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A globally-applicable conceptual model for extreme precipitation events

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Forecasting extreme precipitation events often comes with limited warning due to large uncertainties associated with convective precipitation. Given the vast socio-economic impacts of the resulting hazards of extreme rainfall, e.g., flash flooding and landslides, fundamental research into what causes these extremes remains an important priority for the community.

Using observational data from the UK a new four-stage conceptual model for extreme precipitation was developed. The conceptual model consists of i) a pre-conditioning phase, ii) a lifting phase, iii) the realization phase, and iv) the transition phase. Throughout the model a three-layered structure for the atmosphere exists: a conditionally unstable layer sandwiched between a low-level layer of increased stability and an upper-level stable layer. The conditionally unstable layer takes the form of a Moist Absolutely Unstable Layer (MAUL), and it is the release of the instability within the MAUL that drives the extreme rainfall.

To release the instability from the MAUL certain properties were observed. The MAUL needs to be associated with weak CAPE (typically < 500 J kg-1 for the UK). The MAUL also requires a warm top to ensure that warm rain processes can dominate and increase the precipitation. However, to make the most extreme events the MAUL also needs to be deep whilst remaining within the other constraints.

The conceptual model was tested over Jakarta and shown to apply in the tropics. Thus, it is a globally-applicable model. Examination of extreme rainfall events in 2024 has shown the importance of the saturation fraction in distinguishing between extremes from convective activity (localised saturation fractions close to one) and large-scale activity (widespread saturation fractions close to one). The ability to distinguish between precipitation modes enhances the forecast via inference of the predictability and characteristics of the system likely to produce the extreme event.

Global model representation shows biases in MAUL base and CAPE suggesting that improved representation of extremes will require improved vertical profiles in the model. However, due to the sparse nature of observed profiles the constraints for the model are limited.

The novel conceptual model for predicting extreme precipitation could help increase the lead time for warnings of extreme events and help focus the planning of emergency responders and public to enable to increase awareness, preparedness, and ultimately save lives.

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Presenting Author

David Flack

Email Address of Presenting Author

david.flack@metoffice.gov.uk

Affiliation of Presenting Author

Met Office

Address of Presenting Author

Met Office, FitzRoy Road, Exeter, Devon, EX1 3PB, UK

Authors: FLACK, David (Met Office); Prof. DAVIES, Paul (Met Office)

Co-author: Prof. FOWLER, Hayley (Newcastle University)

Presenter: FLACK, David (Met Office)