The control of cloud and moisture on extratropical cyclone evolution

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Skillful weather forecasts and climate projections spanning timescales from hours to centuries are vital for protecting lives and livelihoods and mitigating the effects of climate change. Errors in these forecasts arise from errors in the initial conditions (the chaotic "butterfly effect"'), boundary conditions (e.g. the sea surface temperature in an atmospheric-only model) and model formulation (so-called "model error").

The aim of this project is to improve weather forecasts through improved knowledge of the control of moist processes on the development of extratropical cyclones (also known as autumn and winter storms) leading to the assessment and reduction of the model error arising from misrepresentation of moisture and cloud.

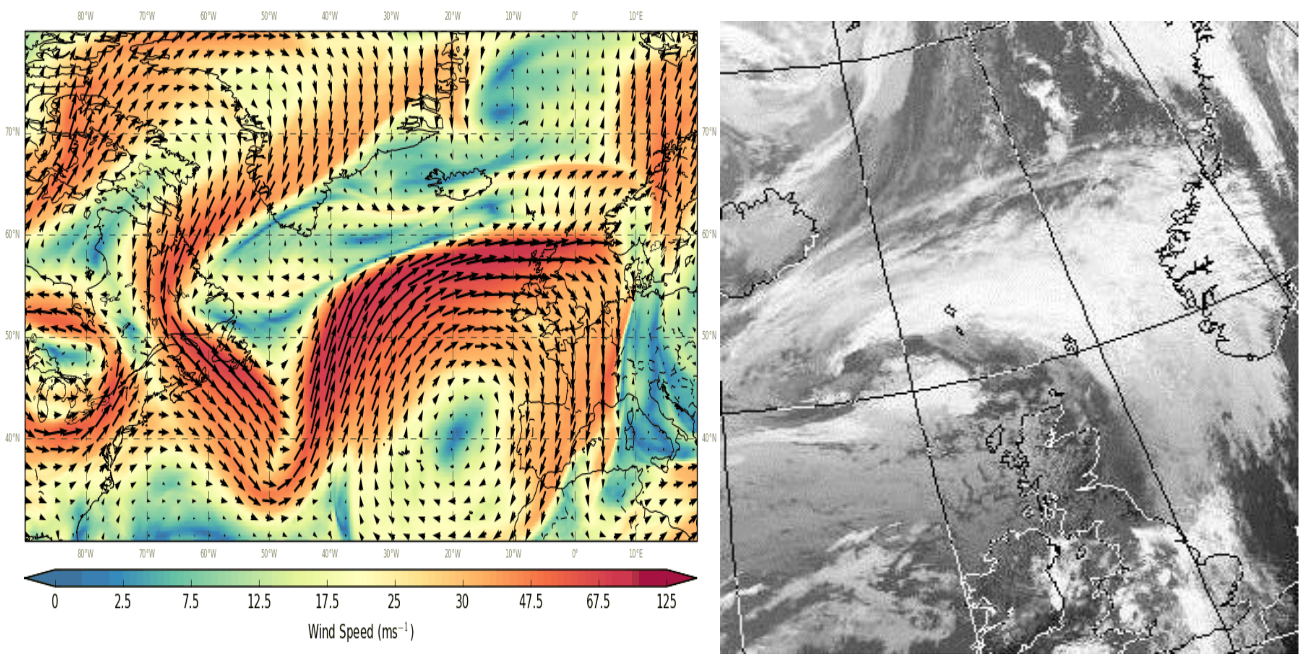

Figure: (left) Met Office wind forecast at approximately tropopause height for 10 UTC on 27 September 2016. (right) Infra-red satellite image from 1037 UTC on the same day (from Dundee satellite receiving station). The UK meteorological research aircraft crossed the jet streak and associated cloud to the North of the UK at this time, taking measurements. The jet streak was associated with the upper-level outflow from an extratropical cyclone that evolved from tropical cyclone Karl. Profs. Methven and Gray flew on this flight as mission scientists.

Recent research has demonstrated systematic weather model forecast errors occurring around the tropopause level (about 10 km height). These errors can propagate downstream, affecting the development of future weather systems, due to their influence on the development, propagation and breaking of the planetary-scale Rossby waves associated with meanders of the tropopause-level jet stream. Ridges and troughs in the jet stream are the major driver of the development of extratropical cyclones (also known as low-pressure systems, autumn and winter storms, mid-latitude cyclones and European windstorms) associated with strong, and often damaging, surface winds and rain.

One type of systematic error is that due to the misrepresentation of diabatic processes such as clouds and radiation. This error results from (i) uncertainties in the representation of clouds, convection and other processes in models and (ii) computational limits on the minimum model grid spacing that can be used for operational forecasts. Understanding the impacts of these uncertainties and their relative importance on extratropical cyclones and the downstream evolution of the atmosphere can target efforts to improve the skill of weather forecasts.

In this project we will collaborate with the ECMWF, the world-leading provider of medium-range (5-15 days) weather forecasts, to characterise errors in moisture and cloud that lead to errors in diabatic (particularly radiative-transfer) processes and determine their impact on downstream forecast evolution. Upper atmosphere ice cloud and water vapour are two areas of uncertainty, where models can have significant systematic errors. For example, recent published research by the ECMWF co-supervisor using aircraft observations showed a factor of two overestimate in humidity (moisture content) in the part of the atmosphere just above the tropopause in the ECMWF model resulting in a large radiative response and potential forecast errors. The role of mesoscale structures (horizontal scales 200-1000 km) that affect the cloud and humidity, such the downwards intrusions of dry air from above the tropopause typically associated with extratropical cyclones, will also be investigated.

We will use the OpenIFS model, a version of the ECMWF operational Integrated Forecast System (IFS) made available for academic use. An idealised configuration of this model can initially be used to study the role of key physical processes and impacts of resolution (i.e. model grid spacing) on the structure and characteristics of cyclones. A number of real case studies will then be investigated with the OpenIFS, including in ensemble mode (multiple realisations of the same forecast to yield probabilites). Some chosen case studies will likely come from the 2016 NAWDEX (North Atlantic Waveguide and Downstream Impacts Experiment) observational campaign that targeted cyclones over the North Atlantic, so that observations can be used to evaluate the model forecasts.

Training opportunities:
This project is in collaboration with the ECMWF, the world-leading provider of medium-range weather forecasts. The proximity of the ECMWF to the Department (~1 mile) facilitates this collaboration and we anticipate regular visits and participation in ECMWF training courses.

Student profile:
This project would be suitable for students with a degree in physics, mathematics or a closely related environmental or physical science.

References:

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NAWDEX field campaign website: www.nawdex.org

OpenIFS model website: https://www.ecmwf.int/en/research/projects/openifs

http://www.reading.ac.uk/nercdtp