High-Resolution Climate Models Reveal Increasing Meteorological Drought Intensity in Fenno-Scandinavia

Ruben Häberli[1,2], Ole Bøssing Christensen[2], Peter Thejll[2], Eigil Kaas[1]

[1] Physics of Ice, Climate and Earth, Niels Bohr Institute, University of Copenhagen

[2] National Centre for Climate Research, Danish Meteorological Institute

Sharing is encouraged

Häberli et al. (preprint)

This presentation is based on the article

"*Unprecedented Extreme Meteorological Droughts Simulated in Fenno-Scandinavia with High-Resolution Climate Models*"

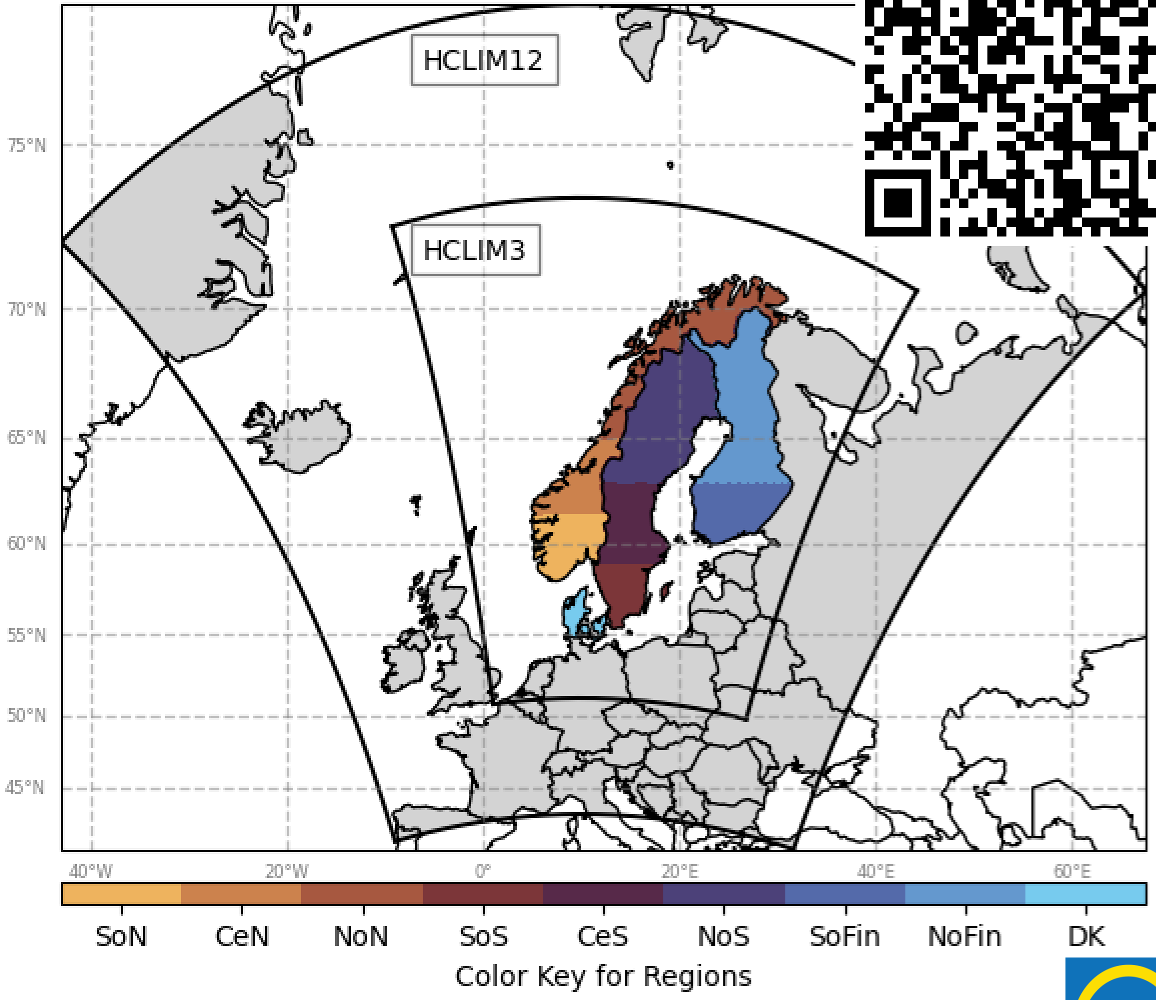
by Ruben Häberli, Ole Bøssing Christensen, Peter Thejll and Eigil Kaas, 13 April 2025, PREPRINT (Version 1), which has been submitted to Climate Dynamics and is currently under review.
https://doi.org/10.21203/rs.3.rs-6056779/v1

Figures reproduced from the manuscript are marked in the supplementary materials but not in the presentation itself, to maintain clarity during the talk.

Introduction

UNIVERSITY OF COPENHAGEN
FACULTY OF SCIENCE

- Future drought trends in the Nordics are uncertain
- New Convection-Permitting regional climate Models (CPMs, 3km) improve summer precipitation simulations
- CPMs implications for drought conditions are still underexplored
- Evaluate the benefits of using CPMs for future drought frequency and intensity using data from Lind et al. (2023)
- New method for standardized indices



From Häberli et al. (preprint)

Sharing is encouraged

Motivation and Objectives

- Studies indicate that **CPMs provide a more accurate representation of extreme precipitation** events. [Ban et al. 2021, Lind et al. 2020]
- **In the Nordics CPMs show an overall decrease in summer precipitation** compared to traditional Regional Climate Models (RCMs) which overestimate precipitation by on avg 25%. [Lind et al. 2020]
- The NorCP project ran the HARMONIE-Climate regional climate model (RCM) **at 12 and 3 km grid spacing for 20-year periods** to capture climate projections. [Lind et al. 2023]
- While this data has been analysed for precipitation extremes, it has **not yet been explored for drought conditions**.
- Objectives of the study
    - Investigate future drought conditions using models with convection-resolving physics.
    - Assess changes in drought probabilities and severity.
    - Evaluate the benefits of using Convection Permitting Models for drought assessments.

The NorCP Project

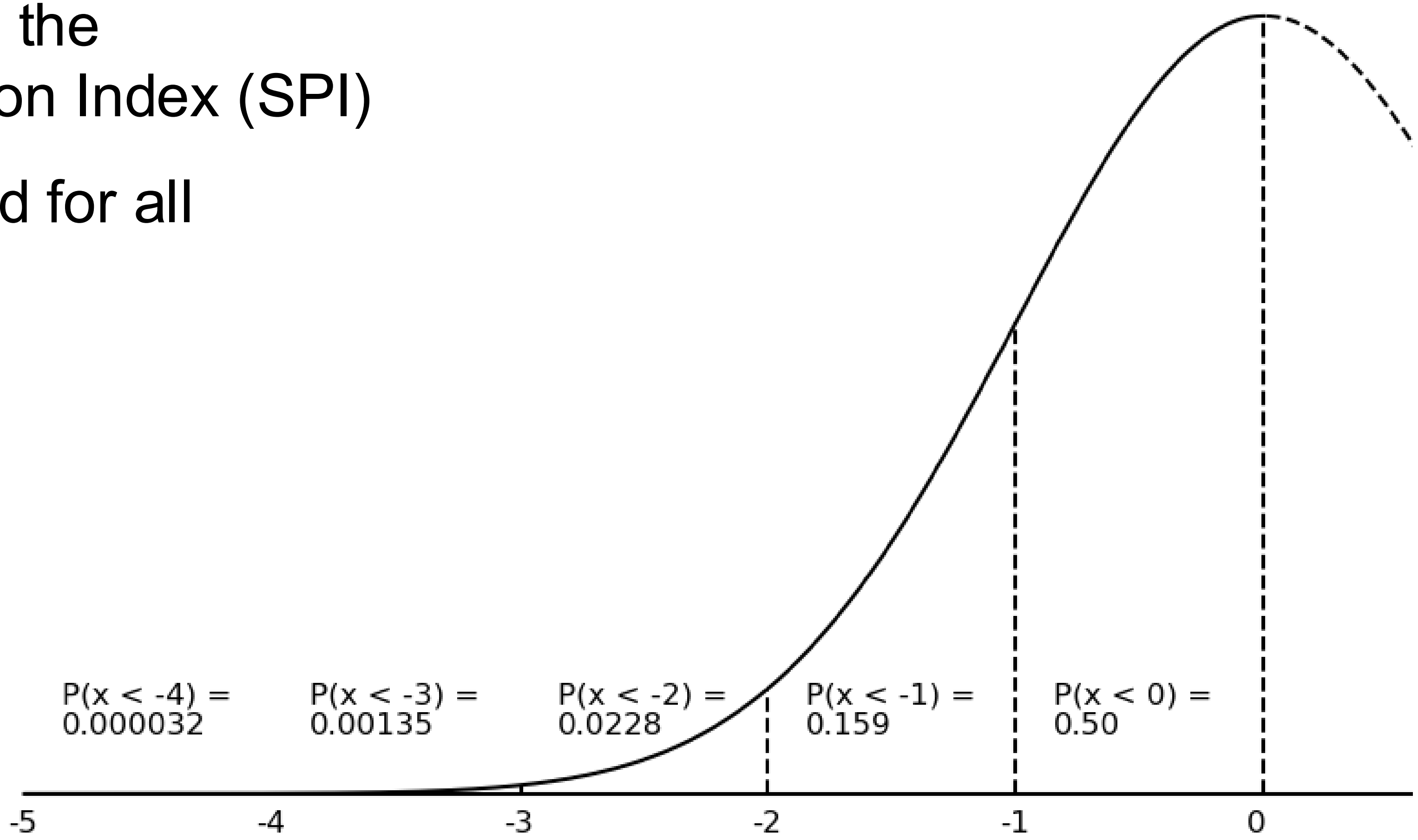
- The Nordic modelling collaboration “NorCP” is performing convection permitting climate simulations at 3 km grid resolution over a northern European domain. (from special project final report NorCP)
- The collaboration is using a common model setup for the climate-adapted version “HCLIM” of the numerical weather prediction model HARMONIE and includes DMI (Denmark), FMI (Finland), MET Norway (Norway) & SMHI (Sweden).
- Within NorCP, the HARMONIE-Climate regional climate model was run at 12 and 3 km grid spacing for 20 year time slices. (Lind et al. 2023)
    - 1985-2005
    - 2040-2060 both RCP4.5 and RCP8.5 scenarios
    - 2080-2100 both RCP4.5 and RCP8.5 scenarios

