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Simulating Future Climate – Predictions to Projections

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NORCE

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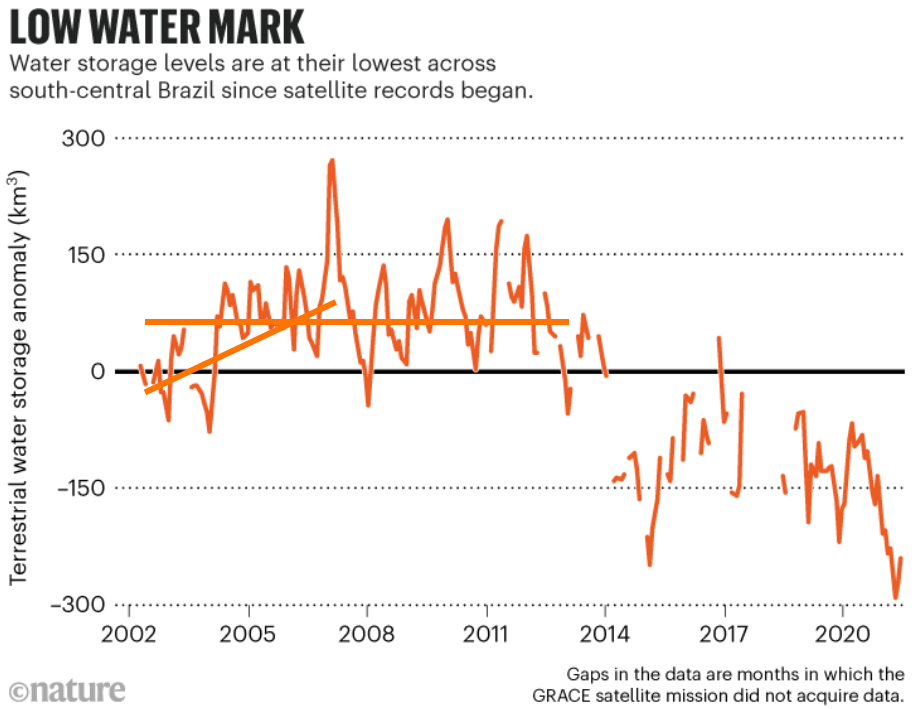
Outline (Part I)

1. Why Simulate Future Climate?
2. Climate Modeling
3. Global and Regional Modeling
4. Climate Information of the Past
5. Future: Prediction vs. Projection
6. Uncertainties
7. Example: Climate Prediction for Hydropower Planning

Is the past an indicator of the future?



Adapted from Getirana et al. (2021, Nature)
https://www.nature.com/articles/d41586-021-03625-w

Based on this, what might future conditions look like?

The past alone is not a useful indicator of the future. The main (but not only) reason is accelerating anthropogenic climate change.

Climate models can simulate and predict (some of) these changes.

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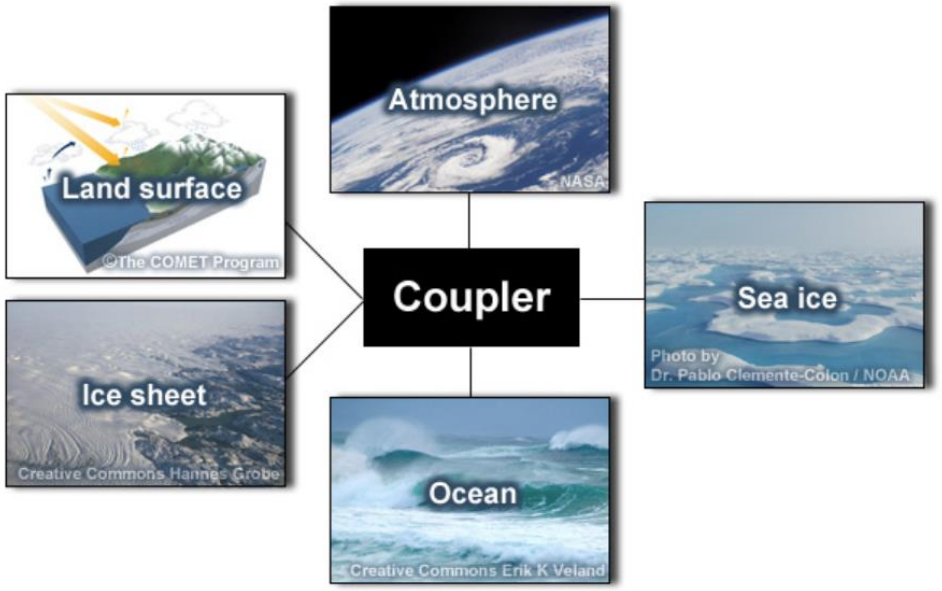
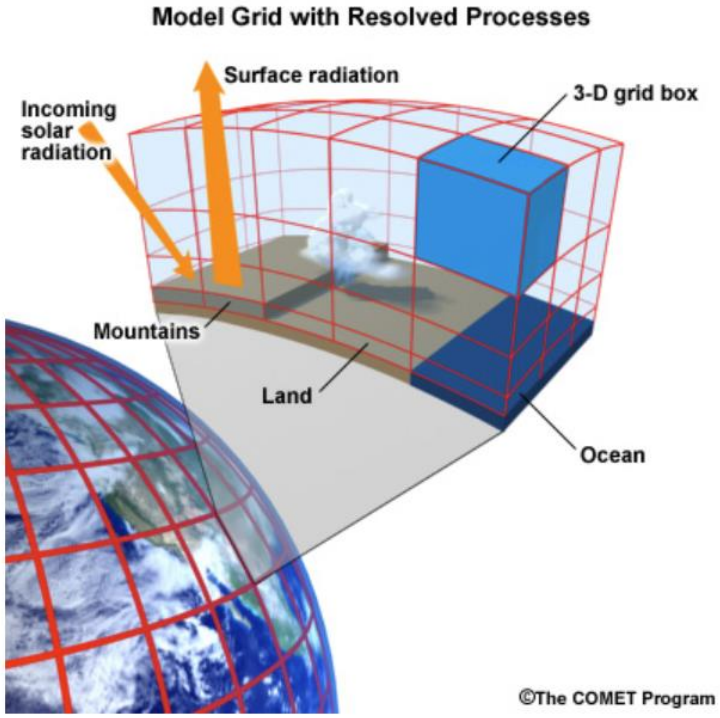
How do we simulate the climate system?



