Vegetation and Surface Studies to Assess Biomass, Fire Susceptibility, and Wetlands State

PI Number 158
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Summary of originally proposed research

We initially proposed to utilize ALOS PALSAR and PRISM data as inputs to a system for wildfire danger monitoring and post-fire vegetation recovery assessment. The availability of L-band data, at dual- or quad-pol, is essential to the accurate derivation of vegetation and terrain parameters that characterize fire fuels and hence probability of fire occurrence. The vegetative fuel maps were proposed to be provided on an annual basis to help plan pre-fire projects such as controlled burns. Vegetation (fire fuel) moisture maps would be used to monitor changing conditions and to produce risk maps. In post-fire damage assessment, radar and optical data would be combined to measure burned areas and determine soil moisture conditions, followed by monitoring vegetation recovery in the months and years afterwards. This research effort has been modified to expand its scope both geographically and in terms of products. Collaborations with other PI teams have been formed for this purpose. In particular, the project was expanded to (1) generate continental-scale wetlands maps of the north-American boreal zone, and (2) develop radar scattering inversion models for identifying vegetation characteristics in forested regions that could be used to map not only fire fuel but also component biomass.

Keywords: SAR vegetation biomass mapping, quantitative inversion, wetlands mapping, radar scattering model, multilayer forest scattering.

1. RESEARCH OBJECTIVES

We have modified the research goals to expand the effort beyond the fire fuel mapping application.

In the first part of the modified effort, we will include a more comprehensive characterization of vegetation and underlying ground. Similar to the originally proposed project, the overall objective of the first part of the modified project is to use the ALOS/PALSAR dual-pol (and where available, quad-pol) and PRISM data to generate vegetation and soil moisture content, vegetation height, and vegetation component density. From these fundamental scene parameters, compound quantities such as component biomass can be synthesized. As a subset of this work, fire fuel map can also be generated for areas prone to fire. Major arts of this work will be carried out in collaboration with Dr. Richard Lucas, University of Wales, Aberystwyth.

The overall objective of the second part of the modified effort is the generation of higher order products such as maps of wetlands. These maps are being produced as part of two major wetlands mapping activities funded by NASA: one with Dr. Kyle McDonald as PI for mapping global wetlands, and the other with Moghaddam as PI for focused time-series wetlands mapping in boreal north America. The latter project also involves the analysis of PALSAR data to produce soil wetness maps, as a new metric for the dynamic moisture regime of wetlands.

For both of the new components, algorithms are being developed based on electromagnetic scattering models, statistical classification techniques, and nonlinear inverse scattering models.

Specific accompishments for the first part (vegetation component biomass mapping) were:

1. assembly of ground truth data
2. theoretical development of radar scattering models in particular for complex multilayered vegetation
3. initial implementation of inversion algorithms for vegetation and soil
4. detailed assessment of ALOS image data for use with algorithms

Specific accomplishments of the second part (wetlands mapping) were:

5. development of wetlands mapping algorithm large areas representative of regional and continental scales
6. assembling time-series datasets of PALSAR data over a small set of high-priority study areas for studies related to soil wetness, vegetation dynamics, and preliminary assessments about permafrost depth.

2. RESEARCH PLAN

The original research plan called for mapping fire fuels, i.e., vegetation biomass and its distribution horizontally and vertically, in the western US. The plan was modified and expanded for the following reasons:

1. During the past 8 years, the PI has formed substantial collaborations with Dr. Lucas on mapping vegetation component biomass. Due to the common goals of the two investigators related to this topic, recognizing the complementary expertise, and the availability of an extensive ground truth data set in Australian woodlands by Dr. Lucas, we decided to take advantage of the opportunity and expand the biomass mapping effort to the new site. This also coincided with the PIs' move from California (JPL) to Michigan, USA, and therefore losing the more immediate access for generating field data for validation of products in the western US sites. Two graduate students, one supervised by each of Moghaddam and Lucas, have focused major parts of their dissertations on the development of forward and inverse scattering methodologies to accomplish the goals of this part of the project.
2. In the same time period, a collaboration was formed with Dr. McDonald for generating large-scale wetlands maps for the north American boreal zone. We started the joint work using JERS-1 data. Once again, recognizing the synergy of our methods and expertise, we decided to join forces and apply some of the same algorithms that were to be developed under the original project to new and more advanced wetlands mapping efforts. We have generated the first state-wide wetlands map of Alaska, and are currently generating a similar map for Canada. In Alaska, the PIs group is also studying time-series imagery from 2-3 selected sites to investigate the feasibility of generating soil wetness indices. As a higher-level product, we are also considering whether the temporal dynamics manifested in PALSAR time series imagery are indicative of permafrost dynamics.

