# K&C Science Report – Phase 1:

# Mapping Boreal Wetlands, Open Water, and Seasonal Freeze-Thaw Status for Assessment of Land-Atmosphere Carbon Exchange


**Kyle C. McDonald, K&C Science Team Member**

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109 USA
kyle.mcdonald@jpl.nasa.gov

**Collaborators**

**Erika Podest, Bruce Chapman**
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109 USA
erika.podest@jpl.nasa.gov

**Mahta Moghaddam, Jane Whitcomb**
Radiation Laboratory, Department of Electrical Engineering and Computer Science
The University of Michigan
1301 Beal Ave
Ann Arbor, MI 48109 USA
mmoghadd@umich.edu

**Ted Bohn, Dennis Lettenmaier**
Surface Water Hydrology Research Group
University of Washington
Seattle, WA 98195-2700
dennisl@u.washington.edu

**John S. Kimball**
Flathead Lake Biological Station
The University of Montana,
32125 BioStation Lane
Polson, MT 59860
johnk@ntsg.umt.edu



***Abstract*— We utilize L-band Synthetic Aperture Radar (SAR) datasets from the JERS-1 SAR and the ALOS PALSAR to map and monitor wetlands in boreal North America and Boreal Eurasia. JERS SAR datasets employed include data acquired, archived and assembled as part of the Global Boreal Forest Mapping (GBFM) project. ALOS PALSAR data include data supplied by the AUIG. We utilize multi-temporal JERS-1 data extending over the last year of JERS mission operations to map variability on open water in Alaska. We apply a novel classification approach to the summertime and wintertime JERS-1 SAR mosaics to develop the first synoptic wetlands map encompassing all of Alaska. We apply this classification algorithm to map wetlands within selected hydrologic basins in northern Eurasia, utilizing both JERS SAR and PALSAR data to map wetlands ecosystem features in those regions. We show initial results for employing these mappings within a hydrologic-methane modelling construct which will eventually provide a diagnostic tool for assessing methane flux dynamics from these**

**ecosystems. We demonstrate the capability of L-band SAR to observe landscape freeze-thaw state within boreal ecosystems for examining spatial and temporal character of seasonal freeze/thaw transitions in a complex boreal landscape. 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. ESDR assembly will be supported under Phase 2 of the Kyoto & Carbon Science Panel activities.**

***Index Terms*—ALOS PALSAR, JERS-1 SAR, K&C Initiative, Wetlands, Freeze/Thaw, Carbon Flux**

## 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 northern 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 freeze/thaw dynamics across the high latitudes, allowing useful inference of recent greenhouse gas emissions as well as supporting prediction of processes governing future land-atmosphere carbon exchange.

Phase I of our research under the Kyoto and Carbon 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. We map wetlands ecosystems in Alaska and Northern Eurasia with L-band Synthetic Aperture Radar (SAR). We investigate the characterization of spatio-temporal heterogeneity in seasonal freeze-thaw transitions in boreal land cover with SAR.

Wetlands mapping activities include the mapping and monitoring of water bodies and demonstration of the capability of multi-temporal SAR to characterize the change in surface water seasonally. We employ a supervised decision tree approach to classify open water for all of Alaska using time series data from the Japanese Earth Remote Sensing Satellite (JERS-1) SAR collected during 1997-1998 as part of the Global Boreal Forest Mapping (GBFM) mission. We demonstrate the utility of L-band SAR for mapping and monitoring surface water dynamics.

We used the summer and winter JERS SAR mosaics, topography, ground-based measurements of land cover, our open water map of Alaska, and other ancillary data layers derived form the SAR and DEM datasets to classify wetlands regionally for all of Alaska. We develop a powerful statistically-based decision tree classification scheme to derive the new wetlands data set. The derived 100 meter resolution map is the first synoptic map of Alaska wetlands generated from a consistent and contiguous data set.

We apply these classification techniques to PALSAR data to develop open water and land cover mappings of several hydrologic basins in Northern Eurasia. Techniques for integrated these products within a process modeling construct that integrates modeling of land surface hydrology with modeling of land-atmosphere methane flux are under development. We perform an initial assessment of the potential of the utilization of the wetlands mappings for assessment of surface hydrologic processes for supporting the characterization of land-atmosphere carbon exchange, performing an initial comparison of our SAR-based products with hydro-methane model derivatives both to assess the utility of the SAR products for supporting hydro-methane modeling and to validate performance of the modeling construct. We find the SAR-based land cover products provide a capability for assessment of land surface hydrologic parameters that support the assessment of methane emissions from wetlands ecosystems.

Development of the integrated remote sensing / process modeling framework is continuing, supporting the efforts of the Northern Eurasia Earth Science Partnership Initiative (NEESPI), a program of internationally-supported Earth systems science research for developing a comprehensive understanding of the Northern Eurasian terrestrial ecosystem dynamics, biogeochemical cycles, surface energy and water cycles, and human activities and how they interact with and alter the biosphere, atmosphere, and hydrosphere of the Earth (http://neespi.org/).

## II. 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 JERS SAR and the ALOS PALSAR specifically focusing on high-latitude wetland regions to prototype products over North American and Eurasian sites. We use multi-temporal datasets to address issues of seasonal change, including seasonal freeze/thaw state change. These prototype land cover classification and freeze-thaw state products are developed to provide 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 remote-sensing 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. We employed multi-temporal L-band SAR data from JERS-1 and 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 the JERS-based open water maps of regions within Alaska to the entire Alaska domain. Multi-temporal SAR imagery is applied to prototype the capability for monitoring seasonal hydrologic dynamics. We assembled regional-scale monthly JERS-1 SAR mosaics from data acquired during 1998. 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 map with the SAR imagery into a decision tree-based classification construct to derive a wetlands map of the whole of Alaska. The resulting product is the first synoptic map of wetlands derived from a single data source covering all of Alaska. Having developed and prototyped these approaches for open water and wetlands mapping, we apply these techniques to develop open water and wetlands mappings of selected hydrologic basins in Northern Eurasia.

For study regions in Eurasia, PALSAR data was used to map open water and its change over selected study basins. We also made use of JERS SAR data in Eurasia as needed to develop open water products supporting our land surface process modeling. Supplementary data from Landsat were used to further refine the open water classification.

### C. *Satellite and ground data*

We utilize JERS-1 SAR datasets acquired as part of the Global Boreal Forest (GBFM) project and PALSAR data available to us through the systematic acquisitions detailed in the Kyoto and Carbon (K&C) Science Plan. For our Alaska effort, we used JERS SAR datasets. JERS data were processed and acquired from the Alaska Satellite Facility and assembled at JPL under the Global Boreal Forest Mapping (GBFM) project. For our Eurasia effort we used fine-bean single pol (HH) and dual-pol (HH+HV) data available though the AUIG. Landscape classification approaches and associated algorithm development and testing were carried out with the JERS data in Alaska, then subsequently applied and extended using PALSAR data over the Eurasian basin-scale study sites.

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 Set available from the U.S. Geological Survey (http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/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.

## III. WETLANDS MAPPING: ALASKA

### A. *Open Water Mapping and Monitoring in Alaska*

Dual season winter and summer JERS SAR mosaics of Alaska assembled from imagery collected primarily during 1997 and 1998 were used extensively in prototyping classification schemes and in developing wetlands mappings of Alaska (Figure 1). We applied the summertime JERS SAR mosaic to map open water at local and regional scales. Figure 2 shows a map of open water for Alaska developed applying a Maximum Likelihood Estimator (MLE) to the summertime SAR mosaic. Various approaches were tested in mapping open water including supervised and unsupervised schemes. The resulting product represents open water condition for the time of acquisition of the SAR images making up the mosaic.

Time series JERS SAR imagery from 1998 was applied to map seasonal change in open water at approximately 44-day repeat intervals. Figure 3 shows a series of mappings developed over a sub-region of Alaska’s North Slope near the Kuparuk River. The map of open water were developed during the 1998 non-frozen period and applied to examine change in surface open water during the non-frozen period. The open water change maps show regions where the area of open water increases relative to the early growing season as well as those locations where open water area decreases.

These efforts are being extended to develop similar mappings with PALSAR data. We are also extending the work with JERS to include Canada to support development of wetlands maps across boreal North America.

### *B. Wetlands Mapping in Alaska*

We utilized the summer and winter JERS SAR mosaics (Figure 1) to develop a synoptic wetlands map of Alaska (Figure 4). Because of the temporal compositing time required in assembly of the mosaics, significant variability exists in land surface hydrologic features that give rise to pass-to-pass variability (striping) in the SAR mosaics. To account for this within our classification schema, we utilized a statistically-based decision tree classification approach based on the random forest software (Breiman, 2001).Random forest generates a large number of decision trees (i.e. a forest) based on ground reference (training) data and input data layers generated from remote sensing and ancillary data sources. Each decision tree is generated through an iterative process wherein nodes are split according to the pixel values in each input data layer covered by the training data. This continues until nodes can no longer be split. Each pixel to be classified is run through every decision tree in the forest. The final class assigned to the pixel is that class selected by the most decision trees in the forest. Classification accuracy is determined by comparing the final classified product to training data withheld during the generation of the forest. The resulting product represents the first synoptically-generated wetlands map available for all of Alaska.

