IMPROVING CLIMATE MONITORING SYSTEMS THROUGH OBJECT-RELATIONAL MAPPING TECHNOLOGIES AND REAL-TIME ANALYTICAL PROCESSING

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Abstract. The article addresses challenges related to climate change research. It provides an overview of contemporary information technologies that facilitate the design of highly efficient climate monitoring information systems, specifically in terms of processing speed and data completeness. Particular emphasis is placed on the use of tools for automatic object-to-database table mapping based on real-time Object-Relational Mapping (ORM) systems, as well as on OLAP technologies, which leverage multidimensional cubes to accelerate the processing of large-scale climate data and enhance the effectiveness of multidimensional data analysis. The developed climate monitoring information system, presented herein, comprises components for aggregated data sets, backend processing, frontend visualization, and an analytical module implemented as OLAP cubes. The system enables scientific research on environmental parameters and supports the development of forecasting models for climate monitoring systems, providing predictive and decision-support capabilities designed to mitigate global warming.

Key words: monitoring information system, climate conditions, forecasting, real-time system, OLAP technologies, database, global warming, big data.

1. Introduction

Climate conditions are of widespread concern for comfortable living, and various methods are used to assess them, including visual and sensory observations, thermometers, humidity sensors, and other instruments. Nowadays, the majority rely on digital devices, such as mobile phones, laptops, tablets, and personal computers equipped with services from mobile operators and web application developers, to monitor weather conditions. All mobile phone manufacturers offer their software, which includes pre-installed applications for monitoring weather phenomena.

Climate conditions influence nearly every facet of society, ranging from food production to transportation infrastructure. Climate can be defined as the long-term pattern of weather conditions at any location on Earth. It has a significant impact on human existence, health, and future development. Climate change is driven by human activities, notably anthropogenic effects on the environment. It is worth noting that the influence of human-induced environmental problems on the planet's viability has increased considerably in recent years. Global warming results from disruptions in the carbon balance within ecosystems and the effects of various pollutants, leading to unpredictable climate variations.

Climatology studies the impact of climate on society and potential climatic changes, incorporating weather forecasts and contributing to future climate projection assessments. By applying various methodologies and considering geographic location, predictions can be made regarding the likelihood of snow, hail, and regional solar energy availability. Scientific research on climate change typically focuses on average weather conditions over defined temporal intervals. For instance, paleoclimatology is concerned with the investigation of Earth's climate over geological timescales through the analysis of tree-ring records, stratigraphic distribution and depth of rocks and sediments, and the study of glacial ice layers. Climate change effects vary according to the geographical location of a region, directly impacting human life, the economy, and natural ecosystems. Researching climate change and developing effective monitoring systems promote the reduction of the adverse effects of extreme weather events and foster efficient management of natural and anthropogenic resources. In the most general case, it can be stated that a weather monitoring system should take into account the specific features of different regions, which may vary in both climate conditions and socio-economic factors. For instance, agricultural zones distant from water bodies may be prone to droughts or hail, whereas coastal regions face increased risks of storms and flooding. These geographical characteristics define the objectives of environmental monitoring systems, emphasizing not only the analysis of climate models but also the integration of data from local weather stations and satellite-based observation systems. The information system for monitoring climate change should ensure the timely collection, processing, and analysis of data necessary for making prompt decisions. When designing such systems, attention should be given to object-relational mapping (ORM) technologies, which enable effective work with large volumes of data stored in relational databases and provide fast access to the necessary information. ORM technologies establish mappings between programming language classes and database tables, enhancing processing efficiency. Additionally, ORM enables data manipulation operations, such as creation, retrieval, modification, and deletion, via object-oriented programming, automatically translating these actions into corresponding relational queries, thereby facilitating efficient data handling. Data stored in databases is represented as objects within the program, ensuring robust bidirectional data interaction. Utilization of ORM reduces the amount of code required for database operations, enhances development productivity, decreases data processing errors, and improves portability across various data types supported by database management systems (DBMS) [1]. Utilizing relational database management systems ensures stable and dependable system operation, which is essential for real-time weather monitoring.

