RESEARCH ARTICLE

Challenges in reanalysis products to assess extreme weather impacts on agriculture: Study case in southern Sweden

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Abstract

The incidence of dry or wet day sequences has a great influence on crops management and development. The lack of spatialized observed data with appropriate temporal resolution to investigate the changes that has occurred during the last century regarding the length and frequencies of those sequences has led to reliance on reanalysis products. However, the question can be raised about the suitability of those products when evaluating such climate indices and their impacts on crop production. Different products are here investigated to evaluate how the succession of dry and wet days are depicted in Sweden. Results show that reanalysis product tends to overestimate the number of wet days and wet periods and underestimate dry periods. We also showed clearly that the frequency and intensity of dry and wet spells returned can differ widely between products. For instance, number of dry spell events can range from 1 to 11 over the same decade for two different products. This paper does not aim to classify the RPs regarding their goodness or efficiency but try to high-lights the divergence between them in representation of spells which could generate substantial differences in climate impact analysis in agricultural modeling.

Introduction

Variations in crop yield at global and European scale have been shown to be strongly influenced by climate variability [1–3], and the frequency of extreme weather events, such as heatwaves, droughts and floods, is increasing [4–6]. This raises urgent food security concerns about crop yields and food production at local and global scale. A major challenge in research assessing weather impacts on crop yields is to use of spatially distributed datasets covering long periods with enough precision on local events, because local crops processes are influenced by short-duration weather conditions [7]. For instance, agricultural water management need to be conducted on a daily basis and cannot be driven by seasonal parameters for effective mitigation of dry or wet spells for optimal crop production. In recent decades perceptions in Northern Europe have shifted from agriculture being likely to experience overall positive effects of climate change, with wetter and warmer weather promoting crop growth [8], to

extreme daily weather events damaging crop production [9]. With overall wetter weather appearing increasingly likely in the Nordic region [10], the impacts on agriculture may be complex [11]. Precipitation increases mainly outside the cropping season and altered rainfall frequency-intensity pattern within the cropping season are expected to increase the incidence of water deficits [12] and excess saturation, negatively affecting crop production [9]. Investigating the links between climate variability, extreme weather, and crop production locally is limited by poor availability of long-term meteorological datasets with high temporal resolution, as few synoptic weather stations offer the necessary >30 years of continuous daily data [13]. In Sweden, for example, the automatic network providing such data (>90% continuous) has only operated since 1995 [14]. Lack of observed data with appropriate temporal resolution has led to heavy reliance on reanalysis products (RPs), such as ERA5 [15] in Europe or MERRA [16] in the US, in research on historical occurrence and impacts of extreme weather. However, questions can be raised about the suitability of RPs when evaluating climate impacts on crop yield, since these evaluations of those products are conducted on annual to monthly basis or concerning isolated daily extreme events [15–18]. However, dry and wet spells during the growing season are as important as daily extreme or monthly indicators for crop yields. The incidence of dry and wet days influences the quantity and quality of the harvested crop [19], and the irrigation/drainage strategy needed to mitigate weather effects. If a large panel of environmental parameters (e.g. soil type, presence of shallow aquifers) can prevent a meteorological drought to be translated into an agricultural drought, meteorological event such as dry spells are however a prerequisite to trigger agricultural water deficit and impact harvest. In addition, the increase of global temperature and the evaporative demand will accelerate the translation from meteorological to agricultural drought. If the number of rainy days and the succession of dry and wet periods ("period" taken here in an ago-hydrological context, i.e. a period of few days) can impact the crop production, divergence between RPs regarding those climatic criterions may therefore influence the analysis of those impacts at local and regional scale. The objective of this study is to highlight the discrepancy that may exist in between different RPs when considering agro-climatic indicators and highlight the potential risk existing into using different RPs to perform analysis regarding meteorological event which could potentially trigger agricultural events by domino effect. In a first step, a study case is taken here as an illustration of the existing discrepancies: data from four RPs are compared to three weather stations located close to long term instrumented agricultural areas. In a second step, to upscale this consideration and illustrate the exiting divergence at larger scale, a comparison of dry spells occurrence from the four RPs are conducted over the entire southern Sweden.

