

M211452EN-H

RESTRICTED

User Guide

Dual Polarization
IRIS and RDA

VAISALA

PUBLISHED BY

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1. About this Document

1.1 Version information

This document on provides information on IRIS and RDA dual-polarization.

Table 1 Document versions (English)

Document code	Description
M211452EN-H	Eighth version. April 2021. IRIS 9.1.0
M211452EN-G	Seventh version. November 2017
M211452EN-F	Sixth version. October 2016

1.2 Related documents

Table 2 Vaisala Weather Radar documentation

Document code	Name
M211849EN	<i>IRIS Focus User Guide</i>
M211850EN	<i>IRIS Focus Administrator Guide</i>
M211904EN	<i>IRIS Focus Release Notes</i>
M211315EN	<i>IRIS and RDA Software Installation Guide</i>
M211318EN	<i>IRIS Programming Guide</i>
M211316EN	<i>IRIS and RDA Utilities Guide</i>
M211319EN	<i>IRIS Product and Display Guide</i>
M211317EN	<i>IRIS Radar User Guide</i>
M211452EN	<i>IRIS and RDA Dual Polarization User Guide</i>
M211322EN	<i>RVP900 Digital Receiver and Signal Processor User Guide</i>
M211320EN	<i>Radar Control Processor RCP8 User Guide</i>

Vaisala encourages you to send your comments or corrections to helpdesk@vaisala.com.

1.3 Documentation conventions



WARNING! Warning alerts you to a serious hazard. If you do not read and follow instructions carefully at this point, there is a risk of injury or even death.



CAUTION! Caution warns you of a potential hazard. If you do not read and follow instructions carefully at this point, the product could be damaged or important data could be lost.



Note highlights important information on using the product.



Tip gives information for using the product more efficiently.



Lists tools needed to perform the task.



Indicates that you need to take some notes during the task.

1.4 Trademarks

Vaisala® is a registered trademark and HydroClass™, IRIS™ and Total Lightning Processor™ are trademarks of Vaisala Oyj.

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2. Introduction to Dual Polarization

2.1 Dual Polarization Overview

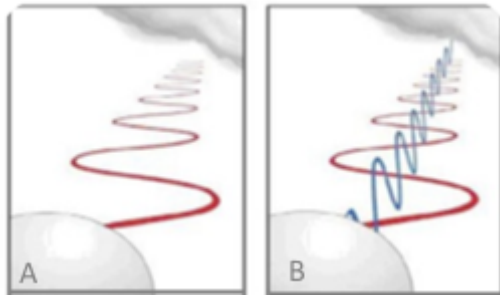


Figure 1 Conventional and Dual Polarization Radars

- A Conventional weather radar
- B Dual polarization weather radar

Conventional weather radars transmit and receive only a single polarization (usually horizontal). Dual polarization radars transmit and receive both horizontal and vertical polarization.

Vaisala Hydrometeor Classification (HydroClass) software makes optimal use of dual-channel measurements to detect the types of scatterers present in the atmosphere, such as rain, hail, snow, graupel, and even non-meteorological targets such as insects, chaff, and sea clutter.

More information

- [HydroClass Overview \(page 43\)](#)

2.2 Horizontal, Vertical, and Enhanced Reflectivities (Z_H , Z_V , Z_{HV})

In the case of amplitude (power) measurements, the power returned to the radar can be related either to the particles diameter in the horizontal plane or vertical plane. When expressing this power through the radar equation, these become horizontal reflectivity (Z_H), which is the traditional single polarization reflectivity, and vertical reflectivity (Z_V).

Z_H and Z_V are typically calculated using an autocorrelation power estimator, or by performing a cross-correlation of the signal with itself.

The autocorrelation technique finds periodic signals buried within noise. A special case is to perform the cross-correlation of the horizontal power to the vertical power. This becomes enhanced reflectivity (Z_{HV}) and can be shown to have greater ability to weak signals in the presence of noise, compared to Z_H or Z_V alone.

All power estimators are sensitive to intervening attenuation from precipitation, requiring a data correction for quantitative use with C- or X-band radars.

2.2.1 Differential Reflectivity (Z_{dr})

In the case of amplitude (power) measurements, the larger horizontal axis of drops causes the power measured at horizontal polarization (of the electric field) to be larger than the power measured at vertical polarization. The ratio of the reflectivity factors Z_H/Z_V , expressed in dB, is called differential reflectivity (Z_{dr}).

- Z_{dr} is generally positive in rain (that is, >1) and is usually less than 5 dB. When the rainfall rate is large, there are typically more large drops, so Z_{dr} is larger.
- Low Z_{dr} and high dBZ indicates the presence of hail, which may be tumbling with no preferred orientation.

Z_{dr} , because it is a ratio of powers, is not sensitive to the radar calibration, as long as the overall gain of the H and V channels is the same (or calibrated).

2.2.2 Differential Phase (Φ_{DP}) and Specific Differential Phase (K_{dp})

In the case of phase measurement, the speed of propagation is also affected by the asymmetry of the larger drops. Because of the longer dimension of the horizontal axis of drops, the medium is more dense for horizontal than for vertical polarization. This causes the horizontal wavelength to be slightly compressed (more phase cycles per unit distance) in comparison with the vertical wavelength, which leads to a phase difference between horizontal and vertical.

This difference is called the differential phase shift, Φ_{DP} . Φ_{DP} increases with range, since the phase shifts faster (more frequency cycles per unit distance) for the compressed horizontal microwaves compared to the faster vertical microwaves.

The range derivative of Φ_{DP} , that is, the change of phase per unit distance, is called specific differential phase (K_{dp}). K_{dp} is almost directly proportional to the rainfall rate, so it has the potential to improve precipitation rate measurements compared to traditional Z-R relationship measurements, which can be highly inaccurate.

More information

- [Attenuation Correction of Z Overview \(page 28\)](#)

2.2.3 Linear Depolarization Ratio (LDR)

Some advanced polarization radars can transmit at one polarization and receive simultaneously in 2 channels, usually the co-polarized and cross-polarized components. For example, when transmitting horizontal, both horizontal (co-polarized) and vertical (cross-polarized) polarized energy are received by 2 separate channels.

In the case of vertical or horizontal, the ratio of the power Z_{cross} or Z_{co} is called the linear depolarization ratio (LDR). The amount of incident radiation that is depolarized by a particle, depends on the particle shape and orientation (for example, canting angle with respect to horizontal). Perfectly spherical particles do not depolarize either horizontal or vertical polarization, so the LDR is 0. Particles that are wet, tumbling and irregularly shaped give larger LDR values. Therefore, LDR values in rain tend to be small, for example, less than -25 dB. Larger values of LDR can occur in the bright band or in the presence of hail.

A radar and antenna system must be optimized to measure LDR by assuring that the antenna, feed and supporting struts, and radome are not themselves depolarizing the transmitted and received radiation. This is called "cross-pol isolation". The integrated cross-pol isolation of the antenna pattern must be more than 35 dB for LDR measurement since -20 dB is a large LDR.

If the radar cannot achieve this level of cross-pol isolation is limited to how accurate the rainfall estimates can be from the dual polarization data.

2.2.4 [RhoHV, PhiDP] [RhoH, PhiH] [RhoV, PhiV]: Correlation Variables

Depending on the capabilities of the radar, several correlation functions can be calculated. These are generally complex, having both an amplitude and phase. These are normalized so that a perfect correlation magnitude is 1 and perfectly decorrelated is 0.

RhoH and PhiDP are the magnitude and phase of the correlation between the horizontal and vertical co-polarized channels. These are available on H/V switching systems or on systems that transmit simultaneous H and V.

PhiDP can be used to infer precipitation rate. RhoHV, in rain, is typically very close to 1 (0.98). RhoHV values can be reduced in the case of irregularly shaped, randomly oriented, wet tumbling particles; thus, RhoHV provides information on the particle type.

RhoH and PhiH are the magnitude and phase of the correlation between the co-polarized and cross-polar channels for H transmission, and simultaneous H and V reception. RhoV and PhiV denote the cross-channel correlation magnitude and phase for vertical transmission. These are available on a dual-channel receiver with transmit, either fixed or alternating. The information content of the cross-pol correlations is the topic of current research.

2.3 Radar System Considerations

A polarization radar is characterized by how it transmits and receives. For simplicity, we assume that the radar uses horizontal and/or vertical polarization. However, other polarization pairs could be used (for example, right and left circular polarization).

2.3.1 Transmit Modes

Fixed (Horizontal or Vertical)

Controlled by a switch or the radar can be fixed to transmit a single polarization. If a switch is used, it can be a simple, slow, waveguide switch rather than a fast switch (pulse-to-pulse).

Alternating (Horizontal and Vertical)

Radar alternates pulse-to-pulse between horizontal and vertical. A high-power, fast switch is used to switch the polarization between the 2 channels.

Simultaneous (Horizontal and Vertical)

Horizontal and vertical are transmitted simultaneously.

2.3.2 Receive Modes

Single-Channel Receiver

Used only for alternating transmission. The receiver typically receives the co-polarized radiation (transmit H and receive H, then transmit V and receive V).

Dual-Channel Receiver

Receives 2 channels (H and V) simultaneously.

The following table summarizes the transmit and receive cases, and the polarization variables that are available for each.

The fixed, dual-channel cases allow the optional dual polarization cross-polarization LDR and the co-pol/cross-pol correlation amplitude and phase to be measured (for example, RhoH and PhiH).



Standard parameters are available for all cases (dBT, dBZ, V, and W).
RVP900 supports all these cases.

Table 3 Transmitter Types

Receiver Type	Transmitter Type			
	Fixed H	Fixed V	Alternating H and V	Simultaneous H+V
Single-Channel	Conventional Radar	Conventional Radar	Z_V , Z_{HV} , Z_{dr} , RhoHV PhiDP, K_{dp}	Not applicable as it does not make physical sense.

Receiver Type	Transmitter Type			
	Fixed H	Fixed V	Alternating H and V	Simultaneous H+V
Dual-Channel	LDRH, RhoH, PhiH	LDRV, RhoV, PhiV	The alternating transmission, dual-channel receiver allows both the co-pol and the cross-pol measurements to be made. It is the most complete. Z_V, Z_{HV}, LDRH	The simultaneous H+V transmission and dual-channel reception (also called the STAR mode for simultaneous transmit and receive). This allows the co-pol measurements to be made ($Z_{dr}, \text{RhoHV}, \text{PhiDP}, K_{dp}$). $Z_V, Z_{HV}, Z_{dr}, \text{RhoHV}, \text{PhiDP}, K_{dp}$ (STAR mode)
			LDRV, RhoH, RhoV, PhiH, PhiV, Z_{dr} RhoHV, PhiDP, K_{dp}	

2.3.3 Summary of Radar System Characteristics

Unlike most polarization radar systems, RVP900 supports all these transmit and receive modes.

The measurement of cross-pol parameters such as LDR (fixed or alternating transmission and dual-channel reception) requires a radar system that has been optimized for cross-pol isolation, for example, an offset feed antenna and no radome. By removing the feed, support struts, and radome from the path of the radiation, the cross-pol isolation can be improved.

The single-channel, alternating method has been used in several polarization radars for Z_{dr} measurement. The advantage of this approach is that it is relatively easy to modify a conventional radar by adding a dual-port feed and a high-power, fast switch above the antenna rotary joints. The disadvantage is that the switch is costly and eventually fails.

The STAR (simultaneous transmit and receive) mode does not require a switch and the components are fairly reliable. The disadvantage of the approach (as it is usually implemented), is that a dual-rotary joint and dual waveguides are required, to duct both the H and the V through the antenna pedestal up to the antenna feed. Despite this, the STAR mode offers the best approach for upgrading an existing radar, or for factory installation on a new radar of conventional design.

2.4 Processing Algorithms

RVP900 supports four polarization modes summarized in the table below. For each case, the standard moments (T, Z, V, and W) are also calculated.

The notation for the outputs used here is similar to that in standard use (for example, Doviak and Zrnic). However, for LDR we use the notation LDRH to indicate that this is the LDR for horizontal transmission. The notation RhoH and PhiH indicates the magnitude and phase of the covariance between the co- and cross-polarized channels for H transmit.

Table 4 Supported Polarization Modes and Outputs

Case	Transmit	Receive	Processing Mode	Polarization Outputs
1	Fixed Horizontal or Fixed Vertical	Dual-Channel	PPP only	LDRH, RhoH, PhiH, or LDRV, RhoV, PhiV
2	Simultaneous H+V (STAR Mode)	Dual-Channel	PPP or Z_{dr} for FFT, Random Phase, and DPRT1&2	Z_V , Z_{HV} , Z_{dr} , PhiDP, K_{dp} , RhoHV
3	Alternating H/V	Single-Channel	PPP only	Z_V , Z_{HV} , Z_{dr} , PhiDP, K_{dp} , RhoHV
4	Alternating H/V	Dual-Channel	PPP only	Z_V , Z_{HV} , Z_{dr} , LDRH
				RhoH, PhiH, LDRV, RhoV, PhiV, PhiDP, K_{dp} , RhoHV

2.4.1 Input Receiver Sample Notation

For the discussion of polarization, we use the notation used by Doviak and Zrnica. The received signal for pulse n from a single range bin is denoted as:

Table 5 Input Receiver Algorithm Notation

Notation	Description	
s_{hh}^n	Receive h: Transmit h	Horizontal co-polar signal
s_{vh}^n	Receive v: Transmit h	Horizontal cross-polar signal
s_{vv}^n	Receive v: Transmit v	Vertical co-polar signal
s_{hv}^n	Receive: h Transmit v	Vertical cross-polar signal

The pulse index is indicated by the superscript instead of the subscript. The first subscript indicates the received polarization and the second subscript indicates the transmit polarization.

If the transmit is the same as the received polarization, this is the co-polarized signal. If the transmit and receive are different, this is the cross-polarized signal.

These variables are complex and are the same as the s_n notation used in *RVP900 Digital Receiver and Signal Processor User Guide*. For example, we can write:

$$S_{hh}^n = I_{hh}^n + jQ_{hh}^n$$

to show the relationship to the received I and Q values. Either filtered and unfiltered versions of the samples can be selected for processing. We drop the s notation for filtered samples.

2.4.2 Notation and Model for Correlations

The pulse pair processing mode is used for all polarization calculations, except that Z_{dr} -only processing for the STAR case can be done in either FFT or random phase as well as pulse pair.

As with the standard moments, autocorrelations form the basis for the processing of the polarization variables.

An autocorrelation is the cross-correlation of a signal with itself. Informally, it is the similarity between observations as a function of the time separation between them. It is a mathematical tool for finding repeating patterns, such as the presence of a periodic signal, which has been buried under noise. However, it is also possible to perform a correlation of the S_{hh} and S_{vv} signal, which is used to create Z_{HV} .

The autocorrelations are computed similarly to the standard moments. For example, in pulse pair mode the autocorrelations for the horizontal transmit co-polar channel are:

$$T_{0hh} = \frac{1}{M} \sum_{n=1}^M S_{hh}^n \times S_{hh}^n$$

$$R_{0hh} = \frac{1}{M} \sum_{n=1}^M S_{hh}^n \times S_{hh}^{n+1}$$

$$R_{1hh} = \frac{1}{M-1} \sum_{n=1}^{M-1} S_{hh}^n \times S_{hh}^{n+1}$$

$$R_{2hh} = \frac{1}{M-2} \sum_{n=1}^{M-2} S_{hh}^n \times S_{hh}^{n+2}$$

For dual polarization systems, these correlations can be applied up to 4 different ways (R_{hh} , R_{vv} , R_{hv} , and R_{vh}), where R_{hv} and R_{vh} are equivalent. The physical model for the channel powers is identical to the model used for the standard moment cases:

Co-Channel Power

$$R_0^{hh} = \frac{1}{M} \sum_{n=1}^{M-1} S_{hh}^n \times S_{hh}^{n+1} = g_h^r g_h^t S'_{hh} + N_h$$

$$R_0^{vv} = \frac{1}{M} \sum_{n=1}^{M-1} S_{vv}^n \times S_{vv}^{n+1} = g_v^r g_v^t S'_{vv} + N_v$$

Diagonal Channel Power

$$R_0^{hv} = \frac{1}{M} \sum_{n=1}^{M-1} S_{hh}^n \times S_{vv}^{n+1} = \frac{g_h^r g_h^t S'_{hh} g_v^r g_v^t S'_{vv}}{2}$$

Here S denotes the actual backscatter average power to the radar. When multiplied by the appropriate transmitter and receiver gains, S yields the actual measured power. Sometimes in comparing powers in 2 channels (for example, Z_{dr} and LDR), we need to know the relative gains of the 2 channels. However, in many calculations, the relative gains cancel out, and in these cases the algorithms are implemented assuming all the gains are equal to 1.

In the R_{hv} term, the noise variable is not present because the noise between the horizontal receiver and vertical receiver is random, having a normalized coherency of 0 with an infinite number of samples. A finite number of samples needs to be used, typically between 30 ... 60, in weather radar signal processing. However, due to the noise coherency going to 0, the noise variance also becomes smaller, allowing us to lower the detection thresholds, while having same false alarm rates as the traditional R_{hh} term. Lowering the detection threshold increases the apparent sensitivity when inserting the R_{hv} term in the radar equation for reflectivity.

In the following algorithm descriptions, we use the notation common in the literature, for example:

$$R_0^{hh} = \frac{1}{M} \sum_{n=1}^{M-1} s_{hh}^n \times s_{hh}^n = (|s'_{hh}|^2) = S_{hh}$$

$$R_0^{vv} = \frac{1}{M} \sum_{n=1}^{M-1} s_{vv}^n \times s_{vv}^n = (|s'_{vv}|^2) = S_{vv}$$

$$R_0^{hv} = \frac{1}{M} \sum_{n=1}^{M-1} s_{hh}^n \times s_{vv}^n = (|s'_{hv}|^2) = S_{hv}$$

2.4.2.1 Noise Bias in Channel Powers, Correlations, and Optional Correction

The average noise powers N_v and N_h are assumed to be receiver noise only.

These bias the autocorrelations at lag 0, that is, the channel power measurements, and must be subtracted. Autocorrelations at lags 1 and 2 are not biased by noise, while cross-channel correlations are biased by finite noise. Cross-channel phases are smeared by finite noise while unbiased, assuming that the noises in the 2 channels are independent (a good assumption).

The channel noise values are measured directly by RVP900 during noise sampling. Using these measurements for correcting the effects of finite noise is configured in the TTY setups. The choices are made with the **mp** non-volatile setup settings:

- **Polarimetric Power Params > NoiseCorrected:YES/NO**

If **YES**, the Z_{dr} and LDR are computed from channel powers, subtracted for noise levels.

The sensitivity is enhanced to observe weather effects in weak echoes (SNR << 10 dB).

At the SNR low limit, Z_{dr} approaches 0 dB as soon as noise levels are properly set.

If **NO**, Z_{dr} values in weak signal regions are biased, and approach the ratio of channel noise levels.

A finite noise level may set a limit for LDR observations.

- **Polarimetric Correlations > NoiseCorrected:YES/NO**

If **NO**, RhoHV , RhoH , and RhoV approach 0 dB in weak echoes

If **YES**, they approach unity.

Phase measurements: PhiDP , K_{dp} , PhiH , and PhiV are not affected by these settings.

2.4.2.2 Clutter Filtering

The polarization variables are computed from data filtered for clutter. The settings are the same, and are user configurable for standard moments.

The filter is applied identically for each polarimetric channel.

2.5 Case 1: Fixed Transmit: Dual-Channel Receiver

2.5.1 Case 1: Input Receiver Samples

In fixed mode, the radar is configured (either permanently or by means of a switch) to transmit either vertical or horizontal polarization with dualchannel reception of both the co- and cross-channel polarizations. For example, the radar can transmit horizontal and receive both horizontal (co) and vertical (cross) polarizations.

The received samples in the 2 transmit cases are as follows:

Transmit Horizontal

$$[S_{hh}^1: S_{vh}^1][S_{hh}^2: S_{vh}^2][S_{hh}^3: S_{vh}^3] \cdots [S_{hh}^M: S_{vh}^M]$$

Transmit Vertical

$$[S_{vv}^1: S_{hv}^1][S_{vv}^2: S_{hv}^2][S_{vv}^3: S_{hv}^3] \cdots [S_{vv}^M: S_{hv}^M]$$

2.5.2 Case 1: Calculation of Polarization Measurands

The processing in this mode is done by pulse pair algorithm. You may select a clutter filter.

Table 6 Polarization Measurands for the Horizontal and Vertical Transmit Cases

Transmit Horizontal	or	Transmit Vertical
$LDRH = 10\text{LOG} \left[\frac{S_{vh}}{S_{hh}} \right]$	or	$LDRV = 10\text{LOG} \left[\frac{S_{hv}}{S_{vv}} \right]$
$= 10\text{LOG} \left[\frac{\langle S_{vh} ^2 \rangle - N_v}{\langle S_{hh} ^2 \rangle - N_h} \right] - XDR$	or	$= 10\text{LOG} \left[\frac{\langle S_{hv} ^2 \rangle - N_h}{\langle S_{vv} ^2 \rangle - N_v} \right] + XDR$
$RHOH = \rho_h $	or	$RHOV = \rho_v $
$PHIH = \arg \rho_h $	or	$PHIV = \arg \rho_v $

The H and V average channel powers are computed with optional noise correction as follows.

Table 7 H and V Average Channel Powers

	Transmit Horizontal	or	Transmit Vertical
Co-	$g_h^r g_h^t S_{hh} = \langle S_{hh} ^2 \rangle - N_h$	or	$g_v^r g_v^t S_{vv} = \langle S_{vv} ^2 \rangle - N_v$

	Transmit Horizontal	or	Transmit Vertical
Cross-	$g_v^r g_h^t S_{vh} = \langle S_{vh} ^2 \rangle - N_h$	or	$g_h^r g_v^t S_{vh} = \langle S_{vh} ^2 \rangle - N_h$

The complex covariance ρ (used above) is as follows:

Table 8 Complex Covariance ρ

Transmit Horizontal	or	Transmit Vertical
$\rho_h = \frac{\langle S_{vh} S_{hh}^* \rangle}{\sqrt{S_{vh} S_{hh}}}$	or	$\rho_h = \frac{\langle S_{vh} S_{hh}^* \rangle}{\sqrt{S_{vh} S_{hh}}}$

Fortunately, the algorithms do not require us to know each gain term. They cancel in the calculation of r , so they are taken as $=1$ in the implementation. However, the differential receiver gain LDR Offset must be known from the calibration to calculate LDR:

dB value is: $XDR = 10 \log xdr$ where the linear value is $xdr \frac{g_v^r}{g_h^r}$.

2.6 Case 2: Simultaneous Dual Transmit and Receive (STAR)

2.6.1 Case 2: Input Receiver Samples

In this mode, there is simultaneous transmit and receive of both vertical and horizontal polarization. For each pulse, there is a measurement of the amplitude in each channel, for example:

$$[S_{hh}^1 : S_{vv}^1][S_{hh}^2 : S_{vv}^2][S_{hh}^3 : S_{vv}^3] \cdots [S_{hh}^M : S_{vv}^M]$$

We assume that the M samples are collected for processing.



Even though there is cross-polarized radiation received in each channel, this cross-polar contribution can be neglected, since the co-polarized received signal is much stronger.

2.6.2 Case 2: Calculation of Polarization Measurands

The processing is done by pulse pair mode. However, both FFT and random phase processing can be performed only if Z_{dr} and standard moments are requested for output. In any mode, you may select a clutter filter.

RVP900 calculates the polarization parameters as follows:

$$ZDR = 10LOG \left[\frac{S_{hh}}{S_{vv}} \right]$$

$$ZDR = 10LOG \left[\frac{\langle |S_{hh}|^2 \rangle - N_h}{\langle |S_{vv}|^2 \rangle - N_v} \right] + GDR$$

$$RHOHV = |\rho_{hv}(0)|$$

$$PHIDP = \arg[\rho_{hv}(0)]$$

Where the following definitions are used:

Transmit Horizontal	or	Transmit Vertical
$g_h^r g_h^t S_{hh} = \langle S_{hh} ^2 \rangle - N_h$	or	$g_v^r g_v^t S_{vv} = \langle S_{vv} ^2 \rangle - N_v$

The noise powers within the 2 channels are denoted as N_h and N_v . The noise corrections to S_{hh} and S_{vv} are optionally configured in the TTY setups. The Z_{dr} Offset is the total (transmit and receive) differential channel gain. It must be calibrated for the system as follows:

dB value is: $ZDR\ Offset = 10LOGoffset$ where the linear value is $offset = \frac{g_v^r g_v^t}{g_h^r g_h^t}$.

The correlation function is computed as follows:

$$\rho_{hv}(0) = \frac{\langle S_{vh} S_{hh}^* \rangle}{\sqrt{S_{hh} S_{vv}}}$$

The gain terms cancel in the calculation of ρ , so in the implementation they are assumed to be =1.

2.7 Case 3: Alternating H/V Transmit: Single Receiver

2.7.1 Case 3: Input Receiver Samples

This is the traditional Z_{dr} radar with a high-power, fast switch that alternates between horizontal and vertical on each pulse. The switch is made just prior to the transmit pulse, so that the transmitter radiates, and then receives at a single polarization for each pulse.

The samples are as follows:

$$[S_{hh}^1][S_{vv}^2][S_{hh}^3] \dots [S_{vv}^{M+1}]$$

For this discussion, we assume that there are $M+1$ total samples with $M/2$ horizontal pulses indexed by (1, 2, 3 ... $M-1$) and $M/2+1$ vertical pulses indexed at (2, 4, 6 ... M).



The processor does not assume that the first pulse in a sequence is horizontal.

2.7.2 Case 3: Calculation of Polarization Measurands

The processing is done in pulse pairs with an optional clutter filter.

RVP900 calculates the following:

$$ZDR = 10 \log \left[\frac{S_{hh}}{S_{vv}} \right]$$

$$ZDR = 10 \log \left[\frac{\langle |S_{hh}|^2 \rangle - N_h}{\langle |S_{vv}|^2 \rangle - N_v} \right] + GDR$$

$$PHIDP = \frac{1}{2} \arg[R_a R_b^*]$$

$$RHOHV = \frac{|\rho_{hv}(T_s)|}{[\rho_{hv} 2T_s]^{0.25}}$$

Using the following definitions:

$$|\rho_{hv}(T_s)| = \frac{|R_a| + |R_b|}{2\sqrt{S_{hh}S_{vv}}}$$

$$\rho(2T_s) = \frac{\sum_{n=1}^{\frac{M}{2}-1} (S_{hh}^*[2n-1]S_{hh}[2n+1] + S_{vv}^*[2n]S_{vv}[2n+2])}{\left(\frac{M}{2}-1\right)(S_{hh} + S_{vv})}$$

$$R_a = \frac{M}{2} \sum_{n=1}^{\frac{M}{2}} S_{hh}^{2n-1*} S_{vv}^{2n}$$

$$R_b = \frac{1}{\frac{M}{2}} \sum_{n=1}^{\frac{M}{2}} S_{vv}^{2n*} S_{hh}^{2n+1}$$

The calculation of the channel powers ($\langle |S_{hh}|^2 \rangle$ and $\langle |S_{vv}|^2 \rangle$) is done using alternating pulses.



In the calculation of R_b , RVP900 uses the extra $M+1$ sample. The gain terms cancel in the calculation of r , so in the implementation they are assumed to be 1.

2.8 Case 4: Alternating H/V Transmit: Dual Receiver

2.8.1 Case 4: Input Receiver Samples

This is the most comprehensive case of polarization operation, since it permits calculation of all of the polarization measurands. In this case, the transmitter alternates pulse-to-pulse between horizontal and vertical polarization, and the dual-channel receiver provides measurement of both the co- and the cross-polarized return as follows:

$$[S_{hh}^1: S_{vh}^1][S_{vv}^2: S_{hv}^2][S_{hh}^3: S_{hv}^3] \dots [S_{vv}^{M+1}: S_{hv}^{M+1}]$$

We assume that $M+1$ samples are collected for processing (an extra sample is required for the calculation R_b as in [Case 3: Alternating H/V Transmit: Single Receiver \(page 17\)](#)).

2.8.2 Case 4: Calculation of Polarization Measurands

RVP900 calculates the following:

- **Co-polar channel measurements**

Z_{dr} , Φ_{DP} , ρ_{HV}

Identical to alternating case, see [Case 3: Alternating H/V Transmit: Single Receiver \(page 17\)](#).

- **Cross-polar channel measurements**

$LDRH$, ρ_{H} , Φ_{iH}

$LDRV$, ρ_{V} , Φ_{iV}

Identical to fixed case, see [Case 1: Fixed Transmit: Dual-Channel Receiver \(page 15\)](#).

The co-polar channel measurements are the same as for the alternating single-receiver case. The cross-polar measurements are calculated using fixed case algorithms, except they are calculated for both H and V polarizations.

2.9 Standard Moment Calculations (T, Z, V, W)

Standard moments are available for each polarization case. Since there can be up to 4 channels of time series input, there are several choices for computing the standard moments. For example, in the STAR mode (see [Case 2: Simultaneous Dual Transmit and Receive \(STAR\) \(page 16\)](#)), the standard moments are computed from:

- S_{hh} samples
- S_{vv} samples
- Average of the results from the S_{hh} and S_{vv} samples



The reflectivity moment can be computed from the S_{hh} , S_{vv} , and S_{hv} samples simultaneously in all 3 choices.

In [Case 3: Alternating H/V Transmit: Single Receiver \(page 17\)](#), the case is handled by averaging the individual channel correlations, and then using the average correlations in the standard moment processing. The averaging must take into account the differential gain of the channels.

The method to use is selected in the setup. There are 4 questions in the **mp** section:

T/Z/V/W computed from: H-Xmt:YES V-Xmt:YES

T/Z/V/W computed from: Co-Rcv:YES Cx-Rcv:NO

Given a choice between vertical and horizontal transmit, the first 2 questions specify which transmit polarization should be used.

When choosing:

- H-Xmt:YES V-Xmt:NO logic, V and W are computed from the H-channel co-receiver
- H-Xmt:NO V-Xmt:YES logic, V and W are computed from the V-channel co-receiver
- H-Xmt:YES V-Xmt:YES logic, V and W are computed from the averaged correlations from both receivers



RVP900 can produce ZH, ZV, and ZHV with any logical selection.

For the fixed H or V case, where there is only one transmit polarization, this question does not apply. The processor uses samples for the polarization that is transmitted.

Given a choice between using the co- or cross-polar receivers, the second 2 questions are define which one should be used. This question applies only to systems that can measure LDR, (fixed or alternating transmit, dual-channel receiver systems).

The tables in [Reflectivity Calibration Parameters \(page 21\)](#) summarize the standard moment calculations for each mode and how to configure the four TTY setup responses.



These are the only supported modes. Some combinations of responses are unsupported. For example, it is not supported to answer both Co-Rcv: NO and Cx-Rcv: NO.

Each table identifies the transmitter/receiver case and what samples are available. The notation **HH** signifies that the s_{hh} samples are available. The tables use "—" to indicate that either a **YES** or **NO** response causes the same result, RVP900 does not care what response is made. In cases where averaging is performed, the type of weighting used is indicated.

2.9.1 Model for Standard Moment Autocorrelations

The model for the moment autocorrelation calculations is as follows (using R_0 as an example):

$$R_0^{hh} = g_h^r g_h^t S'_{hh} + N_h$$

$$R_0^{vv} = g_v^r g_v^t S'_{vv} + N_v$$

$$R_0^{hh}, R_0^{vh}, R_0^{vv}, R_0^{hv}$$

The autocorrelations of the samples at lag 0.

$$S_{hh}, S_{vh}, S_{vv}, S_{hv}$$

The average power returned from the scatterers.

$$g_h^r, g_v^r$$

Receiver gains for horizontal and vertical receive.

$$g_h^t, g_v^t$$

Transmitter gains for horizontal and vertical transmit.

$$N_h, N_v$$

Measured noise power of the samples.

The power that is measured in a channel has comprises:

- Backscattered power from the targets that is effected by the transmitter and receiver channel gains
- Receiver noise, which is measured by RVP900 during noise sampling

In R_1 and R_2 autocorrelations, the model is similar, except there is no noise bias.

2.9.2 Reflectivity Calibration Parameters

For dBZ calculations, a calibration constant is required; the dBZ_0 value described in *RVP900 Digital Receiver and Signal Processor User Guide*.

Depending on the polarization case and the technique selected for standard moment calculation, it may also be required to have Z_{dr} Offset and LDR Offset:

- Z_{dr} Offset
The ratio of the total gains (transmit/receive) of the 2 co-receive channels.
- LDR Offset
The ratio of the receiver gains in a dual receiver system.
This is not required for [Case 2: Simultaneous Dual Transmit and Receive \(STAR\) \(page 16\)](#) or [Case 3: Alternating H/V Transmit: Single Receiver \(page 17\)](#).

