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Changes in sector-specific climate indices: an extension to HadEX3

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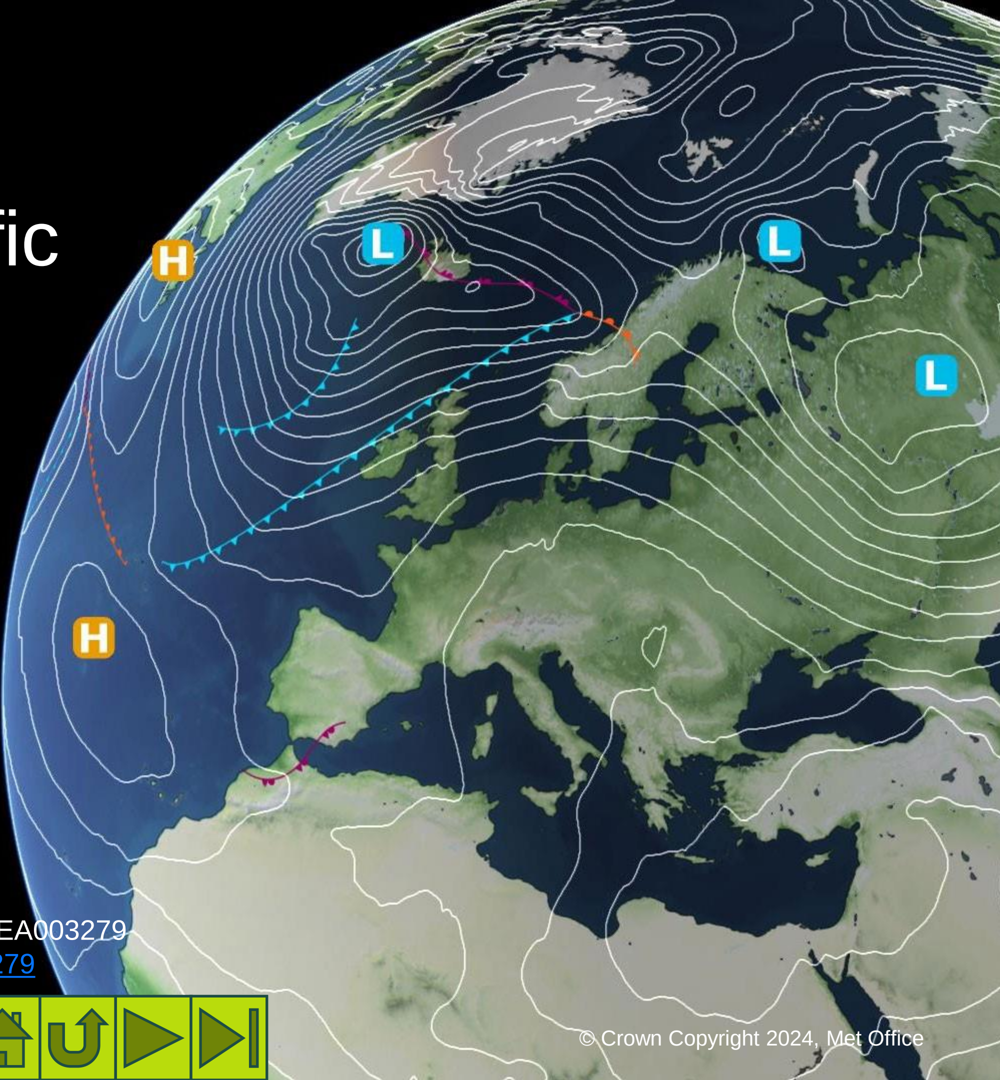

Robert J. H. Dunn, et al., 2024 Earth and Space Science, 11, e2023EA003279
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023EA003279

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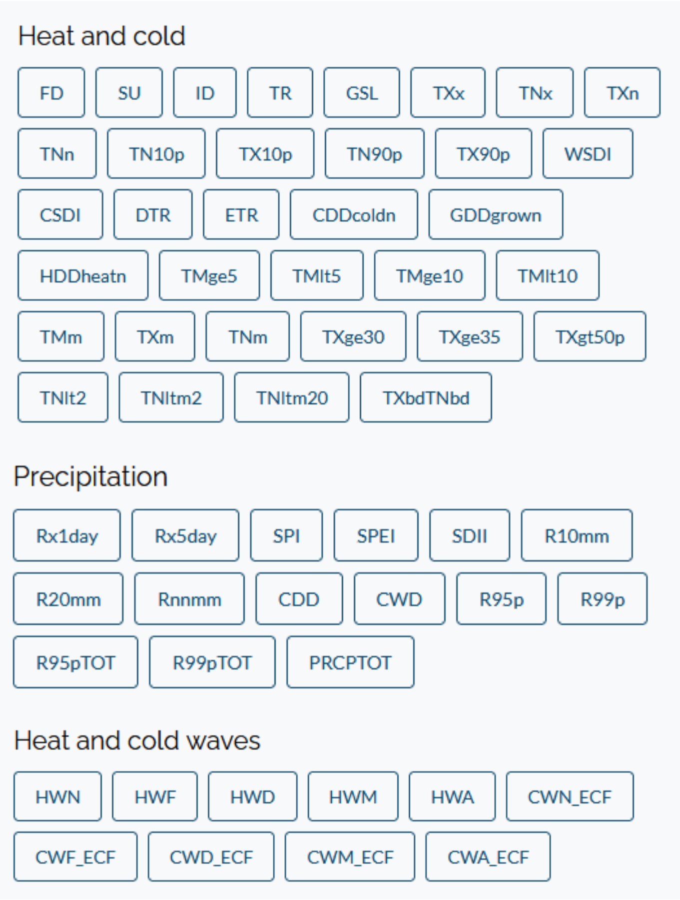
Sector Specific Indices

- The ETCCDI set of climate indices for moderate extremes are widely used
  - Were developed for Detection & Attribution, as well as Climate Monitoring
  - Have a climatological focus
- The WMO ET-SCI have developed additional indices relevant for different sectors
  - Experts from Agriculture, Health, and Water Resources co-developed these additional indices
- Extension to global HadEX3 dataset of gridded extremes indices now includes these extra ET-SCI indices

http://www.metoffice.gov.uk/hadobs/hadex3



https://www.climdex.org/learn/indices/

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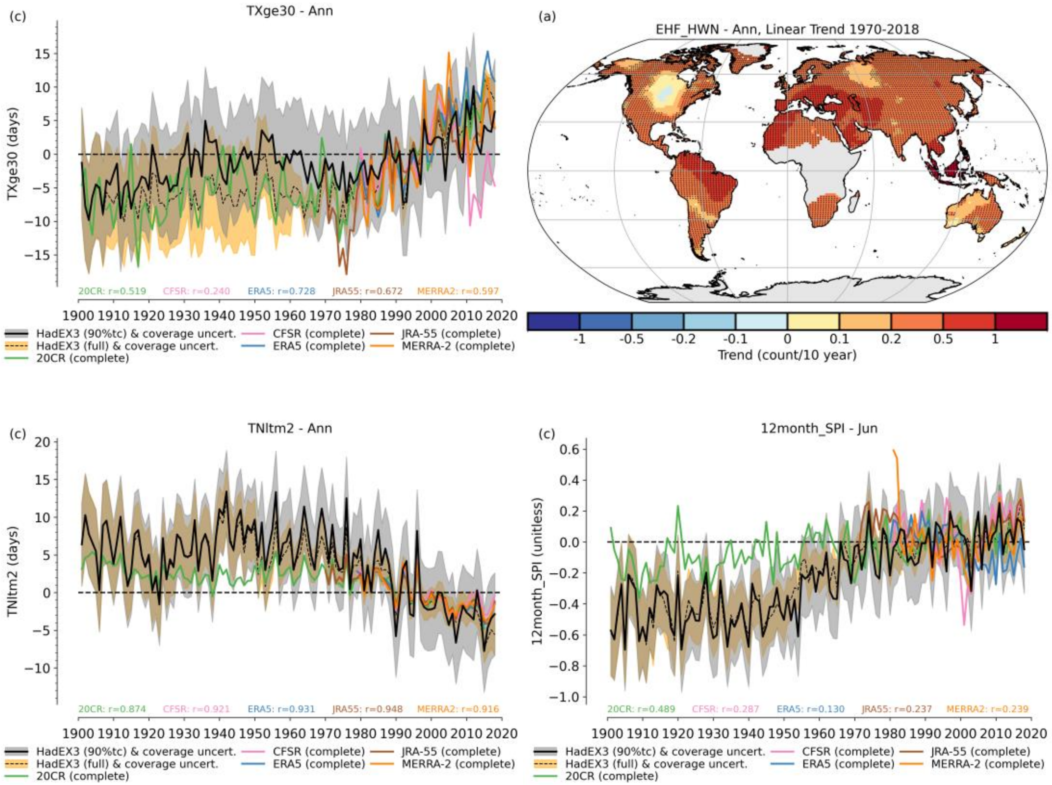
Dunn et al. 2024. *Earth and Space Science*, 11, e2023EA003279
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023EA003279

HadEX3-ETSCI

- [Heat wave indices](#) show widespread increases in intensity, frequency and duration.
- Other temperature indices also consistent with warming world
  - Linked both to health and agricultural impacts
- Corresponding decreases in low temperatures, linked to reduced frosts
- Additional indices for water resources show no strong “global” trends
- Come talk to me about these 80 indices!



