HURRMIT

The Identification and Testing of Hurricane Mitigation Hypotheses

Sponsored by the Department of Homeland Security (DHS)
Science and Technology (S&T) Directorate

BACKGROUND

- **Because natural disasters are a continuing threat to the security of the of the United States, they come under the purview of DHS [The Homeland Security Act of 2002 (Public Law 107-296)]**

- **In most cases the challenge is coping with their aftermath**

- **In limited cases it may be possible to proactively mitigate their destructive effects**

- **Hurricane mitigation is a better possibility now due to new published concepts and instrumentation, powerful computers and advanced numerical models**

- **The HURRMIT effort is the outgrowth of the February 2008 DHS/ESRL workshop in Boulder, Colorado**

Key Scientific Objectives of HURRMIT

- Quantitatively Test Most Promising Hurricane Mitigation Hypotheses by Mean of Rigorous Numerical Simulations that are Interactive with and Validated by Hurricane Observations

- Coordinate/Use Data from WISDOM and UAS Projects and NOAA Aircraft Missions

KEY HURRMIT SCIENTISTS

- **Dr. Joe Golden, CIRES/GSD**
- **Dr. William Woodley, WWC, Inc.**
- **Prof. William Cotton, CSU/CIRA**
- **Prof. Daniel Rosenfeld, Hebrew University of Jerusalem, Israel**
- **Prof. Alex Khain, Hebrew University of Jerusalem, Israel**
- **Prof. Isaac Ginis, U. of Rhode Island and GFDL Collaborator**

PROPOSED HYPOTHESIS TESTING

- **Seeding with tiny hygroscopic aerosols to suppress warm rain (Rosenfeld et al. 2007 and Cotton et al., 2007)**

- **Seeding with radiation-absorbing aerosols (i.e., carbon black) at the storm periphery (Gray et al, 1976)**

- **Seeding with radiation-absorbing aerosols (i.e., carbon black) at storm top (Alamaro et al., 2006)**

LIKELY OUTCOME OF HURRMIT

- Better understanding of hurricane structure and behavior

- Improved hurricane forecasts, especially forecasts of hurricane intensity (Likely helpful to NOAA's HFIP)

- Evaluation of the hurricane mitigation hypotheses based on scientific credibility and operational feasibility

- Panel of experts will prioritize the field testing of HURRMIT hypotheses and make recommendations to DHS

HURRMIT HYPOTHESIS ILLUSTRATION

- **Investigation of the scientific basis, possibilities and limitations of hurricane seeding with ultra-fine hygroscopic particles to decrease intensity**

- **Two groups (Rosenfeld et al. and Cotton et al.) have pursued this investigation independently and published in refereed scientific journals**

- **Both indicate that seeding with ultra-fine hygroscopic particles can decrease hurricane intensity**

- **These groups have merged into the HURRMIT group that has expertise with meteorological observations and numerical modeling**

- **The development and evaluation of hurricane mitigation hypotheses must involve modeling AND observational validation**

Conceptual Steps

- **The ingestion of ultra-fine hygroscopic aerosols decreases droplet sizes, suppresses coalescence and increases cloud vigor**

- **The original concept was to invigorate the periphery of a hurricane by hygroscopic seeding, thereby robbing the storm core of energy and decreasing its intensity**

- **The effects of the seeding were investigated numerically**

Simulations of Hurricane seeding at HUJI (Rosenfeld et al., 2007)

Model description:

- The Weather Research and Forecasting Model (WRF)
- 2 Nested grids of 9 and 3 km.
- Initiation using Katrina on 27 August 2005 00 GMT
- Bulk-microphysics parameterization by Thompson et al. (2004)
- Seeding simulated by shutting off drop-drop collisions.
- Sea spray simulated by restoring drop-drop collisions where surface wind>22 m/s.

Three numerical experiments:

CONTROL: Warm rain allowed everywhere.

NWRP: Warm rain suppressed where surface wind<22 m/s.