## IV. Wetlands Mapping: Eurasia

### *A. Open water and wetlands mapping in Eurasia*

Having developed and prototyped classification and mapping approached from JERS SAR in Alaska, we utilize PALSAR data acquired form the AUIG to map open water and wetlands land cover in northern Eurasia. We focus on a selection of basins within the Northern Eurasian Earth Science Partnership Initiative (NEESPI) domain (Figure 5). The effort here is to develop remote sensing-based products to support modelling of surface hydrodynamic processes and associated methane production. Primary controls to land-atmosphere methane flux in these ecosystems include soil temperature, water table position, and vegetation productivity. Thus development of open water and wetlands vegetation maps lends itself well to supporting the needed hydro-methane modeling infrastructure for understanding present methane emissions and forecasting effects of climate and land cover changes on future methane emissions.

Fine-beam PALSAR imagery was acquired over each NEESPI sub-region. Mosaics of the PALSAR scenes covering the basins were assembled. Supplementary Landsat data were acquired and assembled over each basin. The PALSAR and Landsat data were coregistered to a DEM. Open water was derived utilizing a decision tree classification scheme applied to the combined PALSAR/Landsat/DEM datasets. Figures 6 through 10 show PALSAR an Landsat data sets and derived open water maps for five of the hydrologic basins shown in Figure 5. A random forest classification approach was employed to develop wetlands vegetation maps (Chaya basin shown in Figure 11).

### *B. Hydro-methane process modeling in Eurasia*

Our process modeling framework (Figure 12; Bohn et al ,2007a,b) consists of the Variable Infiltration Capacity (VIC) hydrological model (Liang et al., 1994), enhanced with ecosystem process model components taken from the Biosphere Energy Transfer Hydrology (BETHY) terrestrial carbon model (Knorr, 2000), and coupled to the wetland methane emissions model of Walter and Heimann (2000). The models are linked as follows: the VIC (enhanced with carbon cycling processes from the BETHY model) component runs at an hourly time step, simulating, among other variables, soil temperature, soil moisture, and net primary productivity (NPP). At the end of the simulation, these hourly time series are aggregated to daily values, and VIC's daily soil moisture is converted to a daily distribution of water table depths across the catchment. Then, for each day, the resulting distribution of water table depths is discretized, and methane emissions are estimated (via the methane emissions model of Walter and Heimann (2000)) as a function of soil temperature, NPP, and water table depth for each water table value in the discretized distribution. The total methane emission of the grid cell, then, is the area-weighted sum of the methane emissions from all of the discrete values of the water table depth.

Initial development and testing of this modeling construct has been performed for the Bakchar Bog region of the Chaya basin (Figure13). A topographic wetness index was derived from SRTM DEM (Bohn et al ,2007a,b). This index was compared to the land cover map of the region derived using random forest classification of ALOS PALSAR imagery. Regions of high topographic wetness index correspond closely with areas of wetland as mapped with PALSAR.

Multi-temporal JERS-1 SAR data were used to produce open water maps of this region. For the modeling component, two open water image swaths were chosen based on their overlap and day of acquisition (Bohn et al, 2006). The first swath was acquired on April 10, 1995 and the second on May 23, 1995. These days represent wide variations in open water saturation. Change in saturated surface extent between day 100 and day 143, year 1995, given by JERS open water classification are compared with the process-based modeling framework estimates for change in water table depth (Figure 14).

## V. Charaterization of Landscape Freeze/Thaw State

Multitemporal SAR data were applied to examine spatial and temporal heterogeneity of seasonal land surface freeze-thaw transitions for a complex boreal landscape. Figure 15 shows JERS SAR applied to map landscape freeze-thaw state for a region of complex land cover in interior Alaska. A seasonal change detection algorithm was applied to time series JERS images to derive landscape surface freeze-thaw state (Entekhabi et al., 2004). Combined with a land cover map, the freeze-thaw state may be discerned according to land cover. This approach facilitates examination of the spatio-temporal dependencies of the seasonal freeze-thaw transitions in complex, heterogeneous landcover situations (Podest 2005).

Figure 16 shows JERS SAR applied to map landscape freeze-thaw state for a region of complex topography in interior Alaska. The seasonal change detection algorithm was applied to time series JERS images to derive landscape surface freeze-thaw state. Combining these maps with a Digital Elevation Model (DEM), the influence of surface topography on the spatio-temporal character of freeze-thaw transitions can be assessed. In the time series shown, differences in the spring thaw and autumn freeze series related to slope aspect can be seen. The difference in the timing of thaw between north and south facing slopes is notable in springtime as is the similar different in autumn freeze-up timing. During spring, south facing slopes are seen to thaw earlier than the north-facing regions. In the autumn, north facing slope freeze earlier that south facing slopes.

## VI. Results and Summary

The objective of our Phase I activity was 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. To this end, we have applied JERS SAR and ALOS PALSAR data to demonstrate their capability for mapping and monitoring open water and wetlands ecosystems in boreal landscapes. We used multi-temporal datasets to address issues of seasonal change, including examining seasonal open water change and spatial and temporal heterogeneity in boreal landscape freeze/thaw state. The wetlands products have been used to perform an initial assessment of a process modelling scheme for examining surface hydrology and associated land-atmosphere methane flux. We have developed the first synoptic map of wetlands across Alaska.

These prototype land cover classification and freeze/thaw state products provide unique of 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. Efforts under Phase II of our K&C work will build on the data assembly capabilities and algorithm development tasks conducted in Phase I, extending and efforts to mapping and monitoring of important wetlands regions world-wide. Data provided by the K&C Initiative will 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.(McDonald, 2007)

## Acknowledgements

This work has been undertaken within the framework of the JAXA Kyoto & Carbon Initiative. ALOS PALSAR data have been provided by JAXA EORC. This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

## References

1. Beven, K J, and Kirkby, M J, 1979, A physically based, variable contributing area model of basin hydrology, Hydrol. Sci. Bull., 24,43-69.
2. Breiman, L., 2001. Random Forests. Machine Learning, 45, 5-32. Open source software available on-line at: www.stat.berkley.edu/~brieman/randomforests
3. Bohn, T. J., D. P. Lettenmaier, K. Sathulur, L. C. Bowling, E. Podest, K. C. McDonald, and T. Friborg, 2007a. Methane emissions from western Siberian wetlands: heterogeneity and sensitivity to climate change Environmental Research Letters, 2 045015 (9pp) doi:10.1088/1748-9326/2/4/045015
4. Bohn, T. J., D. P. Lettenmaier, E. Podest, K. C. McDonald, K. Sathulur, and L. Bowling, 2007. "Methane emissions from Western Siberian wetlands: heterogeneity and sensitivity to climate change," Proceedings of the 2007b Fall Meeting of the American Geophysical Union, 10-14 December, San Francisco, California.
5. Bohn T. J., D. P. Lettenmaier, K. Sathulur, L. C. Bowling, and K. C. McDonald, 2006. Northern Eurasian Wetlands and the Carbon Cycle: Model Estimates of Carbon Storage and Methane Emissions, Proceedings of the 2006 Fall Meeting of the American Geophysical Union, 11-15 December, San Francisco, California
6. Entekhabi, D., E. Njoku, P. Hauser, M. Spencer, T. Doiron, J. Smith, R. Girard, S. Belair, W. Crow, T. Jackson, Y. Kerr, J. Kimball, R. Koster, K. McDonald, P. O'Neill, T. Pultz, S. Running, J.C. Shi, E. Wood, and J. van Zyl, 2004. The Hydrosphere State (HYDROS) Mission Concept: An Earth System Pathfinder for Global Mapping of Soil Moisture and Land Freeze/Thaw," IEEE Trans on Geosci and Remote Sensing, 42 (10) pp. 2184-2195.
7. Knorr, W., 2000, Annual and interannual CO2 exchanges of the terrestrial biosphere: process-based simulations and uncertainties, Global Ecol. Biogeogr., 9, 225-252.
8. Liang, X., Lettenmaier, D., Wood, E., and Burges. S,. 1994. A simple hydrologically based model of land surface water and energy fluxes for general circulation models, J. Geophys. Res., 99(D7), 14415-14428.
9. McDonald, K. C., 2007. "Earth Science Data Record Assembly in Support of ALOS K&C Wetlands Theme Science," The First Joint PI Symposium of ALOS Science Program, Kyoto, Japan, 19-23 November 2007.
10. Podest, E. P. 2005. Monitoring Boreal Seasonal Freeze/Thaw Transitions with Spaceborne Microwave Remote Sensing. PhD Dissertation, University of Dundee, Scotland.
11. Walter, B. and Heimann, M. 2000, A process-based, climate-sensitive model to derive methane emissions from natural wetlands: application to five wetland sites, sensitivity to model parameters, and climate, Glob. Biogeochem. Cycles, 14(3), 745-765.
12. Whitcomb, J., M. Moghaddam, K. C. McDonald, J. Kellndorfer, and E. Podest, 2009. "Wetlands map of Alaska using L-band radar satellite imagery," Canadian Journal of Remote Sensing.

Dr. Kyle McDonald is currently a Principal Scientist in the

Water and Carbon Cycles Group at the Jet Propulsion Laboratory, California Institute of Technology, in Pasadena, California. He received the Bachelor of Electrical Engineering degree (co-operative plan with highest honors) from the Georgia Institute of Technology, Atlanta, Georgia in 1983, the M. S. degree in numerical science from Johns Hopkins University, Baltimore, Maryland in 1985, and the M. S. and Ph.D. degrees in electrical engineering from The University of Michigan, Ann, Arbor, Michigan in 1986 and 1991, respectively.