A further essential feature of the proposed monitoring system is its capability to integrate with external data sources, providing access to real-time weather conditions and climate change data [2]. This capability is critically important for predicting short-term variations such as sudden temperature fluctuations or approaching storms. Data from various information sources must be processed to detect anomalies and other potentially hazardous situations. For analytical purposes, classical statistical methods—such as regression and time series analyses—are utilized to improve forecasting accuracy and system reliability [3].

In conclusion, the development of an effective climate monitoring system necessitates the integration of diverse data sources, efficient data processing and visualization, and the assurance of reliable and stable operation under real-time conditions. The integration of ORM technologies, relational databases, and advanced climate observation applications facilitates the creation of contemporary solutions that cater to diverse user requirements while ensuring efficient weather monitoring and forecasting capabilities [4].

2. Limitations

Various approaches to weather prediction exist, ranging from relatively simple sky observations to highly complex computerized mathematical models. Numerous software applications are capable of monitoring climate conditions, detecting droughts, and forecasting hazardous weather events for agriculture and production. However, accurate weather forecasting remains challenging due to the dynamic nature of the atmosphere. Analysis of the subject domain and existing solutions in the development of monitoring information systems revealed that many current applications are unable to deliver sufficient processing speed for large data volumes or the capability to integrate with diverse data sources. Furthermore, not all systems offer intuitive visualization tools. Developing monitoring systems that leverage object-relational mapping technologies and real-time analytics can greatly improve climate research capabilities.

3. Research objective

This study aims to analyze existing weather monitoring tools and software applications that utilize climate change prediction systems, and examine a developed monitoring system intended to improve the detection of global warming impacts caused by both climatic variations and anthropogenic factors. The proposed forecasting system is designed to integrate modern technologies aimed at optimizing processing efficiency by ensuring effective interoperability between object-oriented programming languages and database management systems, alongside real-time data processing utilizing OLAP cubes.

4. Development of a climate monitoring information system

This study focuses on identifying the most critical characteristics of climate monitoring information systems [5]. Specifically:

1) Existing web-based systems facilitate enhanced understanding by researchers and communities of complex climate change processes and indicators, enabling more effective responses to climate-related challenges through improved accessibility and data interpretation.

2) Monitoring information systems enable the collection and analysis of large-scale climate data, which is particularly crucial for scientific research on climate change patterns and global warming impacts. These systems also support evidence-based policymaking to address climate-related societal challenges.

3) Purpose-built web systems enhance collaboration among researchers, activists, government agencies, and the public by facilitating data and information exchange, as well as sharing best practices for climate adaptation.

4) Modern environmental monitoring systems equip citizens and policymakers with tools to derive evidence-based conclusions regarding the impacts of individual or collective climate actions. Such recommendations actively encourage the adoption of eco-friendly alternatives, support for low-carbon policies, and implementation of pollution control initiatives.

5) Existing climate monitoring systems facilitate real-time tracking of environmental changes and the formulation of targeted adaptation strategies to address emerging climate conditions, thereby mitigating ecological risks, preserving ecosystem resilience, and improving human well-being.

A comparative analysis of existing solutions will be conducted to gain a comprehensive understanding of the design processes of climate change monitoring information systems. Current web applications primarily serve to collect research data and establish collaborative decision-making frameworks by defining pathways for climate change monitoring and adaptation.

The Climate Data Analysis Tools Platform enables researchers to investigate planetary climate processes, with a particular focus on investigating diverse climate aspects and tracking temperature variations, precipitation patterns, atmospheric composition, and other key parameters [6]. During analysis, the system performs various computations, including trend analysis, assessment of variable conditions over specified periods for defined geographical areas, and correlation studies. The platform offers a comprehensive suite of tools for downloading, processing, and transforming multi-source climate data. A significant advantage of the system is its advanced visualization capabilities, which generate analytical outputs including graphs, charts, geospatial maps, and heatmaps. These visualization features substantially enhance researchers' data analysis capabilities.

Developed by the National Aeronautics and Space Administration (NASA), the Worldview web application facilitates dynamic user engagement through configurable data type selection and parameter customization, enabling highly adaptable visualization of climate research outputs [7]. The platform's interactivity and real-time change monitoring capabilities serve as critical tools for both researchers and general users.

