Turbulence Ahead!

Air travel in a warmer world

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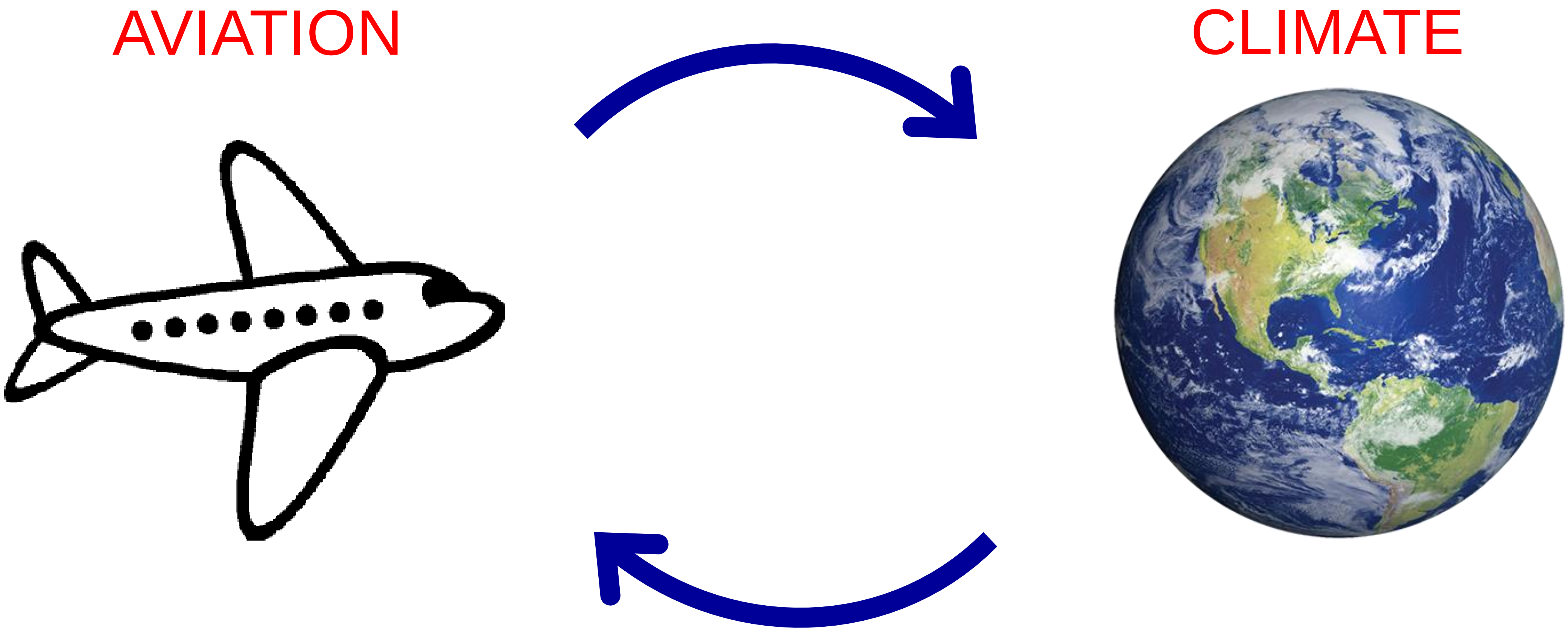
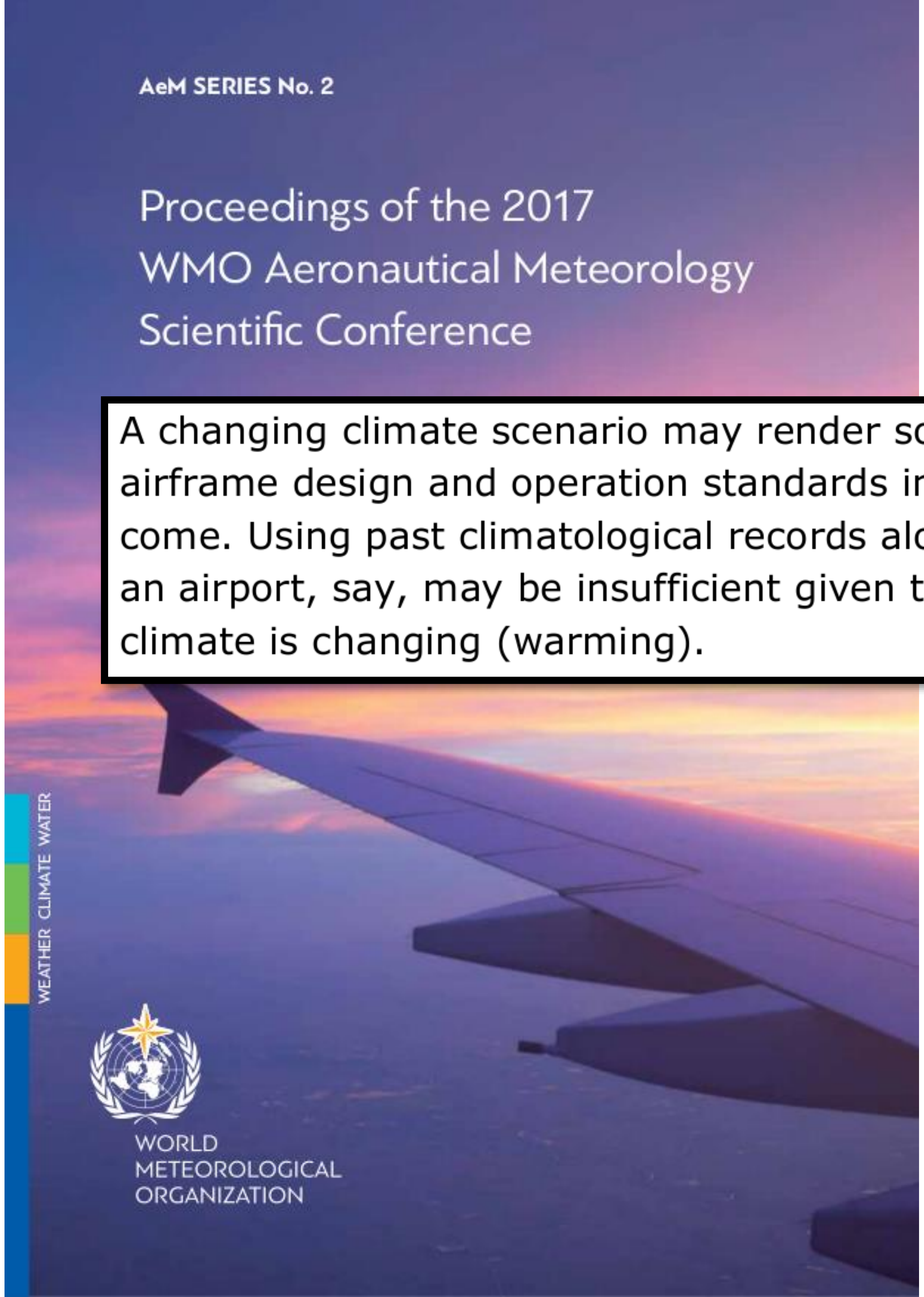
THE ROYAL SOCIETY

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

University of Reading

A two-way interaction





A changing climate scenario may render some of today's aerodrome, airspace and airframe design and operation standards inadequate in the years or decades to come. Using past climatological records alone as an indicator of future climate at an airport, say, may be insufficient given the (current) rate at which the world's climate is changing (warming).

RECOMMENDATION 3

In the context of **climate change and variability on aviation and associated science requirements**, the conference *recommended* that:

- The potential impacts of climate change and variability on aviation operations on the ground and in the air, downscaled to the local level, must be well researched and communicated;
- The mitigation of extreme weather events and the adaptation to a changing climate demands a multidisciplinary effort involving both the physical and the [...] ust [...] ust, [...] he [...] ents [...] ario [...] oving [...] tial [...] e and airframe design and operation standards inadequate in the years or decades to come. Using past climatological records alone as an indicator of future climate at an airport, say, may be insufficient given the (current) rate at which the world's climate is changing (warming).

STATEMENT

The conference *stated* that:

- There is a tremendous amount of ongoing cross-disciplinary research in the field of aeronautical meteorology (MET). This collaborative scientific excellence should be leveraged to enable the future global air traffic management (ATM) system;
- The role of MET as a key enabler to aviation's vision for a globally interoperable, harmonized ATM system of the future that is safer, more efficient and more environmentally responsible will only be realized through the accelerated transition of scientific research and technological advancement into operations based on aviation users' needs, new and improved community partnerships, trust, transparency and openness; and
- As the potential impacts of climate change and variability on aviation operations become better understood, the research community should continue to advance relevant science and communicate in a style that is well understood by the user.