Methodology

- This study is based on HARMONIE-Climate regional climate model simulations (cycle 38) at 12 km (RCM) and 3 km (CPM) grid spacing for the following time slices and scenarios. (Lind et al. 2023)
    - Historical (CTRL): 1986-2005 (baseline period for precipitation distribution)
    - Mid century (MC): 2041-2060 both RCP4.5 and RCP8.5 scenarios
    - Late century (LC): 2081-2100 both RCP4.5 and RCP8.5 scenarios
- EC-Earth and GFDL (only historical and RCP8.5) downscaled for HCLIM.
- The Standardized Precipitation Index (SPI) was chosen for drought analysis.
    - Recommended by the WMO, as it is flexible and easy to calculate.
    - Possibility to look at different drought time-frames of 1, 3, 6, or more months.
    - Typically requires at least 30 years of data but 20 years is adequate for this study.
- The XCLIM python package [Bourgault et al., 2023] was used to calculate the SPI.

Multi-Threshold Method

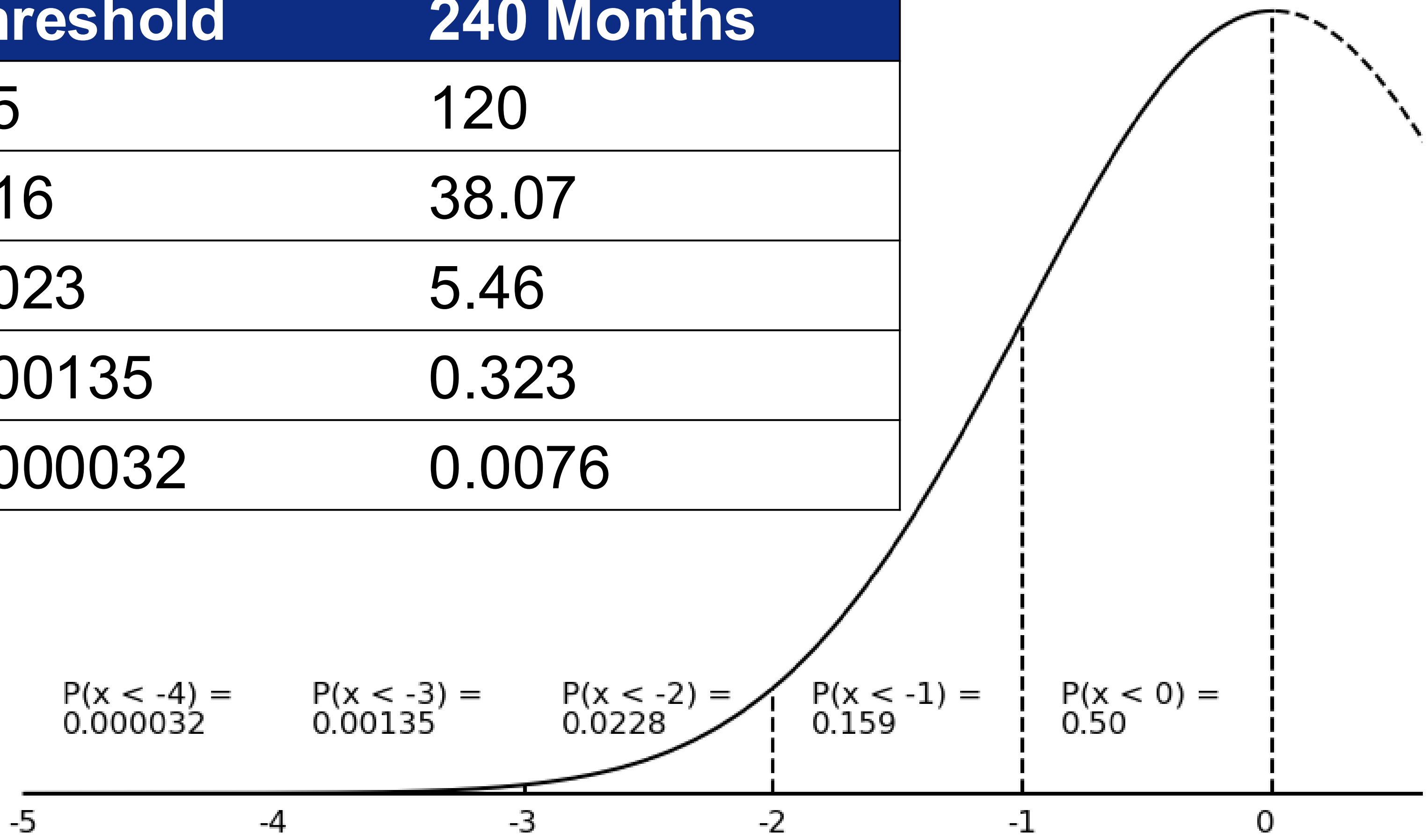
- In this study we analysed changes in drought frequency using the Standardized Precipitation Index (SPI)
- This method can be used for all standardised indices



From Häberli et al. (preprint)

Multi-Threshold Method

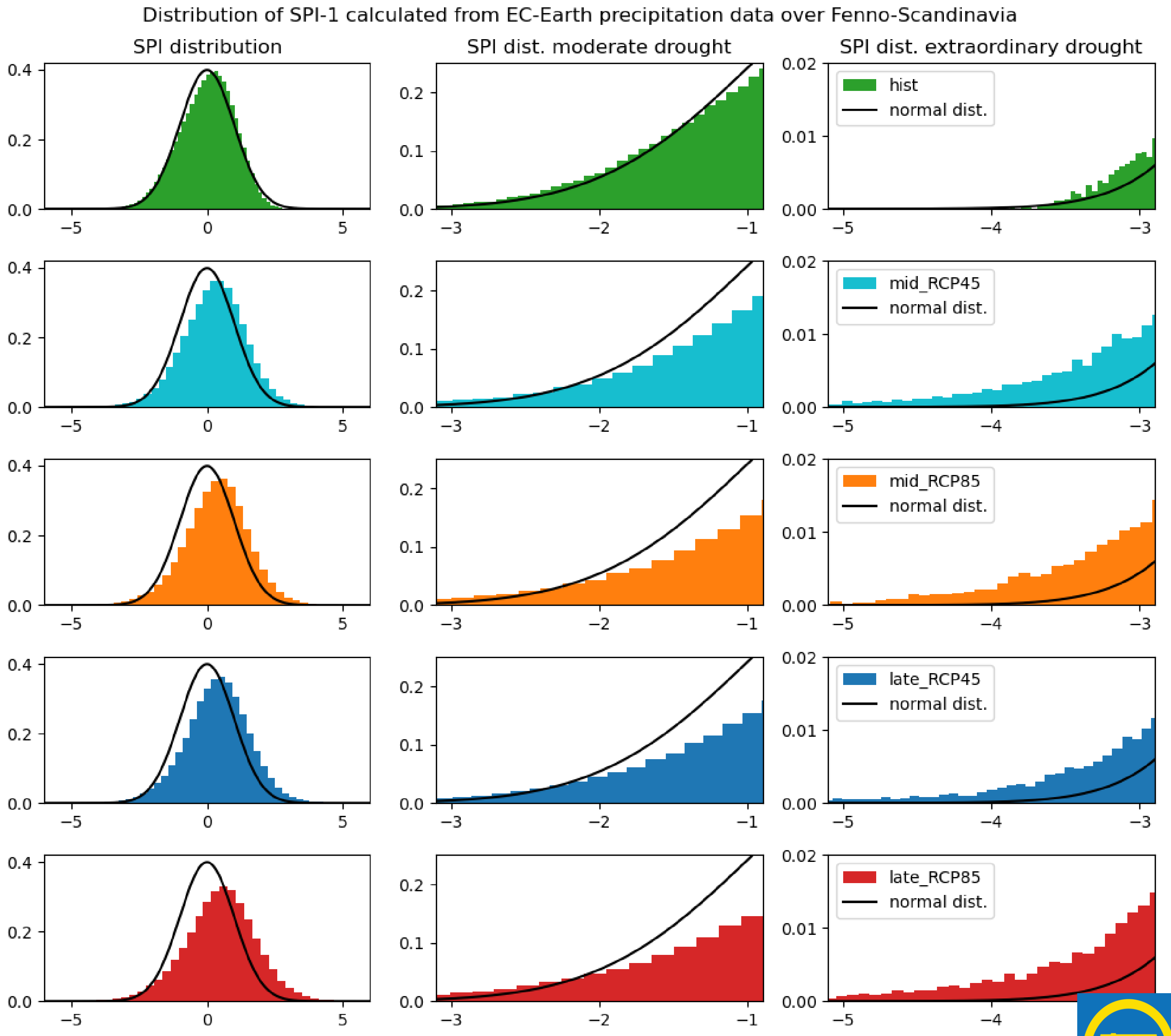
Drought	Threshold	Share Below Threshold	Occurrences in 240 Months
Mild	0	0.5	120
Moderate	-1	0.16	38.07
Severe	-2	0.023	5.46
Extreme	-3	0.00135	0.323
Exceptional	-4	0.000032	0.0076



From Häberli et al. (preprint)

Method

Example of how the distribution moves to more precipitation but still the tale on the negative end with more drought shows an increase in frequency.



