Temporally compounding high-impact events in hydropower-dominated renewable electricity systems in Europe

Work in progress

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Background

- With increasing installed capacity of renewable electricity → more dependence on variations in weather and climate.
- Due to the non-linearity between the climate and energy system, extreme impact events might occur under compounding meteorological conditions.
- Long-lasting high pressure (HP) systems are known drivers of extreme high residual load events in European renewable electricity systems with wind and solar photovoltaic production[3]. But how do these systems impact hydropower reservoirs?
- Temporally compounding is relevant due to dispatchable nature of hydropower reservoirs.

Terminology

Instantaneous Residual Load (**IRL**): Difference between demand and non-dispatchable electricity production (wind, PV solar, and run-of-river)

Residual Load (**RL**): like IRL but including hydropower reservoir production

Methodology – Large climate ensemble with energy modelling framework

LENTIS data[1]: A large ensemble with 1600 years (160x10 years) of daily climate data

Present day capacities (gridded)

An energy modelling framework[2]

Per grid cell:
- PV, wind energy and run-of-river production
- hydropower reservoir inflow

On a country level:
- electricity demand
- reservoir hydropower dispatch

Three weeks rolling dispatch optimization, so no perfect foresight.

This gives us **a 1600 year distribution** of daily renewable electricity production and demand in present-day climate

Compounding conditions: low reservoir inflow during high IRL events

HP systems during IRL events also characterized by little precipitation.

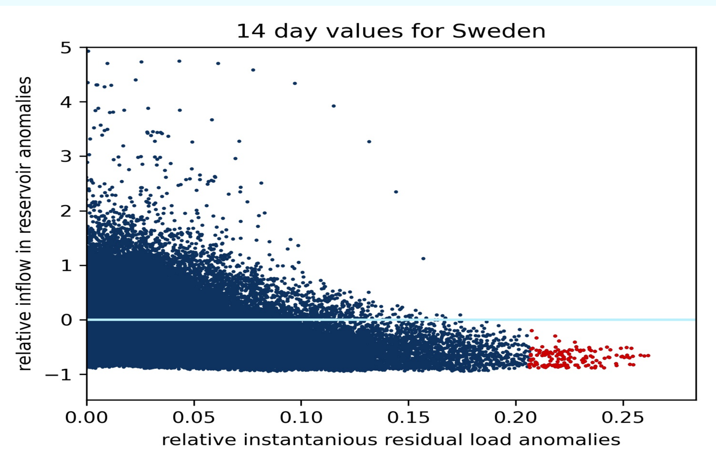

Figure 1: 14-day relative reservoir inflow anomalies vs relative IRL anomalies for Sweden. In red the 160 highest relative anomalies.

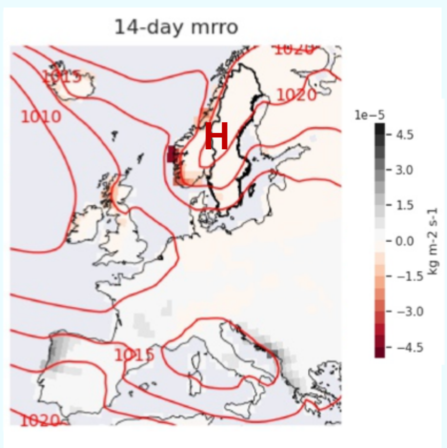

Figure 2: composite of runoff anomalies during 1-in-10 year IRL events in Sweden.

Temporally compounding – three types of events

1 Empty reservoirs at start of long-lasting high pressure systems in winter

High pressure system during reservoir filling season.

