Methods for simulation of weather and climate (mobility).

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***Abstract*—to be continued...**

I. INTRODUCTION

To simulate both mobility and energy use, realistic modeling of the weather is necessary. In this paper, you will discuss ways in which we can do this. Considering the effect of the position of the virtual city, seasons, and the ability to represent specific phenomena (storms, snow, heat waves).

II. TOPICS

A. *STEP (short-term ensemble prediction system) computation algorithm*

Ensemble forecasting is a method used in or within numerical weather prediction. Instead of making a single forecast of the most likely weather, a set (or ensemble) of forecasts is produced. This set of forecasts aims to give an indication of the range of possible future states of the atmosphere. Ensemble forecasting is a form of Monte Carlo analysis. The multiple simulations are conducted to account for the two usual sources of uncertainty in forecast models:

- The errors introduced by the use of imperfect initial conditions, amplified by the chaotic nature of the evolution equations of the atmosphere, which is often referred to as sensitive dependence on initial conditions;
- The errors introduced because of imperfections in the model formulation, such as the approximate mathematical methods to solve the equations.

Ideally, the verified future atmospheric state should fall within the predicted ensemble spread, and the amount of spread should be related to the uncertainty (error) of the forecast. In general, this approach can be used to make probabilistic forecasts of any dynamical system, and not just for weather prediction. [1]

Today ensemble predictions are commonly made at most of the major operational weather prediction facilities worldwide, including

- National Centers for Environmental Prediction (NCEP of the US)
- European Centre for Medium-Range Weather Forecasts (ECMWF)
- Météo-France

[1]

Key Components of Ensemble Prediction Systems:

- Base Models: Ensemble systems typically consist of multiple base models, each trained independently on the same or different datasets.
- Diversity: The effectiveness of ensemble methods relies on the diversity among the base models. If the models are too similar, the ensemble may not provide significant improvements.
- Combination Method: Ensemble methods employ a combination or aggregation method to merge the predictions of individual models into a single, more accurate prediction.
- Weighting: In weighted averaging, each base model's prediction is assigned a weight, and the final prediction is a weighted sum of individual predictions.
- Training and Validation: Base models are trained on historical data, and the ensemble system is validated and calibrated using separate datasets to ensure its accuracy

An ensemble-based probabilistic precipitation forecasting scheme has been developed that blends an extrapolation nowcast with a downscaled NWP forecast, known as STEPS: Short-Term Ensemble Prediction System. The uncertainties in the motion and evolution of radar-inferred precipitation fields are quantified, and the uncertainty in the evolution of the precipitation pattern is shown to be the more important.

The use of ensembles allows the scheme to be used for applications that require forecasts of the probability density function of areal and temporal averages of precipitation, such as fluvial flood forecasting—a capability that has not been provided by previous probabilistic precipitation nowcast schemes.

The output from a NWP forecast model is downscaled so that the small scales not represented accurately by the model are injected into the forecast using stochastic noise. This allows the scheme to better represent the distribution of precipitation rate at spatial scales finer than those adequately resolved by operational NWP.

1) Advantages of Ensemble Forecasting:

- Improved Accuracy: Ensemble forecasting often provides more accurate predictions than individual models by leveraging the collective knowledge of diverse models.
- Quantifying Uncertainty: Ensemble systems offer a way to estimate the uncertainty associated with predictions. The spread or variability among ensemble members provides a measure of prediction confidence.
- Reduced Overfitting: By combining multiple models with different training data or parameters, ensemble methods reduce the risk of overfitting to a particular dataset.
- Enhanced Generalization: Ensemble methods can generalize well to different scenarios and datasets, making them versatile for various applications.
- Flexibility: Ensemble systems can incorporate a variety of models and data sources, making them adaptable to different prediction tasks and domains.

2) Disadvantages of Ensemble Forecasting:

- Difficulty in Model Selection: Selecting appropriate models for the ensemble requires careful consideration, and the effectiveness of the ensemble may be sensitive to the choice of models.
- Potential for Redundancy: If the base models in the ensemble are too similar, there might be limited diversity, reducing the effectiveness of the ensemble approach.
- Overemphasis on Certain Models: In some cases, if a particular model consistently outperforms others, that dominant model might heavily influence the ensemble's performance.
- Increased Training Time: Training multiple models requires additional time and computational resources compared to training a single model.

3) Motivation: Ensemble forecasting is the prevailing method used for weather forecasting worldwide today, by most of the major operational weather prediction facilities. It is widely used because it is more accurate than individual models, and it provides a measure of prediction confidence.

B. Openweather API

OpenWeatherMap is a weather API that provides weather data for any location on the globe. It uses machine learning (ML) to significantly advance both the accuracy and computing speed of global assemble forecasting models, a practice that was impossible only a few years ago [3].

OpenWeatherMap offers a variety of APIs, including the One Call API 3.0, which provides current weather and forecasts, minute forecast for 1 hour, hourly forecast for 48 hours, daily forecast for 8 days, and government weather alerts [3]. The API also provides weather data for any timestamp for 40+ years historical archive and 4 days ahead forecast, daily aggregation of weather data for 40+ years archive and 1.5 years ahead forecast, hourly forecast for 4 days, 16 days forecast, and climatic forecast for 30 days [3]. In addition, OpenWeatherMap provides beautiful multi-layer maps that create the visual perception of weather. You can choose from a set of OpenWeather Model layers such as wind, temperature, pressure, and others, or select radar data for a detailed precipitation picture [3].

