A Brief History of Tropical Cyclone Field Programs

Michael M. Bell

With contributions from many, many people...
Motivation

• Many outstanding field experiments on TCs have been conducted over the years, with significant contributions from hundreds of individuals
• Impossible to cover everything, so I focused on results I felt were most relevant for upcoming 2020 field experiments
• Biased towards my own experience and research, but there are many, many more science impacts than those listed here
• Apologies in advance if I forgot something crucial!
The Hurricane's Inner Core Region. I. Symmetric and Asymmetric Structure

Dennis J. Shea and William M. Gray

Dept. of Atmospheric Science, Colorado State University, Fort Collins 80521

(Manuscript received 14 July 1972, in revised form 1 August 1973)
Composite 700 hPa Structure from Hurricanes 1999-2012
*From Martinez et al. (2017)*

**Tangential Wind**
- Eye (< 0.6RMW)
- Inner-core (0.6-2RMW)
- Outer-core (> 2RMW)

**Vertical Vorticity**
- 3 significant differences

![Graphs showing tangential wind and vertical vorticity profiles](image-url)
Track

Intensity

Structure

Environment

Rainfall

NHRP (1957-1969)

Project STORMFURY (1962 - 1983)
Modification was attempted in four hurricanes on eight different days. On four of these days, the winds decreased by between 10 and 30%. The lack of response on the other days was interpreted to be the result of faulty execution of the seeding or of poorly selected subjects.

However, in the mid-1980s observations in unmodified hurricanes indicated:
1. That cloud seeding had little prospect of success because hurricanes contained too much natural ice and too little supercooled water.
2. That the positive results inferred from the seeding experiments in the 1960s stemmed from inability to discriminate between the expected results of human intervention and the natural behavior of hurricanes.
Mesoscale and Convective-Scale Characteristics of Mature Hurricanes. Part I: General Observations by Research Aircraft

DAVID P. JORGENSEN
NOAA, Atlantic Oceanographic and Meteorological Laboratory, Hurricane Research Division, Miami, FL 33149

(Final manuscript received 7 February 1983, in final form 27 December 1983)

FIG. 4. Profiles of radar reflectivity, tangential wind $V_T$, radial wind $V_R$, cloud water content $W_C$, vertical wind $W_V$, temperature $T$, and dew point $D_p$, from (a) Hurricane Anita, (b) Hurricane Frederic, (c) Hurricane Allen on 1 August, and (d) Hurricane Allen on 8 August. All wind data are relative to the moving storms. The radar reflectivity cross section was generated by compositing vertical scans from the tail radar at four samples per min. Locations of the peaks of the horizontal and vertical wind are indicated in parentheses. The aircraft flew from west of the centers inward to the eyes.
Airborne Doppler Radar Observations in Hurricane Debby

Frank D. Marks, Jr.¹ and Robert A. Houze, Jr.²
FIG. 3. (a) Time–height cross section of vertical incidence tail radar reflectivity (dBZ) from LA for 1721–1728 UTC. The LA flight track was at 450 m. Solid and dashed lines denote vertical velocity, and radar reflectivity is denoted by colors using the color scale on the right. (b) Time series plots of $w$, horizontal wind speed, $P_s$, and $\theta_e$ for the period 1721–1730 UTC. Updrafts labeled 1, 2, 3, and 4 and wind speed peaks I and II are described in the text. The thick dashed lines in (b) approximately delineate the outer and inner radii of strong eyewall reflectivity maxima in the lower troposphere (1 - 5-km altitude).

From Marks et al. (2008)
Elsberry, 1989: International Experiments to Study Tropical Cyclones in the Western North Pacific*
Presented at Second International Workshop on Tropical Cyclones, 27 November 1989, Manila, Philippines
Interaction of Typhoons with the Taiwan Orography. Part I: Upstream Track Deflections

Tien-Chiang Yeh* and Russell L. Elsberry

Department of Meteorology, Naval Postgraduate School, Monterey, California

(Manuscript received 20 January 1993, in final form 15 June 1993)

Dec. 1993

Yeh and Elsberry

Zonal acceleration, but some southward deflection relative to barrier blocking effect

Zonal deceleration and southward deflections

Only small oscillations about track as in ocean control -- No barrier effect

Northward deflection relative to blocking effect

REGION-C  REGION-B  REGION-A

Fig. 27. Schematic summary of upstream track deflections in three regions for west-moving tropical cyclones approaching Taiwan.
Fig. 3. Dropwindsonde wind speed profile from the eyewall of Hurricane Georges at 0008 UTC 20 Sep 1998.

Fig. 8. Mean hurricane wind speed profiles for the eyewall and outer-vortex regions. Wind speeds are averaged and expressed as a fraction of the profile wind speed at 700 hPa. The minimum number of profiles used to construct the averages is also indicated.