Dr. McDonald has been employed in the Science Division at the Jet Propulsion Laboratory since 1991. He specializes in electromagnetic scattering and propagation, with emphasis on microwave remote sensing of terrestrial ecosystems. His research interests have primarily involved the application of microwave remote sensing techniques for monitoring seasonal dynamics in boreal ecosystems, as related to ecological and hydrological processes and the global carbon and water cycles. Dr. McDonald has been a Principal and Co-Investigator on numerous NASA Earth Science investigations. He is a member of NASA's North American Carbon Program (NACP) science team, NSF's Pan-Arctic Community-wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP) Science Steering Committee, and the ALOS PALSAR Kyoto & Carbon Initiative science panel. He has been a member of the NASA BOREAS and BOREAS Follow-on science teams, the NASA Scatterometer instrument team, the NASA Ocean Vector Winds Science Team, and the NASA Cold Land Processes (CLP) Steering Committee.

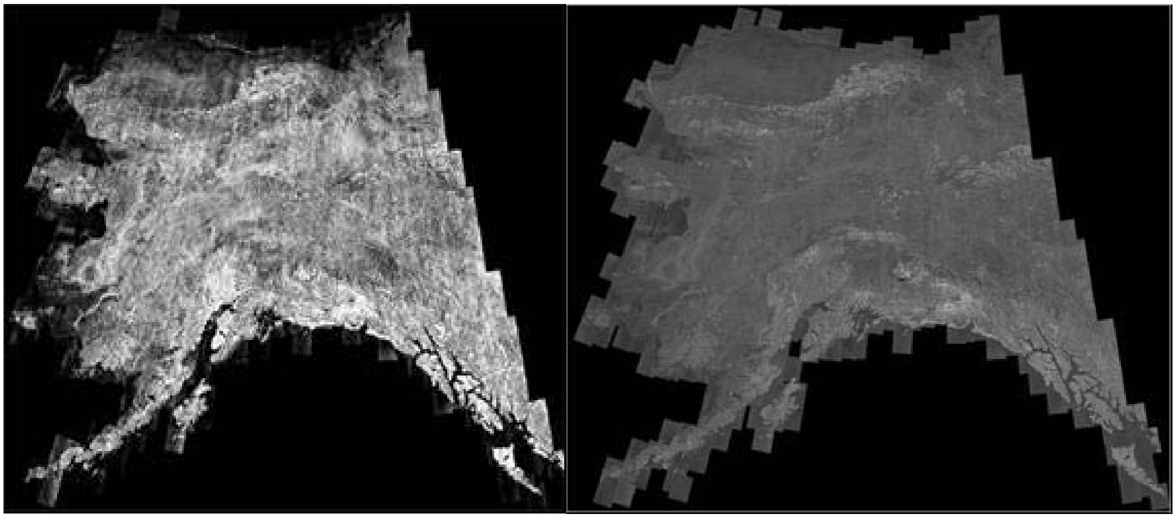


**Figure 1**: Mosaics of JERS-1 SAR images covering Alaska. Data are drawn from the large database of SAR images collected as part of the Global Boreal Forest Mapping (GBFM) project. Shown are mosaics representative of summertime thawed (left) and wintertime frozen (right) conditions. The complete JERS SAR dataset images collected within the Alaska Satellite Facility (ASF) receiving station mask during 1997-1998 allow mapping of open water and wetlands for the Alaska domain.

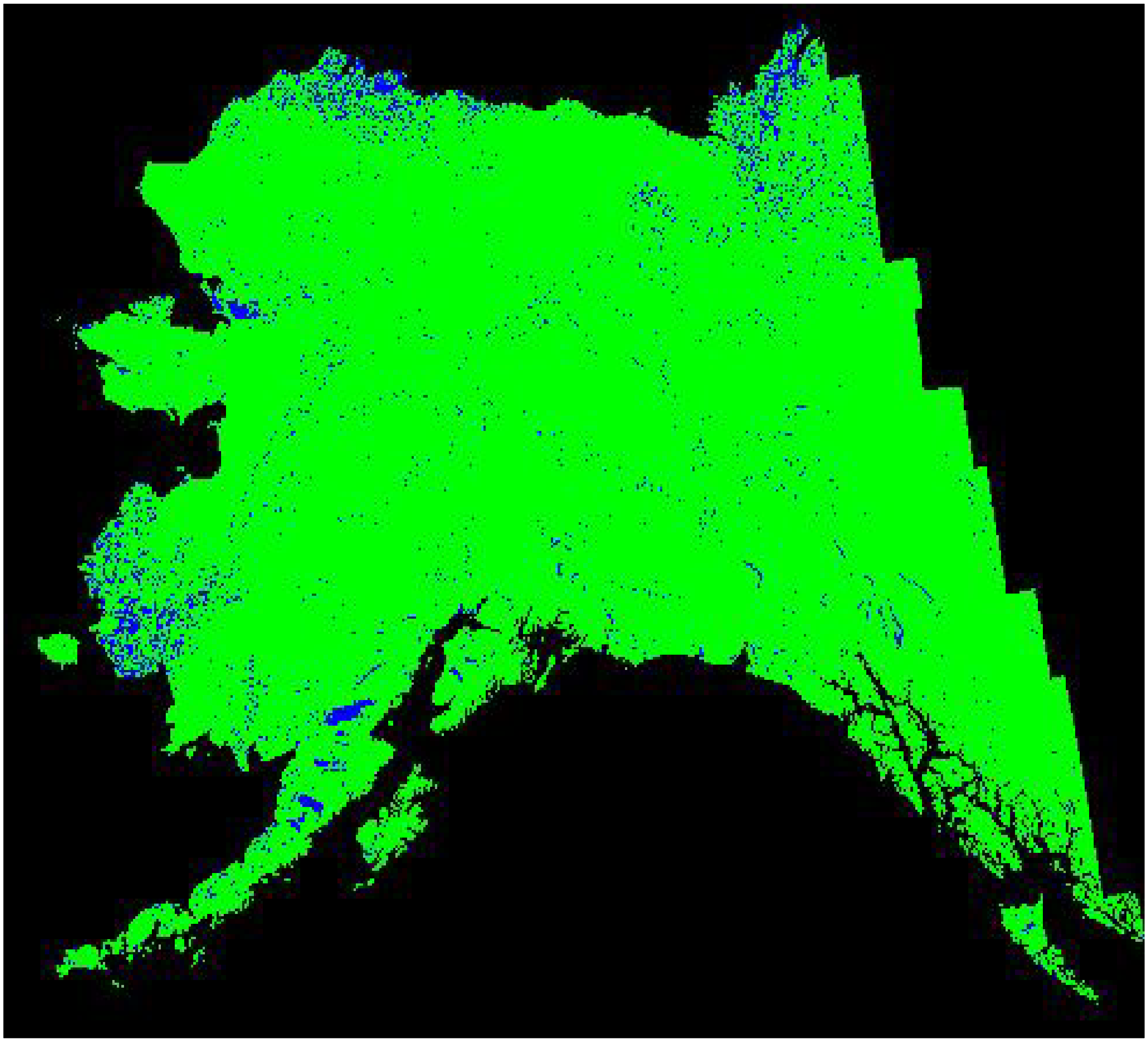


**Figure 2.** The open water map above was generated using an MLE supervised based approach applied to the Alaska JERS-1 summer mosaic. The product has spatial resolution of 100 meters. A DEM was used to mask out areas of high topography where radar shadowing was confused as open water.

