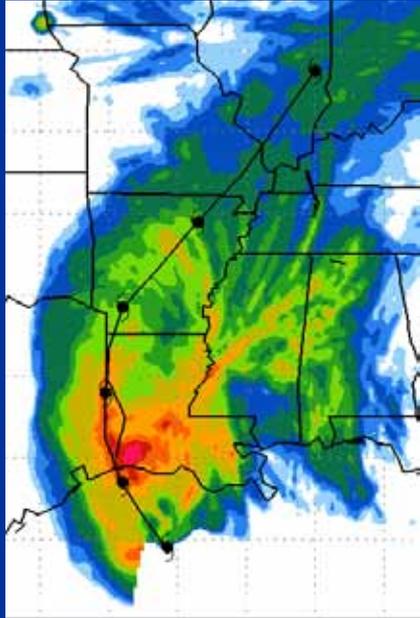


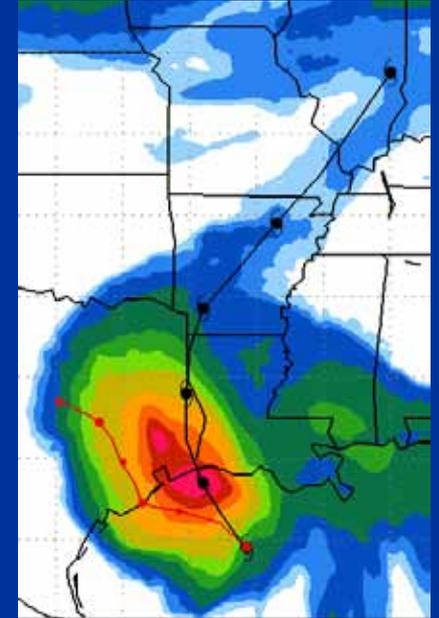
Improving the Validation and Prediction of Tropical Cyclone Rainfall



Timothy Marchok
NOAA / GFDL

Robert Rogers
NOAA / AOML / HRD

Robert Tuleya
NOAA / NCEP / EMC / SAIC



Additional Collaborator: Manuel Lonfat, Risk Management Solutions

This project was funded by the Joint Hurricane Testbed (JHT)

Goals

- Develop a set of rainfall validation schemes specifically designed for TCs
- Produce model QPF error statistics for a set of historic U.S. landfalling storms.
- Develop a forecasting tool based on R-CLIPER that utilizes vertical shear forecast data and the effect of topography.

Outline

- Models & storms
- Development of TC QPF validation techniques
Ø1998-2004 base sample vs. 2005 season
- Skill indices based on new techniques
- New forecasting tool based on R-CLIPER

Models included in this study

GFDL

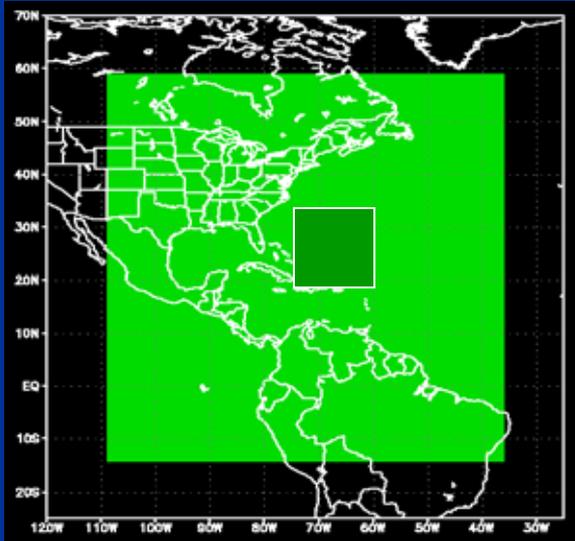
Regional

$1/2^\circ, 1/6^\circ$

(2-nest)

42 levels

2003 version



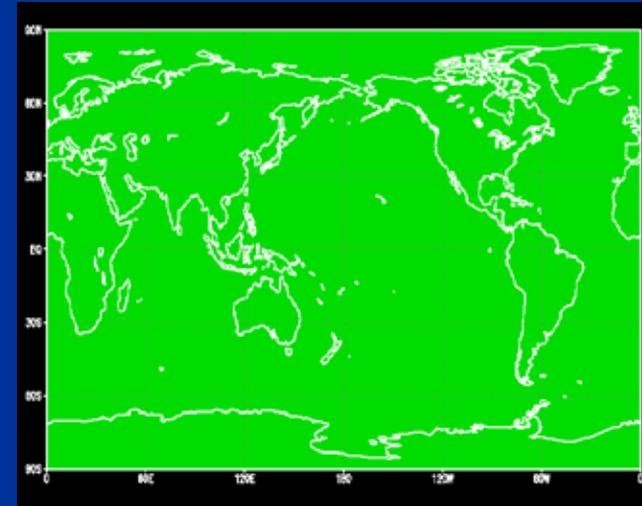
NCEP/GFS

Global

T384

($\sim 0.4^\circ$)

64 levels

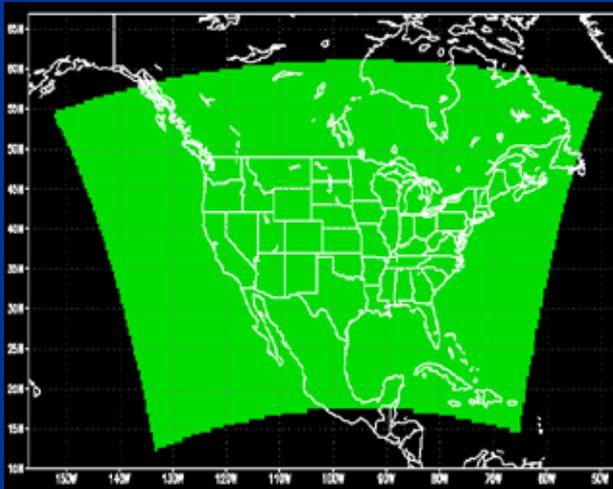


NCEP/NAM

Regional

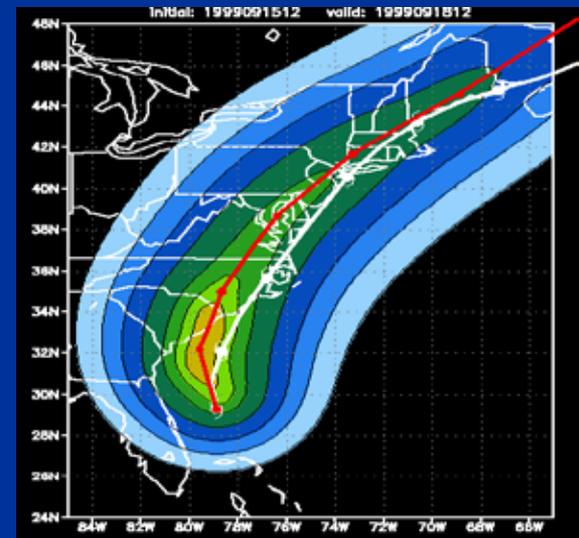
12 km

60 levels



Rainfall-CLIPER

Climatology-based
parametric
model



U.S. Landfalling Cases for Model Evaluation: 1998-2004 Base Sample

<i>1998</i>	<i>1999</i>	<i>2000</i>	<i>2001</i>	<i>2002</i>	<i>2003</i>	<i>2004</i>
Bonnie 95	Bret 100	Gordon 55	Allison 45	Bertha 35	Bill 50	Bonnie 45
Charley 40	Dennis 60	Helene 65	Barry 60	Edouard 35	Claudette 75	Charley 125
Earl 70	Floyd 90		Gabrielle 60	Fay 50	Grace 35	Frances 95
Frances 45	Harvey 50			Hanna 45	Henri 30	Gaston 65
Georges 90	Irene 70			Isidore 55	Isabel 90	Ivan 110
Hermine 35				Kyle 35		Jeanne 105
				Lili 85		Matthew 40

U.S. Landfalling Cases for Model Evaluation: 2005 Season

- Arlene
- Cindy
- Dennis
- Katrina (Florida)
- Katrina (Louisiana)
- Ophelia
- Rita
- Tammy
- Wilma

Outline

- Models & storms
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Ø1998-2004 base sample vs. 2005 season
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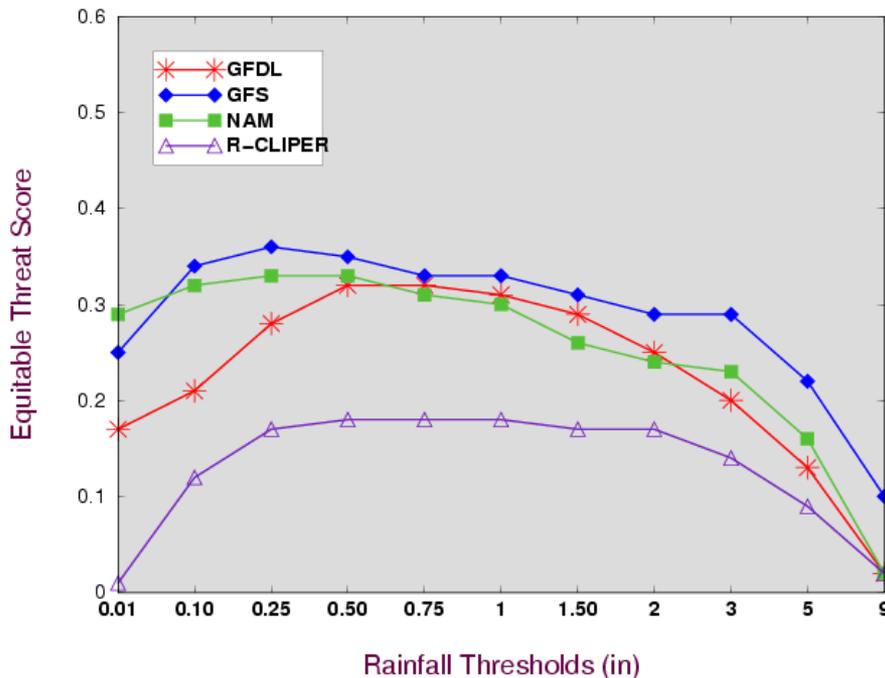
Parameters describing skill of TC QPF forecasts

- Rainfall patterns
- Rainfall volume
- Extreme amounts
- Sensitivity to track errors

