GEWEX/GHP annual meeting 2017
17th -19th October, 2017, Kathmandu, Nepal

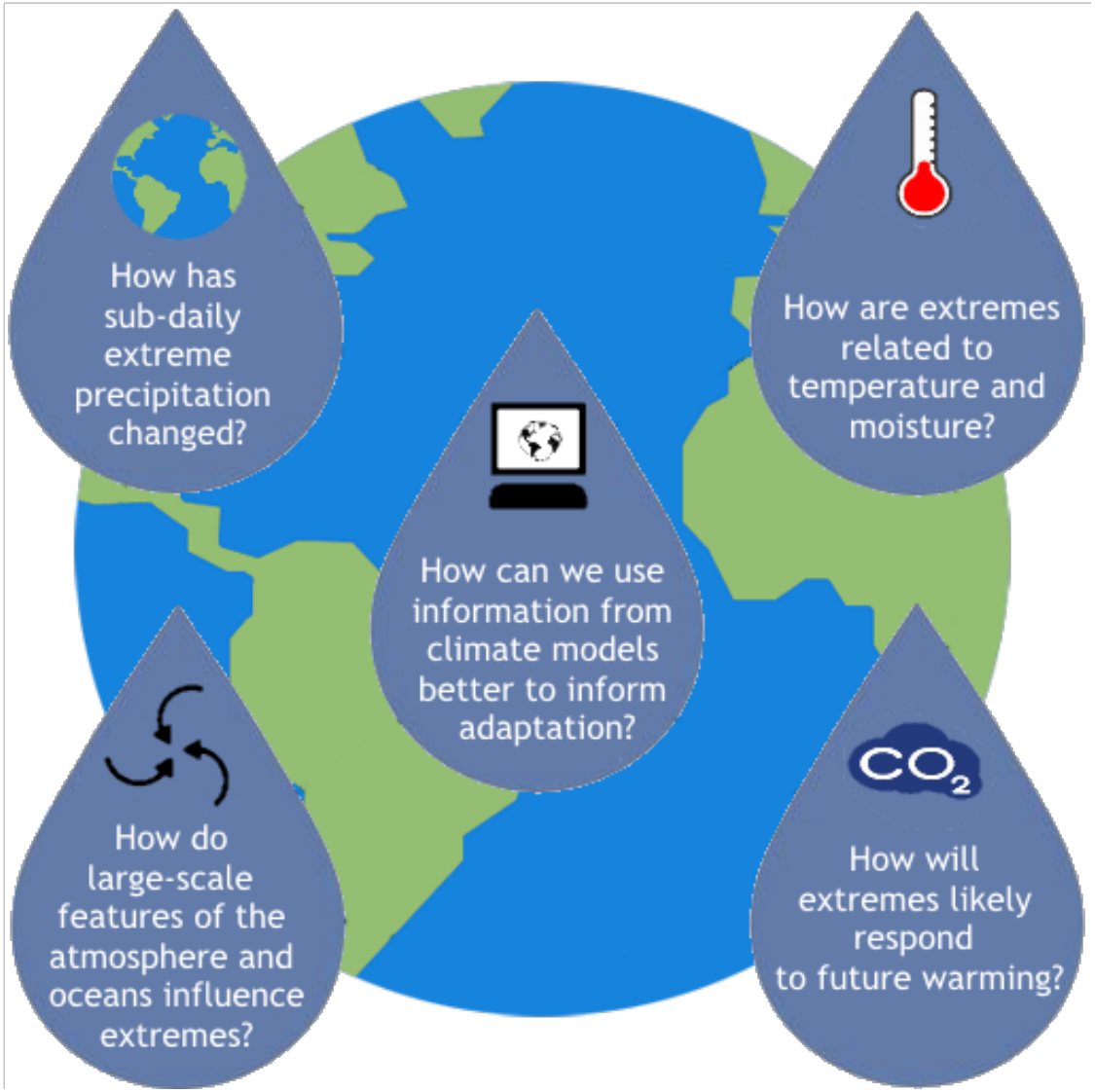
European Research Council
Established by the European Commission

Understanding changes in short-duration heavy rainfall under global warming: The GEWEX cross-cut on sub-daily rainfall extremes (INTENSE)

Dr Nathan Forsythe

On behalf of Prof Hayley Fowler
Newcastle University, UK

INTENSE research questions



Thanks to:

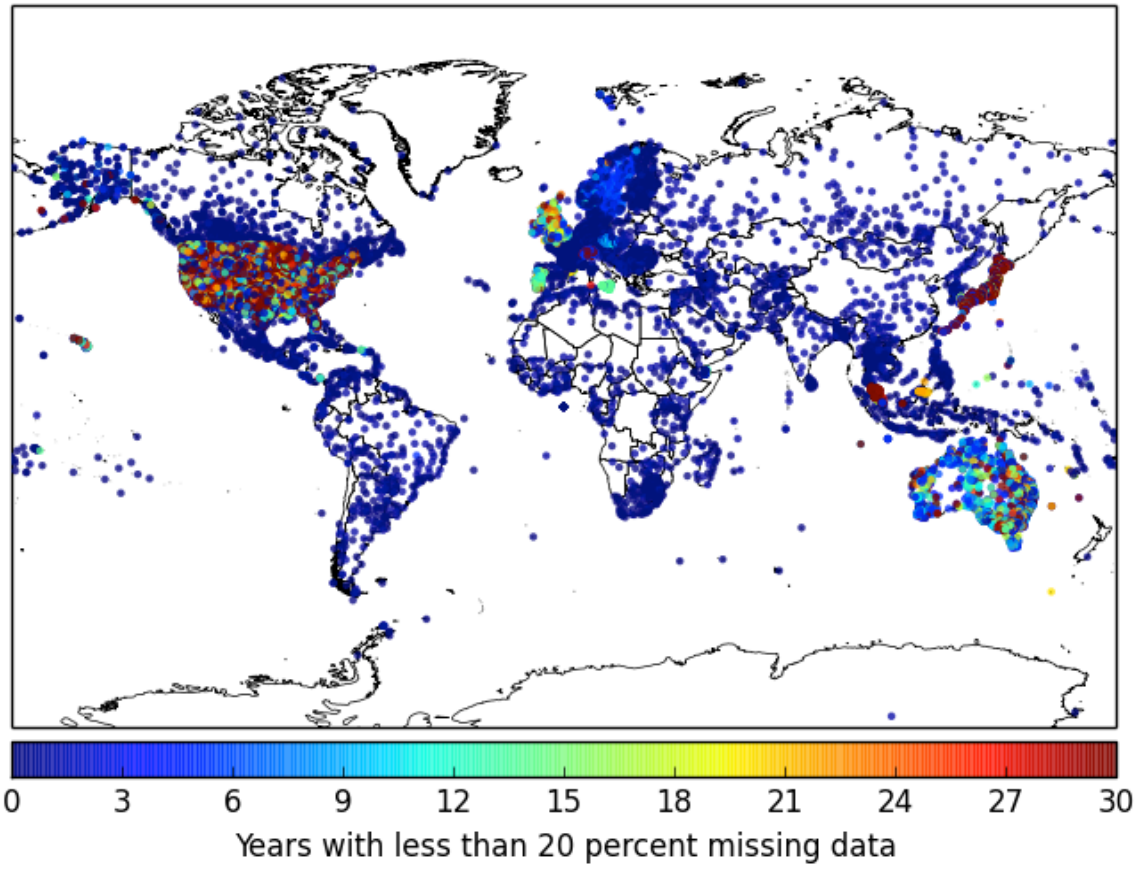
- Lizzie Kendon and team, Robert Dunn, Nigel Roberts (UK Met Office)
- Stephen Blenkinsop, Renaud Barbero, Steven Chan, Liz Lewis, Selma Guerreiro, Xiao-Feng Li (Newcastle University)
- INTENSE partners (especially Geert Lenderink, Seth Westra, Christoph Schär, Nicolina Ban, Jason Evans, Lisa Alexander)

