Investigating boundary layer processes in tropical cyclones in the Met Office operational forecasting model

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Project partners: Met Office (potential CASE award); Bureau of Meteorology

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Project description / Motivation

Each year tropical cyclones cause enormous amounts of damage due to their destructive winds, heavy precipitation and their effects on the sea, e.g. storm surges. The 2017 tropical cyclone season in the Atlantic was a particularly destructive one. Hurricane Irma (Fig. 1) reached wind speeds of 180 mph (285 km h^{-1}), and caused damage of around US$ 64.76 billion as well as 44 deaths directly and 85 indirectly in several Caribbean Islands and Florida. Hurricane Maria reached a maximum wind speed of 175 mph (280 km h^{-1}) and caused 112 fatalities and US $91.61 billion in damages. Hurricane Maria moved directly over Puerto Rico and left considerable destruction in its wake. Being able to accurately forecast the track and intensity of these high impact weather systems is crucial to enable people to take appropriate action in time to minimise the damage to livelihood, property and economy.

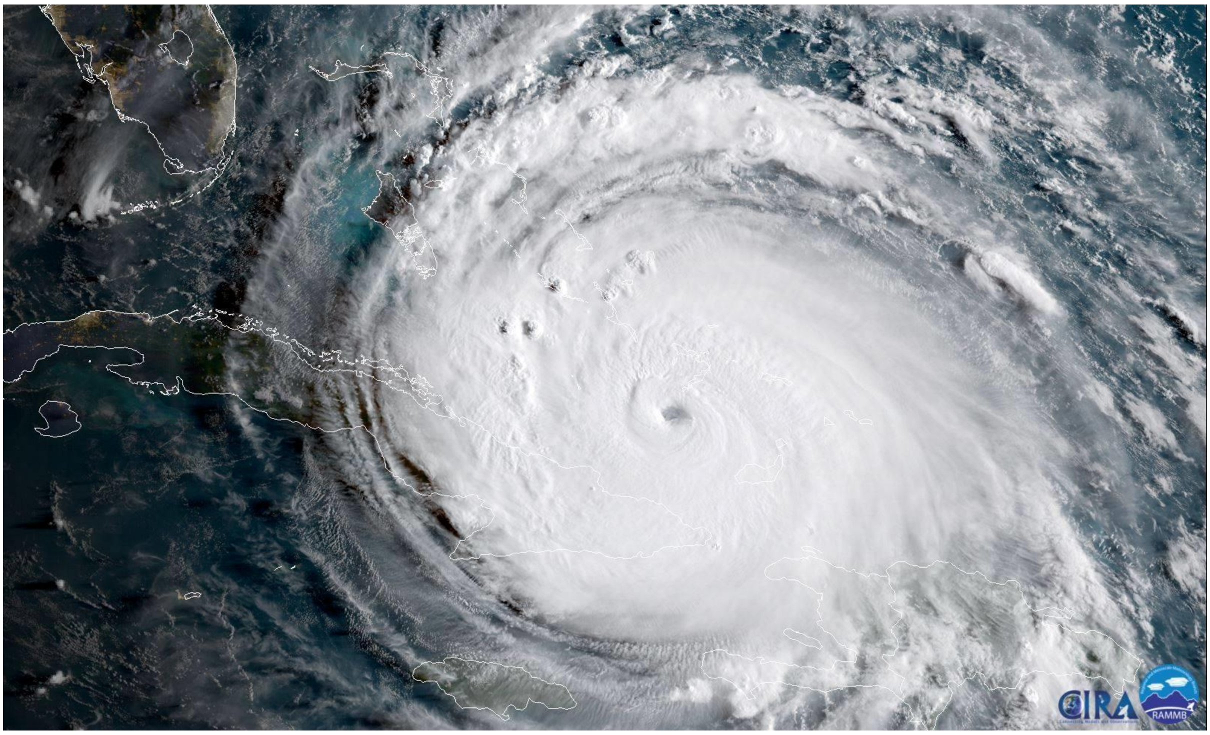

Fig. 1: Satellite image of Hurricane Irma on 08 September 2017. Image Courtesy: NASA (https://www.nasa.gov/image-feature/geocolor-image-of-hurricane-irma).

The strongest winds in tropical cyclones are typically found within the boundary layer. The boundary layer is directly influenced by the roughness of the Earth's surface. It responds to the surface forcing (frictional drag, evaporation and transpiration, heat transfer) on a timescale of an hour. The depth of the boundary layer ranges from a few hundred meters to kilometres, and is variable in time and space (Stull, 1997). Since it is these boundary layer winds that directly impact on people and buildings, there is a strong need to understand the processes and characteristics of this part of the atmosphere. The boundary layer also plays an important role during the intensification of tropical cyclones by mediating exchange of heat and moisture between the ocean and the atmosphere. Boundary layer structures can also influence the organisation of convection above the boundary layer. Accurately modelling the intensification of tropical cyclones remains one of the main challenges of tropical cyclone research.

Despite the importance of the boundary layer in tropical cyclones, the extreme environment means there are few direct observations within the boundary layer. Boundary layer parametrisation schemes in global models are not developed with such extreme conditions in mind and are not well tested against the observations. Processes such as frictional heating which are typically neglected may become important in such cases. Similarly, the air-sea exchange parametrisations are not well validated for high wind speed conditions due to lack of observations and there remains a high degree of uncertainty in these schemes. Much of what is known about the role the boundary layer in tropical cyclones comes from idealised simulations. The extent to which these ideas still apply in real tropical cyclones is less well understood.

