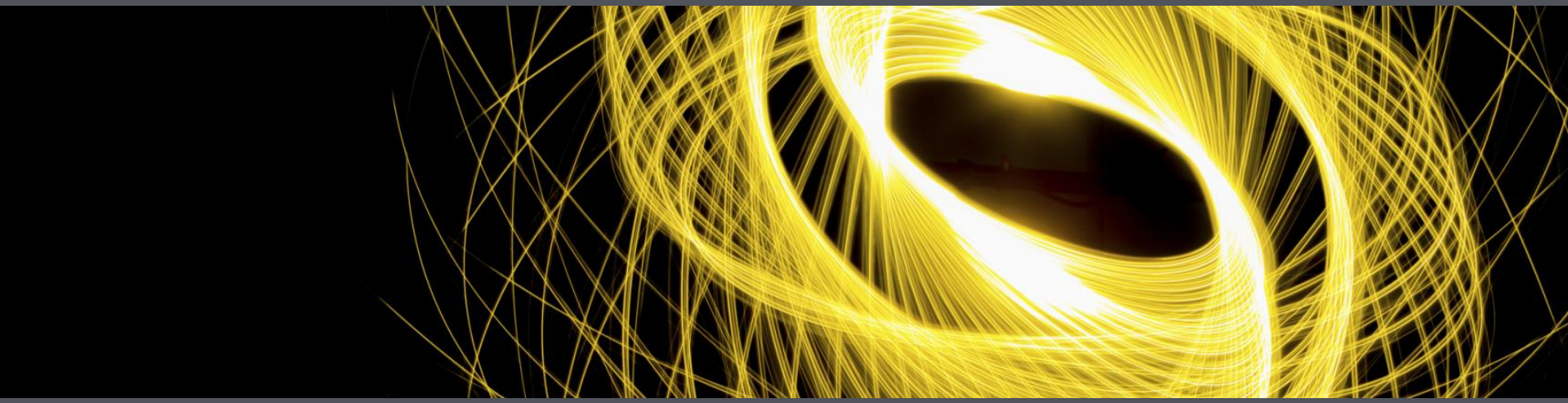
Quantifying the effects of climate change on aircraft take-off performance at European airports

2025 NZ Aviation Meteorology Symposium, February 2025



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Motivation

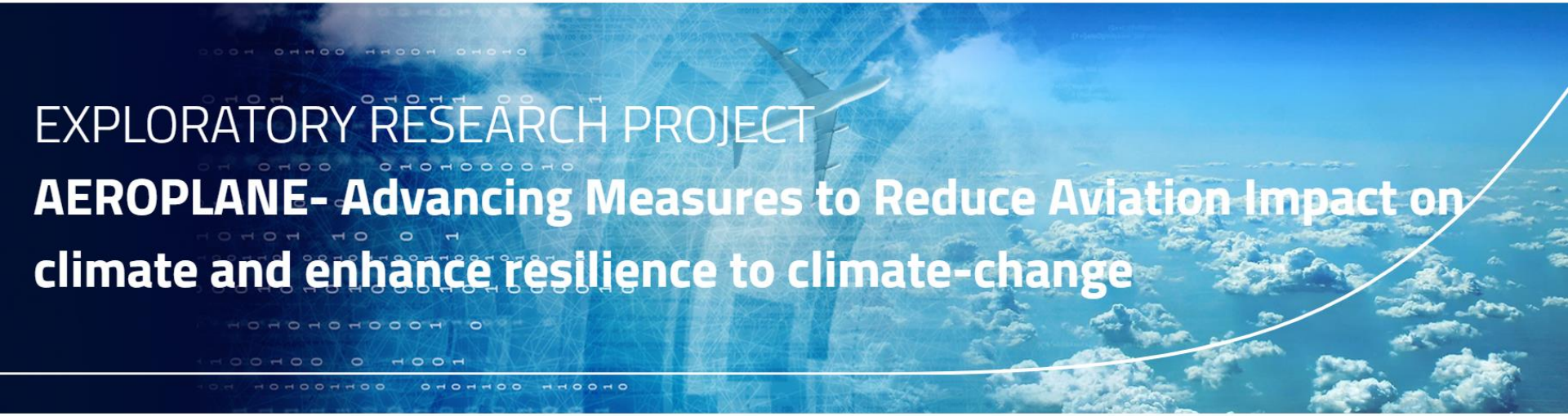
AIRPORTS

British Airways kicks 20 passengers off flight because heat wave made plane too heavy

By Guy Birchall · **The Sun**

Published July 29, 2018 12:30pm EDT | Updated July 29, 2018 12:37pm EDT

AEROPLANE project



1.Quantify the impact of contrails on cirrus clouds and deepen the understanding of aviation non-CO2 effects on climate;

2. Identify the most relevant climate metrics to assess and predict the aggregated impact of CO2 and non-CO2 emissions on climate change;

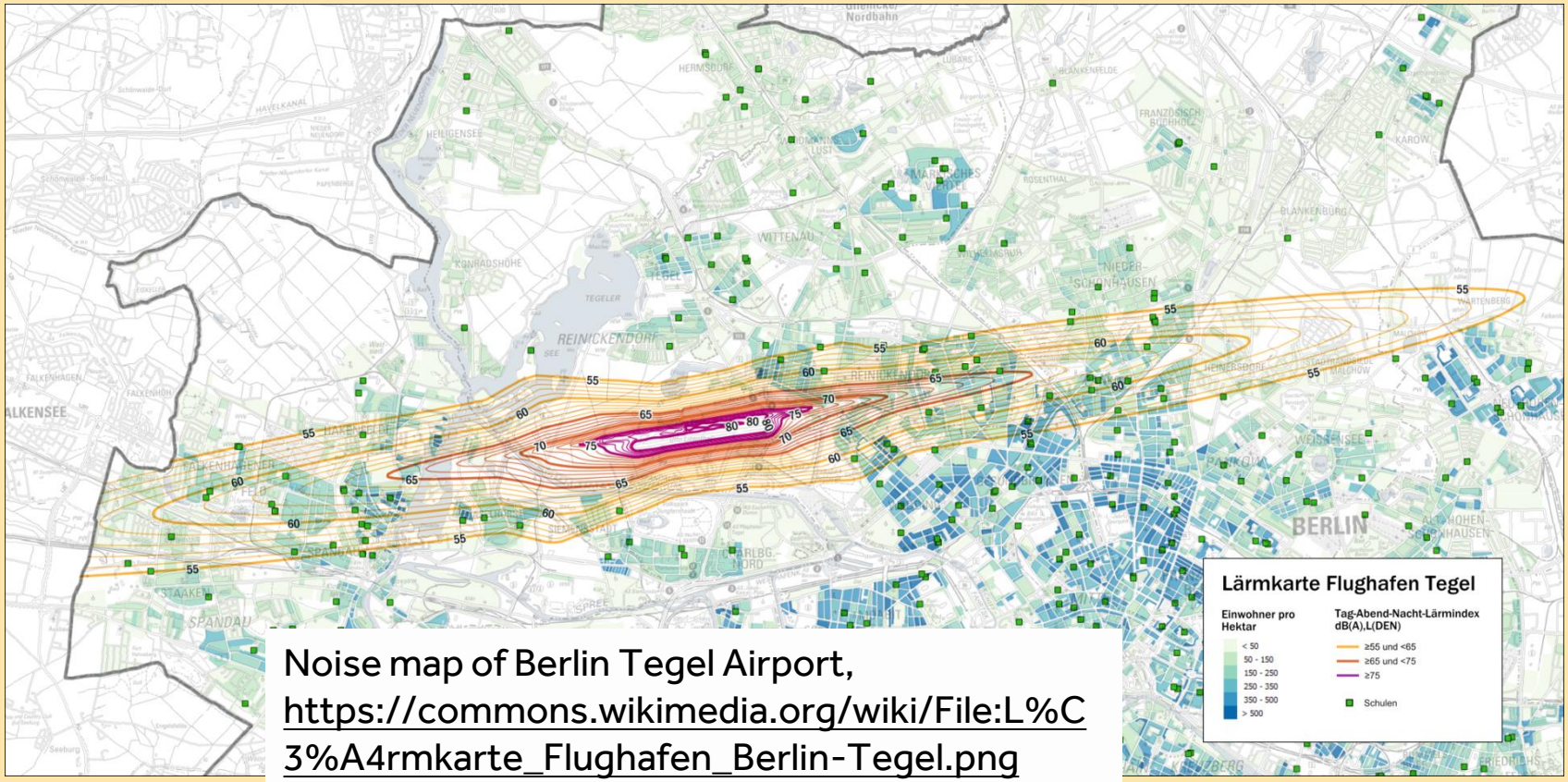
3. Quantify the impact of climate change on aviation focusing on the impact of higher temperatures on aircraft performance during take-off

