Radar calibration procedures and scanning strategies for ground validation

Luca Baldini

CNR -Institute of Atmospheric Sciences and Climate, Rome
Italy

V. Chandrasekar

Colorado State University and Finnish Meteorological Institute

Acknowledgments:

Walt Petersen, Dave Hudack,
Tomoo Ushio, Luiz Machado

Motivation

- GPM program needs to integrate data from globally distributed heterogeneous radars contributing to the GV effort

- In particular GV radars
  - belong to various agencies
  - have different technical characteristics
  - work in different climatic region

- It is therefore useful to have a set of “community accepted“ standards and protocols for maintaining the quality, meta data.

Outline

1. **Guidelines for weather radar calibration**
   Calibration concepts (Chandra et. al keynote talk at the AMS radar Conference 2011)
   To be formalized into a GPM document according the feedback from the community

2. **GV radar scanning strategies**
   Guidelines for GV
   CHUVA Fortaleza scanning design

Weather radar calibration

- Accuracy of radar measurement parameters can have significant impact on accuracy of applications.
- Radar is a complex system consisting of too many components such as transmitters, receivers, amplifiers, filters, microwave components, etc. It is difficult to be able to characterize every component.

$$dBz = dBm(received\ power\ in\ mw) + C + 20\log(R)$$

$$C = \left(\frac{cT_0}{2}\right)\left(\frac{G_r}{l_r}\right)\left[\frac{\lambda^2 P_t G_0^2}{(4\pi)^3 r_0^2}\right]\left[\frac{\pi\theta_1\phi_1}{8\ln 2}\right]\pi^5 |K_w|^2$$

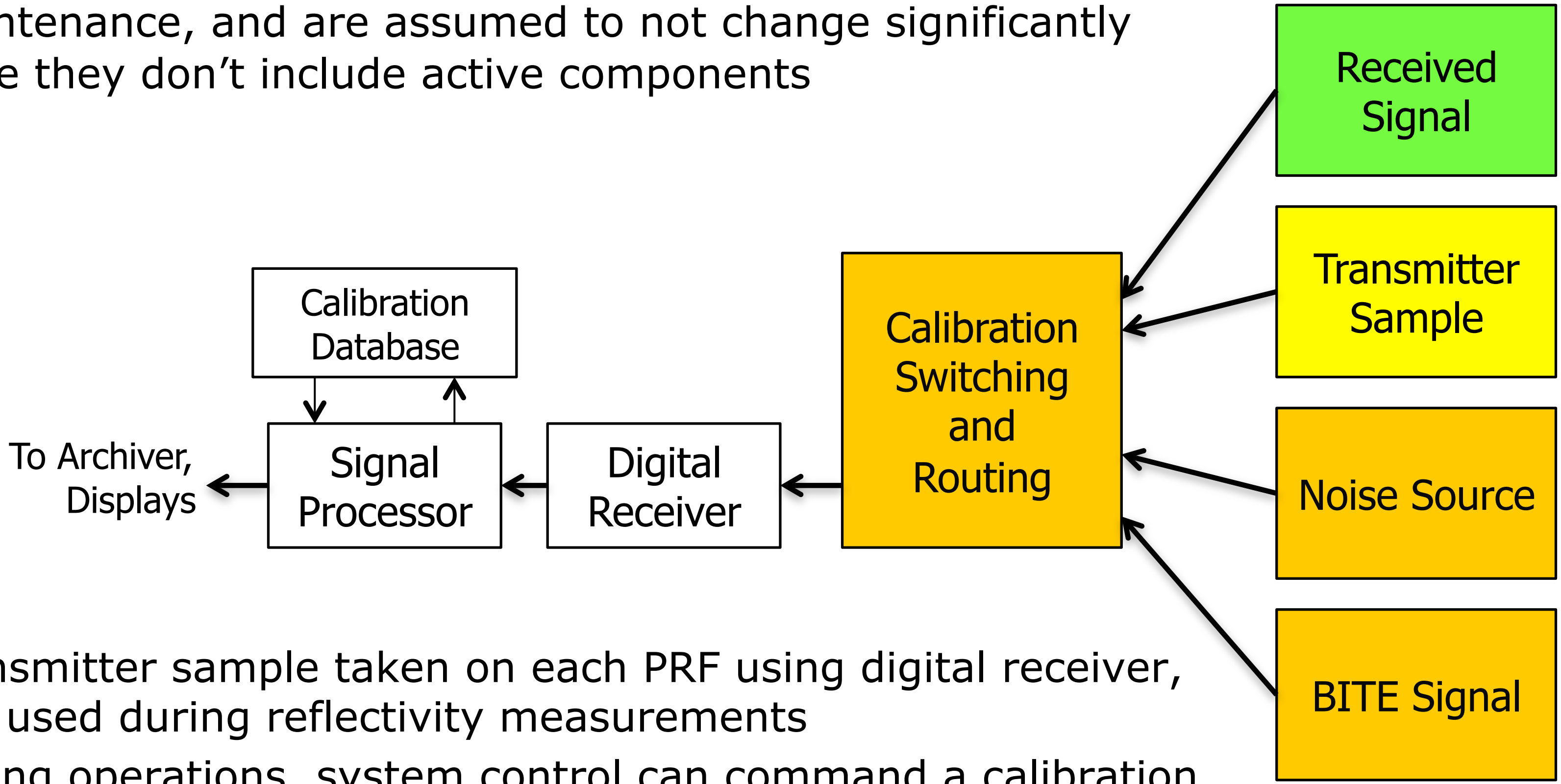
- For this reason methodologies able to evaluate and characterize the system as a whole are often preferred.
- Automated procedures to monitor subsystems have been developed.
- GPM GV community desperately needs standards (Protocol, best practices manual)
- With standards manufacturers will comply , and it will save time and effort instead of "defining things" every time.

Weather radar calibration

- Two basic elements
  - Built in radar calibration subsystem
  - Methodologies for verification of calibration

Radar calibration subsystem for GV radars

- Radar includes switching for microwave signals to permit self-calibration using the digital receiver and signal processor
- Signal paths are characterized during installation and periodic maintenance, and are assumed to not change significantly since they don't include active components

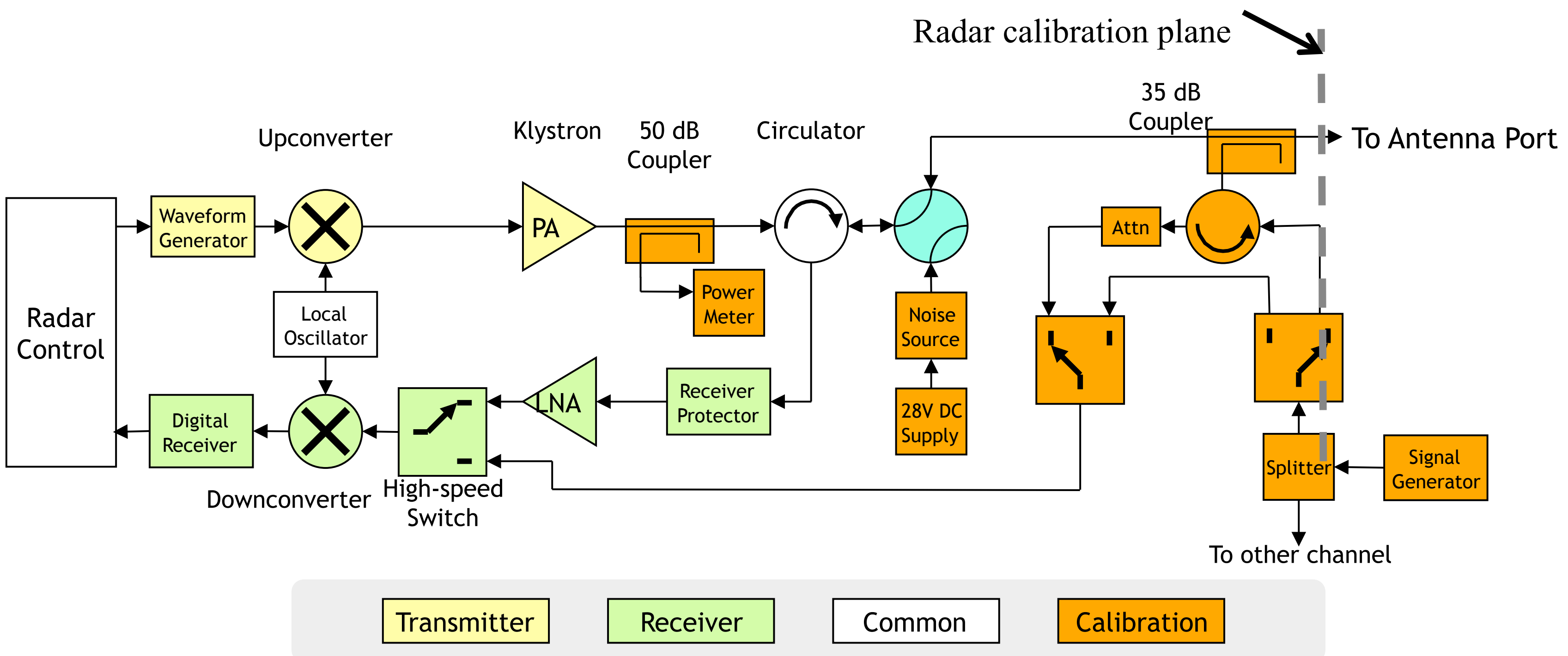


- Transmitter sample taken on each PRF using digital receiver, and used during reflectivity measurements
- During operations, system control can command a calibration that characterizes active components to resolve unknowns
- Calibration database can be used to detect anomalous calibrations and flag them for further investigation

