Scanning cloud radar observations

Lessons learned using the SWACR at Azores and SGP
Anticipated data products and linkages to science questions

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Background

- Six scanning dual-wavelength cloud radars are scheduled to deploy at the fixed and mobile ARM sites

- Radars—Primary: **35-GHz** radar frequency channel for cloud detection frequency; Secondary: **94-GHz or 9.4-GHz**: enhanced detection and additional constraints in quantitative cloud properties retrievals.

- **Doppler**, **polarimetric** and **radiometer** mode: enhance the data quality and improve cloud properties retrievals.

- Early efforts: defining sampling strategies, hydrometeor detection, data quality control and gridding of 3D radar observations

SWACR deployments at Azores and SGP

SWACR: a vertically pointing W-band ARM Cloud Radar (WACR) modified to operate on a scanner (S-WACR).

Deployed at Azores and SGP to sample 3D cloud structures and to evaluate various sampling strategies.

Azores: stratocumulus and scattered cumulus

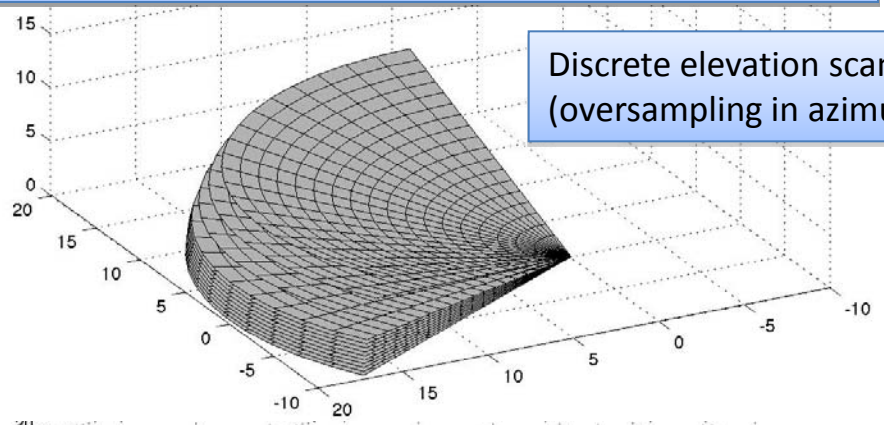
SGP: precipitation and cirrus clouds

SWACR is a 94-GHz radar, e.g., not the primary SACR frequency, with smaller antenna, less sensitivity and limited hardware/software (processing/scanning) capabilities

SWACR – Azores: Initial Scan Strategies

PPI Reflectivity Scan (Duration: 1-hr)

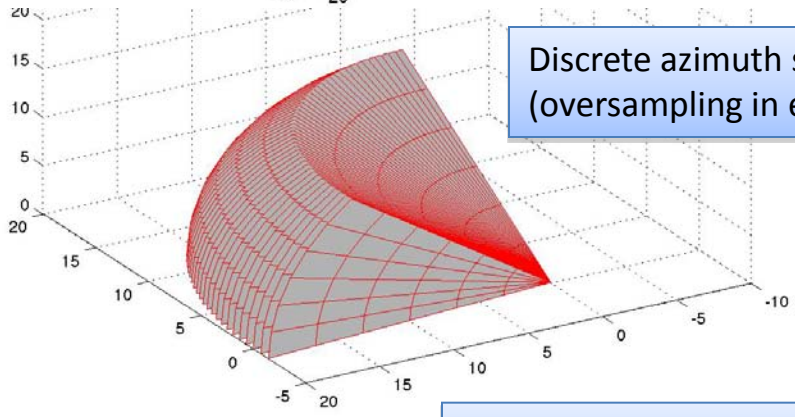
- 120 degree azimuth sector scan with a center at 315 degrees. The elevation angles range from a 1 degree grazing tilt to 24 degrees (1,2,3,4,5,6,7,8,10,15,20,24).



Discrete elevation scans (oversampling in azimuth)

RHI Reflectivity Scan (Duration: 1-hr)

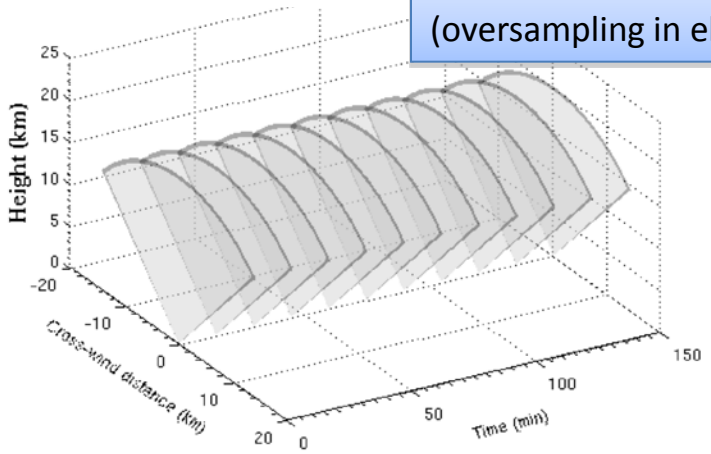
- Sequence of RHI scans (0-45 degrees) repeated over a set of azimuth (direction) angles. The sector is limited to 90 degrees and the azimuth step set to 2 degrees.



Discrete azimuth scans (oversampling in elevation)

Crosswind RHI Scan (Duration: 1-hr)

- Crosswind horizon - to - horizon RHI scan provides cross-wind scans of the atmosphere that passes over and around the radar location.



One of the dimensions is time (oversampling in elevation)

Highest metric of performance of a particular scan strategy: Ability to capture (detect) the 3D structure of clouds

- Constant elevation scans (360° or sector) exhibited poor performance in detecting cloud locations and defining their boundaries This is attributed to the:

- Narrow beamwidth of the SWACR/SACR's

- Nature of clouds: Shallow layers, important to detect cloud boundaries (need good vertical resolution)

- Cone of silence – where all other ARM instruments are sampling

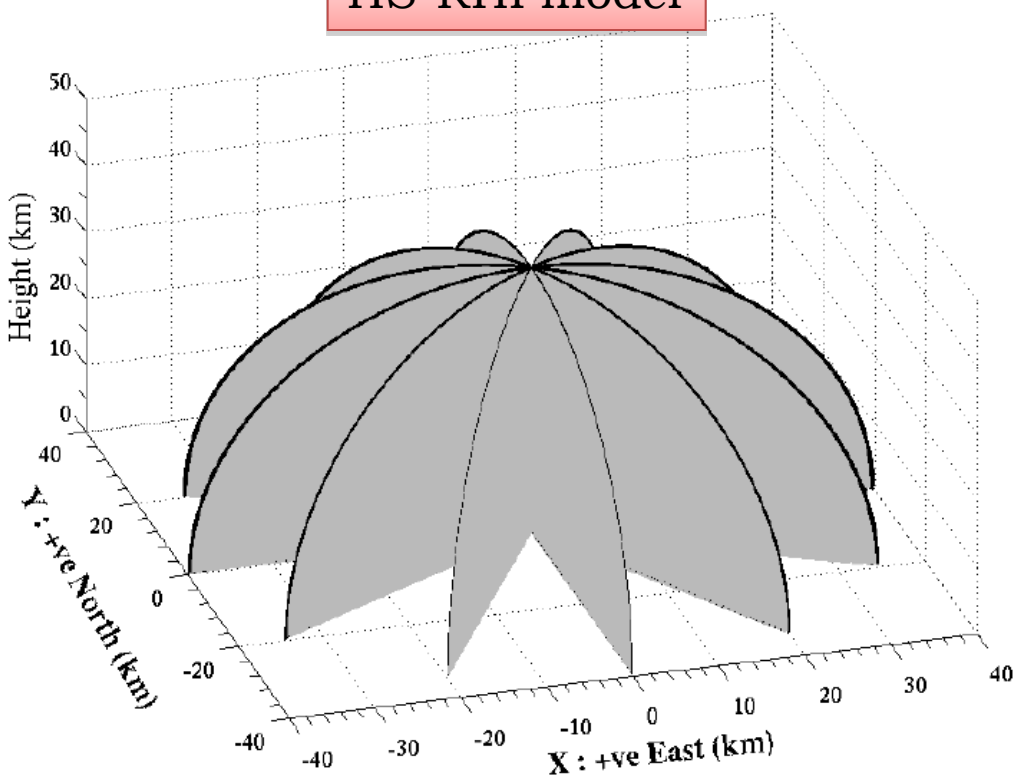
Recommendation: Contrary to the practice used in weather radars, the SACR's should develop sampling strategies that are based on sequences of constant azimuth scans

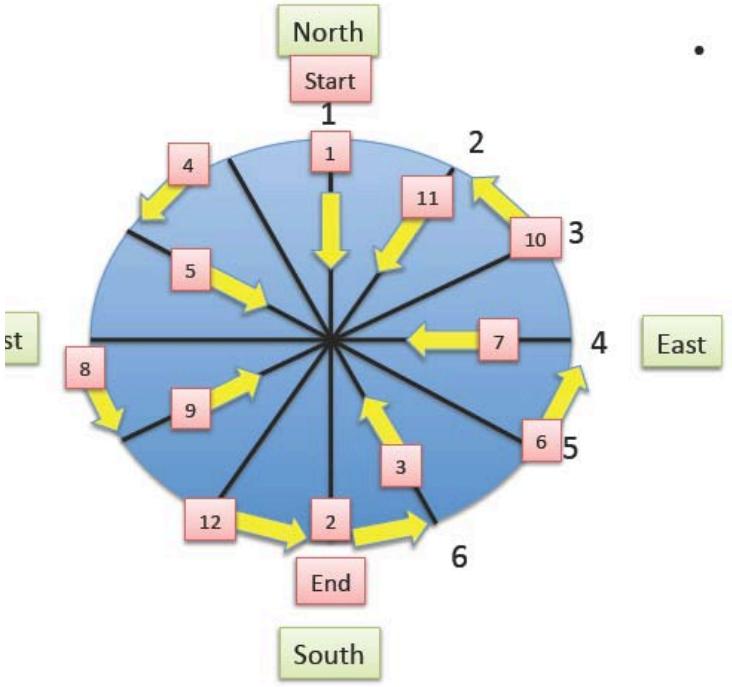
Another lesson learned at Azores: Important to sample the atmospheric column over the ARM site to enhance synergy with other ARM sensors

- Frequent revisiting of the zenith pointing is needed for description of cloud conditions near the ARM site. This lead to the modification of the RHI sector scan
- Cross-wind horizon-to-horizon scans satisfy this requirement
- Need to introduce a general ("all clouds") sampling mode for climatology purposes
- Maintain same scan strategy for 30-60 min

