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P 124

What is the sea-surface temperature threshold for tropical cyclone formation?

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1. Background:

1.Tropical Cyclones (TCs) source the majority of their energy from the release of lower troposphere conditional instability

- ❑ Heat and moisture fluxes from the sea surface to the atmosphere generate the conditional instability
- ❑ There is a widely held belief that a minimum sea surface temperature (SST) threshold exists

  Palmén (1948) 26˚ C

  Gray (1968) 26.5˚ C

2. Observations suggest there are many exceptions (Dare and McBride, 2011, DM11)

- ❑ In a 28 year global TC dataset (1981—2008) DM11 showed:

  6.7% of TCs were located over water < 26.5˚ C at formation time

  1.7% of TCs were located over water < 25.5˚ C at formation time
- ❑ Taking into account that TCs form over a period of days, and errors occur in storm intensity estimates, DM11 repeated the calculation with respect to the maximum SST in the previous 48 hours.

  1.5% of TCs experienced SST < 26.5˚ C for the entire 48 hours prior

  0.5% of TCs experienced SST < 25.5˚ C for the entire 48 hours prior
- ❑ DM11 argued that all but 4 of the 10 exceptions that made up the 0.5% were not true tropical formations, and conclude that 25.5˚ C is the SST threshold.

2. Questions:

1. Can a threshold be a threshold if there are exceptions?

2. Should we expect exceptions due to imprecise data?

3. Are some storms receiving substantial amounts of energy from the release of baroclinic instability?

- e.g., subtropical/tropical hybrid storms
- DM11 excluded all storms flagged as subtropical or extra tropical, and all formations polewards of 35˚
- We believe this does not exclude all systems with strong baroclinic energy sources, and it also excludes some tropical circulations.

4. SST thresholds for storms that form within the dynamic tropics:

1.The SST threshold depends on:

- How many exceptions are to be accepted
- The time period prior to formation in which the SST is considered to be relevant.

2.The SSTs at the time of formation and at 6 hourly intervals up to 48 hours prior were determined for each TC.

3.The number of TCs that formed at SSTs below various threshold values over a variety of time periods is presented in Table 2.

4.Table 2 identifies two possible strict thresholds (based on yellow shading):

- 24.5˚ C applied over the previous 18 hours
- 25.0˚ C applied over the previous 36 hours

5.If we accept up to 10 exceptions due to imperfect data we arrive at four possible SST/time-period threshold combinations (blue shading).

6.Alternatively we can investigate individual storms and argue for their exclusion.

7.For the 16 storms in the -26.5 column, t=-30 row (they also appear in other columns) we found one or more of the following:

- Very weak and short-lived.
- Strong baroclinic influence (e.g., very close to the STJ, or other 200 hPa jet features nearby).
- No evidence of any circulation in ERA-interim reanalysis data.
- No evidence of a mid-level circulation in ERA-interim reanalysis data.

8.With these storms removed a new group of possible thresholds is evident in Table 3.

- 24.5˚ C applied over the previous 18 hours
- 25.0˚ C applied over the previous 24 hours
- 26.5˚ C applied over the previous 30 hours

9.Further manual investigation could lead to the elimination of more storms, which could further increase the SST threshold applied over shorter time periods.

5. Conclusion:

1.The concept of a SST threshold is valid for TCs that derive the majority of their energy from the release of surface-based conditional instability.

2.A simple objective technique for eliminating TCs that form in a strongly baroclinic environment was applied.

3.A range of possible SST thresholds exists depending on the time period prior to formation for which the threshold is applied.

4.With a sample of questionable TCs removed, threshold values consistent with Palmén (1948) and Gray (1968) begin to emerge.

