Are tropical waves an untapped source of predictability in the tropics?

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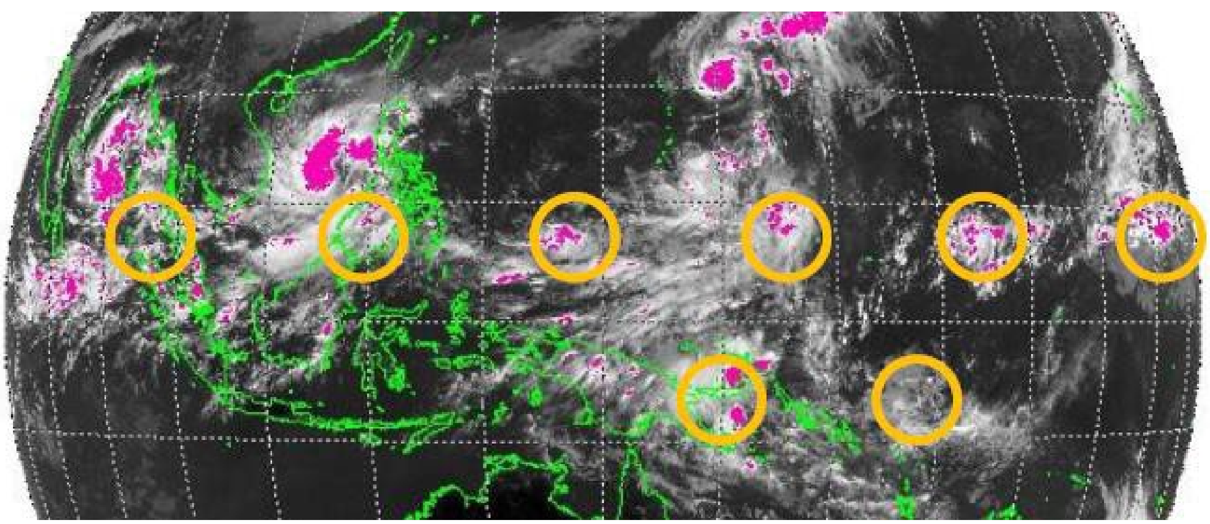
Weather in the tropics is dominated by the predictable diurnal cycle of convection. In many countries it rains heavily for a short period at approximately the same time every day. However, some days this diurnally driven rainfall is much heavier and more persistent than others and some days it does not rain at all. There is strong evidence in the scientific literature that these variations in rainfall are caused by the passage of atmospheric tropical waves. Furthermore, there is evidence from idealised global prediction experiments that, on large-scales, the atmosphere in the tropics is inherently more predictable than in the extratropics – hypothesised to be the result of tropical wave propagation (Judt, 2020). At present however, forecast models are poor at exploiting this potential predictability and skill falls rapidly in tropical forecasts. For example, convectively-coupled Kelvin waves travel too quickly and decay too quickly in atmospheric models meaning that the associated high impact weather is also misrepresented (Ferrett et al, 2020, Yang et al, 2021). This poses three major questions: i) How does the rapid growth of uncertainty in convection on small scales affect large-scale tropical waves? Are the fundamental limits of tropical weather predictability governed by tropical waves? Why are Kelvin waves, and their coupling with convective rainfall, not well represented in models, and how does this damage forecasts?



HIMAWARI satellite image showing high cloud (white) and heavy rainfall (pink). Convective weather systems associated with westward moving equatorial waves outlined in yellow. In this November case, rainfall features are displaced north of the equator.

This PhD project will begin by investigating the structure, dynamics and life-cycle of convectively-coupled Kelvin waves and how these differ in observations and models. The embedded convection will be examined in a frame of reference moving with the waves. We will use reanalysis, observation data, global ensemble forecast data and a unique set of large tropical domain high resolution ensemble forecasts produced by UK Met Office. The purpose of this PhD project is then to understand the interaction between the waves and embedded convection and then to use this to investigate how the small initial differences in forecasts grow with time and upscale from the convection to the tropical waves. How does this affect the longer-range predictions on large-scales that are essential to early warning of high impact weather with sufficient lead time for emergency action?

Ensemble forecasts are needed to address this problem. We will exploit data from the Met Office global operational forecast system (MOGREPS-G) where the model grid used cannot resolve individual thunderstorms and contrast this with the results of experimental limited area model ensembles with grid spacings of 4.5 and 2.2 km that are described as "convection-permitting (CP)", since deep convection is partially resolved.

In ensemble forecasting a set of forecasts is started at the same time, each with slightly different initial conditions and physical parameter settings. The purpose of ensembles is to predict the growth in uncertainty in the forecast of the atmospheric state at later times associated with chaos. In the Tropics, ensemble forecasts are considered under-dispersive, meaning that the forecast ensemble spread is on average much smaller than the forecast error. This is a major problem because it means that ensembles are less likely to give early warning of the possibility of high impact weather. The reasons for the poorer performance in the Tropics are a major unknown. However, the model representation of the atmospheric phenomena giving rise to chaos is likely to be central. Deep convection and cumulonimbus thunderstorms, associated with the high surface temperature and humidity in the Tropics, results in very rapid growth of spread on scales of 1-100 km. Although the large-scale conditions favourable for thunderstorms might be predictable, the timing and location individual storms has very short-range. We look to larger scale phenomena for longer-range predictability. For example, equatorial waves that propagate eastwards or westwards along the equator, depending on the wave type (wavelengths >> 1000 km). However, even on these largest scales the current global ensembles do not spread fast enough with lead time, indicating some fundamental problem with forecasting systems. It is hypothesised that it is the interaction between phenomena dominant on different scales that is mis-represented and the project seeks to test this hypothesis. This has application to understanding the behaviour of ensemble forecasts and how to improve them.

Training opportunities:
The project could involve a combination of the development of theory (building on existing theories for tropical dynamics and predictability) and computer modelling using the Met Office global forecast model and idealised models proposed to examine the growth of uncertainty and predictability. The balance of activities depends on your skill set and strengths and the direction you chose to take the project. You will receive masters-level training in the physics of the atmosphere, tropical and extratropical atmospheric dynamics and global numerical modelling.
As part of the CASE studentship with the Met Office you will work on placement with co-supervisor Anne McCabe in the Foundation Science area at Met Office headquarters, interfacing with the people developing the numerical model and ensemble systems. You will also work with people involved in the evaluation and exploitation of ensemble forecasts and have an opportunity to interact with operational forecasters.

Student profile:
The project would be suited to a student with a degree in physics, mathematics or science subject with a strong mathematical content. Some experience with computer programming would be good. Prior knowledge of atmospheric and environmental science is desirable, but not essential.

References:

Ferrett, S. et al (2020) Linking extreme precipitation in Southeast Asia to equatorial waves. Quarterly Journal of the Royal Meteorological Society, 146, 665-684, https://doi.org/10.1002/qj.3699

Judt, F. (2020) Atmospheric predictability of the tropics, middle latitudes, and polar regions explored through global stormresolving simulations. J. Atmos. Sci., 77, 257–276, https://doi.org/10.1175/JAS-D-19-0116.1

Yang, G.-Y., Ferrett, S., Woolnough, S. J., Methven, J. and Holloway, C. (2021). Real-time identification of equatorial waves and evaluation of waves in global forecasts. *Weather & Forecasting,* 36, 171-193, https://doi:10.1175/WAF-D-20-0144.1.

https://research.reading.ac.uk/scenario/