Climate Change in Aviation Impacts

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THE ROYAL SOCIETY

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

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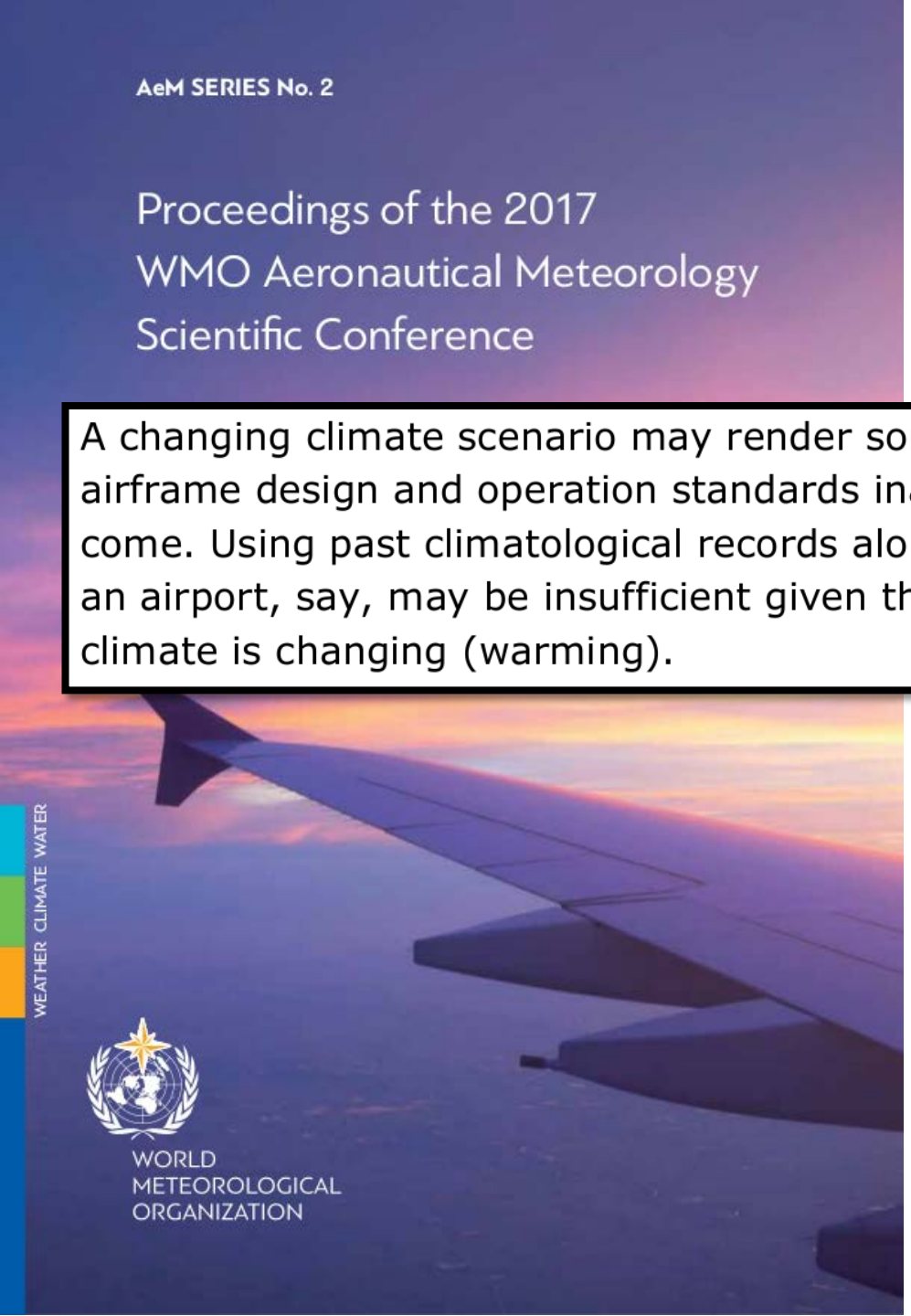
AeM SERIES No. 2

Proceedings of the 2017 WMO Aeronautical Meteorology Scientific Conference



WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

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 social sciences. Furthermore, all stakeholders in meteorology and aviation must work together, including through WMO and ICAO, to build consensus on robust, sustainable global solutions;

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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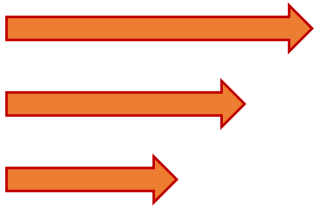
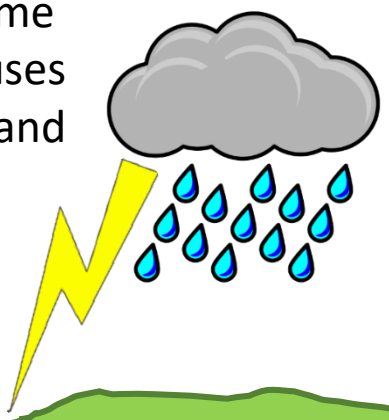
Climate change impacts on aviation

