A Dipole of Tropical Cyclone Outgoing Long Wave Radiation

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NERC SCIENCE OF THE ENVIRONMENT

Background and Motivation

- Satellite imagery has been used as means to understand tropical cyclone (TC) dynamics since their inception in the 1960s. Their use has increased with increasing computational resources, imaging capabilities and resolution, enabling us to constrain different dynamic TC processes operating through a range of heights and distances in the atmosphere.
- The primary focus of research into TC satellite imagery is restricted to the inner TC circulation (r<600km). To date there has been very little research analysing TC satellite imagery out to large radii (500< r < 2000 km) where the cyclone interacts with its environment.
- In this study we investigate and explain the common features associated with TCs in longwave infra-red imagery and ERA-5 reanalysis data. We demonstrate how identifying these features can improve the ECMWF ensemble forecast (EPS) in a perfect model environment.

Conclusions

- There is a clear OLR dipole associated with tropical cyclones where low OLR fluxes are found in the inner TC circulation and a region of high OLR is found north west of the TC center.
- Strong links can be made between the high OLR region and low level divergence and upper level convergence. These convergence signals induce subsidence throughout the troposphere in the region of high OLR, implying that there is an asymmetry to the secondary circulation.
- The position of these divergence signals is determined by the environmental flow and its interaction with the vortex at large distances.
- The OLR fields whilst capturing this dipole signal can improve TC track forecasts through the use of a sub-ensemble.

Methods and Dataset

- The observed dataset constitutes 191 TC observations imaged with the Goes15 and Himawari8 satellites at central wavelengths of 10.7 and 11.4 µm respectively. Each image was centered on the TC position in the international best track archive and encompass a radius from the TC center of 2000km
- All images were taken at the TC lifetime maximum intensity and TCs achieved a range of intensities from category 1 – 5.
- The ERA-5 data for each of the observed cyclones was analysed at the time the image was taken, providing a complete dataset of the TC dynamics for 27 layers in the troposphere at 0.25° resolution.
- The full ECMWF EPS was downloaded for 28 cyclones, from all basins, across their entire lifespan where each TC achieved category 4 intensity.
- This ensemble forecast is composed of 50 members, produced every 12 hours and operates at 15km resolution. Whilst the EPS operates at 240s temporal resolution, data fields are available at 6hr increments.
- Our work resides wholly within the model environment under the principal of [1]. This enables us to take any arbitrary EPS and extract 1 ensemble member as a target TC where the arithmetic mean across the remaining 49 members constitute the baseline ensemble forecast for that target. A smaller sub-ensemble from this baseline ensemble constitutes our improved forecast of the target [2].
- We select sub-ensembles using a k-nearest neighbour algorithm (k-nn) applied to 3600x3600km OLR fields produced by the EPS, 6 hrs after model initiation. OLR fields are centered on the TC minimum surface pressure.