RVP900 supports a single calibration reflectivity dBZ_0 . In most cases, it is assumed that the dBZ_0 is for the horizontal co-receive (HH) channel. The exception is for fixed vertical polarization, in which the algorithm assumes that the calibration is for the vertical co-receive (VV) channel. LDR Offset and Z_{dr} Offset are also downloaded and used to adjust the dBZ_0 .

as required, depending on the user's selection for the standard moments. For example, in STAR mode, if the user selects dBZ to be computed from the VV channel, the dBZ_0 for the HH and a Z_{dr} Offset adjustment are used to calculate the dBZ in the VV channel. See [Calibration Considerations \(page 94\)](#).

Table 9 Case 1H: Fixed Horizontal Transmit, Dual Channel Receive- (HH, VH)

dBZ ₀ from HH Channel	TTY Setup Question Responses			
Calculate T, Z, V, W from:	HXmt	VXmt	CoRcv	CxRcv
HH (co) (Recommended)	—	—	YES	NO
VH (LDR Offset ⁻¹ weighting)	—	—	NO	YES
HH+VH (xdr ⁻¹ weighting)	—	—	YES	YES

HH Channel (Co-Pol)

HH channel (co-pol) is the recommended channel for linear polarization because, for linear polarization, the co-polar channel has the strongest signal. Processing is identical to a conventional radar.

VH Channel (Cross-Pol)

VV channel (cross-pol) is used for circular or elliptic transmit polarization. Since the algorithm assumes that dBZ_0 is from the co-polar channel, x_{dr} is used to adjust the autocorrelations as follows:

$$T_0 = x_{\text{dr}}^{-1} T_0^{vh}$$

$$R_{(0)} = x_{\text{dr}}^{-1} R_0^{vh}$$

$$R_1 = x_{\text{dr}}^{-1} R_1^{vh}$$

$$R_2 = x_{\text{dr}}^{-1} R_2^{vh}$$

$$N = x_{\text{dr}}^{-1} N_v$$

These adjusted autocorrelations are used as input to the standard moment processing for a conventional radar. For example, in reflectivity processing, the radar equation can be written as follows (see *RVP900 Digital Receiver and Signal Processor User Guide*):

$$Z^{vh} = CS_{vh} r^2 = \left[\frac{Cr^2 N_v}{g_v^r g_h^t} \right] \left[\frac{r^2}{r_0^2} \right] \left[\frac{T_0^{vh} - N_v}{N_v} \right]$$

$$\text{where } T_0^{vh} = g_v^r g_h^t S_{vh} - N_v$$

$$= \left[\frac{Cr_0^2 N_h}{g_h^r g_h^t} \right] \left[\frac{r^2}{r_0^2} \right] \left[\frac{T_0^{vh} - N_v}{N_h} \right]$$

The third term is $1/X_{\text{DR}}$ and is written as follows:

$$Z^{vh} = \left[\frac{Cr_0^2 N_h}{g_h^r g_h^t} \right] \left[\frac{r^2}{r_0^2} \right] \left[\frac{xdr^{-1} T_0^{vh} - xdr^{-1} N_v}{N_h} \right]$$

The first term is the dBZ_0 for the HH channel. We can use the dBZ_0 for the HH channel to calibrate the cross-channel, if we first adjust the cross-channel noise and power by $1/xdr$, and then normalize by N_h . The reflectivity calculation assumes that the calibrated xdr value compensates for any differences in the radar constant between the 2 channels. We do not need separate radar constants for the 2 channels.

HH+VH Channels

HH+VH channels are used for elliptic transmit polarizations that give comparable return signal in both the co- and cross-channels. The approach is to obtain average autocorrelation functions as follows:

$$T_0 = \frac{T_0^{hh} + xdr^{-1} T_0^{vh}}{2}$$

$$R_0 = \frac{R_0^{hh} + xdr^{-1} R_0^{vh}}{2}$$

$$R_1 = \frac{R_1^{hh} + xdr^{-1} R_1^{vh}}{2}$$

$$R_2 = \frac{R_2^{hh} + xdr^{-1} R_2^{vh}}{2}$$

$$N = \frac{N_h + xdr^{-1} N_v}{2}$$

These adjusted autocorrelations are used as input to the standard moment processing for calibration with respect to the HH channel.

Table 10 Case 1V: Fixed Vertical Transmit and Dual Channel Receive- (VV, HV)

dBZo from VV Channel	TTY Setup Question Responses			
Calculate T, Z, V, W from:	HXmt	VXmt	CoRcv	CxRcv
VV (co)	—	—	YES	NO
HV (xdr weighting)	—	—	NO	YES
VV+HV (xdr weighting)	—	—	YES	YES

This is the only case for which the calibration constant dBZ_0 for the VV channel should be downloaded to the signal processor.

VV Channel (Co-Pol)

VV channel (co-pol) is the recommended channel for the case of linear polarization. The reason is that for linear polarization, the co-polar channel has the strongest signal. Processing is identical to a conventional radar.

HV Channel (Cross-Pol)

HV channel (cross-pol) is used for circular or elliptic transmit polarization when most of the return is in the cross-pol channel. Since the algorithm assumes that dBZ_0 is from the co-polar channel, xdr is used to adjust the autocorrelations as follows:

$$T_0 = xdrT_0^{vh}$$

$$R_0 = xdrR_0^{hv}$$

$$R_1 = xdrR_1^{hv}$$

$$R_2 = xdrR_2^{hv}$$

$$N = xdrN_h$$

These adjusted autocorrelations are used as input to the standard moment processing with dBZ_0 calibrated with respect to the VV channel.

VV+HV Channels

VV+HV channels are used for elliptic transmit polarizations that give comparable return signal in both the co- and cross-channels. The approach is to obtain average autocorrelation functions as follows:

$$T_0 = \frac{T_0^{vv} + xdrT_0^{hv}}{2}$$

$$R_0 = \frac{R_0^{vv} + xdrR_0^{hv}}{2}$$

$$R_1 = \frac{R_1^{vv} + xdrR_1^{hv}}{2}$$

$$R_2 = \frac{R_2^{vv} + xdrR_2^{hv}}{2}$$

$$N = \frac{N_v + xdrN_h}{2}$$

These adjusted autocorrelations are used as input to the standard moment processing algorithms with dBZ_0 calibrated with respect to the VV channel.

Table 11 Case 2: Simultaneous Transmit and Receive- STAR (HH, VV) & Case 3: Alternating Transmit Single-Channel Receive (HH, VV)

dBZo from HH Channel	TTY Setup Question Responses			
Calculate T, Z, V, W from:	H-Xmt	V-Xmt	Co-Rcv	Cx-Rcv
HH	YES	NO	—	—
VV (Z_{dr} Offset ⁻¹ weighting)	NO	YES	—	—
HH+VV (gdr ⁻¹ weighting)	YES	YES	—	—

A fundamental difference between these 2 cases is that for all standard moment processing choices, the STAR case has double the number of samples compared to the single-channel alternating case. The processing is otherwise identical.

HH Channel

Since the HH channel is directly calibrated, this is the recommended choice. Processing is identical to a conventional radar.

VV Channel

In VV channel, GDR is used to adjust the autocorrelations as follows:

$$T_0 = gdr^{-1}T_0^{vv}$$

$$R_0 = gdr^{-1}R_0^{vv}$$

$$R_1 = gdr^{-1}R_1^{vv}$$

$$R_2 = gdr^{-1}R_2^{vv}$$

$$N = gdr^{-1}N_v$$

These adjusted autocorrelations are used as input to the standard moment processing algorithms with dBZ_0 calibrated with respect to the HH channel.

HH+VV Channels

HH+VV channels approach gives the benefit of doubling the number of samples used for the reflectivity calculation as follow:

$$T_0 = \frac{T_0^{hh} + gdr^{-1}T_0^{vv}}{2}$$

$$R_0 = \frac{R_0^{hh} + gdr^{-1}R_0^{vv}}{2}$$

$$R_1 = \frac{R_1^{hh} + gdr^{-1}R_1^{vv}}{2}$$

$$R_2 = \frac{R_2^{hh} + gdr^{-1}R_2^{vv}}{2}$$

$$N = \frac{N_h + gdr^{-1}N_v}{2}$$

These adjusted autocorrelations are used as input to the standard moment processing algorithms with dBZ_0 calibrated with respect to the HH channel.

Table 12 Case 4: Alternating Dual-Channel (HH, VH, VV, HV)

dBZo from HH Channel		TTY Setup Question Responses		
Calculate T, Z, V, W from:		HXmt	VXmt	CoRcv
				CxRcv

dBZ ₀ from HH Channel	TTY Setup Question Responses			
	YES	NO	YES	NO
HH	YES	NO	YES	NO
VH (xdr ⁻¹ weighting)	YES	NO	NO	YES
VV (gdr ⁻¹ weighting)	NO	YES	YES	NO
HV (xdr/gdr weighting)	NO	YES	NO	YES
HH+VV (gdr ⁻¹ weighting)	YES	YES	YES	NO
HV+VH (xdr & gdr weighting)	YES	YES	NO	YES

HH Channel

Since the HH channel is directly calibrated, this is the recommended choice. Processing is identical to a conventional radar.

VH Channel

Processing is identical to [Case 1: Fixed Transmit: Dual-Channel Receiver \(page 15\)](#).

VV Channel

Processing is identical to [Case 2: Simultaneous Dual Transmit and Receive \(STAR\) \(page 16\)](#)) and [Case 3: Alternating H/V Transmit: Single Receiver \(page 17\)](#).

HV Channel

The weighting in HV channel uses both **xdr** and **gdr** as follows:

$$T_0 = \frac{xdr}{gdr} T_0^{hv}$$

$$R_0 = \frac{xdr}{gdr} R_0^{hv}$$

$$R_1 = \frac{xdr}{gdr} R_1^{hv}$$

$$R_2 = \frac{xdr}{gdr} R_2^{hv}$$

$$N = \frac{xdr}{gdr} N_h$$

These adjusted autocorrelations are used as input to the standard moment processing algorithms with dBZ₀ calibrated with respect to the HH channel.

HH+VV Channels

Processing is identical to [Case 2: Simultaneous Dual Transmit and Receive \(STAR\) \(page 16\)](#)) and [Case 3: Alternating H/V Transmit: Single Receiver \(page 17\)](#).

HV+VH Channels

The weighting in HV+VH processing must correct for both transmitter and receiver effects in order to use the HH channel dBZ₀ as follows:

$$T_0 = \frac{\frac{xdr}{gdr}T_0^{hv} + xdr^{-1}T_0^{vh}}{2}$$

$$R_0 = \frac{\frac{xdr}{gdr}R_0^{hv} + xdr^{-1}R_0^{vh}}{2}$$

$$R_1 = \frac{\frac{xdr}{gdr}R_1^{hv} + xdr^{-1}R_1^{vh}}{2}$$

$$R_2 = \frac{\frac{xdr}{gdr}R_2^{hv} + xdr^{-1}R_2^{vh}}{2}$$

$$N = \frac{\frac{xdr}{gdr}N_h + xdr^{-1}N_v}{2}$$

These adjusted autocorrelations are used as input to the standard moment processing algorithms with **dBZ₀** calibrated with respect to the HH channel.

Suppose that we want to compute the average of the reflectivities for the VH and HV channels. An example this weighted averaging is as follows:

$$\begin{aligned} Z^{hv+vh} &= Cr^2 \frac{S_{hv} + S_{vh}}{2} \\ &= Cr^2 \frac{\frac{T_0^{hv} - N_h}{g_h^r + g_h^t} + \frac{T_0^{vh} - N_v}{g_v^r + g_h^t}}{2} = \frac{Cr^2}{g_h^r g_h^t} \frac{(T_0^{hv} - N_h) \frac{g_h^t}{g_v^t} + (T_0^{vh} - N_v) \frac{g_h^r}{g_v^r}}{2} \end{aligned}$$

but since $xdr = \frac{g_h^r}{g_v^r}$ and $gdr = \frac{g_v^r g_v^t}{g_h^r g_h^t}$

$$Z^{vh+hv} = \frac{Cr^2}{g_h^r g_h^t} \left[\frac{\frac{xdr}{gdr}T_0^{hv} + xdr^{-1}T_0^{vh}}{2} - \frac{\frac{xdr}{gdr}N_h + xdr^{-1}N_v}{2} \right]$$

$$Z^{vh+hv} = \frac{Cr^2}{g_h^r g_h^t} [T_0 - N] = \left[\frac{Cr^2 N_h}{g_h^r g_h^t} \right] \left[\frac{r^2}{r_0^2} \right] \left[\frac{T_0 - N}{N_h} \right]$$

The first term in brackets is precisely **dBZ₀** for the HH channel. If we average the correlations using the appropriate **gdr** and **xdr** weighting, the average reflectivity is obtained by using conventional processing with the HH channel **dBZ₀**.

3. Attenuation Correction of Z

3.1 Attenuation Correction of Z Overview

In dual polarization radars, the measurements consist of measuring the amplitude and phase of the received waveforms in the two separate channels. PhiDP is the phase difference between the 2 polarization channels at each range bin.

The PhiDP quantity primarily comes from the propagational effects as the RF energy passes through some medium to the measurement point and back again to the transmitter/receiver. The PhiDP measurement tends to be a noisy, unstable quantity, due to the slightly different backscattering phase shifts from the scatterers at the range point and statistical measurement errors.

The unambiguous range of PhiDP is 360° in the simultaneous operation mode. However, phase changes of more than 360° are common, especially with smaller wavelength radars, and cause PhiDP to be phase wrapped.

PhiDP is directly related to the amount of liquid water content the transmitted energy passes through to get to the scatterers at a specific range bin. Therefore, PhiDP has advantages when used to estimate attenuation caused by liquid water. In dual polarization radars, the range derivative, or specific differential phase (K_{dp}) is also a key data type to indicate rainfall rates.

Before to using PhiDP for any of these applications, it must be conditioned and unfolded. Here, conditioning means to smooth out the inherent noisy properties of the data, yet be able to capture and maintain the range and amplitude resolution common within intense rain cells. See [PHiDP Unfolding and Conditioning \(page 29\)](#).

The conditioned PhiDP is fed to:

- A dual polarization-based attenuation correction algorithm. See [Dual Polarimetric Attenuation Correction \(page 31\)](#).
- An adaptive K_{dp} algorithm. See [Adaptive \$K_{dp}\$ Moment Estimation \(page 35\)](#).

After these are applied, the IRIS and RDA software makes optimal use of the dual-channel measurements, creating data types for the following applications:

- Hydrometeor particle identification
- Lightning hazard potential forecasting
- Detection of convection and stratiform rain
- Highway snow removal
- Airport terminal operation
- Rain/snow line demarcation
- Melting height detection
- Weather modification for hail mitigation
- Insurance industry claims verification
- Military detection of chaff
- Data quality improvement by elimination of non-meteorological targets
- Improved precipitation forecasting
- Hydrological modeling

Dual polarimetric attenuation correction is a collection of algorithms, which may be performed in real-time, in the RVP900 signal processors, or in the IRIS application software. See [Dual Polarimetric Attenuation Correction \(page 31\)](#).

More information

- [Differential Phase \(PhiDP\) and Specific Differential Phase \(Kdp\) \(page 8\)](#)

3.2 PHiDP Unfolding and Conditioning

When computed for each range bin, PhiDP is inherently noisy, especially in volume samples not having meteorological scatterers present.

PhiDP can typically have values greater than 360° of phase difference, causing folding in the valid data ranges used in IRIS/RDA. Therefore, the first processing steps are to smooth and unfold the PhiDP data.

The following methodologies are available for unfolding and conditioning PhiDP data:

- Least squares fit (LSQ). ¹⁾
- Cubic spline fit. ²⁾

The cubic spline fit is the recommended process. The methodology to be executed is a user-selectable option in IRIS and RDA processing.

3.2.1 Least Squares Fit

In the Least Squares Fit (LSQ) model, the PhiDP unfolding procedure is combined with the conditioning/filtering of PhiDP.

The measured PhiDP are stored as 32-bit unsigned integers. The PhiDP ambiguity interval is mapped linearly into the full range of unsigned integers.

At each bin, an LSQ, weighted with FIR filter coefficients, is performed to compute "conditioned" PhiDP. This LSQ is performed 3 times at each bin, each having a unique phase shift being tracked. One phase shift, ϕ , is constantly adjusted to keep the current PhiDP in the middle of the ambiguity interval. For the other 2 LSQs, the phases are shifted by the ambiguity interval, $\phi \pm \frac{2}{3}$. The LSQ with the lowest signal-to-noise ratio is assumed to be the unfolded quantity.

The following figure shows the input data and outcomes of this LSQ technique.

1) Panov, S., R. Keranen, and V. Chandrasekar, 2008: Assessment of the Polarimetric Attenuation Correction Implementation in the RVP8 Signal Processor. 5th European Conference on Radar in Meteorology and Hydrology, Helsinki, Finland.

2) Chandrasekar, V., and Y. Wang, 2009: Adaptive Specific Differential Phase at Dual-Polarization Radar International Application Published under the Patent Cooperation Treaty. WO 2009/114868 A1.

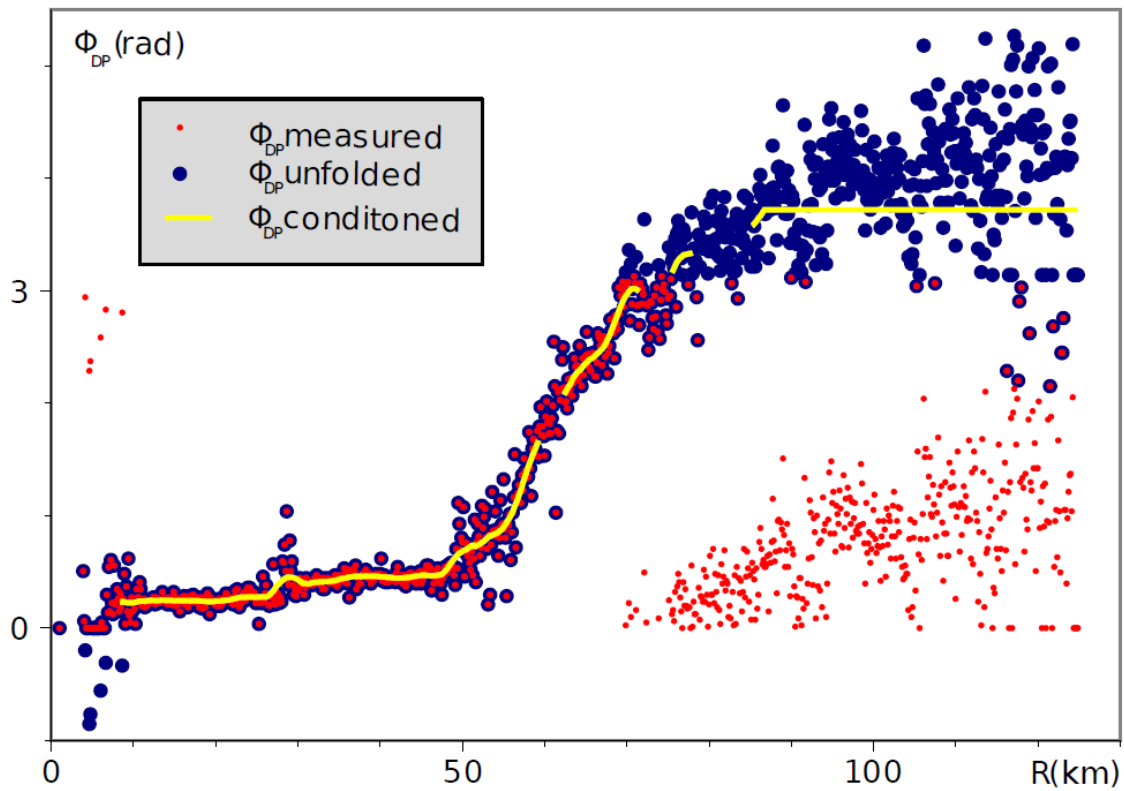


Figure 2 Unfolding and Conditioning of Bin to Bin PhiDP

3.2.2 Cubic Spline Fit

LSQ is a practical phase unfolding approach, however; it creates a test condition to check for phase unfolding when at times the test may fail.

The cubic spline fit approach transforms the PhiDP between the 2 receive channels to the complex domain, creating an Angular PhiDP vector. This is a similar concept used when creating I,Q for signal processing. The advantage in using Angular PhiDP is that the data remains continuous in the complex domain, where as the traditional PhiDP moments in the real domain phase wraps with abrupt jumps. To compute the Angular PhiDP moment:

$$\vartheta(r) = e^{j\psi_{dp}(r)} \text{ for STAR mode dual polarization}$$

$$\vartheta(r) = e^{j2\psi_{dp}(r)} \text{ for alternating mode of dual polarization}$$

Where $\vartheta(r)$ is the Angular PhiDP at some range and ψ_{dp} is the total differential phase.

For information on conditioning and smoothing of Angular PhiDP, see [Adaptive K dp Moment Estimation \(page 35\)](#).

3.3 Dual Polarimetric Attenuation Correction

Dual polarimetric attenuation correction is a collection of algorithms, using the unfolded and conditioned PhiDP.

These algorithms may be performed in real-time within the RVP900 signal processors, or within the IRIS application software.

Table 13 Performing Attenuation Correction with RVP or IRIS

RVP or IRIS	Description	Advantages and Disadvantages
RVP900 DP Attenuation Correction Processing	Ray data are processed in the RDA, and the bin level moments are output in real-time for each range bin.	<p>The RDA software can apply immediate corrections with the signal processor being available on real-time data output. This becomes important in mission critical now-casting within the 0 ... 1 hr time frame, where the latest observed information is needed for precise decision making.</p> <p>With RDA, all moments are available in every bin. When performing the function in IRIS, certain moments within the bins are thresholded.</p> <p>This approach is well suited for applications where IRIS software is not active, since the particle type can be displayed directly by the customer's display software.</p>
IRIS DP Attenuation Correction Processing	<p>Dual polarization data comes from RVP900, or from a third party processor, and are passed to an IRIS/Radar or an IRIS/Analysis system that is enabled with the dual polarization feature license.</p> <p>The bin level algorithms produce ingest data, which are formatted as RAW products for archival, or for rerouting in the network.</p> <p>The correction algorithm can also be applied to historical data.</p>	<p>IRIS processing has an advantage since the original Z and Z_{dr} moments are uncorrected for attenuation; IRIS makes new data types.</p> <p>IRIS processing allows for creating the corrected moments with archived data. This allows you to compare the results of the correction.</p> <p>Disadvantages to using IRIS are the time delay to have the corrected moments and that data is likely already been thresholded causing some range bins to have missing data.</p>

Signal attenuation in precipitation is a well known problem for weather radars using smaller wavelengths, like 3 ... 5 cm (1.18 ... 1.97 in) in the X- and C-band spectrums. The attenuation causes a decrease in the Z and Z_{dr} measurements, making their use in quantitative analysis limited. The attenuation effects also impact the outcomes of the 'fuzzy logic' set of algorithms like HydroClass. It is important to estimate the amount of attenuation, and make corrections to the Z and Z_{dr} data types prior to processing algorithms. These corrections ultimately improve the ability to accurately estimate rainfall, differentiate hydrometeors, and assess data quality metrics.

In case of the dual polarization radar, the differential propagation phase moment PhiDP , provides an excellent method to estimate attenuation of Z and Z_{dr} , as the change in PhiDP is directly related to the liquid water content along the propagation path. PhiDP is not affected by attenuation or calibration errors, but allows large, accurate corrections.

The traditional single polarization attenuation correction is based on the following relationship:

Equation 1

$$A(r) = a[Z(r)]^b$$

where $A(r)$ is the specific attenuation and $Z(r)$ is the intrinsic reflectivity at any particular range gate. This particular equation is implicit, where an unknown value $A(r)$, is expressed through another unknown value $Z(r)$. The expression to solve for total two-way attenuation is:

Equation 2

$$\text{dBZc} = \text{dBZ} + 2C\Delta r \sum Z^E$$

where the $2C\Delta r \sum Z^E$ term estimates the total two-way attenuation to the range bin, based on the accumulated reflectivity measurement. C and E are constants in this estimation. This equation becomes unstable very quickly and must be highly constrained in order that the corrected reflectivity does not end up having less value than the original.

With dual polarization radar an independent estimate of the specific attenuation is possible:

Equation 3

$$A(r) = \alpha K_{dp}(r)$$

In practice, the $\text{PhiDP}(r)$ measurements to product K_{dp} have much lower accuracy than $Z(r)$, and deviate significantly from the pure “propagation” component. However, the estimate of total cumulative attenuation along the radial is quite accurate and can be used as a constraint for the range specific attenuation corrections.

The IRIS/RDA implementation of dual polarimetric attenuation correction is illustrated in the following figure.

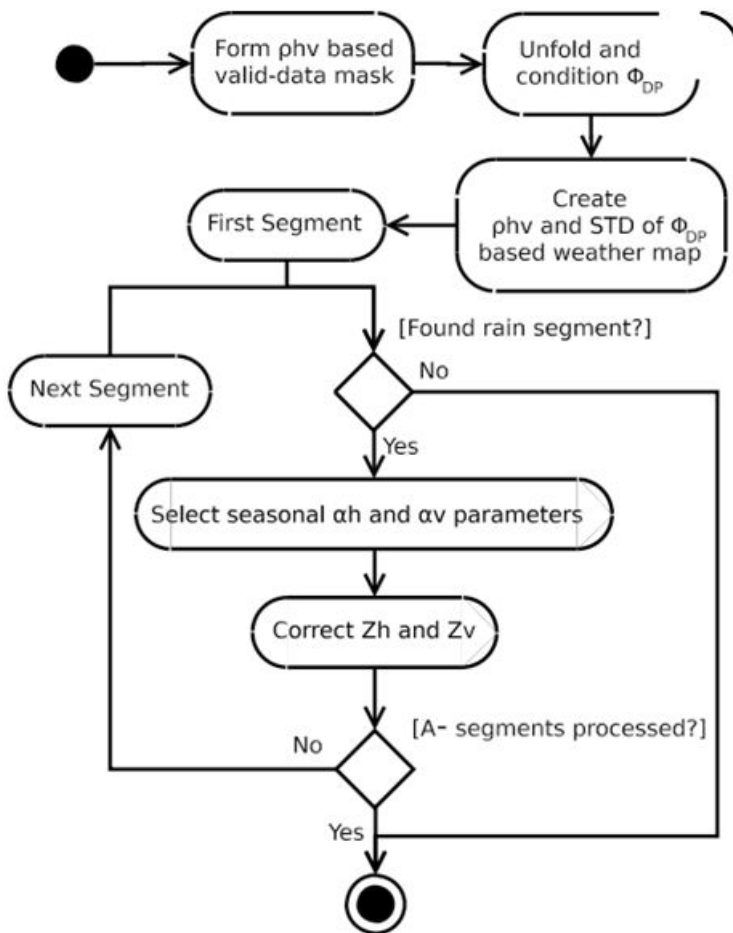


Figure 3 Dual Polarimetric Attenuation Correction Processing Stages

3.3.1 Weather Classification Algorithm

The first processing step is to identify segments along the radial where attenuation occurs. The radial is broken into one or more segments where each segment is either flagged as "liquid rain" or "no weather". The liquid rain portions of the segment are used to calculate the constrained Φ_{DP} . This step is a hydrometeor classifier.

The simple weather classification ensures that changes in Φ_{DP} from non-meteorological targets like ground clutter, point targets, refractivity gradients, and insects do not introduce errors in the attenuation estimate. Reflectivity and differential reflectivity values outside of the segments, identified as rain, are not corrected. Also, small ice particles add only a minute amount to the overall one-way path attenuation. Therefore, once the beam propagation along the radial is higher than the freezing level, additional attenuation is no longer calculated.

The weather classification algorithm relies on 3 known principles or rules about hydrometeor particles:

- Hydrometeors particles tend to have a high value of the co-polar correlation coefficient, RhoHV. A mean RhoHV is computed over a defined length. If the mean value becomes lower than the threshold, range bins are flagged to not use the data. The default value used within this classifier is 0.85.
- Quantitative measurements of PhiDP tend to be highly correlated, from range bin to range bin, when hydrometeor targets are present. This gives a "smooth" looking data field versus more "noisy" fields that are likely to have non-meteorological particles. Therefore, the texture over some area is used as a discriminator. The standard deviation of PhiDP is calculated over the same range as the mean RhoHV. This is used to represent texture along the radial.
- Convective and stratiform meteorological events have some size to them; typically more than a few kilometers. This rule is used to decide when to enter a rain segment and how long this segment must be before exiting to a no weather segment.

Each range bin is uniquely evaluated as being rain or no weather using **Equation 1** and **Equation 2** in [Dual Polarimetric Attenuation Correction \(page 31\)](#).

3.3.2 Iterative PhiDP Correction

For segments identified as rain, a first guess of intrinsic reflectivity is created. The approach is to use the same expression seen in **Equation 2** in [Dual Polarimetric Attenuation Correction \(page 31\)](#), but substituting the change of PhiDP from the beginning to the end of the segment for Z.

This appears as:

Equation 3

$$dBZc = dBZc + 2C\Delta r \sum (\theta_{r \min} - \theta_{r \max})^E$$

For the first rain segment nearest to the radar, the system PhiDP values are initially set by a configuration setting in the RVP900 **dspX** menus. However, this system PhiDP value is constantly updated with the average PhiDP values seen in the first bins of the rain segments.

The initial guess of the intrinsic reflectivity is adjusted using an iterative process, which is constrained by the total attenuation along the entire radial. The total attenuation is now determined by:

Equation 4

$$A = \frac{1}{2} \alpha_h \Delta \Phi_{DP}$$

where the α coefficient is a constant, slightly dependent on temperature. The adjustment is performed by using the ratio of the total attenuation and a summation of measured reflectivity values to the particular range bin to scale the correction.

Equation 5

$$dBZc = dBZ(r) + \frac{A}{\sum_{r=\min}^{r=\max} 10^{0.1b(dBZ(r-1))}} \sum_{r=\min}^r 10^{0.1(dBZb(r-1))}$$

In this manner, the sum of the corrections applied to each range bin are equivalent to the total attenuation, as determined by $\Delta\Phi_{DP}$.

This first guess of intrinsic reflectivity, sometimes called the DP method, may be output from IRIS or the RVP900 software for research purposes. For operational radars, the full IDPC methodology should be used and is the default selection.

3.4 Adaptive K_{dp} Moment Estimation

The specific differential phase, K_{dp} , is the range derivative of the Angular PhiDP, described in [Cubic Spline Fit \(page 30\)](#). This is written as:

$$K_{dp}(r) = -j \left\{ \frac{\vartheta'(r)}{\vartheta(r)} \right\} + e(r)$$

Angular PhiDP has no folding, but is still noisy due to backscattering effects and measurement errors. When performing differentiation of noisy data in the more traditional LSQ method of calculating K_{dp} , the errors are magnified in the K_{dp} output.

With the continuous complex form of Angular PhiDP data, a cubic spline methodology is chosen, because it has the greatest smoothness over all functions evaluating derivatives. Any smoothing function can be overly aggressive causing loss in data fidelity; the over smoothed situation. Therefore, an adaptive process is created to adjust the smoothing function.

The weather classification algorithm described in [Weather Classification Algorithm \(page 33\)](#) is re-used to calculate K_{dp} . The weather classification algorithms defines segments having liquid rain versus other segments. In areas where there is no liquid rain, K_{dp} should be 0. This assumption provides a convenient end condition to determine all the coefficients needed in the cubic spline equation.

The cubic spline processing ³⁾ of the Angular PhiDP is performed in 2 steps. The first pass uses a standard fixed smoothing function, which evaluates the mean and dispersion of Angular PhiDP. The dispersion results from the first pass is then used as a weighting function to adapt or scale the smoothing function to match the properties of the Angular PhiDP data. This adaptive function ensures that the trade-off between smoothness and data fidelity is optimized.

3.5 Setting-up Attenuation Correction of Z

You need a valid dual polarization license code to use the dual polarization attenuation correction function. The code is activated and encrypted in the setup utility GUI field **License**. Two use cases are possible:

- Real-time correction in RVP900
- IRIS dual polarization attenuation correction during the ingest/re-ingest process

3) Wang, Y., and V. Chandrasekar, 2009: Algorithm for Estimation of the Specific Differential Phase. *J. of Atmospheric and Oceanic Technology*, 26, 2565-2578.

The configuration in both cases is specified within the file `/usr/sigmat/config/dualpol.conf`. See [Dual Pol Configuration File for Attenuation Correction of Z](#) (page 37).