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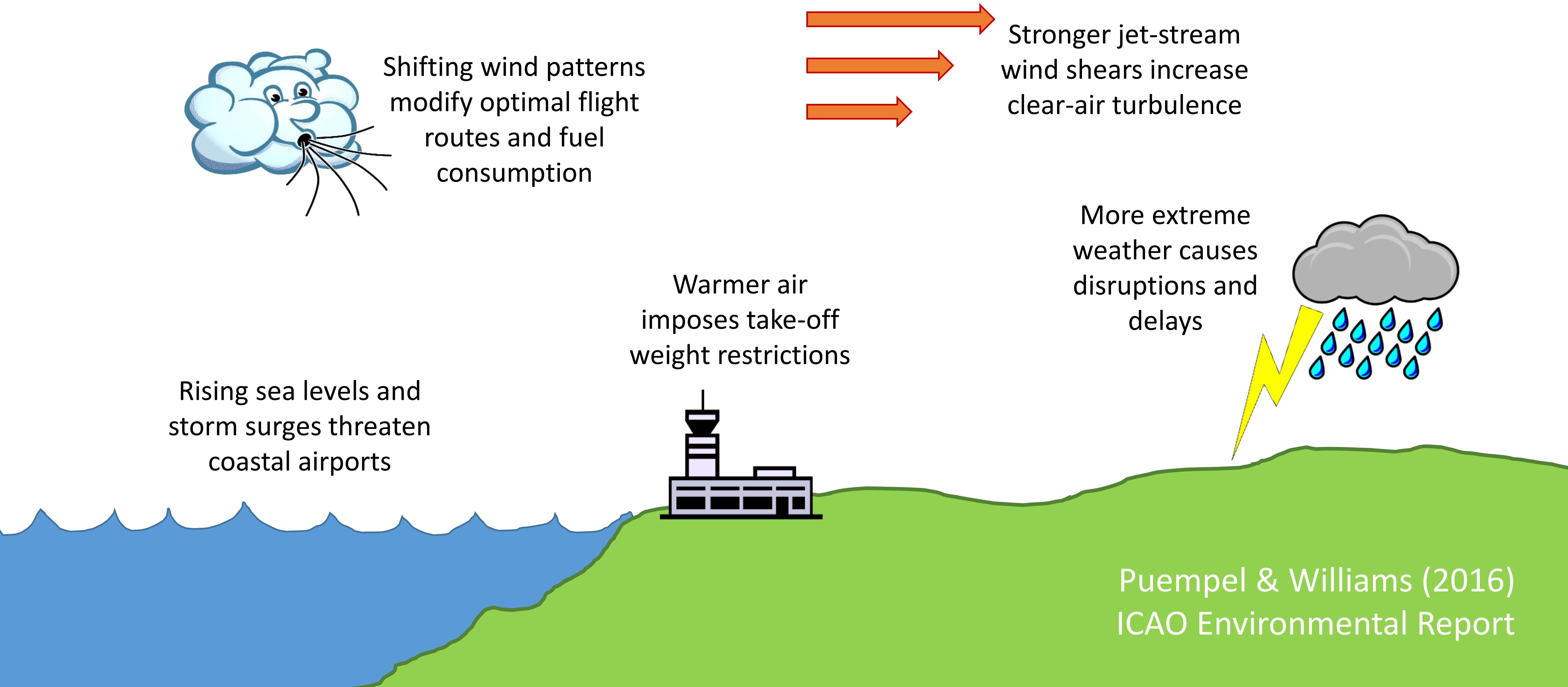
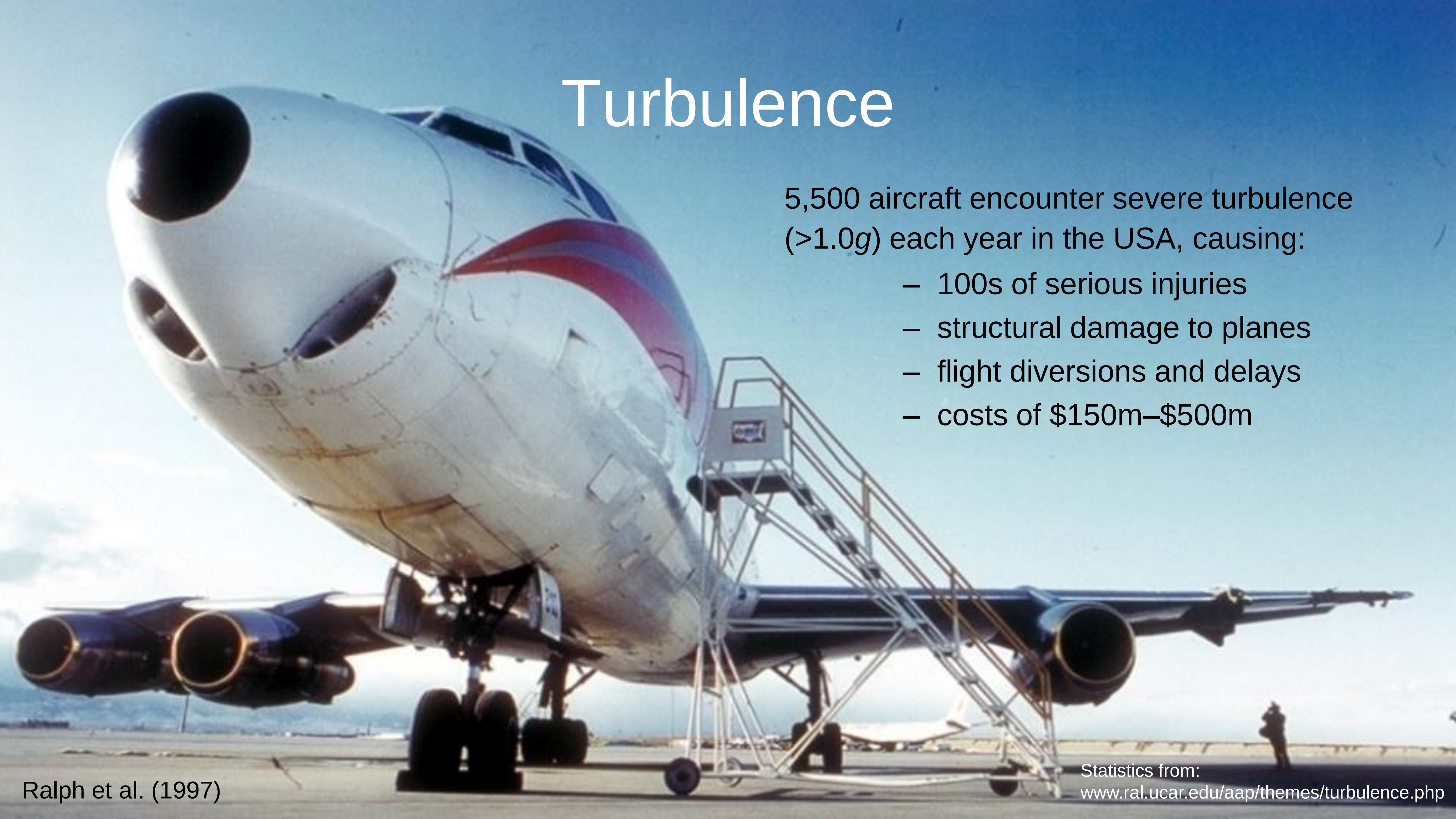
Climate change impacts on aviation



Turbulence



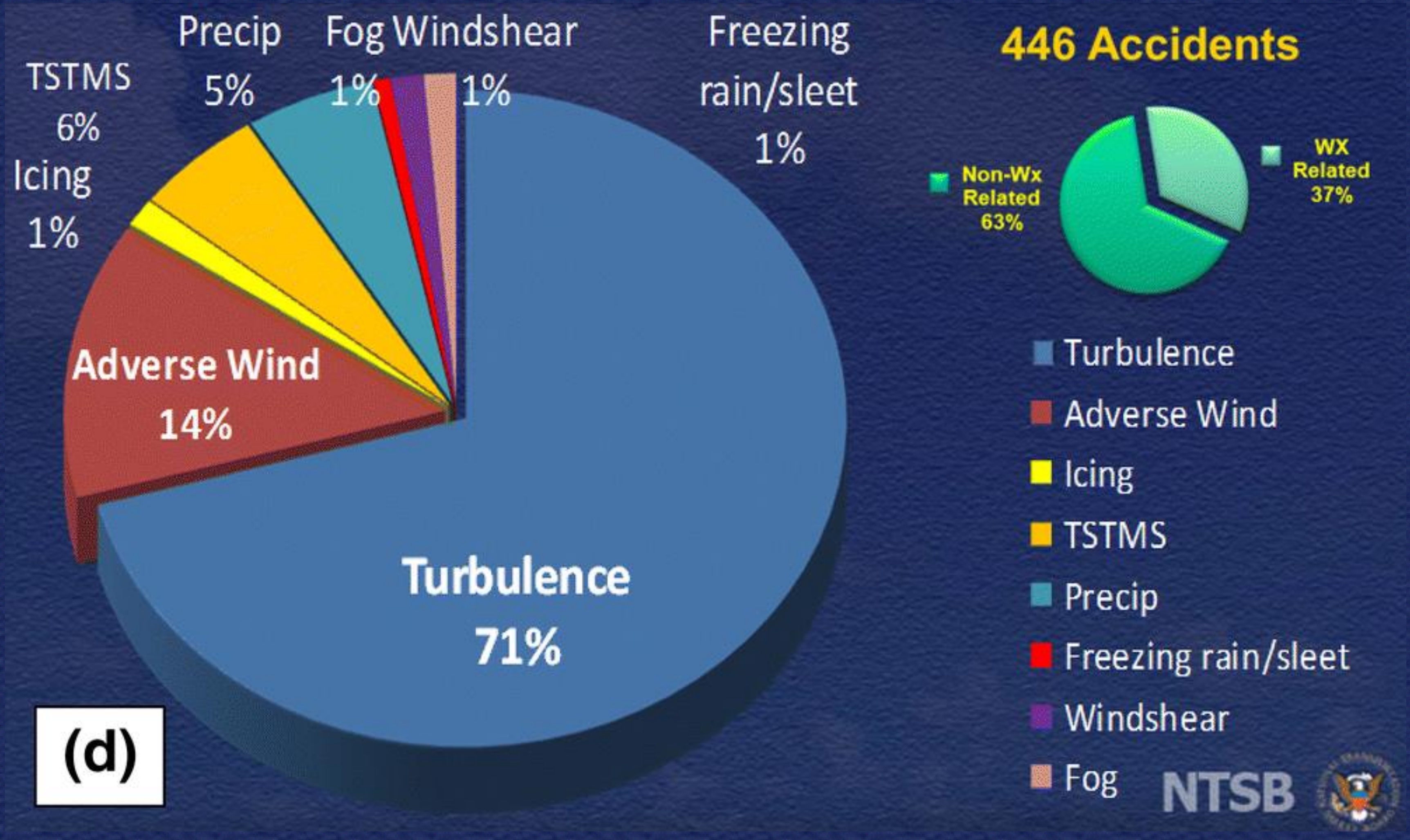
5,500 aircraft encounter severe turbulence (>1.0*g*) each year in the USA, causing:

