

Do It Yourself 7

POLinSAR Training Course

1 Objectives

To provide a self taught introduction to POLinSAR coherence 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.

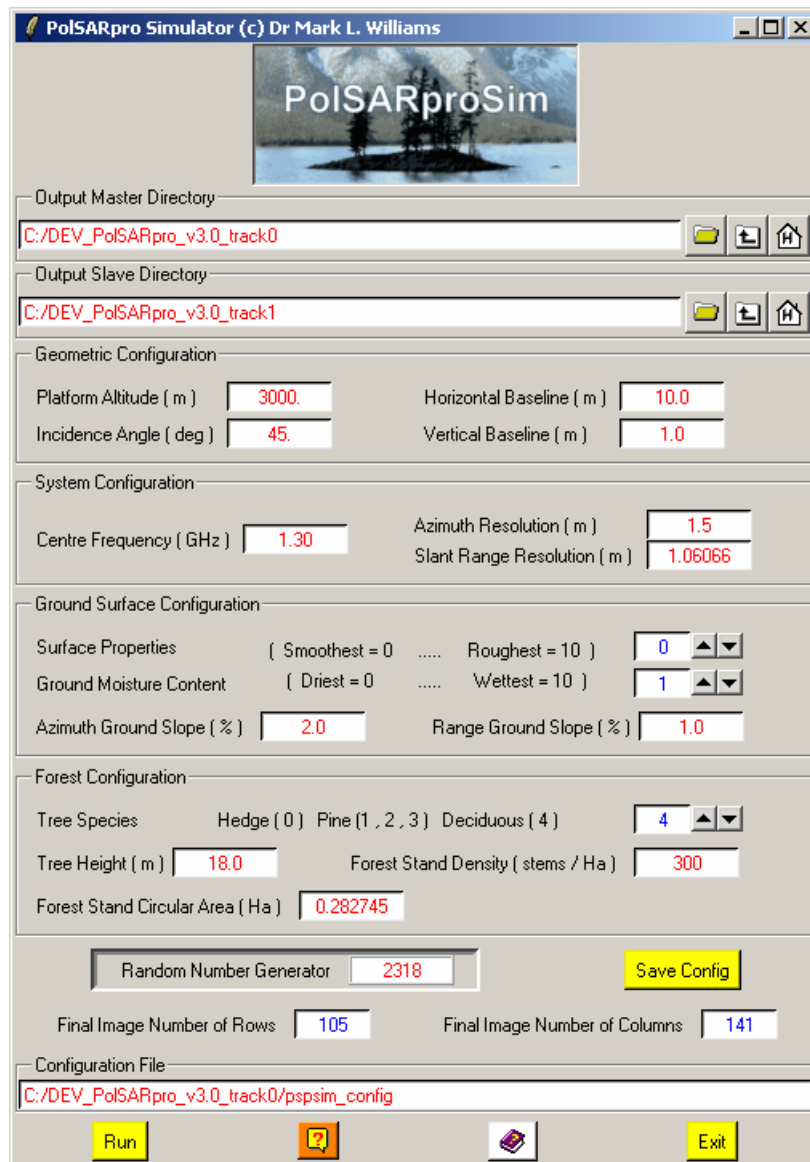


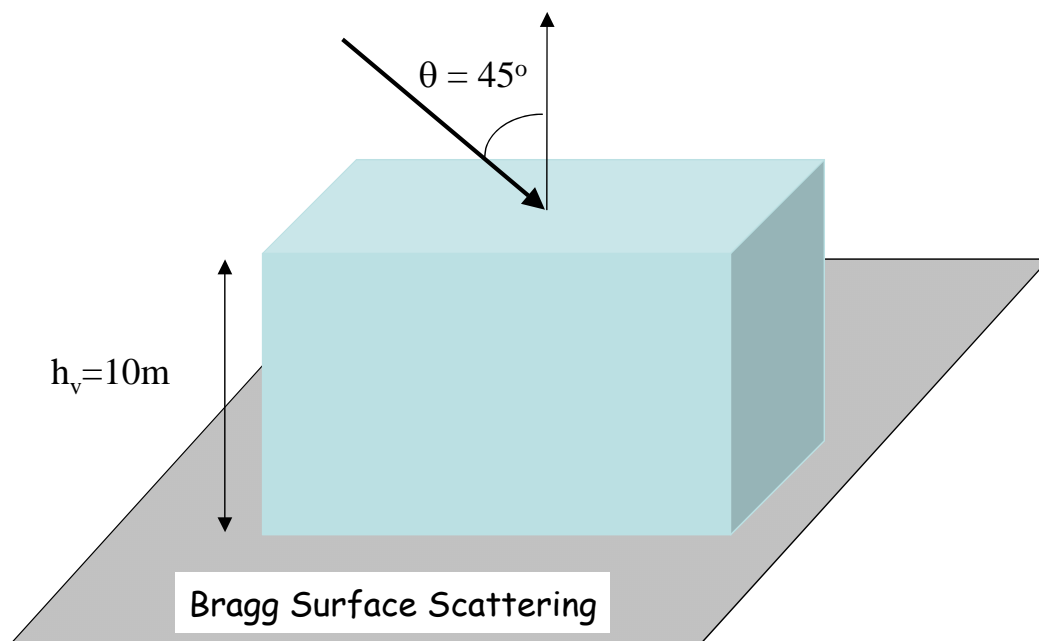
Figure 1: PolSARpro Simulator

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 ($\lambda = 0.23061\text{m}$) illuminates the scene at $\theta = 45$ 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.



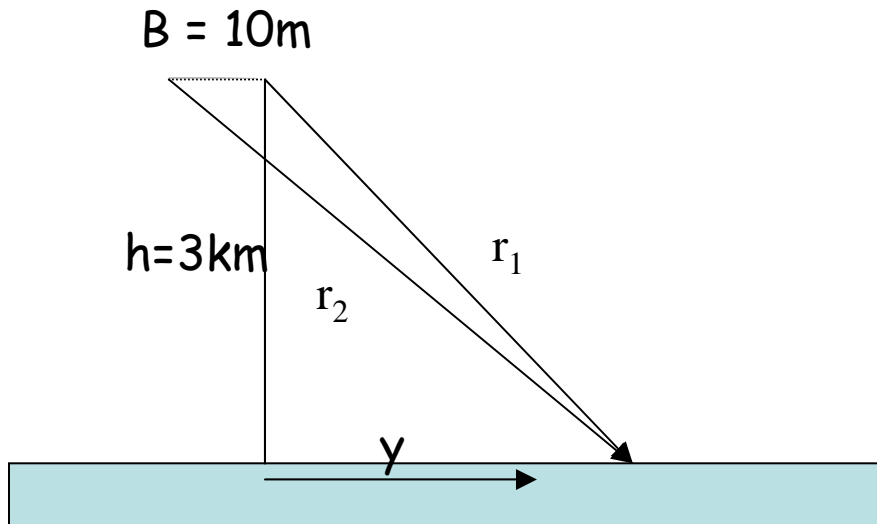


Figure 2 : POLinSAR simulation geometry

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 $Nrow \cdot Ncol \cdot 2 \cdot 4$ bytes, i.e. $Nrow \cdot Ncol \cdot 2 \cdot 32$ 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 :

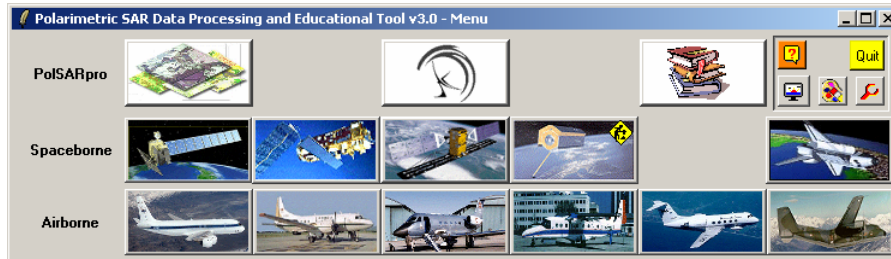


Figure 3 : PolSARpro v3.0 Main Menu



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

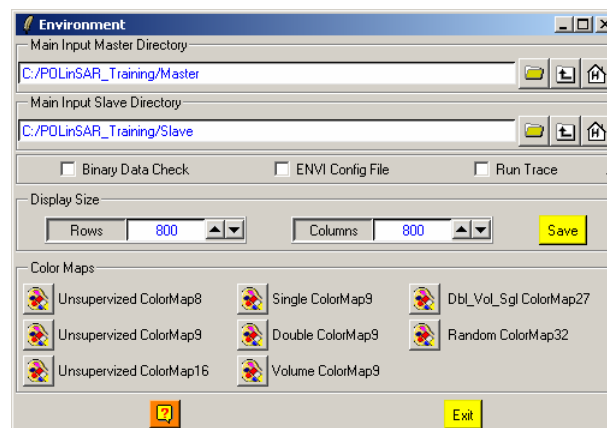


Figure 5 : Environment widget with the POLinSAR Training Data Sets settings

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)

