Increased light, moderate, and severe clear-air turbulence in response to climate change

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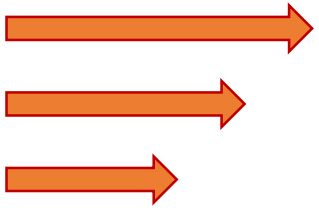
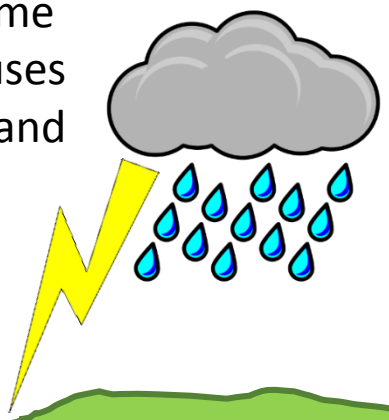
Climate change impacts on aviation

Shifting wind patterns modify optimal flight routes and fuel consumption



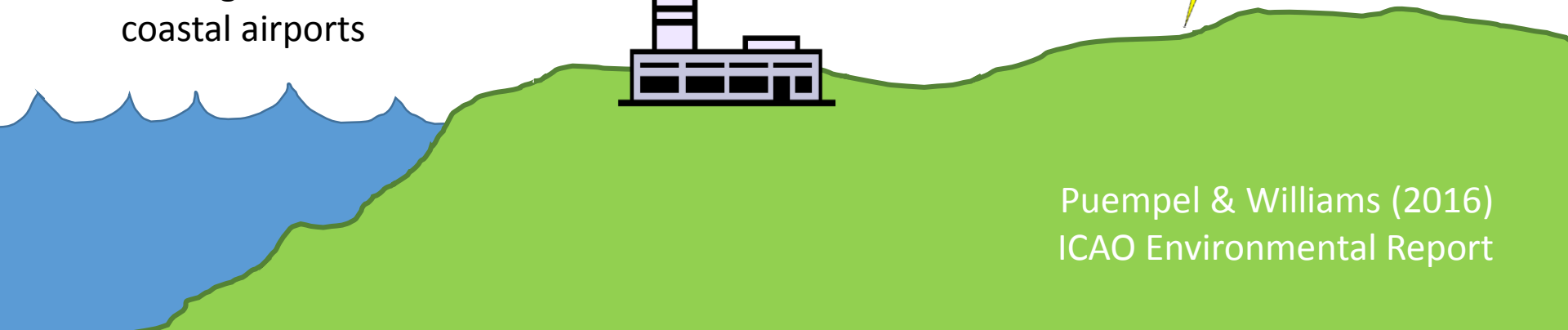
Stronger jet-stream wind shears increase clear-air turbulence

More extreme weather causes disruptions and delays



Warmer air imposes take-off weight restrictions

Rising sea levels and storm surges threaten coastal airports



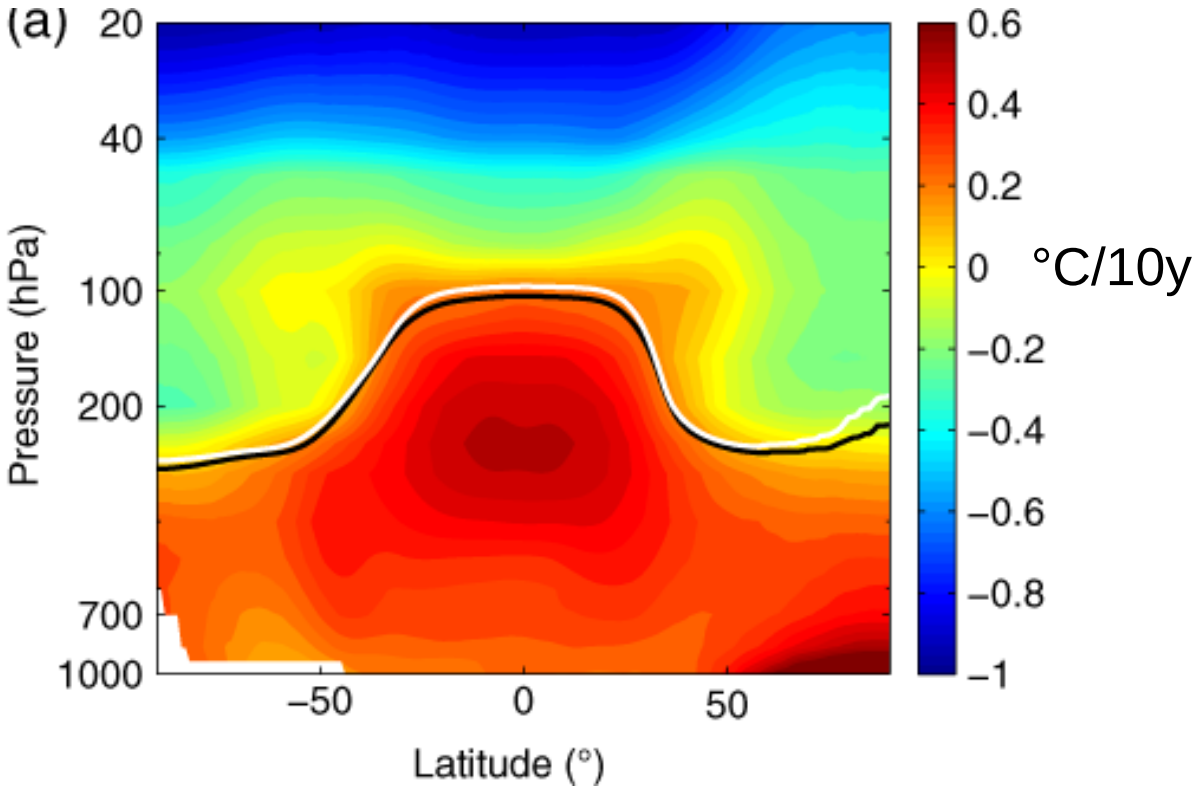
Puempel & Williams (2016)
ICAO Environmental Report

