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Research paper

Spatial data infrastructure components to provide regional climate information services

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A B S T R A C T

The assessment of expected climate changes on a regional scale requires appropriate data and information products that must be easily accessible and usable for decision makers. The regional climate information platform ReKIS is a long-established project of three German federal states to address this purpose. However, with increasing content, this web-based data exchange platform lacked in suitable metadata descriptions, search functionalities and interoperability, thus hampering the discovery and access of suitable information. This paper describes the extending and enhancing of ReKIS using state-of-the-art components of Spatial Data Infrastructures (SDI). The components support metadata acquisition, maintenance and publishing using a metadata catalogue. The implementation of a WebGIS server increases interoperability by offering OGC-compliant services and a web framework for knowledge-transfer allows for non-expert access to climate services. The approaches were developed and implemented in a real-world scenario and are suitable for a transfer to other comparable platforms and use cases.

Practical implications

Depending on the unique geographical characteristics of a region, the impact of and exposure to climate change can vary, highlighting the need for regional climate information to adequately respond to climate change impacts (Shepherd, 2019). Consequently, the adaptation measures to climate change need to be tailored to the settings of an area (Donnelly et al., 2018). To design and implement effective adaptation measures, it is necessary to combine local knowledge, topographic and monitoring data, and climate models to understand the unique characteristics of a region and evaluate the current and future impacts of climate change. Regional climate information web platforms can support synthesis and provide scientific research outcomes for a broad audience. Part of this audience are local actors such as policymakers and public authority employees who develop and implement adaptation measures. Specifically for these stakeholders, such platforms should provide relevant climate information to support the appropriateness and effectiveness of the adaptation measures. The provision of actionable information requires transforming climate data into decision-relevant knowledge (Nsengiyumva et al., 2021). Typically, current regional climate information platforms provide either raw data or processed information like diagrams. However, a notable gap exists in platforms that seamlessly combine searchable data with easily accessible, low-threshold information. Ensuring data is both searchable and usable necessitates the establishment of metadata, followed by methods for collecting, harmonizing, and integrating this metadata. Facilitating the integration of provided data into spatial planning applications requires data as services, utilizing standards such as the OGC interfaces (Open Geospatial Consortium, 2019). To address and engage authorities and politics in using the provided information for decision-making, the mere provision of data is not sufficient. Rather, the contents of the information platform must be “actively” promoted (Kronenberg et al., 2021). A proven tool to embed environment-related information in form of graphs, text contents and maps are story maps. Vollstedt et al. (2021) proposed story maps as a straightforward solution to communicate climate research results and to easily engage stakeholders. In addition to their simple technical implementation, story maps are suitable for describing the data, services and information offered on a platform in an addressee-oriented

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manner.

This study uses a real-life example to show how a regional climate information platform can be adapted to the above requirements. The initial version of the platform primarily addressed climate experts, who were highly skilled in working with and interpreting the offered data sets. The data was offered without providing a search interface or underlying metadata. With the increasing volume and diversity of provided data, the platform and its contents became more complex.

The proposed methodology should serve as a blueprint for operators of comparable platforms to implement the following:

- Addition of structured metadata, utilizing a standard metadata schema (e.g. GeoDCAT-AP), to categorize and describe the offered data.
- Integration of a workflow to collect, harmonize and distribute the metadata to the system components.
- Ensuring interoperable data exchange by providing data as OGC-compliant services.
- Provision of story maps as a method to communicate climate information in a low-threshold manner.

To minimize the additional workload to acquire metadata, this has been integrated into the existing workflows. The metadata is, as far as possible, automatically collected and exchanged between different system components to avoid repetitive acquisition. These extensions of the well-established platform helped to provide various new methods to access and explore geodata and to account for different levels of user expertise, without a complete redesign of the existing platform – For instance, the integration of a "search-by-location" feature provides users with more intuitive access to geodata. Additionally, the inclusion of a structured keyword vocabulary in the metadata catalogue has facilitated the semantic linking of datasets. As a result, similar datasets are now suggested to users when viewing metadata records. Furthermore, interoperability has been improved by implementing standardized metadata utilizing the GeoDCAT-AP schema and making datasets available through the OGC CSW interface and an API. This allows potential harvesting by other national and European Open Data platforms, and therewith extends the outreach and impact of the platform's data resources. These advances represent a significant step forward in improving the discoverability and accessibility of data, while maintaining compatibility with existing system infrastructure.

Introduction

In its latest report, the Working Group II of the Intergovernmental Panel on Climate Change (IPCC) emphasised the need to develop adaptation measures to face the unavoidable impacts of climate change (IPCC, 2022). The aim is to reduce the exposure of the population to potential singular extreme weather events or hazards. In order to plan effective measures, it is necessary to combine meteorological and climatological data, as well as climate projections, which can be referred to as climate adaptation services (Hoffmann et al., 2020). To ensure the appropriateness of measures on a local scale, these adaptation services must be aligned with the unique characteristics of a region, such as topography or land-use distribution (Giorgi, 2019; Stagl et al., 2015). This highlights the need for climate models with high spatial resolution that are able to describe the small-scale climate phenomena of a region.

Looking at the currently available data repositories, global level platforms such as the Copernicus Data Store[1] provide large scale data, metadata, and detailed documentation. At the regional level, platforms tend to focus on pre-processed data or factsheets and do not provide access to the data (e.g. the Bavarian Climate Information System[2]). Alternatively, there are platforms that make the data available without providing detailed metadata (for example, the regional climate data download platform from the research project ReKliEs-De[3]). Only few spatial data web platforms offer data with supplementary information, data descriptions and, above all, contents prepared for the demand of different audiences. Specifically, there is a lack of climate information platforms for the regional scale, such as for federal states, districts, municipalities, or cities.

In response to this gap, the Web-platform ReKIS[4] aims to combine both by providing easily accessible content and documentation about the impact of climate change as well as data on the regional climate system. The platform acts as a state-wide information system for the German federal states Saxony, Thuringia, and Saxony-Anhalt (Kronenberg et al., 2021). ReKIS addresses both, experts by offering climate products such as data or analysis-tools, and non-experts by providing easily accessible information like factsheets or articles. In the past, the platform lacked detailed and easily explorable metadata, effective data-search functionality, and interoperable data provision. To improve this situation, the existing platform was extended and enhanced in cooperation with the ReKIS operators. A data publication concept was implemented using methodologies of Spatial Data Infrastructures (SDI). Additionally, methods for effectively collecting and curating metadata have been developed.

To increase use and value of the data and to encourage shareholder action, it is essential to translate climate data into decision-relevant knowledge (Nsengiyumva et al., 2021). Policymakers need easily digestible and locally relevant climate information in order to develop targeted adaptation measures (Singh et al., 2018). In this regard, Findlater et al. (2021) have shown that current climate services are often only data-driven and neglect usability for decision-making. Recognizing this issue, this research aligns with the ongoing research project KlimaKonform,[5] which actively involves local authorities in identifying their needs and adaptation capacities. The resulting information services are integrated back into the enhanced ReKIS.

This paper addresses the question of how an existing platform, such as ReKIS, can be enhanced to provide climate information more effectively, considering the diverse needs of users. In particular, possibilities for improving the functionality of the platform are analysed in order to meet the different requirements of scientists, local authorities and private individuals. While recent studies such as those by Hoffmann et al. (2020) and Palutikof et al. (2019) focus primarily on understanding the users' requirements of a climate information platform, this study deals with the platform maintainer's perspective, in particular with the aspects of acquiring metadata and publishing and providing data, and low-threshold information.

The challenge of providing climate data in a searchable and machine-readable format and methods to improve the findability and usability of data are investigated. A suitable software stack is selected and customized for data providers with differing prerequisites concerning metadata management. The data management and publication concepts presented in this study are examined through praxis-related use-cases, contributing valuable insights to the ongoing discourse on Spatial Data Infrastructures (SDI). By presenting ReKIS as a proof-of-concept for the design and as a best practise example for the implementation of similar regional climate information platforms, ultimately contributing to the broader goal of effective climate adaptation services.

[1] https://cds.climate.copernicus.eu/cdsapp#!/home (last accessed: Dec 18, 2023).

[2] https://klimainformationssystem.bayern.de/ (last accessed: Dec 18, 2023).

[3] https://reklies.hlnug.de/home/ (last accessed: Mar 19, 2024).

[4] https://rekis.hydro.tu-dresden.de/ (last accessed: Dec 18, 2023).

[5] https://klimakonform.uw.tu-dresden.de/ (last accessed: Dec 18, 2023).

Requirements and objectives

ReKIS was developed and introduced in 2012 as a web platform to provide regional climate information. Unlike national or international platforms, ReKIS supplies regionalised data to accurately describe the local conditions of the Central German region. The goal is to support laymen, experts, and administration in local and regional decision-making on climate adaptation issues (Kronenberg et al., 2021).

The platform benefits from the exchange of information and data between the administrative units of the three participating federal states. An editor in each federal state is responsible for transmitting data provided by the state offices. These data are pre-evaluated raster climate data for different climate parameters such as temperature, precipitation, global radiation, or climatic water balance. The data is derived from observation data covering periods from 1961 to 2016.

In cooperation with the German Weather Service (DWD), a climate ensemble called "Mitteldeutsches Kernensemble" was developed fitting the Central German region. This ensemble contains the necessary climate models to cover the bandwidth of potential scenarios of the specific area (Franke et al., 2020). Based on this ensemble, regionalised climate data and projections are prepared by scientists from the KlimaKonform project. The data is updated on a weekly basis and provided via ReKIS.

ReKIS addresses diverse audiences with different technical skills including scientists, local government stakeholders and private individuals. In addition to the users of the platform, there are other roles involved including data providers, developers, and site administrators. This results in diverse requirements the platform must meet to offer an effective climate service. Firstly, the provided climate information needs to be presented appropriately to the specific needs of the various target groups. Scientists, for example, will need detailed data and research documentation, whereas municipal staff need rather simple and comprehensive fact sheets. As stated by Nsengiyumva et al.(2021), climate data only become valuable when it is transformed into decision-relevant information based on the specific needs of the users. Secondly, site operators and developers must also be able to cope with the variety of data formats and constantly growing amount of climate data. In order to deal with the increased complexity of the platform and the different user groups, it was necessary to redesign the platform architecture (Kronenberg et al., 2021). With the new architecture components, the following objectives shall be achieved:

1. Improve data transparency with metadata:

Previously, there was only rudimentary documentation of climate data and the underlying models. Especially for scientists (but also for other users) a detailed description of the data is essential to assess the data's appropriateness for their specific use case ("fitness-of-use") (Bernard et al., 2014; Kliment, 2013; Morueta-Holme et al., 2018). Metadata supports users to decide, for instance, if the data cover the right area, time period and topic, whether the data quality (in particular resolution, and accuracy) is sufficient, or who the responsible contact persons are (Habermann, 2018).

