

Response to reviewers' comments on essd-2025-610

11 March 2026

We thank the reviewers for taking the time to give insightful and challenging comments. We have separated all comments/questions and given the responses below. Reviewer comments are given in *italic* while responses with normal font.

Reviewer Comment 1 (RC1)

1. First a somewhat provocative question: What is the purpose of creating this reanalysis? And who are the intended users? The authors claim that it is an important data set that is asked for by both public and private bodies and the high resolution is important for local applications. It is also touched upon at the very end of the paper but not very much. It would be beneficial for the paper and for understanding the need for this reanalysis if a few real use cases were presented.

The DANRA regional reanalysis was developed to address the pressing need for high-resolution, locally relevant climate data in Denmark, where the complex interactions between land, sea, and atmosphere require finer spatial and temporal detail than global reanalyses can provide. Its kilometer-scale resolution and gap-free consistency are specifically designed to support applications where coarser resolution reanalysis datasets would be less adequate. Examples on such are well reflected in some of the ongoing applications of DANRA data which we are aware of:

- Regional climate information: DANRA is currently being integrated into Denmark's regional climate atlas initiatives, providing the detailed spatial and temporal data needed to map local climate trends and inform long-term planning.
- Drought and water resource research: The dataset's high resolution enables precise modeling of soil moisture, evaporation, and precipitation patterns, supporting both agricultural advisors and water management authorities in assessing drought risks and optimizing resource allocation.
- Urban flooding and drainage systems: Municipalities and engineers use DANRA to simulate extreme rainfall events and model urban flooding scenarios, improving the design and resilience of drainage infrastructure.
- Compound weather events: By capturing the interplay between temperature, precipitation, wind, and storm surges, DANRA facilitates research into compound extremes (e.g., concurrent heatwaves and droughts or storm surges coinciding with heavy rainfall), which are critical for comprehensive risk assessment.
- Coastal risk management: The dataset's fine-grained resolution supports detailed modeling of storm surges, sea-level rise, and coastal erosion—key priorities for coastal communities and infrastructure planners.

- Public health and urban resilience: Localized data on heatwaves, cold spells, and extreme precipitation help health authorities and city planners develop targeted strategies to protect vulnerable populations.

- Data-driven innovation: Early adopters in research and industry have already utilized DANRA for training machine learning models in weather forecasting and validating satellite-derived climate products, demonstrating its versatility as a foundational dataset.

While specific user projects are not disclosed in this first publication, DANRA's design directly responds to needs articulated by Danish public bodies (e.g., for climate reporting and regulatory assessments) and private sector stakeholders (e.g., for site-specific risk and impact analyses). By providing open access to this high-fidelity resource, we enable users across sectors to cite DANRA in their own work, fostering transparency, collaboration, and evidence-based decision-making.

2. Another major thing is the observation usage. Since observations and the use of observations, is a very crucial part of a reanalysis, as the authors also point out, it would be nice with a bit more information on what observations are used and how. The background error statistics for example, how is that derived, for what period and is it the same during the entire reanalysis? A figure of how the number of observations changes during the period or how the coverage changes would also be nice to see.

We add now in the paper a table to list the observation stream used in the DANRA reanalysis, some texts on which parameters are assimilated, also a figure to illustrate evolution of the number of conventional observation data assimilated in the DANRA upper air assimilation,

About derivation of the background error covariances in DANRA's 3DVAR upper-air assimilation, a paragraph has been added in the manuscript to explain the approach. Basically, the process involves a two-step iterative approach: first, short-range ensemble forecasts for two-week periods (starting 1 January and 1 July 2017) generate provisional covariances from ERA5 EDA data. These are refined through 3DVAR-based EDA over two-month runs, with 6-hour forecast ensembles used to derive final background error covariances. While a time-varying proxy would be ideal, DANRA uses fixed seasonal statistics from 2017, applying CARRA's method of linearly weighting winter and summer structure functions to reflect seasonal variations in the analysis.

3. Several acronyms are not defined in the paper (HARMONIE-AROME, ACCORD...). Please look through and define the acronyms the first time they appear.

We have gone through the paper and defined the acronyms, however, the acronym HARMONIE-AROME includes two further acronyms that we have chosen not to define as we believe it will cause more confusion than clarity.