Results - Observations

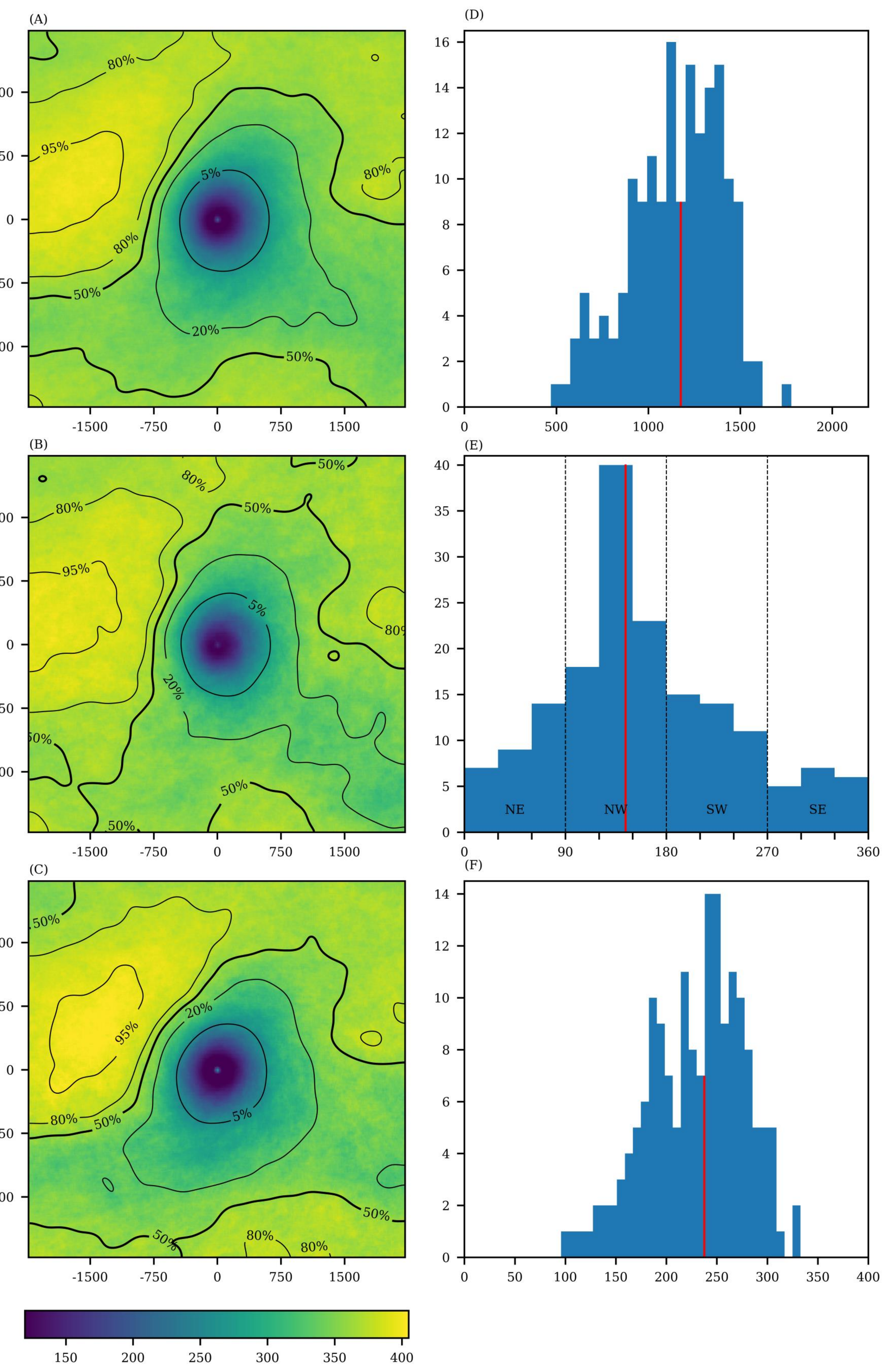

Figure 1 Composite OLR fields across the whole dataset (A), for category 1-3 TCs (B), for category 4-5 TCs (C). Histograms of the location of the high OLR mass center, where (D) shows the radius (km) and (E) shows the angle measured from due east to the TC center. The magnitude of the OLR dipole is plotted in (F).

- Taking the mean behaviour across the whole dataset (Figure 1A) demonstrates that there is a large dipole associated with TCs in OLR fields.
- High OLR is positioned north west of the TC and low OLR within the TC.
- The orientation of this dipole is independent of the TC intensity
- Figure 1F shows the magnitude of the OLR dipole (Wm^{-2}) which is also independent of the cyclone intensity.
- No association has been found between the orientation of the OLR dipole and vertical wind shear

