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Rainfall Hazard from Tropical Cyclones

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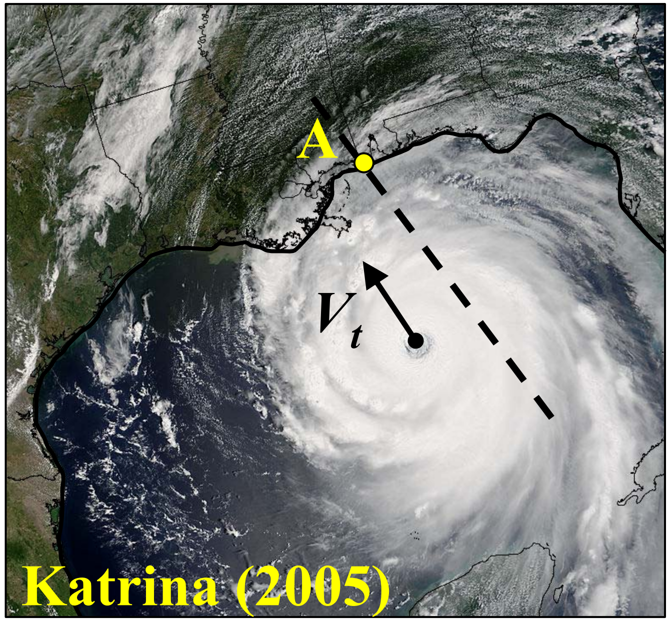
Objective

Long-term rainfall risk from TCs at a given location A:



$\lambda_D(i)$: rate at which **$I_{max}(D)$** exceeds i at location A (events/year)

$I_{max}(D)$: maximum rainfall intensity at location A for averaging duration D

Risk analysis ⇨

$$\lambda_D(i) = \lambda \int_{\text{all } \boldsymbol{\theta}} \overbrace{P[I_{max}(D) > i|\boldsymbol{\theta}]}^{\textit{focus}} \; \overbrace{P[\boldsymbol{\theta}]}^{\textit{local recurrence (literature)}} d\boldsymbol{\theta}$$

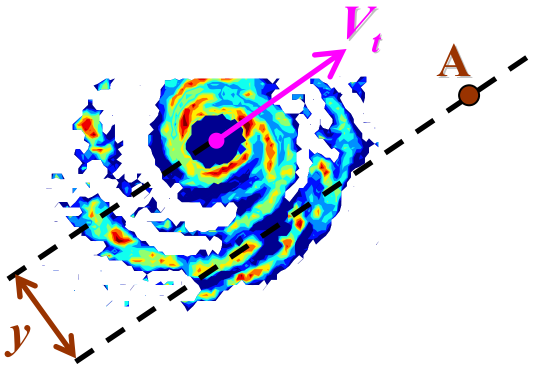
TC arrival rate [events/yr]

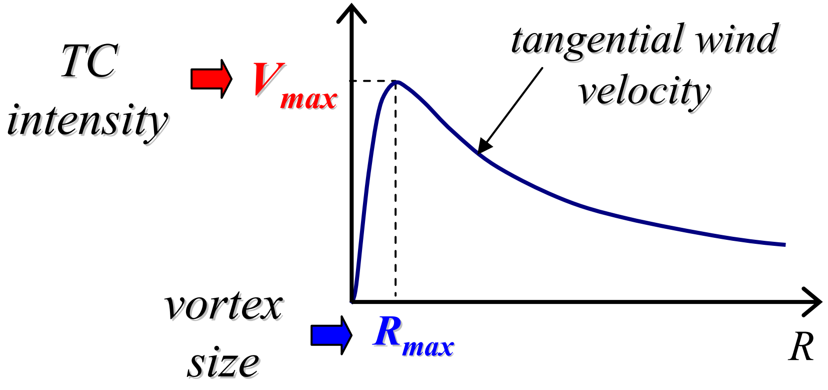
*probability that $I_{max}(D)$ exceeds **i** in a TC with characteristics* $\boldsymbol{\theta}$

