Energy and Water Cycles in Hurricanes

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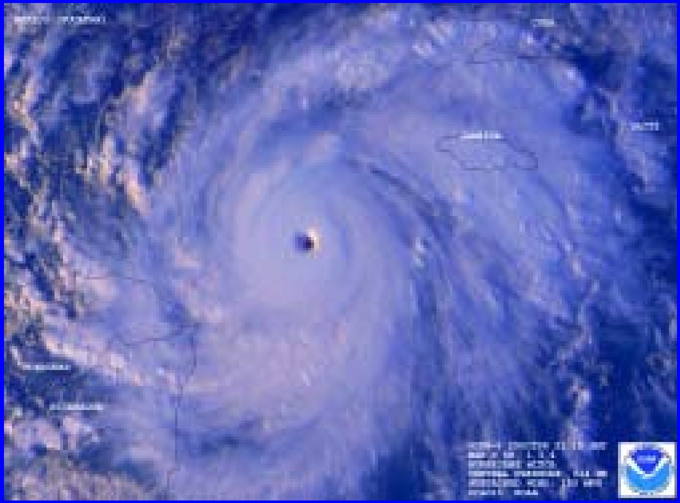
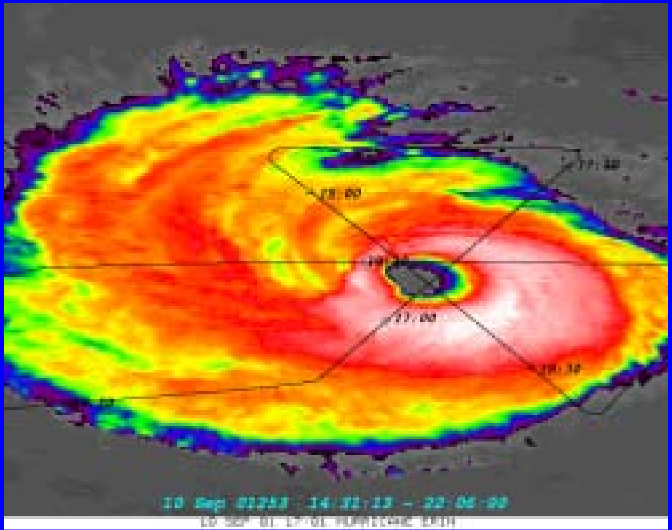
Research Objectives

- Model validation using TRMM and CAMEX data

- Budget studies (momentum, heat, water)
  - Warm core formation mechanisms
  - Intensification mechanisms
  - Water cycling in hurricanes

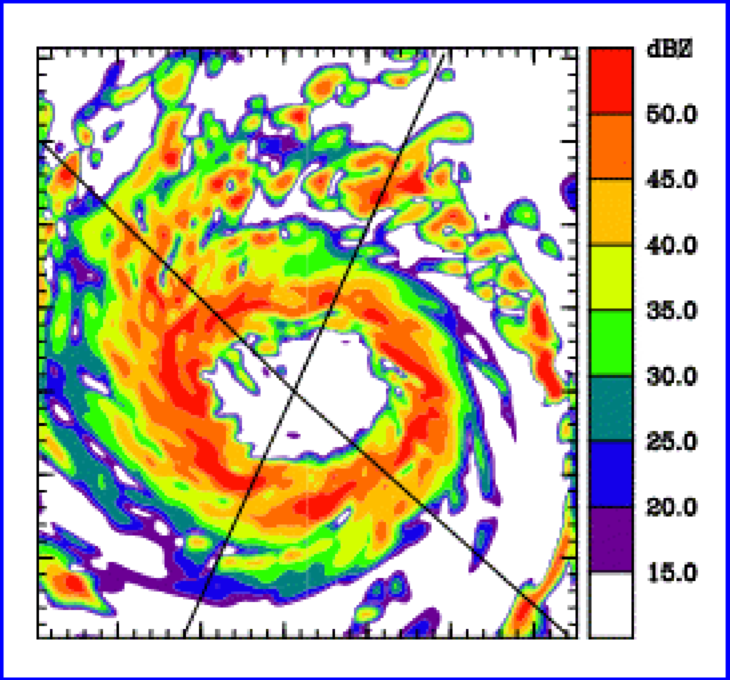
- Storm dynamics
  - Comparison of idealized and full-physics models
  - Role of vortex Rossby waves and vorticity mixing





Recent Accomplishments

- Dynamic balance models
  - Applied to Hurricane Bob (1991)
  - Tools developed will be applied to CAMEX cases
- 2-km Hurricane Bonnie simulation
  - Validation against TRMM, EDOP



1.3-km grid scale simulation of Hurricane Bob (1991)