Materials and methods

Four gridded reanalysis products are compared in this study: MESAN [20] (Resolution 5-km, availability 1979–2013), NASApower (Resolution 0.5˚, availability 1990-present, derived from MERRA-2 [16]), Ag-ERA5 (Resolution 0.1˚, availability 1979–2018, derived from ERA5 [15]), and UERRA-HARMONIE [18] (Resolution 11-km, availability 1961–2018). NASApower was downloaded from the dedicated web platform (https://power.larc.nasa.gov/), Ag-ERA5 was downloaded from the Copernicus Climate data store (https://cds.climate.copernicus.eu/), and MESAN was provided by the Swedish Hydrological and Meteorological Institute (SMHI) (https://www.smhi.se/data/oppna-data/meteorologiska-data/analysmodell-mesan-1.30445). All three datasets were used in their native format. The last product—UERRA-HARMONIE– were issuing from the UERRA project which produce daily precipitation data from 6am to 6am. To adjust to agro-hydrological standard and for comparison with the other RPs, the version used was a reprocessed dataset with daily precipitation summed from 00.00–24.00h kindly
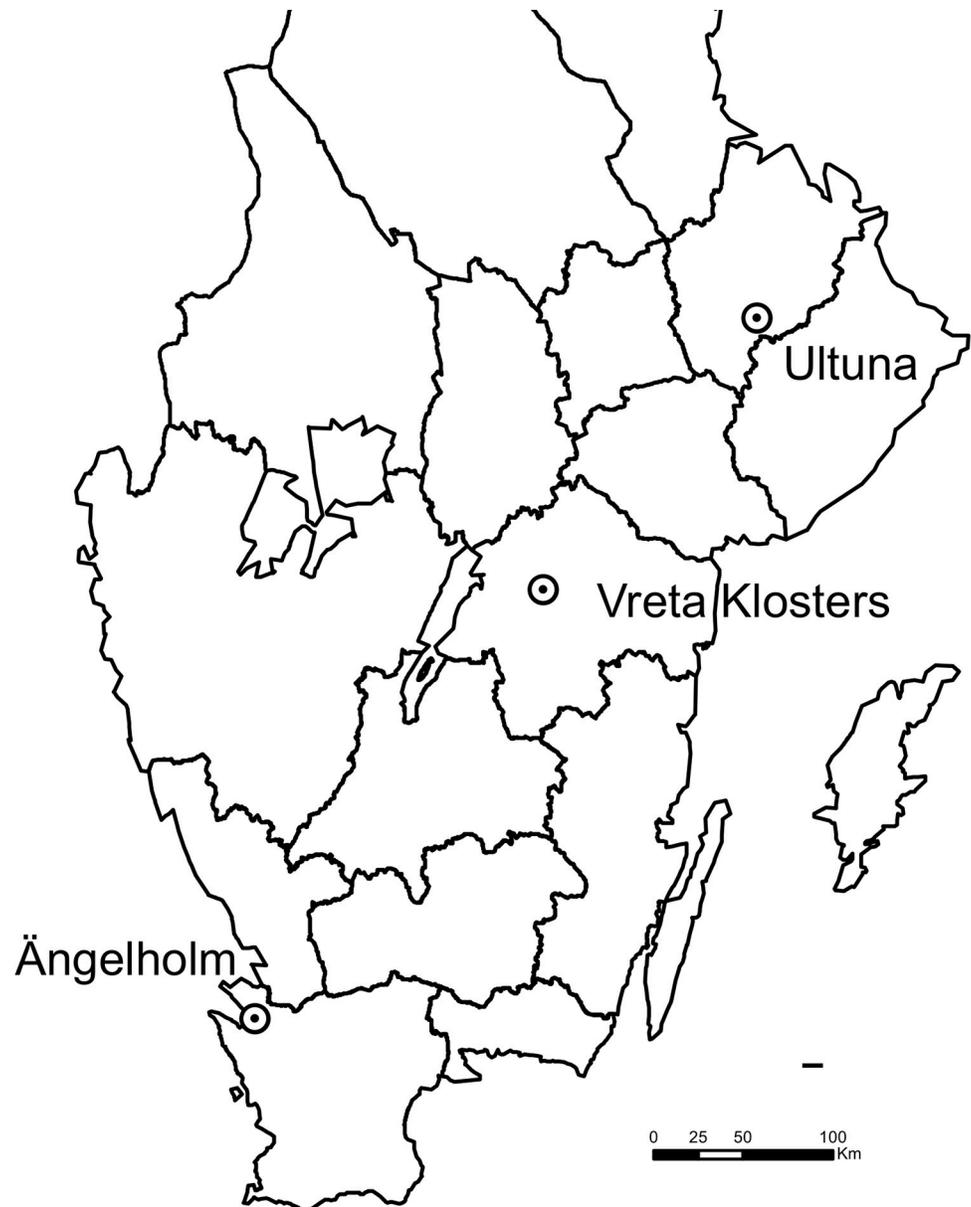
Fig 1. Location of the three study sites (base map from [22]).

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provided by SMHI, which manages the UERRA project. Data from each dataset were extracted using the CDO package of the Max Planck Institute [21]. Overlapping grid cells from each dataset was compared with observed data from three SMHI meteorological stations (Fig 1 and Table 1).

The period of comparison (1990–2000) was chosen as a the only 10-years period with no missing data in any of the dataset. The evaluation has been focused on data for the period April 1st to September 30th, which corresponds to the theoretical crop season in Sweden.

In a first step, all four RPs have been compared to the weather stations, at daily and monthly time step for traditional climatic parameter: maximum and minimum temperature as well as total precipitation. This first assessment can be seen as what is commonly done to assess the

Table 1. Location name, coordinate and elevation of the three meteorological station compared to RPs products. Data have been downloaded from the LantMet database of the Swedish university of agricultural sciences [23].

