Do It Yourself 8

Polarization Coherence Tomography (P.C.T) Training Course

1 Objectives

To provide a self taught introduction to Polarization Coherence Tomography (PCT) processing techniques to enable users to learn the basic principles of this topic.

To achieve this, it is proposed to employ a test POLinSAR data set with ‘perfect’ ground truth. This test set is the ‘hedge’ simulation output from the PolSARpro – Simulator (see figure n°1), provided by Dr. Mark Williams ©, and already widely used as a test scene in POLinSAR training.

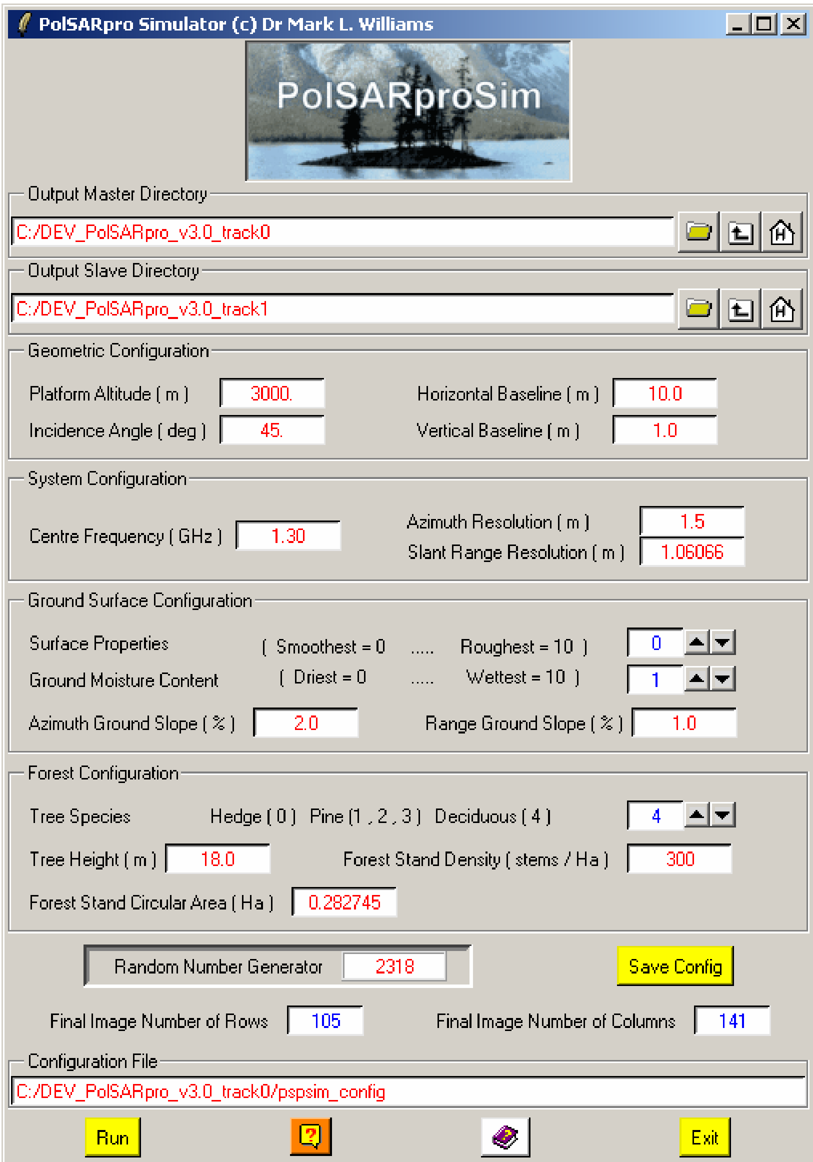
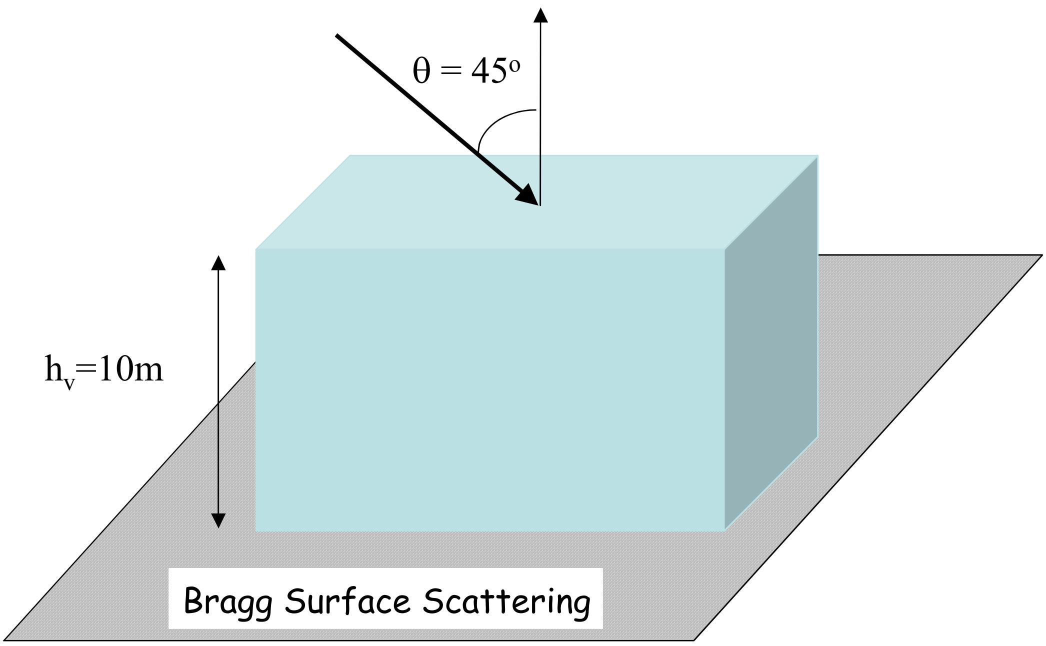


Figure 1: PolSARpro Simulator

The test data set is designed to mimic the same airborne performance of the ESAR L band system, except there are no residual motion, baseline or co-registration errors and no problems associated with temporal and SNR decorrelation sources. In this way the users can get used to POLinSAR principles in a controlled environment before applying the techniques to real world data sets.

As a secondary objective, the modules generated can also be used for dual polarised POLinSAR inversion studies on arbitrary data sets (ESAR, SIRC etc) to complement the more robust but complicated multipolarisation algorithm developed by DLR.

The test data set has the structure shown in figure 2. Here we see a flat ground with a 10m high vegetation layer in the centre of the scene. This layer is comprised of a Gaussian distribution of branches with mean length of 1.5m and standard deviation of 0.2m with a density or mean volume fraction of 0.2. The L band signal (λ = 0.23061m) illuminates the scene at θ = 45 degrees incidence from an altitude of 3km. A 10m horizontal offset baseline is used for the interferometry.
The SAR simulator allows convolution of the scattered field with an instrument point spread function, chosen in this case with a resolution of 0.6905m in azimuth and 1.3811m in ground range. The image pixel size is then sampled at 0.5m x 0.5m in ground range and azimuth. These values are typical of those used for airborne sensors.