SWACR/SGP: Introduction of "all-cloud conditions" mode
Possible to have temporal gaps between such measurements

HS-RHI model



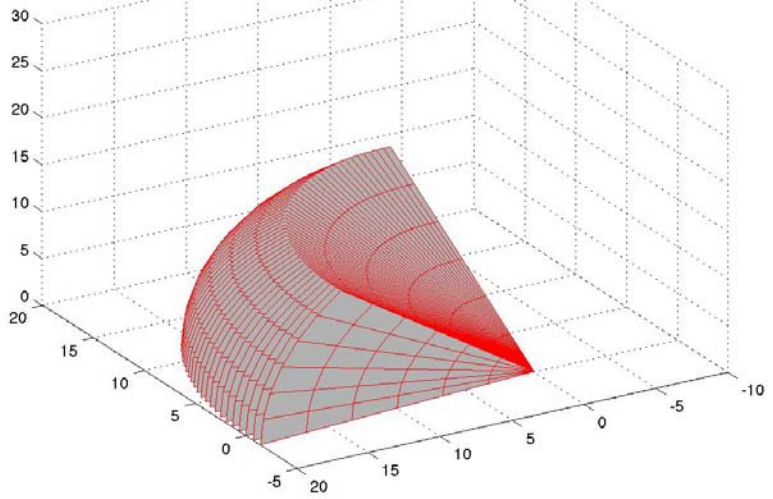


Hemispheric Sky Cross Sections
6 - Horizon-to-Horizon scans
Implemented at the SWACR/SGP

Takes 3-min to complete all six scans

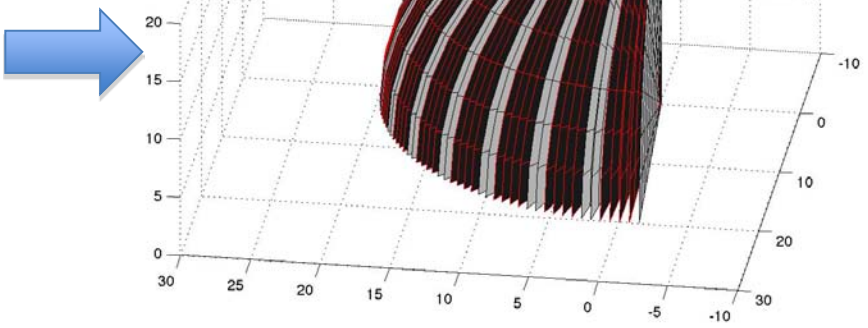
SWACR/SGP: Modification of the RHI sector scan to cover cloud conditions near and on top of the ARM site.

Azores



BL-RHI model

SGP



90° azimuth sector
Centered along BL wind direction
2-degrees azimuth step
Oversampling from 0° to 45° elevation
Max elevation angle 45°
Cone of silence (gap over the ARM site column)

90° azimuth sector
Centered along BL wind direction
2-degrees azimuth step
Oversampling from 0° to 60° elevation
A subset of the RHI scans (every 10° azimuth goes zenith (90°)
No cone of silence (spacing of above 60° elevation scans sufficient for gridding)

First generation of sampling modes for the SACR's

Cloud conditions (no measurable amount of rain at the ground)

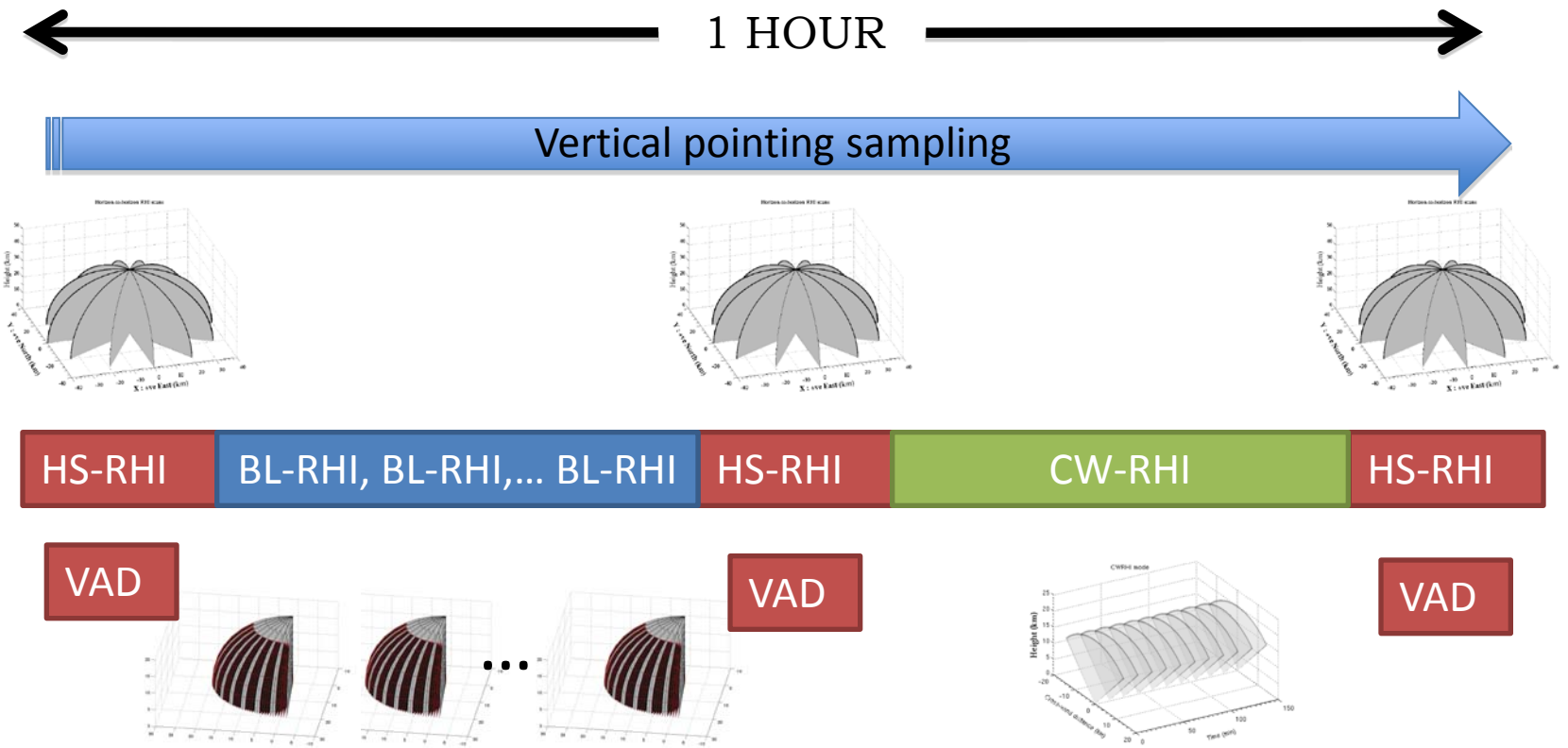
Repeat HS-RHI scan every 30 min (takes 3 min to complete)

Repeat BL-RHI between HS-RHI's (~ 5 times)

Repeat CW-RHI between HS-RHI's

Precipitation conditions (measurable amount of rain at the ground)

Vertically pointing mode (Doppler spectra)



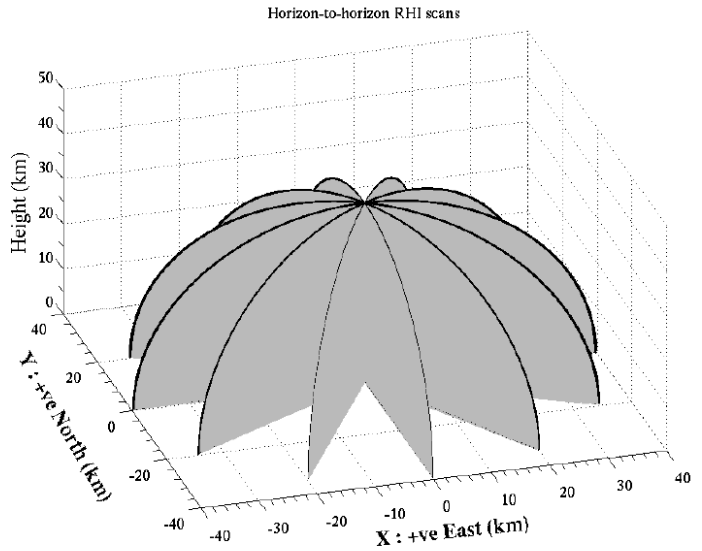
Scanning Cloud Radars
Scientific objectives and data products

Scientific objective	Recommended Data product
3D cloudy atmosphere radiative transfer issues Model subgrid cloud variability Evaluation of satellite retrievals of cloud system properties	-"Frozen" 3D-structure of clouds properties (boundaries, LWC etc) - Possible to have temporal gaps between such measurements
Lifecycles of clouds and convective systems and cloud-aerosol interactions Cloud turbulence, entrainment	-"Volume-Imaging" of cloud properties (boundaries, WC, dynamics) -Repeat several times to capture evolution/lifecycle
Strengthen the microphysical/dynamical column retrievals	-Vertical pointing, Doppler spectra recording

Scanning Cloud Radars
High-level description of 3D cloud sampling

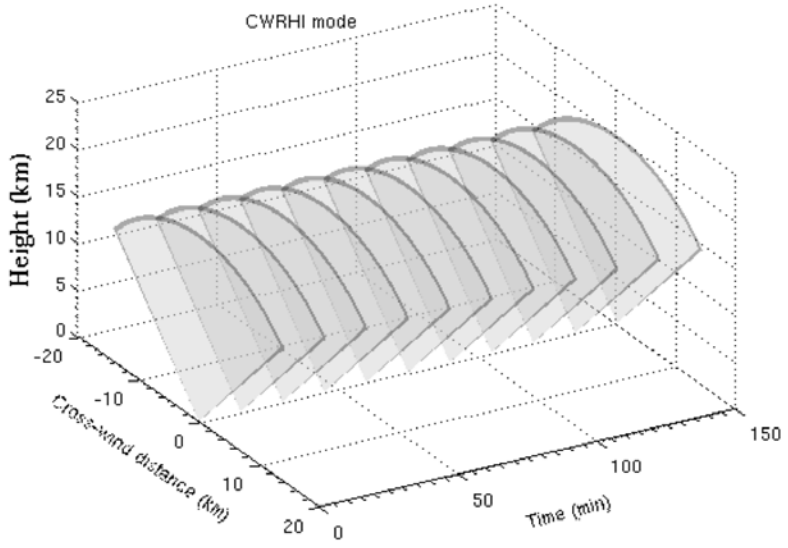
HS-RHI

Hemispheric Sky Cross Sections
6 - Horizon-to-Horizon scans
Duration: 3 min
Repeat: Every 30 min
All-cloud-conditions mode



