Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Max-Planck-Institut für Meteorologie

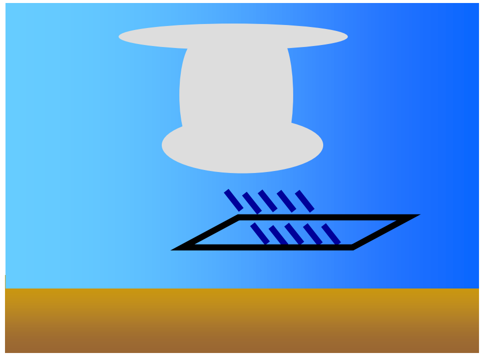
FESSTVaL
Field Experiment on Submesoscale Spatio-Temporal Variability in Lindenberg

Observing Precipitation at the Submesoscale using Radars

7. June 2021

Felix Ament, Finn Burgemeister,
Marco Clemens, Ingo Lange, Bastian Kirsch,
Katharina Lengfeld et al.

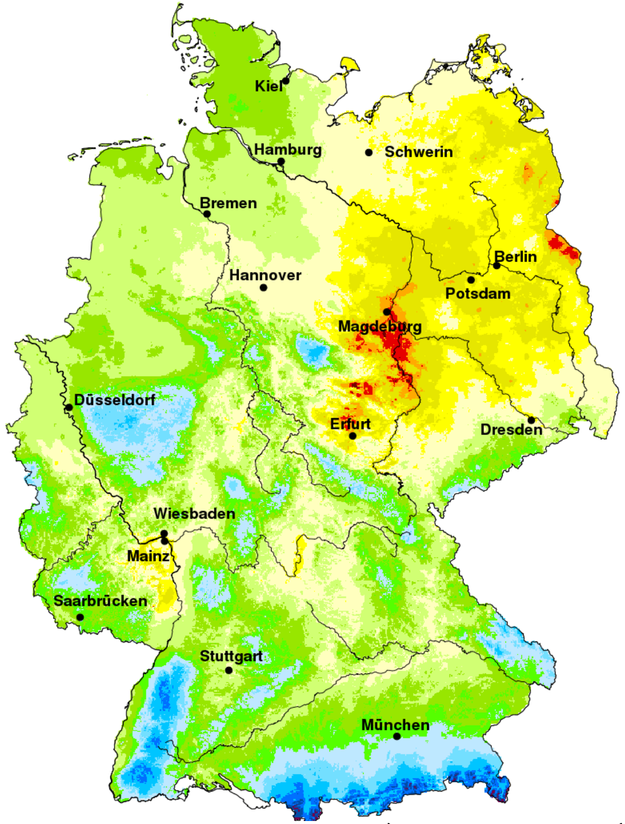
Observing precipitation



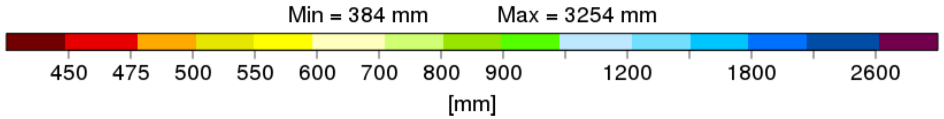
(Wikipedia)

Flux of water (liquid or frozen) through an horizontal plane

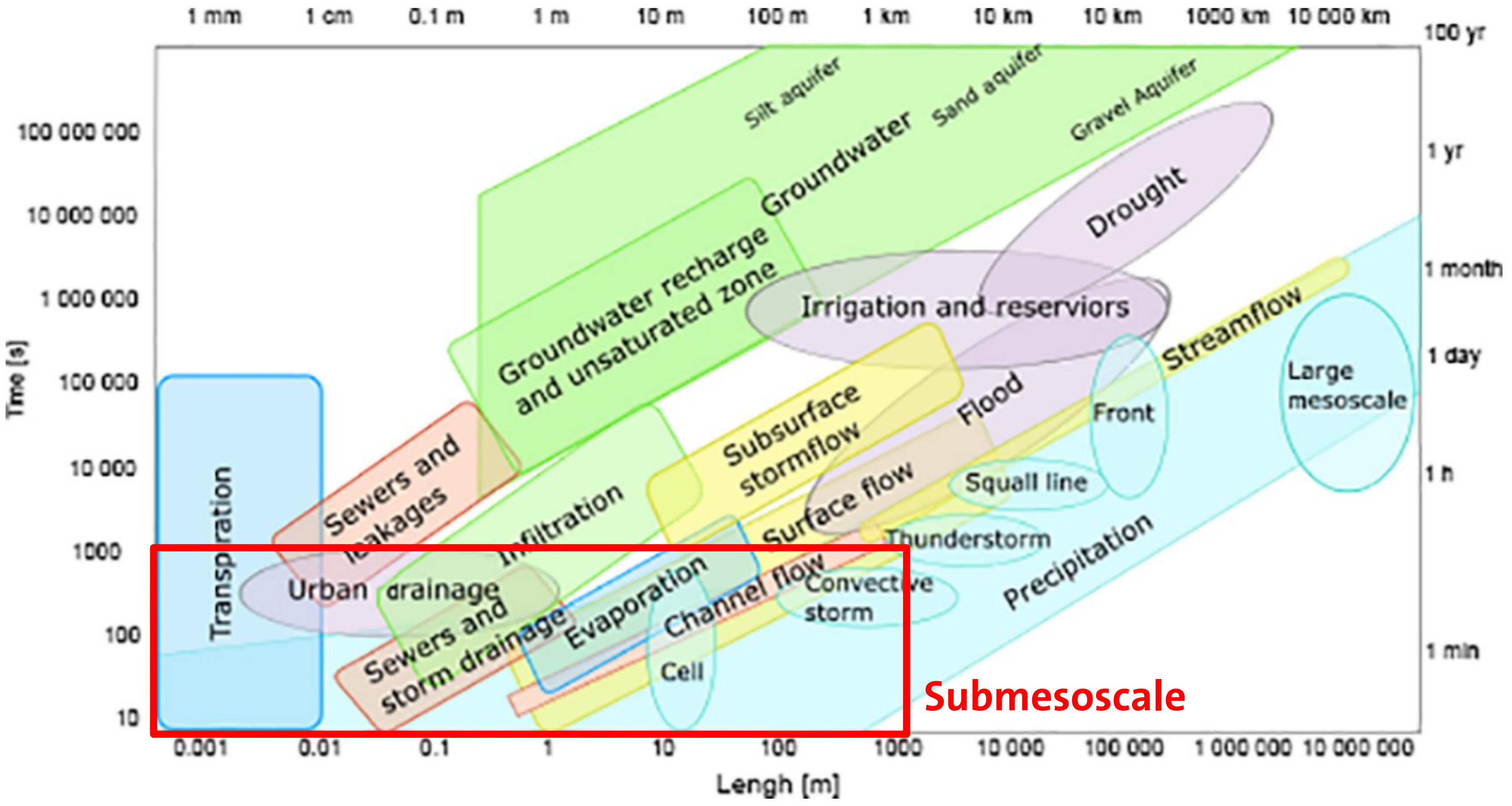
Observed quantity	Definition	Unit
Precipitation height	Amount of accumulated water over an area and for an time interval	kg/m^2 = mm (water column)
Precipitation rate	Precipitation height per time unit	mm / h (or $kg/m^2/s$)
Duration		s



(DWD Klimaatlas)



Scales in hydrology



Atmospheric processes

Surface processes

Underground processes

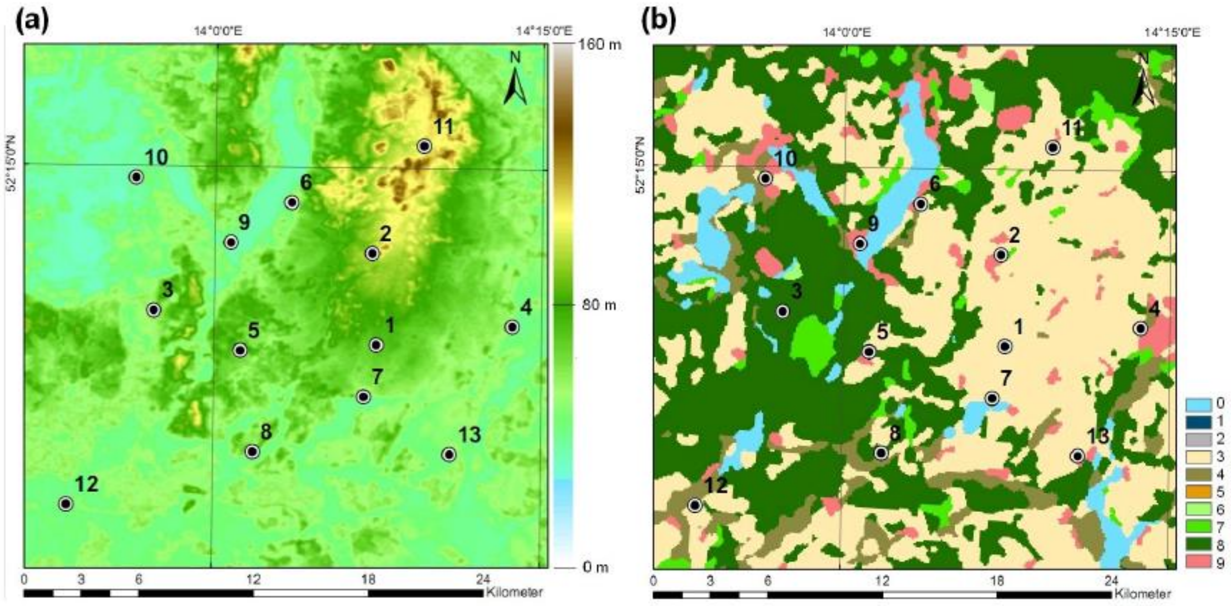
Urban processes

Impact on society

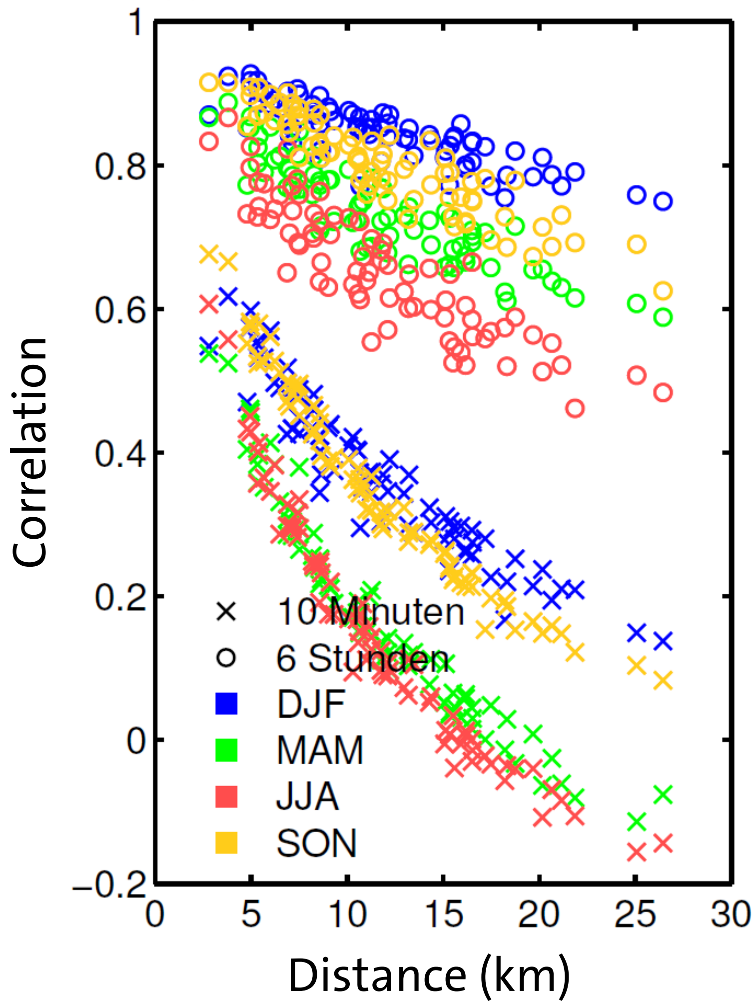
Christiano et al, Hydrol. Earth Syst. Sci. , 2017

Submesoscale Variability of Precipitation

Analysis of dense gauge network at Lindenberg



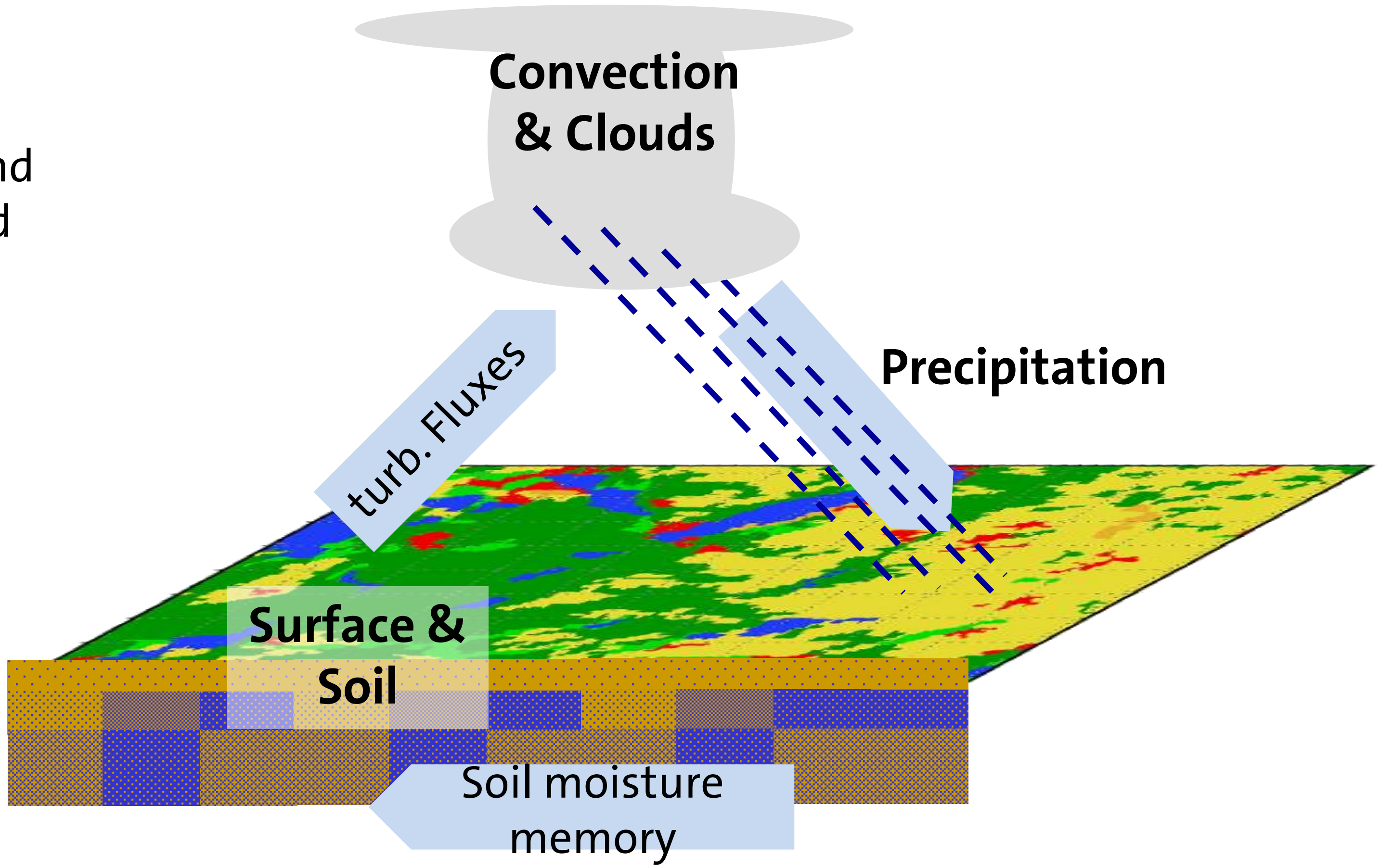
Ertl, Diplomarbeit UHH, 2010



Rainfall Variability at the Submesoscale

FESSTVaL OBS

- Remote Sensing @ MOL, Falkenberg and Birkholz; Apollo and MESSY networks
- X-Band Radar @ Falkenberg; DWD Radarnetwork
- Soil moisuture network & DWD@Falkenberg

