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Statistical Analysis of Tropical Cyclone Genesis

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1 October 2016

Contents

Why do we care about tropical cyclone genesis?

- Understanding the conditions that form a tropical cyclone.
- Whether the frequency of tropical cyclones change?
- Will the spatial distribution of genesis change?

Who is interested?
Insurance and reinsurance companies, government authorities, disaster relief agencies.

Data

Best Track archive for the Western North Pacific (WNP) provided by the Joint Typhoon Warning Center (JTWC).

- Storm tracks that reach a maximum sustained wind speed of at least 25kts.
- 1945 to present and is updated annually.
- 6-h intervals the time, location and wind speed of the cyclone.

ERA-Interim global atmospheric reanalysis product produced by the European Centre for Medium-Range Weather Forecasts (ECMWF).

- It provides gridded data at various spatial and temporal resolutions of a large variety of surface parameters, upper-air parameters and other atmospheric information.

What is tropical cyclone genesis?

There are many ways to define genesis of a tropical cyclone:

- the first data point that is recorded on the storm track,
- time and location on the cyclone track where the maximum sustained wind speed reaches a threshold for the first time,
- first data point that is recorded on the storm track restricted to the storms that develop into a tropical cyclone.

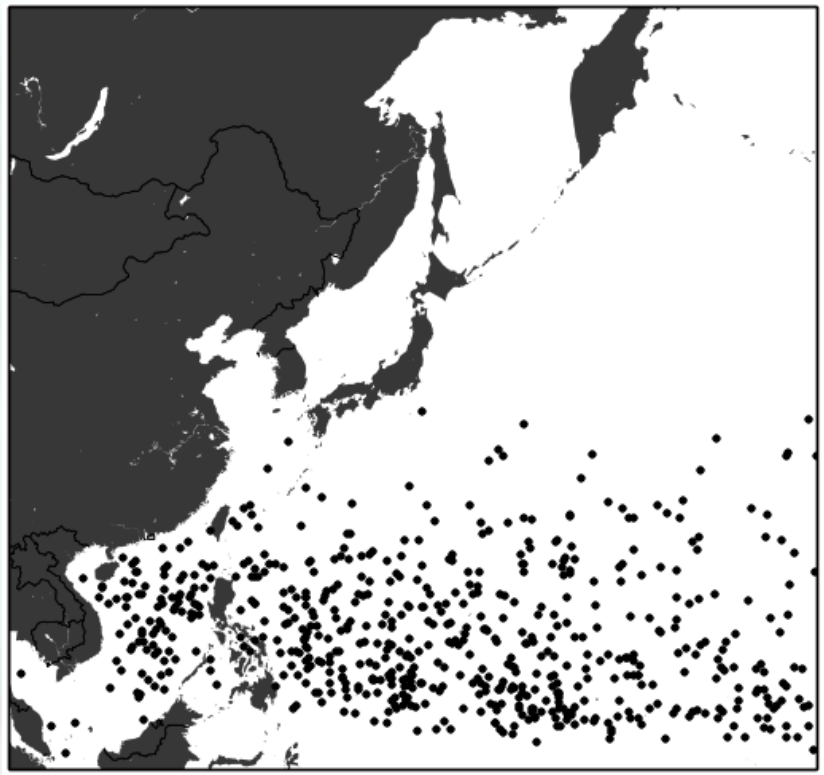


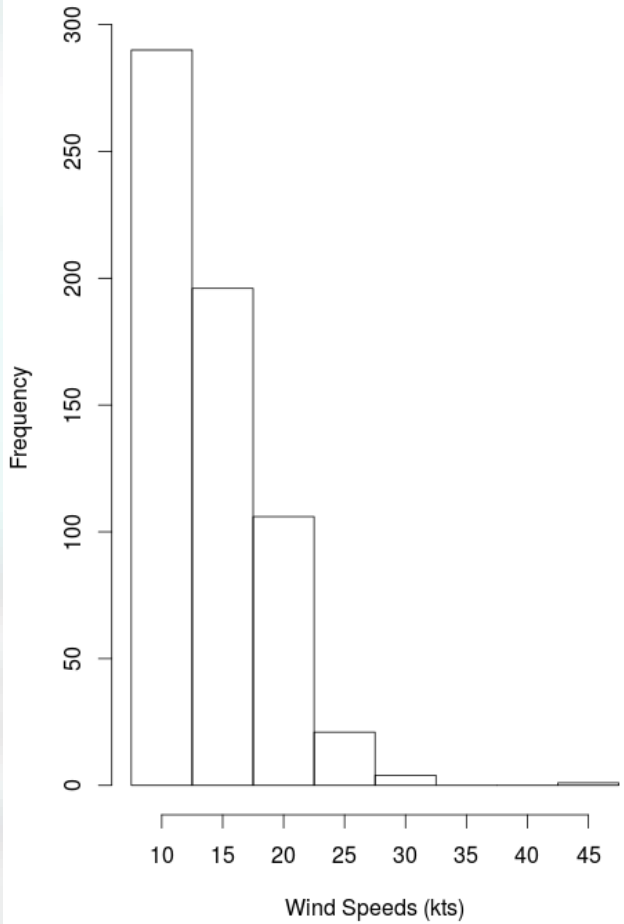
Figure : WNP first point on the track 1991 - 2010.

