

Local climate services for all, courtesy of large language models

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Large language models can summarize, aggregate, and convey localized climate-related data to people in a cost-effective and expeditious manner. We have built a simple, proof-of-concept prototype and argue that the approach holds the potential to truly democratize climate information.

As the global climate is warming rapidly, people around the globe need to consider climate change in their long-term plans. Examples include future-proofing housing, evaluating business models, and developing resilient infrastructure. It is relatively straightforward to obtain information on climate change impacts at the global and national level, for example from the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC)¹. However, the impacts of climate change matter most at the local scale. It is still a challenge to obtain user-focused statements on climate change impacts that are directly relevant to specific applications and localities.

Climate services have been introduced to address this challenge^{2,3}. However, it is overwhelmingly impractical for them (in their present form) to accommodate the vast array of climate-related questions that individuals worldwide may have. In addition, the information is often not accessible to the general public without extensive training in climate science, geography, and statistics. Services such as ChatGPT that are built on large language models (LLMs) should, in theory, excel at broadening the reach of climate information to any interested individual anywhere on Earth, but are, so far, lacking access to sufficiently detailed local information on future changes in weather and climate, and their impacts. If this hurdle can be overcome, it could be a game changer in the effectiveness of adaptation efforts in a world undergoing rapid warming.

Here we present ClimSight, a simple prototype demonstration tool for such a novel climate information system. We argue that with a moderate amount of development and access to more advanced climate model output—including global km-scale simulations—large-language-model-based systems can provide actionable climate information to anyone with access to a computer.

An automated climate service

We built ClimSight to combine the strength of large language models with geographical information about the location of interest and climate information from model simulations. Consider an individual who owns a parcel of land in Morocco and contemplates its use for wheat cultivation. They are aware of changes in the climate, and concerned regarding potential impacts on their agricultural venture.

We set ClimSight to work on the following query: “I intend to cultivate wheat. What are the implications of climate change?” This inquiry pertains to a specific geographical point at approximately 31.6912°N latitude and 8.1098°W. We present ClimSight’s assessment of potential climate-related risks and benefits of the endeavor for this location near Marrakech, Morocco in Box 1.

The machinery behind our demonstrator is relatively simple and currently relies just on a few data sources. The input required from the user is the query and specific location, expressed in geographic coordinates (latitude and longitude) for the place of interest. Based on this ClimSight automatically gathers two sets of data:

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Box 1 | Summary of the potential risks and benefits arising from climate change for growing wheat in Saâda, Marrakech Prefecture, Morocco (31.6912N, 8.1098W), generated by ClimSight**Climate impact on wheat cultivation in Saâda, Morocco**

Climate change could significantly impact your plans for wheat cultivation in Saâda, Morocco.

Temperature:

The current mean monthly temperature in your location varies from 8.58 °C to 34.645 °C. In the future, the monthly temperatures are expected to rise, with a range from 13.17 °C to 40.88 °C. This increase can affect the growth of wheat crops, as they are sensitive to temperature changes. Wheat prefers a cooler climate for its growth and development, with an optimal temperature for germination of around 12–25 °C. With the expected rise in temperature, there could be serious implications for wheat production such as decreased yield and increased susceptibility to pests and diseases.

Precipitation:

The current monthly precipitation flux ranges from 0.01941 mm/month to 4.794 mm/month. However, future predictions indicate a decrease in precipitation, with a range from 0.003157 mm/month to 2.608 mm/month. Wheat crops require around 450–650 mm of rainfall annually, preferably well-distributed throughout their growth period. A decrease in rainfall could lead to water stress, impacting wheat growth and yield.

Wind:

The future u and v wind components indicate an increase in wind speed. High wind speeds can cause physical damage to the wheat crops, disrupt pollination, and lead to moisture loss.

Policy and regulatory implications:

In Morocco, climate change adaptation policies are in place to support sustainable agriculture. The Green Morocco Plan (2008–2020) aims to modernize agriculture and make it more resilient to climate change. It is advisable to align your wheat cultivation plans with these policies to benefit from potential government support.

Recommendations:

Given the future climate predictions, it would be prudent to consider the following:

- **Irrigation:** Due to the predicted decrease in rainfall, consider implementing efficient irrigation systems to ensure adequate water supply.
- **Heat-resistant varieties:** Look into heat-resistant wheat varieties that can withstand higher temperatures.
- **Wind protection:** Implementing windbreaks in your field could provide some protection against the predicted increase in wind speed.
- **Policy alignment:** Ensure your practices align with local climate change adaptation policies to potentially benefit from financial and technical support.

(Please note, this analysis is based on the provided future climate predictions. It is advisable to continuously monitor local weather and climate trends for more accurate decision-making.)

- (1) Information such as country, region, city and street, elevation, current land use, soil type, and distance to the closest coastline.
- (2) Pre-computed global climate model output for the model gridpoint that is closest to the user's coordinates from a single ensemble member of the AWI climate model simulations (part of the Climate Modeling Intercomparison Project (CMIP6)⁴) for two 30-year periods, 1985–2004 for present-day, and 2070–2100 for a future climate scenario. The system extracts data for temperature, precipitation, and wind.

