The Rise and Fall of

THE HURRICANE AEROSOL AND MICROPHYSICS PROGRAM (HAMP)

By
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A. Khain, and I. Ginis

IDENTIFICATION AND TESTING OF HURRICANE MITIGATION HYPOTHESES

OUTGROWTH OF FEBRUARY, 2008 DHS/ESRL WORKSHOP IN BOULDER

25 international scientists attended

KEY SCIENTISTS:

- Dr. Joe Golden, Golden Research & Consulting
- Dr. William Woodley, WWC, Inc.
- Dr. William Cotton, CSU/CIRA
- Prof. Daniel Rosenfeld, Hebrew University, Israel
- Prof. Alex Khain, Hebrew University
- Prof. Isaac Ginis, U. of Rhode Island

Key Scientific Objectives:

- QUANTITATIVELY TEST MOST-PROMISING MITIGATION HYPOTHESES BY MEANS OF RIGOROUS NUMERICAL SIMULATIONS, SUPPORTED BY NECESSARY OBSERVATIONS
- COORDINATE/USE DATA FROM WISDOM AND UAS PROJECTS AND NOAA AIRCRAFT MISSIONS

PROPOSED HYPOTHESIS TESTING :

- TC IMPACTS OF SMALL AEROSOLS: SUPPRESSING WARM RAIN
- TC IMPACTS OF RADIATION-ABSORBING AEROSOLS AT STORM PERIPHERY
- TC IMPACTS OF RADIATION-ABSORBING AEROSOLS AT STORM TOP
- PUMPING COOL WATER TO OCEAN SURFACE IN FRONT OF HURRICANE

Key First-Year HAMP Results

- Small aerosols often play an important role in modulating hurricane intensity changes
- New modeling approaches with explicit microphysics show promise in predicting these impacts
- Aerosols also affect lightning production as a predictor of storm intensity changes
- Some model results compare well with new aircraft tropical cloud data over India

NOAA Coordination

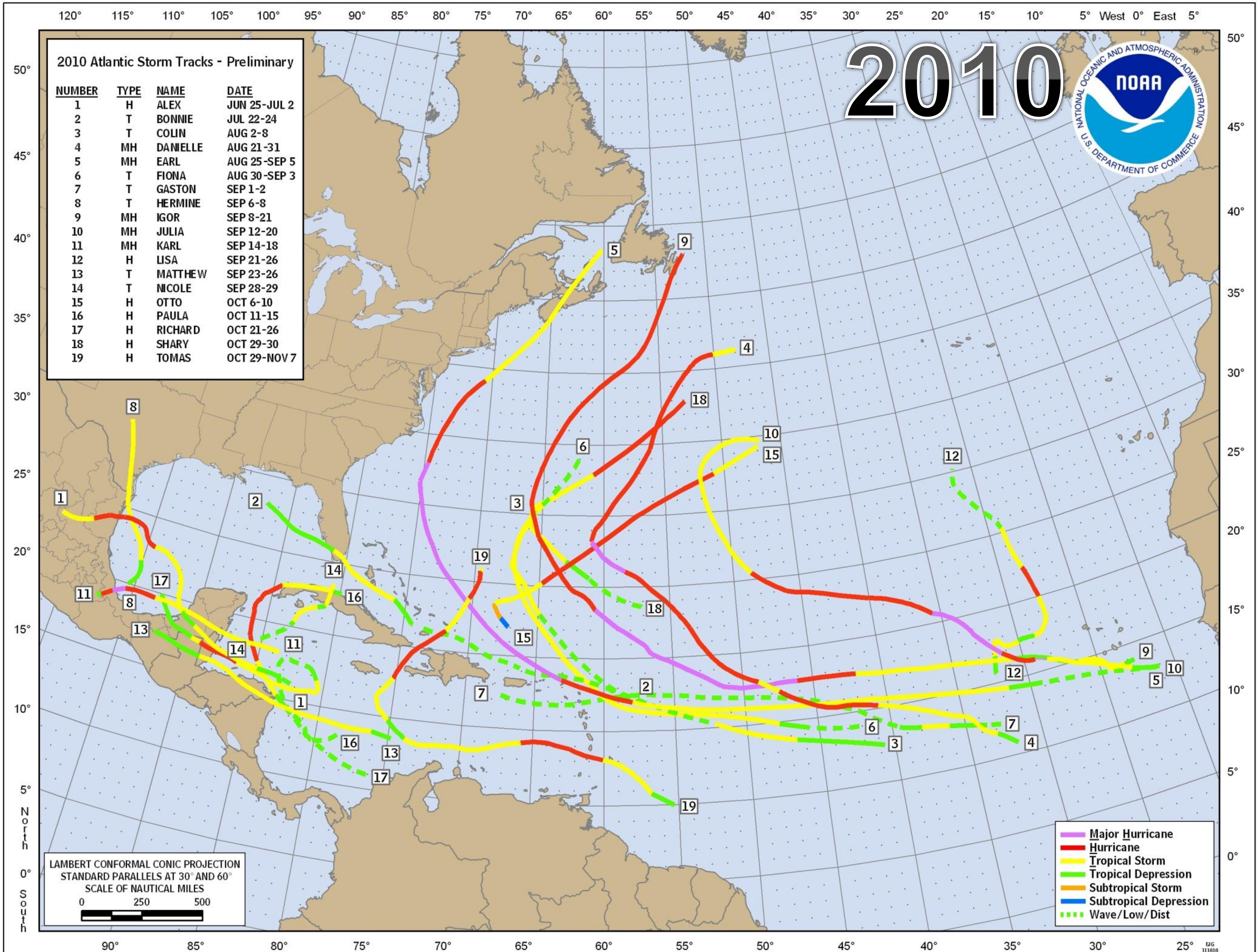
--Briefed Director, NHC and Hurricane Forecasters in January,2010

