Investigating Tropical Cyclone Landfall

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Introduction:

Our projects focus on different phenomena relating to Tropical Cyclone (TC) landfalls. Project 1 (left) aims to analyse historical data, and past and future climate models to identify if the behaviour of TCs has changed and will continue to change. Project 2 (right) aims to investigates the dependency of the vertical wind profiles of TCs near landfall on the Rossby number by analysing the historical profiles from storms in the South China sea.

Method:

TC Selection Criteria

1. Windspeed at landfall > 33m/s
2. TC must spend at least 18 hours over land
3. Windspeed over land must decay by at least 10% over the whole period
4. No missing data points (ensures model doesn't break down)

Hypothesis to Test

Global warming heats up oceans and increases Sea Surface Temperature → Oceans, which act as heat sources, provide more energy and moisture to TCs → This powers TCs to higher intensities and facilitates slower decays over land

Algorithm

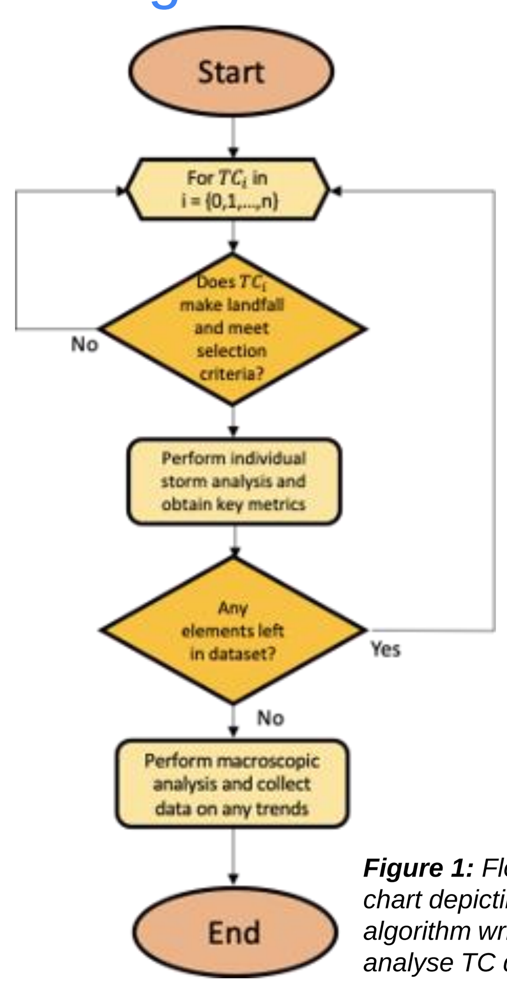
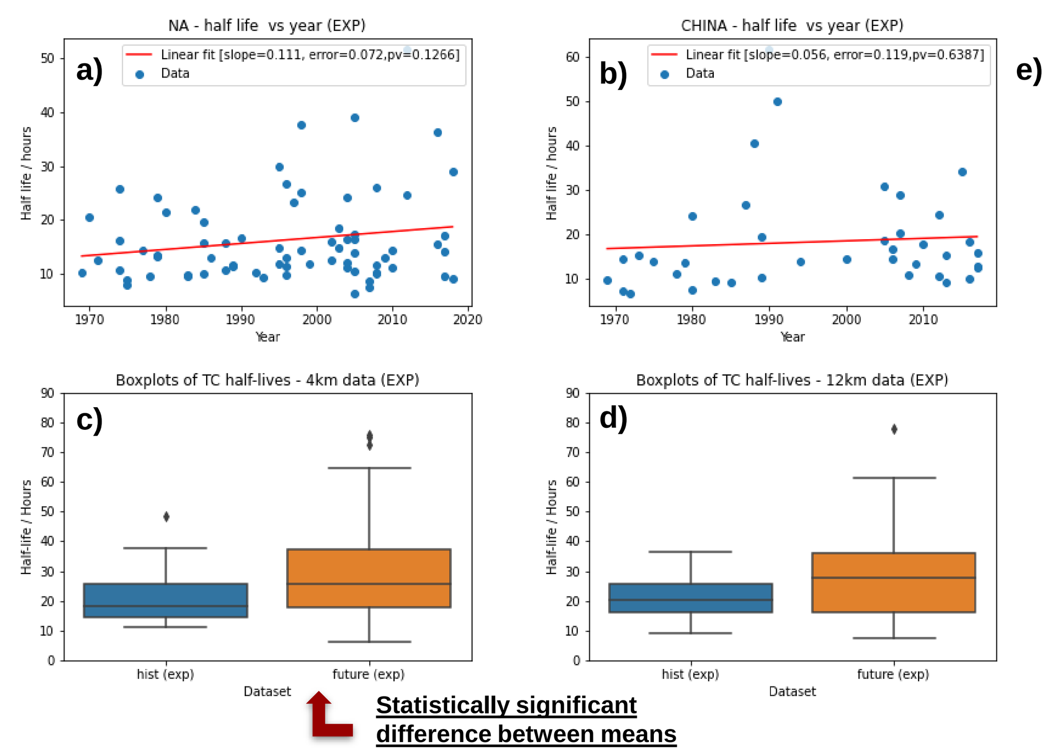