4. In the manuscript, only three parameters are verified, temperature at 2 meters, wind at 10 meters and precipitation. This is of course interesting for the extreme weather events presented but from a model evaluation perspective it would be interesting to also see verification of other model parameters. I am confident that the authors have looked at this so what is the motivation for not including more verification in the paper?

We appreciate the reviewer's insightful suggestion regarding the inclusion of additional model parameters for verification. Indeed, a comprehensive evaluation of upper-air parameters such as temperature, wind and humidity profiles, was conducted as part of quality assurance during DANRA production. These inter-comparisons, performed against radio sonde data, yielded overwhelmingly positive results in favor of DANRA over ERA5. The detailed monthly verification statistics for these upper-air parameters (alongside weather parameters against surface observations) are available on the DANRA-book page, where interested readers can explore the results in greater depth.

While we recognize the value of presenting these findings directly in the manuscript, the choice to focus on surface parameters was primarily driven by logistical constraints. Specifically, the generation of a 30-year time series based on monthly statistics for upper-air parameters proved challenging, particularly following the departure of the staff member who had previously compiled the surface parameter time series. Nevertheless, we are confident that the inclusion of the DANRA-book link will provide readers with access to the broader verification context, should they wish to delve further into the upper-air performance.

To address this point more fully, we have added a short paragraph to the manuscript, highlighting the positive verification results for upper-air parameters and direct readers to the DANRA-book link for additional details. We believe this approach strikes a balance between conciseness and transparency, while also acknowledging the reviewer's valid interest in a more comprehensive evaluation.

5. The authors mainly refer to the higher resolution being the reason for the improvements compared to ERA5. Are the improvements only attributed to the higher resolution or are there other factors contributing to this, like additional observations, better parametrisations or similar?

We agree that the added value of DANRA over ERA5 arises from a combination of factors, but we emphasize that the kilometer-scale grid resolution is the predominant driver of its improvements. At this resolution, DANRA operates as a cloud-resolving and convection-permitting model, which fundamentally enhances its ability to represent small-scale weather phenomena—particularly those dominated by convective processes (e.g., localized heavy rainfall and coastal wind patterns). This capability is critical for applications in Denmark, where complex coastal and topographic features demand fine-scale atmospheric representation.

That said, local enhanced observations (e.g., higher-density observations and reprocessed satellite products) and physical representation that benefit from finer resolution surface data further contribute to DANRA's performance. These elements work synergistically with the high resolution to reduce biases and improve fidelity, especially in regions where ERA5's coarser grid (e.g., ~31 km) smooths out critical local gradients.

In summary, while the kilometer-scale resolution is the cornerstone of DANRA's added value, the integration of dense observations and optimized model capacity ensures that this resolution is fully leveraged for accurate, locally relevant reanalysis.

We agree that while the paper describes the massive effort put into data acquisition, the summary and conclusion mostly attributes the improved performance to resolution. We have highlighted the observation use in the revised manuscript.

Specific comments:

Lines 42-43: It says that HARMONIE-AROME Cycle 40h1 is the operational model in Denmark and Norway. That might have been true at the time but that information is old by now. I think that this should be stated by writing e.g. "the operational model at the time of the project start" or something similar. Besides HARMONIE-AROME Cycle 40h1 was used by several more countries than Denmark and Norway.

The sentence has been reformulated with a parenthesis stating the time of operational status.

Line 45: It says "...improved modelling for the 'cold' climate condition..." but it is never mentioned what those improvements contain.

A reference to the CARRA system documentation stating these changes has been added

Line 195: "It would be faster if index files were pre-computed and GRIB files were uncompressed". How much faster and what would this mean for storage space?

This depends heavily on how data is stored. For practical purposes, we sorted output based on variable and type (analysis or forecast). By chunking the dataset, one chunk for one analysis variable, spanning about two months temporally, compares roughly in size with one day in the native grib (uncompressed, without chunking). The value of compressing grib messages depends on how output is grouped. In our system, compressing the grib files reduced the required storage by ~30%. The full compressed grib dataset takes up roughly 60% of the zarr dataset. Thus, for creating a two month timeseries for one location requires reading less than 10Mb of data, the same in compressed grib files requires reading ~280Mb.

Lines 199-200: "users should not have to fetch and read too many time steps" and "too many grid points". How many are too many? Please be more specific or reformulate.

We have reformulated in order to highlight our intentions

Figure 7: DANRA always shows lower wind speed than ERA5. In the end of the period, when the bias is positive, this is good but during the first half of the period it is not good. Any explanation to why?