--Worked with Robert Black, HRD on P3 flight-tracks for aerosol data in TCs

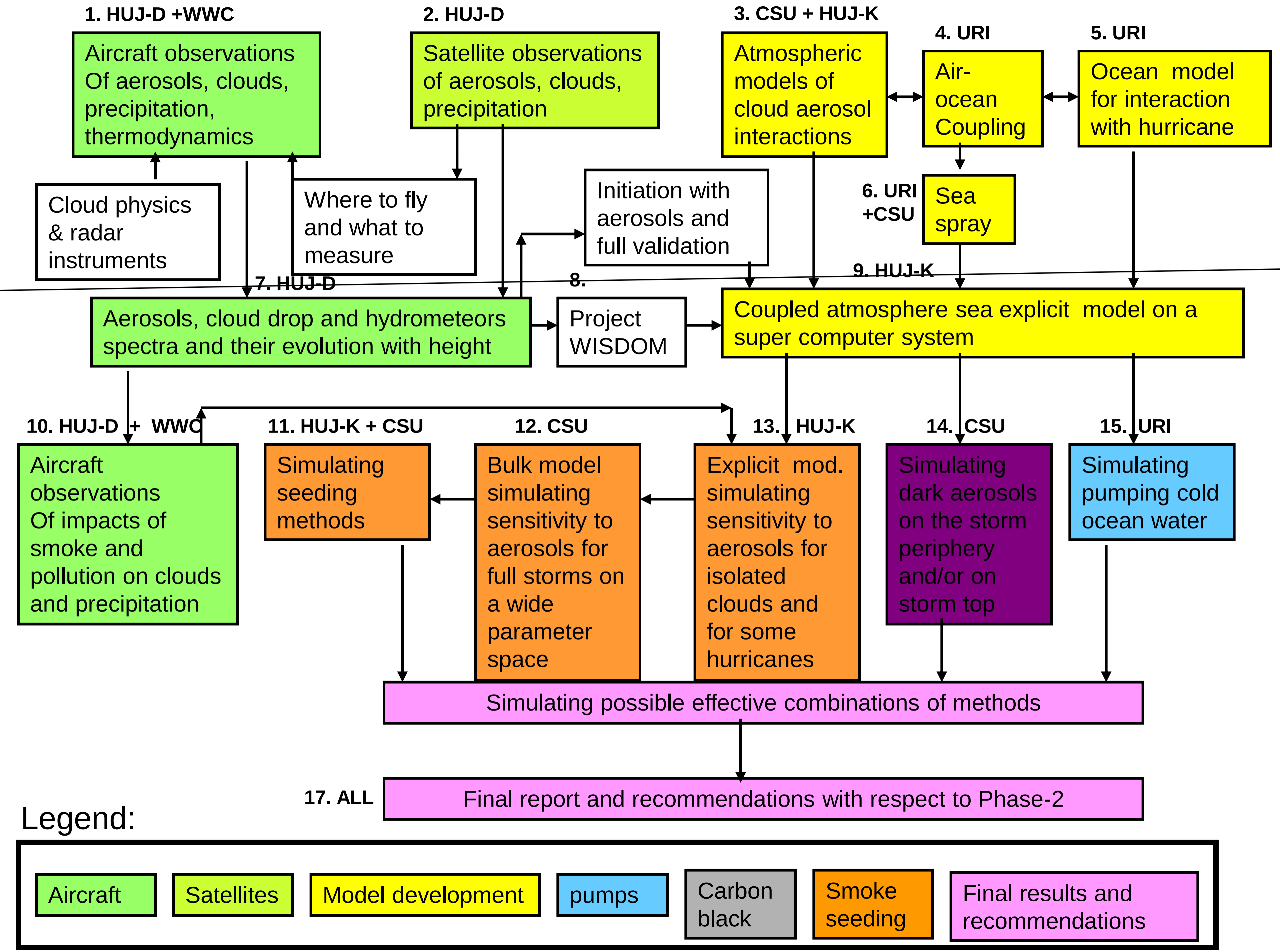
--Purchased new CCN/PCASP instruments and delivered to AOC/NOAA for P3

--AOC used GaTech CCN counter on N42

--Limited P3 flight data finally obtained on "TOMAS"


2010 Atlantic Storm Tracks - Preliminary
NUMBER TYPE NAME DATE
1 H ALEX JUN 25-JUL 2
2 T BONNIE JUL 22-24
3 T COLIN AUG 2-8
4 MH DANIELLE AUG 21-31
5 MH EARL AUG 25-SEP 5
6 T FIONA AUG 30-SEP 3
7 T GASTON SEP 1-2
8 T HERMINE SEP 6-8
9 MH IGOR SEP 8-21
10 MH JULIA SEP 12-20
11 MH KARL SEP 14-18
12 H LISA SEP 21-26
13 T MATTHEW SEP 23-26
14 T NICOLE SEP 28-29
15 H OTTO OCT 6-10
16 H PAULA OCT 11-15
17 H RICHARD OCT 21-26
18 H SHARY OCT 29-30
19 H TOMAS OCT 29-NOV 7
2010
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
Major Hurricane
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Wave/Low/Dist
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30° AND 60°
SCALE OF NAUTICAL MILES
0 250 500
West East
North
South

Karl-Igor-Julia


1. HUJ-D +WWC
Aircraft observations Of aerosols, clouds, precipitation, thermodynamics
2. HUJ-D
Satellite observations of aerosols, clouds, precipitation
3. CSU + HUJ-K
Atmospheric models of cloud aerosol interactions
4. URI
Air-ocean Coupling
5. URI
Ocean model for interaction with hurricane
Cloud physics & radar instruments
Where to fly and what to measure
Initiation with aerosols and full validation
6. URI +CSU
Sea spray
7. HUJ-D
Aerosols, cloud drop and hydrometeors spectra and their evolution with height
8.
Project WISDOM
9. HUJ-K
Coupled atmosphere sea explicit model on a super computer system
10. HUJ-D + WWC
Aircraft observations Of impacts of smoke and pollution on clouds and precipitation
11. HUJ-K + CSU
Simulating seeding methods
12. CSU
Bulk model simulating sensitivity to aerosols for full storms on a wide parameter space
13. HUJ-K
Explicit mod. simulating sensitivity to aerosols for isolated clouds and for some hurricanes
14. CSU
Simulating dark aerosols on the storm periphery and/or on storm top
15. URI
Simulating pumping cold ocean water
Simulating possible effective combinations of methods
17. ALL
Final report and recommendations with respect to Phase-2
Legend:
Aircraft
Satellites
Model development
pumps
Carbon black
Smoke seeding
Final results and recommendations

HAMP Future Plans?

- Future plans endorsed by May Panel Review
- May test additional hypotheses on key intensity change factors (carbon black, ocean cooling, etc)
- Focus Phase 2 on intensity change forecasting
- Gather aerosol+microphysics data with NOAA or Navy P3s on TCs

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.

Numerical studies

A brief description of results obtained by group headed by

Alexander Khain

Department of Atmosphere Science

The Hebrew University of Jerusalem

Participants: Dr. Barry Lynn, Dr. A. Pokrovsky, Dr. M. Pinsky

PhD students: Nir Benmoshe, J. Spund, L. Magaritz

System manager: H-Z. Kruglyak

Consulting: Dr. Jimy Dudhia (NCAR)

December 2009

The HAMP hypotheses:

I. Aerosols affect clouds within TC leading to redistribution of latent heat release within hurricanes and affect TC intensity

II. There is a possibility to decrease the intensity of hurricanes by seeding cloud bases of hurricanes at their periphery with submicron aerosols

To justify the HAMP hypotheses using numerical models it is necessary:

1) To develop a microphysical scheme suitable for quantitative evaluation of effects of aerosols on cloud microphysics and dynamics

2) To implement this microphysics into models of individual clouds and perform simulations of evolution of individual maritime deep cumulus clouds under different aerosol conditions

3) To implement this microphysics into an advanced TC model and perform simulations of TC evolution under different aerosol conditions simulating effects of natural as well as seeded aerosols

Development of a novel non-parameterized spectral bin microphysics (SBM)

