A. COVER PAGE

Name of state: South Dakota

Cooperative agreement number: NCC5-588

Research project title: Cross-Calibration of Landsat and IKONOS Sensors for Use in Precision Agriculture.

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Date: May 5, 2004

B. PROGRESS REPORT

1. Abstract of the original proposal.

Precision agriculture, or site specific farming, has changed all the old agricultural equations. In short, site specific farming uses differentially corrected global positioning systems (DGPS) and geographic information management systems (GIS) to vary management within fields to optimize returns. Site-specific farming is based on the idea that the right inputs can be applied at the right place at the right time. However, to develop site-specific recommendations, accurate information is needed. Remote sensing can help fill this need.

For remote sensing to have value to land managers, the information must be accurate, and contain information that can be used directly by decision support systems. In other words, the remote sensing data must be radiometrically corrected, cross-calibrated to other sensors being used by the grower, available in a timely manner, and corrected for atmospheric distortions. The research conducted by the authors of this proposal has shown that one of the largest errors associated with using remote sensing information is incorrect calibration of atmospheric effects.

The objectives of this study are to:

1. Conduct cross-calibration of Landsat TM, Landsat ETM+, and IKONOS sensors, using standard reflectance measurements, within wheat, grass and soybean fields, and
2. Develop/evaluate rules to identify the "best" sensor for given agronomic applications, including applying various levels of atmospheric correction to the sensor data.

Field research will be conducted in 2001, 2002, and 2003. In each year, cross calibrations will be conducted three times at each site (May-June, July-July, August). The sites will be fields uniformly planted to soybeans, wheat, and grass and will be approximately 65 ha in size. Research will contain three different components. In the first component, the atmospheric corrections for the different sensors will be determined. This component will also examine the sufficiency of scene-based atmospheric correction only or scene-based correction that includes the deployment of field equipment for the various agronomic applications of remote sensing.

In the second component, models relating spectral characteristics to crop health will be developed. In the third component, the models (developed in component 1 and 2) will be validated. Regression analysis will be used to determine the ability of IKONOS, Landsat TM (Landsat 4 and 5), and Landsat ETM+ (Landsat 7) to predict the yield limiting factors. Findings from this study will be used to develop precision farming guidelines for selecting remote sensing information sources.

2. Accomplishments compared to original goals

The expected results of the project were to:

a. Develop protocols for cross-calibration of operational Landsat sensors with IKONOS sensors.

During the first year of this project, remote sensing data (Landsat, IKONOS, and QuickBird) along with atmospheric scattering data were collected over targets of known reflectance using a variety of ground-based sensors. Based on ground collected and remote sensing data, new radiometric calibration procedures for QuickBird and Landsat 5 were developed and tested. The results of this work are described below. Algorithms for correcting for atmospheric absorption and scattering have been implemented and improved.

b. Determine error bounds on the radiometric corrections for satellite-based measurements.

QuickBird and Landsat data were compared with known reflectance values from calibrated tarps. Regression analysis of known and calculated reflectance values were compared. This analysis forms the basis for evaluating atmospheric scattering algorithms.

c. Develop an understanding of the scaling limitations of IKONOS and Landsat data.

The project evaluated the impact of different scales on agricultural uses in farmers' fields. In year 1, collaborating farmers only wanted to use high resolution data. By the third year, the collaborating managers saw the need for having both Landsat (coarse resolution) and high resolution data. Different data can be used for different problems. For example, Landsat data can be used to predict crop yields, while the higher-resolution QuickBird and IKONOS data are useful for characterizing pest problems. A guideline paper in collaboration with DibitalGlobe (Dr. Jack Paris) and Resouce21 (Mark Holoubek) was prepared that summarizes these results. The guideline paper is available at http://plantsci.sdstate.edu/precisionfarm/.

d. Develop agronomic models based on remote sensing measurements.

The study developed models that:

- Estimate within field yields. This model is based on principle component analysis of remote sensing data. The "best" model utilized several remote sensing sampling dates (Chang et al., 2004a).
- Estimate whole field yields. This model was based on multiple regression analysis of remote sensing data. Collaborating producers provided data for model development (Clay et al., 2004a). This model will be field tested and validated in years 4 and 5.
- Determine the extent of weed infestation in soybeans. This model was based on bare soil and weeds having different reflectance characteristics (Chang et al., 2004b). Our goal is to field test these models in years 4 and 5.
- Use remote sensing measurements to simultaneously estimate yield losses due to water and N stress in corn. These models were developed based on research conducted in 2003 and will be validated in years 4 and 5.

During year 1, the project concentrated on developing a technique to simultaneously quantify the N and water stress in production fields. Numerous scientists have noted that stress causes changes in plant reflectance. Many plants undergo several different stresses simultaneously. In order to develop remote sensing models that quantify stress, we need to first be able to measure stress. This project pioneered the development of a method that utilizes ^{13}C discrimination to separate the combined effects of N and water stress into the individual components. Once separated, remote sensing models can be developed that predict the degree of water and N stress that a plant is undergoing.

- Estimate soil water content. During the first two years of the study, data were collected and used to develop a model that estimates available soil water. Model development will continue through the third year of the study, followed by model validation in years 4 and 5.

e. Determine the usefulness of satellite data for precision agriculture.

Satellite data were found to be useful for producers for some aspects of agriculture but not others. Landsat, IKONOS, and QuickBird data were very useful as a tool to assist scouting activities. Producers evaluated several of these sensors. Based on their experiences remote sensing success stories were prepared. The success stories can be viewed at http://plantsci.sdstate.edu/precisionfarm/. The producers discovered that remote sensing data can be used to show the extent of problems affecting crop development.

f. Share findings with local communities through workshops and teacher training. The workshops will be targeted toward producers and consultants.

During the first three years of the project, numerous training opportunities have been provided to teachers, producers, and crop consultants. These training opportunities have provided hands-on training in the use of GIS and remote sensing data. One unique program supported by this project is the Adopt-a-Farm website. The goal of the website is to document how remote sensing and spatial information can be used to improve management decisions. The website contains an extensive geospatial technology curriculum. The curriculum was prepared by SDSU agricultural education majors in collaboration with South Dakota Agriculture teachers.

g. Continue collaboration with NASA scientists.

Collaborations with NASA scientists were continued and expanded during the project. In June of 2003, a Landsat Team conference was hosted at SDSU. At the conference representatives from several NASA Centers were present. In Washington, DC, during the NASA EPSCoR conference, SDSU researchers met with Jack Xiaong and Bill Barnes of NASA MODIS at Goddard, James Dodge of EOS at NASA Headquarters, as well as Brian Markham, John Barker, Jim Butler, and other Landsat Goddard personnel. On May 20, 2004, a group of SDSU Scientists (D.E.Clay, S.A. Clay, C.G. Carlson, and K. Dalsted) traveled to Stennis Space Center to present research findings and discuss current and future activities with Rodney McKellip, Project Manager, Applications Research Division, Earth Science Applications Directorate, and with Vick Zanoni (Technical Advisor for the SD NASA EPSCoR Cross Calibration Project), also of the NASA Earth Science Applications Directorate. In 2003, the precision farming/cross calibration activities were discussed with Keith Morris (Ag20/20 Project Manager, Commercialization Remote Sensing), Jack Paris (DigitalGlobe), and Mark Holboubek (Recource21). Based on these discussions, Mark Holoubek visited Brookings for a Precision Farming Conference and Jack Paris co-authored a Guideline Paper on the use of remote sensing.

