CEOI Grant
Seedcorn Research proposal

High Frequency Doppler Radars for a Polar Precipitation Mission (HIDRA4PPM)

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Contents

Atmospheric Science Case

- Motivation: High latitude snowfall rate, snow water content and the advantage of two radar frequencies

- Link snow crystal morphology, radar reflectivity and ratio of radar reflectivity at two frequencies.

- Set up radar model of the atmosphere and use this to extract properties of the snow crystals.

Critical Radar Technology

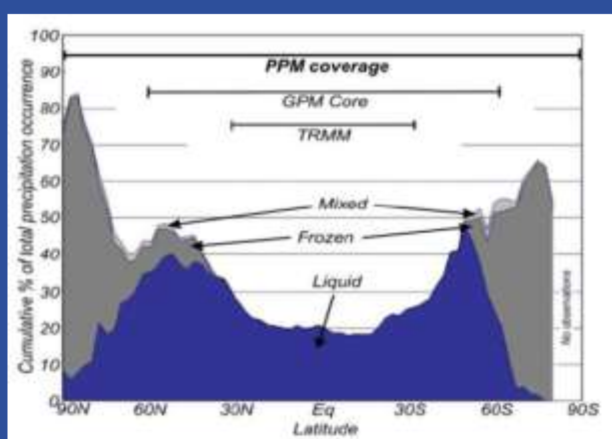
- Requirements for frequency multiplier driver of radar transmitter power amplifier assessed at 140 & 220 GHz

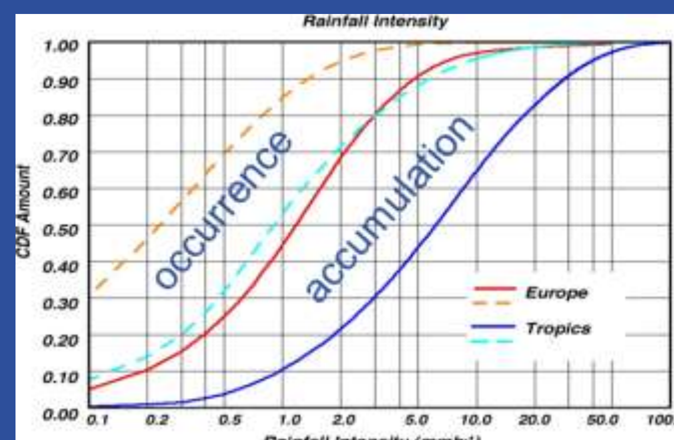
- Current status of multiplier technology and design options

- Outline multiplier designs and sub-system descriptions.

Scientific motivation for measuring snowfall at high radar frequencies

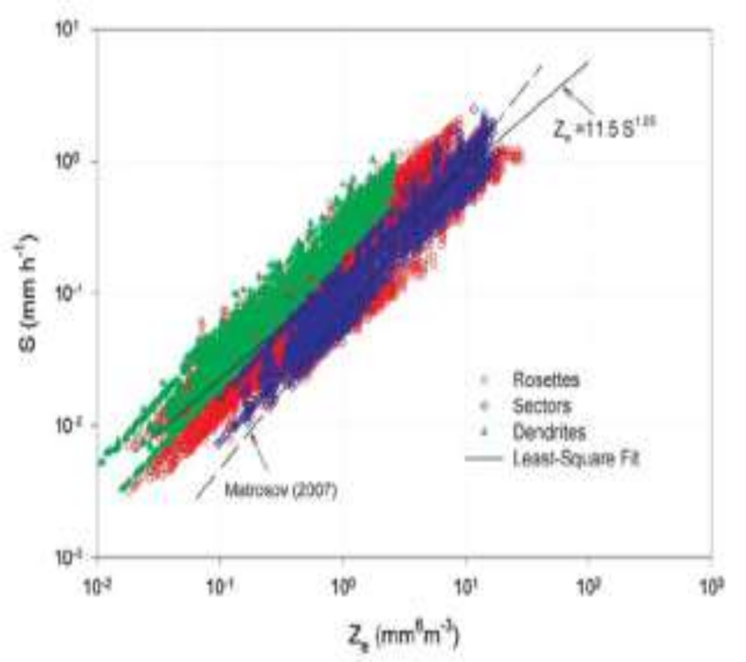
- Lack of accurate, wide-spread precipitation observations at high latitudes → difficult to establish a baseline → needed to study future *trends* in the water and energy budgets
- At high latitudes, the majority of precipitation falls as snow (left hand figure)
- Measuring snowfall is very complicated:
  - High spatial and temporal variability
  - Complexity in snow crystal habits, densities, and particle size distributions
- Fraction of precipitation events which may be classified as 'light' precipitation increases with latitude (right hand figure)
  - Drives requirement for high frequency radar observations → provides higher sensitivity

