CHAPTER EIGHT

Conclusions

This thesis has investigated the potential of temporal, spatial, spectral and polarisation characteristics of SAR backscatter for the study of biomass and land cover class of tropical forests in two study areas in Brazilian Amazonia. To conclude, the main findings are divided by subject and summarised, starting by underlining the answers to the questions posed within the objectives (section 1.4). Finally, the significance of findings and future work directions are suggested.

8.1. Temporal analysis

No biomass change was detectable with temporal JERS-1 LHH backscatter.

- A positive backscatter/biomass relationship was found \((r = 0.87)\) and indicated saturation in \(\sigma^o\) at biomass levels of around 90 T ha\(^{-1}\).
- A cyclical pattern in \(\sigma^o\) for young regenerating forest plots was detected. The pattern was seasonal with the dry season corresponding to lower \(\sigma^o\) and the wet season corresponding to higher \(\sigma^o\). This result indicated the influence of vegetation and soil water content on \(\sigma^o\).
- The behaviour of \(\sigma^o\) was more strongly time-dependent for plots below the \(\sigma^o\) asymptote (e.g., young regenerating forest plots). Although less temporally dynamic than these young regenerating forest plots, intermediate regenerating and mature forest plots presented a similar \(\sigma^o\) behaviour.
Conclusions

- The influence of rainfall was assessed and was found to be an important source of variation in $\sigma^2$. The influence was clearer for young regenerating forest plots, where the change in the water content of vegetation and soil moisture were probably detected.
- To eliminate the influence of varying vegetation and soil water content on backscatter, the use of SAR data from the dry season was recommended.

8.2. Spatial analysis

The addition of GLCM derived contrast to backscatter potentially increases the accuracy of biomass prediction and mapping.

- Seven texture measures showed, in simulated images, discrimination of image texture independently of image contrast. They were: GLCM derived contrast, entropy, correlation, chi-square, SADH derived mean of sum vector, local statistics derived entropy and variogram derived range.
- These seven texture measures were calculated for real SAR images and the correlation between them and the log of biomass estimated. Only GLCM derived contrast increased the correlation between backscatter and log of biomass.
- Values of variogram derived range highlighted the diversity of vegetation/canopy structures found in the field. However, no relationship was found between range, log of biomass and dominant species (and therefore upper canopy structure). Image spatial resolution (18 m), pixel transects (as opposed to pixel matrices) used to derive the variograms and the models used to fit the data could have limited the analysis.
- GLCM and SADH derived texture measures extracted using different window sizes and quantisation levels indicated that textural information was dependent on quantisation levels. Both window sizes contained the same amount of textural information.
- The strong relationships between some texture measures, particularly the ones derived from the GLCM and log of biomass were related to the age-related roughness of the vegetation canopy.
8.3. Spectral and polarisation analysis

Multiwavelength and multipolarisation SAR data only had limited utility for the classification of a surrogate for biomass in regenerating tropical forests.

- Exploratory statistics and discriminant analysis showed that median-filtered SAR bands had increased discrimination ability of land cover classes (as compared to non-filtered SAR bands).
- Cross-polarised HV and HVF (median-filtered) bands presented increased discrimination of land cover classes as compared to the other SAR bands.
- Neural networks can be used for the classification of land cover in tropical forest.
- The reduction of speckle was essential for land cover classification using SAR data, even if the data were previously averaged by multi-look processing.
- Higher overall training and testing accuracies were achieved with SAR and TM bands in combination, as compared with SAR bands only.
- Regenerating forest stages were discriminated in SAR and TM bands when merged into young (0-5 years) and intermediate (6-18 years) regenerating forest classes.
- The use of TM bands, coupled with SAR texture band (GLCM contrast) and different SAR bands and polarisations made it possible to discriminate regenerating forest up to around 13 years old.
- The overall accuracy for classification of mature forest, pasture, young (0-5 years) and intermediate (6-18 years) regenerating forest classes was around 87%.
- Pasture and mature forest were discriminated accurately in both SAR data and combined SAR and TM data.

8.3. Summary

The main findings of this thesis are:

- The $\sigma^o$ temporal characteristics were not related to biomass accumulation. Water content of vegetation and soil were the main cause of temporal $\sigma^o$ change.
• The $\sigma^o$ spectral and polarisation characteristics had some utility for the mapping of regenerating forest stages, but require the combination with optical sensor data.
• The spatial characteristics of $\sigma^o$ have shown a strong relationship with the biomass of tropical forests. The addition of GLCM contrast information to $\sigma^o$ potentially increased the accuracy of biomass estimation from SAR data.

The temporal, spatial, spectral and polarisation characteristics of $\sigma^o$ present great potential for the study of regenerating tropical forests. However, this research is still hindered by the lack of specific knowledge about $\sigma^o$ mechanisms in tropical forests. For example, the $\sigma^o$ asymptote at biomass levels of around 90 T ha$^{-1}$ (for LHH band) is a real limitation that encourages future research into the use of other tropical forest biophysical properties as biomass surrogates when trying to estimate biomass and biomass change from SAR data.

8.4. Significance of results and future directions

The findings of this research supported the use of SAR data, particularly their spatial domain, for the study of regenerating tropical forests. However, to move further and achieve more accurate biomass estimates and mapping with SAR data, some avenues have yet to be fully explored.

Analysis of temporal backscatter would benefit from knowledge of land cover changes, rainfall intensity and biomass accumulation rates of regenerating tropical forests. A change detection approach (as used by Quegan et al. 2000) could isolate sources of backscatter variation and allow their quantification. The quantification of all sources of backscatter variation is far from complete, but in this research the importance of water content in regenerating tropical forests and soils was revealed.

A measure that best captured the spatial variability of vegetation/canopy structure was GLCM contrast calculated on a LHH band. The assessment of the use of GLCM contrast (and other texture measures) needs to be done using different SAR bands and polarisations, particularly LHV. The strong relationship between some texture measures and the log of biomass means that textural information is required if biomass is to be estimated accurately from SAR data.
Research is needed to assess the performance of neural networks and fuzzy classifiers in the classification of regenerating forest stages (as defined by the biophysical properties of vegetation). The successional paths proposed by Foody et al. (1996) and Lucas et al. (2000) could provide the land cover classes whose characteristics might be more related to backscatter than stage/age of regenerating forests.

The synergy between SAR and optical sensor data stands to enhance the discrimination of regenerating forest stages and ultimately tropical forest biomass and carbon content estimation. Further studies using combined SAR and optical sensor data for the study of regenerating tropical forests are needed.

An operational biomass mapping scheme for Amazonia would require the production of high-spatial resolution SAR image mosaics and the derivation of texture measures. To refine the Amazon basin land cover map produced by Saatchi et al. (2000) with regenerating forest stage classes, optical sensor images could be integrated with the SAR data, at least on the critical deforestation and regrowth areas defined by PRODES (Deforestation Project - INPE 2000). Monitoring and mapping of regenerating tropical forest stages using such a methodology could be operational, using for example multipolarisation L band SAR data from ALOS (Advanced Land Observing Satellite) once it has been launched.

Earth observation with SAR systems is a valuable tool for increasing our understanding of environmental processes and the management of human activities that result in environmental disturbance. This thesis has provided an insight into the possibilities offered by SAR data for helping to fill some of the gaps in specific areas of knowledge about tropical forest ecosystems and their local scale assessment.


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