Overview of QPE/QPF techniques and hydrological applications

Siriluk Chumchean

Department of Civil Engineering
Mahanakorn University of Technology

Typhoon Committee Roving Seminar 2011, Malaysia (20-23 September 2011)

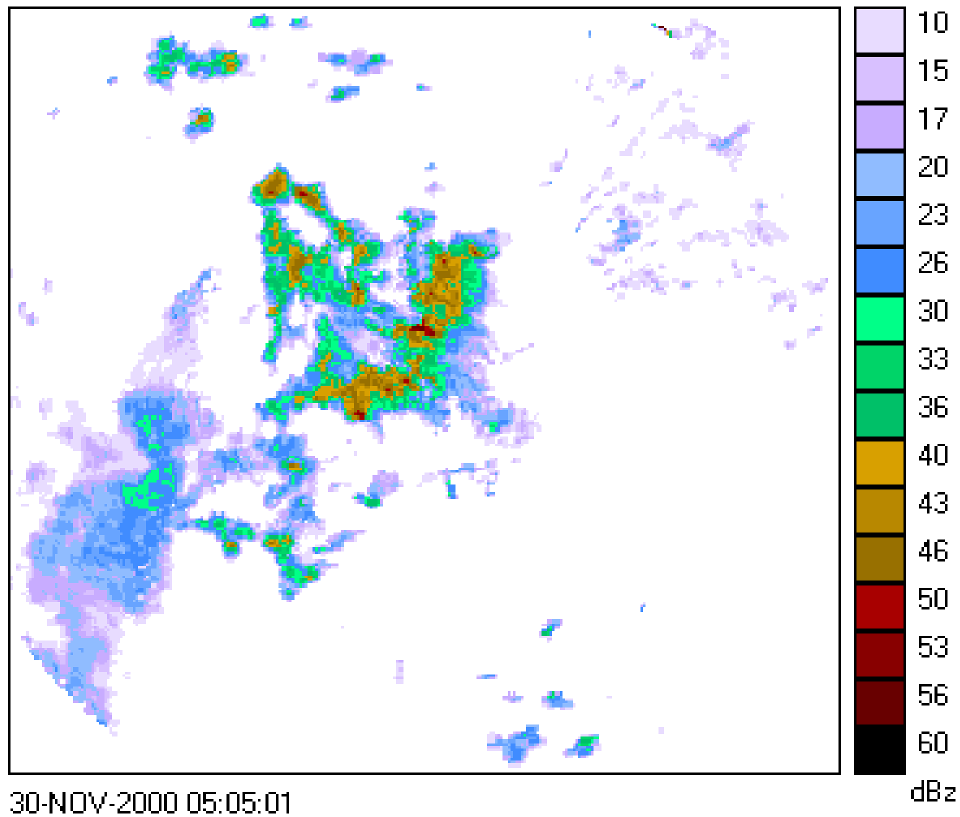
Talk Structure

- **Lecture A1**: QPE techniques and development
    - Real-time radar rainfall estimates
    - Case studies
- **Lectuer A2**: QPF techniques and development
    - QPF techniques (Radar-based nowcasting)
    - Operation and research development systems
    - QPF accuracy assessment
    - Case study : Bangkok rainfall forecasting system
- **Lecture A3**: Hydrological Applications
    - Cases studies

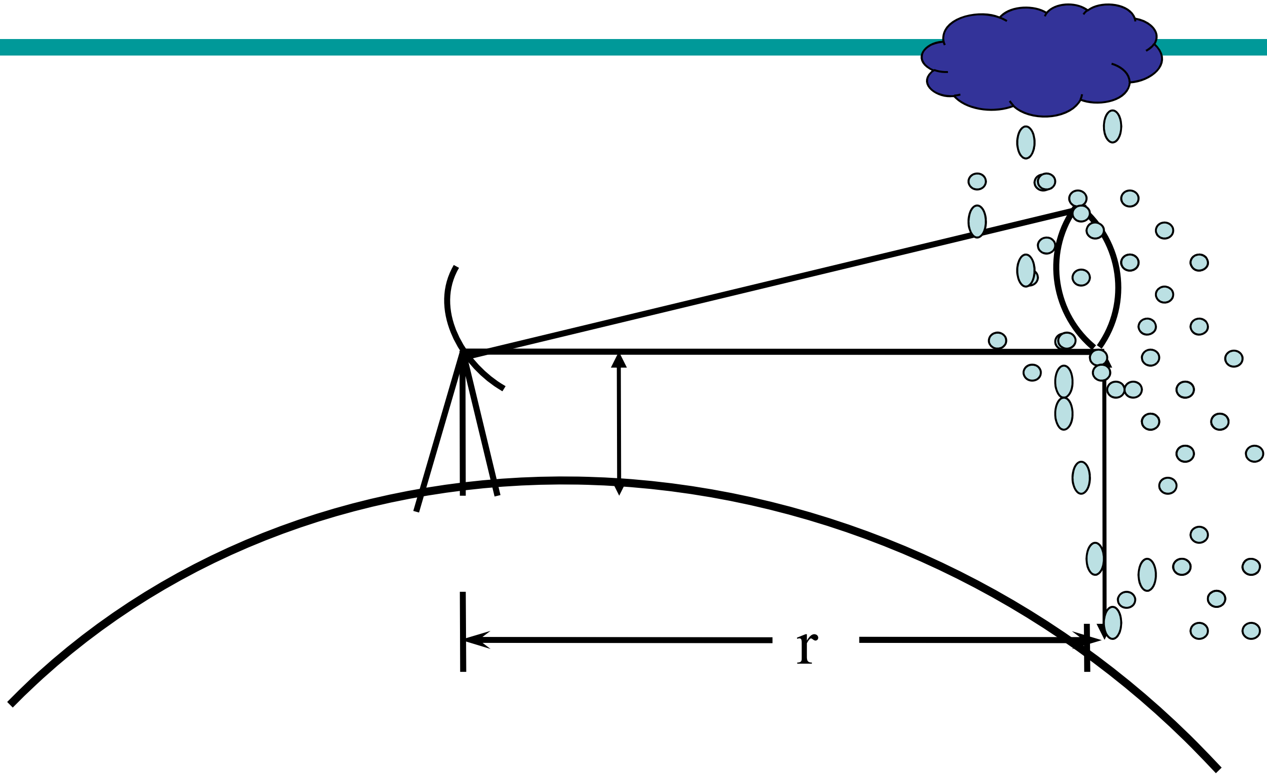
Real-time Radar Rainfall Estimation – An Overview

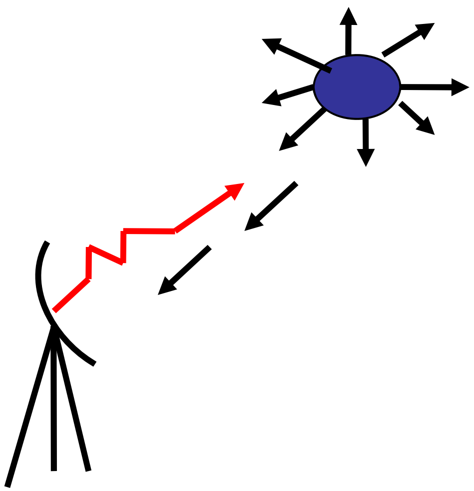
Why do we need weather radar ?

- Measure rainfall continuously covering large area
- Provide fine spatial and temporal resolution
- Can be used to project the storm trajectory, i.e., provide a short-term storm forecast



Basic concept of measuring rainfall using radars





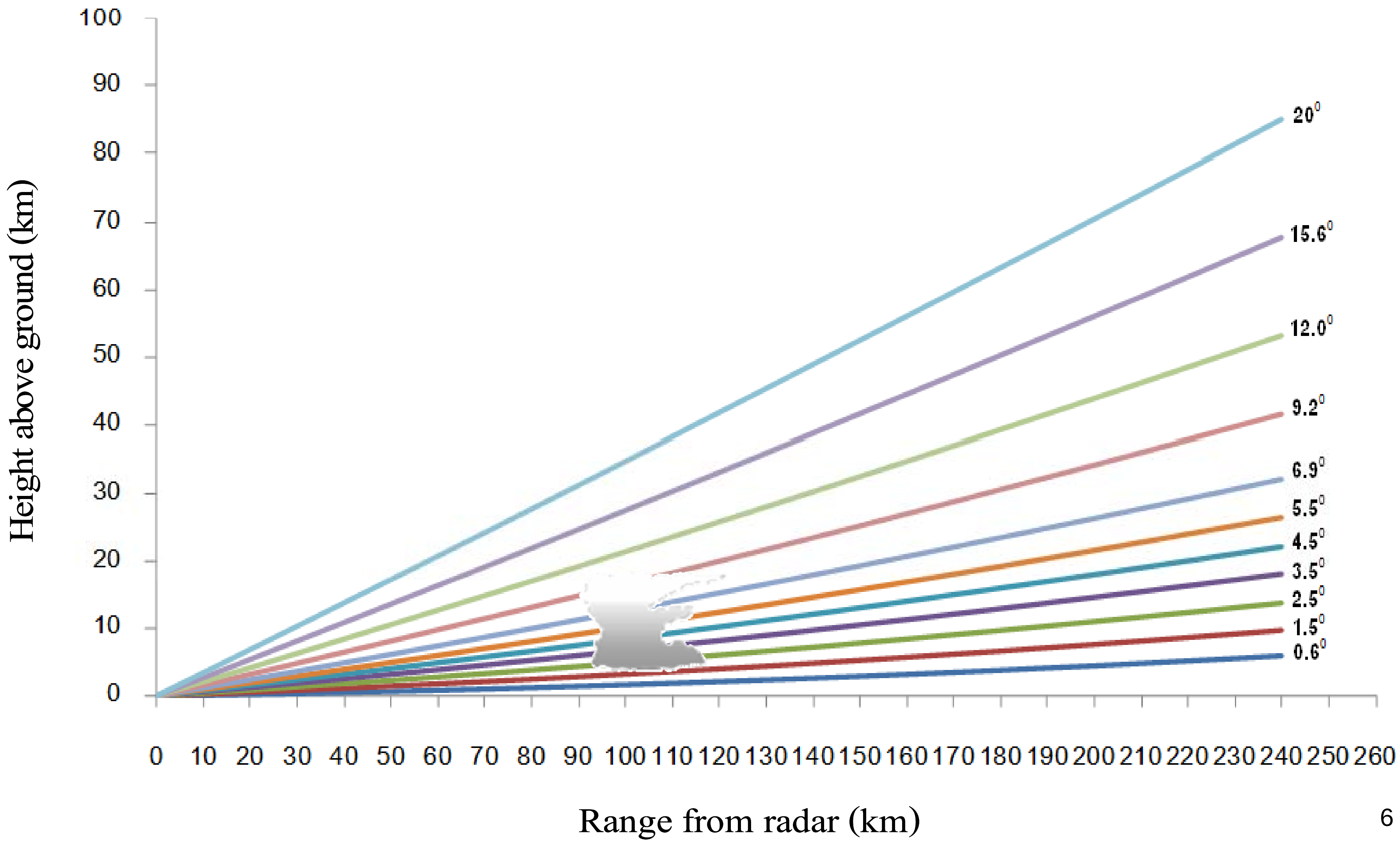
$$p = \frac{C * K * Z}{r^2}$$

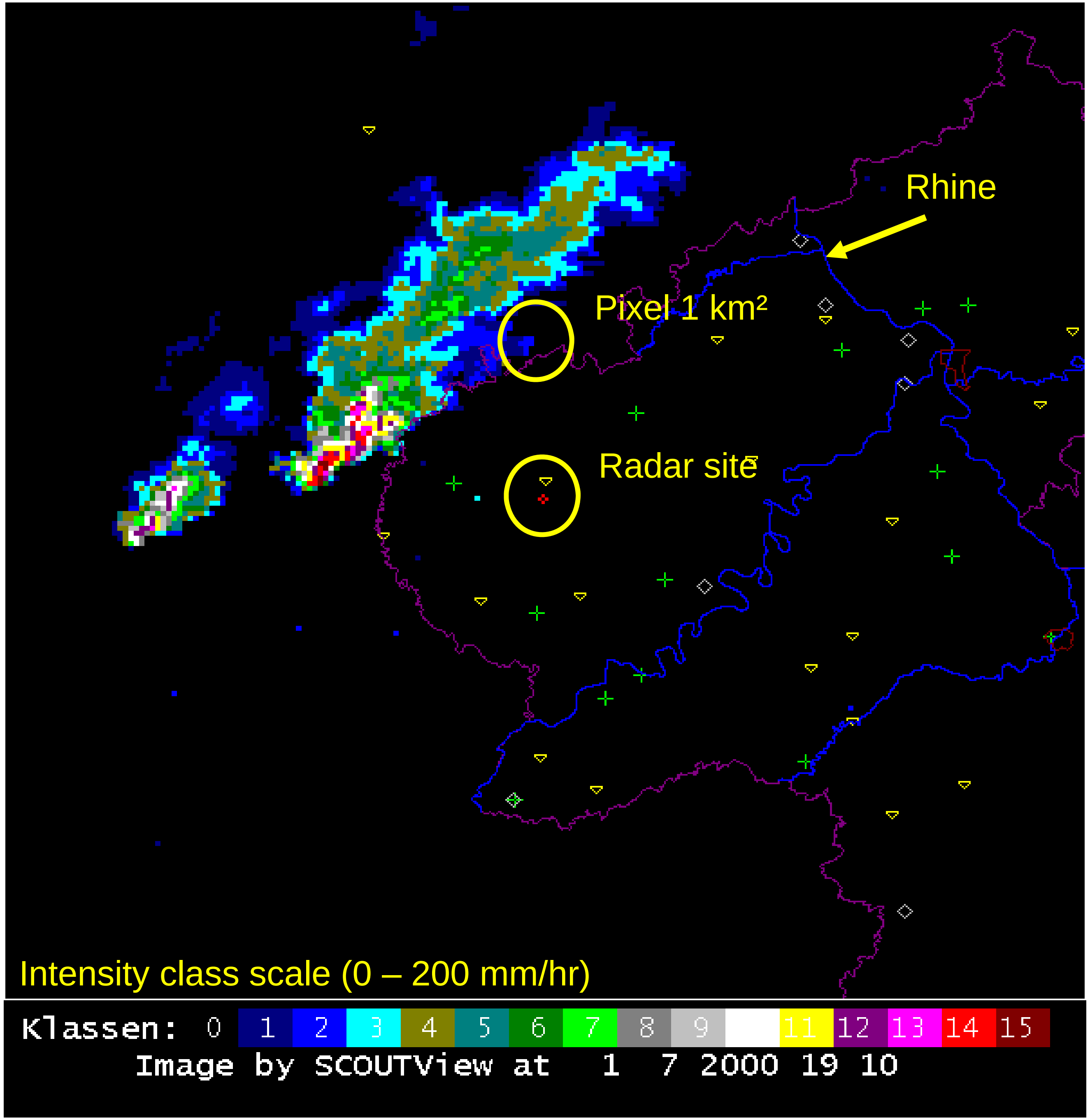
$$z = AR^b$$

where: A,b – radar parameters; Z – reflectivity;

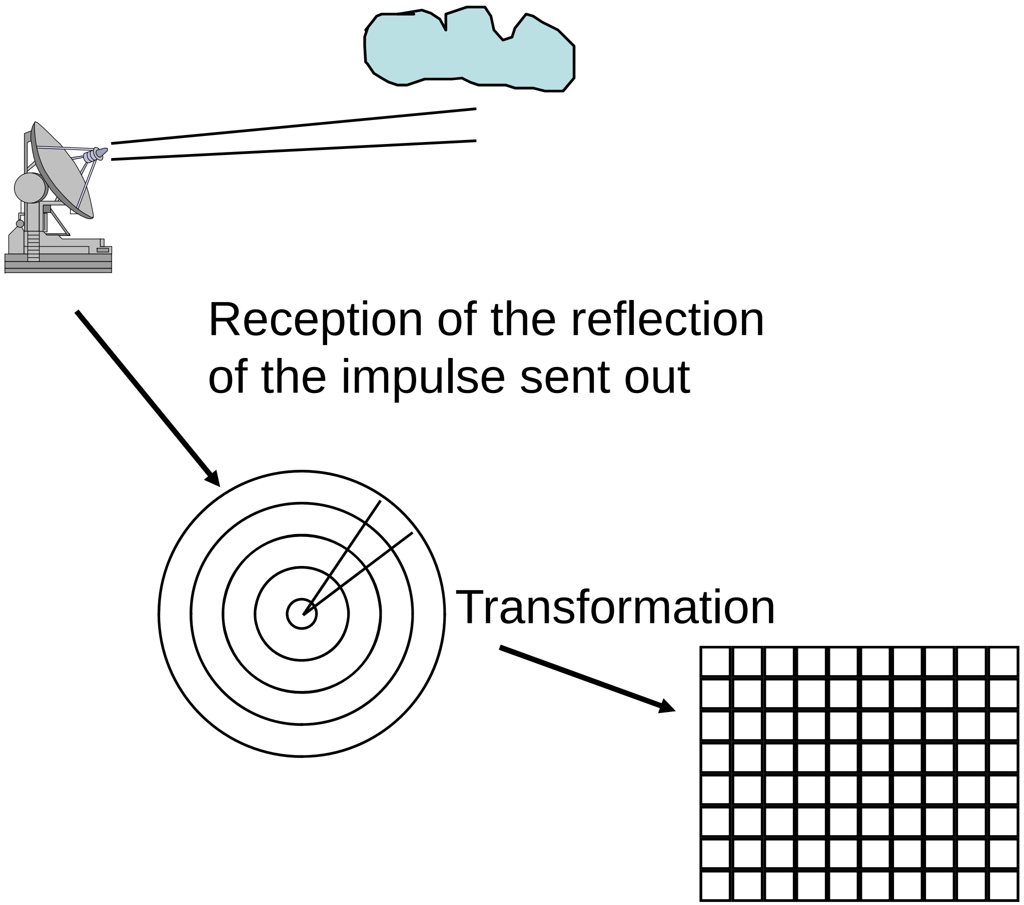
R - rainfall

Volume scan data




Rhine
Pixel 1 km²
Radar site
Intensity class scale (0 – 200 mm/hr)
Klassen: 0 1 2 3 4 5 6 7 8 9 11 12 13 14 15
Image by SCOUTView at 1 7 2000 19 10