CW-RHI

Cross-Wind Range Height Indicator
Requires wind direction input
Repeat Horizon-to-Horizon scan N-times
Duration: 15 min to 60 min
Best scan strategy for high clouds



Scanning Cloud Radars
High-level description of 3D cloud sampling

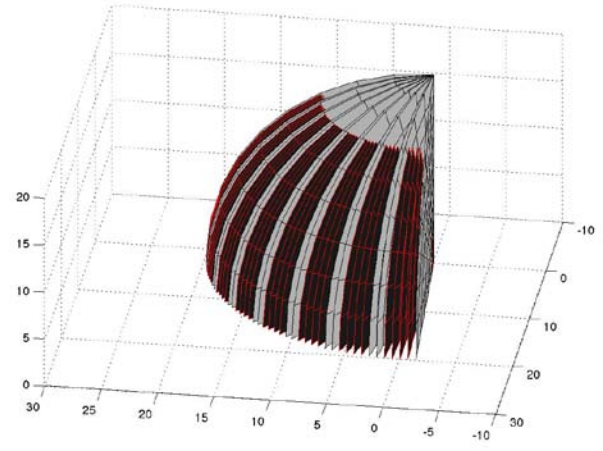
BL-RHI

+90º azimuth sector around wind direction. 2º azimuth resolution

Duration: 5 min

Repeat: 3-6 times (lifecycle)

Best scan strategy for low clouds



VPR

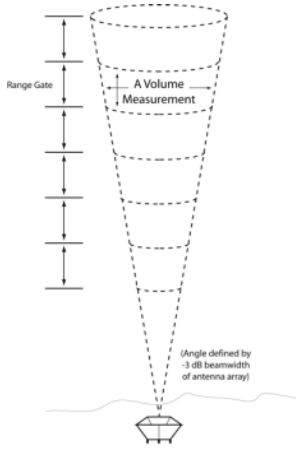
Vertically pointing mode

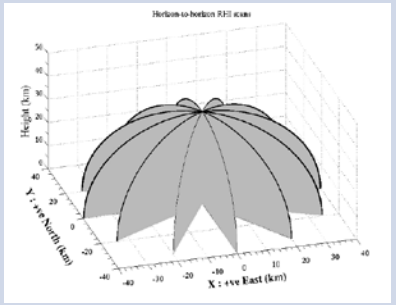
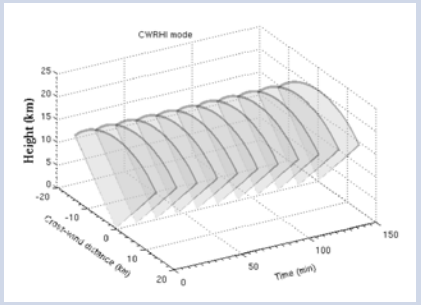
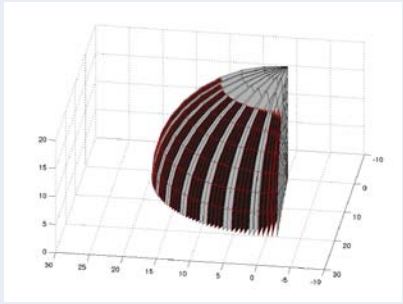
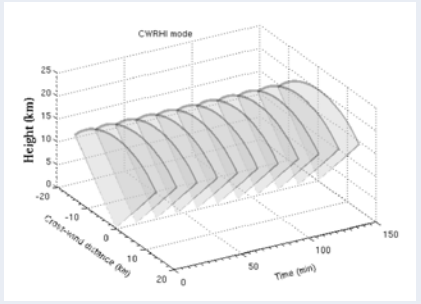
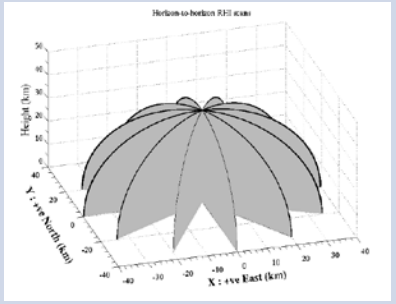
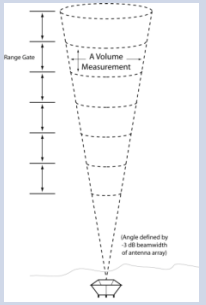
All modes visit zenith frequently

Collection of Doppler spectra

Duration: always in rain

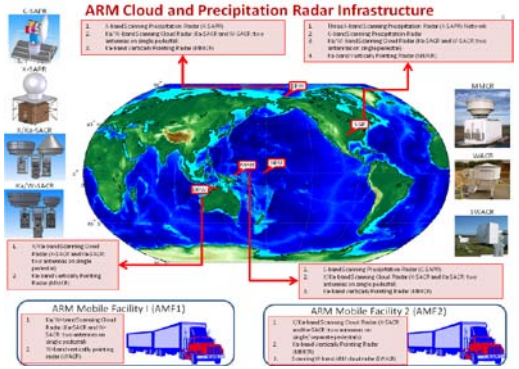
Best scan strategy for precipitation



Scientific objective	Relevant scan strategy
3D cloudy atmosphere radiative transfer issues GCM subgrid cloud variability Evaluation of satellite retrievals of cloud system properties	 
Lifecycles of clouds and convective systems and cloud-aerosol interactions Cloud turbulence, entrainment	 
Strengthening the microphysical/dynamical column retrievals	 

Scanning Cloud Radars
Data Products – Processing structure

Input files
Ingested SACR data: Calibrated reflectivity and polarimetric values
Auxiliary data: Atmospheric sounding, ceilometer and surface rainfall

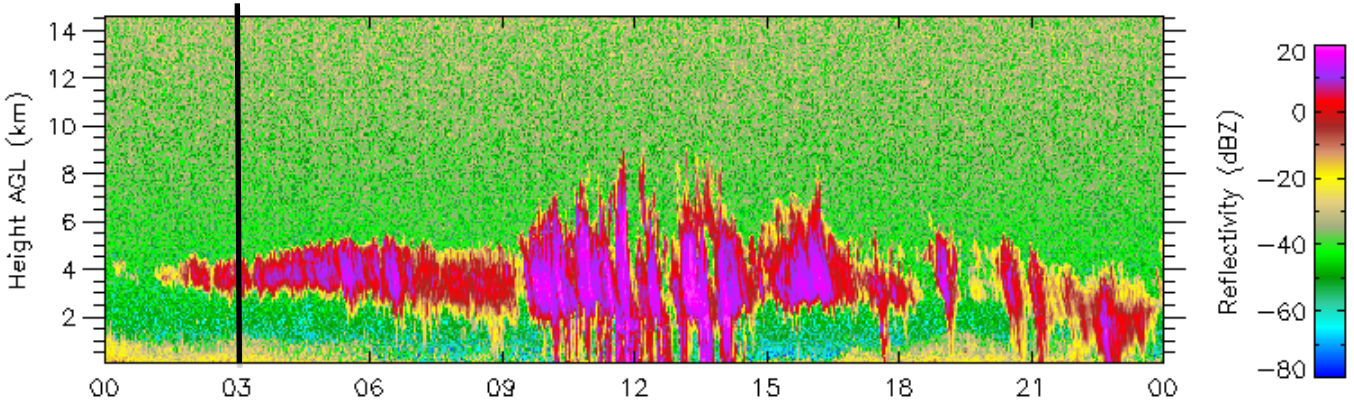


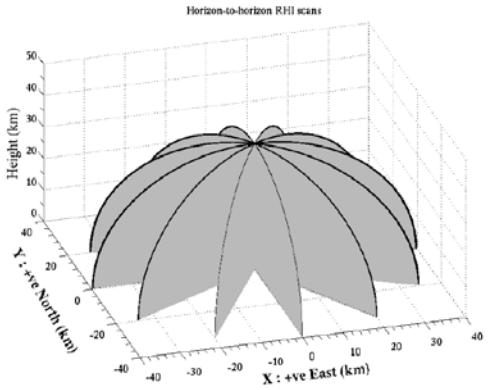
Radar coordinate system
Hydrometeor mask
WV attenuation correction
Doppler folding correction

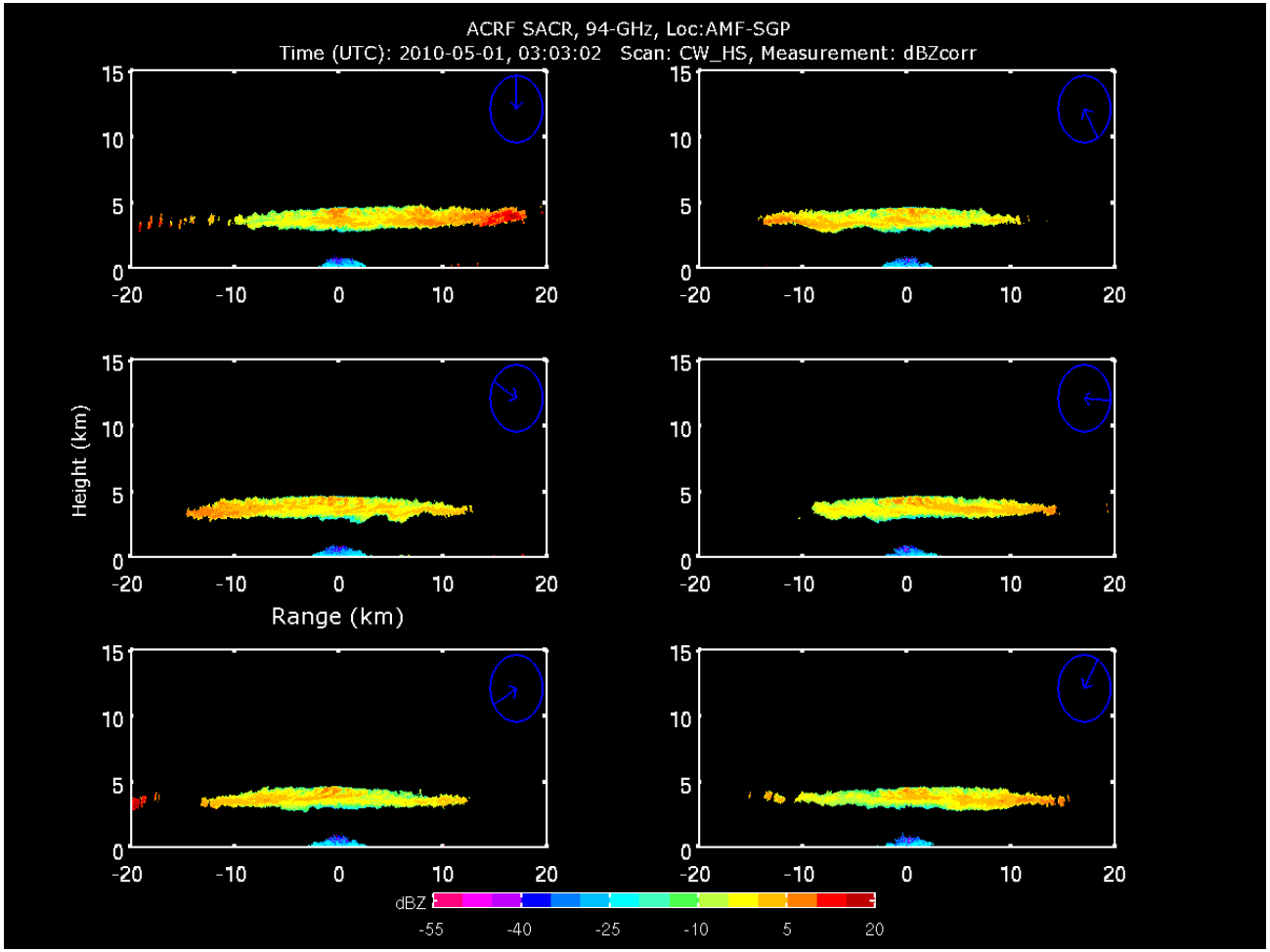
Radar data file (netcdf)
Visualization (image/movie)
Archiving
Web interface

