ACE Radar Sub-Team
Progress Report Nov 6 2008

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ACE Radar - Heritage / evolution:
- What are the gaps left uncovered by CloudSat/CALIPSO? (Fogs, marine stratocumulus, etc.).
- In which areas the current CloudSat radar only retrievals are less reliable?
- In which areas the current CloudSat/CALIPSO radar/lidar retrievals are less reliable?
- Which of these gaps will (maybe) be covered by EarthCARE?
- Which of these gaps can be covered by Dual-Frequency, Scanning, Doppler, Polarimetric capabilities?

Preliminary Instrument Requirements

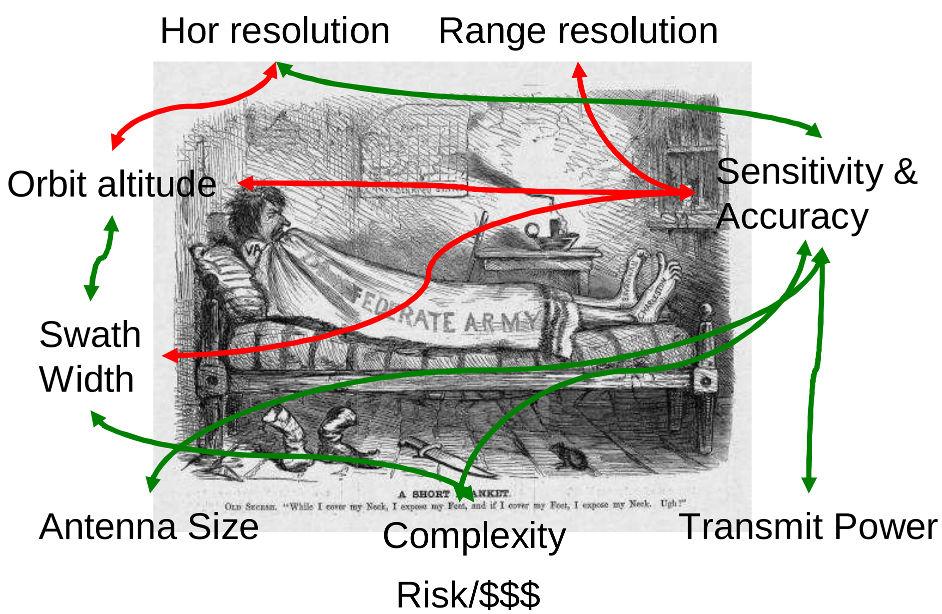
The following requirements were defined based on input from **ACE SWG Cloud Modeling and Retrievals Teams**, and others during 2008.

ACE radar team will keep these requirements as reference while they are being refined. **Further input** from the Cloud community is **expected**.

Items in green are being addressed by simulation studies. Items in red are considered primary minimum performance requirements.

- Minimum detectable reflectivity factor
  - **-35 dBZ** on "primary channel" for cloud applications (-40 dBZ goal)
  - **-10 dBZ** on "secondary channel" for drizzle, convection, μphys. (-20 dBZ goal)
  - Surface clutter degradation limited to **250 m above sea surface**
- Range resolution: **250 m** (50 m goal).
- Horizontal resolution:
  - **~1km** on primary channel (100 m goal).
  - **~2km** on secondary channel (100 m goal).
- Swath:
  - TBD km. Rationale: "Enough to capture the context for convective systems, and the pdf of main characteristics for stratiform clouds". (~200 km goal)
- Doppler:
  - **0.2 m/s** for cloud sedimentation/habits (0.1 m/s goal)
  - **1 m/s** for convective activity (0.5 m/s goal).

Main Trade-Off & Observing System Simulations

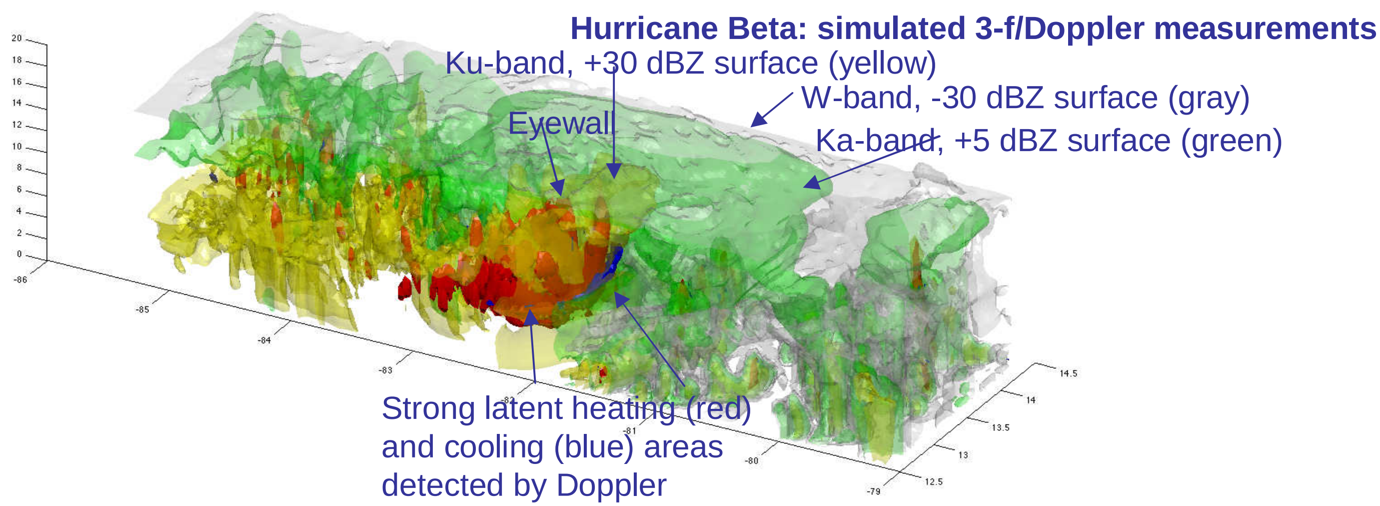


$$Z_{sens} \propto \frac{L_{atm} L_{sys}}{f^4 A_{eff}} \cdot \frac{B_{noise}}{(P_t \tau)} \cdot \frac{1}{\sqrt{N_{ind}}} \cdot r^2$$

