Tropical Cyclogenesis (TCG)



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Outline Material for the Talk

- Climatology and Intraseasonal Variability
- Conditions & pathways for TC genesis
- TC genesis Theories
- TC genesis Forecasting
- Useful resources for TC genesis forecasting
- Operational (NHC) products for TC genesis information

WMO TC Definition

 "A warm-core, non-frontal synoptic-scale cyclone, originating over tropical or subtropical waters, with organized deep convection and closed surface wind circulation about a welldefined center."



TCG Climatology

Principal Areas of Tropical Cyclone Formation

Tropical Cyclones, 1945–2006



Factors Governing Tropical Cyclone Formation Climatology

- In long-term mean there is a lag between:
- Most favorable thermodynamics (static stability)
- Most favorable dynamical conditions (in terms of vertical wind shear).
- The atmosphere tends to be more unstable <u>later</u> in the season.
- The vertical shear tends to be weaker <u>earlier</u> in the season.



FIG. 7. Climatological time series of the scaled shear, instability, and moisture variables.



Atlantic

Distinct Peak in mid September Lower secondary Peak in mid October

East Pacific

More spread-out bimodal distribution





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Large Scale Conditions Associated with TC Formation

- Upper-tropospheric anticyclonic outflow over the area
- Enhanced lower tropospheric relative vorticity
- Appearance of curved banding features in the deep convection
- Falling surface pressure: 24-hour pressure changes (falls) of usually 3 mb or more





Large Scale Conditions Associated with TC Formation

- A pre-existing disturbance containing abundant deep convection
- Latitudes poleward ~5°
- Adequate ocean thermal energy
 - SST >26°C extending to a depth of 60 m
- A "sufficiently" unstable atmosphere & deep layer of moist air
- Small vertical shear of the horizontal wind





Favorable Pathways For Tropical Cyclogenesis

"We observe universally that tropical storms form only within pre-existing disturbances...An initial disturbance therefore forms part of the starting mechanism. A weak circulation, low pressure and a deep moist layer are present at the beginning. The forecaster need not look into areas which contain no such circulations."

Herbert Riehl (1954)

Precursor Pathways

Precursors can be divided up into two categories, tropical origin or non-tropical origin

Tropical Origin

- Tropical Waves
- Intertropical Convergence Zone Breakdowns

Non-Tropical Origin

- Upper-level Trough Interactions
- Decaying Frontal Boundaries
- Tropical Transition
- Mesoscale Convective Systems (MCSs)
- Central American Gyres (CAGs)

In the Atlantic basin, the pathways of all TC genesis are roughly split up evenly between tropical and non-tropical origions

Tropical Waves

Periodic waves emerge in the Atlantic emerge off Africa during the season



Recent Examples

Maria (2017) Sam (2021) Earl (2022)

• Intertropical Convergence Zone (ITCZ) Breakdown



Convective systems that form along the ITCZ gradually intensify, helping to break down the initial trough into discrete vortices that can become tropical cyclones

b) July 28



c) August 3



• Upper-Level Trough Interactions



Recent Examples Gaston (2022)

©The COMET Program

Upper-Level Trough Interactions



Recent Examples Gaston (2022)

Moisture source interacts with the upper-level trough, triggering convection that helps to intensify the surface circulation

Precipitable Water (mm)

Upper-Level Trough Interactions



Recent Examples Gaston (2022)

Moisture source interacts with the upper-level trough, triggering convection that helps to intensify the surface circulation

Precipitable Water (mm)

Hurricane Olga (2001)

 Tropical Transition – Process of a cyclone evolving from a non-tropical cold core low to a subtropical or tropical cyclone with a warm core low

Deep convection developing near the center an important process leading to tropical transition



Decaying Frontal Boundary



Temperature gradient with front gradually decays as it moves over warm ocean, but acts as focal point for new convection that spins up a low-level circulation

> Tropical Storm Bill (2021)

Central American Gyres

Broad cyclonic circulation that form over Central America in the early and latter portions of the Hurricane Season

TC circulations can form a smaller feature within the larger circulation, or evolve from a CAG into a TC as wind field contracts



Mesoscale Convective System



Thunderstorm activity leads to the formation of a surface circulation

Recent Examples

Henri (2021)

INNER CORE MAY ORIGINATE AS A MID-LEVEL MESO-VORTEX (NEAR 700 MB) THAT FORMS IN ASSOCIATION WITH AN MCS



PRE-GORDON DISTURBANCE, 9/13/00 1145 UTC (~24 HOURS PRIOR TO GENESIS)



Zehr (1992)

