RPG cloud radar chirp table

Training Report

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I. Introduction

In addition to the official documentation provided by the instrument manufacturer, Radiometer Physics (RPG), this report aims to offer supplementary insights not covered in the RPG radar manual. Some of the information presented here stems from discussions between the author and Alexander Myagkov, RPG scientist.

The RPG cloud radar operates as a Frequency Modulated Continuous Wave (FMCW) radar, which differs from pulse radars in how it acquires measurements of cloud radar variables versus range or height. However, the Doppler processing used to derive Doppler spectra remains fundamentally the same for both pulse and FMCW atmospheric radars.

In the first part (sections II-VI), this document provides details on the RPG cloud radar chirp table, which defines key measurement parameters such as the unambiguous maximum range, the unambiguous maximum Doppler velocity, and the resolution in both range and Doppler domains. A single parameter set cannot be used for tropospheric observations. Consequently, the chirp table typically includes three or four chirp sequences tailored to different range or height intervals. This segmentation is necessary because the measured Intermediate Frequencies (IF) determine the range or height, and the usable IF signal bandwidth is insufficient to cover the entire troposphere. As a result, the final atmospheric profile is constructed from multiple chirp sequences.

Section VII presents a summary of the interactive session focused on constructing a chirp table with four sequences for comprehensive tropospheric measurement. This session was conducted online on March 5th and was attended by 35 participants from the Cloudnet national facilities, utilizing cloud radar measurements. The session was led by Christine Unal, Rob Mackenzie, and Renju Nandan from Delft University of Technology.

Following the summary, Section VIII provides a compilation of questions raised during the training session along with their corresponding answers. The entirety of this report is dedicated to operations at a frequency of 94 GHz.

II. Chirp Program Management in the RPG Radar Host Computer Display

In the RPG radar display, users can select the **"Chirp Program List"** option to access a list of available chirp programs for each delivered RPG radar. The maximum amount of chirp programs is 10. If the maximum of 10 chirp programs is reached, the list of 10 chirp programs can be copied. It is present in the directory CONFIG: CHIRP.TBL. Copy CHIRP.TBL to CHIRP_XX.TBL. Then, some chirp programs can be deleted and new ones can be created. Figure 2 illustrates the buttons (bold) mentioned below.

- **"Load Radar List"**: This function loads the list of available chirp programs from the radar computer. However, new chirp tables are not created from this list but rather from the chirp program list stored on the host computer. Typically, both lists contain the same programs.
- **"Load Host List"**: This option loads the chirp programs from the host computer. After clicking this button, you are asked if you would like to overwrite the present table (Figure 1). Clicking 'Yes' to this button will load the contents of the 'CHIRP.TBL' file that is located in the /CONFIG directory of the Host software. This is required to access the 'Edit Chirp Programs' features, which will be greyed out until the Host List is loaded.

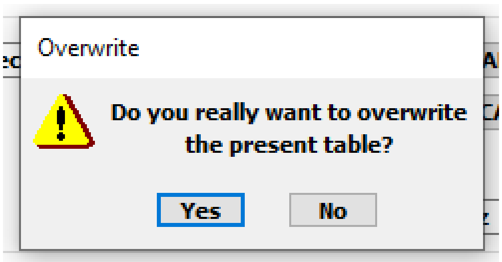

Figure 1: Message displayed after clicking 'Load Host List'

- **"Edit Chirp Program"**: Once the Host List has been loaded, the individual programs within the list can be edited. There is a limit of 10 on the number of programs allowed in the list. Each program is given a number ('CG Prog-No') between 1 and 10. Each program is given a name in the list. The names of the programs have been typically descriptive of what the purpose of the program is.
- **To change a program name:** Select the program from the drop down list that you would like to change. Edit the name in the 'Prog. Name' field. Click the **'Save Program'** button. You can have a maximum of 14 characters in the program name.
- **To copy a program:** Select the program from the drop down list that you would like to copy. Click the **'Copy Program'** button. This will create a copy of the program at the bottom of the drop down list. Select the new copy of the program and edit the name in the 'Prog. Name' field. Click the **'Save Program'** button. This will ensure that there are not two programs with the same name in the Chirp list.
- **To modify a program:** Select the program that you wish to edit from the drop down list. Adjust the parameters in the 'Chirp Generator Program'. There are limits and boundary conditions built into the generator program. Frequently you will find that if you type a desired value into one of the fields, the program will alter the input to the nearest next lowest value. For example: You want to change the value of the 'Resolution (m)' for chirp 1 in the table in Figure 2. The current value is '25.6'. Mostly the available values are multiples

of this number. So, the next available value is likely to be '51.2'. However if you enter '51' the generator will change the entered value to the nearest lower value, not the nearest value. And so the value will change back to '25.6'. To change to the 51.2 value, it is best to enter a value larger than the required value, i.e 52. The chirp generator will then change the entry to the nearest lower value of 51.2. It is in this way that you can find what values are available for a chosen specification by trial and error of entering increasing larger numbers. In selecting a different value, it may have the consequence of changing another parameter in the chirp table. The process of editing the chirp table is a compromise between optimising the values of the variables most important to your measurement and minimising the effect that the change has on the other variables.