The OpenWeatherMap geographic information system provides weather condition data and fosters a collaborative development environment. Its application programming interface (API) enables seamless integration into various software applications and services. Developed by the British company OpenWeather Ltd, the system leverages artificial intelligence and machine learning to deliver global environmental data. The company's primary areas of expertise include energy, logistics, agriculture, and other industrial sectors. OpenWeatherMap sources its data through collaborations with meteorological agencies, including the U.S. National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization, and the European Space Agency [8]. Its global coverage and detailed information on extreme climate events make OpenWeatherMap a valuable resource for climate change and global warming research.

The Climate Explorer web application is designed to provide users with access to diverse climate datasets and visualisation tools. Notably, the platform supports data retrieval from various sources, including satellite imagery and meteorological measurements. For enhanced understanding of climate dynamics, users can generate graphs, maps, and other visual representations [9]. Climate Explorer also enables comparative analysis of climate indicators across different regions and time intervals, facilitating effective examination of climate change patterns.

The Climate Prediction Center (CPC) monitoring system is recognized for its global observation of climate parameters such as temperature and precipitation at multiple spatial scales [10]. The center publishes a range of climate products, including maps and analytical reports highlighting ongoing trends and anomalies. This information is vital for scientists, researchers, and policymakers. Using long-term weather data, the CPC produces seasonal forecasts to help anticipate extreme events, including droughts and floods.

Another prominent tool, the Climate Data Store (CDS), developed by the European Centre for Medium-Range Weather Forecasts, serves as a central repository for climate-related data. The platform offers access to extensive observational datasets and model outputs through an interactive interface, enabling users to generate custom reports and perform statistical analyses [11]. By providing open access to critical climate data, CDS supports scientific research and the development of predictive climate models. Its accessibility to both experts and the public facilitates broader engagement with climate science and policy. Collectively, these tools and platforms provide essential capabilities for understanding and interacting with climate dynamics. They constitute a vital component of global strategies for advancing environmental sustainability and shaping climate policies directed toward achieving a secure and resilient future.

Information Model of the Research Object

The domain analysis represents the first step in developing a complex information system, as it provides a comprehensive understanding of the specific environment in which the system will function. The subject area of weather monitoring encompasses a broad range of scientific and practical knowledge, including the study of climatic processes, the use of meteorological instruments, data collection and processing technologies, and modern information approaches to weather data analysis.

To support the development of the climate monitoring information system, a structural diagram of the system has been created (Fig. 1). Architectural approaches to processing large climate datasets in modern society are shaping the future of technological progress. With the exponential growth of available data volumes, researchers are refining architectural solutions to optimize data analysis, processing, and storage. Centralized architectural models enable efficient big data processing by organizing information according to specific parameters while incorporating parallel processing to enhance system performance and scalability.

Accurate climate change forecasting requires classification of the most commonly used big data technologies. The MapReduce programming model is employed for distributed computation, while data storage relies on the Hadoop Distributed File System (HDFS) of the Apache Hadoop platform. For real-time processing, Apache Spark and Apache Flink are widely used, as they support distributed, low-latency stream processing. The Resilient Distributed Datasets (RDD) concept enables both batch and stream processing for generating up-to-date information. Apache Flink, in turn, delivers an event-driven architecture for stream analysis, rendering it well-suited for the timely identification of climate change trends. Machine learning technologies, implemented through TensorFlow and PyTorch libraries, enable efficient data forecasting and analysis by providing interfaces for constructing and training models applicable to large-scale climate trend prediction.

