



Modifying the Hurricane Hazard: Dream or Reality

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**Hurricane Mitigation Leadership Forum
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WeatherPredict
CONSULTING INC.

History of Hurricane Modification Efforts

Cloud Seeding:

- In 1946, Vincent Shaefer and Irving Langmuir (1932 Nobel Prize in chemistry) discovered that CO_2 crystals (dry ice) can turn supercooled water in clouds into ice crystals. “Seeding” those clouds with dry ice would encourage precipitation.
- In 1948, Bernard Vonnegut discovered that Silver Iodide (AgI) works even better



Project CIRRUS (1947)

- Was a pioneering weather modification effort by Army, Navy, General Electric Co. headed by Langmuir
- Seeded a hurricane off Georgia/Florida coast using a B-17 bomber
 - 80 kg of Crushed Dry Ice
 - Some change in clouds on radar but no other documented changes
- The hurricane was moving east before the seeding but reversed course after seeding and came ashore near Savannah, Georgia
- Some people blame the seeding for hurricane's turn to the west (Associated Press, *Time* magazine), including lead U.S. Weather Bureau hurricane forecaster Grady Norton

B-17 bomber



1947 Hurricane: Oct. 9-16



Summary of Project CIRRUS

- Scientists had no theory of how seeding should effect a hurricane. Project CIRRUS was canceled and attempts to modify hurricanes were set back for many years

- After the experiment, Langmuir wrote:

“The main thing that we learned from this flight is that we need to know enormously more that we do at present about hurricanes....I think that, with increased knowledge, we should be able to abolish the evil effects of these hurricanes”.

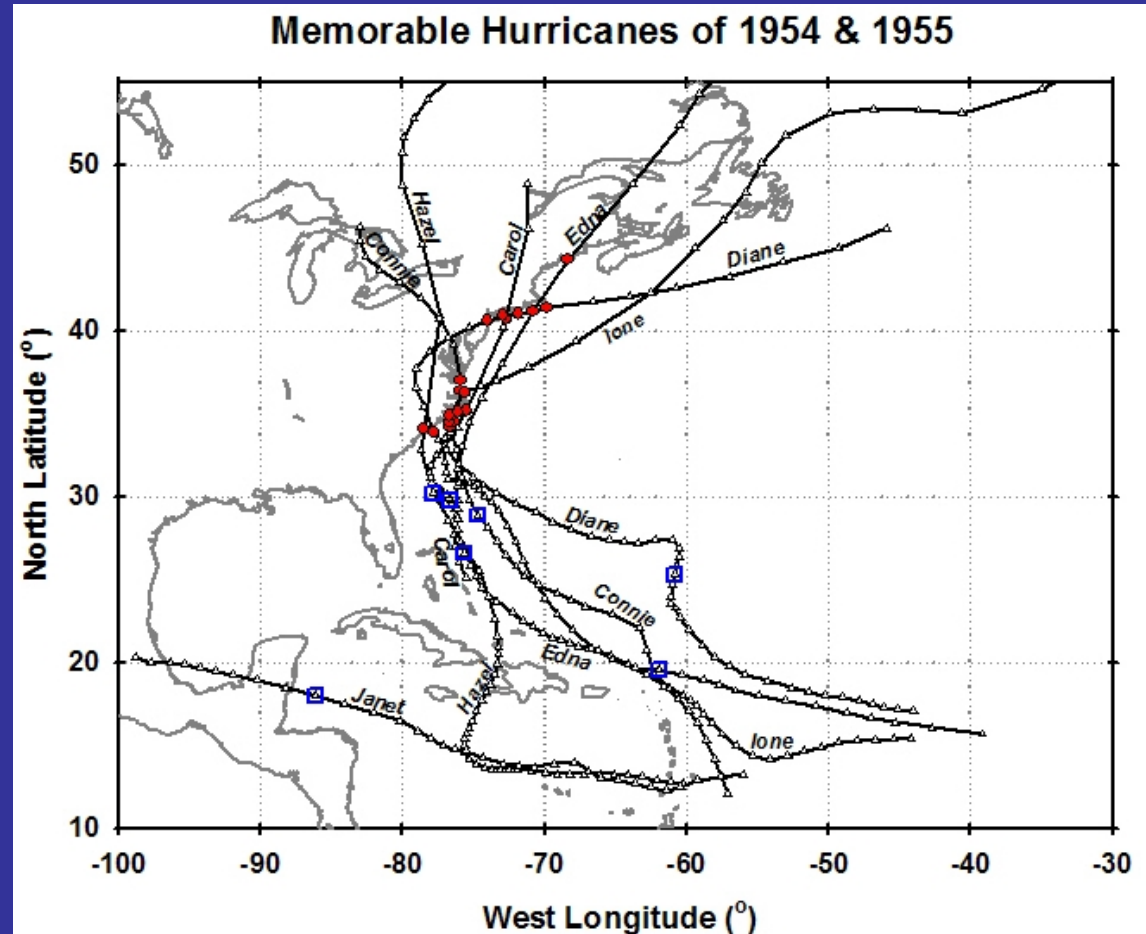
East Coast Blasted by Hurricanes in 1954-55

Results: 400 dead, \$2B damage (adjusted to 2005)

1954: Carol, Edna and Hazel

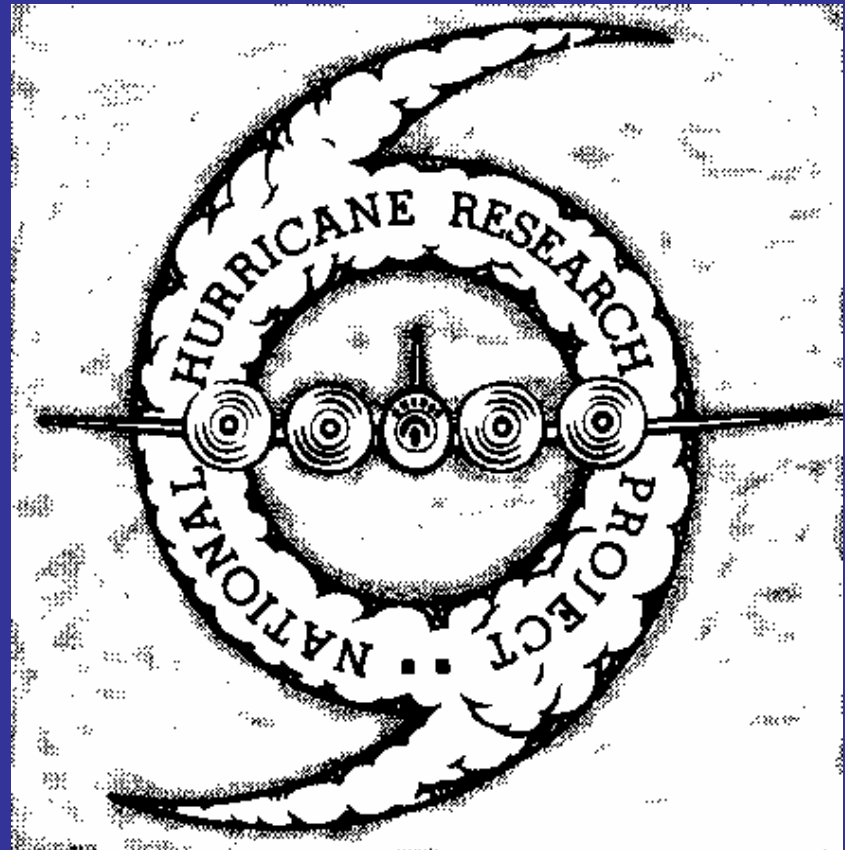
1955: Connie, Diane and Ione

Navy P2-V Lost in Hurricane Janet



National Hurricane Research Project

- The results of the 1954-55 hurricane seasons prompted Congressional action in 1955 mandating the formation of the National Hurricane Research Project under the U.S. Weather Bureau



National Hurricane Research Project

Goals:

