LATENT HEAT IN EXTRATROPICAL ATLANTIC CYCLONES IN A CLIMATE MODEL AND REANALYSIS

National Centre for Atmospheric Science
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1. Motivation and background

- Extratropical cyclones are one of the major weather risks in the mid-latitudes due to the high winds and intense precipitation they produce.
- Understanding how these systems may change under the influence of climate change is critical to assessing future climate risk.
- To have confidence in the predictions of changes in extratropical cyclones from climate models, it is essential that they are capable of adequately simulating the processes which drive such cyclones, such as the magnitude and location of latent heat release associated with condensation of water vapour.
- The structure of extratropical cyclones in a high resolution climate model (HiGEM) has been found to compare well to those produced in reanalysis (Catto et al., 2010). This project investigates the specific role of latent heat in these storms and will incorporate remote sensing data to verify the ability of both reanalysis and climate models to reproduce the key features and processes that drive and control the evolution of extratropical cyclones.

2. Method

- To identify storms, an objective feature tracking algorithm is used (Hodges, 1994, 1995, 1999).
- This part of the study focusses on Atlantic cyclones.
- Precipitation is not an analysed field in ERA-Interim. The 12-hour forecast precipitation field is not affected by adjustment associated with spin-up of the forecast model. The precipitation rate used here is a 6-hour accumulation sampled around the 12-hour forecast. All other fields are 12-hour forecast fields. The HiGEM precipitation is a 2-hourly accumulation centred on the time the other fields are sampled.

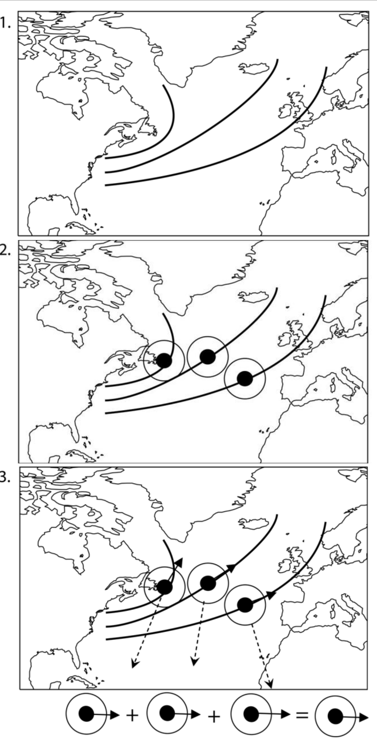


Figure 1: Schematic of the compositing technique (from Catto et al., 2010). (1) The tracks are identified in the 850hPa vorticity field and selected based on intensity, location and duration. (2) A spherical cap is centred on all points on the track for radial fields to be extracted and the point of maximum intensity is identified. (3) The cap is rotated to the direction of the storm and is extracted for averaging.

3. Atlantic cyclones

(a) General features

The key structural features of Atlantic cyclones in ERA-Interim and HiGEM are comparable.

Fig.2: The pattern and magnitude of system relative winds are similar, with maxima located in the region of the cold conveyor belt at lower levels. The maximum system relative winds are stronger in ERA-Interim.

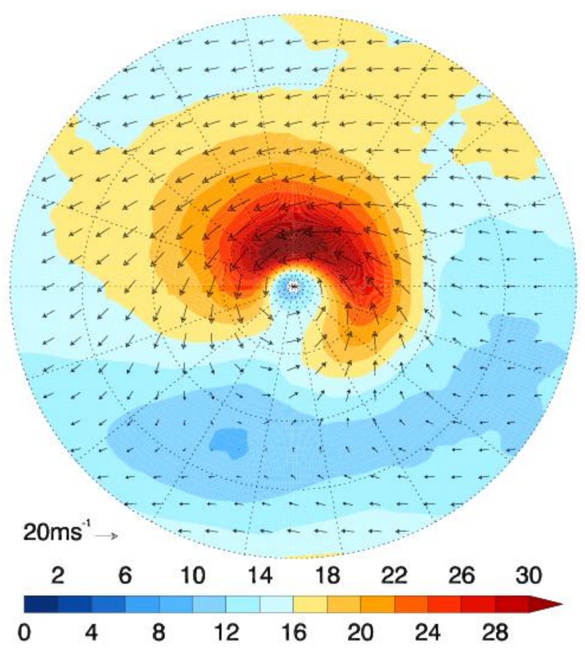
Fig. 3: Maximum ascent is located where the warm conveyor belt rises over the cold conveyor belt. The zone of maximum ascent is also the region of most intense precipitation in both ERA-Interim and HiGEM.