- 100s of serious injuries
- structural damage to planes
- flight diversions and delays
- costs of $150m–$500m

Ralph et al. (1997)

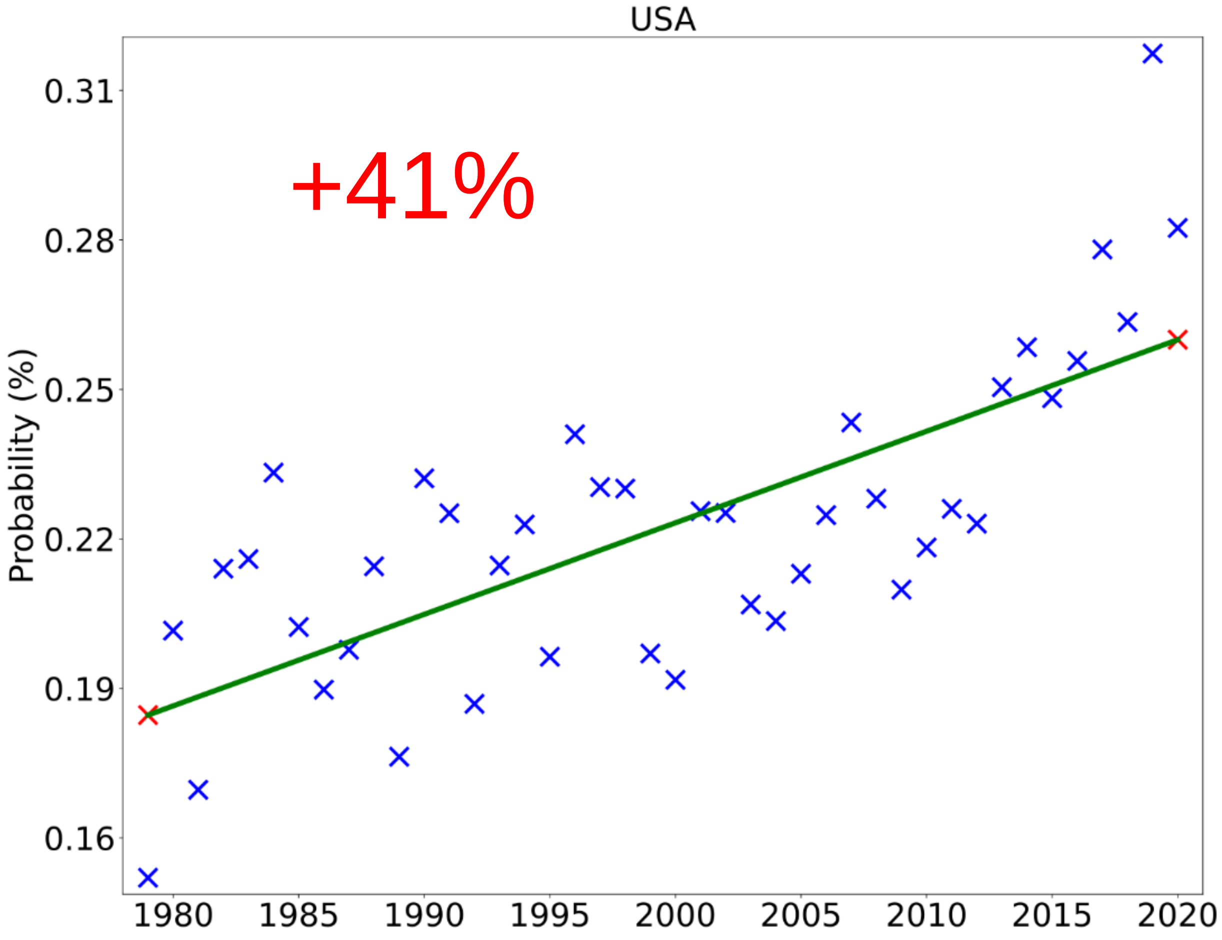
Statistics from:
www.ral.ucar.edu/aap/themes/turbulence.php

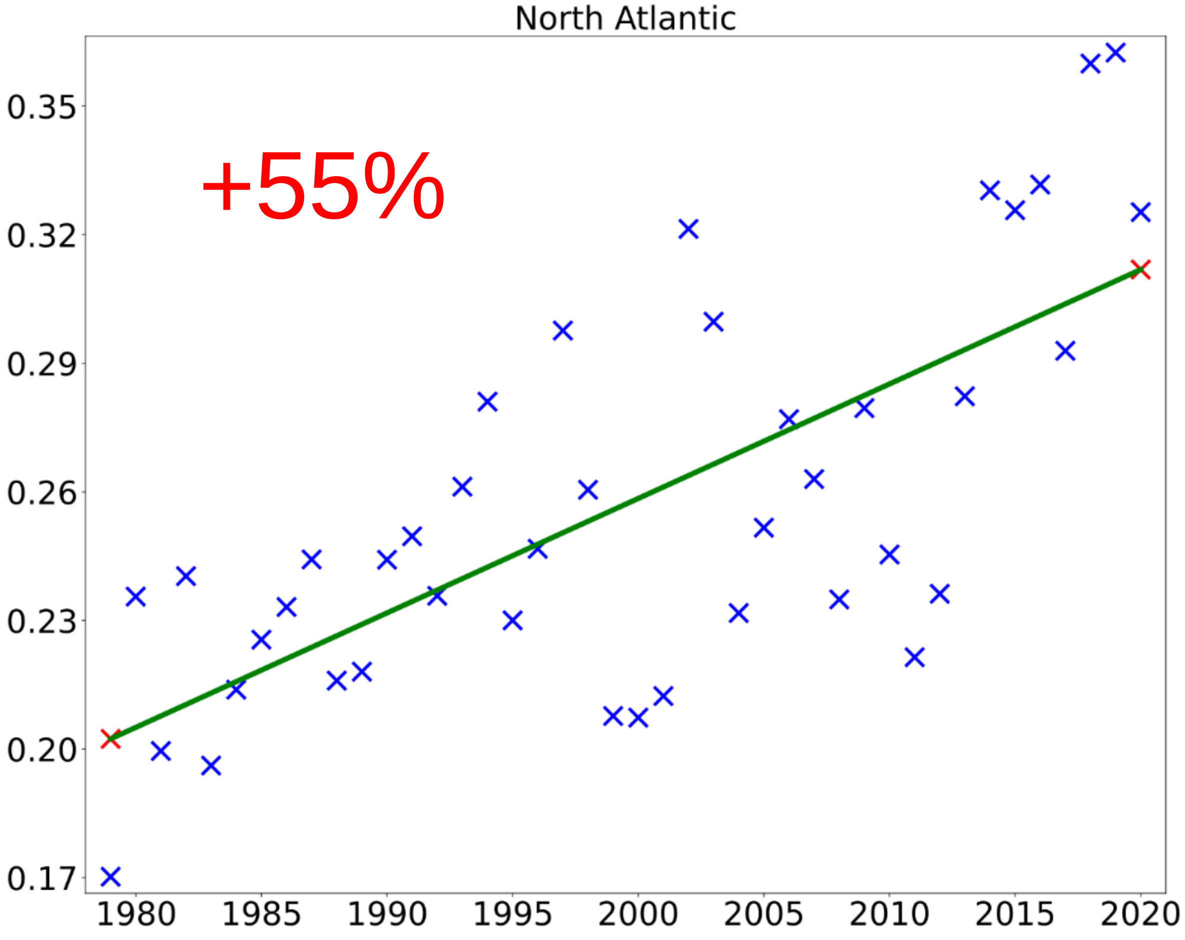
Turbulence



Gultepe, Sharman, Williams et al. (2019)

