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Transatlantic flights likely already bumpier due to climate change

Abstract: Using data based on observations, we find the vertical wind shear (the change in wind speed with height) over the North Atlantic Ocean has increased by 15% since 1979 at a typical transatlantic flight cruising altitude. As wind shear is a key driver of clear-air turbulence – a major aviation hazard – this result supports findings of increased turbulence in future climate model projections.

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The North Atlantic flight corridor is the busiest oceanic airspace in the world. Fundamental to its operation is the jet stream – a narrow ribbon of fast west-to-east flowing air (sometimes over 200 mph) that peaks in strength at around 30,000 - 40,000 feet (the cruising altitudes of most commercial aircraft) and encircles the globe between 30-70°N. The jet stream exists primarily because the equator is warmer than the north pole. Aircraft can use the jet stream to their advantage; eastbound flights can exploit its beneficial tailwinds, and vice versa. The change in wind speed with height within the jet stream (called vertical wind shear) exists in a state of balance (known as thermal wind balance) with the temperature difference between the equator and pole at each horizontal level. Changes to this temperature difference change the wind shear within the jet stream. Vertical wind shear is a particularly important factor for consideration with respect to aviation, as it is a key driver of clear-air turbulence – something probably everyone who has flown in an aircraft has experienced.

Anthropogenic climate change is having a huge impact on temperatures around the world, but not in the form of equal warming everywhere. In the lower 5 km or so of the atmosphere, the Arctic is warming faster than anywhere else – a phenomenon called 'Arctic amplification'. The stratosphere – the layer of atmosphere extending from approximately 10 to 50 km – is actually *cooling* due to increasing greenhouse gas concentrations (and, historically, due to ozone depletion). In the tropics, temperatures are warming faster aloft than near the surface thanks to the enhanced release of latent heat in increasingly warmer convection. To complicate matters further, the tropopause (the boundary between the troposphere and stratosphere) slopes downwards toward the pole, meaning in mid-latitudes a horizontal surface is in the stratosphere (and hence, cooling) at higher latitudes and the troposphere (where it is warming) at lower latitudes. This varied 3-D profile of temperature change has a big impact on the jet stream through thermal wind balance. Not only does the shear at any level depend on changes at that level, but the ultimate speed of the jet maximum depends on how these changes add up through the column in the vertical – so changes lower down can impact the speed aloft.

In our study, we use reanalysis data to assess how temperatures and winds have changed in the North Atlantic region over the period 1979-2017. Reanalysis datasets are the best estimate of the past state of the atmosphere; they are gridded model output based on observations providing a continuous and consistent record in time and space. They are subject to uncertainty, so we use three different datasets from different meteorological organizations around the world to quantify this. We use four times daily values of west-to-east (zonal) winds and temperatures on constant pressure levels from the surface (1000 hPa) to 200 hPa, but we focus on 250 hPa – where the jet stream strength is maximized and corresponding to a typical cruising altitude of ~34,000 feet.

Our main finding is that the annually-averaged vertical shear in the west-to-east wind averaged over the North Atlantic (defined as the region bounded by 30-70°N, 10-80°W) at 250 hPa has increased by 15% over the past four decades, with a range of 11-17% across the three different datasets. This result is statistically significant. We find that this is because the temperature difference between the pole and equator has correspondingly significantly increased at this altitude. We also find that the wind *speed* in the jet stream has not changed, because the increasing temperature difference aloft is being offset by the weakening temperature difference below (thanks to Arctic amplification). This can be thought of like a balanced tug-of-war; the lower-level changes have acted to slow down the jet, but the upper-level changes have acted to speed it up, so there has been no overall change.

These findings support previous modelling studies which suggest clear-air turbulence – primarily driven by wind shear – will increase with climate change. Our study provides the first observation-based findings that increased turbulence may already be occurring; it is difficult to quantify whether turbulence has increased from in-situ aircraft measurements (due to, e.g. changes in aircraft design and flight routing, and increased numbers of aircraft). Turbulence is not only unpleasant, but also dangerous and costly – and it may be that climate change has already made your flight bumpier, and will continue to do so under current warming scenarios.