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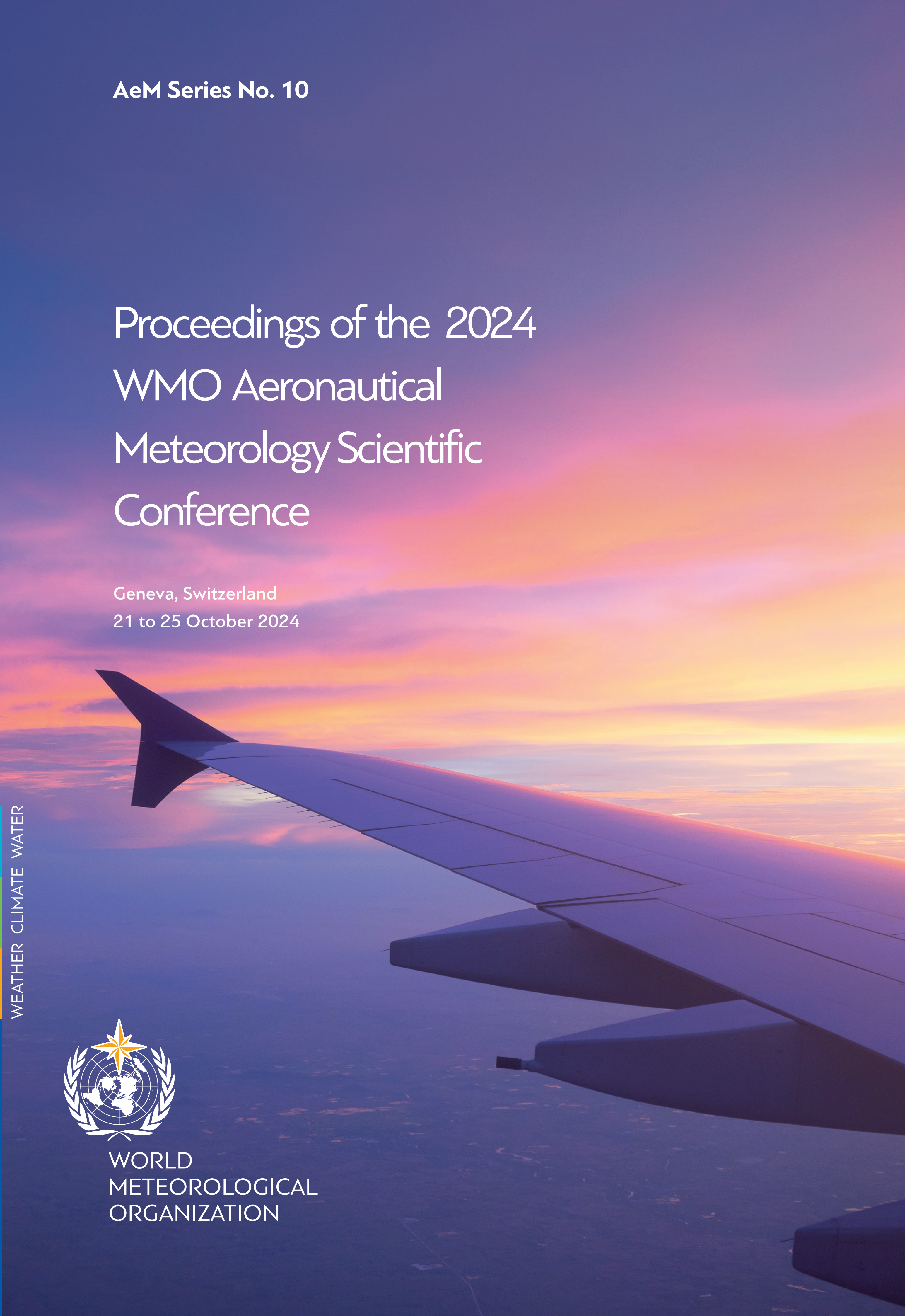

# Proceedings of the 2024 WMO Aeronautical Meteorology Scientific Conference

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# QUANTIFYING INCREASED AIRCRAFT TAKE-OFF DISTANCES UNDER CLIMATE CHANGE AT EUROPEAN AIRPORTS

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Presented by Dr Jonny Williams

Link to presentation

Climate change is already having a noticeable effect on several aspects of air travel, such as reduced take-off mass and increased required runway length (Gratton et al., 2020), as well as an increase in turbulence (e.g. Williams et al., 2013). In this work, we present results delivered as part of the European Union, and Single European Sky Air Traffic Management Research (SESAR) joint undertaking-funded Advancing Measures to Reduce Aviation Impact on climate and enhance resilience to climate-change (AEROPLANE) project (https://www.sesarju.eu/projects/AEROPLANE).