The winds of climate change

Temperature changes driven by CO_2 in IPCC climate simulations

Stronger north–south temperature gradient at flight cruising altitudes

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



Vallis et al. (2015)

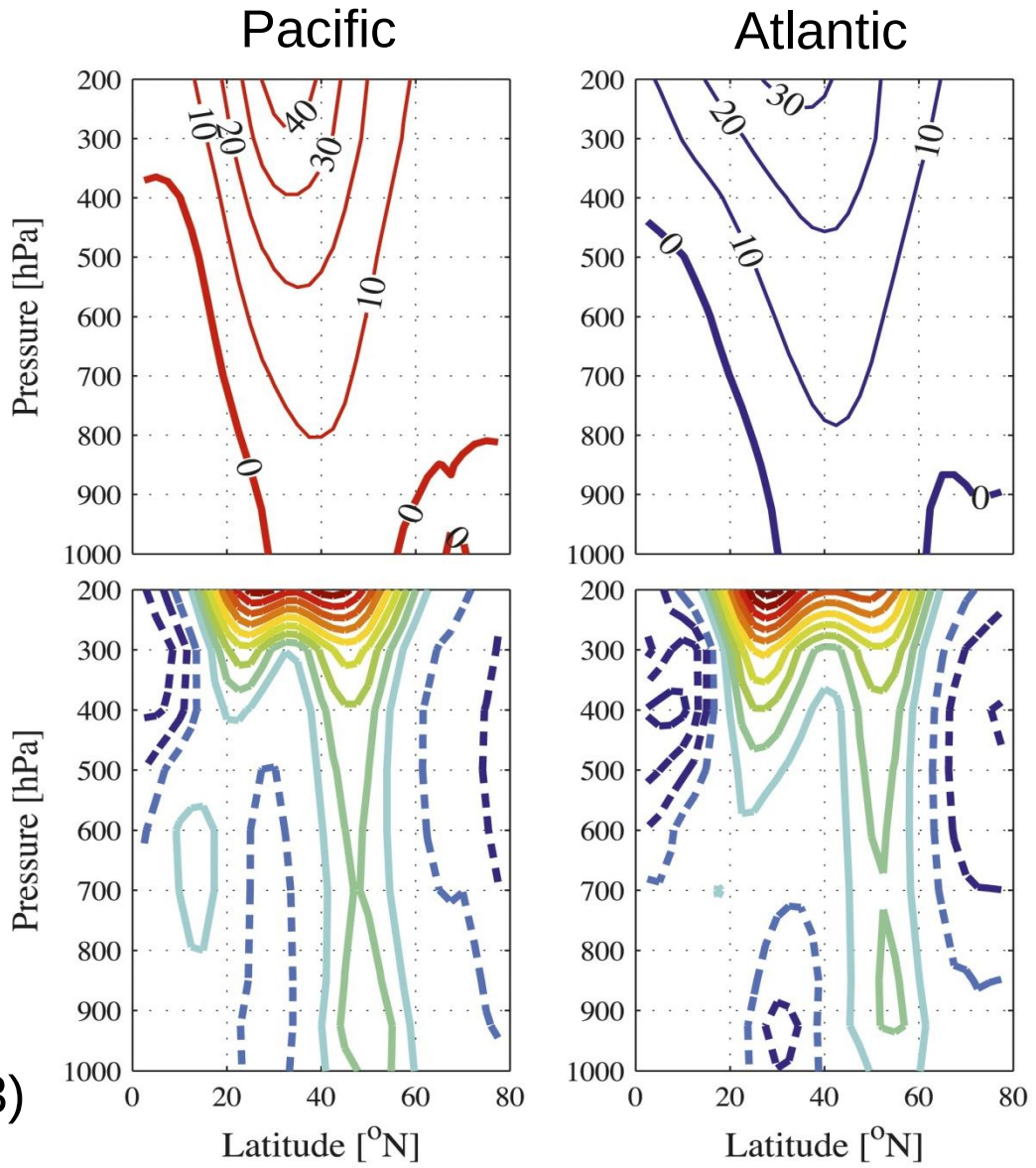
The winds of climate change

Jet-stream changes driven by CO_2 in IPCC climate simulations

Stronger eastward winds & windshears at flight cruising altitudes

