Extreme events

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(with some slides from Jana Sillmann and some thoughts from Claudia Tebaldi)
Extreme events
*Through a precipitation lens*

1. **Defining** extreme events

2. **Observing** extreme events

3. **Absolute** questions, **relative** answers

4. **Scales** of relevance: Going from **global** projections to **local impacts**
Challenges

- Extreme events are **rare** in space and time
- Universally valid **definitions**
- Lack of observational **data**
- **Scale** mismatch between observation and model output

**Approaches in IPCC AR5**

- **Indices** for climate extremes, such as defined by the Expert Team on Climate Change Detection and Indices (ETCCDI)
- Extreme value analysis → **Return values/periods**
Extreme precipitation projection from HadCM (~1998)

Allen and Ingram (2002)
CMIP5 Multi-model mean extreme precip change

Δ Rain rate (%/K)

Percentile

Pendergrass and Hartmann (2014)
Extreme precipitation change varies across CMIP5 models

Model response
Shift+increase

Rain rate change (%/K)

Percentile

Pendergrass and Hartmann (2014)
Possible role for convective organization

Pendergrass, Reed, and Medeiros (2016)
Definition of extremes matters...

Wet-day percentiles are sensitive to the fraction of wet days and can produce misleading results when applied to climate change

Definition of extremes matters ... 

Heavy summer precipitation changes from ENSEMBLE RCM simulations (SRES A1B)

Schär et al (2016) *Climatic Change*
Definition of extremes matters ...

• **Climate Extremes Indices** as defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) or Sector-Specific Climate Indices (ET-SCI)

• **Percentile Indices**, e.g. p97.5, p99

• **Extreme Value Statistics** (e.g., return value estimation based on Generalized Extreme Value Distribution)

Approaches are complementary and should be used according to given context or scientific question
developed an internationally coordinated set of climate indices - core set consists of 27 descriptive indices

FD, ID, SU, TR
TXn, TNn, TXx, TNx
TN10p, TX10p, TN90p, TX90p
CSDI, WSDI
GSL, DTR
Rx1day, Rx5day
SDII
R10mm, R20mm, Rnmm
CDD, CWD
R95pTOT, R99pTOT
PRCPTOT

focus on counts of days crossing a threshold; either absolute/fixed thresholds or percentile/variable thresholds relative to local climate
# Indices for Climate Extremes (IPCC AR5)

**Box 2.4, Table 1** | Definitions of extreme temperature and precipitation indices used in IPCC (after Zhang et al., 2011). The most common units are shown but these may be shown as normalized or relative depending on application in different chapters.

