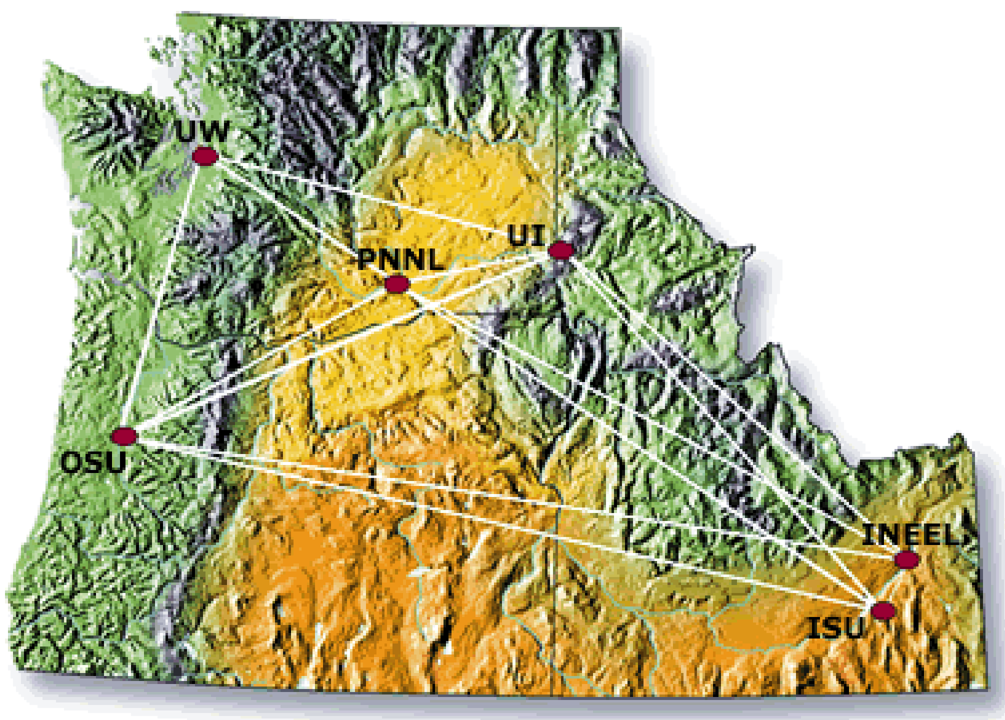
PACIFIC NORTHWEST REGIONAL COLLABORATORY

ANNUAL REPORT FOR SYNERGY VII (2007)



BY

BATTELLE PACIFIC NORTHWEST DIVISION

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PACIFIC NORTHWEST REGIONAL COLLABORATORY

PACIFIC NORTHWEST NATIONAL LABORATORY
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PACIFIC NORTHWEST REGIONAL COLLABORATORY ANNUAL REPORT FOR SYNERGY VII – FY07

1.0 Executive Summary

During this final year of the Pacific Northwest Regional Collaboratory we focused significantly on continuing the relationship between technical teams and government end-users. The main theme of the year was integration. This took the form of data integration via our web portal and integration of our technologies with the end users. The PNWRC's technical portfolio is based on EOS strategies, and focuses on "applications of national priority: water management, invasive species, coastal management and ecological forecasting." The products of our technical approaches have been well received by the community of focused end-users. The objective this year was to broaden that community and develop external support to continue and operationalize product development.

The main technical focus areas and significant outcomes are summarized below:

1. Coastal Applications (OSU and PNNL)

- *Impervious surface mapping* – One critical need for managing nearshore habitat restoration is current data on the extent and spatial arrangement of the impervious surface in the runoff zone. The PNWRC Coastal team has developed new methods to accurately derive impervious surface maps from Landsat and ASTER sensor data. These maps of the amount and distribution of impervious surface can greatly influence the policy of shoreline development.
- *Coastal Planning* – The PNWRC Coastal group has also integrated our coastal data and nearshore expertise into OSU's ENVISION application. ENVISION incorporates both terrestrial and nearshore GIS datasets to examine the impact of changes in shore zone policies on nearshore processes and ecological function. The coastal applications task team (PNNL, OSU) worked closely with the City of Bainbridge Island (CBI) to tailor the application of ENVISION to nearshore issues that the City is currently facing (Shoreline Master Plan updates) and will face in the future (long range land use/growth plan), including development of the impervious surface product that can be utilized in ENVISION.

2. Streamflow Forecasting and Water Planning (UI and PNNL)

- *Snow Cover Mapping Operationalization* – The streamflow working group depends heavily on NASA MODIS products to determine extent and distribution of snowcover. The dynamic snowcover mapping system was developed at Idaho National Laboratory (INL) to provide this information. Development this year included a methodology to measure confidence of snow cover observation/prediction and automatic metadata generation. The spatial area of the mapping has been extended to include all of the Pacific Northwest.
- *The Hybrid Water Model Application* – One thrust of the PNWRC water work group was to extend the functionality of the "hybrid" model to include ensemble forecasting ability in rain-on-snow watersheds. In addition, the model was set up and run in example basins in the

inland northwest (Dworshak) and the Cascades (Snohomish) to evaluate model for short-term to seasonal streamflow forecasts, and the ability to utilize daily remotely-sensed snow cover products and real-time streamflow and meteorology measurements.

- *Snowmelt Runoff Model (SRM) Enhancement and Rollout* – A second thrust of the water workgroup focused on improving the operation of SRM, modeling impacts of climate change, and delivering a GIS-ready tool to end users. The downscaling of the medium range (4-10 day) weather forecasts was improved, and several more watersheds were added to the online streamflow forecast system. A GIS plug-in tool was developed, documented and distributed to interested users to bring SRM functionality onto the desktop of water planners in the region.

3. Rangeland Assessment and Invasive Species (ISU, INL and PNNL)

- *Dynamic Phenology Visualization/MODIS Signature Mapping* – The timing of phenological development in an area can provide critical information on the health and condition of the region. The PNWRC rangeland workgroup collaborated to fuse the spatial growing degree model with cheatgrass phenological data to develop an automatable system for landscape visualization of phenological development. The rangeland team developed a method and prototype visualization tool to exploit the high temporal resolution and global availability of the MODIS data. This prototype, demonstration tool provides dynamic, landscape level, satellite phenological information fused with local GIS data to focus analysis down to a user's site of interest.

- *Cheatgrass Predictive Modeling* – Adaptive multi-scale, multi-species sampling methods are effective at capturing local scale heterogeneity and can be effectively used to estimate species numbers outside of the sample area. A predictive model based on field data and Landsat spectral data was initialized and run. The initial results of the analysis indicate that Landsat, when combined with other landscape variables can be used effectively to predict hot spots.

- *Anomaly Mapping* – The PNWRC rangeland teams developed complementary and distinct methods to identify areas of concern over extremely large land areas using MODIS and Landsat. The information from these mapping techniques can give land managers an indication of land at risk or in poor condition.

- *Sagebrush Canopy Data Fusion* – The rangeland group furthered the development of canopy mapping techniques by utilizing Landsat data in association with high-resolution images of shrub canopy. The approach results in accurate maps of shrub canopy cover which is of particular concern to fire, rangeland and wildlife managers.

4. Homeland Security Application (PNNL, UW – Applied Physics Laboratory)

- *NASA data for Maritime Domain Knowledge* – This effort explored the potential of using new NASA satellite information to develop a proof-of-concept for improving marine domain awareness and coastal security through better monitoring and surveillance. Current and proposed monitoring and surveillance systems depend on reliable knowledge of their ocean coverage. It was shown through this effort that it is feasible to use the sensors from the CloudSat and CALIPSO missions to update and improve model predictions of the lower atmospheric temperature and moisture distributions.

The PNWRC made significant progress towards developing a regional portal to access the PNWRC technologies and data. The NW Explorer (http://nwexplorer.info) is designed to be a system to monitor sustainability indicators that provide an understanding of long-term trends in regional sustainability. This year the focus was for the technical teams to more tightly integrate with the NW Explorer and ad, significant functionality involving three broad areas: 1) improved interfaces for application integration, particularly related to water accounting 2) improved user interfaces including personalization, persistent views, search, and developer support and 3) implementation of a water accounting system allowing a scalable, distributed approach water management and allocation. This cross-cutting regional web portal integrates the four technical project areas will have impact for planners and decision makers in the Pacific Northwest and beyond.

2.0 Achievements in 2007

2.1 NORTHWEST EXPLORER (NW EXPLORER) WEB PORTAL

OBJECTIVES AND GOALS

The objective of the NW Explorer task was aligned with the main PNWRC thrust for the year: to integrate the tools and project descriptions into a regional framework. The NW Explorer portal is the main integration and data delivery tool used for all the technical projects and the goal for the year was to populate the database and improve the data viewing and delivery tools.

TECHNICAL PROGRESS / APPLICATIONS

Personalization Feature and Search Engine Feature Development

Microsoft's ASP.Net 2.0 and SQL Server 2005 personalization and user profile security features was leveraged to create the NW Explorer's personalization feature. User views (or bookmarks) were added to the NW Explorer. After being defined, a user's list of views is always available in the NW Explorer's main menu so that the user can quickly return to a query's results.

The NW Explorer's search engine was enhanced to address the issues of searching dynamically generated content.

Project Partner Web Service Integration, Database Management Enhancements and Web Portal Maintenance

OSU continued to work with PNWRC project partners to help integrate their web services into the NW Explorer. This effort included the continued provision of standards for data and interoperability. OSU developed and implemented protocols to evaluate and maintain the NW Explorer system operation. General improvements to the design of the NW Explorer and its databases were performed as determined by PNWRC project partner's needs, user requests, and site usage patterns.

Water Accountant System Development

A portion of the NW Explorer effort was spent on developing the Water Accountant, IT architecture in support of integrated water resources management of the Columbia and Willamette River Basins. The accountant supported the integration of data from the PNWRC partners and others; support decision making and analysis by water resource managers and users; and provides web-based visualization and analysis tools.

Update and Revision of the NW Explorer User Interface

This was a new goal added to OSU's list as part of adaptive management. The progress included redesigned front page. The new front page showcases the PNWRC project contributions in a graphic list. The list is linked to both in-depth and technical content web pages.

A number of additional generic web page viewers were developed. These included a multi-location map and data viewer, which displays map showing locations where data is available. Also OSU developed the map image viewer for temporal archives of data (used for INL snowcover integration).

Personalization Feature Development

The personalization feature was added to the NW Explorer. This included login, password, and forgotten password features. User views (or bookmarks) were added to accommodate dynamically built web pages that are based on user selections (stored in server session state) across multiple pages. This is termed view persistence. A user's list of views is available in the NW Explorer's main menu so that the user can quickly return to a query's results later without having to rebuild the query. The database was also improved to support the additional personalization functions.

OSU developed a prototype dashboard, user-definable multi-view display configuration, for the NW Explorer. The prototype enabled the assembly of a composite web page consisting of multiple views, e.g., snow cover, hydrographs, and climate forecasts, based on existing bookmarks in the user's profile.

Search Engine Feature Development

OSU verified that the full text search capabilities of text database fields were updated concomitant with dynamic update of content.

Project Partner Web Service Integration, Database Management Enhancements and Web Portal Maintenance

The interoperability schema was revised to accommodate the project partners in their efforts to integrate with the NW Explorer. These revisions did not break existing applications and were backwards compatible with existing implementations. These changes included the following:

- OSU updated the schema and web service definition to accommodate temporal sequences of data. This feature was requested by INL to accommodate their workflow. The change was also reflected in the Explorer via a new viewer that permitted the browsing of a temporal series of snow covers.
- Concomitant with the change in schema, the underlying database was enhanced to support temporal sequences of data. An expiration date was included to specify the deletion of stale data, or to limit the accumulation of data. Also the database was improved to support arbitrary point locations whereas previously data was referenced to only the built-in multi-scale spatial containers.
- OSU revised the schema to permit XML document fragments to be validated against it. To assist project partners with integration and client web service testing, the Developer's Data Integration web-based test page was updated, http://sustainability.pnwrc.org/nwets/default2.aspx.

– Maintenance of the NW Explorer did not continue subsequent to the end of the project terms because of a lack of continuity funding. The lack of continuity funding also impacted the final work on the NW Explorer harvester. The harvester was enhanced to treat the harvests of time-series data, and also the treatment of the archiving of shelf-life limited data.

2.2 COASTAL APPLICATIONS

OBJECTIVES AND GOALS

Bring PNWRC capabilities and tools to bear on the task of assessing alternative future scenarios of change for City of Bainbridge Island in Puget Sound to complement the city's significant new planning effort. Work with the City planning department and with PNWRC partners to map trajectories of growth and development and assess impacts on ecological processes and ecosystem services, particularly related to near-shore habitat protection.

TECHNICAL PROGRESS

Shoreline Master Planning Scenario Development

This effort 1) worked directly with stakeholders and identified alternative sets of land and growth management policies, 2) resulted in the generation of policy relevant spatially-explicit datasets derived from remotely-sensed and other data sources, 3) identified stakeholder-relevant landscape metrics and ecosystem service measures, among them impervious surface and also shoreline ecosystem controlling factors, and 4) demonstrated the use of the alternative futures tool, ENVISION, and generated a starter set of alternative policy scenarios for future review and development by stakeholders.

