IS-ENES3 Milestone MS14/M3.5

Report: Workshop on climate indices - Eastern Europe perspective

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ABSTRACT

A special workshop was organized in Eastern Europe on Climate indices requirements. Used by a broad user community for many applications outside the climate modelling community, climate indices provide compact impact-oriented information on key physical parameters. A reference specification of a core set of indices has been developed by the joint CCl/CLIVAR/JCOMM Expert Team (ET) on Climate Change Detection and Indices (ETCCDI), and these have been implemented in different computational software including the ICCLIM tool. Within the workshop the existing indices were evaluated and the need for new ones in existing and new communities was explored. Organized by: SMHI, CERFACS, KNMI, and FPUB.

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1. Objectives

The IS-ENES3 consortium was organized an online workshop ‘Climate indices - Eastern European perspective’. The workshop was an online effort to collect information on the current status about usage and implementation of different climate indices in the region. All collected information was used to draft requirements and recommendations for the future. The main objective of the report is to review the usage of existing indices and explore the future needs in these broader and new communities. The workshop was organized as two online meetings, combined with online surveys and online interviews between them.

2. Description of work: Methodology and Results

Introduction

Used by a broad user community for many applications, climate indices provide compact information on key physical parameters. A reference specification of the indices has been developed by the joint CCl/CLIVAR/JCOMM Expert Team (ET) on Climate Change Detection and Indices (ETCCDI)[1], known as ETCCDI list of indices, but since this initial effort, many new developments have emerged. In particular, additions have been developed by the WMO/CCl Expert Team on Sector-specific Climate Indices (ET-SCI)[2] as well as by the collaborative effort of European Climate Assessment & Dataset (ECA&D)[3] and the EU-INDECIS project[4]. These share the core set developed by ETCCDI but have also added various impact-oriented climate indices. Moreover, various local and/or targeted indices have been developed during recent years.

Within the IS-ENES3 project, the special workshop on climate indices requirements in Eastern Europe was organized[5]. The IS-ENES3 project aims at further engaging with the community of users of IS-ENES services, by widening the user base through training, engaging the community in co-creating standards and expressing needs, and engaging the younger generation.

The workshop objective was to evaluate the established practices regarding climate indices and explore the current and future needs, including broader and new communities in Eastern Europe. This workshop was organized not only for climate scientists but also for researchers and users from different disciplines (agriculture, forestry, water resources, public health, etc.) who often use different climate indices.

The workshop was an online effort, organized as a combination of several activities: two online meetings, one online survey, and online interviews. The initial online meeting was organized to present the main goals and planned activities which are the foundation for this report. Also during the initial meeting, the discussion on different topics related to climate indices was initiated. After the initial meeting, the online survey was set up. When the survey was finished, an online interview with a limited number of the survey participants was organized to better understand some of the issues raised during the initial meeting and following main results from the survey. Finally, additional discussion about the main findings of the survey and interviews was organized during the second online meeting.

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1 http://etccdi.pacificclimate.org/index.shtml

2 https://www.wcrp-climate.org/etccdi

3 https://www.ecad.eu

4 http://www.indecis.eu

5 https://is.enes.org/events/workshops/workshop-climate-indices-eastern-european-perspective

The topics related to the climate indices that were covered during all activities are: indices definition, usage and current practices; data sources for indices calculation; software for calculation and visualization; gaps and limitations in current knowledge, and recommendation for future developments.

There were 97 registered workshop participants (60 from Eastern Europe, 31 from Western Europe, one from America, one from Asia and 4 from international organizations; 28 different countries in total), from which 77 attended the initial online meeting. After the initial meeting, there were 32 participants from 19 countries that filled in the survey (Figure 1). Although the main focus was on the Eastern European countries, 7 survey participants were from Western Europe. These additional responses outside of Eastern Europe were useful as they were seen as an opportunity to draw some tentative comparison between two regions in terms of practices related to the calculation and application of climate indices. After the survey, six online interviews were conducted with representatives from Bulgaria, Estonia, the Republic of North Macedonia, Romania, Serbia and Turkey. Finally, at the end of September, the results of the survey were presented during the final online meeting attended by 32 participants.

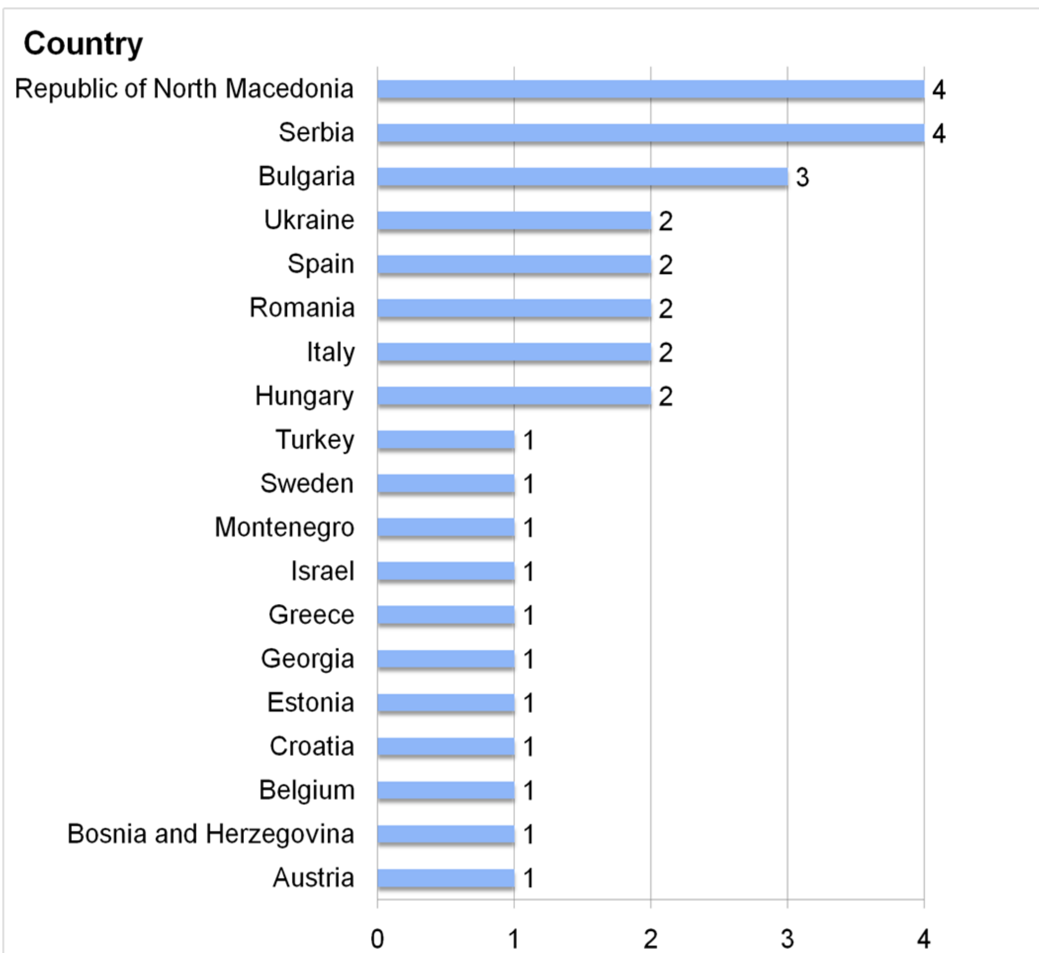


Fig. 1 Number of respondents from different countries that participated in the survey.

Participants in the survey represented a variety of expertise (Figure 2), with the largest number of participants with expertise in Climatology. According to survey results, 28 out of 32 participants listed Climatology as one of the areas of expertise. For the other sectoral expertise, Agriculture was represented with the largest number of responses, followed by experts in Water, Health, Energy, Forestry, Biodiversity, and Meteorology. Several other areas of expertise had one response.