4. Create user-centric, innovative services for a greener and more climate-resilient aviation

https://www.sesarju.eu/projects/AEROPLANE

Take-off performance study areas

1. Take-off distance required – TODR.
2. Maximum take-off mass – MTOM.
3. Noise pollution. This work is underway and will not be discussed further here.

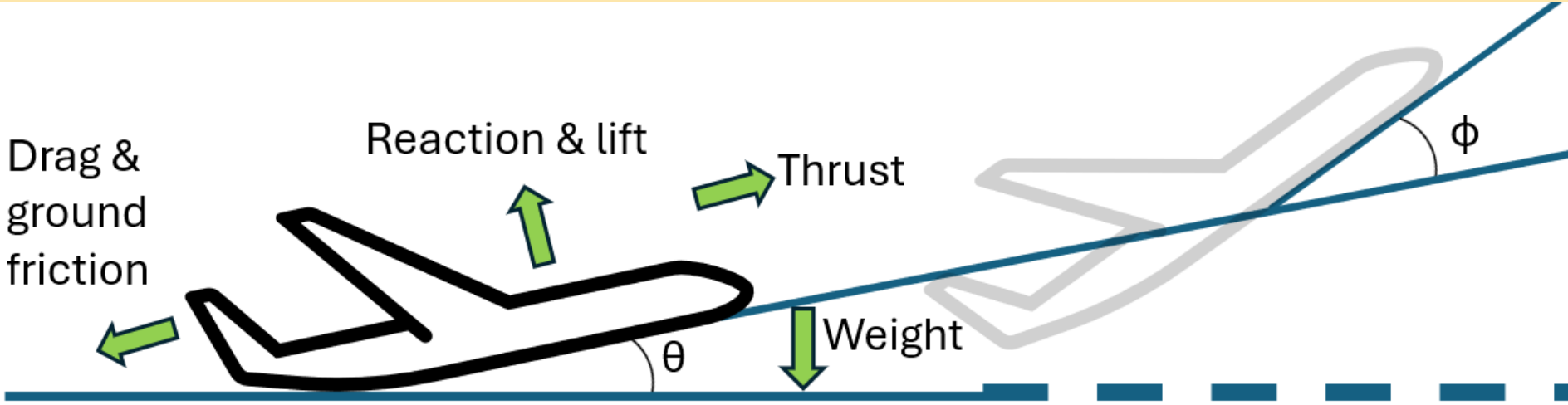


Noise map of Berlin Tegel Airport, https://commons.wikimedia.org/wiki/File:L%C3%A4rmkarte_Flughafen_Berlin-Tegel.png

Take-off distance calculation

```python
def TODR(
    m=defaultm,
    rho=defaultrho,
    CL=defaultCL,
    deltav=deltav,
    Hp=Hp,
    vmax=150,
    printHp=False,
    use_openap=True,
    tas=tass[1],
):

    if printHp:
        print("Hp = " + str(Hp))

    VTAS = np.arange(0, vmax, step=deltav)

    myDict = {}

    if use_openap:
```

- Python
- Jupyter notebooks
- openAP (www.openap.dev)
- Seaborn (https://seaborn.pydata.org/)
- Airbus A320
- Model adapted from Gratton et al., 2020, appendix 2.

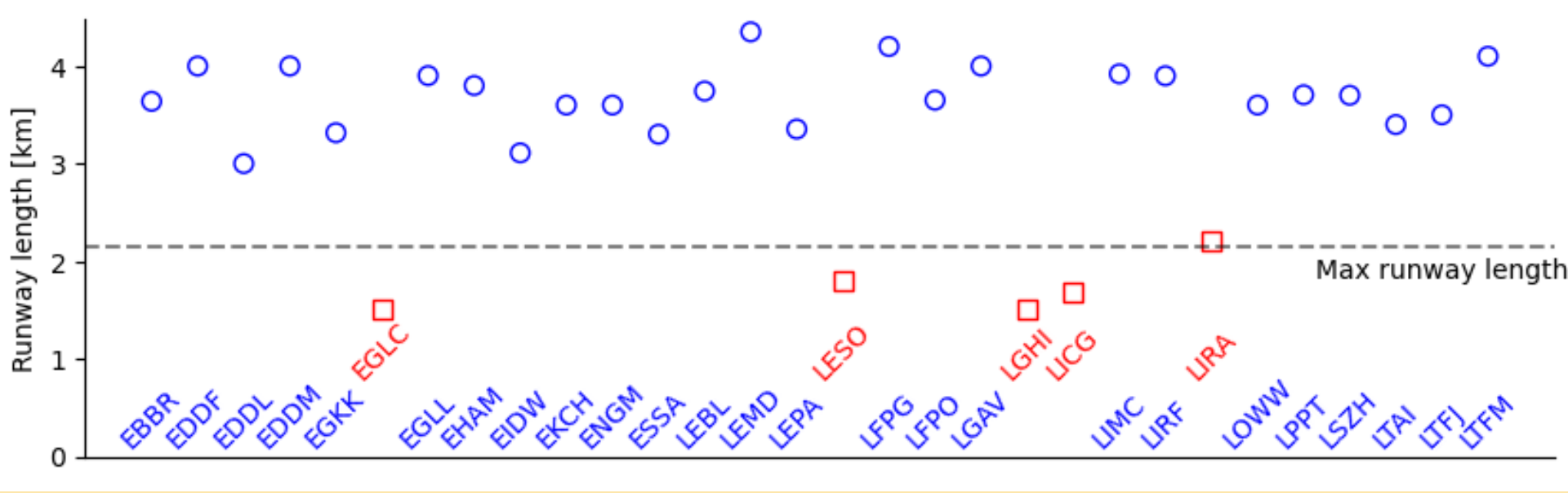


Study sites


EGLL
EGLC
EGKK
ENGM
ESSA
EKCH
EIDW
EHAM
EBBR
EDDL
LFPG
EDDF
LFPO
EDDM
LOWW
LSZH
LIMC
LESO
LIRA
LIRF
LTFM
LTFJ
LEBL
LEMD
LEPA
LPPT
LGAV
LGHI
LICG
LTAI

