Horizontal Wind Plan Position Indicator (PPI) Measurement Conducted by RPG radars within the EarthCARE/Cal Val Framework

Complementary notes/discussion next to the RPG manual

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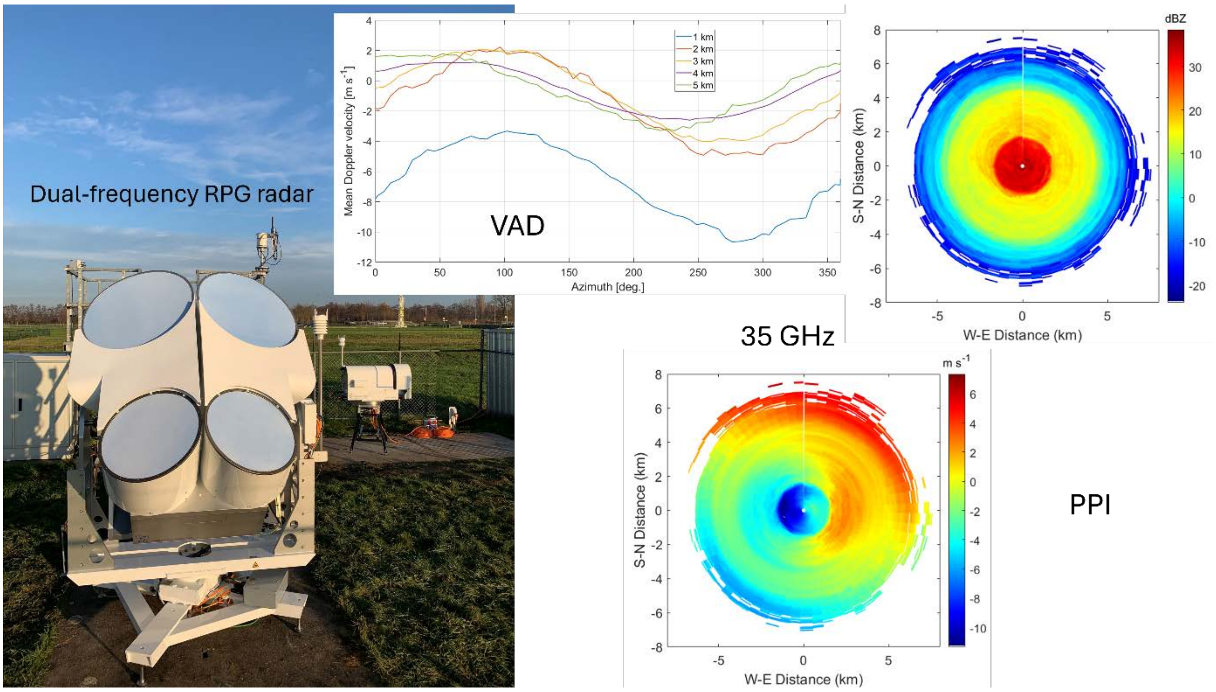
The RPG manual (operation and software) can be found on the RPG website.



Plan Position Indicator (PPI) for Horizontal Wind Profiling.

The Plan Position Indicator (PPI) technique, employed for horizontal wind profiling, involves a full azimuth scan to gather atmospheric Doppler data. An exemplar configuration and encountered challenges are elucidated in the article "Combined wind lidar and cloud radar for high-resolution wind profiling" authored by José Dias Neto, Louise Nuijens, Christine Unal, and Steven Knoop (Earth Syst. Sci. Data, 15, 769–789, 2023).