For both of the new/modified components of the project, the overarching goals have been met and several key products have been generated. These will be explained in the next section.

3. RESEARCH IMPLEMENTATION

The status and progress in each of the two research components will be discussed here.

Radar Forward and Inverse Scattering Models for Mapping component biomass

A generalized radar scattering model based on wave theory was developed in support of first element of this project. The model predicts polarimetric radar backscattering coefficients for structurally complex vegetation comprised of multiple species and layers (Figure 1). Compared to conventional two-layer crown-trunk models, modeling of actual forests has been improved substantially, allowing better understanding of microwave interaction with vegetation.

The model generalizes an existing single-species discrete-scatterer model and, by including scattering and propagation effects through judiciously defined vegetation layers, enables its application to an arbitrary number of species types. The scatterers within each layer are modeled as finite cylinders or disks having arbitrary size, density, and orientation, as in the predecessor model. The distorted Born approximation is used to represent the propagation through each layer, while scattering from each is modeled as a linear superposition of scattering from its respective random collection of scatterers. Interactions of waves within and between each layer and direct scattering from the ground are accounted for. The model was validated using extensive ground samples in 23 wooded savanna sites located in Queensland, Australia, and comparison with ALOS PALSAR and NASA JPL AIRSAR data. Results indicate good agreement between simulated and actual backscattering coefficients, particularly at HH and VV polarizations. More discrepancies are found at HV polarizations and can be explained by uncertainties in the knowledge of input parameters, such as inaccuracies in the surface model, surface roughness parameterization, and soil moisture. Validation of the model focused specifically on two wooded savanna sites occurring within the Brigalow Belt Bioregion (BBB) in central southeast Queensland, Australia. In the Tara Downs subregion, the considered structural formations were mature and older regrowth forests of mixed species composition dominated by Brigalow (*Acacia harpophylla*). In the Injune Collaborative Landscape Project (ICLP) area, more complex forests of mixed species composition were considered. In both cases, field data were available to support parameterization of the model, and ALOS/PALSAR and NASA Jet Propulsion Laboratory (JPL) AIRSAR were available for validating simulations of the backscattering coefficient, with these acquired during periods of field data acquisition. The results have been reported in conference presentations and a journal paper currently undergoing peer review. Figure 1 shows an example of the comparisons of the theoretical predictions and radar data measured by PALSAR.

Discrepancies between model and data can be attributed to inaccuracies in the surface model and the parameterization related to surface roughness and knowledge of soil moisture, the difficulty in extracting actual SAR data from the forest stand used to parameterize the model, calibration errors in SAR data, and misregistration of the SAR data themselves. In the next generation of the multispecies multilayer model, the rough ground surface will be replaced with a more realistic and accurate framework that includes the HV contribution from the surface, as well as allowing larger roughnesses. The specific choice of the model is currently under evaluation. Its next-generation will also address topographic variations, which will allow a more general applicability to any landscape type. Future plans also include assessment of interspecies interaction, as well as higher-order scattering mechanisms, for example ground-crown-ground, ground-trunk-ground.

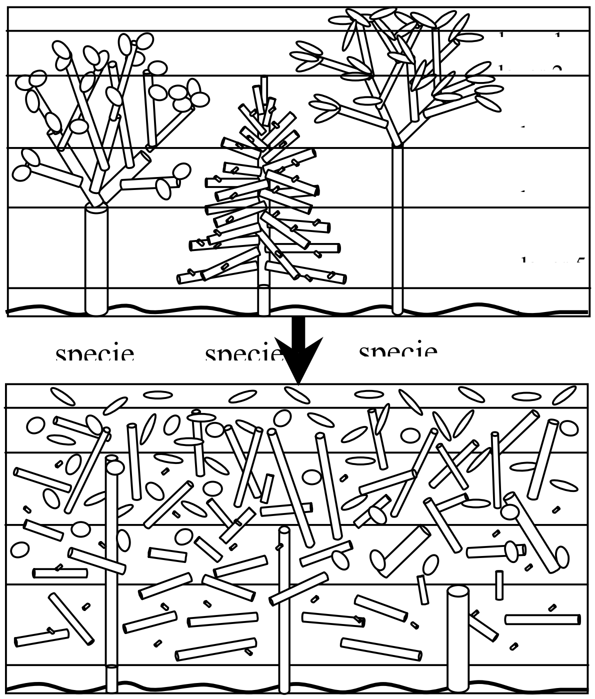

Figure 1. Realistic geometry of forest with three species $N_S = 3$ (on top) and actual realization in model (on bottom). Arbitrary number of layers can be accommodated similarly.

