Rapid Prototyping Capability for Earth-Sun System Sciences

Final Report

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National Aeronautics and Space Administration (NASA)

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Online Information

Reports and papers associated with this funded work can be found online at http://www.gri.msstate.edu/research/nasa_rpc/

Date of Submission

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Summary of Original Plan
The original proposal was to develop a very extensive computational environment (infrastructure) into which many simulation codes would be ported and from which many remote users could modify parameters and settings to optimize the scientific value of future NASA space-based instruments. A few projects would be executed to test the infrastructure.

This approach was abandoned in light of the projected high development and maintenance costs, as well as the expected difficulty in convincing the owners of most key codes to allow their codes to be put in such an environment. This was discussed and a change of direction initiated at a NASA Earth Science, Applied Sciences workshop near NASA Langley in April 2006.

Final Plan
By the Preliminary Design Review (PDR) in May 2006, extensive interaction with NASA personnel at NASA Headquarters, Langley, Goddard, Marshall, and Stennis Space Center had led to a change in scope. At the PDR, the following plan was presented and approved.

Infrastructure
The infrastructure to support Rapid Prototyping Capabilities (RPC) provides the capability to rapidly evaluate innovative methods of linking science observations. To this end, the RPC now provides the capability to integrate the tools needed to evaluate the use of a wide variety of current and future NASA sensors and research results, model outputs, and knowledge, collectively referred to as “resources”. It is assumed that the resources are geographically distributed and thus RPC provides the support for the location transparency of the resources.

The system was developed in phases by Dr. Tomasz Haupt and his team:

Phase I: Interactive web site for describing the experiments and gathering feedback from the community.

Phase II: RPC data server acting as a cache for experimental data (Unidata’s THREDDS server).

Phase III: Online tools for data processing (“transformations”).

Phase IV: Support for batch processing.

Phase V: The RPC system deployed at NASA Stennis Space Center and becomes a seed for a Virtual Organization.

All but Phase V was accomplished. The system can be used from NASA SSC, but the system does not physically reside on NASA SSC computers

In support of the infrastructure, several components were developed:

- Information visualization tools: Dr. T. J. Jankun-Kelly and a graduate student assisted in the development of web-based visualization tools as part of the Performance Metric Workbench, specifically information visualization tools. Towards this end, Dr. Jankun-Kelly worked on two
related goals. First, to create a novel web-based architecture for performing information visualizations and second, to demonstrate the effectiveness of this architecture via a visualization example motivated by one of Dr. Charles O’Hara’s RPC projects.

- A data visualization applet: John van der Zwaag and Vladimir Alarcon developed a data visualization applet and Haupt’s team integrated it into the RPC infrastructure. The work was published and demonstrated at AIPR 2006: Theory and Application of Model-based Image Analysis, Washington DC, October 12, 2006.

- Optimal methods to visualize hyperspectral data by Shangshu Cai and others: The Cai work has resulted in a PhD dissertation and 2 IEEE Transactions on Geosciences and Remote Sensing to date, with a manuscript to IEEE Transactions on Visualization and Computer Graphics that should be submitted in December 2008.

Dr. Haupt’s team work has been presented at two AGU Annual Conferences and has been documented in several papers at other conferences. See aforementioned website for complete list.

Projects

Integrating NASA Data and Model Products for Crop Surveillance And Productivity Estimation To Provide Enhanced Inputs To USDA FAS PECAD/CADRE DST (PI: Dr. Charles O’Hara, MSU)

Executive Summary (see associated project final report for more details)

The goal of a Rapid Prototyping Capability (RPC) is to speed the evaluation of potential uses of NASA research products and technologies to improve future operational systems by reducing the time to access, configure, and assess the effectiveness of NASA products and technologies. The capability developed will accomplish this goal and contribute to NASA’s Strategic Objective to “advance scientific knowledge of the Earth system through space-based observation, assimilation of new observations, and development and deployment of enabling technologies, systems and capabilities including those with potential to improve future operational systems”. (NASA, 2005)

The main research objective was to evaluate the use of remote sensing – that include the current and future sensors, and grid based meteorological datasets to reduce the need for field data and for providing improved predictive capabilities to monitor and model crop bio-productivity.

