Convective Organization in the Atlantic ITCZ
Underlying dynamics and Response to Aerosol Perturbations

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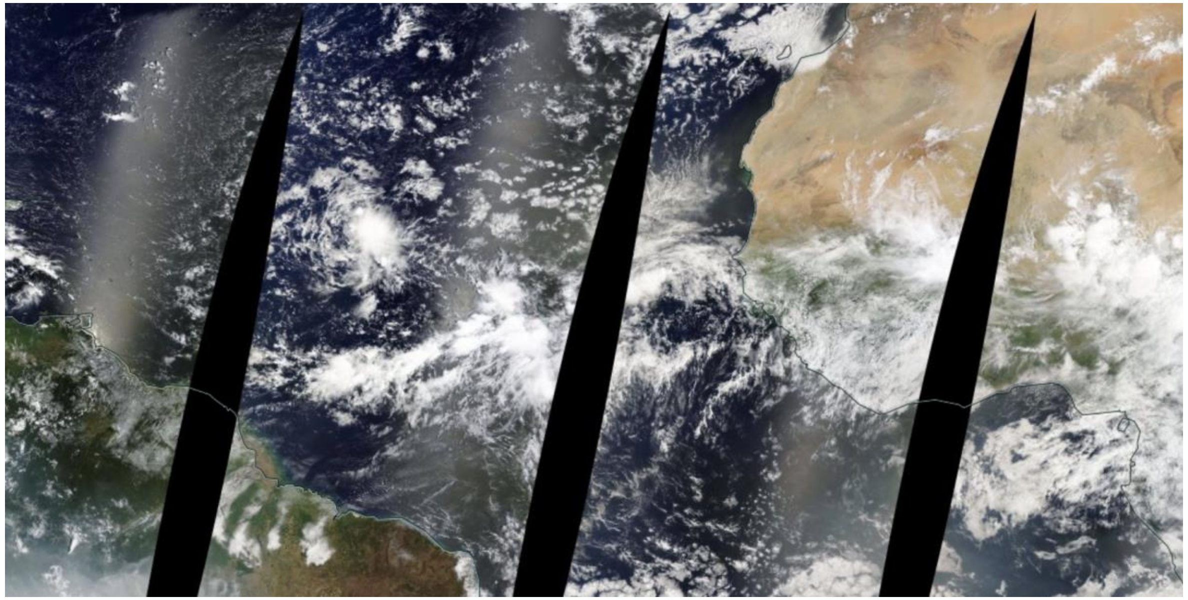
Motivation

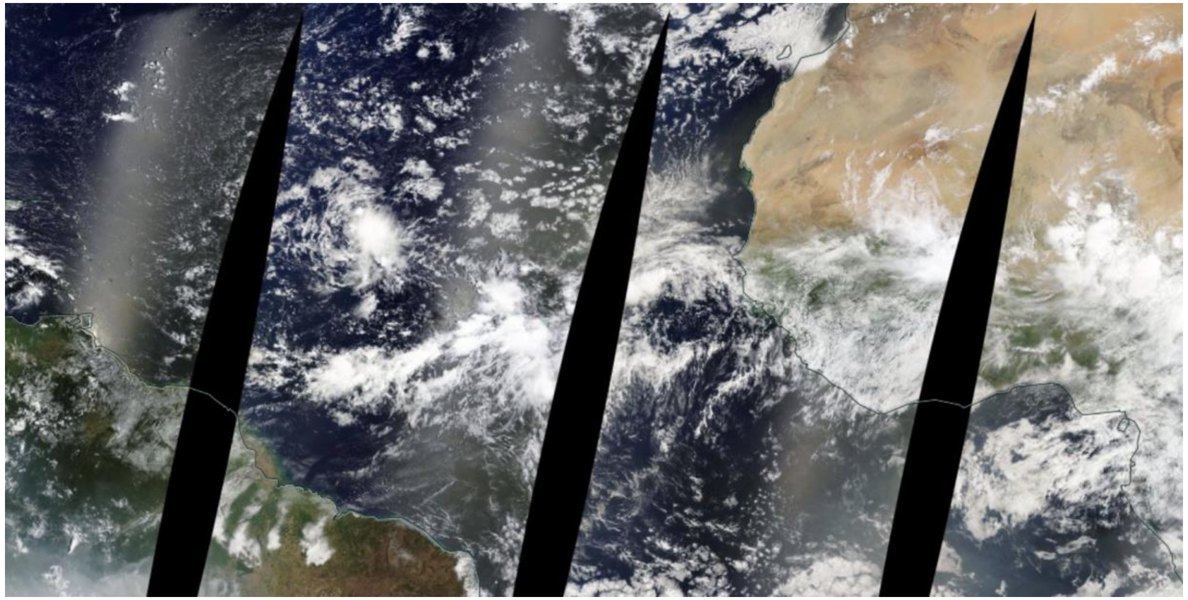
- Organized structures of tropical convection span a wide range of spatial scales



Courtesy: NASA Worldview

Motivation

- Organized structures of tropical convection span a wide range of spatial scales
- Convective organization indices quantify organization by single numbers
- **But patterns are scale-dependent**
  -- scale-dependent metrics essential to quantify patterns across multiple scales in a large regional or global scene
- Organized convective structures have a significant radiative effect
  -- great uncertainty in our understanding of the ***chain of processes leading to up to this***



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Key questions

- ***What do km-scale organization patterns of tropical deep convection quantitatively look like?***
- ***How do aerosol perturbations influence such organized convection?***

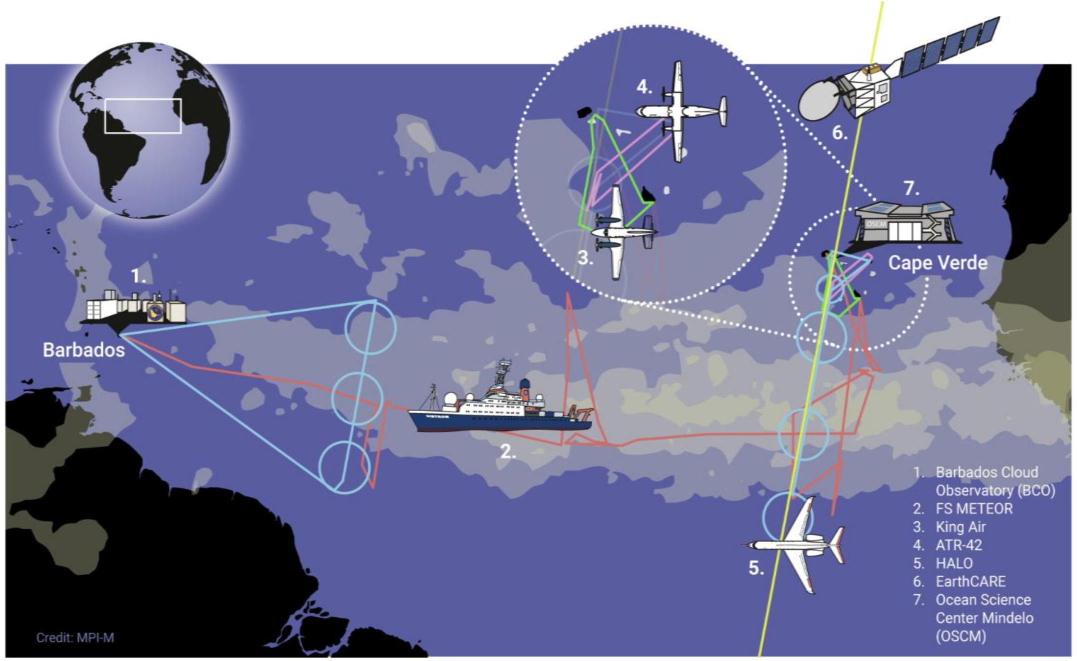
ICON + HAM-lite

- ICOsahedral Nonhydrostatic model (ICON) *[Segura et. al., GMD (2025)]* coupled with interactive aerosol module HAM-lite *[Weiss et. al., GMD (2025)]*
- Configured with two-moment cloud microphysics scheme *[Seifert and Beheng, Meteor. Atmos. Phys. (2006)]*