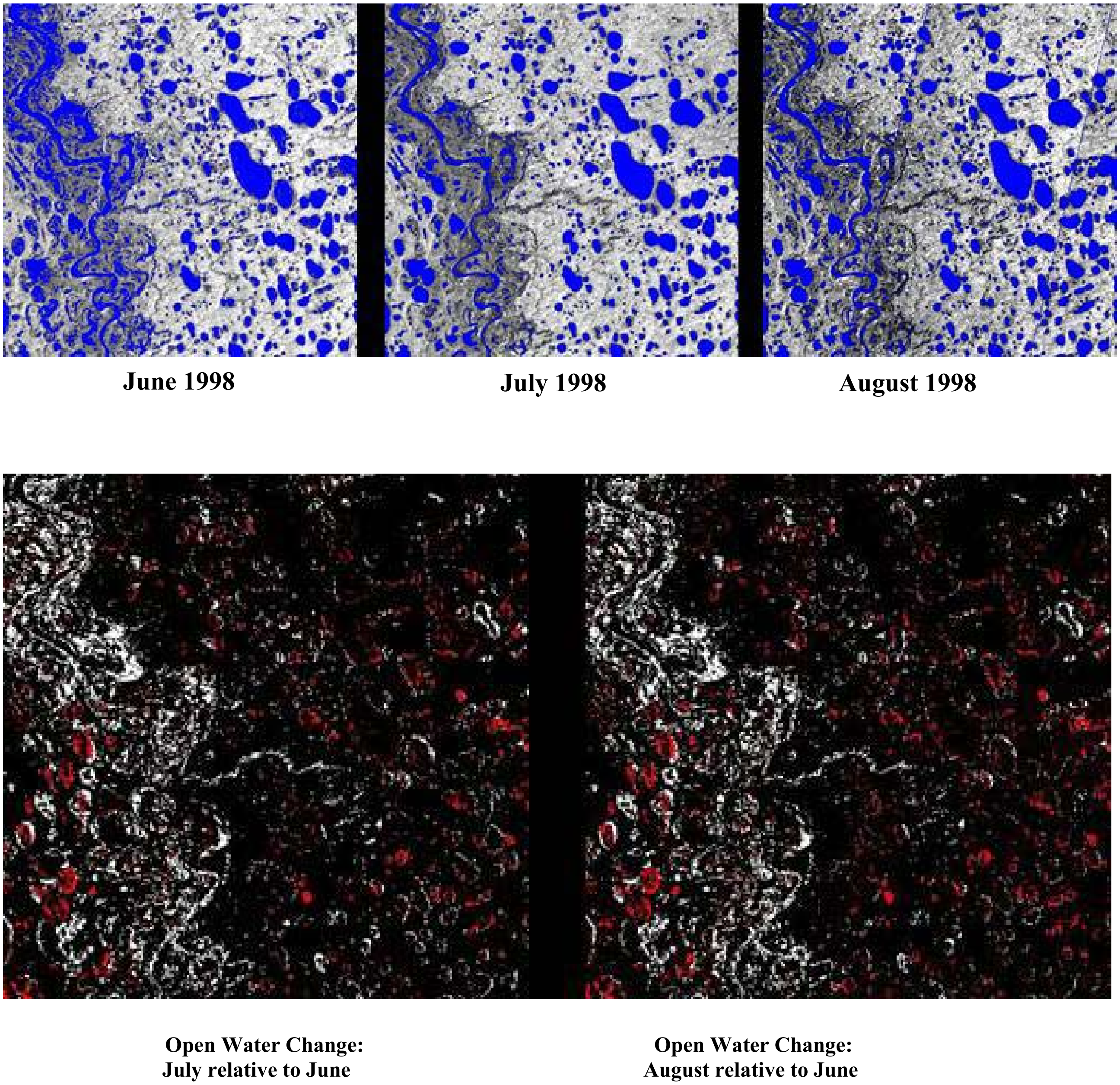



**Figure 3:** Time series maps of open water and change in open water for a 40 km x 40 km region of the Kuparuk River basin on Alaska's North Slope. These maps were derived from JERS SAR data collected during 1998. The top series of three maps show open water (blue) overlain on the JERS backscatter (grey scale). The lower two maps show the associated change in open water (derived from the open water maps above) during the short Arctic growing season. These change maps delineate regions of increasing (shown in red) and decreasing (shown in white) open water relative to open water conditions in June.

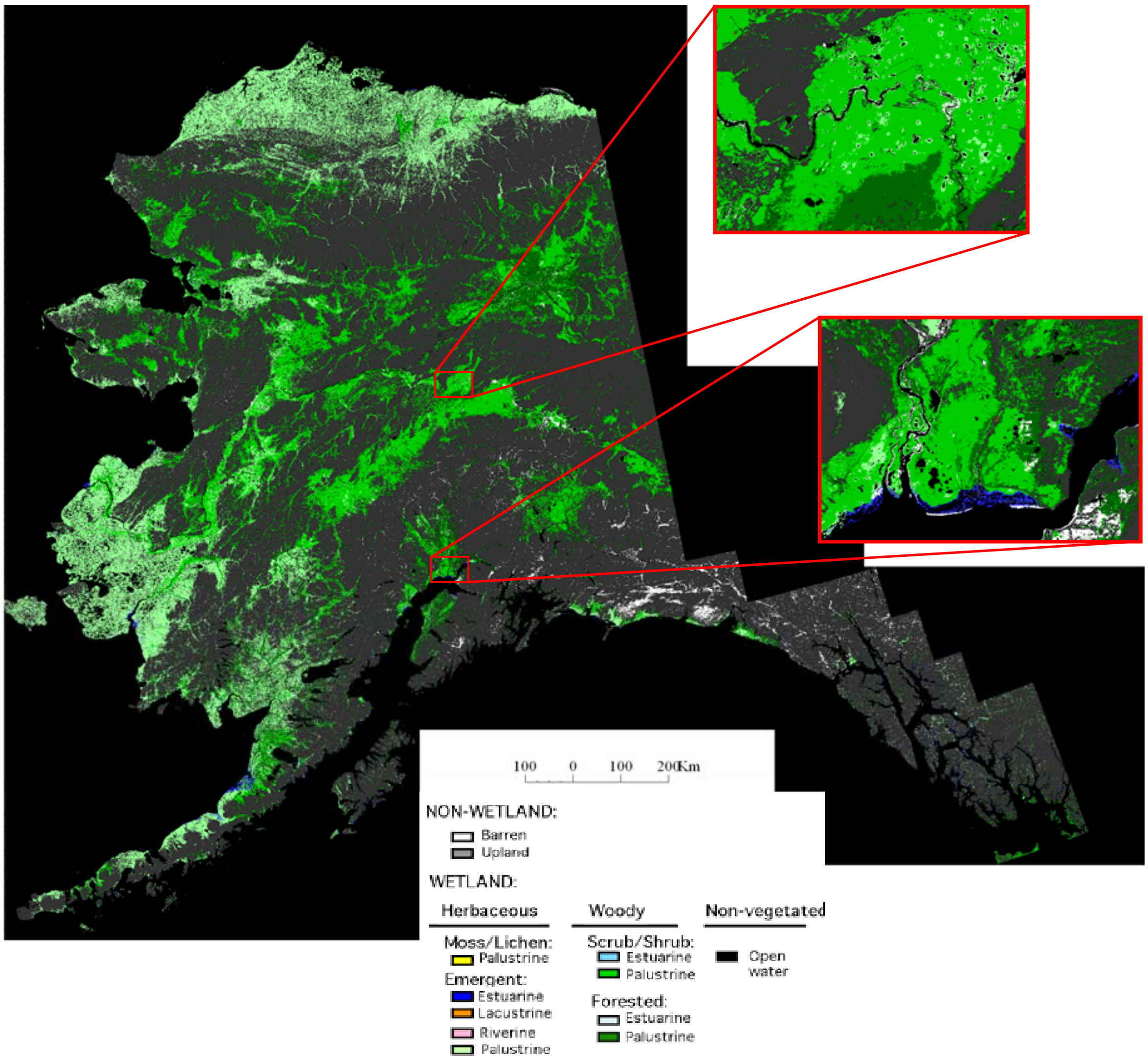



**Figure 4**. The wetlands map of Alaska generated from JERS radar imagery and ancillary data sets. The resolution of the map is 100 m. Top-level vegetation class accuracy rates range between 69.5% and 95% and the overall accuracy rate is approximately 89.5% based on all correctly classified pixels. The most prominent vegetated wetland classes are palustrine emergent, scrub/shrub, and forested. The other vegetation classes have only very small spatial coverage, not easily visible at the scale of this figure (Whitcomb et al., 2009).

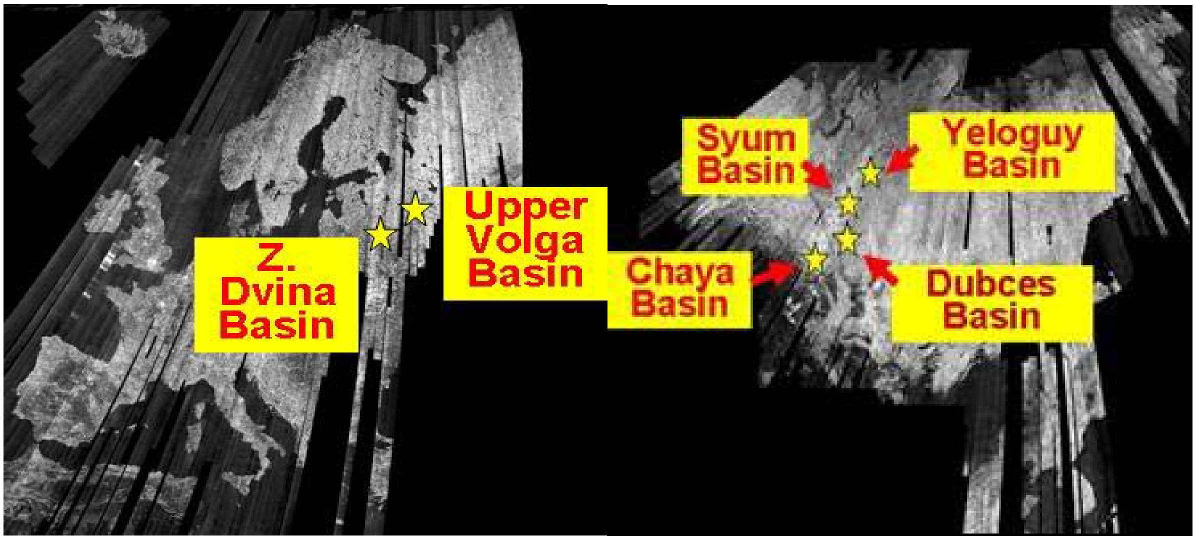
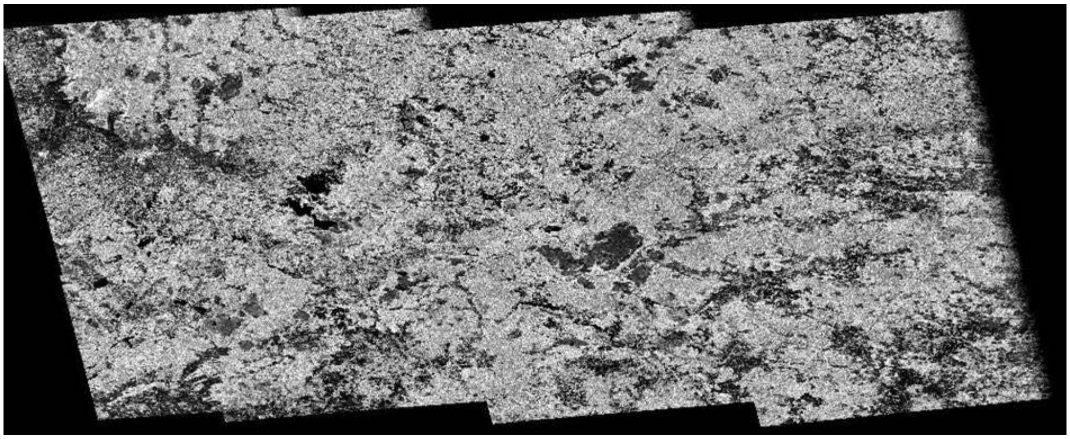
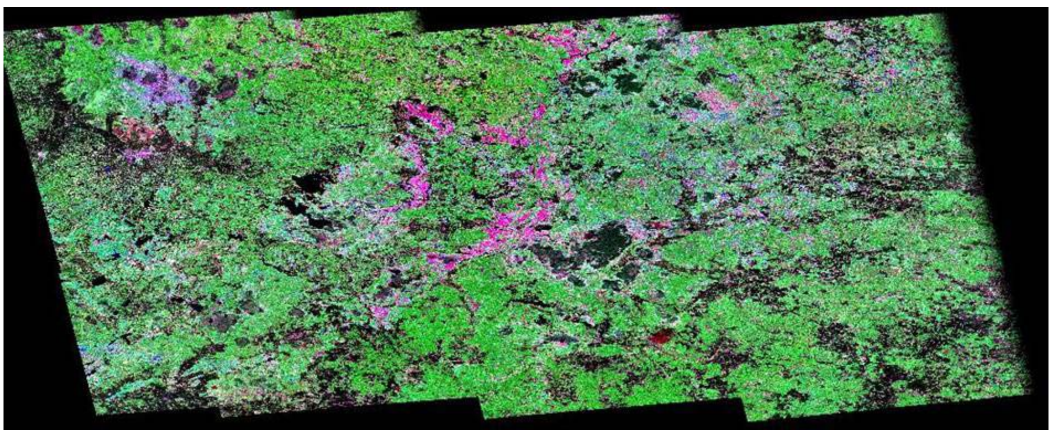