Working Directly With Stakeholders on the Island

During the first quarter the PNWRC coastal team initiated discussions with end users at City of Bainbridge Island (CBI) about future scenario modeling. During quarter two, the PNWRC partners held discussions with end users at City of Bainbridge Island about future scenario modeling. Subsequent meetings addressed the development of timelines and agendas for posing policy alternatives within the ENVISION model evaluation of Bainbridge Island

Generating Spatially-Explicit Datasets

GIS data files transferred from CBI to the PNWRC coastal team for preliminary assessment. OSU received from PNNL collated, mapped, and formatted data for ENVISION. Additional exchanges occurred to forge an iterative improvement in representation of landscapes on CBI.

Identifying stakeholder-Relevant Landscape Metrics and Ecosystem Service Measures

OSU and PNNL conducted Evaluative Policy workshop with CBI stakeholders for ENVISION input (April 27th, 2007).

Using the Alternative Futures Tool, ENVISION.

OSU performed initial alternative future analysis for CBI and held ENVISION workshop at CBI.

OUTREACH AND INTEGRATION

OSU presented a conference paper titled, Bolte, J., Guzy, M., Woodruff, D., Judd, C., "Alternative Futures Analysis for Bainbridge Island Washington," Puget Sound Georgia Basin research conference (March 26-29).

OSU held an ENVISION coastal planning workshop at the City of Bainbridge Island to present the tool, example results and request updated policy information for subsequent runs.

2.3 STREAMFLOW FORECASTING AND WATER PLANNING

OVERARCHING OBJECTIVE

The objective for this year was to continue to develop and evaluate an improved method for short-term to seasonal streamflow forecasts with the ability to utilize daily remotely-sensed snow cover products and real-time streamflow and meteorology measurements.

TECHNICAL PROGRESS / APPLICATIONS

Snow-Cover Mapping

Snow-Covered Area (SCA) is an important hydrologic variable for both volumetric and daily stream flow forecasting. Satellite data provide the ideal way to map snow cover in mountain regions; in particular the Moderate Resolution Imaging Spectroradiometer (MODIS) Daily Snow Cover Product dataset. However, the utility of these datasets have been limited, due to the large number of scenes that are contaminated with cloud cover. To improve the utility of these datasets for the snowmelt season, a new procedure was developed to predict snow-cover in cloud-obscured areas using a snow occurrence map technique. Results show that this method effectively increases the usefulness of the MODIS Snow Cover product in mapping the daily evolution of snow cover extent.

Objectives and Goals

The primary objectives and goals for the PNWRC snow-cover mapping project were to 1) refine region wide methodology for cloud-free snow cover extent, 2) develop a method for calculating and reporting confidence level for prediction on a pixel by pixel basis, 3) evaluate the potential for the incorporation of other active and future EOS measurements to improve snow cover and snow water equivalent mapping for water management information systems, 4) produce a snow cover extent database for the PNW based on Aqua and Terra Daily MODIS Snow-Cover products and 5) integrate the models and results into NW Explorer

Technical Progress

The snow cover prediction method was successfully applied to the Pacific Northwest with the addition of a dynamic metadata file describing the information content of the cloud-free data product. In addition the entire process was ported from the Unix operating system to windows to facilitate more efficient accomplishment of the automated processing. A prediction confidence methodology was as also developed which assigns a confidence score to each pixel based on the following equation:

CS = (Ratio of Zone Coverage * 0.25 + Ratio of Occurrence * 0.25 + Snow Class * 0.50)

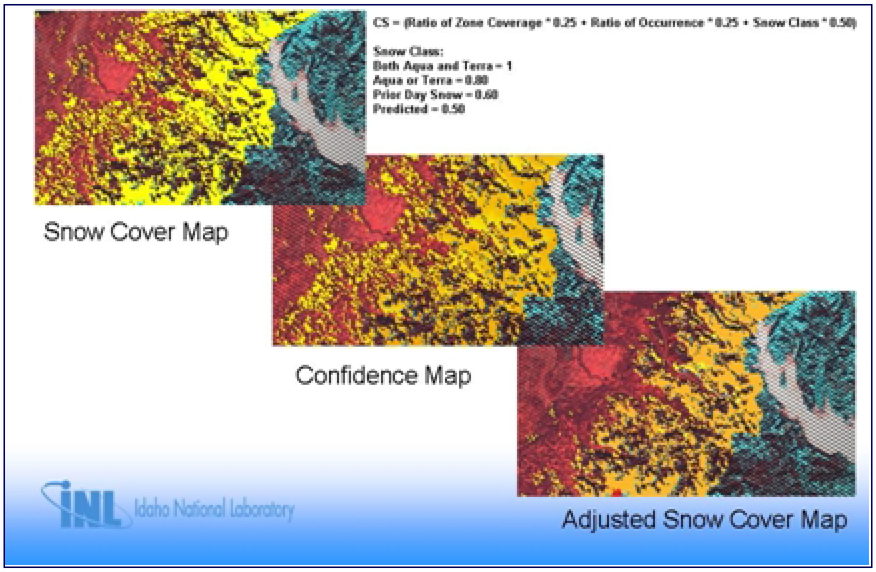

Figure 1. Cloud-Free MOSID Daily Snowcover Confidence Grid

In addition, the entire cloud-free snow cover database has been made available to collaboration partners via an FTP server.

As a follow on, a comparison of derived snow-cover data and NOAA SNODAS data was conducted in two stages. First, 3 individual case studies were performed using Landsat data as truth data. In general MODIS derived snow cover performed better when compared to SNODAS data, which over predicted snow cover area. Presented here is the Teton region study which shows the SNODAS reporting snow cover in valleys which have no cover in Landsat or MODIS data. It is important to note that minimal predictions occur in these scenes due to minimal cloud cover for the dates selected.

The second stage compared a time series of both SNODAS and the derived snow cover data for the Upper Snake River Basin for the April 2007. The SNODAS data consistently reported a greater snow covered area which is in agreement with the stage 1 results.

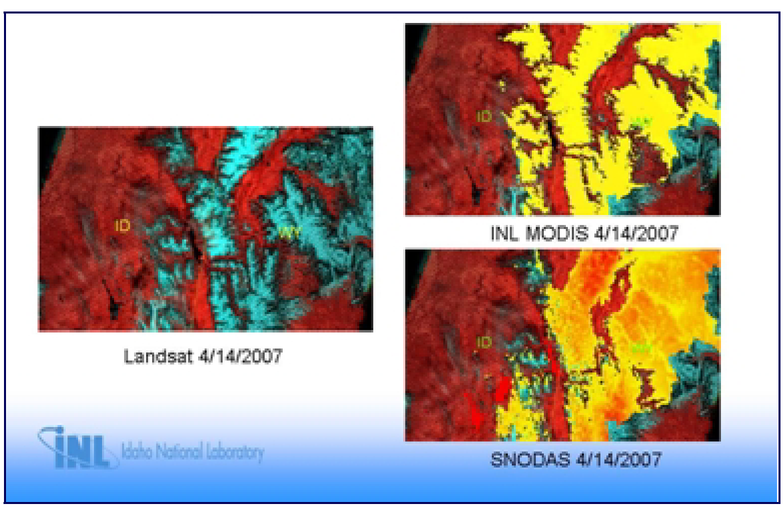

Figure 2. Cloud-Free SCA vs. SNODAS

Outreach

In order to expose the research performed under this project the following outreach was conducted. A paper entitled “Extending the Utility of MODIS Daily Snow Cover Products through Snow Cover Prediction of Cloud Obscured Areas in Idaho’s Big Lost River Basin” was submitted and accepted for publication in Geoscapes Journal (April 08). In addition, this work was presented at the 2007 Western Snow Conference and the 2007 Inland Northwest Research Alliance Environmental Sensing Symposium. Contacts were made at both conferences and future collaborations with Boise State University and The University of Montana are possible.

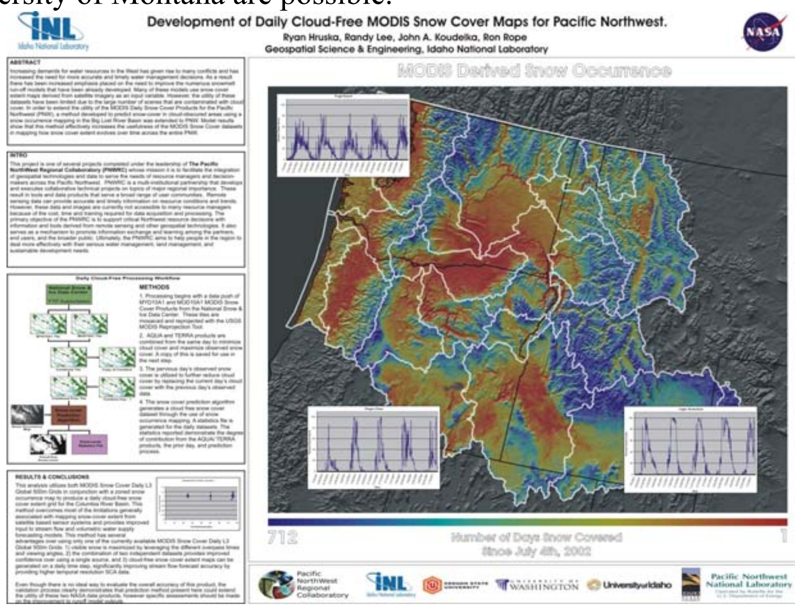

Figure 3. Development of Daily Cloud-Free MODIS Snow Cover Maps for Pacific Northwest (Ryan Hrusk, Randy Lee, John A. Koudelka, Ron Rope, Geospatial Science and Engineering, Idaho National Laboratory)

Integration with the NW Explorer was also accomplished; models results are posted daily and exposed via a webservice to the explorer for ingestion.

Snowmelt Runoff Model (SRM)

Objectives and Goals

The objective of the SRM method in the PNWRC were to 1) implement SRM within Arc-GIS to complete package/tool set for model input and operation (Python programming), 2) provide training to end users on Arc-based tools for model input and model operation, 3) extend model implementation and real-time forecasting in 2007 snowmelt season to several basins, including basins with significant rain-on-snow events; make data available in real time to NW Explorer

We also developed equations for downscaling of medium-term (1-14 days) air temperature forecasts for 150 stations in WA and OR, performed real-time downscaling for 127 stations in Idaho, western Montana, OR and WA to provide updates to NW Explorer in real time

Technical Progress

The PNWRC water team Completed the development of equations for the downscaling of air temp forecasts for OR and WA stations (150 stations) as well as downscaled global climate scenarios out to the year 2100 for predictive runs of the SRM. The real-time forecasts for the Big Wood, North Fork of the Clearwater, and the South Fork of the Boise for 2007 snowmelt season were delivered and made accessible via the NW Explorer.

Significant effort was put forth devising a method to downscale the precipitation forecasts so that they can be incorporated into the ensemble streamflow forecasting process. Uncertainties in the downscaled temperature and precipitation values within watersheds can be used to generate an ensemble of possible streamflow values – initial testing for ensemble forecasting done in the Big Wood Basin for the 2007 snowmelt season.

The beta version of the ArcGIS-based-SRM modeling package was completed and was used for training in the Feburary trainings sessions for end users (see outreach section below). This plug-in features a tool for automatic watershed delineation within a Digital Elevation Model (DEM) based upon location of streamflow gauge and a tool for disaggregating basins into elevation zones.

Outreach and Integration

U of I hosted training sessions on the Snowmelt Runoff Model Toolbar in Boise (mid-Feb). The 2.5 day session attended by NRCS, IDWR, COE and PNNL personnel. (includes input data prep tools as well as real-time forecasting)

PNNL and University of Idaho water group met with U.S. Army Corps of Engineers (USACE) Walla-Walla staff to present and discuss PNWRC capabilities and tools for enhanced streamflow forecasting.

The University of Idaho's Snomelt Runoff Model (SRM) ArcGIS extension was requested by Yale University group for summer workshop to model peak flow timing in the Salmon River Basin for a NASA DEVLOP program.

University of Idaho watershed group is currently working with Ron Abramovich (NRCS-Boise) to set up the ArcGIS version of SRM to model the Upper Snake River at Flagg Ranch near Moran, WY.

The PNWRC water team had a significant presence at the Western Snow Conference, April 2007 actions included:

- Short course: Snowmelt Runoff Model Toolbar during the 75th Annual Western Snow Conference.
- Paper: Harshburger, B.J., B.C. Moore, T.R. Blandford, K.S. Humes, V.P. Walden "Evaluation of Streamflow Forecasts for Multiple Basins in the Pacific Northwest

Using an Enhanced Version of the Snowmelt Runoff Model." Award: 2007 James E. Church Award for the Best Student Paper.