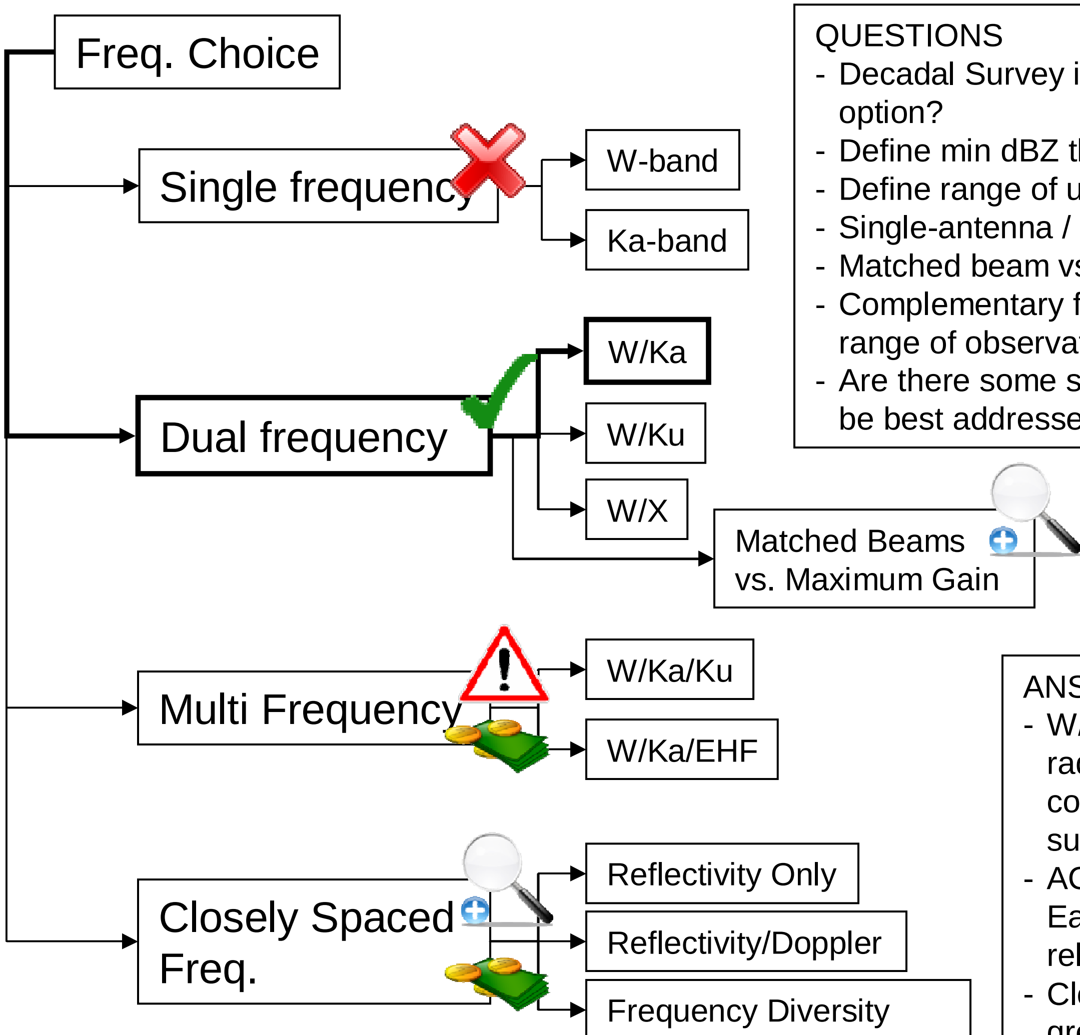
	Reference (EarthCARE)	Modified	Delta dBZ Sensitivity
Distance (km)	450	**715**	4.02
Number of beams	1	**64**	9.03
Range Res. (m)	500	**250**	6.02
Diversity	1	**8**	-4.52
Antenna Surf (m2)	4.91	**100**	-13.09
			1.47

Radar Team studies:

1) Provide benchmark simulations to allow the Cloud Modeling and Retrieval Teams to refine scientific requirements.
2) Examine current state of the art and projected evolution of viable technologies and methods to achieve instrument requirements



Frequency Choice



QUESTIONS
- Decadal Survey indicates W/Ka: is any other frequency a credible option?
- Define min dBZ threshold requirement for each frequency
- Define range of usefulness of each frequency pair
- Single-antenna / multi frequency vs. multiple antenna: pros & cons
- Matched beam vs full illumination: pros & cons
- Complementary frequencies vs. cooperating frequencies (I.e., extend range of observations vs. overlapped measurements).
- Are there some specific cloud-aerosol interaction processes that would be best addressed by a specific frequency (or pair)?

