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science for a changing world

A History of Ash Avoidance

Thomas J. Casadevall

U. S. Geological Survey, Denver, Colorado, USA

WORLD METEOROLOGICAL ORGANIZATION
Seventh International Volcanic Ash Workshop
Anchorage, Alaska, October 19-23, 2015

U.S. Department of the Interior
U.S. Geological Survey

ESTUDIO SOBRE LA CRISIS VOLCANICA DE LA CORDILLERA DE LOS ANDES

Exploraciones aéreas sobre el Volcán Quizapu en erupción

POR

JULIO BUSTOS NAVARRETE

Director del Observatorio del Salto
y Profesor de la Escuela de Aviación

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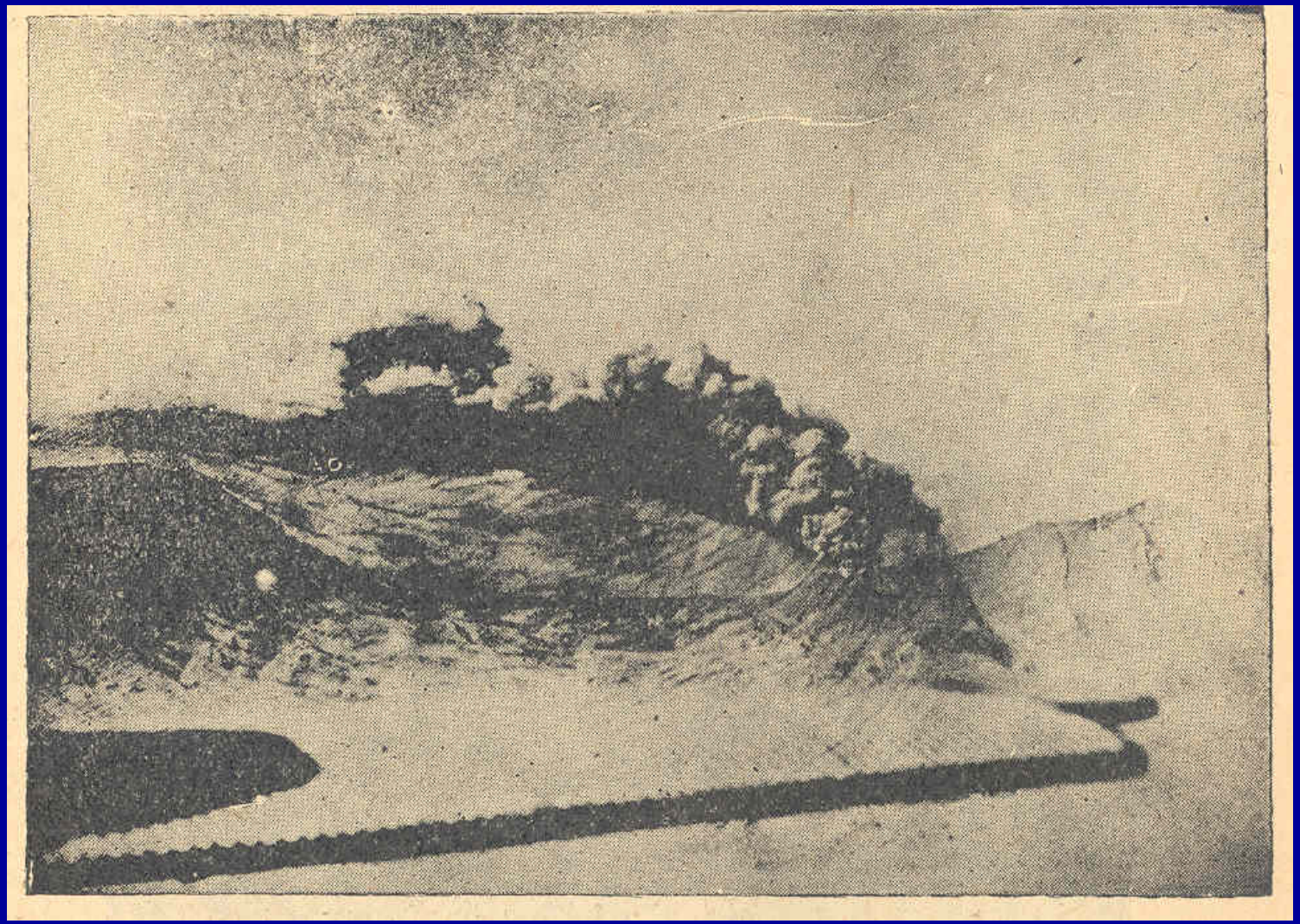
Quizapu, Chile April 12, 1932



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Our goals

- Volcanoes and their activity
- Airplanes, airports, and their vulnerability
- History of encounters
- Communicating the hazard
- Mitigating the risk
- Future outlook / Volcanological guidance

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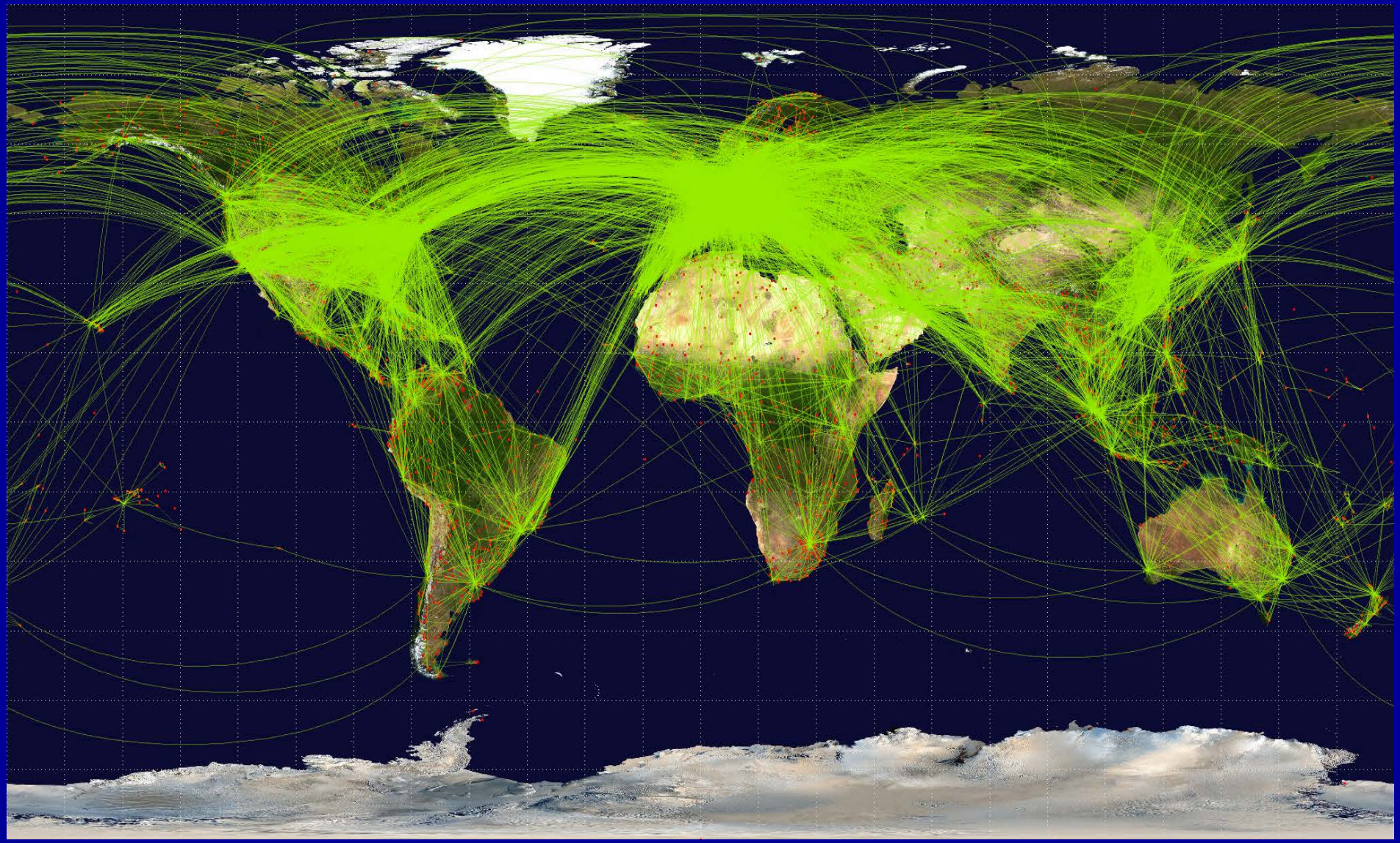
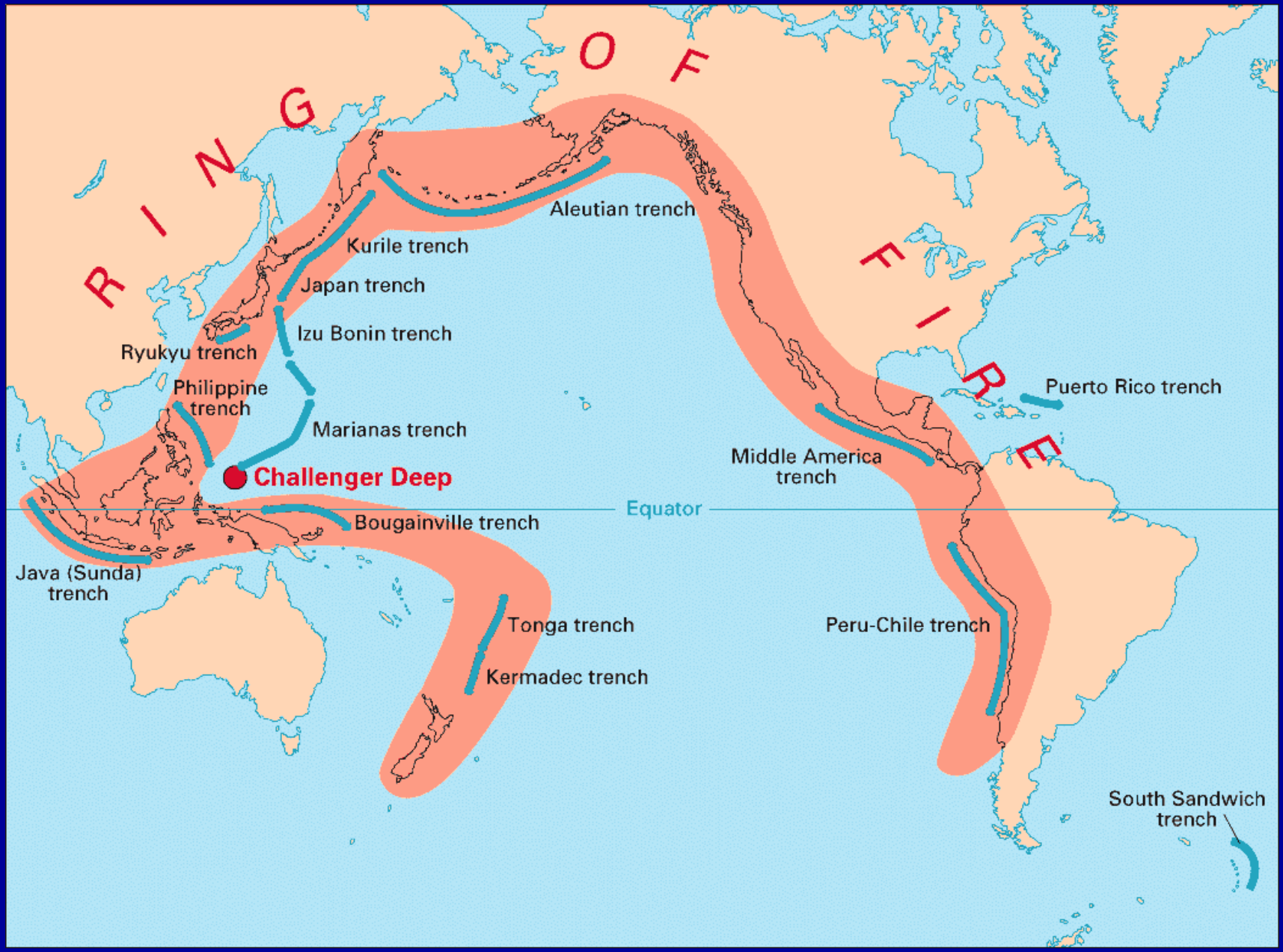
Global Air Routes

source: Airline Route Mapper, Open Flights




RING OF FIRE
Aleutian trench
Kurile trench
Japan trench
Izu Bonin trench
Ryukyu trench
Philippine trench
Marianas trench
Challenger Deep
Bougainville trench
Java (Sunda) trench
Tonga trench
Kermadec trench
Puerto Rico trench
Middle America trench
Equator
Peru-Chile trench
South Sandwich trench

