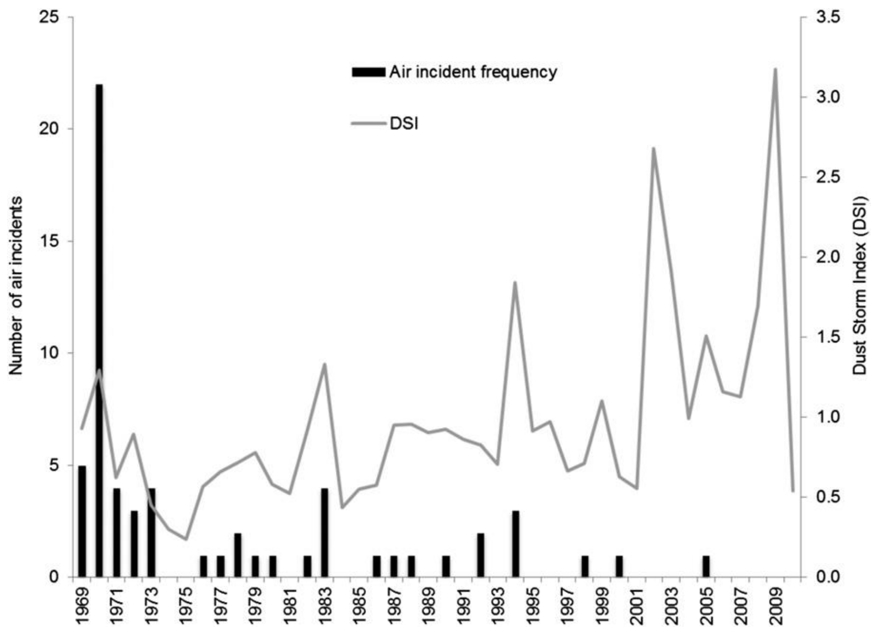


Source: Baddock et al. (2013)

Baddock et al. (2013)

Categories of effects

- Navigation (57.4 %)
- Communication (9.8 %)
- Damage (4.9 %)
- Visibility (23.0 %)
- Other (4.9 %)



Source: Baddock et al. (2013)

Technological advancements

- GPS units in aircraft
- Improved communication

Some more recent fatal aircraft crashes

- **30 January 2000:**
  179 dead, Kenya Airways, Cote d‘Ivoire
- **7 May 2002:**
  18 dead, Egypt Air, Tunisia
- **25 May 2011:**
  10 dead, Air Ambulance, India
- **19 August 2012:**
  31 dead, Alfa Airlines, Antonov AN-26, Sudan

Source: https://www.indiatoday.in

Source: Middleton (2017)

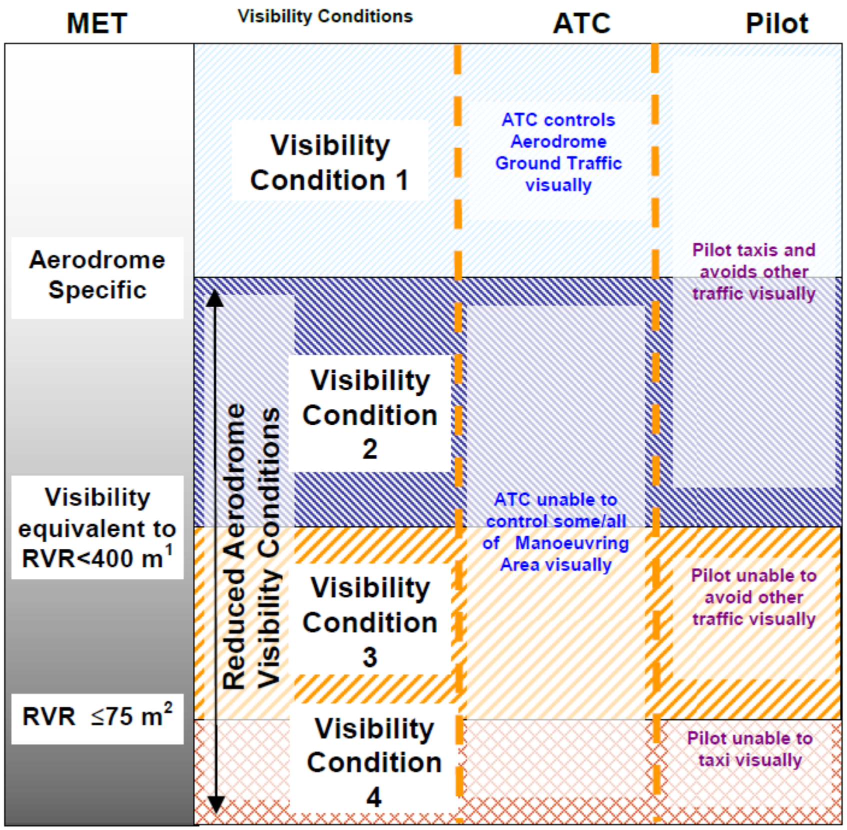
Problems in aviation: Visibility

Poor visibility

- Is often associated with strong winds

Visibility:

- Baddock et al. (2014): Relationship between dust concentrations and visibility: $C = 4050 * V^{-1.016}$
- **Low visibility procedures** (LVP) to ensure safe operations



Source: ICAO 2016

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Problems in aviation: Visibility

- Significant delays
- Rerouting
- Flight cancellations
- Disturbances in airport operations
  - Airport ground staff (tarmac)
  - Cleanup: remove sand/dust from runways and other critical areas

AlKheder and AlKandari (2020):

- Large differences between scheduled and actual arrival and departure times during dust storms at KIA

Source: https://www.dabangasudan.org/en/all-news/article/haboob-blankets-sudan-capital-shuts-down-airport

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Brownout

- In-flight visibility restriction due to sand or dust in the air
- Often associated with helicopter rotor downwash
- Soil composition, wind
- Accidents during near-ground flights (takeoff and landing)

Source: U.S. military/Department of Defense

Dust devils

- Sudden changes in wind speed and direction
- Reduced visibility

Lorenz and Myers (2005):

- Review of U.S. air accident reports
- 1995 to 2005
- 97 incidents pointing to dust devils as a contributing factor
- Several fatal accidents

Source: NASA/U. of Michigan

Lekas (2019)

- Electrostatic charging due to mineral dust
- Time to reach an **electrostatic equilibrium** depends on soil dust particle size and concentration (for given flight speed)
- Higher particle size and concentration → shorter time
- Time is very short (some tenths of second to 3 s)
- Electrostatic charging due to soil dust is of equal importance to other sources of electrostatic charging

Electric charging can

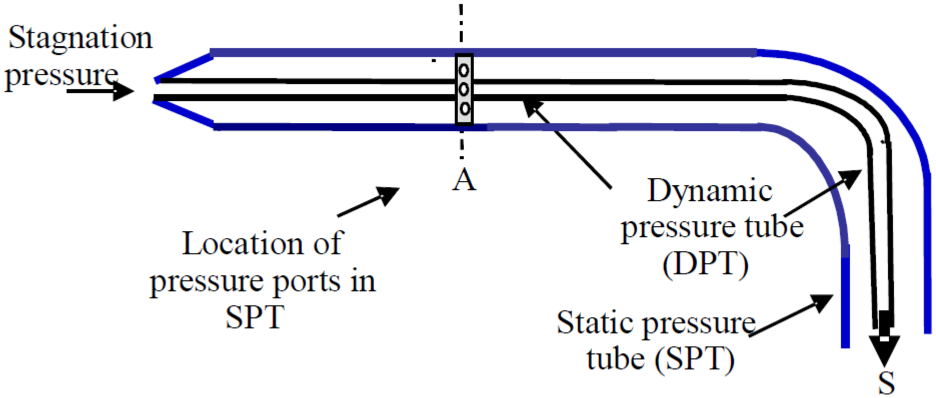
- induce noise on the radio communications of the aircraft
- be hazardous for ground personnel or during operations (e.g., refueling)
- lead to problems to onboard electronic devices if the are not well protected

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Blockage of the Pitot tube

- Pitot tube (PT) measures pressure
- Pressure data are converted to air speed
- Several fatal accidents due to wrong air speed associated with tube blocking
- PT blocking caused by ice, volcanic ash, sand, insects

Source: https://imgr1.flugrevue.de/image-169FullWidth-7188a391-1442863.jpg



Source: Jackson (2015)

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Nickovic et al. (2021): Ice nucleation

- Air France accident on 1 June 2009: aircraft crashed into the tropical Atlantic
- Pitot tubes were iced
- Mineral dust particles are efficient ice nuclei
- Desert dust might have played an important role