Journal articles (in preparation, submitted and in press):

- Harshburger, B.J., T.R. Blandford, K.S. Humes, V.P. Walden, B.C. Moore, R.J. Dezzani "Spatial Interpolation of Snow Water Equivalency Using Surface Observations and Remotely Sensed Images of Snow-covered Area."
- Harshburger, B.J., T.R. Blandford, K.S. Humes, V.P. Walden, "Real time forecasts for Big Wood, North Fork of the Clearwaters and the South Fork of the Boise."
- Blandford, T.R., K.S. Humes, B.J. Harshburger, B.C. Moore, V.P. Walden, H. Ye, Seasonal and synoptic variations in near-surface air temperature lapse rates in a mountainous basin, Journal of Applied Meteorology and Climatology, in press.

PNWRC members of the UI team attended the IDWR sub-committee Climate Change Impacts to Water Supply workshop, and gave a presentation on improved forecasting capabilities. The team also attended and gave a presentation on streamflow forecasting and climate change at the first annual Idaho Environment Workshop, organized by the Nez Perce Tribe with partners from more than 15 local, state and federal agencies.

The UI and PNNL water teams met with end users at the Army Corp of Engineers in Walla Walla, WA to demonstrate forecasting tools.

The U of I water team attended the Idaho Climate and Water Resource Forecast for 2007 Water Year and the annual Mountain Climate Workshop in September 2006 where they presented a poster on the climate downscaling capabilities developed under PNWRC.

University of Idaho's watershed group has been in contact with Ahmed Tekeli who is employed by the Turkish State Meteorological Service about the ArcGIS-SRM version (contact from Western Snowmelt Conference)

SRM Late-Breaking News

The student team supported by PNWRC has formed a consulting company and recently won a Phase I SBIR from NASA:
http://sbir.gsfc.nasa.gov/SBIR/abstracts/07/sbir/phase1/SBIR-07-1-S6.04-8590.html?solicitationId=SBIR_07_P1

Hybrid Hydrological Model

Objectives and Goals

The objective of this portion of the PNWRC water task was to continue development and application of an ensemble streamflow forecasting system using data assimilation of streamflow and spatial snowpack that considers explicitly the uncertainty in meteorological forecasts, model structure and parameters, and the observations used for model updating. A simplified version of the Distributed Hydrology Soil Vegetation Model (Wigmosta et al. 1994, 2002) was developed at the Pacific Northwest National

Laboratory (PNNL) and is used to model snow and moisture states using ensembles of past meteorological traces. Primary inputs to the model include observed precipitation, mean air temperature, elevation, and land cover. Uncertainty in weather forecasts is addressed explicitly by using ensembles of possible future meteorological realizations to drive the model. This approach allows the model to be updated with spatial snow cover and measured streamflow using an Ensemble Kalman-type data assimilation strategy.

Technical Progress

The Hybrid Hydrological Model was developed to estimate unregulated streamflow at the outlet of a drainage basin. Spatial variability in basin characteristics and meteorology is represented using a raster-based computational mesh (Figure 4) at a spatial scale consistent with the remote sensing product in use (e.g., 500 m for MODIS). Snow accumulation and melt, evapotranspiration, and simplified vertical soil water movement are simulated in each computational unit (i.e., cell). Downward percolation out of the soil-rooting zone from each cell is summed for all computational units, each time step, and input to the subsurface saturated zone, which produces streamflow at the basin outlet. Any surface runoff produced is also aggregated and assumed to leave the basin during the time step it was generated. The Hybrid Hydrological Model does not allow explicit cell-to-cell water flow routing. Instead, surface runoff and subsurface flow are aggregated at the basin scale.

Model output ensembles are produced using ensembles from past traces of meteorological forcing as a surrogate for the future conditions. The approach also accounts for model parameter uncertainty through a sampling strategy within the calibrated parameter space. Nine parameters in the hydrologic model are determined through calibration. An evolutionary computation optimization scheme called "Particle Swarm Optimization (PSO)" is used to calibrate the model (Eberhart and Kennedy 1995; Gill et al. 2006). The calibration is performed in a way such that multiple initializations are simulated to search within the plausible parameter space, each giving a so-called optimal parameter set; thus, defining a narrowed region (also called feasible region) within the parameter space giving equally feasible solutions. Each ensemble of meteorological input is run with a parameter set sampled from the feasible region, thus giving an ensemble of model output (streamflow in this case). This approach not only accounts for uncertainty within the inputs and the parameters but also reduces the computational burden required to run individual ensemble members.

For this study, observed streamflow refers to daily inflow to the Dworshak Reservoir estimated by the USACE using a mass balance approach based primarily on measured changes in pool elevation and the amount of water released from the dam. The potential error associated with back-calculating inflow via mass balance is expressed using an ensemble of estimated inflows. With this approach, the ensemble of model output generated using a meteorological ensemble and sampling from the feasible parameter space, is combined with the ensemble of streamflow observations to update the model state. This is done by using a data assimilation scheme called Ensemble Kalman filter (EnKF). The model output ensemble is assimilated with the observation ensemble using a weighting scheme, which is governed by the covariance of the model and the observation ensemble. Thus, as the observation error covariance approaches zero, the actual measurements (i.e., inflow estimates) are trusted more and the model output is trusted less. Similarly, as the model estimate error covariance approaches zero the observations are given less weight and the predictions are given more weight.

The EnKF assimilation scheme is outlined in Figure 5. During a given time step, a single parameter set is selected from the feasible region and the model is run for the first meteorological ensemble member, then a second parameter set is selected and the model is run for the next meteorological ensemble member. The process is repeated for all ensemble members, generating a model output ensemble. The model output ensemble is then assimilated with the observation ensemble via EnKF to update model states and the process is repeated for the next time step. The EnKF approach developed in this study accounts for: 1) Model Parameter Uncertainty, where the model is calibrated with historical data to obtain best parameter sets that yield equally feasible solutions;
2) Meteorological Forecast Uncertainty, where an ensemble meteorological forecasts is generated by sampling historical record based on similarity (Hausdorff Norm) of current conditions with previous years; the model also allows ensembles of short-term forecasts from numerical weather models to be used; 3) Model Uncertainty, where for each forecast ensemble member a parameter set is drawn from the equally feasible region assuming a uniform distribution and the model is run, generating ensemble output;
4) Observational Uncertainty, where an ensemble of observations is generated using measured values and estimated measurement error (streamflow and snowpack properties), and 5) Data Assimilation with Ensemble Kalman Filter, where the covariance of ensembles is used for weighting to update model soil water storages and model snow properties.

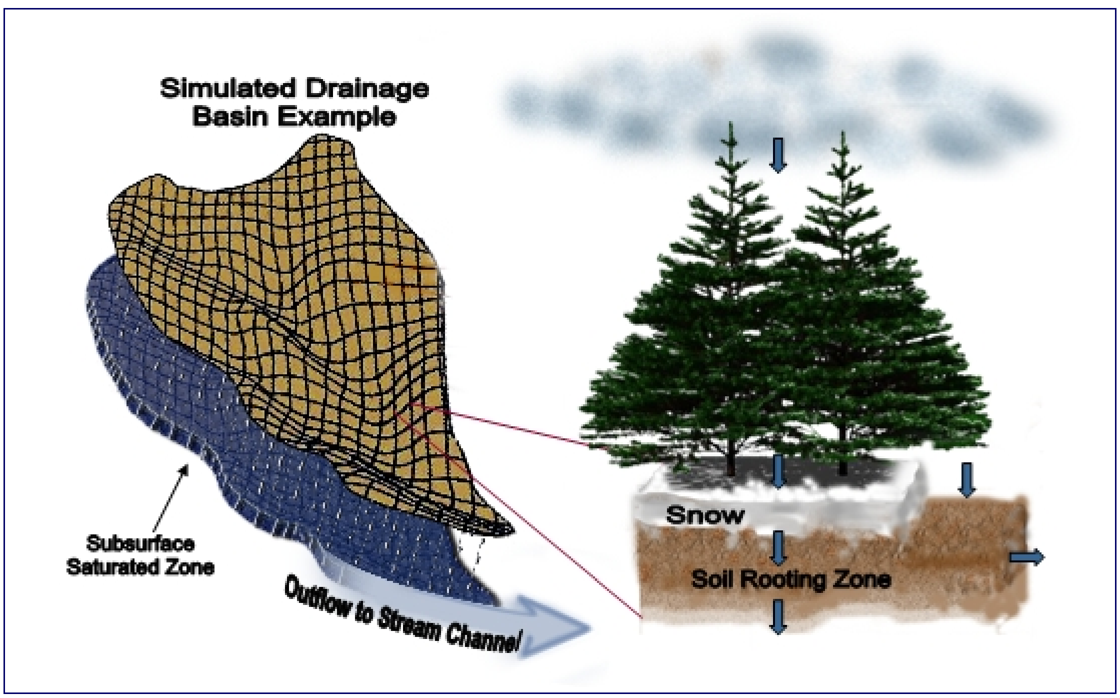

Figure 4. Hybrid Hydrolgical Model

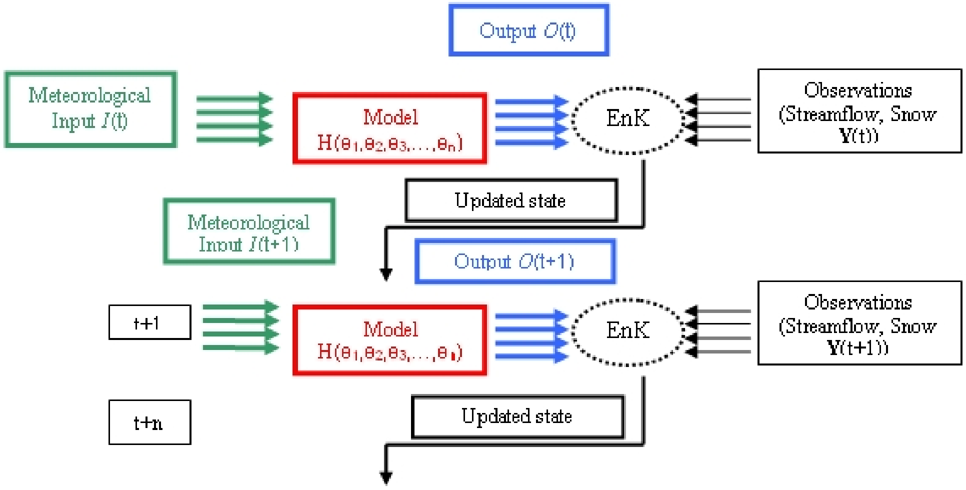

Figure 5. Flow Diagram for Ensemble Updates Showing the Modeling Process

Dworshak Inflow Forecasts

The streamflow forecasting methodology is applied to the 6325-km^2 Dworshak watershed in north-central Idaho (Figures 4 and 7) and compared to the NRCS volumetric forecasts and to daily inflows estimated by the USACE. The Dworshak watershed is located within the greater Snake and Columbia River watersheds and is characterized by mountainous and rugged terrain with elevations ranging from 300–2400 m. This area exhibits a dominant land cover of coniferous forest and hydrography is generally an east to west flowing system with high-gradient streams. The watershed is typified by orographic-influenced precipitation events sourced from Pacific-based moisture where the long-term mean annual precipitation ranges from 700 mm in the lower elevations to 1650 mm in the upper reaches of the basin. Temperature and precipitation lapse rates are used to distribute meteorological inputs to all model grid cells using an elevation difference approach.

Figure 6. Location of the Dworshak Watershed in North-Central Idaho

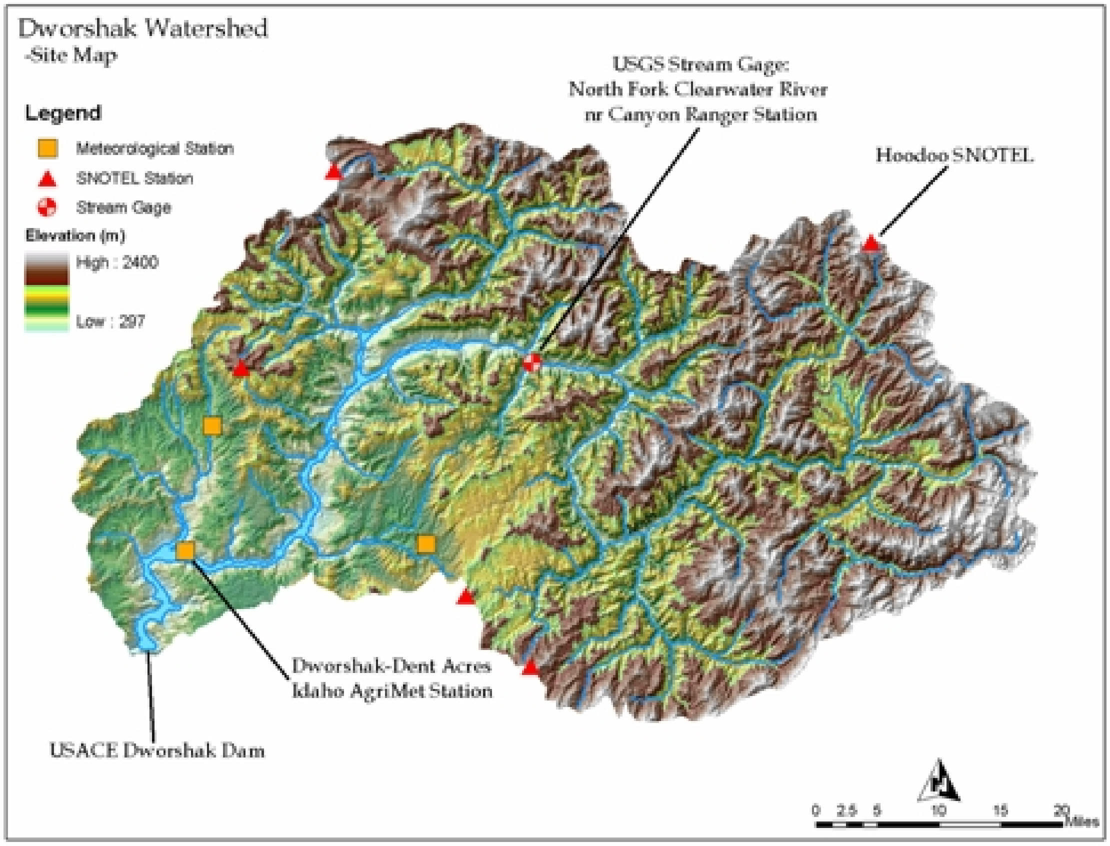

Figure 7. Site map of the Dworshak Watershed Showing Instrumentation Sites

The NRCS issues seasonal streamflow volume forecasts for the Dworshak Reservoir during the melt season (April to July) each month starting in October. These estimates are based on multiple regression techniques using snow, precipitation, and streamflow observations from the previous months. For comparison with the NRCS volumetric forecasts, the daily ensemble forecast volumes are aggregated from April through July to provide total forecast volumes.