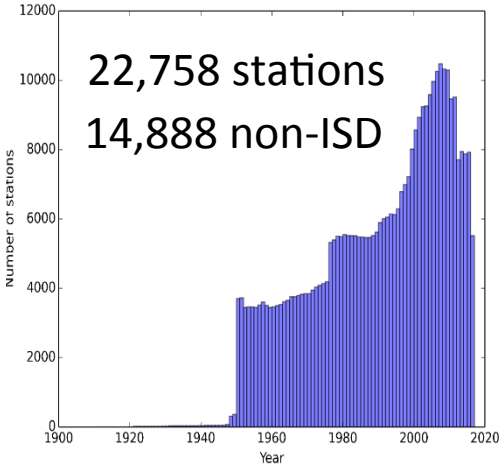
INTENSE: INTElligent use of climate models for adaptatioN to non-Stationary hydrological Extremes (2M€ ERC Consolidators Grant)

INTENSE Update

- 5 full-time PDRA's working on project at Newcastle University : Dr Stephen Blenkinsop, Dr Elizabeth Lewis, Dr Xiaofeng Li, Dr Selma Guerreiro and Dr Steven Chan (based at UK Met Office), Dr Geert Lenderink (part-time, KNMI, Netherlands) and team at UK Met Office led by Dr Lizzie Kendon
- Standard request letter and identified routes to data providers (with Lisa Alexander). Data provided for many countries – **Elisabeth Lewis**
- Development of quality control procedures for sub-daily precipitation using UK data **– Stephen Blenkinsop**
- Understanding trends in sub-daily precipitation extremes and preliminary analysis of dynamical and thermodynamic drivers **– Renaud Barbero (now at IRSTEA, France)/Geert Lenderink**
- Understanding extreme rainfall processes using convection-permitting models **– Steven Chan/Lizzie Kendon**
- **Website: https://research.ncl.ac.uk/intense/**

INTENSE: Sub-daily precipitation data collection to date…





% missing data	% stations
0	6.8
<10	38.6
<20	53.8
<30	61.6
<40	65.3
<50	68.1
<60	70.3
<70	72.5
<80	73.8
<90	76.5

Getting: Spain, Argentina, Ecuador, Columbia, Bahamas, the Philippines, New Zealand, a few stations in Kenya, Tuvalu, the Caribbean, South Africa, Colombia, Fiji, Israel , India, Denmark, Slovenia, Iran, Bangladesh, Russia, Hungary, Czech Republic, China, Uruguay, Vanuatu, Hong Kong, Poland, Vietnam, Mexico

1. Quality control of hourly data
(Blenkinsop et al, 2017; IJC & Lewis et al, in prep(b))

2. Adapt checks to work globally using CLIMDEX daily indices (Lewis et al, in prep(b))

Site specific tests

- rain gauge metadata,
- implausible large values (1h & 24h records)
- Monthly maximum 1-day precipitation
- long dry periods due to gauge malfunction
- accumulated totals (often at 9am)
- repeated values
- Change in resolution
- Duplicate records

Nearby gauge comparisons

- Statistical test of consistency with nearby gauges but problematical for extremes in summer/autumn therefore only partially applied

Multiple QC flags applied to each hour for each test

Automated rule base to define exclusions
For example:
- all implausible hourly totals
- "large" hourly totals if in winter at 9am after ≥23 dry hours
- "large" hourly totals if after gauge non-operation (long dry spell)

Produce new sub-daily precipitation indices from new global dataset

INTENSE

Monthly maximum indices

- **Rx1hr** Monthly maximum 1-hour precipitation
- **Rx3hr** Monthly maximum 3-hour precipitation
- **Rx6hr** Monthly maximum 6-hour precipitation
- **Rx1hrP** Percent of daily total that fell in the Monthly maximum 1-hour precipitation

Diurnal cycle indices

- **LW1H** Monthly likely wettest hour within a day
- **LD1H** Monthly likely driest hour within a day
- **DLW1H** Dispersion around Monthly likely wettest hour within a day
- **S1HII** Simple hourly precipitation intensity index
- **CW1H** Maximum length of wet spell

Frequency/threshold indices

- **R10mm1hr** Monthly count of hours when PRCP ≥ 10mm
- **R20mm1hr** Monthly count of hours when PRCP ≥ 20mm
- **Rxmm1hr** Annual count of hours when PRCP ≥ nnmm, nn is a user defined threshold

General indices

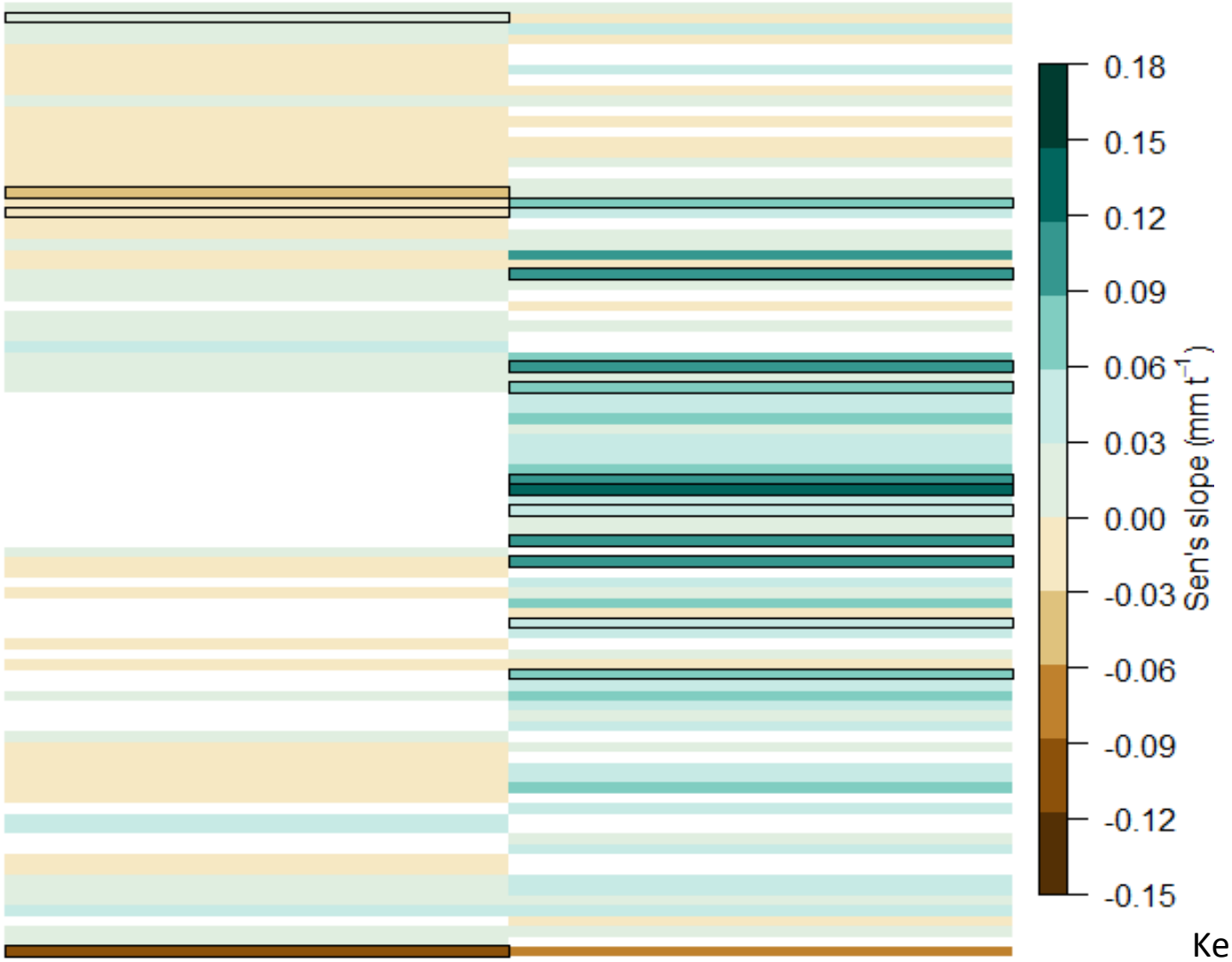
- **PRCPTOT1hr** Annual total precipitation in wet hours

Lewis et al, in prep(c)

Analyses of trends in intense rainfall: UK extremes

DJF 1h JJA 1h

Sen's slope statistics for 1h p95 (1985-2014)



Change in mean intensity of top 5% of events (*p95*).

