Point-by-point response to the reviews

Manuscript egusphere-2026-4014: "LESSONS report: Fine-scale representation of consecutive dry days"

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We thank the three reviewers, Jonathan Wille (RC1), Eleonora Dallan (RC2) and Marc Lemus-Canovas (RC3), and the community commenter Sivarajah Mylevaganam (CC1, CC2) for their constructive comments. Detailed replies with additional figures were posted in the discussion (AC1 to AC4). Below, we first list all relevant changes and then answer each comment briefly. As LESSONS Reports are limited to about 2000 words in the main text, the new analyses are documented in the Supplement and summarised in the main text.

Reviewer comments are reproduced in dark red italics; long general comments are summarised. Line numbers refer to the track-changes version of the revised manuscript.

List of relevant changes

1. **Main lesson** refined around spatial resolution: CDD depends on the grid spacing and, at the kilometre scale, on single events close to the threshold; it should only be compared between data sets of similar resolution (Abstract, l. 19–22; Sect. 4, l. 199–204) [RC1].

2. **Introduction:** meteorological drought defined as a precipitation deficit relative to normal conditions (l. 28–30) [CC1]; use of CDD in IPCC AR6 and global projections and its resolution dependence (l. 35–37) [RC1].

3. **Data and methods:** nesting of COSMO-CLM in ERA5 (l. 55–56) [CC1]; interpolation method of HYRAS (l. 57–58) [RC2]; definition of Moran's I (l. 73–74) [RC1]; RAPSD now computed on the largest square of common valid grid cells (333 km × 333 km), since the pysteps routine assumes square fields (l. 76).

4. **Figure 1:** areas without data shown in grey; caption explains the colour bar, the dry anomaly of COSMO-CLM and gives the mean CDD over the largest common domain of all data sets (l. 125–129) [CC1, RC2].

5. **Figure 3:** Moran's I recomputed with a strict radius-based neighbourhood and RAPSD on the square domain (caption l. 138–141); conclusions unchanged.

6. **Section 3:** value range now given for the common domain (l. 82–83, Table S1) [CC1]; magnitudes not evaluated at individual grid cells (l. 89) [RC2]; the brushstrokes in RADKLIM arise from the same mechanism (l. 112–113, Fig. S5) [RC2].

7. **Section 4:** contribution of the grid spacing to the lower CDD of ERA5 (l. 148–150, Sect. S3) [RC1, RC2]; station density and interpolation artefacts of HYRAS (l. 150–154) [RC2]; underestimation of light precipitation by RADKLIM specified and mean CDD compared with HYRAS (l. 170–174) [RC2]; basis of the statement on the CPM, including a rain-gauge benchmark (l. 176–179, Sect. S6) [RC2, RC3]; role of the run-length definition (l. 189–190, Sect. S4) [RC1]; example and generalisation of the events separating neighbouring cells (l. 192–195, Sect. S7) [RC1, RC3]; what a station network can resolve (l. 196–198) [RC2].

8. **Supplement:** new Sects. S3 (resolution dependence, Fig. S3), S4 (other indices of the same simulation, including summer days, Fig. S4), S5 (RADKLIM examples, Fig. S5), S6 (comparison with 1862 rain gauges, Fig. S6) and S7 (events separating neighbouring grid cells, Fig. S7), and Table S1 (statistics over the common domain).

9. **Code and data availability:** source of the rain-gauge data (l. 211–213). **Acknowledgements** extended (l. 237–240).

10. **References added:** IPCC (2023), Petrova et al. (2024), Van Loon and Van Lanen (2012), Wille et al. (2025).

Reviewer #1 (Jonathan Wille, RC1)

General comment

[Summary] CDD at kilometre scale measures something different than CDD on coarse grids; at high resolution it is less suited to convey average precipitation patterns but expresses the spatial variability of precipitation. The lesson should be refined around the resolution and the context in which CDD is used.

Response: We agree. Aggregating the COSMO-CLM precipitation to coarser grids before computing CDD increases the number of wet days and reduces the mean CDD over Germany from 26.8 days (3 km) to 24.5 days (30 km) and 23.0 days (99 km), so that a coarse-grid CDD describes dry spells of area-mean precipitation. We therefore refined the lesson: CDD depends on the resolution, at the kilometre scale it is often decided by a single near-threshold event, and its spatial variability may serve as a diagnostic of precipitation intermittency.

