EGU22-541

(24 May 2022)

How well do convection-permitting climate models represent sub-daily precipitation upper tail in complex orography?

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Background – 1. Convection-permitting climate models

Convection-permitting climate models (CMPs) (e.g. Prein et al., 2015), compared to coarser resolution climate models:

- have higher spatial resolution (< 4 km)
- explicitly represents the atmospheric deep convection (a dominant source of heavy precipitation in many regions)
- have improved representation of orography and land-surface heterogeneities

→ A much more realistic representation of sub-daily precipitation statistics

The high computational requirements of CPM runs restrict the existing simulations to relatively short time periods (10–20 years), too short for deriving precipitation frequency analyses with conventional Extreme Value approaches.

Some issues

→ High uncertainties on the provided information
→ Difficulties in attributing the observed changes to specific physical and meteorological processes

Prein, A. F., Langhans, W., Fosser, G., Ferrone, A., Ban, N., Goergen, K., Keller, M., Tölle, M., Gutjahr, O., Feser, F., et al. (2015), A review on regional convection-permitting climate modeling: Demonstrations, prospects, and challenges, Rev. Geophys., 53, 323– 361. doi:10.1002/2014RG000475.

Background – 2. The event-based statistical model

Alternative methods, based on the so called Metastatistical Extreme Value Distribution, were recently proposed (e.g. Marani and Ignaccolo, 2015; Marra et al., 2019) for deriving frequency analyses from shorter data records, promising improved applications based on CPMs.

The **Simplified Metastatical Extreme Value (SMEV) methodology** is a recent framework for extreme precipitation frequency analysis.
It relies on the concept of *ordinary events* (the independent realizations of a process of interest)

- The ordinary events distribution is assumed as known
- The EV distribution is derived by considering:
  occurrence frequency of the ordinary events
  i. inter-annual variability of their intensity distribution and of their occurrence frequency

- Multiple types of ordinary events and their changes can be considered in the formalism (Marra et al., 2019)
- It proved highly effective in reducing the stochasting uncertainties (Zorzetto et al., 2016)
- The distribution parameters and their yearly number are treated separately

→ return levels can be quantified from short data records (Zorzetto et al., 2016)
→ gives the chance of developing attribution studies (Marra et al., 2021; Dallan et al., 2022)

Dallan, E., Borga, M., Zaramella, M., & Marra, F. (2022). Enhanced summer convection explains observed trends in extreme subdaily precipitation in the eastern Italian Alps. Geophysical Research Letters, 49, e2021GL096727. https://doi.org/10.1029/2021GL096727
Marani M., Ignaccolo M. (2015). A metastatistical approach to rainfall extremes, Advances in Water Resources, Volume 79, 2015, Pages 121-126, ISSN 0309-1708, https://doi.org/10.1016/j.advwatres.2015.03.001.
Marra F., Zoccatelli D., Armon M., Morin E. (2019). A simplified MEV formulation to model extremes emerging from multiple nonstationary underlying processes. Advances in Water Resources, 127, 280–290. https://doi.org/10.1016/j.advwatres.2019.04.002
Marra, F., Armon, M., Adam, O., Zoccatelli, D., Gazal, O., Garfinkel, C. I., et al. (2021). Towards narrowing uncertainty in future projections of local extreme precipitation. Geophysical Research Letters, 48, e2020GL091823. https://doi.org/10.1029/2020GL091823
Zorzetto E., Botter G., Marani M. (2016). On the emergence of rainfall extremes from ordinary events. Geophysical Research Letters, 43, 8076–8082. https://doi.org/10.1002/2016GL069445

Background – 3. Reverse orographic effect

In Trentino area, Formetta et al. (2022) (EGU2022-549) found two main modes of orographic relationship for extreme precipitation:
an orographic enhancement for durations >~8 hours
a reverse orographic effect for hourly and sub-hourly durations

They are caused by the interaction with orography of three precipitation regimes, related to the underlying physical processes:

i. Peak intensity of convective cells (~5-20 min)
ii. Yield of convective cells (~30-60 min)
iii. Subsequent cells and stratiform processes (longer durations)

→ We expect CPM not to be able to fully represent the interactions between convective cells and orography at the hourly durations

