Redfield to STORMFURY: A History of Hurricane Research

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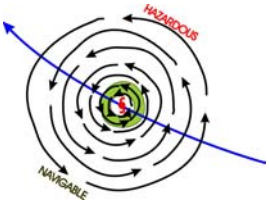
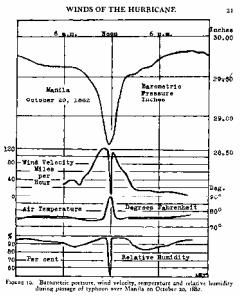
The Redfield-Reid-Piddington Paradigm

- **Benjamin Franklin**'s observation that storms move rather than form in place
- **William Redfield**'s notion of circular storms--based upon tree-falls after the New-England hurricane of September 1821
- Collaboration with Col **William Reid** of the Royal Engineers
- **Henry Piddington** and the *Sailor's Hornbook…* 1848
- **Joseph Henry** established telegraph reporting and weather maps in the US, 1847-49
- **Fr. Viñes** at Belén issued first hurricane forecast 11 SEP 1875 (2 days in advance!)
- Ships began to have radios from 1904

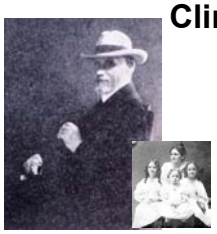


WINDS and PRESSURE of a HURRICANE

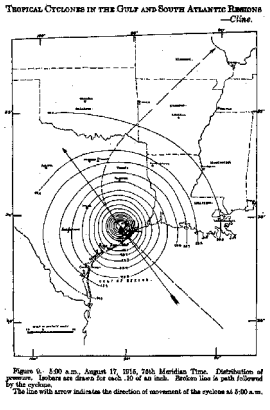
- Jesuit Fathers in Cuba and the Philippines
- **Fr. Viñes** built upon hurricane heritage of the Spanish empire
- **Fr. Depperman** in Manila
- Typhoon in Manila 20OCT1882 →
- Anglos appropriated this knowledge, often without giving proper credit



Isaac Monroe Cline

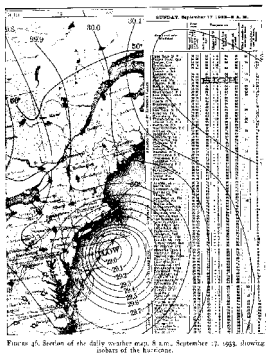


- MIC at Galveston in 1900
- Wrote *Tropical Cyclones* (1926)
- First North American book since Redfield that added new knowledge
- Pioneered
  - Composite analysis
  - Study of storm surge



Basic Knowledge from the 1940-1960s

- Books:
  - Ivan Ray Tannehill, *Hurricanes, Their Nature and History* (1938)
  - Herbert Riehl, *Tropical Meteorology* (1954)
  - Dunn and Miller: *Atlantic Hurricanes* (1960)
- Riehl taught military meteorologists at the University of Chicago during the WWII (including Joanne Simpson)



The First Hurricane Penetration: LTCOL Joseph Duckworth

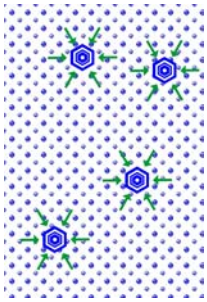
27 July 1943, AT-6 TEXAN
"Surprise Hurricane"
Nav: Lt. Ralph O'Hare
Wx: Lt William Jones-Burdick

1944 Was a Bad Year For Tropical Cyclones

- Great Hurricane (Mid SEP)
  - Affected US Coast from Carolinas to New England
  - Sank a Destroyer and 2 Coast Guard Cutters
  - Drowned 390, primarily mariner
- First "routine" aerial reconnaissance
- Halsey's Typhoons
  - Dec 18 1944
  - Sank 3 Destroyers
  - Killed 790 Sailors
  - Many other ships damaged
  - 186 Aircraft Destroyed
  - Happened again in June 1945

Supercooled Water

- Both freezing and condensation generally require nuclei to start the process
- Natural clouds have plenty of condensation nuclei (100,000/liter) but few freezing nuclei (10-100/liter)
- Consequently clouds colder than 0°C often contain liquid H_20 that has not yet frozen.
- May be as cold as -20°C
- When some ice does form,
  - the ice crystals grow
  - at the expense of supercooled water droplets
  - Bergeron-Findeisen process
- Artificial freezing nuclei can promote growth of snow that melts to form rain