- Limited-area, land-atmosphere coupled simulations at 5 km horizontal resolution; prescribed SST from ERA5

- Free running simulations initialized on 10/08/2024, ***set up to align with ECOMIP***

- Initial and lateral boundary conditions from ERA5 and CAMS reanalysis



https://orcestra-campaign.org/intro.html

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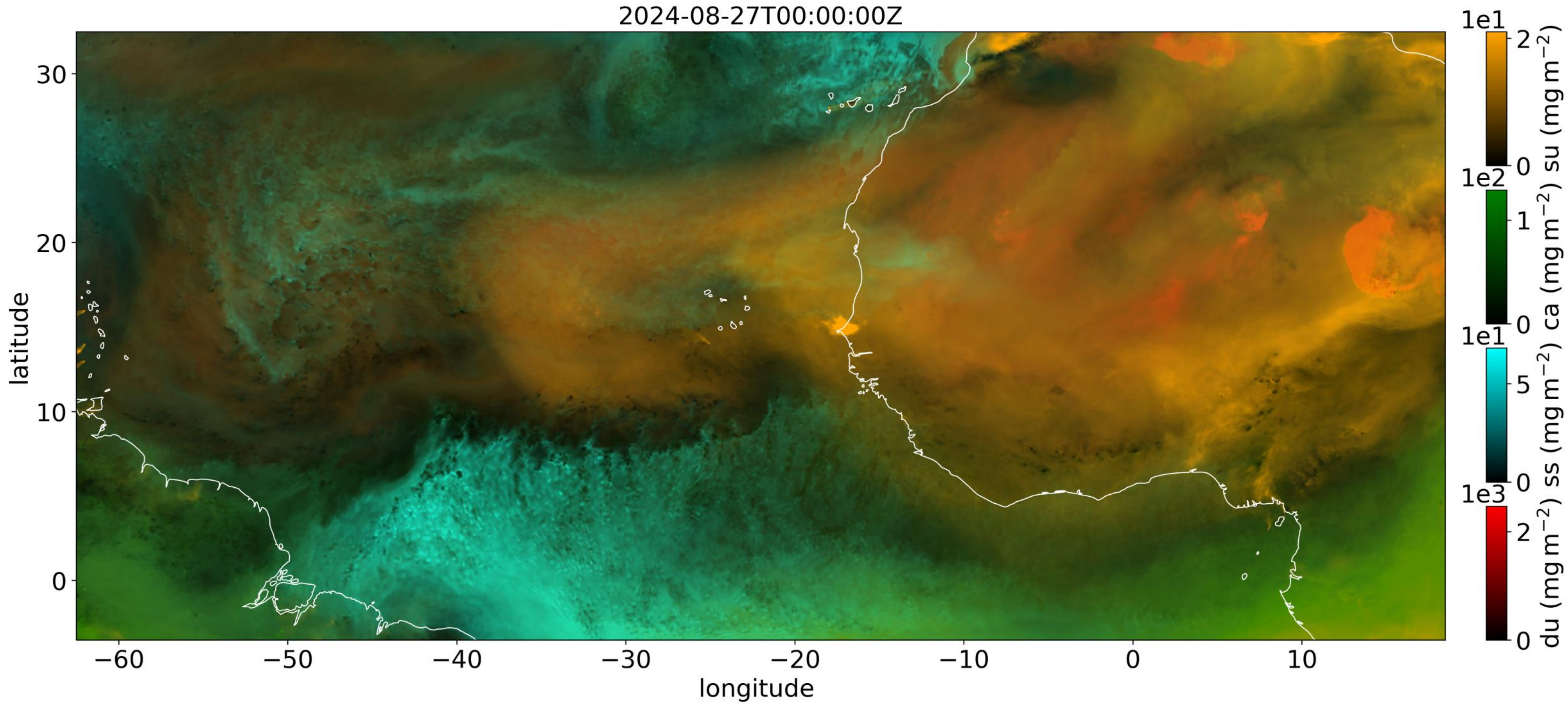
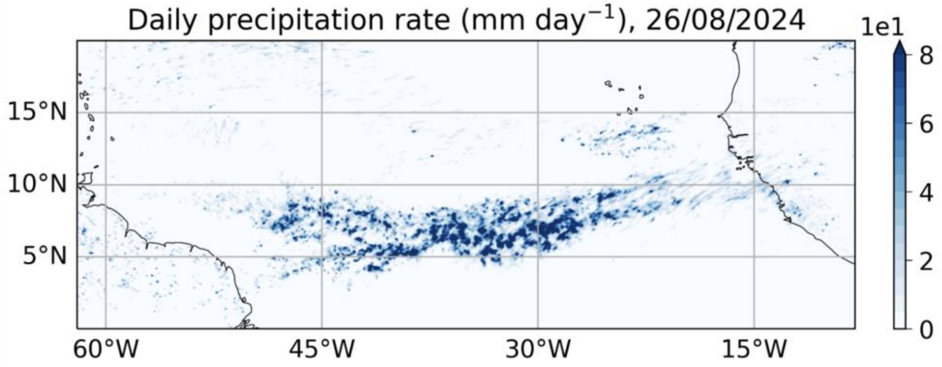


Extreme precipitation patterns



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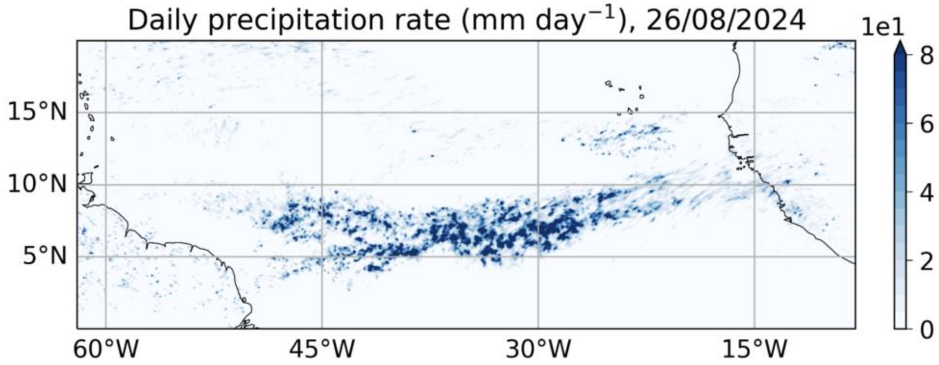
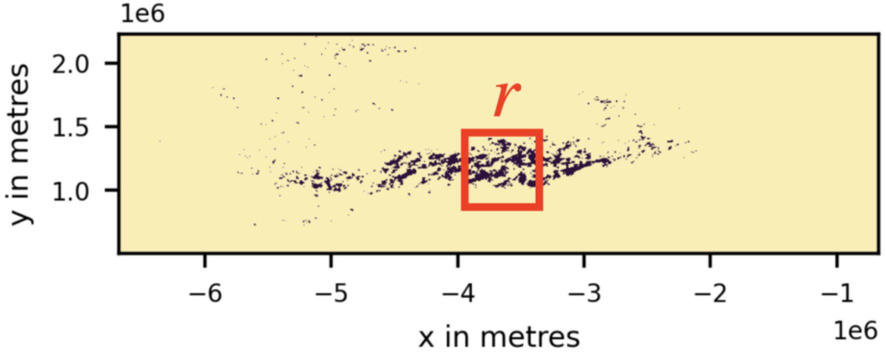