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Historically Active Volcanoes

Indonesia	75
United States	65
Japan	58
Russia	52
Chile	42

from Siebert et al, 2010

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Global Volcanism

- ~ 575 “historically” active terrestrial volcanoes
- ~ 200 of these have some type of geophysical monitoring or observation
- ~ 12 eruptions annually with VEI of 2+ affecting “cruise-altitude” airspace

sources: WOVO, Smithsonian Institution

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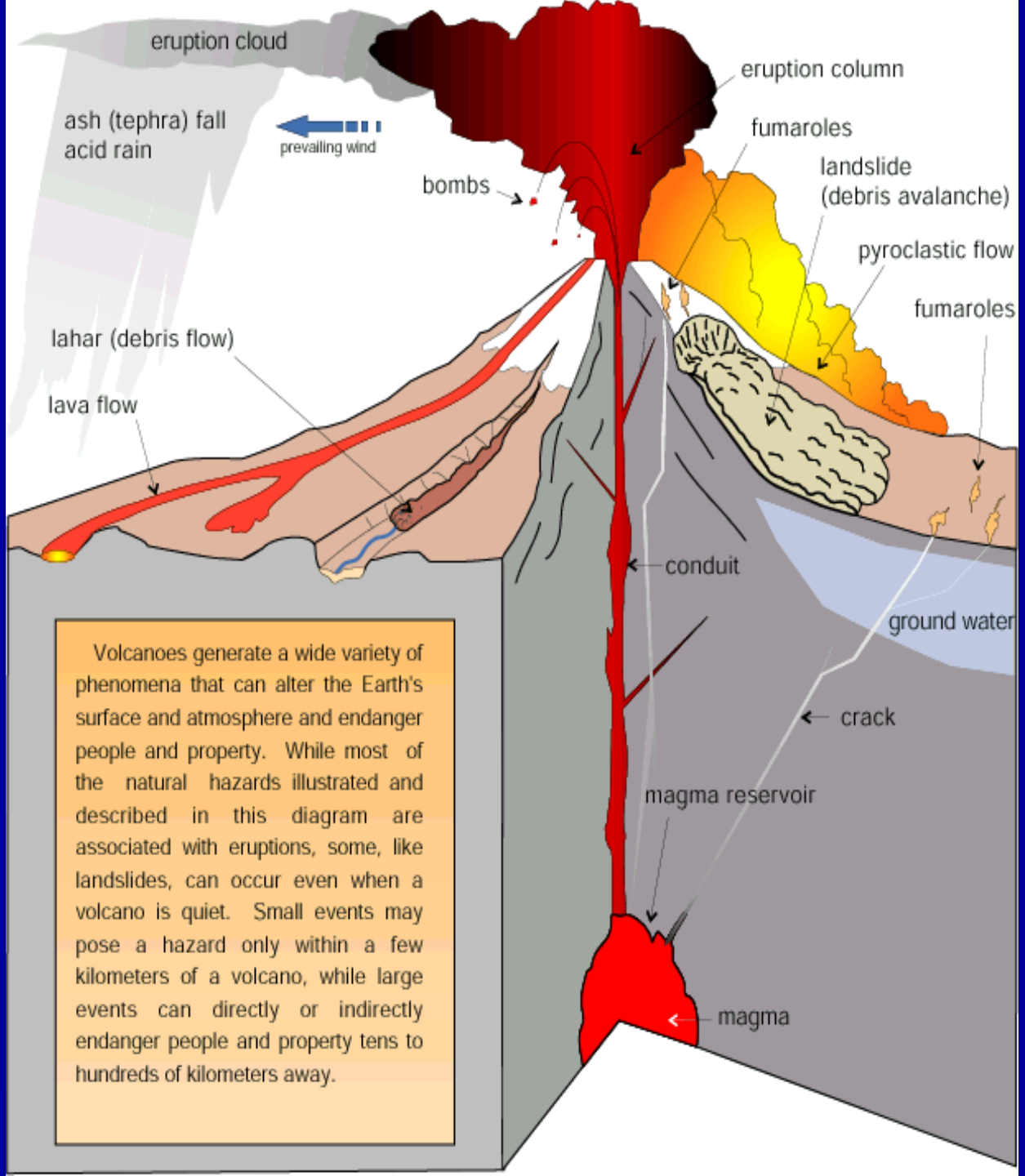
Volcano Hazards



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Volcanic Plumes and Ash Clouds

- Quiescent plumes
- Eruption columns
- Ash clouds

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Quiescent Plumes

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Eruption Columns

- dark-colored pillars of ash and gas that rise rapidly above a volcanic vent to altitudes exceeding 100,000 feet (>30 km)

- dense concentrations of ash and gas seldom directly affect an area more than a few tens of kilometers from the volcanic vent

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Calbuco eruption, Chile April 22, 2015

source: Carlos Gutierrez, AP

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Eruption Clouds

- ash is carried by upper level winds for hundreds to thousands of kilometers
- may enter the stratosphere and encircle the globe in days to weeks
- typically lose their heaviest ash load over a period of a few hours to a few days
- difficult to distinguish from weather clouds
- pose the greatest threat to aircraft

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Redoubt eruption cloud, Anchorage airport, March 1990

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Rabaul eruption, September 1994

source: Space Shuttle, (STS-64) NASA

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Calbuco, Chile, April 22-23, 2015

USGS

source: NASA, MODIS sensor

Volcanic Ash

(finely fragmented rock and minerals)

- fine-grained *(<1 micron to > 100 microns)*
- hard and angular *(= highly abrasive)*
- melts in jet engines *(clogs engines and causes stalling)*

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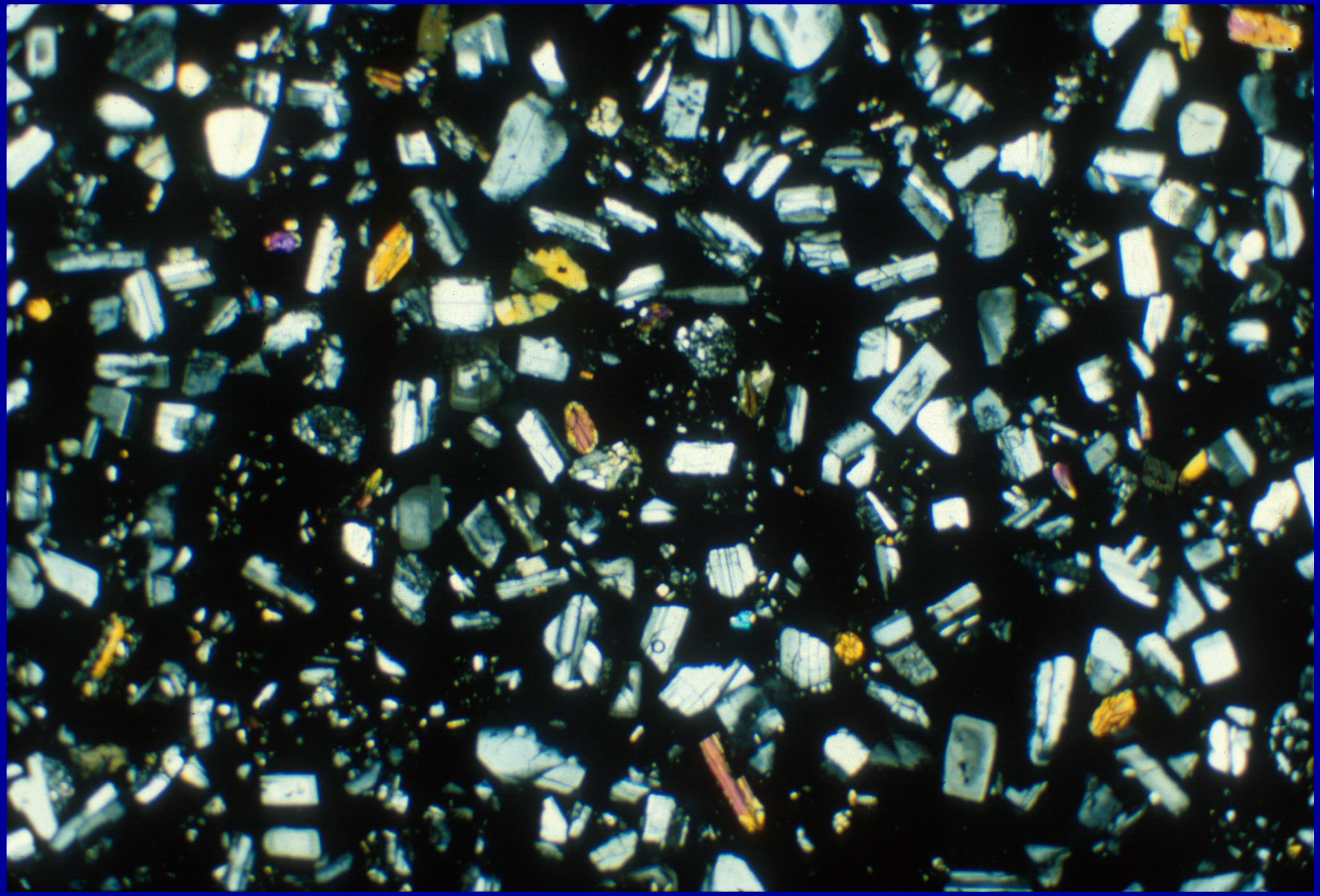

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Global Volcanism

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sources: WOVO, Smithsonian Institution

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Major eruptions of the 21st Century
VEI > 3+, affecting aviation

- Reventador, Ecuador 2002
- Chaiten, Chile 2008
- Eyjafjallajökull, Iceland 2010
- Merapi, Indonesia 2010
- Puyehue-Cordón Caulle, Chile 2011
- Sinabung, Indonesia 2014-2015
- Kelut, Indonesia 2014
- Calbuco, Chile 2015

