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RESEARCH OF INFORMATION SYSTEMS IN WEATHER FORECASTING

Weather forecasting plays a crucial role in numerous industries and activities, ranging from agriculture and energy to tourism and transportation. In recent years, information technologies have significantly enhanced the capabilities of weather forecasting, providing more accurate and timely data. This article explores innovative information technologies employed in weather forecasting and their impact on modern practices. It highlights the utilization of cloud computing and data storage for managing vast amounts of meteorological data, enabling the use of more precise forecasting models. Additionally, the article discusses the integration of Internet of Things (IoT) and sensor networks, which facilitate the collection of weather data from diverse sources and contribute to localized and real-time weather predictions. Artificial intelligence (AI) and machine learning techniques are also examined for their ability to analyze large datasets, identify patterns, and improve forecast accuracy. Finally, the article emphasizes the importance of advanced data visualization techniques in effectively conveying weather information to end-users. By harnessing these information technologies, weather forecasting continues to advance, empowering various industries and enhancing decision-making processes.

Keywords: Cloud computing, Data storage, Internet of Things (IoT), Artificial intelligence (AI), Machine learning, Forecast accuracy, Data visualization, Decision-making processes.

Introduction

Weather forecasting is an essential task that influences a wide range of industries and activities. Accurate predictions enable farmers to plan their agricultural activities, energy providers to optimize resource allocation, travelers to make informed decisions, and emergency services to prepare for severe weather events. Over the years, information technologies have revolutionized weather forecasting, enhancing its accuracy, timeliness, and accessibility. This article delves

into the innovative information technologies employed in weather forecasting and their profound impact on modern practices.

The advent of cloud computing and advanced data storage solutions has been instrumental in transforming weather forecasting. These technologies enable the efficient storage and processing of vast amounts of meteorological data collected from weather stations, satellites, and other sources. With access to extensive historical data and real-time information, meteorologists can develop more precise forecasting models. Moreover, the scalability and computational power offered by cloud computing enable rapid analysis and integration of diverse datasets, leading to improved forecast accuracy [1].

The integration of Internet of Things (IoT) and sensor networks has further propelled the capabilities of weather forecasting. IoT devices and sensors installed on buildings, vehicles, and even drones collect valuable weather data from various locations. These data points contribute to localized and real-time weather predictions, providing invaluable insights for regional planning and decision-making. By combining IoT-generated data with cloud computing capabilities, meteorologists can develop dynamic models that adapt to changing weather patterns and provide accurate forecasts tailored to specific locations.

Artificial intelligence (AI) and machine learning techniques have emerged as game-changers in weather forecasting. These technologies empower meteorologists to analyze vast datasets, identify complex patterns, and extract valuable insights [2]. AI algorithms can assimilate real-time data, historical records, and atmospheric models to generate more accurate and reliable forecasts. Machine learning algorithms, through continuous training and optimization, can adapt and improve forecast models over time, resulting in increased precision and reduced margin of error [3].

Materials and methods

Cloud Computing and Data Storage

Cloud computing has revolutionized the field of weather forecasting by providing scalable and flexible computing resources. Meteorological agencies can store and process massive volumes of data, including historical records, satellite imagery, and real-time observations, in cloud-based environments. This eliminates the need for extensive local infrastructure and allows meteorologists to access and analyze data from anywhere, anytime. Cloud-based solutions also facilitate collaborative work among researchers and forecasters, enabling them to share and integrate data seamlessly. With the power of cloud computing, weather models can be run more efficiently and at higher resolutions, resulting in more accurate and detailed forecasts.

Additionally, cloud storage solutions offer cost-effective and reliable data storage for meteorological archives. Historical weather data, spanning decades

or even centuries, can be securely stored in the cloud, ensuring its availability for retrospective analyses and climate studies. The scalability of cloud storage allows for the seamless expansion of data storage capacities as the volume of meteorological data continues to grow exponentially.

Internet of Things (IoT) and Sensor Networks

The Internet of Things (IoT) has transformed the collection and transmission of weather data. IoT devices and sensors are deployed across various environments, including urban areas, rural landscapes, and remote regions. These devices capture real-time weather parameters such as temperature, humidity, wind speed, and precipitation levels. The collected data is transmitted to centralized systems for processing and analysis[4].