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

Started in West Palm Beach
using a military aircraft



Hurricane Modification Project STORMFURY

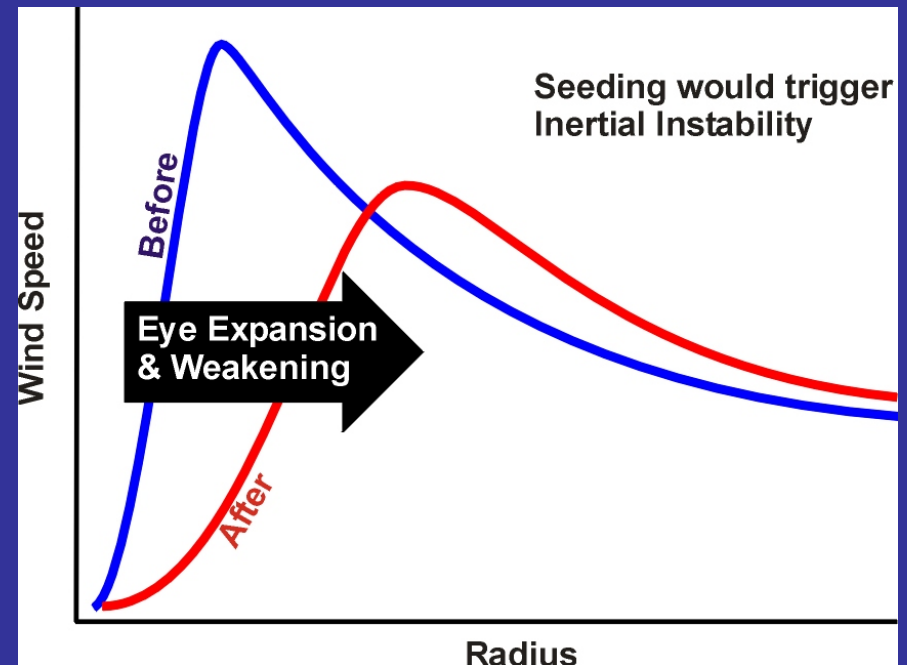
- Began in 1961 under initial leadership of Robert and Joanne Simpson
- The Simpsons hypothesized that seeding could reduce hurricane wind speed by 10-15%.

STORMFURY

Hurricane Modification Strategy

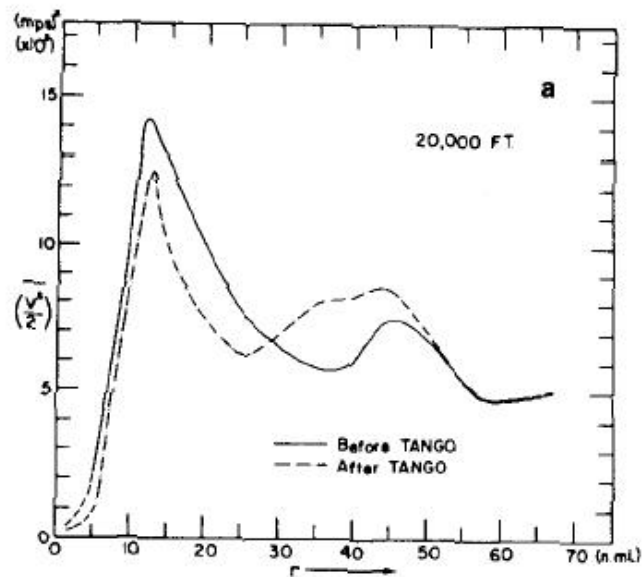
Main scientific hypothesis:

Seeding with silver iodide in the hurricane eyewall would freeze the supercooled liquid water in clouds, releasing heat that could cause the eyewall to expand and reform at a larger radius resulting in lower wind speeds.

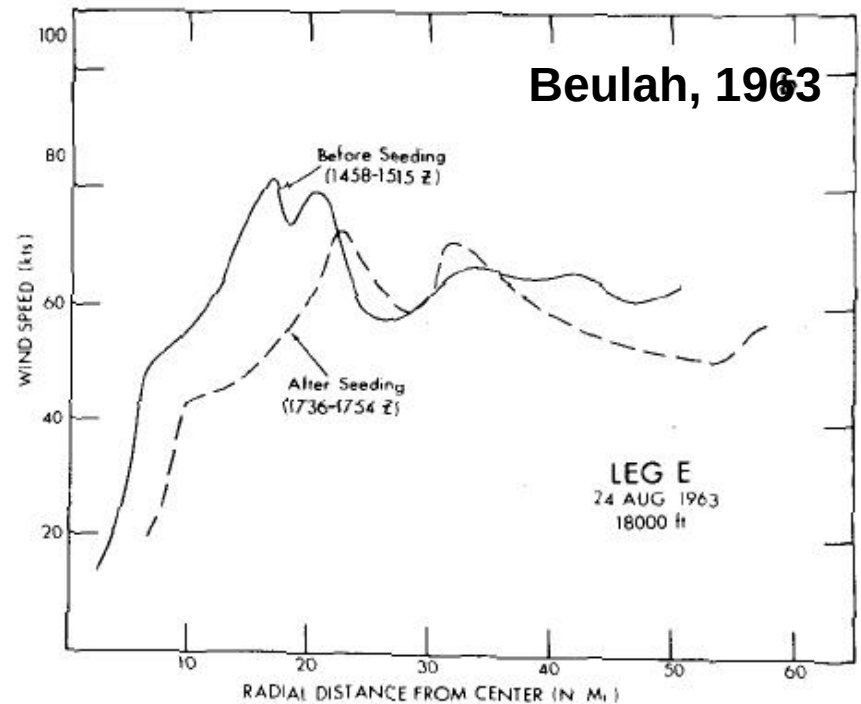


STORMFURY Promising Results

Esther, 1961



Beulah, 1963



Project STORMFURY

- Despite encouraging results six years after seeding Hurricane Beulah past before another hurricane was seeded in 1969
- The criteria for storm selection were very stringent
 - Hurricane had to be a mature one with a well developed eyewall
 - Within an operational range of aircraft operating from Puerto Rico, Bermuda, or Florida
 - Remained well away from land for at least 24h after seeding
- Better observing tools were developed before the next hurricane seeding

Negative Publicity

- STORMFURY planned to seed Hurricane Betsy (1965), but it was called off at the last moment.
- Betsy took a very erratic track, hitting south Florida and then Louisiana.
- The media, general public and Congress were suspicious that Betsy had been seeded and blamed STORMFURY for the outcome.
- It took two months to convince Congress that Betsy had not been seeded.

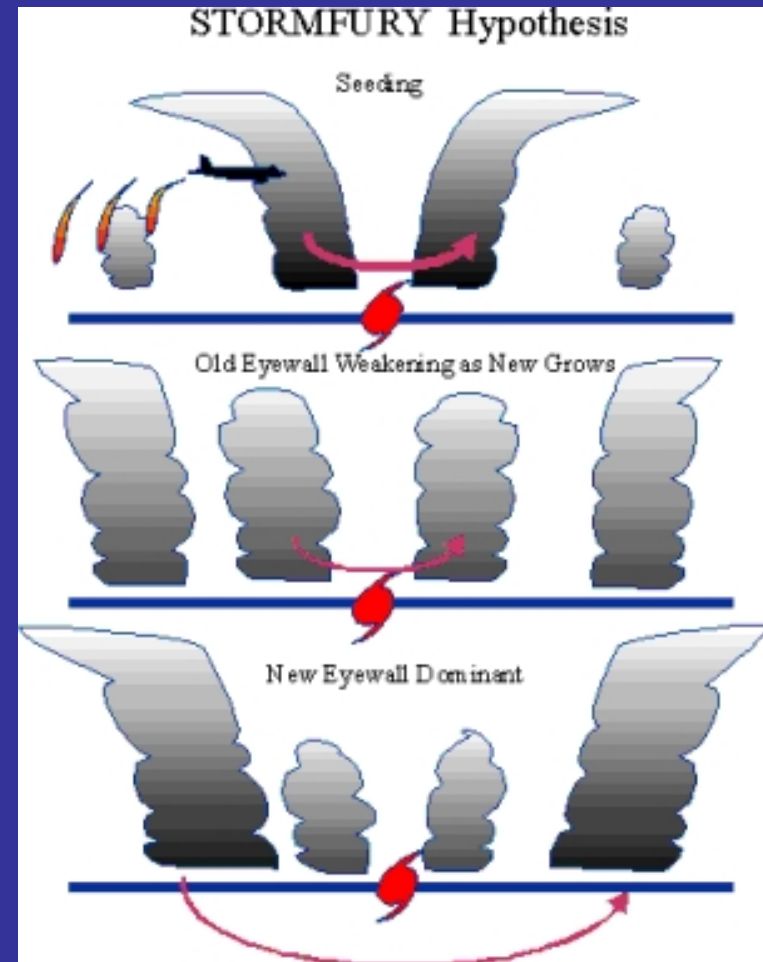
Hurricane Betsy (1965)