The inversion of the SAR backscatter model takes place in the context of finding the optimum set of vegetation parameters that minimizes the L2 norm of the difference between the measured SAR data and the ones predicted by the closed-form model. In other words, estimates of the unknown parameters are obtained through an algorithm that produces the optimal variable resulting in the best match between SAR measurements and the closed form model. It is often necessary to use more than one SAR frequency band in this analysis. In particular, C-band data may be used to estimate crown layer characteristics (e.g., branch densities and moisture contents). These estimates are then used to simulate their contribution at L-band, thereby allowing the backscatter to be adjusted such that only stem and ground effects remained. The L-band data are then used to estimate stem and ground variables (e.g., stem moisture content and soil moisture).

This framework for modeling and inversion was developed by the PI several years ago, and tested to a limited extent for some test sites (independent of the Australian study site). The algorithms are currently being adapted for the Australian site. A student jointly mentored by Drs. Lucas and Moghaddam is currently working on the implementation and validation. This algorithm will be the basis of generating component biomass values (through the information derived for crown and stem characteristics) in the Australian site, and can be generalized and extended to other sites including California site (the latter assuming that ground truth can be obtained). Publications are expected from this work once the results have been thoroughly validated.

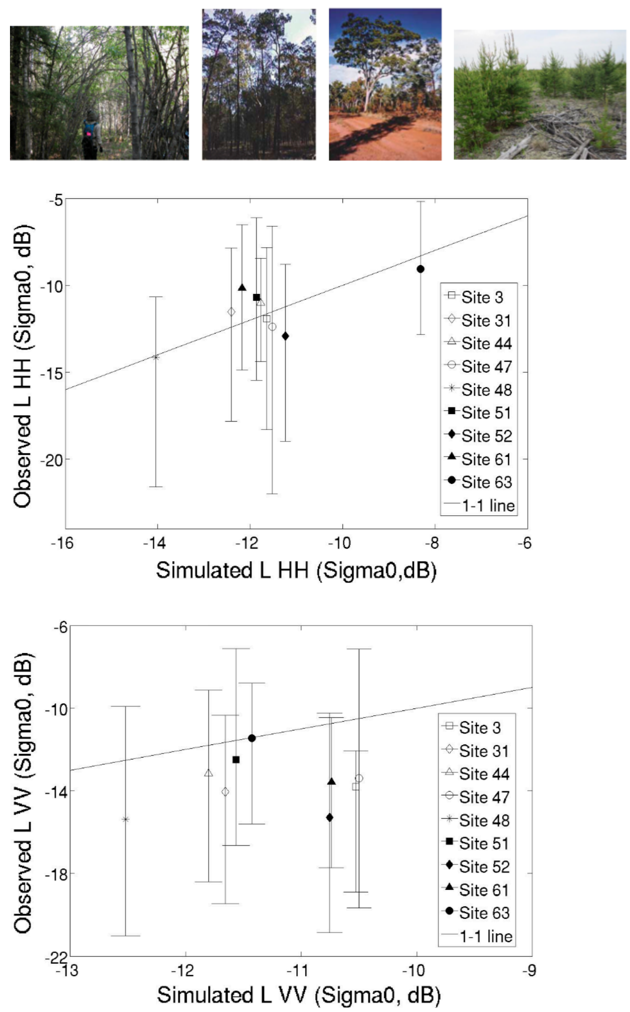

Figure 2. Top: Examples of woody vegetation species for which field data and SAR data were available. Middle and bottom: results of discrete scatterer model (Burgin et al. 2011) simulated and validated with ALOS/PALSAR data for a subset of the plots. HH and VV polarizations are shown.

Wetlands Mapping

Led by the PI and in collaboration with Dr. McDonald, we have developed an algorithm for large-scale mapping of wetlands in the boreal regions. Boreal wetlands present a unique challenge in mapping from space, in that they are highly dynamic systems and can vary rapidly over a short period of time. We initially applied the algorithm to JERS-1 data [5], and are currently applying it to PALSAR data [6]. For JERS-1, we used two seasons of SAR imagery to produce a thematic map of wetlands throughout Alaska, which is the first of its kind.