In the Netherlands, two variants of scanning RPG cloud radars are in operation: a dual-frequency system (operating at 35 and 94 GHz) and two single-frequency systems (operating solely at 94 GHz). The choice of frequency, $\left(f = \frac{c}{\lambda}\right)$, bears significance in PPI wind profiling, as the maximum unambiguous Doppler velocity $(V_{\max})$ differs between the frequencies. Specifically, the maximum unambiguous Doppler velocity at 35 GHz is proportionally larger compared to 94 GHz for the same unambiguous maximum range $(R_{\max})$, as dictated by the Range-Doppler dilemma equation.

$$R_{\max}V_{\max} = \frac{c\lambda}{8} = \frac{c^2}{8f}$$

The measured Doppler velocity (v_D), which depends on range (r) and azimuth angle (ϕ) during a PPI measurement is:

$$v_D(r,\phi) = \left[W(r,\phi) - v_f(r,\phi)\right]\sin(\alpha) + v_H(r)\cos\left[D(r) \pm \pi - \phi\right]\cos(\alpha)$$

Where D and v_H are the horizontal wind direction and speed, respectively. W is the vertical wind, v_f the mean fall velocity of the hydrometeors contained in the radar resolution volume centered at r and α is the elevation angle of the radar beam (related to the horizon). D and ϕ relate to the North and the wind direction (D) is defined as the direction from which the wind originates. The measured Doppler velocity is defined negative when hydrometeors approach the radar.

To mitigate the influence of high wind speeds on the measured Doppler velocity, an increase in the elevation angle is advocated. Consequently, PPI scans for wind profiling are typically conducted at an elevation of 85° at 94 GHz (yielding smaller maximum velocities) and 75° at 35 GHz.

Prior to delving into an example of chirp table, the article "A W-band Radar-Radiometer System for Accurate and Continuous Monitoring of Clouds and Precipitation" authored by Nils Kuchler, Stefan Kneifel, Ulrich Lohnert, Pavlos Kollias, Harald Czekala, and Thomas Rose (JTECH, 34, 2375-2392) offers a comprehensive introduction to the RPG cloud radar system.

1) Example of chirp table for PPI wind profiling

Consider an illustrative instance of a chirp table tailored for PPI wind profiling (presented as a representative table rather than an optimized one). The maximum rotation speed is set at 5° per second, resulting in a complete PPI scan every 72 seconds (calculated as 360/5). Within the RPG radar system, specifications can be customized across different ranges. In the example table provided, three range intervals are delineated: from 100 to 600 meters, from 600 meters to 2000 meters, and from 2000 meters to 12000 meters.