Using future simulations of the period 2035–2064 from an ensemble of climate models from the 6th Coupled Model Intercomparison Project, CMIP6 – as well as historical (1985–2014) data from the same models – we are investigating how take-off distance required is projected to change in the future for 30 European airports. The sites were chosen to include the 25 busiest airports (as defined by the European Civil Aviation Council in 2019) plus 5 which are experiencing issues related to take-off performance or noise pollution already (e.g. RomeToday, 2023).

All data shown here are for an Airbus A320 at maximum payload for summer (June–July–August, JJA) using UKESM1-0-LL climate model data for Brussels Zavantem Airport (International Civil Aviation Organization code EBBR). An upcoming publication will discuss the wider model ensemble as well as quantifying future maximum take-off mass (MTOM) changes.

The climate models which were chosen are as follows (see https://www.ipcc.ch/report/ar6/wg1/ for more information):

1. ACCESS-ESM1-5 (CSIRO Commonwealth Scientific and Industrial Research Organisation, Australia).
2. CMCC-ESM2 (CMCC Centro Euro Mediterraneo sui Cambiamenti Climatici, Italy).
3. CNRM-ESM2-1 (CNRM Centre National de Recherches Météorologiques and CERFACS Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique, France).
4. CanESM5 (CCCMa Canadian Centre for Climate Modelling and Analysis, Canada).
5. EC-Earth3 (EC-Earth Consortium Europe).
6. GFDL-ESM4 (NOAA-GFDL National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, USA).
7. IPSL-CM6A-LR (IPSL Institut Pierre Simon Laplace, France).
8. MPI-ESM1-2-LR (MPI-M Max Planck Institute for Meteorology, Germany).
9. NorESM2-LM (NCC NorESM Climate Modelling Consortium, Norway).
10. UKESM1-0-LL (MOHC Met Office Hadley Centre, UK).

These models span a range of values of equilibrium climate sensitivity, that is, the rate of change of temperature with respect to increasing greenhouse gas concentrations (e.g. Cox et al., 2018).

When comparing the future projection simulations to historical data, we use three Shared Socioeconomic Pathways, or SSPs: SSP1-2.6 (*sustainability*), SSP3-7.0 (*regional rivalry*), and SSP5-8.5 (*fossil-fuelled development*) (O'Neill et al., 2017). SSP1-2.6 is the lowest emissions future, and SSP5-8.5 is the highest. The use of these different scenarios allows for an exploration of the inherent uncertainties present in future greenhouse gas emissions.

The study of Trentini et al. (2023) describes the bias-correction pipeline used in generating the input data used in this study. We also use a Quantile Delta Mapping step here (e.g. Cannon et al., 2015) and the daily maximum temperature (maximum temperature at 2 metres in the last 24 hours (mx2t24), https://codes.ecmwf.int/grib/param-db/) and surface pressure at each site are used to calculate the air density.

This is done using the ideal gas law, $P = \rho \cdot R \cdot T$, where $P$ is the air pressure, $\rho$ is the air density, $R$ is the specific gas constant for air, and $T$ is the temperature (2 m above the ground). Future work will also take the effects of changing specific humidity into account.

We use an adapted version of the model for take-off distance required (TODR) from the work of Gratton et al. (2020). This model calculates the net force balance (drag versus thrust horizontally; lift versus weight vertically) on an aircraft accelerating from rest with constant thrust until the lift exceeds the weight, resulting in take-off. We use open access data from the aircraft manufacturer and the openAP database (Sun et al., 2020) throughout.

Figure **16** shows box and whisker plots of the TODR for the historical and future projection periods for Brussels Zavantem Airport using UKESM1-0-LL data in JJA. It shows that (due to climate-change) median take-off distances may increase by up to ≈70 m by mid-century, albeit with considerable day-to-day variability, as indicated by the 'whiskers' and outliers in Figure **16**.