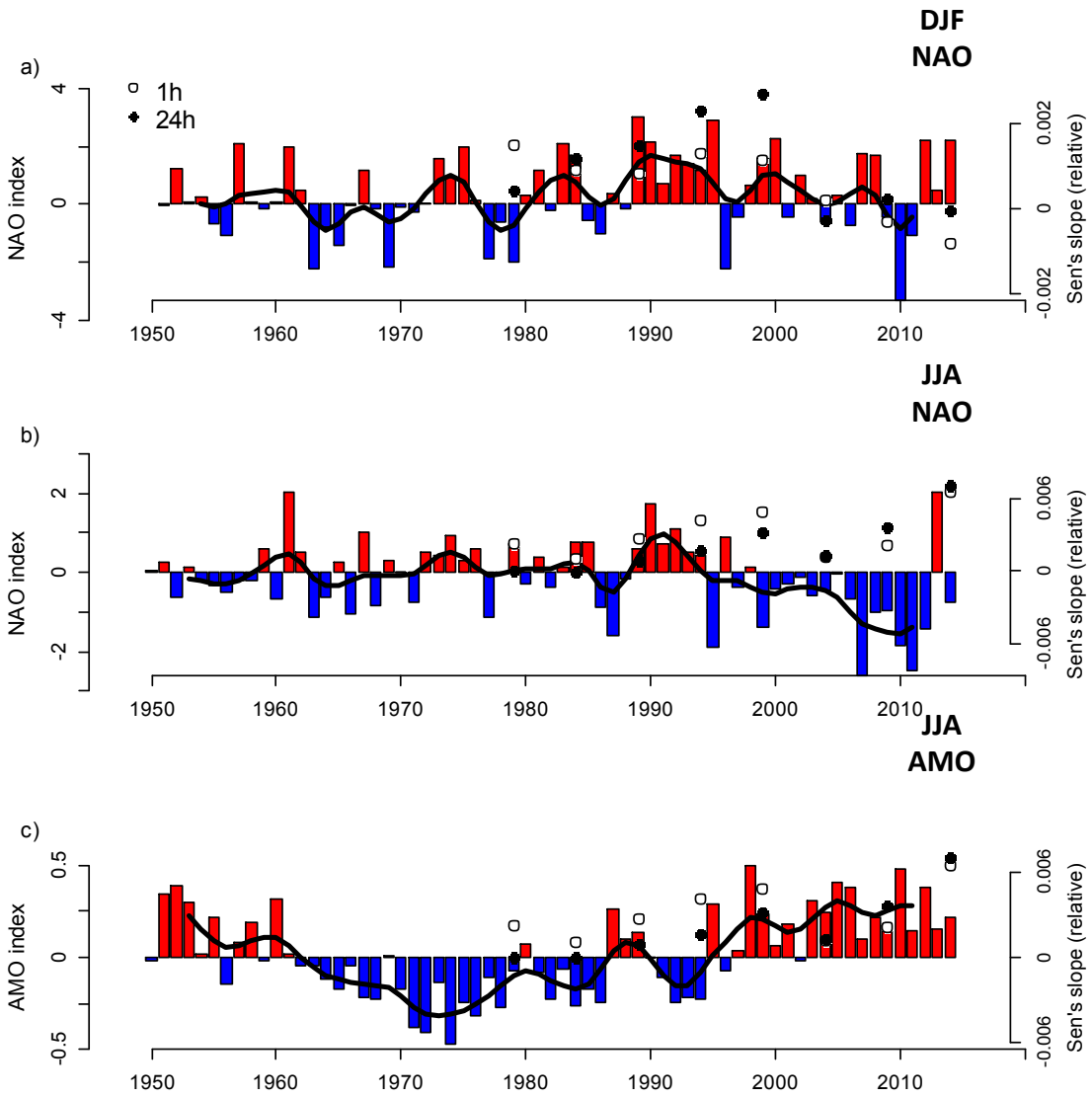
Estimated using Sen's slope (relative) and significance using MK.

Recent intensification of summer extremes (mostly non-significant).

But no signal of increases in hourly emerging before daily.

Kendon et al., *J Clim, submitted*

Analyses of trends in intense rainfall: UK extremes



Points indicate mean seasonal relative Sen's slope for 1h and 24h p95 for the running 30y period ending at the plotted point.

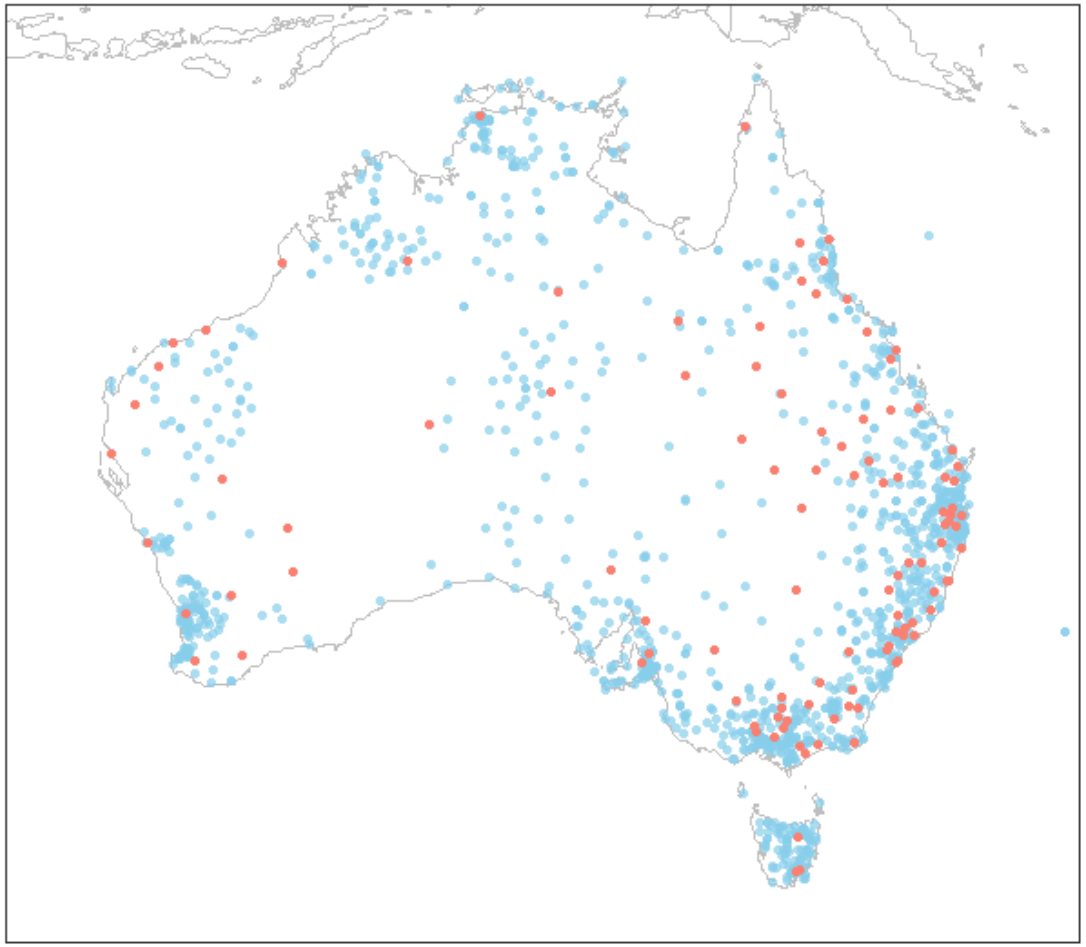
Bars indicate teleconnection indices (black line=smoothed)