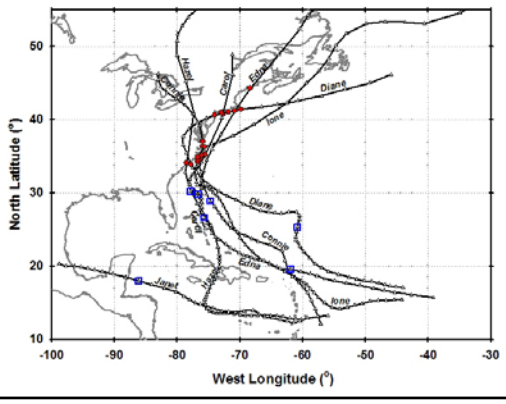
Cloud Seeding

- Vincent Shaefer discovered that CO_2 crystals can start clouds freezing, 1946
- Bernard Vonnegut discovered that Silver Iodide works, too
- Kurt Vonnegut and Ice-9
- Irving Langmuir goes nuts

PROJECT CIRRUS

- Army, Navy, General Electric Co.
- GE quits because of legal worries
- Extensive seeding with AgI smokes to increase rainfall
- Exaggerated claims of success
- Seeded a hurricane off Georgia/Florida coast
  - 13 October 1947
  - 80 kg of solid CO_2
  - Some change in clouds on radar but no other documented changes
  - Reversed track to landfall in Georgia and South Carolina
- But Robert Simpson worked to start a National Hurricane Research Project, modeled on the Thunderstorm Project

Memorable Hurricanes of 1954 & 1955



Results of the 1954 & 1955 Seasons

- Hurricanes Carol, Edna, Hazel, Connie, Diane & Ione
  - 400 dead
  - $2B damage (adjusted to 2005)
- Congress starts National Hurricane Research Project

National Hurricane Research Project

- Study hurricane formation
- Study hurricane structure and dynamics
- Seek means for hurricane modification
- Seek means for improvement of forecasts

NHRP, 1959

Started in West Palm Beach Using Military Aircraft

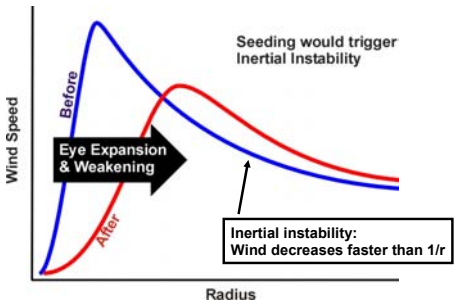
Soon Had Its Own Airplanes and Crews

Modification Strategy

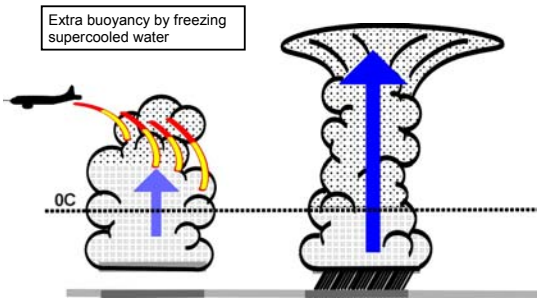
- Well thought-out, mainstream science
- Trigger symmetric instability, or
- Construct an outer eyewall, through cloud seeding with AgI
- Required abundant supercooled water
- Expanded eye should have weaker winds through partial conservation of angular momentum

Bob and Joanne Simpson

Initial STORMFURY Hypothesis

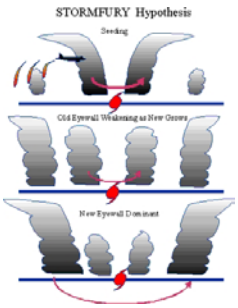


Dynamic Seeding

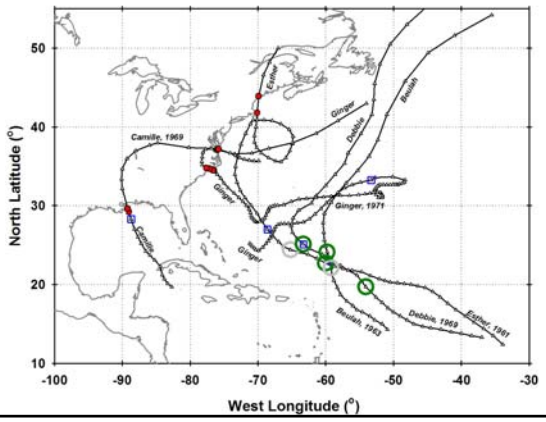


Revised STORMFURY Hypothesis

- Targeted intense hurricanes with small eyes
- Seed the first rainband outside the eye
- Build a new eyewall around the old
- New eyewall strangles the old