Changes: Abstract, l. 19–22; Sect. 4, l. 199–204; Supplement Sect. S3.

SC#1: Introduction

Introduction: In the first paragraph, I recommend discussing why CDD is a popular drought metric used in important climate reports and studies. For instance, you can cite and discuss the results from (Petrova et al. 2024) which uses CDD to highlight the growing risk of drought in future climate projections. Of relevance for this report is that the study was done with coarser CMIP5/CMIP6 models and would have much different results with kilometer-scale models. It might be worth citing and discussing Wille et al. (2025) which showed that CDD decreases in kilometer-scale models when interpolated to a coarser resolution, but with differences in whether the model had convection parameterization or no parameterization.

Response: Added: CDD is used for meteorological drought in the IPCC AR6 and in global projections of dry spells (Petrova et al., 2024), which rely on grids of about 100 km, and kilometre-scale models yield shorter dry spells when remapped to such grids (Wille et al., 2025).

Changes: l. 35–37.

SC#2: Discussion

Discussion: It could be interesting to give an example of a negative or incorrect conclusion of drought evaluation that could be reached when using CDD at the higher resolution.

Response: The example is contained in Fig. 2: the two neighbouring cells in Fig. 2b differ by 34 days in CDD, although they received 143 and 149 mm from April to October. Over the common domain of COSMO-CLM and RADKLIM, 70 % (COSMO-CLM) and 84 % (RADKLIM) of the adjacent cells whose CDD differ by at least 10 days are separated by events below 2 mm, and such jumps are most frequent in dry years, with 2018 showing the highest share of 30 years.

Changes: l. 192–195; Supplement Sect. S7, Fig. S7.

SC#3: Moran's I at coarser resolutions

I really like the analysis of Moran's I in Figure 3. One small additional analysis that could be interesting is to interpolate the COSMO-CLM to a couple coarser resolutions (like the ERA5 and CMIP6 level resolutions) and repeat the analysis. I would expect the spatial autocorrelation to increase with higher resolution which would strengthen the argument that CDD becomes more stochastic at the higher resolution.

Response: Done for grid spacings of 6 to 99 km. At a fixed radius of about 100 km, Moran's I increases from 0.17 (3 km) to 0.32 (51 km), as expected by the reviewer, while the mean CDD decreases; about 40 % of the difference between COSMO-CLM and ERA5 is explained by the grid spacing alone. While extending the analysis, we also recomputed Fig. 3 with a strict radius-based neighbourhood and the RAPSD on a square domain; the conclusions are unchanged.

Changes: l. 148–150; Fig. 3 and l. 73–76; Supplement Sect. S3, Fig. S3.

Line 57: Please briefly define what Moran's I is for the readers who are not familiar with this term.

Response: Definition added.

Changes: l. 73–74.

Line 139: You can bolster your argument here by saying that other threshold dependent climate indices, like days above a certain temperature threshold, have a higher spatial autocorrelation and are less stochastic, even at a higher resolution. Thus, CDD is uniquely problematic given its high spatial variability when examined at a high resolution.

Response: We tested this with indices from the same simulation. The number of dry days, with the same field and threshold as CDD, is much smoother (Moran's I of 0.97 versus 0.80 for adjacent cells), and so is the number of summer days (0.93). The noise thus stems from the run-length definition combined with the threshold.

Changes: l. 189–190; Supplement Sect. S4, Fig. S4.

Reviewer #2 (Eleonora Dallan, RC2)

General comment

[Summary] The paper is clearly written and suitable for publication as LESSONS report after minor revisions.

Response: We thank the reviewer for the positive assessment.

Figure 2: The radar product also shows "brush-stroke" patterns. Is this due to the same mechanism illustrated for the CPM in Figure 2? Adding a similar example based on two radar grid points could help clarify this point.

Response: Yes. Fig. S5 shows two pairs of adjacent RADKLIM pixels: CDD of 52 and 27 days (228 and 235 mm from April to October) and of 40 and 19 days (164 and 165 mm), separated by single days

with 1.0 to 1.1 mm. Over all adjacent pairs with CDD differences of at least 10 days, 84 % are separated by events below 2 mm in RADKLIM (70 % in COSMO-CLM).

