# Polarimetric PALSAR SAR data for forest cover mapping in Siberia

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***Abstract***
This paper provides an initial assessment of the qualification of polarimetric parameters for forest cover mapping in Siberian boreal forest. This investigation is carried out in the framework of JAXA's Kyoto and Carbon Initiative. The impact of the additional polarimetric information will be related to the backscattering intensities derived with the respective polarimetric acquisitions. The dataset consists of two Level 1.1 PLR scenes acquired during the calibration/validation phase and is thus not determined by the schedule of the ALOS acquisition strategy. First results show the capability of polarimetric parameters to extend the intensity based data set in terms of a higher overall separability of forest and non forest and to some extend the feasibility of subdividing both basic classes.

## 1. INTRODUCTION

The potential of Synthetic Aperture Radar (SAR) data for forestry applications is substantiated by a huge number of publications. SAR data is widely used for forest cover mapping [1], forest disturbance mapping (e.g. logging, forest fire, and wind damage) [2, 3, 4] and forest biomass assessment [5, 6, 7]. Lower frequencies proved to be of particular adequacy. Polarimetric parameters are not commonly used for clear-cut or fire scar mapping, although they proved to provide some capabilities, e.g. the HHVV phase difference was found to be different for forest and clear-cuts [8]. This could be due to the lack of an operational polarimetric data source.
With the successful launch of ALOS a new dimension in spaceborne L-band SAR data acquisition has been achieved. The polarimetric mode of PALSAR allows the coherent acquisition of all four polarisations and thus provides access to the complex scattering matrix. The scattering matrix in turn provides the basis of polarimetric techniques such as signal decomposition or polarisation synthesis. Those techniques allow a more profound SAR data analysis and can eventually relate the signal to ground scattering mechanism and thus physical properties of the scatterers. Further parameters of interest for forestry applications derived from the complex scattering matrix are the complex polarisation ratio, the maximum contrast of unpolarised power, the polarimetric coherence and the degree of polarisation. All these parameters extent the SAR database and can help to increase the discrimination of the desired forest classes.
This paper includes the investigation of the polarimetric HHVV coherence as well as the Cloude [9, 10], the Freeman [11], and the Krogager [12] decomposition parameters regarding their suitability for forest cover, clear-cut, and burnt area mapping. The feasibility of these parameters will be related to the one of the SAR intensities.

## 2. STUDY AREA

The study area is located in central Siberia (see Fig. 1). The Middle Siberian Plateau in the southern part of the territory is characterised by hills up to 1,700 m. The northern part is flat with heights up to 500 m. Taiga forests (birch, aspen, pine, larch etc.) dominate and cover ca. 82% of the region. The site exhibits continental climatic conditions. The yearly amount of precipitation is generally below 450 mm; the winters are very cold and dry, the summers are warm and include the precipitation season.

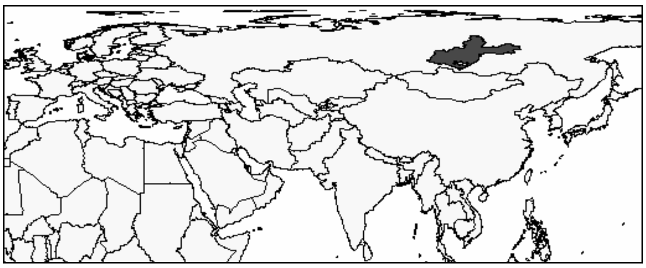

*Figure 1. Study area in central Siberia*

## 3. METHODOLOGY OF INVESTIGATION

Aim of this investigation is to assess the potential of polarimetric parameters to extent the SAR data set for forest cover and disturbance mapping. For this a simple and straight forward approach was preferred. Each of the selected polarimetric parameters was used individually as input for a pixel-based class signature examination and a separability study. The considered classes are "former clear-cut", "recent clear-cut", "fire scar", and "forest". Of all investigated polarimetric parameters only those with potential to improve the database are presented here. The samples were selected based on high resolution optical data. A clear-cut was labelled "former clear-cut" when considerable regrowth (coverage with green woody vegetation > 50%) was identified.