Rainfall patterns

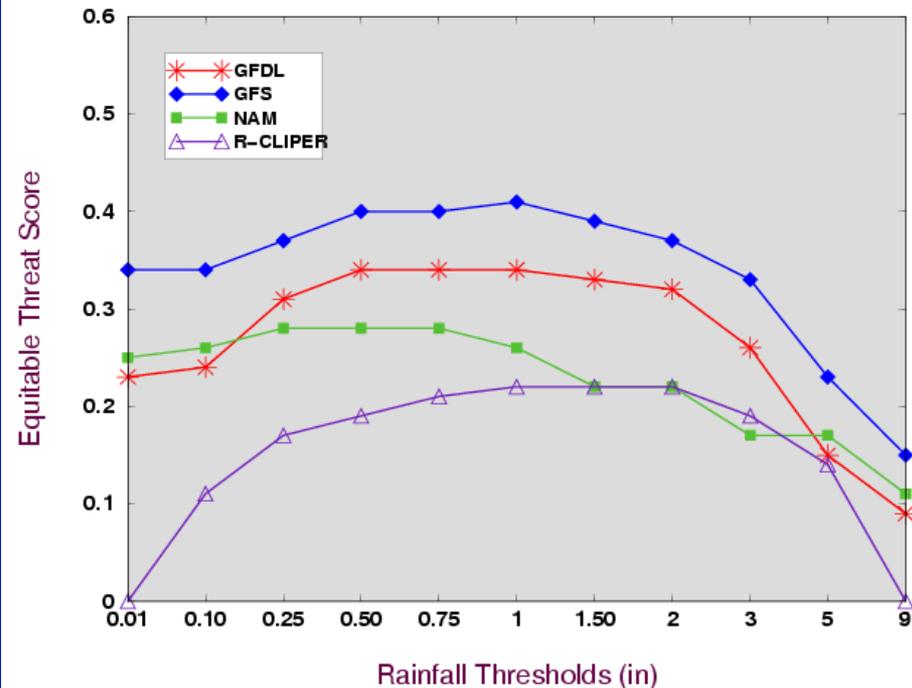
1998-2004

Equitable Threat Score Comparison for Landfalling Atlantic Storms, 1998-2004



2005

Equitable Threat Score Comparison for Landfalling Atlantic Storms, 2005



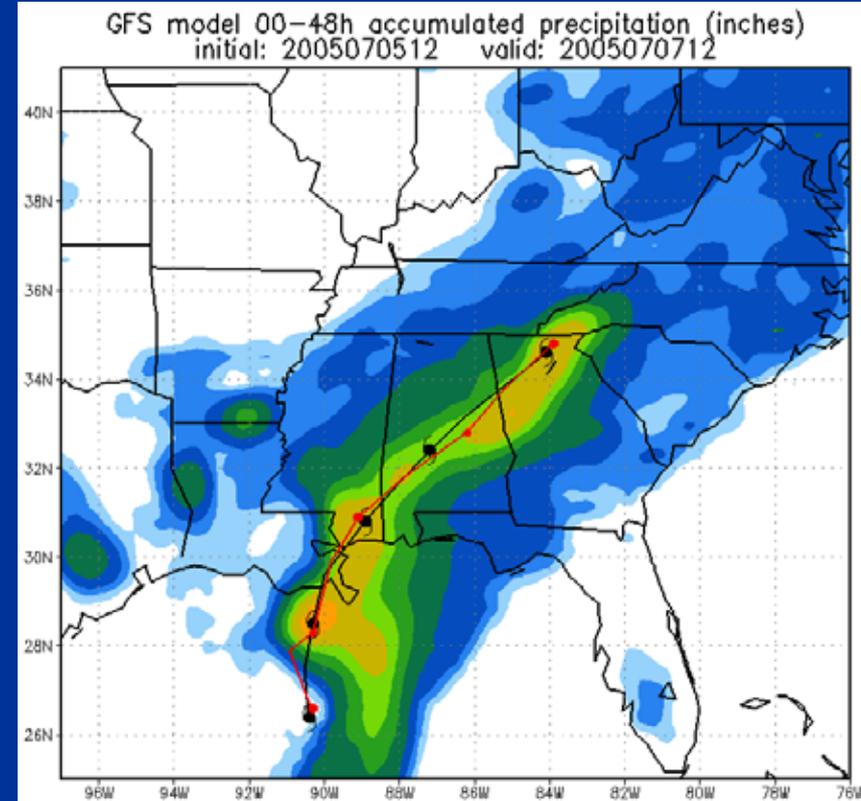
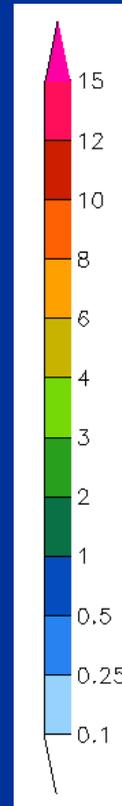
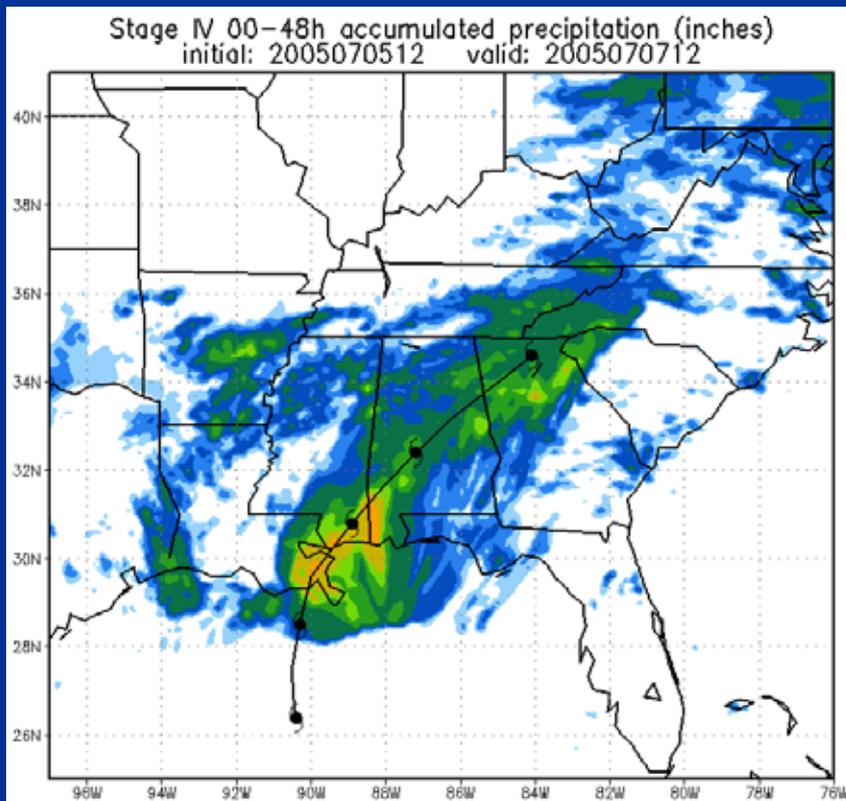
Equitable threat score comparison

Rainfall volume

Example: Tropical Storm Cindy (2005)

Stage IV (Observed)

