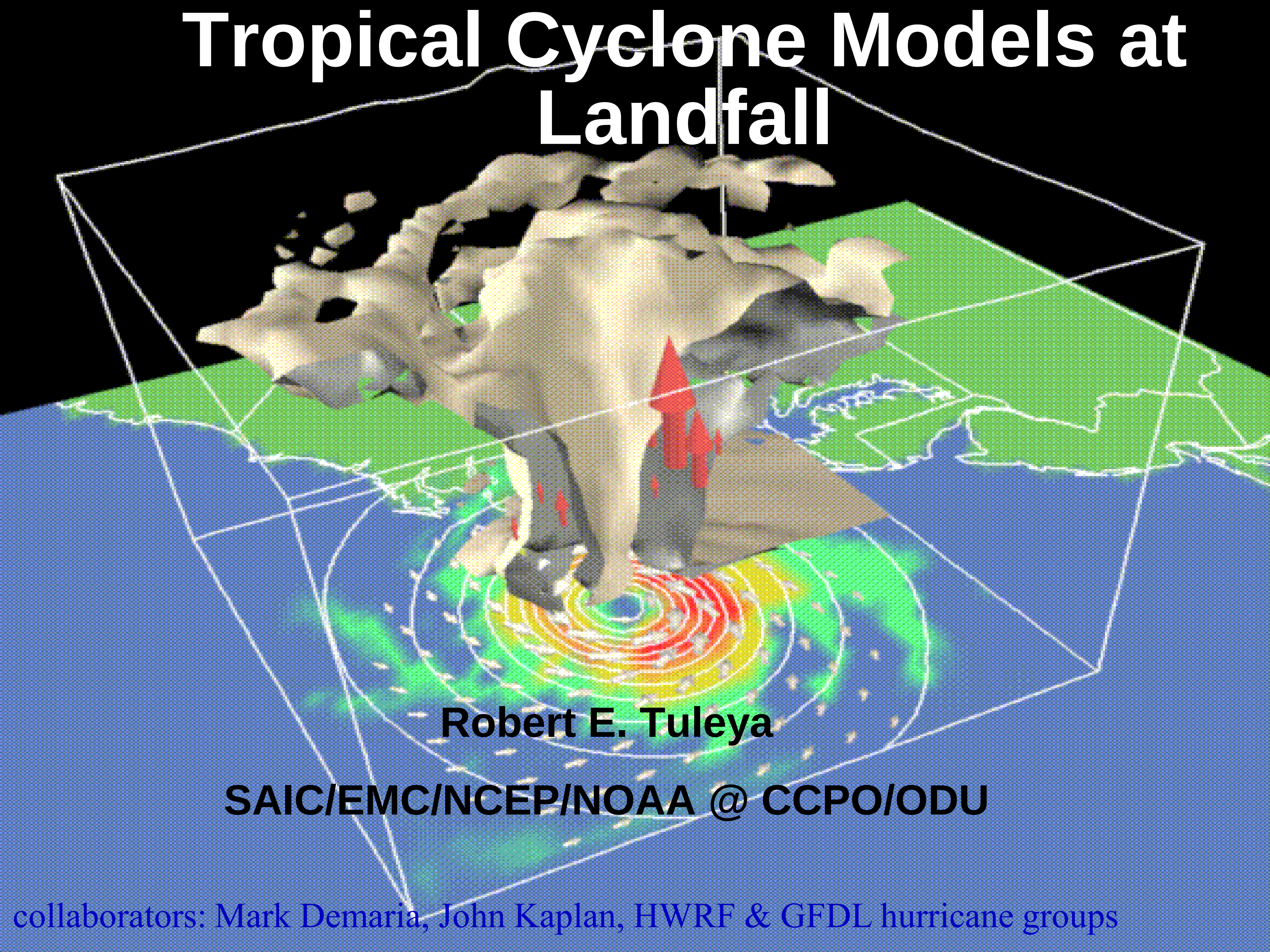
Tropical Cyclone Models at Landfall



Robert E. Tuleya

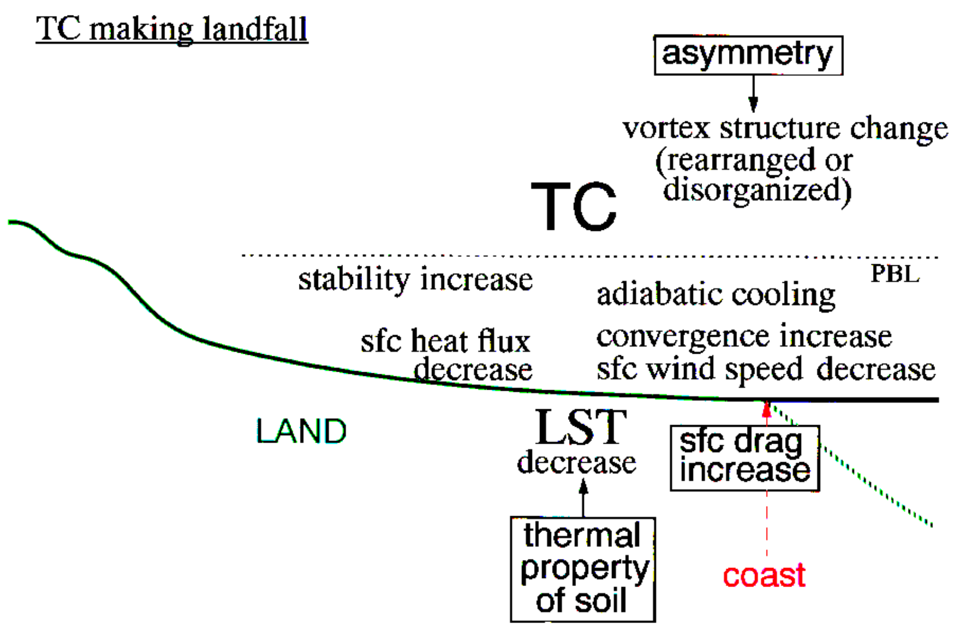
SAIC/EMC/NCEP/NOAA @ CCPO/ODU

collaborators: Mark Demaria, John Kaplan, HWRF & GFDL hurricane groups

Increased complexity (Example of landfall)

- Axi-symmetric models

  (Ooyama,1969, Rosenthal,1971)
- Arbitrarily cut evaporation CE=0
- 3-D (Tuleya and Kurihara, 1978)
- Steering current ---move b.c. through domain
- Predict sfc temperature (requires sfc fluxes including radiation)
- Predict moisture at surface
- Model land surface more completely



Rosenthal

TABLE 8.—*Experiments that examine the relative importance of air-sea exchanges of sensible heat, latent heat, and momentum during the mature stage of the model cyclone. The initial data are from hour 288 of experiment S35.*

Experiment	C_D	C_S	C_L
S35	eq (3)	eq (3)	eq (3)
Q13	do.	0	do.
Q14	do.	eq (3)	0
Q15	0	do.	eq (3)
Q16	eq (3)	2×eq (3)	2×eq (3)

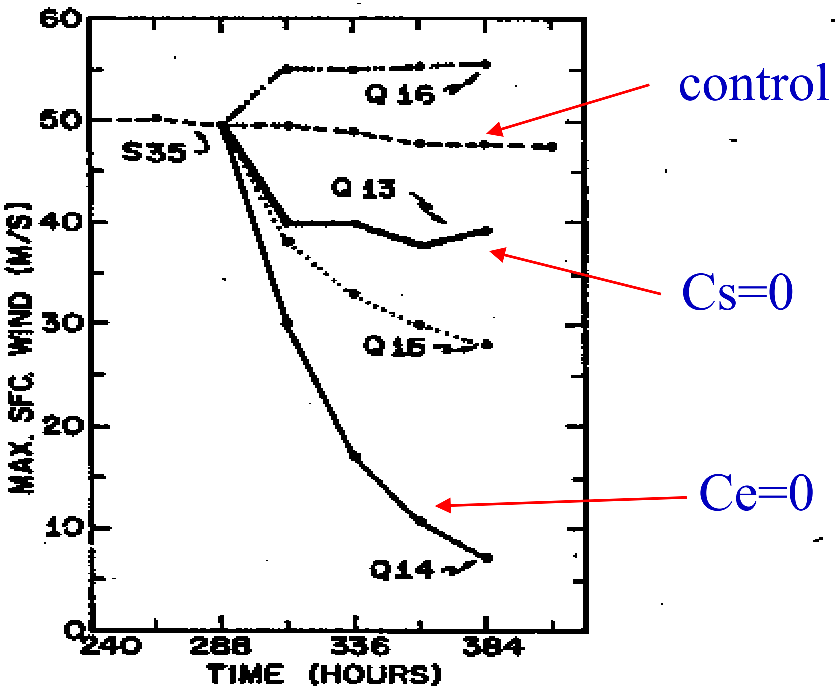
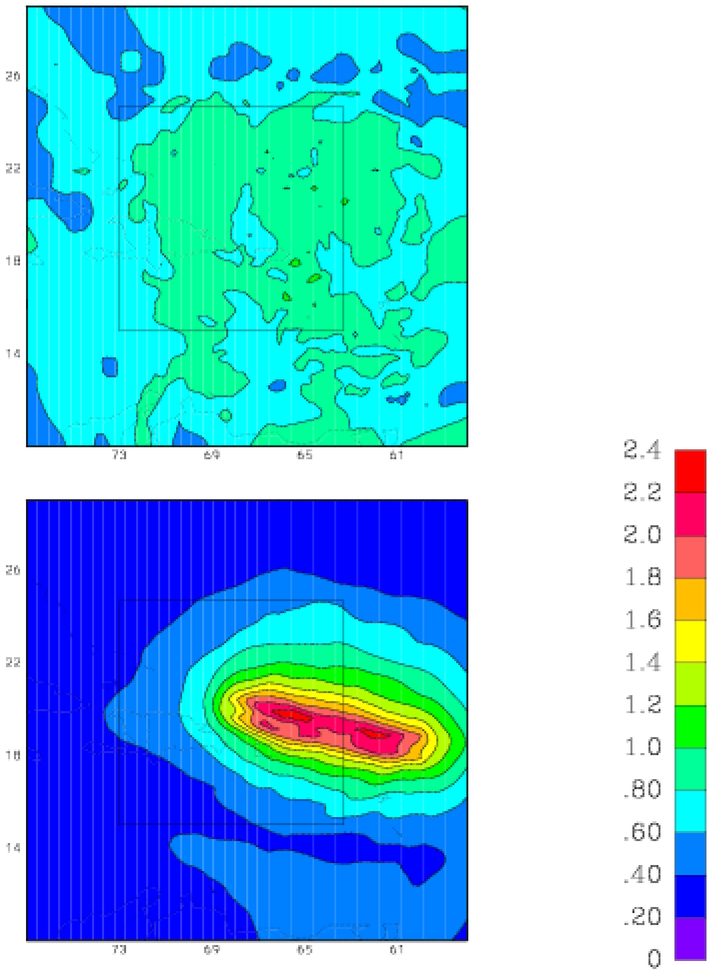


FIGURE 12.—Comparison of maximum surface winds for experiments that study the relative importance of air-sea exchanges of sensible heat, latent heat, and momentum during the mature stage of the model cyclone. Initial data are taken from hour 288 of experiment S35. The experiments compared with the control are Q13 ($C_S=0$), Q14 ($C_L=0$), Q15 ($C_D=0$), and Q16 ($C_S=C_L=2C_D$). See table 8 for details.