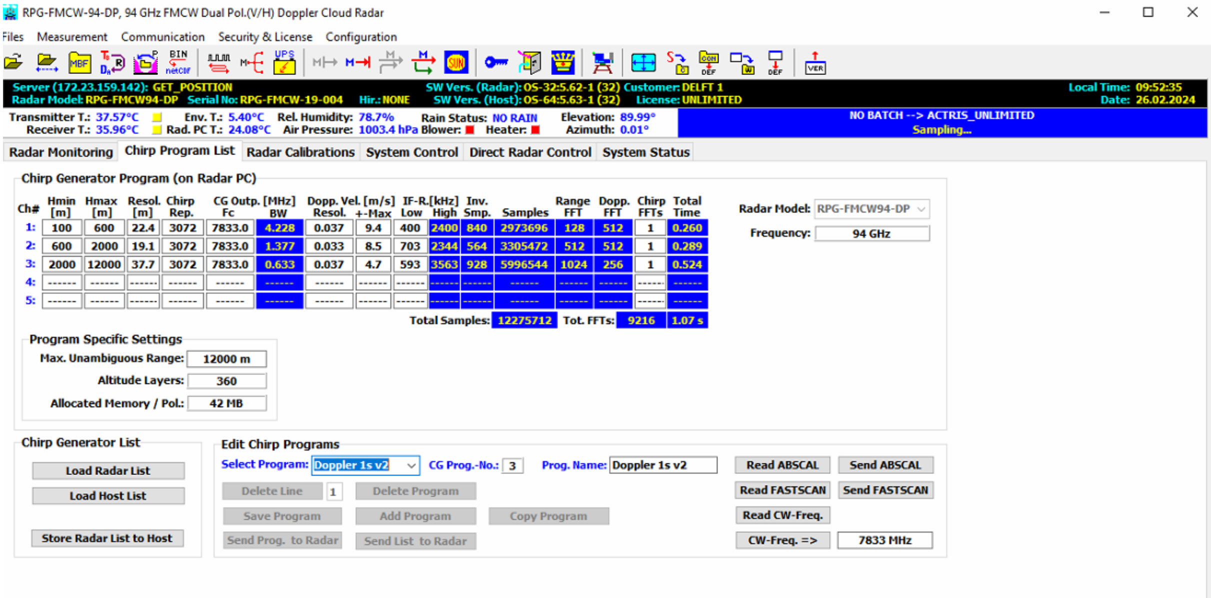


Figure 1: Illustrative Chirp Table for an RPG Radar Operating at 94 GHz. This figure depicts an example chirp table tailored for an RPG radar operating at 94 GHz, specifically designed for Plan Position Indicator (PPI) mode to derive vertical profiles of horizontal wind. The elevation angle for PPI mode is set at 85°. Parameters displayed in the white columns are adjustable manually to accommodate specific measurement requirements.

Notably, observe the modest values of maximum unambiguous Doppler velocity (depicted in column 8): 9.4, 8.5, and 4.7 meters per second, respectively. The selection of a maximum range of 12 kilometers corresponds to a height of 11954 meters (calculated as 12000 x sin (85° x π/180)). Typically, a maximum range of approximately 12 kilometers suffices for encompassing the entire troposphere during vertical profiling (α=90°) or PPI scans for horizontal wind profiling (α=85°), particularly in mid-latitudes. Adjustments to this maximum range may be warranted for different latitudinal zones (polar, tropical). It's pertinent to note that the first two columns (Hmin, Hmax) denote ranges [height = range x sin(elevation)].

For the first interval (chirp 1), 22 range bins are measured spanning from 100 meters to 600 meters, yielding a range resolution of 22.4 meters. During the data acquisition process, 512-time samples (DopFFT) are gathered for Doppler processing (512 consecutive chirp 1 sequences). This procedure yields 22 complex Doppler spectra, each comprising 512 Doppler bins, with a Doppler resolution of 3.7 centimeters per second (Dopp. Vel. Resol.). Subsequently, averaging is executed to diminish spectrum variance and enhance sensitivity. In this instance, the number of averages is set at 6 (derived from 3072/512), which may be considered relatively low. A total of 3072 chirp 1 sequences are measured within a duration of 0.26 seconds (Total time).