GFS



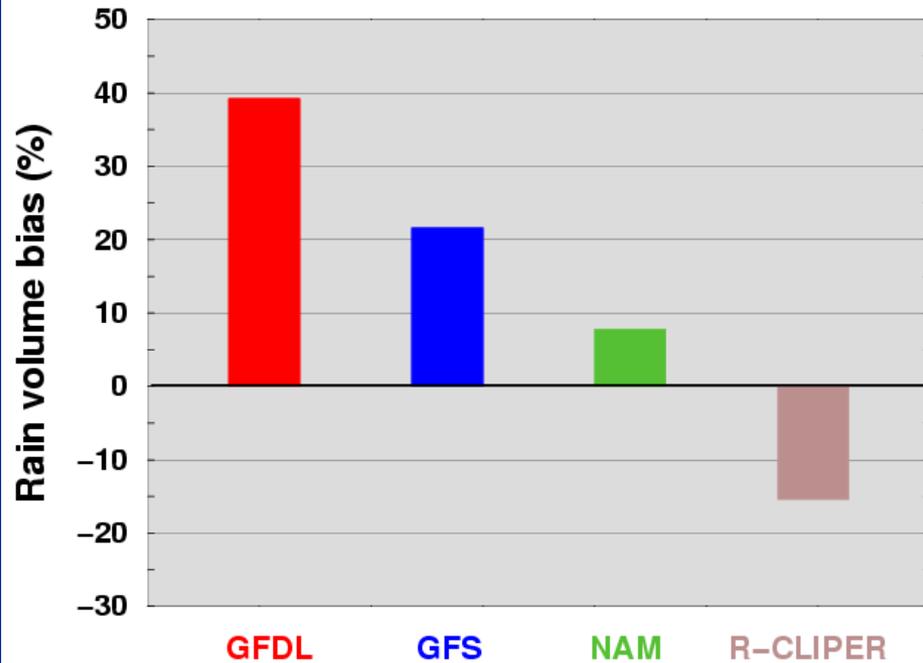
Rainfall volume

Comparison of rain volume bias by model

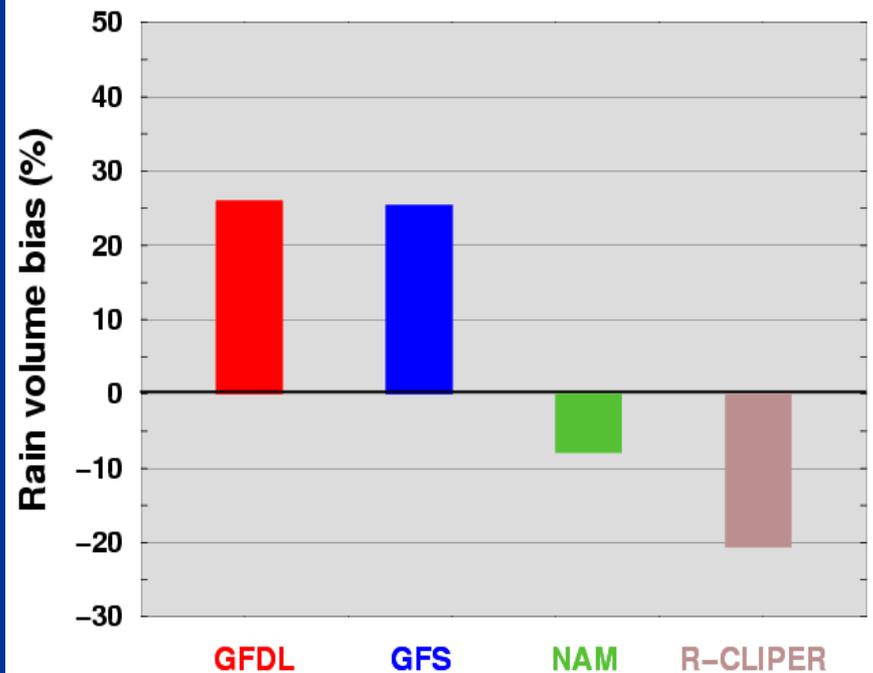
1998-2004

2005

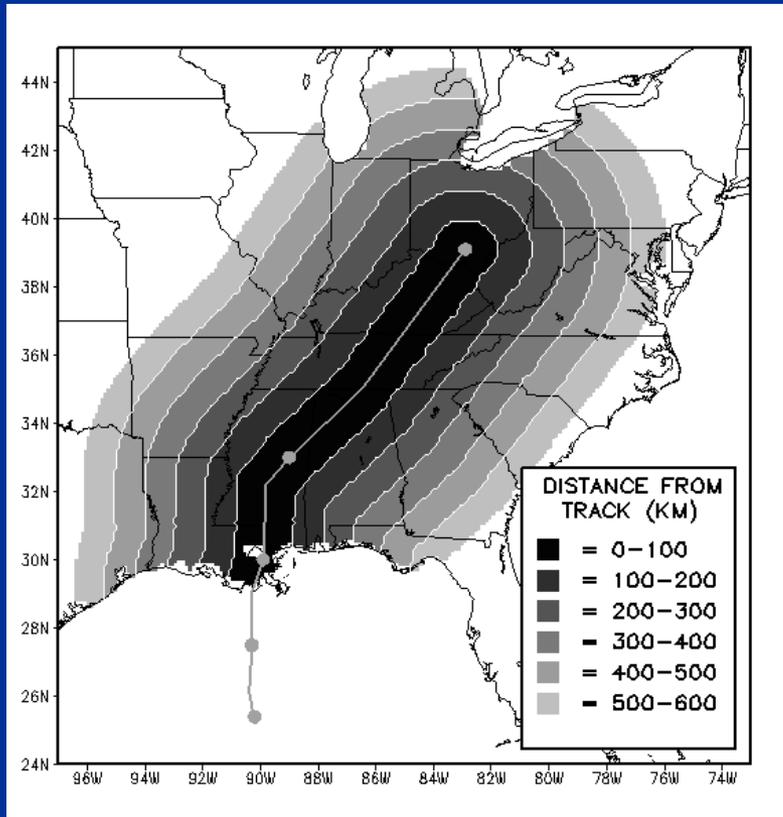
Rain volume bias per case
1998-2004 storms



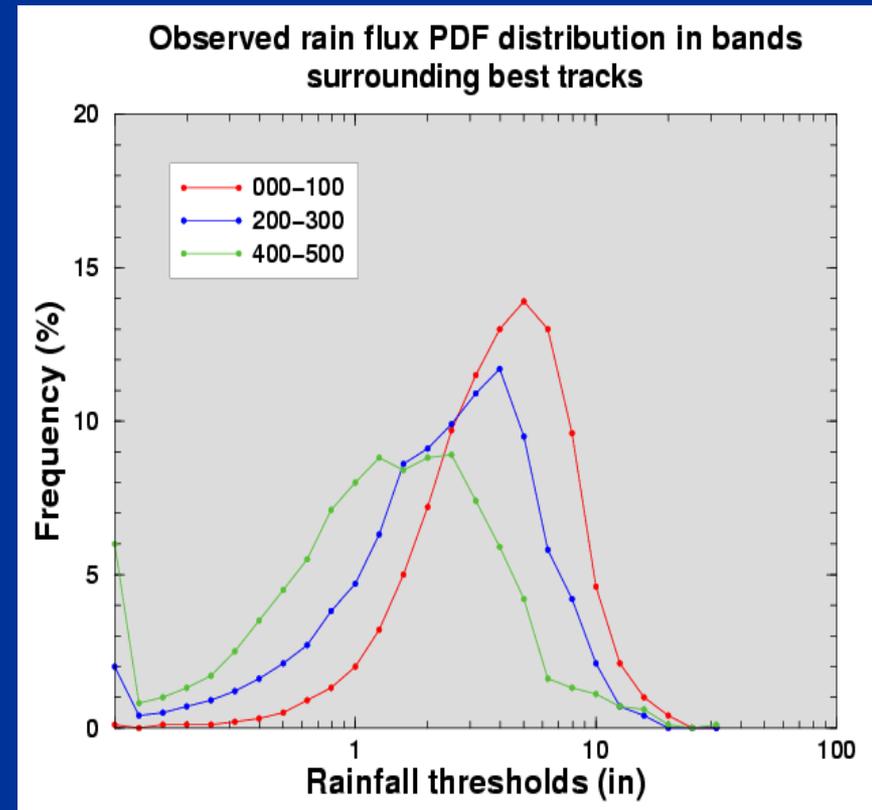
Rain volume bias per case
2005 storms



Rainfall volume: "Rain flux" and track-relative analyses



Observed rain flux PDF for all 1998-2004 storms in selected bands surrounding best track

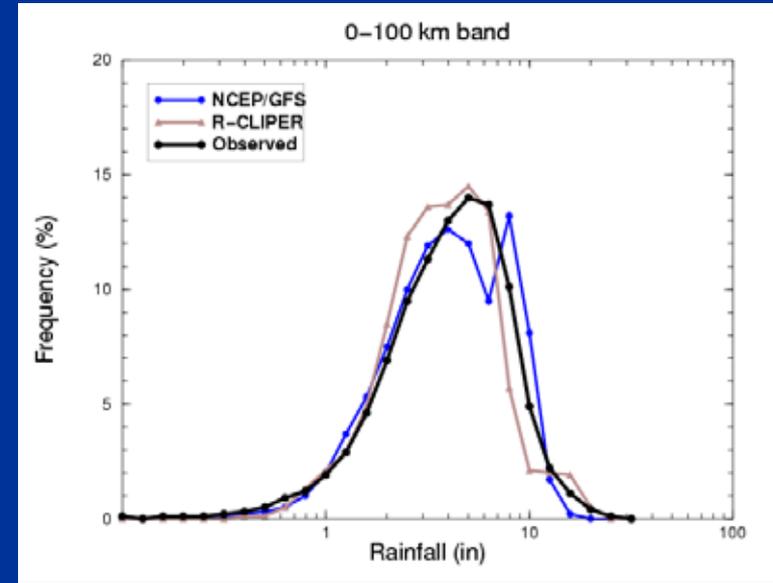
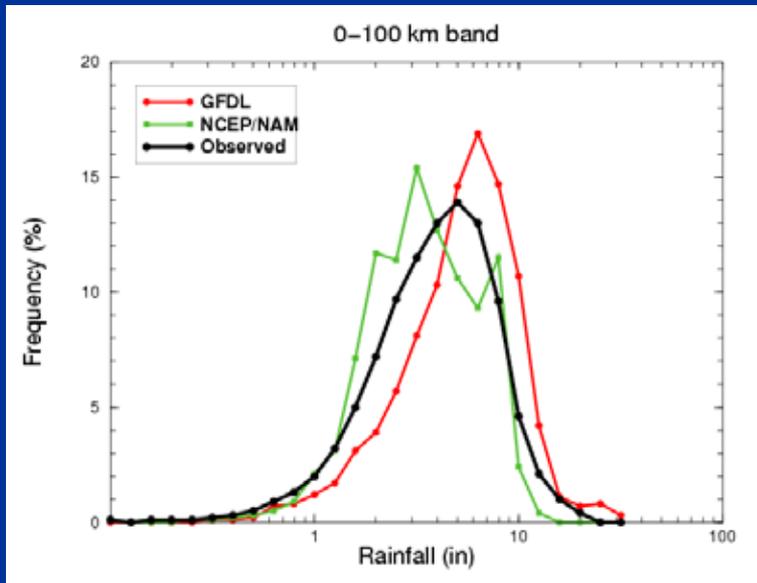


Rain volume: Rain flux in select bands

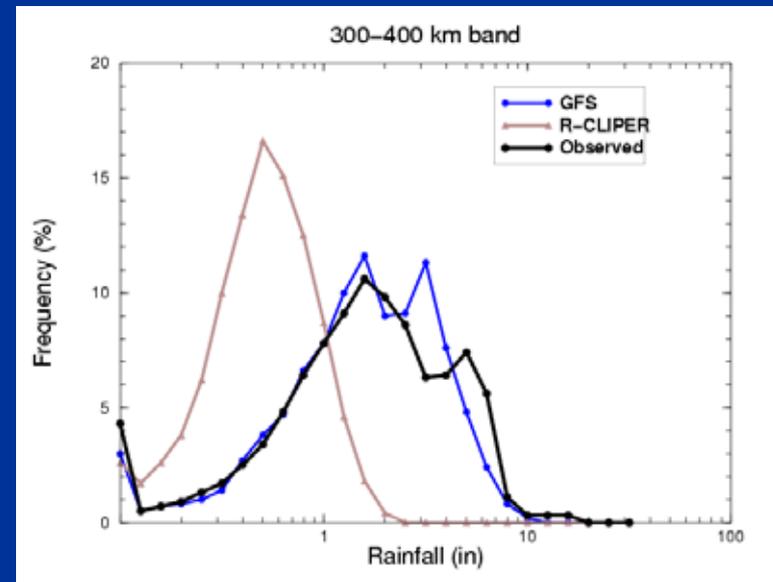
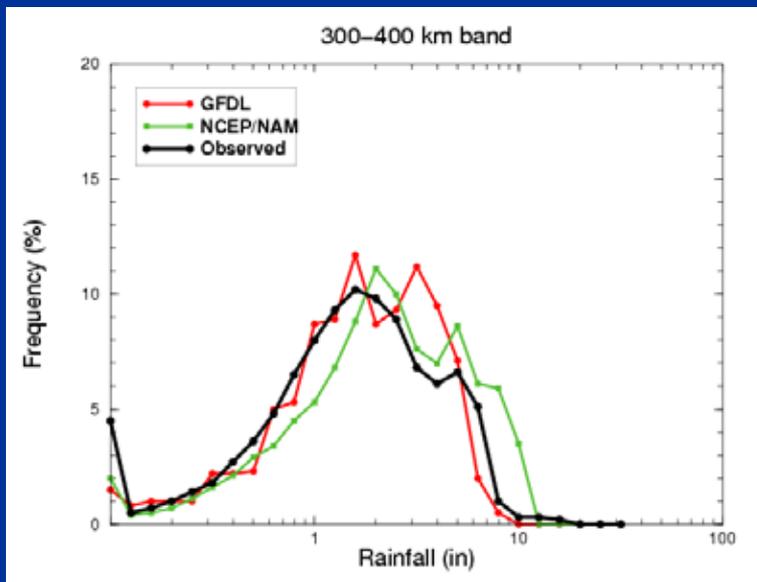
GFDL, NAM