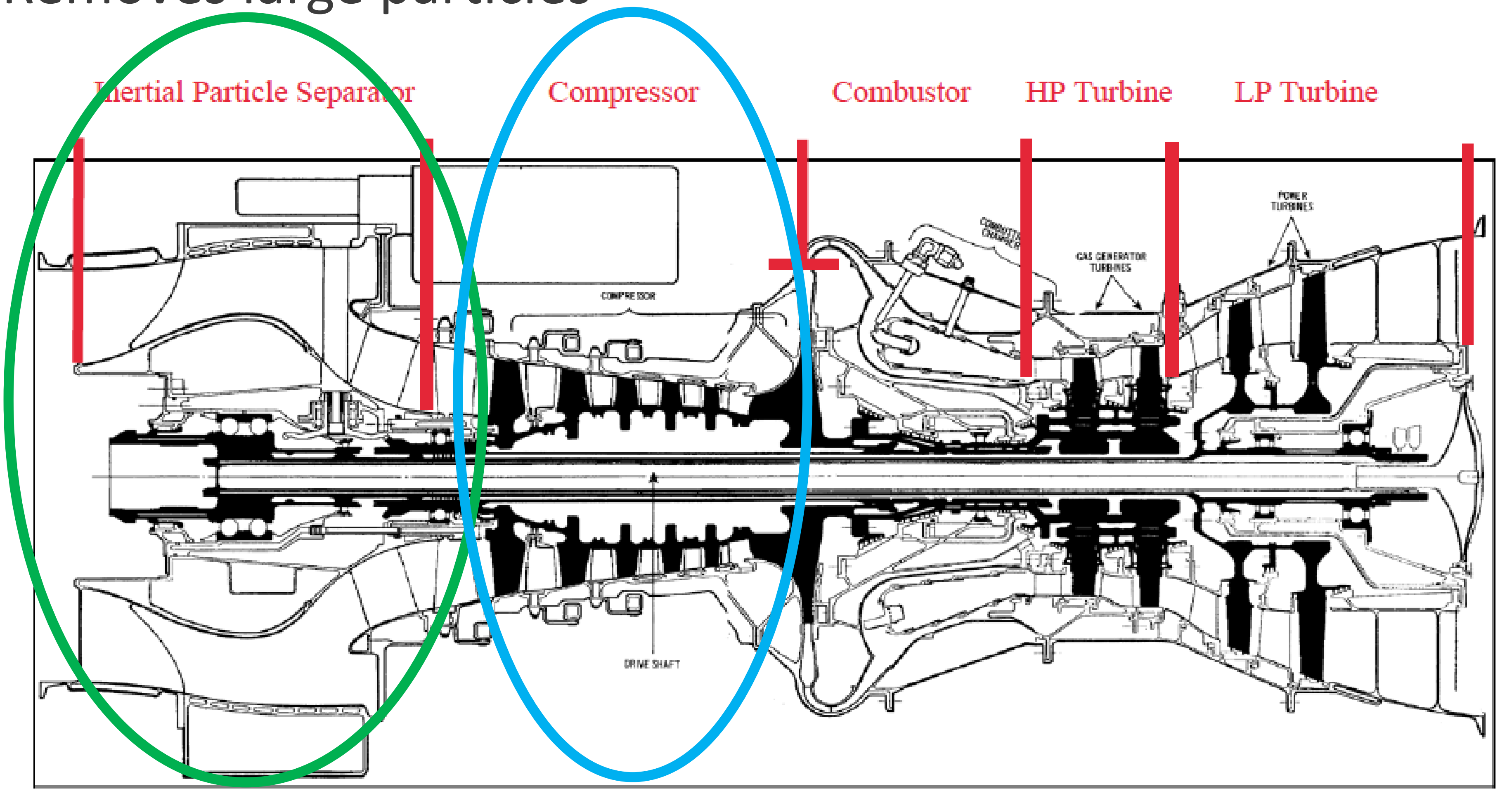
Source: Wikipedia

- Similar accident on 24 July 2014 (Air Algerie)
- Engine pressure ratio became erroneous because of instrument icing

Problems in aviation: Mechanical problems

Engine

Removes large particles



Source: Bojdo and Filippone (2019)

Erosion of compressor blades

- Compressor: cold area of the engine
- High hardness of atmospheric dust
- Friction and impact degradation (surface damages)
- Gap size augmentation
- Leads to gas flow deterioration and gradual loss of engine performance
- Affect engine efficiency and compressor stability