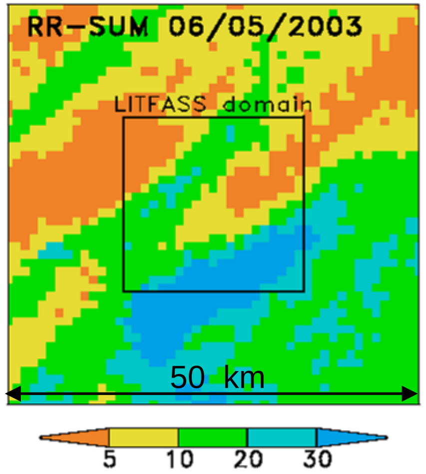


Relevance of submesoscale rain variability

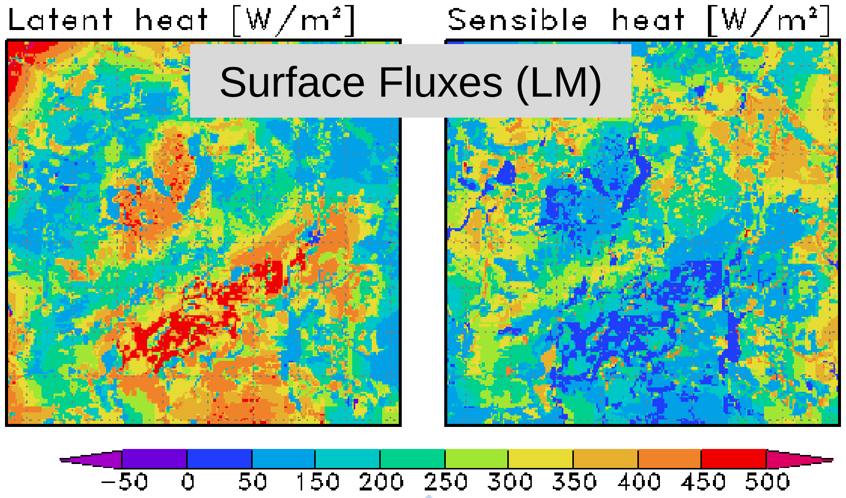
- Cold pools
- Generation of soil moisture variability
- User perspective: „Do I get wet?“ – Individual threats

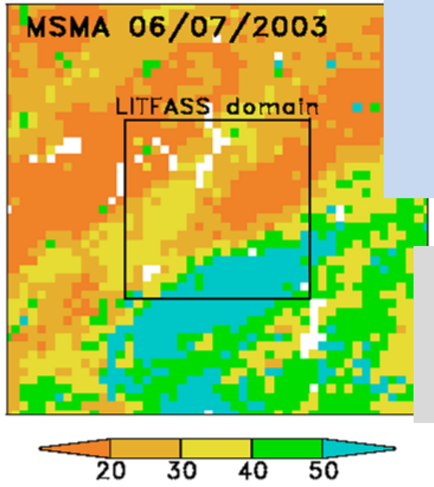
Anniversary of elderly cousine LITFASS 2003, 7 June 2003

Precipitation (Radar – two days before)



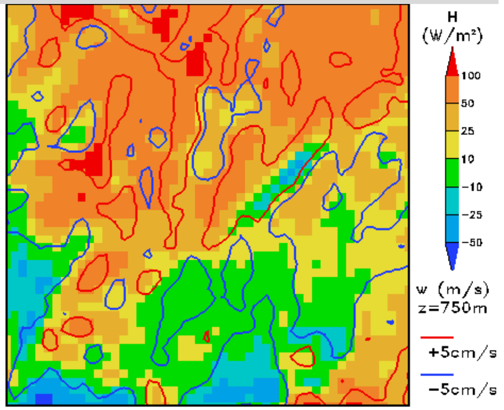
Surface Fluxes (LM)

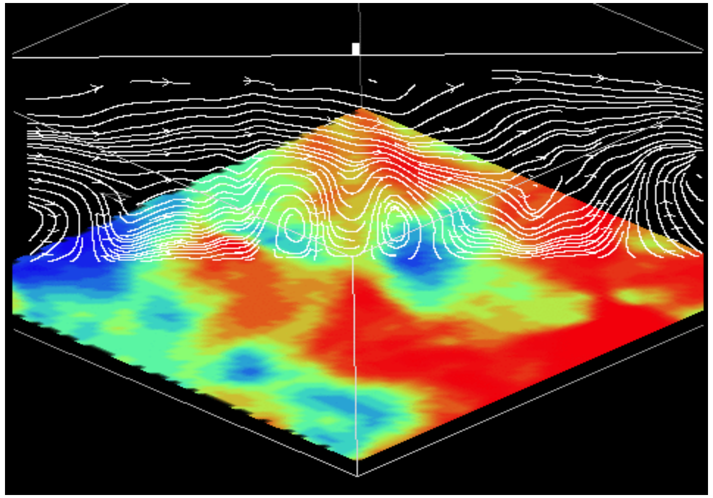




Relative root zone soil moisture

ABL circulation, (LM)

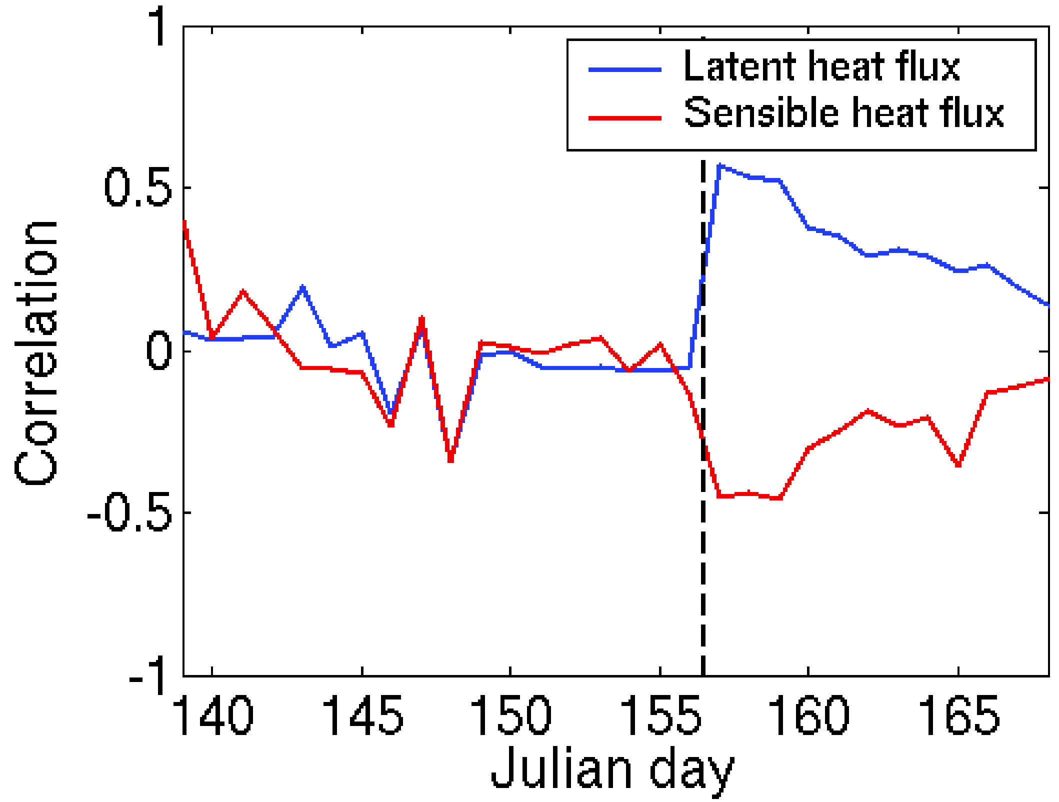




Anniversary of elderly cousin
Soil moisture memory

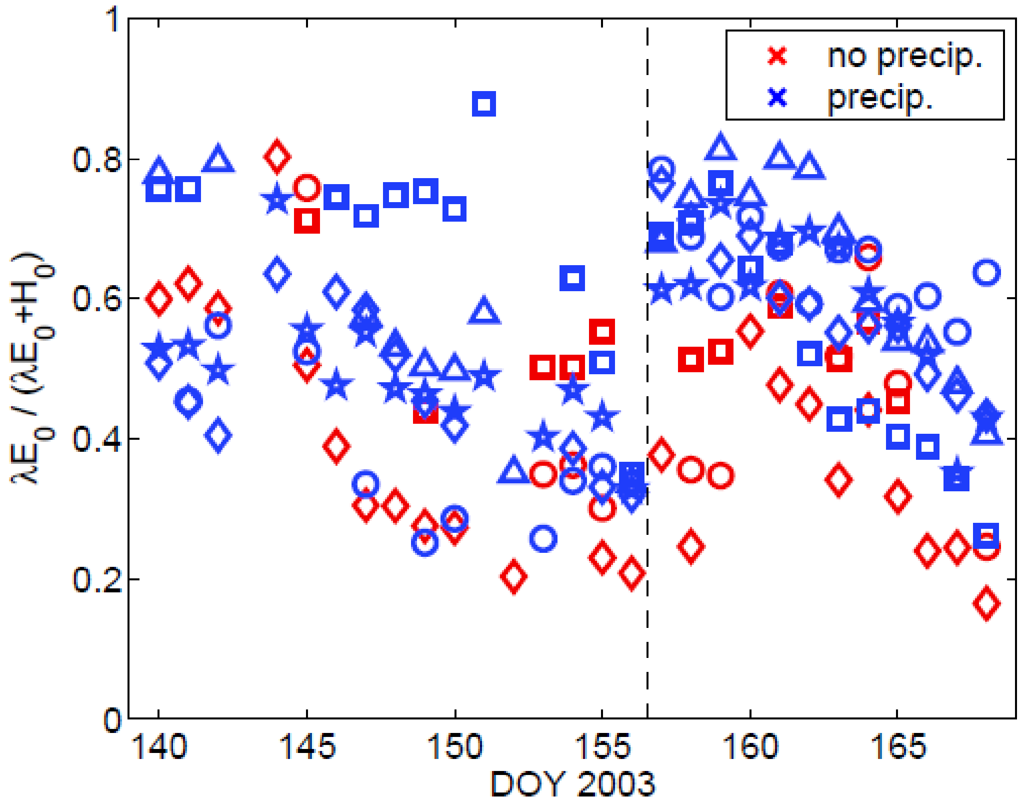
FESSTVaL

Modell - Pattern correlation



(Correlation of precipitation observed at day 156 with modeled turbulent fluxes.)

OBS – Evapotranspiration efficiency

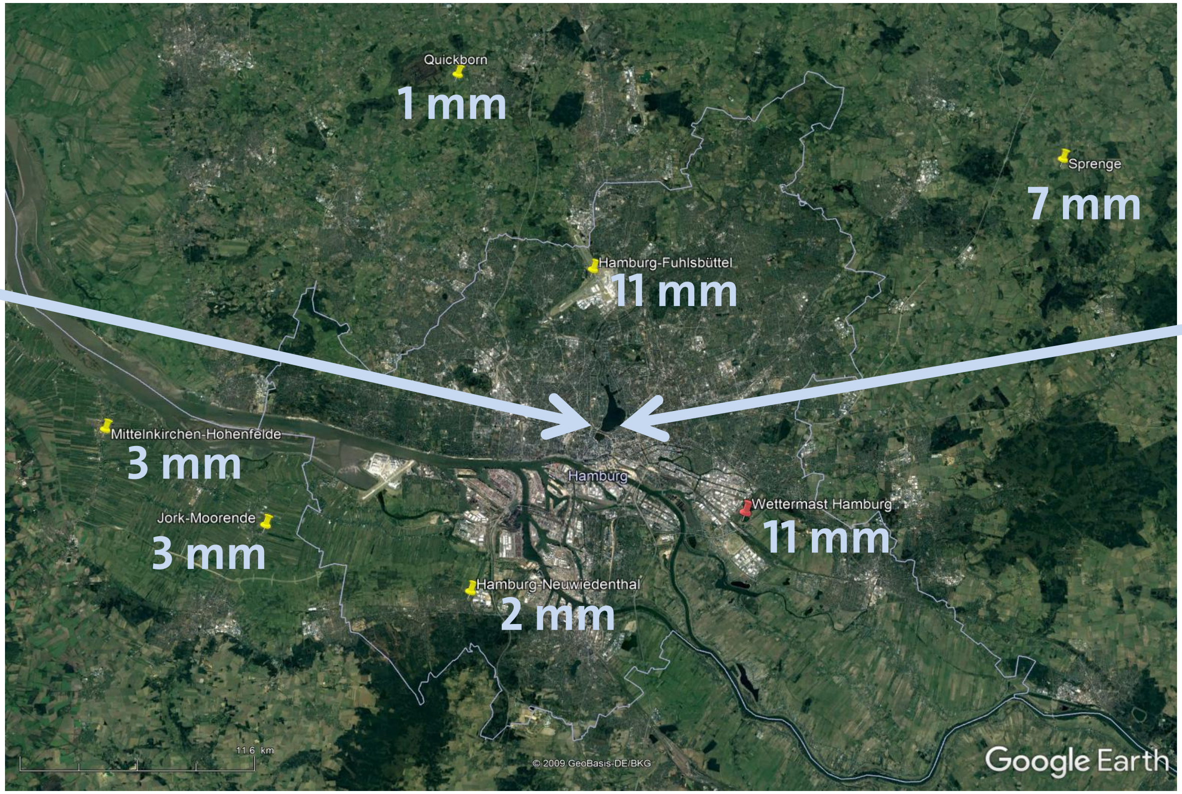


Urban case: 6 June 2011 @ Hamburg – locally some precipitation…

Daily sum @ weather stations

Subway station Gänsemarkt

(www.youtube.com/watch?v=FxHDCUEf0dM)

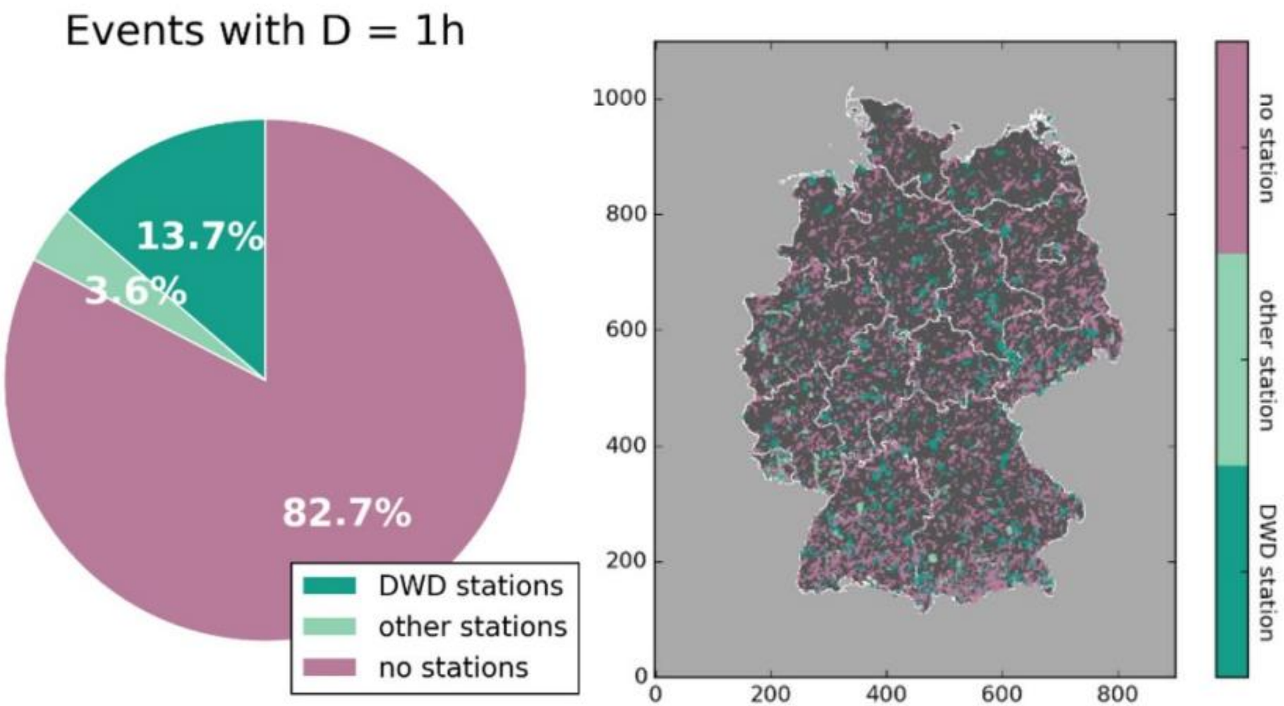


Mühlenkamp

(Hamburger Abendblatt)

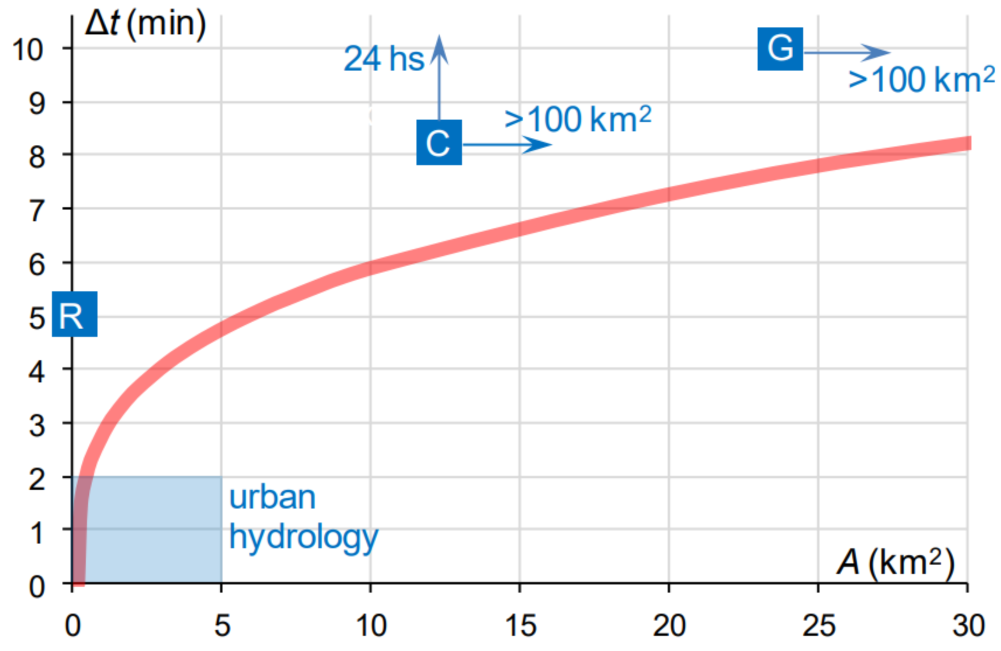
Spatial and temporal resolution

Heavy rain events (RR>25mm within 1h) overserved by gauge network?