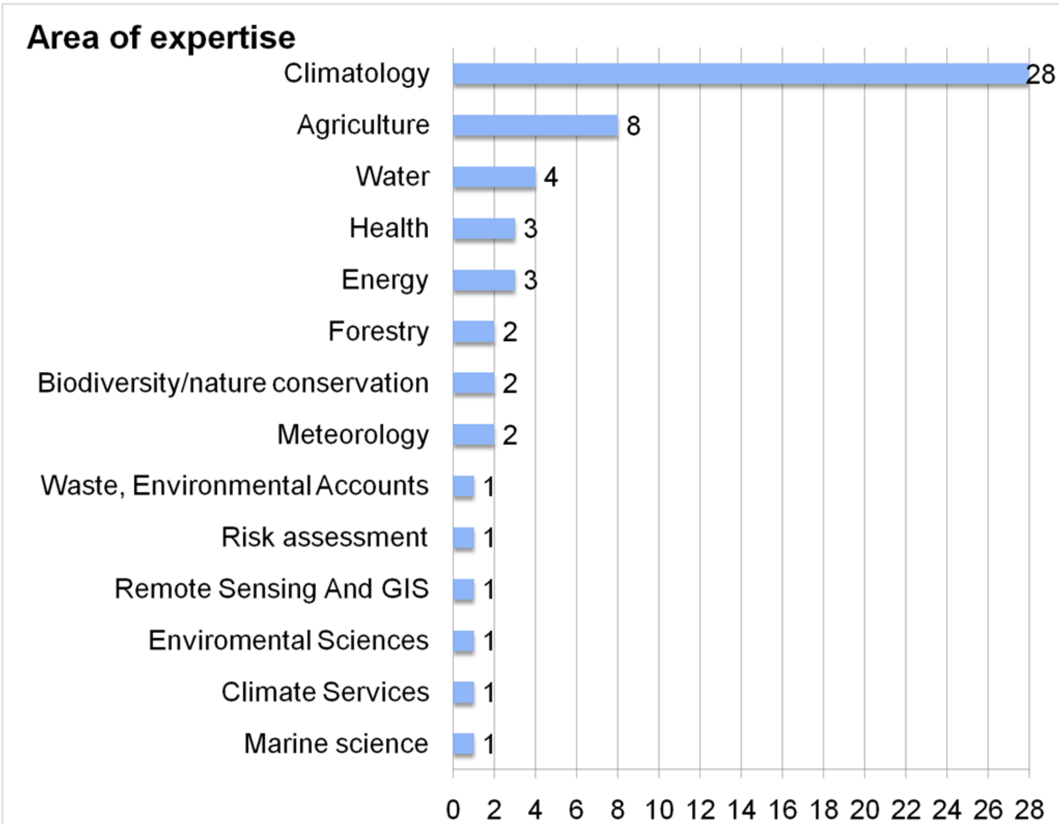
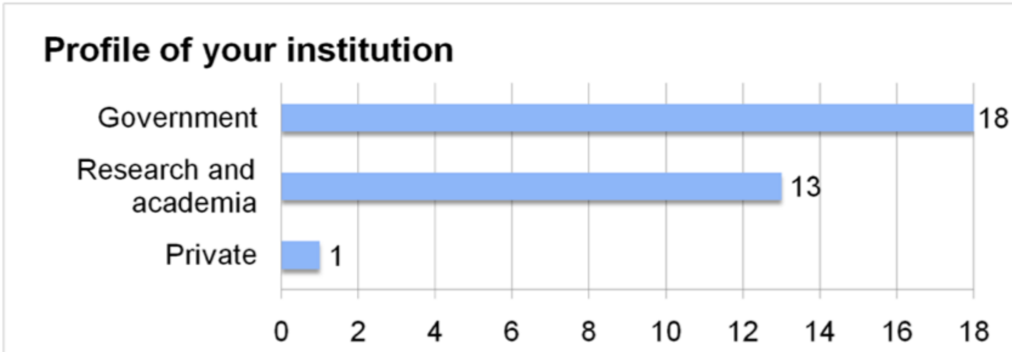


Fig. 2 Area of expertise of the survey participants (multiple expertises were possible to select).

There was almost equal representation of governmental institutions and research and academia, with only one representative of the private sector (Figure 3a). Half of the participants consider themselves as climate data users, six of them as climate data providers, and about one third as both, climate data providers and users (Figure 3b). The majority of participants expressed their personal views and experiences in working with climate indices while five of them expressed general experience at their institution (Figure 3c).

a)



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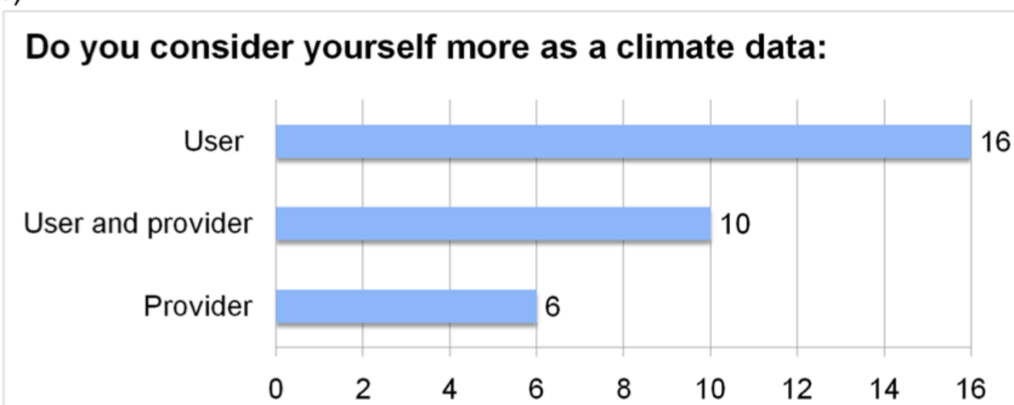

c)

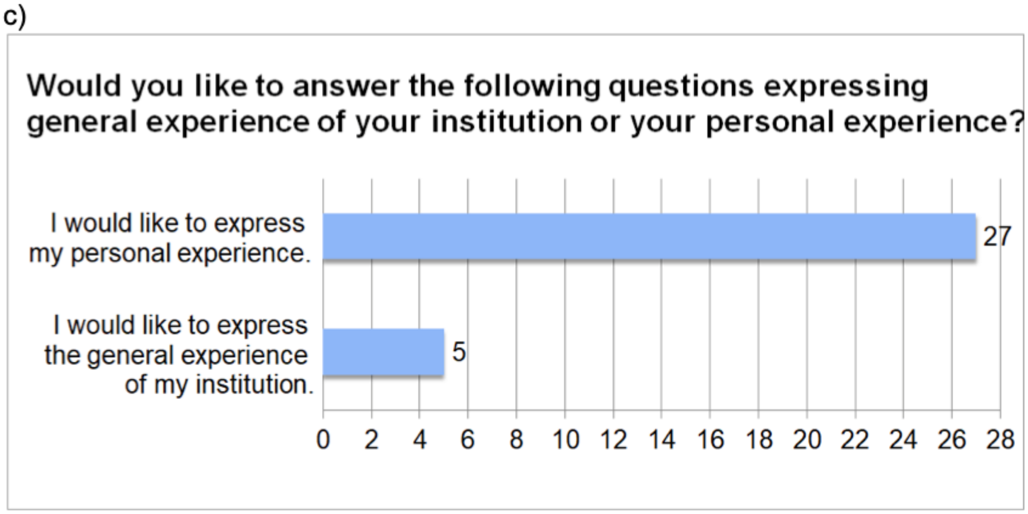

Fig. 3 General information of survey participants.

Indices definitions

Indices are diagnostic tools used to describe the state of a climate system[6]. Each climate index is based on a certain parameter(s) and describes only certain aspects of the climate, so there are a variety of climate indices that have been defined. Currently, there are several so-called indices lists that include indices definition, and sometimes a short explanation about index usage, or suggestion for potential index application in different sectors. Some of the lists are prepared as a part of international working groups activities, e.g. ETCCDI[7] and ET-SCI[8], others by international projects, e.g ECA&D[9] and INDECIS projects[10]. The goal of the workshops and the survey was to understand which indices and indices lists are most commonly used in the region, and also to collect information on whether some new or additional indices that are not part of these lists are used too. A quarter of survey participants think that existing climate indices do not satisfy their needs (Figure 4), implying that additional indexes should be developed and included in the existing common lists. The most commonly used indices definition list is the ETCCDI list, followed by ET-SCI and ECA&D list (Figure 5). Four participants were not aware of any climate indices list.

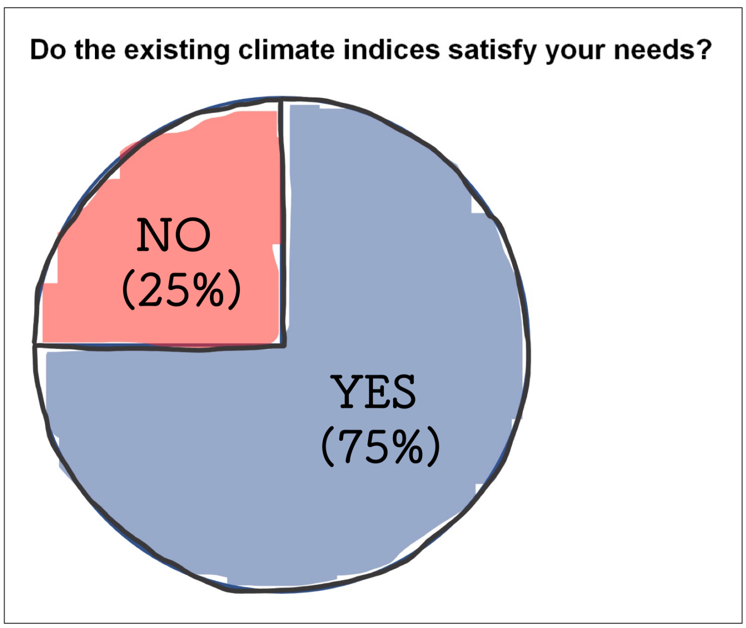

Fig. 4 Satisfaction of survey participants with existing climate indices.