Location name and references	Coordinate	Altitude (m)
Ultuna	59.82; 17.65	36
Vreta kloster	58.48; 15.51	54
Ängelholm	56.30; 12.86	20

ability of RPs product to describe local climate conditions. After this first analysis, our investigation focus on more specifics agro-hydrological parameters. Three different indicators have been chosen in this study: number of "rainy days", "wet spells" and "dry spells". Rainy days have been defined as days where the precipitation is above or equal to 1mm. This limit is also used to characterize dry and wet spells based on the widely used definition of spells as a periods of at least five consecutive days with precipitation lower and higher or equal to 1 mm, respectively [24]. For each parameters and each time steps, four different metrics are calculated over the entire 10 years period: Lin's concordance correlation coefficient, percent bias, roots mean square error and coefficient of determination (Table 2).

Subsequently to this local analysis, a spatial comparison was made of dry spells sequences from the 4 RPs investigated. MESAN is taken as a reference and compared to the three others products to evaluated their divergence. For this analysis, three subcategories of dry spells are considered: spells of 5 to 9 days, spells of 10 to 14 days and spells of at least 15 days. This last analysis aims to upscale the comparison and investigate if the discrepancy observed locally between products can be seen at regional level. Data manipulation, comparison, statistics, were produced using R studio (Table 2).

Results and discussion

We used simple local examples in a preliminary attempt to assess the challenge of discrepancies between RPs. We compared four RPs against observations from weather stations near long-term agricultural trials in southern Sweden. In a first step we compared the values for precipitation and temperature at monthly and daily time steps (Table 3). Observed and RP-derived minimum (T_{min}) and maximum (T_{max}) temperature showed relatively strong correlations for both daily and monthly values, with CCC >0.95, R^2>0.95, RMSE<2 for monthly values and CCC>0.87, R^2>0.77, RMSE<2.5 for daily values. Regarding the Pbias, which are identical for monthly and daily series, two sites (Vreta Kloster and Ängelholm) return a bias lower than 10% and only at the site of Ultuna is found a bias values between 10% and 20%. The scores for the different metrics calculated on precipitation series are slightly lower than

Table 2. R package and formula for each metrics. (*O* = observation and *R* = reanalysis).

Metrics	Formula	Range	R package
Lin's concordance correlation coefficient (ccc) [25]	$\frac{2\left[\frac{1}{n}\sum_i^n (O_i-\bar{O})\left(R_i-\bar{R}\right)\right]}{(\bar{R}-\bar{O})^2+\frac{1}{n}\sum_i^n (R_i-\bar{R})^2+\frac{1}{N}\sum_i^n (O_i-\bar{O})^2}$	[-1 to 1] 1 = Perf. fit	Epi
Percent Bias (Pbias)	$\left[\frac{\sum_{i=1}^N (O_i-R_i)*100}{\sum_{1=1}^N O_i}\right]$	]-∞; +∞[0 = Perf. fit	HydroGOF
Coefficient of determination (R^2)	$R^2 = \frac{\sum_i^N (O_i-\bar{O})(R_i-\bar{R})}{\sqrt{\sum_i^N (O_i-\bar{O})^2}\sqrt{\sum_i^N (R_i-\bar{R})^2}}$	[0 to 1] 1 = Perf. fit	lm
Roots mean square error (RMSE)	$\sqrt{\frac{\sum_i^n (O_i-R_i)^2}{n}}$	[0; +∞[0 = Perf. fit	HydroGOF

Table 3. Metrics for daily and monthly precipitation and temperature for each of the three sites over the 1990–2000 decade.

		PcP		Tmax		Tmin	
		Daily	Monthly	Daily	Monthly	Daily	Monthly
		Ultuna					
R^2	MESAN	0.89	0.95	0.99	0.99	0.96	0.99
	NASA Power	0.39	0.77	0.94	0.98	0.85	0.97
	UERRA HARMONIE	0.37	0.63	0.94	0.99	0.90	0.98
	AgERA5	0.40	0.77	0.96	0.99	0.86	0.97
RMSE	MESAN	1.34	8.53	0.58	0.18	1.32	0.83
	NASA Power	3.67	24.96	2.04	1.58	2.40	1.48
	UERRA HARMONIE	3.65	31.32	1.53	0.68	1.93	1.10
	AgERA5	3.27	18.38	1.44	0.87	2.26	1.35
Pbias	MESAN	7.40	7.40	-0.20	-0.20	11.10	11.10
	NASA Power	34.40	34.40	-7.90	-7.90	18.30	18.40
	UERRA HARMONIE	36.90	36.90	-2.50	-2.50	11.60	11.60
	AgERA5	18.10	18.10	-4.40	-4.40	15.60	15.60
CCC	MESAN	0.94	0.97	0.99	0.99	0.97	0.98
	NASA Power	0.61	0.77	0.94	0.95	0.90	0.94
	UERRA HARMONIE	0.60	0.68	0.97	0.99	0.94	0.97
	AgERA5	0.63	0.84	0.97	0.98	0.91	0.95
		Vreta Kloster					
R^2	MESAN	0.18	0.46	0.80	0.96	0.79	0.95
	NASA Power	0.34	0.50	0.78	0.96	0.81	0.95
	UERRA HARMONIE	0.06	0.43	0.77	0.96	0.80	0.95
	AgERA5	0.33	0.52	0.79	0.96	0.82	0.96
RMSE	MESAN	4.29	26.70	2.88	1.36	2.38	1.15
	NASA Power	4.07	32.18	2.78	1.04	2.20	0.94
	UERRA HARMONIE	5.40	32.56	2.94	1.06	2.40	1.13
	AgERA5	3.69	23.89	2.73	0.98	2.14	0.94
Pbias	MESAN	-7.80	-7.80	6.20	6.20	-8.30	-8.30
	NASA Power	26.70	26.70	-2.30	-2.30	-1.70	-1.70
	UERRA HARMONIE	24.10	24.10	2.60	2.60	-7.10	-7.10
	AgERA5	6.60	6.60	1.30	1.30	3.40	3.40
CCC	MESAN	0.42	0.67	0.88	0.96	0.88	0.96
	NASA Power	0.57	0.63	0.88	0.97	0.90	0.98
	UERRA HARMONIE	0.25	0.59	0.87	0.97	0.89	0.97
	AgERA5	0.57	0.72	0.89	0.98	0.91	0.98
		Ångelholm					
R^2	MESAN	0.78	0.98	0.99	0.99	0.98	0.99
	NASA Power	0.45	0.70	0.91	0.97	0.83	0.97
	UERRA HARMONIE	0.34	0.65	0.92	0.97	0.90	0.97
	AgERA5	0.51	0.73	0.95	0.99	0.88	0.98
RMSE	MESAN	2.37	7.50	0.99	0.86	0.71	0.25
	NASA Power	3.79	23.67	1.99	1.42	1.93	0.89
	UERRA HARMONIE	4.35	29.14	1.60	0.76	1.52	0.82
	AgERA5	3.67	29.32	1.25	0.57	1.62	0.75