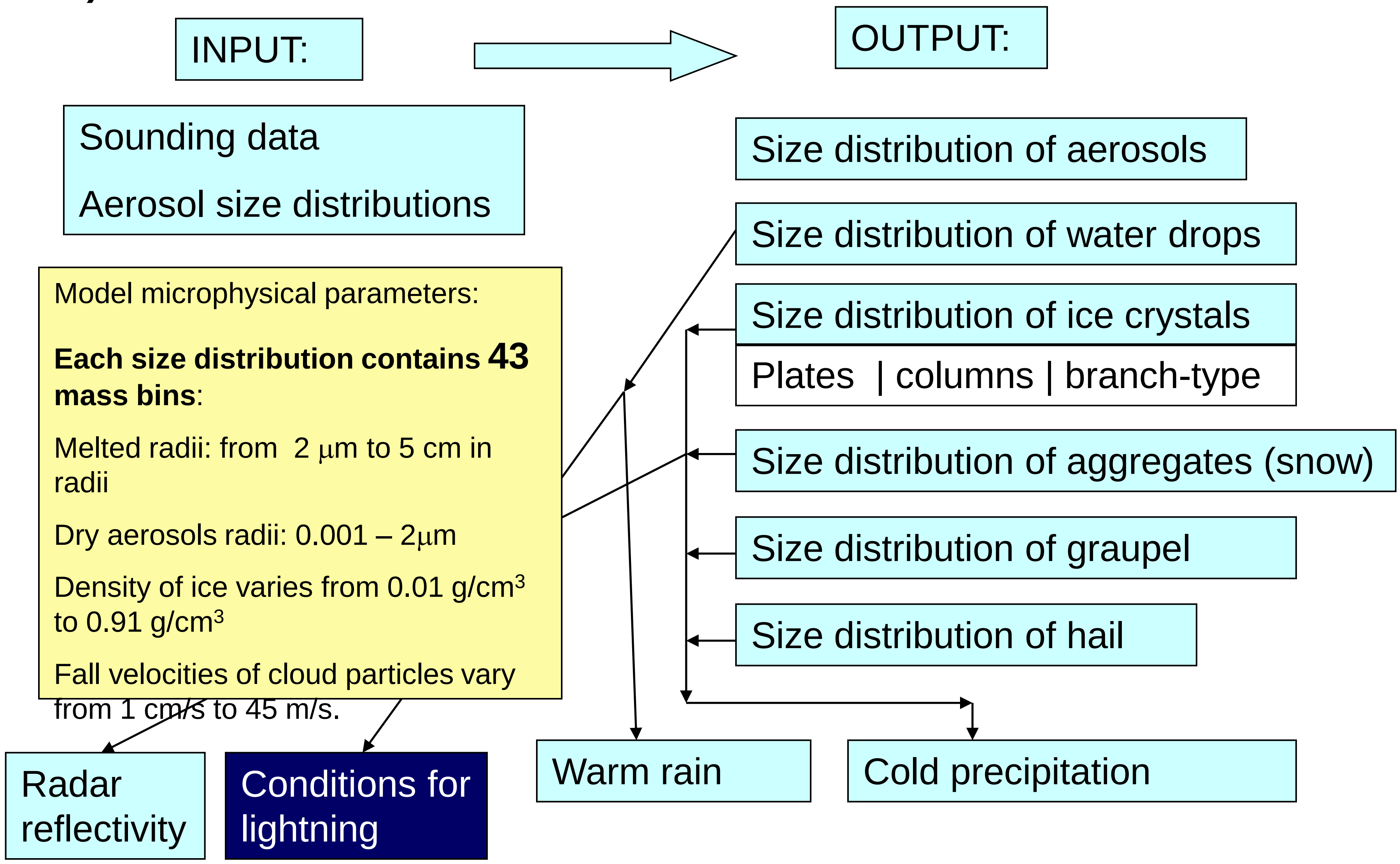
Table 1. Main differences between the bulk-parameterization schemes and SBM

	Bulk parameterization schemes (currently used in the TC models)	Spectral bin microphysics
Distribution functions	Prescribed *a priori*	Calculated in the course of the model integration
Aerosol treating	Not taken into account	Effects of aerosols on dynamics and microphysics are taken into account
Drop nucleation	Crude parameterization. Typically concentration of droplets either not calculated or is prescribed a priory.	Droplet concentration and size are calculated using information about cloud dynamics and aerosols.
Condensation growth	Crude parameterization. No physically based equations are solved.	Solving the equations for diffusion condenstation of droplet and ice particles. The size and shape of particles is taken into account
Collisions between droplets	Crude parameterization. It is assumed that the rate of collisions is proportional to the mass of droplets	The accurate kinetic equation for stochastic collisions is solved
Collisions between droplets and raindrops	Very simplified equation for "continuous growth" is used with mean value of collision efficiency	The accurate kinetic equation for stochastic collisions is solved
Settling of particles	Particles belonging to the same class (e.g., snow, or raindrops, etc) fall with a given averaged fall velocity.	Fall velocity of particles of each mass and each class fall with their own fall velocities, so that large particles fall faster, while small ones fall slower
Evaporation, freezing, etc	The processes are described under assumption that the shape of size distributions does not change (which is wrong)	The processes are described using the first principle equations, according to which size distribution shapes change appropriately
Adjustment to observations	Each change in the environment conditions (say, aerosol concentration, sounding, etc.) requires tuning the model parameters to get reasonable results	No tuning is required

Fig.1

A scheme of microphysical processes in the Hebrew University Cloud Model (Fig. 2)

2-D HUCM spectral bin microphysics (Khain et al. 1996, 2004, 2005, 2008, 2009)



The effects of aerosols on individual convective clouds under conditions typical of TC periphery

2-D, mixed phase,
Hebrew University Cloud Model (HUCM) with spectral bin microphysics (Khain et al., 2004,2008,2009)

Computational area 172 km x 16 km
Resolution: 250 m x 125 m.
Dynamical time step: 5 s
Microphysical time step: 0.2- 1 s.

Fig. 3

Cloud Water Content, t=25 min

Low aerosol concentration **High aerosol concentration**

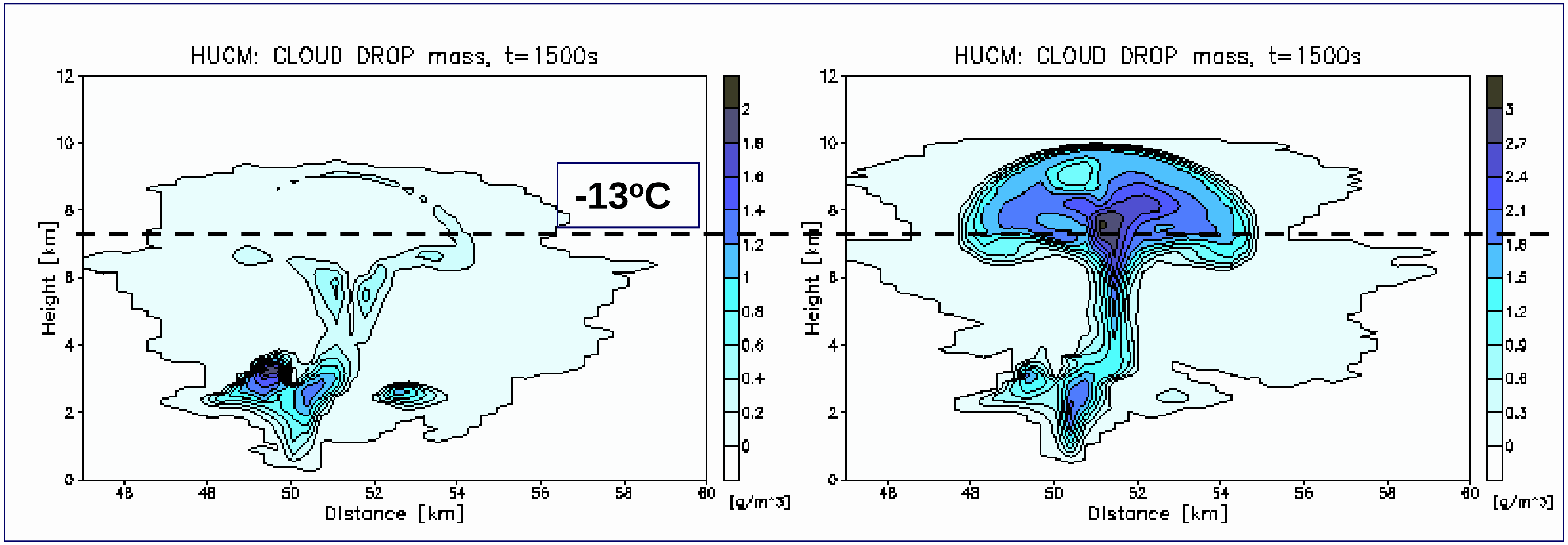
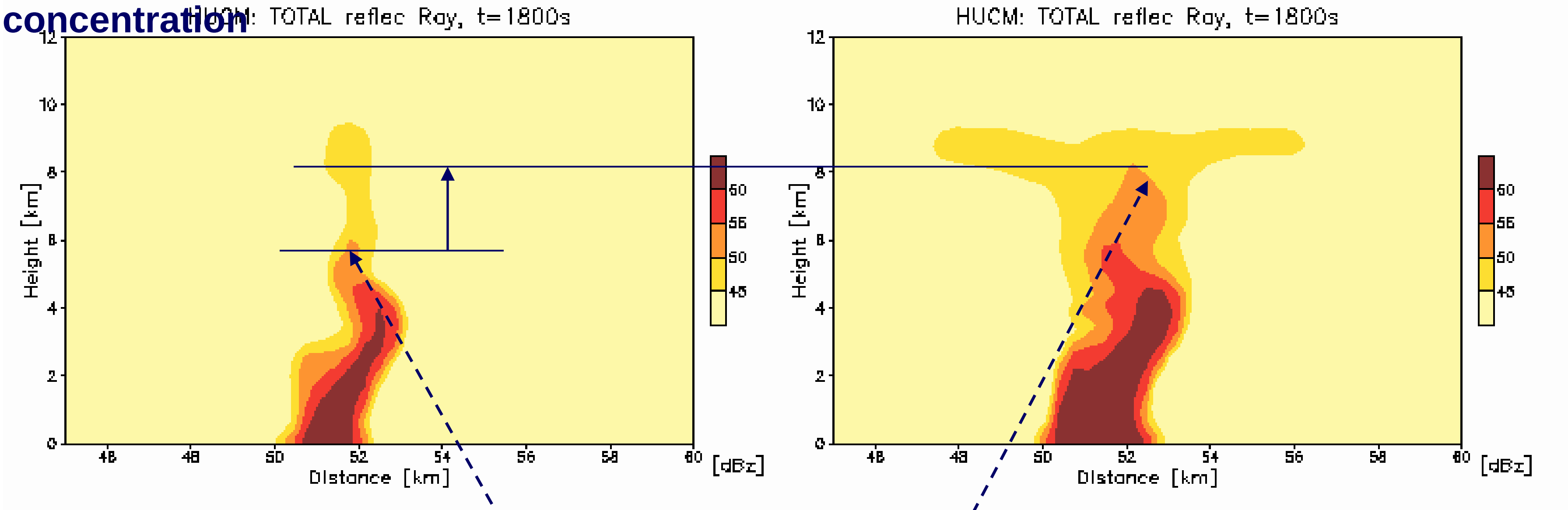


