A Radar System Designed for Validation of Cloud Resolving Models

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Cloud REsolving MOdel Radar (CREMORA)
Scientific Justification

Why do we need to know 3-D structure of cloud systems?

- 3-D radiative transfer issues
  - Radiative flux profile (heating rates)
- Lifecycle of convective systems – all phases of evolution
  - Initiation
  - Updraft and downdraft structure
  - Hydrometeor evolution with time and location in updraft
  - Partition of condensate into precipitation and outflow (anvil)
- Evaluation of
  - Cloud System Resolving Models (one pathway to parameterization development and to climate models)
  - Satellite retrievals of cloud system properties

Slide provided by Tom Ackerman

More on CRM's…

LES and CRMs appear as the well suited tools that fill the gap between sparse observations and parameterization development

(e.g., Randall et al. 1996; Xu et al., 2002)

"…there are no complete data set to verify the performance of all aspects of numerical simulations by these models, a standard approach that has been widely adopted in the community is the intercomparison study…"

(e.g., Boyle et al. 2000; Ghan et al. 2000)

"A comprehensive evaluation of state-of the-art CRMs will require state-of-the-art observations."

Moncrieff et al. (1997)

What is state-of-the-art observations?

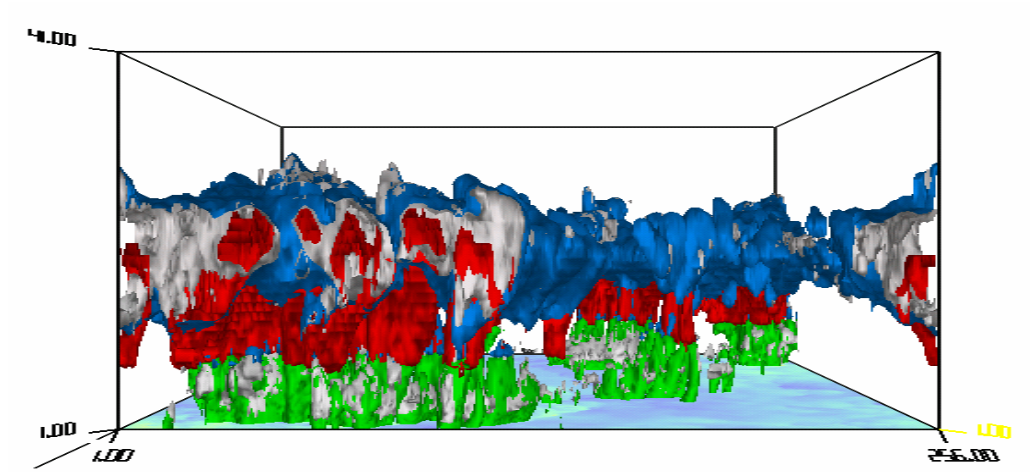
4D characterization of the water vapour, cloud water and ice, and precipitating water and ice.

Horizontal Divergence

Vertical Air Motion

Vertical Mass Flux

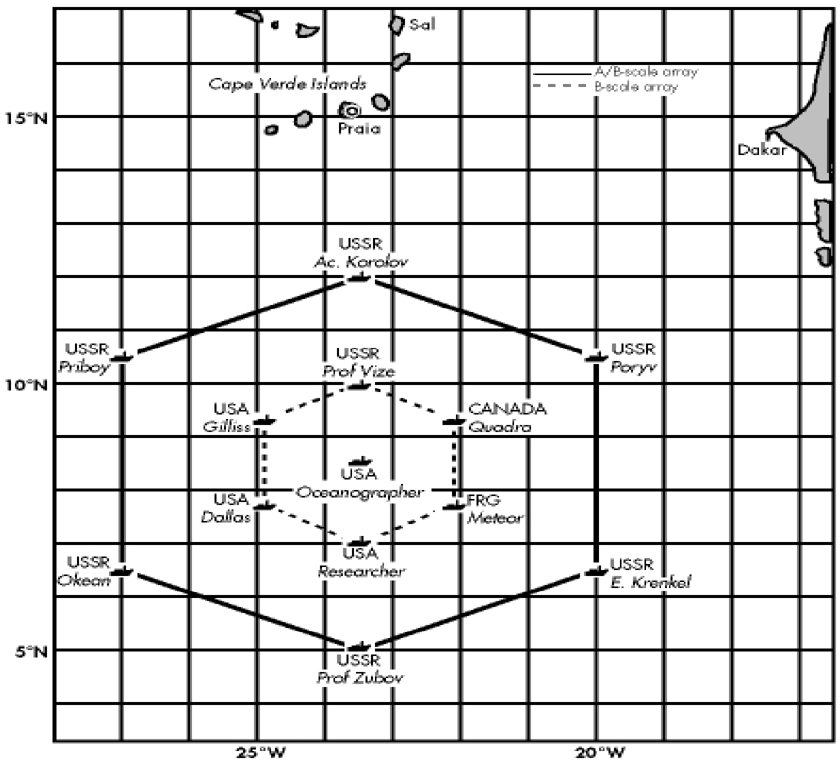
Latent heat Release Profile



GCE model-simulated cloud hydrometeor mixing ratios for an ARM case (June 12 to June 17, 1997). Tao et al., 2003

[e.g., *Houze*, 1989; *Tao et al.*, 1993; *Mapes and Houze*, 1995; *Kummerow et al.*, 1996].

Global Atmospheric Research Program's (GARP) Atlantic Tropical Experiment (GATE, 1974)



Eastern Tropical Atlantic Ocean

Shipborne C-band radar

Analysis based on radar films from photographically recorded data of the radar PPI images

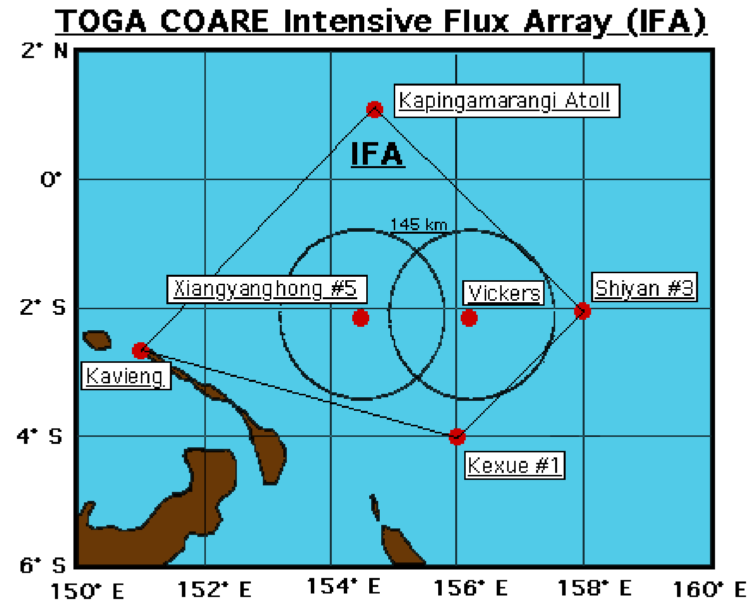
Houze and Chen, 1977

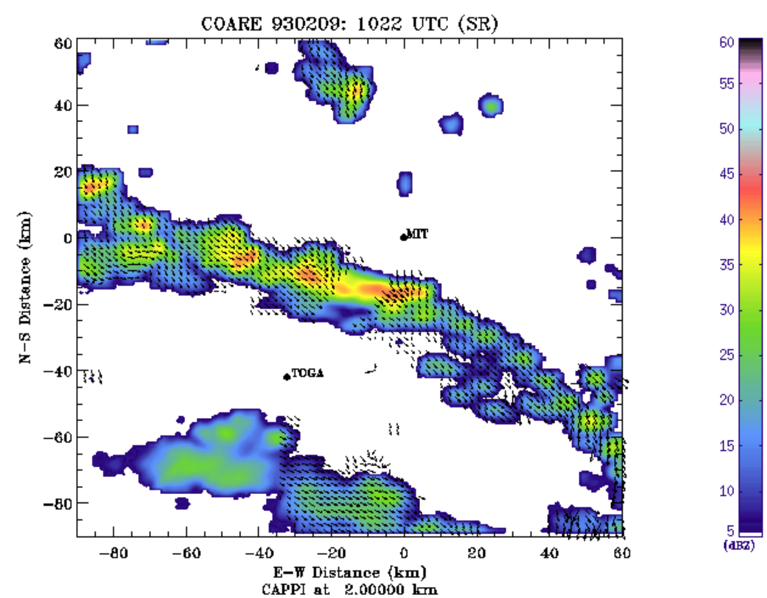
South China Sea Monsoon Experiment (SCSMEX)