As a first case, the results of the streamflow volume forecasts in this paper are compared to those issued by NRCS on October 1st (without updating). In the second case, the ensembles are updated using streamflow until the end of February, with no update from there on. The volume forecasts from April through July are then compared with results from NRCS issued on March 1st. The cases are shown by a schema in Figure 8.

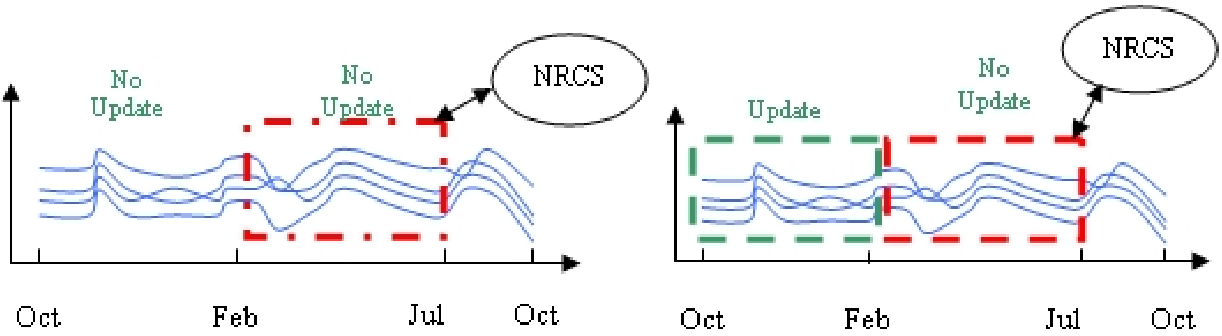

Figure 8. Approach for Streamflow Updating, (a) No Streamflow Updating for the October 1 Forecasts, (b) Observed Streamflow Was Used During the October – February Timeframe to Update the Model Prior to March 1 Forecasts

System Application – Short-Range Forecasts

System Application - Short-Range Forecasts

The one-, three-, and seven-day model forecast results for the WY 2006-2007 are shown in Figures 9 - 11. These results are obtained using model simulations forced with historical climate traces as a surrogate for the future climate (WY 2006–2007). The model ensemble spread is shown in the shaded region where as the observations are plotted as the red line. Notice that the forecasts model ensembles agree with the observations and the 1- and 3-day ensemble spread brackets the observations for the entire time period. In addition, notice that the model ensemble spread becomes greater as the lead time and magnitude of the streamflow becomes greater.

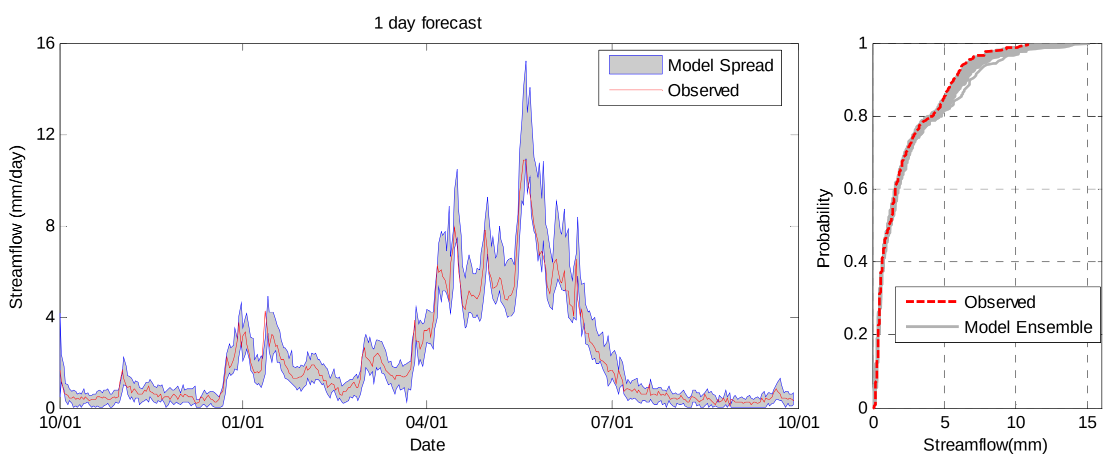

Figure 9: Streamflow forecasts 1-day

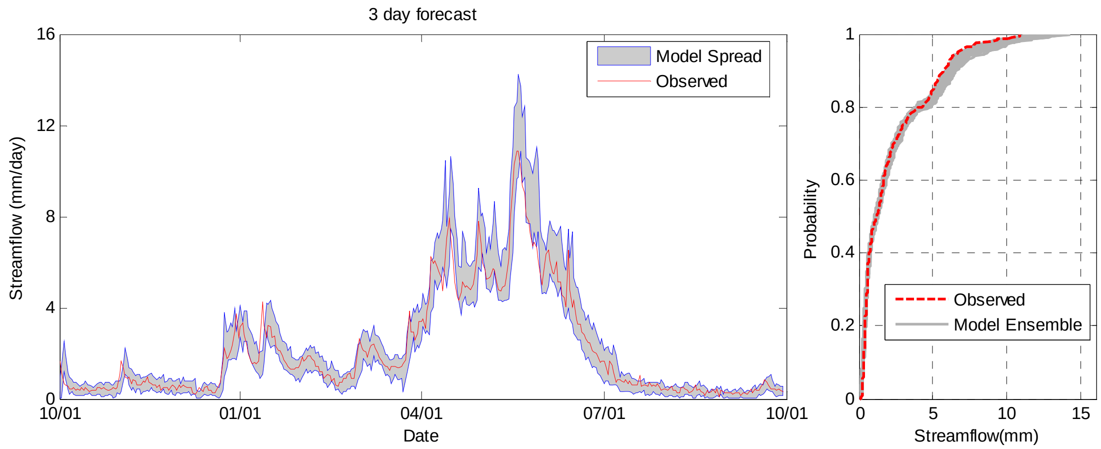

Figure 10: Streamflow forecasts 3-day

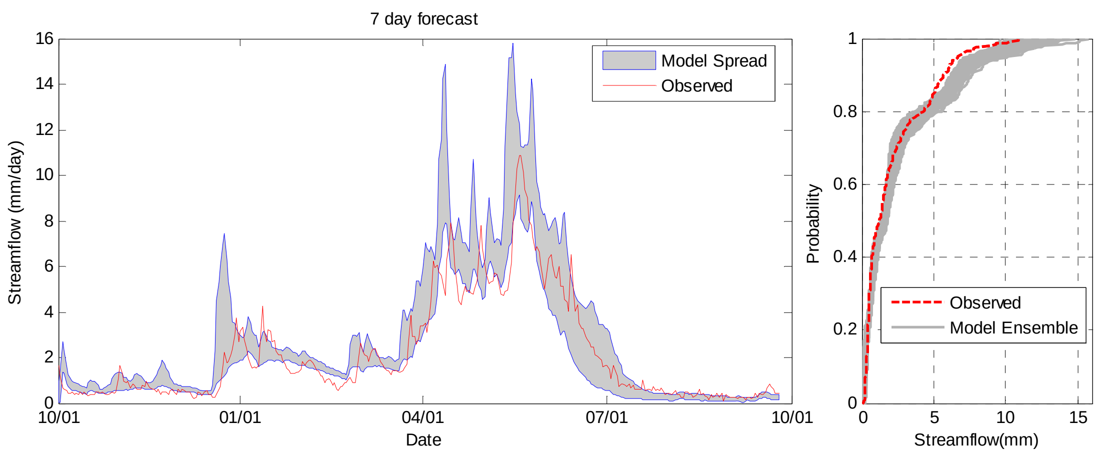

Figure 11: Streamflow forecasts 7-day

The results for root mean square error (RMSE), Nash-Sutcliffe efficiency coefficient (NS), bias, mean absolute error (MAE), mean square error (MSE), and coefficient of determination (R^2) are summarized in Table 1. The goodness-of-fit results show a good fit between the forecasts and the observations. It is further noticed that the values deteriorate as the forecast lead time increase.

Table 1: Forecast goodness-of-fit

	k-day Forecasts		
	one-day	**three-day**	**seven-day**
RMSE	0.48	0.58	0.97
NS	0.95	0.93	0.82
Bias	-0.13	-0.11	-0.31
MAE	0.29	0.34	0.59
MSE	0.23	0.33	0.95
r^2	0.97	0.95	0.89

System Application – Seasonal Volumetric Forecasts

Volumetric forecasts are estimated for the melt season of April-July for the water years 2000-2007. October 1st forecasts show a slightly better correlation coefficient (0.2) than the NRCS (0.002), but the results are generally poor. In the second phase, an EnKF scheme was used to update model states using daily streamflow observations till March 1st and no update was done for the rest of the year. The March 1st R^2 is 0.85 for the current method compared to 0.64 for NRCS forecasts (Figure 12).

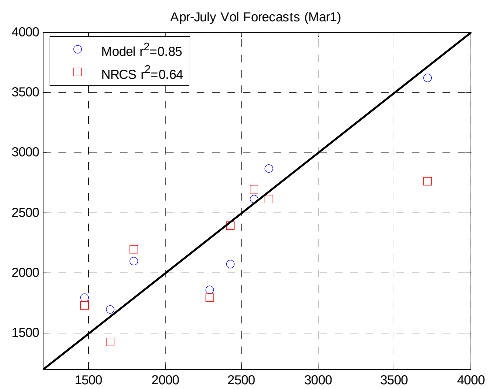

Figure 12: Streamflow volume forecasts for April-July issued on March 1st .

OUTREACH AND INTEGRATION

A number outreach activities were conducted over the last year including meetings with the NRCS Portland Forecast center staff, Bureau of Reclamation staff, and multiple meetings with USACE Walla-Walla staff. These potential end users were enthusiastic about the ability to more accurately predict water flow and the effect it could have on optimizing dam operation.

Other significant interactions included:

- Two meetings with Dungeness River Management Team members and a meeting with Peninsula College students and staff.
- A poster was presented and the Western Snow Conference and three papers will be presented at the American Geophysical Union Fall Meeting.
- A paper was published in the Proceedings of the 75th Annual Western Snow Conference and a manuscript will be submitted to Water Resources Research in January.
- This work also contributed to enhancement in methodology on U.S. ACE contract "QEQUAL-W2, Watershed Hydrologic Modeling, and Water Temperature/Flow Optimization of the Dworshak Reservoir/Lower Snake River System."

2.4 Rangeland Assessment and Invasive Species

Objectives and Goals

The PNWRC rangeland team focused on 4 primary thrusts during this working year: dynamic phenology visualization, cheatgrass predictive modeling, MODIS signature/anomaly mapping and sagebrush canopy data fusion. The objective was to develop these tools such that they can be integrated into the current decision-making paradigm at federal, state and local resource management agencies.

Technical Progress

Dynamic Phenology Visualization

Temperature is a primary factor affecting cheatgrass growth and senescence. Temperature is easily determined for discrete points where weather station data are available. However if one wants to look at spectral response in imagery with respect to temperature, these data must be interpolated across the landscape. Since the primary physiographic factors affecting temperature and available moisture are elevation, aspect and slope, available digital elevation models (DEM) can be used to create a spatially continuous temperature map from which one can derive growing degree day maps. The growing degree days are then accumulated throughout the growing season to exploit the relationship between the Cumulative Growing Degree Day (CGDD) and plant phenology. Stratification of the landscape and remote sensing imagery by cumulative growing degree day can assist with analyzing spectral and phenological data.

Cumulative growing degree day grids were created for the years 2000 through 2007 (April) for the Snake River Plain. A method, script and data set now exist and are being used to support the other objectives of this work. Additional efforts to verify the CGDD model's accuracy still needs to occur. Once confidence in this model is secured, it can be used to support decisions that use this information to schedule management activities such as pesticide application, grazing management, research on climate change trends and its effects on flora and fauna phenology. This same model can also be used with modeled, future temperature data for analyzing the effect of climate change scenarios on the timing of phenological development.