3.5.1 Setting-up Real-time Correction in RVP900

This corrects the original Z and ZDR moments. To activate the feature, make sure that:

- ▶ 1. Signal Processor is licensed for dual polarization.
- 2. Signal Processor fundamental operating mode in **dsp**x settings is configured for dual polarization.

Table 14 Fundamental RVP900 Operating Mode: 3

#	BW	DynR	Filt	Pol	IFD	Description
0	Full	Norm	Norm	1	1	Standard single channel
2	Full	Norm	Norm	2	2	Dual Pol on separate IFDs
3	Half	Norm	Norm	2	1	Dual Pol on single IFD
4	Half	Wide	Norm	1	1	Extra wide dynamic range
5	Half	Norm	Long	1	1	Extra long/fast FIR filters

- 3. The dual polarization attenuation filter is enabled using the selection in the **mp** TTY setups:

Polarimetric Attenuation Correction:"USER" or "ALWAYS"

3.5.2 Setting-up IRIS Dual polarization Attenuation Correction

You activate the attenuation correction in the IRIS **Setup** utility.

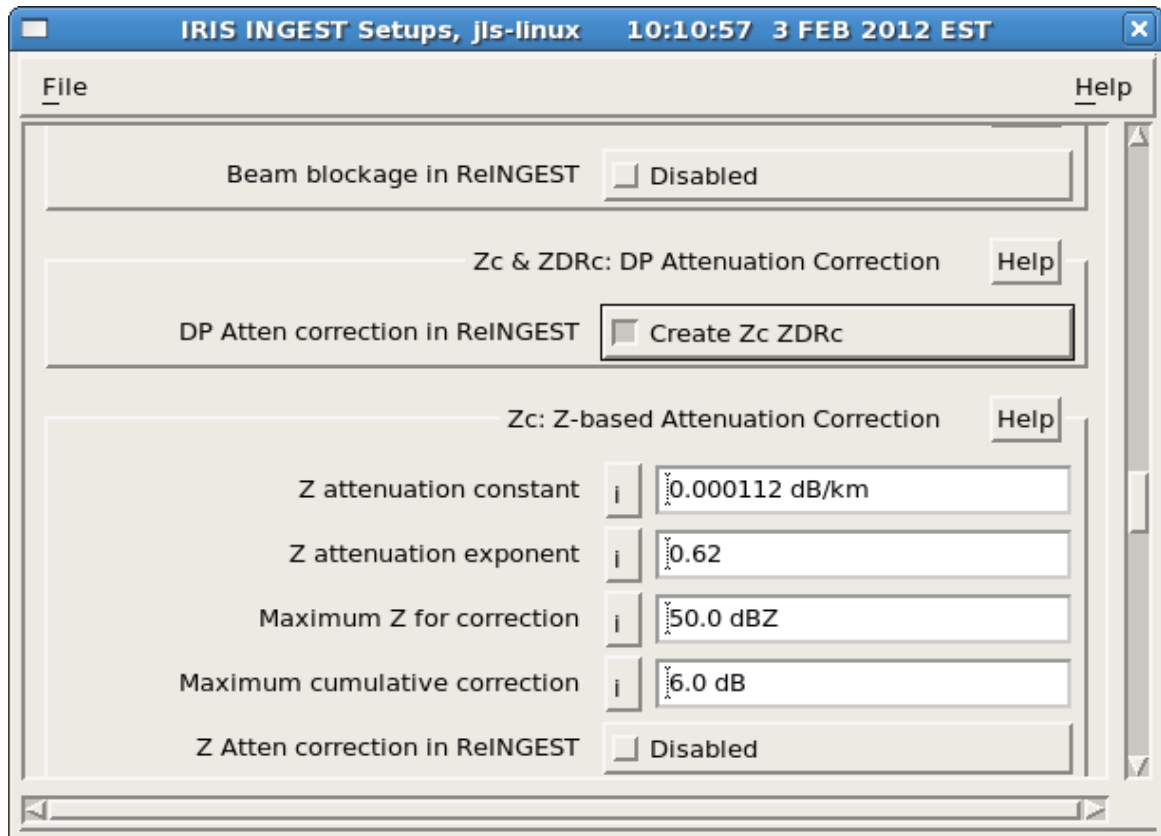


Figure 4 IRIS/Setup Utility - Ingest Tab

- ▶ 1. In IRIS task configuration menu in the processor configuration, enable **DP Attn Cor Z ZDR** and remember to set in the **dspix** utility:
Polarimetric Attenuation Correction:"USER"
2. In IRIS **Setup** utility ingest tab, enable the **DP Atten correction in ReINGEST**.
3. Restart the IRIS system

The installed and activated **Dual Polarimetric Attenuation Correction** runs promptly on appropriate input data and computes results using the current configuration.

3.6 Dual Pol Configuration File for Attenuation Correction of Z

The distinct parameter lines are listed and described below, with their default settings for C-band radars.

The first section of the configuration file sets the parameters used to calculate the actual attenuation at each range bin.

```
#=====#
#Attenuation correction
# Algorithm selection. Available options:
# DP - propagational depolarization based attenuation
#      (dBZ_real(r) = dBZ_measured(r) + alpha PhiDP(r)).
# IDPC - iterative DP constrained attenuation correction.
#      Single iteration with DP corrected dBZ(r) as
#      an initial dBZ(r).
algorithm = IDPC
```

This setting selects of the dual polarimetric attenuation corrections is based on the iterative constrained process or only the first guess field. The recommended setting for all operational systems is **IDPC**.

```
# DP attenuation constant for horizontal polarization alpha_h = 0.105
```

This setting sets the value of the constant used within **Equation 4** (see [Iterative PhiDP Correction \(page 34\)](#)) when computing the total horizontal reflectivity attenuation along the radial. The 0.08 value is the recommended global setting.

This value is slightly variable with temperature. The following table shows the estimated **alpha_h** correction coefficients for several wavelengths and mean temperatures provided by Jameson 1991.

Table 15 Estimated **alpha_h** Correction Coefficients for Different wavelengths and Mean Temperatures

Temperature (°C)	S-band (2.80 GHz)	C-band (5.48 GHz)	X-band (9.34 GHz)
0	0.026	0.097	0.248
10	0.019	0.081	0.241
20	0.015	0.066	0.230
30	0.012	0.053	0.213
40	0.009	0.043	0.195

```
# DP attenuation constant for vertical polarization
alpha_v = 0.065
```

This setting sets the value of the constant used in **Equation 4** when computing the total vertical reflectivity attenuation along the radial. The 0.105 value is the recommended setting. The value is slightly variable with temperature.


```
# The melting layer (aka bright band) above sea level.
# No attenuation is added in the part of the ray above ML
melting_layer = 1300.0
```

This setting sets the height of the 0° C level above the surface reference height in IRIS. This sets a limit in the correction algorithm to not add accumulate additional attenuation when the beam is above this height. This value is only used within the IRIS/Reingest process. RVP900 uses the melting level values specified in setup memory location.

```
# The above value for melting layer is used only if melting
# layer altitude is not set for processed data set or if
# the following flag is set to 'yes'
force_conf_melting_layer = no
```

When re-ingesting data into IRIS and performing dual pol attenuation correction, setting this question to **yes** overwrites the melting level height originally stored with the data. This allows users to correct wrong heights or add a height value to archived data which may not have had the variable stored.

```
# The b parameter from the reflectivity based attenuation
# equation:  $A(r) = a Z(r)^b$ 
b_exp = 0.78
```

This sets the value of the exponent within the summation terms seen in equation 5. The recommended value for C-band radars is 0.78 and 0.46 for X-band radars.⁴⁾

The PhiDP section of the configuration file sets the parameters used to condition and unfold PhiDP for input to the attenuation correction, either the LSQ or Cubic Spline⁵⁾ techniques.

```
# PHIDP processing parameters

# PHIDP processing algorithm type (in IRIS reingest, use
# dspx for RVP):
# LSQ - Weighted least square fit to a linear function
#       FIR filter coefficients are used as weights. Use
#       fir_width to control width of the filter.
# SPLINES - Smoothing and numerical derivatives calculation using cubic
# splines algorithm
PhiDP_alg = SPLINES
```

4) Gorgucci, E., and V. Chandrasekar, 2005: Evaluation of Attenuation Correction Methodology for Dual-Polarization Radars: Application to X-Band Systems. *J. of Atmospheric and Oceanic Technology*, 22, 1195-1206.

5) Chandrasekar, V., and Y. Wang, 2009: Adaptive Specific Differential Phase at Dual-Polarization Radar International Application Published under the Patent Cooperation Treaty. WO 2009/114868 A1.

This parameter allows you to choose SPLINES or LSQ method during IRIS/Reingest processing. In RVP900 processing, a similar question is in the **dspix mp** menu.

```
# Smoothing factor for the first, non-adaptive, stage of
# cubic splines processing (in IRIS reingest, use
# dspix for RVP)
standard_smoothing_factor = 0.1
```

For IRIS/Reingest, this parameter sets the smoothing factor during the first pass through the Angular PhiDP data when performing cubic spline processing. In RVP900 processing, a similar question is in the **dspix mp** menu.

```
# Smoothing factor for the second, adaptive, part of
# cubic splines processing (in IRIS reingest, use
# dspix for RVP)
adaptive_smoothing_factor = 1.1
```

For IRIS/Reingest, this parameter sets the adaptive smoothing factor during the second pass through the Angular PhiDP data when performing cubic spline processing. This factor will be adjusted with a weighting function. In RVP900 processing, a similar question is in the **dspix mp** menu.

```
# The width, in km, of FIR filter used as weights in
# LSQ processing. (in IRIS reingest, use
# dspix for RVP)
fir_width = 3.0
```

For IRIS/Reingest attenuation correction, the impulse response of the FIR filter is configured in kilometer widths. In RVP900 processing, these parameters are set in the **dspix mp** menu. This variable also sets the range window for calculating K_{dp} .

The data thresholding parameters are used to reduce the amount of data being considered during the attenuation correction process. This is performed to reduce the CPU load on the computer.

```
# =====
# Data thresholding parameters (for processing mask)

# The shortest distance, in km, at which polarimetric
# measurements, such as PHIDP, RHOHV, ZDR, etc, are
# meaningful.
recovery_range = 1.0
```

Close to the radar site the dual polarimetric data values may not be representative of the intrinsic values due to near-field antenna issues. This setting specifies an initial range limit to ignore during the attenuation correction processing.

```
# Lowest allowed/meaningful SNR
snr_lim = 3.0
```

With very weak signals the PhiDP measurements become very noisy. A signal to noise ratio threshold may be set. This flags range bins, having SNR below this value, to not be included into the calculations.

```
# Lowest allowed/meaningful RHOHV
rhohv_lim = 0.8
```

Hydrometeor particles typically have RhoHV values greater than 0.85. The setting creates a threshold to not allow data from range bins having RhoHV values below the criteria to enter the calculations.

The weather classification algorithm parameters are used in creating the rain versus no weather classifications. See [Cubic Spline Fit \(page 30\)](#).

```
# =====
# The weather classification algorithm parameters. (for the
# build in weather mask)

# Number of sequentially "good" bins needed to transition
# from "no weather" to "rain".
# Note: It is also the width of the gate used to compute
# STD of PHIDP, and mean value of RHOHV. [bins]
long_gate = 15
```

This question defines the width of a sliding window to calculate the average RhoHV and standard deviation of PhiDP at specific range bins. The window width is defined in range bin units.

```
# Number of sequentially "bad" bins needed to transition
# to "no weather". [bins]
short_gate = 10
```

When the range bin is currently in a rain segment, but the average RhoHV and PhiDP standard deviation are below the thresholds, this setting states how many consecutive range bins must be below the criteria to exit the rain segment.

```
# Lowest allowed mean RHOHV at the transition to "rain"
rhohv_enter_r = 0.85
# Highest standard deviation of PhiDP at the transition
# to "rain" [deg]
PhiDP_std_enter_r = 7
```

These 2 criteria are the definitions when the range bin is considered to be the start or a rain segment. Both criteria must be met to define the start of a rain segment.

```
# Low mean RHOHV that triggers exit from "rain"
rhohv_exit_r = 0.70

# High standard deviation of PhiDP that triggers exit
# from "rain" [deg]
PhiDP_std_exit_r = 15.0
```

This sets the thresholds when the range bin is thought to be bad and should be in the No Weather category. When either of the actual values are below the average RhoHV or above the standard deviation of PhiDP, the bin is flagged as bad. When a consecutive number of [short gate] bins are flagged as bad the rain segment transitions to No Weather.

```
# Lowest allowed SNR in "hail" region
# Note: Should be higher then snr_lim
# snr_exit_h = 8.0
# Lowest allowed RHOHV in "hail" region.
# Note: Should be lower then rhohv_lim_r.
# rhohv_exit_h = 0.6

# Standard deviation of PhiDP that triggers exit from "hail"
# Note: Should be higher then PhiDP_std_exit_r
# PhiDP_std_exit_h = 20.0
```

As hail is uniquely different than the presumed rain and No Weather classification, there is a different amount of attenuation than with liquid hydrometeors. In the future, the attenuation correction algorithm will include a different computation to calculate the amount of attenuation within the hail segment. For now, the parameters to distinguish a hail segment are place holders for future development.

This section allows you to specify parameter quantities per site. This is especially useful in the case of IRIS/Reingest receiving data files from multiple radar sites. To use this parameter, state [SITENAME] as a header line and repeat any of the name-value pairs from within this configuration file that must be unique to that site.

```
# =====
# per-site sections can be used to add per-site variation
# of the parameters set in the general section.
[wes-grad]
alpha_h = 0.1
```

4. HydroClass

4.1 HydroClass Overview

Vaisala Hydrometeor Classification (HydroClass) software makes optimal use of dual-channel measurements to detect the types of scatterers present in the atmosphere, such as rain, hail, snow, graupel, and even non-meteorological targets such as insects, chaff, and sea clutter.

In addition to the improvements in precipitation estimation that are achieved with dual-polarization radar, HydroClass provides the ability to deduce and map the types of scatterers enhances the power of dual-polarization radar for applications such as:

- Hail detection
- Lightning hazard potential forecasting
- Detection of convection and stratiform rain
- Highway snow removal
- Airport terminal operation
- Rain/snow line demarcation
- Melting height detection
- Weather modification for hail mitigation
- Insurance industry claims verification
- Military detection of chaff
- Data quality improvement by elimination of non-meteorological targets
- Improved precipitation forecasting
- Hydrological modeling

4.2 HydroClass Algorithms

HydroClass is a collection of echo identification algorithms in the IRIS and the Digital Signal Processor (RVP900). The HydroClass algorithms output an **HCLASS** data type of echo identification. It is analogous to other data types, such as DBZ, V, Z_{dr} , and so on. For example, the **HCLASS** data type may be used as input to IRIS products such as PPI, CAPPI, XSECT, and WARN.

The HydroClass algorithms can be activated in many steps of radar data processing, depending on the customer use case:

- RVP900 HydroClass Processing
Ray data are processed in RVP900 and the bin level class assignments are output in real-time for each range bin. This approach is well-suited to applications where IRIS software is not active since the particle type can be displayed directly by your display software.

- **RVP900 and IRIS/Radar Processing**
The identification of convection and stratiform rain is based on vertical radar echo structures, which show up in volumes of sweep data. These data are available in the processes of IRIS/Radar. The HydroClass classification of convective and stratiform rain is implemented as part of the IRIS/Radar real-time process.
- **IRIS HydroClass Processing**
Dual polarization data come from RVP900 or from a third party processor, and are passed to an IRIS/Radar or an IRIS/Analysis system that is enabled with the HydroClass feature. The bin level algorithms produce **HCLASS** ingest data, which can be formatted as RAW products for archival or for rerouting in the network. **HCLASS** products are color-coded maps of precipitation classification categories, which can be output to and displayed on other IRIS workstations and IRIS/Web clients. Output of the GIF and other standard image formats is also supported. Archived RAW data can also be reprocessed into classes.

4.2.1 Gate Contents and Precipitation Patterns

Regarding consideration of data radar echo, HydroClass echo identification and classification methods belong to the following categories.

Local (Bin-to-Bin) Classification

These algorithms analyze the echo features in each volume element of observation (gate bin) to estimate the bulk contents of the volume element.

Typically, each gate bin is declared to consist of scatterers of a given type (a class of hydrometeors or of other scatterers). The algorithm may use features of data in the next surroundings of the gate. Even broader information can be used as a specific constraint. In the first order, each bin assignment is deduced from the data features of that particular bin.



Most HydroClass classification methods belong to the local bin-to-bin category.

Spatially Distributed Objects (Weather Pattern)

The type precipitation is sometimes best described as a weather event (pattern), characterized as an extended object in the atmosphere.

A weather event derives its features from large scale spatial (and temporal) distributions. Bin-to-bin consideration ignore these aspects of data. Precipitation patterns are evident to a trained radar meteorologist, and deterministic algorithms exist to identify specified event types.

A classic example is the division into stratiform and convective precipitation. HydroClass supports this type of methodology, too.

4.2.2 HydroClass Fuzzy Logic

HydroClass methods use the fuzzy logic approach to polarimetric radar echo identification. Fuzzy logic allows algorithms to cope with varied levels of consistency, instead of exclusive statements of "yes" and "no". The fuzzy logic outputs can be thought of as degrees of consistencies. In most published literature and in the Vaisala documentation, these output values are known as the rule strengths (RS).

The rule strengths should not be confused with probabilities because the fuzzy memberships and rules typically represent empirically defined sets, rather than statistical likelihoods of events. The latter relates to the frequentist approach to probability. Fuzzy logic is well suited for identifying radar echoes and hydrometeor types because the radar moment signatures of different radar targets and hydrometeors are not mutually exclusive or unique.

The input variables to a fuzzy logic algorithm are first passed into membership functions (MBF). Membership functions quantify the consistency of the particular input variable within a specified output set. A value of 0 means the input variable is not included for a given set and a value of 1 describes a fully included variable. Values between 0 ... 1 characterize partial or fuzzy membership. Membership functions can be one-dimensional or multi-dimensional. For example, consider the use of reflectivity (Z_H) for characterizing hail. It is known empirically, that for lower reflectivity values below ~45 dBZ, the presence of significant hail is unlikely. Using this knowledge, a one-dimensional membership function can be designed for this simple case, shown in the following figure.

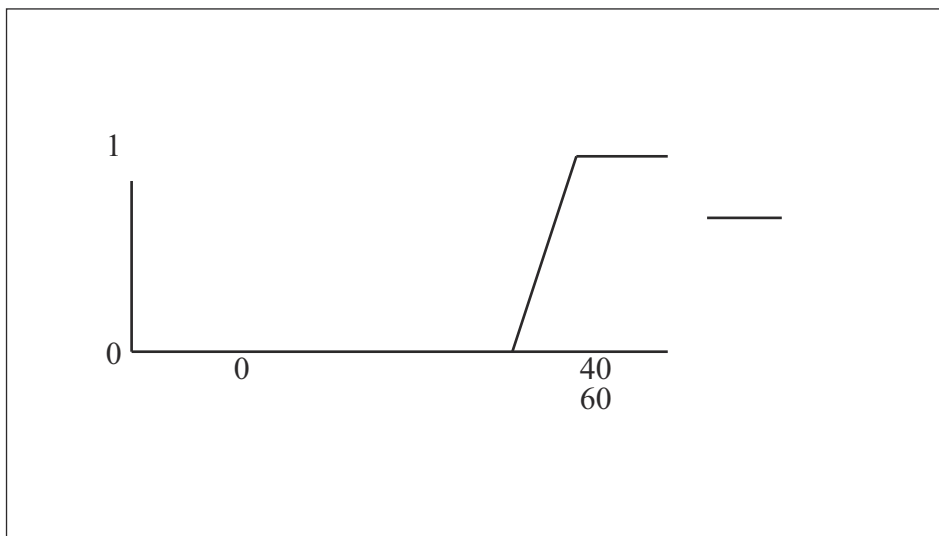


Figure 5 Membership Function in a Generic Fuzzy Logic Algorithm Schematic View

Using this membership function alone, a reflectivity at range bins of lower values implies a rule strength of 0 for hail, that is, the observation is inconsistent with hail. With multiple radar moments available as input, the rule strength for hail is an appropriate functional combination of all the membership functions using the inputs. Multiple outputs can be evaluated by constructing rule strengths to each outcome hypothesis. A deterministic outcome is obtained by comparing the rule strengths, at each range bin.

4.2.3 HydroClass: A Synthesis of Public Methods

The HydroClass library is a collection of public echo identification methods resulting from major developments in the weather radar community. The main sources of origin are:

- **Meteo**
HydroClass results of fuzzy classification for the S- and C-band polarimetric weather radar echoes, evolved and field tested by the Colorado State University (CSU), Fort Collins, USA, and by their research partners.^{1) 2) 3)}
- **Precip**
HydroClass results of echo and hydrometeor classifiers for the polarimetric version of the S-band WSR-88D, developed by the National Severe Storms Laboratory (NSSL), and evaluated for operational use in the Joint Polarimetric Experiment (JPOLE) and subsequent transition of the NEXRAD radar network into polarimetry.^{4) 5) 6)}
- **Cell**
HydroClass results of analysis of the vertical structure precipitation echo, historical developments for single polarization radars.⁷⁾; originally the method intended for detecting hail events, here applied to detecting general cases of convective precipitation.

The implementation HydroClass is a synthesis that respects the integrity of each algorithm. Their best aspects are materialized through their sequential arrangement with:

- **PreClassifier** (adapted from JPOLE)
An echo classifier algorithm serves as a prior quality control to:
 - **MeteoClassifiers** (of CSU origin) and **PrecipClassifier** (of NSSL origin)
Alternative methods of gate-to-gate hydrometeor classification
 - **CellClassifier**
A weather pattern classifier of convection and stratiform rain used as a further attribute to the previous classifications

HydroClass software supports full tunability of the algorithms through a comprehensive set of parameters. The default parameter settings reflect the original algorithms, with variant settings for polarimetric radars operating at C-band and S-band. Users may customize the settings based on local knowledge, experience, and application needs.

For more information, see [HydroClass Classifiers \(page 48\)](#).

1) Bringi, V. N., and V. Chandrasekar, 2001: *Polarimetric Doppler Weather Radar: Principles and Applications*. Cambridge UP, 636.
 2) Lim, S., V. Chandrasekar, and V.N. Bringi, 2005: *Hydrometeor Classification System Using Dual Polarization Radar Measurements: Model Improvements and In Situ Verification*. *IEEE Transactions on Geoscience and Remote Sensing*, 43.4, 792-801.
 3) Liu, H., and V. Chandrasekar, 2000: *Classification of Hydrometeors Based on Polarimetric Radar Measurements: Development of Fuzzy Logic and Neuro-Fuzzy Systems, and In Situ Verification*. *J. of Atmospheric and Oceanic Technology*, 17.2, 140-164.
 4) Park, H., A.V. Ryzhkov, D.S. Zrnic, and K.-E. Kim, 2008: *The Hydrometeor Classification Algorithm for the Polarimetric WSR- 88D: Description and Application to an MCS*. *Weather and Forecasting*, 24, 730-748.
 5) Schuur, T. et al., 2003: *Observations and Classification of Echoes with Polarimetric WSR-88D Radar*. Rep. NOAA, Norman, OK, University of Oklahoma. Web: http://www.cimms.ou.edu/~schuur/jpole/JPOLE_HCA_report_pdf.pdf.
 6) Straka, J.M., D.S. Zrnic, and A.V. Ryzhkov, 2000: *Bulk Hydrometeor Classification and Quantification Using Polarimetric Radar Data: Synthesis of Relations*. *J. of Applied Meteorology*, 39.8, 1341-1372.
 7) Waldvogel, A., B. Federer, and P. Grimm, 1979: *Criteria for the Detection of Hail Cells*. *J. of Applied Meteorology*, 18.12, 1521-1525. See also Foote, G.B. at al *ibid*.

4.2.4 HydroClass Classification Data

HydroClass echo identification results are reported as the **HCLASS** data type, which is managed similarly to other IRIS/RDA data types (for example, binary formatted RDA outputs and the IRIS archive data RAW).

The **HCLASS** data type is special in regards to the property of enumeration. The data values do not represent a continuum of measurements. For example, their arithmetic operations have no meaning, which calls for special approaches for the operations of interpolation and averaging which are often needed when the gate data are projected into IRIS products.

The **HCLASS** data consist of several bit segments of enumerated data, filled by the multiple HydroClass classification methods. A set of algorithms can be configured to run simultaneously, and provide complementary echo identification information for each bin. Digesting and presenting such rich information is a challenge to selection, but does provide opportunities for logically merging the classification results for best overall interpretation of data. IRIS product software includes extensions for computing IRIS **HCLASS** products as conveniently as other data types.

4.2.4.1 Nearest Neighbor in Interpolations

Interpolation of data is needed in IRIS products that include a cross-section (**XSECT**). The **HCLASS** data are interpolated with a rule of the nearest neighbor.

In its simplest form, the **HCLASS** value in any point **X** along a straight line between the points **A** and **B**, in which the **HCLASS** data values are **HCLASS(A)** and **HCLASS(B)**, is obtained in the parametrization:

$$\vec{X}(t) = \vec{Ax}(t) + \vec{Bx}(1 - t), \text{ when } t \in [0, 1]$$

$$HCLASS(\vec{X}) = HCLASS(\vec{A}), \text{ when } t \leq 0.5$$

$$HCLASS(\vec{X}) = HCLASS(\vec{B}), \text{ when } t \geq 0.5$$

This approach generalizes to interpolating in the **N**-dimensional data grid:

$$HCLASS(\vec{X}) = HCLASS(\vec{A}_i)$$

where \vec{A}_i has the shortest distance to the data point \vec{X}

$$r_i = \left| \vec{X} - \vec{A}_i \right| = \min \left\{ r_j = \left| \vec{X} - \vec{A}_j \right|, \text{ when } A_j \in proximatedata \right\}$$

4.2.4.2 Majority Rule in Averaging

Averaging of data is needed when projecting high resolution data into IRIS products.

The **HCLASS** data are averaged with the rule of majority consensus, which selects the **HCLASS** value that appears most frequently in the set of data being averaged. A value is selected randomly among equally frequent values.

4.3 HydroClass Classifiers

4.3.1 Preclassifier

The HydroClass **PreClassifier** is an implementation of the JPOLE algorithm, following closely the reference.⁸⁾

The JPOLE algorithm uses the fuzzy logic approach and is the first processing step for HydroClass. It uses polarimetric variables to classify the data in the range bins as:

- GC/AP (Ground Clutter/Anomalous Propagation)
- BIO or biological targets
- METEO or hydrometeor scatterers

Five radar variables are used as input to the JPOLE algorithm. These variables are:

- Horizontal reflectivity Z_H
- Differential reflectivity Z_{dr}
- Cross-correlation coefficient Rho_{HV}
- Texture parameter of the Z_H field $TX(Z_H)$
- Texture parameter of differential phase $TX(\Phi_{DP})$

To obtain $TX(Z_H)$, the Z_H data is averaged over a running average window and then the smoothed estimates of Z_H are subtracted from the original values, in other words the standard difference, effectively. A similar procedure is used for computing $TX(\Phi_{DP})$. The length of the running window is configurable, the default being 5 bins for $TX(Z_H)$ and 10 bins for $TX(\Phi_{DP})$.

The following figure shows how trapezoidal membership functions are used for the JPOLE algorithm.

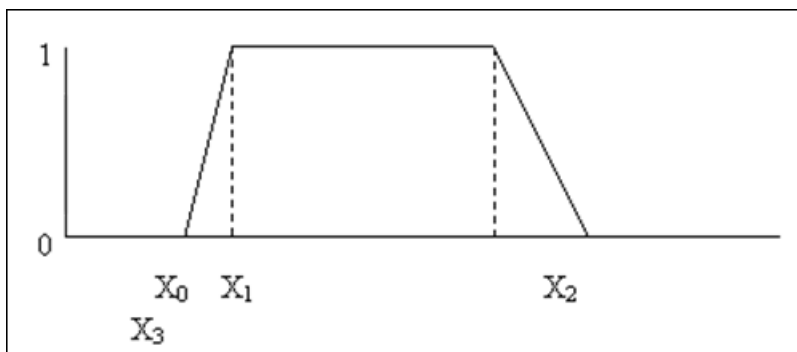


Figure 6 Example of Trapezoid Function used as a Parametrization of the Membership Function in the JPOLE Algorithm

8) Schuur, T. et al., 2003: Observations and Classification of Echoes with Polarimetric WSR-88D Radar. Rep. NOAA, Norman, OK, University of Oklahoma. Web: http://www.cimms.ou.edu/~schuur/jpole/JPOLE_HCA_report_pdf.pdf.

The following figures show the displays of the default JPOLE membership functions. The computation of additive rule strengths and class identification with maximum aggregation are in the literature reference.

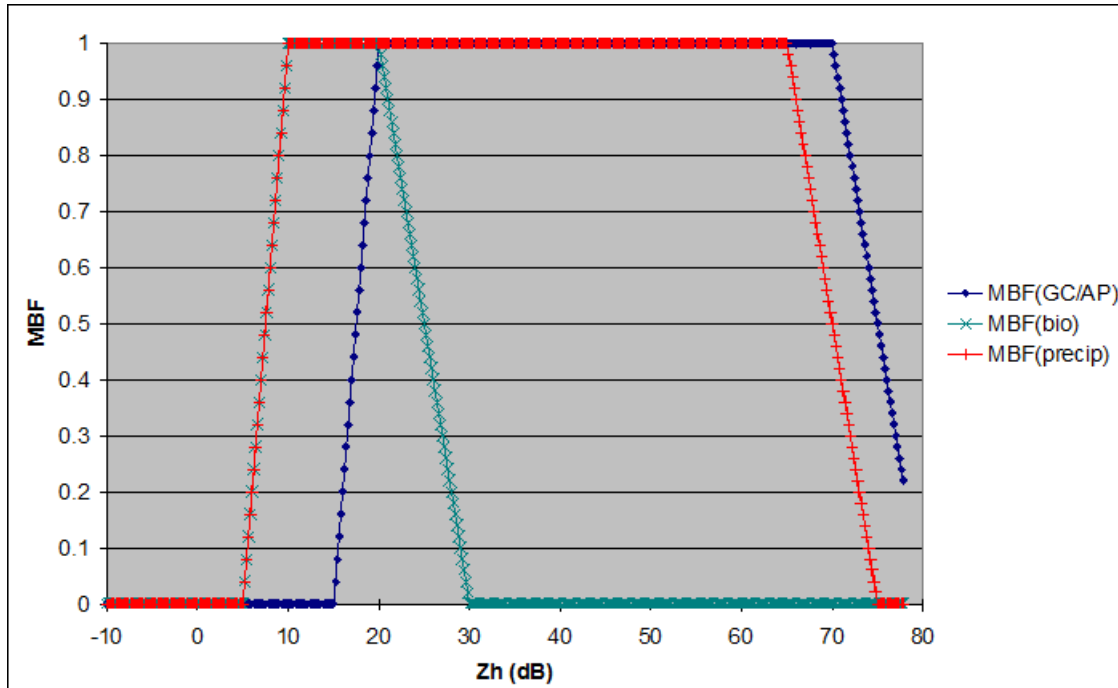


Figure 7 Default Settings of the JPOLE Membership Functions for Z_H

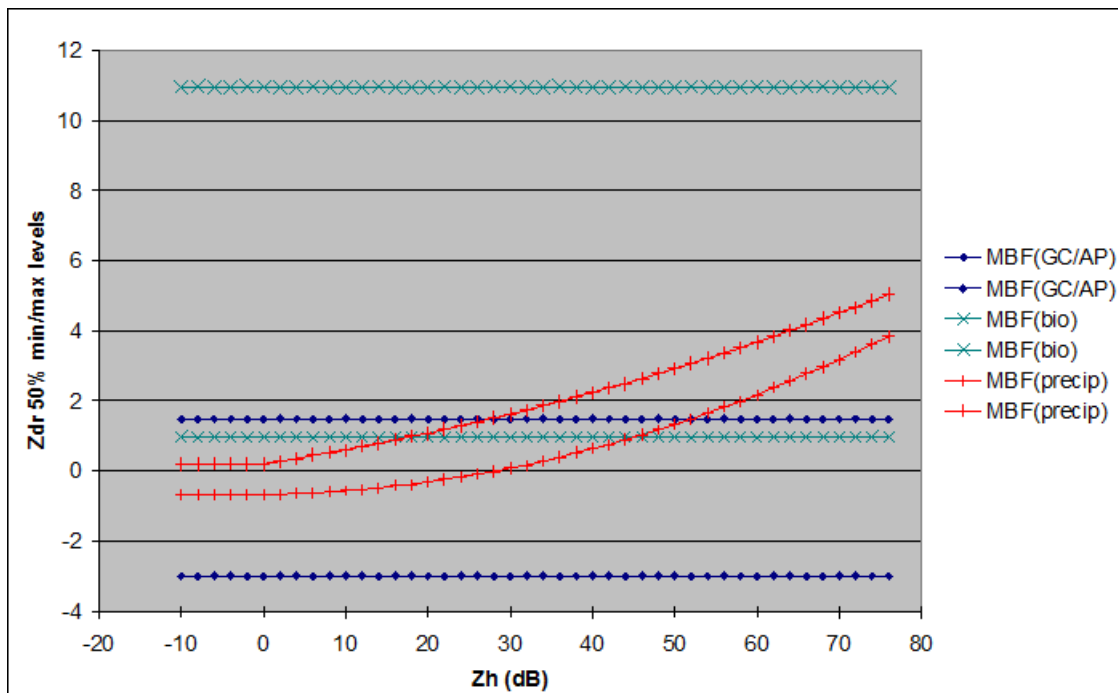


Figure 8 Default Settings of the JPOLE 2D Membership Functions for Z_{dr}

The two-dimensional (2D) membership functions are expressed as 0.5 contour levels as function of reflectivity. Class compatibilities are greater than 0.5 when Z_{dr} values fall between the regions depicted by the contours.