Gridding (3D-ARSCL)
3D locations and radar
Observables - Cloud field statistics
All scanning modes will be gridded

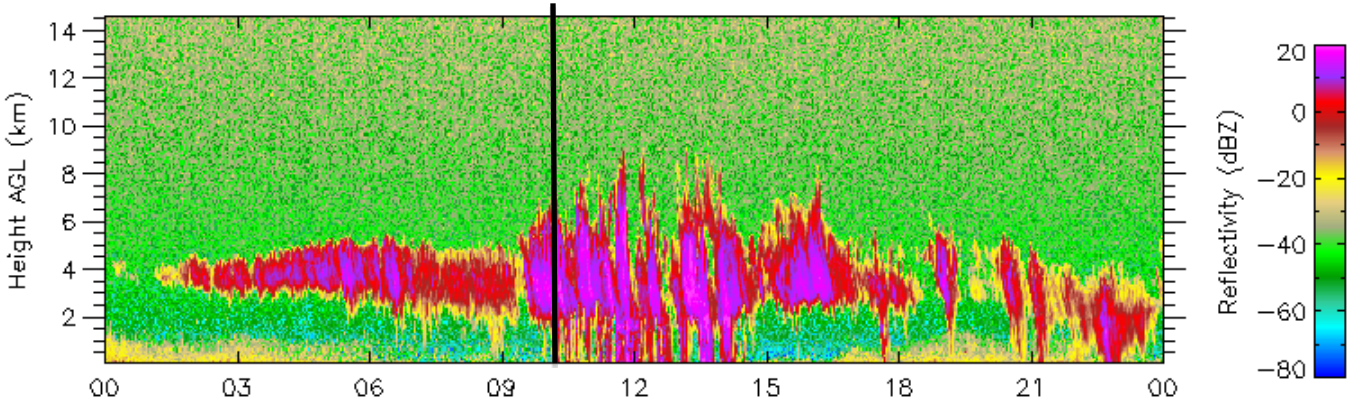
3D-ARSCL data file (netcdf)
Visualization (image/movie)
Archiving
Web interface