- **Sending the modified chirp table to the radar:** Once a program has been edited and the chirp table has been modified, it can be saved by clicking the 'Save Program' button. This will update the 'CHIRP.TBL' file on the Host PC. There will now be a difference between the Host chirp table and the radar chirp table. To transfer the new chirp table to the radar, the **"Send List To Radar"** function must be used. This operation requires administrator privileges and all radar measurements should be terminated before uploading the new chirp table. After sending the new chirp table, wait for a message from the radar to confirm it was successfully updated. RPG recommend to also restart the Host software.

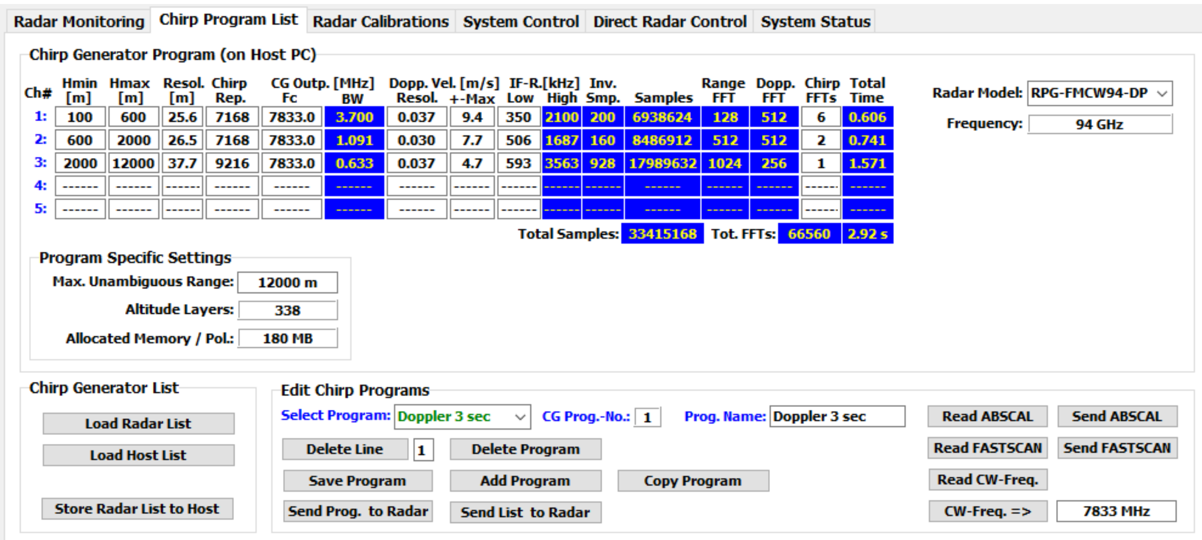

Figure 2: An example of chirp table, displaying the 'Doppler 3 sec' chirp program that has been created by RPG.

III. Technical Description of Chirp Sequence Table and Radar Measurement Parameters.

1. Overview of Chirp Sequence Table

Figure 1 presents a tabular representation of chirp sequences, structured in rows and columns. Each row corresponds to a distinct chirp sequence, with typically three or four different chirp sequences being sufficient for tropospheric measurements. The columns represent various measurement variables that define radar specifications. Certain variables, indicated in dark blue, are fixed and cannot be modified by the user. These variables adjust automatically based on the selection of other parameters. Additionally, in some versions of the chirp table, the chirp generator parameter section may be unavailable.

2. Radar Profiling and Elevation Angle Considerations

A significant number of RPG radars operate in a vertical profiling mode, where the radar beam elevation angle (α) is set to 90°. The elevation angle (α) is defined as the angle between the horizon and the radar beam direction.

- **Hmin [m]**: Represents the minimum height when α = 90° or the minimum range when α ≠ 90°, with height = range x sin(α).
- **Hmax [m]**: Denotes the maximum height at α = 90° or the maximum range at α ≠ 90°. To ensure continuous tropospheric coverage, the following condition is maintained across consecutive chirp sequences: **Hmax**(1) = **Hmin**(2) and **Hmax**(2) = **Hmin**(3)
- **Resol. [m]**: Defines the height or range resolution.