The cheatgrass phenological response model was developed using the CGDD grids. Developing phenological response models for other species (both flora and fauna) could support scheduling of management activities where phenological timing is critical to maximize effectiveness.

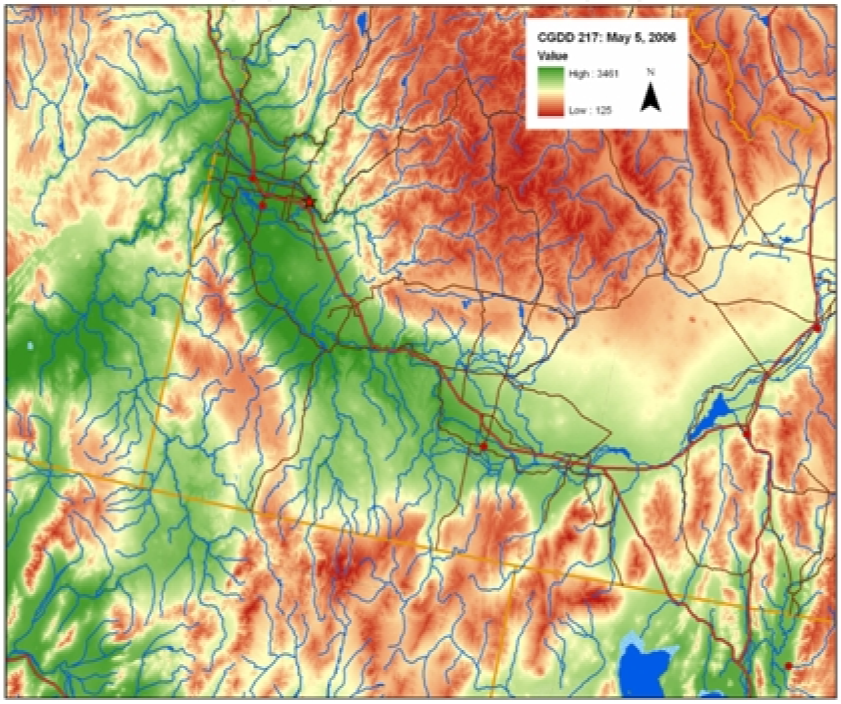

Figure 13. May 5, 2006 CGDD grid Cumulative Growing Degree Days for the Snake River Plain Beginning October 1, 2005

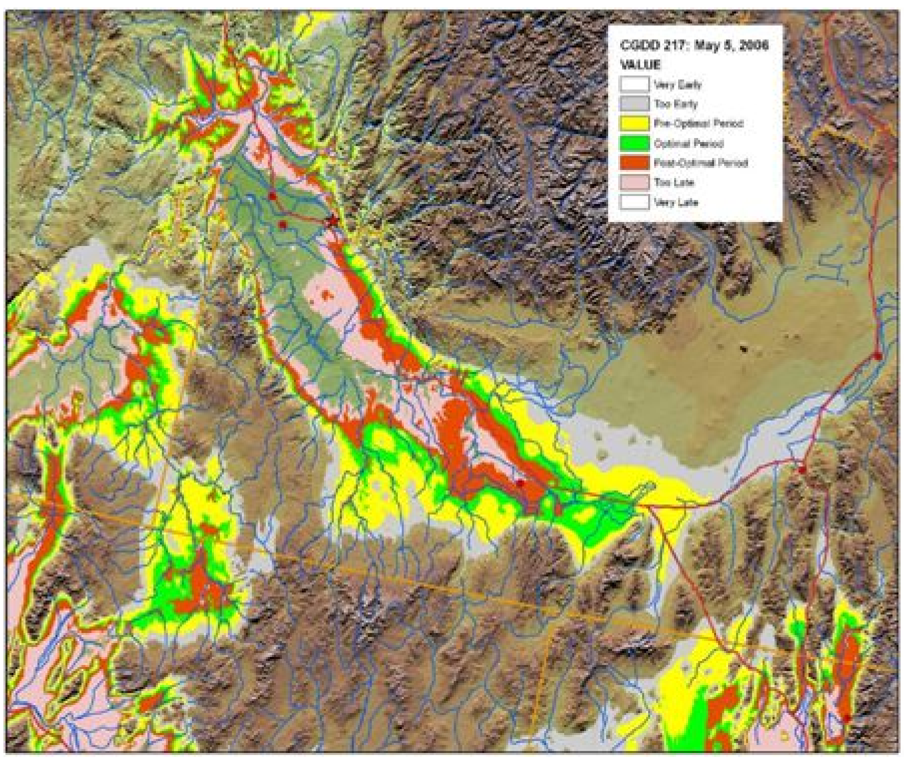

Figure 14. Status of Phenological Progression of Cheatgrass on May 5, 2006 Optimal Image Acquisition Period to Detect Cheatgrass

Cheatgrass Predictive Modeling

Background

Understanding the distribution of invasive species across the landscape is imperative for preventative treatment to decrease the spread of invasives, preserve wildlife habitat, and sustain biodiversity. Just as importantly, knowledge of the distribution of invasives such as cheatgrass (*Bromus tectorum*) is paramount to reducing the risk of large wildfires.

Field measurements of invasives are time consuming and incomplete over large tracts of land. Remote sensing can play an important role in identifying invasives across the landscape. However, the scale of remote sensing measurements may not lend itself to identifying small patches of weeds. Thus, new methods are needed to aid in the prediction of invasives over large areas.

Idaho State University is developing methods to identify the probability of occurrence of invasive species such as cheatgrass (*Bromus tectorum*) over a demonstration area in the USDA Reynolds Creek Experimental Watershed in Owyhee County Idaho. This demonstration area is used to model cheatgrass prediction (where cheatgrass is present and is not present with assigned probabilities). The prediction maps (Figures 1 and 2). represent areas that are susceptible to invasion. Since the model utilizes temperature data, future climate data can easily be input for predictions of distribution and spread of invasive species under this altered regime.

Methods

In summer 2006 over 100 multi-scale plots were sampled. We identified individual plant species and recorded location, slope, elevation, and the total number of species (native and non-native). In addition, the percent cover of cheatgrass, shrub, bare ground, rock, litter, moss, dead wood and dung was ocularly estimated. This point data set was combined with corresponding remote sensing indices such as the normalized difference vegetation indices (NDVI) values from Landsat 5 (May 1 and June 18, 2006). The statistical software package SYSTAT was used to preliminarily analyze this data to help identify variables most useful in predicting areas of high cheatgrass cover, number of natives, and number of non-natives. To predict a range of cheatgrass cover across the field area, we applied a maximum entropy model (Maxent; Phillips et al., 2006) to cheatgrass point data and a suite of continuous raster variables, including shrub cover, soil texture, elevation, slope, climate data (cumulative growing degree day grids), and remote sensing indices derived from Landsat 5 (May 1 and June 18, 2006).

Results
Cheatgrass

Decision Tree Classifications calculated in SYSTAT for cheatgrass cover indicated that, in areas of low cheatgrass cover, the predictor variables most influential for cheatgrass were total number of species, number of invasives, shrub cover, and NDVI. In areas of high cheatgrass cover, the most important predictor variable was the NDVI. The Maxent model was subsequently designed to include a continuous map of shrub cover, and additional remote sensing indices, include wetness, greenness, and brightness. Maxent results indicated that, for cheatgrass presence, the predictor variables with the greatest contribution were climate, shrub, soil, greenness and brightness. Variables that contributed the most in predicting areas of cheatgrass absence were climate, wetness, curvature, and soil texture.

Advancements and Conclusions

Adaptive multi-scale, multi-species sampling methods are effective at capturing local scale heterogeneity and can be effectively used to estimate species numbers outside of the sample area. We used stepwise regression statistical analysis to identify the most important predictor variables from field or remotely sensed data for identifying cheatgrass and the number of invasives across the landscape. These predictor variables were then used to develop a predicted surface of cheatgrass distribution with Maxent.

These analyses are meant to serve as spatial indicators for the BLM to perform more specific and intensive field surveys to investigate cheatgrass ‘hotspots’. This will provide important first step towards planning for long-term management and trend analysis. These spatial maps can be used to prioritize areas for monitoring, control, and treatment. With funding from the BLM to continue work on cheatgrass, we will focus on susceptibility to invasion and future cheatgrass distributions with future climate scenarios.

MODIS Signature / Anomaly Mapping

Data from the MODIS sensor is underutilized for local scale analyses because of the relatively low spatial resolution of the sensor. However, the temporal resolution of the sensor is very high compared to other space-borne sensors (Landsat, SPOT etc.). In addition, the cost per acre of MODIS data is extremely low. When these data are utilized for visualizing rangeland condition and status, the relative value (benefit/cost ratio) is extremely high. The PNWRC rangeland team has developed a method and prototype visualization tool to exploit the high temporal resolution and global availability of the MODIS data. We have further combined the MODIS NDVI information with existing landscape decision unit GIS data so the user can take advantage of the information fusion and synthesis without having to perform complex GIS overlays.

The results of this analysis are included in a web demonstration toolset that has been favorably reviewed by BLM and USGS rangeland specialists at workshops through the northwest.

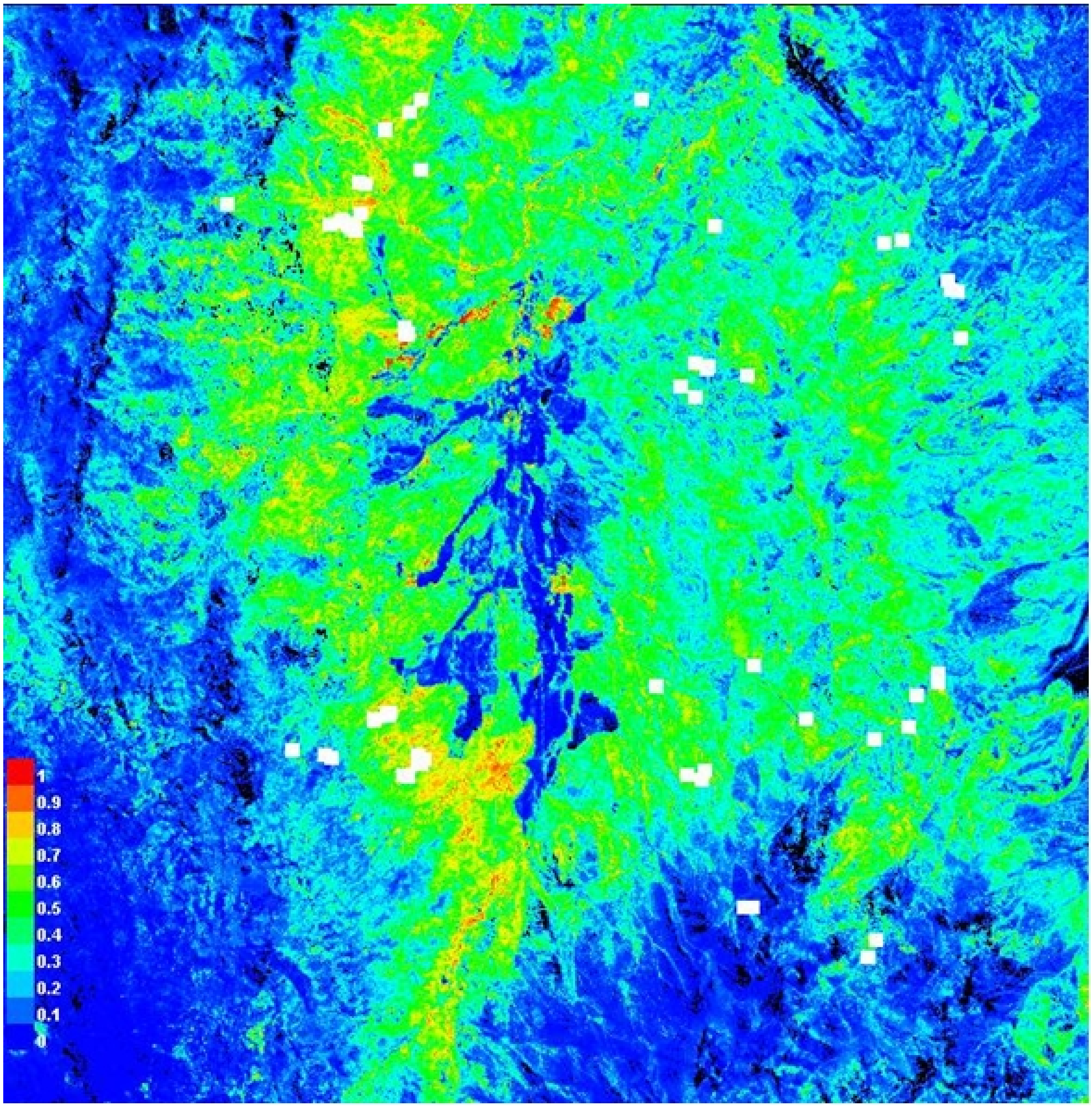

Figure 15. Maxent Model for Cheatgrass Presence: Warmer Colors Show Areas With Better Predicted Conditions for the Occurrence of Cheatgrass, White Dots Show the Presence Locations Used for Training, and Violet Dots Show Test Locations

