TERENO: German network of terrestrial environmental observatories

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Abstract: Central elements of the TERENO network are "terrestrial observatories" at the catchment scale which were selected in climate sensitive regions of Germany for the regional analyses of climate change impacts. Within these observatories small scale research facilities and test areas are placed in order to accomplish energy, water, carbon and nutrient process studies across the different compartments of the terrestrial environment. Following a hierarchical scaling approach (point-plot-field) these detailed information and the gained knowledge will be transferred to the regional scale using integrated modelling approaches. Furthermore, existing research stations are enhanced and embedded within the observatories. In addition, mobile measurement platforms enable monitoring of dynamic processes at the local scale up to the determination of spatial pattern at the regional scale are applied within TERENO.

1   The aim of TERENO

The general aim of TERENO is to conduct integrated and long-term observation studies of climate change and global change impacts on the terrestrial system across Germany (Bogena et al., 2012; Zacharias et al., 2011). In the context of TERENO a terrestrial system is defined as a system consisting of the subsurface environment (pedosphere and hydrosphere), the land surface including the biosphere, the lower atmosphere, and the anthroposphere. These systems are organized along a hierarchy of evolving spatial scales of structures ranging from the local scale (i.e. ~100 m²) to the regional scale (i.e. >1000 km²). Furthermore, temporal scales ranging from directly observable periods (i.e. sub-hourly to several years) to long time scales (centennial to multi-millennial) derived from geoarchives are considered. With regard to the latter, TERENO focuses on precisely dated and annually to sub-seasonally resolved synchronized long-term data from lake sediments and tree rings. From monitoring and process studies on climate and environmental signal transfer into these archives, novel transfer functions will be developed. Data sets from these archives can then be generated for a direct calibration and verification against present-day instrumental data. The result will be a database of highest precision on the natural background variability of climate and landscape evolution for multi-millennial time scales.

TERENO combines observations with comprehensive larger scale experiments and integrated modeling to increase our understanding of the functioning of terrestrial systems and the complex interactions and feedback mechanisms among their different compartments. A geographically distributed framework combining monitoring with regionalization is mandatory for covering this range of spatial and temporal scales. Thus the spatial scale of a terrestrial observatory ideally covers the landscape scale ($>10^4$ km²), in order to facilitate thorough descriptions of the given climatic gradients, terrestrial and atmospheric feedback, socioeconomic disparities, and demographic gradients. By combining observatories within Germany, larger scale atmospheric feedbacks and impacts can be investigated, and thus a more pronounced general link to the atmospheric research community can be established.

2   The TERENO observatories

Within TERENO, four terrestrial observatories were selected because they represent typical landscapes in Germany and other central European countries, which are predicted to be highly vulnerable to the effects of global and climate change (Figure 1). Furthermore, the four terrestrial observatories within these regions can be expected to most appropriately exhibit the dominant terrestrial processes and the different roles of groundwater, surface water, soils, and their links to the atmospheric boundary layer. All of the regions selected are either already affected by climate change or will probably react sensitively in the foreseeable future.
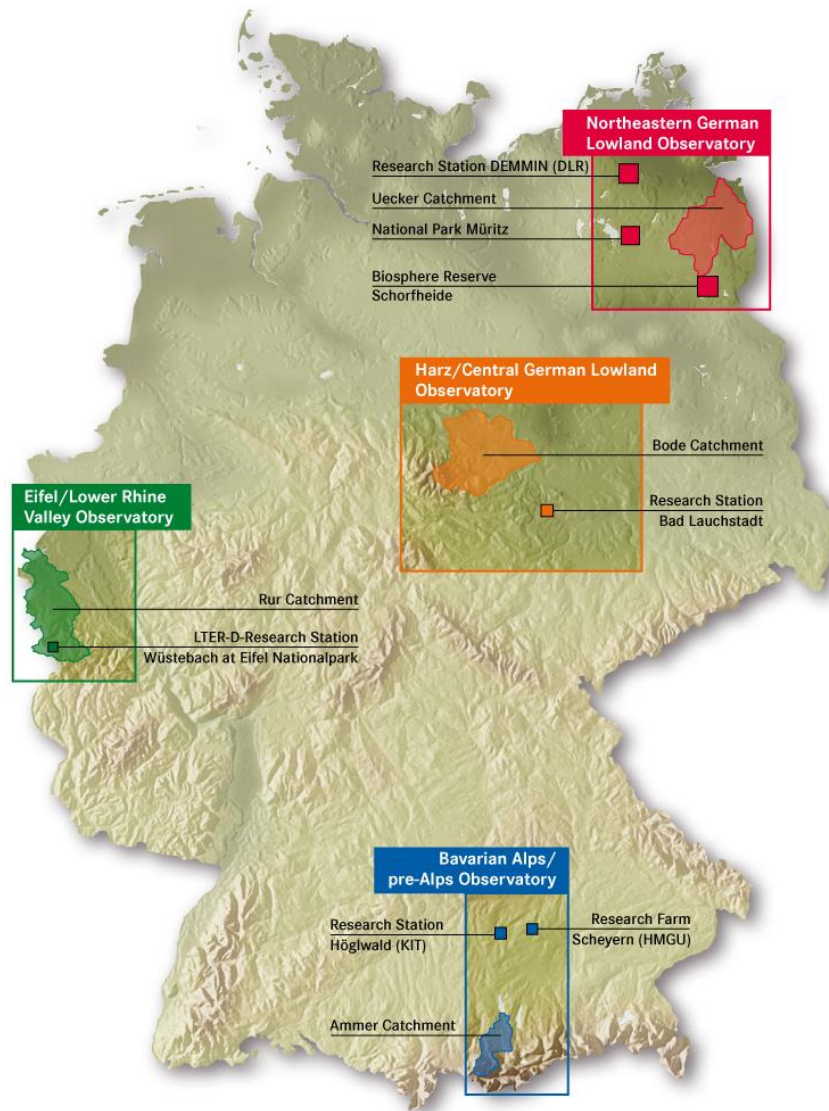
Figure 1: Map of Germany, indicating the locations of the four selected TERENO observatories, including the experimental catchments and research stations (Zacharias et al., 2011).