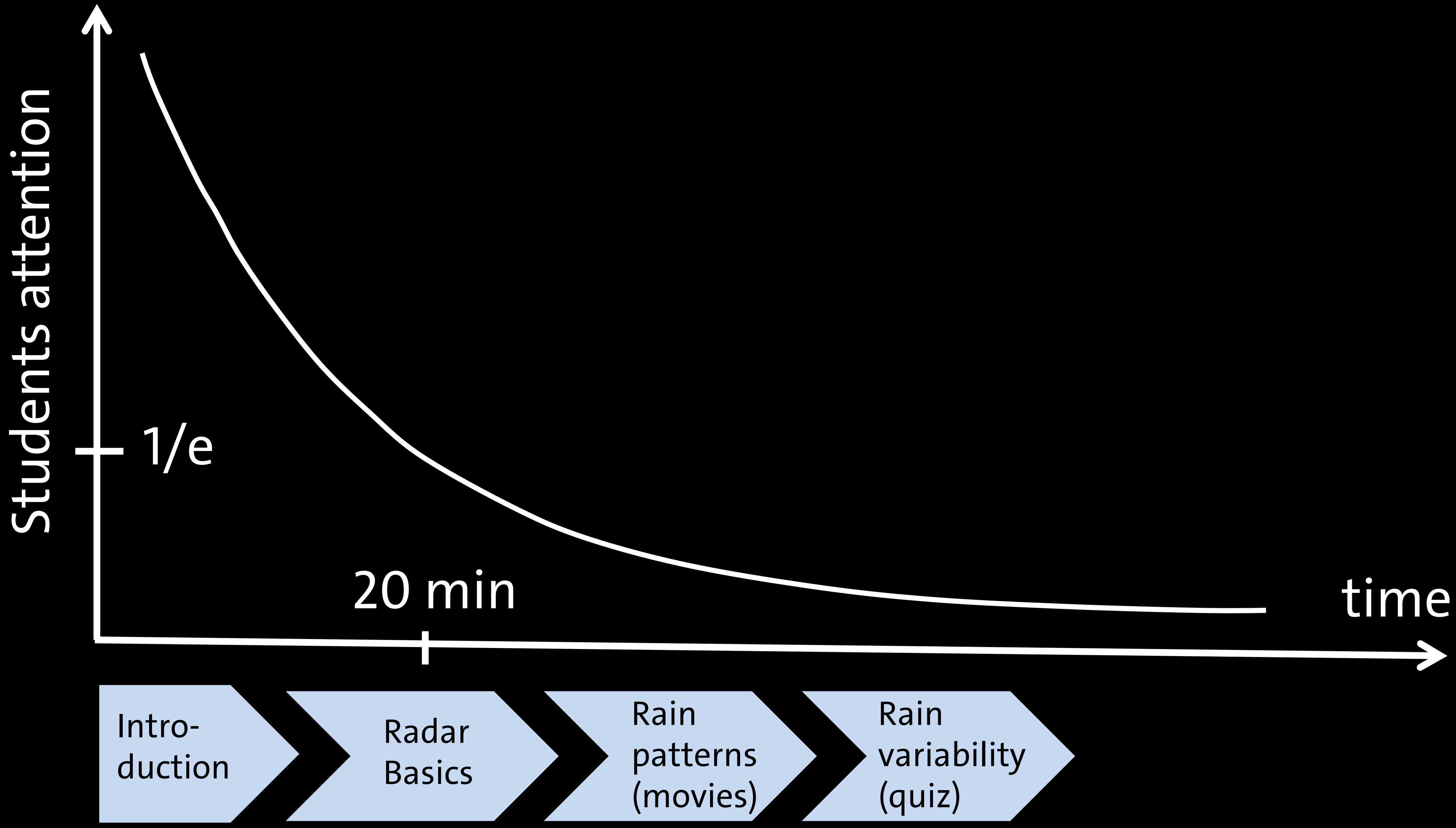


Lengfeld et al., Environ. Res. Lett. , 2020

Required temporal resolution depending on catchment area



Sokol et al., Remote Sensing , 2021

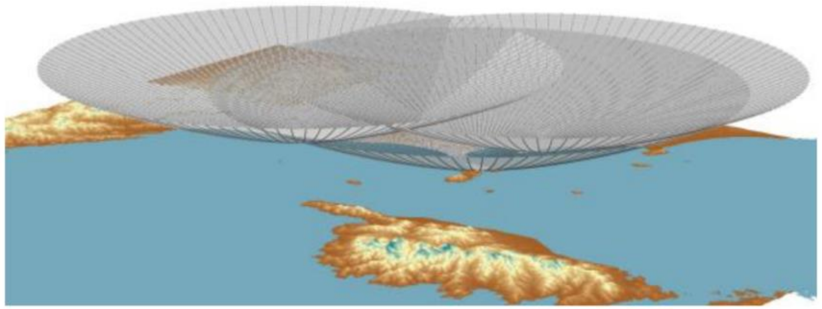


Students attention
1/e
20 min
time
Intro-
duction
Radar
Basics
Rain
patterns
(movies)
Rain
variability
(quiz)

RADAR - RAdio Detection And Ranging

- Emission of an electromagnetic wave, which is reflected at a target
- Time delay of echo determines range
- Received signal is used to characterize the target
- Usually, azimuthal scans

(Weatherradar Universität Bonn, old one)

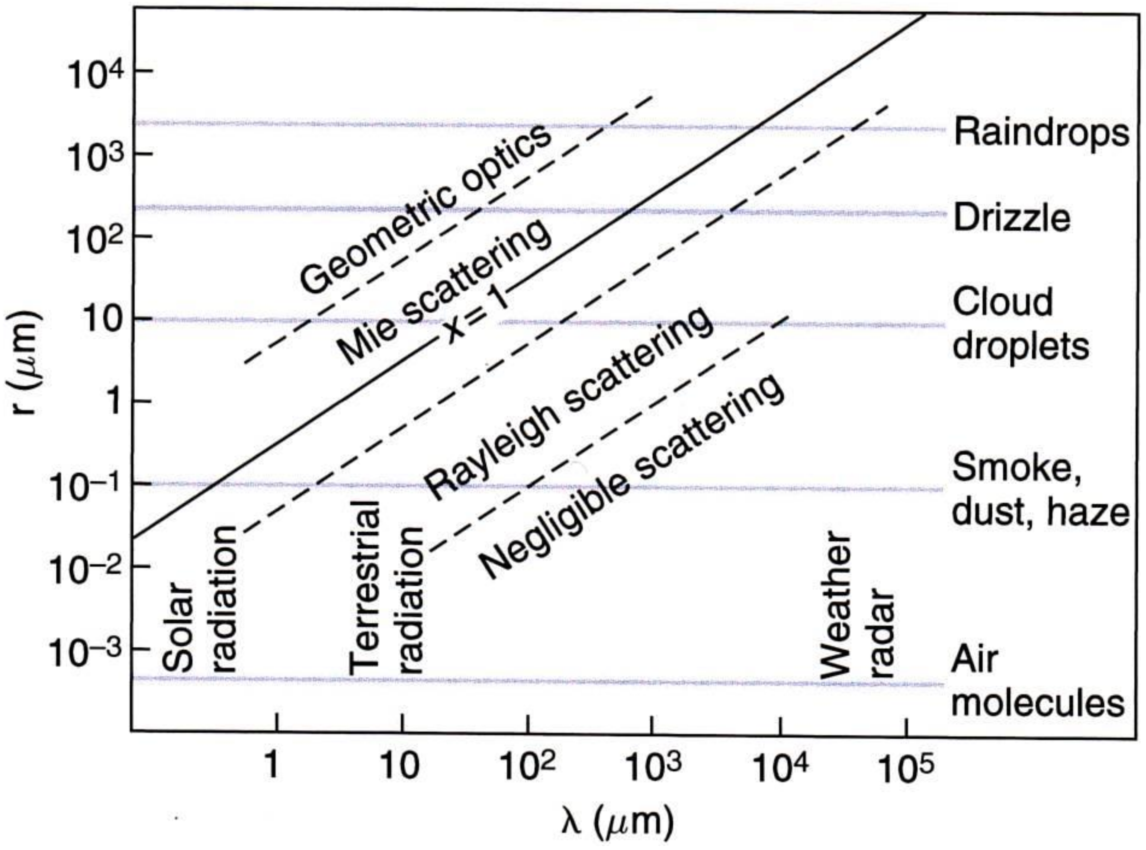


(Antonini et al, Atmosphere , 2017)

Targets of precipitation radar

- Ratio of particle radius and wavelength determines scatter regime
- Rayleigh scattering: reflectivity factor *Z* is proportional to the sixth power (D^6) of the drop size diameter *D*.

	λ cm	ν GHz	*l* m
S-band	8–15	2–4	6–10
C-band	4–8	4–8	3–5
X-band	2.5–4	8–12	1–2

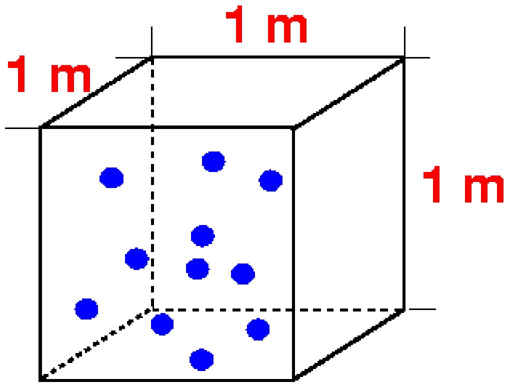


(aus Wallace and Hobbs)

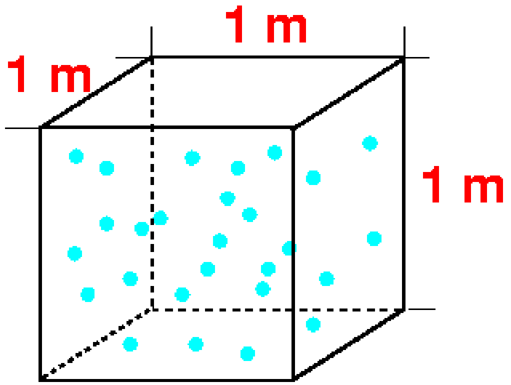
Radar uncertainty
„What are 3dB (=factor of 2) among friends?“

Idealized Example

D = 1 mm
N = 100 drops



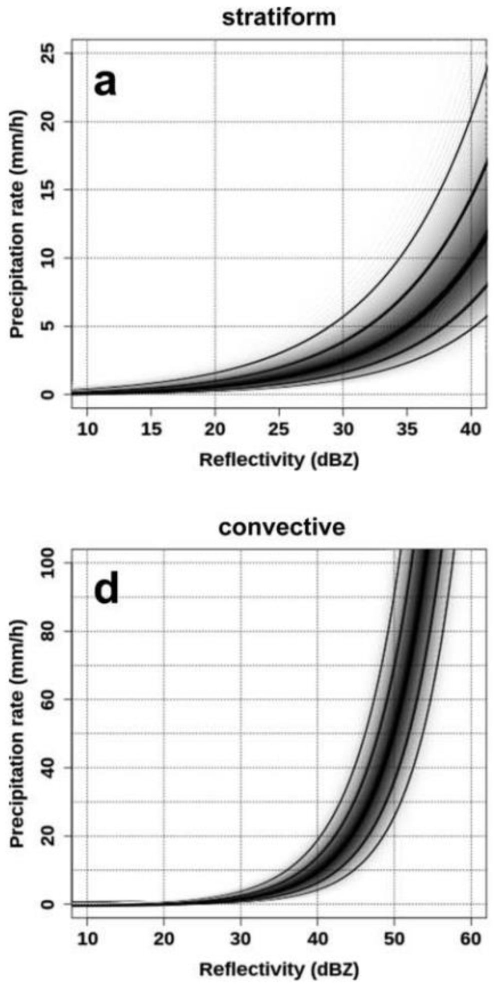
D = 0.5 mm
N = 6400 drops



Similar radar reflectivity (~D^6), but ...

$\mathbf{m_w}$= 52 mg H20
R = **0.8 mm/h**

$\mathbf{m_w}$= 418 mg H20
R = **3.1 mm/h**

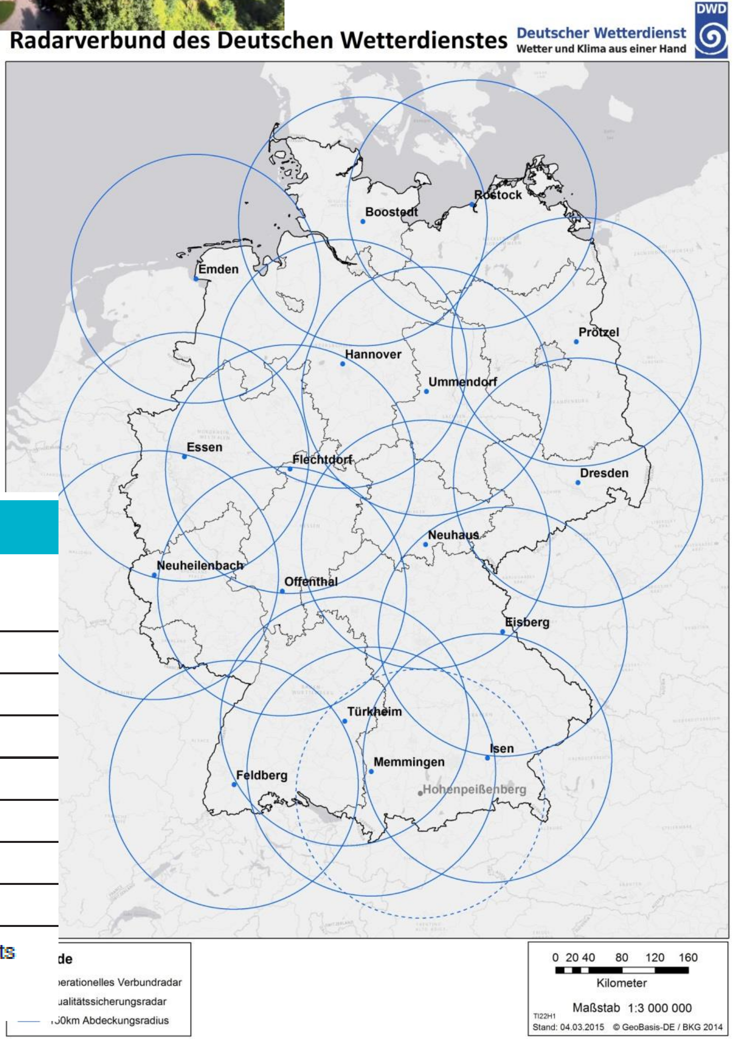


Kirstetter et al., Water Resour. Res., 2015

C-Band Radar Network by DWD

- C-Band-Radar
  (~5 cm wavelength)
- 5 m diameter of dish
- 10 rotation per minute
- ~200 km range
- Operational resolution:
  250m – 1km; 5 min
- Doppler & Dual-
  Polarization

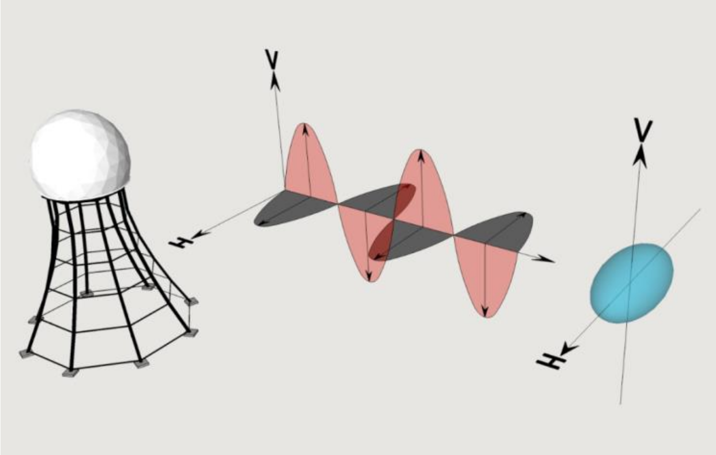
SYSTEM	DWSR-5001C
Operating Frequency	5400 - 5900 MHz
Pulse Width	0.2 - 3.0 usec
Range Resolution	Minimum 16m
Pulse Repetition Frequency	200-2400 Hz, user selectable
Range	Minimum 600km
Maximum Velocity (unambiguous)	up to 128 m/s
Sensitivity-reflectivity	- 22 dBz at 30 km
Clutter Suppression Capability	≥ 46 dB
Data Output	UZ, Z, V, SW (dual-polarization moments Zdr, Phv, Φdp, KDP, LDR)

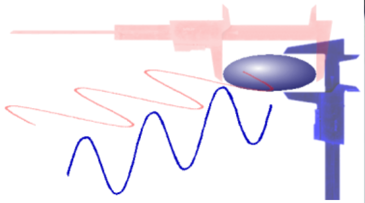


Dual-Polarization

Principle

Emission of pulses with different polarization and separate measurement of the received signal in both polarization directions.