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Sector specific extension to HadEX3

Robert Dunn, Nicholas Herold, Lisa Alexander et al., 2024
Earth and Space Science, **11**, 4, e2023EA003279
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EGU Abstract

Sharing is encouraged

HadEX3: history & methods

Robert Dunn, Lisa Alexander, Markus Donat et al, 2020
JGR-Atmospheres, **125**, 16, e2019JD032263
https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019JD032263

Sharing is encouraged

Comparing extremes indices in recent observational and reanalysis products

Robert Dunn, Markus Donat, Lisa Alexander, 2022
Frontiers in Climate **4**
https://www.frontiersin.org/articles/10.3389/fclim.2022.989505/full

Back to ETSCI – indices for Health

Sharing is encouraged

Interplay of reference periods and percentile-based extreme temperature indices

Robert Dunn & Colin Morice, 2022
Environ. Res. Lett. **17** 034026
https://iopscience.iop.org/article/10.1088/1748-9326/ac52c8

Sharing is encouraged

EGU Abstract

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Sector specific extension to HadEX3

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Robert Dunn, Nicholas Herold, Lisa Alexander et al., 2024

Earth and Space Science, **11**, 4, e2023EA003279

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023EA003279

EGU Abstract

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Why sector specific indices?

- Climate extremes indices allow for the characterisation of extremes and comparison of extremes across the globe
  - ETCCDI extremes indices have been used for >20yrs
  - Developed with Detection & Attribution, and Climate Monitoring in mind, from a climatological perspective
- ET on Sector-specific Climate indices (ET-SCI) held workshops with experts in Agriculture, Health and Water Resources to develop additional indices
  - Also relevant to DRR, Energy & Forestry
  - Can be used singly or in combination e.g. to identify climate risks

The World Meteorological Organization
Commission for Climatology

Expert Team on Sector-Specific Climate Indices

OUR MISSION

- Promote the use of globally consistent, sector-specific climate indices to bring out variability and trends in climate of particular interest to socio-economic sectors, and to help characterize the climate sensitivity of various sectors.
- Further develop the ClimPACT software, which is used to generate sector-specific climate indices, including their time series based on historical data.
- Extend ClimPACT to include indices derived from other climate variables that are relevant for sector impacts.
- Develop the training materials needed to raise capacity and promote uniform approaches around the world in applying these techniques.
- Coordinate and lead regional workshops building on the experience gained from previous workshops.

Lisa Alexander (co-lead), Australia
Adam Kalkstein (co-lead), USA
Atika Kasmi, Morocco
Tosiyuki Nakaegawa, Japan
Jorge Vazquez Aguirre, Mexico
Danielle Barros Ferreira, Brazil
Lia Megrelidz, Georgia

https://climpact-sci.org/assets/etsci/etsci-what-en.pdf

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Climpact indices

- ETCCDI + ET-SCI indices come to over 80 metrics.
  - Combined set termed “Climpact” indices
- Additional ones follow similar approach
  - Some extend the fixed threshold indices
    - ID [TXlt10], SU [TXgt25] now includes:
      - TNlt2, TNltm2 etc
  - Some have user defined thresholds
    - E.g. CSDI*d*, TX*d*TN*d*
  - Include other well-known indices
    - E.g. CDDcold*n*, GDDgrow*n*, SPEI & SPI
  - Heatwave (and cold-wave) indices
    - Following Perkins & Alexander (2013)

Heat and cold

FD SU ID TR GSL TXx TNx TXn
TNn TN10p TX10p TN90p TX90p WSDI
CSDI DTR ETR CDDcoldn GDDgrown
HDDheatn TMge5 TMlt5 TMge10 TMlt10
TMm TXm TNm TXge30 TXge35 TXgt50p
TNlt2 TNltm2 TNltm20 TXbdTNbd

Precipitation

Rx1day Rx5day SPI SPEI SDII R10mm
R20mm Rnnmm CDD CWD R95p R99p
R95pTOT R99pTOT PRCPTOT

Heat and cold waves

HWN HWF HWD HWM HWA CWN_ECF
CWF_ECF CWD_ECF CWM_ECF CWA_ECF

https://www.climdex.org/learn/indices/

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Extension to HadEX3

- HadEX3 initially a data set of gridded ETCCDI extremes indices (Dunn et al., 2020)
- Extending by including the ET-SCI indices in the same format
- Same method as HadEX3
  - Find out more about the HadEX datasets & methods here
- Indices which use a reference period in their construction are available with 1961-1990 and 1981-2010.
  - For more on reference periods see here

Met Office Hadley Centre observations datasets

> Home > HadEX3 >

HadEX3: Gridded land surface extremes indices

The dataset contains land-based climate extremes produced through the coordination of the joint WMO CCl/WCRP/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) and the WMO Expert Team on Sector-specific indices (ET-SCI). It currently comprises of over 80 indices of temperature and precipitation on a 1.25° x 1.875° grid from 1901 to 2018. The indices represent seasonal and/or annual values derived from daily station data. Data are calculated using the Climpact2 software, or have been submitted to the project as pre-calculated indices.

Brief description of the data

Data have been supplied either as calculated indices or as timeseries of Tmax, Tmin and daily precipitation accumulations for each station. These data have been standardised, and for each index, the stations with sufficient data and coverage selected for inclusion in the dataset. A number of quality control checks are applied to test for reasonable values, for issues in the metadata and for duplicate stations (which may have been submitted via two different input data collections). We use the Angular Distance Weighting gridding method, which combines weighted averages of stations within a decorrelation length scale of a grid box centre. Final output netCDF files are produced, containing the annual, and where appropriate, monthly gridded fields.

We automatically produce a number of plots and diagnostics as part of the creation scripts, and these are also available (ETCCDI, ET-SCI). However, as these have been created automatically, not all have been checked and so e.g. colour-scales may not be the most appropriate.

The current version is 3.0.4 (7th January 2022 for ETCCDI, extended 14th March 2024 for ET-SCI indices). For full details see the Changelog.

HadEX3 is also available at CEDA Archive (Centres for Environmental Data Analysis): HadEX3 at CEDA.

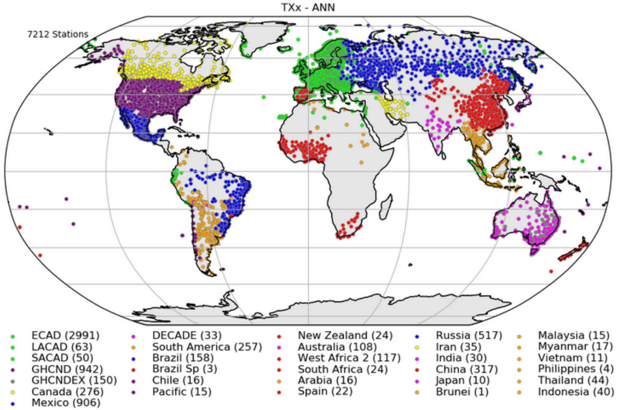
Keep in touch

Follow us on twitter: @metofficeHadOBS for updates, news and announcements.

For more detailed information, follow our HadEX blog. Here we describe bug fixes, routine updates and other exploratory analysis.

Please get in touch if you have any feedback on the data files or plots.

Figure shows the distribution of HadEX3 stations for TXx (top), and TXge30 (bottom), both for annual indices.



DOWNLOAD DATA >> Data are available from the download page without charge under the Open Government License. Please read the terms and conditions.

References

When using the dataset in a paper, the following are possible citations to use.

Dunn, R. J. H., et al. (2024), Observed global changes in sector-relevant climate extremes indices - an extension to HadEX3, ESS 11, e2023EA003279

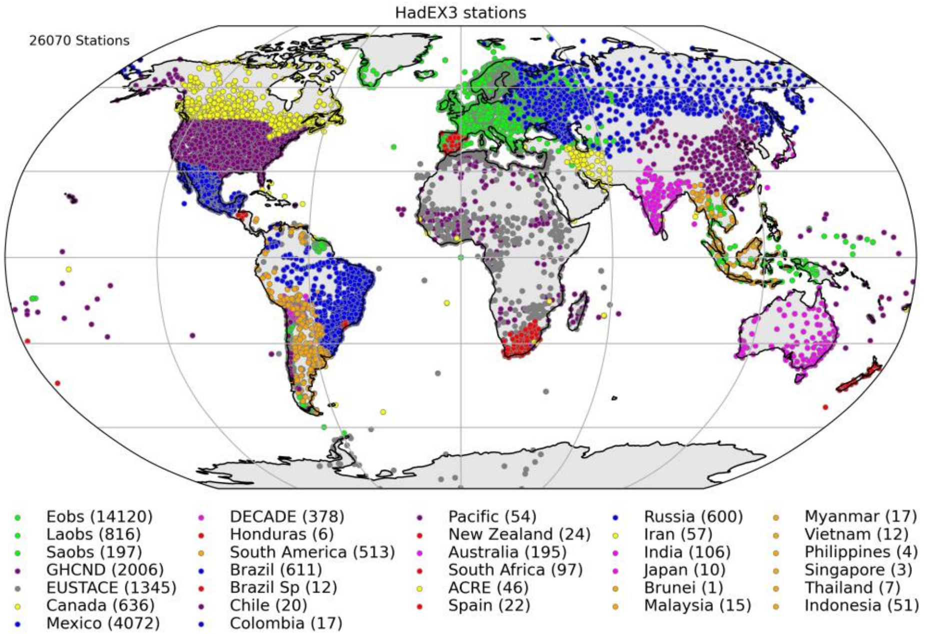
Dunn, R. J. H., Donat, M. G. and Alexander, L. V. (2022), Comparing extremes indices in recent observational and reanalysis products, Frontiers, 4

Dunn, R. J. H., et al. (2020), Development of an updated global land in-situ-based dataset of temperature and precipitation extremes: HadEX3, JGR-A, 125, e2019JD032263

Dunn et al. 2024. *Earth and Space Science*, 11, e2023EA003279
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023EA003279

Data sources

- Build on HadEX3 (Dunn et al, 2020)
- Same data sources where possible
  - Daily Tmax, Tmin and precip data
  - Precalculated indices
- Additional sources
  - EUSTACE stations (Brugnara et al, 2019)
  - GHCNd (Menne et al., 2012) over China and Africa



