Mapping Wetlands of the North American Boreal Zone from Satellite Radar Imagery

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Abstract – **The accurate assessment of spatial and temporal distributions of wetlands can have a large impact in improving the estimates of the global net carbon exchange. This paper presents the methodology and sample results for the first large-scale wetlands map of the north American boreal zone, derived from JERS-1 and ERS-2 SAR imagery. The finished product will be a consistent baseline map, which can be subsequently used for time-series analyses when continuous satellite radar observations become available. The wetlands class maps are generated using a combination of optimization-based class rule definitions and a supervised classification algorithm. The wetlands class types are those defined by the Canadian Wetlands Classification System. Results are validated at a number of study sites and compared to existing local-scale wetlands maps.**

I. INTRODUCTION

Boreal wetlands have a critical role in processing methane, carbon dioxide, nitrogen, and sulfur, as well as in sequestering carbon. The type and extent of high latitude wetlands are important indicators of methane source areas, while upland forests in the taiga are important methane-consuming sinks. The accurate assessment of spatial and temporal distributions of wetlands can have a large impact in improving the estimates of the global net carbon exchange. Roughly 15% of the north American boreal region is occupied by wetlands, including up to 40% of the area of some Canadian provinces such as Manitoba. It is difficult to identify wetlands on a global scale using widely available optical remote sensing data and techniques, which are not able to detect standing water conditions under most vegetation. Synthetic Aperture Radar (SAR) signals of multiple frequencies and polarizations, on the other hand, are well suited to locating wetlands because of their ability to detect various combinations of standing water and vegetation structure and moisture conditions. SARs also penetrate cloud cover and do not require solar illumination, allowing the collection of frequent seasonal data. However, no large-scale wetlands mapping efforts have been carried out thus far due to unavailability of SAR data sets with sufficient frequency and polarization diversity. With the recent availability of the JERS-1 north American boreal mosaic augmented by the partial ERS-2 overlapping data, it is now possible to generate the first large-scale maps of wetland extent, and set the stage for performing time-series analysis with future planned SAR satellite systems.

We use JERS-1 (L-band HH polarization) and, where available, coregistered ERS-2 (C-band VV polarization) SAR mosaics to produce the first large-scale wetlands class map of the north American boreal zone. The main challenge here is defining a uniform set of classes that would be applicable throughout the region. The validation task is especially complicated, since ground observations and previous small-scale studies have each defined their own specific classes which vary from site to site. We adopt the definition set forth in the "Canadian Wetlands Classification System," which identifies five major wetland classes of fens, bogs, swamps, marshes, and open water. These classes are defined based on distinctive abiotic parameters such as hydrology, water chemistry, or mineral material. A supervised classification approach is used where class rule definitions are derived using an optimization algorithm from training sites in focused study areas. A regularization procedure de-emphasizes the training sites which are known not to be conclusive in deriving class rule definitions. Our wetlands products are compared to existing local-scale maps for validation, taking care to correctly consolidate each site's class definitions with the five standard wetlands classes above. More extensive validations are planned in cooperation with various wetlands research groups.

II. WETLANDS CLASS DEFINITIONS

The five types of wetlands used in our classification maps are as follows:

1. **Bogs**: Dominated by sphagnum moss with tree or shrub cover, their surface is raised or level with surrounding terrain, with water at or near surface.
2. **Fens**: Their surface is level with water table, water flows at or under surface with fluctuating level, and l are dominated by graminoids and shrubs.
3. **Swamps**: Forested wetland with Water table at or below the surface, they have tall shrubs and deciduous or coniferous trees.
4. **Marshes**: Have shallow, fluctuating surface water,

and may contain emergent aquatic vegetation (reeds, grasses, sedges, floating macrophytes).

5. **Shallow Water**: They are transitional between seasonally wet wetlands (bogs, fens, marshes, swamps) and permanent deeper waters (lakes). Examples are ponds, pools, shallow lakes, sloughs, reaches, and channels.

III. APPROACH

There are several considerations in developing and validating the large-scale wetlands class map of the north American boreal zone. Wetlands extents are dynamic, while existing satellite SAR data will produce a snap-shot (spanning several months) which may not exactly coincide with the wetlands states in the validation data sets. Additionally, validation sites have used different class definitions, such that existing smaller scale wetlands maps each contain a different set of classes which have to be deciphered in terms of the above proposed unified definitions. Furthermore, in many cases the difference between wetlands classes are not easily discernible from remote sensing data. For instance, fens may be difficult to distinguish from bogs due to their similar radar scattering behavior. Also, some uplands cannot be easily distinguished from wetlands with remote sensing data without using topographic information.