[6] One formal definition can be found in AMS Glossary of Meteorology

[7] http://etccdi.pacificclimate.org/list_27_indices.shtml

[8] https://climpact-sci.org/indices/

[9] https://www.ecad.eu/download/millennium/millennium.php

[10] http://www.indecis.eu/docs/Deliverables/INDICIS-list_4.2.pdf

To meet their own needs and those of their users in turn, several participants indicated the practice of modification of existing definitions and/or development of their own indices. Some additional indices that are not included in the commonly referring lists and that are used by participants are given in Table 1.

Also, some of the participants expressed experience in the implementation of complex indices (indices that combine multiple climate variables) (Figure 5). The reasoning behind the indices that are developed or modified is additional flexibility in terms to a specific time of the year or specific needs from different sectors.

Tab 1. Indices reported by participants that are not included in commonly referring indices lists.

Index/Index purpose	**Reference**
Groundwater drought index	/
Evapotranspiration stress index	/
Soil moisture availability index	/
Products based on Meteosat	/
Clothing resistance parameter	rmets.onlinelibrary.wiley.com/doi/full/10.1002/joc.681 aseestant.ceon.rs/index.php/geopan/article/view/23717 www.mdpi.com/2073-4433/12/1/84
First autumn frost	/
Last spring frost	/
Number of zero (temperature) crossing days	/
Indices codesigned with the wine, olive oil and wind sectors	cran.r-project.org/web/packages/CSIndicators/index.html
Drought and heat stress indices for decadal predictions	www.nature.com/articles/s41612-021-00189-4
Season for frequency indices occurrence (e.g. SU, FD) given in the first and the last day of occurrence in a year/month	/
Length of the season with difference frequency indices (e.g. SU, FD) given in total number of days in a year/month	/

There are also some additionally reported indices that use data other than the air temperature and precipitation accumulation, which are the common input for indices calculation, like Wind Power Density, Wind Capacity Factor, Evapotranspiration Stress Index, Soil Moisture Availability Index, and satellite products based on Meteosat. On the other hand, participants pointed out that implementation of new and complex indices, although they can help to overcome some deficiency in indices, also require a lot of additional research.

In addition, it was underlined that most of the indices, and mostly percentile based, that are commonly used, often represent moderate events (the one that typically occur a few times every year), but indices for the rare extreme high-impact[11] events (once-in-a-decade) that lie in the tails of the distribution should be considered for analysis of extremes as well. A number of the existing indices are not relevant enough in some fields or sectors to show the impact of certain climate hazards (e.g. the exposure to river ice - as a function of freezing degree day[12] or accumulated freezing degree day[13]). In addition, there are no well established specific indicators/indices that can be used to assess the exposure to hydrometeorological hazards specific to mountain environments that can be exacerbated by climate change (e.g. flash floods, rapid snow melting, landslides, rain on snow events).

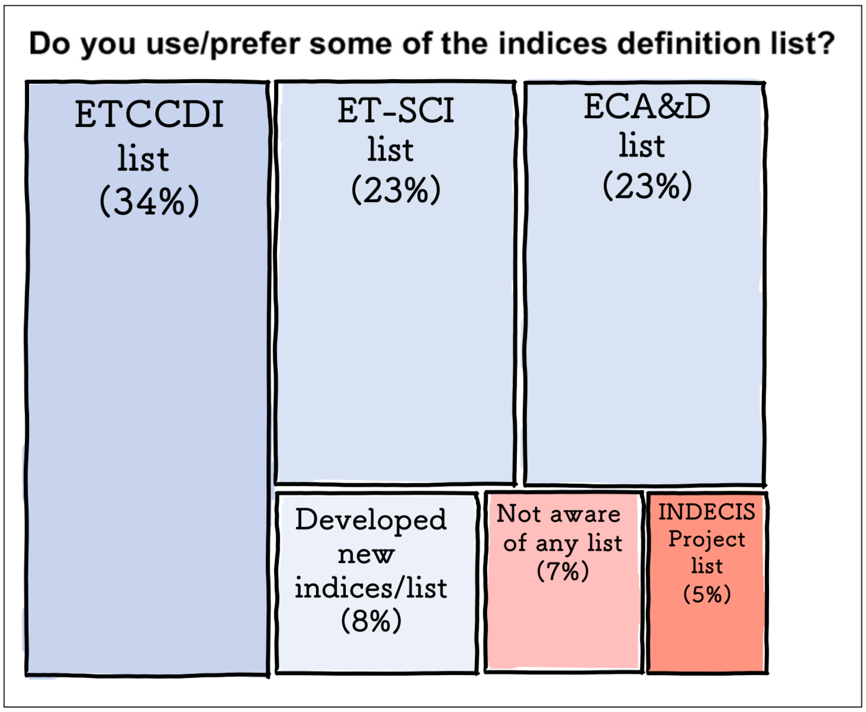

Fig. 5 Preferred indices definition list by the survey participants (percentage of 57 responses, multiple choices were possible).

Some participants indicated that indices derived from sub-daily data should be defined as well taking into account the importance for some sectors, such as agriculture and energy (wind and solar energy, general electricity consumption). There is also a need to develop indices about wind, radiation, relative humidity and insolation, as well as further research on tailored indices in collaboration with impact scientists and application experts.

[11] https://www.ecad.eu/documents/WCDMP_72_TD_1500_en_1.pdf

[12] download.comet.ucar.edu/memory-stick/hydro/basic_int/river_ice/navmenu.php_tab_1_page_9.0.0.htm

[13] download.comet.ucar.edu/memory-stick/hydro/basic_int/river_ice/navmenu.php_tab_1_page_8.0.0.htm

The usage of indices can depend on the type of required analysis but also on users' understanding and expectations. Regarding an index type, the participants reported that the fixed threshold indices are regularly used (Figure 6). This type of indices is easy to implement and also easy to understand by the general public and many users. In addition, they are convenient for local applications and therefore generally used in weather warnings and different climate analyses, e.g. climate bulletins. However, a limitation is that the threshold value may be primarily relevant for a specific climatic region. For example, the index "number of summer days" (SU) has a temperature threshold of 25 °C, which may be regarded as too low for southern Europe. Moreover, it should be noted that indices based on thresholds can be sensitive to systematic differences between data from different sources. For example, if indices derived from meteorological observations are compared with indices calculated from climate projections, biases in the latter can be a source of potential problems and inconsistency.

To a lesser extent, participants responded in terms of application of percentile-based indices. Percentile-based indices are more robust and comparable across different climatic regions so they are more convenient for analyzing large geographical areas as well as for climate predictions and studies focusing on climate variability, climate change and associated extremes. However, care should be taken when comparing the percentile-based indices since they are very sensitive to which period is used as the reference.

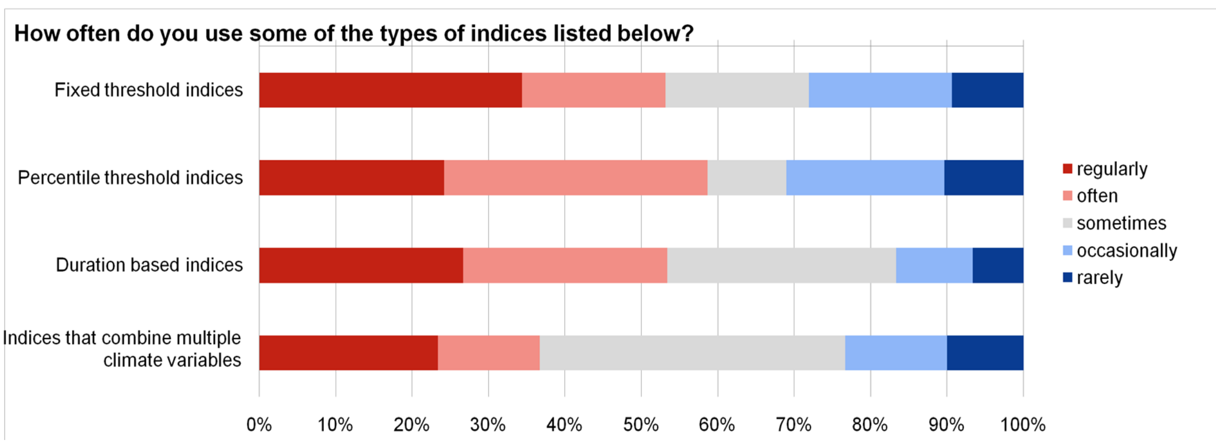

Fig. 6 Frequency of use of some types of climate indices (multiple choices were possible).

For duration based indices and indices that combine multiple climate variables, in terms of their use, the category *sometimes* was the one which was the most selected (Figure 6). These indices are commonly applied to estimate the impact of some weather/climate extremes in various sectors (e.g. health, agriculture). The complex indices require more data and often from different sources (ground measurements, satellite observations, modeling) and often the data that are not available continuously. Sometimes they require variables with higher time resolution such as sub-daily and/or hourly. In addition, these indices are usually more complicated for understanding. Also, sometimes if the indices units are given in can create confusion to the users/stakeholders (e.g. magnitude and amplitude of heat waves and cold waves calculated based on excess heat and cold

factors). In general, complex indices are less demanded by users because most of the time they don't know enough about them but they are very well accepted if explained well.
As a general conclusion, as complexity of the indices types increases, the general use decreases. Therefore, the simplicity of index definition, and additionally if it is combined with self explaining name, can be seen as an advantage in terms of how often an index will be used.