99th percentile
threshold



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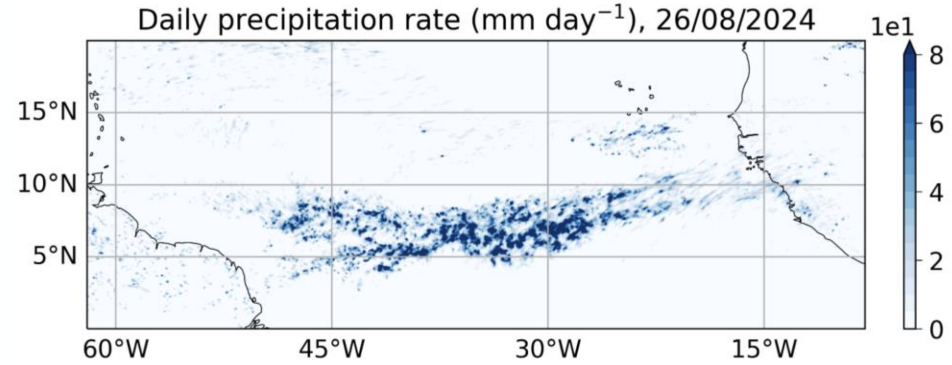

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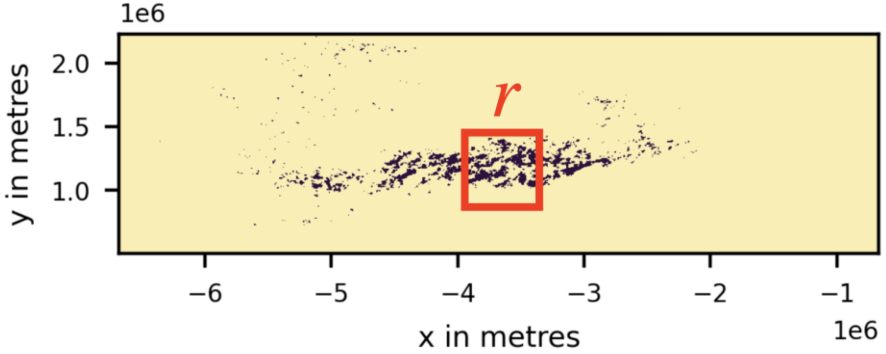

$N(\mathbf{x}, r) \rightarrow$ Number of extreme precipitation events in a square box of size r^2 centred on an event at x

$N(\mathbf{x}, r) \sim r^{D_{pr}(\mathbf{x})}$ $\mathbf{D_{pr}}$ --> Fractal dimension of set on which events are distributed

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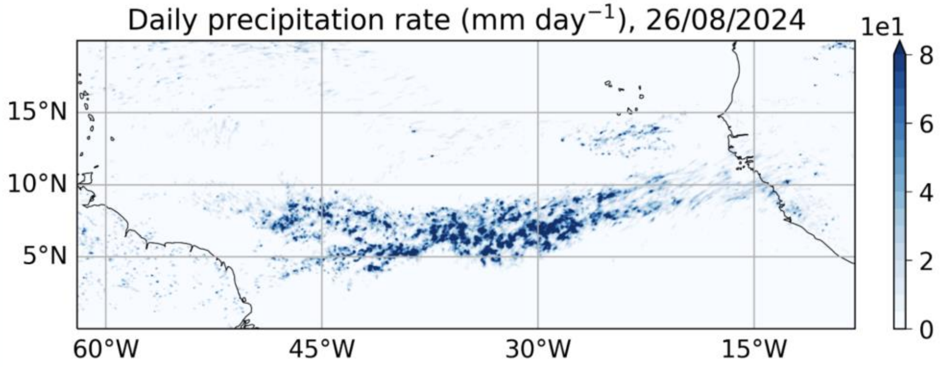

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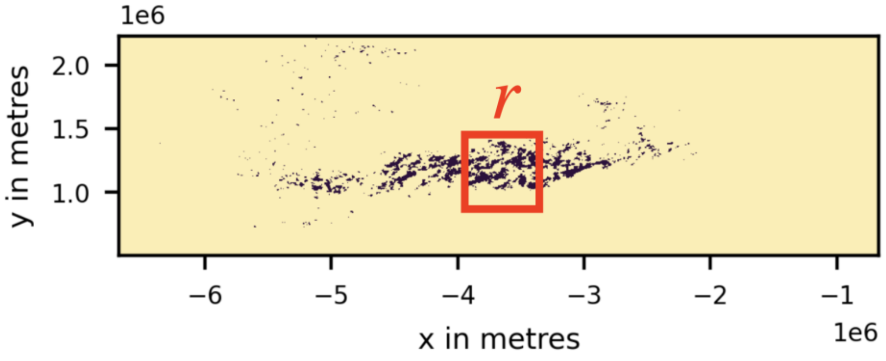

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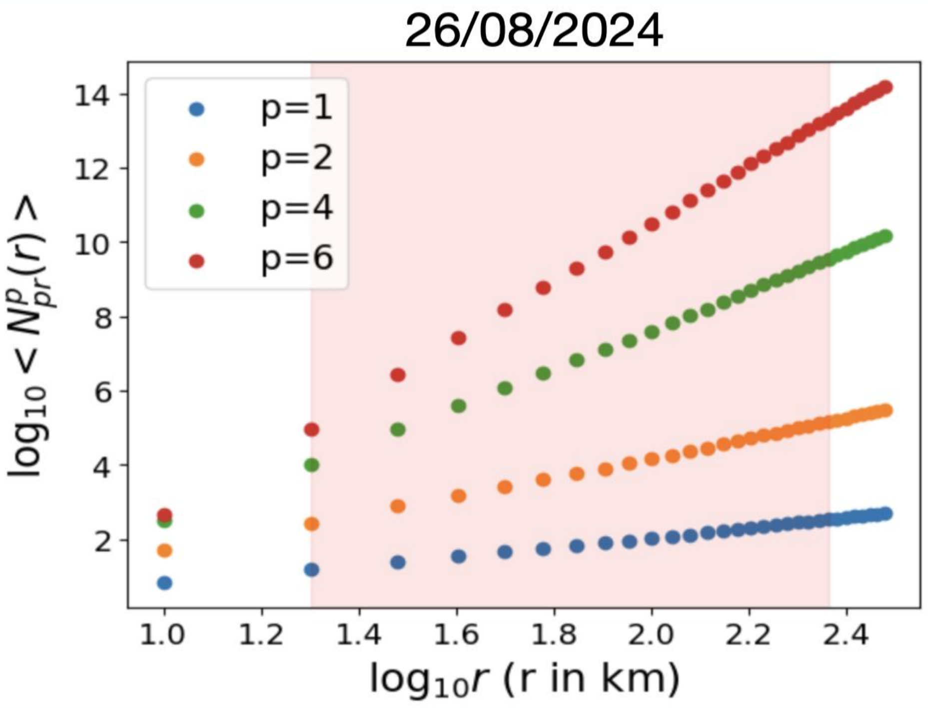
$N(\mathbf{x}, r) \sim r^{D_{pr}(\mathbf{x})}$ **D_{pr}** --> Fractal dimension of set on which events are distributed

