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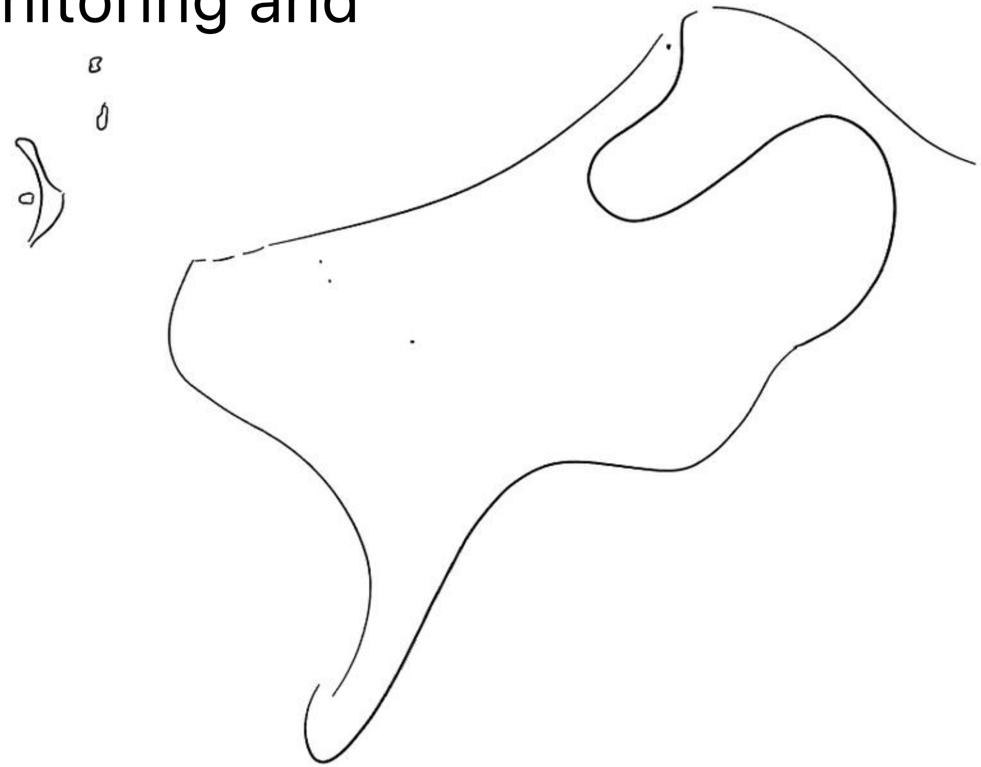
Towards smarter weather radar

A simulation study on adaptive scanning strategies for improved precipitation monitoring and forecasting



Delft University of Technology

Context of this research

Weather radar networks are growing in number, size and variety

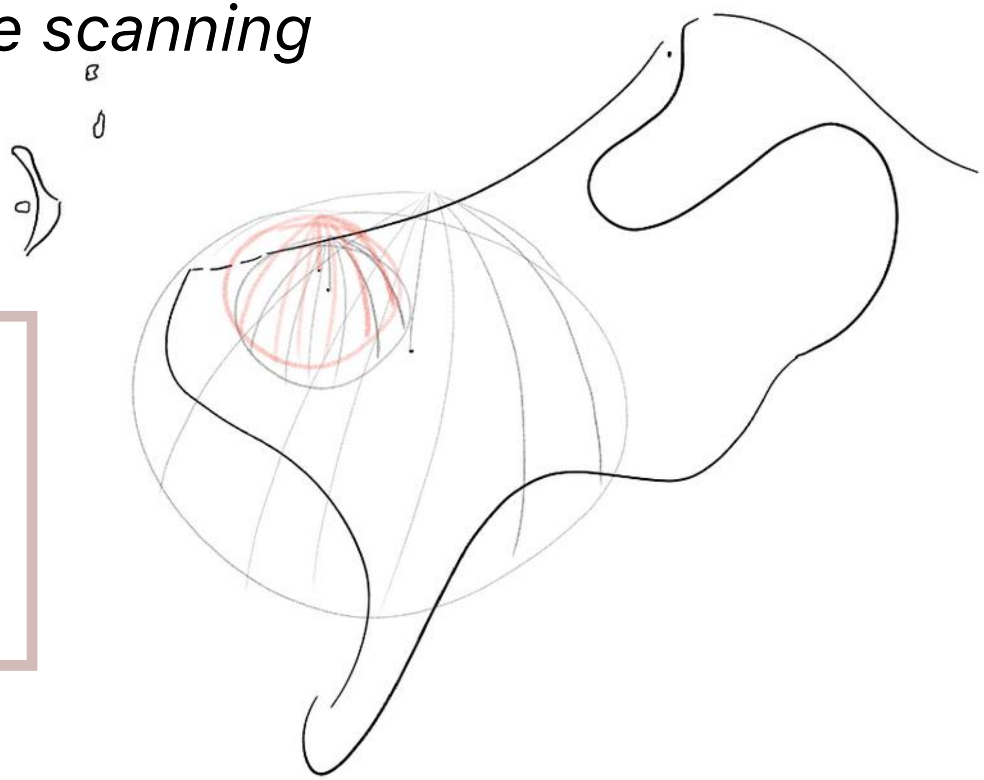
Unrealised potential

Radars operate using independent scanning techniques

Larger focus on better radar data processing rather than improved data collection strategies.

Problem statement

- *Weather radar network in the Netherlands*
  - *KNMI C-band radar // Herwijnen – Fixed scanning*
  - *X-band radar // Rotterdam – Fixed scanning*
  - *MESEWI X-band radar // Delft – Adaptive scanning*