Simplified scheme of radar processing



Measurement of rain drops

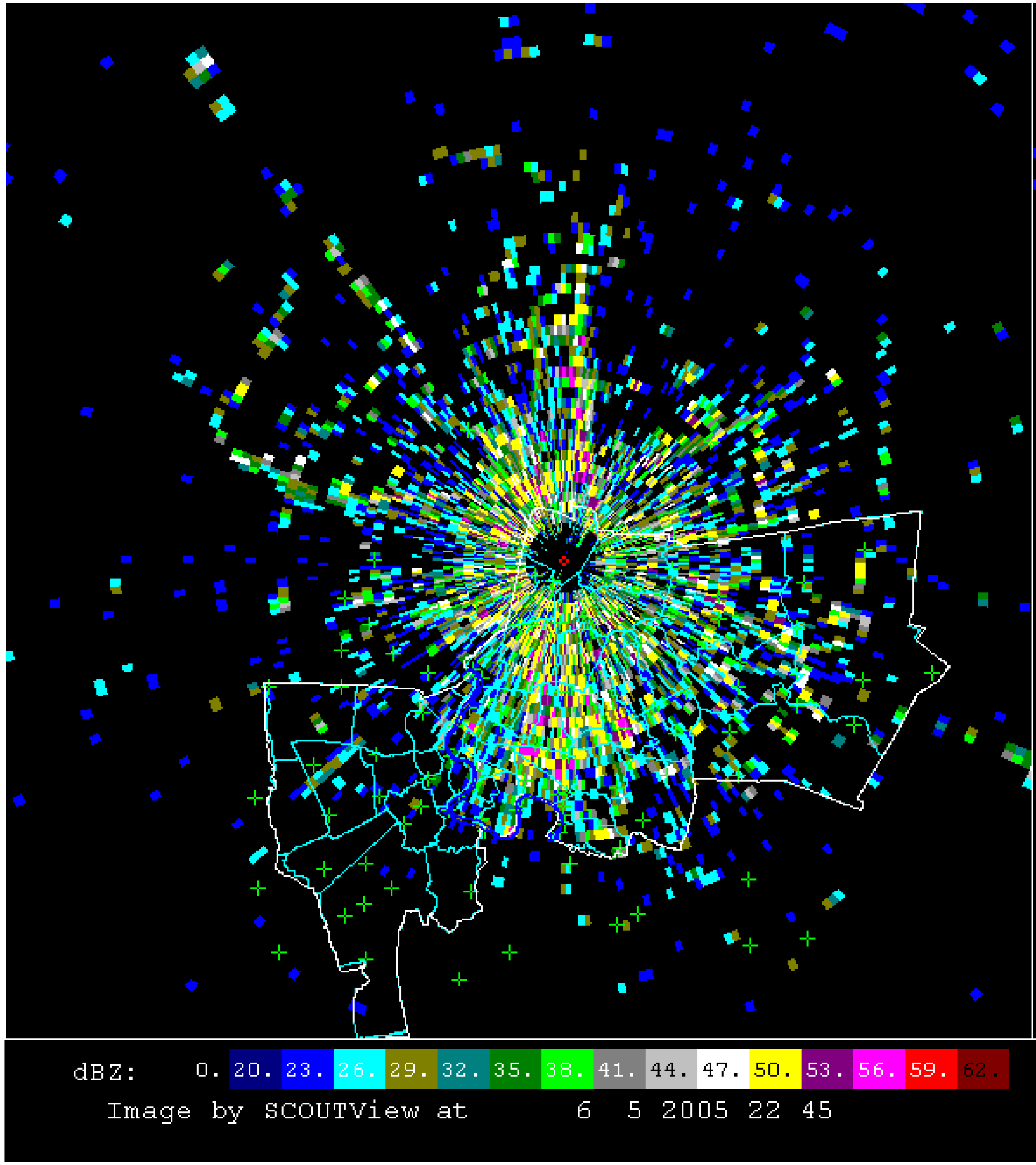
↓

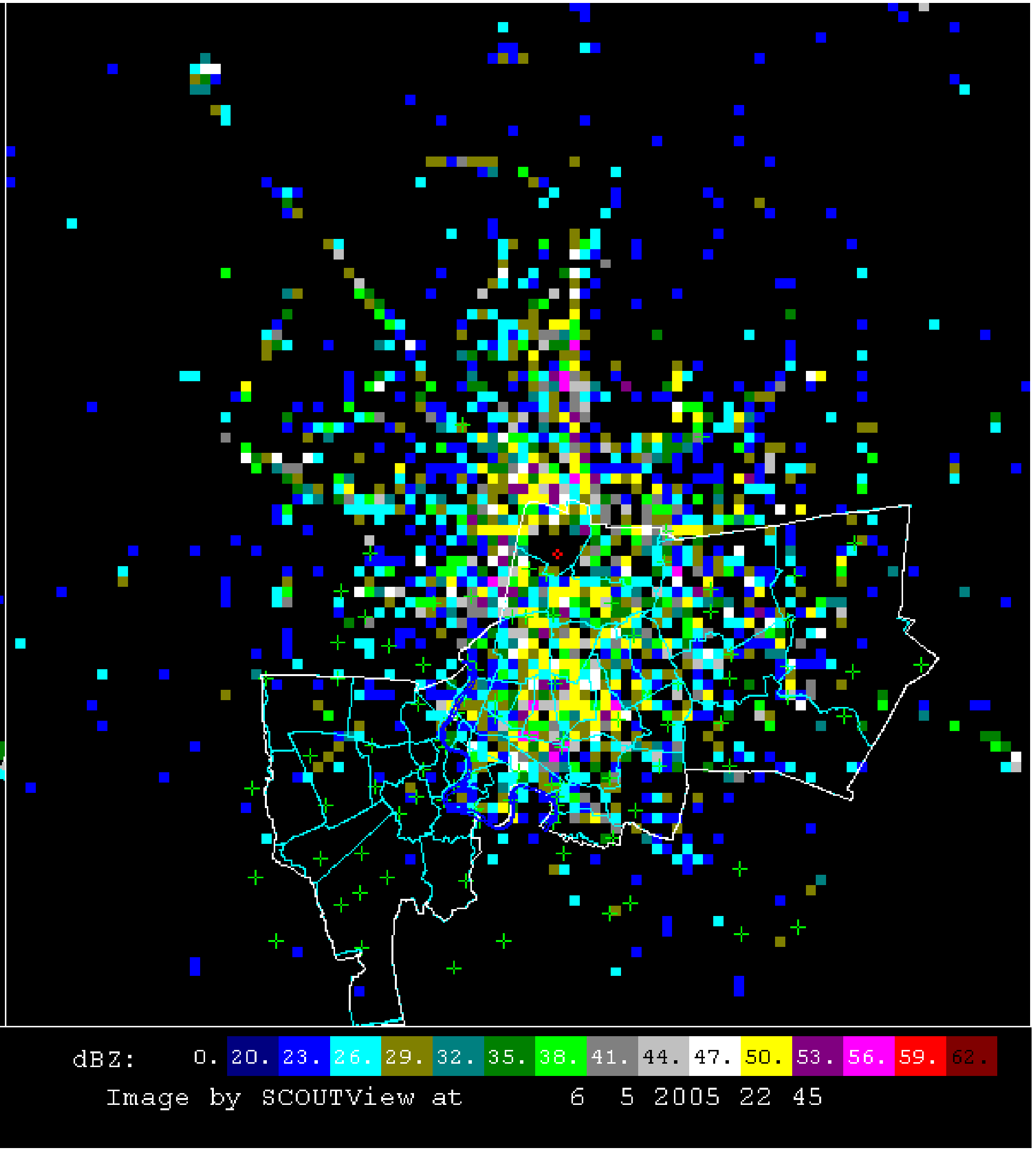
Radar image in polar coordinates
- continuous values

↓

Radar products, e.g. in cartesian coordinates
- values in 256 classes

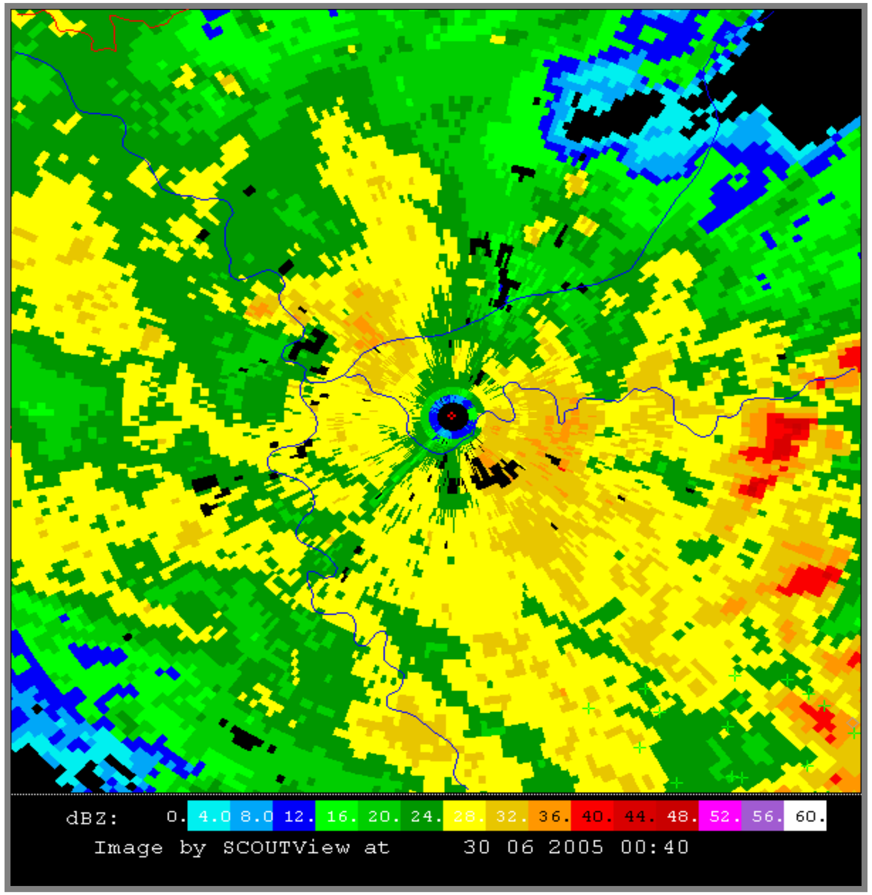
Polar and cartesian coordinates





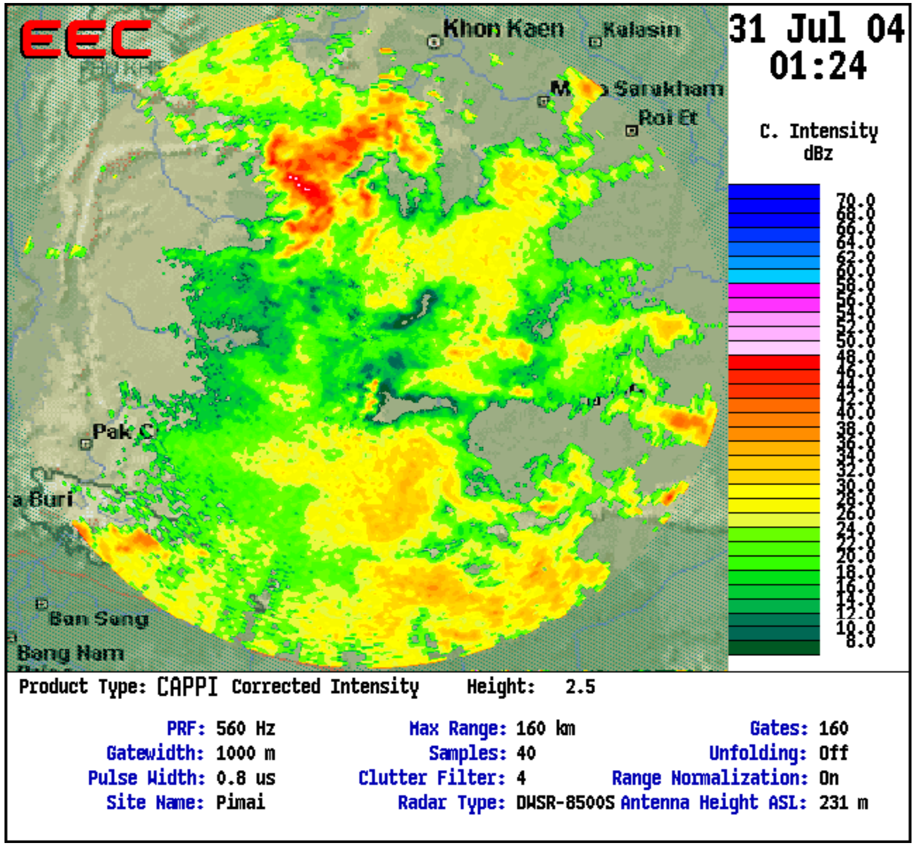
PPI

PPI reflectivity map is extracted from the raw reflectivity data from the beam at a particular elevation angle.



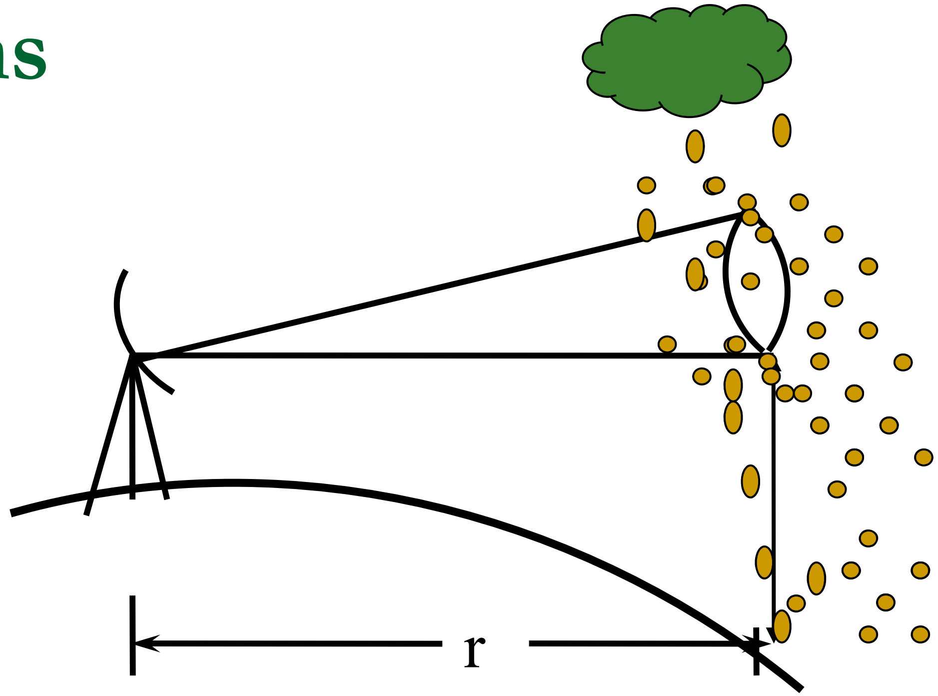
CAPPI

Constant Altitude Plan Precipitation Indicator (CAPPI)



Problems and Limitations

- Are parameters measurable?
- Are parameters stable?
- Does reliability stay constant with distance away from the radar?
- What about obstructions (buildings, mountains)?
- What about multiple raindrops and rain-clouds in the path of the beam?
- What about the effect of the earth's curvature?
- What about differences in rain profile on ground versus high elevations?



$$Z = AR^{b}$$

where

A,b – radar parameters

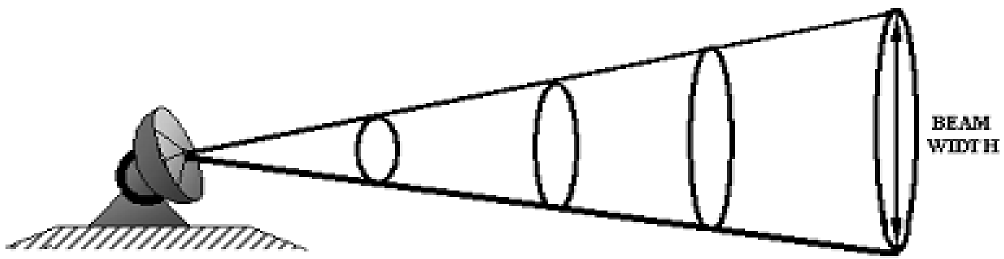
Z – reflectivity

R - rainfall

Problems of using weather radar?