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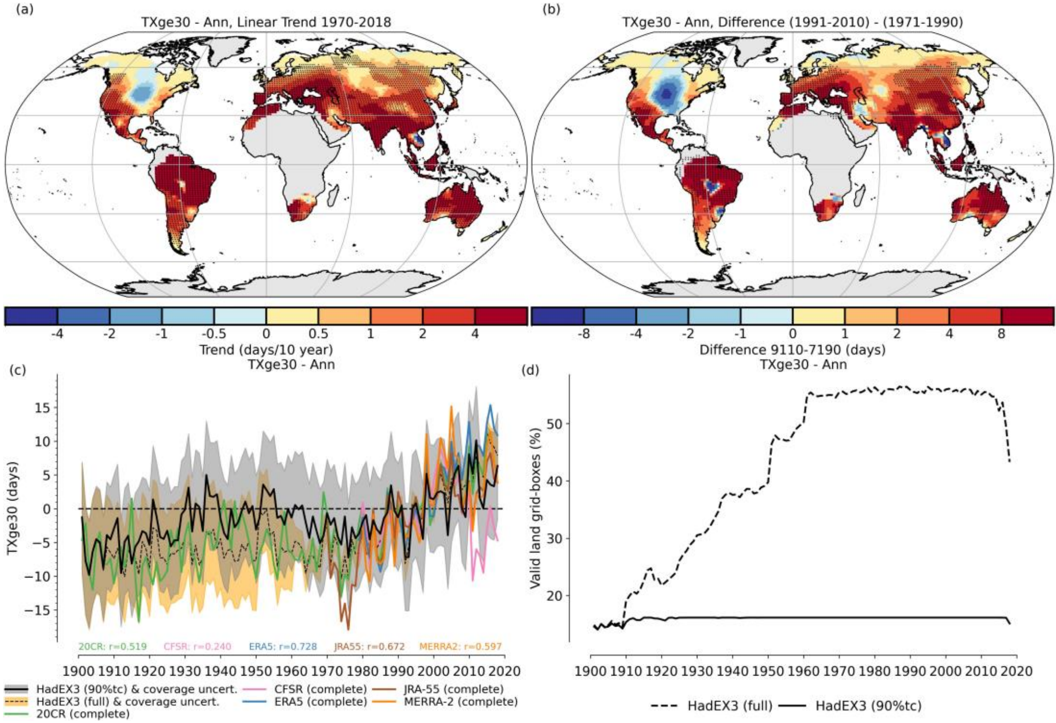
Dunn et al. 2024. *Earth and Space Science*, 11, e2023EA003279
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023EA003279

Indices for Health 1

- Many ETCCDI indices already relevant to health
  - Fixed threshold (ID, FD etc), also duration (WSDI, CSDI) and percentile values (TX90p etc)
- TXge30, extends SU [TXge25]
  - Useful for high temperature in mid-latitudes
- Timeseries also showing
  - Coverage uncertainties
  - Modern reanalyses products
  - [More comparison to reanalyses]()



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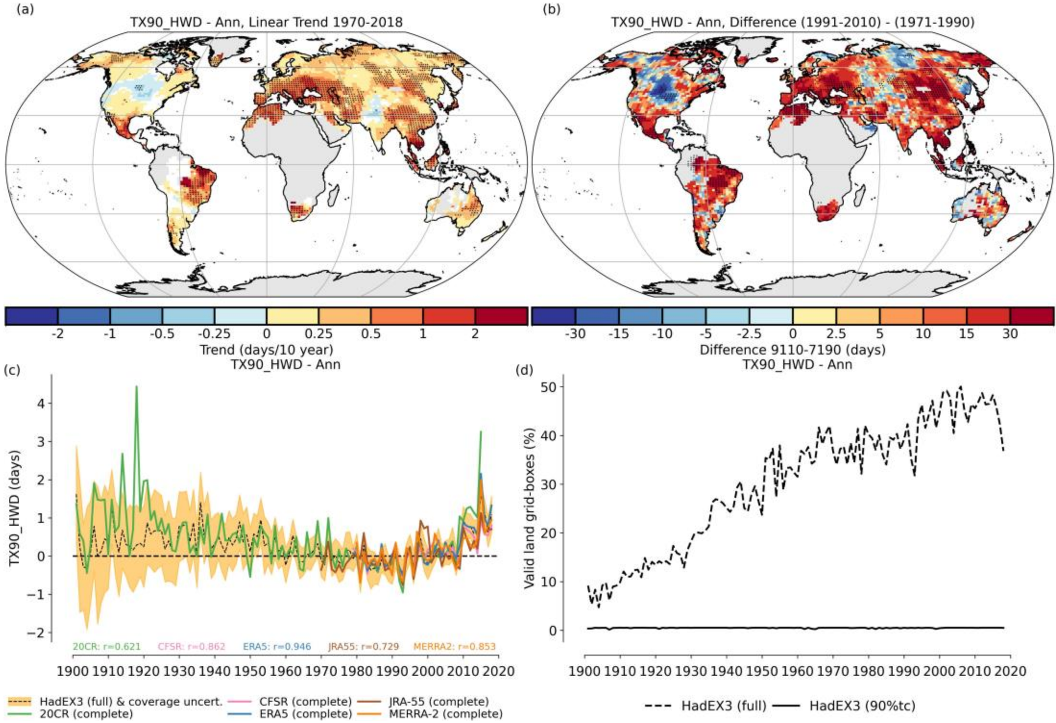
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023EA003279

Indices for Health 2

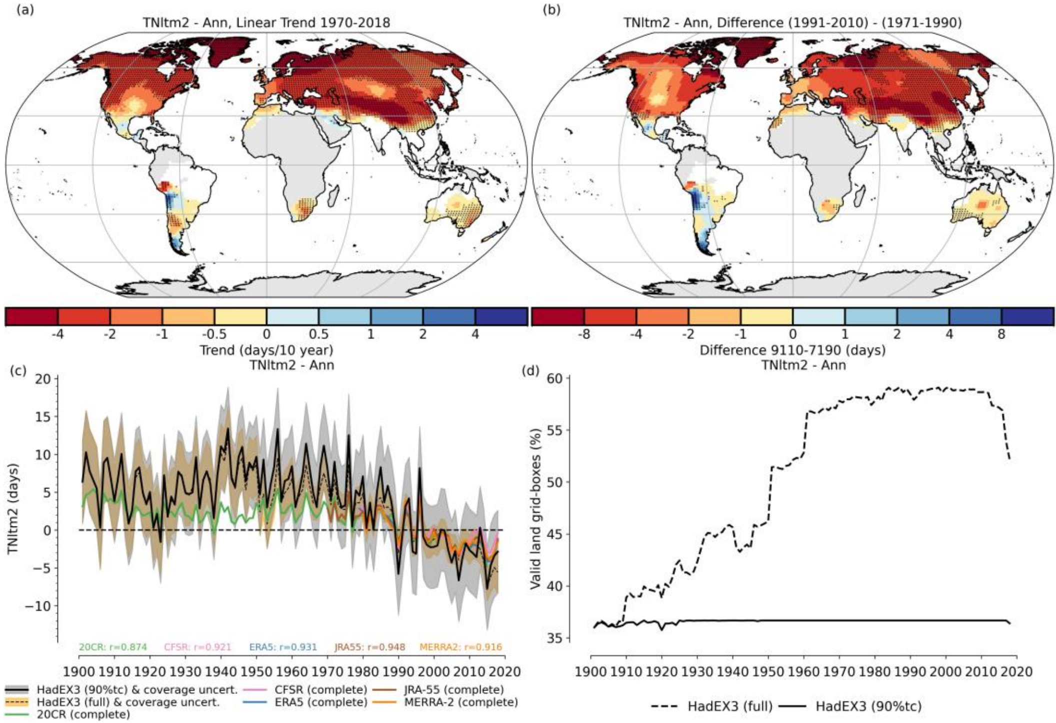
- Heatwave indices
  - Showing Heatwave Duration here (HWD; Perkins & Alexander, 2013)
- Heatwaves defined using periods above TX90
  - Can also use TN90 or Excess Heat Factor (EHF; Nairn & Fawcett, 2015)
- If no heatwave, then index undefined, so very little area (even in reanalyses) has >90% temporal completeness



Dunn et al. 2024. *Earth and Space Science*, 11, e2023EA003279
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023EA003279

Indices for Agriculture

- Many temperature indices useful e.g.
  - TNlt2, when the ground cools faster than the (2m) air, capturing grass frost.
  - FD (TNlt0) for air frost
  - TNltm2 for hard-freeze (shown right)
- Mean temperature indices now also available (e.g. TMlt5, TMgt10)
- GDDgrow*n* (Growing Degree Days) builds on GSL (Growing Season Length)