GPS Dropwindsonde Wind Profiles in Hurricanes and Their Operational Implications

James L. Franklin
Tropical Prediction Center, National Hurricane Center, NOAA/National Weather Service, Miami, Florida

Michael L. Black
Hurricane Research Division, NOAA/National Oceanic and Atmospheric Administration, Miami, Florida

Krystal Valde
Tropical Prediction Center, National Hurricane Center, NOAA/National Weather Service, Miami, Florida

(Manuscript received 9 June 2002, in final form 3 October 2002)
The storm center = (123.8, 20.9)
The radius of 15m/s wind = 250 km (CWB)

short barb: 5 KTs; long barb: 10 KTs; triangle: 50 KTs
(1 KT = 0.5144 m/s)
Track

Intensity

Structure

Rainfall

Environment

NHRP (1957-1969)

STORMFURY (1962 - 1983)

Hurricane Rainband and Intensity Change Experiment (RAINEX 2005)

NOAA Intensity Forecasting Experiment (IFEX 2005-2019)

TCM-90

DOTSTAR (2003-)

TCM-90
Kinematic structure of convective-scale elements in the rainbands of Hurricanes Katrina and Rita (2005)

Deanna A. Hense^1 and Robert A. Houze Jr^1

Received 23 September 2007; revised 14 January 2008; accepted 25 February 2008; published 5 August 2008.

Fig. 35. Composite of Doppler radar data collected in Hurricane Katrina by an aircraft during 2026–2036 UTC 28 Aug 2005 showing the structure of the principal rainband when the storm was at category-5 intensity. (a) Plan view showing the reflectivity pattern (color shading) and Doppler-derived airflow (vectors) at the 35-km level observed while the aircraft was flying along the track shown by the blue line. The straight black line passes through a convective-scale updraft associated with one of the intense reflectivity cells. (b) The reflectivity and Doppler-radar-derived airflow in the plane of the cross section along the black line in (a). (c) Plan view showing the reflectivity pattern and Doppler-derived airflow at the 20-km level observed while the aircraft was flying along the track shown by the blue line. (d) The reflectivity and Doppler-radar-derived airflow in the plane of the cross section along the black line in (c). (Adapted from Hense and Houze 2008.)
Hurricane Intensity and Eyewall Replacement

Robert A. Houze Jr.,^1 Shuyi S. Chen,^2 Bradley F. Smull,^1 Wen-Chau Lee,^3 Michael M. Bell^3
Fig. 8. North–south vertical cross section of quad-Doppler radar analysis from N42 and ELDORA and in situ flight level data at 1.5 km from N42. (a) Radar reflectivity (color), vertical velocity (contour, m s⁻¹), and secondary circulation (vector); (b) wind speed, vertical velocity, surface pressure, and pseudoequivalent potential temperature. Note that axes are reversed to indicate a north–south vertical cross section, not an axisymmetric mean.

From Bell et al. (2012)
Track

Intensity

Structure

Rainfall

Environment

NHRP (1957-1969)
STORMFURY (1962-1983)
RAINEX 2005
TCM-90
DOTSTAR (2003-)
IFEX (2005-)

THORPEX Pacific Area Regional Campaign (TPARC)
Tropical Cyclone Structure (TCS08)
From Houze et al. 2009

From Bell and Montgomery (2010)

Hagupit (2008) from TPARC/TCS08

Ophelia (2005) from RAINEX

From Houze et al. 2009
Typhoon Sinlaku (2008)

Mean dBZ

Altitude (km)

Radius (km)

Mean Divergence ($10^{-4}$s$^{-1}$)

Foerster et al. 2014
From Black et al. (2002)

From Didlake and Houze (2013)

From Foerster et al. (2014)

<table>
<thead>
<tr>
<th>Storm</th>
<th>Ocean basin</th>
<th>Lat (°N)</th>
<th>Wind [kt (m s⁻¹)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jimena</td>
<td>East Pacific</td>
<td>13.4</td>
<td>114 (59)</td>
</tr>
<tr>
<td>Olivia</td>
<td>East Pacific</td>
<td>17.5</td>
<td>115 (59)</td>
</tr>
<tr>
<td>Guillermo</td>
<td>East Pacific</td>
<td>13.6</td>
<td>123 (63)</td>
</tr>
<tr>
<td>Sinlaku</td>
<td>West Pacific</td>
<td>33.0</td>
<td>68 (35)</td>
</tr>
</tbody>
</table>
Stratiform precipitation spins-up mid-levels
Deep convection spin-ups low-levels
Both are important to genesis

From Bell and Montgomery (2019)
From Rogers et al. (2017)
Hurricane Patricia
1700-1800 UTC 23 October (2015)

(a) Tangential Velocity (shaded, m s⁻¹), Transverse Circulation (vectors, m s⁻¹)

(b) Potential temperature (shaded, K), Absolute Angular Momentum (contoured, 10⁶ m² s⁻¹)

From Martinez et al. (2019)
Hurricane Patricia
1700-1800 UTC 23 October (2015)

(a) Absolute Vorticity (shaded, $10^{-3}$ s$^{-1}$), $\partial \theta / \partial z$ (contoured, K km$^{-1}$)