Kendon et al., *J Clim, submitted*

Detecting continental-scale changes in hourly extremes: Australia

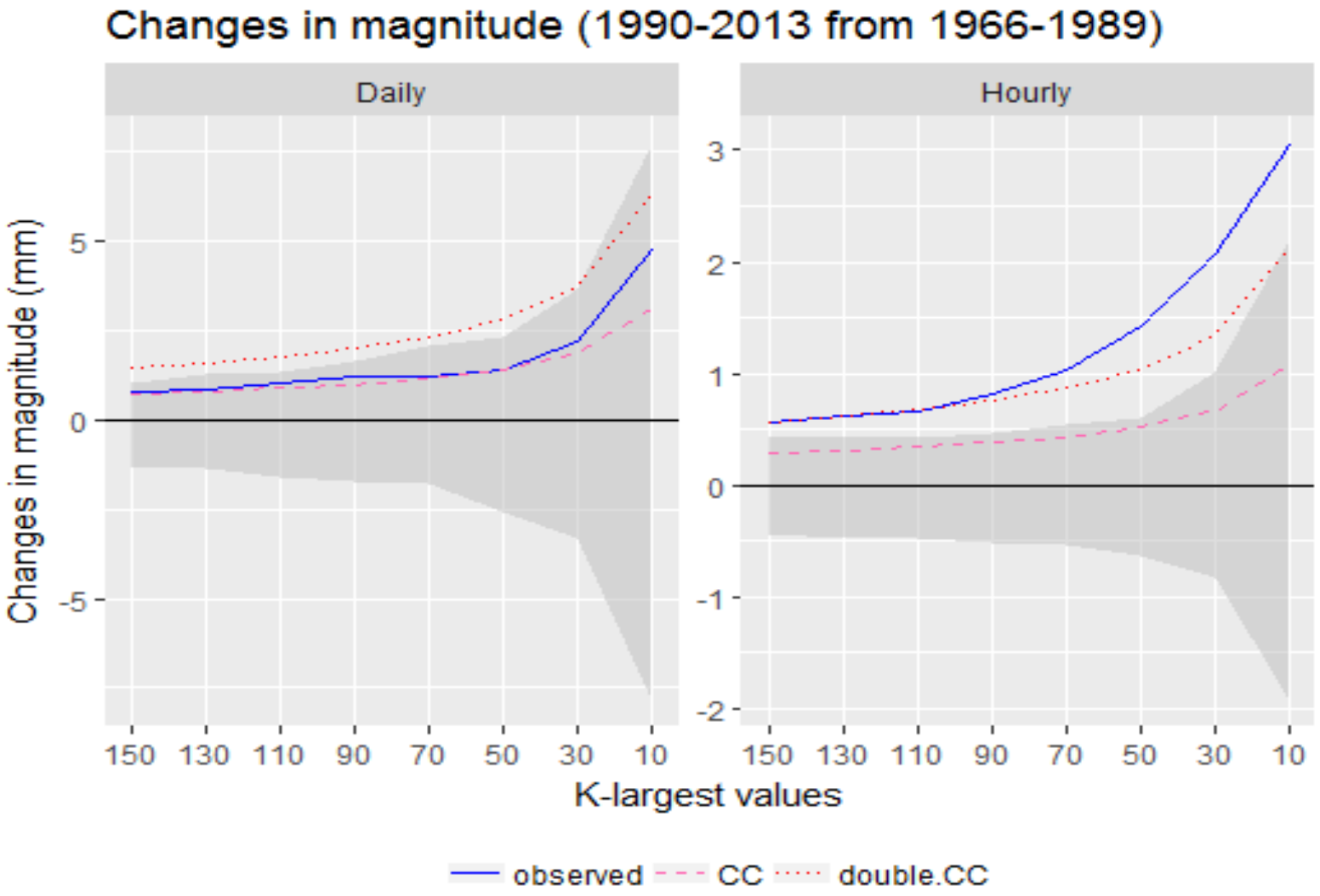
- 107 gauges
- Two 24 year periods:
  - 1966-1989
  - 1990-2013
- <30% missing data