NO DATA
980531 00:00:00

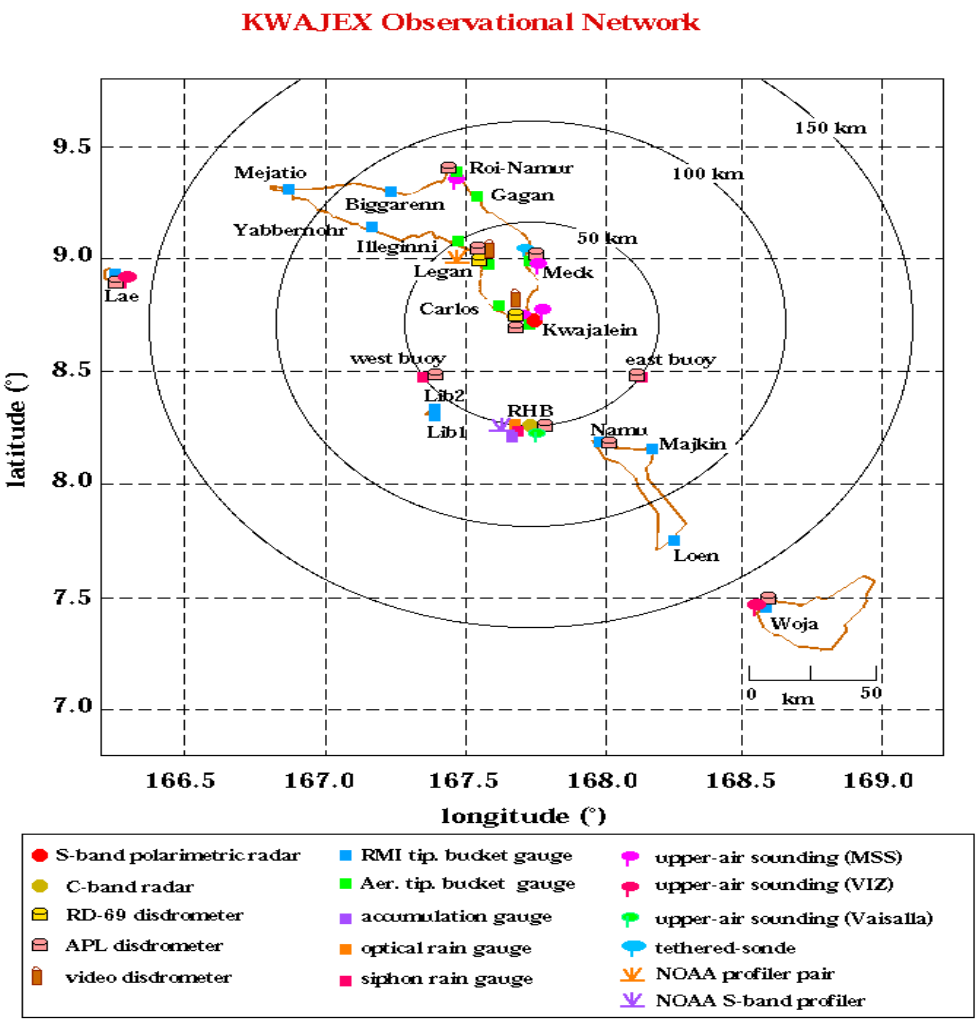
5 April to 31 August, 1998

TOGA-COARE 1992-1993





TRMM KWAJEX 1999



S-band radar at Kwajalein Atoll

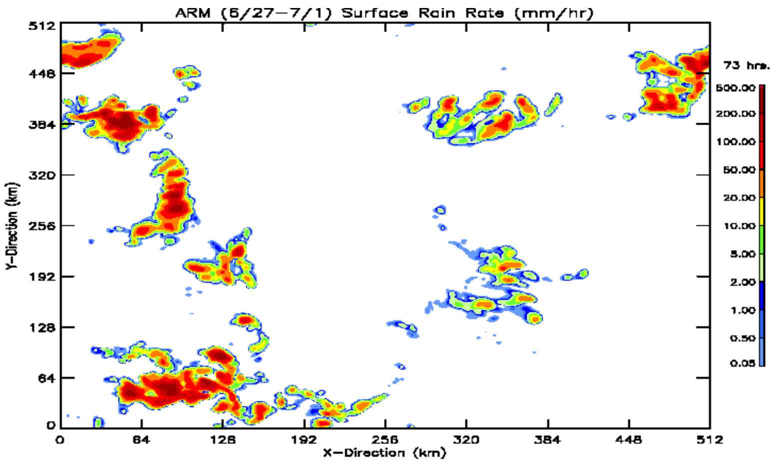
Operates since 1998 in support of TRMM

Brown's C-band radar during the IOP

Schumacher and Houze, 2000

Use of Radar Data from Previous Experiments for CRM Evaluation

- Time-resolved, three-dimensional precipitation dataset.
- Echo Morphology – Area of Coverage and Cloud Tops
- Echo type (formation, intensity and dissipation)
- Horizontal and Vertical Variability
- Speed and Direction of echoes
- Time-domain average rainfall



Tao et al., 2003

Is the answer to CREMORA a weather radar system (10 or 5.5 cm wavelength)?

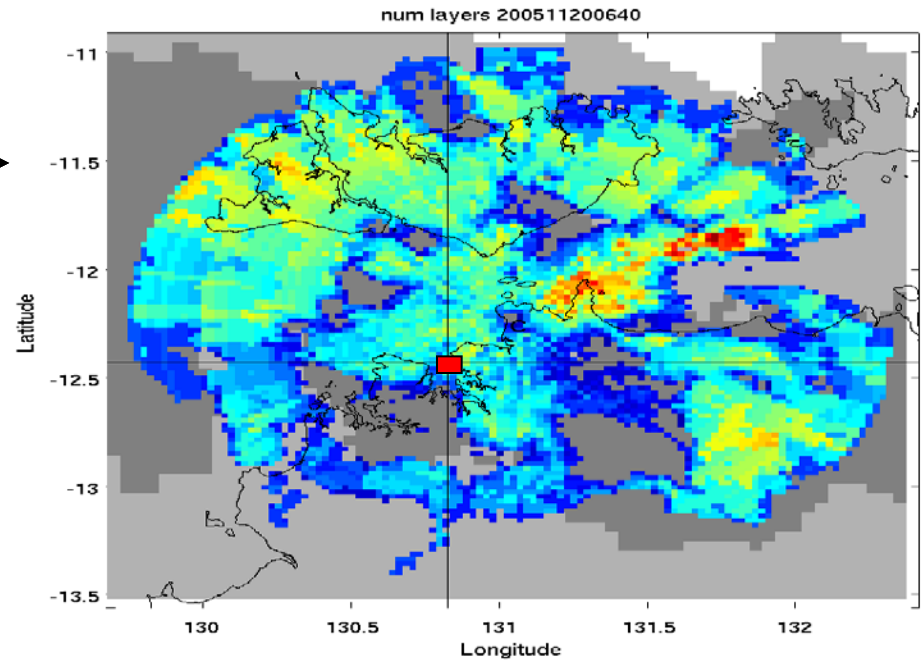
Yes and No!