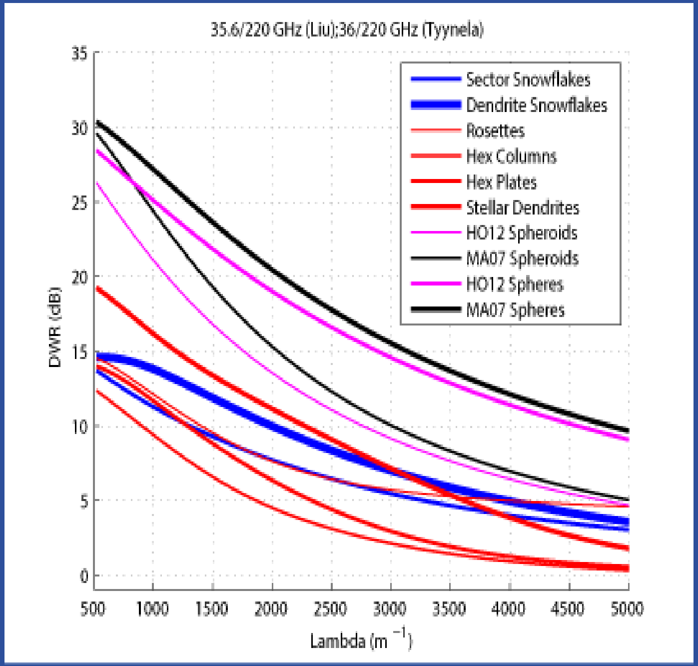




Single or multiple frequency approach?

- Currently use empirical relations to estimate snowfall rate S from radar reflectivity Z_e
  - Strongly dependent on the snow microphysical properties (particle habit, fall velocity and size distribution, see left panel)
- Single frequency observations provide no information on the microphysics of the target volume
  - Need to make assumptions on microphysics → large uncertainties in estimated S
- Two (or more) frequency channels enables dual wavelength ratios (DWRs) to be measured
- DWR is sensitive to snow microphysics (particularly particle size, see right panel) → potential to constrain the $Z_e(S)$ relationship used to estimate the snowfall rate

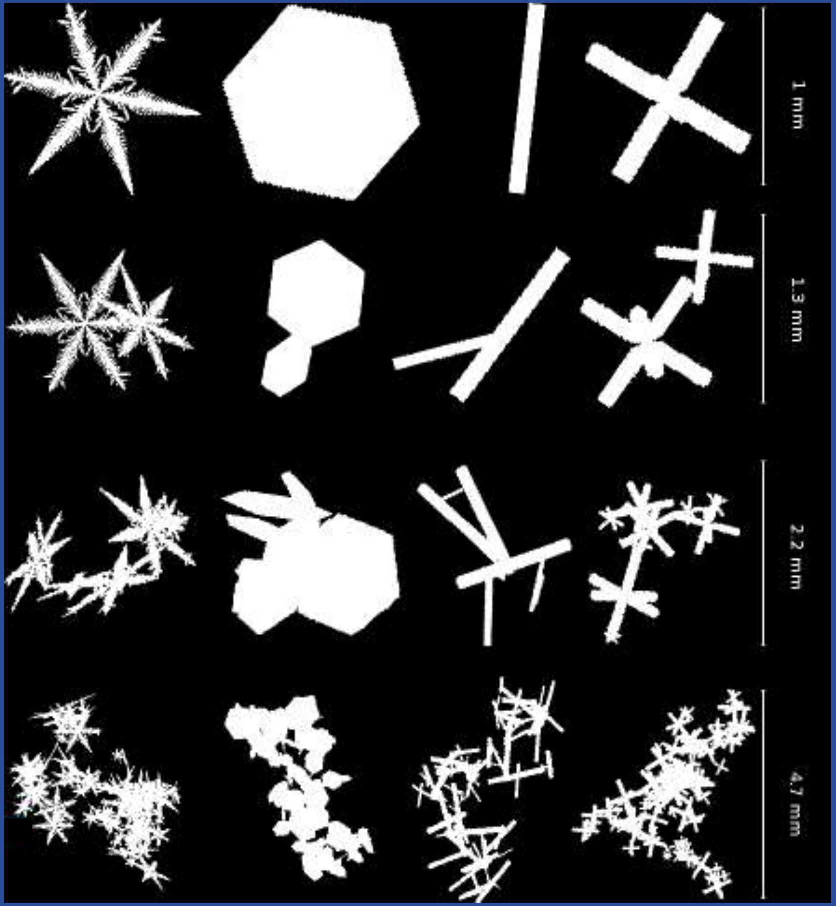




Single scattering property database

Centre for eo Instrumentation

- Jani Tyynela, University of Helsinki
- 4 snow habits
- 9 frequencies (GHz): 3, 14, 36, 60, 90, 120, 150, 180, 220
- Modelled aggregates consisting of 1, 2, 10 or 100 crystals (50 random cases each)
- Calculated optical cross sections:
  - Backscattering (HH, VV and VH)
  - Absorption
  - Extinction
- Also D_{max}, mass
- Other scattering property databases are available (Petty, Liu) but do not consider randomly formed aggregates

