Tropical Cyclone Genesis: What we know, and what we don’t

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![Image of a hurricane](image-url)
Definitions

**Tropical Cyclone:** General term for a warm-core, non-frontal, rotating, organized system of clouds and thunderstorms that originates over tropical ocean and has a closed low-level circulation.

Includes:
- **Tropical Depression:** Maximum sustained wind up to 17 m/s (34 kts)
- **Tropical Storm:** Maximum sustained winds 18-32 m/s (35-64 kts)
- **Hurricane***: Maximum sustained winds of 33 m/s (65 kts) or higher

**Energy source:** thermodynamic disequilibrium between the ocean surface and the atmosphere above it

*Different term used in different regions
Definitions
Climatology: Genesis
Climatology: Basin by Basin

Source: UK Met Office
Climatology: Seasonal Cycle
Climatology: Seasonal Cycle

June

July

September

October

August

November

Likely
More Likely
Most Likely
Prevailing Tracks

NOAA
TO UNDERSTAND GENESIS, NEED TO EXPLAIN...

• The dynamics and thermodynamics of how an individual storm forms
  – Or why it doesn’t

• Climatology
  – Where TCs form
  – When TCs form
  – How many TCs form
WHAT WE KNOW

1. Tropical cyclones need a favorable environment in order to form and intensify.

2. Tropical cyclones form from pre-existing disturbances.
Necessary Environmental Conditions

- High vorticity
- At least 5 degrees from equator
- Warm sea surface temperature (>27°C)
- Deep warm layer (~60m)
- Weak vertical wind shear
- High relative humidity

Gray, 1968
Climatology: Genesis

Global Genesis Events 1971-2001
Warm Ocean over Sufficient Depth: Why?

- A hurricane’s energy comes from a surface heat flux between the air and the ocean.
  - Need sufficient thermodynamic disequilibrium between ocean and atmosphere
  - Partially achieved by having a warm enough SST

- A hurricane’s winds lead to upwelling of water.
  - Need a deep warm layer so this upwelling water will not be too cold
Weak Vertical Wind Shear: Why?

- Disrupts formation of deep, moist column that is imperative for genesis
- Vertical wind shear tilts the vortex and causes convective asymmetries
  - Prevents release of latent heat from being locally concentrated
  - Ventilates dry air from the environment into the disturbance

Tang and Emanuel, 2010
Trigger Mechanisms

- Low level convergence in the tropics
- Cold fronts that progress far south into tropical latitudes
- Monsoon trough
  - Characterized by near equatorial seasonal westerly winds and enhanced rainfall
  - Monsoon trough breakdown, monsoon gyres
- Equatorial waves
- Intraseasonal oscillations (MJO) – enhanced convective activity in active phase
- Easterly waves
African Easterly Wave

Overview
Climatology
What We Know
Theories
Climate Change

Emanuel 2004,
African Easterly Wave tracks, August-September, 1985

Pytharoulis and Thorncroft, 1999
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  – How many TCs form ??
THEORIES OF TROPICAL CYCLOGENESIS
Why are easterly waves a favorable location for genesis?

**Marsupial Paradigm**

- Pouch: favored region for TC formation

- Protected area where air is repeatedly moistened by convection and protected from dry air intrusion

- Once TC has formed, can exist on own and leave the pouch

Pouch = Intersection of trough axis and wave critical line → region of closed circulation

Wang, Montgomery, and Dunkerton 2009
Key transition: Saturate column to stop downdrafts

Evaporation of rain into unsaturated environment creates downdrafts that transport dry air into the boundary layer.

This fights against surface fluxes, which work towards increasing boundary layer humidity.
Key transition: Saturate column to stop downdrafts

As it continues to rain, atmosphere becomes saturated.

Downdrafts are stopped! Boundary layer humidity can recover and start to increase from surface fluxes.
Once downdrafts stopped, intensification via WISHE

- WISHE = Wind Induced Surface Heat Exchange

- Increasing surface wind speeds produce increasing surface fluxes, while the increased heat transfer leads to increasing storm winds

- WISHE mechanism generally accepted, but disputed by some (alternate theory for intensification via vortical hot towers)
TROPICAL CYCLONES AND CLIMATE CHANGE
How we make TC-climate projections

- Expectations from theory
- Changes in environmental parameters
  - Genesis index

- Direct tracking of tropical cyclones in climate models E.g. Camargo 2013

- Dynamical downscaling E.g. Knutson et al. 2007
  - Drive regional higher resolution model with boundary and initial conditions from climate models

- Statistical/dynamical downscaling
  - Tracks initiated by random seeding.
  - Intensity model integrated along each track, using environmental conditions from climate model
    - Emanuel et al. 2006, Emanuel et al. 2008, Emanuel 2013
    - Vecchi and Soden 2007
Projections

- Reduction/no change in global mean TC frequency \((likely)\)
  - Decrease in relative humidity
  - Increase in wind shear in some places
- Increase in frequency of most intense TCs \((more likely than not)\)
- Increase in TC intensity \((likely)\)
  - Increase in potential intensity
- Variations from basin to basin
  - El Nino-like warming pattern –more and stronger storms in Pacific but fewer in Atlantic?
- Increase in TC rain rates \((likely)\)
- Increase in impacts of storm surge \((even for same intensity/surge)\)
  because of sea level rise
- Don’t know about changes in size
- Don’t know about changes in extratropical transition
- Don’t really know about changes in track (effect of poleward shift in jet?)

SREX 2012, Knutson et al 2010
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