TROPICAL CYCLONE GENESIS

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Outline / Topics

• Climatology
• Large-scale conditions associated with tropical cyclone (TC) formation
• Relation to ENSO, intraseasonal variability
• Theories of genesis
• Meso-scale aspects of genesis
• TC genesis in global models
• Web sites of genesis parameters
• Operational (NHC) genesis forecasting
• Forecast exercise
WMO Definition of a Tropical Cyclone:

“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 well-defined center.”
Principal Areas of Tropical Cyclone Formation

Tropical Cyclones, 1945–2006

Saffir-Simpson Hurricane Scale:
- tropical depression
- tropical storm
- hurricane category 1
- hurricane category 2
- hurricane category 3
- hurricane category 4
- hurricane category 5
Factors Governing the Climatology of Tropical Cyclone Formation in the Atlantic Basin

- In the long-term mean, typically, there is a lag between the occurrence of the most favorable thermodynamic conditions (in terms of static stability) and the most favorable dynamical conditions (in terms of vertical wind shear).
- The atmosphere tends to be more unstable later in the season.
- The vertical shear tends to be weaker earlier in the season.

**Fig. 7.** Climatological time series of the scaled shear, instability, and moisture variables.
Highly peaked with a secondary peak in mid-October

Bimodal distribution
Note that TC genesis is not a function of the number of available disturbances.
Large-Scale Conditions and Other Characteristics Associated with TC Formation

Necessary but not sufficient conditions!

- 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
Large-Scale Conditions and Other Characteristics Associated with TC Formation (cont’d)

- 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
“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)
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.

Blue—favorable upper-level conditions (lower shear and more unstable)

Magenta dots are TC genesis points in early 2012
MADDEN-JULIAN OSCILLATION: RELATED TO INTRASEASONAL VARIABILITY IN TC ACTIVITY?

Composite evolution of 200hPa velocity potential anomalies ($10^5$ x m$^2$/s) and points of origin of tropical systems that developed into hurricanes/typhoons.

200-hPa Velocity Potential Anomaly: 5N-5S 5-day Running Mean

ACTIVE PERIOD IN ATLANTIC BASIN

200 MB VELOCITY POTENTIAL 5°N-5°S 5-DAY RUNNING MEAN
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
Idealized CCKW-influenced TC genesis

Day -2

Region of enhanced cyclonic vorticity generation

Background easterly flow

Disturbance

Eastward propagating CCKW, indicated by negative OLR anomalies and low-level anomalous westerly winds
Idealized CCKW-influenced TC genesis

Day -1
Idealized CCKW-influenced TC genesis
Idealized CCKW-influenced TC genesis
Idealized CCKW-influenced TC genesis

Newly-declared TC

Day +2
How are Intraseasonal Oscillations Used at NHC?

• Used as a way to increase forecaster confidence in a given situation if conceptual model of CCKWs 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 individual CCKWs, and thus the forecaster can add value to the deterministic models.

• No operational standard on use of CCKW in genesis forecasts (about half of forecasters use it).
Influence of El Niño/La Niña on TC Genesis

• During El Niño episodes, fewer TCs form over the deep tropical Atlantic and Caribbean; tendency for more to form 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 (La Niña)
2 Formal Theories of TC

Genesis

- CISK (Ooyama, Charney and Eliasen)
- WISHE (Emanuel)
CISK

Acronym for:
Cond**itional Instability of the Second Kind**

- A cooperative feedback between small-scale convection (frictionally-induced convergence and latent heat release) and the larger-scale circulation (a growing disturbance)

- A simplified linear theory which assumes that flow is in gradient balance

- When latent heat release balances surface frictional dissipation, the cyclone maintains its intensity

**NOTE: ALTHOUGH THIS THEORY IS FREQUENTLY ATTACKED, IT STILL HAS SOME INTUITIVELY APPEALING ASPECTS!**
CISK

LARGE-SCALE WAVE

LOW-LEVEL CYCLONIC VORTICITY

EKMAN PUMPING (FRICTIONALLY-INDUCED CONVERGENCE)

TRANSVERSE (SECONDARY) CIRCULATION

RELEASE OF LATENT HEAT

VORTEX TUBE STRETCHING

INCREASE OF LOW-LEVEL CYCLONIC VORTICITY
CISK Schematic

Convection grows stronger as more moisture flows into surface low

Latent heat release causes air to expand and surface low to strengthen

Incipient disturbance

Frictional convergence of moisture causes rising motion

Air flows outwards and Coriolis turning forms upper anticyclone

Stronger convection gives more latent heat

As surface low strengthens, moist frictional convergence, convection and surface low have positive feedback to each other

Winds strengthen as low develops; frictional convergence

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“The more fundamental question about the CISK concept is how can cooperation between cyclone-scale and convective-scale circulations produce their simultaneous development including the formation and intensification of a warm core? It is difficult to see how it can happen because, if there are no sources, $\theta_e$ is simply redistributed by these motions individually, and therefore by the total motion, without creating a new maximum. Conditional instability simply converts the vertical variation of $\theta_e$ to the horizontal variation while the mass distribution in $\theta_e$ space is conserved. Any instability that changes this distribution, therefore, inevitably involves processes other than cooperation between cyclone-scale circulation and convective clouds. Since the cooperation alone does not produce new instability, the concept of CISK as distinguished from the usual conditional instability can hardly be justified.”

