A Flood Early Warning System Based on an Integrated Precipitation Forecasting with Global Datasets for Adapting Weather Extremes in Data-scarce Nile Delta

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Abstract

This research is part of the ongoing research project - Climate change Adaptation to ManagE the risks of extreme hydrologicaL and weather events for food security in vulnerable west Nile delta (CAMEL). The study area, West Nile Delta, is an important region in Egypt featuring agricultural and industrial significance to the nation, whilst it faces serious crises from the interaction of complex environmental problems (e.g. flooding) which is exacerbated by climate change in the recent decades. Under the pressure of growing population, food security has become a national issue. In the latest decades, the region has experienced more extreme weather events; the severe rainfall events have resulted in flooding destroying massive crops and causing losses of human life and livestock. The evolvement of society in this region has made the people living in the flood-prone area – mostly farm labours - relatively socio-economic vulnerable. This research hence focuses on the urgent foregoing issue - disastrous pluvial flooding, which seeks to mitigate the issue of crop production loss and human casualty caused by climate change. Therefore, an adaption measure of an early warning system for extreme events caused by heavy rainfall has become an urgent demand. However, the scarcity of data (e.g. insufficiency in the coverage of gauge stations and radar stations) has always been a main obstacle to relevant measures in Egypt. The research hence seeks to cope with such difficulty whilst to build an integrated flood early warning system for Egypt. Based on the integration of Nowcasting method (applying GPM and MPE satellite radar observation) and NWP method (downscaling ECMWF data) as the substitution for the insufficient ground observations, the integrated approach can take the advantages of both data sources to perform better forecasting. However, GPM and MPE data, compared with ground observation data, still reflects relative disadvantages in spatial and temporal resolution in terms of Nowcasting application. Besides, notwithstanding Nowcasting method can make up for the spatial resolution of the NWP method, its mainstream - optical flow approach based on the Lagrangian method - still lacks confidence in dealing with local advection circumstance, as well as fast and drastic formation and dissipation of precipitation. The research hence seeks to improve Nowcasting, by applying a phase-based frame interpolation method based on the Eulerian method, to refine the resolution of data to improve the performance of Nowcasting. It features better performance in precipitation change, strong precipitation divergence (i.e. light contrast), and computational efficiency. The improved Nowcasting, for further integrating with the NWP method, is being tested and proposed, which will end up with a recommendation of policy and a novel tool – real-time flood early warning system – so as to accommodate the hydrological extremes towards climate change in Egypt.

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Abstract

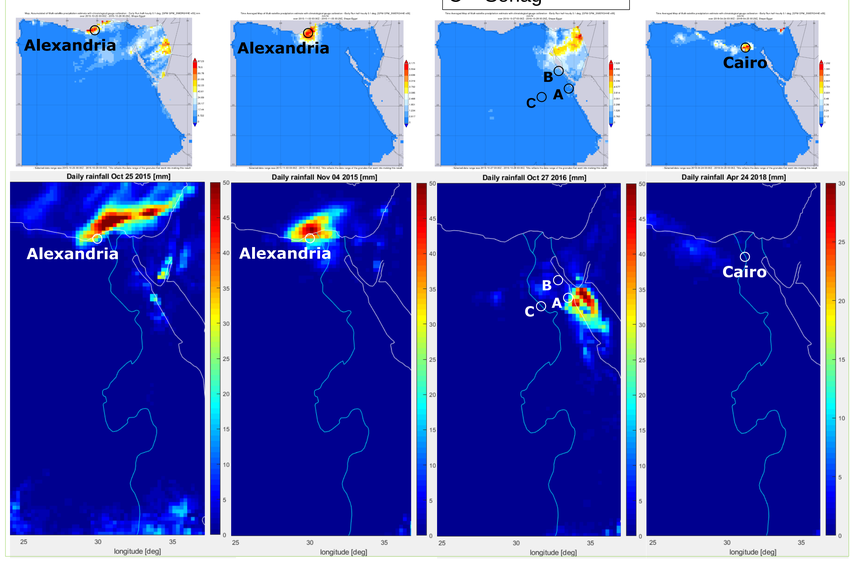
This research is part of the ongoing research project − Climate Change Adaptation to ManagE the Risks of Extreme HydrologicaL and Weather Events for Food Security in Vulnerable West Nile Delta (CAMEL). The study area − West Nile Delta − is an important region in Egypt dominated by agricultural and industrial activities, whilst it is a vulnerable area facing extreme weather and changing climate crises (e.g. flooding, rising temperature, sea level rise), and a relatively vulnerable area in Egypt in terms of socio-economic respect. In the latest decades, the region experienced more extreme weather events due to climate change; the severe rainfall events resulted in flooding destroying massive crops and causing losses of human life and livestock. Adaption towards the environmental challenges has therefore become an urgent demand, particularly an early warning system for extreme events caused by heavy rainfall. However, the depletion scarcity of data (i.e. insufficiency in coverage of gauge stations and radar stations) has always been a main obstacle to the development of hydrological early warning tools and of adaptions in Egypt. Therefore, the research aims to build an integrated flood early warning system for Egypt, based on the integration of Nowcasting of satellite precipitation observation and numerical weather prediction (NWP). Global data resources are hence applied (i.e. GPM, MPE and ECMWF data) as the substitution for the ground observations.