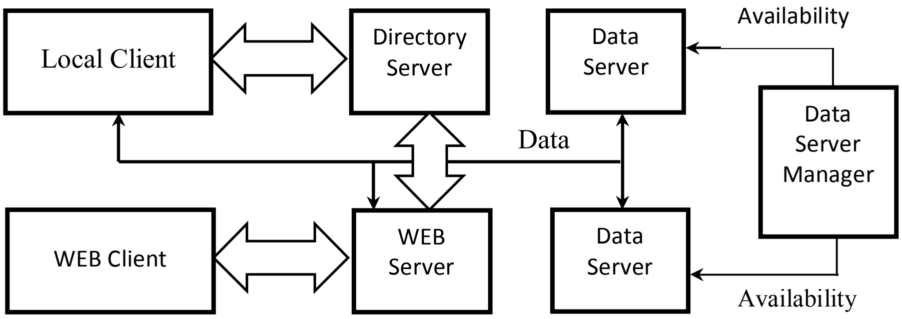

Fig. 1. Structure of the Climate Data Monitoring Information System

Developers of climate monitoring systems must address the challenge of selecting optimal architectural frameworks and technological tools for efficient big data processing. The first step involves identifying the types of data to be processed, given their heterogeneous nature. Climate data originates from a variety of sensors and weather stations and is typically represented as extensive time-series datasets. Geospatial data provides the spatial context of climatic phenomena and is defined by specific geographic coordinates. Climate data forms a complex information structure encompassing multiple parameters that characterize atmospheric phenomena. For instance, temperature is measured using thermometers, infrared thermometers, and thermistors, while atmospheric humidity, expressed as water vapor percentage, is measured by hygrometers and psychrometers. Monitoring humidity distribution across atmospheric layers is crucial for understanding climate mechanisms and enhancing forecast accuracy. Other key climate parameters include atmospheric pressure (measured by barometers) and precipitation (assessed via rain gauges, radar, and acoustic sensors), which are essential for water balance assessment.

Designing an information system requires defining the structure of climate data and identifying internationally recognized datasets along with their core characteristics.

The dataset developed by the Joint Research Centre (JRC) includes global temperature records and is intended for studying and monitoring climate change. It offers a comprehensive assessment of global warming [12]. Temperature data is collected from both land-based stations and marine platforms (e.g., buoys and floating thermometers). The main advantage of this dataset is its broad geographical coverage, as it incorporates temperature variations across all continents. The JRC dataset spans significant temporal ranges, enabling long-term climate trend analysis and a deeper understanding of both natural and anthropogenic influencing factors.

The ERA5 dataset, developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), represents a data reanalysis of key climate parameters (temperature, humidity, atmospheric pressure, etc.) and a comprehensive assessment of atmospheric and surface conditions. The reanalysis methodology fundamentally combines actual observational data with numerical modeling to produce a coherent, high-resolution representation of global climate patterns [13]. This approach enables the correction and harmonization of measurements from diverse sources to generate objective climate diagnostics relevant to global warming phenomena. The ERA5 dataset achieves exceptional accuracy due to its high spatial and temporal resolution, with global data being updated hourly at a spatial resolution of up to one kilometer. This fine-grained resolution capability allows for precise monitoring of short-term meteorological events and detailed analysis of atmospheric process dynamics.

The Climate Prediction Center (CPC) dataset includes information and forecasts on various climate parameters, such as temperature, precipitation, and others. The center provides access to scientifically coordinated information resources for studying and predicting climate change, particularly in light of seasonal variations. The range of collected data includes not only temperature indicators but also precipitation levels, enabling a comprehensive representation of climate conditions on both local and global scales [10]. When analyzing seasonal changes throughout different periods of the year, the data can be applied in environmental studies of water resources, agriculture, and energy to develop adaptation strategies and informed decision-making. A major advantage of CPC is its expertise in studying El Niño and other climatic phenomena that impact global and regional climate conditions, which enables researchers to develop appropriate risk management strategies and forecast potential impacts on specific regions.

One of the most widely used resources for studying climate change and assessing its impacts is the dataset from the National Aeronautics and Space Administration, the NASA GISS Surface Temperature Analysis (GSTA). The agency's records include data on global and regional temperature variations throughout the planet. Climate change research data relies on information gathered from a wide network of meteorological stations, floating platforms, and other sources. A key advantage of this dataset is its ability to provide long-term data for trend forecasting, enabling the observation of climate change patterns and associated risks [14]. Another important strength is the high level of accuracy and reliability of the analysis results, achieved through the application of various mathematical and statistical methods for data adjustment.