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

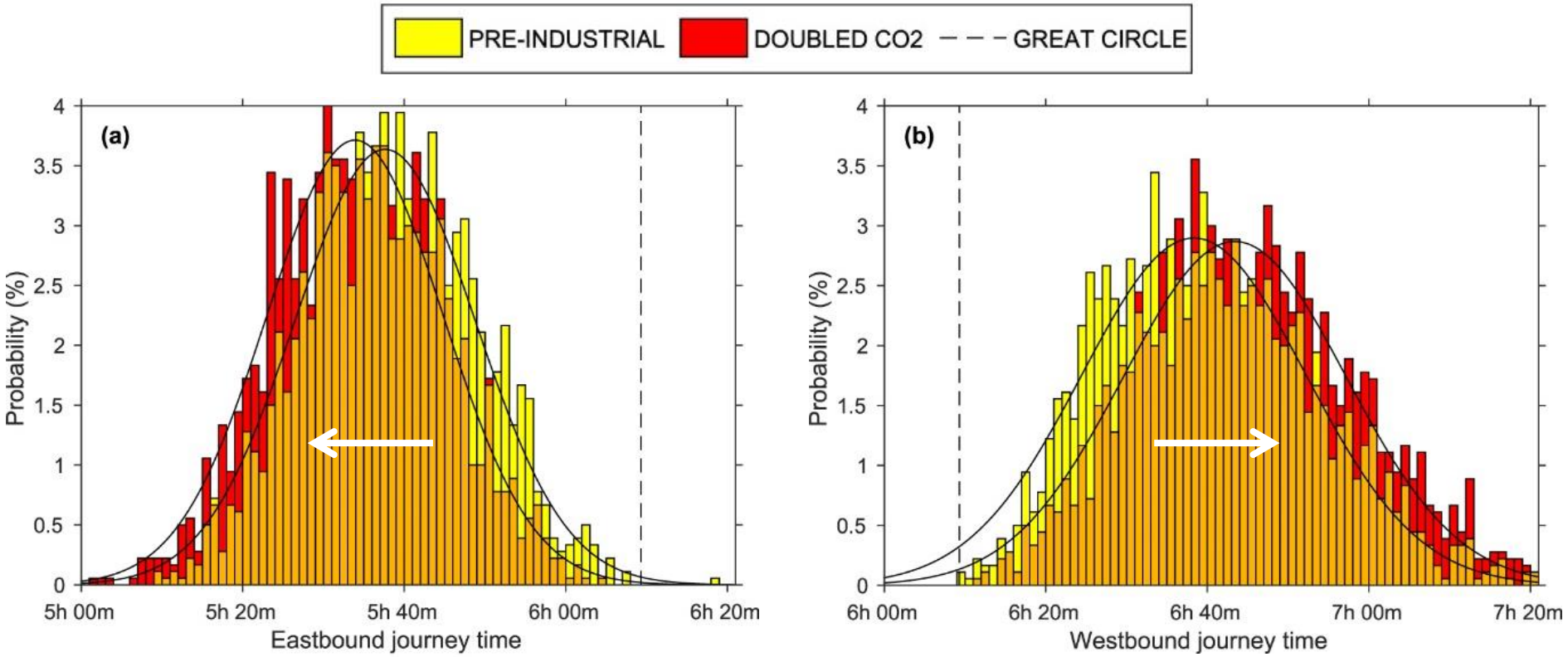
Delcambre et al. (2013)



C20 (10 m/s contours)

C21 – C20 (0.25 m/s contours)

Flight times in a changing climate

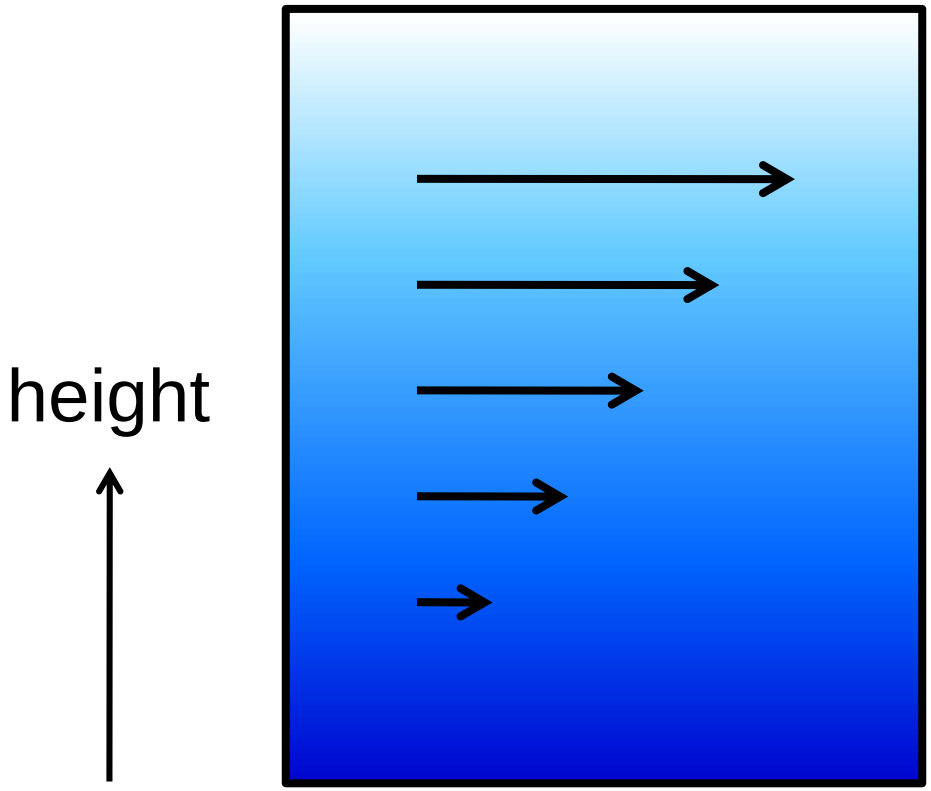


Likelihood of taking under 5 h 20 min more than doubles from 3.5% to 8.1%

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

Williams (2016)

Clear-air turbulence (CAT)