Our classification utilizes a number of supporting data sources in addition to the summer and winter JERS image mosaics just described:

a) Summer and winter JERS image texture

This is derived from the full resolution (12.5m) SAR imagery as the normalized square of the ratio of the standard deviation and the mean of the pixel intensities.

b) Summer and winter image collection date layers

In these layers, each date is implemented as a four-character code indicating the year and day of year of SAR data acquisition. They provide a time tag for the within-mosaic temporal variations, which are quite pronounced in many locations. This allows the algorithm to group radar imagery from the same or adjacent dates to come up with a decision rule for correcting for time-varying backscatter.

c) Digital elevation model (DEM)

This was obtained from the USGS, and has been tie-point warped to align it with the JERS imagery. As the JERS imagery were not georectified during mosaic assembly, this alignment reduces geometric errors due to image misalignment and topographic variability. The DEM was used to calculate the slope image and also serves as an input data layer to Random Forests.

d) Land surface slope

This was calculated from the tie-point aligned DEM using a slope computation algorithm available within the PCI image processing software package. It was used to mask out all areas with slopes exceeding 3°. This was done based on the assumption that terrain with higher slopes than this would be unable to retain enough water to act as wetlands. It also reduces the impact of geometric errors resulting from the lack of orthorectification.

e) Open water mask

This was generated from the JERS backscatter using a supervised Maximum Likelihood Estimator (MLE) classification approach. The DEM and derived slope were incorporated to correct for misclassifications in areas of steep topography where layover and shadowing were prevalent.

f) Proximity-to-water image

This was calculated in PCI from the open water mask, with distance to the nearest water calculated as a simple count of pixel widths.

g) Latitude data layer

This was calculated by translating the ACEA coordinates of each pixel into latitude and longitude.

2) Ground Reference Data

The ground reference data used for training and validation are a combination of data collected from the National Wetlands Inventory and the Alaska Geospatial Data Center.

Following the wetlands classification system adopted by NWI, we use the NWI reference data set to categorize wetlands as belonging to one of nine wetlands classes. Classes are identified as a combination of geomorphology (i.e., estuarine, lacustrine, palustrine, and riverine) and vegetation structure (i.e., emergent, scrub/shrub, forested). Additionally, each such class is subcategorized into a number of flooding regimes that indicate shorter-term hydrologic changes. Since the JERS imagery offers insufficient time resolution to characterize the dynamic nature of these flooding regimes, they have been aggregated in our final classification.

Our classification algorithm has been based on a novel classification technique known as Random Forests. We also developed a suite of software in PCI Geomatica EASI for data ingestion, processing, and interfacing with the core Random Forests algorithm. Our data processing methodology is shown in Figure 3.

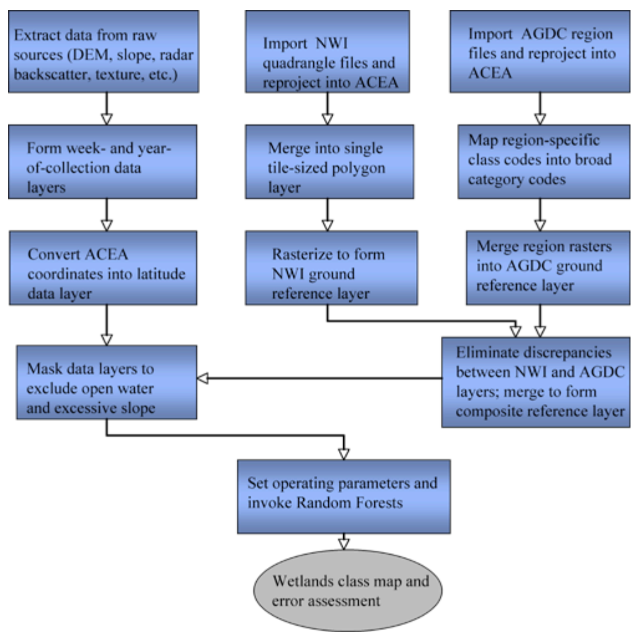

Figure 3. The function suite recently developed for data ingestion and processing leading to the wetlands map of Alaska from JERS-1 data. Same methodology is applied for PALSAR.

The classified wetlands map of Alaska is shown in Figure 4. It has a resolution of 100m. A preliminary visual inspection of the results suggests that the classified results are in good agreement with the reference data in areas for which reference data are available. Our more rigorous error computations show an unaggregated error rate of 25.5% calculated based on the average of all tiles before aggregating classes. Per-tile aggregated accuracies range from 80% to 97%, and an overall aggregated accuracy rate of approximately 89.5% based on all correctly classified pixels.