1. Reflectivity measurement error

- ground clutter
- attenuation
- vertical reflectivity profile
- beam geometry

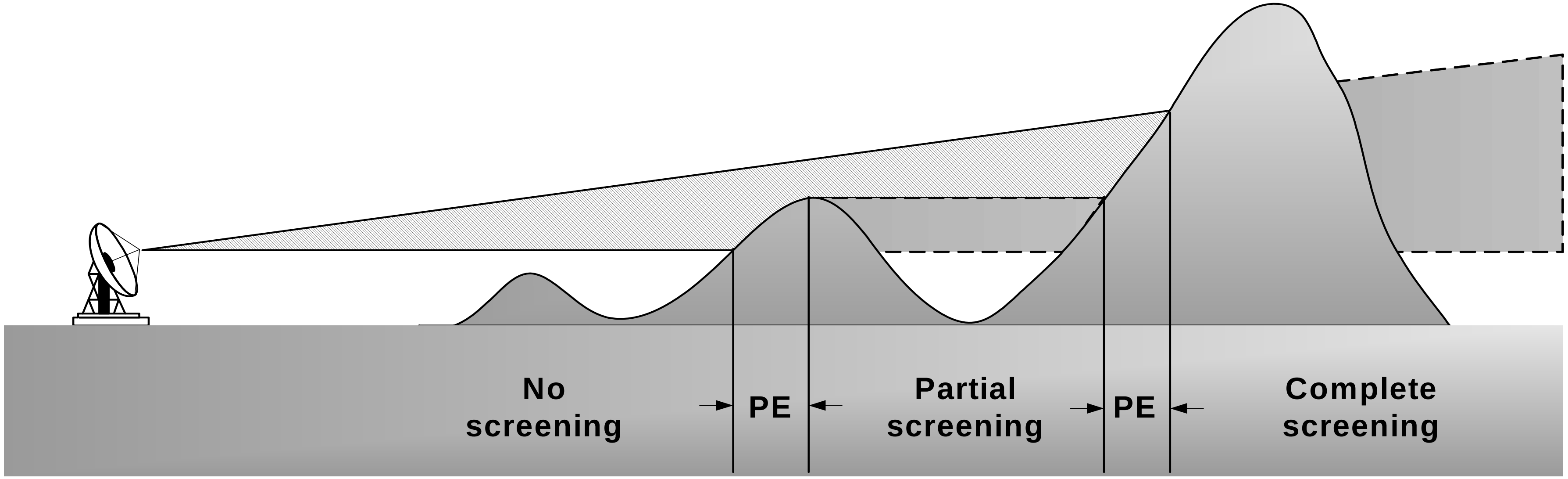


2. Reflectivity-rainfall rate conversion error

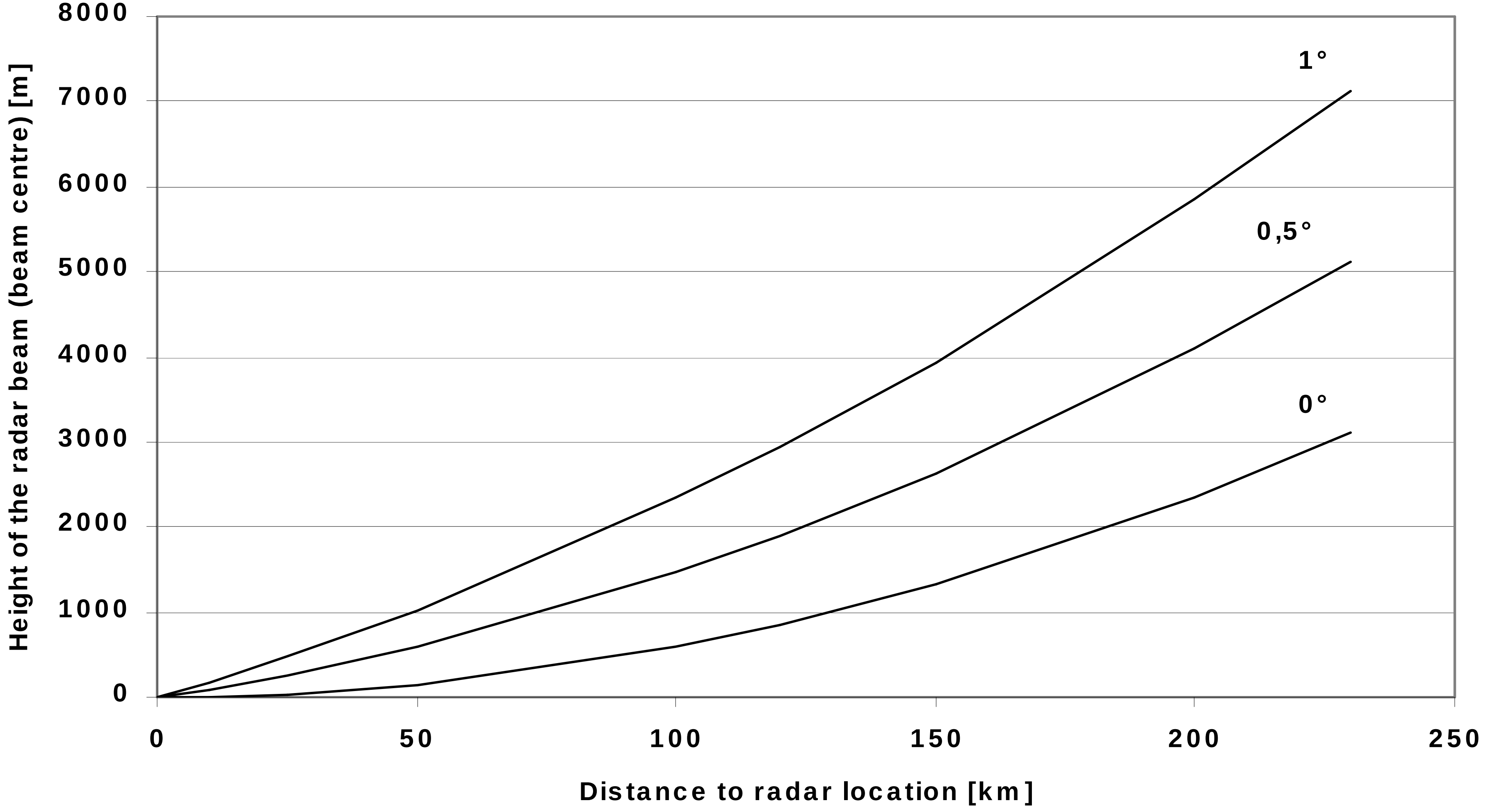
3. Residual errors when compared with rain gauges

Some difficulties …

- Ground-clutter, bright-band, hail, attenuation, range dependent bias – not so difficult to remove as they can be noticed easily

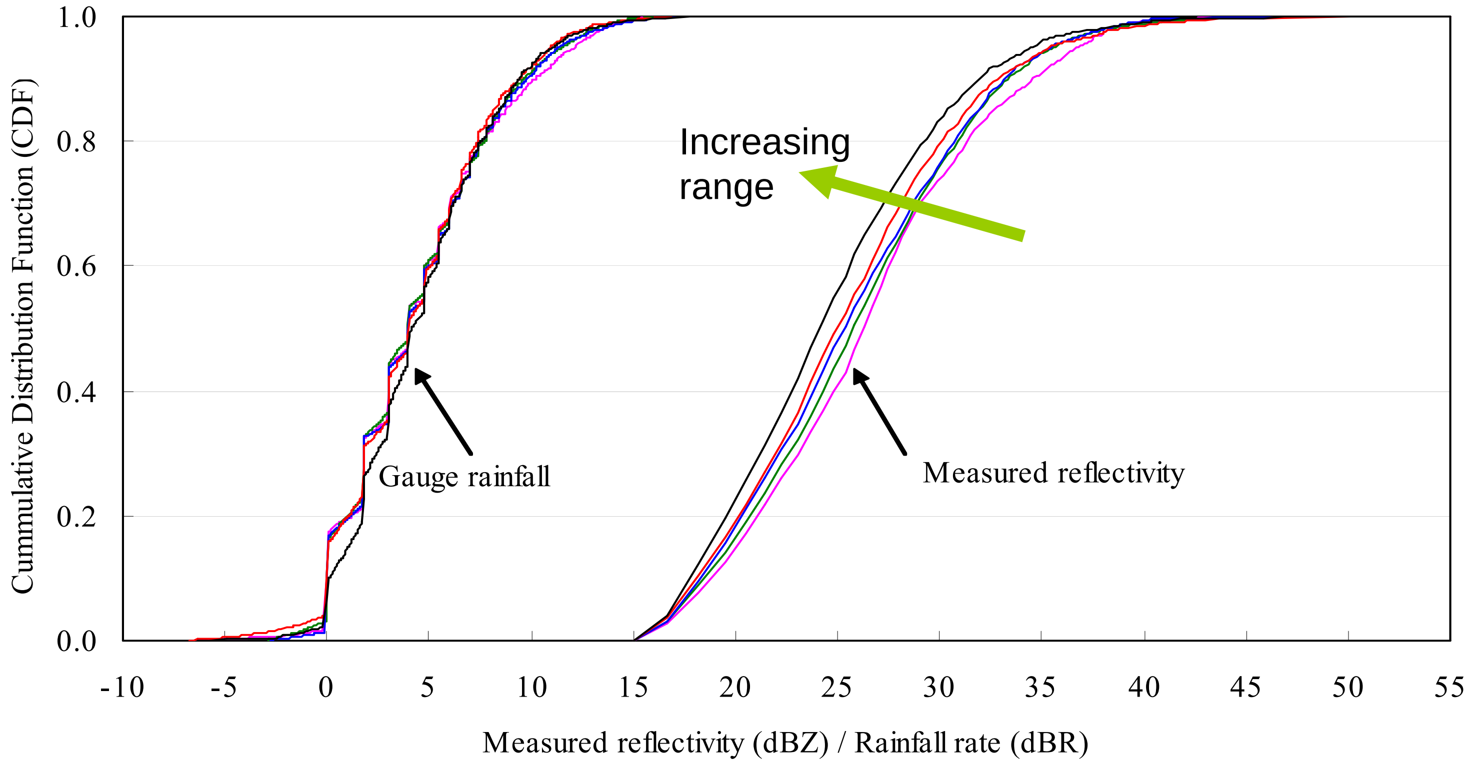


Some difficulties … Distance vs height of radar beam

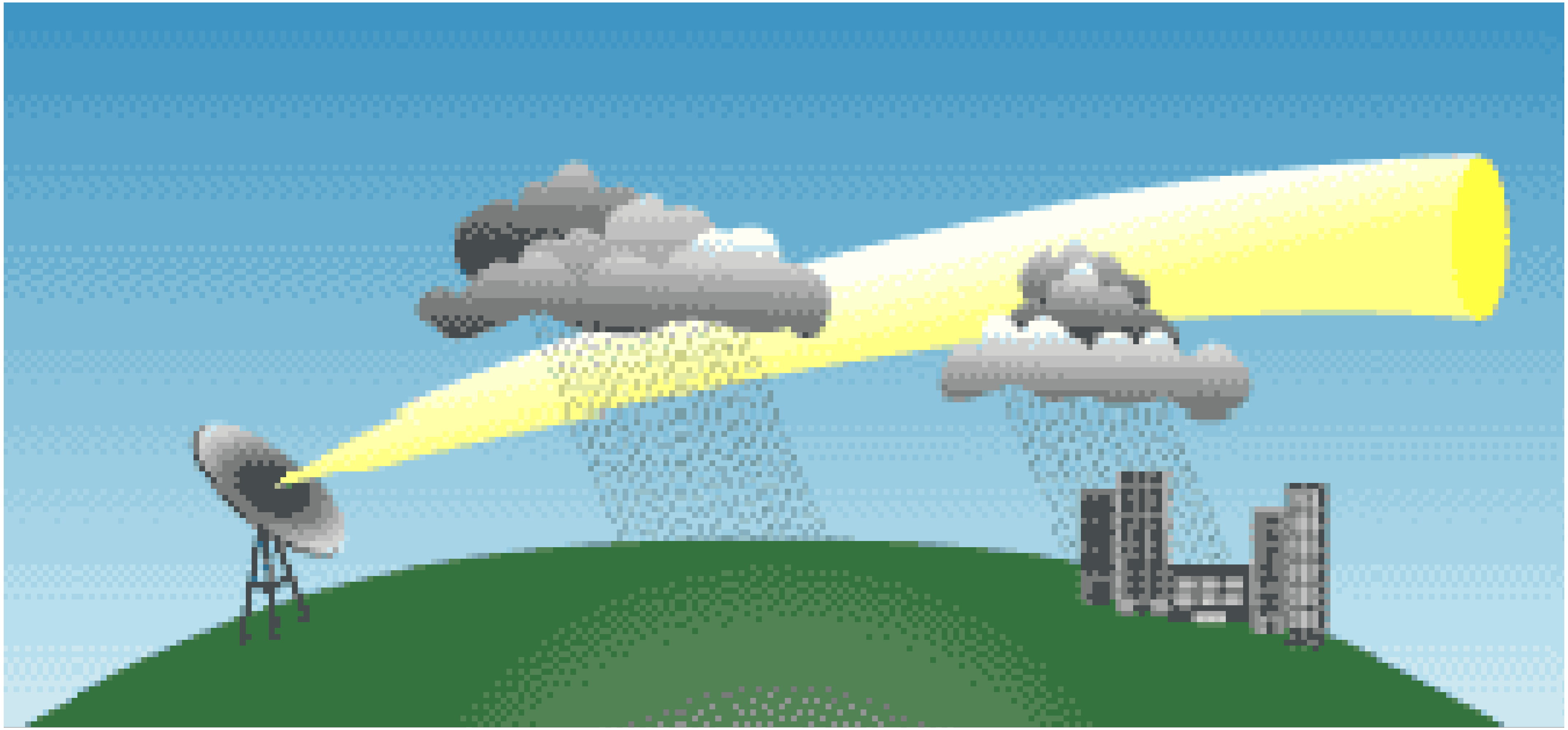


Some difficulties …

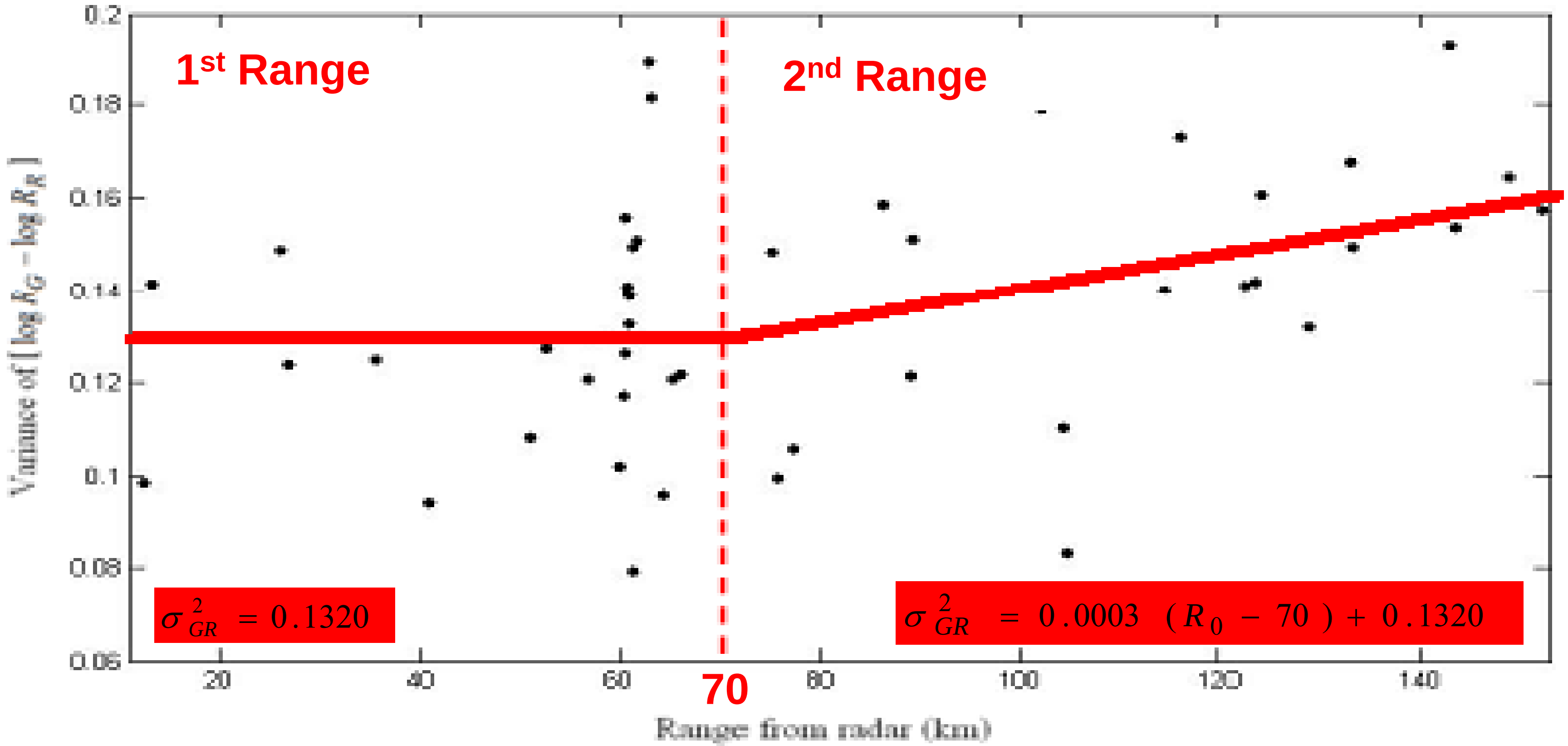
- Increasing uncertainty in measured reflectivity as a function of range



Some difficulties …Range dependent errors



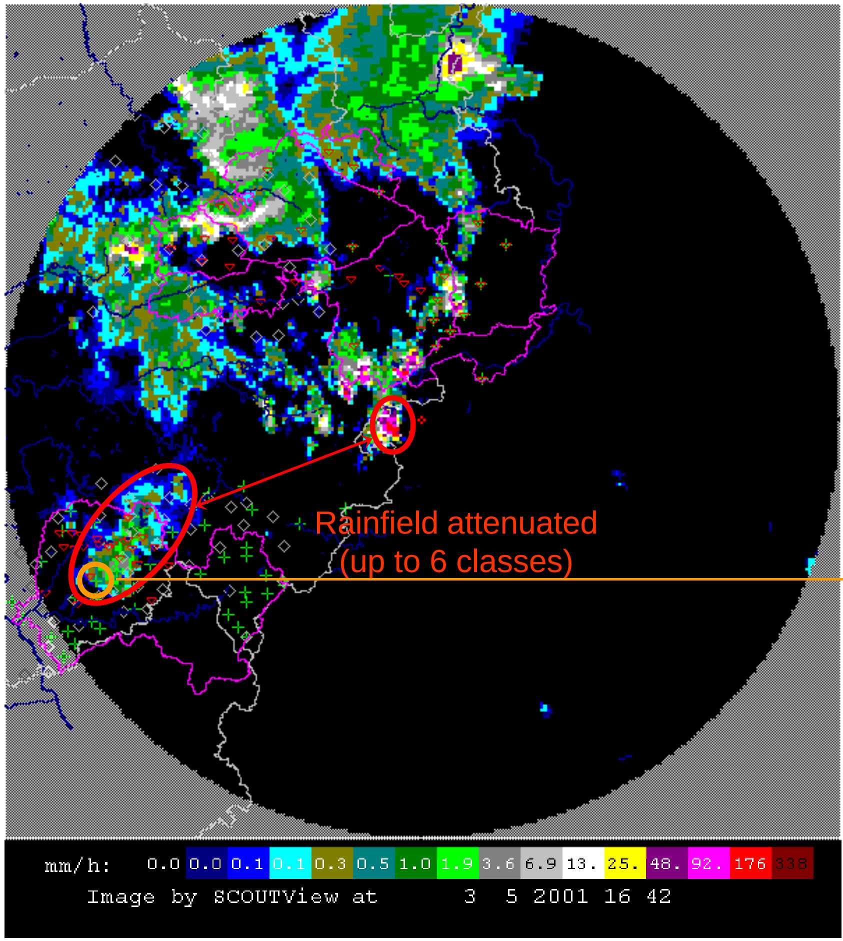
Some difficulties …Range dependent errors