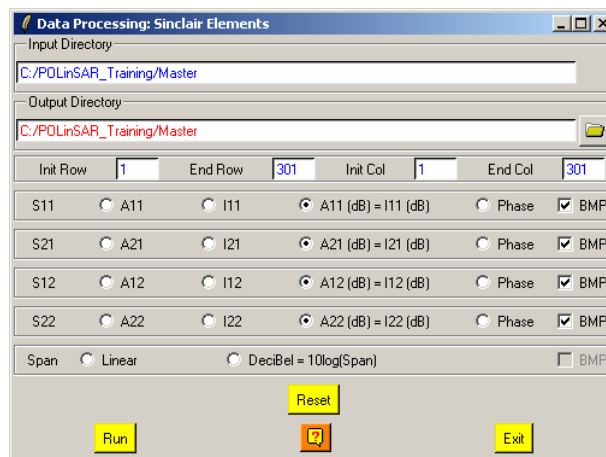


Figure 6 : Sinclair Elements widget

The four channels may be processed at a time. Select the type $A_{ij} \text{ (dB)} = I_{ij} \text{ (dB)}$ that will create the power images for each channel ($I_{ij_dB.bin}$). Select the BMP option to enable the creation of corresponding output bmp files ($I_{ij_dB.bmp}$).

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.

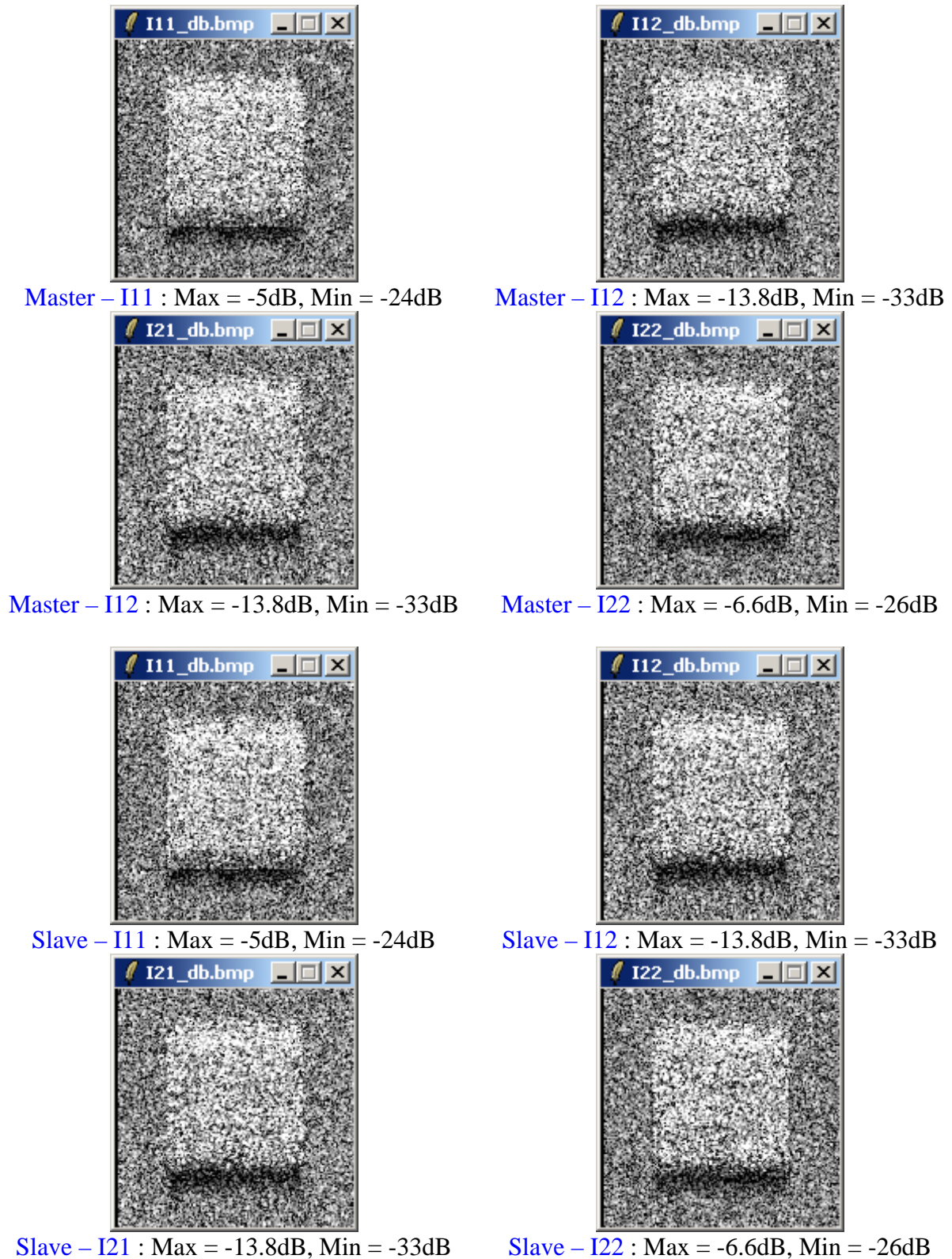


Figure 7 : SAR images for the 4 polarisation channels and two baseline positions 1 (master) and 2 (slave) of the simulated scene

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)

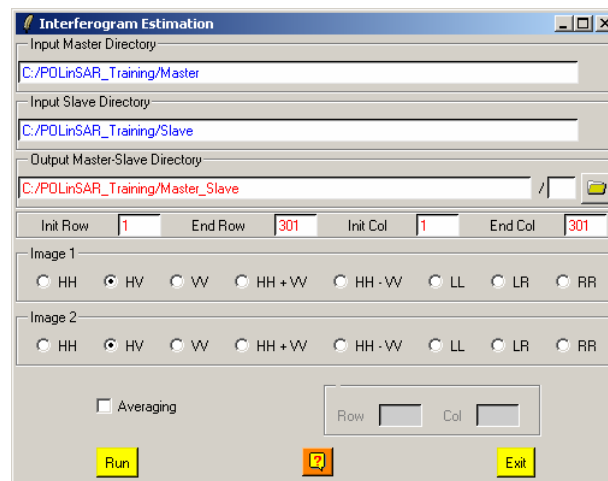


Figure 8 : Interferogram Estimation widget

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.

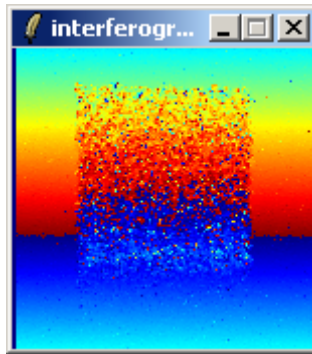


Figure 9 : Raw Phase of the Interferogram for HV Polarisation

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)

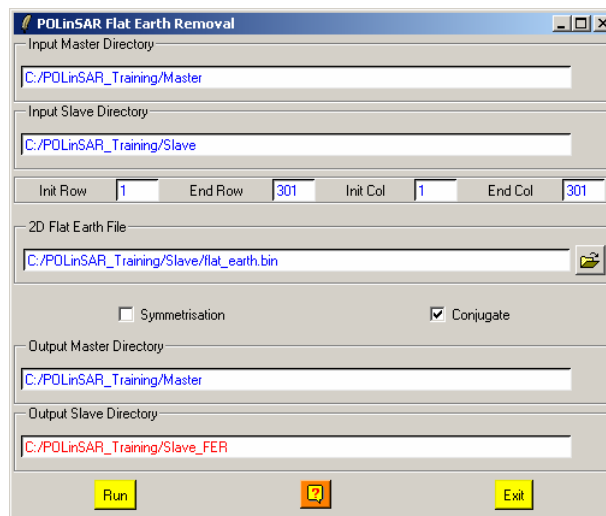


Figure 10 : Flat Earth Removal widget

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.

