Tropical Cyclones: Technical Appendix

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Step-by-step algorithm for calculating gridded wind speed data for a specific country that is implemented in R:

Step 0. Input data that we need before running the code

1. Two shape files of the country: one on a country level and one - on the same level as firm data (most often - ADM2)

2. 0.1×0.1 degree grid for the country and its 200km buffer: both vector and raster formats

3. Shape file with hurricanes' eyes over the country and its 200km buffer - subset of IBTrACS point data

4. Shape file with all hurricanes - IBTrACS point data

Step 1. Choosing a reporting agency from IBTrACS

International Best Track Archive for Climate Stewardship, or IBTrACS, is best track data on tropical cyclones from different reporting agencies. Importantly, this is not a reanalysis but a collection of various sources.

The main variables are time and location of the cyclone's eye, Maximum Sustained Wind Speed (MSW), Minimum Central Pressure. Original agency data is most often reported at 6-hours intervals, but interpolated to 3-hours intervals by IBTrACS creators for consistency.

Main variables are reported by several agencies. For example, MSW is reported by all 14 agencies. For some storms, MSW reports overlap. For example, in Vietnam, 70% of 3-hourly interval observations have MSW recorded by more than 1 agency (from 2 to 4).

However, MSW from different agencies are not easily comparable. According to the official Technical Documentation of IBTrACS from 2019, *"Wind speeds of tropical cyclones are reported very differently by many of the international agencies. Knapp et al. (2010) investigate many of these differences. They find that there is no simple global conversion between these* *wind speeds. While a multiplicative factor can describe the numerical differences (Harper et al. (2010)), there are procedural and observational differences between agencies that can change through time, which confounds the simple multiplicative factor. This results in a difficulty in plotting global wind speed values. To be clear, wind speed values between one agency (e.g., JMA) are not comparable to wind speeds from another (e.g., JTWC) due to many issues. Some of these differences are well described but some are unknown, which means there is no simple way to compare values of wind speeds between various agencies.".*

There are many papers that compare wind speed data from different agencies and show that different sources may have different trends and different spatial patterns. Knapp et al. (2010) plot global maps of interagency differences in MSW means after converting to one averaging period, and argue that those differences are significant. Moreover, Schreck III et al. (2014) compare winds in IBTrACS-WMO and NHC+JTWC globally and show that there are large discrepancies ("NHC+JTWC has more 96-kt storms than IBTrACS-WMO in the west Pacific but fewer in the Australian region"). There are also papers that study specific regions, and not global data, but still find discrepancies. For example, Tran et al. (2022) show that long term trends in landfalling tropical cyclones over Southeast Asia are slightly upward in JTWC but decreasing in the CMA and TOKYO datasets (1970-2019).

I think Emanuel et al. (2018) is a relatively recent source that shows there is still a need for reanalysis for tropical cyclones data. This is a summary from a 2017 conference where researchers such as Knapp, Schreck (their papers cited above) conclude that they should move towards a homogeneous global-level source of tropical cyclones data (such as HURDAT2 for North Atlantic region).

It seems that researchers that study tropical cyclones generally follow this rule and do not combine data from different agencies. I searched specifically for Vietnam papers since this is the country we use in our analysis and it is often affected by storms. I searched for any papers that study tropical cyclones, not specifically ones that refer directly to IBTrACS. Takagi et al. (2014) use data from JTWC, Nguyen et al. (2019) and Nguyen et al. (2021) - from IBTrACS-JMA. *(can add other countries later)*

Since there is no straightforward solution, we will use 3 IBTrACS subsets for each country:

1. Main method: using JTWC, one of the U.S. agencies. JTWC has the most coverage in terms of original observations number and its averaging period corresponds to the one used in the physical model. Moreover, using one agency as the main method will allow us to compare results between countries.

2. First robustness check: using a reporting agency with the best available data for the specific country (can be JTWC or not). If it's not a US agency, we will need to use a rescaling factor from Harper et al. (2010)

3. Second robustness check: using a second-best agency to show if there is a sensitivity of the results to the choice of the agency. If it's not a US agency, we will need to use a rescaling factor from Harper et al. (2010)s

Agency	N
US Agencies	
atcf	112
cphc	151
hurdat	**81040**
jtwc	**105493**
nhc_working_bt	1374
tcgp	350
tcvightals	326
tcvitals	613
Other	
Tokyo	26248
CMA	**68524**
HKO	41045
New Delhi	5241
Reunion	14078
BoM	17934
Wellington	8928
ds824	**75966**
TD9636	25727
TD9635	20622
Neumann	40562
Chenoweth	15380

Table Notes: Number of Original Observations: location and MSW are not missing and not interpolated by IBTrACS.