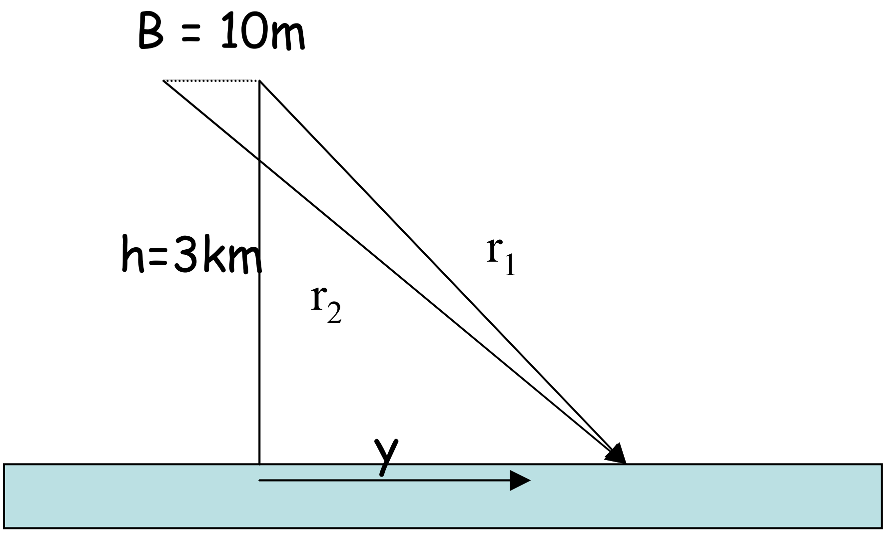


Figure 2 : POLinSAR simulation geometry

The simulator thus produces 8 data files: s11.bin, s12.bin, s21.bin and s22.bin for each end of the baseline under the two automatically created directories: master and slave.
The data files all have the same binary format (complex variables), and are coded under the form of interlaced float numbers representing real and imaginary parts. A Nrow by Ncol image of a complex variable (e.g s11.bin) contains Nrow*Ncol*2*4 bytes, i.e. Nrow*Ncol*2*32 bits.
In each directory, a configuration text file (config.txt) indicates the considered image dimensions and polarimetric type required by PolSARpro.

At least, in the directory slave, the flat earth file (flat_earth.bin) and the kz file (kz.bin) associated to the simulated data set, have been created.

It is proposed to employ this 10m baseline data set in the following training sequence:

2 Reading POLinSAR data sets

2.1 Main input directory selection

PolSARpro v3.0 is running and from the main menu (figure 3), is selected :

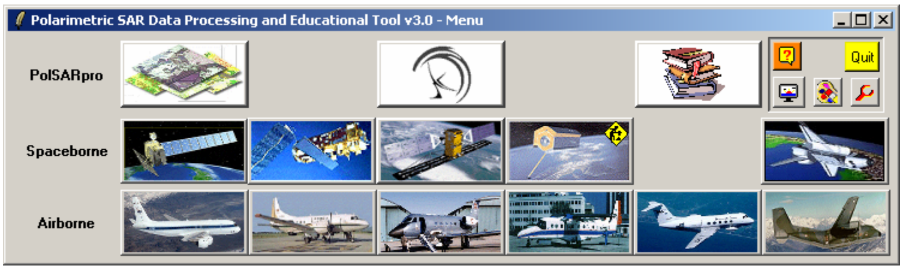


Figure 3 : PolSARpro v3.0 Main Menu

 ➔ Multi Data Sets ➔ Dual POLinSAR

From the main PolSARpro v3.0 - POLinSAR widget (figure 4), click on Environnement and the Environment widget appears (figure 5)

Figure 4 : PolSARpro v3.0 – POLinSAR widget

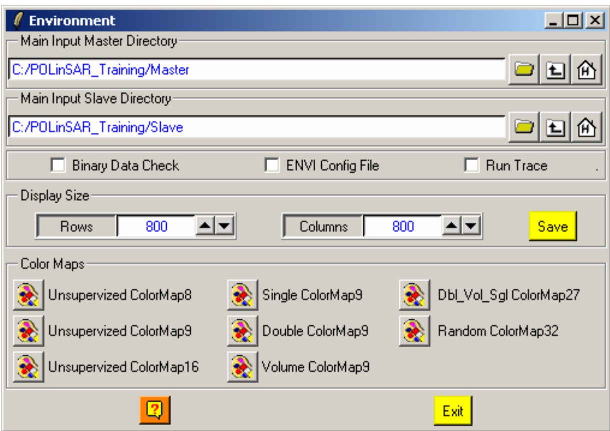


Figure 5 : Environment widget with the POLinSAR Training Data Sets settings

It is recommended to unselect the ENVI config option in order to avoid the creation of numerous header files.

Then set the Main Input Master Directory to the POLinSAR_Training data set directory:

~/POLinSAR_Training/Master.

Then set the Main Input Slave Directory to the POLinSAR_Training data set directory:

~/POLinSAR_Training/Slave.

The main input directories are a key basic internal variable for PolSARpro and the values may change during the processing. It is then recommended to let this window open when using PolSARpro

2.2 View the total power images of the training data sets.

From the main PolSARpro v3.0 - POLinSAR widget (figure 4), click on :

Process ➔ **S2** ➔ **S2 Elements** ➔ **Master**

and the Sinclair Elements widget appears (figure 6)

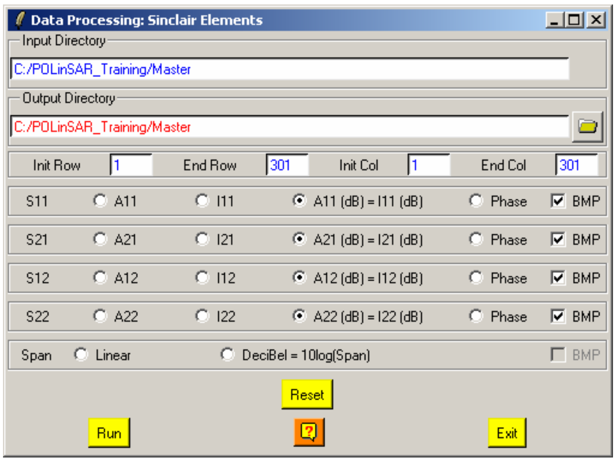


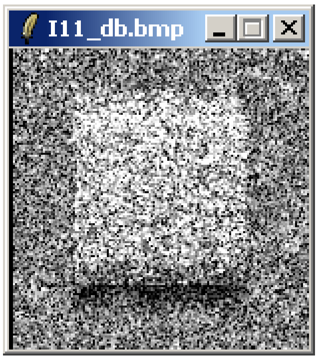
Figure 6 : Sinclair Elements widget

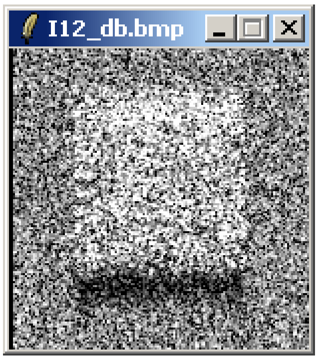
The four channels may be processed at a time. Select the type Aij (dB) = Iij (dB) that will create the power images for each channel (Iij_dB.bin). Select the BMP option to enable the creation of corresponding output bmp files (Iij_dB.bmp).