<table>
<thead>
<tr>
<th>Index</th>
<th>Descriptive name</th>
<th>Definition</th>
<th>Units</th>
<th>Figures/Tables</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>TXx</td>
<td>Warmest daily Tmax</td>
<td>Seasonal/annual maximum value of daily maximum temperature</td>
<td>°C</td>
<td>Box 2.4, Figure 1, Figures 9.37, 10.17, 12.13</td>
<td>Box 2.4, 9.5.4.1, 10.6.1.1, 12.4.3.3</td>
</tr>
<tr>
<td>TNx</td>
<td>Warmest daily Tmin</td>
<td>Seasonal/annual maximum value of daily minimum temperature</td>
<td>°C</td>
<td>Figures 9.37, 10.17</td>
<td>9.5.4.1, 10.6.1.1</td>
</tr>
<tr>
<td>TXn</td>
<td>Coldest daily Tmax</td>
<td>Seasonal/annual minimum value of daily maximum temperature</td>
<td>°C</td>
<td>Figures 9.37, 10.17, 12.13</td>
<td>9.5.4.1, 10.6.1.1, 12.4.3.3</td>
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<tr>
<td>TNn</td>
<td>Coldest daily Tmin</td>
<td>Seasonal/annual minimum value of daily minimum temperature</td>
<td>°C</td>
<td>Figures 9.37, 10.17, 12.13</td>
<td>9.5.4.1, 10.6.1.1</td>
</tr>
<tr>
<td>TN10p</td>
<td>Cold nights</td>
<td>Days (or fraction of time) when daily minimum temperature &lt;10th percentile</td>
<td>Days (%)</td>
<td>Figures 2.32, 9.37, 10.17, Tables 2.11, 2.12</td>
<td>2.6.1, 9.5.4.1, 10.6.1.1, 11.3.2.5.1</td>
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</tr>
<tr>
<td>TN90p</td>
<td>Warm nights</td>
<td>Days (or fraction of time) when daily minimum temperature &gt;90th percentile</td>
<td>Days (%)</td>
<td>Figures 2.32, 9.37, 10.17, Tables 2.11, 2.12</td>
<td>2.6.1, 9.5.4.1, 10.6.1.1, 11.3.2.5.1</td>
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<td>2.6.1, 9.5.4.1, 10.6.1.1, 11.3.2.5.1</td>
</tr>
<tr>
<td>FD</td>
<td>Frost days</td>
<td>Frequency of daily minimum temperature &lt;0°C</td>
<td>Days</td>
<td>Figures 9.37, 10.17, 12.13, Table 2.12</td>
<td>2.6.1, 9.5.4.1, 10.6.1.1, 12.4.3.3</td>
</tr>
<tr>
<td>TR</td>
<td>Tropical nights</td>
<td>Frequency of daily minimum temperature &gt;20°C</td>
<td>Days</td>
<td>Figures 9.37, 12.13</td>
<td>9.5.4.1, 12.4.3.3</td>
</tr>
<tr>
<td>RX1day</td>
<td>Wettest day</td>
<td>Maximum 1-day precipitation</td>
<td>mm</td>
<td>Figures 9.37, 10.10, Table 2.12, 12.27</td>
<td>2.6.2.1, 9.5.4.1, 10.6.1.2, 12.4.5.5</td>
</tr>
<tr>
<td>RX5day</td>
<td>Wettest consecutive five days</td>
<td>Maximum of consecutive 5-day precipitation</td>
<td>mm</td>
<td>Figures 9.37, 12.26, 14.1</td>
<td>9.5.4.1, 10.6.1.2, 12.4.5.5, 14.2.1</td>
</tr>
<tr>
<td>SDII</td>
<td>Simple daily intensity index</td>
<td>Ratio of annual total precipitation to the number of wet days (≥1 mm)</td>
<td>mm day⁻¹</td>
<td>Figures 2.33, 9.37, 14.1</td>
<td>2.6.2.1, 9.5.4.1, 14.2.1</td>
</tr>
<tr>
<td>R95p</td>
<td>Precipitation from very wet days</td>
<td>Amount of precipitation from days &gt;95th percentile</td>
<td>mm</td>
<td>Figures 2.33, 9.37, 11.17, Table 2.12</td>
<td>2.6.2.1, 9.5.4.1, 11.3.2.5.1</td>
</tr>
<tr>
<td>CDD</td>
<td>Consecutive dry days</td>
<td>Maximum number of consecutive days when precipitation &lt;1 mm</td>
<td>Days</td>
<td>Figures 2.33, 9.37, 12.26, 14.1</td>
<td>2.6.2.3, 9.5.4.1, 12.4.5.5, 14.2.1</td>
</tr>
</tbody>
</table>

- No drought index  
- More application relevant indices to support adaptation
Differences between reanalyses can be as large as intermodel spread

Need for better global coverage of observations and improvement of reanalysis products

Model and reanalysis performance depends on region and index under consideration
4.3. Metric Analysis of Model Performance

The overall performance of individual models in simulating the 1981–2000 climatology of the indices is summarized in a "portrait" diagram (Figure 10) as introduced in G08 and discussed in section 3.2. The portrait diagram displays the relative magnitude of spatially averaged RMSE for each index (rows) and for each model (columns). The colors characterize the magnitudes of the RMSEs, with warmer colors indicating models that perform worse than others, on average, and colder colors indicating models that perform better than others, on average. The model performance is assessed with respect to the four reanalyses, ERA40 (left triangle), ERA-Interim (upper triangle), NCEP1 (right triangle), and NCEP2 (lower triangle) of each cell of the diagram. HadEX2 is not used as a reference data set due to its limited spatial coverage for some indices.

In addition to individual models, the performance of the so-called mean and median models is also displayed in...
In addition to individual models, the performance of so-called mean and median models is also displayed in each cell of the diagram. HadEX2 is not used as a reference data set due to its limited spatial coverage for some indices.
20-year return period of max 5-day precipitation

Fig. S5. Changes in temperature and precipitation extremes in the CMIP5 ensemble. Symbols to the right of the box-and-whisker plots indicate the 95% confidence intervals.

