Global Intensification in Observed Short-Duration Rainfall Extremes

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Climate change is likely to affect the intensity, frequency and temporal structure of heavy rainfall (IPCC, 2014)

Mexico, Sep 2013

Australia, Jan 2011

https://www.instagram.com/p/By3SerGnDXi/?igshid=dopwsu601et2

Extreme precipitation intensity should increase with temperature at approx. Clausius-Clapeyron

Air temperature influences extreme rainfall intensity due to the increased water vapour-holding capacity of warmer air that follows the Clausius–Clapeyron (CC) relation:

$$\frac{\partial e_s}{\partial T} = \frac{L_v e_s}{R_v T^2}$$

Es is the saturation vapor pressure at temperature *T*, *Lv* is the latent heat of vaporization, and *Rv* is the gas constant

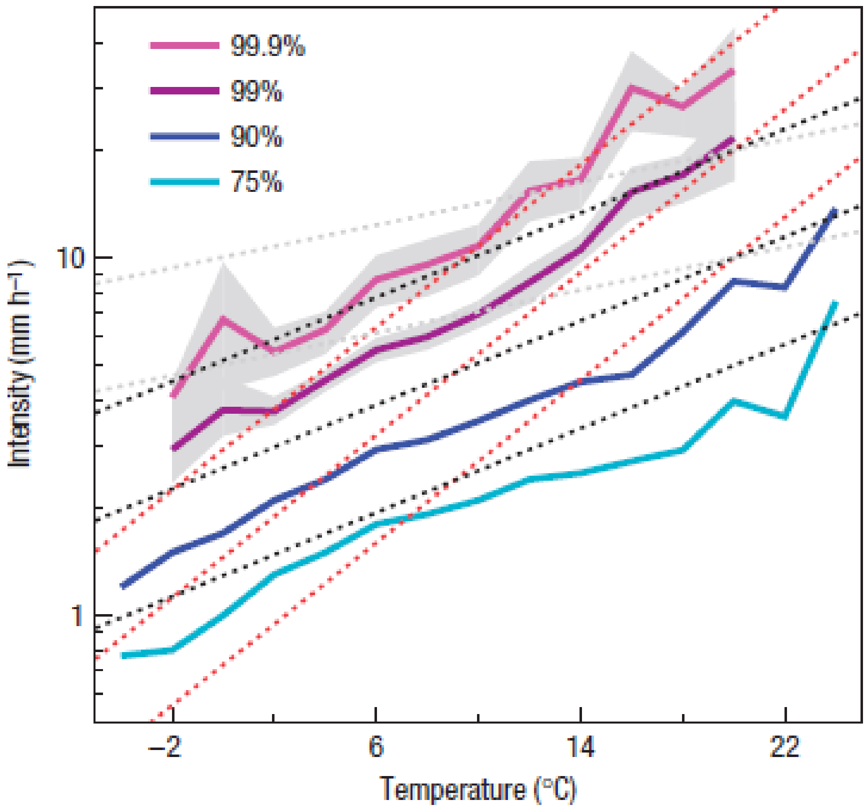
CC ≈ 7%C^{-1} is a reasonable approximation

Due to energy constraints, total precipitation will increase at a slower rate meaning intensity increases must be offset by duration and frequency changes

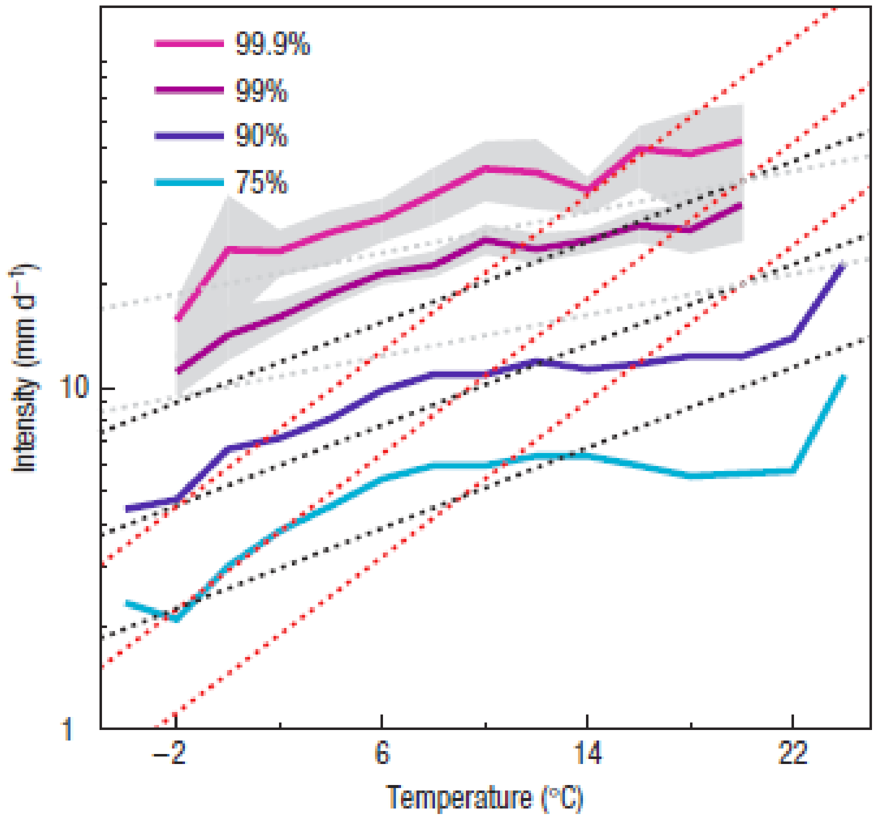
Trenberth et al. (2003)

Temperature-precipitation scaling strengthens at short time scales – so will hourly precipitation intensities increase at a faster rate with warming?

Hourly



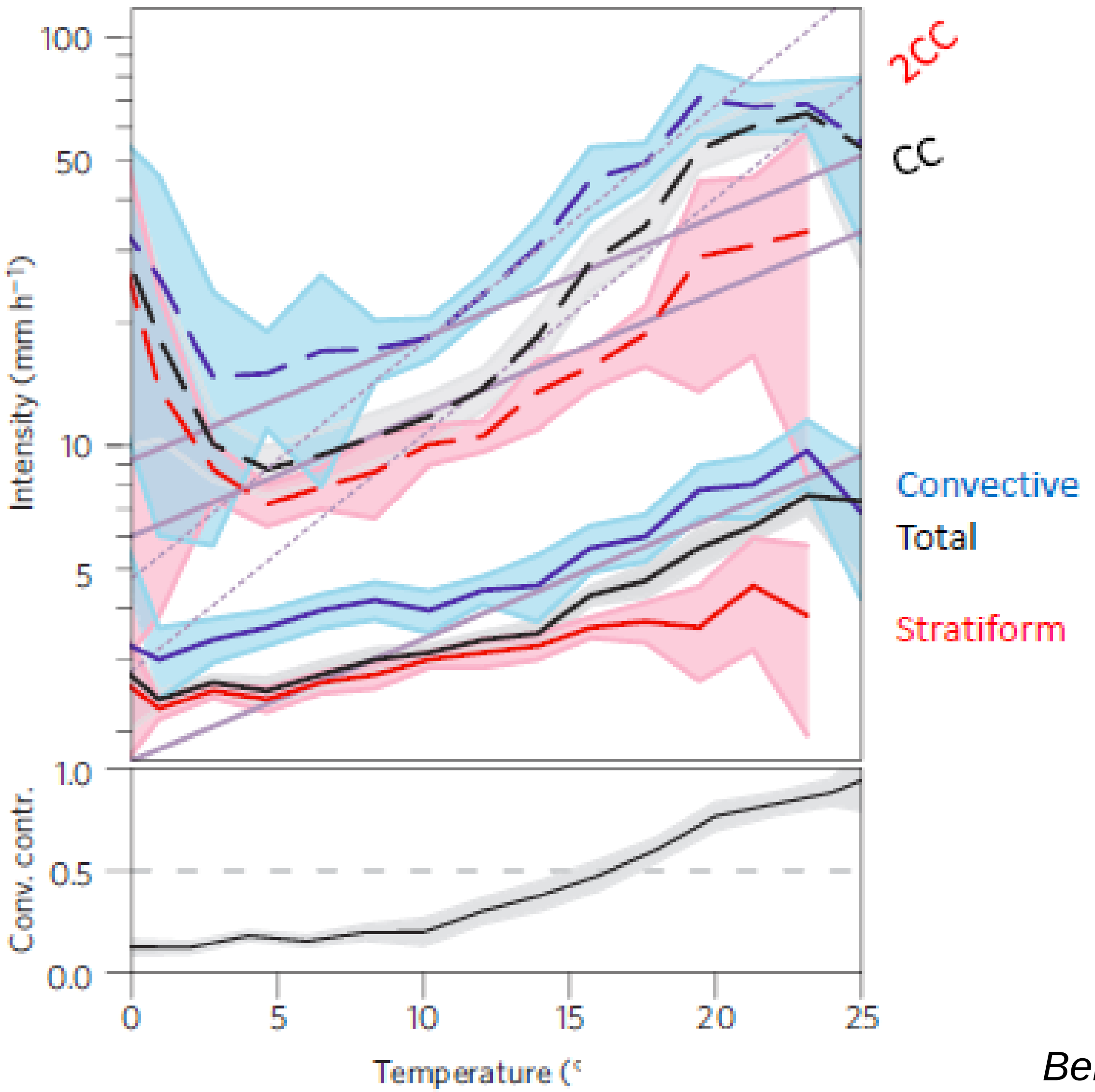
Daily



Defined using a linear regression between the natural logarithmic of rainfall and near-surface air temperature

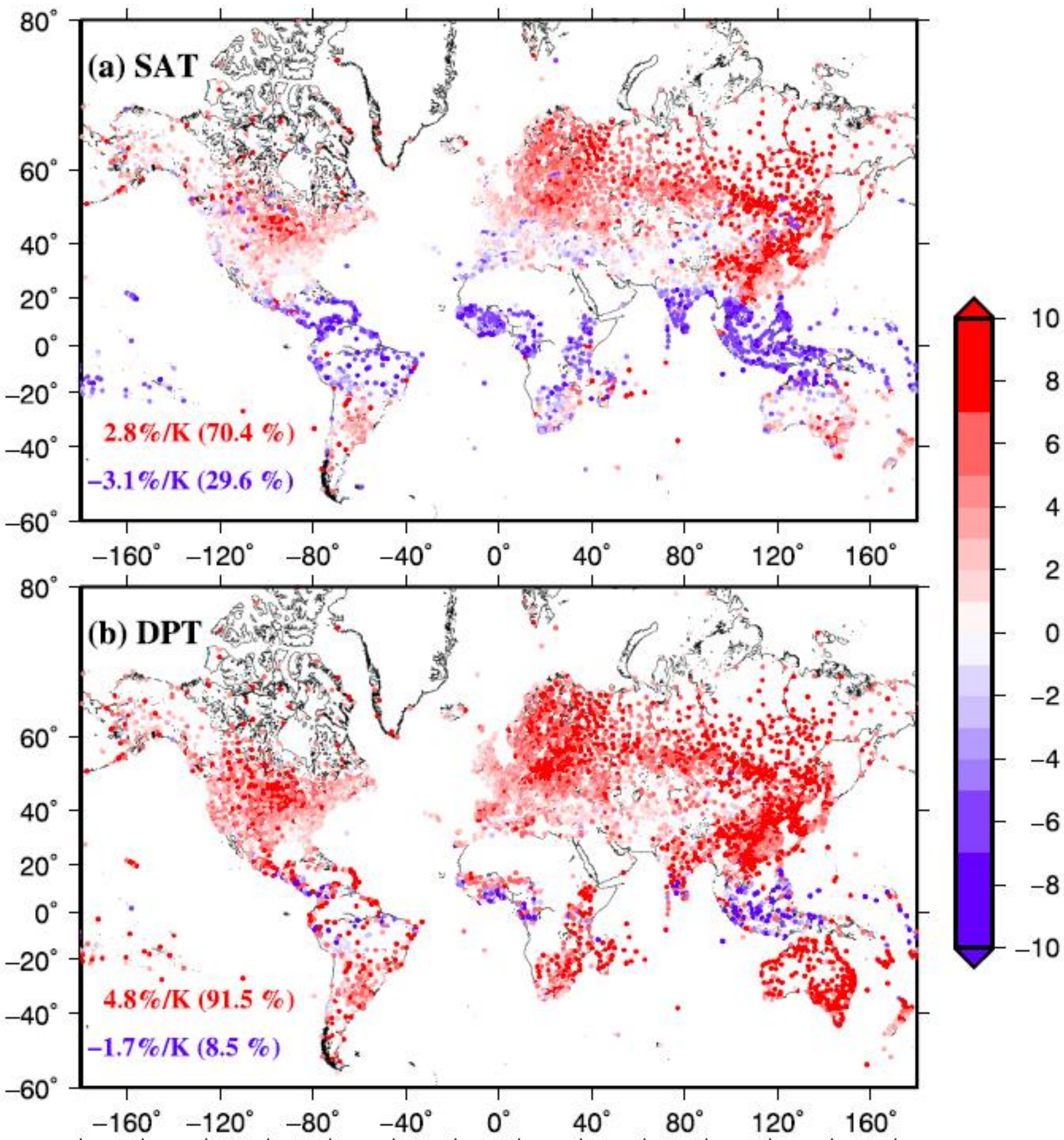
Lenderink and Meijgaard (2008)

