SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

A Study of the High-Performance Computing Parallelism in Solving Complexity of Meteorology Data and Calculations

Mohd Ridhuan Noor Affendi[1], Masnida Hussin[1,*], Dana Hasan[2]

[1] Faculty of Computer Science and Information Technology, University of Putra Malaysia (UPM), Selangor, Malaysia
[2] College of Science, Computer Science Department, University of Garmian, Kalar, Iraq

ABSTRACT

This paper investigates the high-performance computing (HPC) implementation in the field of meteorology, the challenges, and the future benefits. It is associated with utilizing HPC parallelism to simultaneously execute multiple tasks or operations for meteorological research. Merely a few people are aware of HPC's role in generating weather forecasting, climate modeling, and data assimilation. Our investigation elaborates on, identifies, and analyzes the features and characteristics of parallel computing that are utilized in it. The paper also focuses on examining parallelization modeling, the algorithms involved, and optimization strategies employed in HPC-enabled meteorological simulations. By addressing significant aspects of HPC in meteorological research, it helps the scientific community identify emerging trends and future directions for leveraging HPC in meteorology. Further issues can be studied for integrating big data analytics and machine learning into HPC computing architectures.

Keywords:

HPC parallelism; HPC-enabled meteorological; meteorology calculations; big data analytics

1. Introduction

The first high-performance computer (HPC) was built in the mid-1960s and has revolutionized every scientific, biological, physic, and mathematical area. Nowadays, HPC is a must-have piece of hardware in the field of meteorology, with contributions given by enabling advanced simulations, data analysis, and weather prediction models. Parallelism in high-performance computing (HPC) refers to the technique of simultaneously executing multiple tasks or operations to solve complex problems efficiently. The objective of this paper is to review the advantages of parallelism in high-performance computing in solving big size of data and numerical meteorology calculations in very fast time for decision-making with high accuracy. Through this lens, we aim to underscore the pivotal role of HPC in fostering advancements in meteorological research and operational forecasting, thereby contributing significantly to our understanding and prediction of weather phenomena.

* *Corresponding author.*
E-mail address: masnida@upm.edu.my

https://doi.org/10.37934/araset.54.1.1626

2. The Importance of Meteorology

Meteorology is the scientific study of the Earth's atmosphere and weather patterns, which play an important role in human life and society. From weather forecasting to climate science, from air quality monitoring to disaster preparedness, meteorology provides valuable information, knowledge, and insights that shape our understanding and enable us to navigate our atmospheric world. These forecasts are invaluable for individuals, businesses, and governments. They guide decision-making regarding agricultural practices, transportation routes, construction projects, emergency preparedness, and resource management.

Meteorology also contributes significantly to the study of climate patterns and changes. Through the analysis of long-term weather data, meteorologists identify climate trends, assess climate variability, and predict future climate scenarios. This information is crucial for addressing climate change and air pollution, developing sustainable strategies, and implementing policies related to environmental conservation and energy production. Accurate meteorological information enables policymakers to implement effective measures to improve air quality, ensuring a healthier and cleaner environment for present and future generations. The windy application for real time and forecast of nitrogen dioxide (see Figure 1) and wind movement (see Figure 2) are shown below.