Stratification inhibits CAT

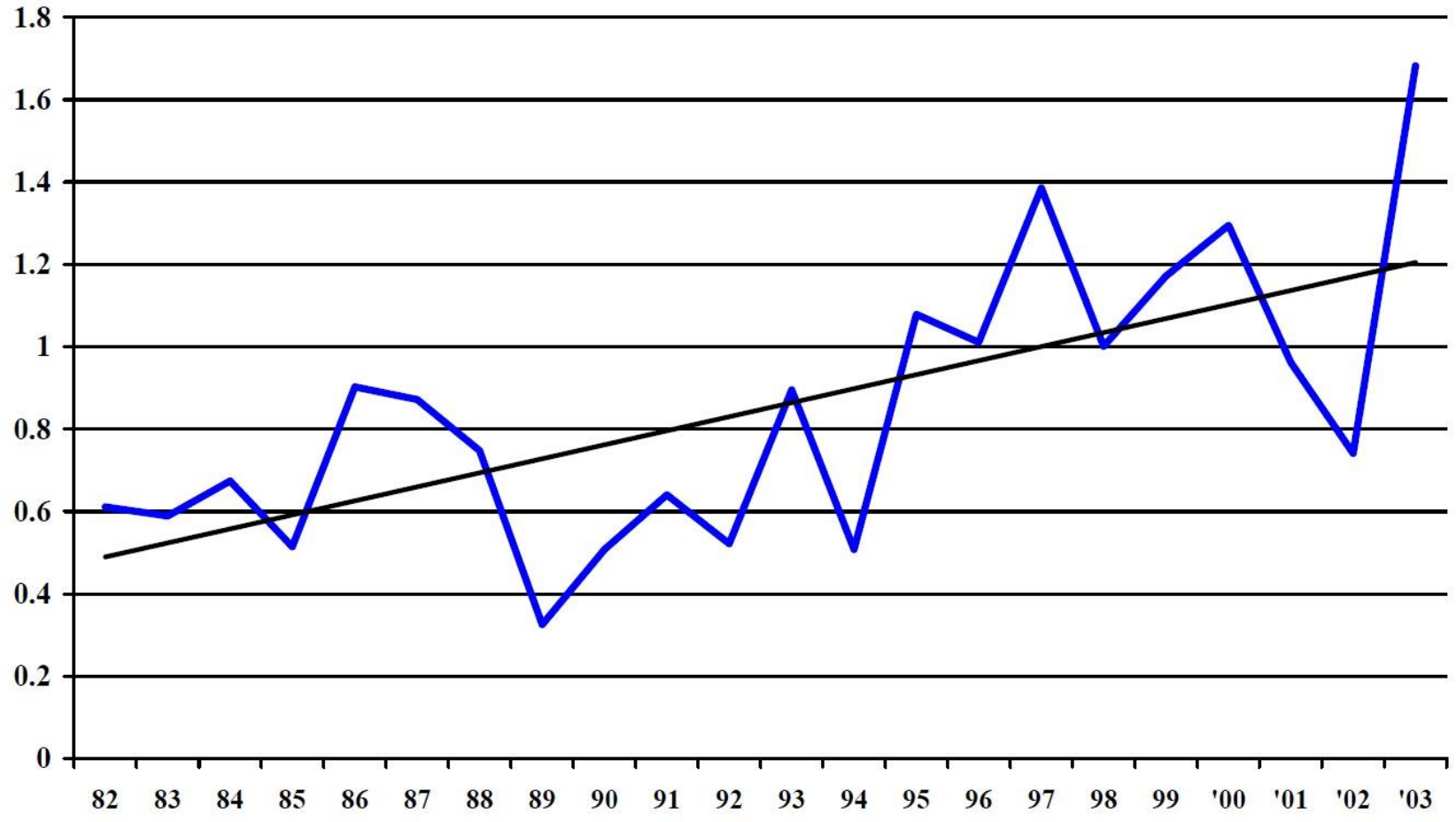
Wind shear encourages CAT

CAT occurs if the wind shear is stronger than the stratification.

Climate change is strengthening the wind shear…

Is CAT increasing?

