The significance of environmental extremes and the need to find them in measured and model data

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CLIMACT

Environmental Extremes - 2023

REUTERS/David Swanson

USA (02.03.2023)– massive snowfall traps residents in mountain towns; communications towers covered in ice

REUTERS/Susannah Ireland

Britain (06.09.2023) – warm weather fuels algal overgrowth; deoxygenation risk to aquatic system

REUTERS/Claudia Morales

Bolivia (26.10.2023) – water level in Lake Titicaca approaching record lows

REUTERS/Tyrone Siu

China (08.09.2023) – heavy rains lead to landslide

REUTERS/Stergios Spiropoulos

Greece **(**07.09.2023**)** – flooding

REUTERS/Alexandros Avramidis

Greece (01.09.2023) – wildfire in Dadia national park

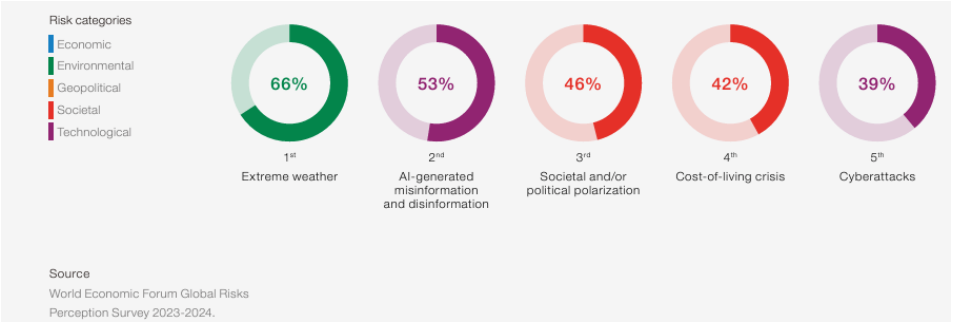
REUTERS/Adnan Abidi

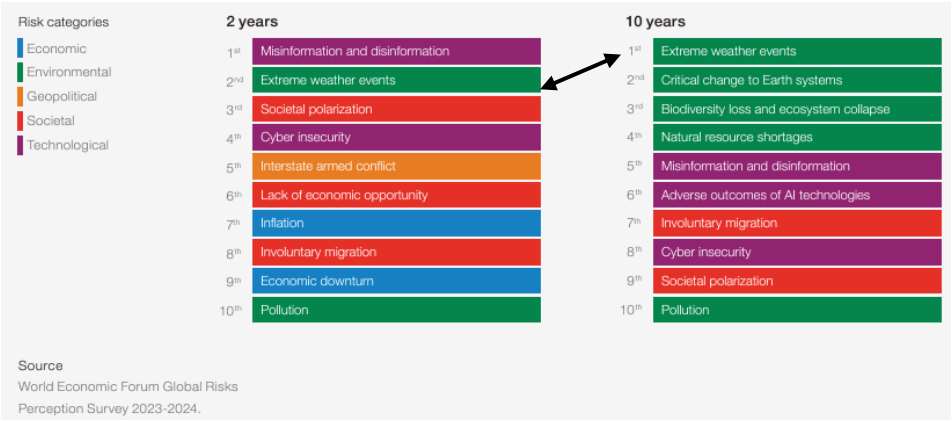
India (15.07.2023) – monsoon clouds over already overflowing Yamuna river

Image source: Reuters Photographers. The Wider Image, 2023 in photos: Extreme Climate. 05.12.2023. https://www.reuters.com/investigates/special-report/year-end-climate-2023/

Snow Extremes – Last Sunday

Rising Risks - Environmental Extremes





WEF Global Risk Report 2024: https://www.weforum.org/publications/global-risks-report-2024/data-on-global-risk-perceptions-2024/

Rising Risks - Environmental Extremes

WORLD METEOROLOGICAL ORGANIZATION
Weather Climate Water

Home / 2023 shatters climate records, with major impacts

2023 shatters climate records, with major impacts

NEWS

Key messages
- 2023 set to be warmest year on record
- Greenhouse gas levels continue to increase
- Record sea surface temperatures and sea level rise
- Record low Antarctic sea ice
- Extreme weather causes death and devastation

Reported on 30.11.2023: https://wmo.int/news/media-centre/2023-shatters-climate-records-major-impacts,