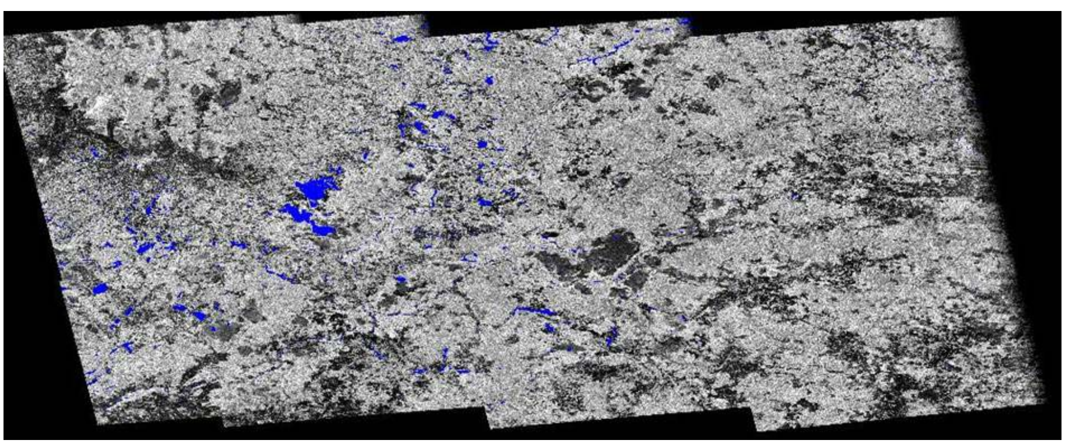

**Figure 5**: Location of the hydrologic basins for which PALSAR fine-beam datasets were utilized in derivation of landcover mappings to support hydrologic and carbon cycle science. Located northern Eurasia, this research supports research being conducted as part of the Northern Eurasian Earth Science Partnership Initiative (NEESPI). PALSAR-based mappings of wetlands features within these basins are being used to validate and calibrate results from hydro-methane process models under development to provide a diagnostic capability for assessing the effects of climate change on land-atmosphere water and carbon fluxes in boreal wetlands regions.



**Z. Dvina (PALSAR mosaic)**

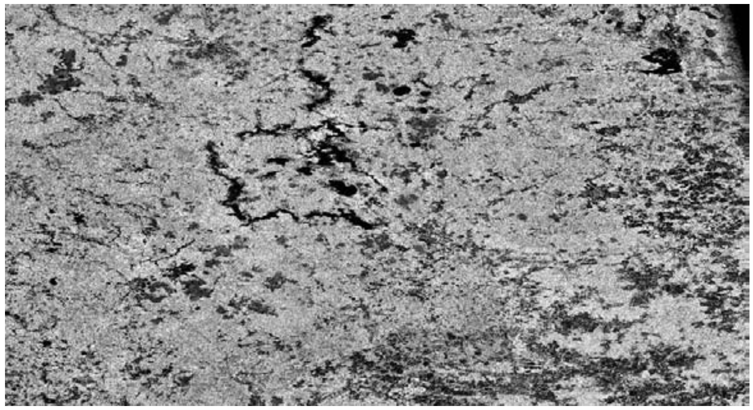


**Z. Dvina (PALSAR fused with Landsat)**



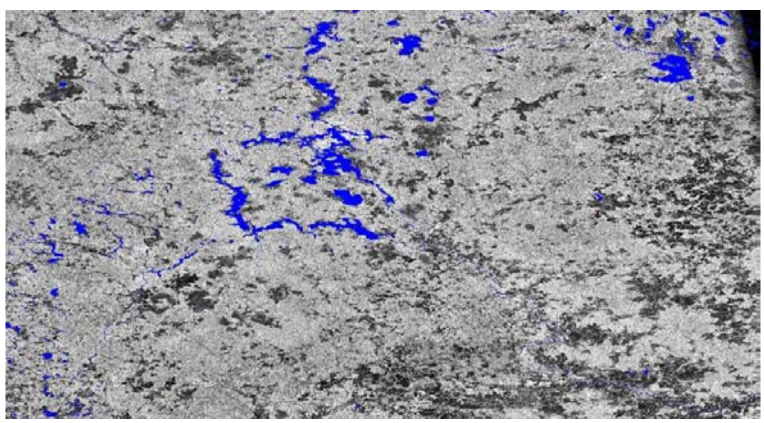
**Z. Dvina (Open Water)**

**Figure 6:** Derivation of open water for the Z. Divina basin. A mosaic of fine-beam PALSAR images is assembled (top) and fused with Landsat data (middle). These combined data are used together with a DEM in derivation of an open water map (bottom).



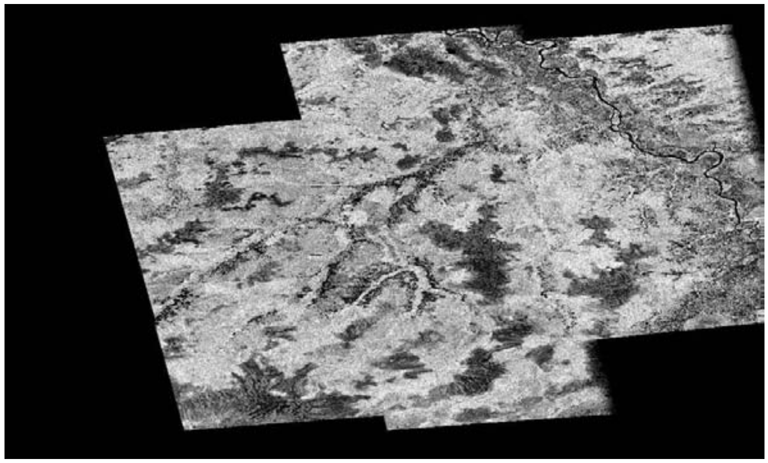
**Upper Volga (PALSAR mosaic)**

**Upper Volga (PALSAR fused with Landsat)**

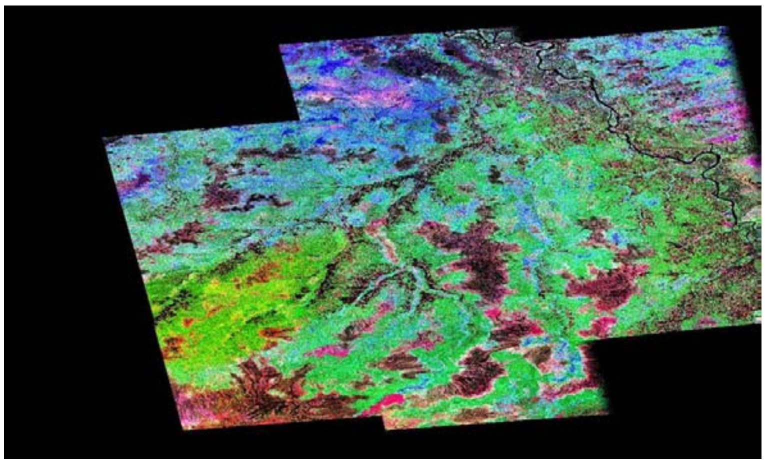


**Upper Volga (open water)**

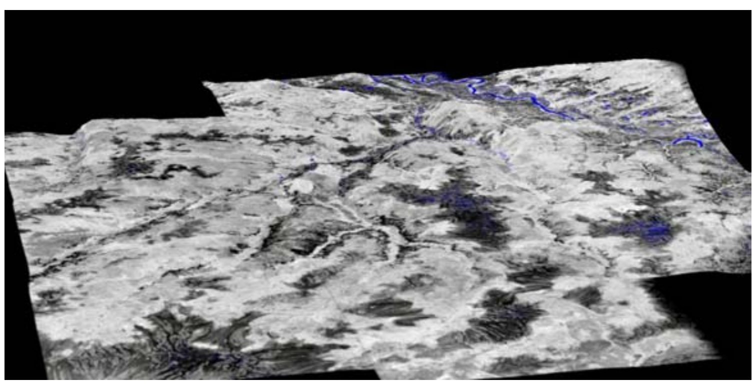
**Figure 7:** Derivation of open water for the upper Volga basin. A mosaic of fine-beam PALSAR images is assembled (top) and fused with Landsat data (middle). These combined data are used together with a DEM in derivation of an open water map (bottom).