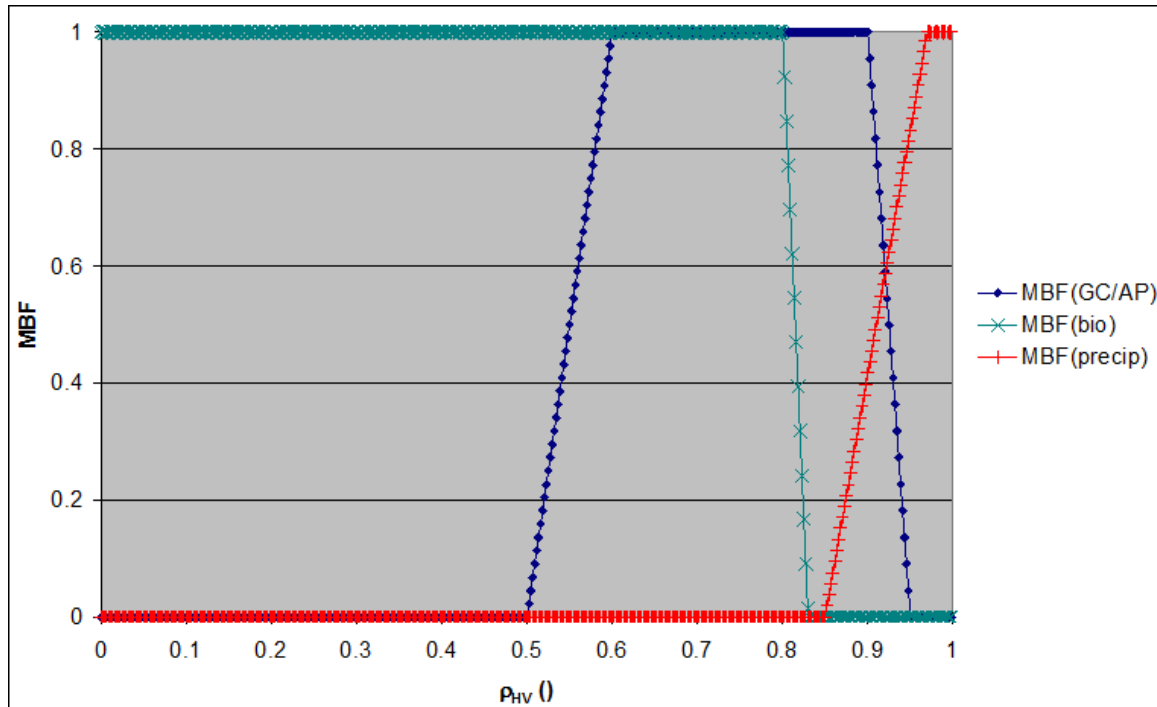


Figure 9 Default Settings of the JPOLE Membership Functions for RhoHV

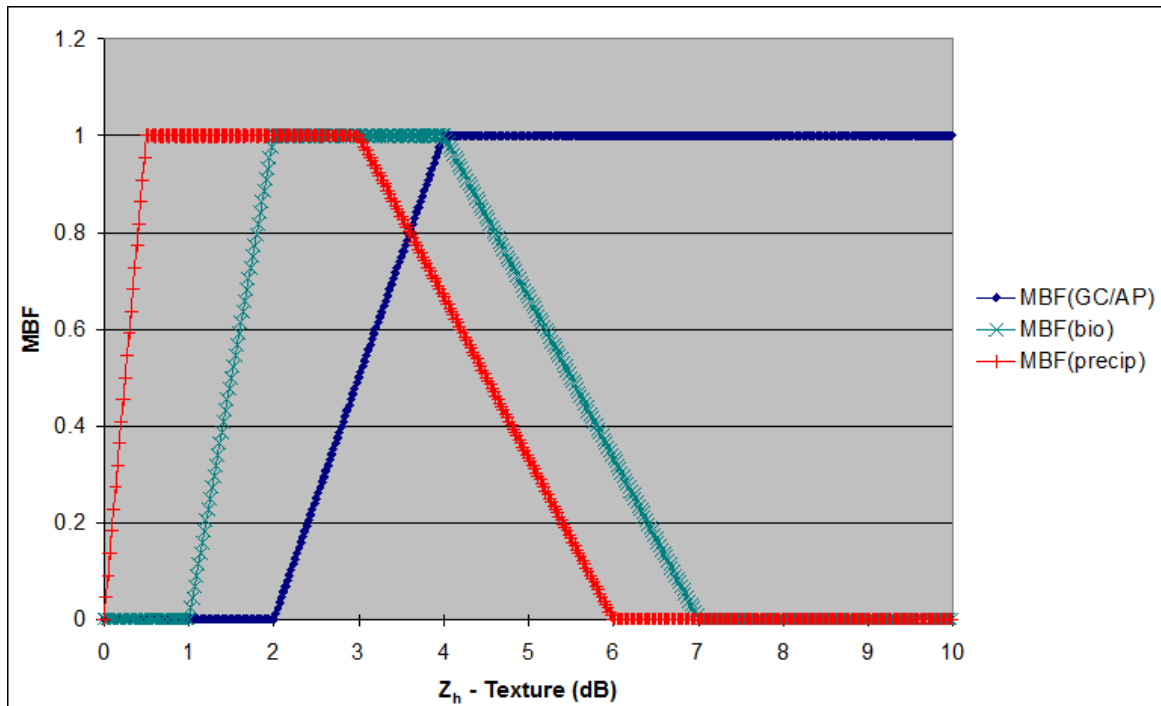


Figure 10 Default Settings of the JPOLE Membership Functions for TX(Z_h)

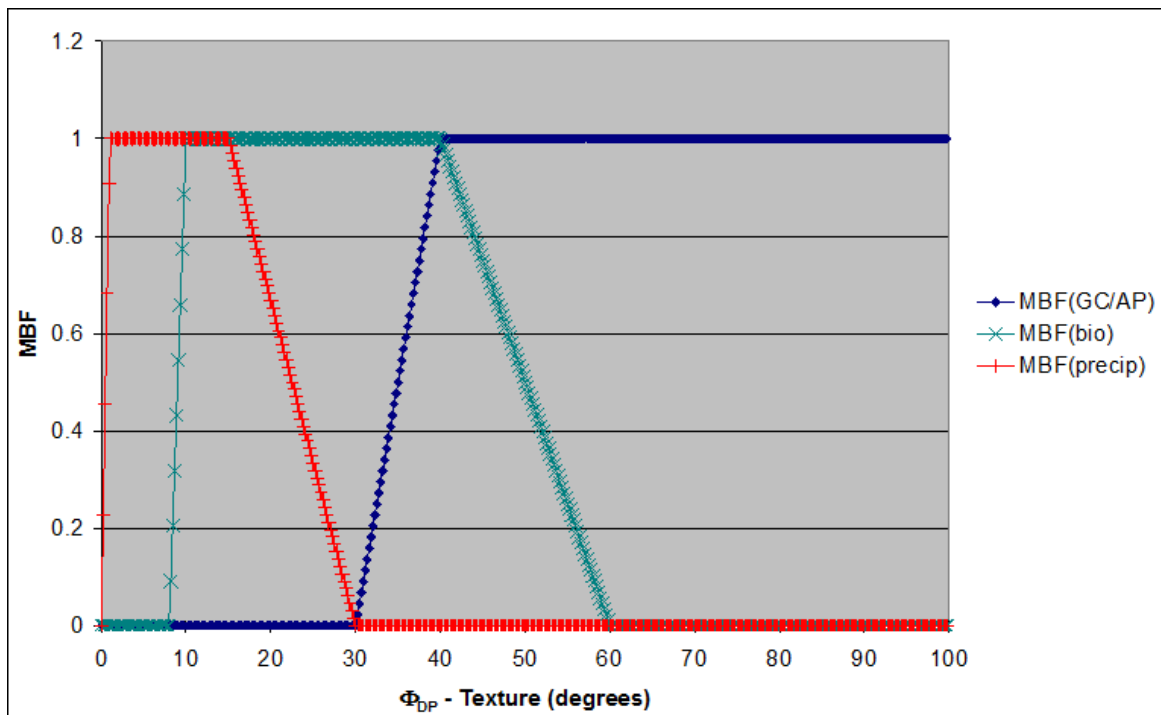


Figure 11 Default Settings of the JPOLE Membership Functions for TX(Φ_{DP})

More information

- [MLHGT Algorithm \(page 91\)](#)

4.3.2 MeteoClassifiers

The default classification system of warm and cold season hydrometeors is based on the fuzzy method approach.⁹⁾

The implementation follows closely the updated version¹⁰⁾, which is the recommended general reference. The main aspects are briefly explained and are followed by the features specific to the present implementation.

The method described in the main reference¹⁰⁾ was developed using radar measurements at the CSU-CHILL Facility (for a technical description, see <http://lab.chill.colostate.edu/chill-technical.html>).

The CHU-CHILL facility is an S-band, Doppler radar with full polarization agility and diversity at Colorado State University, U.S. The referenced classification system represents state-of-the-art knowledge and it has been verified by comparing the CSU-CHILL measurements with the in-situ airborne observations made with instruments such as 2D cloud particle measurement probe, high volume particle sampler (HVPS) and hail spectrometer.¹⁰⁾

In the fuzzy method approach, the signatures of specified hydrometeor classes are quantified as a set of membership functions (MBF), which take the measured dual-polarization parameters obtained at each bin as input. The strength of each hydrometeor class is then expressed as the outcome (rule strength) of an inference function which takes the MBF values as input. The membership functions and the inference rule strength function formalize the meteorological interpretation encoded in the classification method.

The membership functions (MBF) of the observable x are parametrized in the CSU method as beta functions:

$$MBF(x; m, a, b) = \frac{1}{1 + \left(\frac{x - m}{a}\right)^{2b}}$$

in which x stands for reflectivity (Z_H), differential reflectivity (Z_{dr}), specific differential phase (K_{dp}), cross-correlation coefficient (HV), or observation altitude (h). The expression specifies the one dimensional case (1D), while evolutions of $MBF(Z_{dr})$ and $MBF(K_{dp})$ at varied reflectivities are detailed further by parametrizing $y = y(Z_H)$ where $y = m, a$, or b . Such parameterization allow extending the 1D MBFs to 2D.

The membership function of the radar observation volume altitude has dependence on the melting layer height (ML), which is thus also used as input. The membership function of altitude can also be formulated as a 2D MBF, in which parameters m and a are dependent on ML.

In IRIS/RDA, the melting layer height is defined to coincide with the 0 °C isotherm, and related expressions in literature algorithms are converted to match the IRIS/RDA definition. ML can be fed in from an external source, or it is acquired from the archived RAW file headers, or it can specified explicitly in the HydroClass configuration.

9) Liu, H., and V. Chandrasekar, 2000: Classification of Hydrometeors Based on Polarimetric Radar Measurements: Development of Fuzzy Logic and Neuro-Fuzzy Systems, and In Situ Verification. *J. of Atmospheric and Oceanic Technology*, 17.2, 140-164.

10) Lim, S., V. Chandrasekar, and V.N. Bringi, 2005: Hydrometeor Classification System Using Dual Polarization Radar Measurements: Model Improvements and In Situ Verification. *IEEE Transactions on Geoscience and Remote Sensing*, 43.4, 792-801.

The classification results are presented by labeling each bin with the hydrometeor class that is most compatible with the observations, that is by choosing the class of highest rule strength. The rule strengths are computed using the equations of the literature reference using the quoted four radar variables and the altitude as input. Threshold parameters associated to each of the rule strengths are used to specify bins for which the class is ambiguous, for example, non-meteorological targets.

More information

- [MLHGT Algorithm \(page 91\)](#)

4.3.2.1 IRIS/RDA MeteoClassifiers Features

4.3.2.1.1 Hydrometeor Classes

The reference method characterizes membership functions for 11 classes, while the results were interpreted in the scheme of 9 final output classes.

Simplicity was considered advantageous for typical applications, and 5 final classes have been defined as the basis for classification in the current implementation:

- Rain
- Wet Snow
- Dry Snow
- Graupel
- Hail

In order to characterize the precipitation phenomena in realistic fashion, a commonly emerging mixture 'rain and hail' has been modelled with specific MBFs, in addition. Outcomes in this intermediate class are merged into the final output class 'hail'.

Membership functions (MBFs) and rule strengths (RS) have been re-optimized using the new class basis in a dedicated effort, see [Customization to Simultaneous Transmission, Simultaneous Receive Mode \(page 54\)](#).

4.3.2.1.2 Prior Quality Considerations

HydroClass uses standard IRIS/RDA measurands as input, and their quality thresholds propagate into HydroClass quality thresholds.

In addition, the `Preclassifier` of non-meteorological versus precipitation echoes (JPOLE algorithm) is used as a prior quality factor to the hydrometeor classifier (CSU algorithm) by passing in the bins classified as meteorological echoes by JPOLE, only.

4.3.2.1.3 Variants for Warm and Cold Seasons

The melting layer height (ML) is one of the inputs for the set of MBFs and RSs. The main mode of the classification system is dedicated to the summer like situation with a positive value of ML. The organization of MBF and RS parameters follow this case of the main reference. See [HydroClass: A Synthesis of Public Methods \(page 46\)](#).

In cold season, any large scale melting layer is absent. The problem of classifying precipitation is better to be started from a different a priori expectation. The task is still nontrivial, as liquid forms of precipitation are not excluded (warm fronts, freezing rain). Significant convection can occur in cold season, too, producing heavy solid hydrometeors.

In order to describe these circumstances, a variant of the method has been constructed for the case ML less than 0, signalling precipitation in cold season. In such climatology, modified MBFs are computed for altitude, and the ML does not enter in MBF calculation in this case. Explicitly, liquid form of precipitation (rain) is allowed up to a fixed altitude of 5 km (3.1 mi) (MSL), wet snow is allowed to a characteristic altitude of winter storms, assumed constant of 2.5 km (1.6 mi), at present. Other types of precipitation are indifferent with respect to altitude.

Other MBFs are unchanged from their warm season settings. Subsequently, modified weights in rule strengths calculation are used.

4.3.2.1.4 Customization to Simultaneous Transmission, Simultaneous Receive Mode

The main literature reference method parameters have been tuned, using data obtained in the alternating horizontal/vertical polarization mode, in which both the co-polar terms are observables, that is, H received from H transmitted (HH) and V received from V transmitted (VV). The cross-polar terms, that is, V received from H transmitted (VH) and the (HV) signals are observables as well. As a consequence, the linear depolarization ratio (LDR) can be promptly used as an input observable, paying special attention to cases of LDR data at low signal to noise ratio.

Operation in the mode of simultaneous transmission and simultaneous receive, known as the 'hybrid' mode, excludes availability of LDR at pulse-to-pulse basis. Adding to this, characteristics of other polarimetric observables depend on the processing mode, in presence of significant propagation effects in particular.

These 2 general reasons suggest for method customizations specific to polarimetric processing modes, and has in part motivated the procedure.

4.3.2.1.5 Fuzzy Parameters Optimized for C-Band

The new features imply reprocessing of the algorithm parameters in the new class basis, in a variety of climates, and in the hybrid polarimetric processing mode. Adding these customizations, the understanding of data and phenomena at S-band was extended to C-band.

The existing CSU parameter optimization procedure was applied to multi- season data samples obtained at the Vaisala polarimetric weather radar prototype at University of Helsinki.¹¹⁾

The data samples represented a variety of weather cases (see the following 3 figures) as follows:

- Summer convection
- Winter storm
- Stratiform frontal precipitation

As result, new membership functions and rule strength coefficients were obtained that are used as default settings for C-band weather radars operating in the 'hybrid' mode. The distributions of the membership functions are visualized in the following figures.

11) Puhakka, T. et al., 2006: University of Helsinki Research Radar Setup. 4th European Conference on Radar Meteorology and Hydrology, Barcelona, Spain.

For numerical values and more details of the membership function parameters, see [Parametrized Fuzzy Parameters \(page 117\)](#).

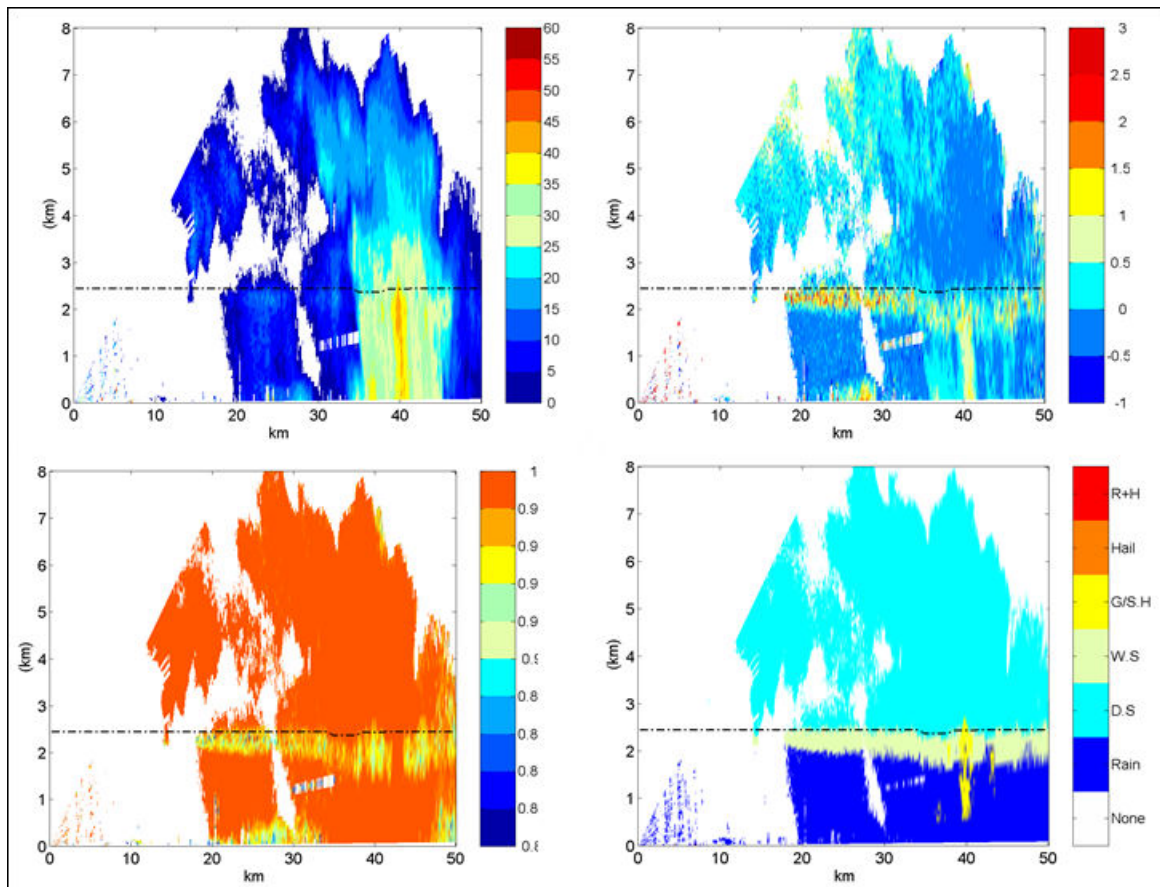


Figure 12 Selected Observables in the RHI Data Sample of a Summer Convection used for Optimizing the Fuzzy Parameters

- 1 Reflectivity Z (dB)
- 2 Differential reflectivity Z_{dr} (dB)
- 3 Cross-correlation coefficient $Rho_{HV}(0)$
- 4 Classification result ('D.S': dry snow, 'W.S': wet snow, 'G/S.H' graupel, small hail)

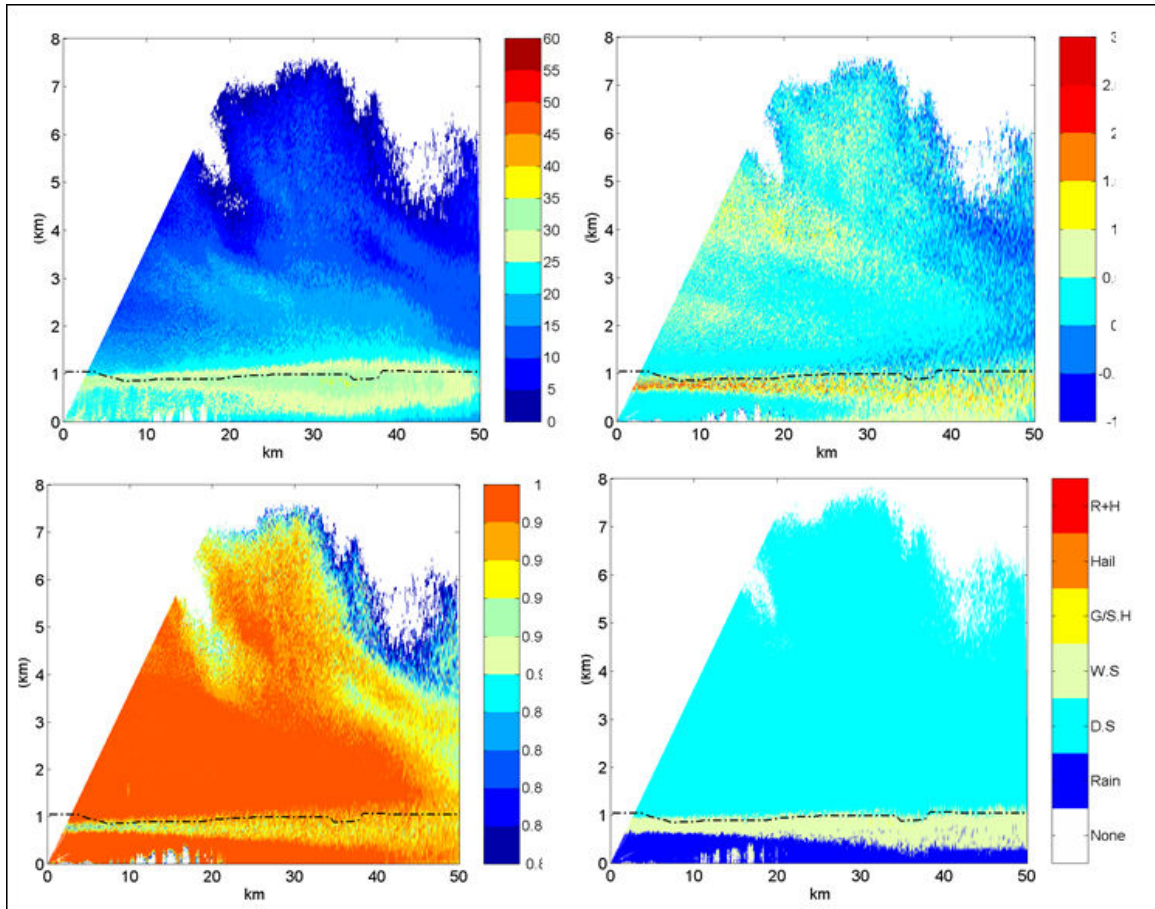


Figure 13 Selected Observables in the RHI Data Sample of a Stratiform Precipitation (Warm Front) used for Optimizing the Fuzzy Parameters

- 1 Reflectivity Z (dB)
- 2 Differential reflectivity Z_{dr} (dB)
- 3 Cross-correlation coefficient $\rho_{HV}(0)$
- 4 Classification result ('D.S': dry snow, 'W.S': wet snow)

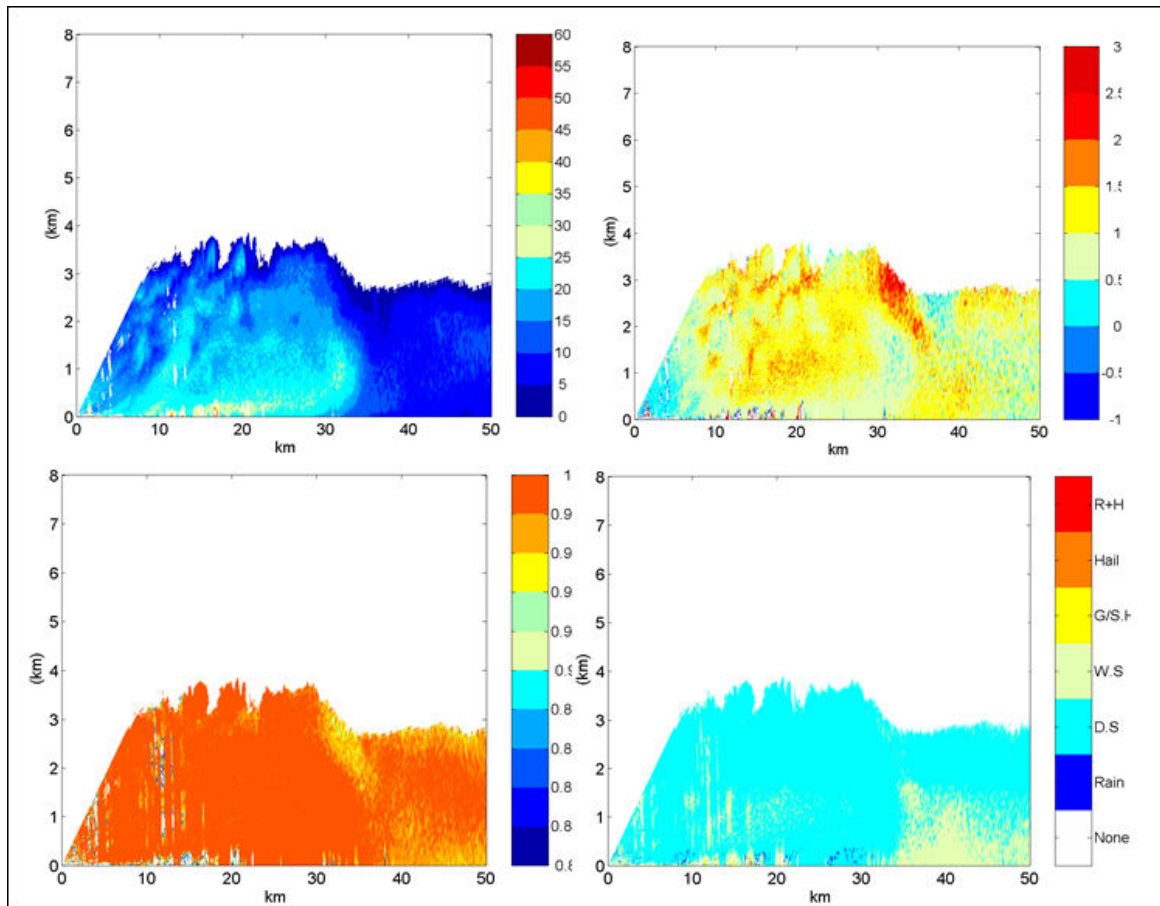


Figure 14 Selected Observables in the RHI Data Sample of a Winter Precipitation Event used for Optimizing the Fuzzy Parameters

- 1 Reflectivity Z_H (dB)
- 2 Differential reflectivity Z_{dr} (dB)
- 3 Cross-correlation coefficient $Rho_{HV}(0)$
- 4 Classification result ('D.S': dry snow, 'W.S': wet snow)

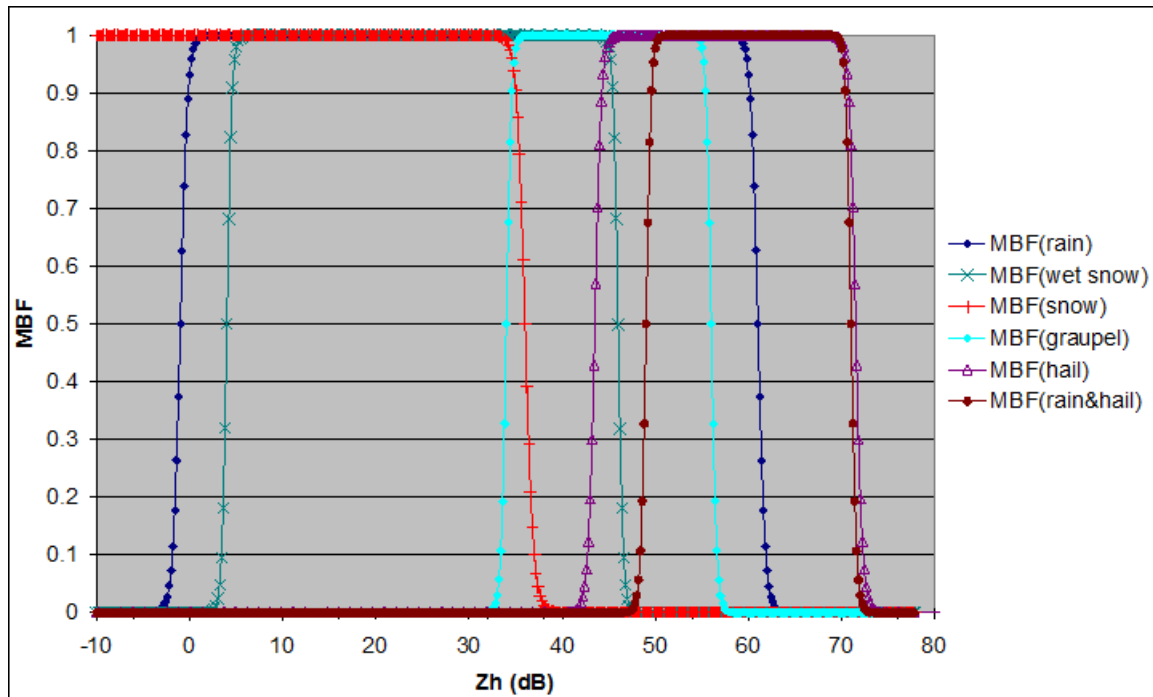


Figure 15 C-band Default Settings of the Membership Functions for Reflectivity (Z_H)

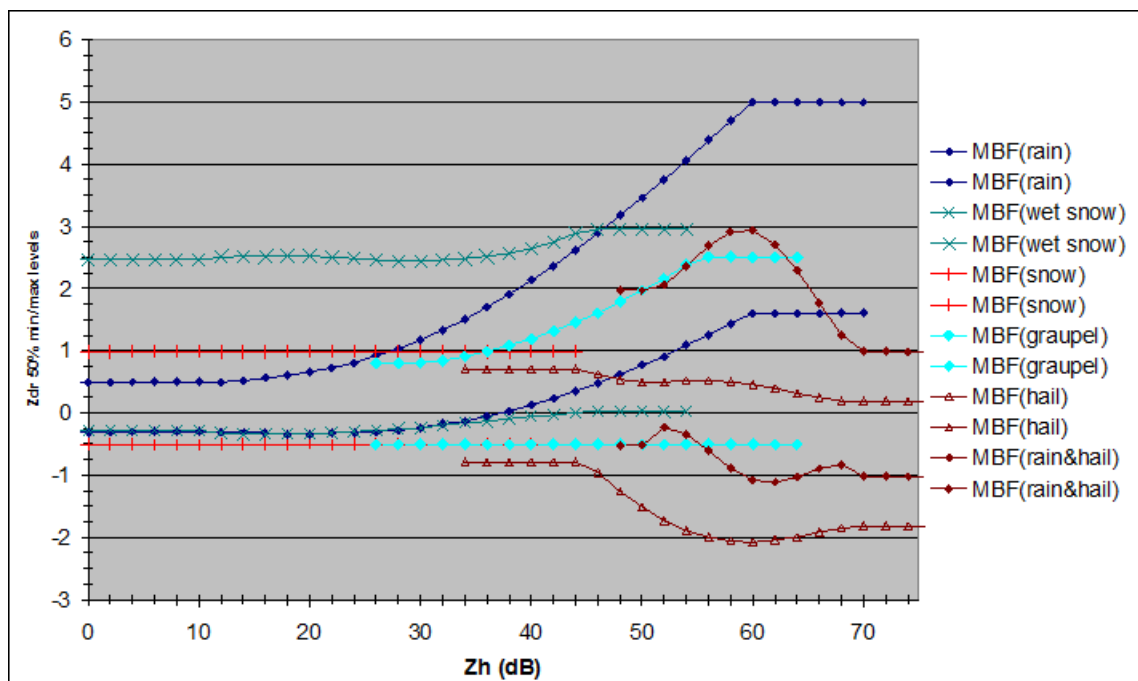


Figure 16 2D Membership Functions for Differential Reflectivity (Z_{dr}) (Expressed as 0.5 Compatibility Contours as Function of Reflectivity)



Class compatibilities are greater than 0.5 when Z_{dr} values fall between the regions depicted by the contours.