probability density of TC ***characteristics θ***

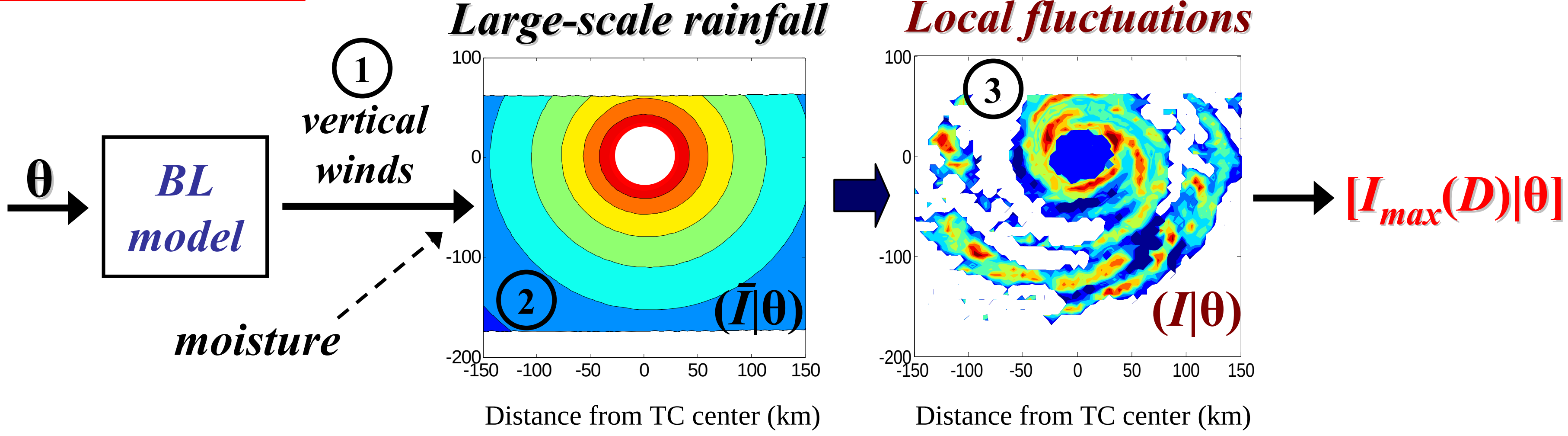
Approach to long-term risk modeling

- **parameters** $\theta = [V_{max}, R_{max}, V_t, y]^T$





$[I_{max}(D)|\theta]$

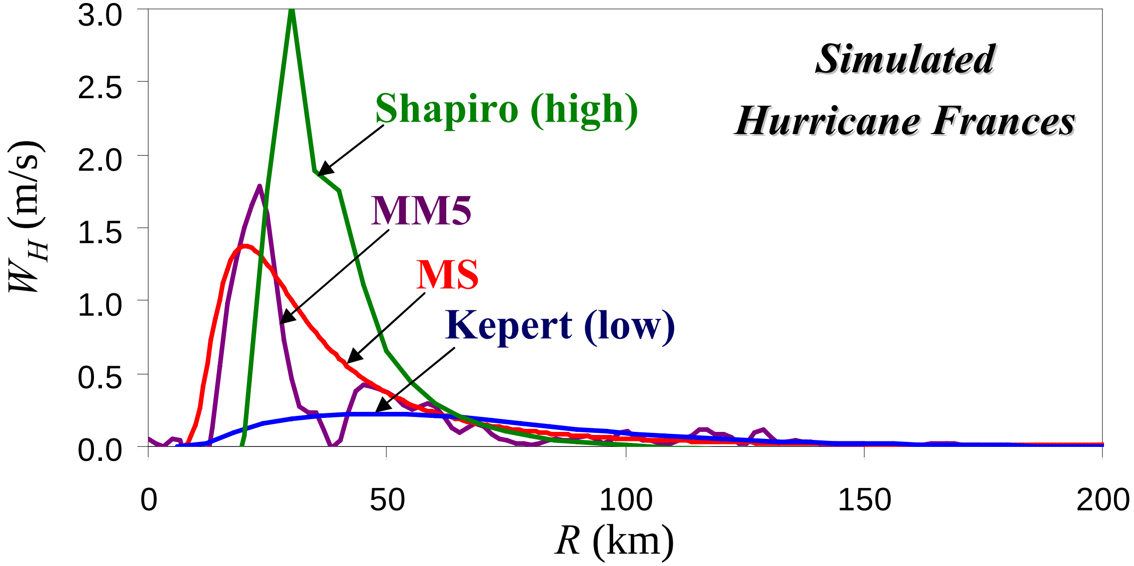


1. Vertical winds

Kepert (2001):

- ✓ *Analytical*
- ✗ *Linearized BL equations*
- ➢ ***It breaks close to the core…***

Vertical wind velocity at H=1km

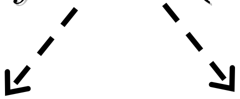


Shapiro (1983):

- ✗ *Slab layer of 1km*
- ➢ ***High vertical velocities…***
- ✗ ***Numerically unstable for $R>R_{max}$***

MS model (Langousis *et al.*, 2008):

✓ *Modification of* **Smith** (1968) BL model



include storm motion V_t

stress *surface boundary*

➢ ***Numerically stable and fast formulation***

2. Rain due to large-scale wind convergence

Assumption:

rainrate= *upward* ***water vapor flux*** *at the top of the boundary layer*

$$\bar{I} \propto W_H$$

large-scale rainfall intensity

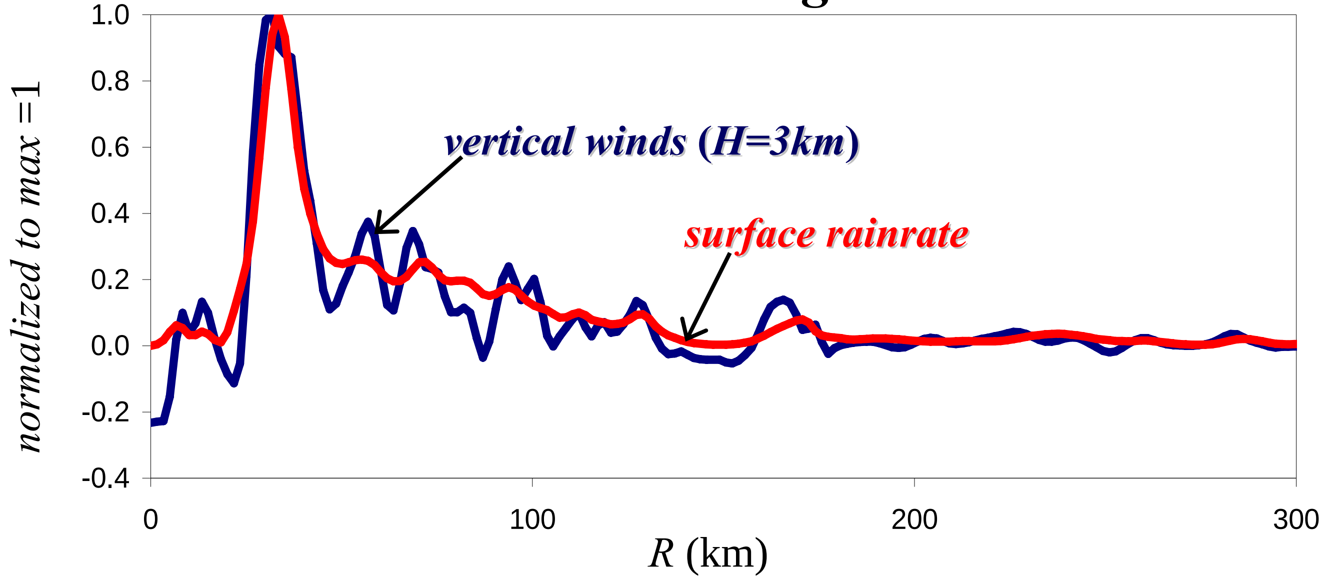
vertical wind velocity at H

const.= moisture content of air

MSR model

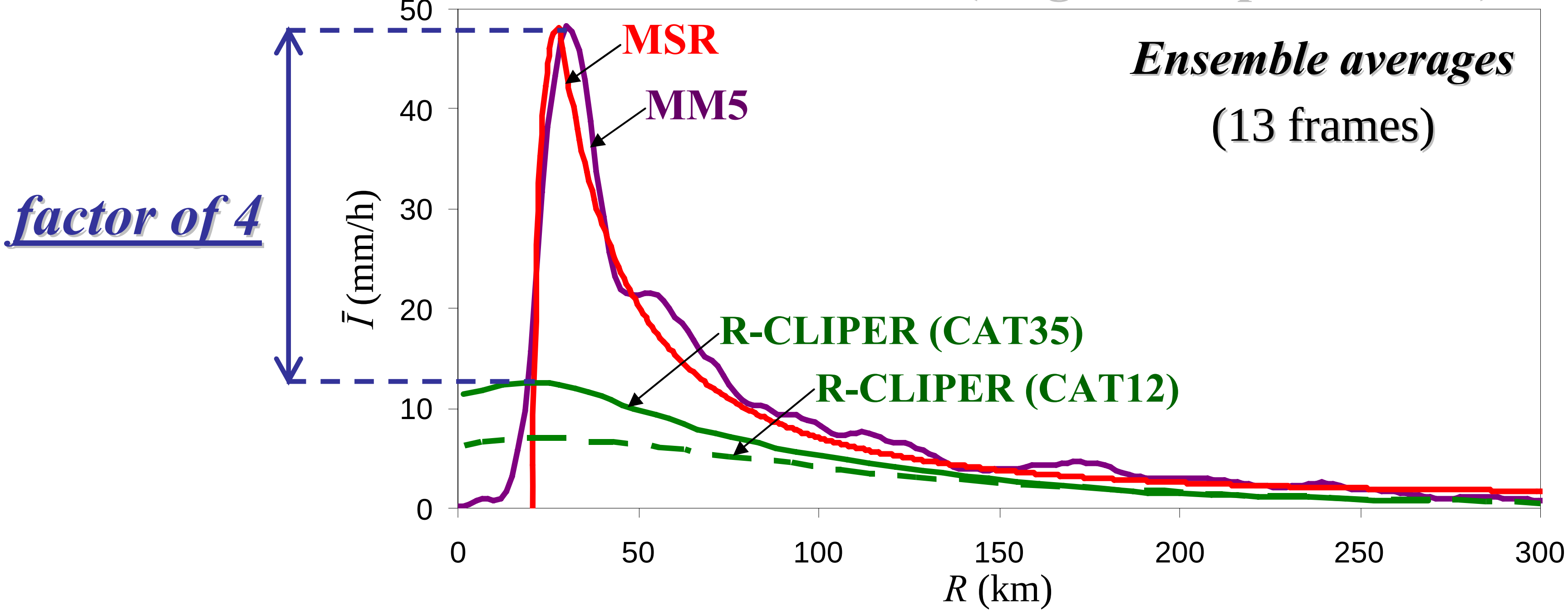
...use MS model to calculate W_H

Validation using MM5



Validation: (a) case study using MM5

***Hurricane Frances* (Aug. 29- Sep. 01, 2004)**

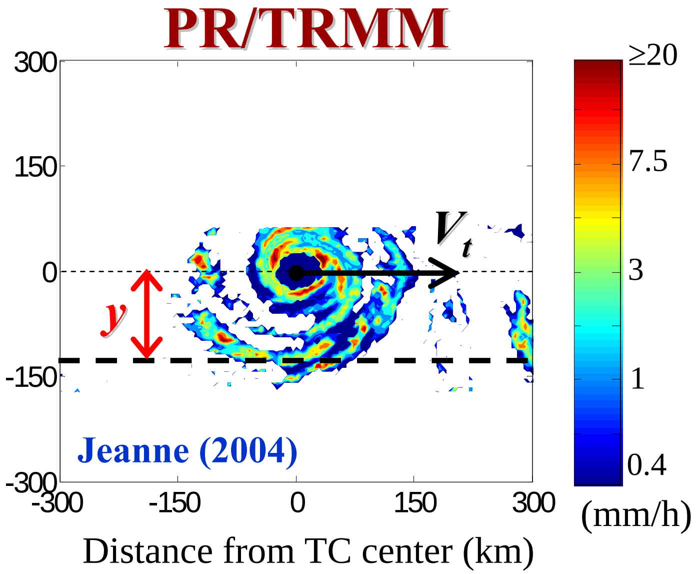


R-CLIPER

- ***TMI** data limitations* ⇨ **biases**
- ***averaging** over storms with considerably ≠ R_{max}*