Info box - Percentile threshold calculation

For the calculation of the percentile-based climate indices (e.g. Warm Spell Duration Index - WSDI or Contribution to total precipitation from very wet days - R95pTOT) the first step is the calculation of the percentile threshold. After the percentile threshold is calculated using a time series of the input variable over some reference time frame often called the base period (e.g. normal period 1961-1990), the index values can be calculated over the arbitrary time period, which can be much longer in comparison to base period. It was shown that the final result for the threshold value, and eventually index value, can be sensitive to decisions in threshold calculation methodology. One of them is the way how the percentile is calculated (from the distribution of the input variable), and another one is the selection of the base period. Probably due to this sensitivity, some of the participants reported that, using different software for the calculation of the same percentile-based climate index and using the same input data set, they obtained different results for index values. To overcome potential inconsistencies and decrease sensitivity related to the selection of the base period, some of the available software for indices calculation have implement so called *bootstrapping procedure* which provide that threshold calculation is more robust*. One of the software with implementation of this procedure is ICCLIM, and the implementation is accompanied with a detailed documentation about the both, the bootstrapping procedure and percentile calculation. Detailed documentation of the implementation of percentile-based indices calculation is important, because it can help users to track potential differences that can appear just by using different software.

(*) Zang et al., 2005, Avoiding Inhomogeneity in Percentile-Based Indices of Temperature Extremes.

Approach to indices calculation and data sources

This section is focused on indices calculation and input data handling. Processing large amounts of data can be very challenging. That is why some institutions have developed applications that allow users to explore, download, and analyze already calculated climate indices.

Following the survey results, online interviews and discussions during the workshop meetings, the overall impression is that the majority of participants calculate indices from input data by themselves and less frequently use already calculated indices and already prepared products. Within the survey, three options were available: 1. We calculate indices from input data, perform analysis and visualization of results; 2. We use already calculated indices and only perform analysis and visualization; and 3. We (only) use already calculated and visualised results and products. Only two responses were negative regarding the first option and these two respondents indicated that they use already calculated indices but perform analysis and visualization themselves (Table 2). In addition, several respondents stated that they use already calculated indices, beside the self-calculated ones.

On the other hand, only two responded that a fully developed product (option 3) is used, but they also positively responded for the first and second option. This implies that none of the respondents uses only products that are pre-calculated, pre-analyzed and pre-visualized by a third party. This clearly indicates that even though such products are available they are rarely used as a sole source of information.

Tab. 2 Approach of survey participants in terms of indices application and usage (multiple choices were possible).

	Number of response																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	**SUM**
We calculate indices from input data, perform analysis and visualization of results.	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**30**
We use already calculated indices and only perform analysis and visualization.	N	N	N	N	N	Y	Y	N	N	Y	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	Y	N	N	N	N	N	Y	N	**6**
We (only) use already calculated and visualised results and products.	N	N	N	N	N	N	Y	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	**2**

Following the responses of the survey participants, 29 out of 32 participants confirmed that they use station observations provided by their national meteorological services as input datasets for indices calculation (Table 3). The second most used input data are gridded observations and climate projections, with 16 positive responses, followed by reanalysis with 14. In comparison to this, satellite and different forecast data (both short and long term forecasts) are rarely used. Two of the respondents indicated that they don't use any data, probably due to the fact that some of them indicated that they use only already calculated indices and products.

In terms of specific databases and dataset, commonly used gridded data are EOBS[14], CarpatClim[15], DanubeClim[16] and ROCADA[17] (a gridded daily climatic dataset over Romania) as well as ERA-5[18] and NCEP/NCAR[19] reanalyses. CMIP5/6 and CORDEX databases are the main sources for climate projection information from which climate indices are calculated. Additionally, a few users explicitly mentioned COPERNICUS data services as an entry point for data access.

Tab. 3 Input data used for climate indices calculation (multiple choices were possible).

	Number of response																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	**SUM**
Station observations	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**29**
Gridded datasets	Y	N	N	Y	N	Y	Y	N	N	N	Y	N	N	Y	Y	N	N	N	Y	N	Y	N	Y	Y	Y	Y	Y	N	Y	N	Y	N	**16**
Reanalysis	Y	N	N	Y	Y	Y	N	Y	Y	N	N	N	N	Y	Y	N	N	N	N	N	Y	N	N	Y	Y	N	Y	Y	N	N	Y	N	**14**
Climate projections	N	N	N	Y	N	N	N	Y	N	N	N	Y	N	Y	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y	N	Y	N	Y	N	Y	Y	**16**
Satellite data	N	N	N	N	N	N	Y	N	Y	N	Y	N	N	N	N	N	N	N	N	N	Y	Y	N	Y	N	N	Y	Y	N	N	N	N	**8**
Short range forecast	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	**2**
Long term forecast	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	**1**

Respondents consider quality control and longer time series of datasets to be of primary importance for future improvements (Figure 7). This is followed by the importance of improving data availability, easier data access and access to a wider set of variables. Less importance for improvement is given to the horizontal resolution of the datasets. There are mixed responses regarding time frequency, some respondents consider it less important to improve while others give this option a higher priority.

Some additional comments and recommendations to improve the input data are made. There is a necessity for increasing the density of the meteorological station network, homogenization of data and extending datasets' coverage back in time. In addition, some participants think shortcomings in high-resolution gridded observations and regional reanalyses should not be neglected. As for the technical aspect, there is a need for stricter adherence to format convention and rules that will ensure easier data handling.

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[14] https://surfobs.climate.copernicus.eu/dataaccess/access_eobs.php

[15] http://www.carpatclim-eu.org/pages/home/

[16] http://www.carpatclim-eu.org/danubeclim/

[17] https://doi.pangaea.de/10.1594/PANGAEA.833627

[18] https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

[19] https://psl.noaa.gov/data/gridded/data.ncep.reanalysis2.html

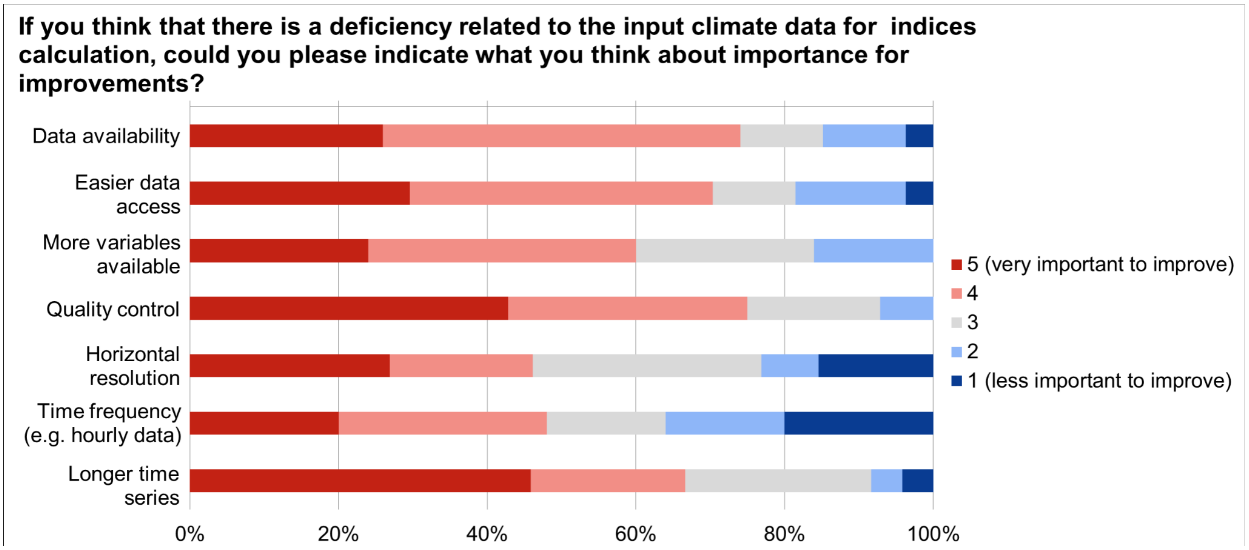

Fig. 7 Importance for improvement of input data according to survey participants.

With regard to already calculated indices, there is a need for more metadata information e.g. more detailed information on methodology and calculation steps from input data to calculated value. In addition, a need for additional sectoral indices is expressed. Some of the participants, in case of already calculated indices, made a request to improve the quality of high-resolution downscaled products. Suggestions were also made that for some products additional information regarding its economic value should be included. Participants proposed potential development of a common repository e.g. a new website or upgrades of existing one, which could contain the information about all available datasets, other web platforms and other relevant information related to climate indices.

It is stressed that there is room for improvement of graphical products since the visualisation of the indices is very important to communicate with the stakeholders. Also, the pre-computed graphical products should be made available in other formats than standard image/document formats (gif, jpg, png, pdf) such as different georeferenced raster formats (e.g. geotiff). These formats are easier to import and analyse in different GIS software, for example in case when climate information should be to overlaid with other local maps (local infrastructure, agricultural land etc.) that are often developed in local geographical coordinate system and not on regular longitude-latitude grid, or rotated grids that are common in regional climate modeling.

