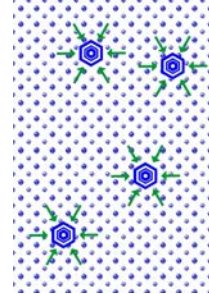


MET 4532

Lecture 26
Hurricane Modification
01NOV17

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 many clouds colder than 0°C contain liquid H₂O 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 CO₂ crystals can start clouds freezing, 1946
- Bernard Vonnegut discovered that Silver Iodide works, too
- Ice-9
- Irving Langmuir goes nuts



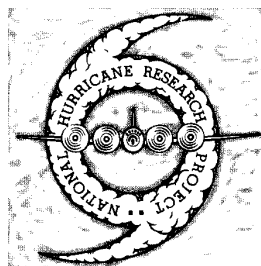
PROJECT CIRRUS



- 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 CO₂
 - Some change in clouds on radar but no other documented changes
 - Reversed track to landfall in GA/SC

Results of the 1954 & 1955 Seasons

- Hurricanes Carol, Edna, Hazel, Connie, Diane & Ione struck US
 - 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



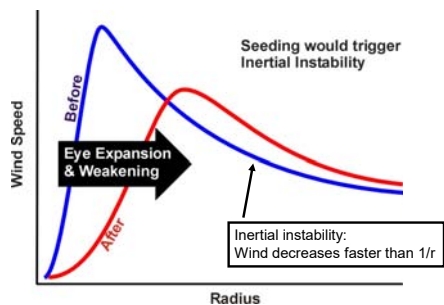
Modification Strategy

- 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

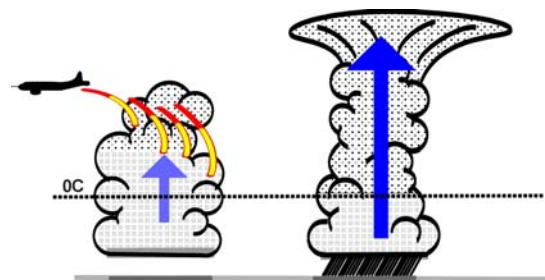
Bob and Joanne Simpson



Initial STORMFURY Hypothesis

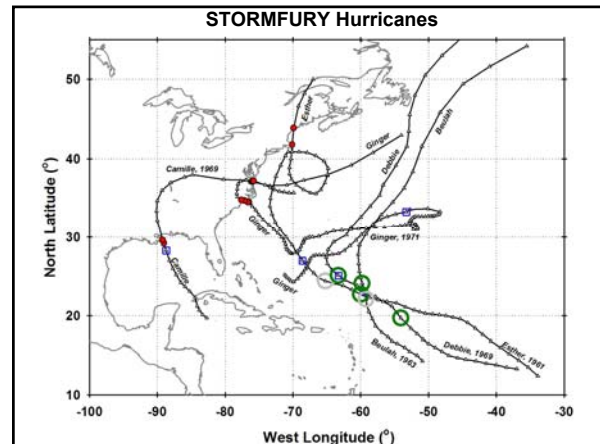
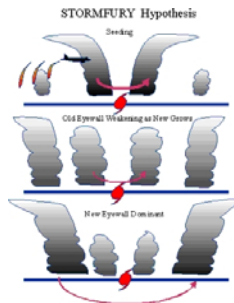


Dynamic Seeding



Revised STORMFURY Hypothesis

- Target 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 Apparent Successes

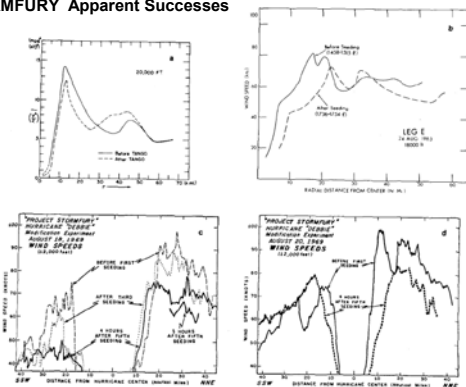


FIG. 1. (a) Radial profiles of wind kinetic energy before and after seeding in Hurricane Esther on 16 September 1961 (Simpson et al., 1963). (b) Radial profiles of wind speed before and after seeding in Hurricane Beulah on 24 August 1963 (Simpson et al., 1964). (c) Hurricane Debbie on 18 and 20 August 1969 (Project STORMFURY, 1970). (d) Hurricane Ginger on 18 and 20 August 1971 (Project STORMFURY, 1970).