precision=0. 1mm



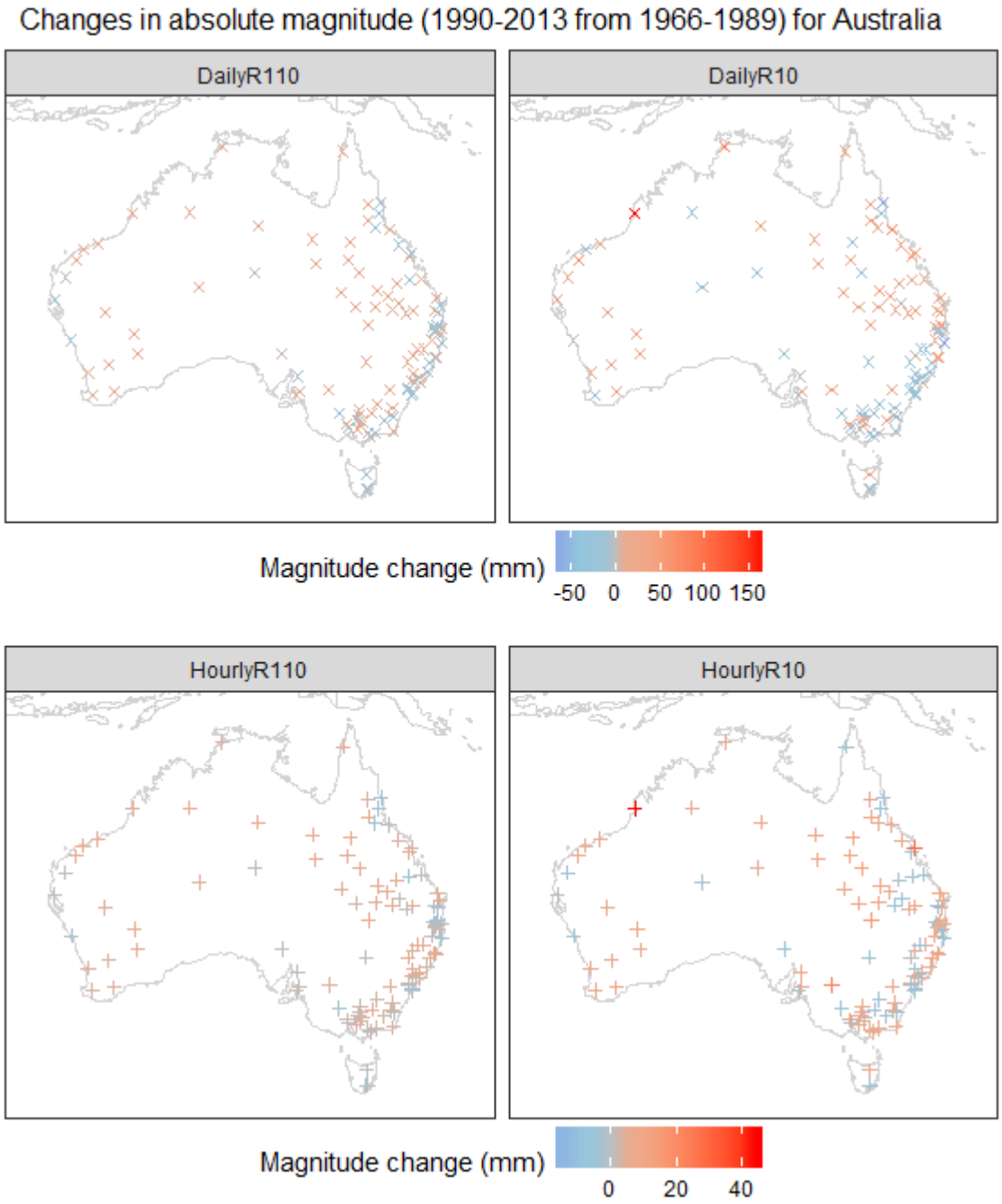
Guerreiro et al., in prep

Australia: Changes in magnitude



precision=0.1mm

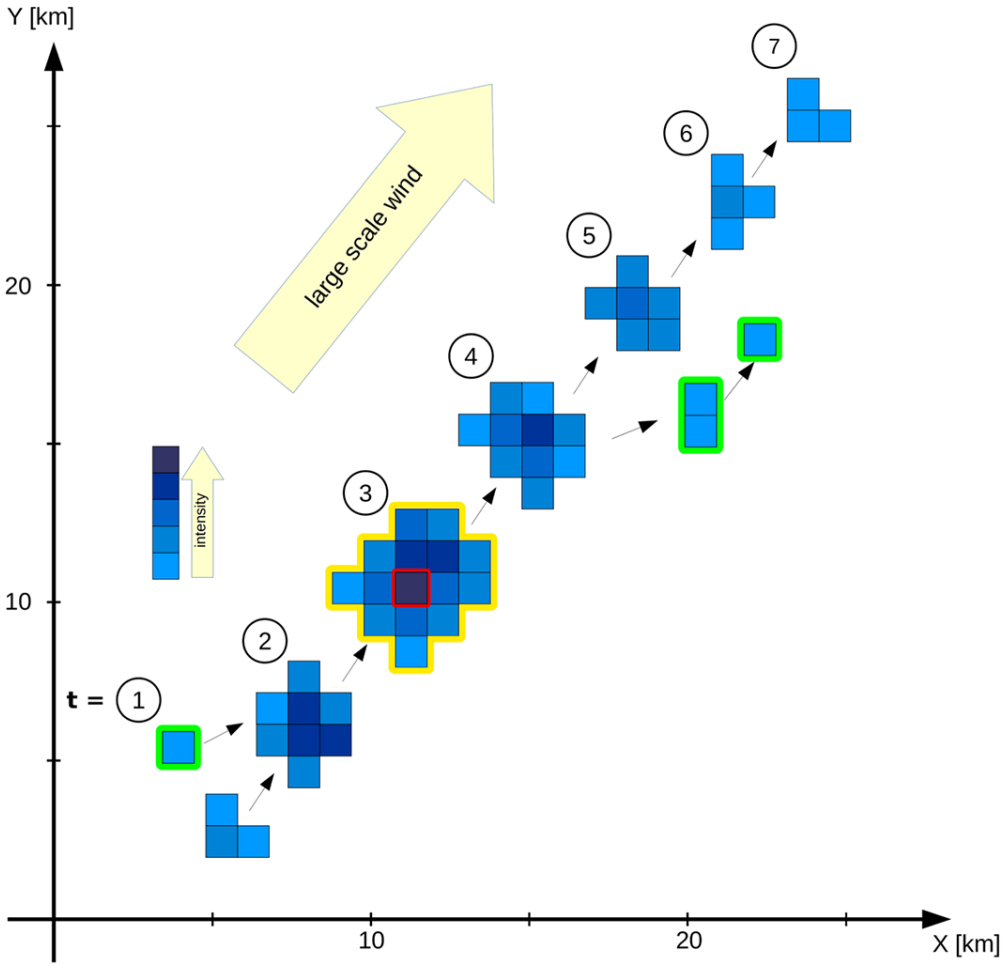
Guerreiro et al., in prep



No clear spatial pattern to gauge-level changes

Guerreiro et al., in prep

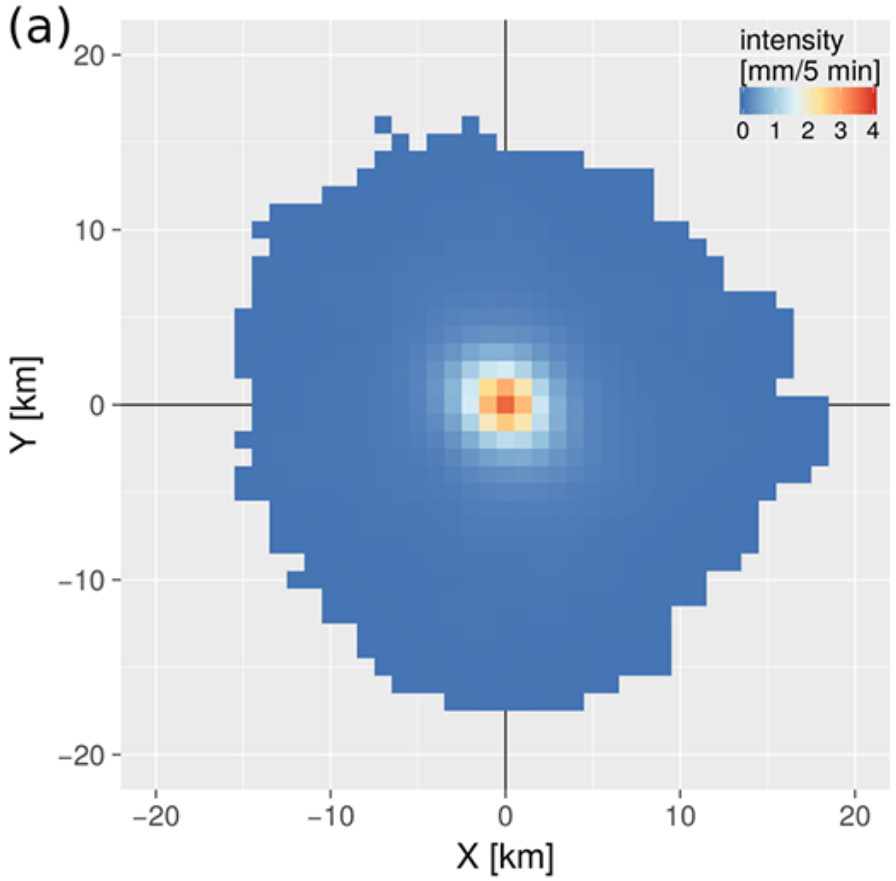
The spatial extent of rainfall events and its relation to precipitation scaling