3. Chirp Generator and Signal Processing Parameters

- **Chirp Rep.**: Specifies the number of consecutive chirps per sequence, utilized in Doppler processing and averaging.
- **CG Outp. Fc [MHz]**: Represents the output frequency of the chirp generator (transmitter). In the W-band, this frequency is multiplied by a factor of 12, yielding the transmitted radar frequency: 7833 MHz x 12 = 93996 MHz ≈ 94 GHz
- **BW [MHz]**: Defines the chirp frequency bandwidth at the chirp generator output. This bandwidth is also multiplied by a factor of 12 in the W-band to obtain the transmitted chirp bandwidth at the antenna output.
- **Dopp. Vel. Resol. [m/s]**: Specifies the resolution of the Doppler velocity measurement.
- **Dopp. Vel ± Max [m/s]**: Defines the maximum measurable Doppler velocity.
- **IF-R Low [kHz]**: Represents the minimum intermediate frequency (receiver), which corresponds to **Hmin** based on the Frequency-Modulated Continuous Wave (FMCW) principle. The minimum value is 300 kHz.
- **IF-R High [kHz]**: Denotes the maximum intermediate frequency (receiver), which corresponds to **Hmax**. The maximum value is 3700 kHz.
- **Inv. Smp.**: Refers to the number of samples within a chirp that are not utilized, classified as "invalid" samples.
- **Samples**: Represents the total number of samples recorded over **Chirp Rep.** chirps, including both valid and invalid samples.
- **Range FFT**: Specifies the number of samples within a received chirp used for range processing via Fast Fourier Transform (FFT).
- **Dopp. FFT**: Indicates the number of samples corresponding to received chirps utilized in Doppler processing via FFT.
- **Chirp FFTs**: Defines the number of subsections within a single chirp. This segmentation enhances bandwidth utilization and enables improved averaging.
- **Total Time**: Represents the total acquisition time required for Chirp Rep. chirps.

This structured breakdown provides a first comprehensive technical overview of the radar measurement parameters and their role in chirp sequence processing.

IV. Range processing

1. Overview of Sequence 1 – W-band

This section examines the consistency of the various parameters and their interdependencies, requiring an understanding of Frequency-Modulated Continuous Wave (FMCW) radar principles.

The received beat signal, corresponding to a transmitted chirp, is a real signal sampled by an Analog-to-Digital Converter (ADC) board. This beat signal contains frequencies related to range, as dictated by the FMCW radar principle. A Fast Fourier Transform (FFT) is applied to extract these frequencies, thereby determining the ranges.

2. ADC Sampling and FFT Processing

Prior to performing the range FFT, the received signal undergoes sampling. The ADC sampling clock is generated by the chirp generator, ensuring synchronization between ramp generation and ADC sampling. In this scenario, the ADC board operates at a **sampling rate** of 11.45 MHz. During the active portion of the chirp, 128 samples (**Range FFT** or N_{FFT}) are collected and used in the range FFT, yielding 128 spectral bins. The spectral resolution is calculated as:

11.45 MHz/128 = 89.45 kHz.

Since the sampled signal is real, the range FFT follows Hermitian symmetry, meaning that only half of the bins (64) contain unique information. These bins span from 0 to 5.725 MHz, corresponding to the Nyquist frequency. The effective utilized frequency range, from 350 kHz (**IF-R Low**) to 2100 kHz (**IF-R High**), results in 19 range bins:

(2100-350)/89.45 = 19 bins

The number of range bins can also be derived from the radar parameters **Rmax**, **Rmin**, and range resolution (**Resol.** = δR):

$$\frac{R_{\max} - R_{\min}}{\delta R} = \frac{600-100}{25.6} \approx 19$$

3. FMCW Radar Equations

Using the relationship between Intermediate Frequency (IF) and range, $\Delta f = f_{IF} = \frac{2S}{c} R$, with S being the chirp's ramp slope, $S = \frac{B_c}{T_c}$ (see Figure 2):

Rmin = 100 m, which is related to **IF-R low**, $\Delta f_{\min} = S\frac{2R_{\min}}{c}$ = 350 kHz,

$$S = \frac{\Delta f_{\min} \cdot c}{2R_{\min}} = \frac{35010^3 \cdot 310^8}{2 \cdot 100} = 3.5 \cdot 1.510^{11} = 5.2510^{11}\ \mathrm{s}^{-2}$$

For **R_{max}** = 600 m, **IF-R high** is automatically selected as

$$\Delta f_{max} = S\frac{2R_{max}}{c} = 5.2510^{11}\frac{2\cdot 600}{310^{8}} = 2.110^{6} = 2100 \text{ kHz}$$

The bandwidth of the transmitted chirp at the antenna output is:

3.7 MHz x 12 = 44.4 MHz.

The range resolution is:

δR =25.6 m

The corresponding transmitted chirp bandwidth is:

$$B_c = \frac{c}{2\delta R} = \frac{310^{8}}{2\cdot 25.6} = 5.85910^{6} \text{ Hz} = 5.9 \text{ MHz}.$$

Since B_c < 44.4 MHz, only a fraction of the full chirp bandwidth is used.