TC Development Theory

WISHE – Wind Induced Surface Heat Exchange

A Positive Feedback Loop

Increasing winds at ocean surface help to extract more heat from the warm ocean

Process helps warm and moisten boundary layer increasing conditional instability

Convection is triggered when sufficient instability is reached

Convection warms tropospheric column further though latent heat release

Process helps increase winds at ocean surface





TC Development Theory

CISK – <u>Conditional Instability of the Second Kind</u>

Feedback between small-scale convection resulting in frictionally induced convergence near the surface

Latent heat release from convection helps enhance the larger-scale circulation as heating balances frictional dissipation, helping the cyclone to maintain its intensity

One drawback of this theory is that it relies on convective available potential energy (CAPE) for convection persist, which does not always exist in abundance in the tropics and is quickly depleted



TC Development Theory

Marsupial Paradigm



A "pouch" is used to denote an area that is favorable 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 \rightarrow region of closed circulation

Forecasting Tropical Cyclogenesis

Important Intraseasonal Predictors for 5-Day Genesis Forecasts



Diagnostic tools involving the MJO and other intraseasonal oscillations are becoming increasingly important but are still used qualitatively

A Tool for Tracking and Forecasting the MJO



- Conceptual model showing idealized phases of MJO progression
- Phases 8 through 3 most active phases for the Atlantic



MADDEN-JULIAN OSCILLATION: RELATED TO INTRASEASONAL VARIABILITY IN TC ACTIVITY?

Composite evolution of 200hPa velocity potential anomalies (10⁵ x m²/s) and points of origin of tropical systems that developed into hurricanes/typhoons





200 MB VELOCITY POTENTIAL 5°N-5°S 5-DAY RUNNING MEAN

Convectively Coupled Kelvin Waves (CCKWs)

- Vertically tilted atmospheric wave that propagates from west to east (opposite of tropical waves)
- As wave approaches, it enhances convective activity, reduces vertical wind shear, and promotes cyclonic vorticity



Schreck (2015)

 Often a few day lag between when CCKW moves over and feature influenced develops into a tropical cyclone

How are Intraseasonal Oscillations Used at NHC?

- Used as a way to increase forecaster confidence in a given situation if conceptual model of MJO and genesis matches model solutions.
- Any adjustments to 5-day genesis probabilities based on intraseasonal signals are small and subjectively determined.
- Global models handle the MJO much more accurately than other intraseasonal signals such as the CCKWs, and the forecaster can add value to the deterministic models.
- No operational standard on use of CCKW in genesis forecasts (forecasters use it to various degrees).

Influence of El Niño/La Niña on TC Genesis

- During El Niño episodes, *fewer* TCs typically form in the deep tropical Atlantic and Caribbean; with development more focused at subtropical latitudes. The opposite generally occurs during La Niña years.
- In the eastern North Pacific, El Niño typically enhances TC activity, with a tendency for stronger hurricanes during El Niño (e.g., 1997, 2006).





2006 (El Niño)

2010

Use of global models relevant for TC genesis forecasting:

- Global models, especially the "big four" ECMWF, GFS, CMC, and UKMET along with their ensembles are critical tools for predicting TC genesis.
- The forecaster looks for persistence among the model guidance, as well as run-torun consistency, to assess the likelihood of genesis.
- The ECMWF is quite reliable, with less genesis false alarms, but it can occasionally struggle with its probability of detection. The GFS has the opposite problem, with good probability of detection yet more prone to false alarms. Both of those models will be discussed on next slides.
- The UKMET model has a high detection rate for genesis but also has an abundance of "false alarms". Therefore, when we see no development in the UKMET forecast, the probability of genesis is low. Recent improvements in the CMC model now make it much more viable for TC genesis forecasting (use to have a bad false alarm rate).

Genesis Verification Atlantic



Figures and data provided by Dan Halperin and Bob Hart

Genesis Verification

East Pacific



Figures and data provided by Dan Halperin and Bob Hart

GFS Genesis Forecasts Summary

Atlantic

- Correctly forecast genesis on several occasions over the eastern Atlantic, however the false alarm rate there was rather high
- Performed very well in tropical Central Atlantic, Caribbean, and Gulf of Mexico.
- Did not perform as well in the subtropical Atlantic, with several systems not anticipated.