(*Continued*)

Table 3. (Continued)

		PcP		Tmax		Tmin	
		Daily	**Monthly**	**Daily**	**Monthly**	**Daily**	**Monthly**
Pbias	MESAN	7.10	7.10	4.80	4.80	-0.10	-0.10
	NASA Power	14.60	14.60	-7.20	-7.20	5.00	5.00
	UERRA HARMONIE	25.40	25.40	1.80	1.80	-5.20	-5.20
	AgERA5	30.60	30.60	-2.60	-2.60	-4.30	-4.30
CCC	MESAN	0.88	0.98	0.98	0.97	0.99	0.99
	NASA Power	0.66	0.81	0.92	0.93	0.91	0.97
	UERRA HARMONIE	0.57	0.74	0.95	0.98	0.95	0.98
	AgERA5	0.71	0.77	0.97	0.99	0.94	0.98

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the score obtained for temperature. For monthly precipitations, the CCC and R remain quite acceptable with a value >0.6. The only exception is the site of Vreta Kloster where the R^2 falls between 0.43 and 0.52. The RMSE falls between 15 and 30 mm for most of the case, however, the error is lower for MESAN for at least 2 sites (Ultuna and Ängelholm). The daily precipitation metrics are substantially lower than the values obtained for daily temperature. If the CCC remain mainly higher than 0.6 for 2 sites, the R^2 in particular falls under 0.5 for most of the site and the RP, with here again an exception for MESAN which return quite acceptable values for daily precipitation for the 2 sites of Ultuna and Ängelholm. The better performances at the studied sites of the MESAN reanalysis can be seen also when considering the Pbias values for daily precipitation. MESAN return a bias lower than 10% in every case when all the others RP seems to be 15 to 30% biased.

The lower agreement seen for daily precipitation is consistent with the inherent characteristics of precipitation as a more stochastic parameter, with higher variation in time and space than temperature. This preliminary analysis showed good representativeness of RPs in depicting the general climate at the local field site, especially on monthly time steps for precipitation.

If our local climates seem to be substantially well depicted, the aim of this study was to evaluate how RPs capture the incidence, distribution, and accumulated duration of wet and dry days, in order to assess the potential impact on agricultural water management and crop development further analysis and modeling. The four RPs were used to depict the number of rainy days ($\geq$ 1 mm) during the 10 cropping seasons at the study sites, as well as the number of wet and dry spell respectively succession of at least 5 days above or under this 1mm threshold. Every time, the same metrics as previously have been calculated (Table 4).

The number of rainy days per cropping season are inconsistently represented by RPs. For the site of Vreta Kloster and all RPs, R^2 and CCC show unsatisfactory values. For both of the other sites, R^2 are slightly better, but the values of CCC, which encompass also the bias, are mostly under 0.5 too. Similarly, to the previous analysis from Table 3, a substantial difference can be seen for CCC values from MESAN compared to the other RPs with a score of about 0.7 for Ultuna and Ängelholm. For the thee site, the RMSE and the Pbias are quite substantial for the representation of rainy days, with again, a better performance for MESAN, particularly regarding the error. In most of the case (i.e. except MESAN and AgER5 at VretaKloster), the values of Pbias indicate a clear overestimation of rainy days per cropping season.

If, despite this substantial bias, the reproduction of rainy days could still be considered as acceptable for at least the MESAN product at two different sites, the scores for wet spells are even lower. Among the three sites and the 4 RPs, only one R^2 (NASApower at Ultuna) and one CCC (NasaPower at VretaKloster) are higher than 0.5. The percent bias in most of the case are quite substantial, showing a large difference of events between observation and reanalysis

Table 4. Metrics for rainy days, wet and dry spells for each of the three sites over the 1990–2000 decade.