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

Rising sea levels

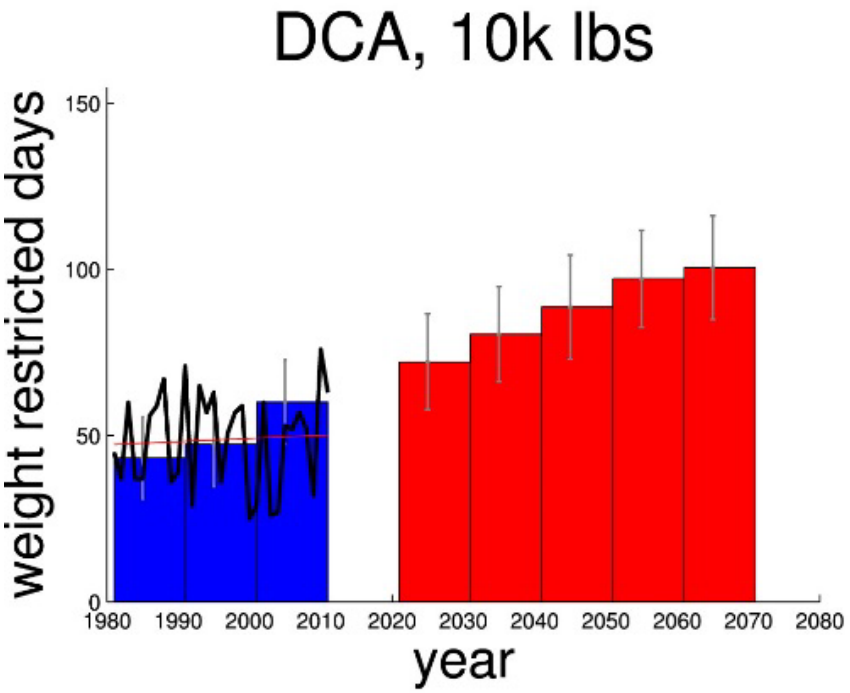
- Global sea-level rise is 3.4±0.4 cm per decade and accelerating
- Airport elevations: LGW +62m, LHR +25m, La Guardia +6m, Dundee +5m, SFO +4m, JFK +4m, Bangkok +2m, Corfu +2m, Schiphol -3m, Atyrau -22m
- Thirteen of the USA's largest airports have at least one runway within reach of a moderate-to-high storm surge (National Climate Assessment 2014)
- Sea-level rise could threaten runway capacity at more than 30 European airports (Eurocontrol 2014)

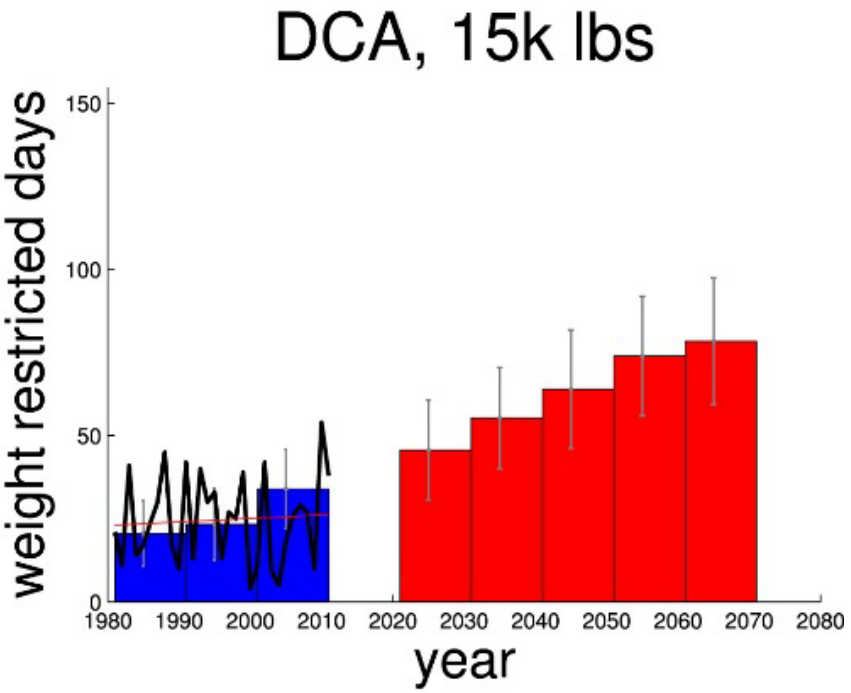
The third runway at Hong Kong International Airport will include 13.4 km of seawall to help protect it from flooding and storm surges

Take-off weight restrictions

Take-off weight restrictions

Washington Reagan National Airport





Coffel & Horton (2015); Coffel, Thompson & Horton (2017)

More extreme weather: lightning

Table 1. Future changes predicted by GCMs. Predicted changes in global mean temperature (ΔT) and percent per global mean °C changes in CONUS annual mean CAPE (ΔCAPE), precipitation (ΔPr), and CG lightning flash rate (ΔCG) are shown for 11 CMIP5 GCMs. Changes are calculated for the years 2079–2088 of the RCP8.5 experiment relative to the years 1996–2005 of the historical experiment.

GCM	ΔCG (%°C)
BCC-CSM1.1	3.4
BCC-CSM1.1(m)	6.9
CanESM2	17.3
CCSM4	9.1
CNRM-CM5	12.2
FGOALS-g2	7.0
GFDL-CM3	17.6
GFDL-ESM2M	15.9
MIROC5	16.3
MRI-CGCM3	14.7
NorESM1-M	10.3
Mean:	11.9

- The annual number of lightning strikes in the USA is predicted to increase by an average of 11.9% per °C of global warming (Romps et al. 2014)
- This figure equates to an increase of about 50% over this century