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



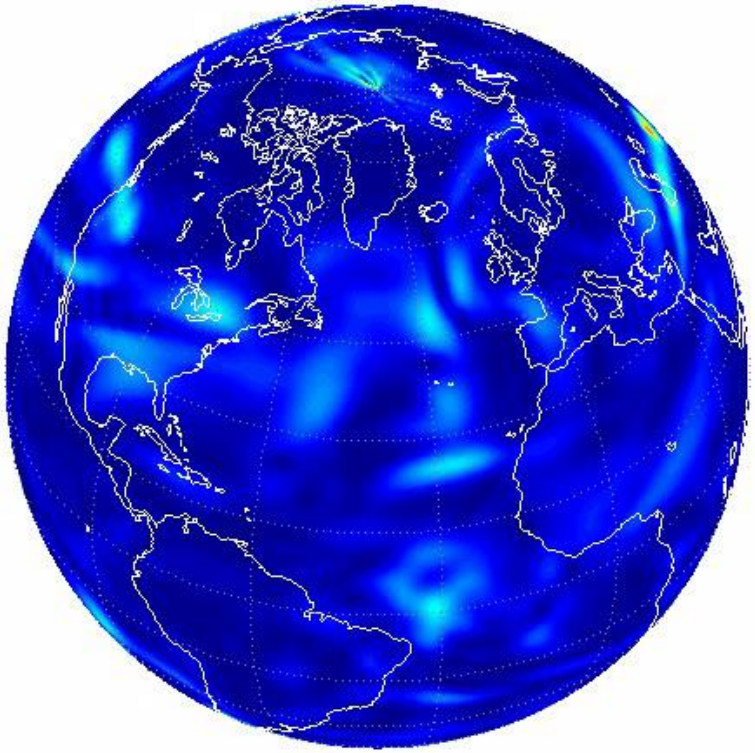
1982

2003

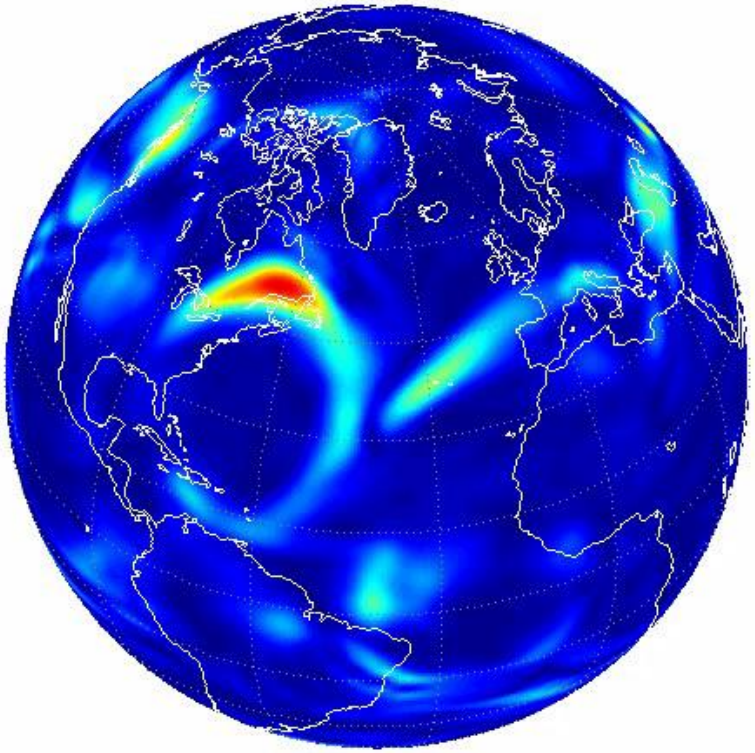
FAA (2006)

Is CAT increasing?

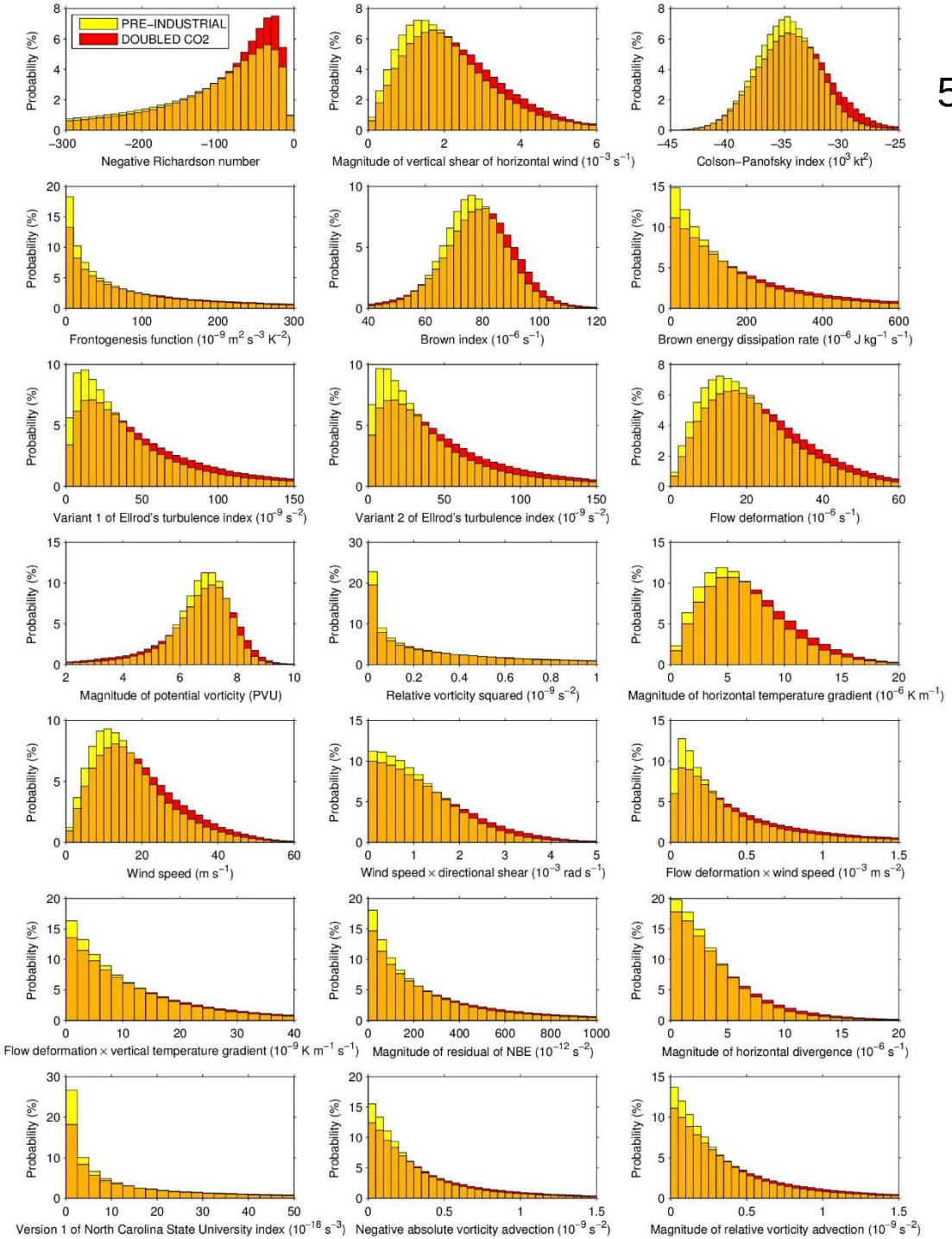
PRE-INDUSTRIAL



DOUBLED CO2



$$\Pi 1 = \left|\frac{\partial \mathbf{u}}{\partial z}\right| \sqrt{\left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2}$$