Random Forests operates by first generating a large number of decision trees, or a "forest" of decision trees, based on the input data layers and with reference to training pixels from within the training regions (regions that have assigned class codes in the ground reference data layer). It then classifies each image pixel by implementing all decision trees in the "forest" and setting the class code of the pixel equal to the class selected by a plurality of the decision trees.

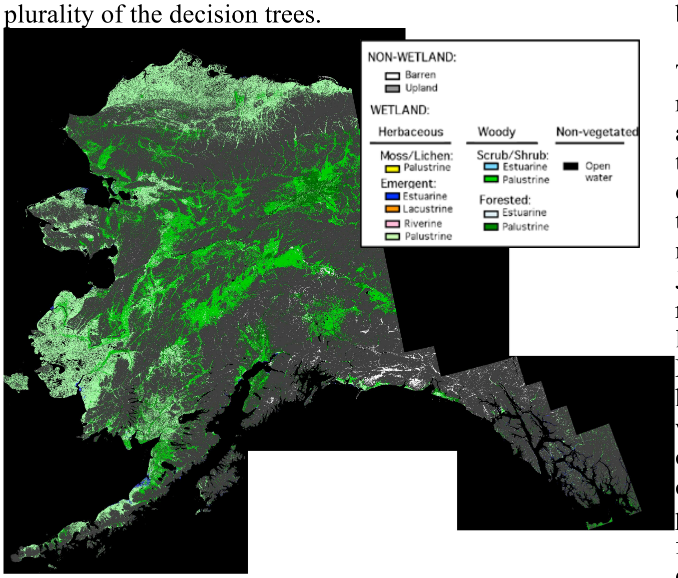

Figure 4. The wetlands map of Alaska from JERS radar Imagery [5].

Our accuracy assessment has been based on the contents of confusion matrices that are generated by Random Forests during each classification procedure. The error statistics reflect the classification performance achieved for training pixels that are left unused during the formation of each decision tree. A typical confusion matrix from Random Forests is shown in Table II. In it, the wetlands are coded as follows: ES=estuarine, P=palustrine, EM=emergent, SS=scrub/shrub, BAR=barren. Repeated class codes correspond to different flooding regimes.

TABLE I. SAMPLE CONFUSION MATRIX

Wetlands Code:	E2EM	E2EM	E2SS	PEM	PEM	PEM	PEM	PSS	PSS	PSS	BAR
Class Number:	1	2	3	4	5	6	7	8	9	10	11
1	1717	259	0	12	51	0	1	0	0	0	63
2	565	12567	121	11	1403	0	420	0	99	0	204
3	0	14	93	0	20	0	0	0	0	0	0
4	70	193	0	29584	6117	0	2683	8	8	0	208
5	703	4742	339	17775	180762	6	42193	364	5344	38	1716
6	0	0	0	1	0	15	0	0	0	0	[illegible]
7	147	1806	7	48704	137116	187	769268	1274	3969	659	2952
8	0	0	0	3	4	0	35	90	0	0	0
9	0	60	0	19	232	0	93	0	1458	0	2
10	0	0	0	18	6	0	20	0	2	208	0
11	4	0	0	5	18	0	6	0	0	0	162

Currently the PALSAR data area being used to complete the same map for Alaska for the 2007 time period. Bothe JERS and PALSAR data are being used to generate the wetlands maps of Canada as well. Figure 5 shows the current state of processing for Canada.

Alaska Decadal Change

We have previously developed a baseline wetlands map of Alaska using JERS imagery from 1997-1998. PALSAR imagery are now being used to produce the 2007-era Alaskan wetlands, and hence to produce a thematic map of change in the intervening decade. The classification algorithm applied to each set of imagery is based upon the Random Forests technique, by using a multitude of decision trees. Processed PALSAR data are being delivered to UM from JPL.

To ensure that a sufficiently wide spectrum of ground reference points are included in each map segment to be able to develop a representative set of decision trees, we typically classify over large geographic regions. Since our PALSAR imagery is provided at resolutions 3-8 times that of our JERS imagery, classifying it requires much more computer memory than does classifying JERS for the same size region. We have investigated resampling strategies to address computational limitations, and have found it necessary to average the PALSAR imagery to the same resolution as JERS. We have also investigated 1) adding the ability to apply weights to the different data layers used in each classification, and 2) adding the ability to base classification runs on a combination of ground reference pixels available locally and a saved decision tree forest from a more remote location. The latter feature would be of value for locations where local ground reference data is sparse but not entirely absent. We are also exploring options for segmenting the data prior to classification. The accuracy of the resulting thematic change map is verified using ground reference data. For the areas classified so far, the classification accuracy is quite high, 88.4% on the average.