⇨ ***smearing of high intensities close to the core***

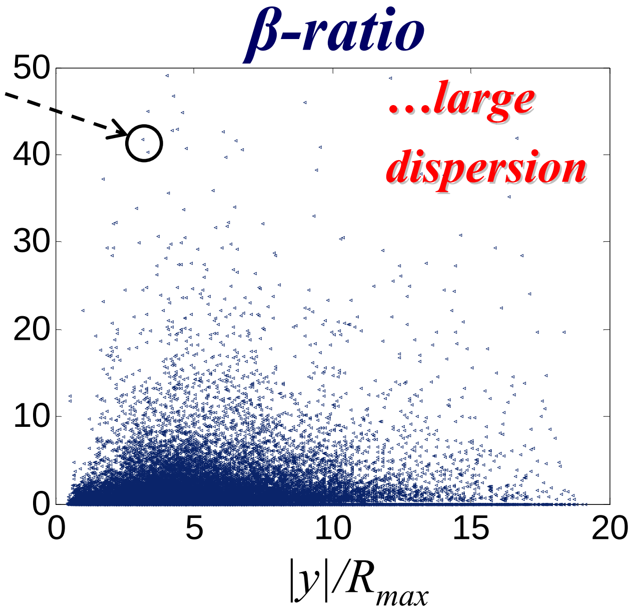
Validation: (b) using PR/TRMM data



$$\beta = \frac{\bar{I}_{PR}}{\bar{I}_{MSR}}$$

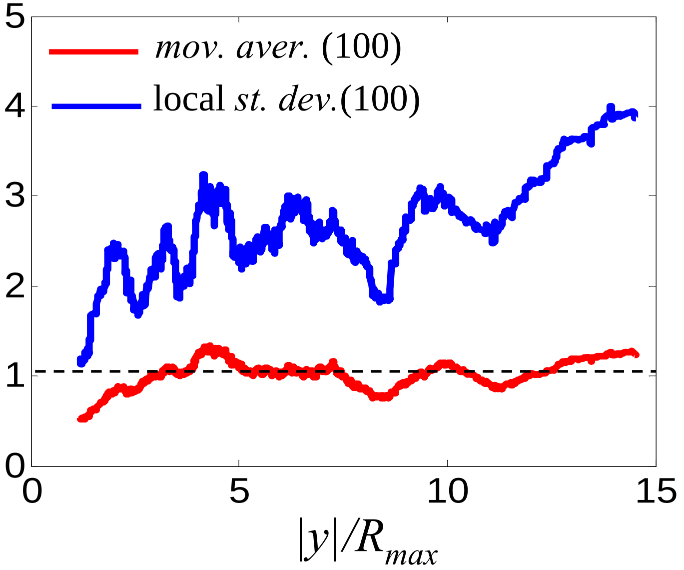
38 storms

48483 *points*



...*almost* ***unbiased***

estimation



Rainfall asymmetry due to motion

Rainfall asymmetry

$$A(R,\theta) = \frac{\bar{I}(R,\theta) - \bar{I}_s(R)}{\bar{I}_s(R)}$$

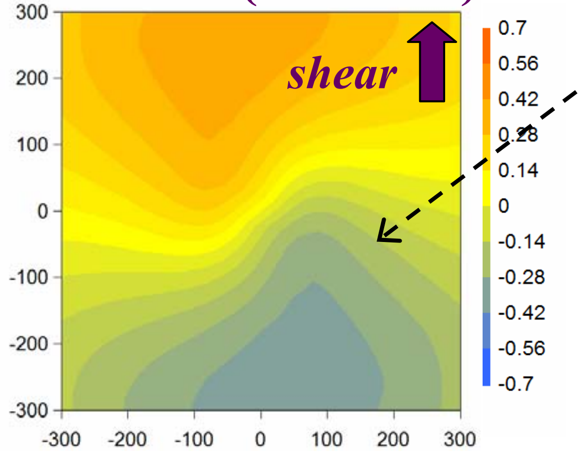
rainfall intensity at (R,θ)

azimuthal average

- ***Motion*** ⇨ ***MSR***
- ***Shear:*** *the difference between the 200 (≈10km) and 800-hPa (≈3km) wind velocities in the annular region between 200 and 800km from the TC center*

➢ *On average, **shear** points to the **right** of **motion**…* (≈ 75°)

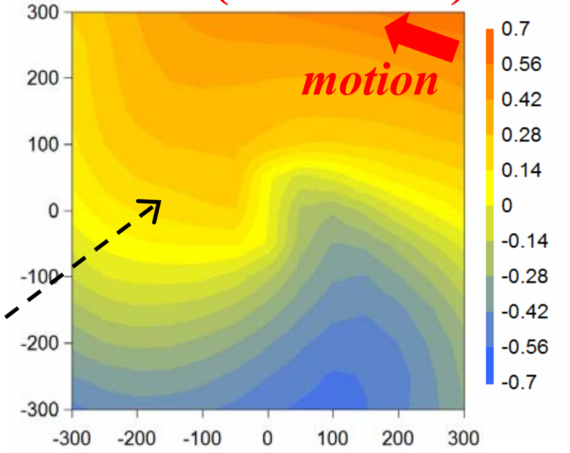
TRMM (observed)



