



ICAO

ENVIRONMENT

ICAO SEMINAR ON
GREEN AIRPORTS

How will climate change affect air travel?

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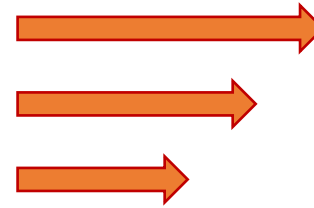
 @DrPaulDWilliams



Climate change impacts on aviation



Shifting wind patterns
modify optimal flight
routes and fuel
consumption

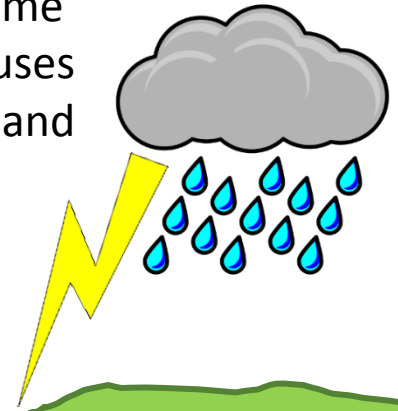


Stronger jet-stream
wind shears increase
clear-air turbulence

Warmer air
imposes take-off
weight restrictions



More extreme
weather causes
disruptions and
delays



Rising sea levels and
storm surges threaten
coastal airports



Puempel & Williams (2016)
ICAO Environmental Report

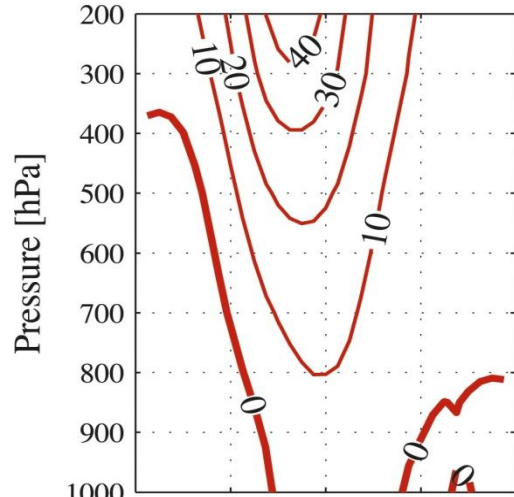
The acceleration of the jet stream

Jet-stream changes driven by CO₂ in IPCC climate simulations

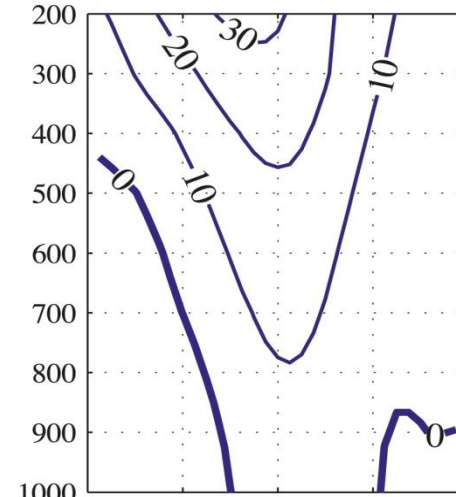
Stronger eastward winds & windshears at flight cruising altitudes