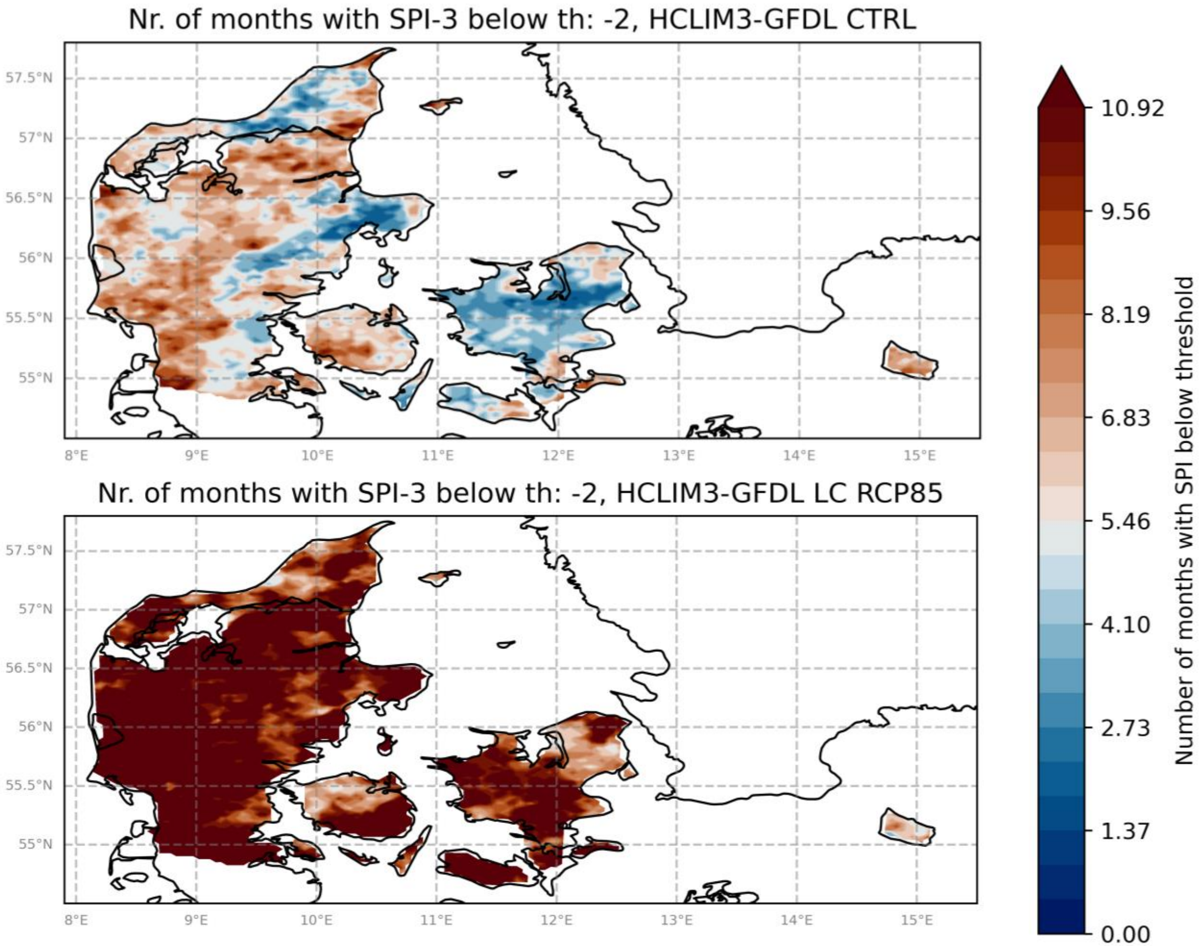
Sharing is encouraged

Example Result

The expected number of months with SPI below -2 is ~5.5 months during the control period of 20 years.

The plots on the right show a comparison of historical vs. future (RCP8.5, 2081-2100) drought frequency.

- Blue means fewer droughts
- Brown means more droughts

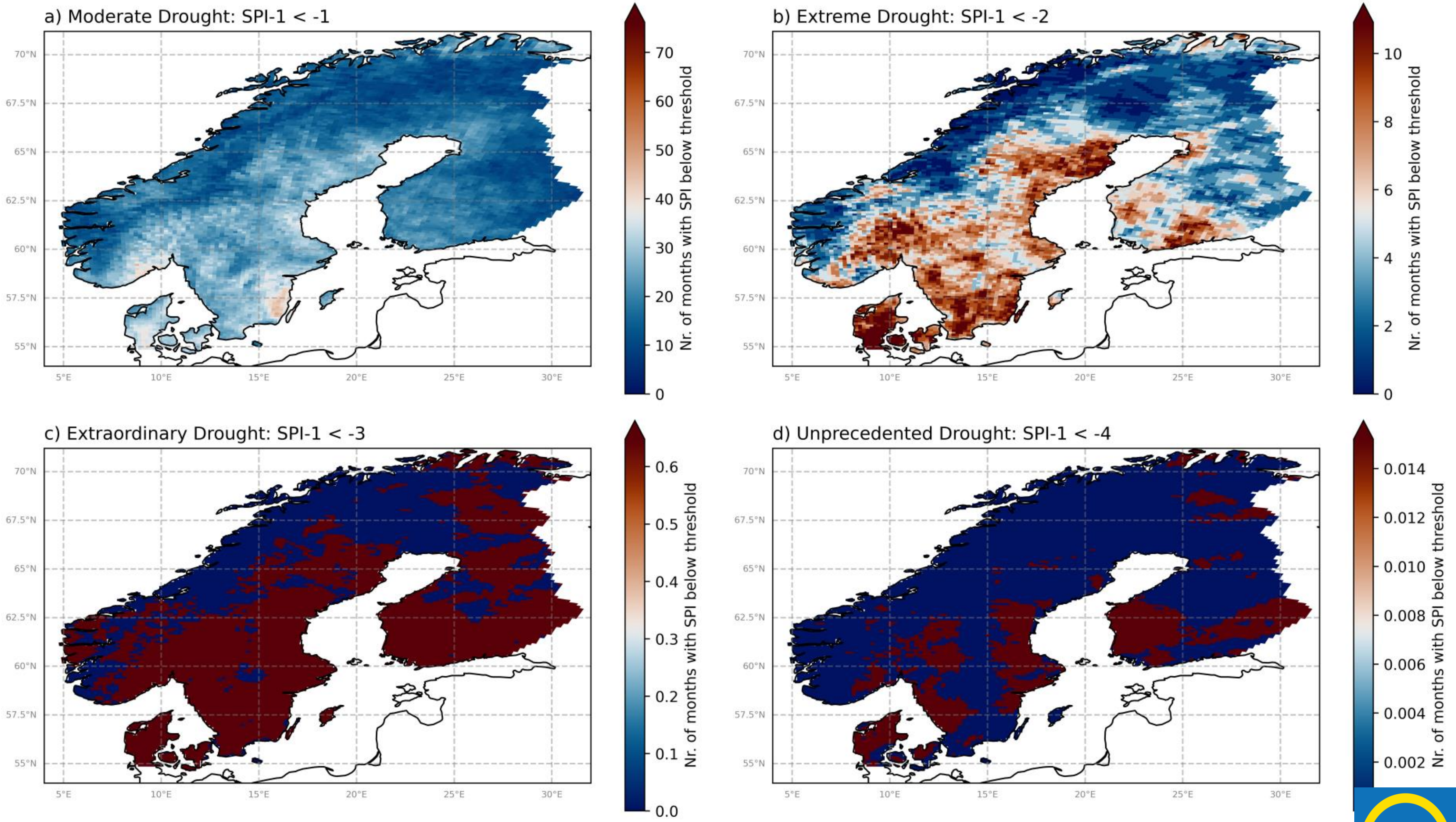


From Häberli et al. (preprint)

Results – Future Drought

Maps of Fenno-Scandinavia showing the number of months with SPI-1 below four different thresholds. The maximum value in dark brown is corresponding to a twofold increase in drought months, while dark blue means that no months had droughts worse than the threshold.