Future operational NASA data and model products were used as inputs to novel processing methods to evaluate the ability to meet the operation needs of the USDA Foreign Agricultural Service. The experimental directions of the project were designed to address operational needs identified by a NASA-USDA interagency working group (IWG) and an agricultural efficiency focus area working group (FAWG) established to define the need for collaborative work to study agriculture and forest monitoring and productivity on a site specific to global scale. The primary needs that were identified by these groups for NASA operational assistance to the USDA which are addressed by this project include 1) Developing new products that quantify rather than qualify agro-meteorological factors, 2) Increasing satellite coverage (either temporal or spatial), and 3) Establishing user-friendly data formats/downloading procedures and data integration.
In this project, MSU, NASA SSC, NASA GSFC, crop model experts, South American soybean experts, NASA SSAI, and ITD worked together to identify specific solutions and to develop and deliver applications to meet selected operational needs in the Agricultural Management national application and defined by the Agriculture Efficiency FAWG. The project focused upon identifying and delivering a set of solutions to meet current and future projected USDA program level modeling and decision support operational needs. The project utilized a systems engineering solution approach to ensure that the project rigorously evaluated agency operation needs, identified the needs of the broader user community, fully scoped the proposed application, matched project objectives to compiled requirements, and developed deliverables that are useful, highly transferable, and easily integrated with existing agency business processes and workflows.

Integrating NASA Data And Model Products In HSPF And SWAT Hydrologic Simulation Models
(PI: Dr. Charles O’Hara, MSU)
Executive Summary (see associated project final report for more details)

This document documents the use of existing and simulated NASA data products to overcome current limited availability of data for watershed hydrology. We used simulated Moderate Resolution Imaging Spectroradiometer land use/land cover (MODIS-LULC), NASA-LIS generated precipitation and evapotranspiration (ET), and Shuttle Radar Topography Mission (SRTM) datasets, in conjunction with standard land use, topographical and meteorological datasets in-vogue within the watershed hydrology modeling community. The proposal is focused in coastal watersheds in the Mississippi Gulf Coast although one of the experiments focuses in an inland watershed. The decision support tools (DSTs) for which the data are integrated are the Soil Water & Assessment Tool (SWAT) and the Hydrological Program FORTRAN (HSPF). These DSTs are endorsed by several other government agencies (EPA, FEMA, USGS) for water management modeling strategies. SWAT and HSPF are effective tools for assessing water resource and non-point pollution problems and were applied in a wide range of scales and environmental conditions across the globe. The models use physiographic and meteorological data extensively. The specific objective of this study was to do a comprehensive comparison of the impacts of using different datasets in both hydrological models within a common experimental unit (same geographic and temporal range) using the same input data products. Precipitation gages and USGS gage stations in the region were used to calibrate and validate the HSPF and SWAT model applications. Land use and topographical datasets were swapped to assess model output sensitivities. NASA-LIS meteorological data were introduced in the calibrated model applications for simulation of watershed hydrology for a period in which no weather data were available (1997-2006). The performance of those NASA meteorological datasets was assessed through comparison of measured and model-simulated hydrographs. Overall, NASA datasets were as useful as standard land use and topographical datasets. Moreover, NASA datasets were used for performing analyses that the standard datasets could not make possible, e.g., introduction of land use dynamics into hydrological simulations, updating watershed hydrology simulations to present times (incomplete standard meteorological datasets did not allow this type of analysis).
Enhancement of USDA SCAN using NASA LIS and AMSR-E (PI: Valentine Anantharaj, MSU)

Executive Summary (see associated project final report for more details)

The NASA Land Information System (LIS) is designed using advanced software engineering principles, allowing the interoperability of land surface models with advanced data assimilation capabilities. The AMSR-E data assimilation experiments carried out in this project demonstrate the utility of the flexible, extensible LIS data assimilation framework to apply hydrological observations and modeling tools. A new module to support AMSR-E data was implemented in LIS to facilitate data assimilation.

Several deficiencies in the system have been identified and partially rectified. The approach and results of the Noah model physics evaluation demonstrate that an in-depth examination of the modeled soil moisture fields against observations at all levels can reveal deficiencies in model physics and result in more accurate soil moisture profile predictions. The SCAN measurements have been crucial in identifying the problem with the free drainage and finding an alternative. The CDF matching technique, used in the data assimilation process, does not correct the mean of the modeled soil moisture fields. When observations are transformed through the CDF matching process, they assume the mean of the modeled fields. If the model has a systematic bias, the assimilation with CDF matching will not correct it. Statistically and meteorologically, the mean behavior of the soil moisture fields is more important than others. Without a correct mean, the increased correlation from any data assimilation may not improve the soil moisture prediction. Therefore, data assimilation should be conducted in conjunction with examining model physics such as the one presented in this report to achieve optimum soil moisture prediction.