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

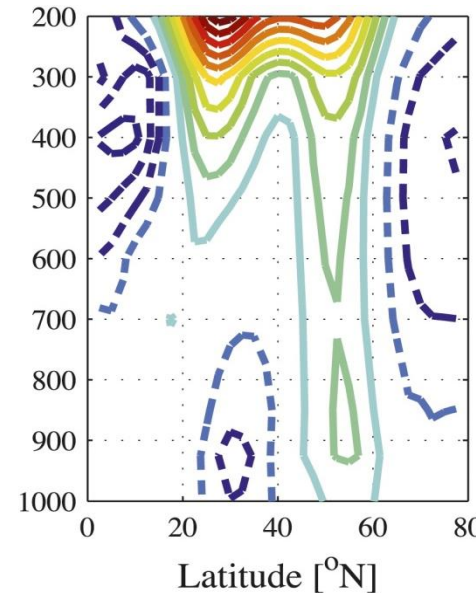
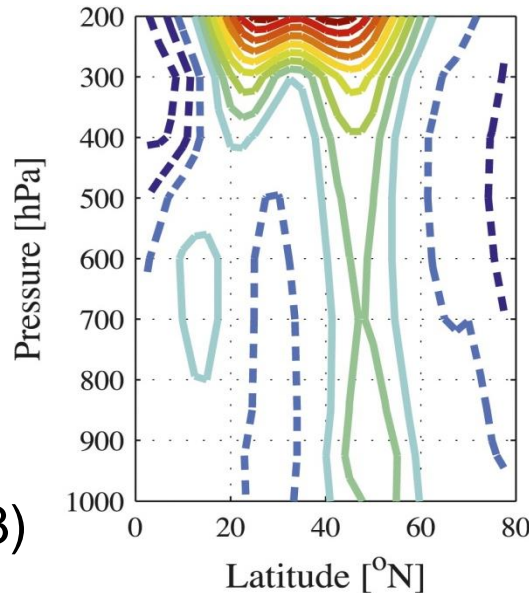
Pacific