		Rainy days	Wet Spells	Dry Spells	Rainy days	Wet Spells	Dry Spells	Rainy days	Wet Spells	Dry Spells
			Utluna			Vreta Kloster			Ängelholm	
R^2	MESAN	0.79	0.27	0.60	0.03	0.05	0.01	0.75	0.01	0.58
	NASA Power	0.68	0.66	0.47	0.15	0.42	0.40	0.51	0.16	0.32
	UERRA HARMONIE	0.81	0.35	0.42	0.30	0.01	0.03	0.57	0.45	0.16
	AgERA5	0.78	0.15	0.37	0.27	0.47	0.07	0.49	0.29	0.51
RMSE	MESAN	7.64	1.17	1.51	19.48	3.16	2.89	6.48	1.68	1.24
	NASA Power	25.78	4.16	2.58	12.62	1.57	2.09	24.27	3.54	2.56
	UERRA HARMONIE	27.49	3.33	2.91	8.58	2.43	2.50	20.83	3.52	2.32
	AgERA5	19.62	2.52	2.35	10.10	1.54	2.04	24.86	3.49	2.76
Pbias	MESAN	12.5	180	-8.5	-22.8	-58.5	9.2	9.4	68	-5.3
	NASA Power	49.4	760	-19.8	8.3	17.1	-13.8	41.5	190	-19.1
	UERRA HARMONIE	54.3	640	-25.5	1.8	-22.0	-3.4	35.4	179	-9.6
	AgERA5	38.7	480	-16.0	-6.7	-19.5	-2.3	42.6	190	-27.7
CCC	MESAN	0.71	0.33	0.71	0.05	-0.09	-0.08	0.69	0.04	0.72
	NASA Power	0.22	0.15	0.47	0.31	0.59	0.55	0.15	0.08	0.37
	UERRA HARMONIE	0.19	0.12	0.35	0.54	0.10	0.18	0.20	0.19	0.33
	AgERA5	0.25	0.10	0.46	0.45	0.57	0.23	0.14	0.11	0.35

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compared to the total number of event. For instance, NASApower at Ultuna returns 43 wet spells when the observed dataset only 5 over the decade, resulting in a Pbias values of 760%. This overestimation of wet spells is quite consistent with the excess number of rainy days identified previously. The performance of RPs to depict the succession of at least five dry days is somehow similar to the performances for rainy days. The MESAN product seems to be the only one to have reasonable scores for all metrics for at least two sites. At Vreta Kloster, it is the NASApower product which return metrics close to acceptable when all others RPs fail to give a reliable estimation of dry spells over the decade. Constantly with the overestimation of rainy days, bias for dry spells is mostly negative.

From this comparison between our observed data at study sites and the different RPs, it appears that rainy days and wet spells are mostly overestimated when dry spells are underestimated. In addition, the performances are different at each location considering each RP: MESAN seems to perform better at Ultuna and Ängelholm sites when the NASApower is the better RP for the site of Vreta Kloster. Metrics in Tables 3 and 4 represent however only three grid cells of each RP, but this local agro-climatic approach is necessary to investigate climate impacts on crop development and yield (quantity and quality). Our final task was to estimate, at larger scale, the difference which could be induced by the choice of a RP. Scaling up the analysis to territory level using classical weather station is generally impossible, as lack of spatialized observed data is the reason for using RPs. We assessed the difference between RPs by comparing them for the study region, i.e., the agriculture-dominated region of southern Sweden. MESAN was taken as a reference, based on its slightly better performances at our local sites (Tables 3 and 4). This reference has been compared to each of the other RPs (NASApower, HARMONIE-UERRA and AgERA5 and the difference in number of dry spells and in percentage of variation reported on a map. (Fig 2). In order to analyses also the potential divergence between events of different intensity, dry spells have been considered here in three subcategories: 5 to 9 days, 10 to 14 days, and more than 14 days.