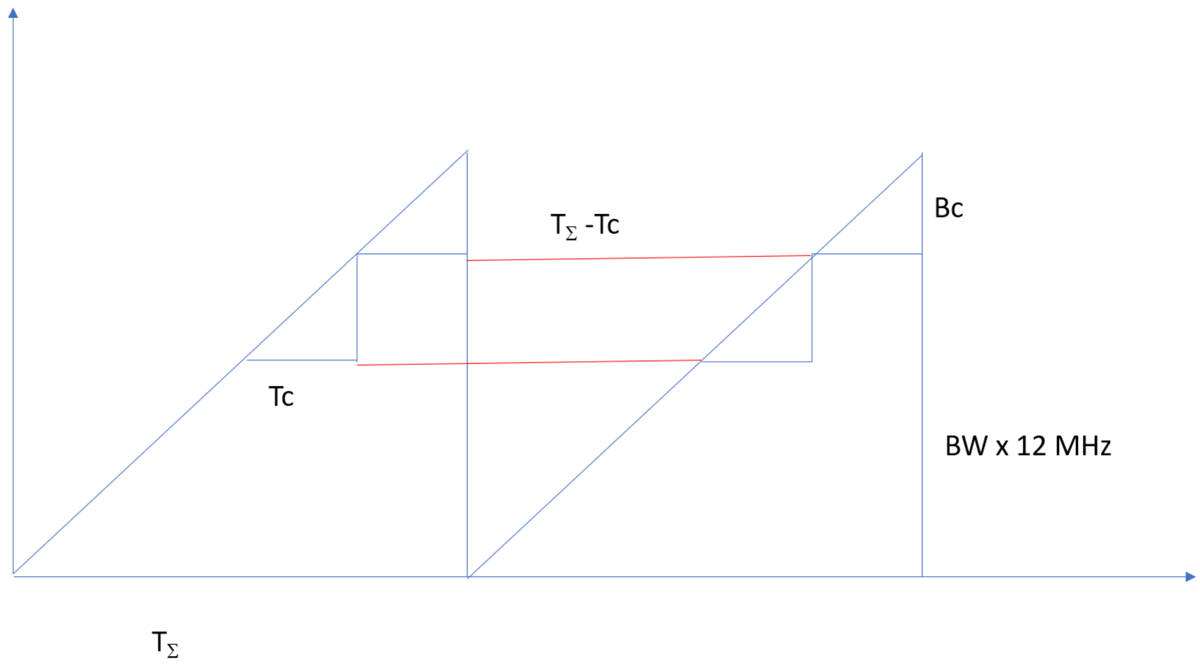

Figure 3: Chirp representation with 2 sub-chirps.

4. Utilization of Sub-Chirps

The transmitted chirp typically extends beyond the utilized portion. The used bandwidth for sequence 1 is approximately 5.9 MHz, while the total chirp bandwidth is 44.4 MHz. This corresponds to:

5.9/44.4 = 13 % of the total chirp

To optimize bandwidth usage, multiple sub-chirps are employed. In this case, six sub-chirps (**Chirp FFTs**) are utilized, resulting in:

6 x 5.859 = 35.154 MHz equivalent to 35.154/44.4 = 79% bandwidth usage

This implies that 21% of the chirp is not utilized for integration and ranging, denoted as "invalid". The same principle applies in the time domain. The total number of ADC samples within a single chirp consists of both "invalid" samples (**Inv. Smp.**) and those used for range FFT:

6 x 128 = 768 samples

For a complete chirp, the total sample count is:

200 + (6 x 128) = 968 samples (**Inv. Smp.** + **Chirp FFTs** x **Range FFT**)

The effective sample utilization ratio is:

768/968 = 79 %.

Utilizing sub-chirps facilitates averaging, with an averaging factor of 6 in the considered case.