## 3. SAR DATA BASE

The dataset (see Fig. 2) consists of two Level 1.1 PLR scenes acquired during the calibration/validation phase. Both scenes are superimposed (Track 0463, Frame 1140). One scene was acquired during the summer period (28th August 2006), the other one at the beginning of the Siberian winter (13th October 2006). The weather conditions during the winter acquisition have been recorded at the station "Oktjabr'skoe", which is about 100 km away from the scene centre. Records document maximum temperatures slightly below 0°C and a thin snow layer of ca. 3 cm (thus not yet actual Siberian winter). The pre-processing of the SAR intensities comprises calibration, orthorectification and topographic normalisation. The approach for the latter step was explained by [13]. The polarimetric parameters were computed as proposed by the respective authors. Afterwards these images have been orthorectified.

Besides forest the image include an enormous amount of clear-cuts and some fire scars. Fig. 3 provides an image subset from the northern part of the scenes featuring a fire scar (top left). Whereas clear-cuts can be easily distinguished with the summer data, they are hardly visible in winter, which is concordant with the literature (e.g. [1, 7, 14]). Fig. 4 presents the respective class signature plots for HV and HH. Compared to summer, backscatter intensity and dynamic range decreased in winter. HH summer intensities could be used to distinguish recent and former clear-cuts. Winter intensities are less relevant.

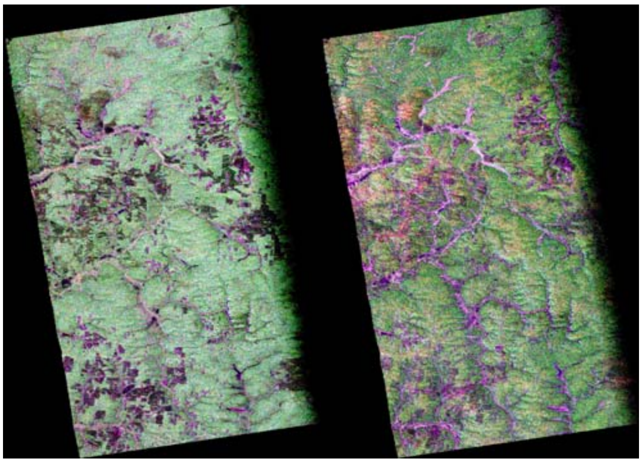

*Figure 2. Investigated PALSAR PLR data (RGB = HH/HV/VV). Left: summer, Right: winter*

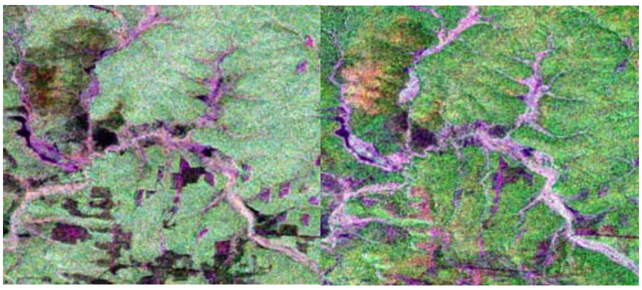

*Figure 3. Zoom in: Summer vs. winter (HH/HV/VV)*

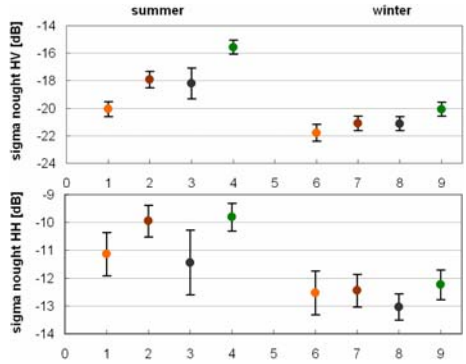


*Figure 4. Signature plot of HV & HH intensity. 1 & 6 = recent clear-cut, 2 & 7 = former clear-cut, 3 & 8 = fire scar, 4 & 9 = forest. Error bars flag std. deviation*