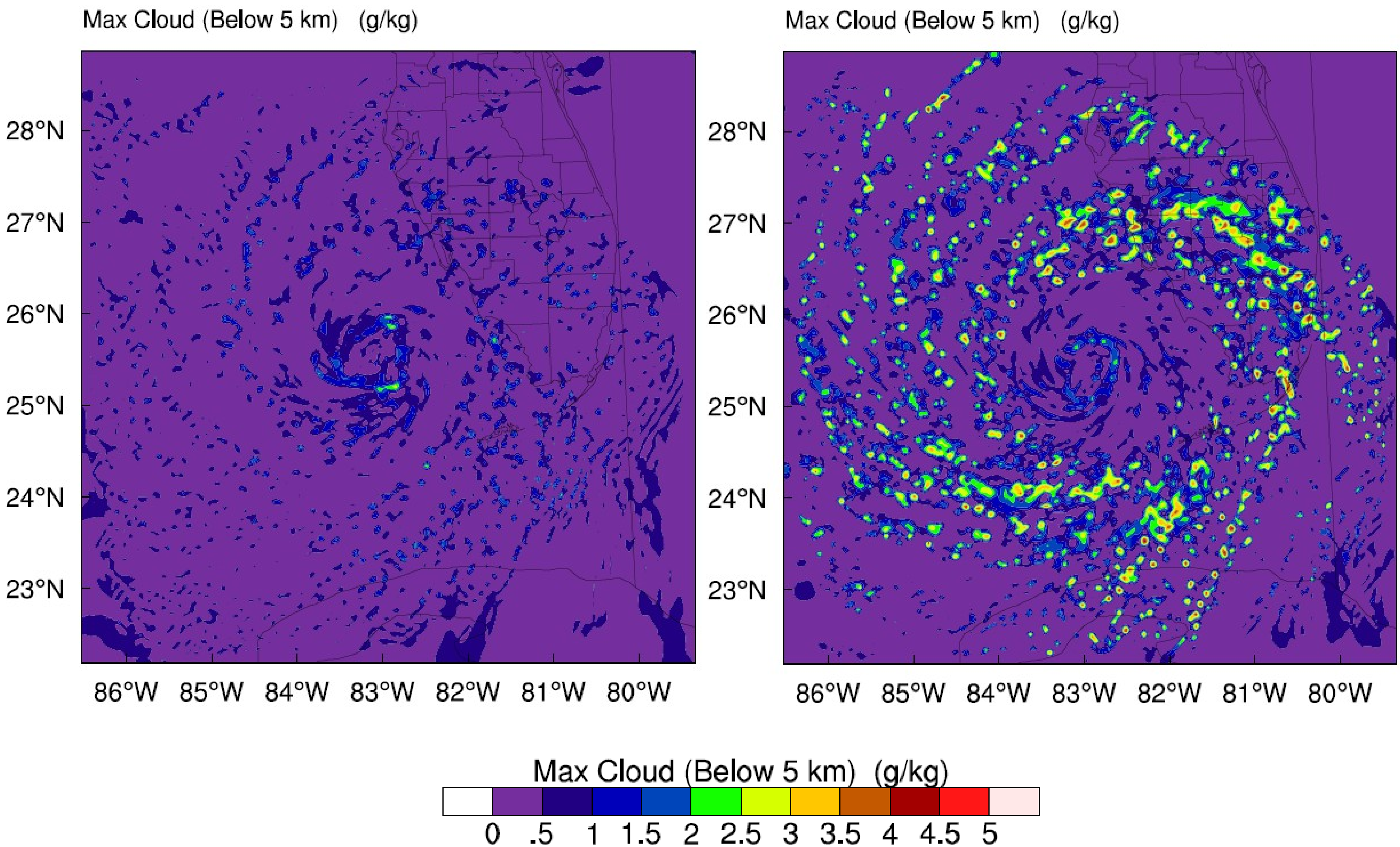
NWR: Warm rain suppressed everywhere

Warm **R**ain

Control

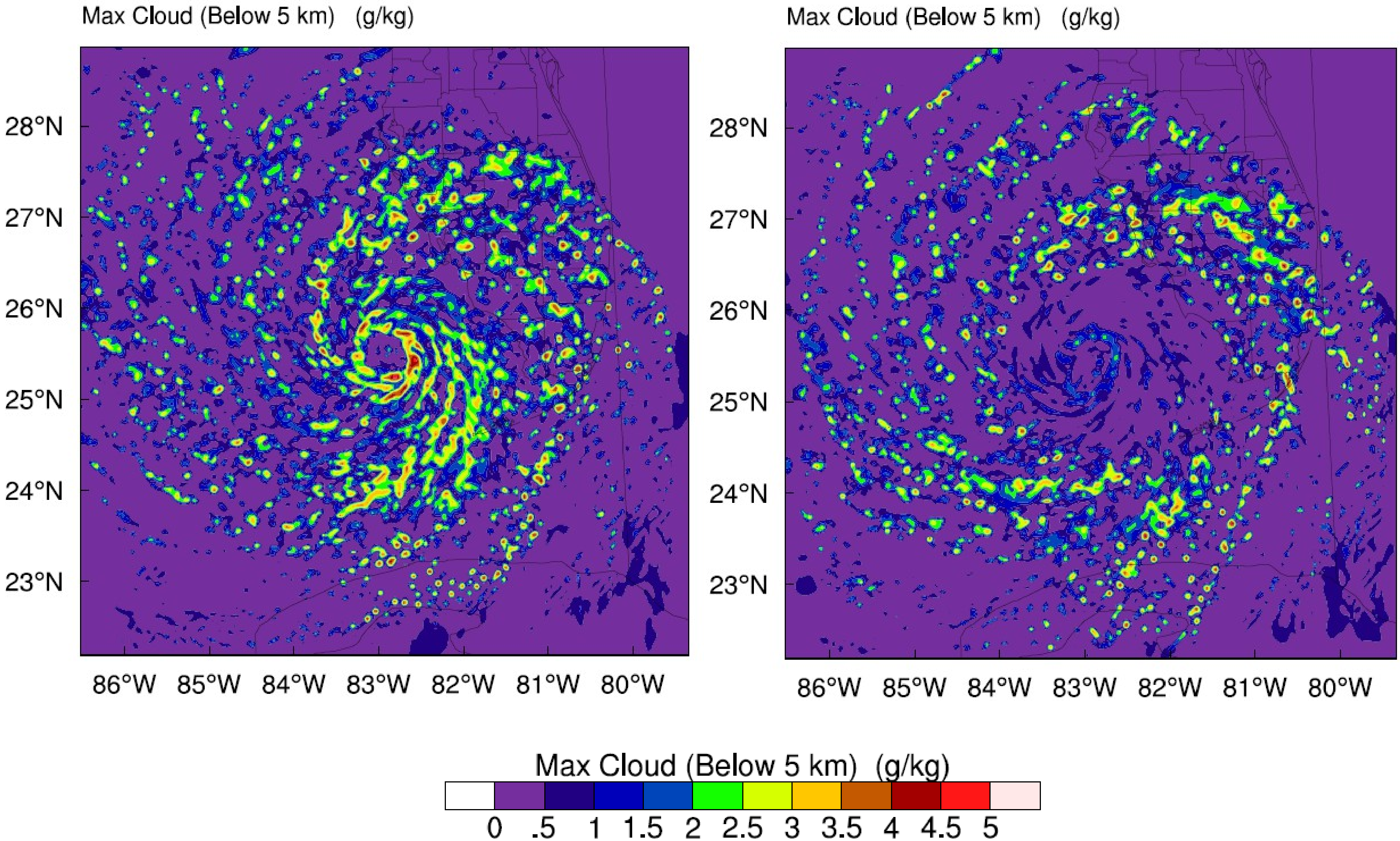
No **W**arm **R**ain **P**eriphery

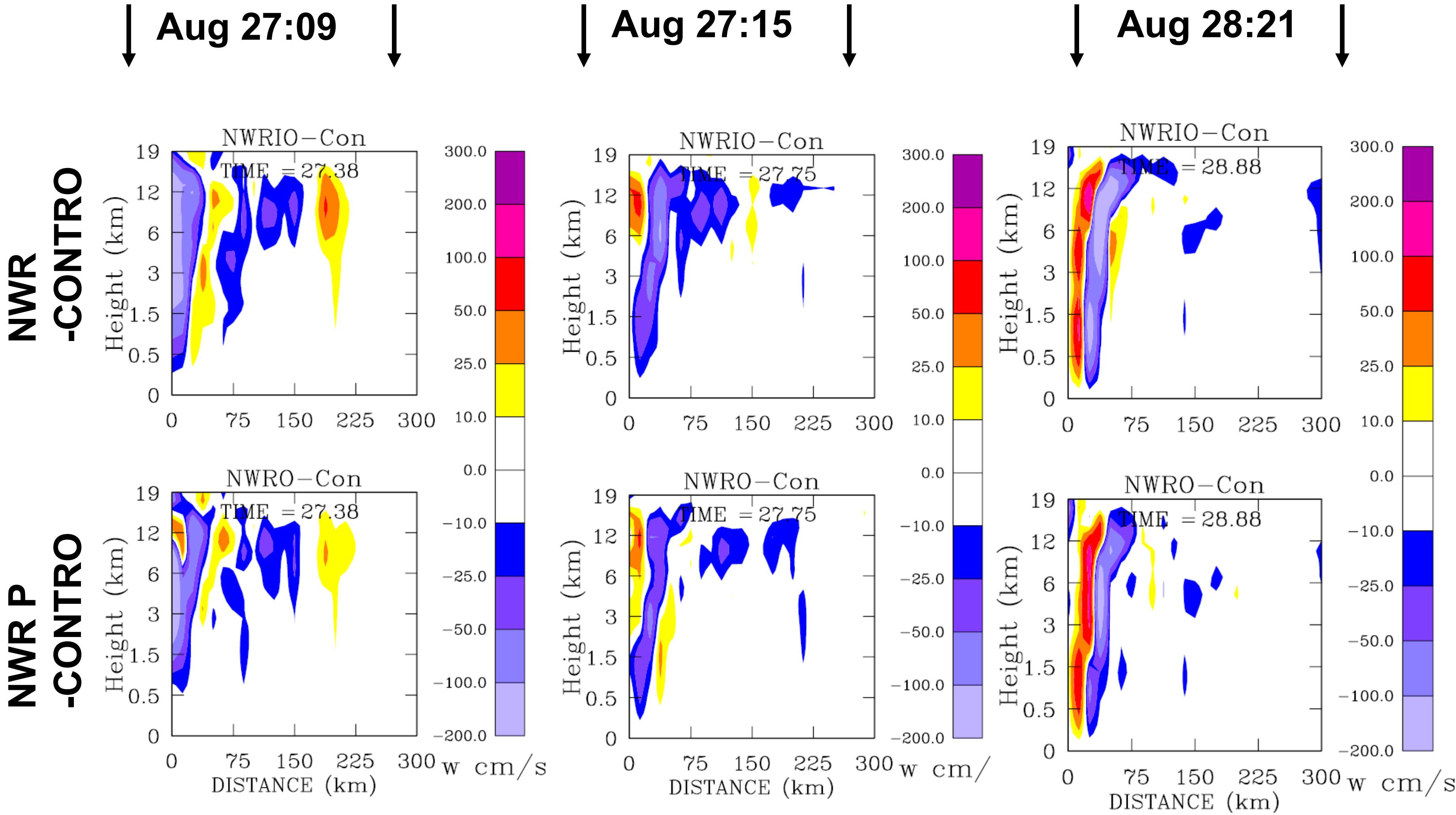
Warm rain suppressed for wind<22 m/s



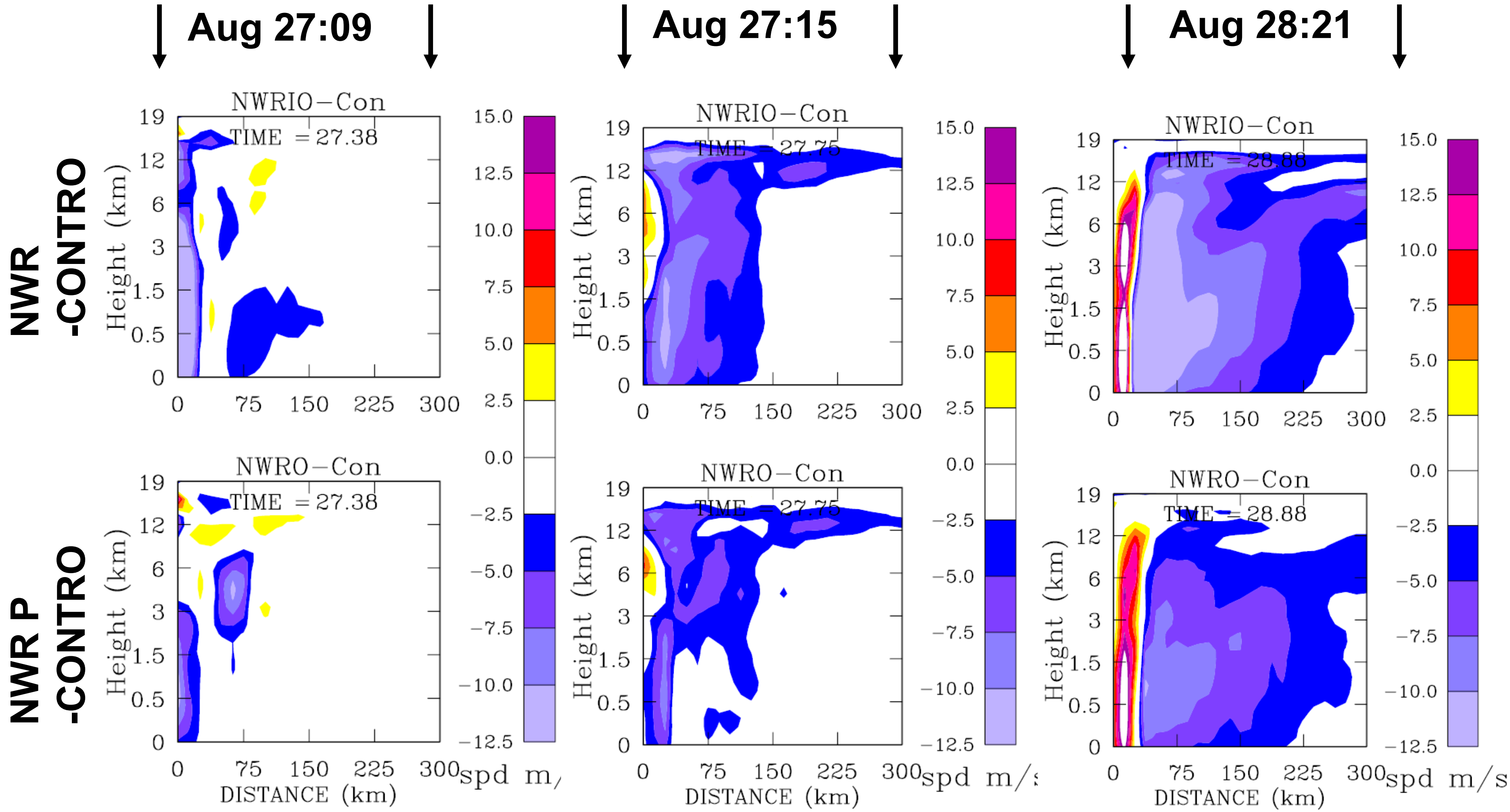
No **W**arm **R**ain
Warm rain suppressed everywhere