USA example: Increasing damages ($) from extreme events

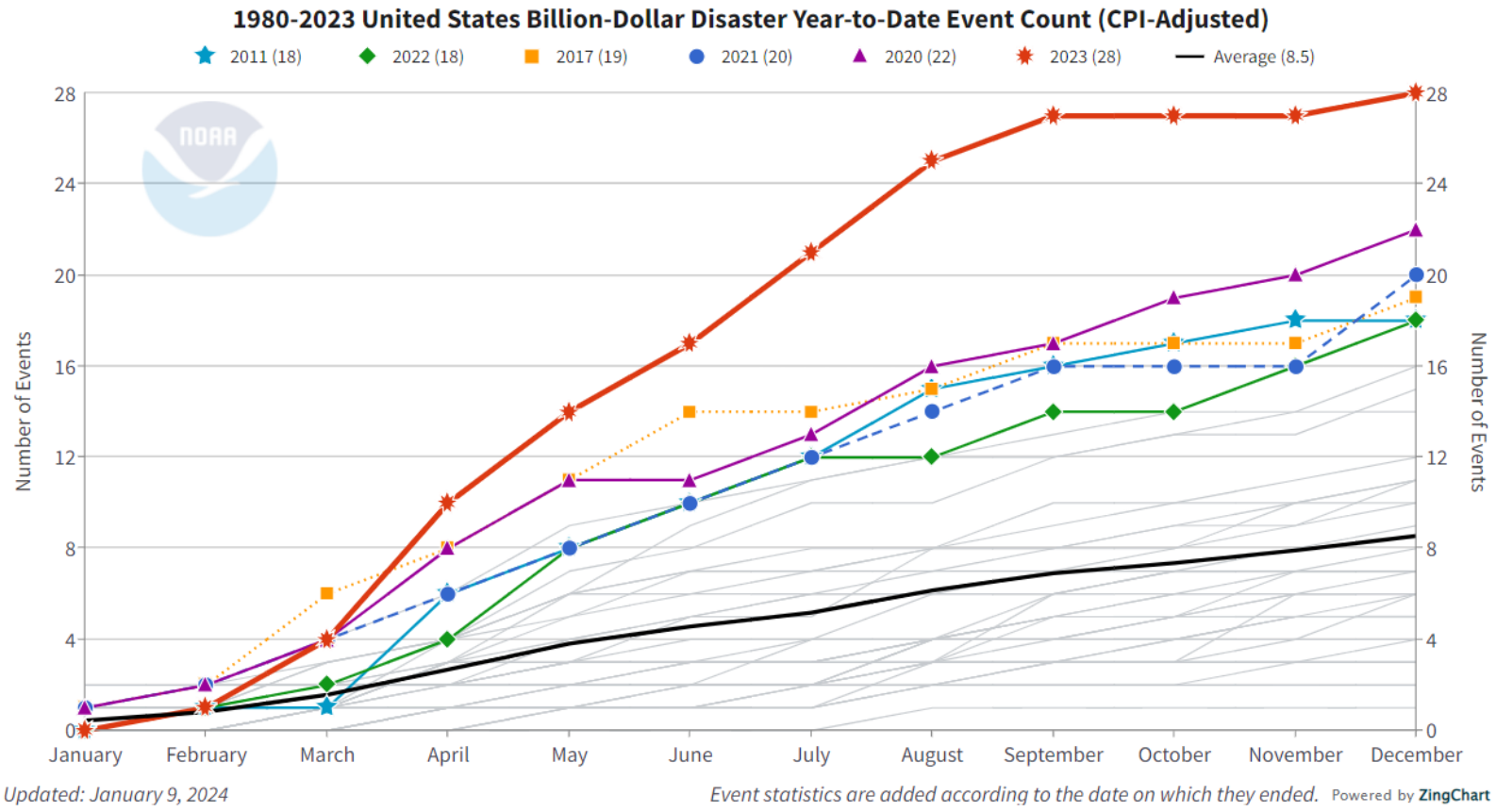
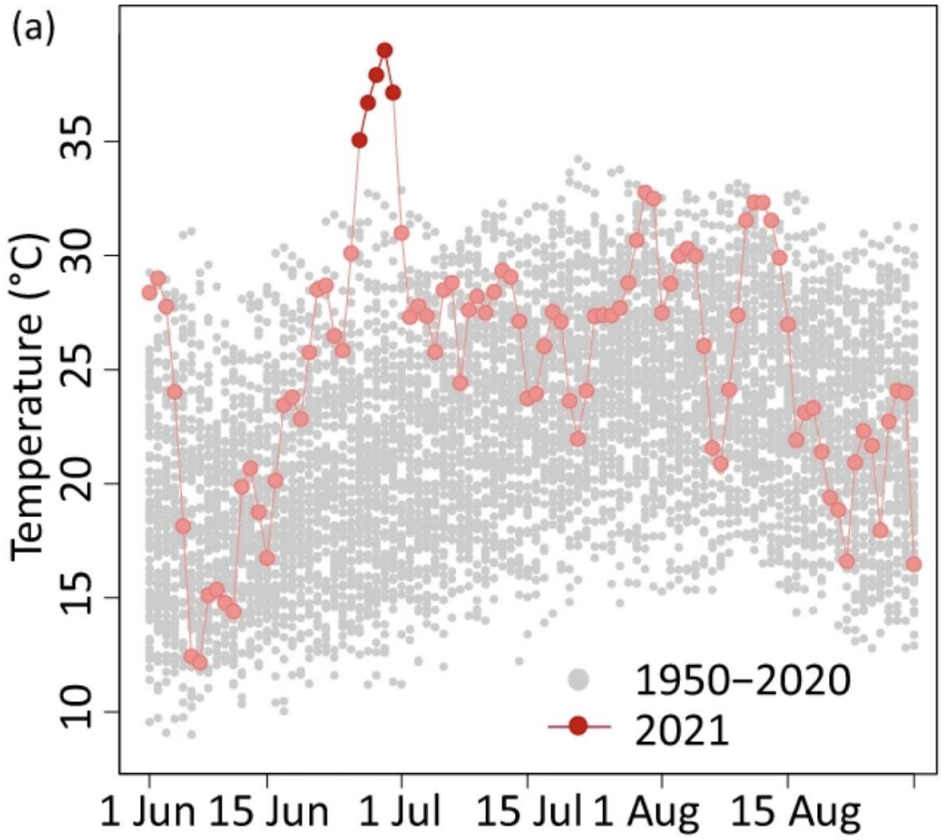
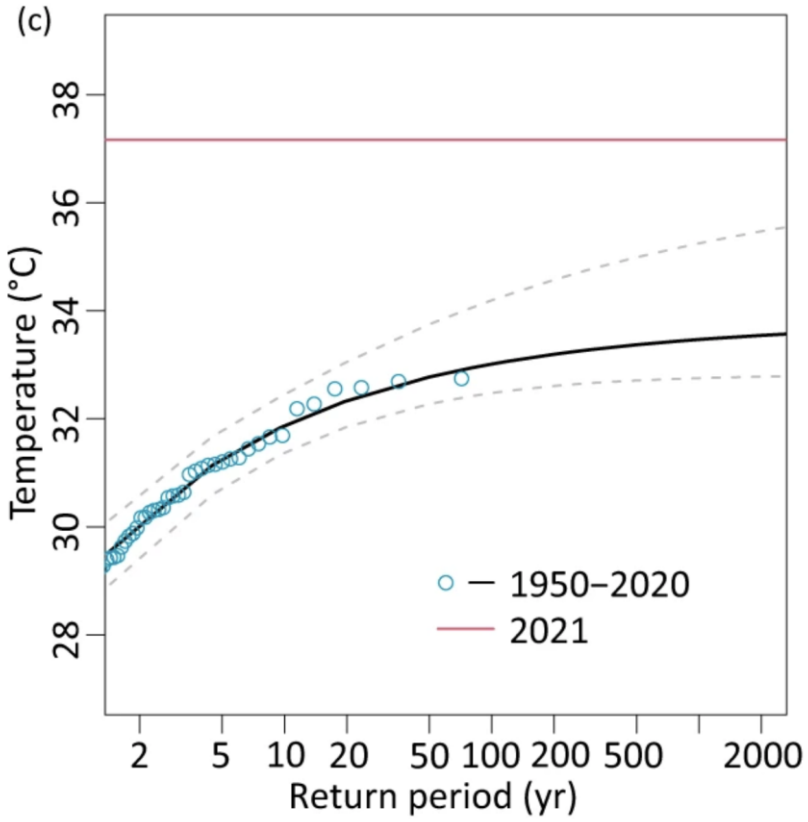


