Supplementary Material to

“Scaling and trends of hourly precipitation extremes in two different climate zones - Hong Kong and The Netherlands”

by G. Lenderink, H. Y. Mok, T. C. Lee, and G. J. van Oldenborgh

a. Additional information on the observational data

De Bilt (DB)

The hourly precipitation data for De Bilt consists of two parts.
For the period 1906 to 2003 we use a data set from the Dutch STOWA project (see http://www.knmi.nl/klimatologie/onderzoeksgegevens/index.html; in Dutch). In this project the hourly precipitation data were quality controlled, and statistics of precipitation extreme were derived for water management. For the period 2004 to 2011 the data was supplemented by observations from the operational observing system at De Bilt. For the period 1990 to 2003 we compared both data sets. On a hourly level differences between the data sets could be up to 1-2 mm, in rare cases even higher. However, the extreme statistics in both data set were comparable, and differences in the computed percentiles used in this study were approximately 1 %.

For temperature we used daily observations for De Bilt. This data has not been specifically homogenized. But, the monthly mean version of this series has been homogenised for the construction of the Central Netherlands Temperature (van der Schrier et al, 2011). In summer, the inhomogeneities in the mean temperature introduced by changes in the thermometer screen and surroundings were found to be +0.1 ºC compared with the modern readings up to 1950, followed by a decline down to -0.4 ºC in 1958 and a return to no bias in 1980. In a 15-year seasonal average such as shown by the red line in Figure S4 the difference averages to less 0.2 ºC, much smaller than the rise in temperature considered there.

The Netherlands (NL)

Here we use hourly observations of 27 stations in the Netherlands for the period 1995 to 2010. These stations are part of the quality controlled observing system in the Netherlands maintained by the Dutch Meteorological Institute (KNMI). Details on the station used and the difference between these stations are discussed in the Supplementary Data of Lenderink and Van Meijgaard (2010). The data is quality controlled according to the WMO standards, but not explicitly corrected for possible inhomogeneities in time. We note that a very similar scaling of hourly precipitation extremes is obtained using only data from 2003 onwards. In this period there have been no trends in mean temperature, no station displacements and no changes in the observational techniques for all stations considered.

Hong Kong Observatory (HKO)

HKO is the meteorological office of Hong Kong. All meteorological instruments were quality assured and all weather observations were taken by qualified weather observers and there were official guidelines for them to follow. Homogeneity test has been conducted to the temperature and rainfall data and no inhomogeneities have been identified; more information can be found in section 2.1 of Wong et al. (2010).

References:

van der Schrier, G., van Ulden, A., and van Oldenborgh, G. J. (2011) The construction of a Central Netherlands temperature, Clim. Past, 7, 527-542, doi:10.5194/cp-7-527-2011

Wong, M. C.; Mok, H. Y. & Lee, T. C. (2010) Observed changes in extreme weather indices in Hong Kong. International Journal of Climatology, published online, DOI:10.1002/joc.2238.

b. Distributions of hourly precipitation from the binned data .

Here, we show two examples of the distribution of hourly precipitation from the data binned according to the dew point temperature from 4 hours before each observation. Bins are two degrees wide, and the probability of exceedance of hourly precipitation is plotted for a selection of bins.