ANSWERS
- W/Ka allows large overlap of measurements, compact radar, and good penetration in precipitation. Strongest convective cores will not be visible all the way to the surface.
- ACE Radar needs to be at least as sensitive as EarthCARE. Requirement on Ka band channel can be relaxed based on DWR usefulness considerations.
- Cloud droplet and ice sizes in the few 100 μm are of great relevance to the cloud-aerosol interaction: W/Ka is too low to directly measure size by Mie contrast.

$$Z_{sens} \propto \frac{L_{atm} L_{sys}}{f^4 A_{eff}} \cdot \frac{B_{noise}}{(P_t \tau)} \cdot \frac{1}{\sqrt{N_{ind}}} \cdot r^2$$

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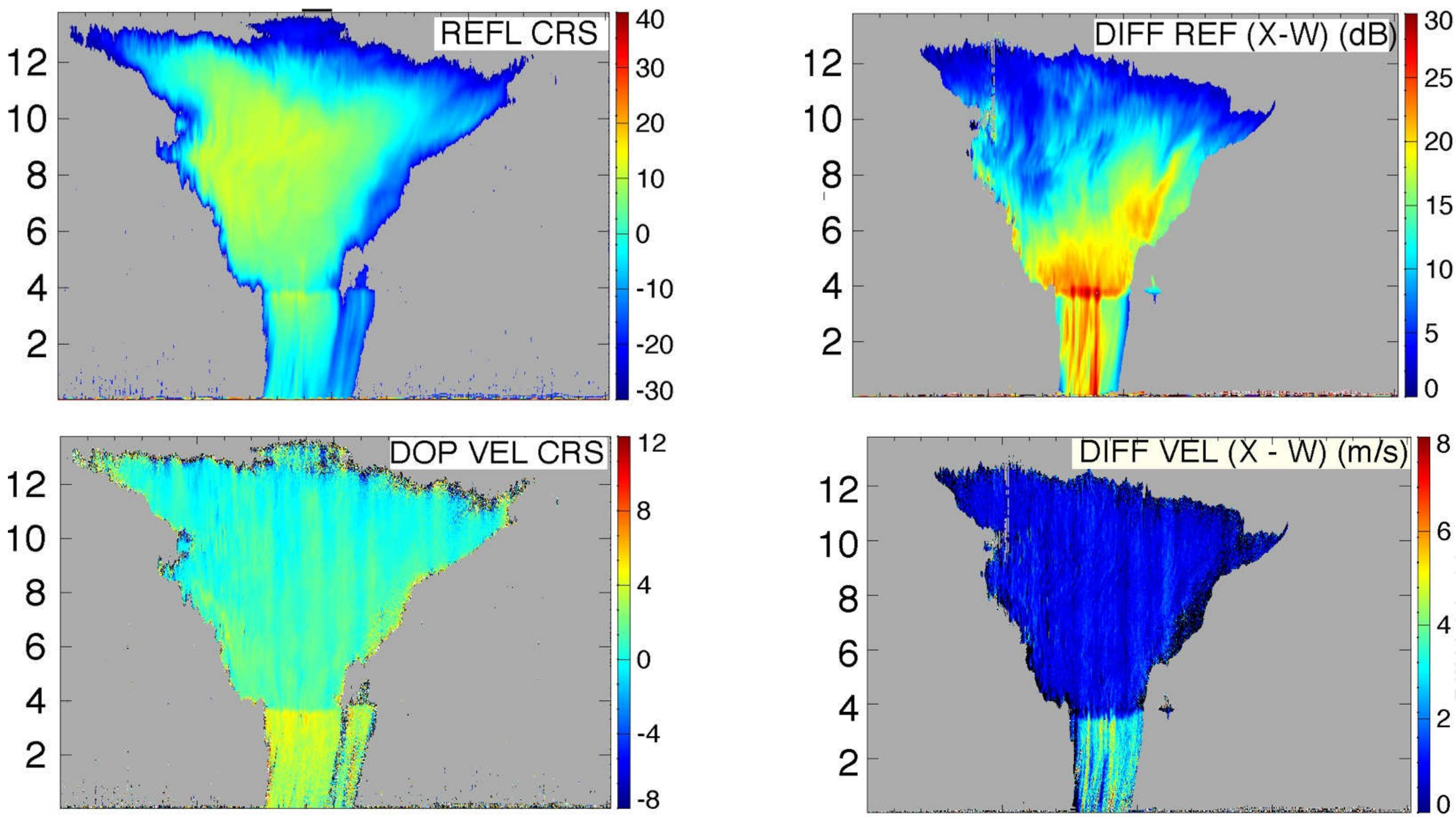
Dual frequency sensitivity requirements



Airbone data available for analysis: EDOP (X), APR-2 (Ku/Ka), ACR (W), CRS (W).

$$Z_{sens} \propto \frac{L_{atm} L_{sys}}{f^4 A_{eff}} \cdot \frac{B_{noise}}{(P_t \tau)} \cdot \frac{1}{\sqrt{N_{ind}}} \cdot r^2$$

Scanning

Scanning vs. Nadir

Questions to be addressed by simulations:

A. Statistics: how correlated are two vertical sections of x (M, D*, Z, etc.) n km apart?
B. Context of convective systems: what is the minimum width to capture the relevant environment for a radar profile?
C. PDF (CFAD) of state and main variables (e.g., θ_L, w, Q_L): what is the minimum swath width capable of capturing the PDF (CFAD) of these quantities for a stratiform system?

Nadir

Pros: greatest radar sensitivity for a given configuration, simplest design, lower risk/cost, technology proven in space at W-band.
Cons: very limited sampling and coverage, lack of third dimension requires use of additional sensors to provide context at all scales.