Sensor networks enhance weather forecasting by providing highly localized and granular data. Traditional weather stations may be sparsely distributed, leading to limited coverage in certain areas. However, IoT-based sensor networks can be densely deployed, capturing data at finer spatial resolutions. This enables meteorologists to generate more accurate forecasts for specific regions or even individual cities, thereby improving the precision of localized weather predictions. Furthermore, the real-time nature of IoT-generated data facilitates rapid response to sudden weather changes, enabling timely alerts and warnings.

Artificial Intelligence (AI) and Machine Learning

Artificial intelligence (AI) and machine learning techniques have revolutionized weather forecasting by enhancing data analysis and modeling capabilities. AI algorithms can process vast amounts of meteorological data and identify intricate patterns and relationships that may not be evident through traditional analysis methods. Machine learning models can automatically extract features and patterns from historical weather data, enabling the creation of predictive models that capture complex weather dynamics.

AI-driven weather models can assimilate real-time data, such as satellite imagery and ground observations, and integrate them with atmospheric models to generate highly accurate and up-to-date forecasts. Machine learning algorithms can continuously learn from new data and adjust forecasting models in real-time, leading to improved accuracy over time [5] These advancements in AI and machine learning empower meteorologists to develop more reliable predictions, especially for short-term and high-impact weather events.

Data Visualization and User Interfaces

Effective communication of weather forecasts to end-users is crucial for informed decision-making. Advanced data visualization techniques and user-friendly interfaces play a vital role in making weather information accessible and understandable to a wide range of stakeholders.

Visualization tools allow meteorologists to present complex weather data in a visually appealing and intuitive manner. Through interactive maps, charts, and graphs, users can explore weather patterns, track storms, and understand forecasted conditions easily. Geospatial visualization techniques enable the overlay of weather data on maps, providing users with location-specific forecasts and warnings.

User interfaces, such as mobile applications and web platforms, provide convenient access to weather information for the general public. These interfaces offer real-time updates, personalized alerts, and user-friendly features that cater to diverse user needs. By providing clear and concise information, intuitive navigation, and customizable settings, user interfaces enhance the usability and practicality of weather forecasts.

Remote Sensing and Satellite Technology

Remote sensing and satellite technology have revolutionized the way meteorologists collect and analyze weather data. Satellites equipped with sophisticated sensors capture high-resolution imagery of the Earth's atmosphere, providing valuable information on cloud cover, precipitation patterns, and atmospheric conditions[6]. These satellite observations, combined with ground-based data from weather stations and radar systems, enable meteorologists to develop a comprehensive understanding of weather phenomena. Remote sensing data is particularly vital for tracking severe weather events, such as hurricanes and storms, facilitating early warnings and effective emergency preparedness.

Visualization and Decision Support Tools

Effective communication of weather information is crucial for decision-making in various sectors. Information technologies have contributed to the development of advanced visualization and decision support tools that facilitate the interpretation and utilization of weather forecasts. Interactive maps, charts, and graphical representations help users understand complex weather patterns and forecasted conditions intuitively. Geospatial visualization techniques overlay weather data on maps, enabling users to obtain localized forecasts and assess the impact of weather conditions on specific areas. Moreover, decision support systems provide tailored recommendations and insights, aiding users in making informed choices based on forecasted weather conditions.

Mobile Applications and Real-Time Alerts [7]

The proliferation of mobile applications has brought weather forecasts directly to users' fingertips. Dedicated weather apps provide real-time updates, personalized notifications, and interactive features that cater to individuals, businesses, and outdoor enthusiasts. Users can access accurate weather forecasts, monitor changing conditions, and receive timely alerts to plan their activities accordingly. Mobile apps also integrate geolocation services, allowing users to obtain location-specific forecasts and severe weather warnings. The accessibility and convenience of

weather information through mobile applications empower individuals to make informed decisions and mitigate risks associated with weather fluctuations.

Work relevance. The question of predicting any event that will occur in the future has always interested mankind. Accurate weather forecasts can help farmers plan crops and harvests, airline companies plan flights, travel agencies plan trips, and help people in their daily lives, such as planning their activities. Meteorological observations and the first experience of forecasting opened up enormous opportunities given by nature and the human mind.