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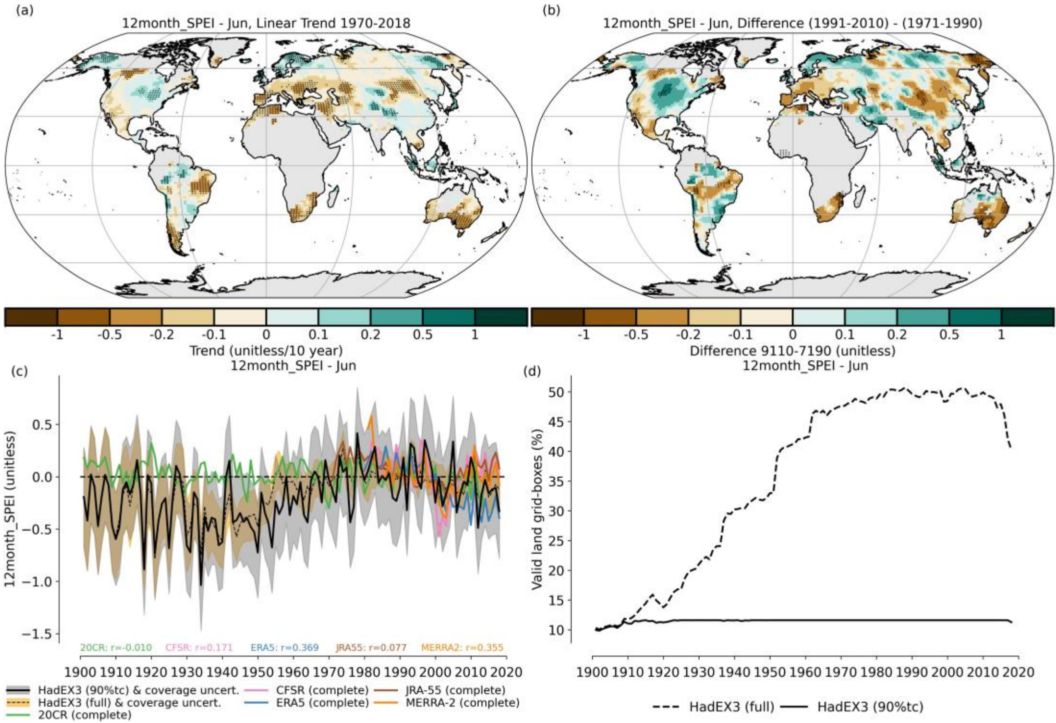
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023EA003279

Indices for Water Resources

- Standardised Precipitation Evapotranspiration Index (SPEI)
  - Available monthly only for 3, 6, 12 and a user-defined accumulation (24 months here)
  - Drought measure extending the SPI by including temperature information
- Consistent global long-term changes are not that apparent in the time series



More resources

- Find out more about HadEX3 and how it was built
- Find out more about comparisons with reanalyses
- Find out more about the impact of reference periods
- Find out more about the heatwave metrics
- Selected references:

  - EUSTACE: Brugnara, Y., Good, E., Squintu, A. A., van der Schrier, G., & Brönnimann, S. (2019). The Eustace global land station daily air temperature dataset. *Geoscience Data Journal*, 6(2), 189–204
  - GHCNd: Menne, M. J., Durre, I., Vose, R. S., Gleason, B. E., & Houston, T. G. (2012). An overview of the global historical climatology network-daily database. *Journal of Atmospheric and Oceanic Technology*, 29(7), 897–910

Contributors & Thanks

- Authors: Robert Dunn, Nicholas Herold, Lisa Alexander, Markus Donat, Rob Allan, Margot Bador, Manola Brunet, Vincent Cheng, Wan Maisarah Wan Ibadullah, Muhammad Khairul Izzat Bin Ibrahim, Andries Kruger, Hisayuki Kubota, Tanya J. R. Lippmann, Jose Marengo, Sifiso Mbatha, Simon McGree, Sandile Ngwenya, Jose Daniel Pabon Caicedo, Andrea Ramos, Jim Salinger, Gerard van der Schrier, Arvind Srivastava, Blair Trewin, Ricardo Vásquez Yáñez, Jorge Vazquez-Aguirre, Claudia Villaroel Jiménez, Russ Vose, Mohd Noor'Arifin Bin Hj Yussof, Xuebin Zhang
- Other data suppliers: Thelma Cinco, Rosaline de Guzman (PAGASA-DOST, Philippines), Imke Durre, Matthew Menne (NOAA-NCEI), Tin Mar Htay (Department of Meteorology and Hydrology, Myanmar), Mahbobeh Khoshkam (I.R. of Iran Meteorological Organization), Gerald Lim, Lim Li-Sha (Meteorological Service Singapore, Singapore), Maria de los Milagros Skansi (Servicio Meteorológico Nacional, Argentina), Chalump Oonariya, Nichanun Trachow (Thai Meteorological Department, Thailand), Cham Pham (National center for Hydro-Meteorological Forecasting of Vietnam, Vietnam), Fatemeh Rahimzadeh (formerly Atmospheric Science and Meteorological Research Center, Iran), Ernesto Salgado Rubio (Servicio Meteorológico Nacional, Honduras), Ardhasena Sopaheluwakan (Agency for Meteorology Climatology and Geophysics (BMKG), Indonesia), Lucie Vincent (Environment and Climate Change Canada, Canada).
- Data from Southeast Asia (excl. Indonesia) was supported by work on using ClimPACT2 during the Second Workshop on ASEAN Regional Climate Data, Analysis and Projections (ARCDAP-2), 25–29 March 2019, Singapore, jointly funded by Meteorological Service Singapore and WMO through the Canada-Climate Risk and Early Warning Systems (CREWS) initiative.
- Daily data for Mexico were provided by the Servicio Meteorológico Nacional (SMN) of Comisión Nacional del Agua (CONAGUA).
- The Pacific data is associated with an ET-SCI workshop in Fiji over 7–11 December 2015 funded by Environment Canada. Additional detail available via https://doi.org/10.1175/JCLI-D-18-0748.1
- We acknowledge the data providers in the ECA&D project (http://www.ecad.eu), the SACA&D project (https://sacad.database.bmkg.go.id), and the LACA&D project.
- We also thank all those who have supplied data for all the HadEX datasets over the past two decades.

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Sharing is encouraged

HadEX3: history & methods

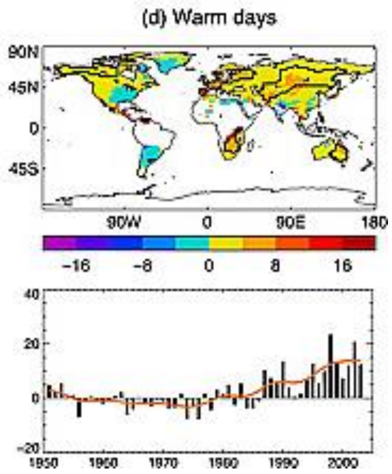
Robert Dunn, Lisa Alexander, Markus Donat et al, 2020

JGR-Atmospheres, **125**, 16, e2019JD032263

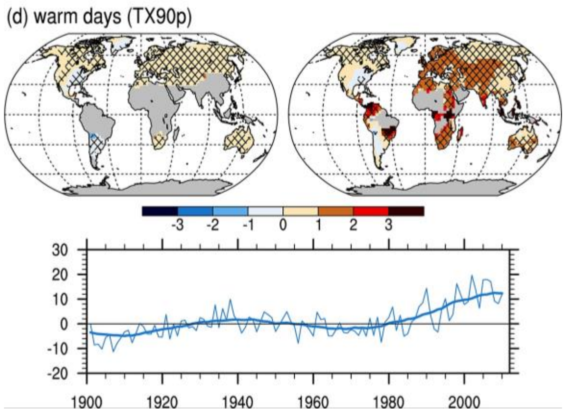
https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019JD032263

HadEX datasets

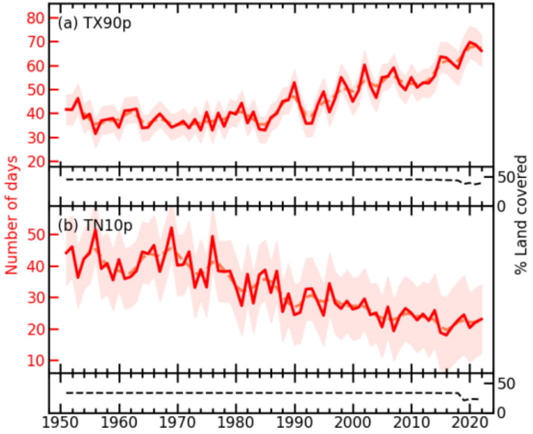
- HadEX (Alexander et al., 2006)
  - First dataset using the ETCCDI extremes indices
  - 1951-2003, static, used in IPCC AR4
- HadEX2 (Donat et al, 2013a)
  - Improved spatial and temporal coverage
  - 1901-2010, static, used in IPCC AR5
- GHCNDEX (Donat et al., 2013b)
  - Based on GHCND stations only
  - Updated, so useful for monitoring
  - Used in BAMS State of the Climate



HadEX



HadEX2



GHCNDEX (from BAMS SotC 2022)

ETCCDI Indices

- The WMO/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI)
    - Measure moderate temperature and precipitation extremes
    - Based on daily Tmax, Tmin and precipitation accumulation
    - Some available as monthly, as well as annual indices

    - Some based on peak values (TXx, Rx1day)
    - Some based on percentile thresholds (TX90p, R95p)
    - Some based on fixed thresholds (SU, R10mm)
    - Some are aggregated indices (WSDI, CWD)
    - And some others are less easily categorised (DTR, ETR, PRCPTOT)
    - There are 29 in total which have been widely used
    - See https://www.climdex.org/learn/indices/ for more information

From https://etccdi.pacificclimate.org/list_27_indices.shtml

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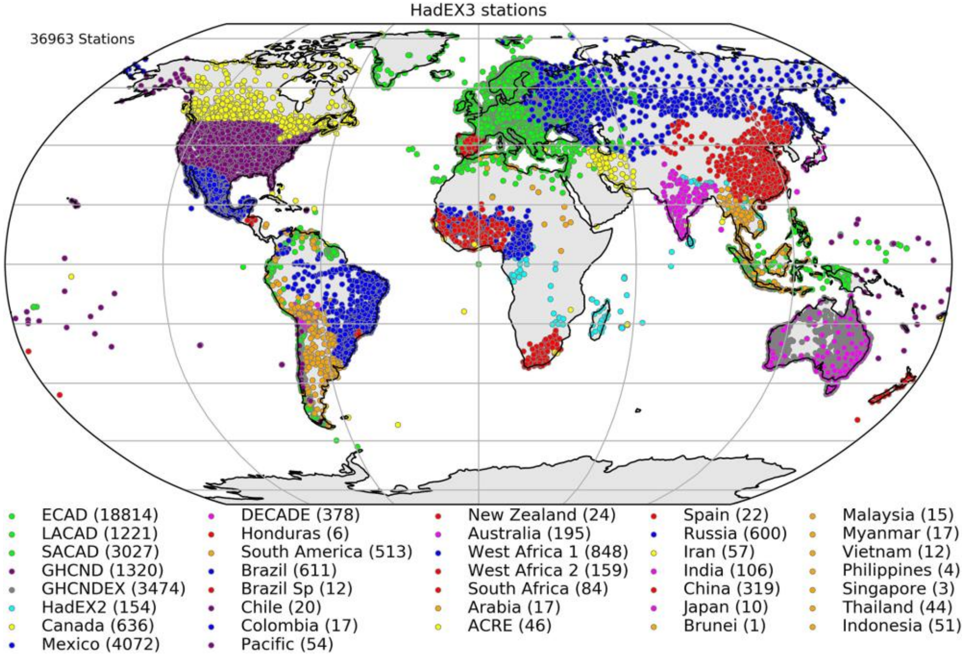
Dunn et al. 2020. *Journal of Geophysical Research: Atmospheres*, 125, e2019JD032263 https://doi.org/10.1029/2019JD032263