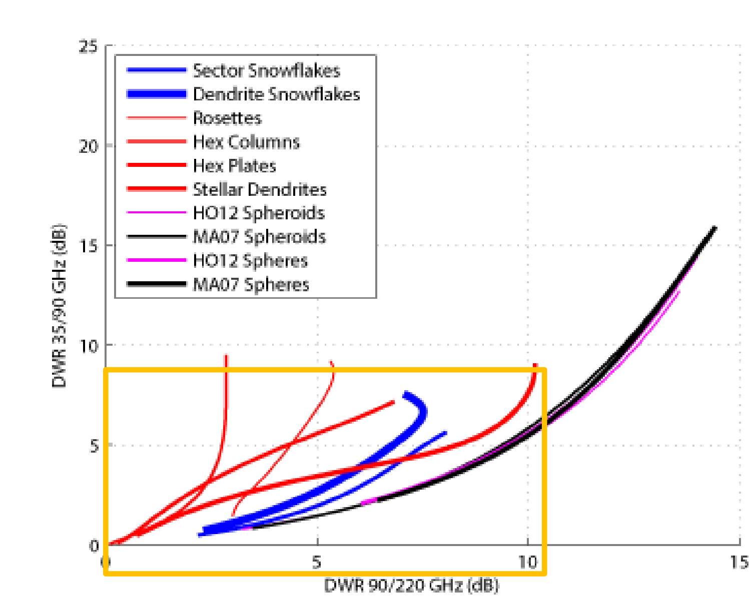


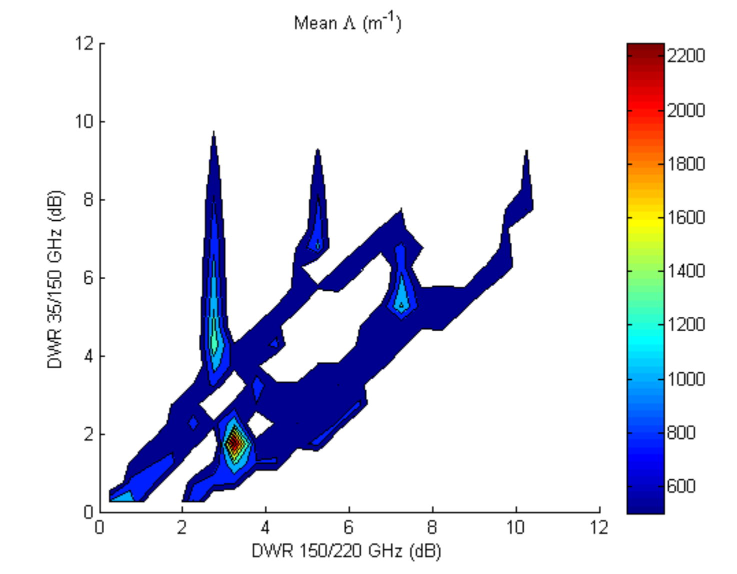
From Tyynela et al 2013 (JGR)