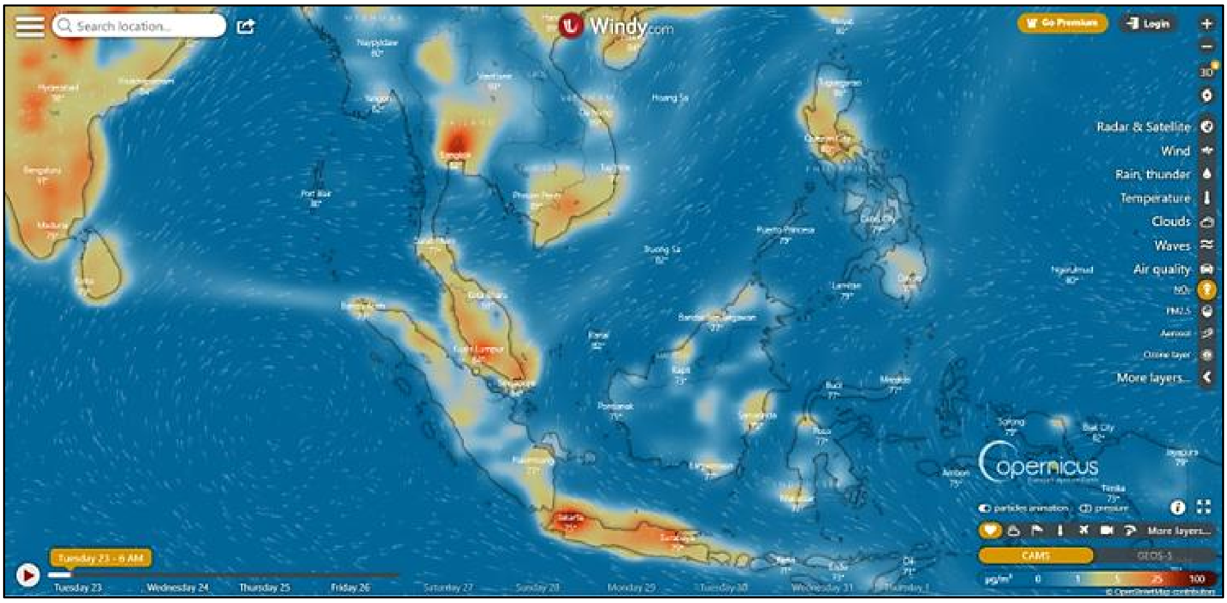

Fig. 1. A real time and forecast of nitrogen dioxide as derived from windy application

In performing future energy, meteorology plays a role in the development and management of renewable energy sources, such as wind, solar, and hydroelectric power. Understanding wind patterns, solar radiation, and weather conditions helps optimize the placement, design, and operation of renewable energy systems. By utilizing meteorological data, renewable energy production can be forecasted, integrated into power grids, and effectively utilized. Meteorology thus paves the way for the expansion of sustainable energy sources, contributing to a greener and more resilient future.

Meteorology directly impacts agriculture, influencing crop growth, pest control, irrigation, and harvest timing. Accurate weather forecasts aid in assessing water availability, preventing crop diseases, and mitigating the impacts of extreme weather events on food production and food security. By integrating meteorological data into agricultural practices, we can enhance productivity, optimize resource usage, and ensure global food security.

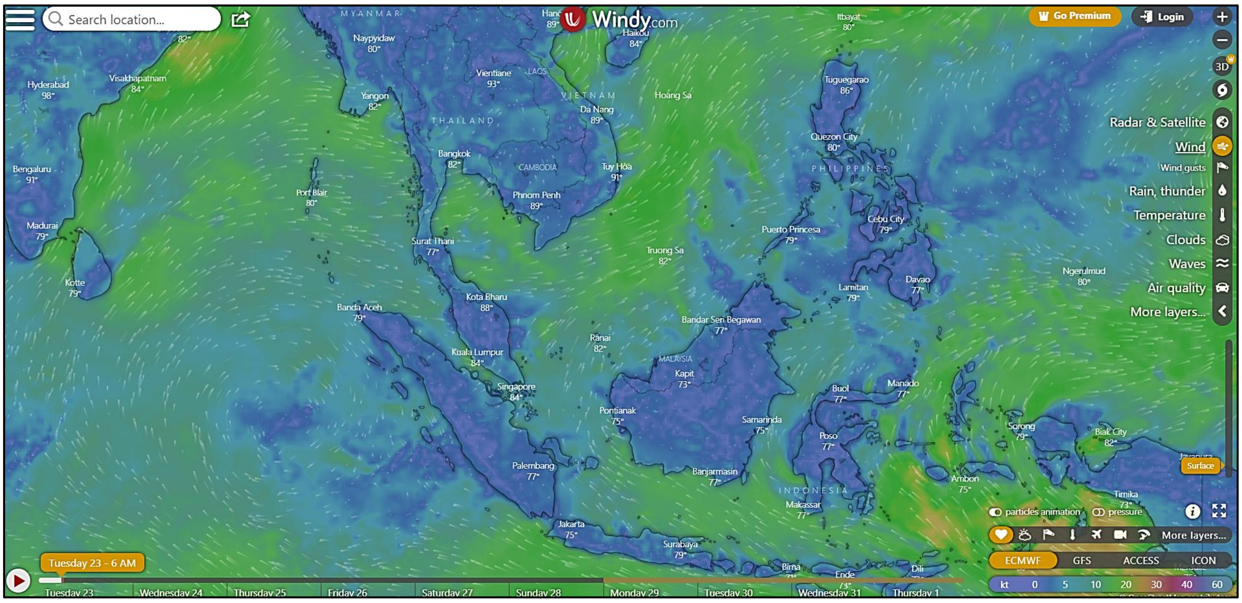

Fig. 2. A real time and forecast of wind movement as derived from windy application

Meteorology is vital for predicting and monitoring natural disasters such as hurricanes (see Figure 3), tornadoes, floods, and wildfires. Through advanced modelling techniques and extensive data analysis, meteorologists can provide early warnings, allowing authorities to take proactive measures. These measures include issuing timely alerts, implementing evacuation plans, and strengthening disaster preparedness.