If distribution is monofractal, $\langle N^p(r) \rangle \sim \int r^{pD_{pr}(\mathbf{x})} \mathscr{P}(\mathbf{x}) d\mathbf{x} \sim r^{pD_{pr}}$

Extreme precipitation patterns



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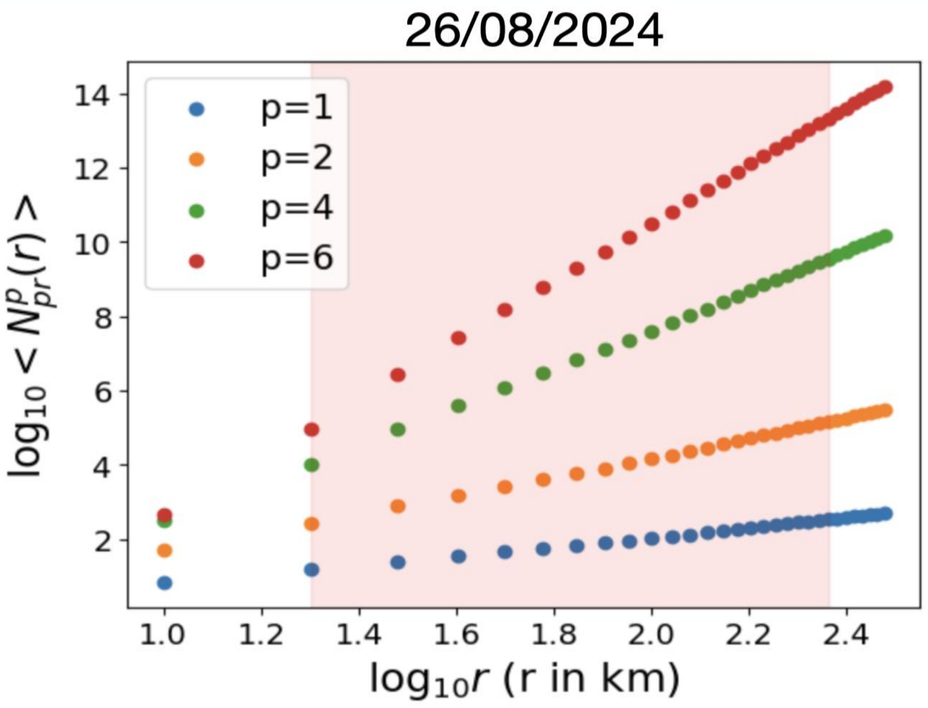

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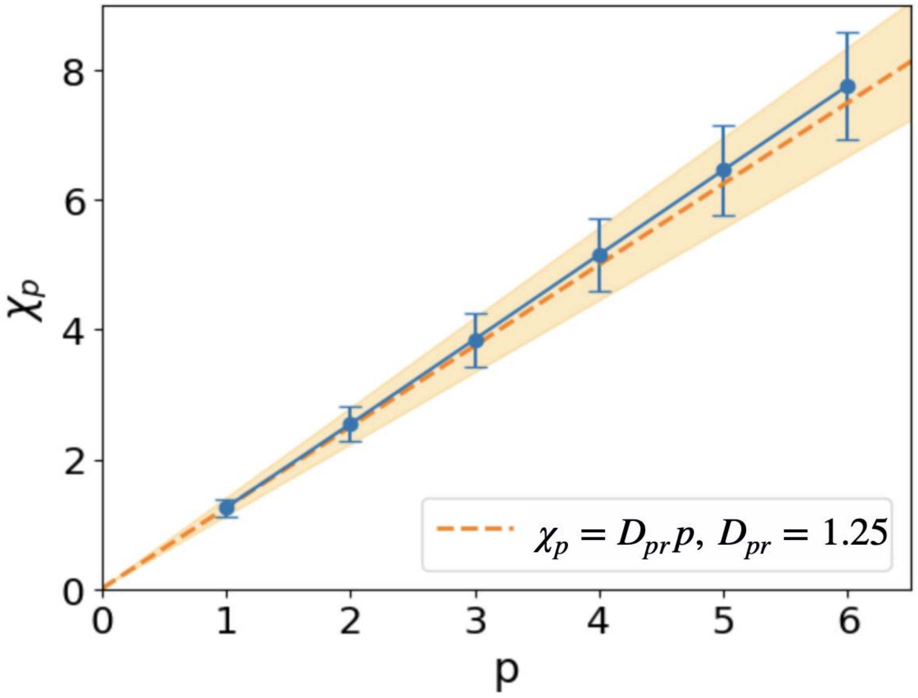

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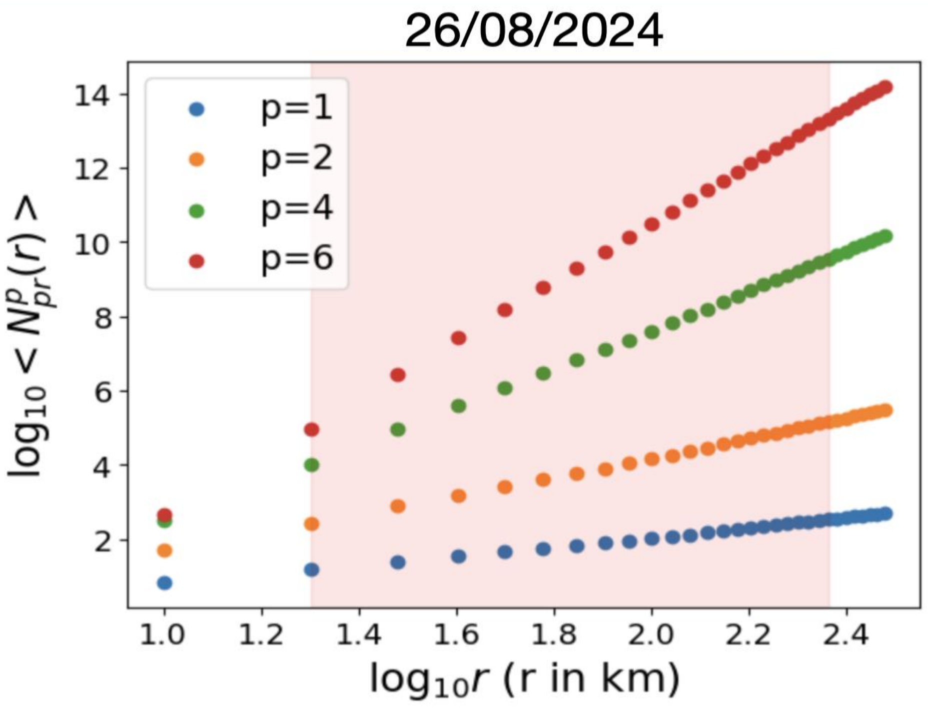