Runway lengths

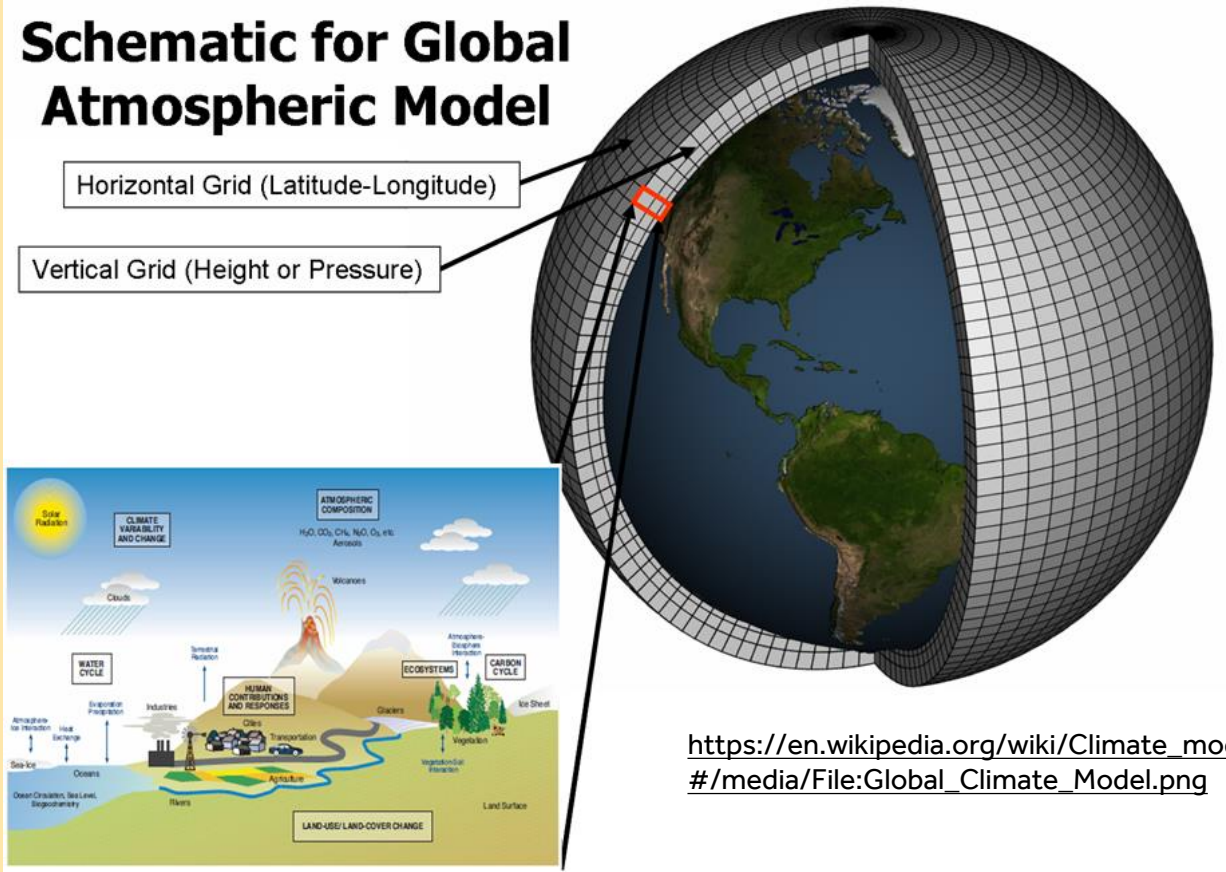
- The maximum runway length for a fully laden Airbus A320 in the figure below was calculated using the international standard atmosphere.



Climate model results

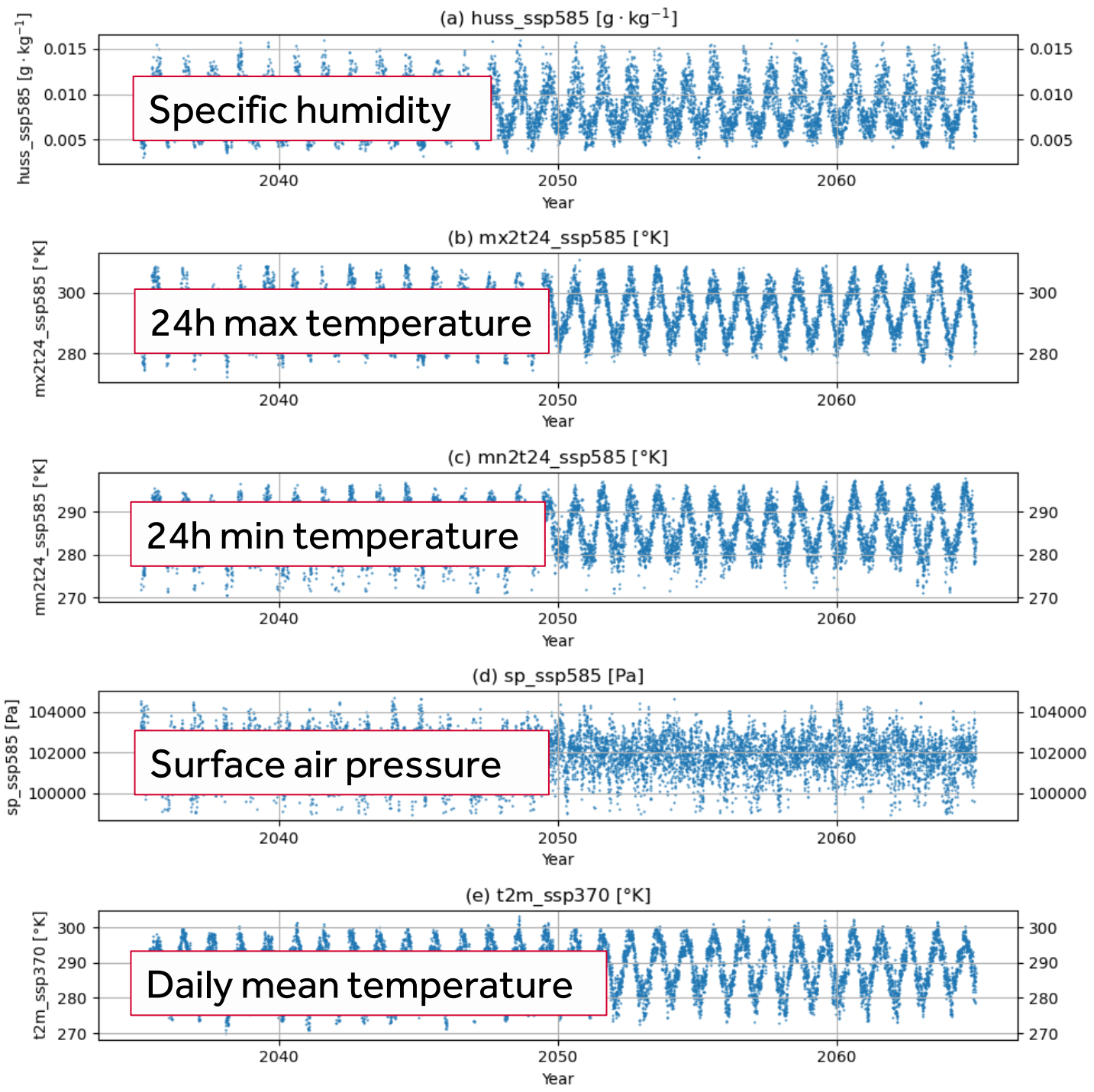
- All climate model is freely available to download from the Earth System grid Federation (ESGF).