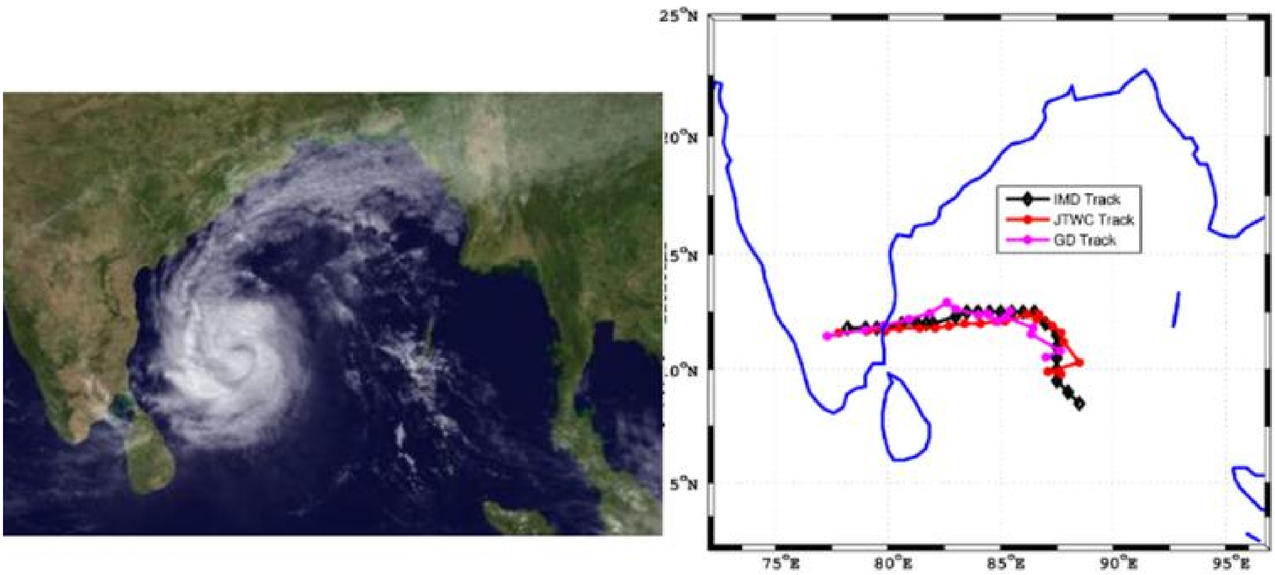

Fig. 3. Satellite imagery hurricane in Bengal Bay and hurricane forecasting with meteorology tools as derived from [1]

Due to the importance of meteorology to life and the environment that have been described and shown in Figure 1, Figure 2, and Figure 3. This complex system needs high-performance computing hardware to ensure success. Meteorologists need to always present this input quickly and accurately.

3. Early Meteorology Computers

One of early computer used for meteorology was the electronic numerical integrator and computer (ENIAC), which was developed during World War II and completed in 1945. Following ENIAC, several other early computer systems were used for meteorological research and operational forecasting. One example is the electronic discrete variable automatic computer (EDVAC), which was a successor to ENIAC and introduced improved programming capabilities. EDVAC was employed for atmospheric research and numerical weather prediction during the 1950s and early 1960s. Another significant early computer used for meteorology was the IBM 7090, a transistorized mainframe computer introduced in 1959. The IBM 7090 and its successor, the IBM 7094, were widely utilized in meteorological institutions and research centres to perform weather simulations and analyse observational data. These early computers laid the foundation for the integration of computational methods in meteorology.

