1. High-Resolution Impact-Based Early Warning System for Riverine Floods

- Full Citation:

Emerton, R., H. L. Cloke, E. Stephens, E. Zsoter, S. J. Woolnough, and F. Pappenberger, 2024: High-resolution impact-based early warning system for riverine floods. *Nat. Commun.*, **15**, 48065, https://doi.org/10.1038/s41467-024-48065-y.

- Main Objective:

The study aims to develop a high-resolution, impact-based early warning system for riverine floods to enhance disaster preparedness and response.

- Methods and Approaches:

The study combines meteorological forecasts, hydrological models (how water moves in rivers), and high-resolution hydrodynamic simulations (how floods spread) to improve flood prediction accuracy. Using a 10-meter spatial resolution, the system enables localized flood forecasting at the street and infrastructure level.

- Key Findings and Results:

The system can predict maximum water levels 24 to 48 hours in advance, enabling timely flood warnings. High-resolution hydrodynamic modeling produces detailed flood inundation maps, identifying at-risk buildings and infrastructure. Its computational efficiency supports real-time operational use, allowing for rapid and accurate flood forecasting.

- Performance Metrics Reported:
    - Lead Time for Warnings: The system predicts maximum water levels 24 to 48 hours before surpassing critical flood thresholds.
    - Computational Efficiency: At a 10-meter resolution, the system runs simulations 211 times faster than real-time events.

- Data Sources and Features Used:

It uses weather models (ICON D2-EPS), hydrological models (mHM), flood simulation models (RIM2D), and geospatial data (OpenStreetMap) to improve reliability. The combination of historical data + real-time observations + model simulations strengthens prediction accuracy.

- Limitations and Challenges Identified:

Many flood-prone areas lack high-resolution terrain, soil, and real-time meteorological data, reducing prediction accuracy. Also, high-resolution flood models require significant computational power, potentially delaying decision-making and emergency response.

- Relevance to Our Project:

The paper's multi-model approach provides a framework for integrating weather and geographic data to improve cloudburst prediction accuracy. Its 10-meter resolution modeling offers insights for localizing warnings, and its impact-based warning system serves as a model for making cloudburst alerts more actionable for emergency response.

2. Domino: A New Framework for Automated Identification of Weather Event Precursors

- Full Citation:

Dorrington, J., C. Grams, F. Grazzini, L. Magnusson, and F. Vitart, 2023: Domino: A new framework for the automated identification of weather event precursors, demonstrated for European extreme rainfall. *arXiv* preprint, arXiv:2306.16787, https://doi.org/10.48550/arXiv.2306.16787.

- Main Objective:

The study aims to develop an automated framework that identifies large-scale atmospheric precursors for extreme rainfall, allowing for earlier and more reliable weather warnings.

- Methods and Approaches:

The study applies logistic regression models to analyze historical weather data and detect recurring atmospheric patterns that precede extreme rainfall. It focuses on large-scale circulation features, such as pressure and wind anomalies, to identify precursors 2 to 6 days in advance across different regions.

- Key Findings and Results:

The system successfully identifies atmospheric precursors that signal extreme rainfall events several days in advance, extending the lead time compared to traditional short-term forecasts. However, precursor patterns vary by region and season, requiring localized adjustments. The framework demonstrates the potential of machine learning in improving early warning systems beyond immediate meteorological observations.

- Performance Metrics Reported:
  - Prediction Lead Time: It identifies precursors 2 to 6 days before extreme rainfall.
  - Model Accuracy: Logistic regression models show statistically significant skill in detecting precursors, though performance varies by location and season.

- Data Sources and Features Used:

The study uses historical atmospheric data to analyze pressure systems, wind anomalies, and large-scale circulation patterns. The dataset includes multiple European regions, providing a diverse test environment for validating precursor identification.

- Limitations and Challenges Identified:

Precursor signals differ by region and season, requiring localized model adjustments. Also, uncertainty remains in linking identified precursors to specific rainfall intensities.

- Relevance to Our Project:

The Domino framework enhances early warnings by identifying atmospheric precursors for extreme rainfall, improving cloudburst prediction lead times. Its machine learning approach boosts accuracy, complementing traditional methods. Additionally, its region-specific analysis supports customized models for better local forecasting.

Synthesis of Insights for Cloudburst Prediction

The two studies provide valuable frameworks for improving cloudburst prediction accuracy and lead time. The high-resolution flood modeling approach from the first study demonstrates how integrating meteorological, hydrological, and geospatial data enhances prediction precision. The Domino framework shows that identifying large-scale atmospheric precursors can extend early warning times by detecting weather patterns 2-6 days in advance. Combining these insights, our project can leverage multi-model approaches, machine learning-based pattern recognition, and high-resolution spatial data to improve cloudburst forecasting.

However, several challenges must be addressed. Computational demands may be high, especially if we adopt high-resolution simulations similar to the flood study. Additionally, forecast uncertainties must be effectively communicated to decision-makers, ensuring they understand risk levels rather than just raw probabilities. The Domino study's regional variations in precursor patterns suggest that cloudburst prediction models will need localized adjustments, requiring extensive data collection across different cities.

To maximize effectiveness, our project can integrate historical rainfall data, real-time meteorological observations, and atmospheric circulation patterns into a hybrid prediction model. Using high-resolution geospatial data, such as satellite imagery, could refine local impact assessments. Additionally, leveraging machine learning techniques from Domino's approach could help identify cloudburst precursors, enhancing prediction lead times beyond standard weather models.

By combining impact-based forecasting, machine learning-driven precursor detection, and high-resolution simulations, our system can improve both cloudburst prediction accuracy and early warning effectiveness, making it more actionable for emergency response and urban planning.

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