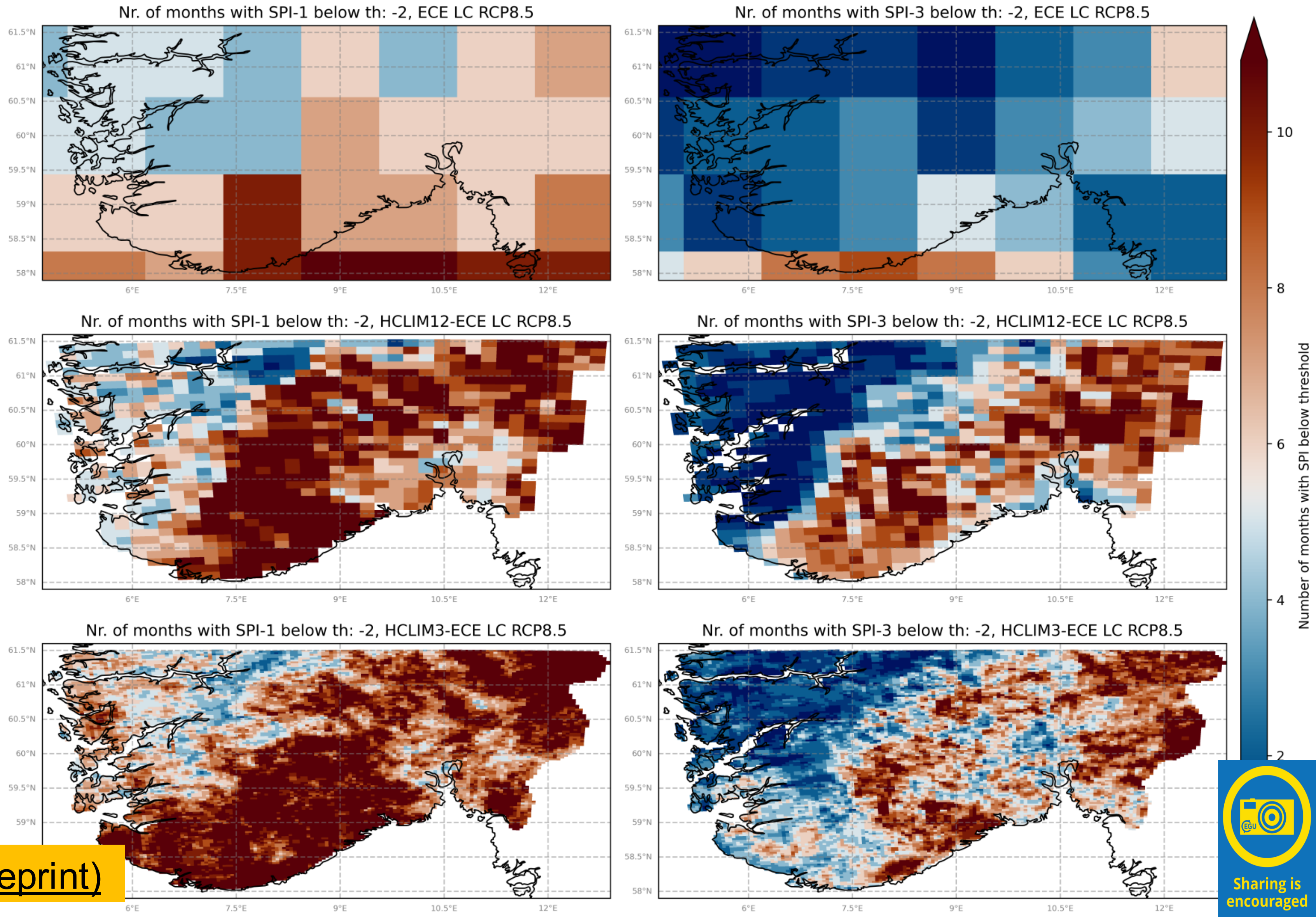
The model shown here is HCLIM12 forced by GFDL with an RCP8.5 scenario for the period 2081-2100.



From Häberli et al. (preprint)

Model Comparison

Comparison of data from the global model (top row), 12km HARMONIE-Climate (middle) and 3km with convection resolving physics (bottom row)

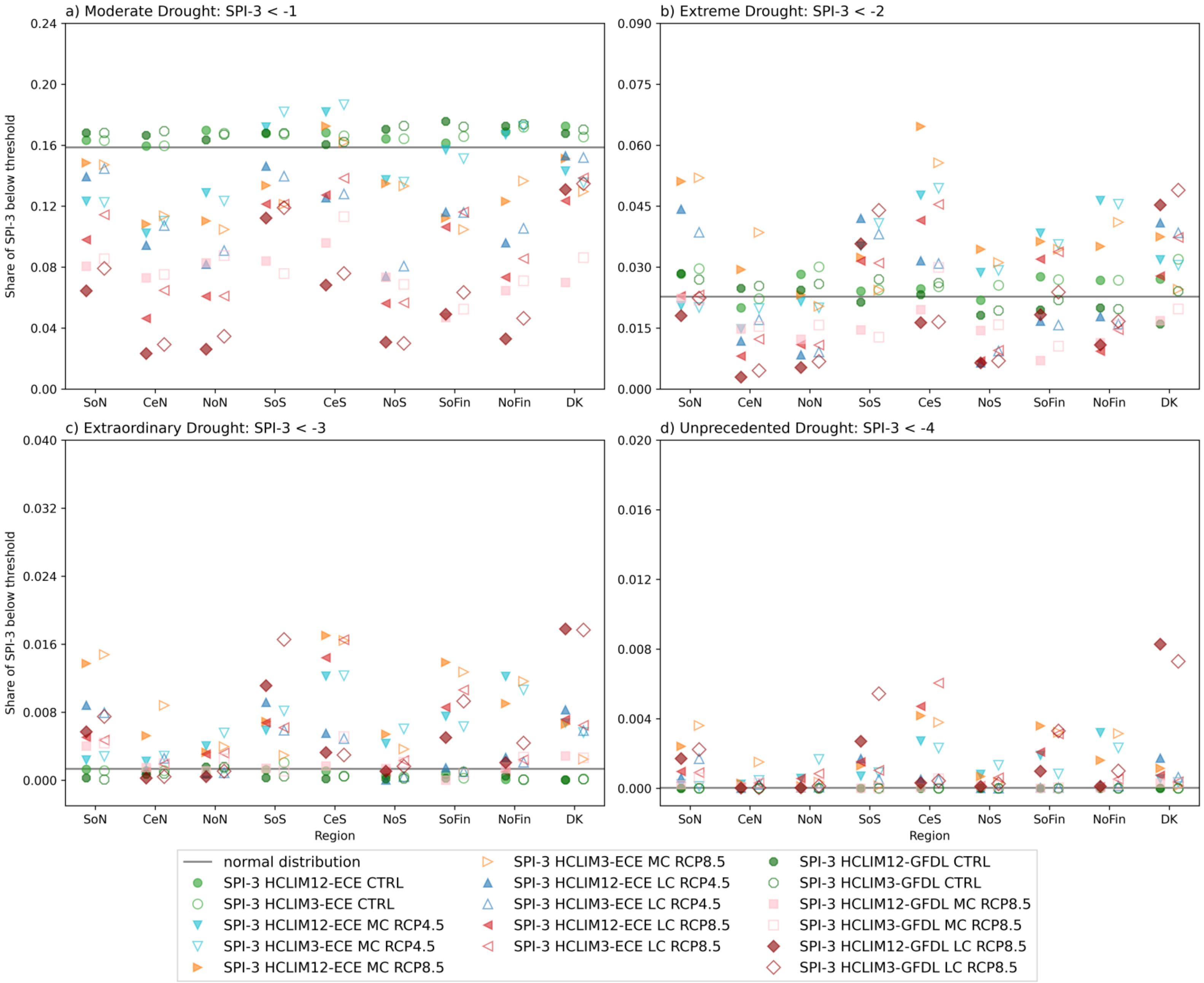


From Häberli et al. (preprint)

Results

SPI-3 – all year

- Fewer moderate droughts
- More extreme droughts
- Unprecedented droughts

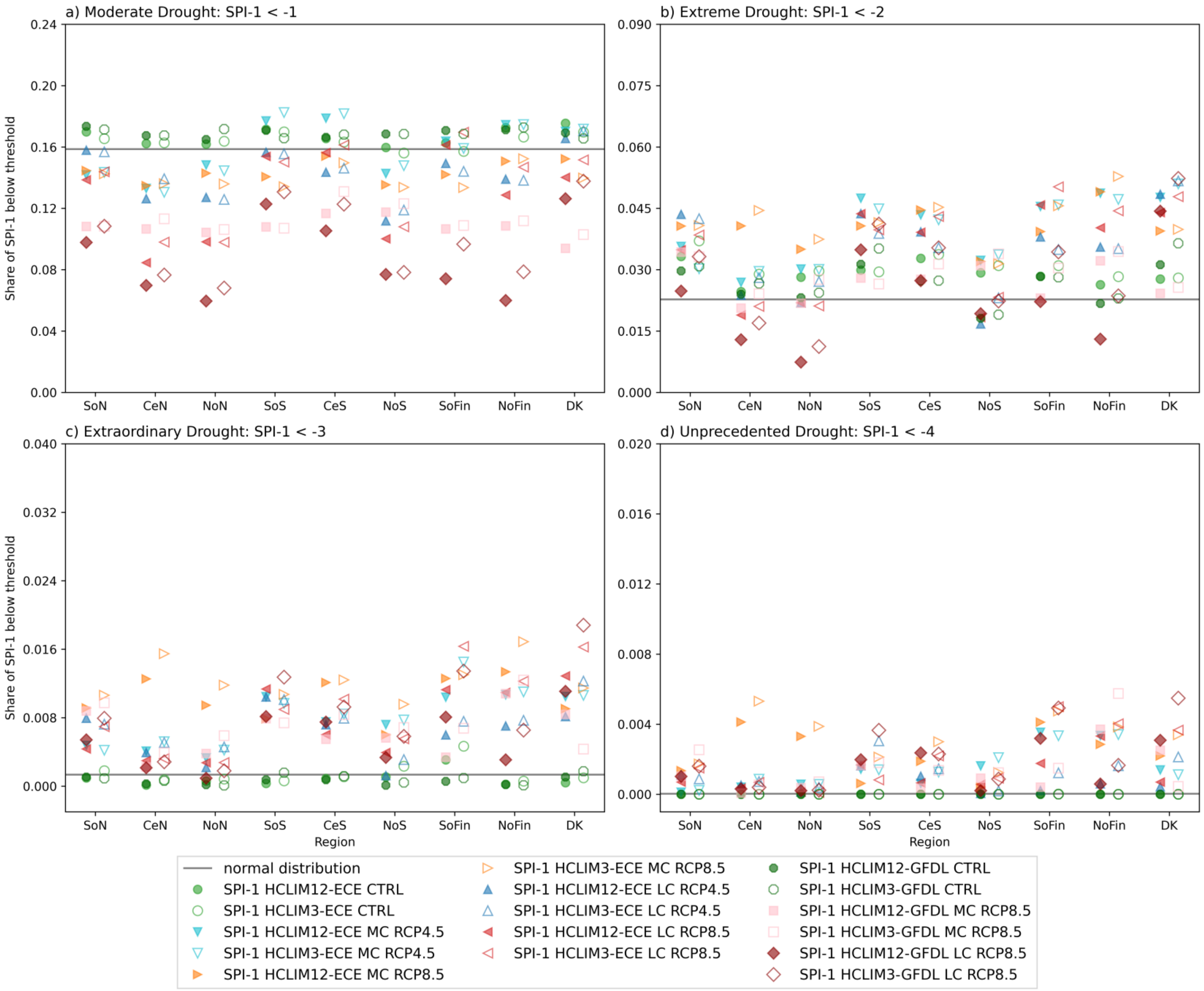


From Häberli et al. (preprint)