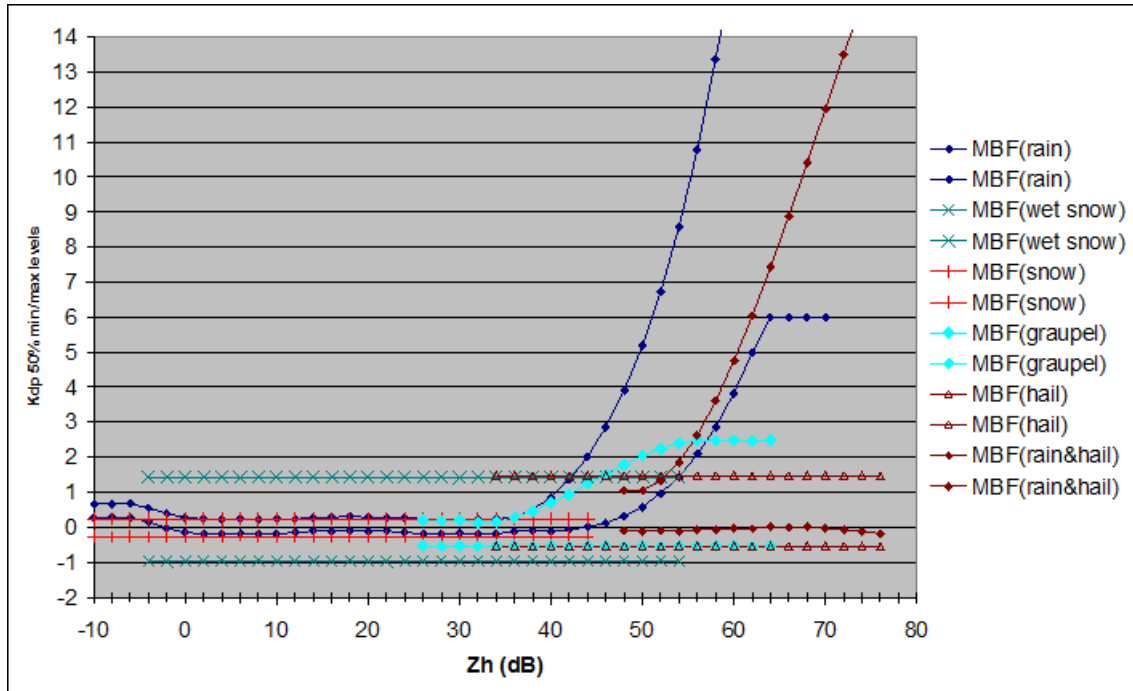


Figure 17 2D Membership Functions for Specific Differential Phase (K_{dp}) (Expressed as 0.5 Compatibility Contours as Function of Reflectivity)

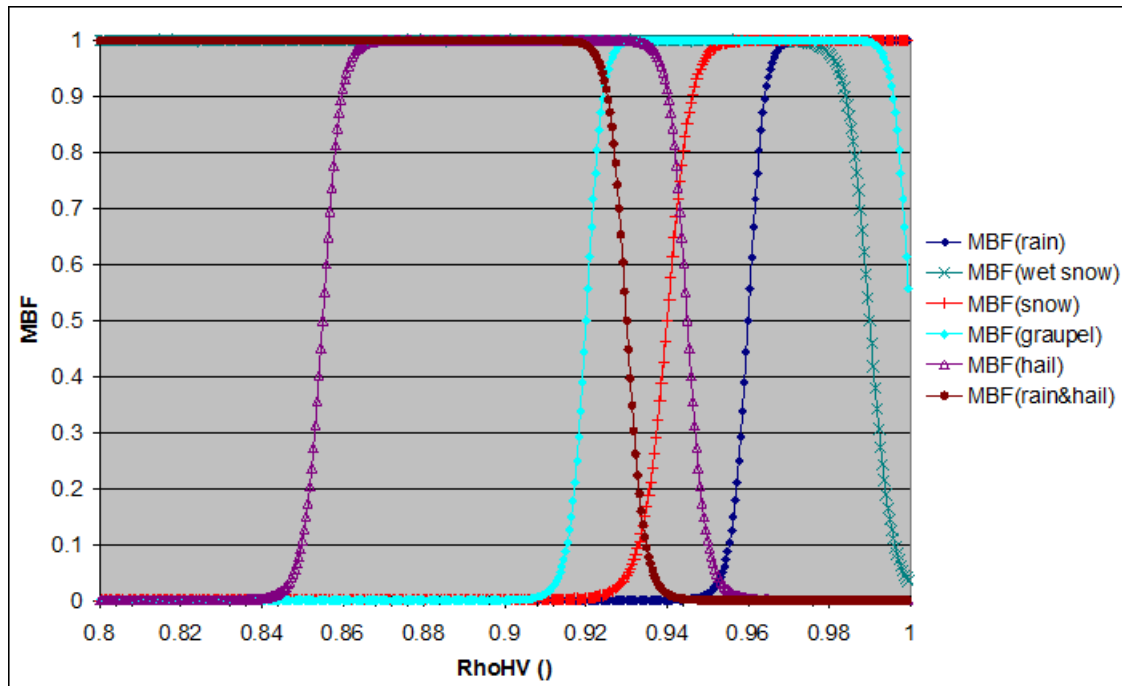


Figure 18 Membership Functions of the Cross-Correlation Coefficient (RhoHV)

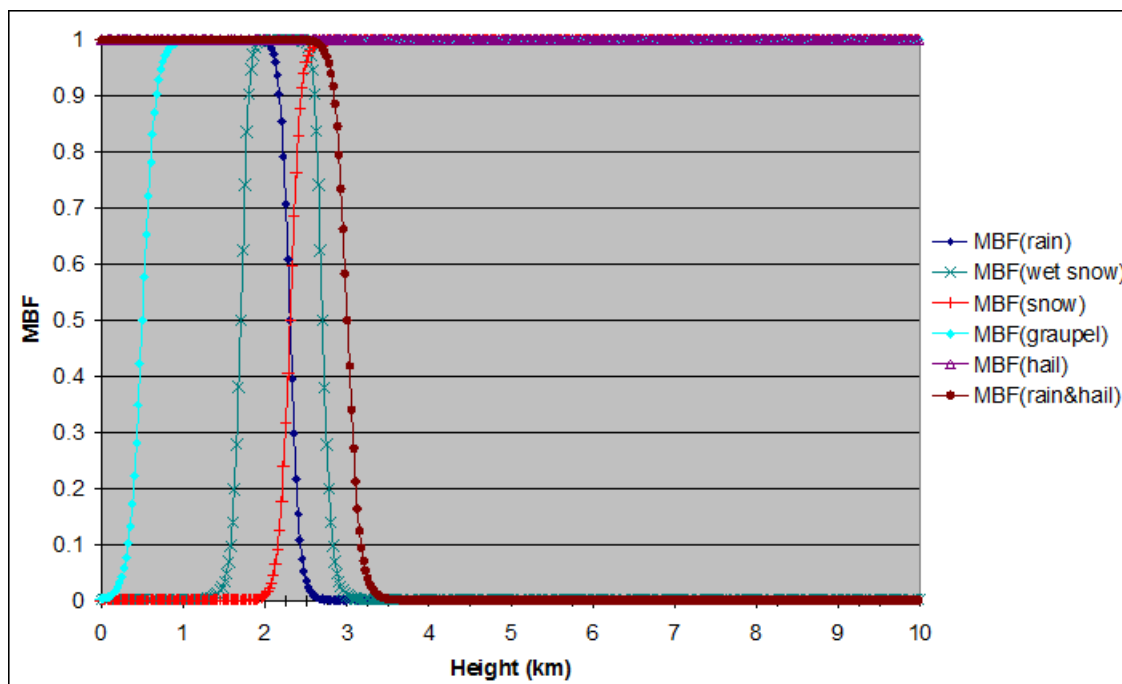


Figure 19 Membership Functions for Altitude (h) (Depicted for Melting Layer Height at 2.5 km)



The contours shift linearly as function of the melting layer height. All heights are expressed with respect to mean sea level.

The optimized expressions for rule strengths (RS) are analogous to the literature reference with the following new default coefficients:

$$RS_i(ML > 0) = MBF_i(Z_H) \times MBF_i(h) \times MBF_i(Z_{dr}) + 0.5 \times MBF_i(K_{dp}) + 0.5 \times MBF_i(RhoHV)2$$

$$RS_i(ML < 0) = MBF_i(Z_H) \times 0.7 \times MBF_i(h) \times MBF_i(Z_{dr}) + 0.3 \times MBF_i(K_{dp}) + 0.5 \times MBF_i(RhoHV)3$$

In these expressions $RS_i(ML > 0)$ and $RS_i(ML < 0)$ refer to rule strengths of a class i for warm and cold season cases, respectively. $MBF_i(x)$ refers to membership functions of variable x for the class i .

4.3.2.1.6 Unimplemented Features

The melting layer height is one of the variables used in the hydrometeor classification fuzzy method. The main literature reference introduces a radar based estimate for a variable melting layer heights in convective storms. In essence, the estimate is based on vertical gradient profiles of differential reflectivity. Other approaches have been proposed for stratiform cases and they also use vertical profiles and/or gradients in reflectivity, differential reflectivity, and/or polarization cross-correlation coefficient, as prime signatures of melting layer.

Observing vertical profiles and/or gradients, unambiguously, requires dedicated scan strategies such as RHI scans, or alternatively several horizontal sweeps at varied elevations in a well designed volume scan. Such requirements contradict a HydroClass design goal of independence on scan strategy. Subsequently, the melting layer height is left as an open method in HydroClass, and the information is fed in as an external input variable.

Methods are available for feeding in the values at momentary basis, see [Running HydroClass \(page 62\)](#).

4.3.3 PrecipClassifier

The **PrecipClassifier** implementation closely follows the fuzzy method of Version 2: Warm season¹²⁾, which includes the default fuzzy parameter values. For the classes of rain, the default values of the membership functions for textures of reflectivity and differential phase take the common values of precipitation of the preclassifier.

This classifier has the same default settings for S-band and C-band radars. The optimal parameters of membership functions for differential reflectivity are somewhat different for C-band radars.

¹²⁾ Schuur, T. et al., 2003: *Observations and Classification of Echoes with Polarimetric WSR-88D Radar*. Rep. NOAA, Norman, OK, University of Oklahoma. Web: http://www.cimms.ou.edu/~schuur/jpole/JPOLE_HCA_report_pdf.pdf.

4.3.4 CellClassifier

The **CellClassifier** implementation is based on the historical signature of hail and convection¹³⁾ : high level of reflectivity at a specified height above the melting layer can be used as a signature of hail (and convection in general).

In this implementation, the general signature of convection is fuzzified as a rule strength, which is a product of 2 membership functions (trapezoids):

- Minimal reflectivity required for convection
- Minimum altitude, with respect to the 0 °C isotherm

For simplicity of configuration, the shapes of the trapezoids are fixed. The full rule strength is reached when the reflectivity is 5 dB more than the minimal threshold, and when the height of those reflectivity levels reaches 1 km (0.6 mi) above the minimum altitude.

4.4 Setting-up HydroClass

HydroClass part of IRIS and RDA releases, and no specific actions are necessary in standard IRIS and RDA installations.

You must have a valid HydroClass license code to use HydroClass. The code is activated and encrypted in the setup utility graphical user interface (GUI) field **License**. Two license codes are provided:

- HydroClass in Reingest
Allows activating the classifier methods of **Preclassifier**, **MeteoClassifiers**, and **PrecipClassifier** in IRIS/Analysis, that is in post processing. This license code also enables processing real-time data with the **CellClassifier** in IRIS/Radar.
- RVP900 HydroClass Generation
Allows activating the classification methods of **Preclassifier**, **MeteoClassifiers**, and **PrecipClassifier** in RDA real-time ray processing.

1. Enable HydroClass in IRIS/reingest using the menu **HClass: Hydrometeor Classification in ReINGEST** in the setup block **Ingest**.
The installed and activated HydroClass runs promptly on appropriate input data and computes results using the current configuration, when appropriate input data arrive or a task with **HCLASS** data type is running.
2. Enable HydroClass in RDA using the menu **Optional Data Parameters** in the setup block **RVP Radar Video Processor**.
HydroClass algorithms process data if the **HCLASS** data type is configured to be reported.

4.5 Running HydroClass

HydroClass is implemented in the major mode of PPP in RVP900.

¹³⁾ Waldvogel, A., B. Federer, and P. Grimm, 1979: *Criteria for the Detection of Hail Cells. J. of Applied Meteorology*, 18.12, 1521-1525. See also Foote, G.B. at al *ibid*.

Alternatively, HydroClass can process any appropriate polarimetric radar data converted into IRIS RAW format. By construction, HydroClass sets minimal requirements on task parameters, while driving certain task settings to extremes may compromise meteorological performance.

Minimally, HydroClass requirements for input data (effectively, the RVP900 run-time parameters, IRIS task parameters, or input RAW characteristics) are:

- Polarization mode: H+V
- Major mode PPP
- Active data types: DBZ, Z_{dr} , K_{dp} , Φ_{iDP} and ρ_{HV}
- If HydroClass is configured to use the external melting layer height (ML), a valid ML value in RVP900, or in the RAW header structure

For uniform meteorological performance, it is recommended to:

- Constrain the observation distances at the scale of 100 km (62.1 mi); far beyond 100 km (62.1 mi), the radar observation volume is expected to contain a lot of structures, in vertical direction in particular, and unambiguous classification of hydrometeors is not well justified
- Prefer reasonable samplings (32 or more) and modest antenna speeds
- Pay balanced attention to all aspects of radar data quality (pedestal alignment, calibration of reflectivity, H- to V-channel calibration balance, noise samplings, radome quality)

4.5.1 Operating RDA/HydroClass with IRIS/Radar

IRIS/Radar is a typical method of operating radar equipped with RVP900 signal processing.

The most convenient mode of using HydroClass at these radars is to activate it at RVP900 and run it within standard IRIS tasks configured to H+V polarization mode and to the RVP900 major mode of pulse-pair-processing (PPP).

In a given IRIS task, you can switch on HydroClass in the data pop-up in the **Processor Configuration** block by enabling:

- **HClass** data type
- Required data types

Given a valid HydroClass configuration file, and valid melting layer height input (if specified that way in HydroClass configuration) no other action is necessary. HydroClass generates the **HClass** data type in the ingest data stream, analogously to other data types.

4.5.2 Operating HydroClass in RVP900

HydroClass is built in as an output data type in RVP900 processing, and it is available to the use case in which RVP900 is operated with the radar software.

In this case, the feature is available by activating the polarimetric **HClass** data type, assuming a standard HydroClass configuration.

4.5.3 HydroClass in IRIS

If HydroClass is enabled in IRIS/reingest, it considers each RAW file routed to reingest and appends the **HClass** data type in the ingest collection when the RAW data input is suitable to HydroClass.

The input radar moments must be recorded in 16-bit data format. The algorithm does not create output from 8-bit RAW data, directly. However, it is relatively straightforward to convert such data sets into 16-bit presentation in IRIS (intermediate RAW products) and use them for obtaining the **HClass** data type.

4.6 Configuring HydroClass

HydroClass application includes a configuration interface that is common to HydroClass in RVP900 and in IRIS. The configuration data is in the configuration template files for C-band radars and for S-band radars, respectively:

```
/usr/sigmet/config_template/hydroclass-C-band.conf  
  
/usr/sigmet/config_template/hydroclass-S-band.conf
```

Copy one of these into the following file:

```
/usr/sigmet/config/hydroclass.conf
```

If you have an X-band radar, use the *hydroclass-C-band.conf* file as a starting point, and edit it for X-band.

The files are equivalent in structure, but with default parameter sets that match with these widely used radar types.

Note that the HydroClass functionality is ready to use after the software install, radar calibration and start of radar operations. The installed configuration meets the first needs of evaluation and general use. HydroClass automatically selects the correct configuration file to match with the radar frequency.

Site-specific customizations are usually only needed in the advanced use cases, that is for optimal performance. The optimization is best made with feedback and needs of the end-user applications. Substantial amount of observational data and their careful consideration are needed for consistent customization of HydroClass.

The configurable features are:

- Choices of activation, and relations of uses of the distinct classification algorithms **PreClassifier**, **MeteoClassifiers**, **PrecipClassifier**, and **CellClassifier**
- Complete sets of fuzzy parameters of these classifier
- Miscellaneous settings, such as origin of melting layer height, data corrections, and quality considerations of the results

HydroClass polls for possible updates of the configuration file and reloads upon file change. The update takes place for each RAW file in IRIS/reingest. Restart of IRIS is not required. Consecutive RAW files are allowed to originate from radars that operate at different frequencies.

HydroClass configuration is checked for each period of PPP major mode in a RVP900 run. Note that for RVP900 radars operated by IRIS, a new task does not trigger a HydroClass configuration update, but a switch to another major mode, for example, FFT, and back to PPP is required. The updates initially trigger an IRIS/RDA message, which are later muted off, in order not to fill log files.

4.6.1 HydroClass Configuration File

A parameter line of the HydroClass configuration file has one of the following format:

```
dpolapp[.SubSpecifier].[ParameterGroup].ParameterItem = 1234
```

SubSpecifier

Parts are optional, typically referring to distinct classifier methods **Preclassifier**, **MeteoClassifiers**, **PrecipClassifier**, and **CellClassifier**.

ParameterGroup

Refers to (a vector of) parameter group, such as membership functions **MBFinputs**.

ParameterItem

Refers to (a vector or a matrix of) parameters.

Each **ParameterGroup** is typically preceded by comment lines, starting with a "#". The number of subsequent parameter lines and the dimensions of the parameter vectors and matrixer reflect structure of the algorithm. The structure of the algorithm is briefly explained in the paragraph of comments at start of each classifier method, indicated by a comment line:

```
#=====
```

4.6.1.1 HydroClass Configuration File Structure

The **HydroClass** configuration files consist of the main blocks listed below.

In typical first usages, you must consider the parameter settings in block (2), with a few additional key in the group (4).

Modifying parameters in groups (5) to (8) is seen as advanced use.

1. Title block and configuration nick name

```
# == RDA/IRIS HydroClass configuration file (C-band) ==
```

2. Main algorithm selection menu selectors for activating distinct algorithms (blocks)

```
# =====
```

3. RDA/IRIS major version, current IRIS/RDA version, and HydroClass revision

```
# =====
```

4. Detailed data quality configurations: miscellaneous quality settings in the block **Quality**

```
# =====
```

As soon as a consistent source of melting layer height is determined at the radar, it is recommended to change the setting:

```
dpolapp.Quality.Aux[0] = 1
```

To

```
dpolapp.Quality.Aux[0] = 0
```

5. Detailed configuration of the Preclassifier output settings and fuzzy parameters of the Preclassifier

```
# =====
```

6. Detailed configuration of the MeteoClassifiers (warm and cold season) output settings and fuzzy parameters of the MeteoClassifiers

```
# =====
```

7. Detailed configuration of the **PrecipClassifier** output settings and fuzzy parameters of the **PrecipClassifier**

```
# =====
```

8. Detailed configuration of the `CellClassifier`, fuzzy parameters of the `CellClassifier`

```
# =====
```

4.6.1.2 HydroClass Configuration File Contents

This section lists the distinct parameter lines with default settings for C-band radars.

Title and Configuration Nickname

The title comment line is machine written:

```
dpolapp.sConfigurationName ="dpolapp_C-band"
```

A descriptive name for the current configuration settings.

This parameter is the only one communicated as meta data in the header structures of IRIS/RDA data. The nickname provides a way of indicating possible evolutions and modifications made to the HydroClass configuration.

The default string "`dpolapp_C-band`" suggests the default settings. It is recommended that you change to a descriptive name when you modify algorithm parameters.

Main Algorithm Selection Menu

```
dpolapp.bRunQuality = 1
```

Activates the quality considerations in the main block **Quality**.

```
dpolapp.usClassificationMethods = 222
```

Activates a combination of the distinct echo classifier methods. Possible settings are:

- "1": **Preclassifier**, only (the **JPOLE** algorithm for meteo versus bio versus **GC/AP**)
- "2": **Meteoclassifiers**, with the **Preclassifier** as a quality mask
- "21": **PrecipClassifier**: the **JPOLE** warm algorithm, with the **Preclassifier** mask
- "22": **PrecipClassifier** and **Meteoclassifiers**, with the **Preclassifier** mask
- "201": **CellClassifier** for stratiform and convective rain, with the **Preclassifier** mask
- "202": **Meteoclassifiers** and **CellClassifier**, with the **Preclassifier** mask
- "221": **CellClassifier** and **PrecipClassifier**, with the **Preclassifier** mask

- "222:" CellClassifier, PrecipClassifier, Meteoclassifiers and CellClassifier, with the Preclassifier mask

Software Version Information

```
dpolapp.sVersion = "8.13"
```

Machine written major IRIS/RDA version. No need to modify this.

```
dpolapp.sRevision = "8.13"
```

Machine written minor IRIS/RDA version. No need to modify this.

```
dpolapp.sDpolappRevision = "15"
```

Machine written HydroClass running version. No need to modify this.

Miscellaneous Quality Settings

```
dpolapp.Quality.Aux[0] = 1
```

Source of the melting layer height input:

- "1": HydroClass uses the melting layer height value suggested in the configuration file.
- "0": instructs HydroClass in IRIS to use the ML value in the input RAW file, and HydroClass in RDA to use the RVP900 process value of ML. The RVP900 value can be updated during operation (dynamically).
- In case `dpolapp.Quality.Aux[0] = 0` but the requested values (in RAW or RVP900) appear undefined, HydroClass reports about the missing input. HydroClass in IRIS moves over to using the value specified in the configuration file, while HydroClass in RDA switches off until a well defined value is provided.

```
dpolapp.Quality.Aux[1] = 2300
```

An estimate of the current ML in meters above mean sea level (MSL). This estimate is used when `dpolapp.Quality.Aux[0] = 1`, see previous field. It is recommended to move to using IRIS/RDA current values in continued use.

```
dpolapp.Quality.OtherInputs[0].dParams[0] = 0.0
```

A posteriori HydroClass specific off-set to H-/V-channel balance (Z_{dr}). The off-set is intrinsic to HydroClass and does not affect the Z_{dr} output data type.

Use of non-zero value is discouraged in real-time applications (HydroClass in RVP900). The recommended IRIS/RDA approach is to use the tools described in *RVP900 Digital Receiver and Signal Processor User Guide* "Calibration Considerations".

General Settings of PreClassifier

```
dpolapp.Preclassifier.iClassifierID = -1
```

Are the PreClassifier results formatted as in the field of **PRECIP_CLASSIFIER** in the bits 3,4,5 from **LSB=0** of the **DB_HCLASS** data type?

- "-1": NO, the legacy HydroClass format
- "1": YES, JPOLE classes of **PRECIP_CLASSIFIER** used

```
dpolapp.Preclassifier.uiMaxNonMeteo = 1
```

This parameter is irrelevant in all cases, except:

```
dpolapp.usClassificationMethods = 1
```

This parameter defines what to do with the bins that fail acceptance to any class of **PreClassifier**. It allows simplifying the class settings further through regrouping. You can re-group **PreClassifier** (un)identified results:

- "1": unidentified are 'uiNonMeteoID'
- "2": in addition, 'GC/AP' are 'uiNonMeteoID'
- "3": in addition, 'BIO' are 'uiNonMeteoID'

```
dpolapp.Preclassifier.uiNonMeteoID = 1s
```

What to do with the regrouped (un)identified results:

- "0": set as thresholded in IRIS/RDA
- "1": report as GC/AP
- "2": report as BIO
- "3": report as PRECIP

```
dpolapp.Preclassifier.dMinRS[0] = 0
```

Minimum rule strength for accepting GC/AP.

```
dpolapp.Preclassifier.dMinRS[1] = 0
```

Minimum rule strength for accepting **BIO**.

```
dpolapp.Preclassifier.dMinRS[2] =0
```

Minimum rule strength for accepting **PRECIP**.

```
dpolapp.Preclassifier.iAux[3] =2
```

The preferred class of the Polarimetric Meteo Index (PMI):

- "2": PMI gets high values when the **PRECIP** class is preferred
- "1": PMI gets high values when the **BIO** class is preferred
- "0": PMI gets high values when the **GC/AP** class is preferred

Settings for Polarimetric Meteo Index

```
dpolapp.Preclassifier.iAux[4] =1
```

PMI mathematical formula.

- "1": the 'score'

$$PMI = 1 - \frac{1}{1 + \left(\frac{RULESTRENGTH_{PREFERRED}}{\max(RULESTRENGTH)_{NONPREFERRED}} \right)}$$

- "0": the likelihood ratio

$$PMI = 1 - \frac{RULESTRENGTH_{PREFERRED}}{\Sigma RULESTRENGTH}$$

See [Calibration Considerations \(page 94\)](#).

Detailed Settings of PreClassifier

```
dpolapp.Preclassifier.OtherInputs[0].iParams[0] = 5
```

The number of consecutive bins used to compute texture of reflectivity.

```
dpolapp.Preclassifier.OtherInputs[1].iParams[0] = 10
```

The number of consecutive bins used to compute texture of differential phase.


```

# MBFinputs and their use:
# Reflectivity in preclassifier:
# Input data: Zh.
# MBF(Zh) is computed as JPOLE trapezoid; an additive factor in rule strength
# MBF: default initialization with parameter settings of Table 1 Ref.1
# Zh MBF trapezoid for GC/AP.
dpolapp.Preclassifier.MBFinputs[0].dMBF[0][0] = 15
dpolapp.Preclassifier.MBFinputs[0].dMBF[1][0] = 20
dpolapp.Preclassifier.MBFinputs[0].dMBF[2][0] = 75
dpolapp.Preclassifier.MBFinputs[0].dMBF[3][0] = 85
# Zh MBF trapezoid for bio scatter.
dpolapp.Preclassifier.MBFinputs[0].dMBF[0][1] = 5
dpolapp.Preclassifier.MBFinputs[0].dMBF[1][1] = 10
dpolapp.Preclassifier.MBFinputs[0].dMBF[2][1] = 20
dpolapp.Preclassifier.MBFinputs[0].dMBF[3][1] = 30
# Zh MBF trapezoid for precipitation.
dpolapp.Preclassifier.MBFinputs[0].dMBF[0][2] = 5
dpolapp.Preclassifier.MBFinputs[0].dMBF[1][2] = 10
dpolapp.Preclassifier.MBFinputs[0].dMBF[2][2] = 75
dpolapp.Preclassifier.MBFinputs[0].dMBF[3][2] = 80
# Differential reflectivity in preclassifier:
# Input data: Zdr (In reingest: adjusted with Quality offset, internally), and
Zh.
# MBF(Zdr;Zh) is computed as JPOLE 2D-trapezoid; additive in rule strength
# Zdr MBF trapezoid for GC/AP.
dpolapp.Preclassifier.MBFinputs[1].dMBF[0][0] = -4
dpolapp.Preclassifier.MBFinputs[1].dMBF[1][0] = -2
dpolapp.Preclassifier.MBFinputs[1].dMBF[2][0] = 1
dpolapp.Preclassifier.MBFinputs[1].dMBF[3][0] = 2
# Zdr MBF trapezoid for bio scatter.
dpolapp.Preclassifier.MBFinputs[1].dMBF[0][1] = 0
dpolapp.Preclassifier.MBFinputs[1].dMBF[1][1] = 2
dpolapp.Preclassifier.MBFinputs[1].dMBF[2][1] = 10
dpolapp.Preclassifier.MBFinputs[1].dMBF[3][1] = 12
# Zdr MBF trapezoid for precipitation.
dpolapp.Preclassifier.MBFinputs[1].dMBF[0][2] = -0.3
dpolapp.Preclassifier.MBFinputs[1].dMBF[1][2] = 0
dpolapp.Preclassifier.MBFinputs[1].dMBF[2][2] = 0
dpolapp.Preclassifier.MBFinputs[1].dMBF[3][2] = 0.3
# A polynomial dependence of the Zdr precipitation trapezoid on Zh
# The Zh range in which the polynomial is applied:
dpolapp.Preclassifier.MBFinputs[1].dP[2][0][0] = 0
dpolapp.Preclassifier.MBFinputs[1].dP[2][0][1] = 80
# Dependency on Zh: left tail constant term P0, linear P1, 2nd order P2, and
3rd order P3.
# The left shoulder is the same.
dpolapp.Preclassifier.MBFinputs[1].dP[2][0][0] = -0.5
dpolapp.Preclassifier.MBFinputs[1].dP[2][0][1] = 0.0025
dpolapp.Preclassifier.MBFinputs[1].dP[2][0][2] = 0.00075
dpolapp.Preclassifier.MBFinputs[1].dP[2][0][3] = 0
# The right tail constant term P0, linear P1, 2nd order P2 and 3rd order P3
# The right shoulder is the same.
dpolapp.Preclassifier.MBFinputs[1].dP[2][2][0] = 0.08

```

```

dpolapp.Preclassifier.MBFinputs[1].dP[2][2][1] = 0.0364
dpolapp.Preclassifier.MBFinputs[1].dP[2][2][2] = 0.000357
dpolapp.Preclassifier.MBFinputs[1].dP[2][2][3] = 0
# Cross correlation coefficient in preclassifier:
# Data type used as input: RhoHV.
# MBF(RhoHV) is computed as JPOLE trapetzoid; an additive factor in rule
strength
# MBF: default initialization with parameter settings of Table 1 Ref.1
# RHOHV MBF trapetzoid for GC/AP.
dpolapp.Preclassifier.MBFinputs[2].dMBF[0][0] = 0.5
dpolapp.Preclassifier.MBFinputs[2].dMBF[1][0] = 0.6
dpolapp.Preclassifier.MBFinputs[2].dMBF[2][0] = 0.9
dpolapp.Preclassifier.MBFinputs[2].dMBF[3][0] = 0.95
# RHOHV MBF trapetzoid for bio scatter.
dpolapp.Preclassifier.MBFinputs[2].dMBF[0][1] = 0
dpolapp.Preclassifier.MBFinputs[2].dMBF[1][1] = 0
dpolapp.Preclassifier.MBFinputs[2].dMBF[2][1] = 0.8
dpolapp.Preclassifier.MBFinputs[2].dMBF[3][1] = 0.83
# RHOHV MBF trapetzoid for precipitation.
dpolapp.Preclassifier.MBFinputs[2].dMBF[0][2] = 0.85
dpolapp.Preclassifier.MBFinputs[2].dMBF[1][2] = 0.97
dpolapp.Preclassifier.MBFinputs[2].dMBF[2][2] = 1
dpolapp.Preclassifier.MBFinputs[2].dMBF[3][2] = 1.01
# Differential phase texture in preclassifier:
# The input data type is computed internally.
#--- MBF(Texture-1) is computed as JPOLE trapetzoid; an additive factor in
rule strength
# MBF: default initialization with parameter settings of Table 1 Ref.1
# PHIDP texture MBF trapetzoid for GC/AP.
dpolapp.Preclassifier.MBFinputs[3].dMBF[0][0] = 30
dpolapp.Preclassifier.MBFinputs[3].dMBF[1][0] = 40
dpolapp.Preclassifier.MBFinputs[3].dMBF[2][0] = 10800
dpolapp.Preclassifier.MBFinputs[3].dMBF[3][0] = 10800
# PHIDP texture MBF trapetzoid for bio scatter.
dpolapp.Preclassifier.MBFinputs[3].dMBF[0][1] = 8
dpolapp.Preclassifier.MBFinputs[3].dMBF[1][1] = 10
dpolapp.Preclassifier.MBFinputs[3].dMBF[2][1] = 40
dpolapp.Preclassifier.MBFinputs[3].dMBF[3][1] = 60
# PHIDP texture MBF trapetzoid for precipitation.
dpolapp.Preclassifier.MBFinputs[3].dMBF[0][2] = 0
dpolapp.Preclassifier.MBFinputs[3].dMBF[1][2] = 1
dpolapp.Preclassifier.MBFinputs[3].dMBF[2][2] = 15
dpolapp.Preclassifier.MBFinputs[3].dMBF[3][2] = 30
# Reflectivity texture in preclassifier:
# Data type is computed internally.
# MBF(Texture-2) is computed as JPOLE trapetzoid; an additive factor in the
rule strength
# MBF: default initialization with parameter settings of Table 1 Ref.1
# Zh texture MBF trapetzoid for GC/AP.