Figure 1: *Flow chart depicting the algorithm written to analyse TC data*

Have TCs increased in duration over land?

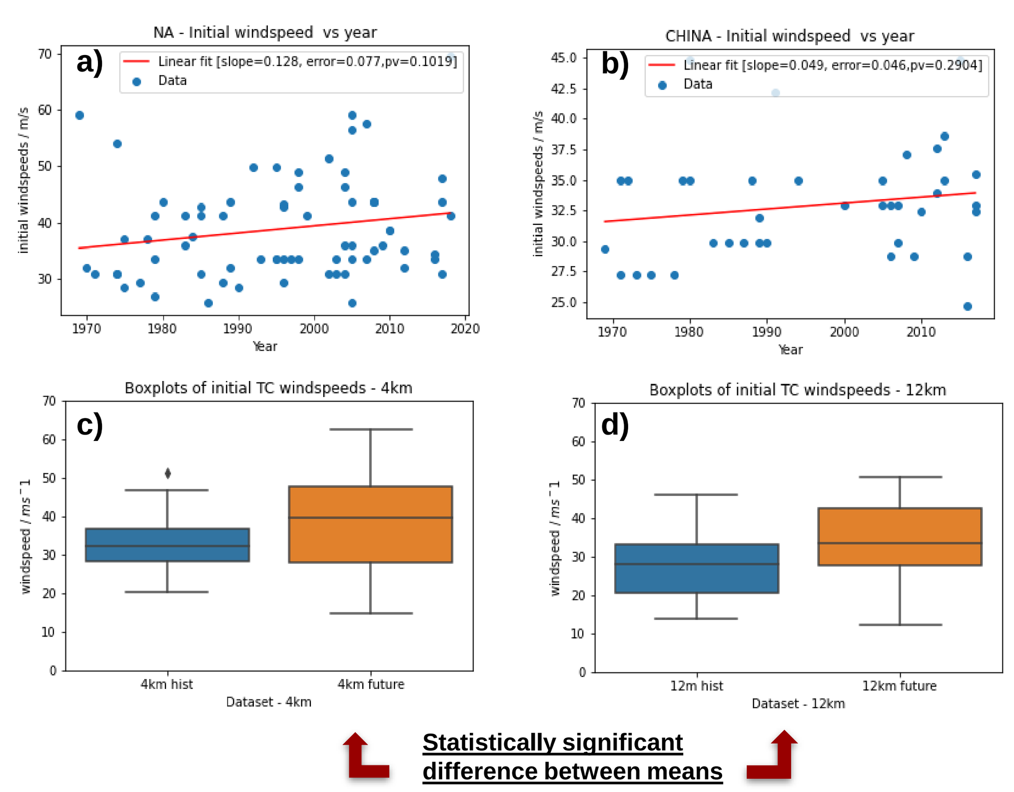


e)