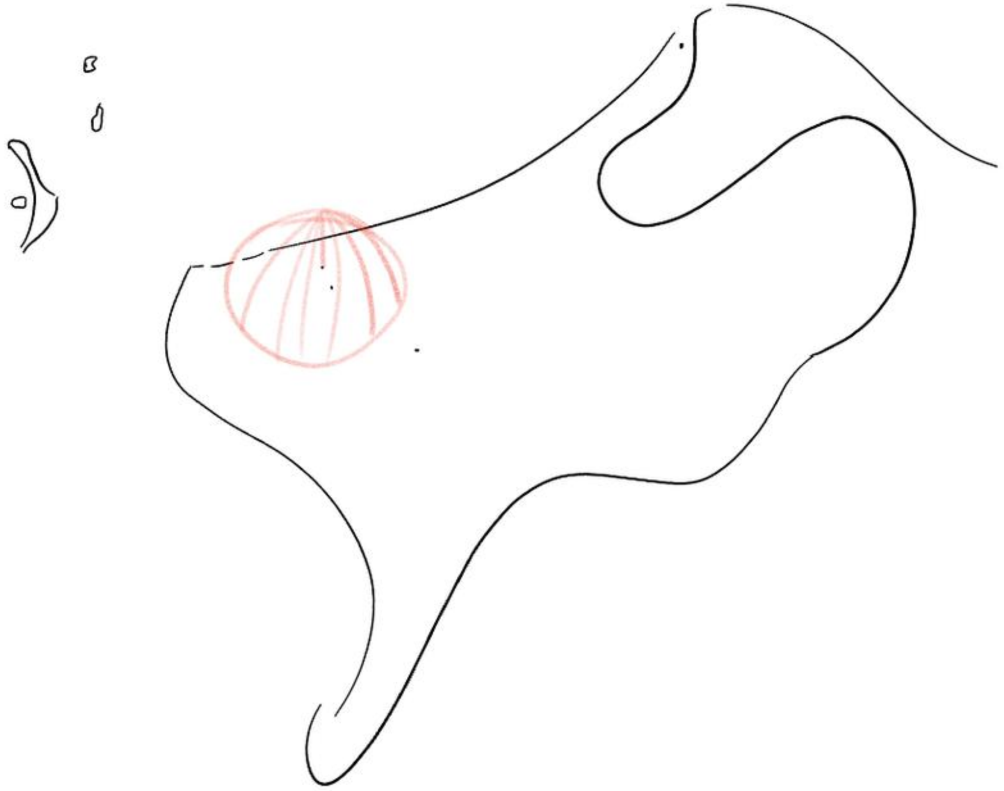


How can we best exploit adaptive scanning capabilities?

Examples of adaptive scanning

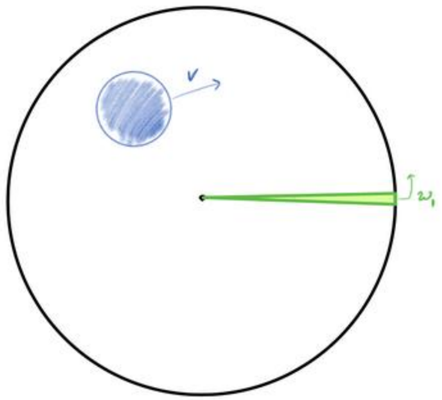
- *Changing where a radar looks:*
  - *Radial measurements (plan position indicators)?*
  - *Only scanning certain sectors?*
  - *Elevation scans?*

- *Changing how a radar looks:*
  - *Sensitivity of the radar?*
  - *Sampling frequency?*
  - *Rotation speed?*

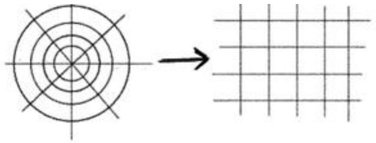


How does rotation speed influence measurements?

- *A simple situation – 1 raincell*
- *A simple radar model – plan position indicator*
- *A simple processing chain – reflectivity*



Interpolating polar grid to Cartesian grid



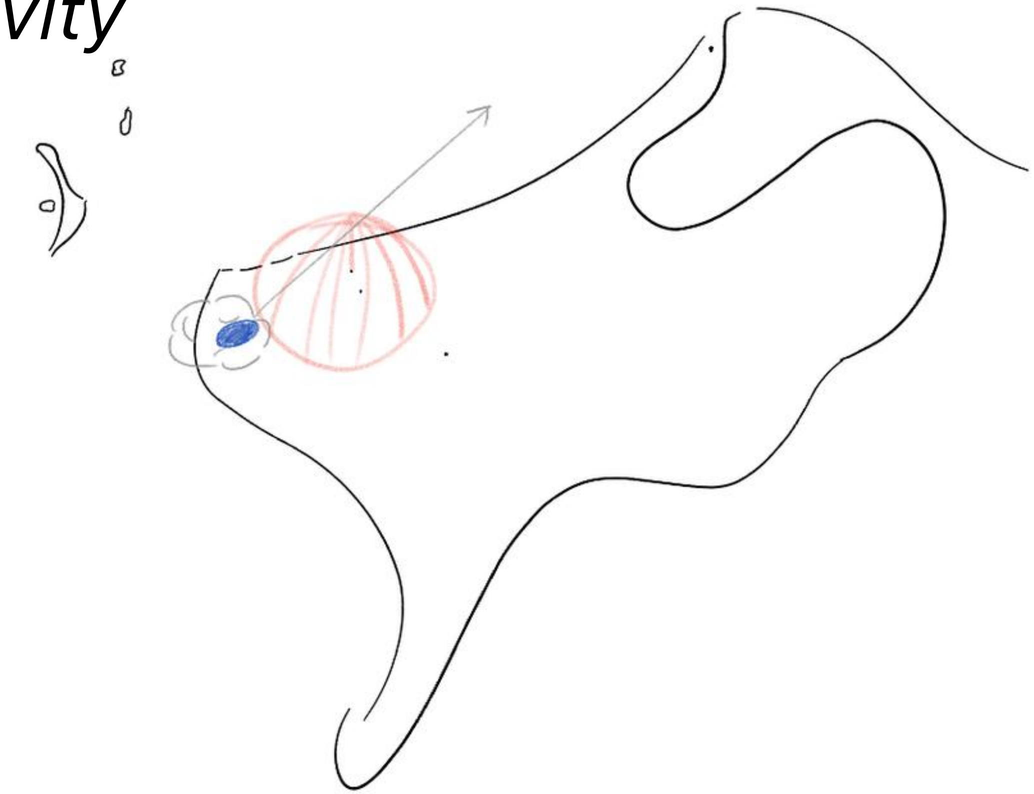
Reflectivity (dBZ) to rainfall intensity (R)