Narrow Swath (<2°)

Pros: provides small scale context, could “fill” the footprint of one radiometer for GPM-style synergy. Technology under development for W-band, proven in space for Ka.
Cons: limited sampling and coverage, swath of few 10s of km requires use of additional sensors to provide context at large scales.

Wide Swath (2-20°)

Pros:, greatest coverage, provides context at all scales up to swath width.
Cons: lowest radar sensitivity,surface clutter enhanced on off-nadir beams. Extremely challenging at W-band with acceptable losses, Ka-band technology more mature but not proven in space for this application.

Adaptive Swath

Sparse Beams

Pros: hybrid solutions could provide high quality, best sensitivity measurements at nadir, while providing somewhat degraded products off-nadir. No significant technological barriers beyond what necessary for standard scanning schemes above.
Cons: increased system complexity.

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Range Resolution

Questions to be addressed by simulations

A. Which specific features require use of better than 500m?
B. Which specific features require use of better than 250m?
C. Which specific features require ground clutter to be limited at 250 m?
D. Adoption of Pulse Compression: pros and cons.

Range Resolution

- 500m
  Pros:best sensitivity, sufficient to capture most clouds, proven in space (Cloud Sat/CPR).
  Cons: reduced sensitivity for thin clouds, unable to capture melting layer structure, affected by in-bin attenuation, ground clutter extends to ~500m.

- 250m
  Pros: compromise solution, proven in space (TRMM/PR).
  Cons: not sufficient to reconstruct profile of some stratiform clouds.

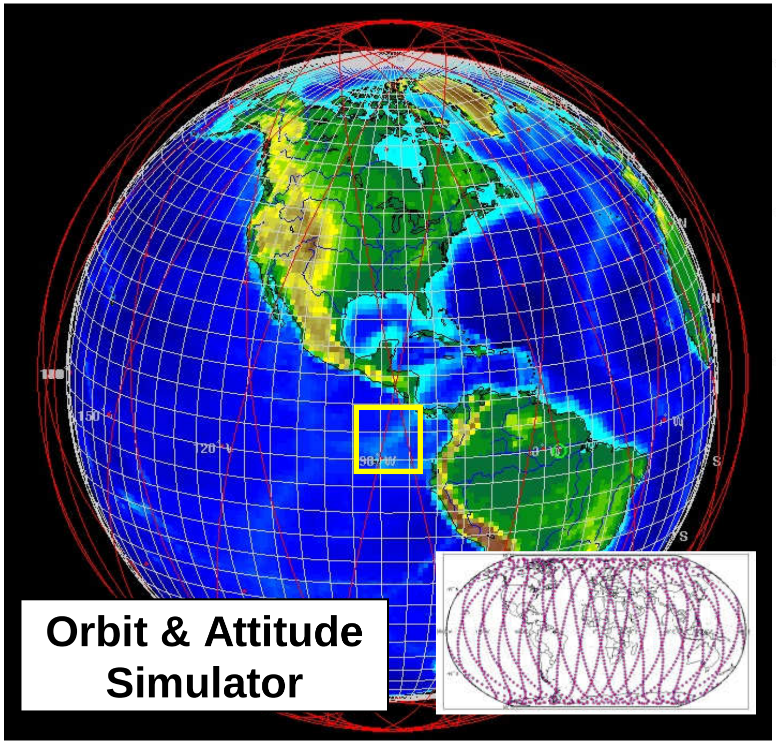
- 50m
  Pros: sufficient to reconstruct most features including melting layer and thin clouds, proven airborne, ground clutter limited to ~50m.
  Cons: worst sensitivity.

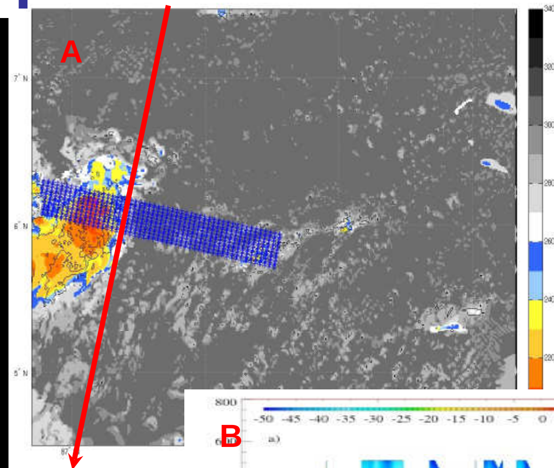
- Pulse Compr.
  Pros: can achieve high range resolution with better sensitivity than short pulse. Proven in airborne systems (APR-2, HIWRAP).
  Cons: range sidelobe requirements very stringent, not proven in space.

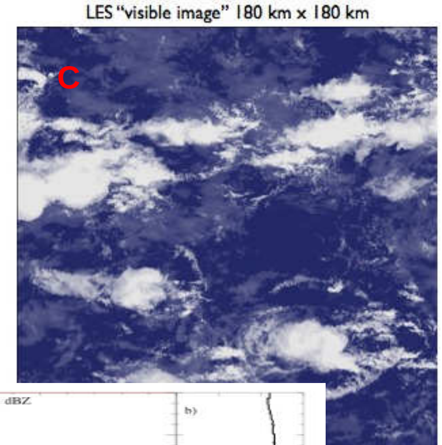
- Same/Diverse
  Two diverse range resolutions could be considered for the different radar channels
  Pros: achieve a larger number of scientific requirements.
  Cons: more complex data processing system and data products.