5. Total Sample Count and Chirp Timing

The total number of samples for sequence 1 is computed as:

Samples = total samples per chirp x **Chirp rep.** = 968 x 7168 = 6938624 samples

The chirp slope $S = \frac{B_c}{T_c} = \frac{BW \cdot 12}{T_\Sigma}$ allows for the calculation of T_Σ and T_c

$T_c = \frac{B_c}{S} = \frac{5.859 10^6}{5.25 10^{11}} = 1.116 10^{-5}$ s = 1.116 10^{-2} ms = 11.16 μs (duration of one sub-chirp)

and $T_\Sigma = \frac{BW \cdot 12}{S} = \frac{44.4 10^6}{5.25 10^{11}} = 8.457 10^{-5}$ s = 8.457 10^{-2} ms = 84.57 μs (total duration of the chirp).

The difference $T_\Sigma - T_c$ provides the maximum skipped range to prevent range aliasing:

$$r_{\max} = \frac{c}{2}(T_\Sigma - T_c) = \frac{3 10^8}{2}(8.457 - 1.116) 10^{-5} = 11.01 10^3 \text{ m} = 11.01 \text{ km}$$

V. Doppler processing

1. Overview of Sequence 1 – W-band

This section evaluates the consistency of the Doppler processing parameters.

2. Maximum Unambiguous Doppler Velocity

The maximum unambiguous Doppler velocity, **Dopp. Vel ± Max** = v_{max}, is defined as:

v_{max} = 9.4 m s^{-1}

This corresponds to the Nyquist Doppler frequency:

$$F_{NYQ} = \frac{2v_{\max}}{\lambda} = \frac{2 \cdot 9.4}{3.1910^{-3}} = 5.89310^{3} \text{ Hz} = 5.893 \text{ kHz}.$$

To increase the maximum unambiguous Doppler velocity of sequence 1, the maximum unambiguous range should be decreased (Range-Doppler dilemma).

The Nyquist Doppler frequency can also be expressed as:

$$F_{NYQ} = \frac{1}{2}F_{SD} = \frac{1}{2T_{\Sigma}} = \frac{1}{2\left(T_c + \frac{2r_{\max}}{c}\right)} = \frac{1}{2\left(\frac{c}{2S\delta R} + \frac{2r_{\max}}{c}\right)}$$

Where F_{SD} is the sampling frequency for the Doppler processing: 1 sample per range (chirp). With the above equation, F_{NYQ} or v_{max} can be increased by decreasing r_{max}, increasing δR (less resolution in range) or increasing the chirp slope S.

3. Chirp Duration and Bandwidth

The total chirp duration is calculated as:

$$T_{\Sigma} = \frac{1}{2F_{NYQ}} = \frac{1}{2 \cdot 5.89310^{3}} = 0.084810^{-3} \text{ s} = 0.0848 \text{ ms} = 84.8\ \mu\text{s}$$

The related chirp bandwidth is:

$$B = ST_{\Sigma} = 84.810^{-6} \cdot 5.2510^{11} = 445.210^{5} \text{ Hz} = 44.52 \text{ MHz}$$

4. Doppler Velocity Resolution

The Doppler velocity resolution, **Dopp. Vel. Resol.** = δv, is determined using the number of samples used for Doppler processing (**Dopp. FFT** = D_{FFT}):

$$\delta v = \frac{2v_{\max}}{D_{FFT}} = \frac{2 \cdot 9.4}{512} = 0.0367 \text{ m s}^{-1} = 3.67 \text{ cm s}^{-1}.$$

5. Averaging in Doppler Processing

The number of averages, N_{av}, is calculated using the total time:

$N_c T_{\Sigma} = N_{av} D_{FFT} T_{\Sigma} = 0.606$ s (**Total Time**) where N_c = **Chirp Rep.** and D_{FFT} = **Doppler FFT**

$N_{av} = \frac{606}{5.12 \cdot 8.48} = 13.957 = 14$ and $N_c = N_{av} N_{FFT} = 14 \cdot 512 = 7168$ (**Chirp Rep.**)

For Doppler spectra computation, 512 chirps (**Doppler FFT**) are used, allowing 14 Doppler spectra to be non-coherently averaged. However, due to the presence of sub-chirps (**Chirp FFTs**) per chirp, the number of non-coherently averaged Doppler spectra increases by a factor of 6:

Final non-coherent average = **Chirp FFTs** x N_{av} = 6 x 14 = 84.

VI. Total Computation Across All Sequences

The total number of range FFTs (**Tot. FFTs**) performed across all sequences is 66560. In Sequence 3, a total of 9216 chirps (**Chirp rep.**) are used to generate range spectra. Additionally, within a large-bandwidth chirp, smaller-bandwidth chirps (**Chirp FFTs**) may be present, contributing to the overall FFT calculations.

The total FFT count is computed as follows:

Tot. FFTs = (7168 x 6) + (7168 x 2) + 9216 = 66560

Furthermore, the total number of layers is 338.