75 dead, \$7.5B damage (adjusted to 2000)



STORMFURY Modified Seeding Hypothesis

- Seed the rain band exterior to the eyewall to promote cloud growth and formation of a new eyewall at greater radius
- New eyewall strangles the old



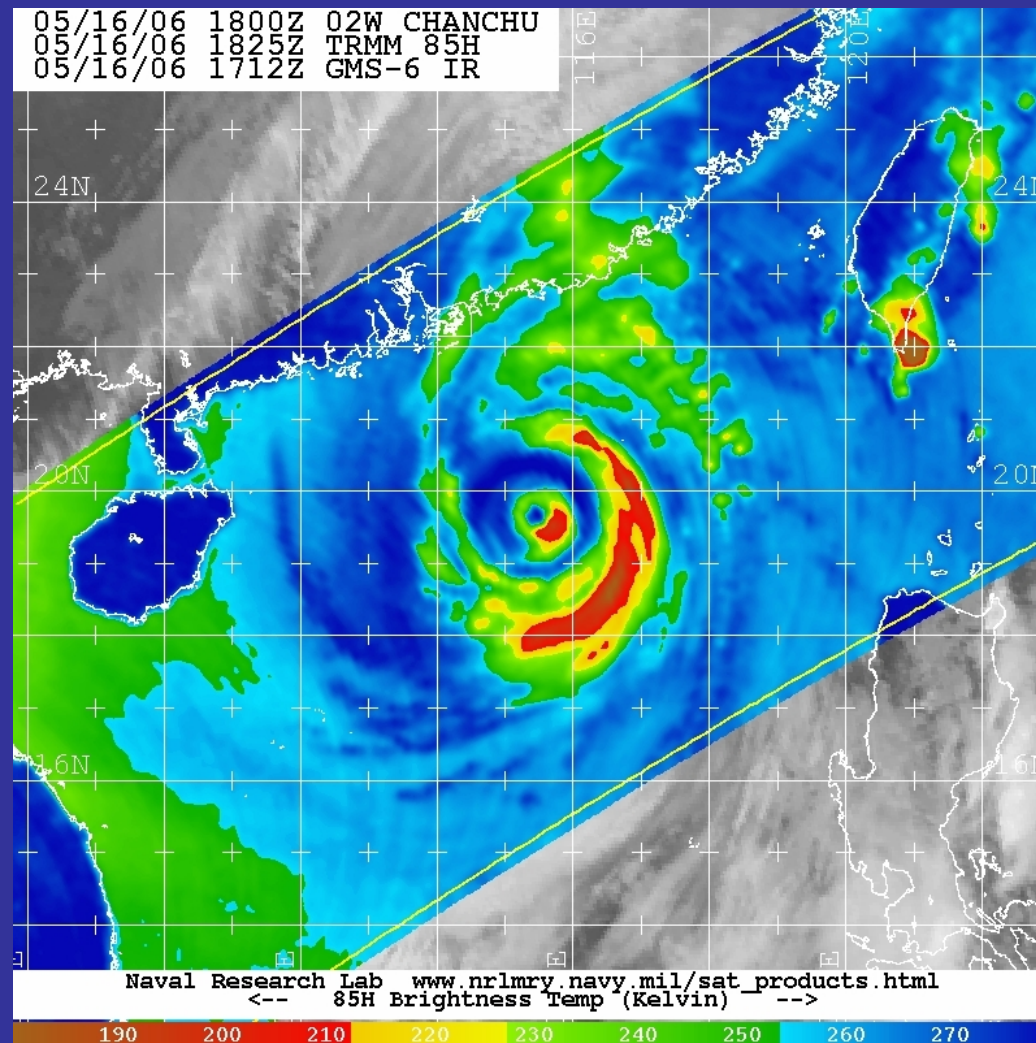
Summary of STORMFURY Experiments

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

STORMFURY Abandoned in 1982

- Meteorological observations cast serious doubt on the STORMFURY seeding hypothesis and on the results of the seeding
- Hurricanes do not have the quantities of supercooled liquid water necessary for dynamic seeding
- Natural fluctuations of the hurricane core are similar to the changes observed following the Debbie seeding

New Understanding of Hurricane Structure & Dynamics



Spaceborne Remote Sensing Revealed Many Concentric Eyewalls

U.S. Weather Modification Programs

- NOAA's Atmospheric Modification Program (AMP) was established in late 1970s, but terminated by the Congress in 1995
- None of the NOAA AMP funds were used to conduct any operational cloud seeding
- At present, operational weather modification programs in the U.S. are supported by the States, utilities or the private-sector with estimated total annual expenditures of \$25-30 million
- There is now very little Federally-supporting research to aid these operational programs in evaluation, or improving their technological base

Weather Modification in Other Countries

- Weather Modification is conducted in 66 countries
- In China alone, the weather modification research and operations program is funded at \$100 million per year. Over 1500 scientists are involved

Where do we presently stand on hurricane modification?

The American Meteorological Society policy statement on weather modification October 2, 1998:

"There is no sound physical hypothesis for the modification of hurricanes, tornadoes, or damaging winds in general, and no related scientific experimentation has been conducted in the past 20 years."

No Federal agencies are presently doing or planning research on hurricane modification.

The proponents...

From the testimony by Dr. Joseph Golden before Senate Subcommittee on Disaster Prediction & Prevention, **November 10, 2005** (Dr. Golden was the last NOAA manager of the NOAA's AMP):

“After the horrendous devastation and loss of life from Hurricanes Katrina and Rita, I have been asked several times about the possibility of hurricane modification. I firmly believe that we are in a much better position, both with the science and the undergirding technology, than we were when Project STORMFURY was terminated... The need for a renewed national commitment and funding for weather modification research has become more urgent.”

The skeptics...

“The limited likelihood of achieving significant hurricane modification even with new knowledge gained through the proposed national research effort suggests that this area be given very low priority. Furthermore, modification raises daunting ethical, legal, and environmental issues.”

Ray J. Ban
Executive Vice President The Weather Channel

John T. Snow
Director, Oklahoma Weather Center
Dean, College of Atmospheric and Geographic
Sciences, University of Oklahoma

Co-Chairs of the Weather Coalition
October 27, 2006

Recent Initiatives

- Sen. Mel Martinez, R-Fla., introduced the **National Hurricane Research Initiative ACT of 2006**, a bi-partisan bill co-sponsored by Sen. Nelson (D-FL), Sen. Vitter (R-LA), and Sen. Landrieu (D-LA).