**Chaya basin (PALSAR mosaic)**

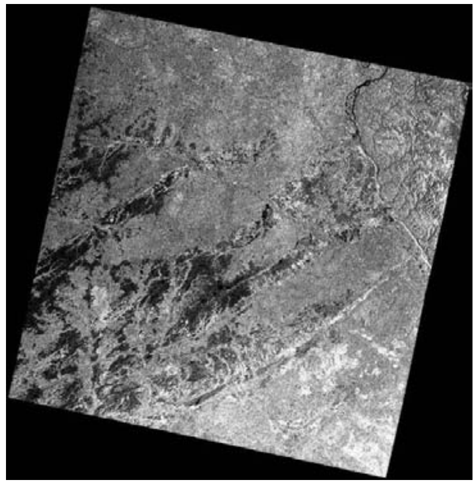


**Chaya basin (PALSAR and Landsat fused)**

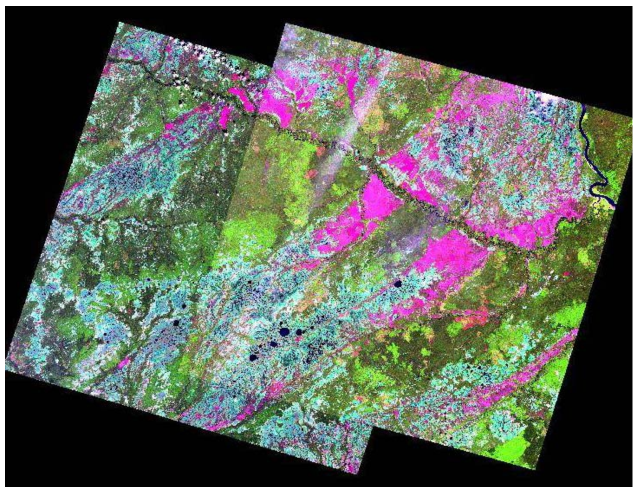


**Chaya basin (open water perspective)**

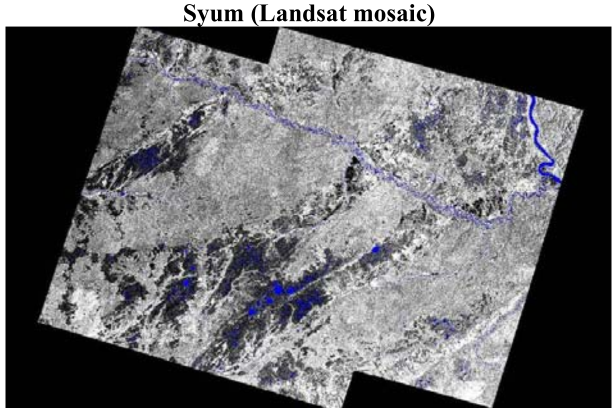
**Figure 8:** Derivation of open water for the Chaya basin. A mosaic of fine-beam PALSAR images is assembled (top) and fused with Landsat data (middle). These combined data are used together with a DEM in derivation of an open water map (bottom). The open water ma p is shown in a perspective view draped over the DEM.



**Syum (PALSAR mosaic)**

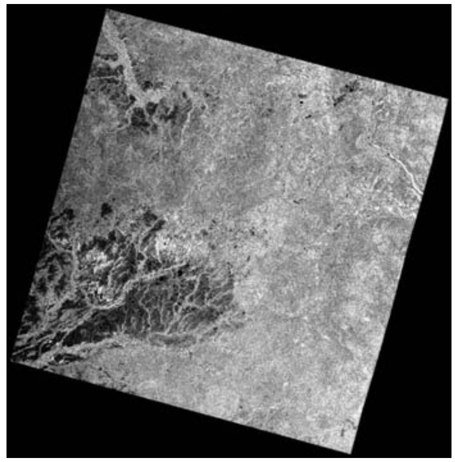


**Syum (Landsat mosaic)**

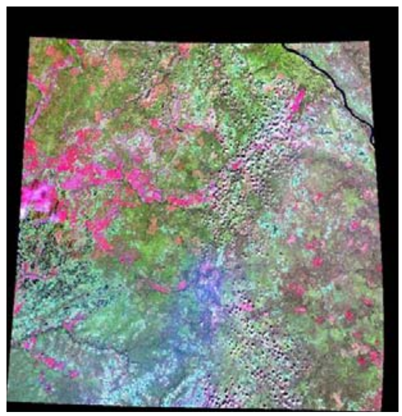


**Syum (open water)**

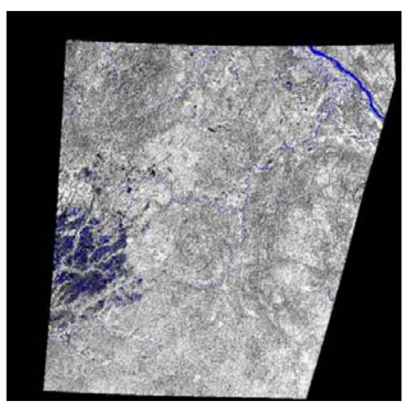
**Figure 9:** Derivation of open water for the Syum basin. A mosaic of fine-beam PALSAR images is assembled (top) and fused with Landsat data (middle). These combined data are used together with a DEM in derivation of an open water map (bottom).



**Yeloguy Basin (PALSAR image)**



**Yeloguy Basin (Landsat fused wit PALSAR)**



**Yeloguy basin open water map**

**Figure 10:** Derivation of open water for the Yeloguy basin. A mosaic of fine-beam PALSAR images is assembled (top) and fused with Landsat data (middle). These combined data are used together with a DEM in derivation of an open water map (bottom).

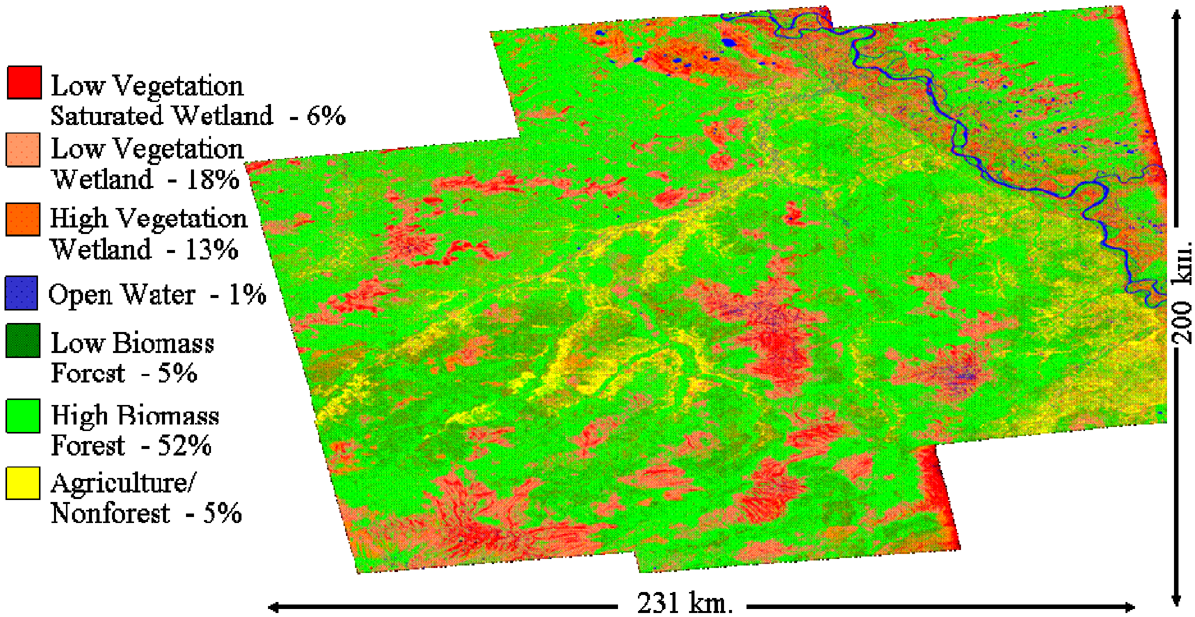



**Figure 11.** Landcover mapping for the Chaya Basin region, focusing on inundated wetland features and derived using ALOS PALSAR with Random Forest classification scheme applied. Landcover classes and the percent regional area covered by each are provided in the key.