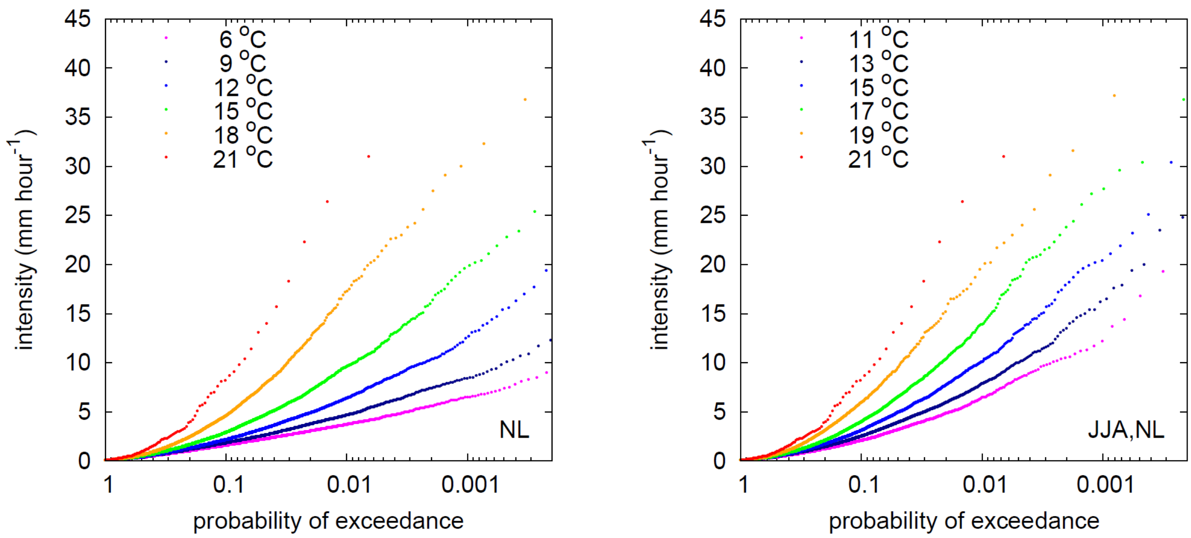

Figure S1. Probability of exceedance of hourly precipitation in a selection of dew point temperature bins. Bins are two degrees wide, and the central value is indicated in the plot. Results are for NL; left observations from the whole year, right observations from only summer months JJA. Only each third point of the distributions is plotted to show the density of the observations better.

c. Dependencies of precipitation intensity on dew point temperature inferred from long term variations.

From the time series plotted in Figure 2 in the main text we computed a regression of ΔPr_h on ΔT_d^*. For the data from De Bilt, this gave 11 % per degree for the period May to October ((MJJASO), and for June to August (JJA) the dependency is even 13 % per degree (Table S1, first column). In particular for summer this is close to the value of 14 % per degree expected from the scaling relations. The relation between ΔPr_h and ΔT_d^* is not only caused by the positive trend over time in both ΔPr_h and ΔT_d^*. After detrending the time series for the linear trend over 1906 to 2010, similar regression coefficients are found (Table S1, second column).

Since we use overlapping periods, the data points in Figure 2 (main text) are clearly not independent, and therefore error estimates cannot simply be deduced from the fit. Therefore, we also computed regression coefficients and the linear trends from non-overlapping 15-year periods, that is, from 1906-1920, 1921-1935 etc. Error estimates are obtained from bootstrapping 15 years out of each 15-year period, and re-computing all statistics from these bootstrap samples. (By re-sampling in this way, the consistency between precipitation and dew point temperature is retained.) Similar regression coefficients are found; that is, 10 and 13 % per degree for MJJASO and JJA, respectively. The uncertainty in these estimates, however, is also substantial since there are only seven independent 15-year periods, and a dependency of 7 % per degree is (just) within the 80% uncertainty range.

De Bilt (DB), The Netherlands

	r_c % °C $^{-1}$	r_c (detr) % °C $^{-1}$	r_c (15y) % °C $^{-1}$	Trend Pr_h(15y) % (100y)$^{-1}$	Trend T_{dew}(15y) °C (100y)$^{-1}$
MJJASO	**11**	**11**	**10±4**	12±8	1.2±0.3
JJA	**13**	**14**	**13±6**	15±11	1.4±0.4
NDJFMA	7	3	7±2	17±5	1.8±0.3
Hong Kong Observatory (HKO), China					
MJJAS	23	-15	16±10	13±6	0.7±0.1
JJA	23	-44	18±10	17±7	0.7±0.1
O-FMA	**16**	**13**	**13±5**	20±11	1.4±0.4