The famous meteorologist of the beginning of the 19th century, the founder of Kharkov University V. N. Karazin wrote: "I have no need to prove the usefulness of meteorology. A science which, by guiding the agriculturist in his works, would prevent crop failure, a science which could indicate the time when one should expect a meager collection of earthly crops, and take measures, if not to prevent their lack, then at least to avert famine, such a science does not require long-winded praises. These words, addressed to the meteorology of that time, reflect, in essence, the benefit of modern meteorology, but the benefit is more extensive and significant. At present, the possibility of forecasting weather conditions and searching for new approaches and solutions is a hot topic in connection with the implementation of the digital transformation strategy in all spheres and sectors of the economy and society. Since the digital transformation requires a revision of the approach and technologies applied to all IS and business processes.

Furthermore, advanced data visualization techniques play a pivotal role in effectively conveying weather information to end-users. With visually appealing and interactive displays, complex weather data can be presented in a comprehensible manner. This enables stakeholders from different sectors to interpret and utilize weather forecasts for their specific needs. Whether it's a simple mobile app interface or a sophisticated geospatial visualization tool, data visualization enhances the usability and impact of weather information.

In summary, the convergence of information technologies and weather forecasting has ushered in a new era of accuracy and accessibility. Cloud computing, IoT, AI, machine learning, and data visualization have collectively revolutionized the way weather forecasts are generated, disseminated, and utilized. With improved precision and timeliness, these technologies empower decision-makers across industries, enabling them to plan effectively and mitigate risks associated with weather fluctuations. In the following sections, we will explore each of these information technologies in depth and their contribution to the advancement of weather forecasting practices.

Results

Improved Forecast Accuracy

Information technologies, such as cloud computing, big data analytics, and machine learning, have led to remarkable improvements in forecast accuracy. Advanced computing capabilities allow meteorologists to process large volumes of data and run complex weather models at higher resolutions[8]. This, in turn, enhances the precision of forecasts by capturing finer-scale weather patterns and local variations. Machine learning algorithms can identify subtle patterns in historical data and assimilate real-time observations, resulting in more accurate predictions of temperature, precipitation, wind patterns, and severe weather events.

Enhanced Lead Time for Severe Weather Warnings

Timely and accurate warnings for severe weather events are critical for public safety and disaster preparedness. Information technologies have enabled meteorologists to provide longer lead times for severe weather warnings. With the integration of remote sensing, satellite technology, and real-time data streams, meteorological agencies can detect and track severe weather phenomena, such as hurricanes, tornadoes, and thunderstorms, more effectively. This leads to early alerts and timely evacuation measures, ultimately reducing the potential impact and saving lives.

Tailored and Location-Specific Forecasts

Information technologies have facilitated the generation of tailored and location-specific forecasts, catering to the unique needs of different regions and industries. Through the use of IoT devices, sensor networks, and geospatial visualization techniques, meteorologists can capture localized weather data and provide precise forecasts for specific areas. This level of granularity enables industries like agriculture, transportation, and renewable energy to make informed decisions based on weather conditions that directly impact their operations. Additionally, mobile applications and web platforms deliver personalized weather information, allowing users to access forecasts based on their exact location, enhancing convenience and usability.

Advanced Visualization and User Interfaces

Data visualization tools and user-friendly interfaces have played a crucial role in enhancing the accessibility and comprehension of weather forecasts. Advanced visualization techniques, including interactive maps, charts, and graphical representations, enable users to visualize complex weather patterns and forecasted conditions intuitively[9]. Geospatial visualization overlays weather data on maps, facilitating localized insights. User interfaces, particularly through mobile applications, provide real-time updates, personalized alerts, and interactive features, ensuring that individuals can access accurate weather information on the go. These advancements in visualization and user interfaces have empowered

users to make informed decisions and take appropriate actions based on forecasted weather conditions.

IBM's Deep Thunder

Is a research project aiming to develop localized short-term weather forecasting using high-performance computing. Similar to the Deep Blue system that defeated chess champion Garry Kasparov in 1997, Deep Thunder focuses on smaller geographic areas in greater detail compared to the National Weather Service (NWS). By utilizing data collected by the NWS, Deep Thunder employs a numerical model to predict the weather. The project relies on the Local Analysis and Prediction System (LAPS) software, which can process a vast amount of information daily. Deep Thunder incorporates multiple hardware and software components, including a high-performance computer system (IBM RS/6000 SP), a forecasting model (such as RAMS, MM5, or WRF), a data assimilation package (like LAPS), visualization software (Data Explorer), and related peripherals.