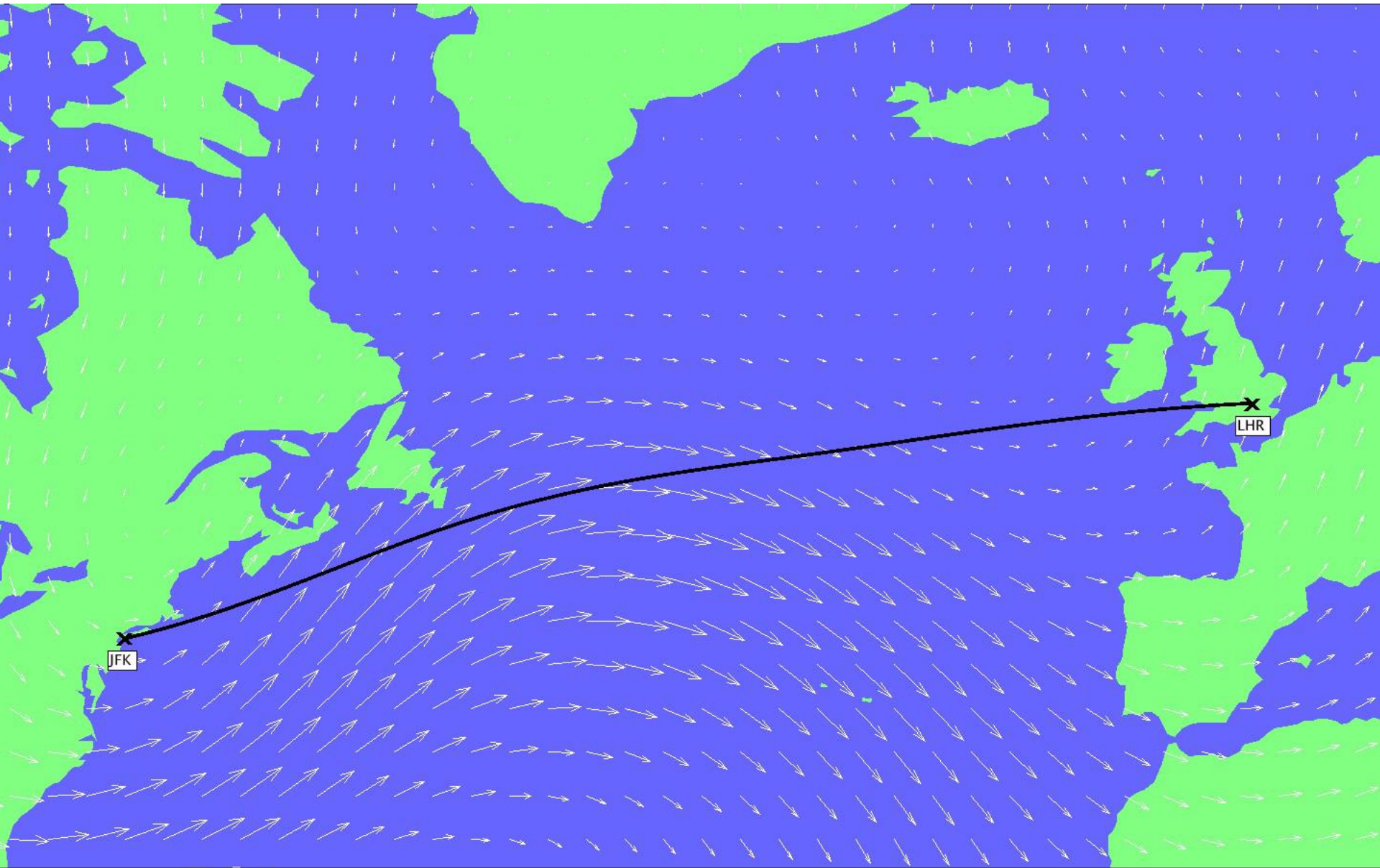
Atlantic



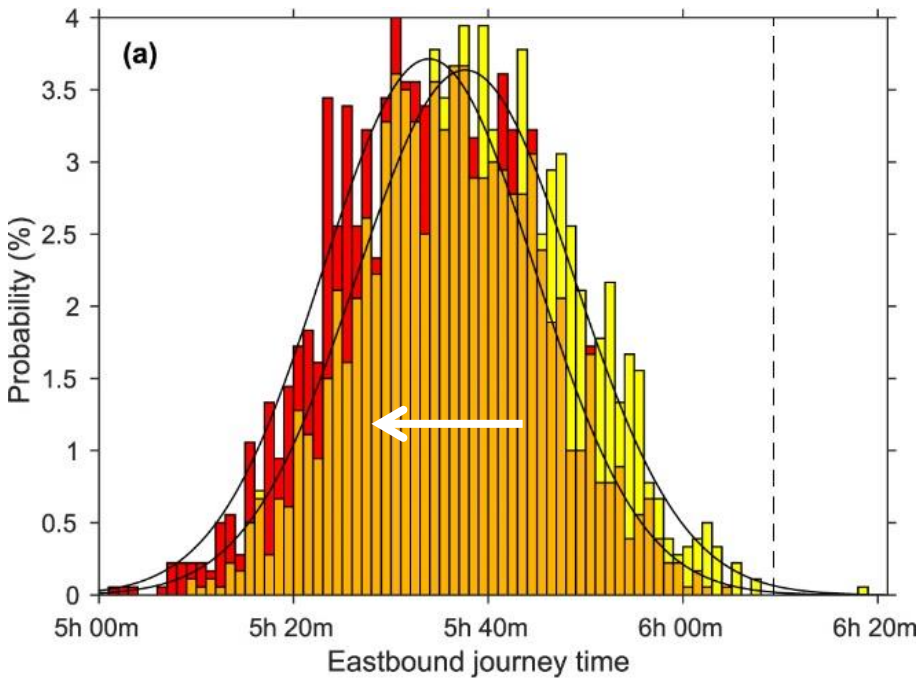
C20
(10 m/s contours)