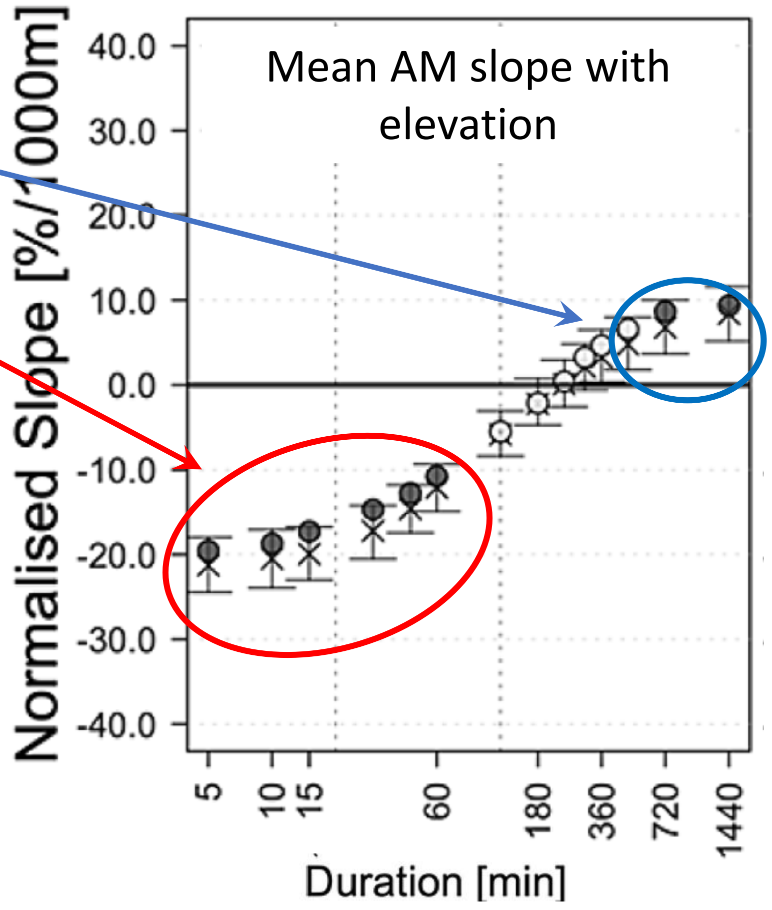


Fig.1 Percentage slope of the relation between mean AM and elevation at different durations (Formetta et al.2022)

Formetta, G., Marra, F., Dallan, E., Zaramella, M., and Borga, M.(2022). Differential orographic impact on sub-hourly, hourly, and daily extreme precipitation, Adv. Water Resour., 159, 104085, https://doi.org/10.1016/j.advwatres.2021.104085

Objectives

General aim

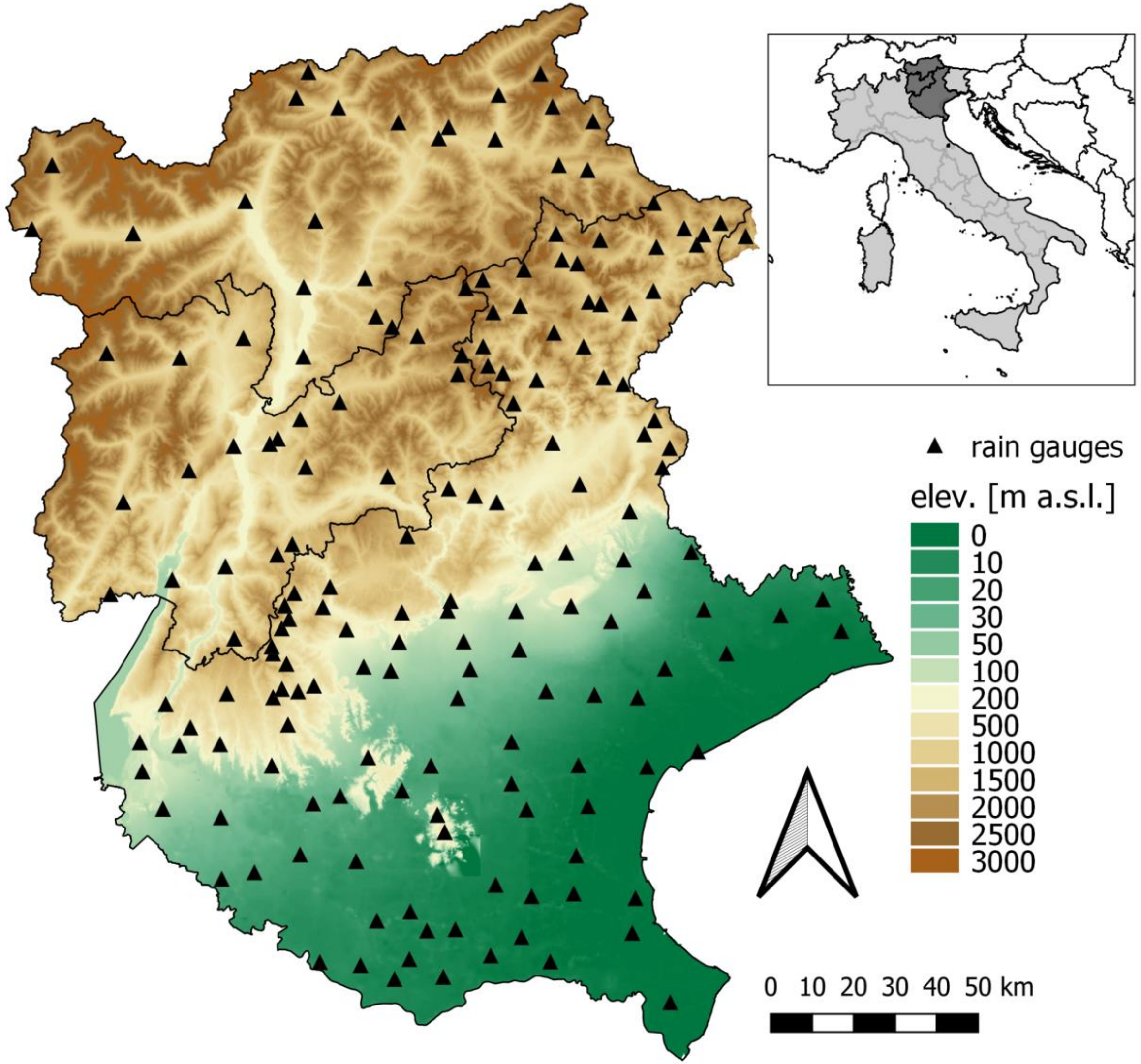
This analysis aims to investigate the CPM ability to represent the reverse orographic effect on the upper tail of hourly precipitation in a complex-orography region in the Eastern Italian Alps,

with a focus on distribution parameters, quantiles estimation and their dependency with elevation