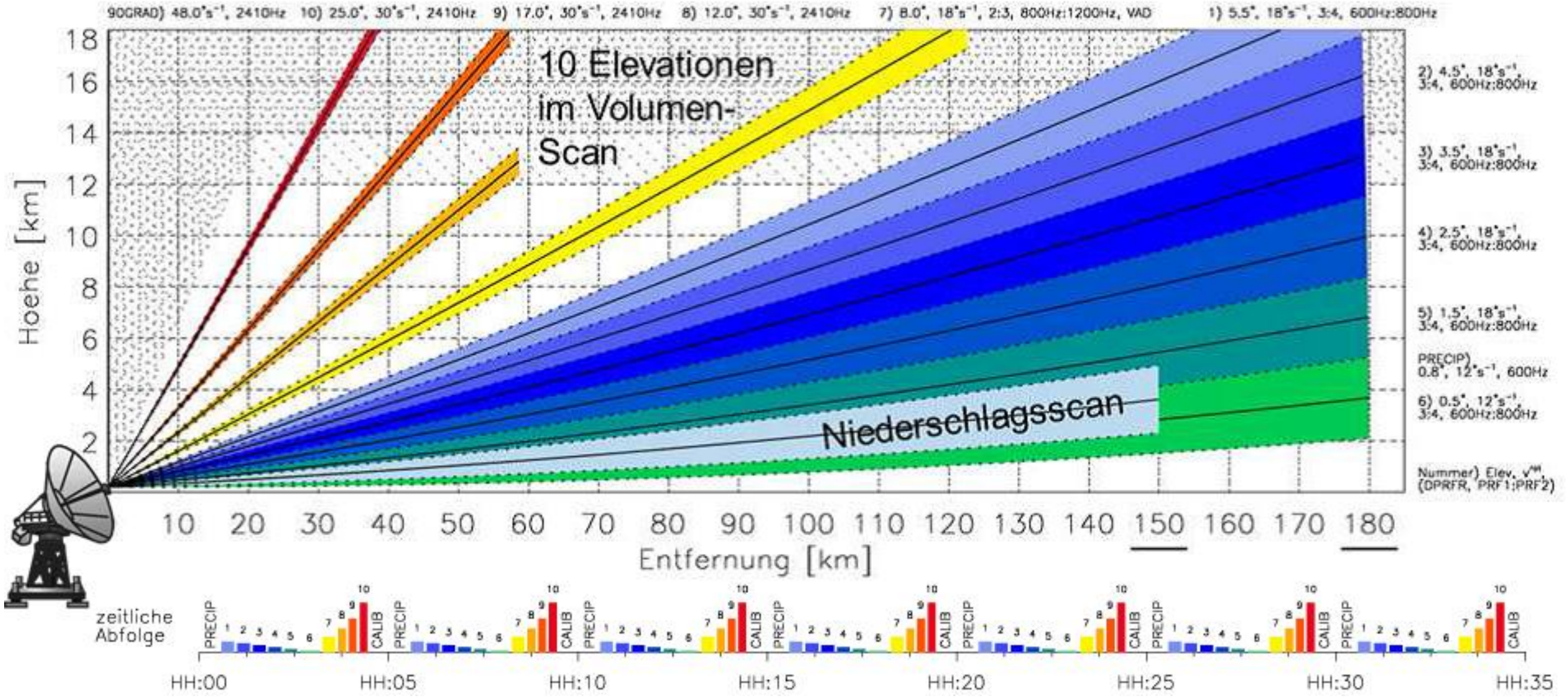




	Definition	Application
Differential reflectivity Z_{DR}	$10\log_{10}\frac{z_{HH}}{z_{VV}}$	Separation between small and big droplets
Linear depolarisation ratio *LDR*	$10\log_{10}\frac{z_{HV}}{z_{HH}}$	Deviation from a sphere ➔ phase detection; detection of bright band
Differential phase Φ_{DP}	$\Phi_{DP}=\Phi_{HH}-\Phi_{VV}$	To water load -> correction of attenuation

➔ 15 June, talk by Clemens Simmer (in German). Please register at https://norddeutschland.dmg-ev.de/

Scan Strategy



(DWD Website)

Local Area Weather RadarII

Self-made X-Band Radar

- 24 rotations / min.
- ~4° fixed evelation
- 67 pulse per °
- 30s integration period

Local Area Weather Radar II

Self-made X-Band Radar

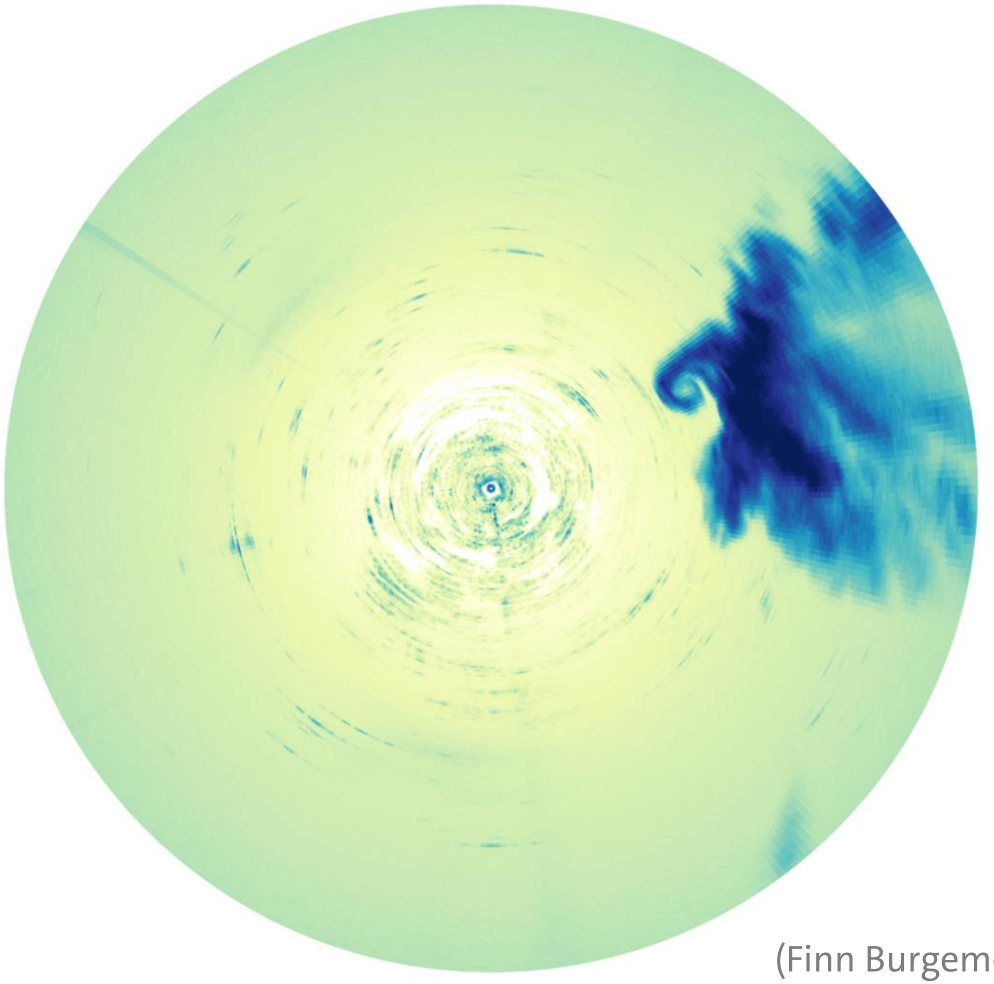
FESSTVaL

- Basis: Ship navigation radar
- 3.1 cm wavelength (X-Band)
- 25kW peak power
- 20 km range
- 60 m range resolution
- 1° azimuthal resolution

What does the radar observe?

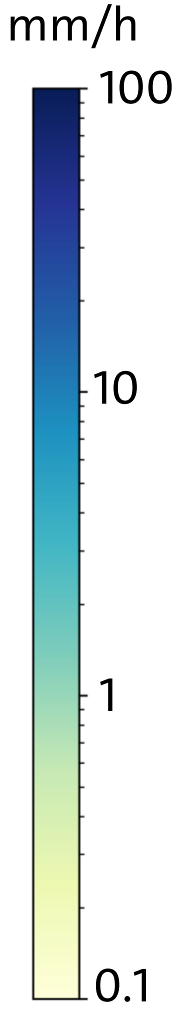
Example: raw data transformed to mm/h

- Noise – widespread, apparently increasing with range
- Fixed echoes
- Dynamical non-meteorological echos (e.g. rings)
- Attenuation

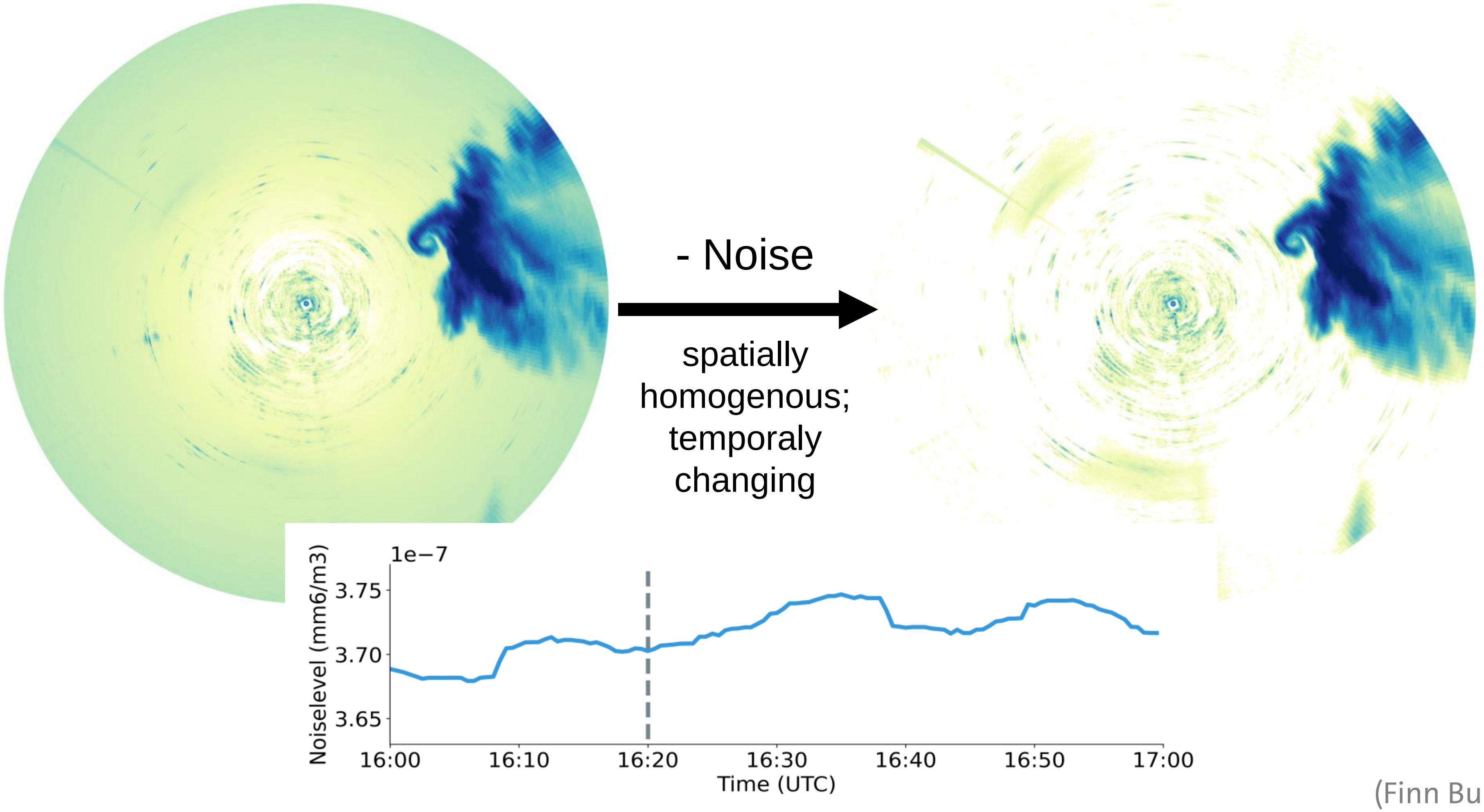


(Finn Burgemeister)

- Rainfall ...
- Including heavy precipitation ...
- and a tornado!



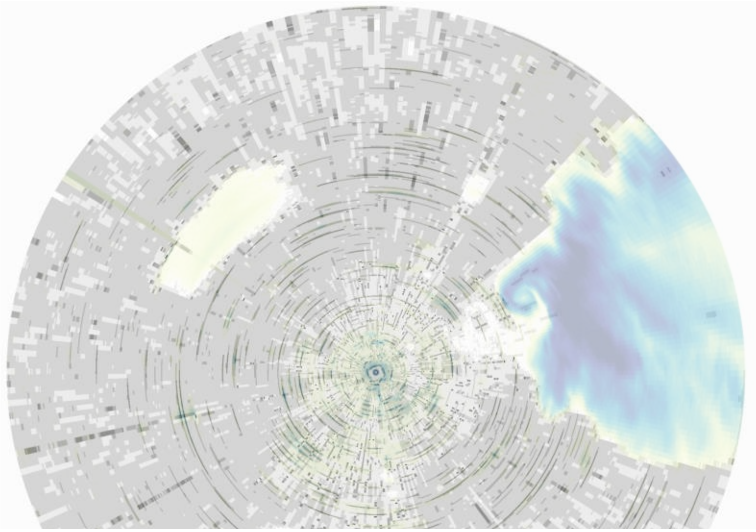
Data processing – Step 1
Subtracting noise



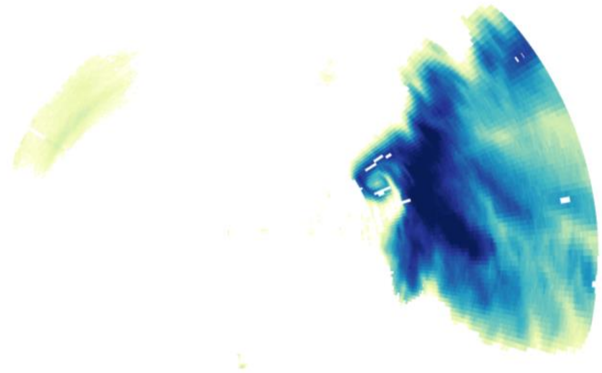
(Finn Burgemeister)

Data processing – Step 2

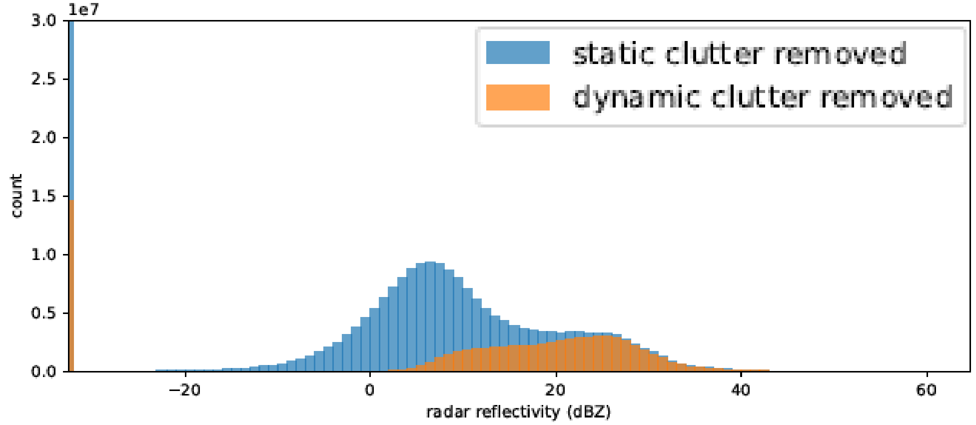
Dynamical detection of non-meteorological signals