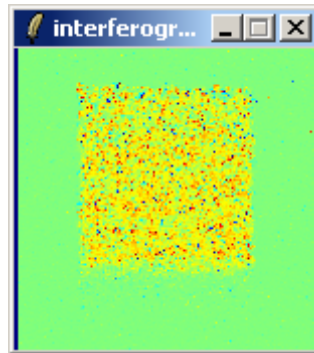


Figure 11 : Raw Phase of the Interferogram for HV Polarisation following Flat Earth Removal

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 :

$$\phi = k_z \cdot h$$

5 Vertical Wavenumber Estimation

Use the vertical wavenumber component k_z and relate it to the sensitivity of the interferometer. First of all, we have to estimate the complex coherence using a user selected window of **1x1**, and display the phase and amplitude.

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

[Process](#) → [S2](#) → [Coherences Estimation](#)

and the [Coherences Estimation](#) widget appears (figure 12)

Users have the opportunity to generate complex coherence binary files at any possible polarization states, including the Lexicographic Linear, Circular, Pauli basis and optimal polarization states derived from Cloude and Papathanassiou coherence maximization procedure. For illustration purposes we generate the complex coherence estimation for the linear polarization channels. The output file names are set to: [cmplx_coh_HH.bin](#), [cmplx_coh_HV.bin](#) and [cmplx_coh_VV.bin](#). The output bmp files are [cmplx_coh_HH_mod.bmp](#), [cmplx_coh_HV_mod.bmp](#) and [cmplx_coh_VV_mod.bmp](#) corresponding to the

coherence amplitudes, and `cmplx_coh_HH pha.bmp`, `cmplx_coh_HV pha.bmp` and `cmplx_coh_VV pha.bmp` to the coherence phases.

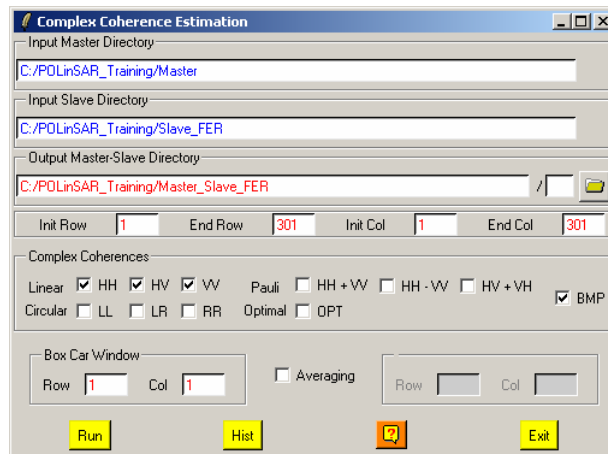


Figure 12 : Coherences Estimation widget

Figure 13 shows the coherence amplitudes and phases for the three linear polarimetric channels for a selected window of **1x1**. A coherence amplitude is traditionally viewed as a grey scale image with white = 1 and black = 0 and gives a direct visual interpretation of areas of high and low coherence. In this extreme case where the window size is equal to **1x1**, all estimated coherences are unity (white), we do not obtain a good estimate of the true value of coherence and have an extreme case of bias in the estimate. Only the phase images are interesting and correspond to the interferograms.

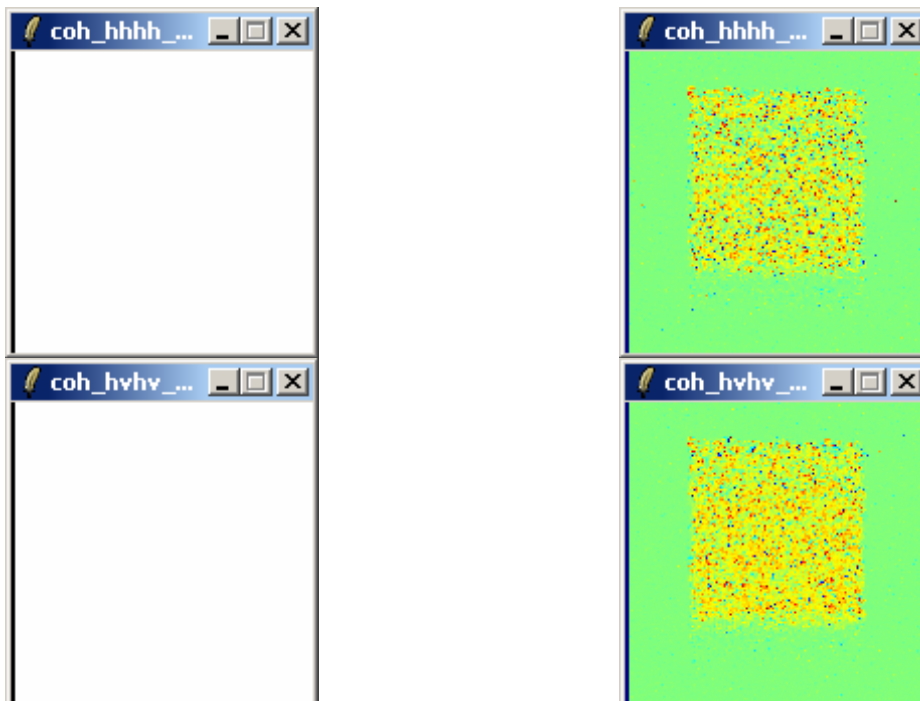




Figure 13 : Coherence images using an 1x1 window
Amplitude (left) and phase (right)

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.

With k_z calculated we can then turn the phase image of figure 10 (or of figure 13) into an equivalent height map.

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

[Process](#) → [S2](#) → [Height Estimation](#) → [Inversion Procedures](#)

and the [Height Estimation from Inversion Procedures](#) widget appears (figure 14)

Users have the opportunity to generate the phase center height files at any possible polarization states, including the Lexicographic (Linear), Circular, Pauli basis and optimal polarization states derived from Cloude and Papathanassiou coherence maximization procedure. For illustration purposes, we generate the complex coherence estimation for the linear HV polarization channel. The output file name is set to: [phase_center_height_HV.bin](#). For this, select **Phase Center Height Inversion Procedure**, then select the corresponding polarisation channel (HV in this case). The output bmp file is [phase_center_height_HV.bmp](#).

Figure 16 shows the phase center height estimations for the HVHV linear polarimetric channel (left), and on the right, the histograms of the phase center heights of the pixels in the canopy zone.

Launching the [Statistics - Histogram](#) functionality can be done by clicking on the button [Hist](#) on the widget (figure 14) 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 15)

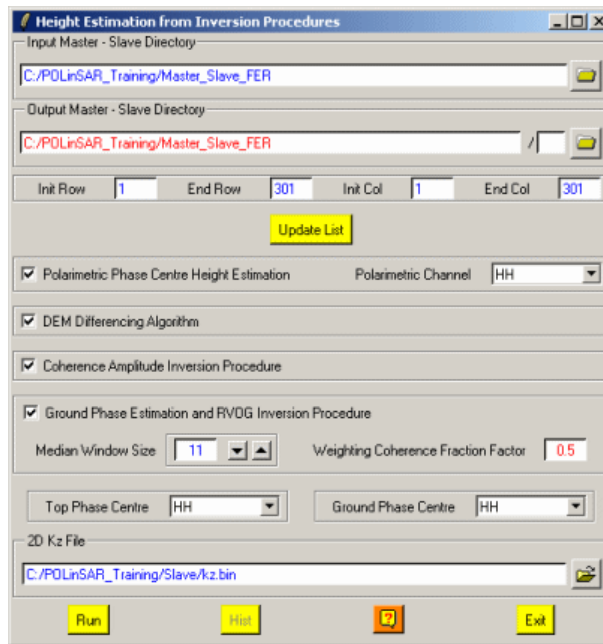


Figure 14 : Phase Center Height Estimation widget

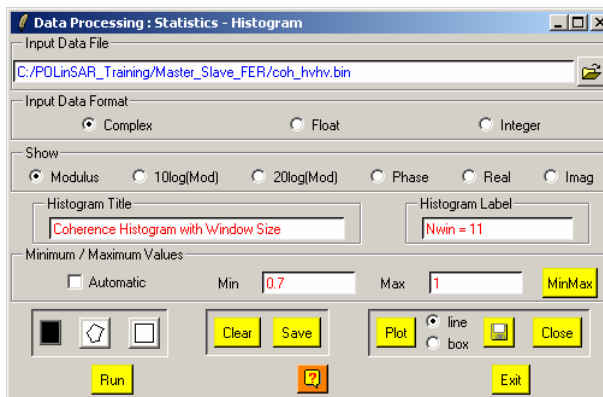
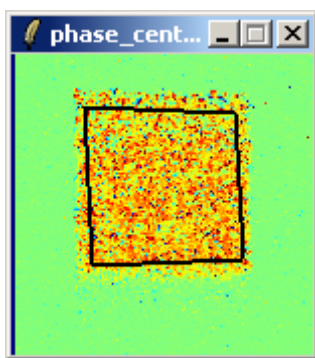