Radar calibration subsystem CSU-CHILL example

- Radar calibration setup, indicating major components
- Only one polarization channel is shown
- Assumes that gain of any active component may change over time

- All measurements are made with respect to the radar calibration plane, at the 35 dB directional coupler

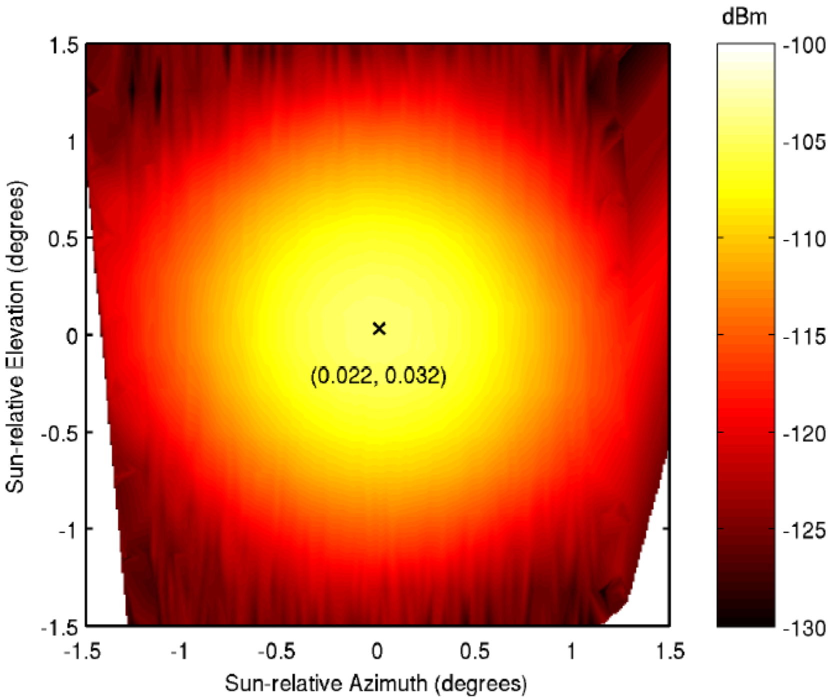


Radar calibration subsystem use of the Sun

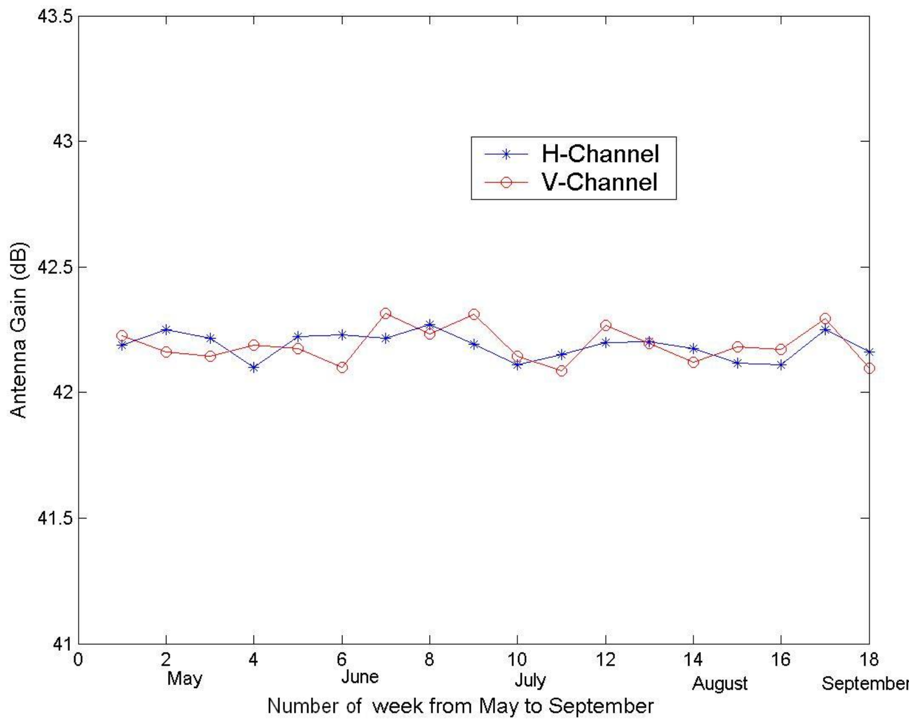
- The Sun is a useful calibration tool because it can be observed from any point on Earth on a regular basis
- The Sun can be treated as a standard noise source whose position at any time and location can be precisely calculated
- The solar flux incident on the surface of the Earth is generally non-polarized and varies between 100 to 300 solar flux units (a SFU is defined to be $1x10^{-22}$ Watts/Hertz/meter^2)
- Measurements can be obtained from the Solar Environment Center or Dominion Radio Astrophysical Observatory at Penticton, BC, Canada
- At 10 cm wavelength the (microwave) sun is approximately 7% larger than the optical sun

Radar calibration subsystem Using the Sun

Scan over the Sun



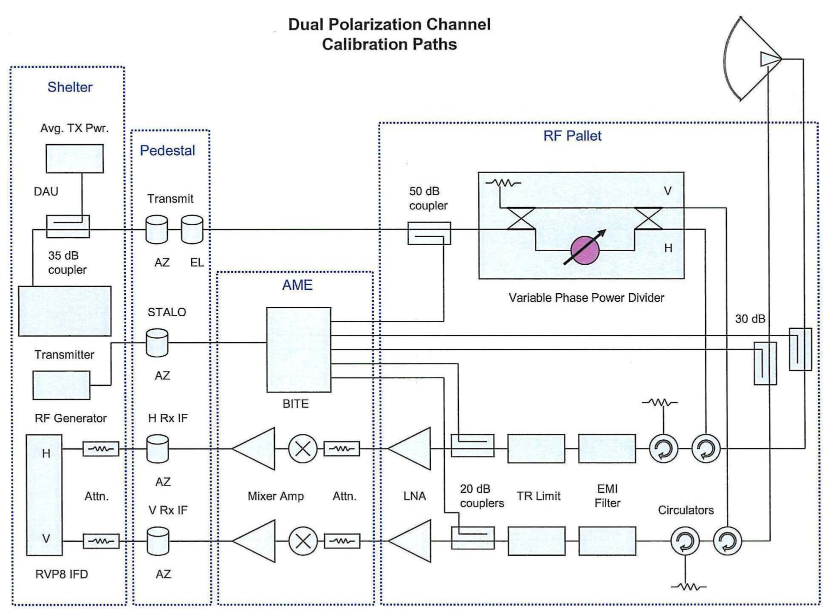
Antenna Gain estimated weekly using solar calibration in H and V channels from May to September, 2003

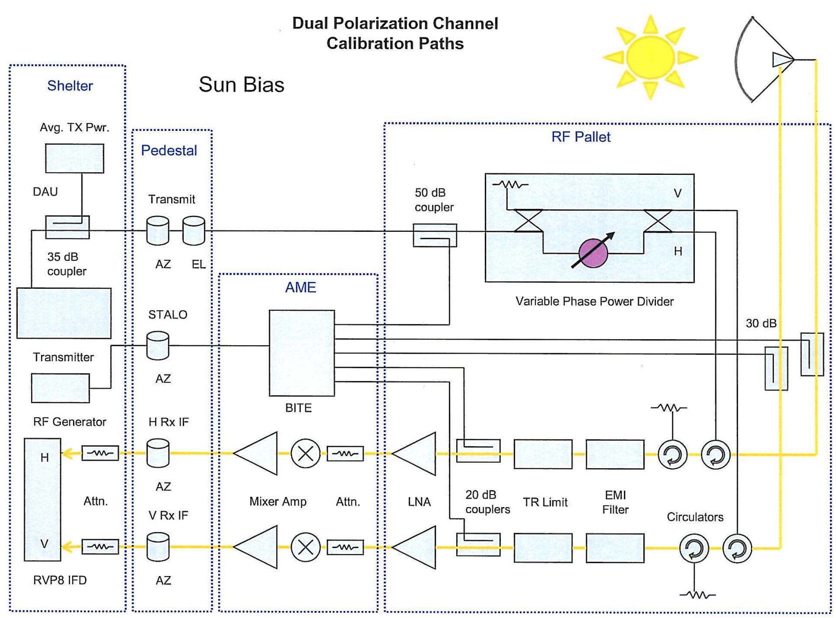


Radar calibration subsystem NEXRAD example

NEXRAD has an elaborated subsystem for calibration

$$Zdr_{Bias} = 2Zdr^{Sun} - 2Zdr_{Rx}^{Sun} + Zdr^{BITE} + Zdr_{Rx}^{Test} + Zdr_{Tx} - Zdr_{Tx}^{Cal\_Bias}$$