Eastern North Pacific

- Performed fairly well in the eastern portion of the basin
- False alarm rate appears higher in the western portion of the basin

GFS Genesis Example – Irma



Some signal early (4-5 days), but signal weakened inside of 60 hours until genesis

GFS Genesis Example – Maria



Weak/No signal until 42 h prior to genesis

GFS Genesis Example – Lee (Genesis #2)



GOES-13 Visible Imagery – 1815 UTC 22 September



Little/No Signal Prior to Genesis

Genesis Probability by Dvorak Number

- Uses Dvorak intensity estimates from all invests/disturbances (both developing and nondeveloping) from 2001-2011.
- Example: Invest with a 1.0 TAFB CI Number has 35% chance of genesis within 48 h.
- Real-time guidance at moe.met.fsu.edu/genesis
- More information in Cossuth et al. (Wea. & Forecasting 2013)

Atlantic TC Genesis Probability by TAFB Fix



Useful Resources for TC Genesis Forecasting

Tropical Cyclone Logistical Guidance for Genesis (TCLOGG)

Developed by Dan Halperin and Bob Hart at FSU

- Provides TC genesis probabilities from deterministic models using regression equations of known atmospheric variables tied to genesis
- Ongoing Hurricane Forecast Improvement Project

Verification About lome Graphics Text Archive Latest Guidance Version Experimental Tropical Cyclone Genesis Guidance I-indicated Genesis Potential | TCGENGIFS Model Output | AL CP/EP IO SH WP Available models in current guidance cycle (init time): CMC [C] (12Z) CECM [E] (00Z) O GFS [G] (12Z) O NAV [N] (06Z) A UKM [U] (00Z) Letters below the genesis probability indicate the models that predicted genesis COL 21% +120 h -120 h Wed Sep 14 16:36 UTC 2022

Tropical Cyclone Logistical Guidance for Genesis (TCLOGG)

Verification 2-day

Verification 7-day



 Individual models contain significant biases but the consensus probabilities (CON) are better calibrated

Tropical Cyclone Logistical Guidance for Genesis (TCLOGG)

Preliminary TC genesis forecast timing verification



 New information included Time of genesis, which helps to determine if probabilities should be included in 2- to 7- day time ranges

Ensemble-based Resources for Genesis

- Several different websites tracks of warm core lows that can be useful to infer how likely a genesis event may occur
- https://www.weathernerds.org/models/ecens.html

ECMWF EPS (50 members) + control GEFS (30 members) + control

Other ensemble datasets (UKMET) often less available and reliable



Other Tools

- CIRA Tropical cyclone-based formation probabilities: http://www.ssd.noaa.gov/PS/TROP/TCFP/index.html
- Single-model ensemble-based probabilities can provide guidance
- Several projects (e.g. Joint Hurricane Testbed), with the goal to provide objective genesis guidance



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ECMWF Ensemble-based Probability (%) of TC genesis for forecasts during the 00-48h period from initial time = 2012102112



Operational NHC products for TC genesis

- Tropical Weather Outlook (TWO)
- "Invests"
- Potential Tropical Cyclone
- New for 2023

OUTLOOK SCHEDULE URL: https://www.nhc.noaa.gov/gtwo.php

TIMES IN EL

- A Special Tropical Outlook can be issued at anytime for significant or unexpected changes
 - 2 am Tropical Outlook
 - 8 am Tropical Outlook
 - 2 pm Tropical Outlook
 - 8 pm Tropical Outlook

TROPICALOUTLOOK Assessment of Tropical Activity



TROPICAL WEATHER OUTLOOK NWS NATIONAL HURRICANE CENTER MIAMI FL 800 PM EDT MON OCT 20 2014

For the North Atlantic...Caribbean Sea and the Gulf of Mexico:

Showers and thunderstorms associated with an area of low pressure located over the southwestern Bay of Campeche have changed little in organization since this afternoon. This system has the potential to become a tropical cyclone during the next couple of days while it moves slowly eastward across the southern Bay of Campeche. Later in the week, the low is forecast to interact and possibly merge with a frontal system over the southeastern Gulf of Mexico or northwestern Caribbean Sea. An Air Force Reserve reconnaissance aircraft is scheduled to investigate the disturbance tomorrow afternoon, if necessary. Interests in the Yucatan Peninsula should monitor the progress of this system.

* Formation chance through 48 hours...medium...50 percent.

• Formation chance through 5 days...medium...60 percent.

Forecaster Brown

Potential for development? Headed where?

TROPICALOUTLOOK 2-Day Formation Potential



- Current location of disturbances
- Formation chance during the next 48 hrs
 - CATEGORICAL (Low, Medium, and High)
 - PROBABILITIES

NHC "Invest" Systems

- NHC opens "invests" to monitor suspicious weather systems more carefully
- There are no standards for opening invests unlike for initiating a tropical cyclone package – based on forecaster prerogative
- Guidance is typically run when a cloud system center is apparent (but not always!)
- Users are reminded to be extremely cautious about using parameters associated with particular "invests" in decision-making



Potential Tropical Cyclones (PTCs)