Distance from TC center (km)

*Ensemble average over all TC **intensities** and **shear** magnitudes*

MSR (simulated)



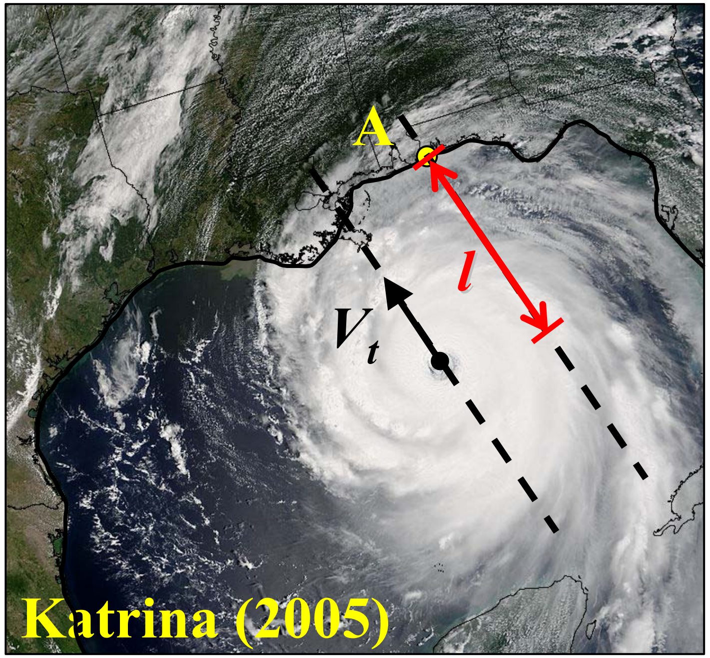
*Ensemble average over all TC **intensities** and **translation speeds***

Distance from TC center (km)

➢ ***A motion based parameterization of rainfall asymmetry suffices for risk analysis***

3. Statistical model for rainfall fluctuations

An observer-type approach:



Katrina (2005)

- ***Interested*** *in* $I_{max}(D)$*, the* ***maximum*** *rainfall* ***intensity at*** *location* ***A*** *for averaging duration* ***D***

…TRMM products are rainfall snapshots

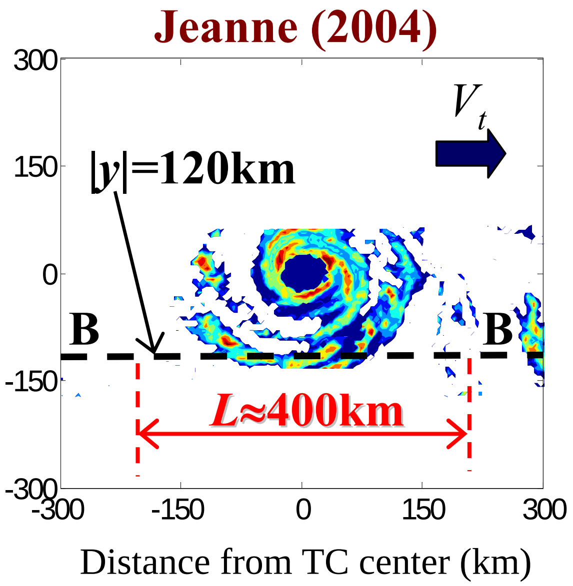
Frozen field assumption

$$I_{max}(D) = I_{max}(l)$$

maximum *spatially averaged rainfall* ***intensity*** *for a continuously sliding window of length* ***l***

$$l = DV_t$$

Statistical model for $I_{max}(l)$ given y



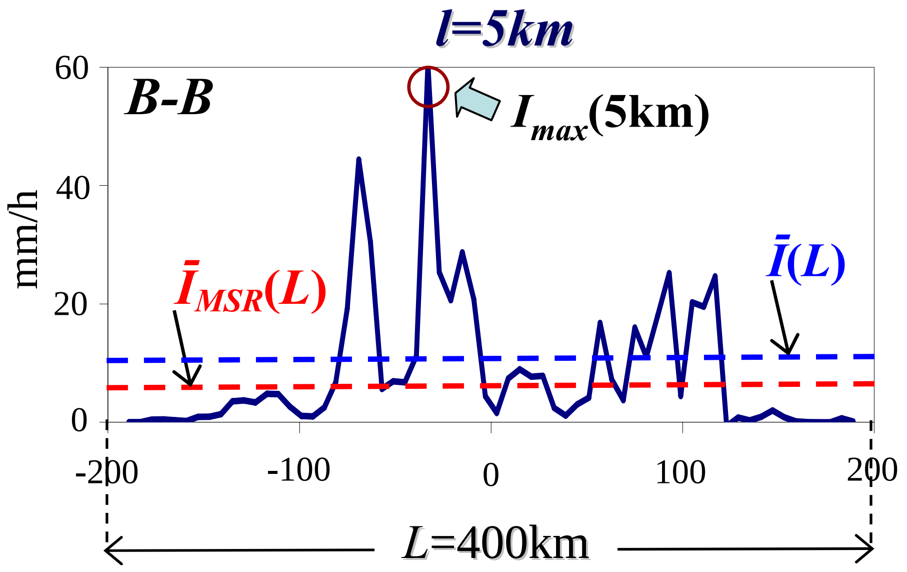
$$I_{max}(l) = \bar{I}_{MSR}(L)\ \varepsilon\ \gamma_{max}(l)$$

