Factors Contributing to Regional Trends in Temperature Extremes

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This simple picture illustrates well global trends in temperature extremes on a warming planet (SREX, AR5).
• Changes in variability can strongly influence changes in extremes (Katz and Brown 1992, Sardeshmukh et al. 2015)

• Trends in extremes may also vary by region, season, time period, and measure. This complicates simple causal interpretations.
Questions

1. How strongly have changes in external radiative forcing constrained regional trends in extremes in recent decades?

2. What are the relative contributions from external forcing and internal variability to regional trends over this period?

3. How closely are regional trends in daily temperature extremes related to seasonal-mean trends?
Approach

• **Model sensitivity study**
  – Use a single model with identical forcings.
  – NCAR CCSM4 (Gent et al. 2011) 20-member ensemble forced by time-evolving GHG, aerosols, solar variations. RCP 6.0 after 2005

• **Compare trends in seasonal-mean temperatures and temperature extremes** over NH land areas for 1979-2013

• **Temperature extremes** are **Highest Daily Maximum** \( (TXx) \), **Lowest Daily Minimum** \( (TNn) \) for either winter or summer

GHCNDEX data (CLIMDEX) for temperature extremes, ECMWF-I for the trends in seasonal means and daily variability
Observed Trends in Warm Extremes
July vs. January $TXx$

July

GHCNDEX TXx JUL Trend 1979-2013
unit: degC / year (stippling indicates significant trends (p<=0.05))

January

GHCNDEX TXx JAN Trend 1979-2013
unit: degC / year (stippling indicates significant trends (p<=0.05))

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Observed Trends in Warm vs. Cold Extremes
July $TXx$ vs. $TNn$

Maximum

Minimum

GHCNDEX $TXx$ JUL Trend 1979-2013
unit: degC / year (stippling indicates significant trends ($p<0.05$))

GHCNDEX $TNn$ JUL Trend 1979-2013
unit: degC / year (stippling indicates significant trends ($p<0.05$))
Model Trends in Warm Extremes
TXx Summer vs. Winter

Summer

Winter

CCSM4 Max Tmx JJA Trend 1979–2013

CCSM4 Max Tmx DJF Trend 1979–2013
Seasonal-Mean Temperature Trends
Winter (DJF)

DJF SfcT Trend 1979–2013

Observed

Model
SST differences lead to circulation differences
External forcing does not strongly constrain winter regional trends.
CCSM4 regional extreme warm trends
Eastern Asia Winter $TXx$

Eastern Asia–DJF $TXx$ Trend

Broad distribution $\rightarrow$ weak constraint
CCSM4 regional extreme warm trends
Eastern North America Winter TXx

Same story
CCSM4 regional extreme warm trends
Western Eurasia Summer $TX_x$

Western Eurasia–JJA $TX_x$ Trend

Tighter summer distribution, all values are positive and $> 1^\circ$ C
The range of trends in extremes is greater than for means. The ranges are both much larger in winter than summer. Large variations in regional mean and extreme trends.
Addressing the Questions

1. How strongly have changes in external forcing constrained regional trends in extremes in recent decades?
   - In winter, regional trends are only weakly constrained
   - In summer, external forcing is a relatively stronger constraint

2. What are the relative contributions from internal variability and external forcing to regional trends in extremes over the same period?
   - In winter, the contributions are roughly comparable
   - In summer, external role is relatively larger (variability smaller)

3. How closely are regional trends in daily temperature extremes related to trends in seasonal-mean temperatures?
   - There is a positive relationship, but with considerable scatter
   - Trends in extremes have a much larger range
Factors Contributing to Regional Trends in Extremes

1. Externally forced local ‘thermodynamic’ trend
   Relative weak constraint in winter, stronger in summer

2. Multidecadal internal variations of the coupled climate system
   Unforced internal variations in SSTs. Dynamics are fundamental

3. Trend gradient: Non-local ‘thermodynamic’ effect
   Influences of temperature trend gradients on variability, e.g. effect of Arctic Amplification on temperature variance (Screen et al. 2015)

4. Land surface forcing and feedbacks
   Manifested by differential effects on $T_{max}$ and $T_{min}$ trends
   Mediated through other variables, e.g., precipitation on soil moisture

5. Unforced internal atmospheric variability
   Weather happens. Can contribute significantly to multi-decadal trends
Summary

- **Temperature extreme trends differ strongly by region and season.** To explain such differences, it is essential to move beyond a simple thermodynamic picture of externally-forced local mean trends to more comprehensive understanding of variability and the physical causes for extremes.

- **Changes in external radiative forcing have influenced but not strongly constrained regional trends in temperature extremes in recent decades.** Much smaller – or larger – trends could have occurred due to internal climate variations.

If a trend seems too slow or too fast for a radiatively forced response it probably is. Suspect an alternate cause. Most often its internal variability, but in some cases other human factors such as land use changes may be important.
What are observed and CCSM4 surface temperature trends?

Summer Mean Temperatures (JJA)

Summer trends mostly warming, less spatial variability
Can the model reproduce observed Asian cooling trend? Comparison of trends in one run with observed trends

Yes. In the model, due to multidecadal internal variability.
What are observed and CCSM4 daily temperature variability trends?

Winter

Temperature variability also has trends. In high latitudes, variability trends are mostly downward.
How strongly have changes in external radiative forcing constrained Global-Mean SST trends?

Annual SST Trend 1979–2013

Probability Density Function

Total Change in °C

OBS

CMIP5
CCSM4
What are observed and CCSM4 surface temperature trends?
Winter Mean Temperatures (DJF)

Arctic Amplification  → weaker poleward temperature gradients
Daily temperature variability trends are linked to trends in gradients
Model reproduces its DJF trends reasonably well. Observations less so.
How strongly have changes in external radiative forcing constrained regional mean summer temperature trends?

Spatial Congruence of CCSM4 runs vs. Ensemble Average

More agreement in summer between runs and with observations
1. Observed trends show large regional and seasonal differences
   - Larger regional trend variations for extremes in January than in July
   - Over a large part of eastern Asia, $T_{xx}$ decreasing in January
   - Over the eastern U.S., $T_{xx}$ increasing in January but not July
   - Over the U.S. and eastern Europe, summer $T_{xx}$ vs. $T_{nn}$ trends differ

2. Model trends in Extremes
   - Far less spatial or seasonal variability, $T_{xx}$ and $T_{nn}$ increase almost everywhere

Model and observed differences are larger in winter than summer