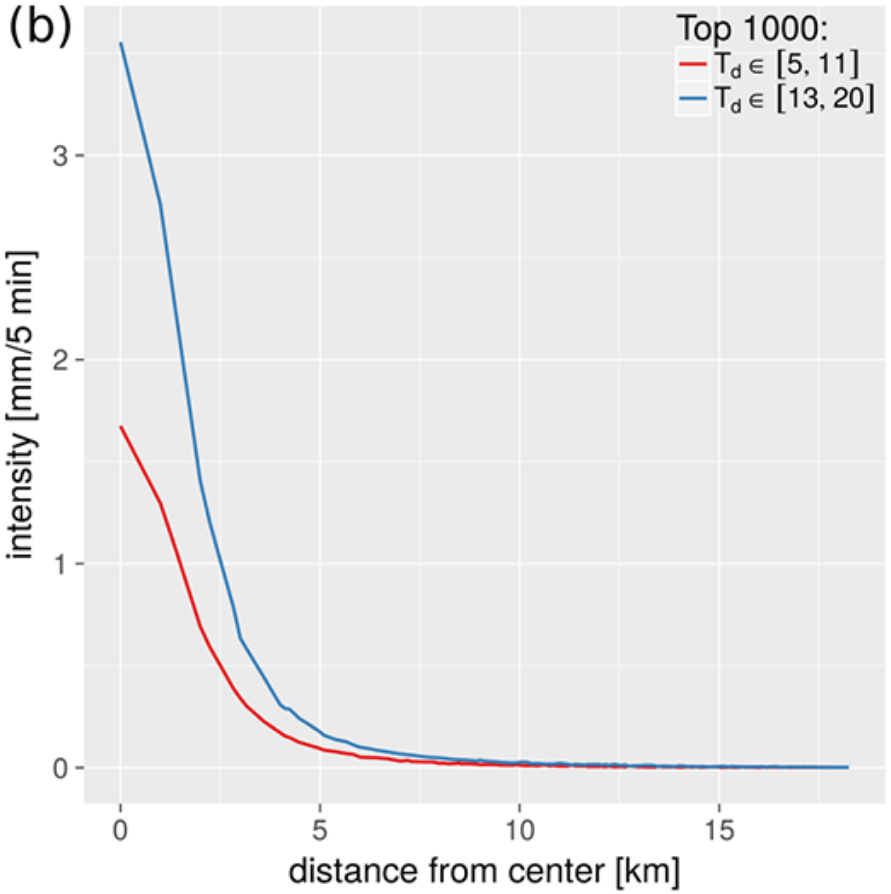


Idealized version of a rain cell track showing how rain cells are advected with the large-scale wind during the life cycle

Lochbihler et al. Geophysical Research Letters
2017GL074857, 26 AUG 2017 DOI: 10.1002/2017GL074857
http://onlinelibrary.wiley.com/doi/10.1002/2017GL074857/full#grl56300-fig-0001

Composite of 1000 strongest precipitating events between 13°C and 20°C at the time of the event peak

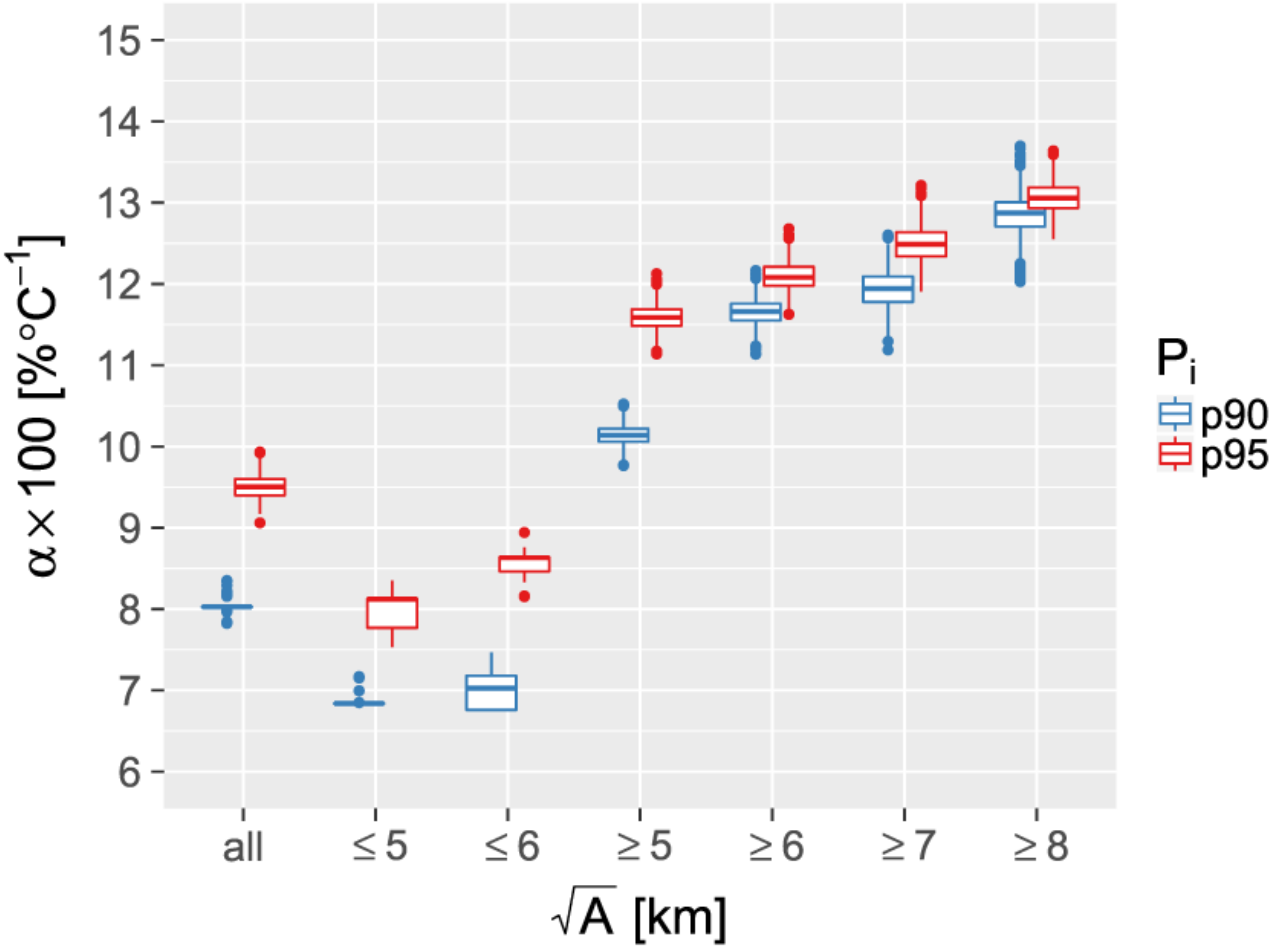




Intensities steeply decrease with growing distance from the center.

Lochbihler et al. Geophysical Research Letters
2017GL074857, 26 AUG 2017 DOI: 10.1002/2017GL074857
http://onlinelibrary.wiley.com/doi/10.1002/2017GL074857/full#grl56300-fig-0002

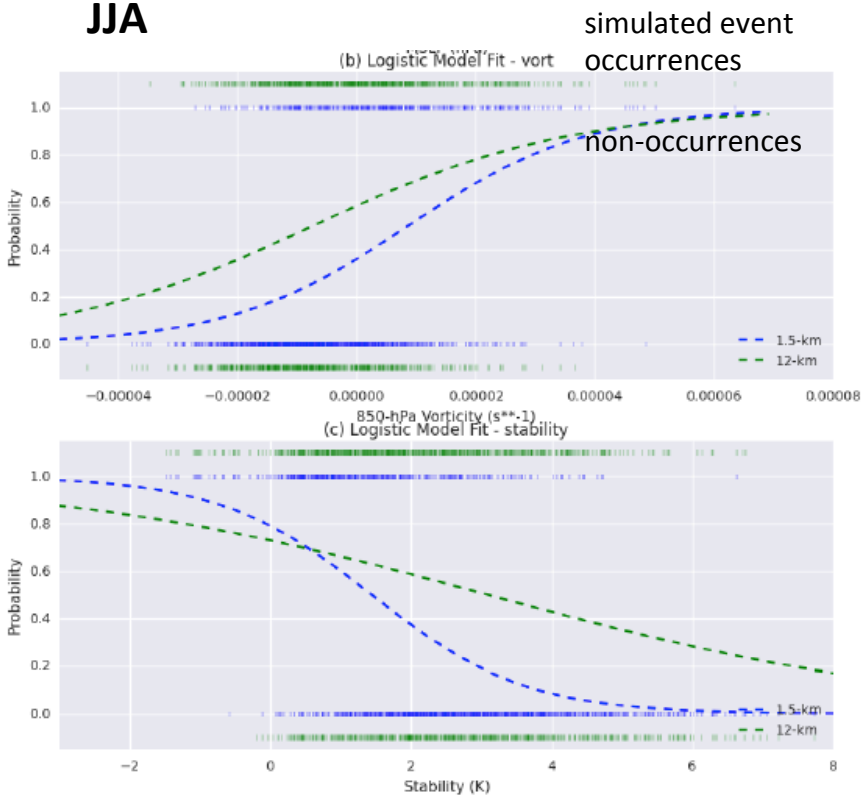
Scaling parameter α for different percentiles and area-constrained subsamples



Lochbihler et al. Geophysical Research Letters
2017GL074857, 26 AUG 2017 DOI: 10.1002/2017GL074857
http://onlinelibrary.wiley.com/doi/10.1002/2017GL074857/full#grl56300-fig-0005

Can large-scale variables be used as predictors of extreme events?