Figure from: https://www.climate.gov/news-features/blogs/beyond-data/2023-historic-year-us-billion-dollar-weather-and-climate-disasters
Full report: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2024). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73

Heat Wave PNW → Not reproduced by model ensembles

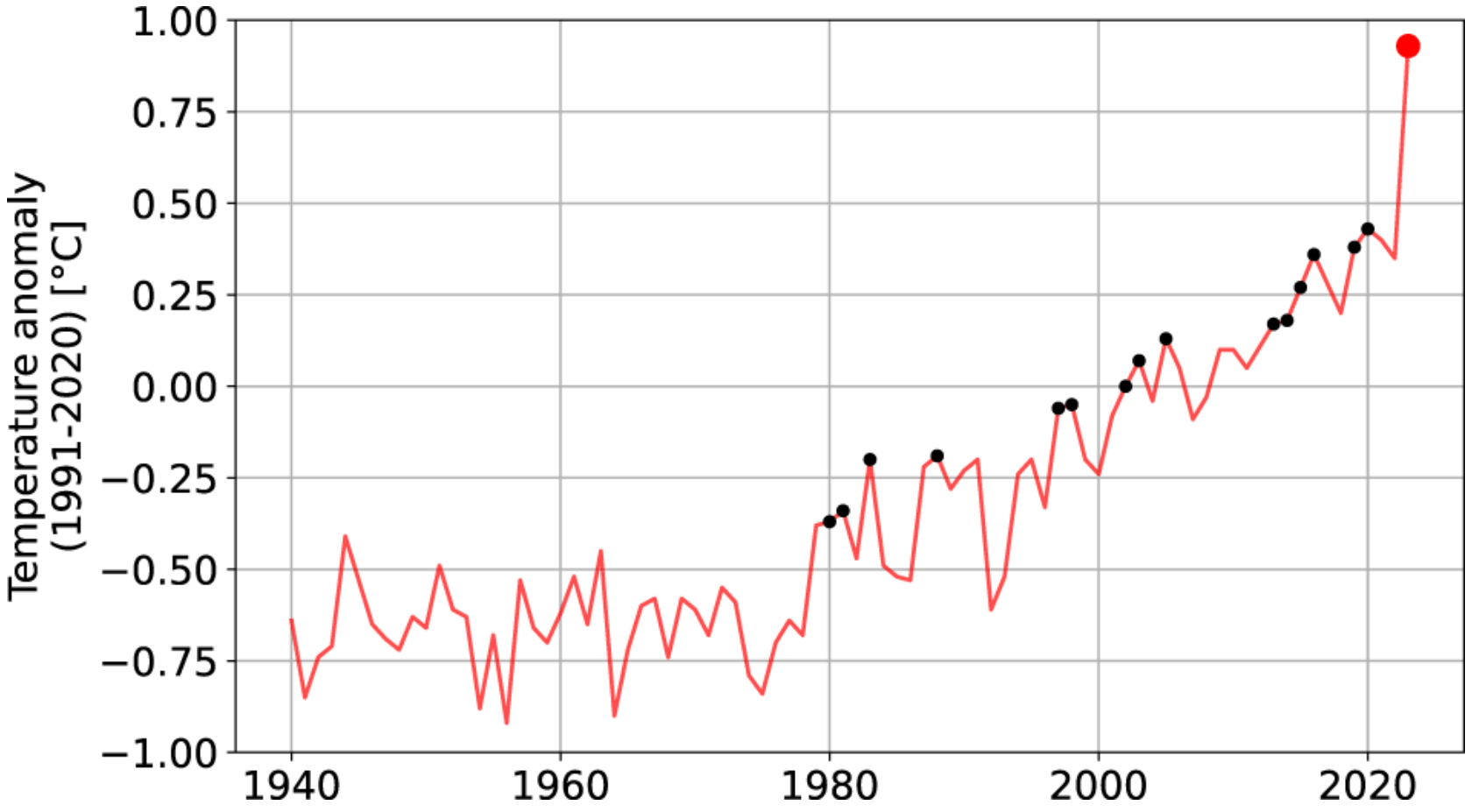




- **Current weather model ensembles would not reproduce this event**
- **It is within a reasonable return period as estimated by GEV**
- **Needs Ensemble Boosting**
- **Predictions with ensemble boosting are called storylines**

Fischer, E.M., Beyerle, U., Bloin-Wibe, L. *et al*. Storylines for unprecedented heatwaves based on ensemble boosting. *Nat Commun* **14**, 4643 (2023). https://doi.org/10.1038/s41467-023-40112-4.

What is an extreme? → September 2023 Global Temperature



- The record year 2023 is within the predicted range of climate model ensembles (annual mean temperature)
- But September 2023 is not!
- Here an ERA5 re-analysis is shown
- Need to find some external forcing that would explain it

Rantanen, M., Laaksonen, A. The jump in global temperatures in September 2023 is extremely unlikely due to internal climate variability alone. *npj Clim Atmos Sci* **7**, 34 (2024). https://doi.org/10.1038/s41612-024-00582-9.

Finding Extremes in Measured Data

Importance

- provides crucial information for planning (e.g., engineering and design of built environment, resources management, etc.)