The locations of maximum ascent and maximum precipitation in HiGEM and ERA-Interim are spatially comparable. The precipitation maxima is significantly greater in ERA-Interim than in HiGEM, though the rate of ascent at this location is comparable in magnitude.

ERA-INTERIM

HiGEM

All plots are composites of the 200 most intense DJF Atlantic storms from a 1998/99-2007/08 period. Composites are at the time of maximum intensity.



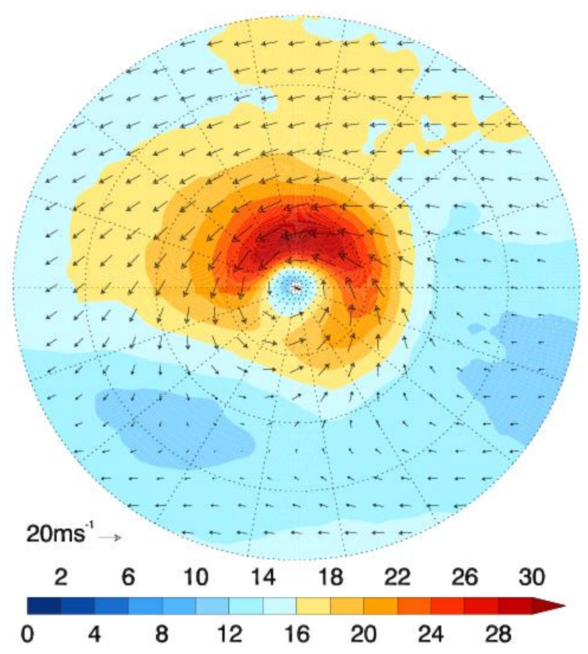
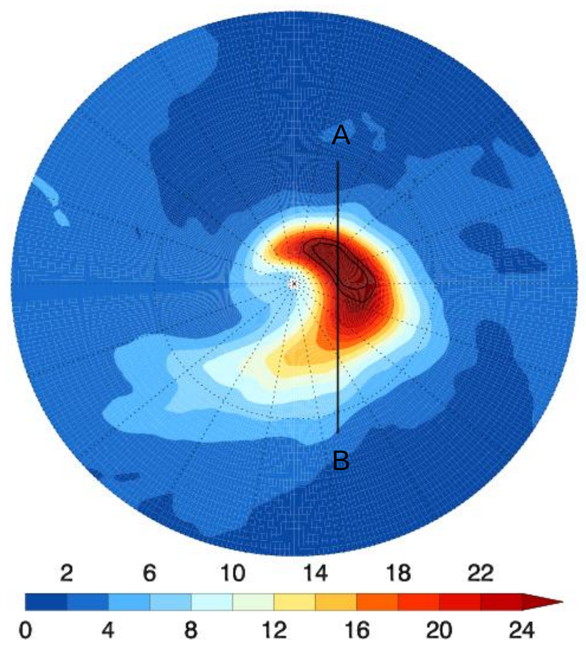


Figure 2: **System relative winds** (in ms^{-1}) at 925hPa for ERA-Interim (left) and HiGEM (right). Plot radii are 20°.

Direction of travel for all composites.



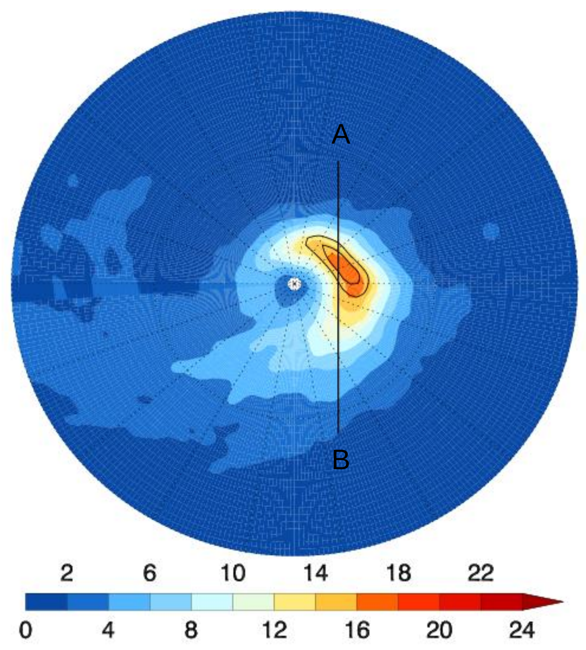


Figure 3: **Precipitation** rate (in mm/day) for ERA-Interim (left) and HiGEM (right). The unfilled contours show maximum **vertical velocity** at 700hPa. Contours are 60 and 70 hPa/hour in both plots. The line labelled AB indicates the location of the cross-section shown in Figure 4. Plot radii are 20°.