Repeat this data processing on the Sinclair elements of the Slave directory.

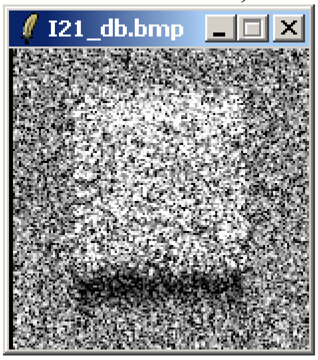
The visualization of all the output bmp files can be made using the PolSARpro – Viewer v3.0.

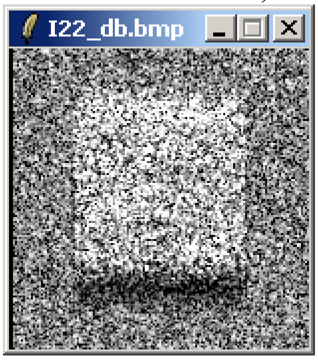
Figure 7 shows the SAR images of the test scene for the 4 channels HH, HV,VH and VV provided by the simulator. Note that for calibrated data HV = VH as required by the reciprocity theorem for backscatter and so only one of the crosspolar channels need be used in the analysis. However providing separate HV and VH data channels can be useful in practice.



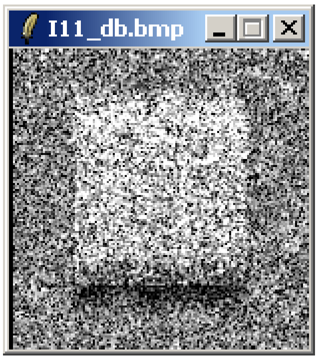


Master – I11 : Max = -5dB, Min = -24dB   Master – I12 : Max = -13.8dB, Min = -33dB

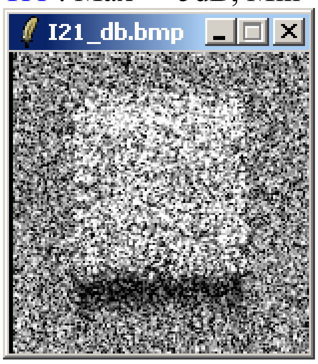


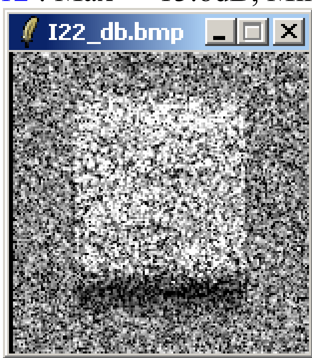


Master – I12 : Max = -13.8dB, Min = -33dB   Master – I22 : Max = -6.6dB, Min = -26dB



Slave – I11 : Max = -5dB, Min = -24dB   Slave – I12 : Max = -13.8dB, Min = -33dB





Slave – I21 : Max = -13.8dB, Min = -33dB   Slave – I22 : Max = -6.6dB, Min = -26dB

Figure 7 : SAR images for the 4 polarisation channels and two baseline positions 1 (master) and 2 (slave) of the simulated scene

In figure 7 we can clearly see the increased backscatter from the hedge layer and note the shadow region at the rear of the hedge due to its 10m elevation. We note too a bright band at the front of the hedge in HH and VV. This is due to a second order ground volume interaction. The simulator accounts for three levels of scattering, direct scattering from volume and surface, second order surface-volume interactions and third order surface-volume-surface interactions. While the third order interactions are generally small it is important to model correctly the first and second order interactions, which requires careful calculation of the effective reflection coefficient from the rough surface and also correct modeling of the polarimetric phase for the second order or dihedral component.

3 Generating a Raw Interferogram.

The next step is to generate a complex interferogram between two images and display the phase, showing vegetation bias and flat earth fringes.

From the main PolSARpro v3.0 - POLinSAR widget (figure 4), click on :

Process ➔ **S2** ➔ **Interferogram**

and the Interferogram Estimation widget appears (figure 8)

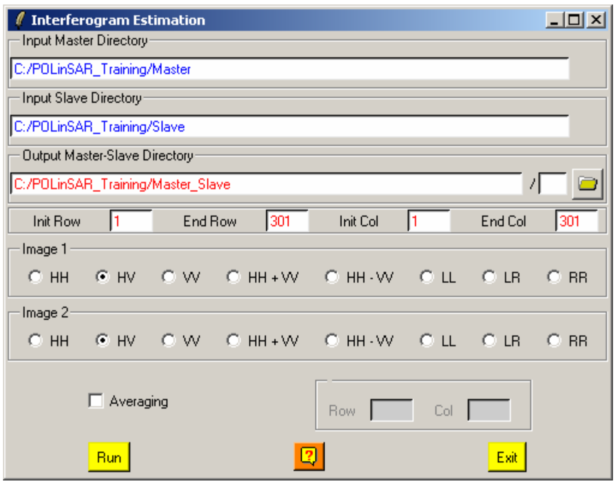


Figure 8 : Interferogram Estimation widget

The interferogram is generated between **Image 1** and **Image 2**, and the user has the possibility to create any combinations between the different polarimetric channels: HH, HV, VV, HH+VV, HH-VV, LL, LR and RR. For illustration purposes we generate an interferogram for the HV polarization channel. The output file name is set to: interferogram_HV_HV.bin and the corresponding output bmp file (interferogram_HV_HV.bmp).

Note: The Output Master-Slave directory is automatically set to:

~/POLinSAR_Training/Master_Slave.

The raw phase of the product is then shown in figure 9. Here we see two features of importance. Firstly we see a background phase variation across the whole scene, which is a function of range only and comprises one complete fringe or 2π phase variation. The second feature we note is the phase noise associated with the canopy layer. This phase noise is due to volume decorrelation and later we shall use this decorrelation to extract information about the height of the vegetation using POLinSAR.

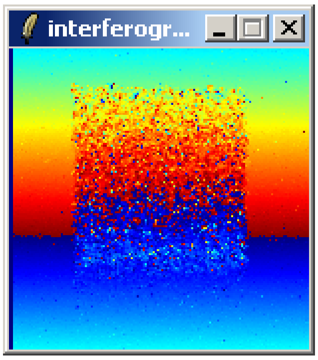


Figure 9 : Raw Phase of the Interferogram for HV Polarisation

4 Flat Earth Removal

Use the Flat Earth reference phase to remove the background phase variations. The Flat Earth file is generated during the POLinSAR data set simulation, by employing the geometry of figure 2 and calculated with the relation (38) of the POLinSAR Training Course lecture note.

From the main PolSARpro v3.0 - POLinSAR widget (figure 4), click on :

Process → **S2** → **Flat Earth Removal**

and the Flat Earth Removal widget appears (figure 10)

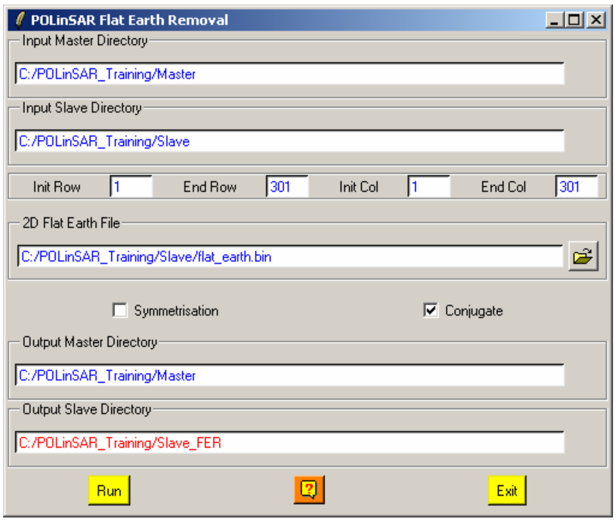


Figure 10 : Flat Earth Removal widget

Enter the 2-D Flat Earth file name, select Conjugate and run the function.