Results

SPI-1 – all year

- Fewer moderate droughts
- More extreme droughts
- Unprecedented droughts

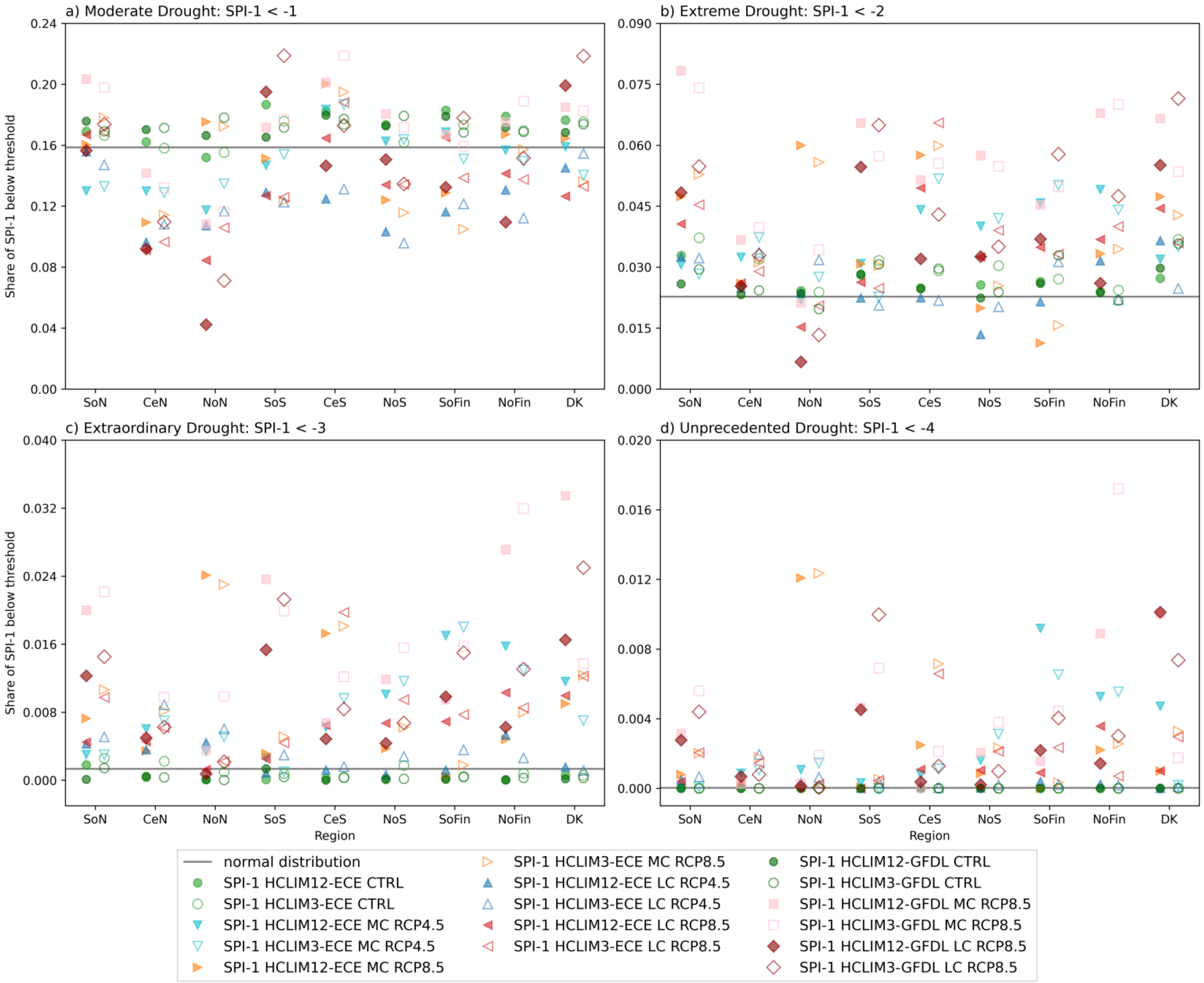


From Häberli et al. (preprint)

Results

SPI-1 – growing season

- Same frequency moderate droughts
- Even more extreme droughts
- Unprecedented droughts

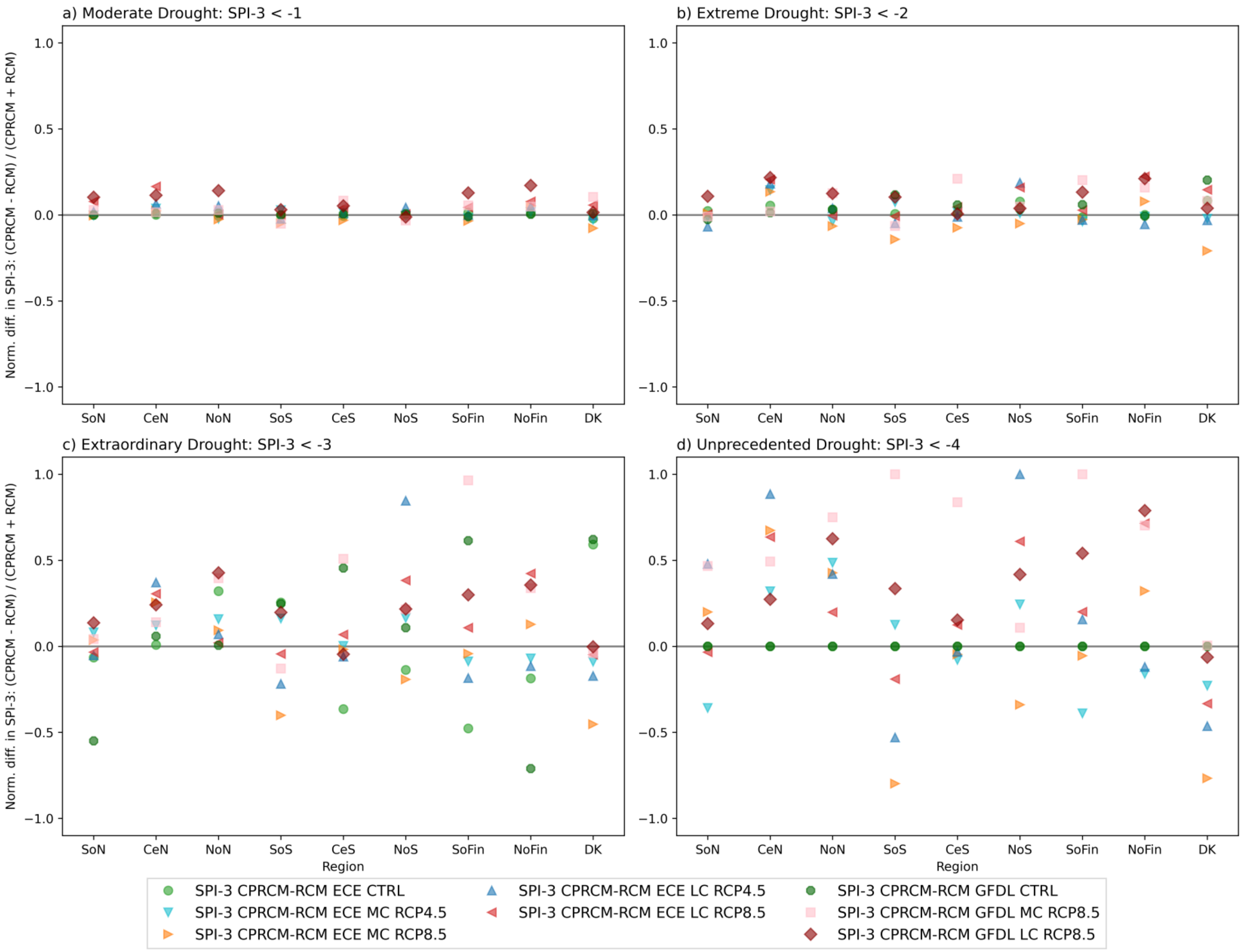


From Häberli et al. (preprint)

Results

Difference in SPI-3 – **CPM minus RCM**

- Positive values indicate more drought in CPM (3km) than in RCM (12km)
- Especially for high intensity droughts
- Data symmetrically normalised