Balance model formulation

Sawyer-Eliassen balance equation for a 2D symmetric vortex: assumes gradient and hydrostatic balance

$$\frac{\partial}{\partial r}\left(\frac{N^2}{r}\frac{\partial \psi}{\partial r}\right)+\frac{\partial}{\partial z}\left(\frac{\bar{\eta}\bar{\xi}}{r}\frac{\partial \psi}{\partial z}\right)-\frac{\partial}{\partial z}\left(\frac{\bar{\xi}\,\partial V/\partial z}{r}\frac{\partial \psi}{\partial r}\right)-\frac{\partial}{\partial r}\left(\frac{\bar{\xi}\,\partial V/\partial z}{r}\frac{\partial \psi}{\partial z}\right)=\frac{\partial Q}{\partial r}-\frac{\partial\left(F\bar{\xi}\right)}{\partial z}$$

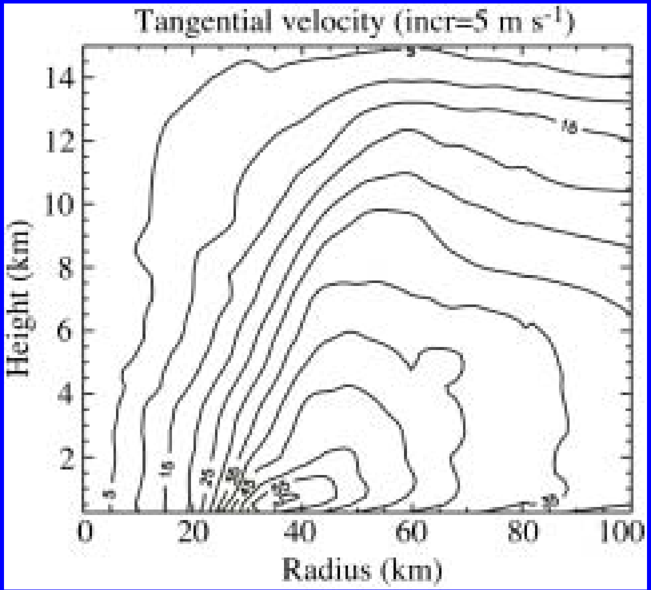
$\psi = streamfunction$ $\quad Q = heating rate$ $\quad F = friction$

Secondary circulation derived from ψ: $\quad U = -\frac{1}{r}\frac{\partial \psi}{\partial z} \qquad w = \frac{1}{r}\frac{\partial \psi}{\partial r}$

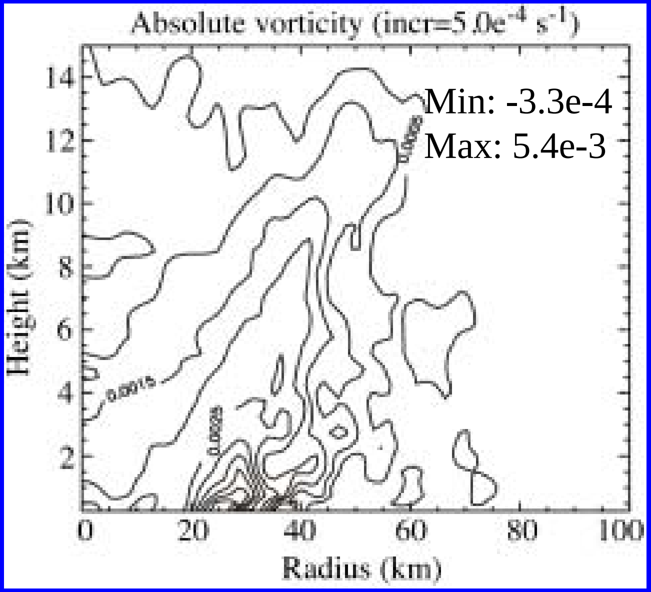
Solution possible if $\quad N^2\left[\bar{\eta}\bar{\xi} - \frac{\bar{\xi}^2}{N^2}\left(\frac{\partial V}{\partial z}\right)^2\right] > 0$

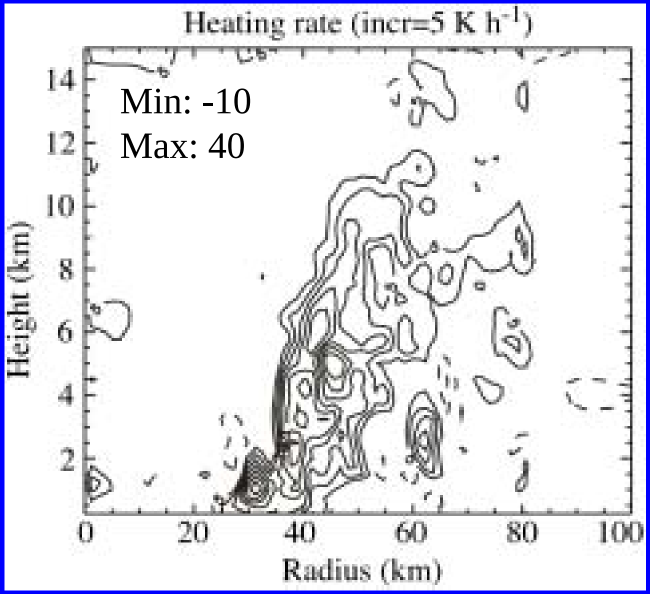
i.e., absolute vorticity >0
and vertical shear not too large