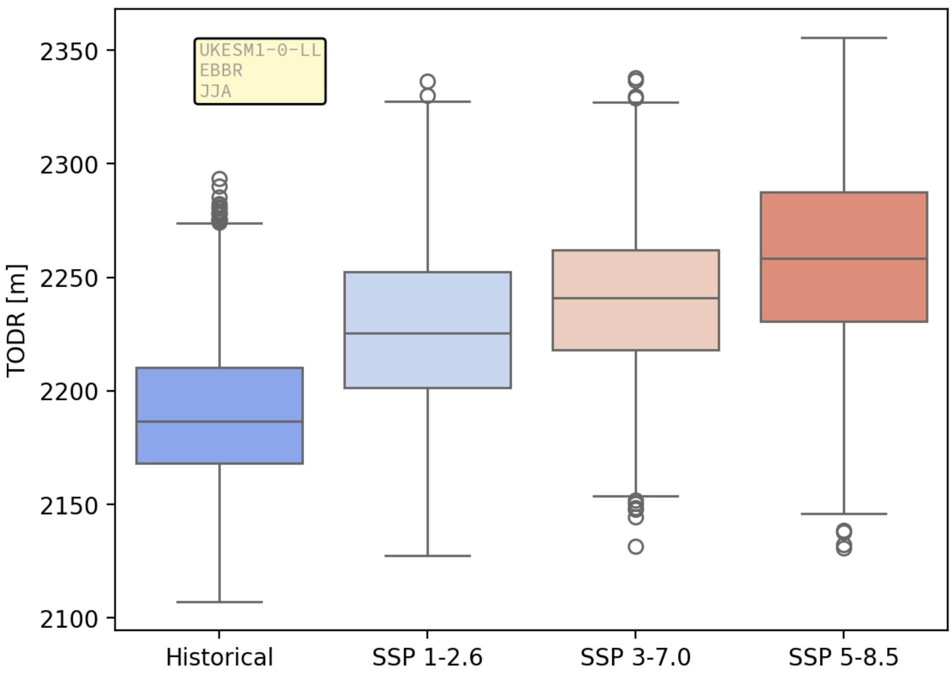


**Figure 16. Box and whisker plots of TODR for Brussels Zavantem Airport using the UKESM1-0-LL climate model in JJA for the historical and future simulations. For each dataset, the central horizontal line is the median, the box's height is the interquartile range and the bars ("whiskers") show the rest of the distribution, with the exception of those data points which are more than 1.5 times the interquartile range away from the median.**

The temperature is not the only input changing, however; air pressure is, too. Figure **17** shows a scatter plot illustrating how the calculated TODR depends on both temperature and air pressure for the historical period. Note that air pressure alone can account for over 50 m of TODR variability, e.g. at 20 °C, as indicated by the yellow arrow in Figure **17**.