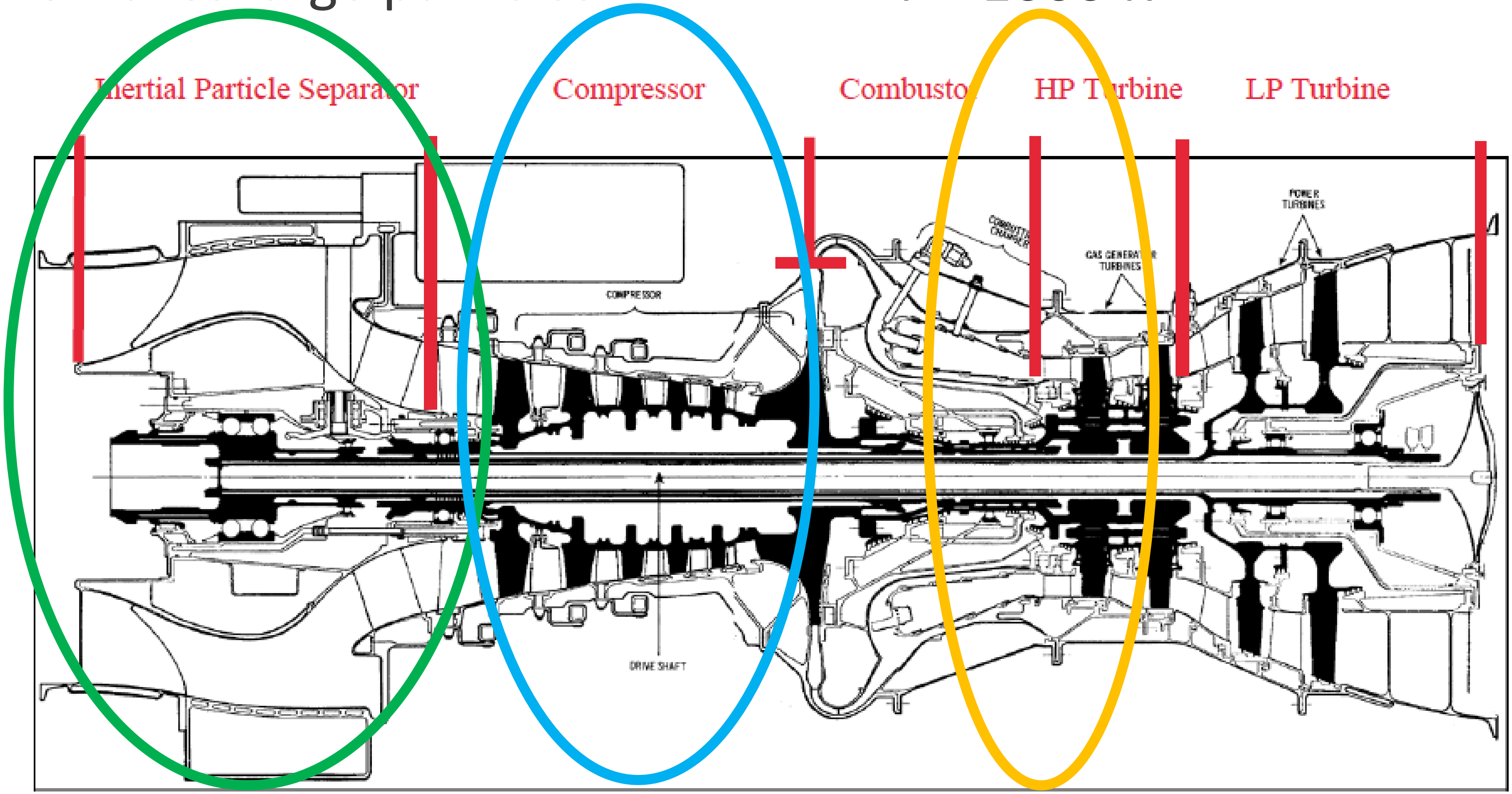
Source: Szczepankowski et al. (2017)

Problems in aviation: Mechanical problems

Rotorcraft engine

Removes large particles

T > 1600 K



Source: Bojdo and Filippone (2019)

Combustor walls, turbine blades

- Combustor & turbine blades: hot area of the engine
- Glass deposit with rough surface
- Rapid loss of performance by disturbing the flow field
- Potential risk during takeoff and landing
- Deposit may also lead to thermal corrosion of an engine component or of electronic devices by blocking cooling holes