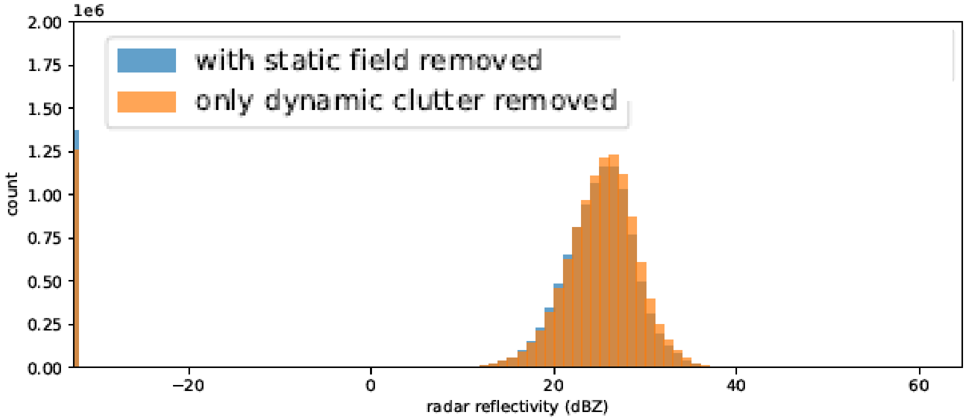


Removal of clutter



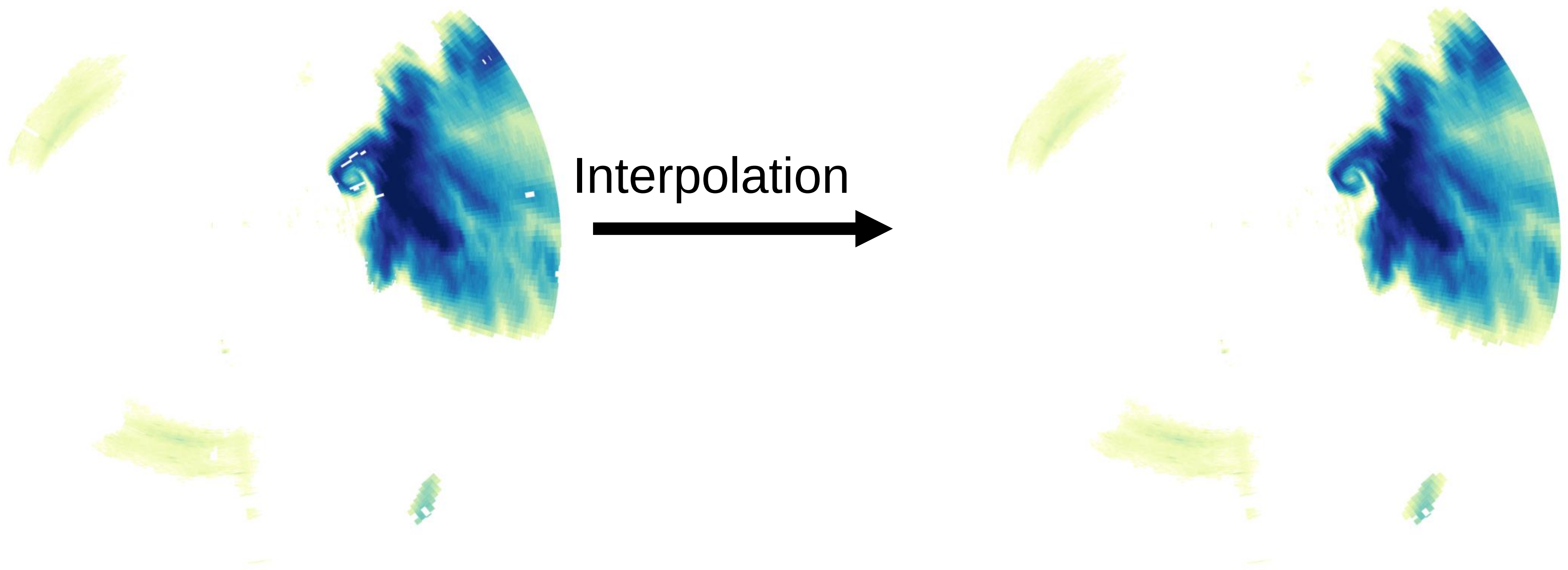
(Finn Burgemeister)





➔ Dynamical Clutter is dominant (typical for urban area?)

Data processing – Step 3
Interpolation

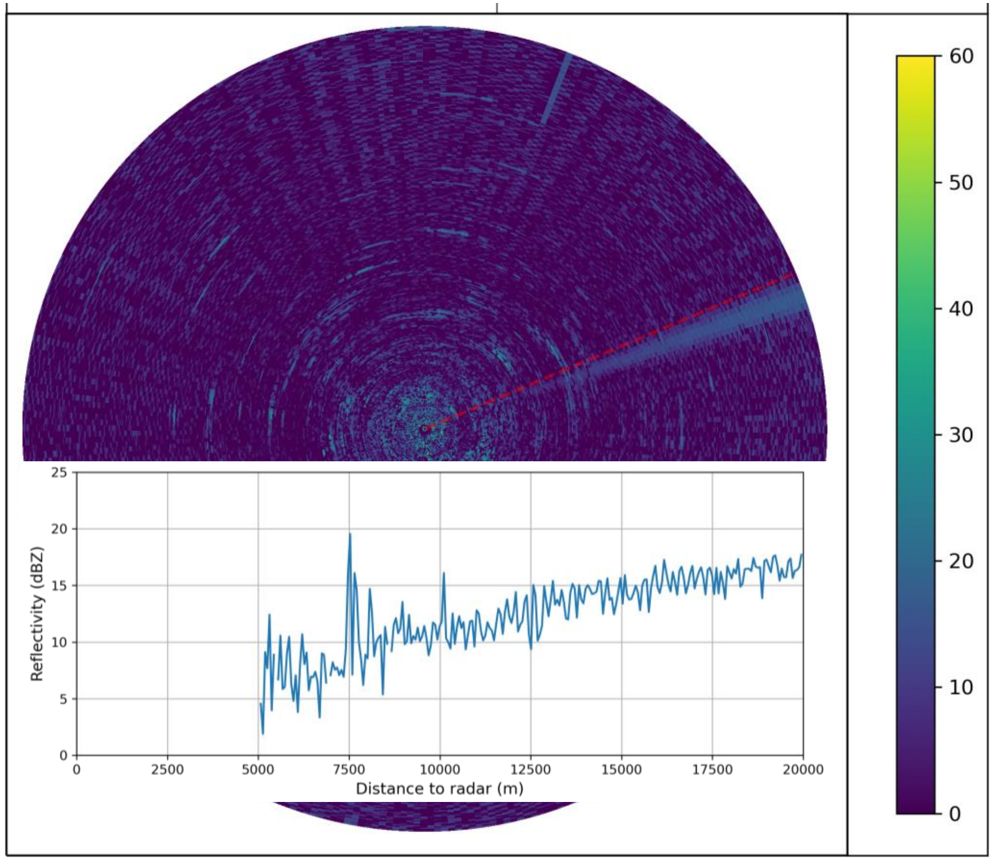


(Finn Burgemeister)

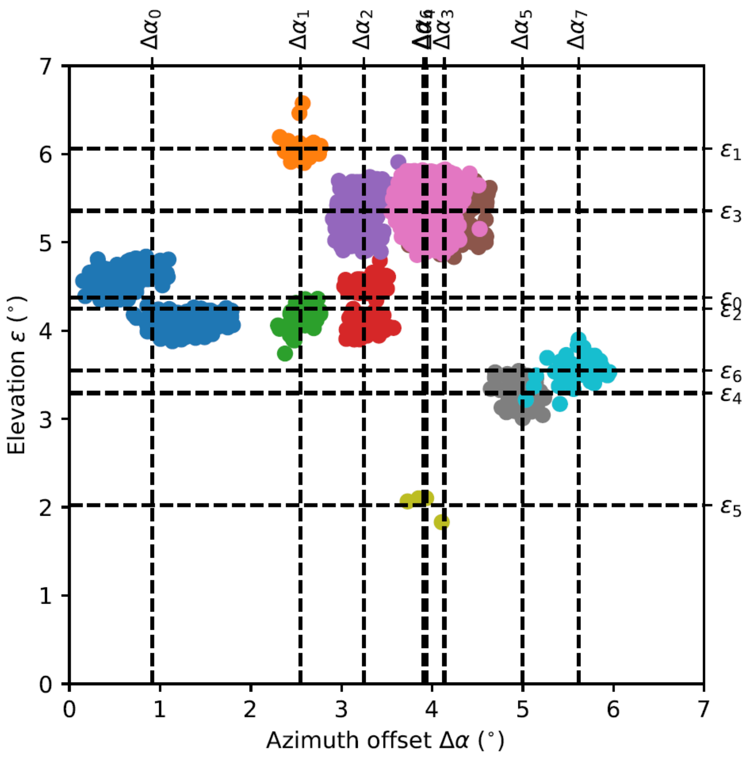
Adaptive Kriging including time-dependent update of parameters

Data processing – Step 4
Alignment & Calibration

Identification of Sun Spikes



Alignment 2013-2021



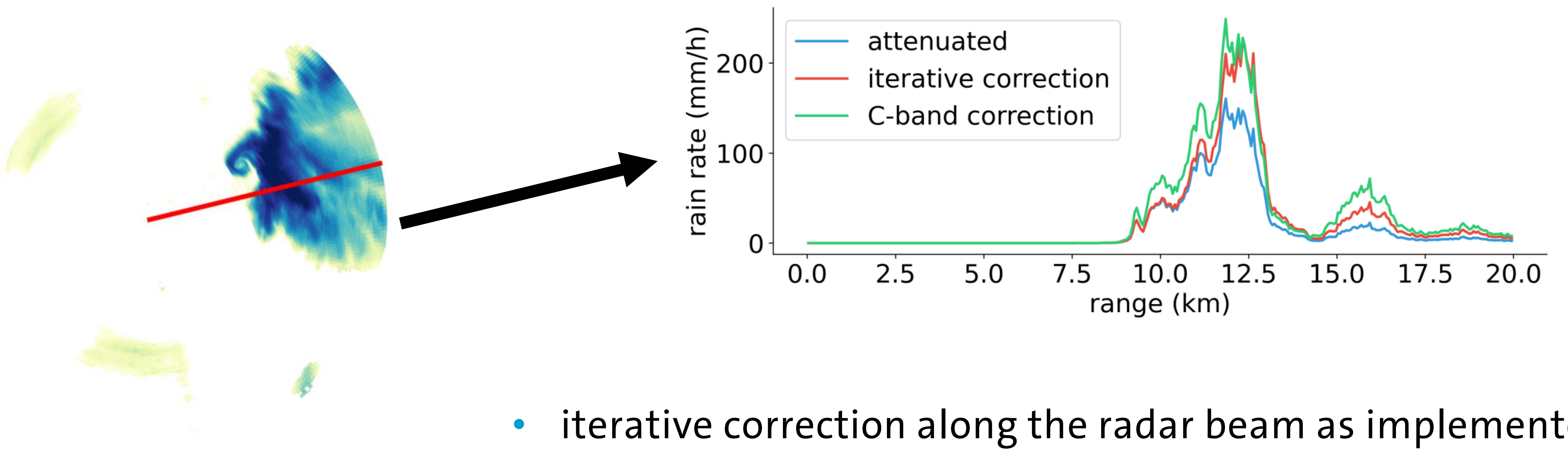
(Finn Burgemeister)

Field calibration

- Calibration of a vertical pointing micro rain radar (MRR) using rain gauges
- Calibration of the X-Band Radar at beam height using the MRR

Data processing – Step 5

Correction for attenuation



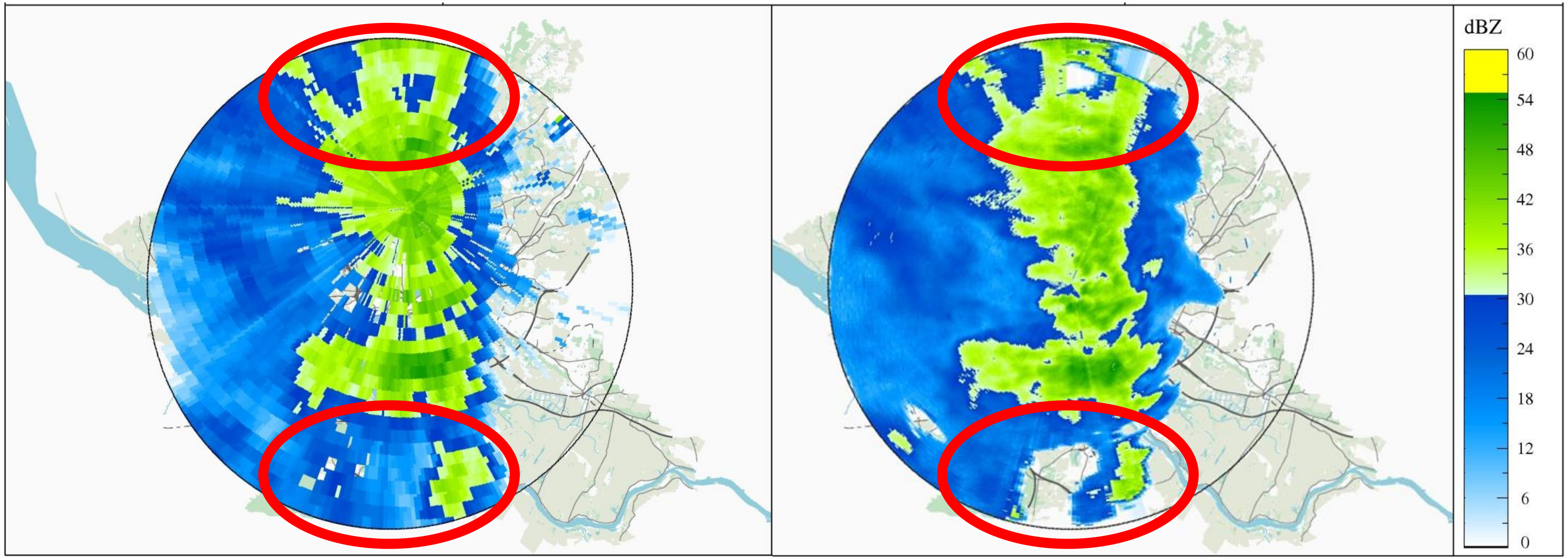
- iterative correction along the radar beam as implemented in *wradlib* (Heistermann, Jacobi and Pfaff, 2013)
- optionally: correction by less attenuated DWD C-Band Radar using isotonic regression (Lengfeld et al., 2016)

Data processing – Step 5

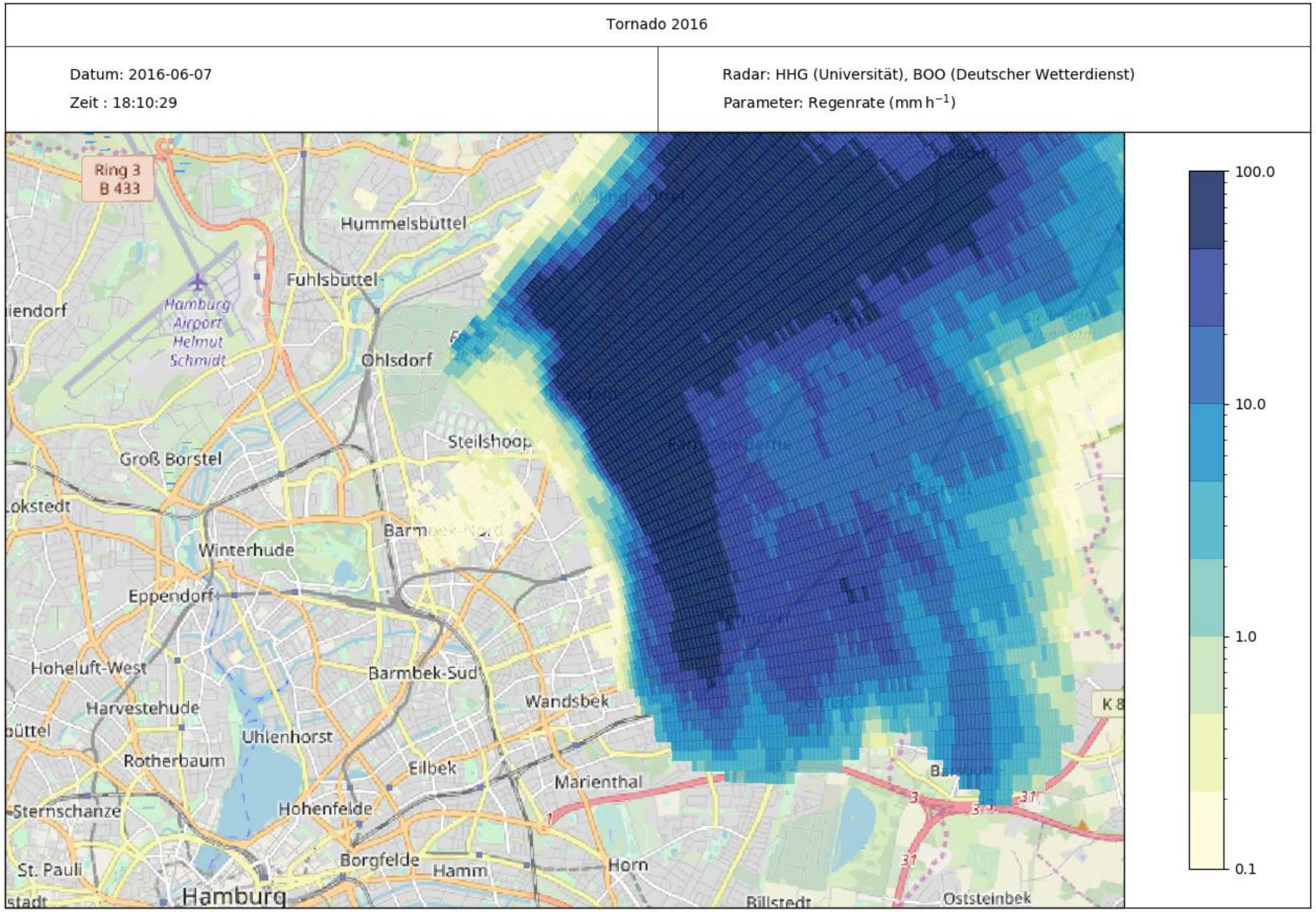
Correction for attenuation using the C-Band radar