4. Advantages HPC In Meteorology

The field of meteorology has greatly benefited from the use of HPC, which refers to the utilization of powerful supercomputer system that compute to tackle complex computational problems. HPC systems have transformed meteorological research and operational forecasting by providing the computational resources necessary to simulate and analysed atmospheric processes with unprecedented detail, time saving and accuracy. To produce accuracy, meteorology relies on the set of collection and analysis of vast amounts of observational data, including temperature, humidity, wind speed, and atmospheric pressure. Data is collected from various sources such as weather radar, satellite, weather balloon, remote-sensing data, weather buoy, ship and aircraft observations [2].

HPC systems offer several advantages in meteorological research such as the weather research and forecasting (WRF) model or the global forecast system (GFS), at higher resolutions and with finer grid spacing [3]. This enhanced resolution allows for more accurate representation of small-scale atmospheric features, including convective storms, localized weather phenomena, and complex terrain effects. HPC-based simulations enable researchers to better understand the dynamics and intensification mechanisms of these events, improving forecasting capabilities and providing valuable information for disaster preparedness and response. Climate models require substantial computational resources to simulate interactions between the atmosphere, oceans, land surfaces, and ice sheets over extended periods. HPC enables researchers to run complex earth system models and investigate the impacts of climate change on regional and global scales. Operational weather forecasting centres worldwide rely on HPC systems to generate accurate and timely forecasts [2]. Faster and more powerful computers allow meteorological agencies to process and assimilate large volumes of observational data, run numerous ensemble simulations, and provide more detailed and reliable forecasts to the public and decision-makers.

5. Meteorology Simulation Models

5.1 Mathematical Model

The large size of data collected needs complex mathematical models and simulations. Some of the known mathematical equations used in meteorology are the Navier-Stokes equations and thermodynamic energy equation.

5.1.1 The Navier-Stokes Equations

The Navier-Stokes equations by Itu *et al.,* [3] describe the conservation of momentum and the motion of fluid in three dimensions. In the context of atmospheric dynamics, the equations are simplified versions of the more general equations and account for forces such as pressure gradients, Coriolis forces due to the Earth's rotation, and viscous effects. The simplified form of the Navier-Stokes equations, often used in meteorology, can be written as follows.

Continuity Equation: $\partial\rho/\partial t + \nabla\cdot(\rho u) = 0$ (1)

This equation represents the conservation of mass. It states that the rate of change of density (ρ) with respect to time (t) plus the divergence (∇·) of the density times the velocity vector (u) is equal to zero. This equation ensures that mass is conserved within the fluid.

Momentum equations: $\partial(\rho u)/\partial t + \nabla\cdot(\rho u \vec{u}) = -\nabla p + \rho g + 2\Omega \times \rho u + \nabla\cdot\tau$ (2)

Where ρu represents the momentum density, p is the pressure, g is the acceleration due to gravity, Ω is the Earth's angular velocity vector, and τ represents the viscous stress tensor. The left-hand side of the equation represents the rate of change of momentum, while the right-hand side consists of various forces acting on the fluid. ∇p represents the pressure gradient force, which accelerates the fluid from regions of higher pressure to regions of lower pressure. The term ρg accounts for the gravitational force, which acts vertically downward. 2Ω × ρu represents the Coriolis force due to the Earth's rotation, where Ω × ρu is the cross product of the angular velocity vector and the momentum density vector. This force influences the direction of fluid motion in rotating reference frames. ∇·τ represents the viscous effects, capturing the influence of internal friction within the fluid.

These equations, along with the thermodynamic energy equation and additional parameterizations for other processes, form the basis for numerical weather prediction models. By discretizing and solving these equations over a grid system, meteorologists can simulate and forecast the behaviours of the atmosphere, providing valuable insights into weather patterns and atmospheric dynamics.

5.1.2 Thermodynamic Energy Equation

The thermodynamic energy equation describes the conservation of energy in the atmosphere, accounting for various energy exchanges and transformations [4]. In the context of meteorology, the simplified form of the thermodynamic energy equation can be expressed as follows.

Thermodynamic energy equation: $\partial(\rho\theta)/\partial t + \nabla\cdot(\rho\theta u) = Q - W$ (3)

In this equation, ρθ represents the potential temperature, u is the velocity vector, Q represents heating or cooling sources, and W represents work done by external forces. The left-hand side represents the rate of change of potential temperature with respect to time and the divergence of the density times the potential temperature times the velocity vector. The term $\partial(\rho\theta)/\partial t$ represents the rate of change of potential temperature with time, accounting for temporal variations in the atmosphere's energy state. The term $\nabla\cdot(\rho\theta u)$ represents the convergence or divergence of energy flux due to the advection of potential temperature by the velocity vector. It describes the spatial redistribution of energy within the fluid. The term Q represents the heating or cooling sources, which can include radiative heating and cooling, latent heat release from phase changes, and sensible heat exchange with the surface. Q can vary depending on the location and atmospheric conditions. The term W represents work done by external forces, such as mechanical work due to atmospheric turbulence or pressure-driven processes. It accounts for energy exchanges associated with work done on or by the atmosphere.