No **W**arm **R**ain **P**eriphery
Warm rain suppressed for wind<22 m/s

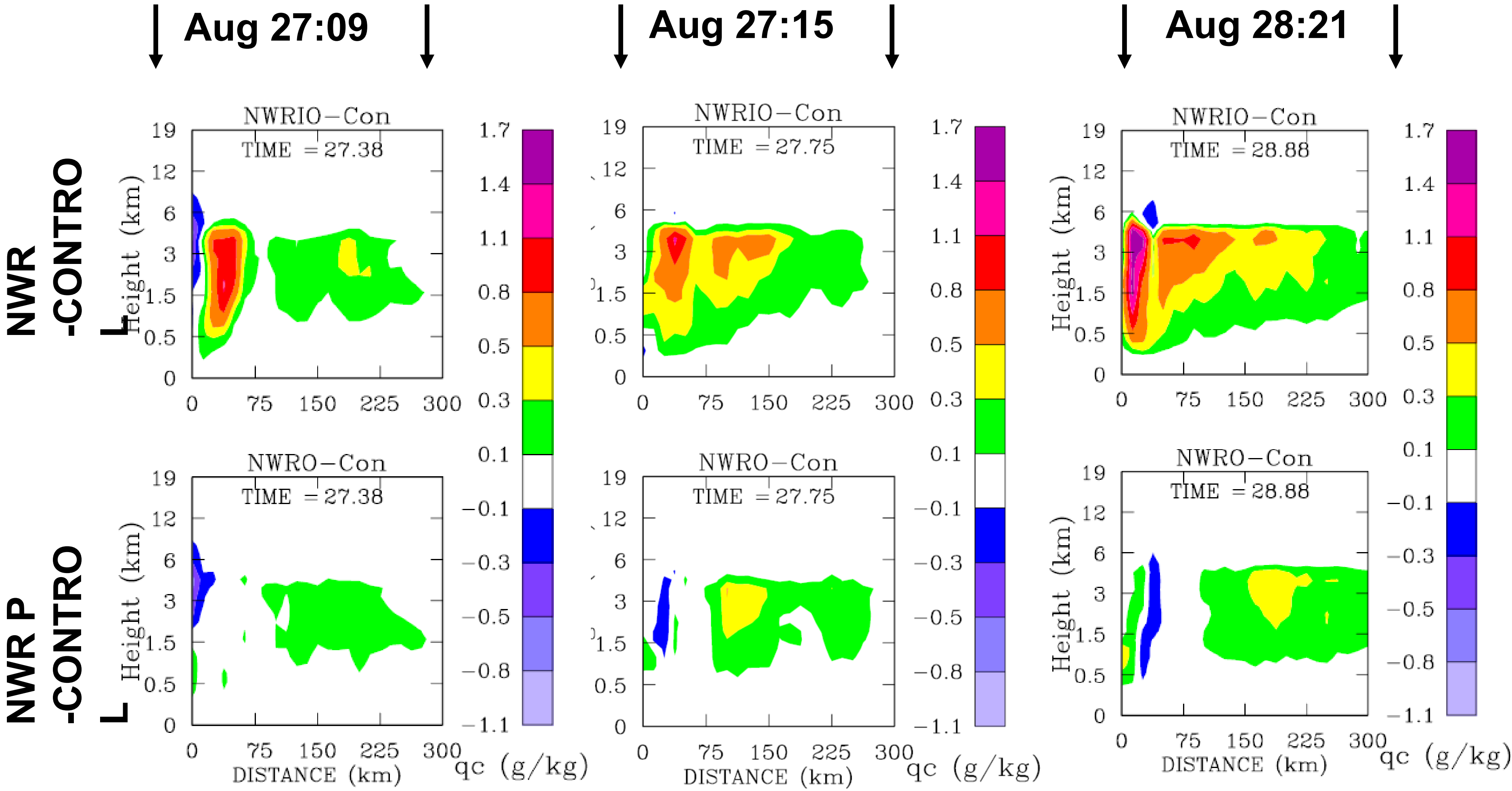




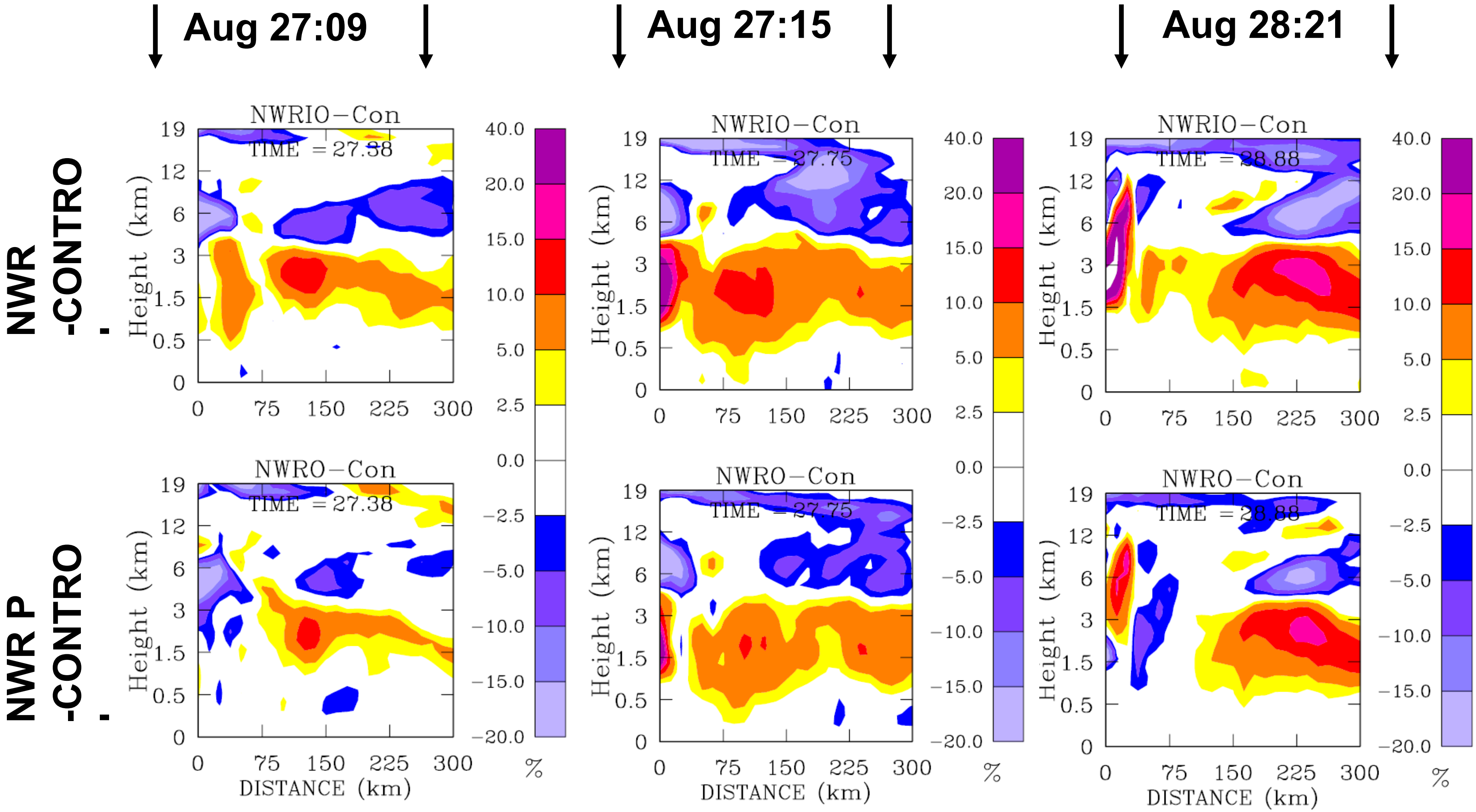
Vertical wind [cm/s]



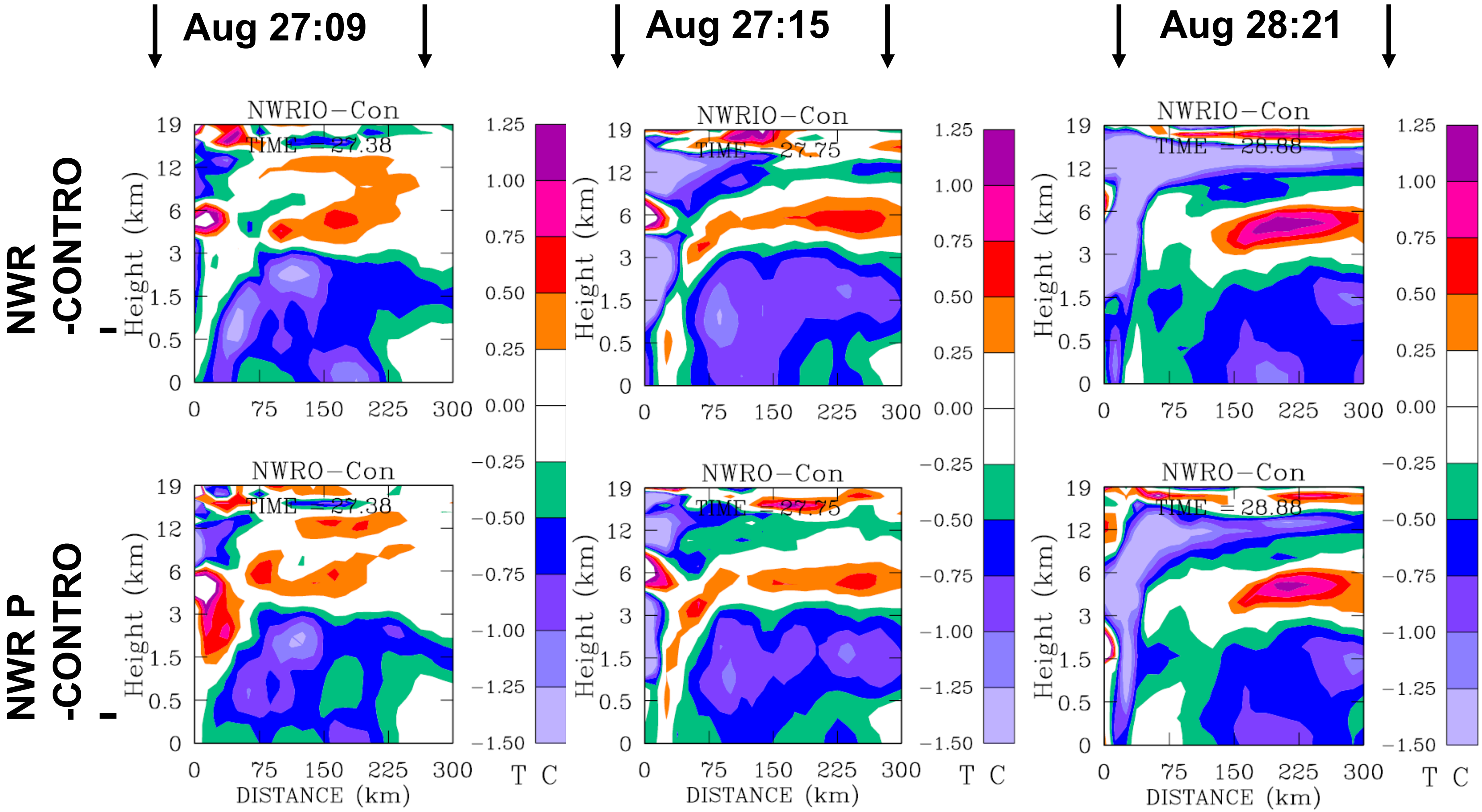
Δ Azimuthal winds [m/s]



