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.
Atlantic
Highly peaked with a secondary peak in mid-October

Eastern North Pacific
Bimodal distribution
Note that TC genesis is not a function of the number of available disturbances.
Typical Non-Tropical TC formation in the North Atlantic (fronts, upper-level lows)

On average, about 25% of Atlantic TCs form from non-tropical sources
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 ~5º
- Adequate ocean thermal energy - SST > 26ºC 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 ($10^5 \times m^2/s$) 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

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

Region of enhanced cyclonic vorticity generation

Background easterly flow

Disturbance

Day -2
Idealized CCKW-influenced TC genesis
Idealized CCKW-influenced TC genesis
Idealized CCKW-influenced TC genesis
Idealized CCKW-influenced TC genesis

Day +2

Newly-declared TC
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:

Conditional 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!
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
Convection grows stronger as more moisture flows into surface low.

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

Frictional convergence of moisture causes rising motion.

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

Air flows outwards and Coriolis turning forms upper anticyclone.

Stronger convection gives more latent heat.

Winds strengthen as low develops; frictional convergence.
“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.

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.

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

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 $\theta_e$ 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
Use of global models relevant for TC genesis forecasting:

- Global models, especially the ECMWF, GFS, and UKMET along with their ensembles are our primary tool for predicting TC genesis.
- The forecaster looks for consistency among the different models, as well as run-to-run consistency, to assess the likelihood of genesis.
- Recent upgrades to the ECMWF have probably improved that model’s performance, but changes to the GFS have apparently degraded its ability to forecast genesis.
- 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.
- Of all the global models used by the NHC, the Canadian global model typically shows the highest number of false alarms.
2014-2016 TC genesis events from the 2016 operational GFS

GFS 2016 TC genesis events
- Hits (352)
- False alarms (136)

2014-2016 TC genesis events from the 2017 parallel GFSX

GFSX 2017 TC genesis events
- Hits (430)
- False alarms (208)
GFS Genesis Problems

- 2017 GFS had issues with under-predicting genesis at longer time ranges in both basins
  - Atlantic: GFS hit 3 of 16 genesis events at 120 h (19%)
  - East Pacific: GFS hit 7 of 18 genesis events at 120 h (39%)
- GFS forecast only half of Atlantic TC formations 48 h in advance
- East Pacific better in the short range – GFS hit 13 out of 18 events at 48 h (72%)
Atlantic GFS Genesis Forecasts

2-day "High" Forecasts
GFS: 15
NHC: 45

5-day "High" Forecasts
GFS: 16
NHC: 89

Preliminary results courtesy of Dan Halperin

- 2-day GFS genesis forecasts had a lot of noise – low probabilities had an under-forecast bias; sample quite small at 40% and above
- 5-day results smoother, but persistent 10-20% under-forecast bias for most probabilities
East Pacific GFS Genesis Forecasts

2-day GFS Genesis Forecasts
- Generally OK, but a big low bias around 30%

5-day GFS Genesis Forecasts
- Results terrible – huge under-forecasts at low to medium probability ranges!

Preliminary results courtesy of Dan Halperin

- 2-day “High” Forecasts
  - GFS: 43
  - NHC: 52

- 5-day “High” Forecasts
  - GFS: 59
  - NHC: 111
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

11/8/2017 Annual HFIP Meeting 41
GFS Genesis Example – Lee (Genesis #2)

GOES-13 Visible Imagery – 1815 UTC 22 September

Little/No Signal Prior to Genesis
Web site for monitoring real-time model forecasts of cyclogenesis:
http://www.emc.ncep.noaa.gov/gmb/tpm/emchurr/tcgen/
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. (Wea. & Forecasting 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

- Ensemble-based probabilities generated (use consensus of this?)
- Several projects (e.g. Joint Hurricane Testbed), with the goal to provide objective genesis guidance
NHC Tropical Weather Outlook

- General assessment of activity in the tropics
- Assesses tropical cyclone formation potential during the next 5 days
- Chance of formation during the first 48 hours and the entire 5-day period are provided

Issued at 0000 UTC, 0600 UTC, 1200 UTC, 1800 UTC
Graphical Tropical Outlook

2-Day Formation Chance

Identifies current location of disturbed weather (discussed in the Tropical Weather Outlook)