Results – ERA-5

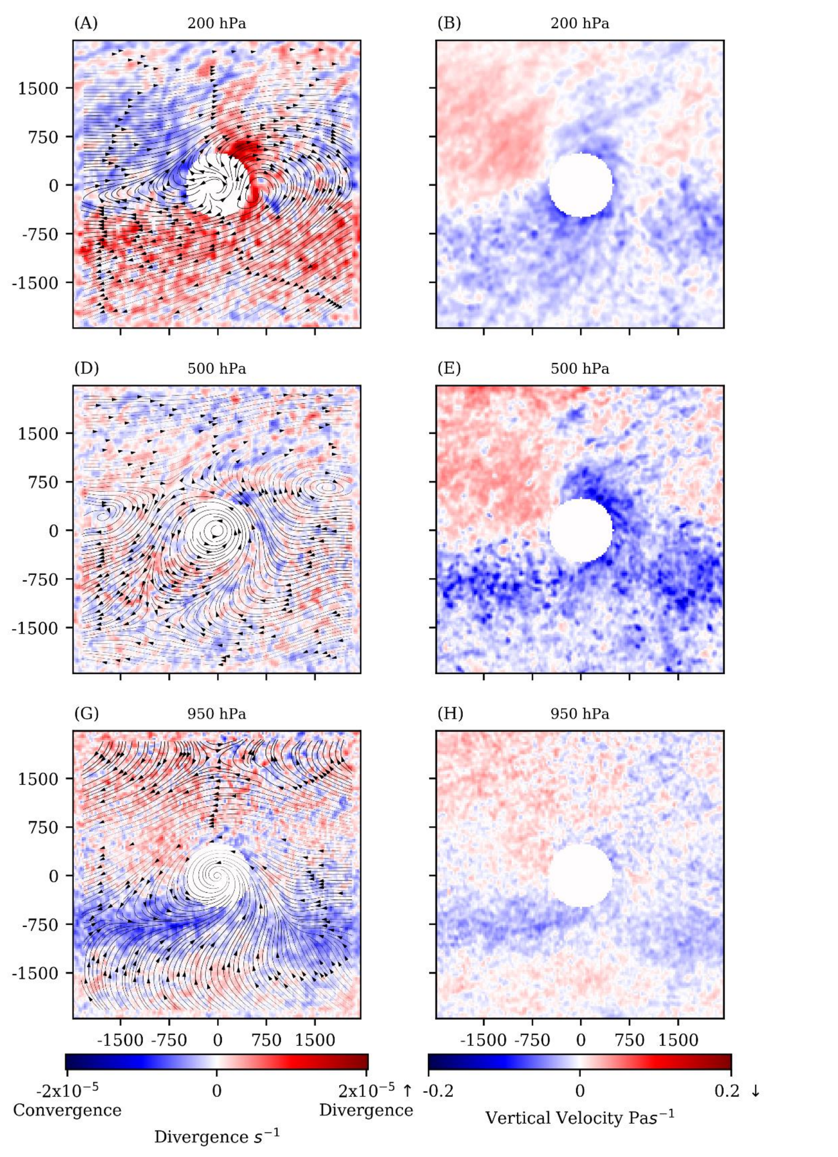

Figure 2 The ERA-5 composite divergence (left column) and vertical velocity (right column) fields at 200, 500 and 950 hPa.

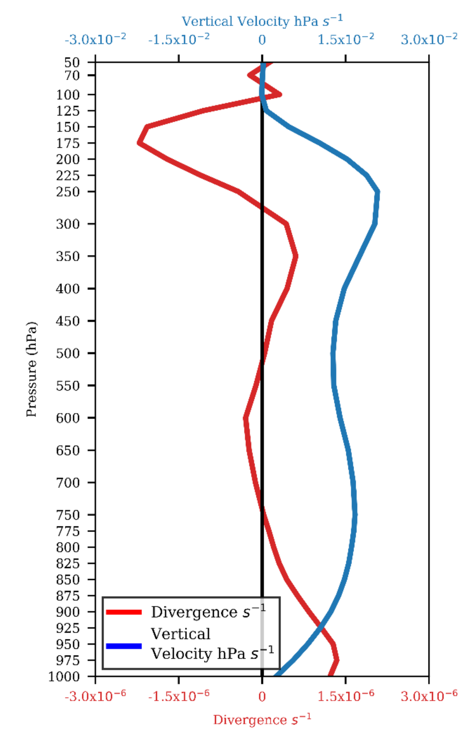

Figure 3 A vertical profile of the divergence and vertical velocity fields in the outer NW quadrant. Averages are taken at each pressure level across all data points in the range 500<r<2000 km.