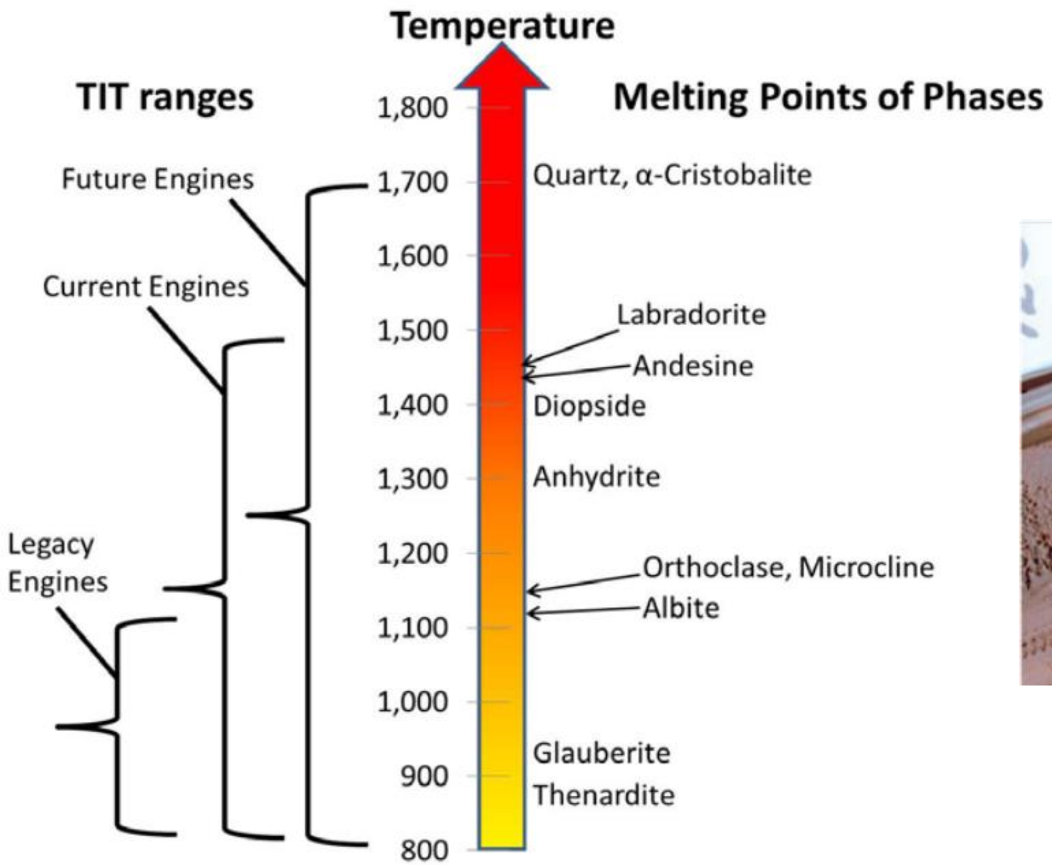
In-flight flame out

- Glass deposit on hot areas of the engine
- Can lead to turbine blades stall
- Flame out: extinction of the flame in the combustion chamber
- KLM867 & BA009: flame out of all engines after flying through volcanic ash

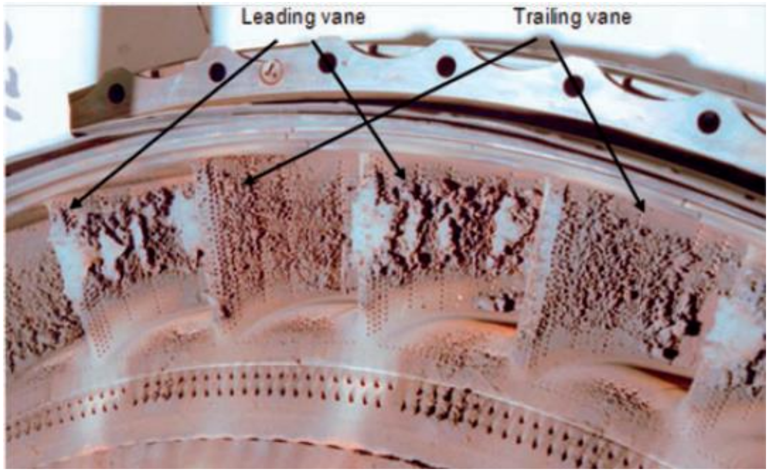
Source: https://i0.wp.com/theavgeeks.com/wp-content/uploads/2019/02/AE86DB53-D4AB-4440-AA58-60117028136D.png?resize=1024%2C576&ssl=1

Problems in aviation: Mechanical problems – Dust melting

Dust melting and engine temperatures



Source: Wood et al. (2017)