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

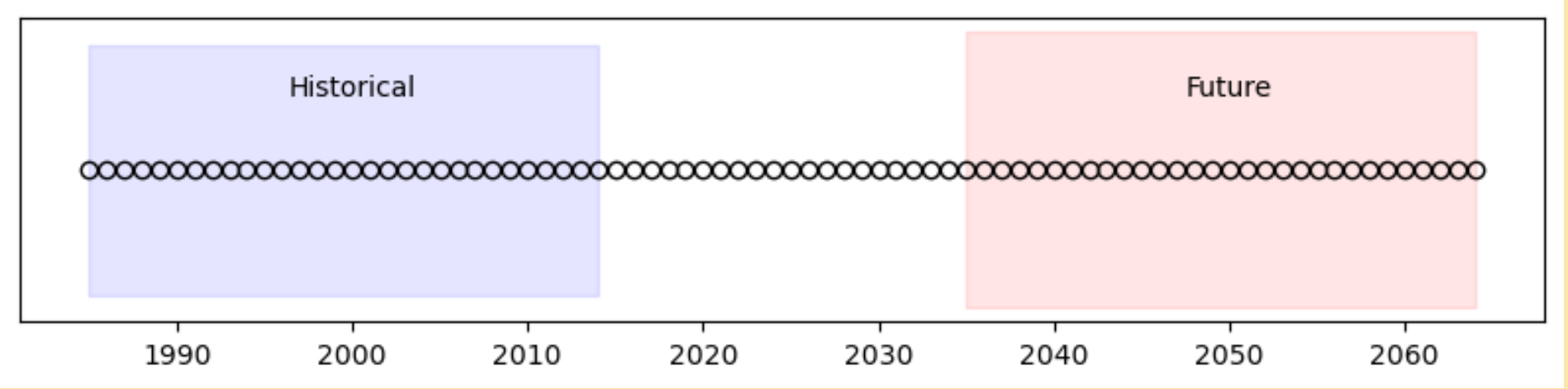


https://en.wikipedia.org/wiki/Climate_model#/media/File:Global_Climate_Model.png

- Example model data for Heathrow airport and the UKESM1-0-LL model.
- All data shown in the remainder of this presentation is for (northern hemisphere!) summer, JJA.

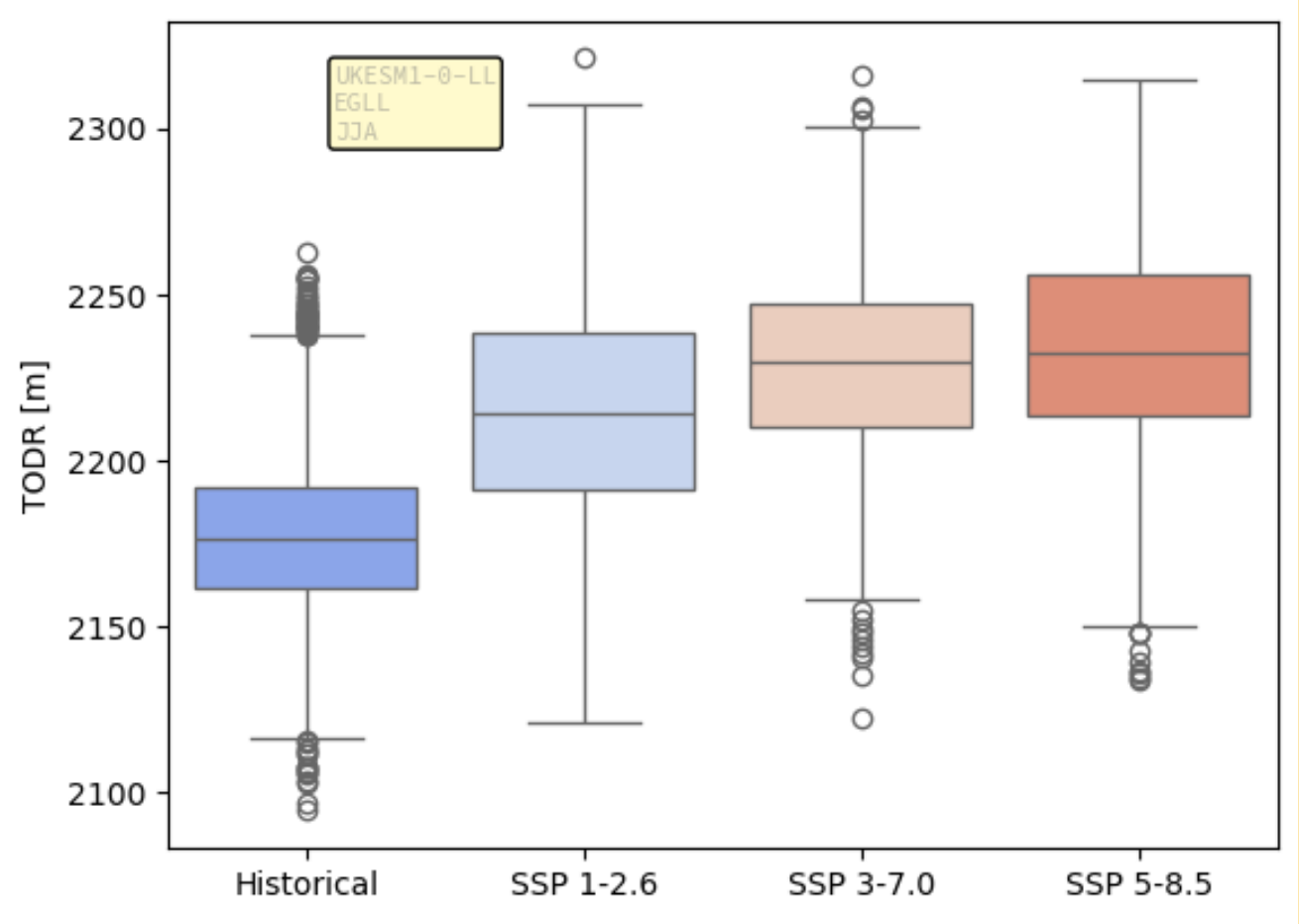


Definition of time periods used



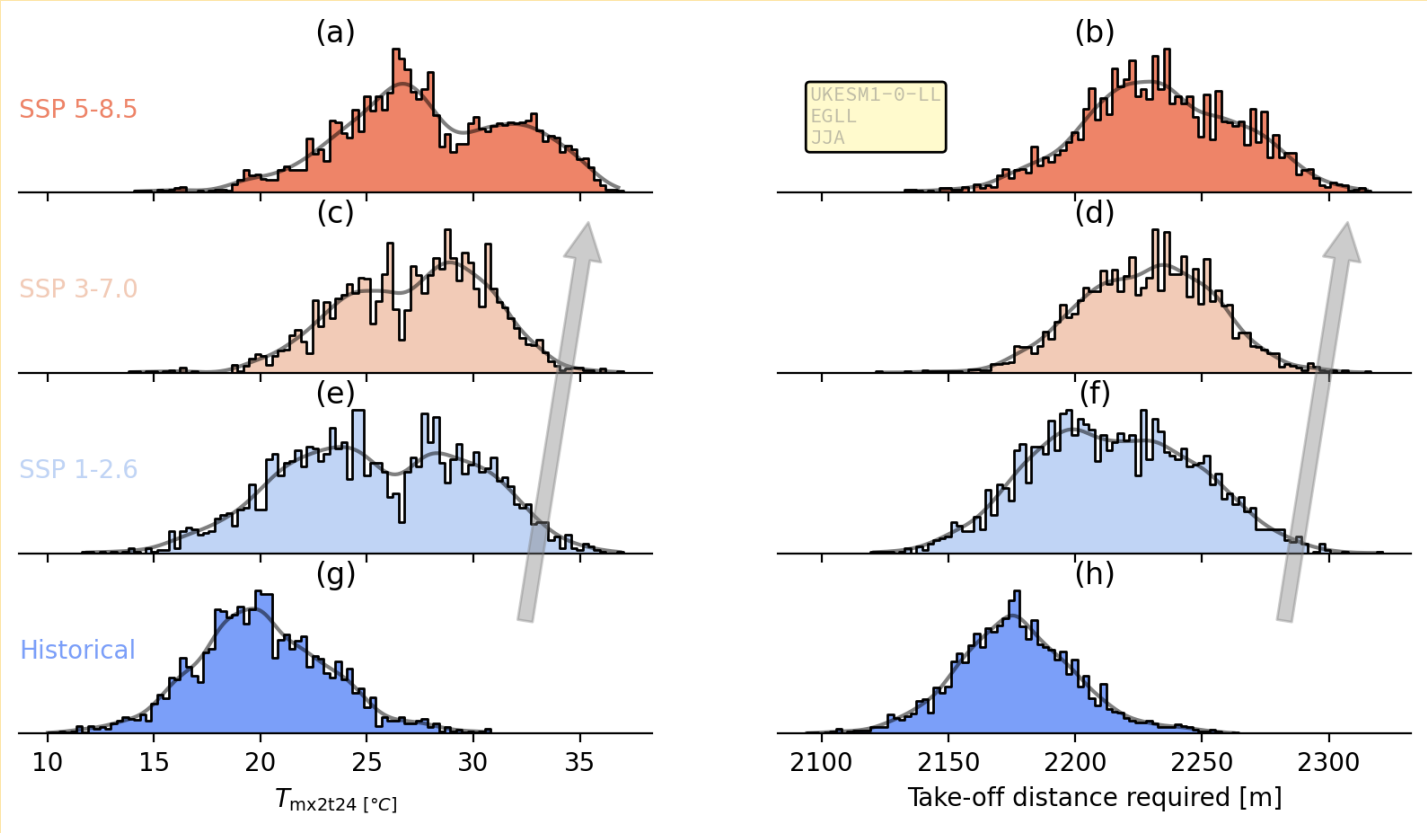
Historical and projected TODRs

Mean values are increase by approximately 50m but the range of values is large, almost 200m in some cases.