Table S1. Regression coefficients (r_c) of extreme hourly precipitation on dew point temperature computed from all 15-years overlapping periods, (detr) after detrending for the linear trend with time, and (15y) from independent, non-overlapping 15-periods. Linear trends from non-overlapping 15-year periods in extreme precipitation and dew point temperature are given in right-most column. Errors are the 80% uncertainty range estimated from 500 bootstrap samples. Shown in bold are regression coefficient for which all three estimates (r_c, r_c(detr), and r_c(15y)) are larger than 10 % per degree.

For HKO only the period O-FMA shows consistent results, with the best estimates of the regression coefficients of 13-16 % per degree. For the wet season (JJA and MJJAS) the three estimates are rather different. In particular, after detrending for the mean trend over the last century even negative regression coefficients are found, indicating that there is no correspondence between variation in ΔT_d^* and ΔPr_h on an inter-decadal time scale.

d Comparison trends in absolute and relative percentiles

Here we show the time evolution of the separate percentiles for DB and HKO. We also compare relative percentiles to absolute percentiles. The absolute percentiles are the 99.5^{th}, 99.9^{th} and 99.95^{th} percentiles, which with a frequency of occurrence of approximately 10% roughly correspond to similar events as the relative percentiles. For DB differences between the absolute and relative percentiles are very small, and also the different percentiles give very similar results. The same also applies when the percentiles are computed directly from the data, instead of from the GPD fit to the data. In that case, there is more noise in the separate percentiles.

For HKO in O-FMA the frequency of occurrence of wet events is ~5% lower, this is substantially lower that in the wet season (MJJAS). The time evolution of the absolute and relative percentiles show similar variations, but the amplitude of the variations is larger with the absolute percentiles. Variations in the frequency of wet events are therefore likely to contribute to the enhanced variability of the absolute percentiles. This suggests that atmospheric circulation changes may play a role in explaining the variations in hourly precipitation extremes (as obtained from the absolute percentiles) in the dry season (O-FMA) in HKO.