The first point to be noted in Fig 2 is the spatial heterogeneity: the divergence between two RPs can be substantially negative at some locations and positive at others. The number of cells
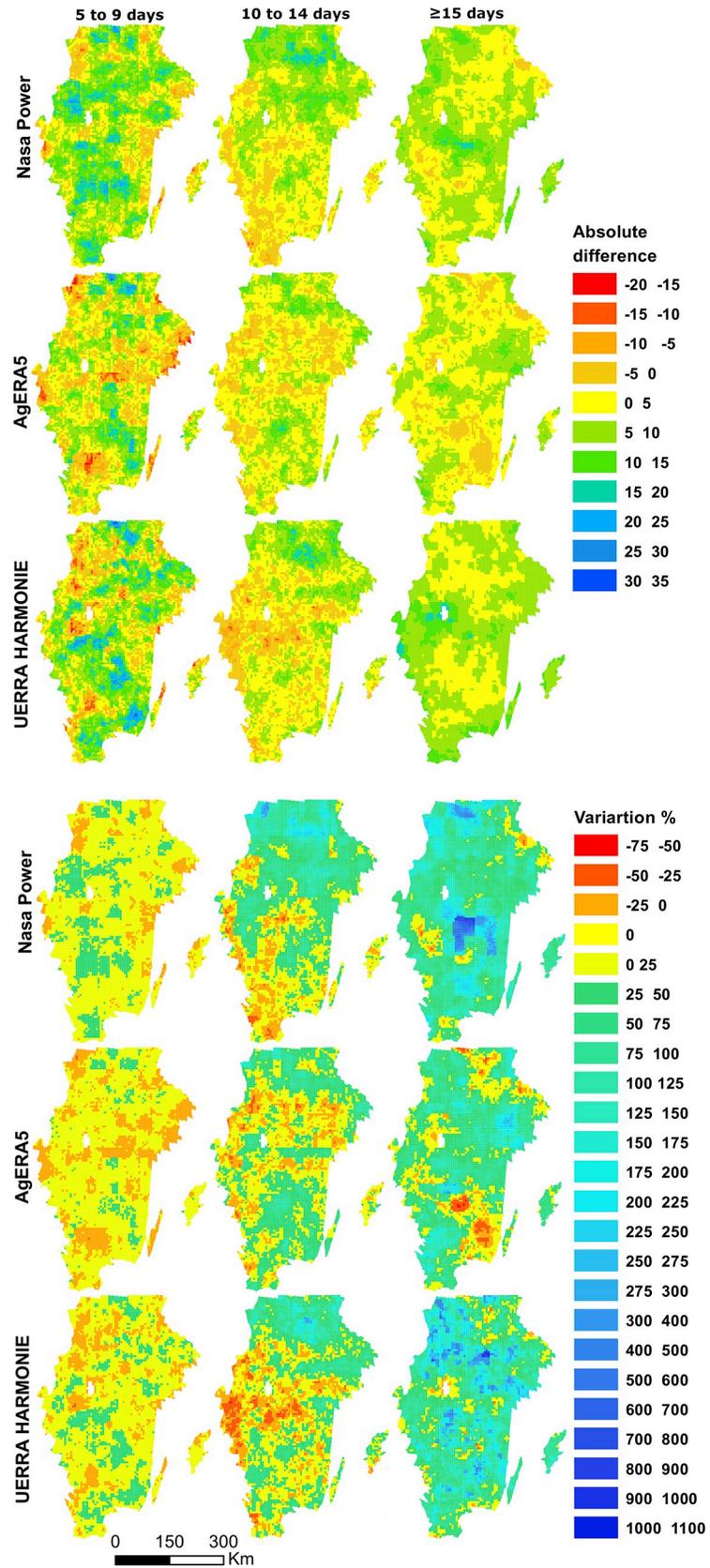
Fig 2. Difference in number of dry spells (top three rows) and corresponding percentage difference (lower three rows) between the MESAN and the three others reanalysis products for southern Sweden, 1990–2000.

where the difference between MESAN and the other RPs is lower or equal to five events during the decade were only oscillating around the average value. For dry spells lasting 5–9 days HARMONIE diverge of less than 5 events with MESAN for 38% of the cells, AgERA5 51% and NASApower 33%. Scores are a bit better for dry spells lasting 10–14 days with respectively 61%, 65% and 51% but decrease again when considering spells of at least 15 days with 43%, 64% and 43%. Those differences in number of events can in addition represent a very substantial difference in percentage between the representation of two RP for the same location. For the cells where the percentage bias is maximum for each of the RP regarding dry spell of at least 15 days, HARMONIE and AgERA5 returned only one event, NASApower returned two, while MESAN returned respectively 11, 25 and 22 events over the decade. Yet, those type of relatively long dry events can have a substantial impact on agricultural practices.

Reanalysis products offer a useful solution to the problem of lack of spatialized observed weather data and are very often used in crop modeling studies [1,3,9,26]. Typical approaches used to validate them are usually considering spatial and temporal large scale factors [15–18]. The ability to describe local monthly climate of all RPs product used here has been confirmed as shown here. However, those scale, as well as the descriptive climatic parameters used to make those assessments may hide some bias on important climatic events of first interest for agro-hydrological research. the bias of dry and wet day sequences highlighted in this paper is coherent with the main objective of RPs which is primarily to characterize the climate at larger temporal and spatial scale. Their usage for agricultural modeling is then adapted to evaluate the interaction between crop production and climate variable at national or regional scale if related to temperature (e.g. [27,28]). However, as illustrated here, those products should be carefully used for assessing climate impacts on more reduced scale especially if the aim is to investigate links between crop production and dry and wet multi-daily periods. As highlighted in Fig 2, a substantial discrepancy between the different products is existing. Very few studies so far have indeed evaluated how reanalysis product represent the successions of dry and wet periods. Among the few, Golian et Al. [29] have conducted a similar study comparing RPs and remote sensing products to evaluate the representation of drought. Their conclusions are similar to the present study, stressing a substantial impact of the precipitation product on the drought analysis. Some other studies have been conducted to evaluate for instance if RPs where producing credible seasonal drought indexes which does not allow to estimate the validity of the occurrence of short dry period (e.g. [30]). One recent publication which could be related to the present study is an investigation on how RPs can capture the occurrence of heavy precipitation cluster across Europe [31]. This latter study concludes on the overall ability of RPs to capture heavy precipitation clustering, but still use a 7 days moving average to characterized a heavy precipitation phenomenon. In addition, it also highlights a consistent area of overestimation over northern Europe, which is in line with our finding of overestimation of wet days and wet spells. One possible factor responsible for the overestimation of rainy days and wet periods, and underestimation of dry periods highlighted here and by the previous mentioned study could be the horizontal resolution of the product. It seems to be supported by the overall best result of the MESAN product (finer resolution). However, at Vreta Kloster study site, the NASApower product, which has a substantially larger resolution than all the other products, performs better, showing that this question is more complicated than just horizontal resolution of the RP. Another factor which should be taken into consideration is the