Zonally averaged 20-year return values of 1986–2005 annual extremes are estimated from 20-year samples using the method of L-moments. The inter-model standard deviation of P
\[ P^5 \]
amplitude of P
\[ P^5 \] deviations are about 20% of the ensemble median amplitude. Differences amongst models for which references to specific models are available are displayed in some regions.

The 1986–2005 sampling standard errors obtained for individual regions where they become comparable to the ensemble median are normalized by the multi-model ensemble median. The inter-model standard deviation of P
\[ P^5 \] amplitude is indicated in brackets after the model labels. Precipitation rates (P
\[ P^5 \]) as simulated by CMIP5 models plotted on a log scale. Units are mm day
\[ -1 \].

The CMAP and GPCP pentad precipitation extremes are displayed from the reanalyses are displayed in black together with 95% bootstrapped confidence intervals. Precipitation rates are represented by several ensemble members, one curve for each ensemble member. There is better agreement between models in mid-latitudes where inter-model standard deviations are about 20% of the ensemble median amplitude. Differences amongst models for which references to specific models are available are displayed in some regions.

Kharin et al (2013)
Observational datasets disagree on extremes

Figure 12. As in Fig. 2, but for data from TRMM 3B42 (solid curves) and GPCP 1DD (dashed curves), averaged between 50°N and 50°S.

Pendergrass and Deser (2017)
Observational datasets disagree on extremes

GPCP 1DD and TRMM 3B42 daily precipitation “observations” 1998-2012
Difference between composites of warm and cold ENSO months, 30 N-S

Pendergrass and Hartmann (2014)
Extreme temperature change is somewhat more robust across datasets and model simulations

Sillmann et al (2013)
Projected extreme precipitation change

CMIP5 multi-model mean rx1day regressed against global mean T, RCP8.5
Robust signal for spatially aggregated extremes

- **Figure 4**
- **Supplementary Figs 11 and 12**
- **Supplementary Fig. 5**
- **Supplementary Fig. 10**

### Spatial PDFs

- Spatially aggregated changes in hot and cold extremes.
- Change in temperature ($\sigma_d$) and cold ($\sigma_c$) index.
- TX$_x$ (CMIP5) vs. TX$_x$ (CESM-IC).
- Change in dry spell length (days) and CDD (CMIP5) vs. CDD (CESM-IC).

### Projected Changes in Extremes

- Intensity of hot extremes (TX$_x$, first row).
- Cold extremes (TN$_n$, third row).
- Dry spell length (CDD, last row).

### Time Periods

- 2041–2060 with respect to 1986–2005 for the RCP8.5 scenario.
- End of the century (2041–2060).

### Key Points

- Consistency across CESM-IC members.
- Reasonable agreement across CMIP5.
- Dominant uncertainty source in extremes.
- Remarkable robust evidence for more frequent extreme events.

### Additional Information

- Perception of climate change by Hansen, Sato, and Ruedy.
- Perception that models allow no robust evaluation.

### References

- Fischer et al. (2013)
- Minimum temperatures in the U.S.

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Getting to the scales of impacts ...

Century  Decade  Season  Month  Week  Day  Hour
Extreme Precipitation – High-Resolution

Terrain height (m)

Summer precipitation (mm/month)

Courtesy of Øivind Hodnebrog, projects HYPRE and SUPER @ CICERO

Center for International Climate and Environmental Research - Oslo
Key points

• Defining extremes is important
  - For many questions, the answer depends on the definition
  - Dedicated metrics for evaluating extremes are essential

• Observing extremes is challenging
  - And often there is a scale mismatch from models

• Climate models don’t capture extremes defined by absolute thresholds well
  - We have more confidence in relative behavior than absolute

• Providing answers on impact-relevant scales is a challenge
CMIP5 models, CO₂ increase scenario

Extreme precipitation change varies widely across models (see also O’Gorman 2012)

These variations are changes isolated at extremes

Pendergrass and Hartmann (2014) J Clim Changes in the distribution of rain
Extra-tropics (>30°)

Smaller but more consistent from the rest of the distribution
Inter-annual variability of extremes is bigger than climate change response

O’Gorman (2012)
Models agree with observations on heavy precipitation between than observations agree with each other

Pendergrass and Hartmann (2014)
Extreme precipitation change

Pall et al (2007)
Rain rate (mm/d) vs. Rain frequency (%) for different datasets:

- **GPCP 1DD**
- **TRMM 3B42**
- **CESM1**

*Source: Pendergrass and Deser (2017)*