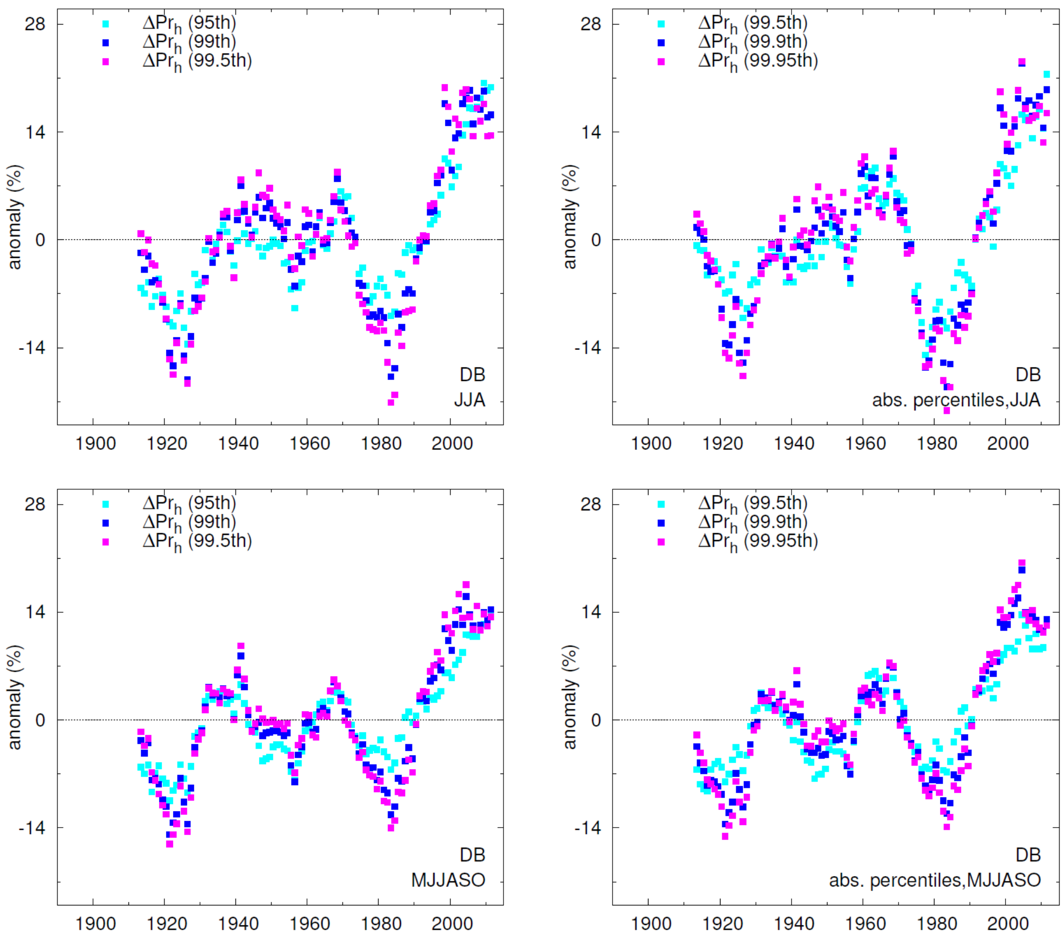

Figure S2. Anomalies of different percentiles computed from 15-year periods; left: percentiles of only wet events (95th, 99th, and 99.5th); right: percentiles of all events (99.5th, 99.9th and 99.95th). The number of wet events is approximately 10 %, so that the same colors in the left and right figures correspond to the similar events. Shown are results for De Bilt (DB) for June, July and August (JJA) and the period May to October (MJJASO).