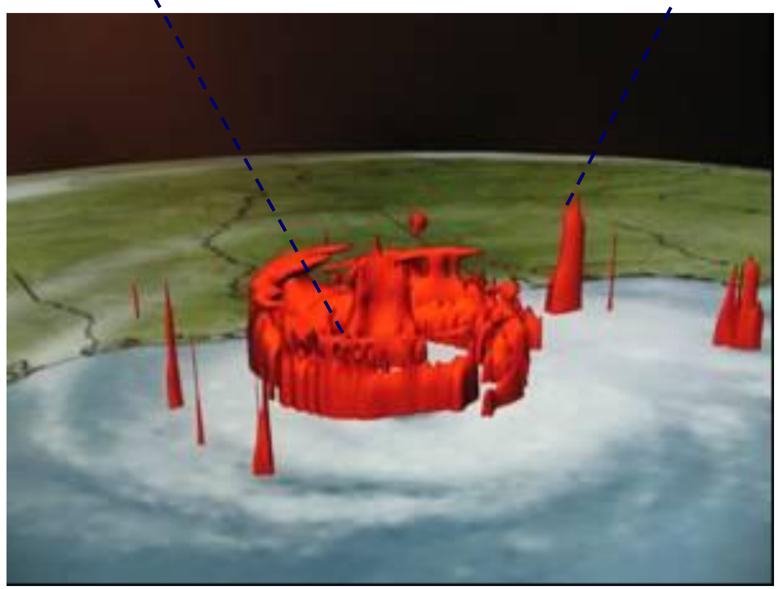
Figure 4. CWC in clouds developing in dirty air is higher and supercooled water reaches higher levels.

t=30 min

Low (maritime) aerosol concentration

High (continental) aerosol concentration





Conclusion

Small aerosols change dramatically the cloud microphysics and dynamics, transforming deep maritime clouds into thunderstorms

The aerosol effects on the cloudiness structure of TCs approaching and penetrating the land

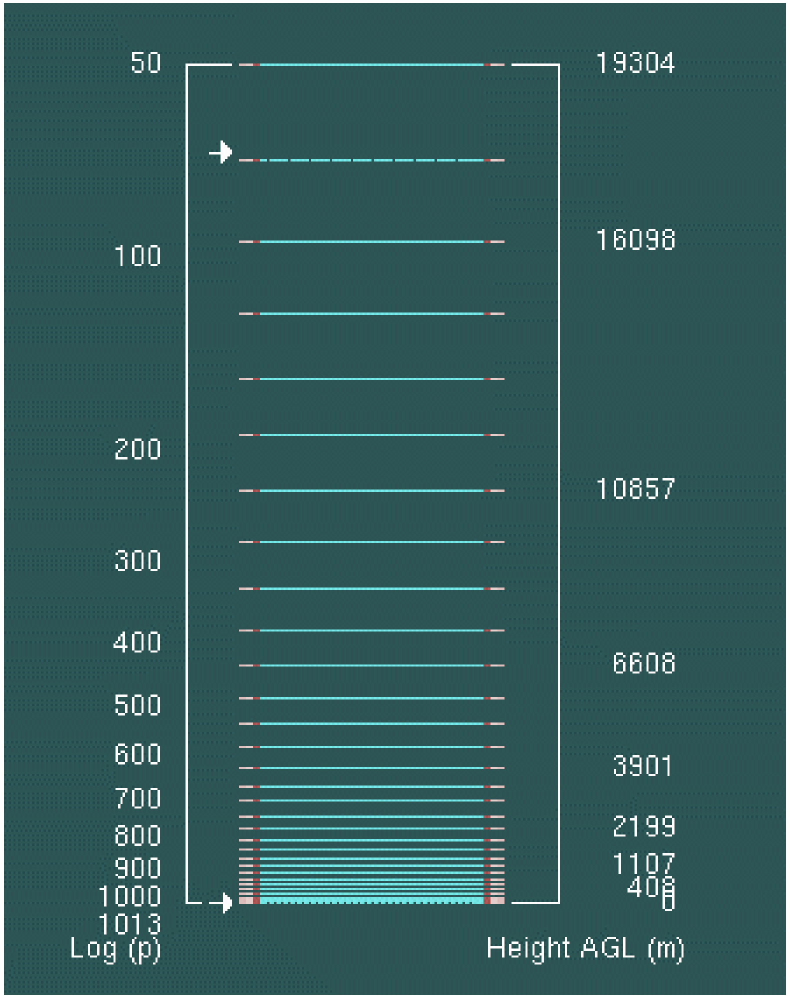
3-D, two nested grid, Weather Research and Forecasting Model (WRF) (Skamarock et al., 2005).