3. List of articles submitted to or published in refereed journals.

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Chang, J. D. E. Clay, C. G. Carlson, C. L. Reese, S. A. Clay, and M.M. Ellsbury 2004. The influence of different approaches to define yield goals and management zones on N and P fertilizer recommendation errors. Agron. J. 96:825-831.

Chang, J. S.A. Clay, D.E. Clay, D.Aaron, and D. Helder. 2004. Comparing spectral reflectance data collected from two different spectroradiometers for ground reflectance measurements. Com. Soil and Plant Anal. (In review)

Chang, J., D. E. Clay, K. Dalsted, S.A. Clay, M. O'Neill. 2004a. Use of spectral radiance at multiple sampling dates to estimate corn (*Zea mays*) yield using principal component analysis. Agron. J. 95:1447-1453.

Chang, J., D.E. Clay, C.G. Carson, S.A. Clay, D.D. Malo, R. Berg, and W. Wiebold. 2003. The influence of different approaches for defining nutrient management zone boundaries on N and P recommendations. Agron. J. 95:1550-1559.

Chang, J., S.A. Clay, and D.E. Clay. 2004b. Detecting weed-free and weed infested areas of a soybean (*Glycine max*) field using NIR reflectance data. Weed Sci. (In press).

Choi, T. and D. Helder, 2003. On-Orbit Modulation Transfer Function (MTF) Measurement. Remote Sensing of Environment. 88:42–45

Choi, T. and D. Helder, D. 2004. In-Flight Characterization of the Spatial Quality of Remote Sensing Imaging Systems using Point Spread Function Estimation. International Society of Photogrammetry and Remote Sensing (ISPRS) in Technical Session #4. (In press)

Clay, D.E., Kitchen, N., Carlson, C.G., Kleinjan, J.L., and Tjentland, W.A. 2002. Collecting representative soil samples for N and P fertilizer recommendations. Online. Crop Management doi:10.1094/CM-2002-12XX-01-MA.

Clay, D.E., P. Danielson, C. Reese, K. Dalsted, and S.A. Clay. 2004a. Whole Field Corn Yield Estimates Using Remotely Sensed and Precipitation Data. Agronomy Journal (In review).

Clay, D.E., S.A. Clay, D.J. Lyon, and J.M. Blumenthal. 2004. Can ^{13}C discrimination in corn (*Zea mays)* grain be used to characterize intra-plant competition for water and nitrogen? Weed Sci. (submitted 1/04, in review).

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Liu, Z., S.A. Clay, and D.E. Clay. 2002. Spatial variability of atrazine and alachlor efficacy and

mineralization in an eastern South Dakota field. Weed Sci. 50:662-671.

Ryan R., B. Baldridge, R. A. Schowengerdt, T. Choi, D.L. Helder, S. Blonski. 2003. IKONOS spatial resolution and image interpretability characterization. Remote Sensing of Environment, 88: Issues 1-2, November 2003 in collaboration with NASA Stennis, Research Systems, and University of Arizona.

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Proceedings of the 6th International Conference of Precision Agriculture July 14-17, 2002, Minneapolis, MN., p. 59.

Ellsbury, M.M., S.A. Clay, D.E. Clay, and D.D. Malo. 2004. Within-field spatial variation of northern corn rootworm distributions. Proceedings of the 2003 Gopttingen Rootworm Symposium. (in press)

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Paz, J.O., W.D. Batchelor, D.E. Clay, S.A. Clay, and C. Reese. 2003. Characterization of Soybean Yield Variability Using Crop Growth Models and ^{13}C Discrimination. ASAE meeting presentation # 033044.

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4. List of patents (pending and awarded). None

5. List of talks, presentations, or abstracts at professional meetings.

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Aaron, D. 2003. Vicarious Data Collections 2003 Summer. Presented at Landsat-7 Calibration Meeting in Lake Tahoe, Dec 11, 2003.

Carlson C.G. and D.E. Clay. 2002, Making cents out of yield potentials. Presented at the Use of Yield Potential Symposium held at the 2002 American Society of Agronomy Annual Meeting.

Carlson, C.G and D.E. Clay. 2003. Overview of Management of low yielding areas. Presented the 2003 American Society of Agronomy National Meeting. Symposium on Precision Farming: Management of low yielding areas. Denver, 2003, Nov. 2-6

Carlson, C.G. and D.E. Clay. 2003. Normalizing yield data. Presented at InfoAg 2003, July 31, 2003.

Carlson, C.G., C. Reese, and D.E. Clay. 2003. One year yield data analysis. Presented at InfoAg 2003, July 31, 2003.

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Clay, D.E. and C.G. Carlson, 2004. Precision Ag Research. Presented at Agvise Soil Fertility Seminars. Brookings, SD, January 8, 2004.

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Leigh, L. 2003. Development of instrumentation system for real time irradiance reference monitoring and scattering detection, Technical advisory board conference, July 31, 2003, Rapid City
Paz, J.O., W.D. Batchelor, D.E. Clay, S.A. Clay, and C. Reese. 2003. Characterization of Soybean Yield Variability Using Crop Growth Models and ^{13}C Discrimination. ASAE meeting presentation # 033044.
Reese, C., D.E. Clay, and C.G. Carlson. 2004. Identifying soil nutrient management zones. UMAC annual meeting, Grand Forks, ND, March 4-5.
Reese, C.L., D. Clay, D. Long, C.G. Carlson, and D. Beck. 2002. Using protein and ^{13}C discrimination to determine the influence of nitrogen and water stress on wheat yields. *In* conference abstracts of the 6th International Conference of Precision Agriculture July 14-17, 2002, Minneapolis, MN, p. 1002.
Schumacher, T.E., M.J. Lindstrum, D.D. Malo, J.A. Schumacher, and D.E. Clay. 2002. Terrain pattern relationships in an eroded hummocky landscape. 2002 ASA, CSSA, SSSA annual meeting. Held in Indianapolis, IN, November 10-14, 2002.
Sudduth, K.A., N.R. Kitchen, W.D. Batchelor, G.A. Bollero, D.G. Bullock, D.E. Clay, H.L. Palm, F.J. Pierce, R.T. Schuler, K. Thelen, and W.J. Wiebold. 2002. Characterizing field-scale soil variability across the Midwest with electrical conductivity. *In* conference abstracts of the 6th International Conference of Precision Agriculture July 14-17, 2002, Minneapolis, MN, p. 54.

Other publications, presentation, workshops, and graduate theses

List of educational tools, guideline papers, and extension bulletins.

Carlson, C.G., D.E. Clay, D.D. Malo, and T.E. Schumacher. 2001. The issues in carbon sequestration. South Dakota State University, Brookings, SD ABS 5-01.

Carlson, C.G., T. Doerge, and D.E. Clay. 2002. Estimating corn yield losses from unevenly spaced corn. SSMG 37. Clay et al. (Ed) *Site Specific Management Guidelines*. Potash and Phosphate Institute. Norcross, GA.

Clay, D. E., Kitchen, N., Carlson, C. G., Kleinjan, J. L., and Tjentland, W. A. 2002. Collecting representative soil samples for N and P fertilizer recommendations. SSMG 38. Clay et al. (Ed) *Site Specific Management Guidelines*. Potash and Phosphate Institute. Norcross, GA.

Clay, D.E. N. Kitchen, J. Kleinjan, and C.G. Carlson. 2004. Using historical management areas to reduce soil nutrient sampling error. GIS in Agriculture, ESRI (In review).

Clay, D.E., C.G. Carlson, and J. Chang. 2004. Identifying the "Best" Approach to Identify Nutrient Management Zones: A South Dakota Example SSMG 41. Clay et al. (Ed) *Site Specific Management Guidelines*. Potash and Phosphate Institute. Norcross, GA.