ARM is the largest owner and user of millimeter wavelength radars

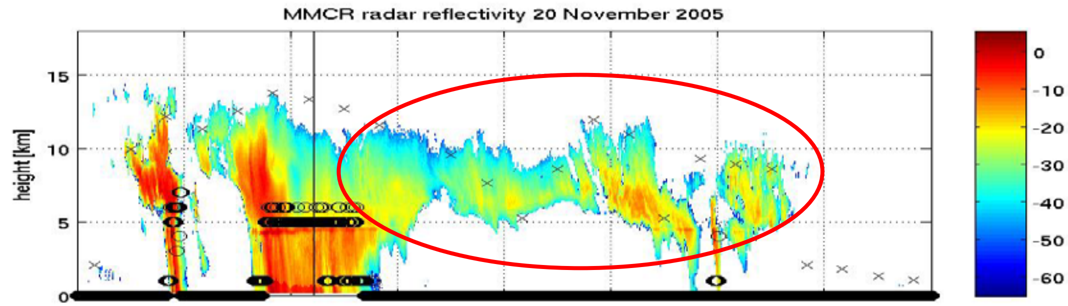
ARM MMCRs saturate with cloud echoes barely detectable by centimeter radars

All clouds are radiative important and integral part of a convective cloud system and its parameterization by CRMs

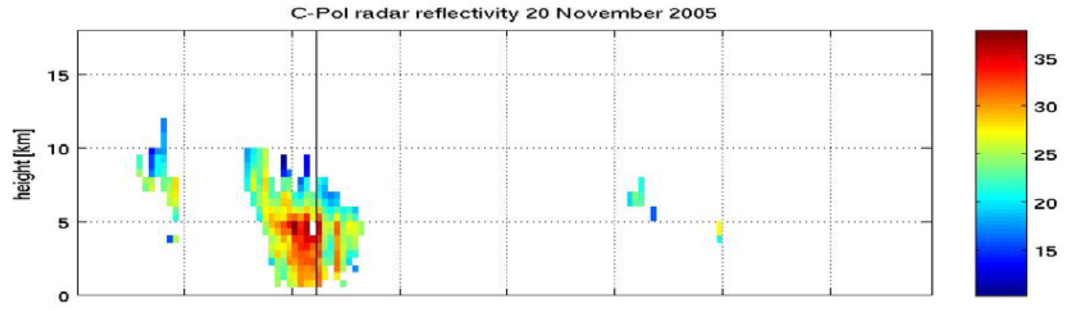
C-POL at TWP-Darwin →



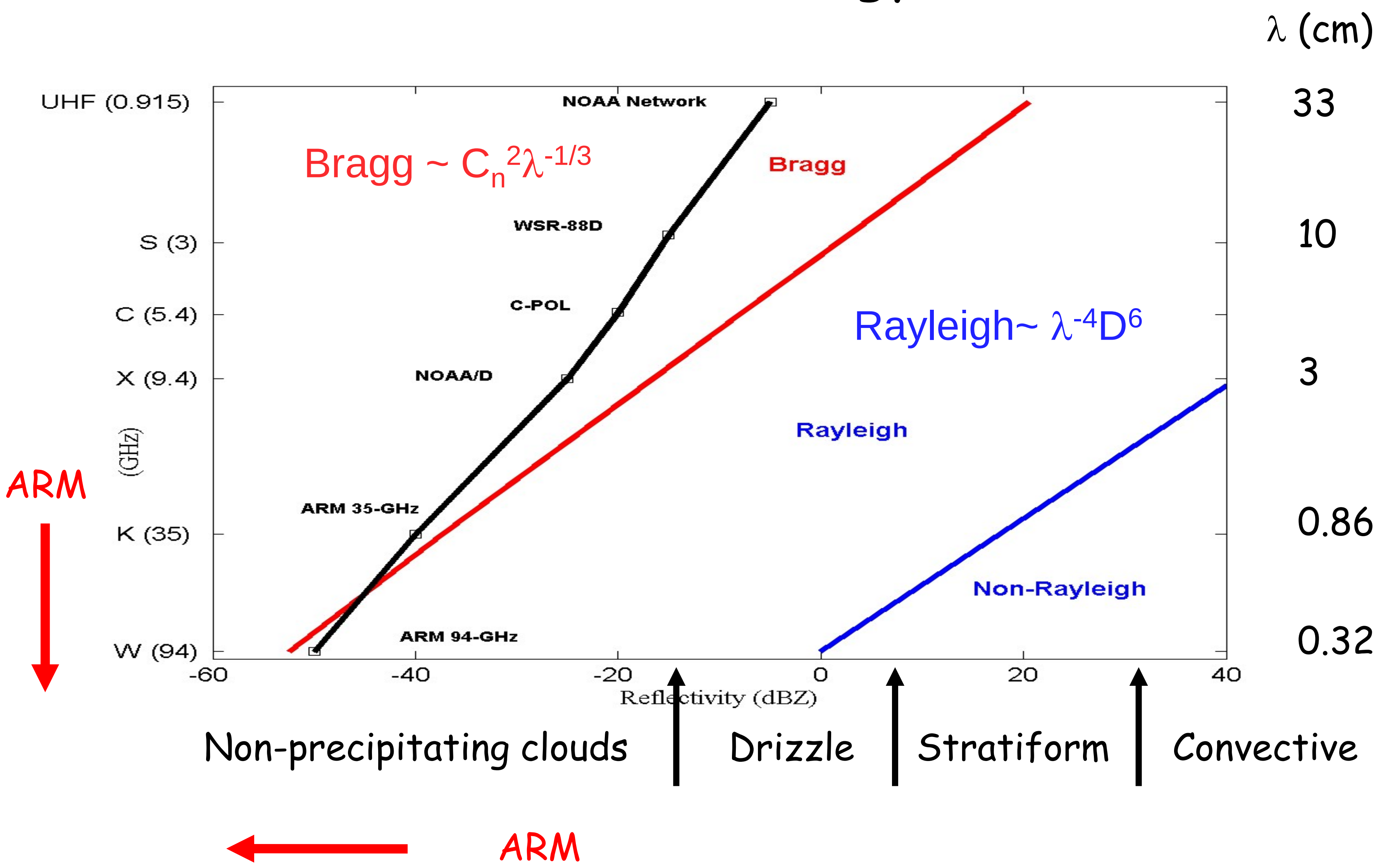
MMCR →



C-POL →



Radar Meteorology 101



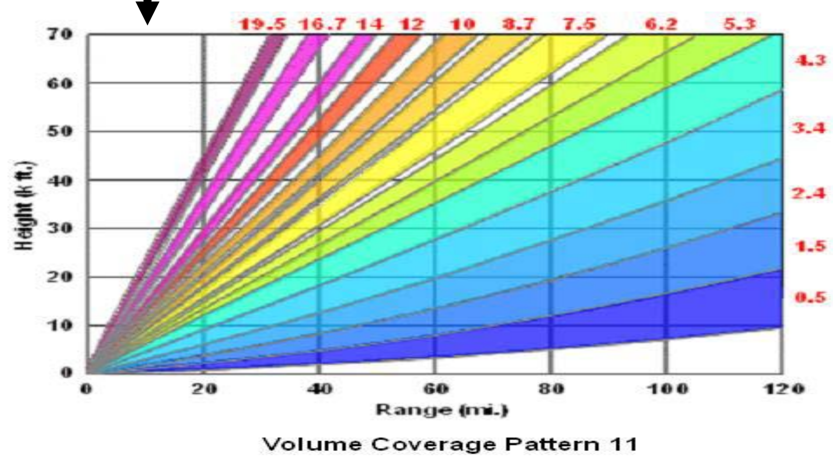
Limitation of Mechanically Scanning Doppler Radars