Balance model inputs



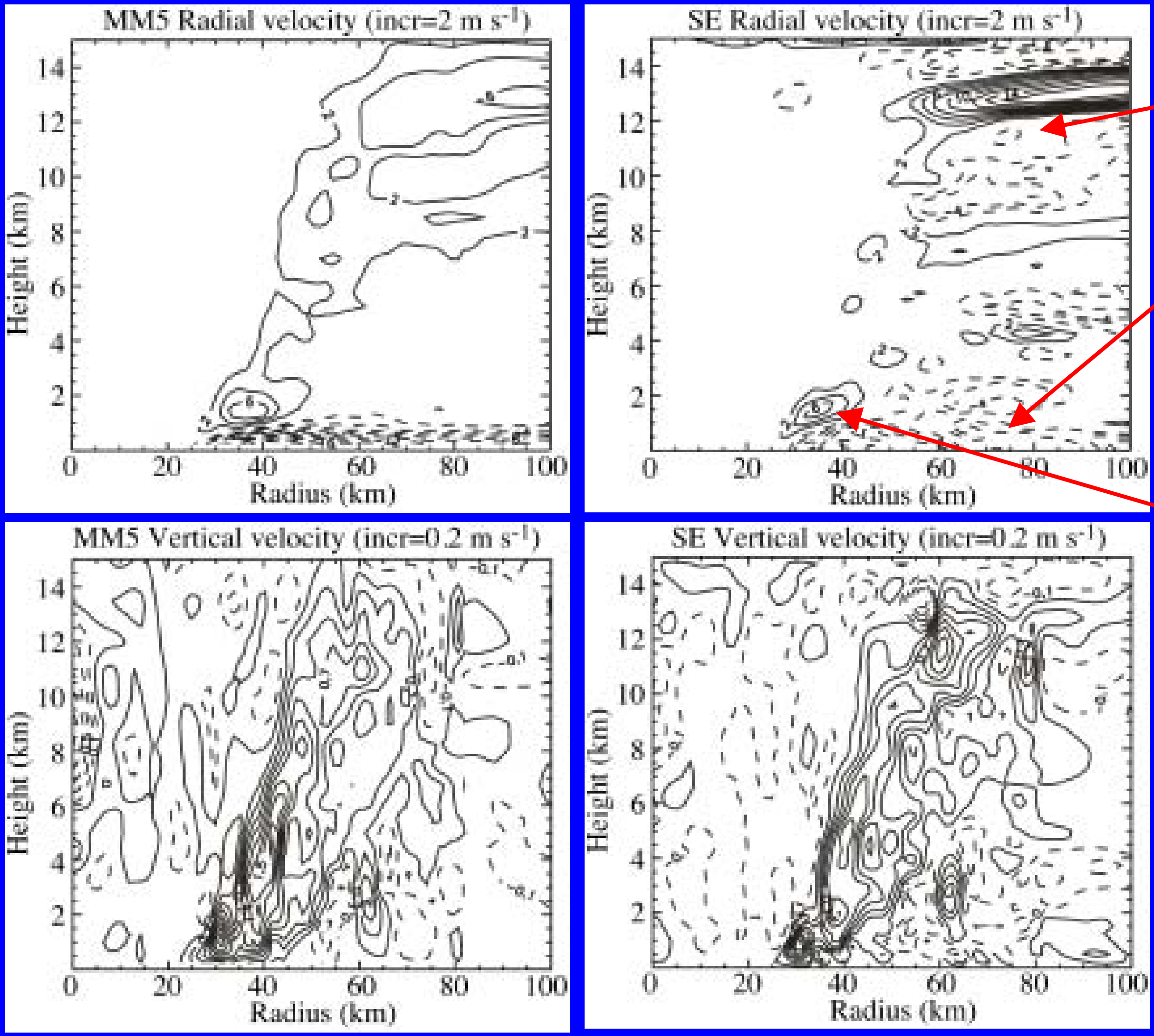
Inputs into the balance model: Azimuthal mean tangential velocity, absolute vorticity, and diabatic heating (friction not shown)





Balance model results

Good qualitative agreement in radial velocities
Good quantitative agreement in vertical velocities