Clay, S.A., J. Chang, D.E. Clay, and K. Dalsted. 2004. Timing of aerial and satellite imagery to improve weed scouting in soybean. SSMG 42. Clay et al. (Ed) *Site Specific Management Guidelines.* Potash and Phosphate Institute. Norcross, GA.

Dalsted, K, J. Paris, D. Clay, S.A. Clay, C. Reese, and J. Chang. 2003. Selecting the Appropriate Satellite Remote Sensing Product for Precision Farming. Site Specific Management Guidelines SSMG-40. PPI Clay et al. (Ed) *Site Specific Management Guidelines*. Potash and Phosphate Institute. Norcross, GA

Gaspar, P., C.G. Carlson, and D.E. Clay. 2003. A "Cookbook" approach for determining the point of maximum economic return. SSMG 39. Clay et al. (Ed) *Site Specific Management Guidelines*. Potash and Phosphate Institute. Norcross, GA.

Kleinjan, J, D.E. Clay, C.G. Carlson, and S.A. Clay. 2004. Developing productivity zones from multiple years of yield monitor data. GIS in Agriculture ESRI (In review).

Reese. C.L., S. Christopherson, C. Fossey, J. Gray, A. Hager, R, Morman, G. Schmitt, B. Showalter, C.G. Carlson, and D.E. Clay. 2001. Trouble-shooting yield monitor systems. SSMG #32. Clay et al. (Ed) *Site Specific Management Guidelines*. Potash and Phosphate Institute. Norcross, GA.

List of symposiums and workshops

Conducted summer workshops at the EROS Data Center and Rapid City on GIS/remote sensing, 31 K-12 teachers attended the week-long training (impact is estimated at 750 students/year).

Landsat User's Group Workshop, SDSU Brookings, SD, June 10-11, 2003.

Integrating Emerging Technologies Into Ag Production Systems. August 28th, 2001 SDSU Brookings, SD. 105 farmers and crop consultants attended. Goal: provide producers with an update on research activities and have hands on training sessions on integrating emerging technologies into their production system.

Soil Moisture Clinic. Representatives from the conservation districts attended the meeting. January 27-29, 2002, Brookings, SD (110 participants).

Youth Engineering Adventure (YEA) 17 June 2002: Two groups of high school freshmen through juniors, 7 students in each group, used new Leica survey-grade GPS unit to survey small watershed on campus, then generated topography map and drainage pathway map and discussed watershed connection and uses of map/watershed knowledge. Each student took home maps of the watershed. Summary of activity available at http://www.engineering.sdstate.edu/yea/index.htm

Aerospace Career Education (ACE) Camp, July 2002, over 20 high school students spent 5 days learning about various aspects of careers in aerospace and related fields, including image processing.

Aerospace Career Education (ACE) Camp, July 2003, over 20 high school students spent 5 days learning about various aspects of careers in aerospace and related fields, including image processing.

Beginner ArcView training for producers. Held March 14th and 21st, 2002. Eleven people attended the training sessions. Topics discussed were: how to import yield data into GIS, how to view yield data as an Event Theme; how to convert the Event Theme into a shape-file, the importance of projections, how to load imagery and view in Arc-View, and how to create a layout to view imagery beside other field data.

Intermediate ArcView training for producers. Supplemented training provided in Beginner training. Held 13 and 21 June 2002 at Britton, SD (3 producers attended).

Integrating emerging technologies in production systems. August 2003, at Brookings. At the conference/workshop a number of scientists and producers made presentations about important topics (management zones, remote sensing, GMO, carbon sequestering, insect management, data management, marketing, and enterprise analysis). Over 120 farmers attended the meeting. Producers using remote sensing to improve management decisions made several presentations. Educational materials were developed and distributed to producers attending the meeting.

Profit center analysis workshop, February 18, 2004, SDSU .

Identifying management zones workshop, February 25, 2005 was held at SDSU. 31 participants.

Semi Annual Soil and Moisture Conference, 11-14 January 2004, South Dakota State University, Brookings, SD. 90 producers.

Presentations to community/producer groups

Jackson, J. and S.A. Clay, Site Specific Weed Management. 6, September 2001 SE Research Farm Field Days, Beresford, SD, 150 participants.

Carlson, C.G. December 2001, Ag Horizons, 200 participants, 1 hr emerging technology presentation.

Carlson, C.G., December 2001, Davison County Precision Farming Meeting, 200 participants, 2 hr emerging technology presentation .

Reese, C., C.G. Carlson, D.E. Clay. 2002. Introduction to Precision Agriculture. At the SD North central Precision farming conference. 16 January 2002, Aberdeen, SD (150 farmers present).

Carlson, C.G. Integrating emerging technologies in farm management, December 2001, Ag Horizons, 200 participants.

Carlson, C.G., Integrating emerging technologies in farm management, December 2001, Davidson County Precision Farming Meeting, (200 participants).

Reese, C., C.G. Carlson, D.E. Clay. 2002. Precision farming the basics. At the SD North Central Precision farming conference. 16 January 2002, Aberdeen, SD (30 farmers present).

Carlson, C.G. coordinator and 30+ SDSU faculty, January 27-29, 2002, Clinic for soil and moisture conserving farmers and ranchers, 110 participants, 19 hr. Soil and water conservation issues.

Carlson, C.G., Carbon and precision farming, January 2002, Central South Dakota Precision farmers, 15 participants.

Carlson, C.G., Emerging technology, January 2002, South Dakota Outstanding Young Farmer Seminar, 30 participants.

Carlson, C.G., Emerging technology, January 2002, Sioux Falls Regional Ag Farmer Seminar, 70 participants.

Carlson. C.G. Emerging technology. February 2002, North Central SD Farmers. Precision farming meeting, 20 participants.

Kleinjan, J. 2002. The basics of precision farming. 12 February 2002, Dakota Lakes Research Farm annual meeting, Pierre, SD (30 people present).

Carlson, C.G. February 2002, Hands on computer training, 5 participants, 3 hr in computer lab.

Carlson, C.G. 2002. Profit center analysis. 13 March 2002. Brookings, SD (5 producers attended).

Carlson, C.G., Emerging technology. March 2002, Minnehaha County Precision Farming Meeting, 25 participants.

Carlson, C.G. Emerging technology. April 2002, 15 participants,

Carlson, C.G. May 2002, South Dakota Water Festival, 1200 participants, 6 hr environmental education.

Carlson, C.G., Emerging technologies June 2002, South Dakota Farm Managers and Rural Appraisers, (45 participants).

Carlson, C.G. The Field is a Profit Center, March 4,2003, 2003 Christianson Seed, Hati South Dakota. 30 producers.

Carlson, C.G., An introduction to Precision Farming, March 6, 2003, 2003 Precision Farming Conference, Aberdeen, South Dakota. 250 producers.

Carlson, C.G. The Field is a Profit Center, March 6, 2003, 2003 Precision Farming Conference, Aberdeen, South Dakota. 250 producers.

Carlson, C.G. Deep Tillage in South Dakota, March 9, 2003, South Dakota Soybean Council, Sioux Falls, South Dakota. 15 producers.

Carlson, C.G. Salt Affected Soils in South Dakota, March 25, 2003, University of Minnesota, Minnesota Academy of Science Seminar on Impairments to Crop Production. 30 scientists

Carlson, C.G. Normalizing yield data. July 30-31, 2003, InfoAg 2003, Indianapolis, Indiana, 45 producers and scientists.