Basic guiding principles / best practices

- All Measurements must be Referenced to the Same Point in the Radar (rear of antenna)
- All Calibration Measurements must be made with the Signal Processor
- Make differential measurements such that errors will cancel out.
- High Density Micro-Electronics packaging must be used to Maintain Accuracy & Repeatability
- Packaging Improves Reliability (~20 years)

Position calibration

- Sometimes neglected, but critical
  - Solar scans: automated procedure
  - Gunners quadrant

Verification/ Validation of Calibration

- End to end techniques
  - Metallic sphere calibration
  - Cross polar power technique
  - Natural properties of precipitation
  - Using ground targets

Calibration protocol

1. Receiver calibration – once every scan
2. Transmit power monitoring – continuous
3. Solar calibration monitoring (can be done very regularly and frequently)
4. Zdr calibration
   - Vertical looking –Target of opportunity
   - Signal source/ crosspol
   - Solar measurements – can be done regularly
5. Sphere calibration – once a year
6. Calibration requires discipline, avoid to many rearrangement of equipment/ connection
7. Overall once a year calibration campaign is recommended

GV radar scanning strategies

GV Field Campaigns

Designed based on the scientific goals of the campaigns (eg. Rainfall studies, convective systems studies, etc…).

- They combines PPI, RHI scan scans and RHI coverage, typically in supervised mode to satisfy requirements posed by different science objectives
- Modeled according to availability of instruments (eg. Aircraft measurements, radar**s**)
- Flexibility of operation is recommended.
- See exercises for LPVEx, MC3E

Long term GV observation

To be applied in long term observations in unattended mode

- Satellite overpasses need to be considered
- Optimal coverage of volume sampled by satellite
- GPM/TRMM: vertical resolution is critical

Design criteria

Design Criteria

A. Accuracy/time updating dilemma

B. Volume measurements
   - Vertical coverage
   - Vertical resolution

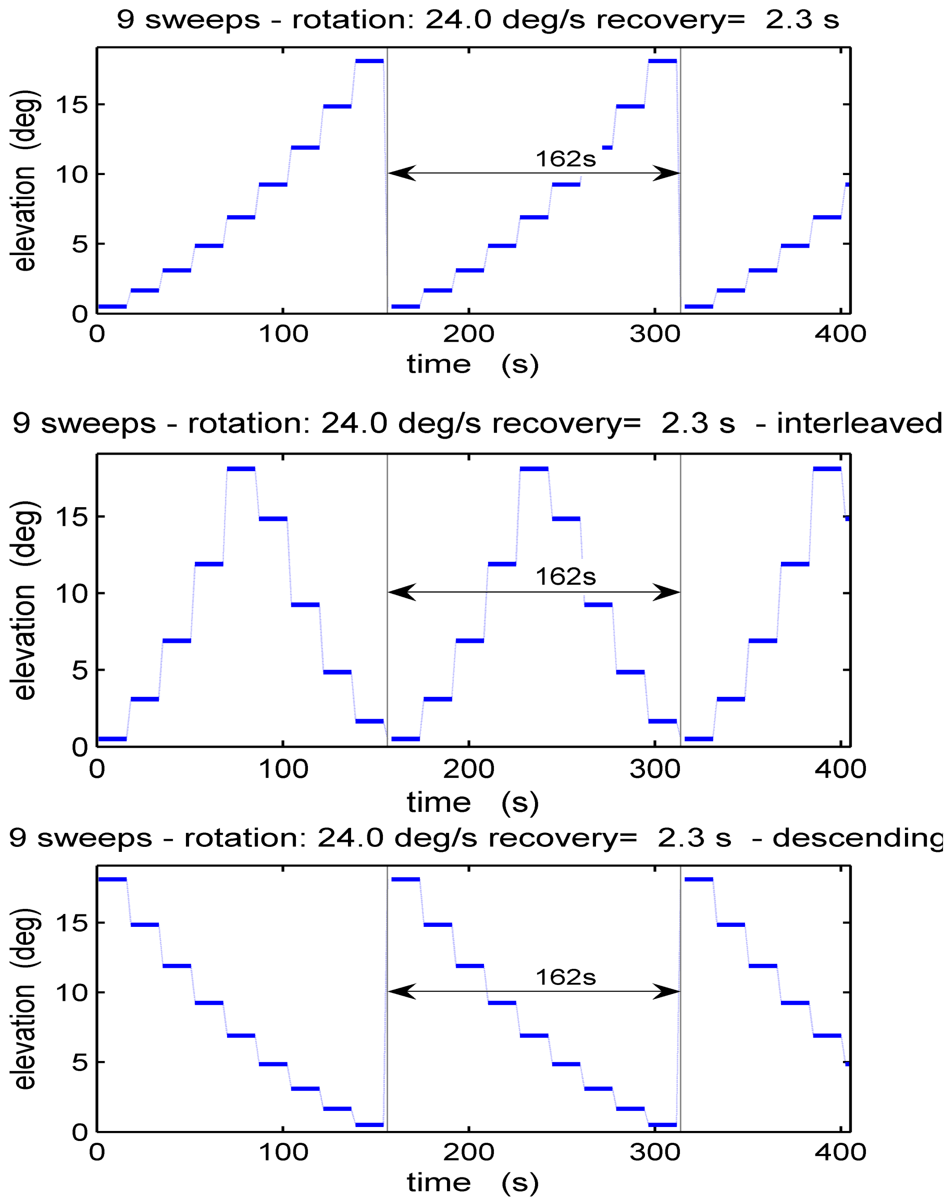
C. Improvement of observation using RHI, sector scan, vertical pointing

A) Accuracy / time updating

Time updating is constrained by:

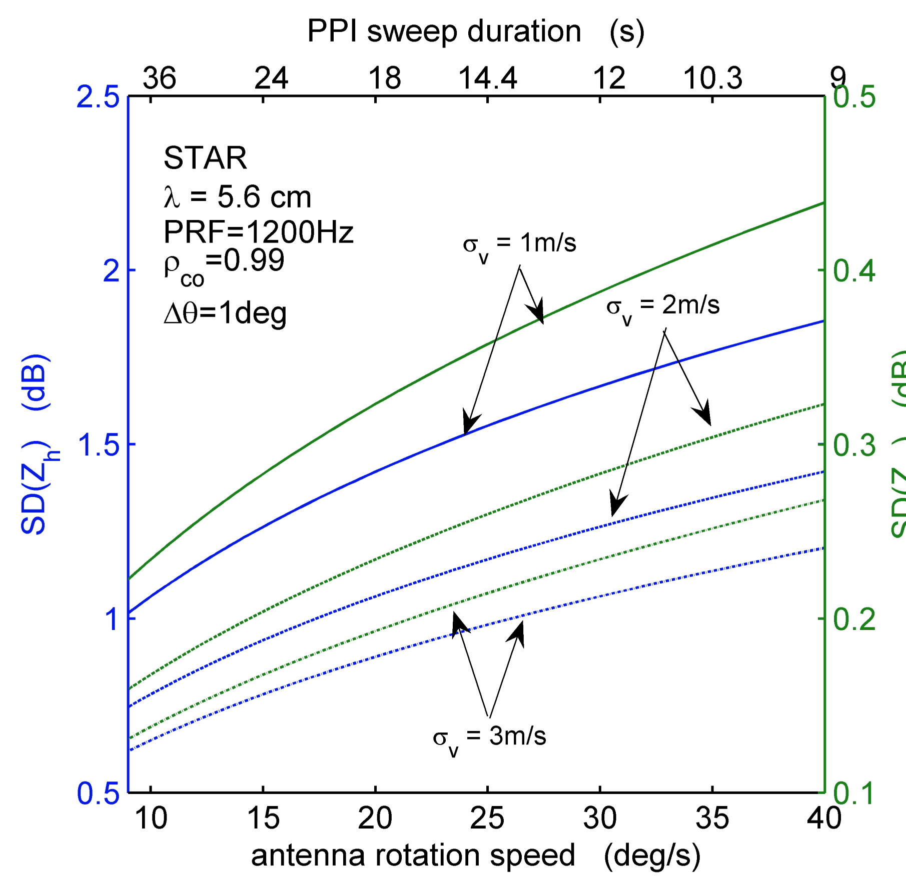
- antenna mechanics
  - max angular velocity: 20÷40°/s
  - max angular acceleration: 10÷20°/s²
  - Positioning accuracy: = ± 0.1°
  - Elevation range
    maximum elevation can be sometimes < 90 deg