Specific objectives

- deriving frequency analysis on 10yr CPM data
- analyzing the dependency of extreme precipitation with elevation
- comparing with observational data

Data



The study area

- An orographically complex area located in the Eastern Italian Alps (Trentino-Alto Adige and Veneto region)

Rainfall data

CPM simulation (ERA-Interim driven COSMO model)

- Coverage period: 2000-2009
- Time resolution: 1h
- Spatial resolution: ~2.2 km
- Station-collocated grid point (SC CPM) and all grid points (GR CPM)

Observation

- ~ 175 rain gauge stations
- Coverage period: ≥ 20 years included 2000-2009
- Elevation range: -3 ÷ 2235 m a.s.l.
- Area: ~ 32000 km2
- Quality control: at least 9 complete year (≤10% gap) in the 2000-2009 period
- Data aggregation: 5min → 1h

Methods – 1. Statistical analysis on rainfall data

On 1h rainfall data series from:

- observation rain gauges (OB)
- station-collocated CPM (SC CPM)
- all CPM grid points (GR CPM)

(* link for the statistical model codes)

1

For each location:

- Definition of "*storms*", that is consecutive records of wet time intervals separated by a dry hiatus (24 h in our study)
- For each duration of interest, definition of ordinary events (the maximum intensities within each storm)

For each location and duration:

- series of ordinary events per year
- computation of the annual maxima (AM)

2

Distribution estimation: in many cases, the right tails of subdaily precipitation intensities is found to be a Weibull distribution (e.g., Marra et al., 2020)

- A Weibull distribution F is assumed, and checked $F(x,\lambda,\kappa) = 1 - e^{-\left(\frac{x}{\lambda}\right)^{\kappa}}$
- Left-censoring of ordinary events (analyzing different censoring thresholds): upper 90% of data is used for hourly durations (**details on the tail test: look at EGU22-3805)**

- distribution parameters (scale λ, shape κ)
- yearly number of events n

3

Calculation of several return levels (2-, 10-, 20-, 50-yr) by inverting the estimated distributions

- estimated return levels

Marra F., Borga M., Morin E. (2020). A unified framework for extreme subdaily precipitation frequency analyses based on ordinary events. Geophysical Research Letters, 47, e2020GL090209.
* Codes available at: Marra, F. (2020). A Unified Framework for Extreme Sub-daily Precipitation Frequency Analyses based on Ordinary Events - data & codes (Version v1). Zenodo. https://doi.org/10.5281/zenodo.3971558

Methods – 2. Bias assessment; Dependency with elevation

1

BIAS ASSESSMENT:
Station-Collocated CPM value / OBservation value

→

Bias on these values:

- Mean annual maxima (AM) in the 10 years
- Distribution parameters
- Return levels