Changes: l. 112–113; Supplement Sects. S5 and S7, Figs. S5 and S7.

Lines 114–116: You mention here the possible underestimation of CDD by ERA5. Since "evaluation of the CDD magnitudes is not the focus of the study" (line 74), perhaps the lesson learned could focus more specifically on the spatial structure and the implications of the threshold-based definition. The same applies to lines 128–130. Alternatively, if the magnitude of CDD is relevant to the discussion, you could add some consideration of the average CDD over the domain when presenting Figure 1.

Response: We followed the second option. The caption of Fig. 1 and Table S1 now give the mean CDD over the largest common domain of all data sets (ERA5 21.0, COSMO-CLM 26.8, HYRAS 24.5 and RADKLIM 24.5 days). On this basis, we show that part of the lower CDD of ERA5 is due to its grid spacing, specify that the underestimation by RADKLIM concerns hourly intensities below 1 mm h^{-1}, and note that the mean CDD of RADKLIM and HYRAS differ by less than 0.1 days.

Changes: l. 89, 125–129, 148–150, 170–174; Table S1.

Lines 117–119: Could you mention the typical inter-station distance? The steep gradients also depend on how close the stations are to each other when their CDD values "differ substantially".

Response: In 2018, 2084 daily rain gauges with data were operated in Germany, i.e. one gauge per 172 km², with a median distance of 8.6 km to the nearest gauge. We also describe the interpolation method of HYRAS precisely.

Changes: l. 57–58, 150–154.

Line 133: On what basis do you conclude that the CPM reproduces the fine-scale spatial patterns of CDD? Similarly, at line 143, on what basis do you conclude that the station-based product misses them? In other words, what is considered the reference or "truth" for these fine-scale patterns?

Response: There is no gridded truth at these scales. The statement rests on the agreement of the spatial statistics of the free-running CPM and the independent radar product, and is now supported by rain gauges: relative to the spatial variance, gauges 5 to 10 km apart differ as much as grid cells of RADKLIM and COSMO-CLM and more than those of HYRAS (normalised semivariance of 0.41, 0.42, 0.38 and 0.26). The statement on station networks was rephrased: a gauge records the local CDD, but a network with one gauge per 172 km² samples rather than maps the fine-scale variability.

Changes: l. 176–179, 196–198; Supplement Sect. S6, Fig. S6.

Reviewer #3 (Marc Lemus-Canovas, RC3)

SC#1: Observational benchmark

The manuscript shows that COSMO-CLM and RADKLIM exhibit similar fine-scale spatial structures, whereas HYRAS and particularly ERA5 produce smoother CDD fields. The similarity between COSMO-CLM and RADKLIM is an interesting result. However, a benchmark dataset is still missing. To me, this is particularly relevant as the authors themselves highlighted that

RADKLIM has uncertainties in the representation of low-intensity precipitation, including an underestimation of low-intensity precipitation events. Since CDD is defined using a threshold of 1 mm/day, these uncertainties are directly relevant to the metric investigated here.

I would suggest the authors compare CDD calculated directly from neighbouring in-situ precipitation stations with the corresponding CDD from COSMO-CLM, RADKLIM, HYRAS and ERA5 at the station locations. This would provide an independent observational benchmark and would allow the authors to assess whether the fine-scale variability identified in the CPM and radar product is actually supported by observations. This could be included as a supplementary analysis/figure to strengthen the main message of the work.

Response: We added a benchmark with DWD daily rain gauges (1862 gauges in the common domain; gauges retained if missing days cannot change their CDD). Gauges 5 to 10 km apart differ by 3.2 days on average, similar to RADKLIM (3.0 days) and COSMO-CLM (3.4 days) and more than HYRAS (1.9 days); the normalised semivariance gives the same picture. The fine-scale variability of the CPM and the radar product is therefore supported by observations. At the gauge locations, RADKLIM CDD is on average only 0.5 days shorter than the gauge CDD, i.e. its underestimation of light precipitation does not cause a noticeable CDD bias.

Changes: l. 176–179; Supplement Sect. S6, Fig. S6.

