A Historical Review on Aviation Turbulence in Our Changing Climate

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Introduction & Motivation

Clear-air turbulence (CAT) is a challenging and hazardous phenomenon that affects aviation safety and passenger comfort during flight. Despite its importance, CAT remains one of the least understood forms of turbulence. This comprehensive literature review aims to provide a holistic understanding of CAT and its intricate relationship with anthropogenic climate change by synthesizing information from seven key sources. Various aspects of CAT, including its observations, prediction techniques, and response to climate change, are explored as a common theme. Additional types of upper-level aviation turbulence are also explored in brief.

Methodology

The analyzed papers use a variety of methods to investigate the response of CAT to climate change:

- GFDL-CM2.1 climate model, North Atlantic flight corridor (50-75°N, 10-60°W), 200 hPa, winter season (CAT peaks in NA sector), anthropogenic forcing simulations (pre-industrial and doubled CO_2).[1,2]
- 21 CAT diagnostics converted into log-normally distributed, cube-rooted EDR values ($m^{2/3}$ s^{-1}).[2]
- Probability distribution functions calculated for each diagnostic to assess turbulence probability within each bin.[2]
- Two HadGEM2-ES simulations analyzed to calculate how climate change could impact CAT in upper troposphere and lower stratosphere (UTLS) in the future – one is a pre-industrial control simulation (picontrol) while the other uses the IPCC RCP8.5 net radiative forcing increase assumption of 8.5 W m^{-2} by 2100.[3]
- CMIP5 HadGEM2-ES simulations later compared to CMIP3 GFDL-CM2.1 simulations among CAT diagnostics for verification.[3]
- ECMWF's ERA-Interim, NCEP/NCAR, and JRA-55 reanalyses were used to quantify the sensitivity of results to uncertainties in the state of the atmosphere.[4]
- Historic CAT diagnosed from climate model simulations and high-res reanalysis data compared by ERA-Interim.[5]
- CMIP6 NorESM2-MM forced by SSP5-8.5 climate scenario used to find climate change impacts on other types of turbulence in addition to CAT.[7]

Probability and Spatial Distributions of CAT Diagnostics

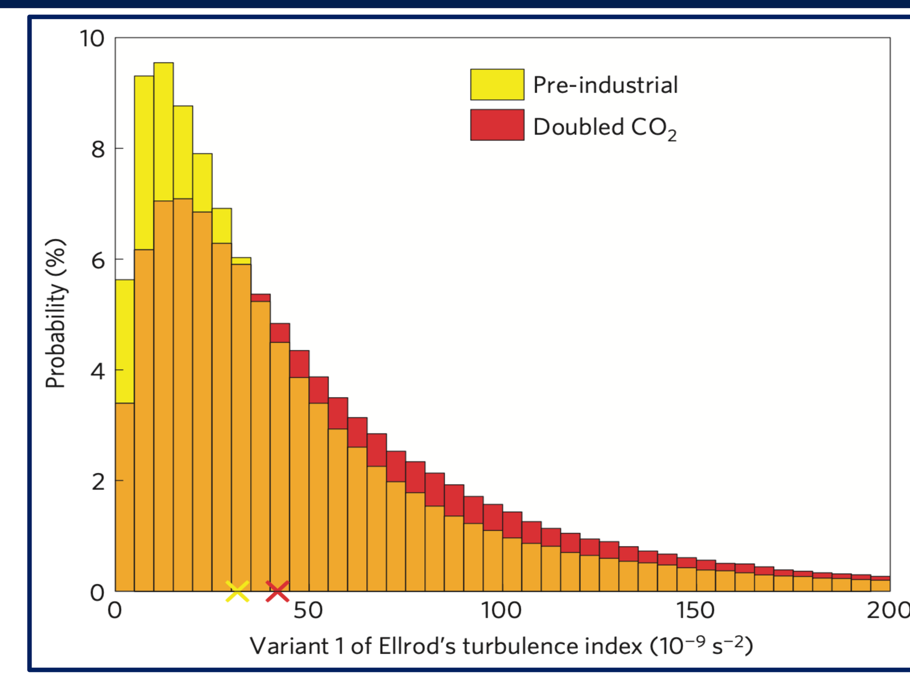

Figure 1: Probability distributions of northern North Atlantic flight-level winter clear-air turbulence (CAT) in a changing climate. The probabilities are computed from 20 years of daily-mean data in December, January, and February, at 200 hPa, and within 50-75°N and 10-60°W. Two histograms are over-plotted, from the pre-industrial and doubled-CO_2 integrations. The overlap between the two distributions is shaded orange. The two crosses on the turbulence axis indicate the medians.[1,2]