STORMFURY Hurricanes



Apparent Successes

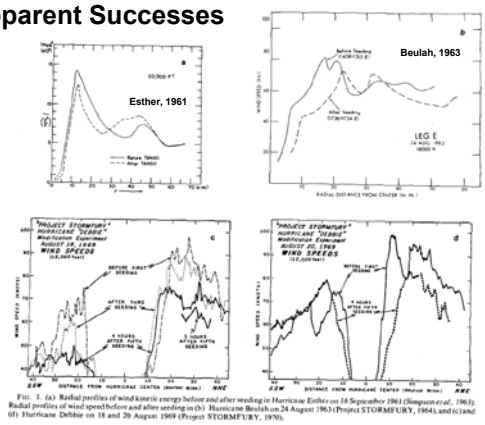


FIG. 1. (a) Radial profiles of wind kinetic energy before and after seeding in Hurricane Esther on 16 September 1961 (Simpson et al., 1963). Radial profiles of wind speed before and after seeding in (b) Hurricane Beulah on 24 August 1963 (Project STORMFURY, 1964), and (c) and (d) Hurricane Debbie on 18 and 20 August 1969 (Project STORMFURY, 1970).

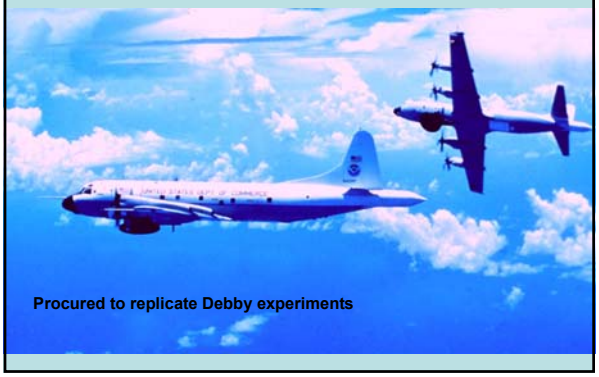
Summary of STORMFURY Experiments

Year	Hurricane	Result
1961	Esther	2 Attempts: I, Apparently slowed intensification; II, Missed eyewall (Hypothesis I)
1963	Beulah	2 Attempts: I, Apparently missed. Did not fit experimental design. II; Eye reformed, winds weaker by 20%
1969	Debbie	2 Attempts, both apparently successful. Winds apparently by weakened by 31% and 15%
1971	Ginger	2 Attempts, did not fit experimental design, no effect

Feasibility Criteria

- ***Political***: Willingness to spend money and accept risks
- ***Operational***: Aircraft, intruments, scientists and aircrew available
- ***Microphysical***: Clouds with supercooled water
- ***Dynamic***: Hurricanes vulnerable to modification strategy
- **Statistical**: Had to be able to distinguish the results of seeding from natural behavior

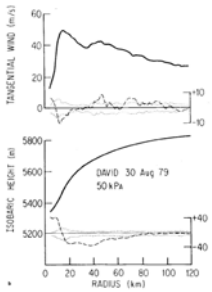
NOAA WP-3Ds



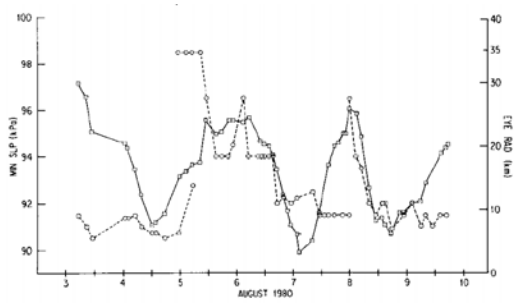
Procured to replicate Debby experiments

Lack of hurricanes in the target area led to extensive observations of un-modified hurricanes

Concentric Eyewalls in Unmodified Hurricanes

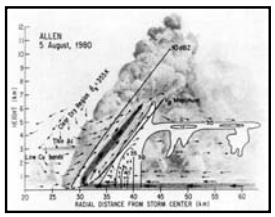


Hurricane Allen



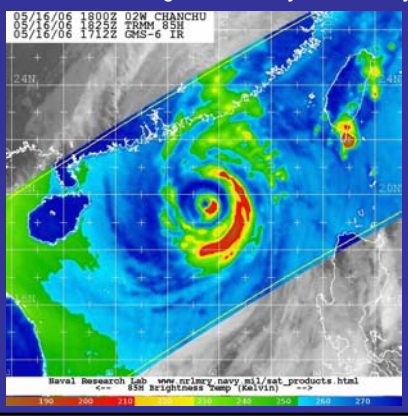
New Understanding of Structure & Dynamics

- Most updrafts weaker than previously thought
- Inclined updrafts unloaded condensate
- Liquid water contents lower
- Observations of widespread radar brightband
- Widespread stratiform rain and mesoscale up- & downdrafts



Jorgensen 1984b

Spaceborne Remote Sensing Revealed Many Concentric Eyewalls



Particle Measurement Systems Probes

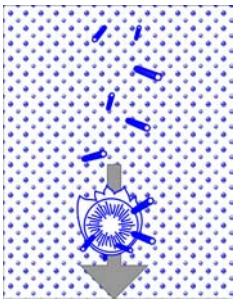
Little supercooled water at temperatures < -10ºC found