Preliminary results show that soil moisture assimilation of SCAN observations is reasonably better, compared to the model simulation alone or the AMSR-E assimilation. At sites where the correlation between AMSR-E and SCAN is comparable to the correlation between the model baseline and SCAN, the assimilation did improve the modeled performance. In addition, given the large systematic discrepancies in soil moisture estimation, it is difficult to reach a definite conclusion on whether or not soil moisture estimation from AMSR-E assimilation is superior to both the model simulation and satellite estimates individually. Nevertheless, these results suggest that there is still room for further developmental efforts in application of AMSR-E remotely sensed soil moisture. Finally, we wish to comment on future use of the data assimilation system built into LIS and its possible developments. In order to improve the performance of data assimilation, we urgently need to improve our knowledge of the scaling issues, and thus narrow down the uncertainties in soil moisture estimation. We are also interested in extending 1D-EnKF to 3D-EnKF, which can spread information from observed to unobserved locations. This approach is especially attractive for assimilation of sparse ground observations. These studies are important for soil moisture estimation, and eventually improving our understanding of weather prediction and climate change.

In summary, the Noah model in the LIS implemented in the Mississippi Delta (even without the need for data assimilation) has demonstrated adequate skill in dynamically extrapolating the soil moisture estimates across a range of spatial and temporal scales that would be of interest for water management applications, such as conservation, irrigation planning etc. Hence, further transitions toward routine applications would be justified in this domain.
Rapid Prototyping of Hyperspectral Image Analysis Algorithms for Improved Invasive Species Decision Support Tools (PI: Dr. Lori Bruce, MSU)
Executive Summary (see associated project final report for more details)

In this RPC experiment, recently developed analysis techniques for hyperspectral imagery were prototyped for inclusion in the National Invasive Species Forecasting System (NISFS). The new decision methodologies were tested using hyperspectral data obtained with a handheld spectroradiometer and hyperspectral imagery obtained via NASA’s HYPERION sensor. The results of this RPC experiment clearly demonstrated the viability of applying remotely sensed imagery, particularly hyperspectral such as that of HYPERION, to the problem of invasive species detection, as well as the image analysis methods’ potential for improving the existing NISFS decision support system.

Rapid Prototyping of NASA Next-Generation Sensors for the SERVIR System of Fire Detection in Mesoamerica (PI: Dr. Greg Easson, UM)
Executive Summary (see associated project final report for more details)

The SERVIR Fire Rapid Response System web site displays and distributes daily images of near-real-time MODIS data processed by the MODIS Rapid Response System. The MODIS Rapid Response System was developed by Science Systems and Applications Inc. scientists at the Goddard Space Flight Center and implanted as the SERVIR extension for the use of personnel involved in environmental monitoring and disaster management in Mesoamerica. This Rapid Prototyping Capability Experiment is designed to examine the continued performance of SERVIR’s fire detection system associated with the anticipated transition from MODIS to VIIRS sensor data. There is an inherent limitation in attempting this analysis prior to the commissioning of the actual VIIRS-based sensors. Our efforts in simulating the VIIRS data require us to make substitutions of sensor type and sensor resolution that cause the comparisons to be subject to this limitation. Our comparisons can, however, identify issues to be addressed in the preparation for the new sensors.

We compared MODIS- to VIIRS-based fire products directly for four study dates during the 2003 Guatemala fire season. We find that there is reasonable agreement between the MODIS- and VIIRS-based products on the basis of direct comparison. While agreement rates are extremely high, largely due to the fact that fires are spatially uncommon, the kappa statistic was used to provide a measure of agreement that takes account of chance agreement. The calculated values revealed good to excellent agreement beyond chance agreement. The highest values were obtained when the MODIS- and VIIRS-based assessments of high confidence fires were compared. The VIIRS-based fire products result in relatively few nominal-confidence fires and almost no low-confidence fires. The excellent agreement on high-confidence fires provides encouragement regarding the continued value of SERVIR’s fire-detection program beyond the life of the MODIS sensors. The difference between the two fire product results was found to be most significant for low and nominal confidence fires, where the overall results revealed that the classifications failed goodness-of-fit tests applied to the MODIS- and VIIRS-based classification distributions.