GFS, R-CLIPER

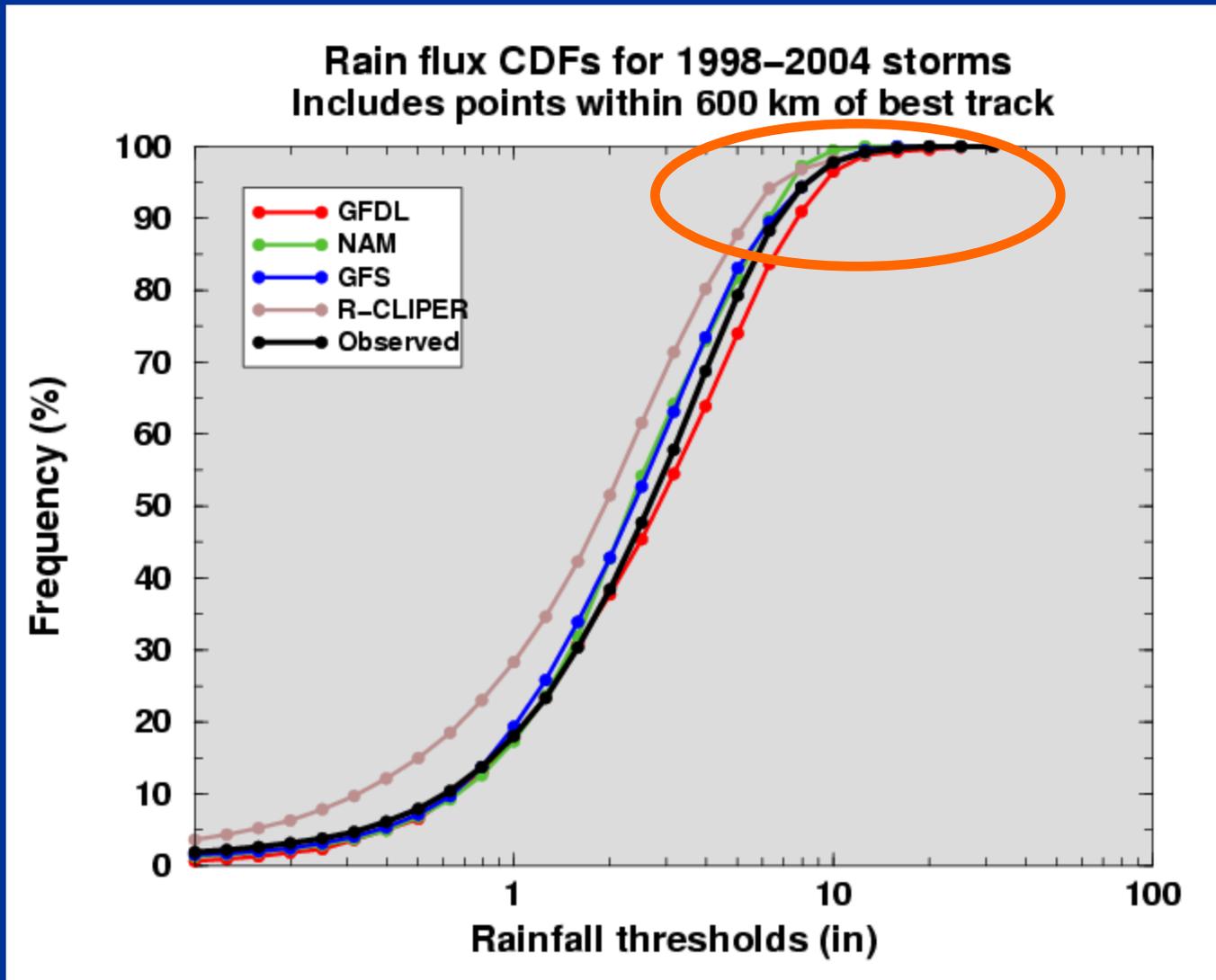
0–100 km



300–400 km



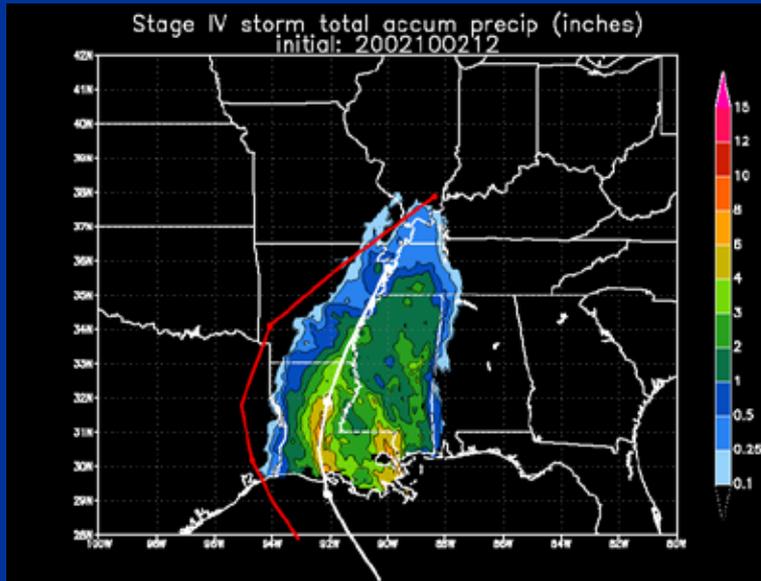
Extreme amounts: Comparison of top 5% of rain flux



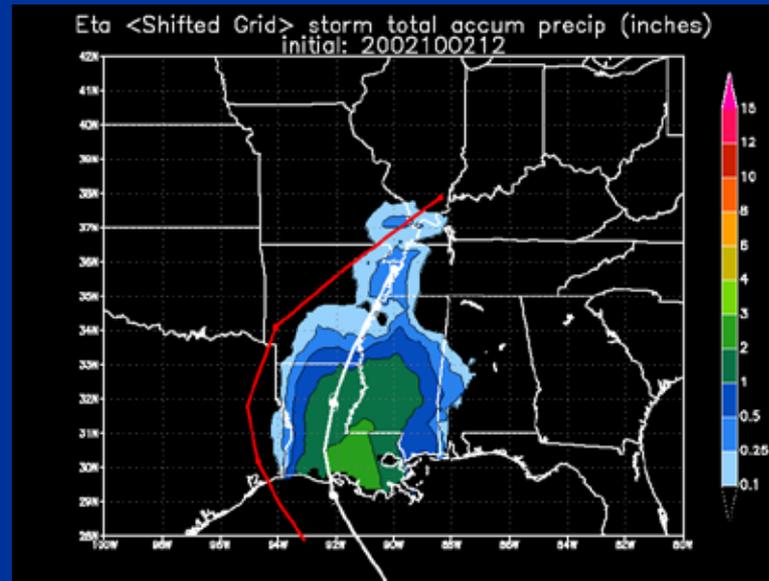
Sensitivity to track error

Example of grid-shifting of rain field

Lili Stage IV



Eta shifted



r increased from 0.36 (unshifted) to 0.85 (shifted)

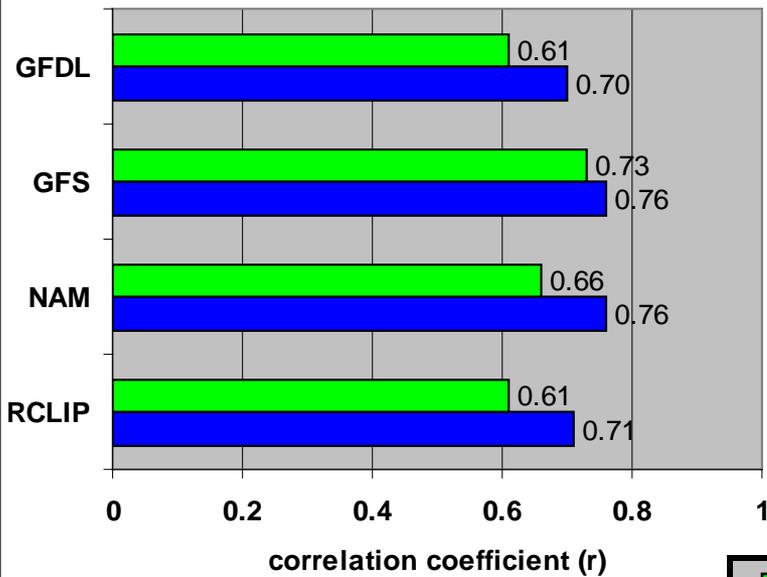
Sensitivity to track error

Impact of grid shift on pattern correlations

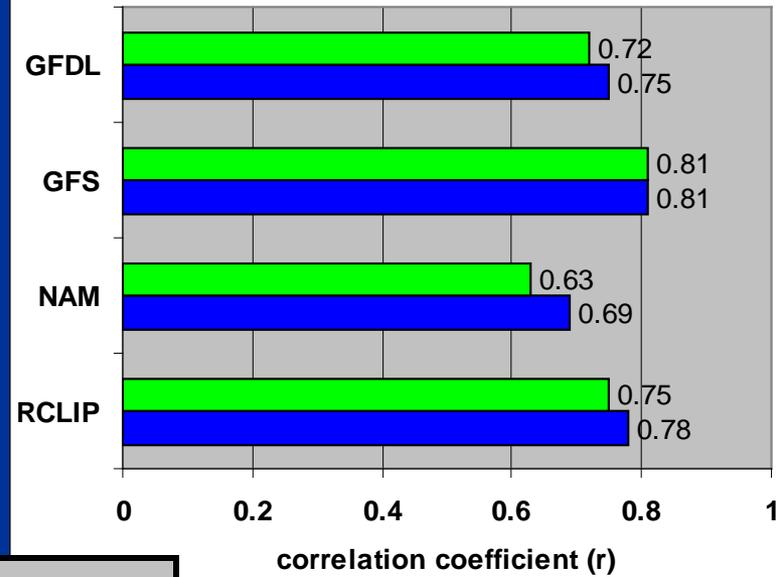
1998-2004

2005

Grid shift impact on correlations (1998-2004)