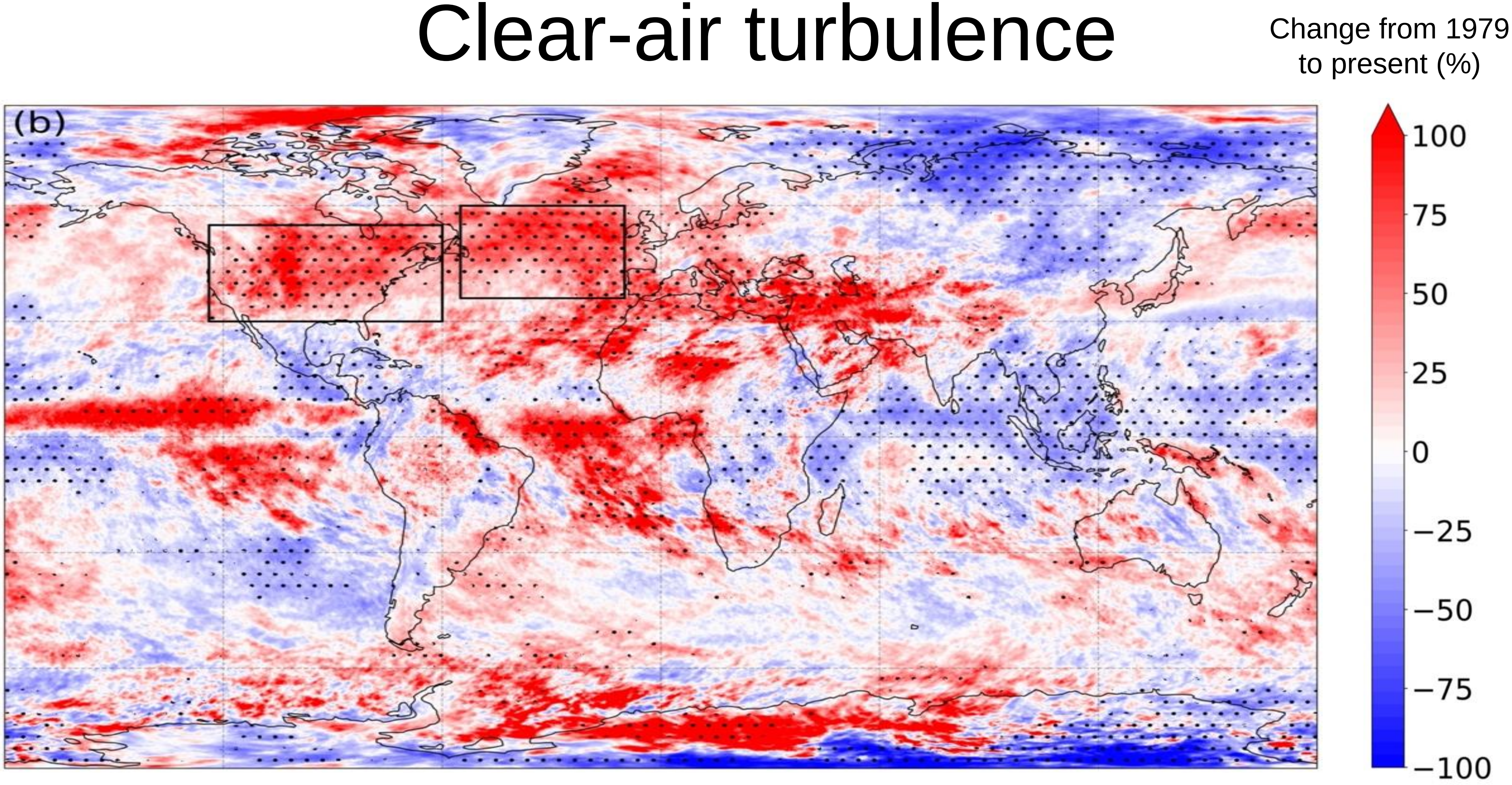
Clear-air turbulence





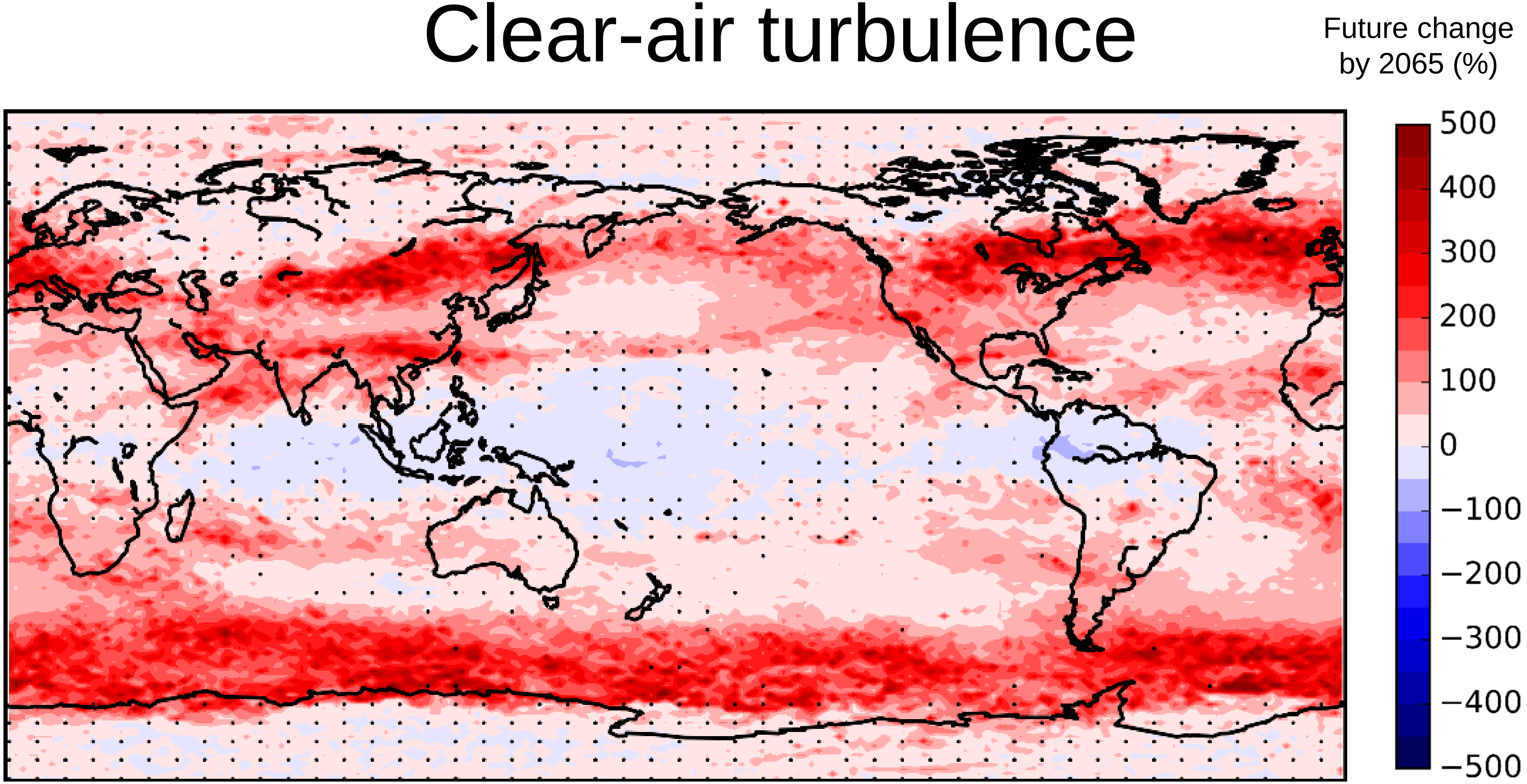
Prosser, Williams, Marlton & Harrison (2023)

Clear-air turbulence



Prosser, Williams, Marlton & Harrison (2023)

Clear-air turbulence



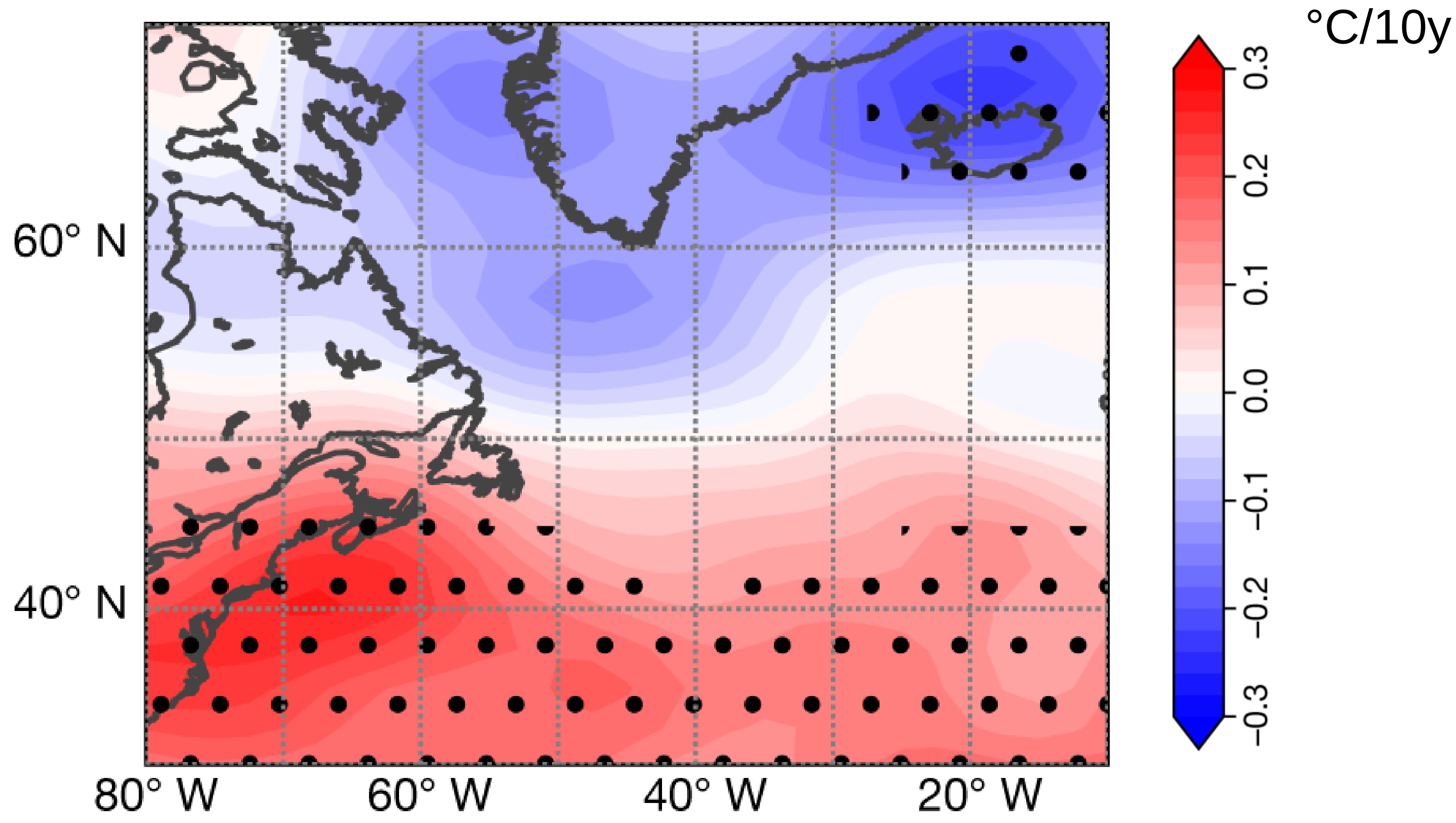
Storer, Williams & Joshi (2017)