Comparing the wetlands type and extent between 1997-era and 2007-era, it appears that the majority of the area investigated so far is unchanged, but there are substantial areas for which wetlands with emergent vegetation have become scrub/shrub wetlands. See Figure 6 (last page). This may indicate that a possible warming trend has resulted in woody vegetation moving north-ward. These results are quite preliminary and need further investigation. Once completed, these results could present important conclusions about the role of climate change in altering the state of the northern wetlands.

4. DEVIATIONS FROM ORIGINAL RESEARCH IMPLEMENTATION

The primary deviation of the research accomplished under the PI agreement was that the techniques we developed could not be tested for the initially proposed site in California because of lack of access to ground truth. This of course did not prevent us from fully carrying on the principal research on algorithm and product development, and in fact we expanded the research objectives and products well beyond what was initially envisioned. In particular, we developed the first thematic 100 m resolution wetlands map of Alaska and large portions of Canada (with rest of Canada currently under processing), and we developed a comprehensive radar scattering model for multilayer forests that together with the inversion algorithms that we have also developed can be used for mapping biomass, fire fuel, etc.

The wetlands mapping effort is continuing with funding from NASA and is also a major component of the ALOS K&C initiative (McDonald lead).

5. PROSPECTS

A substantial body of work has been produced under this project, and made possible by generous provision of radar data from ALOS/PALSAR. The prospect of having access to the next generation of radar data, to be provided by the PALSAR follow-on mission, leads us to continue our activities in the following areas and to generated many exciting products:

- Continue the implementation of inversion algorithm for component biomass for Australian woodlands and other areas for which ground truth may be available, and validate inversion algorithm for a representative set of stands using PALSAR data
- Complete the mapping of wetlands of Canada with PALSAR, and for both Alaska and Canada, assess the decadal change in wetlands extent and type by comparing JERS and PALSAR results. This decadal change product could potentially shed light on important climate change questions in the northern latitudes.
- Continue analysis of time-series data over selected regions of Alaska, and develop correlations between information retrieved from PALSAR and temporal dynamics of permafrost.
- The PI is also the PI for the NASA Earth-Ventures-1 AirMOSS mission, which is an airborne P-band mission for retrieval of root zone soil moisture to inform investigations of net ecosystem exchange in north America in support of carbon and water cycle studies. The AirMOSS mission will continue through 2015, and therefore opportunities will be sought to investigate joint retrievals of forest canopy parameters using P-band and L-band SAR data once the next generation PALSAR is launched. AirMOSS plans to carry out detailed ground truth data collection over 9 biomes in north America, providing a benchmark data set that could strongly benefit the joint studies mentioned above.

Publications resulting from this project:

Burgin, M., D. Clewley, R. Lucas, and M. Moghaddam," A generalized radar backscattering model based on wave theory for multilayer multispecies vegetation," *in revision*.

Burgin, M., and M. Moghaddam, "Investigating spatial aggregation techniques using a heterogeneous radar landscape simulator for reducing uncertainties of soil moisture retrieval from SMAP," IGARSS'11, Vancouver, Canada, July 2011, 4 pages.

Clewley, D., R. Lucas, M. Moghaddam, P. Bunting, J. Dwyer, J. Carreiras, "Forest parameter retrieval from SAR data using an estimation algorithms applied to regrowing forest stands in Queensland," IEEE-IGARSS10, July 2010, 4 pages

Tabatabaeenejad, A., M. Burgin, and M. Moghaddam, "Potential of L-band radar for retrieval of canopy and subcanopy parameters of boreal forests," *in revision*.

Whitcomb, J., M. Moghaddam, K. McDonald, E. Podest, and J. Kellndorfer, "Mapping vegetated wetlands of Alaska using L-band radar satellite imagery," C. J. Remote Sensing, vol. 35, no. 1, pp. 54-72, February 2009. **Winner of the "best paper of the year" award from CJRS.**

Whitcomb, J., M. Moghaddam, K. McDonald, and E. Podest, "Mapping Canadian wetlands using L-band radar satellite imagery," Proc. IGARSS'09, July 2009, 4 pages.