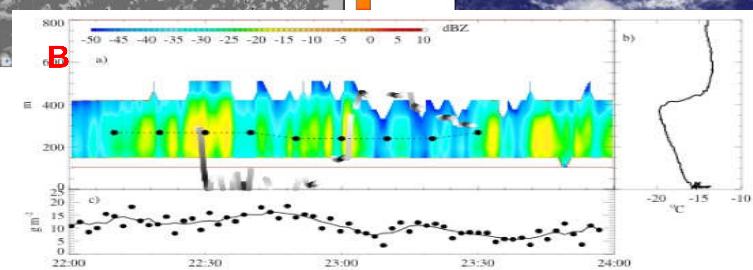
$$Z_{sens} \propto \frac{L_{atm} L_{sys}}{f^4 A_{eff}} \cdot \frac{B_{noise}}{(P_t \tau)} \cdot \frac{1}{\sqrt{N_{ind}}} \cdot r^2$$

Radar Simulator:
orbit simulation, platform motion and pointing









Modules

- ✓ Arbitrary orbit simulator "Pzero"
- ✓ Earth Ellipsoid
- Geoid anomaly
- Topography
- ✓ Scan strategy and pointing vectors
- ✓ Platform motion component

Modules

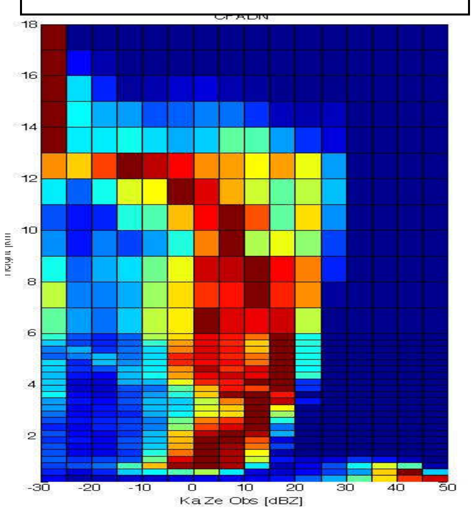
- WRF (333m – 1500m, bulk)
  - A ✓ TC4 ITCZ convection
  - NAMMA Pre-Helene
  - ✓ RITA
  - Hail Po Valley
- DHARMA (50-1000m, binned) (A.Fridlind, A.Ackerman, GISS)
  - ✓ DYCOMS-II 11 July 2001 31N 122W lightly drizzling stratocumulus
  - B ✓ SHEBA 7 May 1998 76N 165W mixed-phase stratus over sea ice
  - ✓ M-PACE 10 October 2004 70N 156W mixed-phase stratocu over ocean
  - ✓ TWP-ICE 22 January 2006 12S 130E active monsoon over ocean
- SAM Large Domain LES (S. Krueger, UU/NSF)
  - C GATE