Grid shift impact on correlations (2005)



■ = Original
■ = Shifted

Outline

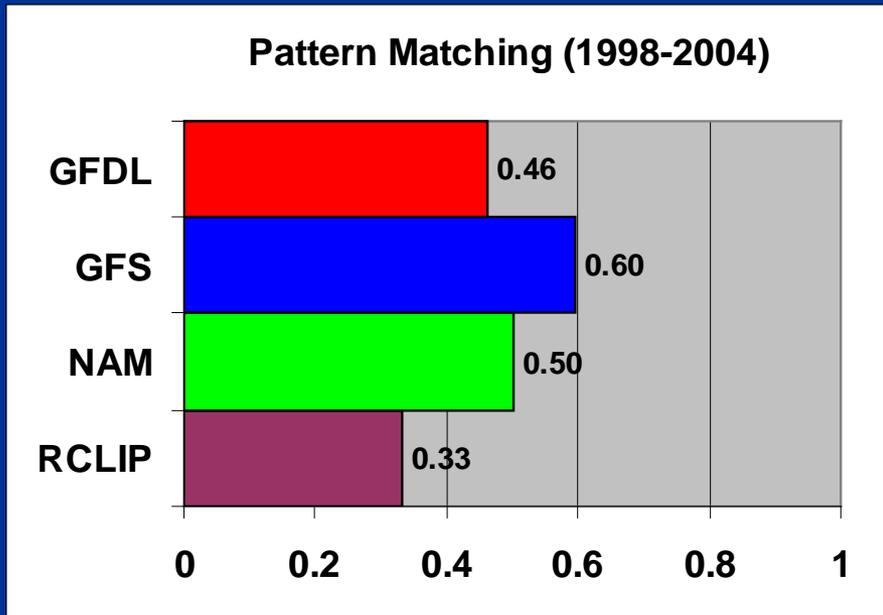
- Models & storms
- Development of TC QPF validation techniques
Ø1998-2004 base sample vs. 2005 season
- Skill indices based on new techniques
- New forecasting tool based on R-CLIPER

Matrix of TC QPF Skill Indices

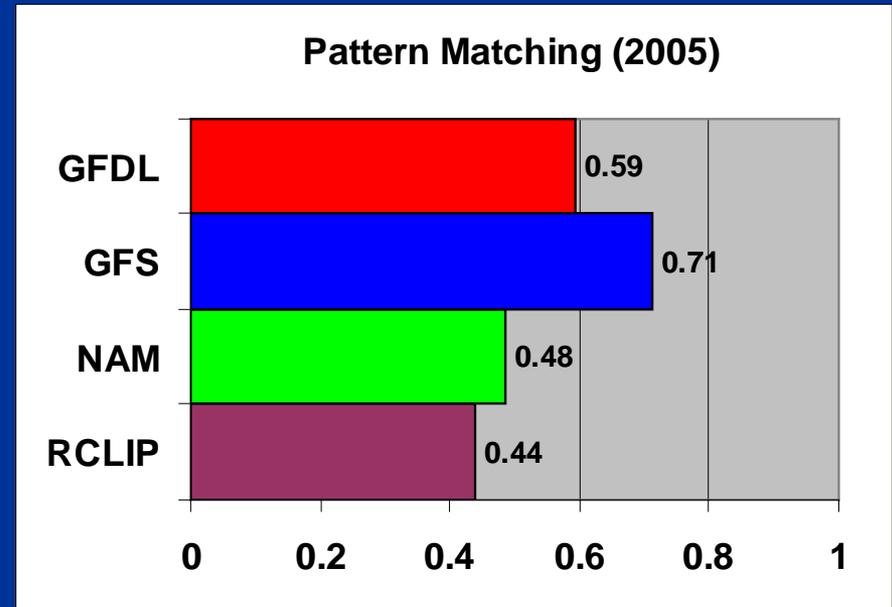
Index	Dependency on Track Error		QPF attribute described			
	Dependent	Independent	Pattern	Mean / Volume	Maximum	Impact of Track Error
Large-Scale ETS			ü			
Pattern Correlation			ü			
Mean Rainfall Error Index				ü		
Large-Scale CDF Median Value				ü		
Track-Relative CDF Median Value				ü		
Large-Scale CDF % in 95th percentile					ü	
Track-Relative CDF % in 95th percentile					ü	
Grid-Shifted Pattern Correlation						ü
Grid-Shifted ETS						ü

Skill Indices: Pattern Matching

1998-2004



2005

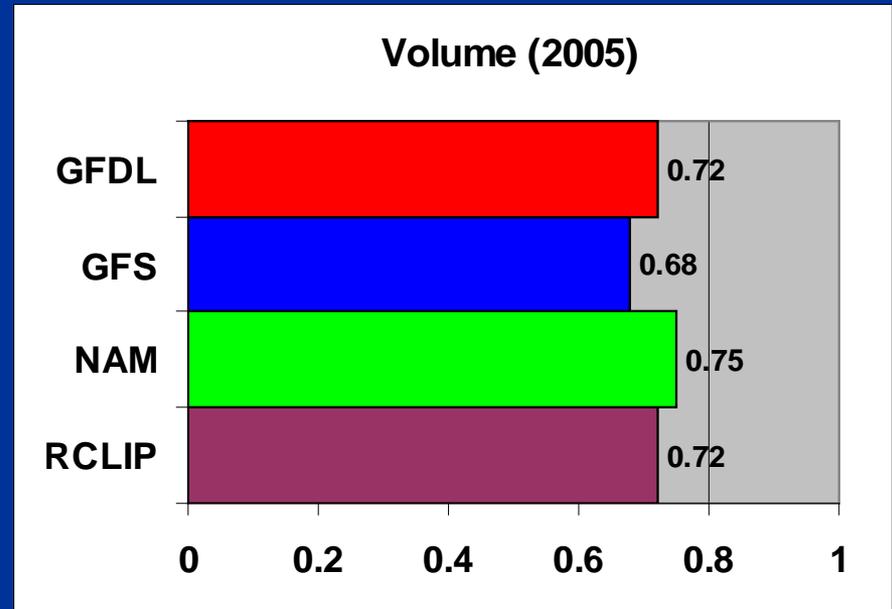
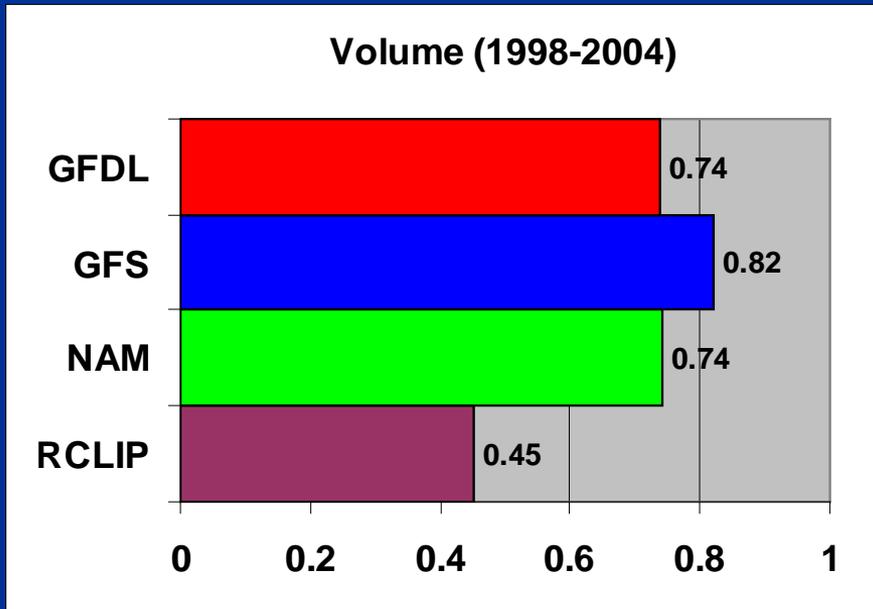


- GFS performs the best in both samples
- All models have skill relative to R-CLIPER

Skill Indices: Volume

1998-2004

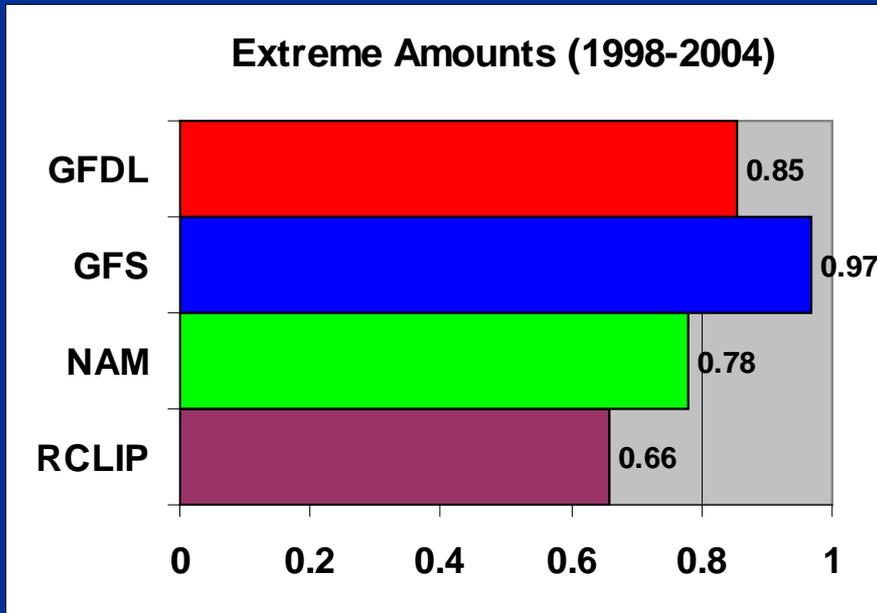
2005



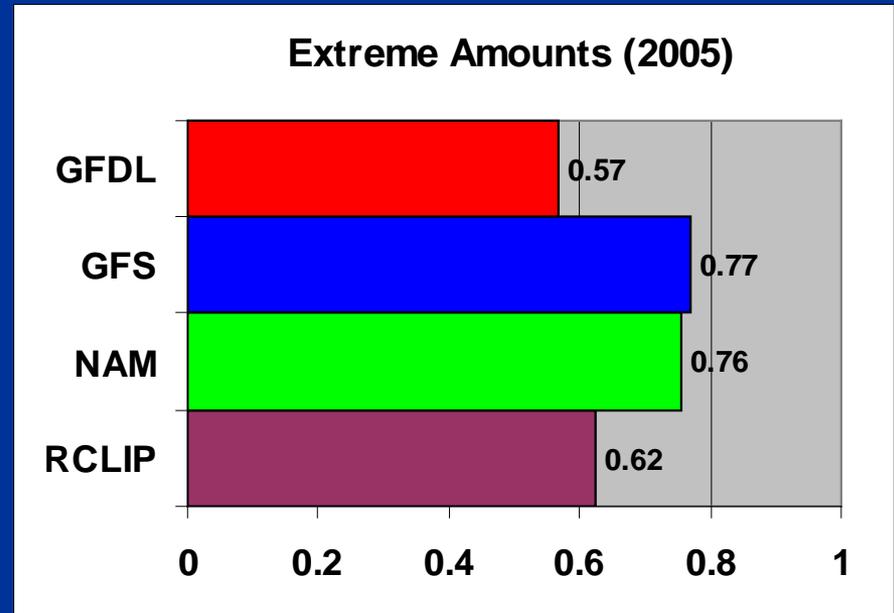
- R-CLIPER significantly better in 2005 season
- GFS worse in 2005 due to over-forecast bias