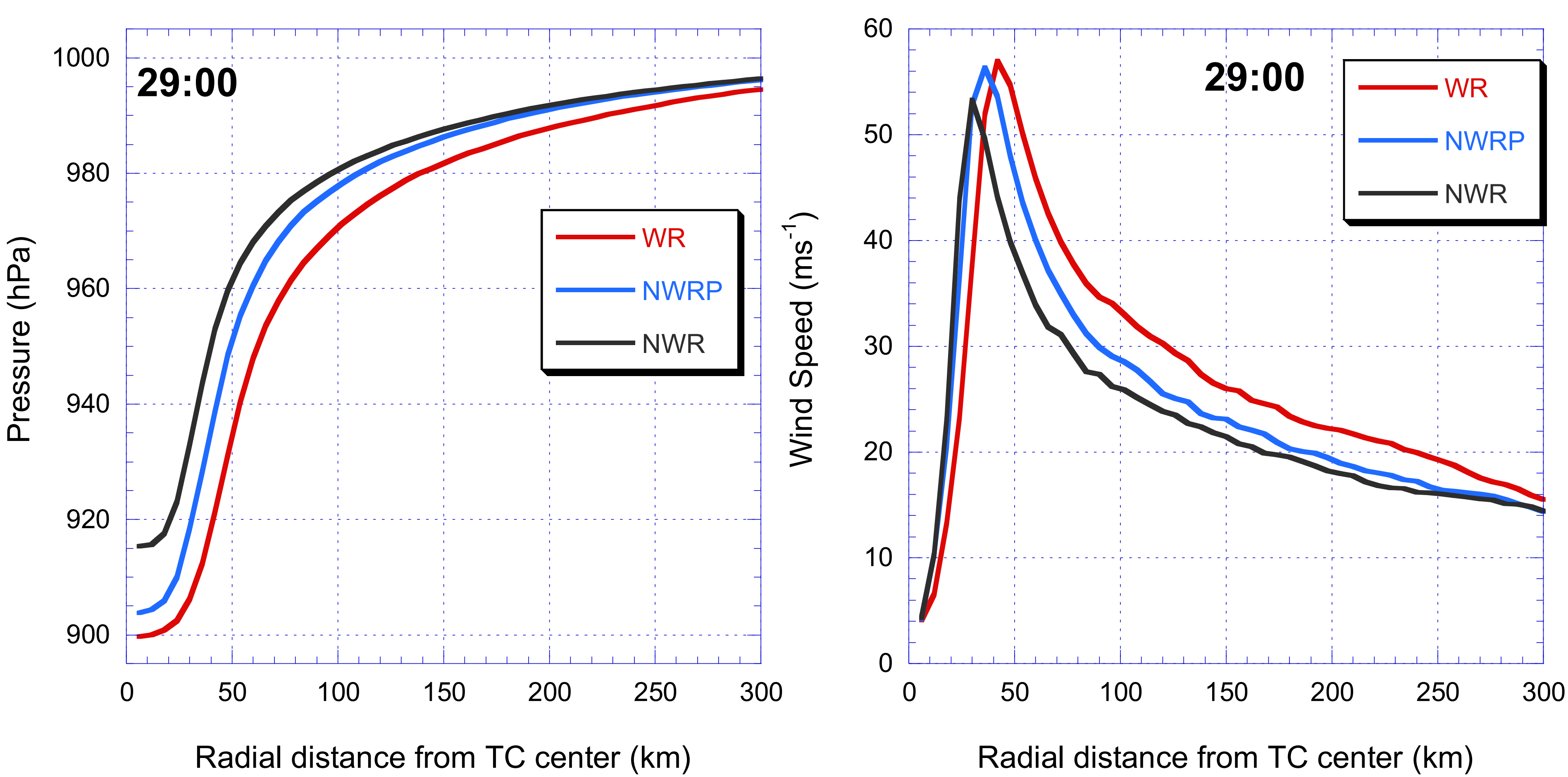
Δ Cloud water [g/kg]

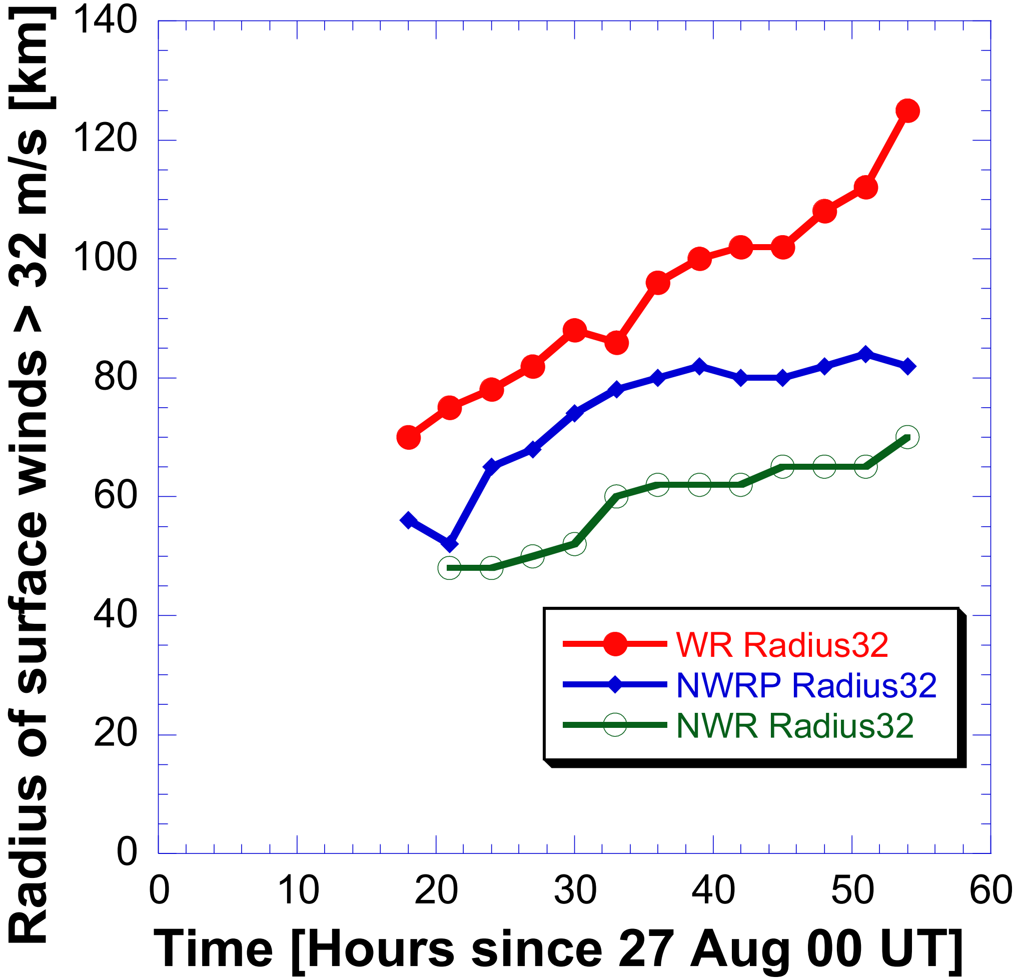


Δ Relative Humidity [%]



Δ Temperature [°C]


29:00
Pressure (hPa)
1000
980
960
940
920
900
0
50
100
150
200
250
300
Radial distance from TC center (km)
WR
NWRP
NWR
29:00
Wind Speed (ms^{-1})
60
50
40
30
20
10
0
0
50
100
150
200
250
300
Radial distance from TC center (km)
WR
NWRP
NWR



Suppression of warm rain causes low level cooling → weakening the storm as measured by area covered with hurricane force winds

CONCLUSIONS FROM ROSENFELD ET AL. (2007) STUDY REGARDING SEEDING AT THE PERIPHERY OF A TC WITH ULTRA-FINE HYGROSCOPIC AEROSOLS

- Clouds in the seeded area are invigorated and evaporative cooling is enhanced

- Sea spray will work against this effect and must be considered in the model simulations

- The buoyancy of the inflowing air is decreased and the inflowing air will rise at a smaller radius due to its decreased buoyancy