scale at which are developed the product (from sub continental to global), which have an impact on the density of local data used to generate the reanalysis.

Conclusion

The study presented in this paper showed clearly that the frequency and intensity of dry and wet spells returned can differ widely between RPs. For our three sites, it appears overall that RPs overestimate the number of rainy days and therefore wet spells but underestimate dry spells. A noteworthy finding here was for also the substantial divergence regarding long dry spells (>15 days), i.e., Meteorological events that are likely to increase the risk of agricultural drought, and imply yield and food security implications at local or even regional level. When RP data are used in agricultural models, this divergence in representation of dry and wet spells can generate substantial differences in impact analysis of crop yields and quality. There are also implications for strategies and investments in agricultural water management (drainage and irrigation), as system design, precision, and cost-benefit must be conducted at high spatial and temporal resolution in order to be meaningful for local farmers and beneficiaries. Our findings indicate that agro-hydrologists and agro-meteorologists need to exercise caution when choosing climate RPs for agricultural research. This paper focus only on the occurrence of dry and wet days i.e. meteorological events that can potentially trigger agricultural events. The importance of a good representation of those dry and wet meteorological periods in agronomical studies are becoming more and more important if we consider also the global temperature rise—so evaporative fluxes—which could cause faster transfer from meteorological event to agricultural event.

Representation of meteorological events resulting in dry and wet spells, which is not generally considered when evaluating RP quality, is a future challenge for agro-climatic research. The scientific community should work to improve representations of important agro-climatic features, in particular the distribution of wet and dry spells, in evaluations of soil moisture and yield responses in agro-climatic investigations. Of the four RPs investigated, MESAN (available until 2013) best depicted dry and wet days and spells at our study sites. MESAN was developed over a more limited area (northern Europe) than the other RPs (European or global scale), which could explain its better representation of agro-climatic parameters at the Swedish field site. It is however important for the authors to highlight that this study was not aiming to point out which RP is better. The aim was to show the divergence that can results in using one RP or another. The goodness of RP is somehow depending upon the location considered. This comparison of RPs was conducted in a region with a dense observation data network, on which the RPs are based. Divergence between available RPs may be even stronger in poorly monitored regions, such as sub-Saharan Africa. The issue of accurate representation of dry and wet spells may also arise in results generated by climate models, which are widely used to project food production over the next century.

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References

1. Ray DK, Gerber JS, MacDonald GK, West PC. Climate variation explains a third of global crop yield variability. Nature Communications. 2015; 6(1):5989. https://doi.org/10.1038/ncomms6989 PMID: 25609225

2. Toreti A, Belward A, Perez-Dominguez I, Naumann G, Luterbacher J, Cronie O, et al. The Exceptional 2018 European Water Seesaw Calls for Action on Adaptation. Earth's Future. 2019; 7(6):652–63. https://doi.org/10.1029/2019EF001170.

3. Vogel E, Donat MG, Alexander LV, Meinshausen M, Ray DK, Karoly D, et al. The effects of climate extremes on global agricultural yields. Environmental Research Letters. 2019; 14(5):054010. https://doi.org/10.1088/1748-9326/ab154b

4. Lorenz R, Stalhandske Z, Fischer E. Detection of a Climate Change Signal in Extreme Heat, Heat Stress, and Cold in Europe From Observations. Geophysical Research Letters. 2019; 46(14):8363–74. https://doi.org/10.1029/2019GL082062.

5. Fischer EM, Knutti R. Observed heavy precipitation increase confirms theory and early models. Nat Clim Change. 2016; 6(11):986–91. https://doi.org/10.1038/nclimate3110

6. FAO. The State of Food and Agriculture 2020. Overcoming water challenges in agriculture. Rome. 2020. https://doi.org/10.4060/cb1447en.

7. Sippel S, Meinshausen N, Fischer EM, Székely E, Knutti R. Climate change now detectable from any single day of weather at global scale. Nat Clim Change. 2020; 10(1):35–41. https://doi.org/10.1038/s41558-019-0666-7

8. IPCC. Climate change 2001: third assessment report, impacts, adaptations and vulnerability of climate change. McCarthy JJ et al eds Cambridge, UK, Cambridge University Press. 2001.