The proposed legislation includes funding for

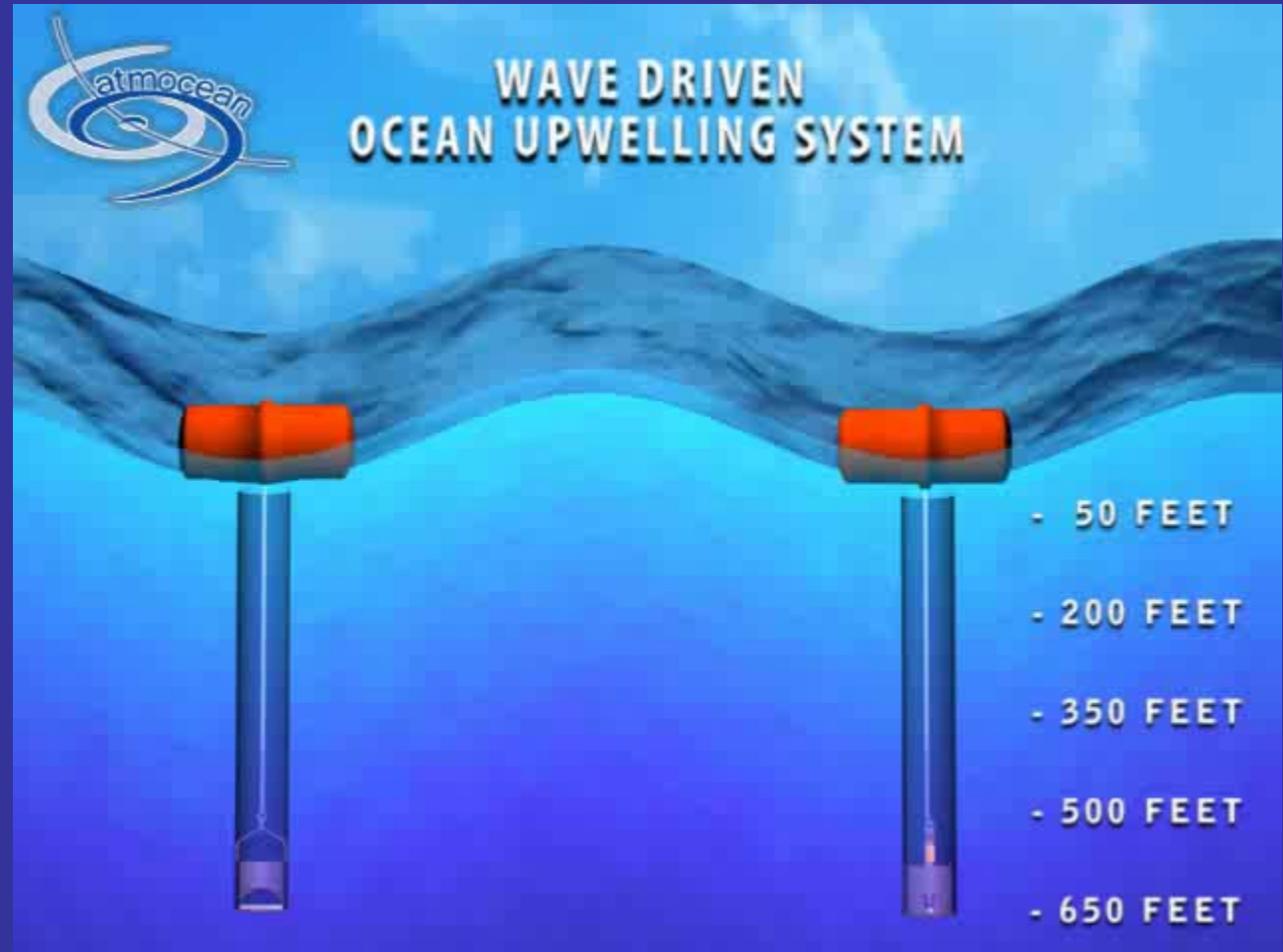
- (D) HURRICANE MODIFICATION- Basic research for modifying hurricanes to reduce the intensity or alter the movement of hurricanes by human intervention, including research to improve understanding of the potential effects of hurricane modification on precipitation and fresh water supply, as well as on climate.
- The Department of Homeland Security convened a workshop (February 6-7, 2008) on hurricane modification in Boulder, CO at NOAA's lab
 - The focus of the workshop was on the identification of viable hurricane modification hypotheses that warrant further study.

New Hypotheses on Hurricane Modifications Proposed at the DHS Workshop

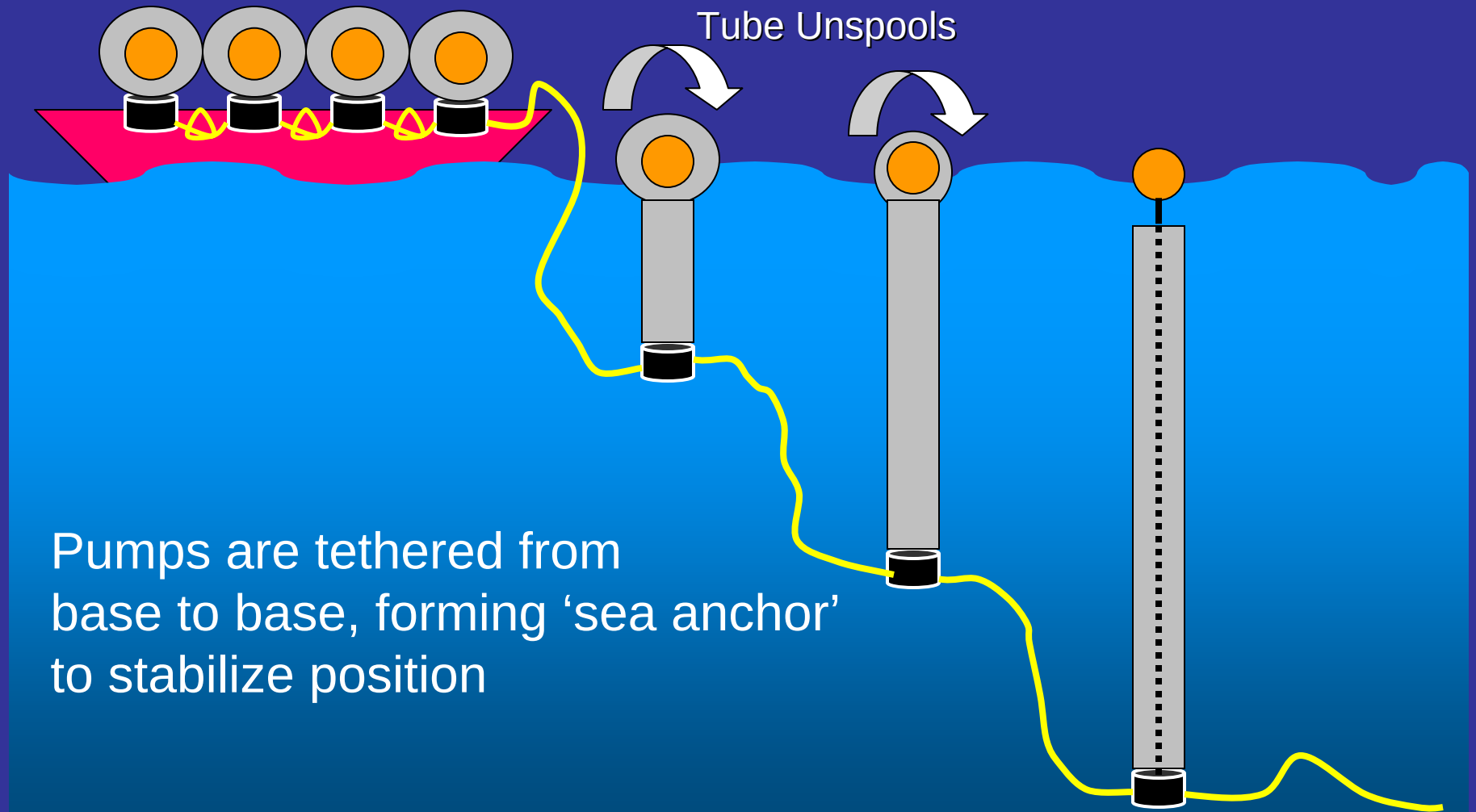
- Cloud seeding with small aerosol particles at the hurricane periphery to suppress warm rain. Numerical simulations suggest that may reduce the wind speed, particularly outside of the eyewall (Cotton et al., Rosendfeld et al.)
- Scattering carbon particles (soot) at the top (50,000 feet) of a hurricane. The particles would absorb heat from the sun to warm-up the hurricane top and so reduce wind speeds (Alamaro and Hoffman)
- Wave-driven ocean pumps to reduce the ocean temperature in front of a hurricane (Ginis and Kithil)

Ocean Cooling with Wave-Driven Upwelling Pumps

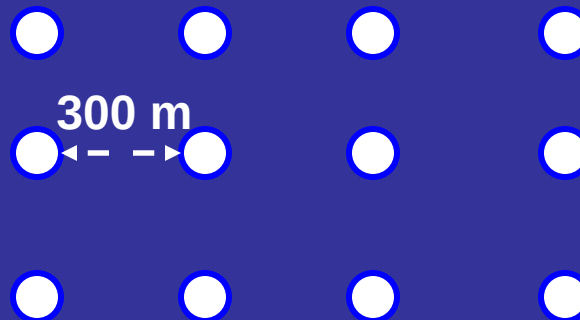
- Operates entirely on wave kinetic energy
- Self-calibrates by pumping more when waves are bigger



How To Deploy Many Pumps



Multiple-Pump Array



Theoretical analysis shows that:

- Cold water released near the sea surface by each pump will remain in the upper mixed layer
- Primary mechanism of horizontal spread of cold water between the pumps is due to gravity