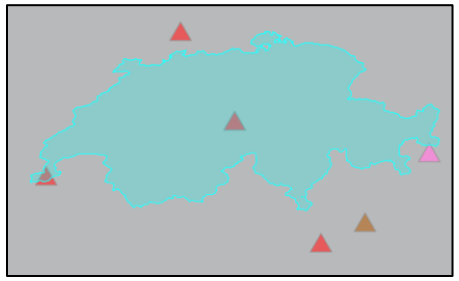
Challenges

- limited availability in measured extremes
- limitations to use in future (particularly far future) predictions

Finding Extremes in Measured Data

Exclusive reliance on historical data can have drawbacks if there we assume no changes (non-stationarity)

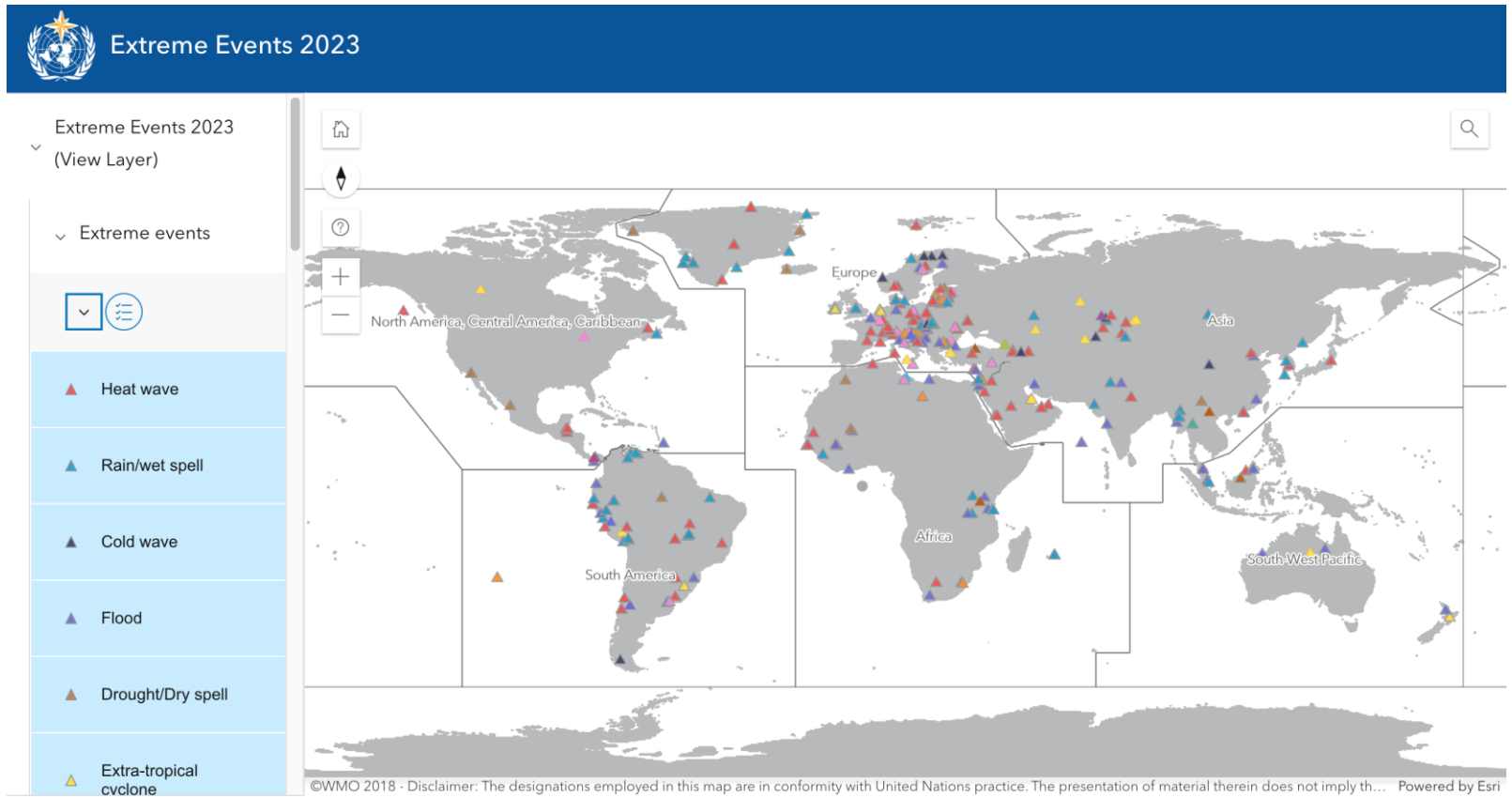
Reported Events in Switzerland for 2023



1) Heat wave – August; Neuchâtel; unusual: ’2nd intense 14-day heat period (32,3 °C mean of daily Tmax) in august since measurements started 1865.’
2) Heat wave – August, Geneva; unprecedented: ’ Most intense 5-day heat period (37,1 °C mean of daily Tmax) since measurements started 1865.’
3) Rain/wet spell – August; Eastern Switzerland; unprecedented : ‘At 5 measurement sites with measurement series more than 100 years it was the highest 3-day precip. total since the beginning of measurements.’
4) Thunderstorms/squall lines – July; La Chaux-de-Fonds; unprecedented : ‘maximum gust over 200 km/h.’

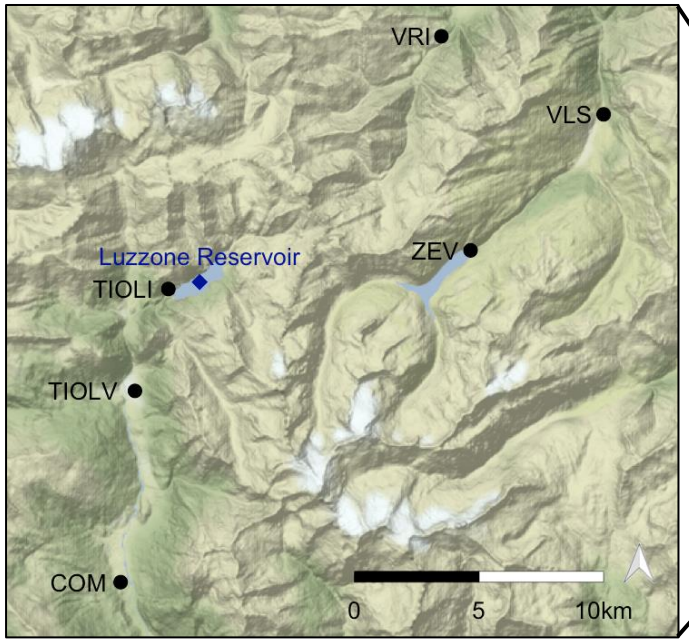
WMO, Provisional State of the Global Climate 2023

