# Number and size-controlled rainfall regimes in the Netherlands: reality or statistical mirage?

Ruisdael Science Day, Utrecht, September 30, 2024

Full article available here: 10.5194/amt-17-4789-2024

Dr. Marc Schleiss

*Dept. Geoscience & Remote Sensing*

Delft University of Technology

## Convective rain

### Short, intense, localized rain

- Occurs when warm, moist air rapidly rises to higher altitudes due to updrafts.
- Thunderstorms, cumulonimbus clouds

## Convective rain

Short, intense, localized rain

- Occurs when warm, moist air rapidly rises to higher altitudes due to updrafts.
- Thunderstorms, cumulonimbus clouds

## Stratiform rain

Widespread, persistent but gentle rain

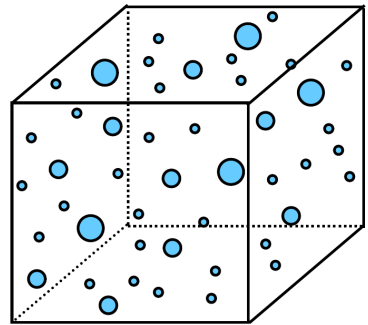
- Occurs when large uniform layers of moist air are slowly lifted over a broad area.
- Nimbostratus clouds

# The Raindrop Size Distribution (DSD)

$$\mathbf{N(D) = N_T \cdot f(D)}$$

$\mathbf{N_T}$ = number of drops per $m^3$

$\mathbf{f(D)}$ = pdf of the drop diameters



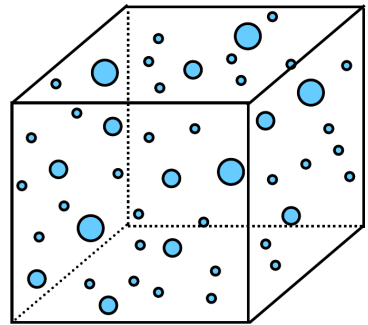
# The Raindrop Size Distribution (DSD)

$$\mathbf{N(D) = N_T \cdot f(D)}$$

$\mathbf{N_T}$ = number of drops per $m^3$

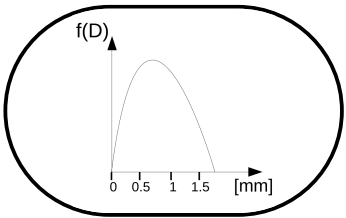
$\mathbf{f(D)}$ = pdf of the drop diameters

DSDs are like fingerprints of rainfall dynamics. They contain the signature of all microphysical processes involved in the formation of rain.



## Warm rain processes

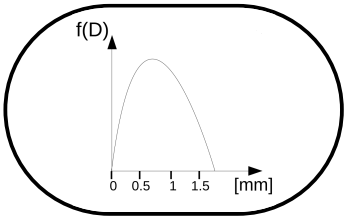
(collisional-coalescence)




Large concentrations of small drops.
Large $N_T$, narrow f(D), small $\bar{D}$

## Warm rain processes

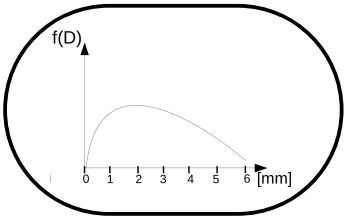
(collisional-coalescence)




Large concentrations of small drops.
Large $N_T$, narrow f(D), small $\bar{D}$

## Cold rain processes

(Bergeron-Findeisen)




Larger drops and broader DSDs
Medium $N_T$, broad f(D), large $\bar{D}$

# Link between reference moment and DSD

$$\underbrace{R}_{rainrate} = \frac{6\pi}{10^4} \underbrace{N_T}_{\#drops} \int_0^\infty D^3 \underbrace{f(D)}_{size} \underbrace{v(D)}_{velocity} dD$$