## 5. RESULTS AND DISCUSSION

### 5.1. Polarimetric HHVV Coherence

Whereas interferometric coherence is commonly used for forestry applications the feasibility of polarimetric coherence (Eq. 1) is still subject of investigation. The polarimetric coherence provides information on the scattering process. Surface scattering creates high coherence, multiple scattering as to be found in forests results in low values.

$$\rho_{HHVV} = \left\langle \frac{S_{HH} S_{VV}^*}{\sqrt{\langle S_{HH} S_{HH}^* \rangle \langle S_{VV} S_{VV}^* \rangle}} \right\rangle \qquad (1)$$

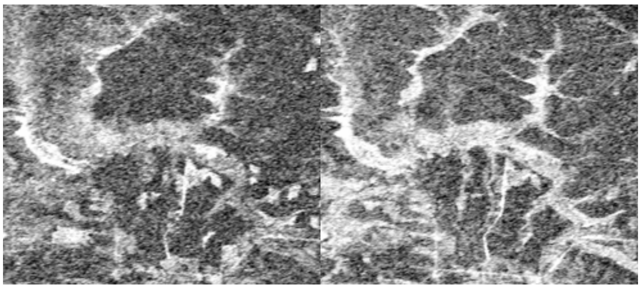

*Figure 5. Subset of $|\rho_{HHVV}|$ . Left: summer, Right: winter*

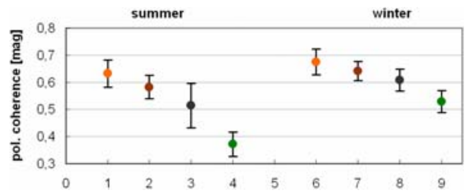


*Figure 6. Signature plot of $|\rho_{HHVV}|$*

Fig. 5 provides the magnitude of the polarimetric coherence. The subset shows the same area as Fig. 3. Especially at the winter acquisition the floodplains feature high coherence. Forest also exhibits higher coherence at the winter scene (compare Fig. 6). Due to initiated crown freezing less multiple scattering emerges. The contrast between clear-cuts and forest is much higher at the summer scene. Especially recent clear-cuts can be clearly discriminated. The fire scar is not visible at both times, although higher coherence compared to forest was measured. Regarding clear-cut detection polarimetric coherence provides additional information, when summer data is used. However, the high noise fraction needs to be considered.

### 5.2. Cloude decomposition parameters

Cloude [9, 10] developed a roll invariant Eigenvector-Eigenvalue based decomposition of the coherency matrix which in turn bases on the Pauli scattering vector. Major advantage of the concluding parameters is their physical interpretability. Alpha indicates the type of mean scattering mechanism; entropy and anisotropy specify the distribution of the scattering mechanisms. Different scattering behaviour of clear-cuts and forest is obvious in Fig. 7.