Estimate:

$$\frac{R_{\max}^{1}-R_{\min}^{1}}{\delta R^{1}}+\frac{R_{\max}^{2}-R_{\min}^{2}}{\delta R^{2}}+\frac{R_{\max}^{3}-R_{\min}^{3}}{\delta R^{3}}=\frac{600-100}{25.6}+\frac{2000-600}{26.5}+\frac{12000-2000}{37.7}=19+52+265=336$$

VII. Interactive Construction of a Chirp Table with Four Sequences for Tropospheric Vertical Profiling

Figure 4 presents the resulting chirp table. The following steps outline the procedure used to generate this table:

a) **Initialize the Chirp Table**
   - Duplicate an existing chirp table with four sequences and assign it an arbitrary name (e.g., *4s, 4 layers v2*).

b) **Define the Maximum Unambiguous Range**
   - Set this parameter equal to the height limit (**Hmax**) of the fourth sequence.

c) **Configure Height Intervals**
   - Specify the height intervals for profiling.

d) **Set Parameters**
   - Define the range/height resolution.
   - Select the maximum unambiguous Doppler velocity.

e) **Adjust Doppler Velocity Resolution**
   - Choose an appropriate Doppler velocity resolution for the setup.

f) **Determine Processing Parameters**
   - Select the number of chirps for processing (**Chirp Rep**.), which directly affects the total observation time.
   - Define the number of sub-chirps (**Chirp FFTs**); however, this aspect was not examined during the session.

g) Fine-Tuning (If Needed)

- Perform additional refinements as necessary.

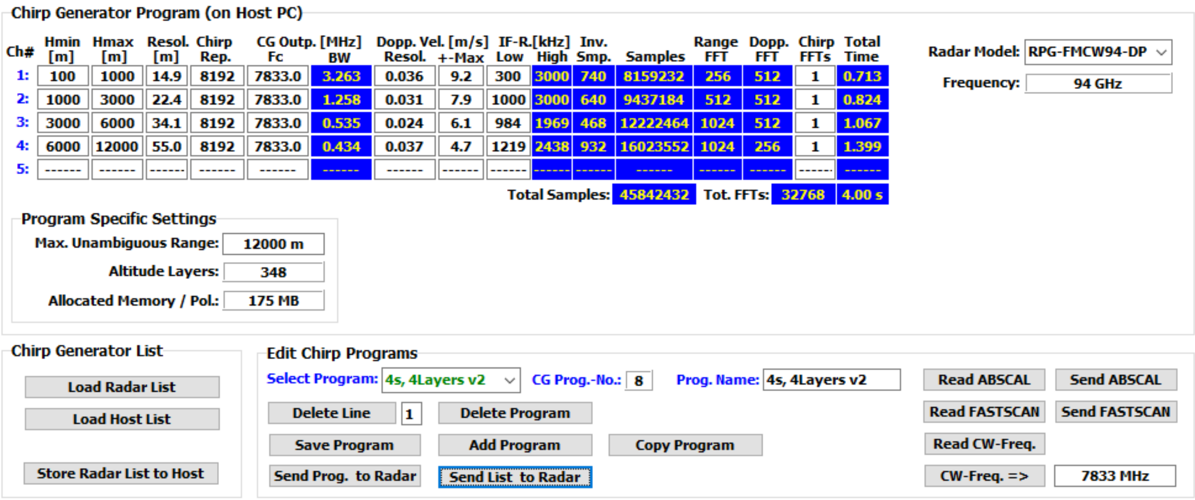

Figure 4: chirp table training output – March 5th

1) Discussion on Maximum Range Selection and Chirp Parameter Adjustments

The interactive session began with a discussion on selecting the maximum range/height. Choosing a common maximum height across all CloudNet national facilities is challenging due to climatological differences. Therefore, the maximum height must be determined based on the specific location of each facility.

For the training session, we ultimately selected a height of 12 km, enabling measurements of cirrus clouds and non-precipitating thunderstorm clouds. Out of curiosity, we also tested 15 km. Reducing the height from 15 km to 12 km primarily impacts the maximum unambiguous Doppler velocity (v_{max})—which increases. This is beneficial since v_{max} is inherently small at 3.2 mm wavelength (94 GHz) due to the range-Doppler dilemma.

$$R_{\max} v_{\max} = \frac{c\lambda}{8}$$

2) Adjustments to the Initial Chirp Table

In the initial copied table, the maximum height (**Hmax**) for the first sequence was 600 m. We decided to increase it to 1000 m, which triggered a system warning indicating that the upper boundary of the IF filter (**IF-R High**) had exceeded its limit of 3700 kHz. To resolve this, we adjusted the IF-R filter interval, lowering IF-R Low to 300 kHz (the filter's lower boundary). This modification altered the chirp slope, which in turn affected:

- (Bc, Tc) and (BW, TΣ)—leading to changes in transmitted bandwidth (range resolution) and/or chirp duration (maximum unambiguous Doppler velocity).

