Study of the impact of Polarizations for DInSAR Displacement Measures

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Abstract

This paper has the purpose to address the problem of the choice of polarization configuration for DInSAR applications. In order to do that the standard linear polarizations (HH,VV and HV) the Hybrid polarizations (RH and RV) and the circular polarizations (RL,LL and RR) have been taken in consideration. Starting from a Quad-Pol ALOS PALSAR stack all the polarization combinations have been derived. Then processing every single stack an analysis of the results obtained on the point targets in different polarizations has been as first carried out. Then in order to asses also the potential of SAR interferometry on distributed targets the decorrelation process varying the polarization configuration has also been studied.

1 Introduction

In the last 10 years SAR missions have exploited the possibility to acquire images with different polarimetric configurations. This capability permits to enlarge the variety of the applications that the radar remote sensing can address. Therefore in planning future missions, aimed to cover an always larger applications field, polarimetric acquisitions are of primary importance. Nevertheless some applications as the ground deformation measurements using DInSAR are quite well assessed in a case of single polarization, even if the benefits of polarimetric modes (dual and quad) have been demonstrated [1]. Hence in order to limit the costs of a mission, the need of a study on the optimal polarimetric configuration for DInSAR arose. The study has been performed using an L-Band Quad-Pol mode (ALOS-PALSAR) stack. The HH, VV and HV polarizations have been independently stacked. Hybrid polarizations RH and RV (Right Circular/Horizontal and Right Circular/Vertical) and Circular Polarizations RR, RL and LL (Right circular/Right Circular, Right Circular/Left Circular and Left Circular/Left Circular) have been derived from the Quad-Pol stacks. Persistent Scatter analysis has been carried out in the different stacks comparing the results in term of measure points density and measure points quality. Then a further check of the estimations agreement has been carried out for the targets detected in more than one polarization. The behavior of the distributed targets has also been studied analyzing the evolution of the spatial coherence in time for the different polarizations.

2 Polarization Synthesis from Quad-Pol Data

The data used for the analysis is a 20 acquisition PALSAR Polarimetry-Mode stack acquired between 2006 and 2011 over the South West area of Munich. The data cover an area of 24 x 60 Km^2 and it is characterized mainly by small urban areas forest and agricultural fields. The three SLCs stacks have a resolution of about 4 meters in azimuth and 20 meters in ground range, and are polarimetrically calibrated for channel imbalance and cross-talks. Faraday Rotation is assumed to be small. As far as the complete scattering matrix is available is possible to generate all the possible polarization combinations. The hybrid-polarimetric solutions that are generated transmitting circular and receiving linear. This can be derived as follows [2]:

$$\begin{bmatrix} S_{RH} \\ S_{RV} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} 1 \\ -j \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} - jS_{HV} \\ S_{VH} - jS_{VV} \end{bmatrix} \tag{1}$$

In many case reciprocity $S_{HV} = S_{VH}$ can be assumed. In order to obtain the circular configuration the transformation both in transmitting and receiving has to be carried out.

$$\begin{aligned} \begin{bmatrix} S_{RR} & S_{RL} \\ S_{LR} & S_{LL} \end{bmatrix} &= \frac{1}{2} T \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} T^{\top} \\ &= \frac{1}{2} \begin{bmatrix} S_{VV} - S_{HH} + 2jS_{HV} & j(S_{VV} + S_{HH}) \\ j(S_{VV} + S_{HH}) & S_{HH} - S_{VV} + 2jS_{HV} \end{bmatrix} \end{aligned} \tag{2}$$

It has to be pointed out this synthesis does not take in account the 3 dB gain that could derive from transmitting the full power on both channels in case of circular transmission configuration.

3 Persistent Scatterers at different polarizations

Interesting it is now to analyze and discuss how Point Targets are detected and perform at different polarizations.

A first term of comparison can be the number of detected scatterers. A similar analysis as in [3] has been carried out in order to evidence the amount of detected targets and how they appear distributed in the different polarizations (Figure 1).