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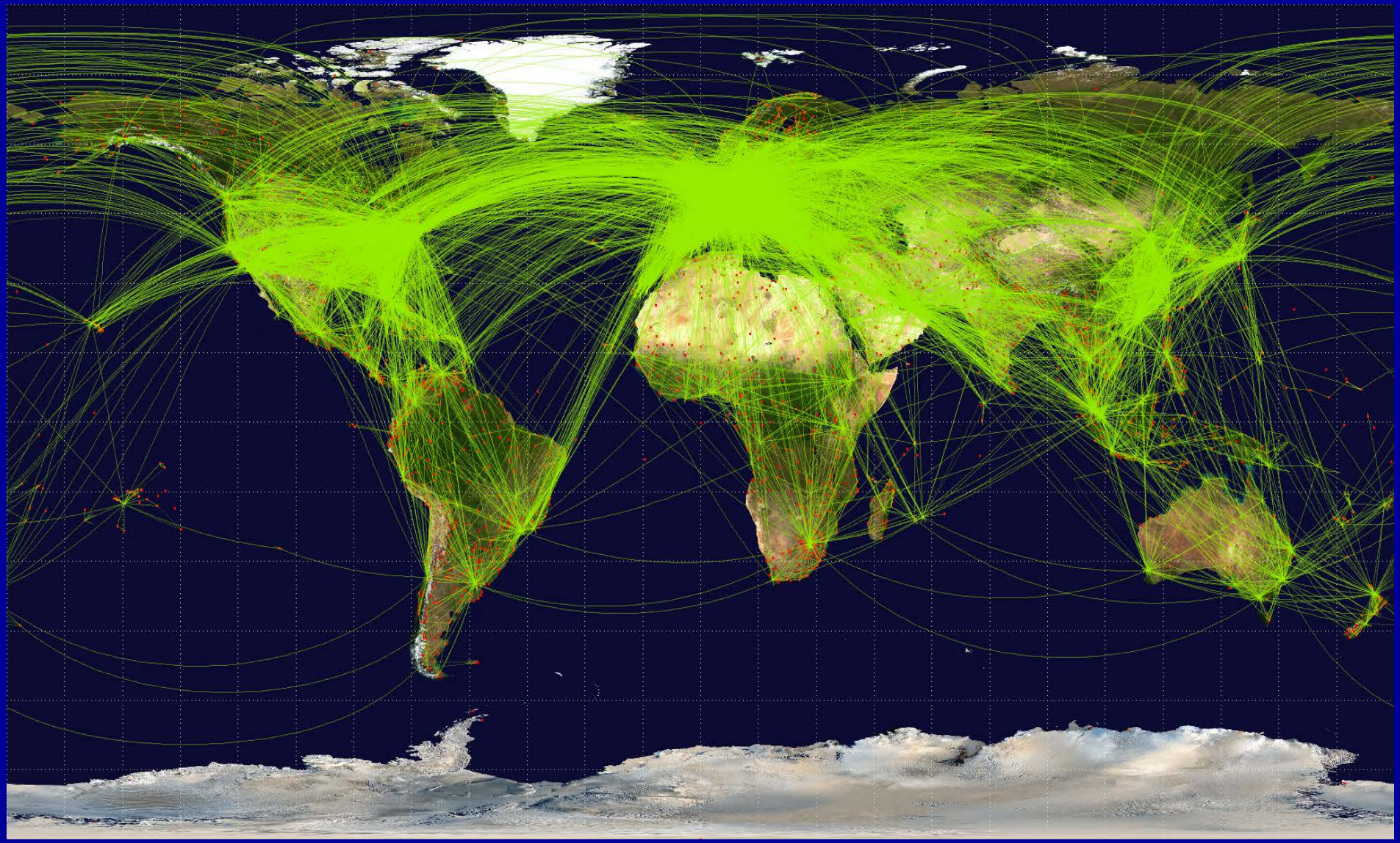
source: Smithsonian Institution

Global Air Routes

source: Airline Route Mapper, Open Flights



Eyjafjallajökull, Iceland 2010

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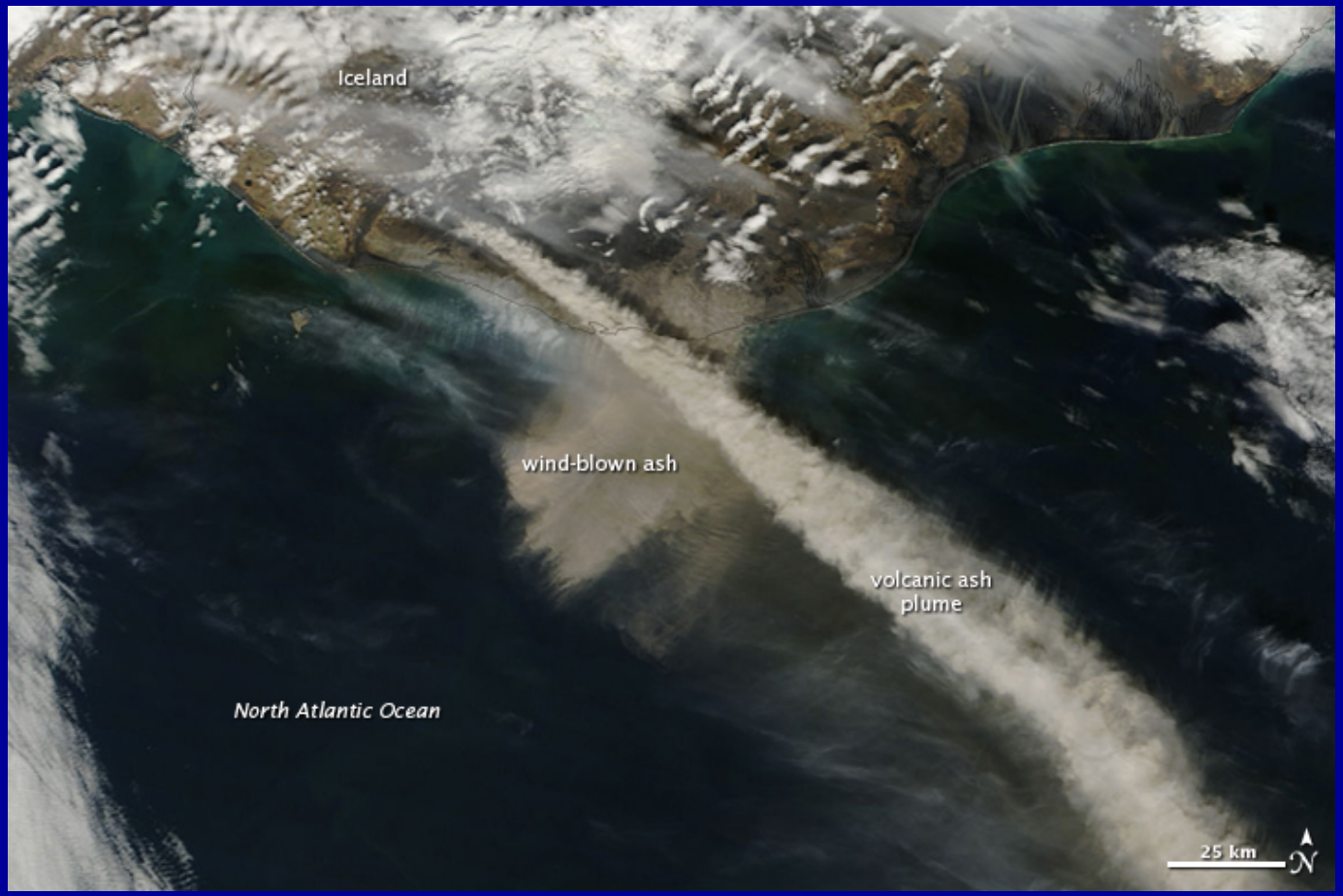
Eyjafjallajökull, Iceland 2010



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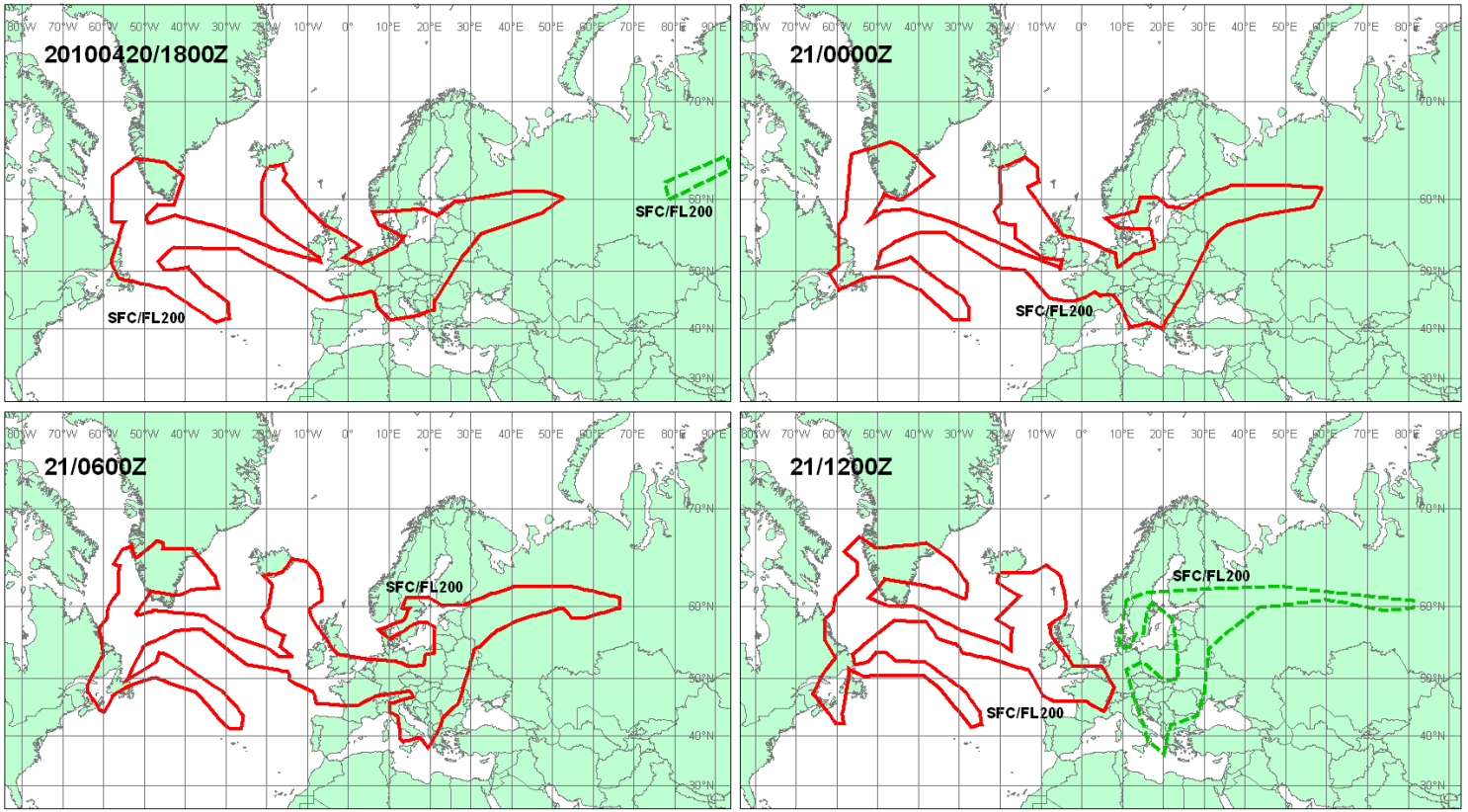
Eyjafjallajökull, Iceland 2010



VA ADVISORY
DTG: 20100420/1800Z
VAAC: LONDON
VOLCANO:
EYJAFJALLAJOKULL 1702-02
PSN: N6338 W01937
AREA: ICELAND

SUMMIT ELEV: 1666M
ADVISORY NR: 2010/027
INFO SOURCE: ICELAND MET OFFICE
AVIATION COLOUR CODE: RED
ERUPTION DETAILS: ERUPTION CONTINUING TO AROUND FL120 TO FL180.

