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Estimating climate extreme indices and the related uncertainties using U. S. Climate Reference Network (USCRN) near-surface temperature

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Summary. — The availability of near-surface temperature records from reference networks enables the quantification of measurement uncertainties, which may have an asymmetrical nature due to effects contributing only to the warm or cold bias. In this work, two extreme indices (Consecutive Frost Days and Consecutive Ice Days) and the related uncertainties are calculated for the period 2006–2020 from the U. S. Climate Reference Network (USCRN) and discussed with the calculation without considering the uncertainties. Overall, the results show an accumulated yearly number exceeding 15 periods of CFD and CIDs, with the largest values at the highest latitude covered by the USCRN considered stations. Propagating asymmetric uncertainties for the specified indices revealed a pronounced, latitude-dependent, influence on the indices' estimations due to accounting for the measurement uncertainties. Positive uncertainties show larger values compared to negative ones for the considered Indices. The assessment of uncertainty is a crucial component in enhancing research and decision-making connected to climate change, as it underscores the incomplete understanding of variability in the climate system and the limitations of climate models and observational instruments.

1. – Introduction

Although quantification of the uncertainties is crucial for climate studies and modeling to increase confidence among the users on the concrete knowledge we have of climate variability, for observational measurement or application-based studies, uncertainty is not frequently used yet, with the assumption that *in situ* measurements provide a ground truth with negligible uncertainties. Particularly for the historical records, the challenges in addressing the uncertainties are very high because of the lack of reliable metadata. However, when available, the measurement uncertainty has proven beneficial by indicating the spread associated with the measured or estimated climate variable.

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With the recent availability of climate reference data sources for a few countries, *e.g.*, [1, 2], there is growing attention to the advantages of quantifying uncertainties for the measurements [3]. Climate data records derived from Earth observation-based data, which include rigorous uncertainty estimates, can improve understanding of climate impacts, support modeling activities, climate-based applications and policy development [4]. Previous studies have depicted that uncertainty in one meteorological variable can affect other estimated meteorological variables [5]. Further, the importance of propagating the uncertainties of instrument measurement errors for climate applications has been revealed [6]. For instance, [7] introduced a novel perspective on the impact of accounting uncertainties in extreme heat and cold indices estimations and revealed the need to adopt a different approach in quantifying the impact of cold and warm extremes when measurement uncertainties are considered compared to the traditional approach.

This work expands on this previous effort by examining the effects of including measurement uncertainty in the estimations of two cold-extreme indices calculated from a climate reference network and investigating the impact of accounting for the measurement uncertainties in their estimations. In comparison to single or short events, the prolonged persistence of extreme events magnifies their negative impact on climate applications. Consequently, by comprehending and explaining the uncertainty behavior on long-term, consecutive events, we can advance our knowledge regarding the role and benefits of using measurement uncertainty in climate applications and related decision-making.

To this end, we use the near-surface temperature (NST) measurements and the associated uncertainties from U. S. Climate Reference Network (USCRN) to address the Consecutive Frost Days (CFD) and Consecutive Ice Days (CID) cold-extreme indices, and discuss differences due to considering the quantified uncertainties in the indices' estimation.

2. – Data and method

USCRN NST data and the related uncertainty estimation have been created within the Copernicus Climate Change Service (C3S). Uncertainty calculations are performed using data from the three Platinum Resistance Thermometers (PRTs) simultaneous measurements recorded in the USCRN data files and using metadata made available by the National Centers for Environmental Information (NCEI) of the National Oceanic and Atmospheric Administration (NOAA). The provided uncertainty in USCRN is asymmetric, where some uncertainty sources can only have a positive (negative) influence that leads to a warm (cold) bias. For instance, the presence of heat-emitting equipment near the temperature sensor can artificially raise the measured temperature, resulting in a warm bias. Conversely, if a temperature sensor is exposed to cooling drafts, the resulting measurements will reflect this downward shift, producing a cold bias.

Maximum and minimum daily temperatures and the associated asymmetric uncertainties have been investigated over ninety-five USCRN stations, selected based on their completeness temporal coverage for the period from 2006 to 2020, as reported in fig. 2 of [7]. For the cold-extreme indices, the CFD (CID) are counted when the minimum (maximum) daily temperature is below zero degree for at least five consecutive days. To propagate the effect of associated uncertainties for the considered indices, we follow the approach applied in [7], but for the number of CFD and CID periods that account for the additional constraint of exceeding the threshold condition for five consecutive days. The positive (negative) uncertainty for the extreme indices is defined as summing the number of consistent periods (at least five consecutive days) exceeding the threshold with the negative (positive) expanded uncertainty (*i.e.*, at 95.4% confidence level) and increasing (decreasing) the number of periods consistent with the threshold of zero degree.

3. – Results

Figure 1 reports the accumulated yearly CFD and CID periods. The results depict a total number of occurrences within 15 periods per year, except for a few stations exceeding 20 for CFD, increasing homogeneously with the latitude from southern to northern stations for both indices, in correlation with the increase in cold temperatures. The occurrences of the CFD are evidently larger than the CID. It is worth noting that the length of the captured periods is accounted for only for the lower bound (at least 5 days), with no constraints on the upper bound; this implies that, over a given year, the duration of various periods may vary between stations. However, this falls outside the considered definition of those indices; therefore, it is not factored into the conducted estimation.