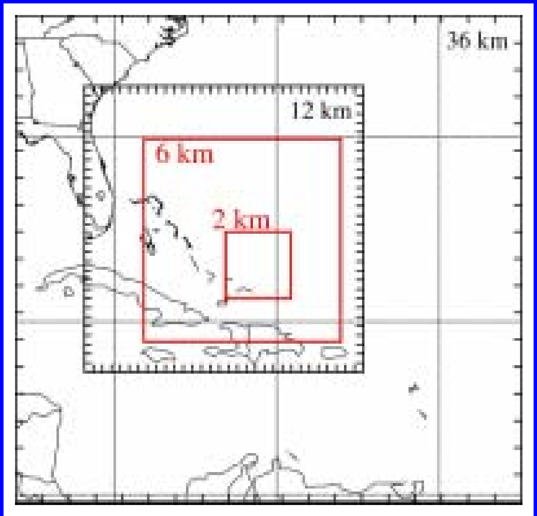


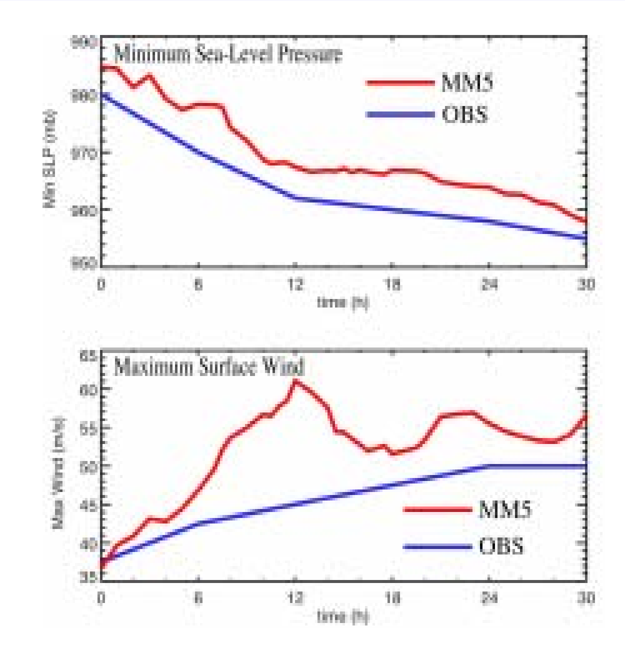
Inertial instability, agradient flow and strong vertical shear cause errors.

Low-level outflow well reproduced despite earlier studies suggesting unbalanced flow