Real data run simulation (initial data every 3hr)
9 km and 3 km resolution, 62500 grid points
31 levels, terrain-following vertical coordinates
3rd Runge-Kutta time integration scheme
Arakawa-C grid with 3:1 grid size ratio
Thompson’s (2007) microphysics bulk parameterization

grid structure,

resolution of the finest grid 3 km

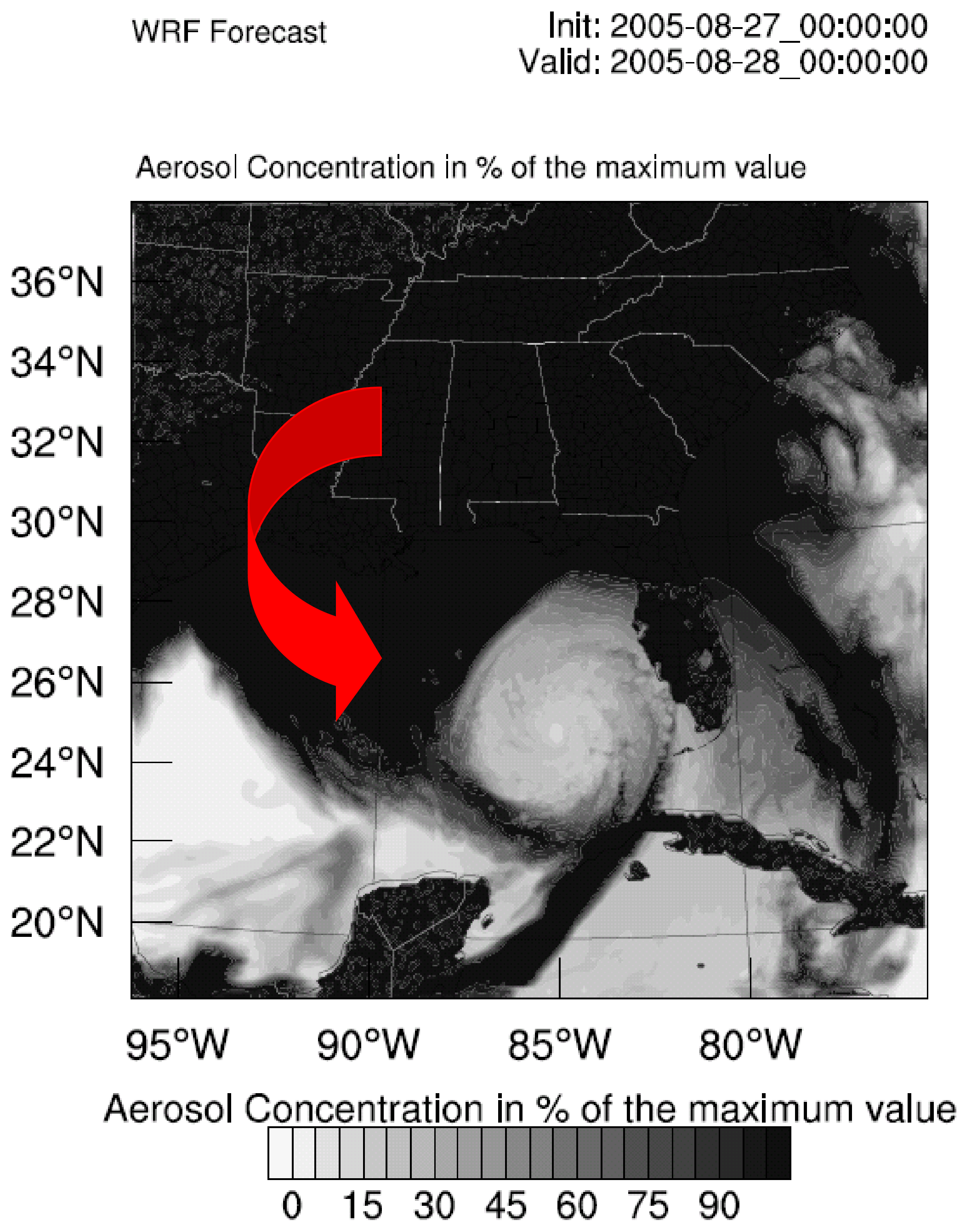
31 levels,
terrain-following vertical coordinates



Spectral bin microphysics is used on movable fine grid

Bulk parameterization

Figure 6



Just to understand the advection process of the scalar value

Figure 7

August 28th

22z, 2005

LOW AP CONCENTRATION

EFFECTS OF CONTINENTAL AEROSOLS

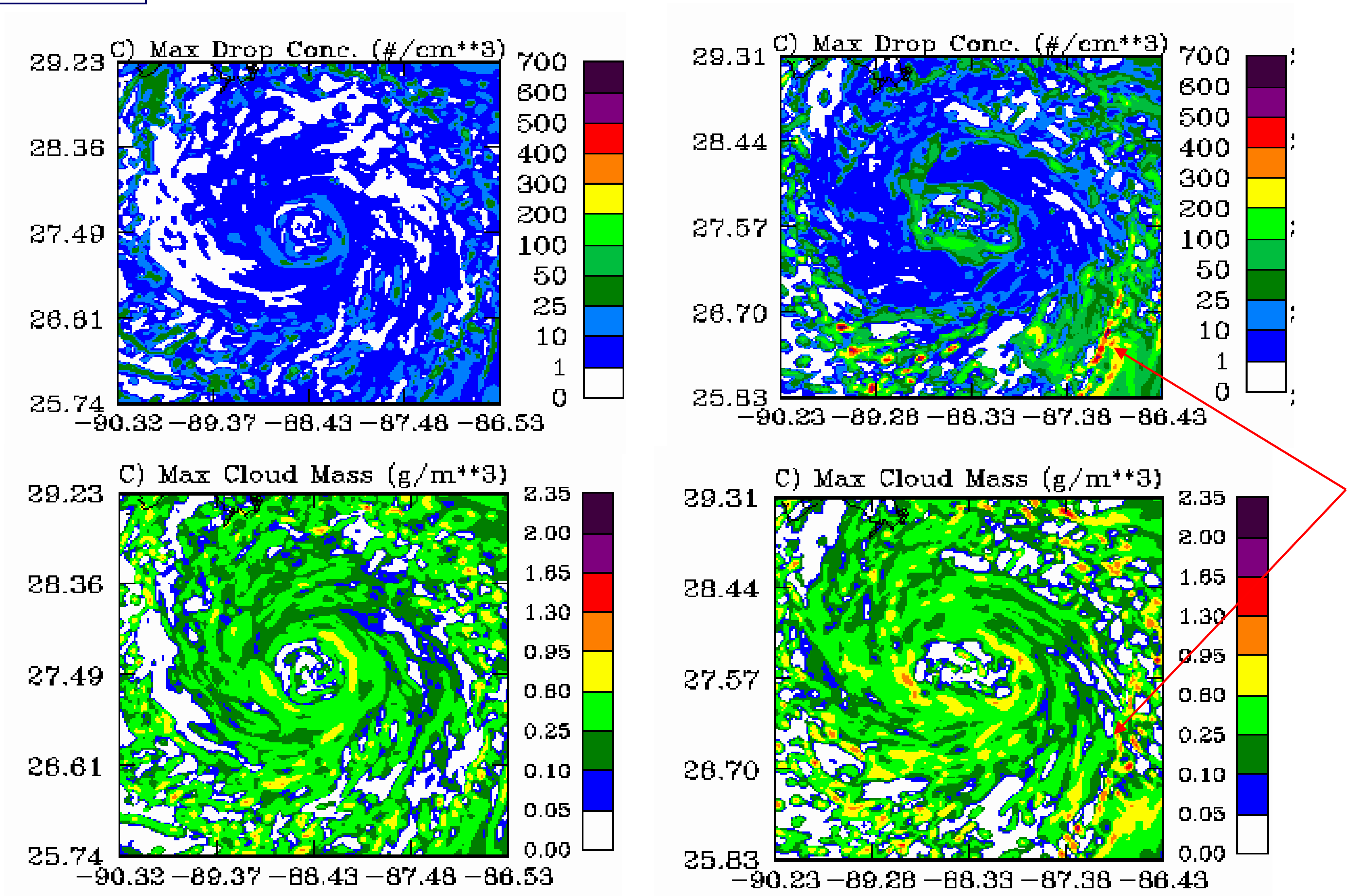


Figure 8. Fields of the maximum droplet concentrations (upper low) and cloud droplet content (CWC) in simulations MAR (left) and MAR-CON (right) at August 28th 22z at the fine grid.

