High frequency Doppler radars for a polar precipitation mission

Neil Humpage[1], Alessandro Battaglia[1], Peter Huggard[2], Manju Henry[2] and Hui Wang[2]

[1]Earth Observation Science, Department of Physics and Astronomy, University of Leicester, Leicester, UK
[2]STFC Rutherford Appleton Laboratory, Harwell, UK

Introduction

- Accurate measurement of snow is key for the understanding of the Earth's climate and water cycle at high latitudes.
- Large-scale accurate estimations of snowfall rates are still not available.
- Multi-frequency radar observations are essential to overcome the snow microphysical deadlock, i.e. the dependence of the retrieved snowfall rate on the assumed microphysical properties: particle habit, fall velocity and size distribution.

The CEOI seedcorn project HIDRA4PPM aims ***to better quantify the information content coming from dual-frequency reflectivity ratio measurements***, and to ***identify the optimal frequency pair for discriminating between snow habits and for narrowing down uncertainties in snowfall rate estimates***. Since the deployment of space-borne radars at such high frequencies is challenging, this work will also include ***a subsystem to component level study of the high power millimetre wave frequency multipliers required to drive the radar transmitter output***.

1. Scientific motivation for measuring snowfall at high radar frequencies

- The lack of accurate, wide-spread precipitation observations at high latitudes makes it difficult to establish a baseline against which future changes in the Earth's water and energy budgets can be measured.
- At high latitudes, the majority of precipitation falls as snow (see left panel of Figure 1); however, measuring snowfall is very complicated. The main challenges are the high spatial and temporal variability, as well as the enormous complexity in snow crystal habits, densities, and particle size distributions.
- The fraction of precipitation events which may be classified as 'light' precipitation increases with latitude. This drives the requirement for higher frequency radar observations of precipitation, since high frequency provides higher sensitivity.

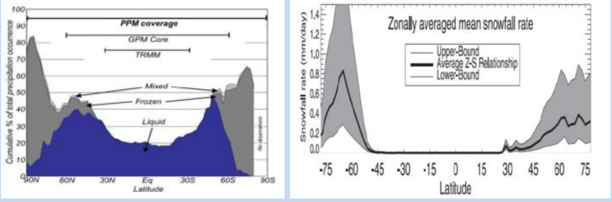

Figure 1: Left: the latitudinal occurrence of different light intensity precipitation types as a percentage of total precipitation occurrence derived from ship observations. Right: Zonally averaged mean snowfall rate retrieved from 94 GHz CloudSat reflectivities.

2. Single or dual 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 of Figure 2).
- Single frequency observations provide no information on the microphysics of the target radar volume → need to make assumptions on microphysics → large uncertainties in estimated S.
- The addition of a second frequency channel enables the dual wavelength ratio (DWR) to be measured. Since the DWR is sensitive to snow microphysics (particularly particle size, see right panel of Figure 2), it can be used to constrain the Z_e – S relationship used to estimate the snowfall rate.

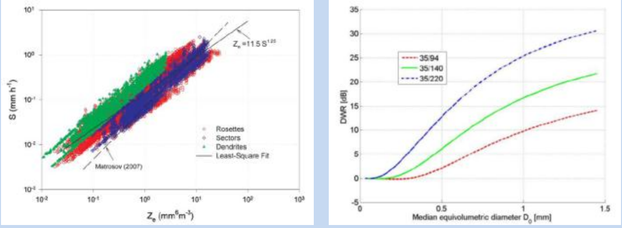

Figure 2: Left: Ze – S relationships for different snow particle habits. Right: Sensitivity of DWR to mean spherical particle size for three different frequency pairs.

3. Work Package 1: Dual frequency studies for snow precipitating clouds

In-depth notional studies of the suitability of higher radar frequencies for dual frequency observations will be performed by coupling the following elements:

- Cloud resolving model simulations of snow scenes;
- Ice crystal single scattering databases;
- Advanced space-borne Doppler radar simulators (see Figure 3).

The aims of Work Package 1 are as follows:

- Simulations of radar reflectivity and mean Doppler velocity profiles will be conducted for the different snow scenes generated by the cloud resolving models, initially adopting the radar configuration listed in Table 1.
- Two further frequencies (140 and 220 GHz) will also be included in the study.
- Dual wavelength ratios and dual Doppler velocity difference for different pairs (35/140, 94/220, 35/220 GHz) will then be computed, and their potential to retrieve a mean size parameter and to discriminate between different particle habits will be assessed.
- The final goal will be to demonstrate the potential improvement in snowfall rate estimates compared with those obtained using a single frequency Z_e – S relationship.

Freq-uency	Mode	Cross-Pol	Ground Footprint[1]	Radi-ometer Accuracy	Pulse Width	PRF	Sensitivity[2]	Range Res-olution	Lowest Resolved Altitude
94 GHz	Doppler Dual Polarization Radar	-23 dB	0.8 km	-	3.3 usec	6 kHz	-34 dBZ	500 m	500 m
		-23 dB	0.8 km	-	0.6 usec	6-14 kHz	-19 dBZ	100 m	<250 m
35 GHz	Non-Doppler Radar	-23 dB	2.0 km	-	1.2 usec	6-14 kHz	-10 dBZ	200 m	<250 m
23.8 / 35 GHz	Passive Liquid Water Radiometer	-23 dB	3.0 km / 2.0 km	1 degK	-	-	-	-	-

Note 1: From 400 km altitude, with 2.0 m antenna
Note 2: Sensitivity calculated for non-interleaved operation, 400km altitude, and integration over 7.5 km of ground track

Table 1: Proposed payload for the EE8 Polar Precipitation Mission.

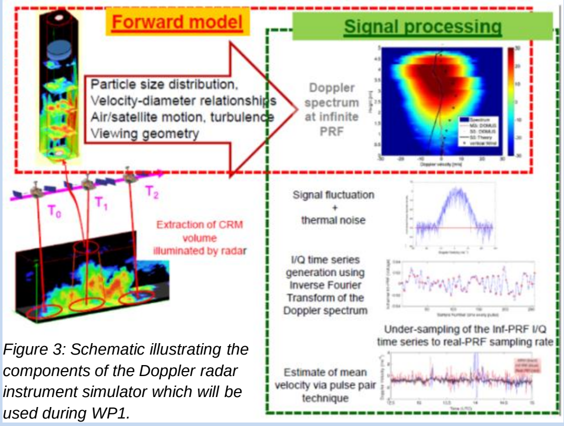

Figure 3: Schematic illustrating the components of the Doppler radar instrument simulator which will be used during WP1.

4. Work Package 2: development of frequency multipliers for a space-borne high frequency radar

- Developing radars with frequencies > 94 GHz opens new technical challenges (to date a 94 GHz pulsed system remains the highest frequency radar).
- Extended Interaction Klystrons (EIKs) are currently available at 140 and 220 GHz ; but supplying drive powers are critical to achieve good sensitivity.

The aims of Work Package 2 are as follows:

- Assess the available drive power for the frequency multiplier along with its output power and frequency bandwidth requirements;
- Review performance and limits of existing multiplication technology;
- Assess improvements necessary to handle higher powers

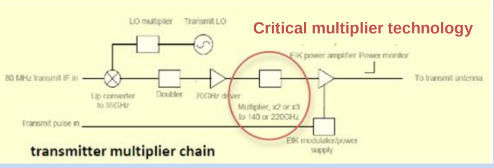

Figure 4: Schematic diagram of the transmit side of a proposed 140 or 220 GHz space-borne radar.