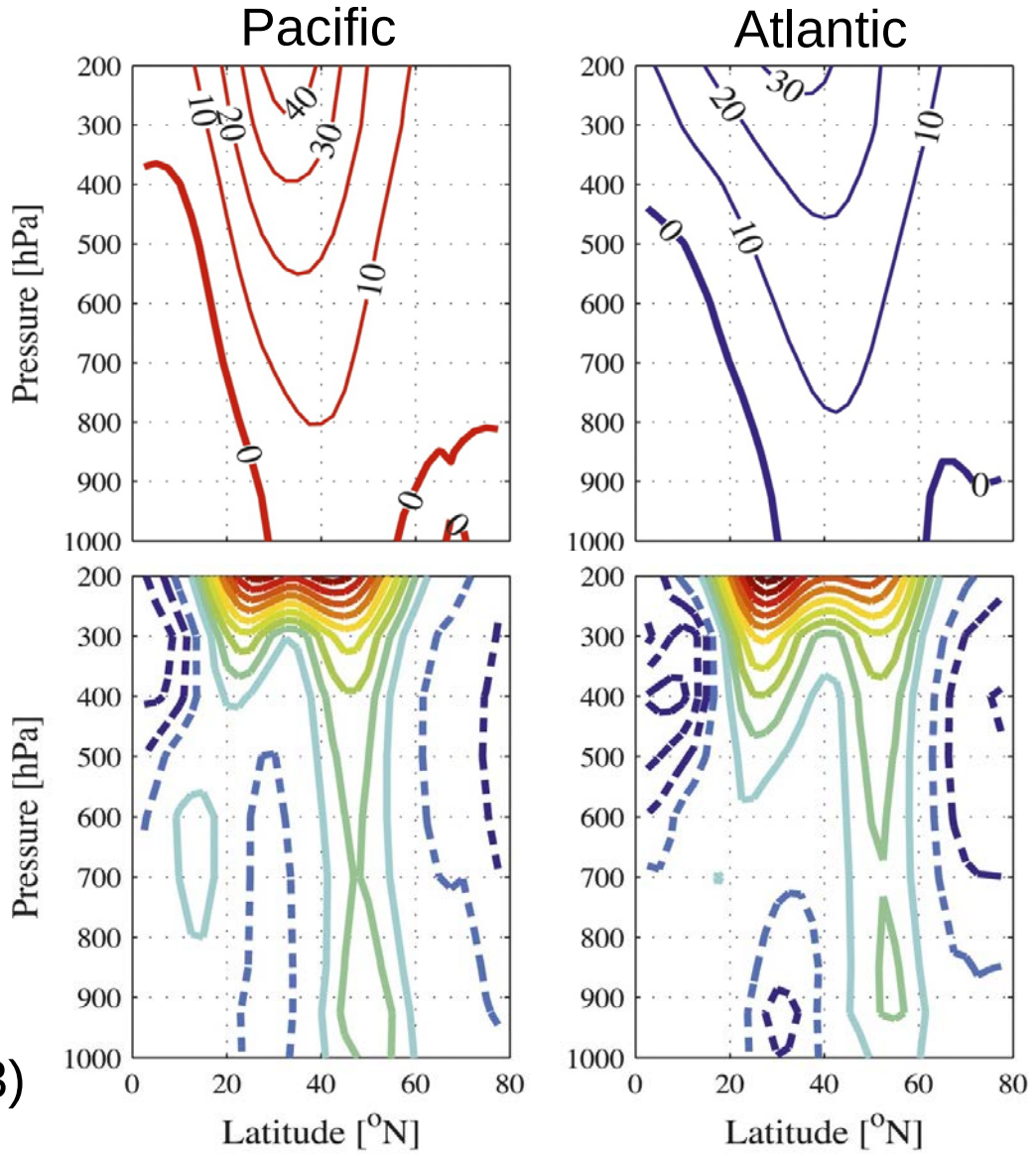
The changing jet stream

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

$$\frac{d\phi(t)}{dt} = \frac{V_a \cos\psi(t) + U(\phi,\theta,z)}{R\cos\theta(t)}$$

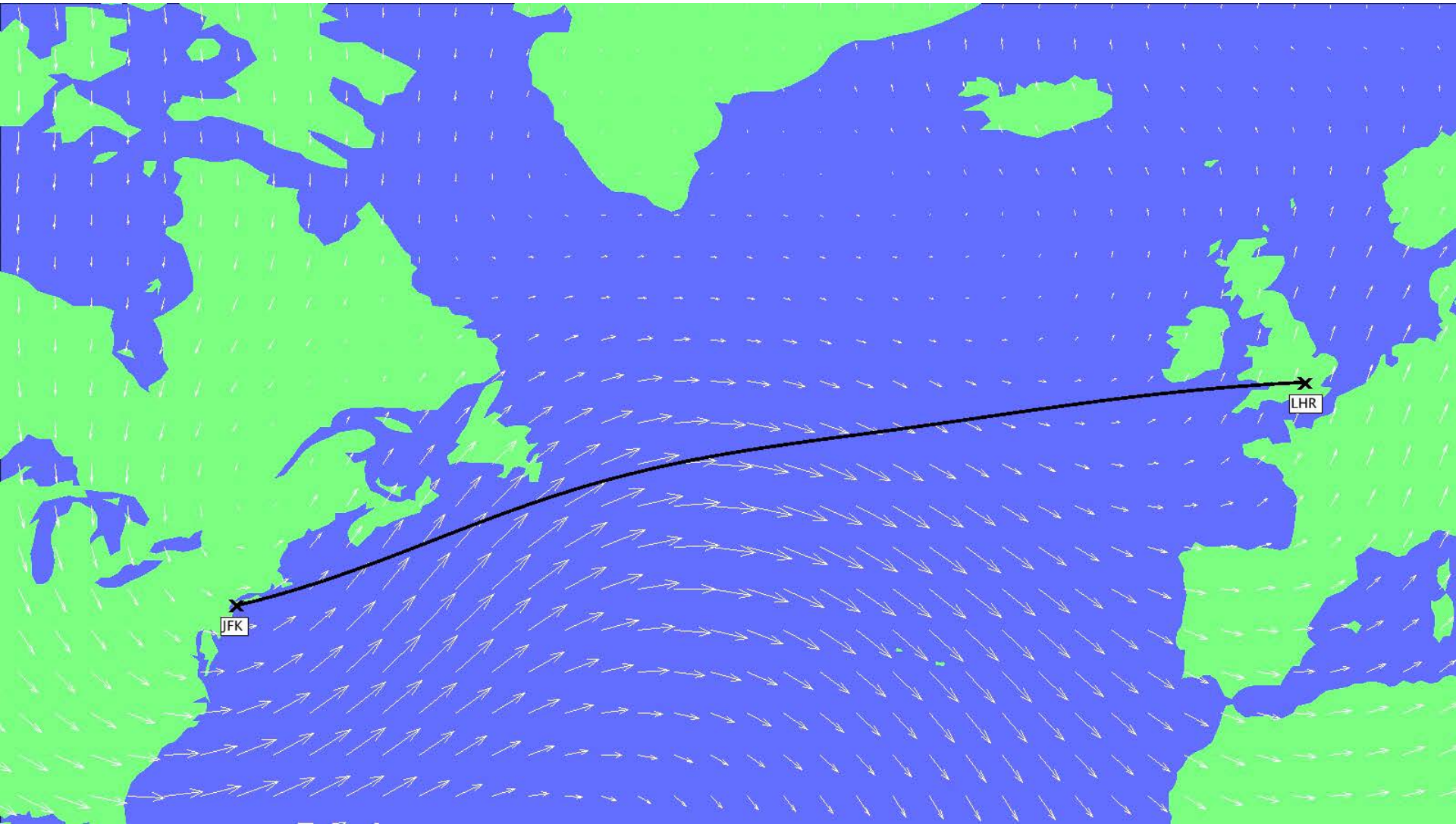
$$\frac{d\theta(t)}{dt} = \frac{V_a \sin\psi(t) + V(\phi,\theta,z)}{R}$$