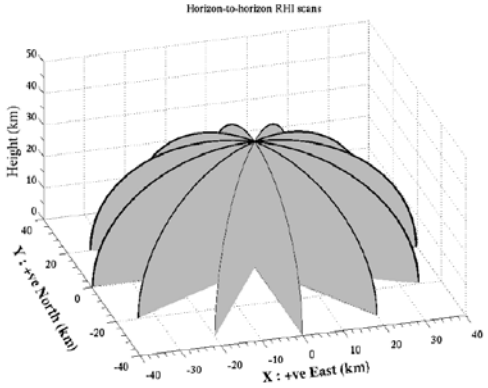


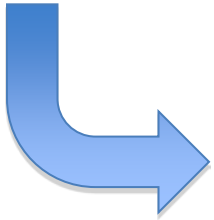


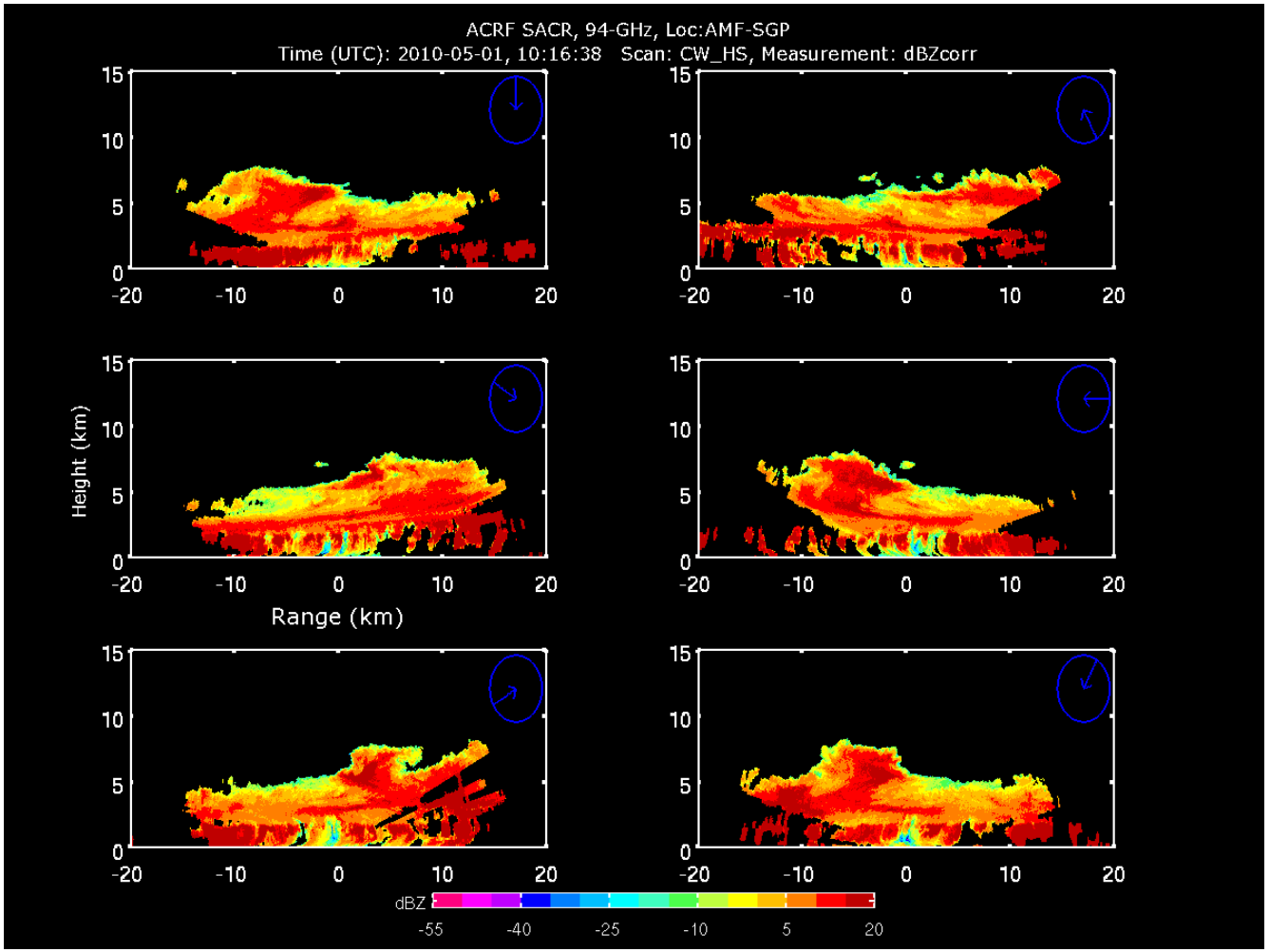


3D-structure of mid-level cloud

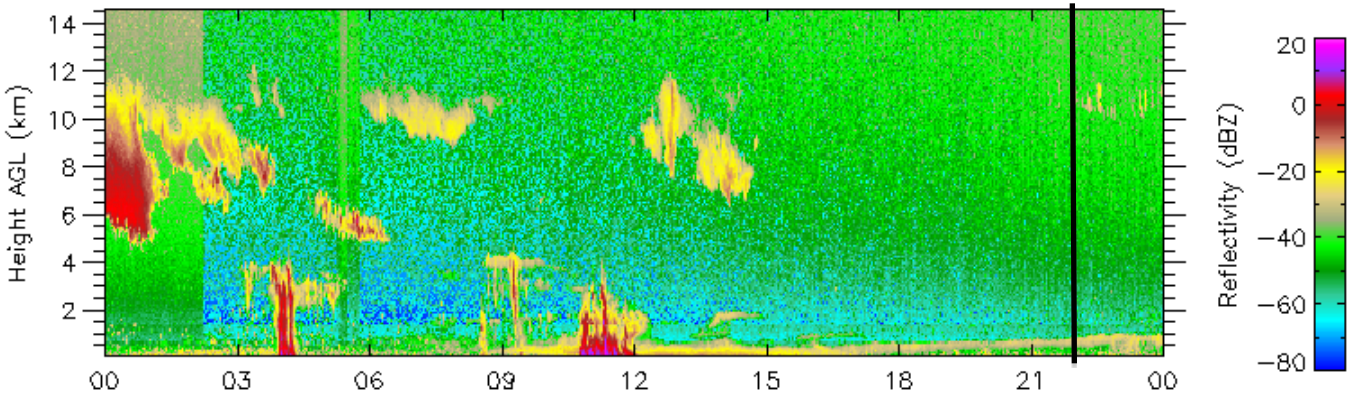


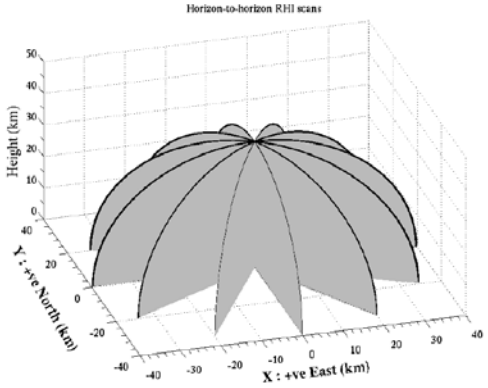


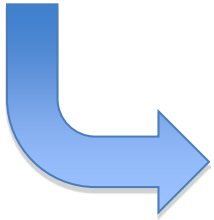


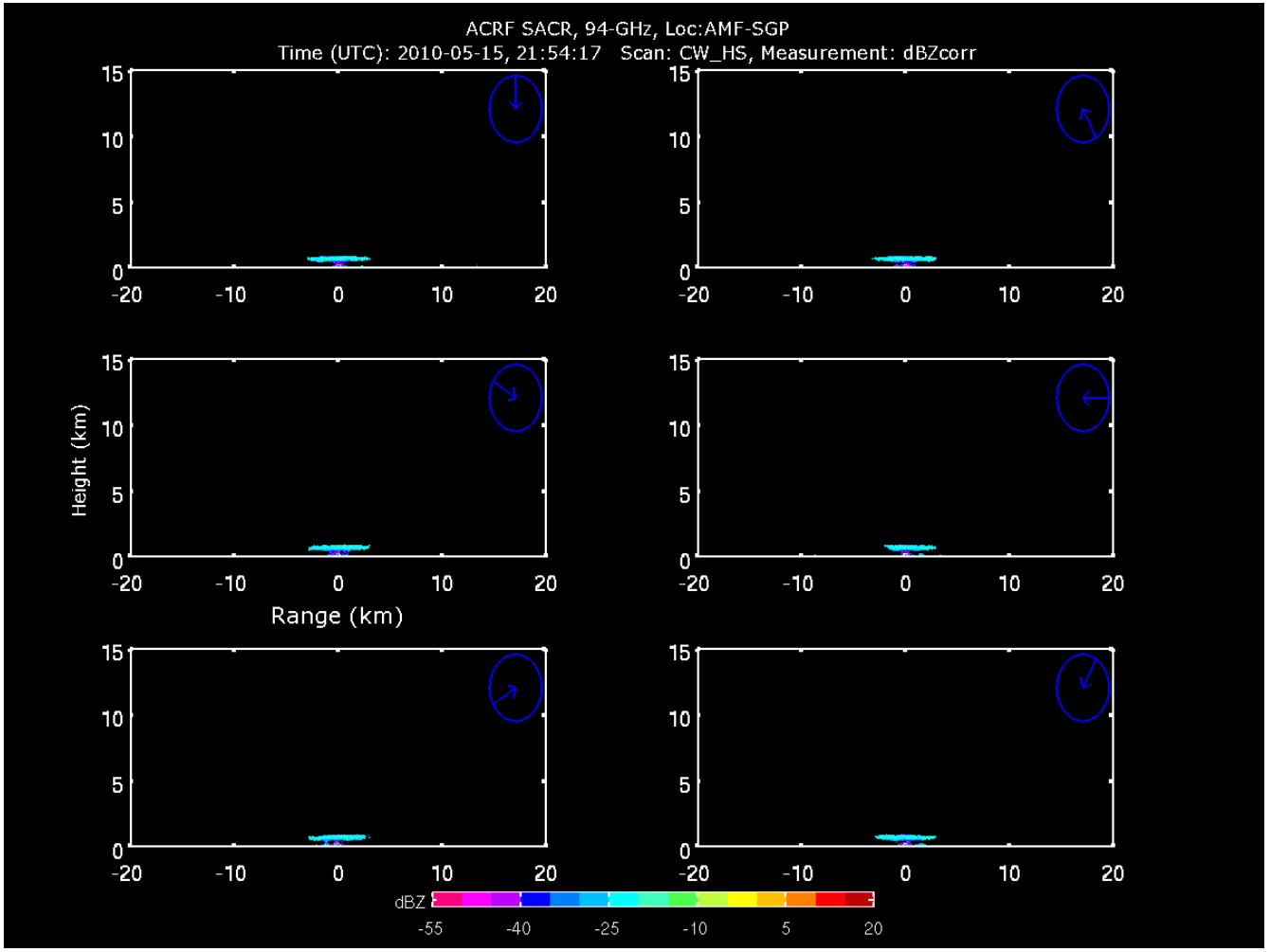


3D-structure of precipitation



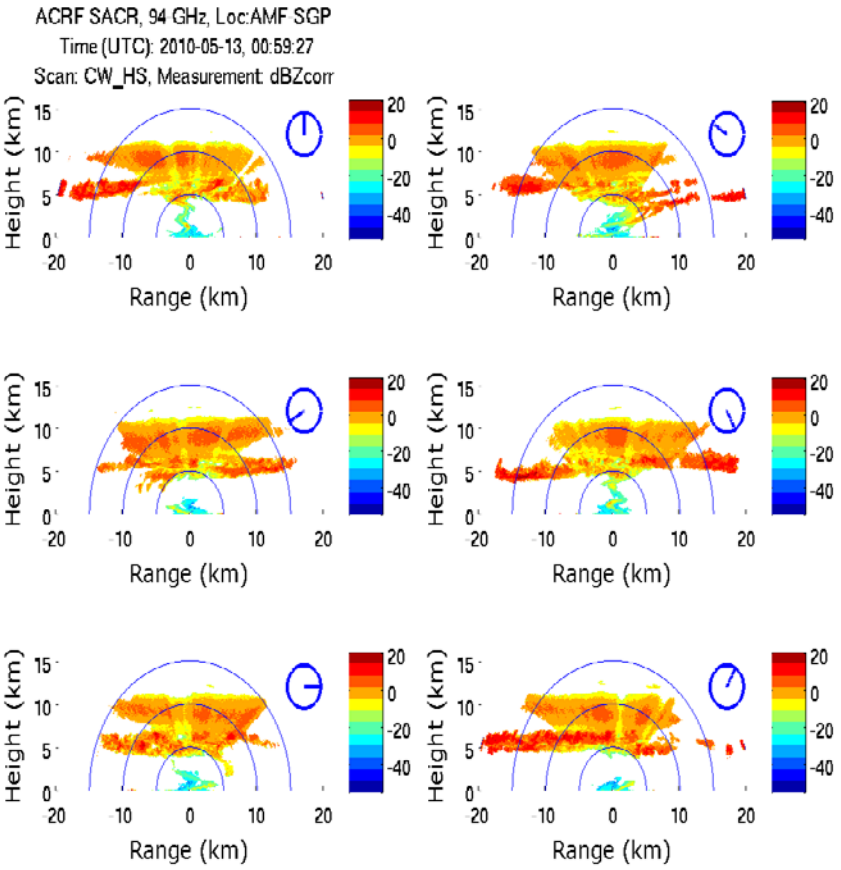




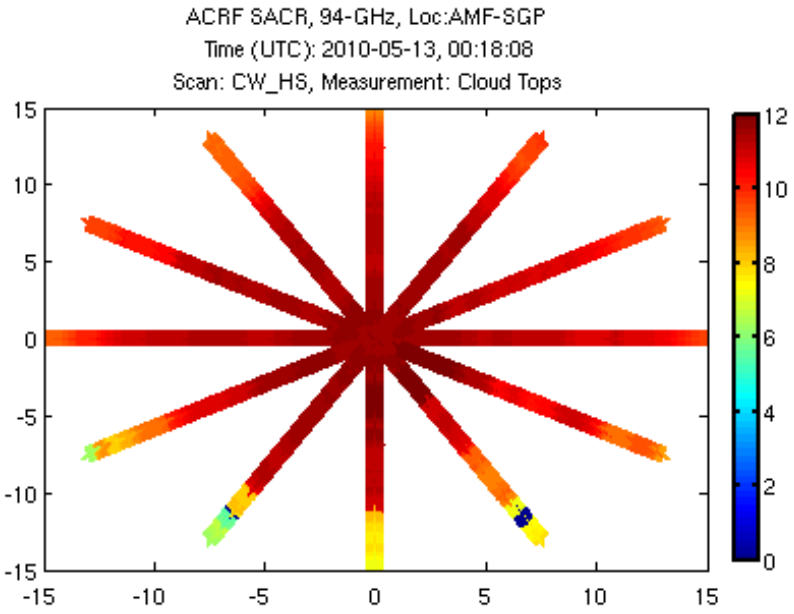


3D-structure of a single-layer stratus cloud

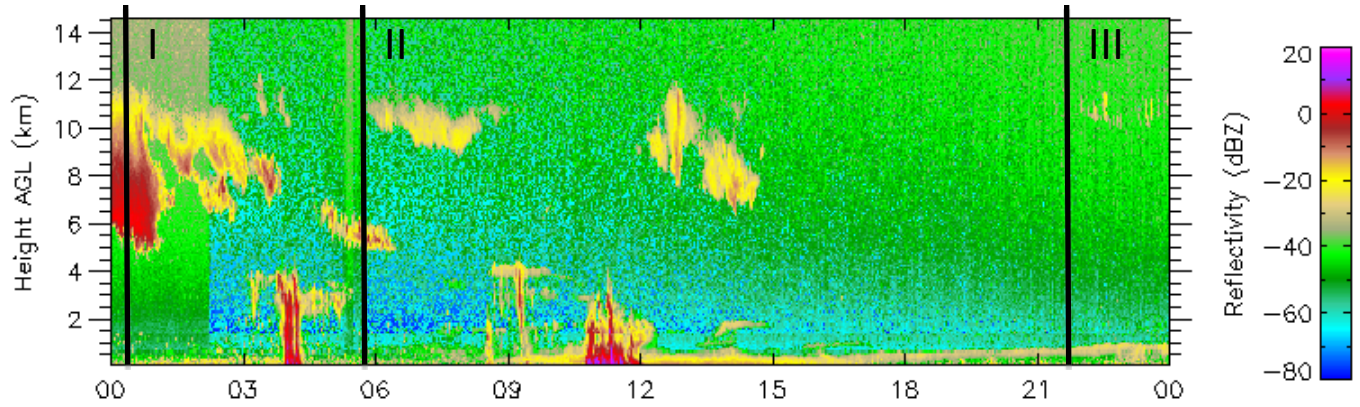
Sample data products from HS-RHI “all clouds” sample mode