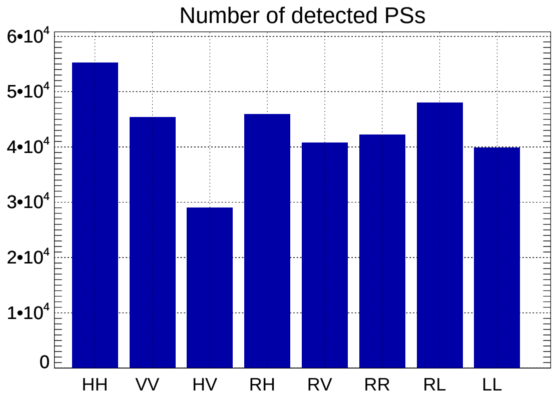

Figure 1: Detected PSs at the different polarizations

In order to keep the information compact and reduce the number of tables and numbers, the confusion matrix showing the common point targets between different polarization configurations has been then plotted (Figure 2).

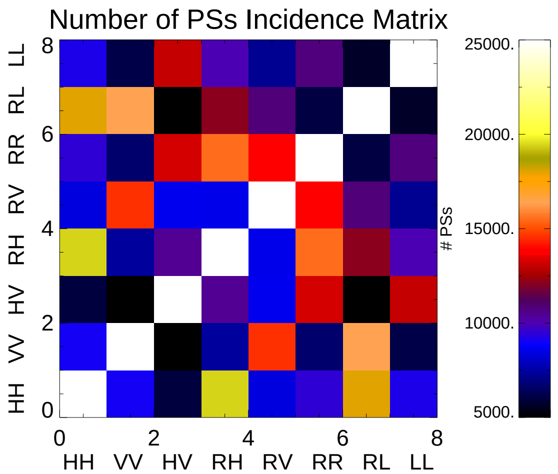

Figure 2: Confusion matrix of the detected PS number

As expected the HH shows the higher number of detected Persistent Scatterers and the HV the lowest. Particularly interesting is to analyze the common PSs between the different configurations. The two linear co-pol configurations (HH and VV) shows a good number of common PSs with the respective hybrid (RH, RV) and with the cross-pol circular one RL. This behavior can be explained looking at polarimetric content in Equations (1) and (2). The Hybrid polarizations are basically a mix between the corresponding linear configurations and cross-polarization HV. The circular cross-polarization on the other side is basically the sum of HH and VV assuming reciprocity. Nevertheless it has to be pointed out that the amount of common PSs even in the best cases (≈ 20000) is relative low in comparison with the total amount of detected point targets (> 50000). This proves the potential of radar polarimetry increasing the amount of measurements in differential SAR interferometry.

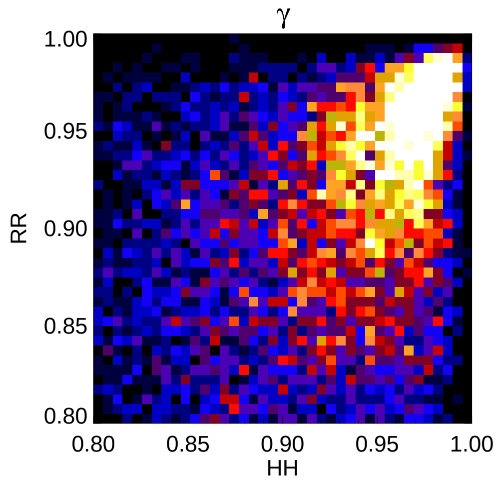

Figure 3: Coherence scatter plot between the common points in HH and RR polarizations.