From COMET MetEd
https://www.meted.ucar.edu/nwp/climate_models/print.htm



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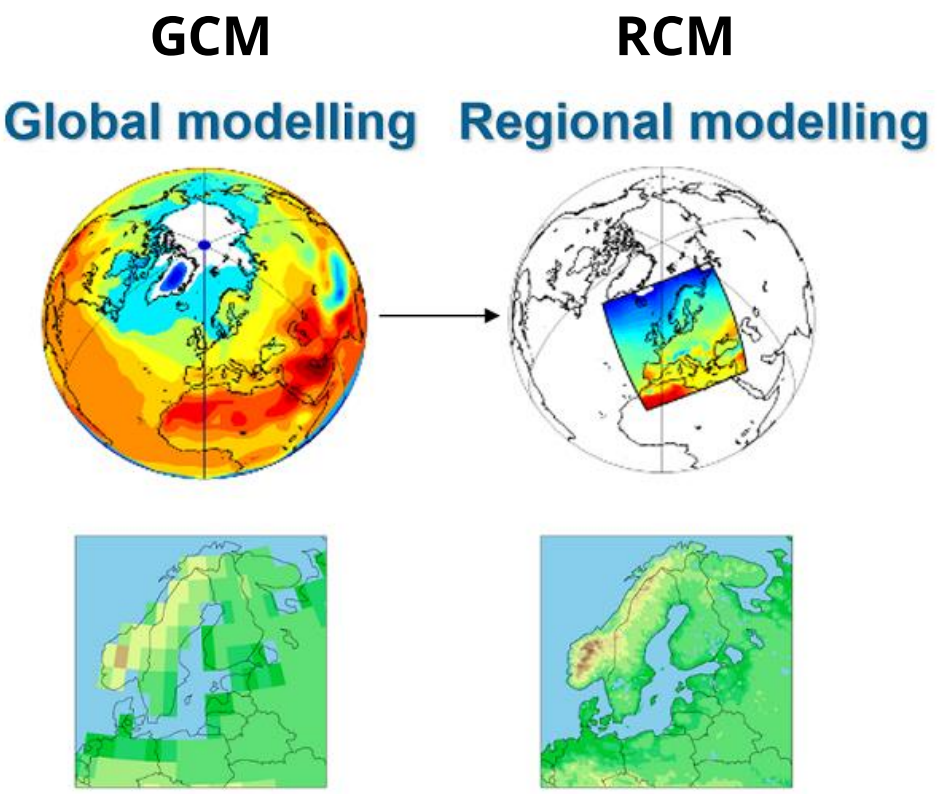
Global and Regional Climate Models

- Typical horizontal scales **30 – 100 km**
- Simulate the Climate General Circulation well
- Lack detail in e.g. orography, coastline, etc. and thus small-scale processes and extremes



https://climate.copernicus.eu/worldwide-regional-climate-projections-now-available-through-c3s

- Needs a global simulation to provide data at the boundaries
- RCMs “downscale” global simulations
- Typical horizontal scales **3 – 25 km**
- Most useful for regional application/ as input to impact models

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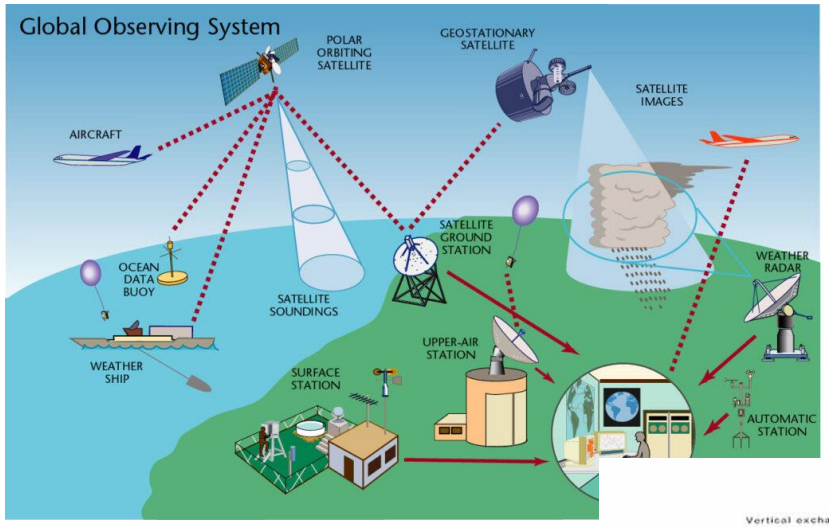
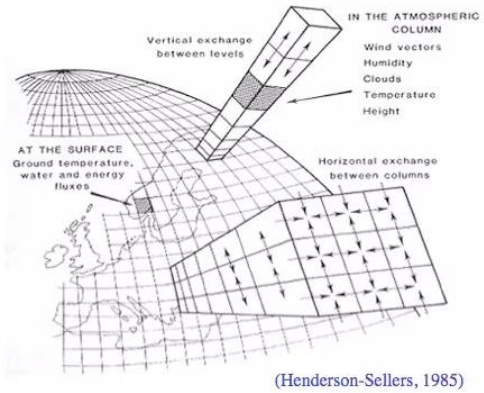
What information is available: past climate

- Direct observations
- Remote sensing (since 1979)
- Reanalysis
  - Observations combined using a climate model
  - Best estimate of true climate state in the (gridded) model world
  - **Global** ERA5 (31km), ERA6 (14 km)
  - **Regional** NORA3 (3km), CERRA (5.5km), …



Global Observing System, WMO



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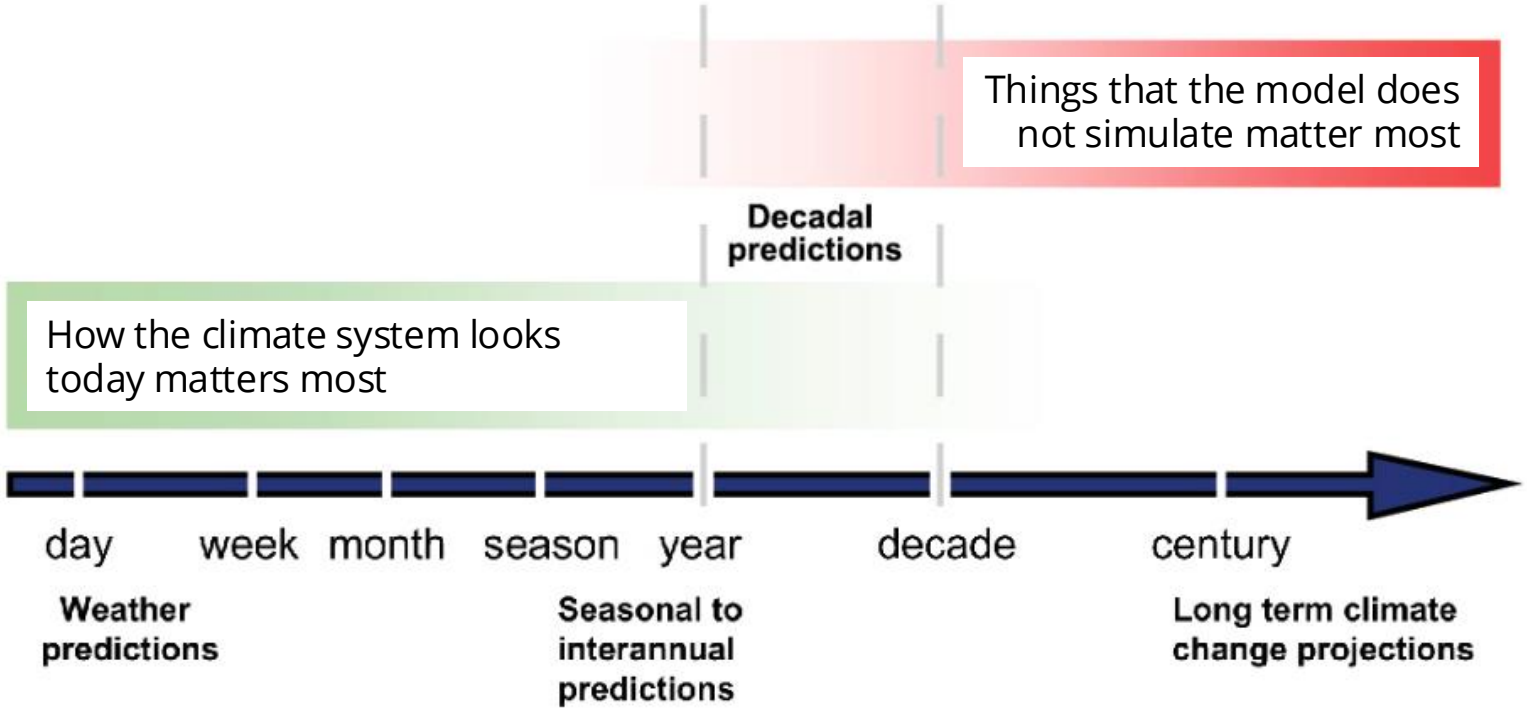
Future climate: predictions or projections?