2. Simplify and ideally automatize the collection of metadata:

Since the amount of metadata grows synchronously with the amount of data, it is necessary to develop workflows to simplify metadata collection, harmonization and integration (Nogueras-Iso et al., 2020; Trilles et al., 2017). It should be noted that data providers (who are also responsible for providing metadata) might not have extensive knowledge of standardized metadata schemas such as ISO 19115,[6] 19119[7] and 19139.[8] For ReKIS, data providers range from scientists that produce climate projections themselves to professionals that are only responsible for data delivery. Ideally, an easy-to-use tool supports metadata acquisition tool for everybody involved, regardless of previous experience. At the same time, the manual efforts for metadata acquisition should be minimized.

3. Increase data discoverability:

Once metadata has been collected, it is necessary to determine an appropriate way to store and present the metadata records. Usually, so-called catalogue services are used to manage metadata (Corti et al., 2018). Catalogues implement features to classify the data (using keywords and/or categories) and make the catalogue contents explorable for users. Here a data repository software tool called CKAN[9] was used. This tool is widely used in public administrations to implement open data platforms (see the Canadian Open Government Portal[10] or the UK open data platform data.gov.uk[11]). It also builds the basis of research data repositories.[12] In contrast to the previous version of ReKIS, which only provided data without metadata through an FTP-based server (File Transfer Protocol), the new metadata catalogue improves data search capabilities, provides search filters, and gives users the ability to assess the quality and usefulness of the data through detailed metadata records.

4. Enable interoperability:

The platform shall support a multitude of participating data providers, and the resulting climate data shall be usable for stakeholders from many different organizations. Standardized service interfaces shall guarantee seamless data exchange over the web and building up an effective distributed information infrastructure (Percivall, 2010). The standards specified by the Open Geospatial Consortium (OGC) are well established to serve this purpose. The OGC services such as Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS) and Catalogue Service for the Web (CSW) shall improve the ability to integrate the data into other spatial planning applications or platforms (for example metadata provision to other regional, national, or European open data portals).

5. Impart climate research outcomes to all target groups: In order to communicate climate-related information to all target groups and present complex research results in an engaging format, "story maps"[13] by ESRI (Environmental Systems Research Institute) were used. Story maps are interactive web pages that can include both spatial content, such as maps and other multimedia and data visualizations. Vollstedt et al. (2021) already proposed using story maps as an effective tool to present climate services to different target groups. The story maps showcase and describe the tools and applications developed in the KlimaKonform project. Additionally, by using OGC services in these applications, the maps and data can easily be updated as new information becomes available.

[6] https://www.iso.org/standard/53798.html (last accessed: Dec 18, 2023).
[7] https://www.iso.org/standard/ 59221.html (last accessed: Dec 18, 2023).
[8] https://www.iso.org/standard/67253.html (last accessed: Dec 18, 2023).
[9] https://ckan.org/ (last accessed: Dec 18, 2023).
[10] https://open.canada.ca/ (last accessed: Dec 18, 2023).
[11] https://data.gov.uk/ (last accessed: Dec 18, 2023).
[12] e.g. https://geokur.geo.tu-dresden.de/index.php/research-data-infrastructure (last accessed: Dec 18, 2023), https://projects.tib.eu/datamanager/applications/ (last accessed: Dec 18, 2023), https://rdm.inesctec.pt/ (last accessed: Dec 18, 2023).
[13] https://storymaps.arcgis.com/ (last accessed: Dec 18, 2023).

Other environmental research data platforms have encountered similar problems as ReKIS and the proposed solutions often include architectural concepts of SDI (Bernard et al., 2014) (Bhattacharya and Painho, 2018; Giuliani et al., 2017; Wohner et al., 2019). The main objective is to enable seamless and system-independent data and functionality exchange between multiple organizations by using common, national, or international standards. This will ultimately improve data accessibility, discoverability, and reusability. The following sections explain how the existing ReKIS was extended by components of an SDI to fulfil the above-mentioned requirements (1–5).

Redesign of ReKIS using SDI concepts

In the following, the newly designed and implemented ReKIS components and their associated functions are described (see Fig. 1 for an overview).

Components for ***data transparency and discoverability***

To improve data transparency and discoverability, a CKAN catalogue providing metadata records has been implemented. By offering text searches and search filters, the catalogue facilitates access to the data and corresponding descriptions. Metadata keywords (tags) are used to classify the data and thus enhance its discoverability. The catalogue service also includes an API, which can convert metadata records into a JSON format, making the catalogue machine-readable and allowing for integration into other applications. The API is used to automate the process of uploading metadata and to connect the catalogue to the main climate information platform (ReKIS). For more details on this connection, see sec. 4.1. Beyond standard features of the CKAN software, changes in the metadata configuration and improved search functionality have been developed, which are introduced in the following.

Metadata configuration

While the standard schemas ISO 19115, 19,119 and 19,139 are commonly used in SDI implementations, we propose the use of an alternative schema.

The mentioned ISO standards are primarily intended for geodata, whereas a climate information system such as ReKIS also include non-geodata such as factsheets or informative figures. Recently, there has been an increasing trend of combining geospatial data with other types of data on open data platforms (Veeckman et al., 2017). As a result, there is a need for metadata schemas that can be used to describe spatial and non-spatial data. In the presented approach, GeoDCAT-AP was used, which combines the ISO schema elements with a schema called DCAT-AP (Raes et al., 2019; Veeckman et al., 2017) (see the implementation[14]). DCAT-AP (Data Catalogue Vocabulary Application Profile) is a widely used metadata schema in European open data portals and is based on the W3C's DCAT (Data Catalogue Vocabulary) specification (W3C, 2020) (Nogueras-Iso et al., 2020; Veeckman et al., 2017). Conformity with European open data portals also retain the option of exchanging metadata with other data catalogues (e.g. catalogues from other climate information platforms).

Another advantage of using GeoDCAT-AP is its comparatively simple structure. The complexity of the ISO metadata standards, with over 300 possible properties, can pose a challenge for data providers, depending on their professional background (Diviacco et al., 2012). Our implementation of GeoDCAT-AP contains only a basic set of 21 metadata elements that we assume the data providers to be familiar with. Table 1 illustrates the implementation of these elements in the catalogue service and how the fields map to the respective GeoDCAT-AP properties. The schema includes information like contact points, links to publications, and technical specifications such as resolution, spatial coverage, and projection.

Beside datasets, the platform also provides access to different components for low-threshold information access (see sec. 3.4), i.e. to interactive web applications that make use of the data and story maps for documentation. To support the discovery of these components they are also described with metadata records in CKAN making use of an adjusted metadata schema.

Controlled keyword vocabularies

To ensure data discoverability via the catalogue, it is advisable to provide them with keywords or tags (Jaromar et al., 2012; Trilles et al., 2017). Therefore, so-called controlled keyword vocabularies (taxonomies) should be utilized to ensure clear and consistent data categorisation (Harpring, 2013; Hedden, 2010). There are several theme-based taxonomies that include terminology for specific topics available. An example of a commonly used vocabulary for environmental data is GEMET (General Multilingual Environmental Thesaurus).[15] GEMET includes a wide range of environmental concepts arranged in a hierarchical structure to describe and categorize metadata records. GEMET is implemented in the European INSPIRE metadata catalogues, e.g. Climate-ADAPT[16] or GEOSS.[17] The GEMET concepts cover the data topics of ReKIS and, therefore, the development of a separate vocabulary was not necessary. However, the integration of other thesauri is also conceivable.

A benefit of using a structured vocabulary is the straightforward semantic linkage of (meta-) datasets. If a user searches for a keyword that is a GEMET term, the catalogue's search engine can extend the search query with related concepts to not only return records with the keyword entered, but also records with the related terms (i.e. broader or narrower concepts). A structured vocabulary also allows to show similar records (that have related keywords), whenever a user views a metadata record. To take full advantage of this functionality, it is advisable to use the vocabularies already when capturing the metadata. This can ensure that all metadata records have keywords that come from the vocabulary used.

There are several types of relationships in which metadata records are considered semantically linked. The simplest case of a link would be that several records have the same keyword in the metadata (Fig. 2).

Metadata records can also be considered as linked if they have different keywords, but the keywords are related to each other according to the thesaurus scheme. For example, GEMET concepts have relationships such as:

- **concepts have another concept that is narrower/broader**: e.g.: *broader*: "atmospheric process" => *narrower*: "air movement"
- **concepts are related by sharing the same (superordinate) theme**: e.g. the *concepts*: "air movement" and "air quality" have the same *theme*: "air"
- **concepts are in the same group, but have different themes**: e.g. *concepts*: "air movement" (*theme*: "air") and "atmospheric process" (*theme*: "climate")

The schema in Fig. 3 illustrates three metadata records that are linked because the used keywords are GEMET concepts with the aforementioned relationships.

[14] https://github.com/GovDataOfficial/DCAT-AP.de (last accessed: Dec 18, 2023).

[15] https://www.eionet.europa.eu/gemet/en/about/ (last accessed: Dec 18, 2023).

[16] https://sdi.eea.europa.eu/catalogue/climate-adapt/eng/catalog.search#/home (last accessed: Dec 18, 2023).

[17] https://sdi.eea.europa.eu/catalogue/geoss/eng/catalog.search#/home (last accessed: Dec 18, 2023).

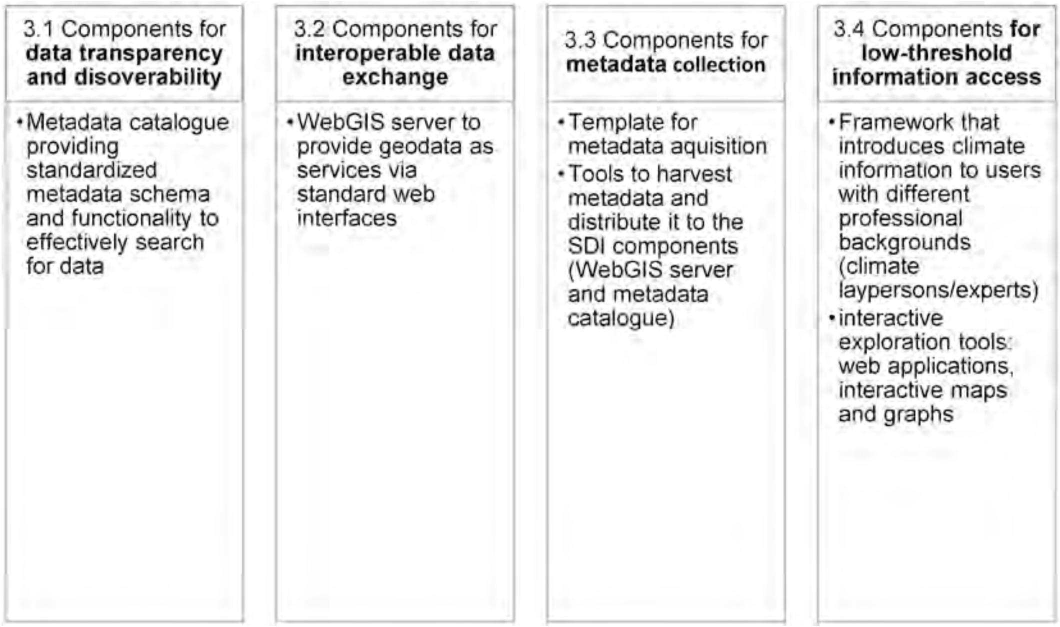

Fig. 1. Overview of the new components extending the ReKIS system architecture.