# Link between reference moment and DSD

$$\underbrace{R}_{rainrate} = \frac{6\pi}{10^4} \underbrace{N_T}_{\#drops} \int_0^\infty D^3 \underbrace{f(D)}_{size} \underbrace{v(D)}_{velocity} dD$$

with drop fall velocity model $v(D) \approx 3.78 D^{0.67}$ m/s

# Link between reference moment and DSD

$$\underbrace{R}_{rainrate} = \frac{6\pi}{10^4} \underbrace{N_T}_{\#drops} \int_0^\infty D^3 \underbrace{f(D)}_{size} \underbrace{v(D)}_{velocity} dD$$

with drop fall velocity model $v(D) \approx 3.78 D^{0.67}$ m/s

In general, R depends on $N_T$ and $f(D)$. However, people have theorized the existence of special regimes in which one of the two components is constant.

# Link between reference moment and DSD

$$\underbrace{R}_{rainrate} = \frac{6\pi}{10^4} \underbrace{N_T}_{\#drops} \int_0^\infty D^3 \underbrace{f(D)}_{size} \underbrace{v(D)}_{velocity} dD$$

with drop fall velocity model $v(D) \approx 3.78 D^{0.67}$ m/s

In general, R depends on $N_T$ and $f(D)$. However, people have theorized the existence of special regimes in which one of the two components is constant.

**Number-controlled**

- f(D) constant
- R is controlled by $N_T$

# Link between reference moment and DSD

$$\underbrace{R}_{rainrate} = \frac{6\pi}{10^4} \underbrace{N_T}_{\#drops} \int_0^\infty D^3 \underbrace{f(D)}_{size} \underbrace{v(D)}_{velocity} dD$$

with drop fall velocity model $v(D) \approx 3.78 D^{0.67}$ m/s

In general, R depends on $N_T$ and $f(D)$. However, people have theorized the existence of special regimes in which one of the two components is constant.

**Number-controlled**

- f(D) constant
- R is controlled by $N_T$

**Size-controlled**

- $N_T$ constant
- R is controlled by f(D)

# Previous studies

The literature on number and size-controlled regimes is very small.

# Previous studies

The literature on number and size-controlled regimes is very small.

**Number-controlled regimes:**

- heavy rain
- intense tropical rain
- orographic rain

# Previous studies

The literature on number and size-controlled regimes is very small.

**Number-controlled regimes:**

- heavy rain
- intense tropical rain
- orographic rain

**Size-controlled regimes:**

- stratiform rain, drizzle
- warm orographic rain
- dissipating stage of convection

**Uijlenhoet et al. (2003):** *The microphysical structure of extreme precipitation as inferred from ground-based raindrop spectra,* J. Atmos. Sci., 60, 1220–1238

**Uijlenhoet et al. (2003):** *The microphysical structure of extreme precipitation as inferred from ground-based raindrop spectra,* J. Atmos. Sci., 60, 1220–1238

- Observational study using DSD data in Florida

**Uijlenhoet et al. (2003):** *The microphysical structure of extreme precipitation as inferred from ground-based raindrop spectra,* J. Atmos. Sci., 60, 1220–1238

- Observational study using DSD data in Florida
- Identified 2 high-intensity events with potentially number-controlled regimes.

**Uijlenhoet et al. (2003):** *The microphysical structure of extreme precipitation as inferred from ground-based raindrop spectra,* J. Atmos. Sci., 60, 1220–1238

- Observational study using DSD data in Florida
- Identified 2 high-intensity events with potentially number-controlled regimes.

**Problems:** single sensor, no objective statistical metric

**Uijlenhoet et al. (2003):** *The microphysical structure of extreme precipitation as inferred from ground-based raindrop spectra,* J. Atmos. Sci., 60, 1220–1238

- Observational study using DSD data in Florida
- Identified 2 high-intensity events with potentially number-controlled regimes.