Carlson, C.G. The Field is a Profit Center, December 2, 2003, Sunbird Oil producers, Huron, South Dakota. 25 producers

Carlson, C.G. GPS – Tile lines and data collection, February 24, 2004, Swiftel Center, Brookings, 50 producers.

Carlson, C.G. Site specific variety placement. March 11, 2004, 2004 Precision Farming Conference, Aberdeen, South Dakota. 250 producers.

Carlson, C.G. Feasibility of on Farm Auto-steer. March 11, 2004, 2004 Precision Farming Conference, Aberdeen, South Dakota. 250 producers.

Thesis and dissertations

Chander, G. 2001. "Landsat-4/5 Band-6 Characterization" Thesis advisor D. Helder, South Dakota State University, Brookings, SD.

Chang, J. 2002. "Using Remote Sensing and Soil Attributes to Characterize the Factors Responsible for Yield Variability" Ph.D. Dissertation, South Dakota State University, Brookings, SD.

Choi, T. 2002. "IKONOS Satellite on Orbit Modulation Transfer Function (MTF) Measurement using Edge and Pulse Method" M.S. Thesis, advisor D. Helder, South Dakota State University, Brookings, SD.

Kim, K. 2005. "Using Remote Sensing and Soil Data to Assess N Yield Response Curves" Ph.D. Dissertation (anticipated 4/05), South Dakota State University, Brookings, SD.

Kleinjan. J. 2002. "Previous Management Impacts on Soil P Levels" M.S. Thesis, South Dakota State University, Brookings, SD.
Micijevic, E. 2003. "Characterization of Outgassing Effects on The Thematic Mapper Cold Focal Plane" M.S. Thesis, advisor D. Helder
Rangaswamy, M. 2003. "Two Dimensional On-orbit MTF Analysis Using a Convex Mirror Array" M.S. Thesis, advisor D. Helder.

6. List of follow-on grants (submitted and funded)

Submitted projects: Funded

Aaron, D. and L. Leigh, SD EPSCoR Program Initiation Grant: Development of a Real Time Reference Monitoring System, $10,000.
Carlson, C.G., D.E. Clay, and S.A. Clay. SD Soybean Research and Promotion Council. 2003. $5,000, first year of a 5 year project funded. Precision farming.
Clay, D.E. and C.G. Carlson. SD Corn Utilization Council 2003 (5 years project, years 2 and 3 funded) $46,000/$136,000 requested, Using deep tillage to improve corn profitability.
Clay, D.E. and S.A. Clay. USDA-CSREES-NRI. Linking ecological and soil property information to improve site specific management. 2001-2003, $150,000.
Clay, D.E., C. Reese, and K. Dalsted. 2000-2005. Team express. NASA/Raytheon through UMAC (UND). $100,000.
Clay, D.E., C.G. Carlson, S.A. Clay, and D. Humburg. EPA 319, $255,000. 4 year project. Using precision manure management to improve water quality and TMDL identified problem areas.
Clay, D.E., S.A. Clay, C.G. Carlson. PPI/United Soybean Board. $18,000. 2004-2005, SD Precision Farming activities.
Clay, D.E., S.A. Clay, C.G. Carlson. PPI/United Soybean Board. $18,000. 2003-2004, SD Precision Farming activities.
Clay, S.A., D.E. Clay, C.G. Carlson, SD NSF EPSCoR, Spatial Statistician for biocomplexity studies. 2002-2004, $80,000.
Helder, D., Aaron, D. Continuation of assessment of high resolution satellite imagery. NASA Stennis Space Center. IKONOS 5 NAG13-03023.
Helder, D., Development of an image assessment system for the Advanced Land Imager. 2004-2006. $417,173. NASA Goddard Space Flight Center.
Helder. D. Am image assessment system for the Landsat TM. 2004-2005, $127,890. USGS EROS Data Center.
O'Neill, M,, D.E. Clay, S. Shin, and K. Dalsted. USGS, SD View, 2002-2004, $187,979.

Submitted projects: Pending

Helder, D., D.E. Clay, and K. Dalsted. 2004. Center for the research, development, and commercialization of advanced information systems for agriculture, disaster mitigation, and homeland security. SD 2010 Initiative. SD Governor's office of economic development.
Clay, D.E., S.A. Clay, and T. Trooien. 2004. An approach for separating interspecies competition for water, N, and light into the individual components. USDA-CSREES-NRI.

Clay, D.E., S.A. Clay, K. Dalsted, and C. Carlson. 2004. Implementing an extension geospatial program for improved resource management. USDA-NASA geospatial extension specialist program.
Waskom, R., B. Seelig, D. Clay, J. Bauder, N. Mesner, Q. Skinner 2004. Coordinated agriculture water quality programming for the Northern Plains and Mountain Regions. USDA-CSREES-406 program.

Submitted project: Not funded

North Dakota, South Dakota, Montana, Wyoming, and Idaho. 2003. A regional proposal entitled "Center for Science and Policy of Sustainability" was submitted to NSF-Science and Technology Center call for proposals.
North Central SARE program: Using remote sensing as a scouting tool for IPM (May 2003).
North Central IPM program: Using Remote Sensed Images to Improve Pest Scouting and Treatment (October 2003).
Regional EPA program: Remote sensed images to improve pest management (March 2003, initially funded, cut due to budget restrictions in regional program).
NASA: EOS Series Satellite Cross Calibration Through the Use of Hyperspectral Focused Field Measurement.
NASA: Evaluation of VIIRS Radiometric Performance and Sensitivity Analysis of VIIRS Calibration on EDR Accuracy.
Clay, D.E., C.G. Carlson, K. Dalsted, and S.A. Clay. Visualization and educational tools for natural resource management. USDA-406 program.

7. Name and frequency of contact with technical monitor

The NASA technical monitor for this project is Vicky Zanoni, NASA Earth Science Applications Directorate, John C. Stennis Space Center, MS. During the project, our research personnel have communicated through e-mail, phone conversations, and have visited with her at Stennis. Project PI, Dr. Dennis Helder, has maintained regular contact with Vicky Zanoni. The monitoring on this project has both formal and informal components.

Technical monitoring and planning activities: Formal

Annual review by SD precision farming advisory/planning board

1. Advisory board meetings, Jan. 2002, Campanile Room, SDSU Student Union.
2. Advisory board meetings, Jan. 2003, Campanile Room, SDSU Student Union.
3. Advisory board meeting, Jan. 29, 2004, Campanile Room, SDSU Student Union.

Producer representatives on the advisory board include Dave Diedrich, Ryan Patterson, Ron Alverson, Lannie Mielke, and Scott Carlson. Representatives from private and other institutions include: S. Murrel (Potash and Phosphate Institute), M. Ellsbury (USDA-ARS-Northern Grain Insect Lab.-entomology), and D. Long (USDA-ARS). Representatives from state agencies include: K. Reitsma (SD Department of Agriculture) and D. Clarke (SD Department of Water and Natural Resources).

Annual review and research coordination by Upper Midwest Aerospace Consortium

1. Planning/review meeting held 21 February 2002 in Grand Forks, ND. Representatives from NASA, EROS data center, SD, MT, WY, ID, and ND attended the meeting.
2. Planning/review meeting held January 2003 in Grand Forks, ND. Representatives from NASA, EROS data center, SD, MT, WY, ID, and ND attended the meeting.