Scaling depends on event type (convective fraction)



Berg et al. (2013)

Global scaling of daily extreme precipitation with surface air temperature and dew point temperature



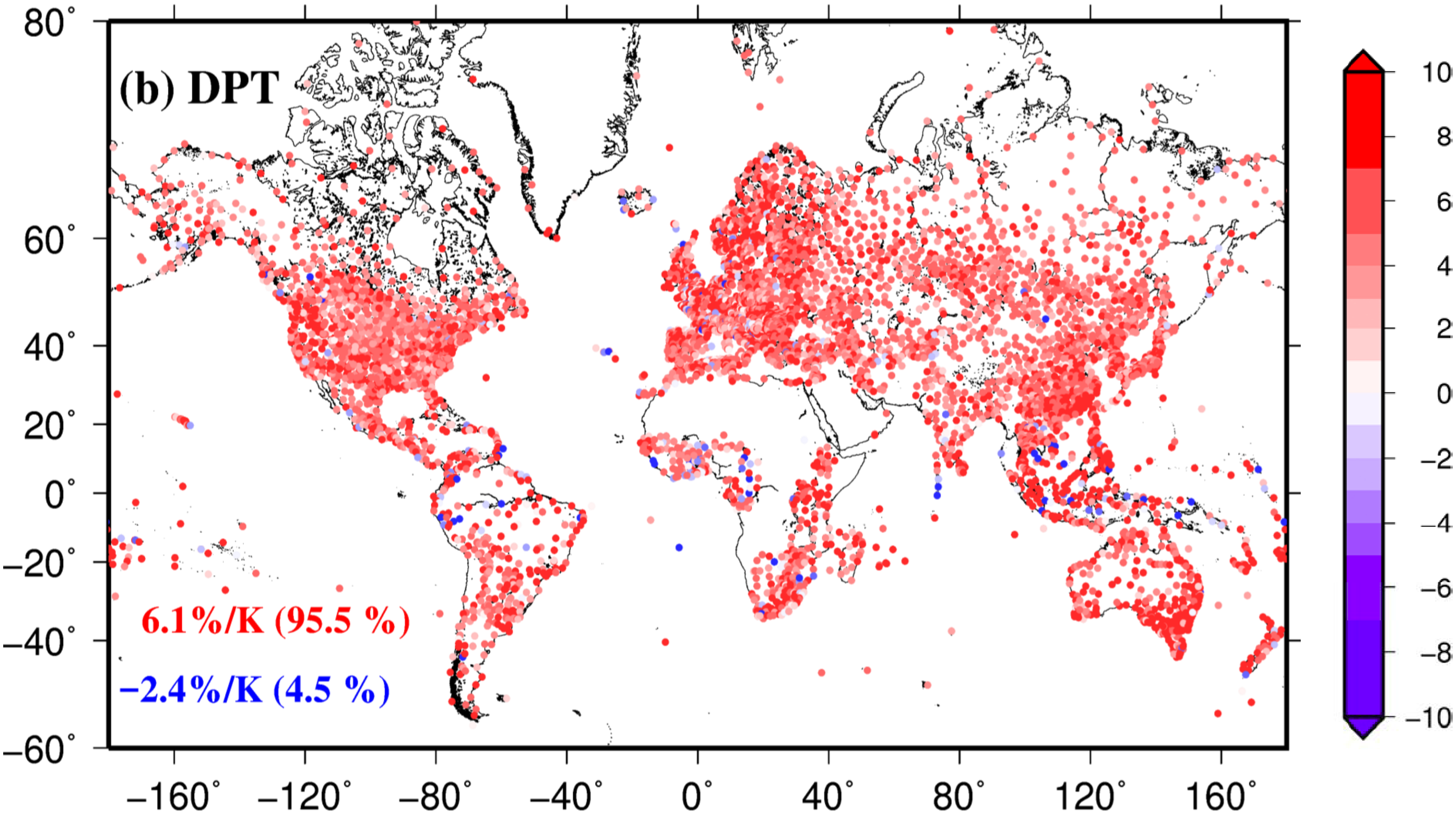
Ground Observations

Td = T - ((100 - RH)/5.)

Wasko et al. (2016)

Ali, Fowler and Mishra, GRL (2018)