TROPICAL DISTURBANCE OVER DIFFERENT SURFACES

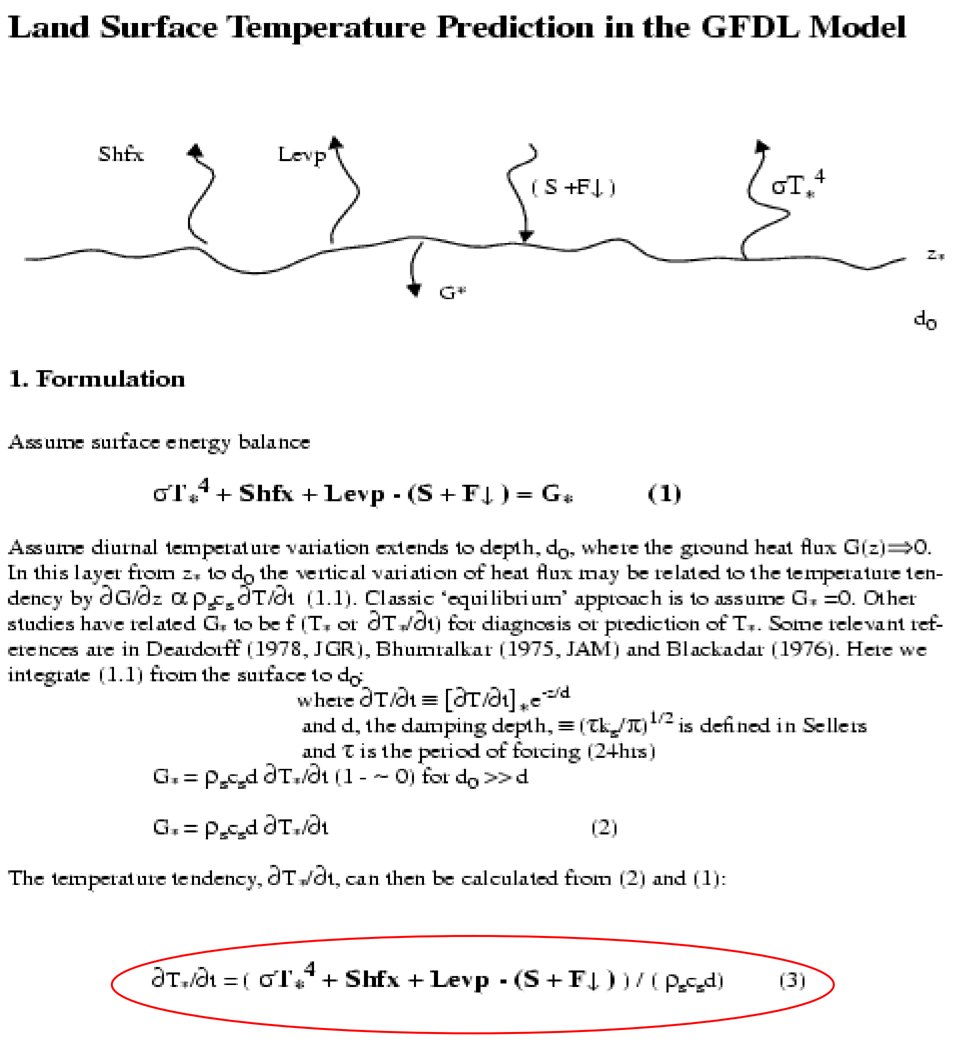
48HR ACCUMULATION



Land sfc evaporation

Ocean sfc evaporation

HWRF & GFDL use slab ground surface layer



Land Surface Temperature Prediction in the GFDL Model

1. Formulation

Assume surface energy balance

$$\sigma T_*^4 + \mathbf{Shfx} + \mathbf{Levp} - (\mathbf{S} + \mathbf{F}\downarrow) = G_* \qquad (1)$$

Assume diurnal temperature variation extends to depth, d_0, where the ground heat flux $G(z) \Rightarrow 0$. In this layer from z_* to d_0 the vertical variation of heat flux may be related to the temperature tendency by $\partial G/\partial z \; \alpha \; \rho_g c_g \partial T/\partial t$ (1.1). Classic 'equilibrium' approach is to assume $G_* = 0$. Other studies have related G_* to be f (T_* or $\partial T_*/\partial t$) for diagnosis or prediction of T_*. Some relevant references are in Deardorff (1978, JGR), Bhumralkar (1975, JAM) and Blackadar (1976). Here we integrate (1.1) from the surface to d_0:

where $\partial T/\partial t \equiv [\partial T/\partial t]_* e^{-z/d}$
and d, the damping depth, $\equiv (\tau k_g/\pi)^{1/2}$ is defined in Sellers
and τ is the period of forcing (24hrs)

$$G_* = \rho_g c_g d \, \partial T_*/\partial t \; (1 - \sim 0) \text{ for } d_0 >> d$$

$$G_* = \rho_g c_g d \, \partial T_*/\partial t \qquad (2)$$

The temperature tendency, $\partial T_*/\partial t$, can then be calculated from (2) and (1):

$$\partial T_*/\partial t = (\, \sigma T_*^4 + \mathbf{Shfx} + \mathbf{Levp} - (\mathbf{S} + \mathbf{F}\downarrow)\,) \,/\, (\rho_g c_g d) \qquad (3)$$

Community NOAH LAND-SURFACE MODEL

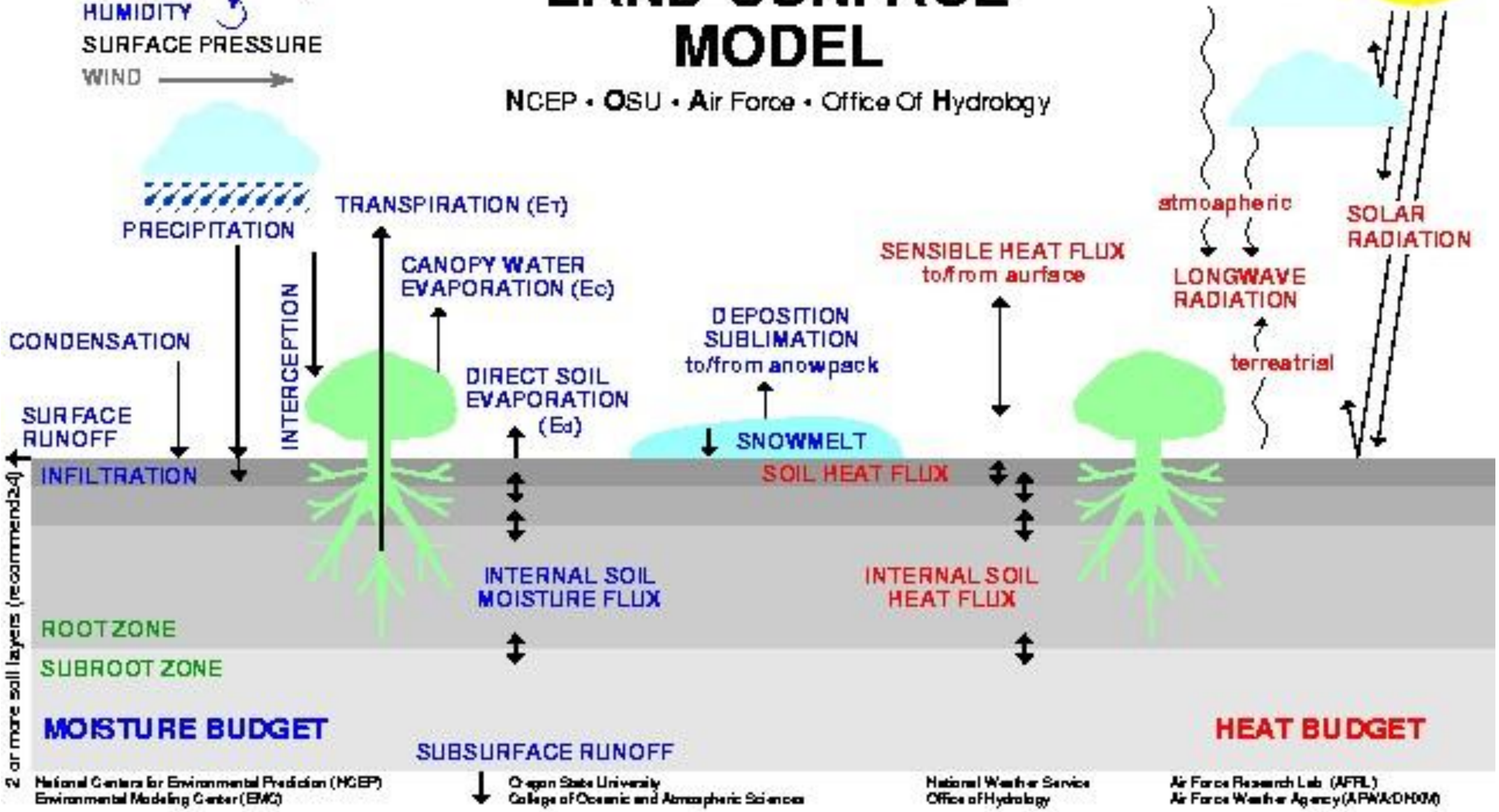
NCEP • OSU • Air Force • Office Of Hydrology

ATMOSPHERIC FORCING (near surface)

- PRECIPITATION
- TEMPERATURE
- HUMIDITY
- SURFACE PRESSURE
- WIND

RADIATION FORCING (at surface)

- DOWNWARD SOLAR
- DOWNWARD LONGWAVE



PRECIPITATION

TRANSPIRATION (E_T)

CANOPY WATER EVAPORATION (E_c)

INTERCEPTION

CONDENSATION

SURFACE RUNOFF

INFILTRATION

DIRECT SOIL EVAPORATION (E_d)

DEPOSITION SUBLIMATION to/from snowpack

SNOWMELT

SENSIBLE HEAT FLUX to/from surface

atmospheric

LONGWAVE RADIATION

terrestrial

SOLAR RADIATION

SOIL HEAT FLUX

INTERNAL SOIL MOISTURE FLUX

INTERNAL SOIL HEAT FLUX

ROOT ZONE

SUBROOT ZONE

2 or more soil layers (recommend≥4)

MOISTURE BUDGET

HEAT BUDGET

SUBSURFACE RUNOFF

National Centers for Environmental Prediction (NCEP)
Environmental Modeling Center (EMC)

Oregon State University
College of Oceanic and Atmospheric Sciences

National Weather Service
Office of Hydrology

Air Force Research Lab (AFRL)
Air Force Weather Agency (AFWA/DNXM)

STATE VARIABLES

- SKIN TEMPERATURE
- SOIL TEMPERATURE
- SOIL WATER
- SOIL ICE
- CANOPY WATER
- SNOW WATER
- SNOW DENSITY

SURFACE PARAMETERS

- VEGETATION TYPE
- GREEN VEGETATION FRACTION
- SOIL TEXTURE
- ROUGHNESS
- ALBEDO
- SLOPE FACTOR

ftp://ftp.ncep.noaa.gov/pub/gcp/ldas/noahlsm/

EMC transitioning to Noah LSM & The EMC Stream Routing Scheme:

1. Computes the concentration time for runoff reaching the outlet of a grid box and the transport of water in the channel system

2. Water can leave the grid cell through (at least) one of the eight directions

3. The runoff transport process is linear and time invariant

4. The causality and the impulse response functions are nonnegative

Lohmann et al., 1998, 2004

Experimental Design

Yihua Wu (EMC)

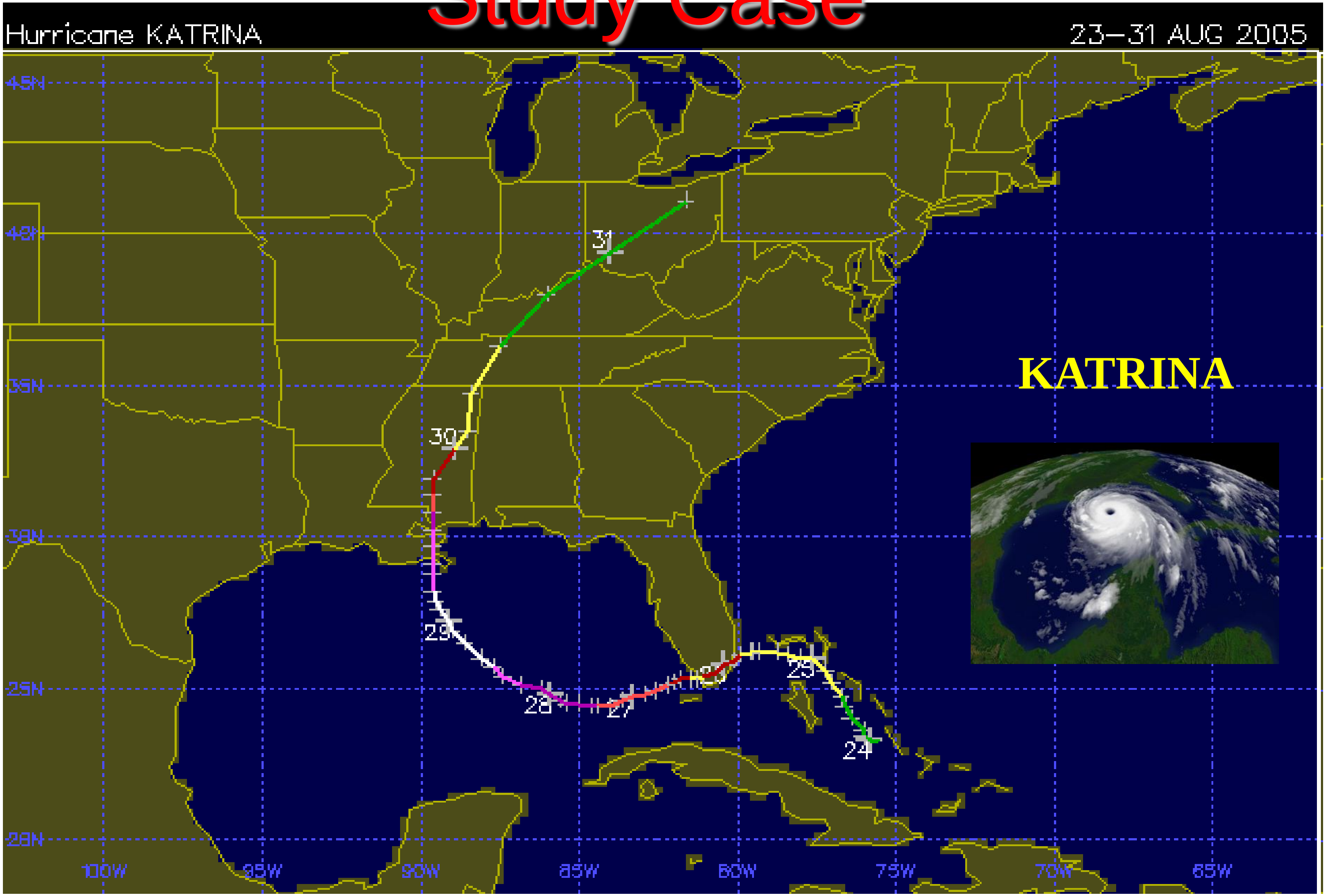
Runs	Physics Options Over Land			Physics Options Over Ocean	
	LSM	Surface Layer Scheme	PBL Scheme	Surface Layer Scheme	PBL Scheme
	Noah	GFDL	GFS	GFDL	GFS
N893.WET	The initial soil moisture for US is from GFS soil moisture				
N893.DRY	The initial soil moisture for US is the combination of GFS soil moisture and NAM soil moisture				