**Problems:** single sensor, no objective statistical metric

---

**Steiner et al. (2004):** A Microphysical Interpretation of Radar Reflectivity-Rain Rate Relationships, J. Atmos. Sci., 61, 1114–1131

**Uijlenhoet et al. (2003):** *The microphysical structure of extreme precipitation as inferred from ground-based raindrop spectra,* J. Atmos. Sci., 60, 1220–1238

- Observational study using DSD data in Florida
- Identified 2 high-intensity events with potentially number-controlled regimes.

**Problems:** single sensor, no objective statistical metric

---

**Steiner et al. (2004):** A Microphysical Interpretation of Radar Reflectivity-Rain Rate Relationships, J. Atmos. Sci., 61, 1114–1131

- Detection method based on Z-R relationship $Z = \alpha R^{\beta}$

**Uijlenhoet et al. (2003):** *The microphysical structure of extreme precipitation as inferred from ground-based raindrop spectra,* J. Atmos. Sci., 60, 1220–1238

- Observational study using DSD data in Florida
- Identified 2 high-intensity events with potentially number-controlled regimes.

**Problems:** single sensor, no objective statistical metric

---

**Steiner et al. (2004):** A Microphysical Interpretation of Radar Reflectivity-Rain Rate Relationships, J. Atmos. Sci., 61, 1114–1131

- Detection method based on Z-R relationship $Z = \alpha R^{\beta}$
- NC regime: $\beta = 1$ ; SC regime: $\beta = 1.63$

**Uijlenhoet et al. (2003):** *The microphysical structure of extreme precipitation as inferred from ground-based raindrop spectra,* J. Atmos. Sci., 60, 1220–1238

- Observational study using DSD data in Florida
- Identified 2 high-intensity events with potentially number-controlled regimes.

**Problems:** single sensor, no objective statistical metric

---

**Steiner et al. (2004):** A Microphysical Interpretation of Radar Reflectivity-Rain Rate Relationships, J. Atmos. Sci., 61, 1114–1131

- Detection method based on Z-R relationship $Z = \alpha R^{\beta}$
- NC regime: $\beta = 1$ ; SC regime: $\beta = 1.63$

**Problems:** Remote sensing data, large uncertainty on $\beta$

# Issues with previous studies

# Issues with previous studies

1. Small sample sizes (circumstantial)

# Issues with previous studies

1. Small sample sizes (circumstantial)
2. No comprehensive uncertainty assessment

# Issues with previous studies

1. Small sample sizes (circumstantial)
2. No comprehensive uncertainty assessment
3. No proper validation through an independent data source

# Issues with previous studies

1. Small sample sizes (circumstantial)
2. No comprehensive uncertainty assessment
3. No proper validation through an independent data source

Lots of speculation and theories but
**No solid observational evidence!**

Parsivel disdrometers and micro-rain radar at Cabauw.

# Data

Approx 2.5 years of data in Cabauw

**Disdrometer data:**

- Time series of $N_T$ and f(D)
- 1 minute resolution
- co-located sensors

**MRR:**

- Vertical profiles of R, Z
- 10 s time resolution
- 35 m range resolution

Ruisdael observatory

# Methodology

## 15-min moving time window

# Methodology

## 15-min moving time window

**Disdrometer measurements**

$N_T$ = # drops per $m^3$
$D_m$ = mean drop diameter

# Methodology

## 15-min moving time window

**Disdrometer measurements**

$N_T$ = # drops per $m^3$
$D_m$ = mean drop diameter

**Statistics**

CV = Coefficient of variation
$\rho$ = Correlation coefficient with R

# Methodology

## 15-min moving time window

**Disdrometer measurements**

$N_T$ = # drops per $m^3$
$D_m$ = mean drop diameter

**Statistics**

CV = Coefficient of variation
$\rho$ = Correlation coefficient with R

$CV(D_m)<0.1$ AND $\rho(N_T,R)>0.9 \rightarrow$ **Number-controlled**
$CV(N_T)<0.1$ AND $\rho(D_m,R)>0.9 \rightarrow$ **Size-controlled**

# Methodology

## 15-min moving time window

**Disdrometer measurements**

$N_T$ = # drops per $m^3$
$D_m$ = mean drop diameter

**Statistics**

CV = Coefficient of variation
$\rho$ = Correlation coefficient with R

**Cross-check**

If both disdrometers detect the same regime within $\pm$ 1 minute, the detection is "confirmed".