Z_e from scattering properties

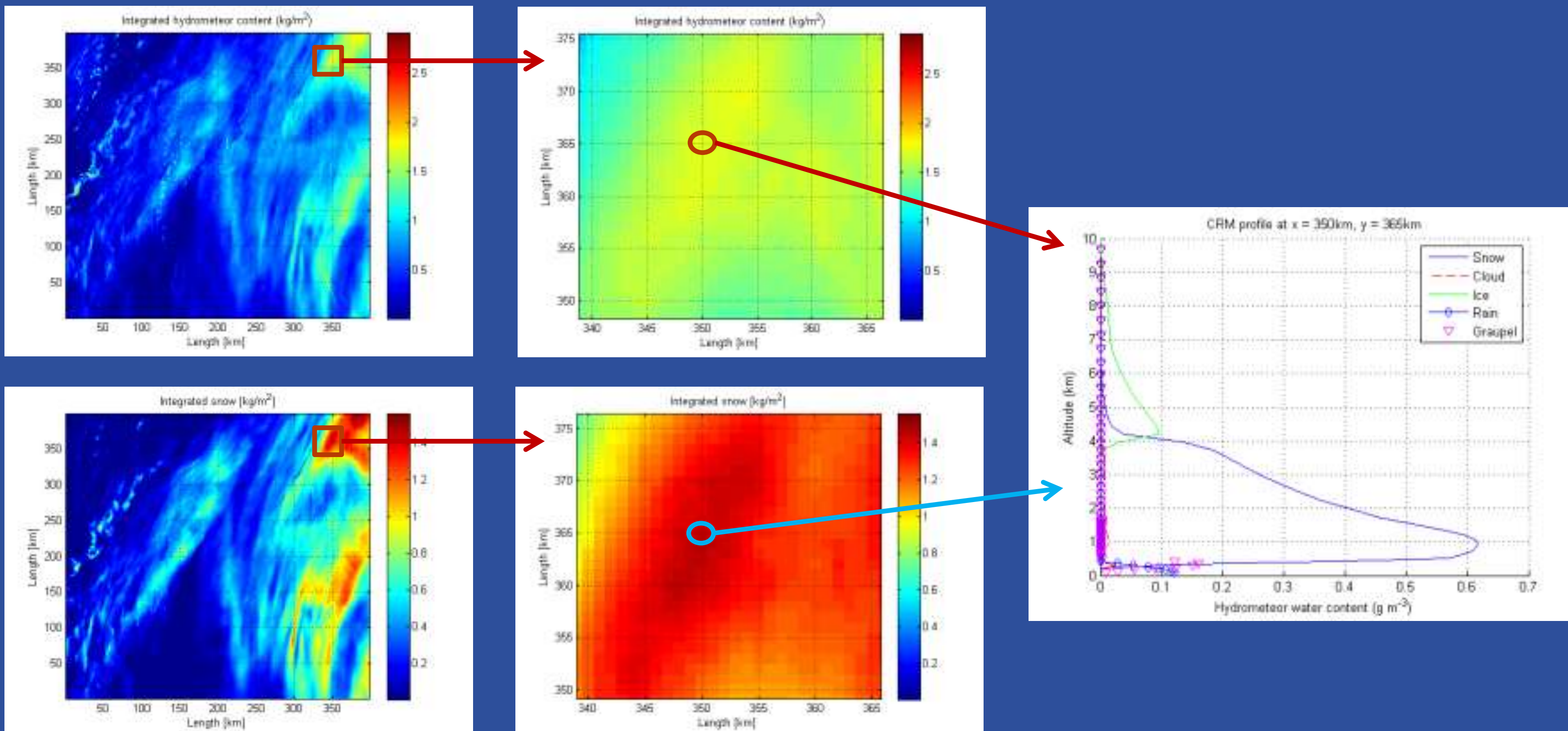
- Particle size distribution (PSD):
  - Assume exponential distribution:
    - $N(D) \sim \exp[-3.67(D/D_0)] = \exp[-\Lambda D]$
  - Evaluate reflectivities for a wide range of median particle diameter D_0:
    - $0.7\ \text{mm} \le D_0 \le 7.3\ \text{mm}$, $500\ \text{m}^{-1} \le \Lambda \le 5500\ \text{m}^{-1}$
  - $\sigma(D)$ = backscattering cross section at wavelength λ
  - λ = radar wavelength
  - K_w = dielectric factor of water at λ
- Dual wavelength reflectivity ratios show strong dependence on PSD, snow habit and the choice of frequency pair → potential to improve snowfall retrievals