The European Climate Assessment & Dataset (ECA&D) platform presents detailed climate data with a strong focus on the European continent [15]. The dataset includes climate parameters such as temperature, precipitation, snow cover, and others, allowing scientists and researchers to obtain comprehensive information on different types of climate change. Its level of detail enables the study of localized climate features in small-scale regions. In terms of temporal coverage, ECA&D supplies datasets that extend over a considerable time frame, giving it an advantage over other datasets in terms of long-term forecasting. Historical records support research on climate evolution and the identification of extreme events that may indicate shifts in the ecological system. Another notable advantage of this resource is its openness and accessibility, enabling efficient, collaborative, team-based research on climate change and its environmental impacts on the planet, as well as the ecological situation.

To study global temperature variations, using the dataset provided by Berkeley Earth proves to be convenient due to its openness, transparency, and accessibility. Its global temperature data are characterized by high accuracy and resolution, made possible through collaboration among a broad group of scientists to ensure reliable forecasting results. The high spatial resolution of the data enables the analysis of temperature changes at regional and local spatial levels [16]. Transparent access to the dataset fosters reliability and facilitates the efficient use of detailed information on data processing and analysis methodologies by scientists, as well as verifying results, replicating experiments, and conducting independent climate analyses. The Berkeley Earth dataset is compiled using various sources of information, including measurements from meteorological stations, satellite observations, and other inputs, which together help create a reliable global temperature map.

The Copernicus Climate Change Service (C3S) platform, an initiative of the European Commission, provides large-scale climate data processing, including temperature, precipitation, and wind speed, for global and regional climate monitoring and analysis. The information system's core objective is to provide reliable information to support the understanding and adaptation of climate change. C3S's high spatial resolution is a key feature that offers detailed data to detect different variations in climate conditions and assess their impact on various global regions [17]. The platform uses advanced technologies and methodologies for processing and analyzing vast volumes of data, ensuring the provision of up-to-date information in the context of rapid climate change. Additionally, C3S supports sectors such as agriculture and energy by providing tailored climate information services and developing strategies and solutions aimed at mitigating global warming.

For climate monitoring information system design and research, it is advisable to utilize the dataset from the Global Historical Climatology Network (GHCN) developed by the National Oceanic and Atmospheric Administration (NOAA). The dataset includes climate variables such as temperature, precipitation, wind speed, and others. Given its extensive geographical distribution, the GHCN dataset captures information from diverse global regions, including both urban and remote rural areas, offering a comprehensive view of climatic variability [18]. The temperature data include measurements of air and surface temperatures, supporting the analysis of thermal regimes across different parts of the world. Precipitation data provide insight into humidity levels and precipitation intensity, essential for studies of water resources and ecological systems. Wind speed measurements help account for atmospheric circulation and other aspects of climatic conditions. The long duration of data collection defines the dataset's temporal depth, making it a valuable tool for examining climate change trends and their evolution over time.

The utilization of these datasets provides powerful tools for scientific research, the development of adaptation strategies, and informed decision-making regarding global climate change, interactions among various climate factors, and forecasting of future trends.

To increase the processing speed of climate data, particularly for rapid and multifaceted analysis, and to enable the manipulation and examination of data from various sources (temperature, humidity, precipitation, wind speed, geographic location), it is advisable to employ real-time analytical processing technology in the form of OLAP cubes when designing the information system. Organizing data into cubes overcomes the limitations of relational databases, which are not well-suited for instantaneous analysis and visualization of large data volumes.

The application of OLAP in analyzing large climate datasets and studying climate change provides tools for research, analysis, and strategic decision-making aimed at a deeper understanding and more effective management of climate phenomena. In particular, the efficient handling of multidimensional data by OLAP cubes supports the integration of diverse dimensions such as time intervals, geographic coordinates, and types of weather events. Consequently, the construction of monitoring information systems involves the building of comprehensive data cubes that facilitate the identification of correlations and patterns in climate variability.

OLAP technologies enable systems to perform fast and efficient access to large volumes of climate data. Analytical operations, such as slicing, filtering, and sorting, support in-depth exploration of various aspects of climate change, help identify patterns, and assess potential impacts. In this context, OLAP integrates data from sources, including satellite imagery, meteorological stations, scientific studies, and models, thus providing a comprehensive and unified data pool. Temporal data analysis across different periods allows the identification of climate trends over time and supports forecasting of potential climate events. These advantages underline the relevance of OLAP cubes in climate data analysis and their role in supporting informed strategic decisions in ecology, risk management, and environmental protection initiatives.