Figure 15 : Data Analysis : Statistics – Histogram widget



Min = -20m Max = +20m
(green color = 0m)

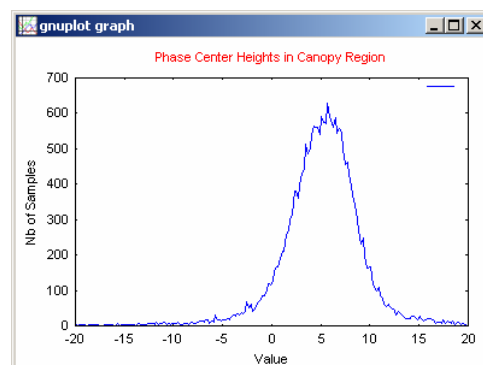


Figure 16 : Phase Center Heights and corresponding histogram over the selected area

We see a mean of 5m, half the canopy height, with a significant spread due to the phase noise caused by volume decorrelation. We see from this example that the phase of the vegetation bias does not correspond simply to the height itself, but generally underestimates the true height by an amount that depends on extinction, structure and the contribution from surface scattering. Further we don't always know the ground reference phase (in this case zero due to

knowledge of the exact geometry) and so in general to estimate height in a robust way we need to take the phase *relative* to some reference point. To do this and further improve the height estimate we first need to include coherence amplitude as well as phase in the inversion.

6 Complex Coherence Estimation

Estimate the complex coherence using a user selected window of $M \times N$, and display the phase and amplitude.

Launch again the [Coherences Estimation](#) widget (figure 12), enter a selected window size of **11x11** and select the corresponding linear channels (HH, HV and VV). The output file names are set to: [cplx_coh_HH.bin](#), [cplx_coh_HV.bin](#) and [cplx_coh_VV.bin](#).

The output bmp files are [cplx_coh_HH_mod.bmp](#), [cplx_coh_HV_mod.bmp](#) and [cplx_coh_VV_mod.bmp](#) corresponding to the coherence amplitudes and [cplx_coh_HH pha.bmp](#), [cplx_coh_HV pha.bmp](#) and [cplx_coh_VV pha.bmp](#) to the coherence phases.

Figure 17 shows the coherence amplitudes and phases for the three linear polarimetric channels. A coherence amplitude is traditionally viewed as a grey scale image with white = 1 and black = 0 and gives a direct visual interpretation of areas of high and low coherence.

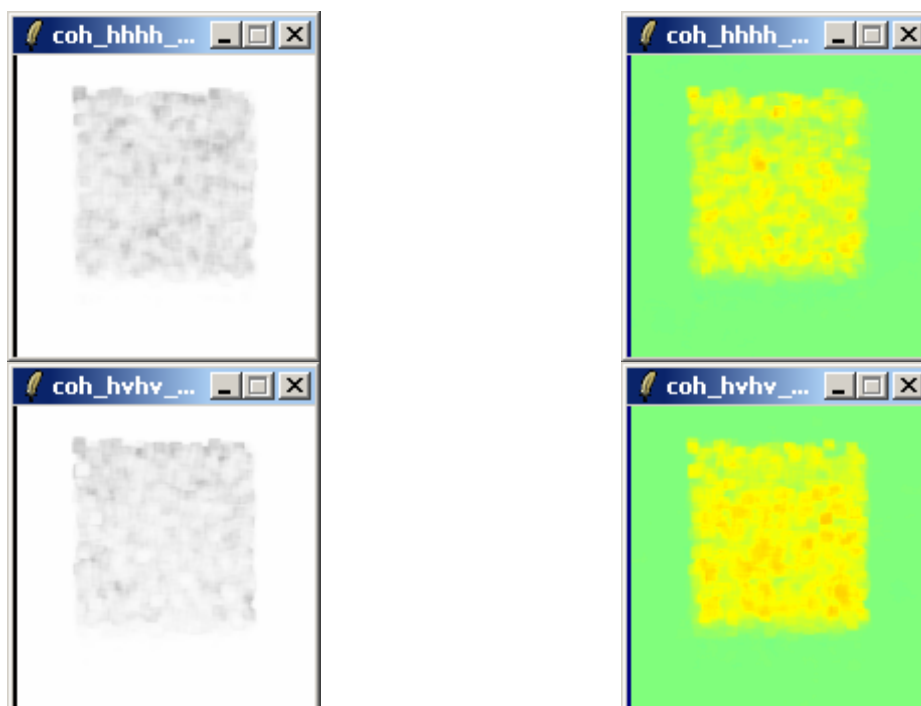




Figure 17 : Coherence images using an 11x11 window
Amplitude (left) and phase (right)

Even if the coherence amplitude is traditionally viewed as a grey scale image, such an image misses completely the important contribution made by phase. To overcome this we employ a mapping of the complex coherence inside a unit circle in the complex plane, with radius equal to the coherence amplitude and phase the polar angle of the coherence point.

To launch the [complex plane display tool](#), from the main PolSARpro v3.0 - POLinSAR widget (figure 4), click on :

[Process](#) → [S2](#) → [Coherences Analysis](#) → [Complex Plane](#)

and the [Coherences - Complex Plane](#) widget appears (figure 18)

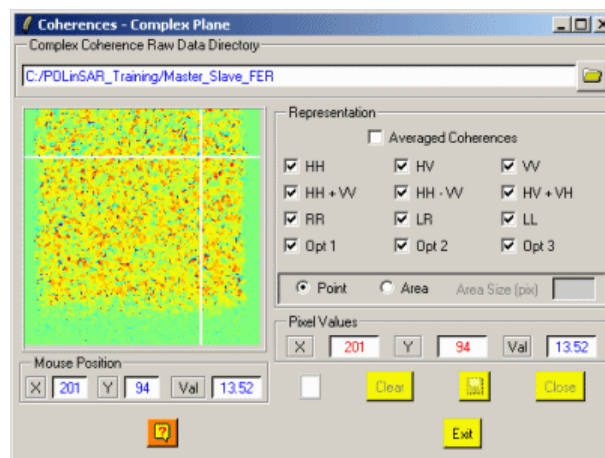


Figure 18 : Coherences – Complex Plane widget

This circle diagram is shown in figure 19. This has the advantage of displaying both phase and coherence amplitude on the same diagram but is limited to a pixel-by-pixel view rather than an image. Nonetheless it is an important tool in POLinSAR as it allows us to view the variation of both phase and coherence with polarisation and hence check the robustness of inversion algorithms based on the shape of the coherence region, that is the region formed inside the unit circle by changes over the complete set of polarisation combinations.

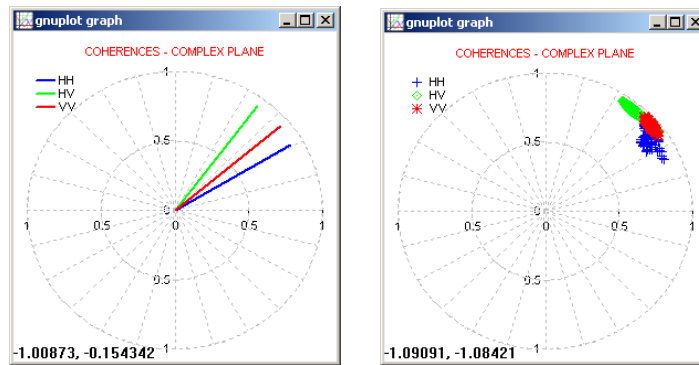


Figure 19 : Polar representations of complex coherence inside the unit circle

7 Coherence Bias and Convergence

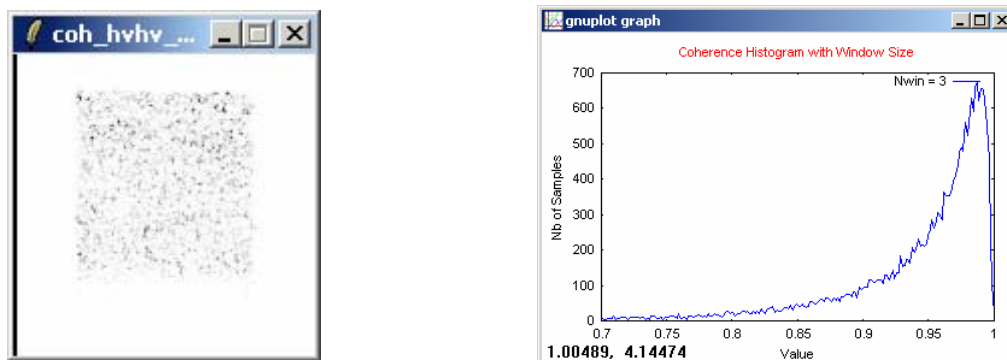
Estimate the coherence using a user selected window of $N \times N$, and look at convergence issues for increasing N , illustrating coherence bias and asymptotic convergence.