RMK: NO SIG ASH ABOVE FL200. ASH CONCENTRATIONS UNKNOWN. THE TWO PLUMES ON 20/1800Z AND 21/1200Z CHARTS ARE BOTH AT SFC/FL200.
NXT ADVISORY: 20100421/0000Z

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Eyjafjallajökull, Iceland 2010

- between April 15 and May 16, 2010, 34 countries imposed flight restrictions
- flight disruptions on a global scale
- more than 100,000 commercial flight cancellations
- ~10 million passengers affected
- estimated economic loss >$US 2.2 billion

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sources: IATA, ICAO,

Framing the issue - Costs

2010 Iceland eruption: estimated losses of between $US 1.7 and $US 2.2 billion *(IATA, 2011)*

1995-1996 Ruapehu, NZ: ~ $US 1.6. million *(Johnston et al, 2000)*

1992 Cerro Negro, Nicaragua: ~ $US 300,000. *(UN-ECLA, 1992)*

1991 Pinatubo, Philippines: ~ $US 100. - 200. million *(Casadevall et al, 1996)*

1989-1990 Redoubt, Alaska: $ US 101. million *(Tuck and Huskey, 1994)*

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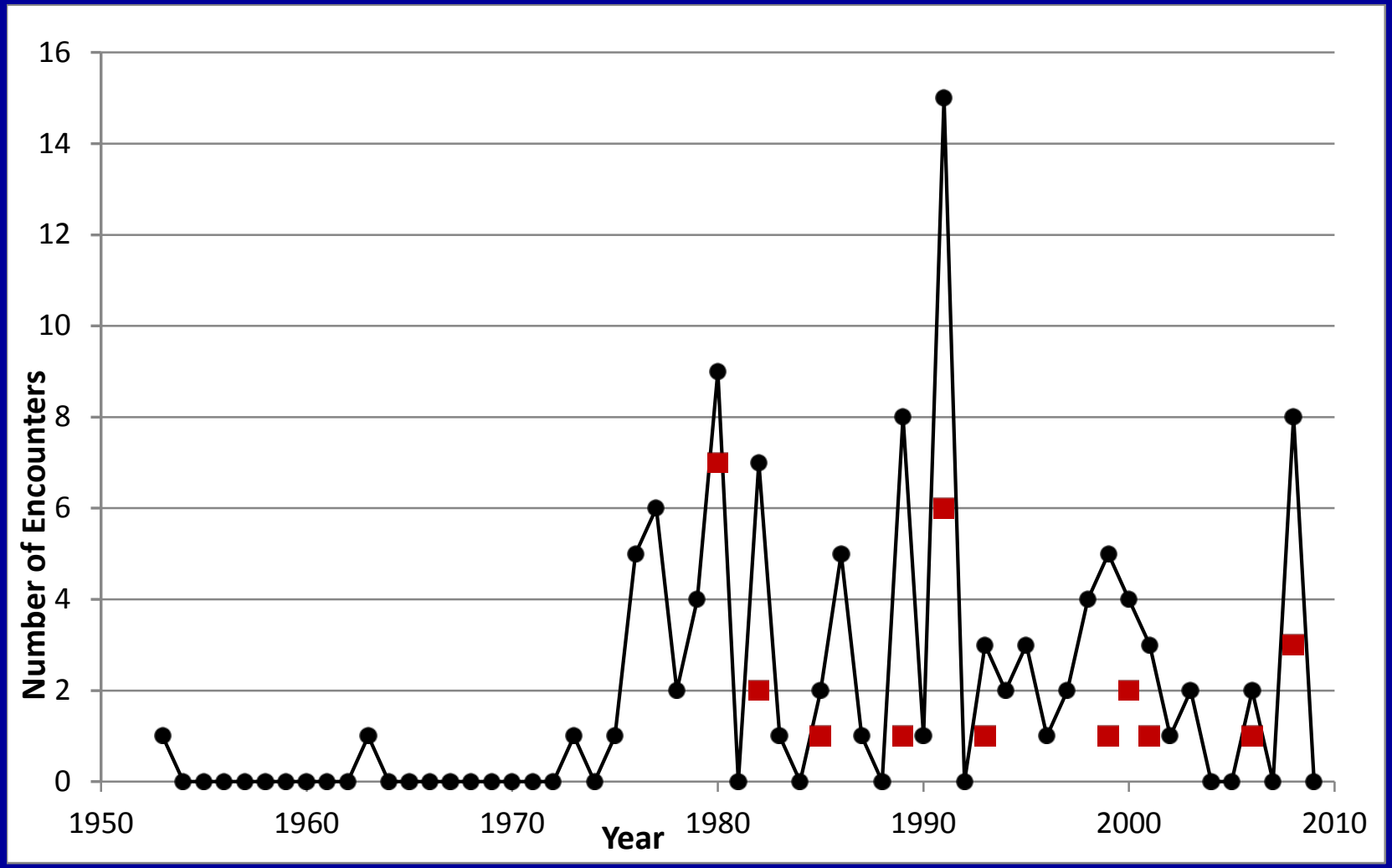
Aircraft Encounters / Year



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Volcanoes responsible for damaging encounters of aircraft with ash clouds

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Encounter Severity Index

- more than 130 reported encounters since 1953
- to classify reports of aircraft encounters with volcanic ash
- 6 classes (ranked from “0” to “5”) of encounter “severity” depending on character of encounter and effects to aircraft and engines

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Encounter Severity Index

0: sulfur odor and anomalous haze

1: light dust in cabin; engine temperatures fluctuate but remain “normal”

2: heavy cabin dust; exterior abrasion; deposition of ash in engines

3: engine vibration and “surging”; engine damage

4: temporary engine failure

5: engine failure or other damage leading to crash

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Encounter Severity Index

Severity Class	Number
5	0
4 *(engine failure)*	9
3	17
2	53
1	12
0	23
Lacking data	15
Total incidents reported	129

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Impacts and Damage
(in flight)

- abrasion of windows and exterior surfaces
- plugging of inlets and pitot system
- erosion of engine parts
- accumulation of melted ash in engine

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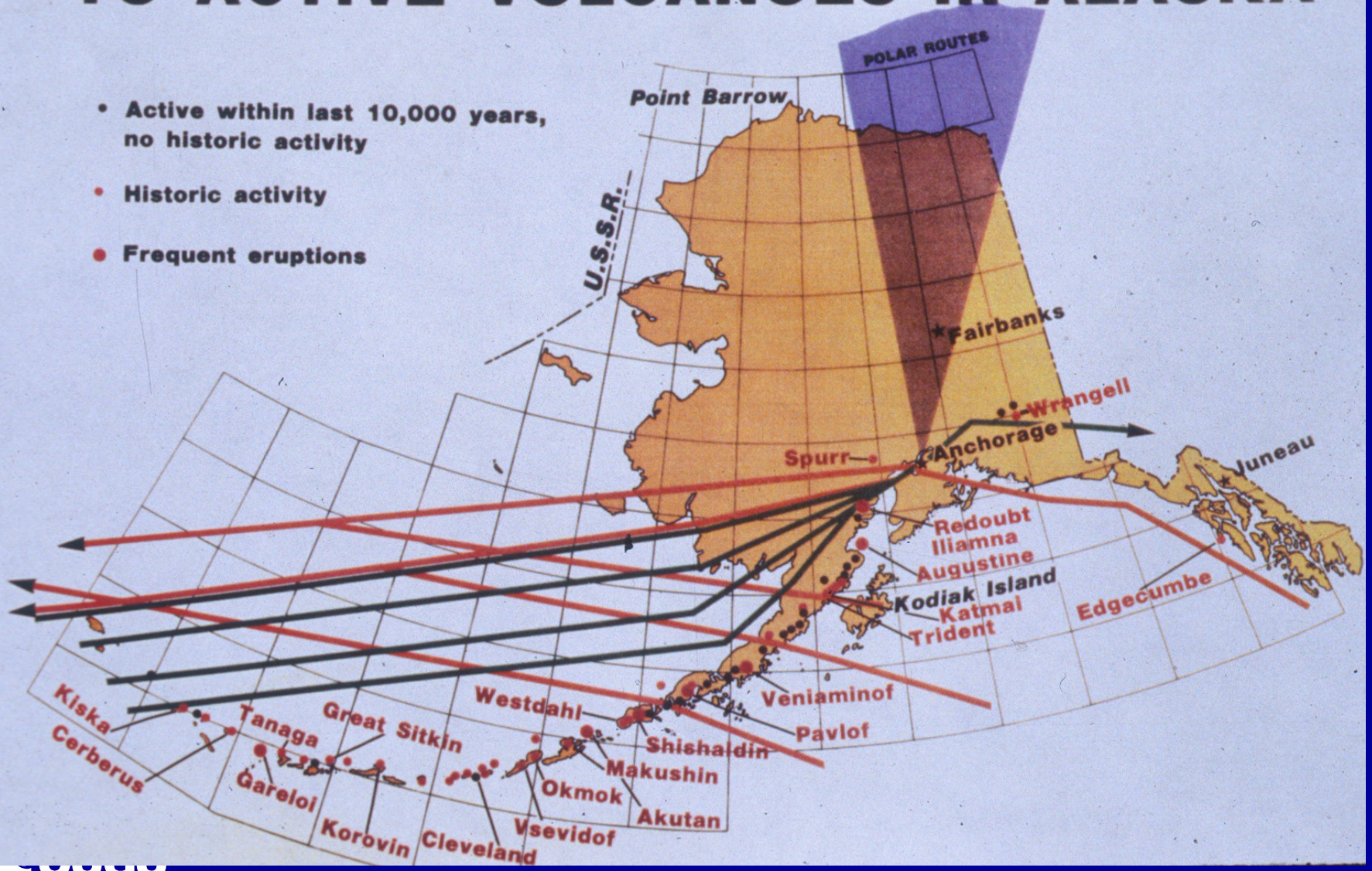
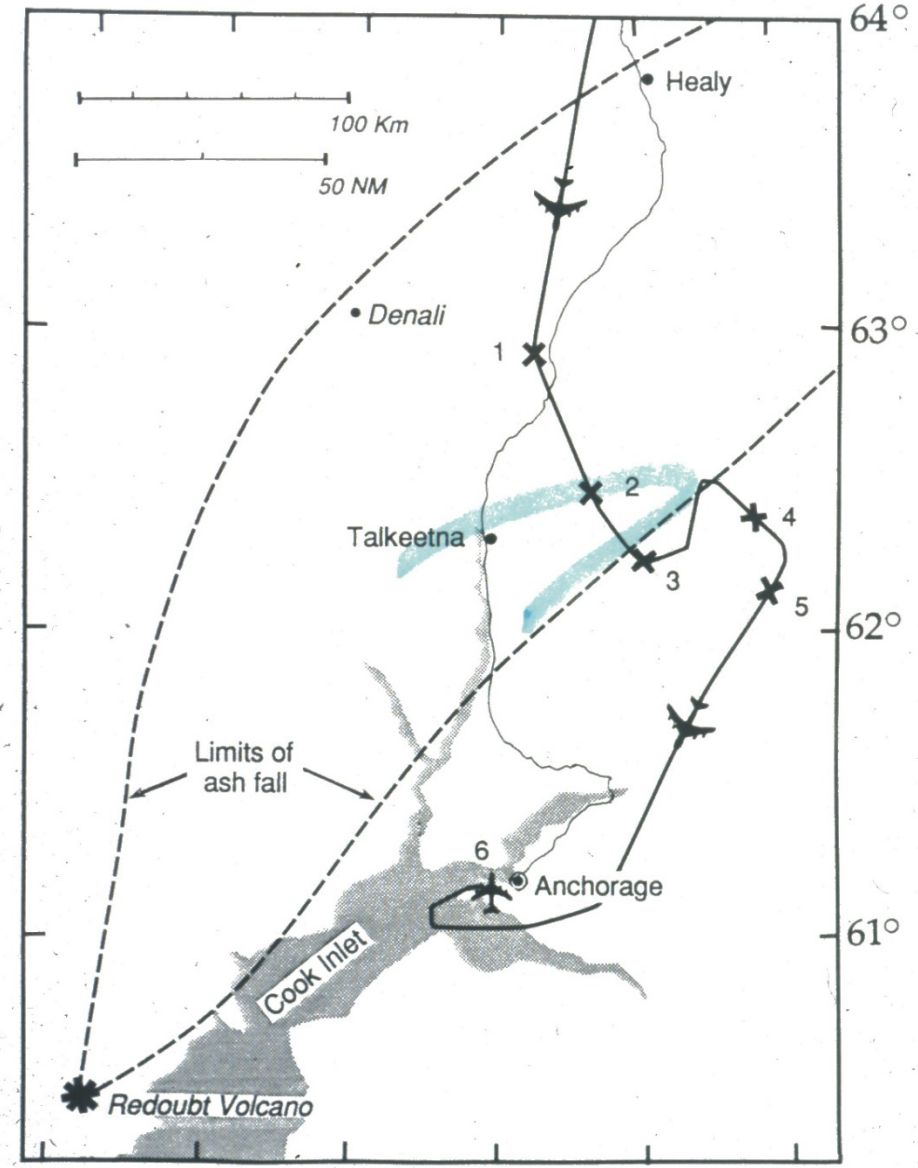
RELATION OF AIR TRAFFIC ROUTES TO ACTIVE VOLCANOES IN ALASKA




64°
63°
62°
61°
152°
150°
148°
100 Km
50 NM
Healy
Denali
Talkeetna
Anchorage
Cook Inlet
Redoubt Volcano
Limits of
ash fall
1
2
3
4
5
6