Narrow beamwidth is critical to maintain reasonable volume resolution (R_{max} < 50 km for 1^o beamwidth)

Scanning Doppler radars don't sample the atmosphere directly above them (cone of silence)

Neighboring radar beams can provide coverage in the "cone of silence"

Cone of Silence

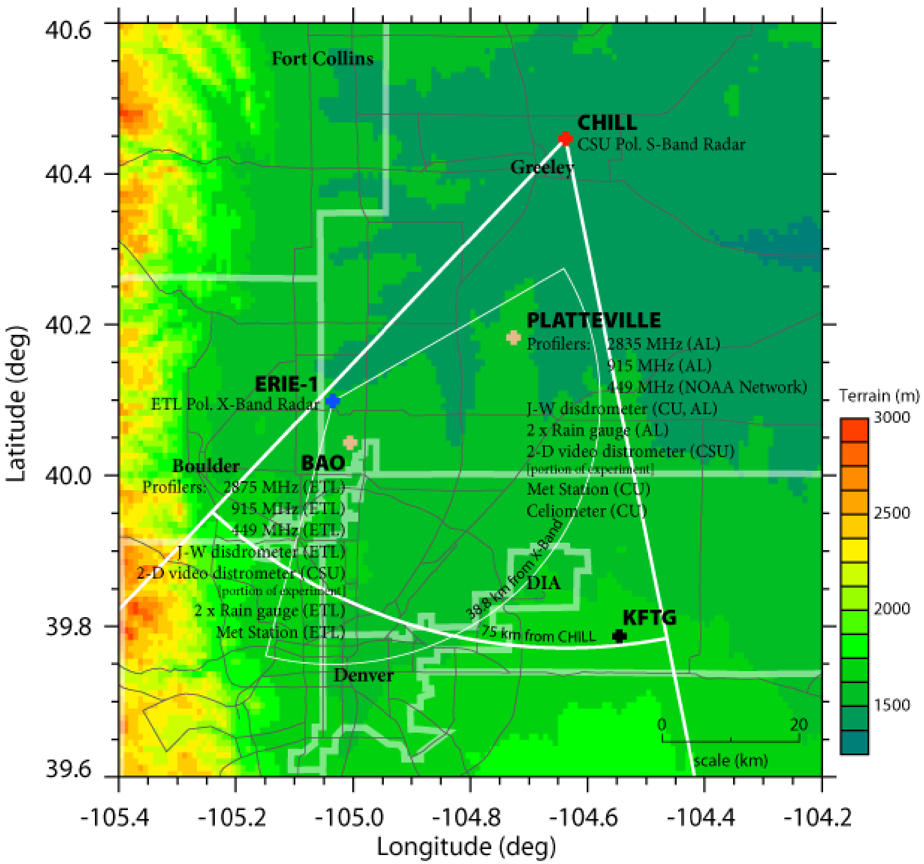


Angles used by the WSR-88D

Take home lessons from other programs…

GPM Front Range Pilot Study

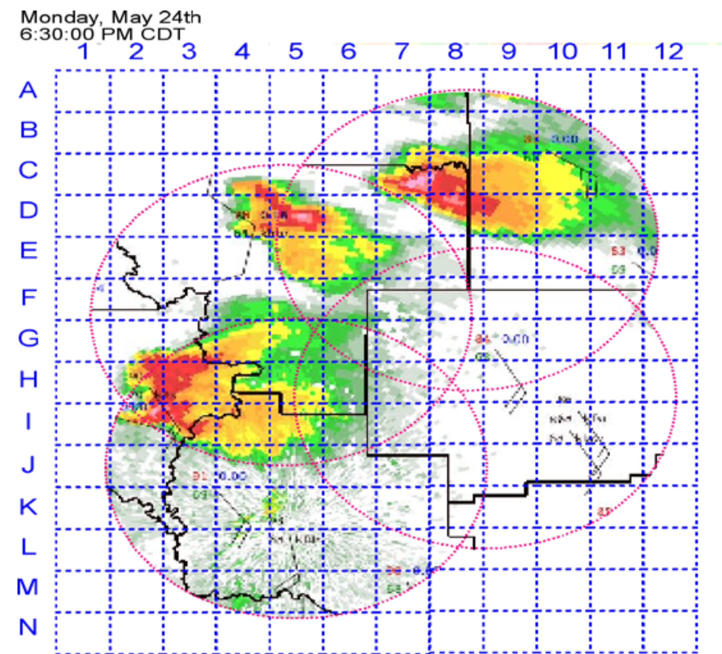
Dual wavelength (10 and 3 cm)
Nested radars



http://radarmet.atmos.colostate.edu/gpm/pilot.html

Collaborative Adaptive Sensing of the Atmosphere (CASA)

3-cm radar network
Adaptive sensing



F. Carr,
U. Oklahoma

Volume Scanning Radar Systems:

- ARM Volume-Scanning Array (AVA)
  3-cm Doppler Radar (three systems)
  Mechanically scanning
  High Sensitivity
  Polarimetric

- 3-D Volume Imaging Radar (3D-VIR)
  3-cm Doppler Radar
  Phased-array antenna
  High sensitivity

ARM Volume-Scanning Array (AVA)

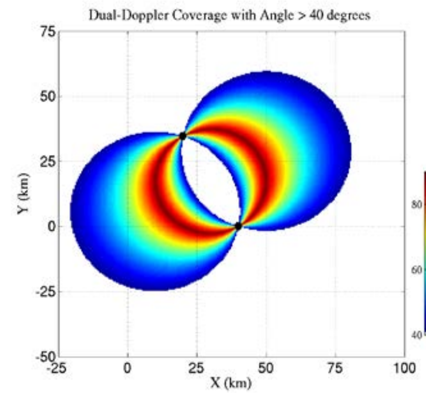
Three scanning 3-cm Doppler radars

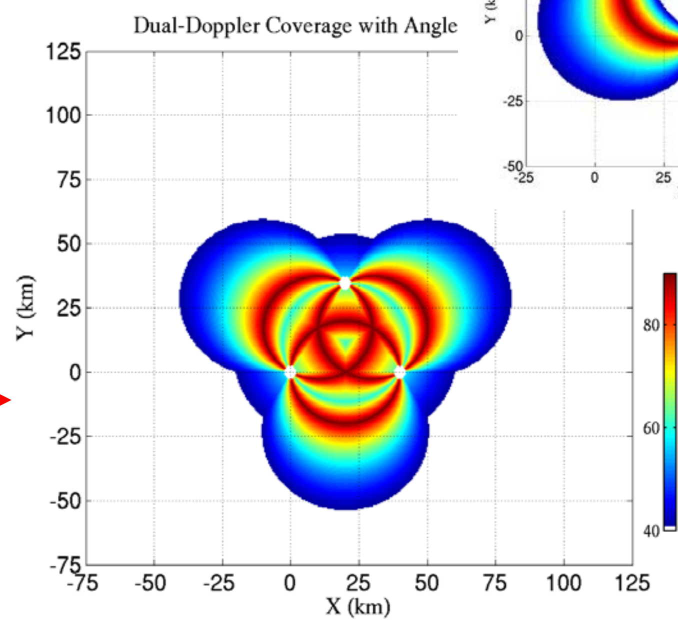
Form equilateral triangle around the ARM site