Climate Variability:
- Season
- Warm/cold ocean
- Dry/wet soils
- …

Examples:
- Yr 21-day forecast
- C3S seasonal predictions
- DCPP decadal predictions



IPCC AR5 WG1 Chpt 11, Box 11.1

Human decisions:
- Emissions
- Land use
- …

Examples:
- CMIP5/6 global
- CORDEX regional

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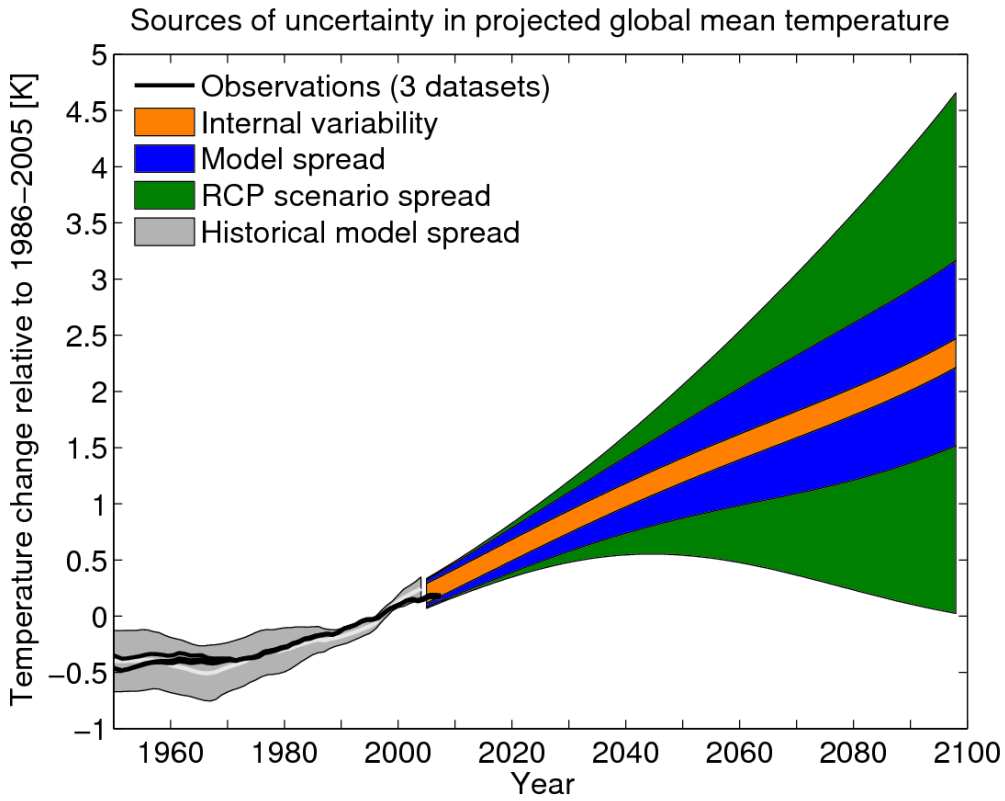
Uncertainties & how we quantify them

- Three sources (known unknowns):
  1) Now-state uncertainty
  2) Scenario uncertainty
  3) Model error
- Ensemble:
  - Use different now-states, different scenarios and different models

  → produce multiple outcomes of future climate by runing multiple simulations from (equally likely but very different)



Hawkins (2013): https://www.climate-lab-book.ac.uk/2013/sources-of-uncertainty/

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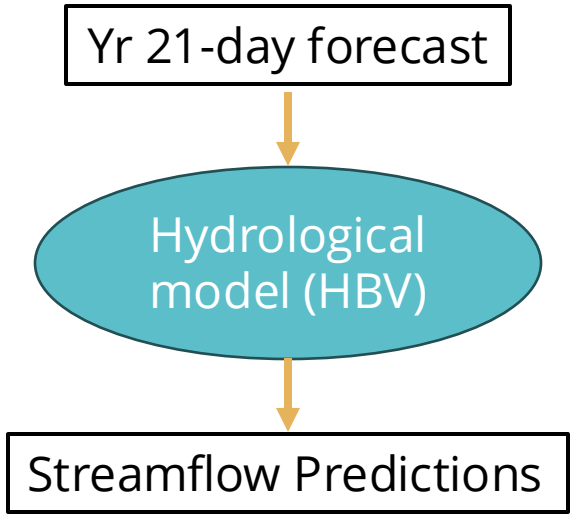
Climate prediction for hydropower planning



Planning tool for small-scale hydropower: probabilistic predictions of river discharge at inidividual plants

Norsk Regnesentral
NORWEGIAN COMPUTING CENTER
småkraft

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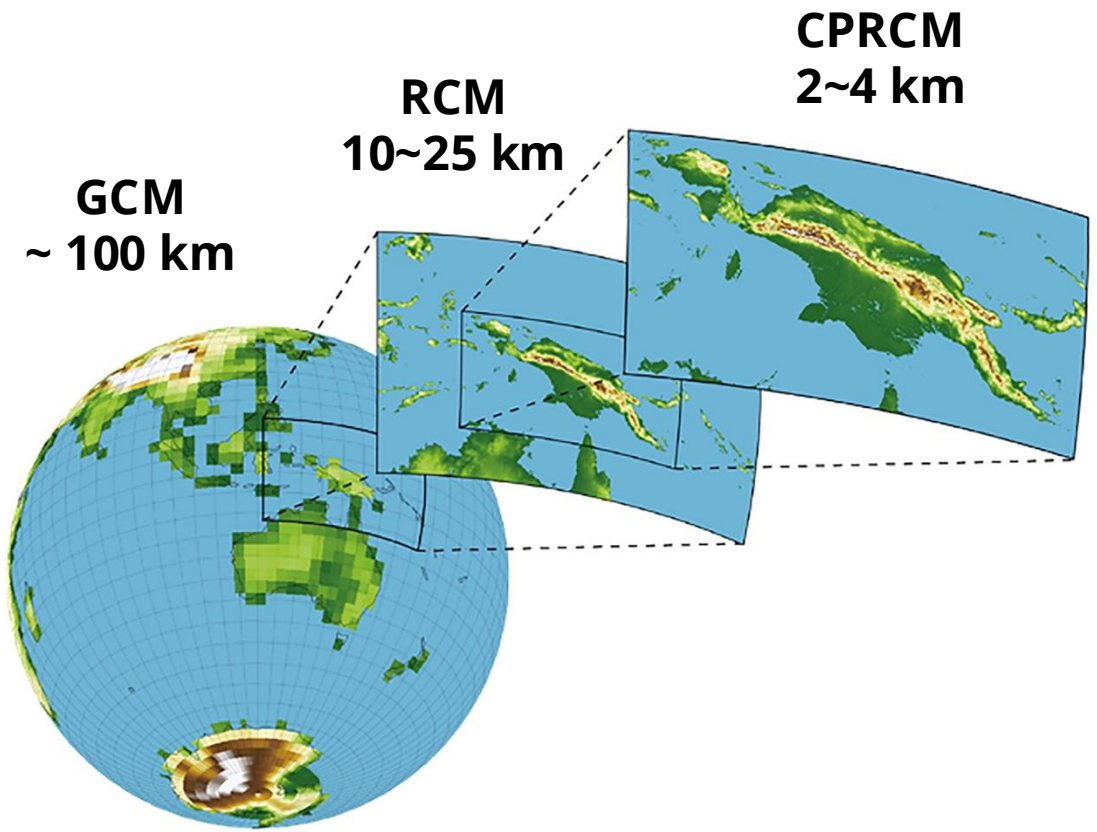
Wrap-up Part I