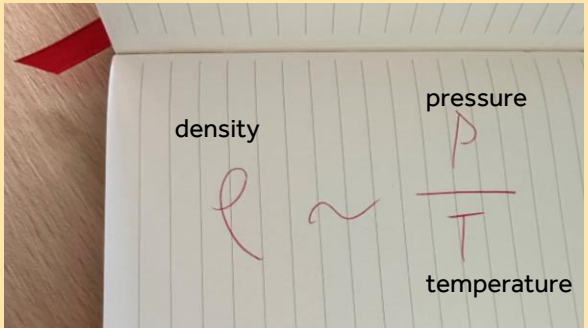
Distributions of TODR and daily maximum temperature

- The increase in the median value temperature is – to a large extent – reflected in the increases in the TODR values.

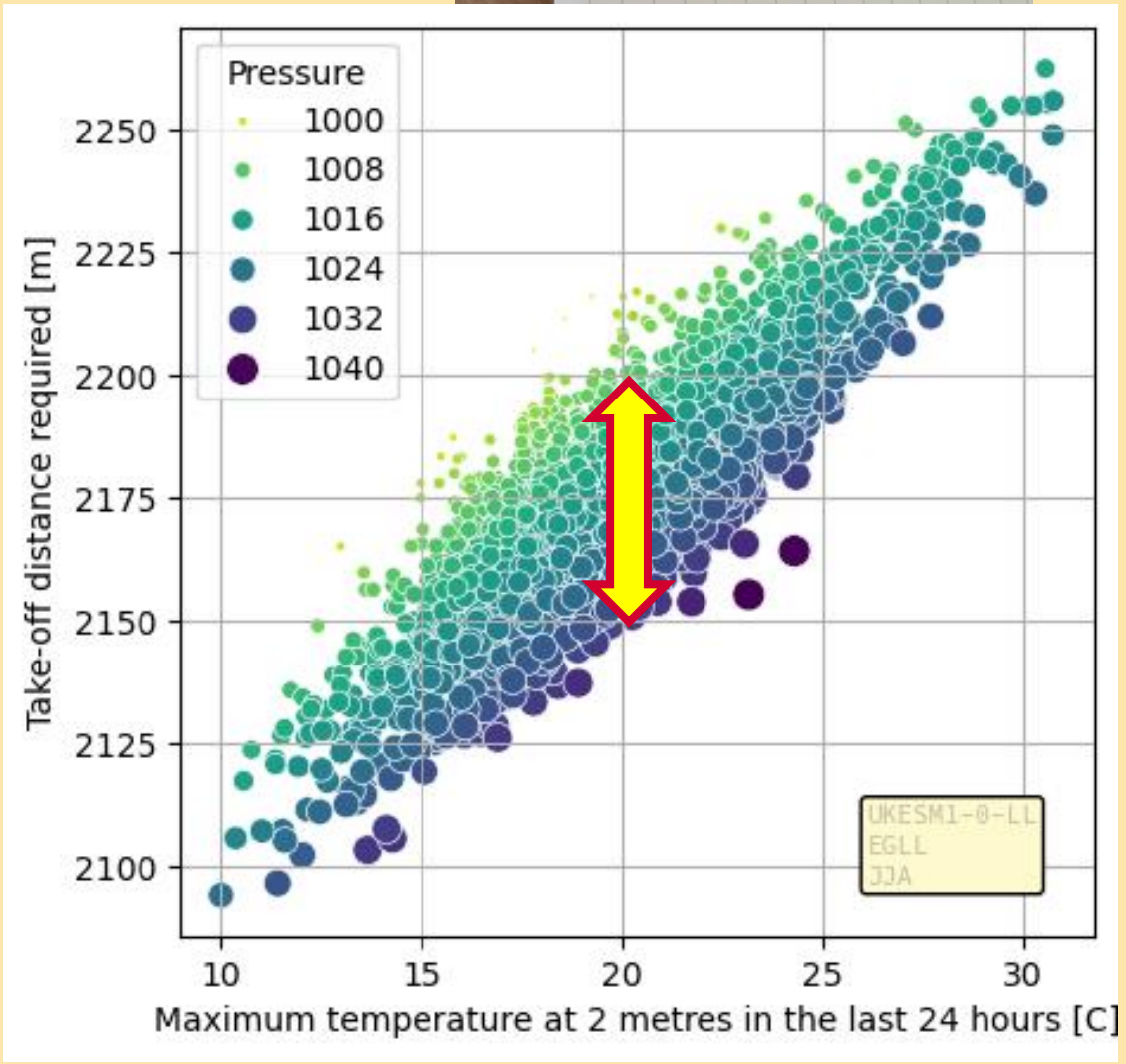


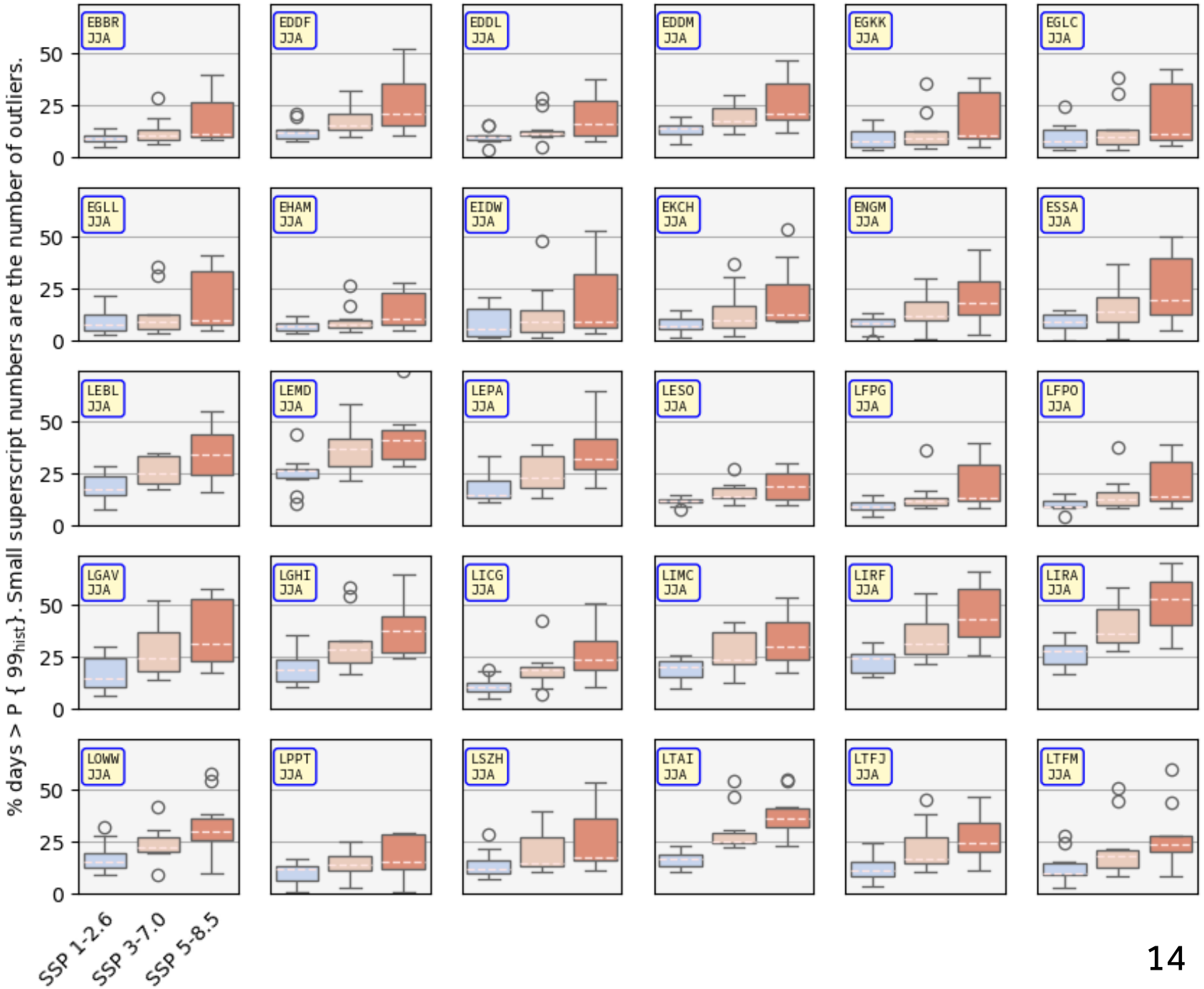
- Note also however that the shapes of the distributions change significantly with warming, reflecting the changes to the distribution in, for example, extreme hot days in the future.