We also compared the accuracy of both the MODIS- and VIIRS-based products against fires observed in both ASTER and LANDSAT-7 imagery. The MODIS-based products compared reasonably well with the
ASTER imagery, with results roughly comparable to those reported by other investigators. When the VIIRS-based products were compared to the same fires detected using ASTER imagery, distinctly poorer results were observed with lower values of the kappa statistic and higher omission error values. This indicates that the challenge of detecting small fires, which presumably may translate to lower confidence fires, is problematic with the VIIRS data and the current VIIRS-based algorithm.

Finally, the two sets of fire products were compared to fires identified by two experts working independently with LANDSAT-7 imagery from the four study days. A total of 60 fires were identified by both experts (each fire independently identified). When these fires were compared to fires detected with the MODIS- and VIIRS-based decision support tool, the results demonstrated moderate, but more importantly nearly equal, success rates for the Terra-based products. The validation fire set was compared to the results obtained using the Aqua-based products yielding distinctly poorer success rates, but those were not considered as significant given the time lag between the collection of the LANDSAT-7 imagery and the Aqua data.

The overall outcome of this RPC is the demonstration that SERVIR’s fire-detection system is expected to continue to perform well detecting fires that are currently being detected at a high-confidence level. Small fires or fires of low intensity do not appear to be as readily detected using the combination of the planned VIIRS sensor and the fire-detection algorithm designed for that sensor. The limitations of this experiment must also be considered. First, we used simulated VIIRS imagery where the current MODIS sensor was used to generate the pseudo-VIIRS dataset. Second, we did not have a confirmed set of fires detected at the surface at the time of imagery collection. Finally, we did not examine the consequences of the improved resolution associated with the expected VIIRS sensor.

Integration of NASA Global Precipitation Measurement Mission Data into the SERVIR Flood Decision Support System for Mesoamerica  
(PI: Dr. Greg Easson, UM)  
Executive Summary (see associated project final report for more details)

This RPC experiment explored the feasibility of using new and future satellites, namely the Tropical Rainfall Measurement Mission (TRMM) and the next generation Global Precipitation Measurement Mission (GPM), to support flood water measurement by SERVIR. Currently available SERVIR products depend upon the continued availability of the AMSR-E sensor, which will not be available long term due to the expected decommissioning of the associated satellite. This RPC experiment constitutes a first attempt to lead to that transition. We have two components of our experiment; each employed TRMM data as a proxy for the planned GPM sensor. Experiment 1 uses the current AMSR-E 36.5GHz channel from the radiometer to the equivalent 63.5GHz band of the TRMM sensor. The current Dartmouth Flood Observatory’s practices regarding a flood hydrograph measurement were applied to data from both sensors. In Experiment 2, the potential for using rapidly available or real time sensor data from TRMM (as a proxy for GPM) to estimate rainfall and river flooding estimates was examined.

The results of Experiment 1 give encouraging results in the continued or improved offering of the Dartmouth Flood Observatory’s flood inundation map. Of the eighteen regional sites where AMSR-E and TRMM results were compared, the six sites with a moderate or strong flood signal revealed a strong correlation (rave= 0.80) with only slight variability between the correlation on these six sites (the standard
deviation was 0.072). When the twelve sites without a strong flood signal are considered, the correlation is weaker (rave= 0.143) and much greater variability (the standard deviation was 0.414).

The results of Experiment 2 give encouraging results in the improvement in the detection of flooding in Mesoamerica. Our estimates rainfall during 1 to 10 October 2005 at the two study sites revealed good agreement between measured and estimated rainfall at one of the sites and poor agreement at the other site. When we applied an empirical approach to estimate cumulative discharge associated with this rainfall, we found fairly good agreement with stream gage measurement of discharge and estimated discharge at one of our sites and poor agreement at another site. These results shows that the planned enhancement of TRMM-based real-time satellite rainfall estimation based on a regional and dynamic bias adjusting scheme may hold promise to overcome the shortcomings observed for the site with poorer agreement.

The combined RPC results suggest that continued availability of the SERVIR flood measurement products will require calibration procedures with the transition to new NASA sensors. The potential for additional products, including the possibility of estimated flood “now casts” may be possible with the continued development of the dynamic bias adjusting scheme using real-time satellite products.