$$Z_e = \frac{\lambda^4}{\pi^5 |K_w|^2} \int_0^{D\max} \sigma(D) N(D)\ dD$$



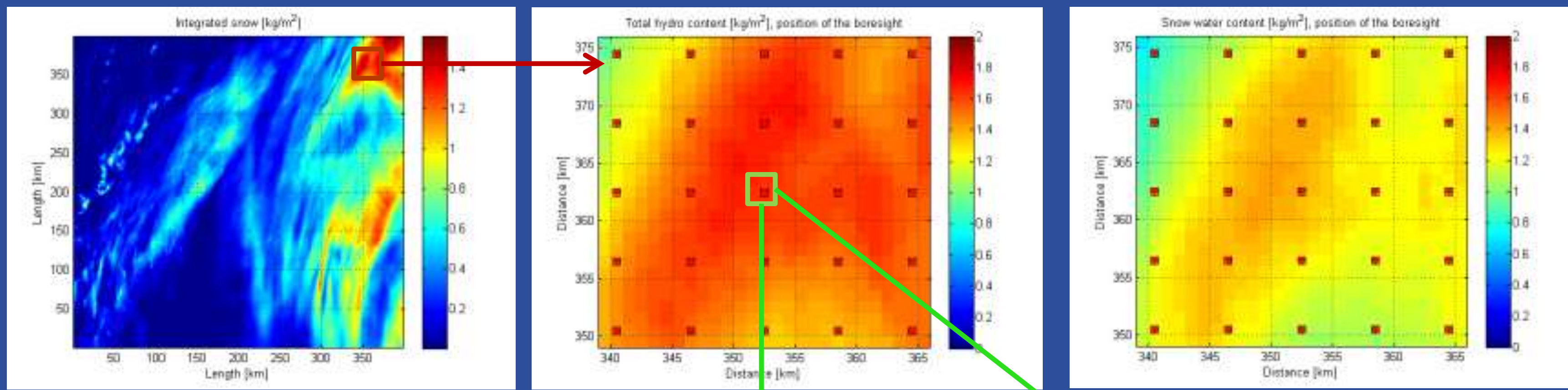


CRM simulations

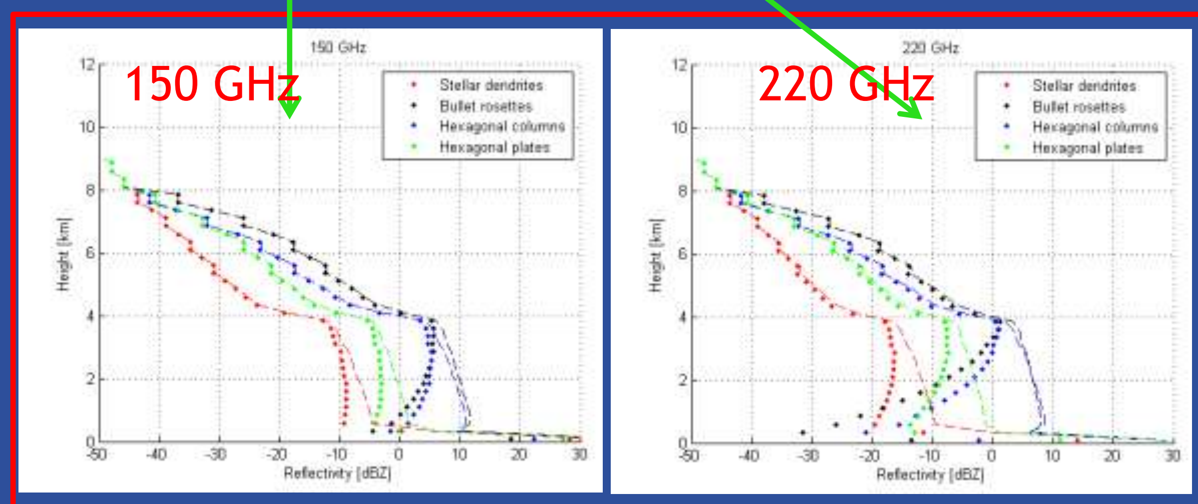


- Different models (GCE,WRF), bulk microphysics (5 hydrometeor types), high resolution (< 100m at lowest altitudes)
- Model output used in this study focuses on a region over Finland (Lat: 58 to 61°N, Lon: 20 to 29°E)
- Use CRM data to describe target scenes for the radar simulator

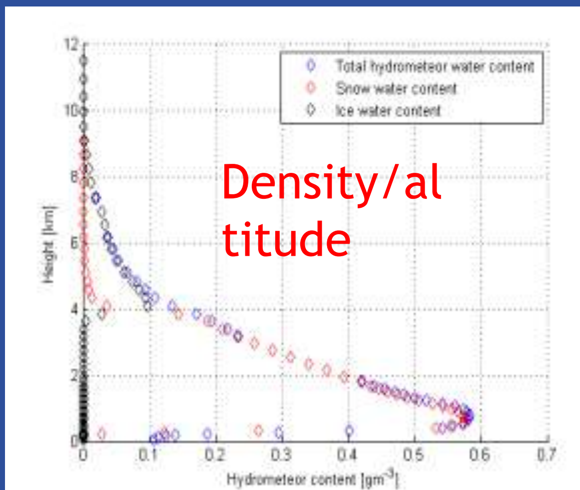
Radar simulator output

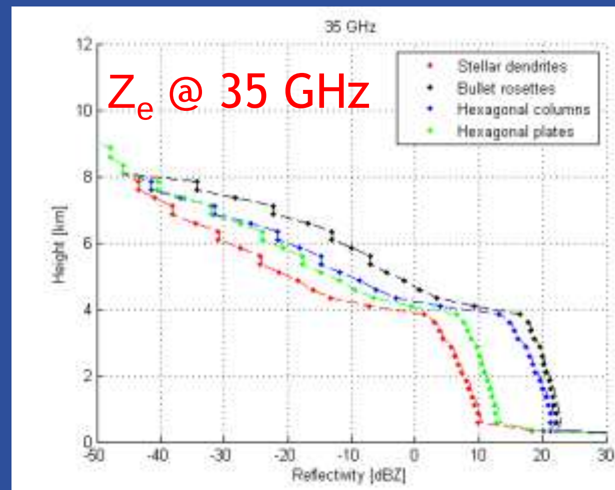


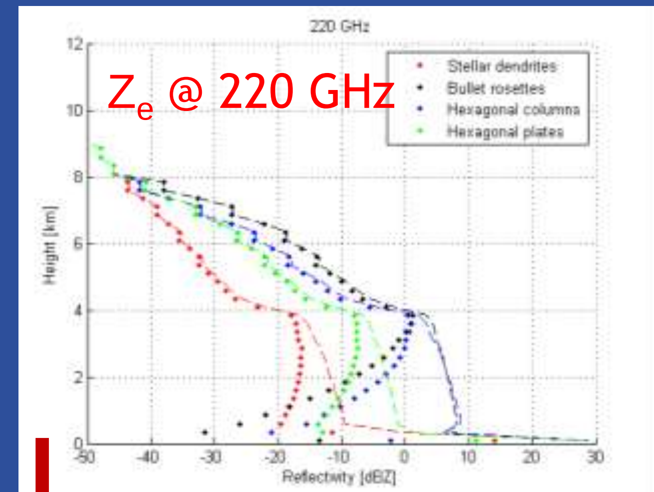
- Red spots indicate the location of each simulated radar shot (nadir)
- Simulator outputs Doppler spectrum profile → used to calculate measured reflectivity by integration
- Both single (exact) and multiple scattering solutions calculated, with/ without attenuation
- Have results for 220, 150, 94 and 35 GHz for each of the four habits
- Essential tool in the absence of previous high frequency radar observations