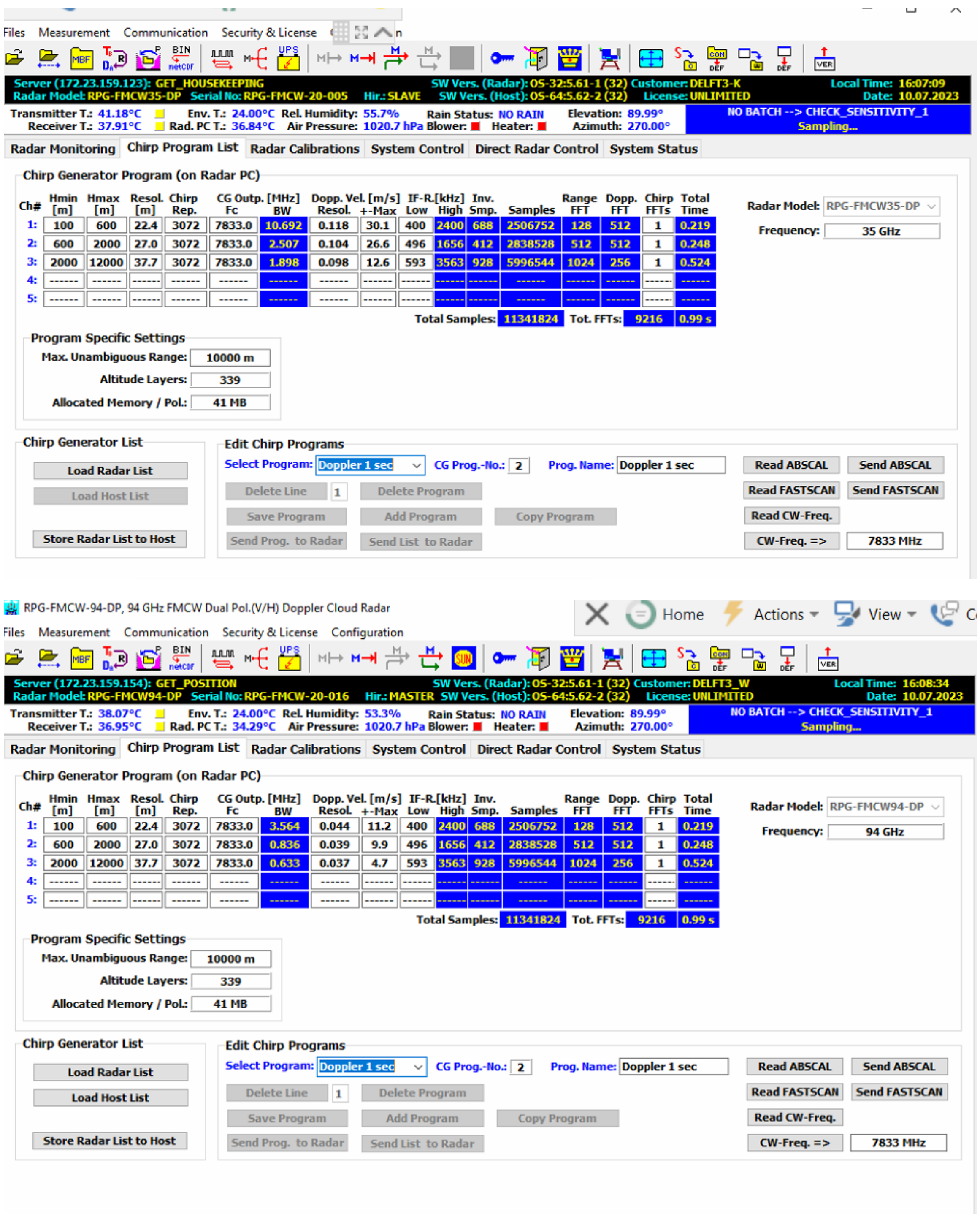


Figure 2: Illustrative Chirp Tables for a Dual-Frequency RPG Radar. This figure presents examples of chirp tables designed for a dual-frequency RPG radar, featuring configurations for both 35 GHz (top) and 94 GHz (bottom) frequencies. While most specifications remain consistent across both frequencies, notable adjustments are primarily observed in the Doppler velocity parameters, including maximum values and resolution.

This process is repeated for chirp 2 and chirp 3 sequences, which occur consecutively. While the acquisition of chirp 1 measurements requires 0.26 seconds, acquiring chirp 2 and 3 measurements demands 0.289 and 0.524 seconds, respectively. The entire troposphere is surveyed within 1.07 seconds. It is imperative to minimize this Total time. Given the azimuthal scanning of the radar and the desire to maintain a high azimuthal resolution (in this case, 5°), a duration of approximately 1 second is deemed appropriate, albeit potentially at the expense of sensitivity.

In the scenario where the RPG radar operates as a dual-frequency system (35 and 94 GHz), leveraging the 35 GHz frequency enhances horizontal wind profiling due to its larger unambiguous maximum Doppler velocity (as indicated in column 8, figure 2 top). Consequently, an elevation of 75° can be chosen to achieve finer resolution in horizontal wind measurements while mitigating Doppler aliasing.

It's important to acknowledge that in this configuration, the 94 GHz radar serves as the "master," while the 35 GHz radar acts as the "slave." This implies that changes to the chirp table for the 94 GHz radar are automatically reflected in the 35 GHz radar, precluding independent modification of the 35 GHz chirp table.

2) Example of Measurement Definition File (MDF) and Measurement Batch File (MBF) for PPI wind profiling.

Operational procedures and software functionalities are extensively covered in the RPG manual (Operation and Software Guide) and are omitted herein. The report "RPG FMCW Cloud Radar Triggered MBF's" authored by Rob Mackenzie offers insights into the scanning tab, timing tab, and MDF/MBF storage tab, briefly discussed below, without employing triggering mechanisms.