Scaling confirmed at 6-7% per °C warming for daily extreme rainfall

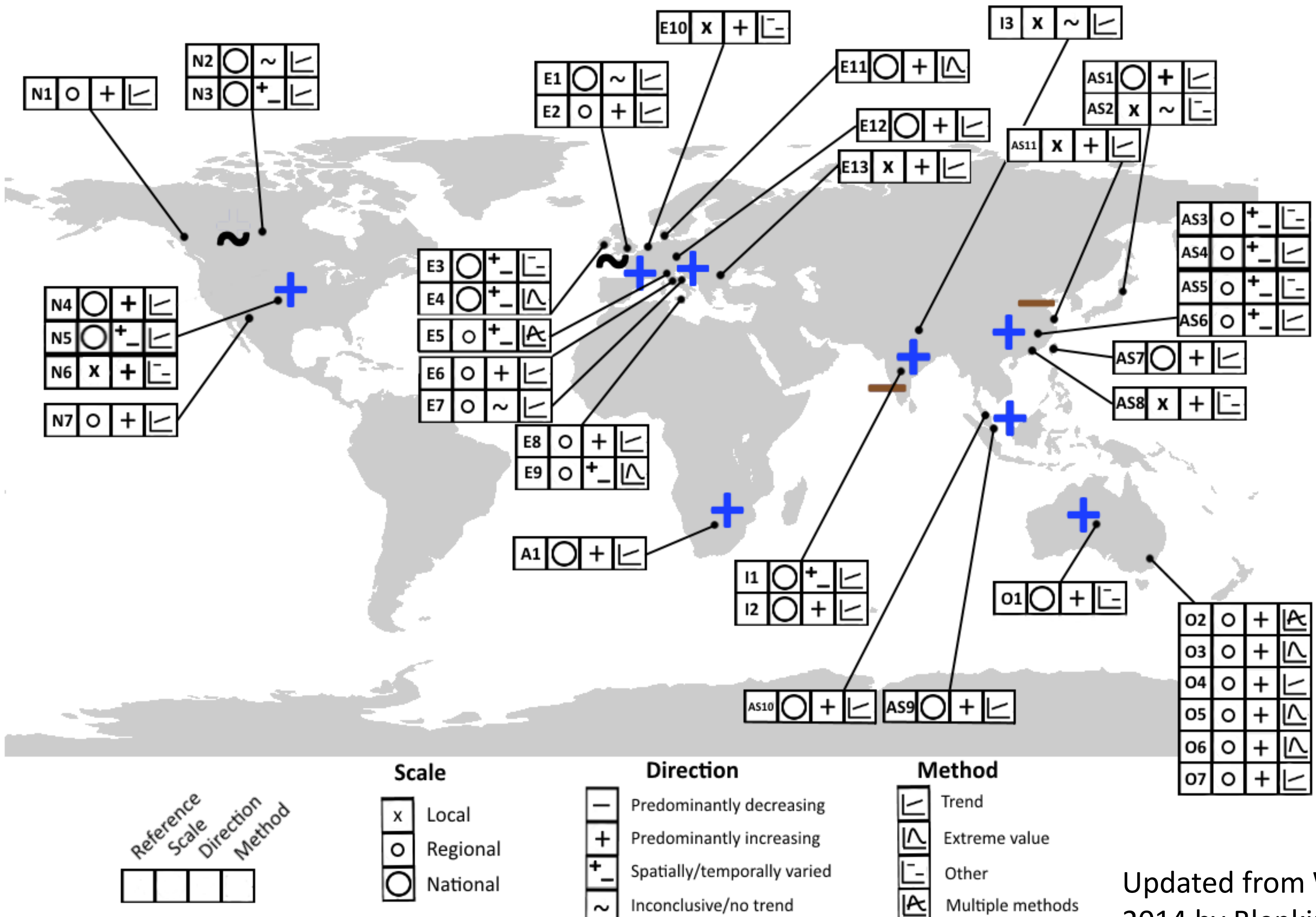


Using Zhang et al. (2017) method

Ali, Fowler and Mishra, GRL, 2018

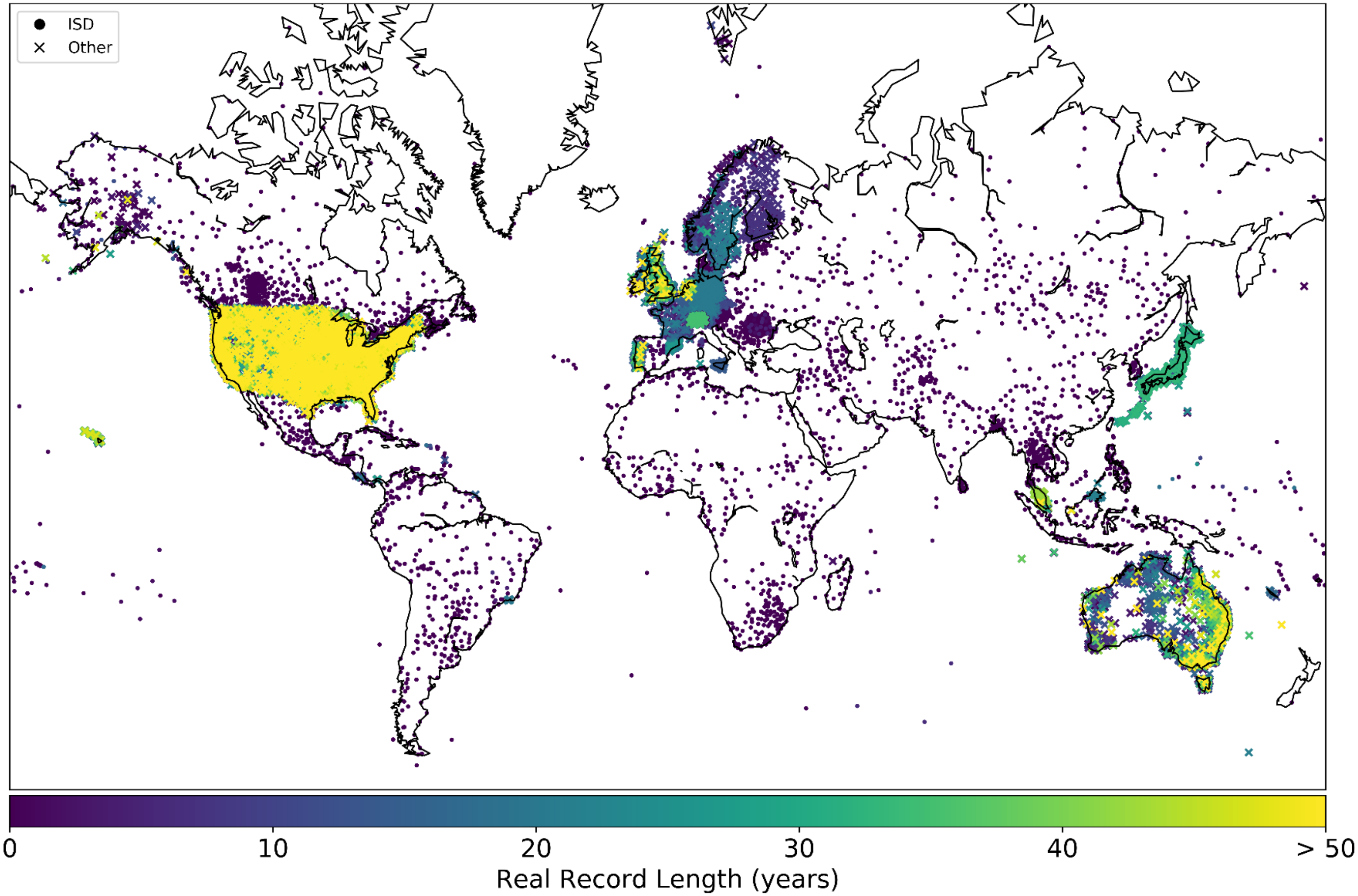
INTENSE

Synthesis of regional changes in sub-daily extreme rainfall intensity



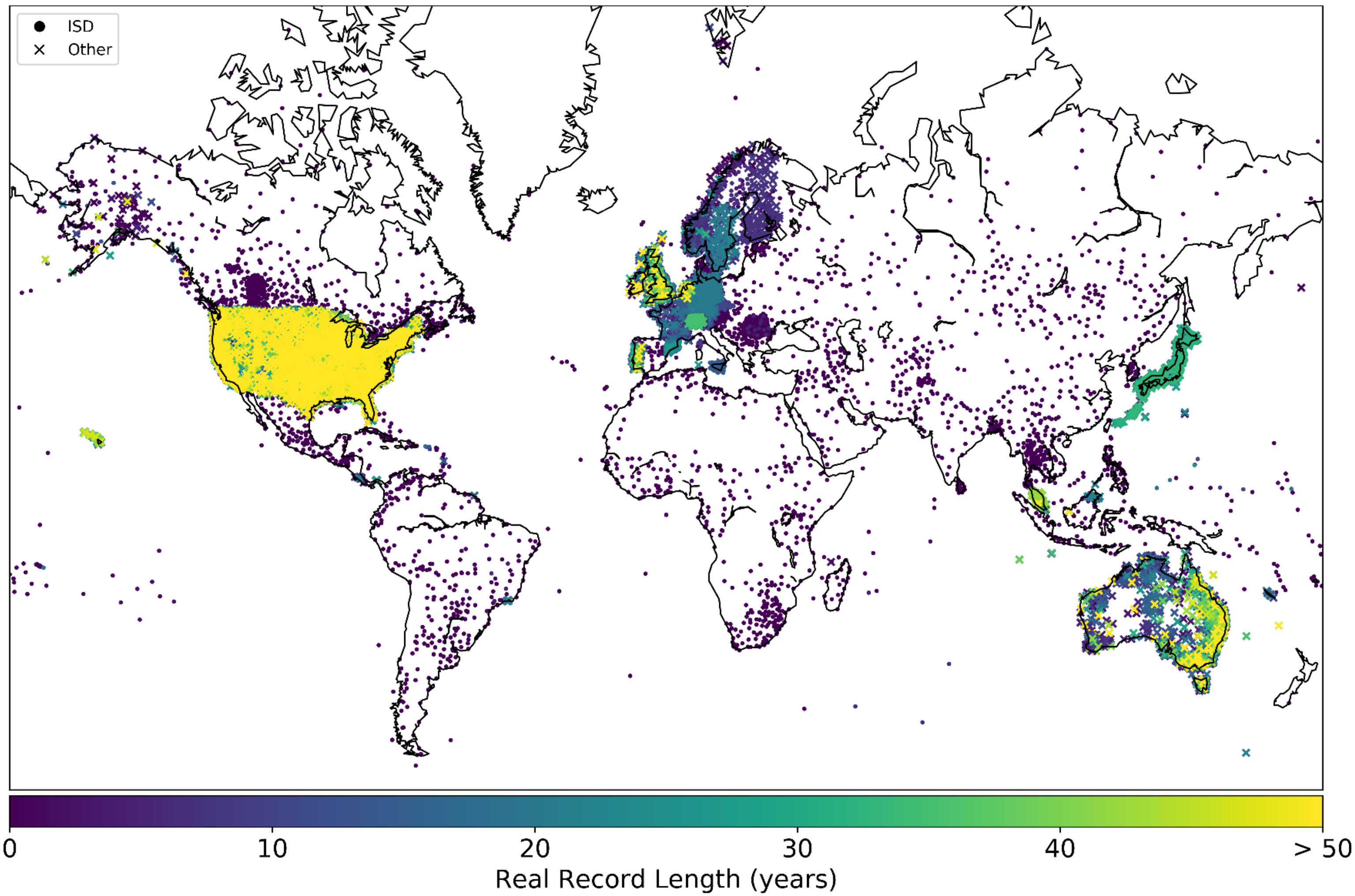
Updated from Westra et al 2014 by Blenkinsop for *BAMS State of Climate 2019*

GSDR- Global Sub-Daily Rainfall dataset -~25,000 stations



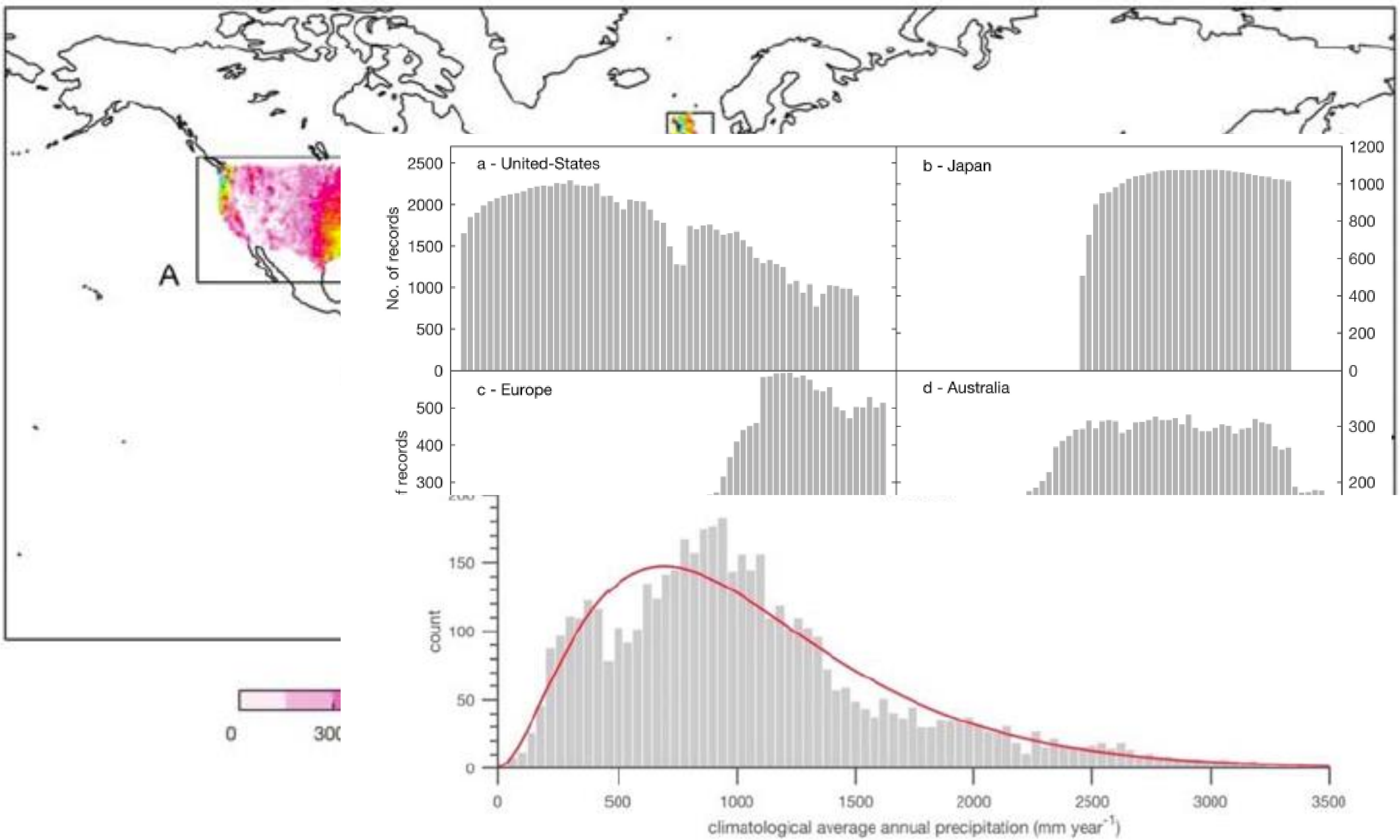
National datasets: UK, US, Canada, Brazil, France, Germany, Spain, Portugal, Italy, Philippines, India, Norway, Sweden, The Netherlands, Finland, Australia, Kenya, Indonesia, Slovenia, Costa Rica, Argentina, Switzerland, Austria, Hungary, Panama, Ireland, Japan, Malaysia, Singapore, Dominica, Trinidad & Tobago

GSDR: Lewis et al. 2019: Journal of Climate



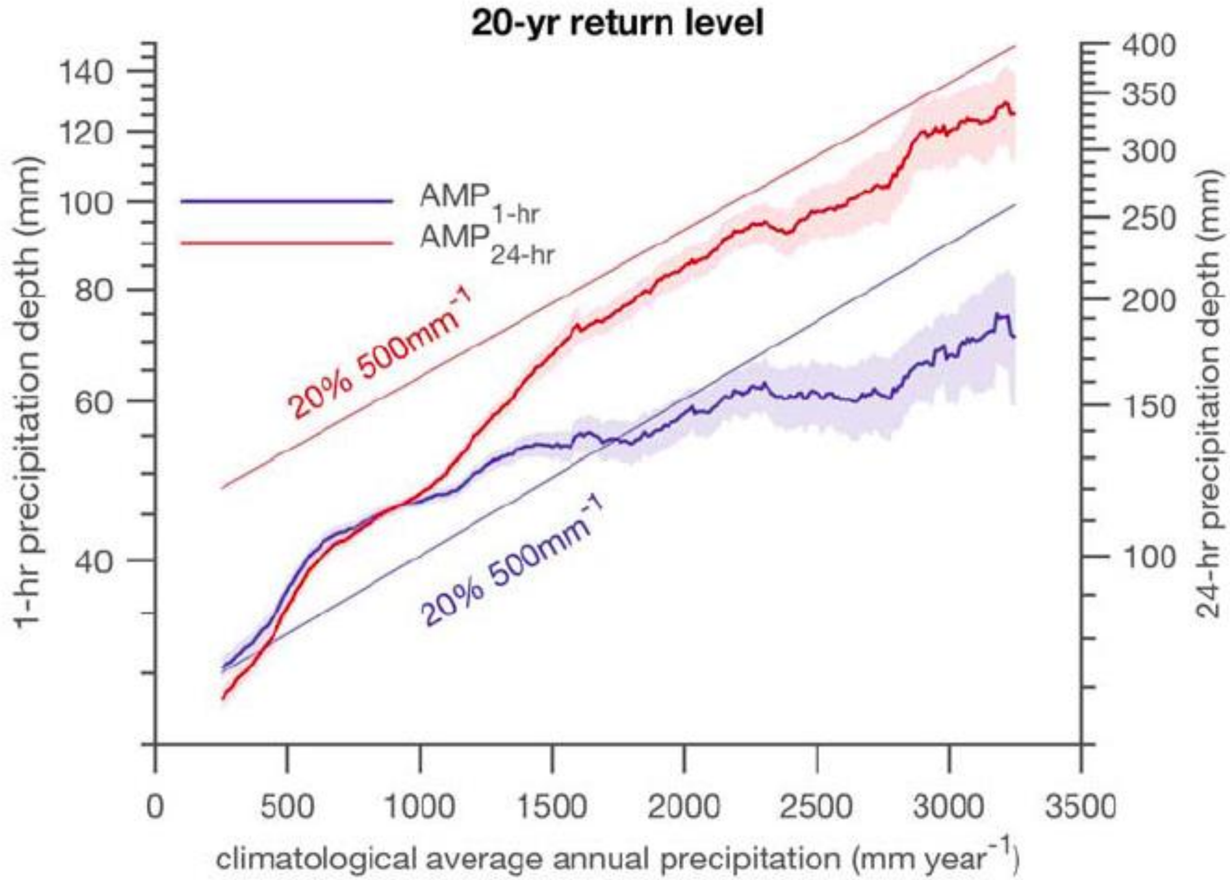
<u>Global dataset:</u> HadISD, approx. 10,000 stations (varying data quality, more useful data at 3h and 6h), freely available <u>sub-daily</u> precipitation data. Plus access to additional datasets (i.e. E Europe, China) to calculate indices.