To optimize performance, we gradually increased the range/height resolution value (Resol)—reducing height resolution at greater altitudes. This approach improves measurement sensitivity by increasing received power, P_r, which naturally decreases with range r. The decrease in received power is compensated by increasing Δr (**Resol**), which also enhances the maximum unambiguous Doppler velocity (see Section V-2).

$$P_r = C\frac{\Delta r}{r^2}z$$

With z being the measured equivalent reflectivity factor, Δr the range resolution and C is a constant.

3) Doppler Velocity Resolution and Time Considerations

We selected a high Doppler velocity resolution (high **Dopp. FFT**), ranging from 2.4 to 3.7 cm/s, which is valuable for Doppler spectrum analysis. The resolution values for both range and Doppler measurements are always integer multiples of their preceding values. In FFT processing, the number of samples follows a power-of-two sequence: 256, 512, 1024, etc. For example, a Doppler velocity resolution of 3.7 cm/s (corresponding to sequence 4) is achieved using 256 time samples for Doppler processing (**Dopp FFT**). To improve the Doppler velocity resolution, the Doppler FFT size must be increased to the next power of two, i.e., 512 samples, resulting in a resolution of 1.85 cm/s. In this configuration, arbitrary resolution values, such as 2.5 cm/s, cannot be selected.

Increasing the Doppler FFT reduces the number of possible Doppler spectrum averages if **Chirp Rep.** remains constant. To counteract this, we increased **Chirp Rep.**, ensuring that the ratio **Chirp Rep. / Dop. FFT** met the recommended value of at least 16 (as suggested by Alexander Myagkov).

Increasing **Chirp Rep.** also extends the total measurement time, reducing time resolution. In this configuration, the time resolution is 4 seconds, which is suitable for vertical profiling. However, within this 4-second window:

- The first kilometer of the atmosphere is measured in the first 0.7 seconds.
- The final sequence (6 to 12 km) is measured during the last 1.4 seconds.

This means that different height levels are not measured simultaneously, which is an important consideration for data analysis.

4) Possible Limitations and Areas for Improvement

- **Height Resolution**

The height resolution of the first sequence (14.9 m) is highly suitable for observing precipitation, where the backscattered signal is strong. However, when targeting liquid water clouds, which produce a weaker backscattered signal, this fine resolution reduces measurement sensitivity. This highlights the fact that chirp table modifications depend not only on the climatological differences among CloudNet national facilities but also on the specific research objectives being addressed.

In contrast, the height resolution of the fourth sequence (55 m)—designed for high clouds—is relatively coarse. This was a necessary trade-off between height resolution and the maximum unambiguous Doppler velocity (4.7 m/s). We opted to maintain a moderate v_{max}, ensuring reliable Doppler velocity measurements.

- **Number of Sub-Chirps**

For the first chirp sequence, the number of sub-chirps can be increased from 1 to 3 without reducing the maximum unambiguous Doppler velocity. This adjustment triples the averaging factor, improving measurement sensitivity (see Section V-5). This adjustment can be applied when the invalid samples factor (**Inv. Smp.**) exceeds the Range FFT size (**Inv. Smp.** > **Range FFT**). In this scenario, the number of unused samples is greater than the number of utilized samples, as discussed in Section IV-4.

VIII. Questions and answers

During the training session, several questions were raised and addressed. Key questions and their corresponding answers are summarized below.

1) What is the maximum possible range?

According to the RPG documentation (Section "The Chirp Table"), the maximum possible range is 20 km. However, selecting this maximum range significantly reduces the maximum unambiguous Doppler velocity. Additionally, at 94 GHz, attenuation due to liquid water, water vapor, and oxygen further limits the maximum achievable range.

Regarding the minimum range, it is defined as 50 m, which corresponds to the start of the far-field region of the 94 GHz cloud radar.

2) Can each height range be filled independently? Are the rows independent?

Yes, each height range can be filled independently.

3) How is the quality of the maximum Doppler velocity determined?

For vertical profiling, the selection of maximum Doppler velocity considers the fall velocities of hydrometeors. At lower altitudes, precipitation with higher fall velocities is observed, whereas at higher altitudes, ice or mixed-phase clouds are dominant. Convection, particularly in thunderstorms, may introduce updrafts and downdrafts that disrupt this stratified view.