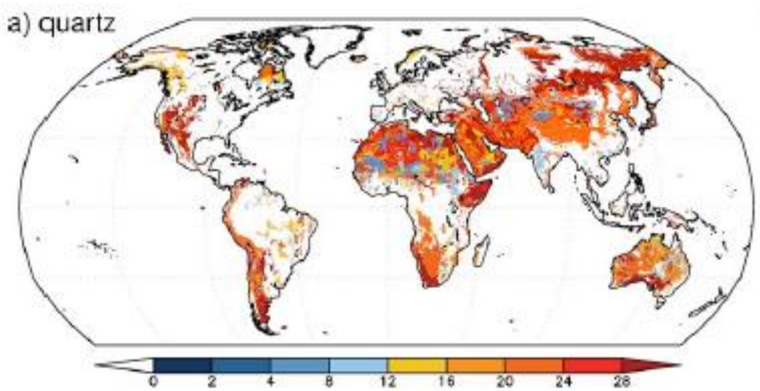


Source: Clarkson et al. (2016)

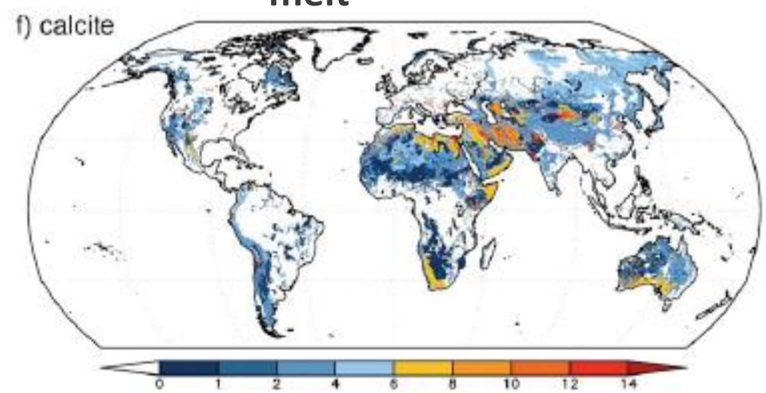
ZAMG
Zentralanstalt für Meteorologie und Geodynamik

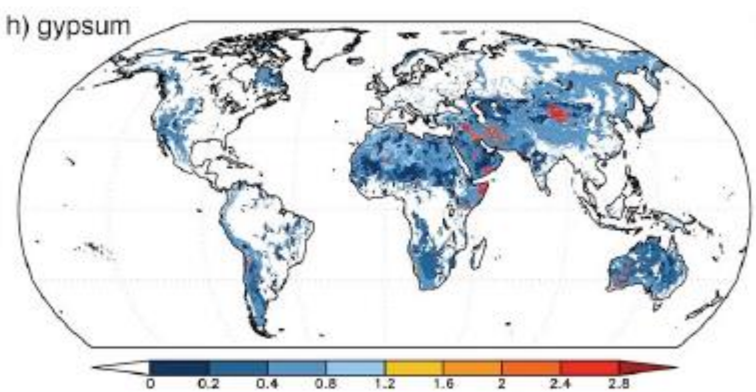
Dust composition and melting temperatures

Quartz: T_{melt} = 1983



Calcite: T_{melt} = 1023 K to 1073 K





Gypsum: T_{melt} = 1117 K

Sources: Nickovic et al. (2012)
Wood et al. (2017)