- Accelerating climate change means the past becomes less and less useful as an indicator of the future
  - Seasonal cycle changes, extremes occur more frequently, …
- Climate models can give a better idea of what to expect
- Regional simulations are generally better suited for impact studies
- Next 10 years: use predictions, beyond that: use projections
- Uncertainties need to be taken into account

Outline (Part 2)

1. Traditional Regional Climate Modeling (RCM) vs. Convection-Permitting Regional Climate Modeling (CPRCM)
2. Added value of CPRCM: at regional and local scales
3. Examples: Projection and Uncertainty
4. Key Takeaways

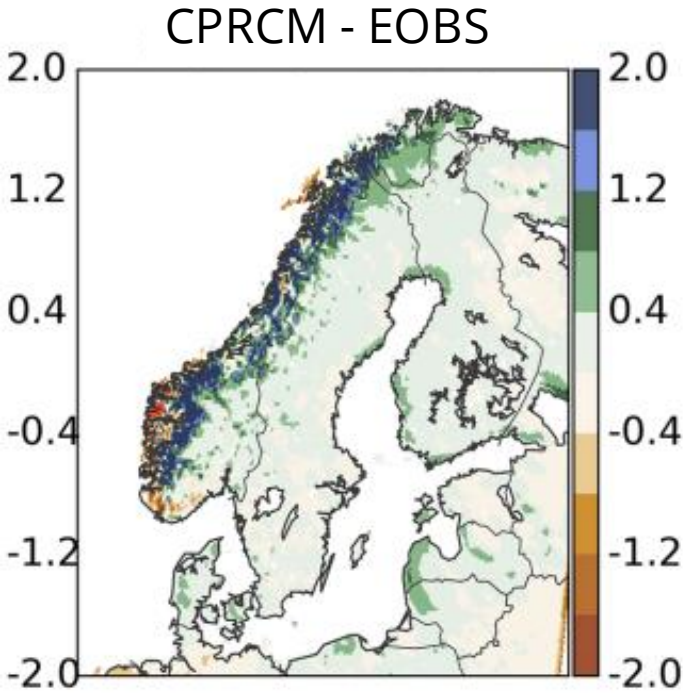
Traditional RCM vs. CPRCM

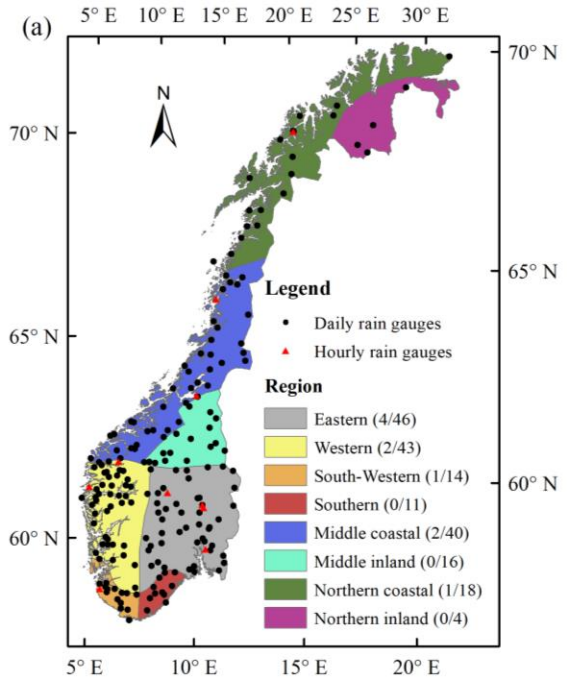


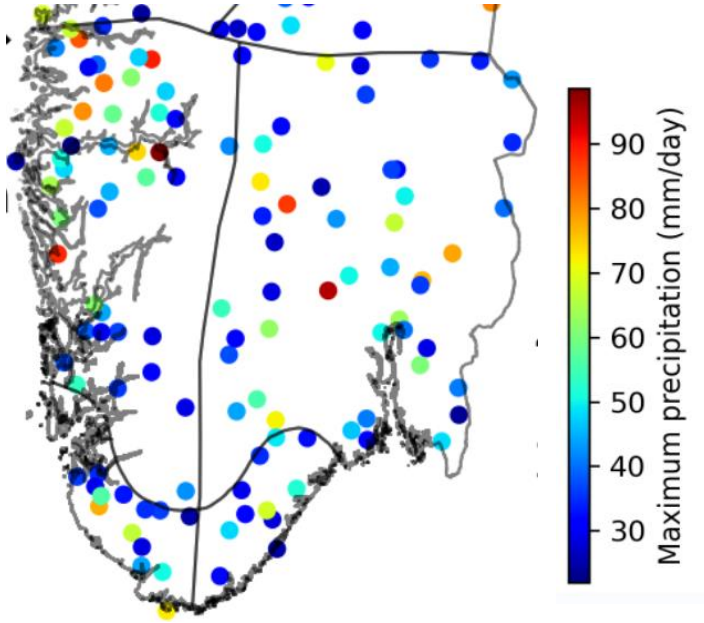
Source: Lucas-Picher, et al. (2021), WIREs Climate Change, Volume: 12, Issue: 6, DOI: (10.1002/wcc.731)

- Telescopic nesting Strategy for CPRCM with multi-nested domains, allowing to zoom over a region up to a 2~4 km grid spacing.
- RCM uses parameterizations, while CPRCM explicitly simulates convective processes.

RCM vs. CPRCM







Continent and country scale

Regional scale

Local scale

Lind et al. (2020,2022)
Dyrrdal et al. (2023, 2023)
Médus et al. (2022)

Xie, K., Li, L., et al., HESS, 2025 (Accepted)