The thermodynamic energy equation, combined with the Navier-Stokes equations by Itu *et al.,* [3] and other equations, forms the foundation for numerical weather prediction models. By solving these equations numerically, meteorologists can simulate and forecast the behaviours of the atmosphere, including temperature changes, atmospheric stability, and the formation of weather systems. The energy equation helps to understand the energy balance within the atmosphere and its influence on weather patterns and atmospheric processes.

5.2 Numerical Weather Prediction (NWP)

Numerical weather prediction (NWP) models use computational methods to simulate and predict atmospheric conditions [1, 5]. These models can be classified into different types based on their spatial resolution, forecast range, and intended applications.

5.3 Global Models

Global models cover the entire earth and provide forecasts on a global scale. They typically have a coarse spatial resolution, often ranging from tens to hundreds of kilometres. Global models are used to generate weather forecasts for large-scale weather patterns, such as the movement of weather systems across continents and the global circulation patterns [6].

5.4 Regional Models

Regional models by Muhamad Yusof [6] cover larger geographic areas and provide relatively lower spatial and temporal resolution. They typically have a grid spacing of tens to hundreds of kilometres and are used for forecasting weather conditions over a specific region, such as a country or a continent and design to covered a forecast period of several days to a week. They provide a broader overview of weather conditions in a specific region. These models are initialized using large-scale atmospheric data that cover the entire region of interest and did not design to focusing on capturing fine-scale initial conditions. Regional models provide deterministic forecasts, meaning they produce a single forecast for a specific location and time.

5.5 Mesoscale Models

Mesoscale models from the previous study conducted by Muhamad Yusof [6] also known as limited-area focus on smaller geographic areas and provide higher spatial and temporal resolution compared to global model. They are designed to capture detailed atmospheric processes at scales ranging from a few kilometres to a few hundred kilometres. These models are primarily used for short-term weather forecasting (typically up to a few days in advance) and are well-suited for predicting specific weather events that occur at smaller scales. They are essential for providing high-resolution guidance for weather hazards and local conditions. Detailed observations and analysis of current atmospheric conditions for initialization is the main data component that will be calculated and processed. These data required to be accurate and timely data feed to provide reliable short-term forecasts. Mesoscale models are design to provide deterministic forecasts, meaning they produce a single forecast for a specific location and time. Users receive a single "best guess" prediction.

5.6 Ensemble Models

Ensemble models by Muhamad Yusof [6], on the other hand, are not limited to a specific scale and can cover a wide range of spatial and temporal resolutions. These model involve running multiple simulations with slightly different initial conditions or model configurations to account for uncertainty in weather predictions. Ensemble forecasts typically have coarser spatial resolutions compared to mesoscale models. The main objective of these models is to assess and quantify uncertainty in weather forecasts. They are valuable for making probabilistic forecasts, identifying potential weather hazards, and understanding the range of possible outcomes. Ensemble forecasts are often used for medium to long-range forecasting (up to several weeks ahead). Ensemble models initialize multiple simulations with perturbed initial conditions to create an ensemble of forecasts. This approach accounts for the inherent uncertainty in initial observations and helps estimate the range of possible future weather scenarios. Unlike the other models, Ensemble model generates a range of possible outcomes with associated probabilities, allowing forecasters to assess the likelihood of various weather scenarios.

6. Enhancing Forecasting Accuracy Through HPC

Enhancing forecasting accuracy is a primary goal in meteorology, and high-performance computing (HPC) systems play a crucial role in achieving this objective. Here are several ways in which HPC enhances weather forecasting accuracy

i. Higher resolution models: It provides more accurate representations of the complex atmospheric processes, leading to improved forecasts [1, 6].
ii. Improved physics parameterizations: It represents sub grid-scale processes, such as convection, turbulence, radiation, and cloud microphysics. These advanced physics schemes account for a broader range of atmospheric processes and interactions, resulting in more accurate forecasts [1, 6].
iii. Ensemble forecasting: It provides a range of possible outcomes and associated probabilities, offering insights into the uncertainty of the forecast. By leveraging the computational power of HPC systems, meteorologists can generate larger ensemble sizes, leading to more robust and skillful predictions [1, 6].
iv. Data assimilation: It is the process of combining observational data with model simulations to generate the most accurate initial conditions for NWP models. The faster computational speed of HPC allows for near-real-time assimilation, incorporating the latest observations and improving the accuracy of initial conditions for forecasts [1, 6].