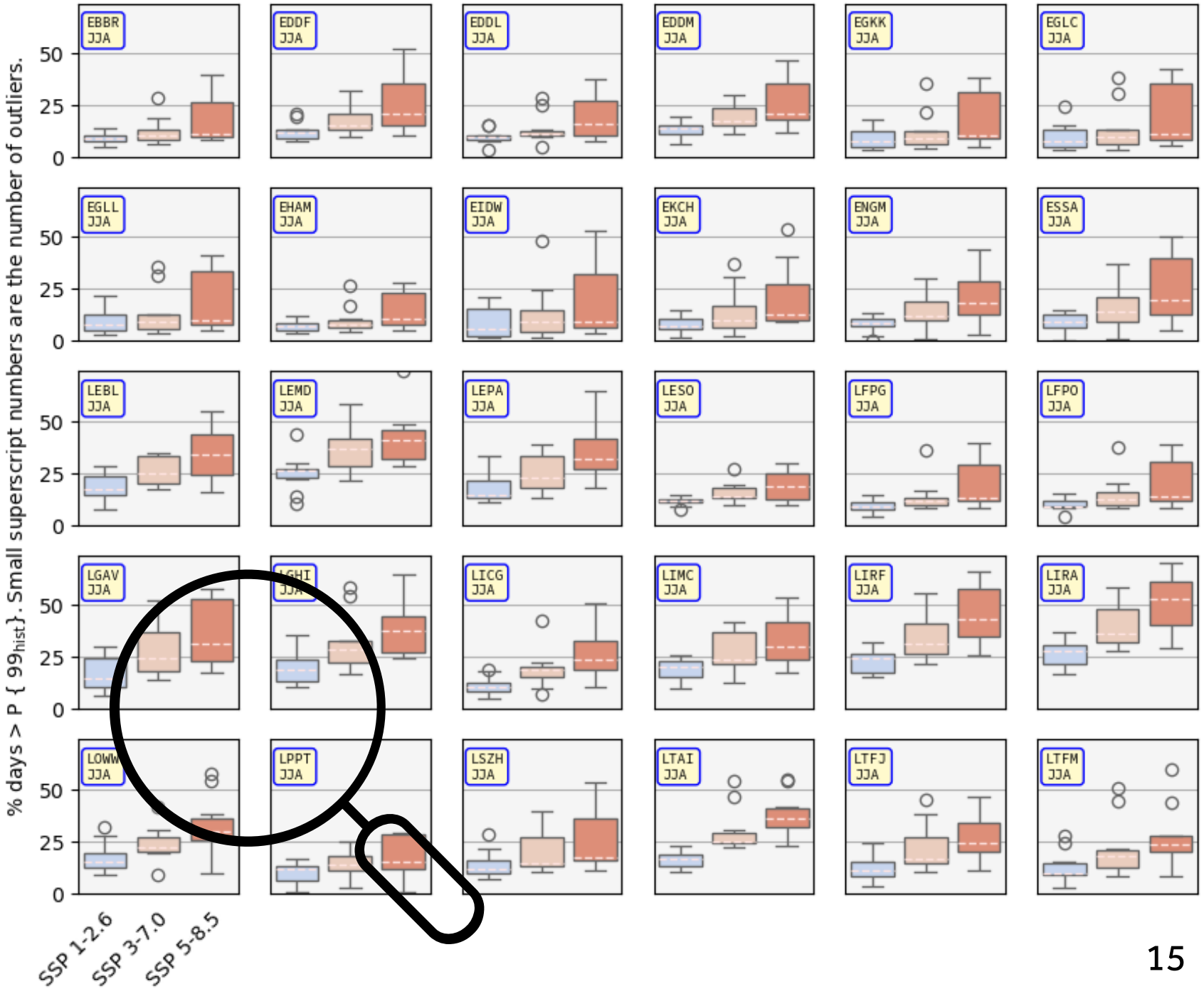
What about the air pressure?



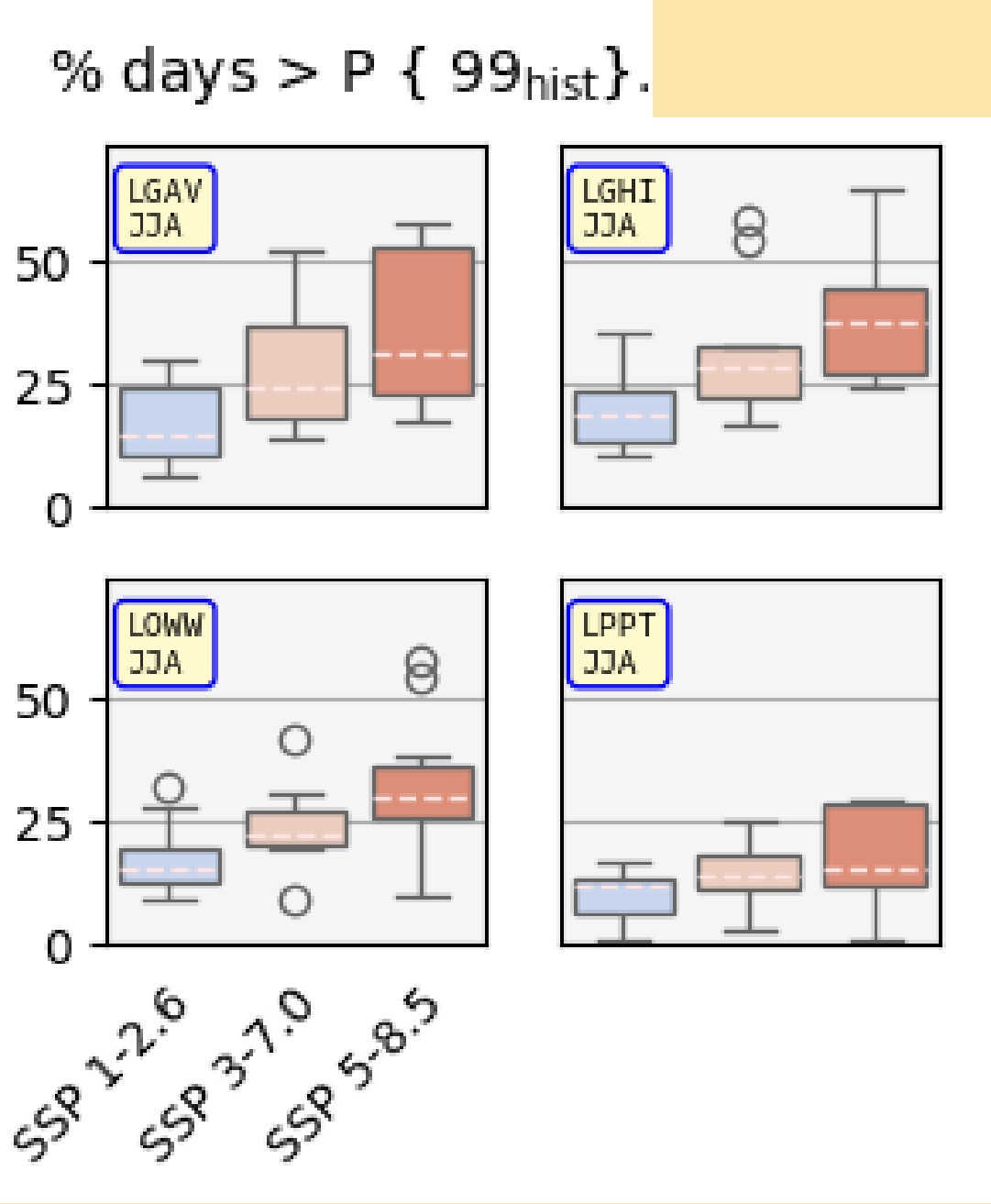
- Although the changes to air temperature are often what we tend to personally 'notice' on a given day, it is the air *density* which goes into the calculation.
- For a given temperature, variations in air pressure can account for changes of up to 50m in TODR.