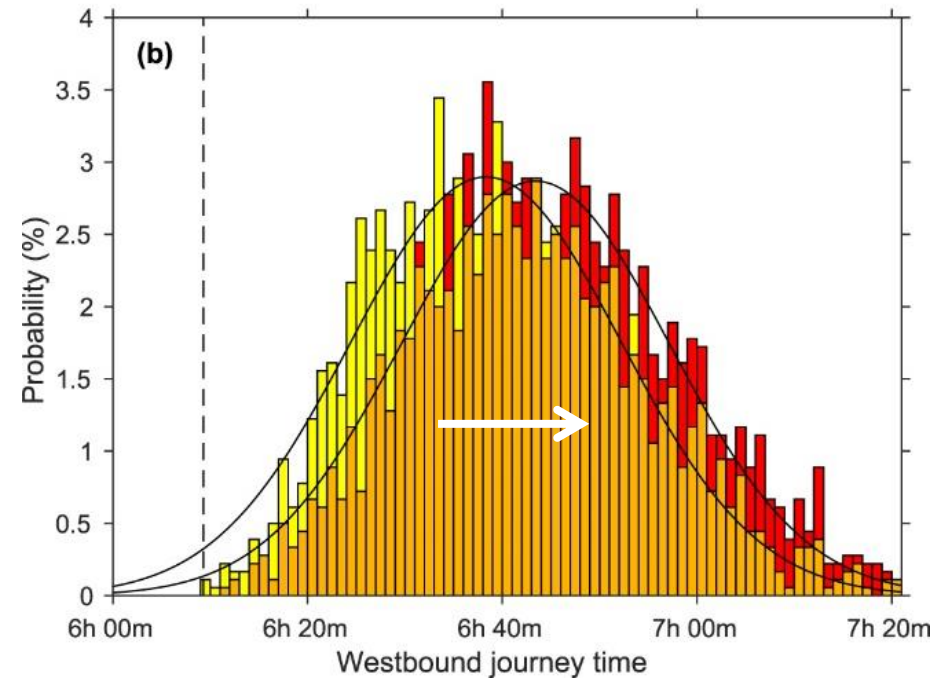
C21 – C20
(0.25 m/s contours)



Changing LHR↔JFK 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%

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

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:

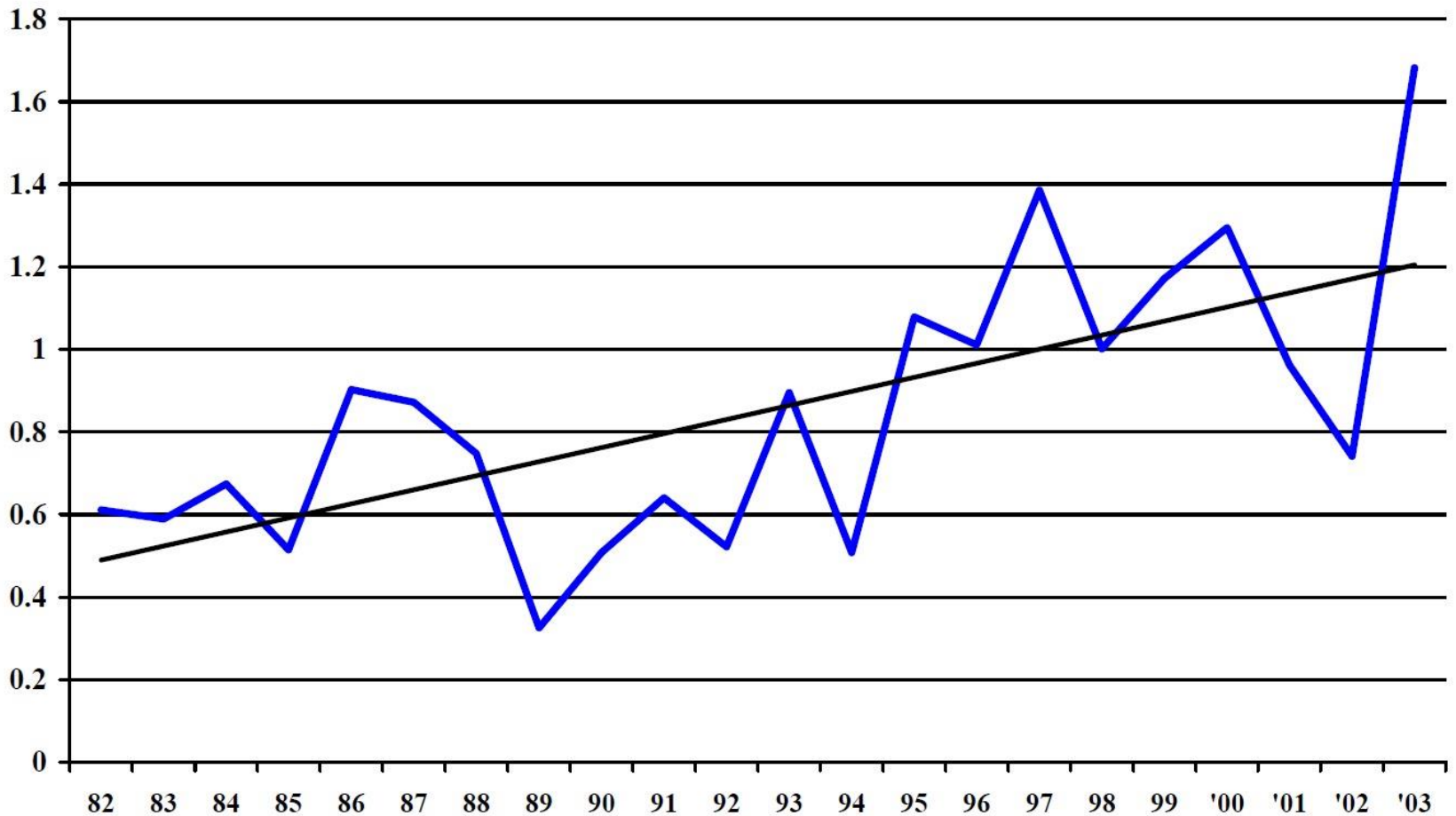
www.ral.ucar.edu/aap/themes/turbulence.php