Problems with definition of first point on the track.

Genesis points can be at different wind speeds (stage of development).

- Conditioned on various different atmospheric conditions since the tropical depression/storm/cyclone is at a different point of development.
- We also condition on future development (database inclusion).

Wind speeds first point on the track



Spatial distribution

- Why is it important?
- Do current models capture the spatial distribution?
- Quantitative measure?
- Effect of changing the definition of genesis.
    - On the modelling of genesis since the emphasis of the atmospheric and surface parameters might change or be excluded completely and other parameters may become significant when we change the definition genesis.

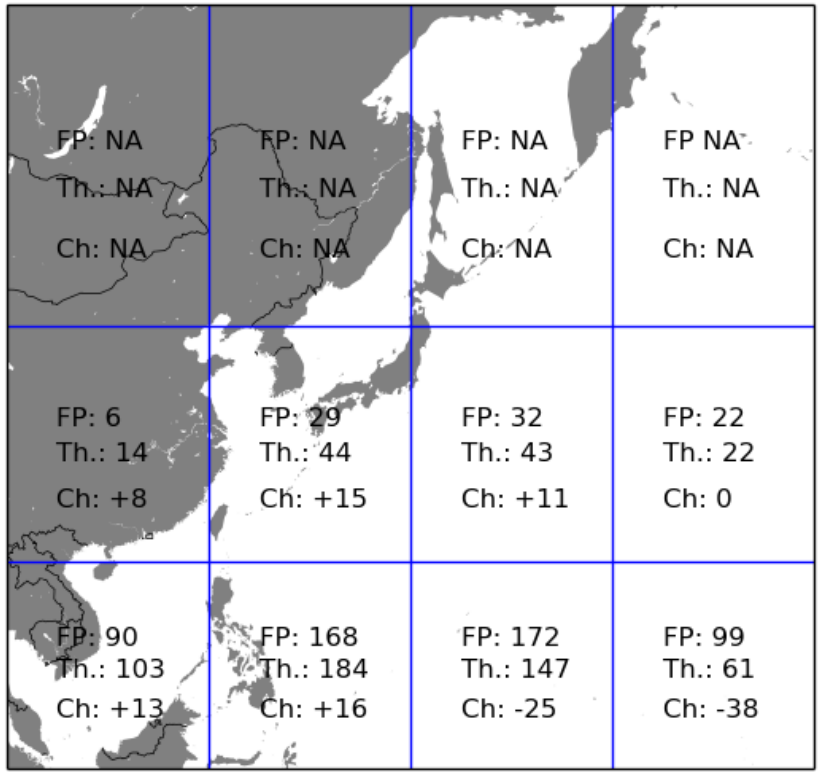


Figure : Shift of first point on track to 25kts threshold, WNP 1991 - 2010.