Annual state NASA EPSCoR Technical Advisory Committee (TAC) meeting: 31 July 2003. Members of the TAC were: (i) Sherry Farwell, SDSMT; (ii) James Rattling Leaf, Sinte Gleska University; (iii) Ron Woodburn, South Dakota Bureau of Information and Telecommunications; (iv) Larry Diedrich, SD State Senator; (v) Mike Collins, Oglala Lakota College; (vi) Gregg Johnson, USGS EROS Data Center; (vii) Dan Swets, Augustana College; (viii) Kevin Dalsted, SDSU; (iix) Edward Duke, SDSMT; (ix) Don Lefevre, Cynetics Corp; (x) J. Foster Sawyer, SD Department of Environment and Natural Resources; and (xi) Daniel Hoyer, RESPEC.

Also, a three-year project review was conducted by NASA technical monitor, Vick Zanoni and Rodney McKellip on May 20, 2004.

Technical monitoring and planning activities: Informal

Project review by NASA scientists:

1. Landsat User's Group Workshop: SDSU Brookings SD: June 10-11, A Landsat calibration conference was hosted at SDSU in which representatives from several NASA centers were present.
2. Trips to NASA centers
    a. Stennis on 20 May 2004 to visit with Rodney McKellip, Project Manager, Applications Research Division, Earth Science Applications Directorate and Vicky Zanoni, project Technical Monitor.
3. Review of proposal and manuscripts
    a. Manuscripts resulting from research activities are critically reviewed by appropriate reviewers of the journals. This review guarantees that the research is scientifically valid.
4. Informal contacts with remote sensing experts at regional and national meetings
    a. At the 6th international conference on Precision farming discussions with Keith Morris (Ag20/20 Project Manager, Commercialization Remote Sensing) were initiated.
    b. At the 2003 annual UMAC meeting discussions with Jack Paris (DigitalGlobe) were initiated.
    c. At the 2002 National Agronomy meetings discussions with Mark Holboubek (Recource21) were initiated.
    d. At the national EPSCoR conference held in Washington, DC, discussions with Jack Xiaong and Bill Barnes of NASA MODIS from Goddard, James Dodge of EOS from NASA Headquarters, and Brian Markham, John Barker, and Jim Butler from Goddard were initiated.

Addresses of advisory and technical monitors board members

Advisory/planning Board

David Diedrich, Diedrich Bros. Farms, Elkton, SD.
Ryan Patterson, Patterson Farms, 10946 425th Ave, Britton, SD 57430.
Ron Alverson, President of the SD Lake Area Corn Processors Cooperative, Chester SD.
Lannie Mielke, 39204 150th Street, Mellette, SD 57461.
Scott Carlson, 44618 199th Street, Lake Preston, SD .
S. Murrel, Northcentral Director, Potash and Phosphate Institute, 3579 Commonwealth Road Woodbury, MN 55125.
M. Ellsbury (USDA-ARS), Northern Grain Insect Research Laboratory, 2923 Medary Av, Brookings, SD.
D. Long (USDA-ARS), Columbia Plateau Conservation Research Center, P.O. Box 370, Pendleton, OR 97801-0370.
K. Reitsma, SD Department of Agriculture, Pierre, SD.
D. Clarke, SD Department of Water and Natural Resources, Pierre, SD.

Technical Advisory Board

Sherry Farwell, SDSMT, Rapid City SD.
James Rattling Leaf, Sinte Gleska University, PO Box 490, One Spotted Tail Drive, Rosebud, SD 57570.
Ron Woodburn, South Dakota Bureau of Information and Telecommunications, Pierre, SD.
Senator Larry Diedrich, (SD state senate), Diedrich Bros. Farms, Elkton, SD.
Mike Collins, Oglala Lakota College, PO Box 490 Kyle, SD 57752.
Gregg Johnson, USGS EROS Data Center, Sioux Fall, SD.
Dan Swets, Augustana College, Sioux Fall SD.
Kevin Dalsted, SDSU, Brookings, SD.
Edward Duke, SDSMT, Rapid City SD.
Don Lefevre, Professsor SDSMT and Cynetics Corp, Rapid City, SD.
Foster Sawyer, SD Department of Environment and Natural Resources, Pierre, SD.
Daniel Hoyer, RESPEC Environmental Consulting and Services, Rapid City, SD.

NASA Scientists providing technical review

Rodney McKellip, Project Manager, Applications Research Division, Earth Science Applications Directorate, John C. Stennis Space Center, MS.
James R. Irons, Deputy Landsat Project Scientist, Biospheric Science Branch, Goddard Space Flight Center
Vick Zanoni, Technical advisor for the Cross Calibration Project, NASA Earth Science Applications Directorate, John C. Stennis Space Center, MS.

8. Personnel information, gender and ethnic distribution

Personnel	Role	Gender male	female	Ethnic background
S.A. Clay	Fac.		X	Caucasian
D.E. Clay	Fac.	X		Caucasian
C.G. Carlson	Fac.	X		Caucasian
C. Reese	Grad/PhD		X	Caucasian
J. Chang	Post Doc.	X		Korean
K. Kim	Grad/PhD	X		Korean
M. Islam	Grad/MS	X		Bangladesh
Z. Liu	RA		X	Chinese
J. Klienjan	RA	X		Caucasian
K. Dalsted	Dir. ERC	X		Caucasian
D. Helder	Fac.	X		Caucasian
D. Aaron	Fac.	X		Caucasian
S. Burckhard	Fac.		X	Caucasian
E. Micijevic	Grad.	X		Caucasian
M. Nath,	Grad.	X		Caucasian
J. Dewald	Fac.	X		Caucasian
J. Boysen	Grad	X		Caucasian
P.Thanapura	Grad/PhD		X	
J. Choi	Res. Assoc.	X		Korean
R. Darbha,	Grad.	X		Indian
M. O’Neill	Dir. GIS Lab		X	Caucasian
T. Ruggles	RA	X		Caucasian
S. Jijazi,	Grad.	X		Indian
E. Olsen	Undergrad.		X	Caucasian
D.W. Clay	Undergrad.	X		Caucasian
A. Kleinjan	Undergrad.	X		Caucasian
C. Skogrond	Undergrad.		X	Caucasian
P. Danielson	Undergrad.	X		Caucasian
R. Brunner	Undergrad.	X		Caucasian
Mark Volz	Grad/geo	X		Caucasian
Lin Lin Jiang	Undergrad.		X	Chinese
B. Junker	Undergrad.	X		Caucasian
Jon Melius	Undergrad.	X		Caucasian
G. Dybsetter	Undergrad.	X		Caucasian
Brian Jaske	Undergrad.	X		Caucasian
Mark Bialas	Undergrad.	X		Caucasian
H. Hilbrands	Undergrad.		X	Caucasian
Christa Knott	Undergrad.		X	Caucasian

9. Progress toward achieving self-sufficiency

Our efforts toward self-sufficiency have involved four different components. First, we have attempted to upgrade our infrastructure; new equipment includes an Automated Sun Radiometer and a Real Time Reference Monitor system. Second, original research papers using remotely-sensed imagery have been submitted and several are in press or in review. The information generated by these experiments has led to further researchable questions. Third, new follow-on proposals have been prepared and submitted to a variety of funding agencies. These projects have concentrated on developing approaches that utilize remote sensing for improved management or improving radiometric calibration of existing data. These projects have generally been rated highly by review panels, and several of these projects have been funded. Fourth, the project participants are actively investigating the feasibility of commercialization of various products that this project has helped develop. This project has created knowledge that can be used by service industries that are assisting land managers to make better decisions.

10. Summary of research results

Remote sensing provides valuable information about natural systems that can be use to improve natural resource management. For remote sensing to be consistently integrated into resource management, the information must be accurate, delivered relatively quickly, and contain information that can be used directly by a decision support system. This project is developing techniques to improve the accuracy of these data and creating approaches for seamless integration of remote sensing into ecosystem management. Many of these techniques will be field tested and validated during the remainder of the year 3 growing season and in years 4 and 5.

