THE FISHWORLD A MONTHLY MAGAZINE
ISSN: 3049-138X
Vol.2(5) May 2025, 360-366

Popular Article

Forecasting Change: The Role of Advanced Meteorology in Climate Adaptation and Fisheries

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DOI:10.5281/FishWorld.15629935

Introduction

Meteorology plays a crucial role in combating climate change by helping us understand and adapt to shifting weather patterns. Meteorologists play an important role in anticipating change by providing critical data and insights that enable communities, governments, and enterprises to adjust efficiently. The world is suffering severely from climate change especially in terms of rise in temperature, and climate varies around the globe. Climate change is caused by both anthropogenic and natural factors, including a lack of vegetation and a significant increase in total carbon dioxide, methane, and other greenhouse gas emissions. The increased temperature are projected to hasten desertification (Sissakian et al., 2013), affecting agriculture (Osman et al., 2019), land use, land cover changes, and water resources in many countries. Conventional risk assessments and infrastructure diagnostics often rely on inspections, which are augmented by conventional monitoring and analytics. Consequently, they fail to provide a comprehensive strategy for prompt decision-making. Moreover, risk-based infrastructure management overlooks recovery from a "beyond-design-life" situation and is insufficient for handling "low-probability, high-consequence" disasters like the 2011 Tohoku earthquake and tsunami. This is because existing risk modeling and assessment frequently fail to account for such situations, while legislation and budgetary restrictions preclude them by adopting several strategies. This article examines meteorology's critical role in climate adaptation and how advances in discipline are impacting our response to the climate catastrophe.

Fisheries management does not function on 50–100-year scales, necessitating shorter-term projections (Hare et al., 2010). The climate modelling community is dedicating significant resources to creating decadal-scale forecasts that encompass both externally induced changes (e.g., CO_2 emissions) and internal variability (e.g., Atlantic meridional overturning circulation, El Niño–Southern Oscillation) (Keenlyside et al. 2008). In the future, various climatic projections about fish population statuses (5–20 years, 20–50 years, 50–100 years) may be made available to scientists, managers, and fishermen (Brander, 2010). However, these projections must include the impacts of both fishing and climate on population dynamics (Planque et al. 2010).

Climate Dynamics

Meteorology is the study of atmospheric phenomena and the complex interconnections that determine weather patterns and climate change. Meteorologists may understand the complicated dynamics of climate systems by evaluating historical data and using advanced models. This understanding serves as the foundation for projecting future climate trends, such as temperature changes, precipitation patterns, and extreme weather occurrences. There is a shift in the climate system caused by internal changes within the climate system or the interplay of its components, as well as changes in external force caused by natural or manmade activity. Climate variability is defined as variability observable in the climate record during periods when the condition of the climate system does not change. If the climatic state changes, which is often defined by a shift in means, the frequency of previously unusual occurrences on the shifted side of the mean may increase with rising climate variability (Salinger, 1994). Global climate models are widely used to evaluate climate risk (Hassan, 2021). These models are effective instruments for simulating the three-dimensional climate system through the application of equations defining energy (first law of thermodynamics), momentum (Newton's second law of motion), mass conservation, and water vapor (ideal gas law). At discrete locations on the surface of the Earth, each equation is approximated for different layers of the atmosphere identified by a regular grid during predefined time intervals (Mohammed et al., 2022). In order to comprehend the future climate and its progression, this was used to compare the expected and actual climatology in a climate model spanning the target region. There are two well-known techniques for downscaling: statistical downscaling (like LARS-WS and SDSM) and dynamical downscaling (like Regional Climate Models; RCMs) (Semenov et al., 2002). In recent years, Statistical Downscaling Models (SDSM) and the Long Ashton Research Station Weather Generator (LARS-WG) have been developed (Wilby and Dawson, 2004). While SDSM employs a regression-based methodology, LARS-WG is based on a stochastic weather generator (Zubaidi et al., 2019) (Costa-Cabralet al., 2013).

Forecasting Climate Change Impacts

Predicting how the climate will affect different areas and ecosystems is one of the main responsibilities of meteorologists. They can predict how various regions of the world will be affected by increasing temperatures, shifting rainfall patterns, and stronger storms by using climate models and simulations. Policymakers, urban planners, and disaster management

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organizations may create proactive measures to reduce risks and safeguard populations by using these projections, which offer essential insights as shown in table 1.

Meteorological Tool	Description	Reference
Weather Radar	Detects extreme weather events and precipitation	Boyle et al., 2005
Climate Risk Assessment	Detects climate data to identify vulnerable areas	Scholze et al., 2006
Climate Models	Projecting future trends using Earth's climate system simulation	Randall et al., 2007
Weather Stations	Collecting observational data on temperature, humidity, etc.	Cuervo-Robayo et al., 2014
Satellite Imagery	Gives access to real-time weather pattern tracking	Chiang et al., 2020
Early Warning Systems	Warns users to extreme weather conditions	Dylewsky et al., 2023

Table 1. Different meteorological tools and their functions

Early Warning Systems

When it comes to creating early warning systems for extreme weather occurrences like hurricanes, heat waves, hailstorms, and floods, meteorologists are essential. Meteorological organizations are able to promptly issue alerts and advisories, allowing individuals the chance to make preparations and take preventive action, by monitoring atmospheric conditions and applying modern forecasting techniques. In the event of climate-related calamities, these early warnings improve community resilience, save property damage, and save lives. The intended beneficiary community must accept warnings as legitimate and actionable, and they must be effectively communicated and disseminated by mandated authorities. Budgets must be decided upon, goods must be moved to the area at risk, public awareness campaigns must be created, and so on. Weather predictions only give enough warning to take limited action, and all of these activities take time. Decision-makers would be better equipped to plan an efficient response if they had more time to prepare.