OLAP technologies, through their three-dimensional data representation, offer high processing speed and performance while operating with large-scale data.

OLAP technologies support analytical functions such as sorting, filtering, drill-down, and roll-up, providing rapid access to aggregated and summarized data. Researchers can examine data at various levels of granularity, selecting the most effective level for specific tasks. In OLAP technologies, data is viewed across multiple dimensions, with each analytical category acting as an axis of the cube. In the case of climate research, dimensions may include temperature, wind speed, and precipitation.

Utilizing OLAP cubes enables organizations to detect trends in data dynamics and to make more informed managerial decisions based on the analysis of large-scale information.

When examining the features of OLAP technologies, it is crucial to highlight that this is a software for business effectiveness management, IBM Planning Analytics, which supports collaborative planning, budgeting, forecasting, interactive analytics, and creation of analytical programs and reports. Additionally, OLAP cubes serve as platforms for creating, managing, and analyzing multidimensional data cubes using SQL Server Analysis Services and real-time analytics with Oracle database. It is also worth highlighting the use of the SAP BW enterprise data management system within OLAP technologies, which enables the capability to collect, store, analyze, and grant access to large volumes of information. SAP BW serves as a centralized data repository, eliminating data fragmentation through data consistency and offering integration and scalability with other systems.

OLAP cube development mechanisms rely on relational and multidimensional database technologies. Specifically, Relational OLAP stores data in relational databases and utilizes SQL queries for analysis. The multidimensional OLAP mechanism stores data in specialized multidimensional databases, allowing highly efficient cube operations. A hybrid mechanism, Hybrid OLAP, which combines the strengths of both approaches, is employed to accelerate data analysis and to store large-scale data details.

In designing the information system for climate change monitoring, an analytical component characteristic of OLAP technologies was utilized:

– design and implementation of mechanisms for connecting to and importing data from sources such as databases, APIs, and archives, enabling data import and transformation;

– ensuring the capability to define hierarchies within cubes to enable detailed data exploration at multiple levels, along with the implementation of a multimodule cube system for the analysis of heterogeneous climate data (temporal, geographical);

– implementation of various graphical and chart-based interfaces to visualize key cube data, along with geographic map representations for studying spatial correlations;

– design of flexible tables for data display with sorting and filtering capabilities, and the use of data grids that allow analysts to perform aggregation, calculations, and other data operations;

– utilizing user-friendly tools for selecting specific data slices and applying filters, along with the development of aggregation systems and efficient computation of cube content, with support for MDX and SQL query languages to enable analysts to create complex analytical queries.

– improving query optimization through the use of caching mechanisms to store query results and enhance performance.

Practical Implementation of the Climate Monitoring Information System

The developed system includes components such as aggregated datasets, a backend for data processing, a frontend for visualization, and an analytical component [19]. The data processing program is responsible for importing and merging information from various sources, preparing the data for further use. The backend component interacts with the data processing program, facilitates data exchange, stores processed information in the database, and provides the foundation for frontend interaction. The frontend component visualizes the processed data and creates an interactive interface for users. The aggregated dataset component combines and processes data from different sources, performs aggregation operations, and forms a unified dataset for further analysis and visualization.

Aggregated Dataset Component

It primarily provides the capability to import data from various sources such as CSV, JSON, and databases, and implements mechanisms for automatic or manual data updates from relevant sources [20]. It also creates mechanisms for merging data from different sources into a unified set and resolves data format or structural inconsistencies to ensure consistency. Another essential characteristic of the data preparation process is error detection and correction, including handling missing values or incorrect data types, as well as removing erroneous or redundant data to maintain high quality and accuracy. To form the aggregated dataset, algorithms are used to extract necessary data from the unified set based on user requirements or business rules, along with the execution of aggregation operations to compute statistical indicators. The final part of this component's functionality includes generating documentation to describe the structure of aggregated data and implementing monitoring mechanisms to ensure stable operation.

