EXTREME WEATHER EVENTS FORECASTING WITH AI - GEOGRAPHY

NEWS: With rising extreme weather events, Artificial Intelligence (AI) is emerging as a transformative tool to improve prediction accuracy beyond traditional models.

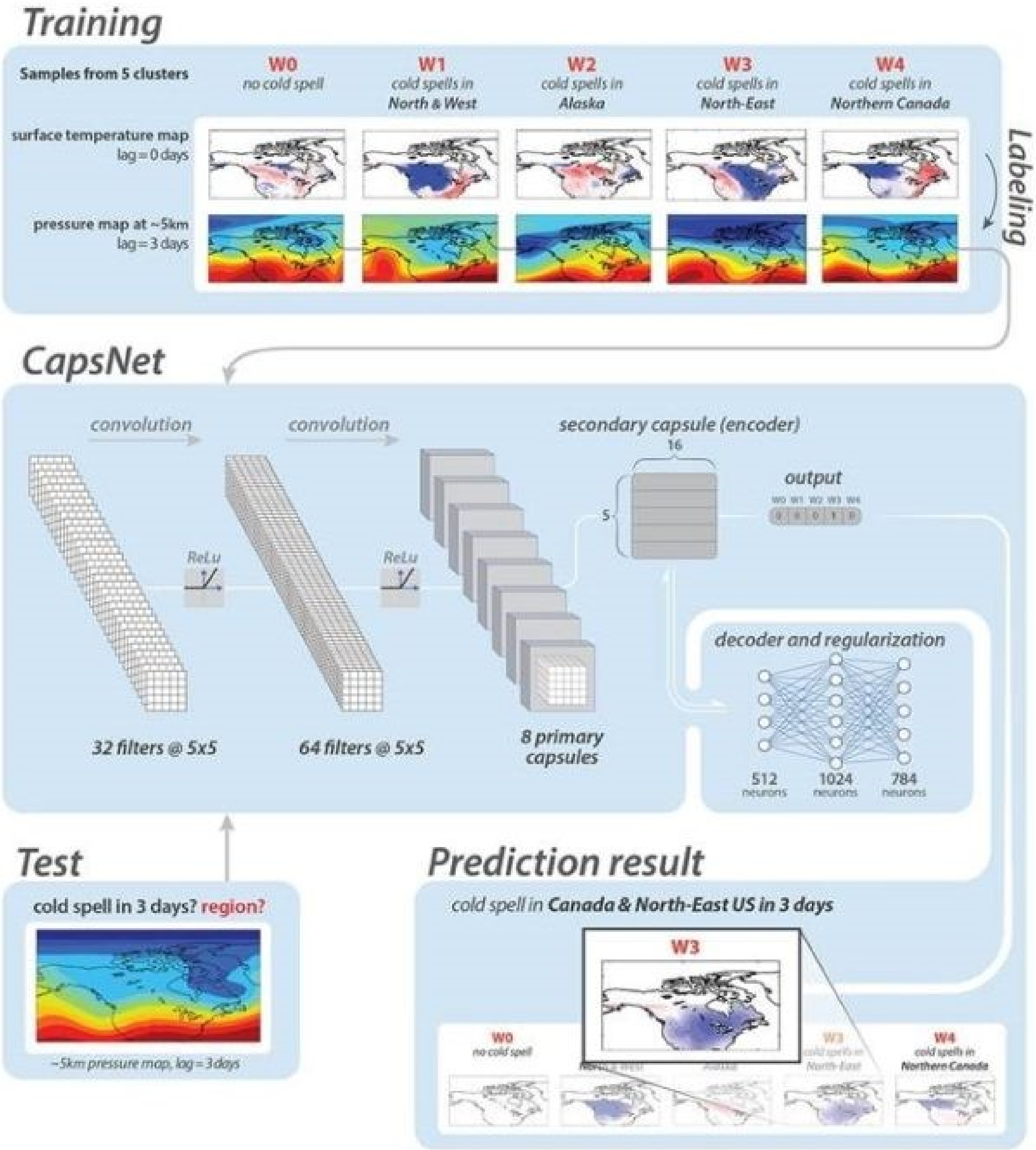
WHAT'S IN THE NEWS?

Traditional Model of Weather Prediction

- **Numerical Weather Prediction (NWP) Models**:
  Traditional weather forecasting primarily relies on Numerical Weather Prediction models, which simulate atmospheric behavior using complex mathematical equations based on the principles of fluid dynamics and thermodynamics.
- **Data Inputs for Models**:
  These models require large-scale observational data, collected from satellites, radars, weather balloons, and surface weather stations, as initial conditions to simulate future weather patterns.
- **Computational Requirements**:
  The mathematical models used in traditional forecasting are computationally intensive, necessitating the use of high-performance supercomputers that can process vast amounts of atmospheric data within reasonable timeframes to produce accurate forecasts.