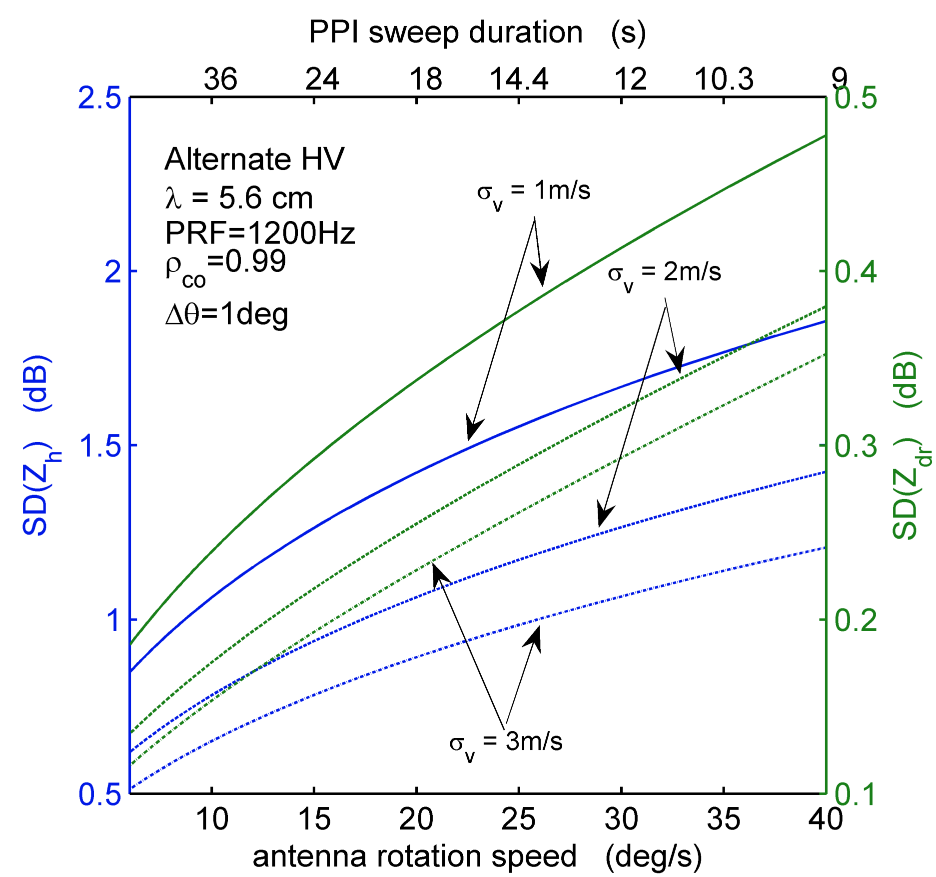
- Measurement errors related to the number of integrated samples/antenna rotation speed



A) Accuracy / updating

- Measurement accuracy is determined by the antenna scan rate through the number of integrated pulses.



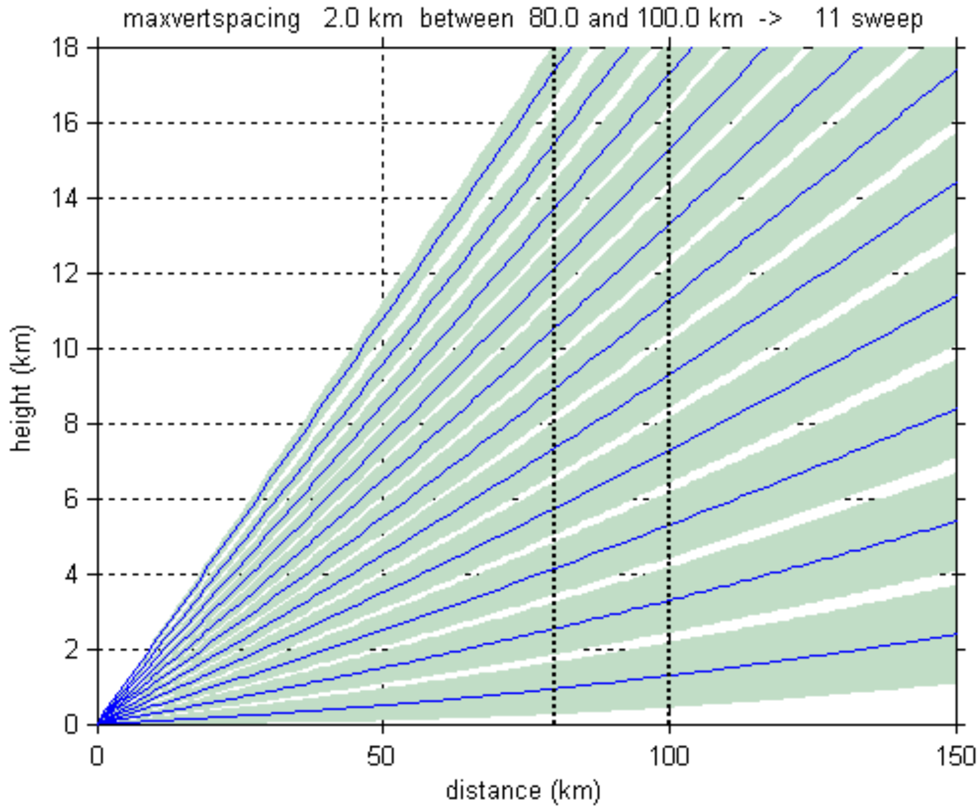


B) Volume measurements: vertical resolution

- Example of constraint
  - Max vertical spacing between beam = 2 km
    - below 18 km
    - distance between