Preliminary Results

~dozen cases

- Track forecasts not impacted by Noah lsm
- Intensity change appears relatively minor
- Some impact on rainfall forecasts
- Runfoff and stream flow impacted by initial soil moisture
- Need to run extensive tests

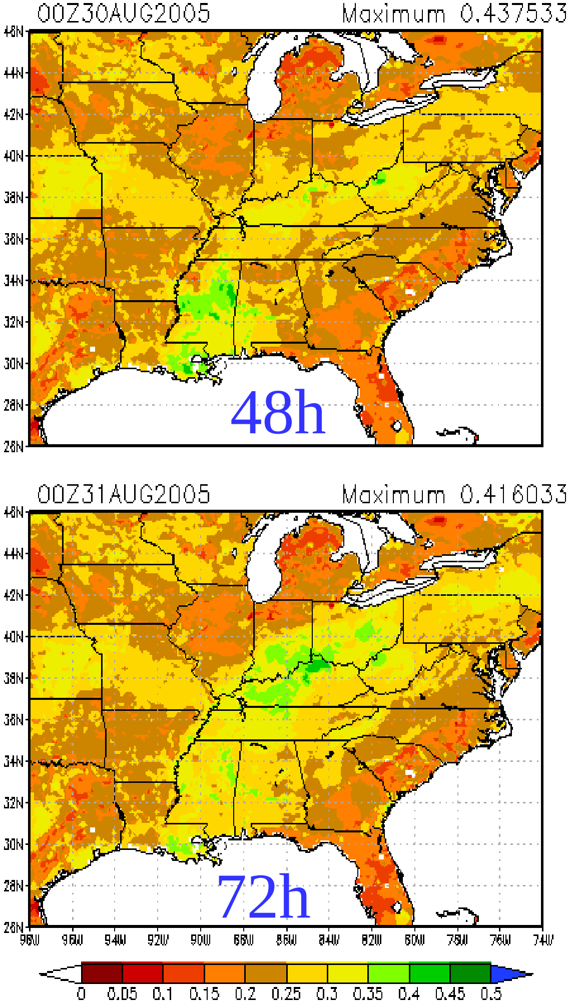
Study Case



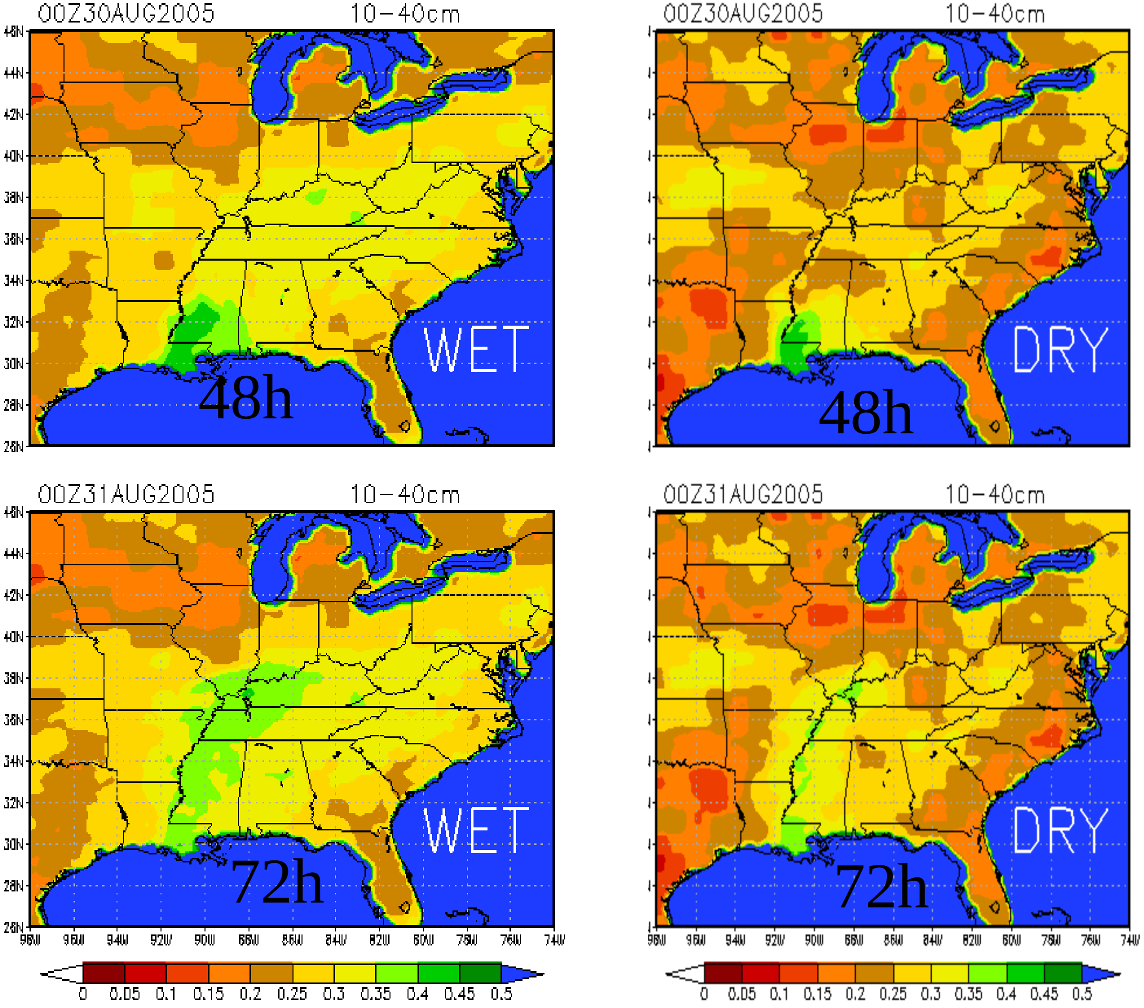
All runs for Katrina started at 00z Aug 28, 2005

Forecasted Soil Moisture for Layer 2

NLDAS

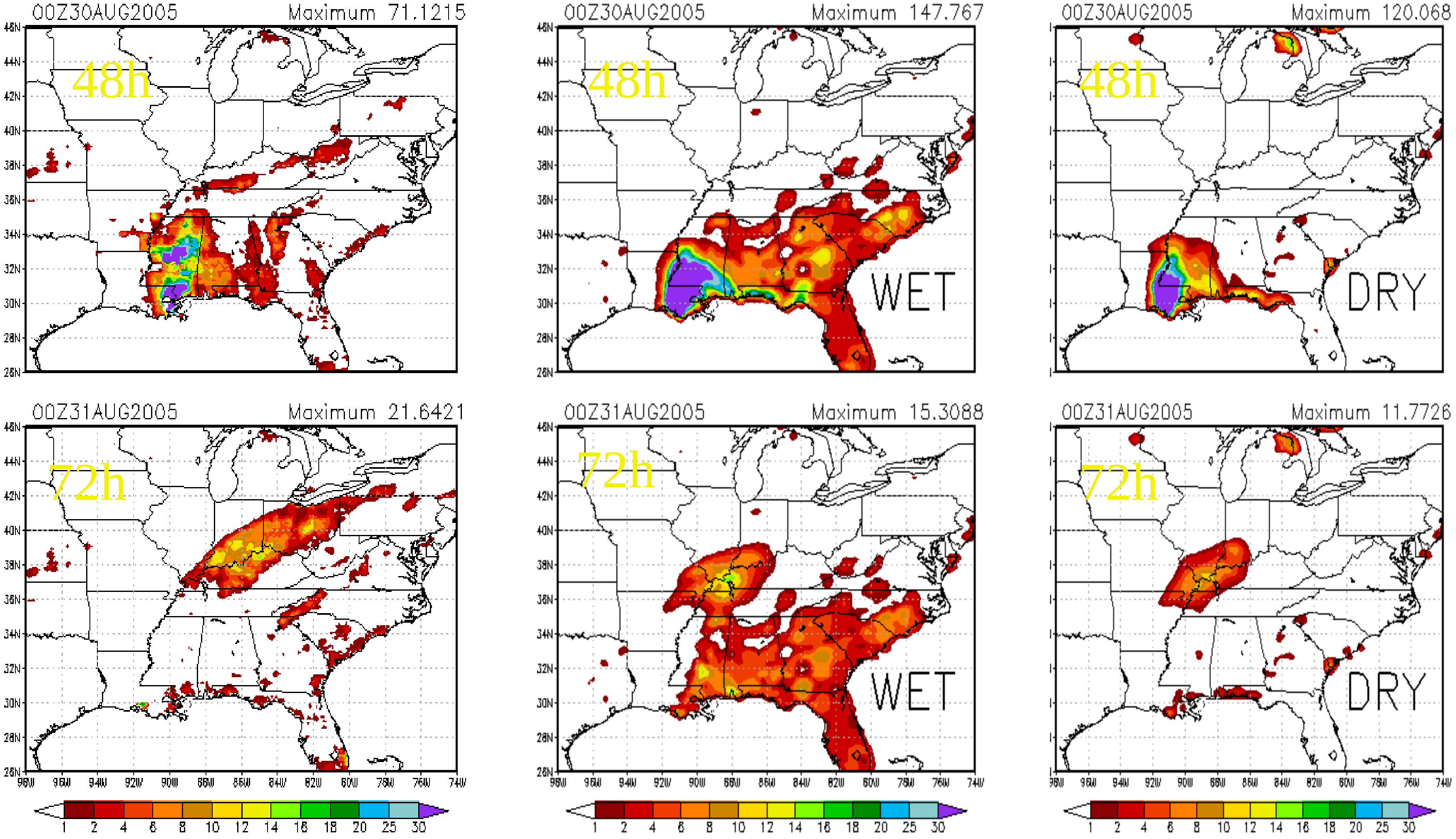


HWRF

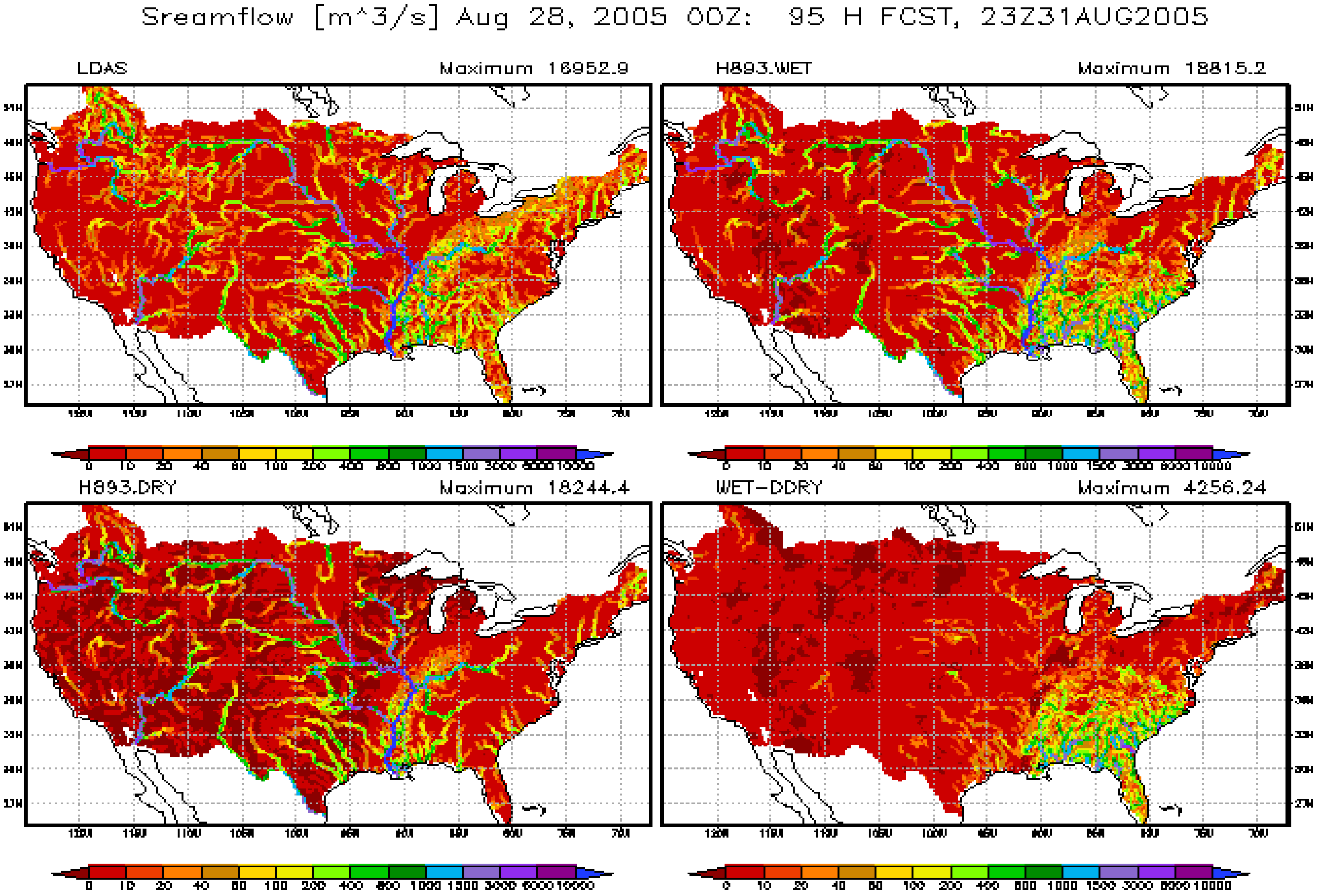


12 Hour Total Runoff (mm)

NLDAS HWRF



Forecasted Stream Flow (m^3 s^{-1})