Remote sensing for improved nutrient and water management

Yield is not the product of random events, but is the result of predictable interactions between climate, biology, and soil forming processes. The two most critical factors limiting plants in the Great Plains are water and nitrogen (N). Research during years 1 and 2 showed that both factors impact yields simultaneously, and that Mitscherlich's law of physiological relationships, "Yield can be increased by each single growth factor even when it is not present in the minimum so long as it not present in the optimum," may apply (Sumner and Farina, 1986).

Developing experimental techniques to quantitatively separate N and water stress effects on yield is necessary to develop remote sensing-based tools to study these factors. Separating these factors is critical because misdiagnosis can result in crop failure, and water and N stress have similar effects on plant reflectance (Schepers et al., 1996). Osborne et al. (2002) solved this problem by developing two remote sensing model, one for plants under water stress and a different model for plants not under water stress.

The development of a remote sensing model that simultaneously determines water and N impacts on plant productivity has been hindered by the lack of experimental techniques for separating these factors. This project pioneered the development of an approach that uses biomass productivity and ^{13}C discrimination to quantify the individual effects of N and water on productivity. By separating these factors, remote sensing models specific for an individual type of stress can be developed. For example, a model based on data collected from the blue, green and NIR bands on 23 July 2003, explained 84% of the observed grain yield loss due to N stress

(Fig.1). Based on information such as this, it may be possible to generate corrective treatment maps. During years 3, 4, and 5 this approach will be validated in experimental plots and tested in producers' fields.

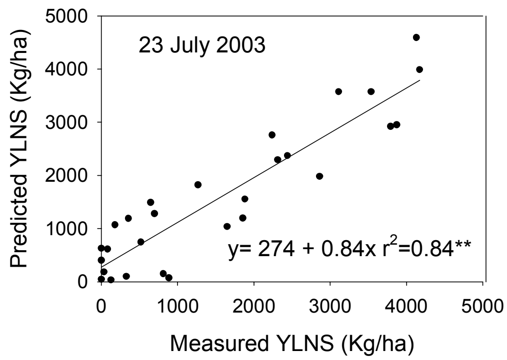

Figure 1. Comparison between measured yield losses due to N stress (YLNS) and remote sensing-based predicted yield losses due to N stress.

Remote sensing for improved pest management

Most soybean fields are not routinely scouted for pests. The hypothesis behind this component of the research is that remote sensing can be used to guide ground scouting activities, identify the extent of weed patches, develop effective pest management strategies, and monitor pest management successes and failures. When integrating remote sensing into pest management, critical decisions that need to be considered include: 1) which wave-bands should be collected; 2) at what date in the growing season should the data be collected; and 3) what spatial resolution needed to detect pests? Small plot research was conducted between 2002 and 2003 to answer these questions. Treatments were soybean with or without weeds. The experiment contained additional controls containing only weeds and no-weeds or soybean. Crop reflectance was measured with either a CropScan field spectroradiometer or using IKONOS satellite data every 2 to 3 weeks during the growing season. Each treatment was replicated 4 times. This research showed that remote sensed imagery taken before crop canopy closure can be used to define areas with more vegetative cover than normal (Fig.2). These areas may have high weed pressures, and after scouting, the image can be used to develop treatment maps. However, differences in residue cover, soil reflectance, and plant emergence result in uncertainties in the remote sensing-based application map. Another optimal time for detecting perennial weeds is after the crop begins to senesce but before a killing frost. This approach may have limited utility if the season has been dry or if the weeds senesce at the same time as the crop. Imagery obtained at late in the season time interval can be used to plan spring, preharvest, or postharvest herbicide applications.

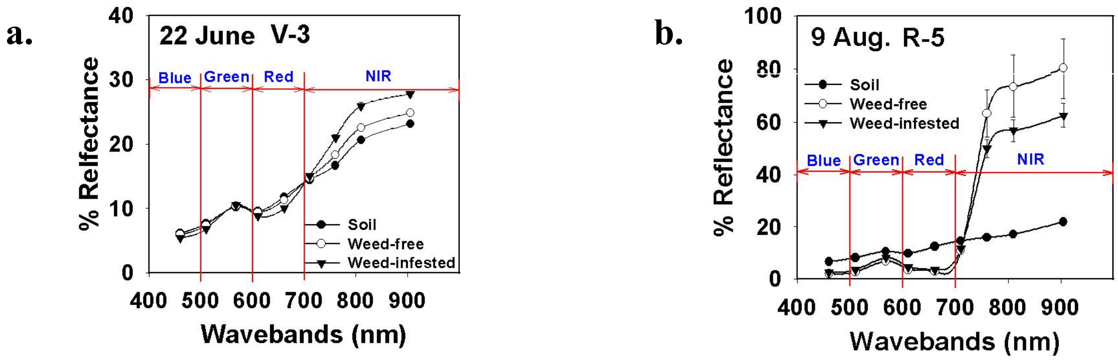

Figure 2. Percent reflectance from weed-free and weedy areas in a soybean field from ground-based CropScan measurements. The difference in reflectance shown in (a) and (b) between weed-free, and weed-infested areas was due to more green vegetation covering the soil.

Cross-Calibration Activities

In the first three years of the project, four areas of work were designated. The first was to collect and archive satellite and ground collected information. Extensive data collections occurred during the summers of 2002 and 2003. Data collected include, ground measured reflectance measurements with radiometers of both calibrated tarps and a grass field. Landsat, QuickBird, and IKONOS data were collected. In 2002 and 2003, data collections focused on cross-calibrations and analysis using a grass based site (and calibration tarps) as the experimental target. In 2002, data collections included: 3 Landsat 7, 3 IKONOS, and 3 QuickBird acquisitions. In 2003, the field activities was expanded to analyze a crop based site. The crop, rotation, and tillage at the site was corn, corn followed by soybean, and strip-tillage, respectively. The goal was to use the ground-collected data and Landsat 7 imagery to determine causes of yield variability. Experiments were conducted at the site to measure yield limiting factors, and to analyze imagery beginning at the early stages of growth (basically a fallow field with small plants on it) up through about a 1-m-tall canopy (the maximum reach of our present spectro-radiometer). Straight ground to top of atmosphere calibration and the enhanced BRDF (bidirectional reflectance distribution function) due to this row crop were both to be analyzed. However, the scan line corrector malfunction of the Landsat 7 ETM+ sensor forced a major redirection of this phase of the project. The only 'good' imagery available from L7 became that which is within the center one-quarter of an image. This forced us to move back to our original grass site with the corn site being only useful for L5 data.

The second goal was to complete the numerical analysis of the extensive 2002 and 2003 data collections. The third goal was to continue development of in-house (SDSU) tools and techniques necessary to achieve the goals of the precision agriculture project team. For goals 2 and 3, it was necessary to develop new algorithms to assist in data reduction. Two basic categories of code were refined: ground data reduction and atmospheric modeling.

The major constituent of a ground collection is a set of hyperspectral (350 – 2400nm) radiance files from multiple targets. These targets include the large areas of 'uniform reflectance' for validation of cross-calibration parameters and areas of step change reflectance, which are used to optically characterize the satellite sensor system (via the modulation transfer function). Each data collection produces from 500 to 1000 spectra that eventually are reduced to a single calibrated hyperspectral (HIS) datum, which is then band integrated to produce a multispectral (MSS) datum that most accurately represents the at-ground radiance and reflectance of the target site. A program for this data reduction had been prototyped by senior undergraduate Beth Rybak. This program was transferred and refined by master's student Young Sun Lee. The program is now refined, tested, and annotated, and it has been extended for general use within the calibration group. All of the 2002 and 2003 data have been ingested and the results have been derived using this product. Modifications, including multispectral banding, were incorporated by another graduate student, Larry Leigh, in the fall of 2003.