50-75°N, 10-60°W

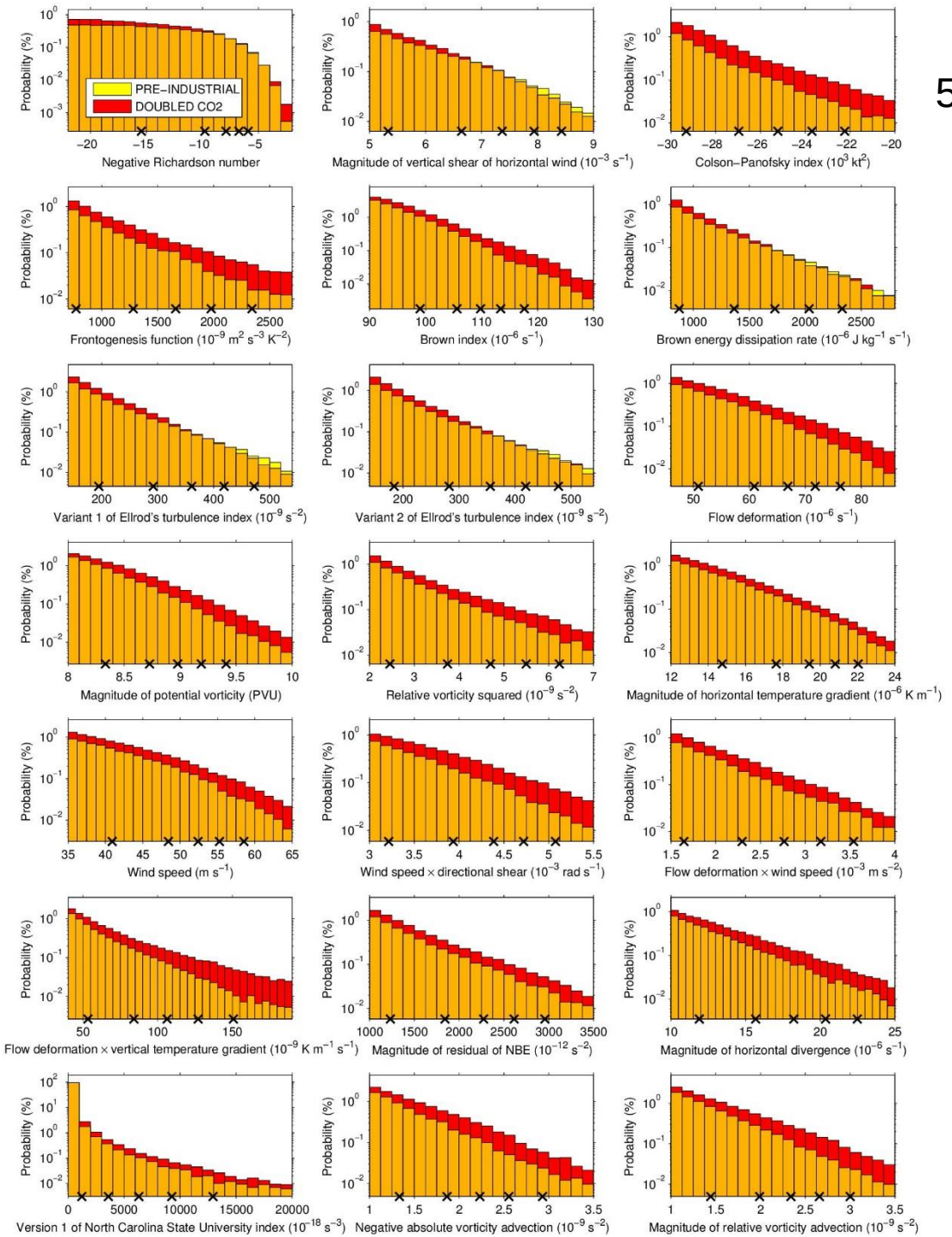
200 hPa

DJF

Williams (2017)