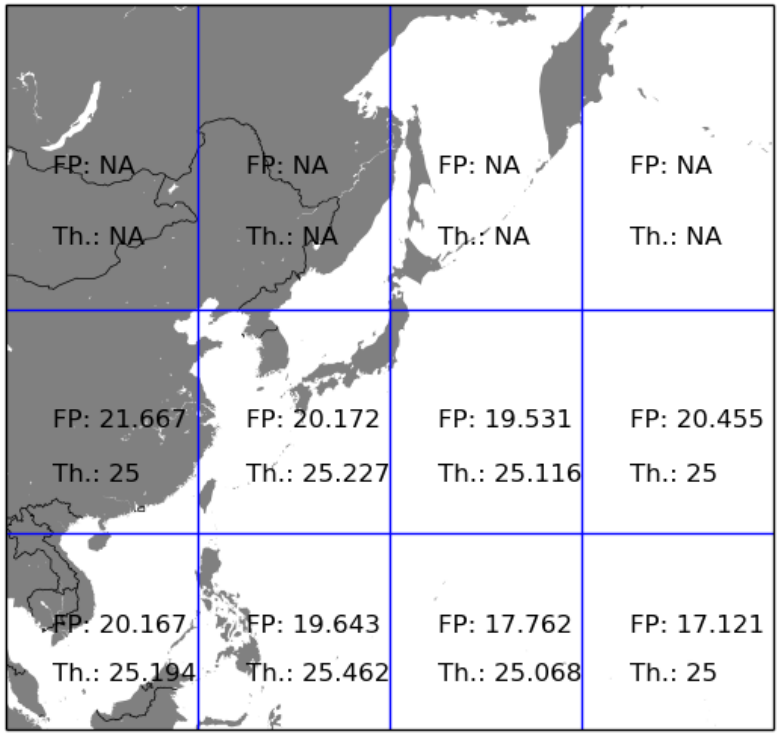


Figure : Mean wind speeds at first point on track (FP) and at 25kts threshold (Th.).

FP: St.Dev lower left: 0.353 St.Dev lower right: 0.3671

What covariates should we use?

Covariates that can be influenced by the presence of a tropical cyclone.

There are "safe" covariates:

- Land
- Latitude / Coriolis force

Other covariates:

- Sea Surface Temperature (SST)
- Relative vorticity
- CAPE
- Humidity
- Vertical wind shear
- PI

Influence on covariates - Causality

The SST tends to be lower on the day and location of genesis than at the same location on previous days.

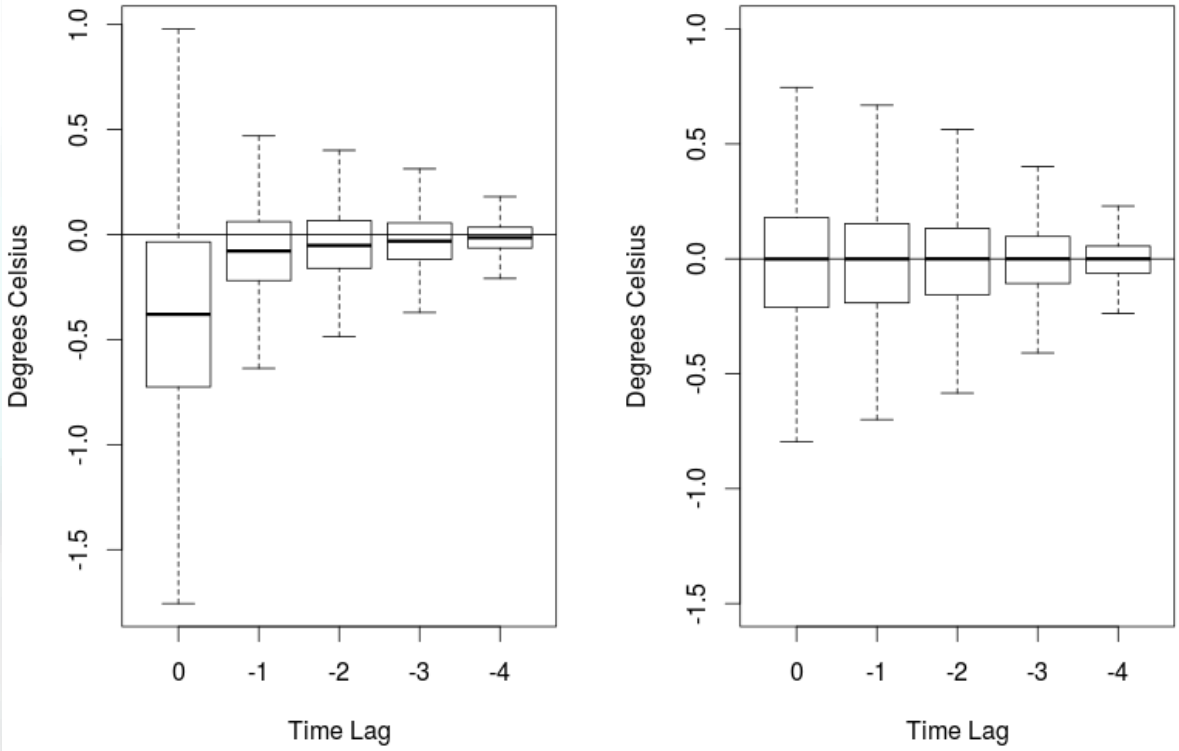


Figure : Left: Tropical cyclone present, Right: no tropical cyclone present.