The atmospheric data reduction for 2001-2002 was primarily completed with the kind assistance of Kurt Thome's remote sensing group from the University of Arizona, and Bob Ryan's group from Stennis Space Center. The 2003-2004 goal for SDSU was to initiate, establish and verify in-house atmospheric modeling capability, and this program has been successful. A reduced MODTRAN capability has been developed and the results verified via comparison to the University of Arizona results. This model is being used to routinely produce 'at-ground' reflectance images using top of atmosphere satellite MSS data for dates in which full on-site ground collections have been completed. Initial investigations have commenced on the viability of modeling through the shadow band radiometer data and 'off-site' data bases (such as AERONET).

It is important to note that even though Landsat 7 is suffering from the SLC (Scan Line Corrector) malfunction, the research team's primary calibration site (3M grass site) is very near the center of a Landsat 7 'test site' and consequently has been routinely imaged even during the malfunction period. Thus, we were able to maintain collection and analysis continuity.

Programs and protocol development

Programs developed in the first two years of the project include an at-ground reflectance analysis program (see above), and a cloud filter program (for sun photometer Langley analysis). Instrumentation for improved temporal incident irradiance monitoring (Real Time Reference Monitoring) was developed and implemented (with the added bonus of a field weather station being incorporated). Techniques and software for first order atmospheric corrections and converting TOA radiance measurements to 'at ground' reflectance were accomplished. In-house atmospheric modeling capacity has concentrated on developing approaches that increase accuracy and reduce turn around time. During the first three years of the study, research has shown that ground based data acquisition and analysis are sufficient to generate a local optical atmospheric model. This model can be used to transfer down to ground level the 'top-of-atmosphere' reflectances as measured by satellite borne multispectral scanning imaging systems. Consequently, masking due to atmospheric effects is reduced. With day-to-day atmospheric effects removed, absolute, rather than relative reflectance values can be used to improve natural resource management.

To achieve this modeling, we have developed an instrumentation set, data collection procedures/protocols, and a series of data reduction programs. This work has been done in close coordination with other NASA research centers and satellite calibration groups. The next phases of the project include three components. These are: Maintenance activity, Productionization, and Angular distribution effects.

Maintenance refers to the continuation of cross-calibration activities. Sensors change over time and, unfortunately, monitoring the optical calibration change of a space borne sensor is nontrivial. However, we have established both procedures and protocols to continue our own cross-calibration activities, and we are closely tied into the science community routinely monitoring the calibrations of these sensors.

Productionization: For atmospheric corrected multispectral imagery to be directly useful within the agricultural community, it must be timely. This means that satellite imagery must be processed and stresses identified while there is still time for mitigation and remediation. Turn-around times for both uncorrected image acquisition and subsequent processing are presently measured in weeks (or even months). Consequently, for the next project phase, we propose to reduce this turn-around to routinely provide corrected images within one week, setting ourselves up for a long term goal of 24 hour 'near real time' processing. While this is an aggressive goal, the individual components are primarily in place as a result of the initial project phases. Software and instrumentation systems have been set up within a common processing code concept to ease the integration path. Developed links (which include ancillary projects such as the IAS program with EROS Data Center), will provide a high efficiency image acquisition path for NASA based sensor systems. The interdisciplinary nature of the precision agriculture project team has eased cross training between plant science, remote sensing, and atmospheric modeling teams.

Angular distribution effects: Atmospheric modeling to remove optical transport effects is an important constituent of improving 'top of atmosphere' measurements of what is really going on at ground level. However, another masking effect, which makes it difficult to interpret vegetation data is related to angular reflectance variation. This is often measured in terms of BRDF (bi-directional reflectance distribution function). This is especially a concern when ground level features are viewed from off-nadir angles (especially a concern with pointable high resolution commercial satellites such as QuickBird). Pilot studies indicate that first order models can be developed for corn and soybeans once they 'canopy over'. Grasses and cereal crops such as wheat have their own complications, however. Consequently, a secondary goal of the next phase of the precision agriculture project will be to develop an equipment base and models that will provide a minimum of a first-order BRDF correction for canopied corn and beans.

Linking agriculture applications with radiometric calibration

As discussed above, most of the work for the first two and one-half years concentrated on developing agricultural applications and improving cross-calibration procedures. In the remainder of year 3 and in years 4 and 5 the impact of an at-surface crop reflectance image on improved natural resource management will be tested.

Atmospheric corrections are band dependent. In figure 3A, atmospheric radiometric intensity adjustments for band 1, 2, 3, 4, 5, and 7 were determined to be 69.6%, 47.1%, 33.7%, 6.28%, 1.85%, and 2.35%, respectively. These values are used to develop an at-surface crop reflectance image. A hypothesis that will be tested in years 4 and 5 is that the at-surface reflectance image can be used in agricultural application models for improved natural resource management. We are in the process of validating the at-surface reflectance images. For example, calculated NIR at-surface reflectance values were compared with known NIR reflectance values. Relative to the QuickBird reported values the physical modeling approach improved the fit in the NIR band between the measured and calculated values (Fig. 3b).

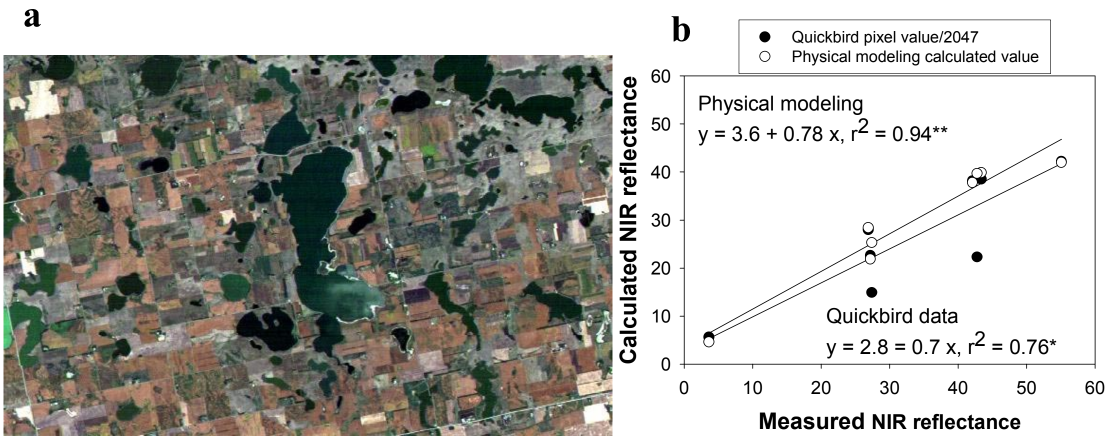

Fig. 3. (a) Typical Landsat 5 TOA multispectral image collected on September 19, 2003. (b) Results from physical modeling for the NIR band data collected on August 23, September 15 and October 21, 2003. The QuickBird data were converted to quasi-reflectance values by dividing the reported pixel values by 2047.