- The average behaviour for each vertical level indicated the cause of the high OLR region NW of the TC center
- At large distances twinned divergence and convergence (left panels) is visible in the environmental winds upon interaction with the cyclone in the lower and upper layers respectively to the north west of the cyclone.
- This signal facilitates a large region of subsidence throughout the entire column (right panels). The vertical cross section over this NW region demonstrates this signal.
- This is the only significant region of subsidence in the cyclone environment and indicates there is an asymmetry to the secondary circulation.

Results - Ensemble Forecast

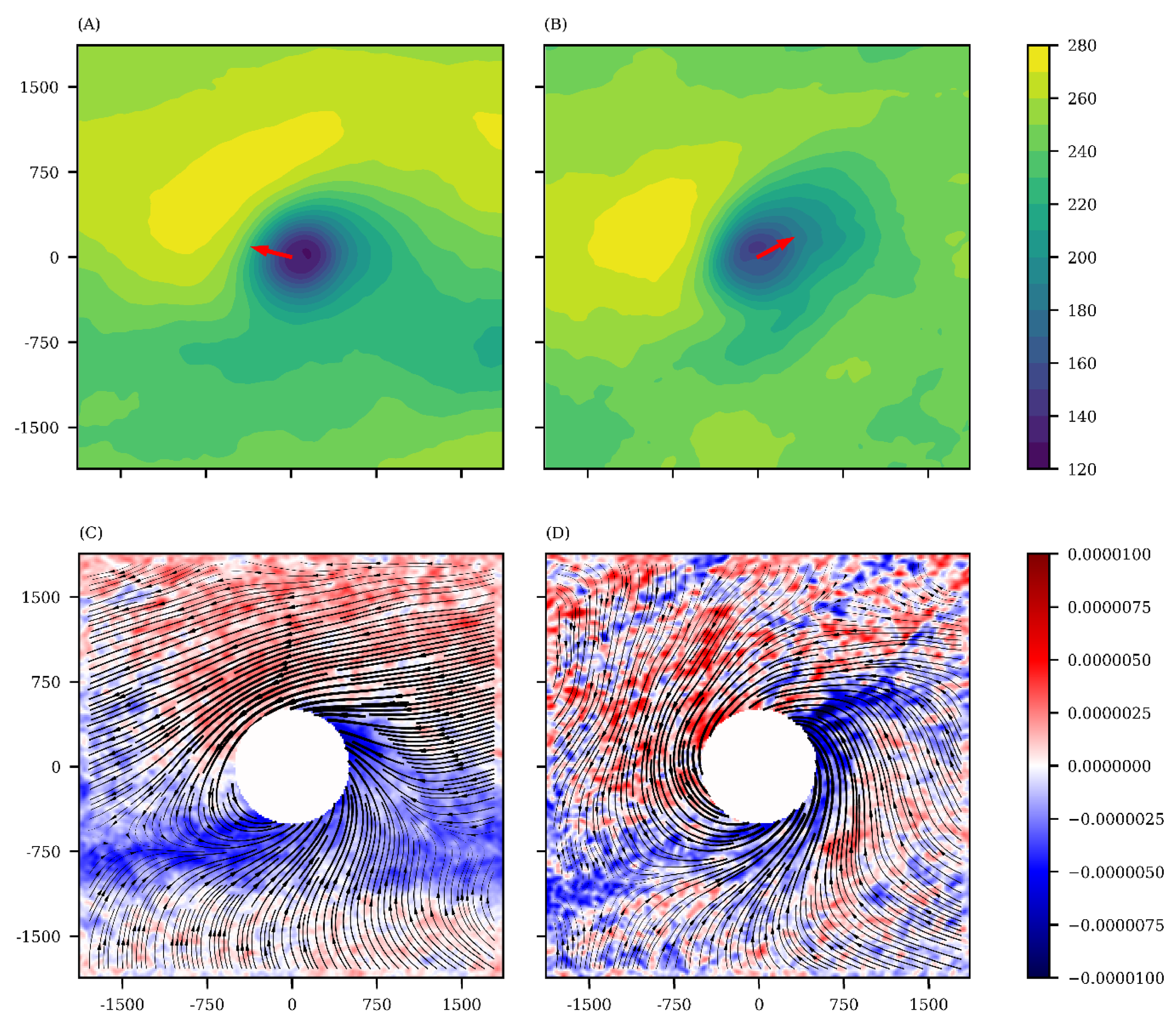

Figure 4 OLR fields (upper) and surface divergence fields overlain by streamlines (lower) for westward (left) and eastward (right) propagating TCs.

- Analysis of the much larger ECMWF EPS dataset reveals some dependency in dipole location between westward (left) and eastward (right) propagating TCs.
- As the cyclone recurves from west to east the environmental wind regime changes.
  - More air is drawn down from the poleward side.
  - This air diverges to the east of the cyclone such that the dipole rotates anticlockwise to an eastward orientation