Skill Indices: Extreme Amounts

1998-2004



2005

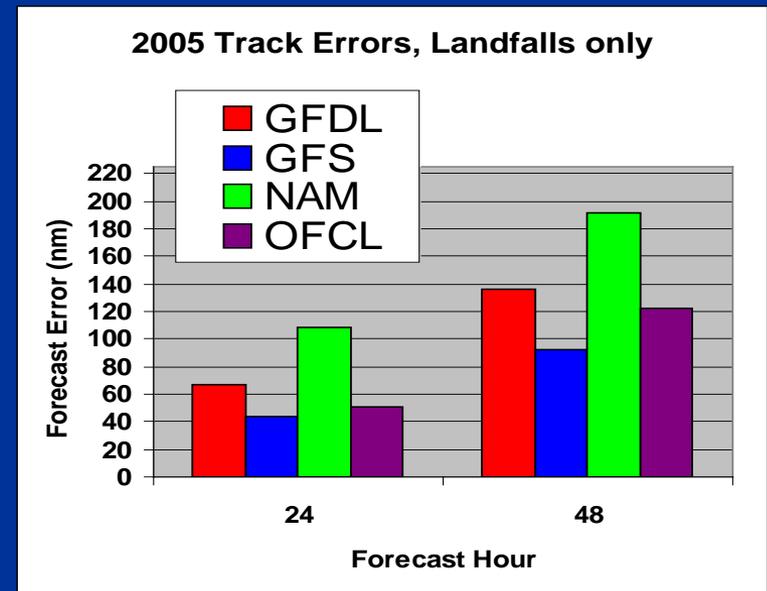
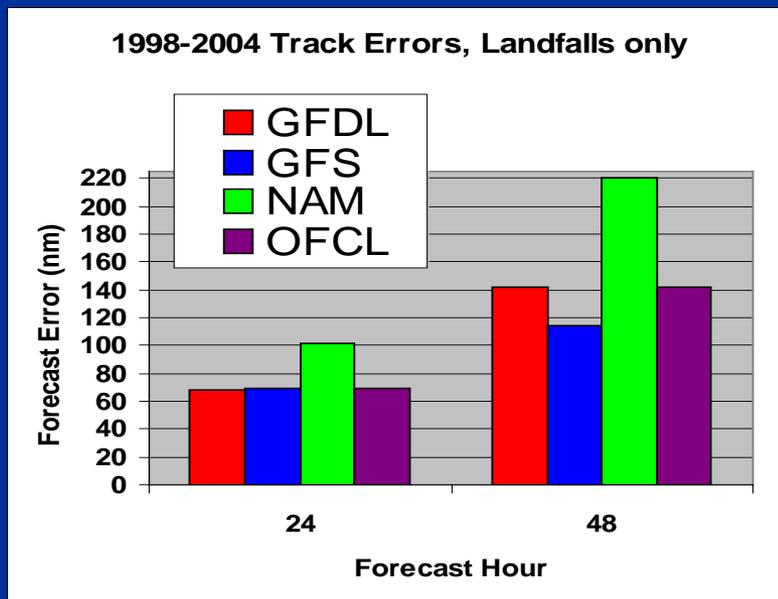
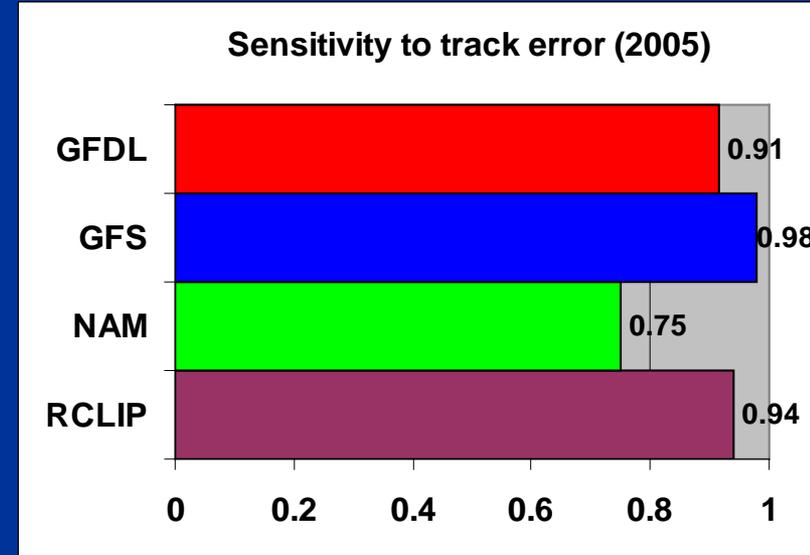
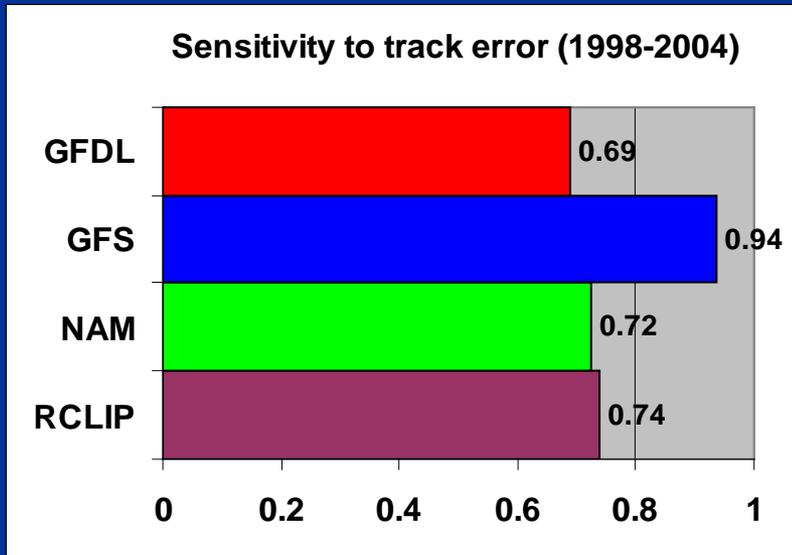


- GFDL worse in 2005 due to core region over-forecast bias
- GFS performs best despite lowest resolution

Skill Indices: Sensitivity to track error

1998-2004

2005



Outline

- Models & storms
- Development of TC QPF validation techniques
Ø1998-2004 base sample vs. 2005 season
- Skill indices based on new techniques
- **New forecasting tool based on R-CLIPER**

Building on R-CLIPER: Inclusion of vertical shear forecast data & topography

Formulation

$$R_{\text{tot}} = R_{\text{R-CLIPER}} + R_{\text{Shear mod}} + R_{\text{topo}}$$

$$R_{\text{tot}}(r, \theta) = a_0(r) + \sum_i \dot{\mathbf{a}} a_i(r) \cos(iq) + \sum_i \dot{\mathbf{a}} b_i(r) \sin(iq) + f(\dot{\mathbf{v}} \cdot \tilde{\mathbf{N}}h)$$