Narrow beamwidth – High sensitivity

Polarimetric - Mobile

Dual-Doppler area





AVA Configuration

Location

- Relevance to ARM site and scanning radiometers

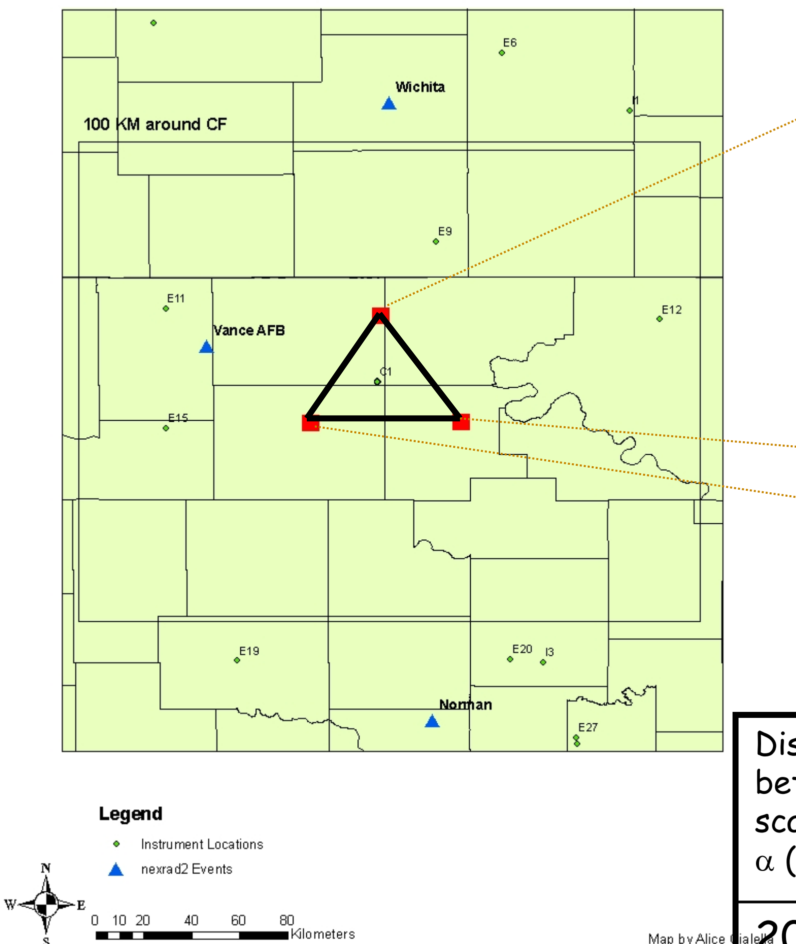
Spacing

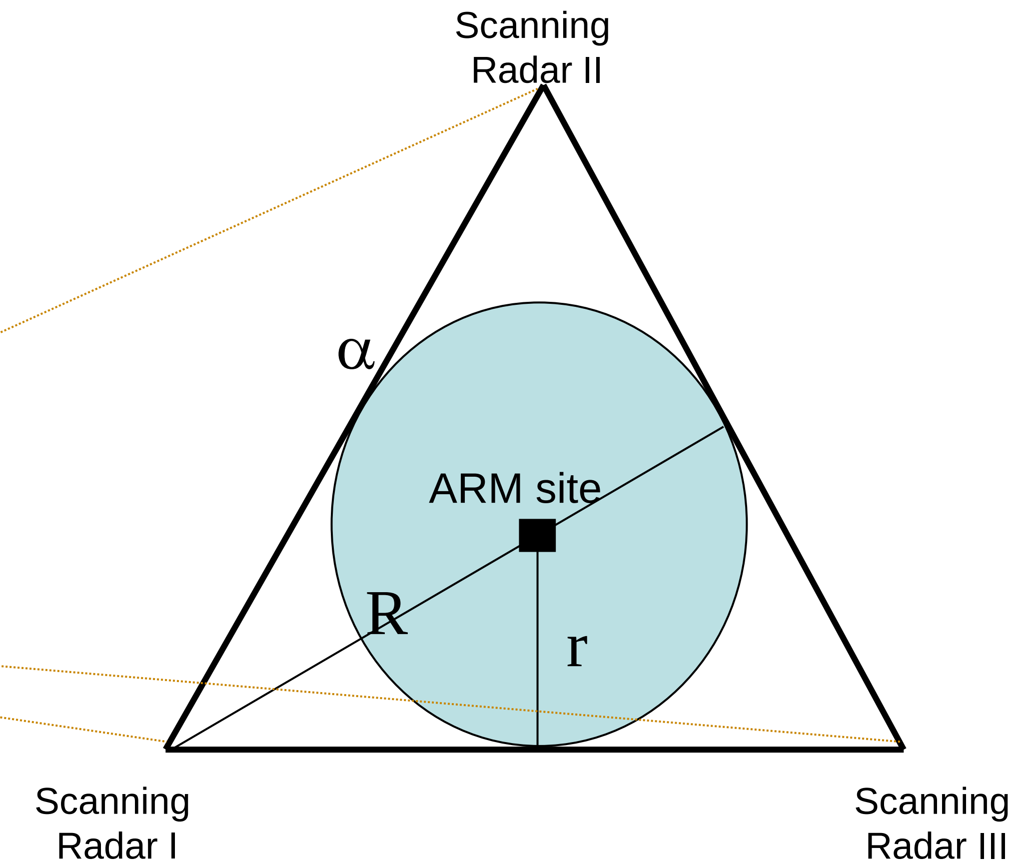
- Maximization of Area of Coverage (sensitivity constrain)
- Maximization of Dual-Doppler Area of Coverage

Scanning Strategy

- Convective clouds are not present all the time
- Adaptive (CRM Evaluation, 3-D radiative transfer, IOP)