Once the information is prepared, we prompt the large language model with an explanation of its intended function and what kind of output is expected. For this application, we have configured the LLM to serve as a localized decision-making assistant that evaluates the impact of climate change on specific activities (see Supplementary Note 1 for the complete prompt). Choosing the most suitable prompt for this task is currently reliant on intuition and experimentation, and requires optimization through a process of trial and error.

The next step is to merge the user request with geographical and climate data. We do this by simply providing text with explanations of what the data are and by giving their actual values. For example, for historical monthly mean temperatures, part of the request to the LLM will look like this:

Current mean monthly temperature for each month: 8.58 11.205 15.184 19.388 25.592 31.53 34.645 33.809 28.966 21.668 13.972 9.394

The completed prompt is then sent to the LLM.

ClimSight is currently quite basic: it gathers only limited information related to the place of interest; it only uses results of one climate model simulation with relatively low spatial resolution; and it does not take into account uncertainty estimates. We also use the 2070–2100 period for future climate scenarios to get a strong climate change signal over the whole globe for demonstration purposes. In reality, most of the users probably will be

interested in the effects on the horizon of the next 10–30 years. Even so, ClimSight shows considerable skill in summarizing and communicating climate information and it successfully connects user requests to climate change information.

We have assembled here three examples of the system that span some potential applications. When queried about growing specific crops, GPT-4 is usually able to retrieve general information on best growth conditions, compare it with climate information, and judge if it is a good idea to grow them in the specified location (Box 1). When asked about the installation of wind turbines in desert areas it warns about the potential impact of dust on blades (Box 2). It can even give you hints on what could be the best commercial activity for a particular place, considering future climate change (Box 3).

Using ClimSight to obtain guidance on future projects is cost-effective: a query to ClimSight costs approximately 6 cents per query using OpenAI GPT-4 API, once the underlying data and climate model simulations are in place.

From proof-of-concept to global service

In our view, there are two particularly encouraging avenues for the enhancement of our proof-of-concept prototype ClimSight that merit further elaboration. First, it looks promising to expand the information available for the specified location, for example using high-resolution geographical data and highly detailed climate information. Projects like the Coordinated Regional Downscaling Experiment (CORDEX), which downscale climate data for various global regions, can offer valuable support in this endeavor for some regions. While CORDEX data do not cover the whole globe, one can select CORDEX high-resolution simulations when they are available for the region and fall back to global, low-resolution simulations otherwise. However, if our goal is to “deliver consistent localized information worldwide”⁵ and hence provide equal opportunities for everyone to prepare for climate

Box 2 | Summary of the potential risks and benefits arising from climate change for building a wind farm in Mezguitem, Morocco (34.4302N, 3.5123W), generated by ClimSight**User request:** "I would like to build a wind farm"**Location:** 34.4302N, 3.5123W**Climate change impact on wind farm project in Mezguitem, Morocco**

Based on the data provided, your project to build a wind farm in Mezguitem, Morocco could be impacted by the changing climate in several ways.

Temperature increase

An increase in temperature is expected in the future from the current average monthly temperature of around 14.3 °C to around 22.4 °C. While this won't directly impact wind turbine efficiency, it could indirectly affect the wind patterns. Warmer temperatures can change atmospheric pressure zones, potentially altering the wind patterns and speeds in your location.

Wind speed changes

The wind speed is crucial for a wind farm, and changes in wind patterns can significantly impact the efficiency of the turbines. The data suggests a slight decrease in the u wind component (west-east direction), which could mean weaker winds from the west in the future. The v component (north-south direction) shows a mixed trend, suggesting some uncertainty in the wind patterns from the north and the south.

However, it's important to note that even small changes in wind speed can greatly affect a wind turbine's power output. A decrease in wind speed could therefore negatively impact the power production of your proposed wind farm.

Precipitation decrease

A decrease in precipitation is forecasted. This is generally beneficial for wind turbines as heavy rainfall can cause wear and tear on the turbines and decrease their lifespan. However, a very dry climate might also lead to dust accumulation on the turbine blades, which can, over time, reduce their efficiency.

Regulatory environment

As for the regulatory environment in Morocco, the Moroccan government is highly supportive of renewable energy projects. Under their national energy strategy, they aim to have 52% of their installed electricity production capacity come from renewables by 2030. This includes a significant contribution from wind energy. Hence, your project aligns well with the national policy.

Conclusion

In summary, while the expected increase in temperature and decrease in wind speed could pose some challenges to your wind farm project, the supportive regulatory environment and the general decrease in precipitation could provide some advantages. It would be advisable to conduct a detailed feasibility study considering these climatic changes to ensure the long-term sustainability and profitability of your project.

change, exploring the utilization of data from forthcoming kilometer-scale global models, made accessible in the future through initiatives like the EU's Destination Earth^{6,7}, will be imperative.