(Arakawa, 2004 J. Climate)

This suggests that another mechanism for TC genesis, that involves thermodynamics and a source of heat, should be invoked.

WISHE is such a mechanism.
Wind Induced Surface Heat Exchange

- Heat release and instability in the free troposphere is governed by the evaporation of moisture from the sea (i.e., the extraction of energy from the underlying ocean surface)

- Evaporation is primarily determined by the magnitude of the surface winds
Deep convection, initiated through Ekman pumping, will produce convective-scale downdrafts that will stabilize the lower layer of the atmosphere.

The troposphere must become nearly saturated in the vortex core.

The enhanced surface fluxes associated with strong surface winds near the core can increase the subcloud moist static energy.

Convection can increase the temperature of the vortex core. In a moist tropical atmosphere, the WISHE process can act as a positive feedback to the warm-core cyclone.

Figure 8. Conceptual model of tropical cyclogenesis from a preexisting MCS. (a) Evaporation of stratiform precipitation cools and moistens the upper part of the lower troposphere; forced subsidence leads to warming and drying of the lower part. (b) After several hours there is a cold and relatively moist anomaly in the whole lower troposphere. (c) After some recovery of the boundary layer $\theta_v$, convection redevelops (From Bister and Emanuel 1997, Copyright American Meteorological Society).
Stage 1-Stage 2 Genesis

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

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

Zehr (1992)
Multiple mid-level mesoscale vortices during genesis stage. (Reasor et al. 2005 *J. Atmos. Sci.*)
WIND AND VORTICITY WITHIN SOUTHERN CONVECTIVE REGION, 8/19/96
Changes to Global Models relevant to TC genesis forecasting:

• In May of 2016 (proposed), the data assimilation scheme of the Global Forecast System (GFS) spectral model will change to a 4-D hybrid ensemble variational analysis, and some additional data will be included (AMSU-A radiances and AVHRR winds).

• Based on retrospective runs of this new GFS for 2013-2015, some slight improvement in TC genesis prediction by the GFS is expected this year.

• Next week, the ECMWF global model will also undergo an upgrade, with an increase in horizontal resolution to about 9 km (with the number of vertical levels remaining at 130), and with improvements to the data assimilation and model physics.

• These changes should lead to an improved structural representation of tropical cyclones, but it is not yet known how these changes will affect the ECMWF forecasts of TC genesis.
Verification of TC cyclogenesis in the GFSX – comparison to current and previous version of the GFS (based on work done by Dan Halperin and Bob Hart)
Preliminary 2015 NATL 48 h Forecast Verification (non-homogeneous)

(a) NATL 48 h

(b) NATL 120 h

Preliminary 2015 EPAC 48 h Forecast Verification (non-homogeneous)

(c) EPAC 48 h

(d) EPAC 120 h
Web site for monitoring real-time model forecasts of cyclogenesis:
http://www.emc.ncep.noaa.gov/gmb/tpm/emchurr/tcgen/

Web site of archived model forecasts of cyclogenesis for 2010:
http://www.emc.ncep.noaa.gov/gmb/tpm/emchurr/gfs_gen_2010/
Genesis Probability by Dvorak Number

- Uses Dvorak intensity estimates from all invests/disturbances (both developing and non-developing) 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. (2013)
FSU Guidance
(http://moe.met.fsu.edu/modelgen)

- Best objective genesis guidance to date
- Uses statistics on dynamical model forecasts of genesis to develop probabilities
- Multi-model consensus gives most reliable forecasts
- Scheme provides guidance on many more systems than are mentioned in the TWO
Other Tools

- CIRA Tropical cyclone-based formation probabilities
- Ensemble-based probabilities generated (use consensus of this?)
- Several projects (e.g. Joint Hurricane Testbed), with the goal to provide objective genesis guidance
TC Genesis Forecasting at the NHC

- Primary guidance comes from global models but considerable subjectivity involved in NHC genesis forecasts.

- Global models can depict TC formation – even in complex cases – fairly realistically.

- GFS and ECMWF seem to have greatest skill, but more systematic verification is needed (consensus-based still the best?)

- Models appear to have some geographical biases – they perform better in the eastern Atlantic and western Caribbean, but worse in the Subtropics.

- Models generally change to some degree annually – so forecasters accustomed to a model’s performance in one season will have to reacquaint himself/herself with the new model each season.