Supporting Climate Resilience

By offering data-driven insights that guide adaptation plans and infrastructure design, meteorology promotes climate resilience. Meteorologists assist in identifying regions susceptible to climate impacts, such as droughts, sea level rise, and disruptions to agriculture, by evaluating climate predictions and sensitivity assessments. Decision-makers utilize this information to help them put policies like improving water management systems, developing resilient infrastructure, and encouraging sustainable land use practices into action. The promise for enhancing the climate resilience of essential infrastructure lies in emerging and disruptive digital technologies that can facilitate decision-making and adaptation by offering prompt and precise asset condition assessments. In order to succeed in this attempt, transdisciplinary roadmap adoption as well as the utilization of computational, communication, and other digital technologies, tools, and monitoring systems are crucial. However, due to a lack of agreement, coordinated strategies, and laws promoting their usage, the promise of these cutting-edge technologies is still mostly unrealized. Emerging digital technologies such as artificial intelligence, point clouds, digital twins, Internet of Things, and building information modeling can contribute to a safer society. These technologies nevertheless have a strong reliance on their operators' interdependencies and the power source.

Innovation in Meteorological Technologies

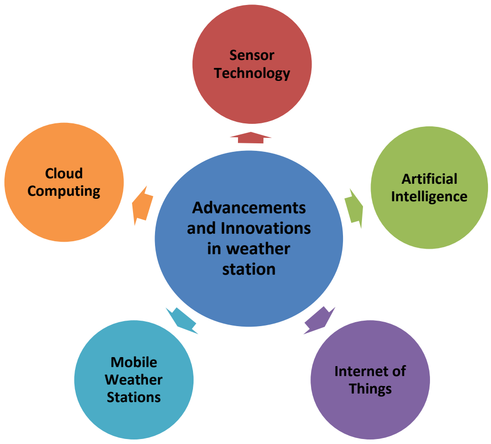
The monitoring and comprehension of climate change is being revolutionized by advances in meteorological technologies. Modern meteorological instruments provide never-before-seen levels of accuracy and precision in weather forecasting and climate modeling, ranging from satellite images and remote sensing to high-performance computers and artificial intelligence. Emerging technologies for better weather forecasting are shown in figure 1. Due to these advancements, meteorologists can now provide more accurate forecasts and customize adaptation plans for certain local conditions. By addressing the shortcomings and problems of conventional management techniques, the broad adoption of new digital technologies in the age of intelligent infrastructure is upending the way we manage our infrastructure. For instance, integrating diverse information and evidence using data mining for various infrastructure systems are made easier by 5G-enabled technologies, nearly instantly (Nguyen et al., 2021). These cutting-edge techniques give end users the ability to communicate, see, and engage with their surrounding environment while paving the path for safer infrastructure through more precise and automated decision-making.

Adaptation and mitigation strategies for climate change encompass a range of areas, including water sustainability plan, which includes comprehensive national planning and management of water resources, infrastructure restoration of water treatment facilities, and the application of substitute water sources, like reclaimed wastewater through the creation of reclaimed water facilities and water collection. To lower climate-altering emissions and enhance the environment, renewable power funding possibilities and climate-resilient infrastructure approaches such as using solar and wind energy in place of fossil fuels are required. According to the findings of Hassan et al. (2023), the LARS-WG model did a good job in downscaling daily temperatures and precipitation.

Figure 1. Emerging advancements and Innovations in meteorological analysis

Forecasting the change for aquaculture and fisheries

In the face of climate change, fisheries are increasingly vulnerable to extreme weather events, rising sea temperatures, and shifting oceanic patterns. Advanced meteorological tools,



including satellite-based monitoring, oceanographic models, and AI-driven climate predictions, play a crucial role in mitigating these challenges. Real-time weather forecasting helps fishers plan safe and efficient operations, reducing economic losses due to storms or unfavorable conditions. Additionally, climate models aid in predicting changes in fish distribution, breeding patterns, and disease outbreaks, allowing for adaptive fisheries management. By integrating meteorological data with sustainable fishing practices, policymakers and stakeholders can ensure long-term resilience in fisheries, safeguarding both livelihoods and aquatic biodiversity. The findings of the research by Hare et al. (2010) indicate that the impacts of climate on fisheries must be recognised, comprehended, and integrated into the scientific recommendations given to managers to attain sustainable exploitation in a changing environment.

Conclusion

A key component of climate adaptation is meteorology, which offers crucial data and perspectives for dealing with the problems brought on by climate change. Meteorologists help communities and decision-makers prepare for and lessen the effects of global warming by predicting change, creating early warning systems, and promoting resilience initiatives. Meteorology's role will remain crucial in constructing a more resilient and sustainable future as we face the challenges of climate change. Climate change, in especially the rise in temperatures in arid and semi-arid regions, is one of the most significant environmental problems faced by human civilization today and has been the focus of multiple studies in recent years. To increase socioeconomic systems' long-term durability in the face of upcoming disruptions, one should not

Publication Date: May 30, 2025

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sacrifice efficiency in the name of building resilience. Further study is required to develop adaptive capability that takes into account the profound uncertainties related to climate change that are supported by digital technology. In this context, standards, design norms, and guidelines are essential. These can include resilience analytics, which is based on management, deployment of digital data, associated cloud architecture, infrastructure monitoring, and regulation of digital technologies, especially with regard to cyber security.

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