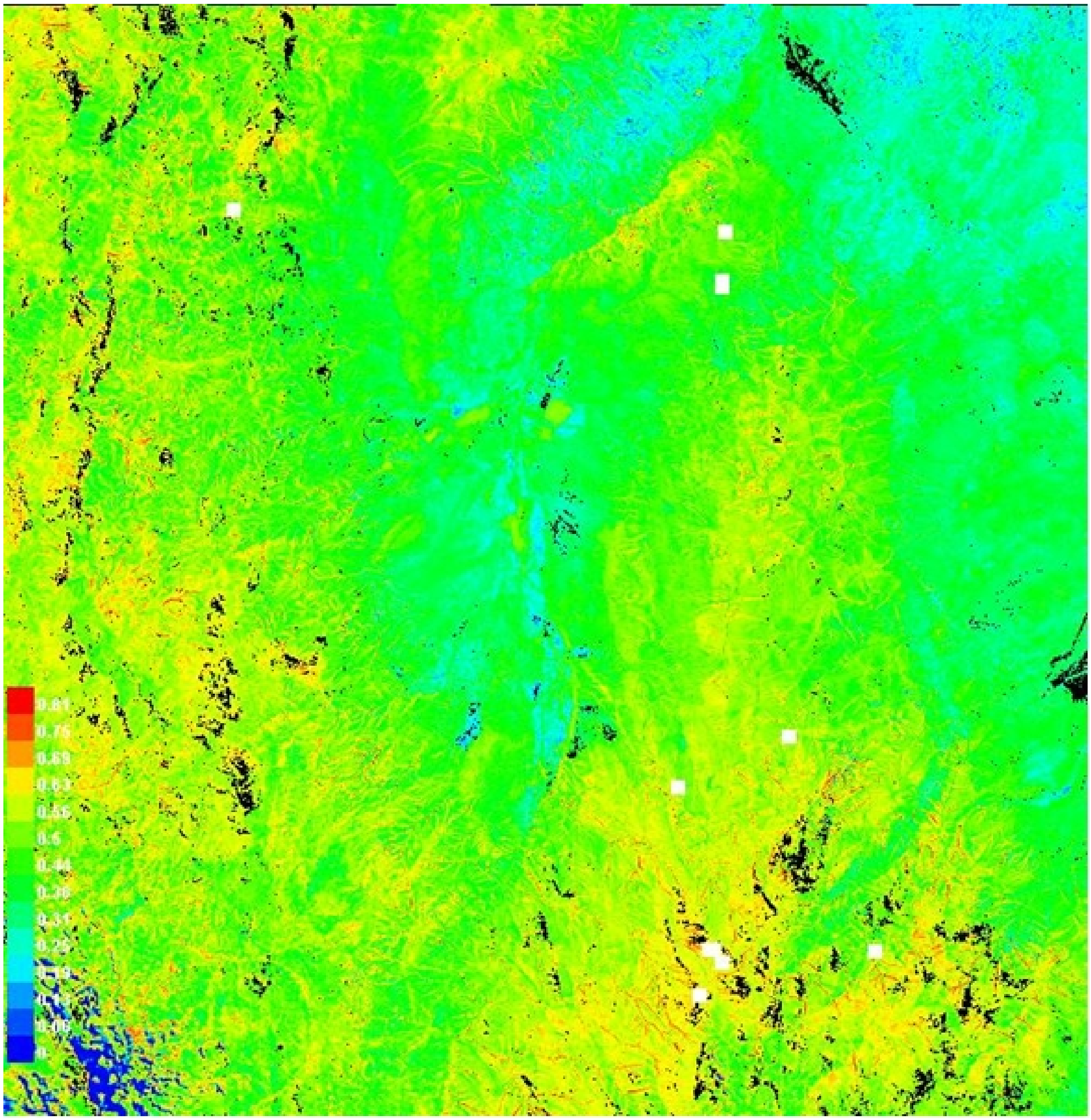

Figure 16. Maxent Model for Cheatgrass Absence: Warmer Colors Show Areas With Better Predicted Conditions for Cheatgrass Absence, White Dots Show the Presence Locations Used for Training, and Violet Dots Show Test Locations

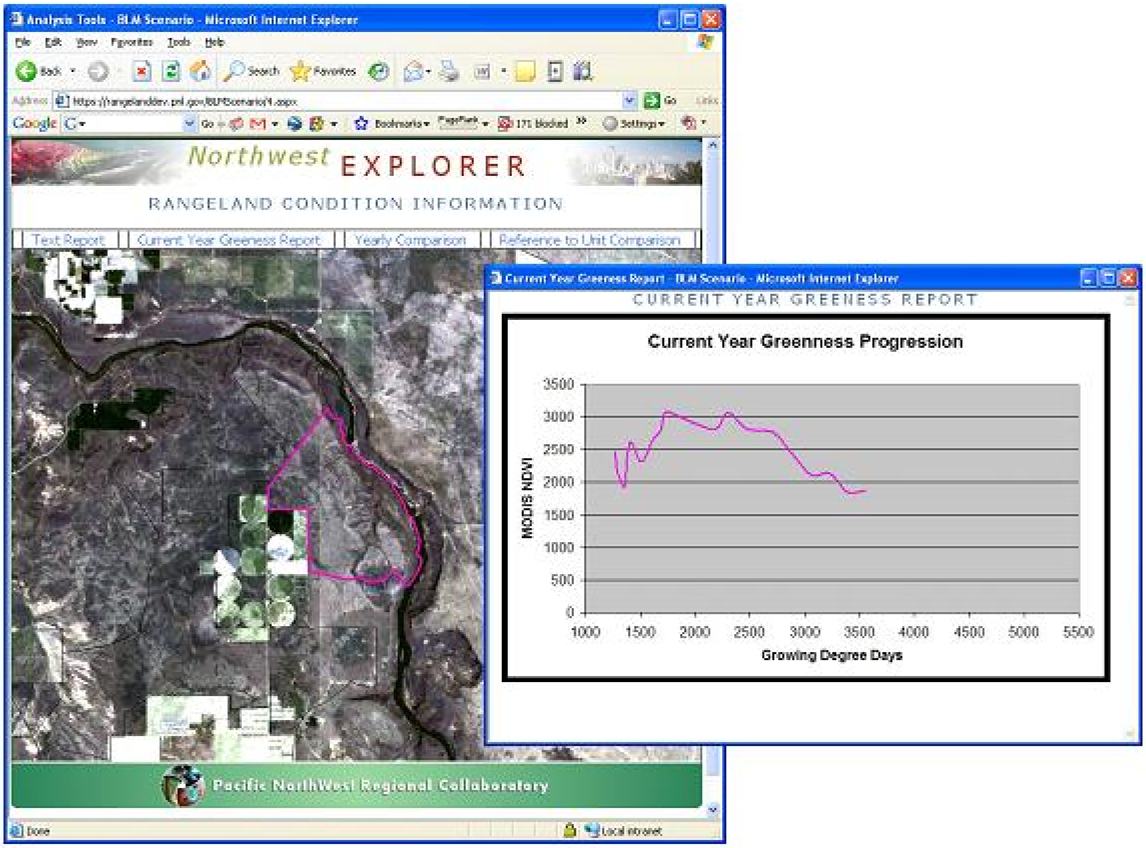

Figure 17. Screen Capture of Proposed Web Tool to Analyze MODIS Greenness Signatures by a Specific Land Unit.

Anomaly Mapping

One of the most difficult problems associated with land management in the western United States is detection potential problem areas. The PNWRC rangeland team has developed a set of complementary approaches to provide a wide-area, landscape solution to this problem. The anomaly detection analysis was applied in 2 distinct ways. In the first approach (temporal anomalies), the definition of an anomaly was based on the behavior of a pixel from a historical perspective considering climate impacts for the year. The second method (spatial anomalies) defined anomalous pixels by comparing individual pixel response to the median response within a larger land unit (strata). In this approach the pixels at the extremes of the distribution within individual strata, were flagged as anomalies.

Temporal Anomalies

This method identified anomalous pixels by comparing the current pixel response to the historical norm. However, identifying the appropriate pixels for comparison is not as simple as selecting MODIS images from a particular anniversary date. Climate and seasonal weather trends affect the phenological development of the plants, which in turn affects the spectral response from a pixel over that area. To account for the differences in weather between years, we utilized the spatial cumulative growing degree (CGDD) data to select phenologically-similar dates. NDVI composites were generated for similar CGGD dates for years 2000-2007. NDVI values for each baseline year were considered as a data cube. The basic statistics associated with each pixel subsequently became the basis for defining an anomaly and potentially identifying a cluster of anomalous NDVI values within an image. When plotted across the landscape for a particular date, these pixels represent locations which do not match the historical expectation and are thus anomalous.

Spatial Anomalies

By first identifying areas of the image that are biologically homogenous, we can then utilize the distribution of spectra to identify very small regions of concern over a very large landscape. To accomplish this, we utilized the best available soil maps as landscape stratification i.e., each polygon had similar soil type, elevation and precipitation and thus potential vegetation. The spectral data were then analyzed by these polygons and the tails of the distribution (pixels furthest from the baseline/mean response) were mapped as areas of concern.

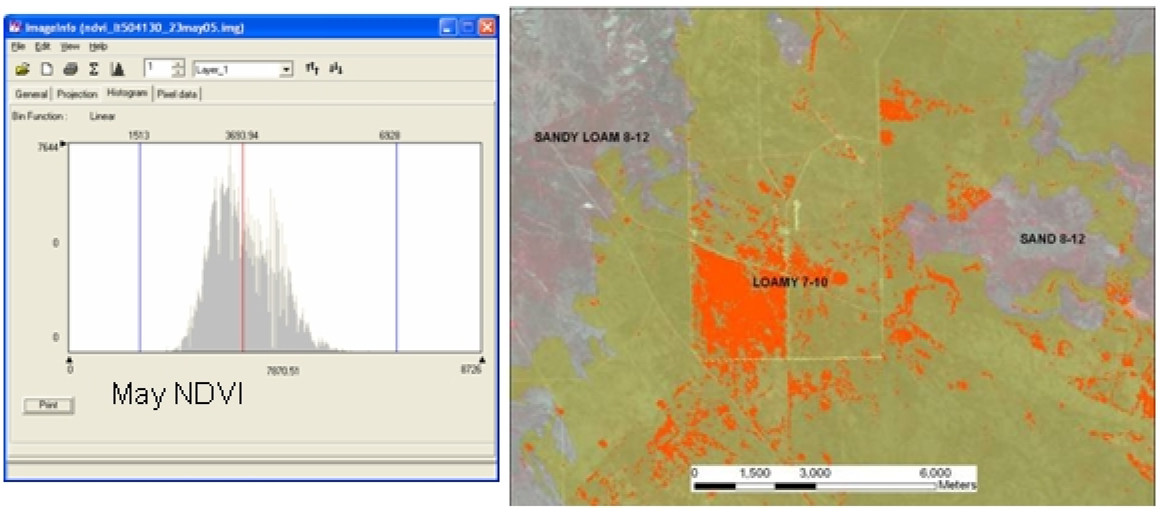

Figure 18. Identifying Anomalous Pixels Within a Landscape Unit by Isolating NDVI Values at the Extreme of the Distribution for That Unit

Landsat and MODIS data were analyzed for a region and the pixels beyond the 10th and 90th percentile were identified as potential anomalies. This was effective for producing map products which highlighted many different management concerns including: excessive soil exposure, invasive weed infestations and tree encroachment into shrub-dominated landscapes.

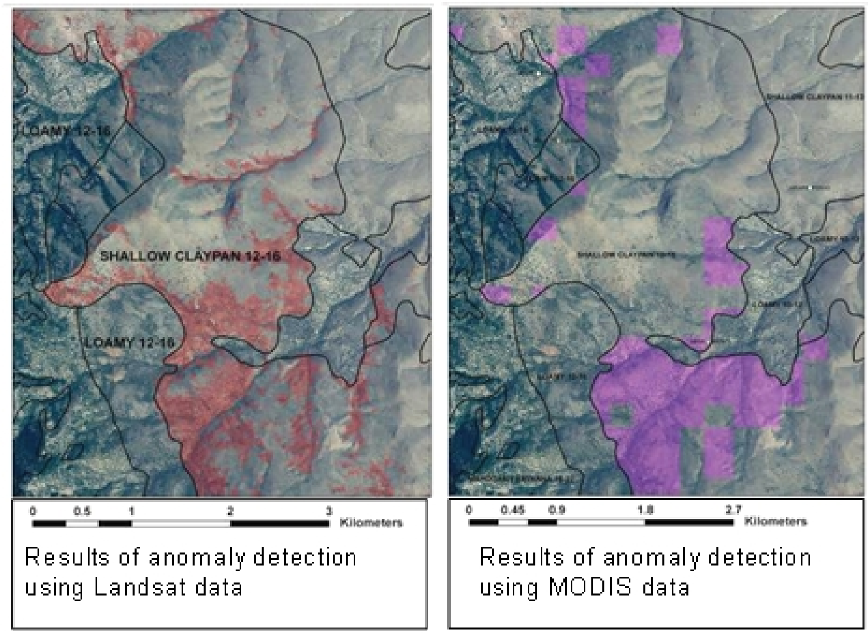

Figure 19. Results of Anomaly Mapping With Landsat and MODIS Imagery Showing Juniper Encroachment Into a Sagebrush Area

The method of analyzing spectral data stratified by ecological site polygons has the potential to be developed into a tool for broader application in rangeland monitoring. A recent publication by Maynard et al. (2007) describes a research similar to what present here. The BLM has expressed interest in this type of tool to assist in monitoring for weed infestation, encroachment and for assistance with the placement of monitoring locations and restoration sites.