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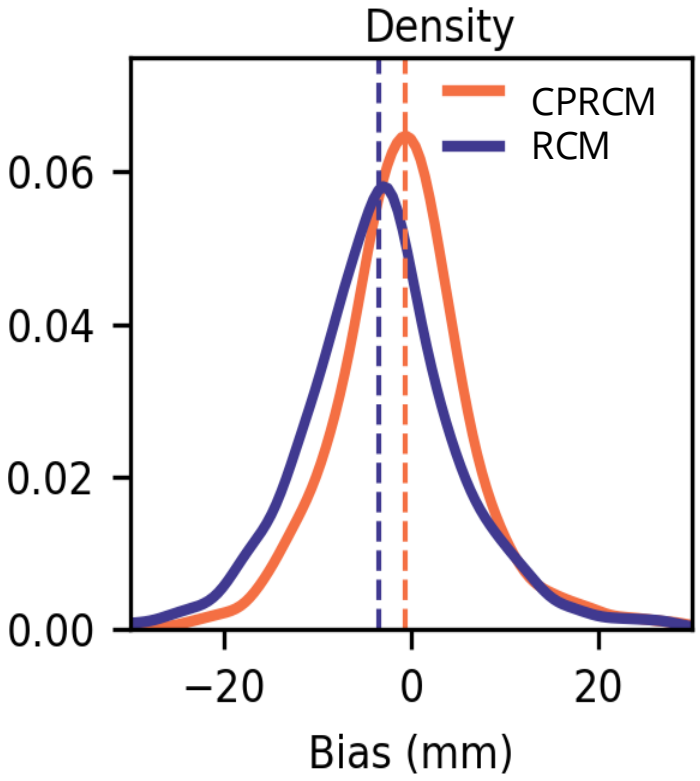
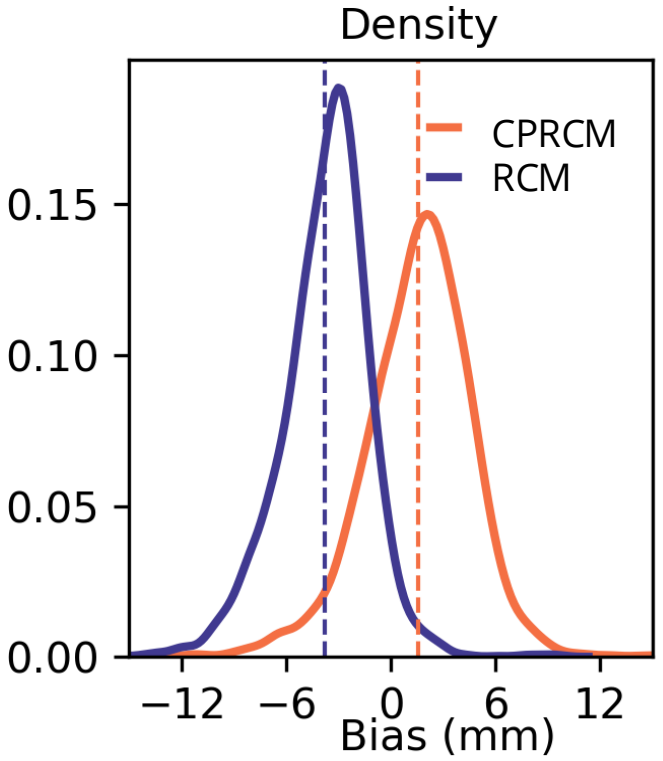
Added value of CPRCM in Norway