Table 1
Mapping of the data catalogue metadata elements to the GeoDCAT-AP schema.

Catalogue metadata fields	GeoDCAT-AP elements
Title (extra:title)	Dataset/dct:title (mand.)
Name (extra:identifier) (mand.)	Dataset/dct:identifier (mand.)
Description (extra:notes)	Dataset/dct:description Dataset/dct:type
Documentation (extra: documentation)	Dataset/foaf:page
Contact Point – Name (extra: contact_name) (mand.) + Contact Point – ORCID (extra: contact_uri)	Dataset/dcat:contactPoint
Information Website (extra:url)	Dataset/dct:isReferencedBy
Keywords (extra:tag_string)	Dataset/dcat:keyword
INSPIRE Theme (extra:theme) (mand.)	Dataset/dcat:theme
Spatial Coverage (extra:spatial) (mand.)	Dataset/dct:spatial
CRS (extra:conforms_to)	Dataset/dct:conformsTo
Spatial Resolution (extra: spatial_resolution)	Dataset/geodcatap: spatialResolutionAsAngularDistance Dataset/geodcatap: spatialResolutionAsDistance Dataset/geodcatap: spatialResolutionAsScale
Spatial Resolution Measured (extra: spatial_resoulution_type)	(already covered by field above)
Temporal Coverage Start (extra: temporal_start)	Dataset/dct:temporal
Temporal Coverage End (extra: temporal_end)	Dataset/dct:temporal
Temporal Resolution (extra: temporal_resoultion)	Dataset/dcat:temporalResolution
Is Version of (extra:is_version_of)	Dataset/dct:isVersionOf
Parent Dataset (extra: related_resource)	Dataset/prov:wasGeneratedBy
Derived from (extra: was_derived_from)	Dataset/prov:wasUsedBy
(CKAN) Organisation (extra: owner_org)	
Dataset Licence (extra:license_id)	

*Components for **interoperable data exchange***

A main objective of providing datasets according to SDI principles is to ensure interoperable data exchange and usage.

In order to support this functionality with ReKIS, we decided to publish most of the spatial datasets on a WebGIS server that conforms to the OGC standards (GeoServer[18]). The goal of this component is to enable easy data integration in other systems, such as Desktop or Web GIS. Setting up this open-source component is relatively simple and yet offers powerful features such as the support for the OGC services. GeoServer provides an API that allows automatic data and metadata uploads. In the ReKIS extension, this API is used to automatically upload the data from the FTP. The server provides WMS and WFS for vector data such as flood risk maps or land use data. Multidimensional data like elevation models or grid interpolated climate data are provided via WCS. The access information to the services is provided in the metadata catalogue already described.

*Components for **metadata collection***

Given the growing amount of data and metadata, it becomes clear that at least partially automated processes for publishing data and metadata are required. Thus, there is need for workflows and tools that simplify this process and allow data providers to store data and capture metadata in one step. The approach is similar to the implementations presented by Nogueras-Iso et al. (2020).

The publication of data and metadata proceeds in three steps: (1) provision of data and metadata, (2) publication of data, (3) distribution and publication of metadata of which the last two are automatic without user intervention (Fig. 4).

In a first step, data and metadata are uploaded to the system. A simple spreadsheet-template (Microsoft Excel) is used as a straightforward method to acquire metadata. This shall include non-expert data providers in the metadata acquisition process and reduce the efforts for repetitive metadata inputs. Data is made accessible via an FTP with an easy understandable folder structure, eliminating the need for specialized tools or user interfaces for data providers. The aim is to provide this

[18] https://geoserver.org/ (last accessed: Dec 18, 2023).

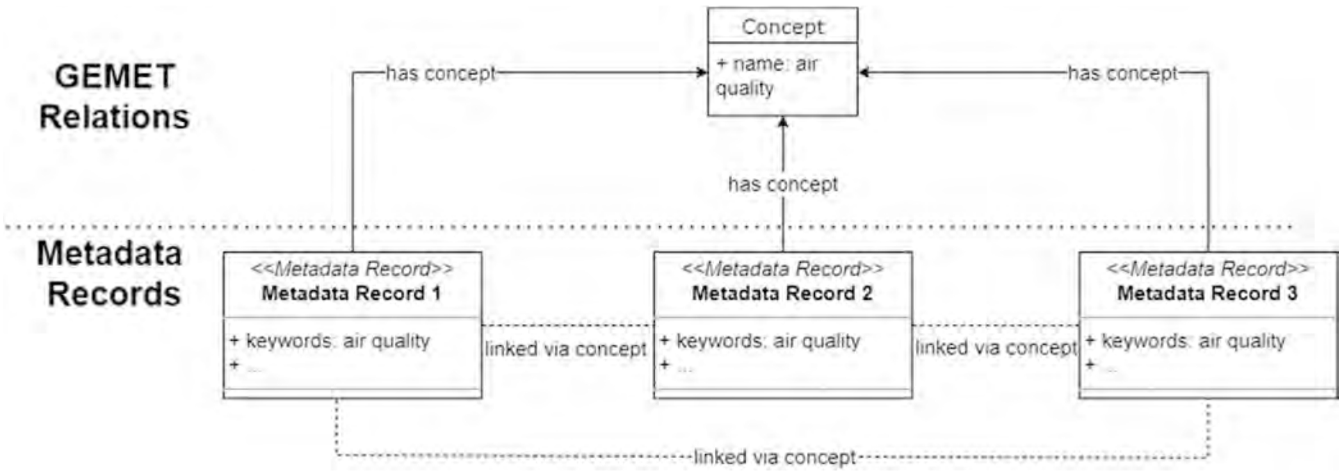

Fig. 2. Schematic representation of a link of multiple datasets that have a common concept. In this example all metadata have the GEMET "air quality" in the metadata property keywords.

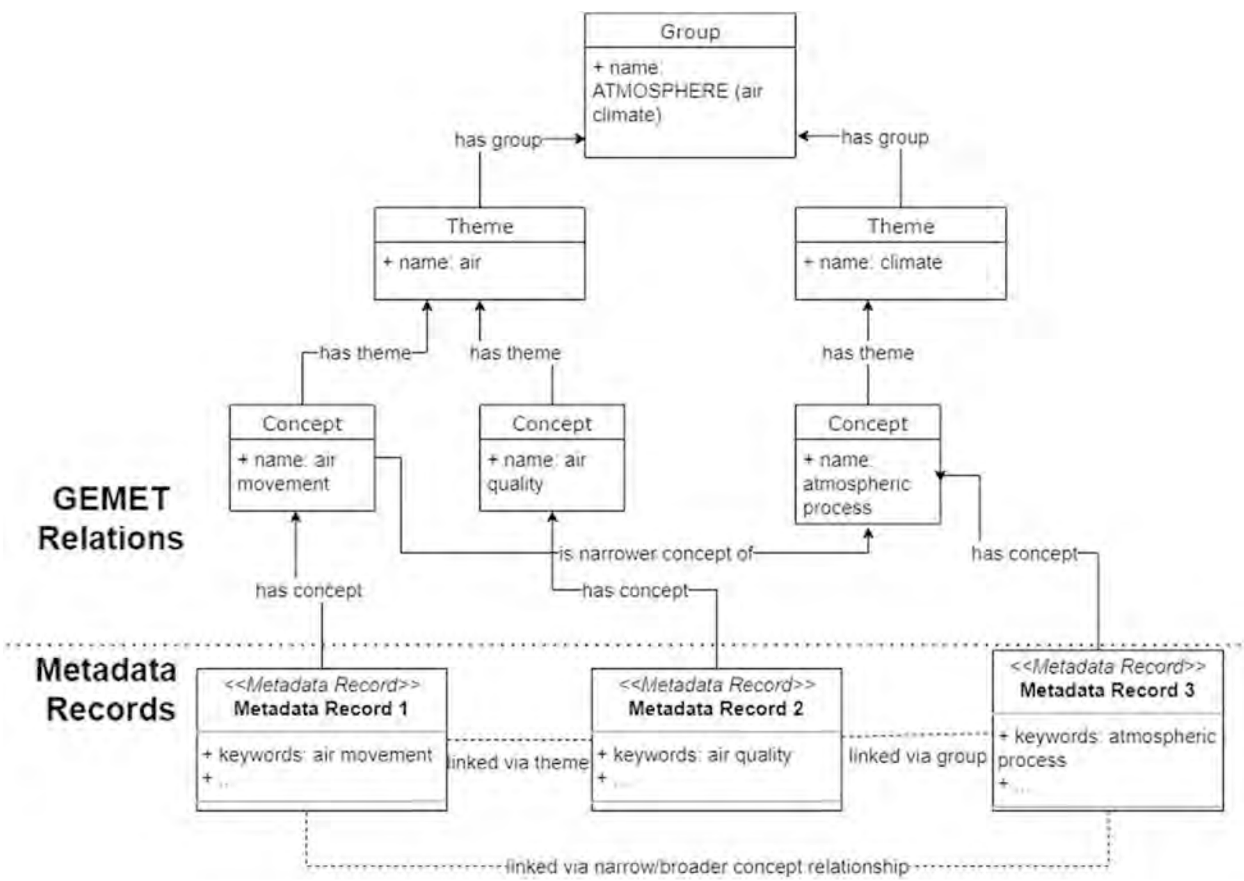

Fig. 3. Schema of three metadata records that have different keywords. The keywords are related according to the GEMET schema. Metadata Record 1 and 2 provide keywords that have a theme in common. Metadata Record 1 has a keyword that is a broader concept of the keyword used in Metadata Record 3. Metadata Record 2 and 3 provide keywords that are within the same group.

process with as few hurdles as possible, in particular with regard to the provision of metadata.