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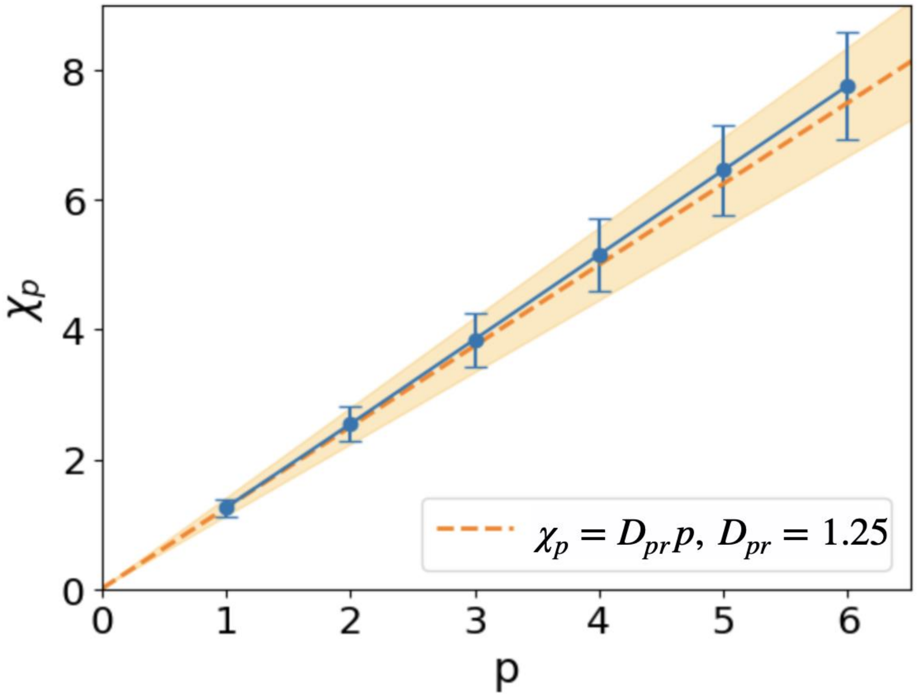

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We are thus able to quantify extreme precipitation patterns at mesoscales ranging from 20 to 200 km

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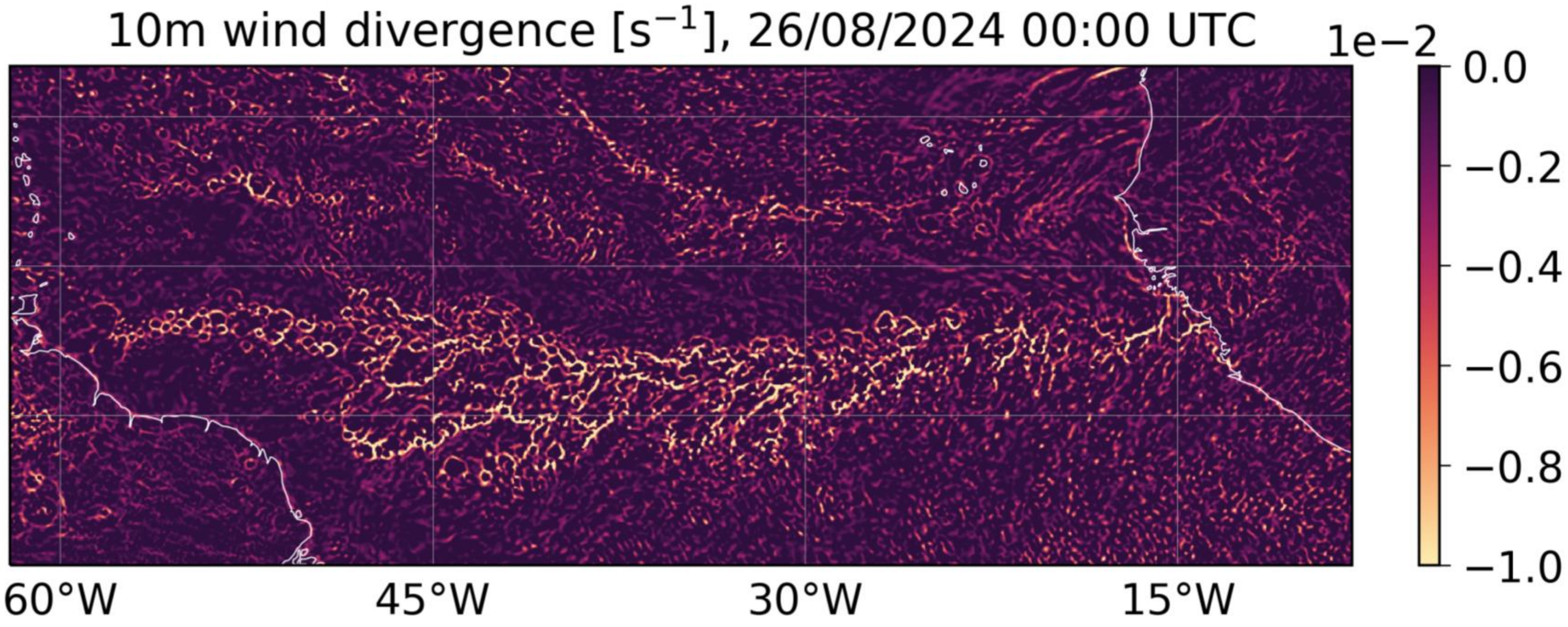