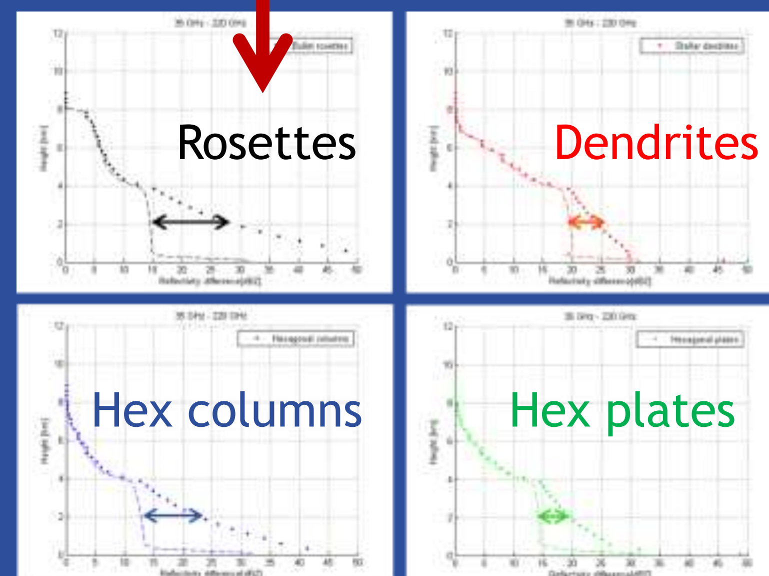


Radar simulator output: reflectivity profiles





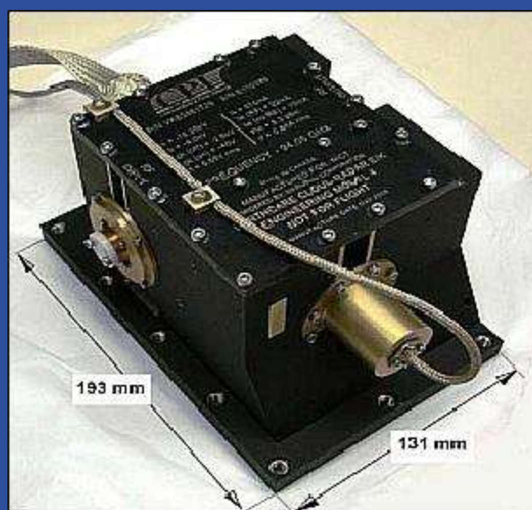




- Dashed curves: single scattering, no attenuation
- Dots: single scattering, attenuation included
- Attenuation is function of snow water content and snow habit → particularly strong dependence in 35/220 GHz DWR profile

Technology background: EIK Amplifiers

- Critical Technology for pulsed space radars at frequencies above 100 GHz
- Final output stage is a vacuum tube amplifier: Extended Interaction Klystron
- Sole source manufacturer: Communication & Power Industries, Canada
- Application: NASA CloudSat: 2 off EIKs provide 94 GHz, 3.3 μs, 2 kW