HadEX3 Data

- ETCCDI indices supported by standardised software
- Training workshops assist with data exchange
- Allowed widest possible set of contributors to HadEX datasets
- Used international, regional and national collections
- Both daily data and precalculated indices were supplied by contributors
- See the contributors [here]



[Back to HadEX3-ETSCI data]

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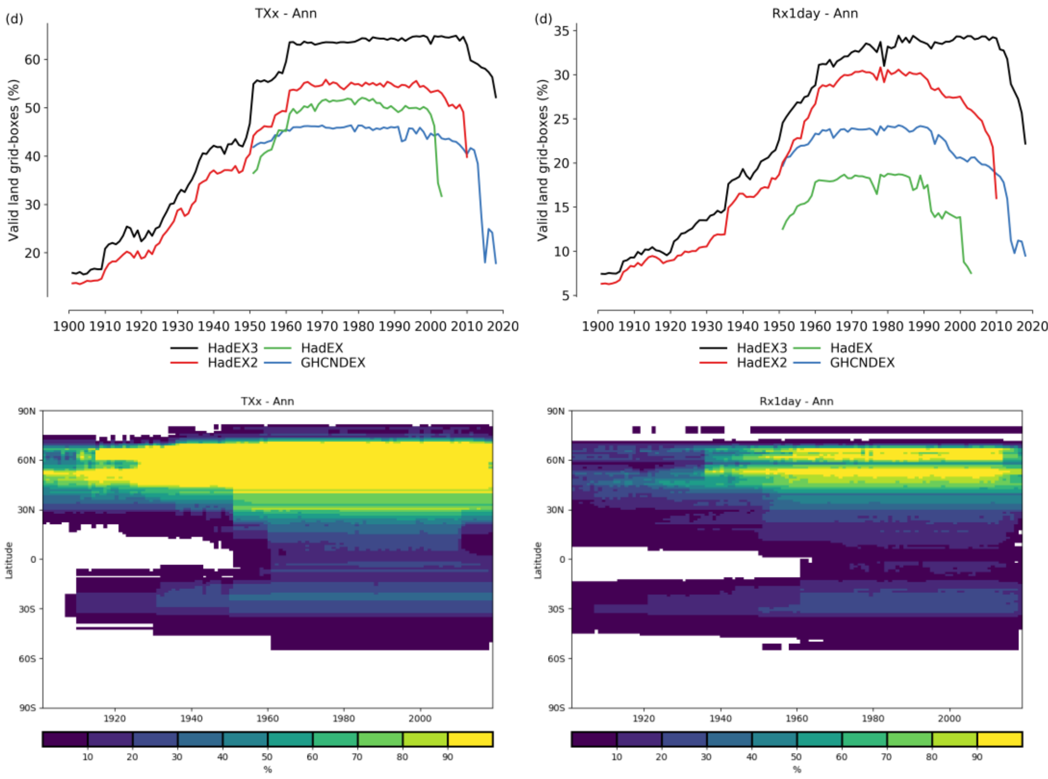
Dunn et al. 2020. *Journal of Geophysical Research: Atmospheres*, 125, e2019JD032263 https://doi.org/10.1029/2019JD032263

HadEX3

- Update on HadEX2
- Covers 1901-2018 as a static set for 29 ETCCDI indices
- Increased spatial coverage from more station data
- Smaller latitude-longitude grid (1.25° x 1.875°)
- Quality control tests on station-level indices
- Currently at v3.0.4, available from:

http://www.metoffice.gov.uk/hadobs/hadex3

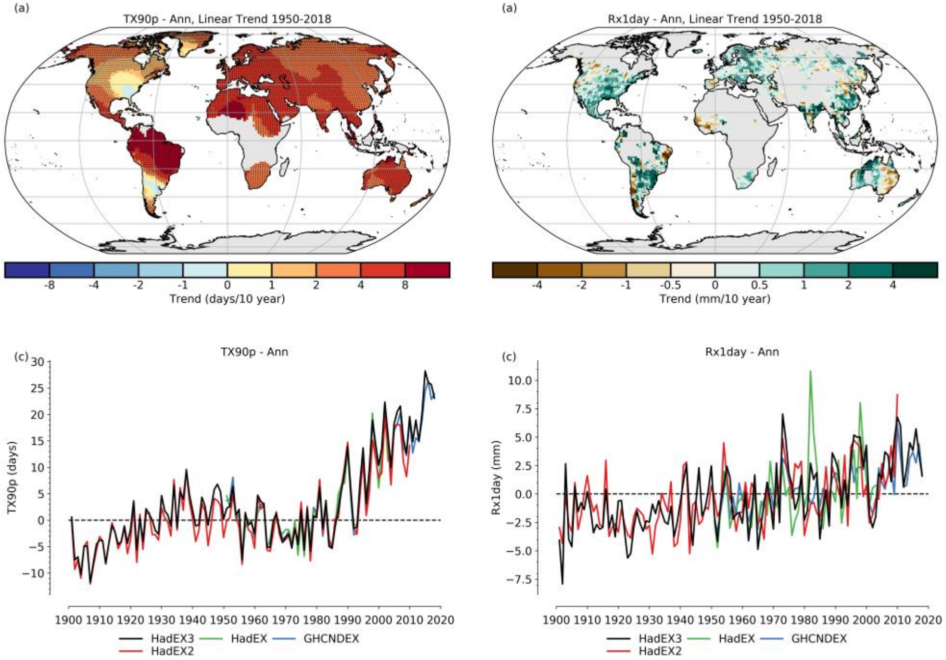


Dunn et al. 2020. *Journal of Geophysical Research: Atmospheres*, 125, e2019JD032263 https://doi.org/10.1029/2019JD032263

HadEX3

- Widespread increase in intensity and frequency of warm temperature extremes
- Corresponding decrease in cool temperature extremes
- Increased intensity of heavy precipitation events
- For indices which use a reference period, netCDF files available for 1961-90 and 1981-2010 reference periods at

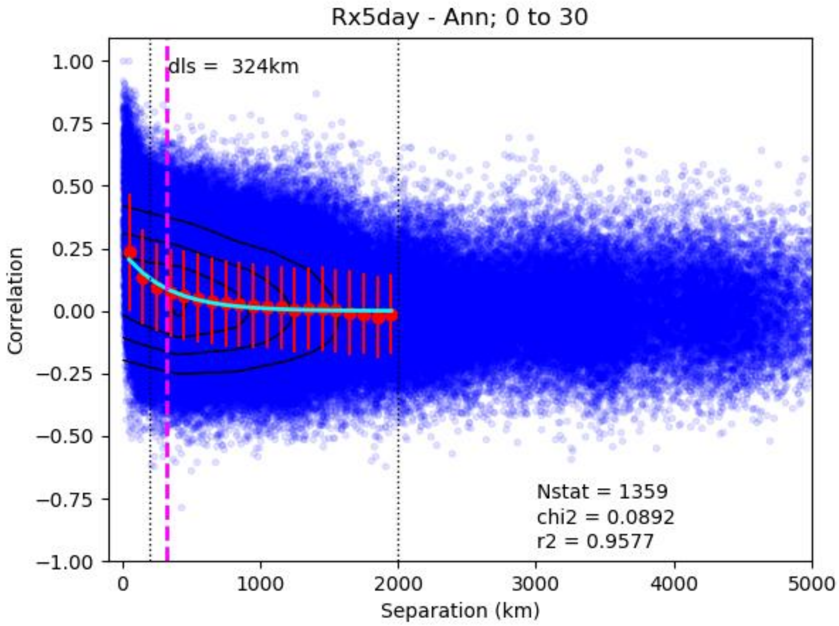
http://www.metoffice.gov.uk/hadobs/hadex3



Dunn et al. 2020. *Journal of Geophysical Research: Atmospheres*, 125, e2019JD032263 https://doi.org/10.1029/2019JD032263

Methods – Angular Distance Weighting

- To convert from station data to space-filling data set
- Angular distance weighting (Shepard 1968).
- Uses a search radius to select stations contributing to grid box
- Radius set by correlation structure of all stations within a latitude band
- Minimum 200km, maximum 2000km
- At least 3 stations with this radius for a grid box to have a value.