$CV(D_m)<0.1$ AND $\rho(N_T,R)>0.9 \rightarrow$ **Number-controlled**
$CV(N_T)<0.1$ AND $\rho(D_m,R)>0.9 \rightarrow$ **Size-controlled**

# Results

| | Potentially number-controlled | Potentially size-controlled |
|---|---|---|
| Detected by 1 disdrometer | 376 | 139 |

# Results

| | Potentially number-controlled | Potentially size-controlled |
|---|---|---|
| Detected by 1 disdrometer | 376 | 139 |
| Confirmed by other | **11** | **12** |

# Results

| | Potentially number-controlled | Potentially size-controlled |
|---|---|---|
| Detected by 1 disdrometer | 376 | 139 |
| Confirmed by other | **11** | **12** |

Less than 10% of all detected regimes are confirmed by the other disdrometer.

**If we group all consecutive, confirmed detections into events, we have:**

**If we group all consecutive, confirmed detections into events, we have:**

- 4 potentially number-controlled events

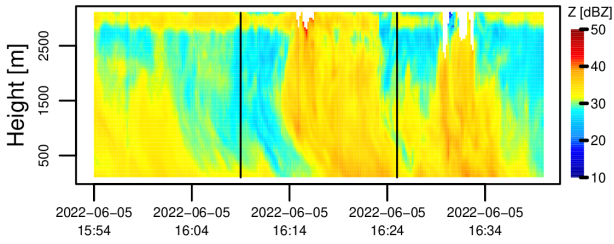
**If we group all consecutive, confirmed detections into events, we have:**

- 4 potentially number-controlled events
- 4 potentially size-controlled events

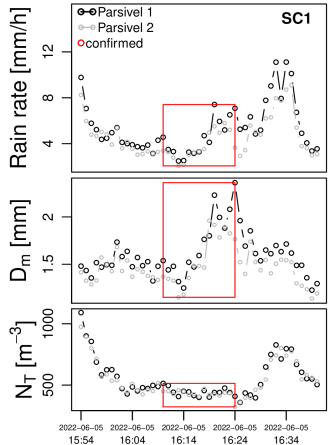
# If we group all consecutive, confirmed detections into events, we have:

- 4 potentially number-controlled events
- 4 potentially size-controlled events

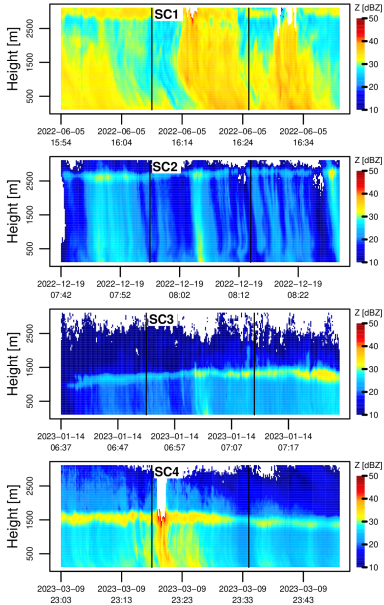
Example of a "size-controlled" event




*As seen by the micro-rain radar*

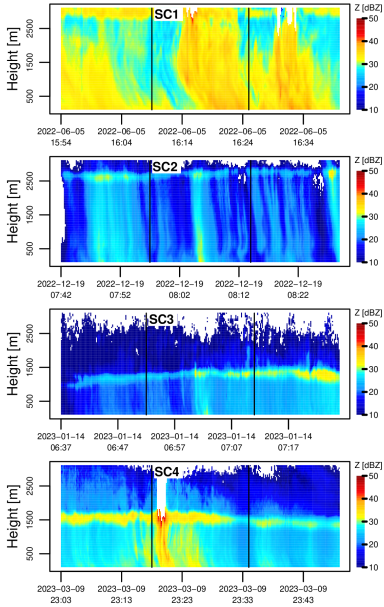



*As seen by the disdrometers*




# Overview of all 4 alleged size-controlled events

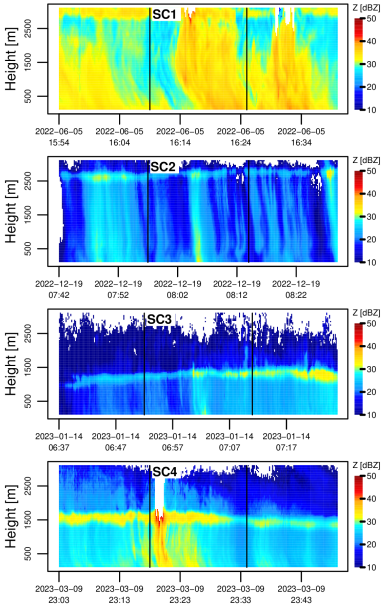
as seen by the micro-rain radar




# Overview of all 4 alleged size-controlled events

as seen by the micro-rain radar

**All 4 events correspond to weak stratiform rain. There are no signs of any special dynamics and fluctuations in DSDs are mostly due to cell motion!**

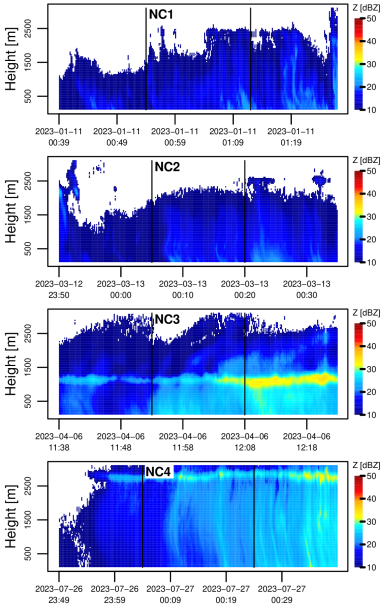



# Overview of all 4 alleged size-controlled events

as seen by the micro-rain radar

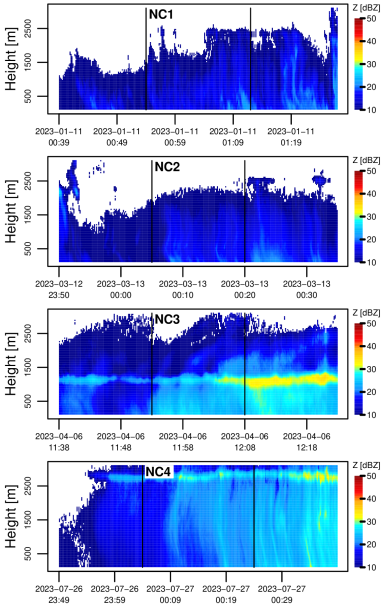
**All 4 events correspond to weak stratiform rain. There are no signs of any special dynamics and fluctuations in DSDs are mostly due to cell motion!**

$\rightarrow$ consistent with expectations from literature!