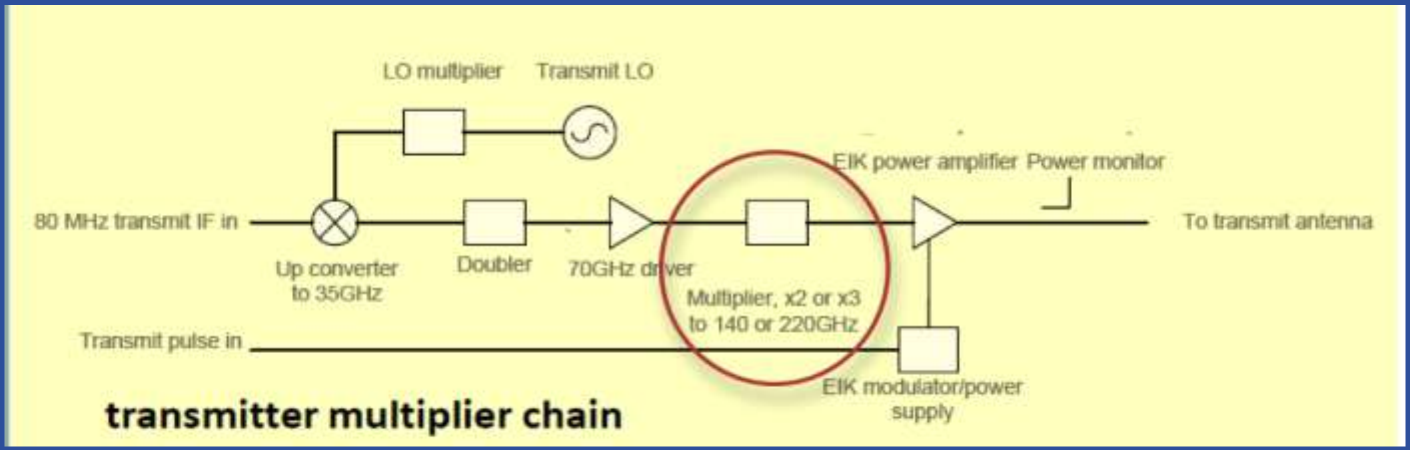


System design and driver requirements

- EIK amplifier gains fall with frequency: input power requirements @ 140 and 200 GHz are so high that they exceed currently available solid state sources

Frequency (GHz)	Pulse duration (μs)	Bandwidth (MHz)	Temperature Range (^{o}C)	Output power (mW)	Proposal output power (mW)
140	< 13	600	10 - 50	Target: 32 Worst case: 50	100
220	< 13	300	10 - 50	Target: 40 Worst case: 160	200

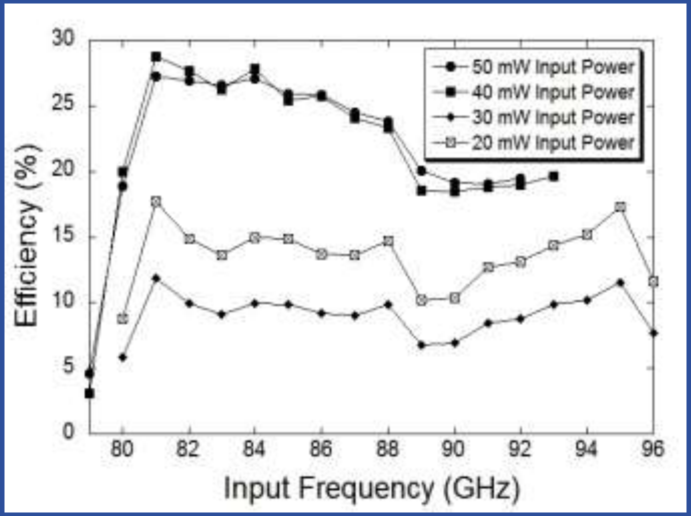
- General approach: do pulse shaping at lower frequencies, < 100 MHz, and then up-convert via frequency multiplication to above 100 GHz:

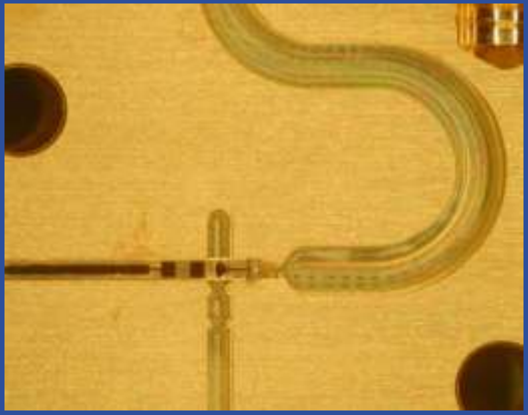


Current status RAL frequency multipliers

Output Frequency (GHz)	Multiplying Function	Input Power (mW)	Output Power (mW)	Efficiency (%)
122	x 2	40	12	30
160	x 2	60	15	25
332	x 2	50	5.5	12
94	x 3	100	15	15
120	x 3	100	15	15