Sreamflow [m^3/s] Aug 28, 2005 00Z: 95 H FCST, 23Z31AUG2005

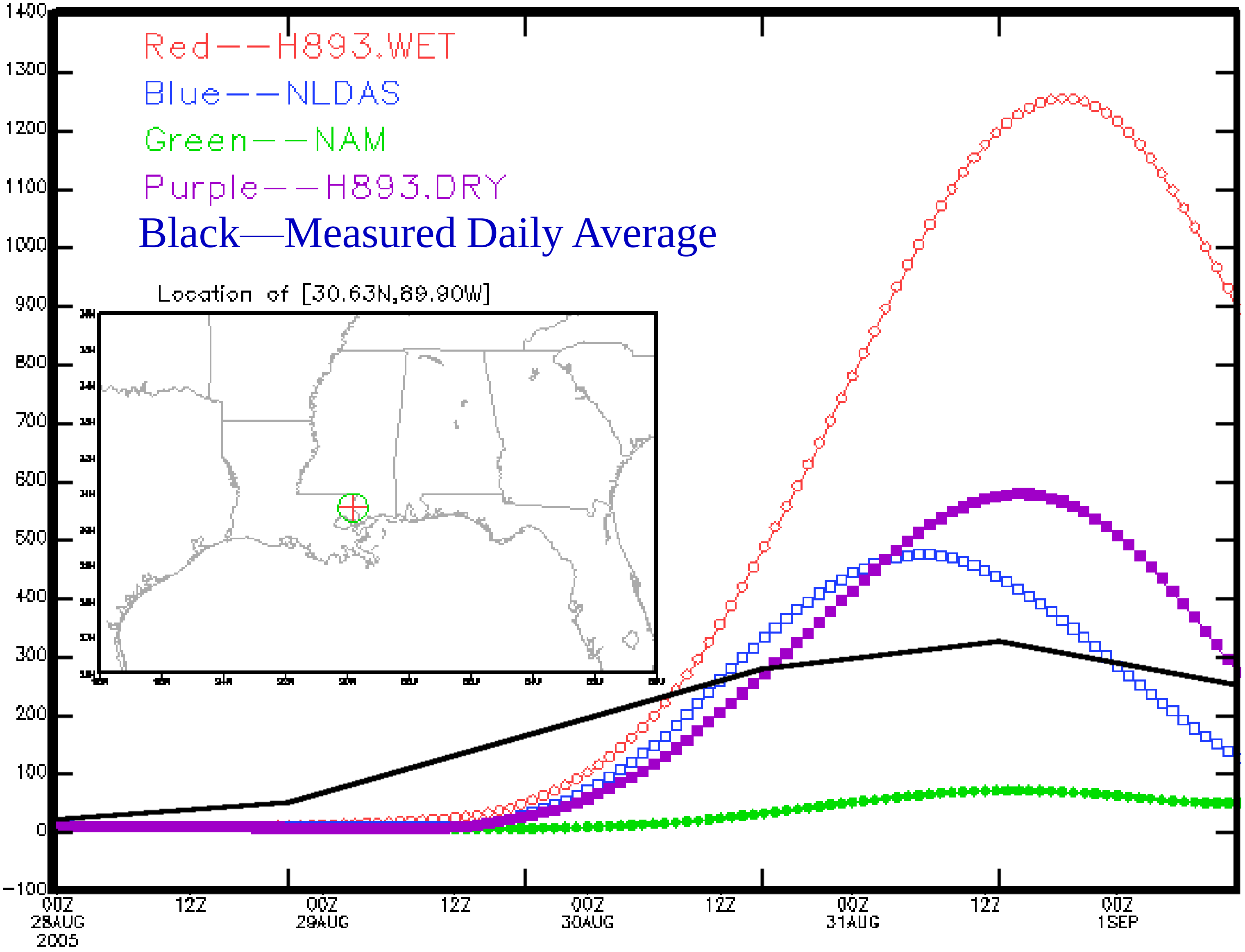
LDAS Maximum 16952.9

H893.WET Maximum 18815.2

H893.DRY Maximum 18244.4

WET-DDRY Maximum 4256.24

Stream flow At 30.63N and 89.90W



Hurricane-specific model products

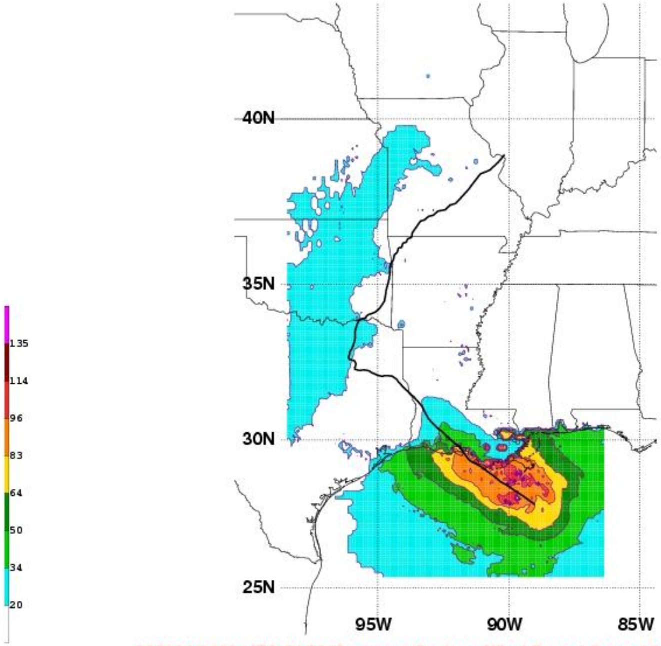
- Storm track & intensity (i.e. “tracker”)
- Low level wind swaths …Meow…

  1st analysis?? … Ted Fujita on Camille (1969)

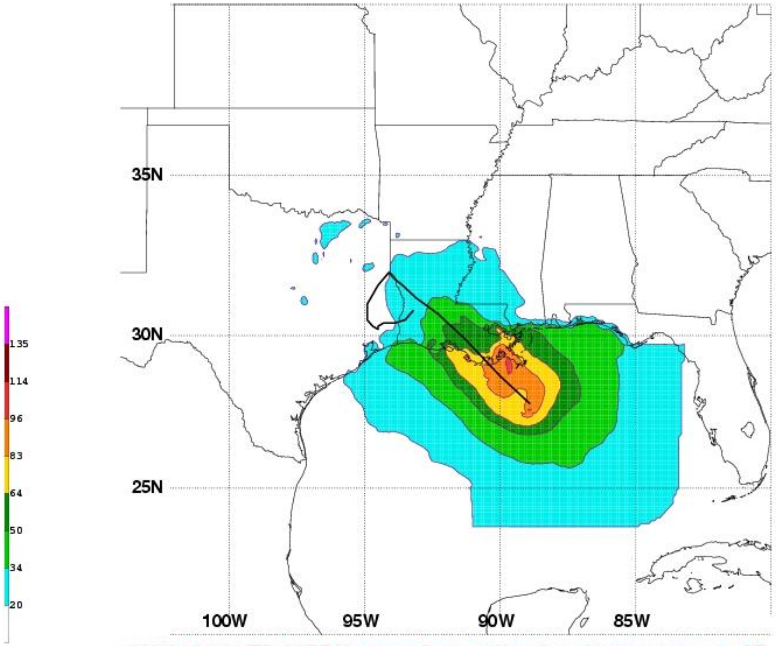
- Rainfall swaths

➢ Be aware of analysis methods used in products above

Low level wind swaths
GFDL HWRF

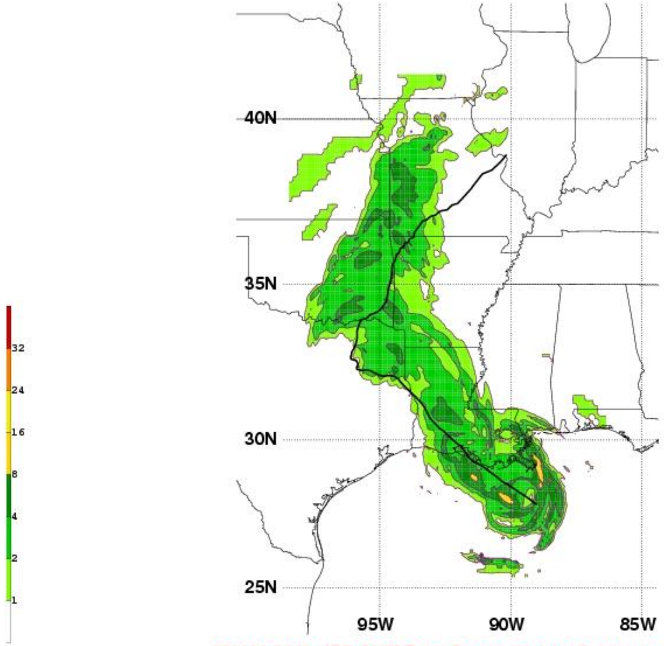


080901/0600 UTC GHM Maximum Surface Wind Speed (knots) for gustav07l

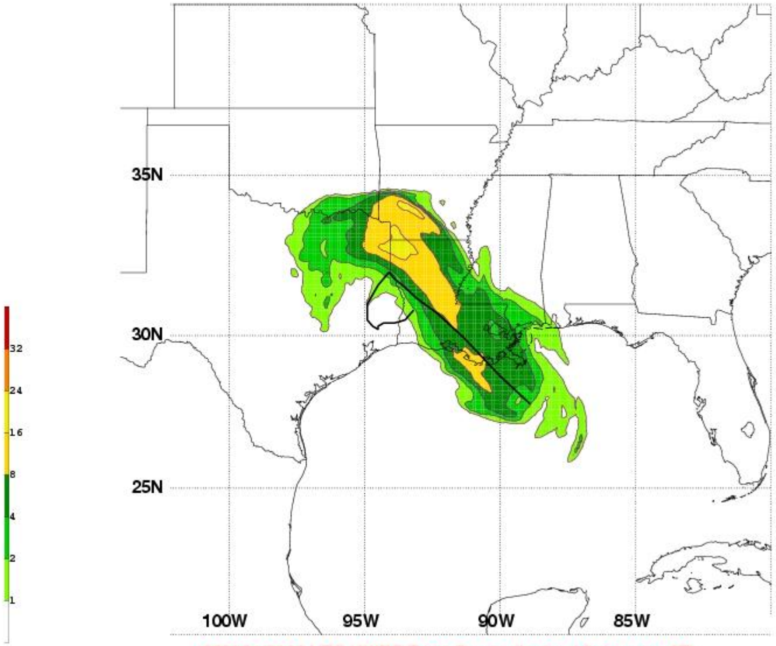


080901/0600 UTC HWRF Maximum Surface Wind Speed (knots) for gustav07l

Storm total precip
GFDL HWRF



080901/0600 UTC GHM Total Precip (inches) for gustav07l



080901/0600 UTC HWRF Total Precip (inches) for gustav07l

Inland decay model

(Kaplan and DeMaria 1995, 2001 & 2006)

(a more simpler approach)

- Assumes exponential decay
- Uses climatology
- Can be used as a baseline for 3-d models
- Can be driven by a variety of forecasts

Background

An empirical decay model (Kaplan and DeMaria 1995, 2001) has been used to predict the decrease in wind speed of landfalling tropical cyclones. The model assumes that a cyclone’s maximum winds decrease exponentially with time after landfall to a non-zero background wind speed using:

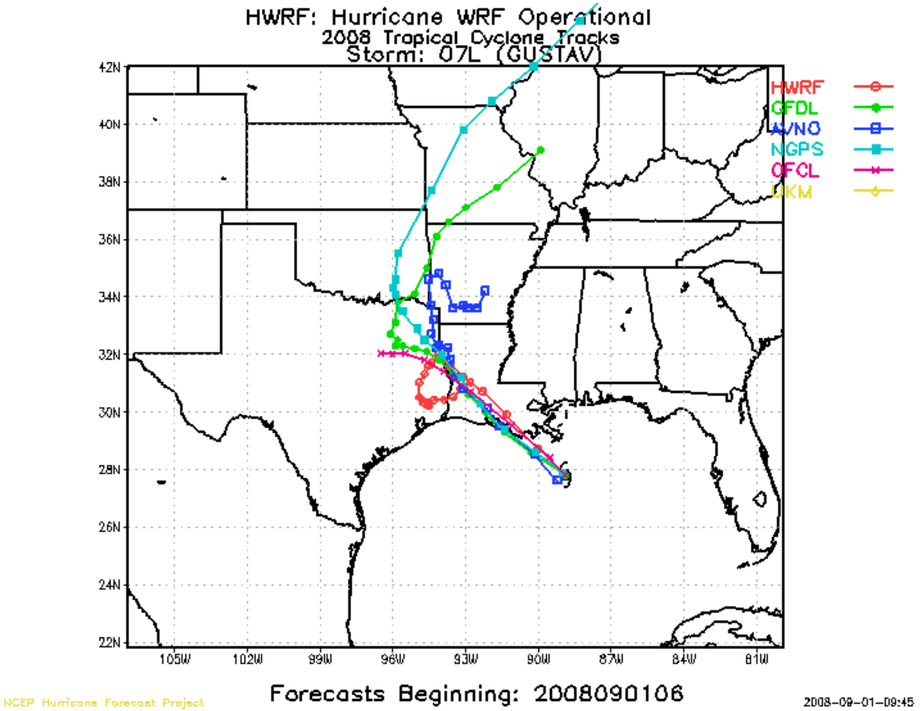
$$V_t = V_b + (RV_0 - V_b)e^{-\alpha t}$$

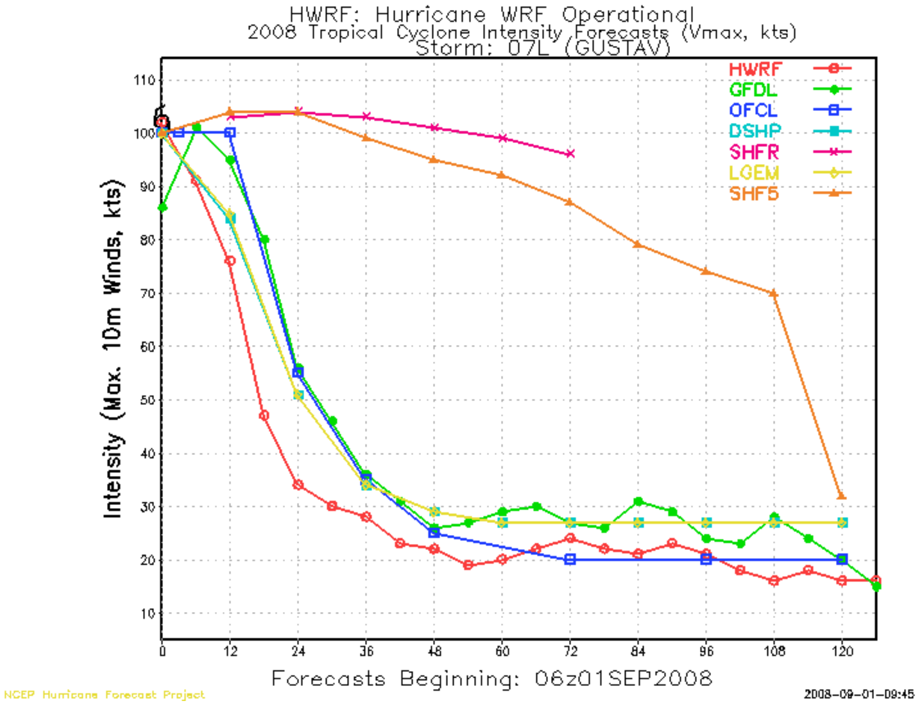
where V_t = the maximum wind at some time t after landfall, V_0 is the landfall wind speed, V_b is the background wind speed and α is the decay constant.

DeMaria et al. (2006) recently developed a revised version of the original Kaplan and DeMaria decay model that improves the prediction for storms that cross islands and peninsulas. The new version decreases the rate of decay of landfalling storms according to the fractional area of the storm that is over land (F_m) during any given time and is given by:

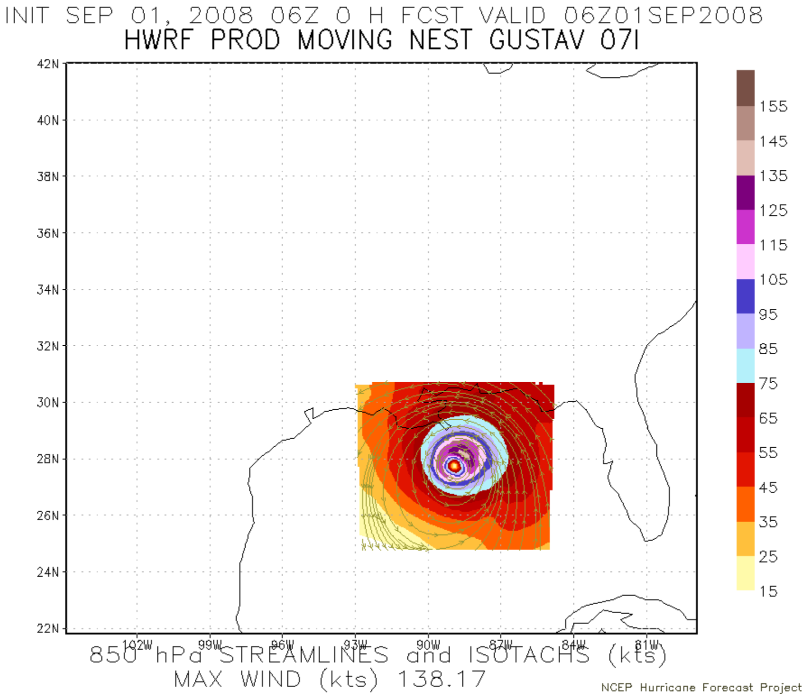
$$V^{t+1} = V_b + (V^t - V_b)e^{-F_m \alpha t}$$

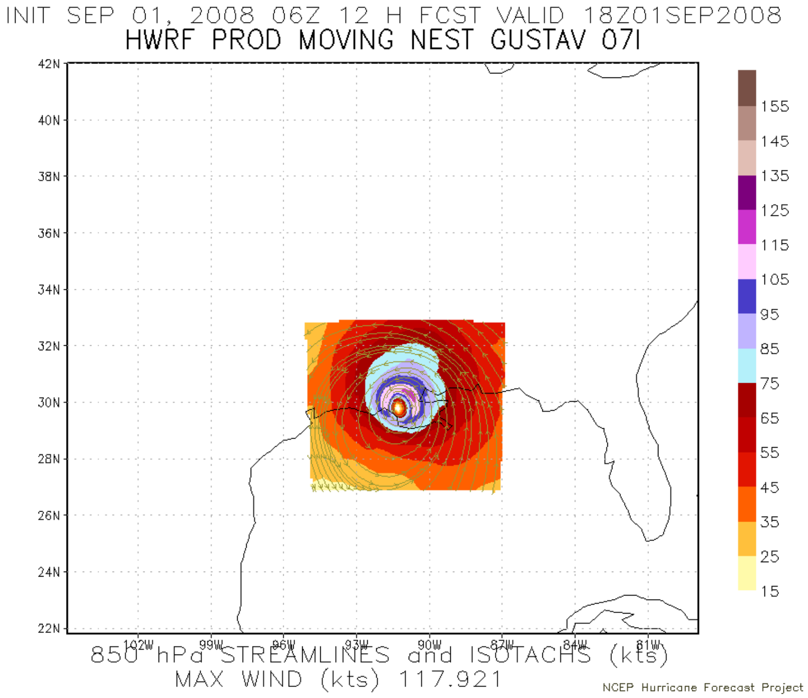
Operation models of Gustav at landfall





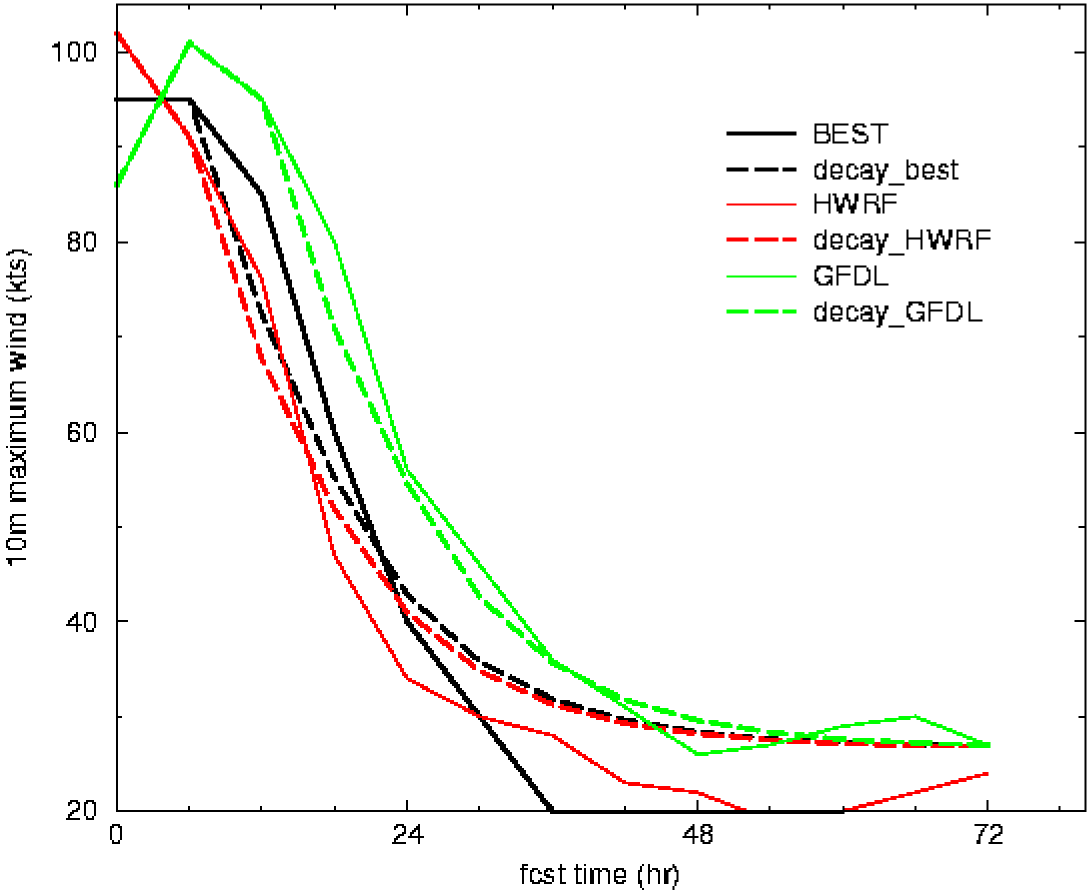
HWRF forecast





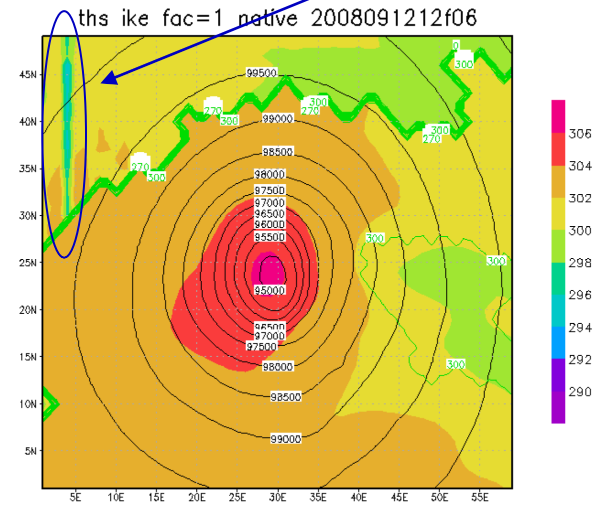
decay_gustav_08090106

decay model vs best–HWRF–GFDL



HWRF THS at f=6hrs IKE

remaining b.c. noise??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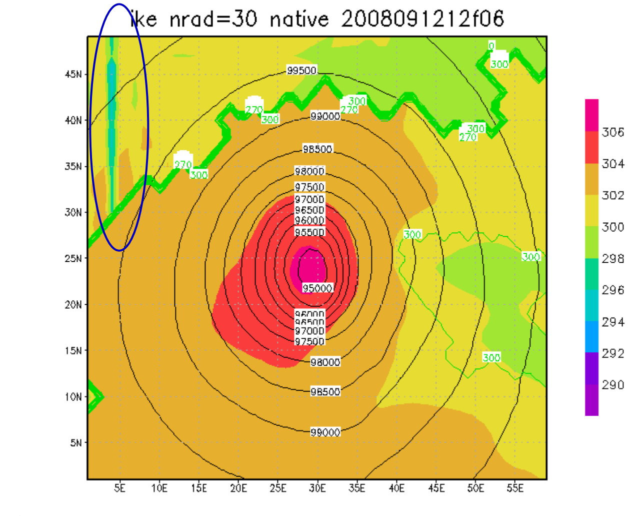
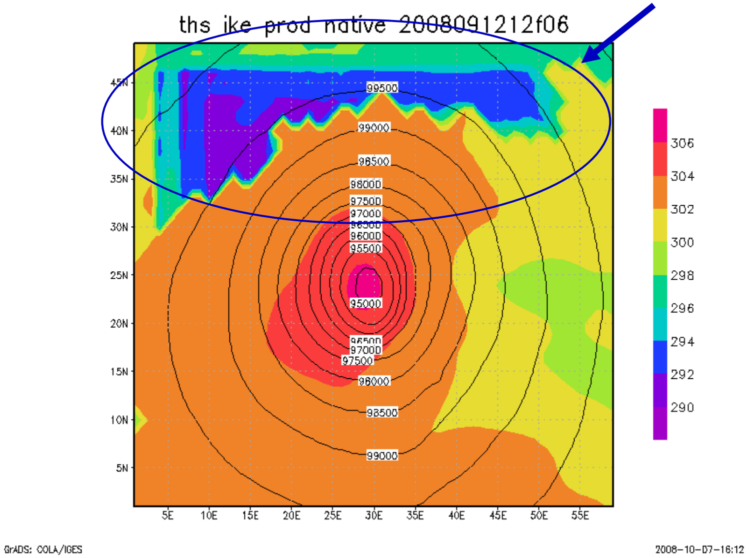