v. Rapid model updates: It updates are particularly important for high-impact weather events, where small changes in atmospheric conditions can significantly affect the forecast outcome [6].
vi. Advanced data processing and post-processing: These techniques include statistical analysis, machine learning algorithms, and ensemble post-processing methods. By leveraging the computational power of HPC, meteorologists can apply sophisticated data analysis techniques to improve the accuracy and reliability of forecasts [1, 6, 7, 19].
vii. Probabilistic and high-resolution forecasting: It captures fine-scale weather features and variations, enabling more precise predictions for localized areas. HPC systems enable the efficient generation of probabilistic and high-resolution forecasts, enhancing forecasting accuracy across various spatial and temporal scales [6].

7. Parallelism in Meteorology Data Processing

HPC parallelism plays a crucial role in meteorology data processing, enabling efficient and rapid analysis of large and complex datasets [8]. Some of the key areas where HPC parallelism is used in meteorology data processing.

7.1 Data Pre-processing and Quality Control

Meteorological datasets often require pre-processing and quality control steps to ensure data accuracy and consistency. In meteorology environment, HPC parallelism can be employed to distribute these tasks across multiple processing units, enabling simultaneous execution of data filtering, outlier detection, interpolation, and data fusion techniques to prepare data for further analysis [9].

7.2 Data Assimilation

Data assimilation is the process of integrating observed meteorological data with model predictions to obtain the best estimate of the current atmospheric state [10]. Parallel processing enables simultaneous analysis of large observational datasets and model simulations, facilitating the efficient estimation of atmospheric states and improving forecast accuracy.

7.3 Numerical Weather Prediction (NWP) Models

NWP models simulate and forecast atmospheric conditions using numerical techniques. These models involve solving complex mathematical equations, such as the Navier-Stokes equations and thermodynamic energy equations, over a large computational domain [1, 6]. Parallel computing enables higher spatial resolutions, longer forecast ranges, and more accurate predictions.

7.4 Ensemble Forecasting

Ensemble forecasting involves generating multiple forecasts by running NWP models with slightly perturbed initial conditions or model parameters. This technique provides a range of possible outcomes and helps quantify forecast uncertainty. Ensemble forecasting using parallel computing allows meteorologists to assess the likelihood and confidence of different weather scenarios and improve probabilistic forecasts [6].

7.5 Big Data Analysis

Meteorological datasets, including satellite imagery, radar data, and climate observations, can be massive in size. HPC parallelism is instrumental in handling big data in meteorology. Parallel processing techniques, such as map-reduce frameworks and distributed computing, facilitate efficient storage, retrieval, and analysis of large meteorological datasets [11]. Parallel algorithms can be applied to perform tasks like image processing, feature extraction, pattern recognition, and statistical analysis on massive meteorological datasets.

By leveraging the computational power of parallel computing, meteorologists can process and analyze vast amounts of data in a timely manner, leading to improved weather predictions, better understanding of atmospheric processes, and enhanced decision-making in various weather-dependent applications.

8. Data Forecasting and Methods

These methods combine observations, historical data, statistical techniques, and numerical weather prediction models to provide accurate and reliable forecasts to predict future weather conditions [12, 13]. There are several types of forecasting methods in meteorology.

8.1 Persistence Forecasting

Persistence forecasting assumes that weather conditions will remain relatively unchanged over a short period. It relies on the notion that current weather patterns will persist into the near future. This method is useful for short-term forecasts in stable weather conditions [14].

8.2 Climatology Forecasting

Climatology forecasting uses historical weather data to determine the average weather patterns for a given location and time of year [15]. It assumes that the future weather will resemble the long-term average. Climatology forecasts are particularly valuable for seasonal and long-term outlooks.

8.3 Analog Forecasting

Analog forecasting identifies similar past weather patterns and uses them as a reference to predict future weather. It involves comparing the current atmospheric conditions with historical data to find analogue situations and their subsequent weather outcomes [16]. Analog forecasting is especially useful for unique or extreme weather events.