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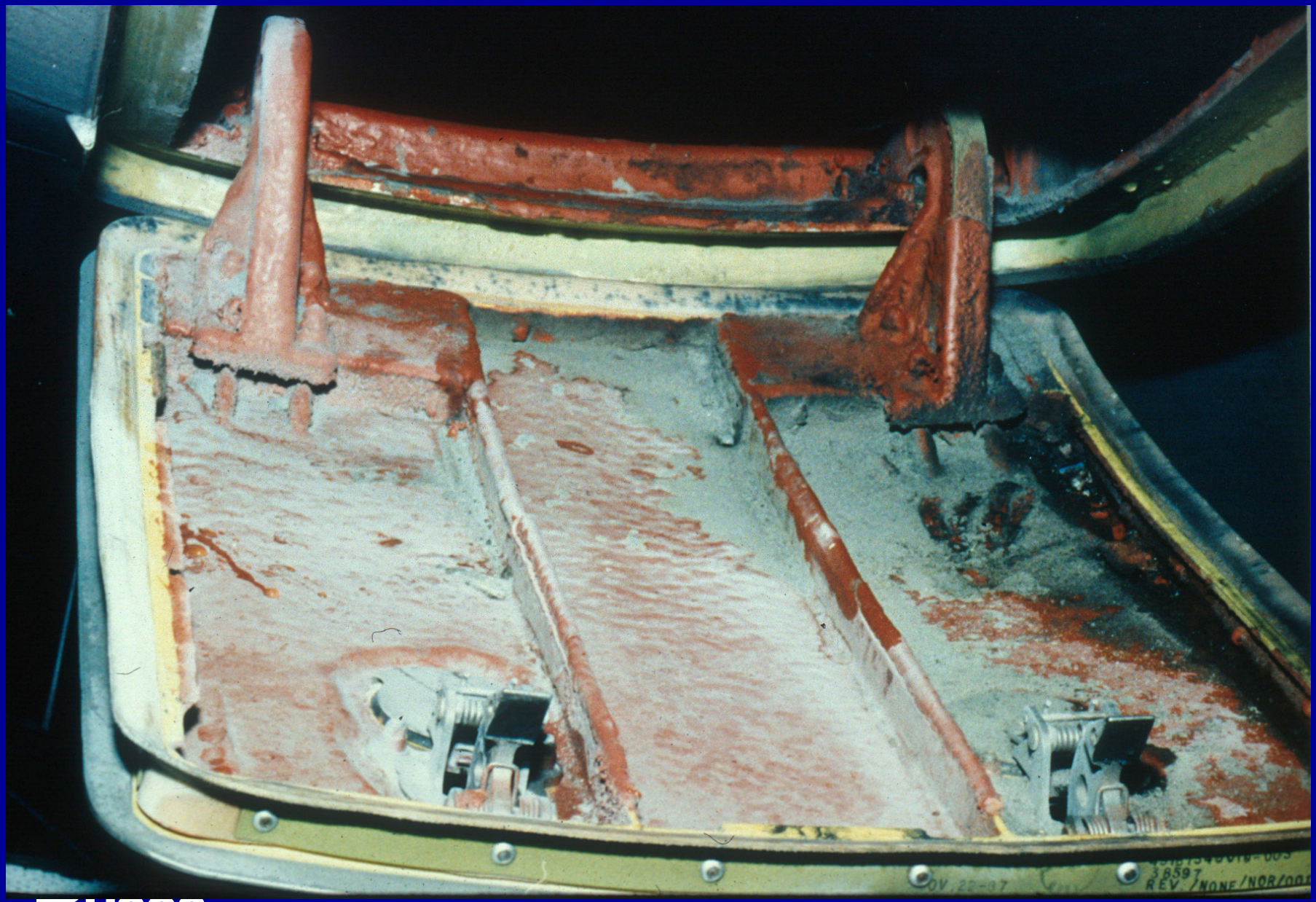

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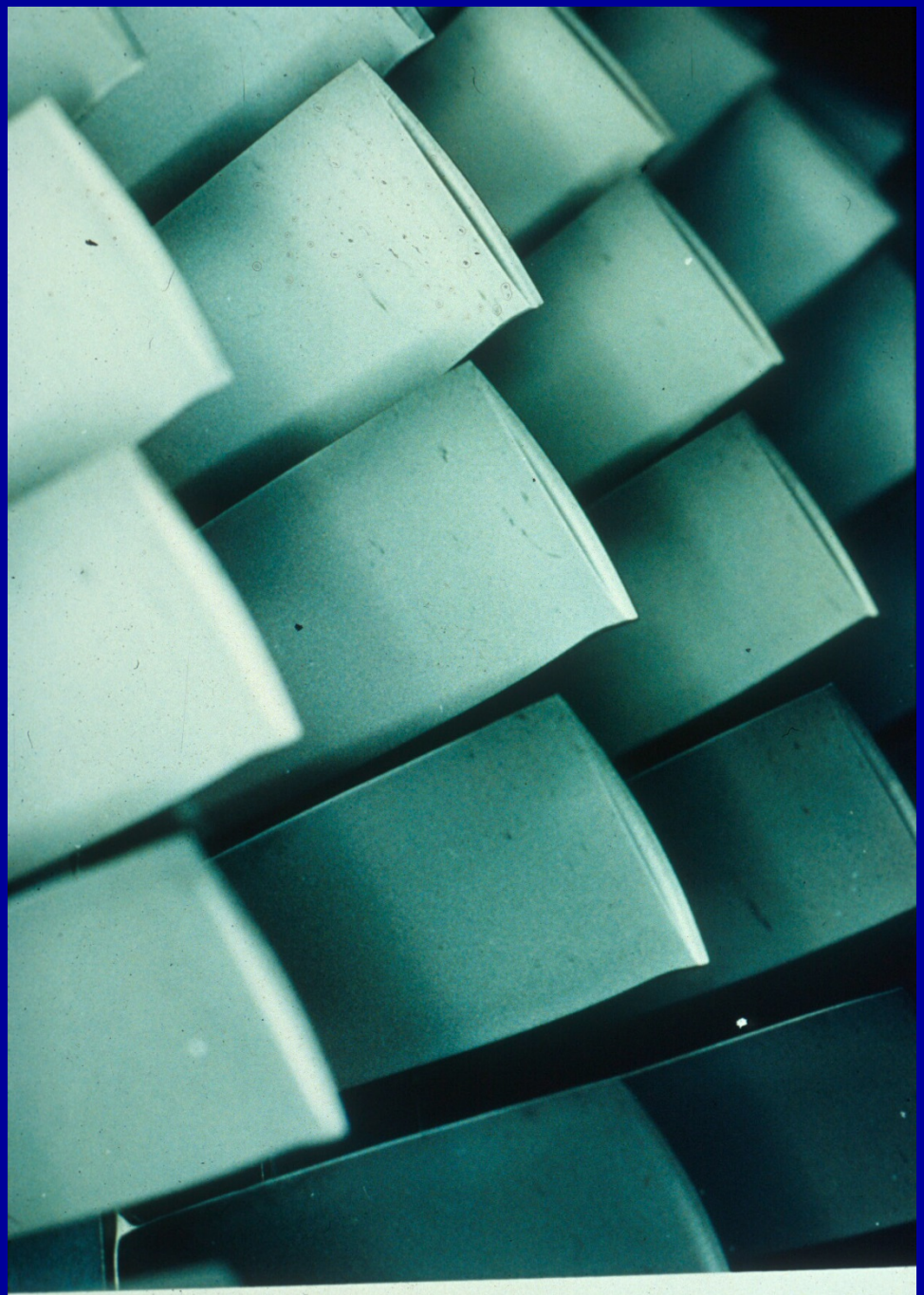

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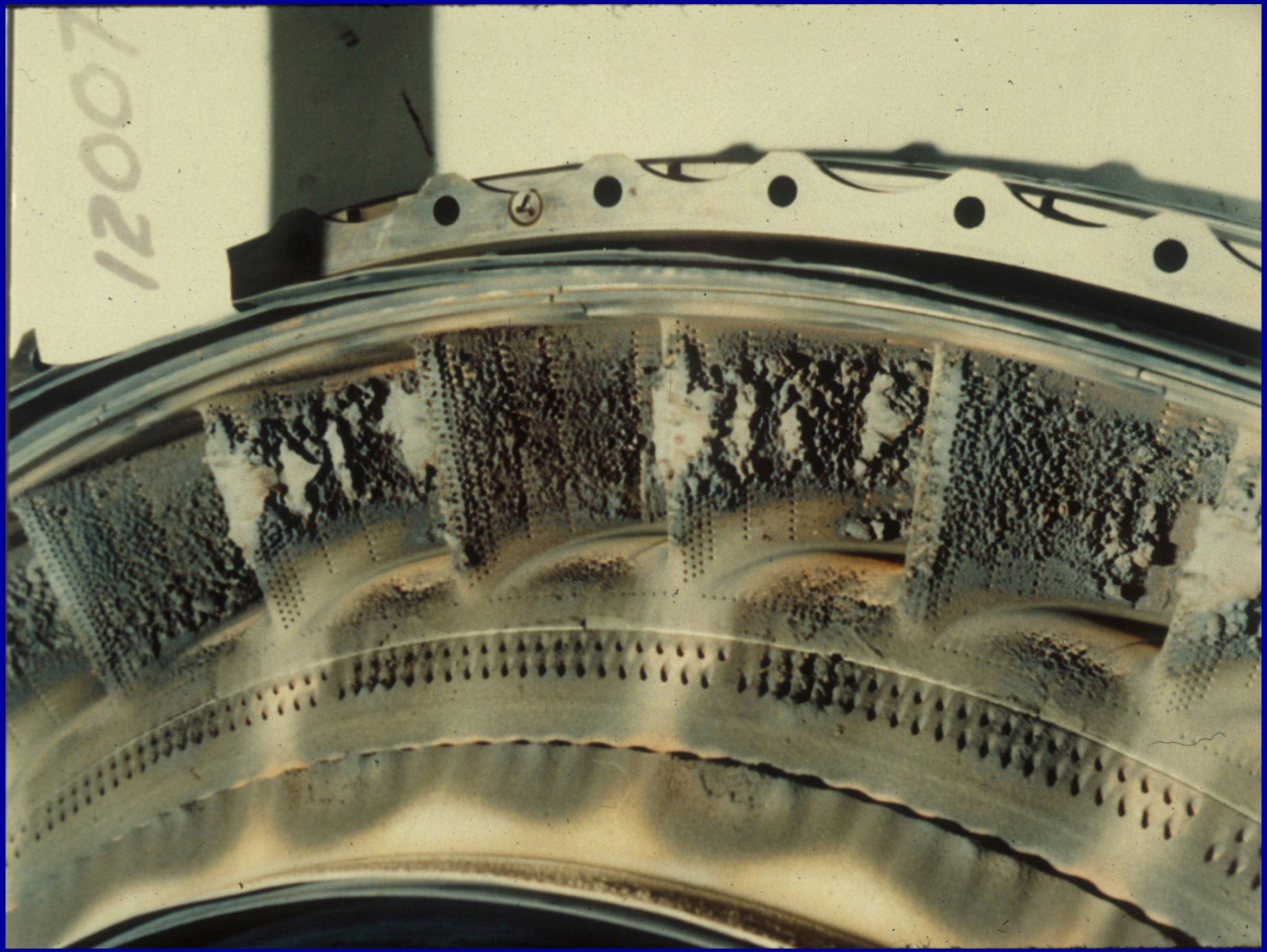
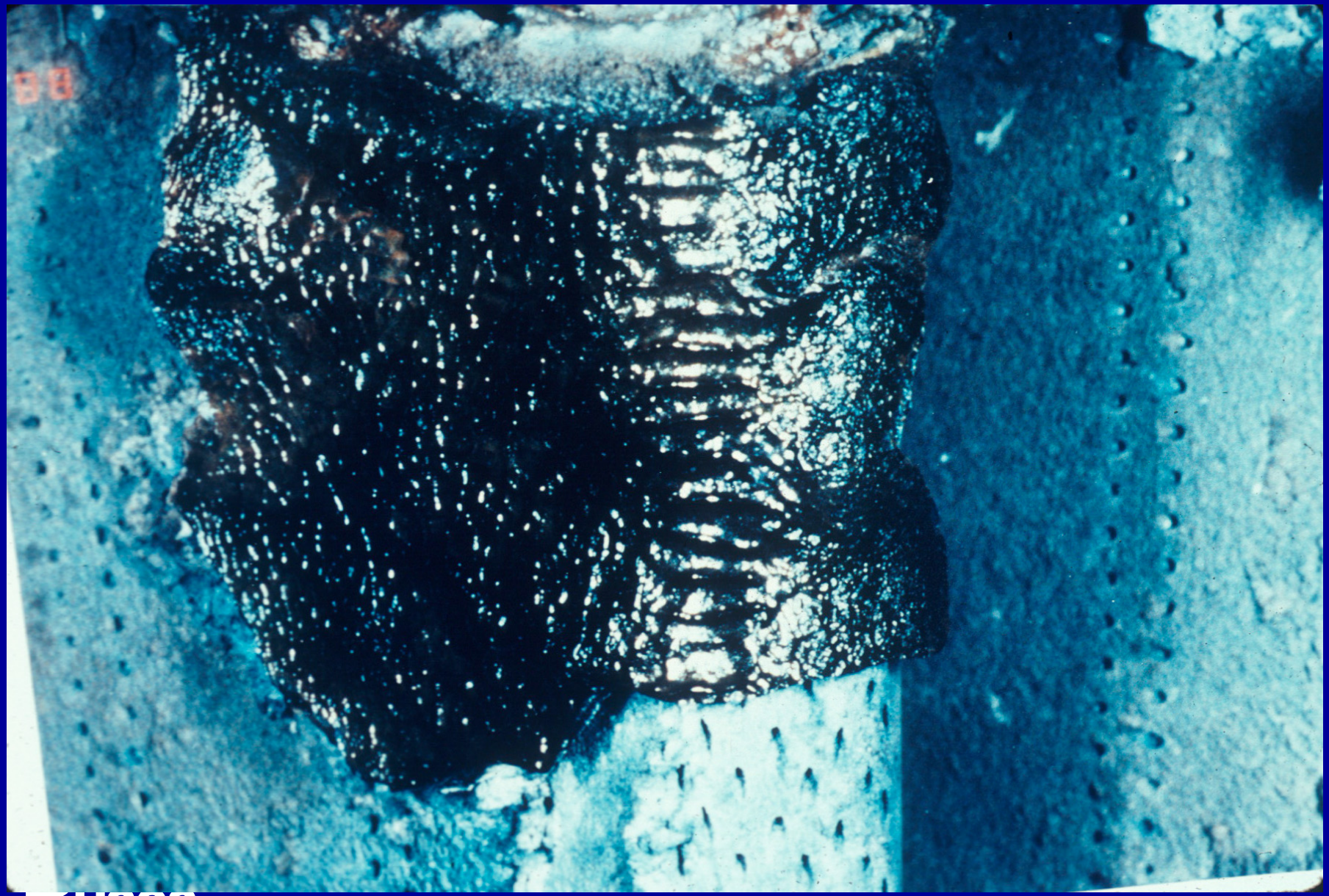