```

```

dpolapp.Preclassifier.MBFinputs[4].dMBF[0][0] = 2
dpolapp.Preclassifier.MBFinputs[4].dMBF[1][0] = 4
dpolapp.Preclassifier.MBFinputs[4].dMBF[2][0] = 10000
dpolapp.Preclassifier.MBFinputs[4].dMBF[3][0] = 10000
# Zh texture MBF trapezoid for bio scatter.
dpolapp.Preclassifier.MBFinputs[4].dMBF[0][1] = 1
dpolapp.Preclassifier.MBFinputs[4].dMBF[1][1] = 2
dpolapp.Preclassifier.MBFinputs[4].dMBF[2][1] = 4
dpolapp.Preclassifier.MBFinputs[4].dMBF[3][1] = 7
# Zh texture MBF trapezoid for precipitation.
dpolapp.Preclassifier.MBFinputs[4].dMBF[0][2] = 0
dpolapp.Preclassifier.MBFinputs[4].dMBF[1][2] = 0.5
dpolapp.Preclassifier.MBFinputs[4].dMBF[2][2] = 3
dpolapp.Preclassifier.MBFinputs[4].dMBF[3][2] = 6
# Other flags: none.

```

General Settings of MeteoClassifiers

```
dpolapp.MeteoClassifiers.uiNonMeteoID = 1
```

This parameter defines what to do with the bins that fail the preceding quality consideration (**PreClassifier**), or fail the acceptance to any class of **MeteoClassifiers**.

- "0": **MeteoClassifiers** redirects the unaccepted and unclassified bins as IRIS/RDA 'CLASS_THRESHOLD'
- "1": **MeteoClassifiers** redirects the unaccepted and unclassified bins as IRIS/RDA "CLASS_NON_MET"

```
dpolapp.MeteoClassifiers.dMinRS[0] = 0
```

Minimum rule strength for accepting rain

```
dpolapp.MeteoClassifiers.dMinRS[1] = 0
```

Minimum rule strength for accepting wet snow

```
dpolapp.MeteoClassifiers.dMinRS[2] = 0
```

Minimum rule strength for accepting snow

```
dpolapp.MeteoClassifiers.dMinRS[3] = 0
```

Minimum rule strength for accepting graupel

```
dpolapp.MeteoClassifiers.dMinRS[4] = 0
```

Minimum rule strength for accepting hail

```
dpolapp.MeteoClassifiers.dMinRS[5] = 0
```

Minimum rule strength for accepting rain/hail mixture (reported as hail)

Detailed Settings of MeteoClassifiers

```
# MBFinputs and their use:
# Reflectivity in MeteoClassifiers:
# Data type used as input: Zh.
# MBF(dBZ) is computed as the CSU beta function.
# MBF: C-band, default settings:
# Zh beta MBF for rain: central value, width, slope
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][0] = 30
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[1][0] = 31
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[2][0] = 40
# Zh beta MBF for wet snow.
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][1] = 25
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[1][1] = 21
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[2][1] = 40
# Zh beta MBF for snow.
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[1][2] = 36
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[2][2] = 40
# Zh beta MBF for graupel/small hail.
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][3] = 45
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[1][3] = 11
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[2][3] = 20
# Zh beta MBF for large hail.
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][4] = 57.5
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[1][4] = 14
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[2][4] = 20
# Zh beta MBF for rain+hail mixture.
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][5] = 60
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[1][5] = 11
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[2][5] = 20
# Altitude in MeteoClassifiers:
# The IRIS/RDA estimate of the melting level height will be used.
# MBF(altitude;melting level) is computed as the CSU beta(ML) function.
# MBF: C-band, default settings:
# Altitude beta MBF for rain: central value, width, slope
dpolapp.MeteoClassifiers.MBFinputs[1].dMBF[0][0] = 0
dpolapp.MeteoClassifiers.MBFinputs[1].dMBF[1][0] = -0.2
dpolapp.MeteoClassifiers.MBFinputs[1].dMBF[2][0] = 20
dpolapp.MeteoClassifiers.MBFinputs[1].dMBF[3][0] = 0
dpolapp.MeteoClassifiers.MBFinputs[1].dMBF[4][0] = 0.5
dpolapp.MeteoClassifiers.MBFinputs[1].dMBF[5][0] = 5
# Altitude beta MBF for wet snow.
```

```

dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][1] = -0.3
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][1] = 0.5
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][1] = 5
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][1] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][1] = 1
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][1] = 5
# Altitude beta MBF for snow.
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][2] = 10
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][2] = 10.2
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][2] = 60
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][2] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][2] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][2] = 0
# Altitude beta MBF for graupel/small hail.
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][3] = 10
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][3] = 10
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][3] = 12
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][3] = 60
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][3] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][3] = 0
# Altitude beta MBF for hail.
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][4] = 10
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][4] = 15
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][4] = 20
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][4] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][4] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][4] = 0
# Altitude beta MBF for rain+hail mixture.
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][5] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][5] = 0.5
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][5] = 20
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][5] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][5] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][5] = 0
# Differential reflectivity in MeteoClassifiers:
# Input data: Zdr (adjusted with Quality offset, internally in reingest), and
Zh
# MBF(Zdr) is computed as the CSU 2D-beta function of Zh.
# MBF: C-band, default settings:
# Zdr 2D beta MBF for rain at Zh=<Zh> dB (central value, width, slope):
dpolapp.MeteoClassifiers.MBFInputs[2].dMBF[0][0] = 0.48155
dpolapp.MeteoClassifiers.MBFInputs[2].dMBF[1][0] = 0.70578
dpolapp.MeteoClassifiers.MBFInputs[2].dMBF[2][0] = 10.958
# Polynomial dependence of rain MBF(Zdr) on Zh-<Zh>
# The center <Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFInputs[2].dMBF[3][0] = 30
dpolapp.MeteoClassifiers.MBFInputs[2].dMBF[4][0] = 30
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraints:
dpolapp.MeteoClassifiers.MBFInputs[2].dP[0][0][0] = 0.047498
dpolapp.MeteoClassifiers.MBFInputs[2].dP[0][0][1] = 0.0017624
dpolapp.MeteoClassifiers.MBFInputs[2].dP[0][0][2] = 6.993E- 06
dpolapp.MeteoClassifiers.MBFInputs[2].dP[0][0][3] = -4.4975E-07
dpolapp.MeteoClassifiers.MBFInputs[2].dP[0][0][4] = 0.1

```

```

dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][0][5] = 5.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][0] = 0.025917
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][1] = 0.00043621
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][2] = -4.8951E-06
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][3] = -5.6218E-08
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][4] = 0.4
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][5] = 8
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][0] = 0.22873
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][1] = 0.0054945
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][2] = -5.8275E-05
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][4] = 8
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][5] = 25
# Zdr 2D beta MBF for wet snow at Zh=<Zh> (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[0][1] = 1.1031
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[1][1] = 1.3594
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[2][1] = 15
# Polynomial dependence of wet snow MBF(Zdr) on Zh-<Zh>
# The center <Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[3][1] = 27.5
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[4][1] = 17.5
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraint:
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][0] = 0.004623
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][1] = 0.00064286
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][2] = 2.2222E-05
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][4] = 1.1
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][5] = 2.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][0] = -0.0091144
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][1] = 0.00021429
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][2] = 3.8384E-05
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][4] = 1
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][5] = 2.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][0] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][1] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][4] = 5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][5] = 20
# Zdr 2D beta MBF for snow at Zh=<Zh> (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[0][2] = 0.25
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[1][2] = 0.75
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[2][2] = 8
# Zdr 2D beta MBF for graupel at Zh=<Zh> (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[0][3] = 0.42969
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[1][3] = 0.92969
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[2][3] = 12.5
# Polynomial dependence of graupel MBF(Zdr) on Zh-<Zh>
# The center <Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[3][3] = 42.5
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[4][3] = 12.5
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th orde;min/
max constraints:

```

```

dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][0] = 0.033714
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][1] = 0.00096429
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][4] = 0.155
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][5] = 1.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][0] = 0.033714
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][1] = 0.00096429
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][4] = 0.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][5] = 2
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][0] = 0.25714
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][1] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][4] = 9
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][5] = 17
# Zdr weight and 2D beta MBF for hail at Zh=<Zh> (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[0][4] = -0.75928
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[1][4] = 1.2778
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[2][4] = 15.859
# Polynomial dependence of hail MBF(Zdr) on Zh-<Zh>
# The center <Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[3][4] = 57.5
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[4][4] = 12.5
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;min/
max constraint:
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][0] = -0.017336
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][1] = 0.0015104
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][2] = -8.3333E-05
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][3] = 4.1667E-06
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][4] = -2
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][5] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][1][0] = 0.0057788
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][1][1] = -0.0045313
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][1][2] = 2.7778E-05
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][1][3] = 1.25E- 05
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][1][4] = 0.1
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][1][5] = 1.3
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][2][0] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][2][1] = -0.14167
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][2][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][2][3] = 0.00066667
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][2][4] = 7
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][2][5] = 17
# Zdr weight and 2D beta MBF for rain+hail mixture at Zh=<Zh> (central value,
width, slope):
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[0][5] = 0.93571
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[1][5] = 2
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[2][5] = 15
# Polynomial dependence of rain+hail mixture MBF(Zdr) on Zh- <Zh>
# The center <Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[3][5] = 60
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[4][5] = 10

```



```

# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraint:
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][0][0] = -0.054167
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][0][1] = -0.0057143
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][0][2] = 0.00016667
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][0][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][0][4] = -0.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][0][5] = 1.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][1][0] = 0.0041667
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][1][1] = -0.02375
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][1][2] = -0.00016667
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][1][3] = 0.00015
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][1][4] = 0.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][1][5] = 3
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][2][0] = -5.9212E-17
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][2][1] = 0.016667
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][2][2] = 5.9212E-19
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][2][3] = -0.00066667
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][2][4] = 5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[5][2][5] = 20
# Specific differential phase in MeteoClassifiers:
# Input data: Kdp, and Zh.
# MBF(Kdp) is computed as the CSU 2D-beta function of Zh.
# MBF: C-band, default settings:
# Kdp 2D beta MBF for rain at Zh=<Zh> dB (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][0] = 0.0079391
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][0] = -0.032435
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][0] = 11.154
# Polynomial dependence of rain MBF(Kdp) on Zh-<Zh>
# The center <Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[3][0] = 30
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[4][0] = 35
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraint:
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][0][0] = -0.0049584
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][0][1] = 0.0020558
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][0][2] = 0.00019114
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][0][3] = 3.9888E-06
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][0][4] = 0.05
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][0][5] = 14
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][0] = 0.011085
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][1] = 0.0029526
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][2] = 0.00010385
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][3] = 6.1086E-07
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][4] = 0.2
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][5] = 8
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][0] = 0.22873
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][1] = 0.0054945
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][2] = -5.8275E-05
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][4] = 9
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][5] = 16
# Kdp 2D beta MBF for wet snow at Zh=25 dB: central value, width, slope.
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][1] = 0.25
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][1] = 1.2

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dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][1] = 10
# Kdp 2D beta MBF for snow at Zh=17.5 dB (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][2] = 0.25
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][2] = 10
# Kdp 2D beta MBF for graupel at Zh=42.5 dB (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][3] = 0.26875
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][3] = 0.76875
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][3] = 12.5
# Polynomial dependence of graupel MBF(Kdp) on Zh-<Zh>
# The center <Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[3][3] = 42.5
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[4][3] = 12.5
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraint:
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][0] = 0.068704
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][1] = 0.001
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][2] = -0.00014815
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][4] = -0.25
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][5] = 1.5
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][0] = 0.068704
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][1] = 0.001
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][2] = -0.00014815
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][4] = 0.3
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][5] = 2
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][0] = 0.25714
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][1] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][4] = 9
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][5] = 17
# Kdp weight and 2D beta MBF for hail at Zh=57.5 dB (central value, width,
slope):
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][4] = 0.5
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][4] = 1
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][4] = 10
# Kdp weight and 2D beta MBF for rain+hail mixture at Zh=60 dB (central value,
width, slope):
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][5] = 2.3714
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][5] = 2.3971
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][5] = 15
# Polynomial dependence of rain+hail mixture MBF(Kdp) on Zh- <Zh>
# The center <Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[3][5] = 60
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[4][5] = 20
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraint:
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][0] = 0.30833
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][1] = 0.0085714
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][2] = -0.00033333
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][4] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][5] = 10

```

```

dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][0] = 0.29667
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][1] = 0.0088571
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][2] = -0.00026667
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][4] = -1
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][5] = 10
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][0] = -0.16667
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][1] = 2.4371E-17
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][2] = 0.0066667
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][4] = 8
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][5] = 25
# Cross correlation coefficient in MeteoClassifiers:
#--- Data type used as input: RhoHV.
#--- MBF(RhoHV) is computed as the CSU beta function.
# # MBF: C-band, default settings:
# RHOHV beta MBF for rain: central value, width, slope
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][0] = 1
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][0] = 0.04
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][0] = 10
# RHOHV beta MBF for wet snow.
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][1] = 0.88
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][1] = 0.11
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][1] = 20
# RHOHV beta MBF for snow.
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][2] = 1
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][2] = 0.06
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][2] = 10
# RHOHV beta MBF for graupel.
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][3] = 0.96
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][3] = 0.04
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][3] = 10
# RHOHV beta MBF for hail.
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][4] = 0.9
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][4] = 0.045
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][4] = 10
# RHOHV beta MBF for rain+hail mixture.
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][5] = 0.8
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][5] = 0.13
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][5] = 30

```

General Settings of PrecipClassifier

```
dpolapp.PrecipClassifier.uiNonMeteoID = 1
```

This parameter defines what to do with the bins that fail the preceding quality consideration (**PreClassifier**), or fail the acceptance to any class of **PrecipClassifier**.

- "0": **PrecipClassifier** redirects the unaccepted and unclassified bins as IRIS/RDA 'CLASS_THRESHOLD'

- "1": **PrecipClassifier** reports the unaccepted **PreClassifier** classifications unchanged, and reports the unclassified bins as IRIS/ RDA "CLASS_NON_MET"

```
dpolapp.PrecipClassifier.dMinRS[0] = 0
```

Minimum rule strength for accepting light rain.

```
dpolapp.PrecipClassifier.dMinRS[1] = 0
```

Minimum rule strength for accepting moderate rain.

```
dpolapp.PrecipClassifier.dMinRS[2] = 0
```

Minimum rule strength for accepting heavy rain.

```
dpolapp.PrecipClassifier.dMinRS[3] = 0
```

Minimum rule strength for accepting large drops.

Detailed Settings of PrecipClassifier

```
# Precip classifier uses the textures of reflectivity and differential phase.
# MBF inputs and their use:
# Reflectivity in rain classifier:
# Input data: Zh.
# MBF(Zh) is computed as JPOLE trapezoid; an additive factor in rule strength
# MBF: default initialization with parameter settings of Table 2 Ref.2
# Zh MBF trapezoid for light precipitation.
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[0][0] = 5
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[1][0] = 10
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[2][0] = 35
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[3][0] = 40
# Zh MBF trapezoid for moderate precipitation.
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[0][1] = 30
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[1][1] = 35
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[2][1] = 45
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[3][1] = 50
# Zh MBF trapezoid for heavy precipitation.
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[0][2] = 40
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[1][2] = 45
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[2][2] = 75
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[3][2] = 80
# Zh MBF trapezoid for large drops.
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[0][3] = 15
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[1][3] = 20
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[2][3] = 45
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[3][3] = 50
# Differential reflectivity in rain classifier:
# Input data: Zdr (In reingest: adjusted with Quality offset, internally), and
Zh.
# MBF(Zdr;Zh) is computed as JPOLE 2D-trapezoid; additive in rule strength
# Zdr MBF trapezoid for light precipitation.
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[0][0] = -0.3
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[1][0] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[2][0] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[3][0] = 0.3
# The polynomial dependence of the Zdr light precipitation trapezoid on Zh
# The Zh range in which the polynomial is applied:
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[4][0] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[5][0] = 80
# Dependency on Zh: left tail constant term P0, linear P1, 2nd order P2, and
3rd order P3.
# The left shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][0][0] = -0.5
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][0][1] = 0.0025
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][0][2] = 0.00075
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][0][3] = 0
# The right tail constant term P0, linear P1, 2nd order P2 and 3rd order P3
# The right shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][2][0] = 0.08
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][2][1] = 0.0364
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][2][2] = 0.000357
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][2][3] = 0
```

```

# Zdr MBF trapetzoid for moderate precipitation.
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[0][1] = -0.3
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[1][1] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[2][1] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[3][1] = 0.3
# The polynomial dependence of the Zdr moderate precipitation trapezoid on Zh
# The Zh range in which the polynomial is applied:
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[4][1] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[5][1] = 80
# Dependency on Zh: left tail constant term P0, linear P1, 2nd order P2, and
3rd order P3.
# The left shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][0][0] = -0.5
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][0][1] = 0.0025
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][0][2] = 0.00075
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][0][3] = 0
# The right tail constant term P0, linear P1, 2nd order P2 and 3rd order P3
# The right shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][2][0] = 0.08
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][2][1] = 0.0364
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][2][2] = 0.000357
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][2][3] = 0
# Zdr MBF trapetzoid for heavy precipitation.
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[0][2] = -0.3
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[1][2] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[2][2] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[3][2] = 0.3
# The polynomial dependence of the Zdr heavy precipitation trapezoid on Zh
# The Zh range in which the polynomial is applied:
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[4][2] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[5][2] = 80
# Dependency on Zh: left tail constant term P0, linear P1, 2nd order P2, and
3rd order P3.
# The left shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][0][0] = -0.5
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][0][1] = 0.0025
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][0][2] = 0.00075
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][0][3] = 0
# The right tail constant term P0, linear P1, 2nd order P2 and 3rd order P3
# The right shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][2][0] = 0.08
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][2][1] = 0.0364
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][2][2] = 0.000357
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][2][3] = 0
# Zdr MBF trapetzoid for large drops.
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[0][3] = -0.3
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[1][3] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[2][3] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[3][3] = 0.3
# The polynomial dependence of the Zdr large drops trapezoid on Zh
# The Zh range in which the polynomial is applied:
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[4][3] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[5][3] = 80
# Dependency on Zh: left tail constant term P0, linear P1, 2nd order P2, and
3rd order P3.

```

```

# The left shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][0][0] = -0.5
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][0][1] = 0.0025
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][0][2] = 0.00075
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][0][3] = 0
# The right tail constant term P0, linear P1, 2nd order P2 and 3rd order P3
# The right shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][2][0] = 0.08
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][2][1] = 0.0364
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][2][2] = 0.000357
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][2][3] = 0
# Cross correlation coefficient in rain classifier:
# Data type used as input: RhoHV.
# MBF(RhoHV) is computed as JPOLE trapetzoid; an additive factor in rule
strength
# MBF: default initialization with parameter settings of Table 2 Ref.1
# RH0hv MBF trapetzoid for light precipitation.
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[0][0] = 0.85
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[1][0] = 0.97
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[2][0] = 1
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[3][0] = 1.01
# RH0hv MBF trapetzoid for moderate precipitation.
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[0][1] = 0.85
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[1][1] = 0.97
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[2][1] = 1
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[3][1] = 1.01
# RH0hv MBF trapetzoid for heavy precipitation.
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[0][2] = 0.85
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[1][2] = 0.97
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[2][2] = 1
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[3][2] = 1.01
# RH0hv MBF trapetzoid for large drops.
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[1][3] = 0.97
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[0][3] = 0.85
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[2][3] = 1
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[3][3] = 1.01
# Differential phase texture in rain classifier:
# The input data type is computed internally.
#--- MBF(Texture-1) is computed as JPOLE trapetzoid; an additive factor in
rule strength
# MBF: default initialization with parameter settings of Table 2 Ref.1
# PHIDP texture MBF trapetzoid for light precipitation.
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[0][0] = 0
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[1][0] = 1
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[2][0] = 15
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[3][0] = 30
# PHIDP texture MBF trapetzoid for moderate precipitation.
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[0][1] = 0
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[1][1] = 1
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[2][1] = 15
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[3][1] = 30
# PHIDP texture MBF trapetzoid for heavy precipitation.
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[0][2] = 0
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[1][2] = 1
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[2][2] = 15

```

```

dpolapp.PrecipClassifier.MBFinputs[3].dMBF[3][2] = 30
# PHIDP texture MBF trapetzoid for large drops.
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[0][3] = 0
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[1][3] = 1
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[2][3] = 15
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[3][3] = 30
# Reflectivity texture in rain classifier:
# Data type is computed internally.
# MBF(Texture-2) is computed as JPOLE trapetzoid; an additive factor in the
rule strength
# MBF: default initialization with parameter settings of Table 2 Ref.1
# Zh texture MBF trapetzoid for light precipitation.
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[0][0] = 0
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[1][0] = 0.5
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[2][0] = 3
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[3][0] = 6
# Zh texture MBF trapetzoid for moderate precipitation.
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[0][1] = 0
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[1][1] = 0.5
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[2][1] = 3
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[3][1] = 6
# Zh texture MBF trapetzoid for heavy precipitation.
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[0][2] = 0
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[1][2] = 0.5
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[2][2] = 3
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[3][2] = 6
# Zh texture MBF trapetzoid for large drops.
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[0][3] = 0
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[1][3] = 0.5
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[2][3] = 3
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[3][3] = 6

```

Settings of CellClassifier

```

dpolapp.CellClassifier.dMinRS[0] = 0.5

```

Minimum rule strength for accepting convective rain.

```

# MBFinputs and their use:
# Reflectivity&Height in cell classifier:
# Input data: Zh and height difference w.r.t. the current 0oC isotherm.
# MBF(Zh,height) is computed as 2D product of trapetzoids; summed up to rule
strength.
# Min Zh required for convection (full fuzzy strength will be +5 dBZ from min).
dpolapp.CellClassifier.MBFinputs[0].dMBF[0][0] = 25
# Min height w.r.t. 0oC isotherm (full fuzzy strength will be +1. km higher ).
dpolapp.CellClassifier.MBFinputs[0].dMBF[4][0] = 0

```


4.7 HydroClass FAQ

The following list is a compilation of issues encountered when using HydroClass in the field.

Q: How does HydroClass treat typical failure cases related to *dpolapp.conf*, such as:

- Configuration file missing?
A: switches off until restart of IRIS/RDA.
- Syntax errors in *dpolapp.conf* parameter lines?
A: switches off until file is fixed.

Q: How to feed in the melting level (ML) value as an external input to HydroClass?

A: When operating:

- RVP900 with IRIS/Radar **setup_change -load** tool, see SRI Product documentation
- RVP900 without IRIS, contact Vaisala
- IRIS/reingest, the ML stored in RAW is used

To use these momentary values of ML, HydroClass configuration *dpolapp.conf* must be set up with:

```
dpolapp.Quality.iAux[0] = 0
```

Alternatively, you can edit and update (either manually or with customized script tools)

```
dpolapp.Quality.iAux[0] = 1
```

and

```
dpolapp.Quality.iAux[1] = 3500
```

(where 3500 represents an example ML value, meters above mean sea level)

Q: How to monitor the ML value used/in use?

A: When operating in IRIS/Radar, use the utility command:

setup_change - list | grep ifalls.

When operating plain RVP900, use **dspix > Mp**

Q: When running HydroClass in distributed PC architectures such as RVPO900/AMR:

- Where is the HydroClass configuration in use?
A: At PC running IRIS/Radar

- Where to update the melting level with `setup_change`?
A: At IRIS/Radar

Q: How do HClass data look when HydroClass is tested using noise source input?

A: In commissioning phase and anytime, a viable method of testing functionality of HydroClass is to couple a coherent noise source to RVP900 IF inputs (for example, AMR built-in noise).

HydroClass can process such a data stream, by configuring RVP900 appropriately.

Observing HClass data stream with ascope, for example, see the data in the following figure.

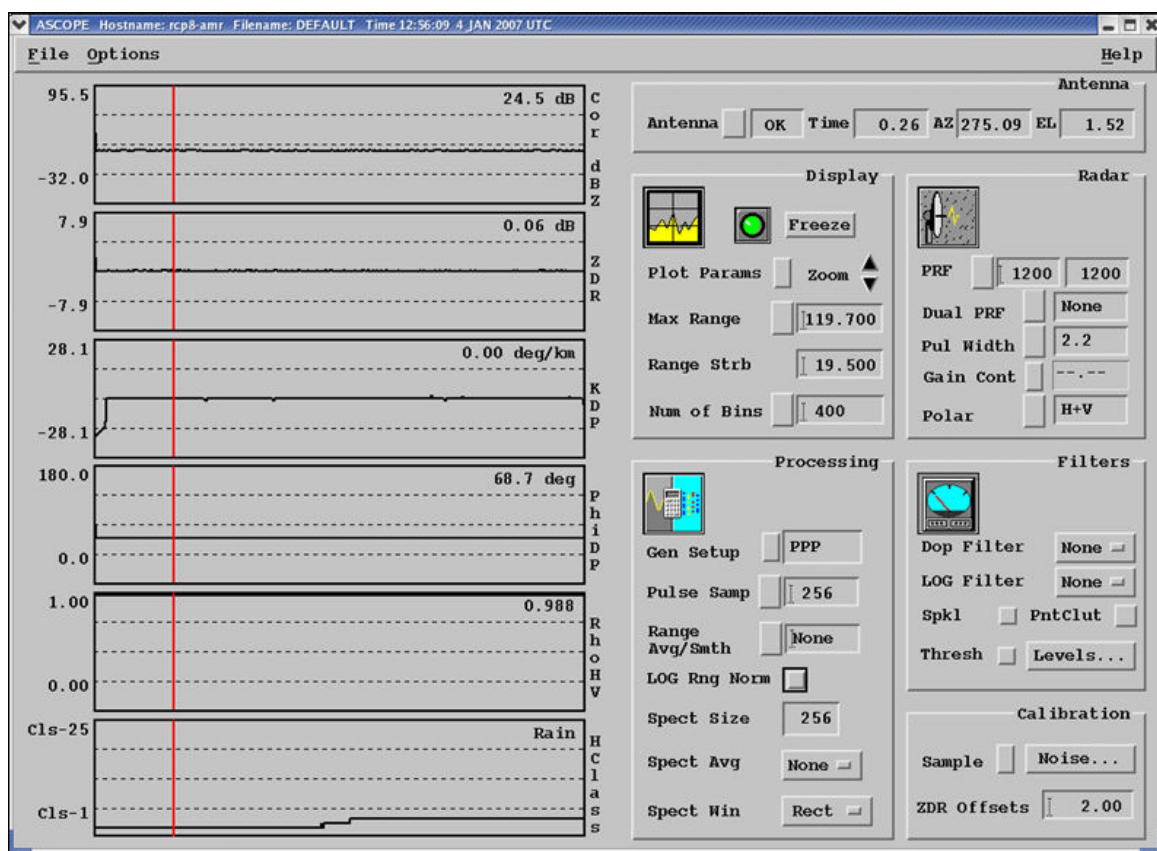


Figure 20 Polarimetric Measurements with HClass in an Ascope View When RVP900 is Processing Artificial Noise Inputs (Correlated IF Signal in Both Receiver Ports H and V)



HydroClass is in default configuration and uses the melting layer height value given in the configuration file (2300 m).

4.8 Additional Notes about HydroClass

- There are limitations in ML height settings when running ascope; it is possible to use the default value of ML in RVP900, or a specified value in *dpolapp.conf* (dynamic update does not work).
- There are limitations in ML settings when running time series data in play-back. RVP900 uses the ML value stored on TS data.
- The HydroClass ML is defined as the 0 °C isotherm. See [CellClassifier \(page 62\)](#) . The melting layer (or the radar bright band) is typically located at altitudes below ML.

5. Melting Level Height Detection

5.1 **MLHGT**: Melting Level Height

The melting level bright band typically represents the location of frozen hydrometeors falling into air warmer than the freezing level, where the particles start to melt.

The height of the melting level is an important aspect to understanding what is happening micro-physically within precipitation systems. Changes of melting level height can assist in determining the likelihood of hail and lightning, and is related to estimating strength of downdrafts due to phase change from ice to liquid. During winter conditions determining the location of liquid versus ice precipitation at the surface is improved with knowledge of the melting level, especially in mountainous terrain.

The presence of the bright band associated with the melting level must be accounted for with quantitative interpretations of weather observations.

In IRIS and RDA software, the **SRI** product uses the melting level height to perform Vertical Reflectivity Profile corrections, to apply Fall Speed corrections to radial velocity, to distinguish between convective and non-convective precipitation, to account for the different attenuation between liquid and ice, and as a membership function in the Hydrometeor Classification function. Thus an automated determination of the melting level height and how it varies spatially and temporally adds value to the overall weather radar system software.

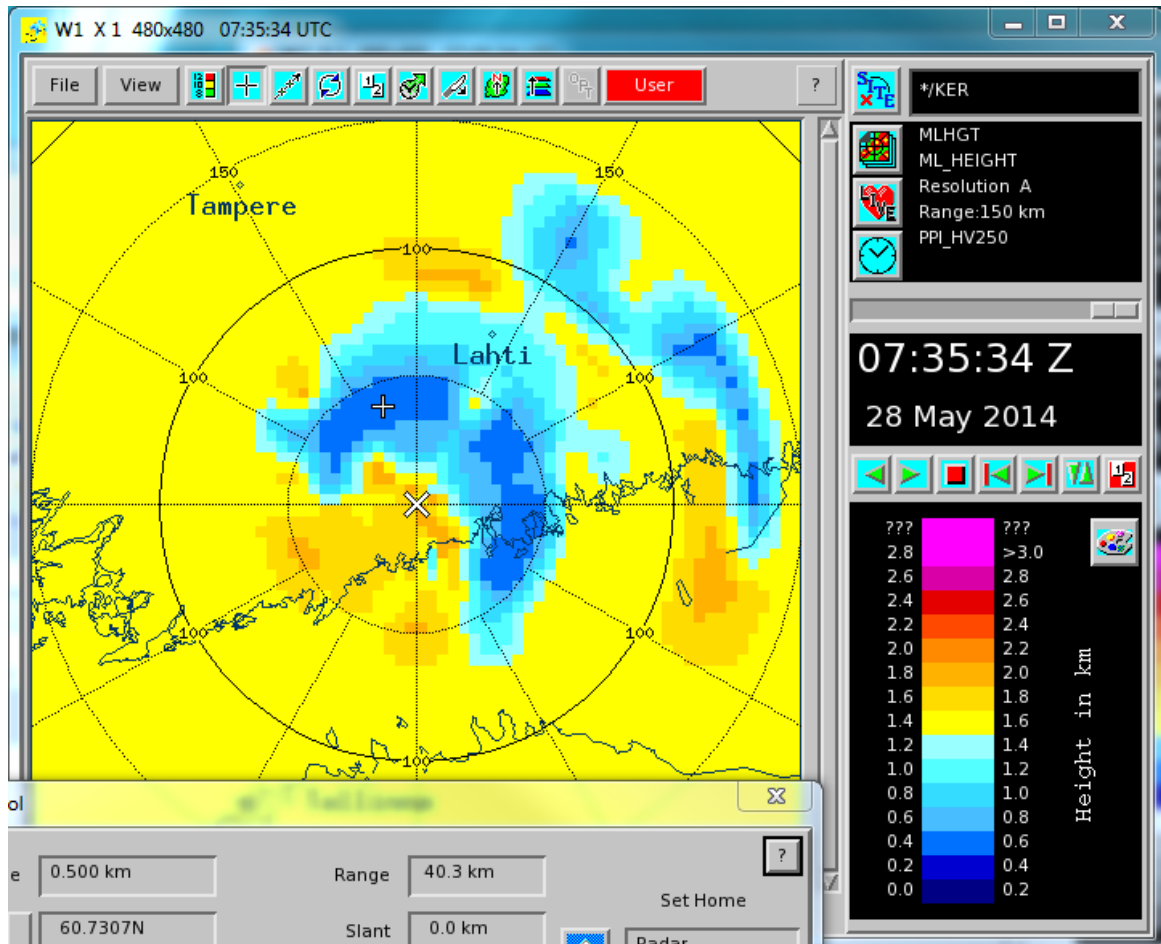


Figure 21 Melting Level Height Detection

The **MLHGT** product produced by IRIS is a depiction of the melting level heights on a Cartesian map. The melting level heights are determined on a user defined grid providing an illustration how the melting level heights changes geographically.