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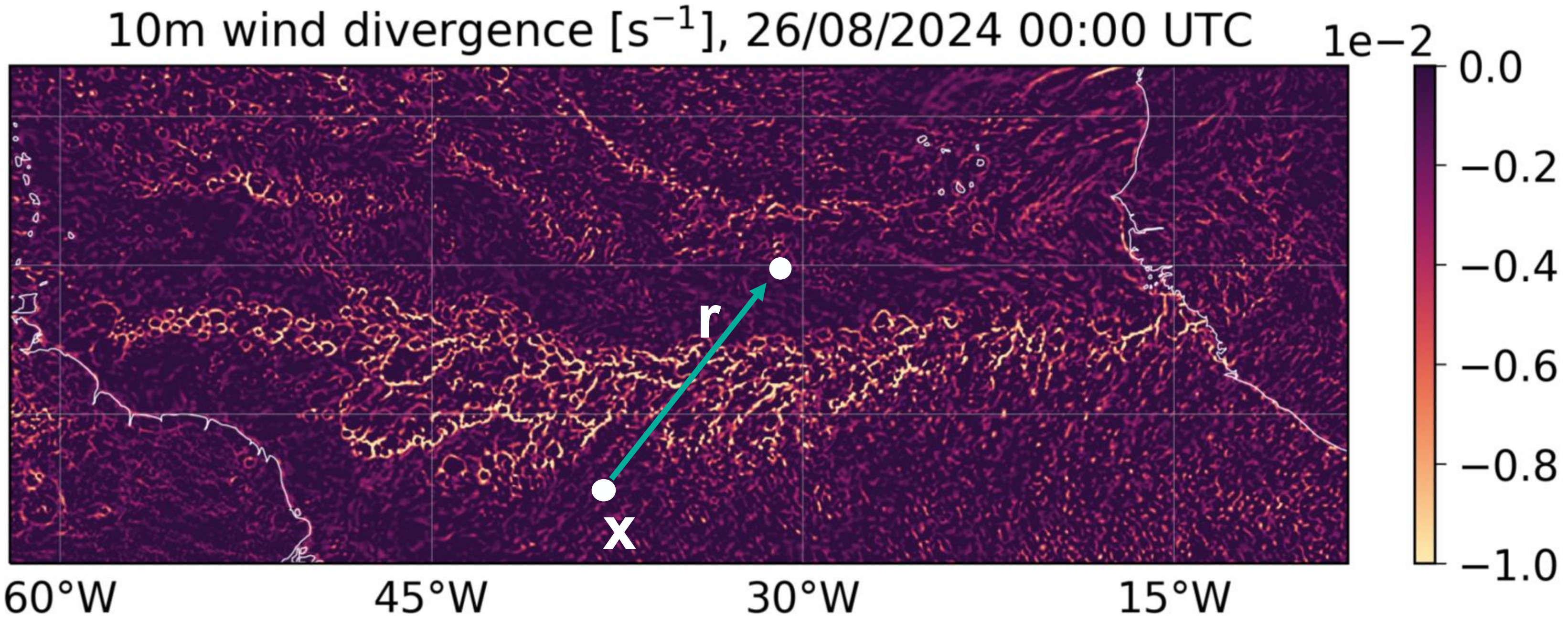

Evaluate surface wind velocity structure functions:

$$S_p^-(r) = \left\langle \delta u^p(r) \Big|_{\delta u<0} \right\rangle$$

$$\delta u(\mathbf{x}, r) = [\mathbf{u}(\mathbf{x}+\mathbf{r}) - \mathbf{u}(\mathbf{x})] \cdot \hat{\mathbf{r}}$$

Underlying dynamics

A heuristic conjecture:

In fully-developed turbulence, $\delta u(\mathbf{x}, r) \sim (r/L)^{h(\mathbf{x})}$ $h > 0$

greater the value of h,
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$$S_p(r) \sim \int_h \delta u^p(h, r)\mathscr{P}_r(h)dh \sim \int_h (r/L)^{ph+d-D(h)}dh$$

$$\mathscr{P}_r(\mathbf{x}) \sim (r/L)^{d-D(h)}$$

d—> embedding dimension

For r << L, $S_p(r) \sim r^{\zeta_p}, \quad \zeta_p = \min_h[ph + d - D(h)]$

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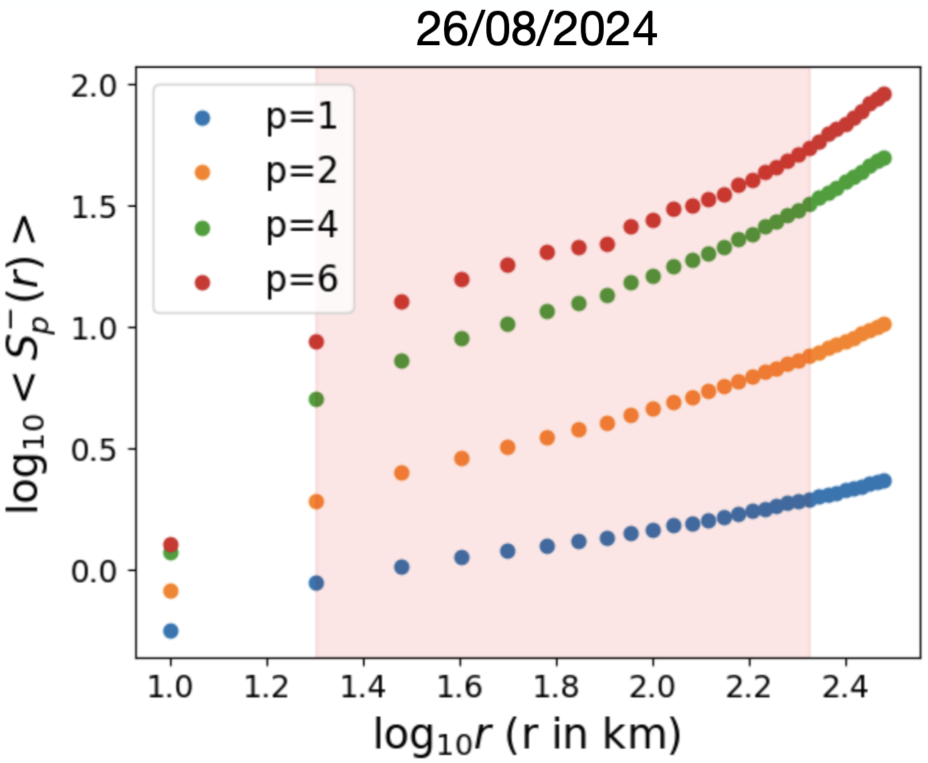
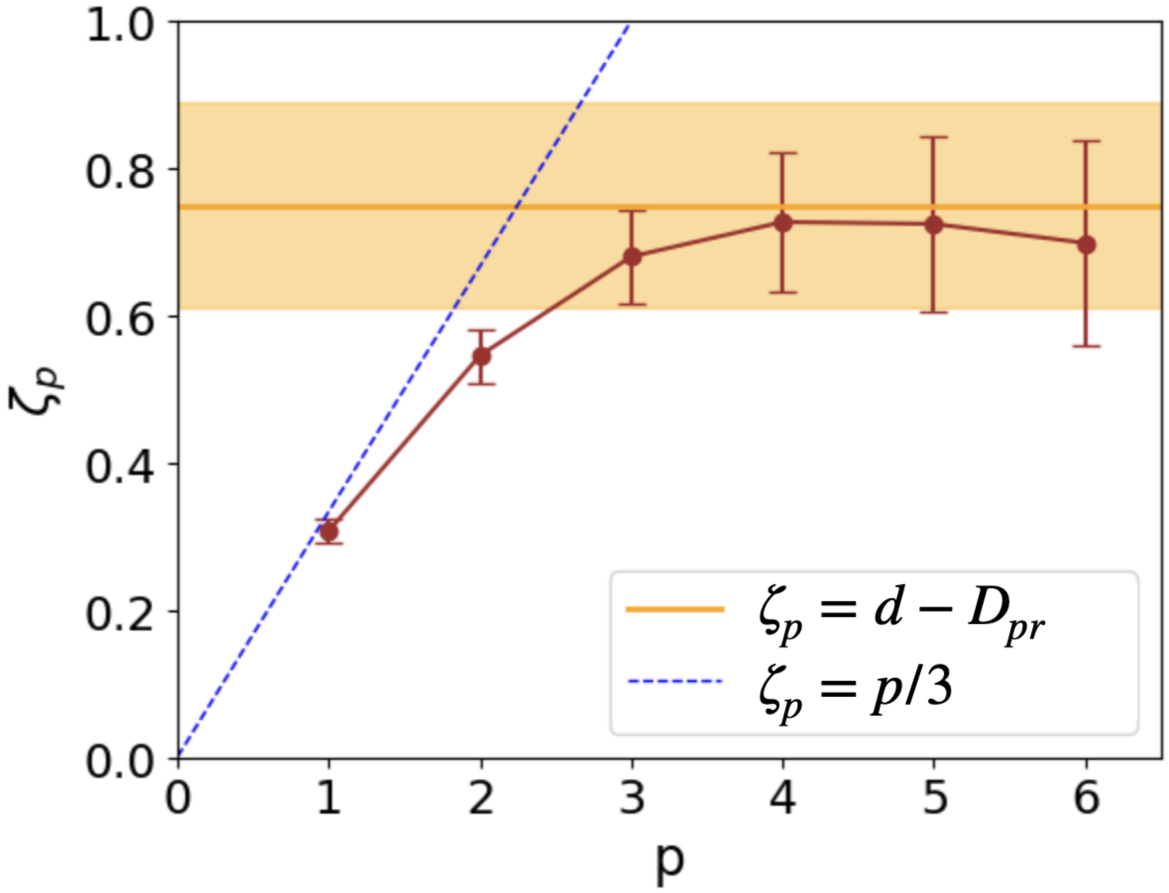
Regions of strong convergence -- *h tends to 0*