Source: https://storymaps.arcgis.com/stories/0f99d8e7611246f684f114d07cae9b56



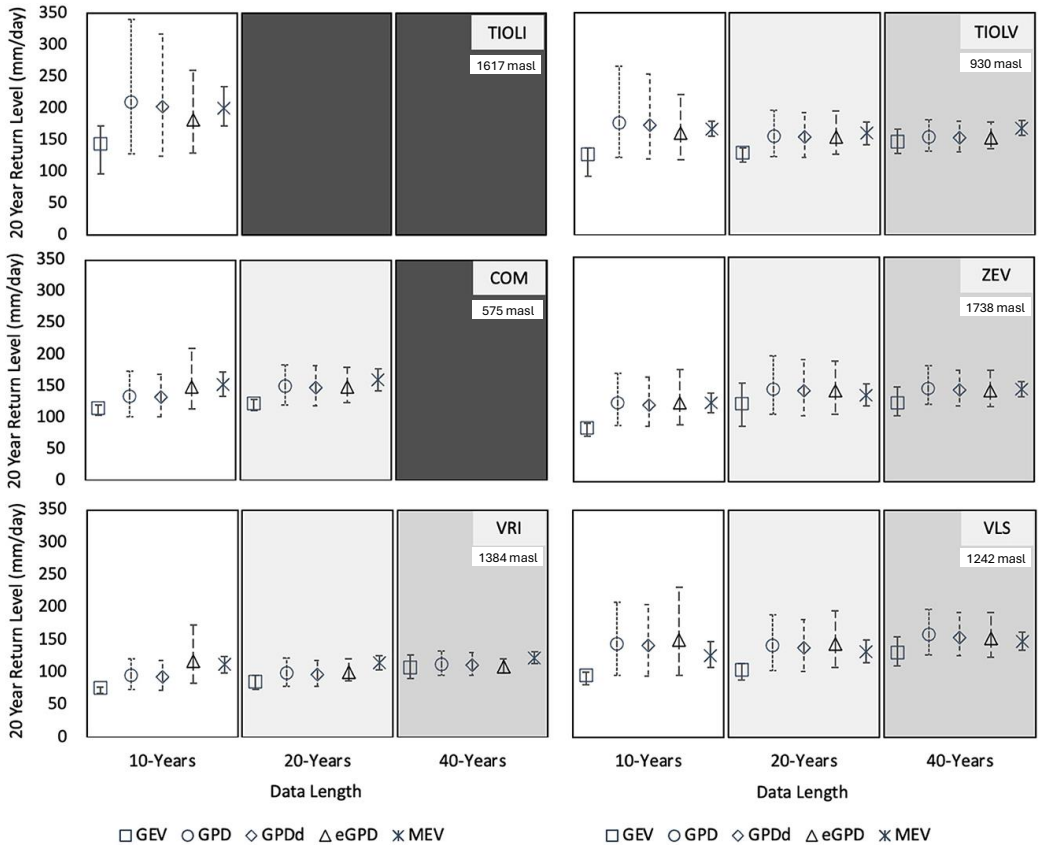
Finding Extremes in Measured Data

Point stations can give useful information, but spatial differences can exist



- Stations in south-eastern Alps within ~30 km of each other
- GEV most sensitive to limited dataset (not surprising)
- Results are location specific

Daily precipitation 20-year return levels at alpine stations using 10, 20, 40 years of data and various calculation approaches



Milojevic, T., et al (2023): https://doi.org/10.3389/frwa.2023.1141786

GEV, GPD, GPDd (declustered), eGPD, and MEV (Weibull distribution applied), based on 10-, 20-, 40-years of daily precipitation data; upper (97.5 percentile) and lower (2.5 percentile) confidence bands obtained from bootstrapping 1,000 runs.