$$R = \left(\frac{1}{\alpha} 10^{dBZ/10}\right)^{1/\beta}$$

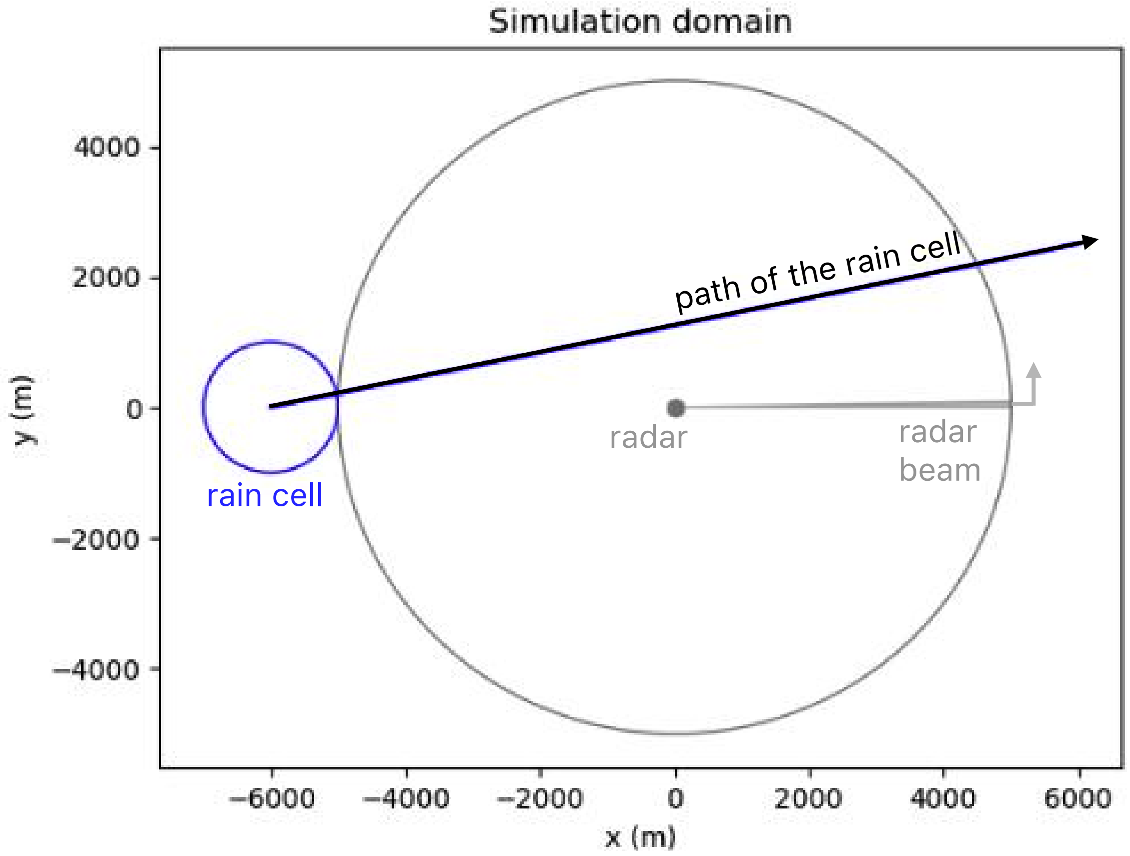
Marshall-Palmer

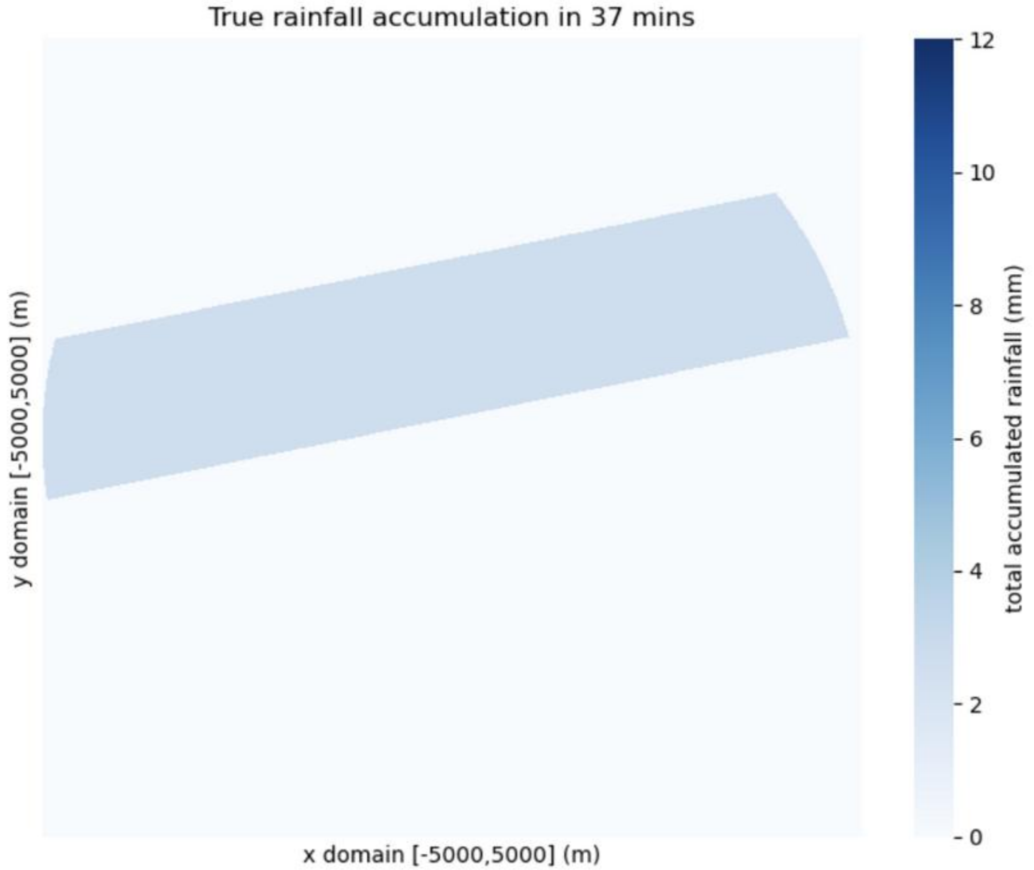
Rainfall intensity (R) to accumulation (A) over total area