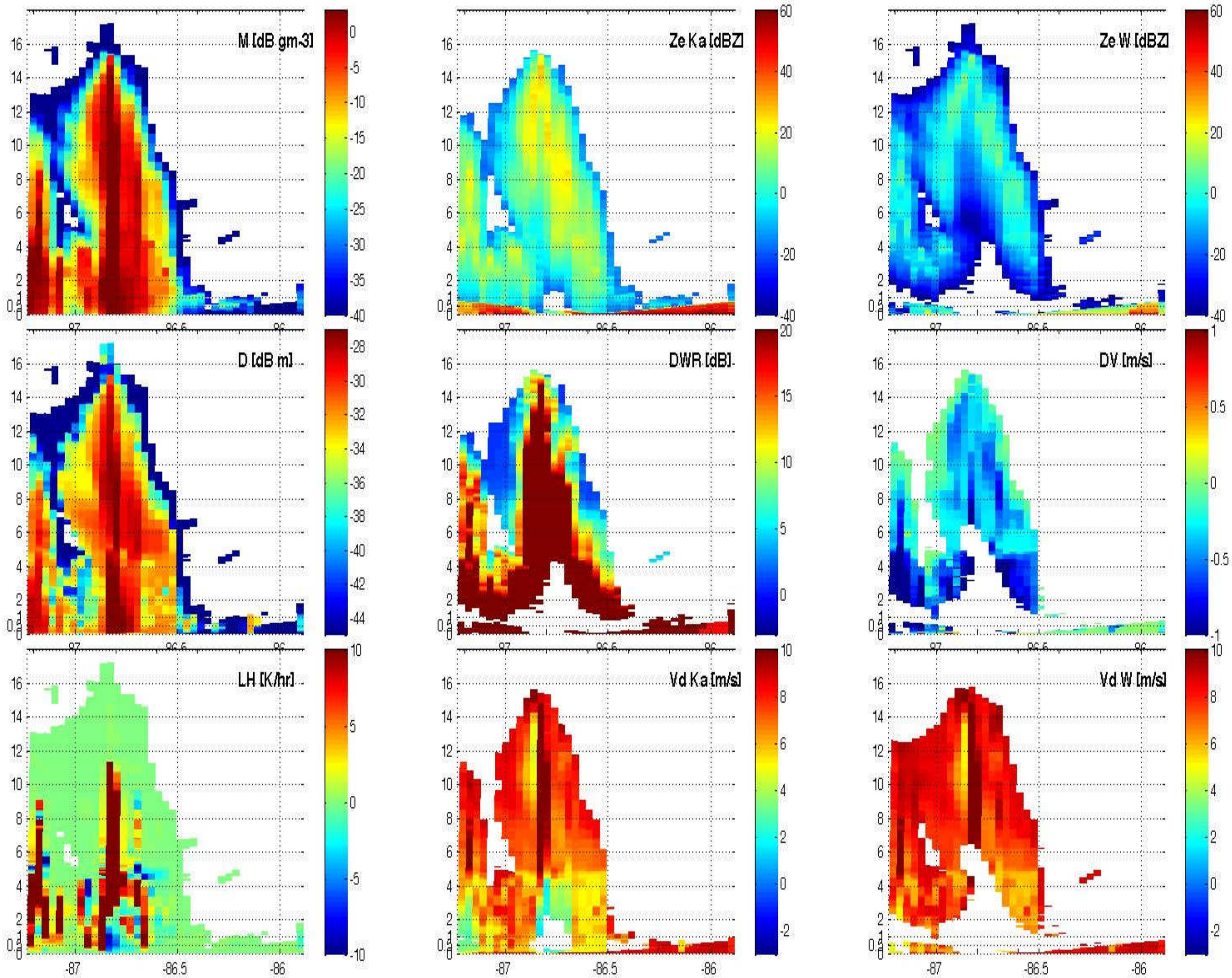
CRM / LES

Radar Simulator

Modules

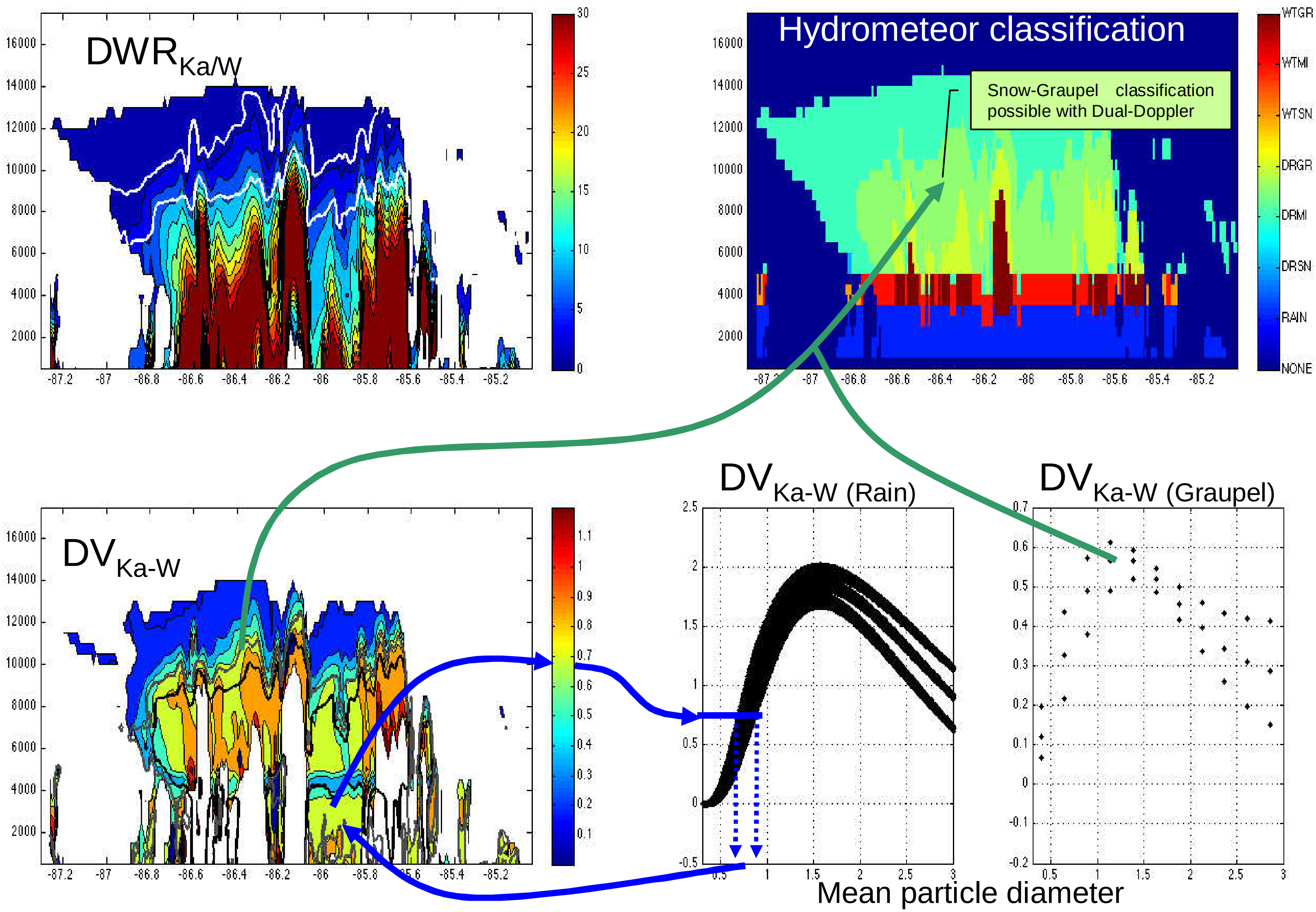
- Active
  - Fast Sub-beam decomposition (3D NUBF)
  - Arbitrary Antenna Pattern (X & Y, H & V)
  - Arbitrary Range Response
  - Surface Scattering
    - Ocean
    - Land
  - Arbitrary PSD, D-M, D-Vt, habits
  - T-Matrix
  - DDA
  - Multiple Scattering (isotropic, simple)
  - Multi frequency
  - Polarimetric
  - Doppler
- Passive
  - Eddington 1D
  - Sub-beam weight
  - IR approximate





ACE SWG - Fall ‘08 Meeting

Dual-Frequency Z/Doppler (Ka-W)



Differential Frequency @ Ka-band

Ka-band Doppler and reflectivity measurements made over 5 - 10% differential bandwidth