JJA



Predictors

1. Coarse resolution model events - can the existence of an "extreme" hourly precipitation event in the 12-km PCM data be used to predict an event in the downscaled 1.5-km CPM simulation?
2. Daily-averaged 850-hPa relative vorticity - fair weather days tend to have negative vorticity, stormy days positive vorticity.
   (linked to synoptic/circulation drivers)
3. Daily-averaged mean sea-level pressure MSLP
   (linked to synoptic/circulation drivers)
4. Daily-averaged vertical moist static stability
   (thermodynamic driver)

- The occurrences of hourly precipitation extremes in the UK CPM simulations can be skilfully predicted by large-scale predictors, encompassing stability and circulation, from the lower-resolution model
- Circulation-based predictors such as vorticity and MSLP demonstrate skill but to a lesser degree than stability

Chan et al, in revision, Clim. Dyn.

INTENSE planned activities

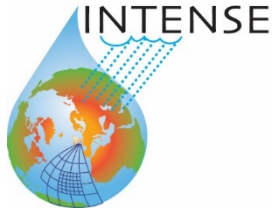
Database

- Continued data acquisition strategy and initiatives on a regional basis to update and expand the existing database. Talks with DWD on data hosting and ETCCDI site (CLIMDEX) for hosting new indices for sub-daily precipitation.
- Development of quality control measures for sub-daily precipitation data including release of common QC code.

Research

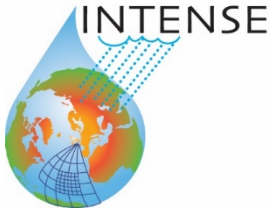
- Global scale analysis of extreme precipitation-temperature relationship.
- Global scale analysis of trends in sub-daily extreme precipitation
- Intensity-Duration-Frequency (IDF) curves generation for UK and global datasets
- Further develop the working group on very high resolution models and common analyses of model outputs.
- First publications of large-scale drivers of sub-daily extreme precipitation
- Initiation of efforts to explore how sub-hourly in situ and satellite observations can help each other.
- Concentration of analysis in Tropics and comparison to CPM model outputs.
- First multi-model CPM comparisons.
- Session and invited talk at AGU fall meeting 2017 and session at GEWEX meeting in May 2018.

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–

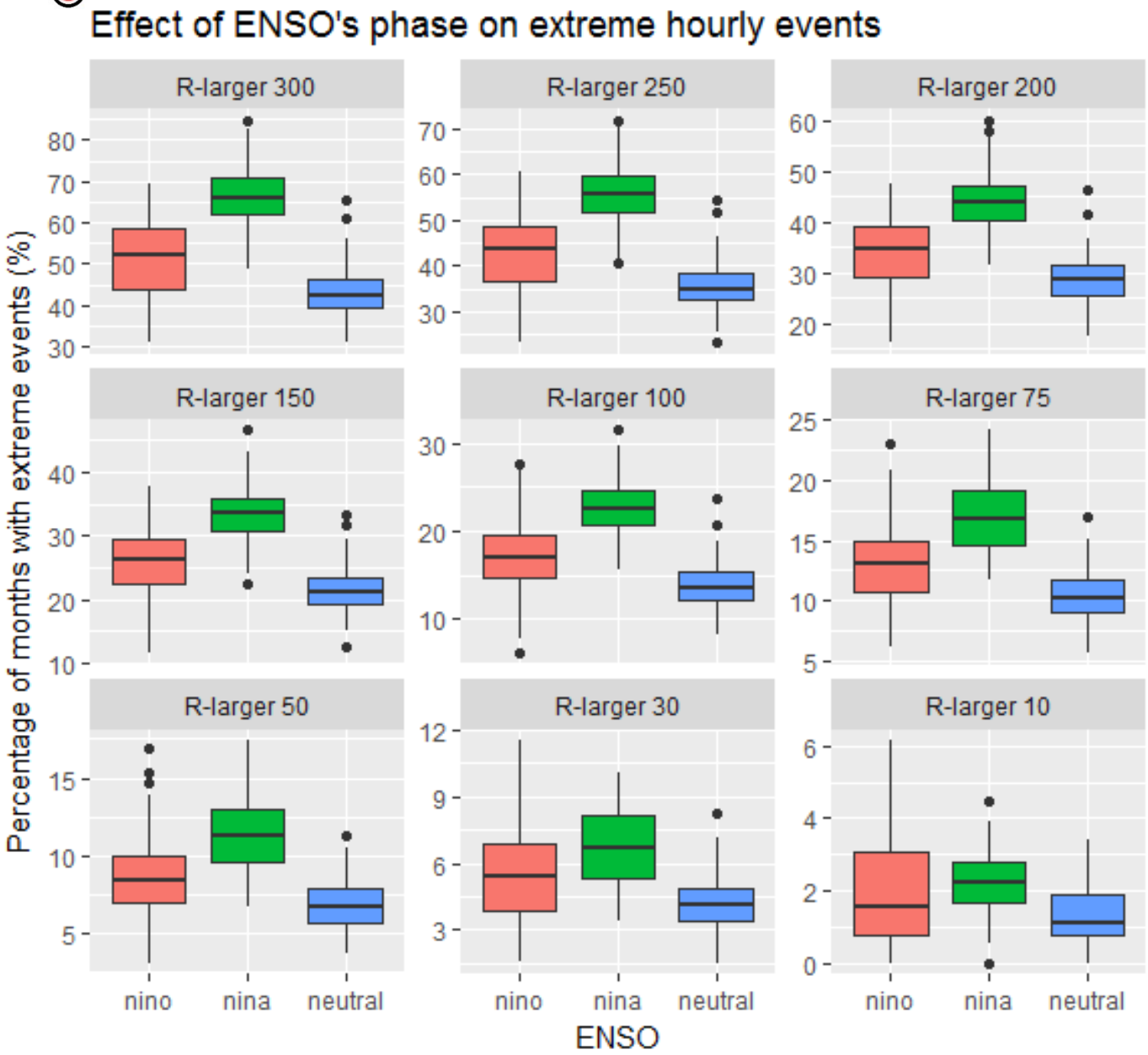
INTENSE publications (2014-15)



- 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.

INTENSE publications (ongoing)