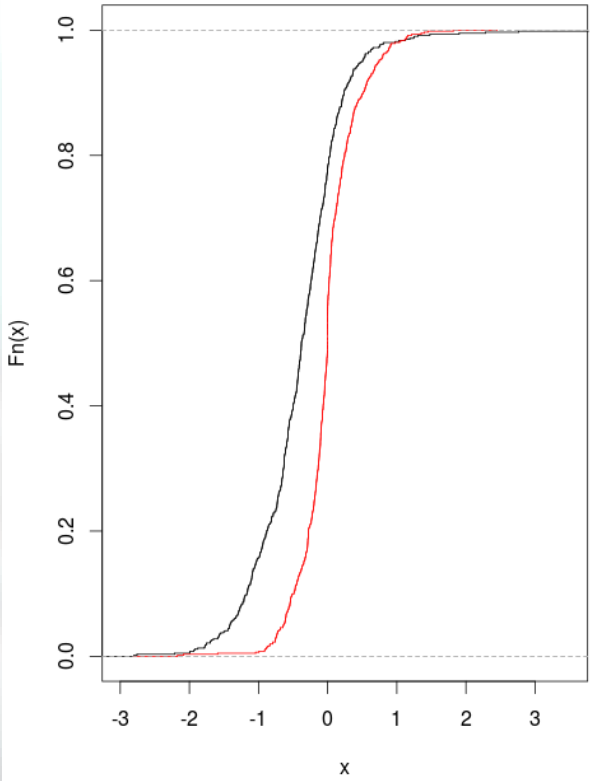
Influence on covariates - Causality

How will we provide some evidence that the tropical cyclone being present causes this drop in SST?

- First to sub-sample our spatial-temporal space $W \subseteq \mathbb{R}^2 \times \mathbb{R}$.
- 1:1 nearest neighbour matching, matches control group observations (i.e. non tropical cyclones) to the cases where we have a tropical cyclone with the smallest distance.
  - By distance we mean which covariates are included in the matching process and combining the included covariates into a distance measure.

Influence on covariates - Causality

- We matched on the following covariates: latitude, vertical wind shear, the percentage of land in a $1^\circ \times 1^\circ$ box around the point of genesis, CAPE, relative vorticity, humidity and month.



Influence on covariates - Causality

Let μ^{TC} and μ^{NTC} be the mean of the temperature changes where we have a tropical cyclone and where we do not respectively. Want to test if the difference between these mean is different from zero.

At a significance level of $\alpha = 0.05$, there is enough evidence to reject the null hypothesis.

A physical reason for this may be that even with starting wind speeds ranging from 10-35kts it is already enough to cause mixing in the ocean which in turn causes up-welling of colder sea water from epipelagic zone to the surface. This results in a cooler SST in the case where the genesis of a tropical cyclone exists.

Possible alternative?

Alternative definition of genesis at the 25kts threshold of the storm tracks.
Benefits:

- significantly reduces the effect of having different starting wind speeds, and hence difference atmospheric and surface conditions,
- not late into the track to maximise data usage,
- it is in line with the criteria in which tracks are added to the JTWC Best Track archive for the WNP.

Models of Genesis

Compare genesis models - any two models may define genesis in a different way.

- Difficulty in comparison is compounded when we consider that different models are developed for different basins and also aim to model different objectives such as the seasonal variation or the inter-annual variation.

Emanuel & Nolan (2004), Camargo et al. (2007)

$$\mathrm{GP} = |10^5 \eta|^{\frac{3}{2}} \left(\frac{\mathcal{H}}{50} \right)^3 \left(\frac{V_{\mathrm{pot}}}{70} \right)^3 (1 + 0.1 V_{\mathrm{shear}})^{-2}$$

where η is the absolute vorticity at 850 hPa (in s^{-1}), $\mathcal{H}$ is the relative humidity at 600 hPa in percent, V_{pot} is the potential intensity (in ms^{-1}), and V_{shear} is the magnitude of the vertical wind shear between 850 hPa and 200 hPa (in ms^{-1}).

Models of Genesis

Bruyère et al. (2012)

$$\mathrm{CGI} = \left(\frac{\mathrm{PI}}{70}\right)^3 [1 + 0.1(V_{\mathrm{shear}} + a)]^{-2}.$$

A constant multiplier has to be included in the index to give it the appropriate magnitude and dimensions.

We are considering a Poisson point process approach. The intensity of the process is defined as follows,

$$\lambda(x, t) = \exp(\mathrm{X}(x, t)\beta), \tag{1}$$

where X denotes the covariates and β the corresponding coefficients. The we fit the model using various sets of covariates and use a goodness-of-fit test to compare the models with observation.