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 accept risk
- **Operational:** Aircraft, instruments, 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 behaviour

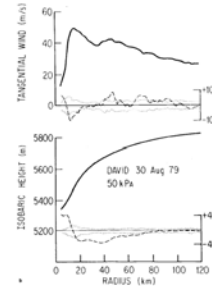
NOAA WP-3Ds



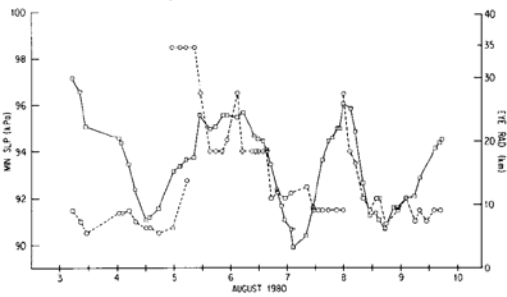
Lack of hurricanes in the target area led to extensive observations of unmodified hurricanes



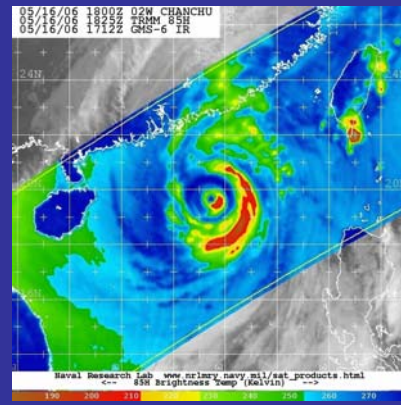
Concentric Eyewalls in Unmodified Hurricanes



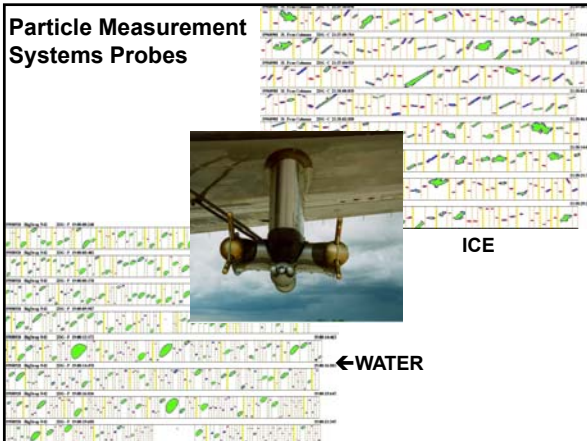
Hurricane Allen



Spaceborne Remote Sensing Revealed Many Concentric Eyewalls

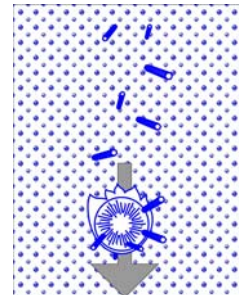


Particle Measurement Systems Probes



Supercooled Water?

- Radar and Knollenberg probes showed little supercooled water
- Hallett-Mossup Process
 - Graupel falling in supercooled clouds grow whiskers-like ice crystals
 - Break off
 - Natural cloud seeding
- Happens in maritime clouds only
- Doesn't look good for cloud seeding in the tropics

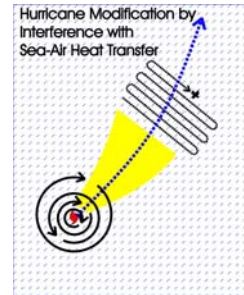


STORMFURY Abandoned Because

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

Other Strategies

- Slicks to retard heat surface heat transfer
- Artificial ocean cooling
- Nuke-em
- Fans to blow hurricanes away from shore
- Exploit sensitivity to initial conditions
- Get them while they are little
- Most proposals underestimate the scale of the undertaking



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

SUMMARY

- Cloud seeding with Silver Iodide
 - Intended to freeze supercooled water
 - Dynamic seeding caused extra buoyancy from latent heat released
 - Mainstream science in 40s – 60s
- Hurricane modification was part of the original NHRP mission
- STORMFURY Hypothesis
 - First, trigger symmetric instability
 - Second, build new outer eyewall through cloud seeding
- Tried 8 times in 4 hurricanes with apparent 50% success
- Abandoned because of
 - Too little supercooled water (Hallett-Mossup process)
 - Naturally occurring concentric eyewall cycles
 - Political/ Legal problems, "Not in MY ocean..."

NEXT TIME: E 227-238,
S&W 203-221