Within the observatories research facilities and test areas of smaller scale are operated to accomplish detailed process studies. Following a concept of hierarchical scales (point-plot-field) these detailed information will be transferred to the regional scale. Furthermore, the equipment of existing research stations (e.g. Dedelow, Demmin, Scheyern, Bad Lauchstädt) is expended and embedded within the observatories. Mobile measurement platforms will be applied for both the monitoring of dynamic processes at the local scale as well as the determination of their spatial patterns at the regional scale.

Figure 2 shows a schematic view of a typical TERENO observation platform composed of the following measurement systems (please refer to the references for more detailed information):
- Measuring systems for the determination of regional precipitation fields using weather radars (1) or densification of precipitation gauging networks (2), e.g. Diederich et al. (2015)
- Micrometeorological eddy-covariance towers (3) for the determination of atmospheric parameter and fluxes of water vapor, energy and trace gases, see e.g. Mauder et al. (2013)

- Sensor networks (4) for determination of environmental parameter at high spatial and temporal resolution, e.g. Rosenbaum et al. (2012), Baatz et al. (2014)
- Monitoring systems for the quantification of water and solute discharge in surface waters and groundwater (5), see e.g. Stockinger et al. (2014), weighable lysimeter systems (6) with controlled lower boundary and soil sensors at different soil depths, e.g. Hannes et al. (2015)
- Ground-based and airborne remote sensing platforms, e.g. microwave radiometer (7), airborne campaigns (8), e.g. Hasan et al. (2014), Jagdhuber et al. (2015)
- Acquisition of satellite-borne data (9), e.g. Montzka et al. (2013), Rötzer et al. (2014)
- Geoarchiving systems (10), e.g. for lake proxy calibration (e.g. Kienel et al. (2013)
- Monitoring systems for the quantification of hourly tree growth increments and water use (11), e.g. Simard et al. (2014)

Figure 2: Schematic view of a typical TERENO observatory platform (see text for more information).

Additional to the remote sensing components and field components described above an information infrastructure is required to secure the functionality of the observatories. This infrastructure is characterized by a high degree of automation and operationalization. These supplementing systems of the TERENO observatories are e.g.: automatic and operational processing chains to near-real-time derivation of value added information products based on in-situ-data (Borg et al., 2014, Sorg & Kunkel, 2015) or based on earth observation data or remote sensing data (Missling et al., 2014).

3   The TERENO Data Infrastructure

Each TERENO observatory is responsible for the organization and storage of its own data, but interlinked using standardized interfaces within a distributed data infrastructure (Kunkel et al., 2013, Koldiz et al., 2012). During instrumentation of the four terrestrial observatories, local data infrastructures were implemented by the TERENO partners (Figure 3). In situ sensor data processing is accomplished by integrated time series management systems, developed and implemented by the TERENO consortium. Persisting and archiving of the sensor data is accomplished within the data storage component of the infrastructure. Data storage in the database and registration of the sensor

metadata both require an underlying data model for time series data. A comprehensive data model for time series data was developed to store environmental observations along with sufficient metadata in order to provide a traceable and complete data processing from raw measurements to usable information. An Observation Data Model was developed to represent the processes of data recording, import and publication adequately. It contains several components, which allow for detailed characterization of the data values, sites and variables, used sensors, configuration of the individual input files, transformation and averaging procedures, responsible parties, sample specifications and publishing information (Kunkel et al., 2013).