Secondly, one current important limitation of the approach lies with the limitations on the amount of data that can be transmitted in a query to LLMs as context. For standard OpenAI GPT-4, this limit currently stands at 8,000 tokens (equivalent to about 32,000 characters), while the special version of the GPT-4, with a larger context, become available recently. A promising avenue to develop our prototype further would be to exploit user-relevant information from trusted sources, including scientific publications, reports, and local regulations, integrated into the final prompt. Using several preliminary requests to the LLM to first optimize the level of summarization for any contextual information, both geographical and user-specific data could help optimize the amount of information transmitted in the last step. Multi-agent conversation where LLMs with different roles or specializations communicate with each other to achieve common goals^{8,9}, could be very beneficial. Generation of several reports and letting LLM evaluate and select the best one could improve the quality and reduce hallucinations.

Many other directions for expanding the scope of the system, and adding more detail can be envisaged. Transitioning to open-source models, such as LLAMA2¹⁰ can democratize ClimSight development by allowing more people to access, modify, and improve the system. It is easier to further fine-tune open-source models (compared to closed solutions like GPT-4) and develop sector-specific extensions tailored to domains like agriculture or urban planning, or make a country-specific version. Fine-tuned models can be used to create separate, targeted services, or work together in one system to generate a better final report. The current simple extraction of monthly means for two periods can be extended by more comprehensive statistical data analysis involving time series from many models, ensemble members, and

neighboring regions. Visualization of data also can be expanded, showing maps, statistics, and uncertainties.

Arguably more important than expansion, however, is the task of ensuring that users are aware of the degree of reliability of the information they receive. Large language models can occasionally generate erroneous information and fabricate facts, and climate projections are subject to their own set of inherent uncertainties and potential biases. It would be important to make the reliability of the system's output intuitively transparent, for example by providing a range of possible future scenarios rather than just one recommendation. Furthermore, incorporating information on local model biases, drift, and ensemble spread would add confidence and trustworthiness to the recommendations communicated to the user.

To the next level

Up to now, thorough assessments conducted by human experts, such as those assembled by staff from climate service centers, have provided the highest level of precision and credibility. However, the scalability and cost-effectiveness of expert assessments are becoming a limiting factor to consider.

ClimSight underscores the potential of combining high-resolution climate data with LLMs as a transformative avenue for democratizing the dissemination of climate change information and supporting local decision-making. Setting up artificial intelligence in the form of LLMs to work with up-to-date and innovative climate change simulations offers a cost-effective service that provides nuanced, location-specific guidance. This approach surmounts the traditional barriers of scalability, expertise, geographical constraints, and usability that have historically impeded effective climate action at the community level.

Repository of the project <https://github.com/koldunovn/climsight>

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Box 3 | Summary of the potential risks and benefits of growing different types of crops in Rivers State, Nigeria (5.3992 N, 6.5163E), generated by ClimSight**User request:** “What is the best crop to grow here”**Location:** 5.3992N, 6.5163E**Climate impact evaluation**

Based on the environmental variables, the location Ogba/Egbema/Ndoni in Rivers State, Nigeria is currently experiencing a tropical climate with a mean monthly temperature ranging from 24.088 °C to 29.071 °C and high precipitation throughout the year. The soil type is Acrisols which are typically acidic and low in base cations but can be suitable for a variety of crops with appropriate management.

In the future, there is a projected increase in temperature and an overall increase in precipitation, particularly in the late part of the year. The wind direction also seems to be shifting more towards the east and south.

Crop recommendations

Taking into consideration the local climate and soil conditions, the following crops could be suitable:

- Cassava: This crop thrives in warm, tropical climates and can tolerate poor soil conditions. With the projected increase in temperature, Cassava could be a viable option.
- Yam: Another popular crop in Nigeria, it requires well-drained loamy soil which can be enhanced by proper soil management. The high rainfall in the area would be beneficial for yam cultivation.
- Oil Palm: Given the proximity to the coast and high rainfall, oil palm could be a lucrative option. It requires high temperatures and abundant rainfall, both of which are present in the area.
- Rice: With the high rainfall expected to continue, rice could be a feasible option. However, it requires careful management to prevent waterlogging or soil erosion due to the high rainfall.

Risks and considerations

The increasing temperature and rainfall can lead to increased pest and disease pressure. Farmers will need to implement effective pest and disease management practices.

The increased wind from the east and south might lead to erosion, especially during the rainy season, and could affect the topsoil fertility. Windbreaks or other protective measures may be necessary.

The soil type, Acrisols, will require careful management and possibly soil amendment to maintain fertility and productivity, as they are typically acidic and low in nutrients.

Lastly, Nigeria has a National Policy on Climate Change and a National Adaptation Strategy and Plan of Action on Climate Change for Nigeria. It is essential to align farming practices with these policies, which promote climate-smart agriculture and adaptation measures.

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