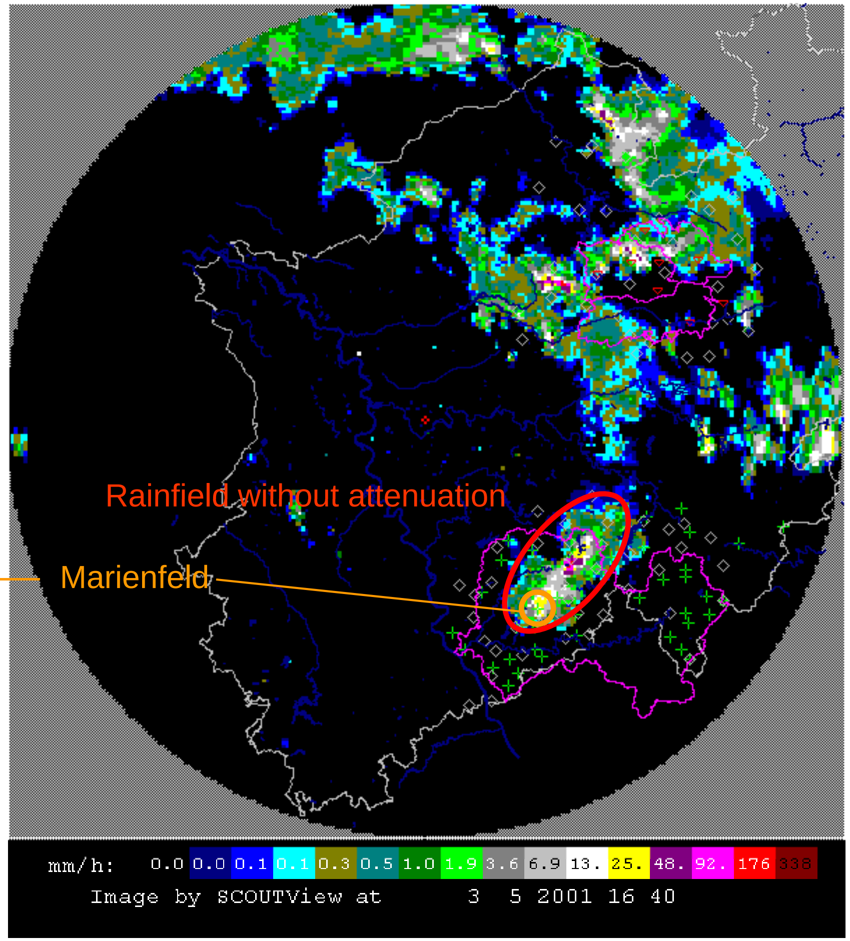
$$\sigma^2_{GR_i} = \frac{1}{N}\sum_{i=1}^{N}\left\{ \left[\log R_G(i) - \log R_R(i)\right]^2 \middle| R_G(i) > r \right\}$$

Anagnostou et al. (1999)

Some difficulties … Attenuation example



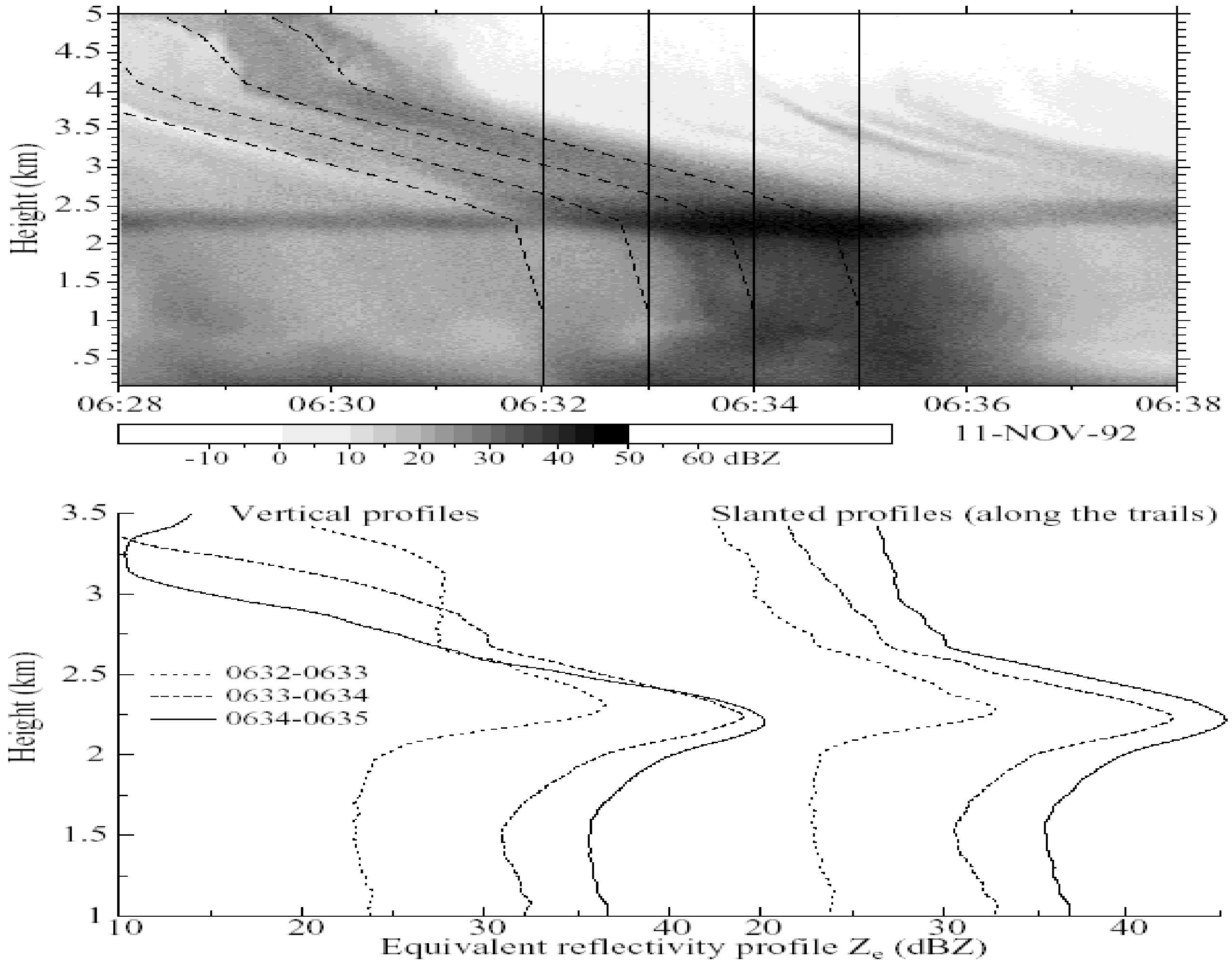
Radar Flechtdorf



Radar Essen

Einfalt (2004)

Some difficulties …Bright-band



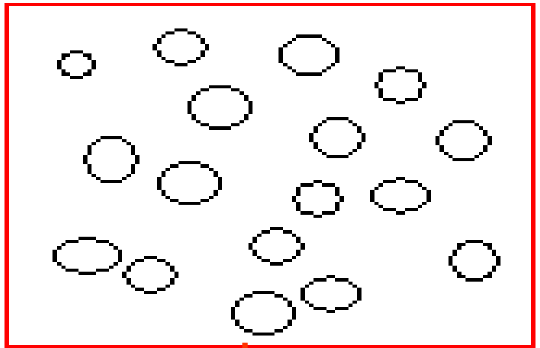
Fabry et al. (1994)

Some difficulties..Effect of storm types on Z-R relation

$$Z = \int_0^{\alpha} N_o e^{-\Lambda D} D^6 \, dD$$

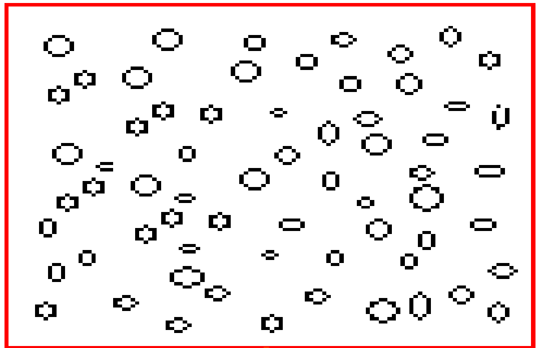
$$R = \int_0^{\alpha} N_o e^{-\Lambda D} \frac{4}{3}\pi \left(\frac{D}{2}\right)^3 v(D) \, dD$$

Convective



Z = 35 dBZ
R = 7 mm/h

Stratiform

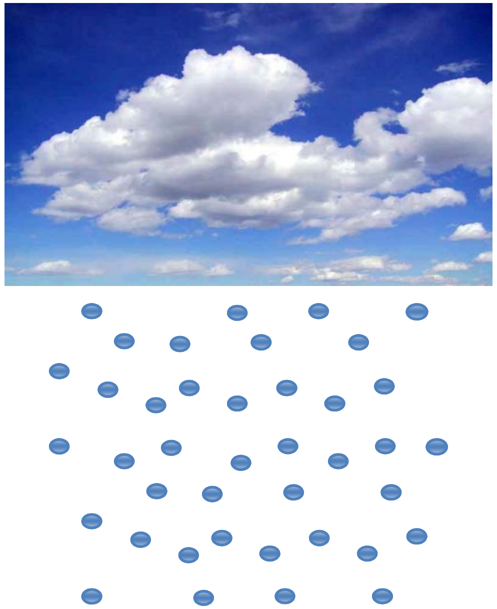


Z = 35 dBZ
R = 10 mm/h

Z-R relationship for each rain-cloud

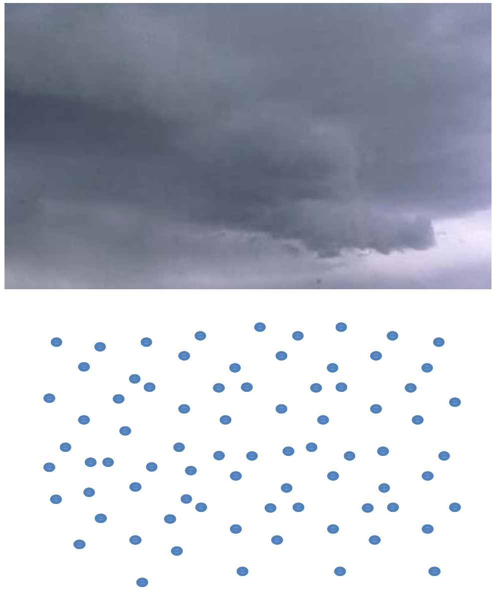
- **Parameters '*a*' and '*b*' varies on rain drop size distribution.**

Cumulus

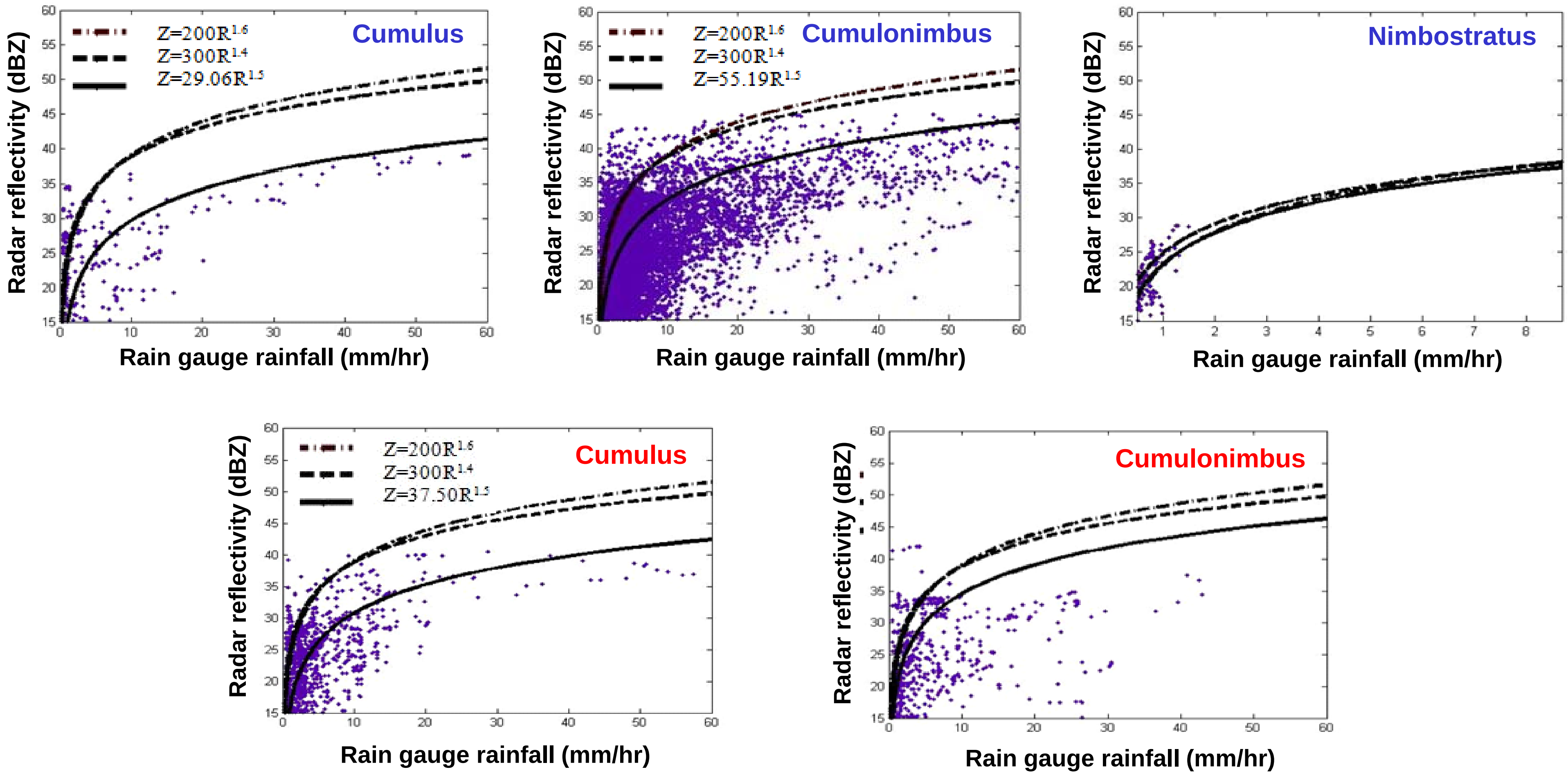


Cumulonimbus

Nimbostratus



Z-R relationship of each type of rain-cloud (Calibration)



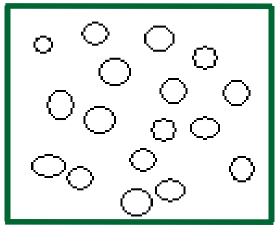
Chumchean et al. (2009)