ike nrad=30 native 2008091212f06

Production version cold sfc temps …. Final Fix !!?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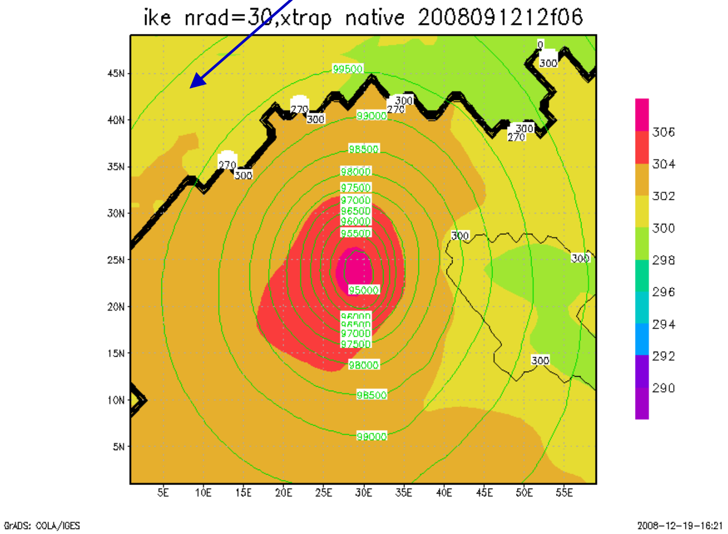
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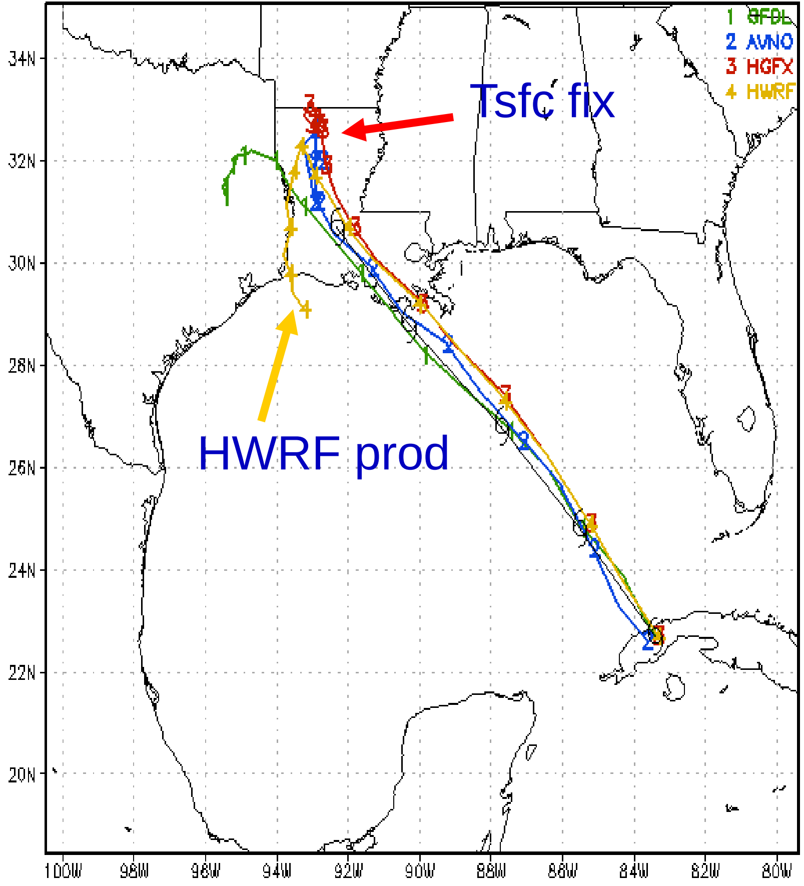
Gustav 083100

Impact of Tsfc fix: (improved track, same intensity)

HWRF (2007 Operational Version) Coupled Model Forecasts
2008 Tropical Cyclone Tracks
Storm: AL0708 (GUSTAV)



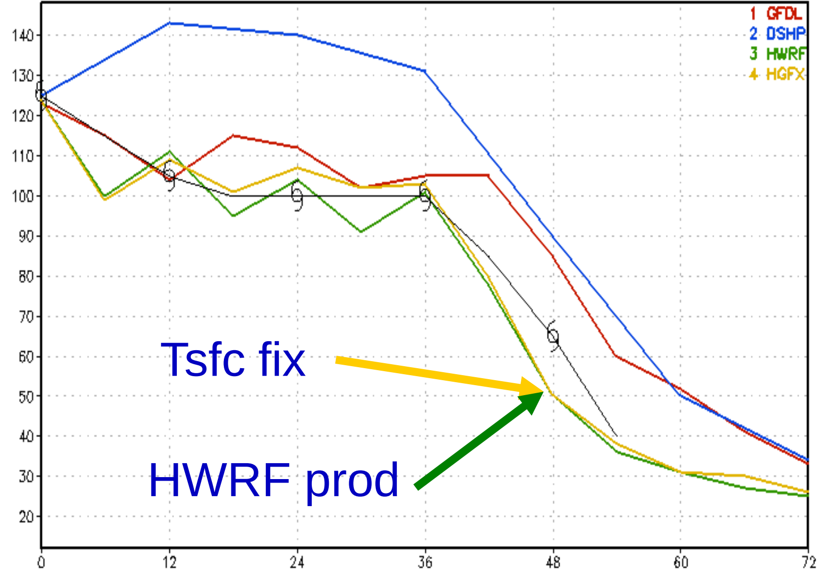
Tsfc fix

HWRF prod

Forecasts: Beginning 2008083100
Observed: Beginning 2008083100, every 12 hours

NCEP Hurricane Forecast Project

HWRF: Hurricane WRF (2007 Operational Version)
2008 Tropical Cyclone Intensities
Storm: AL0708 (GUSTAV)