C-Band Radar Hamburg

X-Band Radar Hamburg



Tornado at 7 June 2016



Radar Basics – Take home messages

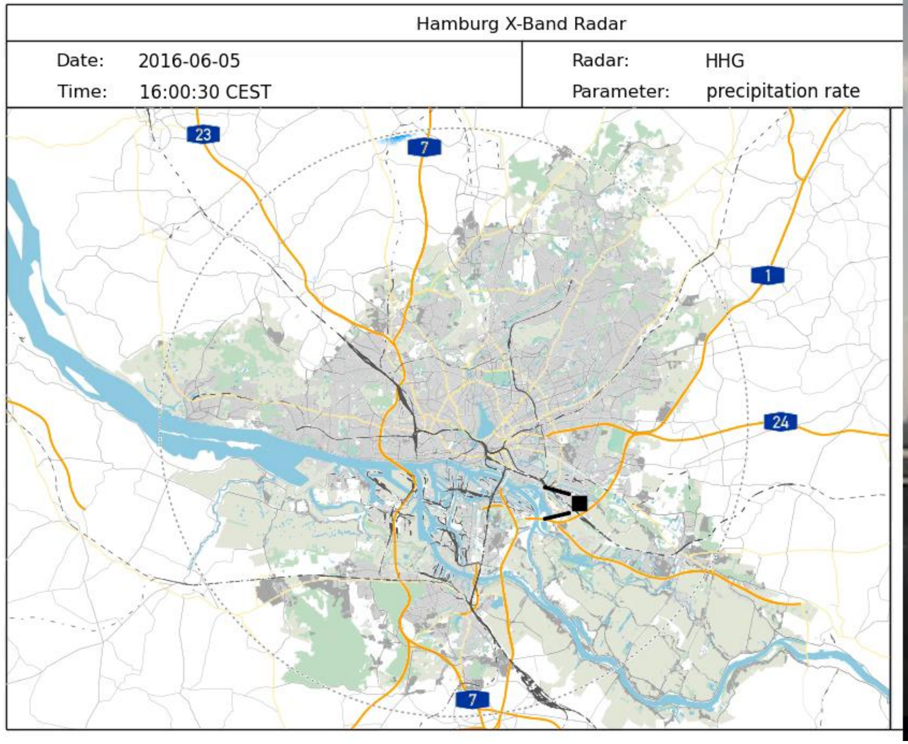
Full areal coverage of precipitation rate, but with many **uncertainties**:

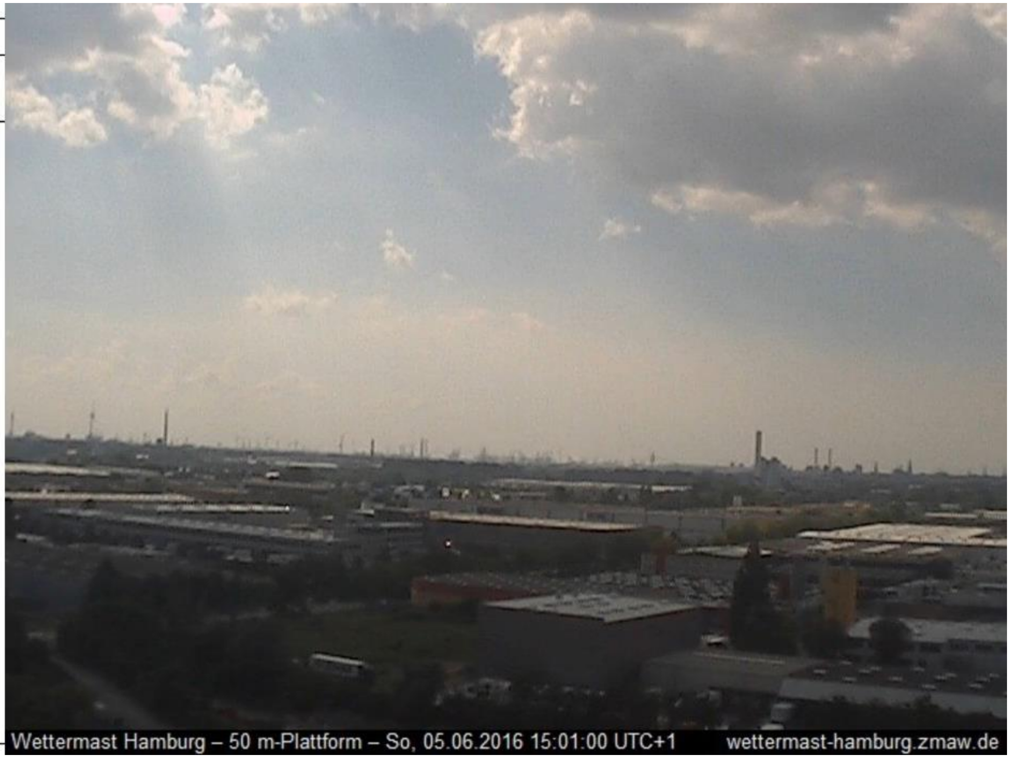
- Scanning cone
- Uncertain relation between reflectivity and rain rate; phase of precipitation
- Clutter and Noise
- Calibration, Attenuation
- …

Advantages operational C-Band: additional Doppler and polarimetric information, volume information

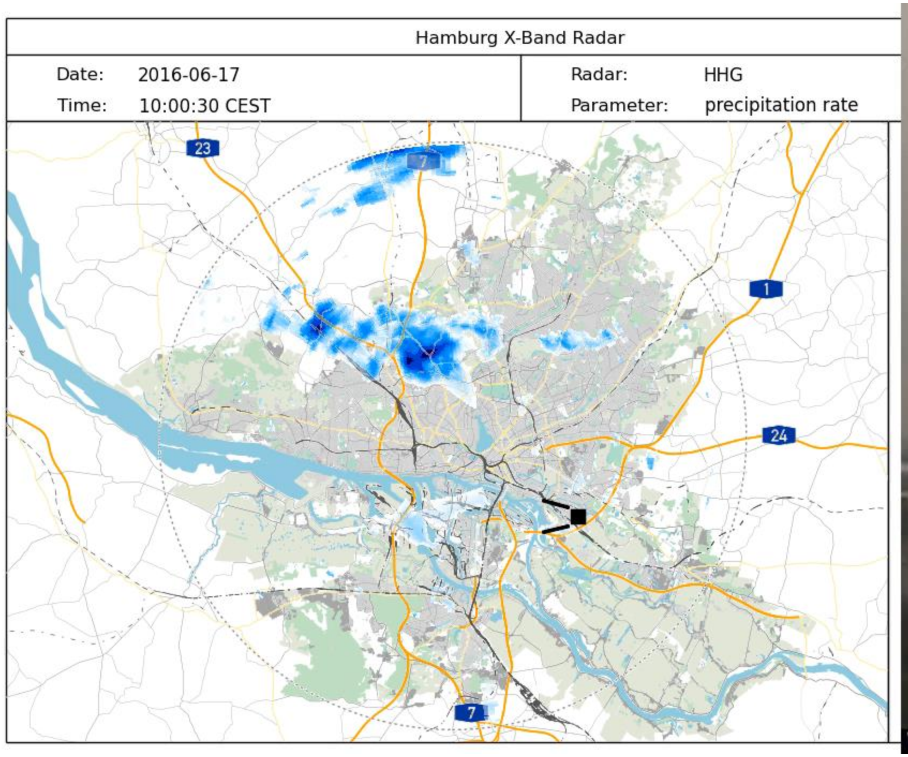
Advantages LAWR (X-Band): rapid scanning, small antenna + cheap

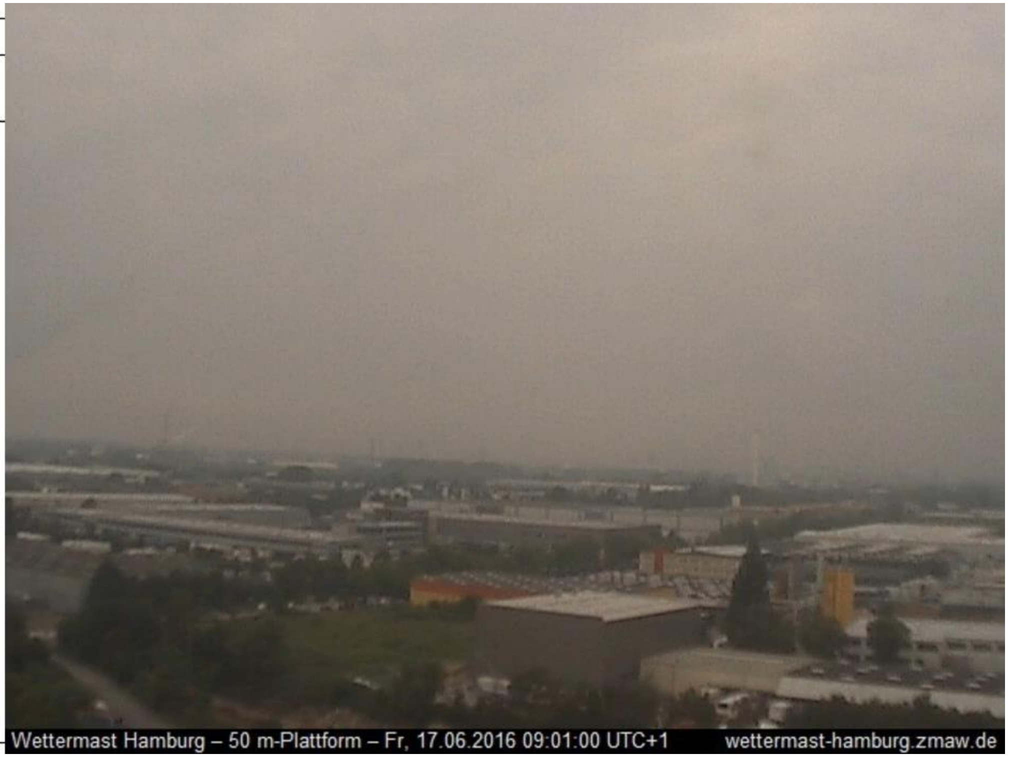
5 June 2016, afternoon - cloud burst



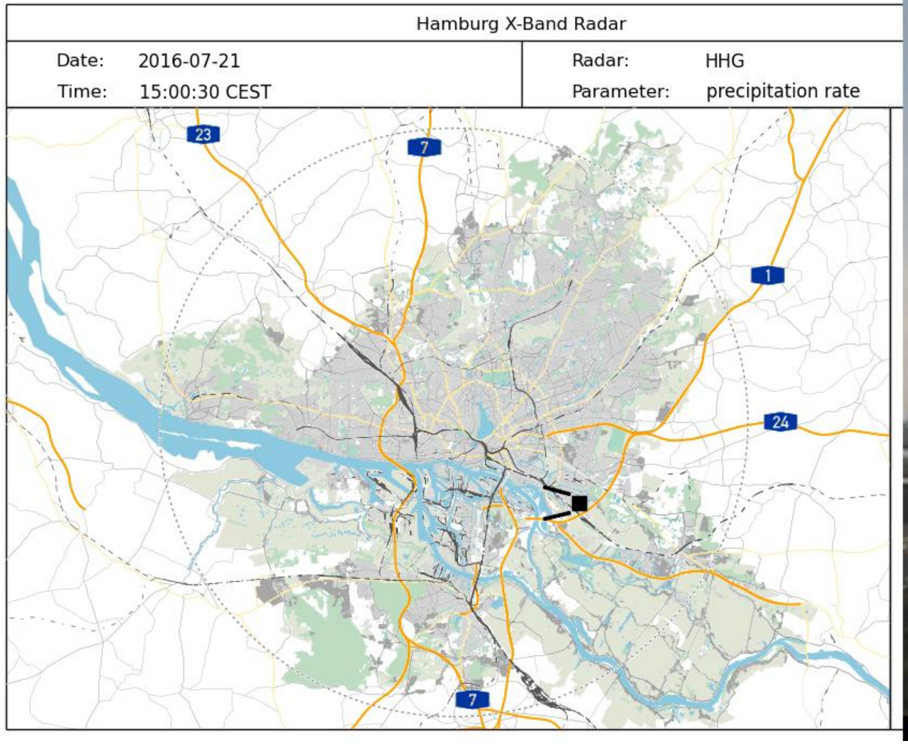


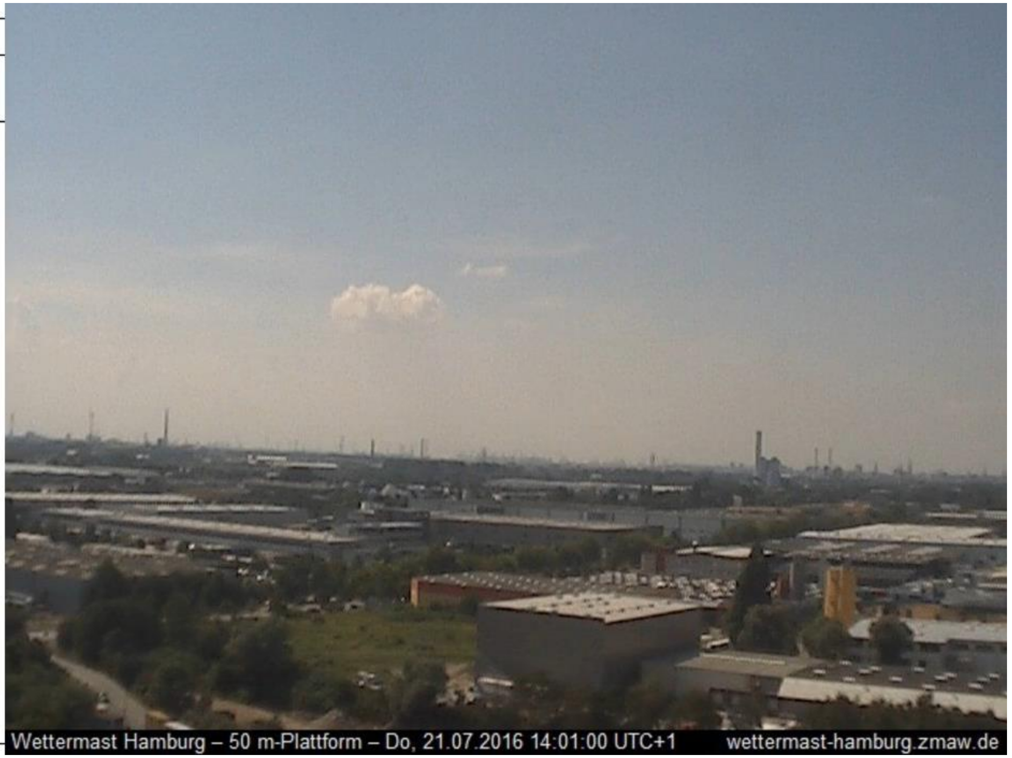
17 June 2016, morning –
all gray = rain everywhere?