Whitcomb, J., M. Moghaddam, E. Podest, K. McDonald, and B. Chapman, "Decadal change in northern wetlands based on differential analysis of JERS and PALSAR data," proc. IGARSS'09, July 2009, 4 pages.

Whitcomb, J., M. Moghaddam, K. McDonald, E. Podest, "Mapping the Great Lakes wetlands based on L-band radar satellite imagery," SWS Annual Meeting, June 2009, Madison, WI.

Whitcomb, J., M. Moghaddam, E. Podest, K. McDonald, and B. Chapman, "Progress on decadal change characterization in northern wetlands based on analysis of L-band satellite imagery," presented at AGU, December 2009.

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Whitcomb, J., M. Moghaddam, K. McDonald, and E. Podest, "Mapping Canadian wetlands using L-band radar satellite imagery," Proc. IEEE-IGARSS09, July 2009, 4 pages.

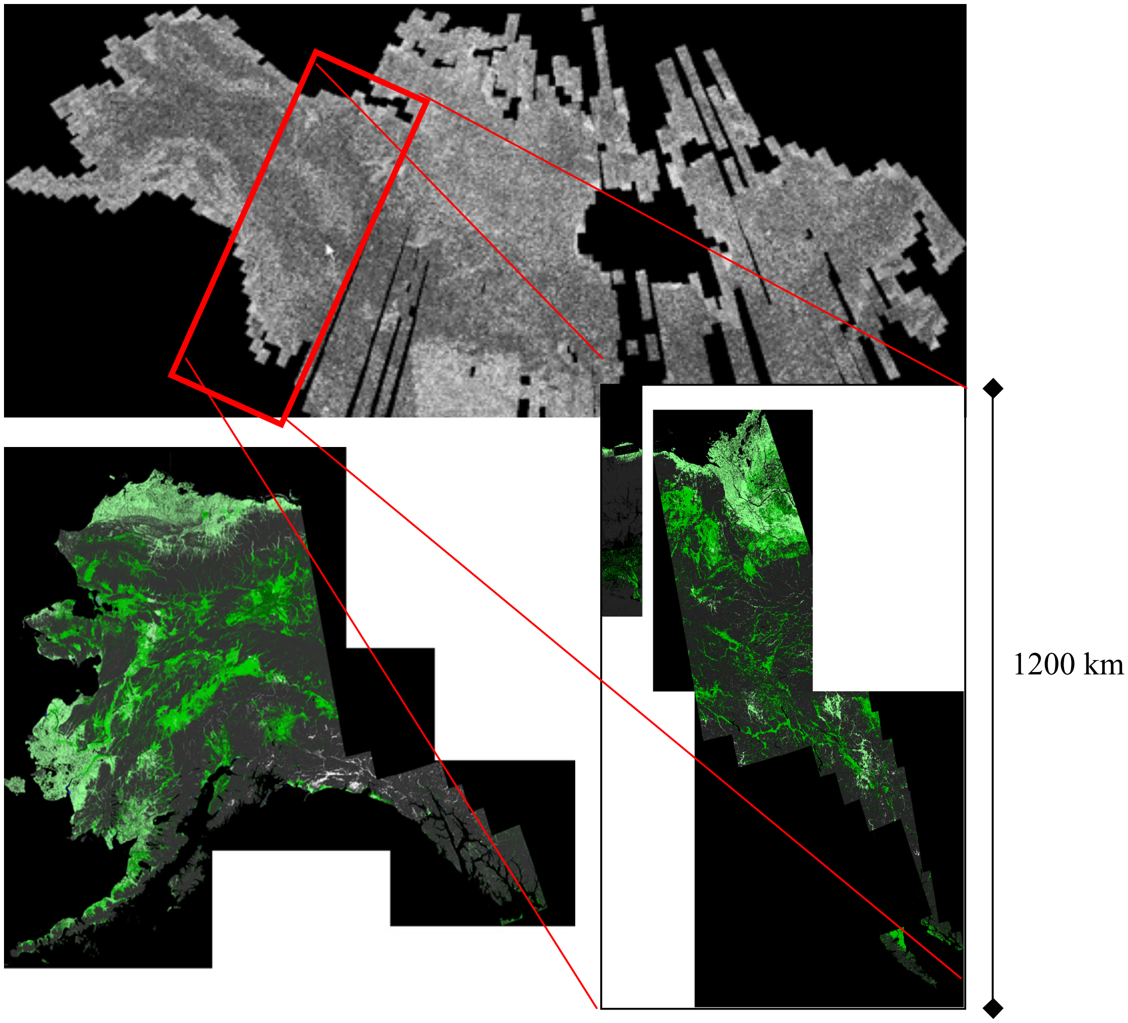

Figure 5. JERS image mosaic (top), and Western Canada wetlands map (Lower right). Alaska wetlands map is shown on bottom left for reference.