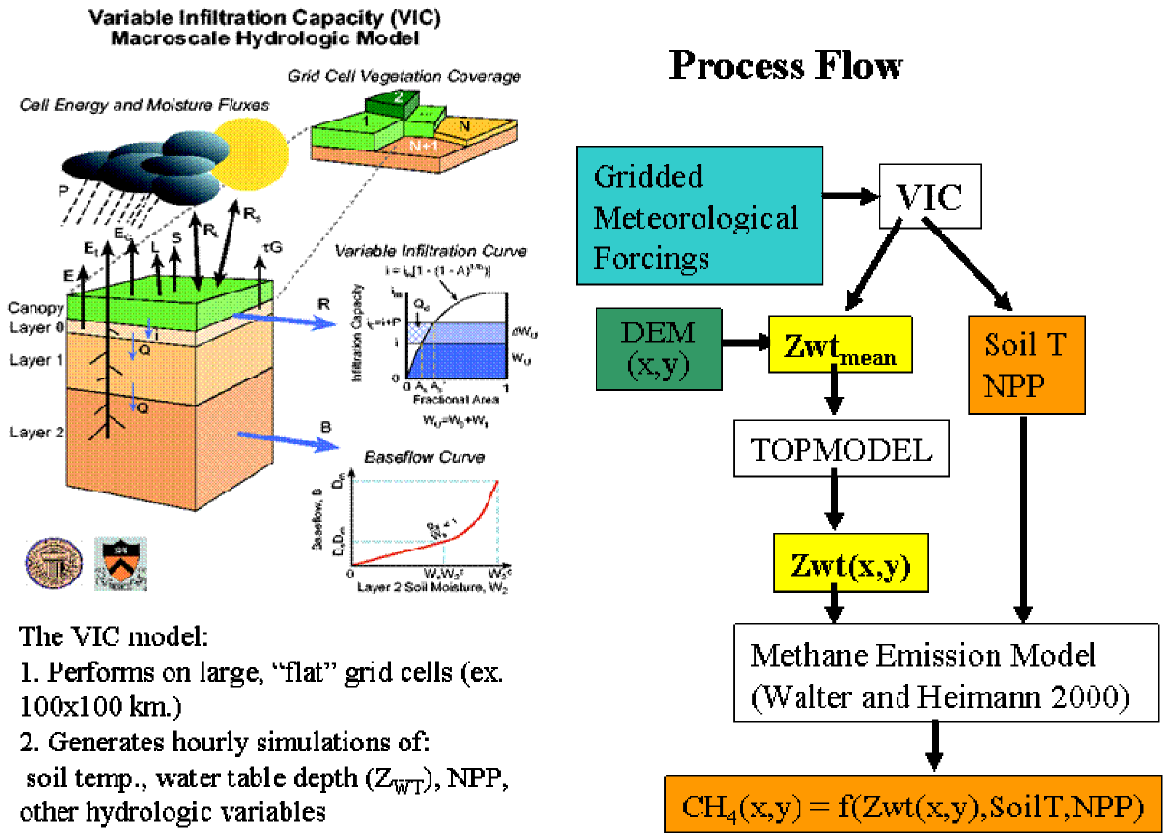



**Figure 12.** Modeling infrastructure utilized in the hydro-methane modeling schema. At left is the structure of the Variable Infiltration Capacity (VIC) model framework. The VIC model provides detailed information on surface hydrology processes, including soil temperature and water table depth. These are two key parameters necessary for estimation of land-atmosphere carbon exchange. At right if the process flow diagram showing the integration of the VIC model within a hydrology-methane modeling construct. This construct is being evaluated as an integrated approach for estimating land-atmosphere methane exchange, as a spatially explicit function of water table depth, soil temperature, and vegetation productivity (NPP) (Bohn et al 2007).

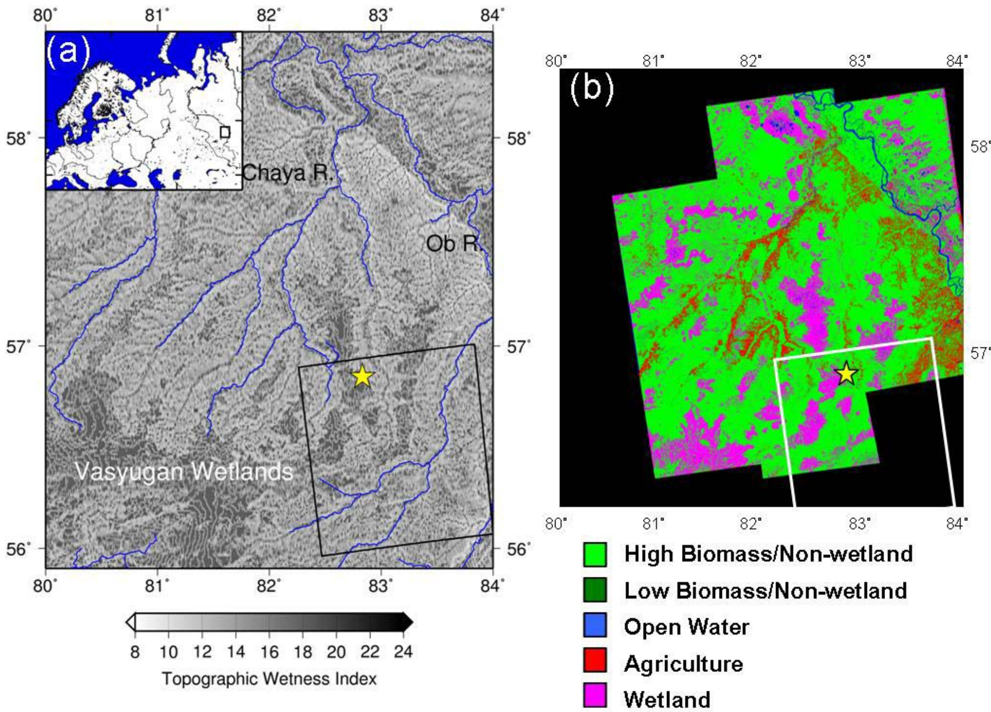



**Figure 13.** Location of the Chaya Basin study region where the hydro-methane modeling framework is being developed and prototyped. At left is a map of the topographic wetness index derived over the region from SRTM DEM. At right is the landcover of the region, derived using random forest classification of ALOS PALSAR imagery. The Bakchar Bog observation site is marked with the yellow star, and the 100 x 100-km EASE-grid cell centered at (56˚ 29’ N, 83˚ 09’ E) is outlined in black (at left) and white (at right). Note the close correspondence between areas of high topographic wetness index (> 14) in the panel at left and areas of wetland in the panel at right.

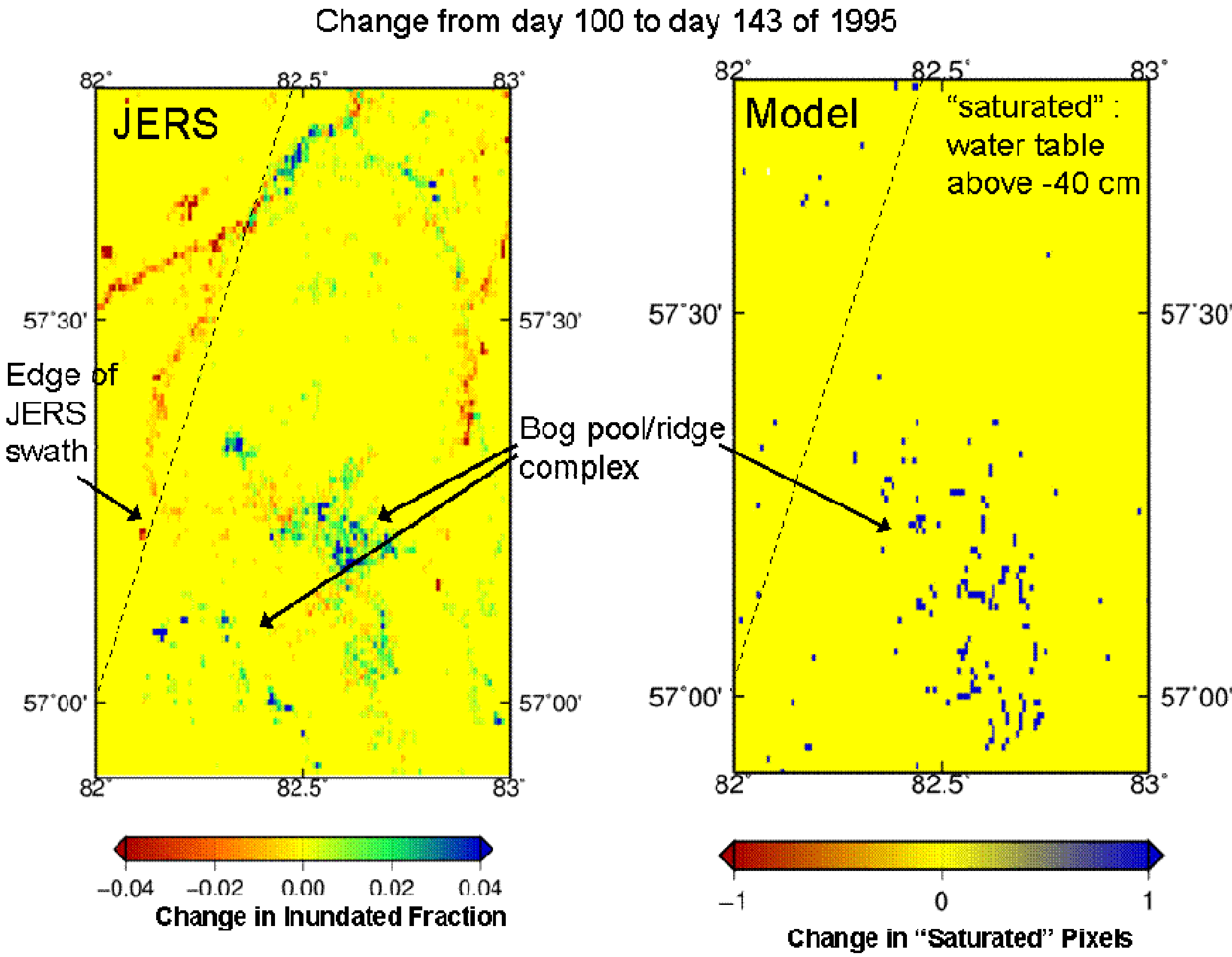



**Figure 14.** Comparison of change in surface inundation derived from JERS SAR (at left) with change in saturated water table derived from the hydro-methane modeling schema (at right) for the Bakchar Bog region of the Chaya Basin. JERS-based maps of open water were derived for year-day 100 and year-day 143 of 1995. Change in inundated area was computed for day 143 relative to day 100 and expressed as a change in inundated area fraction. Blue pixels contained open water on day 143 but not day 100. Red pixels contained open water on day 100 but not day 143. Model-based water table depth was computed for these same days. Saturated soil was defined as that region with water table depth less than 40 cm. The change in water table depth was determined from these modeled data. Change in saturated pixels is defined as the change in water table above 40 cm depth. At right, blue pixels had water table depth shallower than 40 cm below the surface on day 143 and deeper than 40 cm below the surface on day 100. Pixel size is 30 arc seconds. The area identified where increase in saturated pixels is evident corresponds to regions of increased surface inundation as determined from the JERS mappings.