$\Longrightarrow \zeta_p \approx d - D_s$ for large p

Underlying dynamics





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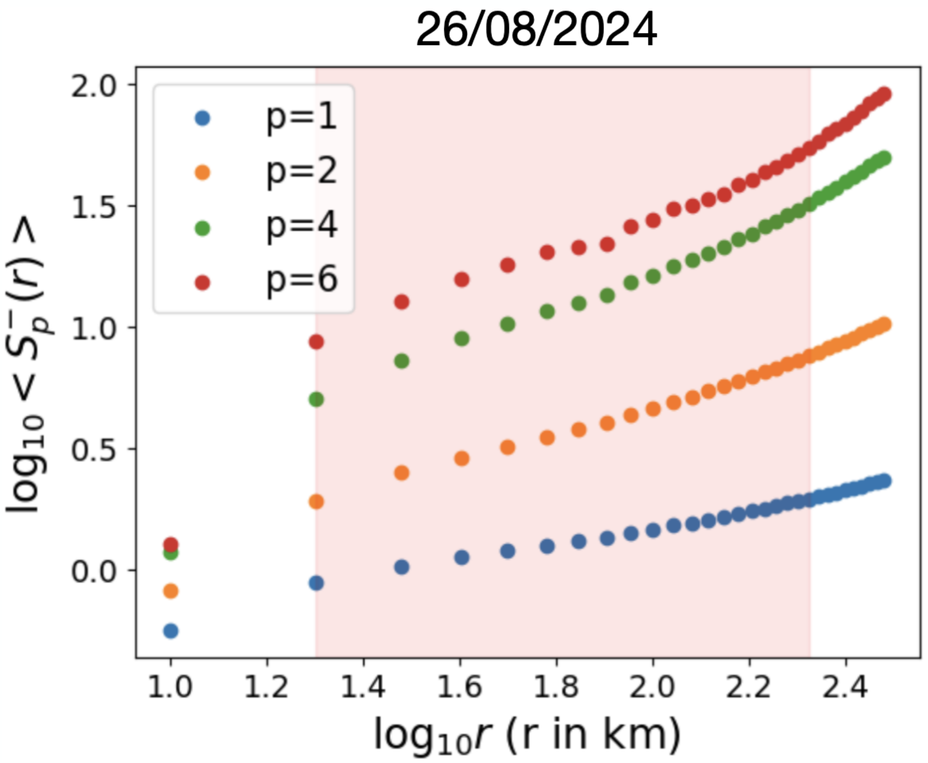

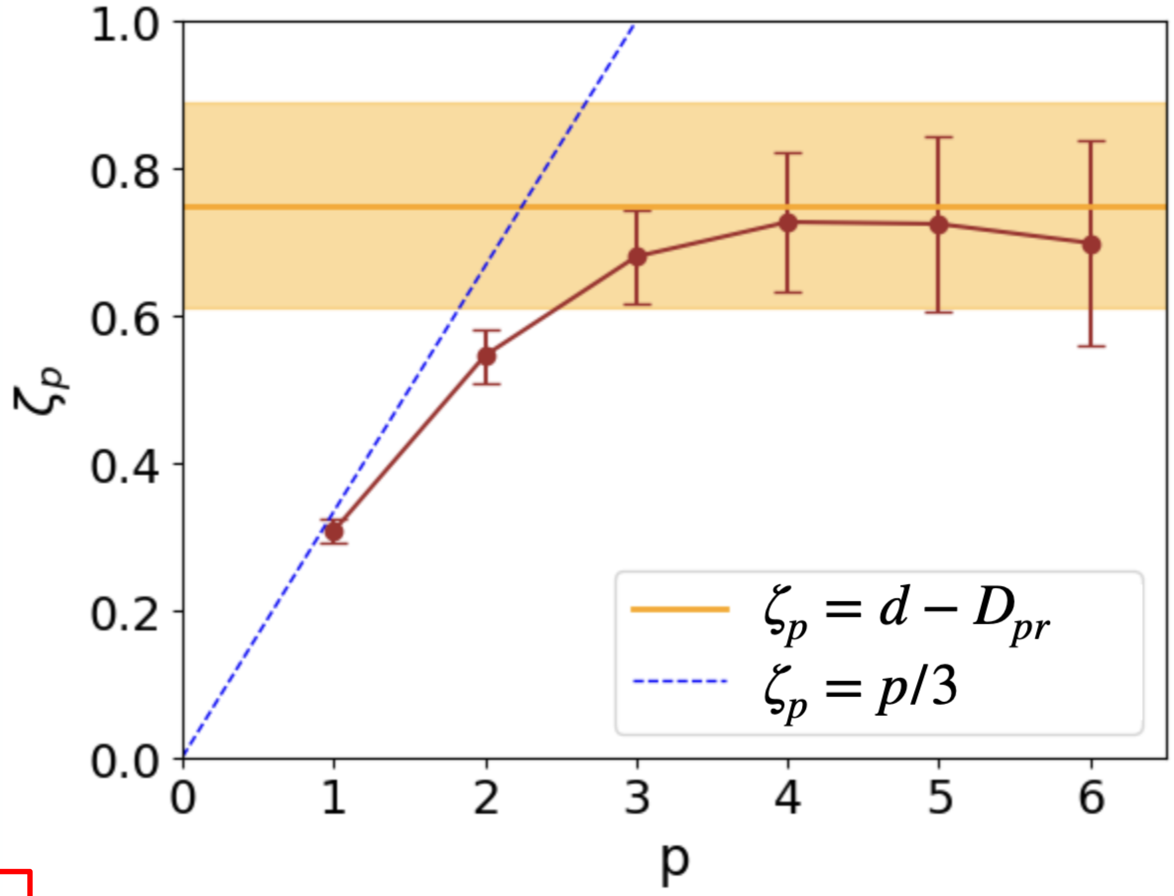

For p >=3, $\zeta_p \approx d - D_s$ $\quad D_s \approx D_{pr}$

Effects of aerosol perturbations

- Control run with **present-day** aerosol emissions
- Cleaner run with anthropogenic and biogenic emissions reduced by 1/3 (**pre-industrial**)