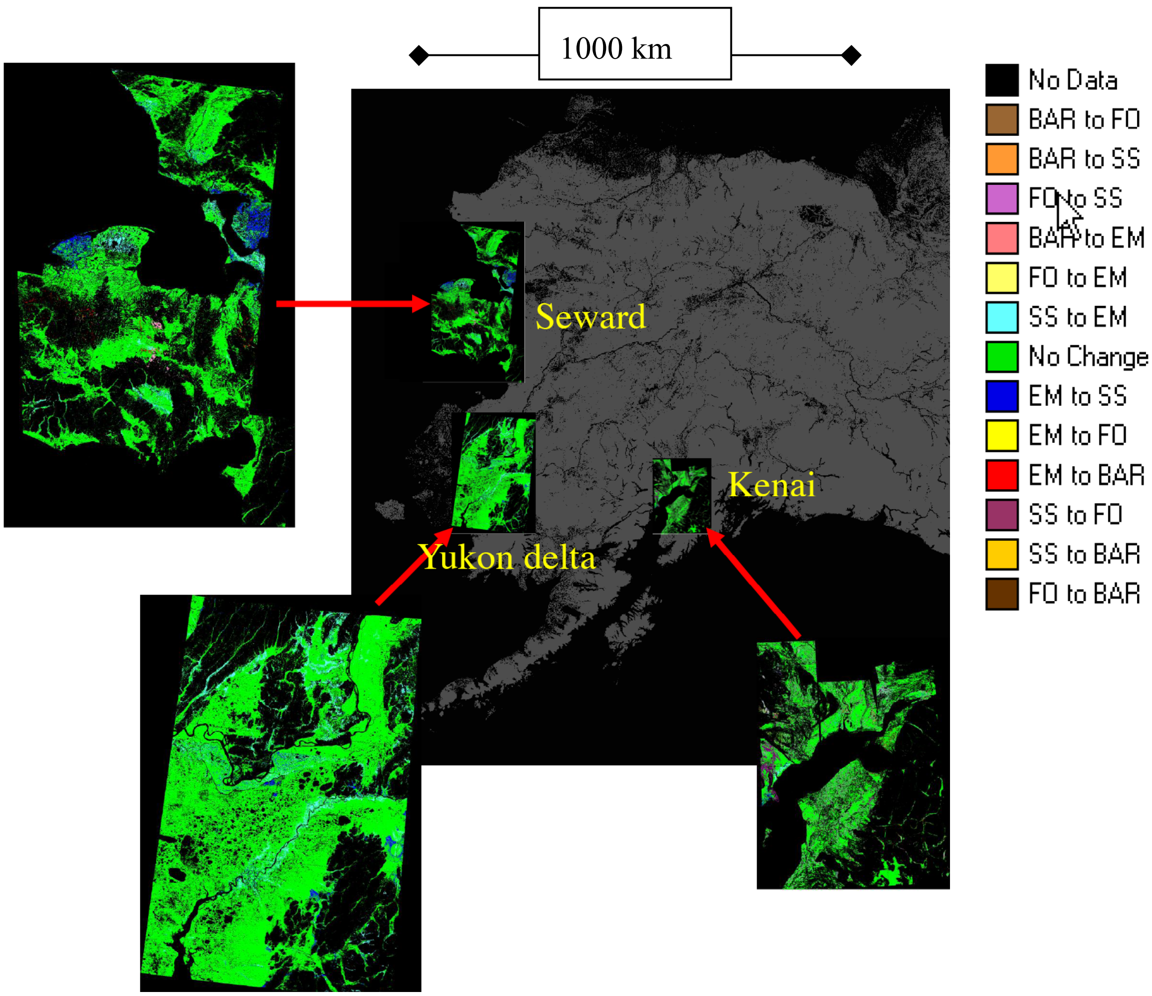

Figure 6. Decadal change in vegetated wetlands in several regions in western Alaska. BAR=barren, FO=forested, SS=scrub/shrub, EM=emergent. These regions appear to be mostly unchanged but with prominent changes from emergent wetlands to scrub/shrub wetlands, possibly suggesting that woody vegetation is encroaching north-ward.