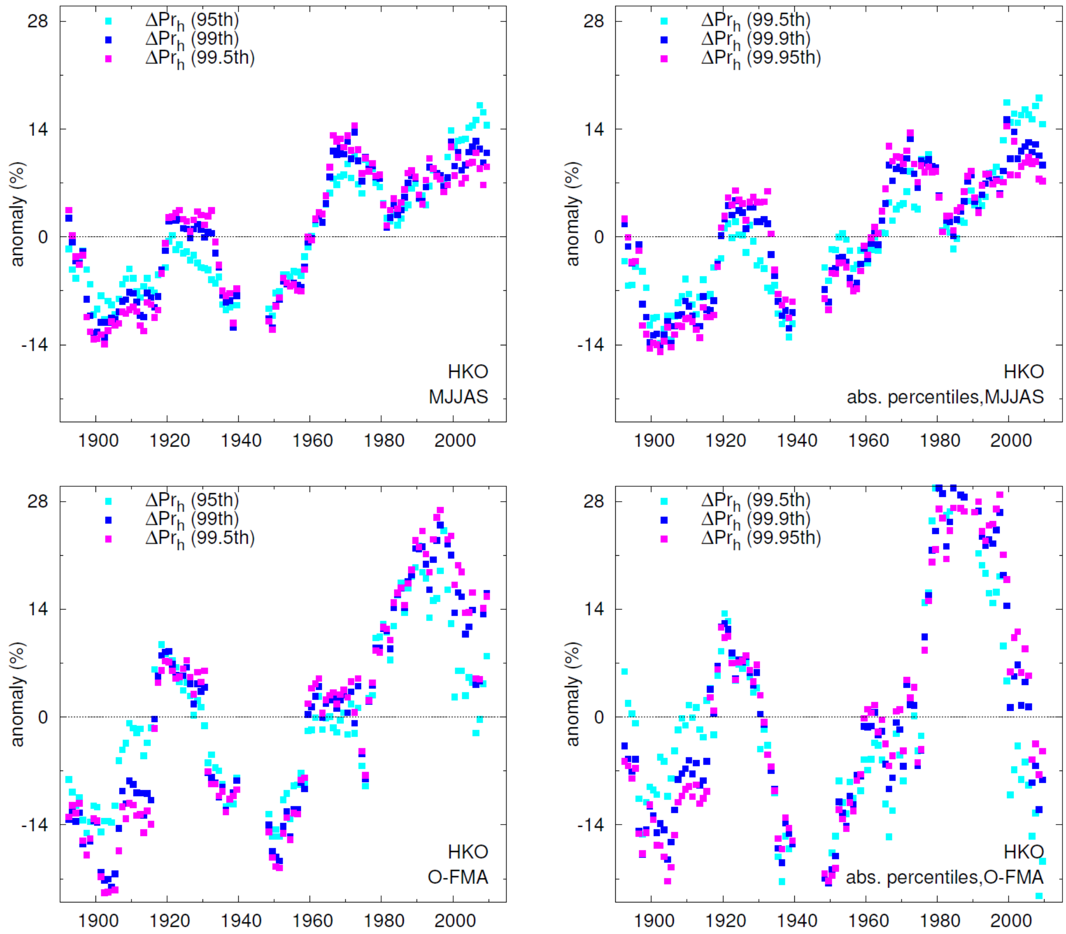

Figure S3. As Figure S2, but now for data from the Hong Kong Observatory (HKO) and period May to September (MJJAS), and the months October, February, March and April (O-FMA).

e. Time evolution of the temperature and dew point temperature

Here we show the time evolution of the time evolution of the mean temperature and the mean dew point temperature, in concert with the time evolution of the dew point temperature on days with heavy rain (as used in the main paper).

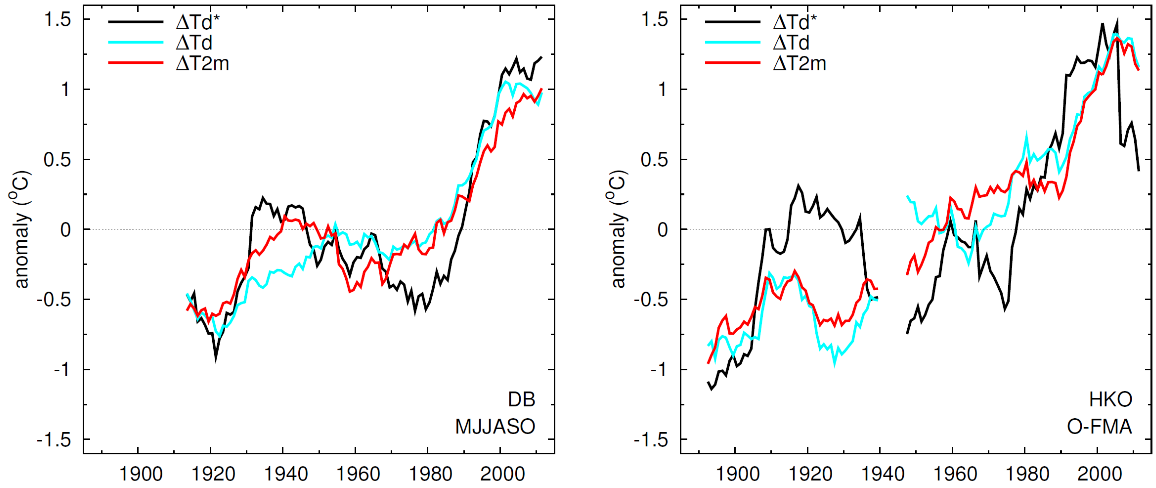

Figure S4. Time evolution of anomalies in the mean temperature (ΔT2m), mean dew point temperature (ΔT_d), and mean dew point temperature (ΔT_d*) on days with heavy rain for De Bilt in the summer halve year (MJJASO) and HKO in the dry season (O-FMA).

f. projected changes in temperature and dew point temperature in Europe

Here we show projected changes in temperature and dew point temperature for Europe in two regional climate model simulations from the ENSEMBLES project (http://www.ensembles-eu.org/; Research Theme RT2b).