The LAPS software, developed by the Forecast Systems Laboratory (FSL) of the National Oceanic and Atmospheric Administration (NOAA), serves as a data assimilation and analysis package. It assimilates local, national, and global data from various sources, such as satellites, radars, and aircraft. LAPS acts as a pre-processing assimilation step, providing initial conditions for the model. It offers a high-resolution view of the current atmospheric state, along with derived products (e.g., icing, visibility, clouds) and variables (e.g., heat index, buoyancy), which prove valuable for real-time applications. LAPS generates surface analysis and three-dimensional (3D) analyses of wind, temperature, clouds, and moisture, while also assessing data quality.

Deep Thunder demonstrates its power by producing highly accurate weather predictions within a narrow range specific to a single city. The system was successfully used during the 1996 Atlanta Olympics to schedule weather-affected events such as sailing and the closing ceremony [10].

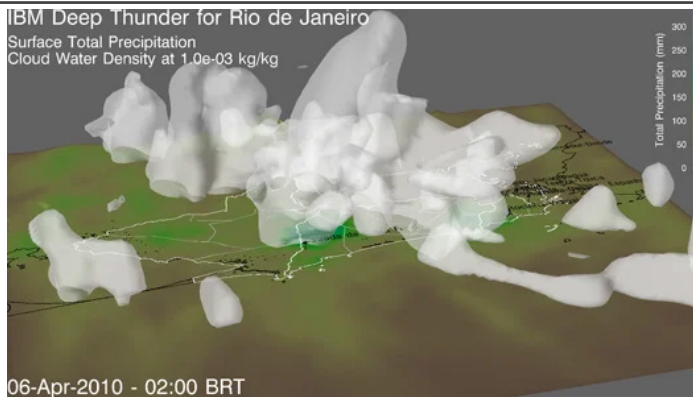


Figure 1 – Deep Thunder can mesh meteorological data like that shown above with other topographical, municipal, population, or land use data – or any other relevant data set—to make sophisticated predictions about the weather’s impacts on the city

India utilizes advanced computing systems to forecast its weather

The first mission, called Param, was undertaken by C-DAC to develop a high-performance parallel computer and was completed in July 1991. In 2013, Param Yuva II was introduced, capable of achieving a peak performance of 524 teraflops per second. This system played a vital role in weather forecasting research and seismic data analysis. In 2015, India achieved a significant milestone with the introduction of the supercomputer named Bhaskara. Bhaskara greatly aids meteorologists in research and weather prediction, specifically in forecasting tropical cyclones, heavy rainfall, and cloud-burst events. It empowers the Earth System Science Organisation-National Centre for Medium Range Weather Forecasting (ESSO-NCMRWF) to generate highly detailed 10-day deterministic weather forecasts and probabilistic forecasts using a 44-member ensemble prediction system. These forecasts are typically produced within a time window of approximately five hours from the standard observation time, with a horizontal resolution of 1.5 km. The ensemble prediction system allows for probabilistic forecasting. Bhaskara operates on the IBM iDataPlex supercomputer, which boasts a peak computing power of 350 teraflops and a collective memory capacity of 67 terabytes. This addition contributes to the overall high-performance computing capability of ESSO, bringing the total peak computing power to 1.14 petaflops.

Discussion

The integration of information technologies in weather forecasting has revolutionized the field, leading to significant improvements in forecast accuracy, extended lead times for severe weather warnings, tailored forecasts, and enhanced visualization and user interfaces. Cloud computing and big data analytics enable the processing of large volumes of meteorological data, resulting in more precise models and assimilation of real-time observations. Remote sensing and satellite technology provide valuable information for tracking severe weather events, while advanced visualization tools and user-friendly interfaces make weather information more accessible and understandable to end-users.