In a second step, the data is published on ReKIS, and parts of the data are automatically uploaded on the WebGIS server. A Python-based script regularly iterates over data in the corresponding folders at the FTP server and uploads new contents to the WebGIS server using its API).[19]

The third step is to distribute the metadata collected with the

[19] https://github.com/simeonwetzel/OGCToCKAN/ (last accessed: Dec 18, 2023).

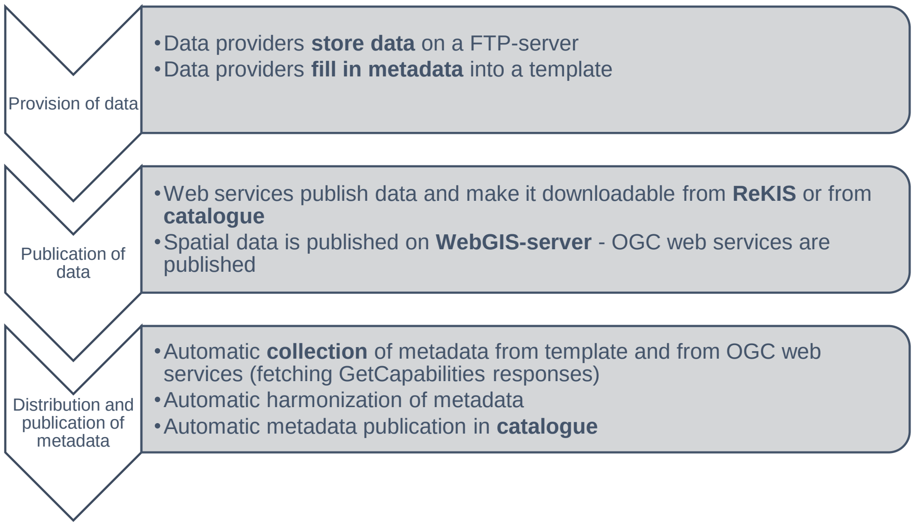

Fig. 4. The process of data and metadata publication.

spreadsheet-template. A second Python-based tool[20] has been developed to automate this distribution process. Initially, the tool uploads or updates metadata from the template to associated datasets on the WebGIS server. The metadata from the OGC web services can then be automatically harvested by the metadata catalogue. Additionally, the tool collects metadata for the remaining data (which is not published as an OGC web service) directly from the spreadsheet template. Finally, the collected metadata is harmonised and ingested into the metadata catalogue.

Components ***for low-threshold information access***

In order to enable non-expert users of the climate information platform to access the information and data offered, story maps are used as a low-threshold method.

Story maps are a visually engaging way to present scientific outcomes that include geospatial data. They can contain maps, text, illustrations, graphs, or other static or interactive media. All contents are sequentially presented and do not require prerequisite knowledge about the data or installed software. For climate-related topics, there are numerous examples where story maps are used for educational purposes (Berendsen et al., 2018; Cope et al., 2018; Groshans et al., 2019; Thürkow et al., 2019; Treves et al., 2021). Recent research has also shown that story maps are also a useful method for scientific communication (Oubennaceur et al., 2021) and for involving local stakeholders in the production of climate services (Vollstedt et al., 2021).

Findlater et al. (2021) indicated that climate services require the involvement of their users to stimulate decision-making processes. They propose an interdisciplinary approach, involving not only climate scientists but also social scientists to identify user needs and deliver tailored products. Story maps are technically straightforward to implement thanks to easy-to-use tools such as those from ESRI. However, the difficulty lies in the conception of the content and the thematically classified integration of various story maps. To produce addressee-oriented content, we analysed the support needs of actors from politics, administration, business, and society in terms of prerequisite knowledge and adaptive capacities. Besides climate experts, representatives of various scientific fields were involved in this process. The result is a broad range of relevant fields of action for the study region, such as adapting to extreme events or assessing and mitigating the consequences for the local economy. On this basis, story maps on the different fields of action provide a region-specific and low-threshold information access. In some cases, this is supported by interactive web-based applications. Examples of these applications are interactive web-maps showing various aspects of projected climate changes[21] and simulation tools for heat in buildings[22] or green infrastructure.[23] Finally, an approach is shown to bundle the various story maps into one page and offer suitable access for users.

Results

Metrics of the updated system

With the inclusion of updated system components, the ReKIS system now incorporates new metadata, data services, and story maps. Specifically, the following content has been published:

- 46 metadata records containing basic geodata / open data (one file for each metadata record).
- 32 metadata records featuring observational data/past climate data comprising 1046 files for various climate indicators and time periods.
- 4 metadata records featuring climate future projections (different models/scenarios) including files for various model runs and scenarios (a total of 60 files).
- 48 services available as WMS and WFS accessible via a WebGIS server.
- 12 story maps including a web application that embeds all story maps (see section 4.2.4).

All components, except for the story maps, are hosted on servers provided by the TU Dresden. The story maps are hosted on cloud servers provided by ESRI. Up to now, the data and metadata volumes were not extensive, and consequently, performance concerns have not been a primary focus.

Beside the provided contents, the essential aspects of this work are

[20] The tool is part of the same module as footnote 18.

[21] https://experience.arcgis.com/experience/a73e28e0b3b14e01a794e33fe892e1e0/page/D2_Meteorologie/ (last accessed: Dec 18, 2023).

[22] https://experience.arcgis.com/experience/a73e28e0b3b14e01a794e33fe892e1e0/page/D1_1_Verwaltungsgeb%C3%A4ude (last accessed: Dec 18, 2023).

[23] https://experience.arcgis.com/experience/a73e28e0b3b14e01a794e33fe892e1e0/page/B2_Stadtbaeume/ (last accessed: Dec 18, 2023).

new functionalities offered by the updated system components. To illustrate these functionalities, the following sections demonstrate these through selected examples. The aim is to highlight how the SDI components support end users in data discovery and to illustrate how non-experts can take advantage of the story maps.

Examples of implemented functionality

Improved data discoverability using keywords

The use of keywords to discover available data is one of the major advantages CKAN brings to the system. When users search for data via the CKAN catalogue, they can use search terms in a Google-like fashion. However, it is also possible to filter the existing metadata records for a specific topic or keyword, for example. The catalogue supports filtering by the tags that were defined in the metadata schema and consistently used in the metadata records (Fig. 5, left). It is also possible to filter by other parameters such as data format (Fig. 5, right).

While these are standard functionalities of CKAN, a distinctive approach to enhance data discoverability has also been introduced. The implementation of structured vocabularies for creating semantic links between metadata records, as discussed in sec. 3.1.2, and, specifically, the developed logic to establish connections between datasets based on their tags, are unique features.

As a result, users encounter in each metadata record view sections titled "Similar Tags" and "Datasets with similar tags." For each tag of a metadata record, it is checked whether:

(1) the tag is a GEMET concept,
(2) the tag has related GEMET concepts (if (1) is true). These are then displayed in the "Similar tags" section,
(3) there are other metadata records that contain the similar tags of (2). These records are then displayed in the "Datasets with similar tags" section.

Fig. 6 demonstrates this feature for an example metadata record. The record shown is a flood risk map dataset, and it includes the keywords **"**atmospheric precipitation", "basic geodata" and "flood". The section "Similar tags" displays keywords that are broader or narrower concepts of the specified keywords (according to the GEMET schema). Under "Datasets with similar tags" metadata records are listed, that include at least one keyword of the similar tags. In this case, this is only a record about "heavy rain in Saxony". This record contains the keyword "rain", which is a narrower concept to the term "atmospheric precipitation". The underlying semantic relations of the GEMET keywords are shown in Fig. 7.

Spatial data search

In addition to standard search functions, CKAN provides a spatial extension that allows users to draw a bounding box in a map interface and catalogue results are filtered accordingly. Additionally, an intuitive and user-friendly approach is to recognise location information directly in the full-text search and filter search results based on the entered location names entered. However, this textual "search-by-location" feature is not offered by the spatial extension of CKAN and had to be implemented. Utilizing this functionality, the users' textual search terms are geocoded, and the result is used as a spatial filter. Fig. 8 shows in detail how a user query gets modified to filter records by a location. If a search query does not contain a place name, the filter is deactivated, and the original search query is used. The applied geocoding API is an open-source solution called Nominatim API[24] which is based on OpenStreetMap[25] data. Although Nominatim is free to use, a usage policy requires users to cache geocoding results. A PostgreSQL[26] database has been set up for this purpose. For each search term entered, coordinates are first searched for in the cached results (see Fig. 8). Only if no result is found, the Nominatim API is requested.

The example search query in Fig. 8 shows a search for precipitation data for the city of Leipzig (Query: "Precipitation Leipzig"). Firstly, the algorithm splits the query by words. It then checks if one of the terms "Precipitation" or "Leipzig" can be geocoded (either in the cache database or via the Nominatim API). Each dataset in the catalogue has a spatial extent that is stored in the metadata via a bounding box. If the coordinates of a geocoded search term lie within this bounding box, the metadata record is shown in the search results. In the example, the term Leipzig can be geocoded, and the corresponding coordinates are used as query parameters.

Link between metadata catalogue and the climate information platform

The CKAN catalogue can be queried from other websites or applications via its API. This functionality is used to integrate the metadata-based search functionality into ReKIS. ReKIS itself offers a search for textual documents and other provided contents. The previous version of ReKIS did not support dataset discovery. The API connection to the catalogue enables integrating the search results obtained from the catalogue (short data description) into those of ReKIS. Dataset short descriptions also include a link to the detailed metadata in the catalogue. This seamless integration might not even be recognized by inexperienced users. Fig. 9 shows an example search request on ReKIS and the respective search results that include catalogue records.

Implementation of story maps

Beyond data provision, the climate information platform ReKIS aims to provide non-experts with information on the impacts of climate change. As already described, the format chosen for this knowledge transfer is story maps.

Several story maps on different topics represent the research results of KlimaKonform. Since the structure of ReKIS was predefined and established, it was not practical to embed all story maps individually. Therefore, another multipage web application[27] was implemented to display all links to the content in a single browser tab. This web application directs local stakeholders to the story map that is relevant to them (Fig. 10). Additionally, the links are also categorized into themes (by fields of action) where users can access the story maps directly. Moreover, story maps and corresponding links are included in the catalogue as metadata records so that they can be searched via ReKIS (comparable to datasets as described in the previous section).