Formation chance during the next 48 hours

- Categorical (Low, Medium, and High)
- Probabilities
Graphical Tropical Outlook

5-Day Formation Potential

- Shows formation potential during the next 5 days
- Initial location of disturbance (X) indicated, if existing at issuance time
- Shading represents potential formation area
- Active tropical cyclones not shown
- Graphic will show the location of active tropical cyclones beginning in 2017

Tropical Cyclone Formation Potential for the 5-Day Period Ending 8:00 pm EDT Tue Sep 25 2012
Chance of Cyclone Formation in 5 Days: ▼ Low < 40% ■ Medium 40-60% ▼ High > 60%

X indicates current disturbance location; shading indicates potential formation area.
Situational Awareness

Graphical Tropical Outlook

Tropical Outlook
July 28 @ 8am
2 Day – 30%
5 Day – 70%

Tropical Outlook
July 31 @ 8am
2 Day – 70%
5 Day – 70%
Special outlook issued to update discussion of the area of low pressure east of Florida.

Updated: An Air Force Reserve unit reconnaissance aircraft is investigating the area of low pressure centered about 110 miles east of Melbourne, Florida. While the low is well defined, the associated thunderstorm activity is just below the organizational threshold required to initiate tropical cyclone advisories. Environmental conditions continue to be favorable for development, and only a slight increase in the organization and persistence of the thunderstorm activity would result in the formation of a tropical depression.

Data from the reconnaissance aircraft indicate that peak sustained winds with the low are about 30-35 mph. The low is moving southwestward at around 5 mph, but is expected to turn westward tonight and northward by Wednesday when it will be near the east coast of Florida. If this system becomes a tropical cyclone, a tropical storm watch could be required for portions of the central or northern Atlantic coast of Florida. A turn toward the northeast near the southeastern U.S. coast is expected by Thursday.

* Formation chance through 48 hours...high...80 percent.
* Formation chance through 5 days...high...80 percent.

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* * *
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
Verification Results of 2- and 5-Day Genesis Forecasts - Atlantic

48-h Genesis Forecasts - 2013-15 Atlantic Basin

5-day Genesis Forecasts - 2013-15 Atlantic Basin

N= 1743

N= 1621
Verification Results of 2- and 5-Day Genesis Forecasts - Pacific
Out of ~60 tropical waves transiting the Atlantic basin each season, less than 1/10 develop. Why?

- A) Waves lose convection off of Africa due to cool waters and have less potential for development
- B) many of them are too close to the equator
- C) environmental factors are generally marginally conducive for development
- D) Waves are closely spaced together and constructively interfere with one another
- E) Both A and C
The Atlantic basin is a marginal basin for TCs

• A) True
• B) False
The instability over the Atlantic basin is greatest:

• A) Late in the hurricane season
• B) Early in the hurricane season
• C) Early to mid hurricane season
• D) None of the above
As a general rule, pressures falls of what magnitude, associated with a tropical disturbance, are indicative that TC genesis is imminent?

• A) 1 mb/24 h
• B) 2 mb/24 h
• C) 3 mb/24 h or more
• D) 0.5 mb/24 h
Stage 1 of TC genesis results in the formation of what phenomenon:

• A) Disorganized convection
• B) An upper-level anticyclone
• C) Often a large burst of convection
• D) A mesoscale convective vortex
• E) C and D
If the 2- and 5-day genesis probabilities are equal in the TWO, what does this mean?

• A) TC genesis, if it occurs, is likely to occur within 2 days
• B) TC genesis, if it occurs, is likely to occur within 5 days
• C) TC genesis, if it occurs, is likely to occur within 3 to 5 days
• D) TC genesis, if it occurs, is likely to occur in a few hours
The opening of an “invest” system signifies that:

• A) NHC is on the verge of issuing TC advisories on that system
• B) NHC wishes to monitor a particular system of interest more carefully
• C) NHC intends to increase the genesis probabilities of this system soon
• D) NHC knows very precisely where and how strong the invest system is
About what percentage of Atlantic TCs form from non-tropical sources each season:

• A) 10%
• B) 50%
• C) 25%
• D) 5%
The requirement that a TC has organized deep convection is:

- A) an objective criterion that can be proven
- B) somewhat subjective
- C) arbitrary and a man-made definition
- D) B and C
Forecast Exercise