Average Mixed Layer Cooling by a Pump Array

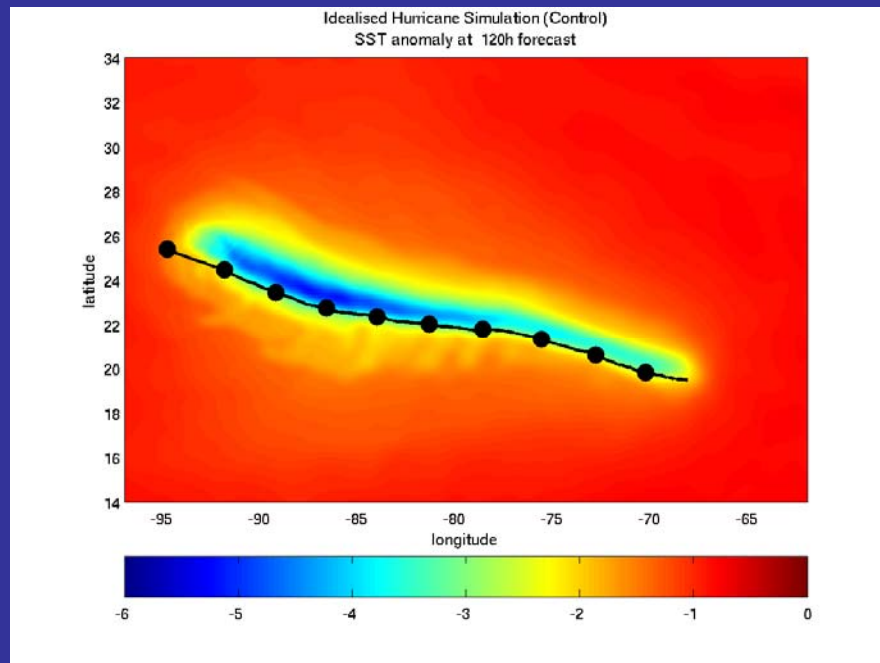
$$\theta = P\Delta T / (hL^2)t$$

P [m³/s] – pump rate, ΔT [°C] – temperature anomaly at the tube top, L [m] – distance between pumps, h [m] -mixed layer depth, t [s] – time,

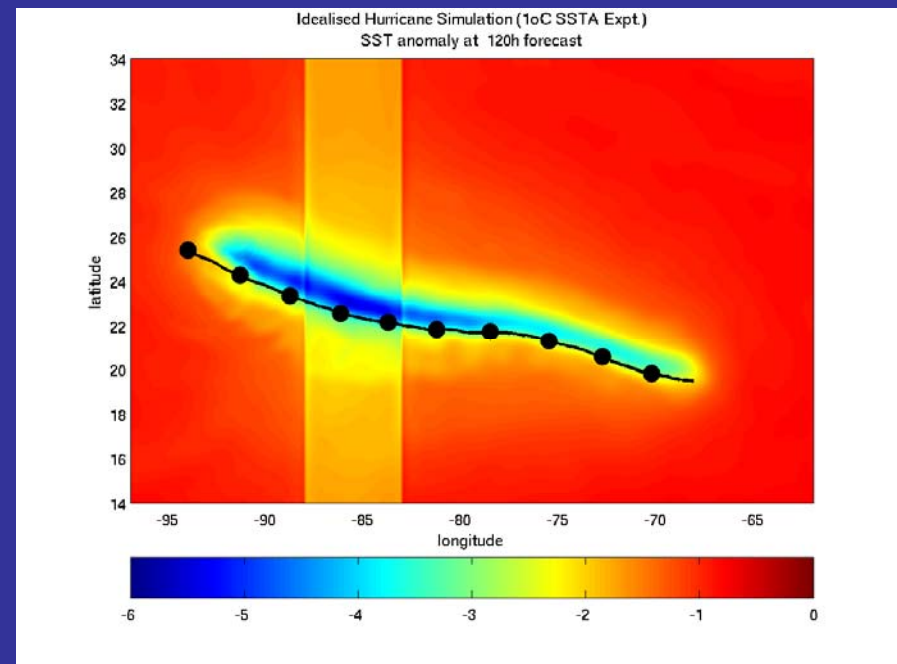
- Assuming 2.1 m³/s flow rate (3m diameter tube, 3m significant wave height, 10 sec period) and 300 m distance between pumps.
- Average mixed layer cooling: **$\theta = 1^\circ\text{C per day}$**

Idealized Hurricane Experiments

Control



2°C cooling in the pump array

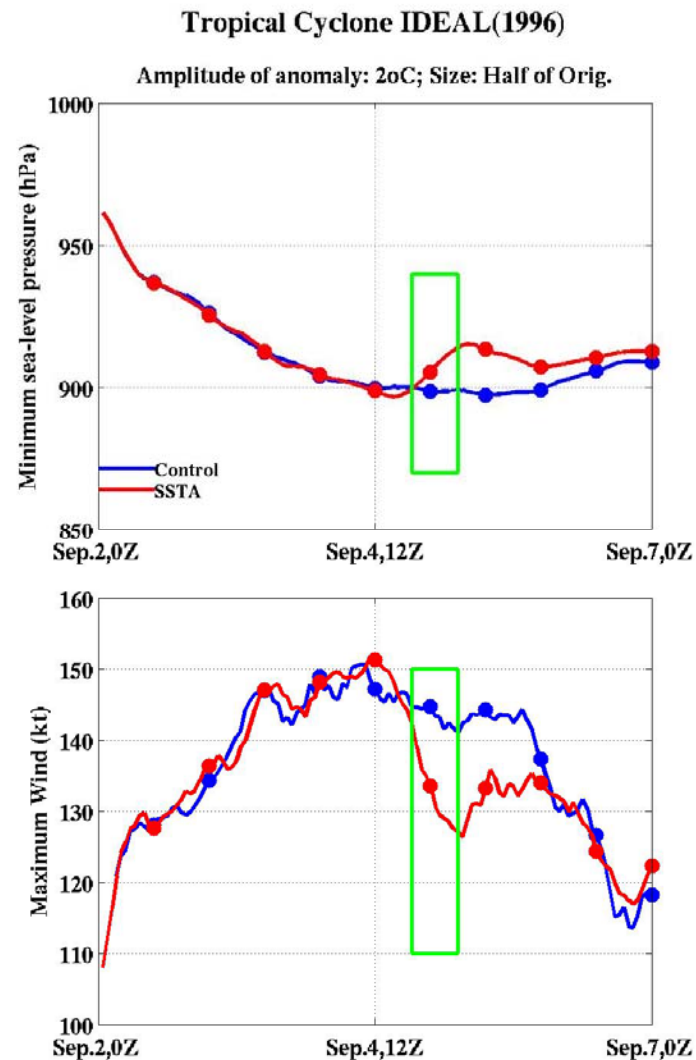


1. Atmosphere: Steady easterly environmental wind of 5 m/s, Hurricane Fran (1996) initial hurricane vortex.
2. Ocean: Initially horizontally uniform and motionless with SST of 28.5°C . Temperature profile typical for the northern Gulf of Mexico in September with mixed layer depth of 30 m.