X = 0.1 0.2 0.3 0.4 0.5 $m^{2/3}$ s^{-1}

LIG LTM MOD MTS SEV



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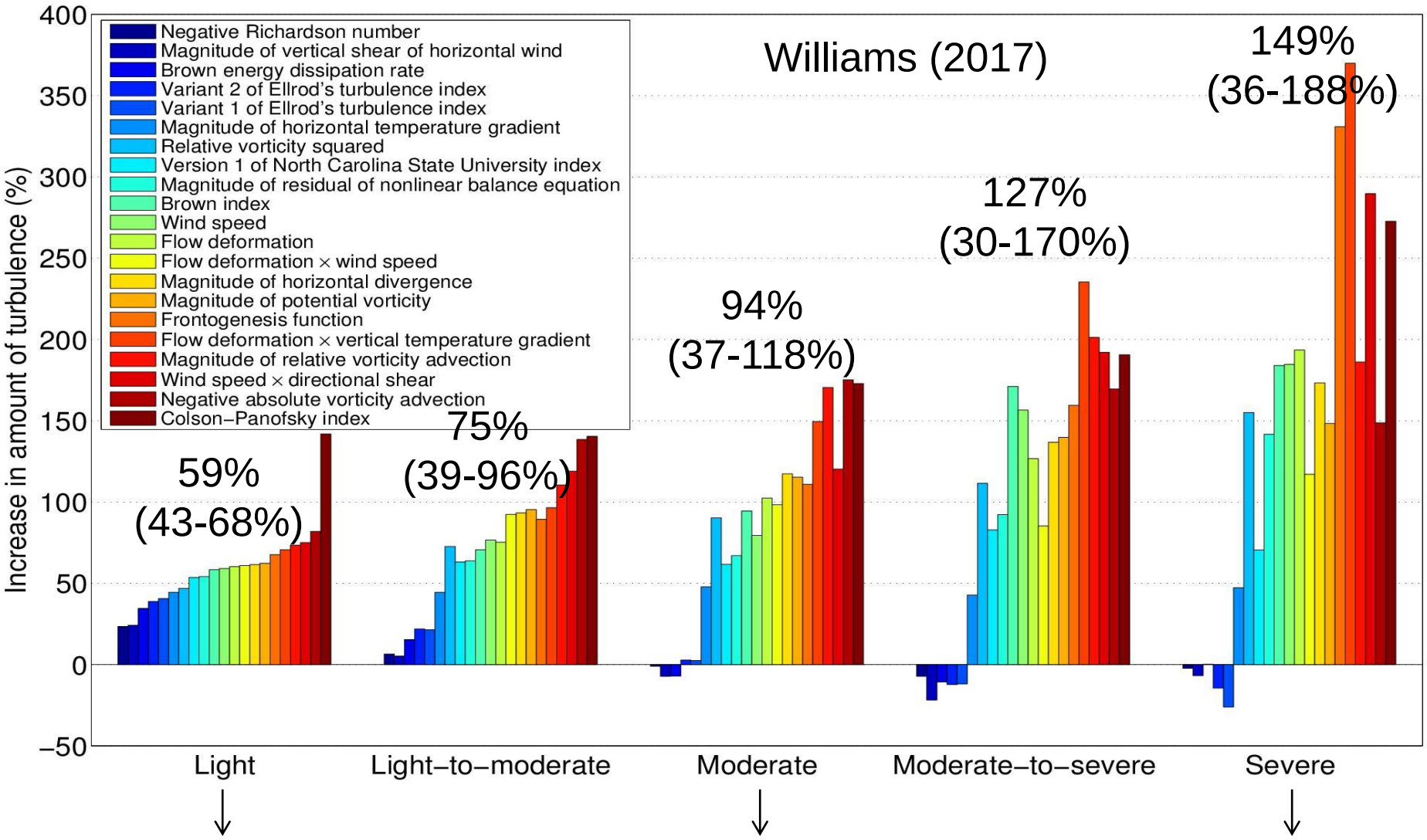
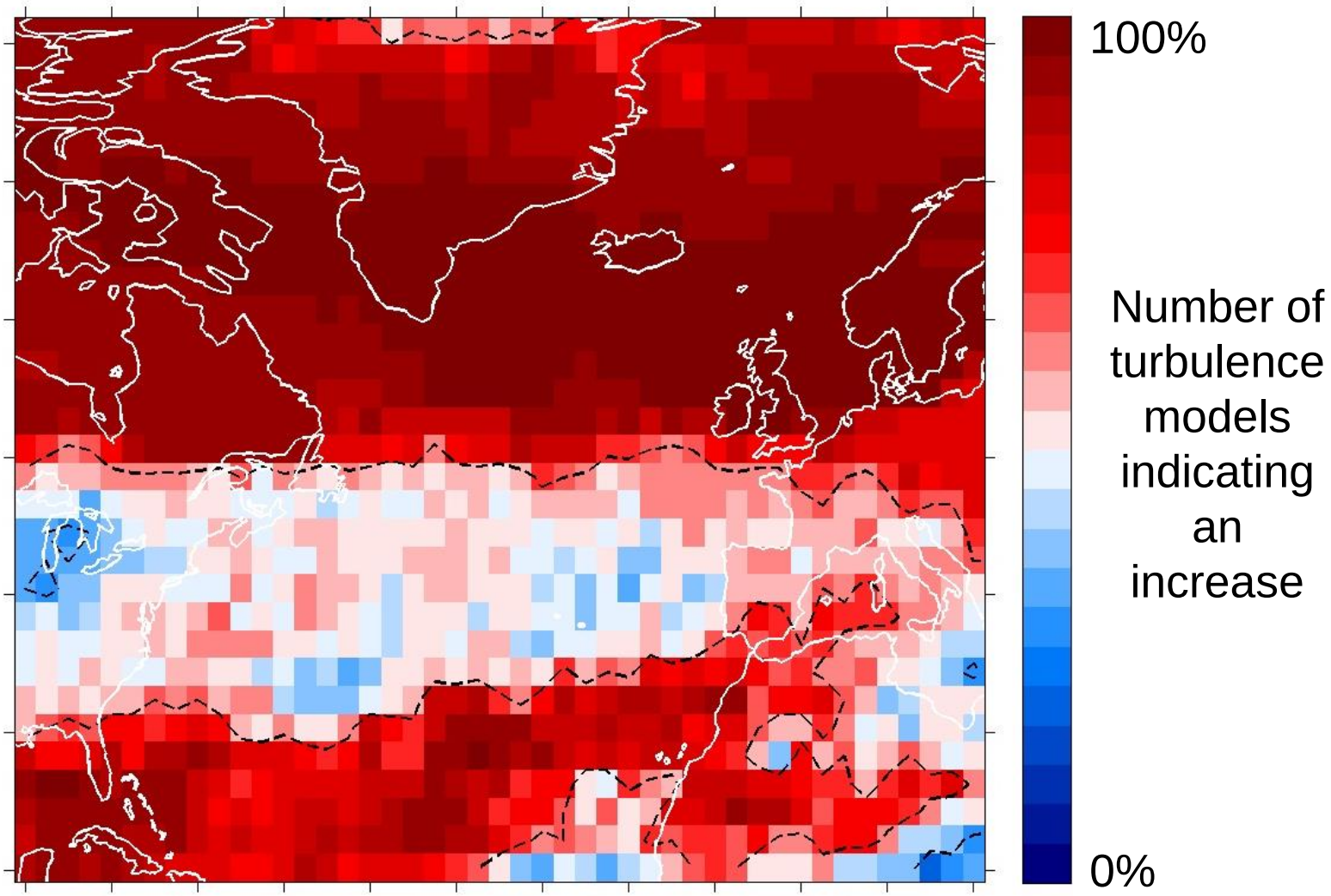