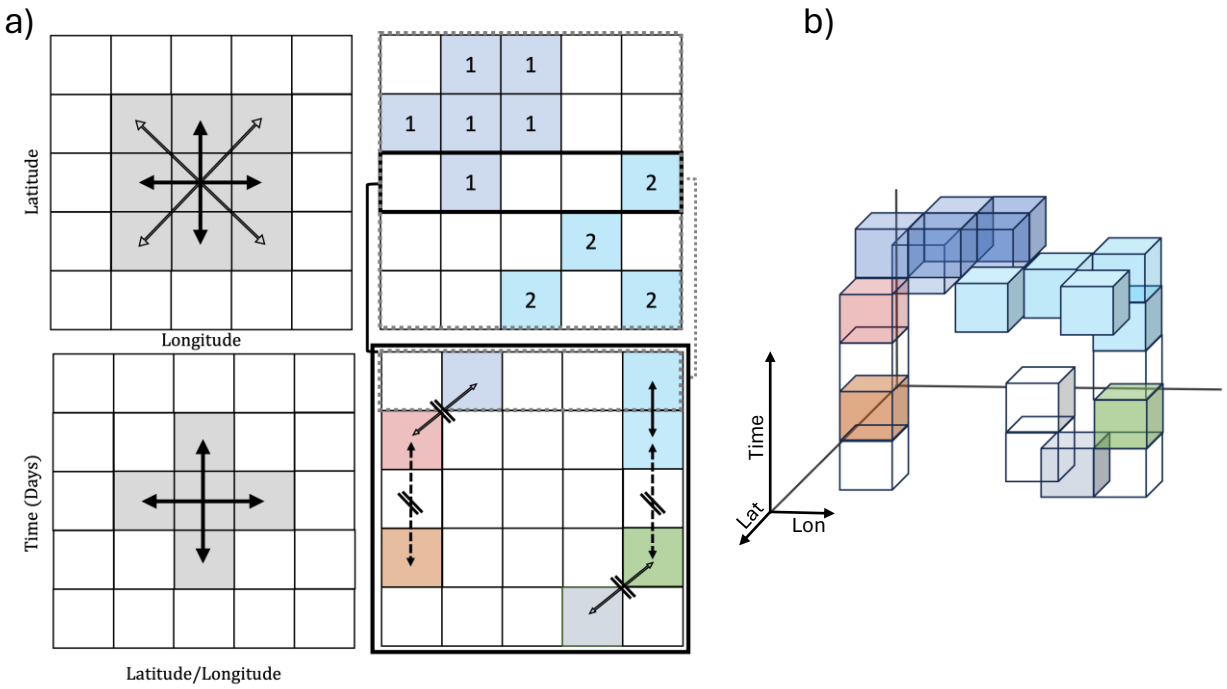
Finding Extremes in Model Data

Importance
- improved spatial coverage
- can be used in far future projections

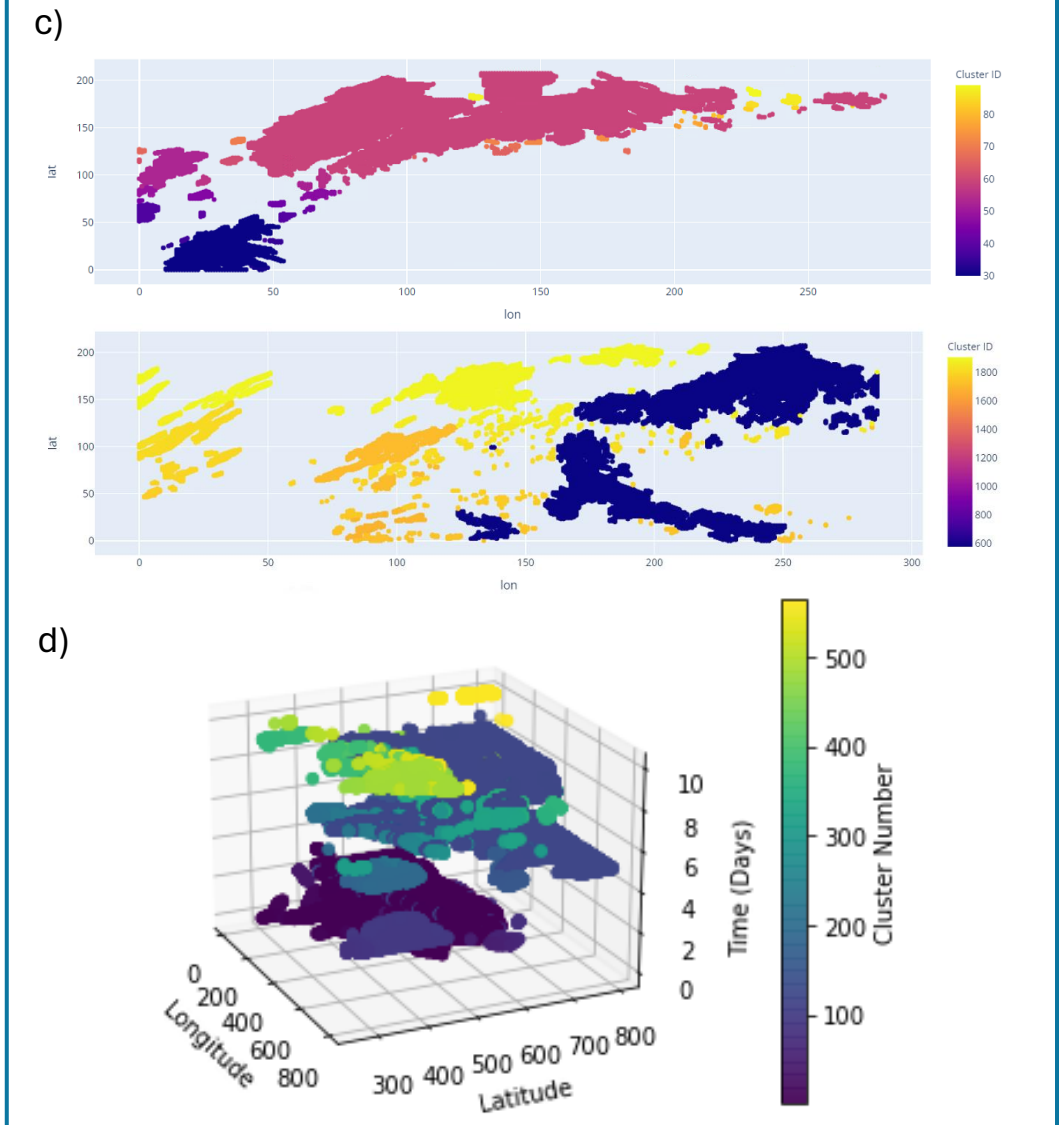
Challenges
- extremes are often poorly represented due to difficulty in avoiding bias in model simulations

Visualizing extremes (COSMO Climate Runs – end of century)