$$\frac{d\psi(t)}{dt} = -\frac{F_{\text{wind}}(t)}{R\cos\theta(t)}$$

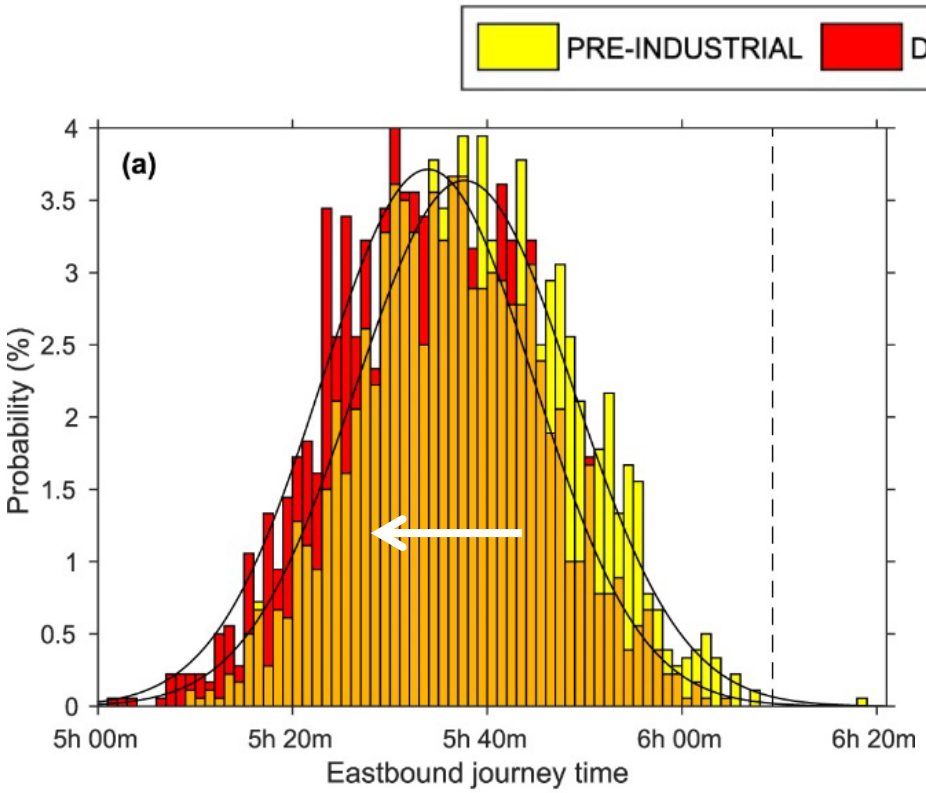
These equations are at the heart of the North Atlantic Organized Track System calculated daily by NAV CANADA and NATS

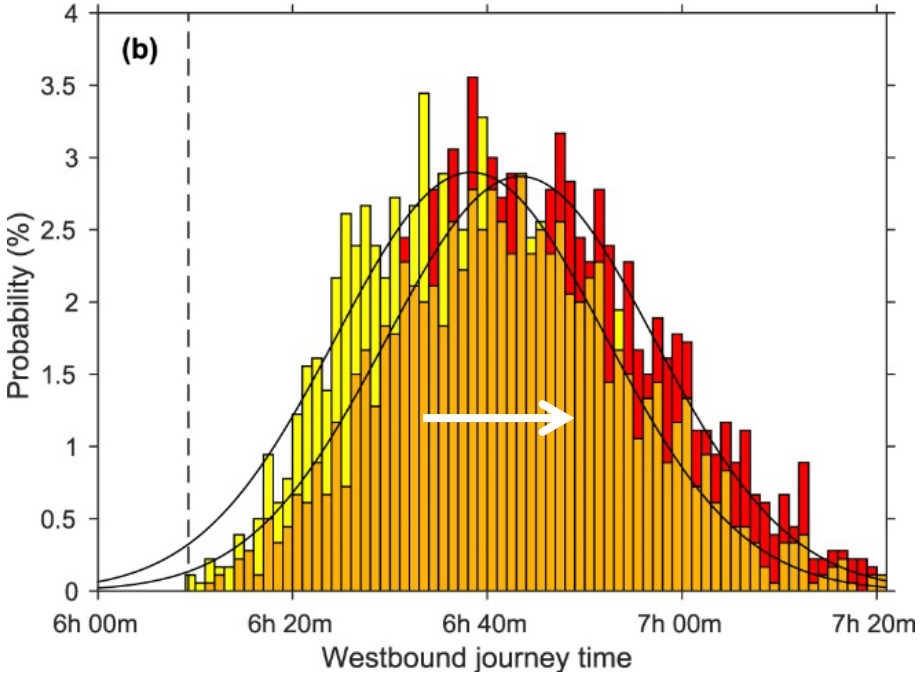
$$\begin{aligned} F_{\text{wind}}(t) = &-\sin\psi(t)\cos\psi(t)\frac{\partial U(\phi,\theta,z)}{\partial\phi} + \cos^2\psi(t)\sin\theta(t)U(\phi,\theta,z) \\ &+ \cos^2\psi(t)\cos\theta(t)\frac{\partial U(\phi,\theta,z)}{\partial\theta} - \frac{\partial V(\phi,\theta,z)}{\partial\phi} \\ &+ \sin\psi(t)\cos\psi(t)\sin\theta(t)V(\phi,\theta,z) \\ &+ \cos\psi(t)\sin\psi(t)\cos\theta(t)\frac{\partial V(\phi,\theta,z)}{\partial\theta} + V_a\cos\psi(t)\sin\theta(t) \\ &+ \cos^2\psi(t)\frac{\partial V(\phi,\theta,z)}{\partial\phi} \end{aligned}$$

Zermelo (1930), Arrow (1949), Kim et al (2015)


JFK
LHR

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%

(Williams 2016, Irvine et al 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