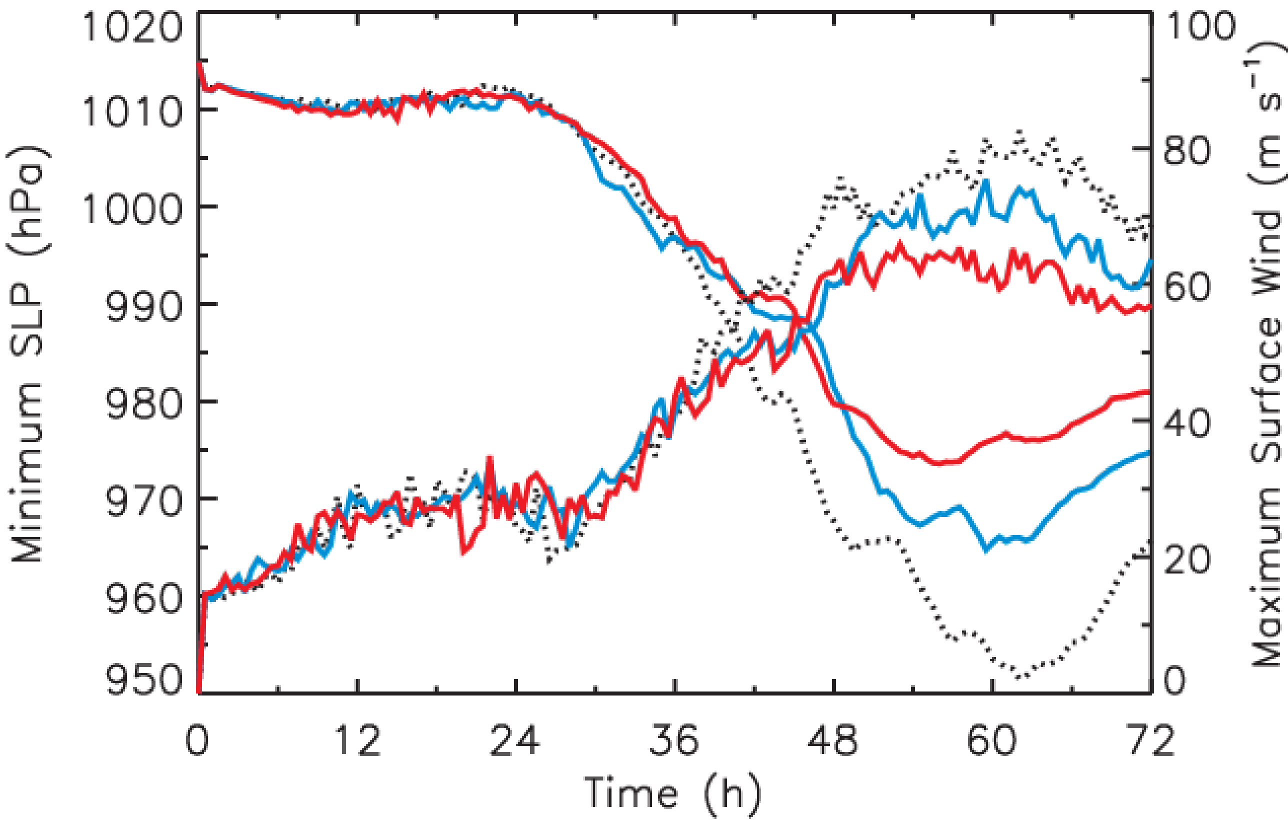
- The area of hurricane force winds is decreased substantially, meaning potentially decreased storm surge

- Despite the overall weakening, the shrinking of the eye keeps the eyewall winds about the same

- These results will be further evaluated with observations and new simulations during HURRMIT

Aerosol influences on deep convection and tropical cyclones

By
William Cotton



Clean – 100 cm^{-3}
Polluted – 1000 cm^{-3}
Double – 2000 cm^{-3}

Simulated storm intensity decreased with increasing CCN concentration.

Practical Seeding Considerations

Seeding 1 kg of hygroscopic particles having diameter of 0.1 μm and density of 2000 kg m^{-3} can fill homogeneously 1 km^3 with a concentration of nearly 1000 particles cm^{-3}. If the seeding is applied around the storm into the converging marine boundary layer that feed the storm clouds, the seeding rate should be matched to the influx rate. With average inward radial winds of 5 ms^{-1} at the 0.6 km deep boundary layer along the nearly 2000 km circumference of the radial distance of 300 km the influx of 6 km^3s^{-1}. This corresponds to a seeding rate of 6 kg s^{-1}, or 21.6 ton per hour. This is practical with large cargo airplanes having payloads exceeding 10 tons.

This means that seeding the full depth of the marine boundary layer with 0.1 mm hygroscopic particles at concentrations of several thousands particles cm^{-3} can be done by dispersing hygroscopic smoke from 5 to 10 cargo airplanes flying in the boundary layer just outside the typhoon spiral cloud bands so that the particles would be drawn into the storm by the low level convergence after having sufficient time to mix well in the boundary layer.

Ultra fine sea spray technology can produce 10^{17} CCN s^{-1} of 0.20 μm diameter (dry-equivalent) particles by using 28 kg s^{-1} sea water. The required rate of $6x10^{18}$ s^{-1} can be achieved by using 60 small vessels with

Simulations of aerosol effects on isolated deep convective clouds
(Responsible: Prof. A. Khain, HUJI)

HURRMIT	**Typical cloud models**
1. Utilization of the cloud model *with spectral bin microphysics*	1. Utilization of the cloud model *with bulk-parameterization*
2. Size distributions (43 bins doubling mass bins) are calculated at each time step for (a) water drops; (b) Columnar, (c) plates- and (d) branch-type crystals; (e) Aggregates (snow), (f) Graupel, (h) Hail,	2. Shape of size distributions is preset, Mass contents or mass/concentrations are calculated
3. The aerosol budget is taken into account	3. No aerosol budget
4. Aerosol size distributions are described by size distribution containing 43 bins with sizes from 0.005 μm to 3 μm)	4. No aerosol size distributions
5. Model input: aerosols and sounding; No tuning of model parameters is required to simulate different clouds	5. To simulate clouds under different conditions the tuning of model parameters is needed.
6. Computational area 50 km x 16 km, model resolution 25 m	6. Typical model resolution is from 300 m to ~3 km

SIMULATION OF HURRICANES:

Responsible: Prof. A. Khain, HUJI, Prof. Ginis (Rhode Island University

HURRMIT

1. Utilization of the TC model

with spectral bin microphysics (WRF_SBM)

2. Size distributions (33 bins doubling mass bins) are calculated at each time step for (a) water drops; (b) crystals, aggregates (snow), (f) Graupel, (h) Hail,

3. The aerosol budget is taken into account

4. Aerosol size distributions are described by size distribution containing 33 bins with sizes from 0.005 μm to 3 μm)

5. TC-ocean interaction will be included during the project.

6. The resolution of the finest movable grid (800 x 800 km) should be 2 km

Typical TC models

1. Utilization of the cloud model *with traditional convective parameterization (no microphysics) or bulk-parameterization*

2. No microphysics /or the shape of size distributions is preset, Mass contents or mass/concentrations are calculated

3. No aerosol budget

4. No aerosol size distributions

5. TC-ocean interaction is included (traditional convective parameterization) to be included for bulk-parameterization schemes

6. Typical model resolution is from 3 km to 10 km

Advantages of spectral (bin) microphysics

1. The ability to describe *microphysical processes* adequately (i.e. latent heat release, evaporative cooling, etc.)

2. The ability to describe *precipitation rate and precipitation spatial distribution* adequately

3. The ability to describe *aerosol effects* of microphysical processes and cloud dynamics adequately

4. The ability to describe *evolution of spay size distribution* and its effect on surface fluxes and on cloud microphysics (precipitation)

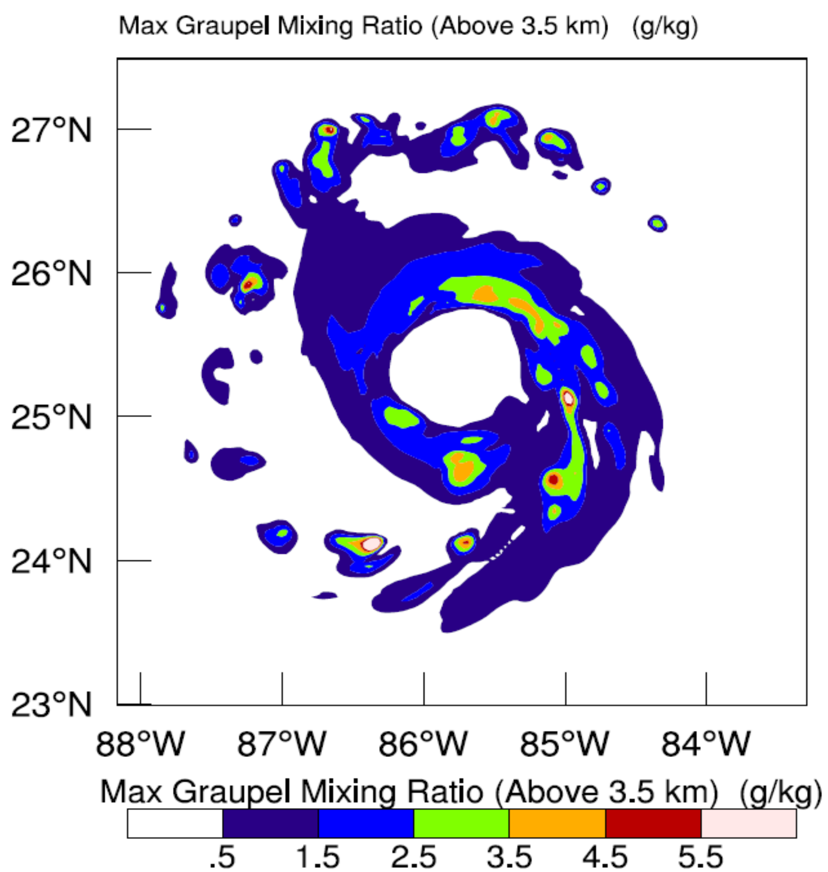
5. The ability to calculate radar reflectivity (according to its definition) and size distribution which allows adequate *comparison with satellite, radar and in situ aircraft observations*.