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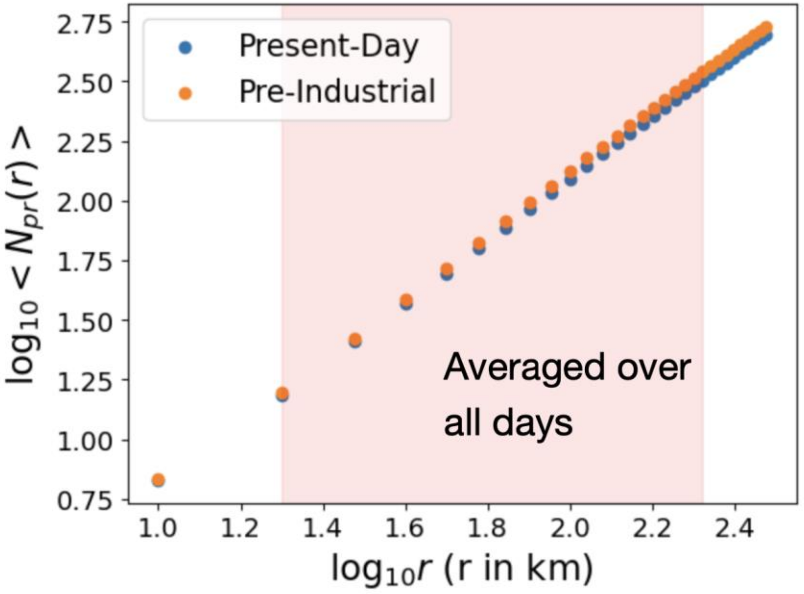
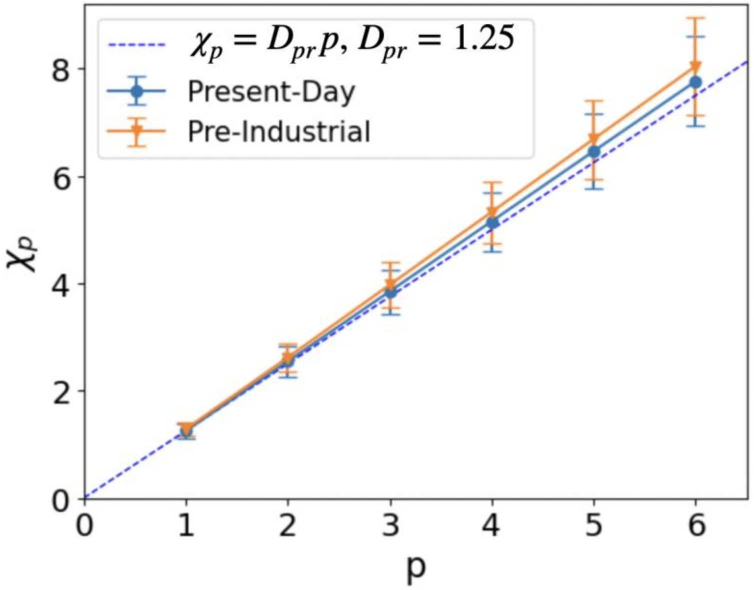
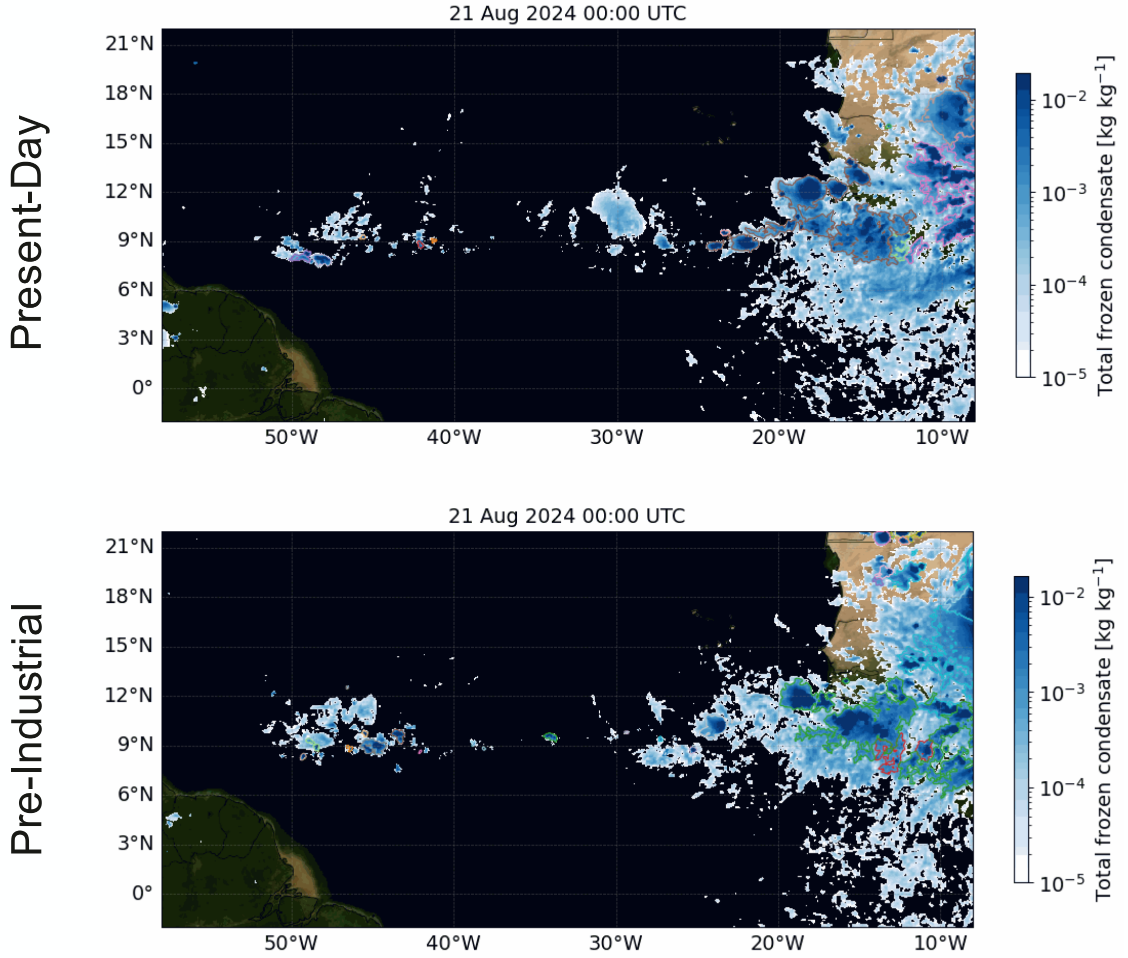




Negligible effect on mesoscale organization patterns.

Summary

- Spatial organization of extreme precipitation events at the lower range of mesoscales (20km to 200km) follow a scale-invariant pattern characterized by fractal dimension D_{pr}
- Quantitative link between D_{pr} and surface wind fluctuations
- Can use EarthCARE to investigate precipitation and updraft patterns along track
- Organization patterns unaffected by changes in aerosol loading -- **predominantly driven by surface turbulence**
- Aerosol perturbations however cause **warm-rain suppression** and alter cloud properties



Courtesy: Mathilde Ritman, Univ. Oxford