Z-R relationship of each type of rain-cloud

- **Rainy season**

Cumulus

$Z=29R^{1.5}$

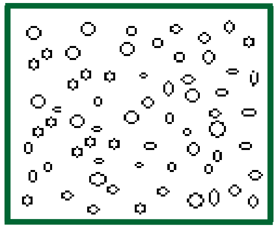


Z = 30 dBZ

R = 10.58 mm/h

Cumulonimbus

$Z=55R^{1.5}$

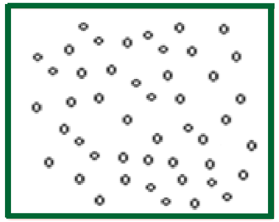


Z = 30 dBZ

R = 6.90 mm/h

Nimbostratus

$Z=208R^{1.5}$



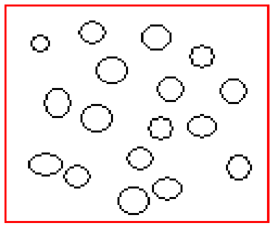
Z = 30 dBZ

R = 2.85 mm/h

- **Summer**

Cumulus

$Z=38R^{1.5}$

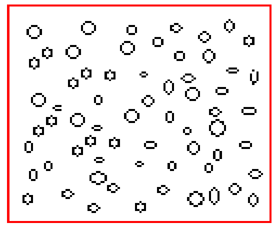


Z = 30 dBZ

R = 8.93 mm/h

Cumulonimbus

$Z=90R^{1.5}$



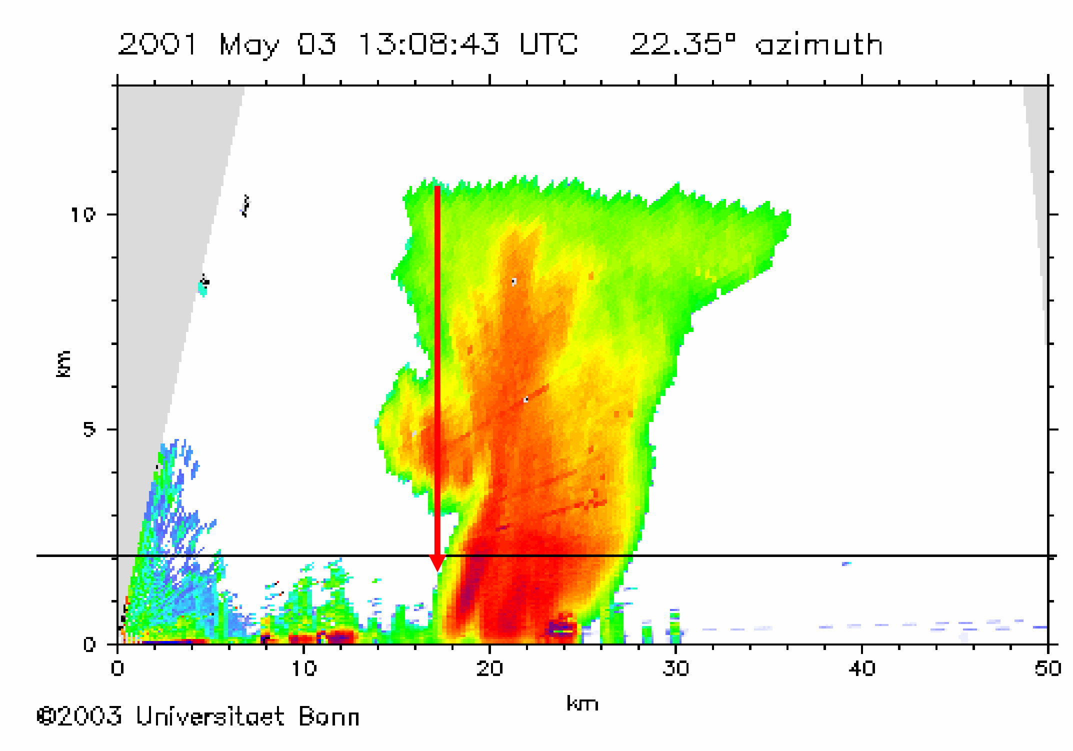
Z = 30 dBZ

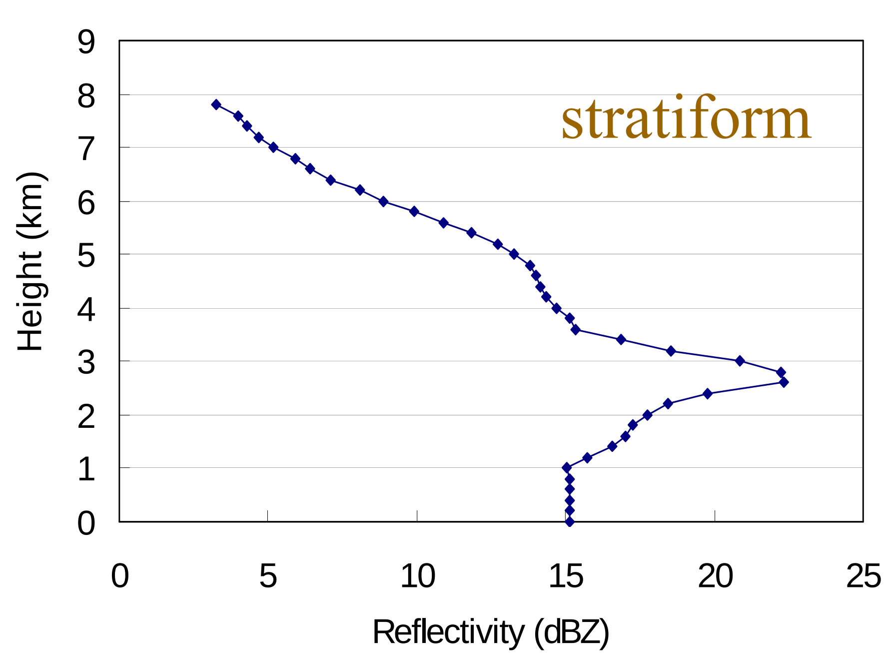
R = 4.99 mm/h

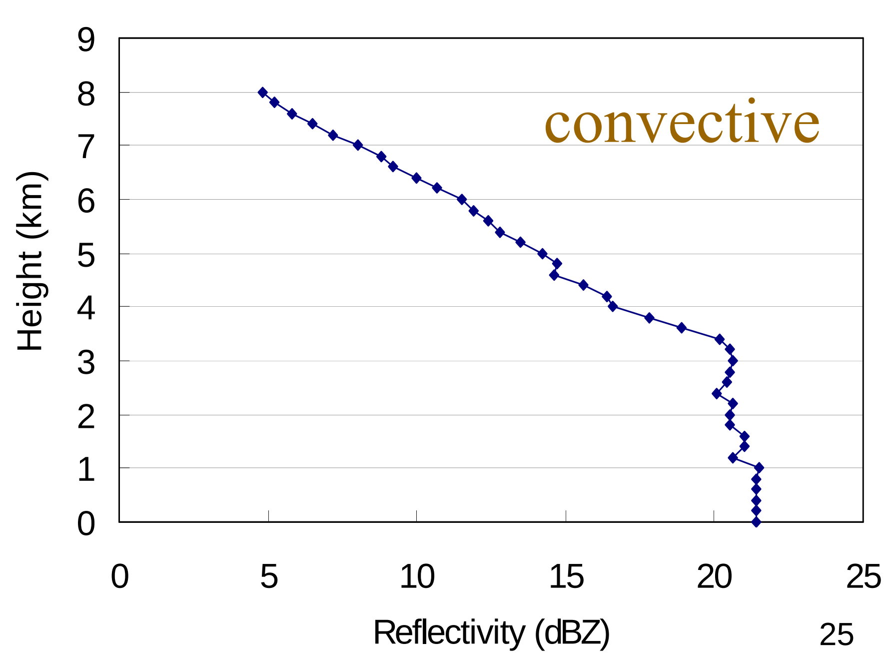
Chumchean et al. (2009)

Some difficulties …

- Variations in Z~R relationships for different storm types







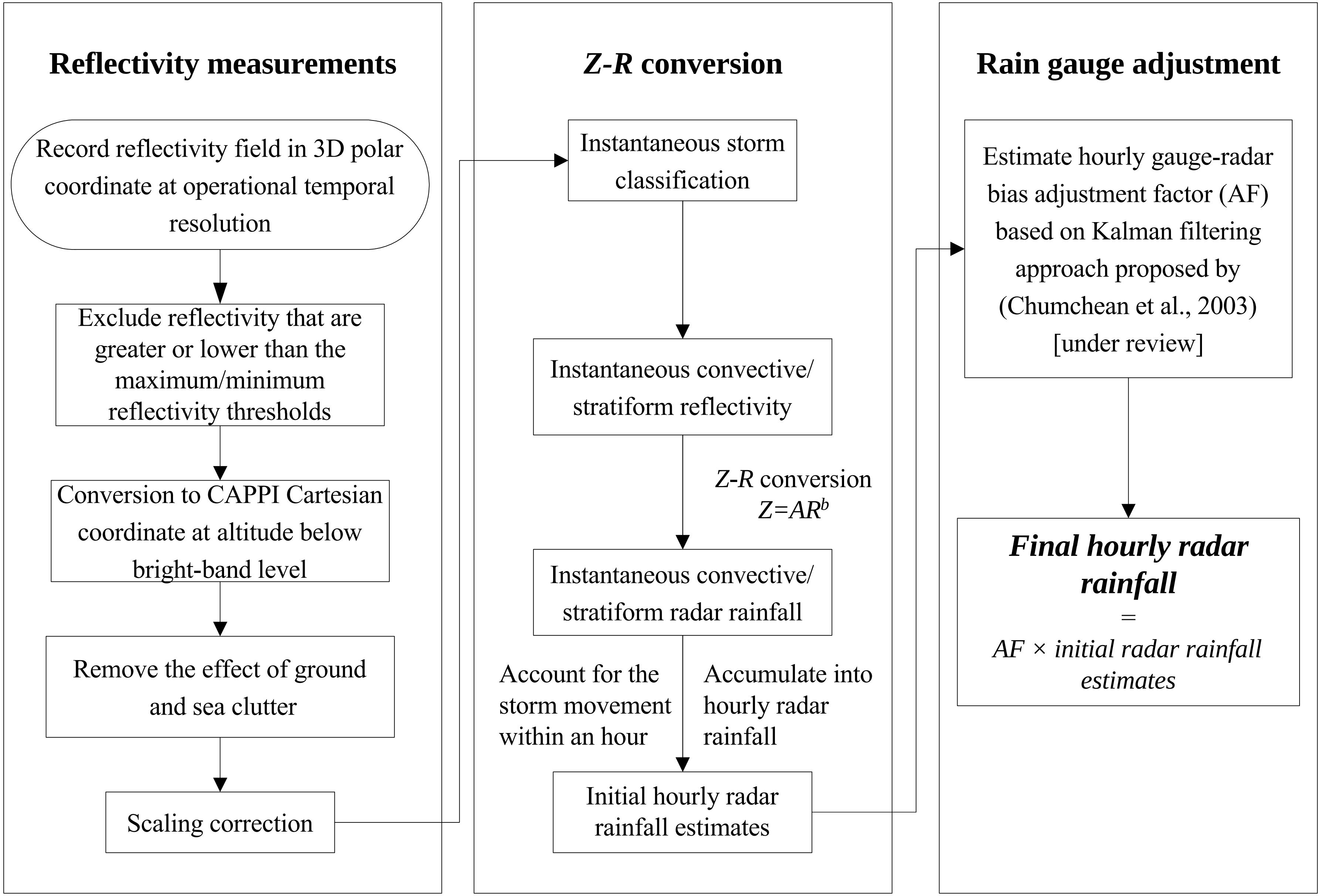
Some difficulties …

- Residual errors – results in a “mean-field-bias”
- Exhibits persistence from one time-step to the next
- Very important in real-time estimation
- Difficult to remove using physical relations

Philosophy

"Estimated radar rainfall must first be corrected for reflectivity measurement errors and *Z-R* conversion errors based on the physical methods, and then a statistical method will be used to remove the average difference (mean field bias) between radar estimates at the rain gauge locations and the corresponding gauge rainfall amounts".

Real-time radar rainfall estimation method



Chumchean et al. (2006)

Real-time radar rainfall estimation

Scaling correction

(to remove range-dependent bias)

+

Storm classification

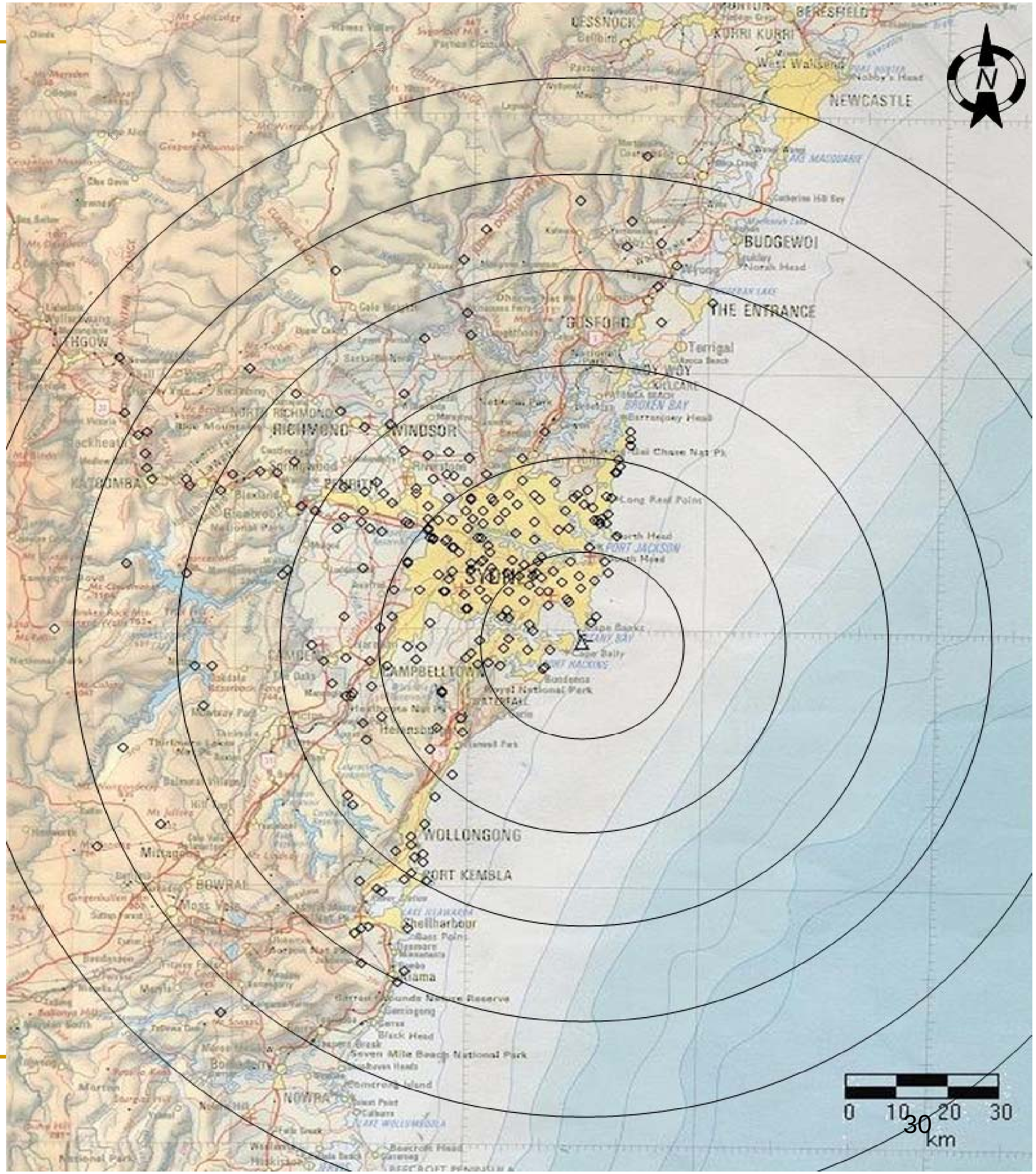
(to remove bias in Z~R relation due to the dominant storm type)

+

Correction of residual mean-field bias

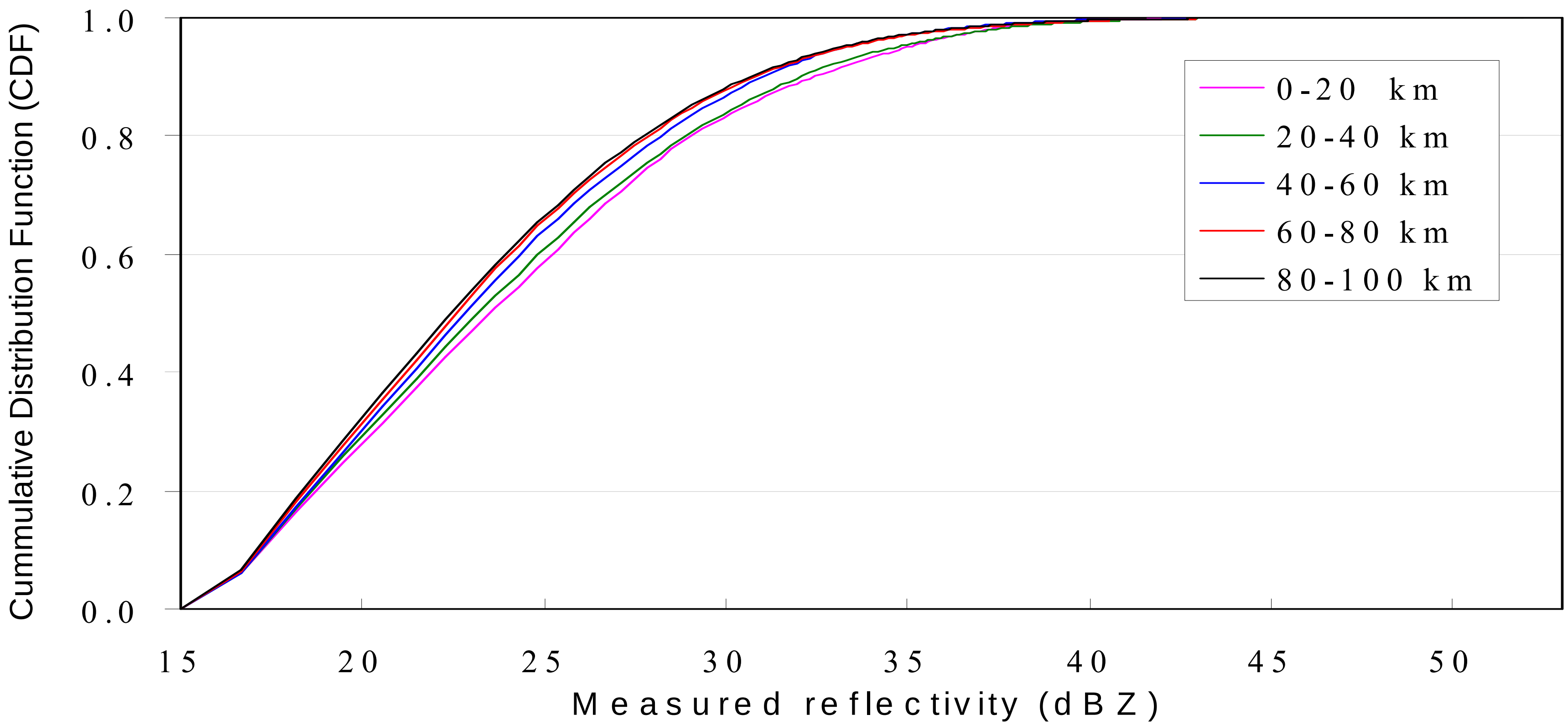
Data

- C-band Kurnell radar
- 10-minute, 1km^2 resolution
- Analysis period November 2000 to April 2001
- 254 hourly rain gauges (SWC,SCA,BoM)