Hurricane Intensity Change

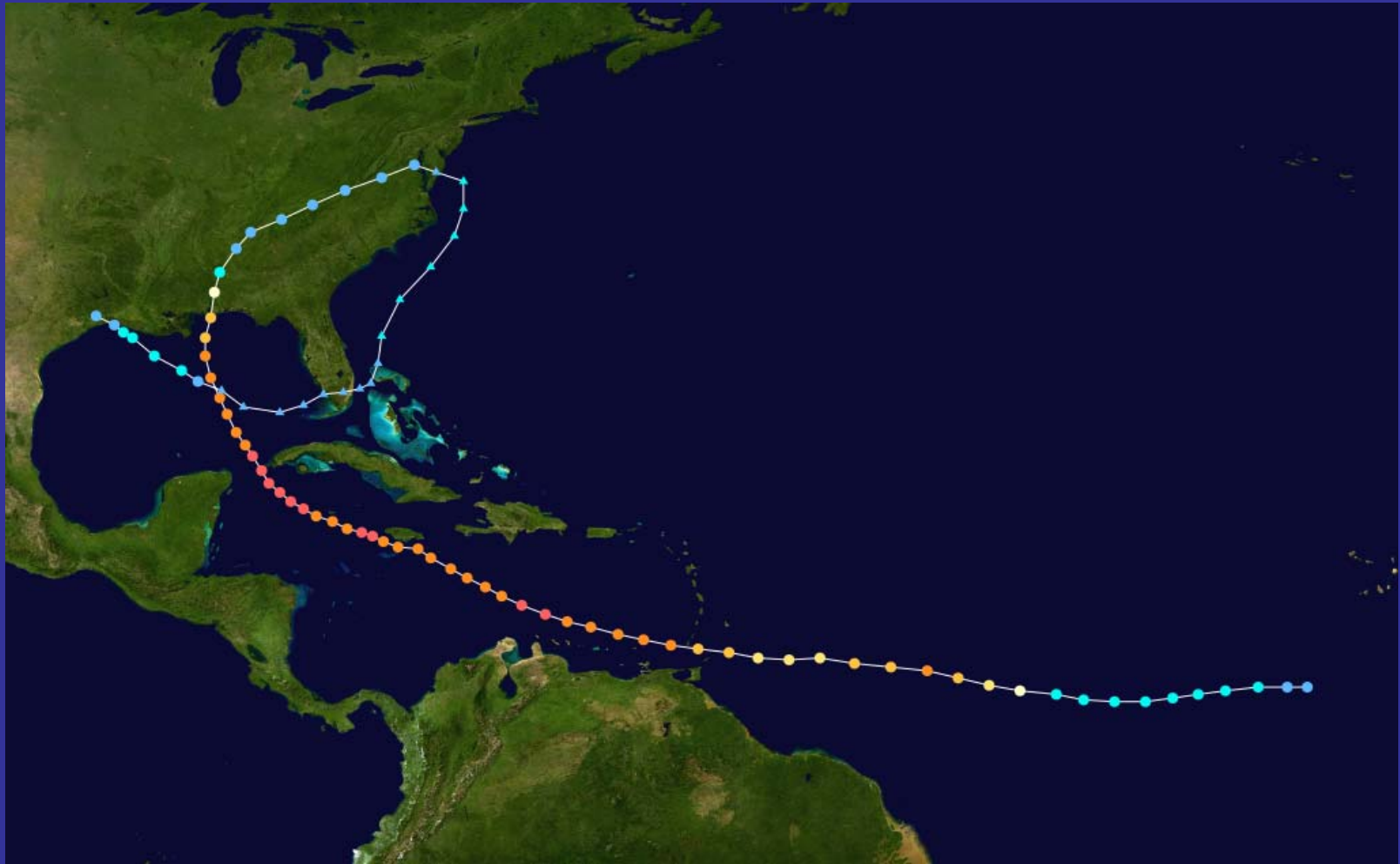
Central
pressure

Maximum
winds



Blue – Control
Red – With pump
cooling

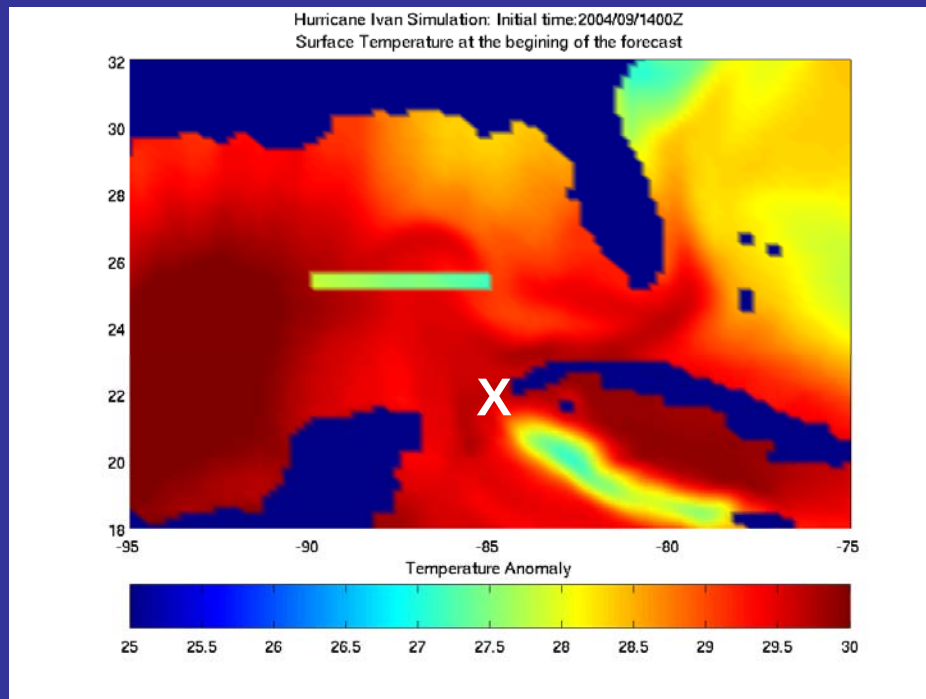
Case Study: Hurricane Ivan (2004)



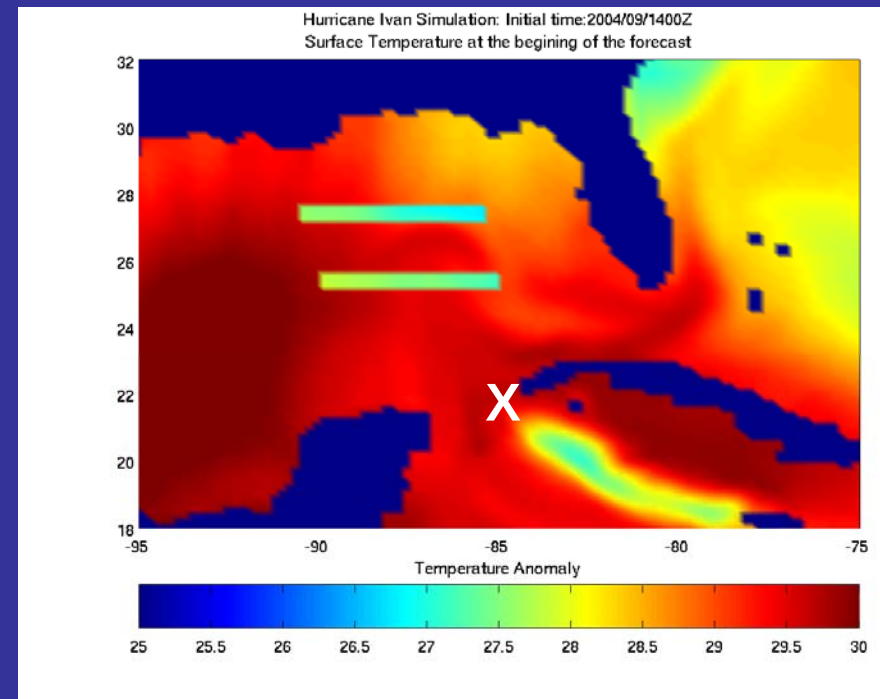
Sea Surface Temperature

Initial time: September 14, 00UTC

One pump array



Two pump arrays

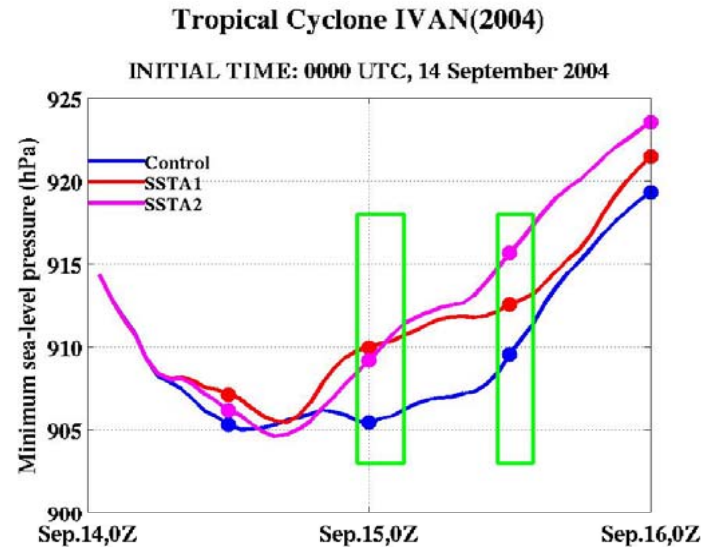


2°C cooling in each pump array

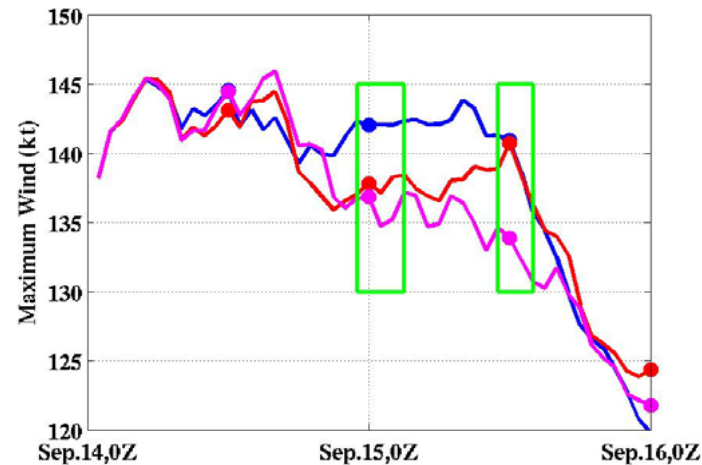
Hurricane Ivan (2004)