HadEX3

- Other resources:

  - Alexander, L. V., et al. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research*, 111, D05109. [*HadEX*]
  - Donat, M. G., et al, (2013a). Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. *Journal of Geophysical Research: Atmospheres*, 118, 2098–2118.
  - Donat, M. G., et al. (2013b). Global land-based datasets for monitoring climatic extremes. *Bulletin of the American Meteorological Society*, 94(7), 997–1006. [*GHCNDEX*]
  - Shepard, D. (1968). A two-dimensional interpolation function for irregularly-spaced data. In Proceedings of the 1968 23rd ACM national conference (pp. 517–524). [*ADW gridding]*

  - https://www.climdex.org/learn/indices/

Comparing extremes indices in recent observational and reanalysis products

Robert Dunn, Markus Donat, Lisa Alexander, 2022

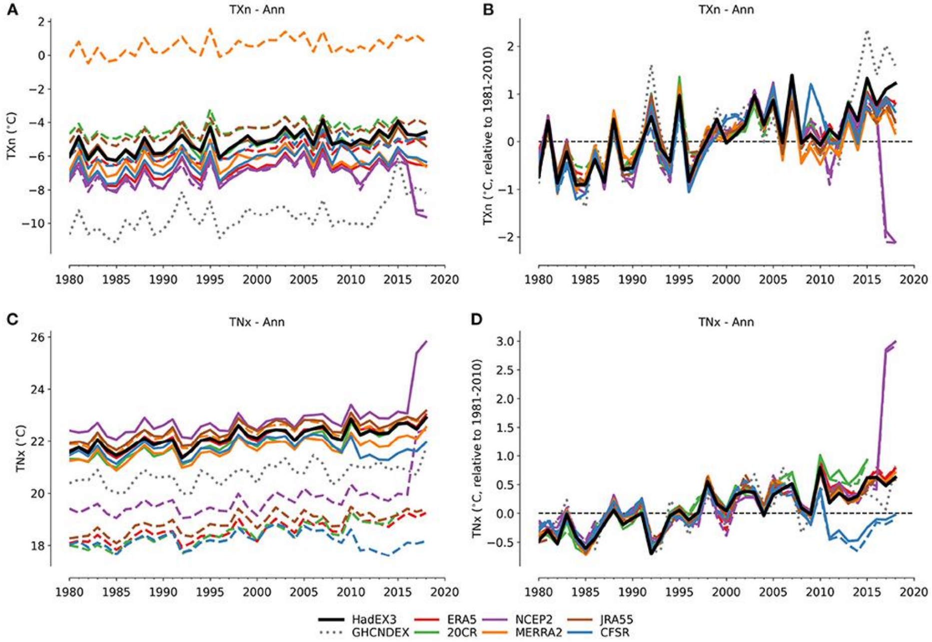
Frontiers in Climate **4**

https://www.frontiersin.org/articles/10.3389/fclim.2022.989505/full

Dunn, Donat & Alexander, 2022 *Frontiers in Climate* **4**
https://www.frontiersin.org/articles/10.3389/fclim.2022.989505/full

Comparisons to Reanalyses

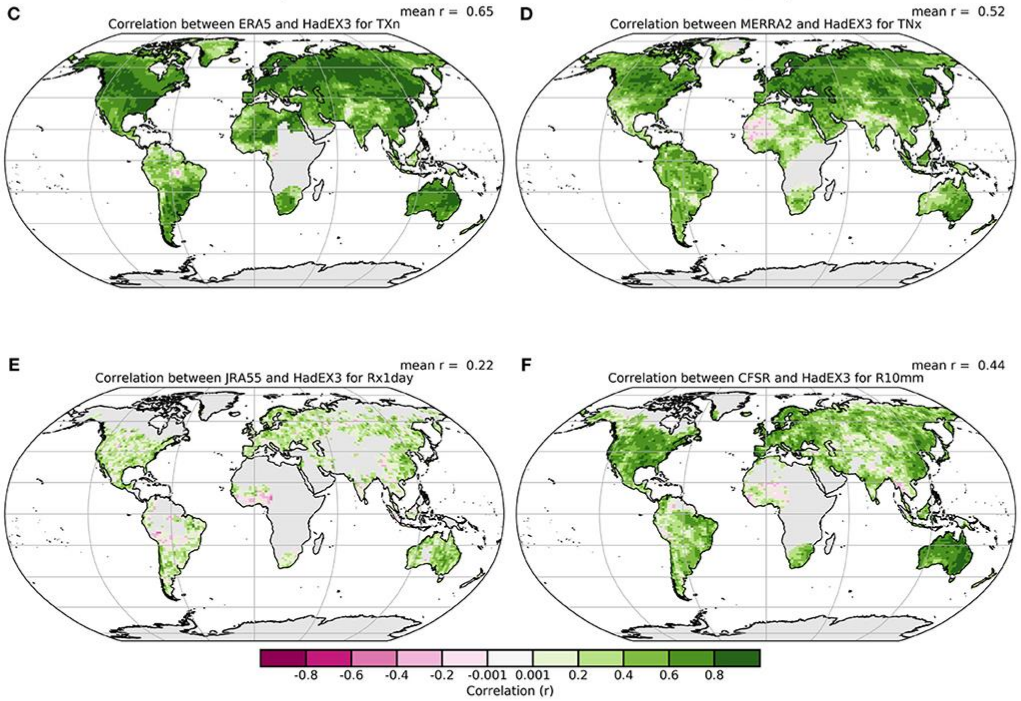
- Calculate ETCCDI indices on set of recent reanalysis products.
  - Match grid size and to common temporal period
- Good agreement for temperature indices between reanalyses and HadEX3
  - Especially when masked to the same coverage
- Normalised curves agree well on interannual variations and also longer-term changes
- Some reanalyses (NCEP2, CFSR) appear to have inhomogeneities when compared to others.



Dunn, Donat & Alexander, 2022 *Frontiers in Climate* **4**
https://www.frontiersin.org/articles/10.3389/fclim.2022.989505/full

Comparisons to Reanalyses

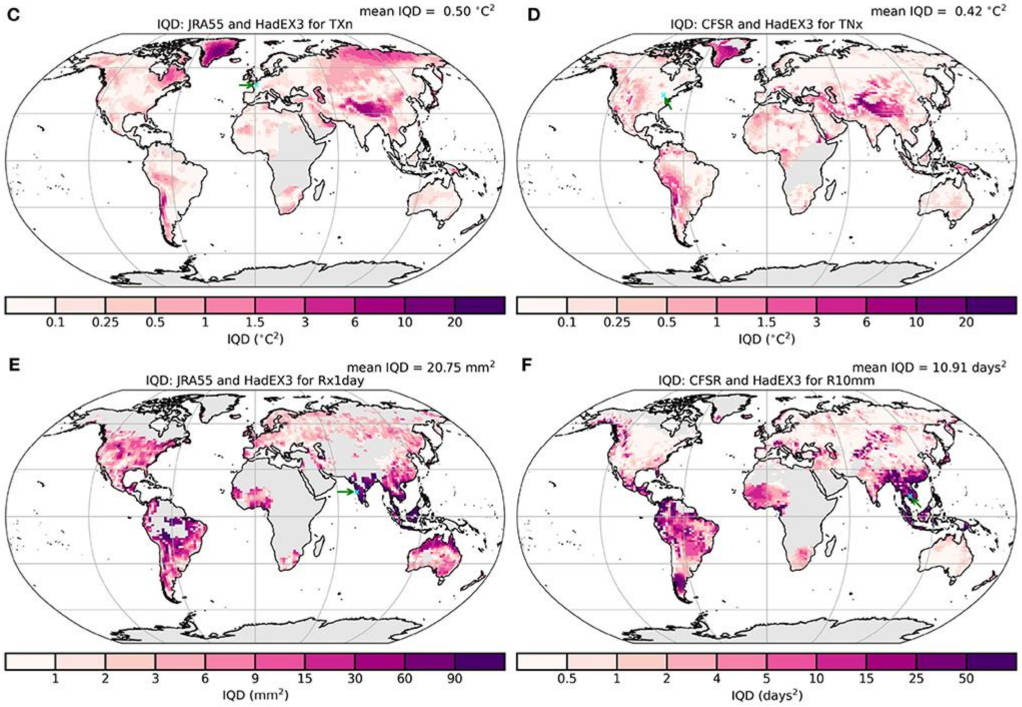
- Correlation on grid-box basis, masked to observational coverage.
- Spatially temperature (C, D) shows greater correlations than precipitation (E, F) indices.
- Precipitation is a more heterogeneous metric, so this is expected
- Anticorrelations seen in some indices (e.g. western Africa in TNx in D)
  - Likely due to interpolation of HadEX3 stations from other climates (e.g. Canary Islands).



Dunn, Donat & Alexander, 2022 *Frontiers in Climate* **4**
https://www.frontiersin.org/articles/10.3389/fclim.2022.989505/full

Comparisons to Reanalyses

- Integrated Quadratic Distance (Thorarinsdottir et al, 2013) measures areas a between cumulative distribution functions.
- Many areas for temperature and precipitation indices show good agreement between the CDFs.
- Others stand out, with some linked to areas of high elevation (mountain ranges)
- But some are linked to intrinsically higher values for these indices in certain locations



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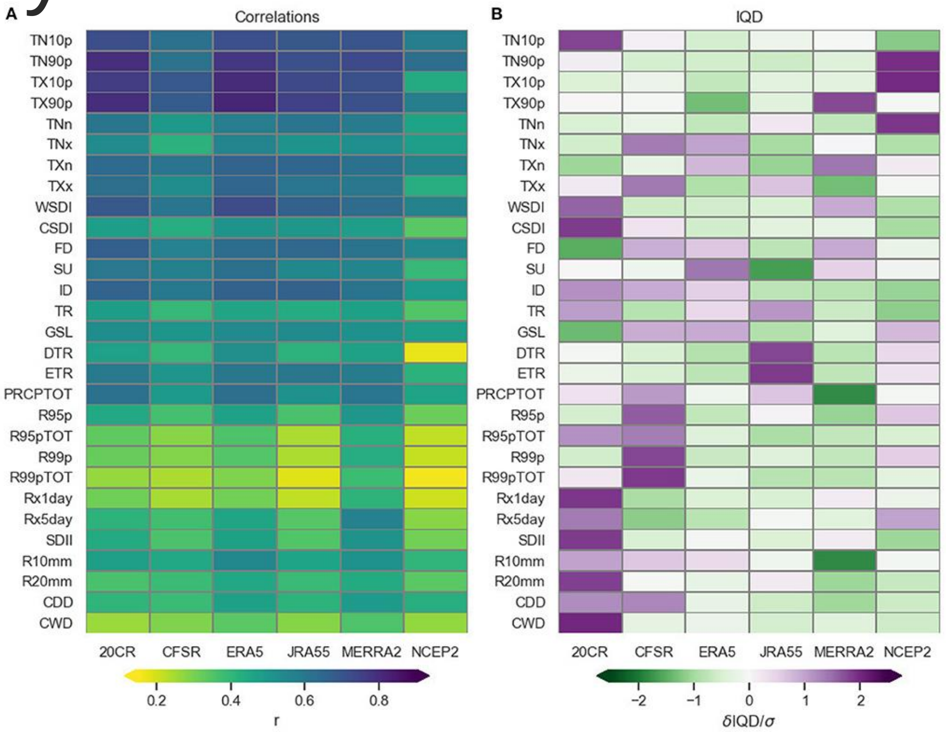
https://www.frontiersin.org/articles/10.3389/fclim.2022.989505/full

Comparisons to Reanalyses

- Summary plots to show how average spatial correlations and integrated quadratic distances (IQD) vary across reanalyses and indices.
- Temperature indices have on average higher correlations.