Ultimately, a combination of several remote sensing data types, topography, in-situ data, and empirical relationships may be needed for the most accurate wetlands dynamics mapping. However, the existing JERS-1 and ERS-2 data sets are also sufficient to generate a significantly better (more accurate, more spatially comprehensive, and higher resolution) wetlands map than what is otherwise available.

Our approach for producing the wetlands map containing the above five classes is based on a supervised classification algorithm for each local study area:

1. Select training sites and assign each to one of the 5 wetlands classes. The training sites are known from either ground observations at validation sites or other already-validated local wetlands maps.
2. Include one or more non-wetlands class as appropriate, such as various upland forested areas.
3. In some cases, training sites are relevant in only a subset of images. Specifically, open water training classes cannot be assigned to ERS images because of their highly dynamic backscatter at C-band. See Figure 1.
4. Derive class rule definitions based on an optimization algorithm such as maximum likelihood or minimum distance. Apply a regularization procedure which allows the exclusion of those training sites from images to which they don't apply. The purpose of regularization is to de-emphasize the training sites which are known to be inconclusive and result in reduced classification accuracy
5. Apply class rules to the image set based on user-defined and acceptable probability thresholds, resulting in the wetlands classification map.

For a baseline wetlands map, it is best to use the same-year summer/winter pair of images from each satellite. For changes in wetlands extent, time-series satellite data are needed.

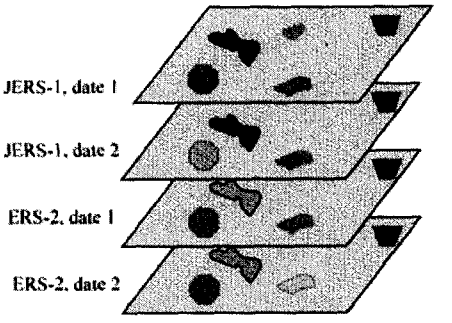

Figure 1. Classification is supervised using an optimization approach to derive class rules. Polygons of different colors represent training sites for each class type. Not all classes may be relevant in all images and may be excluded, as depicted by shaded regions, in a subset of images.

This approach is a more elegant equivalent of a decision-tree algorithm. It derives the class rules in a systematic and automated fashion after the training sites are defined, while allowing for fine-tuning and "manual" adjustments by incorporating a regularization procedure.

Classification of the large-scale area from the JERS-1 mosaic and ERS-2 partial mosaic needs to be carried out in a consistent fashion once the local-scale maps and rules are developed and validated. The rules derived for one site do not necessarily apply to other sites, since the same wetlands classes may have slightly different characteristics in different ecoregions, and hence have distinctly different radar backscattering behavior. A unified set of rules hence needs to be developed that takes into account the variabilities of each wetlands class type across the north American boreal region. The large-scale coregistration of JERS-1 and ERS-2 imagery also needs to be verified and a consistent geographical projection applied.

The principal classification approach currently being considered depends on having one or more validation sites in each ecoregion (boreal shield, Atlantic maritime, taiga shield, taiga cordillera, etc.). After verifying the classification rules at each site and if there is more than one site available for a given ecoregion, a new set of rules are developed for that ecoregion by combining the individual rule sets via a second optimization procedure. The new set of rules will then be applied to that ecoregion, and the classification accuracy validated again at the same study sites. A second approach that will also be evaluated is to derive the classification rules in one step using all the validation sites at once in one large optimization problem. Although the results of this method are not expected to be as accurate as the first approach, it is more straightforward to apply and may be more useful for other large-scale applications where a limited number of validation sites are available.

IV. RESULTS

The north American boreal mosaic of JERS-1 imagery (Figure 2) has been completely assembled for two seasons and is being

used for developing the wetlands products discussed here. The mosaic is available at a 100 m resolution scale, with individual scenes also available at the original 12.5 m resolution. The ERS-2 data are also available at similar resolutions for the area covered by the Alaska SAR facility mask as well as several other locations. The wetlands map will be provided at both the 1 Km and 100 m resolution scales. At specific sites of interest, higher-resolution products will also be made available.

Figure 2. JERS-1 summer mosaic of the north American boreal zone.