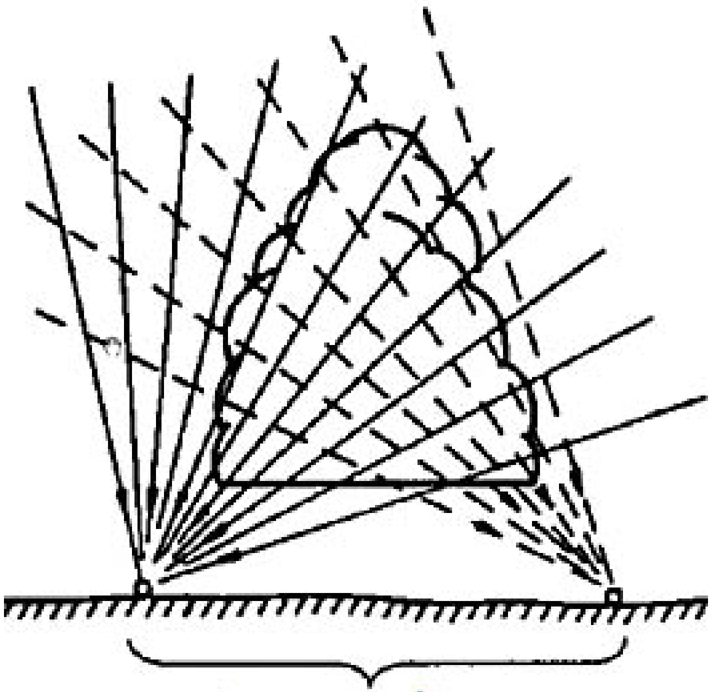
Southern Great Plains





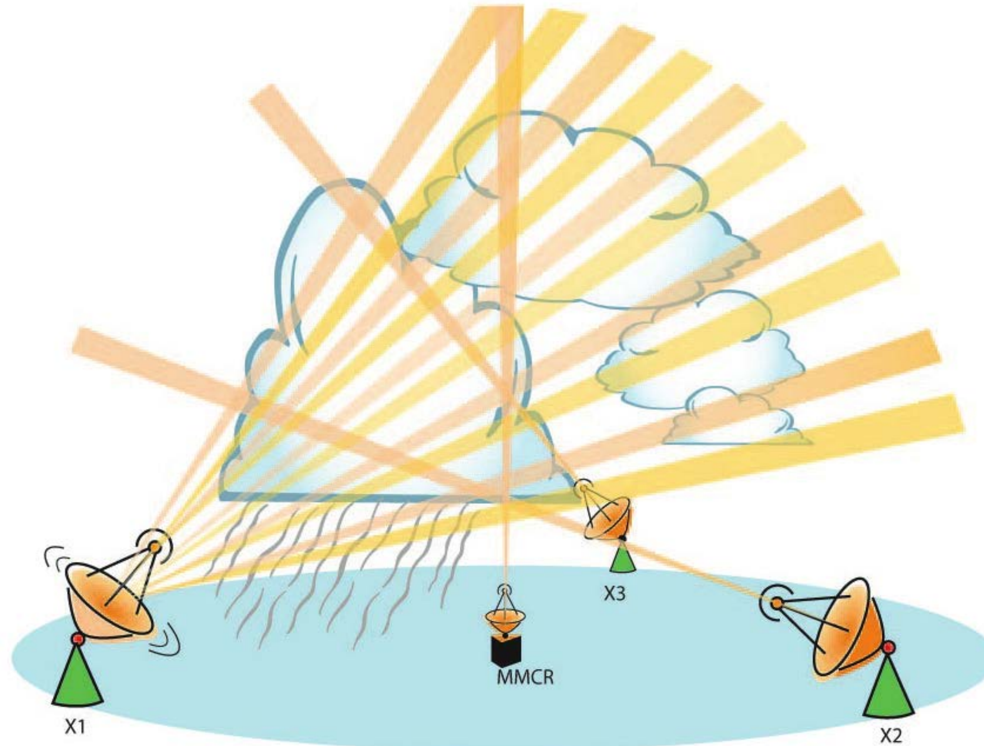
Distance between scanning radars α (km)	Inner Circle Radius r (km)	Distance between scanning radar and ARM site R (km)	Inner Circle Area (km^2)
20	5.8	11.6	106
30	8.6	17.2	232
40	11.5	23.0	415

ARM Volume-Scanning Array (AVA)



scanning radiometers

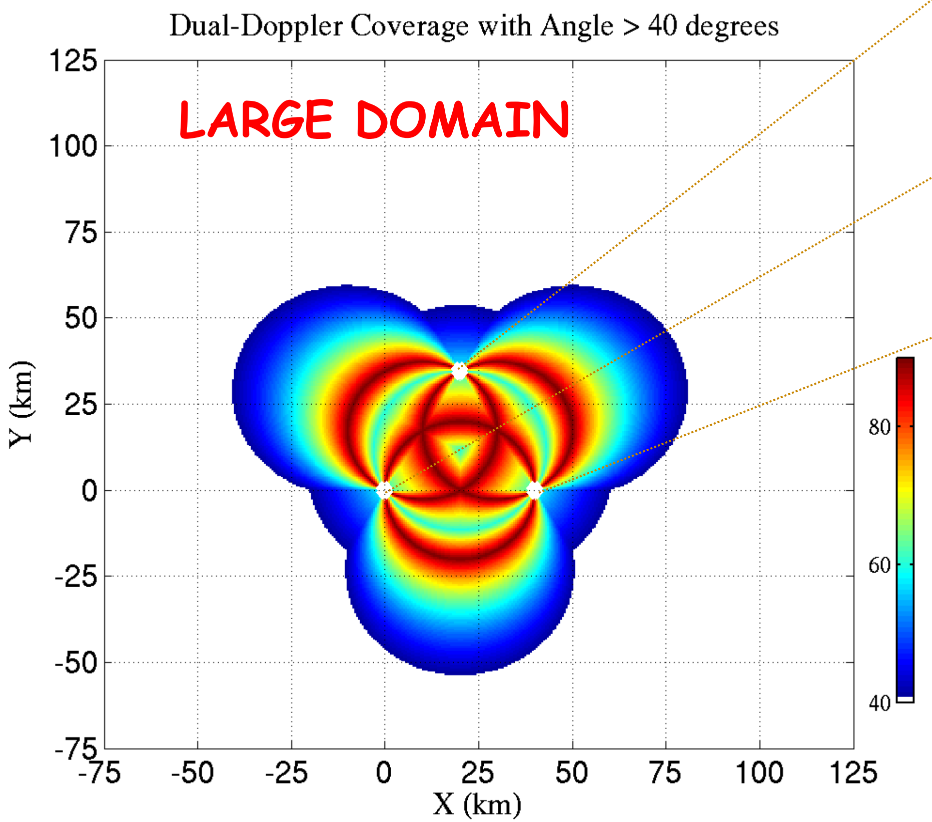
Warner 1986

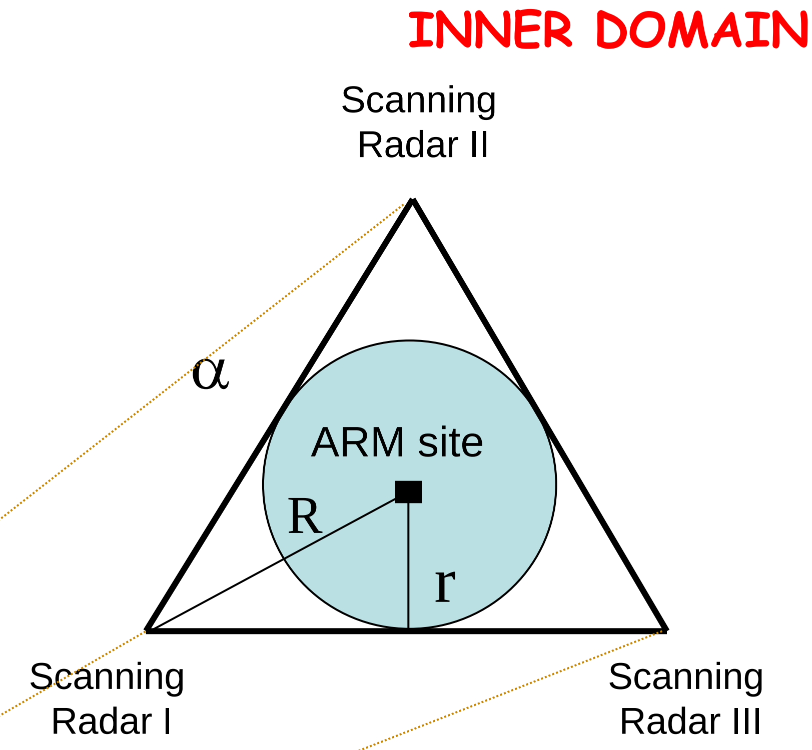


scanning radars

Map all clouds/precipitation within 5-8 km (inner) domain from ARM site

If precipitation is present…
…radars scan large domain (360°)
…for dual-Doppler coverage
… CRM evaluation



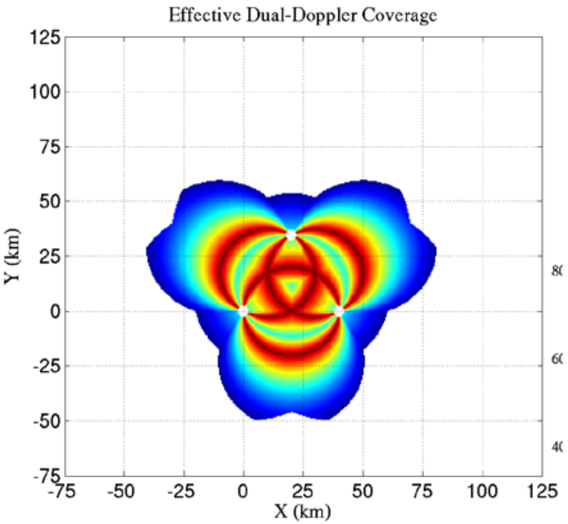


If precipitation is not present…
…radars scan inner domain (60°)
… to map ALL clouds important
… to 3-D radiative transfer
…and LES evaluation