Clear-air turbulence

Temperature changes 1979–2017 at 250 hPa in reanalysis data

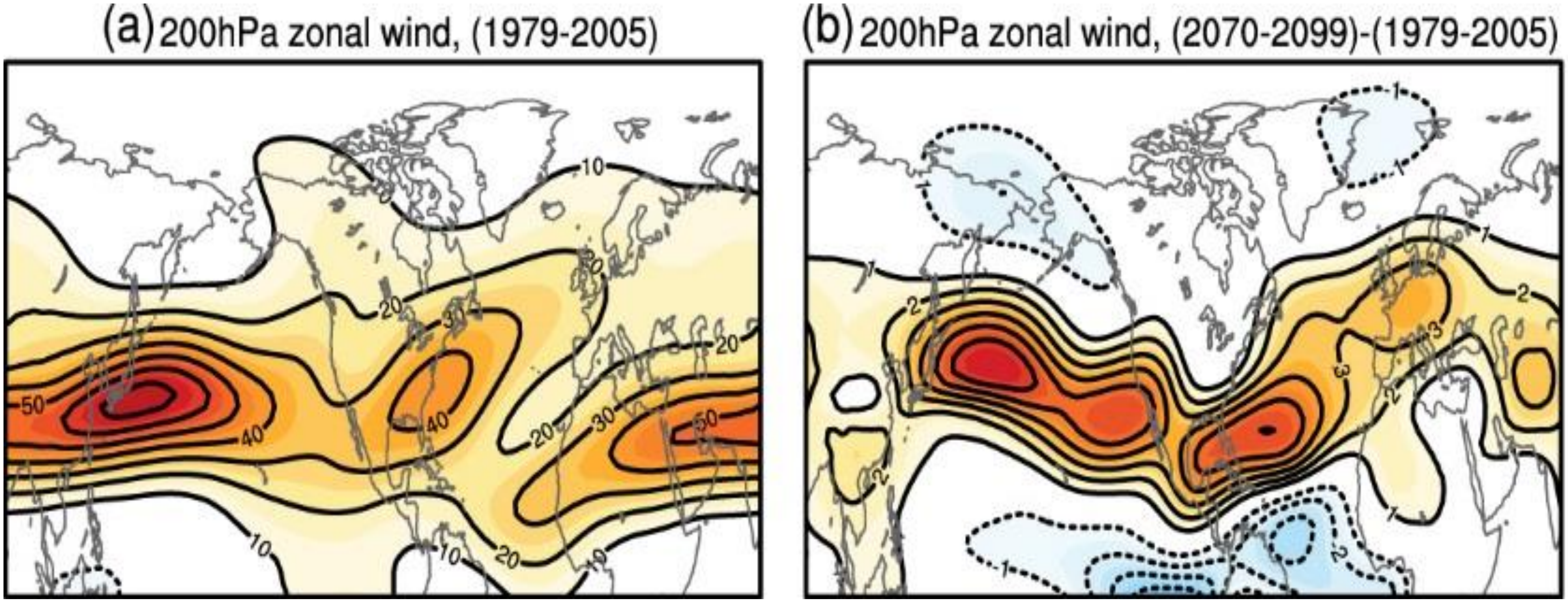
Stronger north–south temperature gradient at flight cruising altitudes

$$\frac{\partial u}{\partial z} \propto -\frac{\partial T}{\partial y}$$



Lee, Williams, and Frame (2019)

Impacts of climate change on flight times

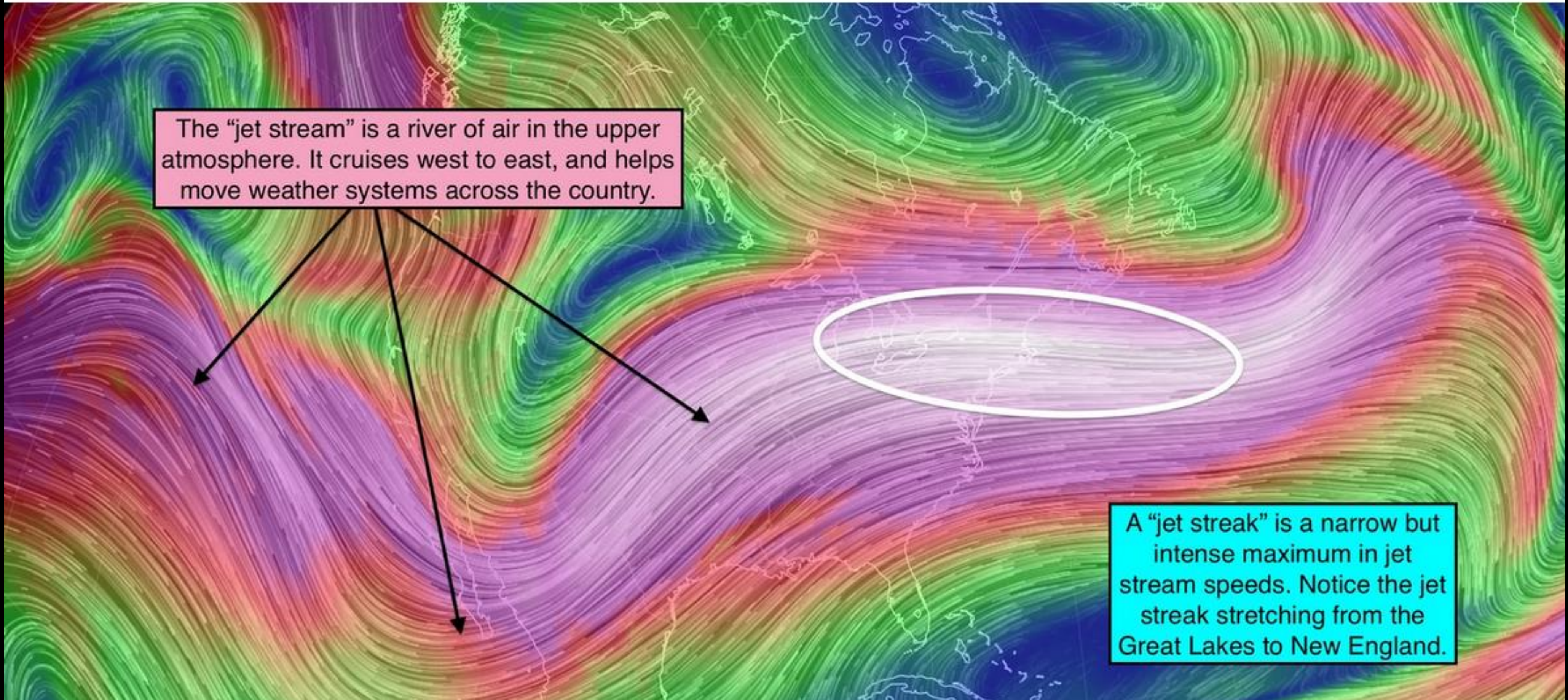


The zonal wind speed (m s^{-1}) in DJF increases in CMIP5 / RCP8.5 (Simpson 2016)