% days > P { 99hist }. Small superscript numbers are the number of outliers.
EBBR JJA
EDDF JJA
EDDL JJA
EDDM JJA
EGKK JJA
EGLC JJA
EGLL JJA
EHAM JJA
EIDW JJA
EKCH JJA
ENGM JJA
ESSA JJA
LEBL JJA
LEMD JJA
LEPA JJA
LESO JJA
LFPG JJA
LFPO JJA
LGAV JJA
LGHI JJA
LICG JJA
LIMC JJA
LIRF JJA
LIRA JJA
LOWW JJA
LPPT JJA
LSZH JJA
LTAI JJA
LTFJ JJA
LTFM JJA
0
25
50
SSP 1-2.6
SSP 3-7.0
SSP 5-8.5

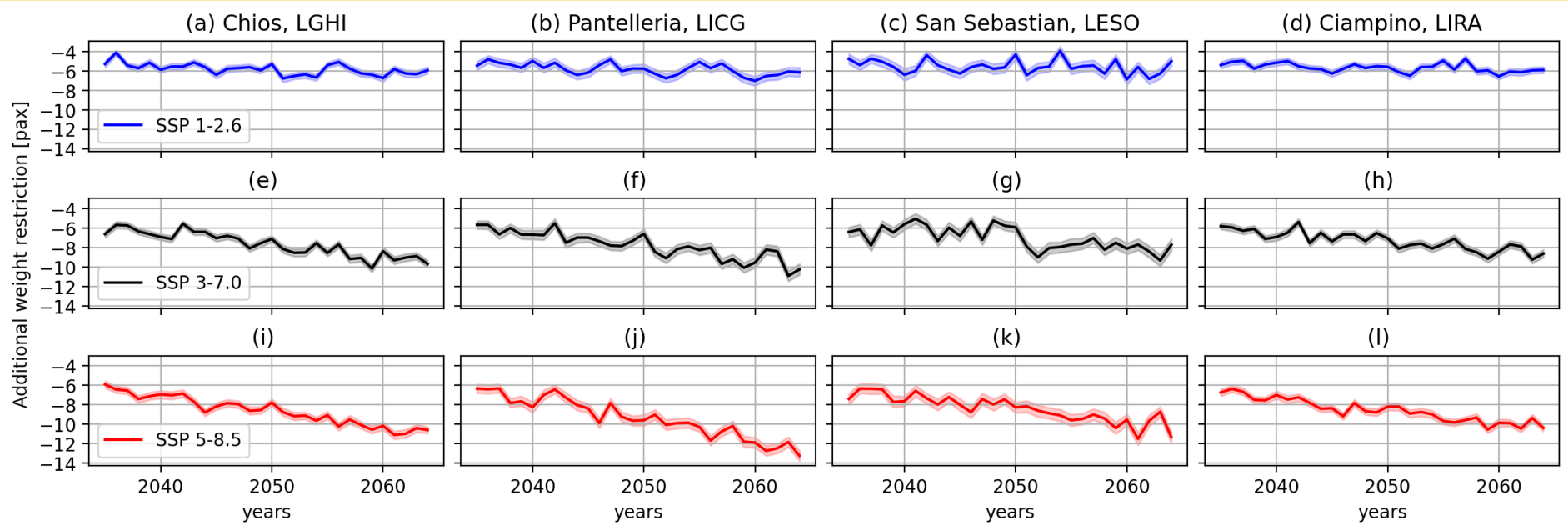

% days > P { 99hist }. Small superscript numbers are the number of outliers.
EBBR JJA
EDDF JJA
EDDL JJA
EDDM JJA
EGKK JJA
EGLC JJA
EGLL JJA
EHAM JJA
EIDW JJA
EKCH JJA
ENGM JJA
ESSA JJA
LEBL JJA
LEMD JJA
LEPA JJA
LESO JJA
LFPG JJA
LFPO JJA
LGAV JJA
LGHI JJA
LICG JJA
LIMC JJA
LIRF JJA
LIRA JJA
LOWW JJA
LPPT JJA
LSZH JJA
LTAI JJA
LTFJ JJA
LTFM JJA
0
25
50
SSP 1-2.6
SSP 3-7.0
SSP 5-8.5