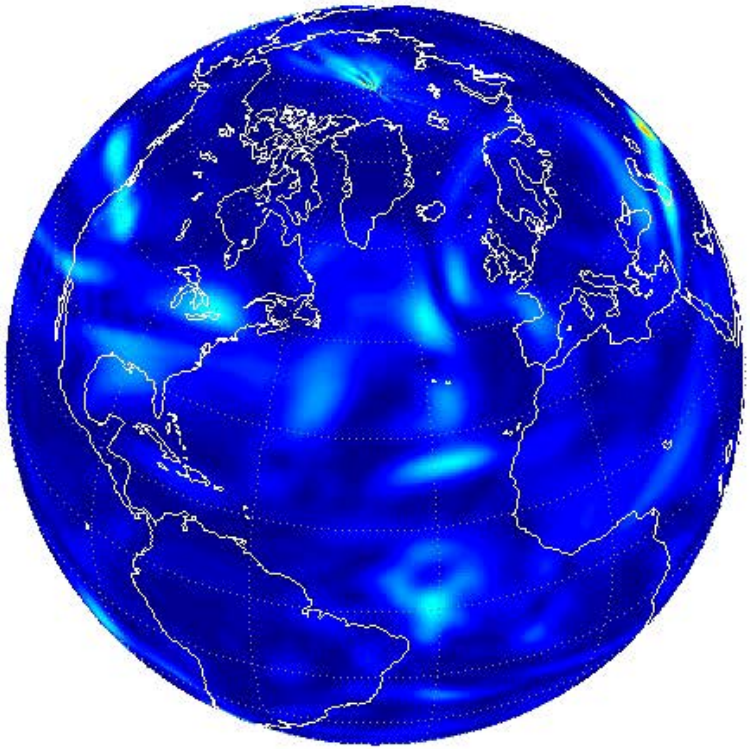
- Extrapolation to all transatlantic traffic (600 crossings per day) suggests that aircraft will collectively be:
  - airborne for an extra 2,000 hours each year
  - burning an extra 7.2 million gallons of jet fuel at a cost of $22 million
  - emitting an extra 70 million kg of CO_2 into the atmosphere, equating to 7,100 British homes

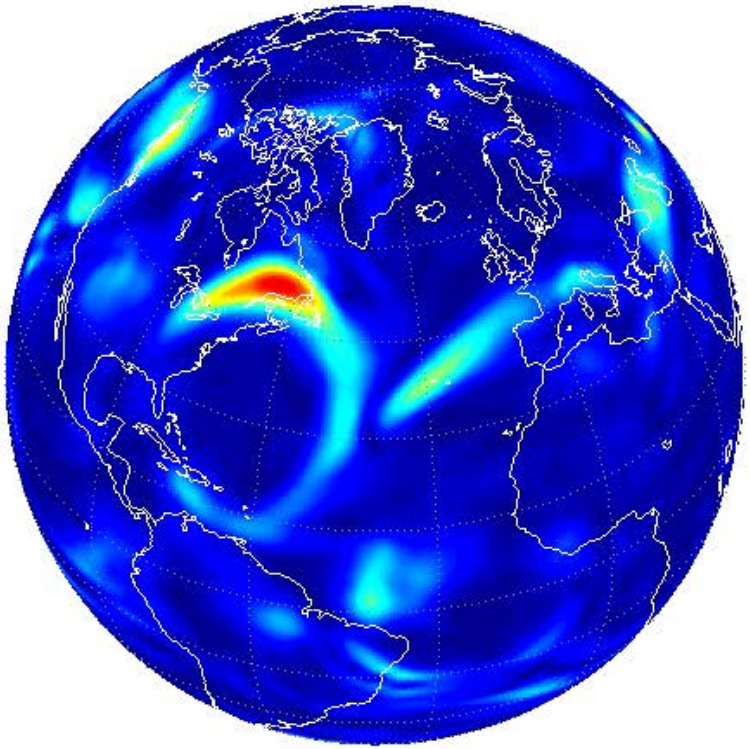
(Williams 2016, Irvine et al 2016)