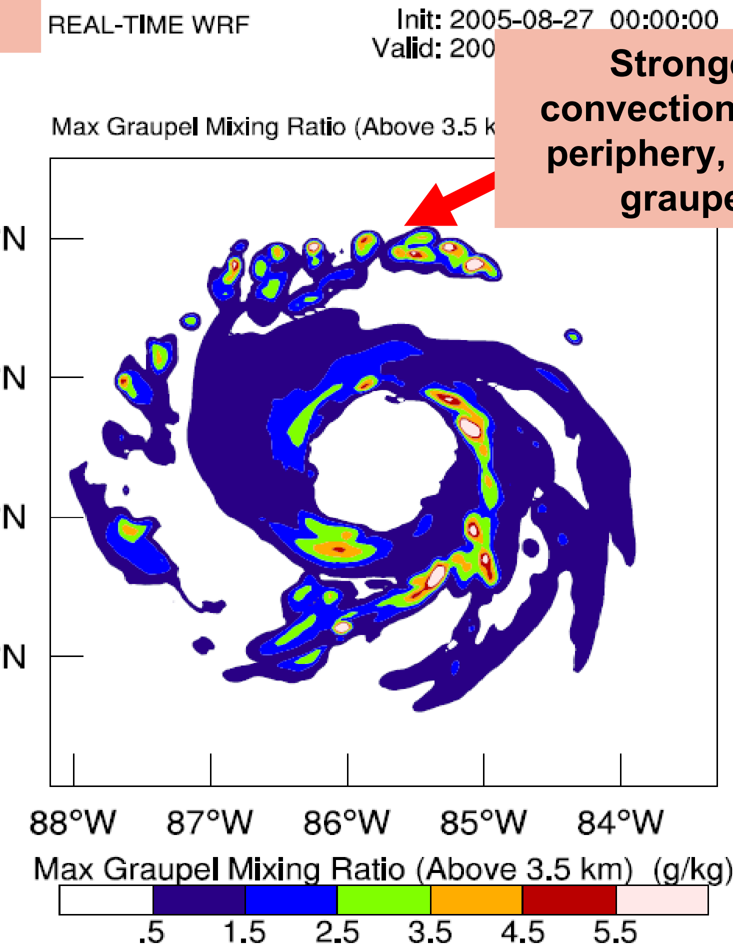
EXAMPLES OF MICROPHYSICAL FIELDS CALCULATED USING WRF-Spectral (Bin) Microphysics

Simulation of hurricane KATRINA

Maritime aerosols | **Penetration of continental aerosols from the land**

GRAUPEL MASS





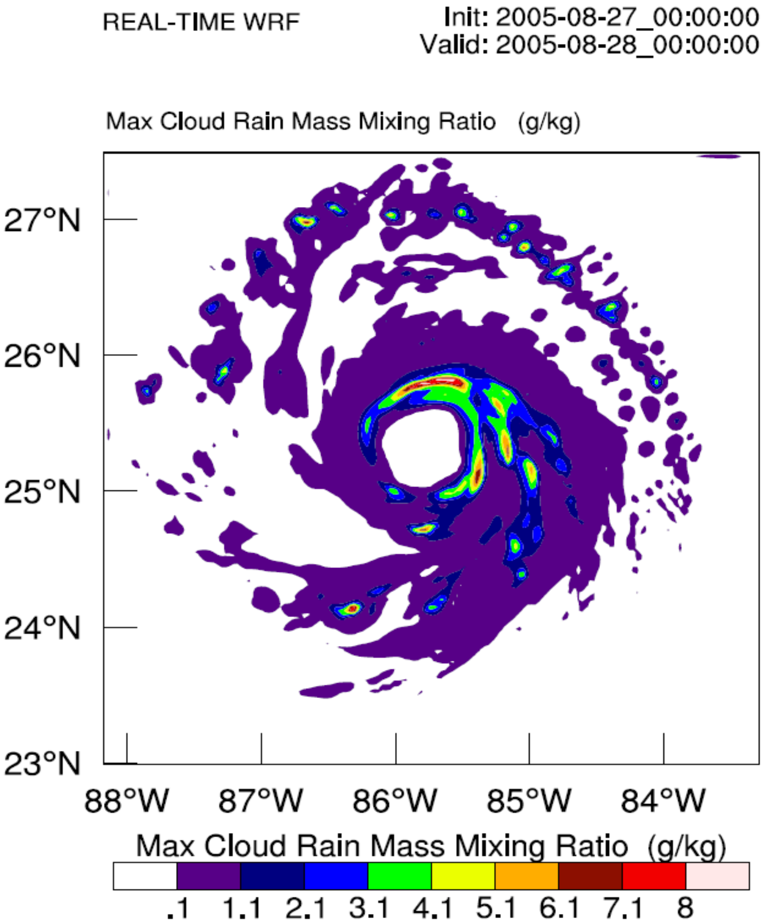
Stronger convection at Tc periphery, more graupel

EXAMPLES OF MICROPHYSICAL FIELDS CALCULATED USING WRF-Spectral (Bin) Microphysics

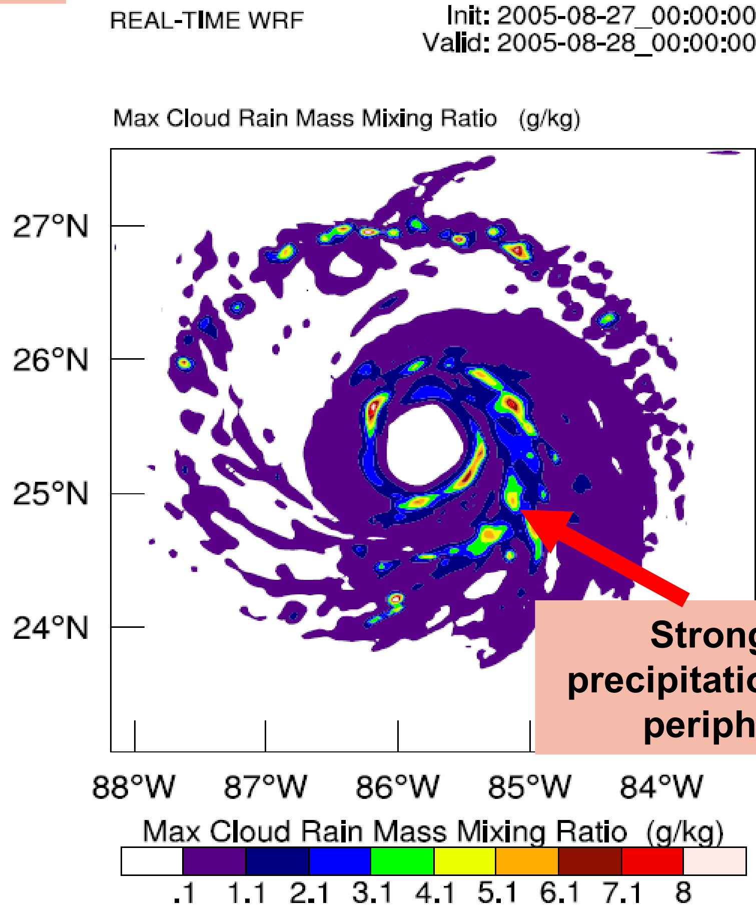
Simulation of hurricane KATRINA

RWC

Maritime aerosols



Penetration of continental aerosols from the land



Stronger precipitation at Tc periphery

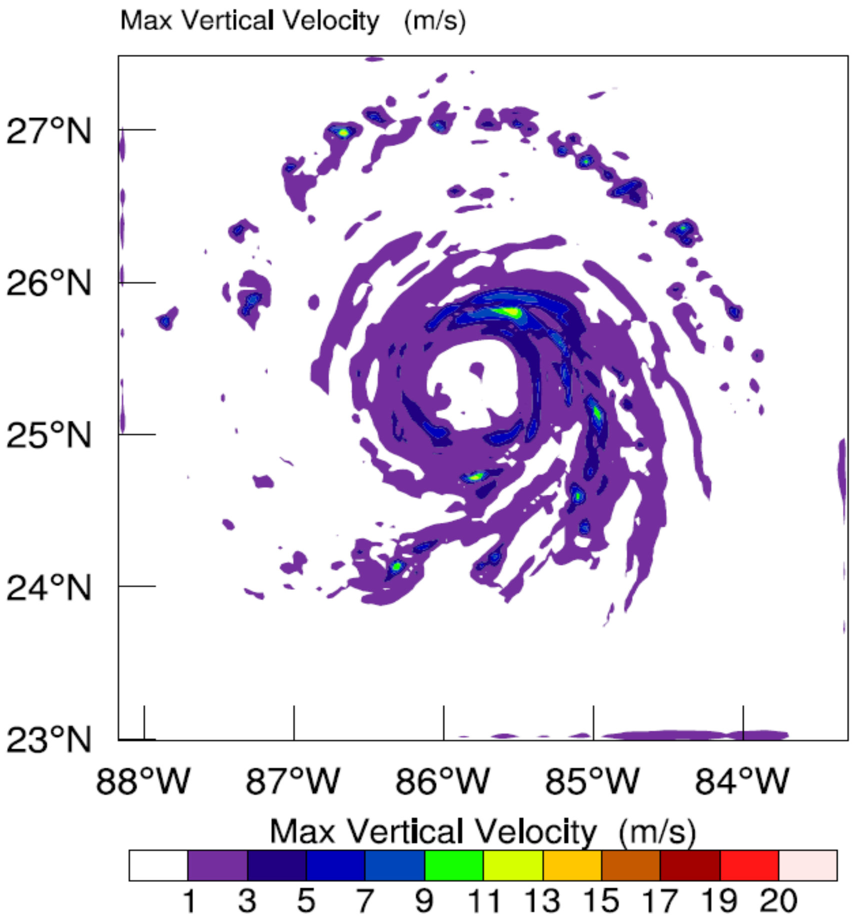
EXAMPLES OF MICROPHYSICAL FIELDS CALCULATED USING WRF-Spectral (Bin) Microphysics