2

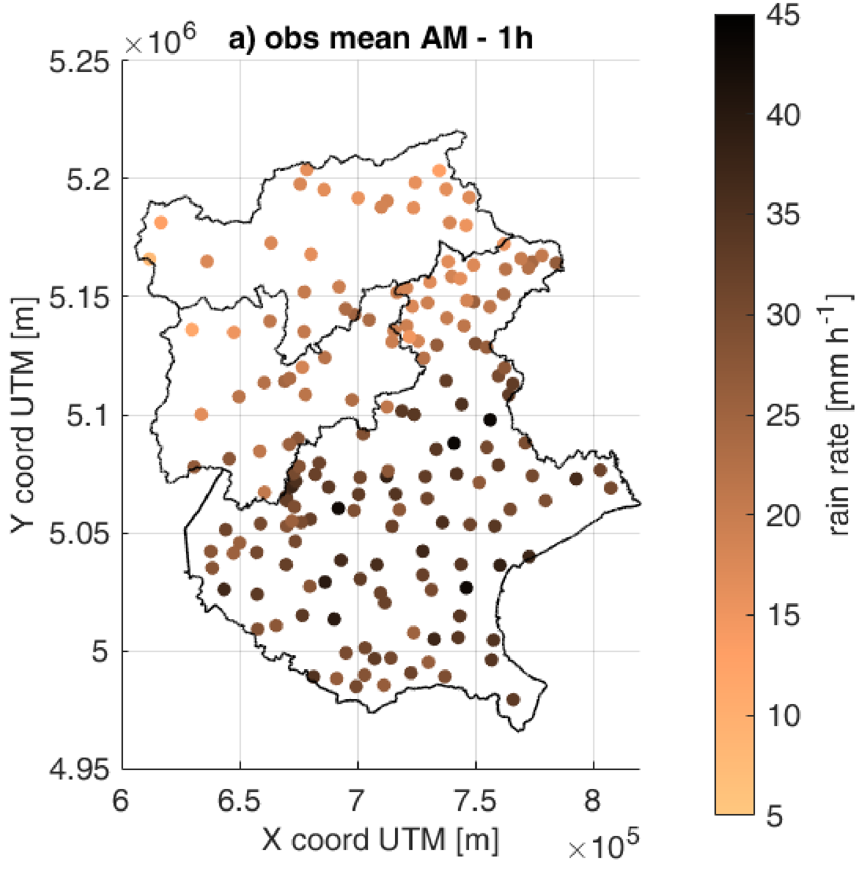
DEPENDENCY WITH ELEVATION

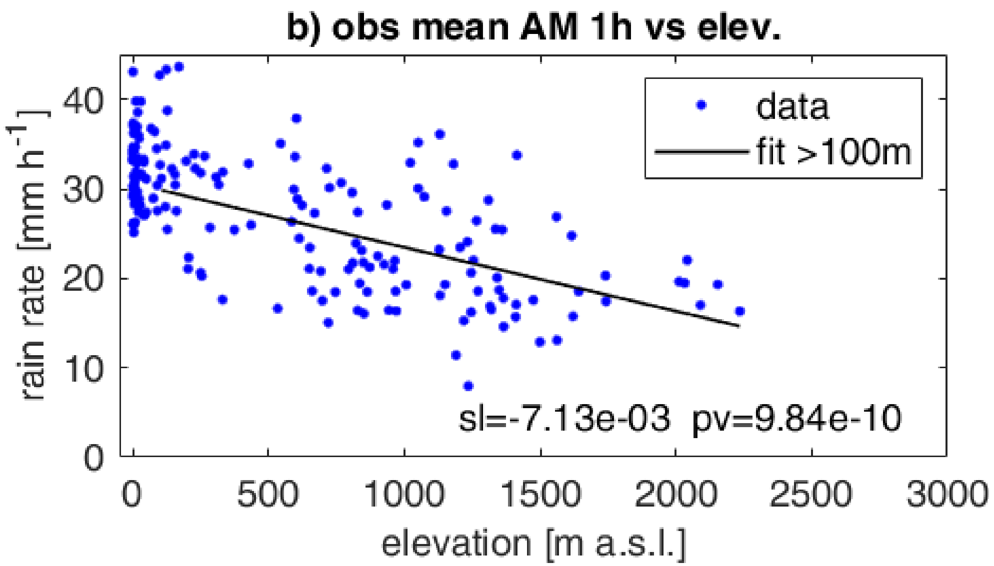
- value vs elevation for both OB, SC CPM, GR CPM
- focus on 1h duration

→

- Slope of the relation between values and elevation
- Biases per elevation classes

