Nonlinear drought response to anthropogenic forcing in CESM

Flavio Lehner\textsuperscript{1,2}, Sloan Coats\textsuperscript{3}
\textsuperscript{1} Climate and Global Dynamics Lab, NCAR, USA
\textsuperscript{2} Research Applications Lab, NCAR, USA
\textsuperscript{3} Woods Hole Oceanographic Institution, USA

Thanks to Dani Coleman\textsuperscript{1}, Nan Rosenbloom\textsuperscript{1},
Isla Simpson\textsuperscript{1}, Clara Deser\textsuperscript{1}, Gary Strand\textsuperscript{1}
Uni-directional drought evolution?

“Regional changes in extreme temperature and precipitation [...] scale robustly with global temperature across scenarios.”
Seneviratne et al. (2016, Nature)

“... human-induced change is uni-directional as long as the responsible changes in forcing (e.g. greenhouse gases) do not reverse in sign.”
Seager (2015, Climate Change)
“Regional changes in extreme temperature and precipitation [...] **scale robustly** with global temperature across scenarios.”
Seneviratne et al. (2016, *Nature*)

“... human-induced change is **uni-directional** as long as the responsible changes in forcing (e.g. greenhouse gases) do not reverse in sign.”
Seager (2015, *Climate Change*)

Nonlinear scaling of drought with warming.
Uni-directional drought evolution?

“Regional changes in extreme temperature and precipitation [...] scale robustly with global temperature across scenarios.”
Seneviratne et al. (2016, Nature)

“... human-induced change is uni-directional as long as the responsible changes in forcing (e.g. greenhouse gases) do not reverse in sign.”
Seager (2015, Climate Change)

Detection of anthropogenic forcing (GHGs and aerosols) on global drought.
Marvel et al. (2019, Nature)

Nonlinear scaling of drought with warming.
Lehner et al. (2017, Geophys. Res. Let.)
Scaling with global temperature

(a) Global

- Precipitation change (% relative to preindustrial)
- Global temperature change (degC)

 CESM rcp85 (40)
Scaling with global temperature

![Graph showing scaling with global temperature change and precipitation change.](image-url)
Scaling with global temperature

![Graph showing precipitation change vs. global temperature change](https://example.com/graph.png)

- **2°C**: 3.6%
- **1.5°C**: 2.8%
- **2°C**: 2.1%
- **1.5°C**: 1.2%

Global temperature change (degC) vs. Precipitation change (% relative to preindustrial)
Scaling with global temperature

(a) Global

Precipitation change (% relative to preindustrial) vs. Global temperature change (degC)

- CESM rcp85 (40)
- CESM 1pt5 (10)
- CESM 2pt0 (10)
- CMIP5 rcp85 (27)

Years:
- 1920s
- 2010s
- 2020s
- 2030s
- 2040s
- 2050s
- 2060s
- 2070s
- 2080s
- 2090s
Scaling with global temperature
Drought changes in CESM

CESM LE
(a) PDSI

Drought change

Change at 4°C warming (normalized drought units)
Drought changes in CESM

(a) PDSI
Drought changes in CESM

(a) PDSI

(b) SM_30CM

(c) SM_200CM

Change at 4°C warming (normalized drought units)
Drought changes in CESM

Departure from linear scaling

\[ D_{\Delta T} = \Delta Q_{\Delta T} - \frac{\Delta T}{\Delta T - 0.5} \Delta Q_{\Delta T} - 0.5^\circ C \]

King (2019, Env. Res. Let.)
Drought changes in CESM

(d) PDSI

Summed departure from linearity (normalized drought units)
Drought changes in CESM

(a) PDSI

(b) SM_30

(c) SM_200CM

(d) PDSI

Change at 4°C warming (normalized drought units)
Drought changes in CESM

(a) PDSI
(b) SM_30CM
(c) SM_200CM

(d) PDSI
(e) SM_30CM
(f) SM_200CM
Drought changes in CESM

20 simulations each:

XAER = aerosols fixed at 1920 (~GHG)

XGHG = GHGs fixed at 1920 (~AER)
Drought changes in CESM

- PDSI (normalized)
- SM_30CM (normalized)
- SM_200CM (normalized)

Maps showing distribution of drought changes over the world for PDSI, SM_30CM, and SM_200CM.
Drought changes in CESM
Summary and conclusions

- **Nonlinearities** with temperature exist, challenging the robustness of warming targets alone to inform about climate change impacts and their possible mitigation.

- **Emission scenario composition** can have important regional impacts, with aerosols being the dominant factor → this complicates interpretation of the observational record.

- Some results depend on **drought metric** used.

- **Good/bad news:** CESM likely overestimates aerosol forcing on precipitation in some regions (not shown).

Thanks!

flehner@ucar.edu
Scaling with global temperature

(a) Global

(b) SE Asia

(c) W US

(d) E Africa