$$A = \sum_{i}^{obs} R_i \times duration_i$$

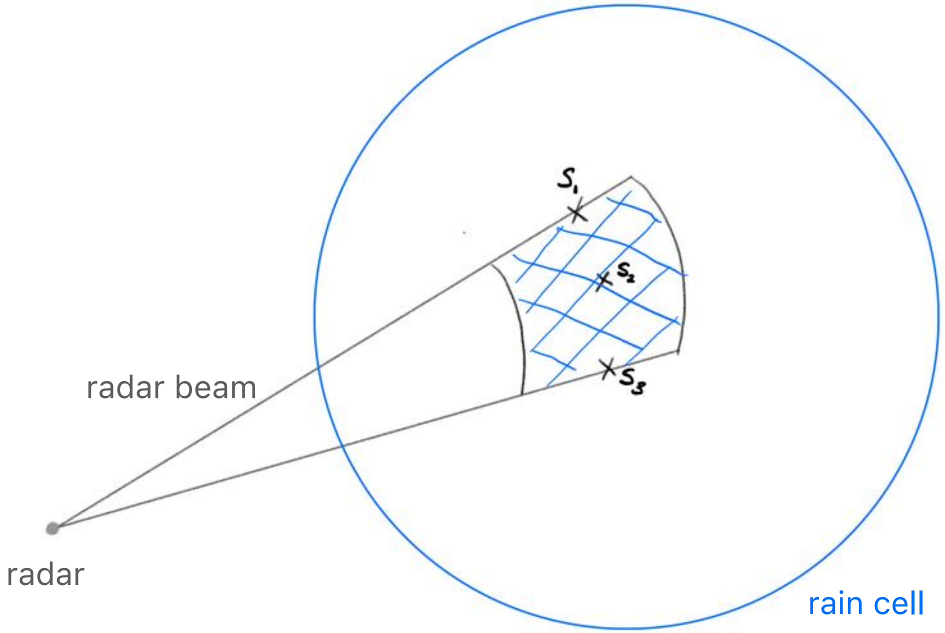


Simulation setup





Sampling method and noise model



$$dBZ = \sum_{i=1}^{3} w_i s_i$$

$$w_1 = w_3 = \frac{1}{4}$$

$$w_2 = \frac{1}{2}$$

Single beam

$$\mu = dBZ + X$$

where $X \sim N(0, 1.5)$

Multiple beams averaged

$$\bar{\mu} = \frac{\sum_i^n \mu_i}{n} \Rightarrow \bar{\mu} = dBZ + X'$$

where $X' \sim N(0, \frac{1.5}{n})$

and n is the number of beams.

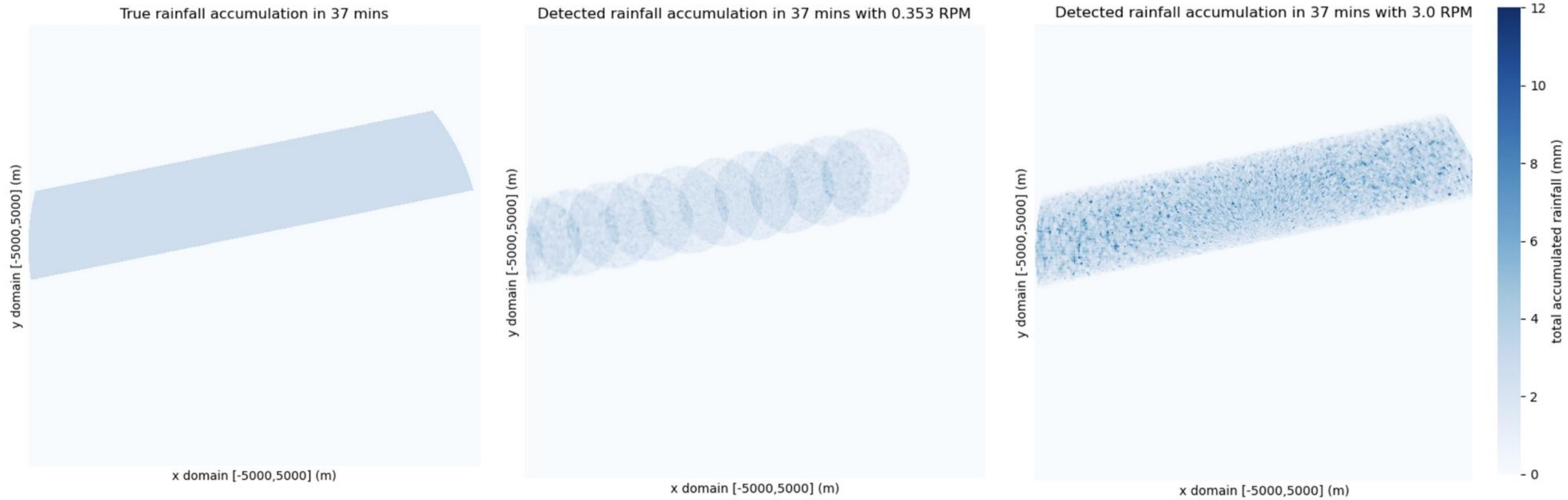
The slower you scan, the more beams are averaged, the less noise you will have.

Measurement noise & rotation speed

Scan speed : slow ⟷ fast

Measurement noise : low high

Observation frequency low high



What do we compare?

Mean squared error

$$MSE = \frac{1}{|D|} \sum_{(x,y) \in D} \left(A_{x,y} - \hat{A}_{x,y} \right)^2$$

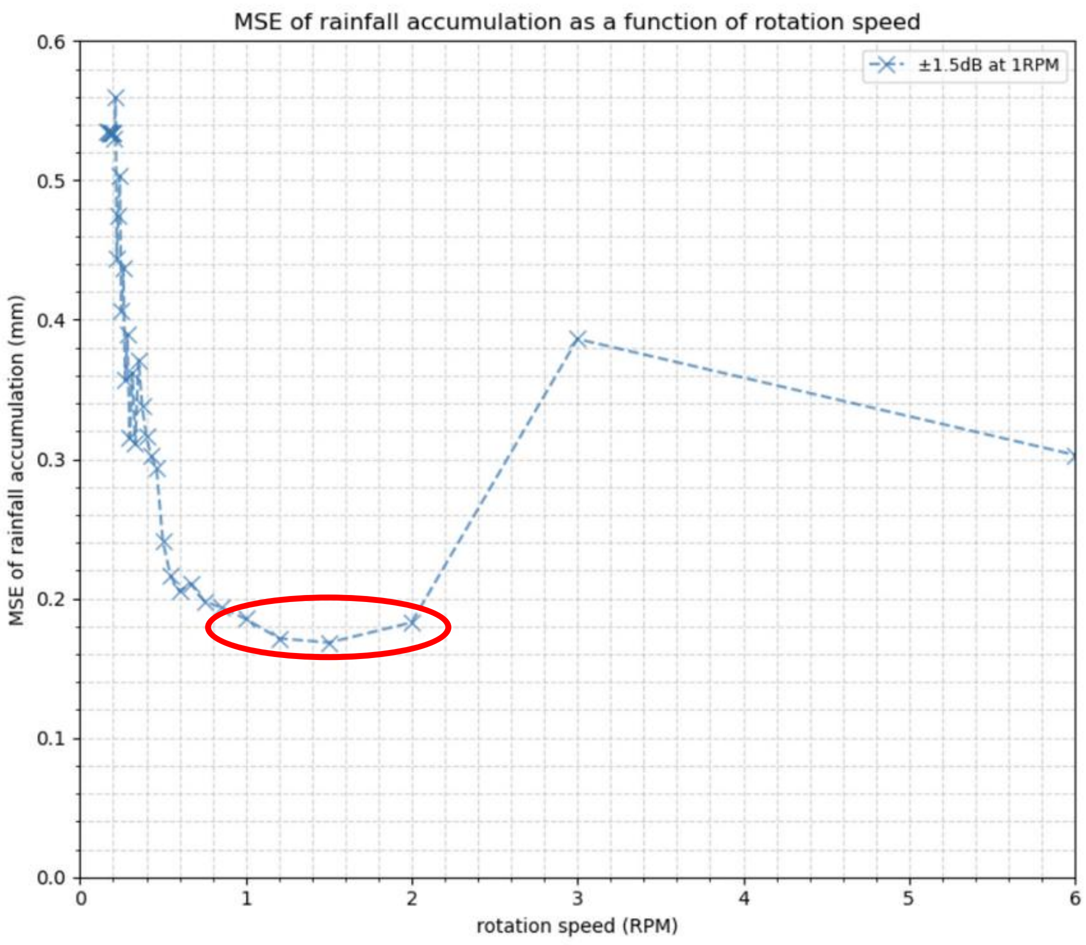
$A_{x,y}$: true rainfall accumulation at point (x,y)