Assessing hourly rainfall climatology



Barbero et al, in revision, WACE

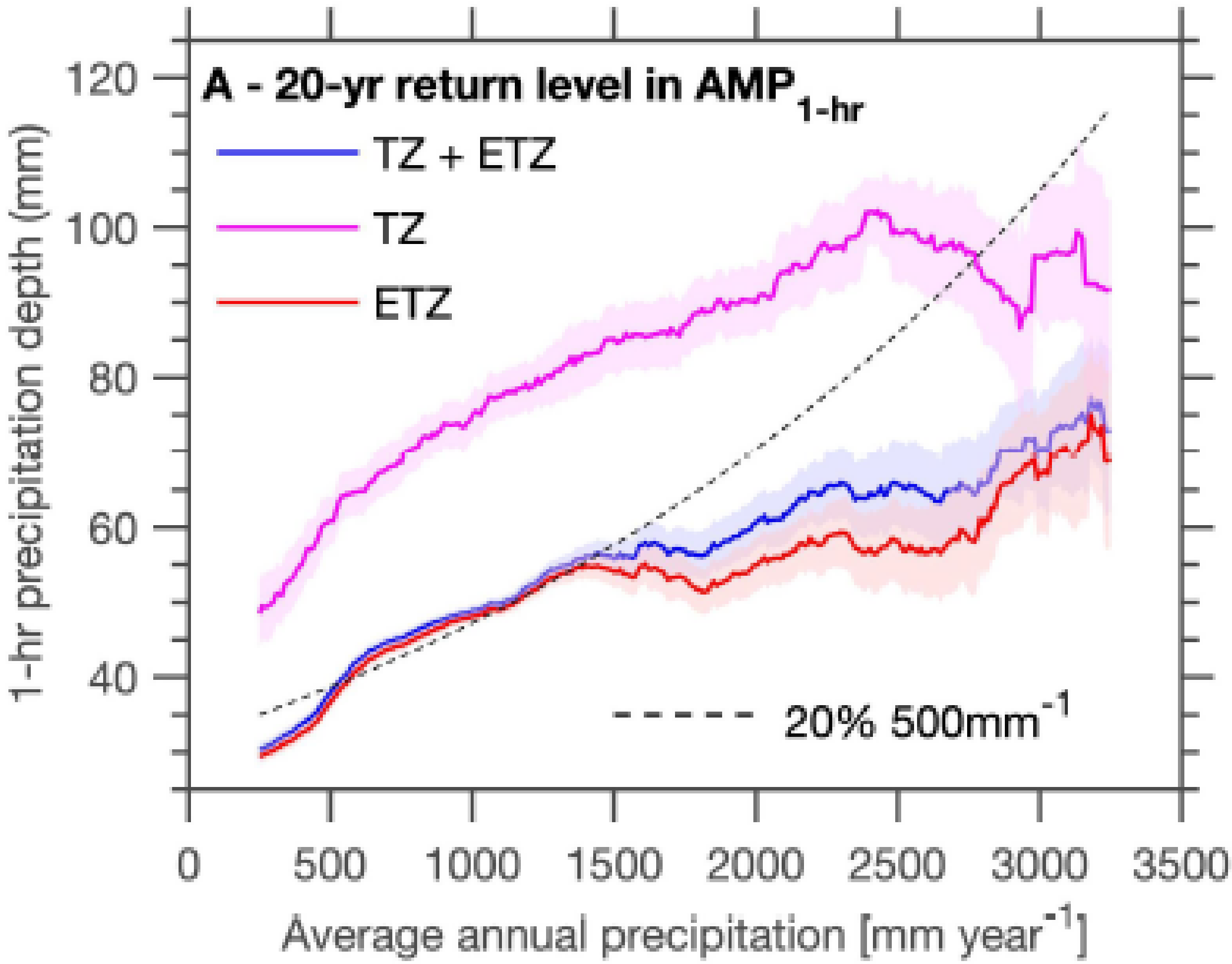
20y-RL estimated from Amax precipitation vs total annual precipitation at daily and hourly scales



Hourly relatively more intense in dry regions (up to 1500mm rainfall)

Barbero et al, in revision, WACE

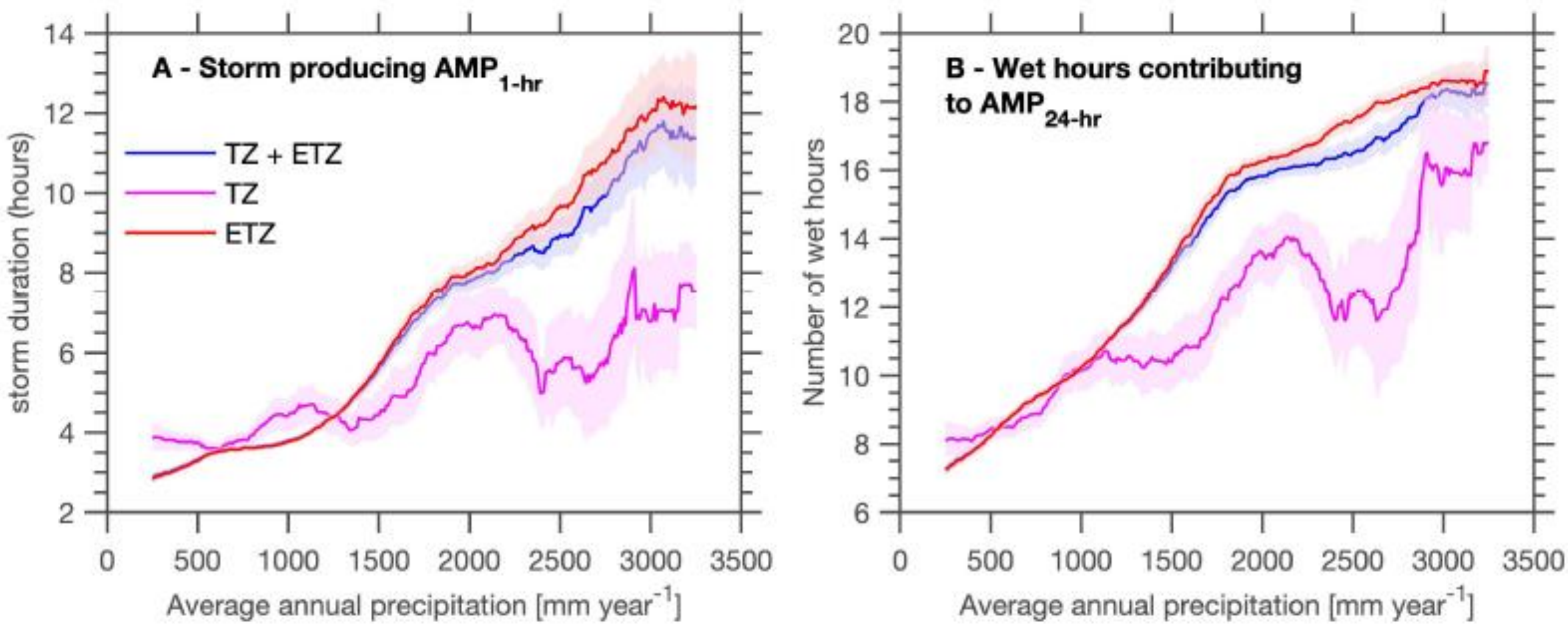
20y-RL estimated from Amax precipitation vs total annual precipitation at hourly scale



