K&C Science Report – Phase 2: Mapping Boreal Wetlands and Open Water for Supporting Assessment of Land-Atmosphere Carbon Exchange

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Abstract- We utilize L-band Synthetic Aperture Radar (SAR) datasets from ALOS PALSAR to map and monitor open water and wetlands in boreal North America and Boreal Eurasia. ALOS PALSAR data include data supplied by the K&C datasets and the AUIG. We utilize multi-temporal SAR data to map variability on open water. We apply a statistically-based decision tree classification approach to the PALSAR data to derived maps of wetlands vegetation for regions within Alaska and Northern Eurasia. We compare these maps to a synoptic wetlands map encompassing all of Alaska that was derived from summertime and wintertime JERS-1 SAR mosaics as part of our Phase I K&C effort. We show associated wetlands change maps for these regions. We apply data from SeaWinds-on-QuikSCAT and AMSE-E to derive global maps if fractional inundation land at a 25km posting. We compare PALSAR-based products with these coarse-resolution products to examine sensitivity of the course resolution data sets to open water and inundated vegetation. This work has formed the basis for assembly of extensive global-scale Earth system data record (ESDR) to include ALOS PALSAR mappings of critical wetlands regions with both fine beam and ScanSAR data sets.

Index Terms—ALOS PALSAR, JERS-1 SAR, K&C Initiative, Wetlands, Inundation

I. INTRODUCTION

Wetlands act as major sinks and sources of atmospheric greenhouse gases and can switch between atmospheric sink and source in response to climatic and anthropogenic forces. Despite their importance in the carbon cycle, the locations, types, and extents of wetlands are not accurately known, in part because suitable remote sensing data with large-area coverage, and their respective classification algorithms, have not been available. The timing of spring thaw can influence boreal carbon uptake dramatically through temperature and moisture controls to net photosynthesis and respiration processes. With boreal evergreen forests accumulating approximately 1% of annual net primary productivity (NPP) each day immediately following seasonal thawing, variability in the timing of spring thaw can trigger total interannual variability in carbon uptake on the order of 30%. Satellite remote sensing is particularly advantageous for complete synoptic study of the behavior of wetlands ecosystems, surface water dynamics, and large-scale seasonal dynamics across the high latitudes, allowing useful inference of recent greenhouse gas emissions as well as supporting prediction of processes governing future landatmosphere carbon exchange.

Phase I of our research under the Kyoto and Carbon (K&C) Initiative focused on development and demonstration of

capabilities for mapping and monitoring of northern wetlands ecosystems and on characterization of seasonal freeze/thaw cycles in northern high latitude ecosystems. As part of our Phase I effort, we mapped wetlands ecosystems in Alaska and Northern Eurasia with L-band Synthetic Aperture Radar (SAR) utilizing both JERS SAR and ALOS PALSAR data. Our Phase II effort utilized ALOS PALSAR data sets to map wetlands in various regions of Alaska and Northern Eurasia.

We employ a supervised decision tree approach to PALSAR data to classify wetlands vegetation and open water for regions of Alaska. This is the same powerful statisticallybased decision tree classification scheme developed previously under our Phase I effort. Along with the PALSAR data, the technique employs topography, ground-based measurements of land cover, a SAR-based open water map, and other ancillary data layers derived from the SAR and DEM datasets to classify wetlands regionally. We also used multitemporal PALSAR data to examine change in open water. Wetlands mapping activities include the mapping and monitoring of water bodies for characterization of the change in surface water seasonally. Comparison of these new PALSAR data set with those derived previously from JERS SAR allows a decadal change assessment in wetlands vegetation. Assessment of these products continues under our NASA science investigations.

We developed a framework for monitoring temporal and spatial dynamics in surface water with ~25-km resolution data sets from SeaWinds-on-QuikSCAT and AMSR-E active/passive microwave data. Comparing our PALSAR products with these over areas where PALSAR data have been collected and analyzed validates the capability of the coarse resolution products to monitor surface water dynamics globally.

Our project is undertaken with support from NASA for constructing a global-scale Earth System Data Record (ESDR) of Inundated Wetlands to facilitate investigations on the role of inundated wetlands in climate, biogeochemistry, hydrology, and biodiversity. The ESDR will enable advances in understanding the role of wetlands in 1) global cycling of methane, carbon dioxide and water, 2) interactions among climate, greenhouse-gas emissions, and water exchange, 3) climate change effects and feedbacks, 4) maintaining ecological health and biodiversity of critical habitats, and 5) management of water resources for long-term sustainability.