Advantages

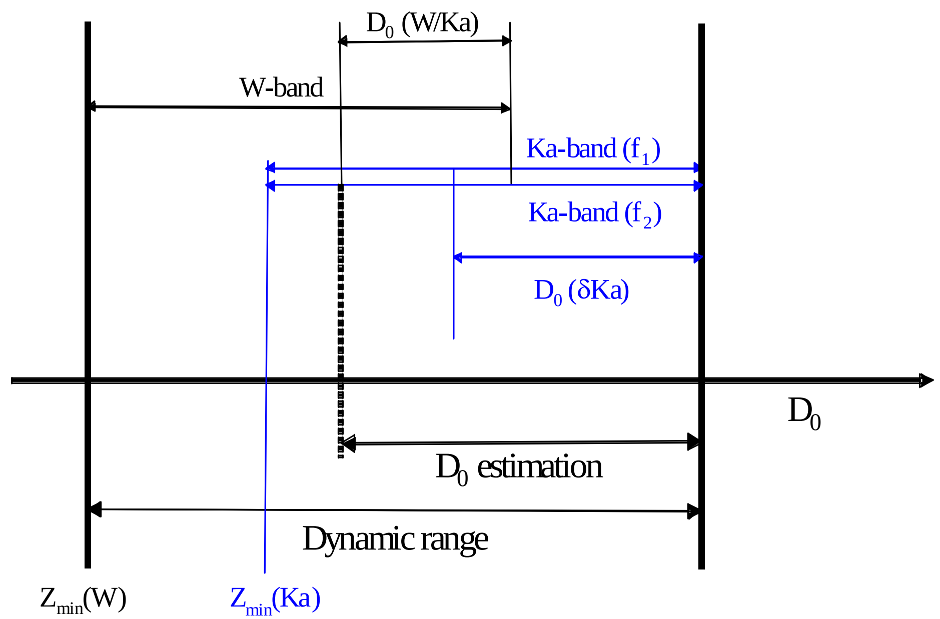
- Extends retrievals to higher D_o and LWC values.
- Extends estimation of D_o deeper into cloud after W-band signal is lost through attenuation
- Provides additional information for W-/Ka-band retrievals
- Matched beams for differential-frequency implementation are easily achieved
- Diff freq data can be processed in two ways
  - To estimate dual-freq ratio
  - Combined to increase number of samples

Technology

- Achievable for specific configurations of Ka-band radar (broadband antenna & pa required)
- Ka-band transceiver technology exists or is close (Ka-band TWTA, solid state T/R modules)

Requires

- Large number of samples to estimate small differential signal levels
- Frequency allocation
- Wide-band components
  - Antenna, power amplifiers



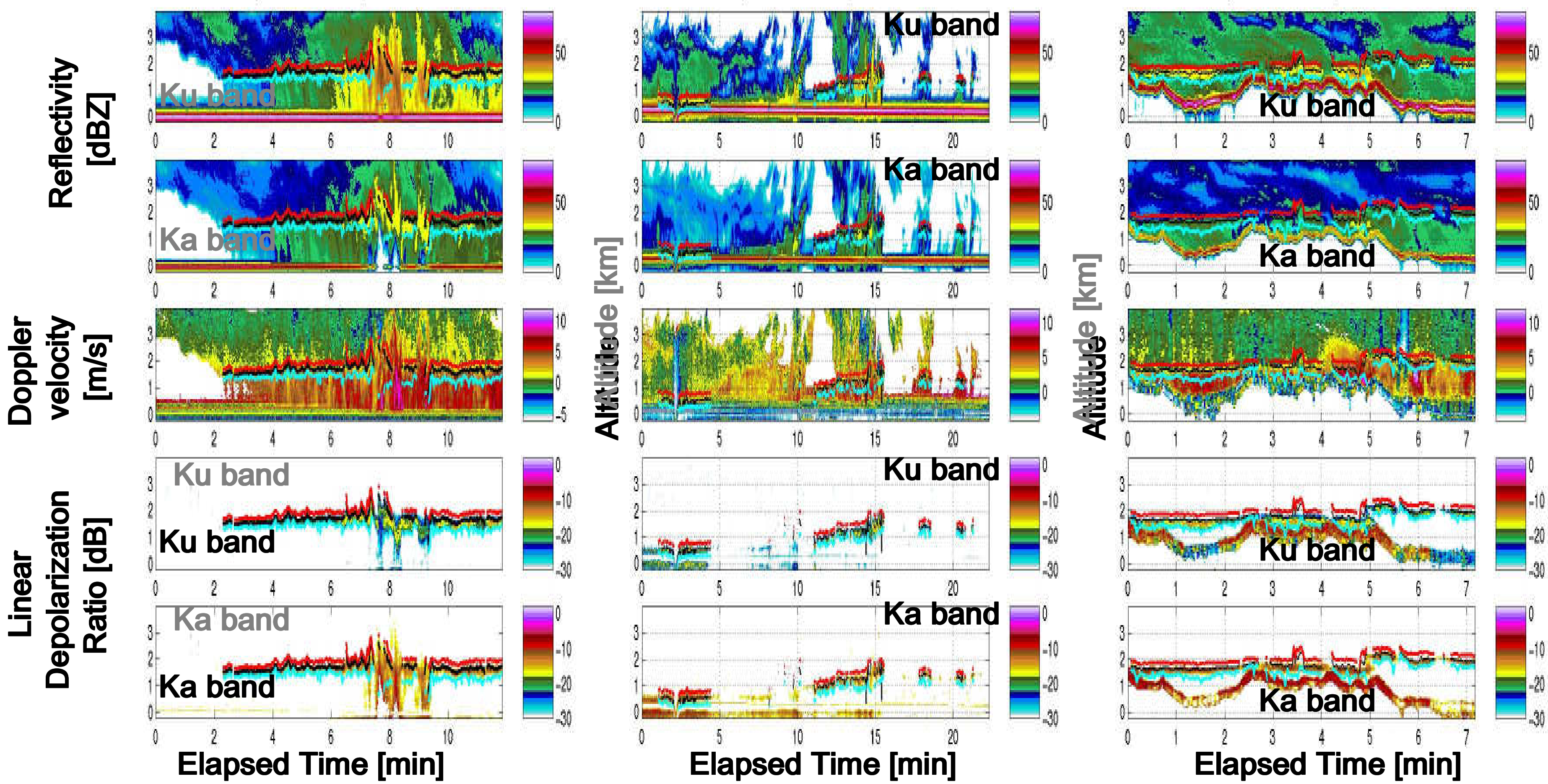
Dynamic ranges overlap for a W-band and Ka-band radar system. Estimates of D_0 can be made from the W/Ka-band combination and the differential Ka-band combination, $D_0(\delta Ka)$.