Half-life datasets	Statistical test	P-value
a) NA historical data	Linear correlation hypothesis test	0.1266
b) China historical data	Linear correlation hypothesis test	0.6387
c) Climate model 4km	Welch's T-test	**0.014**
d) Climate model 12km	Welch's T-test	0.070

***Figure 2**: Key statistical results in determining if half-lives are correlated with time for all three datasets, where **a**,**b** depict NA and mainland China historical data respectively and **c**,**d** are for the climate model 4km and 12km data respectively. In **a**,**b** the high p-values imply that there is no statistically significant linear correlation between half-life and time for these datasets (the inverse model results reproduce the same conclusions). **c**,**d** depict boxplots of TC exponential model half-lives for historical (blue) and future (orange) data from the climate model at 4km and 12km , Welch's T-tests were performed on left and right boxplots yielding the results in the table which show that, at the higher resolution of 4km, there is sufficient evidence, at a 5% significance level, to say that the half life means of the historical and future datasets are statistically different.*

Have TCs increased in intensity?



e)

ws0 datasets	Statistical test	P-value
a) NA historical data	Linear correlation hypothesis test	0.1019
b) China historical data	Linear correlation hypothesis test	0.2904
c) Climate model 4km	Welch's T-test	**0.0074**
d) Climate model 12km	Welch's T-test	**7.30e-5**

***Figure 3**: Key statistical results in determining if initial windspeeds at landfall (ws0) are correlated with time for all three datasets, where **a**,**b** depict NA and mainland China historical data respectively and **c**,**d** are for the climate model 4km and 12km data respectively. In **a**,**b** the high p-values imply that there is no statistically significant linear correlation between ws0 and time for these datasets **c**,**d** depict boxplots of TC exponential model half-lives for historical (blue) and future (orange) data from the climate model at 4km and 12km , Welch's T-tests were performed on the historical vs future datasets for both yielding the results in the table **e** which show, at a 5% significance level, there is sufficient evidence to reject the null hypothesis for both sets of 4km and 12km data that the averages of historical and future dataset are identical.*

References:

[1] Kaplan J, DeMaria M. 'A Simple empirical model for predicting the decay of tropical cyclone winds after landfall'. (1995) *J. Appl. Meteor.*,**34,** 2499–2512
[2] Montgomery M, Snell H, Yang Z. 'Axisymmetric Spindown Dynamics of Hurricane-like vortices'. Journal of Atmospheric Sciences. 2001; 58.421-435. DOI: 10.1175/1520-0469
[3] Knapp, K. R., M. C. Kruk, D. H. Levinson, H. J. Diamond, and C. J. Neumann, 'The International Best Track Archive for Climate Stewardship (IBTrACS): Unifying tropical cyclone best track data'. (2010) *Bulletin of the American Meteorological Society*, 91, 363-376, DOI:10.1175/2009BAMS2755.1
[4] B. Cushman-Roisin and J. Beckers, "The Ekman Layer", International Geophysics, pp. 239-270, 2011. Available: 10.1016/b978-0-12-088759-0.00008-0.