$\hat{A}_{x,y}$: measured rainfall accumulation at point (x,y)

D : simulation domain.

- *Is no rain measured as no rain?*
- *Is present rain measured correctly?*

Simulation result



Scan speed :	slow	fast
Measurement noise :	low	high
Observation frequency	low	high

- *Balance between the measurement noise and the observation frequency*

Variable rotation speed

Go slow if you see rain, go fast if you do not

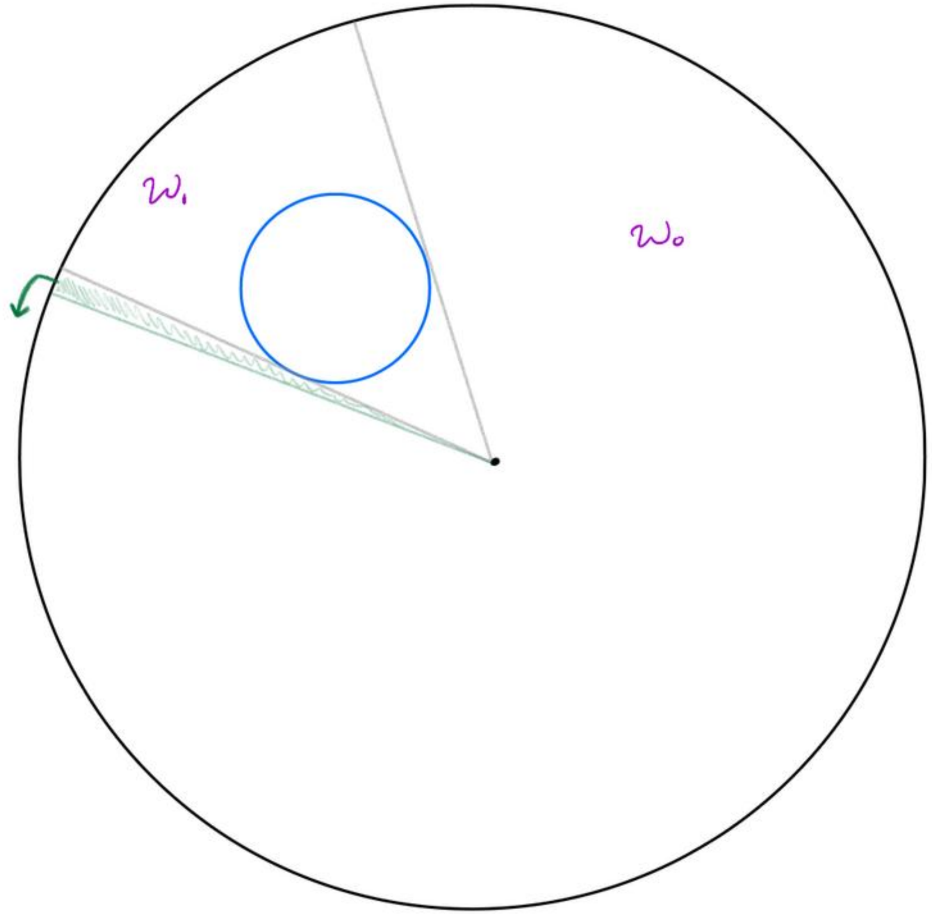
$w(\theta)$ as the angular velocity at angle θ.

$$w(\theta) = \begin{cases} w_1 & \text{if a raincell is present} \\ w_0 & \text{if no raincell is present} \end{cases}$$

$\bar{w}$ as the effective rotation speed

ie. average w over 1 PPI.