Ralph et al. (1997)

Turbulence injury trends

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



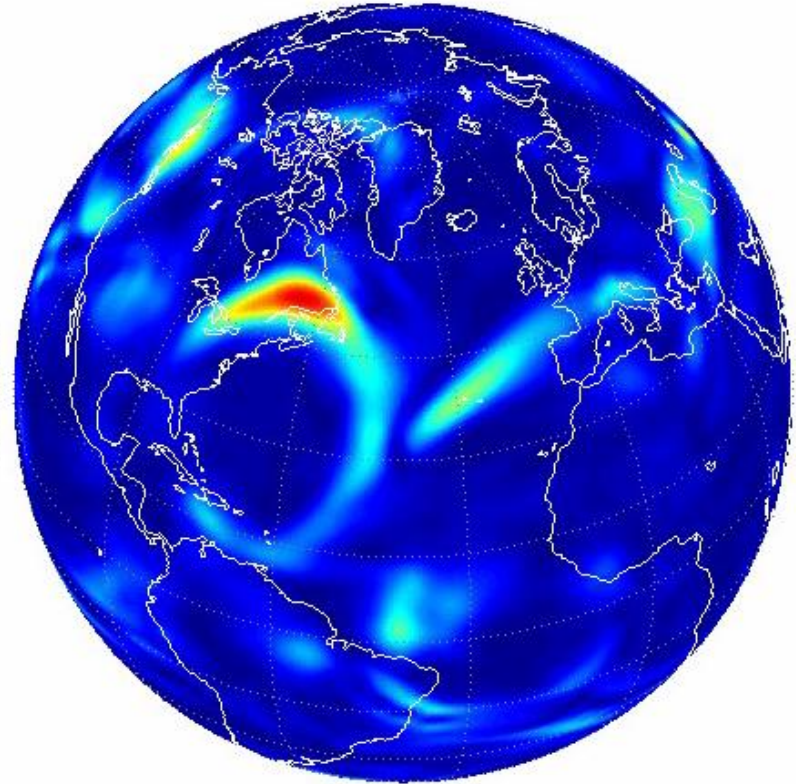
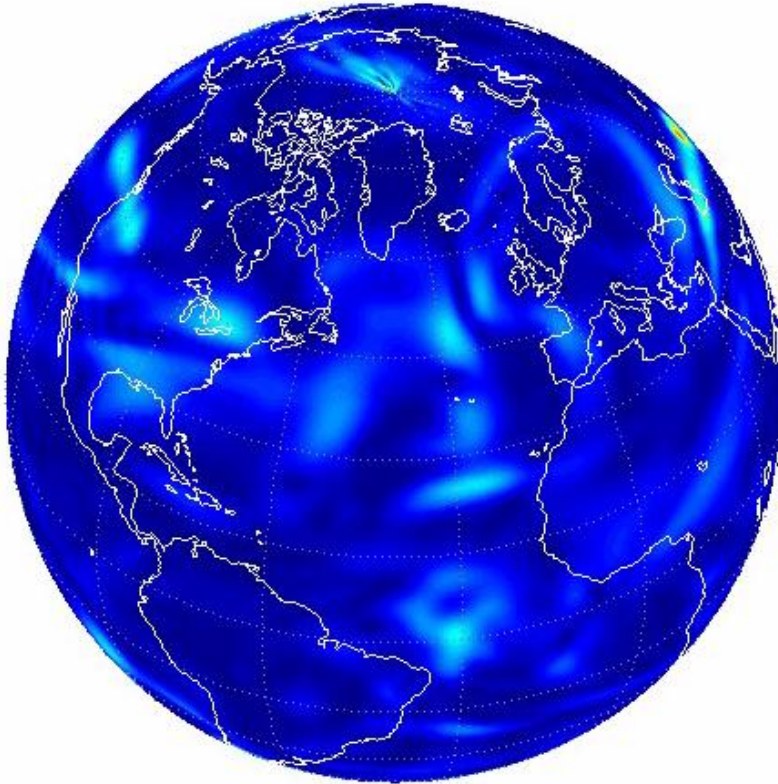
1982