5.Our answer to the title question depends on:

- Which storms are included/excluded
- The time period prior to formation under consideration
- How many exceptions one is willing to accept in recognition of imperfect data

6. From this analysis of all individual TCs across the globe between 1981 and 2008, a robust necessary condition for TC formation seems to be that:

- **The precursor system experiences SST > 26.5˚ C some time in the preceding 24 hours.**

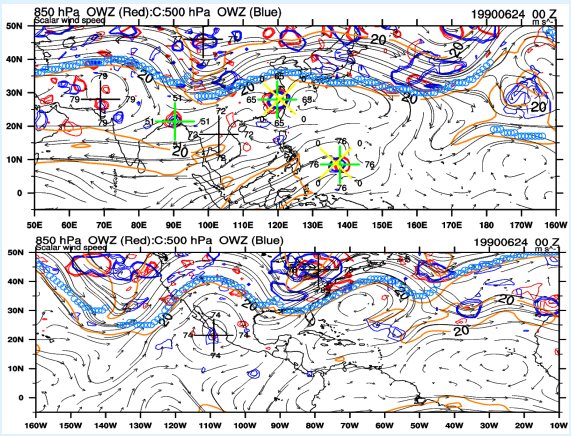

Figure 1: The poleward extent of the dynamic tropics is defined to be the equatorward edge of the subtropical jet. A simple objective method for identifying this boundary is to use the first 25 m s^{-1} 200 hPa contour poleward of 7˚ latitude where the windspeed increases with latitude (blue circles). The 20 m s^{-1} 200 hPa wind speed contour is in brown. Black crosses mark circulations of interest. Green (yellow) crosses objectively determined (observed) TCs. Regions of enhanced rotation at 850 (500) hPa are contoured in red (blue).

3. Eliminating non-tropical baroclinic storms:

1.Since we define TCs to be storms that derive most of their energy from the release of conditional instability, we must eliminate from the analysis storms that form in strongly baroclinic environments.

2.This can largely be achieved using a dynamic definition of the tropical region:

- The region of high tropopause spanning the equator.
- The tropopause poleward edge typically has a steep slope that is in thermal wind balance with the subtropical jet.
- We use the subtropical jet at 200 hPa to define the tropical/subtropical interface
- A northern hemisphere example is illustrated in Fig. 1.

3.Table 1 shows how this categorization compares with the storms flagged in the IBTrACS TC database.

- 31 of the *non-tropical* flagged storms in IBTrACS were found to form outside the dynamic tropics. (Agreement)
- Only 9 of the 2113 *tropical* flagged storms in IBTrACS were found to form outside the dynamic tropics,
- 12 of the 43 *non-tropical* flagged storms in IBTrACS were found to form within the dynamic tropics.

	IBTrACS storm categories			
	TS	NR	SS/ES	Total
Tropical	2104	93	12	2209
Subtropical	9	7	31	47
Total	2113	100	43	2256

Table 1: Numbers of various storm types in the 28 year period (1981—2008) at the formation time. IBTrACS storm types: TS = tropical cyclone, NR = not rated, SS = subtropical storm, ES = extratropical storm. Storm types based on the objective dynamic tropics definition: Tropical = storm formed equatorward of the subtropical jet, Subtropical = storm formed poleward of the subtropical jet.

	< 24.5	< 25.0	< 25.5	< 26.0	< 26.5
t = 0	7	15	30	64	137
-6	5	8	17	31	67
-12	2	4	8	14	38
-18	0	3	5	13	27
-24	0	1	3	7	22
-30	0	1	2	5	16
-36	0	0	1	3	14
-42	0	0	1	3	14
-48	0	0	1	3	14
	< 10	10 -- 20	20 -- 40	40 -- 80	> 80

Table 2: Numbers of TCs located over water less than the five SST threshold values (upper row, ˚ C) over various preceding time periods (left column, hours).

	< 24.5˚ C	< 25.0˚ C	< 25.5˚ C	< 26.0˚ C	< 26.5˚ C
t = 0	6	12	27	55	121
-6	4	6	14	23	51
-12	1	2	6	7	22
-18	0	1	3	6	11
-24	0	0	1	1	6
-30	0	0	0	0	0
-36	0	0	0	0	0
-42	0	0	0	0	0
-48	0	0	0	0	0
	< 10	10 -- 20	20 -- 40	40 -- 80	> 80

Table 3: As in Table 2 but with the 16 suspect TCs removed.

References:

Dare, R. A. and J. L. McBride, 2011: The threshold sea surface temperature condition for tropical cyclogenesis. *J. Clim.*, 24, 4570—4576.

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Palmén, E., 1948: On the formation and structure of tropical hurricanes. *Geophysica*, **3**, 26—38.