The general intention of the start page is to inform about relevant fields of actions in the context of adaptation to the impacts of climate change. The fields of actions that have been elaborated in KlimaKonform can be categorized in (a) extreme weather events, (b) projected climate changes in the region, (c) implications for the economy, and (d) adaptive capacities. The presented information should arouse interest of stakeholders and motivate them to delve deeper into the topic.

Further, the start page features an overarching story map providing a "virtual tour" through the study area (Fig. 11). When users browse the slides, they are navigated through the various locations in the study region of KlimaKonform.

An example of such a story map is shown below. It describes various aspects of the projected climate change in the entire study area from a meteorological perspective. Starting with a general overview of climate change impacts, the trends of standard climate variables are presented in interactive maps (Fig. 12). The maps are embedded in describing text

[24] https://nominatim.org/release-docs/latest/api/Overview/ (last accessed: Dec 18, 2023).

[25] https://www.openstreetmap.de/ (last accessed: Dec 18, 2023).

[26] https://www.postgresql.org/ (last accessed: Dec 18, 2023).

[27] ArcGIS Experience was used as a framework for building the web application: https://www.esri.com/en-us/arcgis/products/arcgis-experience-builder/overview (last accessed: Dec 20, 2023).

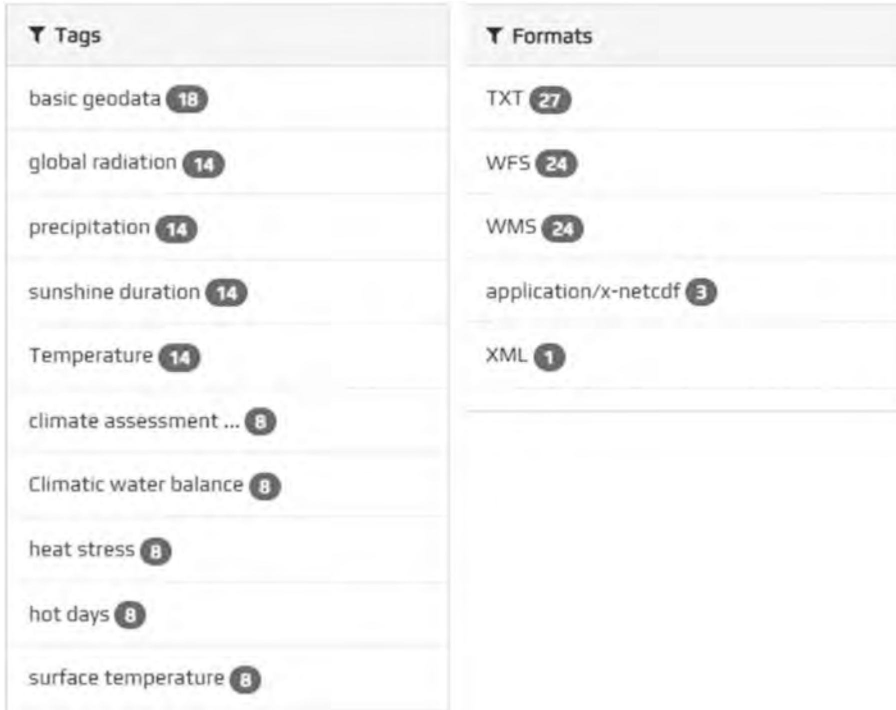

Fig. 5. Catalogue user interface to filter datasets by tags (left) or by data format (right).

blocks. The example shows trends of the annual maximum temperatures in the study area. The slide control allows to compare seasonal variability in one map.

Hereafter, the story map continues with a block about extreme weather events. Each thematic block starts with an introduction. Users can easily switch between the blocks via a navigation bar on top of the page (see Fig. 13). In addition to the maps, there are also diagrams that illustrate simulation data (Fig. 14). The story is completed by a block on health risks resulting from increasing heat.

Typical application scenarios

This section provides practical examples of the enhanced system introduced earlier. To reflect the perspectives of different possible user groups, three scenarios are given. The first scenario shows the workflow of data providers. It demonstrates how data and metadata are stored and then distributed to the different system components. The second and third scenarios illustrate how end users search for data or information. The second scenario involves expert users. In contrast, the users of the third scenario have no background knowledge about climate data and only want to obtain general information about possible climate impacts in a region. See (Fig. 15).

Application scenario 1 (role: data provider)

Data supply to the ReKIS system is limited to an authorised group of users with access to the FTP-based data store. As mentioned in sec. 2, these are either scientists from the KlimaKonform project or editors from the federal states administrations. The following example illustrates the workflow from the provision of data to its publication.

To release a new climate dataset on ReKIS including a data service and a metadata record, data providers must follow a two-step process. Firstly, they need to upload the data file to a specific folder allocated for data submissions on the FTP server. Secondly, they are required to store the corresponding metadata in the spreadsheet template. A Python script facilitates the automated uploading of data onto the WebGIS server. The metadata template includes assistance for populating text fields and incorporates data validation for cells, preventing faulty entries. If the metadata fields are accurately completed in the template and can be associated with a service published on the WebGIS server, the metadata is automatically uploaded to the metadata catalogue. Presently, there is no notification to data providers if no corresponding service is identified on the WebGIS server, but this could be a valuable feature to consider for future enhancements. As a result, the data can now be discovered and downloaded via ReKIS and in the catalogue.

Application scenario 2 (role: end user / skill: expert, scientific background)

As part of the KlimaKonform research project, public authority employees in municipalities receive ReKIS training to effectively use the platform and the information provided. The scenario considers such users working on an adaptation strategy for the municipality. They know from the climate factsheets of ReKIS that heavy rainfall events will play a certain role in the future. Therefore, the employees would like to obtain data on this topic. Hence, they are looking for observational data that includes the climate parameter "precipitation" covering the last decade (Fig. 16). One possibility is to search for data using the ReKIS search form. For example, if the users enter the search term "precipitation" in ReKIS, the search results will show all metadata records that have the keyword "precipitation" either in the title, description, or metadata tags (Fig. 9). The users click on one of these search results and the data catalogue opens in a new browser tab. The metadata allows to evaluate whether the data is suitable, and the corresponding datasets can be downloaded and imported into a GIS software, for instance. If the search results are not yet exactly matching the users' requirement, they can refine the search using the catalogue search filters.

Application scenario 3 (role: end user / skill: no scientific background)

In this scenario, users without background knowledge and, for example, purely private interest in the possibilities of regional climate adaption want to find out to what extent the region they live in is affected by the impacts of climate change (Fig. 17). To do this, they use the ReKIS search or manually browse the information platform. ReKIS provides factsheets for the users' municipality that show changes of temperature and precipitation for past periods as well as the projected future changes.

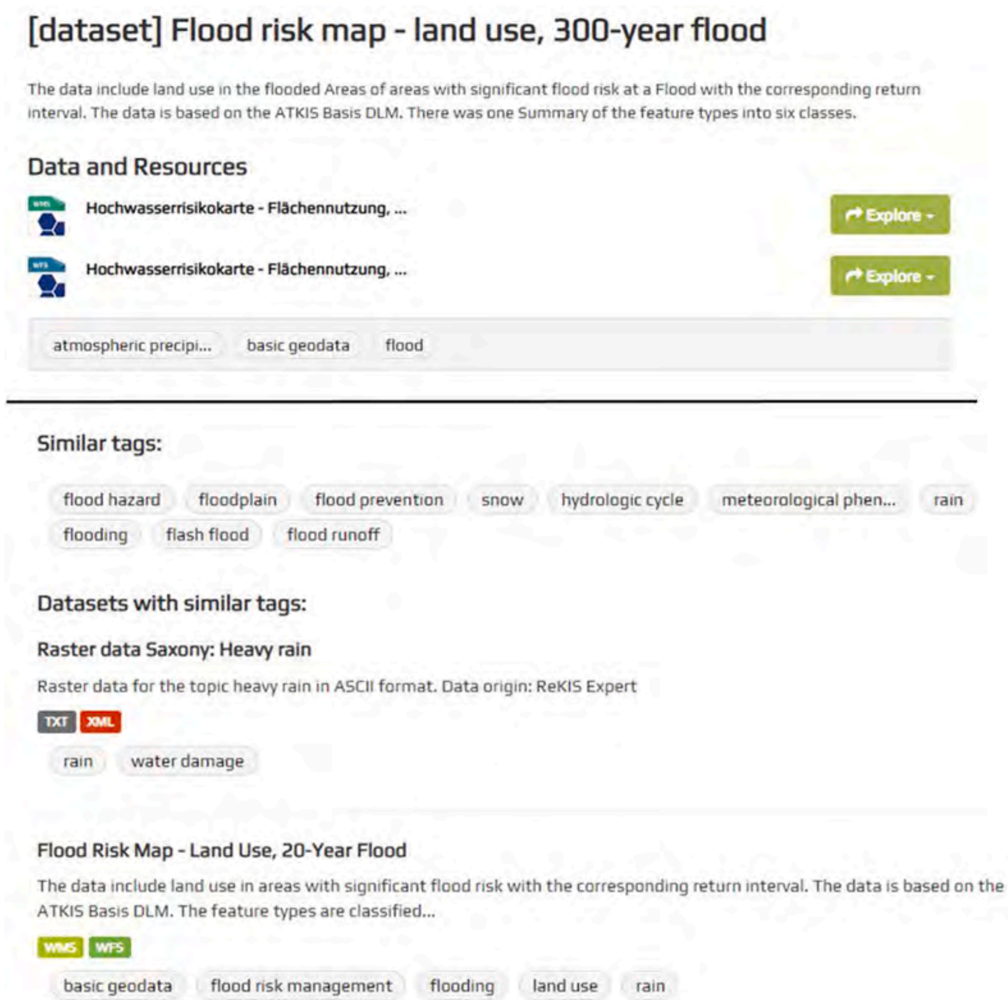

Fig. 6. An example dataset showing how metadata records are semantically linked using controlled keyword concepts.