Software

There are various software packages for climate indices calculation as well as software for their graphical presentation. This section provides an overview of the software in use by the survey participants.

The standard spreadsheet software, such as MS Excel, OpenOffice Calc or Google sheets are the software packages that are selected by the largest number of survey participants, 18, as a common tool for indices calculation (Figure 8). Regarding other options, there were 13 responses for offline software, specially developed for indices calculation, no matter if it is developed by a third-party or in-house. Online software received significantly less positive responses.

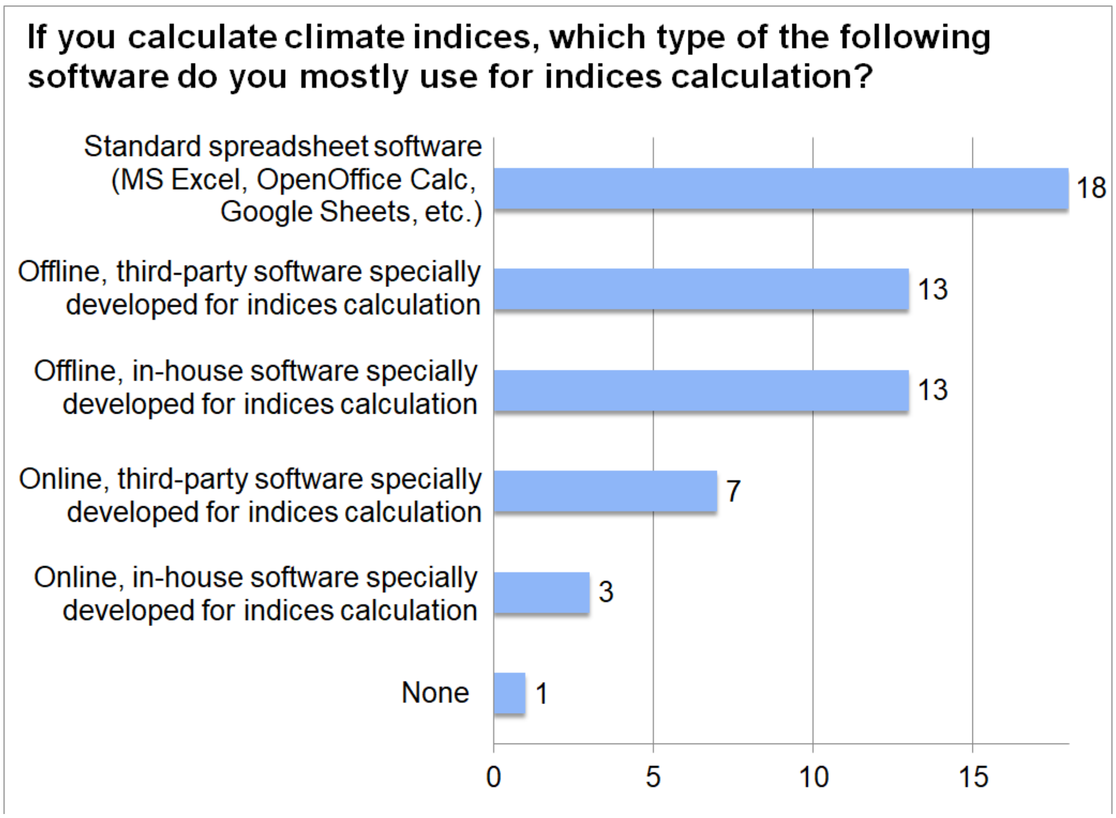

Fig. 8 Type of software used for indices calculation by survey participants (multiple choices were possible).

For visualisation of results, the most applied software is offline software developed by third-party (20 responses) and standard spreadsheets (18 responses), followed by offline in-house and online developed by third party software (Figure 9). Again, following the survey results, online software is less “popular” among the participants.

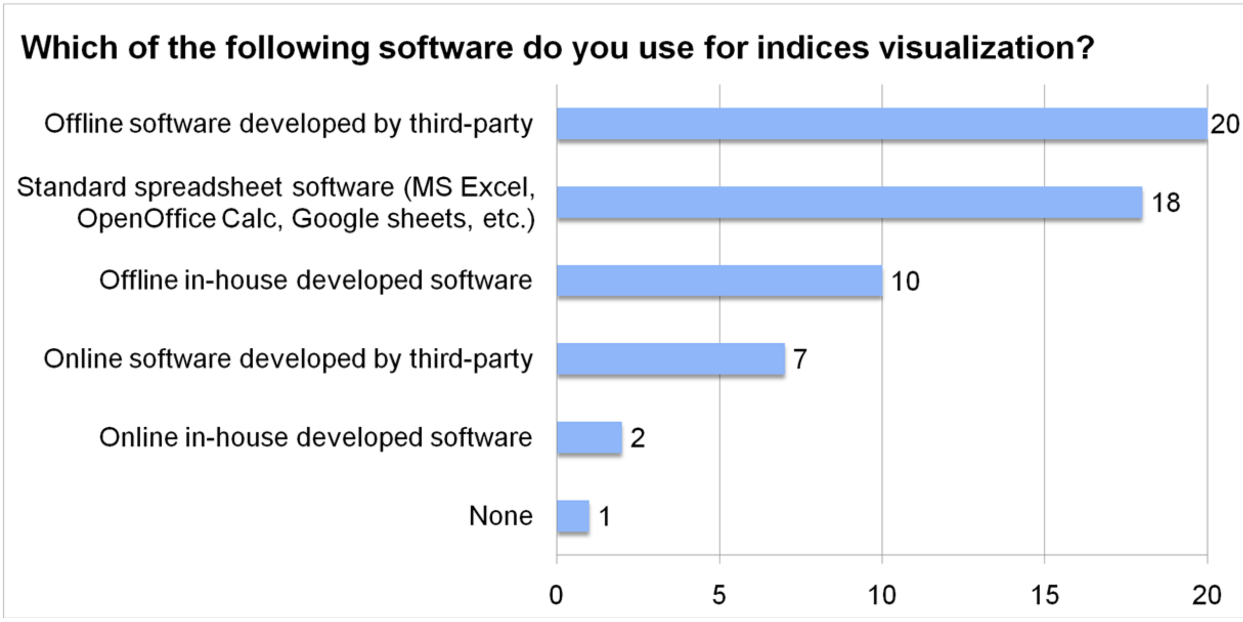

Fig. 9 Type of software used for indices visualization by survey participants (multiple choices were possible)

When it comes to specific software packages there is a diversity of applied software for the calculation and visualization of climate indices (Figure 10 and 11). The most implemented softwares for climate indices calculation are ClimPACT, different R packages including RClimDex, and various Python packages/libraries. In case of online platforms two of them are listed, Climate4Impact and CDS Toolbox. MS Excel was explicitly mentioned twice, as software for indices calculation (Figure 10), which can seem contradictory in comparison to previous questions for which there were 18 responses that standard spreadsheet software is used for calculation (Figure 8). One of the possibilities for these differences can be that beside specialized software for indices calculation spreadsheets are still in use, maybe, for some less demanding tasks, testing etc.

R and GIS software packages are in the greatest use for visualisation of climate indices followed by the Python packages (Figure 11).

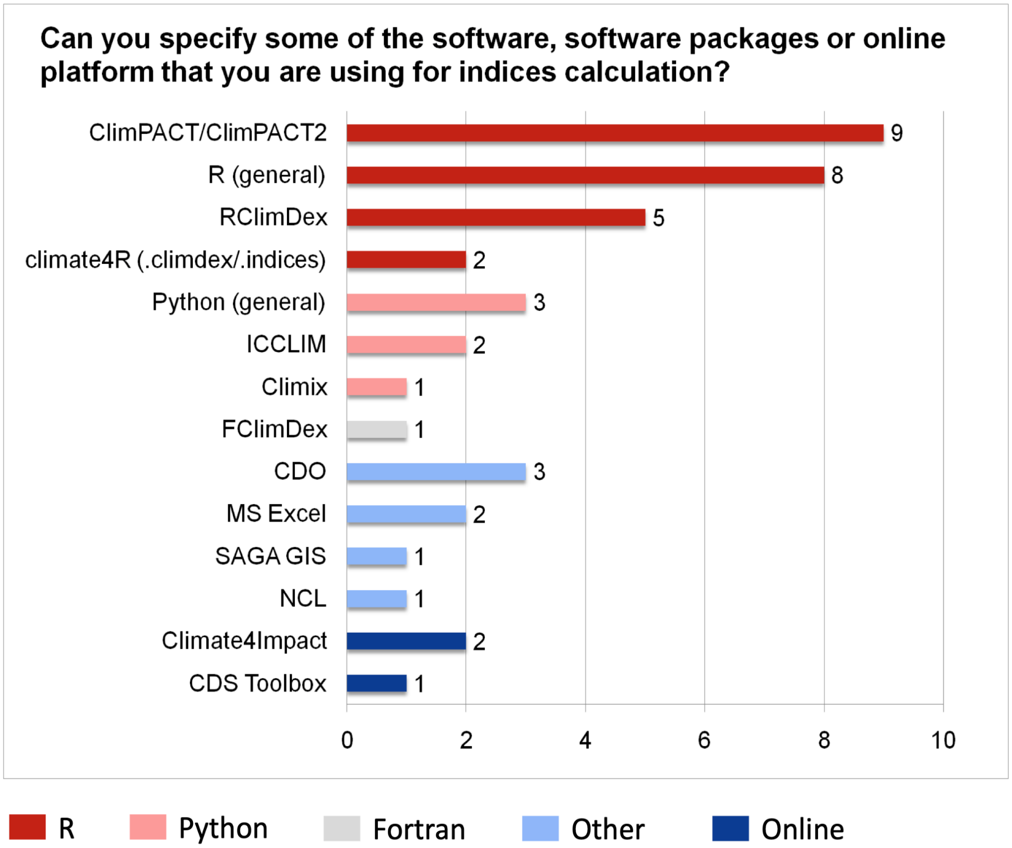

Fig. 10 Software and software packages that are used for indices calculation (multiple answers).