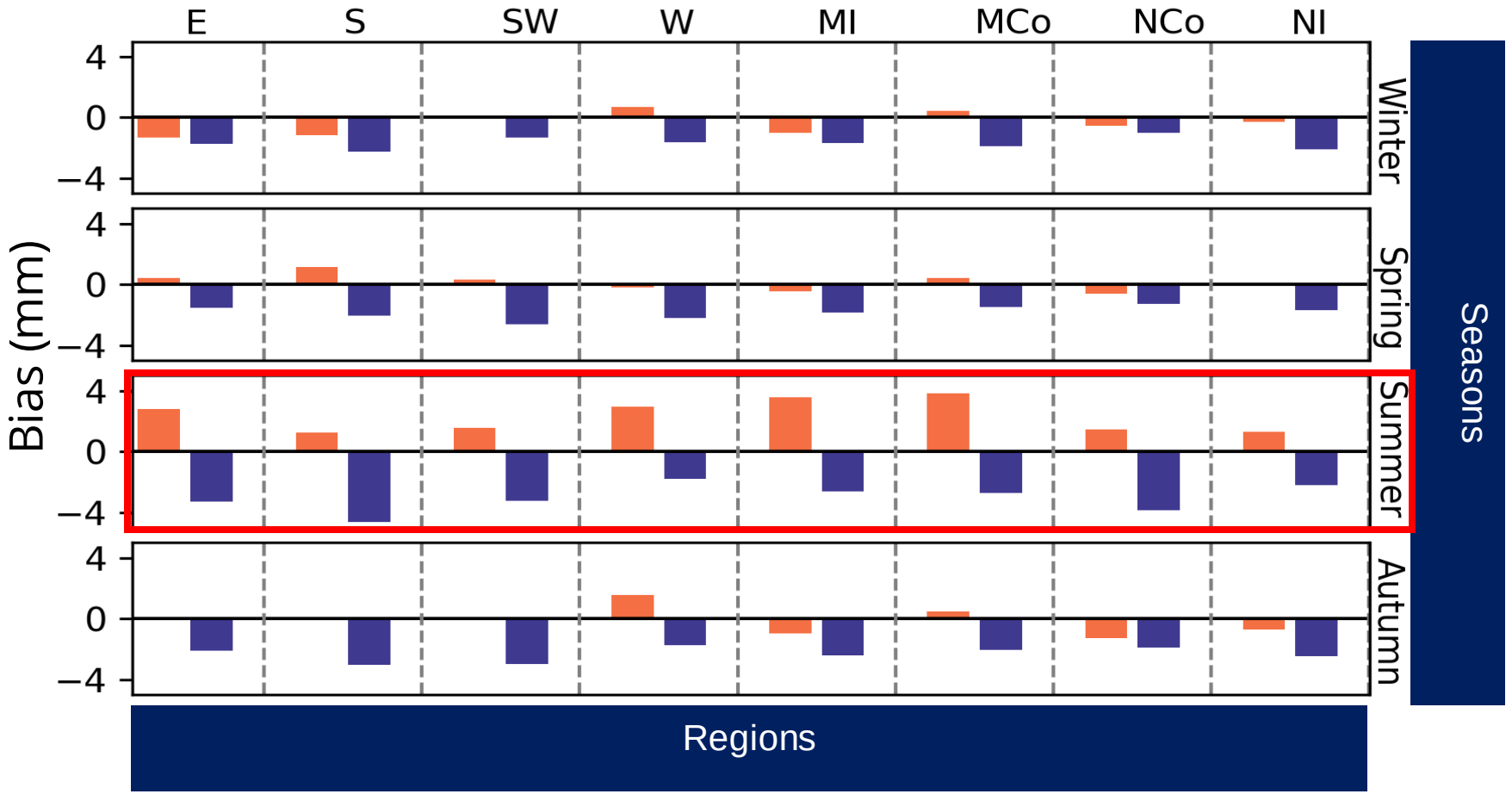


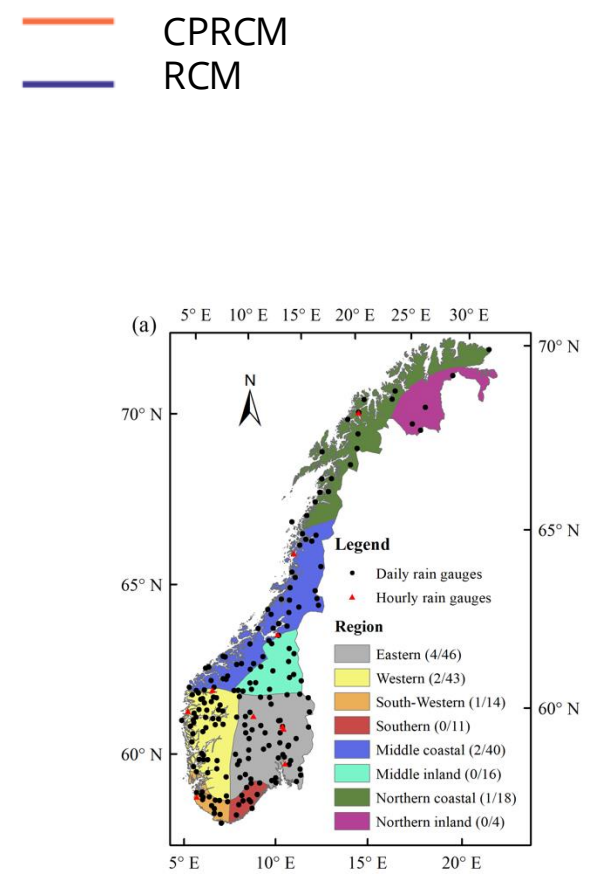
Maximum 1-day precipitation



Maximum 1-hour precipitation

Added value of CPRCM at regional scale





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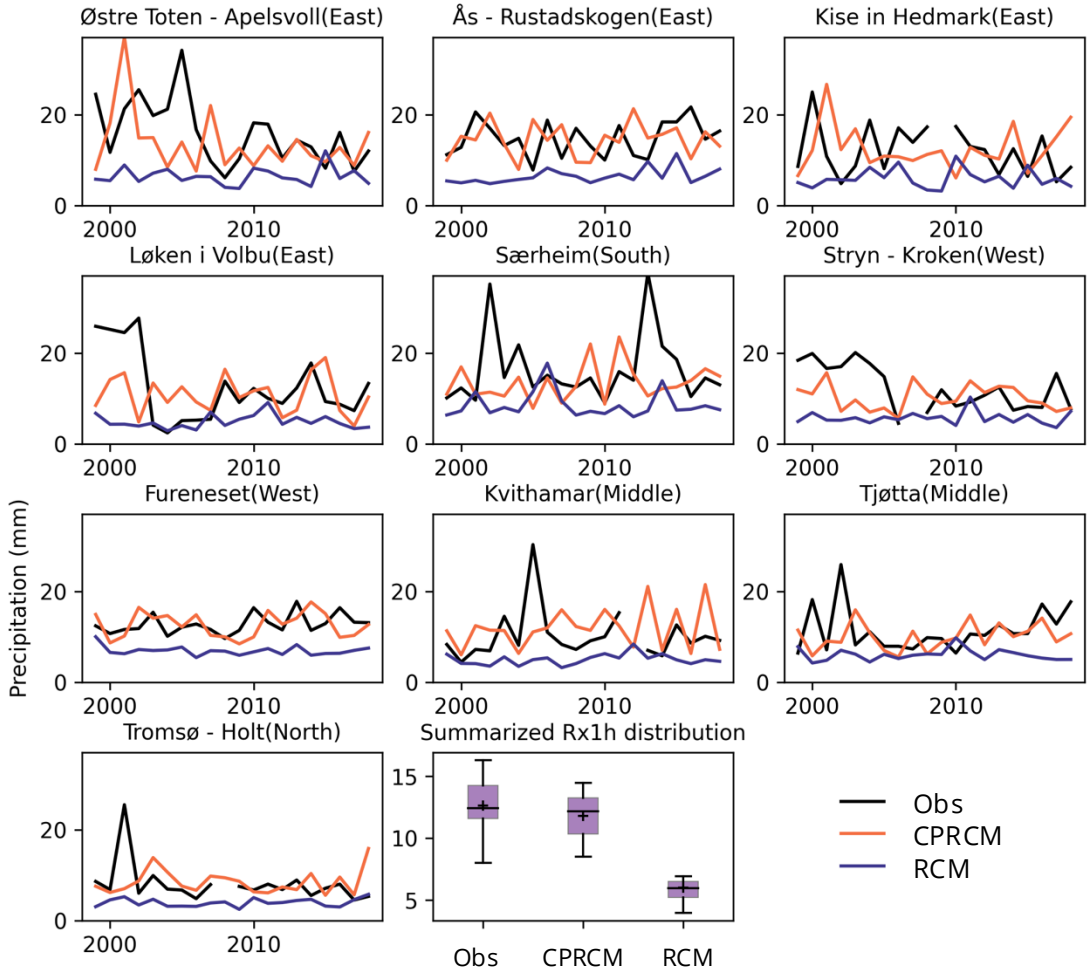
Added value at local scale



- Time evolution of annual maximum 1-hour precipitation (Rx1h) during 1999-2018 for 10 rain gauges.
- CPRCM better captures the magnitude of Rx1h than RCM.
- RCM significantly underestimates hourly extreme precipitation at stations.

Comprehensive analysis performed for Norway by Xie, K., Li, L., et al., HESS, 2025 (Accepted)

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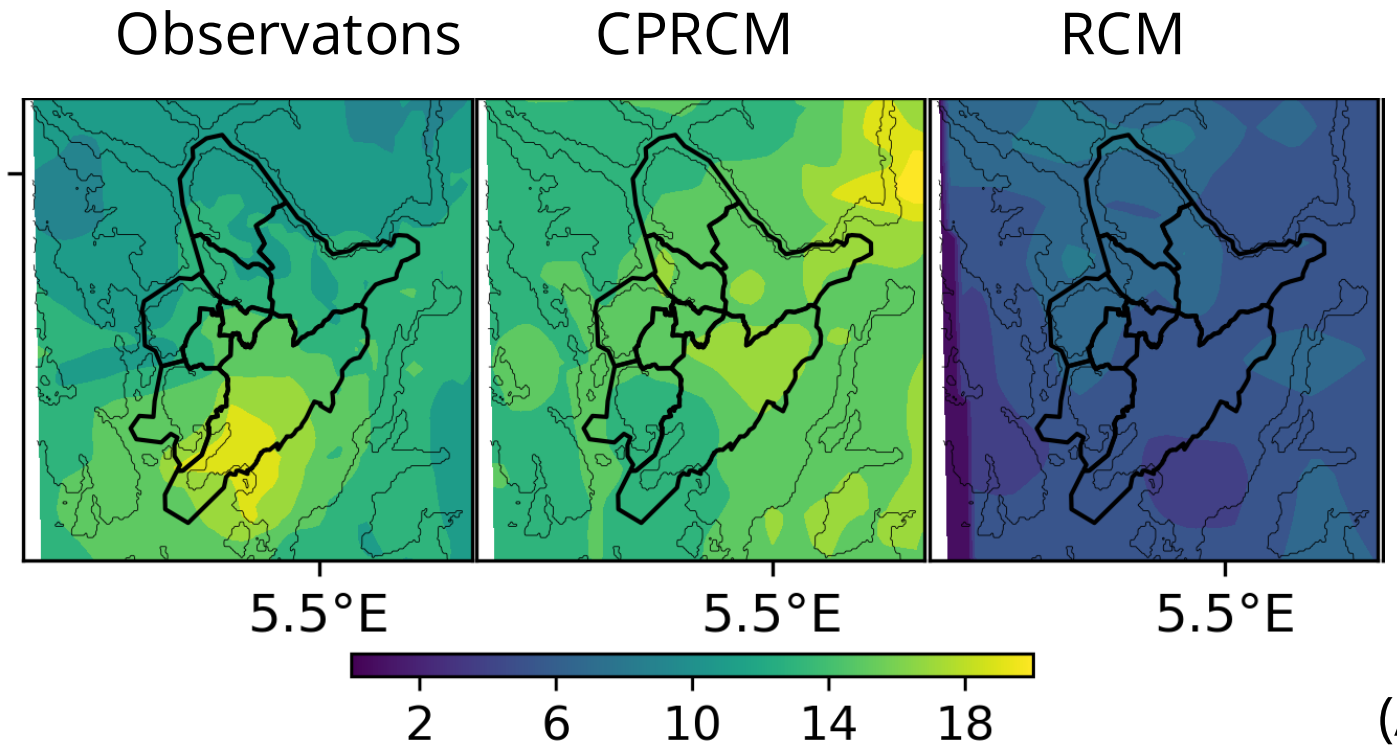
Example: resolution matters for local extremes