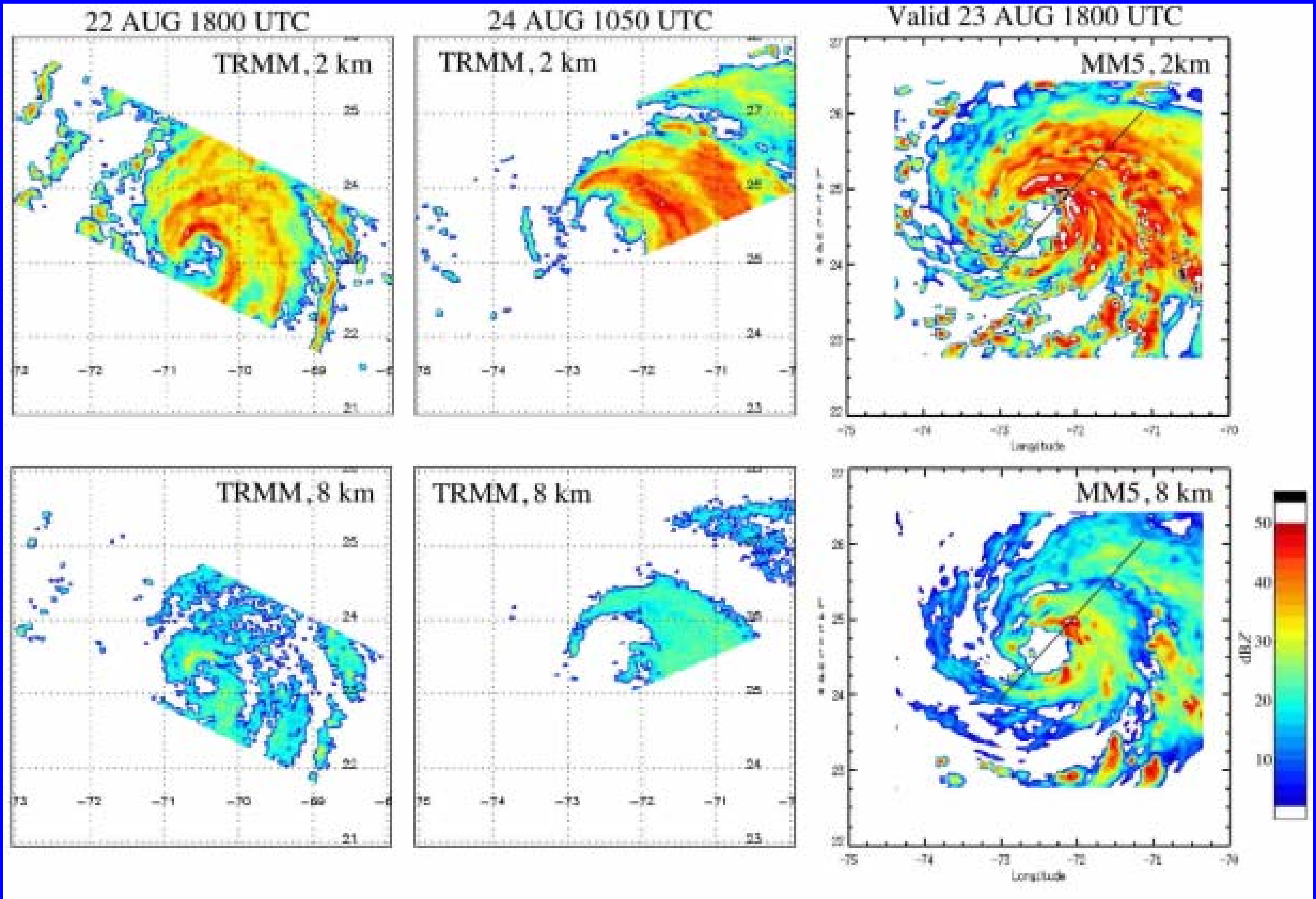
Bonnie Simulation

- PSU/NCAR MM5 model
  - Nonhydrostatic with multiple nests
  - Initialized with ECMWF analyses
- Four grids (36, 12, 6, and 2 km)– 6, 2-km grids started at 6 h
- 12 UTC, 22 AUG to 18 UTC, 23 AUG 1998
- 4D-VAR initialization of bogus vortex
- Physics
  - Modified Blackadar PBL
  - Goddard version of 3-ice microphysics



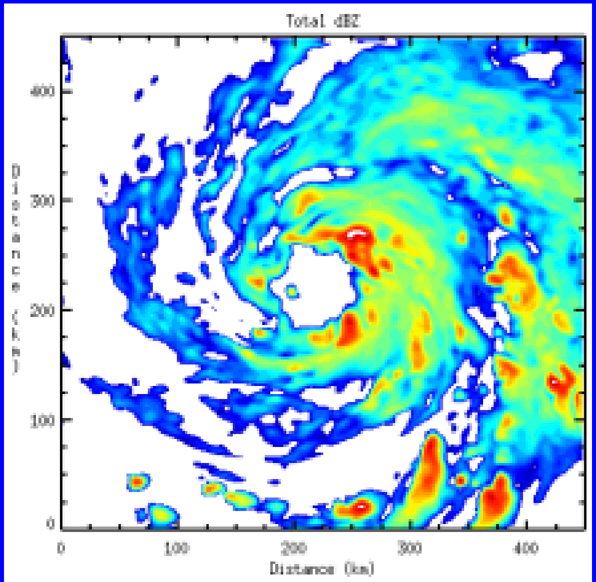


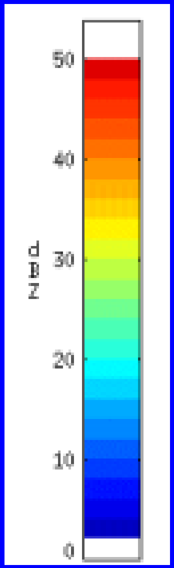
Validation of Bonnie Simulation using TRMM