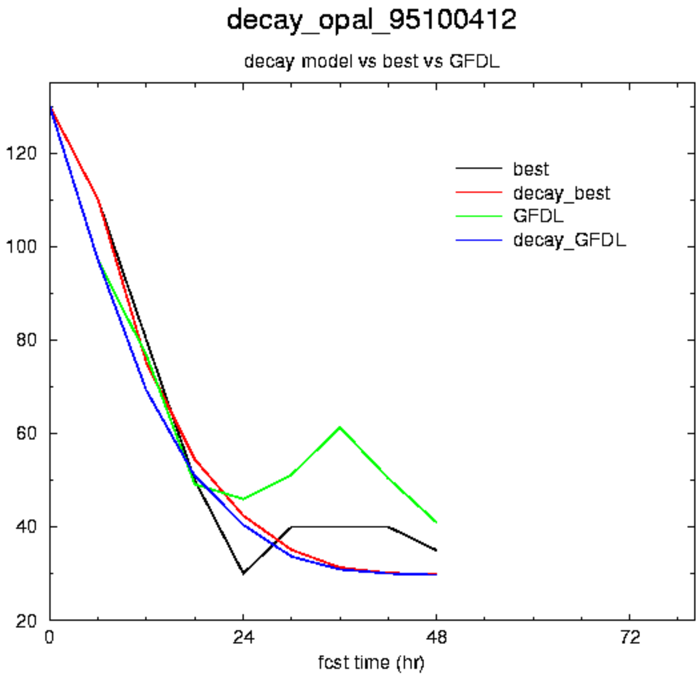
Tsfc fix

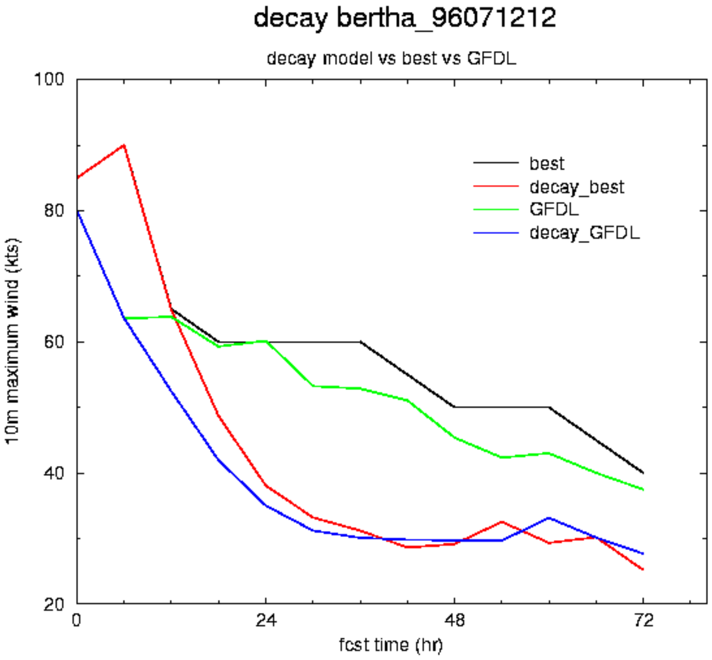
HWRF prod

Forecasts: Beginning 2008083100
Observed: Beginning 2008083100, every 6 hours

NCEP Hurricane Forecast Project

more examples of GFDL and inland decay model



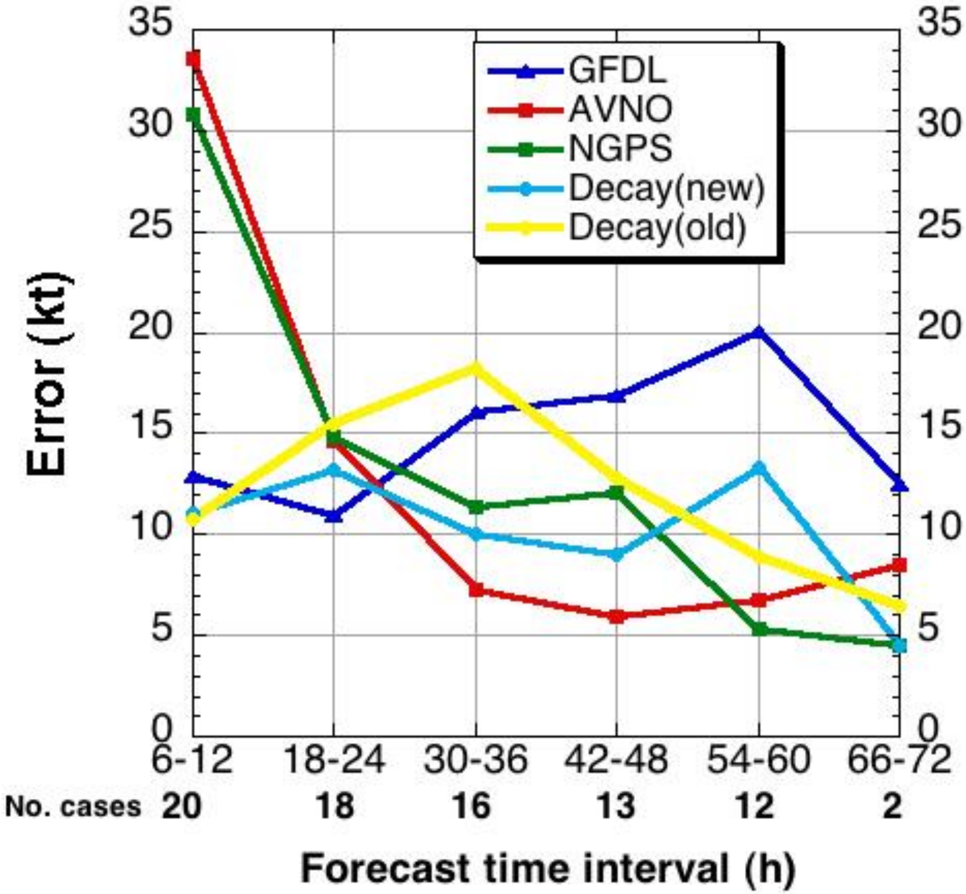


More systematic verification of decay over land

John Kaplan

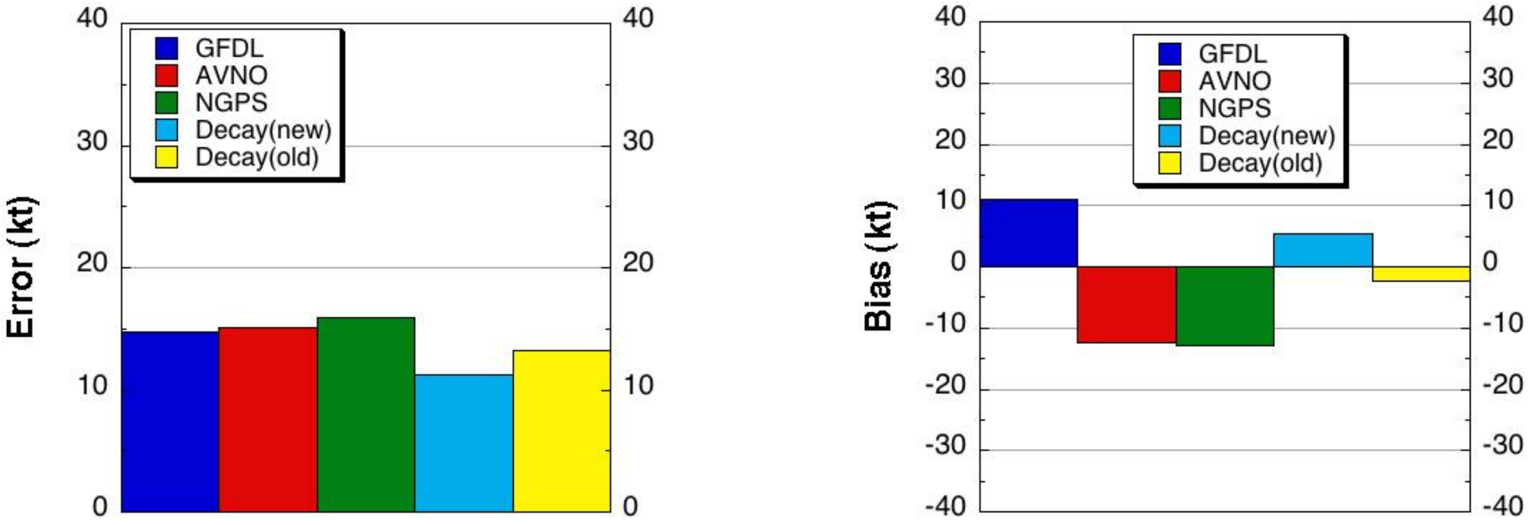
- Compared inland decay model to NWP models
- Need to compare with HWRF and more cases
- Nagging problem of observations??

Absolute error in the model forecasted maximum wind



Sample mean absolute error and mean bias of the model maximum wind forecasts for all time intervals (0-72 h)

Mean Error N=81 Mean Bias



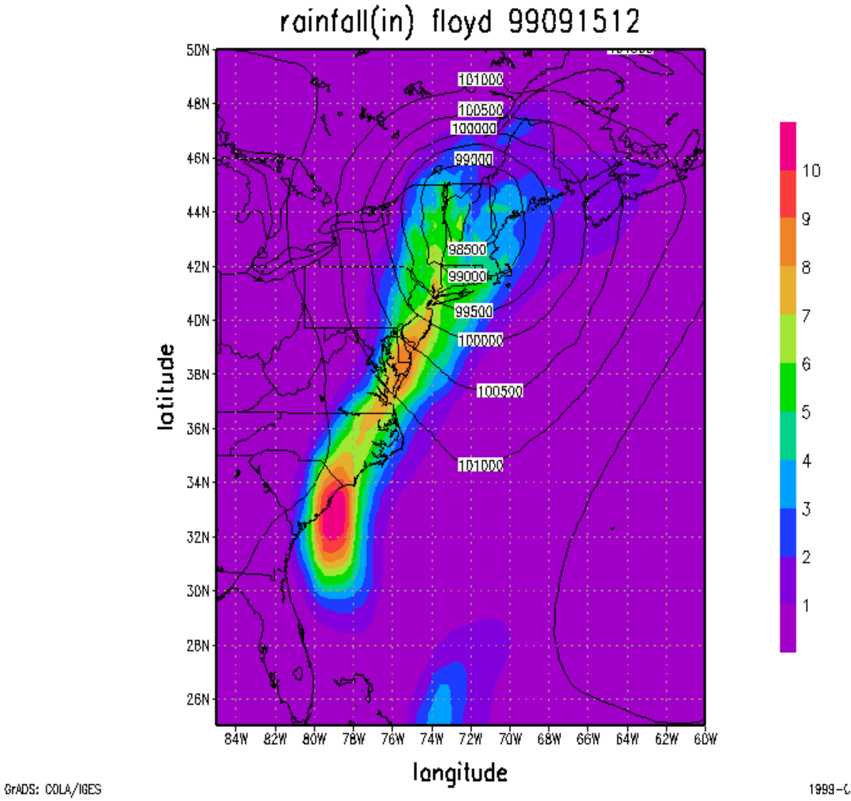
Evaluation of 2-d fields

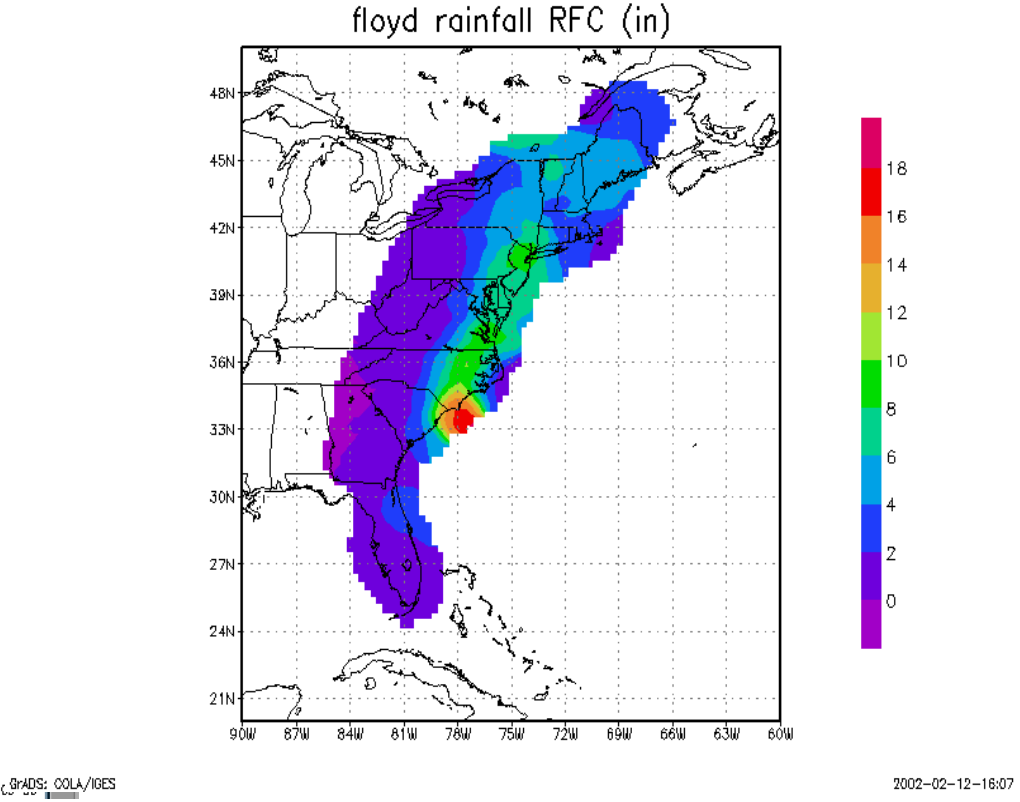
Rainfall & Wind

- Evaluation metrics

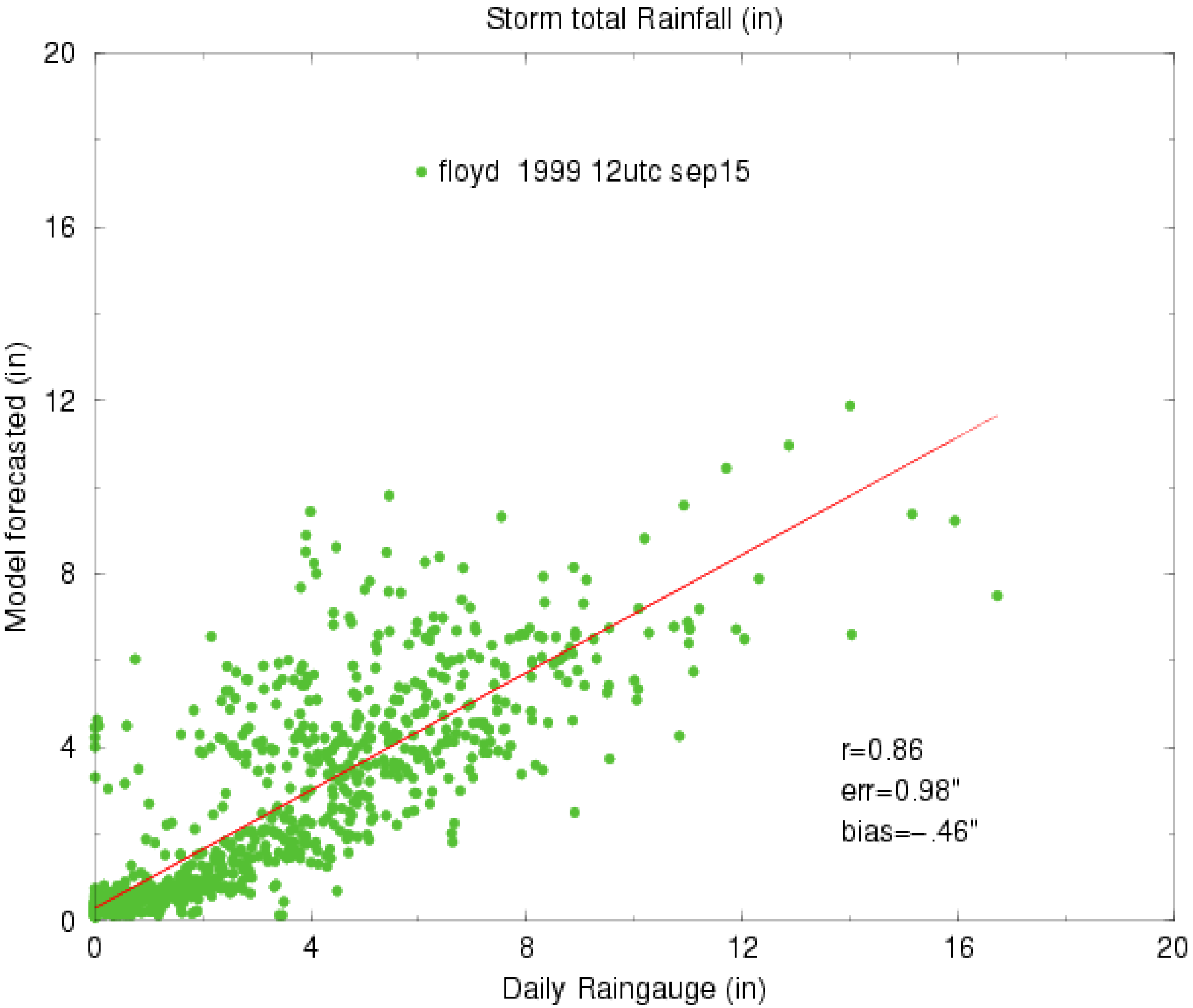
  Absolute mean error, rms, bias&threat, pdf, taylor diagram??
- Spatial and temporal scale??