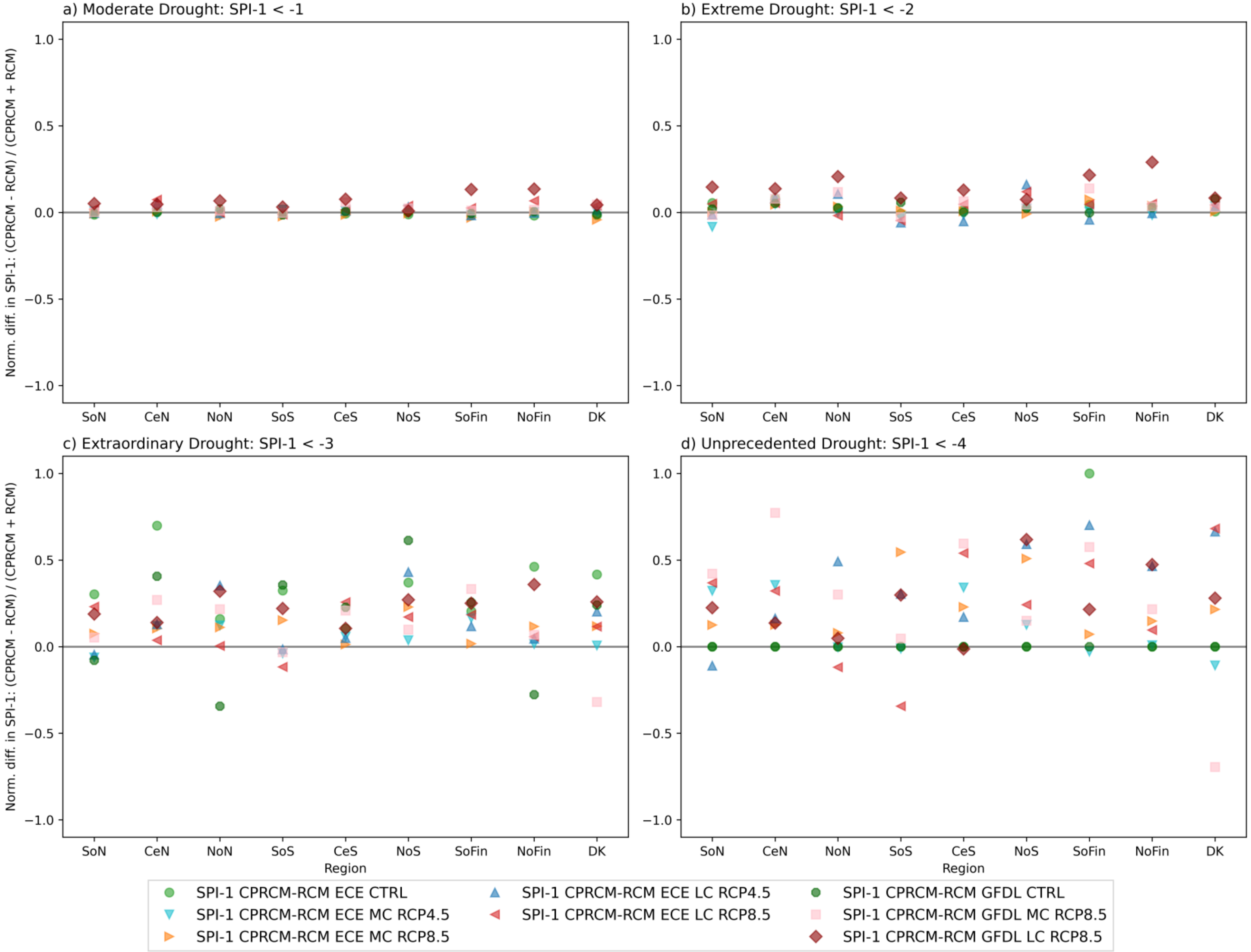


From Häberli et al. (preprint)

Results

Difference in SPI-1 –
CPM minus RCM

- Positive values indicate more drought in CPM (3km) than in RCM (12km)
- Especially for high intensity droughts
- Data symmetrically normalised



From Häberli et al. (preprint)

Sharing is encouraged

Conclusion

We calculated future Meteorological Droughts in Fenno-Scandinavia using the SPI from Convection-Permitting regional climate Model (CPM) data.

- **Moderate droughts:** decrease in freq., small change during growing season
- **Extreme droughts:** increase in frequency, particularly in the growing season
- **Unprecedented droughts:** Appear from mid-21st century, intensify toward late century
- **CPM vs RCM:** The CPM projects higher drought frequency than the 12 km-resolution RCM

We recommend the use of the multi-threshold method to better capture drought complexity in a changing climate.

Acknowledgments & Contact Information

We gratefully acknowledge the NorCP project for providing the data that made this research possible.

University of Copenhagen

Physics of Ice, Climate and Earth

Tagensvej 16

2200 Copenhagen

DENMARK

ruben.haeberli@nbi.ku.dk

Paper under review at Climate Dynamics:

Unprecedented Extreme Meteorological Droughts Simulated in Fenno-Scandinavia with High-Resolution Climate Models (Häberli et al.)

Supplementary Material:

Sharing is encouraged

Reference list (excerpt)

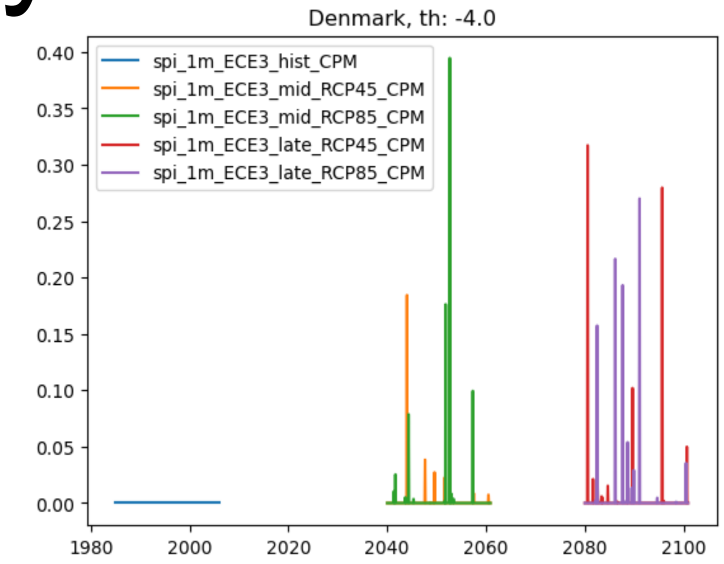
Lind et al., 2020	Lind, P., Belušić, D., Christensen, O.B. *et al.* Benefits and added value of convection-permitting climate modeling over Fenno-Scandinavia. *Clim Dyn* **55**, 1893–1912 (2020). https://doi.org/10.1007/s00382-020-05359-3
Lind et al., 2023	Lind, P., Belušić, D., Médus, E. *et al.* Climate change information over Fenno-Scandinavia produced with a convection-permitting climate model. *Clim Dyn* **61**, 519–541 (2023). https://doi.org/10.1007/s00382-022-06589-3
Ban et al., 2021	Ban, N., Caillaud, C., Coppola, E. *et al.* The first multi-model ensemble of regional climate simulations at kilometer-scale resolution, part I: evaluation of precipitation. *Clim Dyn* **57**, 275–302 (2021). https://doi.org/10.1007/s00382-021-05708-w
IPCC AR6 WR1	IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:10.1017/9781009157896.
Bourgault et al., 2023	Bourgault et al., (2023). xclim: xarray-based climate data analytics. Journal of Open Source Software, 8(85), 5415, https://doi.org/10.21105/joss.05415
Stagge et al., 2015	Stagge, J.H., Tallaksen, L.M., Gudmundsson, L., Van Loon, A.F. and Stahl, K. (2015), Candidate Distributions for Climatological Drought Indices (SPI and SPEI). Int. J. Climatol., 35: 4027-4040. https://doi.org/10.1002/joc.4267
Spinoni et al., 2020	Spinoni, J., and Coauthors, 2020: Future Global Meteorological Drought Hot Spots: A Study Based on CORDEX Data. *J. Climate*, **33**, 3635–3661, https://doi.org/10.1175/JCLI-D-19-0084.1.

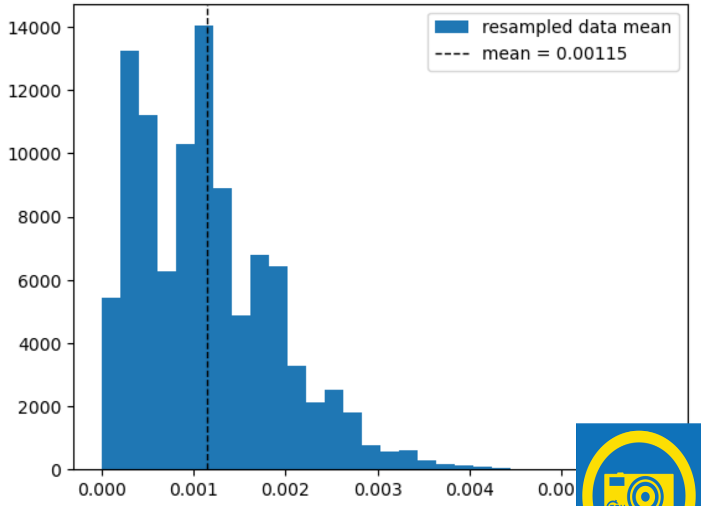
Full list of references in Häberli et al. (preprint)