12007



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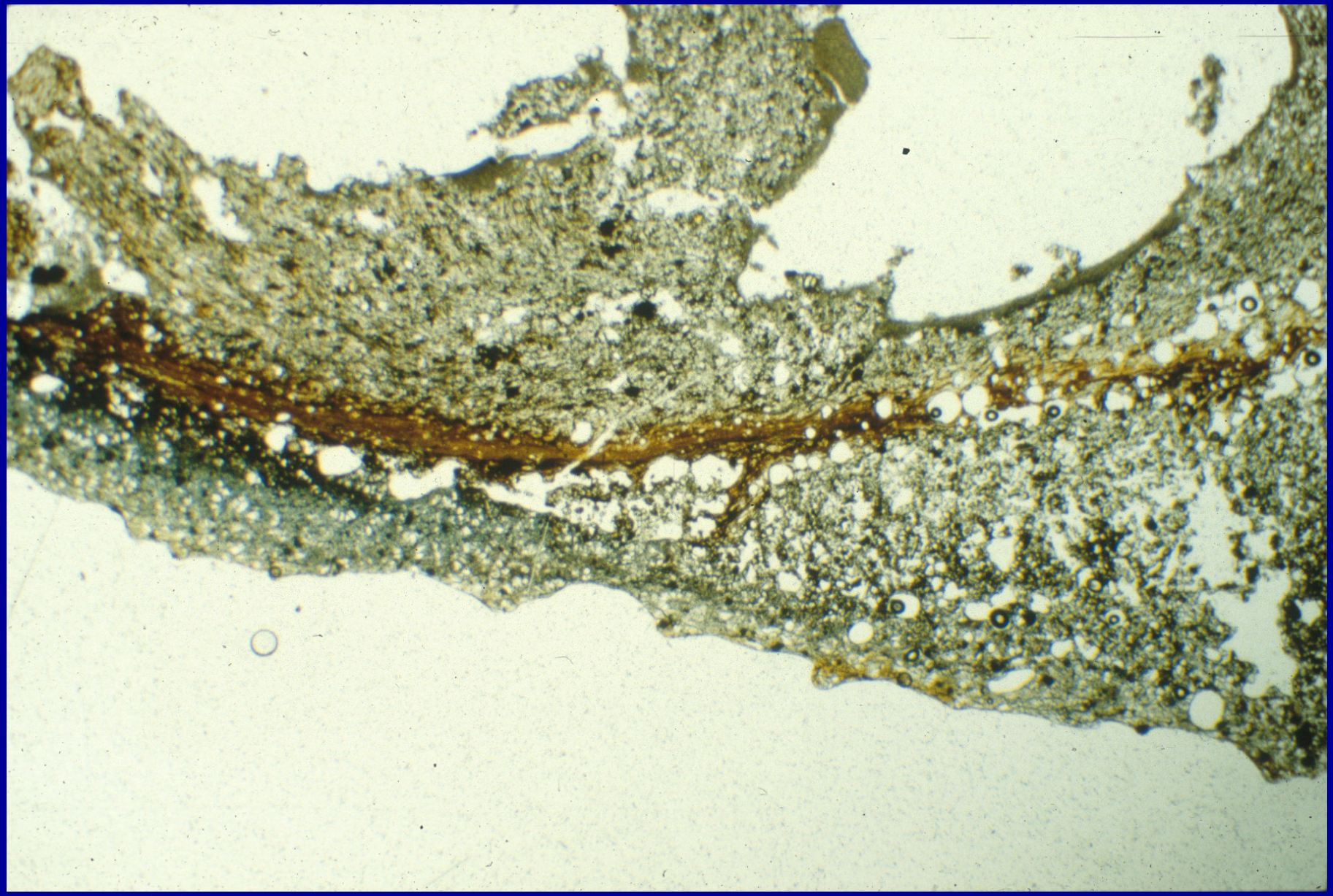

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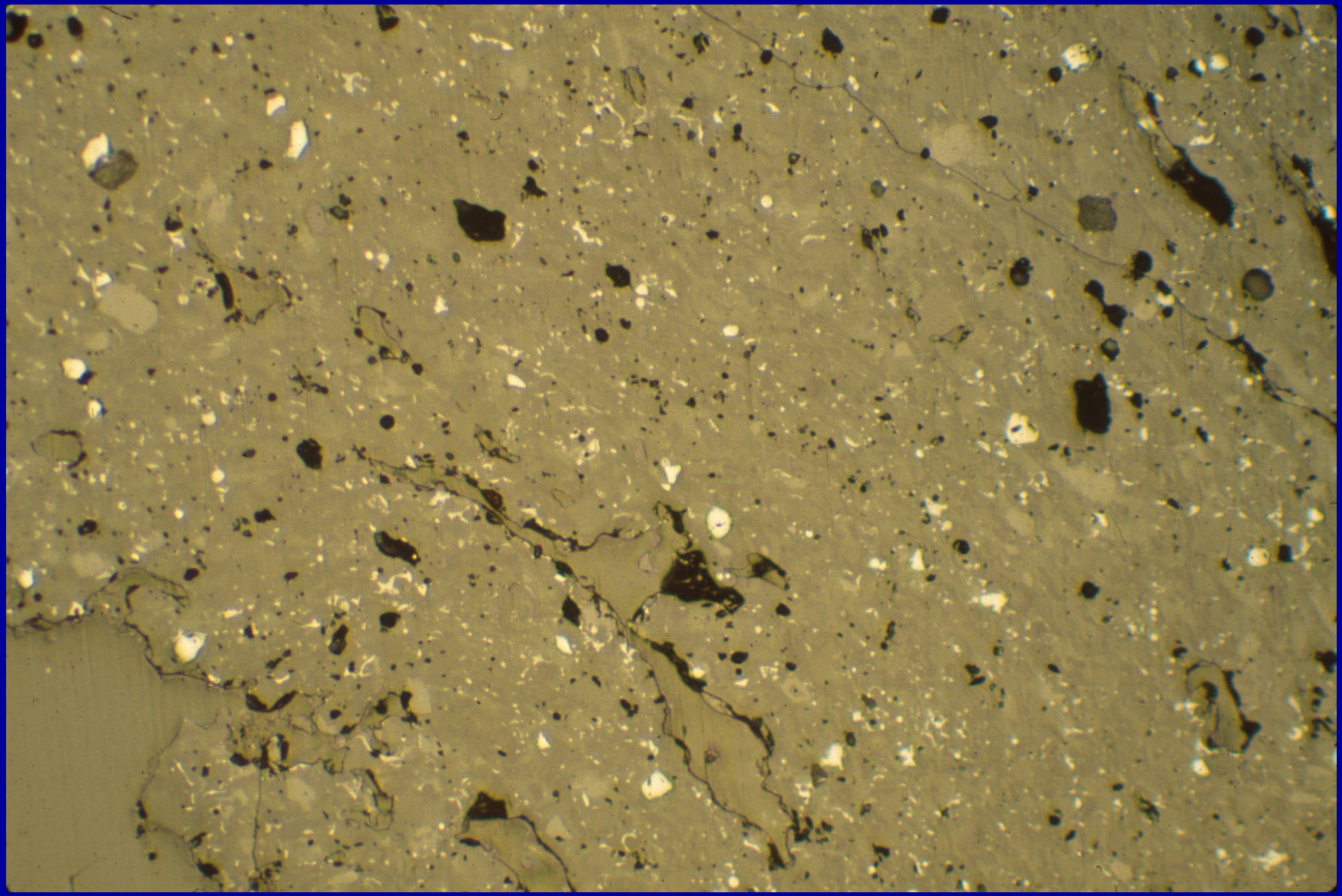

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Impacts and Damage
(on the ground)

- contamination of airport surfaces and aircraft on-the-ground
- contamination of electrical circuits
- reduction of visibility
- ash is slippery when wet – affects braking and turning

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Vesuvius eruption, Italy, 1944