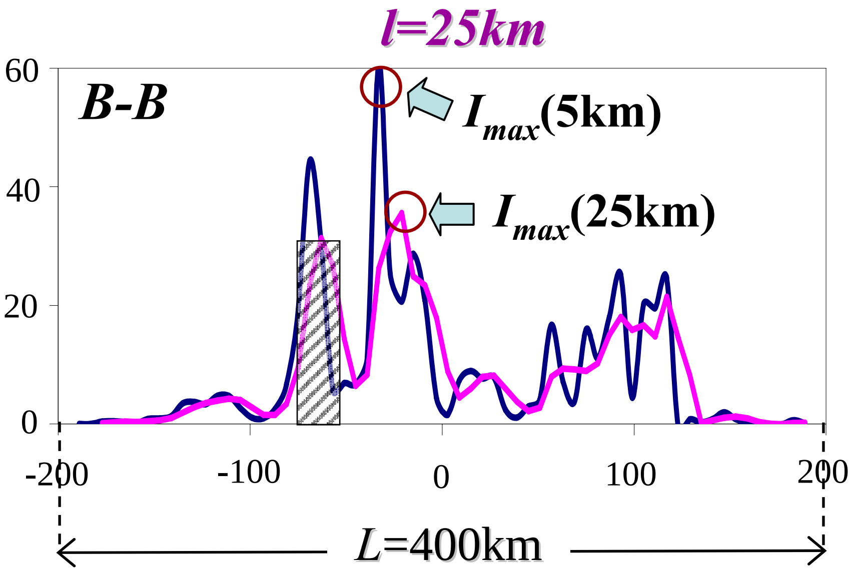
__MSR__ estimate for the mean __rainfall intensity__ inside __L__

corrects the __model__ mean relative to the __empirical__ mean

__amplification factor__ for the maximum inside l

- *rainband fluctuations*
- *model biases*





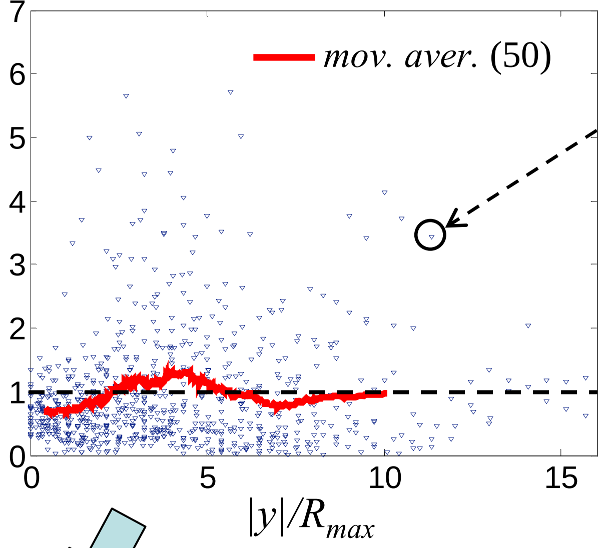
Statistical model for ε given *y*

...almost

unbiased

estimation

38 storms ⇨ 789 cross-sections



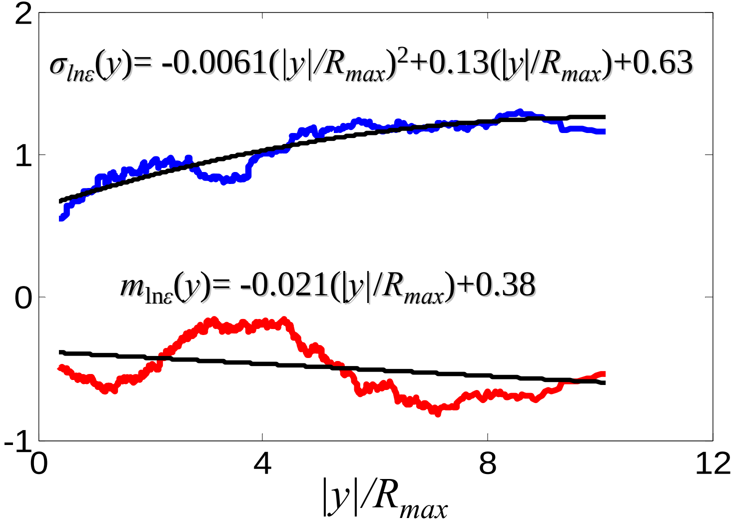
$$\varepsilon = \frac{\bar{I}(L)}{\bar{I}_{MSR}(L)}$$