Note: The Output Slave directory is changed and automatically set to:

~/POLinSAR_Training/Slave_FER.

where FER stands for Flat Earth Removal.

Run again the Interferogram Estimation process to form the modified interferogram, and we obtain the new phase image shown on figure 11.

Note: The Output Master-Slave directory is automatically set to:

~/POLinSAR_Training/Master_Slave_FER.

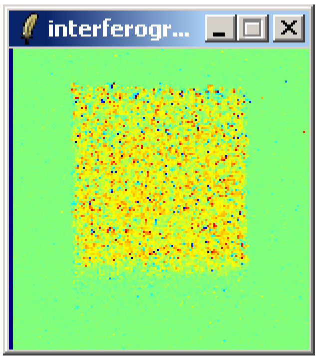


Figure 11 : Raw Phase of the Interferogram for HV Polarisation following Flat Earth Removal

Here we see that the phase of the flat surface is now constant at zero degrees. This becomes our ground phase reference across the whole scene. We can again see the phase noise due to the vegetation layer but note in addition that there is a bias or offset to the mean phase of around 1 radian in this region. This is called vegetation bias and reflects that fact that the mean phase centre in the vegetation lies above the ground (positive phase). Again, in POLinSAR we make use of the variations of this phase centre with polarisation to estimate the vegetation height. Before we can estimate height from phase however we need to calculate the scale factor or vertical wavenumber k_z, which relates phase to height via the relation :
$\phi = k_z.h$

5 Vertical Wavenumber Estimation

The k_z file is generated during the POLinSAR data set simulation, by employing the geometry of figure 2 and calculated with the relation (39) of the POLinSAR Training Course lecture note. The k_z is a function of angle of incidence, for a fixed baseline B, k_z is higher in the near range where θ is small and decreases in the far range when θ increases. However for this small scene of only 100m range swath from 3km altitude the variation of angle of incidence is small and hence k_z is approximately constant with a value of 0.1282 for a 10m baseline. Hence a vegetation bias of 1 radian corresponds to a height of 7.8m.

6 Polarization Coherence Tomography Procedure

From the main PolSARpro v3.0 - POLinSAR widget (figure 4), click on :

Process ➔ S2 ➔ Polarization Coherence Tomography (PCT)

and the Polarization Coherence Tomography Procedure widget appears (figure 12)

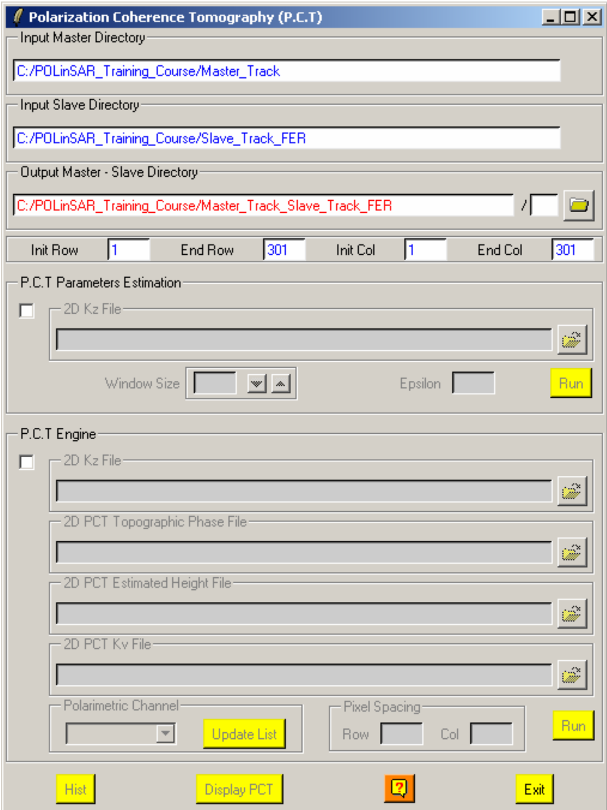


Figure 12 : Polarization Coherence Tomography procedure widget

6.1 *PCT Parameters Estimation*

The starting point is to consider estimation of the surface phase ϕ_0 and the normalised wavenumber k_v.

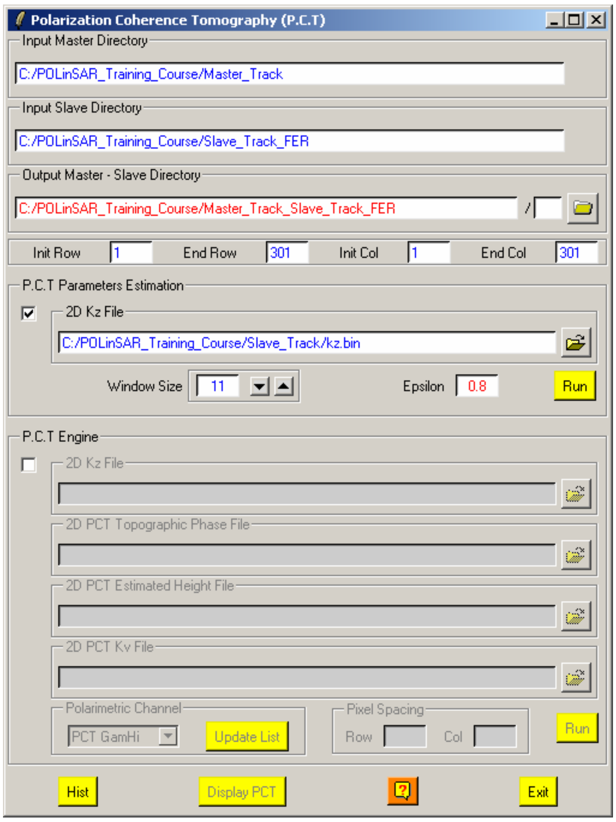


Figure 13 : PCT Parameters Estimation

The PCT Parameters Estimation functionality proposes the following processing steps:

1) Create two optimal reference polarization channels:

The procedure isolates candidates for the two volume and surface dominated polarization channels $\underline{w}_1$ and $\underline{w}_2$ (using physical models or phase/coherence optimisation) and calculate the corresponding optimal interferometric complex coherences γ_{Hi} and γ_{Lo} (see equation 52 of the PCT Training Course lecture note).
The output binary files are *cmplx_coh_PCTgamHi.bin* and *cmplx_coh_PCTgamLo.bin*. The corresponding BMP output files are *cmplx_coh_PCTgamHi_mod.bmp*, *cmplx_coh_PCTgamHi_pha.bmp*, *cmplx_coh_PCTgamLo_mod.bmp* and *cmplx_coh_PCTgamLo_pha.bmp*.