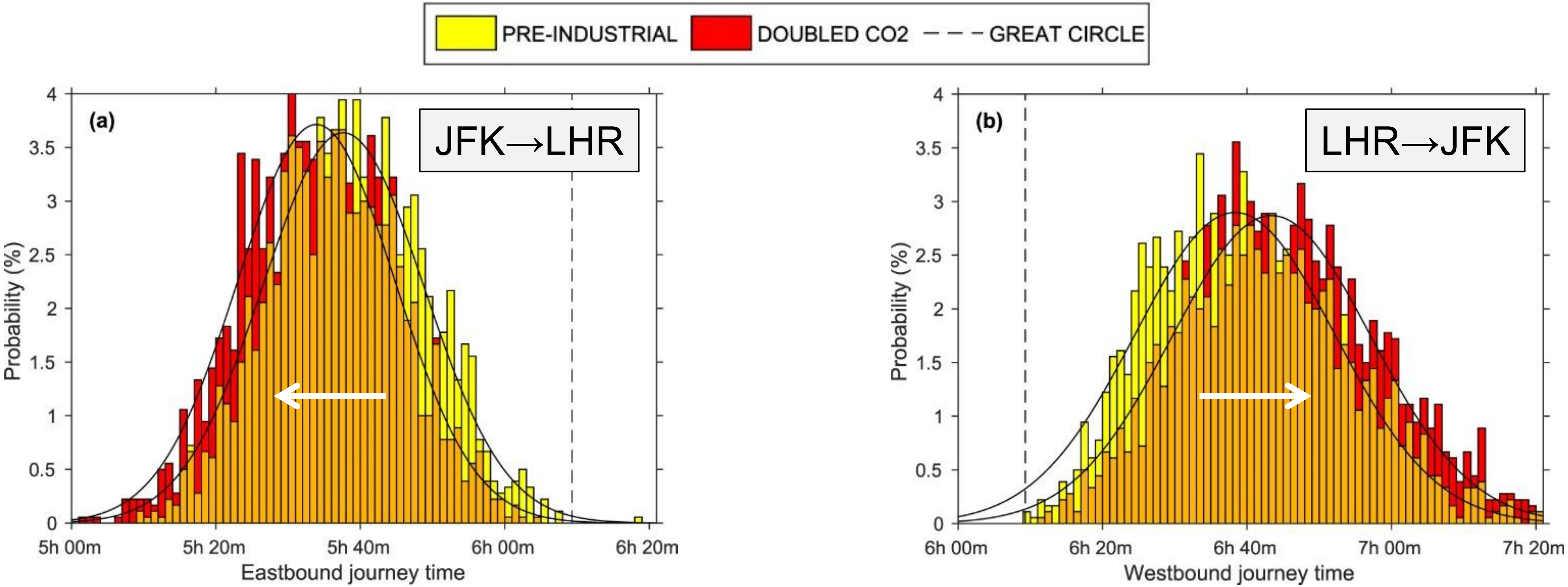
The Washington Post
Democracy Dies in Darkness

Flight reaches 801 mph as a furious jet stream packs record-breaking speeds

19 February 2019



Impacts of climate change on flight times

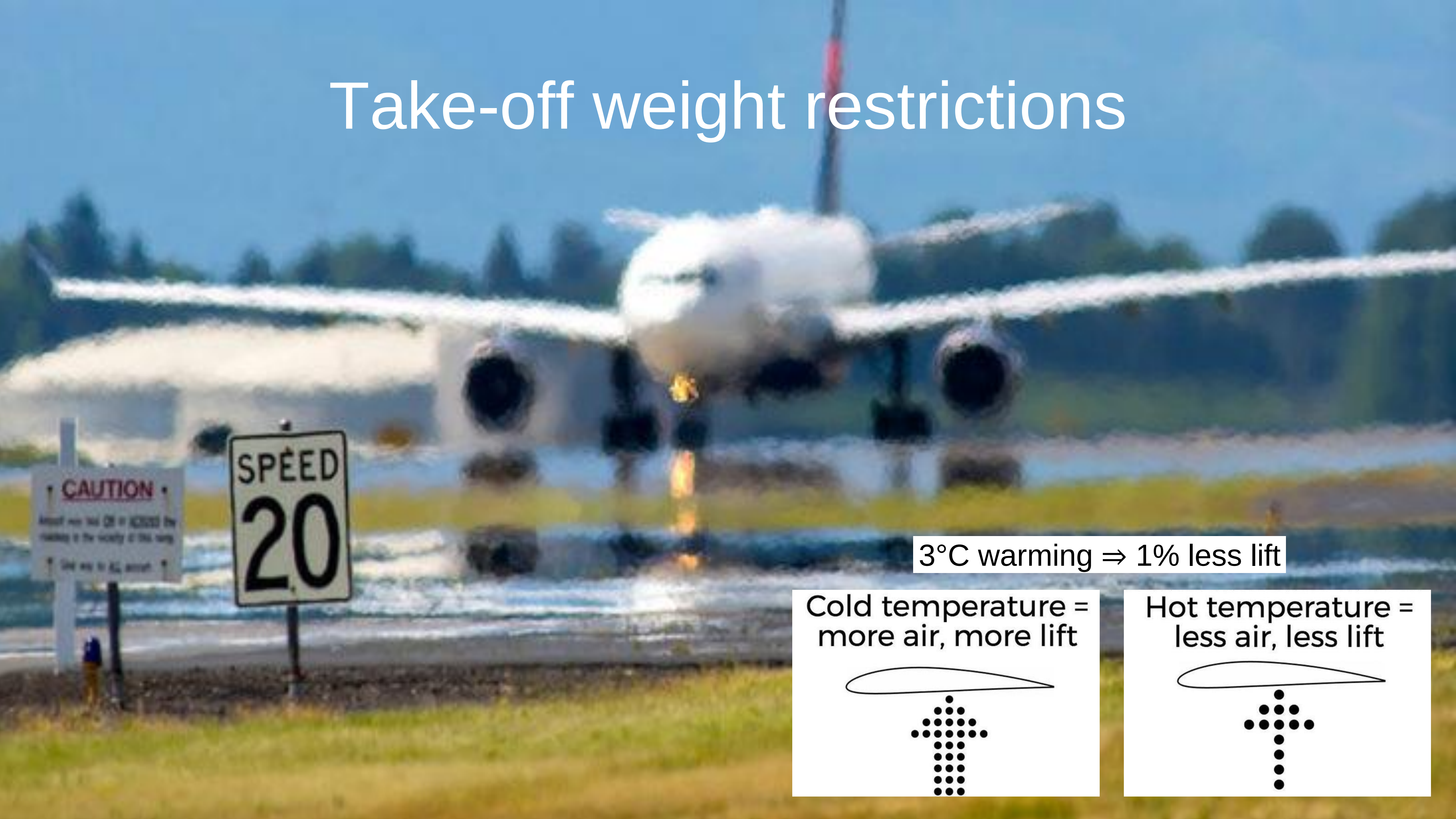


Likelihood of taking under 5 h 20 min more than doubles from 3.5% to 8.1%

Likelihood of taking over 7 h 00 min nearly doubles from 8.6% to 15.3%

Williams (2016)