Simulation of hurricane KATRINA

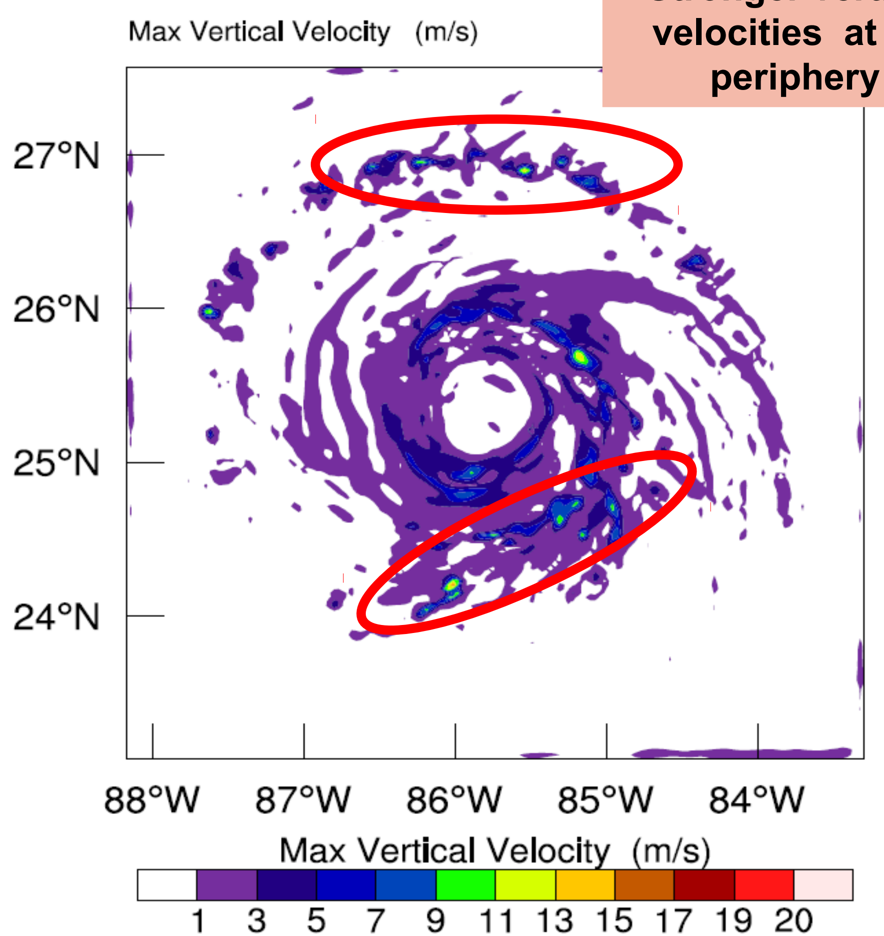
Maritime aerosols

Penetration of continental aerosols from the land

W



Stronger vertical velocities at TC periphery



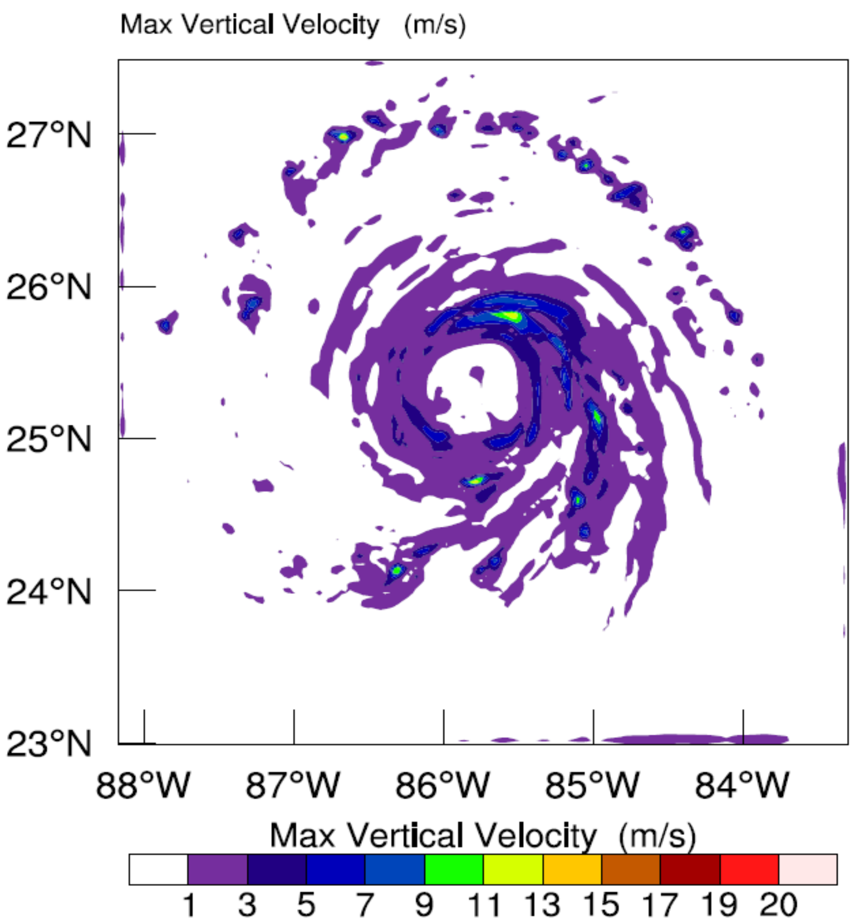
EXAMPLES OF MICROPHYSICAL FIELDS CALCULATED USING WRF-Spectral (Bin) Microphysics

Simulation of hurricane KATRINA

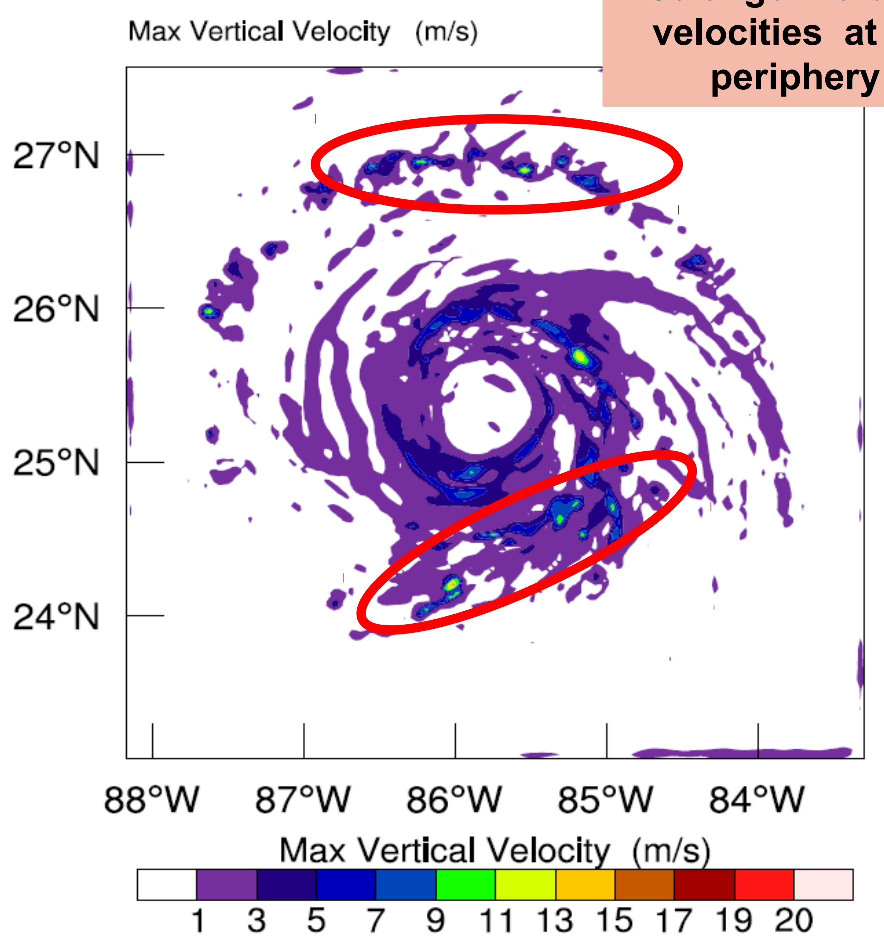
Maritime aerosols

Penetration of continental aerosols from the land

W



Stronger vertical velocities at TC periphery



Conclusions

1. It may be possible to decrease the area covered by hurricane force winds in a TC by injecting small CCN at the periphery.

2. The seeding window decreases when the storm intensifies due to the increased sea spray that enforces warm rain.

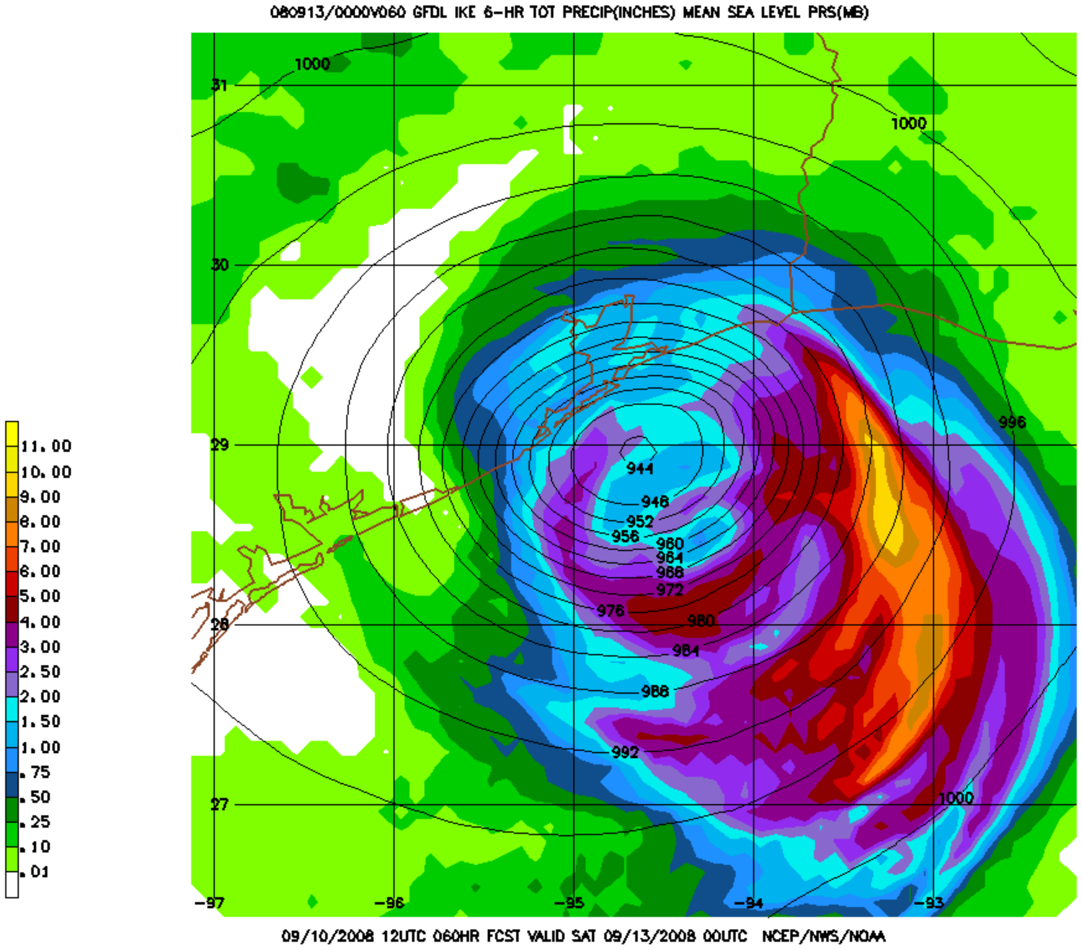
3. This mechanism suppresses low level diabatic heating by warm rain and promotes low level evaporative cooling.