Increased clear-air turbulence

PRE-INDUSTRIAL

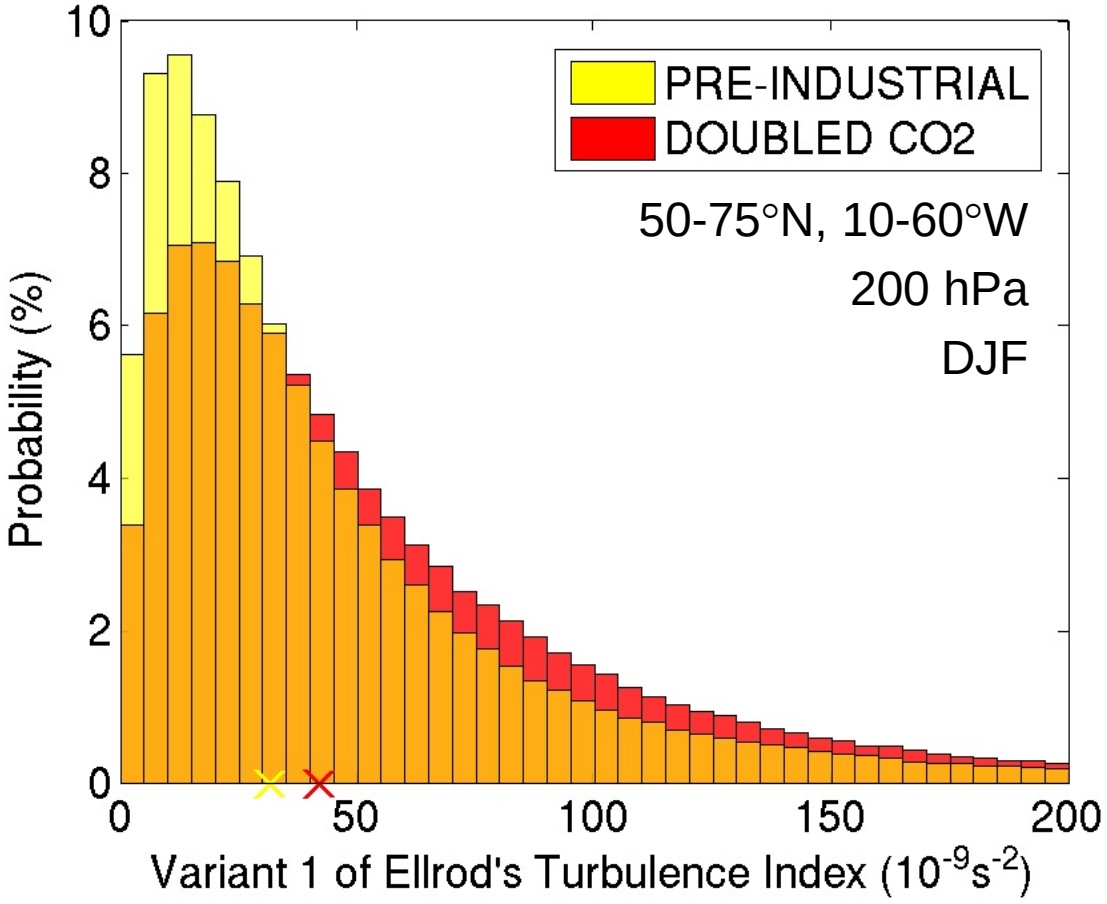
DOUBLED CO2



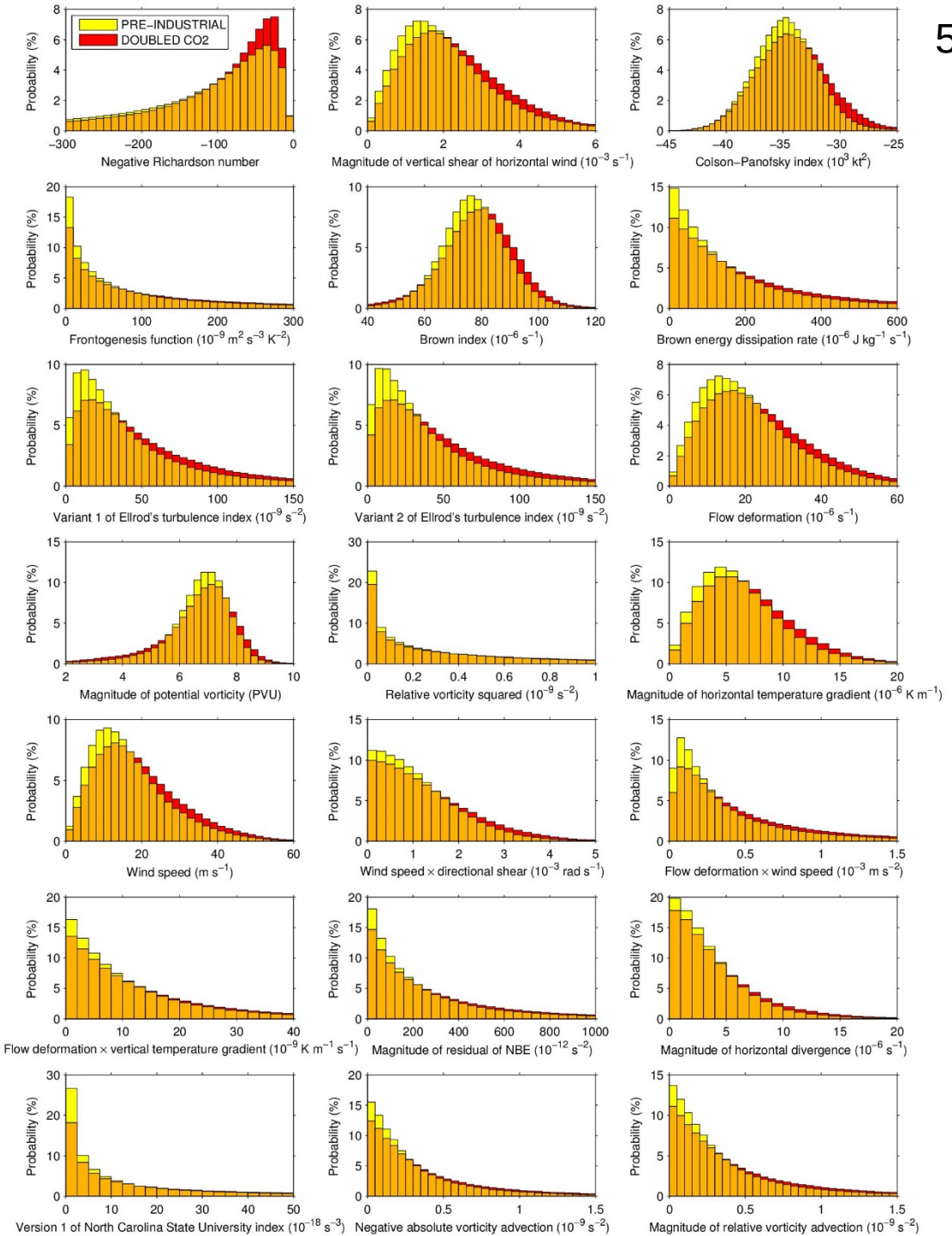


$$\mathrm{TI1} = \left|\frac{\partial \mathbf{u}}{\partial z}\right| \sqrt{\left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2}$$

Increased clear-air turbulence



Williams & Joshi (2013)