In addition, the transition from negative to positive bias occurs when the number of verification observations is constant. How do you explain this transition? Are there any other observations introduced in the data assimilation during this time?

This is a good observation, and not easy to answer fully. The general structure of the bias suggests that ERA5 in general has overall stronger winds than DANRA, confirmed by Figure 5, showing ERA5 has tendencies to overestimate low wind speeds (< 10 m/s) and underestimate strong wind speeds, the former conditions being the most common. The trend in bias occurs in the same period as where a large increase in assimilated satellite surface pressure measurements (see Hersbach et al, 2020, Figure 3b). Given the direct impact of surface pressure on wind speeds it is reasonable to suspect that this trend, observed in both datasets, is caused by the increase in observations.

Line 256: There is a ? after North Jutland.

Fixed reference

Line 272: "...resulting in a markedly higher wind speed than CERRA." It should most likely be ERA5 instead of CERRA.

Correct. Fixed

Line 283: Another ?. Missing reference?

Fixed reference

Line 284: I don't understand what the authors are trying to say with this sentence? Please be a bit more specific.

The sentence has been reformulated for clarity

Line 320 and Figure 9: The small dots marking the synop stations are really hard to see, especially in areas with high temperature (dark colours)

We have made minor changes to the figure in the hopes that it becomes more visible

Line 321: "these variability" should probably be "this variability".

Sentence has been reformulated

Line 346: Summary and outlook. I can mostly see a summary and not really any outlook. Am I missing something or could this be extended e.g. with some use cases as mentioned in the general comments or more specific ideas and plans for what this data set could be used for?

Reviewer Comment 2 (RC2)

This paper presents a kilometre-scale reanalysis system developed exclusively for Danish weather- and climate-related studies and tools developments.

General comments:

The DANRA reanalysis modelling system and observations are mainly based on well-established modelling and observation infrastructures, such as Arctic, European and global Copernicus reanalysis systems. These systems are well documented. This paper describes specific modelling and observation processing that enhance the system over the Danish area of interest. The Authors demonstrate the added value of the system through verification procedures and case studies by comparing DANRA-produced datasets with the above-mentioned reanalysis datasets. In the moment where data-driven model development is in focus, I found it important that DANRA analyses are made available for this purpose.

Depending on the development and studies' needs, more information about the upper-air datasets would be valuable and would make this paper more comprehensive. Although I agree that the added values from HARMONIE-AROME-based model systems are mostly in better description of the near-surface parameters and fields.

Minor comments/suggestions:

line 4: ...climate reanalysis model or system that...

Changed accordingly

line 17: ... weather and climate evolution or change

Added change

line 20: ...public sectors.

fixed

Line 34: I would define the model discretisation better by separating the horizontal and vertical discretisation.

We have reformulated the discretization

Line 75: describe what parameters are analysed/changed instead of "near-surface and soil properties"

We have added the surface parameters

line 92: I'd use another word than "extensive array" to make it more explicit

We have re-worded the sentence

line 104: used in the ERA5 reanalysis and archived in MARS

Fixed

line 116: what does it mean "CERRA (2018-2021)" I don't understand this

The years indicated the period over which the work done in CARRA and CERRA took place.
Has been removed

line 128: in observation reporting via

fixed

line 130: I'd add a connecting word, like Meaning, the final ... because the first sentence is hanging somehow...

We have reformulated the sentence

line 133 : 1994, through ..., were ... use commas

Fixed

line 137: this looks to me a continuation of the previous sentence, so shouldn't be in separate paragraph.

Fixed

Line 161: "exhibits significant drops in magnitude and at hourly intervals" I'd make it clear that the drops are observed every 3 hours and the datasets are hourly.

We have reformulated the paragraph

Line 256: resolve the question mark. And instead of "wind speeds" "wind intensities"

Fixed

line 269: (Fig. 8c)

Fixed

line 283: resolve the question mark

Fixed

line 287: please find better wording than "most crucial elements in NWP"

We have reformulated

line 294: "had travelled" sounds a bit strange; I'd use other words.

We have reformulated

Line 300: "the time point when", sounds strange to me

We have reformulated

line 358: post-processing with shorter line

Fixed

line 375: delete (Danish Reanalysis) since what DANRA is well explained above.

Fixed