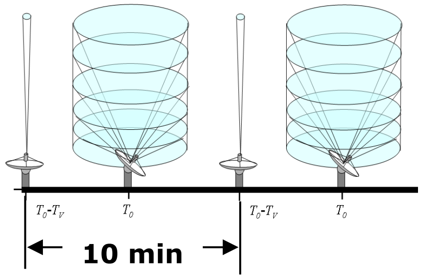
      80 and 100 km

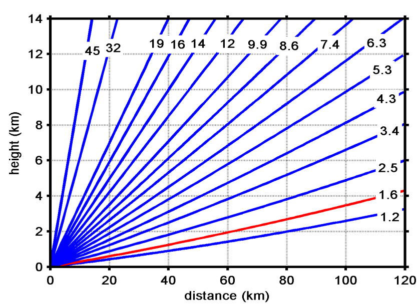
EXAMPLE from TRMM GV
11 sweeps

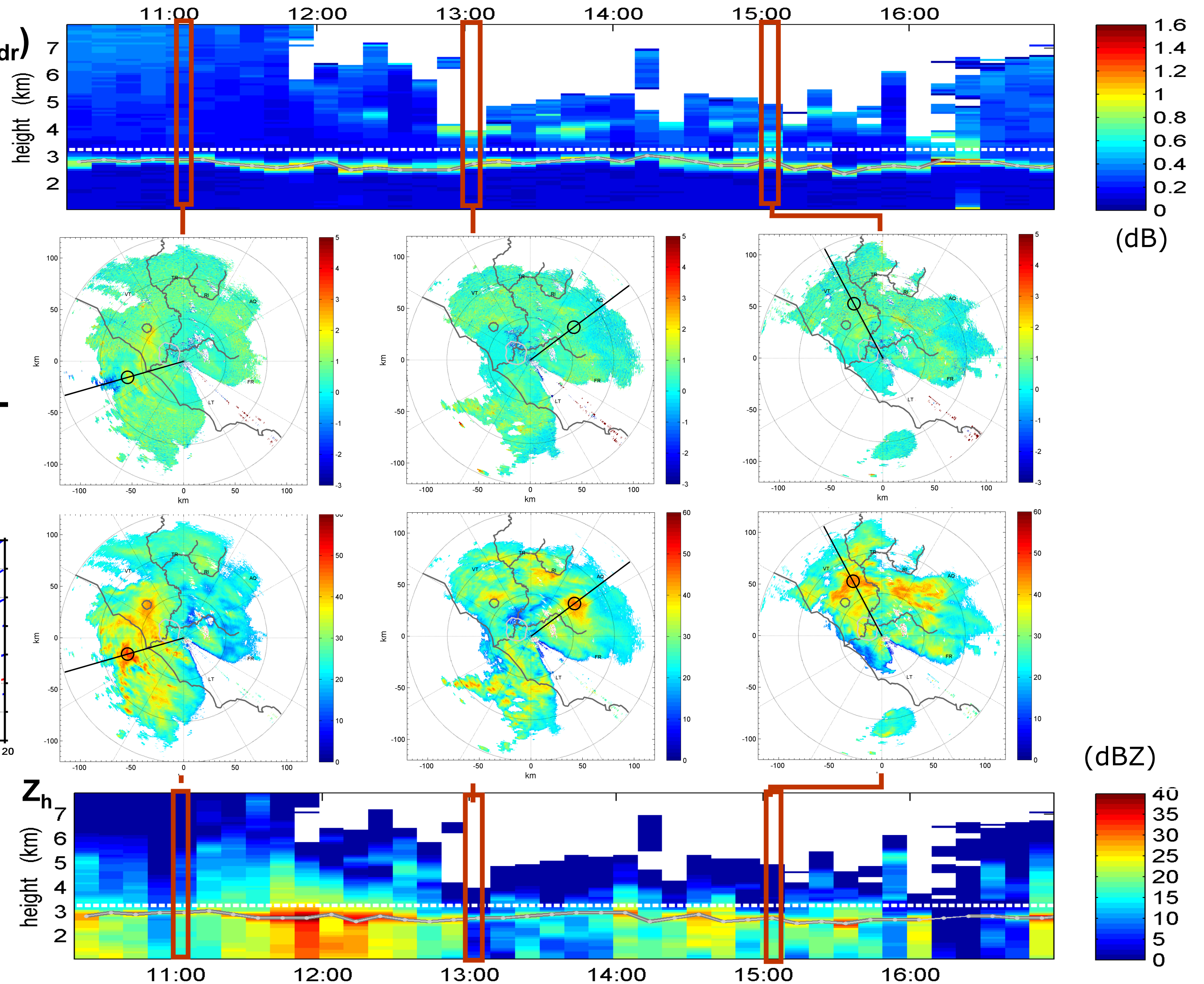


C) Improving volume observations: vertical observation s

ISAC-CNR Polar 55C radar, Rome, 2008-09-19

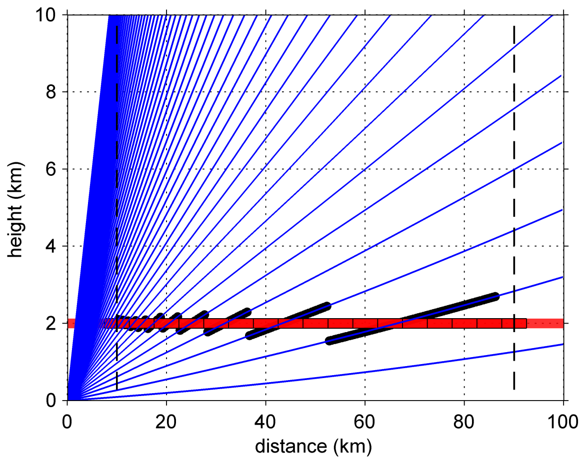






C) Improving volume observations: RHI/ PPI sector scanning

- vertical resolution using RHI oversampling



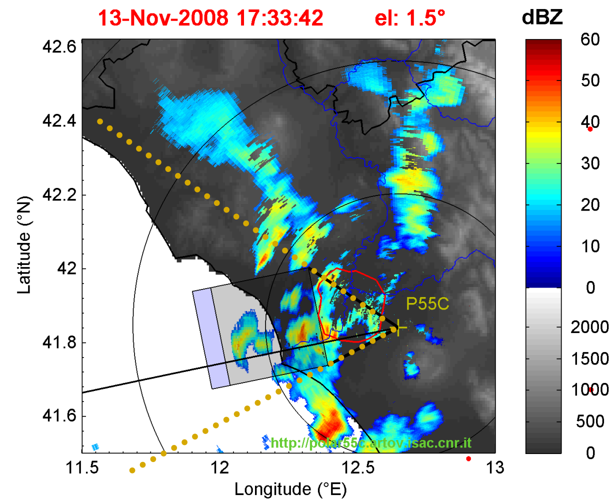
$\Delta el = 1$ deg

Δr = 0.250 km

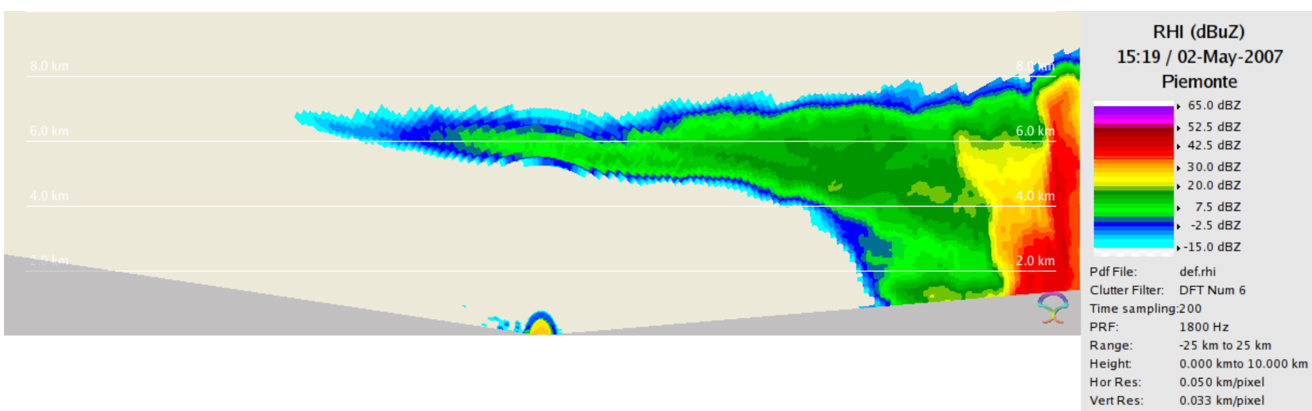
el_{max}=49.5 deg

el_{min}=0.5 deg

- Sector scanning: when/where?