Grid cells of simulated data can be grouped into clusters based on contiguity (connected components) according to specified grouping rules to create “clusters”



Component grouping rules in a) 2D, planar views; b) 3D view



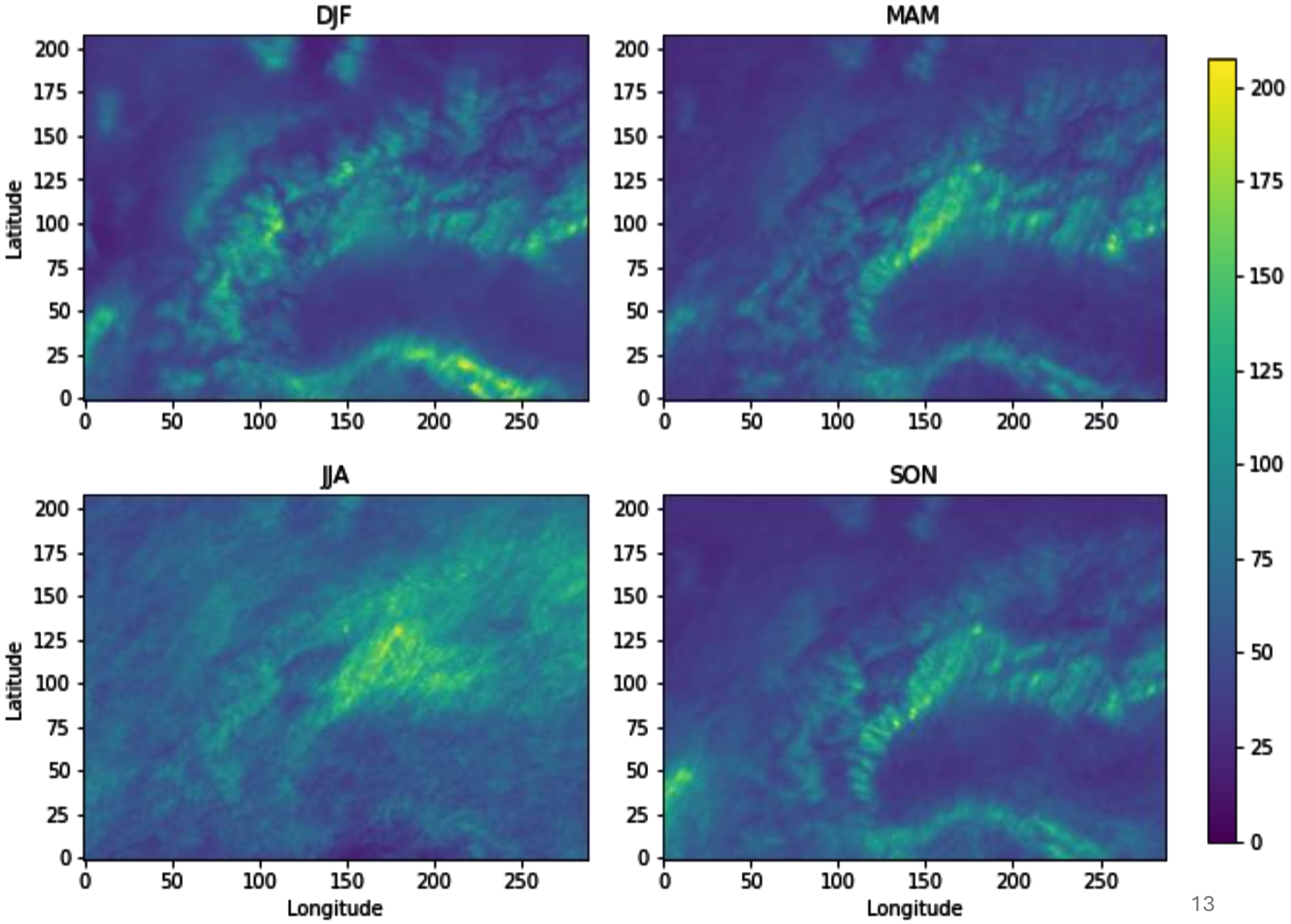
Sample cell clusters for daily precipitation in c) 2D single day time slices; d) 3D multi-day subset