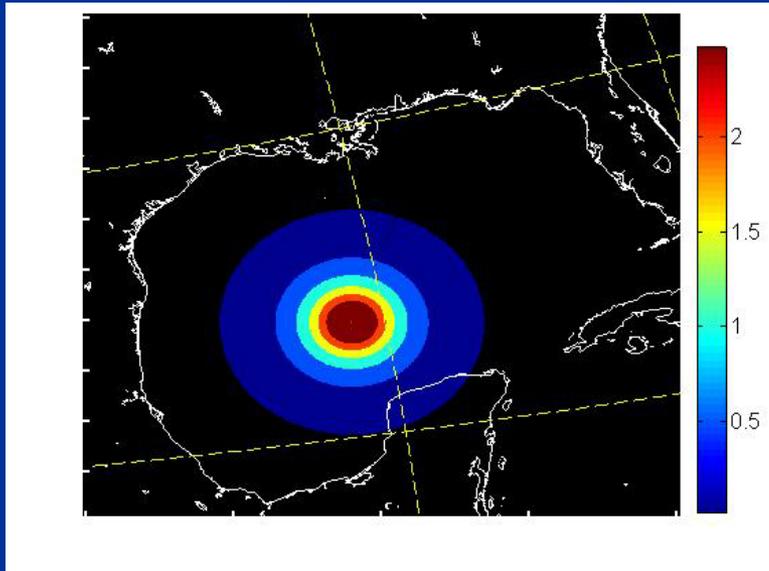
Standard R-CLIPER

Shear modification

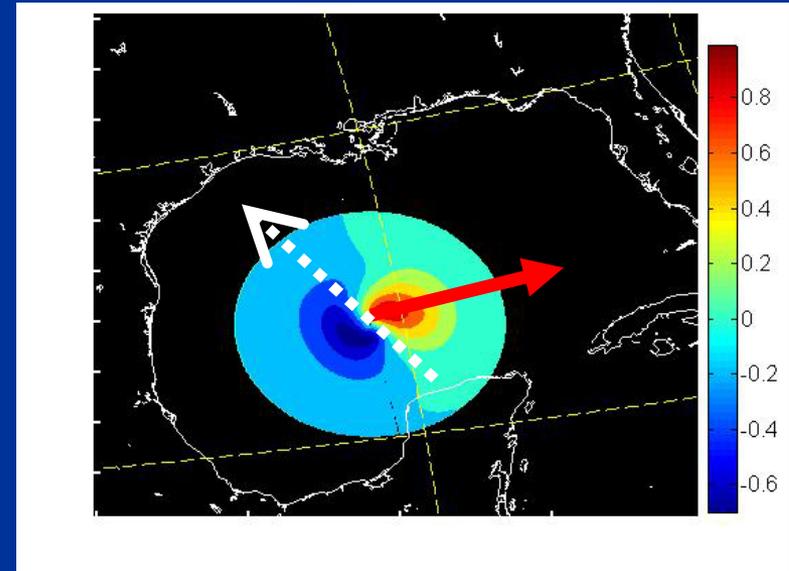
Topography modification

Example of shear footprint: Hurricane Ivan

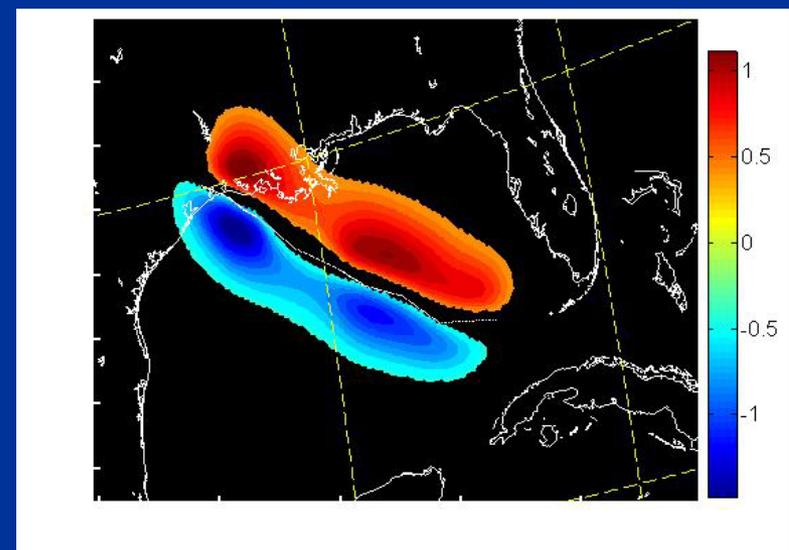
a) Contribution from Wavenumber 0

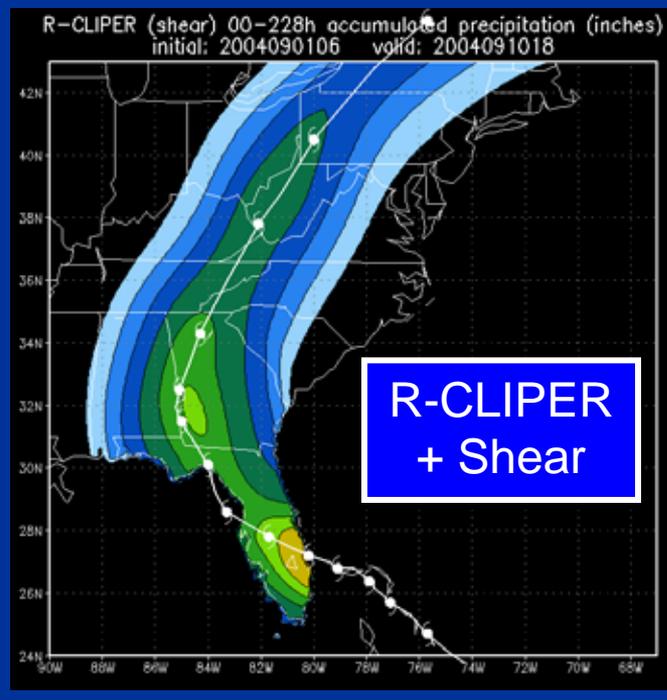
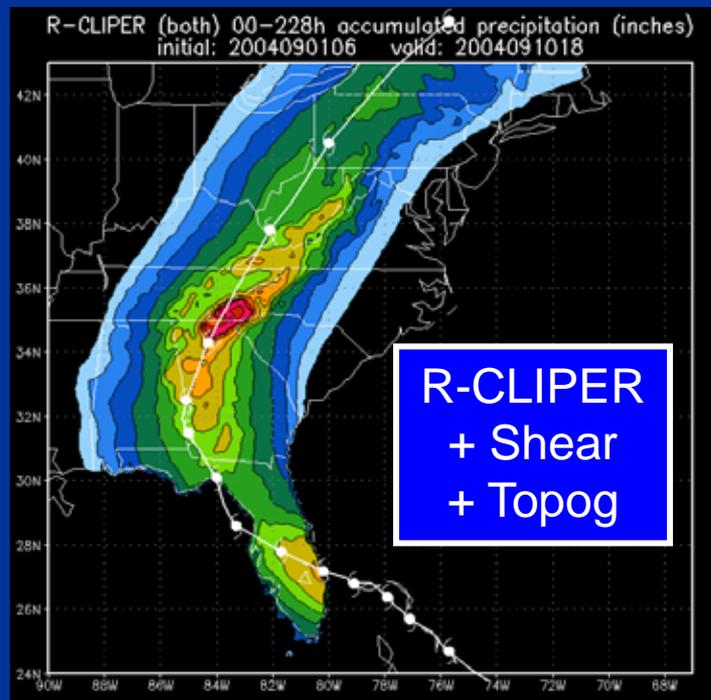
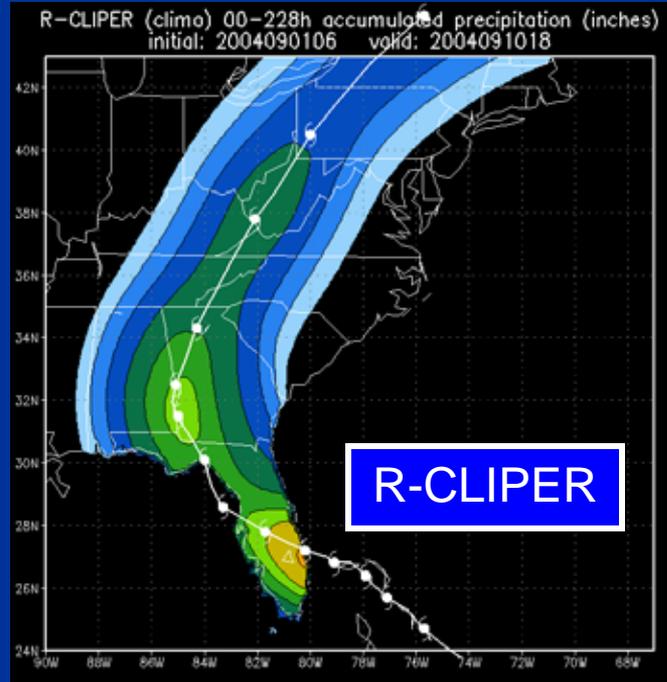
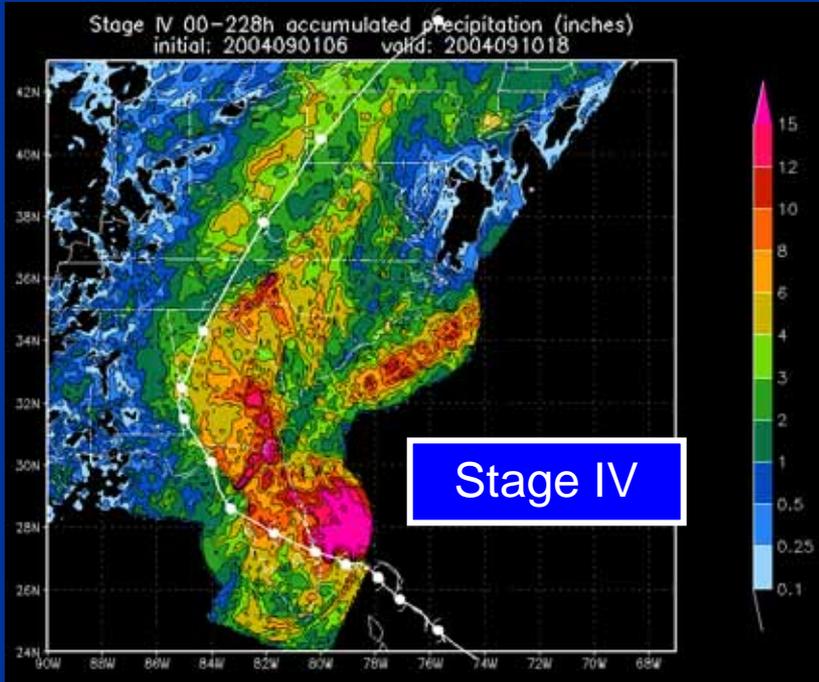


b) Contribution from Wavenumbers 1,2



c) Shear footprint is “stamped” on a lon/lat grid every 15 minutes, providing a contribution to storm total accumulation