Initial time: September 14, 00UTC

Central
Pressure



Maximum
Winds



Blue – Control
Red – one pump
array
Magenta- two pump
arrays

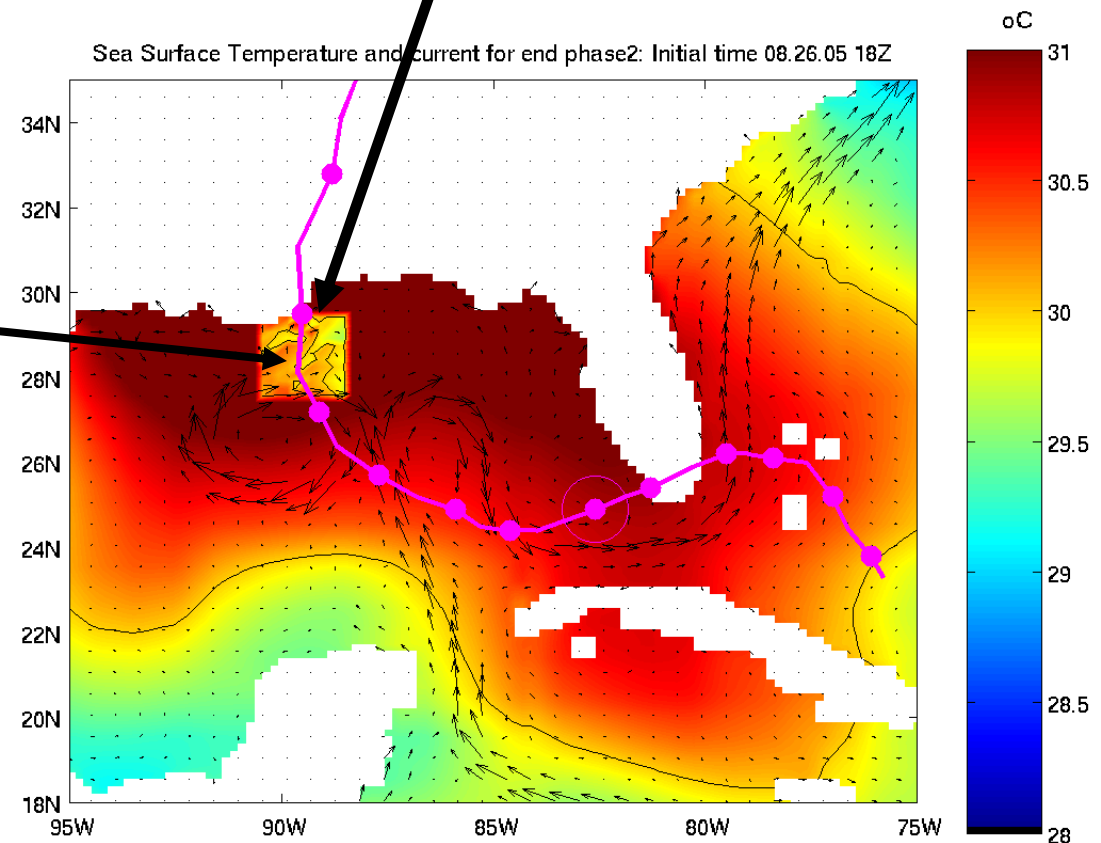
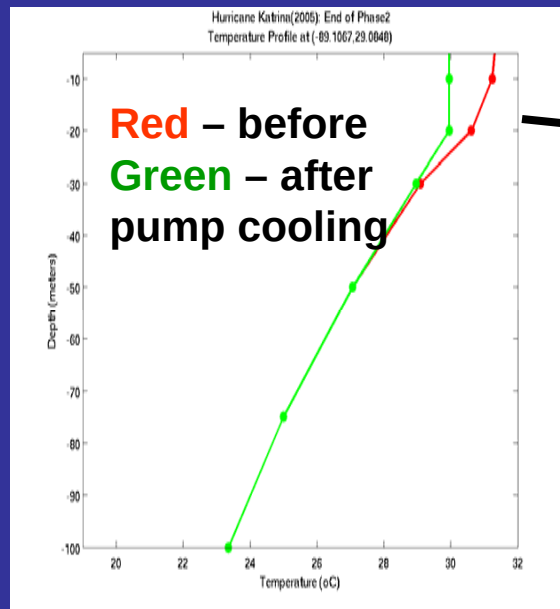
Case Study: Hurricane Katrina (2005)



Sea surface temperature at the beginning of the hurricane Katrina simulation: August 26, 18UTC

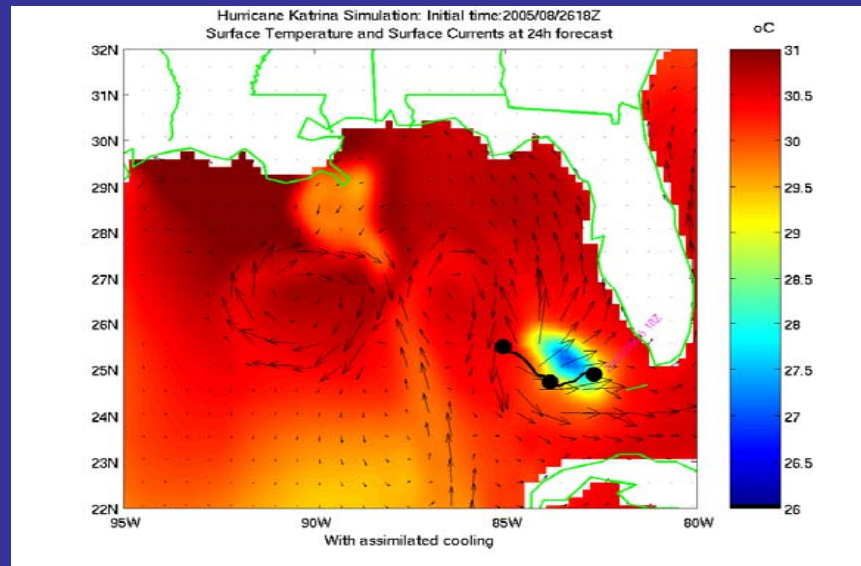
Pump cooling calculations assume 1m diameter tube, 250m distance between pumps.