ICE

←WATER

Ice Multiplication

- Radar and Knollenberg probes showed little ice
- Hallett-Mossop Process
  - Graupel undergoing wet accretion of supercooled clouds droplets grow whiskers-like ice crystals
  - $-8 \leq T \leq -3$ºC,
  - Droplet diameter > 23 μm
  - Break off
  - Natural cloud seeding
- Happens in maritime clouds only
- Explains lack of supercooled water
- Doesn't look good for cloud seeding in the tropics



Hallett & Mossop, 1974, *Science*

STORMFURY Abandoned Because

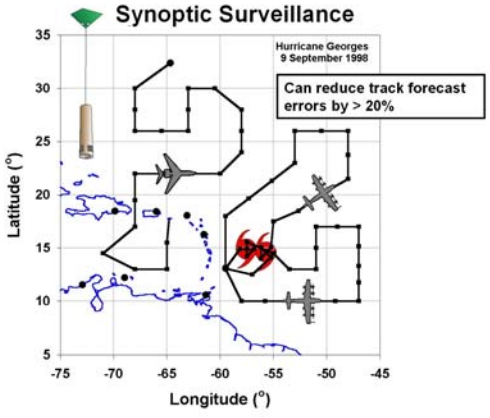
- Limited supercooled water
- Eye expansion happens in unmodified hurricanes
- Political difficulty with finding experimental subjects

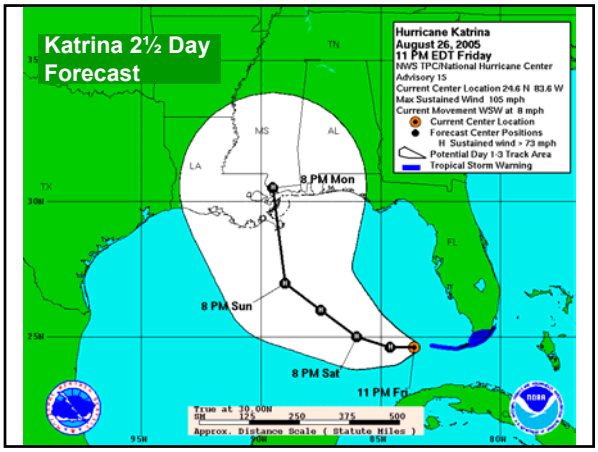
Protocol for Future Hurricane Modification Strategies

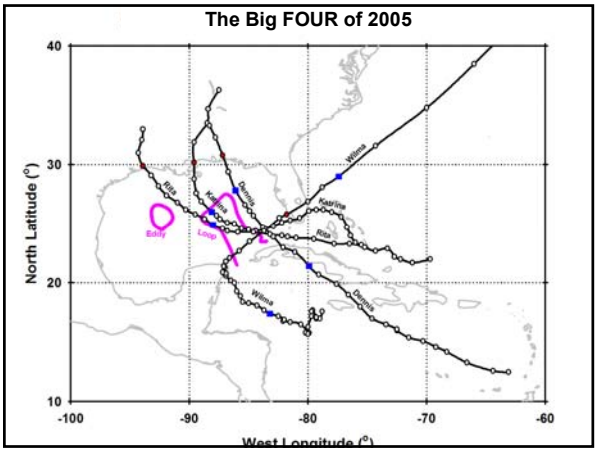
- Laboratory or small-scale field trial
- Numerical simulation
- Quantitative plan for logistics and operations
- Assessment of benefits in relation to costs

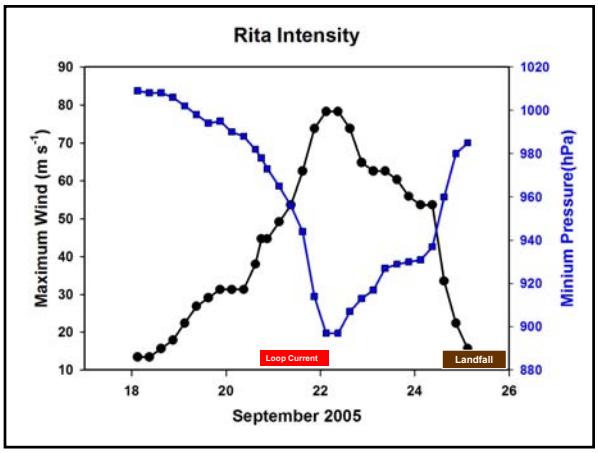
Is There Life After STORMFURY?

Synoptic Surveillance









2007 Research Priorities

- Keeping Momentum on Track Forecasts
- Intensity—Rapid Deepening
  - Atmospheric environment, shear and …
  - Oceanic heat source and coupling
  - Hurricane's internal dyanmics
- Forecasting impacts
- Climate change?
- Next Generation Models
  - Formulation
  - Initialization