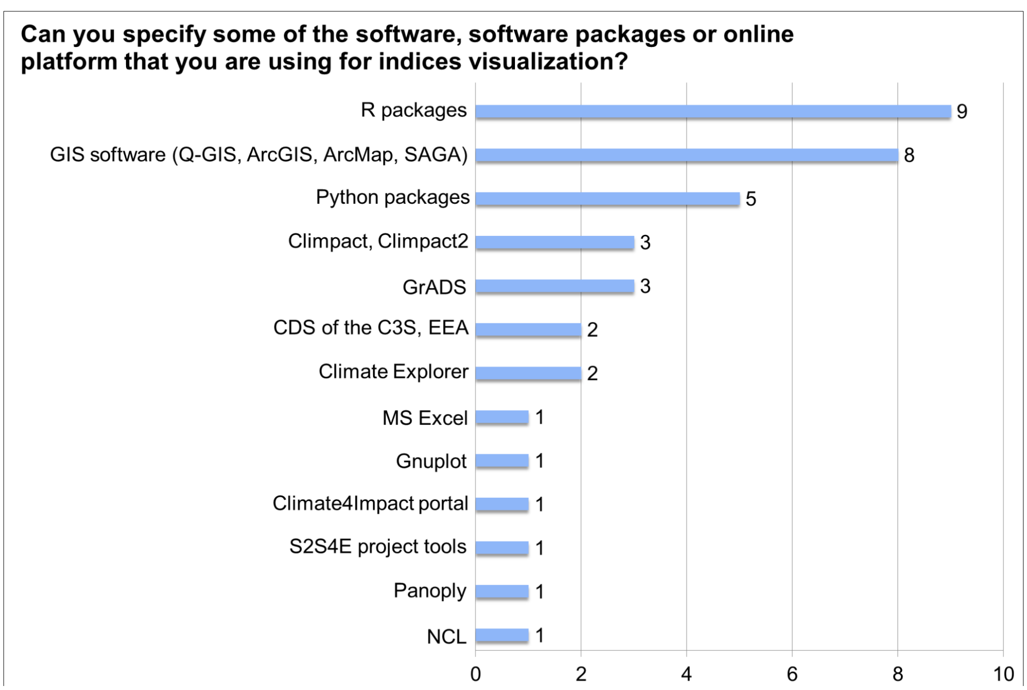

Fig. 11 Software and software packages that are used to visualize (multiple answers).

Info box - Are climate indices from different sources comparable – the case for climate index metadata

A careful analysis shows that sometimes there are different interpretations of what seems like a well defined climate index. Moreover, there are variations in the software implementations. Concrete examples are the precipitation-based indices r95p and r99p. Depending on the source document for the definition and the software system used for calculation the result is either number of days when the threshold is exceeded, or the percentage of the total amount of precipitation received during days when the precipitation exceeded the threshold. That is, depending on what tools are used one may get incompatible results. Another example concerns length of vegetation period (or growing season length) where there are several indices with very different definitions. Some are simply counting the number of days with mean temperature above some threshold (could be e.g. 0 ºC, 4 ºC, or 5 ºC), while the definition provided by ETCCDI involves both starting and ending conditions to exclude the odd unseasonally warm days early/late in the year.

As long as only one tool is used for index calculation, or an analyst is reviewing the data such incompatibilities may be less problematic, although still inconvenient. If however, climate index calculation is embedded in a more automated workflow or data is shared between different institutes, or combined from different sources, maybe using on-line services like climate4impacts, it becomes imperative that the data files contain enough detailed information about the file content and the used algorithms to prevent fusion of incompatible data. This is the reason for having climate index metadata in the files. In addition to general metadata about geographical location (or domain if it is gridded data), time coverage, etc., climate index metadata should contain specific information that allows the index to be clearly specified. There is an ongoing community effort, CLIX-META (see https://github.com/clix-meta/clix-meta) to collect and compile a catalogue of relevant metadata for a wide range of climate indices. The aim is to provide a standardised description of the necessary climate index metadata. And that this is provided in a format suitable for manual production of climate index data and by software developers alike. CLIX-META contains information about index name according to standardised rules, the authority behind the index definition (e.g. ETCCDI or ECA&D), units, and so on. And these metadata elements should as far as possible conform to existing metadata standard, the Climate and Forecasting Conventions, which is in widespread use by the climate community.

Application

Any changes in the frequency or severity of extreme climate events would have profound impacts on nature and society. Therefore, studying and monitoring them can be essential for impact assessments and developing targeted adaptation plans. This section is dedicated to the question of how climate indices are applied.

Almost all participants, 28 out of 32, selected research (impact studies, vulnerability assessment, risk assessment, etc.), as a purpose for indices use (Figure 12). On the other hand, an equal number of 12 responses goes to application for routinely produced operational products (climate monitoring reports/bulletins, early warning system, seasonal forecast products, etc.) and specific/custom climate service products. Beside these three options, climate indices are also used for purposes which include: sectoral climate change adaptation and mitigation studies, climate risk management, for providing regional "basic" climate information to policymakers and schools and for preparation of climate services products for different European projects (all these are indicated as *Other* in Figure 12).

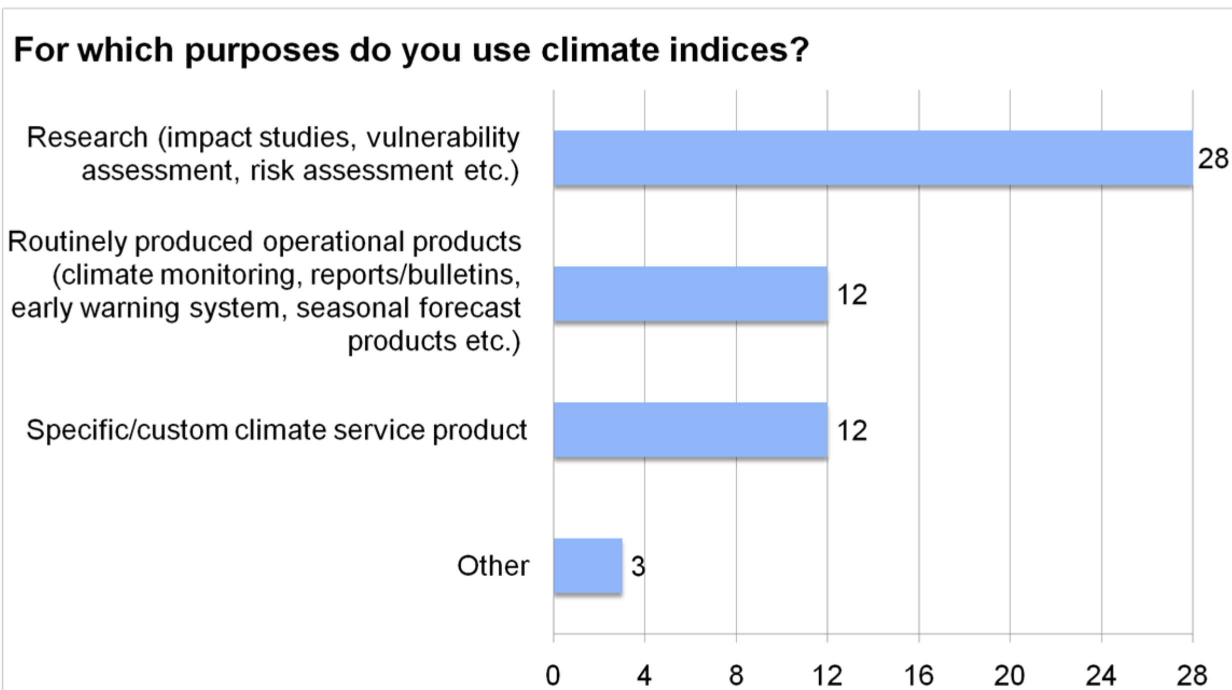

Fig. 12 Purpose of using climate indices (multiple choices were possible).

