How will climate change affect air travel?

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Rising sea levels and storm surges threaten coastal airports.

Warmer air imposes take-off weight restrictions.

Shifting wind patterns modify optimal flight routes and fuel consumption.

Stronger jet-stream wind shears increase clear-air turbulence.

More extreme weather causes disruptions and delays.

Puempel & Williams (2016)
ICAO Environmental Report
The acceleration of the jet stream

Jet-stream changes driven by CO$_2$ in IPCC climate simulations

Stronger eastward winds & windshears at flight cruising altitudes

\[
\frac{\partial u}{\partial z} \propto -\frac{\partial T}{\partial y}
\]

Delcambre et al. (2013)

C20 (10 m/s contours)

C21 – C20 (0.25 m/s contours)
Changing LHR↔JFK flight times

Williams (2016)

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)
Changing LHR↔JFK flight times

• Have these changes already begun?
  – The North Atlantic jet stream wind speeds reached 250 mph on 8-12 January 2015
  – An eastbound JFK→LHR crossing took only 5 h 16 min, which is the current non-Concorde record
  – Westbound LHR→JFK crossings took so long that two flights had to make unscheduled refuelling stops in Maine

• Extrapolation to all transatlantic traffic (600 crossings per day) suggests that aircraft will collectively be:
  – airborne for an extra 2,000 hours each year
  – burning an extra 7.2 million gallons of jet fuel at a cost of $22 million
  – emitting an extra 70 million kg of CO₂ into the atmosphere, equating to 7,100 British homes

Williams (2016)
Turbulence

Aircraft encounter moderate turbulence (>0.5g) 65,000 times and severe turbulence (>1.0g) 5,500 times annually in the USA. These encounters:

– cause about 40 fatalities and 100s of serious injuries
– cause structural damage to planes
– cause flight diversions and delays
– cost airlines $150m–$500m

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

Ralph et al. (1997)
Turbulence injury trends

Number of serious injuries (including fatalities) caused by turbulence, per million flight departures (US carriers)

FAA (2006)
Is CAT increasing?

PRE-INDUSTRIAL

DOUBLED CO2

\[ \text{TI} = \frac{\partial u}{\partial z} \sqrt{\left( \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \right)^2 + \left( \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right)^2} \]
“Slight strain against seat belts; unsecured objects may be displaced slightly; food service may be conducted with little difficulty walking”

“Definite strain against seat belts; unsecured objects are dislodged; food service and walking are difficult”

“Occupants are forced violently against seat belts; unsecured objects are tossed about; food service and walking are impossible”
Is CAT increasing?
Summary

- A basket of CAT measures diagnosed from climate simulations is **significantly modified** if the CO$_2$ is increased.
- At cruising altitudes on transatlantic flights in winter, the diagnostics show a **59% / 94% / 149%** increase in the prevalence of light/moderate/severe CAT, with similar results on other flight routes and in other seasons.
- We conclude that, all other things being equal, climate change will lead to **bumpier flights** later this century.
- Flight paths may become **more convoluted** to avoid stronger and more frequent patches of turbulence, in which case **journey times will lengthen** and jet fuel consumption will increase.