Snow vs. graupel contributions

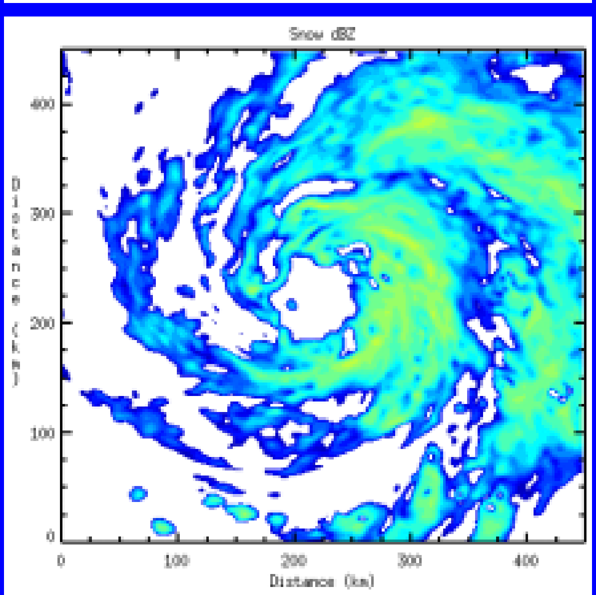
Total dBZ

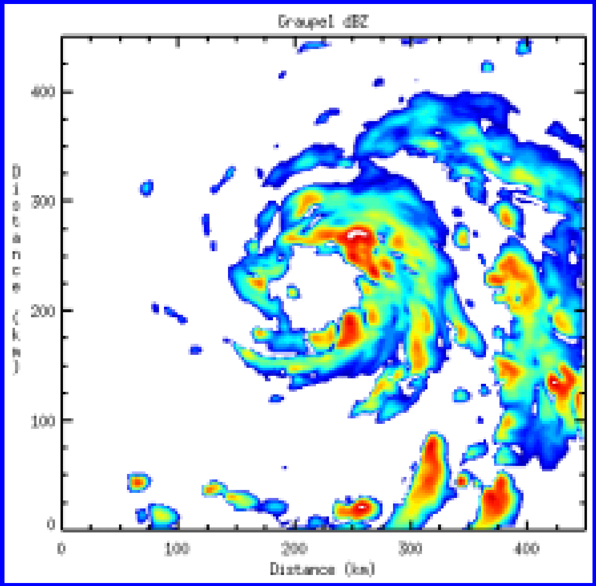




Partitioning of dBZ into snow and graupel contributions suggests excessive graupel production

Snow dBZ

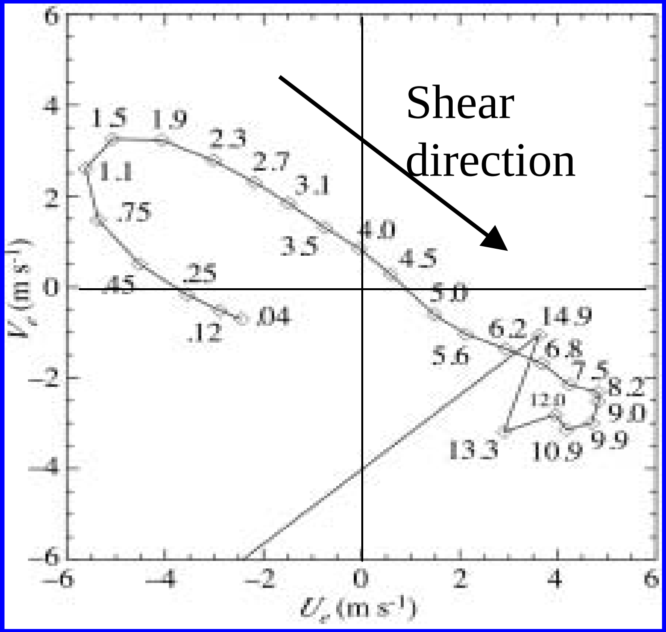




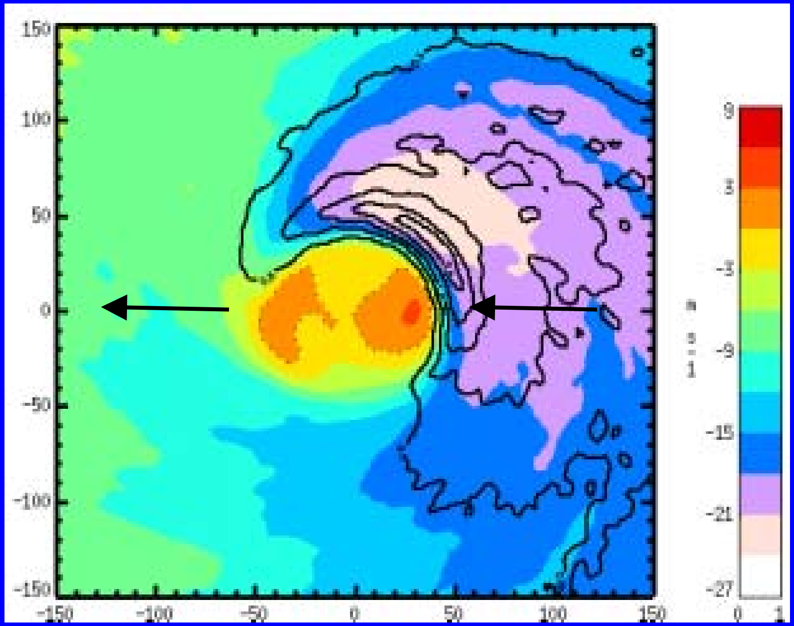
Graupel dBZ

Ongoing CAMEX-3 Research

- Hurricane Bonnie
  - Sensitivity to microphysics
  - Effects of shear on asymmetries–rain max downshear left, role of relative flow vs. vortex tilt