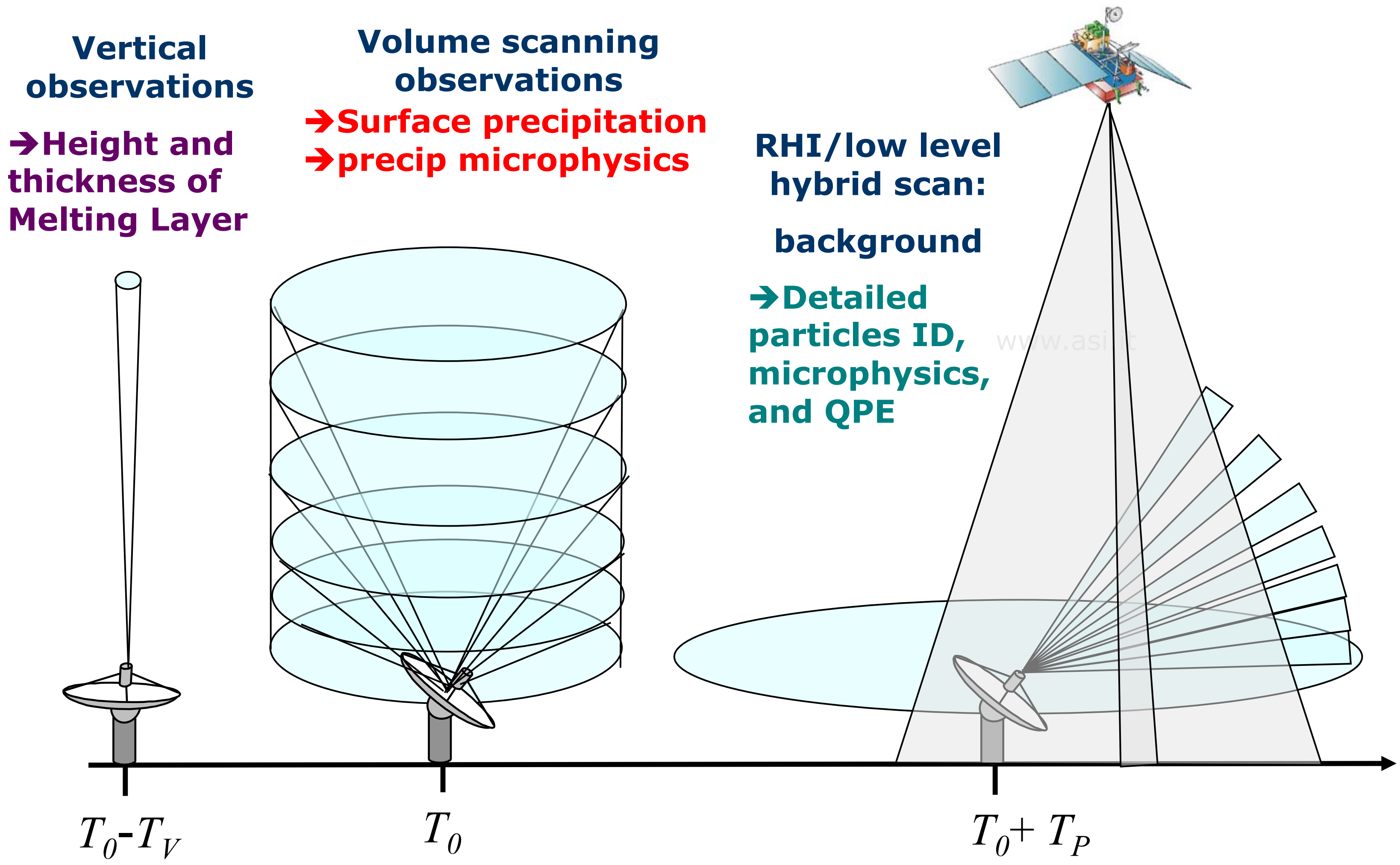
- RHI spanning more than 90 deg



ARX, ARPA Piemonte, Italy

- Coverage of sectors using RHI can improve sampling close to the radar

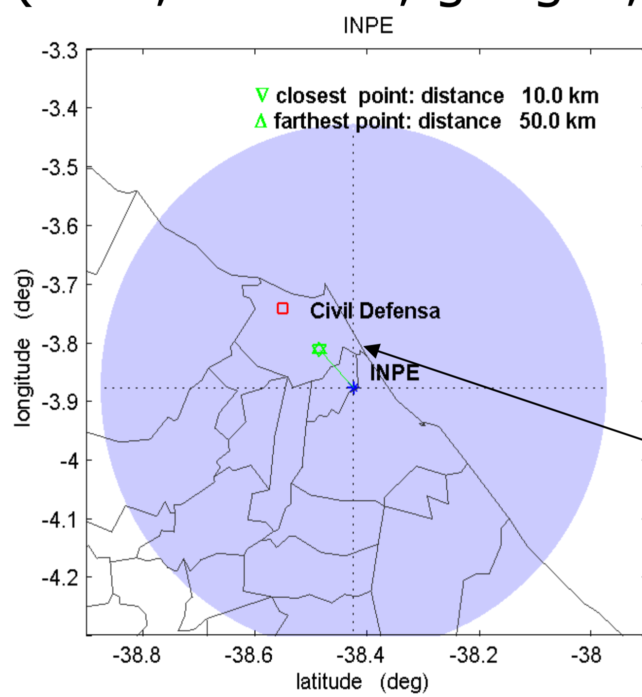
Single radar composite GV strategy

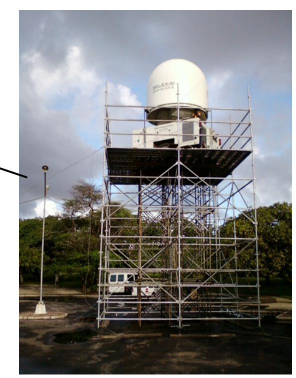


Multiple radars: coordinated dedicated tasks in a network configuration

CHUVA– Fortaleza experiment

- Science objectives
  - warm rain (WR)
  - Mesoscale Convective Systems (MCS)
- Instruments:
  - DX 50 dual polarization radar (first CHUVA experiment)
  - Cluster of instruments (MRR, Parsivel, gauges, sounding)
  - **Radar site (INPE**
    Lat : -03 52 42.45
    Lon : -38 25 28.2
    height = 26 m
  - **Civil Defensa:**
    Lat = -3 44 34.84
    Lon = -38 33 04.2
    height = 14 m

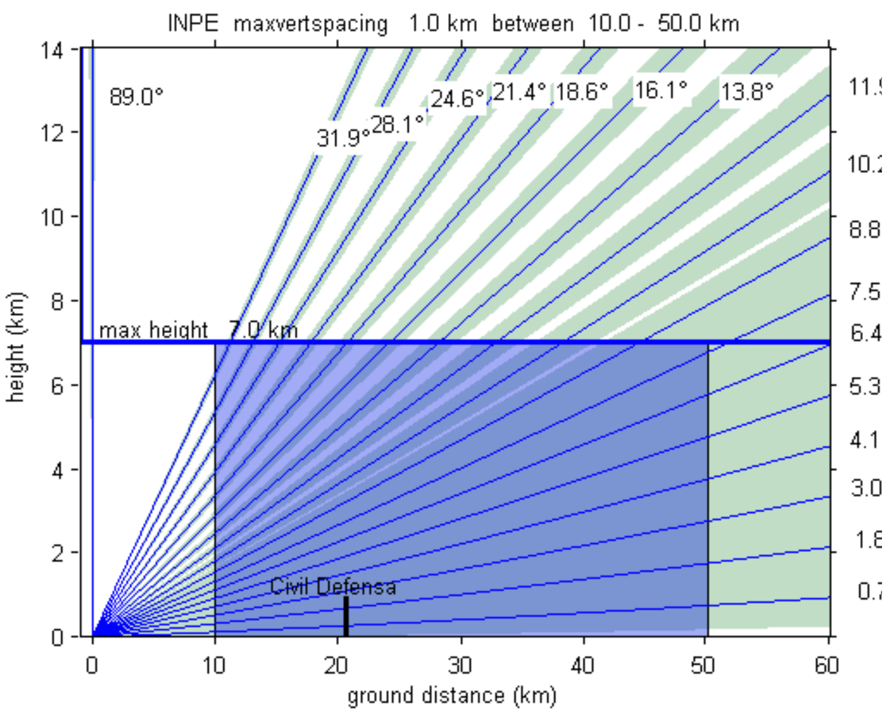


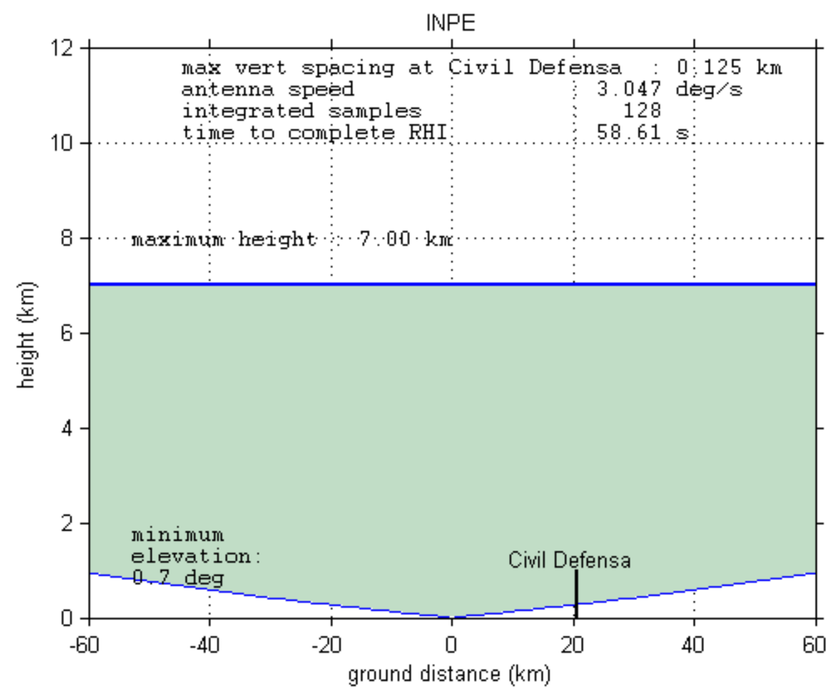


CHUVA Fortaleza warm rain scanning

Target scan repetition frequency for warm rain is **7 minutes and 30 seconds**..