The ESDR will provide the first accurate, consistent and comprehensive global-scale data set of wetland inundation and vegetation, including continental-scale multitemporal and multi-year inundation dynamics at multiple scales. Each component of the ESDR has been designed to facilitate a range of studies by addressing critical gaps in data and understanding of the role of inundated wetlands in important cycles and processes. The regional high-resolution component derived from the SAR observations provide key information needed for to continental-scale studies focusing regionalon biogeochemistry, hydrology, plant and animal biodiversity, water resource management, and long-term sustainability of wetland ecosystems. The global, monthly ~25 km inundation data set, spanning almost two decades, represents a unique,

comprehensive source of quantitative information to support analyses and modeling of wetlands in global cycling of methane, carbon dioxide and water, and in simulating interactions among climate, greenhouse-gas emissions, and water exchange for past, current and future time periods. Comparison and validation of these data sets will ensure selfconsistency within the ESDR. Description of the project

A. Relevance to the K&C drivers

The overarching objective of our project is to develop products that demonstrate, support, and provide a capability for characterization of carbon cycling processes in boreal/Arctic wetlands ecosystems and as related to seasonal freeze/thaw cycles in ecosystems in boreal/Arctic regions. We capitalize on the systematic acquisition strategies implemented for the ALOS PALSAR specifically focusing on high-latitude wetland regions to prototype capabilities over North American and Eurasian sites. We use multi-temporal datasets to address issues of seasonal change. These prototype land cover classification products are developed to enable unique and key information for use with ecosystem process models for assessing land-atmosphere carbon exchange.

Wetlands exert major impacts on biogeochemistry, hydrology, and biological diversity. The extent and seasonal, interannual, and decadal variation of inundated wetland area play key roles in ecosystem dynamics. Wetlands contribute approximately one fourth of the total methane annually emitted to the atmosphere and are identified as the primary contributor to interannual variations in the growth rate of atmospheric methane concentrations. Climate change is projected to have a pronounced effect on global wetlands through alterations in hydrologic regimes, with some changes already evident. In turn, climate-driven and anthropogenic changes to tropical and boreal peat lands have the potential to create significant feedbacks through release of large pools of soil carbon and effects on methanogenesis. Despite the importance of these environments in the global cycling of carbon and water and to current and future climate, the extent and dynamics of global wetlands remain poorly characterized and modeled, primarily because of the scarcity of suitable regional-to-global remotesensing data for characterizing their distribution and dynamics.

In the northern high latitudes open water bodies are common landscape features, having a large influence on hydrologic processes as well as surface-atmosphere carbon exchange and associated impacts on global climate. It is therefore important to assess their spatial extent and temporal character in order to improve hydrologic and ecosystem process modeling. Spaceborne SAR is an effective tool for this purpose since it is particularly sensitive to surface water and it can monitor large inaccessible areas on a temporal basis regardless of atmospheric conditions or solar illumination.

B. Overview of Work approach

Our project focused on a combination of local-scale hydrological basin study sites and regional-scale study areas in North America and Eurasia. Dataset assembly, algorithm development, and algorithm prototyping were initially conducted in boreal North America, primarily in Alaska. As the scope of our work is global, we support assembly of largescale PALSAR data sets are continental scales world-wide. This work is integrated within the K&C Phase II efforts of Bruce Chapman and Laura Hess.

We employed multi-temporal ALOS PALSAR to map open water bodies in Alaska and Eurasia. A supervised decision tree-based approach was used to generate open water maps. We expand on previous work conducted with the JERS SAR. Multi-temporal SAR imagery is applied to prototype the capability for monitoring seasonal hydrologic dynamics. Digital Elevation Models (DEMs) and derived slope were also employed in the decision tree classifier. These supplementary data aided significantly in improving the classification performance in topographically complex regions where radar shadowing was prevalent.

We integrate the open water maps with the SAR imagery into a decision tree-based classification construct to derive maps of wetlands vegetation for the study regions in Alaska and Eurasia. The resulting products are compared to our Alaska wetlands map previously derived with JERS data under our Phase I effort. Maps of decadal change in wetlands vegetation are derived.

C. Satellite and ground data

We utilize PALSAR data available to us through the systematic acquisitions detailed in the Kyoto and Carbon (K&C) Science Plan. For our Alaska effort, we previously used JERS SAR datasets. We now utilize PALSAR fine-beam single pol (HH) and dual-pol (HH+HV) data available though the K&C datasets and the AUIG. Landscape classification approaches and associated algorithm implementation were carried out with the PALSAR data over regions of Alaska and Northern Eurasia.