170 GHz Doubler

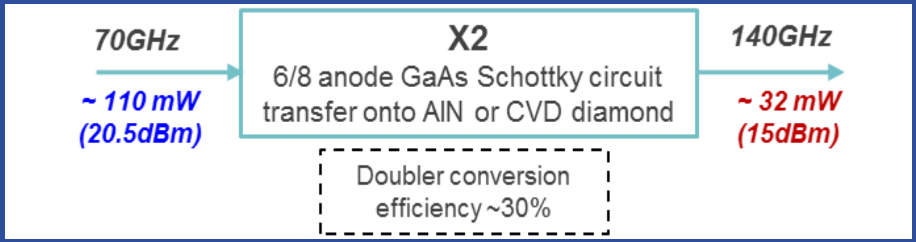




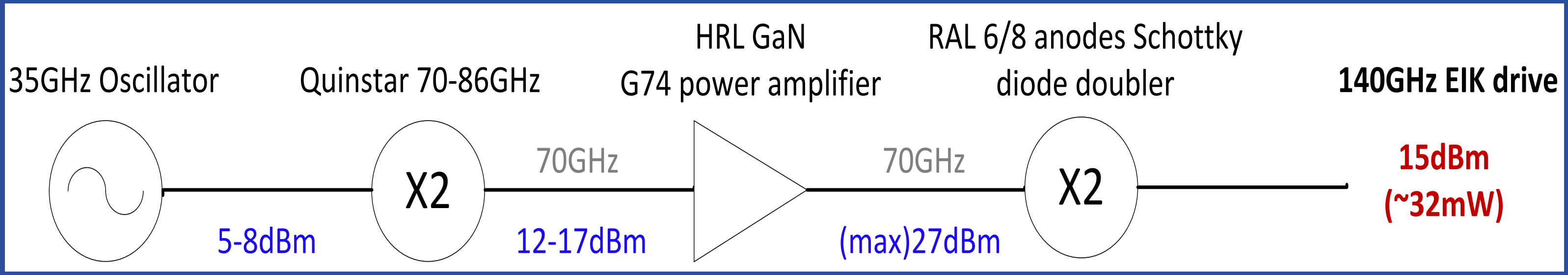
Routes towards achieving higher output powers

- Trade-offs:
  - Number and configuration of diodes
  - Semiconductor material: GaAs, GaN
  - Substrate: GaAs, AlN, CVD Diamond
  - Frequency multiplication factor: x2, x3
  - Application of power combining
  - Available source power

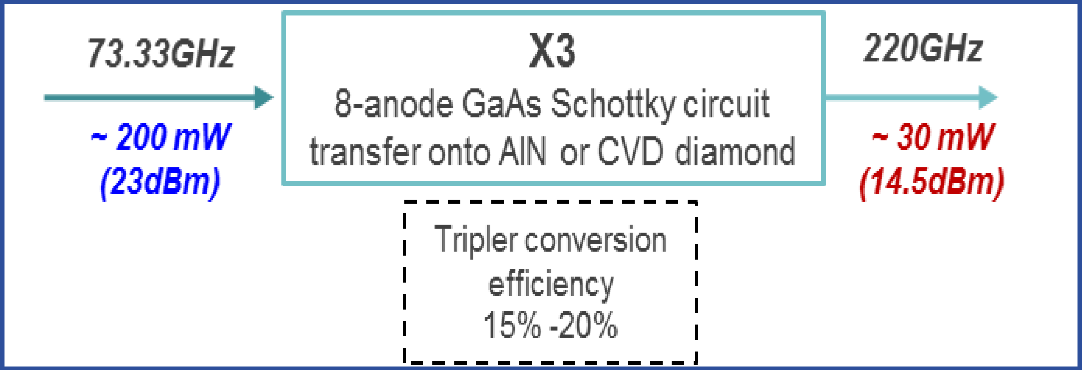
- Construction of 140 GHz driver



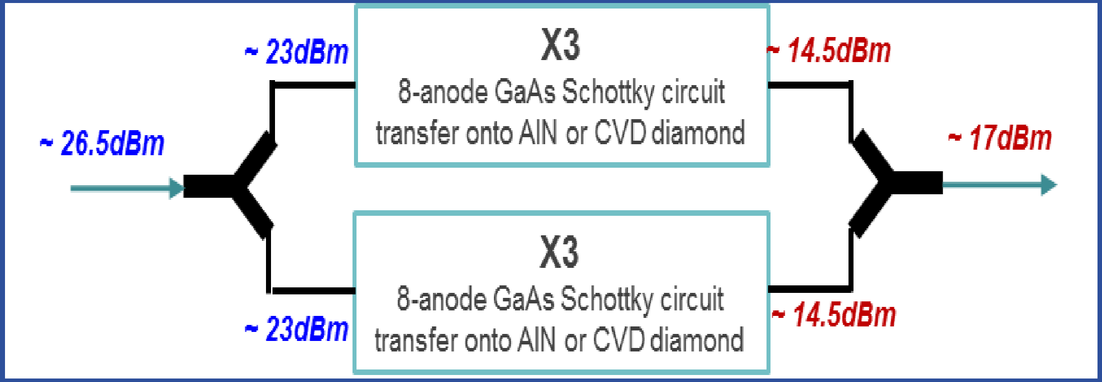
- Practical system



Construction of 220 GHz driver



- Practical system needs to apply waveguide power combining



- 70 GHz drive chain same as used for 140 GHz source.

Conclusions

- Previous single frequency retrievals of SWC and snowfall rate limited by strong dependence of snow optical properties on crystal shape
- Significant improvement in SWC and snowfall rate information may be obtained using frequency pairs (35/220 GHz) and triplets (35/90/140 GHz or 35/90/220 GHz)
- End-to-end radar simulator set up and tested on various snow scenes at various frequencies - a valuable tool given lack of observational data at higher frequencies
- Requirements for driver of radar transmitter power amplifier assessed at 140 & 220 GHz
- Technical routes to realise these drivers, based on frequency multiplication presented
- Outline designs, and supporting components, described.