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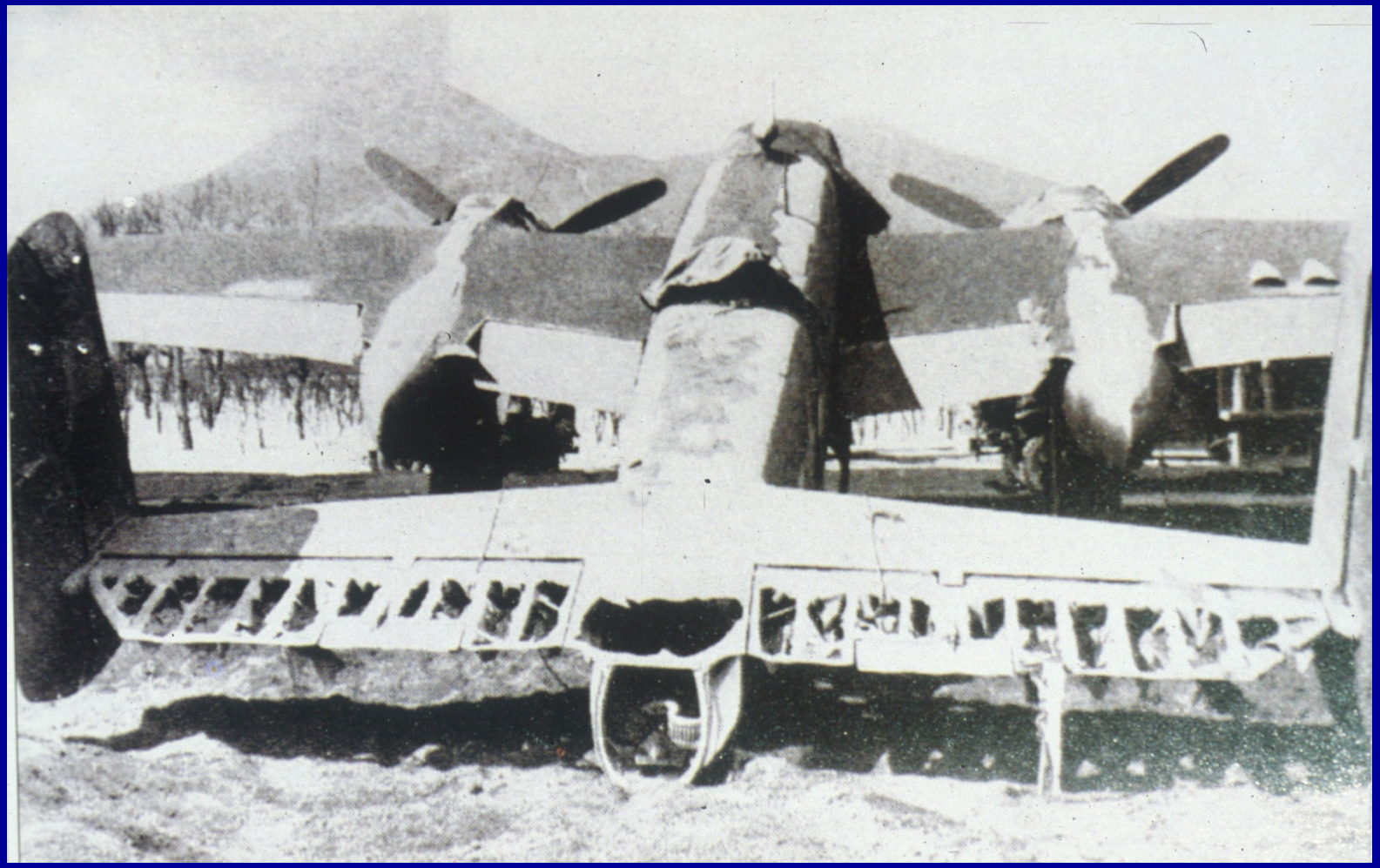
Vesuvius eruption, Italy, 1944



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Moses Lakes, Washington, May 19, 1980

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Reventedor ashfall at Quito airport, Ecuador Oct. 1999

USGS

Feb. 2014 Kelut ashfall at Yogyakarta airport, Indonesia

source: AFP photo / Ninoy

USGS

June 1991 Pinatubo ashfall, Cubi Pt. NAS

source: US Navy photo

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Ashfall, Rabaul airport, PNG 1994

source: Russell Blong

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How do we avoid encounters?

- avoid ash
- timely communication of volcano information
- increase awareness that volcanic hazards extend well beyond the area adjacent to the volcano and may extend 100s to 1000s kms downwind
- early detection of ash in the airspace
- pilot training to address the volcanic ash threat

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View from the cockpit – Maipu volcano, Chile

source: Captain Salas, 2010

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Communications and Information:
A View from the Cockpit

- Pilots always manage risk and weigh their options based on information
- Pilots need information that is:
  - Timely
  - Believable
  - Understandable
  - Clear
  - Integrateable with their operations

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Captain Carlos Salas, IFALPA - Europe

Communicating the Hazard

- Color Codes
- Volcano Observatory Notice for Aviation (VONA)
- SIGMETS
- Volcanic Ash Advisories (VAA)
- Volcanic Ash Graphical Products (VAG)

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Eruption Notification

THIS IS AN ERUPTION NOTIFICATION FROM THE _____ OBSERVATORY. SEISMIC (or other data) INDICATE THAT A (small, moderate, large) ERUPTION OF _____ VOLCANO, LAT_____, LONG _____, BEGAN AT _____UTC ON (date). THE LEVEL OF CONCERN COLOR CODE IS (orange, red).

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AVO LEVEL-OF-CONCERN COLOR CODE

Color	Intensity of Unrest at Volcano	Forecast
GREEN	Volcano is in quiet, "dormant" state.	No Eruption anticipated
YELLOW	Small earthquakes detected locally and (or) increased levels of volcanic gas emissions.	An eruption is possible in the next few weeks and may occur with little or no additional warning.
ORANGE	Increased number of local earthquakes. Extrusion of a lava dome or lava flows (non-explosive eruption) may be occurring.	Explosive eruption is possible within a few days and may occur with little or no warning. Ash plume(s) not expected to reach 25,000 feet above sea level
RED	Strong earthquake activity detected even at distant monitoring stations. Explosive eruption may be in progress.	Major explosive eruption expected within 24 hours. Large ash plume(s) expected to reach at least 25,000 feet above sea level.

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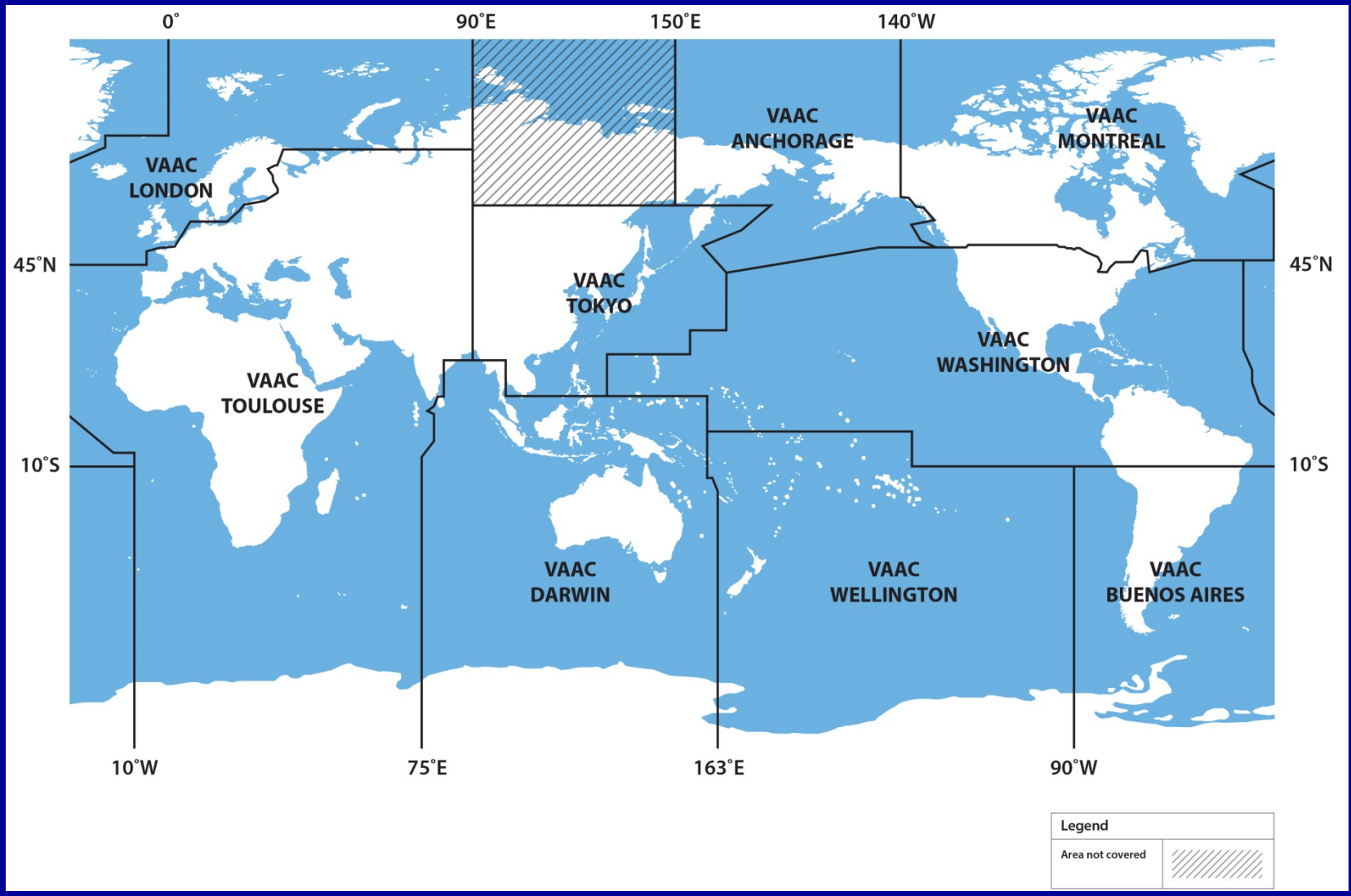
Volcanic Ash Advisory Centers



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Volcanic Ash Advisory Centers

Anchorage
Buenos Aires
Darwin
London
Montreal
Tokyo
Toulouse
Washington
Wellington

- established in the early 1990s by Intl. Civil Aviation Organization (ICAO)
- coordinate and disseminate information on atmospheric volcanic ash clouds affecting aviation
- VAACs operated by national weather forecasting organizations

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METEO FRANCE : Welcome to Toulouse VAAC - Microsoft Internet Explorer

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version française

The Toulouse Volcanic Ash Advisory Center

Volcanic ash

VAAC's role

Toulouse VAAC

The MEDIA model

Sample of outputs

Miscellaneous

Etna INGV webcams

African volcanoes

Vaac Toulouse, Météo-France
42 Avenue G. Coriolis, 31057 Toulouse Cedex, France
E-vaac@meteo.fr
mail :

Internet

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Movement of Volcanic Ash

- not detectable in the cockpit using current technology
- difficult to distinguish ash cloud from weather cloud
- reliance on radar remote sensing
- track using satellite remote sensing
- forecast movement using numerical models