(b) Dry Potential Vorticity (PVU, $10^{-6}$ K kg$^{-1}$ m$^2$ s$^{-1}$), Transverse Circulation (vectors, m s$^{-1}$)

From Martinez et al. (2019)
Track

Intensity

Structure

Environment

Rainfall

NHRP (1957-1969)
STORMFURY (1962 - 1983)
TEXMEX (1992)
RAINEX 2005
TPARC/TCS08
ITOP 2010
SHOUT (2016)

TCM-90
CAMEX-3 (1998)
DOTSTAR (2003-)
IFEX (2005-)
TCSP(2005)
PREDICT 2010
HS3 (2012-2014)
TCI-15
Baiyu Front Flooding in Japan 2018

Five largest natural catastrophes in 2018 by overall losses (in U.S. billions)

- Camp Wildfire | U.S. | Nov. 8-25  | $16.5
- Hurricane Michael | U.S., Cuba | Oct. 8-10 | $16.0
- Hurricane Florence | U.S. | Sept. 10-27 | $14.0
- Typhoon Jebi | Japan, Taiwan | Sept. 1-6 | $12.5
- Flood, landslide | Japan | July 5-9 | $9.5

Source: Munich Re Group
George Perret/USA TODAY

States setting hurricane rainfall (in inches) records since 2017

<table>
<thead>
<tr>
<th>State</th>
<th>Rainfall (inches)</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texas</td>
<td>60.58</td>
<td>1,865</td>
</tr>
<tr>
<td>Hawaii</td>
<td>52.02</td>
<td>1,321</td>
</tr>
<tr>
<td>North Carolina</td>
<td>35.93</td>
<td>913</td>
</tr>
<tr>
<td>South Carolina</td>
<td>23.63</td>
<td>600</td>
</tr>
</tbody>
</table>

Source: National Weather Service
Hurricane Harvey’s path and intensity between best track and WRF forecasts

From Feng and Bell (in prep)
Probability density function $Z-Z_{DR}$

From Feng and Bell (in prep)
Environment

Rainfall

Structure

Intensity

Track

PRESENT

T-PARCII

KPOP-TP

TCRI/APHEX

NHRP (1957-1969)
STORMFURY (1962 - 1983)
TEXMEX (1992)
RAINEX 2005
TPARC/TCS08
ITOP 2010
SHOUT (2016)

TCM-90
CAMEX-3 (1998)
DOTSTAR (2003-)
IFEX (2005-)
TCSP(2005)
PREDICT 2010
HS3 (2012-2014)
TCI-15
PRECIP Conceptual Framework

- The heaviest precipitation occurs where the rainfall rate is the highest for the longest time

\[ R = I \times D \]

- \( R \) = rainfall accumulation
- \( I \) = rainfall intensity
- \( D \) = rainfall duration

- **Primary objective** is to simplify complexity of multi-scale interactions by identifying key ingredients and processes in the two limiting cases of high intensity and long duration events in a moisture-rich environment
SQ1: Are the primary forcing mechanisms for extreme rainfall due to unique dynamic or thermodynamic processes, or some combination of both?

SQ2: Do extreme rainfall events result from fundamentally different physical processes compared to ordinary rainfall events, or are they just due to stronger forcing and an optimal combination of ingredients?

SQ3: What are the most important factors in predictive skill for warm season extreme rainfall, and what model improvements, physical parameterizations, or observations and their effective assimilation will result in the largest forecast improvements?
From Wu et al. (2017)

From Chen et al. (2007)

From CWB Database
NCAR Micro-Pulse Differential Absorption LIDAR (DIAL)

- Accurate, continuous profiles of water vapor every 5 minutes in clear-air
- Low-cost, low-maintenance, long life & stable for unattended operations
- Eye-safe & invisible radiation
9M core-hours allocated in 2021 by NCAR CISL HPC Allocations Panel (CHAP) on Cheyenne (to be requested again in 2022)

Core-hours donated by NCAR/MMM
2x daily

MPAS Global 15 km to 3 km

PSU WRF EnKF 3 km
Real-time Himawari & S-Pol Assimilation

WRF 1-km over domain
LES 111-m resolution over Yonaguni island

40-members, 4x daily

IOPs (research)
Lessons Learned

• It helps to have a field project in the most active hurricane season on record. Kudos to Bob Houze for an outstanding multi-year seasonal prediction!
• Field experience is very important for early career scientists
• Synergy between modeling and observations continues to grow and is important aspect of field campaigns
• New insights are closely coupled with new technologies, but human brain is still best technology we have
• Expect the unexpected and plan for contingencies
• *Partnerships are the key to success!*
Thank you!

NHRP (1957-1969)
STORMFURY (1962 - 1983)
TEXMEX (1997)
RAINEX 2005
TPARC/TCS08
ITOP 2010
SHOUT (2016)

PRECIP
TAHOPE
T-PARCII
KPOP-TP
TCRI/APHEX

TCM-90
CAMEX-3 (1998)
DOTSTAR (2003-)
IFEX (2005-)
TCSP(2005)
PREDICT 2010
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