Correction of range dependent bias due to radar beam geometry

Application of scaling in measured reflectivity



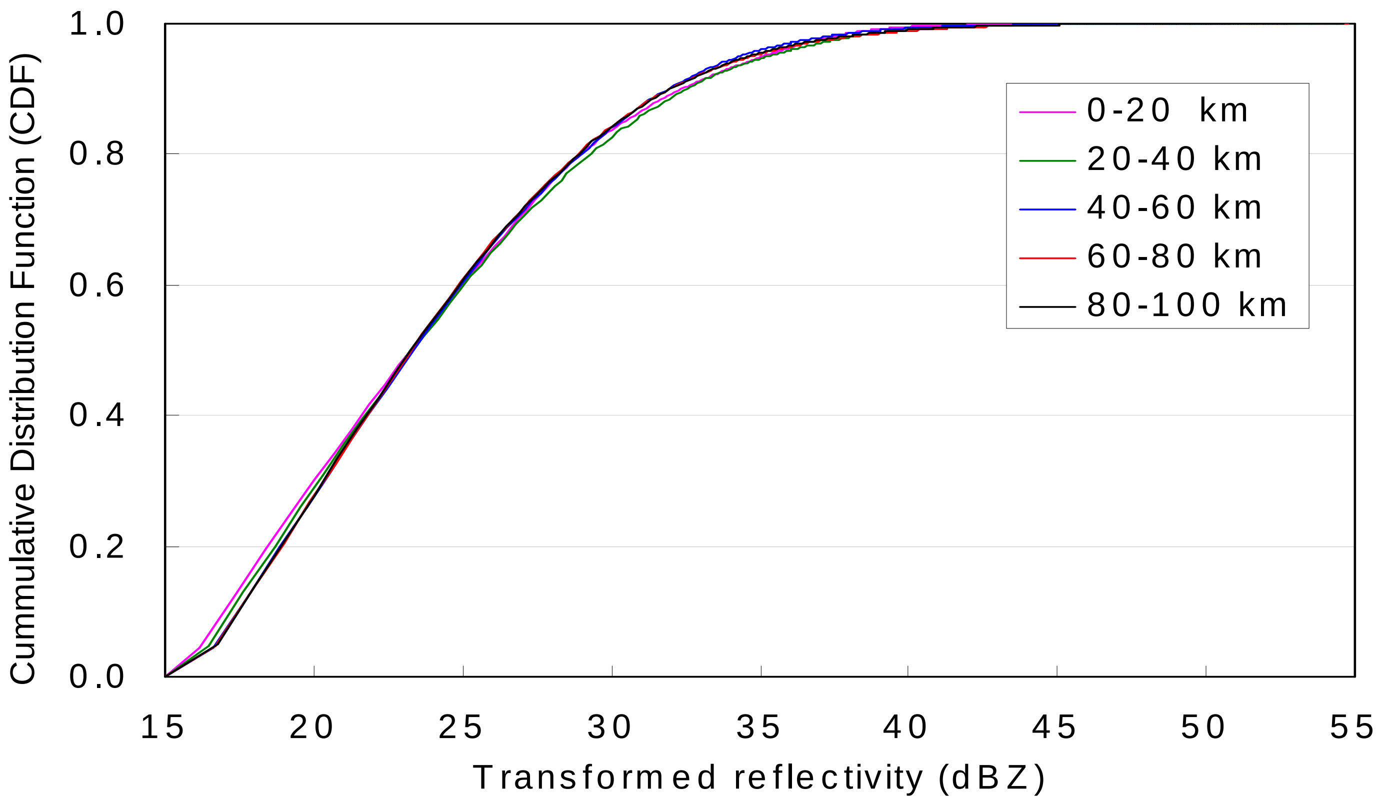
Assume simple scaling holds for measured reflectivity

$$Z_D \overset{dist}{=} (d/D)^{-\eta} Z_d$$

Scale transformation function

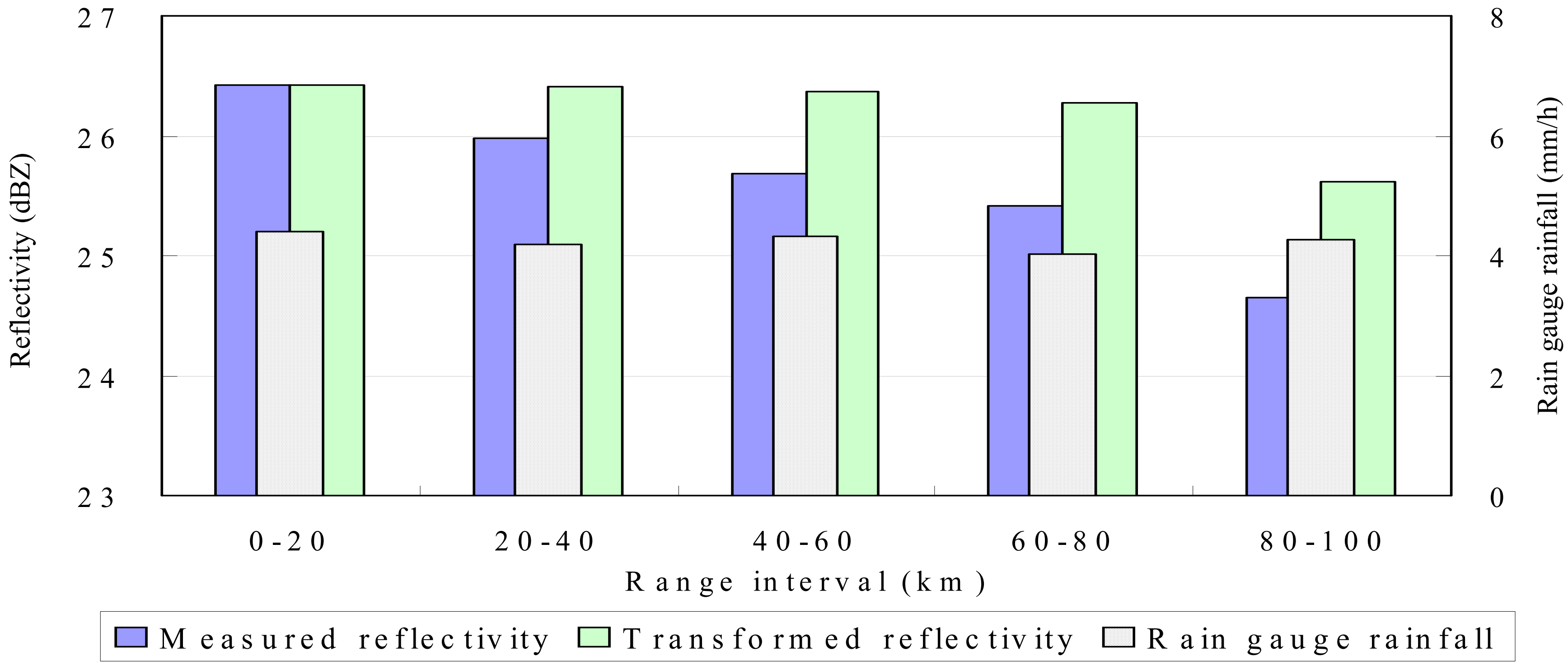
The proposed scale transformation formula is :

$$Z_{\text{transformed (dBZ)}} = (20/D)^{-0.024} Z_{\text{D(dBZ)}}$$



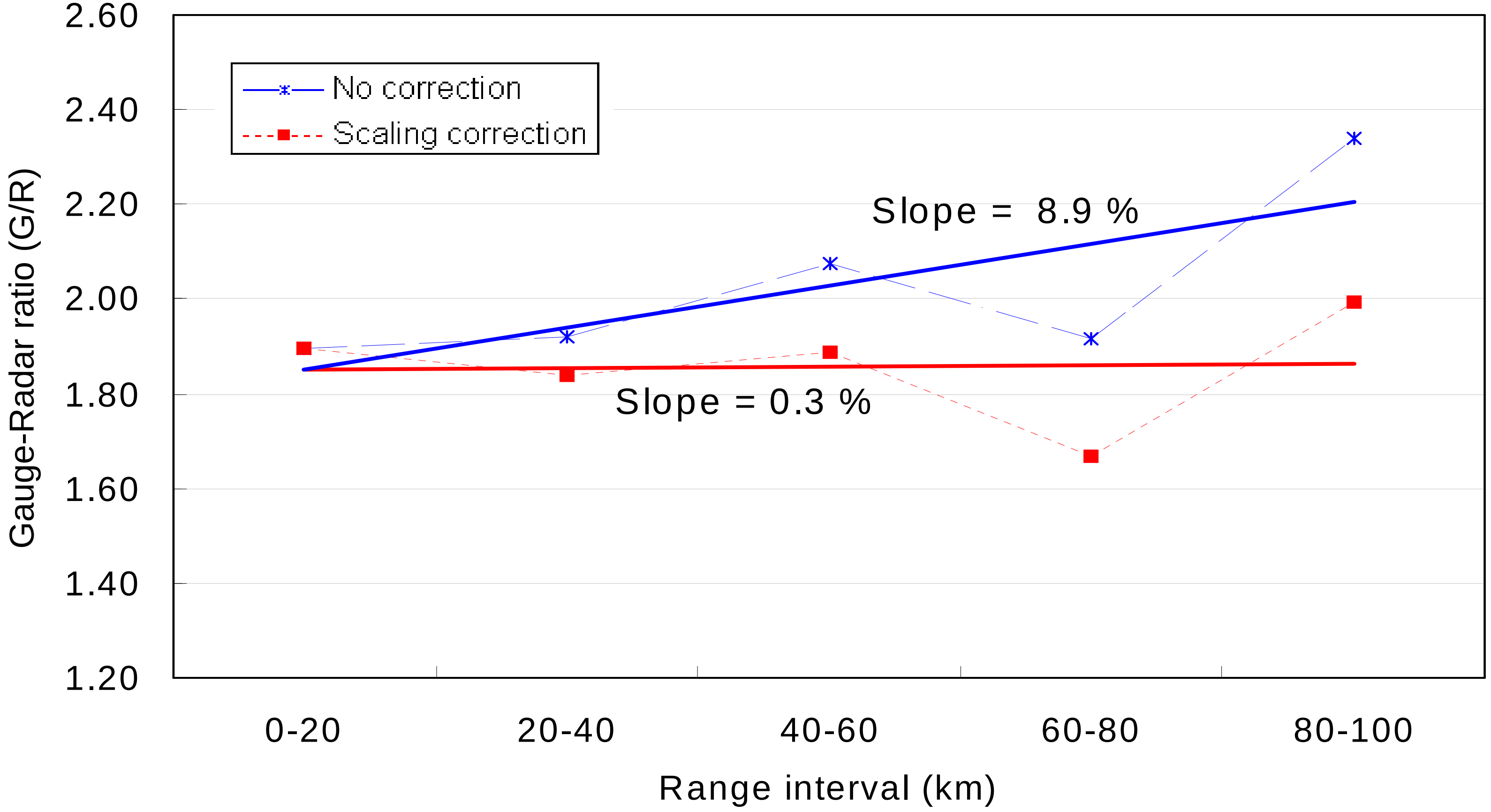
Range-dependent bias correction

Using simple-scaling theory[1]: $Z_{\text{transformed (dBZ)}} = (20/D)^{-0.024} Z_{D(\text{dBZ})}$



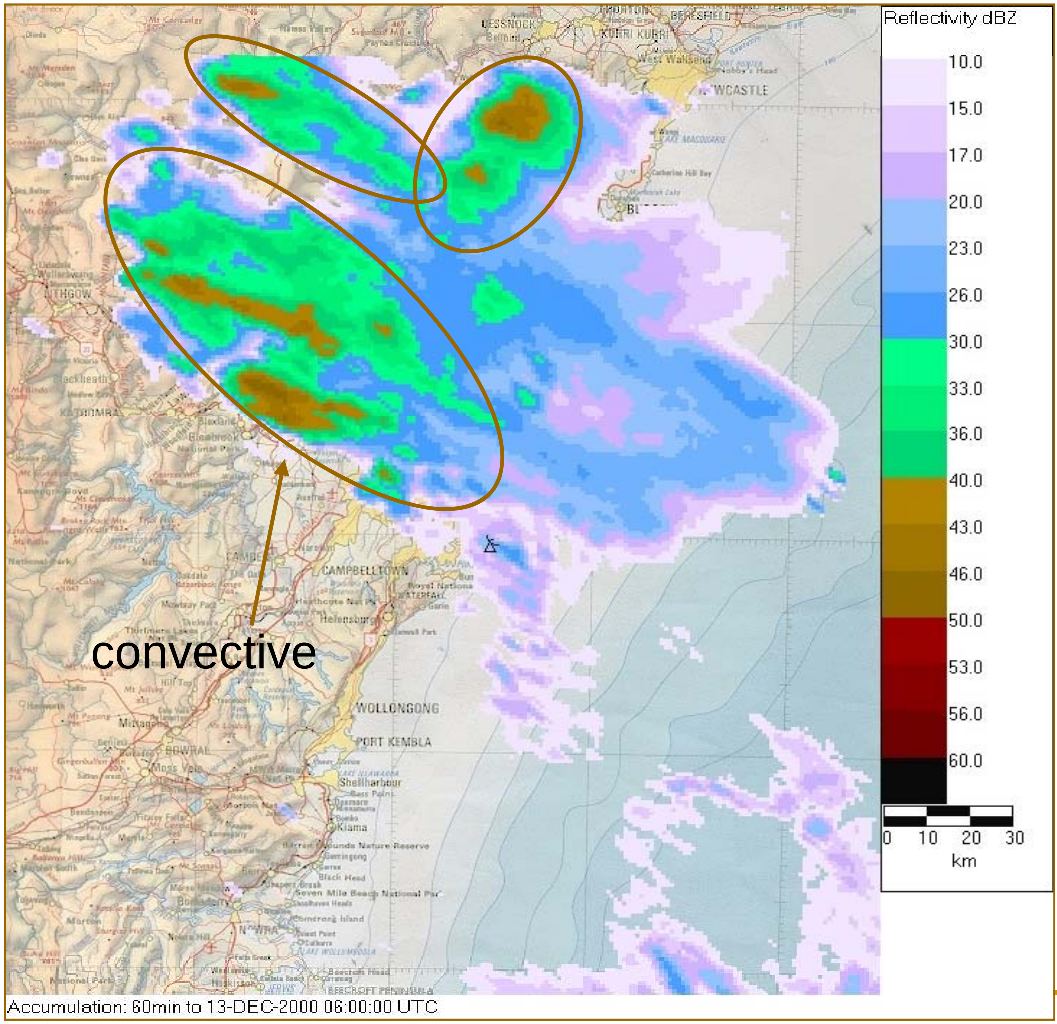
[1]Chumchean et al, 2004, J Atmospheric and Oceanic Technology

Effectiveness of scale transformation function in correcting range dependent bias in radar rainfall



Effect of storm types on radar rainfall Estimates (Z-R conversion error)

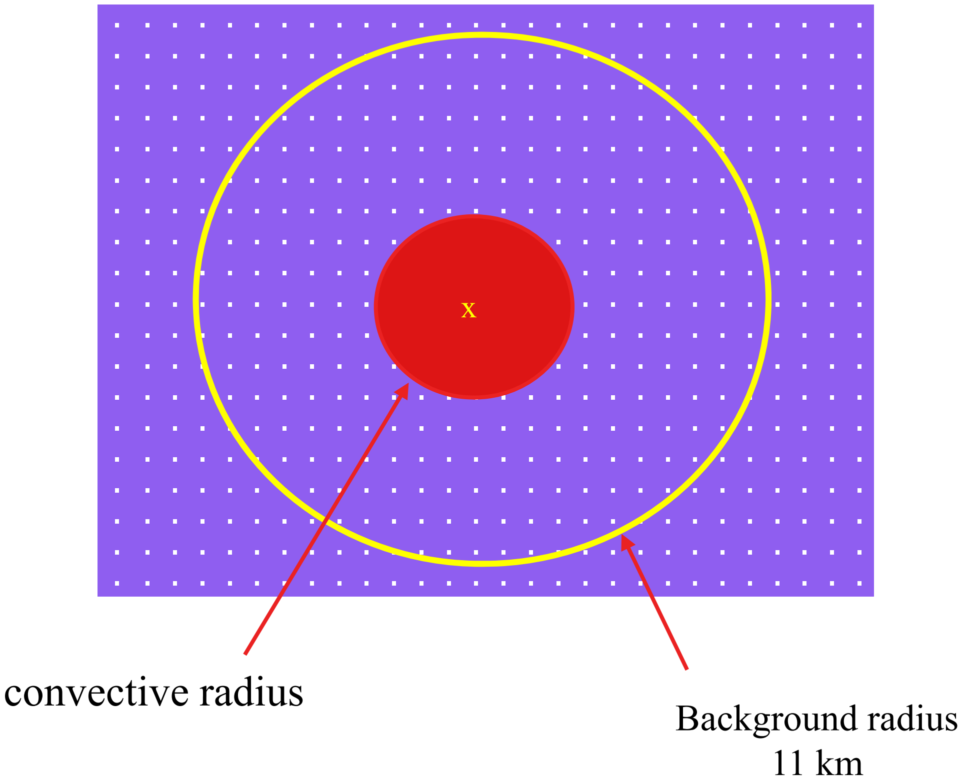
Instantaneous pixel classification



- Apply Steiner et al.(1995) storm classification method to use for separation of instantaneous reflectivity of each pixel into convective or stratiform components
- Revise the classification criteria to be suitable for instantaneous reflectivity of the Kurnell radar

Parameter for pixel classification

(after Steiner et al., 1995)