8.4 Statistical Forecasting

Statistical forecasting methods utilize historical data and statistical techniques to analyse patterns and relationships between weather variables. Regression analysis, time series analysis, and pattern recognition algorithms are employed to develop statistical models for forecasting. These models can capture trends, seasonal variations, and correlations among different weather parameters [17, 18].

8.5 Ensemble Forecasting

Ensemble forecasting involves running multiple simulations with slight variations in initial conditions or model parameters to account for uncertainty in weather predictions. By creating an ensemble of forecasts, statistical analysis is applied to generate probabilistic forecasts and assess the likelihood of different weather outcomes [10].

8.6 Machine Learning Techniques

Machine learning algorithms, such as artificial neural networks, decision trees, and support vector machines, are increasingly being used in meteorology to analyse large datasets and make predictions [19, 20]. Machine learning models can identify complex patterns and relationships in weather data, improving forecasting accuracy.

8.7 Numerical Weather Prediction (NWP)

NWP is a data-driven approach that involves simulating the behaviour of the atmosphere using mathematical equations and observational data [6, 17]. NWP models divide the atmosphere into a grid and apply numerical integration techniques to solve the equations and predict future weather conditions. These models assimilate real-time observations to initialize the simulations and provide detailed forecasts for specific locations and timeframes.

9. Conclusions

In conclusion, HPC parallelism plays a vital role in advancing meteorological forecasting. Meteorology involves analyzing large amounts of data, performing complex simulations and calculations, and executing computationally intensive models to understand and predict weather patterns. HPC parallelism allows meteorologists to harness the power of multiple processors, enabling them to process large datasets and perform simulations more quickly and accurately. HPC parallelism facilitates ensemble forecasting, where multiple simulations with slightly different initial conditions or model parameters are executed simultaneously. Ensemble forecasting provides probabilistic predictions, capturing uncertainties in weather forecasts and enhancing forecast reliability. In general, utilization of HPC parallelism in meteorology requires careful consideration of load balancing, efficient data distribution, minimizing communication overhead, and optimizing algorithms. It is important to thoroughly understand its components for effective and high-performance computing.

Acknowledgement
This research was not funded by any grant but supported by Faculty of Computer Science and Information Technology UPM

References
[1] Maity, Subhendu, SubbaReddy Bonthu, Kaushik Sasmal, and Hari Warrior. "Role of parallel computing in numerical weather forecasting models." In *IJCA Special Issue on International Conference on Computing, Communication and Sensor Network CCSN2012*, vol. 4, pp. 22-27. 2013.