ZAMG
Zentralanstalt für Meteorologie und Geodynamik

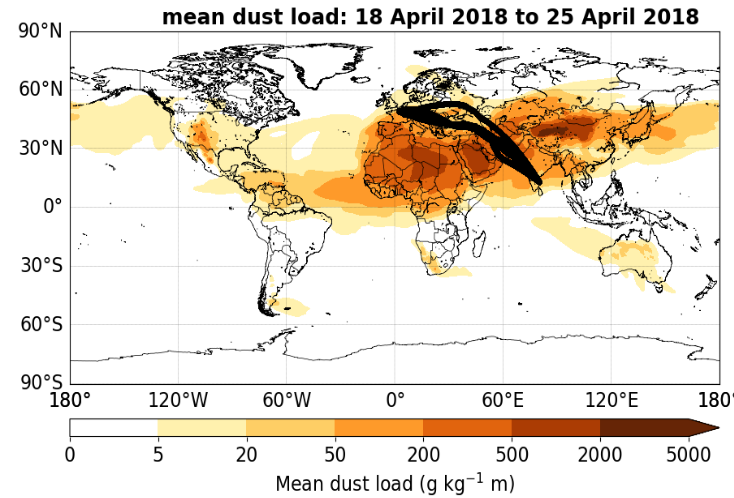
Maintenance costs

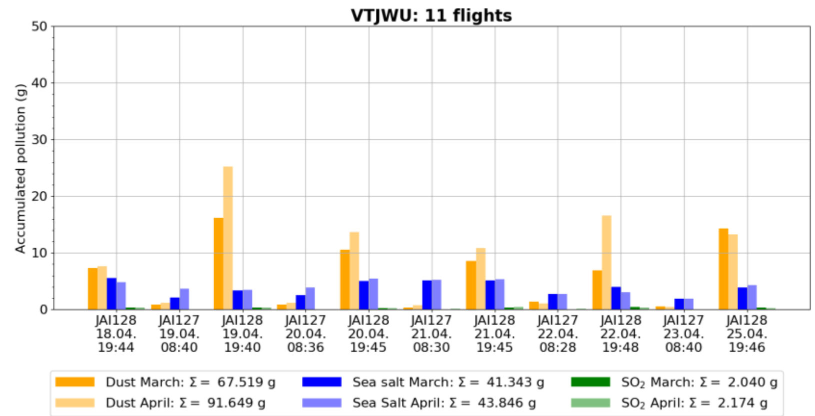
- High dust load for aircraft
  Paris ←→ Chennai

- Highest dust load for flight JAI128 on 19 April 2018 (25 g per engine)

- Takeoff in Chennai
  - high dust concentration and
  - high fuel consumption

- Assumption:
  1 kg dust per engine
  costs between 50 000 € and 100 000 €
  → Up to 5000 € loss for this flight