Data Processing Program

During the development of the software interface, the capability to process various data formats in requests is ensured, namely JSON or formats with nested objects, along with the support for parallel processing mechanisms to enable fast execution of simultaneous data retrieval and aggregation queries, with caching implemented to store the results of frequently repeated queries. Following a detailed analysis of business requirements, the database type that best meets the system's needs is selected (relational, non-relational, or a combination). Another important component is the creation of indexes and database optimization mechanisms to improve query performance. The next part handled by the backend is the implementation of business logic through the development of configurable rules, as well as the creation of a modular system for easy expansion and modification of business logic without significant changes to the code. Monitoring involves maintaining an event log to track the operation of the business logic and developing tools to analyze the performance of the information system and identify optimization potential points. Another backend task is the implementation of a module testing system to verify the correctness of the business logic, and the provision of debugging tools for efficient detection and elimination of errors. The final part of the data processing program involves support for scalability, in particular, the use of an architecture that enables horizontal scaling to ensure high availability and performance as data volumes increase, as well as resource optimization through the development of optimized algorithms for memory and process management, aimed at reducing server resource consumption, and the improvement of database queries to ensure efficient processing of big data.

Frontend Component

The most important part of the frontend is data visualization, particularly the development of interactive charts that enable zooming, dragging, and filtering data in real-time, as well as the addition of animations to highlight changes in data dynamics for improved understanding. Another key aspect is the creation of interactive maps using the Leaflet library and other mapping tools, enabling users to explore climate data in detail. The system enables the inclusion of various layers and the placement of markers, allowing users to access additional information. The developed information system incorporates an intuitive and user-centered interface, designed to facilitate seamless interaction. Moreover, it features a responsive layout architecture, ensuring optimal accessibility and usability across a wide range of devices and screen resolutions. The implemented functionality enables users to utilize parameterized queries and select display parameters, such as time intervals or geographic regions. It also offers filtering and sorting features for convenient analysis of specific data segments. The component incorporates advanced search capabilities for quick and easy retrieval of particular data, as well as analytical tools in the form of statistical indicators and options for data comparison. The visual design of the implemented monitoring system includes the selection of a color palette and typographic elements that ensure readability, facilitate the perception of information, and enhance user interaction with the interface. The detailed description of the functions and approaches of the developed frontend component demonstrates the interface's intuitiveness, efficiency, and aesthetic appeal, providing users with relevant and valuable information.

5. Experiments

The database was designed to collect, store, and analyze large volumes of climate data for studying climatic conditions over an extended period. During the development of the database, various ideas and concepts were applied to ensure coverage of a wide range of heterogeneous data and their effective usage. The main design focus is illustrated as follows (in Figure 2).

1. The database is designed to collect various climate parameters such as temperature, humidity, sunshine hours, and precipitation, reflecting the multidimensional nature of the data.

2. To ensure location accuracy and data relevance, all records are linked to the geographic location of measurement stations. The location table includes geographic coordinates and station information.

3. Keys are used to establish links between datasets, ensuring efficient data access and fast analysis, highlighting the connection between specific locations and climate parameter types.

4. The introduced capability to add new types of climate data without altering the main tables demonstrates the flexibility and scalability of the designed database.

The database is intended for use in global climate research and will assist in uncovering relationships that can help address issues related to global warming. This database has been converted into an OLAP cube for data analytics purposes.