1) Advantages: Here are some of the advantages of OpenWeatherMap

- **Accuracy and speed** - OpenWeatherMap uses machine learning to significantly advance both the accuracy and computing speed of global assemble forecasting models, a practice that was impossible only a few years ago [3].
- **Global coverage** - OpenWeatherMap provides weather data for any location on the globe [3].
- **Historical data** - OpenWeatherMap provides weather data for any timestamp for 40+ years historical archive and 4 days ahead forecast, daily aggregation of weather data for 40+ years archive and 1.5 years ahead forecast, hourly forecast for 4 days, 16 days forecast, and climatic forecast for 30 days [3].
- **Multi-layer maps** - OpenWeatherMap provides beautiful multi-layer maps that create the visual perception of weather [3].

2) Disadvantages: Here are some of the disadvantages of OpenWeatherMap

- **Limited free plan** - OpenWeatherMap offers a free plan that allows 60 calls per minute, one million calls per month, and 5-day forecast, but it does not include historical data [3].

3) Motivation: OpenWeatherMap is a weather API that provides accurate weather data for any location on the globe. Making use of the STEP algorithm explained previously. Combining this algorithm with machine learning (ML) to significantly advance both the accuracy and computing speed.

Also with the free plan we get up to 60 calls per minute, one million calls per month, and 5-day forecast, which is more than enough for our application. Although the free plan doesn't include historical data, we can save the data and make our own historical data. The Downside of this approach is that we have to wait for the data to be collected.

In case we want forecast data for more than 5 days, we have to implement our own model to predict the weather (making use of the collected historical data), or upgrade to a paid plan.

C. ClimaX

ClimaX is the first foundation model designed to perform a wide variety of weather and climate modeling tasks. For weather, these tasks include standard forecasting tasks of relevant weather variables like temperature, humidity, etc. with various lead-times at various resolutions, both globally and regionally. For climate, ClimaX can help to make better long-term projections, or to downscale lower resolution model outputs to higher resolutions. At its core, ClimaX is a multi-dimensional image-to-image translation architecture based on

Vision Transformers (ViT).

ViT-based architectures are especially well suited for modeling weather and climate phenomena since they naturally tokenize the spatial nature of multiscale data akin to different spatial-temporal inputs. Additionally, they offer the opportunity to extend tokenization towards a wide range of multichannel features. [**?**]

1) Results highlights: Forecasting the future values of key weather variables at different temporal horizons is critical to ensuring the safety of communities and infrastructure around the world.

ERA5 is the latest climate reanalysis produced by ECMWF, providing hourly data on many atmospheric, land-surface and sea-state parameters together with estimates of uncertainty. [**?**]

ERA5 reanalysis data from the ECMWF underlies as the key source of data for training and evaluating machine learning models on this task with performance of Operation IFS being the current state-of-the art numerical weather prediction baseline.

ClimaX when fine-tuned on the same ERA5 data, even at medium resolutions 1.40625°already performs comparably, if not better than IFS on short and medium-range predictions, while being substantially better at longer horizon predictions.

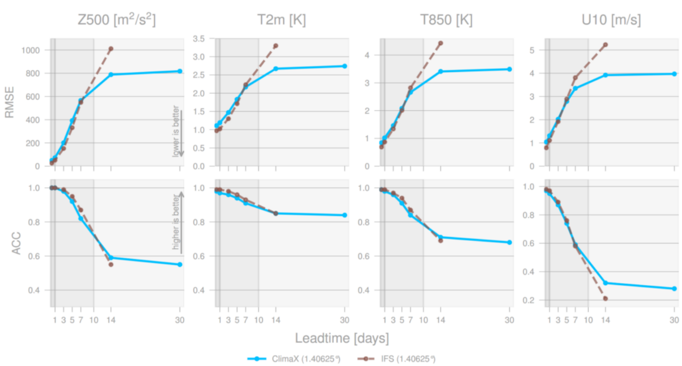

Fig. 1. ClimaX vs IFS on global forecasting of key weather variables at different lead time horizons

In the graphs above, we compare the performance of ClimaX vs IFS on global forecasting of key weather variables at different lead time horizons:

- Temperature T2M (2m above ground)
- Temperature T850 (850hPa)
- Wind speed U10M (10m above ground)
- Geo-potential height Z500 (500hPa)

The graphs on the first row show the RMSE (root mean squared error) of the predictions, while the graphs on the second row show the ACC (accuracy) of the predictions. The x-axis shows the lead time in days. As we can see, for example, on the Z500 graph, both models start at %accuracy 100 and 0 RMSE.

As the lead time increases, the accuracy of both models decreases, and the error increases. What a decrease in accuracy means is that the model is less confident in its predictions.

The lower the accuracy, the more uncertain the model is and the higher the error. A higher error means that the model is less accurate and less trustworthy.

But as we can see, ClimaX performs somewhat comparably to IFS on short and medium-range predictions, while being substantially better at longer horizon predictions (in most of these graphs, 14 days and above).

2) Motivation: ClimaX provides a variety of different spatial-temporal resolutions and input channels, which can be used for a wide variety of weather and climate modeling tasks. Being benchmarked against other state-of-the-art models, it holds its own and even outperforms them in some cases.

D. GraphCast

III. Conclusion

Acknowledgment

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

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