$$\bar{w} = \frac{\sum_{i}^{360} w(i)}{360}$$



Variable rotation speed

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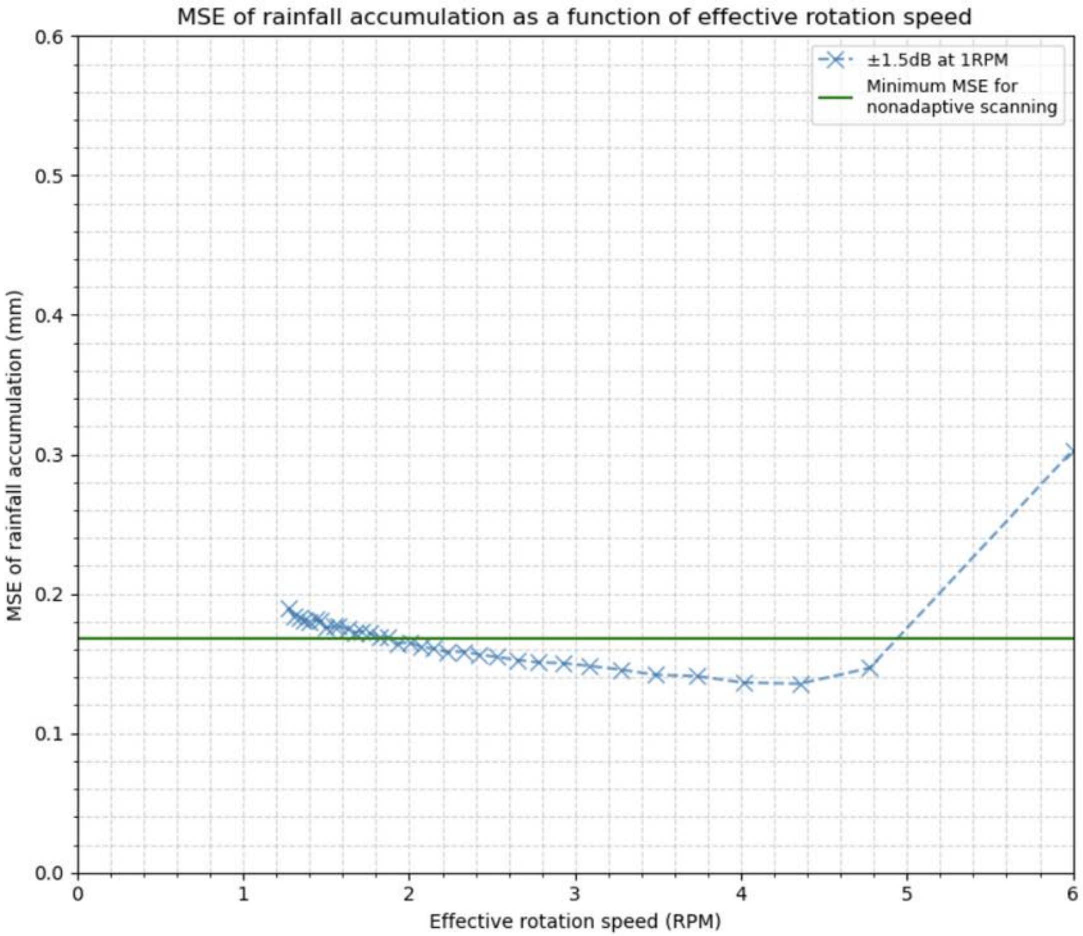
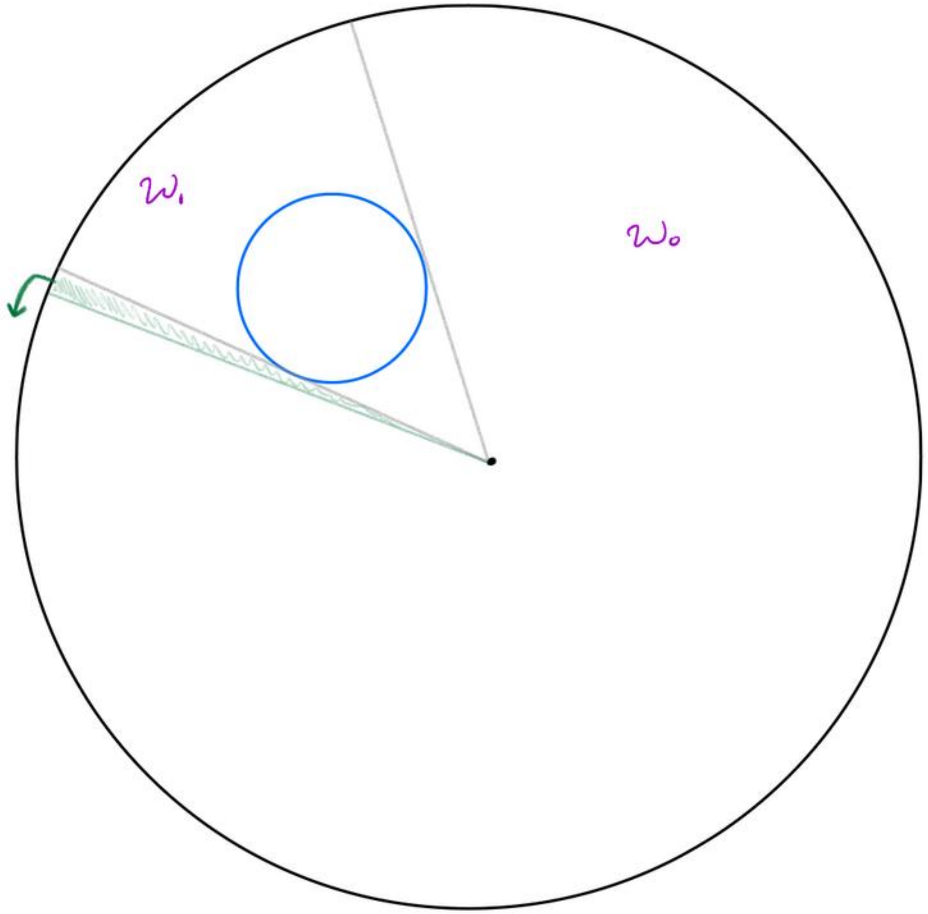
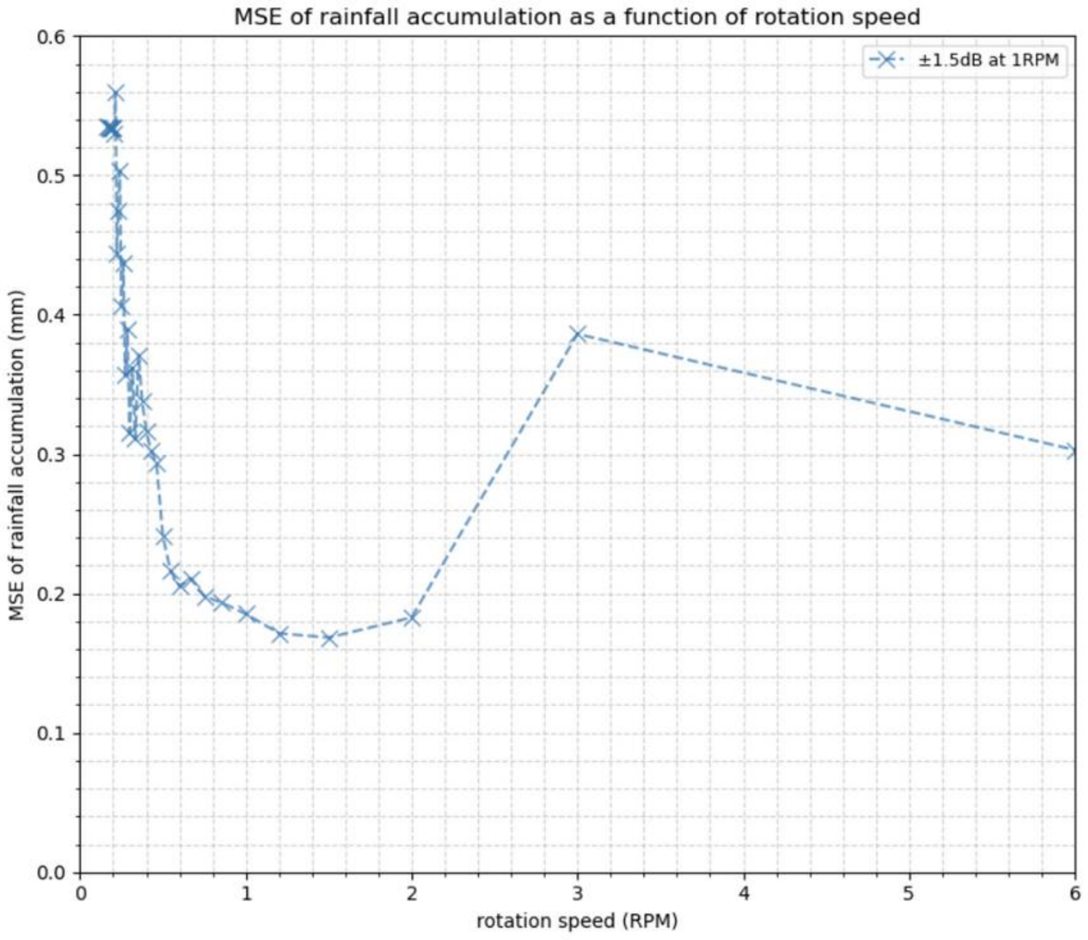


