P-band PolSAR data inversion for forest biomass estimation

This thesis took place during the preparation phasis of the BIOMASS ESA (European Space Agency) mission, which plans to exploit for the first time ever a P-band (435 MHz) spaceborne SAR, with the aim at mapping forest biomass and height worldwide for the period 2023-2028. The use of the P-band comes from its unique sensitivity to forest biomass, in relation to its ability to penetrate through dense media like tropical forests. The BIOMASS mission is based on the use of three imaging modes: Polarimetry (PolSAR), Interferometry (PolInSAR) and Tomography (TomoSAR), and aims at delivering forest biomass and height maps every 7 months at a resolution of 4 ha, as well as maps of severe disturbances at 0.5 ha.

The thesis has been organised around the development of a processing chain made of several modules in order to map forest biomass from P-band PolSAR images, and for a wide range of forest type and observation conditions. The two main modules consist in the development of a PolSAR indicator related to forest biomass and in a Bayesian method built on likelihood functions derived from a predictive electromagnetic model (MIPERS-4D).

A first study focused on the comparison between various PolSAR based indicators adapted to forest biomass estimation on several test sites. In particular, this thesis emphasises the possibility of minimising the effects of topography with the joint use of digital elevation models (DEM) which give an approximation of terrain slopes and with the fully polarimetric covariance matrix from which it is also possible to extract topographic information like the azimuthal component of terrain slopes.

In order to improve the link between backscatter coefficients and biomass, the minimisation of speckle effects has also been studied in the specific framework of BIOMASS acquisitions plan, meaning the adaptation of state-of-the-art filtering techniques for polarimetric SLC time series data. This work results in the development of a multi-channel filter adapted to PolSAR time series, which has been demonstrated on the TropiSAR data acquired at the Paracou test site, and described in the submitted paper "Multi-temporal speckle filtering of polarimetric P-band SAR data over dense tropical forests in French Guiana: application to the BIOMASS mission", in which a new indicator to quantify filtering performances has been also highlighted, in connection with the capacity of P-band PolSAR data to characterise the azimuthal slopes.

These works contribute to develop an inversion method accounting for the challenging constraints of spatial and temporal generalisation for the future BIOMASS acquisitions at global scale. The developed method proposes the combination of the so-called t0 indicator derived from PolSAR data in order to optimise the relationship with forest biomass, with a Bayesian method minimising the dispersion effects thanks to likelihood functions derived from the MIPERS-4D model. The observation conditions related to the temporal or spatial variability can be thereby accounted for, and the method application to the P-band airborne SAR data acquired during the BIOMASS mission preparation phases show its great interest to avoid the direct propagation of dispersive factors into biomass.

These contributions enabled to adapt and improve the processing chain, and paved to way to further prospects of new insights such as the method generalization with PolInSAR and PolTomoSAR indicators, in order to achieve a more thorough exploitation of the upcoming BIOMASS data.