Approx. same rate of rise with AAP but offset at higher rate in the Tropics

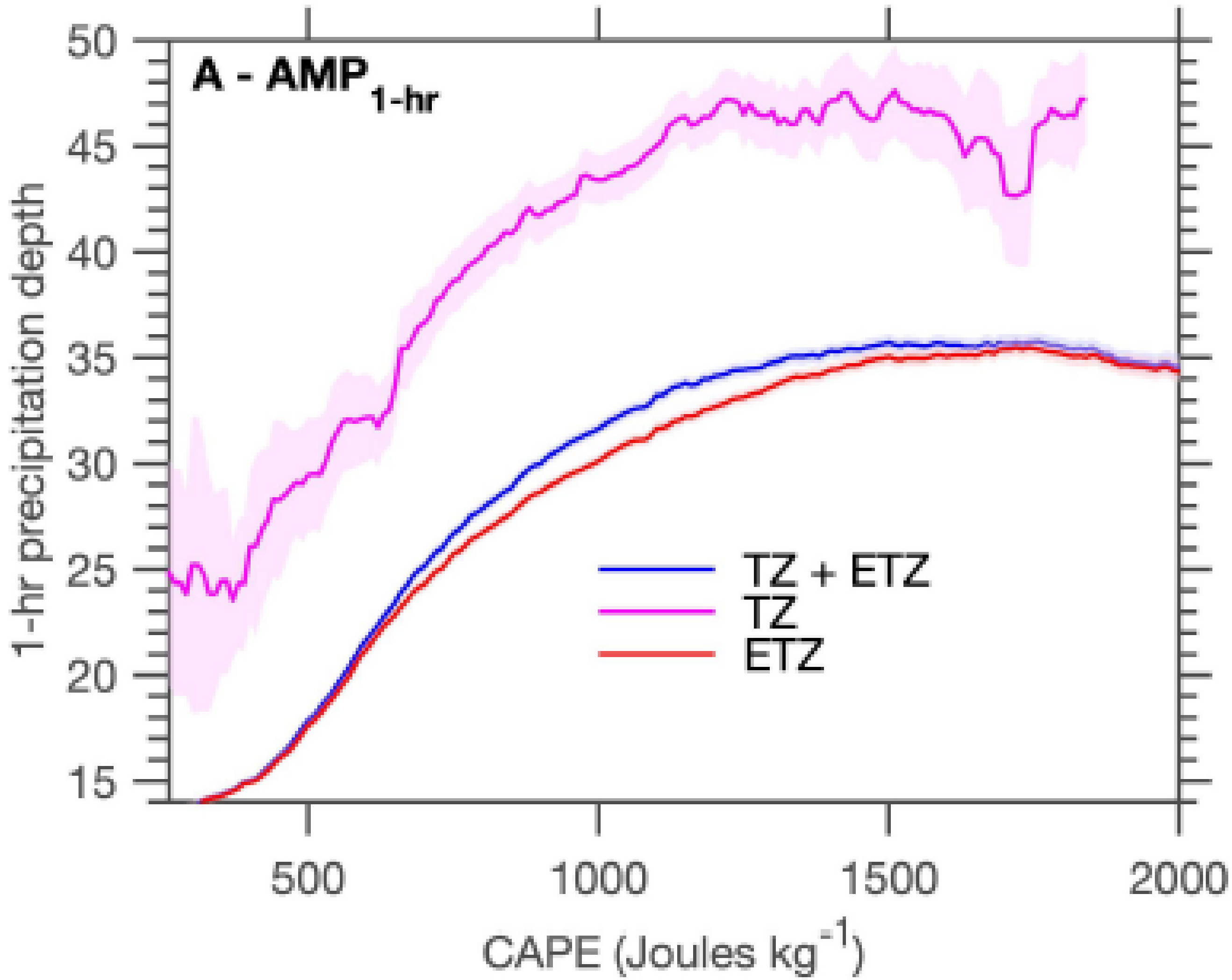
Barbero et al, in revision, WACE

Storm duration producing 1hr AMP and wet hours contributing to 24hr AMP



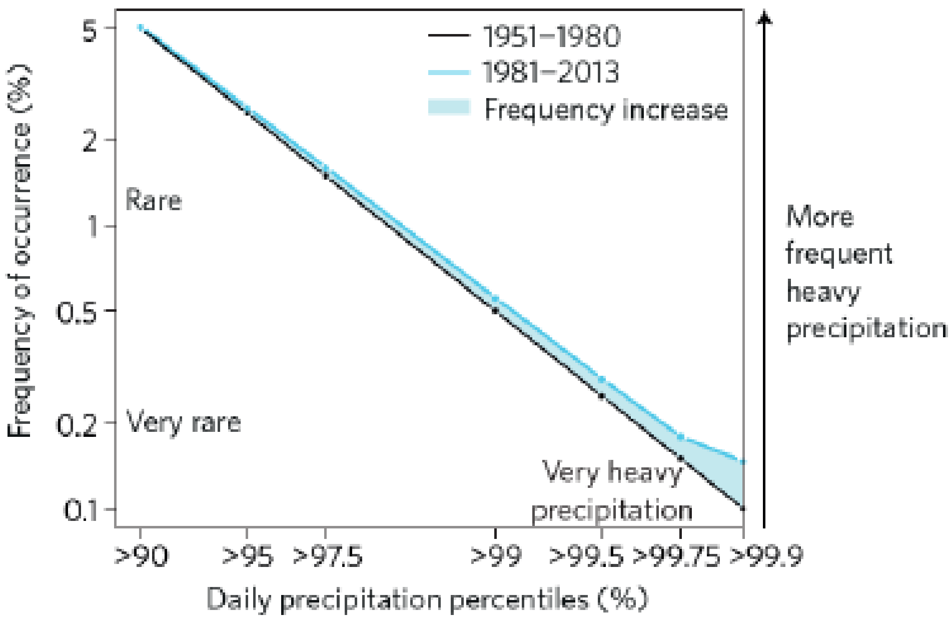
Barbero et al, in revision, WACE

1hr AMP and maximum CAPE observed over previous 24-hr period

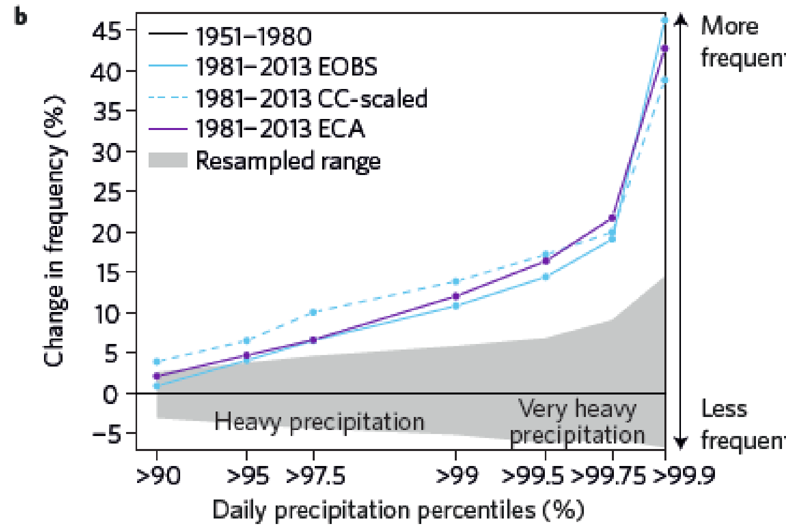


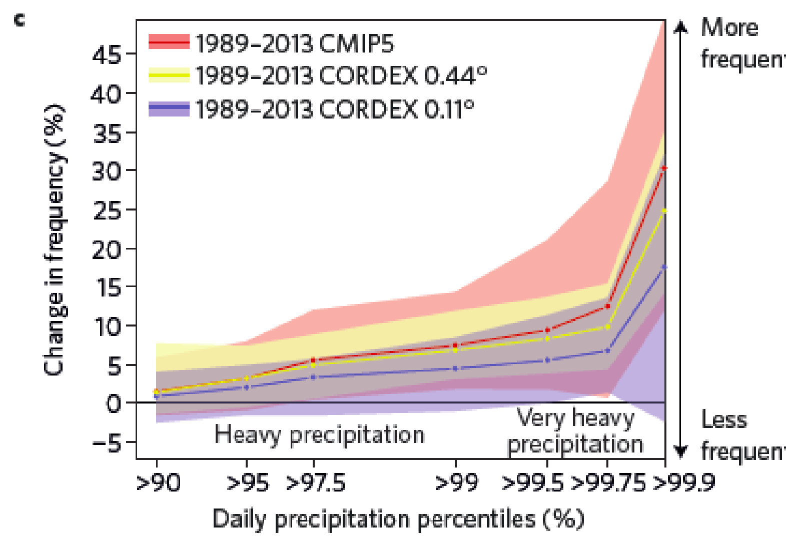
Barbero et al, in revision, WACE

Increase in the frequency of daily heavy precipitation consistent with CC scaling



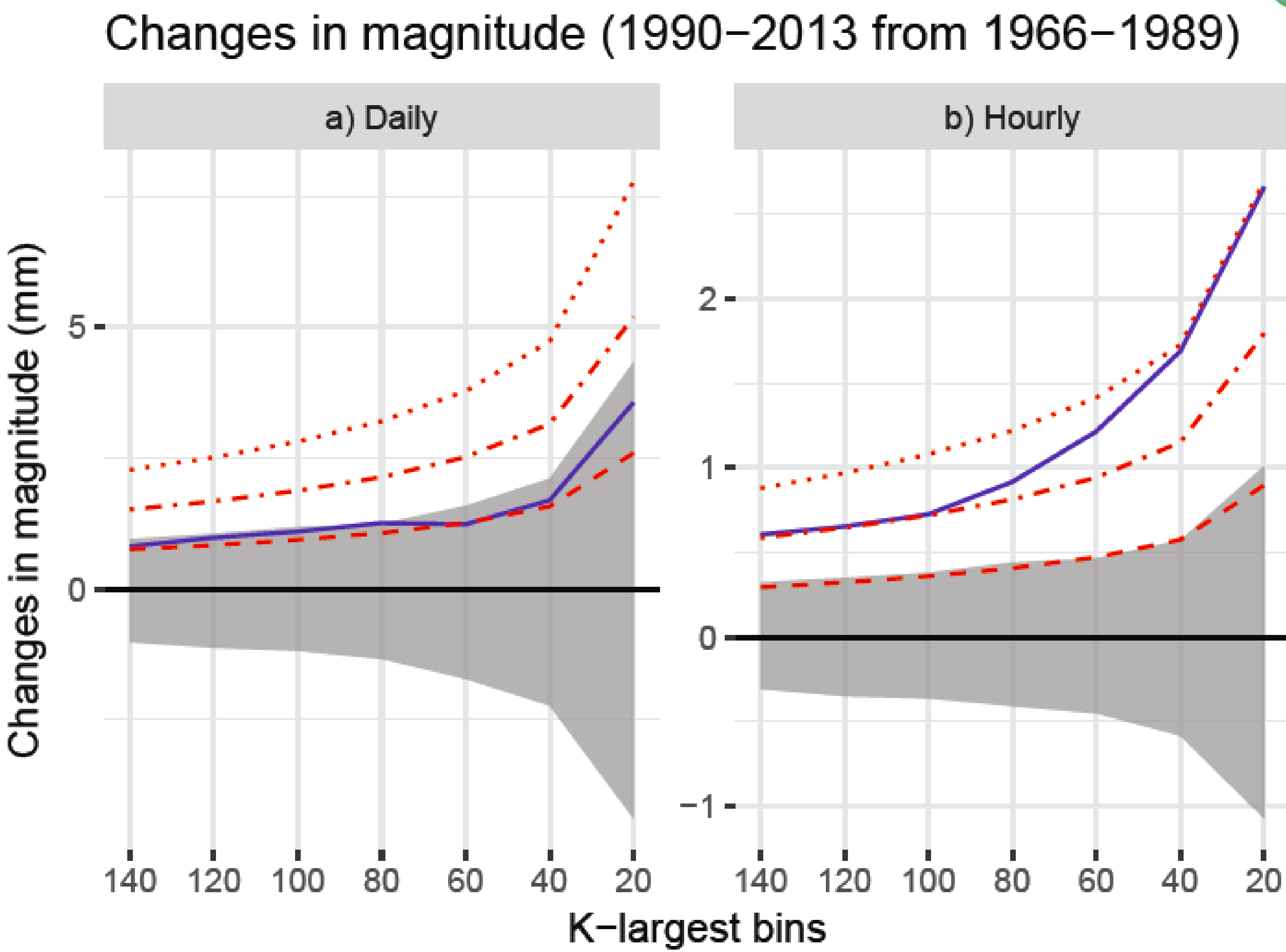
Over Europe, EOBS gridded observation data set





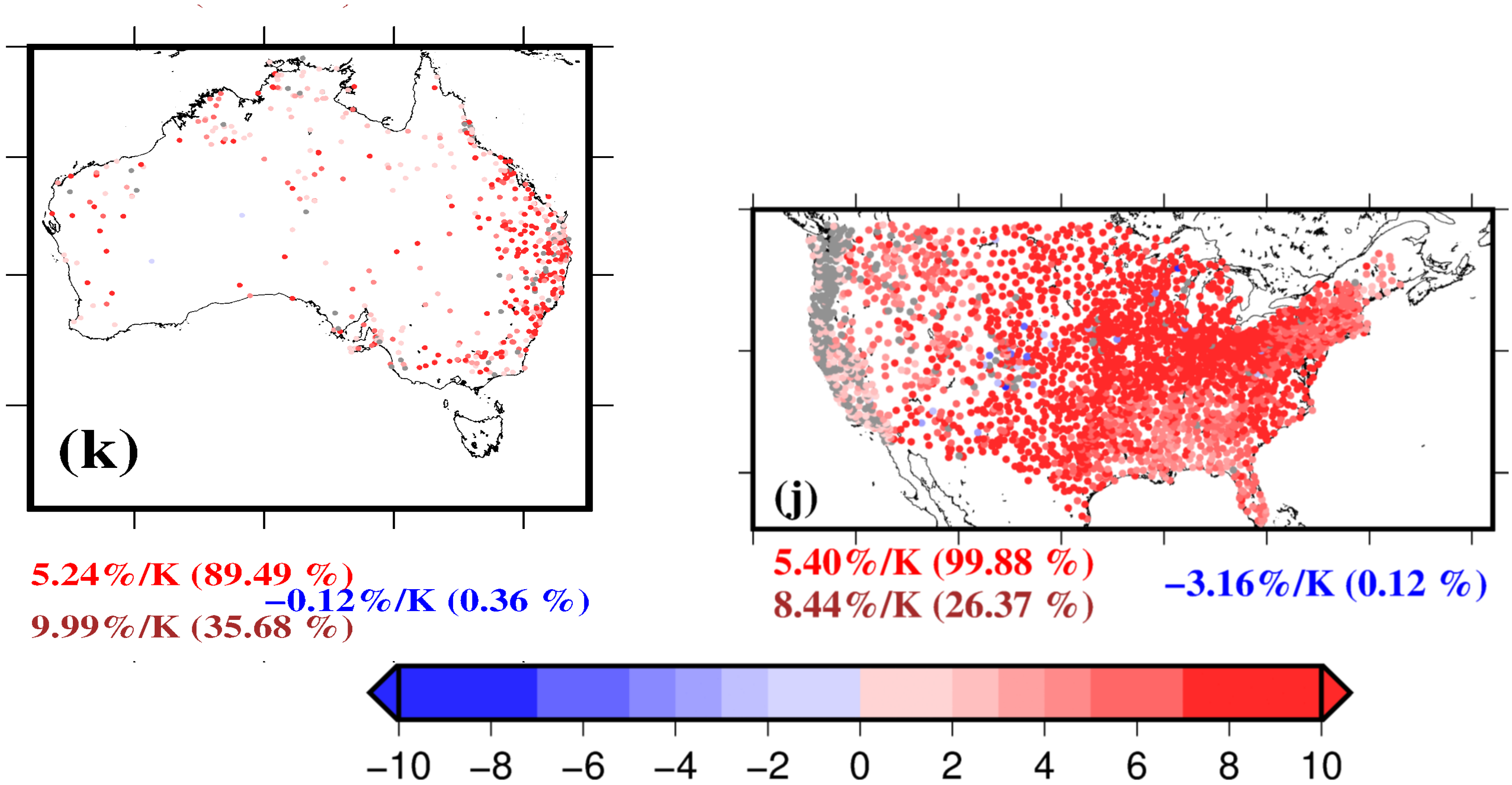
Fischer and Knutti, Nature Climate Change, 2016

Australia: Changes in magnitude



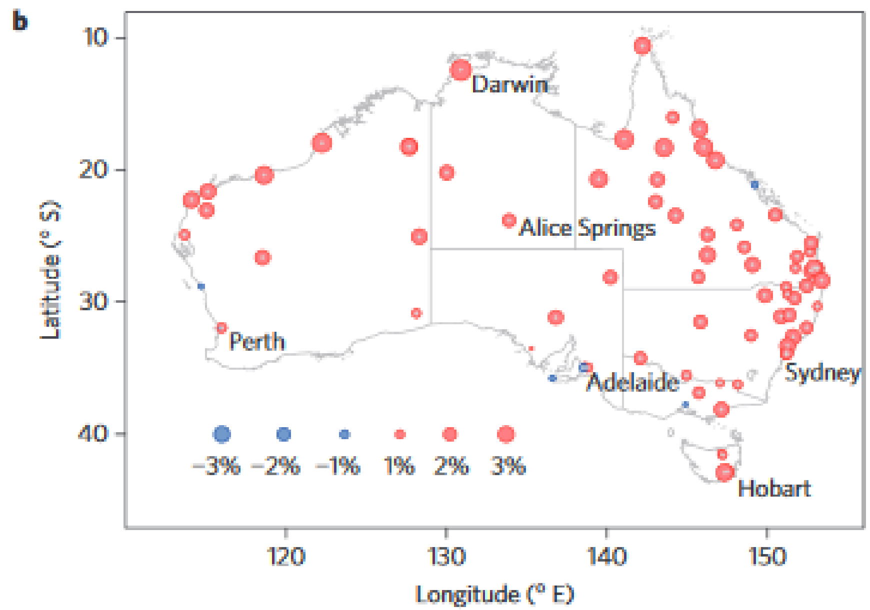
Guerreiro et al., Nature Climate Change, 2018

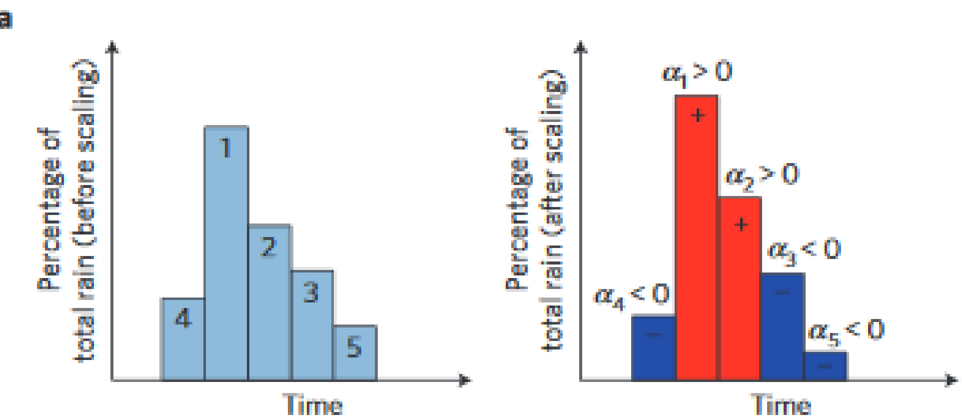
Global dewpoint temperature scaling of hourly extreme precipitation