It should be noted that these anomaly identification techniques could be adapted to any type of landscape for myriad problems. For example a system could be set up to utilize MODIS daily or weekly to monitor for oil spills or in forested ecosystem to monitor for changes in vegetation vigor due to insect or disease outbreaks.

Sagebrush Canopy Data Fusion

Developing capabilities to map shrub canopy cover in the shrub-steppe has been a challenge for the remote sensing community. Current methods for measuring shrub canopy cover require intensive field measurements. Transect or plot sampling for canopy cover can provide useful data from discrete locations, but is insufficient for developing a landscape-level understanding of shrub cover and distribution.

Our approach combines Landsat spectral data with spatial information from high resolution sensors to not only characterize the canopy cover, but also identify the shrub type (i.e., sagebrush, rabbitbrush, greasewood, etc). The high resolution spatial data is processed via a unique texture algorithm to minimize the color effects and maximize the observable changes in brightness due to shrub canopy cover. This texture data is then fused with the color information from Landsat or ASTER to derive information on species and life form of the shrub.

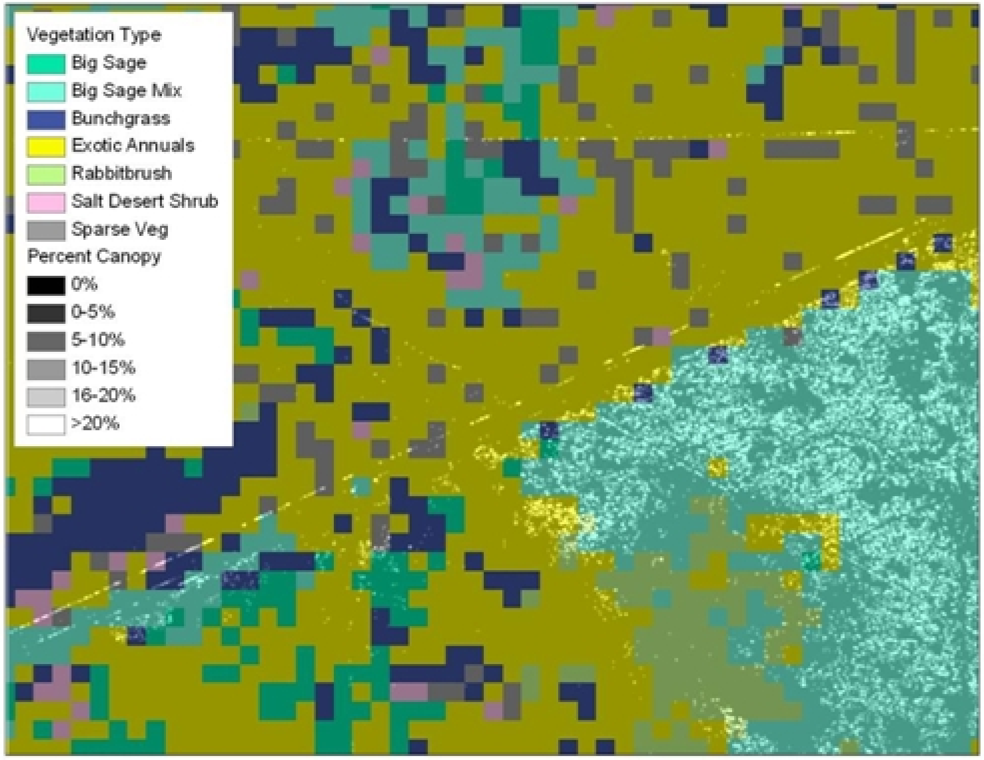

Figure 20. High-Resolution Canopy and Landsat Vegetation Map Provides Rangeland Fire and Wildlife Specialists With Critical Landscape Information

We have developed a simple and effective technique to map shrub canopy in various shrubland ecotypes using high-resolution imagery, Landsat satellite and sparse field data. Due to the nature of the texture ratio response, these techniques are applicable without image stratification or segmentation. This technique will allow land management agencies to rapidly assess shrub cover changes in arid lands. These techniques are applicable to many different arid and semi-arid shrubland environments and the data can be combined with other satellite-derived data in a GIS framework such that complex ecological relationships are highlighted. The USGS, BLM and USFWS have all expressed interest in this model approach and in several cases are pursuing funding for large projects.

Outreach and Integration

The rangeland team presented a PNWRC poster at the 2006 Workshop on Collaborative Watershed Management & Research in the Great Basin (participants included BLM, USFS, USDA); the poster was presented with PNNL and INL discussing rangeland remote sensing. A second poster on the PNWRC mission was also presented.
Throughout this final year of the PNWRC, the rangeland team met has met with BLM end users in Idaho, Nevada and Oregon numerous times. Specific interactions are detailed below:

Owyhee Uplands Pilot Project Meeting, Boise, ID, March 2007

Mitchell, Jessica and Glenn, Nancy "Landscape Patterns of Species Diversity and Invasive Species Hotspots," – ISU

Tagestad, Jerry and Downs, Janelle "Applications of Satellite and Aerial Imagery for Rangeland Characterization." – PNNL

Rope, Ronald and Lee, Randy "Optimal Image Acquisition Tool for Cheatgrass Detection." – INL

Tagestad, Jerry and Downs, Janelle "Characterizing Sagebrush Canopy Cover: Spatial Texture and Image Fusion Techniques", presented at the Society of Range Management, Reno, NV, February 2007. – PNNL

Glenn, Nancy "Implementation of Remote Sensing Techniques for Invasive Species Management," presented at NASA Applications Invasive Species Planning Meeting, Washington DC, March 2007. – ISU

Rangeland task lead presented rangeland tool overview at the regional BLM office in Ely, NV (May)

BLM Workshops, Boise, ID; Lakeview and Burns, OR; Winnemucca, NV November and December 2007

Workshops on using PNWRC's proposed tools to support rangeland decision making were held in Idaho, Oregon and November. The workshops were attended by BLM rangeland, fire and GIS specialist to discuss the usefulness of MODIS and Landsat (ASTER) data products for decision support. Considerable time was spent eliciting feedback from these specialists. The findings were very encouraging for the development of a dynamic rangeland support interface. Some of the comments:

"Current information on the phenological condition of an area is very important"

"Information on the critical green up time for an area is very valuable for timing grazing"

"We would use that tool a lot"

"Knowing location of previous or current year anomalies would allow for more careful placement of monitoring plots"

"Anomaly tool could be used in focusing location of restoration projects"

In general, support was very high for the type of tool which synthesizes landscape level information and fuses is with site-specific GIS data for context. One of the most valuable aspects of this type of tool is that the local districts throughout the west would a have a consistent system to retrieve phenological and condition information.

2.5 Maritime Domain Knowledge

Objectives and Goals

This effort assesses the use of unique satellite information to improve coastal and open ocean security through more accurate estimation of sensor and AIS coverage. The following discussion introduces concepts important to the understanding of this opportunity.
A number of surveillance and reconnaissance platforms and sensors are available for monitoring and surveillance of coastal ship traffic. Chief among these are US Coast Guard surface search radars and the Automated Identification System (AIS) for surface vessel identification.

This effort used satellite data from the CloudSat/CALIPSO mission to determine if this data could improve the knowledge of the lower marine atmospheric temperature and moisture structure. Key elements of that structure are the sea surface temperature and the height of the top of the inversion layer. The availability of conventional data – NDBC buoys, radiosonde stations, and numerical weather prediction model outputs were also examined.

Technical Progress / Applications

The NPS Meteorology Department has developed an automated program called SEMEO (Satellite Electro-Magnetic Electro-Optical) that uses remote sensing from satellite to characterize ducting conditions over large oceanic regions. SEMEO uses existing satellite sensors to detect the presence of cloud-topped marine boundary layers and to sense the cloud-top temperature, giving an estimate of the cloud-top height. In addition to estimating the location and strength of elevated ducts, a probability of whether each duct will reach the surface will also be assigned by the SEMEO program. The output of SEMEO can be input into radar propagation prediction programs to enhance situational awareness within the operational area. The SEMEO program is designed to work in regions where there is a well-defined stratocumulus cloud deck and corresponding inversion just above the cloud top that creates a trapping region, conditions prevalent in the Southern California coastal and off-shore region.
SEMEO has the following components:

1. Marine stratus cloud identification (cloud screen algorithm).
2. Ingest of external temperature field to represent the lower boundary layer at the air-sea interface.
3. Algorithm to estimate cloud-top height.
4. Algorithm to estimate trapping layer strength and depth.
5. Algorithm to estimate the probability of a surface-based duct.
6. Formatting of refractivity information for tactical use.

The refractive profile below the inversion can be estimated using information derived in the SEMEO cloud-top height algorithm and numerical model estimates of surface pressure. A parameterization is included in SEMEO to estimate the modified refractive index through the inversion. The parameterization estimates the trapping layer strength (ΔM) and the trapping layer depth. When combined with the 850mb modified refractive index (computed from numerical model fields), the SEMEO process provides a five-point modified refractive index vertical profile, surface to 850mb.

Although SEMEO has been designed for stratus-topped inversions such as in Southern California, the concept is introduced here as a stepping off point for expanding the concept to use unique satellite sensors from the CALIPSO/CLOUDSAT mission.

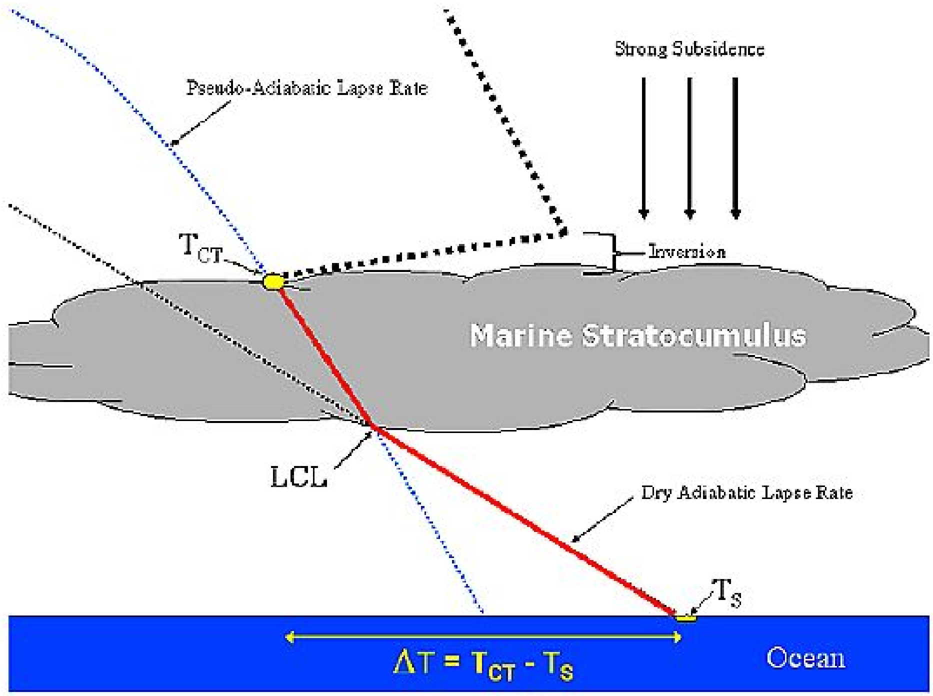

Figure 21. Surface Temperature (TS) and Satellite Infrared Cloud-Top Temperature (TCT) Are Known Values. The lifted condensation level (LCL) is the base of the cloud. The dry adiabatic lapse rate is used in the cloud-free region and the pseudo-adiabatic lapse rate is used within the cloud. From Jordan and Durkee (2003).

To determine if data from the CloudSat/CALIPSO mission could improve the knowledge of the lower marine atmospheric temperature and moisture structure. Key elements of that structure are the sea surface temperature and the height of the top of the inversion layer. The availability of conventional data – NDBC buoys, radiosonde stations, and numerical weather prediction model outputs were examined. These data were used to develop atmospheric M profiles for input into the 11 Navy's Advanced Propagation Model (APM) to predict surveillance coverage of the US NW coastal region. In addition, satellite estimates of sea surface temperature and boundary layer top were compared to conventional data to determine if they would provide significant improvements to the APM predictions.