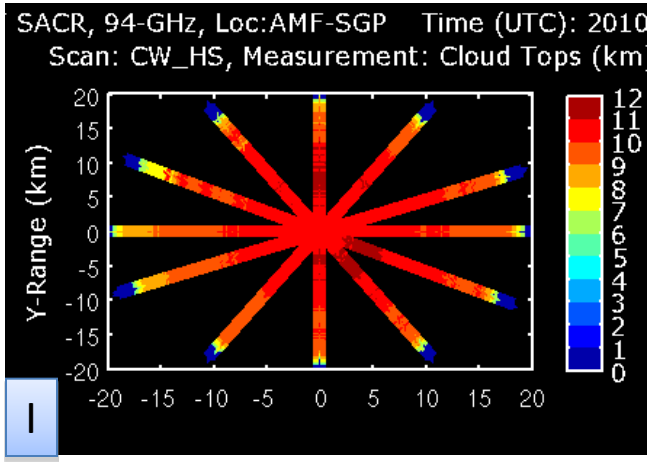


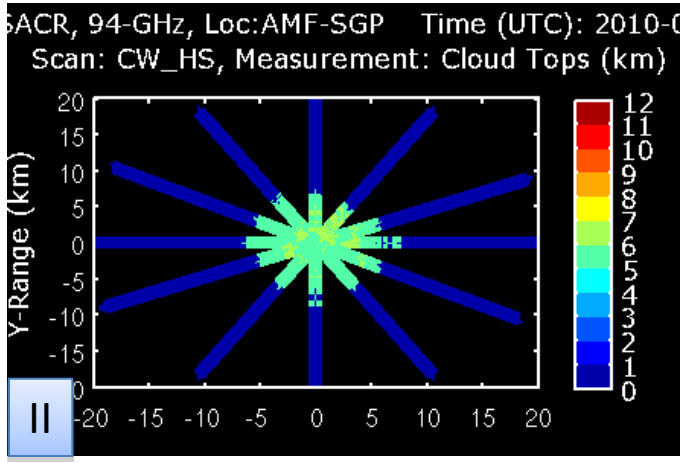
Grid RHI scans
Apply cloud classification

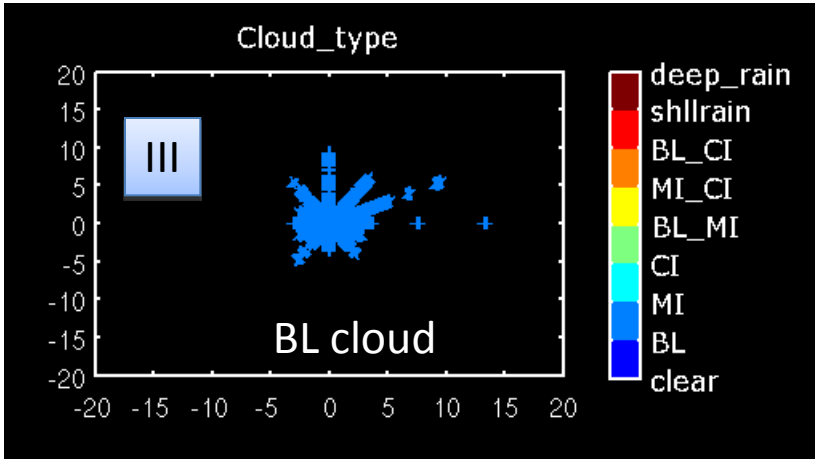


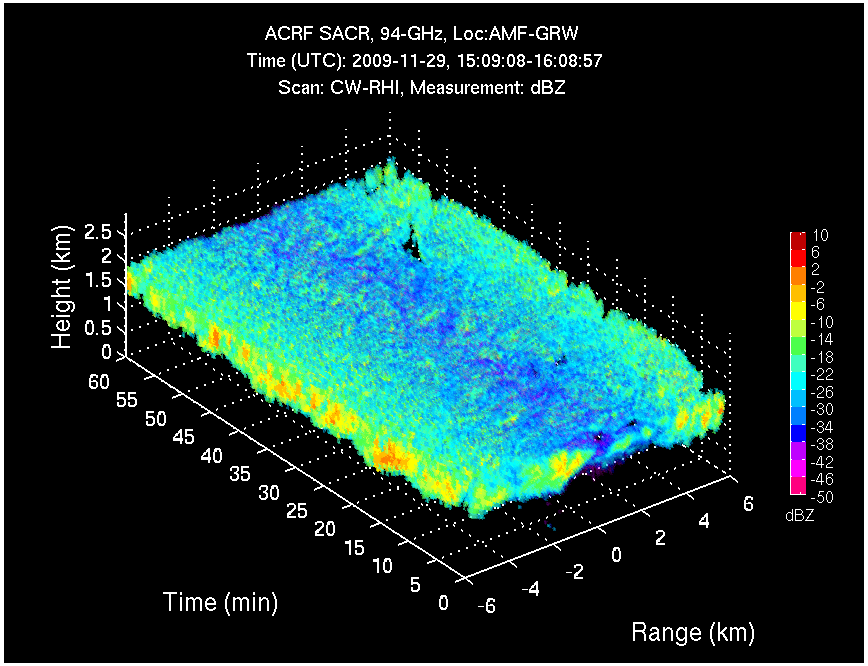
Products: Cloud top height
Cloud thickness
Number of layers
Cloud types


I
II
III
Height AGL (km)
14
12
10
8
6
4
2
00
03
06
09
12
15
18
21
00
Reflectivity (dBZ)
20
0
−20
−40
−60
−80


SACR, 94-GHz, Loc:AMF-SGP Time (UTC): 2010
Scan: CW_HS, Measurement: Cloud Tops (km)
Y-Range (km)
20
15
10
5
0
-5
-10
-15
-20
-20 -15 -10 -5 0 5 10 15 20
12
11
10
9
8
7
6
5
4
3
2
1
0
I

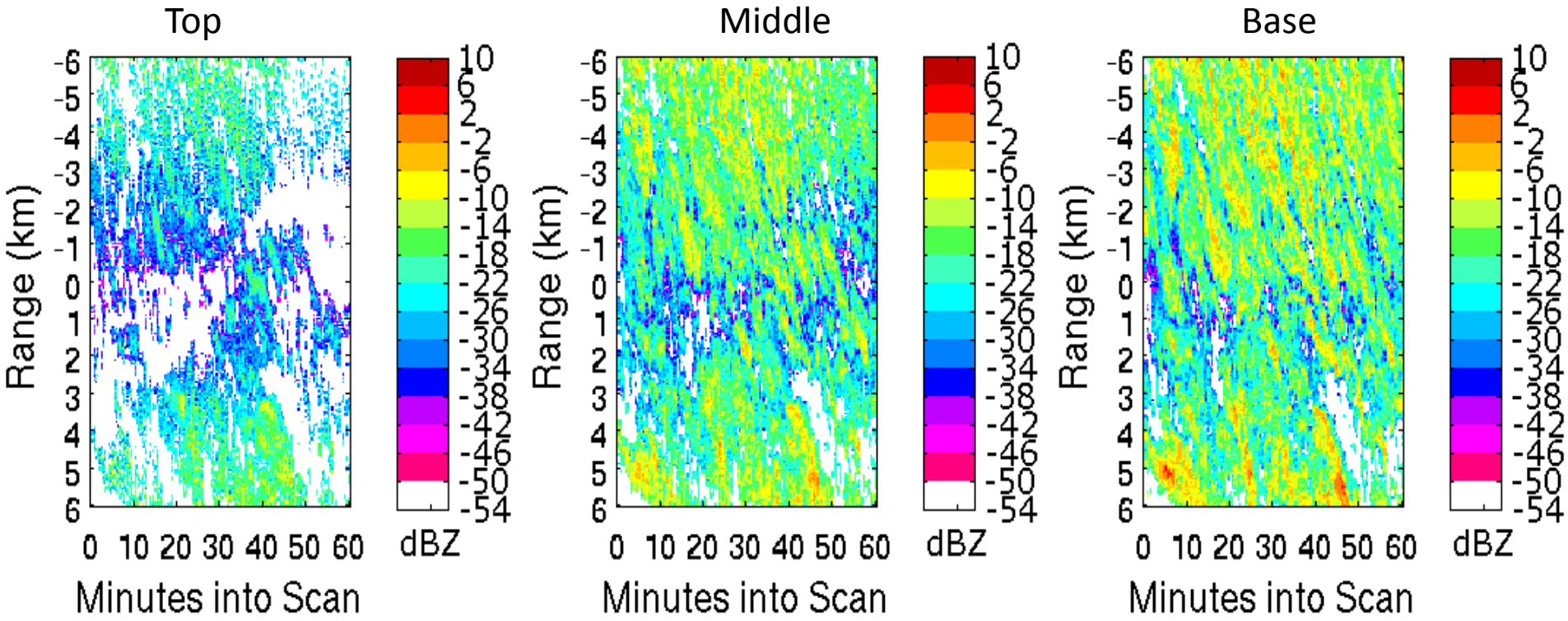

ACR, 94-GHz, Loc:AMF-SGP Time (UTC): 2010-0
Scan: CW_HS, Measurement: Cloud Tops (km)
Y-Range (km)
20
15
10
5
0
-5
-10
-15
0
-20 -15 -10 -5 0 5 10 15 20
12
11
10
9
8
7
6
5
4
3
2
1
0
II


Cloud_type
III
BL cloud
20
15
10
5
0
-5
-10
-15
-20
-20 -15 -10 -5 0 5 10 15 20
deep_rain
shllrain
BL_CI
MI_CI
BL_MI
CI
MI
BL
clear

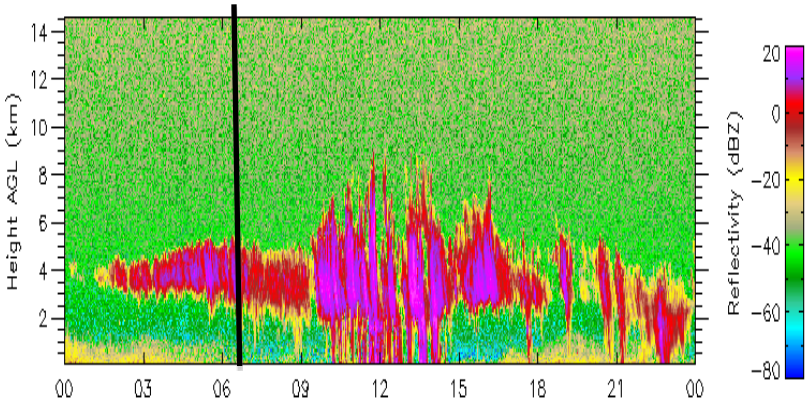


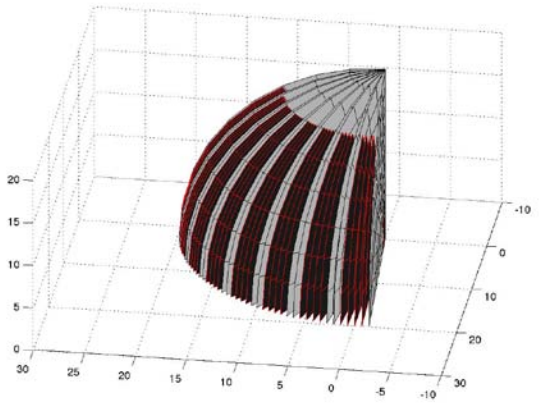
3D-Gridded Data (ARSCL) sample from Azores