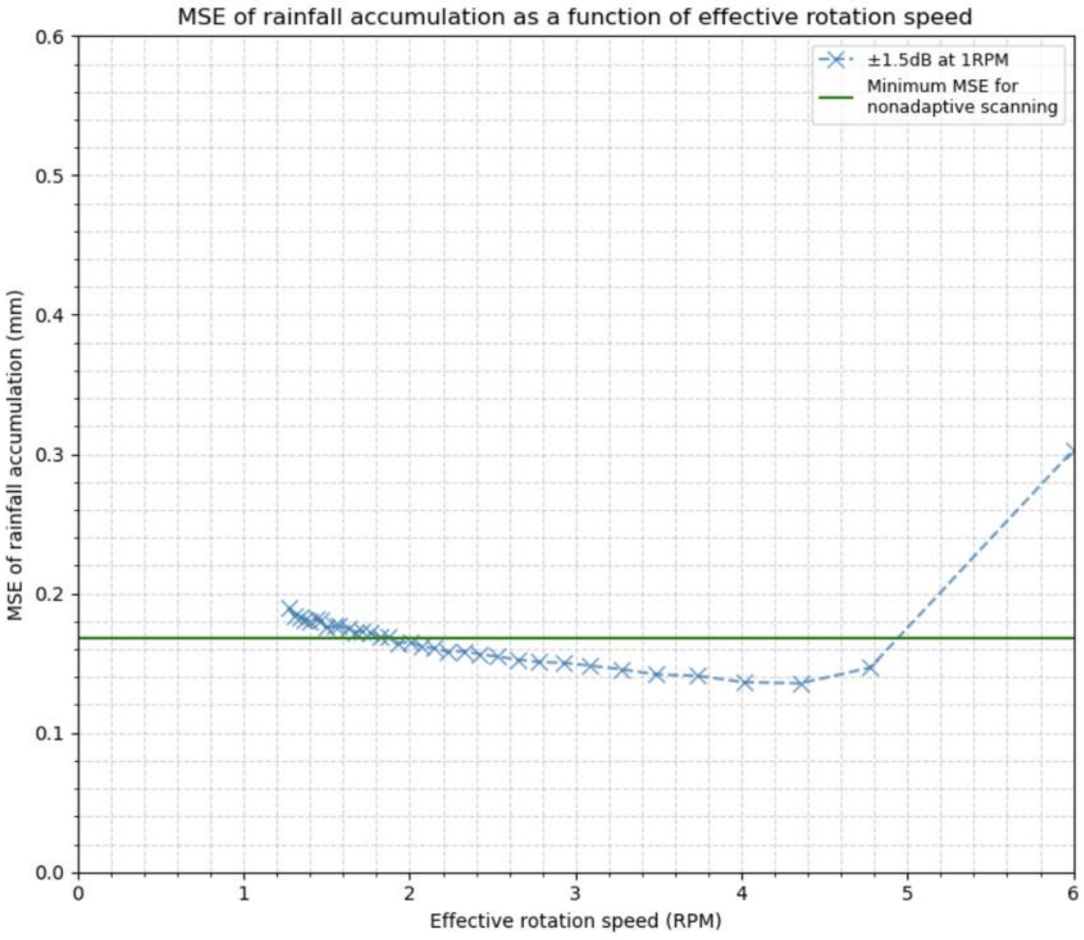


Conclusions

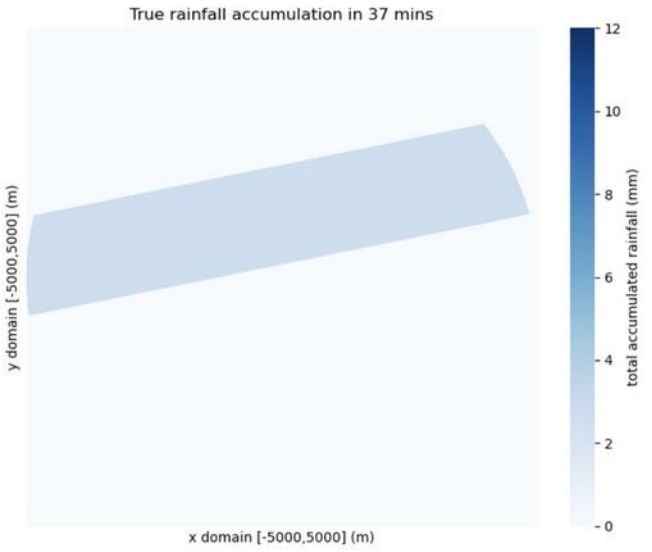
- *Even a simple case shows us the delicate balance between measurement noise and observation frequency*
- *More quantitative tests on scanning strategies are required*
- *A lot of possible improvements:*
  - *Multiple radars*
  - *Variable rainfall intensity*
  - *The vertical dimension*