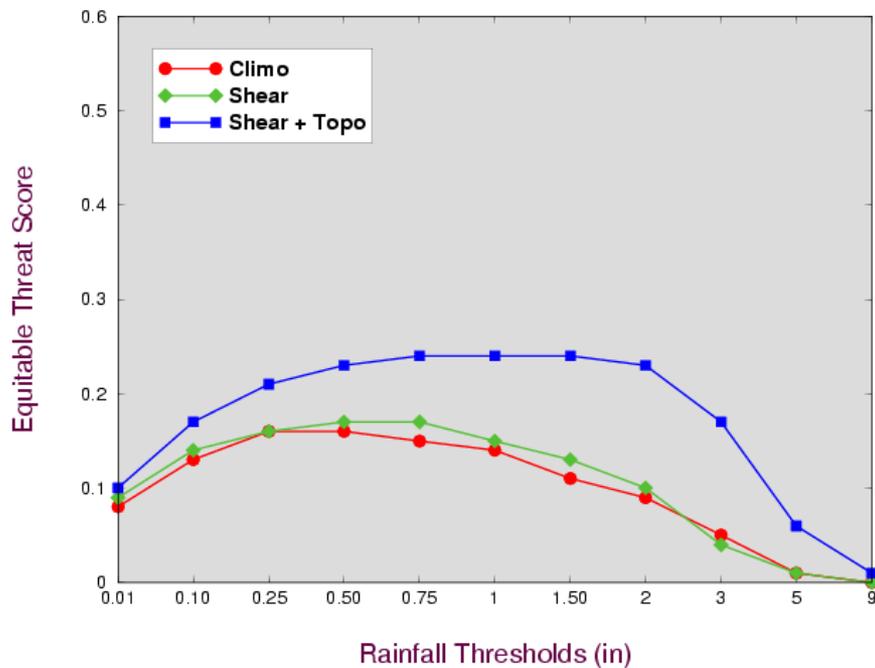




Examples of R-CLIPER / SHRAPS validations

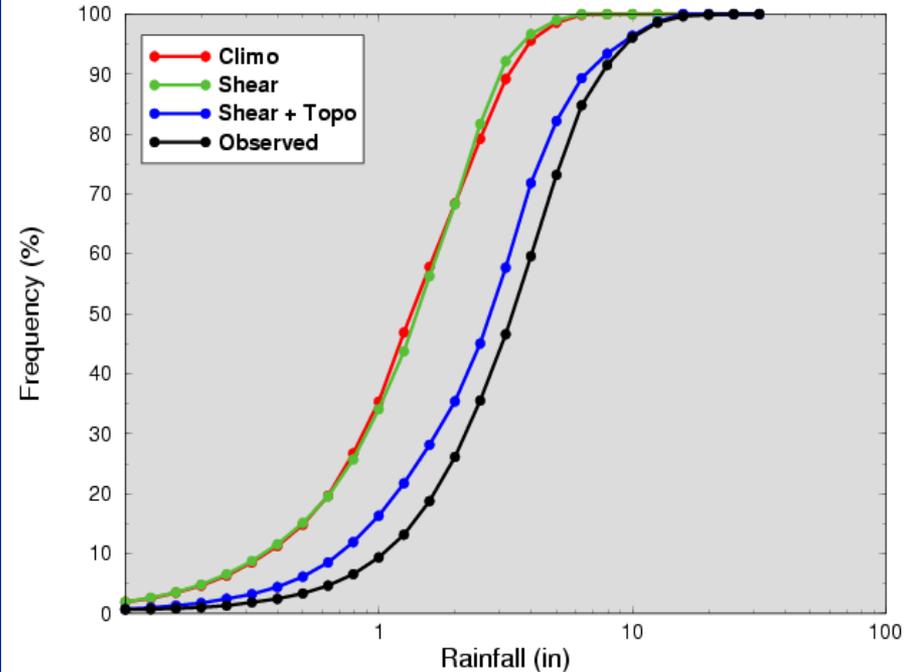
Equitable Threat Score

ETS Comparison, 2004 Atlantic storms
Using three versions of R-CLIPER



Rain flux CDF

Rain flux CDFs, 2004 Atlantic storms
Using 3 versions of R-CLIPER (600 km threshold)



Summary

- Developed QPF validation schemes specific for unique characteristics of TC rainfall.
- Developed TC QPF skill indices to allow for objective year-to-year comparisons of operational TC rainfall forecasts.
- Used the new techniques to provide TC QPF statistics for a baseline 1998-2004 sample as well as for the 2005 season.
- Developed a forecasting tool based on R-CLIPER that includes the effects of vertical shear and topography.

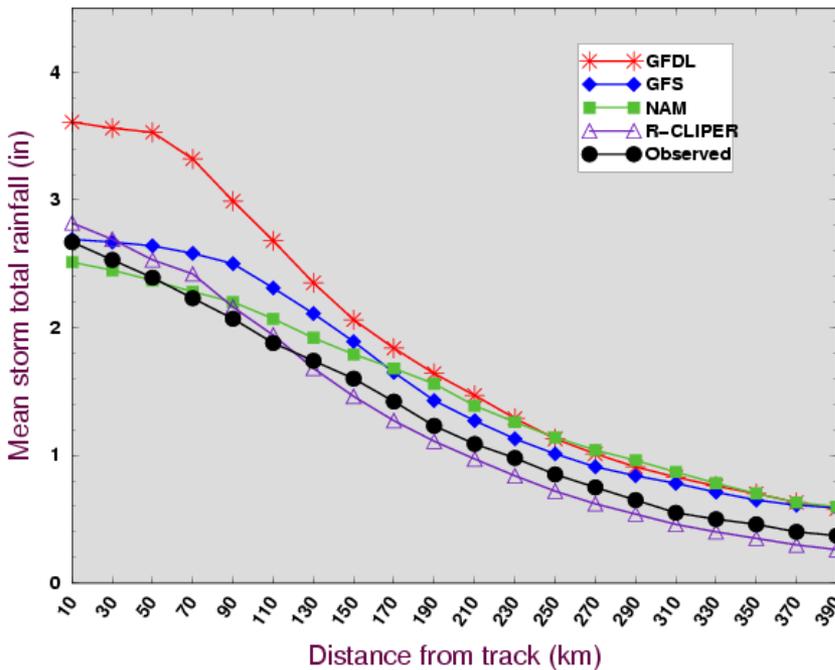
Additional work...

- Work with TPC to automate R-CLIPER forecasts and allow for transmission of forecast data via NWS AWIPS network.
- Implement "SHRAPPS" version with both shear & topography
- Streamline the TC QPF validation system to facilitate easier end-of-season TC rainfall verification.

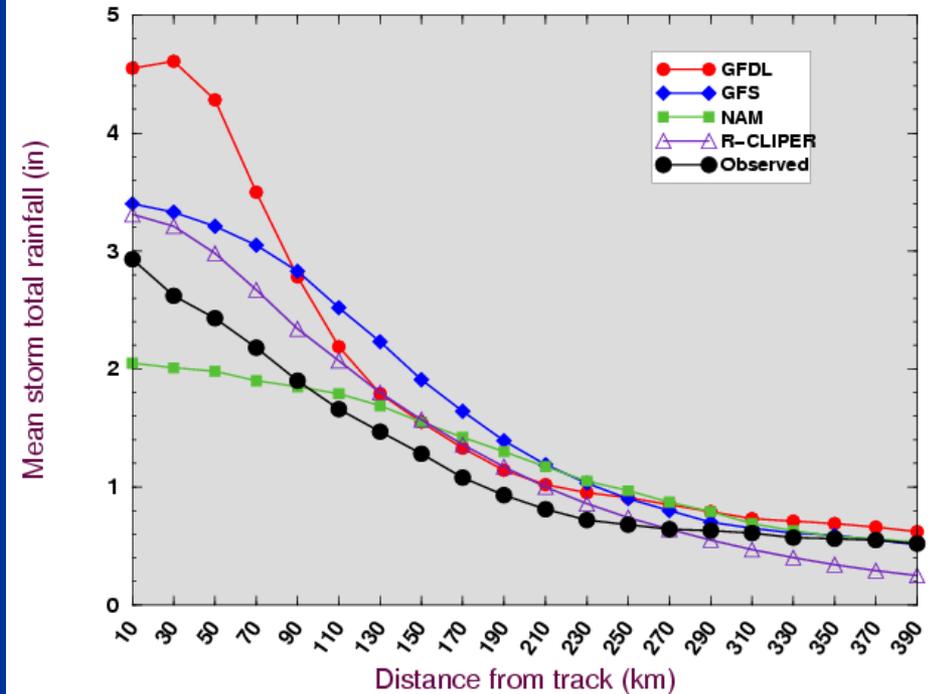
Extra slides.....

Rainfall volume

Mean Storm Total Rainfall Comparison
Landfalling Atlantic Storms, 1998–2004



Mean Storm Total Rainfall Comparison
Landfalling Atlantic Hurricanes, 2005

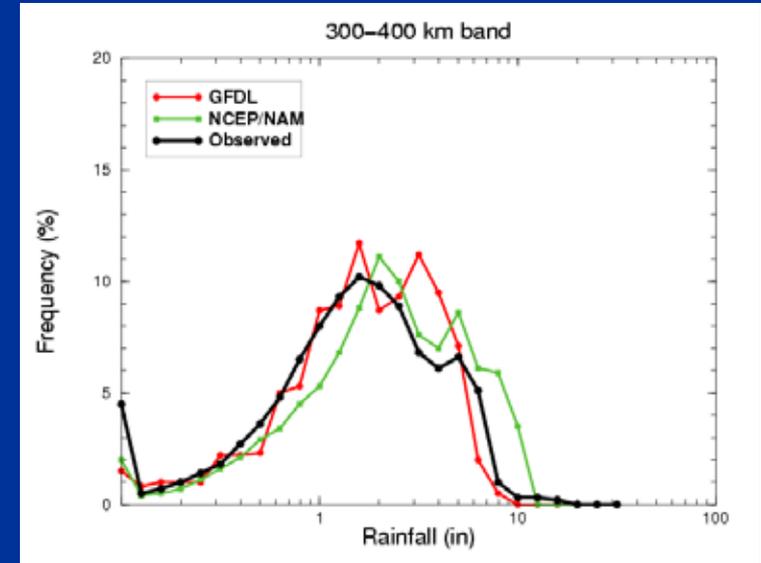
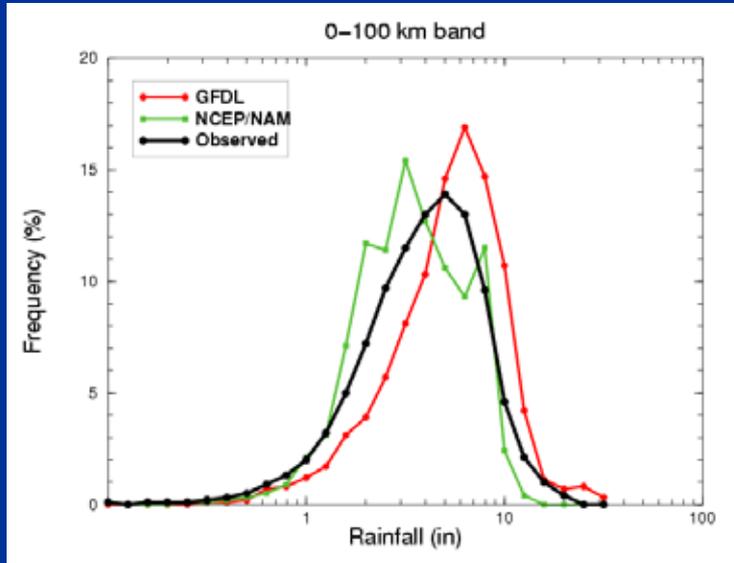


Rain volume: GFDL & NAM rain flux in select bands

0 – 100 km

300-400 km

1998 -
2004



2005