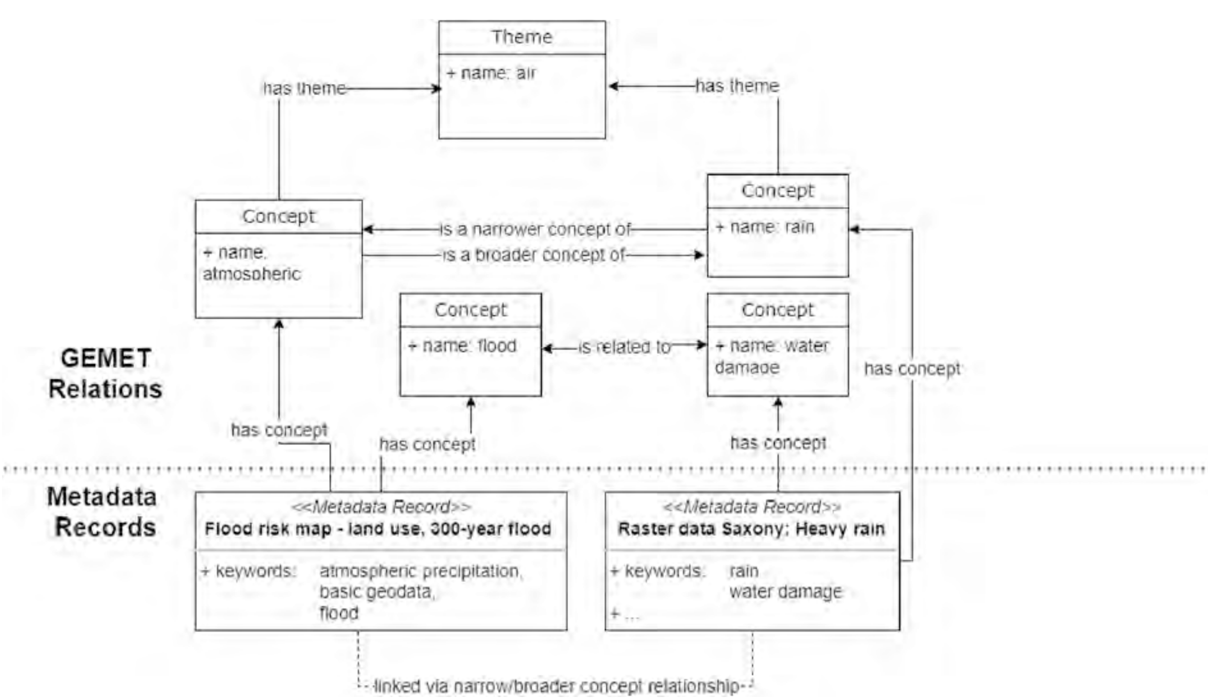

Fig. 7. Semantic link between a metadata record about flood (left) and another record about heavy rain (right).

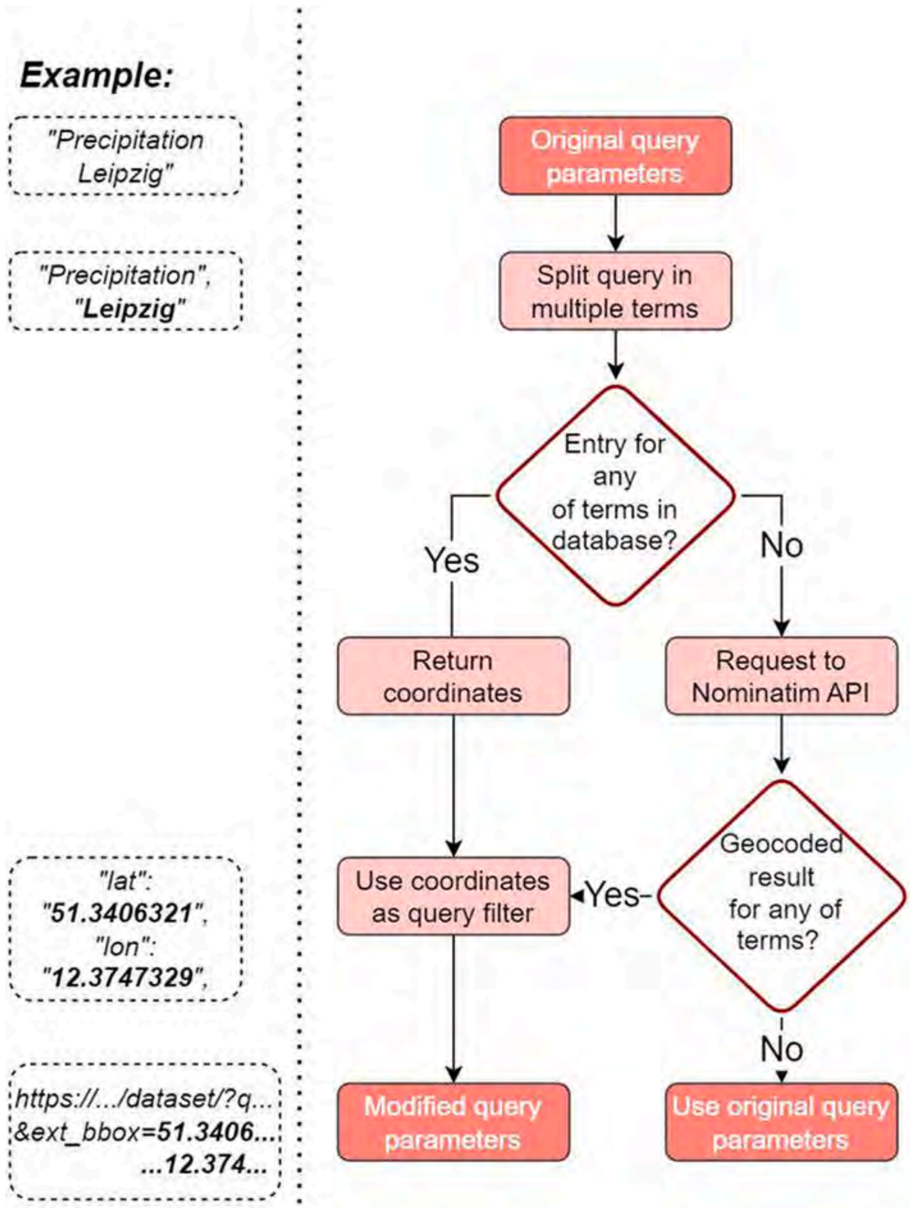

Fig. 8. Workflow used to enable a spatial "search by location" query in the catalogue.

Alternatively, the users can browse the story maps containing the web application (as described in sec. 4.2.4*)*. As explained in sec. 4.2.4, the users can obtain climate information either via the "virtual tour" or by directly selecting a field of action. Given the lack of expertise, such users will be adequately provided with information and without getting access to the data or metadata themselves.

Conclusion and perspectives

The paper illustrates how the climate information platform ReKIS was extended by new Spatial Data Infrastructure (SDI) components. It demonstrated how the contents of ReKIS can be better searched and users retrieve more suitable information to be transferred into climate-relevant decisions.

The effectiveness of metadata acquisition

The use of more detailed metadata required a novel approach to metadata acquisition and cataloguing. As ReKIS is a long-established project of three federal states, it was not practical to change or completely replace the previous procedures of (meta-) data publication. While the proposed spreadsheet-based metadata acquisition may not be a cutting-edge solution, it is practical, easy to use and allows for automatic processing without additional interfaces. In addition, it is possible to subsequently add or edit the individual metadata fields of existing catalogue entries via the web interface of the CKAN (Comprehensive Knowledge Archive Network) catalogue. Further mechanisms to automate the metadata collection are conceivable. For example, the associated data could be checked to automatically fill individual metadata fields. In the case of geodata, an example would be the automatic acquisition of the spatial extent or the spatial resolution of a raster dataset. A corresponding approach has for example been suggested by Wagner et al. (2021). This stand-alone software can analyse geodata and acquire and update missing metadata properties. The authors propose it as a complementary component that can be integrated into existing data repositories or catalogue services. Climate projection data are often provided in NetCDF format. Here, climate variables or temporal dimensions could be read out. However, the disadvantage of automatically

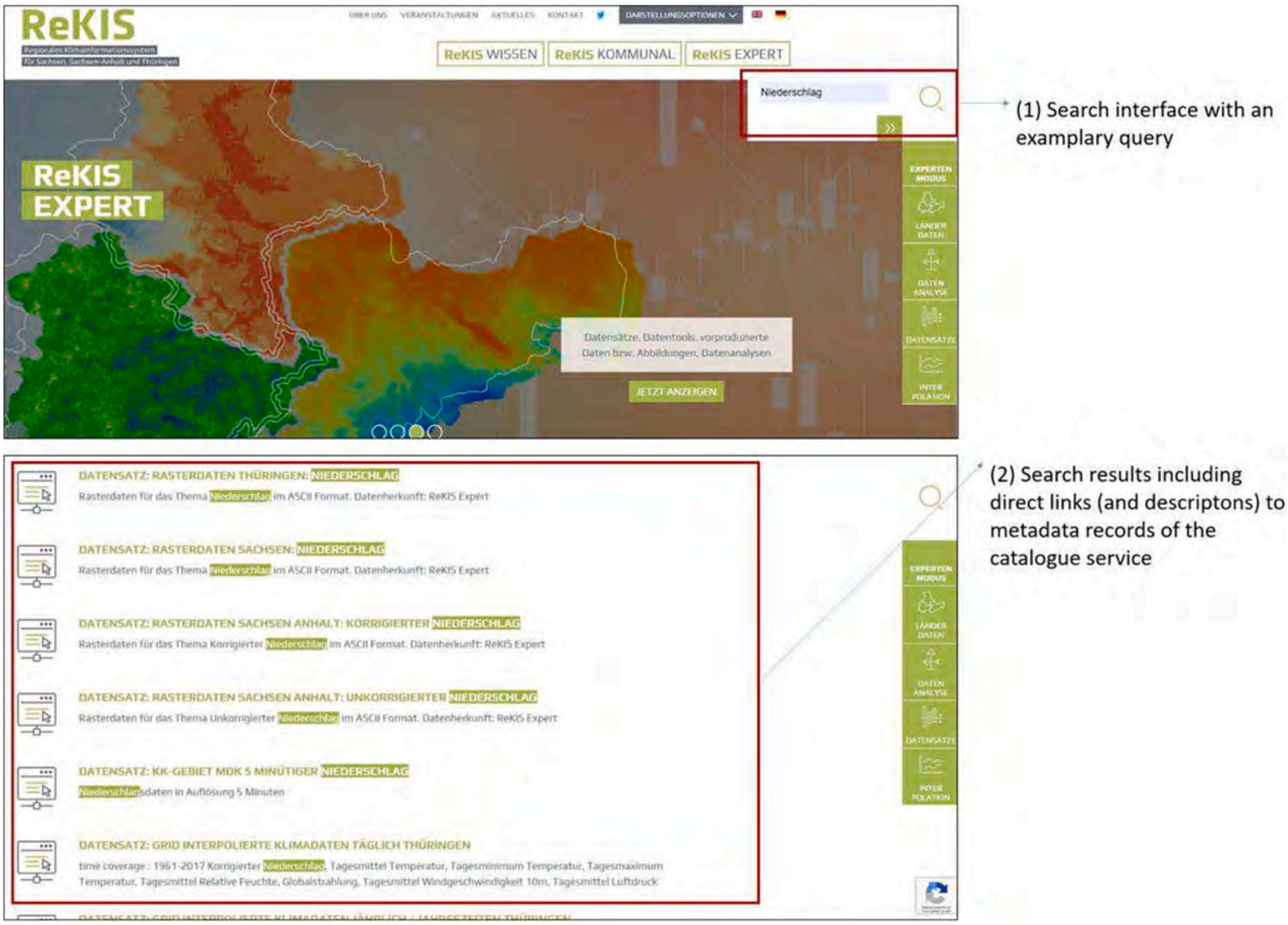

Fig. 9. Example for a search request on ReKIS (1) and respective search results (2).