- A genesis parameter which combines 850-mb circulation, shear, instability, and moisture has shown some promise for anticipating TC formation.
Excerpted from the TWO at 1800 UTC 8/26/14:

“A tropical wave is forecast to move off the west coast of Africa late this week. Conditions appear to be favorable for some development thereafter while the system moves westward at 10 to 15 mph across the eastern Atlantic.

* Formation chance through 48 hours...low...near 0 percent.
* Formation chance through 5 days...medium...40 percent.”
Verifying 850 mb winds, vorticity, and mslp for 120 h: nada!
Gonzalo – GFS Forecasts Valid
00Z 12 October 2014
Genesis forecasts for Joaquin

- Little signal at long-range in GFS, broad low/trough in ECMWF
- ECMWF detected genesis about a day earlier than the GFS
A TROPICAL WAVE OVER WEST AFRICA IS EXPECTED TO MOVE OVER THE FAR EASTERN ATLANTIC IN ABOUT THREE DAYS. SOME DEVELOPMENT IS POSSIBLE AFTER THAT TIME WHILE THE SYSTEM MOVES WEST-NORTHWESTWARD AT 10 TO 15 MPH. THIS SYSTEM HAS A LOW CHANCE...NEAR 0 PERCENT...OF BECOMING A TROPICAL CYCLONE DURING THE NEXT 48 HOURS...AND A LOW CHANCE...20 PERCENT...OF BECOMING A TROPICAL CYCLONE DURING THE NEXT 5 DAYS.
A TROPICAL WAVE LOCATED OVER WEST AFRICA IS EXPECTED TO MOVE WESTWARD AT 10 TO 15 MPH...AND AN AREA OF LOW PRESSURE COULD FORM AFTER THE WAVE MOVES OFF OF THE COAST ON FRIDAY. SOME DEVELOPMENT OF THIS LOW IS POSSIBLE LATE THIS WEEK OR EARLY THIS WEEKEND BEFORE UPPER-LEVEL WINDS BECOME UNFAVORABLE BY EARLY NEXT WEEK. THIS SYSTEM HAS A LOW CHANCE...10 PERCENT...OF BECOMING A TROPICAL CYCLONE DURING THE NEXT 48 HOURS...AND A MEDIUM CHANCE...30 PERCENT...OF BECOMING A TROPICAL CYCLONE DURING THE NEXT 5 DAYS WHILE IT MOVES NEAR THE CAPE VERDE ISLANDS.
A broad area of low pressure associated with a tropical wave is producing showers and thunderstorms over western Africa. This system should move westward over the far eastern Atlantic Ocean on Friday... and near the Cape Verde Islands late Saturday. Environmental conditions appear conducive for development... and a tropical depression could form over the weekend. After that time... the environment is forecast to become less conducive while the system moves toward the west-northwest over the eastern Atlantic. This system has a medium chance... 40 percent... of becoming a tropical cyclone during the next 48 hours... and a medium chance... 50 percent... of becoming a tropical cyclone during the next 5 days.
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
Tropical Weather Outlook

- Gives a general synopsis of weather systems in the Atlantic basin that have the potential for tropical cyclone formation during the next 48 hours.
- Disturbances are color-coded by their likelihood/probability of formation: low, medium, or high.
- Issued every 6 hours during the hurricane season
  - 0000, 0600, 1200, 1800 UTC
  - 2 AM, 8 AM, 2 PM, 8 PM EDT
5-day Genesis Product

THIS SYSTEM HAS A LOW CHANCE...
10 PERCENT...OF BECOMING A TROPICAL CYCLONE DURING THE NEXT 48 HOURS...

THIS SYSTEM HAS A MEDIUM CHANCE...
40 PERCENT...OF BECOMING A TROPICAL CYCLONE DURING THE NEXT 5 DAYS.
### 5-day Genesis Product

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<th>Disturbance</th>
<th>1-2 Day (%)</th>
<th>3-5 Day (%)</th>
<th>1-5 Day (%)</th>
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</tr>
<tr>
<td>#3</td>
<td>0</td>
<td>20</td>
<td>20</td>
</tr>
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- 5-Day probability will always be the same or higher than the 2-day.
- Since the probabilities are additive, can back out the 3-5 day %
Overview graphic shows entire basin, with single disturbance graphics available to avoid cases of overlapping areas

(X) indicates initial location of disturbance, if it exists at the issuance time

Arrows connect initial position of disturbance with area of formation potential
Special Tropical Weather Outlook

- Issued **anytime** that there are significant changes with respect to disturbances in the regular Tropical Weather Outlook.

- Can be updated for either the 2- or 5-day probabilities

- Most commonly updated when formation probabilities are too low

- Often used to report findings of a recon invest mission
Verification Results of 2- and 5-Day Genesis Forecasts - Atlantic
Verification Results of 2- and 5-Day Genesis Forecasts - Pacific

48-h Genesis Forecasts - 2013-15 East Pacific Basin

5-day Genesis Forecasts - 2013-15 East Pacific Basin

N= 2009
N= 1869
Forecast Exercise