Floyd 091512
model vs. daily gauges



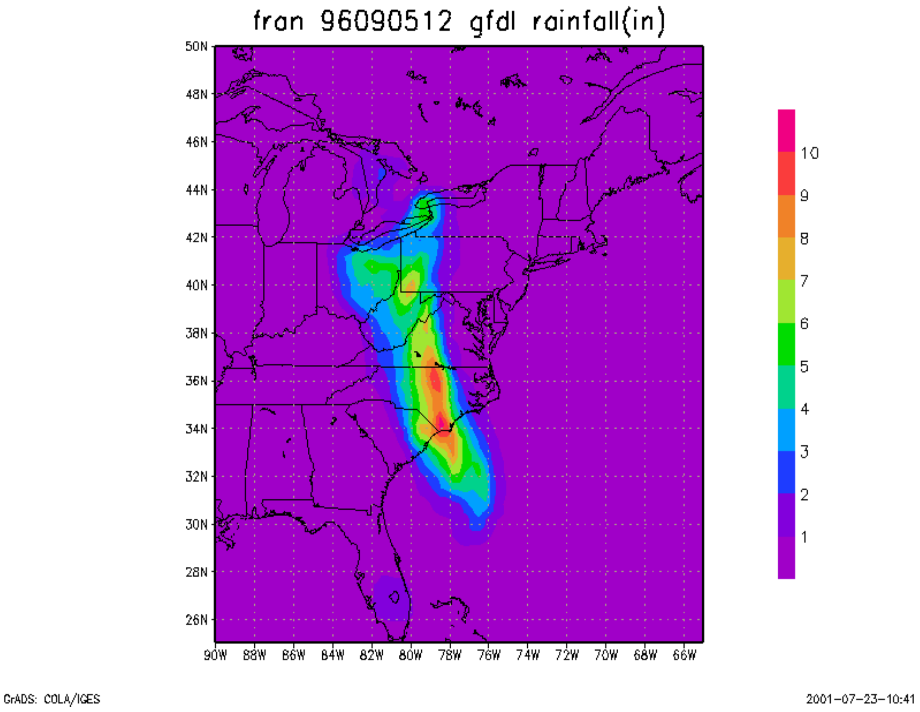


GFDL Model vs Observation

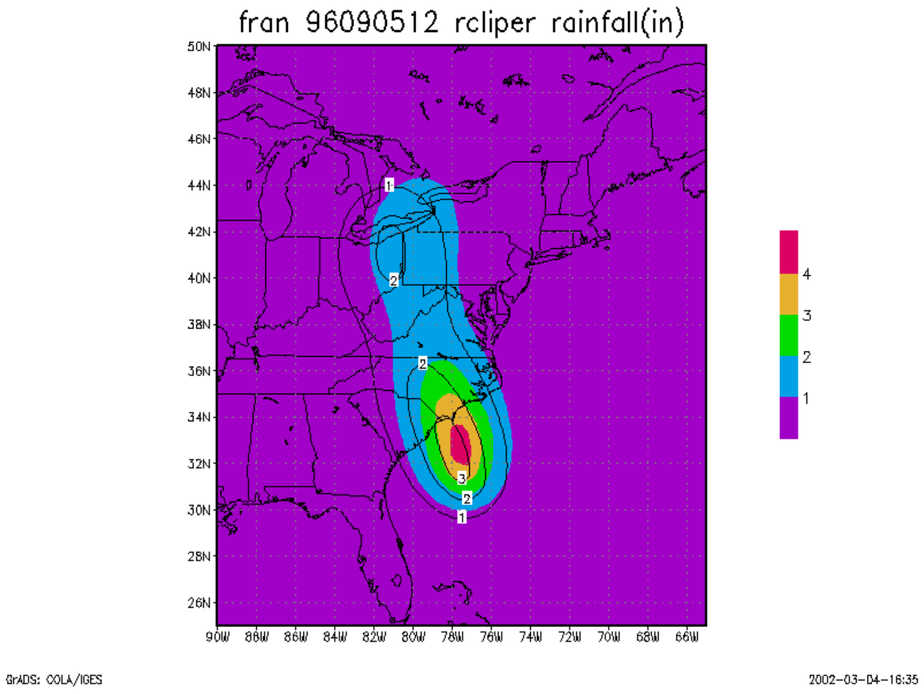


Model vs Rainfall Cliper

Model



Best vs Model track
Rcliper



Evaluation of 2-d fields wind, rainfall, etc issues

- Evaluate from nhc ‘vitals’ file

  restricted to incremental quadrants

  vitals file data valid over land??
- Evaluate at observations location (e.g. Tuleya et al, 2007)

  non-homogeneity of observation type and coverage
- Evaluate on homogeneous analysis grid

  (e.g Marchok et al, 2007)

  blends in all data types

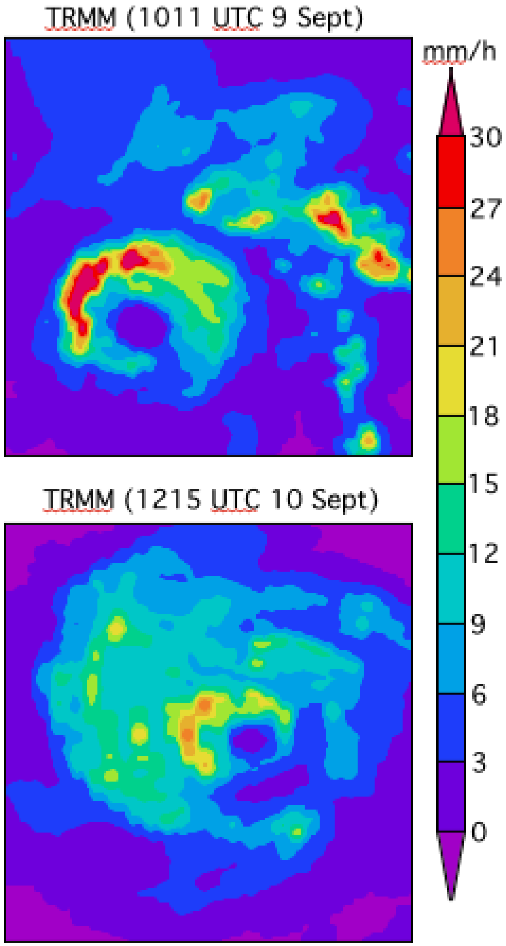
  normalize both observations and model data to standard reference values..i.e. standard open terrain

How to assess small scales ??

- High resolution fields appear more realistic but….
- Small scale fields reduce ‘skill’ if out of phase with observations (e.g. GFS vs GFDL and ETA models rainfall)
- Need to transition to ensemble or probabilistic approach

Simulation of Hurricane Erin (2001)

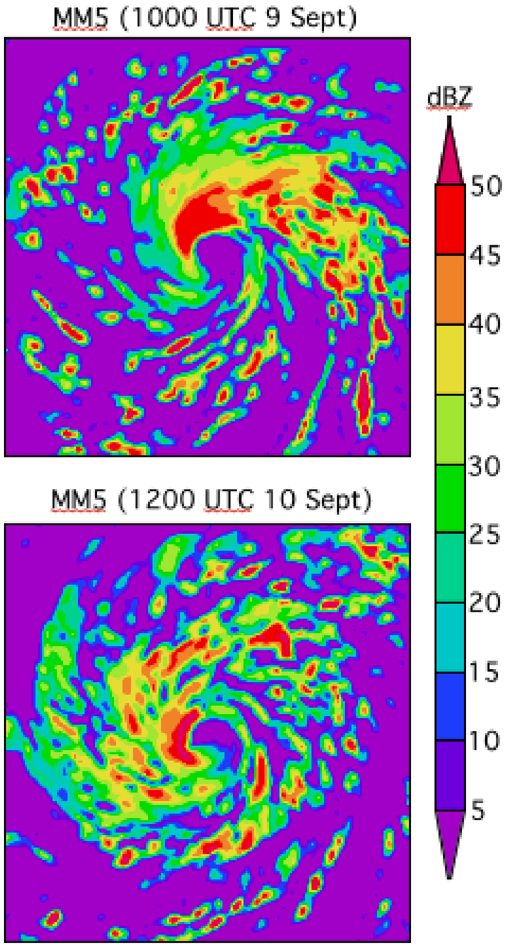
Observed precipitation structure



TRMM (1011 UTC 9 Sept)

TRMM (1215 UTC 10 Sept)

Simulated precipitation structure



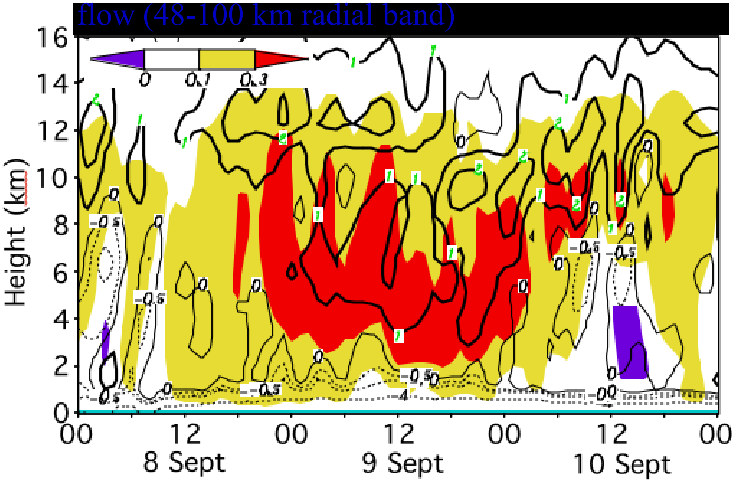
MM5 (1000 UTC 9 Sept)

MM5 (1200 UTC 10 Sept)

- Observed and simulated precipitation show shift of rainfall to western side from Sept. 9 to 10 (left).

- This shift corresponds to a weakening of the eyewall vertical motions and switch from midlevel outflow to inflow (below).

Colors: Azimuthally averaged vertical motion (28-80 km radial band). Contours: Averaged radial flow (48-100 km radial band)



L. Wu and S. Braun, NASA/GSFC

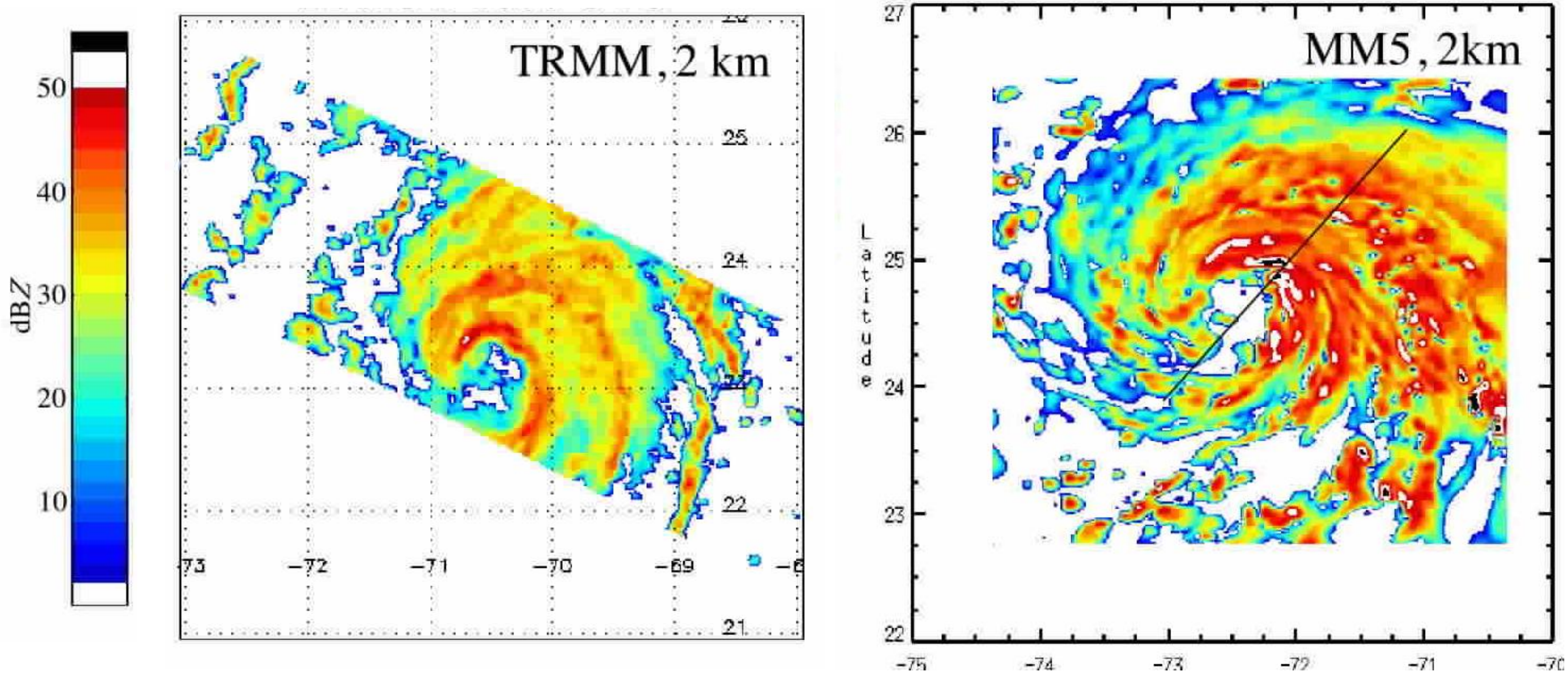
SUMMARY

Starting to evaluate 2-D fields

- More than track and intensity
- Realistic patterns may not lead directly to increase skill
- Advocate using parametric models as baseline and use directly with model data track & intensity to separate out track & intensity error effects
- Comments and suggestions please!!!

Validation of a Hurricane Bonnie Simulation using TRMM Precipitation Radar

- MM5 simulation with innermost grid of 2-km grid spacing
- Model reproduces asymmetry and multiple convective rainbands



TRMM radar reflectivity

MM5 simulated reflectivity

S. Braun, NASA/GSFC