Vertical atmospheric profiles are routinely available every 12 or 24 hours from NOAA radiosonde launch sites. The Quillayute airport radiosonde station located at 47.95N 124.55W (Figure 22) was used for this study based on its proximity to the NW coast and its position under the CloudSat/CALIPSO mission track. The radiosondes carry a sensor package that samples the pressure, temperature, humidity, and winds once per second as the sonde package ascends carried by a helium-filled balloon. These sondes provide a very high vertical resolution profile of the atmosphere suitable for calculating accurate radar propagation. Unfortunately, they are handicapped by two factors: they are only updated every 12 or 24 hours, resulting in long periods where the environmental conditions in the rapidly varying NW weather regime may have changed; and, they are located over land so they don't capture the very near-ocean-surface temperature and humidity conditions.

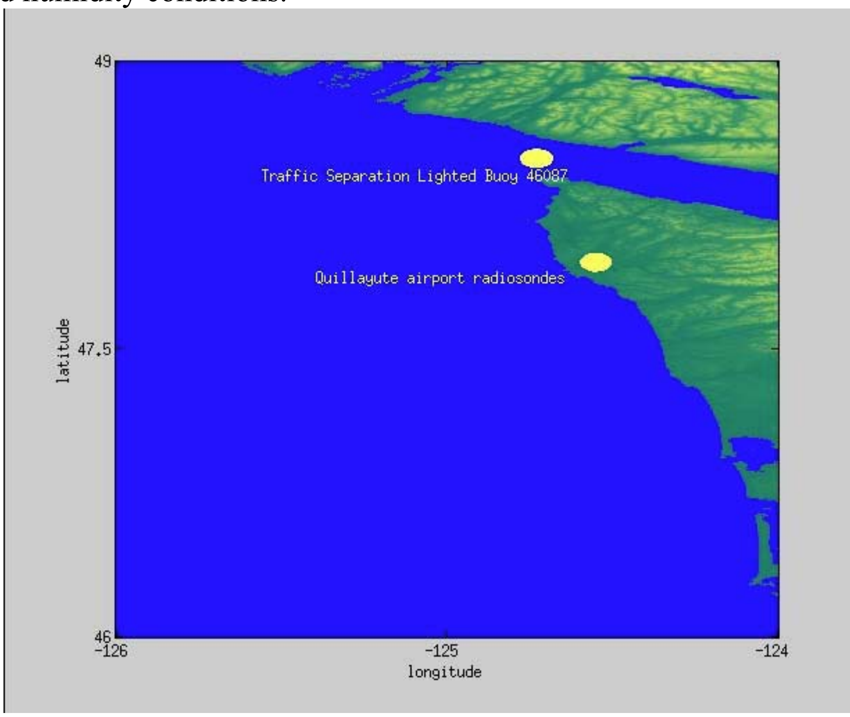

Figure 22. Map of Washington Coastal Zone Indicating Location of NDBC Buoy 46087 and the Quillayute Radiosonde Launch Station

The parameters necessary to define a ground truth validation of the evaporative duct at one location are sea surface temperature, wind speed air temperature, humidity and pressure all at a reference height. One buoy near the sounding location provides water temp at a depth of 0.6 meters, wind speed, and air temp, dew point and pressure at varying heights. Sea surface temperature data is available from buoy station 46087 (Figure 22). Station 46087 is a 3-meter discus buoy (Figure 23) located at 48.49N and 124.73W and was chosen for its proximity to the Quillayute radiosonde launch station and the overpass track of the CloudSat/CALIPSO mission.

Two approaches were taken to assess the value of A-train satellite data for improving the input to the APM. The first approach was to use the MODIS sea surface temperature data in conjunction with COAMPS model predictions to describe the evaporative duct condition near the ocean surface. This information was compared to an evaporative duct defined using the measurements from buoy 46087. Nine consecutive days from the end of July in which the weather was fairly constant were chosen to make the measurements. This data is displayed in Figure 24. Since the wind speed is sufficiently high in July to keep the ocean surface layer well mixed, the MODIS skin temperature and the buoy water temp at 0.6 meters are generally in agreement. Also, the skin temperature, which is highly variable under light wind conditions, doesn't demonstrate much variability on the dates chosen. Consequently, there was little impact on the evaporative duct calculations from the satellite data. This impact would likely be greater under light wind conditions.

Figure 23. A NOAA 3m Discus Buoy

The second approach was to use model output that is brought into the CloudSat data processing stream to define the refractivity environment and augment it with cloud detection from the CALIPSO lidar. This procedure is similar but not identical to the SEMEO method described earlier. Given the presence of a cloud, the SEMEO method uses sea surface temperature as measured by a buoy, temperature at 840mb and cloud top temperature as inputs, then derives cloud top and bottom elevation and an air column profile, from which a modified refractivity profile is calculated. The procedure used in this effort uses cloud top and bottom from the satellite and a fully defined air column from numerical model output. This may not be the optimum approach; however, for the scope of this effort, it was decided to follow the proven SEMEO method more closely.

Several days of CloudSat/CALIPSO data from four seasons were examined. Although anomalous refractivity conditions can occur at any time, they are most prevalent during the summer months over the NE Pacific Ocean. Consequently, the random sampling used led to six days from the summer of 2006.

CONCLUSIONS

Two approaches were taken to explore the impact of using CloudSat/CALIPSO satellite data to improve EM propagation assessment. The first approach, to replace buoy sea surface temperature measurements (at 0.6m below the surface) with MODIS skin temperatures, did not show any significant impact. The evaporative duct is normally very sensitive to the ocean skin temperature/surface air temperature difference as the moisture vapor pressure is very sensitive to this temperature difference. However, the dates chosen were all during July when wind speeds were sufficient to keep the ocean surface layer well mixed leading to similar skin and buoy temperatures.

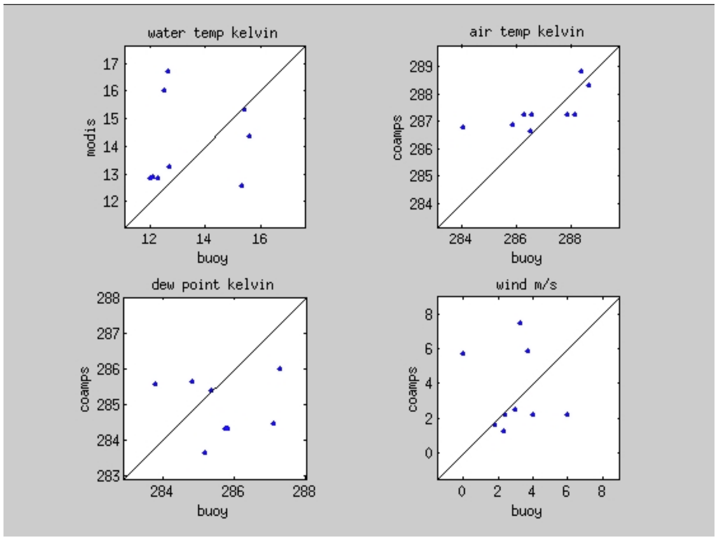

Figure 294. Surface Parameters as Measured by the Buoy Versus MODIS and COAMPS Predictions.

The second approach was to follow the SEMEO methodology developed at the Naval Postgraduate School to infer the marine layer inversion height and strength from cloud top measurements. The CALIPSO data provide a significant improvement to the SEMEO method of estimating cloud height and thickness from cloud top and surface temperatures as CALIPSO measures the cloud top and thickness directly. This improved CALIPSO method was then used to modify the model predicted moisture and temperature profile to drive EM propagation calculations. The CALIPSO measurements indicated both a stronger temperature inversion than predicted by the coarse vertical resolution model but also a more highly variable inversion height. These differences in vertical atmospheric profiles lead directly to significant differences in both AIS and SSR coverage in the six dates examined.

The above study was only a very small sample to test the hypothesis that AIS and SSR coverage assessment could be improved using CloudSat/CALIPSO data. The study indicates there is a high probability that this data would be useful for routinely updating coverage assessment. However, in order to use this method operationally, the method would need to be refined using a large data set covering all seasons and significant validation and verification with in situ measurements would need to be undertaken.

OUTREACH AND INTEGRATION

The results of this investigation have been sent to numerous NASA program managers as well as the principal investigators for CloudSat and CALIPSO. The feedback has been overwhelmingly positive. We are continuing to pursue an integration meeting with theses decision-makers to further develop this idea in a larger application.

Appendix A

List of Publications and Presentations

Appendix A

List of Publications and Presentations

Davidson, K. L., 2005: Assessment of Atmospheric Factors in EM/EO Propagation, MR4416 Course Notes. Department of Meteorology, Naval Postgraduate School, Monterey, CA, 263 pp.

Derley, D. T., 2006: Remote Sensing of the Refractive Environment above the Marine Stratocumulus-Topped Boundary Layer. Masters Thesis, Naval Postgraduate School, Monterey, CA, 85 pp.

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Appendix B

List of Undergraduate / Graduate Student Involvement

Appendix B

List of Undergraduate / Graduate Student Involvement

Idaho State University

Jessica Mitchell, MS in GIScience & PhD in Engineering and Applied Sciences, Land Resources/Invasive Species

Brian Davis, Post-baccalaureate in Geotechnologies, Land Resources/Invasive Species

Ben McMahan ISU M.S. Land Resources: Cheatgrass

David Streutker ISU Postdoc Land Resources: Cheatgrass

Walt Bulawa ISU Post Masters Land Resources: Cheatgrass

University of Idaho

Brandon Moore – M.S. Geography – completed
(Downscaling of medium-term air temperature forecasts used for streamflow forecasts (Idaho and western Montana); Programming of model and other tools in ArcGIS)

Troy Blandford – M.S. Geography – completed
(Study of monthly and seasonal variations in air temperature lapse rates in small mountainous basins – used for snowmelt model)

Brian Harshburger – Ph.D. – anticipated May 2008
(Improvement and validation of a streamflow forecasting model utilizing MODIS snow cover area products; ensemble streamflow forecasting in snowmelt-dominated basins; mapping of snow-water equivalent using MODIS data, landscape variables and ground measurements)

Meghan Monahan – M.S. – completed Dec 2008
(Use of small footprint lidar and multispectral imagery to map canopy fuel characteristics)

Steve Robischon – M.S. completed
(Initial programming to create data streams for NW Explorer)

Riley Tschida – M.S. – anticipated May 2008
(Integration of multispectral and small footprint lidar data to classify wildland fuel models on the Nez Perce reservation)

Nicholas Tratz, B.S.
(Analysis of relationships between snow covered area from multispectral imagery, wintertime temperatures, and landscape variables)

Craig Tarter, B.S.
(Assisted in downscaling of medium term air temperature forecasts for Washington and Oregon; programming for web-based delivery of long-term downscaled products)

Wenguang Zhao UI Post-doc Bio/Ag Eng Met forecasts

Brandon Moore UI MS/Geography Meteorological forecasts

Brian Harshburger UI Ph.D/Geography Snowmelt modeling

Troy Blandford UI MS/Geography Snowmelt modeling

Steve Robischon UI MS/Geography Snowmelt modeling

Battelle /PNNL

Kyra Emory Columbia Basin A.A. Land Resources/Invasive Species

Nicole Bleich U-Southern Mississippi Post-Masters Land Resources/Invasive Species

Rajiv Prasad Utah State University PostDoc Water Resources

Daniel Juarez Heritage College B.S. Land Resources/Forestry

INEEL

Ryan Hruska University of Idaho Post Masters Water Resources

OSU

Indi Suprisina Oregon State Univ PhD Sustainability Atlas

Ariana Henning Oregon State Univ M.S. Sustainability Atlas

Pat Beger Oregon State Univ PostDoc Sustainability Atlas

Matt Cox Oregon State Univ PhD Sustainability Atlas

UW (Forestry)

Elizabeth Louis UW MS Land Resources/Forestry

Sooyoung Kim UW MS Land Resources/Forestry

Farhad Mehta UW MS Land Resources/Forestry

Honora Lo UW PhD Land Resources/Forestry

Finn Krogstad UW PhD Land Resources/Forestry

Finn Krogstad UW PhD Land Resources/Forestry

UW (hydrology)

Kostas Andreadis UW MS Water Resources

Marketa Mcguire UW MS Water Resources

Appendix C

Status Update for Time Extension Period

Water

- Submitted journal article to Water Resources Research, "Short-Term to Seasonal Ensemble Streamflow Forecasting through Data Assimilation", M. Kashif Gill, Mark S. Wigmosta, André M. Coleman, Lance W. Vail, and Rajiv Prasad.
- Developed informational animation demonstrating application of the Hybrid Model to the Dworshak basin.
- Input PNWRC results to NW Water informational brochures
- Created an animation of forecast and temporal changes for Dworshak reservoir

Coastal

- Met with OSU to determine the future direction of software development and marketing activity coordination between OSU and PNNL
- Completed development of ENVISION software application demonstration for nearshore applications in Puget Sound.
- Finalizated of ENVISION tool customization for demonstration client – City of Bainbridge Island.
- Conducted review of demonstration project in Seattle with emphasis on presentation upgrades and marketing strategies for the future

Rangeland

- We have been invited to showcase our prototype phenology tool at the National BLM Deputy State Director's for Resources meeting in Washington, D.C. June 4, 2008
- Drafted a response to the ROSES 2008 solicitation with a collaborative proposal in the Decision Support topic area