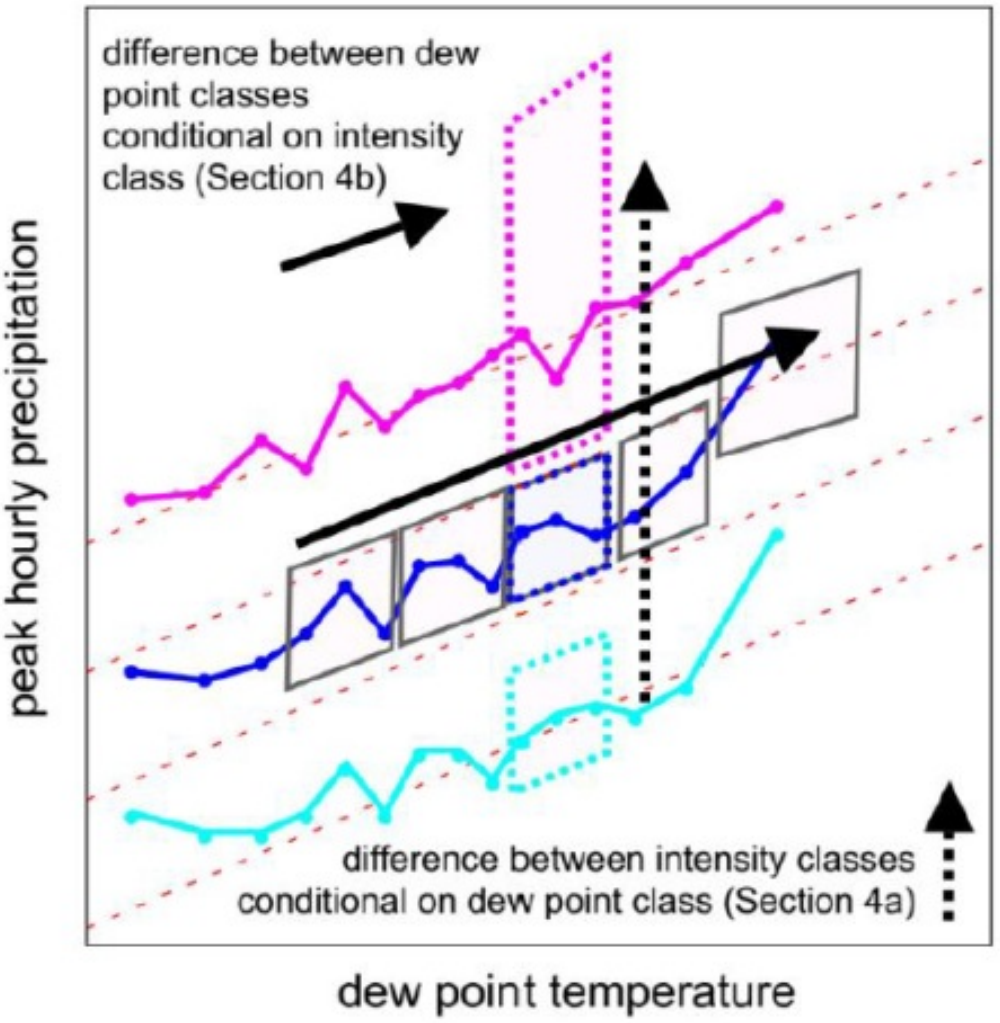
- Barbero, R., Westra, S., Lenderink, G., Fowler, H.J. Temperature-extreme precipitation scaling: a two-way causality? **Submitted to International Journal of Climatology**, June 2017.
- Barbero, R., Abatzoglou, J., Fowler, H.J. Upper-level dynamics contribution to short-duration rainfall extremes in the contiguous United States. **Submitted to Climate Dynamics**, Sep 2017.
- Chan, S.C., Kendon, E.J., Roberts, N.M., Blenkinsop, S., Fowler. H.J. Synoptic predictors for extreme hourly precipitation events in convection-permitting climate simulations. **Journal of Climate**, accepted subject to minor revisions.
- Chan, S.C., Kahana, R., Kendon, E.J., Fowler, H.J. Projected changes in extreme precipitation over Scotland and Northern England using a high-resolution regional climate model. **Submitted to Climate Dynamics**, July 2017.
- Kendon, E.J., Blenkinsop, S., Fowler, H.J. Will changes in short-duration precipitation extremes be detectable before daily extremes? **Submitted to Journal of Climate**, June 2017.
- Guerreiro, S., **Fowler, H.J.,** Barbero, R., Lenderink, G., Westra, S., Super Clausius-Clapeyron increases of hourly extreme rainfall detected at continental scale. **In prep. Nat. Climate Ch.**
- Lewis, E., Blenkinsop, S., Quinn, N., Woods, R., O'Loughlin, F., Freer, J., Coxon, G., **Fowler, H.J.** A National Scale Hourly Gridded Rainfall Product for Great Britain. **In preparation**.
- Lewis, E., **Fowler, H.J.,** Blenkinsop, S. A global sub-daily rainfall dataset. **In preparation for Journal of Climate.**
- Barbero, R., Lewis, E., **Fowler, H.J.,** Lenderink, G., Westra, S. Sub-daily rainfall extremes in the climate record: climatology, seasonality and diurnal cycle. **In preparation for Journal of Climate.**



Influence of ENSO reduces for the most extreme hourly events

Guerreiro et al., in prep

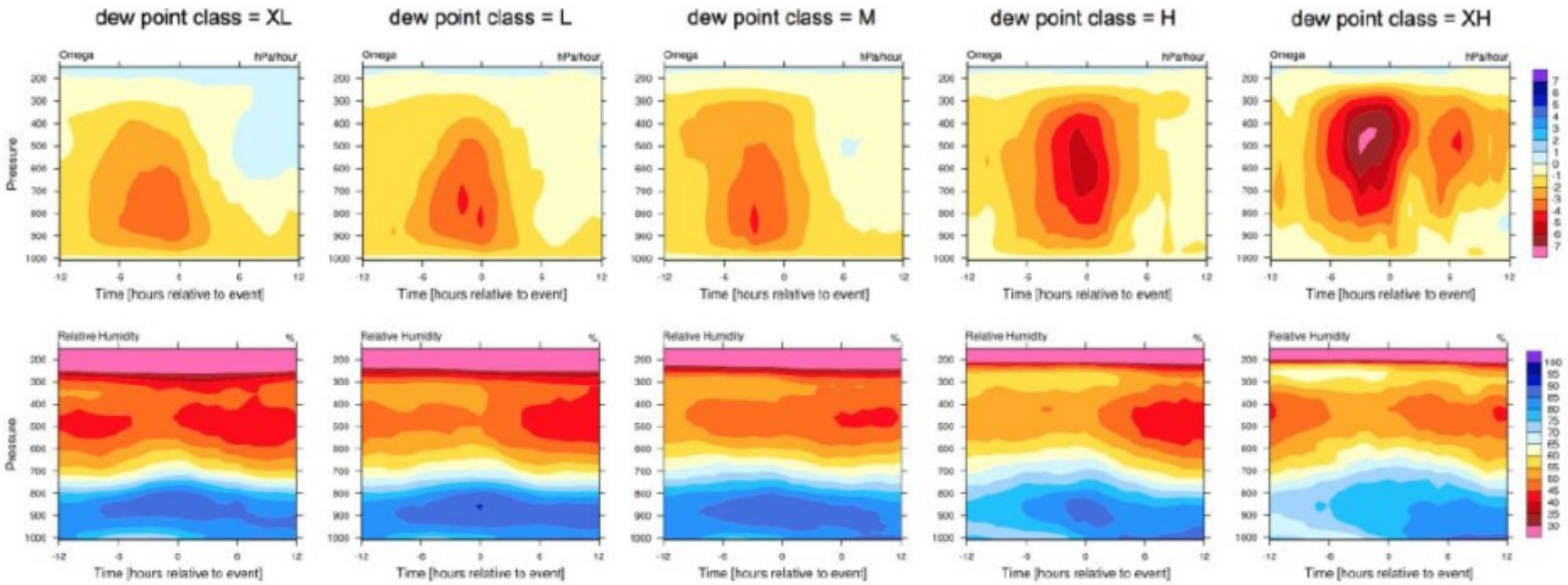
Understanding local dynamics



Highest peak intensities associated with largest spatial events

Opposite result to Wasko et al. GRL (2016)

Lenderink et al., 2017, J. Climate, doi:10.1175/JCLI-D-16-0808.1



Results show the prominent role of large-scale circulation as measured here by the large-scale vertical velocity. Intense events are, on average, associated with high omega values, which cause a substantial convergence of moist air.

Lenderink et al., 2017, J. Climate, doi:10.1175/JCLI-D-16-0808.1

Summary

- **We can expect rainfall extremes to increase with global warming** but limited observational evidence of changes due to lack of sub-daily records.

- **Evidence that extremes scale with regional and global temperature and 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.**

- **Significant projected changes to future convective summer storms from very-high-resolution convection-permitting models.** These events are underestimated by coarse resolution models. Great potential in linking understanding gained from observations and new modelling developments.