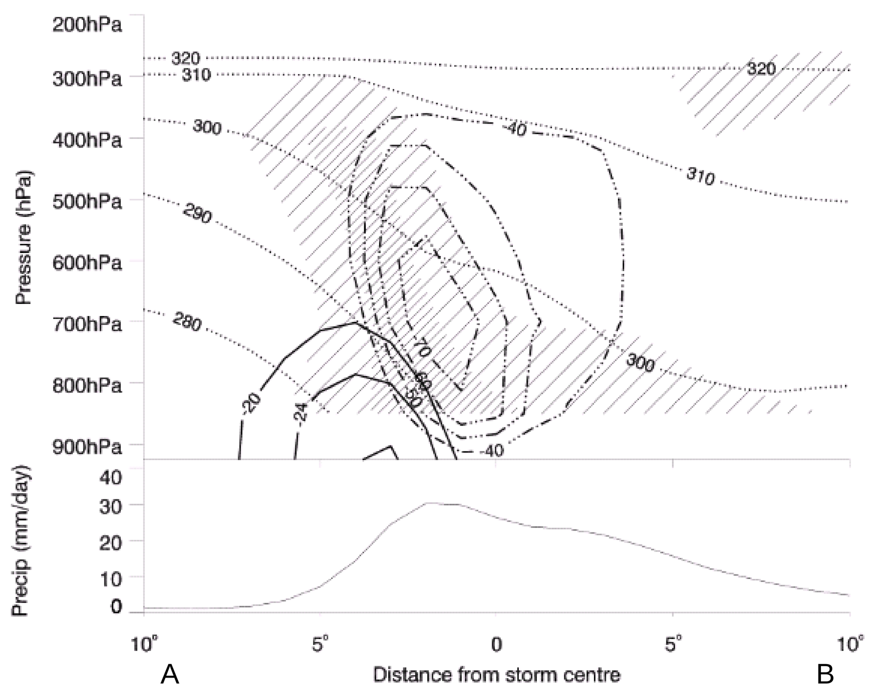
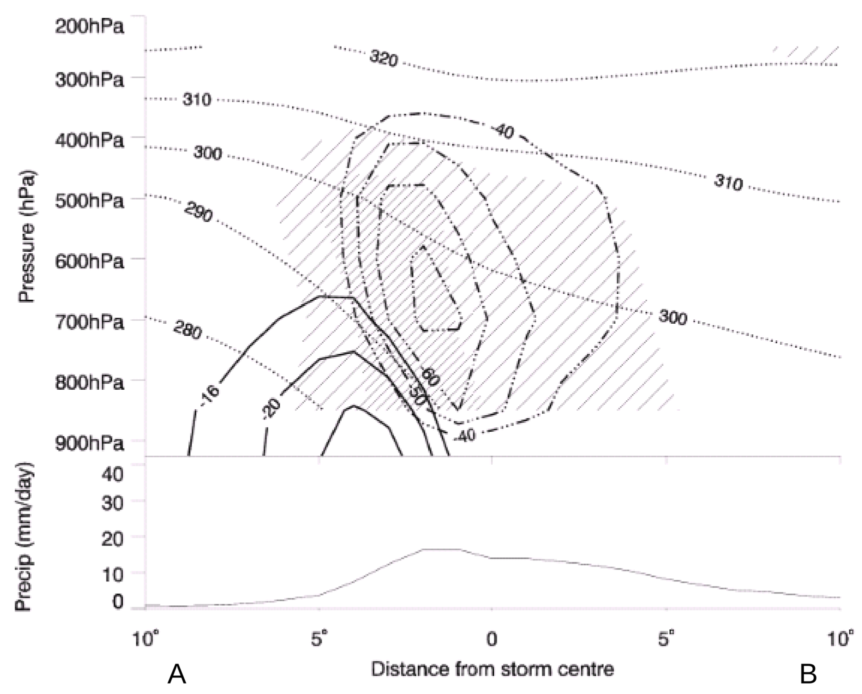


Figure 4: Cross-sections of ERA-Interim (left) and HiGEM (right). The plots are cross-sections along the AB line in Figure 3, where the warm conveyor belt is located. Contours are maximum system relative **u-component** of the wind (in ms^{-1}, solid lines), $\boldsymbol{\theta_e}$ (K, dotted lines, not shown below 850hPa), maximum **vertical velocity** (hPa/hour, negative as ascent). The tight hatching indicates **relative humidity** greater than 90%, the loose hatching greater than 75% (relative humidity not shown below 850hPa). The lower plot is **precipitation** rate (mm/hour) along the AB line.