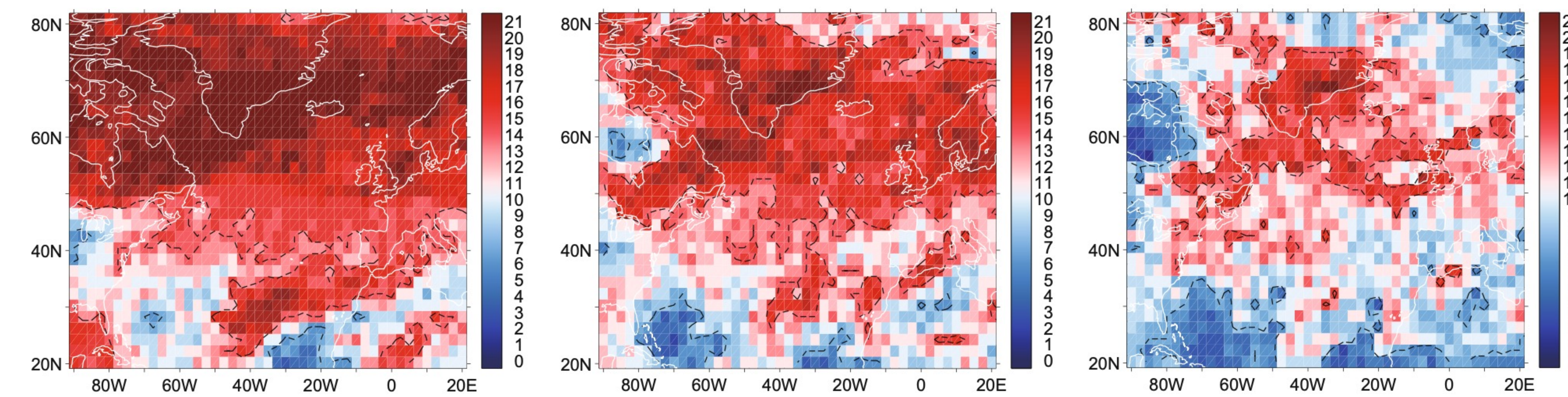

Figure 2: Spatial distributions of the number of the 21 clear-air turbulence (CAT) diagnostics to show an increase in the frequency of light-or greater (left), moderate-or-greater (center), and severe-or-greater (right) CAT at 200 hPa in winter. The increase refers to the change in a doubled-CO_2 simulation compared to a pre-industrial simulation. Red shading indicates that most of the diagnostics show an increase, and blue shading indicates that most show a decrease. The black dashed lines, which are contours at 7 and 14, delineate the regions in which at least two-thirds of the diagnostics agree on the sign of the change.[2]