Hodograph of storm-relative environmental flow



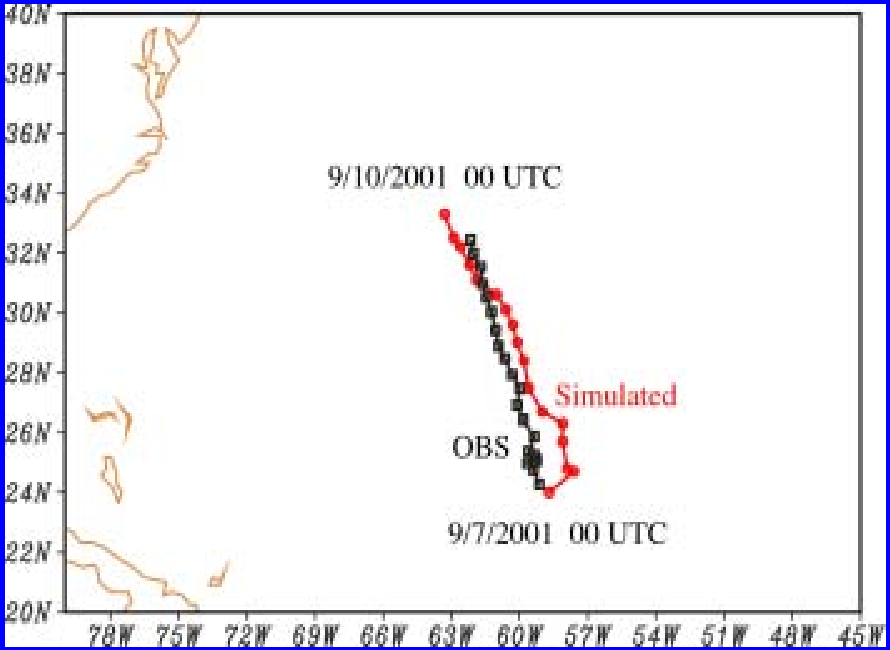
Colors: Time-avg. radial wind at 122 m
Contours: Time-avg. rain mixing ratio
Arrows: Relative env. boundary layer flow

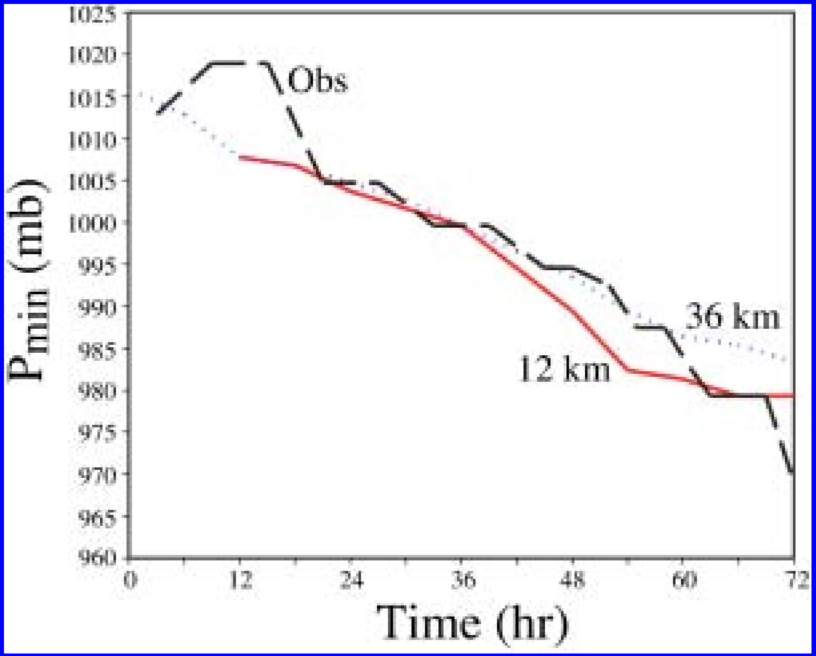
Future CAMEX-3 Research

- Hurricane Bonnie
  - Application of boundary layer model to examine relative flow effects on asymmetries
  - Application of nonlinear balance models to Bonnie
    - 2D symmetric balance diagnostics
    - 3D asymmetric balance diagnostics
  - Water and heat budgets
  - Comparison of simulated radiances to observations, sensitivity to microphysics

Ongoing CAMEX-4 Research

- Hurricane Erin
- 00 UTC, 7 Sept to 00 UTC, 10 Sept 2001—+24 h in progress
- Two grids (36, 12 km)—Higher resolution runs in progress
- No bogus vortex