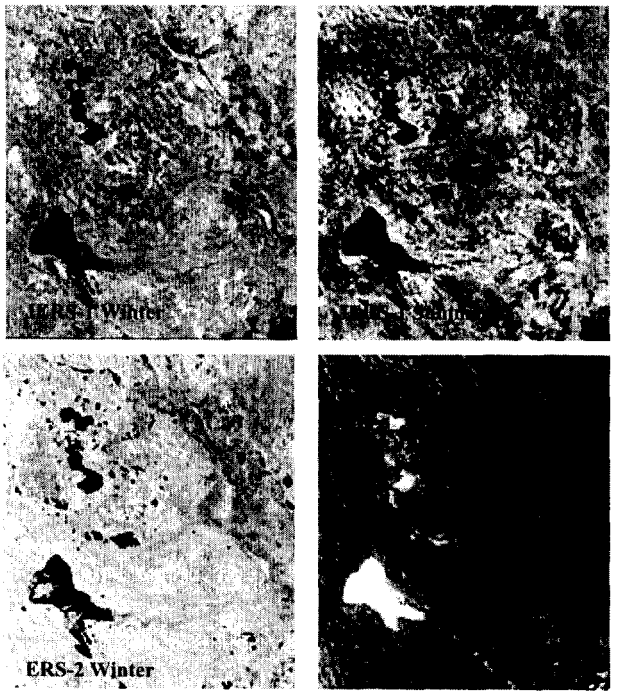

Figure 3. JERS-1 and ERS-2 seasonal images over BOREAS SSA.

Figure 3 shows sample images from JERS-1 and ERS-2 for a study site in central Saskatchewan, which was part of the BOREAS southern study area (SSA). A land-cover classification map generated by the BOREAS science team [1] using ground observations and Landsat TM data was used to derive the wetlands class rules. A significant portion of this area is composed of nonwetlands, which was taken into account. Figure 4 shows the wetlands class map of this region based on our class definitions and validated against the BOREAS land-cover map.

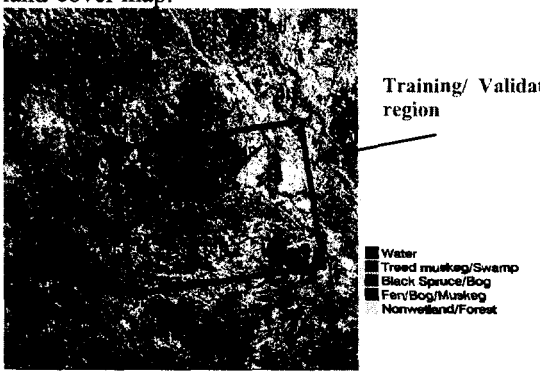

Figure 4. Wetlands map of the BOREAS SSA.

Another example is shown in Figure 5 from Tanana Flats, Alaska, where a wetlands map generated by Balser at University of Alaska, Fairbanks was used to both generate the class rules and to validate the JERS-1 based results [2]. Several more examples will be shown at the presentation, as well as a preliminary wetlands map of the entire mosaic area.

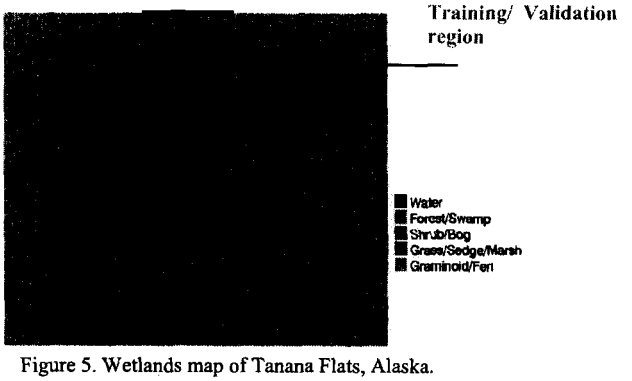

Figure 5. Wetlands map of Tanana Flats, Alaska.

V. SUMMARY

The assembled mosaic of the JERS-1 SAR and partial mosaic of the ERS-2 SAR over the north American boreal zone are used to generate a large-scale wetlands map of the region at 1 Km resolution. An optimization-based supervised classification algorithm is applied. Numerous sites are used to validate the results, and to derive a large-scale class rule set applicable to the entire region.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] BOREAS Information System, ORNL DAAC.

[2] Balser, A., Combining Landsat TM and Multitemporal ERS-1 Imagery to Improve Classification Accuracy and Detail in the Tanana Flats Wetlands Complex, Interior Alaska. M.S. Thesis, University of Alaska, Fairbanks, 1996.