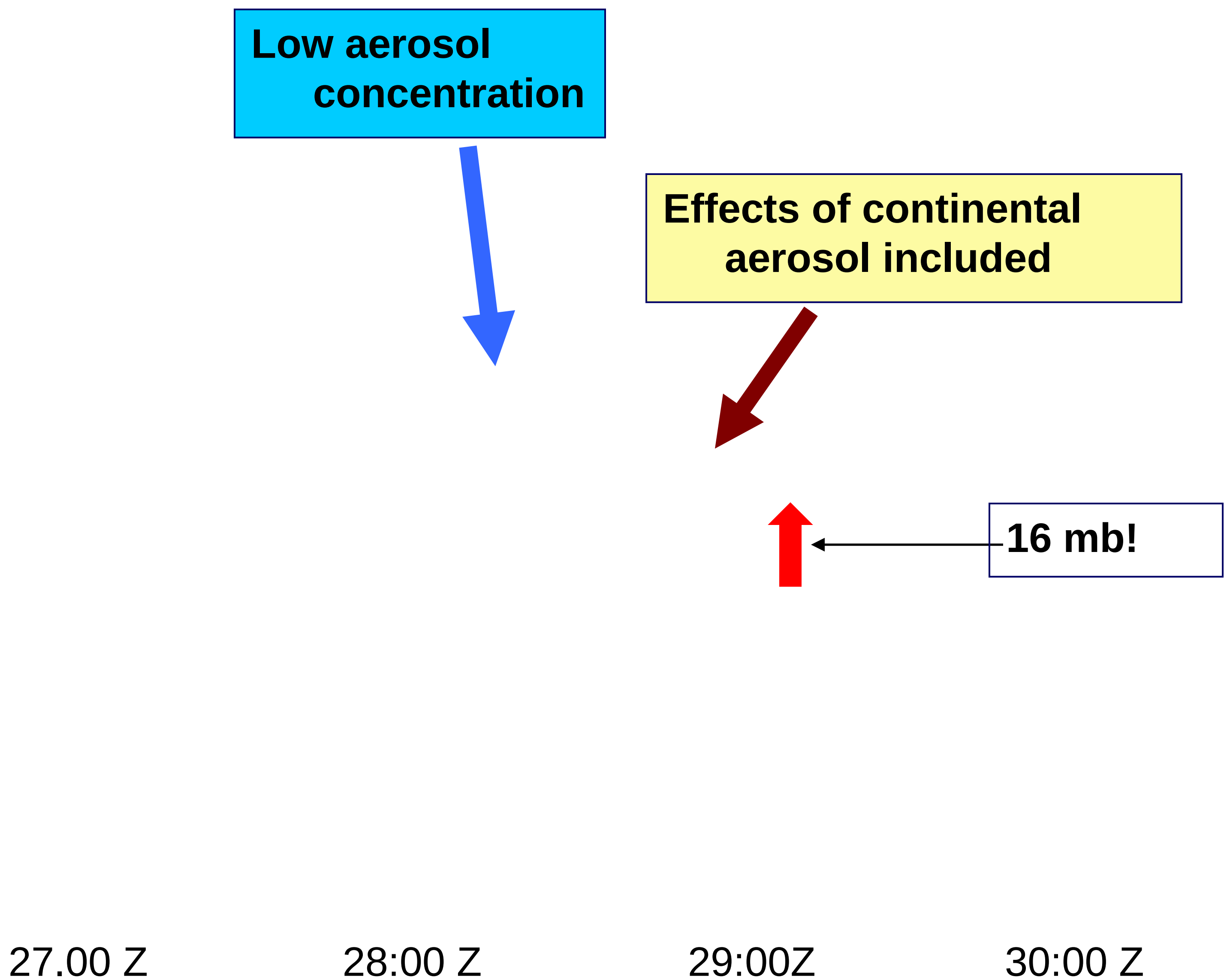


Figure 9. Time dependence of minimum pressure in numerical experiments and hurricane Katrina (August 2005)