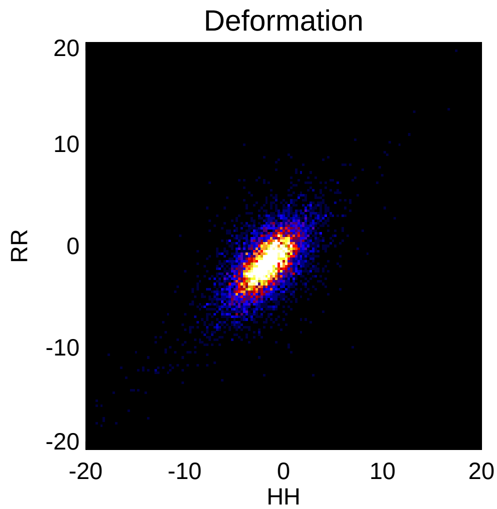

Figure 4: Deformation scatter plot between the common points in HH and RR polarizations. The observed offset is due to a different reference point in the SAR scene

Comparing the results between linear and circular configurations the results are in line with the considerations above. For the comparison linear co-pol (HH) and circular co-pol (RR) a significantly better result for the linear can be observed (Figure 3). The temporal coherence scatter plot shows the HH coherences to be in general better as the RR ones. Comparing the results no systematic effects can be observed and the relative standard deviation of the measures is around $2.5[mm/y]$ that can be considered in the order of the precision of the method (Figure 4). Much more agreement, in term of accuracy, can be found between HH and RL (Figure 5). The relative accuracy between the two processing is also significantly better ($1.8[mm/y]$) (Figure 6).

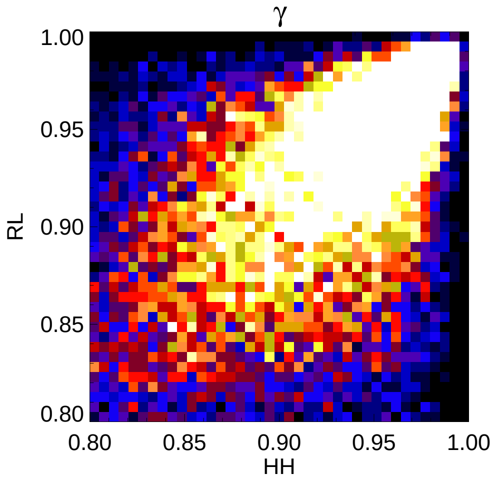

Figure 5: Coherence scatter plot between the common points in HH and RL polarizations.

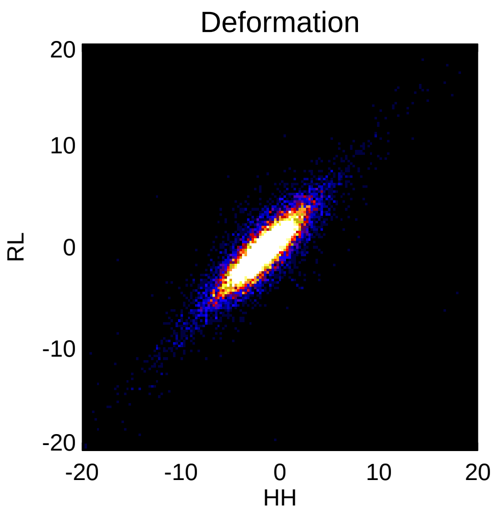

Figure 6: Deformation scatter plot between the common points in HH and RL polarizations. The observed offset is due to a different reference point in the SAR scene

In order to assess eventual systematic trends in space between the results also a spatial comparison over the common PSs have been carried out between the different polarization. As could be expected no trend could be observed. The same checks have been also performed for the estimated topography updates. As for the deformation estimations for the common PSs a very good agreement can be found. Interesting is to observe topography updates maps of all PSs in different polarizations, as far as it is possible to observe the different features recorded by the different configurations. The Hybrid-Polarizations, in general, seem to perform a bit worse that the corresponding linear configuration probably due to the HV component that is not performing very well for point targets. It is now possible to draw some conclusion about this study on the point targets.

