ROBUST ESTIMATION OF PASTURE BIOMASS USING DUAL-POLARISATION TERRASAR-X IMAGERY

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1. INTRODUCTION

Modern dairy farming in New Zealand requires measurements of pasture growth at regular intervals in order to maintain the best efficiency of dairy operations. Monitoring of pasture growth is required at more frequent intervals in spring, when pasture growth is greatest, and less in winter. Differences between the measured and target pasture biomass may require intervention to maintain target levels, such as extended grazing to reduce an excess of pasture, while supplement feeding or decreased stocking rates may be required when the pasture biomass is below target. Accurate estimates of available pasture feed and quality can be undertaken using a variety of different techniques. On the test farm used in this study, a rising plate meter is used as part of a weekly farm walk. Although this method is reliable and well established, it requires some skill for correct operation, it is time consuming for a large farm.

The aim of this research is to determine whether TerraSAR-X dual-polarisation imagery can be used to estimate pasture biomass, without a dependence on surface environmental conditions. The research uses a temporal sequence of dual-polarisation images from TerraSAR-X for a test site near Lincoln, in Canterbury, New Zealand.

2. MOTIVATION

In an earlier paper [1], we demonstrated that there is a linear relationship between exotic pasture biomass and combinations of co- and cross-polarisation X-band imagery from TerraSAR-X. That study compared results from HH&HV and VV&VH dual-polarisation TerraSAR-X combinations, with two image dates per polarisation combination. There were several shortcomings in that earlier study. First, with only two repeated observations per polarisation combination, the study failed to provide convincing evidence of robustness with respect to surface environmental conditions. Second, the study area contains several different grass types and at least two different soil types, so the earlier study is confounded by the possible effect of these categorical variables.

This paper extends our previous work in [1] in several ways. First, a total of 18 TerraSAR-X images is analysed over a period of over a year, with nine images per dual-polarisation combination (HH&HV and VV&VH). Second, indicator variables for the grass variety and soil type are added. Third, we provide two alternate methods of statistical analysis, one from classical statistics, and a second Bayesian regression method that incorporates uncertainty in pasture biomass and the inverse-regression nature of the problem. Both regression methods suggest that the estimation of pasture biomass is invariant to surface conditions, under certain conditions.

3. METHODS

The study site is the Lincoln University Dairy Farm [2], which is a 186-ha irrigated property with 21 paddocks and, at peak, milking 670 cows. A farm walk is conducted every Tuesday morning, during which the biomass in each paddock is estimated using a rising plate meter. TerraSAR-X imagery is acquired as close as possible to the farm walk, and additional information is recorded on rainfall and irrigation preceding the imagery, and the position of irrigators and stock between farm walk and image acquisition. In practice, the time difference between the farm walk and the time of the TerraSAR-X overpass ranges from 2 to 24 hours. Other information on soil and grass types is also available, and details concerning stock movement and farm operations around the time of the TerraSAR-X image acquisition are also noted.

The polarisation combination (HH&HV or VV&VH) was randomly chosen for the first acquisition date, and the polarisation combination was alternated thereafter. The date and time of each image acquisition were chosen to be as close as possible to the date and time of the regular farm walk. For this study area and image mode, two local incident angles were possible, one at approximately 33 degrees, and a second at approximately 44 degrees; image acquisitions were chosen to give approximately the same number of each local incident angle. The image acquisition dates were not regular through the year, but instead were matched to the period of greatest farm activity — more frequent acquisitions in the spring and summer period, and fewer in autumn and winter. The experimental design was chosen to sample though the year, over both local incident angles, and both dual-polarisation combinations, with fixed effects due to soil type and pasture variety. However, the design is not strictly balanced over all controlled factors, and interactions between soil type and grass variety are fixed by the study site.

Each TerraSAR-X image acquired was converted from digital numbers to sigma-nought in units of db, using the calibration factor, noise count and incidence angle information, found in the XML metadata file associated with each TerraSAR-X image. The imagery was rectified to the New Zealand Map Grid projection and checked by overlaying farm boundary information. Statistics for each paddock from the associated farm walk were assembled, as well as image statistics, and other image acquisition, grass variety and soil type. The statistical analysis was performed in the R environment [3] as well as WinBUGS [4].

5. ANALYSIS

The backscatter from the two components of each dual-polarisation combination is strongly correlated and collinearity of this degree can cause difficulties in regression, so the components were decorrelated by using the mean and difference between the two values. Two separate methods of analysis were carried out, one using a conventional model incorporating all factors in a linear regression model, and a second Bayesian analysis that modeled the inverse-regression nature of the problem.

In the conventional analysis, models were fitted using the separate VV&VH and HH&HV dual-polarisation combinations, with the acquisition date, soil type and grass variety as factor variables. This model predicts pasture biomass using dual-polarisation sum-and-difference and the various factor variables. Interactions up to order one were permitted between the different variables. Invariance with respect to each factor variable was indicated by non-significance in the p-value associated with the factor.

In the Bayesian analysis, the model predicts dual-polarisation sum-and-difference as a function of pasture biomass and the various factor variables using WinBUGS [4]. This form of analysis reflects the underlying causal physical relationship between ground surface conditions (e.g. soil type, grass biomass) and the retrieved dual-polarisation brightness. This model is the inverse of the commonly-assumed (and strictly incorrect) classical analysis. Again, interactions of the explanatory variables up to order one were permitted. Invariance with respect to each factor variable was indicated by inspection of the posterior density of the associated variable. Additional checks were made in this case to check that the required sampling conditions in WinBUGS were correctly observed for this problem.

An additional factor included in both the conventional and Bayesian analysis is the uncertainty of the field-measured pasture biomass. This uncertainty is fixed from earlier calibration analysis of the relationship between the measured compressed grass height from the rising plate meter, and sampled dry matter pasture biomass. For the conventional analysis, the error-in-variable regression is carried out using the SIMEX algorithm [5], which is a computationally-intensive modeling method.

4. RESULTS

For the conventional analysis, it is shown that the estimation of pasture biomass using the HH&HV combination is invariant to image date, soil type and grass variety. For the VV&VH combination, the estimation of pasture biomass is invariant to soil type and grass variety, but weakly dependent on the date (in other words, some dates have a significant effect). The data for one date (1 September 2008) was anomalous, in the sense that the predictions from the regression model were consistently low (or, alternatively, the field-measured values were consistently high). The removal of data from this date had a highly-significant effect on the regression, reducing the standard error significantly.

The residual standard error of the best regression is 263 kg/ha, which represents an uncertainty with respect to the ground-measured pasture biomass in the range 7.7–17.8%. For the Bayesian analysis, the same result for significance is achieved as in the conventional analysis, for both dual-polarisation combinations. The difference between the two forms of analyses is that this inverse regression analysis gives asymmetric posterior distributions of the residual and for each factor variable, as might be expected. The effect of this difference in analysis forms is that predictions from the Bayesian analysis have a lower residual standard error for the estimated pasture biomass.

Collectively, the results of the analysis suggests that dual-polarisation X-band TerraSAR-X imagery can be used to estimate pasture biomass, independent of surface environment conditions (notably, surface moisture variations). Correct prediction of the pasture biomass requires correct calibration of the radar imagery, and the best results (lowest residual standard error) were obtained by using a Bayesian inverse model analysis.

5. REFERENCES

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