Visualizing extremes

99th percentile in Present (1995-2005)

99th percentile in Far Future (2089-2099)

Model data at 2.2 km resolution, dynamically downscaled with the regional climate model COSMO for emission scenario RCP8.5

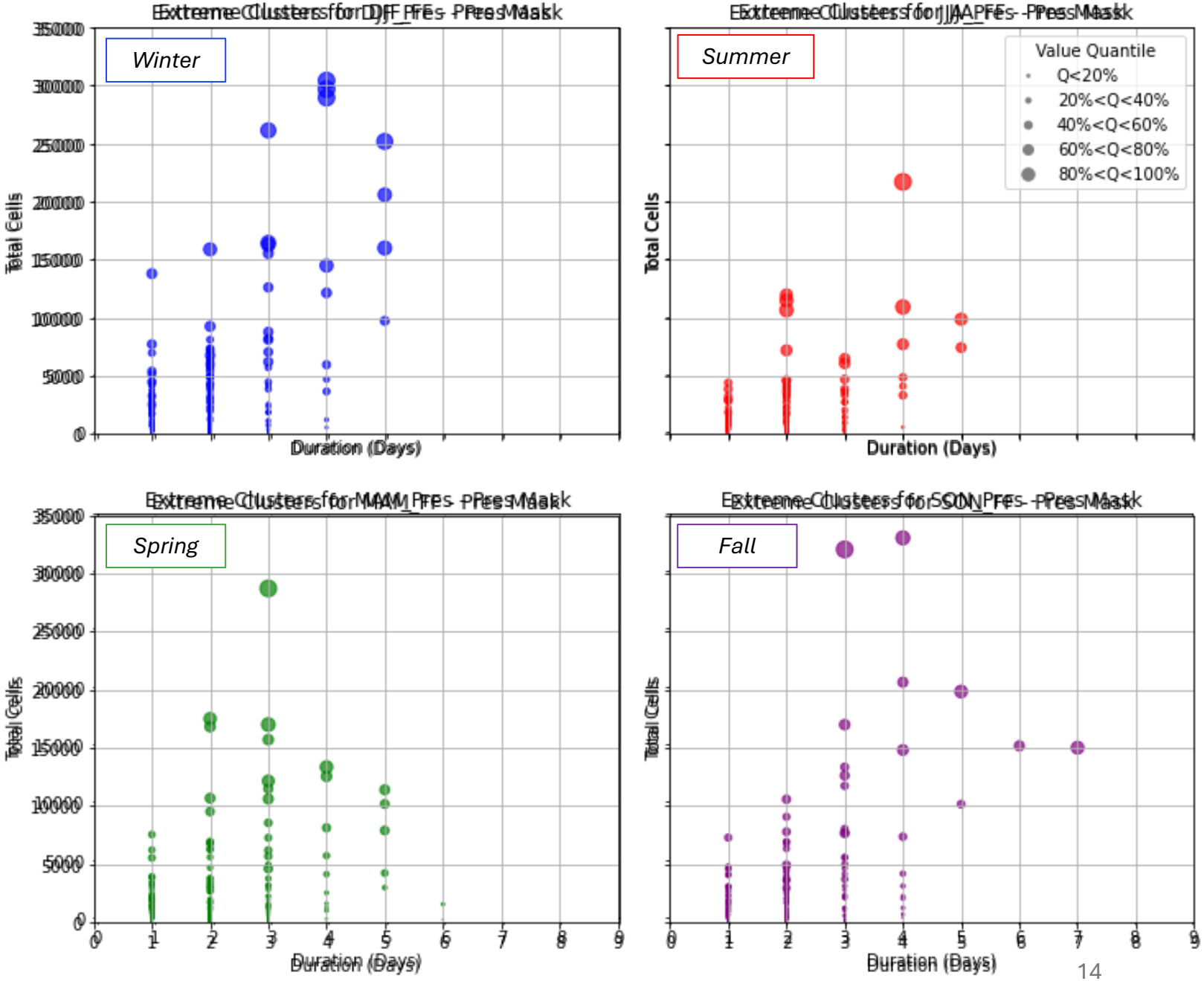


Spatio-temporal changes in extreme precipitation events

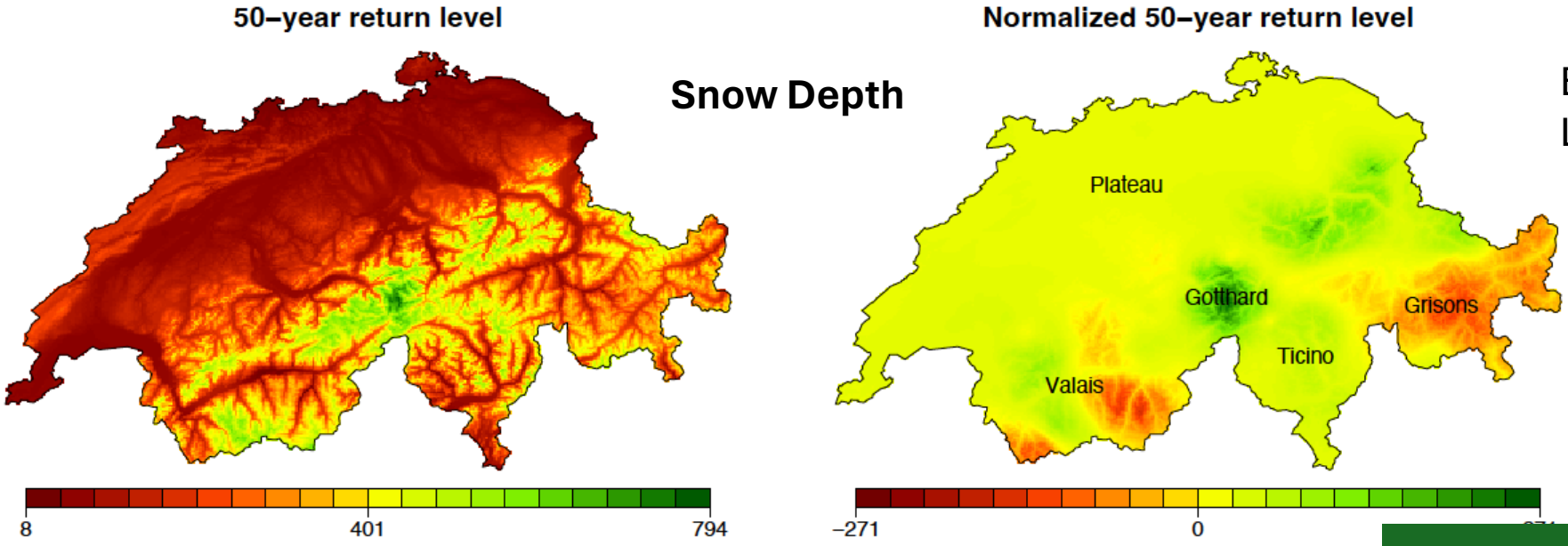
Present (1995-2005)

Future (2089-2099)

- More extreme events of larger magnitude in ‘far future’
- Frequency shift



The spatial aspect is very important

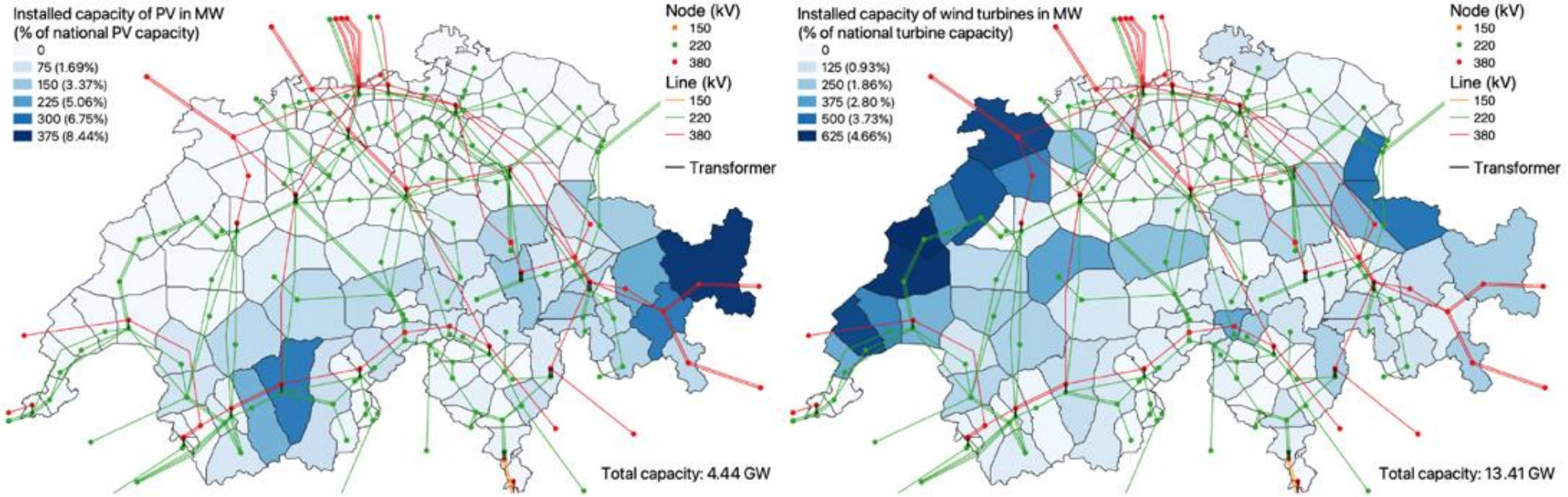


Blanchet and Lehning, 20010

Return levels for snow depth in Switzerland based on GEV smooth spatial modelling.

- **Why is this important?**
- **Natural hazards !**
- **Water supply !**
- **Biodiversity**

Charting the Way to a Fully Renewable Switzerland with PV and Wind



Dujardin et al., Env. Res. Lett., 2021

Optimizing Installation for Import Reduction;
Locations for Wind and PV:

- shows very good **complementarity** between wind and PV
- considers grid constraints
- favors the mountains especially for PV
- favors Jura for wind (but also Alps)

- **Hidden Extremes?**
- **Grid may fail on a dark low-wind winter day**
- **Import may be limited**
- **Need to consider many additional aspects such as biodiversity**

Concluding Statements

- Extreme events are often the trigger for increasing our knowledge
- Lives and the functioning of our societies depend on a correct estimation of such events
- It remains challenging to quantify past and predict future extreme events
- The aspects of trends and space require special attention
- Extreme events are sometimes not obvious not even when related to weather (Dunkelflaute)
- Our role as scientists is to anticipate events and allow for proper planning

Ice covers communication towers as massive amounts of snow trap residents of mountain towns in San Bernadino County, Crestline, California, U.S. March 2, 2023. REUTERS/David Swanson

Thank you

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