50-75°N, 10-60°W

200 hPa

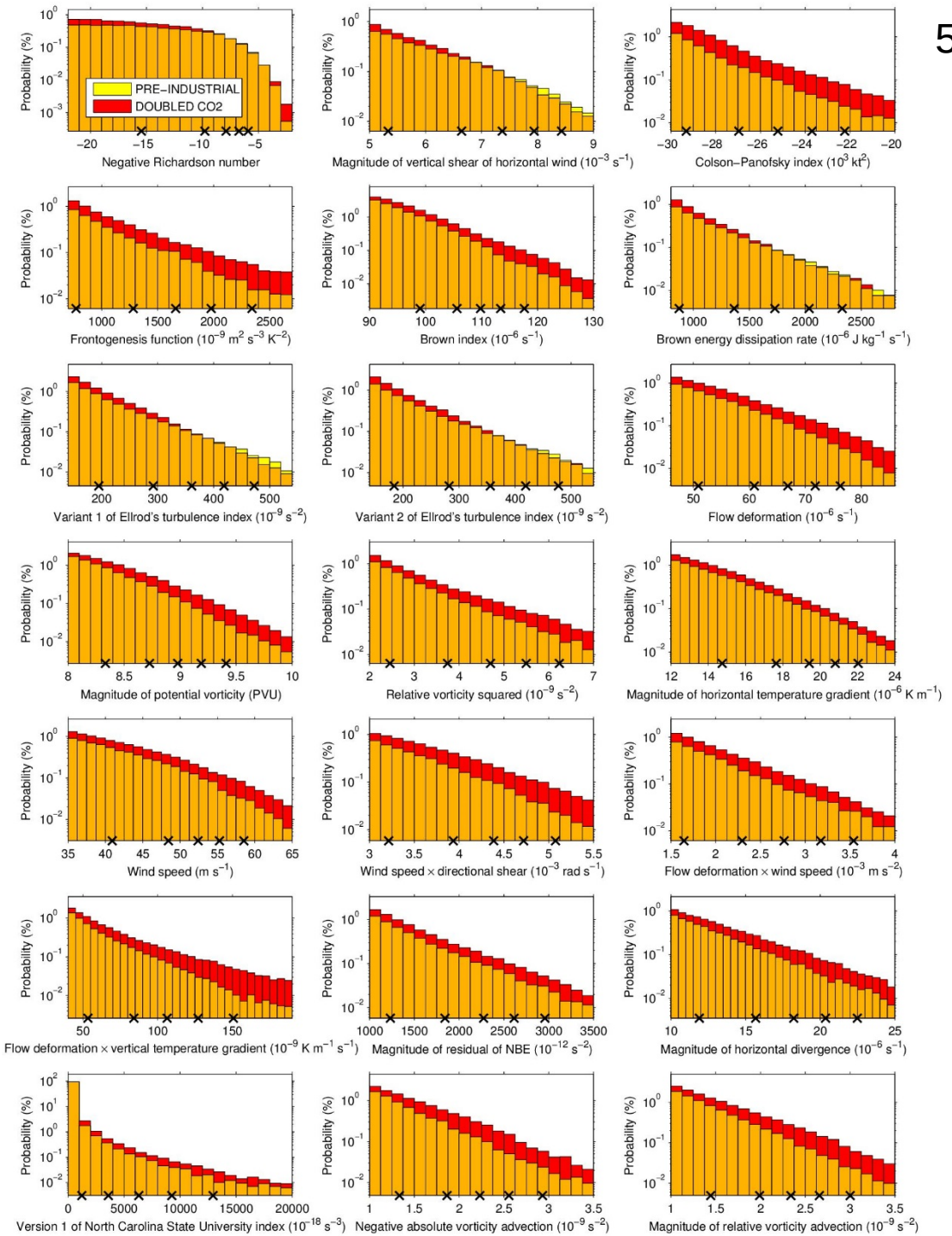
DJF

Williams (2017)

50-75°N, 10-60°W

200 hPa

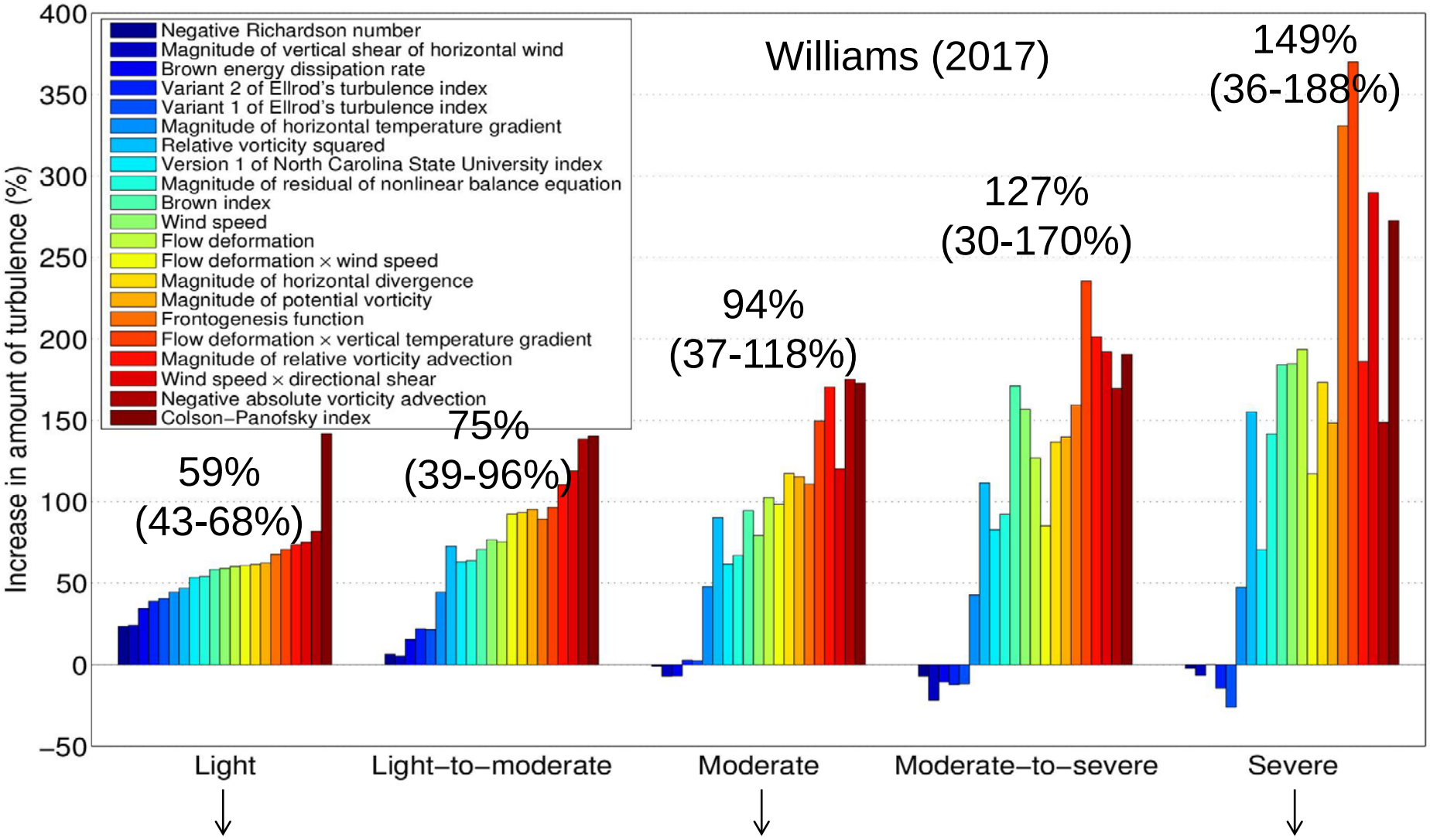
DJF



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

LIG LTM MOD MTS SEV

Williams (2017)