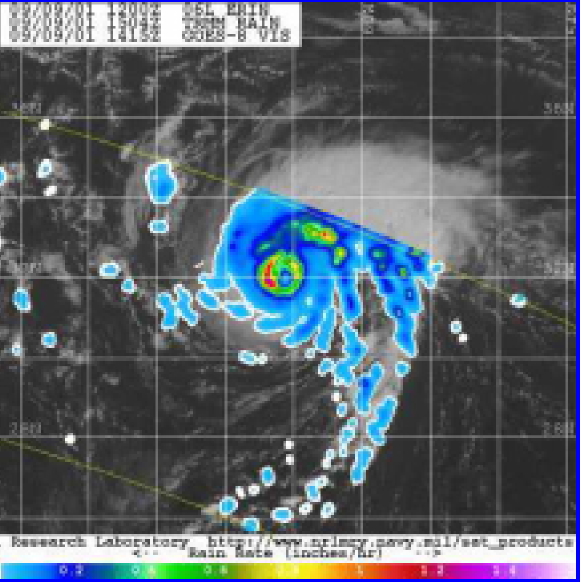


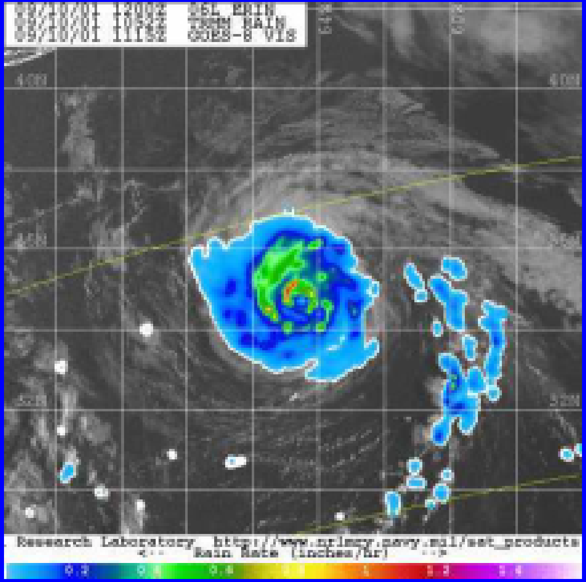


Simulations results from Dr. Liguang Wu (GEST/UMBC)

Hurricane Erin–TRMM vs. MM5

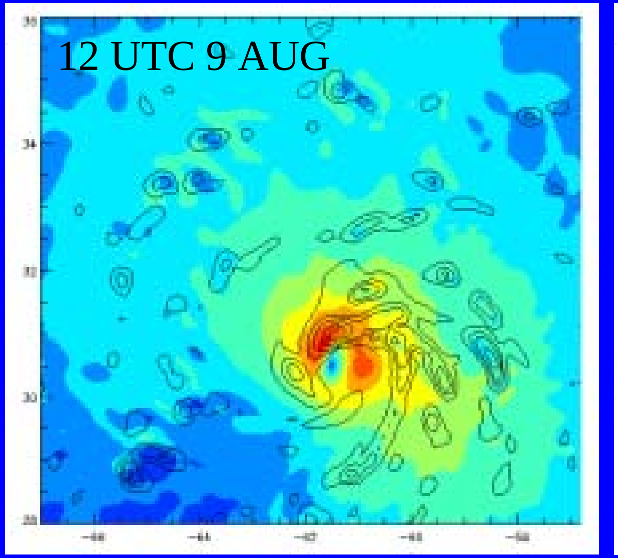
TRMM/TMI rainfall

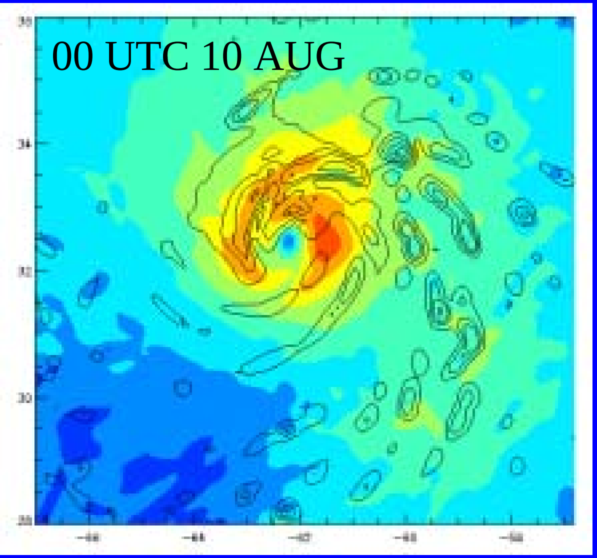




Simulated surface winds (shading) and explicit precipitation (contours)

Simulation shows reasonable transition in structure





Future CAMEX-4 Research

- Hurricane Erin
  - Extend length of simulation
  - Extend to higher grid resolution (~1-4 km)
  - Validate against TRMM, CAMEX-4 data
  - Examine intensification mechanisms
  - Examine possible development of secondary wind maximum, outer rainband structure changes