Comparisons to Reanalyses

- Many modern reanalyses compare well to HadEX3, though there is variation amongst all products
- Future work will investigate where some of these differences arise.
- Other resources
  - Donat, M. G., Alexander, L. V., Herold, N., and Dittus, A. J. (2016). Temperature and precipitation extremes in century-long gridded observations, reanalyses, and atmospheric model simulations. *J. Geophys. Res*. 121, 11,174–11,189
  - Thorarinsdottir, T. L., Gneiting, T., and Gissibl, N. (2013). Using proper divergence functions to evaluate climate models. *SIAM/ASA J. Uncertain. Quant*. 1, 522–534
  - Thorarinsdottir, T. L., Sillmann, J., Haugen, M., Gissibl, N., and Sandstad, M. (2020). Evaluation of CMIP5 and CMIP6 simulations of historical surface air temperature extremes using proper evaluation methods. *Environ. Res. Lett*. 15:124041

Interplay of reference periods and percentile-based extreme temperature indices

Sharing is encouraged

Robert Dunn & Colin Morice, 2022

Environ. Res. Lett. **17** 034026

https://iopscience.iop.org/article/10.1088/1748-9326/ac52c8

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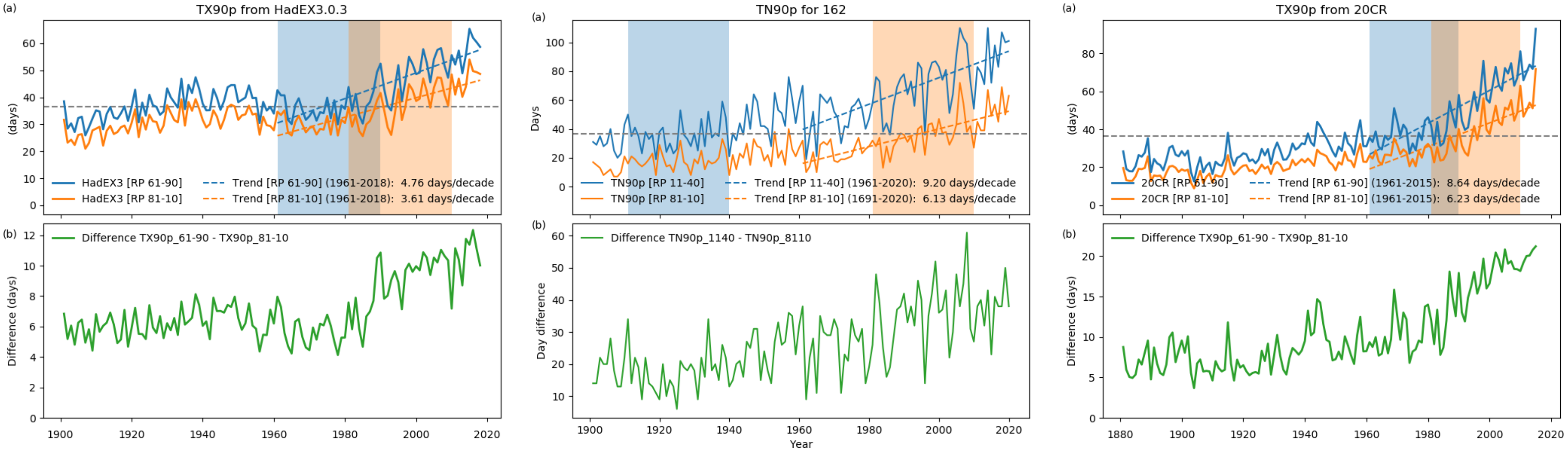
Dunn & Morice 2022 *Environ. Res. Lett.* **17** 03402
https://iopscience.iop.org/article/10.1088/1748-9326/ac52c8

Reference periods & percentile-based indices

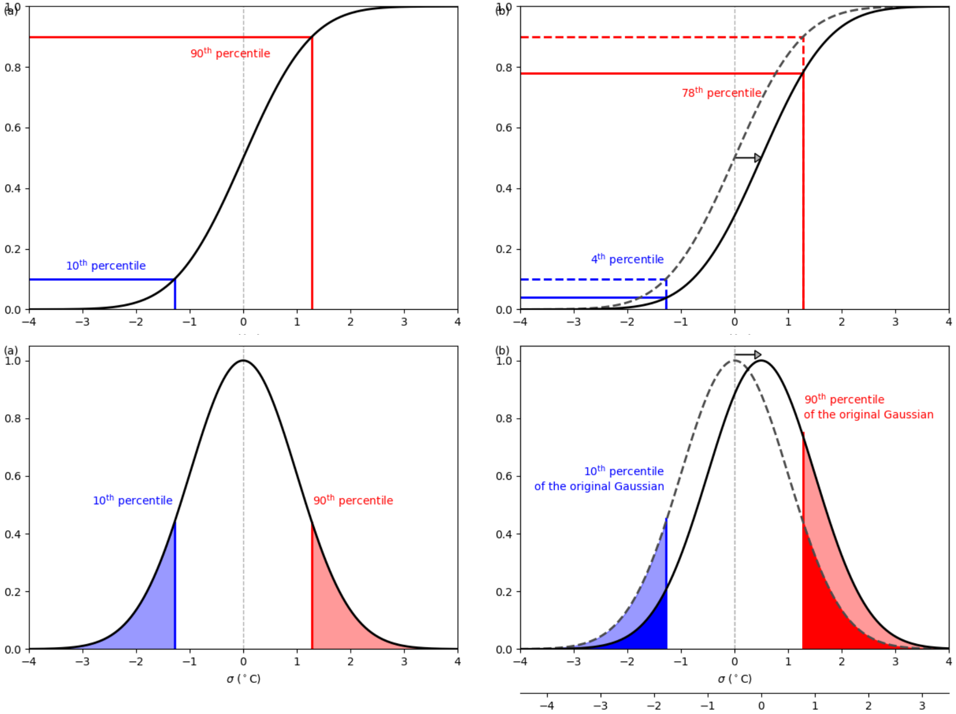


- Non-stationary difference when comparing TX90p across reference periods
- Seen for “global” averages from obs & single station (ECAD162), and for reanalyses
- Linear trends over same period differ when using same daily data.

Dunn & Morice 2022 *Environ. Res. Lett.* **17** 03402
https://iopscience.iop.org/article/10.1088/1748-9326/ac52c8

Reference periods & percentile-based indices

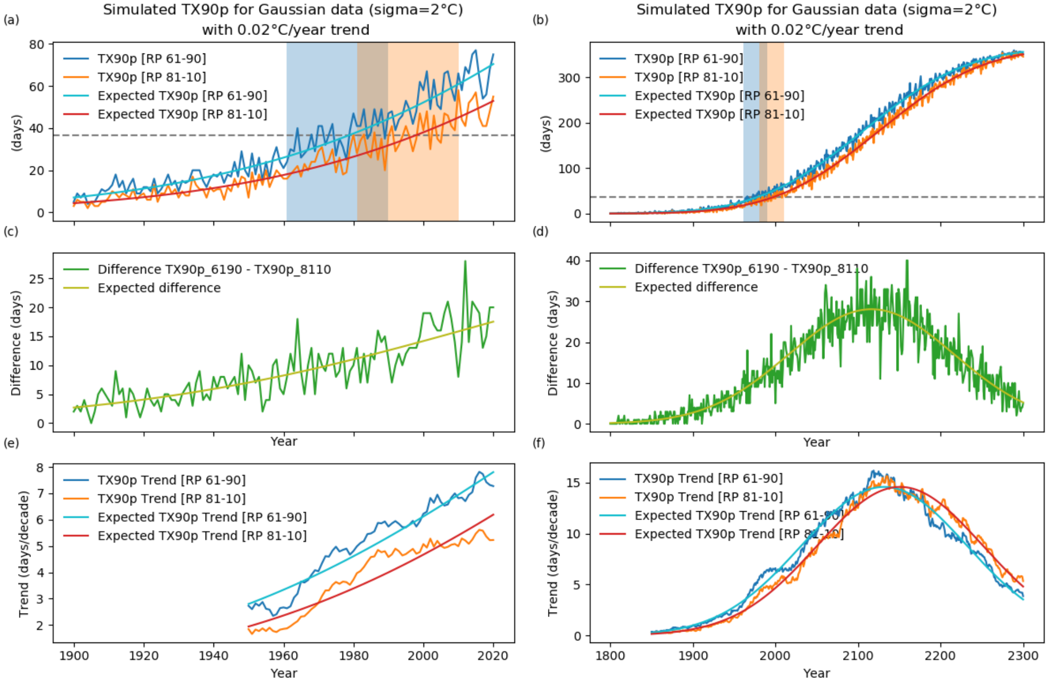
- A warming climate affects how reference periods influence indices
- In the example, using an earlier reference period (corresponding to cooler conditions) means that the thresholds are not at 10 & 90%, but 4 & 78%
- This is not symmetric (6% change in lower, 12% change in upper) or monotonic.