- PTCs give NHC the option to issue watches and warnings for land areas when the system is not yet a tropical cyclone
- Initial advisory issuance is not directly tied to tropical cyclone formation chance
- Initial issuance criteria include:
 - Likely impacts
 - Need for tropical cyclone watches or warnings for land areas
 - Desire to avoid switching warning types (tropical vs. non-tropical)



WMO Early Warning for Caribbean Countries PTC Module -- https://etrp.wmo.int/course/view.php?id=293

Extension of the Tropical Weather Outlook to 7 Days - New for 2023

- The time period covered by the NHC Tropical Weather Outlook will be expanded to 7 days beginning in 2023
- The Outlook will provide 2- and 7day probabilities of tropical cyclone formation
 - 7-day probabilities replace 5-day
- The 7-day genesis area will be depicted on the Graphical Tropical Weather Outlook



NATIONAL HURRICANE CENTER

TROPICAL WEATHER OUTLOOK NWS NATIONAL HURRICANE CENTER MIAMI FL 800 PM EDT MON OCT 20 2023

For the North Atlantic...Caribbean Sea and the Gulf of Mexico:

Southwest Gulf of Mexico (AL92):

Showers and thunderstorms associated with an area of low pressure located over the southwestern Bay of Campeche have changed little in organization since this afternoon. This system has the potential to become a tropical cyclone during the next couple of days while it moves slowly eastward across the southern Bay of Campeche. Later in the week, the low is forecast to interact and possibly merge with a frontal system over the southeastern Gulf of Mexico or northwestern Caribbean Sea. An Air Force Reserve reconnaissance aircraft is scheduled to investigate the disturbance tomorrow afternoon, if necessary. Interests in the Yucatan Peninsula should monitor the progress of this system.

* Formation chance through 48 hours...medium...50 percent.

• Formation chance through 7 days...medium...60 percent.

Forecaster Brown

2-Day Graphical Tropical Weather Outlook Remains Unchanged



- Current location of disturbances
- Formation chance during the next 48 hours
- Categorial Probabilities
 (Low, Medium, and High)

7-Day Graphical Tropical Weather Outlook



- Initial location of disturbance (x) indicated
- Formation potential during the next 7 days

Shading represents formation area

What's the chance this area forms during the next 7 days?

Categorial Probabilities (Low, Medium, and High)

7-Day Graphical Tropical Weather Outlook

- What does a 7-day Tropical Weather Outlook mean for messaging pre-genesis disturbances?
 - Systems are likely to be introduced into the TWO sooner
 - Systems are likely to move into the medium and high categories earlier producing longer lead times
 - Genesis areas are likely to be larger, especially for systems with a fast forward speed



Example of a Seven-Day Graphical Tropical Weather Outlook

How is the Extension to 7-Days Possible?



How reliable are these probabilistic forecasts?

How is the Extension to 7-Days Possible?



Three-year sample of 7-day in-house probabilities have proven to be quite reliable.

Outlook Now Includes Invest Numbers* and Geographicall Descriptors

Tropical Weather Outlook NWS National Hurricane Center Miami FL 200 AM EDT Fri Sep 2 2022

For the North Atlantic...Caribbean Sea and the Gulf of Mexico:

Active Systems:

The National Hurricane Center is issuing advisories on Tropical Storm Danielle, located about 925 miles west of the Azores.

East of the Leeward Islands (AL91):

Satellite imagery indicates there has been little change in the organization of the area of low pressure located several hundred miles east of the Leeward Islands during the past several hours. Although environmental conditions remain only marginally conducive, any additional development of the system over the next few days would lead to the formation of a tropical depression. The disturbance is expected to move slowly west-northwestward, toward the adjacent waters of the northern Leeward Islands. Regardless of development, locally heavy rains may occur over portions of the Leeward Islands during the next couple of days, and interests in that area should monitor the progress of the system. An Air Force Reserve Hurricane Hunter aircraft is scheduled to investigate the system this afternoon, if necessary. Additional information on this system can be found in High Seas Forecasts issued by the National Weather Service. * Formation chance through 48 hours...medium...50 percent.

* Formation chance through 7 days...high...70 percent.

Eastern Tropical Atlantic:

Shower activity associated with a broad area of low pressure located just northwest of the Cabo Verde Islands has increased some over the last several hours, but remains poorly organized. This system is moving into an area of less favorable environmental conditions, and significant development is not anticipated.

- * Formation chance through 48 hours...low...10 percent.
- * Formation chance through 7 days...low...10 percent.

- In 2022, geographic headers were added for active systems and disturbances
- Beginning in 2023, invest numbers (AL90-99) will be included when available there is an active invest open in association with the disturbance

• These changes should:

- Make the text product more readable and scannable
- Minimizes confusion between multiple systems, especially when it's busy

Note: Headers will likely not be bold in the actual product





PollEv.com/nhcpoll903