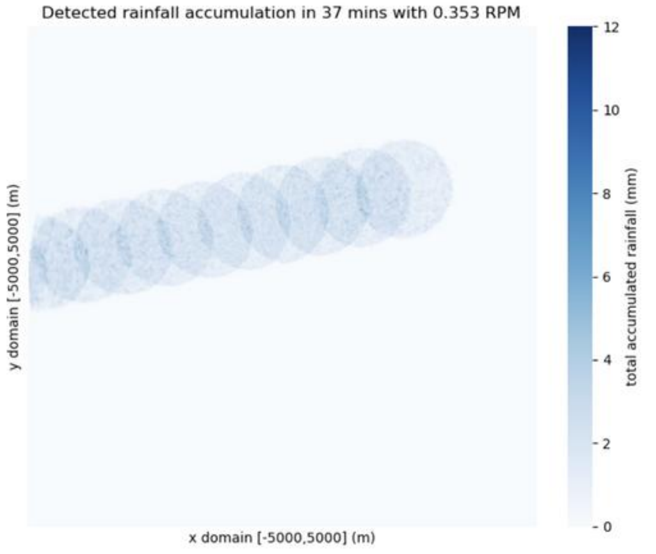
Simulation result

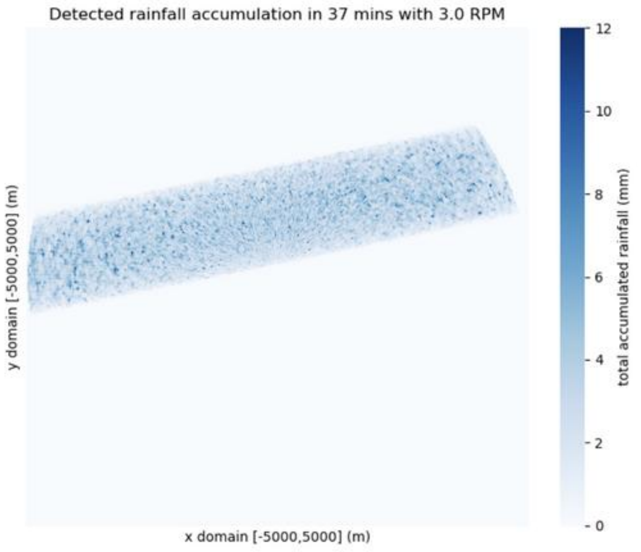


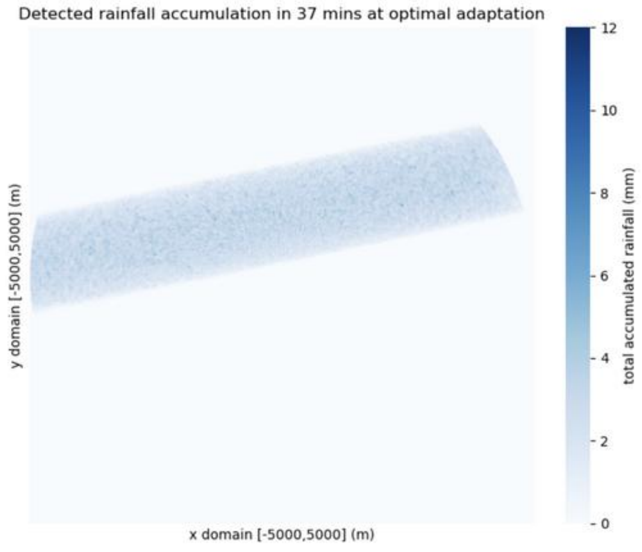


Sanity check

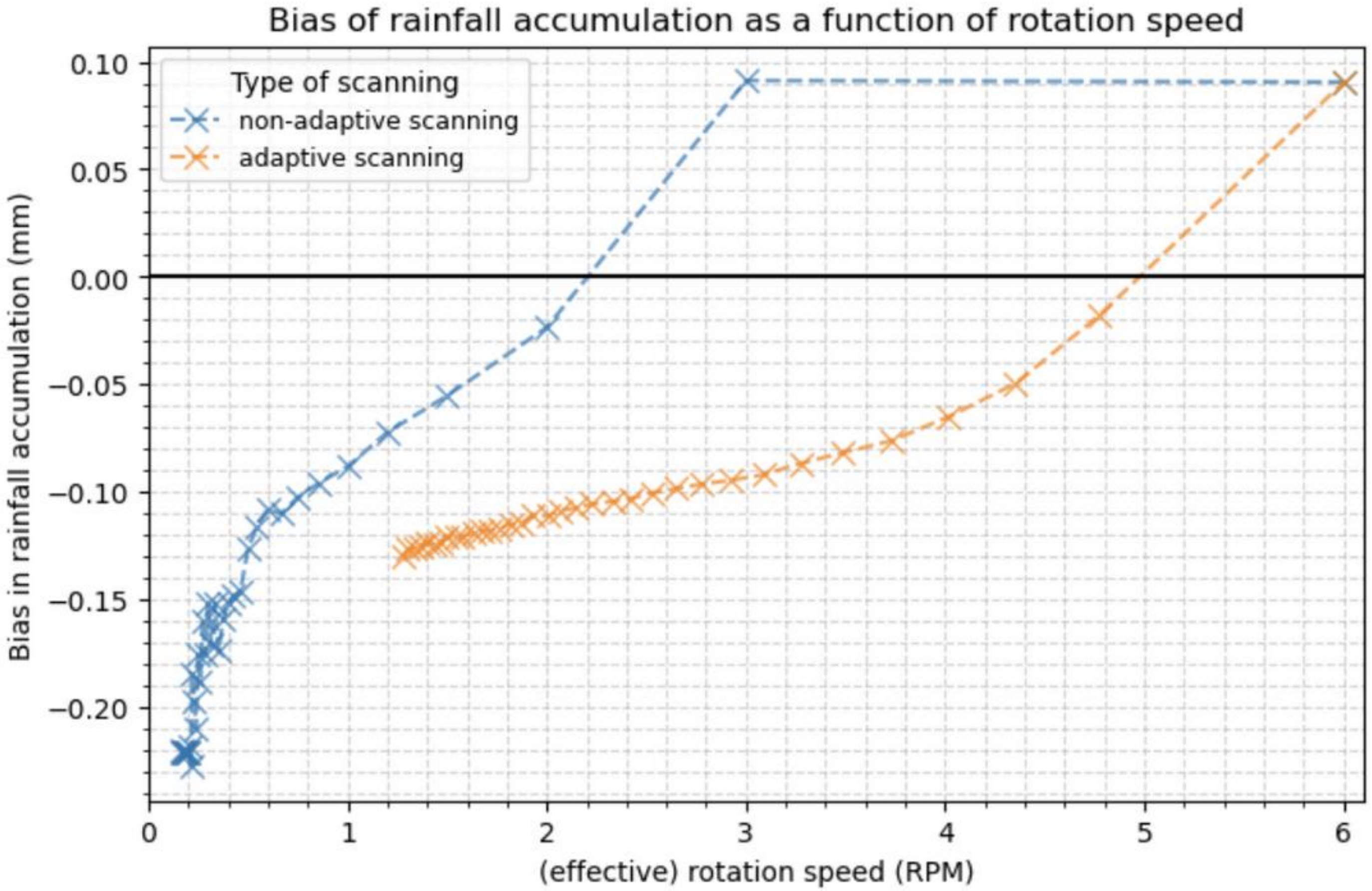








Bias?



Bias of rainfall accumulation as a function of rotation speed
Type of scanning
non-adaptive scanning
adaptive scanning
Bias in rainfall accumulation (mm)
(effective) rotation speed (RPM)
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
0
1
2
3
4
5
6