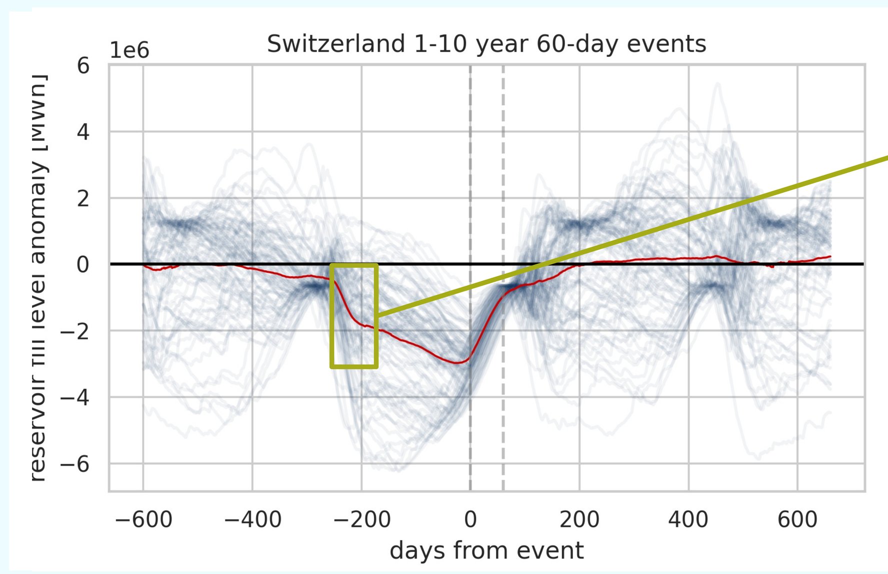

Figure 3: Reservoir fill level anomalies in 1-in-10 year high RL winter events of 60-day duration for Switzerland. In red the mean of all events. 0 is the first day of event. Vertical dashed lines outline event period.

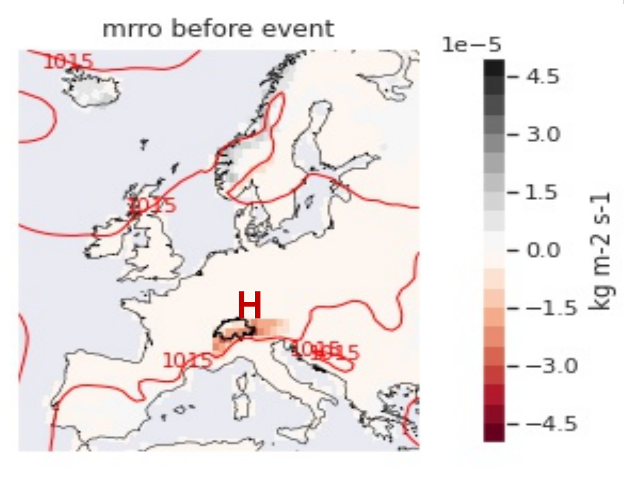

Figure 4: Composite of runoff anomalies during 260-200 days before start of 1-in-10 year 60-day RL winter events in Switzerland.

2 Low runoff in summer after extremely cold winters

After little precipitation during event soil moisture is first recharged*.

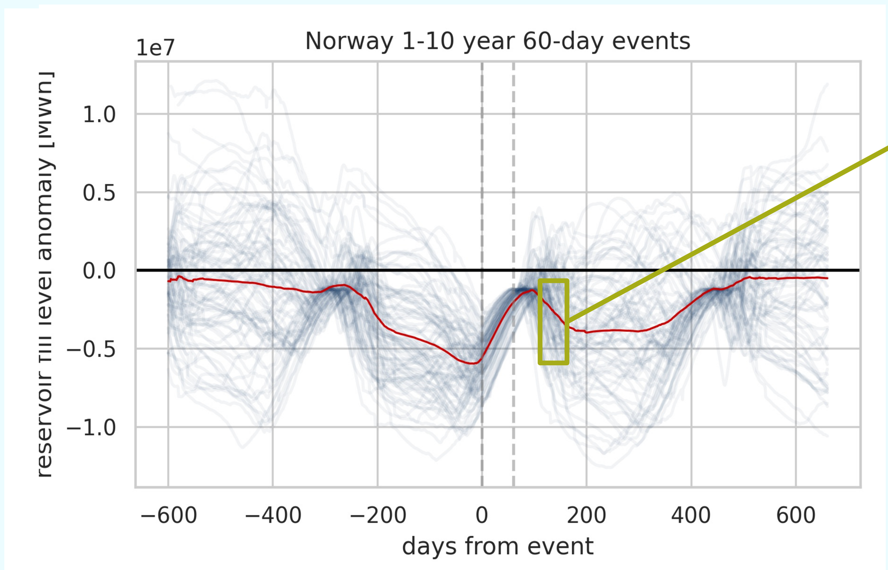

Figure 5: Like Figure 1 but for winter events in Norway.

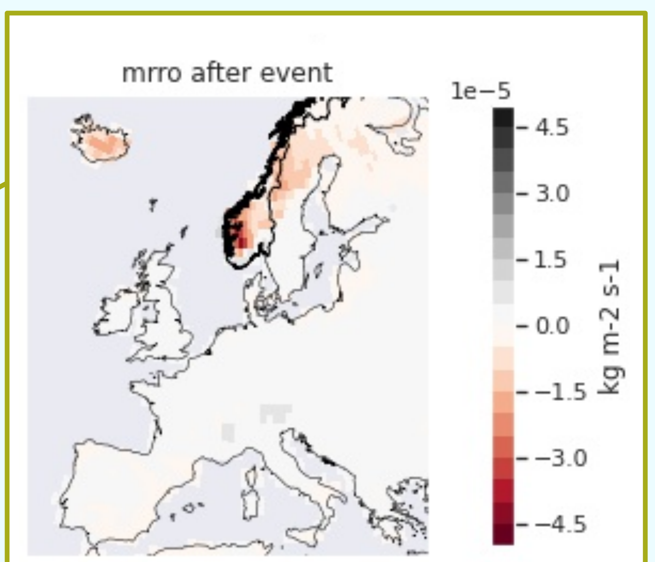

Figure 6: Like figure 2 but for period 100-150 days after events in Norway.