Almost all data are accessible freely as soon as quality assessment of the data was performed set. The corresponding services are accessible from the TERENO data portal exclusively, since the TERENO data policy requires notification of the responsible scientists about data downloads (see Chapters 3.1 and 3.2)
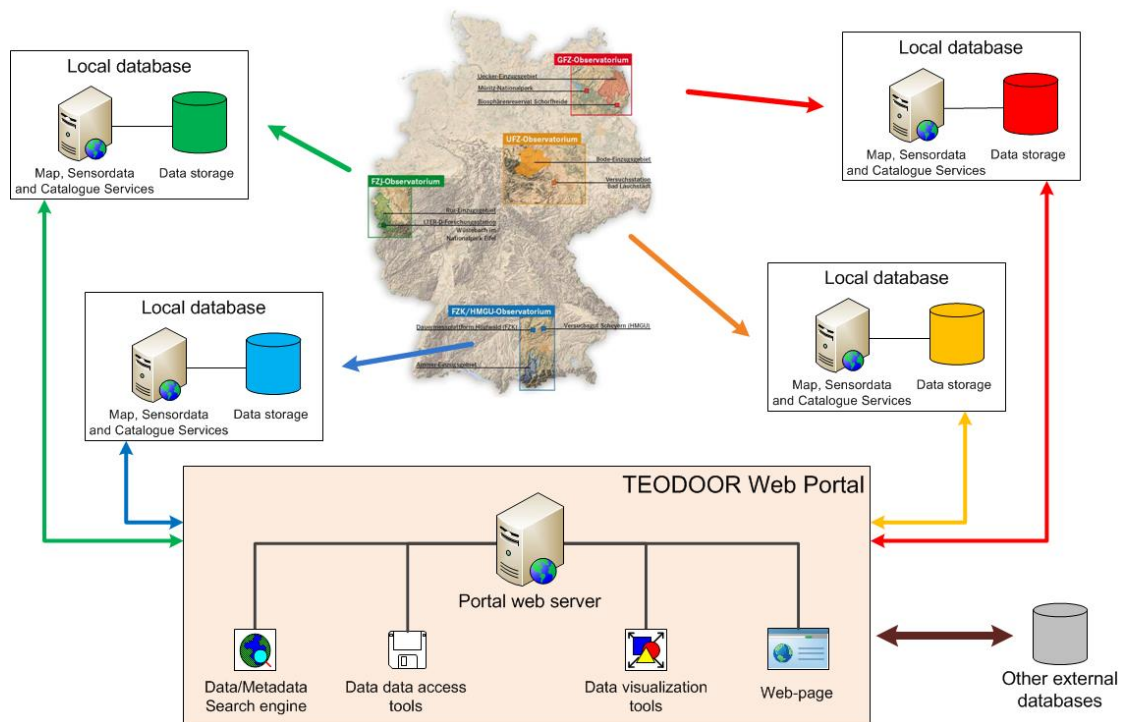
Figure 3: The design of the TERENO infrastructure for the distribution of the data

3.1 The data portal TEODOOR

The data portal TEODOOR facilitates the online provision of TERENO data. It is hosted by Forschungszentrum Jülich and can be accessed via https://teodoor.icg.kfa-juelich.de/ (Kunkel et al., 2013). TEODOOR uses common standards for the metadata description of datasets based on the INSPIRE directive for spatial data infrastructures (http://inspire.jrc.ec.europa.eu) allowing for search throughout the entire data base. Standard protocols for accessing the data (such as OGC web services, http://www.opengeospatial.org/) are used to guarantee compatibility to the related individual data infrastructures of the TERENO partners. The TEODOOR portal allows versatile community access to data sources. Property rights for different data levels are regulated. Three different levels have been established for data acquired within the project: Unevaluated data (level 1) cannot be accessed prior to quality assessment. Quality controlled data (level 2) can be accessed directly. Derived data products (level 3) can be accessed either directly or according to the directives of copyright holders, in case the data are copyright protected. Algorithms for the automated

processing to provide these data layers are currently under development. It is also planned to issue document object identifiers (DOI) to datasets for unique referencing and citation purposes (Klump & Bertelmann, 2013).

3.2 Data policy

Data governance and data stewardship programs, data architecture and data management programs are much more effective if they are supported by a directive concerning the data management policy. A data policy statement (TERENO, 2015), required for data processing and data exchange, was developed in a common approach by all TERENO partners. A main aspect of the data policy was the definition of the data ownership (intellectual property rights) and data access rights concerning the directives of funding organizations differentiated by types of digital resources, their process status, the data creator and the data source. As a rule, all data are freely accessible within the TERENO community and accessible also to the public as soon as at least a first quality check was performed on the data and no other usage restrictions are existent, e.g. due to ongoing PhD-studies or external copyright issues.

4   Outreach

TERENO is closely linked to other environmental observatory networks (e.g. ICOS, CZO, FLUXNET, LTER etc.) and other institutions (e.g. environmental agencies, universities). The infrastructures of TERENO (sites, instruments, data management etc.) are used in several project collaborations with partners from universities and other research organizations. TERENO is also engaged in research training (e.g. annual summer schools and technical courses) as well as in supporting scientific education of Universities (e.g. accomplishment of field excursions).

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