A less uniform spatial pattern, but a significant margin of uncertainty has been obtained by propagating the positive and negative uncertainties for CFD and CID. The percentage uncertainty reaches values up to 100% (*i.e.*, equal to the number of detected events without accounting for the uncertainties) at a few years and stations (fig. 2). This introduces a probability scenario for the occurrence of CFD and CID compared to the method without uncertainties.

For both frost and ice days, the probability of surpassing the zero degree threshold is decreased or increased, respectively, by the propagation of the negative and positive uncertainty; when a constraint is added that any of the five consecutive days is consistent with the considered threshold within the measurement uncertainties, the differences in the probability of occurrence of CFD and CID compared to the traditional estimations of a single event, a less uniform spatial uncertainties patterns are obtained, particularly for the positive uncertainty(see fig. 4 in [7]).

Overall, the estimation of the uncertainties for the considered indices depicts pronounced differences from the conventional estimation method and can improve our understanding of climate extremes and, consequently, climate actions and policies.

4. – Conclusions

This work aims to underline the need of providing measurements uncertainties in support of climate studies and applications. Through propagating uncertainties in the climate extreme indices from USCRN NST data and their associated uncertainties, we

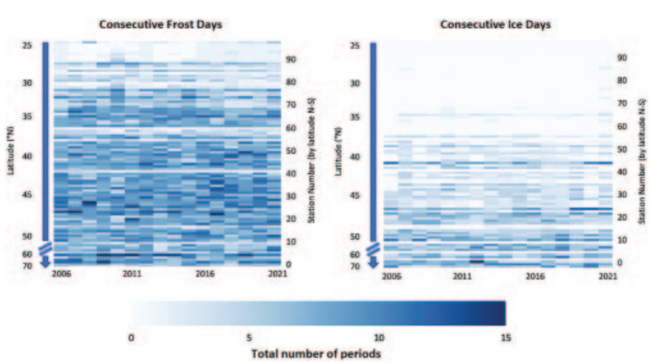

Fig. 1. – Accumulated yearly CFD (left panel) and CID (right panel) periods from USCRN NST. USCRN stations are ordered by increasing latitude from top to bottom in the y-axis.

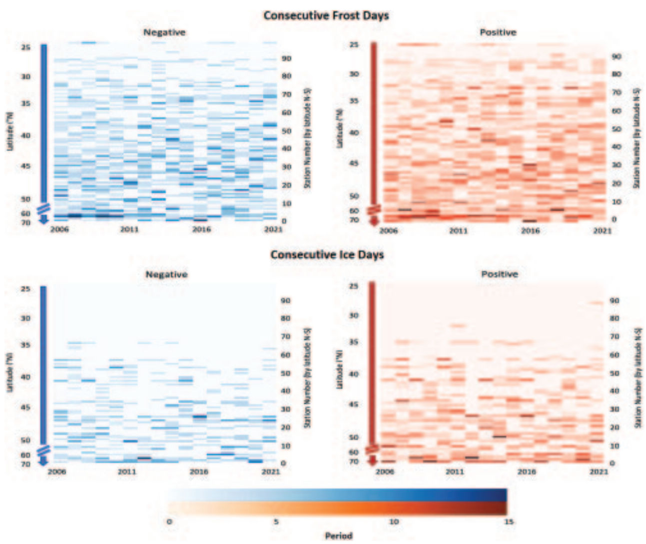

Fig. 2. – Top panels, negative and positive uncertainties for the estimated number of CFD periods calculated using the USCRN measurement uncertainties of NST; bottom panel, same top panel but for CID. USCRN stations are ordered by increasing latitude in the y-axis from top to bottom.

can quantify the probability of climate extremes, within uncertainty range. The propagation of uncertainties in the considered indices highlights a relevant impact in the interpretation on how the cold extremes should be interpreted in light of the accompanying uncertainties, especially when it comes to positive uncertainty that lowers the likelihood of the extremes. The applied approach holds applicability across various domains, indices, climate-based studies or validation activities. It is worth mentioning that uncertainty behavior is not uniform; this depends on several factors, including measurement location, instrument and/or the nature of indices or applications. Therefore, a general conclusion may be elusive, but a discernible indication was provided that accounting for uncertainty quantification can improve research and decision-making processes linked to climate change.

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REFERENCES

[1] Bell J. E. *et al.*, *J. Hydrometeorol.*, **14** (2013) 977.
[2] Bodeker G. E. *et al.*, *Bull. Am. Meteor. Soc.*, **97** (2016) 123.
[3] Madonna F. *et al.*, *J. Geophys. Res. Atmos.*, **127** (2022) e2021JD035220.
[4] Merchant C. J. *et al.*, *Earth Syst. Sci. Data*, **9** (2017) 511.
[5] Ukhurebor K. E. *et al.*, *Measurement*, **165** (2020) 108110.
[6] Zumwald M. *et al.*, *Wiley Interdiscip. Rev. Clim. Change*, **11** (2020) e654.
[7] Madonna F. *et al.*, *J. Geophys. Res. Atmos.*, **128** (2023) e2022JD038057.