# Overview of all 4 alleged number-controlled events

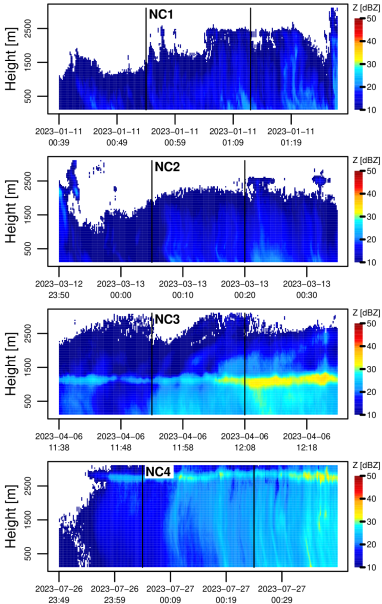
As seen by the micro-rain radar




# Overview of all 4 alleged number-controlled events

As seen by the micro-rain radar

**2 drizzle events (NC1 ; NC2) and 2 stratiform events (NC3 ; NC4). No special dynamics. Very homogeneous rain with small drops!**




# Overview of all 4 alleged number-controlled events

As seen by the micro-rain radar

**2 drizzle events (NC1 ; NC2) and 2 stratiform events (NC3 ; NC4). No special dynamics. Very homogeneous rain with small drops!**

$\rightarrow$ not consistent with literature!

# Are these 8 events really that special?

or are we just seeing ghosts?

# Are these 8 events really that special?

or are we just seeing ghosts?

Disdrometers see rainfall dynamics from the perspective of a **fixed observer** on the ground. This is very different from the dynamics along a rain shaft.

# Are these 8 events really that special?

or are we just seeing ghosts?

Disdrometers see rainfall dynamics from the perspective of a **fixed observer** on the ground. This is very different from the dynamics along a rain shaft.

Steiner et al. (2004) test on
Micro-rain radar data

# Are these 8 events really that special?

or are we just seeing ghosts?

Disdrometers see rainfall dynamics from the perspective of a **fixed observer** on the ground. This is very different from the dynamics along a rain shaft.

Steiner et al. (2004) test on Micro-rain radar data

$$Z = \alpha R^{\beta}$$

# Are these 8 events really that special?

or are we just seeing ghosts?

Disdrometers see rainfall dynamics from the perspective of a **fixed observer** on the ground. This is very different from the dynamics along a rain shaft.