In terms of different sectors for which climate indices are applied (Figure 13), the sector with the greatest number of responses is Agriculture, which is not surprising, since that sector has a long tradition in climate indices application. The other two sectors which stand out with the number of responses are Water and Health. Finally, sectors with less responses are Energy, Forestry and Biodiversity/Nature conservation. The additional sectors that survey participants listed and that were not mentioned as an option in this survey question are Marine science, Regional climatology, Tourism, DRR, General public, Retail, which received one or two responses (all aggregate as *Other* in Figure 13).

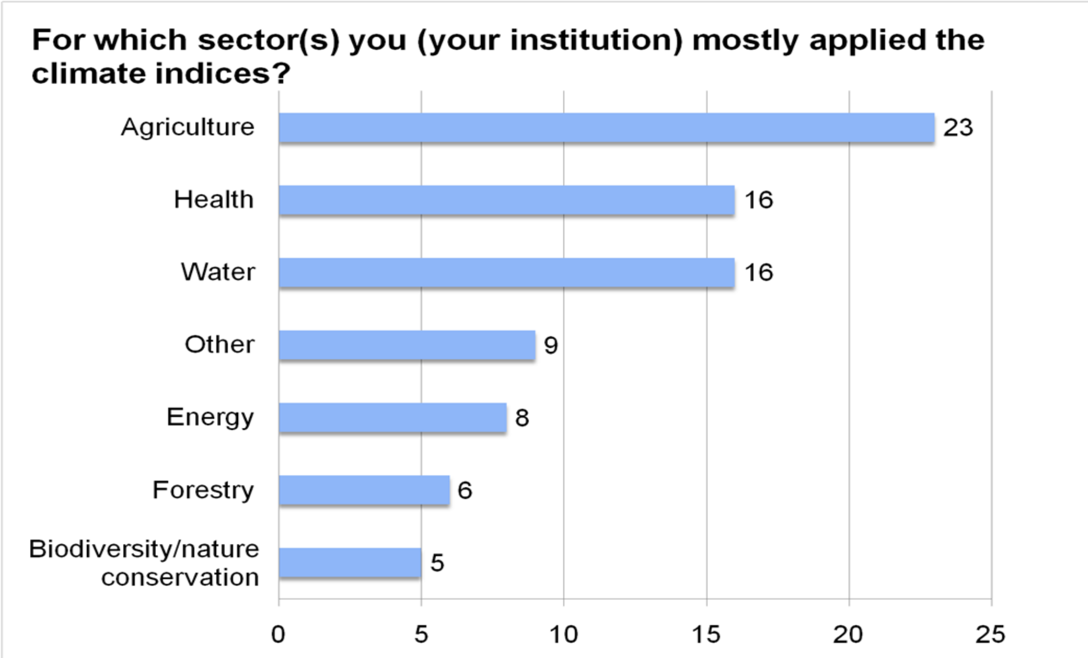

Fig. 13 Sectors in which climate indices are applied (multiple choices were possible).

According to the survey responses, the Heat (27 responses), Drought (26 responses) and Heavy precipitation/wet spell indices (24 responses) are almost equally applied (Figure 14). Slightly less interest is in Cold indices, with 18 responses. Beside these, participants listed additional indices related to wind and multi-sectoral indices like Thermal stress indices and Heating degree days which can be considered as heat indices.

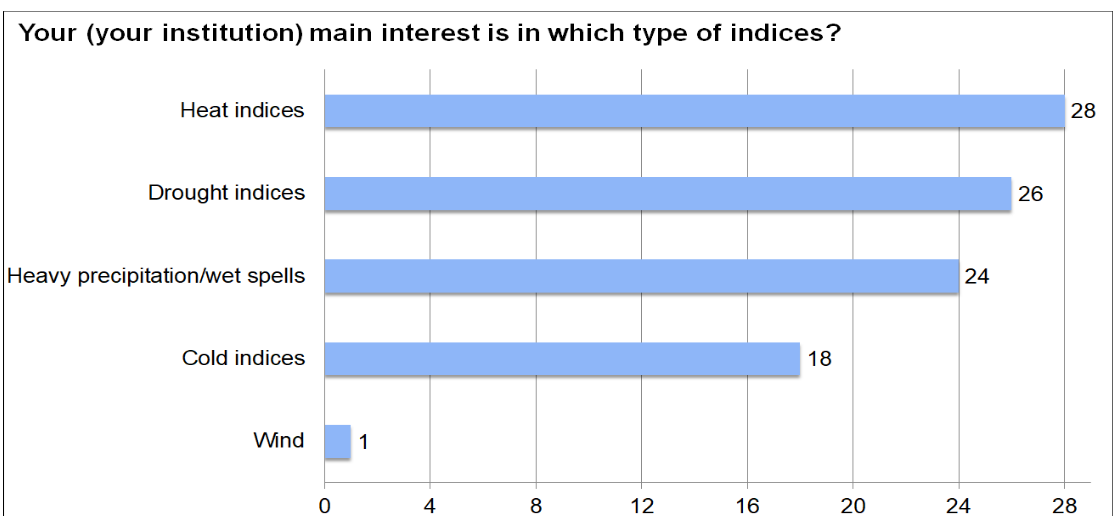

Fig. 14 Types of applied indices by survey participants (multiple choices were possible).

Comments on potential improvements

Following the discussions during online meetings, survey results and online interviews some comments on potential improvements in different aspects related to climate indices for Eastern Europe are collected.

For the explicit question in the survey regarding which improvements participants would like to see in the future all proposed answers were almost equally weighted (Figure 15).

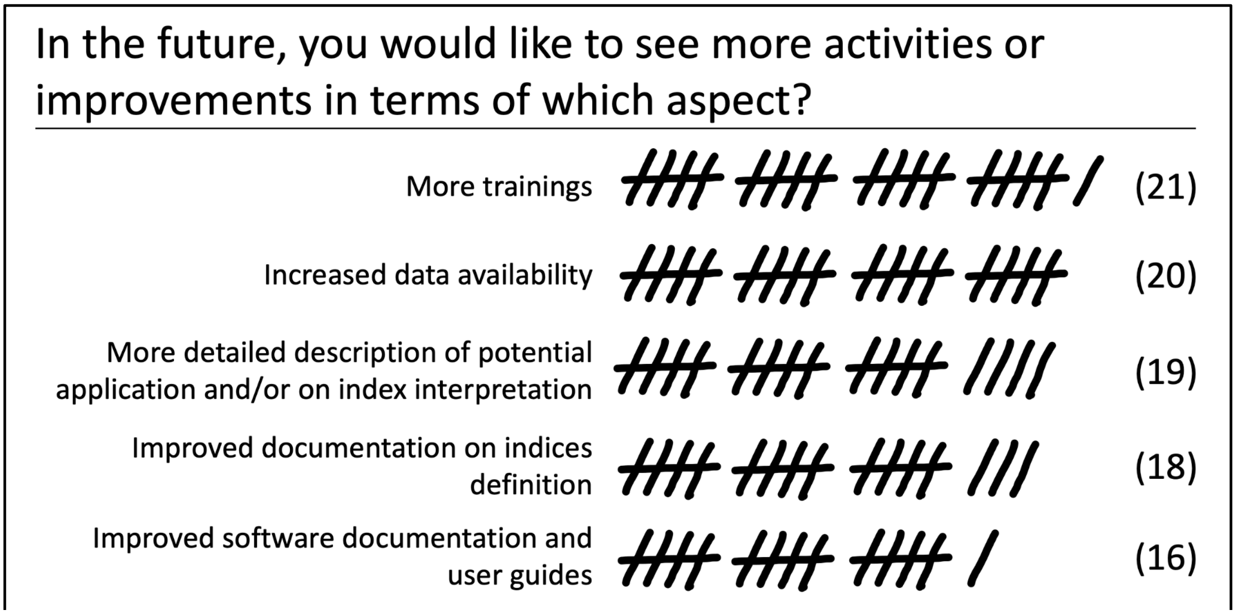

Fig. 15 Expected improvements and activities in the future (number of responses, multiple choices were possible).

Within the IS-ENES3 project, some of the project activities are already focused on improvements that are mentioned by participants as important one, such as improved documentation of indices and further advances and additional development of the software for indices calculation and visualization. For example, a new version of the ICCLIM tool will be much more flexible with new options that are mentioned by participants as important, e.g. calculation over the custom season or custom annual cycle not only January to December. Also, the online schools dedicated to the impact modeling that were organized as a part of the project, covered some aspects of the calculation and application of the climate indices in impact modeling. Currently, short trainings are planned, and again, calculation, visualization and application of climate indices will be part of training programs. During the online discussion and online interviews many of participants again underlined that they see more training on different aspects (calculation/visualization software, data access, application etc.) as a priority. There was an explicit proposal for organization of summer schools on climate indices and software, specifically for master and PhD students at the Eastern European universities. Increased data availability is also underlined as an important aspect that can be improved. In the first place easier access and access with less restrictions for some data such as observation from meteorological stations, since national services often have some institutional/national policy that pose restrictions in terms of number of stations and variables that are available with free access. There was also a call for improvements in the available dataset, respondents consider quality control and longer time series as very important for the future. There is a necessity for increasing the density of the meteorological station network, homogenization of data, and extending datasets' coverage back in time. A request was also made for unification of the calendar type of the model's time axis, or some common protocol for conversion from 360 to 365 day calendar, and in general stricter adherence to format convention and rules that will provide easier data handling.