To calculate coherence we need to specify a window size for the local averaging process around the pixel under consideration. Coherence is related to phase variance and hence is akin to estimation of second order statistics of a stochastic variable. The choice of window size is therefore crucial to the quality of the estimate of coherence obtained. To illustrate this process, the generation of histograms of the estimated coherence in the canopy region for various window sizes can illustrate the quality of the estimate.

Launch again the [Coherences Estimation](#) widget (figure 12), select **linear**, and run this function for different selected window size of **3x3**, **5x5**, **7x7**, **11x11** and **15x15**.

For each window size process, launch the [Statistics - Histogram](#) functionality (figure 15), select the same vegetation area and plot the corresponding histograms

Figure 20 shows the coherence images of the whole scene for different window sizes and the corresponding histograms. Note that the coherence over the surface regions is unity while the coherence over the canopy area reduces due to volume decorrelation.



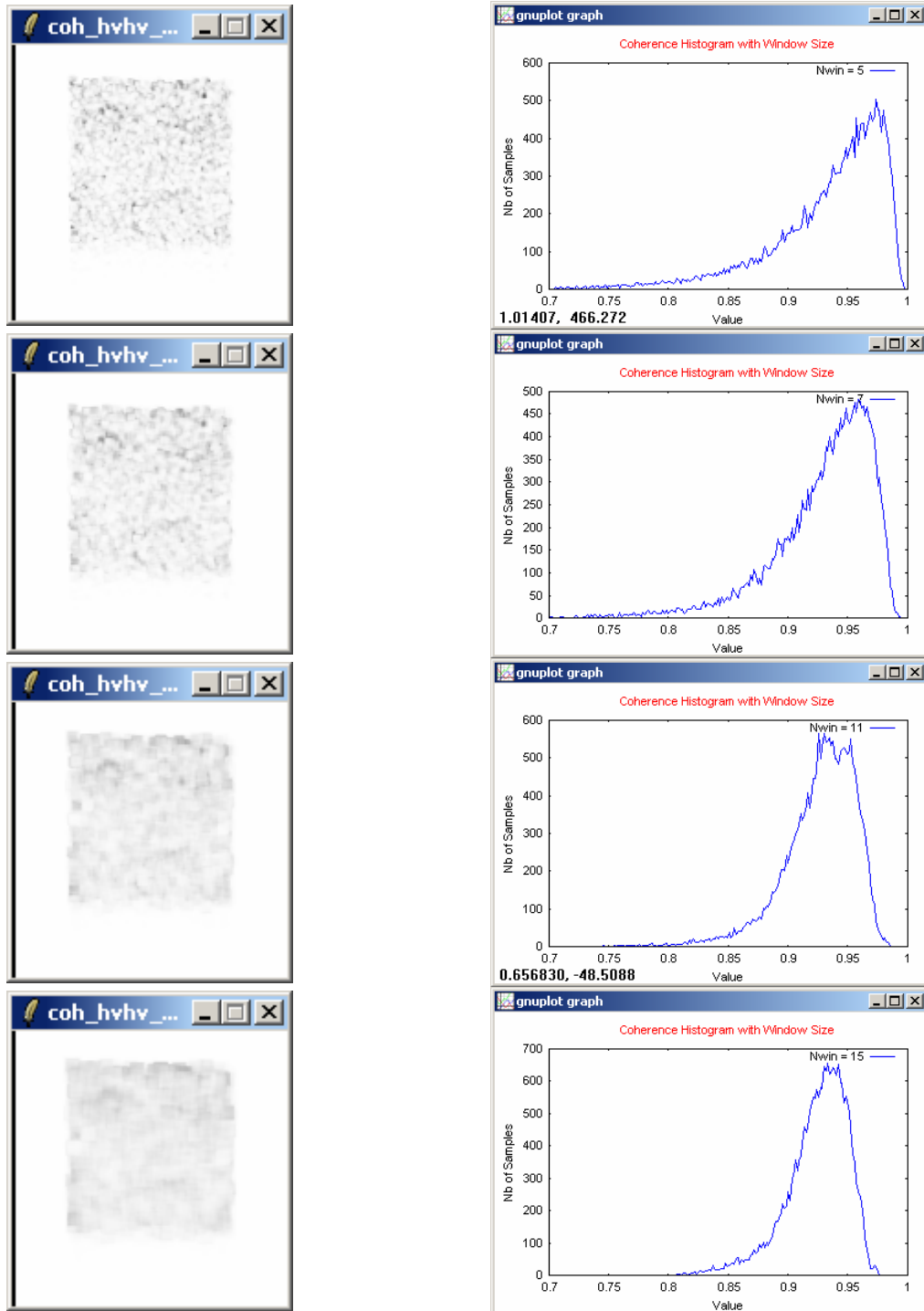


Figure 20 : Coherence Amplitude Images and Histograms of Coherence Estimate over the selected area for different window size ($N = 3, 5, 7, 11, 15$)

Note that the $N = 3$ window is too small. We see a residual bias in the peak of the histogram and a very wide distribution of coherence points. $N = 7$ shows some improvement but still a bias offset. $N = 11$ starts to show some convergence. This we can see because for $N = 15$ we see little change in the peak of the histogram, although of course there is some narrowing of the width of the distribution for the larger window.

For this reason we select $N = 11$ for further investigations.

Having now established estimates of both phase and coherence we use the data to illustrate the accuracy of three important POLinSAR inversion algorithms: The DEM differencing, the coherence amplitude and finally the RVOG algorithms.

8 Height Inversion Procedures

8.1 Inversion Algorithms

The three proposed POLinSAR inversion algorithms are grouped together inside the same widget and use the same input information: the pair of selected polarisation channels.

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

Process → **S2** → **Height Estimation** → **Inversion Procedures**

and the **Height Estimation from Inversion Procedures** widget appears (figure 23)

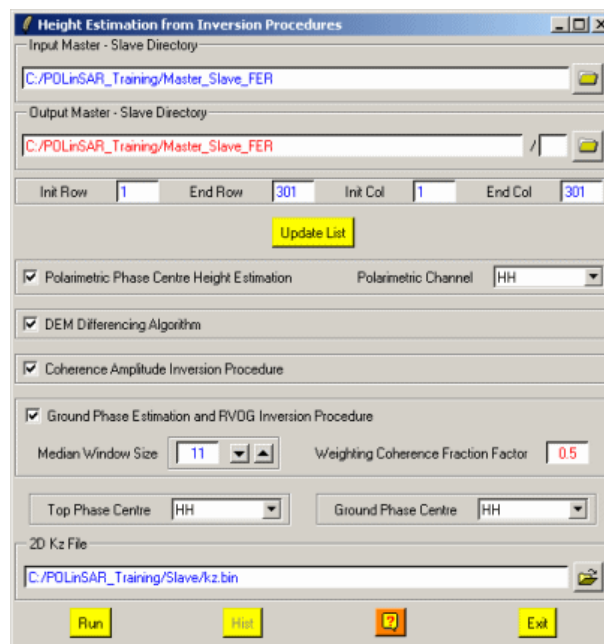


Figure 23 : Height Estimation from Inversion Procedures widget

The three proposed inversion procedures are:

- DEM Differencing Algorithm
- Coherence Amplitude Inversion Procedure
- Ground Phase estimation and RVOG Inversion Procedure

In these different height inversion procedures, it is important to choose a priori two polarisation channels, one with a phase centre close to the ground, obtained for polarisation \underline{w}_s , and the other with a phase centre close to the canopy top for polarisation \underline{w}_v .