Derivation of the remote sensing-based mappings makes use of important ancillary data sets incorporated within the classification construct. These include DEMs, Landsat imagery, and ground measurements acquired from external project sources and applied here for training and validation. DEMs from the Shuttle Radar Topography Mission (SRTM) were employed for the Eurasian basin regions where the basins fall within the domain of the SRTM datasets (i.e. south of 60 deg. N latitude; http://srtm.csi.cgiar.org/). For Alaska, we employ the GTOPO30 Global 30 Arc Second Elevation Data available Set from the U.S. Geological Survey (http://eros.usgs.gov/#/Find Data/Products and Data Availab le/gtopo30_info). Landsat data were used to supplement the landcover classification efforts in Eurasia. The Landsat data were available to us from a database assembled by the Cartography lab at JPL.

II. DATA SET ASSEMBLY: WORLD-WIDE-WEB-BASED MOSAICKING TOOL

Derivation and utilization of these large-scale products from relatively fine resolution radar imagery necessitates establishment of a large database of SAR images and development of effective software tools supporting image manipulation and regional-scale analysis. To support this end, we are constructing a user-accessible data system available through a World Wide Web portal to facilitate assembly, analysis and distribution of data sets. This framework interfaces powerful and flexible software tools for mosaic assembly of SAR images and derived products, and for data product display, assessment, and distribution to the science community. Data products will be accessible via this interface through a project web site at JPL and now under development at The City College of New York. Figure 1 shows an example of the user interface developed to facilitate on-demand mosaicking tasks. Figure 2 is an example mosaic assembled with the software accessible through the user interface.



Fig. 1: World-Wide-Web-based interface for assembly and dissemination of PALSAR-based data sets. Shown here is the user interface for PALSAR database query. The interface allows query, selection, and assembly of imagery into mosaics suited to user requirements.

Organization of the image products and examination of those products based on desired criteria is simplified by utilizing widely-available Earth data visualization tools. By construction of "KML" files and a stack of multi-resolution data sets, vast quantities of SAR or other data sets, including associated digital elevation data and other data set components



Fig. 2: Mosaic of HH-polarized backscatter PALSAR imagery of Alaska. This initial mosaic was assembled from fine-beam imagery using the software running though the user interface as presented in Figure 1. Our team continues to work to acquire and assemble data missing in the to fill voids to complete the continental-scale coverage.

can be easily displayed in combination with currently accessible optical imagery. Flexible mosaicking is achieved through use of an on-line mosaicking tool combined with visualization tools for data examination, selection of the data sets for mosaicking through a link to a webpage (based on thematic or temporal considerations), and lastly, execution of software on the server to mosaic the user-specified data. Therefore, in addition to producing a wetland classification for each PALSAR data collection cycle, it will be possible to construct a wetland classification corresponding to, for example, maximum or minimum inundation extent, or, using ancillary sources of information, maximum or minimum rainfall periods, or any other condition of scientific interest that can be quantified by date and location.

This type of visualization software can also facilitate the comparison of the global inundation data sets and the regional



Fig. 3: Wetlands maps derived from JERS-1 SAR. Part of our work under K&C Phase II involved extending our wetlands map of Alaska to now include large regions of Western Canada, indicted by the red rectangle on the JERS mosaic. Previously, we used summer and winter JERS-1 imagery to develop the thematic map of wetlands throughout Alaska shown here. This product has an aggregate accuracy approximately 89.5% relative to US National Wetlands Inventory data for this region. Derivation of the extended map utilized decision trees saved from the Alaska classification, applying them to regions of Western Canada.

PALSAR-based data sets. Since the SAR data are unevenly distributed temporally and spatially, this visualization capability greatly simplifies combined analysis of these data sets. Each can be loaded into visualization software for inspection, with particular regions and/ or time spans identified. Based on this visualization, the appropriate data sets can be downloaded and analyzed.

III. BOREAL WETLANDS MAPPING

Our work during Phase I of our K&C activities included derivation of the first synoptic wetlands map of Alaska (Fig. 3; Whitcomb et al 2009). This product was generated using dual season winter and summer JERS SAR mosaics of Alaska. Derivation of this product utilized a statistically-based decision tree classification approach based on the random forest software (Breiman, 2001). Under K&C Phase II, we built upon these efforts to extend our work with JERS SAR to derive wetlands maps of large regions of western Canada (Fig. 3) and to map extensive regions of Alaska using ALOS PALSAR (Fig. 4). Having generated data sets from JERS and PALSAR, we then derived change maps depicting change on wetlands vegetation across a decade (Fig. 5).

In northern Eurasia, we applied fine-bean PALSAR data to examine changes in wetlands inundation for the Chaya Basin, Russia (Fig. 6). A random forest classification approach was employed here to develop the wetlands maps. The classifications depict open water and principal vegetation classes (e.g. non-vegetated, herbaceous, shrub, woodland, forest) and their associated inundation state. The examples from PALSAR shown here were generated from fine-beam PALSAR data provided through the K&C project and the JAXA AUIG. These maps are supporting efforts to develop a hydro-methane modeling construct for assessing landatmosphere carbon exchange in northern wetlands ecosystems.