Results – 1. Observed reverse orographic effect



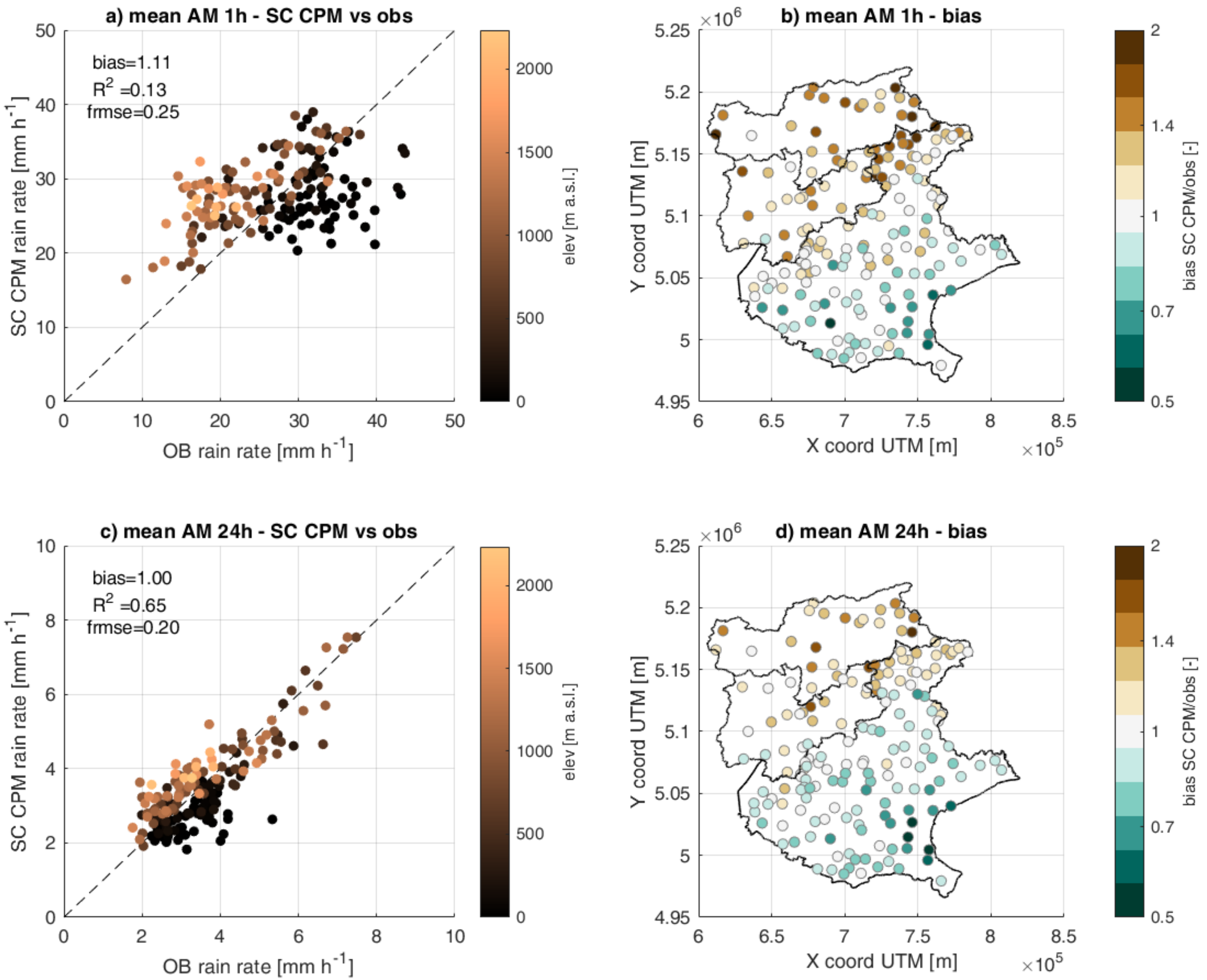


1 Key messages

Observed 1h AMs show

- Clear spatial pattern in the area, with higher intensity in the flat area
- Signif. decreasing intensity with elevation (normalized slope= - 30% km^{-1})

Results – 2. AMs bias



a), b) 1h duration:

- Mean bias: overestimation
- More overestimation at the higher elevation

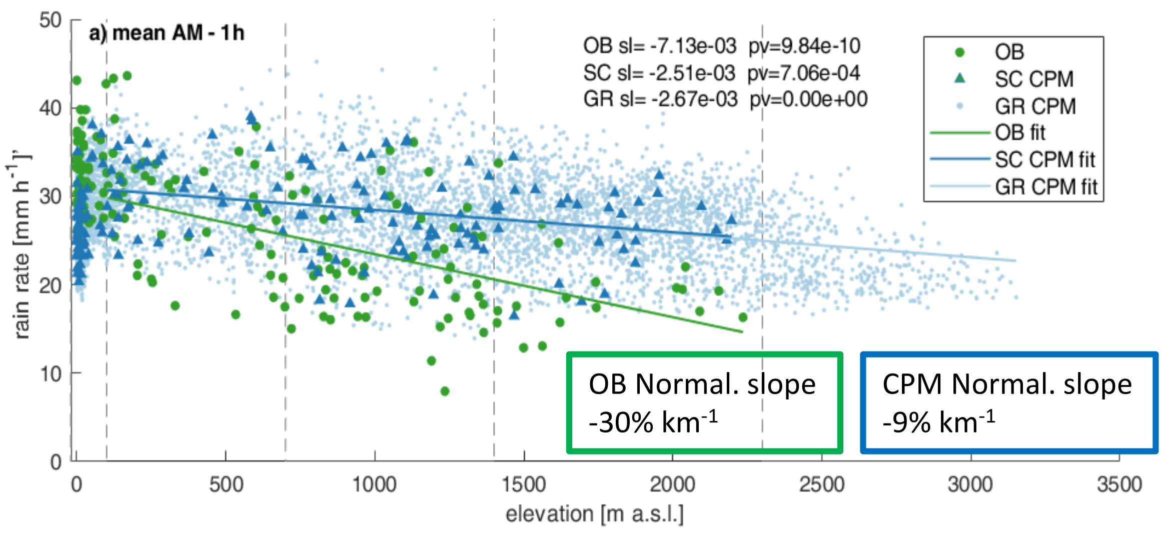
c), d) 24h duration:

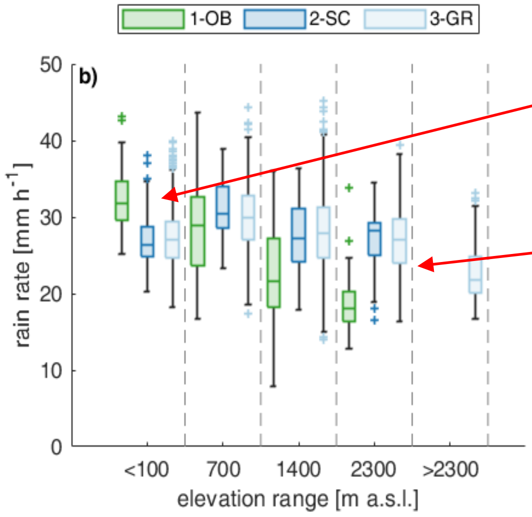
- Mean bias = 1
- Slight overestimation at the higher elevation