2003

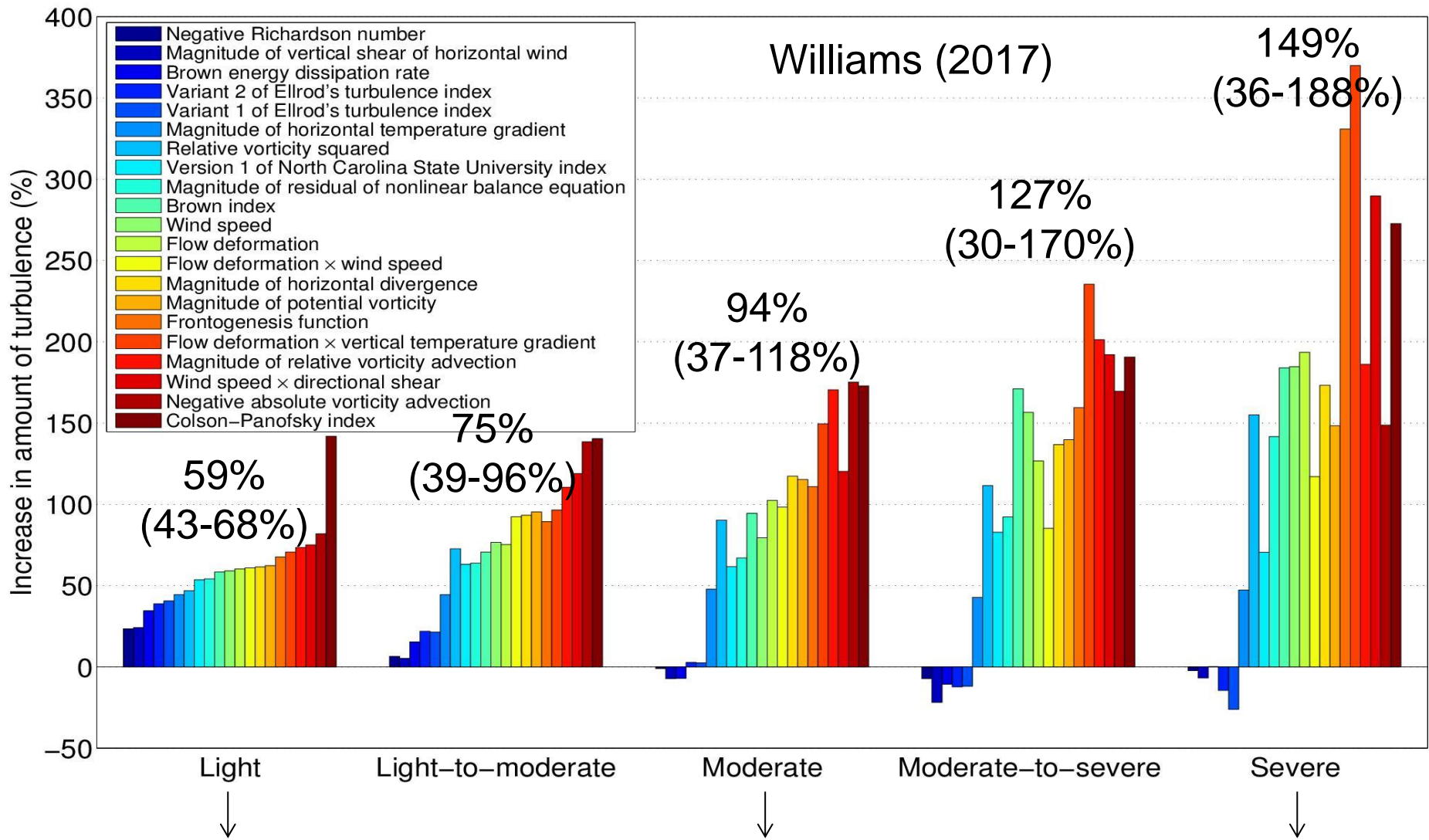
Is CAT increasing?