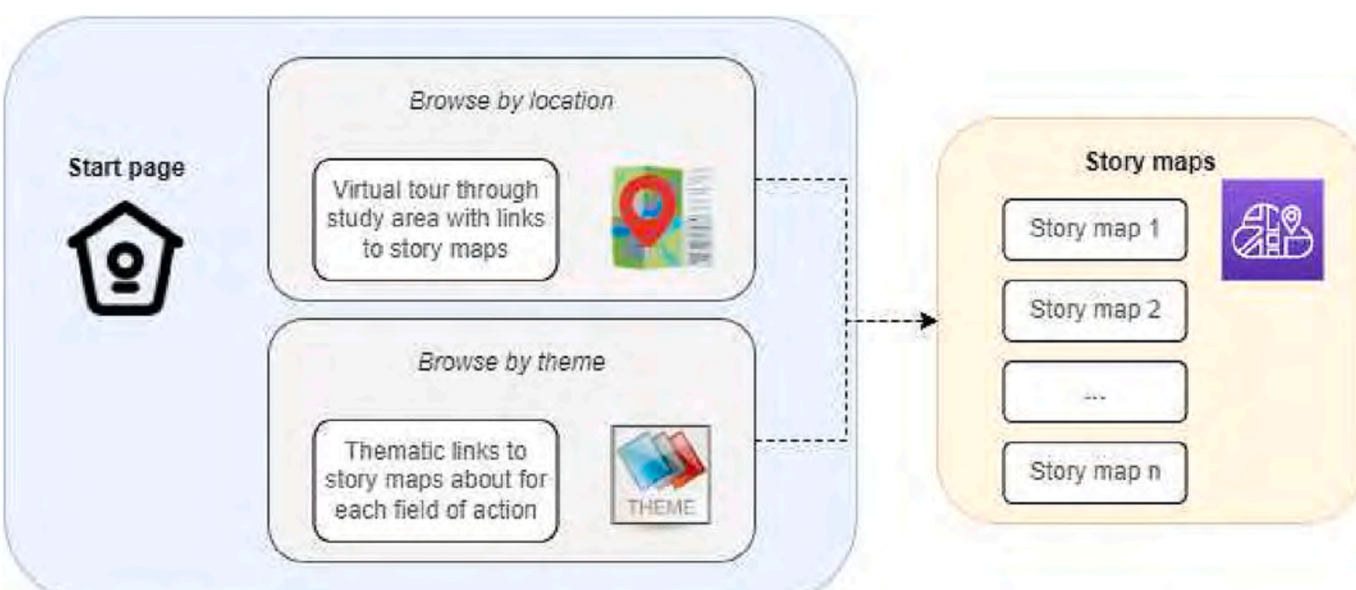

Fig. 10. Structure of the story map framework.

adding or editing metadata fields is the lack of quality control. Therefore, if such automations will be implemented in future, an additional quality assurance process is required.

Usability aspects of the catalogue component

In order to assess the suitability of the data for a particular use case,

Fig. 11. Schematic representation of the interactive tour through the study area. Each slide belongs to a place where research was carried out in the project. The respective location is focussed on in the map. In addition to a brief description, the thematically appropriate story map is linked via the button.

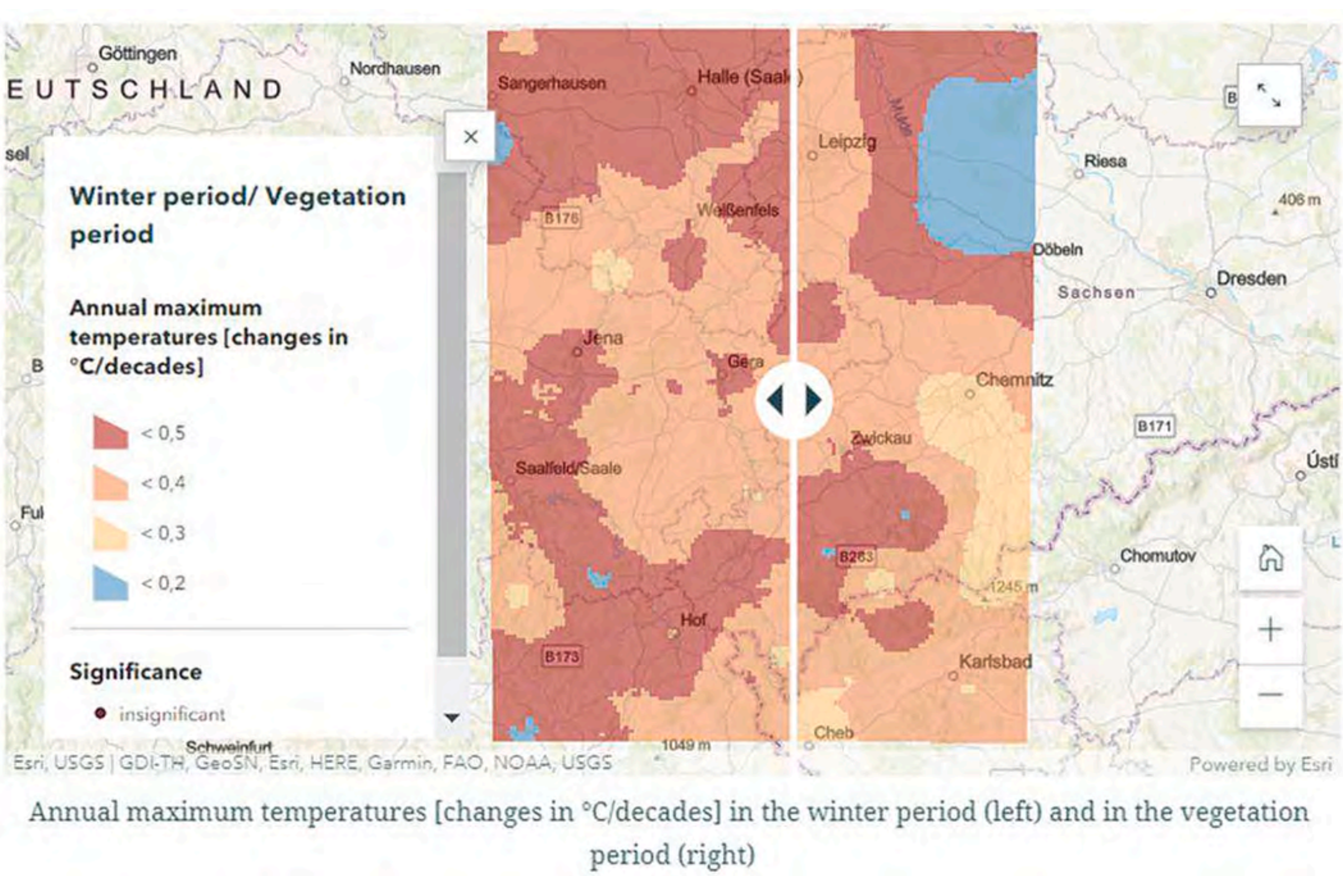

Fig. 12. Excerpts from a story map about expected climate changes in the study area.

specific metadata fields or search filters must be present. For climate data, for example, data characteristics such as the spatial and temporal coverage, up-to-dateness, a description of the underlying scenario, or the presence of certain climate variables can determine whether the data are suitable or not. Here, a further comparison with other data portals for climate data or specific user feedback will be helpful, to find out which metadata fields and which search filters are missing in the catalogue. The Copernicus Climate Data Portal (CDS)[28] offers numerous search filters tailored to climate data and could serve as a model for further enhancements of ReKIS. In order to improve the catalogue, user evaluations and user feedback workshops are planned.

[28] https://cds.climate.copernicus.eu/#!/homé (last accessed: Dec 18, 2023).

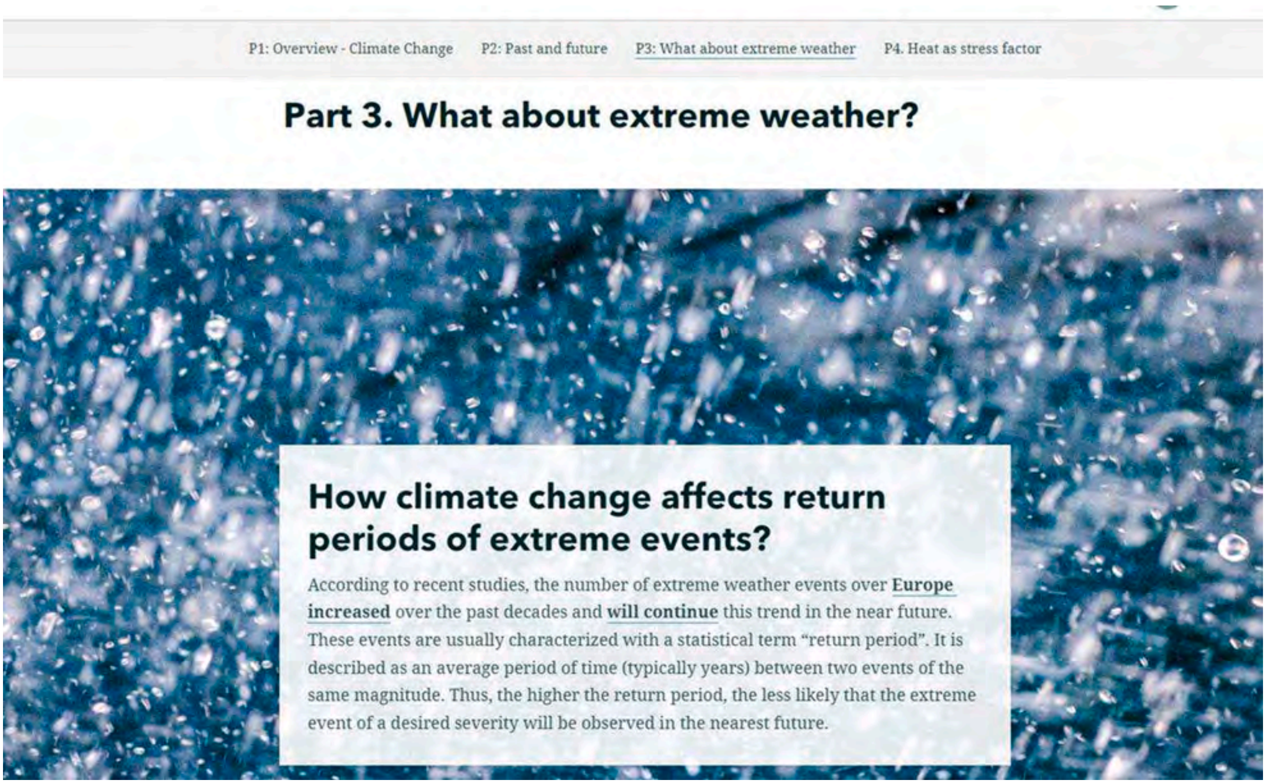

Fig. 13. Excerpts from a story map about climate changes in the sturdy area: Introduction slide for a block about extreme weather events.