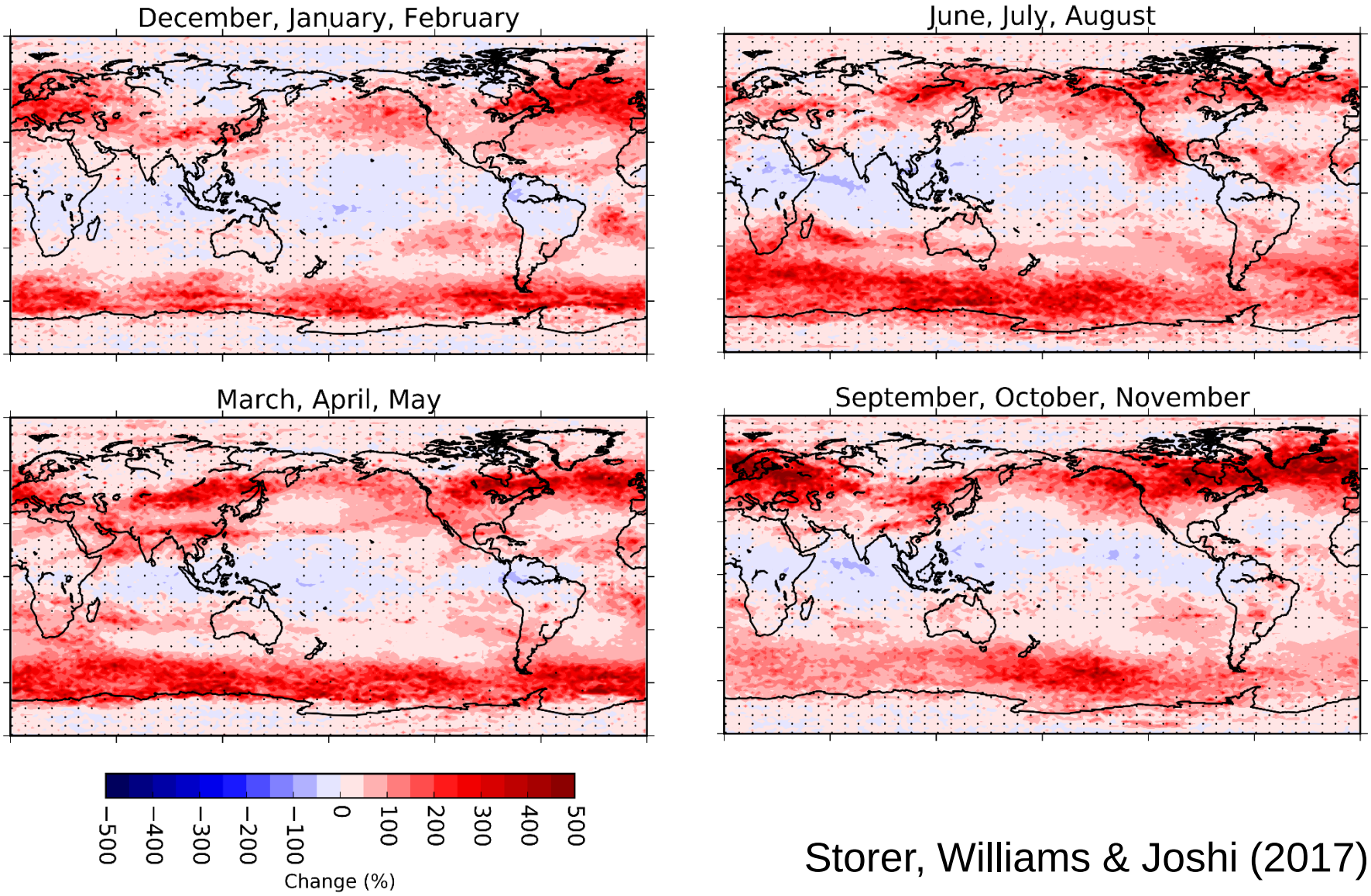


"Slight strain against seat belts; unsecured objects may be displaced slightly; food service may be conducted with little difficulty walking"

"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"

Increased clear-air turbulence



Storer, Williams & Joshi (2017)

Greg Dalton: Michael Mann, speaking of weather, you were boarding a plane one time and the pilot asked to speak to you. Tell us that.

Michael Mann: That's right. I thought I was in trouble.

Greg Dalton: Not because you are drunk and disorderly, no.

Michael Mann: No, the flight attendant came back and asked me “Are you Michael Mann?” And I didn’t know if I should answer yes or no. And the pilot had recognized me and wanted to talk with me. And in fact he was convinced that he is seeing the impact of climate change on aviation, on turbulence in the atmosphere. And he was quite informed, it turns out that he follows, you know, the climate literature in the blogs. And he knew sort of knew what he was talking about and he was absolutely convinced that he is seeing changes in sort of turbulence that are unusual in his career. And that he thinks are a manifestation of climate change. And it’s consistent with what we expect we do expect more turbulent energy in the atmosphere as it warms up.

And so to me that really drove home not just the fact that I have to be careful in what I do and say because people do actually recognize me now and then. But it really conveyed to me in a very profound way the fact that the impacts of climate change are no longer subtle. People are feeling them and seeing them in their daily lives and I think that's making a huge difference when we try to communicate to the science and its implications to the public. They sort of get it now at a level that I don't think they did in the past.

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

Questions?

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