2) Topographic phase estimation:

This procedure uses the two optimal reference interferometric complex coherences γ_{Hi} and γ_{Lo} in the appropriate order to estimate the topographic phase ϕ_0 (see equations 50 and 64 of the PCT Training Course lecture note).
The output binary file is *PCT_TopoPhase.bin* and the corresponding BMP output file is *PCT_TopoPhase.bmp*.

3) Height estimation:

This procedure identifies a volume polarization channel (from appropriate selection of optimum states $\underline{w}_{Hi}$ and $\underline{w}_{Lo}$) and calculates k_v. Then it estimates height from k_z and k_v. (see equations 55, 56, 57 and 65 and 66 of the PCT Training Course lecture note).
The output binary files are *PCT_Kv.bin* and *PCT_Height.bin*, and the corresponding BMP output files are *PCT_Kv.bmp* and *PCT_Height.bmp*.

Figure 14 shows the Interferometric Phase of Polarization with Highest and Lowest Centre obtained by phase optimisation

PCT Gamma High PCT Gamma Low

Figure 14 : Optimal Reference Polarization Channels phase images

Figure 15 shows the Surface Phase Estimate based on Line fit between the high and low phase centre, where it can be seen a further reduction in bias with a residual noise about the correct mean value of zero. This phase image will then provide one of the two parameters required for PCT, namely ϕ_0.

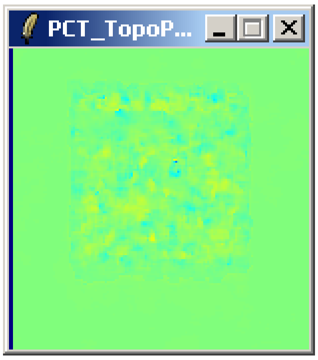
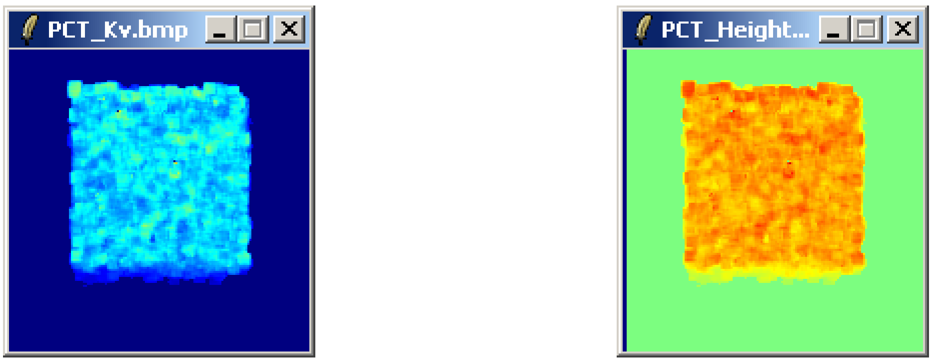


Figure 15 : Ground topographic phase image

Figure 16 shows the normalised k_v baseline and the height estimations obtained by using the high phase centre together with ϕ_0.



Min = 0 Max = +2

Min = -25m Max = +25m (green color = 0m)

Figure 16 : Estimates of normalised baseline k_v and height.

Launching the Statistics - Histogram functionality can be done by clicking on the button **Hist** on the widget (figure 13) or from the main PolSARpro v3.0 - POLinSAR widget (figure 4), by clicking on :

Process ➔ **S2** ➔ **Data Analysis** ➔ **Histograms**

In both cases, the Data Analysis : Statistics - Histogram widget appears (figure 17)

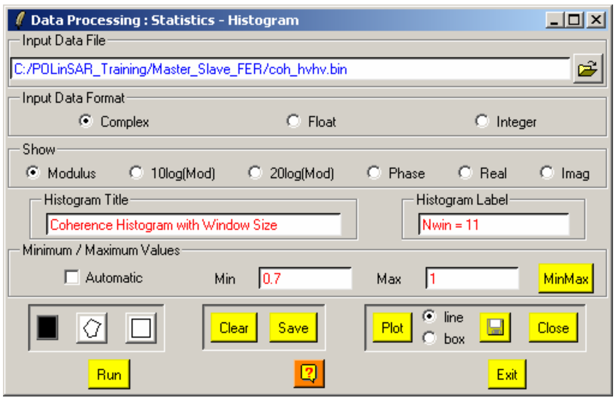
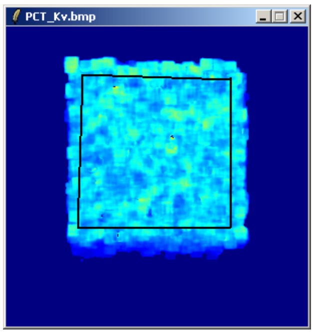
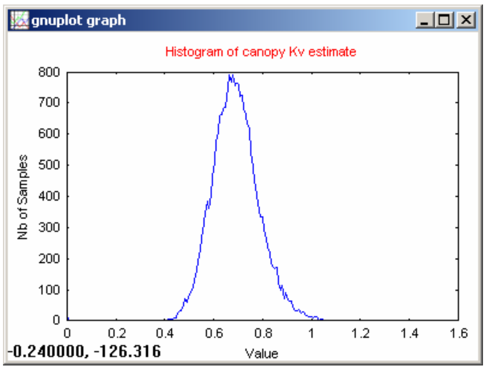


Figure 17 : Data Analysis : Statistics – Histogram widget

Figure 18 shows the histogram of the k_v estimates over the nonzero regions of the selected vegetation area.





Min = 0 Max = +2

Figure 18 : Phase Center Heights and corresponding histogram over the selected area

6.2 PCT Engine

Now as the different parameter estimates for all the polarization independent parameters require for PCT, namely ϕ_0, k_v, have been obtained, we can turn to consider the use of these for reconstruction of the vertical structure function for each pixel in the image.

The first step is to select from the combo box, the polarisation channel among the proposed list on which will be applied the PCT procedure.
The elements of this list correspond to the complex coherence files previously generated. If some polarisation channels are missing, they have to be generated using the **Complex Coherence Estimation** functionality. In this case, it is important to click on the button **Update List** in order to update the different polarisation channel lists.

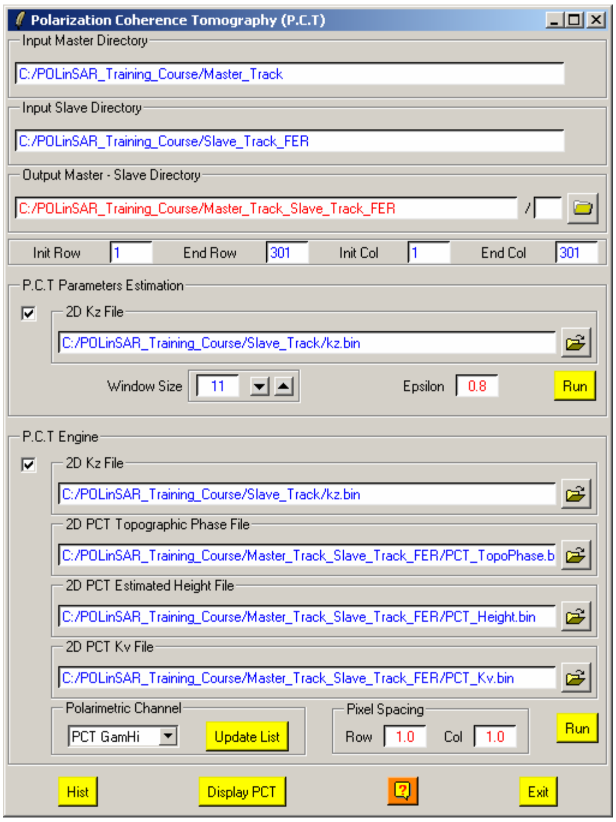


Figure 19 : PCT Engine

The PCT Engine functionality proposes the following processing steps:

1) Calculate Legendre Spectrum :

The procedure calculates the Legendre function (*f0*, *f1* and *f2*) then derives the two Legendre coefficients (*a10* and *a20*) for the selected polarization channel w (see equations 22, 44, 62 and 68 of the PCT Training Course lecture note).
The output binary files are *PCT_f0.bin*, *PCT_f1.bin*, *PCT_f2.bin*, *PCT_a10.bin* and *PCT_a20.bin*. The corresponding BMP output files are *PCT_a10.bmp* and *PCT_a20.bmp*.

2) Construction of the vertical structure :

From the determination of the Legendre parameters a_{10} and a_{20}, the procedure reconstructs the normalized vertical scattering structure function for each pixel in the image, in order to obtain a 3-D image, PCT providing the z variation for each xy pixel of the SAR image (see equation 69 of the PCT Training Course lecture note).
The 3D output files are *~/Tmp/PCT_Tomo.asc* and *~/Tmp/PCT_Tomo.bin*.

Figure 20 shows the histogram of the Legendre Coherence functions (f0, f1 anf f2) estimates over the nonzero regions of the selected vegetation area.

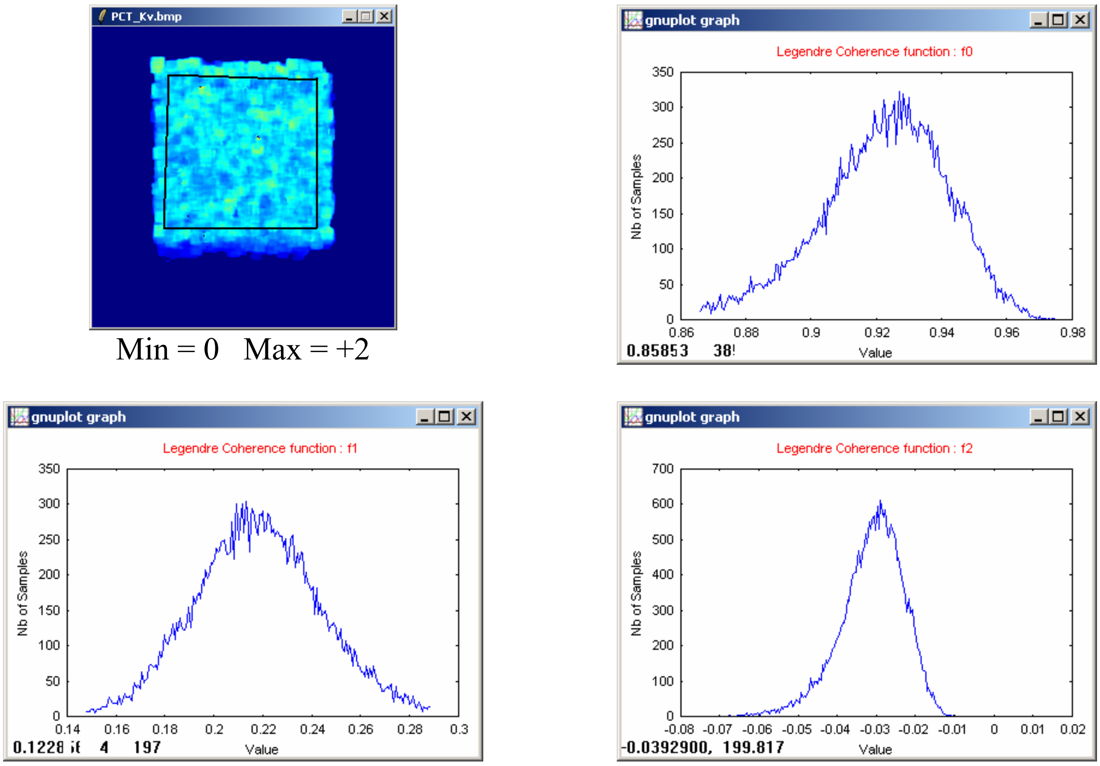


Figure 20 : Histograms of the Legendre functions over the selected area

Figure 21 shows the Legendre coefficients a10 and a20 for the Volume dominated channel (γ_{Hi}), and the corresponding histograms of the estimates over the nonzero regions of the selected vegetation area.

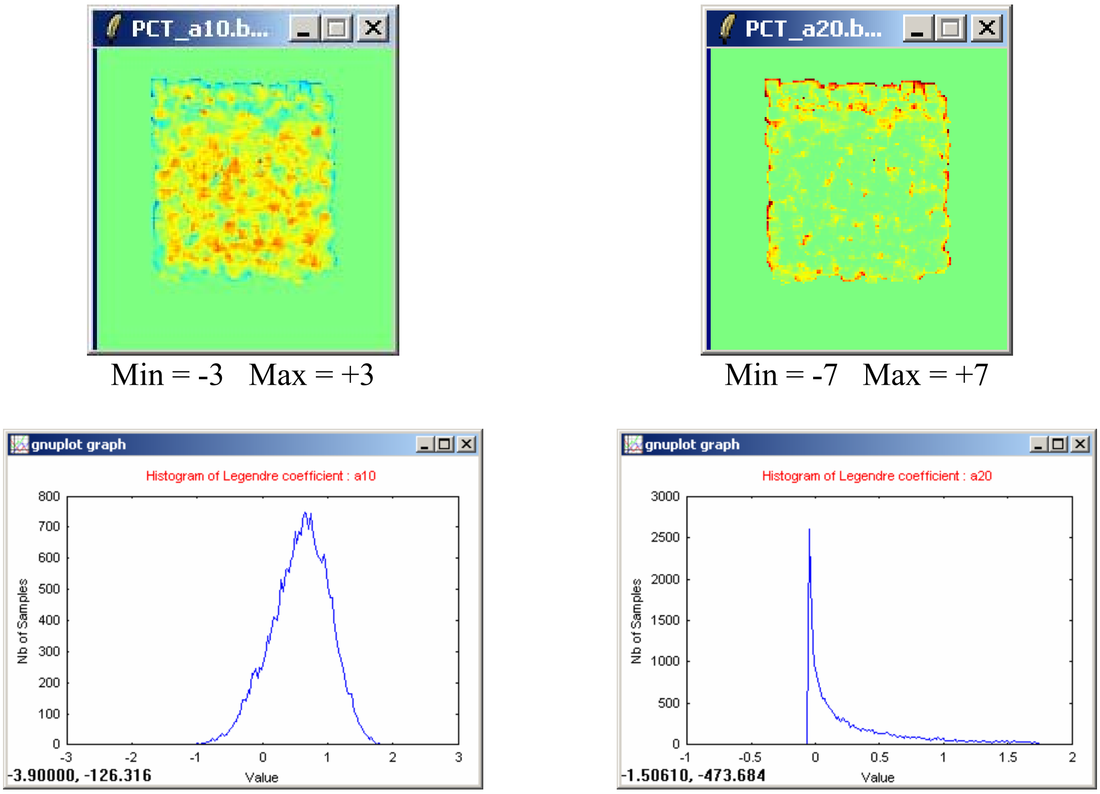


Figure 21 : Estimated Legendre coefficients for the Volume dominated channel (γ_{Hi})

Figure 22 shows the Legendre coefficients a10 and a20 for the Surface dominated channel (γ_{Lo}), and the corresponding histograms of the estimates over the nonzero regions of the selected vegetation area.