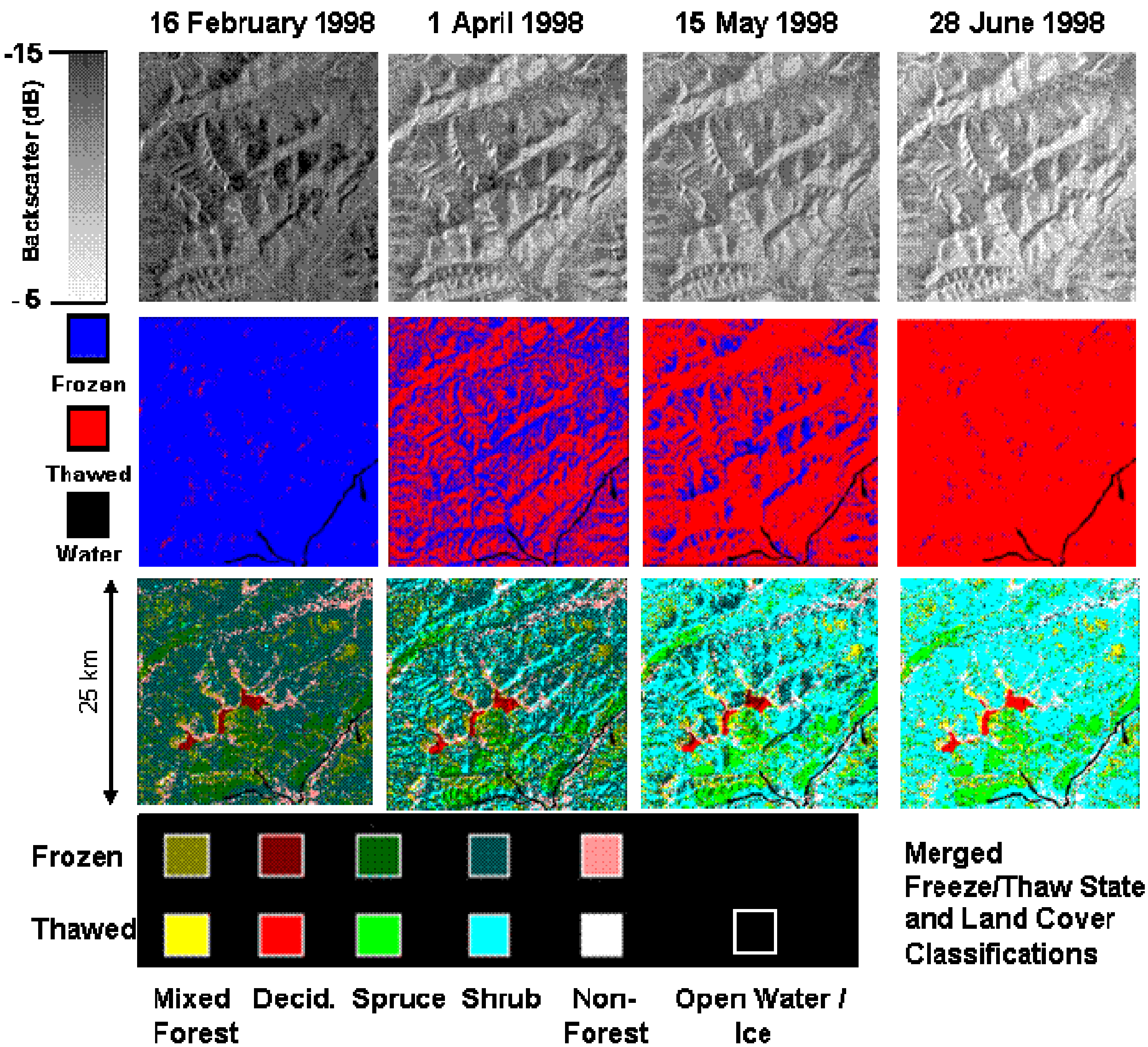



**Figure 15:** JERS SAR applied to map landscape freeze-thaw state for a region of complex landcover in interior Alaska. A seasonal change detection algorithm was applied to time series JERS images (top) to derive landscape surface freeze-thaw state (middle). Combined with a landcover map, the freeze-thaw state may be discerned according to landcover (bottom).This approach facilitates examination of the spatio-temporal dependencies of the seasonal freeze-thaw transitions in complex, heterogeneous landscapes.

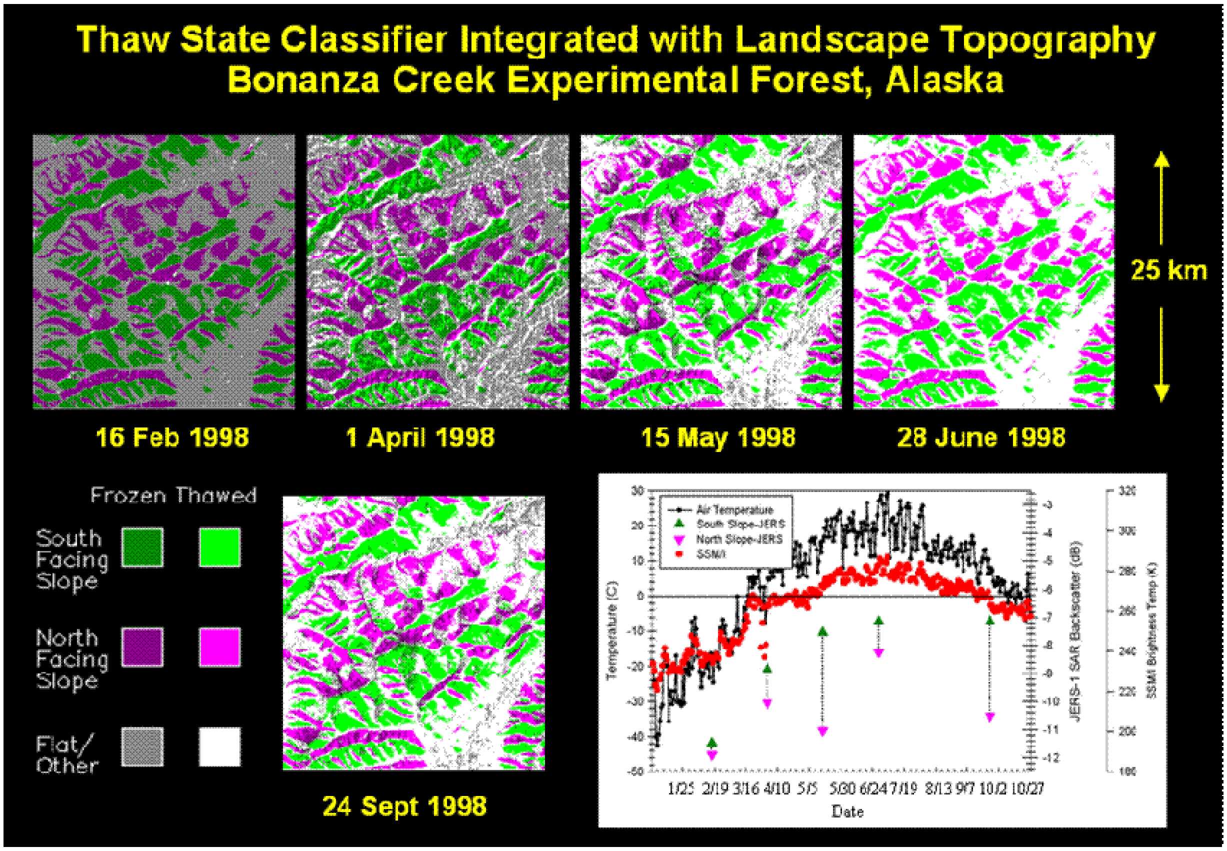



**Figure 16:** JERS SAR applied to map landscape freeze-thaw state for a region of complex topography in interior Alaska. A seasonal change detection algorithm was applied to time series JERS images (top) to derive landscape surface freeze-thaw state. Combined with a Digital Elevation Model (DEM), the influence of surface topography on the spatio-temporal character of freeze-thaw transitions can be assessed. In the time series shown, differences in the spring thaw and autumn freeze series related to slope aspect can be seen (e.g. bottom right graph).