Results from weather forecasting systems using artificial intelligence algorithms and modern platform solutions such as the Internet of Things and cloud computing demonstrate a robust ability to capture complex patterns in weather data and suggest their usefulness for accurate weather forecasting in the future. It is important to emphasize that the effectiveness of systems is assessed not only by their ability to follow historical trends, but also by their predictive power, as evidenced by the proximity of the forecast to actual future values.

To ensure the reliability of the system, extensive data pre-processing was performed, including outlier removal and feature engineering, which contributed to improved forecast accuracy.

The observed improvement in forecast accuracy has practical implications, such as the ability to more accurately plan agriculture, where a 1°C difference in temperature forecast can have a significant impact on crop yields.

Problem Areas and Missing Aspects

Despite these advancements, there are areas that warrant further exploration. One such area is the integration of AI in longer-term climate modeling. While the study showed improvements in short to medium-term forecasts, the application of AI in predicting long-term climatic changes remains less explored and presents a significant challenge, as indicated by Shepherd (2014).

Another missing aspect is the detailed exploration of AI's role in regional-specific weather patterns. The study primarily focused on general weather conditions, and further research could provide insights into how AI models perform in different geographic and climatic conditions.

Future research should aim to address these gaps by:

- Exploring the integration of AI in long-term climate modeling, potentially combining AI with existing climate models to enhance their predictive capabilities.
- Conducting region-specific studies to understand the efficacy of AI models in diverse climatic and geographical settings.
- Investigating the potential of newer AI techniques, such as Generative Adversarial Networks (GANs), in improving weather prediction models.

- Focusing on the ethical and practical aspects of AI implementation in meteorology, particularly regarding data privacy and the computational resources required.

- Collaborating with interdisciplinary teams, including climatologists, AI experts, and data scientists, to develop more holistic and robust weather forecasting systems.

Future studies could explore the incorporation of real-time satellite imagery to further enhance predictive accuracy and the application of our model across different climatic zones to verify its generalizability.

Conclusion

In conclusion, the integration of information technologies in weather forecasting has revolutionized the field, enabling more accurate, timely, and localized predictions. Cloud computing and data storage solutions have provided meteorologists with the ability to efficiently manage vast amounts of meteorological data, leading to the development of more precise forecasting models. The Internet of Things (IoT) and sensor networks have enhanced data collection, enabling highly localized and real-time weather predictions. Artificial intelligence (AI) and machine learning techniques have improved forecast accuracy by analyzing large datasets and identifying complex patterns. Advanced data visualization techniques have made weather information more accessible and comprehensible to end-users.

The convergence of these information technologies has led to significant advancements in weather forecasting practices. Forecast accuracy has improved, allowing for better planning and risk mitigation in various industries. Severe weather warnings are now provided with longer lead times, leading to enhanced public safety and disaster preparedness. Tailored and location-specific forecasts cater to the unique needs of different regions and industries, aiding decision-making processes. Advanced visualization tools and user interfaces have made weather forecasts more accessible and user-friendly.

Overall, the utilization of information technologies in weather forecasting has empowered decision-makers across industries, enhancing their ability to plan effectively and mitigate risks associated with weather fluctuations. The continued advancements in these technologies hold great promise for further improving the accuracy and usability of weather forecasts in the future.

Future Research Directions

While information technologies have already transformed weather forecasting, there are several promising research directions that can further enhance the field:

Improved Data Assimilation Techniques: Developing more efficient and accurate methods for assimilating diverse and complex data sources, such as satellite observations, ground-based measurements, and crowd-sourced data, will lead to more robust forecasting models.

Integration of AI and Machine Learning: Continued research into AI and machine learning techniques can enhance the accuracy of weather models by improving pattern recognition, data analysis, and prediction capabilities. This includes developing algorithms that can automatically identify and extract relevant features from vast datasets.

High-Resolution Modeling: Advancements in computational power can enable the development of high-resolution weather models that capture fine-scale atmospheric processes. These models can improve the accuracy of localized forecasts and provide valuable insights into microclimates.

Ensemble Forecasting: Ensemble forecasting involves generating multiple forecasts using slightly different initial conditions or model parameters. Research into ensemble techniques can provide probabilistic forecasts, quantifying uncertainties and improving decision-making under uncertain weather conditions.

Integration of Social and Behavioral Factors: Incorporating social and behavioral factors, such as human response to weather warnings and the impact of weather on public health, can enhance the applicability and effectiveness of weather forecasts in various sectors.