21 July 2016, afternoon – local thunderstorms

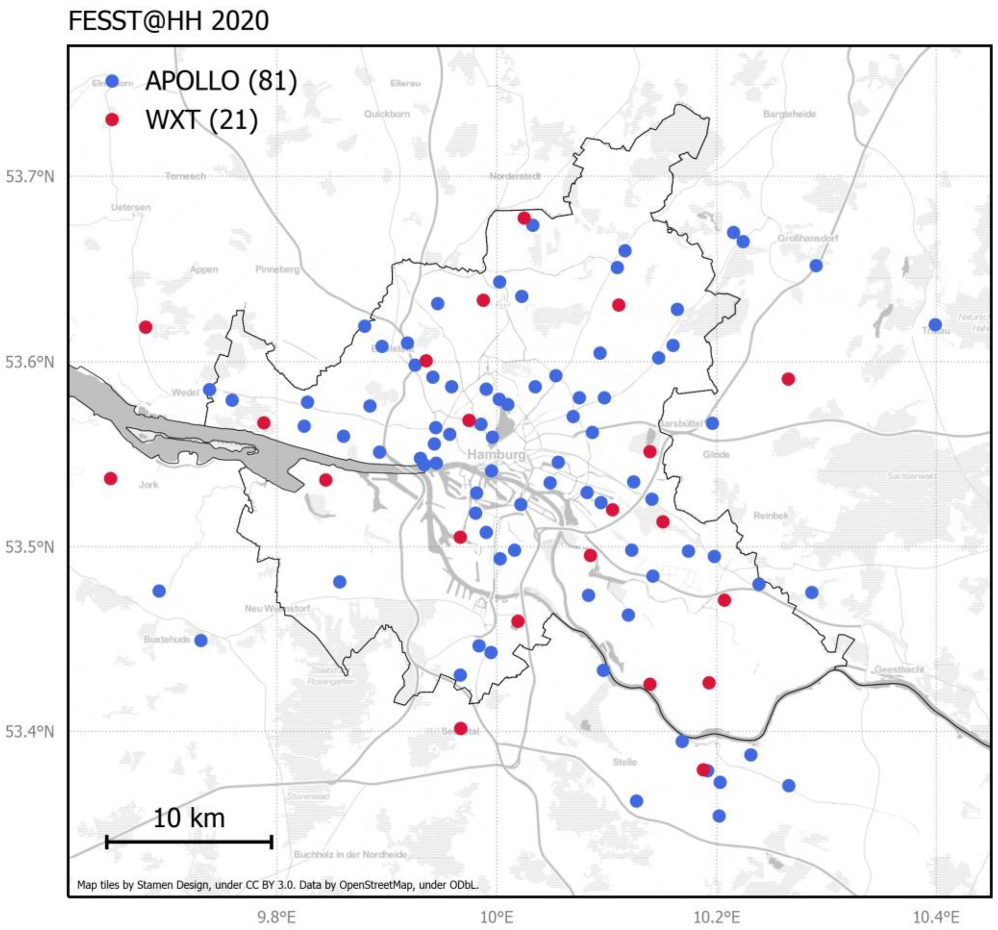




FESST@HH
- HomeOffice PreCampaign at Summer 2020

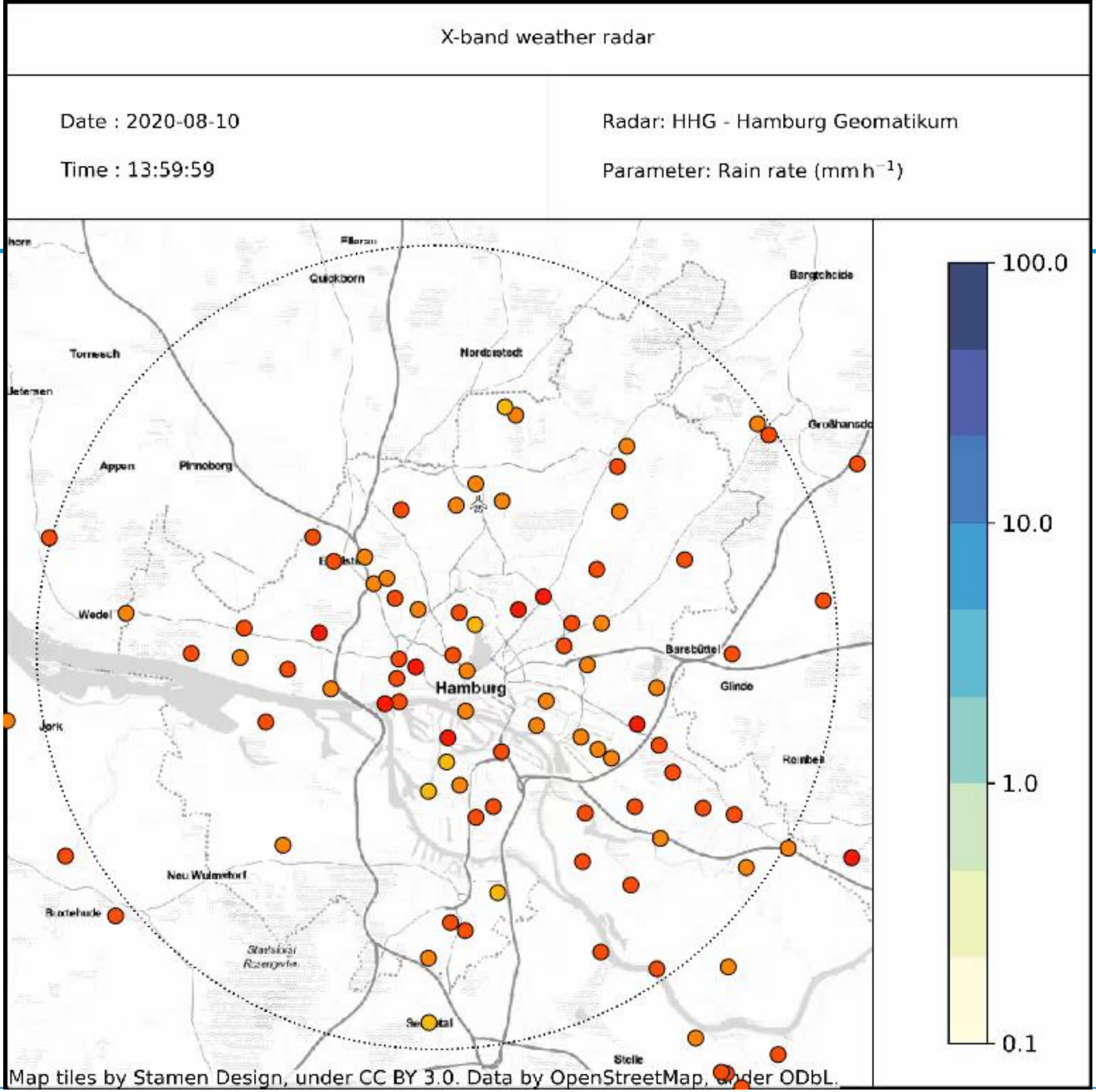
Apollo @ 1s
T, p

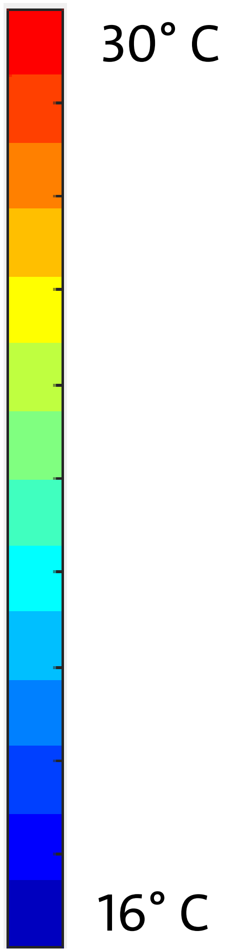
WXT @ 10s
T, p, RH, v_h, RR



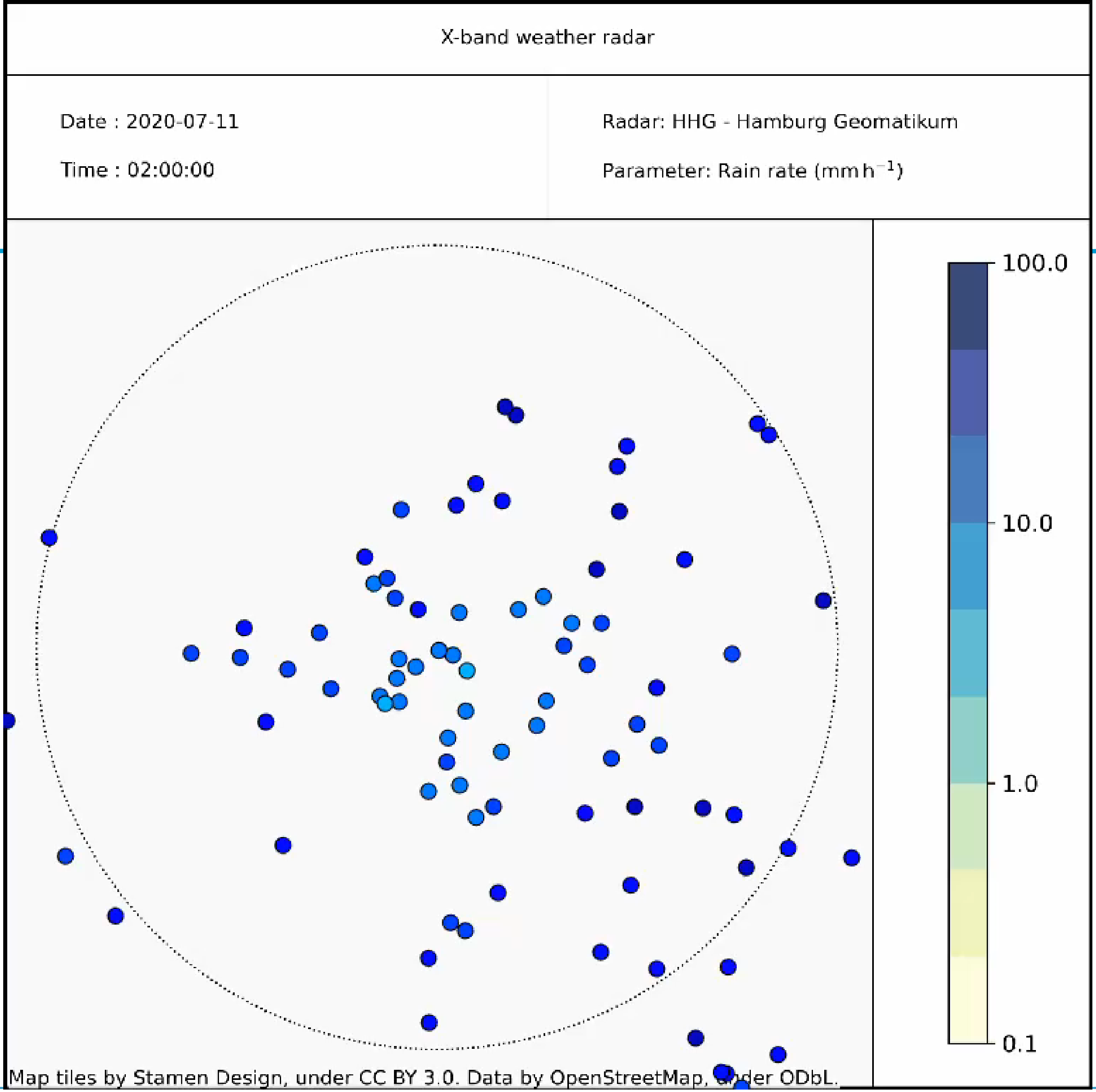
(Bastian Kirsch)

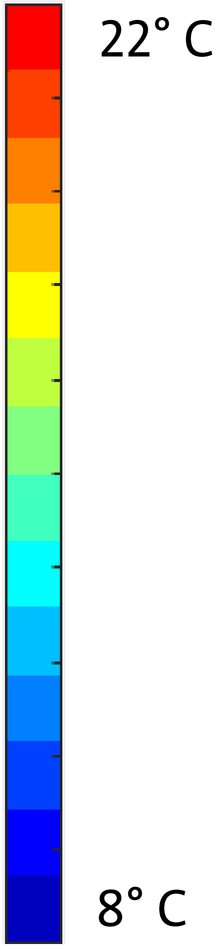
FESST@HH
10 August 2020





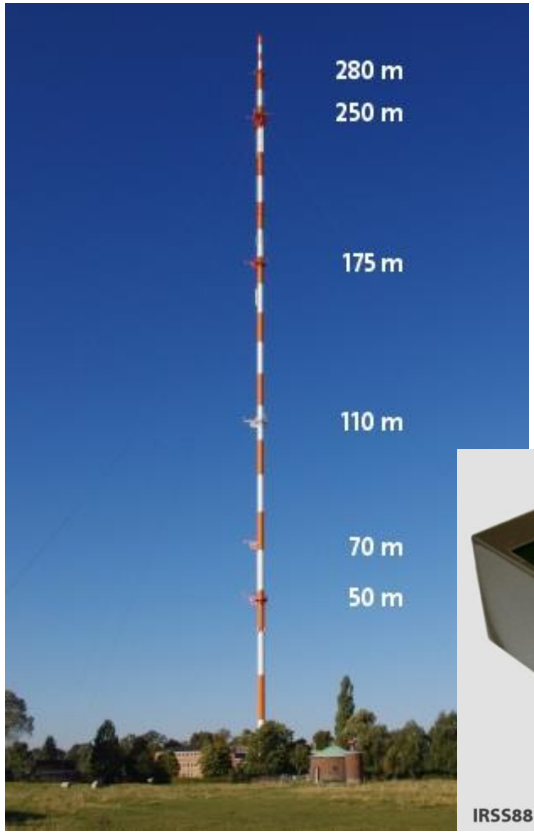
FESST@HH
11 July 2020





Precipitation statistics at Hamburg

Wettermast Hamburg

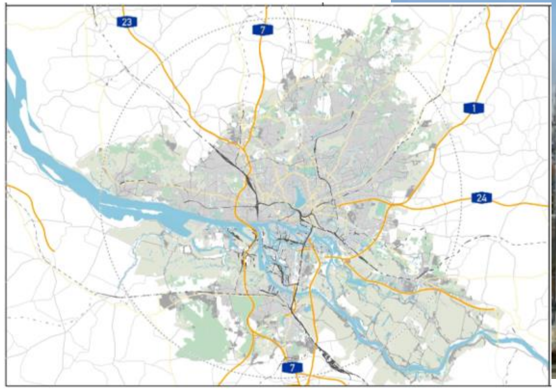


- Precipitation detector IRSS88
- Measurement every second 2010-2019

http://wettermast.uni-hamburg.de

Wetterradar Hamburg

- 20 km range
- 60 m range resolution
- Summer 2019

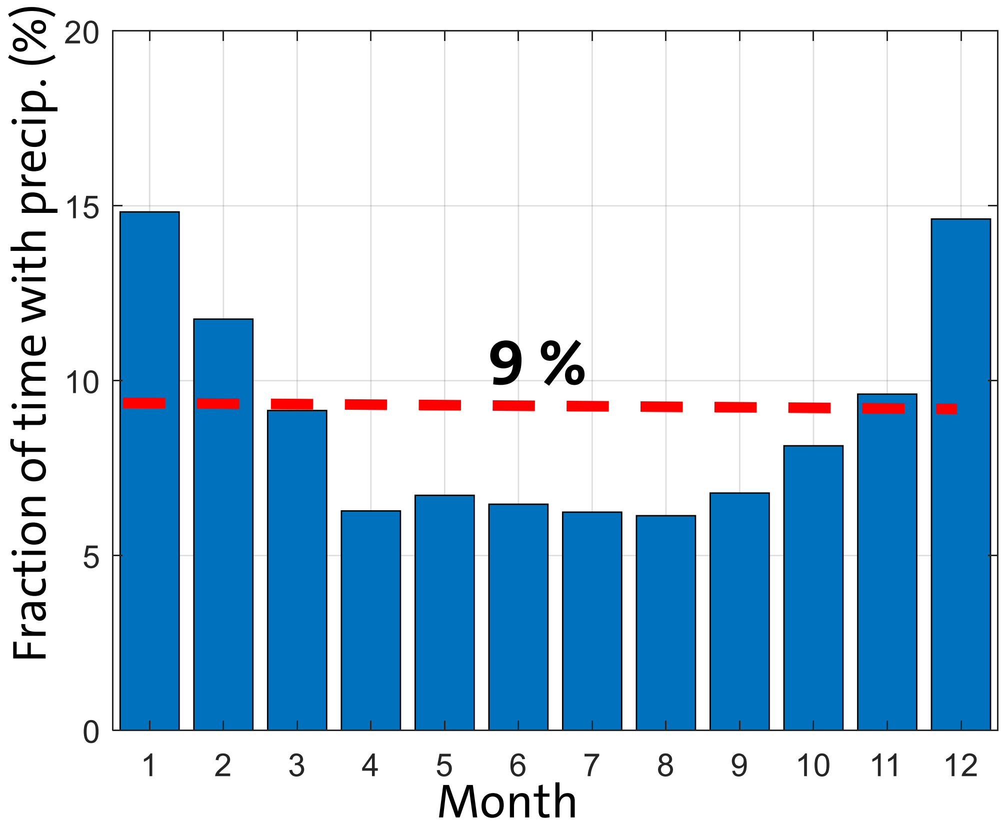


http://wetterradar.uni-hamburg.de

How often do we experience precipitation at Hamburg in Summer 2019?