Steiner et al. (2004) test on Micro-rain radar data

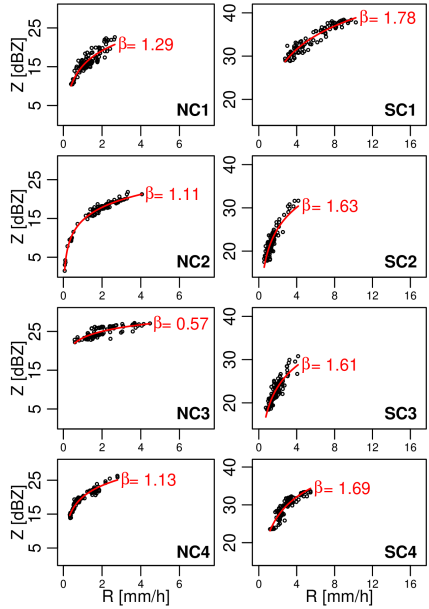
$$Z = \alpha R^{\beta}$$

**What we expect**

**NC regime:** $\beta = 1$

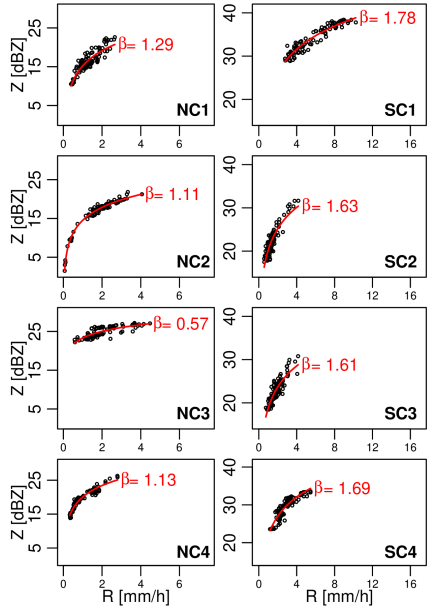
**SC regime:** $\beta = 1.63$

# Results of Steiner test:



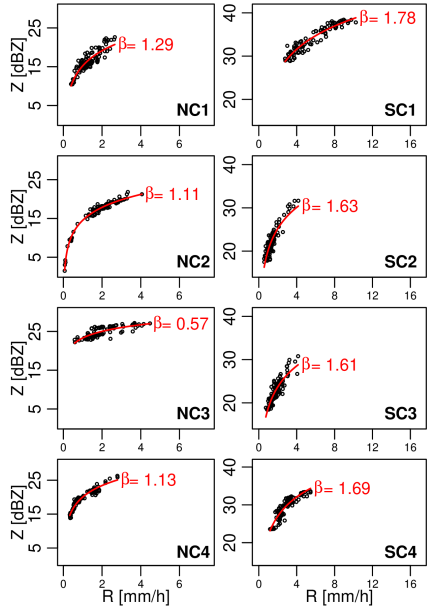
# Results of Steiner test:

- SC2 ; SC3 and SC4 close to expectations



# Results of Steiner test:

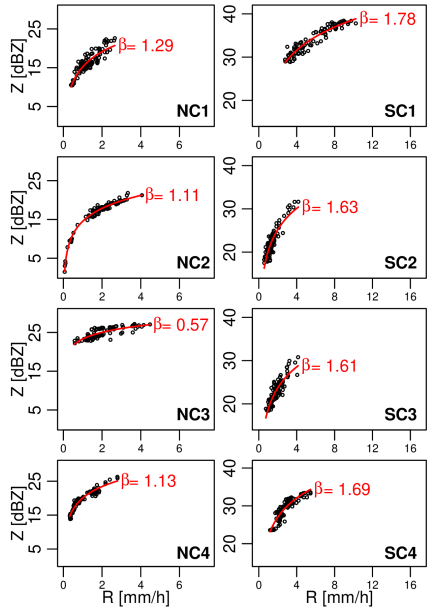
- SC2 ; SC3 and SC4 close to expectations
- Inconsistent values for NC regimes



# Results of Steiner test:

- SC2 ; SC3 and SC4 close to expectations
- Inconsistent values for NC regimes

The uncertainties on $\beta$ ($\pm$ 0.15) make it hard to conclude anything meaningful!



# Summary and Conclusions

# Summary and Conclusions

1. No conclusive evidence of number/size-controlled regime.

# Summary and Conclusions

1. No conclusive evidence of number/size-controlled regime.
2. Reference framework is crucial. Cell motion is a problem.

# Summary and Conclusions

1. No conclusive evidence of number/size-controlled regime.
2. Reference framework is crucial. Cell motion is a problem.
3. Moving window might be too long for capturing special regimes.

# Summary and Conclusions

1. No conclusive evidence of number/size-controlled regime.
2. Reference framework is crucial. Cell motion is a problem.
3. Moving window might be too long for capturing special regimes.
4. The large measurement uncertainty of disdrometers is a problem.

# Summary and Conclusions

1. No conclusive evidence of number/size-controlled regime.
2. Reference framework is crucial. Cell motion is a problem.
3. Moving window might be too long for capturing special regimes.
4. The large measurement uncertainty of disdrometers is a problem.
5. Difficulty of task casts doubts about previous claims in literature.

# Thank you for your attention!

Acknowledgment: The Ruisdael Observatory is a scientific research infrastructure financed by the Dutch Research Council (NWO, grant number 184.034.015).

The team:
- Rob Mackenzie
- Mahaut Sourzac
- Andre Castro
- Christine Unal

Data available at:
TU Delft: `https://ruisdael.citg.tudelft.nl`
KNMI: `https://dataplatform.knmi.nl`
ACTRIS: `https://www.actris.eu`

If you want to know more: m.a.schleiss@tudelft.nl

NWO
Netherlands Organisation for Scientific Research

Ruisdael observatory

TU Delft