There are many ways to choose these two polarisation channels but here we give a typical example of the logic involved.

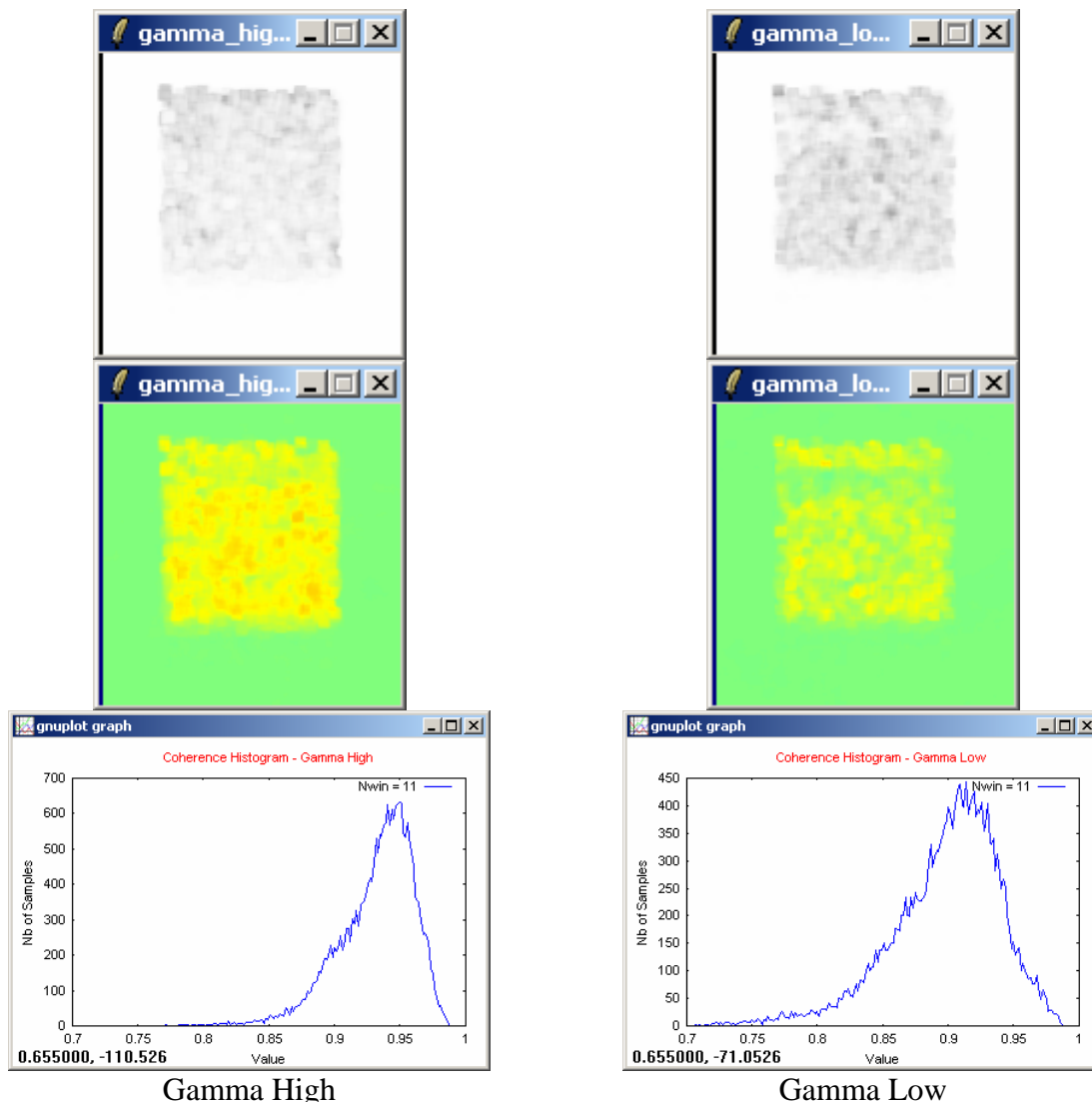
The cross-polarised or HV channel can often be expected to have a high phase centre, as the ratio of surface to volume scattering is generally small in this case. Hence the ‘upper’ interferogram can be formed from HV polarisation.

To select a lower channel we use the fact that dihedral or double bounce scattering has a phase centre lying on the surface and so as long as the double bounce is stronger than the volume in the selected channel then the phase centre will lie close to the ground. The HH-VV channel is closely matched to such a dihedral component and hence we can choose the second interferogram in this polarisation combination.

For this, select from the two combo boxes, the two polarisation channels among the proposed list. 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.

For illustration purposes we select the HV channel as a upper phase centre and HH-VV as the lower phase centre. The window size was set to **11x11**.

Figure 22 shows the coherence amplitudes and phases for the two selected polarisation channels, and the histogram of the coherence estimate over the selected vegetation area.



Gamma High

Gamma Low

Figure 22 : Coherence amplitude and phase images and histograms of coherence estimate over the selected area

8.2 DEM Differencing Algorithm

Once the two polarisation channels selected, differencing the interferograms and normalising by k_z then provides a direct estimate of relative height.

Running the [DEM Differencing Algorithm](#) functionality provides the output file named [DEM_diff_heights.bin](#) and the corresponding output BMP file : [DEM_diff_heights.bmp](#).

Figure 24 shows the resulting height estimate and the corresponding histogram of the height estimate over the selected vegetation area.

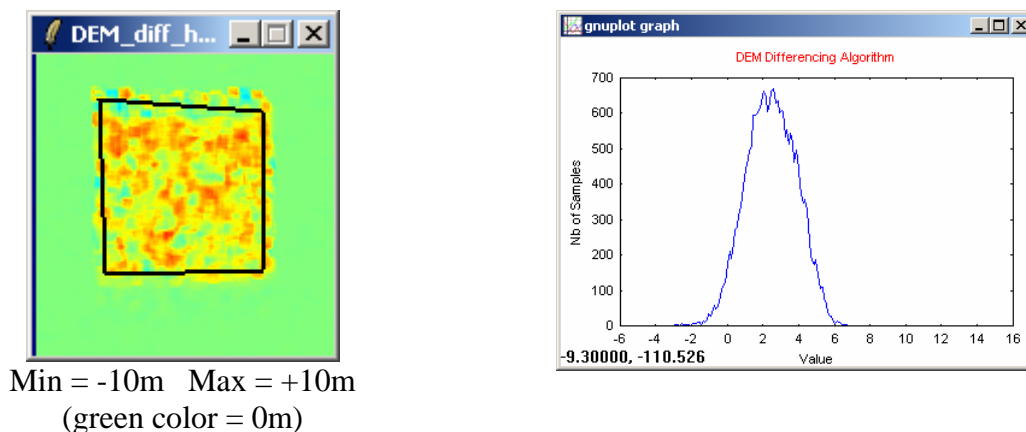


Figure 24 : DEM Differencing Heights and corresponding histogram over the selected area

We note two important points:

1. The height is severely underestimated using this algorithm. The phase centres are only separated by a few metres inside the canopy. Physically this is due to the presence of a strong volume scattering component in all polarisation channels and also because the HV phase centre lies not at the top but approximately half way up the volume (see figure 16).
2. The second key point is that sometimes the height estimate is negative. This arises because the HV phase centre lies below the HH-VV and our assumption of the ‘upper’ and ‘lower’ phase centres is reversed.

8.3 Coherence Amplitude Inversion

As an alternative to the DEM differencing approach we can use the coherence amplitude in a channel we believe to have only volume scattering present ($\mu = 0$). Again we can adopt the HV channel as a good approximation to this. We then use the relation between height and coherence for a *known* extinction in the layer. If we assume zero extinction then we obtain the ‘sinc’ relation (see the [POLinSAR Training Course](#) lecture note for in-depth demonstration).

Running the [Coherence Amplitude Inversion](#) functionality provides the output file named [Coh_heights.bin](#) and the corresponding output BMP file : [Coh_heights.bmp](#).

Figure 25 shows the resulting height estimate and the corresponding histogram of the height estimate over the selected vegetation area.