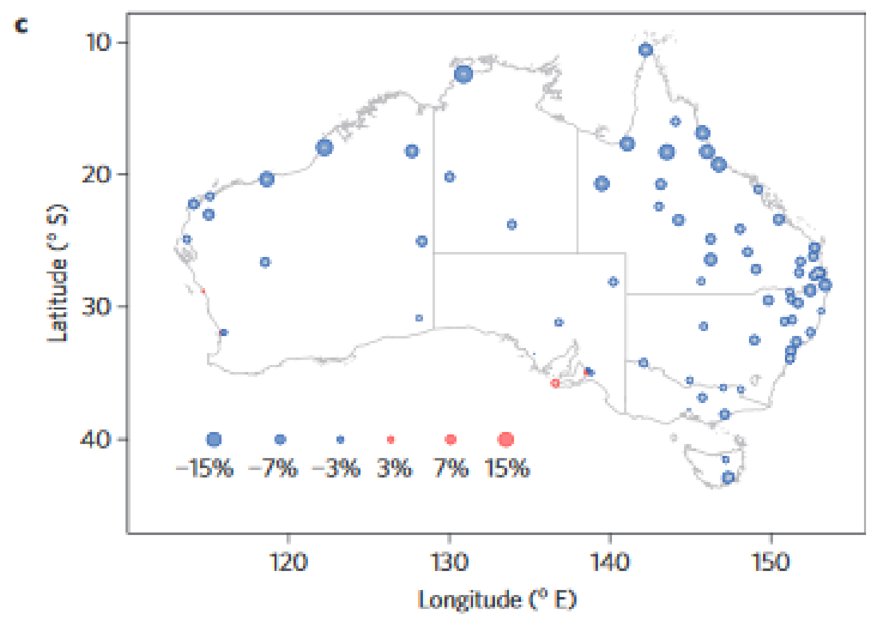


Ali et al., in prep

More intense peak precipitation and weaker precipitation during less intense times – is found at higher temperatures, regardless of the climatic region and season



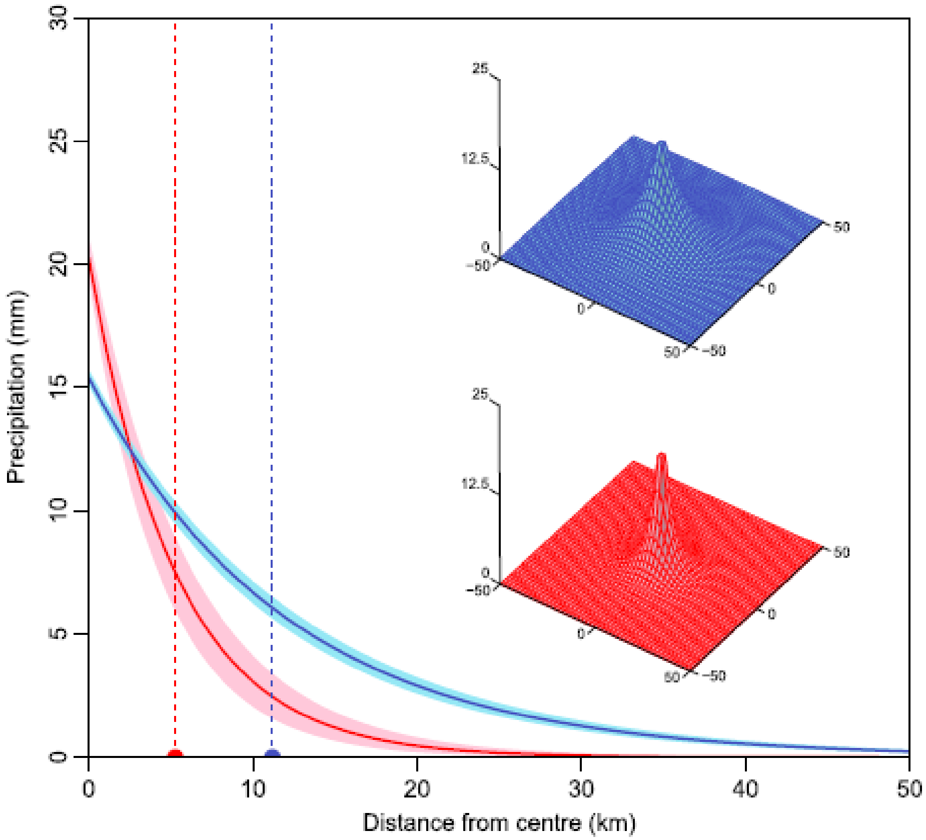




Wasko and Sharma, 2015, *Nature Geoscience*

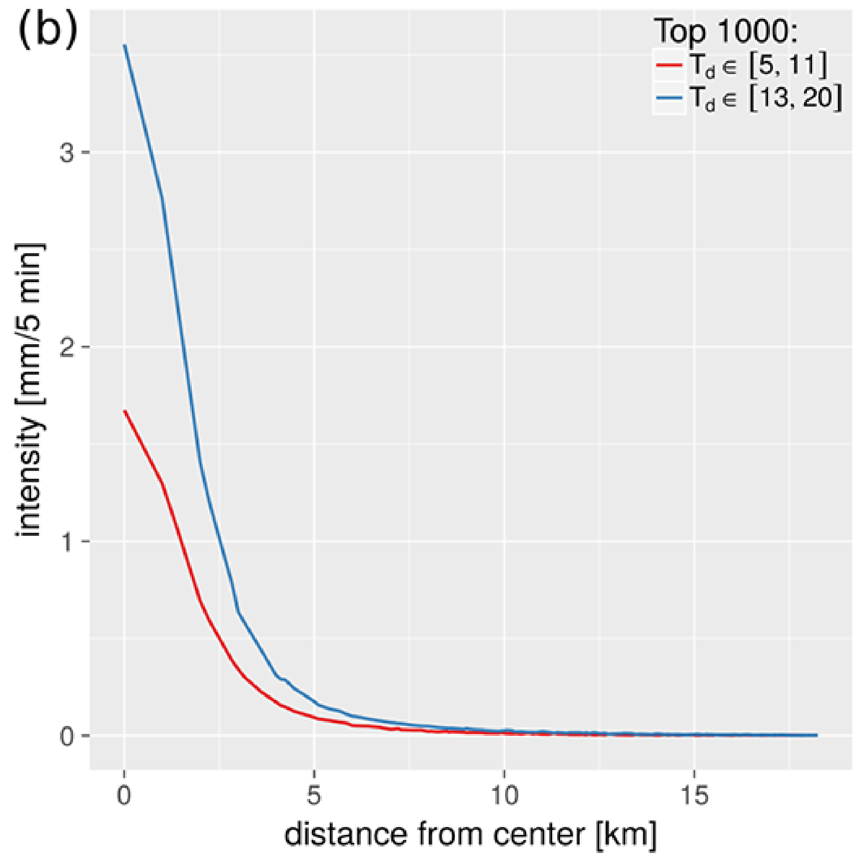
Effect of temperature on storm size and intensity: Observed changes

Australia



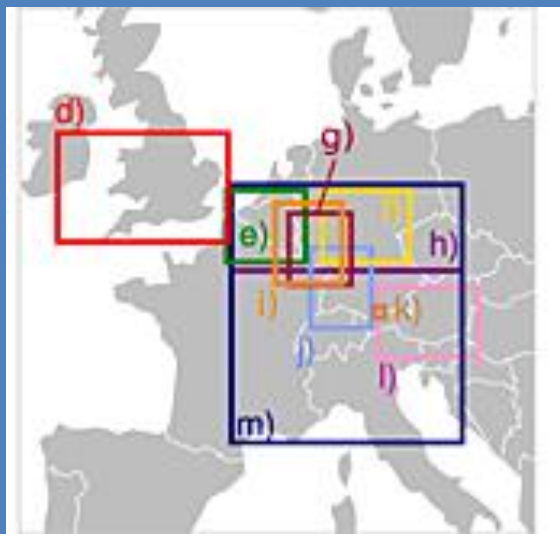
Wasko et al. 2016

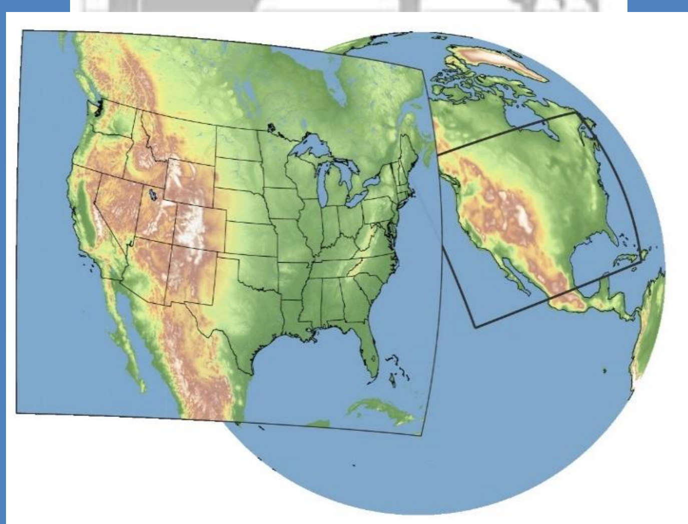
The Netherlands



Lochbihler et al. 2017

Convection-Permitting Climate Models





Grid spacing ≤ 4 km
Explicitly represent convection without need for parameterisation scheme.

Now many studies and continental-scale domains

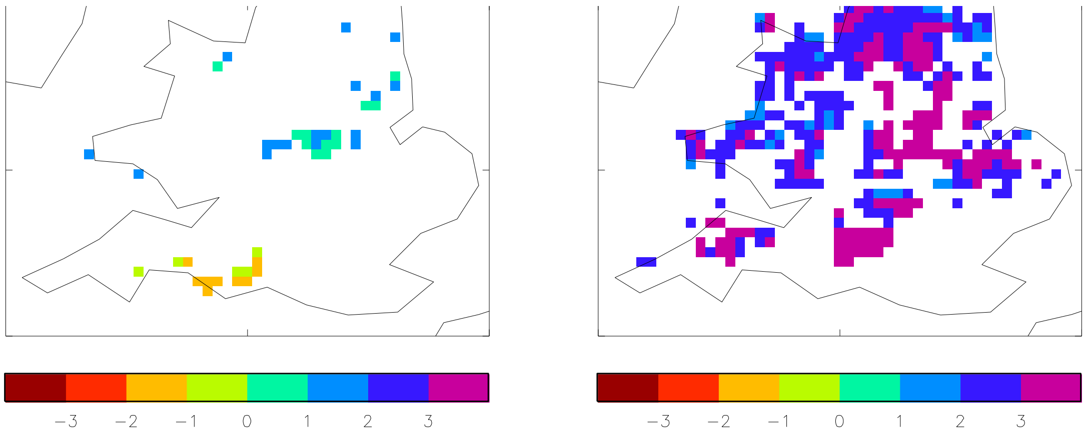
Included in UKCP18

More realistic extremes, duration, frequency of events and diurnal cycle.

