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What are the implications of climate change for trans-Atlantic aircraft routing and flight time?

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ABSTRACT

The effect of wind changes on aircraft routing has been identified as a potential impact of climate change on aviation. This is of particular interest for trans-Atlantic flights, where the pattern of upper-level winds over the north Atlantic, in particular the location and strength of the jet stream, strongly influences both the optimal flight route and the resulting flight time. Eastbound trans-Atlantic flights can often be routed to take advantage of the strong tailwinds in the jet stream, shortening the flight time and reducing fuel consumption. Here we investigate the impact of climate change on upper-level winds over the north Atlantic, using five climate model simulations from the Fifth Coupled Model Intercomparison Project, considering a high greenhouse-gas emissions scenario. The impact on aircraft routing and flight time are quantified using flight routing software. The climate models agree that the jet stream will be on average located 1° further north, with a small increase in mean strength, by 2100. However daily variations in both its location and speed are significantly larger than the magnitude of any changes due to climate change. The net effect of climate change on trans-Atlantic aircraft routes is small; in the annual-mean eastbound routes are 1 min shorter and located further north and westbound routes are 1 min longer and more spread out around the great circle. There are, however, seasonal variations; route time changes are larger in winter, while in summer both eastbound and westbound route times increase.

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Introduction

It is well-known that greenhouse gas emissions from transport contribute to climate change (e.g. Fuglestvedt et al., 2008; Lee et al., 2009); however climate change itself could have potentially large impacts on the transport sector. Despite this, the most recent Intergovernmental Panel on Climate Change (IPCC) report (Arent et al., 2014) notes that there have been few studies which quantitatively address the impacts of climate change on transport. The aviation sector in particular may be affected by changes to temperature, winds and extremes in weather (see reviews by Koetse and Rietveld (2009) and Peterson et al. (2008)), since its operations both on the ground and in the air are heavily weather dependent.

The focus of this paper is on changes to upper-level winds, particularly the jet stream, caused by climate change. There are several ways in which these could affect the aviation industry. Changes to the position and strength of the jet stream could affect both the incidence of wind storms and the variability in wind direction at airports, both of which influence runway

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capacity (Peterson et al., 2008; Koetse and Rietveld, 2009; Eurocontrol, 2013). A strengthened north Atlantic jet stream has been shown to have the potential to increase the incidence and strength of clear-air turbulence (Williams and Joshi, 2013). Several studies have identified upper-level wind changes as having the potential to impact aircraft routing (Love et al., 2010; Eurocontrol, 2013, 2009), but there is uncertainty as to the size of any impacts. Eurocontrol (2009) suggest that any wind changes will be small and therefore have minimal impacts on aircraft routing; however Eurocontrol (2013) note a potential for increased fuel costs and CO_2 emissions if the jet shifts become large enough that eastbound flights are less often able to take advantage of the strong tailwinds. Williams (2016) analyse the change to aircraft routing under a doubling of CO_2 from pre-industrial levels and find a decrease in eastbound route time and an increase in westbound route time such that the round-trip time increases. Karnauskas et al. (2015) inferred a small increase in route time for flights between Hawaii and the continental US, resulting from an increase in the mean strength of upper-level winds, but the effect on routing was not analysed. This study focuses on the changes to upper-level winds in the north Atlantic and, using multiple climate models with a high emissions scenario, provides quantitative estimates of the impact on trans-Atlantic flight routing, both in terms of route location and route time.

There is a growing scientific consensus that on average the northern hemisphere mid-latitude jet streams may shift northwards with climate change (Meehl et al., 2007; IPCC, 2013). In the near-term (early to mid twenty-first century), there is low confidence in these climate projections since the projected impact on the jet stream is very small compared to the natural variability in the jet stream. In the longer-term (by the end of the twenty-first century), there is medium confidence in a poleward shift of 1–2° in the mid-latitude jet streams if greenhouse gas concentrations remain high (IPCC, 2013). The degree of change to the jet stream is not uniform across the northern and southern hemispheres and also varies by region. For the north Atlantic sector, Barnes and Polvani (2013) estimated a mean poleward shift of 1° in the annual-mean. However on a seasonal timescale, there is less consensus between the models on the direction of the change in latitude or speed, particularly in winter (Woollings and Blackburn, 2012; Barnes and Polvani, 2013; Simpson et al., 2014).

Trans-Atlantic flight routing is strongly influenced by the jet stream. Since typical aircraft cruise altitudes coincide with the altitude of the jet stream, when the jet stream position is favourable eastbound flights can be routed to take advantage of the strong tailwinds in the jet stream, reducing the flight time and fuel use. Conversely, westbound flights can be routed away from the strong headwinds, which would otherwise increase the route time and fuel use. Considering minimum-time routes, Irvine et al. (2013) showed that the time taken to fly the New York to London routes can vary by over 60 min (assuming a constant true airspeed) due to the influence of the varying jet stream winds, and there are strong correlations between the location of the jet stream and the location of the quickest route.

From an economical perspective, changes to aircraft routing matter since wind changes that cause a systematic change in route time will likely change the overall fuel burn and operating cost (since this also has a component related to time in the air). There is an additional motivation, in that changes to fuel use imply changes to CO_2 emissions, since the two are directly related. Aircraft CO_2 emissions are currently around 2.5% of the total global CO_2 emissions and likely to be the largest impact of aviation on climate (Lee et al., 2009). There is substantial pressure on the aviation industry to reduce its CO_2 emissions. The question is, will climate change work for or against the aim of reducing CO_2 emissions? Fuel burn and related CO_2 emissions are not directly studied here. However, minimum-time routes minimise the air-distance flown at a constant altitude, which is equivalent to minimising fuel burn.

This paper analyses climate model predictions of the change in flight-level winds between the present-day and 2100 under a high greenhouse gas emissions scenario, with a particular focus on the jet stream over the north Atlantic. This analysis uses freely-available climate model data used in the latest climate change assessment by IPCC (2013). A description of the climate model data, and method to calculate the position and strength of the jet stream are given in Section 'Jet stream analysis'. The associated impacts on trans-Atlantic air traffic are assessed by using modelled present-day and future flight-level winds input to flight routing software to calculate daily minimum-time routes between London and New York, and Madrid and Miami. This allows a quantitative estimate of the impact of climate change on flight routing, both in terms of changes to the location of the optimum routes and the time taken to fly them. The flight routing software is described in Section 'Route analysis'. Results are presented in Section 'Results' and conclusions in Section 'Discussion and conclusions'.

Methodology

Jet stream analysis

Wind data were used from climate model simulations of the present-day and future climates from the Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble (Taylor et al., 2012). These data are freely available through the Earth System Grid Federation (http://pcmdi9.llnl.gov/esgf-web-fe/). For the purposes of this study, daily-mean wind data were used. Of the few pressure-levels at which daily data are available, only 250 hPa, which equates to a pressure altitude of 34,000 ft, corresponds to typical aircraft cruise altitudes (the nearest alternative levels in the CMIP5 data archive are well above and below the range of standard aircraft cruise altitudes); hence model data on a pressure-level of 250 hPa were used here. Data were used from two experiments: to study the present-day climate, data were used from the historical simulation, for the period 1979–2005, and to study the impact of climate change data were used from the representative concentration pathway 8.5 scenario (RCP8.5) for the period 2073–2099. The historical simulation replicates the present-day climate by

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