For horizontal wind profiling utilizing the Plan Position Indicator (PPI) technique, two Measurement Definition Files (MDFs) are generated:

2-a) Measurement Definition File 1 (MDF 1)

Scanning Tag: Initiates at a start azimuth of 0° and terminates at a stop azimuth of 359.9° (scan #1), constituting frame #1 (Start scan #1, stop scan #1) with a single repetition.

Timing Tag: Specifies a "LIMITED" measurement duration of 72 seconds.

MDF/MBF Storage: Chooses "Store MDF."

2-b) Measurement Definition File 2 (MDF 2)

Scanning Tag: Commences at a start azimuth of 359.9° and concludes at a stop azimuth of 0° (scan #1), forming frame #1 (Start scan #1, stop scan #1) with a single repetition.

Timing Tag: Designates a "LIMITED" measurement duration of 72 seconds.

MDF/MBF Storage: Selects the "Store MDF" option.

2-c) Further clarifications

A technical limitation encountered necessitated the utilization of 359.9° instead of 360° for azimuth settings.

The nomenclature of the two MDFs is visible in the MDF list illustrated in Figure 3. Consequently, two consecutive data files will be generated, denoted as BaseN_YYMMDD_HHmmSS_PXX_PPI, where PXX denotes the chirps table.

2-d) Measurement Batch File (MBF)

The MBF comprises a sequence of MDFs enumerated in the left window of Figure 3 (MDF list). By selecting "Store MBF," an MBF is generated and assigned a distinct name. In the depicted scenario, the cloud radar executes a pair of PPI scans at an elevation of 75°. The initial PPI entails an azimuthal sweep from 0° to 359.9° (MDF 1), followed by a subsequent PPI with an azimuthal sweep from 359.9° to 0° (MDF 2). This sequence, encompassing clockwise and counterclockwise rotations, is repeated 15,000 times (Batch Repetitions). Utilizing the "MBF timing" function enables users to visually inspect the generated MBF in relation to timing and angle configurations.

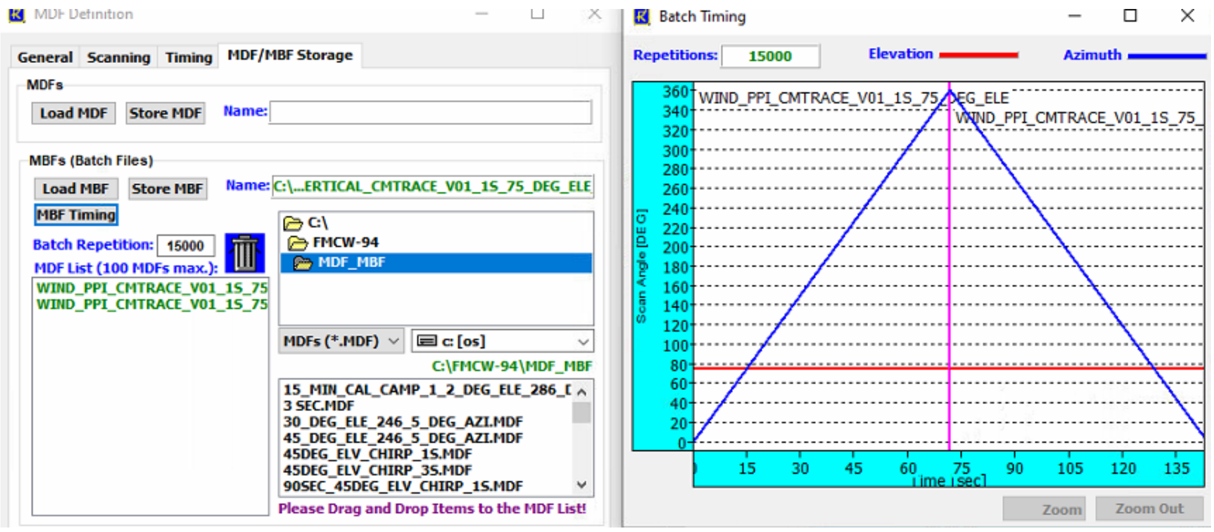


Figure 3: Exemplary MBF Configuration (No Triggering)