9. Beillouin D, Schauberger B, Bastos A, Ciais P, Makowski D. Impact of extreme weather conditions on European crop production in 2018. Philosophical Transactions of the Royal Society B: Biological Sciences. 2020; 375(1810):20190510. https://doi.org/10.1098/rstb.2019.0510 PMID: 32892735

10. Kovats RS, Valentini R, Bouwer LM, Georgopoulou E, Jacob D, Martin E, et al. Europe. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, et al., editors. Climate Change 2014: Impacts, Adaptation, and Vulnerability Part B: Regional Aspects Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2014. p. 1267–326.

11. Wiréhn L. Nordic agriculture under climate change: A systematic review of challenges, opportunities and adaptation strategies for crop production. Land Use Policy. 2018; 77:63–74. https://doi.org/10.1016/j.landusepol.2018.04.059.

12. Mankin JS, Seager R, Smerdon JE, Cook BI, Williams AP. Mid-latitude freshwater availability reduced by projected vegetation responses to climate change. Nature Geoscience. 2019; 12(12):983–8. https://doi.org/10.1038/s41561-019-0480-x

13. WMO. World Meteorological Organization—guidelines on the calculation of climate normals. World Meteorological Organization Geneva, Switzerland, 2017.

14. Olsson J, Södling J, Berg P, Wern L, Eronn A. Short-duration rainfall extremes in Sweden: A regional analysis. 2019. https://doi.org/10.2166/nh.2019.073

15. Hersbach H, Bell B, Berrisford P, Hirahara S, Horányi A, Muñoz-Sabater J, et al. The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society. 2020; 146(730):1999–2049. https://doi.org/10.1002/qj.3803.

16. Gelaro R, McCarty W, Suárez MJ, Todling R, Molod A, Takacs L, et al. The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). Journal of Climate. 2017; 30(14):5419–54. https://doi.org/10.1175/jcli-d-16-0758.1 PMID: 32020988

17. Landelius T, Dahlgren P, Gollvik S, Jansson A, Olsson E. A high-resolution regional reanalysis for Europe. Part 2: 2D analysis of surface temperature, precipitation and wind. Quarterly Journal of the Royal Meteorological Society. 2016; 142(698):2132–42. https://doi.org/10.1002/qj.2813

18. Ridal M, Olsson E, Unden P, Zimmermann K, Ohlsson A. HARMONIE Reanalysis Report of Results and Dataset. UERRA Deliverable D2. 7. 2017.

19. Xie W, Xiong W, Pan J, Ali T, Cui Q, Guan D, et al. Decreases in global beer supply due to extreme drought and heat. Nature Plants. 2018; 4(11):964–73. https://doi.org/10.1038/s41477-018-0263-1 PMID: 30323183

20. Häggmark L, Ivarsson K-I, Gollvik S, Olofsson P-O. Mesan, an operational mesoscale analysis system. Tellus A: Dynamic Meteorology and Oceanography. 2000; 52(1):2–20. https://doi.org/10.3402/tellusa.v52i1.12250

21. Schulzweida U. CDO User Guide 1.9.9. 2020.

22. Lantmateriet. 2020. Available from: https://www.lantmateriet.se/en/geodata/geodata-products/product-list/division-of-district-download-vector/.

23. SLU. LantMet-database. Available from: https://www.slu.se/fakulteter/nj/om-fakulteten/centrumbildningar-och-storre-forskningsplattformar/faltforsk/vader/lantmet/.

24. Task Team on Definitions of Extreme Weather and Climate Events—Guidelines on the Definition and Monitoring of Extreme Weather and Climate Events. World Meteorological organisation (WMO), 2016.

25. Lin L. A Concordance Correlation Coefficient to Evaluate Reproducibility. Biometrics. 1989; 45(1):255–68. https://doi.org/10.2307/2532051 PMID: 2720055

26. Agnolucci P, De Lipsis V. Long-run trend in agricultural yield and climatic factors in Europe. Climatic Change. 2020; 159(3):385–405. https://doi.org/10.1007/s10584-019-02622-3

27. Toreti A, Maiorano A, De Sanctis G, Webber H, Ruane AC, Fumagalli D, et al. Using reanalysis in crop monitoring and forecasting systems. Agr Syst. 2019; 168:144–53. https://doi.org/10.1016/j.agsy.2018.07.001 PMID: 30774182

28. Pelosi A, Terribile F, D'Urso G, Chirico GB. Comparison of ERA5-Land and UERRA MESCAN-SUR-FEX Reanalysis Data with Spatially Interpolated Weather Observations for the Regional Assessment of Reference Evapotranspiration. 2020; 12(6):1669. https://doi.org/10.3390/w12061669

29. Golian S, Javadian M, Behrangi A. On the use of satellite, gauge, and reanalysis precipitation products for drought studies. Environmental Research Letters. 2019; 14(7):075005. https://doi.org/10.1088/1748-9326/ab2203

30. Chen S, Gan TY, Tan X, Shao D, Zhu J. Assessment of CFSR, ERA-Interim, JRA-55, MERRA-2, NCEP-2 reanalysis data for drought analysis over China. Climate Dynamics. 2019; 53(1):737–57. https://doi.org/10.1007/s00382-018-04611-1

31. Yang Z, Villarini G. Examining the capability of reanalyses in capturing the temporal clustering of heavy precipitation across Europe. Climate Dynamics. 2019; 53(3):1845–57. https://doi.org/10.1007/s00382-019-04742-z