Climatological Trends and Other Upper-Level Aviation Turbulence Types

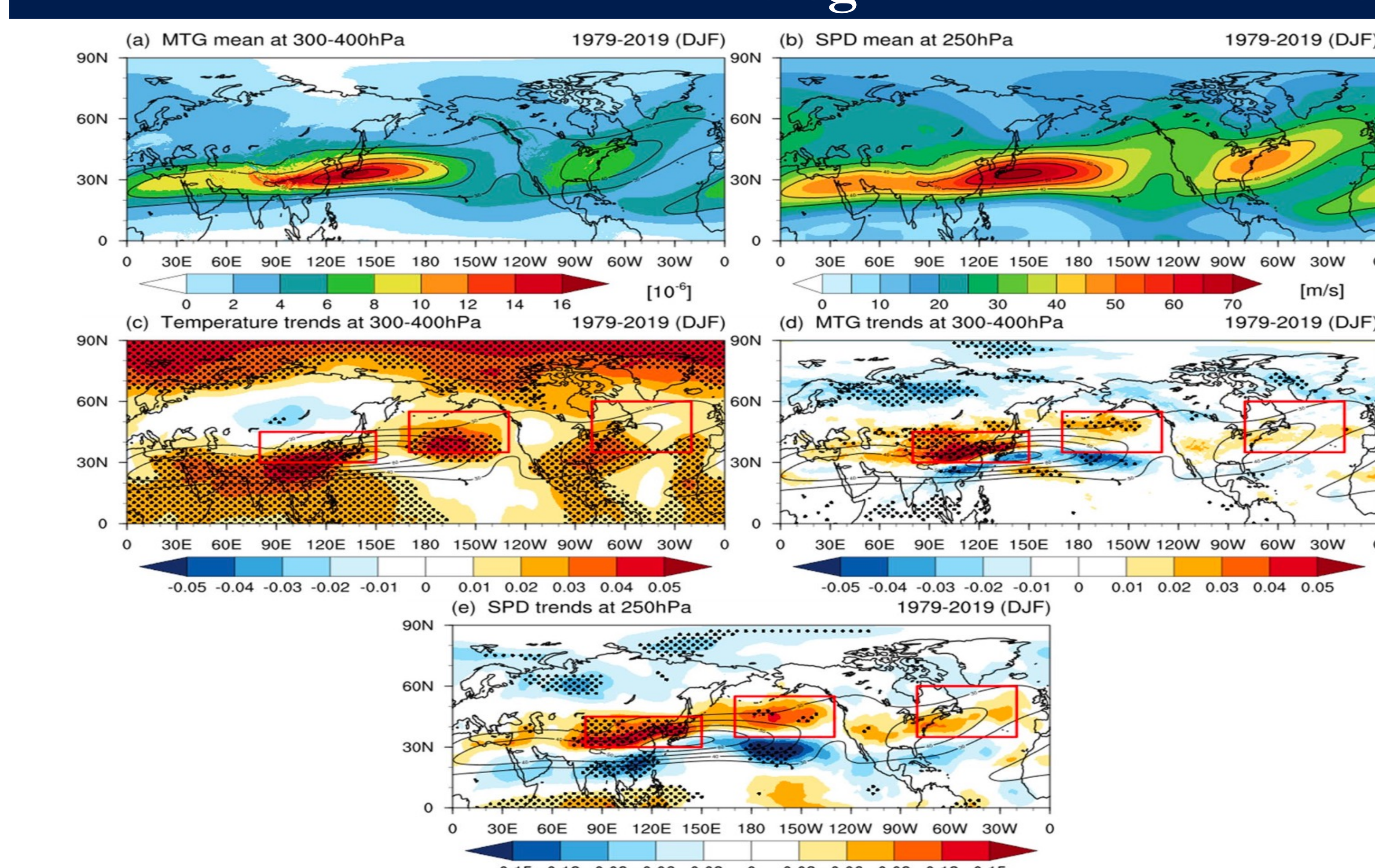

Figure 3: (a and b) Averaged meridional temperature gradient (MTG) and horizontal wind speed (SPD) at 300-400 hPa and 250 hPa for 41 years (1979-2019) respectively with shading. DJF mean trends (shading) of (c) temperature at 300-400 hPa, (d) MTG at 300-40 hPa, and (e) horizontal wind speed at 250 hPa. Black contour and stippling depict the zonal wind speed at 250 hPa and significant trends (P-value < 0.05, n = 41). Red boxes indicate East Asia, Eastern Pacific, and Northwestern Atlantic regions from the left.[6]