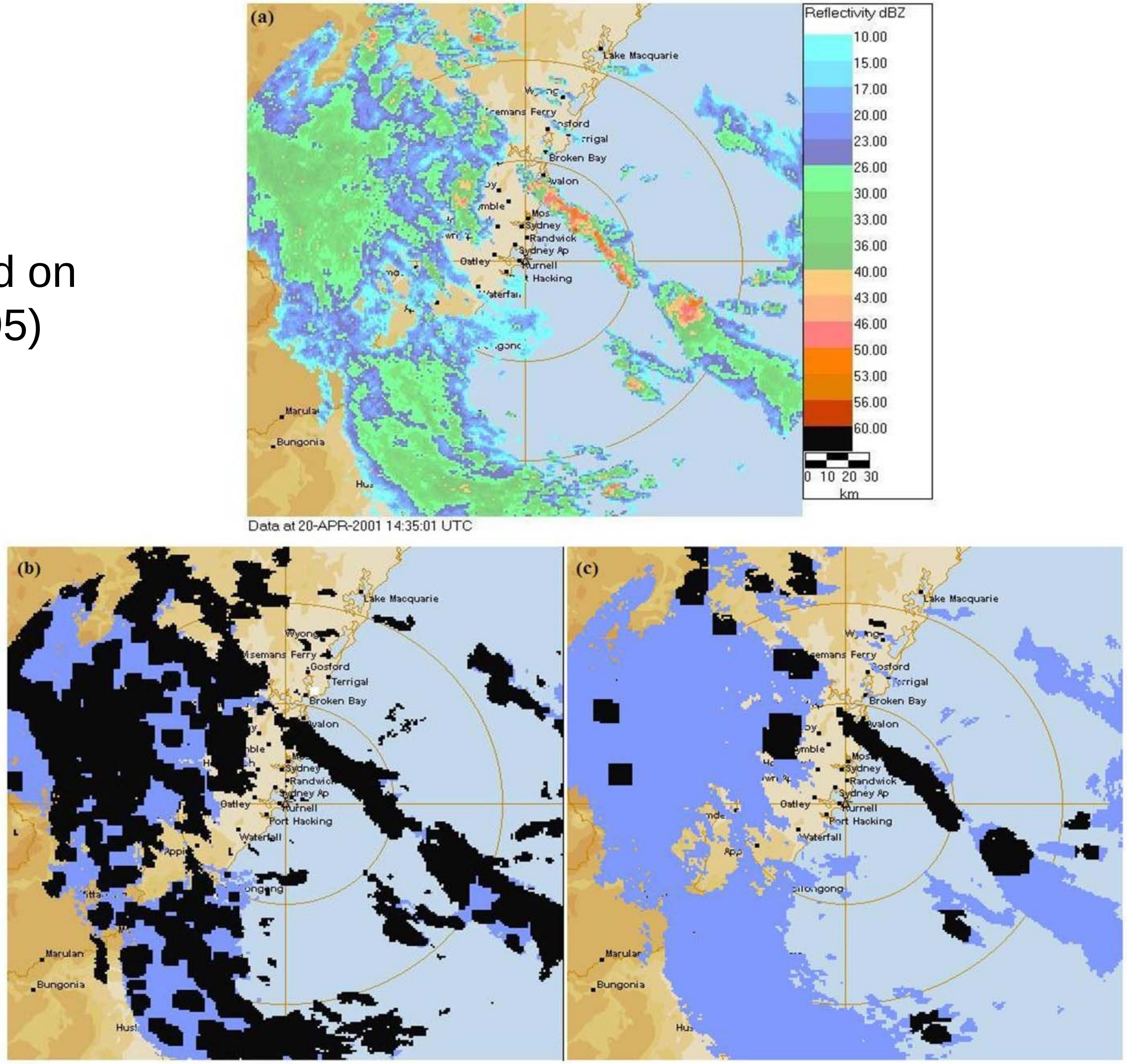


- convective centre
- background radius
- convective radius
- minimum convective threshold*
- maximum stratiform threshold*

* = proposed additional classification parameter

Classification results: calibration

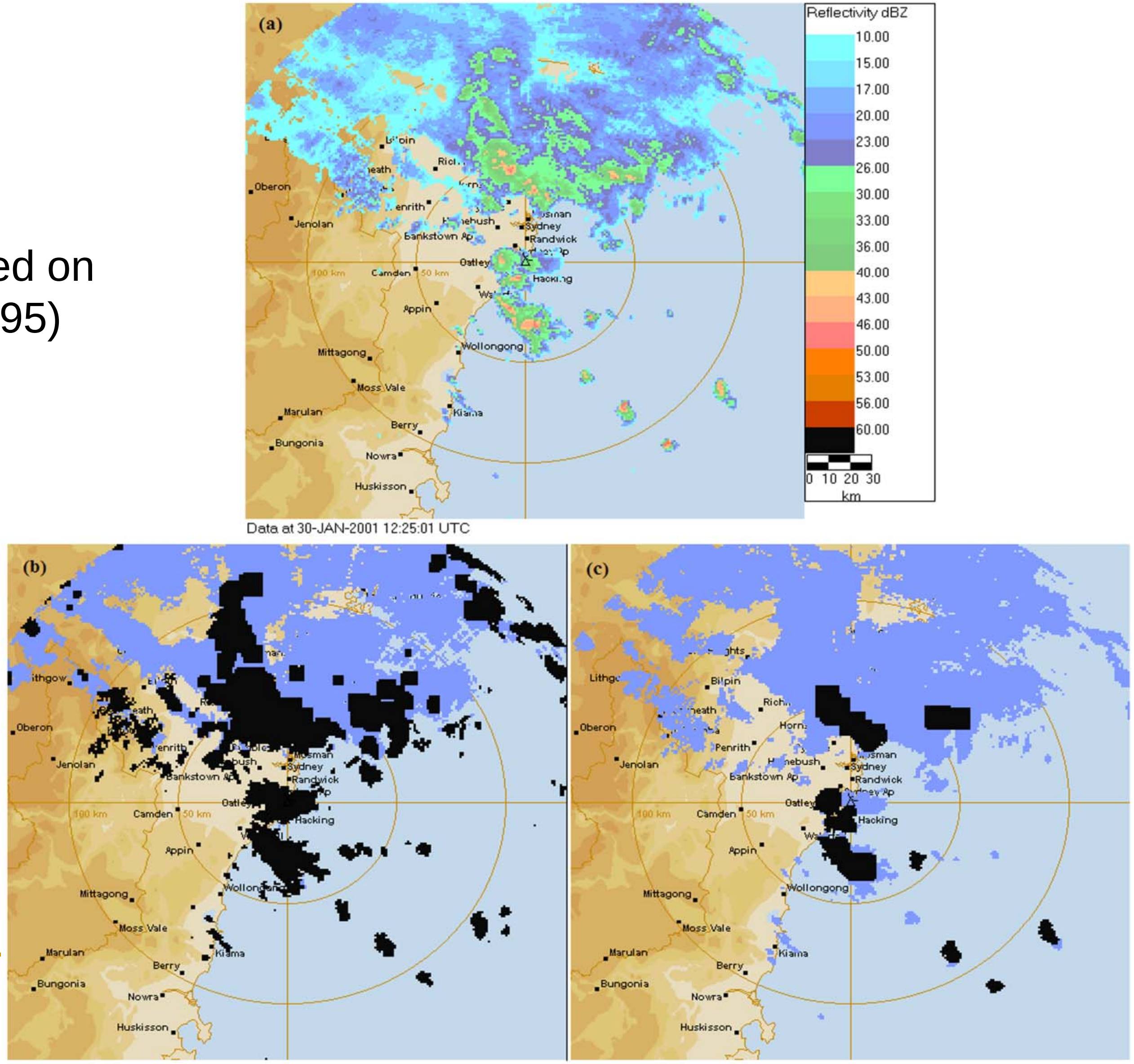
Using modified Parameters based on Steiner et al. (1995)



Using modified pixel based classification approach

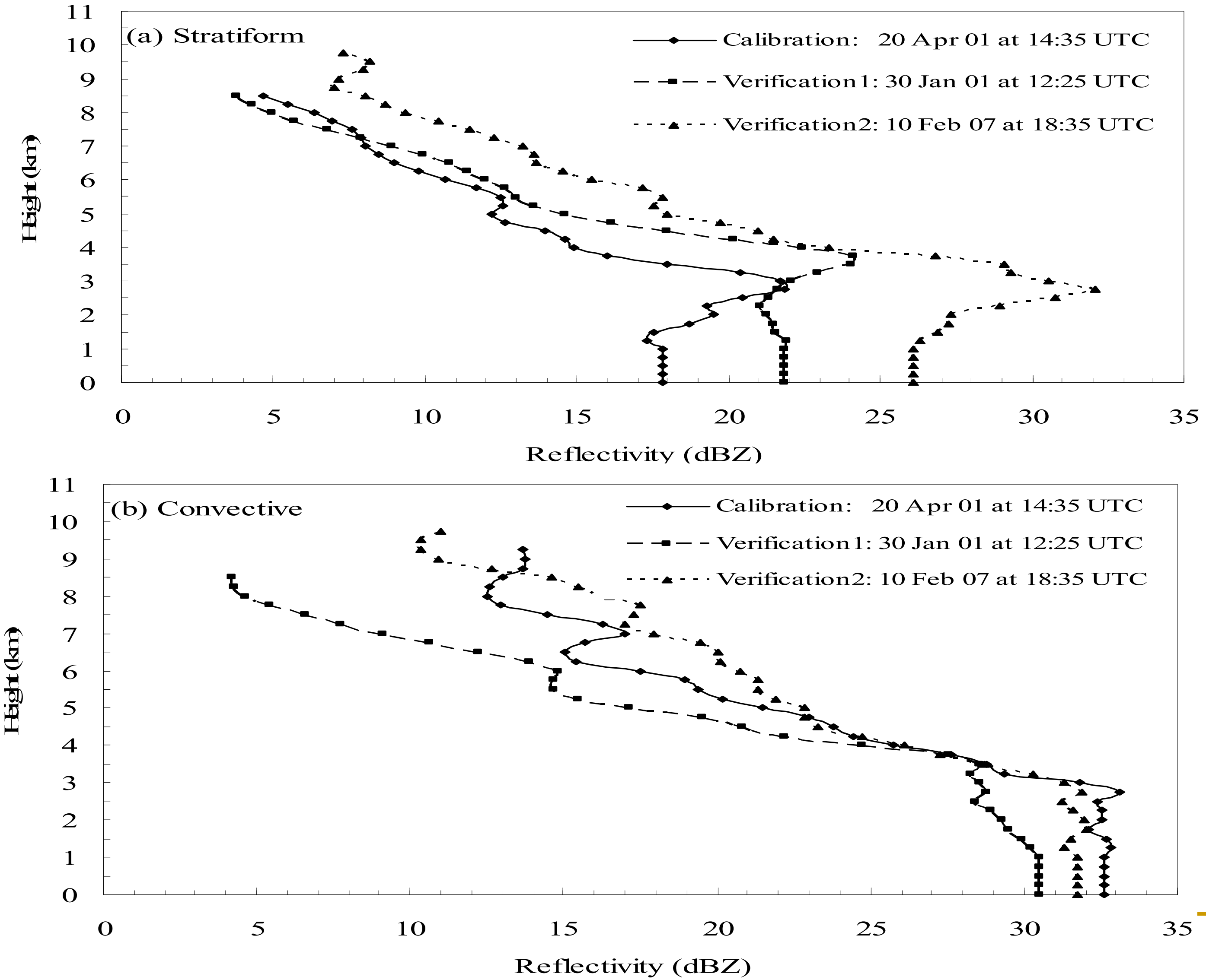
Classification results: verification

Using modified Parameters based on Steiner et al. (1995)



Using modified pixel based classification approach

Verification using VPR



Correcting for mean field bias in real-time radar rainfall estimates using Kalman Filtering techniques

?

Rain gauge rainfall (G) = AF x Radar rainfall (R)

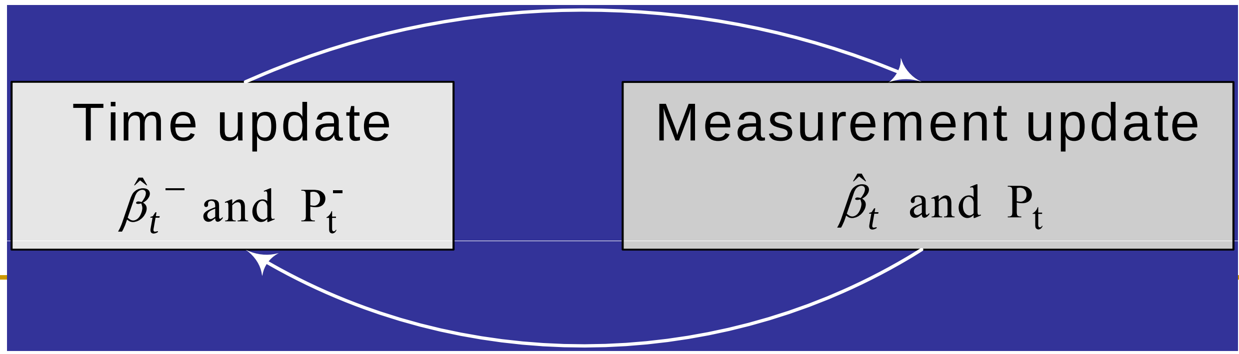
AF = adjustment factor or mean field bias

Advantage of Kalman filtering technique over the simple G/R

1) It accounts for the “noise” in the measurements when updating the mean bias.

2) It provides an estimate of the error in the computed bias.

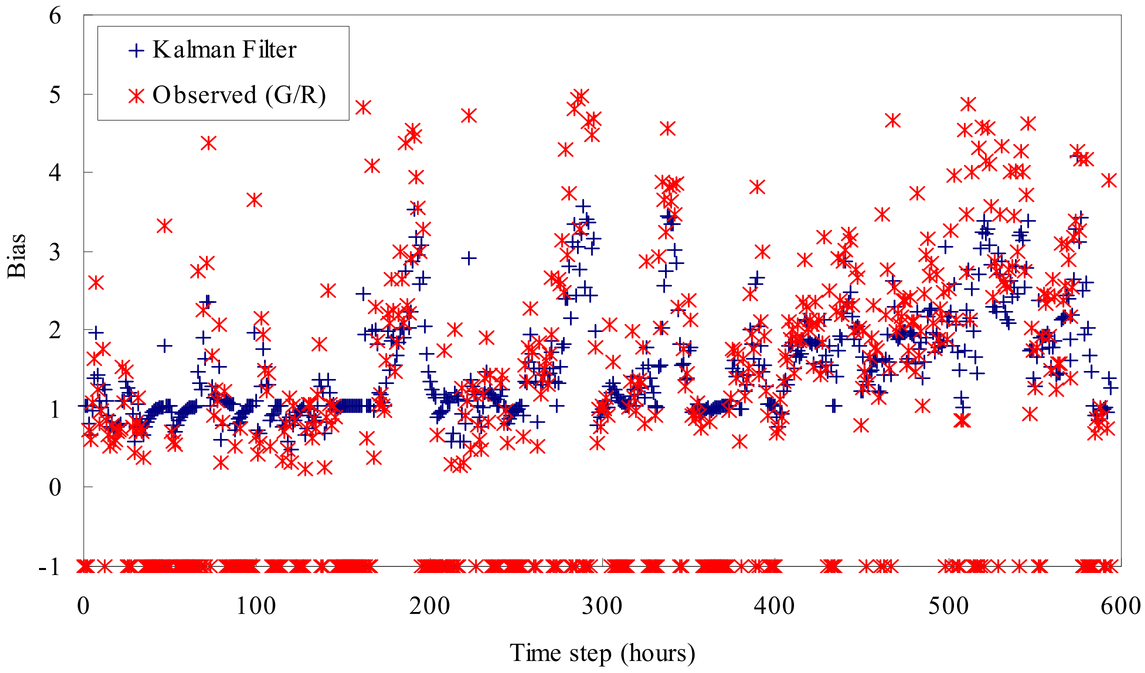
3) It combines an estimate of the bias and its error variance made an hour earlier with the current measurements and its estimated measurement error variance to compute an updated bias estimate and new forecast for the next hour.



Residual mean-field bias correction[1]

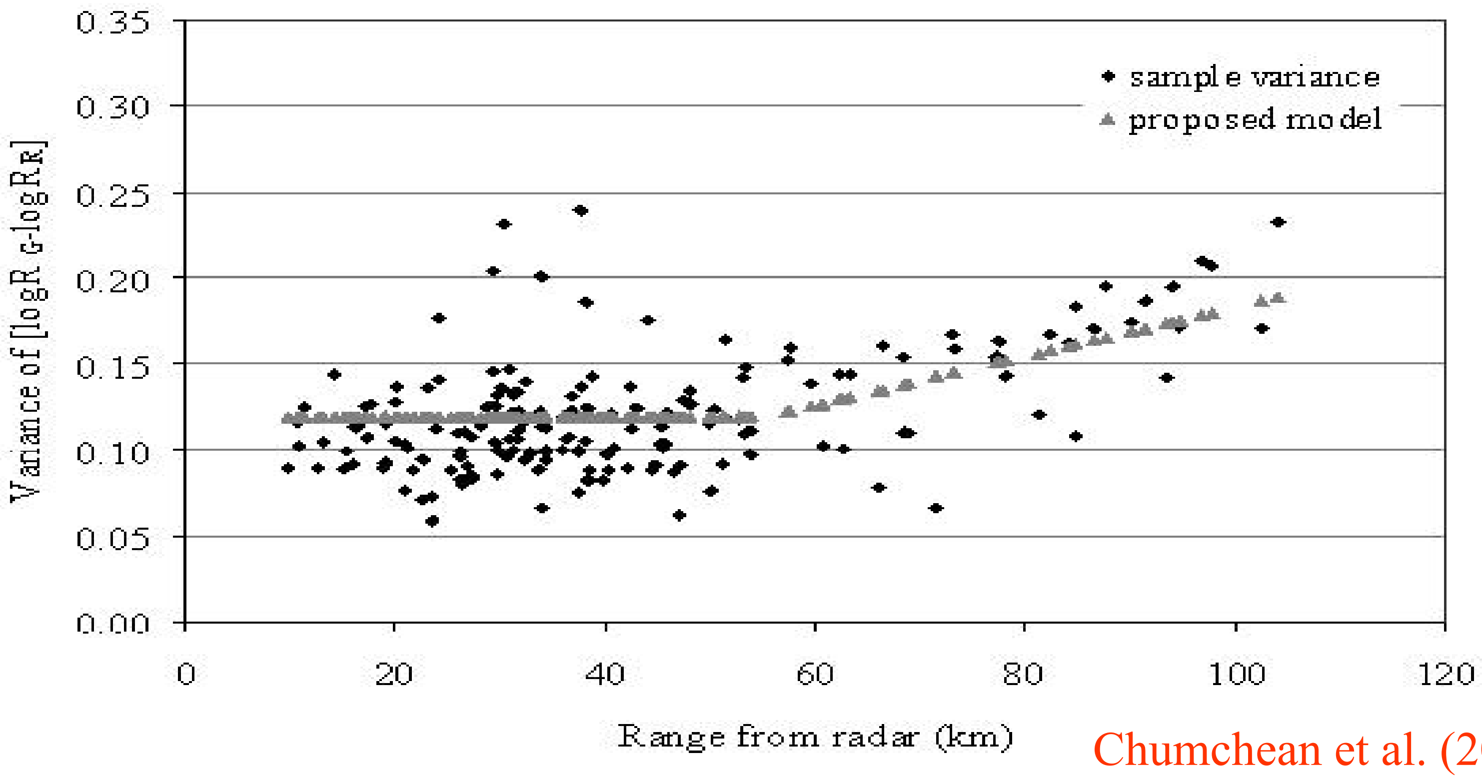
- Logarithmic Mean Field Bias (β)
- Assumed β exhibits Markovian dependence (Kalman process model assumed AR1)
- Kalman measurement error model specified as function of range[2]

$$\beta_t = \frac{1}{n}\sum_{i=1}^{n}\log_{10}\left(\frac{G_{i,t}}{R_{i,t}}\right)$$



[1]Chumchean et al, 2006, Journal of Hydrology,[2]Chumchean et al, 2003, Physics and Chemistry of the Earth, 28(3), 27-39.