empirical *rainfall mean inside interval L*

MSR *rainfall estimate*

...ε ~ lognormal

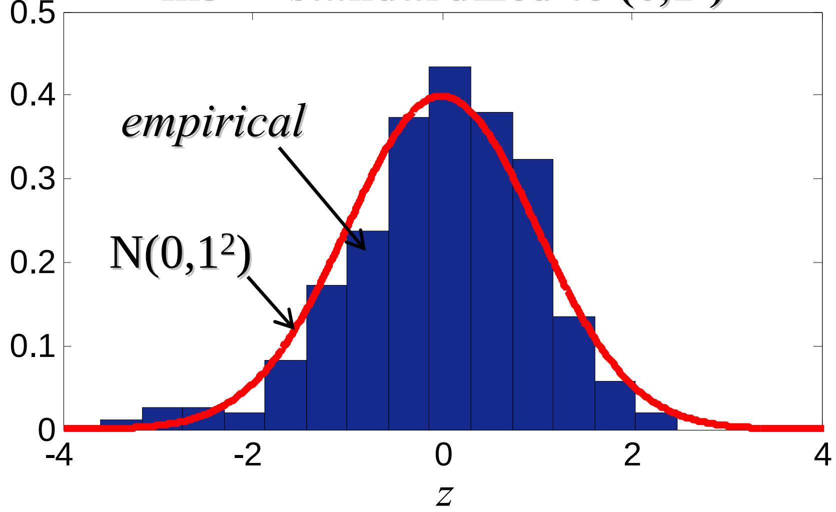
Statistics of lnε



$\sigma_{\ln\varepsilon}(y)$= -0.0061($|y|/R_{max}$)^2+0.13($|y|/R_{max}$)+0.63

$m_{\ln\varepsilon}(y)$= -0.021($|y|/R_{max}$)+0.38

lnε ⇨ standardized to (0,1²)



Two statistical models for $\gamma_{max}(l)$ given y

➢ Maxima approach :

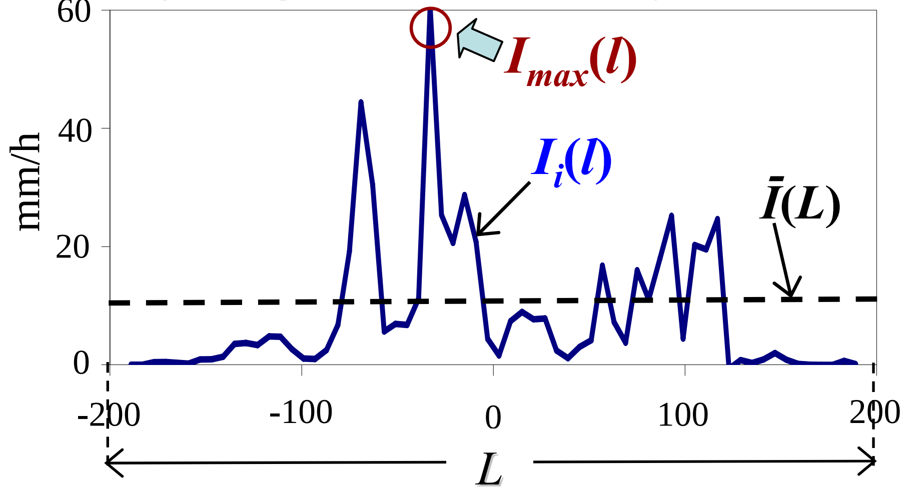
M1

$$\gamma_{max}(l) = \frac{I_{max}(l)}{\bar{I}(L)}$$

maximum *rainfall* ***intensity*** *inside a continuously sliding window of length l*

empirical *mean inside L*

…for a generic scale l and y-location



➢ Marginal approach:

M2

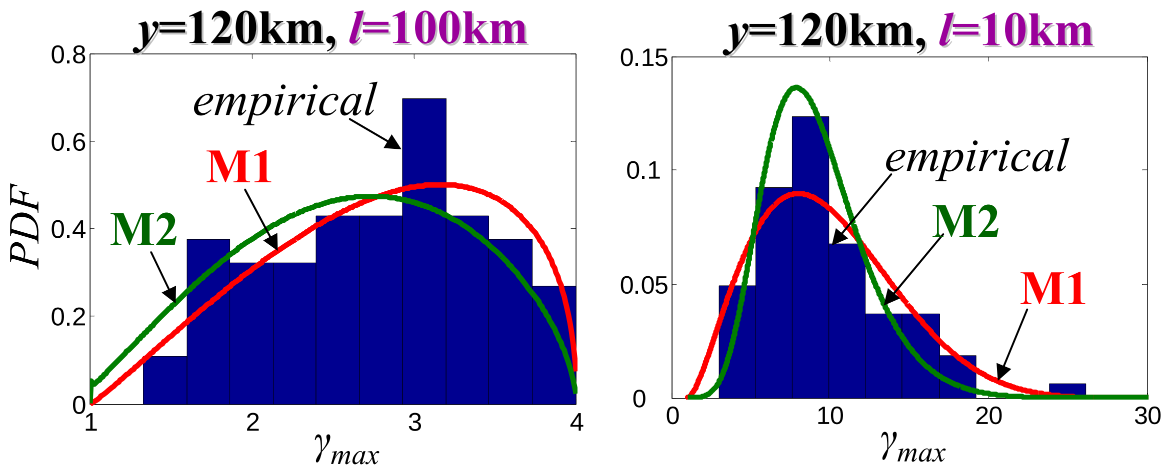
$$\gamma_i(l) = \frac{I_i(l)}{\bar{I}(L)}$$

random variable *with unit mean*

average *rainfall* ***intensity*** *inside l*

⇨ $\gamma_{max} = max\{\gamma_1, \ldots, \gamma_{L/l}\}$

γ_{max}, γ_i ~ scaled beta dist.