Current Data Issue & Study Flooding Events

The building of Aswan dam and of dams upstream in the Blue Nile river substantially reduce the annual peak of river discharge in the Nile. The annual flooding of Nile has become a history. However, due to climate change, Egypt is facing more disastrous pluvial flooding events in the recent decades, which has caused not only crop production loss but human casualty. To tackle the pluvial flooding issue, it reflects an even higher demand in ground observation of precipitation than the fluvial flooding one. Therefore, the research seeks to employ global data resources and propose an advanced approach, based on the integration of Nowcasting method (applying satellite radar observation, such as GPM, MPE) and NWP method (applying ECMWF data), so that the combined approach can take the advantages of both methods to perform better. Four pluvial flooding events causing casualties in recent decade have been used to show the differences between GPM (upper) and NWP (lower) observation, which are:

A

October 25 2015 Alexandria	November 04 2015 Alexandria	October 27 2016 A – Hurghada B – Ras Gharib C – Sohag	April 24 2018 Suburb of Cairo



Methods: Integrating Nowcasting & NWP

Generally known that Nowcasting method has advantage in short term performance (i.e. a couple of hours) , whilst NWP has advantage in long term performance (i.e. a couple of days). Therefore, how to integrate Nowcasting and NWP so as to better preform rainfall forecasting is the main task before inputting the forecast in flooding early warning tools.

As Nowcasting is based on radar observation, in order to apply Nowcasting approach in Egypt, we need to cope with the data scarcity issue that Egypt has not equipped with ground radar. The research hence seeks to apply satellite data to replace ground radar data. However, the research found that the performance of directly applying satellite data has yet to be satisfactory due to the current limitation in data resolution, which means to find a better way to apply satellite data in Nowcasting is one of the main tasks of the research project.

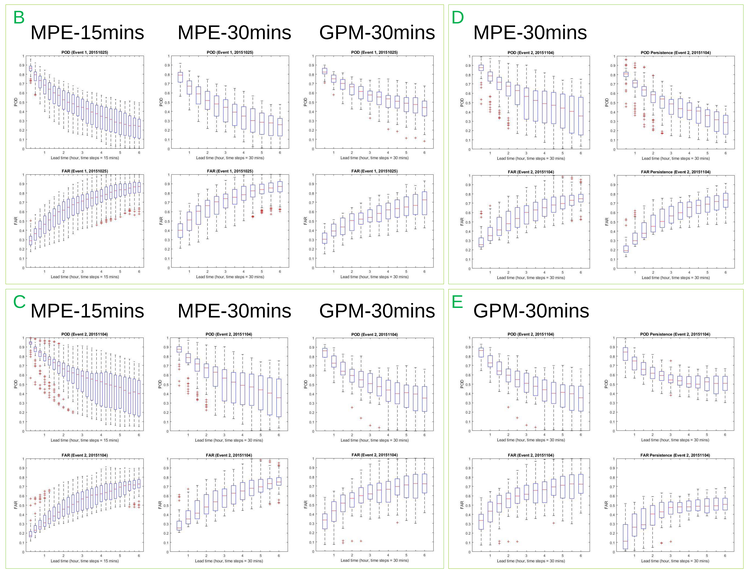
This research hence selected two satellite data products with more potential in Nowcasting performance, which are GPM and MPE product.

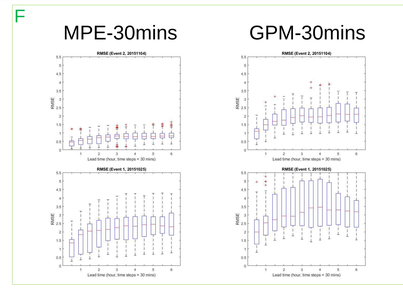
- GPM is available in 0.1° (≈10 km) spatial resolution and 30 minutes temporal resolution.
- MPE is available in 3 km spatial resolution and 15 minutes temporal resolution.