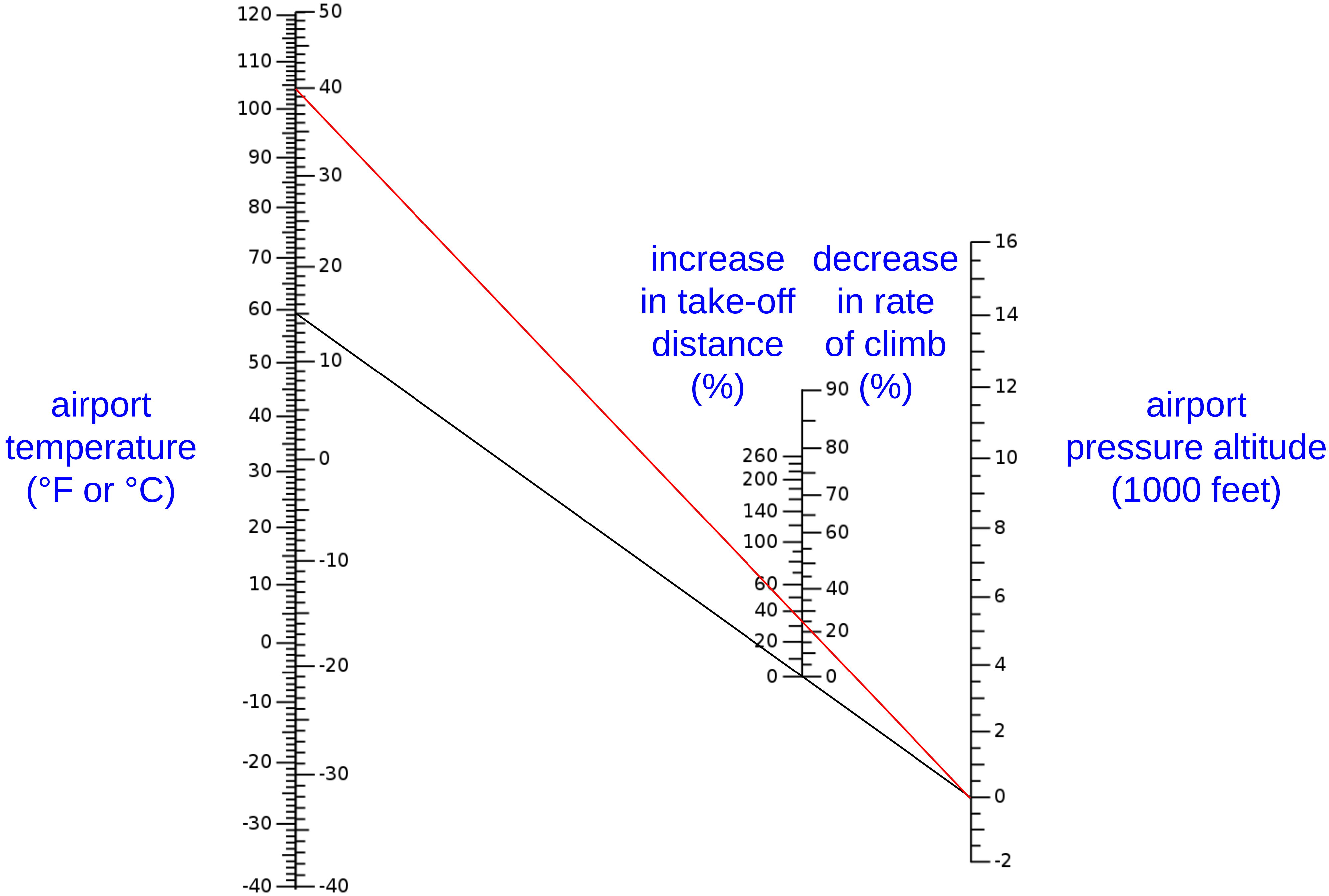
Take-off weight restrictions



3°C warming ⇒ 1% less lift

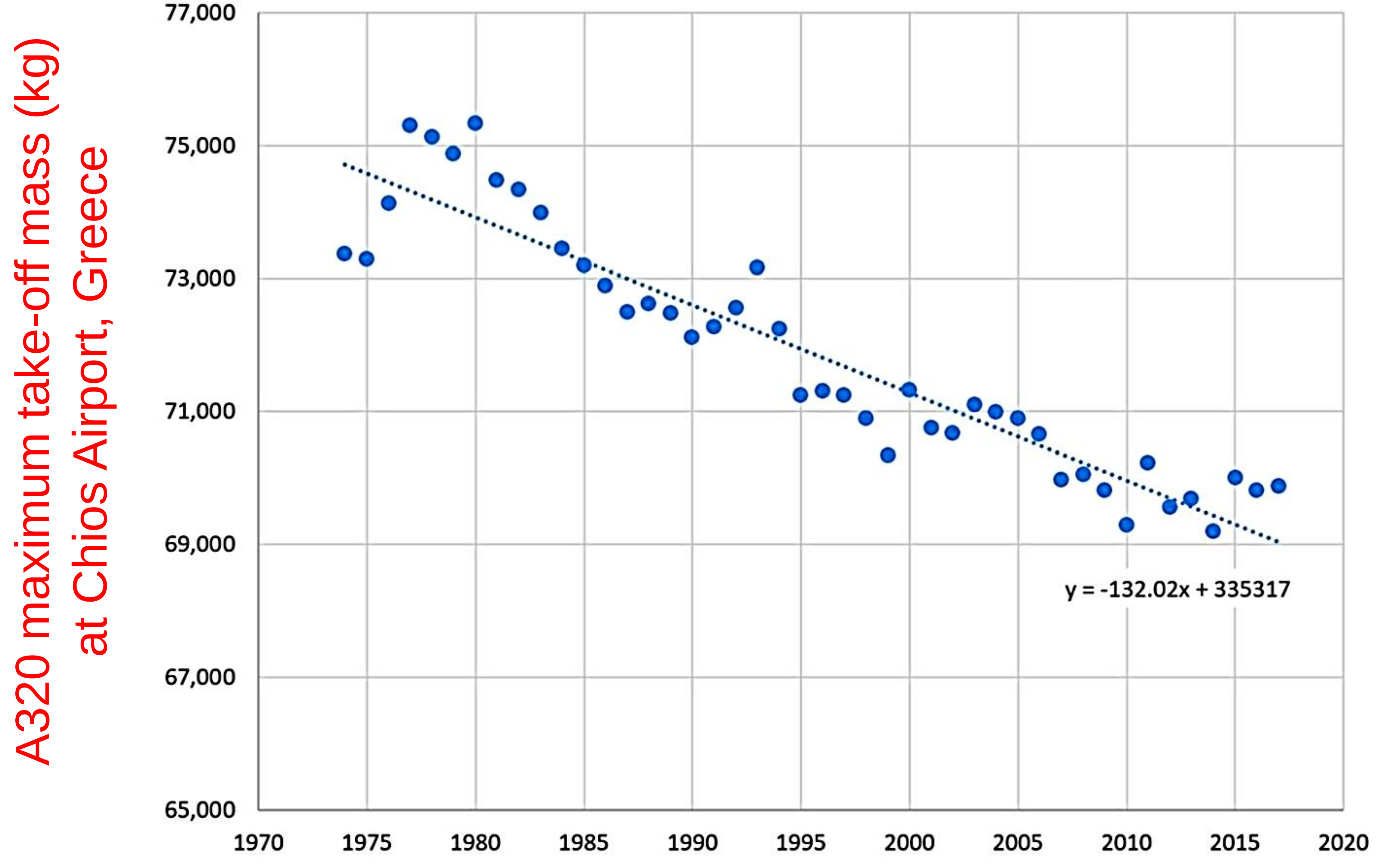
Cold temperature = more air, more lift

Hot temperature = less air, less lift



airport
temperature
(°F or °C)
increase
in take-off
distance
(%)
decrease
in rate
of climb
(%)
airport
pressure altitude
(1000 feet)

Take-off weight restrictions



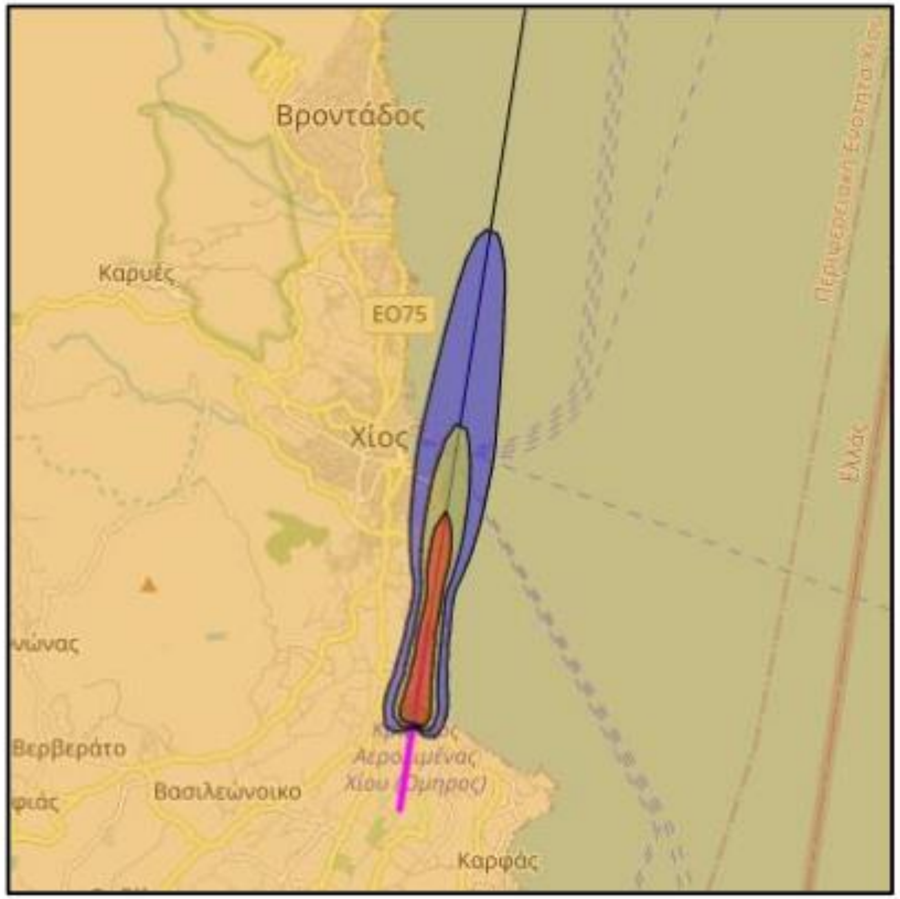
Decrease over 30 years:

- nearly 4,000 kg
- 38 pax + luggage
- 1,300 km of fuel

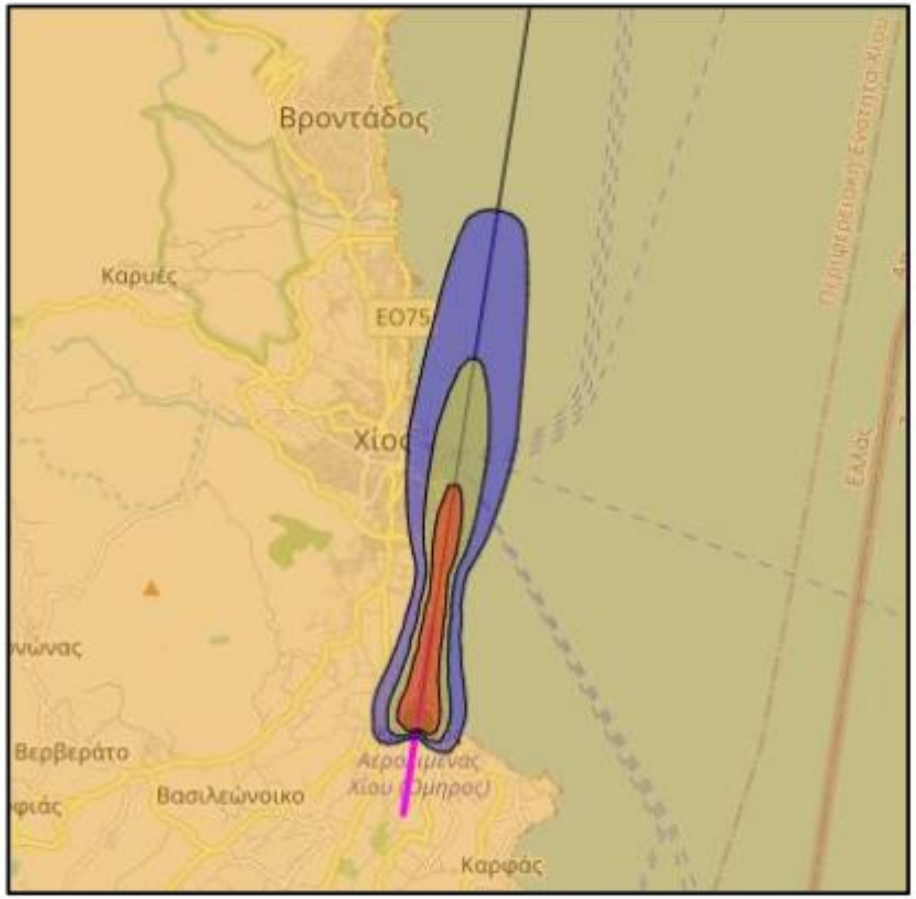
Gratton, Padhra, Rapsomanikis & Williams (2020)