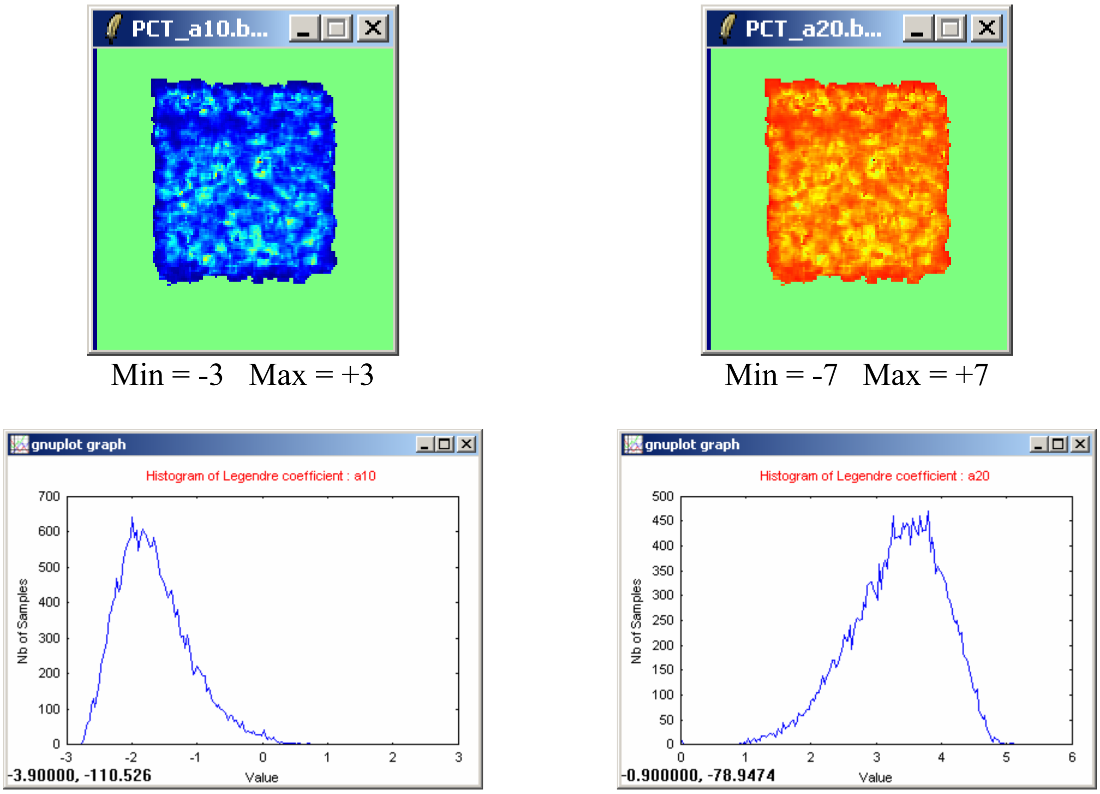
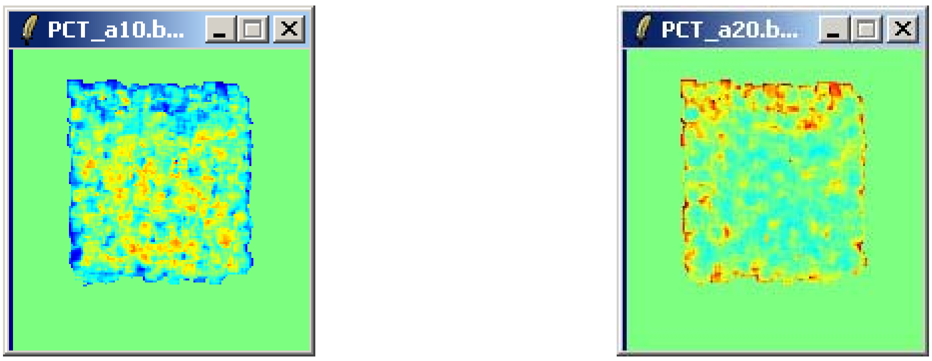


Figure 22 : Estimated Legendre coefficients for the Surface dominated channel (γ_{Lo})

Figure 23 shows the Legendre coefficients a10 and a20 for the HV polarization channel, and the corresponding histograms of the estimates over the nonzero regions of the selected vegetation area.



Min = -3 Max = +3 Min = -7 Max = +7

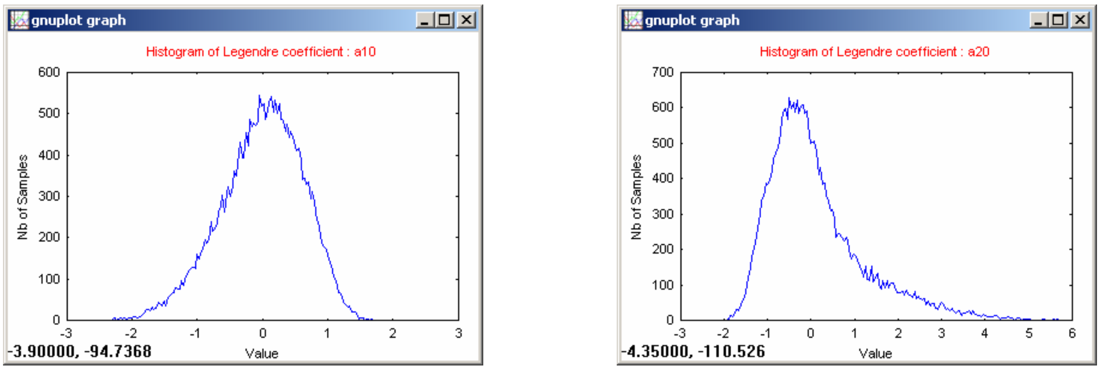


Figure 23 : Estimated Legendre coefficients for the HV polarization channel

Figure 24 shows the Legendre coefficients a10 and a20 for the HH polarization channel, and the corresponding histograms of the estimates over the nonzero regions of the selected vegetation area.