PRE-INDUSTRIAL

DOUBLED CO2



$$\text{TI1} = \left| \frac{\partial \mathbf{u}}{\partial z} \right| \sqrt{\left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \right)^2 + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right)^2}$$



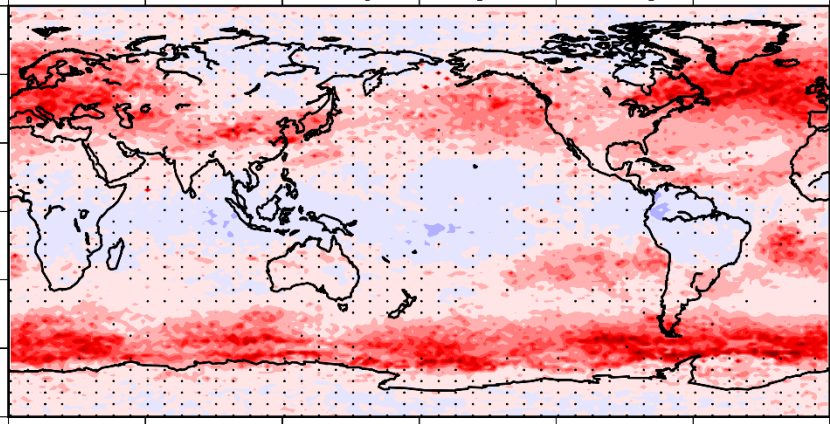
“Slight strain against seat belts; unsecured objects may be displaced slightly; food service may be conducted with little difficulty walking”