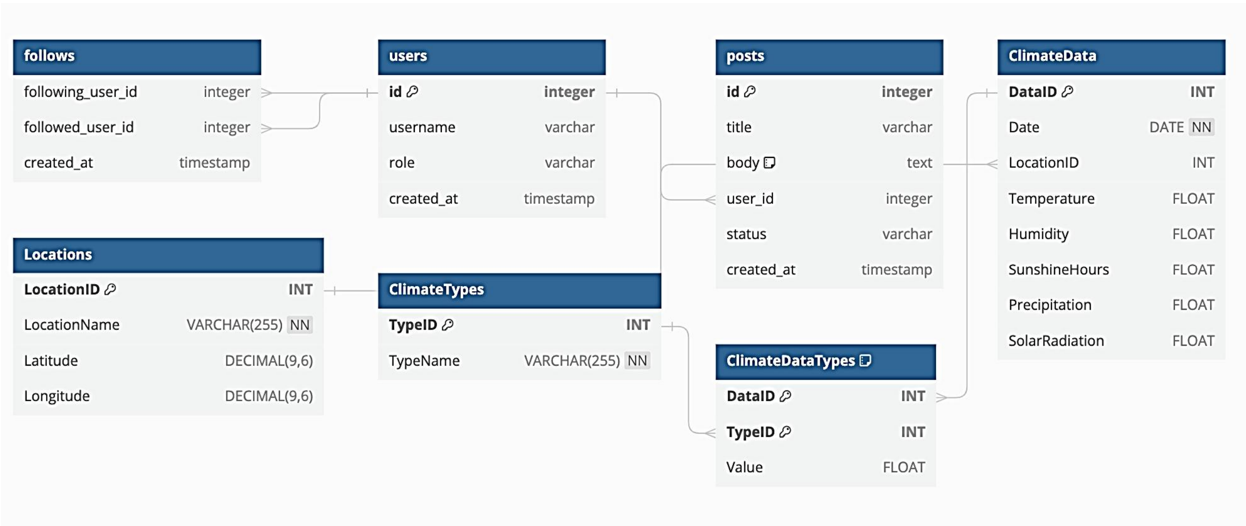

Fig. 2. Diagram of the designed database

The database was designed with OLAP technologies in mind, where key climate parameters are treated as cube dimensions, enabling fast and efficient analysis of data across various measures. To ensure quick access to large volumes of data, indexing and query optimization mechanisms are employed, which are crucial when working with an OLAP cube. Pre-calculated aggregated and summary data, which are regularly updated, support rapid execution of aggregate queries within the database. The OLAP systems used, such as Microsoft Analysis Services, incorporate technologies for transforming climate data. These systems also implement numerous optimizations to enable fast data analysis. The ETL (Extract, Transform, Load) process: Before transformation into an OLAP cube, the information system applies the Extract, Transform, Load (ETL) process for data processing, including data cleansing, table merging, and the creation of aggregated values to prepare the data for analysis in the OLAP system.

Following the analysis and transformation of climate data, key factors were identified—namely, core facts including temperature, humidity, hours of sunshine, precipitation, and solar radiation. These factors are critical for understanding climate change and its impact on global warming. For effective analysis, the data were organized into main tables: ClimateFacts, Locations, TimeDimensions, and ClimateTypes. Information about temperature, humidity, and solar radiation is stored in the ClimateFacts table with a high level of detail. The FactDimensions table contains relationships among location values, time, and types of climate data. Thus, the designed database provides the capability to study climate factors efficiently, detect relationships and trends in climate change, considering significant temporal parameters, particularly in the context of global warming challenges.

6. Conclusions

Based on the analysis of data characterizing climate conditions, it has been determined that this data can be classified according to two main factors: location, defined by geospatial data, and climate data, which is collected from various sensors and meteorological stations and, in the simplest case, consists of measurements of temperature, humidity, precipitation intensity, and wind speed. To enhance the efficiency of climate monitoring information systems a comprehensive approach was applied, based on the interaction of object-oriented programming languages and database management systems, as well as real-time processing based on OLAP cubes. OLAP technologies, which use multidimensional cubes to represent heterogeneous information, increase performance and improve the process of storing details of big data. To enhance the efficiency of climate monitoring information systems that process large volumes of data received from a vast number of meteorological stations, OLAP technologies were employed during the system design. These technologies utilize multidimensional cubes to represent heterogeneous information, thereby increasing processing speed and improving the storage of detailed big data. The designed climate monitoring information system includes components such as aggregated datasets for efficient representation of input information, a backend for processing this information, and a frontend for data visualization, including report generation, graph and chart construction, and displaying research results on maps. The system's database was designed with OLAP technologies in mind, where key climate parameters are considered as cube dimensions, enabling fast and efficient analysis of heterogeneous data such as temperature, humidity, precipitation, and wind speed. To ensure rapid access to large volumes of data, indexing operations are used in the database. The designed climate change monitoring information system enables the study of climate factors, detecting trends in climate change across different regions, and allows society to take measures to address the problem of global warming.

Conflict of Interest

The authors declare that there are no financial or other potential conflicts of interest related to this work.

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