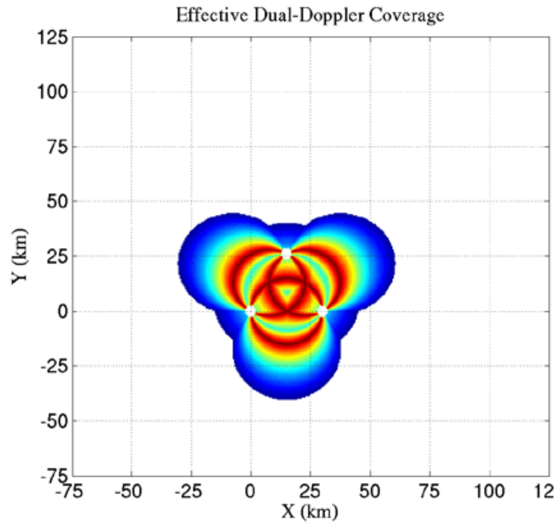
Distance between the radar sites α (km)	Area of coverage (km²) within 50 km from radar sites	Area of coverage (km²) with "good" Dual-Doppler coverage	"Effective" area of coverage (km²)
20	11,000	2,430	2,430
30	12,670	5,470	5,470
40	14,380	9,730	9,230

CRM grid: 2x2 km

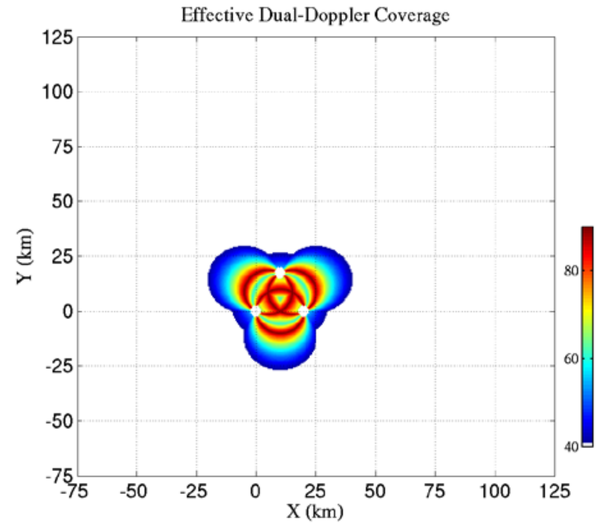
A ~ 2430 grid points



A ~ 1367 grid points

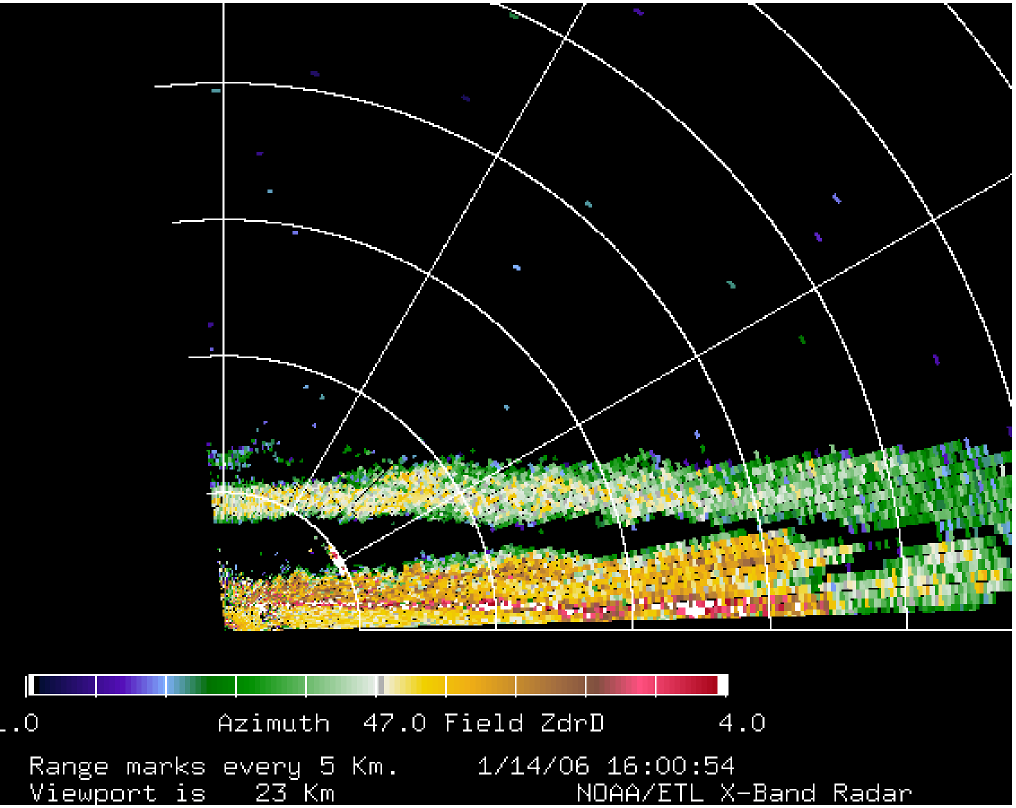


A ~ 607 grid points



Polarimetry in X-band radars provides:

A relatively straightforward and robust way to correct for attenuation effects in rain which otherwise prevent quantitative precipitation estimations (QPE) and cloud retrievals (in presence of rain)



Polarimetric radar parameters such as differential reflectivity (ZDR) and/or circular depolarization ratio (CDR) which can be used to distinguish among different ice hydrometeor habits

Slide provided by Sergey Matrosov

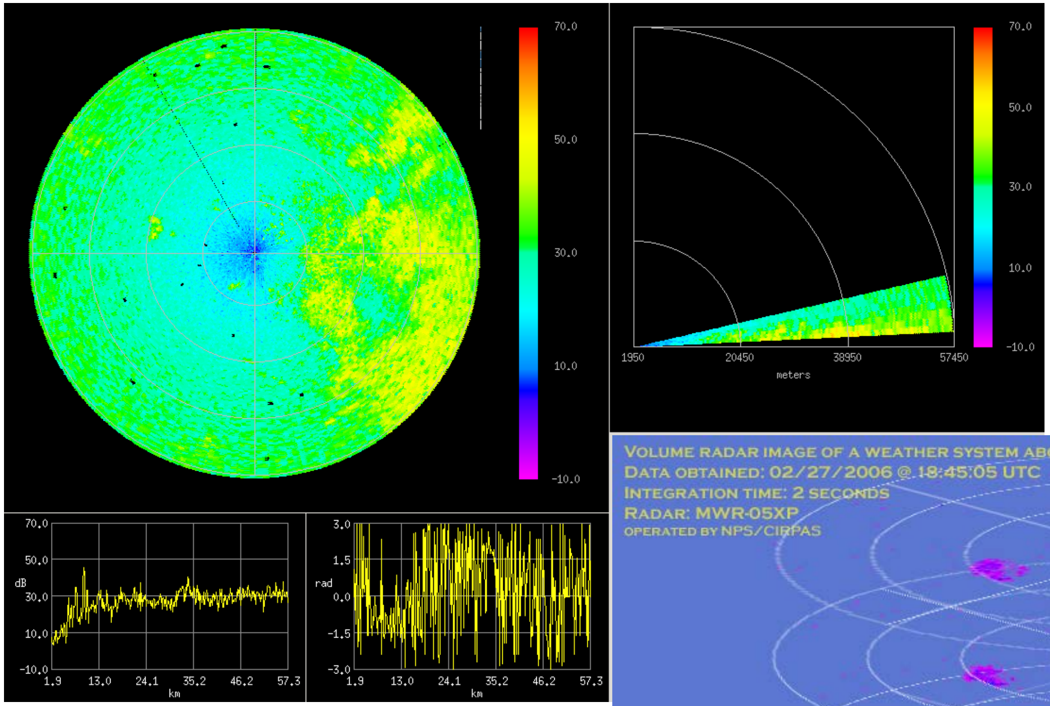
3D Volume Imaging Radar (3D-VIR)