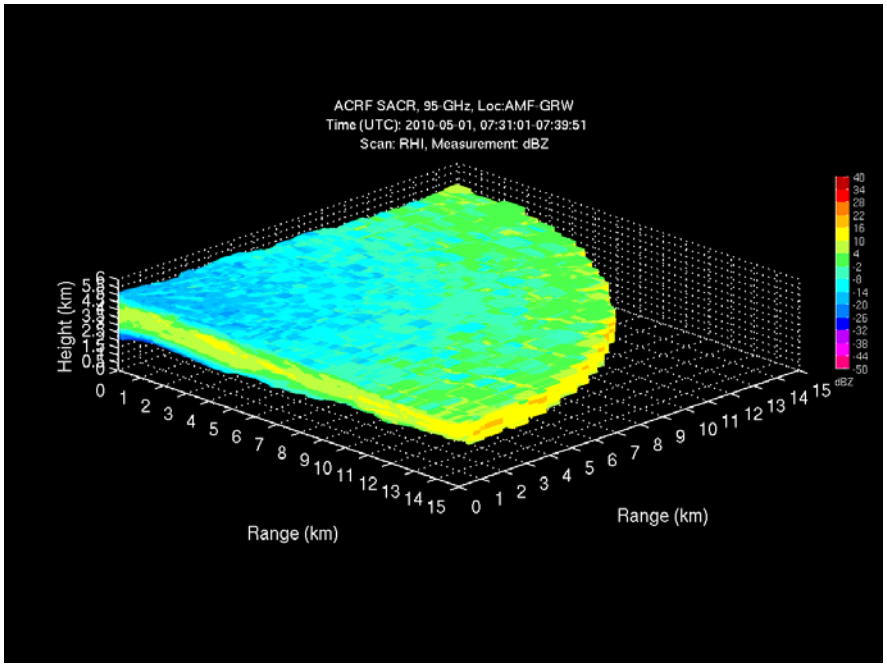
Horizontal structure at different cloud levels

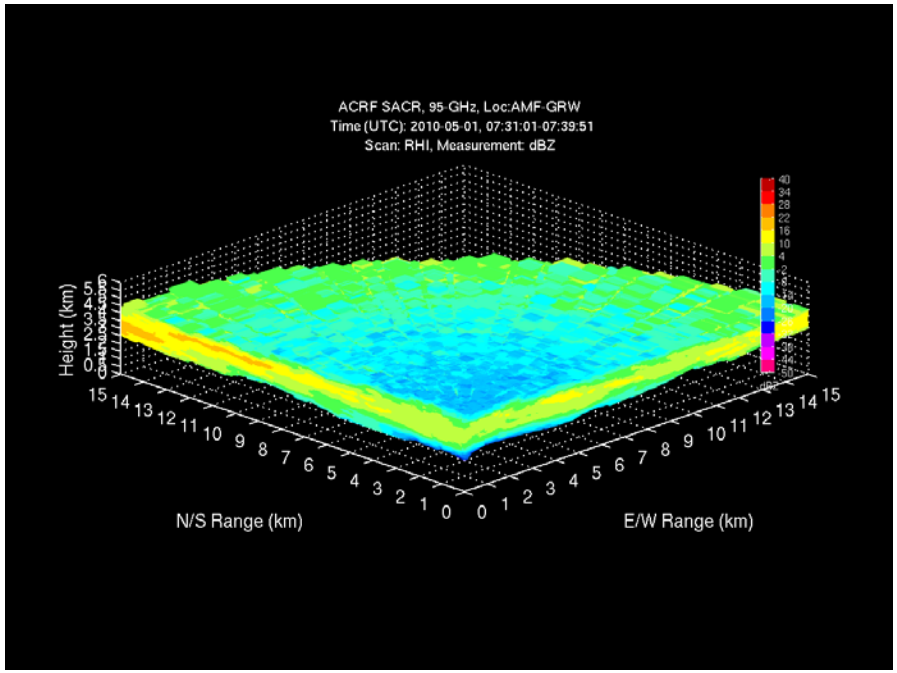


3D-ARSCL (Gridded Hydrometeor Locations) from SGP using the new BL-RHI sampling strategy









Summary and Challenges - I

The short-term deployment of the SWACR at Azores and SGP provided the opportunity to test various 3D cloud sampling strategies

Use of RHI scans is favored due to the narrow radar antenna beamwidth, the nature of clouds and the desire to sample the sky over the ARM site

Four scan strategies that meet these requirements are considered:

HS-RHI: "All cloud conditions" sampling mode – Cloud sate

BL-RHI: "Suitable for BL clouds", provides temporal evolution

CW-RHI: "Suitable for high clouds", time is one the dimensions and,

VPR: "Precipitation mode", dual-frequency retrievals in precipitation

Automatic detection of wind direction and surface precipitation is required to provide "close-loop" adaptive scan strategies (e.g., for centering the BL-RHI and CW-RHI scans and for changing to VPR mode).

Summary and Challenges - II

- Data products status
- The scanning cloud radar hydrometeor mask algorithm is completed. Refinements needed for insect removal using polarimetric measurements and clutter removal at 9.4-GHz.
- WV attenuation correction algorithm is completed using nearest sounding
- Doppler velocity unfolding algorithm prototype is completed, evaluation is underway
- Prototype radar data gridding algorithm (for HS-RHI, BL-RHI and CW-RHI scan modes) has been developed, evaluation/refinement is undergoing
- Prototype images/movies format and netcdf data file formats (radar coordinate system and 3D-ARSCL) are completed

- Challenges
- New radars have several new technological aspects and we need to evaluate their performance in the field
- A web interface for fast review/validation of prototype algorithms as more radars come online is needed
- Gridded data and higher order products (e.g., cloud boundaries, cloud phase and cloud types) are highly desirable, however, an extensive evaluation is required.

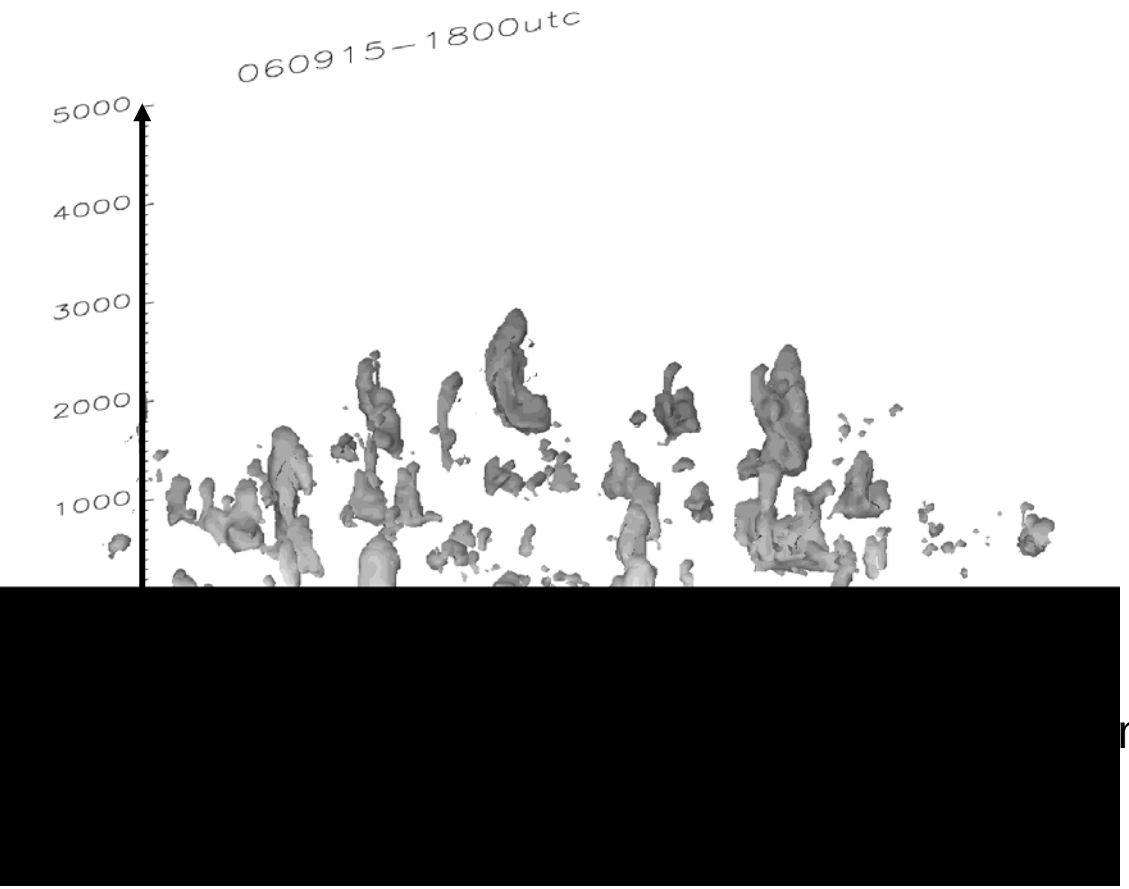
Proposed Small Cumulus Lifecycle Studies using Scanning Cloud Radar Observations

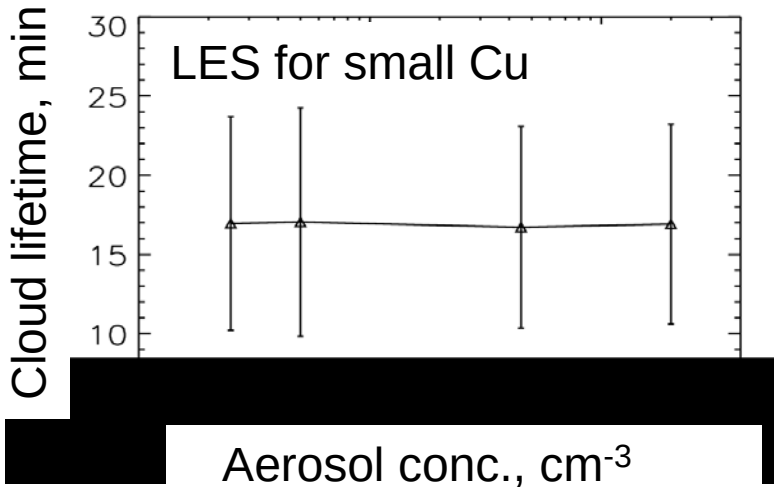
- Cu Cloud Life Cycle Observations
  - Cloud Statistics
    - Time evolution of cloud elements at different stages in their lifetime
  - Aerosol Effects
    - Changes in cloud life cycle characteristics with different subcloud aerosol loading
  - Context for measurements from upward facing sensors

- Related Process Studies (3-D)
  - Precipitation
    - Formation
    - Temporal and spatial variability
    - Evaporation
  - Entrainment
    - In cloud circulations at cloud top and sides