There are a few other agencies with high number of observations that are potential coverage for the main method. JTWC is followed by HURDAT (in terms of number of observations) but HURDAT only covers Atlantic Ocean and Eastern Pacific Ocean, or places close to the US coast. Among non-US agencies, CMA is also too location specific to be picked as the main data source (storms are mostly around China). DS284 is a potential alternative source (NCAR/UCAR Research Data Archive) since its coverage is global.

2. Missing values: MSW

0. MSW based on Pressure? But what if both are missing? What should we do with missing wind values? We can find an empirical relationship between MSW and pressure. BUT: in Vietnam data, when MSW is missing in the US agency data, the pressure is also missing. What should we do in this case?

1. Dropping all storms that have no MSW at all. For Vietnam, there are 16 storms that have no wind speeds reported by US agency (among those that fall inside the buffer). They account for 201 observation in 3-hourly data.

2. Dropping a row of missing values in the start and in the end of the storm. Just because I interpolate winds, the result is that we get a sequence of missing values either in the beginning or the end of the storm. (NAs in the middle are being interpolated from previous and next existing values, whether they are in or outside the buffer). For Vietnam, it is 13.8% of hourly observations (after dropping storms with no MSW in any period).

3. Implementation of HURRECON model

The equation to estimate sustained wind velocity (V_s) at any point P in the northern hemisphere is the following:

$$V_s = F[V_m - S(1 - sinT)V_h/2] \times [(R_m/R)^B exp(1 - [R_m/R]^B)]^{\frac{1}{2}}, \tag{1}$$

where F is the scaling parameter for effects of friction (water = 1.0, land = 0.8), V_m is the maximum sustained wind velocity over water anywhere in the tropical cyclone, S is the scaling parameter for asymmetry due to forward motion of storm (1.0), T is the clockwise angle between the forward path of tropical cyclone and a radial line from tropical cyclone center to point P, V_h is the forward velocity of the tropical cyclone, R_m is the radius of maximum winds (20–80 km), R is the radial distance from the tropical cyclone center to point P, and B is the scaling parameter controlling the shape of the wind profile curve (1.2–1.5).

4. Limitations when implementing the model (limitations that are not related to missing intensities)

1. Choice of parameters. In the model above we use several "arbitrary" parameters: R_m and B. Boose et al. (2004) uses several different scenarios for R_m and B: (a) 20 km, 1.5; (b) 40 km, 1.4; (c) 60 km, 1.3; and (d) 80 km, 1.2. For now, I randomly picked scenario (c). In the future, we want to implement an algorithm that will endogenize those parameters (from pressure? find papers on this!)

2. Dropping singleton observations. For Vietnam I drop 2 observations that are singletons. It means that these are the observations that are the last observation for that storm, and they are the only observations inside the buffer (based on 3-hours data). Alternatively, we can extrapolate the location for the next storm's position (?)

3. Dropping observations where $min \neq 0$. The algorithm drops all observations that are not whole hour (minute variable not equal 0). Vietnam does not have these instances. If there are countries that have such observations - what should I do? Round up time, approximate linearly to the next closest hour?

4. Dropping spurs. Based on technical documentation of IBTrACS, "IBTrACS software can not determine which position is accurate, so both are maintained and alternate positions are given the title of spurs while the main track is labelled as a 'main' system."

5. Keeping all types of storms. As of now, I keep all types of storms and not only tropical cyclones, hurricanes, typhoons. Alternative storms are weaker, such as depressions, dissipating storms, etc. If we want to count the occurrence on some level, we may want to subset, for example, stronger storms only.

6. Dropping "last" observation in the storm. We cannot calculate winds if we don't know the next location of the storm. As in **2.** we can try to extrapolate this later. For Vietnam, there are 129 observations, or 129 storms, for which this exiting point exists. (Again, it means it's the last observation both in and out of the country-specific buffer area).

5. Endogenizing model's parameters

There are plenty of algorithms, empirical and analytical, that may help researchers to estimate B and R_m. I decide to only consider the algorithms that do not use pressure data (since they are more often missing than wind speeds), or other, more rarely reported variables (such as 34 kt wind radii maximum extent).

Willoughby and Rahn (2004) only use maximum wind speed and latitude to estimate both B and R_m.

$$R_m = 51.6exp(-0.0223V_m + 0.0281\phi),$$

$$B = 1.0036 + 0.0173V_m - 0.0313lnR_m + 0.0087\phi,$$

where ϕ is latitude, and other variables are the same as defined in **3.** above.

Knaff et al. (2007) also only use wind speed and latitude to estimate R_m:

$$R_m = m_0 + m_1V_m + m_2(\phi - 25),$$

where m_1, m_2, m_3 are parameters estimated separately for each basin (and reported in the paper).

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