Objectives

The scientific objectives of the PhD project are:

i. Conduct a detailed investigation into the representation of the boundary-layer structure and processes in simulations of real tropical cyclones;
ii. Develop an understanding of the model's sensitivity to the representation of boundary layer processes in tropical cyclones, and investigate ways of improving this to more accurately forecast cyclone development.

In particular, according to your particular research interests, the studentship could involve the following:

(1) Investigate the representation of the boundary layer structure of selected tropical cyclones in Met Office Unified Model (MetUM) simulations at different horizontal resolutions.
(2) Compare the modelled boundary-layer structure with flight-level (e.g. wind, temperature, radar), and dropsonde (wind, temperature, moisture) observations from the U.S. Hurricane Research Division aircraft reconnaissance program to identify potential model biases.
(3) Investigate the three-dimensional thermal and wind structure in the boundary layer for selected storms and compare them to existing simplified models in the literature.
(4) Investigate the representation of the height of the boundary layer in the model simulation. Is the height represented correctly? If not, how can we improve the representation of the height of the boundary layer in the MetUM?
(5) Develop ways to improve the representation of the boundary layer in the model and to minimise the identified model biases.
(6) Investigate the coupling between the boundary-layer and the free-troposphere in tropical cyclones, in particular how the boundary layer may control the initiation and structure of convection in the cyclone.
(7) Compare the MetUM set up at the Met Office to the tropical cyclones system at the Bureau of Meteorology for the same Atlantic tropical cyclone. Both systems use the MetUM, but will different data assimilation systems and slightly different model configurations and parametrisations. Do different data assimilation systems have an impact of the representation of boundary-layer processes and hence on tropical cyclone development?

Potential for high-impact outcome

The Met Office has a close working relationship with the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). The Philippines are severely affected by the most intense tropical cyclones. Forecasting the track and intensity of these storms is a key challenge for numerical weather prediction models such as the MetUM, in both global and regional configurations. This project provides a way to investigate aspects of the tropical cyclone boundary layer in detail, to evaluate how certain dynamical processes are represented in the model with the aim of improving our ability to forecast these storms more accurately, ultimately benefiting people at risk. We will focus on tropical cyclones in the Atlantic, as there are generally better observations available for these cyclones from the US Hurricane Research Division. Inner-core tropical cyclones dynamics are the same in each ocean basin, which is why the results of the project will be useful for PAGASA too. Close collaboration with the Met Office and the Bureau of Meteorology will ensure the results of this study will feed into model development. The outcome of this study may also provide guidance for forecasters. The project will generate results for several papers, with at least one being suitable for submission to a high impact journal.

Training

The student will work under the supervision of Dr Andrew Ross and Dr Juliane Schwendike from the University of Leeds, Dr Adrian Lock and John Edwards from the Met Office, and Dr Jeff Kepert from the Bureau of Meteorology, Australia. Co-supervision will involve regular meetings between all partners and regular visits to the Met Office in Exeter. The student might have the opportunity to visit the Bureau of Meteorology and Monash University in Melbourne, Australia. The successful PhD student will have access to a broad spectrum of training in numerical modelling, through to managing your degree or to preparing for your viva (http://www.emeskillstraining.leeds.ac.uk/). This project provides a high level of specialist scientific training in:

(1) Numerical modelling and use of cutting-edge supercomputers;
(2) Analysis of in-situ measurements from aircraft and ground-based monitoring sites;
(3) State-of-the-science application and analysis of global atmospheric reanalysis data;
(4) A computer programming language (e.g. Python) to perform complex analysis techniques;
(5) Effective written and oral communication skills.

The student will be part of the Dynamics and Clouds Group, which is embedded in the Institute for Climate and Atmospheric Science (ICAS) within the School of Earth and Environment. The Dynamics and Clouds Group is a large and active group of people working on a range of problems, with particular interests in the tropics and the role of convection. The group meets regularly and these group meeting provide an excellent opportunity to discuss your work as well as to learn more about what others are working on. We encourage you to be an active member of the Dynamics and Clouds Group.

Industrial partner

The proposal has been agreed as a “Partnership Project” with the UK Met Office and the student will benefit from Met Office supervisors as well as academic supervisors at Leeds. Leeds has a strong record of close collaboration with the Met Office and is one of only 4 universities in the Met Office Academic Partnership. The project aligns with existing collaborations between Leeds and the Met Office on boundary layer meteorology and tropical meteorology. The successful student will spend time working with the industry supervisors at the Met Office. For a good student the project is also eligible for one of the Met Office CASE awards.

Student profile

The student should have a keen interest in the challenges of understanding and modelling the weather and a strong background in a relevant quantitative science (meteorology, maths, physics, engineering, environmental sciences). Experience of scientific programming / data analysis is desirable, but not essential.

Further reading

http://www.see.leeds.ac.uk/research/icas/dynamics-and-clouds/

Chan, J. C. L., and J. D. Kepert (2010). Global perspectives on tropical cyclones. World Scientific.

Emanuel, K. (2003). Tropical Cyclones. Annual Review of Earth and Planetary Sciences, 31, 75-104.

Stull, R. (1997). Introduction to boundary layer meteorology, Kluwer Academic Publishers.

Or the following excellent webpage:

http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqA.html