Appendix

Natural Variability / Uncertainty

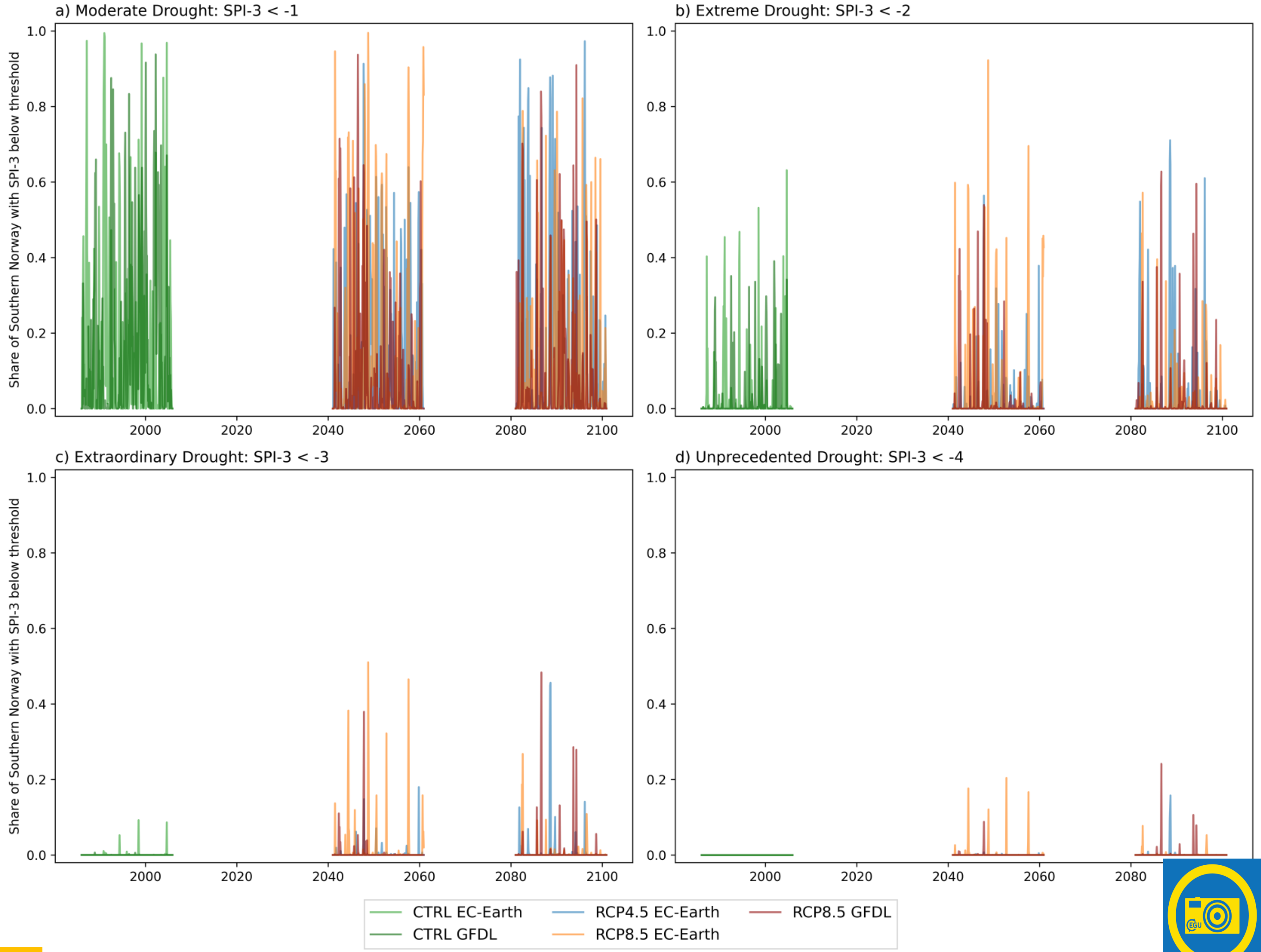
- Quantify the uncertainty in these results.
- For every time step (month in our case), we calculated what share of the cells were below the thresholds (see top right).
- Selecting (with replacement) as many data points from each time series as there are months in the original time series.
- Repeat to get 100’000 new datasets that were resampled from the original data.
- Figure in the bottom right shows the natural variability of the mean value for the data series
- This shows us that the mean value we calculated from the original data agrees with the internal variability of the data, meaning that the points shown in the frequency analysis section of this paper are robust results and not just outliers.
- The full results of the bootstrapping are shown in the next slides.





Drought Freq.

Share of Southern Norway with an SPI-3 below multiple thresholds under different greenhouse gas concentration scenarios, as well as during the historical period. This was calculated using the CPRCM at 3 km resolution (HCLIM3) with both GFDL and EC-Earth global models.

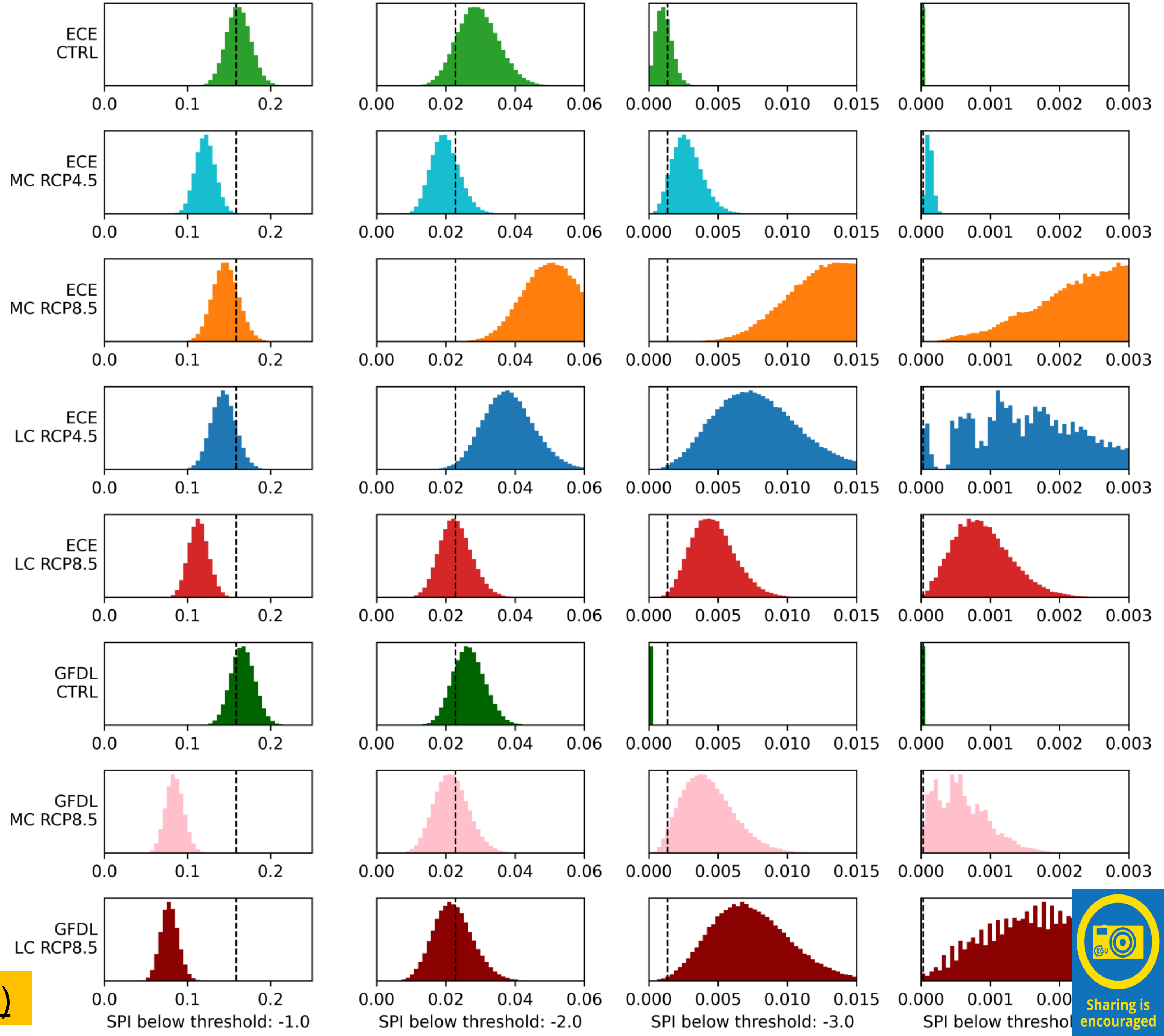


From Häberli et al. (preprint)

Bootstrapping

The natural variability of the SPI-3 data over Southern Norway gives an idea for the significance of the data shown in the previous figures. The vertical dotted lines show the theoretically expected values for the historical period.

The further away from the vertical dotted line the distribution is, the more significant the result. Shown here is the resampling from the CPRCM at a 3 km resolution. The global climate model and the greenhouse gas concentration scenario used are shown to the left.