Needed for robust projections of change to duration and intensity of summer convective rainfall
- *Kendon et al, BAMS, 2017*

Future change in heavy rainfall

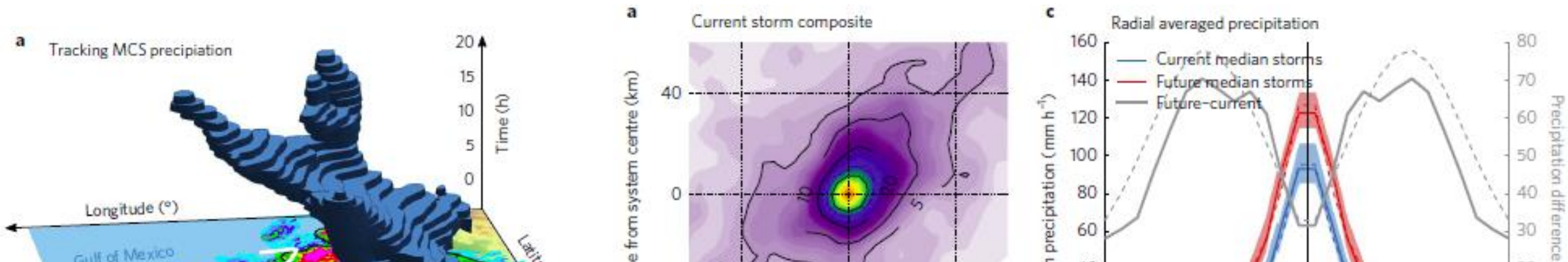
12km model future change | 1.5km model future change



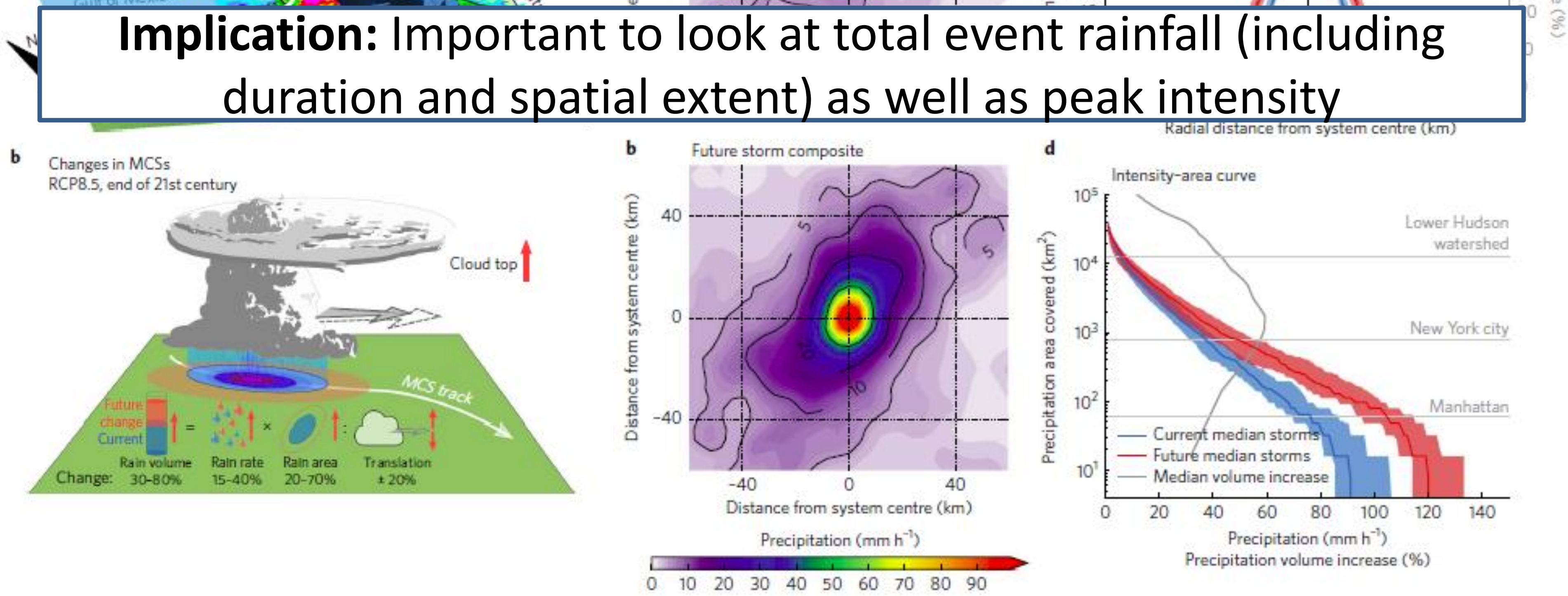
Kendon et al, 2014, Nature Clim. Change

- Summer precipitation intensities increase by 30-40% for short-duration extreme events – even larger increases in Scotland
- Hourly events over 30mm show a five-fold frequency increase
- Used to provide revised guidance for UK sewer design for UK Water Industry Research (UKWIR) project (with CH2M). Will be revised again with UKCP18 outputs.

Effect of temperature on storm size and intensity
Future projections

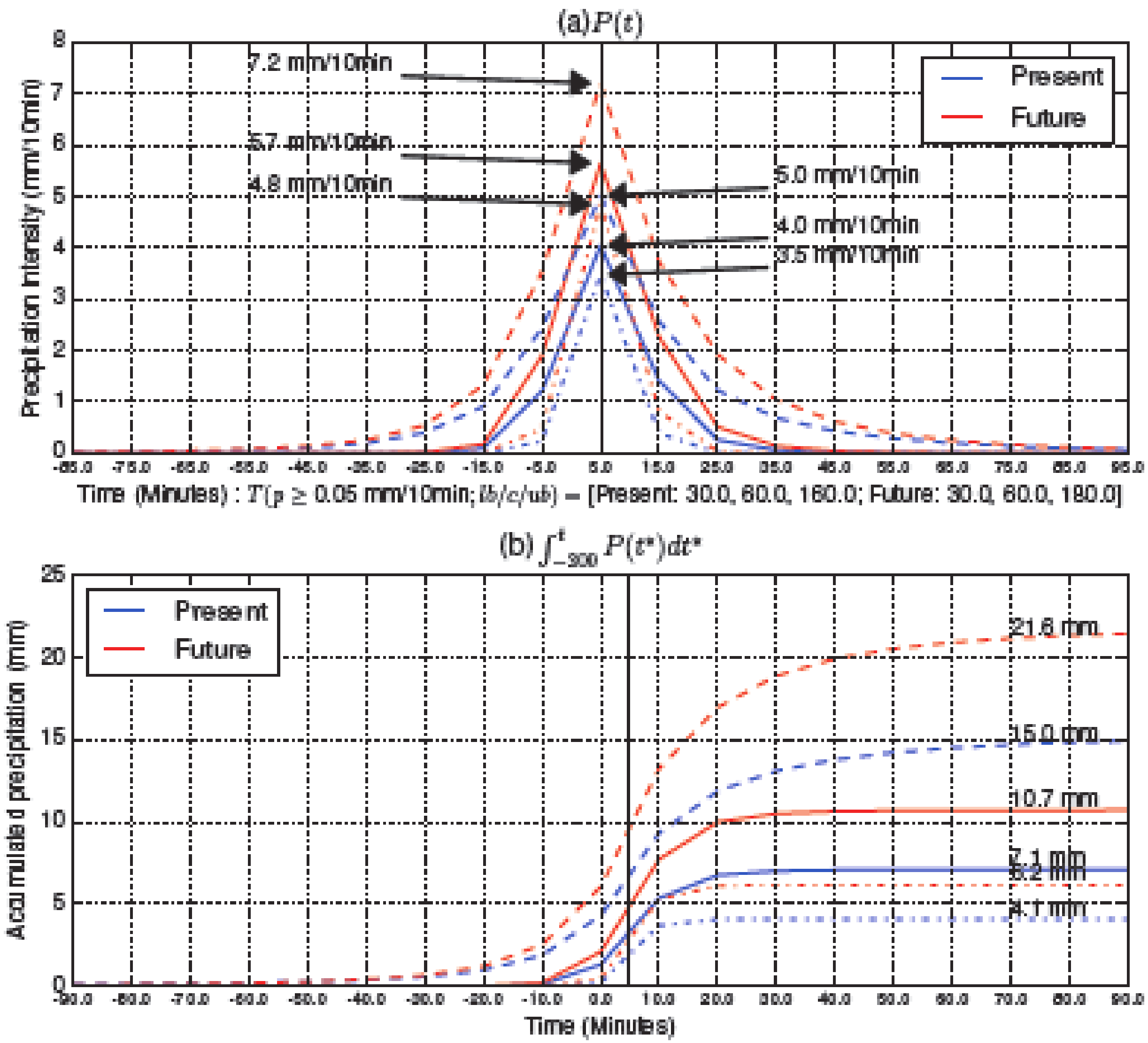


Implication: Important to look at total event rainfall (including duration and spatial extent) as well as peak intensity



Prein et al, 2017, NCC

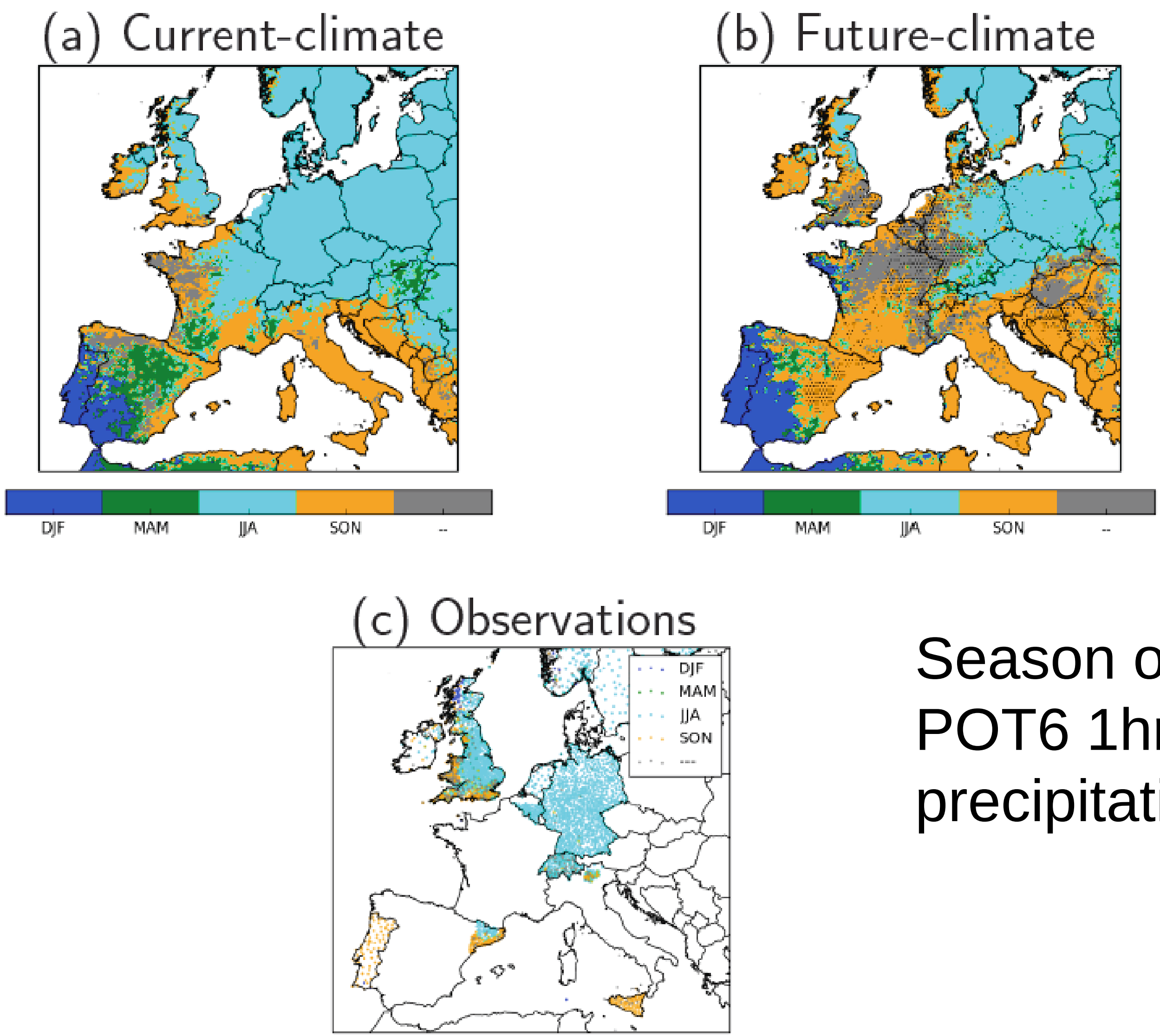
Longer duration events and higher peak intensities as temperature increases



- Rainfall composites for peak 10-min intensity > 99 percentile.
- (a) 10-min intensity
- (b) accumul. since t-300