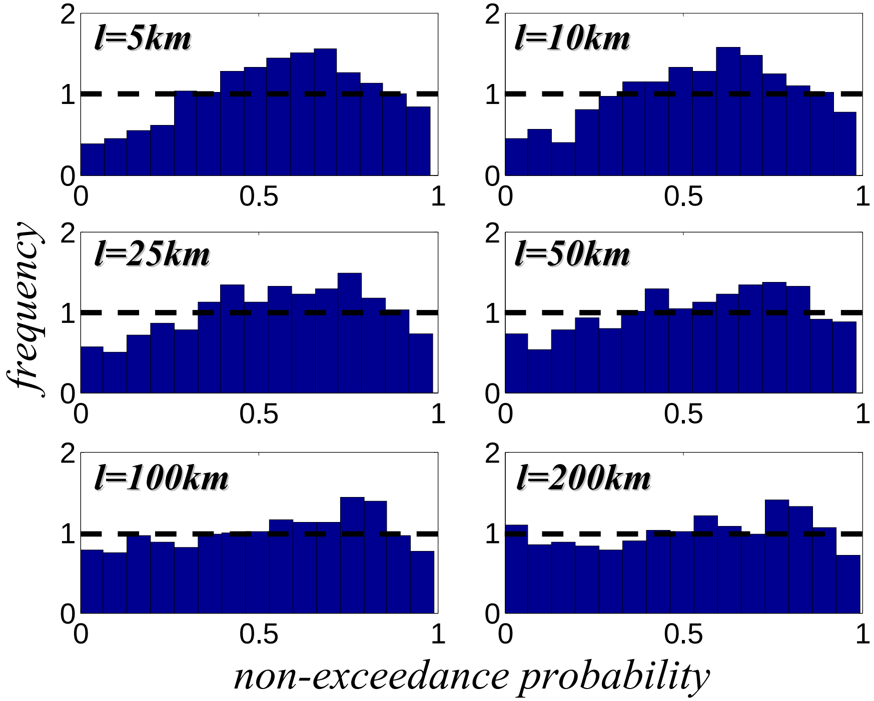


…overall evaluation

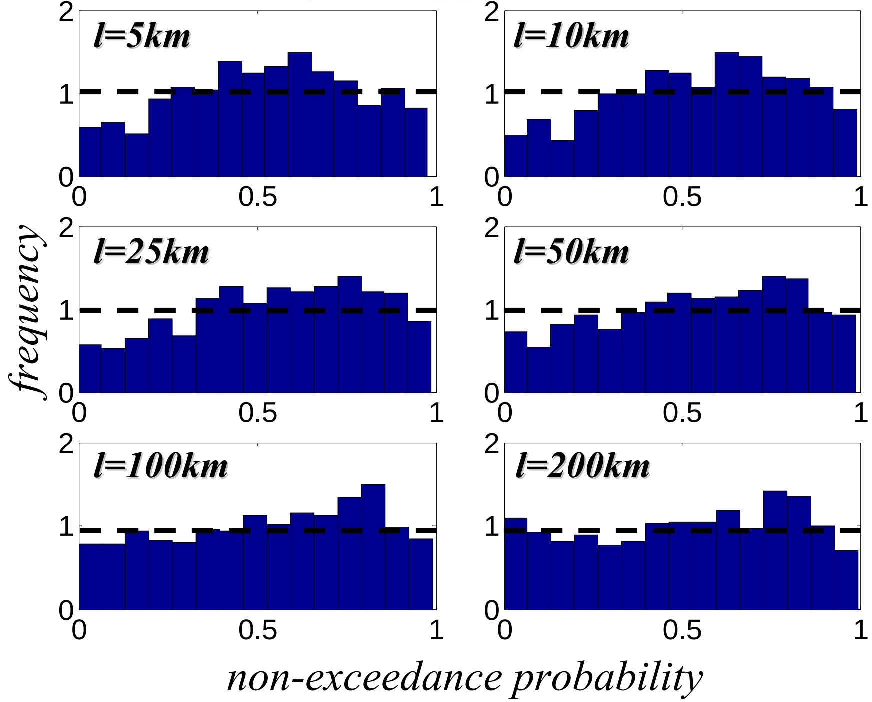
- *For each spatial scale **l** and distance **y**, use the **model*** ⇨ $\boxed{I_{max}(l) = \bar{I}_{MSR}\,\varepsilon\,\gamma_{max}(l)}$

*to calculate the **theoretical** non-exceedance **probability** of the **empirical maxima**.*

Maxima approach (M1)



Marginal approach (M2)



Shape close to uniform ➡ *good **agreement** between **empirical** and **theoretical** maxima **at all scales l***

Conclusions

➢ *We developed a statistical **framework** to calculate **peak rainfall intensities** from TCs:*

$[I_{max}(D)|\boldsymbol{\theta}]$

- *Explicit parameterization of the hurricane:* $\boldsymbol{\theta}=[V_{max}, R_{max}, V_t, y]^T$
- *Physical model to obtain **large-scale rainfall** given* $\boldsymbol{\theta}$
  (*inter*-storm variability)
- *Scale dependent statistical model for **rainfall fluctuations***
  (*intra*-storm variability)

❖ *We showed that for **risk analysis** it suffices to parameterize **rainfall asymmetry** in terms of **motion** ⇨ TC tracks readily available*

⇨ *We **validated** the model using **MM5** and **PR** rainfall data from TRMM*

Future work

- *effect of topography during landfall*
- *areal reduction*

Thanks!