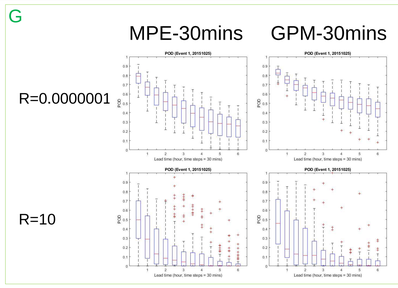
Results: Nowcasting Improvement

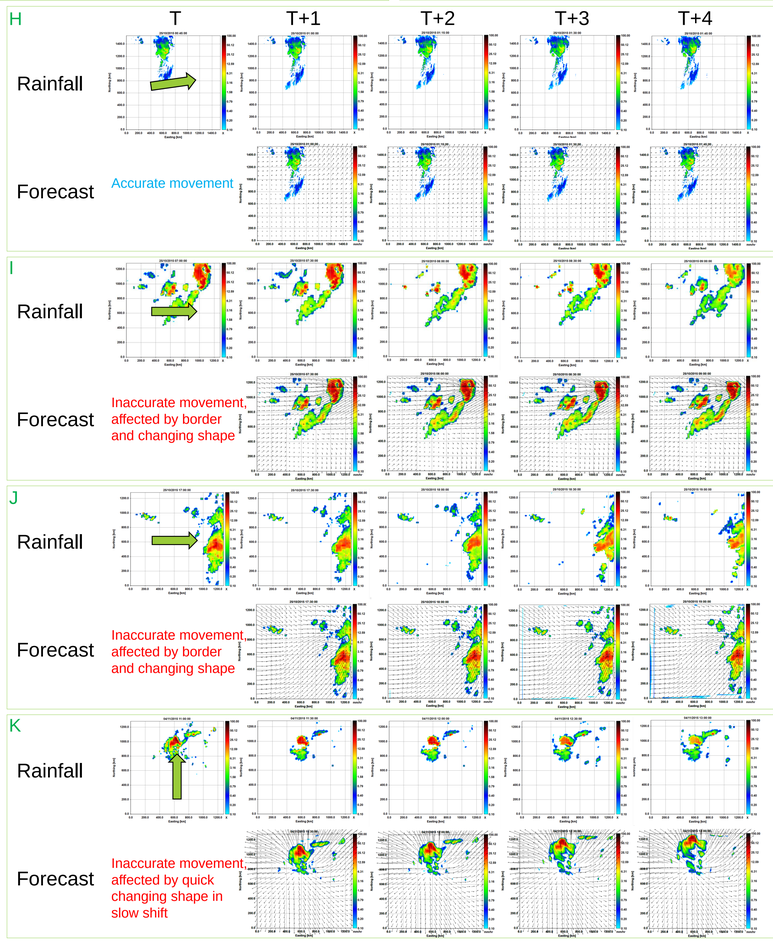
The findings of comparing GPM and MPE in Nowcasting are as follows,

1. MPE-15mins apparently performs better than MPE-30mins and GPM-30mins, whilst there is not clear difference between MPE-30mins and GPM-30mins, from POD and FAR analysis (Figure B and C).
2. Through persistence check, MPE-30mins shows Nowcasting performs better than assuming no movement, whilst GPM-30mins shows Nowcasting often performs worse than assuming no movement (Figure D and E).
3. Through RMSE comparison, MPE-30mins has less errors and more concentrated distribution than GPM-30mins (Figure F).
4. Through qualitative performance analysis in terms of the vector filed, MPE-15mins has 50.7% accuracy, whilst MPE-30mins and GPM-30mins has only 38.8% and 35.3% respectively.
5. Comparing the forecast hitting threshold R>0.0000001 and R>10 (mm/hr), both MPE-30mins and GPM-30mins decrease dramatically before 2 hours lead time, which shows more challenge in heavy rainfall in Nowcasting (Figure G).









Conclusion

1. Figure H, I, J, and K show how Nowcasting works by the prediction of vector field, which also demonstrate that the relativity between shift speed and shape changing speed is the key of accurate prediction.
2. The foregoing finding allows us to conclude that there are mainly three ways to improve the current Nowcasting method, particularly for the application of satellite data:
   1. to improve data, for better resolution (>the presented work);
   2. to apply AI, to avoid shape changing affecting vector prediction (>potential research);
   3. to involve different method into Nowcasting, such as a phase-based frame interpolation method based on Eulerian method (>the ongoing work).

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