- ***Volume scanning parameter***
  - The goal is to achieve at least a 1 km vertical spacing in the shaded area, bounded by a maximum height of 7 km.
- ***RHI scanning parameters***
  - Exploit the possibility of performing a 180 deg RHI
  - Assure minimum 125-m spacing at the Civil Defensa site.
  - Integrated samples = 128





CHUVA Fortaleza MCS scanning

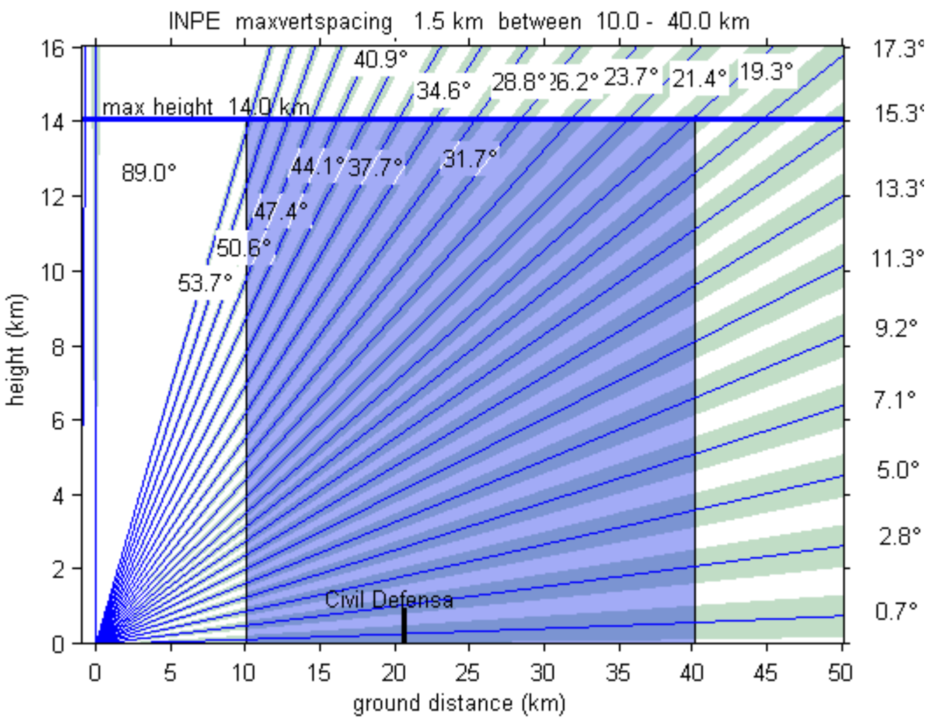
Repetition of a volume scanning composed of a volume and **two** RHI

1. along the radar azimuth of the instrumented site

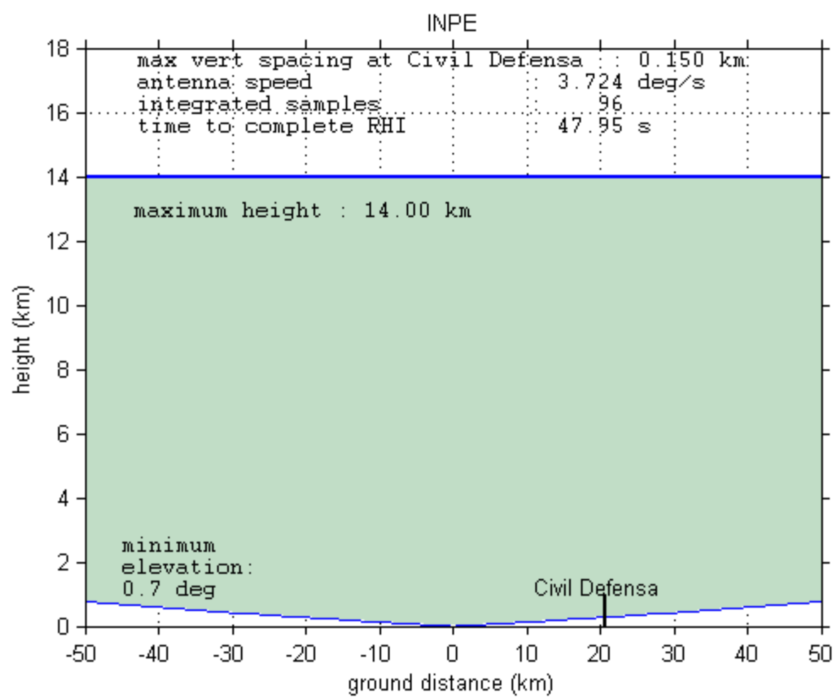
2. according to an arbitrary azimuth that can be set according to the advection.

Target scan repetition frequency for Mesoscale Convective System is **10 minutes**.

- To design volume scanning, the maximum height is set to 14 km. The maximum vertical spacing inside the shaded volume is 1.5 km.

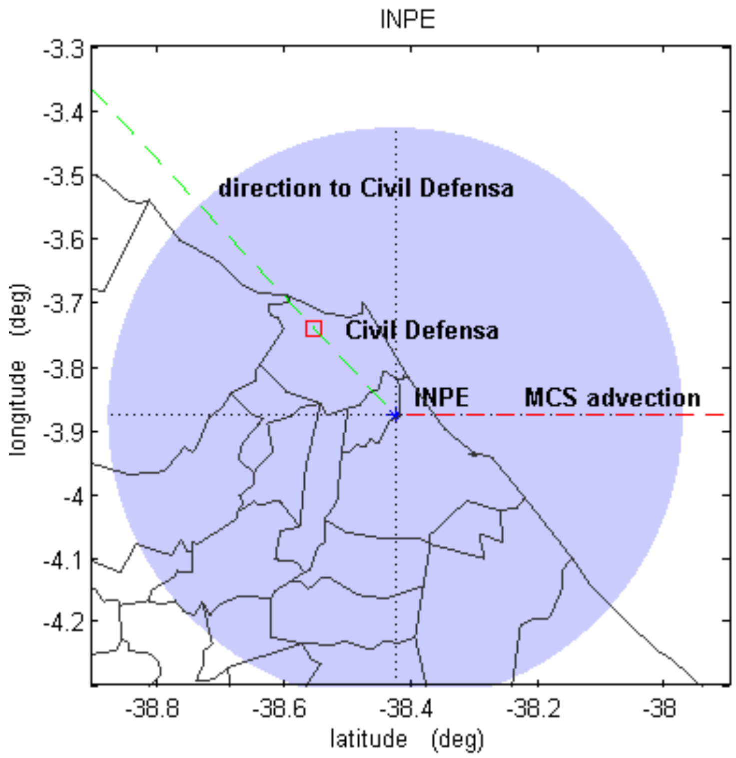


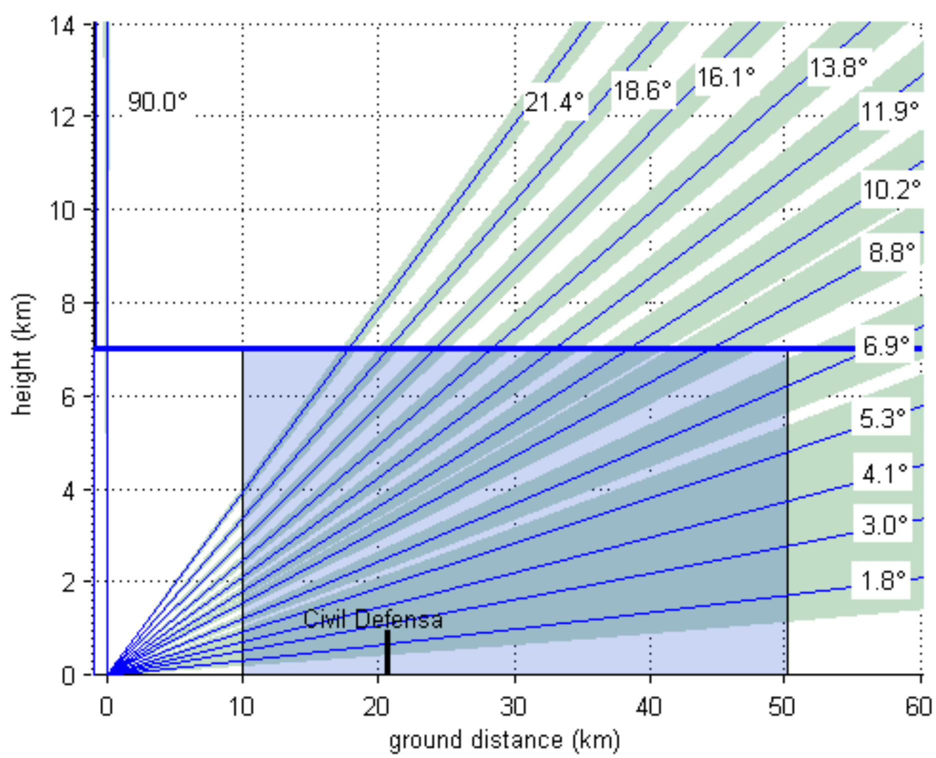
- The parameters of RHI scanning (number of pulses, antenna speed) are chosen according to the following criteria
  - 180 deg RHI
  - minimum 150-m spacing at Civil Defensa.
  - Number of integrated samples = 96