(Averaged from 2010-2018)

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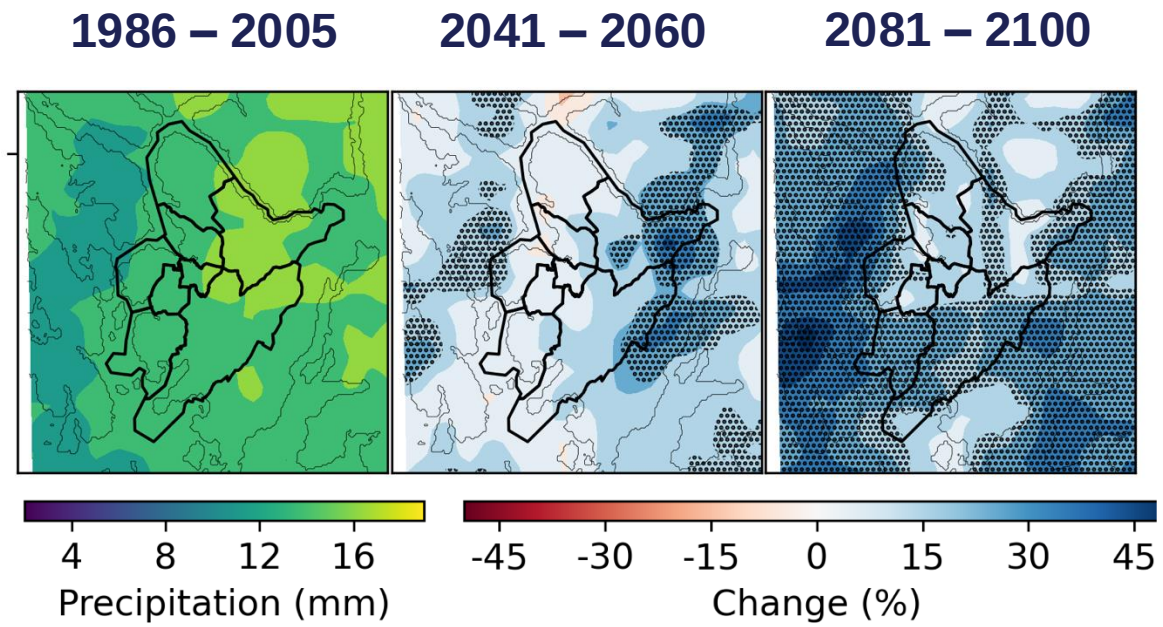
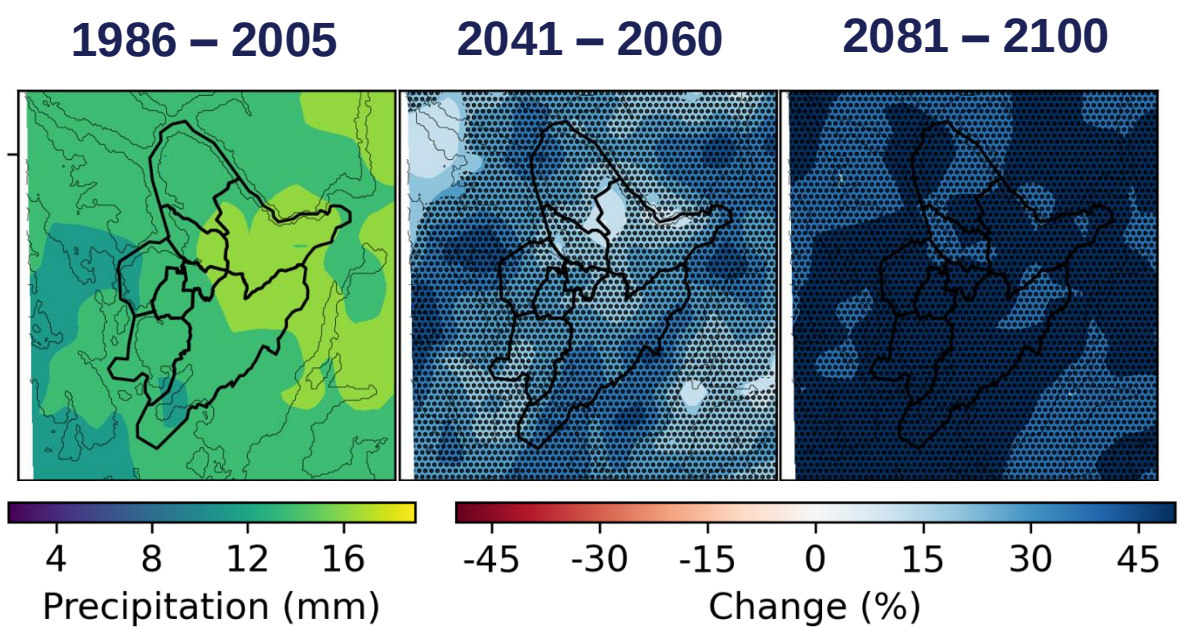
Example: Future projection