Tracking Cloud Lifetime with LES

Tracking100s of clouds

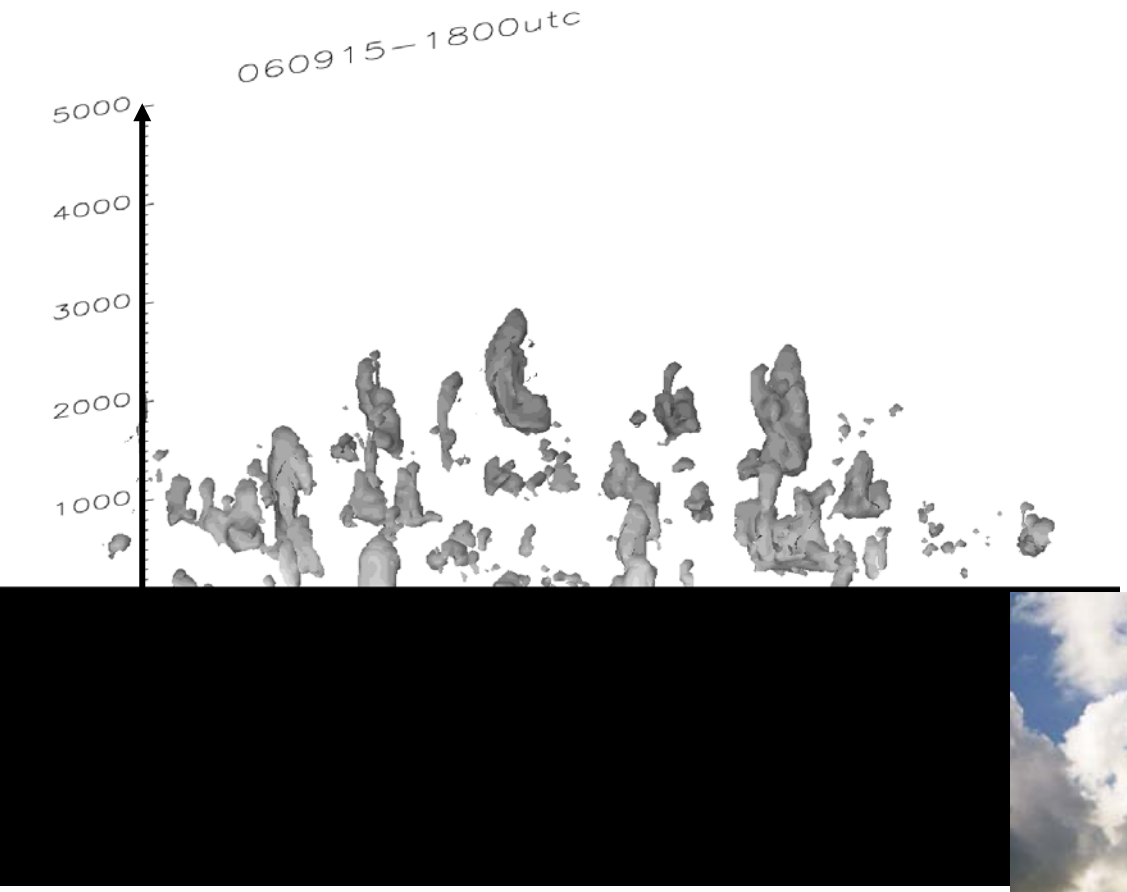


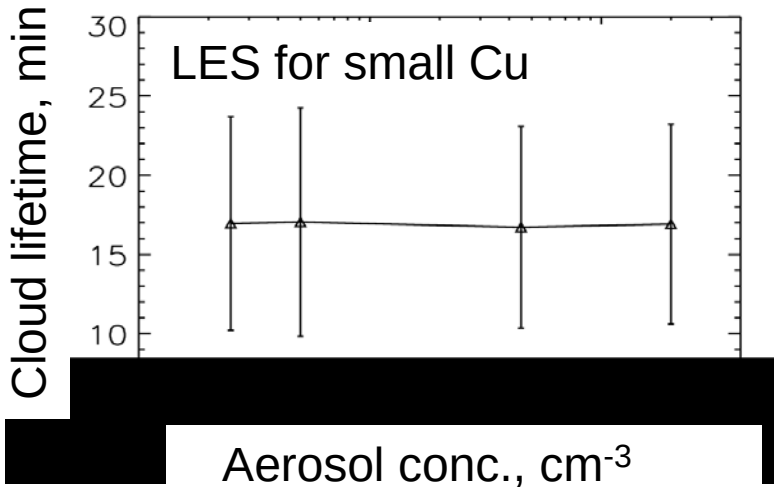


No influence of aerosol on cloud lifetime

Tracking Cloud Lifetime with LES

Tracking100s of clouds





No influence of aeros
lifetime

Small Cu Time Lapse

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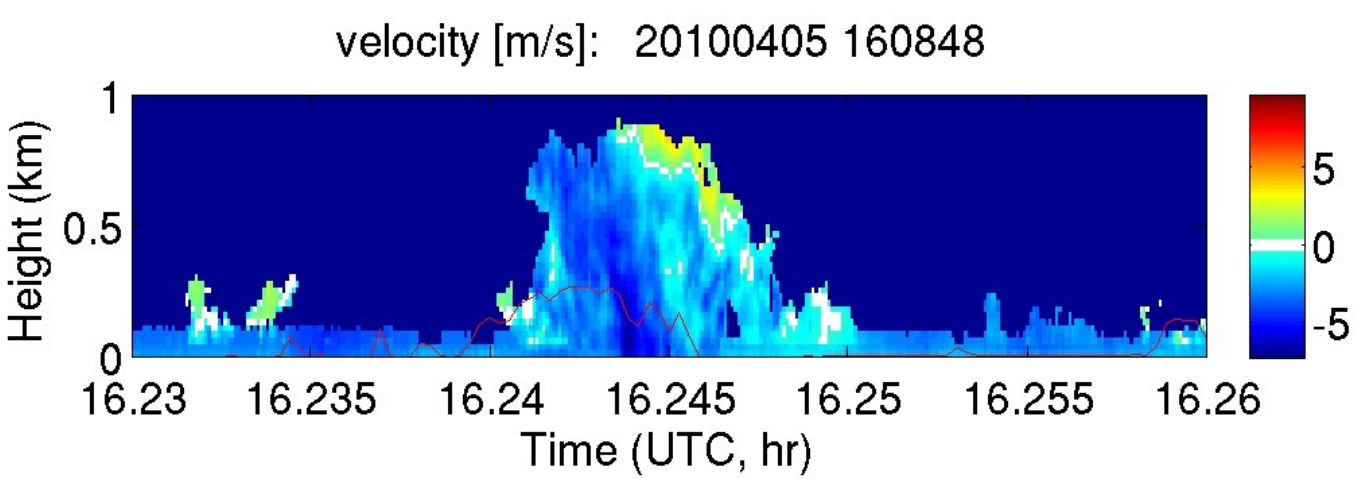
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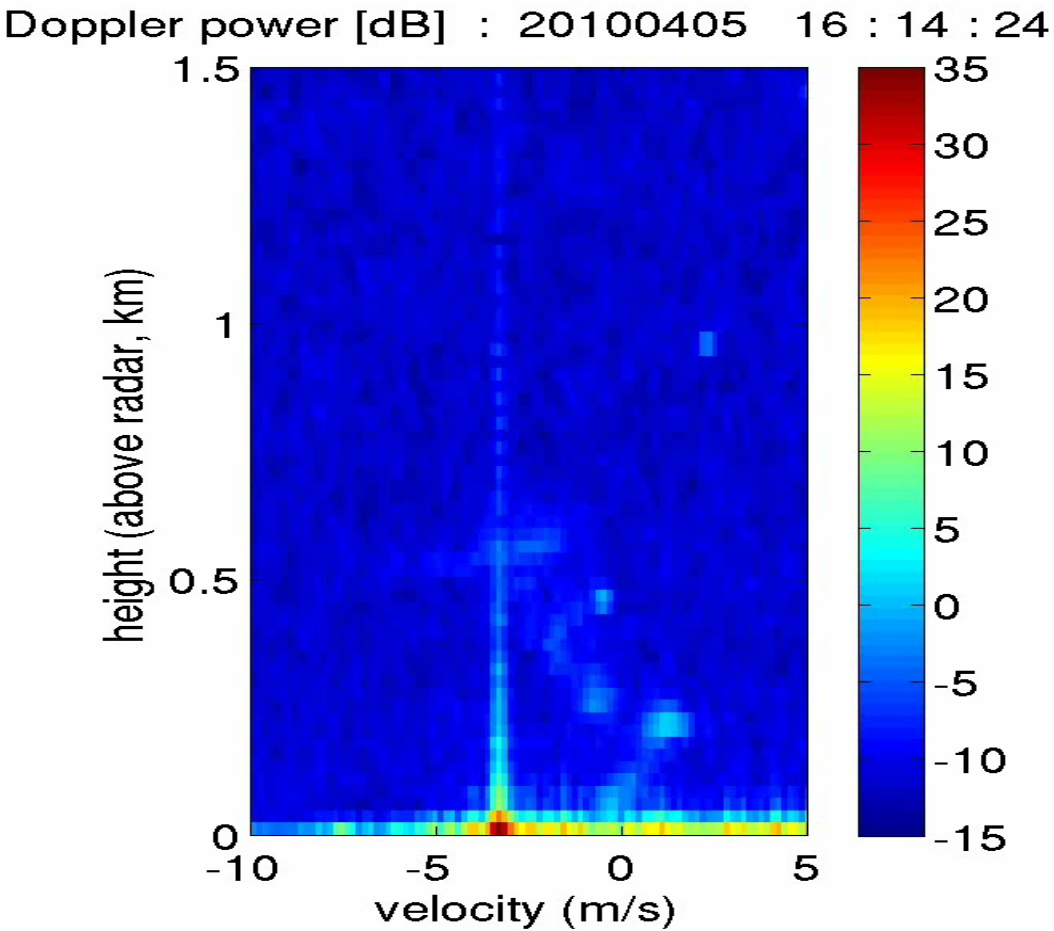
Height (km)
1
0.5
0
16.23
16.235
16.24
16.245
16.25
16.255
16.26
Time (UTC, hr)
5
0
-5


Doppler power [dB] : 20100405 16 : 14 : 24
height (above radar, km)
1.5
1
0.5
0
-10
-5
0
5
velocity (m/s)
35
30
25
20
15
10
5
0
-5
-10
-15

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Precipitation and Lifetime of Small Cumulus



5 minutes ⟶

Photos from Barbados; Courtesy Joe Prospero



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