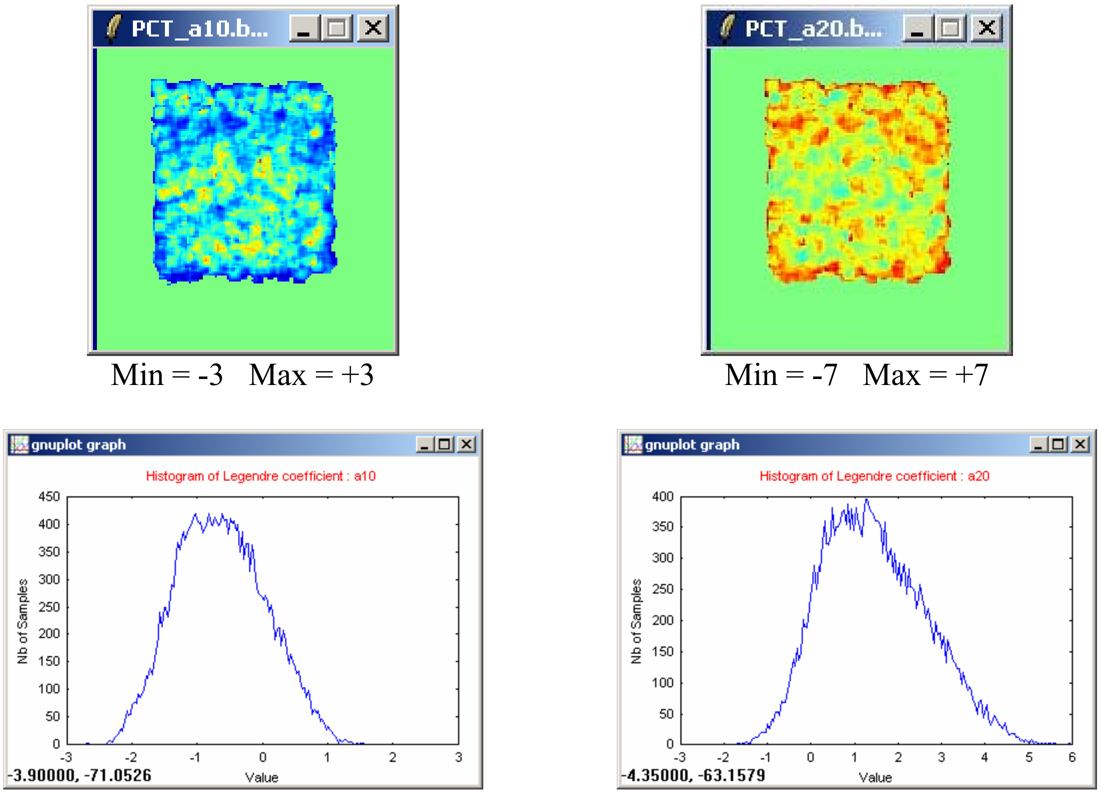


Figure 24 : Estimated Legendre coefficients for the HH polarization channel

6.3 PCT Display

Once the Polarization Coherence Tomography procedure is performed, it is thus possible to display the vertical scattering structure function along an azimuth or range cut across the image.

To visualize the variation of the vertical scattering structure function, obtained from the estimated height and phase, along an azimuth or range slice, the PCT Display functionality can be launched by clicking on the button **Display PCT** on the widget (figure 19) and the associated widget appears (figure 25).

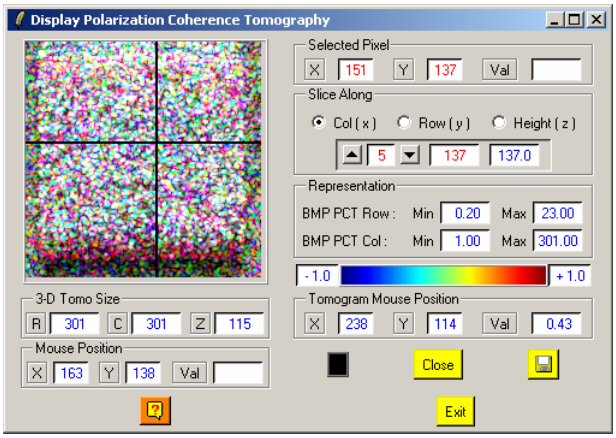
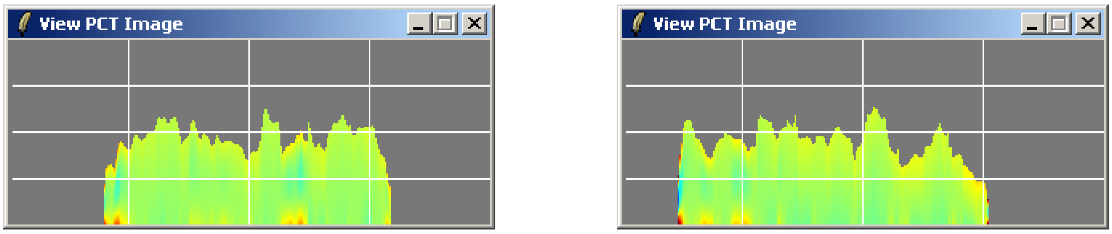


Figure 25 : PCT Display

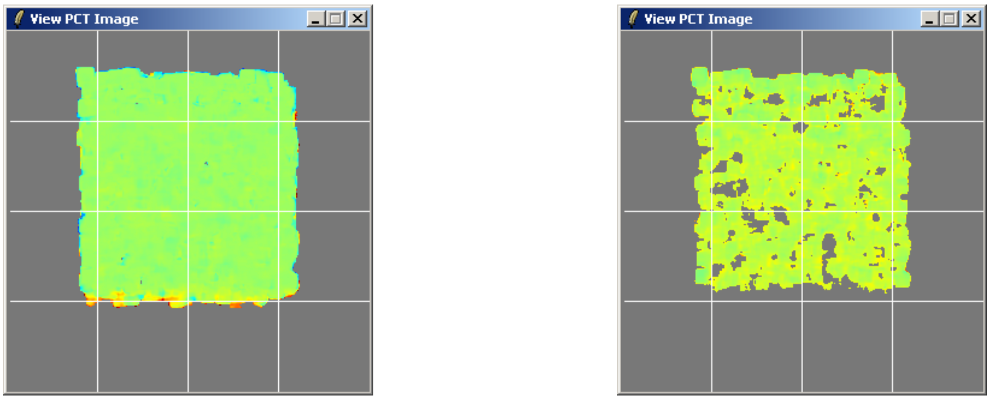
Figure 26 shows azimuth and range slices through canopy (using row 171 and col 150) for optimal interferometric complex coherences γ_{Hi} using estimated parameters.



Min = -1 Max = +1   Min = -1 Max = +1

Figure 26 : Estimated Normalized Tomogram – Azimuth and Range slices

Figure 27 shows two examples of vertical slices through canopy (using z = 3m and z = 9m) for optimal interferometric complex coherences γ_{Hi} using estimated parameters.



Min = -1 Max = +1 (z = 3m)   Min = -1 Max = +1 (z = 9m)

Figure 26 : Estimated Normalized Tomogram – Vertical (z) slices

7 Polarisation Selection

In the previous analysis we have employed the optimal interferometric complex coherences γ_{Hi} as the volume dominated channel.

In practice there may be other options available. For example it is common to operate imaging radars in a dual polarisation mode where the transmitter emits a single polarisation but the receiver has 2 orthogonal channels so enabling a co and cross-polar measurement. The JAXA ALOS-PALSAR for example is able to transmit H and receive H and V so obtaining only 2 polarisation combinations HH and HV. It is interesting to see the change in height retrieval performance with this restricted combination. The test data set can be used to investigate this.

HV can be used as the volume dominated channel but HH can be used in place of HH-VV for the surface channel.

Start the all procedure from step 6.1 and comment the new results obtained