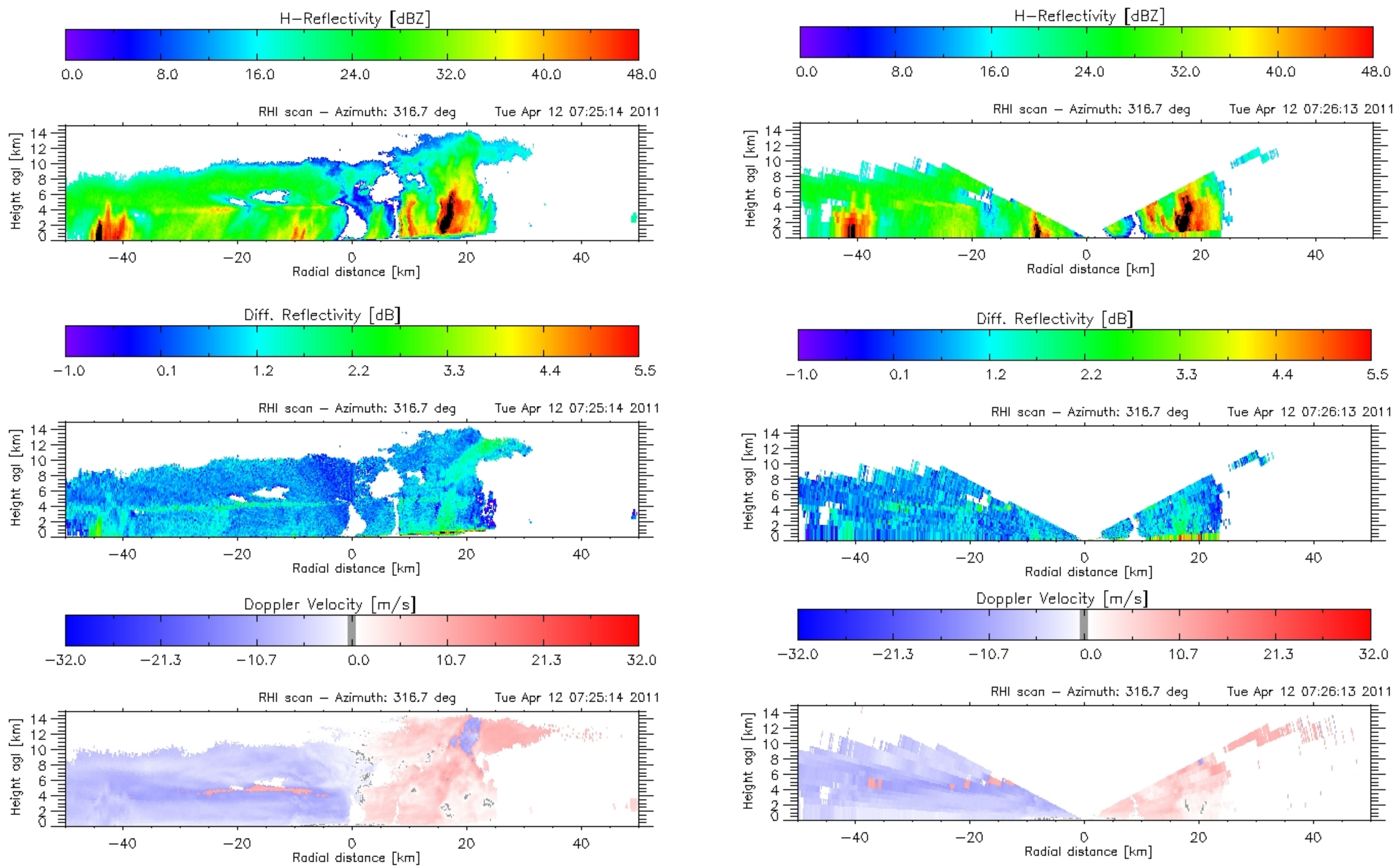
CHUVA Fortaleza scanning

- 13 elevations volume scan (decreasing elevations) and one Zdr calibration scan (+ 89° elevation) with high speed
- Two RHI direction of the civil Defensa Site and one with 90° azimuth -> direction of the sea)
- One PPI is performed with staggering mode
- Below an elevation of 1.8° degree there is almost complete signal blocking
- Three composite scans completed within 20 min with room for hourly zero check





Example 2011 04 12 07:25



Courtesy Marc Schneebeli, EPFL

Summary

1. **Guidelines for weather radar calibration**

   Calibration techniques reviewed

   Stress on automated calibration

   Feedback to finalize a best practice document within this year for the International Community

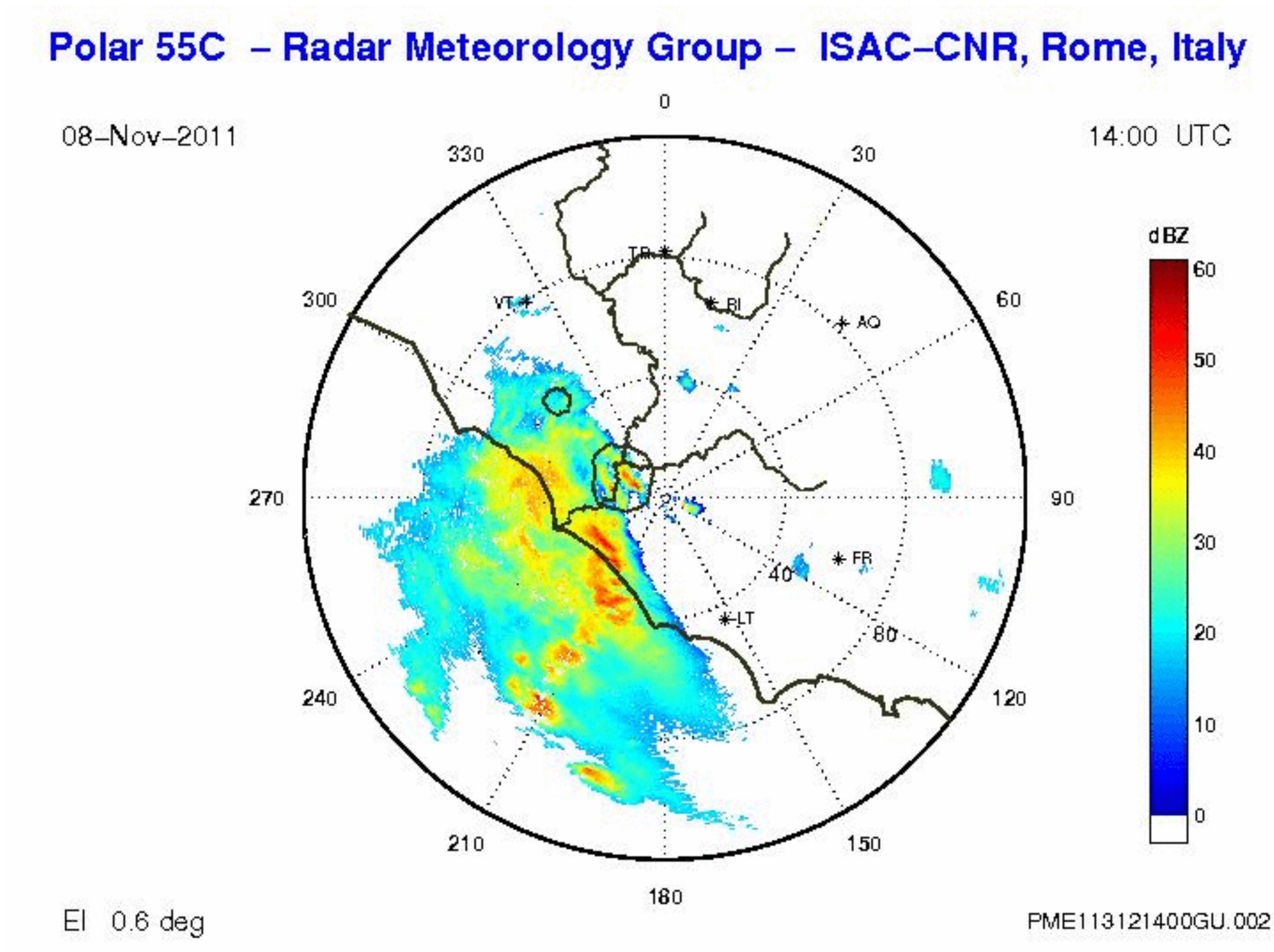
2. **GV radar scanning strategies**

   Guidelines for GV long term observation and GV experiments

   Cooperation within GPM International the design of CHUVA Fortaleza

Thanks !

PS:



Polar 55C – Radar Meteorology Group – ISAC–CNR, Rome, Italy
08–Nov–2011
14:00 UTC
0
30
60
90
120
150
180
210
240
270
300
330
TR
VT
RI
AQ
FR
LT
40
80
dBZ
60
50
40
30
20
10
0
El 0.6 deg
PME113121400GU.002