Future change of annual maximum 1-hour precipitation



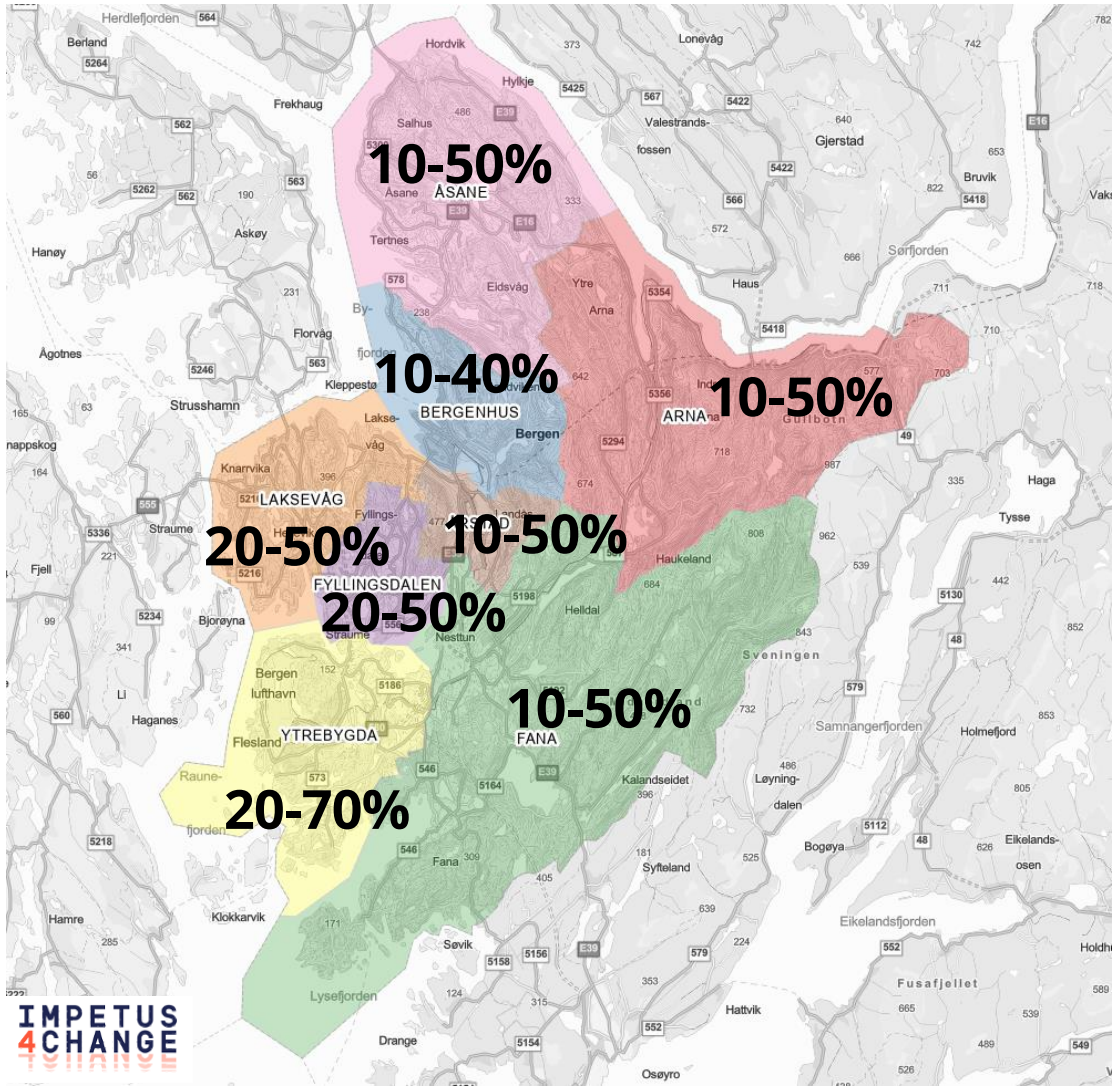
‘dry’ model



‘wet’ model

A detailed assessment of future projection in Norway by Xie, K., Li, L., et al., JGR, 2025 (under review)

Uncertainty: can it capture local differences?



- Future summer maximum 1-hour precipitation increases by 2081-2100

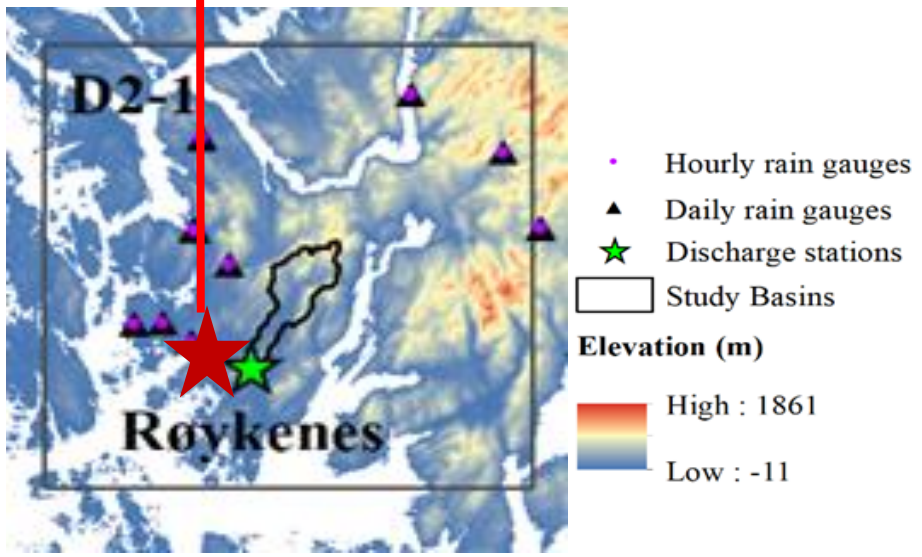
model uncertainty
>
local differences

Flood risk projection and uncertainty (Røykenes basin)

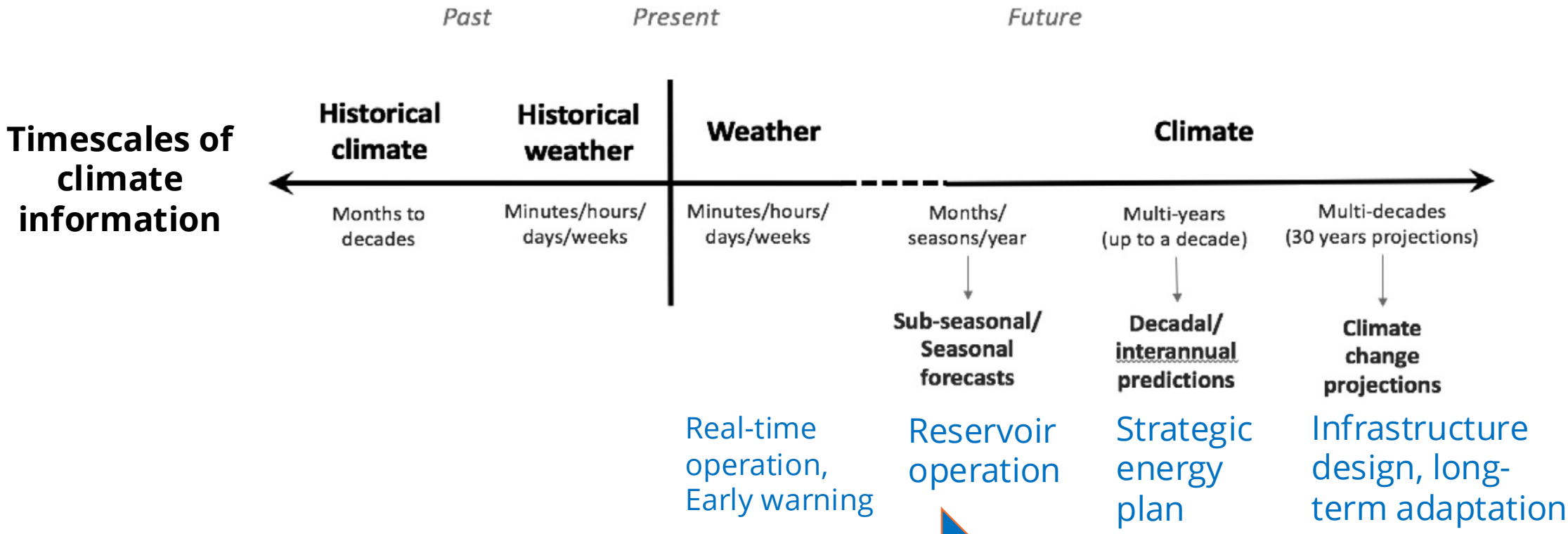
- Two hydrological models are used: a physically-based distributed WRF-Hydro model and a lumped conceptual HBV model.
- Compared to 1986-2005, the flood frequency will increase ~10% by 2041-2060 and ~20% by 2081-2100 under the RCP8.5 scenario.
- Uncertainty ranges: 1% ~ 20% for 2041-2060 and 10% ~ 30% for 2081-2100.

Høsten 2005 kom det store nedbørsmengder i Bergen. Dete blidet er tatt utenfor Nesttun senter.FOTO: BERGENS TIDENDE (ARKIV)

Nesttun, Autumn 2005 flood



Tailoring climate information for hydropower adaptation



Courtesy: I4C project (modified)

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Key Take-aways:

- **CPRCMs offer high-resolution insights and better represent local extreme events** – but uncertainty remains high and results must be interpreted carefully.
- **There's no one-size-fits-all solution.** The type climate data you need – its lead time, spatial resolution, model setup- dependent on the decision you're making.
- **Let's work together.** We are happy to help connect you with the right climate data or tools tailored to your needs.

Thank you!

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