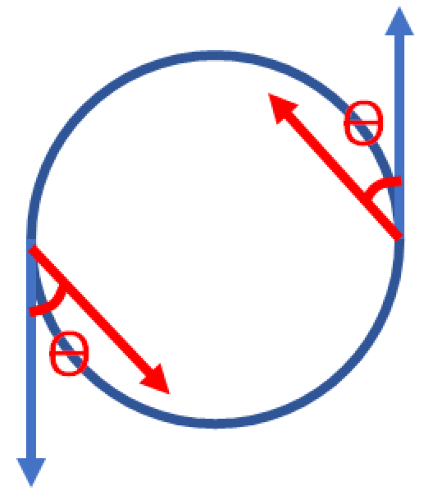


***Figure 4**: Diagram of inflow. Blue is the **geostrophic flow**. Red is the observed flow. ϴ is the deflection.*

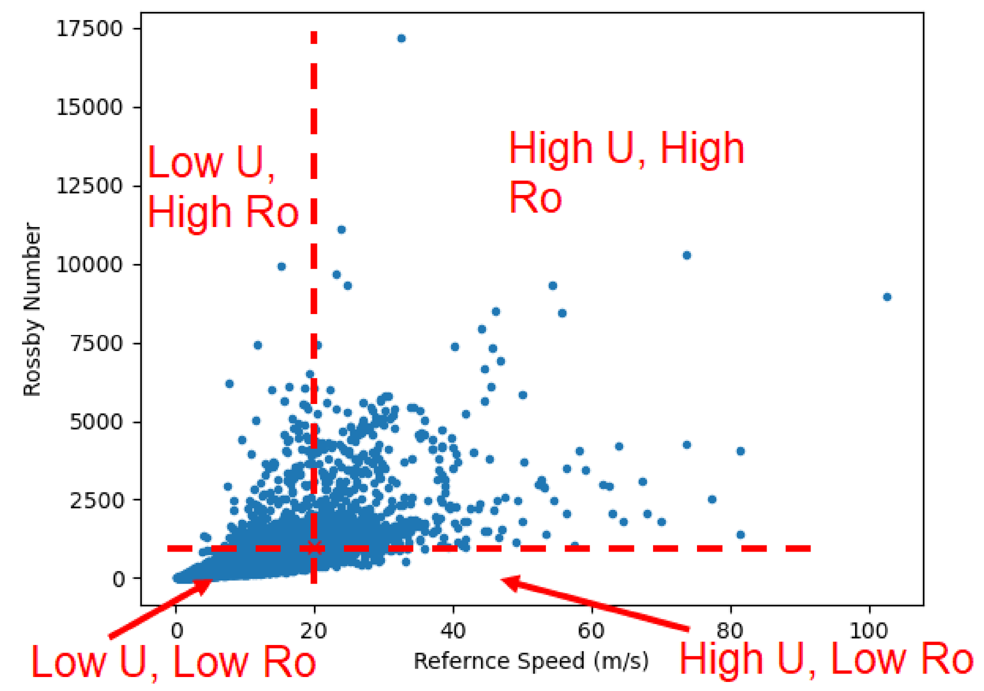


***Figure 5**: Scatter Plot of Ro against U. Red dotted lines and labels indicate the quadrants.*

Theory:

The motion in a TC is governed by **Primary** and **Secondary** circulation.

Surface friction acting on the boundary layer reduces the Coriolis force, causing **ageostrophic inflow.**

For a given time and position during a storm, the **Rossby number** for the vertical profile can be calculated by the following formula:

$$\mathrm{Ro} = \frac{U}{Lf}$$

where *U* and *L* are respectively the reference speed and distance to TC centre, and *f* is the Coriolis parameter.