Executive Summary (see associated project final report for more details)

The purpose of this Rapid Prototyping Capability (RPC) experiment is to determine the capability of the Moderate Resolution Imaging Spectroradiometer (MODIS) to assist biologists by providing necessary information to accurately model the growth of particular species of seagrass. Seagrass beds are one of the most important coastal ecosystems in the northern GOM and are subject to multiple interactive anthropogenic and natural disturbances. The decline of this crucial nursery habitat has implications for several important fisheries, as well as coastal environmental and human health. The current method of obtaining the necessary information for seagrass models involves collecting the data manually at the site location. This experiment will compare results between the model using data collected in the field and the model that uses information provided by MODIS, and to assess the strengths and weaknesses of these approaches in an effort to provide the most reliable tools to local resource managers.

**Use of NASA Satellite Assets for Predicting Wildfire Potential for Forest Environments in Guatemala  (Pls: Drs. Greg Easson, UM, and Bill Cooke, MSU)**

Executive Summary (see associated project final report for more details)

An RPC experiment was undertaken to evaluate MODIS and simulated VIIRS NDVI time series data for monitoring leaf litter conditions in seasonal evergreen forests (SEF). Leaf litter moisture content is the most important factor influencing fire potential in SEF in Mesoamerica, yet options for the spatial and temporal monitoring of fuel moisture content are limited. The approach taken to this research was to
compare MODIS and simulated VIIRS NDVI indices compared with KBDI values. Visual analysis, Spearman-Rho statistical analysis and seasonal-trend decomposition (STL) were undertaken. Visual analysis of the data suggested that neither the 400m simulated VIIRS NDVI data or the MODIS NDVI time series data to be particularly well correlated with inverse KBDI, though the simulated VIIRS NDVI appeared somewhat better than the MODIS. Spearman’s Rho statistic confirmed this finding with relatively low values for VIIRS NDVI and MODIS NDVI and KBDI -0.39 and -0.47 respectively. However, the visual correlation for both MODIS NDVI and simulated VIIRS NDVI improved considerably with the seasonal detrending of MODIS and VIIRS data sets. Next steps include cross-correlation of detrended inverse VIIRS NDVI and inverse KBDI, and MODIS NDVI and inverse KBDI. Recommendations are made for de-trending vegetation indices as a prerequisite for assessing the value of a vegetation index for fire potential research. Additional research with relating other important simulated VIIRS indices including EVI, NDWI, SWISI and NMDI is also recommended.

**Rapid Prototyping of NASA Next Generation Sensors with the Nonpoint-Source Pollution and Erosion Comparison Tool (N-SPECT)** *(PI: Dr. Greg Easson, UM)*

Executive Summary *(see associated project final report for more details)*

The purpose of this RPC experiment was to determine the compatibility of the current version of the Nonpoint-Source Pollution and Erosion Comparison Tool (N-SPECT) with a NASA next generation sensor relating to precipitation data by using the Tropical Rainfall Measuring Mission. By assessing the compatibility of N-SPECT with NASA next generation sensors, water resource managers in coastal and inland areas will have another source of precipitation measurements available to use in analyzing water quality issues. Currently, the recommended precipitation data for input into N-SPECT is annual or event scenarios using Parameter-elevation Regressions on Independent Slopes Model (PRISM) data or precipitation data from NOAA National Climatic Data Center. This experiment compares the results of N-SPECT output for erosion, runoff and sediment concentration by using a large, single precipitation event and applying it to three temporally different Coastal Change Analysis Program (C-CAP) datasets for basins on the Gulf coast of Mississippi to determine the validity of using a NASA next generation sensor as a substitute for the recommended precipitation datasets to successfully run N-SPECT. The project successfully demonstrated the compatibility of NASA next generation sensors, specifically simulated GPM precipitation data, with the N-SPECT model.