Dual Polarization radar data is used as input along with a priori information. As with other IRIS products, the **MLHGT** product may be animated in time and overlayed with other data to increase situational awareness of the precipitation structure in the atmosphere.

5.2 MLHGT Algorithm

IRIS dual polarization raw volume data is used as input for the **MLHGT** algorithm. This data may come from either single **PPI**, volume, **RHI**, or sector scans. The algorithm also functions independently from scan geometry matching data from the scan polar co-ordinate system to an Earth relative co-ordinate system. However as with any radar observation, a higher number of elevations in a volume scan provides the best results.

The following figure shows the **MLHGT** algorithm flow diagram. The top level illustrates the radar observation inputs, followed by prior information. The blocks represent consecutive functional steps. A key qualifier for each step is expressed in parenthesis.

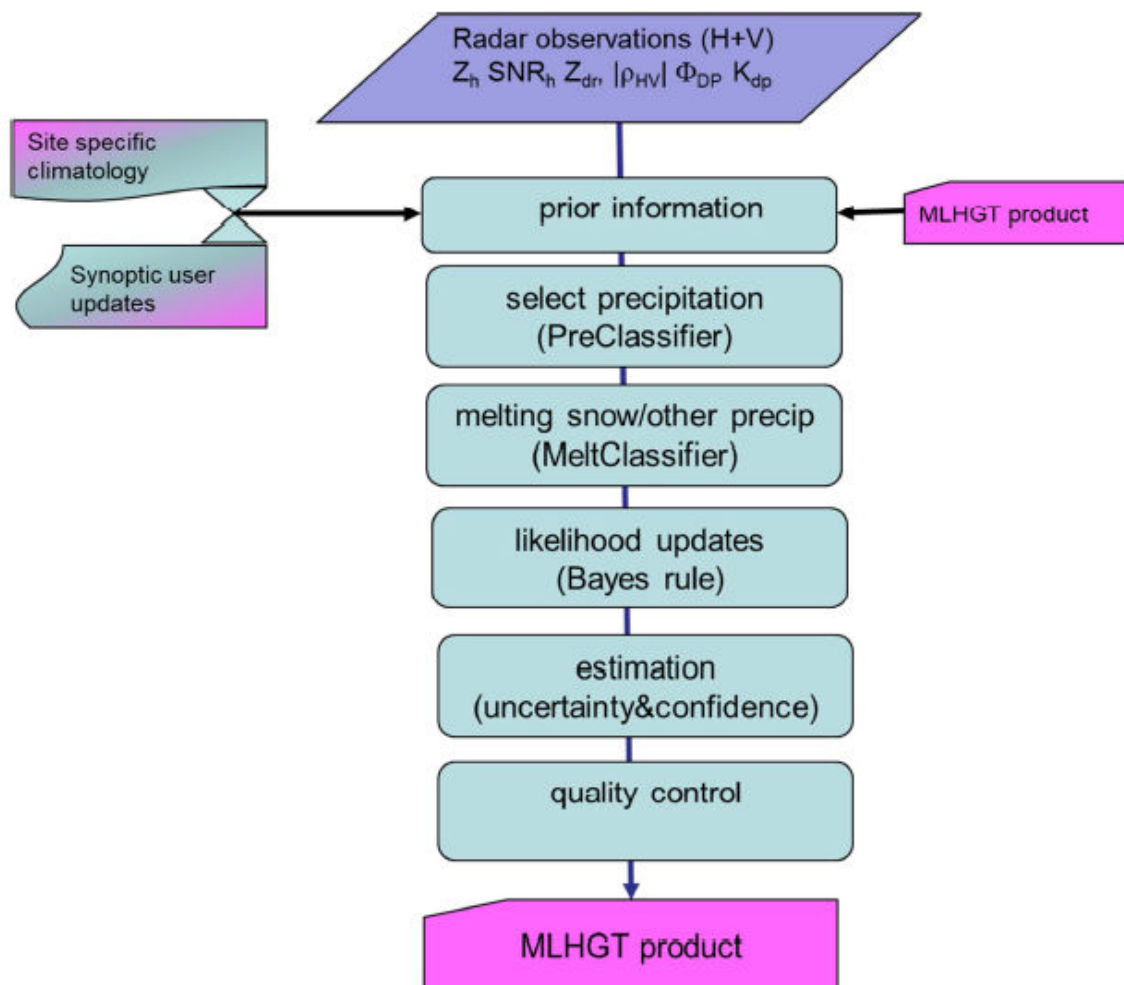


Figure 22 MLHGT Algorithm Flow Diagram

The first step in the processing is to ensure only precipitation particles are being considered for the melting level height estimates. The **PreClassifier** tags each range bin as being from precipitation or non-precipitation targets. The non-precipitation flagged bins are removed from the considered data.

The precipitating bins are then classified into 'melting snow' or 'other precipitation' by a dedicated fuzzy algorithm known as **MeltClassifier**. **MeltClassifier** is similar to the **MeteoClassifier** used in **HydroClass**. However, the **MeltClassifier** substitutes a Signal to Noise Ratio (SNR) Membership function (MBF) in place of the melting level height MBF used by the **MeteoClassifier**. The SNR MBF is configured for low SNR to be part of the 'melting snow' and high SNR in 'other precipitation'. Other particle types such as rain, dry snow, hail, and graupel which are normally characterized or also grouped into the 'other precipitation' class.

The statistical method known as Bayesian Rule is used to infer the likelihood of a region being either 'melting snow' or 'other precipitation', using a priori information and posterior conditioning. The a priori information is the first estimate of the 0 °C heights from an outside source. This could be automatically inserted from radiosonde or NWP data, or could come from the climatological values found in IRIS/Setup.

The likelihood of the **MLHGT** can be updated by each subsequent radar observation over time building up a confidence in the estimate. If there are a high number of 'melting snow' or 'other precipitation' bins in a region, and the ratio of one condition versus the other is high, confidence increases quickly. Likewise, if there is a low number of classifications in the region or if the ratio of 'melting snow' to 'other precipitation' is almost equal, the confidence remains low. Once the minimum confidence is reached the melting level height form MLHGT is assigned to that region, else the height remains to be the climatological value. The Bayesian inference can be conceptually understood as constructing a display of vertical cross-sections in which the most likely position of the ML can be visually recognized by inspection of the **MeltClassifier** decisions.

The regions are presented as columns of data in an Earth co-ordinate system. The user is allowed to configure the vertical resolution and azimuthal size of each region. The columns size in range domain are scaled to match their size in azimuth. The columns range extent grows proportionally as the size in azimuth as distance from the radar increases. Thus the columns are effectively the same shape throughout the domain. This is advantageous because the statistics is improved at farther distances, due to an increasing number of data points, which compensates for the loss in resolution by beam broadening.

More information

- [MeteoClassifiers \(page 52\)](#)
- [Preclassifier \(page 48\)](#)

6. Calibration

6.1 Calibration Considerations

Polarization systems require additional calibration as compared to conventional systems. There are 3 aspects to the calibration:

- dBZ₀ measurement in both channels for dBZ and dBT calibration
- GDR measurement for Z_{dr} calibration
- XDR measurement for LDR calibration

6.1.1 dBZ₀ Calibration for dBZ

RVP900 supports separate calibration of both polarization channels. Measurement of dBZ₀ for each channel of a dual polarization system is identical to the conventional radar case described in *RVP900 Digital Receiver and Signal Processor User Guide*.

For a single-channel switching system, the only difference between the horizontal and vertical signal paths occurs after the high power switch, that is, differential insertion loss of the switch itself and any differential insertion loss of the waveguides and feed after the switch. This means that for single-channel switching systems it may be sufficient to calibrate at one polarization and then adjust the calibration of the other channel by the differential gain GDR. See [GDR Calibration for Z_{dr} \(page 94\)](#).

6.1.2 GDR Calibration for Z_{dr}

The Z_{dr} Offset is the dB value of the relative gain between the co-polarized channels including both transmitter and receiver gain, that is:

$$ZDROffset = 10\log \frac{g_v^r g_v^t}{g_h^r g_h^t} \text{ and } gdr = \frac{g_v^r g_v^t}{g_h^r g_h^t}$$

GDR is input into the processor as a dB value. However, for these analyses, the linear **gdr** value is sometimes more convenient.

In principle, if dBZ₀ could be calibrated perfectly in both channels, measurement of GDR would not be required. In practice, this is not possible because dBZ₀ cannot be calibrated to an absolute accuracy sufficient for Z_{dr}, that is, to 1/16th of a dB. Therefore, RVP900 uses the GDR approach.

Since GDR includes both transmitter and receiver differential gains, accurate calibration requires that an actual target be observed.

The following steps show one way to do this is.

1. Set the GDR to be 0 dB using your application software (for example, for Vaisala IRIS systems in the setup utility RVP section).
2. Disable clutter filtering for Z_{dr} in either your application software (by selecting filter 0) or explicitly in the RVP900 TTY setups **mp** section.

3. Place the antenna at 90° elevation (vertical incidence) during moderate to heavy rain. The melting layer should be at a height that is well above the recovery zone of the T/R and in the antenna "far zone". A melting layer higher than 2 km (1.2 mi) is suggested, but you must consider the specific characteristics of the radar.
4. Collect Z_{dr} data at vertical incidence while the antenna is rotating in azimuth.
5. Use a separate application program to average the Z_{dr} values around a full 360° at each range bin (height).
Generate a plot of 360-average Z_{dr} against height.
6. Check that the average Z_{dr} values in regions of strong signal (>20 dB SNR) below the bright band are approximately constant with height. This is the
Use this value in your application software for GDR.
7. Enter the value and repeat the calibration to verify that the average Z_{dr} is now 0 dB.

The rationale for this approach is that, when viewed at vertical incidence, rain should have a Z_{dr} of 0 dB since the drops all appear circular. The reason for averaging over 360° is to cancel-out effects from sidelobe contamination from nearby ground targets and other artifacts of the antenna/feed/radome system. For example the radome may have an obstruction light on the top. Some of these artifacts can be minimized by assuring the weather targets are strong, that is, heavy rain is preferred for this calibration.

6.1.3 Offset Calibration for LDR

XDR is the dB value of the relative gain between the co- and cross-receiver channels for LDR measurements. Analogous to GDR, it is defined as the dB value of the ratio of the vertical to horizontal receiver gains, for example:

$$XDR = 10 \log \frac{g_v^r}{g_h^r} \text{ and } xdr = \frac{g_v^r}{g_h^r}$$

The following techniques are available for calibrating XDR:

- [Using the Sun to Measure LDR \(page 95\)](#)
- [Using a Signal Generator to Measure LDR \(page 96\)](#)
- [Using a Linear Feed Horn to Measure LDR \(page 96\)](#)

For all these calibration methods, Vaisala recommends that you

- Turn the transmitter off.
- Set XDR to 0 dB in the application user software
- Configure the RVP900 TTY setups as follows:
 - Noise correction enabled for LDR and noise sample taken prior to the measurements (with care not to sample with a test signal turned-on or while looking at the sun).
 - Clutter correction disabled for LDR.

6.1.3.1 Using the Sun to Measure LDR

Use the sun to measure LDR. The measured value of LDR is the XDR offset.

- ▶ 1. Measure the LDR in fixed mode for both LDRH and LDRV.

2. Check that the values are reciprocal (for example, +1 dB and -1 dB).
If the values are not precisely reciprocal, use the average of the absolute value (for example, for +1.4 and -1.2, use 1.3).
3. Enter the XDR value.
4. Retest to verify that the sun has been properly corrected to have zero LDR.

6.1.3.2 Using a Signal Generator to Measure LDR

You can measure LDR using a signal generator with a waveguide connection.

- ▶ 1. Connect a signal generator with a splitter to both channels and measure XDR directly.
This does not account for any effects that are before the coupler (for example, waveguide, feed, radome, antenna gain).

6.1.3.3 Using a Linear Feed Horn to Measure LDR

This approach requires a calibrated linear feed horn with an RF source located several hundred meters from the radar.



Signal multi-path effects may bias the results from this technique.

- ▶ 1. Maximize the H channel return and measure the response using the RVP900 **pr** command **Filtered** power in the **Primary Channel**.
- 2. Rotate the feed horn to vertical and maximize the power in the **Secondary Channel**.
The difference in dB is XDR.

7. Quality Control

7.1 Thresholding Polarization Parameters

The thresholding of polarization parameters by the processor eliminates bins with weak or uncertain signals. Note that the thresholding can be disabled if you want to see all of the data regardless of the data quality.

All the polarization parameters are based on power ratios. RVP900 requires that each power term in a ratio pass a signal-to-noise test similar to the log power test. For example, there are up to four different powers that can be calculated (alternating dual-channel case) so the tests for each of these are:

$$\frac{\langle |S_{hh}|^2 \rangle}{N_h} > N_{thresh}$$

$$\frac{\langle |S_{hv}|^2 \rangle}{N_h} > N_{thresh}$$

$$\frac{\langle |S_{vv}|^2 \rangle}{N_h} > N_{thresh}$$

$$\frac{\langle |S_{vh}|^2 \rangle}{N_h} > N_{thresh}$$

where the linearized threshold that is input as the dB LOG threshold, that is:

$$N_{thresh} = 10^{\frac{LOGthresh}{10}}$$

For example, a valid LDRH requires both a valid S_{hh} and a valid S_{vh} . The parameters RhoH and PhiH have the same requirement since they are the magnitude and phase of the cross-correlation function which is based on S_{hh} and S_{vh} .

There are 2 exceptions:

Z_{dr}

Z_{dr} requires that S_{hh} and S_{vv} pass the signal-to-noise tests noted above. However, Z_{dr} can be additionally thresholded by any of the other threshold parameters (**LOG**, **SIG**, **SQI**, **CSR**) similar to a standard moment. See *RVP900 Digital Receiver and Signal Processor User Guide* for a description of the standard moment thresholding.

PhiDP for single channel alternating case

PhiDP requires that S_{hh} and S_{vv} pass the signal-to-noise tests noted above. In the single channel alternating case, PhiDP must also satisfy the additional test that the Doppler velocity at the range bin must be valid, that is, not thresholded by its own criteria. This is because the algorithm for PhiDP in this case subtracts the phase change due to the Doppler velocity. If the Doppler velocity is uncertain, the algorithm cannot produce reliable results.

Appendix A. Default Configuration File for S-band Radars

```
# ==== RDA/IRIS HydroClass configuration file (S-band) ====
# HydroClass configuration name:
# use a descriptive name max 15 characters, saved in ingest header when IRIS
dpolapp.sConfigurationName = "dpolapp_S-band"
```

```
# =====
# Main algorithm menu. Activate algorithms by selecting (1:yes, 0:no):
# Activate quality actions (see block Quality):
dpolapp.bRunQuality = 1
# Activate the identification algorithms:
# 1: Preclassifier, only (the JPOLE algorithm for meteo vs. bio vs. GC/AP)
# 2: Meteoclassifiers, with the preclassifier mask
# 21: Precip classifier (the JPOLE warm algorithm, with preclassifier mask.
# 22: Meteoclassifiers and Precip classifier, with preclassifier mask.
# 201: Classifier for stratiform and convective rain (volume level analysis),
with preclassifier mask.
# 202: Meteoclassifiers and stratiform/convective classifier, with
preclassifier mask.
# 221: Precip classifier and stratiform/convective classifier, with
preclassifier mask.
# 222: Precip classifier, Meteoclassifiers and stratiform/ convective
classifier, with preclassifier mask.
dpolapp.usClassificationMethods = 222
```

```
# =====
# RDA/IRIS major version
dpolapp.sVersion = "8.13"
# RDA/IRIS revision
dpolapp.sRevision = ".0"
# dpolapp running version
dpolapp.sDpolappRevision = "15"
```

```

# =====
# Detailed data quality configurations:
# Input source of the melting layer height:
# 1: retrieve the value in this configuration file
# 0: use the value in RAW reingested (reingest), or the value in INU record
(rda):
dpolapp.Quality.iAux[0] = 1
# The explicit melting layer height. Signed integer [m]:
dpolapp.Quality.iAux[1] = 2300
#
# Mode of input data quality considerations
# 0: select the input data passing quality thresholds (recommended).
# 1: select all the computed input data (possible in RDA, only).
dpolapp.Quality.iAux[2] = 0
#
# Extra ZDR balance offset to be applied [dB] (applicable in reingest, only):
dpolapp.Quality.OtherInputs[0].dParams[0] = 0

```

```

# =====
# Detailed configuration of the preclassifier.
# Fixed features:
# Preclassifier has 5 input observables: Zh, Zdr, RhoHV, Zh- texture, Phidp-
texture.
# There are 3 output classes: GC/AP, BIO, PRECIP.
# The rule strength function RS is sum of MBF(i) and the class assignment is
max RS.
#
# Are the results to be formatted as PRECIP_CLASSIFIER in the bits 3,4,5 from
LSB=0 of DB_HCLASS(2)?
# default: -1 (NO, the legacy HydroClass format), 1:PRECIP_CLASSIFIER
dpolapp.Preclassifier.iClassifierID = -1
# IF (usClassificationMethods>1, Preclassifier outcomes are interpreted as
'NoMet' or 'Precipitation')
# .. see details in blocks of MeteoClassifiers, PrecipClassifier and
CellClassifier.

# ELSE IF (usClassificationMethods=1, i.e. preclassifier alone):'
# .. one can re-group Preclassifier results into 'uiNonMeteoID':
# .. 1: unidentified are 'uiNonMeteoID'; 2:'GC/AP' are 'uiNonMeteoID', too;
3:'BIO' are 'uiNonMeteoID', too.
dpolapp.Preclassifier.uiMaxNonMeteo = 1
# .. 'uiNonMeteoID' group is redirected:
# .. 0:IRIS/RDA threshold, 1:'GC/AP' 2:'BIO' 3:'PRECIP'
dpolapp.Preclassifier.uiNonMeteoID = 0
# Class specific thresholds on rule strengths for a class to be accepted
(recommend:0.)
dpolapp.Preclassifier.dMinRS[0] = 0
dpolapp.Preclassifier.dMinRS[1] = 0
dpolapp.Preclassifier.dMinRS[2] = 0
# Polarimetric quality index, given the set of 'PRECIP', 'BIO' and 'GC/AP'
# The preferred class. Default: 2 'PRECIP'. Alternatives: 1 'BIO', 0 'GC/AP'
dpolapp.Preclassifier.iAux[3] = 2
# PMI formula. Default: 1: 'score' (1-(1/(1+RSpref/ max(RScomplement)))) 0:
likelihood ratio
dpolapp.Preclassifier.iAux[4] = 1

# Preclassifier computes the textures of reflectivity and differential phase.
# Texture-1:
# Input data: Zh.
# Range interval for averaging [Nr of gates]:
dpolapp.Preclassifier.OtherInputs[0].iParams[0] = 5
# Texture-2:
# Data type used as input: Phidp.
# Range interval for averaging [Nr of gates]:
dpolapp.Preclassifier.OtherInputs[1].iParams[0] = 10

# MBFinputs and their use:
# Reflectivity in preclassifier:
# Input data: Zh.
# MBF(Zh) is computed as JPOLE trapetzoid; an additive factor in rule strength
# MBF: default initialization with parameter settings of Table 1 Ref.1

```

```

# Zh MBF trapetzoid for GC/AP.
dpolapp.Preclassifier.MBFinputs[0].dMBF[0][0] = 15
dpolapp.Preclassifier.MBFinputs[0].dMBF[1][0] = 20
dpolapp.Preclassifier.MBFinputs[0].dMBF[2][0] = 75
dpolapp.Preclassifier.MBFinputs[0].dMBF[3][0] = 85
# Zh MBF trapetzoid for bio scatter.
dpolapp.Preclassifier.MBFinputs[0].dMBF[0][1] = 5
dpolapp.Preclassifier.MBFinputs[0].dMBF[1][1] = 10
dpolapp.Preclassifier.MBFinputs[0].dMBF[2][1] = 20
dpolapp.Preclassifier.MBFinputs[0].dMBF[3][1] = 30
# Zh MBF trapetzoid for precipitation.
dpolapp.Preclassifier.MBFinputs[0].dMBF[0][2] = 5
dpolapp.Preclassifier.MBFinputs[0].dMBF[1][2] = 10
dpolapp.Preclassifier.MBFinputs[0].dMBF[2][2] = 75
dpolapp.Preclassifier.MBFinputs[0].dMBF[3][2] = 80
# Differential reflectivity in preclassifier:
# Input data: Zdr (In reingest: adjusted with Quality offset, internally), and
Zh.
# MBF(Zdr;Zh) is computed as JPOLE 2D-trapetzoid; additive in rule strength
# Zdr MBF trapetzoid for GC/AP.
dpolapp.Preclassifier.MBFinputs[1].dMBF[0][0] = -4
dpolapp.Preclassifier.MBFinputs[1].dMBF[1][0] = -2
dpolapp.Preclassifier.MBFinputs[1].dMBF[2][0] = 1
dpolapp.Preclassifier.MBFinputs[1].dMBF[3][0] = 2
# Zdr MBF trapetzoid for bio scatter.
dpolapp.Preclassifier.MBFinputs[1].dMBF[0][1] = 0
dpolapp.Preclassifier.MBFinputs[1].dMBF[1][1] = 2
dpolapp.Preclassifier.MBFinputs[1].dMBF[2][1] = 10
dpolapp.Preclassifier.MBFinputs[1].dMBF[3][1] = 12
# Zdr MBF trapetzoid for precipitation.
dpolapp.Preclassifier.MBFinputs[1].dMBF[0][2] = -0.3
dpolapp.Preclassifier.MBFinputs[1].dMBF[1][2] = 0
dpolapp.Preclassifier.MBFinputs[1].dMBF[2][2] = 0
dpolapp.Preclassifier.MBFinputs[1].dMBF[3][2] = 0.3
# A polynomial dependence of the Zdr precipitation trapezoid on Zh
# The Zh range in which the polynomial is applied:
dpolapp.Preclassifier.MBFinputs[1].dP[4][2] = 0
dpolapp.Preclassifier.MBFinputs[1].dP[5][2] = 80
# Dependency on Zh: left tail constant term P0, linear P1, 2nd order P2, and
3rd order P3.
# The left shoulder is the same.
dpolapp.Preclassifier.MBFinputs[1].dP[2][0][0] = -0.5
dpolapp.Preclassifier.MBFinputs[1].dP[2][0][1] = 0.0025
dpolapp.Preclassifier.MBFinputs[1].dP[2][0][2] = 0.00075
dpolapp.Preclassifier.MBFinputs[1].dP[2][0][3] = 0
# The right tail constant term P0, linear P1, 2nd order P2 and 3rd order P3
# The right shoulder is the same.
dpolapp.Preclassifier.MBFinputs[1].dP[2][2][0] = 0.08
dpolapp.Preclassifier.MBFinputs[1].dP[2][2][1] = 0.0364
dpolapp.Preclassifier.MBFinputs[1].dP[2][2][2] = 0.000357
dpolapp.Preclassifier.MBFinputs[1].dP[2][2][3] = 0
# Cross correlation coefficient in preclassifier:
# Data type used as input: RhoHV.
# MBF(RhoHV) is computed as JPOLE trapetzoid;an additive factor in rule
strength

```

```

# MBF: default initialization with parameter settings of Table 1 Ref.1
# RHOHV MBF trapetzoid for GC/AP.
dpolapp.Preclassifier.MBFinputs[2].dMBF[0][0] = 0.5
dpolapp.Preclassifier.MBFinputs[2].dMBF[1][0] = 0.6
dpolapp.Preclassifier.MBFinputs[2].dMBF[2][0] = 0.9
dpolapp.Preclassifier.MBFinputs[2].dMBF[3][0] = 0.95
# RHOHV MBF trapetzoid for bio scatter.
dpolapp.Preclassifier.MBFinputs[2].dMBF[0][1] = 0
dpolapp.Preclassifier.MBFinputs[2].dMBF[1][1] = 0
dpolapp.Preclassifier.MBFinputs[2].dMBF[2][1] = 0.8
dpolapp.Preclassifier.MBFinputs[2].dMBF[3][1] = 0.83
# RHOHV MBF trapetzoid for precipitation.
dpolapp.Preclassifier.MBFinputs[2].dMBF[0][2] = 0.85
dpolapp.Preclassifier.MBFinputs[2].dMBF[1][2] = 0.97
dpolapp.Preclassifier.MBFinputs[2].dMBF[2][2] = 1
dpolapp.Preclassifier.MBFinputs[2].dMBF[3][2] = 1.01
# Differential phase texture in preclassifier:
# The input data type is computed internally.
#--- MBF(Texture-1) is computed as JPOLE trapetzoid;an additive factor in rule
strength
# MBF: default initialization with parameter settings of Table 1 Ref.1
# PHIDP texture MBF trapetzoid for GC/AP.
dpolapp.Preclassifier.MBFinputs[3].dMBF[0][0] = 30
dpolapp.Preclassifier.MBFinputs[3].dMBF[1][0] = 40
dpolapp.Preclassifier.MBFinputs[3].dMBF[2][0] = 10800
dpolapp.Preclassifier.MBFinputs[3].dMBF[3][0] = 10800
# PHIDP texture MBF trapetzoid for bio scatter.
dpolapp.Preclassifier.MBFinputs[3].dMBF[0][1] = 8
dpolapp.Preclassifier.MBFinputs[3].dMBF[1][1] = 10
dpolapp.Preclassifier.MBFinputs[3].dMBF[2][1] = 40
dpolapp.Preclassifier.MBFinputs[3].dMBF[3][1] = 60
# PHIDP texture MBF trapetzoid for precipitation.
dpolapp.Preclassifier.MBFinputs[3].dMBF[0][2] = 0
dpolapp.Preclassifier.MBFinputs[3].dMBF[1][2] = 1
dpolapp.Preclassifier.MBFinputs[3].dMBF[2][2] = 15
dpolapp.Preclassifier.MBFinputs[3].dMBF[3][2] = 30
# Reflectivity texture in preclassifier:
# Data type is computed internally.
# MBF(Texture-2) is computed as JPOLE trapetzoid; an additive factor in the
rule strength
# MBF: default initialization with parameter settings of Table 1 Ref.1
# Zh texture MBF trapetzoid for GC/AP.

```



```
dpolapp.Preclassifier.MBFinputs[4].dMBF[0][0] = 2
dpolapp.Preclassifier.MBFinputs[4].dMBF[1][0] = 4
dpolapp.Preclassifier.MBFinputs[4].dMBF[2][0] = 10000
dpolapp.Preclassifier.MBFinputs[4].dMBF[3][0] = 10000
# Zh texture MBF trapetzoid for bio scatter.
dpolapp.Preclassifier.MBFinputs[4].dMBF[0][1] = 1
dpolapp.Preclassifier.MBFinputs[4].dMBF[1][1] = 2
dpolapp.Preclassifier.MBFinputs[4].dMBF[2][1] = 4
dpolapp.Preclassifier.MBFinputs[4].dMBF[3][1] = 7
# Zh texture MBF trapetzoid for precipitation.
dpolapp.Preclassifier.MBFinputs[4].dMBF[0][2] = 0
dpolapp.Preclassifier.MBFinputs[4].dMBF[1][2] = 0.5
dpolapp.Preclassifier.MBFinputs[4].dMBF[2][2] = 3
dpolapp.Preclassifier.MBFinputs[4].dMBF[3][2] = 6
# Other flags: none.
```

```

# =====
# Detailed configuration of the CSU hydrometeor classifier.

# Fixed features:
# MeteoClassifiers has 5 inputs (Zh, ML, Zdr, Kdp, RhoHV).
# There are five application classes: RAIN, WET SNOW, SNOW, GRAUPEL/SMALL
HAIL, HAIL.
# MeteoClassifiers considers hail and rain mixtures, and assigns likely
mixtures as HAIL. # MeteoClassifiers use the CSU sum/product hybrid as the rule
strength (RS), the class
result is MAX(RS).
# RS class weights: Zh:1, ML:1(summer i.e. ML>0)/ 0.333(winter, ML<0)
#Zdr: 0.5(ML>0)/0.2333(ML<0), Kdp: 0.25(ML>0)/0.1(ML<0), Rhv 0.25(ML>0)/
0.333(ML<0).
# The results are formatted as METEO_CLASSIFIER in the bits 0,1,2 starting
from LSB=0 of DB_HCLASS(2).

# MeteoClassifiers considers the Preclassifier(JPOLE) 'meteo' bins, only.
Other input bins are 'NoMet'
# MeteoClassifiers will redirect the 'NoMet' and unclassified bins as:
# 0: thresholded or 1: 'NoMet' or any other class of MeteoClassifiers.
dpolapp.MeteoClassifiers.uiNonMeteoID = 1
# Class specific thresholds on rule strengths
# Recommend 0.0 i.e. all JPOLE 'meteo' bins are assigned to a CSU class
dpolapp.MeteoClassifiers.dMinRS[0] = 0
dpolapp.MeteoClassifiers.dMinRS[1] = 0
dpolapp.MeteoClassifiers.dMinRS[2] = 0
dpolapp.MeteoClassifiers.dMinRS[3] = 0
dpolapp.MeteoClassifiers.dMinRS[4] = 0
dpolapp.MeteoClassifiers.dMinRS[5] = 0
# MBFinputs and their use:
# Reflectivity in MeteoClassifiers:
# Data type used as input: Zh.
# MBF(dBZ) is computed as the CSU beta function.
# MBF: S-band, default settings:
# Zh beta MBF for rain: central value, width, slope
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][0] = 30
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[1][0] = 31
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[2][0] = 70
# Zh beta MBF for wet snow.
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][1] = 30
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[1][1] = 16
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[2][1] = 35.6
# Zh beta MBF for snow.
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[1][2] = 36
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[2][2] = 81.6
# Zh beta MBF for graupel/small hail.
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][3] = 41.5
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[1][3] = 11.5
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[2][3] = 36
# Zh beta MBF for large hail.
dpolapp.MeteoClassifiers.MBFinputs[0].dMBF[0][4] = 57.5

```

```

dpolapp.MeteoClassifiers.MBFInputs[0].dMBF[1][4] = 13.5
dpolapp.MeteoClassifiers.MBFInputs[0].dMBF[2][4] = 30
# Zh beta MBF for rain+hail mixture.
dpolapp.MeteoClassifiers.MBFInputs[0].dMBF[0][5] = 57.5
dpolapp.MeteoClassifiers.MBFInputs[0].dMBF[1][5] = 13.5
dpolapp.MeteoClassifiers.MBFInputs[0].dMBF[2][5] = 30
# Altitude in MeteoClassifiers:
# The IRIS/RDA estimate of the melting level height will be used.
# MBF(altitude;melting level) is computed as the CSU beta(ML) function.
# MBF: S-band, default settings:
# Altitude beta MBF for rain: central value, width, slope
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][0] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][0] = -0.2
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][0] = 20
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][0] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][0] = 0.5
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][0] = 5
# Altitude beta MBF for wet snow.
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][1] = -0.3
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][1] = 0.5
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][1] = 5
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][1] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][1] = 1
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][1] = 5
# Altitude beta MBF for snow.
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][2] = 10
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][2] = 10.2
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][2] = 60
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][2] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][2] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][2] = 0
# Altitude beta MBF for graupel/small hail.
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][3] = 10
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][3] = 12
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][3] = 60
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][3] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][3] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][3] = 0
# Altitude beta MBF for hail.
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][4] = 10
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][4] = 15
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][4] = 20
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][4] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][4] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][4] = 0
# Altitude beta MBF for rain+hail mixture.
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[0][5] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[1][5] = 0.5
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[2][5] = 20
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[3][5] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[4][5] = 0
dpolapp.MeteoClassifiers.MBFInputs[1].dMBF[5][5] = 0
# Differential reflectivity in MeteoClassifiers:
# Input data: Zdr (adjusted with Quality offset, internally in reingest), and
Zh