Chan et al. ERL, 2016

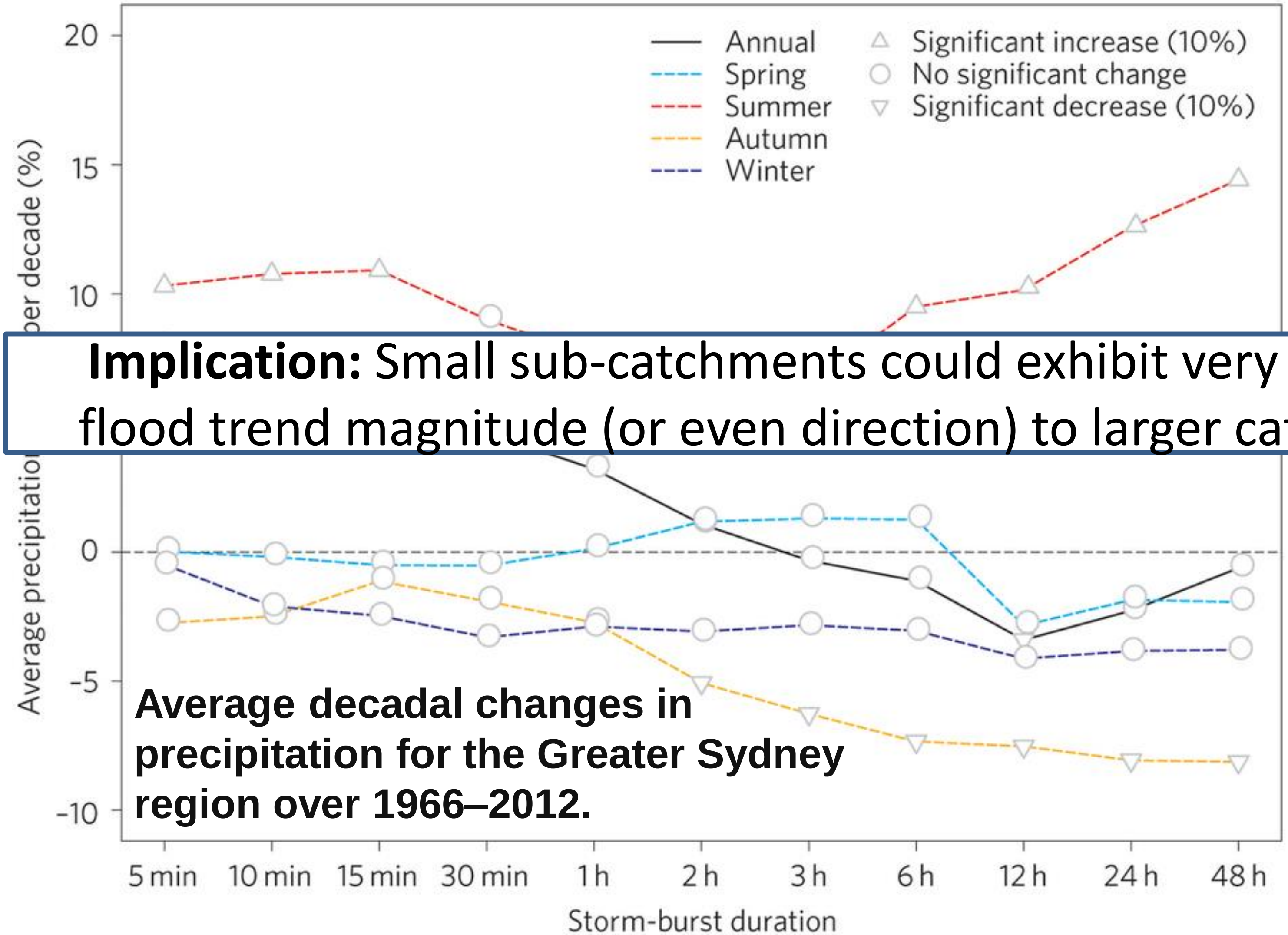
European CPM – projected changes
Seasonality change of heavy 1hr precipitation



Season of maximum POT6 1hr precipitation events

Chan et al, submitted

Opposite seasonal trends



Implication: Small sub-catchments could exhibit very different flood trend magnitude (or even direction) to larger catchments

Average decadal changes in precipitation for the Greater Sydney region over 1966–2012.

Zheng et al. 2015, Nature Climate Change

Summary

- **We can expect rainfall extremes to increase with global warming**.
- **Evidence that extremes scale with regional and global temperature and some evidence of super-CC scaling for hourly extremes** but several challenges remain in identifying relative response to warming in observations at daily and sub-daily timescales. Changes/trends different for different seasons and frequency/magnitude changes.
- **Greater understanding of large-scale drivers and interaction with thermodynamics is needed.**
- Great potential in linking understanding gained from observations and new **very-high-resolution convection-permitting model** developments.
- Need for updates to **flood risk estimation methods** and **guidance for surface water flooding climate allowances**.

INTENSE publications (2019)

- Lewis, E., Fowler, H.J., Alexander, L., Dunn, R., McClean, F., Barbero, R., Guerreiro, S., Li, X-.F., Blenkinsop, S. 2019. GSDR: A global sub-daily rainfall dataset. **Journal of Climate**, DOI: 10.1175/JCLI-D-18-0143.1.
- Lenderink, G., Lind, P., van Meijgaard, E., Belusic, D., van Ulft, B., Kjellström, E., Fowler, H.J. 2019. Systematic increases in the thermodynamic response of hourly precipitation extremes in an idealized warming experiment with a convection-permitting climate model. **Environmental Research Letters,** DOI: 10.1088/1748-9326/ab214a.
- Moron, V., Barbero, R., Evans, J., Westra, S., Fowler, H.J. 2019. Weather types and hourly to multi-day rainfall characteristics in Tropical Australia. **Journal of Climate**, DOI: 10.1175/JCLI-D-18-0384.1.
- Pumo, D., Carlino, G., Blenkinsop, S., Arnone, E., Noto, L.V., Fowler, H.J. 2019. Sensitivity of extreme rainfall to temperature in semi-arid Mediterranean regions. **Atmospheric Research**, 225, 30-44, DOI: 10.1016/j.atmosres.2019.03.036.
- Champion, A.J., Blenkinsop, S., Li, X.F., Fowler, H.J. 2019. Synoptic-Scale Precursors of Extreme UK Summer 3-Hourly Rainfall. **Journal of Geophysical Research: Atmospheres,** 124 (8), 4477-4489.
- Barbero, R., Abatzoglou, J., Fowler, H.J. 2019. Contribution of large-scale midlatitude disturbances to hourly precipitation extremes in the United States. **Climate Dynamics**, 52 (1-2), 197-208, DOI: 10.1007/s00382-018-4123-5.

INTENSE publications (2018)

- Ali, H., Fowler, H.J., Mishra, V. 2018. Global observational evidence of strong linkage between dew point temperature and precipitation extremes. **Geophysical Research Letters**, 45, 12320–12330, DOI: 10.1029/2018GL080557.
- Barbero, R., Westra, S., Lenderink, G., Fowler, H.J. 2018: Temperature-extreme precipitation scaling: a two-way causality? **International Journal of Climatology**, DOI: 10.1002/joc.5370.
- Chan, S.C., Kendon, E.J., Roberts, N.M., Blenkinsop, S., Fowler. H.J. 2018. Synoptic predictors for extreme hourly precipitation events in convection-permitting climate simulations. **Journal of Climate**, 31(6), doi: 10.1175/JCLI-D-17-0404.1.
- Chan, S.C., Kahana, R., Kendon, E.J., Fowler, H.J. 2018. Projected changes in extreme precipitation over Scotland and Northern England using a high-resolution regional climate model. **Climate Dynamics**, DOI: 0.1007/s00382-018-4096-4.
- Kendon, E.J., Blenkinsop, S., Fowler, H.J. 2018: When will we detect changes in short-duration precipitation extremes? **Journal of Climate**, DOI: 10.1175/JCLI-D-17-0435.1.
- Forestieri, A., Lo Conti, F., Blenkinsop, S., Fowler, H.J., Noto, L.V. 2018: Regional frequency analysis of extreme rainfall based on an objective data analysis. Application to Sicily (Italy). **International Journal of Climatology,** DOI: 10.1002/joc.5400.
- Forestieri, A., Arnone, E., Blenkinsop, S., Candela, A., Fowler, H.J., Noto, L.V. 2018: The impact of climate change on extreme precipitation in Sicily, Italy. **Hydrological Processes,** DOI: 10.1002/hyp.11421.

INTENSE publications (2018)

- Morbidelli, R., Saltalippi, C., Flammini, A., Corradini, C., Wilkinson, S.M., Fowler, H.J. 2018. Influence of temporal data aggregation on trend estimation for intense rainfall. **Advances in Water Resources,** 122, 304-316, DOI: 10.1016/j.advwatres.2018.10.027.
- Guerreiro, S., Fowler, H.J.**,** Barbero, R., Westra, S., Lenderink, G., Blenkinsop, S., Lewis, E., Li, X.-F. 2018. Detection of continental-scale intensification of hourly rainfall extremes. **Nature Climate Change,** 8(9), 803-807, DOI: 10.1038/s41558-018-0245-3.
- Lenderink, G., Barbero, R., Westra, S., Fowler, H.J. 2018. Reply to comments on “Temperature-extreme precipitation scaling: a two-way causality?” **International Journal of Climatology,** 38(12), 4664-4666, DOI: 10.1002/joc.5799.
- Blenkinsop, S., Fowler, H.J., Barbero, R., Chan, S.C., Guerreiro, S.B., Kendon, E., Lenderink, G., Lewis, E., Li, X.-F., Westra, S., Alexander, L., Allan, R.P., Berg, P., Dunn, R.J.H., Ekström, M., Evans, J.P., Holland, G., Jones, R., Kjellström, E., Klein-Tank, A., Lettenmaier, D., Mishra, V., Prein, A.F., Sheffield, J., Tye, M.R. 2018. The INTENSE project: using observations and models to understand the past, present and future of sub-daily rainfall extremes. **Adv. Sci. Res.,** 15, 117-126, DOI: 10.5194/asr-15-117-2018.
- Lewis, E., Quinn, N., Blenkinsop, S., Fowler, H.J., Freer, J., Tanguy, M., Hitt, O., Coxon, G., Bates, P., Woods, R. 2018. A rule based quality control method for hourly rainfall data and a 1km resolution gridded hourly rainfall dataset for Great Britain: CEH-GEAR1hr. **Journal of Hydrology,** 564, 930-943, DOI: 10.1016/j.jhydrol.2018.07.034.

INTENSE publications (2016-17)

- Lochbihler, K., G. Lenderink, and A. P. Siebesma (2017), The spatial extent of rainfall events and its relation to precipitation scaling, **Geophys. Res. Lett.,** 44, doi:10.1002/2017GL074857.
- Lenderink, G., Fowler, H.J. 2017. Understanding Precipitation Extremes. **Nature Climate Change**, 7, 391–393, doi:10.1038/nclimate3305.
- Lenderink, G., Barbero, R., Loriaux, J.M., Fowler, H.J. 2017. Super Clausius-Clapeyron scaling of extreme hourly precipitation and its relation to large-scale atmospheric conditions. **Journal of Climate**, DOI: 10.1175/JCLI-D-16-0808.1
- Barbero, R., Fowler, H.J., Lenderink, G., Blenkinsop, S. 2017. Is the intensification of precipitation extremes with global warming better detected at hourly than daily resolutions? **Geophysical Research Letters**, DOI: 10.1002/2016GL071917
- Chan, S.C., Kendon, E.J., Roberts, N.M., Fowler. H.J., Blenkinsop, S. 2016. The characteristics of summer sub-hourly rainfall in a high-resolution convective permitting model. **Environmental Research Letters**, 11, 094024, doi:10.1088/1748-9326/11/9/094024.
- Kendon, E.J., Ban, N., Roberts, N.M., Roberts, M.J., Chan, S. Fowler, H.J., Fosser, G., Evans, J. and Wilkinson, J. 2016. Do convection-permitting regional climate models improve projections of future precipitation change? **Bull. Am. Meteorol. Soc.**, DOI: 10.1175/BAMS-D-15-0004.1.
- Blenkinsop, S., Lewis, E., Chan, S., Fowler, H.J. 2016. Quality control of an hourly rainfall dataset and climatology of extremes for the UK. **International Journal of Climatology**, DOI: 10.1002/joc.4735.
- Chan, S.C., Kendon, E.J., Roberts, N.M., Fowler, H.J., Blenkinsop, S. 2016: Downturn in scaling of UK extreme rainfall with temperature for future hottest days. **Nature Geoscience**, 9, 24–28, DOI: 10.1038/NGEO2596.

INTENSE publications (2014-15)

- Hegerl, G.C, Black, E., Allan, R.P., Ingram, W.J., Polson, D., Trenberth, K.E., Chadwick, R.S., Arkin, P.A., Sarojini, B.B., Becker, A., Dai, A., Durack, P.J., Easterling, D., Fowler, H.J., Kendon, E.J., Huffman, G.J., Liu, C., Marsh, R., New, M., Osborn, T.J., Skliris, N., Stott, P.A., Vidale, P.L., Wijffels, S.E., Wilcox, L.J., Willett, K.M., Zhang, X. 2015: Challenges in Quantifying Changes in the Global Water Cycle. **Bulletin of the American Meteorological Society,** 96, 1097–1115, doi: http://dx.doi.org/10.1175/BAMS-D-13-00212.1
- Blenkinsop, S, Chan, S, Kendon, E.J, Roberts, N.M., Fowler, H.J. 2015. Temperature influences on intense UK hourly precipitation and dependency on large-scale circulation. **Environmental Research Letters**, 10, 054021, doi:10.1088/1748-9326/10/5/054021.
- Westra, S., Fowler, H.J., Evans, J.P., Alexander, L.V., Berg, P., Johnson, F., Kendon, E.J., Lenderink, G. and Roberts, N.M. 2014. Future changes to the intensity and frequency of short-duration extreme rainfall. **Rev. Geophys.**, 52(3), 522–555 DOI: 10.1002/2014RG000464.