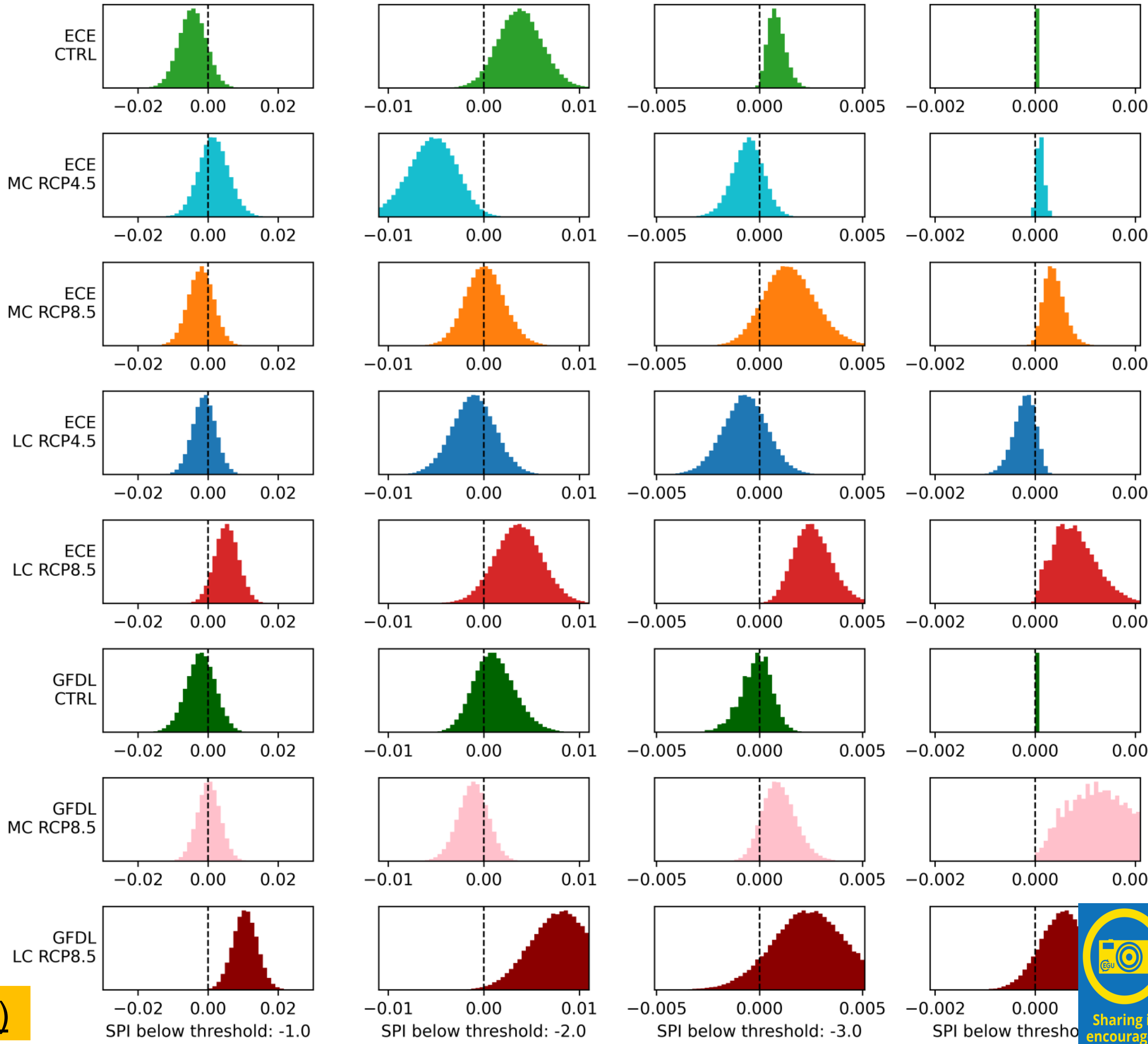
Danish Meteorological Institute

From [Häberli et al. (preprint)]

Sharing is encouraged

Bootstrapping

The natural variability of the differences in SPI-1 between the CPRCM and the RCM data over Southern Norway gives an idea for the significance of the data. The further away from zero the distribution is, the more significant the result. The global climate model and the greenhouse gas concentration scenario used are shown to the left.



Danish Meteorological Institute

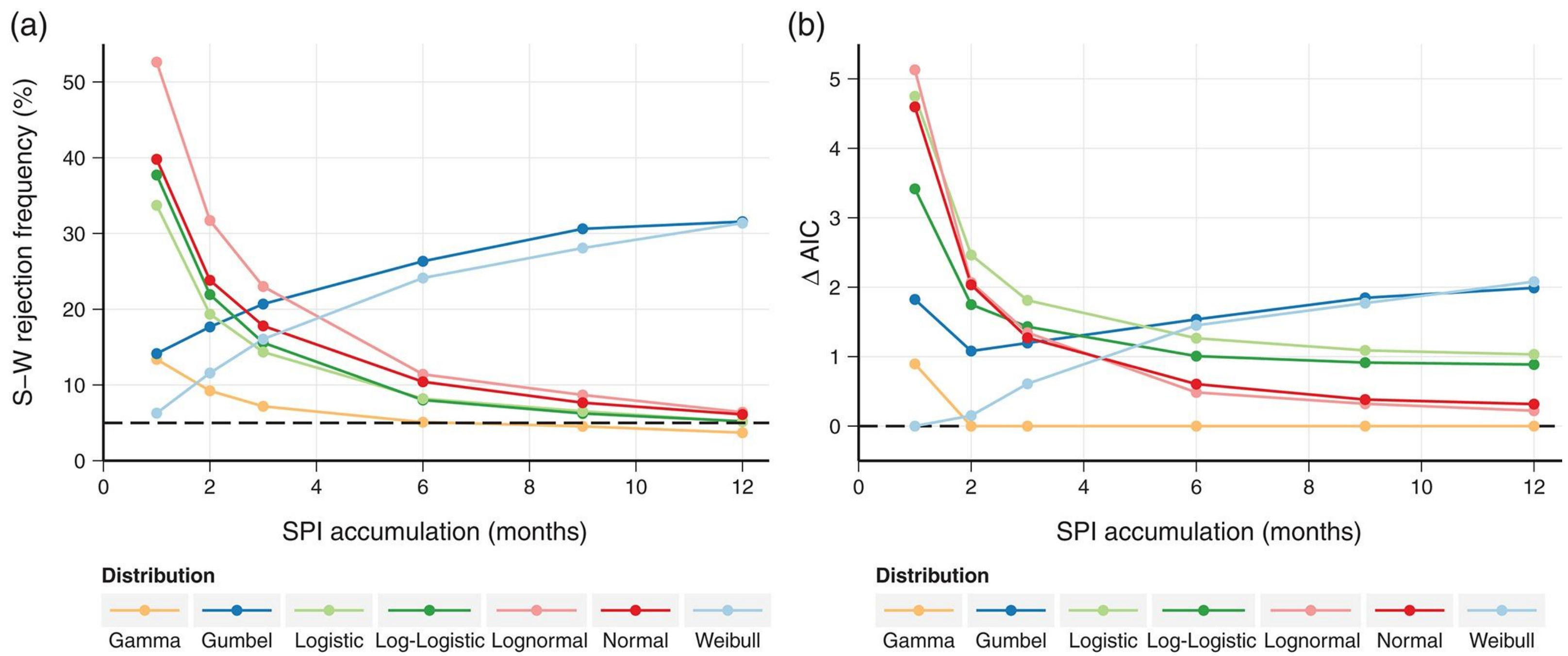
From Häberli et al. (preprint)

Sharing is encouraged

FAQ - Gamma distribution

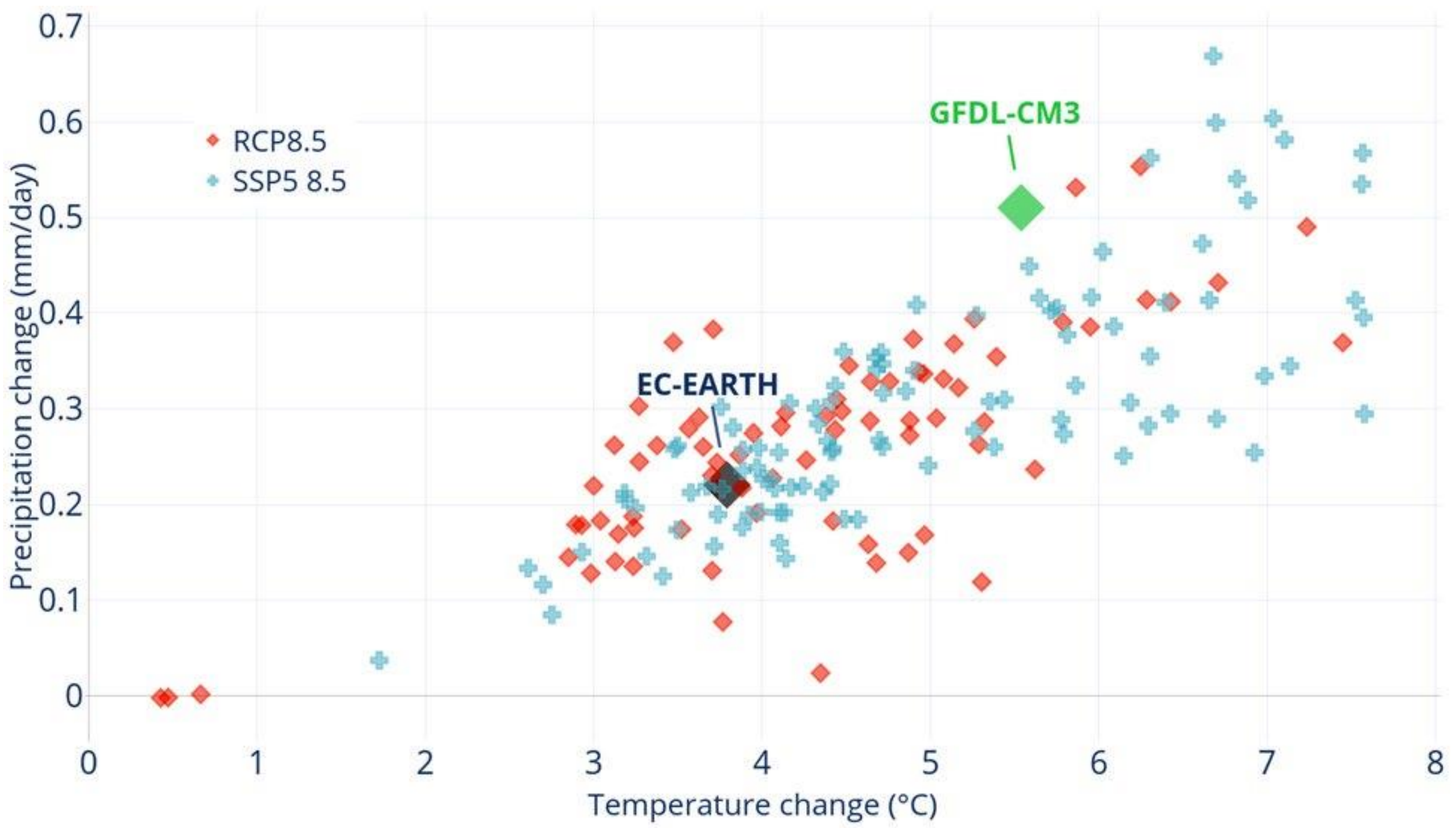
The two-parameter gamma distribution is recommended for general use when calculating SPI across all accumulation periods and regions within Europe, in agreement with previous studies.

The gamma distribution's general success is attributed to its relatively flexible shape parameter, which is clearly suited to the range of accumulated precipitation distributions in Europe.



From [Stagge et al. 2015]

FAQ - Forcing models



From [Lind et al. 2023]