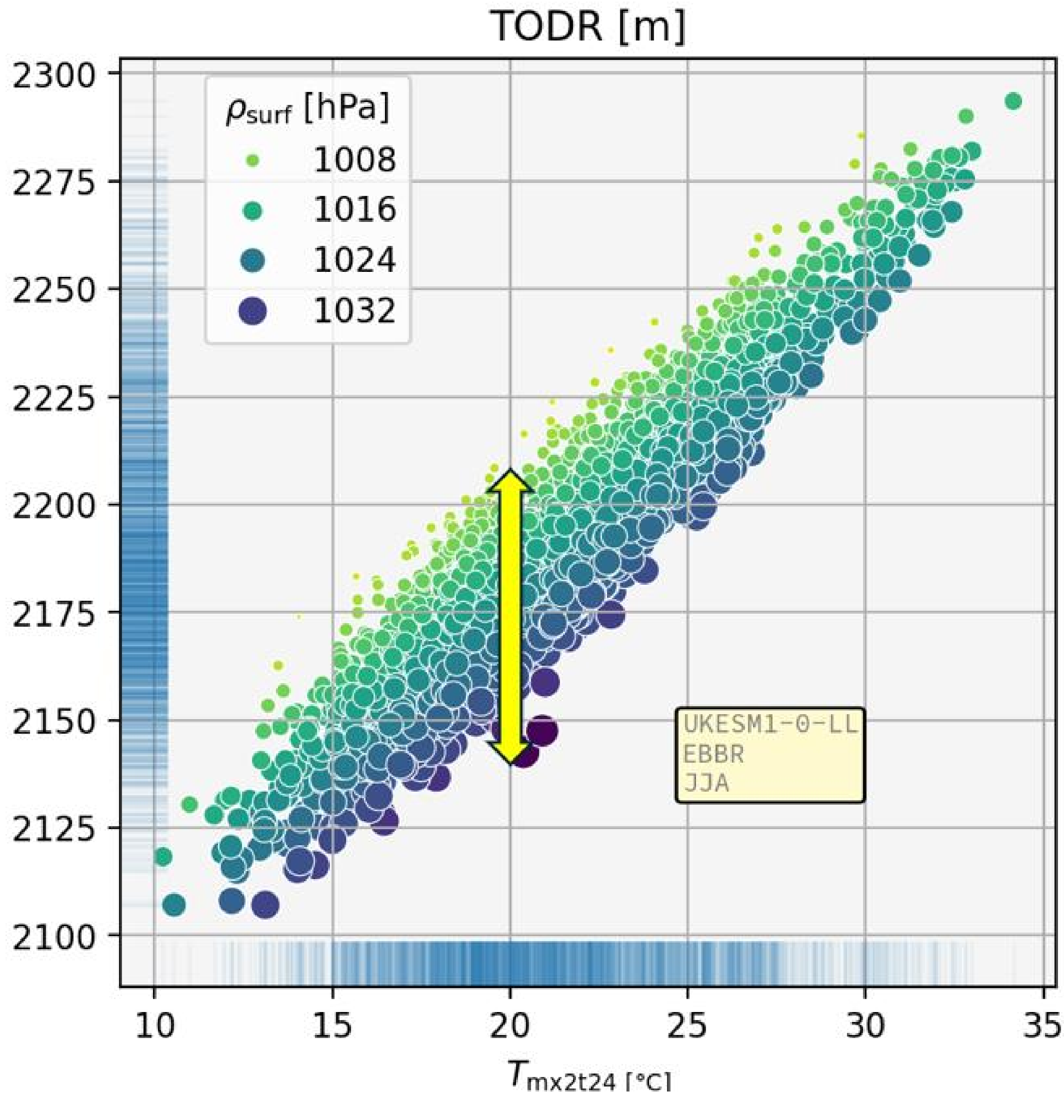


**Figure 17. Scatterplot of TODR as a function of daily-maximum temperature and air density (symbol colours and sizes) for Brussels Zavantem Airport in JJA using UKESM1-0-LL. The yellow vertical arrow indicates the range of variability in TODR for a given temperature of 20 °C (see main text).**

Finally, Figure **18** shows the temperature and TODR distributions separately and illustrates that, as well as the increase in overall (peak) TODR, the shape of the distribution is also subject to change. This is in agreement with robust literature predictions on the shifts of extreme temperature distributions in the future (e.g. Zhang et al., 2022).

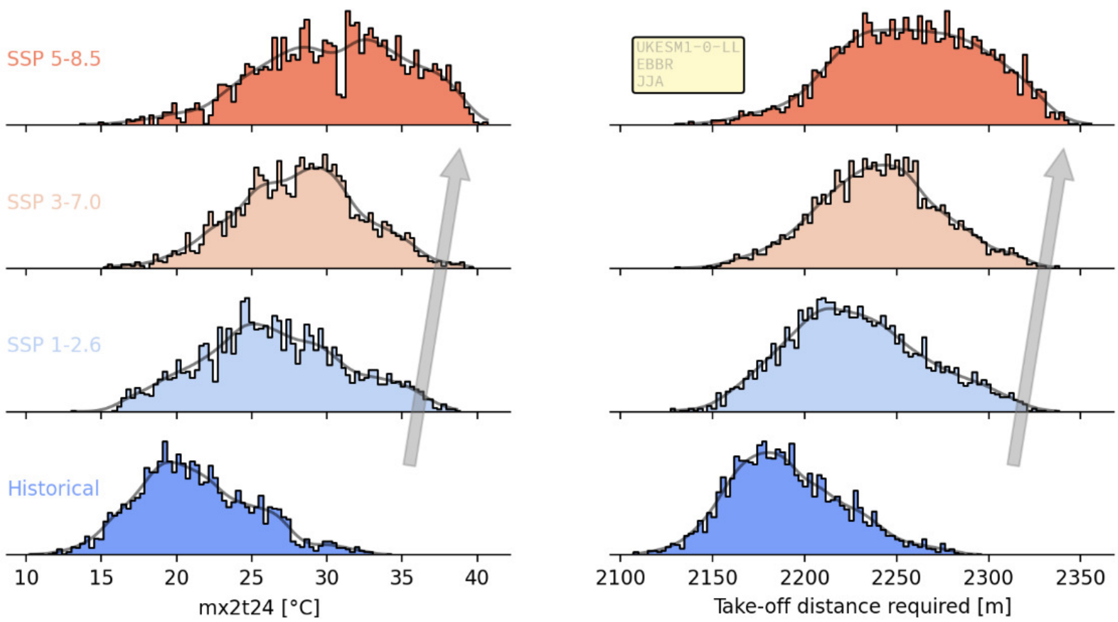


**Figure 18. Daily maximum temperature (left) and TODR (right) distributions for Brussels Zavantem Airport using the UKESM1-0-LL climate model in JJA. The arrows illustrate increased greenhouse gas forcing.**

This work has important implications for future runway planning and utilization metrics and fuel usage forecasting and will predominantly affect airports with runways which are already length limited, that is, where required take-off distances are comparable to or longer than runways.

However, airports with longer runways will be affected too since take-off accelerations do not always start at runway extrema.

There are also other climate change-induced consequences for airport operations such as noise management during take-off (due to changing climb angles and sound propagation properties) and this is the subject of ongoing work.

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