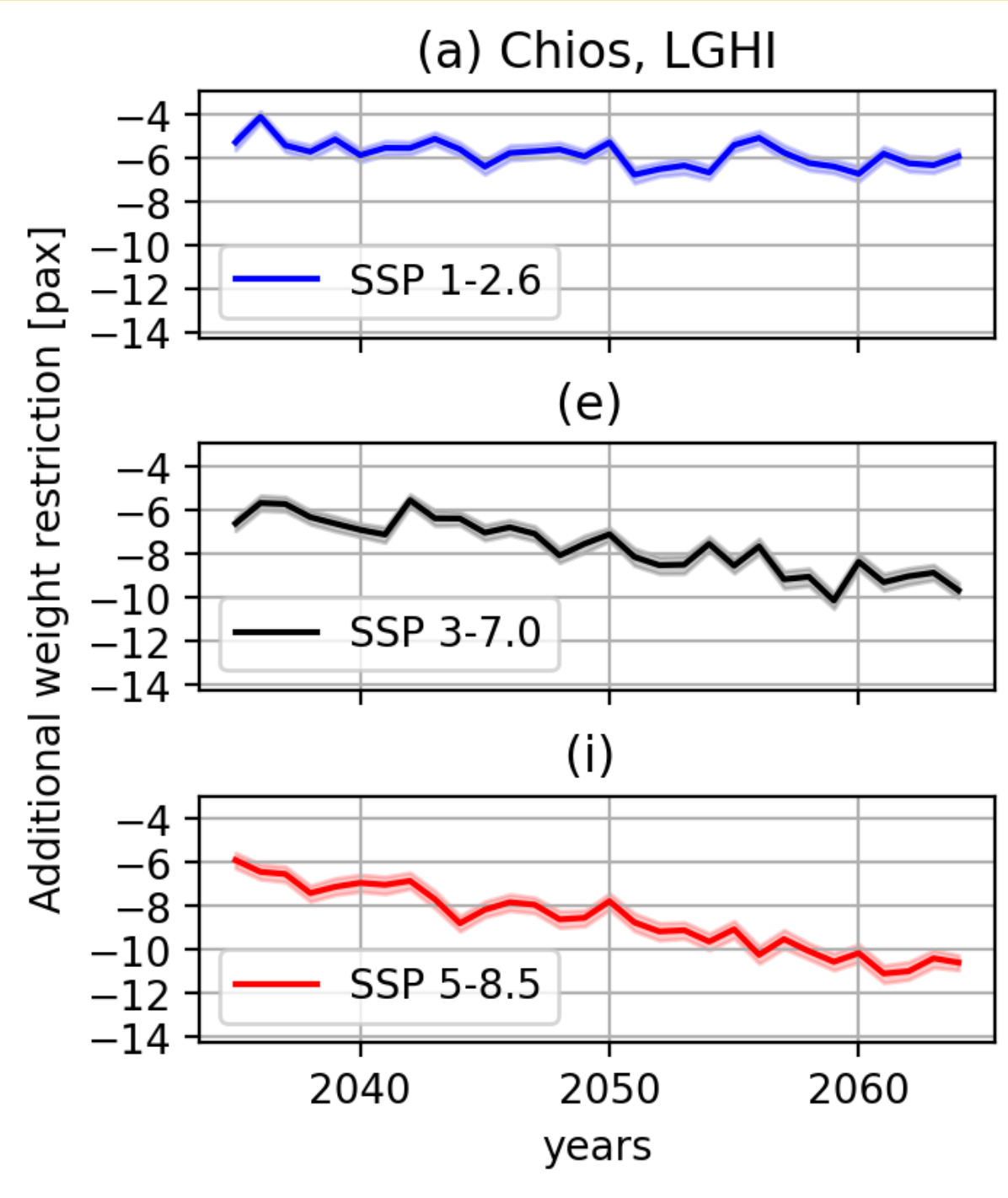
- The 99th percentile represents extreme high TODR values which occur (by definition) 1 day out of a 100, or 1% of the time.
- For some airports, average values of up 50% are projected over the 30-year future periods considered.
- In other words, days with exceptional, 1/100-day conditions historically, may occur up to half the time in the future.
- This is likely to have significant impacts on runway maintenance procedures and will necessitate weight restrictions at airports with short runways.



Maximum take-off mass, MTOM

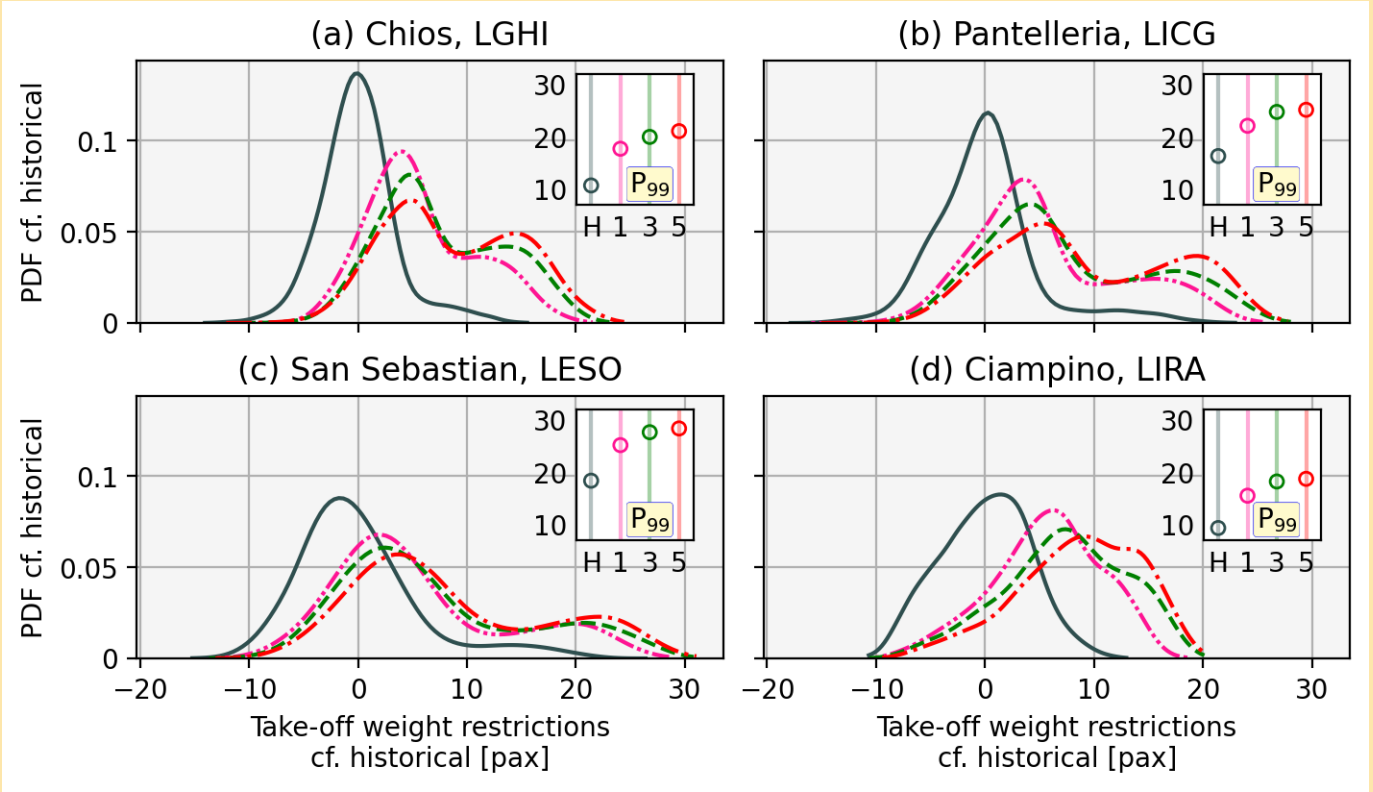
- For airports with short runways, additional – compared to historical values – values of weight restrictions of up to ≈10 passengers equivalent per flight may need to be enforced in the future.




(a) Chios, LGHI
(e)
(i)
Additional weight restriction [pax]
−4
−6
−8
−10
−12
−14
SSP 1-2.6
SSP 3-7.0
SSP 5-8.5
2040
2050
2060
years

Probability distributions of MTOM

- This shows the probability distribution function of individual days' MTOM values, relative to the average historical value at each site.



1. The distribution changes shape significantly with large increases in the number of extreme hot days
2. Extreme values of passenger equivalent weight reductions may exceed 20 passengers per flight by 2065.

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Quantifying the Effects of Climate Change on Aircraft Take-Off Performance at European Airports

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Conclusions

- We have used a take-off performance model to calculate summer take-off distance required for the Airbus A320 for:
  - 30 European airports.
  - 3 possible future emissions scenarios.
  - 10 state-of-the-art climate models.

- Due to climate change, the magnitude *and* distribution of take-off distance required is projected to change significantly, even for comparatively small future warming, and although variability is large, extreme values may be up to ~100m larger in the future.

- Climatic conditions necessitating extreme (99th percentile) runway utilisation are expected to occur as much as half the time in the future.

- Many airports have runways which are more than long enough to cope with this, but at least 4 of our study sites may have to reduce payloads by as much as much as ≈10 passengers per flight by 2065 compared to historical values.

Acknowledgements

- The European Union and SESAR Joint Undertaking for funding.
- Collaborators within the AEROPLANE project at AMIGO Climate, Deep Blue, EUROCONTROL and Reading & Leipzig Universities.
- Helpful discussions with colleagues at several of our study sites.
- You all for your attention and invitation to speak today.