SC#2: Implications for drought conditions and impacts

The authors state that the observed spatial variability in CDD for short distances has implications for drought monitoring, impact assessment, drought propagation and low-flow analyses,etc, but none of these implications is explicitly discussed. In particular, it remains unclear to me whether large differences in CDD at kilometre scales translate into meaningful differences in drought conditions or impacts. I encourage the authors to discuss this scale dependence more explicitly and, if possible, provide at least one example illustrating whether the fine-scale CDD variability has consequences for a relevant application.

Response: We now discuss this explicitly. Large CDD differences at kilometre scales mostly do not reflect differences in the water input: the neighbouring cells in Fig. 2b differ by 34 days in CDD but received 143 and 149 mm from April to October, and 70 % (COSMO-CLM) and 84 % (RADKLIM) of the abrupt transitions are caused by single events below 2 mm. These transitions are most frequent in dry years, when CDD is consulted most. As we did not run an impact model, the lesson is formulated in terms of water input and for the applications listed by the reviewer.

Changes: l. 192–195, 199–204; Supplement Sects. S5 and S7.

Community comments (Sivarajah Mylevaganam, CC1 and CC2)

General comment

[Summary] The 1 mm threshold is not fully aligned with the measurement precision of modern instruments, and the conclusions are based on 2018, considered the best reflection of severe drought conditions in Europe.

Response: The 1 mm threshold is the ETCCDI definition of a dry day, well above the resolution of rain gauges; thresholds of 0.1 and 2 mm give qualitatively similar patterns (Fig. S2). The conclusions are not restricted to 2018 (Figs. 4 and S1); 2018 is the year with the strongest effect among 30 years (Supplement Sect. S7).

Comment #1: Definition of meteorological drought

[Summary] L. 26–27: defining meteorological drought as the absence of rainfall contradicts the consensus; rainfall and precipitation must be distinguished.

Response: Corrected: meteorological droughts are now defined as periods with a deficit of precipitation relative to normal conditions, and 'rainfall' was replaced by 'precipitation'.

Changes: l. 28–30, 172.

Comment #2: Rainfall versus precipitation in the data sets

[Summary] The data sets measure total precipitation, not only rainfall, which is inconsistent with an 'absence of rainfall' definition.

Response: All four data sets provide total precipitation, and CDD is defined on daily precipitation; the inconsistent wording was corrected (see C1).

Changes: l. 28–30.

Comment #3: The cited reference

[Summary] The handling editor should verify whether Liu et al. (2023) supports this definition.

Response: Liu et al. (2023) characterise meteorological drought by the Standardized Precipitation Index and quantify its propagation to agricultural, surface water and groundwater drought, which supports the cascade for which we cite it. The definition is now taken from Van Loon and Van Lanen (2012).

Changes: l. 28–30.

Comment #4: Nesting of COSMO-CLM in ERA5

[Summary] L. 46–47: explain how ERA5 (31 km) provides the boundary conditions of the 3 km COSMO-CLM simulation, in the context of the loss of ETCCDI indices at coarse resolution.

Response: The ERA5-driven COSMO-CLM run is nested directly into ERA5, which provides the lateral boundary conditions every hour; the fine-scale precipitation is generated by the model itself. The effect of the resolution on CDD is shown in the new Supplement Sect. S3.

Changes: l. 55–56; Supplement Sect. S3.

Comment #5: Value range and colour bar of Figure 1

[Summary] L. 68: the stated range of 7 to 100 days does not match the colour bar of Fig. 1, which ends at 60 days.

Response: The range referred to the entire model and reanalysis domains. Within the common domain of all data sets, CDD ranges from 11 to 68 days. We kept the colour bar, which covers more than 99.9 % of the values; values above 65 days are shown in the darkest colour, as now stated in the caption.

Changes: l. 82–83, 125–126; Table S1.

Comment #6: North-western boundary region in Figure 1

[Summary] Fig. 1: ERA5 and COSMO-CLM show high values in the north-west, whereas HYRAS and RADKLIM appear white there.

Response: The white areas were areas without data, now shown in grey. The high values of COSMO-CLM over the Benelux countries and western Germany are a dry anomaly of the free-running simulation, far from its domain boundary, and not an artefact; this is stated in the caption.

Changes: Fig. 1 and caption, l. 126–127.