Also, participants emphasized the need for harmonisation of index definitions and software for its calculation. It was proposed that some kind of benchmark data set, that will include input data and calculated indices from that input data, should be developed. This benchmark dataset will help to test different software and other tools which results then can be verified against benchmark data. Such a benchmark data set can be accompanied by different indices lists that are developed in the past. Also, this can help to better understand differences between indices definitions, even if they have similar or same names. The benchmark data can be developed for both, one dimensional time series (station data, for selected stations) and two dimensional, spatial time series such as EOBS, for example.

Even though the existing indices lists cover a wide range of indices, a quarter of survey respondents think that existing climate indices don't satisfy their needs. To meet their needs and needs of their users, several participants indicated the practice of modification of existing definitions, and/or development and the reasoning behind is that modification was motivated by additional flexibility in terms of a specific time of the year or specific needs from different sectors. Some of the comments were that one of the priorities should be the development of indices based on other parameters like a wind, humidity, insolation and radiation, and which would then be included in the existing lists that are most used. There is also a need to develop tailored indices in collaboration with impact scientists and application experts. Some of indices that are developed and that are already in use, and not listed in the standard lists are: Groundwater drought index and Clothing resistance parameter, Evapotranspiration stress index and Soil moisture availability index. Some of these indices are not solely based on temperature and precipitation, so their inclusion in the standard lists are in line with the request that other variables should be considered too. Also, there was a call for wider use of percentile-based indices to allow comparisons with other regions having different climatic conditions. The participants also pointed out that implementation of new and complex indices, although can help to overcome some deficiency, also requires a lot of additional research.

It was underlined that most of the indices represent moderate to severe extreme events, but not rare extreme events. On the other hand, a number of the existing indices are not relevant enough in some fields or sectors, to show the impact of certain climate hazards. For example, there are no specific indicators/indices that can be used to assess the exposure to hydrometeorological hazards specific to mountain environments that can be exacerbated by climate change e.g. flash floods, rapid snow melting, landslides, rain on snow events. Another raised question related to the indices defined for extreme events (especially of the fixed thresholds) was their suitability for climate applications in Eastern Europe for various environments (e.g. urban, mountain, coastal). Finally related to the extreme events, but not exclusively, it was underlined that indices using sub-daily data should be defined as well. These new indices can be important for the analysis of extreme events but also for some sectors, such as agriculture and energy (wind and solar energy, general electricity consumption).

There is a need for more metadata information e.g. information on how the input data have been manipulated, either in the case of already calculated indices or the software that is used for calculation. For example in case of complex indices, such as SPI, to have step by step calculation procedure will be very beneficial. Another, concrete proposal was related to the 29. February, in terms of inclusion/exclusion of it when different indices are calculated, even more it was recommended that some common rule about "29. February" should be agreed and maybe made mandatory.

It is stressed that there is room for improvement of graphical products since the visualisation of the indices is very important to communicate with the stakeholders. Also, the pre-computed graphical products should be made available in other formats than standard image/document formats (gif, jpg, png, pdf) such as different georeferenced raster formats.
Another aspect of potential improvement is a more detailed description of potential application and/or on index interpretation.

Participants proposed potential development of a common repository e.g. new website or upgrade to an existing one, which could contain the information about all available datasets and other relevant information.

There is also a requirement for an online tool that allows the stakeholders to adapt different indices to their needs without the necessity of having programming knowledge, and for more tutorials on software usage.

Some specific suggestions for software improvement for climate indices calculation are made, i.e:

- To have the option to select the custom period of the year over which an index is calculated. For example, in agriculture to determine the change that extremes occur during certain vulnerable growth stages or hydrology to have period that covers hydrological year calculations from August to July and not just from January to December;
- To have an option of Mann-Kendal and Sen's slope estimator in addition to the standard OLS (Ordinary Least Squares) and change point test as a part of the trend analysis;
- To provide the dates of the events as an output (e.g. dates of heat wave occurrence);
- In case of percentile indices, that output also include calculated percentile thresholds;
- Specifically, for ClimPACT, which creates all files regardless of whether the sites contain all the required input data or only precipitation data. Some of these files are empty or contain "missing data" which burdens the memory and disk space.

Comparison to the previous survey

During the ORIENTGATE[20] project, in 2013 a similar survey was conducted. A review of currently used climate indicators among project partners across the region of SEE was done. In total, information was collected from 12 partners.

Concerning input data for climate indices calculation, the need for harmonised and accessible data was expressed. Almost all indices from the ETCCDI list (Expert Team on Climate Change Detection and Indices, list available at that time), modified ETCCDI indices and the additional ones (user requested) were being used. The modification of indices was done in terms of differently defined thresholds for temperature and precipitation amount according to the climate characteristics of certain areas. This practice still continues to apply.

Indices that were in use can be divided into two main groups: the ones based on temperature and precipitation data and indices that require other meteorological and hydrological data for their calculation (complex indices). The indices based on temperature and precipitation were most frequently used because of availability of the needed data. Meanwhile, some indices that were in use are added to now commonly referring indices lists.

At that time, online or offline third-party software was not available or not widely known in the region, so for indices calculation mainly custom developed programs in Excel and Fortran were being used. Like today, there was different software for visualization of indices. The most common ones applied, then and now, are different GIS applications. In addition, the application of the indices has not been changed on a larger scale. Many indices were used for operational practice, different impact studies, and for preparation of the national strategic documents.

[20] The project "A structured network for integration of climate knowledge into policy and territorial planning" (ORIENTGATE, http://orientgateproject.rec.org/), 2012-2014. Project was financed by the South East Europe Transnational Cooperation Programme of the European Commission.

3. Conclusion

During online activities and events that were organized within the workshop, a great variety of information on climate indices issues were collected. Over 70 attendees from over 20 countries participated in some part of the overall process that included presentations, discussions, survey, interviews and report reviewing.

The general impression is that climate indices are seen as a valuable tool for both research and operational usage, and that further advances in this field are expected in the region. On the other hand, since that in recent years many new developments were seen in the field, (new indices, new data sets, new software etc.), there was almost a unique call from participants for more training and workshops that should be organized in the region, with strong practical components and that will cover different aspects.

Even though there are many different climate indices that are included in the widely known so called indices lists, defined by different organizations and projects, one quarter of survey participants stated that existing indices do not satisfy all their needs. The development of additional and new indices is often driven by demands to meet needs of sector specific requests from different stakeholders. Although indices are applied in many different sectors, sectors that are dominant as "users" of climate indices are agriculture, health and water resources.

In general, the usage of different types of indices decrease proportionally to index complexity, going from simple, e.g. fixed threshold indices, to indices that are calculated from multiple input variables. Indices that are commonly used for different applications are rarely calculated from other variables than temperature and precipitation. The simplicity of the index can be seen as a tentative guidance when a new index is developed. Simple, intuitive and self-explanatory indices can be seen as advantageous in terms of potential future usage and acceptance in a wider community.

In addition, in case of more complex indices such as percentile based or multi-parameter such as SPEI, calculation of an index can be linked to potential uncertainties. For example, in case of percentile based indices, to overcome some of the reported problems, many software developed specifically for indices calculation introduce the so-called bootstrap method for calculation of the percentile threshold value. Even though these developments are welcomed and contribute to a more robust calculation of an index, participants expressed the need for better documentation and additional information on these methodological approaches, in software documentation but also in software output (e.g. to include percentile thresholds as an output or to include dates of events). The need for better documentation was also expressed in terms of some very technical things such as handling of 29th February in case of some indices calculation, or handling of a 360 day calendar when models output is used for input.

In terms of input data for indices calculation, the station observations are used more frequently in comparison to gridded products. This indicates that data availability can be an issue, having in mind that there are still different policies in many countries that are often an obstacle for free access and data sharing when it comes to station observations. On the other hand, gridded products can help to overcome this situation, but with some known limitations, such as representation of local extremes.

Great majority of survey participants indicated that they calculate indices and do analysis by themselves, rather than to use available already pre-calculated indices by other institutions or projects. This can imply that such data sets, that are pre-calculated and that already exist, potentially should have better promotion and should be accompanied with better documentation, metadata and maybe better data quality analysis.

When it comes to the software for indices calculation, online tools are much less in use in comparison to off-line solutions. It was underlined that even though there are many different software that is specifically developed for indices calculation, more documentation is needed, especially the part related to methodological decisions (e.g. percentile threshold calculation, complex indices calculation etc.). R and Python, or libraries and packages developed under these languages dominate in the field. For visualization together with R and Python, different GIS software is used. From that perspective, there was a call that output from software used for indices calculation, should include other output formats (especially for two dimensional raster fields) that are more common for GIS software, beside widely accepted NetCDF.