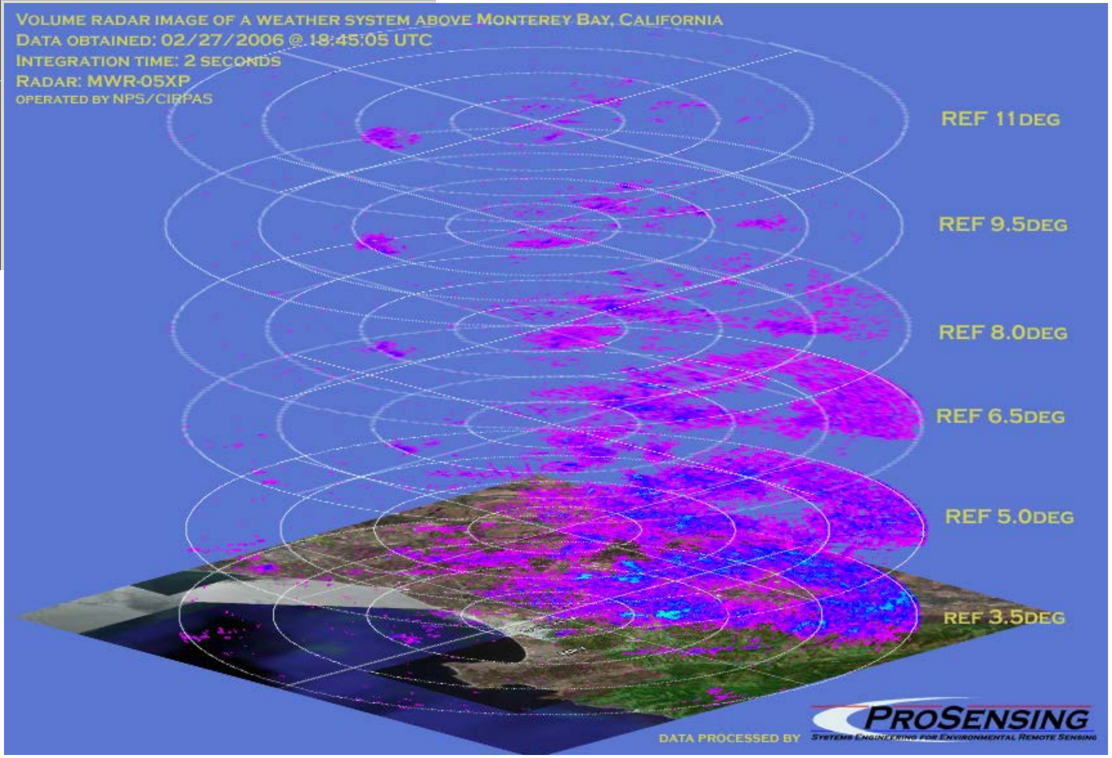
The **3D-VIR** will mapping the 3-D cloud structure over an extensive area (40x40x20 km volume box – “local scale”) around the ARM site.

New emerging radar technologies:

- Phased array antennas
- Pulse compression
- Agility
- Adaptive scanning

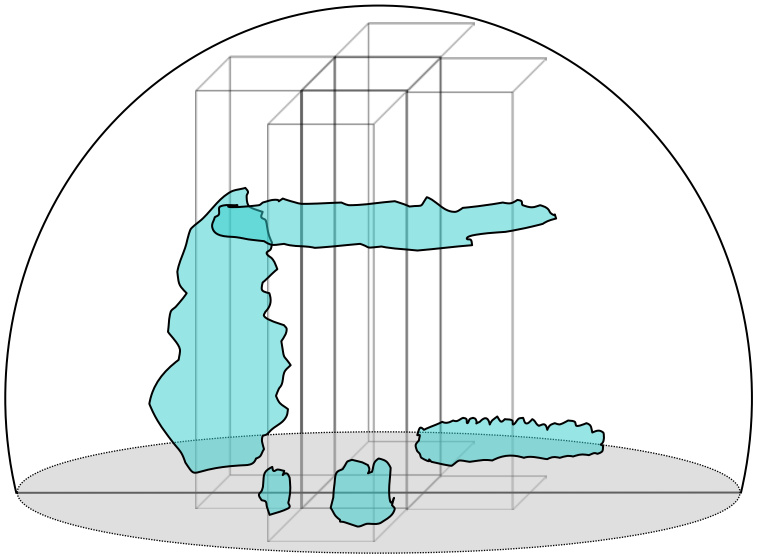
Simultaneous PPI/RHI display

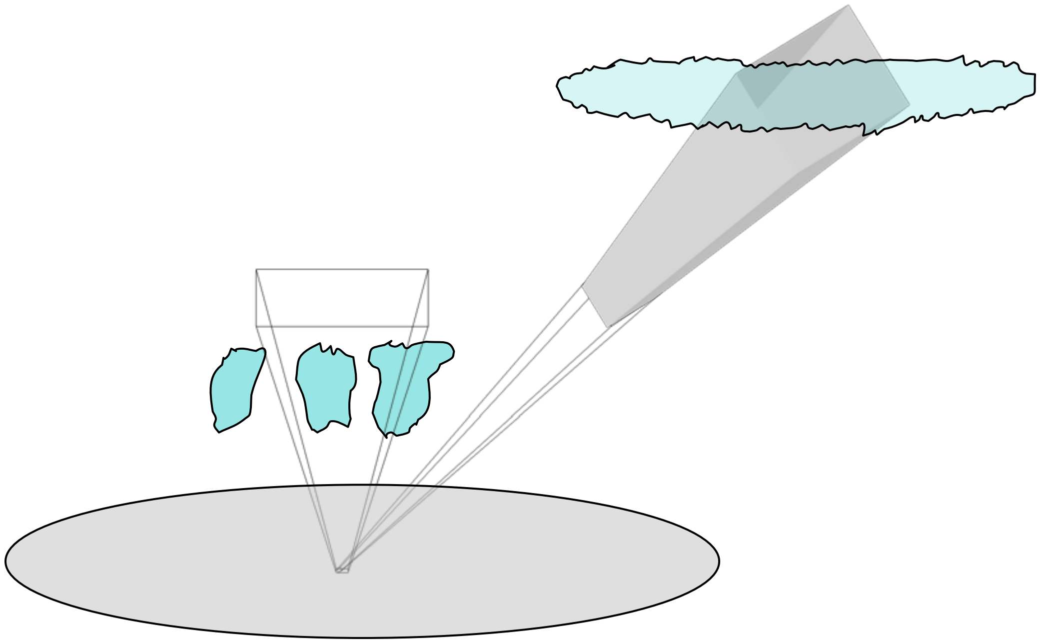




Slide provided by Prosensing Inc.

Multi-Task Radar Concept





3D Volume Imaging Radar (3D-VIR)

Surveillance Mode....................... Hemispherical Scanning
Surveillance box.......................... 40x40x15 km
Sensitivity at boundary.............. -20 dBZ
Range Resolution....................... 60 m
Temporal Resolution.................. 1 min
Products...Doppler moments

3D Volume Imaging Radar (3D-VIR)

IOP Mode....................... Sector Scanning
Range Resolution....................... 30 m
Temporal Resolution.................. 10 sec
Products...Raw I/Q, Doppler Moments

Volume Scanning Radar(s)

System	Tri-Doppler	Phased-Array
Volume Imaging	🗎	🗎
Dual Doppler	🗎	
Polarimetric	🗎	
Sensitivity	🗎	🗎
Technology	Mature	State-of-the-art
Cost	$$$	$$$
Operation		🗎

Summary

Ideal : A volume scanning system that can map the 4-D structure of clouds and precipitation

In addition to the 4-D mapping of cloud and precipitation we need:

- Accurate measurements of radar reflectivity - key to retrievals
- Polarimetric capability - key to QPE and ice particle habit
- Dual Doppler capability - key to horizontal divergence

Recent developments in radar technology allow us to think out the traditional radar meteorology box