Low aerosol concentration | Aerosol effects are taken into account

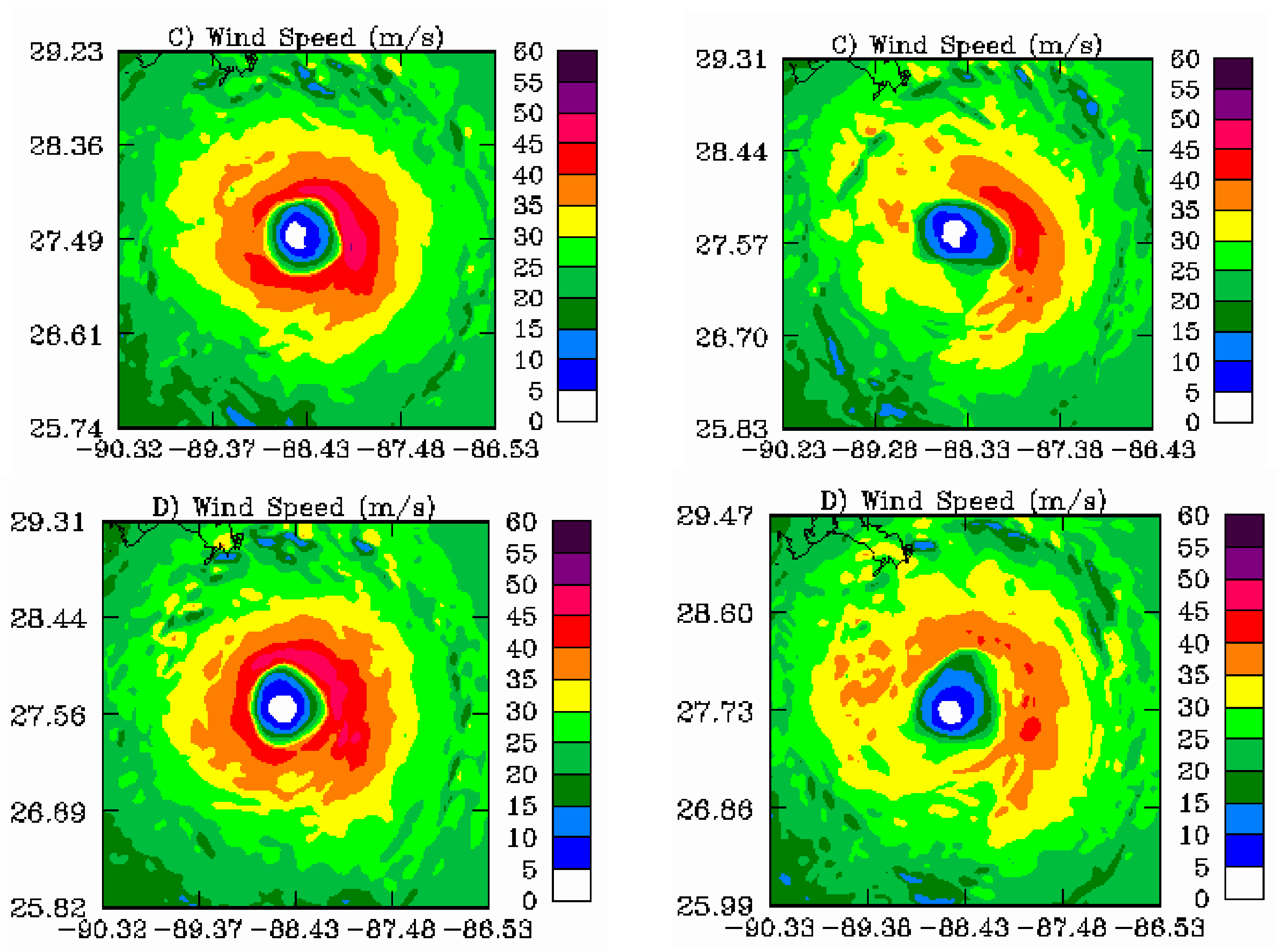


Figure 10 The fields of maximum wind speed 28 Aug. 21 z (upper panels), and 22 z. in runs with low aerosol concentration (left) and with effects of continental aerosols taken into account (right).

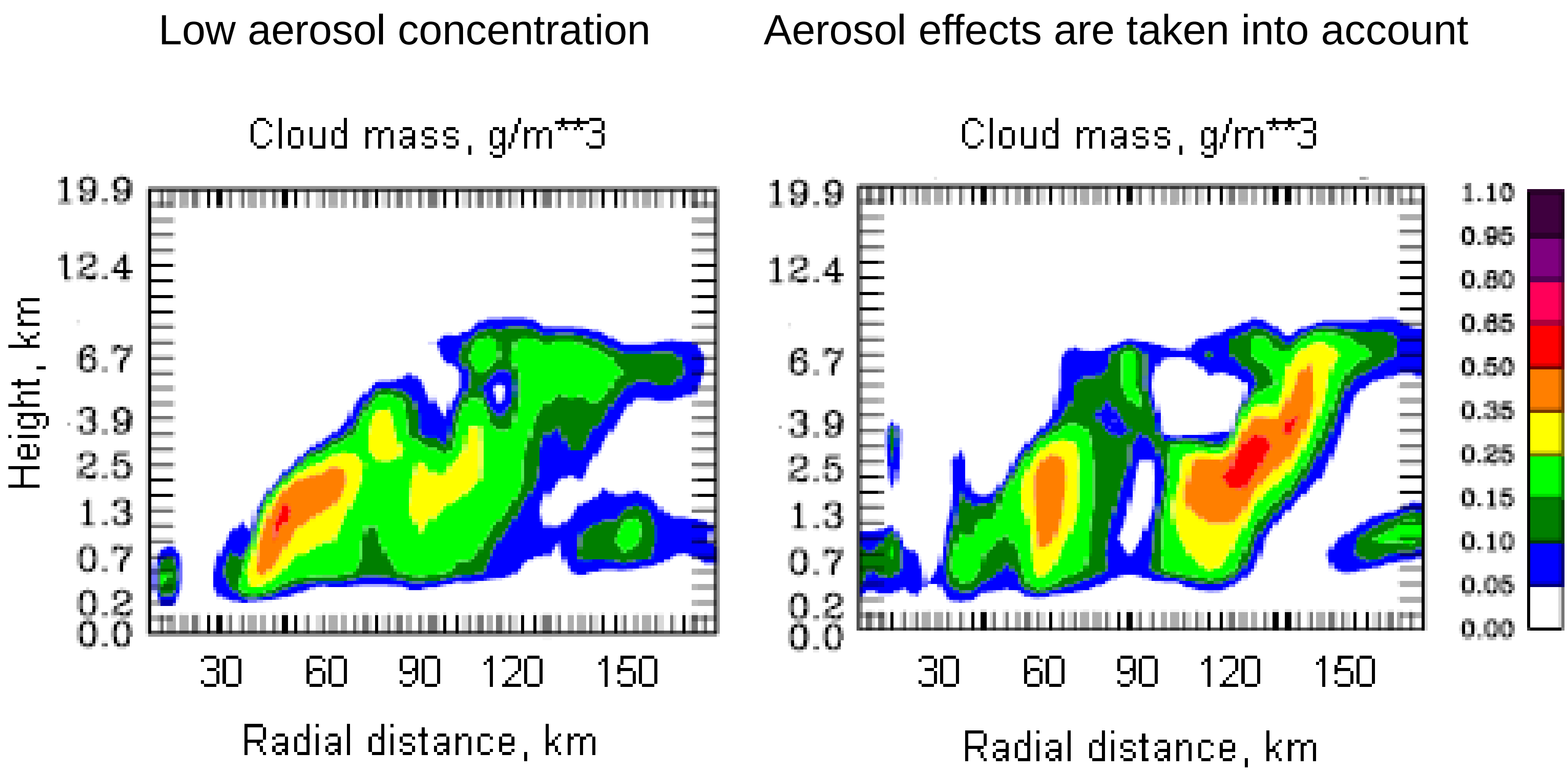


Figure 11. The vertical cross-section of azimuthally averaged CWC in simulations MAR (left) and MAR-CON (right) at time instance when the maximum difference in the TC intensities took place.