```

```

# MBF(Zdr) is computed as the CSU 2D-beta function of Zh.
# MBF: S-band, default settings:
# Zdr 2D beta MBF for rain at Zh=<Zh> dB (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[0][0] = 1.5334
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[1][0] = 1.6292
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[2][0] = 17.5905
# Polynomial dependence of rain MBF(Zdr) on Zh-<Zh>
#The center<Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[3][0] = 30
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[4][0] = 31
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraints:
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][0][0] = 0.0766
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][0][1] = 0.00013578
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][0][2] = - 1.4943E-05
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][0][3] = 2.6655E-07
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][0][4] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][0][5] = 5.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][0] = 0.0438
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][1] = -0.0011
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][2] = - 8.6469E-06
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][3] = 1.1002E-06
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][4] = 0.4
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][1][5] = 8
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][0] = 0.4983
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][1] = -0.0128
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][2] = - 9.0093E-05
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][3] = 1.2834E-05
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][4] = 8
dpolapp.MeteoClassifiers.MBFinputs[2].dP[0][2][5] = 30
# Zdr 2D beta MBF for wet snow at Zh=<Zh> (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[0][1] = 1.5
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[1][1] = 1.7
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[2][1] = 37.9
# Polynomial dependence of wet snow MBF(Zdr) on Zh-<Zh>
# The center<Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[3][1] = 30
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[4][1] = 16
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraint:
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][0] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][1] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][4] = 1.1
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][0][5] = 2.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][0] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][1] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][4] = 1
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][1][5] = 2.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][0] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][1] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][2] = 0

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dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][4] = 5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[1][2][5] = 20
# Zdr 2D beta MBF for snow at Zh=<Zh> (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[0][2] = 0.25
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[1][2] = 0.95
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[2][2] = 20.7
# Zdr 2D beta MBF for graupel at Zh=<Zh> (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[0][3] = 0.2983
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[1][3] = 0.9283
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[2][3] = 9.7482
# Polynomial dependence of graupel MBF(Zdr) on Zh-<Zh>
# The center<Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[3][3] = 41.5
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[4][3] = 13
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th orde;min/
max constraints:
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][0] = 0.035
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][1] = 0.0015
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][4] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][0][5] = 1
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][0] = 0.035
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][1] = 0.0015
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][4] = 0.5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][1][5] = 2
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][0] = 0.3
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][1] = 0.008
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][4] = 5
dpolapp.MeteoClassifiers.MBFinputs[2].dP[3][2][5] = 15
# Zdr weight and 2D beta MBF for hail at Zh=<Zh> (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[0][4] = -0.75
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[1][4] = 1.45
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[2][4] = 32.2
# Polynomial dependence of hail MBF(Zdr) on Zh-<Zh>
# The center<Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[3][4] = 57.5
dpolapp.MeteoClassifiers.MBFinputs[2].dMBF[4][4] = 13.5
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;min/
max constraint:
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][0] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][1] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][4] = -2
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][0][5] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][1][0] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][1][1] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][1][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[2].dP[4][1][3] = 0

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dpolapp.MeteoClassifiers.MBFInputs[2].dP[4][1][4] = 0.1
dpolapp.MeteoClassifiers.MBFInputs[2].dP[4][1][5] = 1.3
dpolapp.MeteoClassifiers.MBFInputs[2].dP[4][2][0] = 0
dpolapp.MeteoClassifiers.MBFInputs[2].dP[4][2][1] = 0
dpolapp.MeteoClassifiers.MBFInputs[2].dP[4][2][2] = 0
dpolapp.MeteoClassifiers.MBFInputs[2].dP[4][2][3] = 0
dpolapp.MeteoClassifiers.MBFInputs[2].dP[4][2][4] = 7
dpolapp.MeteoClassifiers.MBFInputs[2].dP[4][2][5] = 17
# Zdr weight and 2D beta MBF for rain+hail mixture at Zh=<Zh> (central value,
width, slope):
dpolapp.MeteoClassifiers.MBFInputs[2].dMBF[0][5] = 0.5045
dpolapp.MeteoClassifiers.MBFInputs[2].dMBF[1][5] = 1.3545
dpolapp.MeteoClassifiers.MBFInputs[2].dMBF[2][5] = 30.0125
# Polynomial dependence of rain+hail mixture MBF(Zdr) on Zh-
<Zh>
# The center<Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFInputs[2].dMBF[3][5] = 57.5
dpolapp.MeteoClassifiers.MBFInputs[2].dMBF[4][5] = 15.5
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraint:
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][0][0] = -0.0461
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][0][1] = - 0.00068749
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][0][2] = 0.00018148
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][0][3] = -5E-06
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][0][4] = -0.5
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][0][5] = 1.5
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][1][0] = -0.0261
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][1][1] = - 0.00068749
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][1][2] = 0.00018148
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][1][3] = -5E-06
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][1][4] = 0.5
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][1][5] = 2
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][2][0] = -0.6002
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][2][1] = -0.0173
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][2][2] = 0.0042
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][2][3] = - 0.00010667
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][2][4] = 20
dpolapp.MeteoClassifiers.MBFInputs[2].dP[5][2][5] = 35
# Specific differential phase in MeteoClassifiers:
# Input data: Kdp, and Zh.
# MBF(Kdp) is computed as the CSU 2D-beta function of Zh.
# MBF: S-band, default settings:
# Kdp 2D beta MBF for rain at Zh=<Zh> dB (central value, width, slope):
dpolapp.MeteoClassifiers.MBFInputs[3].dMBF[0][0] = 0.7916
dpolapp.MeteoClassifiers.MBFInputs[3].dMBF[1][0] = 0.8538
dpolapp.MeteoClassifiers.MBFInputs[3].dMBF[2][0] = 17.2646
# Polynomial dependence of rain MBF(Kdp) on Zh-<Zh>
# The center<Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFInputs[3].dMBF[3][0] = 30
dpolapp.MeteoClassifiers.MBFInputs[3].dMBF[4][0] = 31
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraint:
dpolapp.MeteoClassifiers.MBFInputs[3].dP[0][0][0] = 0.0011
dpolapp.MeteoClassifiers.MBFInputs[3].dP[0][0][1] = - 0.00071936
dpolapp.MeteoClassifiers.MBFInputs[3].dP[0][0][2] = 0.00015317

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dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][0][3] = 5.0804E-06
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][0][4] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][0][5] = 14
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][0] = 0.0132
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][1] = - 0.00043912
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][2] = 6.8089E-05
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][3] = 2.6246E-06
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][4] = 0.2
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][1][5] = 8
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][0] = -0.0093
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][1] = -0.033
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][2] = 0.00090559
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][3] = 5.3507E-05
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][4] = 4
dpolapp.MeteoClassifiers.MBFinputs[3].dP[0][2][5] = 55
# Kdp 2D beta MBF for wet snow at Zh=25 dB: central value, width, slope.
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][1] = 0.5
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][1] = 0.6
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][1] = 12.6
# Kdp 2D beta MBF for snow at Zh=17.5 dB (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][2] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][2] = 0.6
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][2] = 12.6
# Kdp 2D beta MBF for graupel at Zh=37.5 dB (central value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][3] = 0.2123
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][3] = 0.4873
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][3] = 9.9993
# Polynomial dependence of graupel MBF(Kdp) on Zh-<Zh>
# The center<Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[3][3] = 37.5
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[4][3] = 8.5
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraint:
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][0] = 0.0045
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][1] = 0.00010064
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][2] = 8.6663E-05
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][3] = - 1.201E-05
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][4] = -0.25
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][0][5] = 1.5
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][0] = 0.0353
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][1] = - 0.00022246
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][2] = - 4.6667E-05
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][3] = 4.1159E-05
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][4] = 0.3
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][1][5] = 2
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][0] = 0.7825
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][1] = -0.0029
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][2] = 0.0028
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][3] = 0.00047804
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][4] = 4
dpolapp.MeteoClassifiers.MBFinputs[3].dP[3][2][5] = 20
# Kdp weight and 2D beta MBF for hail at Zh=57.5 dB (central value, width,
slope):
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][4] = 0.25
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][4] = 0.85

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dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][4] = 18.4
# Kdp weight and 2D beta MBF for rain+hail mixture at Zh=57.5 dB (central
value, width, slope):
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[0][5] = 1.8241
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[1][5] = 1.9253
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[2][5] = 26.8047
# Polynomial dependence of rain+hail mixture MBF(Kdp) on Zh-
<Zh>
# The center<Zh> and the Zh range in which the polynomial is applied:
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[3][5] = 57.5
dpolapp.MeteoClassifiers.MBFinputs[3].dMBF[4][5] = 15.5
# Polynomial coefficients; the linear, the 2nd, the 3rd, and the 4th order;
min/max constraint:
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][0] = 0.3156
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][1] = 0.0124
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][2] = - 0.00066667
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][3] = -3.8E- 05
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][4] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][0][5] = 10
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][0] = 0.3138
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][1] = 0.0122
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][2] = - 0.00062963
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][3] = - 3.4667E-05
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][4] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][1][5] = 10
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][0] = 2.6738
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][1] = 0.0805
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][2] = -2
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][3] = 0
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][4] = 4
dpolapp.MeteoClassifiers.MBFinputs[3].dP[5][2][5] = 70
# Cross correlation coefficient in MeteoClassifiers:
#--- Data type used as input: RhoHV.
#--- MBF(RhoHV) is computed as the CSU beta function.
# # MBF:S-band, default settings:
# RHOHV beta MBF for rain: central value, width, slope
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][0] = 1
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][0] = 0.04
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][0] = 10
# RHOHV beta MBF for wet snow.
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][1] = 0.88
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][1] = 0.11
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][1] = 20
# RHOHV beta MBF for snow.

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dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][2] = 1
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][2] = 0.06
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][2] = 10
# RHOHV beta MBF for graupel.
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][3] = 0.96
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][3] = 0.04
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][3] = 10
# RHOHV beta MBF for hail.
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][4] = 0.9
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][4] = 0.045
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][4] = 10
# RHOHV beta MBF for rain+hail mixture.
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[0][5] = 0.8
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[1][5] = 0.13
dpolapp.MeteoClassifiers.MBFinputs[4].dMBF[2][5] = 30
```

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# =====
# Detailed configuration of the JPOLE rain classifier.

# Fixed features:
# Precip classifier has 5 input observables: Zh, Zdr, RhoHV, Zh-texture, Phidp-
texture.
# There are 4 output classes: LIGHT, MODERATE and HEAVY PRECIPITATION, and
LARGE DROPS
# The rule strength function RS is sum of MBF(i) and the class assignment is
max RS.
# The results are formatted as PRECIP_CLASSIFIER in the bits 3,4,5 starting
from LSB=0.

# Precip classifier considers the Preclassifier(JPOLE) 'meteo' bins, only.
# Precip classifier will leave other than 'meteo' bins unchanged, and redirect
new unclassified outputs as:
# 0: thresholded or 1: 'GC/AP' or any class of precipClasses.
dpolapp.PrecipClassifier.uiNonMeteoID = 0
# Class specific thresholds on rule strengths for a class to be accepted.
dpolapp.PrecipClassifier.dMinRS[0] = 0
dpolapp.PrecipClassifier.dMinRS[1] = 0
dpolapp.PrecipClassifier.dMinRS[2] = 0
dpolapp.PrecipClassifier.dMinRS[3] = 0

# Precip classifier uses the textures of reflectivity and differential phase.

# MBFinputs and their use:
# Reflectivity in rain classifier:
# Input data: Zh.
# MBF(Zh) is computed as JPOLE trapetzoid; an additive factor in rule strength
# MBF: default initialization with parameter settings of Table 2 Ref.2
# Zh MBF trapetzoid for light precipitation.
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[0][0] = 5
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[1][0] = 10
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[2][0] = 35
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[3][0] = 40
# Zh MBF trapetzoid for moderate precipitation.
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[0][1] = 30
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[1][1] = 35
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[2][1] = 45
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[3][1] = 50
# Zh MBF trapetzoid for heavy precipitation.
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[0][2] = 40
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[1][2] = 45
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[2][2] = 75
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[3][2] = 80
# Zh MBF trapetzoid for large drops.
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[0][3] = 15
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[1][3] = 20
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[2][3] = 45
dpolapp.PrecipClassifier.MBFinputs[0].dMBF[3][3] = 50
# Differential reflectivity in rain classifier:
# Input data: Zdr (In reingest: adjusted with Quality offset, internally), and

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Zh.
# MBF(Zdr;Zh) is computed as JPOLE 2D-trapetzoid; additive in rule strength
# Zdr MBF trapetzoid for light precipitation.
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[0][0] = -0.3
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[1][0] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[2][0] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[3][0] = 0.3
# The polynomial dependence of the Zdr light precipitation trapezoid on Zh
# The Zh range in which the polynomial is applied:
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[4][0] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[5][0] = 80
# Dependency on Zh: left tail constant term P0, linear P1, 2nd order P2, and
3rd order P3.
# The left shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][0][0] = -0.5
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][0][1] = 0.0025
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][0][2] = 0.00075
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][0][3] = 0
# The right tail constant term P0, linear P1, 2nd order P2 and 3rd order P3
# The right shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][2][0] = 0.08
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][2][1] = 0.0364
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][2][2] = 0.000357
dpolapp.PrecipClassifier.MBFinputs[1].dP[0][2][3] = 0
# Zdr MBF trapetzoid for moderate precipitation.
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[0][1] = -0.3
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[1][1] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[2][1] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[3][1] = 0.3
# The polynomial dependence of the Zdr moderate precipitation trapezoid on Zh
# The Zh range in which the polynomial is applied:
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[4][1] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[5][1] = 80
# Dependency on Zh: left tail constant term P0, linear P1, 2nd order P2, and
3rd order P3.
# The left shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][0][0] = -0.5
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][0][1] = 0.0025
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][0][2] = 0.00075
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][0][3] = 0
# The right tail constant term P0, linear P1, 2nd order P2 and 3rd order P3
# The right shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][2][0] = 0.08
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][2][1] = 0.0364
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][2][2] = 0.000357
dpolapp.PrecipClassifier.MBFinputs[1].dP[1][2][3] = 0
# Zdr MBF trapetzoid for heavy precipitation.
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[0][2] = -0.3
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[1][2] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[2][2] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[3][2] = 0.3
# The polynomial dependence of the Zdr heavy precipitation trapezoid on Zh
# The Zh range in which the polynomial is applied:
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[4][2] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[5][2] = 80

```

```

# Dependency on Zh: left tail constant term P0, linear P1, 2nd order P2, and
# 3rd order P3.
# The left shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][0][0] = -0.5
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][0][1] = 0.0025
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][0][2] = 0.00075
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][0][3] = 0
# The right tail constant term P0, linear P1, 2nd order P2 and 3rd order P3
# The right shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][2][0] = 0.08
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][2][1] = 0.0364
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][2][2] = 0.000357
dpolapp.PrecipClassifier.MBFinputs[1].dP[2][2][3] = 0
# Zdr MBF trapezoid for large drops.
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[0][3] = -0.3
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[1][3] = 0

dpolapp.PrecipClassifier.MBFinputs[1].dMBF[2][3] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[3][3] = 0.3
# The polynomial dependence of the Zdr large drops trapezoid on Zh
# The Zh range in which the polynomial is applied:
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[4][3] = 0
dpolapp.PrecipClassifier.MBFinputs[1].dMBF[5][3] = 80
# Dependency on Zh: left tail constant term P0, linear P1, 2nd order P2, and
# 3rd order P3.
# The left shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][0][0] = -0.5
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][0][1] = 0.0025
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][0][2] = 0.00075
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][0][3] = 0
# The right tail constant term P0, linear P1, 2nd order P2 and 3rd order P3
# The right shoulder is the same.
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][2][0] = 0.08
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][2][1] = 0.0364
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][2][2] = 0.000357
dpolapp.PrecipClassifier.MBFinputs[1].dP[3][2][3] = 0
# Cross correlation coefficient in rain classifier:
# Data type used as input: RhoHV.
# MBF(RhoHV) is computed as JPOLE trapezoid;an additive factor in rule
strength
# MBF: default initialization with parameter settings of Table 2 Ref.1
# RHOHV MBF trapezoid for light precipitation.
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[0][0] = 0.85
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[1][0] = 0.97
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[2][0] = 1
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[3][0] = 1.01
# RHOHV MBF trapezoid for moderate precipitation.
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[0][1] = 0.85
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[1][1] = 0.97
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[2][1] = 1
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[3][1] = 1.01
# RHOHV MBF trapezoid for heavy precipitation.
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[0][2] = 0.85
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[1][2] = 0.97
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[2][2] = 1

```

```

dpolapp.PrecipClassifier.MBFinputs[2].dMBF[3][2] = 1.01
# RH0hv MBF trapetzoid for large drops.
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[0][3] = 0.85
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[1][3] = 0.97
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[2][3] = 1
dpolapp.PrecipClassifier.MBFinputs[2].dMBF[3][3] = 1.01
# Differential phase texture in rain classifier:
# The input data type is computed internally.
#--- MBF(Texture-1) is computed as JPOLE trapetzoid;an additive factor in rule
strength
# MBF: default initialization with parameter settings of Table 2 Ref.1
# PHIDP texture MBF trapetzoid for light precipitation.
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[0][0] = 0
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[1][0] = 1
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[2][0] = 15
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[3][0] = 30
# PHIDP texture MBF trapetzoid for moderate precipitation.
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[0][1] = 0
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[1][1] = 1
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[2][1] = 15
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[3][1] = 30
# PHIDP texture MBF trapetzoid for heavy precipitation.
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[0][2] = 0
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[1][2] = 1
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[2][2] = 15
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[3][2] = 30
# PHIDP texture MBF trapetzoid for large drops.
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[0][3] = 0
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[1][3] = 1
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[2][3] = 15
dpolapp.PrecipClassifier.MBFinputs[3].dMBF[3][3] = 30
# Reflectivity texture in rain classifier:
# Data type is computed internally.
# MBF(Texture-2) is computed as JPOLE trapetzoid; an additive factor in the
rule strength
# MBF: default initialization with parameter settings of Table 2 Ref.1
# Zh texture MBF trapetzoid for light precipitation.
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[0][0] = 0
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[1][0] = 0.5
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[2][0] = 3
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[3][0] = 6
# Zh texture MBF trapetzoid for moderate precipitation.

```

```

dpolapp.PrecipClassifier.MBFinputs[4].dMBF[0][1] = 0
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[1][1] = 0.5
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[2][1] = 3
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[3][1] = 6
# Zh texture MBF trapetzoid for heavy precipitation.
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[0][2] = 0
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[1][2] = 0.5
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[2][2] = 3
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[3][2] = 6
# Zh texture MBF trapetzoid for large drops.
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[0][3] = 0
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[1][3] = 0.5
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[2][3] = 3
dpolapp.PrecipClassifier.MBFinputs[4].dMBF[3][3] = 6
# Other flags: none.

```

```

# =====
# Detailed configuration of the classifier of stratiform vs. convective
precipitation.

# Fixed features:
# Convective check considers the pair of Zh and height w.r.t 0oC isotherm.
# The rule strength function RS is a column sum of MBFs
# The results are formatted as CELL_CLASSIFIER in the bits 6-7 starting from
LSB=0.

# Cell classifier considers the Preclassifier(JPOLE) 'meteo' bins, only. Other
bins are set thresholded.
# Rule strength threshold on the CONVECTIVE class.
dpolapp.CellClassifier.dMinRS[0] = 0.5

# Cell classifier considers columns in the volume data of multiple sweeps.

# MBFinputs and their use:
# Reflectivity&Height in cell classifier:
# Input data: Zh and height difference w.r.t. the current 0oC isotherm.
# MBF(Zh,height) is computed as 2D product of trapetzoids; summed up to rule
strength.
# Min Zh required for convection (full fuzzy strength will be +5 dBZ from min).
dpolapp.CellClassifier.MBFinputs[0].dMBF[0][0] = 35
# Min height w.r.t. 0oC isotherm (full fuzzy strength will be +1. km higher ).
dpolapp.CellClassifier.MBFinputs[0].dMBF[4][0] = 0

```

Appendix B. Parametrized Fuzzy Parameters

The hydrometeor classification membership functions are parametrized either as 1D or 2D beta functions.

The evolution of the 2D membership beta function parameters $y=y(Z_H)$ where $y=m, a, \text{ or } b$ were optimized using the CSU approach.

The parameter dependencies are expressed as fifth order polynomials, with coefficients listed in [Table 17 \(page 119\)](#) to [Table 19 \(page 120\)](#).

Parametrizing 2D membership function with polynomials simplifies the implemented software, as the approach is common to CSU and the **JPOLE** algorithms.

The following table shows the beta function parameters of all the 1D membership functions. It also gives insight into the 2D membership functions, expressing their projections at the reference levels of the auxiliary input variables. For example, the parameter values of 2D membership functions of **MBF**(Z_{dr}, Z_H) visualize the shape of the MBF at $Z_H = 0 \text{ dBZ}$.

Table 16 Parameters for 1D and 2D Membership Functions at Specified Reference Planes of the Second Function Variable

MBF	Hydrometeor Class ID	m	a	b
MBF(Z_H [dB]) 1D				
-	1) rain	30.0	31.0	40.0
-	2) wet snow	25.0	21.0	40.0
-	3) snow	0.0	36.0	40.0
-	4) graupel/small hail	45.0	11.0	20.0
-	5) hail	57.5	14.0	20.0
-	6) hail, rain mixture	60.0	11.0	20.0
MBF(height [km]) 2D @ melting level height (MSL) = 2.5 km (warm season)				
-	1) rain	0.0	2.3	5.0
-	2) wet snow	2.2	0.5	5.0
-	3) snow	10.0	7.7	60.0
-	4) graupel/small hail	10.0	9.5	60.0
-	5) hail	0.0	15.0	20.0
-	6) hail, rain mixture	0.0	3.0	20.0
MBF(height [km]) 1D @ melting level height < 0 km (cold season, storm height =5 km)				
-	1) rain	0.0	0.5	5.0

MBF	Hydrometeor Class ID	m	a	b
-	2) wet snow	0.0	2.5	5.0
-	3) snow	10.0	15.0	20.0
-	4) graupel/small hail	10.0	15.0	20.0
-	5) hail	10.0	15.0	20.0
-	6) hail, rain mixture	10.0	15.0	20.0
MBF(Z_{dr} [dB]) 2D				
@ $Z_H = 30$ dBZ	1) rain	0.5	0.7	10.0
@ $Z_H = 27.5$ dBZ	2) wet snow	1.1	1.4	15.0
@ $Z_H = 0$ dBZ	3) snow	0.5	0.75	8.0
@ $Z_H = 42.5$ dBZ	4) graupel/small hail	0.43	0.9	12.5
@ $Z_H = 7.5$ dBZ	5) hail	-0.76	1.28	15.9
@ $Z_H = 60.0$ dBZ	6) hail, rain mixture	0.94	2.0	15.0
MBF(K_{dp} [dgr/km]) 2D				
@ $Z_H = 30$ dBZ	1) rain	0.05	0.2	11.1
@ $Z_H = 25$ dBZ	2) wet snow	0.25	1.2	10.0
@ $Z_H = 7.5$ dBZ	3) snow	0.0	0.25	10.0
@ $Z_H = 42.5$ dBZ	4) graupel/small hail	0.27	0.77	12.5
@ $Z_H = 57.5$ dBZ	5) hail	0.5	1.0	10.0
@ $Z_H = 60.0$ dBZ	6) hail, rain mixture	2.37	2.40	15.0
MBF (Rho_{HV} []) 1D				
	1) rain	1.00	0.04	10.0
-	2) wet snow	0.88	0.11	20.0
-	3) snow	1.0	0.06	10.0
-	4) graupel/small hail	0.96	0.04	10.0
-	5) hail	0.90	0.045	10.0
-	6) hail, rain mixture	0.80	0.13	30.0



In the following tables, parametrization is expressed with 5th order polynomials of the difference with respect to the reference plane of the quoted auxiliary observable. The polynomial coefficients $P_0 \dots P_4$ are in increasing order, P_0 values shown in [Table 16 \(page 117\)](#). The **Max/Min** column expresses the boundaries that the parametrized polynomial values must fall within.

Table 17 Parametrized Evolution of the Parameter m of the 2D Membership Functions

m	ID	P1	P2	P3	P4	Max/Min
MBF(height [km]) (warm season)						
-	1)	0.0	0	0	0	-
-	2)	0.0	0	0	0	-
ML-2.5	3)	1.0	0	0	0	-
-	4)	0.0	0	0	0	-
-	5)	0.0	0	0	0	-
-	6)	0.0	0	0	0	-
MBF(Z_{dr} [dB])						
(Z_H-30) ± 30 dBZ	1)	4.75E-02	1.76E-03	6.99E-06	4.50E-07	5.5/0.1
($Z_H-27.5$) ± 17.5 dBZ	2)	4.62E-03	6.42E-04	2.22E-05	0.0000E+0	02.5/1.1
(Z_H-0) ± 327 dBZ	3)	0	0	0	0	0.5/-0.5
($Z_H-42.5$) ± 12.5 dBZ	4)	3.37E-02	9.64E-04	0	0	1.5/0.155
($Z_H-57.5$) ± 12.5 dBZ	5)	-1.73E-02	1.51E-03	-8.33E-05	4.17E-06	5.5/0.1
(Z_H-60) ± 10 dBZ	6)	-5.41E-02	-5.71E-03	1.67E-04	0	5.5/0.1
MBF(K_{dp} [dgr/km])						
(Z_H-30) ± 35 dBZ	1)	-4.96E-03	2.06E-03	1.91E-04	3.99E-06	14/0.05
($Z_H-27.5$) ± 17.5 dBZ	2)	0	0	0	0	0.25/0.25
(Z_H-0) ± 327 dBZ	3)	0	0	0	0	0/0
($Z_H-42.5$) ± 12.5 dBZ	4)	6.87E-02	1.00E-03	-1.48E-04	0	2.0/0.3
($Z_H-57.5$) ± 12.5 dBZ	5)	0	0	0	0	0.5/0.5
(Z_H-60) ± 10 dBZ	6)	3.08E-01	8.57E-03	3.33E-04	0	10./0.0

Table 18 Parametrized Evolution of the Parameter a of the 2D Membership Functions

a	ID	P1	P2	P3	P4	Max/Min
MBF(height [km]) (warm season)						
-	1)	1.0	0	0	0	-
-	2)	-1.0	0	0	0	-
ML-2.5	3)	0.0	0	0	0	-
-	4)	-1.0	0	0	0	-
-	5)	0.0	0	0	0	-
-	6)	1.0	0	0	0	-

a	ID	P1	P2	P3	P4	Max/Min
MBF(Z_{dr} [dB])						
(Z_H -30) \pm 30 dBZ	1)	2.59E-02	4.36E-04	-4.89E-06	-5.62E-08	8/0.4
(Z_H -27.5) \pm 17.5 dBZ	2)	-9.11E-03	2.1429E-04	3.84E-05	0.0000E+00	2.5/1.1
(Z_H -0) \pm 327 dBZ	3)	0	0	0	0	0.5/-0.5
(Z_H -42.5) \pm 12.5 dBZ	4)	3.37E-02	9.64E-04	0	0	2.0/0.5
(Z_H -57.5) \pm 12.5 dBZ	5)	5.78E-03	4.53E-03	2.78E-05	1.25E-05	0/-2
(Z_H - 60) \pm 10 dBZ	6)	4.17E-03	-2.38E-02	-1.67E-04	1.50E-04	3.0/0.5
a	ID	P1	P2	P3	P4	Max/Min
MBF(K_{dp} [dgr/km])						
(Z_H -30) \pm 35 dBZ	1)	1.11E-02	2.95E-03	1.04E-04	6.11E-07	8/0.2
(Z_H -27.5) \pm 17.5 dBZ	2)	0	0	0	0	0.4/0.4
(Z_H -0) \pm 327 dBZ	3)	0	0	0	0	0.25/0.25
(Z_H -42.5) \pm 12.5 dBZ	4)	6.87E-02	1.00E-03	-1.48E-04	0	2.0/0.3
(Z_H -57.5) \pm 12.5 dBZ	5)	0	0	0	0	1/1
(Z_H - 60) \pm 10 dBZ	6)	2.97E-01	8.86E-03	2.67E-04	0	10./0.1

Table 19 Parametrized Evolution of the Parameter b of the 2D Membership Functions

b	ID	P1	P2	P3	P4	Max/Min
MBF(height [km]) (warm season)						
-	1)	0	0	0	0	-
-	2)	0	0	0	0	-
ML-2.5	3)	0	0	0	0	-
-	4)	0	0	0	0	-
-	5)	0	0	0	0	-
-	6)	0	0	0	0	-
MBF(Z_{dr} [dB])						
(Z_H -30) \pm 30 dBZ	1)	2.29E-01	5.49E-03	-5.83E-05	0	25/8
(Z_H -27.5) \pm 17.5 dBZ	2)	0	0	0	0	20/5
(Z_H -0) \pm 327 dBZ	3)	0	0	0	0	8/8
(Z_H -42.5) \pm 12.5 dBZ	4)	0	0	0	0	12.5/12.5
(Z_H -57.5) \pm 12.5 dBZ	5)	2.103E-18-	1.42E-01	2.47E-19	6.67E-04	17/7

b	ID	P1	P2	P3	P4	Max/Min
$(Z_H - 60) \pm 10$ dBZ	6)	-5.92E-17	1.67E-02	5.92E-19	-6.67E-04	20/5
MBF(K_{dp} [dgr/km])						
$(Z_H - 30) \pm 35$ dBZ	1)	2.29E-01	5.49E-03	-5.83E-05	0	16./9.
$(Z_H - 27.5) \pm 17.5$ dBZ	2)	0	0	0	0	10/10
$(Z_H - 0) \pm 327$ dBZ	3)	0	0	0	0	10/10
$(Z_H - 42.5) \pm 12.5$ dBZ	4)	2.57E-01	0	0	0	17.0/9
$(Z_H - 57.5) \pm 12.5$ dBZ	5)	0	0	0	0	10/10
$(Z_H - 60) \pm 10$ dBZ	6)	-1.67E-01	2.44E-17	6.67E-03	0	25/8.0

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Glossary

\$IRIS_ROOT

Entry point of the IRIS/RDA install tree

CSU

Colorado State University

CSU-CHILL

Radar research facility at CSU <http://lab.chill.colostate.edu/chill-technical.html>

differential reflectivity (ZDR)

Ratio between the horizontal reflectivity and the vertical reflectivity (dBZh - dBZv). ZDR depends on the asymmetry of the shape, orientation, and falling behavior of the particles. Positive values indicate more prominent horizontal echoes (such as from large raindrops), and negative values indicate more prominent vertical echoes (such as from hail and graupel).

DP

Dual Polarimetric

FFT

An RVP signal processing mode based on Fast Fourier Transform. See also [PPP](#).

GC/AP

Ground clutter and anomalous propagation

IF

Intermediate Frequency. The frequency to which a carrier wave is shifted as an intermediate step in transmission or reception.

IRIS

Interactive Radar Information System. A suite of software tools for configuring, calibrating, and operating a complete weather radar system.

JPOLE

Joint Polarization Experiment

K_{dp}

Specific Differential Phase Shift. The range derivative of the differential phase (PhiDP) expressed in degrees per km. It is nearly linearly proportional to the rainfall rate.

MBF

Membership function

Melting Layer

Melting layer or ML (height). Altitude at which falling snow starts to melt. This forms the top of the Bright Band. Also called the 0°C height.

MLHGT

Melting Level Height Detection

NSSL

National Severe Storms Laboratory, Oklahoma, USA

PhiDP

Differential Propagational Phase Shift. The phase difference between the HH and VV (co-polarized) channels of a polarization radar. It is calculated by taking the argument of the covariance of these two channels. The differential phase increases with range more rapidly in regions of heavy rain.

PPP

Poly-Pulse Pair. An RVP signal processing mode based on pulse pair correlations. See also [FFT](#)

radar control processor (RCP)

Radar control processor. Controls and monitors weather radar system sub-units.

RDA

Radar Data Acquisition software used in RVP900

Reflectivity (Z)

Z_H - horizontal, Z_V - vertical, Z_{HV} -horizontal and vertical.

Property of the target that describes how much of the energy is reflected from the target. Radars are calibrated to directly give the reflectivity from the received backscattered energy. Unit for the reflectivity is mm^6/m^3 . The logarithmic value is in dBZ. Also called reflectivity factor.

RhoHV

Correlation Coefficient. The magnitude of the correlation between the HH and VV channels of a dual polarization radar operating in STAR mode or switching mode in the range [0,1]. Rain values are typically > 0.98 . Wet tumbling hail has smaller values. This value is useful in helping to identify the particle type.

RS

Rule strength

RVP900

Vaisala Digital Receiver and Signal Processor RVP900. A product suite consisting of Vaisala IF Digital Receiver RVP901 and Vaisala Signal Processor RVP902.

STAR mode

Simultaneous Transmit And Receive. The operational mode of a dual polarization radar where the radar transmits simultaneously horizontally and vertically.

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Technical support



Contact Vaisala technical support at helpdesk@vaisala.com. Provide at least the following supporting information as applicable:

- Product name, model, and serial number
- Software/Firmware version
- Name and location of the installation site
- Name and contact information of a technical person who can provide further information on the problem

For more information, see www.vaisala.com/support.

Warranty

For standard warranty terms and conditions, see www.vaisala.com/warranty.

Please observe that any such warranty may not be valid in case of damage due to normal wear and tear, exceptional operating conditions, negligent handling or installation, or unauthorized modifications. Please see the applicable supply contract or Conditions of Sale for details of the warranty for each product.

Recycling



Recycle all applicable material.



Follow the statutory regulations for disposing of the product and packaging.

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