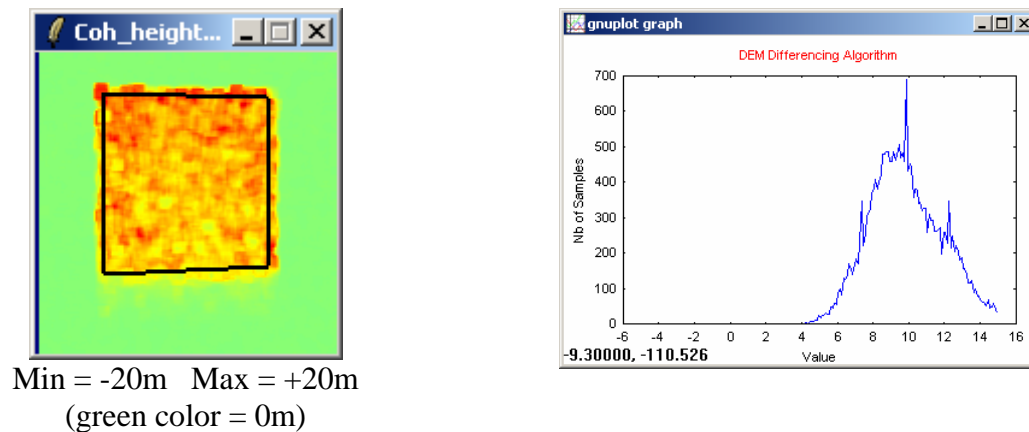


Figure 25 : Coherence Amplitude Inversion Heights and corresponding histogram over the selected area

Here we see a much better estimate, closer to the true height of 10m. However several points are overestimated and also such an approach is sensitive to density (extinction) and structure (crown depth) variations in the vegetation. For this reason we turn finally to consider the combination of phase and coherence in equation 37 of the [POLinSAR Training Course](#) lecture note, for robust height estimation.

8.4 Ground Phase Estimation

The first stage in better using phase information is to try and locate the true ground position. This we can do using the two interferograms in two polarisations, similar to the DEM differencing approach.

However this time we employ both the phase and coherence of the two interferograms to compensate the volume offset in the ground channel. If we choose HV as the ‘volume’ dominated channel and HH-VV the ‘surface’ dominated channel we obtain the ground phase estimate shown in figure26 (again using an 11 x 11 window).

Running the [Ground Phase Estimation](#) functionality provides the output file named [Ground_phase.bin](#) and the corresponding output BMP file : [Ground_phase.bmp](#).

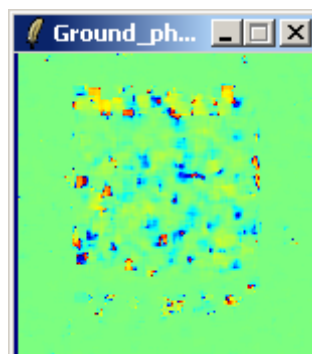


Figure 26 : Ground Phase Estimate based on HV and HH-VV interferograms

We note that the true ground phase in this example is zero and can see that most of the vegetation bias has in fact been removed.

However, the phase estimate is noisy, due to inversions of the HV and HH-VV phase centres and also to density variations in the canopy. In general therefore ground phase estimation requires a more sophisticated approach than just the simple dual polarisation line fit.

To filter the phase jumps in figure 26, we adopt a simpler solution, namely by using a median filter (note that a conventional smoothing or mean filter would be inappropriate for such phase filtering and the median approach provide a better way to suppress phase jumps of the type observed in figure 26).

Figure 27 shows the result of applying a strong **21 x 21** median filter.

Running the [Ground Phase Estimation](#) functionality provides the output file named [Ground_phase_median.bin](#) and the corresponding output BMP file: [Ground_phase_median.bmp](#).

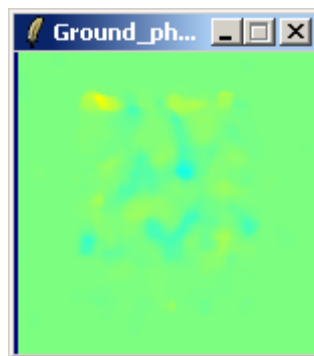


Figure 27 : Median Filtered Ground Phase Estimate

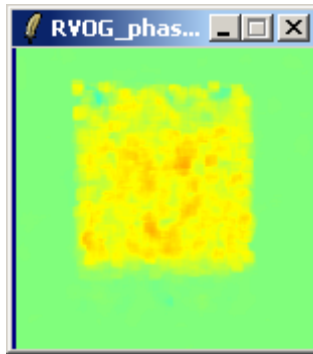
Here we see some residual phase errors but note that the phase jumps in figure 26 have been removed. Having obtained a better estimate of the true ground position, we can now employ equation 37 of the [POLinSAR Training Course](#) lecture note, to combine phase and coherence information in a way that is robust to structure and density fluctuations.

8.5 Phase and Coherence Estimation

Using figure 27 as an estimate of the ground phase ϕ_o in equation 37 of the [POLinSAR Training Course](#) lecture note, we can then estimate the two components required for height.

Firstly we obtain the height of the HV phase centre, now from the estimated ground position, as shown in figure 28.

Running the [RVOG Inversion Procedures](#) functionality provides the output file named [RVOG_phase_heights.bin](#) and the corresponding output BMP file: [RVOG_phase_heights.bmp](#).



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

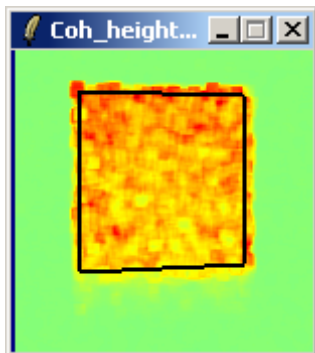
Figure 28 : Height Estimate from Ground Phase Estimate

This again confirms a height around half way up the canopy at 5m. The difference between this result and figure 16 is that we are now compensating for arbitrary ground topography variations and hence are providing a more robust algorithm approach.

As outlined in the discussion around equation 37 of the [POLinSAR Training Course](#) lecture note, we must now compensate this underestimation of height by adding a fraction of the coherence based height estimate ([Weighting Coherence Fraction Factor \$\epsilon = 0.4\$](#)). When combined, we obtain the final height image shown in figure 29.

Running the [RVOG Inversion Procedures](#) functionality provides the output file named [RVOG_heights.bin](#) and the corresponding output BMP file : [RVOG_heights.bmp](#).

Here we see a good estimate of the true 10m height of the canopy. This is confirmed by plotting histogram of the height estimates over the canopy region as shown in figure 29.



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

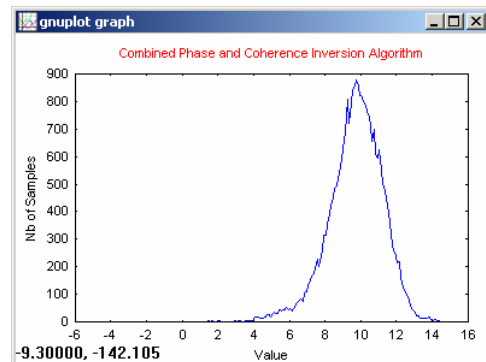


Figure 29 : Height Estimate from Combined Phase and Coherence and corresponding histogram over the selected area

Comparing the different histograms (figures 24, 25 and 29), we confirm that the DEM difference is the poorest method, the coherence amplitude and phase/coherence methods provide similar mean values but the latter has smaller dispersion and, as mentioned earlier, is more robust to vertical structural variations.

8.6 Scene Heights Profiles

To compare the different inversion results, we propose to represent some azimuth and / or range transects of the scene.