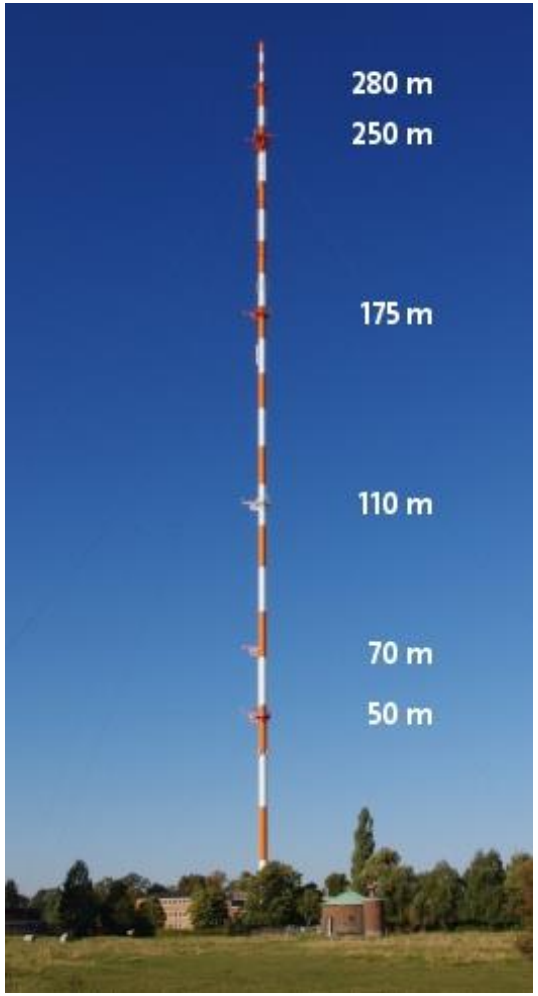
- A 0.01 %
- B 4 %
- C 21 %
- D 53 %

How often is rainfall at Hamburg?

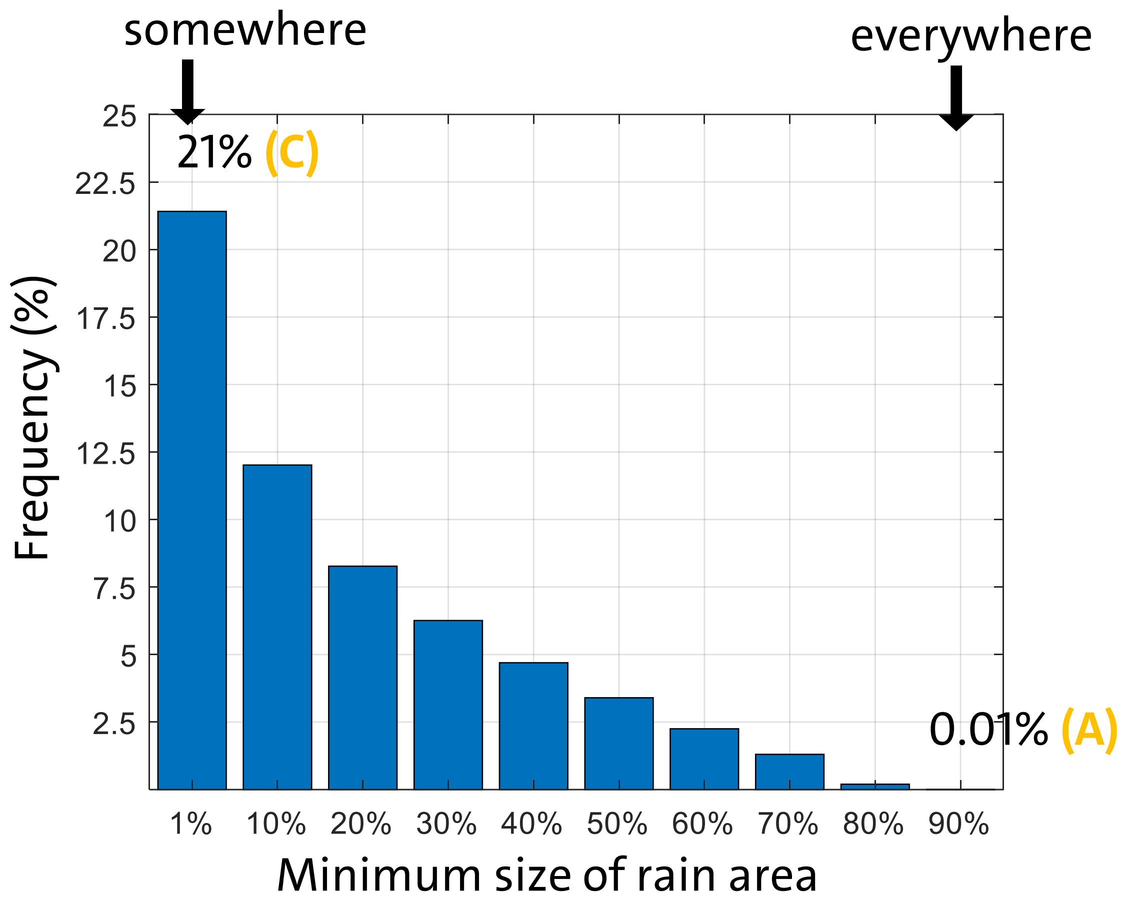


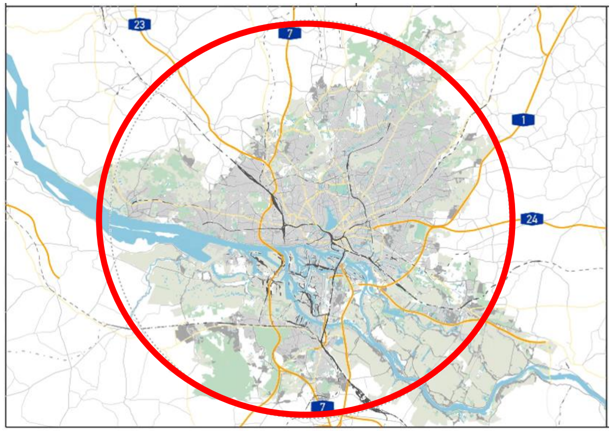
- Point measurements
- Period 2010-2019

- Summer 2019: 4% (B)



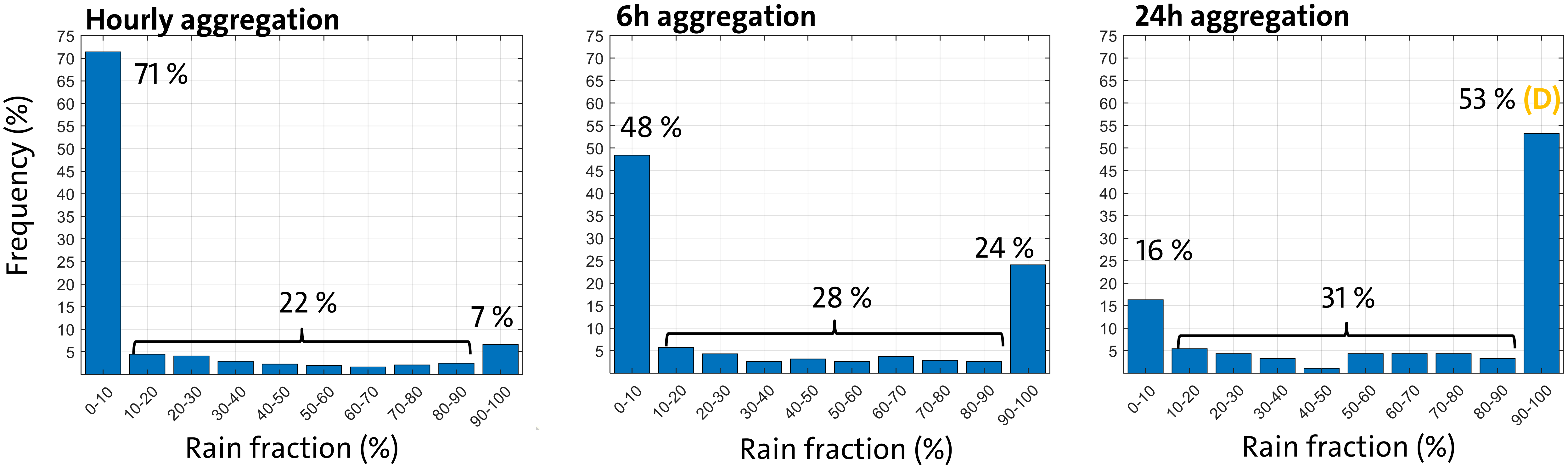
How often do we have rain somewhere in the city?



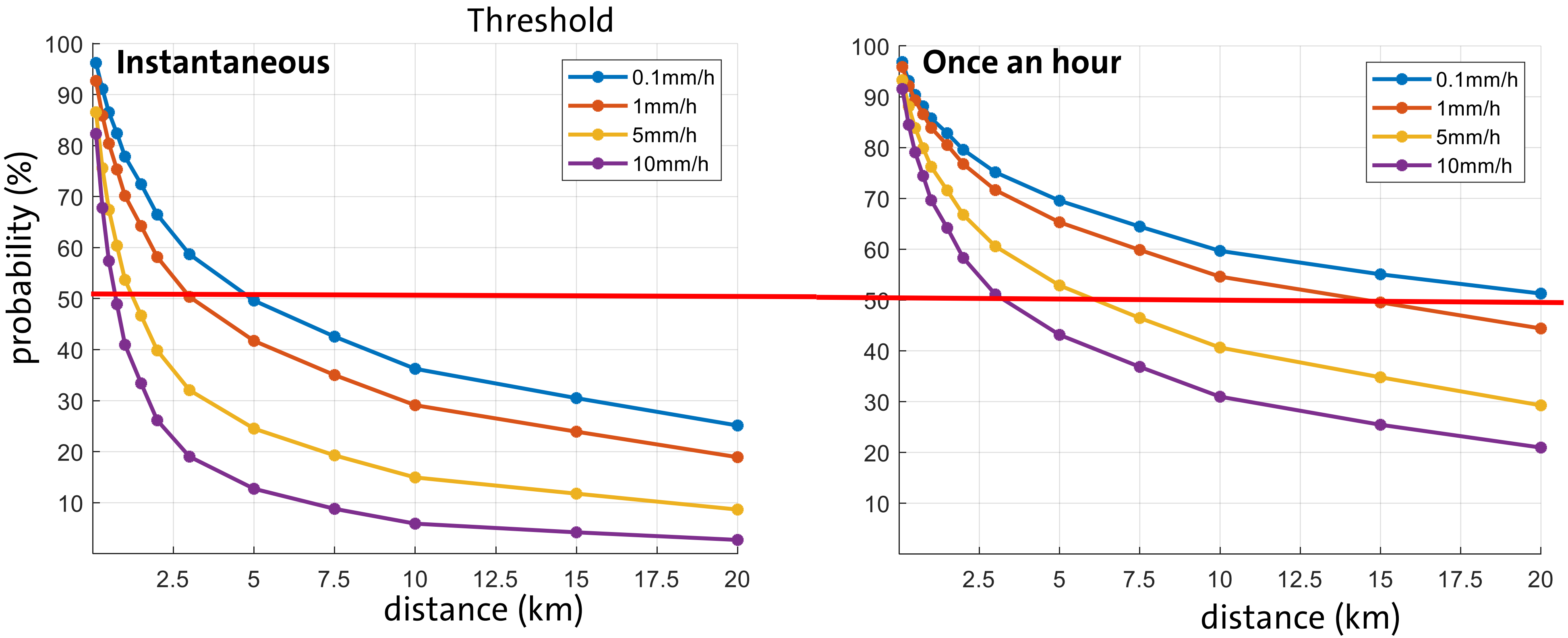


- Full aerial coverage (1256 km², 120000 Pixel)
- Statistics Summer 2019

Precipitation probability within a time interval

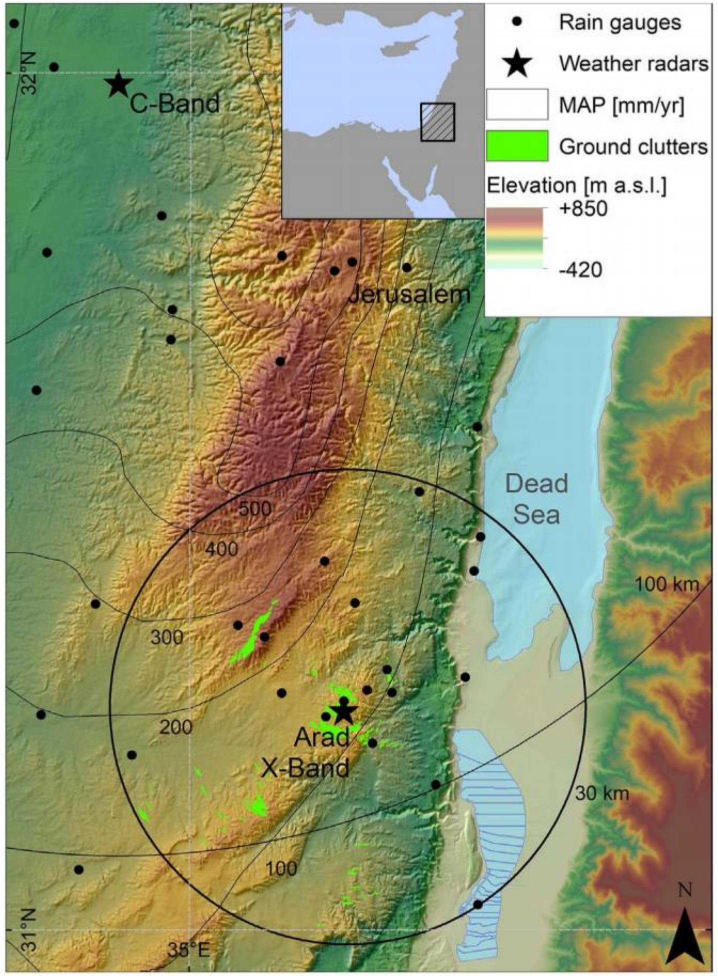


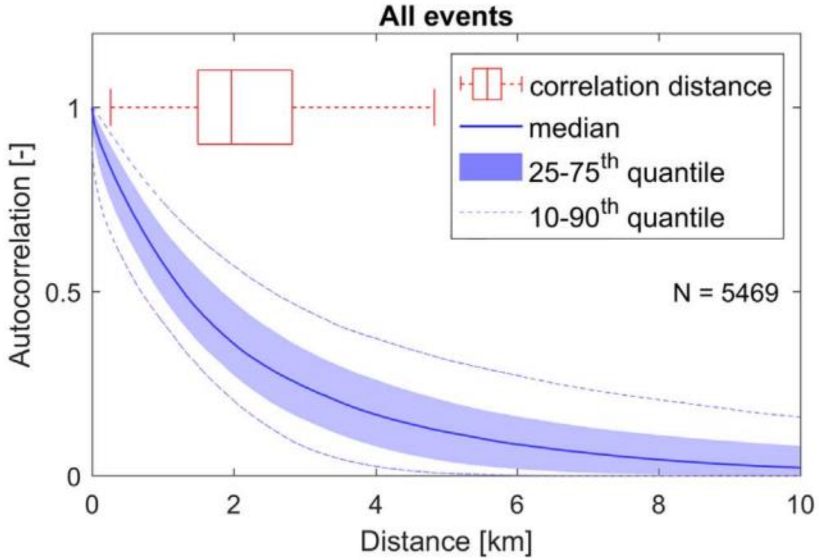
Precipitation here, but also at some distance apart?

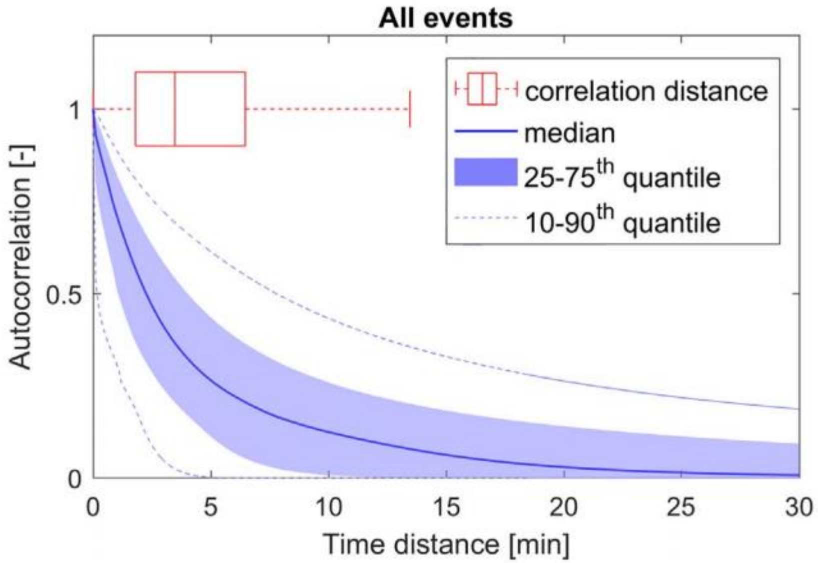


- Full aerial coverage (1256 km², 120000 Pixel)
- Statistics Summer 2019

Very different location – quite similar results







Marra and Morin, Atmos. Research, 2018

Some final thoughts ...

There is still a lot to do:

- Describing precipitation variability at submesoscale.
- Feature based analysis: how do convective cells relate to cold pools?
- Tracing the heterogeneity form precipitation via soil moisture to convection ...
- ... including all other sources of heterogeneity: soil variability, wind, boundary layer evolution, advection ...

FESSTVaL
Field Experiment on Submesoscale Spatio-Temporal Variability in Lindenberg