More noise around airports

50 dB
55 dB
60 dB



Airbus A320



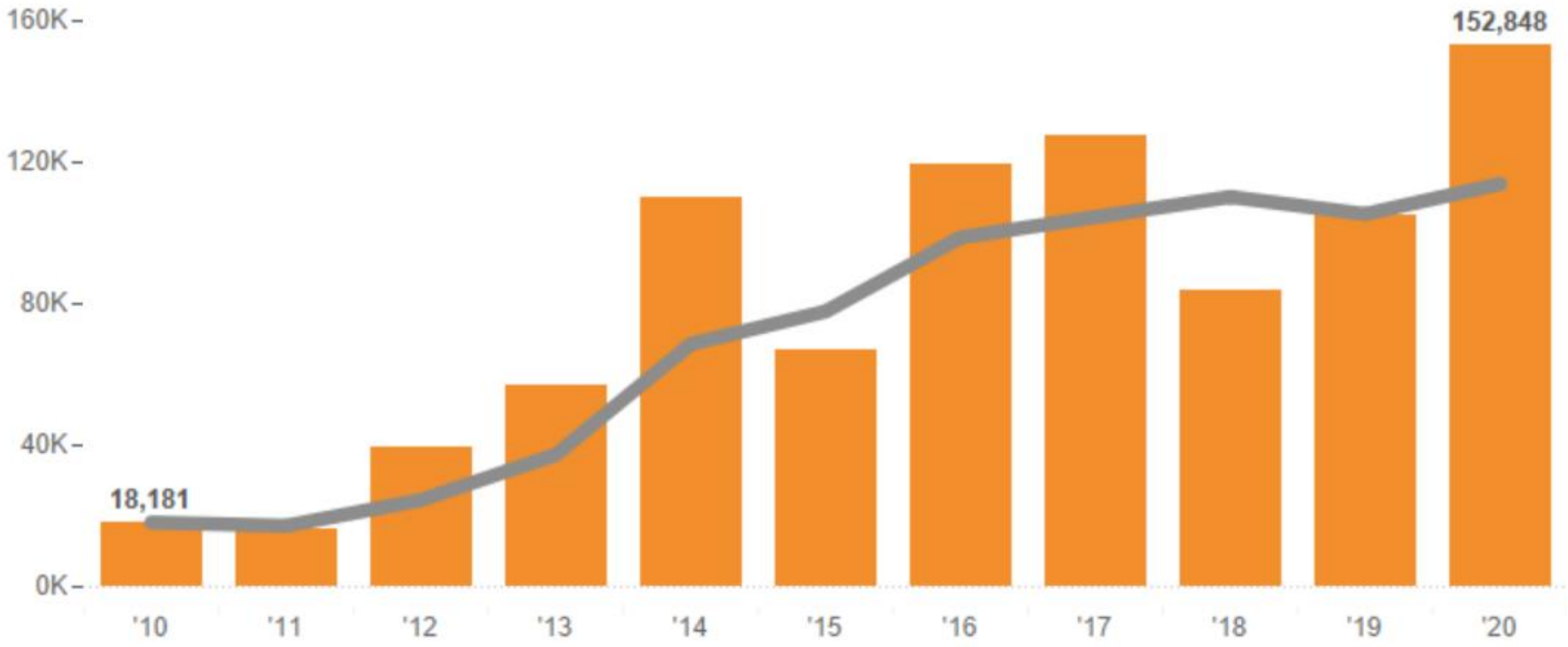
Boeing 737

Noise contour areas are growing at 2% per decade

Padhra, Rapsomanikis, Gratton & Williams (2022)

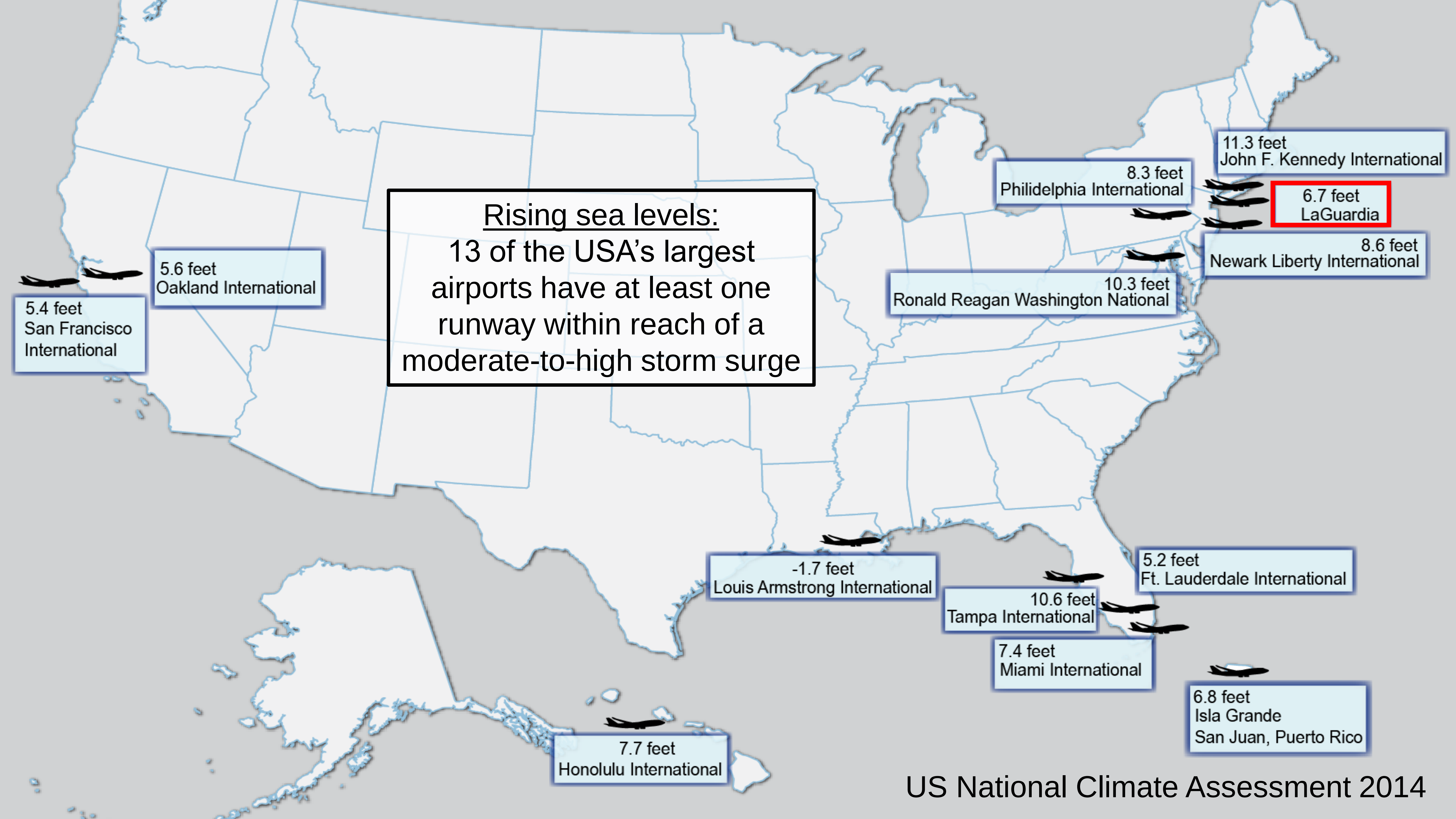
Lightning

Annual number of
Arctic lightning strikes
(2010–2020)



Holzworth et al. (2021)

The annual number of lightning strikes in the USA is projected to increase by 12% for each 1°C of global warming (Romps et al. 2014)


Rising sea levels:
13 of the USA's largest airports have at least one runway within reach of a moderate-to-high storm surge
11.3 feet
John F. Kennedy International
8.3 feet
Philidelphia International
6.7 feet
LaGuardia
8.6 feet
Newark Liberty International
10.3 feet
Ronald Reagan Washington National
5.6 feet
Oakland International
5.4 feet
San Francisco International
-1.7 feet
Louis Armstrong International
5.2 feet
Ft. Lauderdale International
10.6 feet
Tampa International
7.4 feet
Miami International
6.8 feet
Isla Grande
San Juan, Puerto Rico
7.7 feet
Honolulu International
US National Climate Assessment 2014

Huffington Post / Frank Giannola

Summary

- Sea-level rise and storm surges threaten runway capacity at many of the world's busiest airports
- Warmer air at ground level is decreasing air density and increasing the need for take-off weight restrictions
- The number of lightning strikes is predicted to increase by around 12% for each 1°C of global warming
- A stronger jet stream will speed up eastbound flights (a bit) but slow down westbound flights (a lot), lengthening roundtrip journeys and keeping transatlantic aircraft airborne for an extra 2,000 hours each year
- The jet stream is already 15% more sheared than when satellites began observing it, and this effect will double or treble the amount of severe clear-air turbulence in the coming decades

Questions?

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