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

Process → **S2** → **Data Analysis** → **Data Profiles**

and the **Data Analysis : Value - Profile** widget appears (figure 30)

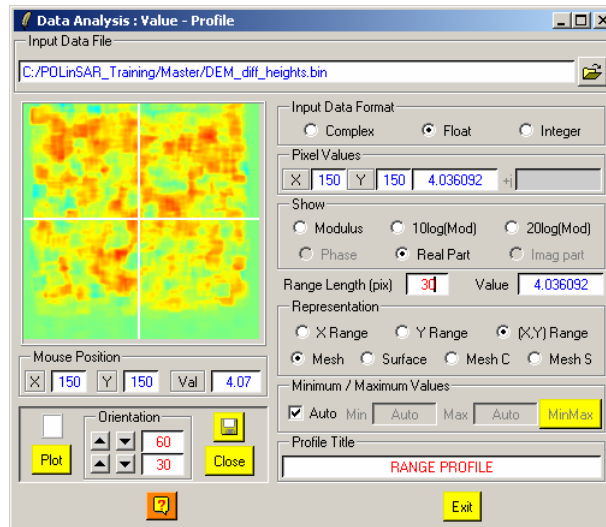
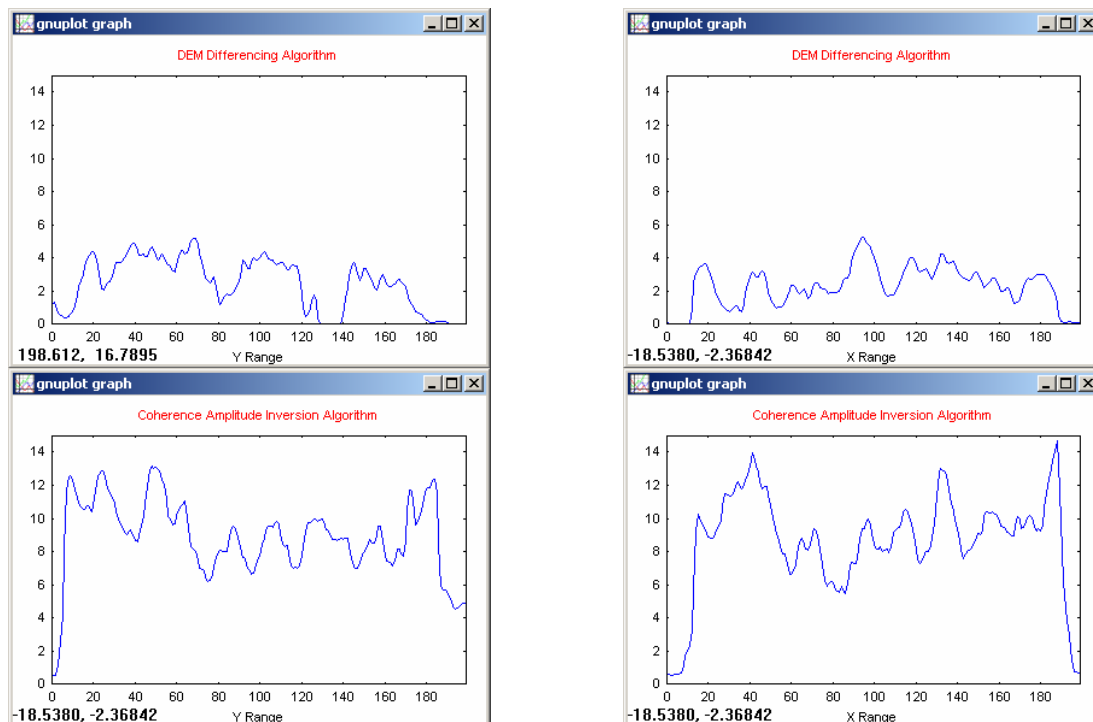


Figure 30 : Data Analysis : Value - Profile widget

Figure 31 shows sample azimuth and range transects through the scene for the three inversion algorithms.



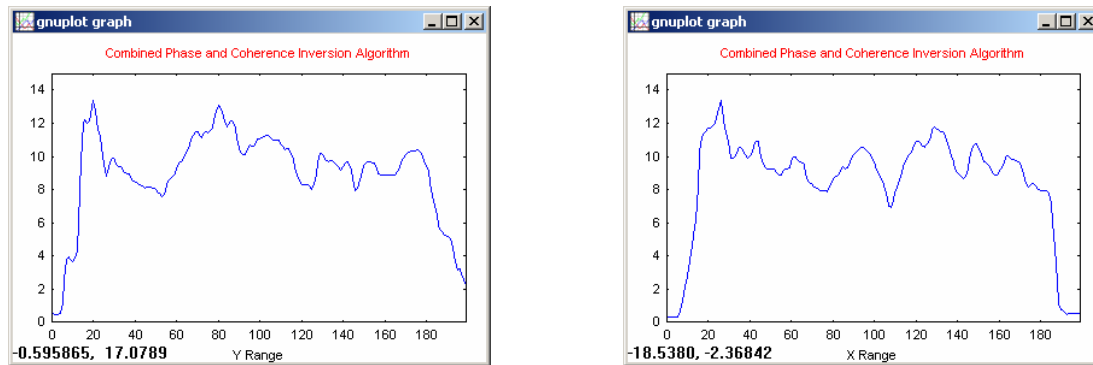


Figure 31 : Azimuth (left) and Range (right) Transects for the three inversion algorithms

Here again we see the comparative performance of the various algorithms. Note that the difference between the coherence only and coherence/phase methods may in fact be used to estimate crown occupancy of the volume. In this case the two estimates are similar and so the estimated crown occupancy is 100%, which is correct in this simulation where the canopy components were distributed from ground to top.

8.7 Polarisation Selection

In the previous analysis we have employed the two polarisation channels, HV selected as a volume dominated channel and HH-VV as a surface dominated component.

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 is still used as the volume dominated channel but now we use only HH in place of HH-VV for the surface channel.

[Start the all procedure from step 8.1 and comment the new results obtained](#)

9 Generalisation to the Coherence Loci

In order to investigate the potential for using polarisations, we need to calculate the boundary of the coherence region inside the unit circle for all polarisation vectors \underline{w} .

In general we can allow different \underline{w} vectors at either end of the baseline (equation 16) but to simplify the analysis we follow the suggestion in equations 19 and 20 of the [POLinSAR Training Course](#) lecture note, to use the same polarisation at either end of the baseline. The boundary of the region can then be found using equation 20.

For each value of phase (equivalent to rotating the unit circle), we obtain the maximum and minimum eigenvalues of the matrix product shown below in equation 40 of the [POLinSAR Training Course](#) lecture note. Having found the eigenvectors corresponding to these

eigenvalues we can then use these as \underline{w} vectors to estimate coherence and plot their complex coherences inside the unit circles. By repeating this calculation for all ϕ values we obtain a shape, the boundary of the coherence region.

We can then see where our ‘standard’ polarisations lie within this boundary to assess the potential for using adaptive techniques to improve the inversion.

To launch the specific [complex plane display tool](#), from the main PolSARpro v3.0 - POLinSAR widget (figure 4), click on :

[Process](#) → [S2](#) → [Coherences Analysis](#) → [Coherence Region – Optimum Triplet](#)

and the [Coherences Loci - Complex Plane](#) widget appears (figure 32)

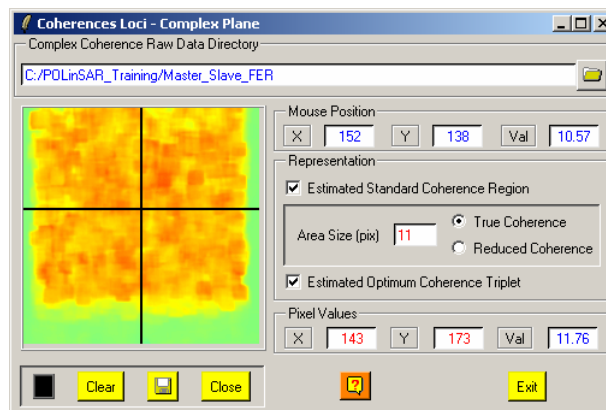


Figure 32 : Coherences Loci – Complex Plane widget

We use the test data set to illustrate this scheme. Since the coherence regions are plotted inside the unit circle of figure 19 it is a pixel based analysis and so we must select a pixel for analysis. Figure 33 shows a typical example for a pixel location in the canopy region.

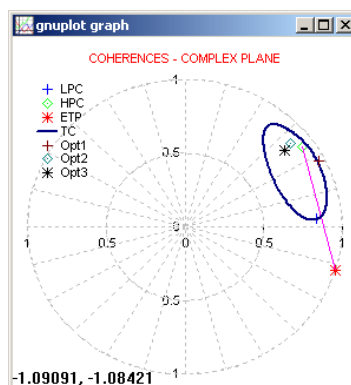


Figure 33 : Polar representations of complex coherence region inside the unit circle

Here we show the region boundary in black ($TC = True\ Coherences$).

In blue we show the HV coherence ($LPC = Low\ Phase\ Center$) and in green the HH-VV coherence ($HPC = High\ Phase\ Center$) as used in the height analysis.

In red we show a line between the HV coherence and median filtered topographic phase point (*ETP = Estimated Topographic Phase*). We see that this lies close to the true phase point at zero.

The three points *Opt1*, *Opt2* and *Opt3* represent the three optimal complex coherences.