Prediction of Weather with AI Models

- **Data-Driven Approach**:
  Unlike traditional models that are grounded in physical laws, AI-based weather forecasting models primarily focus on analyzing large datasets to discover patterns, without explicitly using equations of atmospheric physics.
- **Learning Patterns and Relationships**:
  Machine learning algorithms are employed to learn the relationships between input variables (such as temperature, humidity, pressure, and wind speed) and resulting weather phenomena (such as rainfall, storms, and cyclones) through pattern recognition.
- **No Prior Knowledge of Physical Laws**:
  AI models do not require prior understanding of the complex physical processes that govern atmospheric systems; instead, they infer correlations purely from the available data.



Advantages of AI Models in Weather Forecasting

- **Ability to Use Big Data**:
  AI models can efficiently handle and analyze massive, heterogeneous datasets gathered from satellites, ground-based sensors, radars, drones, and even unconventional sources like social media reports, enhancing the richness and granularity of forecasting inputs.
- **Handling Nonlinear Systems**:
  Earth's atmospheric processes are highly nonlinear and chaotic. AI models, especially deep learning systems, have the potential to identify subtle, complex, and nonlinear cause-effect relationships that might be missed by traditional physics-based models.

- **Adaptability to Local Conditions**:
  AI models can be fine-tuned to specific regions, taking into account local topography, urban structures, vegetation patterns, and microclimates, thereby offering highly localized and customized weather predictions.

- **Real-Time Forecasting and Nowcasting**:
  Due to their ability to quickly process incoming data, AI systems enable real-time forecasting or "nowcasting" (predicting weather for the next few hours), which is crucial for disaster preparedness, emergency response, and urban management.

Challenges in AI-Based Weather Forecasting

- **Complexity of Weather Systems**:
  Weather systems are inherently dynamic, interconnected, and influenced by a multitude of variables across scales, posing challenges for AI models to accurately capture and predict evolving weather patterns.

- **Human Resource Gap**:
  The development and deployment of AI-based weather models require interdisciplinary expertise combining meteorology, climatology, data science, and machine learning. However, there is currently a shortage of professionals trained in both domains.

- **Inadequate Sensor Network**:
  India's vast and diverse geography demands dense, regionally distributed meteorological sensor networks for accurate data collection. Gaps in sensor coverage, especially in remote and rural areas, limit the effectiveness of AI models.

- **Impact of Climate Change**:
  As climate patterns shift due to global warming, AI models trained on historical data may face declining predictive accuracy. The future climate may present new patterns not previously observed, necessitating continuous retraining and model adaptation.

- **Data-Related Issues**:
  High-quality, consistent, and complete datasets are crucial for training AI models. However, sensor errors, inconsistencies in data formats, missing data points, and spatial-temporal coverage gaps, particularly in less-monitored regions, degrade model performance.

- **Black Box Nature of AI Models**:
  Many AI systems, particularly deep neural networks, function as "black boxes" with limited transparency into how decisions or forecasts are made. This lack of interpretability hinders trust among stakeholders, including operational meteorologists and the general public.

Weather Prediction in India

- **Current Framework**:
  In India, the Indian Meteorological Department (IMD) relies heavily on satellite observations and numerical models powered by supercomputers for weather forecasting activities.
- **Key Meteorological Satellites**:
  INSAT-3D, INSAT-3DR, and INSAT-3DS are the primary satellites used for meteorological purposes. They provide critical data related to cloud dynamics, cloud top temperatures, atmospheric water vapor, and ocean surface parameters, assisting in rainfall estimation, cyclone tracking, and weather modeling.

Initiatives to Improve Weather Forecasting Efficiency

- **Mission Mausam**:
  Launched to modernize India's meteorological capabilities, Mission Mausam aims to:
  - Develop cutting-edge technologies and systems for weather surveillance.
  - Implement next-generation radars and satellites equipped with advanced instrument payloads for more accurate observations.
  - Promote the development of improved Earth system models and the adoption of AI/ML-driven data analysis methods to enhance forecasting precision.
- **National Monsoon Mission (2012)**:
  This initiative was designed to transition the country toward a weather prediction system that relies more heavily on real-time, ground-based observations rather than purely model-based projections, thereby enhancing the accuracy of monsoon and seasonal forecasts.
- **Expansion of Doppler Radar Network**:
  To improve short-term forecasts, especially for rainfall and thunderstorms, IMD has expanded its network of Doppler weather radars from 15 in 2013 to 37 in 2023, providing better regional coverage and timelier predictions.
- **Weather Information Network and Data System (WINDS)**:
  Under the Ministry of Agriculture and Farmers Welfare, WINDS aims to install over 200,000 ground weather stations across India. This ambitious project is expected to generate long-term, hyper-local weather data critical for precise, location-specific forecasts and agricultural planning.

Source: https://www.thehindu.com/sci-tech/science/artificial-intelligence-india-forecasting-extreme-weather/article69452413.ece#:~:text=Despite%20several%20challenges%2C%20scientists%20b