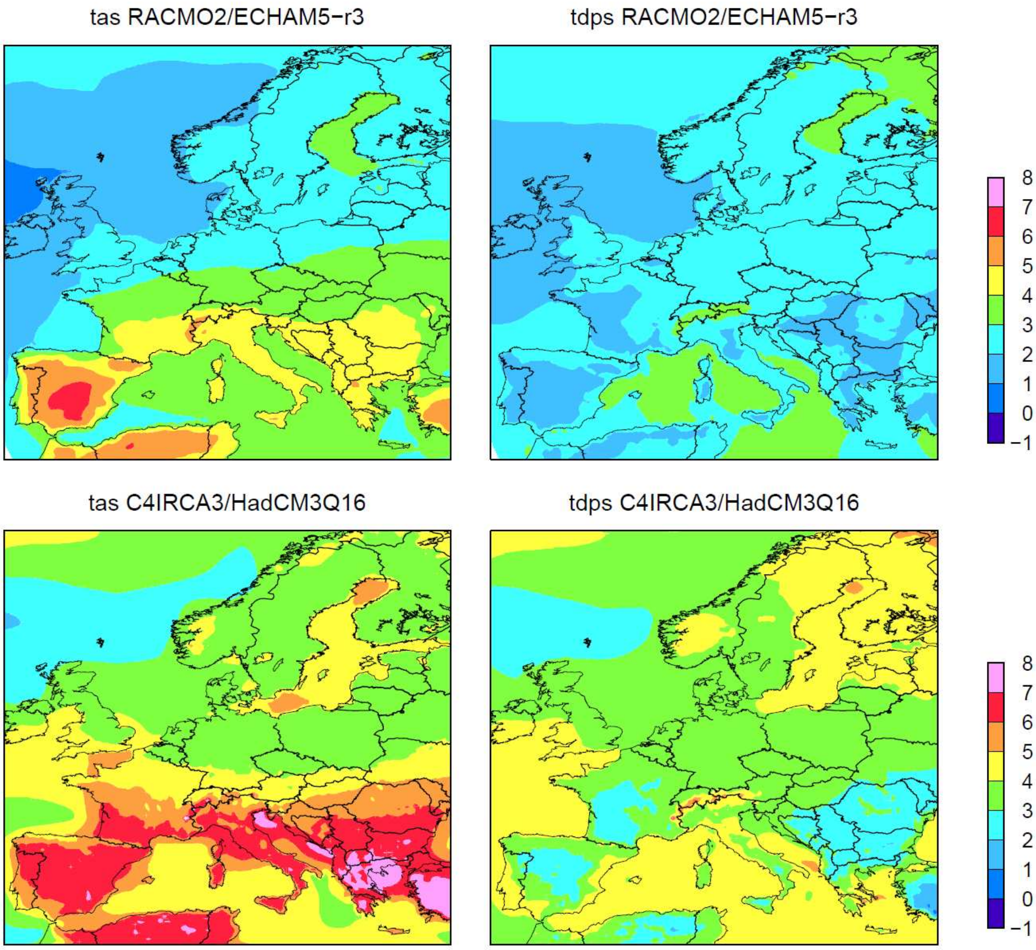

Figure S5. Projected changes for summer (JJA) (2071-2100 compared to 1971-2000) in two regional climate model simulations for Europe. Left panels show the temperature change (tas); right panels the dew point temperature change (tdps). Upper panels are results from the regional climate model RACMO driven by boundaries from ECHAM5. Lower panels show results from the regional climate model RCA3 (operated by Community Climate Change Consortium for Ireland (C4I)) driven by a version of HadCM3 with a high climate sensitivity. Both integrations use A1b greenhouse gas emissions.