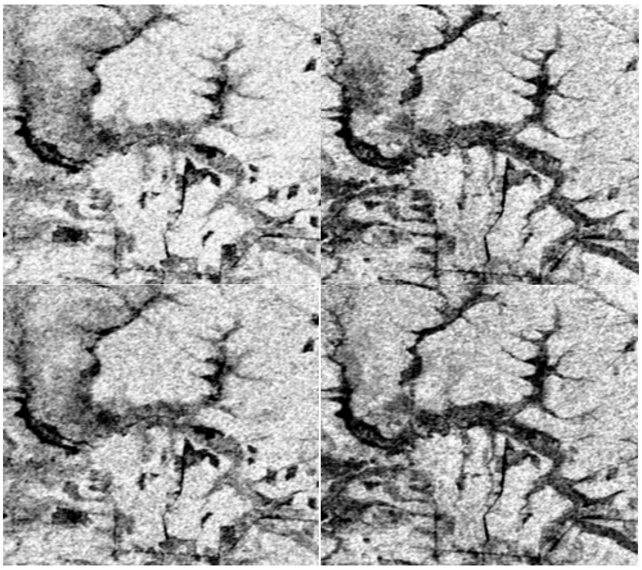

*Figure 7. Entropy (top) & alpha (bottom). Left: summer, right: winter*

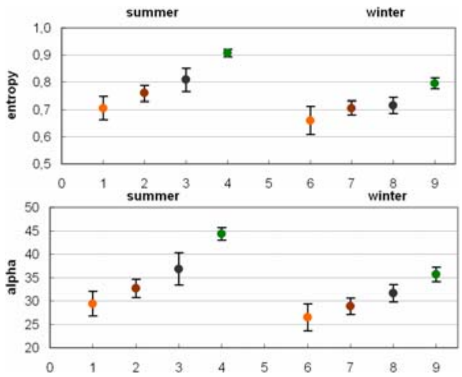


*Figure 8. Signature plots of entropy & alpha*

The anisotropy (not depicted) provides no additional information here. Again the summer scene is more suited for clear-cut detection. The dynamic range is decreased at the winter scene. However, the winter entropy allows the recognition of the fire scar. Generally, the thematic information of alpha and entropy does not differ significantly (see also Fig. 8). Recent clear-cuts could be well detected. Even former clear-cuts can be recognised. The distinction of fires scars could be problematic.

### 5.3. Freeman decomposition parameters

Freeman [11] proposed a decomposition which separates the backscattered power with a modelled covariance matrix into three fractions: volume scattering (Pv), double bounce (Pd) and surface scattering (Ps). Each of these scattering processes is described by a scattering model. This approach is not roll invariant and topography can affect the fractioning. However, this procedure seems suited for forestry applications since the contrast between forest and clear-cuts as well as fire scars is increased (compare Figs. 9 & 10). Especially Pv allows clear discrimination of the classes. Fig. 10 demonstrates that even the discrimination of recent and former clear-cuts might be feasible. Summer data are clearly preferable.

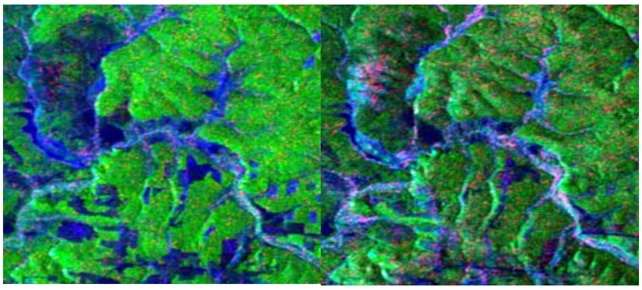

*Figure 9. Freeman decomposition (Pv/Pd/Ps). Left: summer, Right: winter*

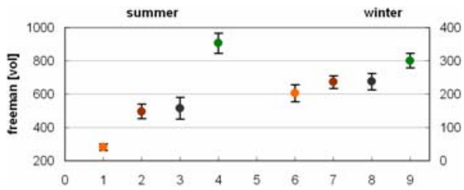


*Figure 10. Signature plot of Pv (volume scattering)*

### 5.4. Krogager decomposition parameters

The coherent Krogager decomposition [12] factorises the scattering matrix as combination of three responses: sphere, helix and diplane. The power scattered by each of these responses is given by $|ks|^2$, $|kh|^2$ and $|kd|^2$ respectively. In this study it was found, that $|kd|^2$ could be a valuable parameter. High contrast between forest and the non-forest classes was found (Figs. 11 & 12). Even a separation of former and recent clear-cut seems feasible. Fire scars feature similar values as former clear-cuts. Again, summer data is preferable.