- Linear co-pol configurations (HH,VV) performs in general better. The RL polarization as far is the result of the sum between HH and VV can also provide comparable performance.
- The configurations having a linear cross-pol component (HV), see Equations (1) and (2, perform in general worse

4 Analysis of distributed scatterers decorrelation

The analysis of the decorrelation of the SAR acquisitions has also been carried out in order to assess an eventual better polarimetric configuration from the decorrelation point of view. The stacking has been independently computed in HH, VV, HV, RH, RV, RR ,RL and LL. For each point of the scene the covariance matrix has been adaptively computed in the different polarizations and the coherence amplitudes extracted. As far as the baselines distribution was very spread, in order to generate a reasonable correlation time series, only the interferometric pairs having wavenumber shift below 10% have been taken in account. Then, the correlation values computed at the same temporal baseline have been averaged together, reducing in this way the estimation variance. Of particular interest assessing the DInSAR potential, is to check the evolution of the decorrelation process in time. This is directly connected to the achievable precision of the deformation measures. The full polarimetric characterization of the area has been exploited to classify the area of interest using a H/α classification [4]. The interest has been focused on the area classified as surfaces as far as they are the typical source of distributed targets for deformation measurements. Observing the distribution histograms of the coherences in time it can be noticed that the histograms are somehow grouped per polarizations following a pattern that was more or less already identified for the point targets. The polarizations containing HH and VV polarizations (HH, VV and RL) shows a better coherence. The hybrid configurations (RH and RV) are slightly worse and the the configurations characterized by a strong linear cross-pol component are significantly worse.

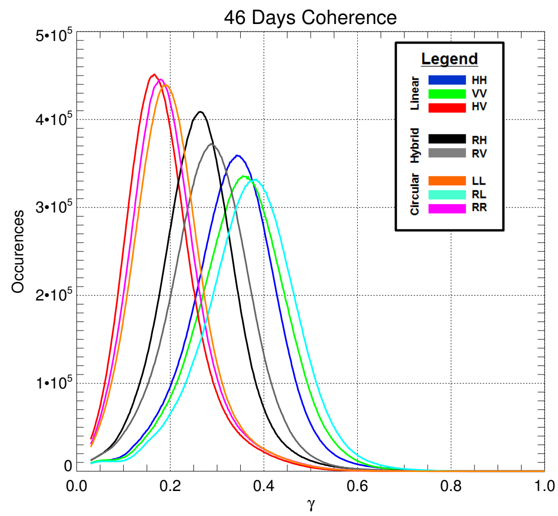

Figure 7: Coherence histograms for 46 days.

This behavior is maintained along the decorrelation process even if the temporal decorrelation predominates increasing the temporal baseline. As mentioned in the first section this study does not allow to take in consideration the power gain that could derive from the circular transmission. Figures 7 and 8 show the described evolution depicting the coherences histograms for surfaces at different temporal baselines.

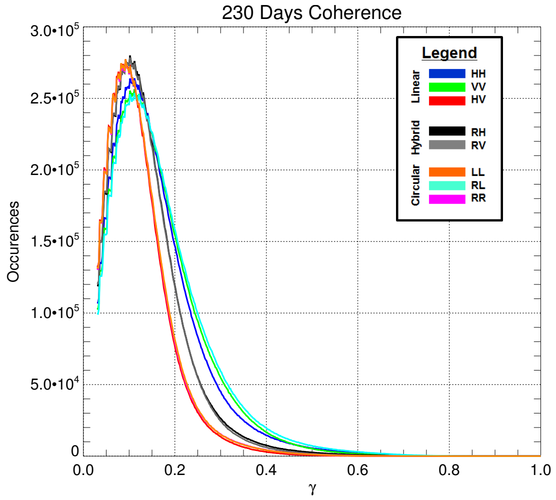

Figure 8: Coherence histograms for 230 days.

5 Discussion and Conclusions

This study had as objective not to give a general impression of the impact of polarimetry on SAR interferometry but to verify what expected from theory on a particular case in order to support a optimal choice of the polarization configuration for DInSAR purposes. The results in general meets the expectation however would deserve a more detailed study. In order to resume it is possible to conclude that:

- Linear co-pol configurations look in general better but also the RL configuration provides comparable performance
- From the PSs point of view the use of more polarizations would of course provide a more dense map, however no gain in coverage have been taken over.
- The power gain provided by the circular transmission could provide a further gain in case of low backscatter areas.

6 Acknowledgments

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