(b) Cross-section through warm conveyor belt

- Cross-sections are taken through a transect (AB) near the location of maximum vertical velocity and precipitation (Fig. 3 and 4).
- The **precipitation** associated with the warm conveyor belt in HiGEM peaks where the point of maximum vertical velocity and isentropic uplift occur.
- The comparable precipitation maxima in ERA-Interim also peaks at this location, but is significantly more intense. The spatial structure of the precipitation fields is comparable, though the absolute amount of precipitation differs.
- The **relative humidity** fields indicate the warm conveyor belt has greater vertical extent in HiGEM compared to ERA-Interim away from the zone of maximum ascent (0-5° from storm centre, towards B).
- The $\boldsymbol{\theta_e}$ contours are similar in HiGEM and ERA-Interim where the warm conveyor belt ascends over the cold conveyor belt. Upstream of this point, HiGEM has a more stable structure, with a more gradual ascent trajectory than ERA-Interim, particularly at lower levels, indicating greater vertical stability in this region in HiGEM.
- The zone of maximum **vertical velocity** corresponds to the leading edge of the 90% relative humidity field in both HiGEM and ERA-Interim. Vertical velocity maxima at this point are comparable in the two datasets. This point coincides with the precipitation maxima in both datasets.
- The precipitation in ERA-Interim is more intense along the warm conveyor belt. However, the steady increase in precipitation up to the point of maximum ascent is comparable in the two datasets. Given the differing vertical storm structure at this point, this is intriguing and is the subject of ongoing investigation.

4. Future work

- Further investigation of the causes of differences between ERA-Interim and HiGEM in the precipitation and relative humidity fields around the warm conveyor belt region, including the parameterisation schemes used in the models.
- Conduct an equivalent case study for the Pacific and compare cyclone composites in the two basins, investigating whether the background climate impacts on cyclone structure.
- Incorporate remote sensing data to provide observed fields which the model and reanalysis fields can be compared to (Fig. 5). Model and reanalysis output, where appropriate, will be compared to remote sensing data using an offline simulator to provide comparable fields for analysis.
- Investigate cyclone structure at other points in cyclone lifecycle.
- Produce composites relative to the position of the cold front, rather than cyclone centre, to enhance signal strength and provide more robust data on the warm conveyor belt.

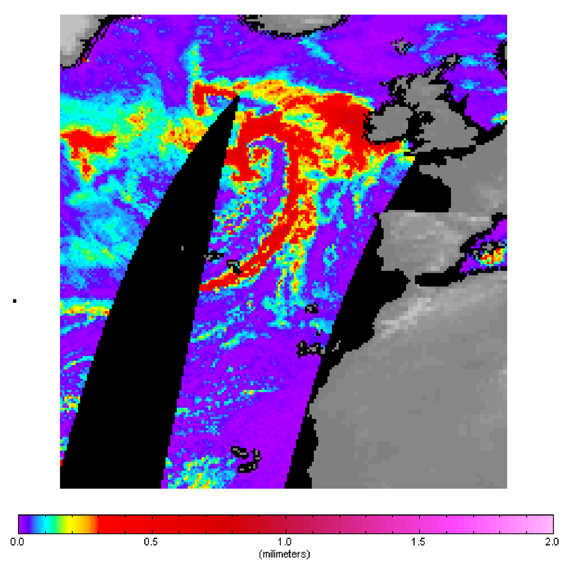


Figure 5: Cloud liquid water path for 16th January 2006 UTC am passes. Image courtesy of Remote Sensing Systems (http://www.ssmi.com).

5. Summary

- Extratropical cyclones in the Atlantic produced by ERA-Interim and HiGEM have comparable structural features, but the precipitation fields differ around the regions of maximum precipitation intensity. This region is associated with the warm conveyor belt and strong vertical ascent. Maximum intensity precipitation is greater in ERA-Interim than HiGEM.
- The warm conveyor belt is deeper and the region of most intense vertical ascent is more narrowly focussed in HiGEM than ERA-Interim.
- Remote sensing data will be incorporated into the study to verify the reanalysis and model output with observations.
- Further work will analyse the warm conveyor belt and the key variables associated with latent heat release in greater detail to establish the causes of the differences between HiGEM and ERA-Interim and how their outputs compare to observed data.

References

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