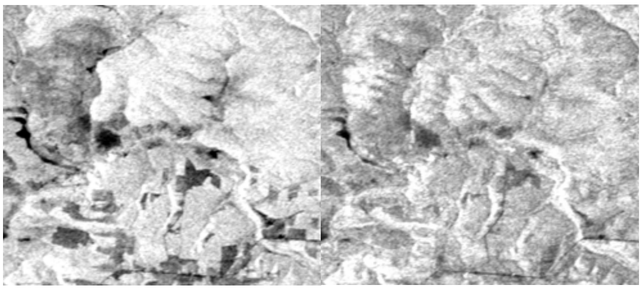

*Figure 11. Krogager decomposition coefficient $|kd|^2$ (diplane component). Left: summer, Right: winter*

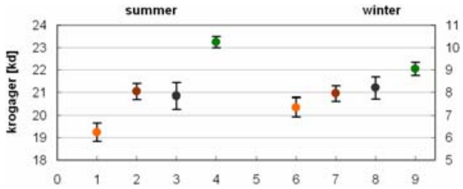


*Figure 12. Signature plot of |kd|² (diplane component)*

### 5.5. Summary of separability measures

Tab. 1 summarises the separability of the considered classes regarding the respective SAR parameter. As separability measure the normalised Jefferies-Matusita distance was chosen (1.0 = signatures separable; 0.0 = signatures inseparable). As the summer scene was found being generally preferable only those measures are presented here.

*Table 1. Normalised JM distances between classes recent clear-cut (1), former clear-cut (2), fire scar (3), forest (4)*

| | 1 - 2 | 1 - 3 | 1 - 4 | 2 - 3 | 2 - 4 | 3 - 4 |
|---|---|---|---|---|---|---|
| $\sigma^0$ HH | 0,34 | 0,20 | 0,40 | 0,23 | 0,08 | 0,29 |
| $\sigma^0$ HV | 0,49 | 0,45 | **0,91** | 0,07 | 0,69 | 0,74 |
| $\sigma^0$ VV | 0,32 | 0,13 | 0,41 | 0,32 | 0,11 | 0,42 |
| $\lvert\rho_{HHVV}\rvert$ | 0,20 | 0,44 | 0,78 | 0,28 | 0,72 | 0,54 |
| Alpha | 0,27 | 0,57 | **0,91** | 0,38 | **0,88** | 0,72 |
| Entropy | 0,32 | 0,58 | 0,89 | 0,35 | **0,88** | 0,80 |
| Pv | **0,71** | 0,65 | **0,99** | 0,15 | **0,91** | **0,95** |
| $\lvert kd\rvert^2$ | **0,72** | **0,70** | **0,99** | 0,13 | **0,90** | **0,95** |

This analysis was conducted on pixel level, thus noise negatively affects the separability and noisier parameters will seem less suited. Therefore, an adapted study should be carried out when mapping on segment level is aspired. On the other hand, filtering can minimise noise.
From Tab. 1 it is obvious, that polarimetric parameters are feasible to extend the SAR database. In many cases they even feature a higher separability compared to the intensities. The latter two parameters might be used to separate recent and former clear-cuts.

## 6. CONCLUSIONS AND OUTLOOK

It could be demonstrated that SAR polarimetry offers great potential to extent the data base for forestry applications. However, the derived polarimetric parameters proved being strongly dependent on seasonal effects. Although only two acquisition dates have been investigated it can be stated that the summer acquisition is clearly preferable. Nevertheless, further investigations need to apply a larger spatial and temporal database. Due to the fact, that some of the polarimetric parameters enable the distinction of two clear-cut classes, it can be assumed that these parameters feature some sensitivity for forest biomass. This matter will be subject of further investigations.
Still, cross polarised PALSAR intensities such as K&C FBD (fine beam dual polarisation) data provide a powerful source of information especially regarding clear-cut detection and forest cover mapping.

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