Radar rainfall error variance model

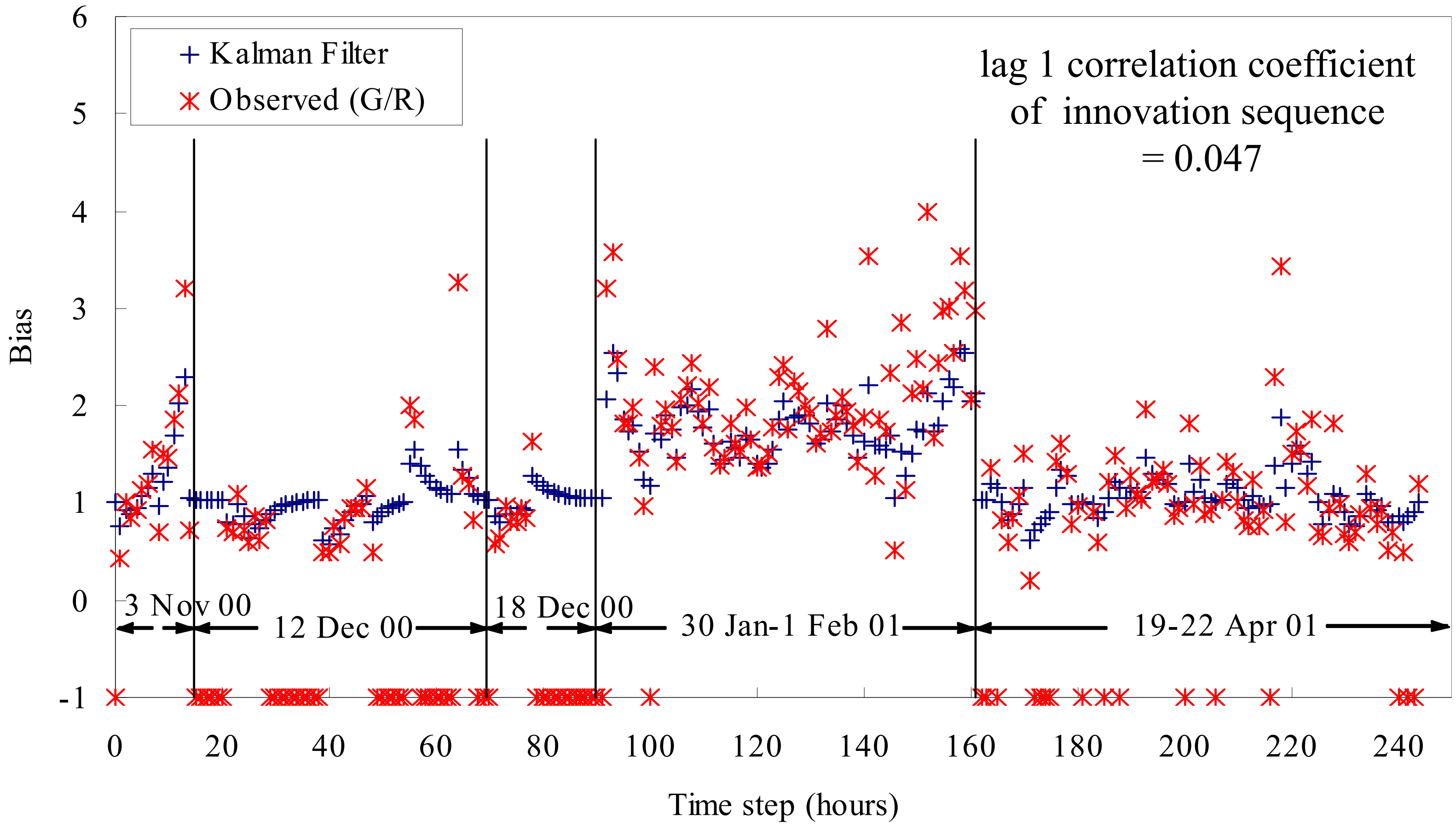


Chumchean et al. (2003)

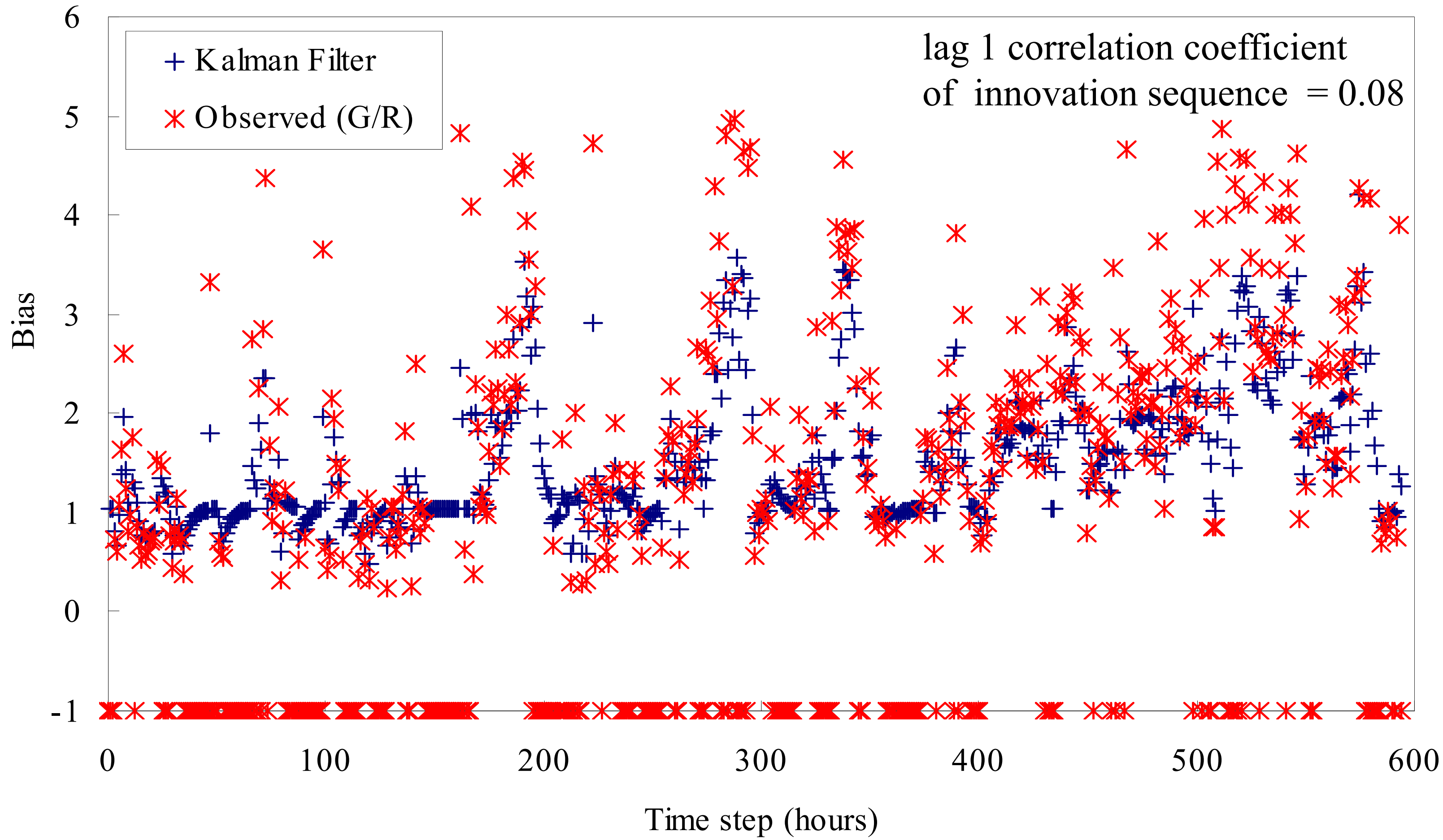
$$\sigma^2_{Y_{i,t}} = -0.015 \times \overline{G}_t + 0.14 \quad ; \quad \text{for } r_i \leq 55 \text{ km}$$

$$\sigma^2_{Y_{i,t}} = -0.015 \times \overline{G}_t + 0.13 \times \frac{(r_i - 55)}{p} + 0.14 \quad ; \quad \text{for } r_i > 55 \text{ km}$$

Comparison of observed G/R and the Kalman-filter estimated bias (Calibration)



Comparison of observed G/R and the Kalman-filter estimated bias (Validation)



Application

- Stepwise application of error correction strategies
- Base reflectivity data free of effects of ground-clutter, bright-beam, hail
- Total rain gauges - 260
- Cross-validation performed by leaving fraction of rain gauges to evaluate predictive uncertainty
- Performance statistic - Root Mean Square Error (RMSE)

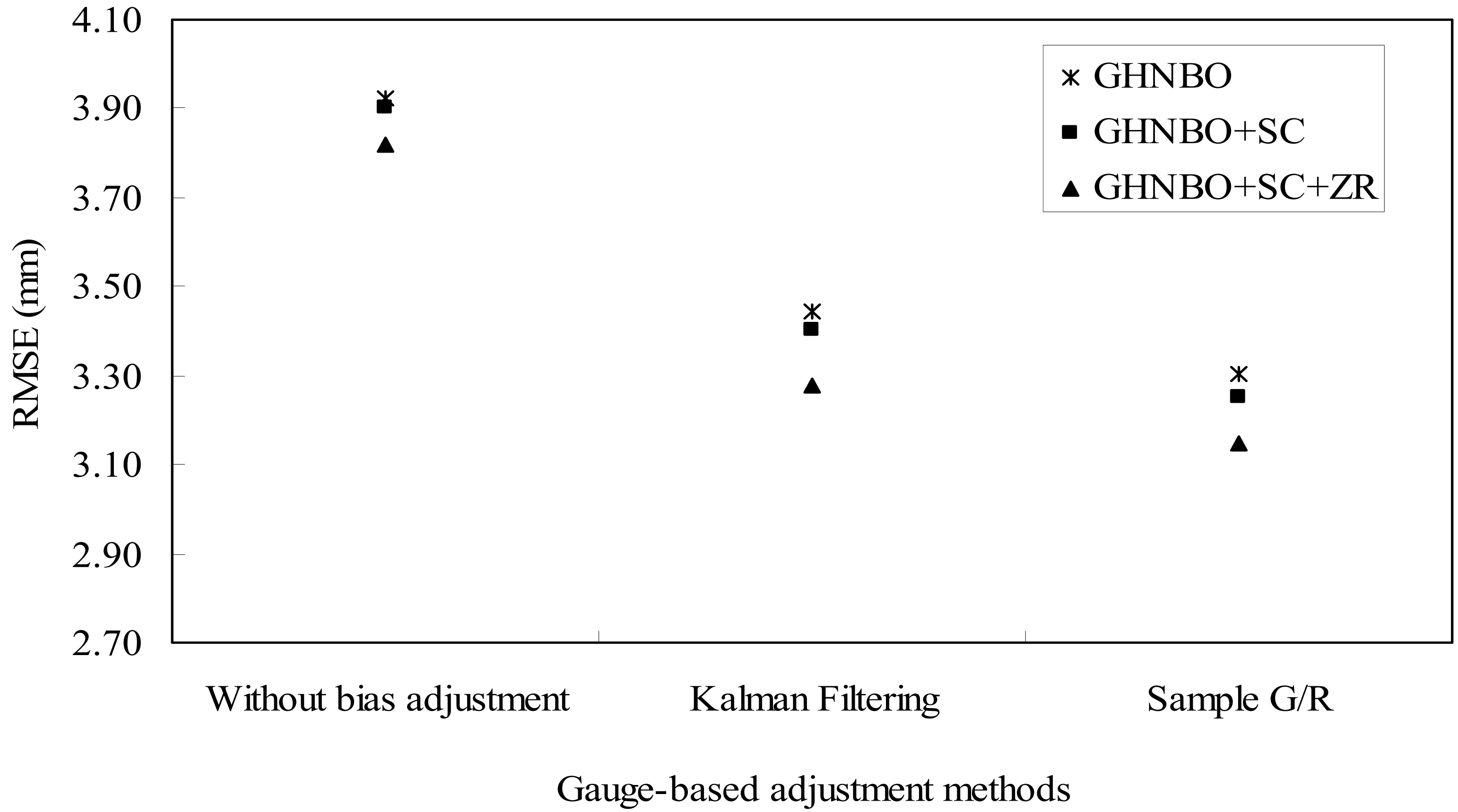
Results

Climatological *Z-R* parameters of convective and stratiform rainfall

($Z = AR^{1.5}$)

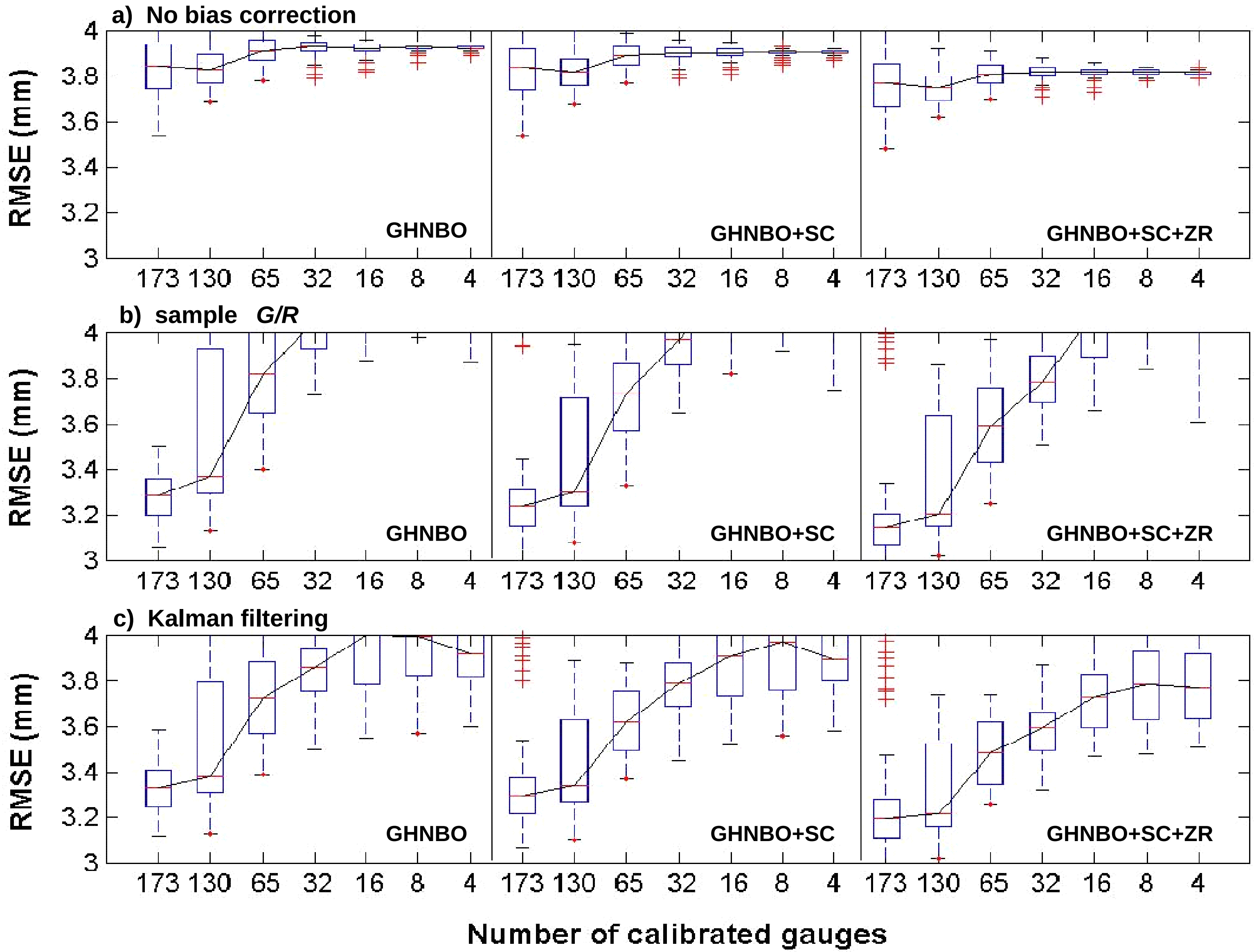
Calibration strategies	***A*** parameter			
	No scaling correction		Scaling correction	
	Convective	Stratiform	Convective	Stratiform
No-classification	128		146	
Hourly pixel classification	150	93	172	100

Results



- 'GHNBO' – Base data
- 'SC' – Scaling correction
- 'ZR' – Storm classification

Results


a) No bias correction
b) sample G/R
c) Kalman filtering
RMSE (mm)
GHNBO
GHNBO+SC
GHNBO+SC+ZR
173 130 65 32 16 8 4
3
3.2
3.4
3.6
3.8
4
Number of calibrated gauges

Conclusions

- A stepwise decrease in RMSE with added levels of error correction
- Correcting mean-field bias more important that correcting the other sources of errors
- Storm classification relatively more important than the correction of range dependent bias
- Kalman filtering much better than use of sample G/R correction, particularly when calibration rain gauges are few

Conclusions

- Range dependent bias and storm-classification, though small, are certainly not insignificant
- Complete model (after mean-field bias correction) explains more than 50% variance of gauge rainfall
- This may be the best we will ever have – remember we are comparing 1kmx1km grid averages to rainfall at a point!