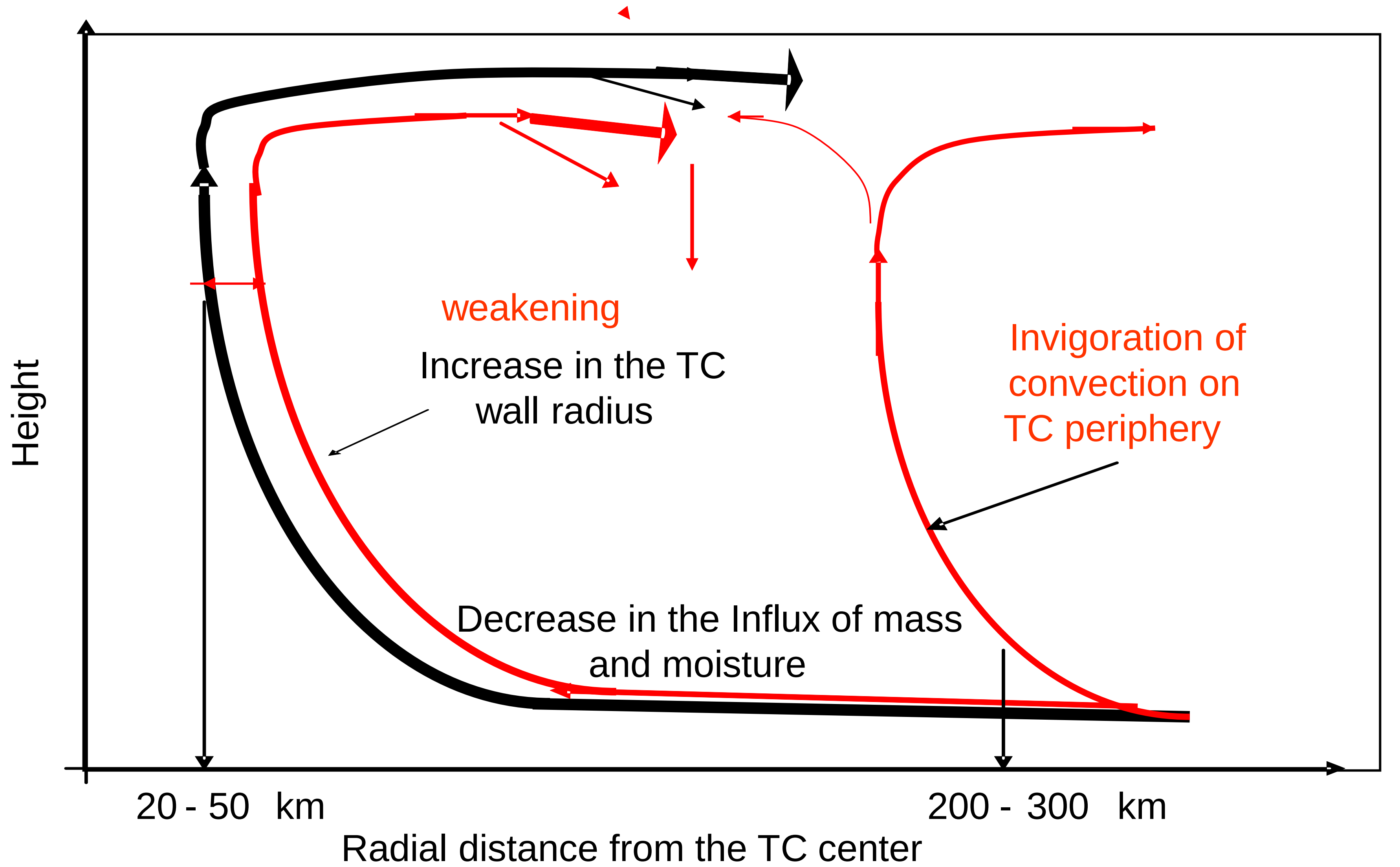


Figure 12. A scheme of aerosol effects on the TC structure leading to TC weakening

Conclusions

- The effects of continental aerosols on structure and intensity of landfalling TCs are simulated using WRF with spectral bin microphysics

- Atmospheric aerosols dramatically affect cloud microphysics and dynamics of TC clouds, precipitation and TC intensity

- Effects of aerosols on the TC intensity is a plausible mechanism of weakening of landfalling hurricanes. No other models (not-coupled with the ocean) are able to predict TC weakening before landfall

NEXT Steps (pending future funding):

1. **Simulations of the in-situ observed cloud structure using high resolution HUCM (in collaboration with the group of Prof. D. Rosenfeld, HUCM).**

2. **Development of spay parameterization on atmosphere-ocean interaction in the TC zone and on the aerosols affecting clouds (in collaboration with the group of Prof. I. Ginis (URI).**

3. **Development of advanced new generation TC-ocean model with spectral bin microphysics that will be used as a benchmark model for calibration of forecast TC models and for scientific investigations of the TC structure, genesis, evolution (intensity) and trajectories (in collaboration with Prof. I. Ginis (URI), numerical group of the Hurricane Research center (Miami) and numerical group of NCAR (J-W. Bao)**

4. **Model intercomparison (with Prof. W. Cotton)**

5. **Simulation of effects of cloud seeding of clouds at the TC periphery on the TC intensity**

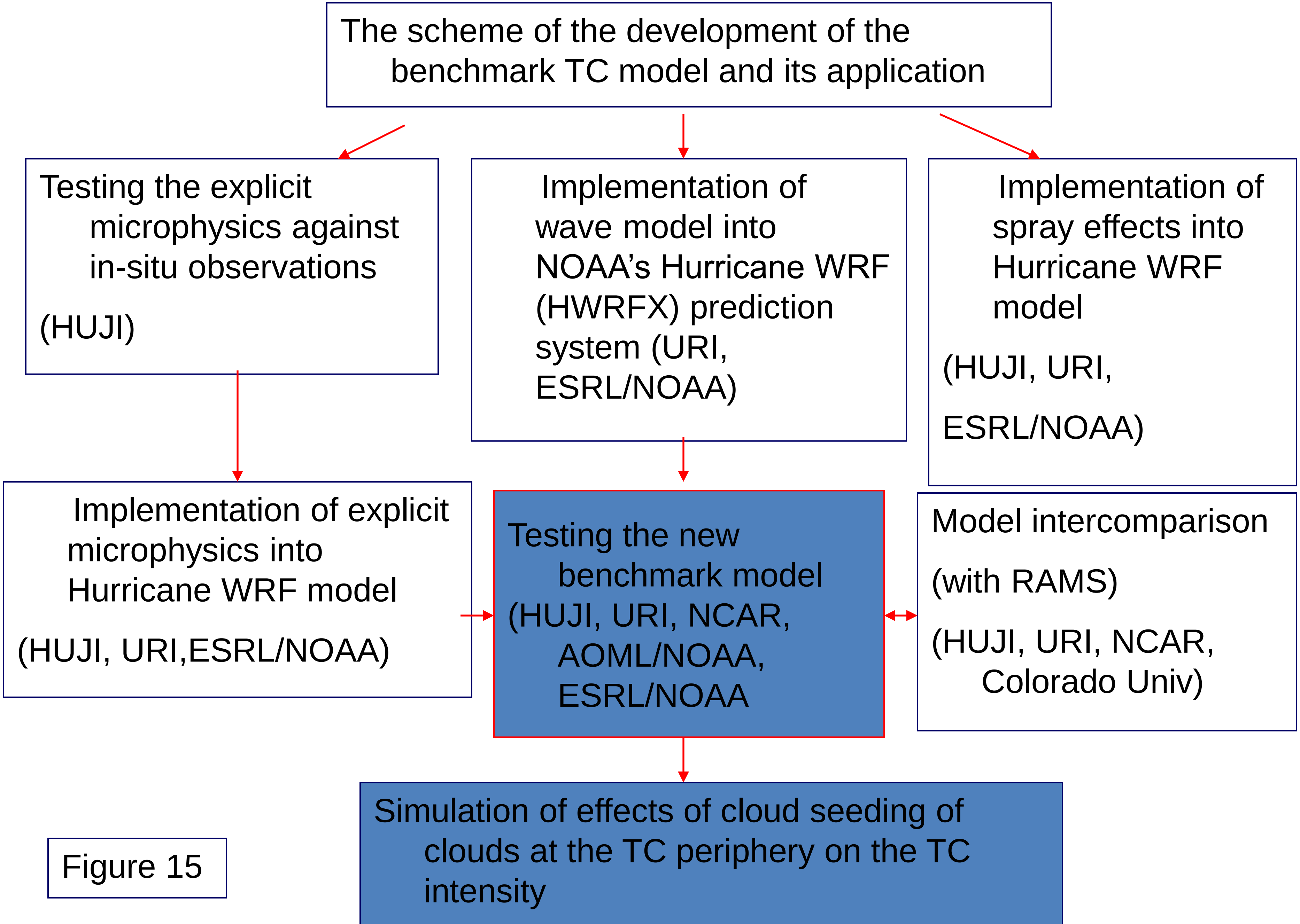

The scheme of the development of the benchmark TC model and its application
Testing the explicit microphysics against in-situ observations
(HUJI)
Implementation of wave model into NOAA's Hurricane WRF (HWRFX) prediction system (URI, ESRL/NOAA)
Implementation of spray effects into Hurricane WRF model
(HUJI, URI,
ESRL/NOAA)
Implementation of explicit microphysics into Hurricane WRF model
(HUJI, URI,ESRL/NOAA)
Testing the new benchmark model (HUJI, URI, NCAR, AOML/NOAA, ESRL/NOAA
Model intercomparison
(with RAMS)
(HUJI, URI, NCAR, Colorado Univ)
Simulation of effects of cloud seeding of clouds at the TC periphery on the TC intensity

Figure 15