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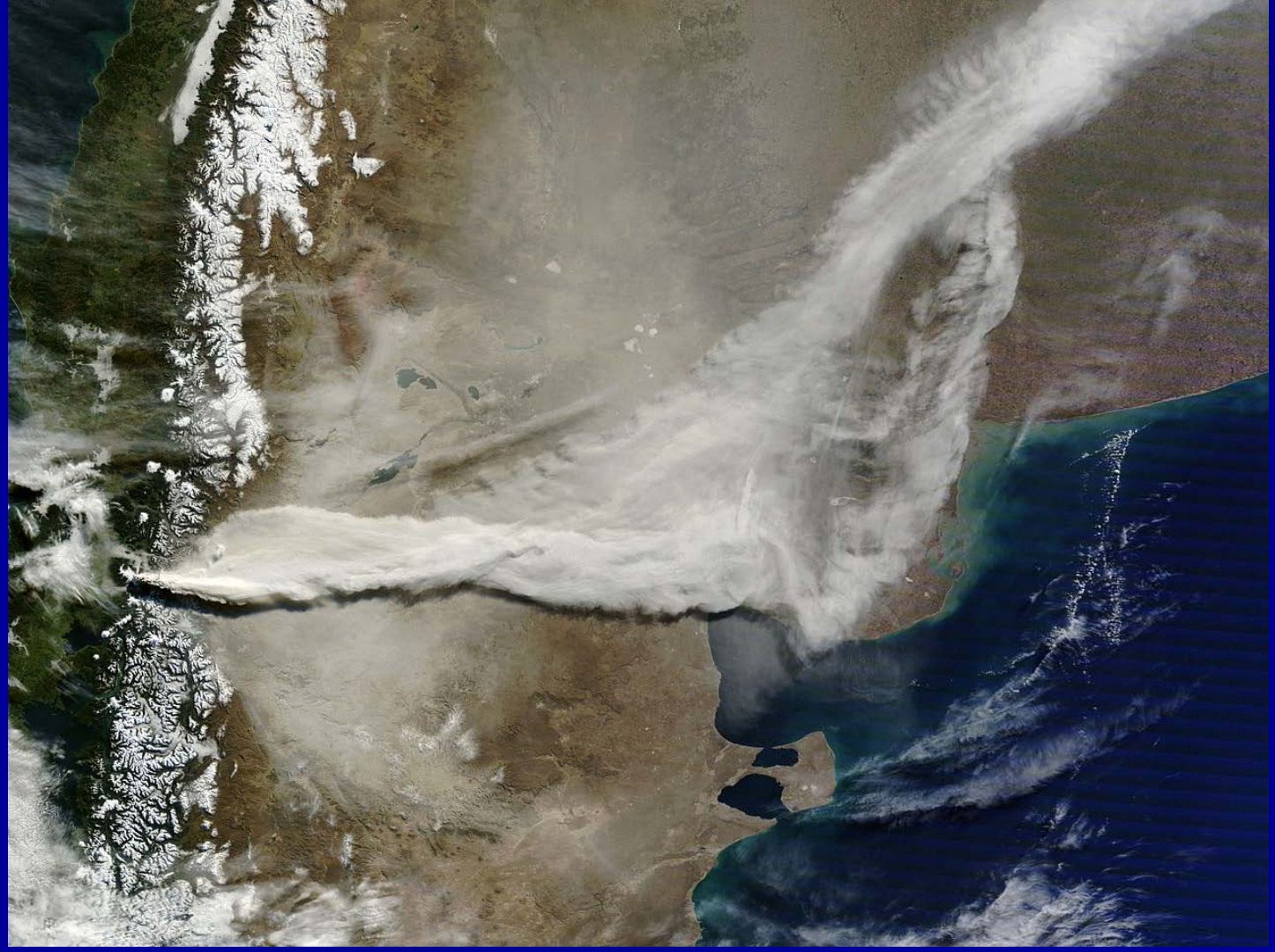

Puyehue-Cordón Caulle, Chile June 2011

MODIS image, NASA Earth Observatory

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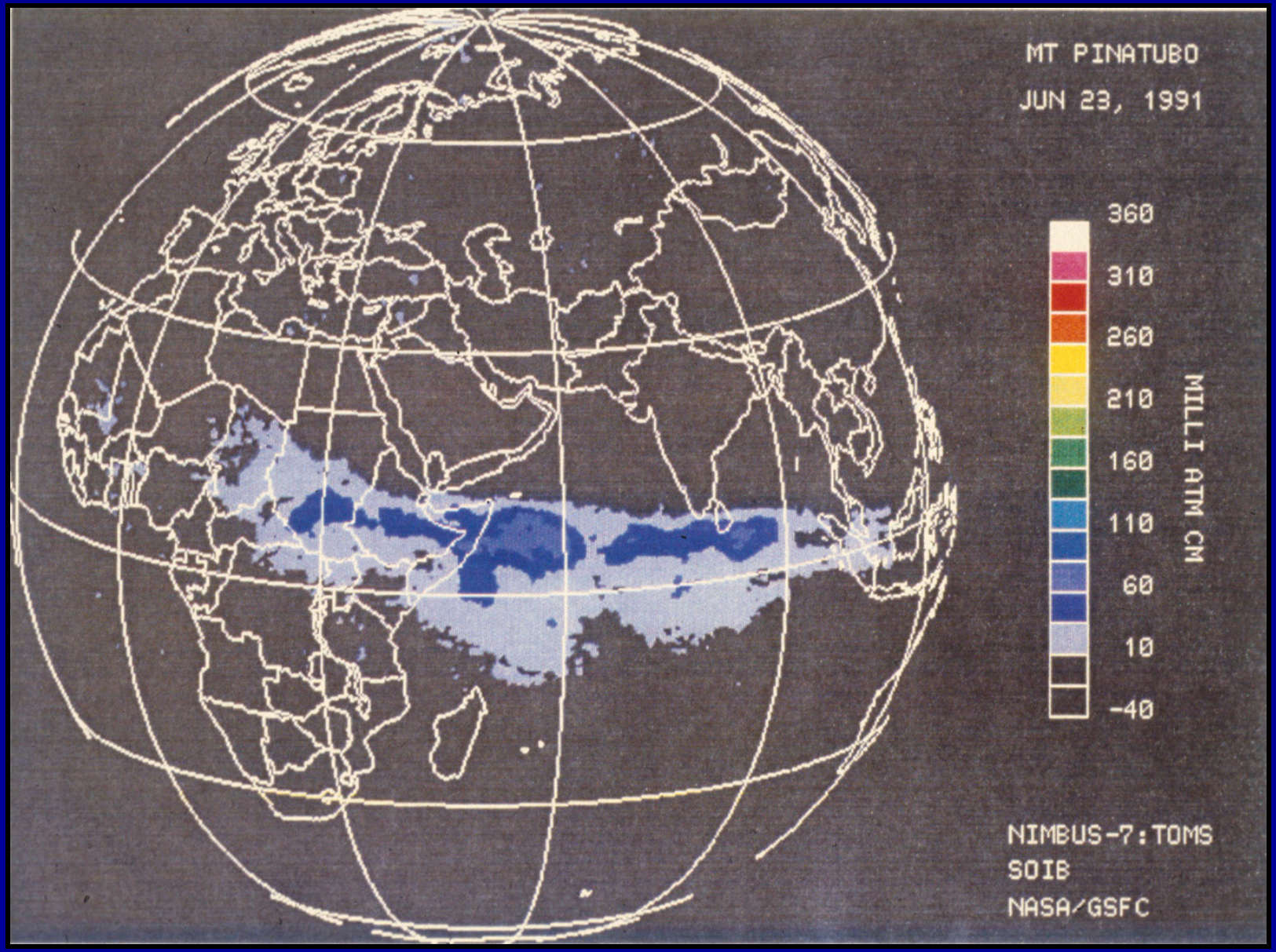
MT PINATUBO
JUN 23, 1991
360
310
260
210
160
110
60
10
-40
MILLI ATM CM
NIMBUS-7:TOMS
SOIB
NASA/GSFC

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Trajectory Forecast Model

- numerical trajectory models forecast dispersion of a pollutant cloud

- input includes start time, duration of input, and altitude of dispersion

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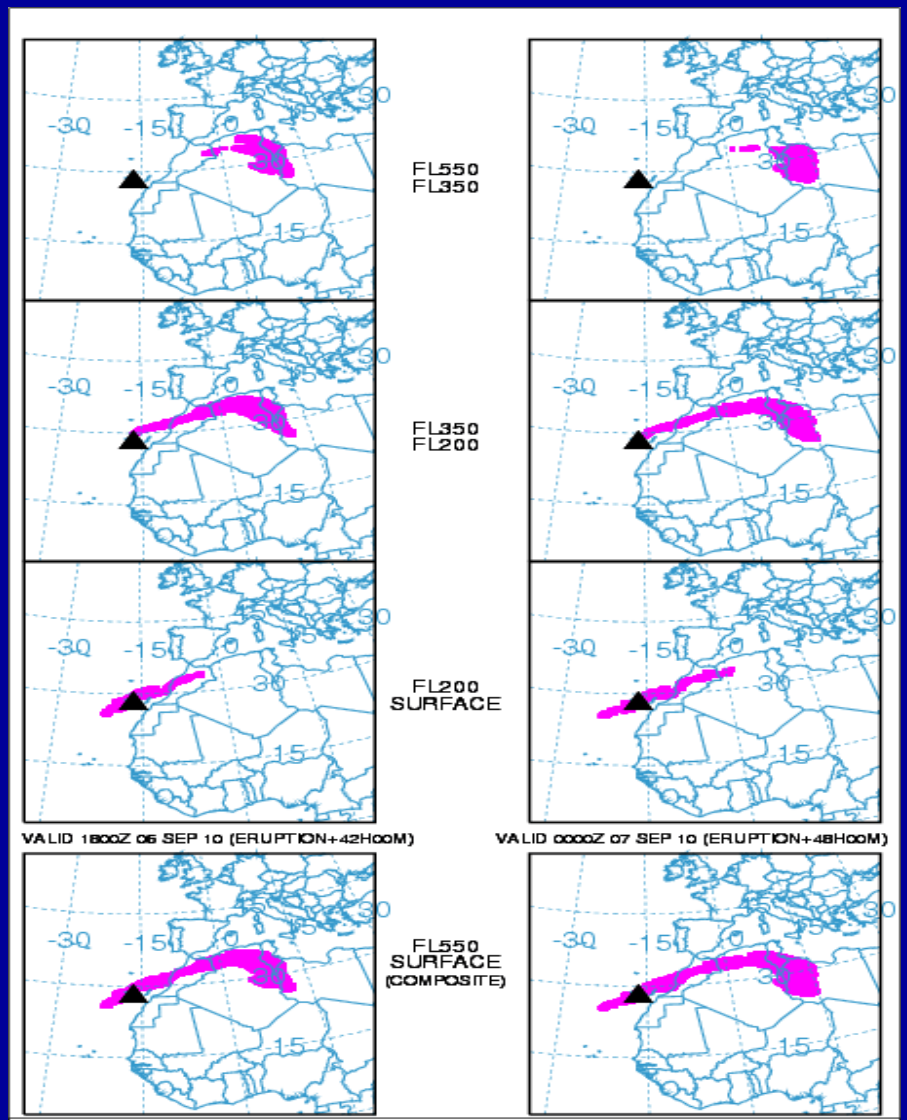
Graphical Product



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Future Developments

- Active in-flight detection of ash
  - ZEUS
  - AVOID
- Volcanic ash ingestion testing
  - VIPR
- Communications protocols – improving the links between volcano observers and VAACs

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ZEUS

- UK Met Office and Natural Environment Research Council have a prototype ash detection device;
- ZEUS **sensor distinguishes electrostatic charge** on the aircraft when volcanic ash is present.
- Sensor tested on a British Airways 747 on long-haul routes
- A prototype sensor on a UK research aircraft and a ***Flybe*** passenger aircraft since 2012

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AVOID

- AVOID (Airborne Volcanic Object Identifier and Detector) to provide real-time imagery of hazards ahead of aircraft.
- Information to the cockpit from two **imaging infrared cameras tuned to detect volcanic ash particles** up to 100 km ahead of the aircraft day or night.
- to give pilot 7 – 10 minutes warning of a potential encounter with ash cloud.
- to convert the image signal into ash concentrations levels, from <1 mg to > 50 mg cubic m

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Volcanic Ash Ingestion Testing
VIPR

- a team of U.S. agencies and engine manufacturers
- test volcanic ash ingestion by a high by-pass jet engine
- determine the effect of exposure to low to moderate ash concentrations (1 and 10 mg/m3)
- uses natural volcanic ash; representative of distal ash clouds many 100's to ~1000 km from a volcanic source

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Volcanic Ash Ingestion Testing

Source material

- Using Mazama eruption ash (~7,700 y.b.p.)
- ~100 kms from vent at Crater Lake, Oregon
- ~70% SiO2

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Volcanological Guidance

- **International Airways Volcano Watch Operations Group**, scientific advisory body to International Civil Aviation Organization (ICAO) to advise and provide guidance on operational requirements related to volcanic ash hazard
- representative from **IUGG / IAVCEI**
- members from VAACs
- **Volcanic Ash Scientific Advisory Group,** formed under auspices of WMO and **IUGG / IAVCEI**, to provide advice on volcanic ash, volcano monitoring, etc…

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Acknowledgements

Marianne Guffanti, USGS

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Ian Lisk, UK Met Office

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Fred Prata, Nicarnica Aviation

Lee Siebert, Smithsonian / USGS

Grace Swanson, Washington VAAC / NOAA

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Thank you

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