Summary

- Various definitions of genesis.
- Conditioning on different meteorological conditions.
- Covariates have causal problems.
- Models are difficult to compare and do not capture spatial distribution.

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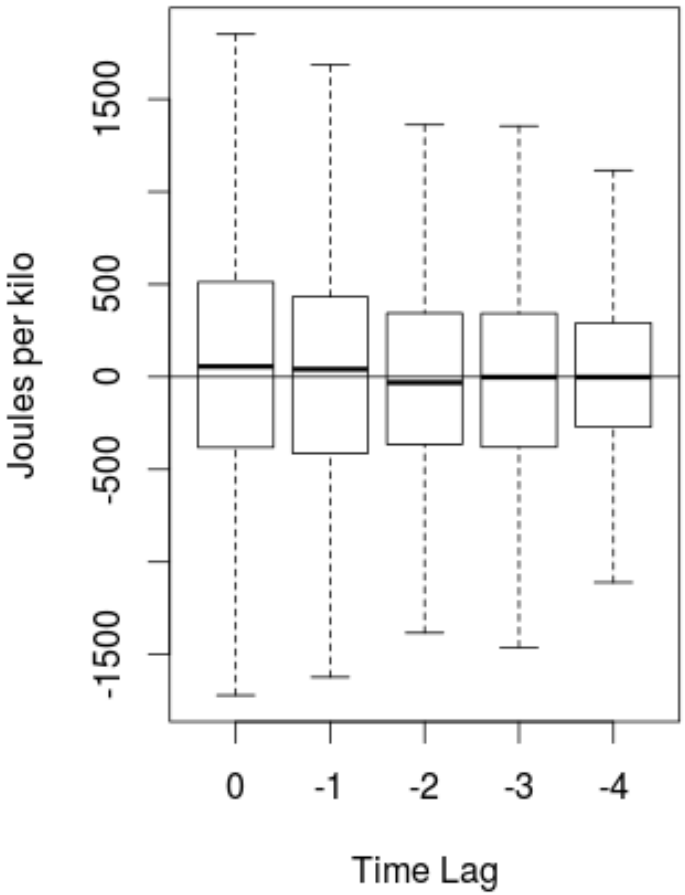
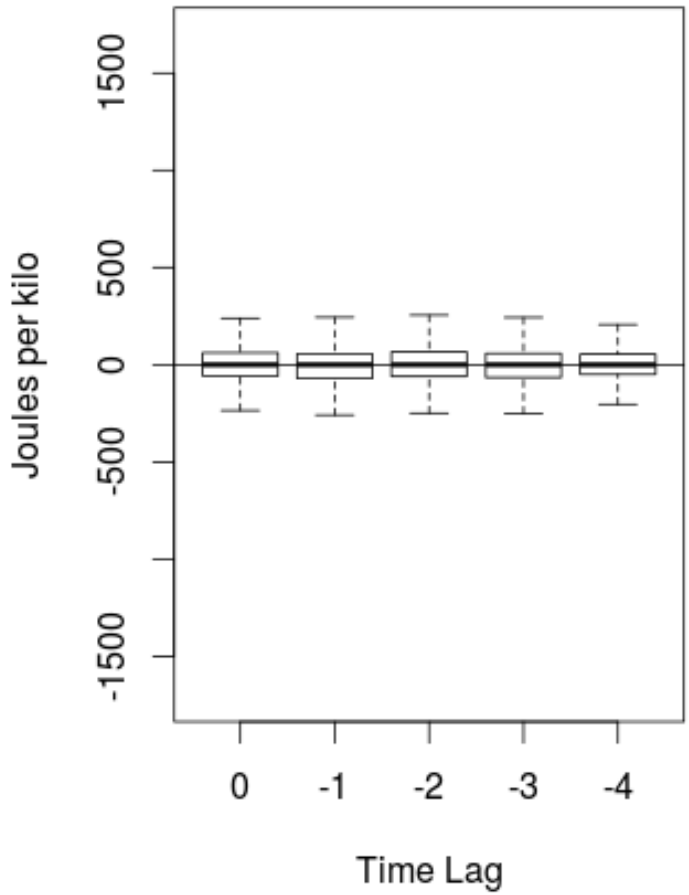
CAPE


Joules per kilo
1500
500
0
-500
-1500
0
-1
-2
-3
-4
Time Lag


Joules per kilo
1500
500
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-2
-3
-4
Time Lag