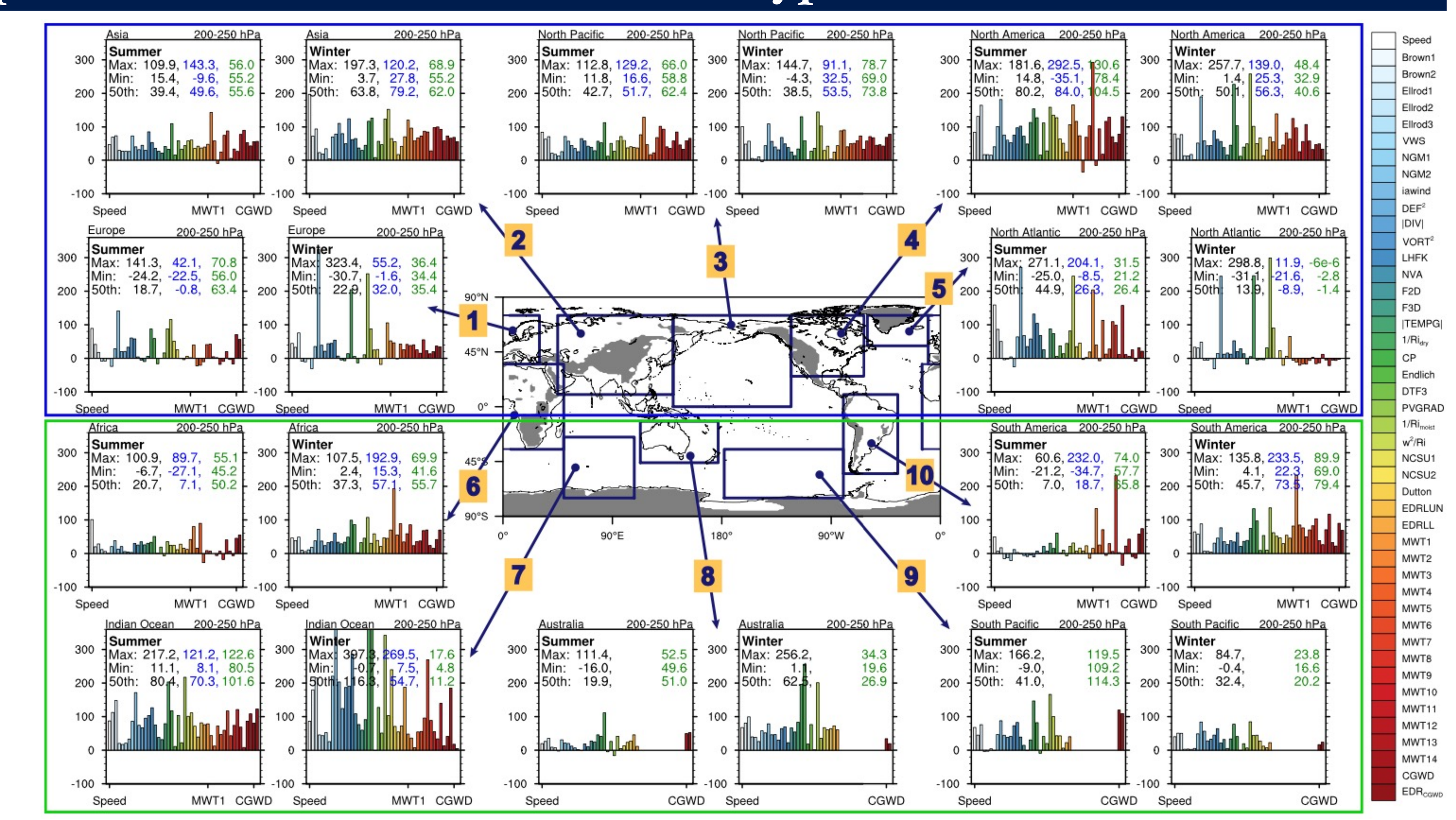

Figure 4: Response of upper-level aviation turbulence (CAT, MWT, and NCT) on NorESM2-MM under climate change scenario SSP5-8.5 over ten specified regions. The bar charts show the percentage change in occurrence frequency of MOG turbulence between 200 and 250 hPa in summer and winter for 45 years. The histograms are calculated using the data within each box with arrows and labels. The maximum, minimum, and median estimates between each type of turbulence are written in each figure (black: CAT, blue: MWT, and green: NCT). On the map, the gray shaded areas indicate MWT-prone regions.[7]

Key Findings

- The prevalence of light turbulence increases by 59%, light-to-moderate by 75%, moderate by 94%, moderate-to-severe by 127%, and severe by 149%.[2]
- The percentage change of CAT amount from pre-industrial times is more pronounced at 200 than 250 hPa, in the spring season (MAM), and over midlatitudes in both hemispheres by 2050-80.[3]
- The increasing trend of CAT potentials is largest in East Asia due to warming in tropics and cooling over Eurasian continent.[6]

Conclusions

- Transatlantic wintertime CAT in the atmosphere will increase significantly in all strength categories as the climate changes, but that does not imply more in-flight injuries or passenger discomfort.[1,2]
- Diagnostic uncertainty dominates over model uncertainty; however, CAT increases are larger when diagnosed from reanalysis data than climate models, suggesting previous quantifications may be underestimates.[5]
- Not only is an increase in CAT expected globally, but so is an increase in MWT (mountain-wave turbulence) and NCT (near-cloud turbulence).[7]

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