4. The decreased low level air buoyancy delays its rising until closer to the center and so causes the eye to shrink.

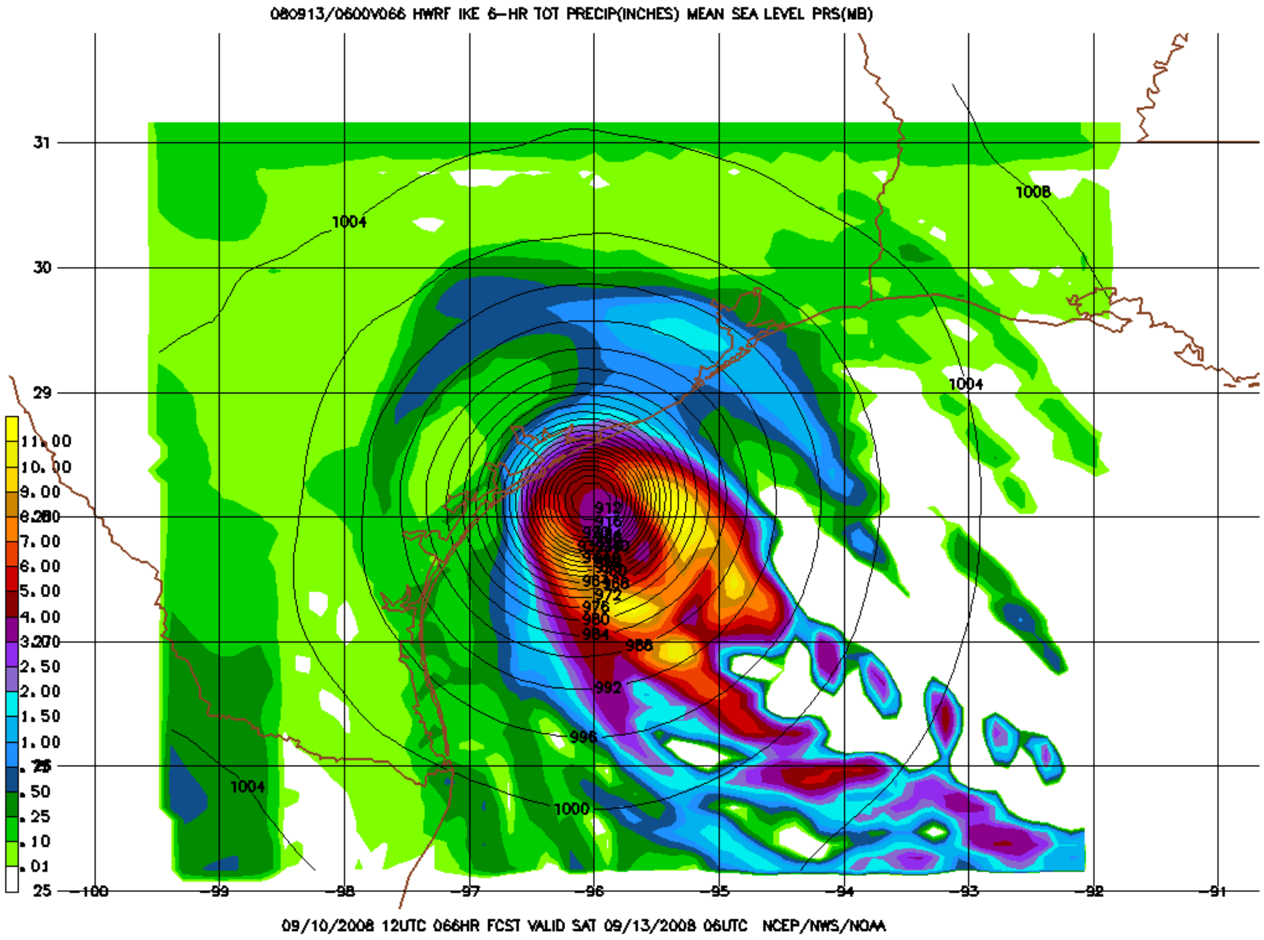
5. The area covered by hurricane force wind decreases substantially. This is important for the storm surge.

6. Despite the overall weakening, the shrinking of the eye keeps the eyewall winds little changed.

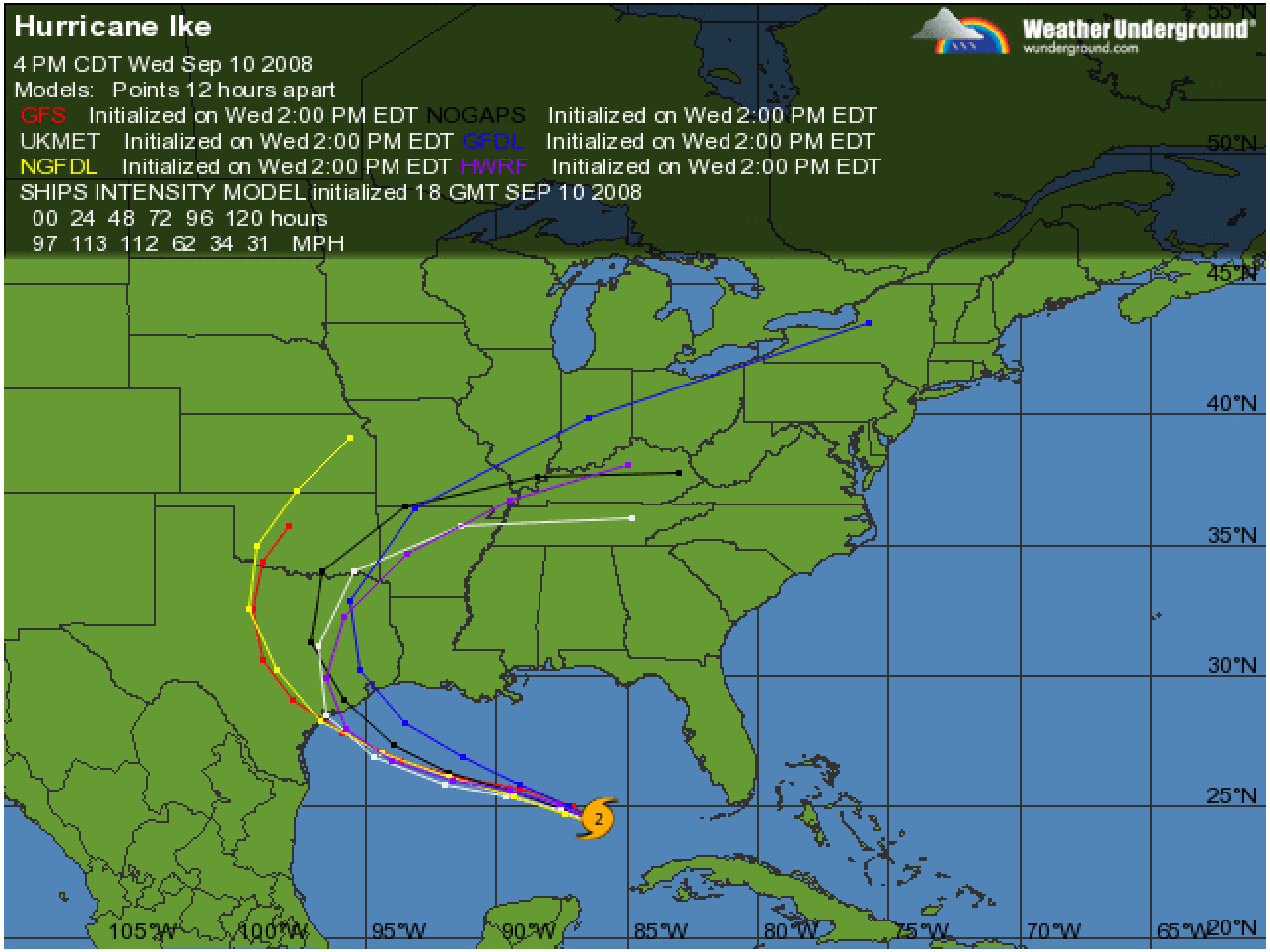
IKE FORECAST: GFDL MODEL



IKE FORECAST: HWRF MODEL



NHC MODEL SPAGHETTI PLOTS



LESSONS LEARNED FROM STORMFURY

- Time of rudimentary instrumentation and numerical models
- Several steps in the conceptual model were verified
- Key supercooled liquid water assumption could not be verified
- If current technology existed in the 1960's, the original Stormfury would not have been conducted
- The Stormfury mistakes need not be repeated
- Before field studies hurricane mitigation hypotheses should be evaluated objectively
- A panel of experts should help set testing priorities