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C. REQUEST FOR CONTINUATION

1. Two-year program plan and budget.

Remote sensing provides valuable information about natural systems that can be used for a variety of purposes including water quality assessment, global warming, homeland (agricultural productivity) security, public health, improved weed control, and improved nutrient management. For remote sensing to be consistently integrated into resource management, the information must be accurate, delivered relatively quickly, and contain information that can be used directly by a decision support system. The Cross-Calibration Project is developing techniques to improve accuracy and creating approaches for seamless integration of remote sensing into ecosystem management. Many of these techniques will be field tested and validated in the remainder of year 3 and in years 4 and 5.

The ability to develop remote sensing based models that simultaneously determine water and N impacts on plant productivity has been hindered by the lack of experimental techniques for separating these two primary stress-causing factors. This project pioneered the development of an approach that uses biomass productivity and ^{13}C discrimination to quantify the individual effects of N and water on productivity. During the remainder of year 3 and in years 4 and 5 this approach will be validated in experimental plots and tested in producers' fields.

Atmospheric modeling to remove optical transport effects is an important constituent of improving 'top of atmosphere' measurement of what is really going on at ground level. However, another masking effect which makes it difficult to interpret vegetation data is related to angular reflectance variation. This is often measured in terms of BRDF (bi-directional reflectance distribution function). This is especially a concern when ground level features are viewed from off-nadir angles (especially a concern with pointable high resolution commercial satellites such as QuickBird). Pilot studies indicate that first order models can be developed for corn and soybeans once they 'canopy over'. Grasses and cereal crops such as wheat have their own complications, however. Consequently, a secondary goal of the next phase of the precision agricultural project with be to develop an equipment base and models that will provide a minimum of a first-order BRDF correction for canopied corn and beans.

As previously discussed, most of the work for the first two and one-half years concentrated on developing agricultural applications and improving cross-calibration procedures. In the remainder of year 3 and in years 4 and 5, the impact of an at-surface crop reflectance image on improved natural resource management will be tested. A hypothesis that will be tested in years 4 and 5 is that the at-surface reflectance image can be used in agricultural application models for improved natural resource management. We are in the process of validating the at-surface reflectance images.

2. Metrics to be used for tracking and evaluating program progress.

Metrics will be used for tracking purposes and to assess the accomplishments of the project. For outreach purposes the project will record: (i) the number of invited and volunteered presentations made to both scientific audiences and the general public, (ii) the number of fact sheets and guideline papers prepared, and (iii) an index of the extent to which producers integrate remote sensing into their management process and their general knowledge level. At workshops and symposia, participants will be asked to fill out surveys. By tracking survey responses over time, we will be able to assess changes in end-user perceptions.

For scientific activities, the metrics that will be used for evaluation will include the number and quality of peer review papers prepared and published, the number and quality of invited and volunteered presentations, and the ability to meet the timetable.

3. Milestones and timetables for achievement of specific objectives during the award period.

Milestones for the final two years of the project are listed below and shown in the accompanying timetable. The over-riding goals are: a) To develop, improve, and validate different approach for radiometric calibration and cross validation of space-based sensors, and b) To develop and validate remote sensing-based models that utilize radiometrically corrected space-based data for identifying the causes of yield reductions in corn, soybean, and wheat fields.

Specific milestones include the following:

- Conduct radiometric calibration field experiments during the summers of 2004 and 2005. In these field experiments the reflectance values on calibrated tarps located in South Dakota will be measured for targeted overpasses of both Landsat and QuickBird satellites.
- Measure atmospheric characteristics during satellite overpasses.
- Develop, test, and modify reflectance models that account for atmospheric characteristics following field campaigns.
- Test and validate these models during the summers of 2005 and 2006.
- Conduct field experiments during the summers of 2004 and 2005 that are designed to determine the simultaneous effects of water, N, and weeds on crop reflectance. These experiments will test and validate models that were developed during the first two years of the project. Validation of the models will include testing of radiometrically calibrated space-based remote sensing in producers' fields.
- Convene annual planning and technical review meeting in January or February each year.
- Prepare and submit proposal for new funding.
- Prepare and submit manuscripts for publication.
- Prepare annual and final reports.

Timetable

Activity	2005-2006				2007-2008			
	Dec.	Mar.	June	Sept.	Dec.	Mar.	June	Sept.
Radiometric Cal.								
Reflectance meas. of different sensors			■	■			■	■
Model testing: Compar. measured and predicted reflectance meas.			■	■			■	■
Model revision					■	■		
Model testing and validation, comparison measured and predicted values.							■	■
Manuscript preparations	■	■	■	■	■	■	■	■
Applications								
Field experiments								
Quantifying yield losses N and water stress in wheat and corn			■	■				
Quantifying pest effects on crop reflectance			■	■				
Analysis								
Remote sensing water budget model tested					■	■	■	■
Remote sensing model predicting yield losses to water and N tested and validated					■	■	■	■
Manuscripts		■	■	■	■	■	■	■
Advisory meetings		■				■		
Reports	■				■			■

4. **Potential towards achieving self-sufficiency beyond the award period of this grant (limit: 1/2 page).**

Self-sufficiency will be gained through two means. First, as success in using remote sensing for agricultural applications is developed, additional funding opportunities should develop from a variety of sources. Based on findings from the first three years of this project, proposals have been prepared and submitted to a variety of funding sources. Most of these proposals have been highly ranked and many of them have been funded.

Second, as economic viability of the proposed work is achieved and the results of this work are relayed to end users, resource managers will increasingly demand this type of information and industrial support will follow. We have held preliminary commercialization discussions with Raven Industries, Daktronics, AGVISE Laboratories, Independent Crop Consultants Association, CRITERON, Potash and Phosphate Institute, and the USGS EROS Data Center. Funding is currently being sought from state and federal goverment, industry, and local economic development agencies, and a proposal has been developed and submitted to the State of South Dakota for a Research 2010 Center. The proposed "Center for Research, Development and Commercialization of Advanced Information Systems for Agriculture, Disaster Mitigation, and Homeland Security" (CAIS) would be dedicated to integrating information from a variety of sources in a real-time, seamless fashion to generate results and products that enhance decision-making and/or profitability for agricultural producers, natural resource managers, health and homeland security organizations. Based on contributions from focus group meetings held in 2003 and 2004, the following objectives for the center were determined: (i) conduct research designed to develop advanced information systems that provide seamless linkages among real-time information acquisition equipment, visualization equipment and software, and decision support systems; (ii) conduct research designed to develop a better understanding of agricultural and natural systems biocomplexity; (iii) develop infrastructure required to convert research into commercial ventures; and (iv) create an Advanced Information Systems Product Incubator.

5. **Potential for the proposed research area to continue to grow in importance in aerospace fields in the future (limit: 1/2 page).**

The integration of a variety of information sources (including remote sensing data) into the decision process is the main premise behind this project. Based on the type of questions that people are asking (what, where, and how to better manage natural resources), the importance of this research will continue to grow. This project will seek to develop systems that link spatial information in novel ways to enhance the end users' ability to make improved decisions.

The convergence of advanced information technologies has poised the remote sensing industry for rapid and perhaps explosive growth. Two factors are primarily responsible for new opportunities for advanced information systems. First, the electronics that comprise remote sensing sensors have been miniaturized. Today's sensors are cheaper, smaller, lighter, and more sensitive than their predecessors. These sensors can discern subtle details that are undetectable by the human eye. Second, the remarkable advances in computing technology, including data storage and information systems, make the analysis of remote sensing data and its transformation into useful information easier and more rapid than ever before. Remote sensing imagery, which only a few years ago required large and expensive mainframe computers just for viewing, can today be visualized and analyzed on inexpensive laptop or even palm-sized computers. Research conducted under this project is expected to directly benefit a number of different applications including, agriculture, public health, homeland security, military, and public planning.