Dunn & Morice 2022 *Environ. Res. Lett.* **17** 03402
https://iopscience.iop.org/article/10.1088/1748-9326/ac52c8

Reference periods & percentile-based indices

- Simple simulation of daily data (mean increasing by 0.02°C/yr), out to 2300 to create artificial curves of TX90p (& TN90p)
- Also showing empirically expected values as solid lines
- Timeseries (a, b) follow a CDF form as the Gaussian moves past the threshold
- Difference (c, d) between timeseries follows Gaussian, and so is non-linear
- Linear trends (e, f) lag by temporal difference in reference periods.
    - Also follow Gaussian form, so show “acceleration” despite linear change in underlying temperature distribution



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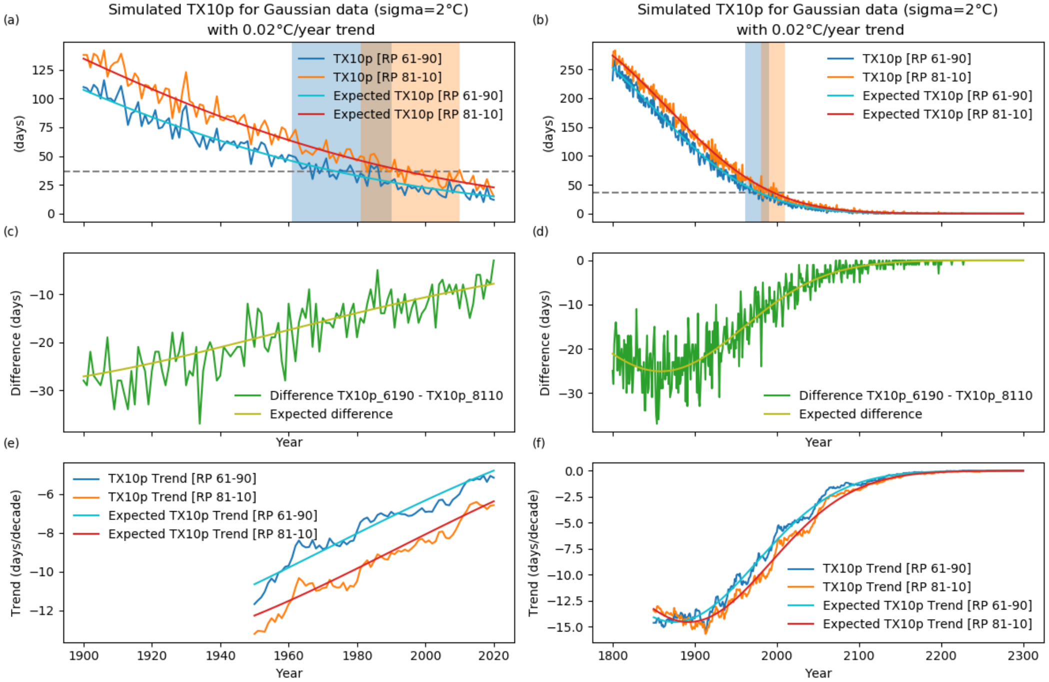
https://iopscience.iop.org/article/10.1088/1748-9326/ac52c8

Reference periods & percentile-based indices

- At lower percentile, zero bounding plays a part
- Under warming climate can reach time where no days are cooler than a 10% set in an earlier reference period
- Index becomes asymptotically less useful
- WMO recommends use of 1961-90 period for long-term climate monitoring
- Lower values of TX10p & TN10p show effect of warming, but no longer measure against current 10th percentile values.



Dunn & Morice 2022 *Environ. Res. Lett.* **17** 03402
https://iopscience.iop.org/article/10.1088/1748-9326/ac52c8

Reference periods & percentile-based indices

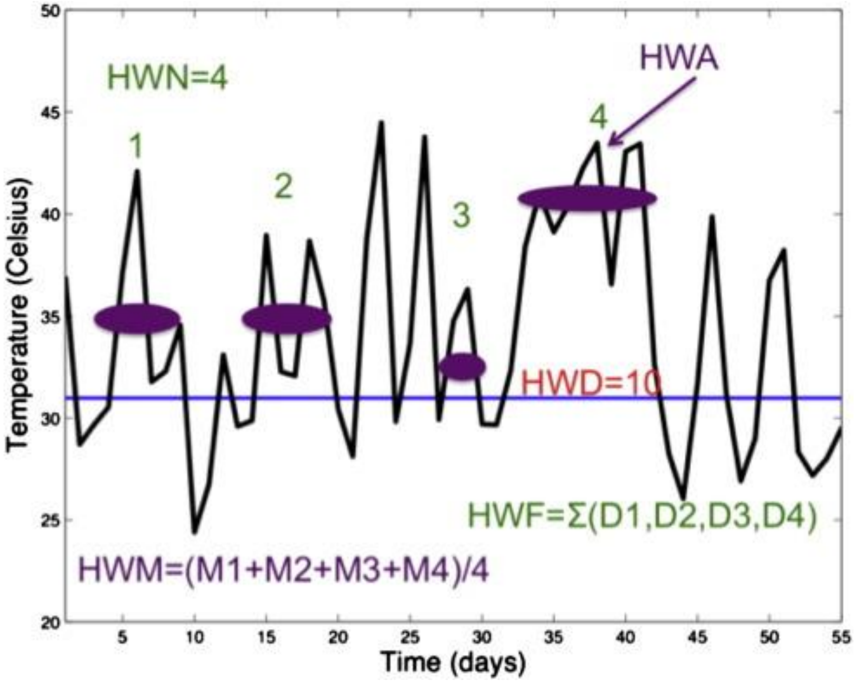
- Comparison of percentile-based indices (e.g. TX90p, WSDI) between different reference periods is non-trivial
- Same underlying daily data can result in very different linear trends, up to 50% larger.
- Recommendations:
  - Reference period used is always clearly stated in any work
  - Trends in these indices are not compared across reference periods
- Other resources:
  - Yosef Y, Aguilar E and Alpert P 2021 Is it possible to fit extreme climate change indices together seamlessly in the era of accelerated warming? Int. J. Climatol. 41 E952–63

Other Material

Useful background slides

Heat wave definitions

- A heatwave occurs when at least 3 days in a row are considered above the respective threshold. In this figure the threshold is represented by the blue line.
- There are 4 discrete events (HWN)
- The length of the longest event is 10 days (HWD)
- The number of heatwave days in the sum of the duration of all four events (HWF)
- The average heatwave magnitude is the average temperature across all for events (HWM)
- The heatwave amplitude is the hottest day of the event with the hottest average (HWA).



Perkins, S. E., 2015, Atmospheric Research, 164-65, 242-67, https://doi.org/10.1016/j.atmosres.2015.05.014 (Fig 2)

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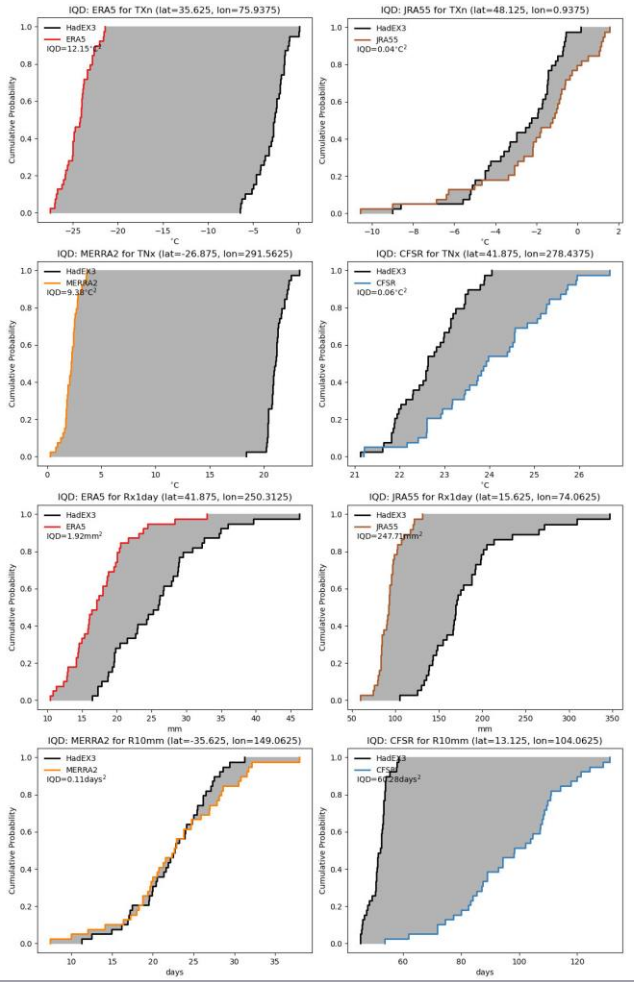
Integrated Quadratic Distance

- Is a measure of the separation of two cumulative probability distriubutions
- It captures both if they are well separated (top left panels)
- And if they have different shapes (bottom right panels)
- Further information at:
  - Thorarinsdottir, T. L., Gneiting, T., and Gissibl, N. (2013). Using proper divergence functions to evaluate climate models. *SIAM/ASA J. Uncertain. Quant*. 1, 522–534. doi: 10.1137/130907550
  - Thorarinsdottir, T. L., Sillmann, J., Haugen, M., Gissibl, N., and Sandstad, M. (2020). Evaluation of CMIP5 and CMIP6 simulations of historical surface air temperature extremes using proper evaluation methods. *Environ. Res. Lett*. 15:124041. doi: 10.1088/1748-9326/abc778



End of presentation

If you have any feedback on the accessibility or other features of my presentation, please do get in touch:

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