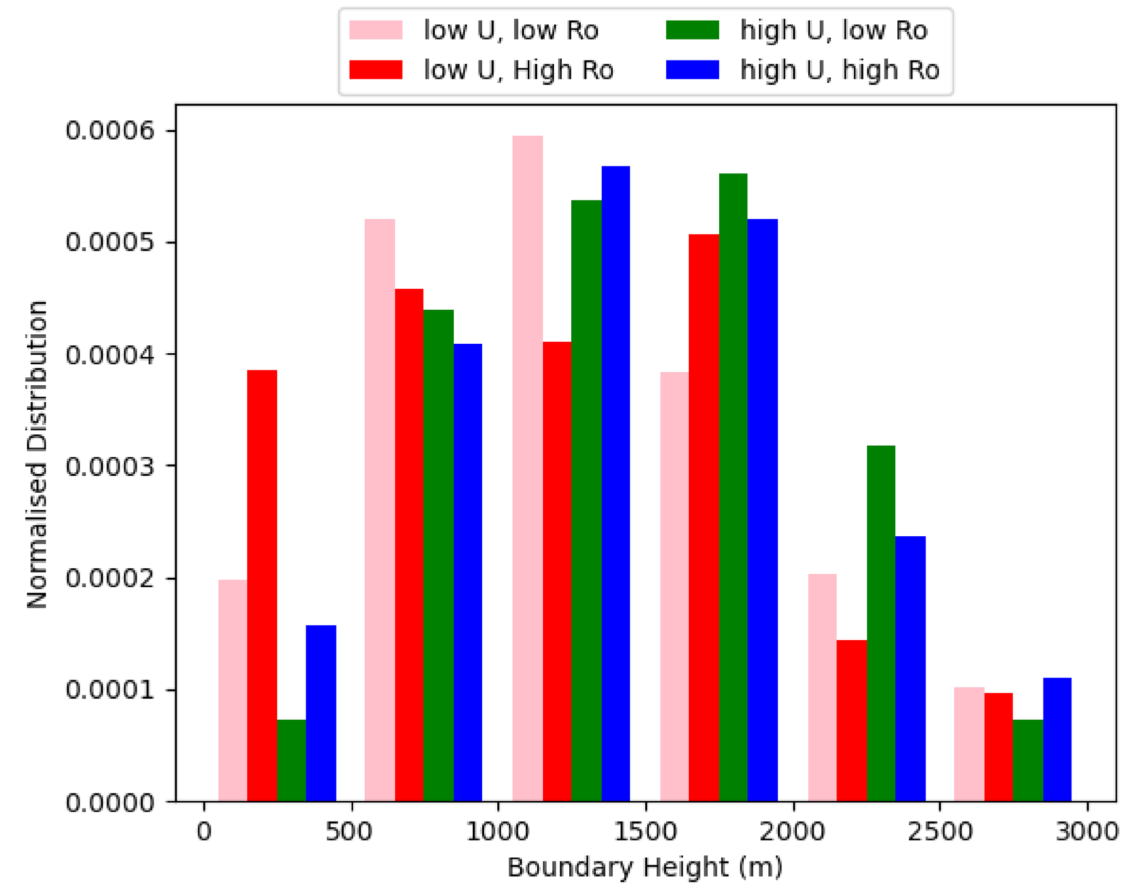


***Figure 6**: Distribution of Boundary Height for each quadrant.*

Method and Data:

The wind profile and track data are provided by **Hong Kong Observatory** and **IBTrACS project** [3].

Deflection (see Fig. 4) and **normalised wind speed** is calculated by referencing data from a particular (reference) height (1500m above surface). This is done to allow comparison and averaging between profiles.

Using the track data, for each profile, the Rossby number is calculated.

For each profile, the **boundary layer height** can be estimated by a **linear interception method** around the reference height.

Quadrant Group	Ground Deflection (degrees)	Boundary Layer Height (m)
Low U, Low Ro	30.47 ± 0.66	1159.39 ± 2.90
Low U, High Ro	29.10 ± 2.20	1051.89 ± 16.14
High U, low Ro	34.00 ± 3.50	1375.08 ± 4.17
High U, High Ro	33.69 ± 1.36	1372.66 ± 32.24

Figure 7: *Table of the Ground Deflection and Boundary Layer height for the quadrant groups.*

Analysis:

Fig. 5 shows an unclear trend between *Ro* and *U.*

Profiles are grouped in quadrants of high and low *Ro* and *U* (see Fig. 6).

The **deflection at ground** for each quadrant group remain within error of each other (see Fig. 7), but all show a much smaller value than that suggested by **Ekman theory** (45º) [4].

The highest and lowest average values of boundary layer height are seen for groups of high and low *U* respectively (see Fig. 7), suggesting a more significant dependency on *U* instead of *Ro*, and therefore *L*.

Conclusion:

Project 1: The results presented above paint an interesting and concerning picture for the state of the world we live in. While only a handful of statistical tests produce conclusive evidence of increasing intensity, it is clear from all the charts and humanity's own first-hand experience that TCs are getting more severe across all corners of the globe, and without large-scale intervention, this trend is only going to accelerate.

Project 2: The investigation shows no dependency of the deflection at ground on *Ro* or *U* whilst the boundary layer height only depends on *U*. Further analysis needs to be conducted with a **larger sample size** of profiles and with profiles from other regions.