- Given that the location of the dipole is determined by the vortex – environment interaction we investigate how OLR fields that capture this dipole signal can be used to improve TC track forecasts, through the use of a sub-ensemble with the ECMWF EPS.

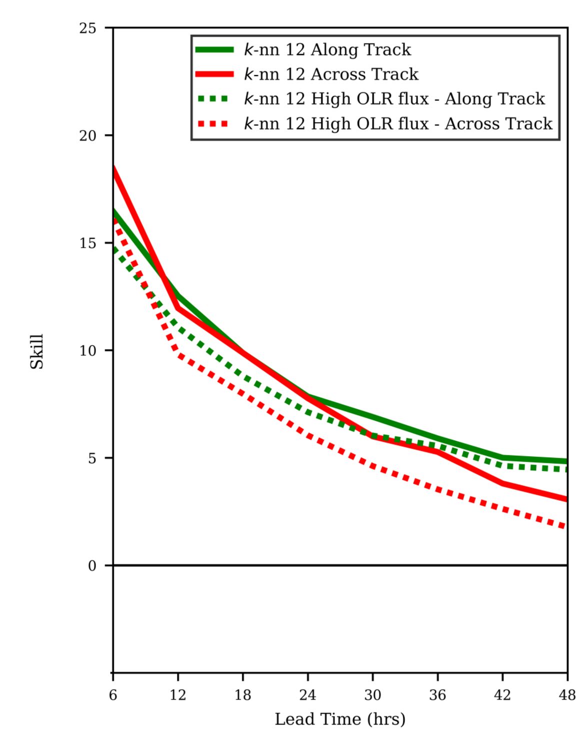

Figure 5 The % reduction in track error when discerning sub ensembles based upon the large scale OLR field (solid lines) and the high OLR region alone (dashed lines)

- Within any published ensemble forecast, selecting a 12 model sub-ensemble, determined by the similarity between target TC OLR field and the OLR fields for each ensemble member produces some improvement in track forecasting.
- This equates to approximately 8% improvement in forecast quality at 24 hours lead time.
- Comparing sub-ensembles which select OLR members exclusively by the high OLR region (dashed) verses the whole 3600x3600km OLR field (solid), yields no significant improvements in track forecasting.
- This improvement is comparable to other sub ensemble selection methods e.g. selecting a sub ensemble by the ensemble members whose TC forecasted position is closest to the target TC position.

References

1. R. Elsberry and L. Carr, "Consensus of Dynamical Tropical Cyclone Track Forecasts—Errors versus Spread", *Monthly Weather Review*, vol. 128, no. 12, pp. 4131-4138, 2000.
2. L. Leslie, R. Abbey and G. Holland, "Tropical cyclone track predictability", Meteorology and Atmospheric Physics, vol. 65, no. 3-4, pp. 223-231, 1998.