2 Key messages

- CPM better represents OB AMs at the daily duration
- CPM overestimates/underestimates 1h AM at high/low elevation

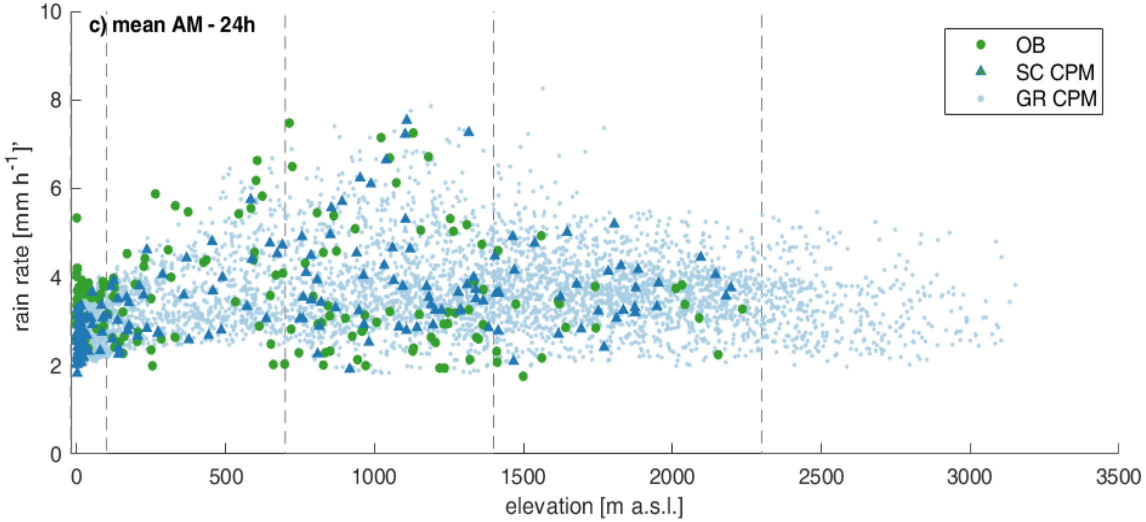
Results – 3. AMs elevation dependency

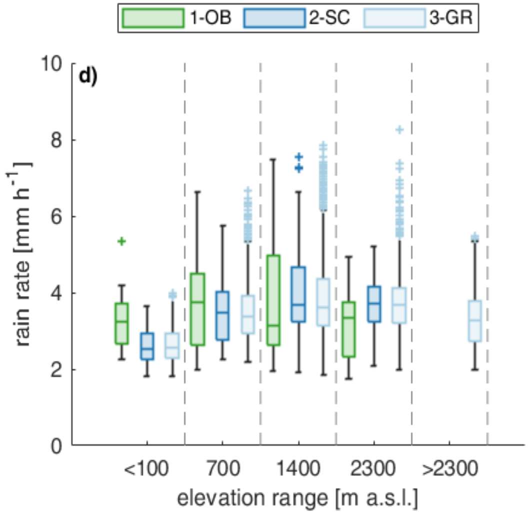




a), b) 1h duration:

- OB strong decreasing intensity not captured by CPM
- CPM understimation at <100 m elev.
- CPM big overstimation at > 700 m elev.





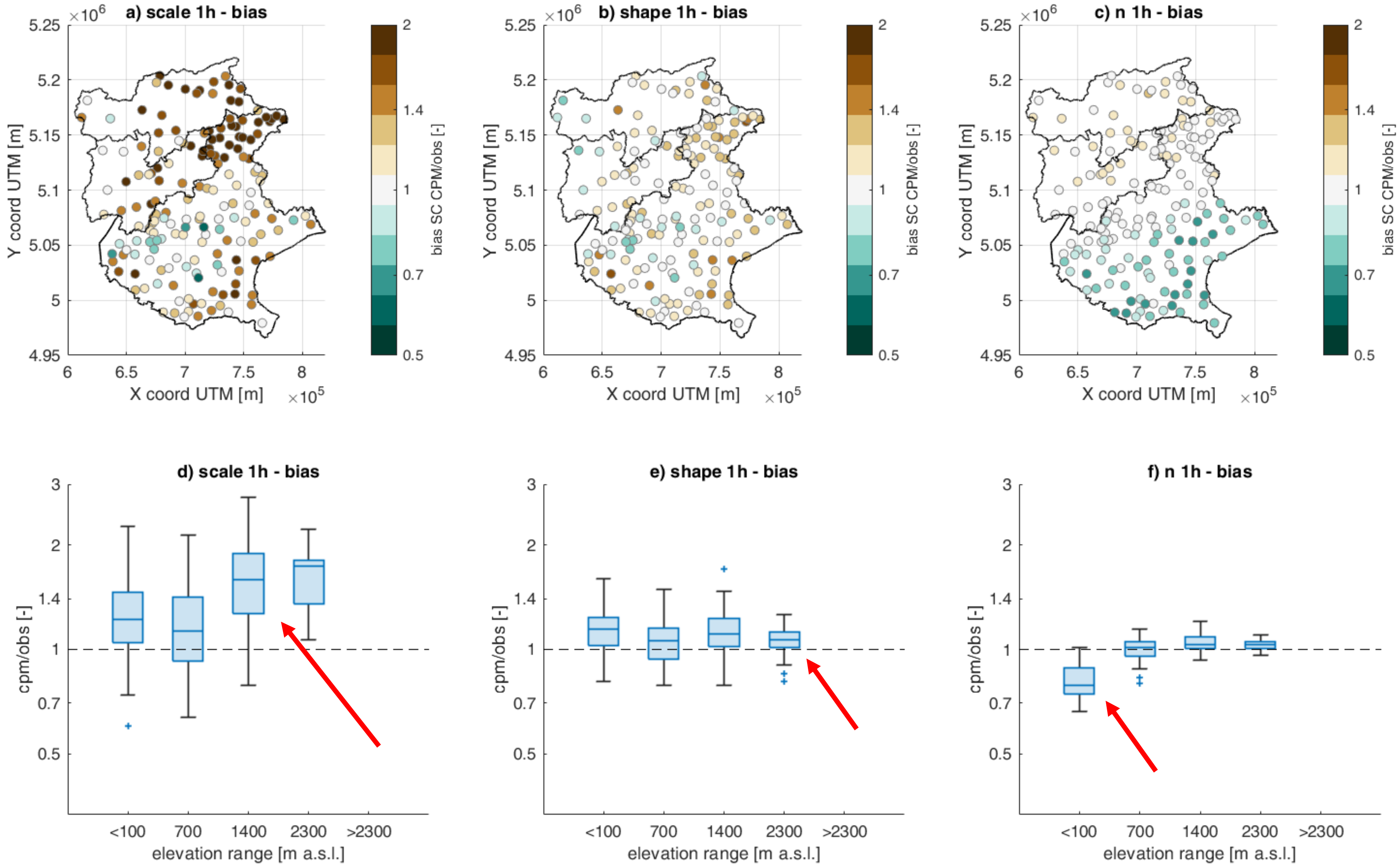
c), d) 24h duration:

- No evident relation with elevation
- OB and CPM show similar intensity and spreading

3 Key message

- Weaker reverse orographic effect on CPM AMs than OB AMs
- Good agreement at the 24h duration

Results – 4. Statistical model: 1h distribution parameters



Scale λ

CPM strongly overestimates λ at >700 m

Shape κ (tail lightness)

CPM lighter tails;

bias~1 at higher elev.

n

CPM strongly understimates n at <100 m

4 Key messages

- Spatial patterns in the bias of the distribution parameters

→ Expected weak orographic effect on estimated rare return levels …

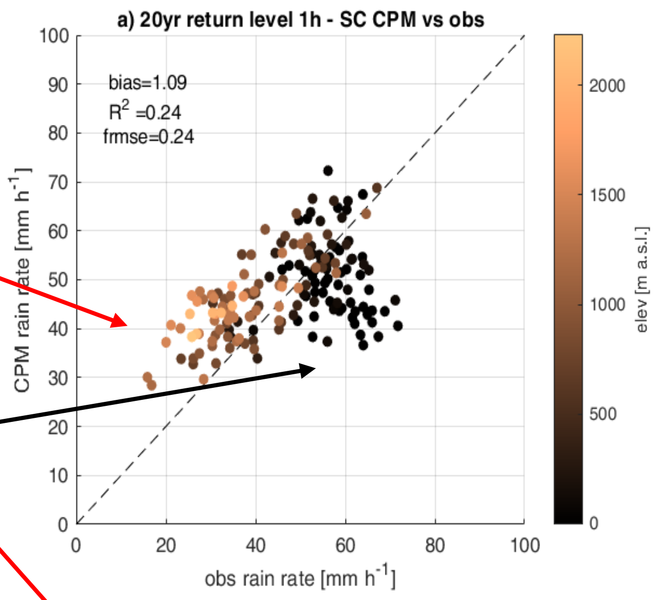
Results – 5. Statistical model: 1h 20yr return levels