"Slight strain against seat belts; unsecured objects may be displaced slightly; food service may be conducted with little difficulty walking"

"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"

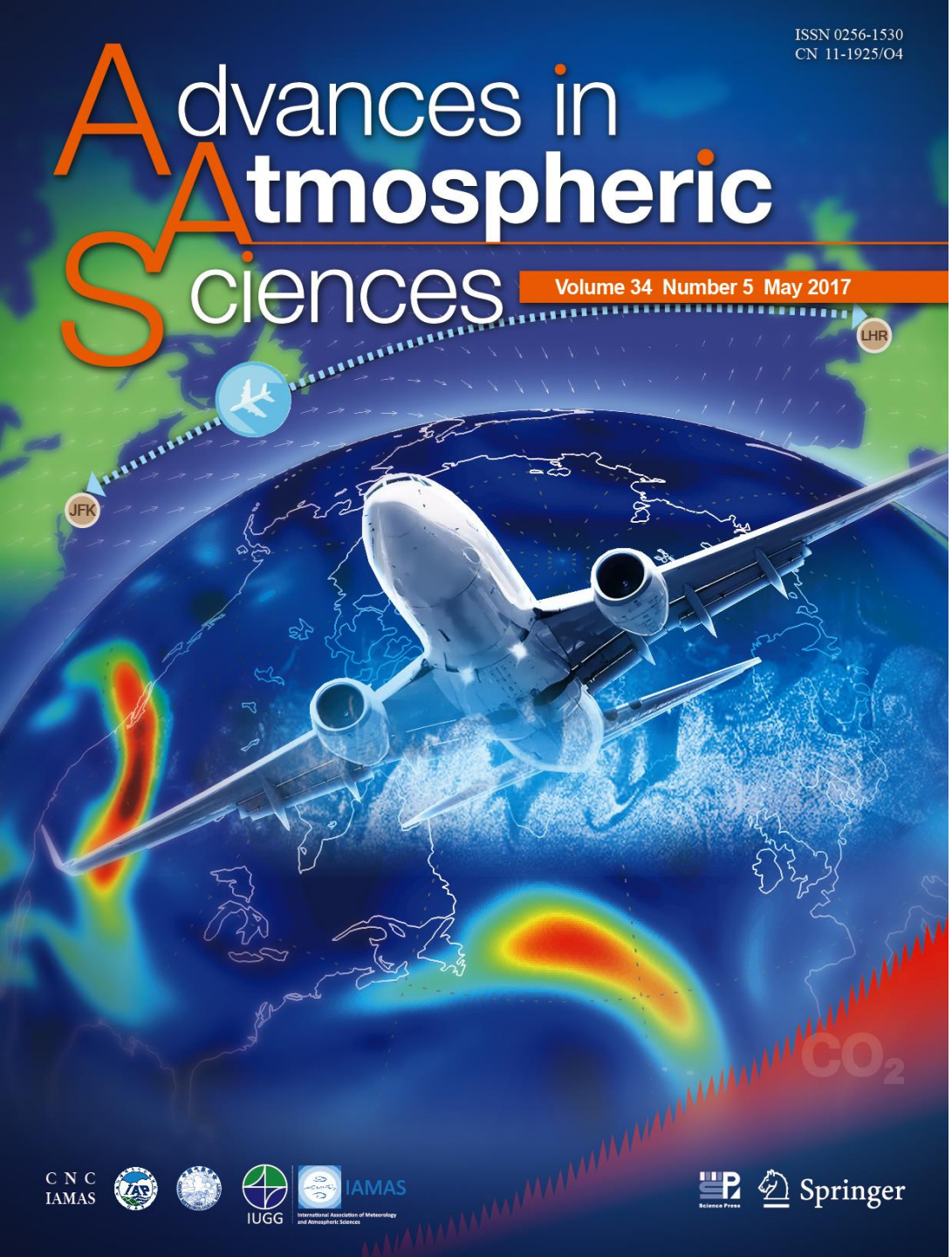
Is CAT increasing?



Williams & Joshi (2013)

Summary

- A basket of 21 CAT measures diagnosed from climate simulations is significantly modified if the CO_2 is doubled
- At cruise altitudes within 50-75°N and 10-60°W in winter, on average the diagnostics show a 59% / 94% / 149% increase in the prevalence of light/moderate/severe CAT
- We conclude that, all other things being equal, climate change will lead to bumpier transatlantic 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



Williams (2017) Increased light, moderate, and severe clear-air turbulence in response to climate change. *Advances in Atmospheric Sciences*, **34**(5), pp 576-586. DOI: 10.1007/s00376-017-6268-2

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