Pump array

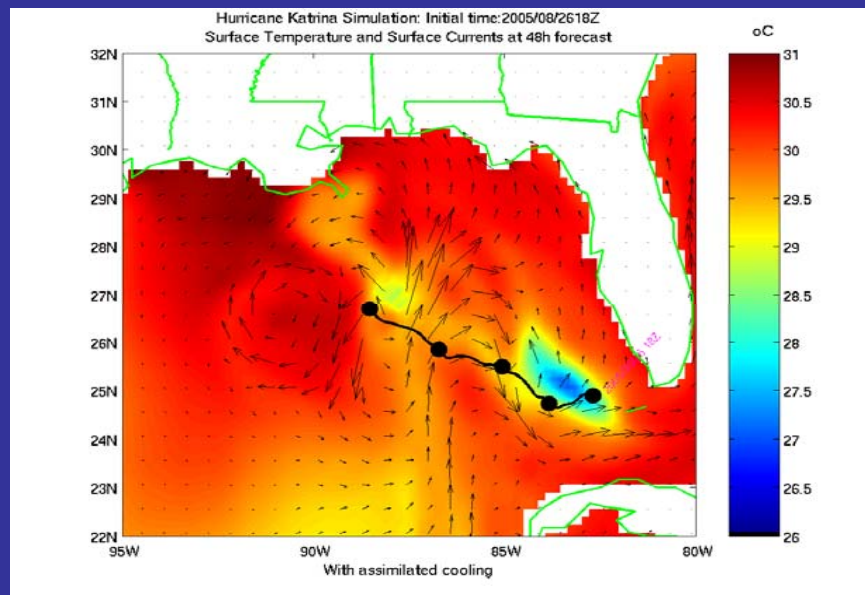


Sea surface temperature simulation

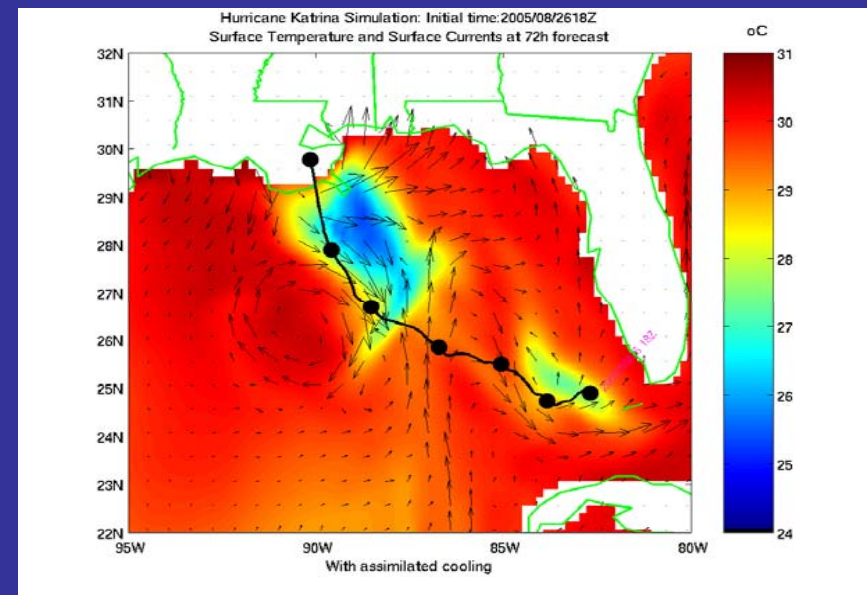
Aug 27, 18Z



Aug 28, 18Z



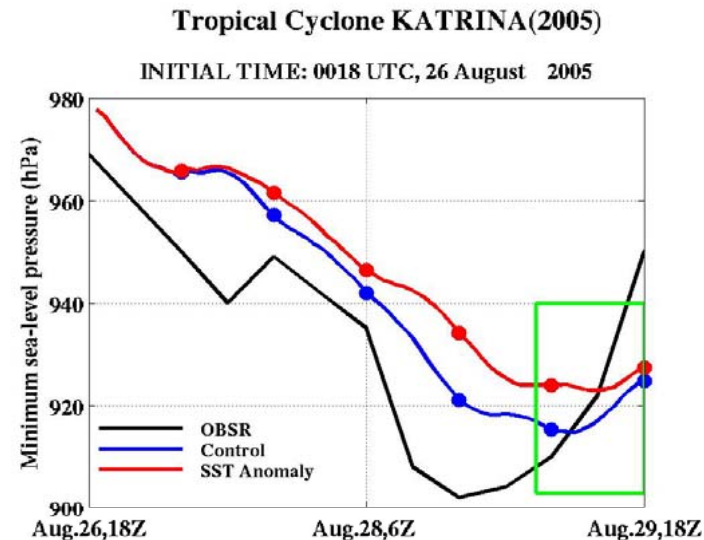
Aug 29, 18Z



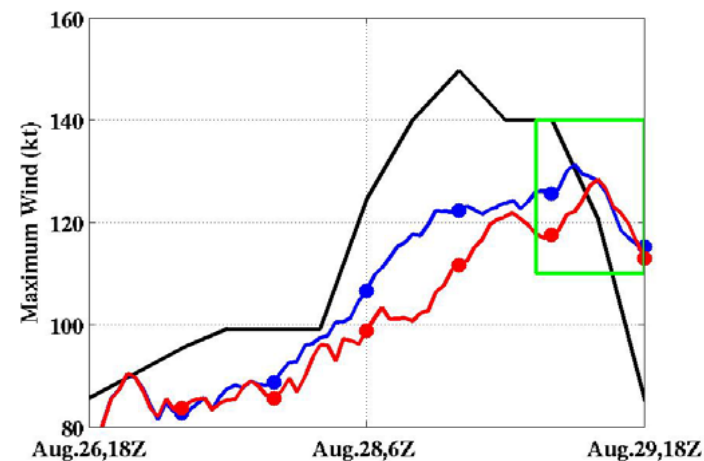
Hurricane Katrina (2005)

Initial time: September 14, 00UTC

Central
Pressure



Maximum
Winds

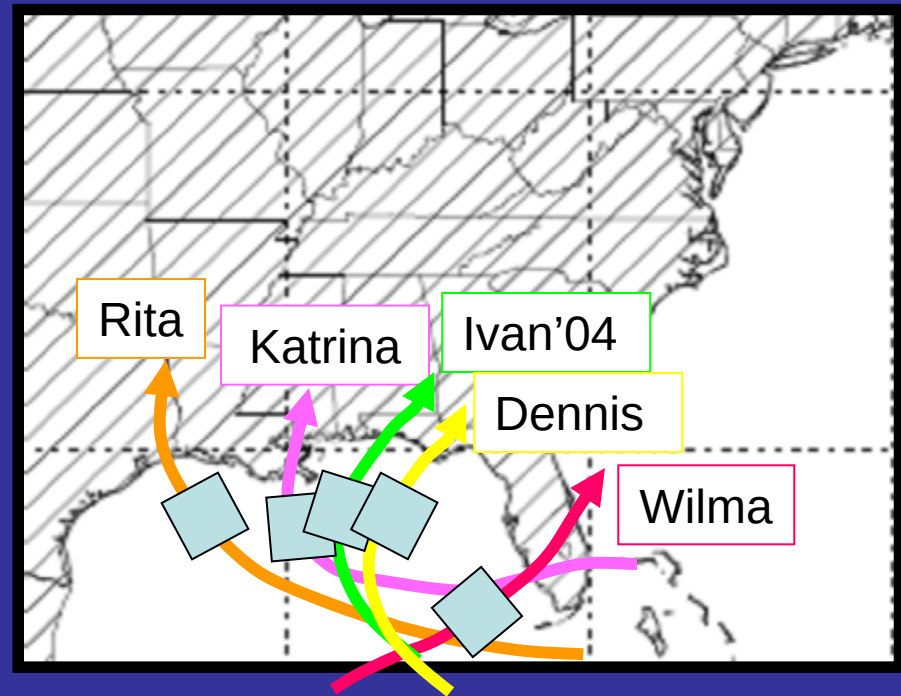


Blue – Control
Red – With Pump
array
Black – Observed

Green box – Pump
array

Pump Deployment Strategy to Reduce Hurricane Intensity in The Gulf of Mexico

- Assume pumps are deployed across a region 150km by 150km.. Estimated Deployment time for ~450 barges (112 tugboats) is ~14 hours.
- Pump dimension 3m diameter by up to 500m deep.
- 333m spacing = total 202,500 pumps
- Pumps are recovered afterward (locations determined from GPS & satellite uplink on each buoy)



Final Thoughts

- The scientific foundation and underlying physics in hurricane modification is sound. We now have both the science and the technology to launch a new research attack on this vexing problem
- Many of my colleagues in academia, NOAA weather research and private sector would welcome the opportunity to contribute to a national program of hurricane modification research if support can be found.

More Thoughts

- In order to be successful in any form of hurricane modification, we must first do a very good job of predicting the hurricane path and intensity
- The key uncertainty, and one which requires enhanced observations, is more continuous and accurate monitoring of the natural fluctuations in hurricane intensity and path
- Any new hypotheses on hurricane modification must be first thoroughly evaluated with high-resolution hurricane-ocean coupled computer models
- Practical, economic and environmental implications of hurricane modification need to be addressed

National Science Board Report: **The Critical Need for a National Hurricane Research Initiative.** NSB-06-104
September 29, 2006

“Can we as a Nation continue to remain vulnerable to hurricanes that are an inevitable part of our future, that have demonstrated the capacity to inflict catastrophic damage to our economy, and that kill hundreds of our citizens?”

The hurricane warning for our Nation has been issued and we must act vigorously and without delay.”