[2] Rautenhaus, Marc, Michael Böttinger, Stephan Siemen, Robert Hoffman, Robert M. Kirby, Mahsa Mirzargar, Niklas Röber, and Rüdiger Westermann. "Visualization in meteorology—a survey of techniques and tools for data analysis tasks." *IEEE Transactions on Visualization and Computer Graphics* 24, no. 12 (2017): 3268-3296. https://doi.org/10.1109/TVCG.2017.2779501
[3] Itu, Lucian Mihai, C. Suciu, F. Moldoveanu, and A. Postelnicu. "Optimized GPU based simulation of the incompressible Navier-Stokes equations on a MAC grid." In *2011 RoEduNet International Conference 10th Edition: Networking in Education and Research*, pp. 1-4. IEEE, 2011. https://doi.org/10.1109/RoEduNet.2011.5993692
[4] Okhotin, V. S., and E. V. Dzhuraeva. "Method for Calculating Thermodynamic Properties of Poorly Studied Liquids." In *2022 VI International Conference on Information Technologies in Engineering Education (Inforino)*, pp. 1-4. IEEE, 2022. https://doi.org/ 10.1109/Inforino53888.2022.9782990.
[5] Pu, Zhaoxia, and Eugenia Kalnay. "Numerical weather prediction basics: Models, numerical methods, and data assimilation." Handbook of hydrometeorological ensemble forecasting (2019): 67-97. https://doi.org/10.1007/978-3-642-40457-3_11-1
[6] Muhamad Yusof, Muhamad Sofian. "Technical Note No. 1/2022: Peningkatan Model Ramalan Cuaca Numerikal Dari 3-Hari Kehadapan Dengan Resolusi 4km Kepada 4-Hari Kehadapan Dengan Resolusi 3km Bagi Seluruh Malaysia." Malaysian Meteorological Department Ministry of Environment and Water (2022).
[7] Chantry, Matthew, Sam Hatfield, Peter Dueben, Inna Polichtchouk, and Tim Palmer. "Machine learning emulation of gravity wave drag in numerical weather forecasting." Journal of Advances in Modeling Earth Systems 13, no. 7 (2021): e2021MS002477. https://doi.org/10.1029/2021MS002477
[8] Barney, Blaise, and Donald Frederick. "Introduction to parallel computing tutorial." HPC@ LLNL (2017).
[9] Shu-chang, Wang, Zhang Wei-min, Li Yi, and Zhao Jun. "Implementation and Tests of Variational Quality Control in Meteorological Data Assimilation System." In 2010 Third International Conference on Information and Computing, vol. 2, pp. 216-221. IEEE, 2010. https://doi.org/10.1109/ICIC.2010.149
[10] Hólm, Elias V., Simon TK Lang, Michael Fisher, Tomas Kral, and Massimo Bonavita. "Distributed observations in meteorological ensemble data assimilation and forecasting." In 2018 21st International Conference on Information Fusion (FUSION), pp. 92-99. IEEE, 2018. https://doi.org/10.23919/ICIF.2018.8455209
[11] Miyoshi, Takemasa, Keiichi Kondo, and Koji Terasaki. "Big ensemble data assimilation in numerical weather prediction." Computer 48, no. 11 (2015): 15-21. https://doi.org/10.1109/MC.2015.332
[12] Chantry, Matthew, Sam Hatfield, Peter Dueben, Inna Polichtchouk, and Tim Palmer. "Machine learning emulation of gravity wave drag in numerical weather forecasting." Journal of Advances in Modeling Earth Systems 13, no. 7 (2021): e2021MS002477. https://doi.org/10.1029/2021MS002477
[13] Pu, Zhaoxia, and Eugenia Kalnay. "Numerical weather prediction basics: Models, numerical methods, and data assimilation." Handbook of hydrometeorological ensemble forecasting (2019): 67-97. https://doi.org/10.1007/978-3-642-40457-3_11-1
[14] Fujiwara, Takahiro, and Yuzuru Ueda. "Load forecasting method for Commercial facilities by determination of working time and considering weather information." In 2018 7th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 336-341. IEEE, 2018. https://doi.org/10.1109/ICRERA.2018.8567019
[15] Vandenberghe, Francois, Mike Barlage, Scott Swerdlin, Judith Gardiner, Ashok Krishnamurthy, and Alan Chalker. "Climatologies Based on the Weather Research and Forecast (WRF) Model." In 2009 DoD High Performance Computing Modernization Program Users Group Conference, pp. 249-253. IEEE, 2009. https://doi.org/10.1109/HPCMP-UGC.2009.41
[16] Liao, Hongsen, Li Chen, and Hui Zhang. "A Visualization System for Weather Forecast Analogs." In 2015 14th International Conference on Computer-Aided Design and Computer Graphics (CAD/Graphics), pp. 121-128. IEEE, 2015. https://doi.org/10.1109/CADGRAPHICS.2015.45
[17] Xie, Jibo, Chaowei Yang, Bin Zhou, and Qunying Huang. "High-performance computing for the simulation of dust storms." Computers, Environment and Urban Systems 34, no. 4 (2010): 278-290. https://doi.org/10.1016/j.compenvurbsys.2009.08.002
[18] Jin, Yan, Dingmei Wang, Ruiping Zhang, and Haiying Dong. "Research on Statistical Downscaling Method of Meteorological Data Based on Photovoltaic Power Forecast." In 2021 IEEE 4th International Electrical and Energy Conference (CIEEC), pp. 1-6. IEEE, 2021. https://doi.org/10.1109/CIEEC50170.2021.9510290
[19] Mishra, Deepti, and Pratibha Joshi. "A Comprehensive Study on Weather Forecasting using Machine Learning." In 2021 9th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO), pp. 1-5. IEEE, 2021. https://doi.org/10.1109/ICRITO51393.2021.9596117
[20] Husin, Nor Azura, Vishnuu Sivajiganason, Norida Mazlan, and Imas Sukaesih Sitanggang. "iRICE Decision Support System: Time-Series Forecasting Model for the Risk Management System." Journal of Advanced Research in Applied Sciences and Engineering Technology 33, no. 2 (2023): 160-173. https://doi.org/10.37934/araset.33.2.160173