The maximum unambiguous Doppler velocity is limited at 94 GHz. The values of v_{max} in Figure 4 are appropriate; however, the value of 4.7 m/s in the 6000 m–12000 m height range results in a coarse height resolution of 55 m. An alternative configuration could use a 30 m height resolution with v_{max} = 3.1 m/s.

If the maximum unambiguous Doppler velocity is insufficient, dealiasing techniques can be applied to estimate the mean Doppler velocity and Doppler spectrum width. A dealiasing software is currently under development for the CLU dataset.

4) **How is the Doppler FFT size determined for each chirp, and how does it impact Doppler velocity resolution?**

The primary consideration is the desired Doppler velocity resolution, which is generally recommended within the range of 4–8 cm/s. Based on research related to precipitation and Doppler spectra of ice/mixed-phase clouds, a preference for 2–4 cm/s is noted (see Figure 4). However, higher Doppler velocity resolution may conflict with sensitivity at larger ranges (see Sections V-4 and V-5).

Differences in Doppler velocity resolution across chirp sequences depend on research objectives and sensitivity requirements. In Figure 4, the Doppler velocity resolutions are comparable. If, for example, the Doppler velocity resolution for sequence 3 (2.4 cm/s) were to be adjusted to align more closely with other sequences, the next available value would be 4.8 cm/s—intermediate values such as 3.6 cm/s or 3.7 cm/s are not possible. This is due to the constraint that both range and Doppler resolution values must be integer multiples of preceding values.

5) **Why is it important to maintain a total measurement time close to 3 seconds?**

As discussed in Section VII-3, during the training session, it was agreed that a total measurement time of 4 seconds is acceptable for vertical profiling. This choice is based on the required time resolution and the importance of capturing atmospheric variations across different height intervals for specific research applications.

6) **Is it always beneficial to optimize bandwidth using more Chirp FFTs?**

Not necessarily. The objective is to ensure appropriate measurement specifications for research rather than merely optimizing bandwidth. However, increasing bandwidth allows for more sub-chirps, which can enhance averaging and improve sensitivity.

For example, in Figure 4, the training session did not explicitly consider bandwidth optimization. However, for sequences 1 and 2, the condition **Inv. Smp.** > **Range FFT** indicates the potential for additional sub-chirps. While this adjustment should be made for sequence 1 (Section VII-4), sequence 2 was not modified due to its impact on the maximum unambiguous Doppler velocity, which would decrease from 7.9 m/s to 7.2 m/s in the 1000 m–3000 m range, where precipitation occurs.

7) **Impact of altitude layers in the "Program Specific Settings"**

Several questions were raised regarding the influence of altitude layers on the chirp table values:

- How do the altitude layers affect the chirp table values?
- The altitude layers differ from the reference values (e.g., 561 compared to 348) and cannot be modified. Why does this impact the chirp table so significantly?
- Is there a way to adjust the altitude layers in "Program Specific Settings"?

The altitude layer count is derived based on selections made in the chirp table for **Hmin**, **Hmax**, and range/height resolution across all sequences (see Section VI). As a result, this value should not be altered manually.

8) **Using multiple chirp tables for the same height range**

Is it possible to use different chirps for the same height range, such as one optimized for range resolution and another for sensitivity?

While it is not possible to use two different chirps within the same sequence in a single table, two separate chirp tables can be created: one optimized for range resolution (Chirp Table 1) and another optimized for sensitivity (Chirp Table 2).

Two measurement definition files can then be generated, each corresponding to one of the chirp tables. However, transitioning between these two measurement configurations introduces a significant dead time in the RPG cloud radar. Therefore, it is not advisable to alternate profiles between Chirp Table 1 and Chirp Table 2 within a single measurement cycle.

IX. Conclusions

The objective of this study, along with the associated training conducted on 5 March, was to iteratively develop a chirp table for vertical profiling of the troposphere, with a particular emphasis on understanding the trade-offs involved and gaining familiarity with the table's parameterization. Given the variability in climatological conditions and research objectives across Cloudnet national facilities, the establishment of a universal default chirp table is not feasible. Instead, the primary aim was to develop proficiency in constructing a good chirp table tailored to specific observational requirements. In subsequent stages, interpolation methodologies are employed to mitigate these discrepancies within the European dataset maintained at CLU.

At Delft University of Technology, chirp tables are typically designed with three or four sequences. For the present campaign, which focuses on liquid water clouds in the lower troposphere (first few kilometers), a three-sequence chirp table was selected. This configuration prioritizes dedicated measurement specifications in the lower atmospheric layers while maintaining more generalized specifications at greater altitudes. Notably, the adoption of a three-sequence chirp table enhances the temporal resolution.