3 Dry springs preceding hot summers

* Not robust over models. Checked with six large ensembles and this was observed in half of them.

+ higher chance of heatwaves after dry springs as a result of land-atmosphere feedbacks.

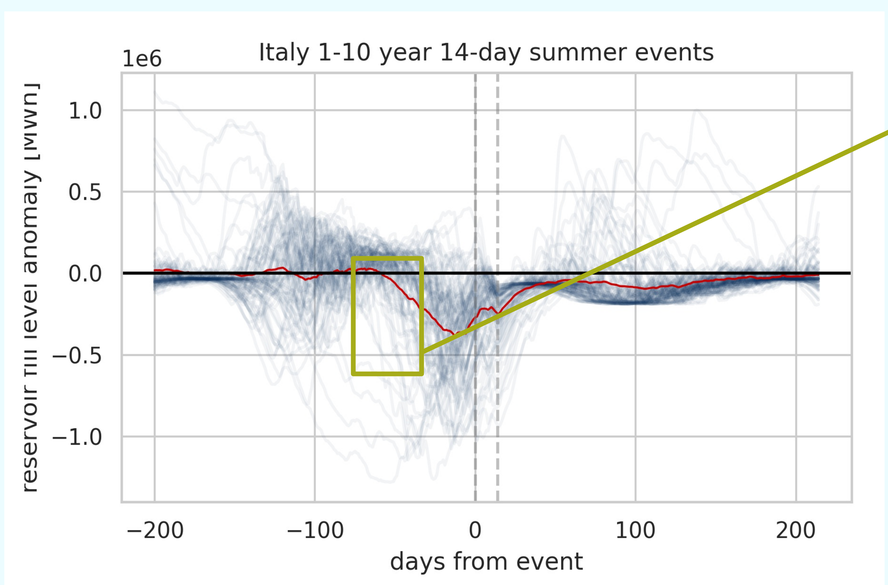

Figure 7: Like Figure 1 but for 14-day summer events in Italy.

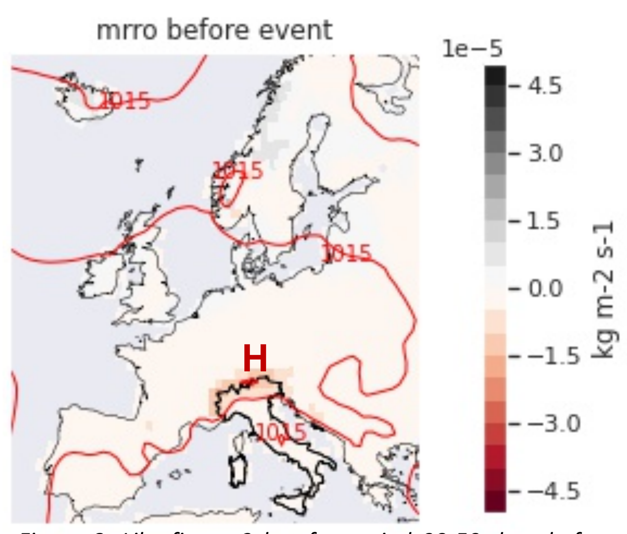

Figure 8: Like figure 2 but for period 90-50 days before start events in Italy.

References

[1] Muntjewerf, L., Bintanja, R., Reerink, T., and van der Wiel, K.: The KNMI Large Ensemble Time Slice (KNMI-LENTIS), EGUsphere [preprint], https://doi.org/10.5194/egusphere-2022-1378, 2023.

[2] van der Most, L., van der Wiel, K., Benders, R. M. J., Gerbens-Leenes, P. W., Kerkmans, P., & Bintanja, R. (2022). Extreme events in the European renewable power system: Validation of a modeling framework to estimate renewable electricity production and demand from meteorological data. Renewable and Sustainable Energy Reviews, 170, [112987]. https://doi.org/10.1016/j.rser.2022.112987

[3] van der Wiel, K., Stoop, L. P., Van Zuijlen, B. R. H., Blackport, R., Van den Broek, M. A., & Selten, F. M. (2019). Meteorological conditions leading to extreme low variable renewable energy production and extreme high energy shortfall. Renewable and Sustainable Energy Reviews, 111, 261-275.

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