IV. COMPARISON OF PALSAR PRODUCTS WITH GLOBAL INUNDATION MAPPINGS: PRODUCT HARMONIZATION.

A unique application of the PALSAR wetlands classification is calibration and validation of our global coarseresolution inundated area data sets. These products constitute the second component of our Earth System Data Record. To derive these products, a regression analysis is carried out on AMSR-E and QSCAT passive and active microwave time series data (July 2002 – July 2009) for each of 54 sites distributed across the globe to derive 13 land cover specific predictive equations. These regressions are used within a mixture model. Outputs of the mixture model are fraction of inundated area (fw; Fig. 7). Data are pre-screened for frozen



Fig. 4: Classification of Alaskan PALSAR imagery collected in 2007, currently in progress. Results show generally good classification accuracy (79-94%).



Fig. 5: Decadal change in wetlands vegetation for regions of Alaska, determined by comparing JERS and PALSAR-based wetlands mappings. From left to right the regions are Kenai Peninsula, Yukon Delta, Seward Peninsula, Tanana River Floodplain, and North Slope.



Fig. 6: PALSAR-based time series classification of wetlands in the Chaya Basin, Northern Eurasia. From left,are shown for June 7, July 23, and August 7, 2007. Red and pink areas represent open water and inundated vegetated wetlands regions, respectively. These data are being enployed to support etmation of methane flux from wetlands regions of the NEESPI study domain, Eurasia (Bohn et al 2006, 2007, 2007a).



inundated Area Fraction

Fig. 7: Global AMSR-E/QSCAT-based coarse-resolution (25 km) inundation fraction mappings. Monthly composites are shown for North and Central America. Each month corresponds to a multi-year average over the period 2003-2008. Dry areas (minimal water fraction) and large water bodies appear as white.

conditions and snow, RFI (radio frequency interference) and precipitation. PALSAR-based open water and inundated wetland products derived at 100 meter resolution were regridded to a 25km EASE grid posting to compute an equivalent fractional open water area at the 25 km resolution (Fig. 8). These were compared with contemporaneous surface inundation fraction products derived from AMSR-E/QuikSCAT at 25 km resolution for different regions in Alaska.

Results (Fig. 9) show that surface water fraction is generally underestimated for open water and open water plus inundated vegetation for the North Slope and Yukon sites. This is the expected trend because in addition to open water, other landscape components are averaged into the measurement at the 25 km footprint. Also, at Ku and K-band, there is decreased sensitivity to conditions under the vegetation canopy and therefore inundated vegetation becomes difficult to detect. A reverse trend is seen in the Seward Peninsula possibly due to contamination of the 25 km pixel from ocean water.

V. RESULTS AND SUMMARY

Our K&C Phase II activity extended efforts and accomplishments from our Phase I project, continuing to develop products that demonstrate, support, and provide a capability for characterization of carbon cycling processes in boreal/Arctic wetlands ecosystems and now including an initial assessment of seasonal and multi-year (decadal) change in boreal/Arctic ecosystems. To this end, we have applied ALOS PALSAR data to map and monitor open water and wetlands vegetation in boreal landscapes. We used multi-temporal PALSAR datasets to examine seasonal wetlands dynamics . We characterized decadal-scale change in wetlands vegetation for large regions of Alaska, comparing our new PALSAR products to those previously derived using JERS SAR. We compared PALSAR wetlands mappings to coarse resolution active/passive microwave products depicting inundated area fraction.

These prototype land cover classification products provide unique and key information for use with ecosystem process models for assessing land-atmosphere carbon exchange. In the northern high latitudes open water bodies are common landscape features, having a large influence on hydrologic processes as well as surface-atmosphere carbon exchange and associated impacts on global climate. Data provided by the K&C Initiative continue to support assembly of a global-scale Earth science data record of inundated wetlands. This data record will be made available to the larger Earth science community, supporting a broad range of scientific investigations.



Fig. 8: PALSAR-based mappings of open water for the Yukon delta region and for a sub-region of Alaska's the North Slope (two dates). The 100-m resolution PALSAR mappings for these and other regions were resampled and posted on a 25 km EASE-Grid posting to compare fractional inundated water derived from contemporaneous AMSR-E/QSCAT data products (long term average shown at left).



Fig. 9: Comparison of PALSAR-based and coarse-resolution AMSR-E/QSCAT-based mappings of surface water fraction for regions within Alaska. Top: Comparisons of open water derived from PALSAR with surface water fraction from the AMSR-E/QSCAT dataset. Bottom: Comparisons of open water (black circles) and open water plus inundated vegetation (red circles) for the Yukon Delta and the Seward Peninsula.

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