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

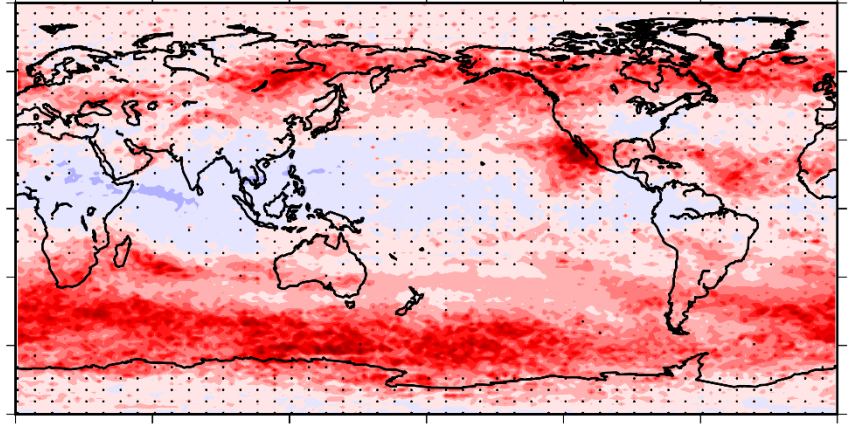
“Occupants are forced violently against seat belts; unsecured objects are tossed about; food service and walking are impossible”

Is CAT increasing?

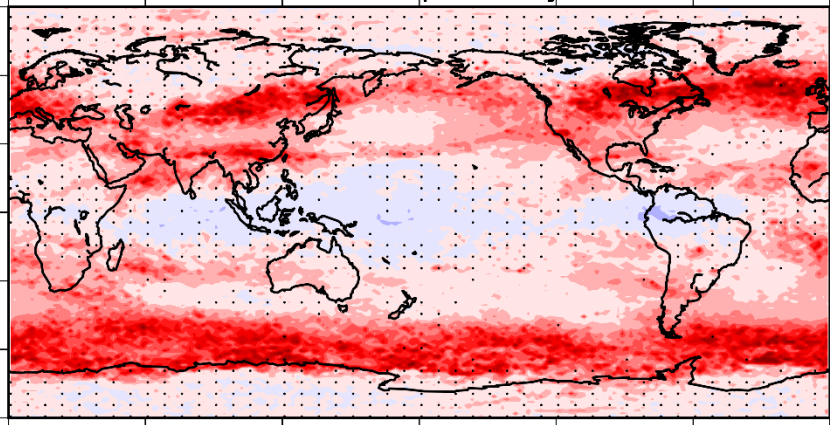
December, January, February



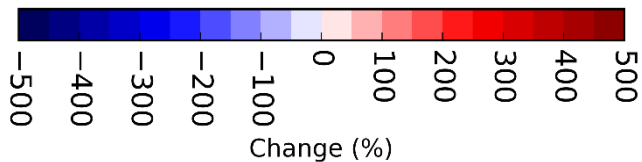
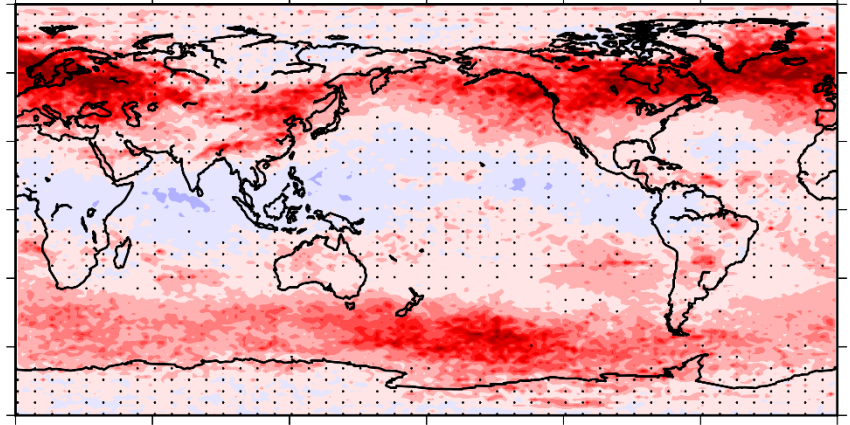
June, July, August



March, April, May



September, October, November



Storer, Williams & Joshi (2017)

Summary

- A basket of CAT measures diagnosed from climate simulations is **significantly modified** if the CO₂ 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**



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