Polarimetric measurements

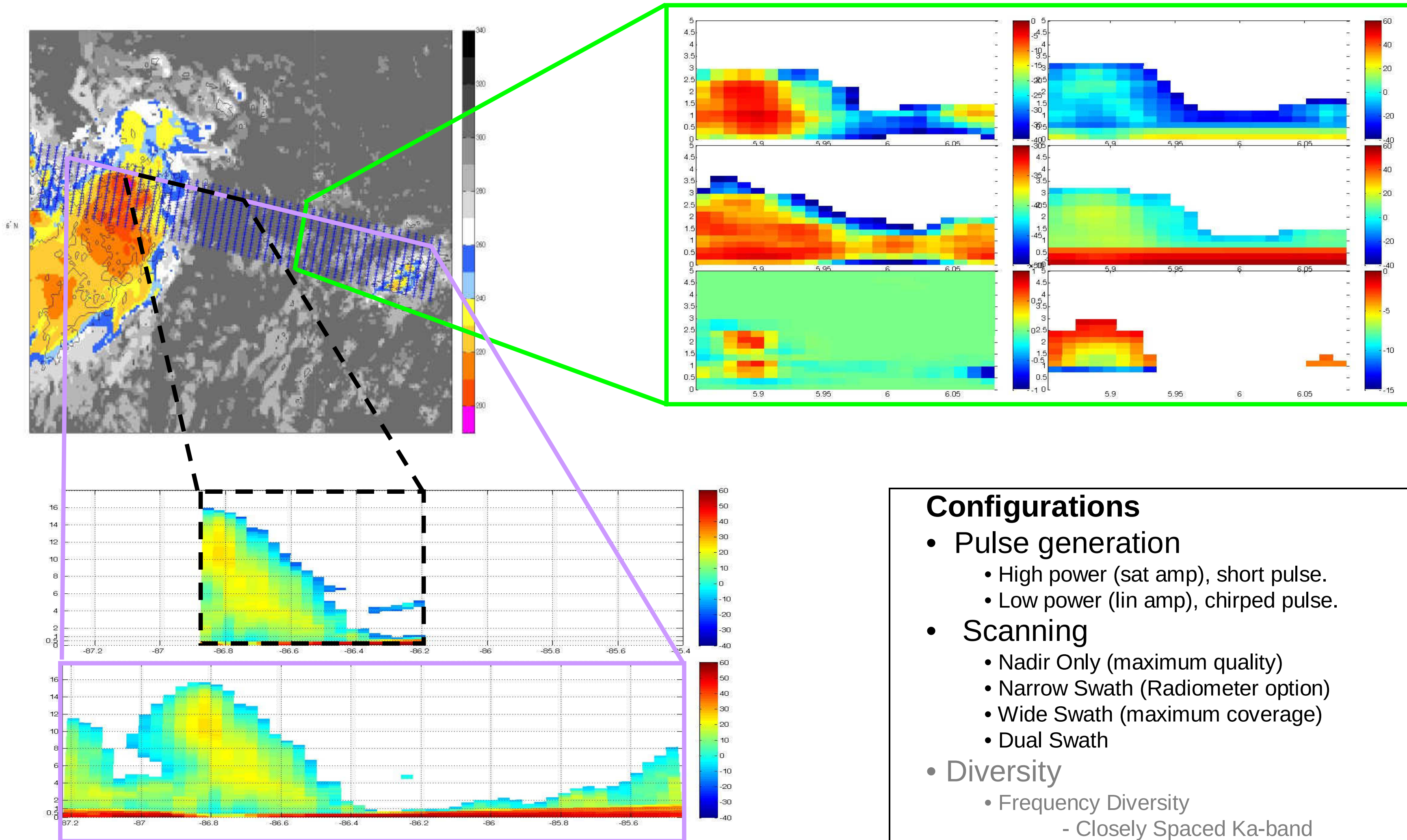
Wakasa Bay – Stratiform system with embedded convection

Wakasa Bay – Changing Freezing Level

Wakasa Bay – Stratiform system over mountains



Simulations Plan



Configurations

- Pulse generation
  - High power (sat amp), short pulse.
  - Low power (lin amp), chirped pulse.
- Scanning
  - Nadir Only (maximum quality)
  - Narrow Swath (Radiometer option)
  - Wide Swath (maximum coverage)
  - Dual Swath
- Diversity
  - Frequency Diversity
    - Closely Spaced Ka-band
  - Polarization Diversity