**Mobile Bay Plume Project** *(PI: Dr. William McAnally)*

Executive Summary *(see associated project final report for more details)*

The Mobile Bay is a 303(d) listed water body with impairment resulting from organic enrichment and low dissolved oxygen. The complex process of mixing fresh and salt water, where they are exchanging sediments, organic material, and contaminants between the sound and the estuary, makes it difficult to determine the exchange rates by ordinary methods. Dissolved oxygen modeling efforts in the Mobile Bay have been designed to provide a platform for addressing Total Maximum Daily Loads (TMDLs). However, more observed data are required to validate the modeling efforts. Data collection has been conducted since November 2007 at the mouth Mobile Bay. The specific purpose of this project is to provide in situ measurements for evaluating remote sensing images and validating numerical models of
the Mobile Bay Plume. In collaboration among NASA Stennis Space Center, Mississippi State University (MSU) researchers and the Dauphin Island Sea Lab (DISL) the data survey has been made within the Bay, Mississippi Sound, and the Gulf of Mexico. Monthly samples are taken at three depths in 32 stations located in the outside plume area and inside of the plume. The following analyses are employed for the samples collected: dissolved organic carbon, total particulate carbon, chlorophyll-a, and total suspended solids. Vertical profiles of light extinction, temperature, specific conductivity, dissolved oxygen, and turbidity are taken with an in-situ meter. Analysis of measurements have revealed the outlines of the plume and provided insight into mixing processes. Currently, eight cruises for the outside plume stations and nine cruises for the inside plume stations, had been made. Approximately 486 samples among the bay and gulf have been analyzed by DISL. A digital database has been created with the different parameters evaluated.

Mobile Bay Water Quality Assessment Using NASA Spaceborne Data Products  (PI: Dr. Jenny Du)

Executive Summary (see associated project final report for more details)

The objective of this project was to use NASA’s spaceborne imagery, i.e., Landsat, in the study of water quality and sediment dynamics in Mobile Bay, Alabama.

Remote sensing techniques are well suited to quantify the spatial variability of the concentrations of sediments and chlorophyll. The correlation between remotely sensed data in the visible to near-infrared (VNIR) bands and in situ water measurements are well studied (Bukata et al, 1995). For instance, data from NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard the Aqua satellite have been widely used to retrieve the ocean water parameters. Due to the high spatial variation and fine waterbody structure along shorelines, it may be beneficial to use remotely sensed images with higher spatial resolution, such as Landsat and ASTER data, which has 30m resolution (Keiner and Yan,
1998; Wang et al., 2004; Zhang et al., 2003), and images with higher spectral resolution, such as Hyperion data with 10nm resolution (Cipollini et al., 2001; Brando and Dekker, 2003; Wang et al., 2005).

In this experiment, we had monthly shipboard measurements, including turbidity, total suspended sediment (TSS), and chlorophyll A, from a sister project. These measurements were used to investigate the quantitative relationship between pixel reflectance in remotely sensed imagery and water quality related parameters. Existing data sources from the U.S. Army Corps of Engineers (Corps) and the Environmental Protection Agency (EPA) were used in this experiment.

Development of Electromagnetic Inverse Scattering Algorithms to Accurately Predict Sea Surface Salinity for Modeling Ocean Circulation (PI: Dr. Erdem Topsakal)
Executive Summary (see associated project final report for more details)

Salinity plays an important role in ocean circulation and fluctuations in salinity are mainly due to changes in freshwater (evaporation, precipitation, melting ice, or river input). Microwave remote sensing techniques have been often applied to the remote sensing of ocean surfaces. Microwave remote sensing from space can provide the necessary temporal and spatial information needed to understand the role of salinity in oceans. For instance, the NASA Aquarius mission, scheduled to launch in 2009 will be flying an integrated L-band (-1GHz) microwave radar and radiometer. In order to use the data collected through current and future NASA missions, there is a need to develop accurate microwave remote sensing methods to predict ocean salinity to understand ocean circulation and climate changes. Fig. 1 shows a 2-D microwave remote sensing scenario for determining sea surface impedance. The sea surface impedance is directly correlated to surface salinity. The main objective of this study was to develop electromagnetic inverse scattering algorithms to efficiently predict the sea surface impedance. Because sea surface salinity is a direct function of sea surface impedance, our main focus was to determine sea surface impedance via remote electromagnetic field measurements.

Figure 2. Microwave Remote Sensing Scenario for Determining Sea Surface Impedance

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Z_{sea} = g(\varepsilon_{sea}(x,f), \sigma_{sea}(x,f))
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Other Activities
In collaboration with NASA/SSC and NASA/GSFC, we organized and ran an RPC Data Access Mini Workshop near NASA/GSFC in Nov 2006. A 12-page final report was submitted to the PM for this project.

We, principally Valentine Anantharaj, organized day long sessions (oral presentations and poster sessions) at the 2006 and 2007 Winter AGU Meetings. The composition of those day long sessions can be found on the AGU website. Copies of the MSU papers and presentations can be found at http://www.gri.msstate.edu/research/nasa_rpc/papers.html

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