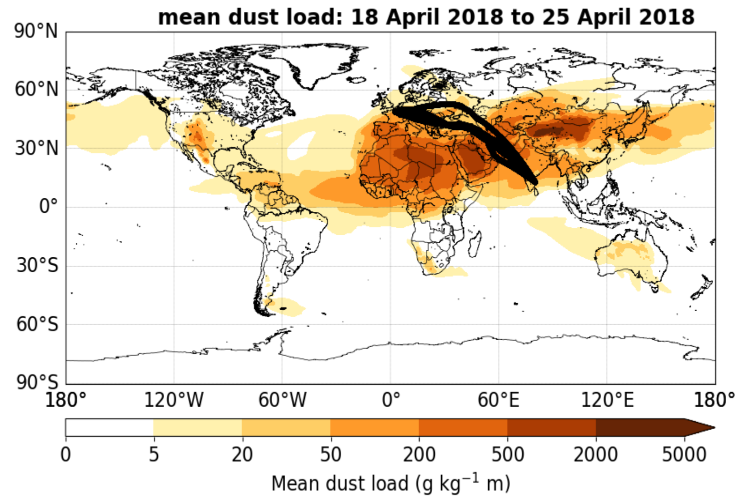


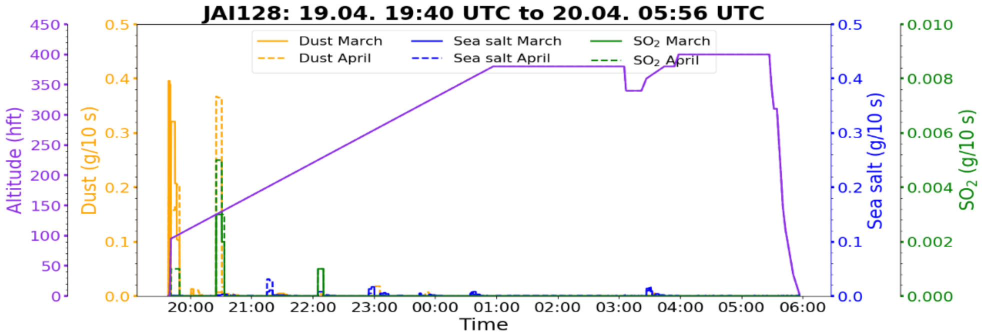


ZAMG
Zentralanstalt für Meteorologie und Geodynamik

Maintenance costs

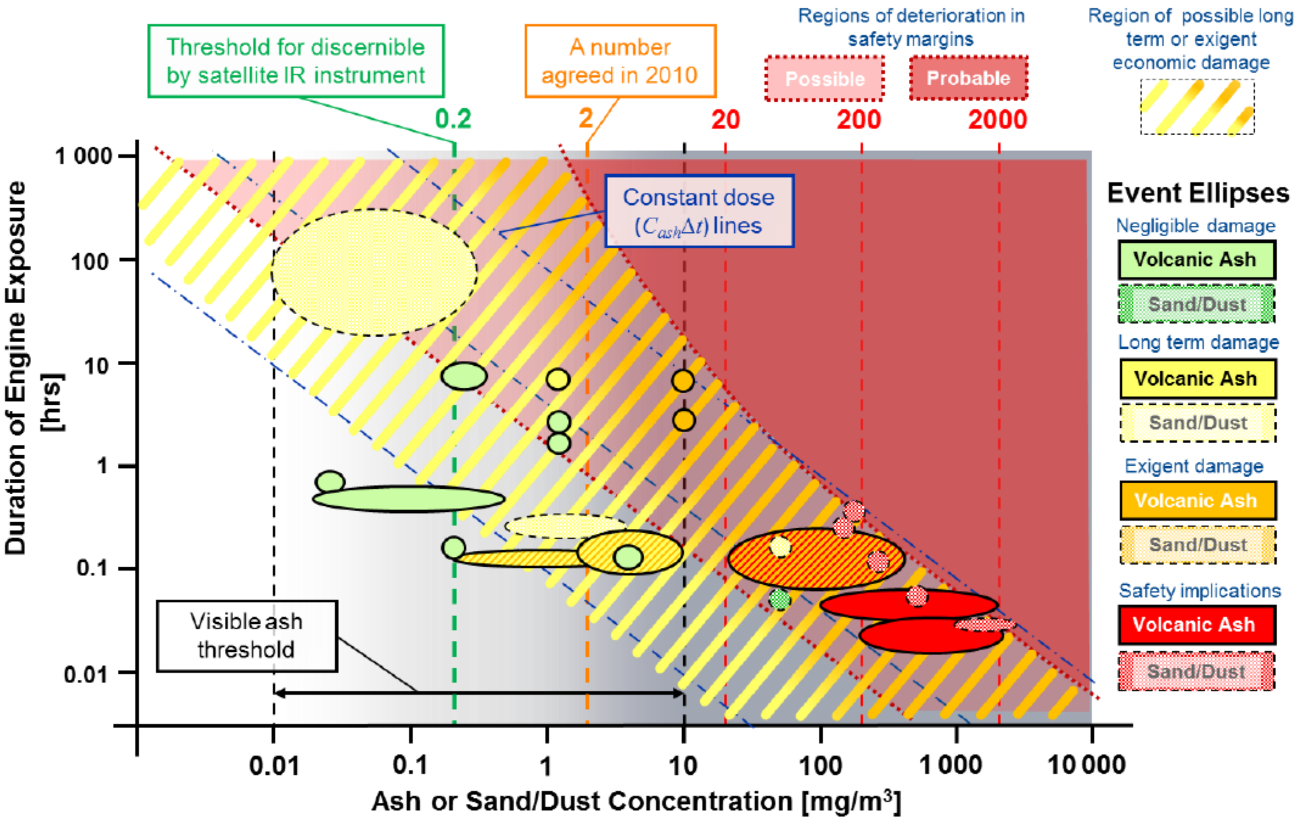
- High dust load for aircraft
  Paris ←→ Chennai
- Highest dust load for flight JAI128 on 19 April 2018 (25 g per engine)
- Takeoff in Chennai
  - high dust concentration and
  - high fuel consumption
- Assumption:
  1 kg dust per engine costs between 50 000 € and 100 000 €
  → Up to 5000 € loss for this flight





ZAMG Zentralanstalt für Meteorologie und Geodynamik

How much ash/dust is needed to significantly damage aircraft gas turbine engines?



Source: Clarkson and Simpson (2017)

ZAMG Zentralanstalt für Meteorologie und Geodynamik

Dust impacts on aviation

- Reduced visibility (often associated with strong winds)
- Electrostatic charging
- Icing
- Mechanical problems:
  - Erosion
  - Corrosion
  - Blockage of cooling holes
  - Engine flame out in flight
  - Blockage of Pitot tube

Key challenges

- Rare events
- High uncertainty in source terms
- Sensitivity to dispersion models
- Availability and variety of observations
- Identification of key products
  for stakeholders

ZAMG Zentralanstalt für Meteorologie und Geodynamik


Thank you for
your attention!
Source: https://www.hydro.aero/assets/images/e/Landing_Gear-965ffba2.jpg