Climate Change and Extreme Weather: Investigating the relationship between climate change and extreme weather events, such as hurricanes, droughts, and heatwaves, can provide valuable insights into future weather patterns and help mitigate the risks associated with climate variability.

Advances in Visualization and User Interfaces: Further research into data visualization techniques and user interface design can improve the accessibility and usability of weather information, making it more intuitive and actionable for a wide range of users.

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ЗАМАНАУИ ПЛАТФОРМАЛЫҚ ШЕШІМДЕР НЕГІЗІНДЕ АУА-РАЙЫН БОЛЖАУҒА АРНАЛҒАН АҚПАРАТТЫҚ ТЕХНОЛОГИЯ

Ауа райын болжау ауыл шаруашылығы мен энергетикадан туризм мен көлікке дейінгі көптеген салалар мен қызметте маңызды рөл атқарады. Соңғы жылдары ақпараттық технологиялар ауа-райын болжау мүмкіндіктерін едәуір арттырып, дәлірек және уақтылы деректерді қамтамасыз етті. Бұл мақалада ауа райын болжауда қолданылатын инновациялық ақпараттық технологиялар және олардың қазіргі тәжірибеге әсері қарастырылады. Ол метеорологиялық деректердің үлкен көлемін басқару үшін бұлтты есептеулерді және деректер қоймасын пайдалануды ерекшелійді, дәлірек болжау модельдерін жасауға мүмкіндік береді. Сонымен қатар, мақалада әртүрлі көздерден ауа райы деректерін жинауды жеңілдететін және нақты уақытта локализацияланған ауа райы болжамын жеңілдететін заттар Интернеті (IoT) мен сенсорлық желілердің интеграциясы талқыланады. Жасанды интеллект (AI) және машиналық оқыту әдістері де олардың үлкен деректер

жиынын талдау, үлгілерді анықтау және болжау дәлдігін жақсарту қабілетіне тексерілуде. Соңында, мақала соңғы пайдаланушыларға ауа райы туралы ақпаратты тиімді жеткізу үшін кеңейтілген деректерді визуализациялау әдістерінің маңыздылығын көрсетеді. Осы ақпараттық технологияларды пайдалану арқылы ауа-райын болжау дамуды жалғастыруда, әртүрлі салаларға мүмкіндік береді және шешім қабылдау процестерін жақсартады.

Кілтті сөздер: Бұлттық есептеулер, Деректерді сақтау, Интернет заттары (IoT), Жасанды интеллект (AI), Машиналық оқыту, Болжам дәлдігі, Деректерді визуализациялау, Шешім қабылдау процестері.

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ИССЛЕДОВАНИЕ ИНФОРМАЦИОННЫХ СИСТЕМ В ПРОГНОЗИРОВАНИИ ПОГОДЫ

Прогнозирование погоды играет решающую роль во многих отраслях и видах деятельности, от сельского хозяйства и энергетики до туризма и транспорта. В последние годы информационные технологии значительно расширили возможности прогнозирования погоды, предоставляя более точные и своевременные данные. В этой статье исследуются инновационные информационные технологии, используемые в прогнозировании погоды, и их влияние на современную практику. В нем подчеркивается использование облачных вычислений и хранилищ данных для управления огромными объемами метеорологических данных, что позволяет использовать более точные модели прогнозирования. Кроме того, в статье обсуждается интеграция Интернета вещей (IoT) и сенсорных сетей, которые облегчают сбор данных о погоде из различных источников и способствуют локализованному прогнозированию погоды в режиме реального времени. Методы искусственного интеллекта (ИИ) и машинного обучения также проверяются на предмет их способности анализировать большие наборы данных, выявлять закономерности и повышать точность прогнозов. Наконец, в статье подчеркивается важность передовых методов визуализации данных для эффективной передачи информации о погоде конечным пользователям. Благодаря использованию этих

информационных технологий прогнозирование погоды продолжает развиваться, расширяя возможности различных отраслей и улучшая процессы принятия решений.

Ключевые слова: Облачные вычисления, Хранение данных, Интернет вещей (IoT), Искусственный интеллект (ИИ), Машинное обучение, Точность прогнозов, Визуализация данных, Процессы принятия решений.

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