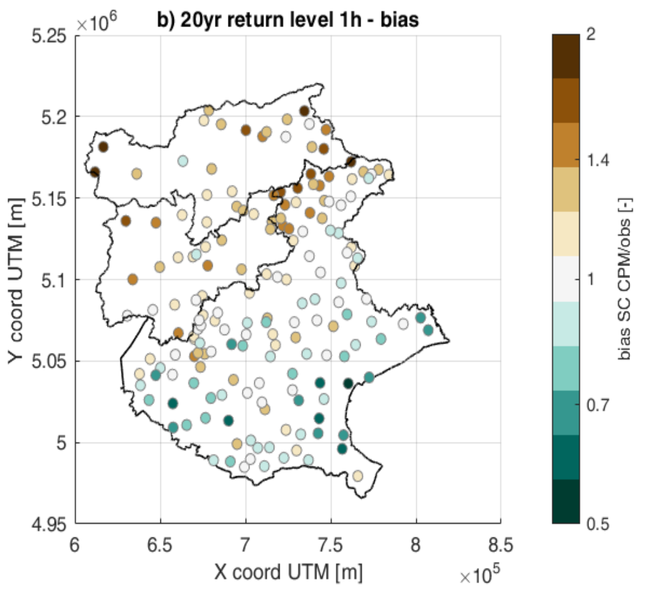
- CPM overestimates at the higher elev

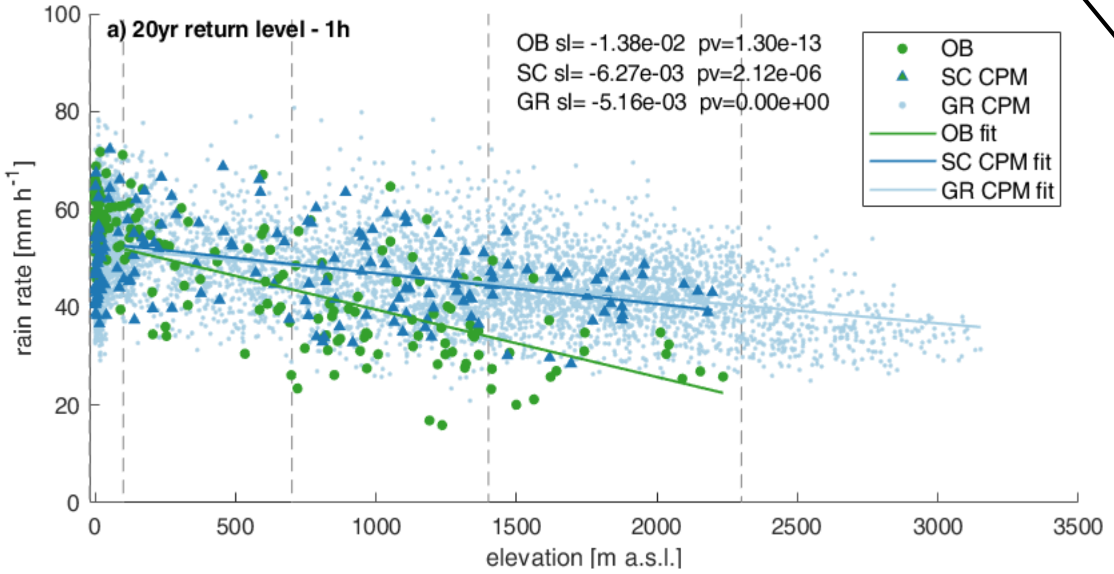
- CPM underestimates in the flat zone

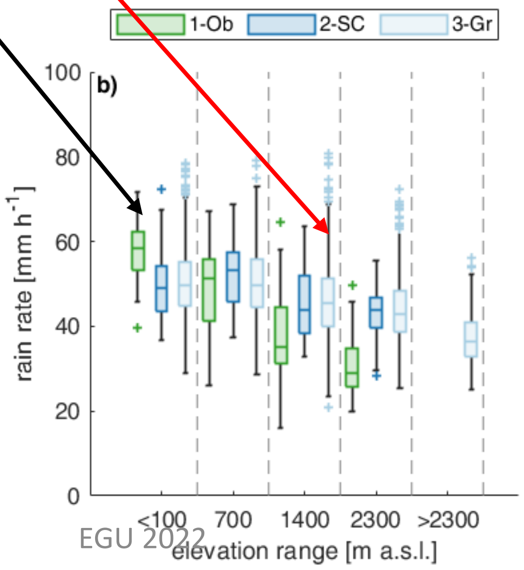
→ CPM return levels show slower slope with elevation

OB Normal. slope -34% km^{-1}	CPM Normal. slope -11% km^{-1}









5

Key messages

- Weak reverse orographic effect at the hourly duration for CPM

→ … to consider in bias correction procedure for CPM …

Conclusions

1. Observed 1h AMs show clear REVERSE OROGRAPHIC EFFECT

2. CPM better represents OB AMs at the daily duration

   CPM overestimates/underestimates 1h AM at high/flat elevation

3. Weaker reverse orographic effect on CPM AMs than OB AMs

4. Spatial patterns in the bias of the distribution parameters:

   Higher scale for CPM at high elevation; low n for CPM at flat elevation

5. Weak reverse orographic effect on extreme precipitation at the hourly duration for CPM

- SMEV allows reliable estimation of large precipitations quantiles for high-resolution climate simulations!
- The bias on hourly extreme precipitation depends on elevation, with increasing overestimation with elevation.
- This seems to confirm our hypothesis that CPMs cannot well represent the "reversed orographic effect" at the hourly duration.

These findings

- can improve our understanding of the changes in the meteorological processes underlying the changes in the precipitation extremes
- could help us develop adjustment approaches that can account for the role of orography at multiple durations.

Thank you for your attention

Waiting for your feedback and questions!

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EGU22-541

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Look also at:

EGU22-3805 | HS7.8 Daily precipitation with stretched-exponential tails could explain the statistics of observed annual maxima (Marra et al.)

EGU22-549 | HS7.8 Differential orographic impact on sub-hourly, hourly, and daily extreme precipitation (Formetta et al.)

EGU22-5924 | CL2.4 Changes in future subdaily extreme precipitation at convection-permitting scale over an alpine transect (Roghani et al.)

EGU22-5453 | AS1.16 Impact of orography on current and future extreme sub-daily precipitation (Lusito et al.)