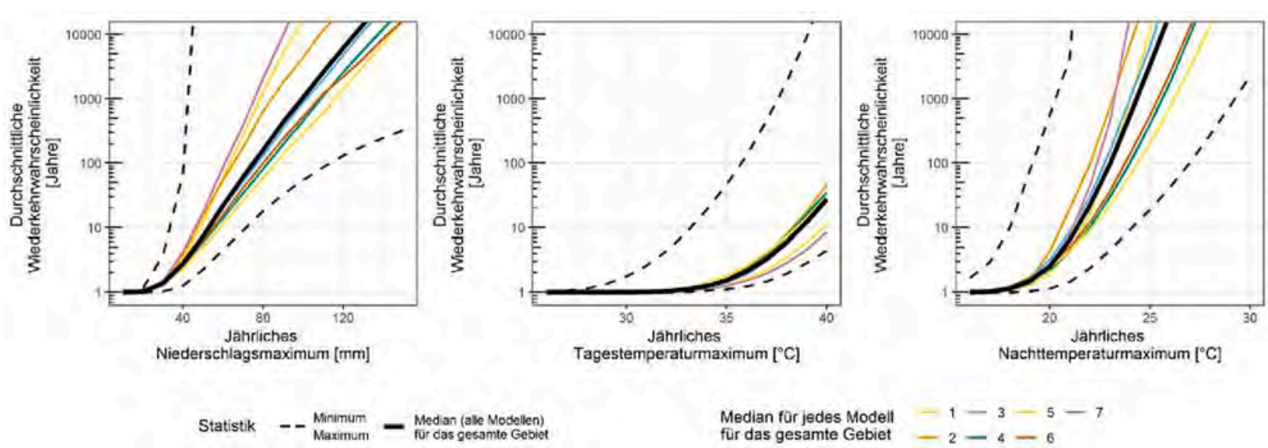

Fig. 14. Excerpts from a story map about expected climate changes in the study area: Visualization of simulation data. This diagram shows projected return periods of heavy daily precipitation and day-night temperatures for 2020–2100.

Transferability of the proposed system on other contexts

From a technical perspective, the architectural components presented here are transferrable to other system settings. The WebGIS server, the metadata catalogue, and the tools for capturing and integrating metadata are all based on open-source technologies. However, the self-developed tools that interact with the catalogue are at least partly dependent on the specific system components. For instance, the mechanisms for loading metadata into the catalogue are adapted to the CKAN API (Application Programming Interface). If a data repository other than CKAN is used or the metadata schema is significantly changed, the parts that interact with the API have to be adjusted. Examples of other geodata catalogue software are GeoNode[29] or GeoNetwork[30] which both have own web interfaces. To reduce the effort for potential new developments, attention was paid to a high modularity software design. Each component has its own software module. At best, only individual parts of the code need to be adapted. System-specific settings such as platform URLs, API tokens or login data are stored in configuration files to quickly adapt to new environments.

At present, there is no established national platform for the provision of regionalised climate information for Germany. Due to the federal

[29] https://geonode.org/ (last accessed: Dec 18, 2023).

[30] https://geonetwork-opensource.org/ (last accessed: Dec 18, 2023).

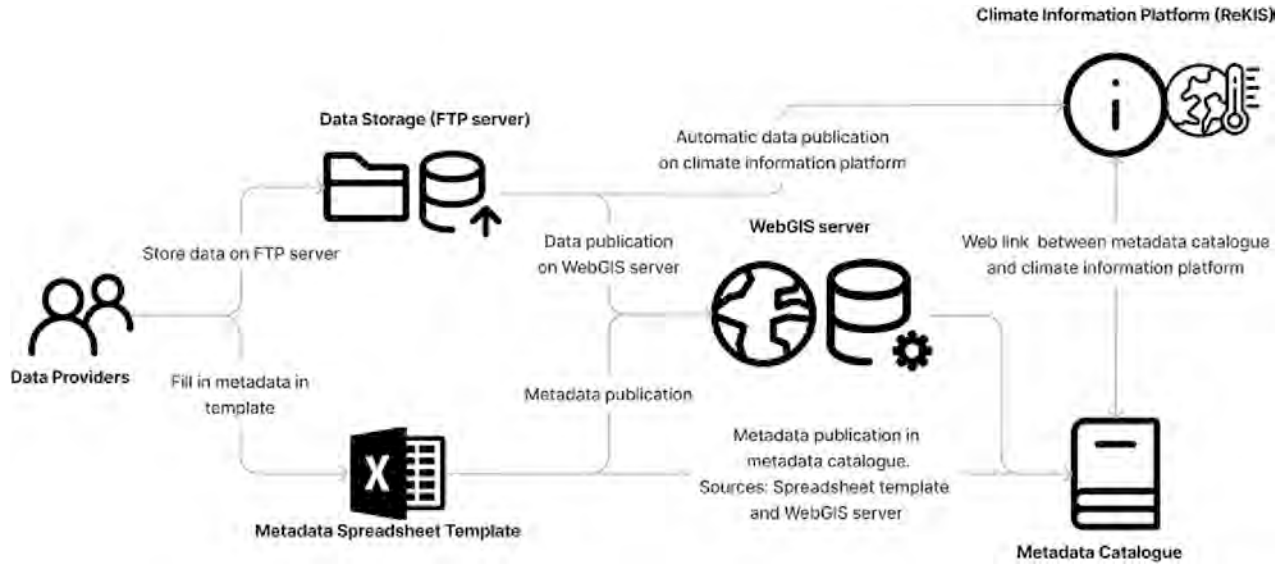

Fig. 15. Scenario 1 – Perspective of a data provider who stores data and metadata.

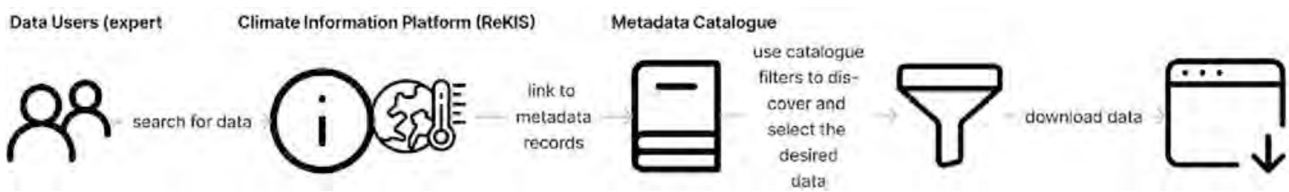

Fig. 16. Scenario 2 – Perspective of an expert user that searches for data.

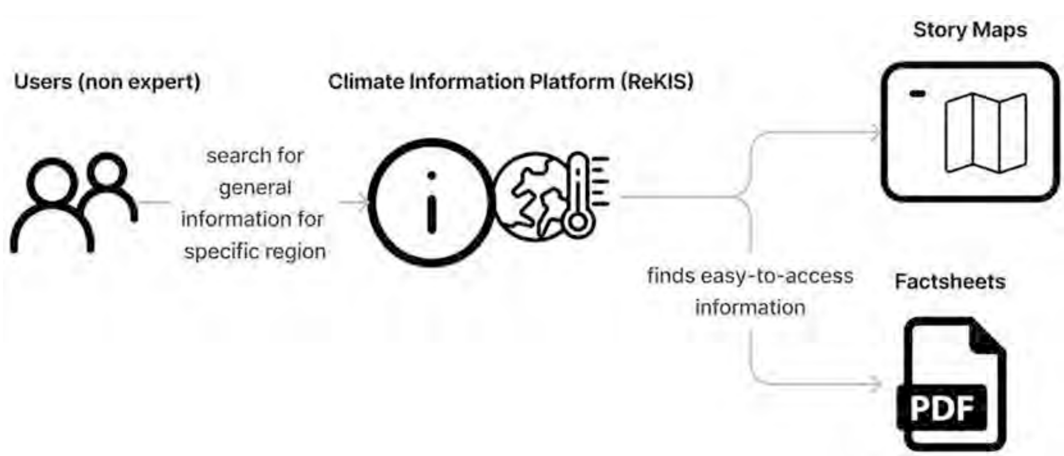

Fig. 17. Scenario 3 – Perspective of a non-expert user who explores general information for his/her region.

structure, platforms are supplied with data from federal state offices (e.g. environmental authorities) and the platforms are also funded by the respective states. The ReKIS platform is an exception as a cross-boundary project with funding and data provision from three federal states. The integration of data from these disparate platforms into a superordinate system, such as a national platform, necessitates the establishment of standardized metadata and data exchange interfaces. The efforts undertaken in this study directly address this need, aiming to contribute to the coherence and interoperability of climate information systems by introducing standardised approaches to metadata and data exchange. As ReKIS now supports standardised data and metadata exchange through the CKAN service, resources could be harvested from national SDIs or European Open Data platforms. Here, the GeoDCAT-AP metadata schema facilitates integration with platforms such as the European INSPIRE Geoportal[31] or the European Open Data Platform.[32] This could increase the visibility and reusability of the resources available in ReKIS or similar platforms. In addition, sharing data or information from climate change information platforms could contribute to the evolution of Common Open Dataspace initiatives such as the newly created Green Deal Dataspace.[33]

31 https://inspire-geoportal.ec.europa.eu/srv/ger/catalog.search#/home (last accessed: Mar 21, 2024).

32 https://data.europa.eu/en (last accessed: Mar 21, 2024).

33 https://green-deal-dataspace.eu/ (last accessed: Mar 21, 2024).

CRediT authorship contribution statement

Simeon Wetzel: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology. **Stephan Mäs:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology. **Lars Bernard:** Writing – original draft. **Ivan Vorobevskii:** Writing – original draft, Data curation. **Rico Kronenberg:** Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Code related to the work will be provided via Github of my insitution eventually.

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