RESEARCH PROPOSAL: "Cross-Calibration of Landsat and IKONOS Sensors for Use in Precision Agriculture"

Submitted to
NASA EPSCoR

by

South Dakota State University
as part of the
SD EPSCoR Proposal
Dennis Helder, Principal Investigator

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Enterprise 2 Earth Science
ESE 2 Resource Management
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Requesting $669,300 from NASA for a 3-year project.

Membership Page

South Dakota State University
- Electrical Engineering Department
- SD Plant Science Department
- Engineering Resource Center
- South Dakota Agricultural Experiment Station
- Physics Department
- Biology and Microbiology Department
- Northern Great Plains Water Resources Research Center
- Civil and Environmental Engineering Department

Potash and Phosphate Institute
South Dakota Corn Utilization Council
South Dakota Independent Crop Consultants
South Dakota Soybean Research and Promotion Council
North Central Soybean Association
USGS EROS Data Center
SD School of Mines & Technology
Stennis Space Flight Center
Goddard Space Flight Center

Table of Contents

Dennis Helder
Director of Engineering Research
Professor of Electrical Engineering
South Dakota State University
PO Box 2220 SDSU
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Education:

Ph.D.	North Dakota State University	1991
M.S.	South Dakota State University	1985
B.S.E.E.	South Dakota State University	1980
B.S.A.S.	South Dakota State University	1979

For the past five years Dr. Helder has worked with Goddard Space Flight Center to develop radiometric calibration for Landsat 4 and 5 Thematic Mappers, and the Landsat 7 Enhanced Thematic Mapper Plus. He is also a co-investigator on the EO-1 Science Validation Team with responsibility for developing the radiometric calibration of ALI and Hyperion. In addition, he is working the Stennis Space Center to develop radiometric, spatial, and geometric characterizations of the IKONOS commercial satellite imaging system. Other activities include over ten years of collaboration with EROS Data Center on Landsat TM, MSS, and SPOT radiometric calibration; membership on the international Committee of Earth Observation Satellites Infrared, Visible, and Optical Sensor's subcommittee; a visiting scientist appointment at Goddard Space Flight Center; and development of the Landsat 7 Image Assessment System with Goddard Space Flight Center.

Dr. Helder teaches courses in Image Processing, Signal Processing, and Probabilistic Methods and has also taught electronics, circuit theory, and electromagnetics along with special topics in adaptive filtering, parallel processing, and wavelets. As one of the principal developers of the South Dakota State University Image Processing Laboratory, Dr. Helder has obtained over $2,000,000 in grant support. Prior to employment at SDSU, he was an RF design engineer at E.F. Johnson Co., Waseca, Minnesota.

PUBLICATIONS (first author only)
D. Helder, W. Boncyk, R. Morfitt, “Absolute Calibration Of The Landsat Thematic Mapper Using The Internal Calibrator,” accepted to IGARSS ‘98, Seattle, WA, July 6-10, 1998.
D. Helder, S. Schiller, R. Malo, “Experimental And Model-Based Derivation Of Atmospheric Point Spread Functions,” accepted to IGARSS ‘98, Seattle, WA, July 6-10, 1998.
D. Helder, W. Boncyk, R. Morfitt, “Landsat TM Memory Effect Characterization and Correction,” Canadian Journal of Remote Sensing, Vol. 23, No. 4, December, 1997, pp. 299-308.
D. Helder, "A Radiometric Calibration Archive for Landsat TM," in the proceedings of SPIE's conference Algorithms for Multispectral and Hyperspectral Imagery, April 9, 1996, Orlando, Florida, SPIE Vol. 2758, pp. 273-284.
D. Helder, J. Barker, W. Boncyk, B. Markham, "Short Term Calibration of Landsat TM: Recent Findings and Suggested Techniques," in the proceedings of IGARSS96: Remote Sensing for a Sustainable Future, Lincoln, Nebraska, pp.1286-89.
D. Helder, J. Hood , D. Krause, "An Adaptive Debanding Filter for Thematic Mapper Images," IEEE Transactions on Geoscience and Remote Sensing, in review.
D. Helder, "Consistent Calibration of the Landsat MSS Archive," Pecora 12 Symposium on Land Information from Space-based Systems August 24-26, 1993, Sioux Falls, SD.

D. Helder, "Comparison of MSS Relative Radiometric Calibration Methods," SPIE OE/Aerospace and Remote Sensing Symposium, April 12-16, 1993, Orlando, FL.
D. Helder, Bruce Quirk, Joy Hood, "A Technique for the Reduction of Banding in Landsat Thematic Mapper Images," Photogrammetric Engineering & Remote Sensing, Vol. 58, No. 10, October 1992, pp. 1425-1431.
D. Helder, "A Debanding Algorithm for Thematic Mapper Imagery," Visual Information Processing Symposium, University of Nebraska-Lincoln, February 8, 1991, Lincoln, NE.
D. Helder, Mike Choate, "Techniques for Removing Odd/Even Detector Noise from Pushbroom Scanners with Large Linear arrays," SPIE OE/Aerospace Sensing Symposium, April 4-8, 1994, Orlando, Florida.
D. Helder, "The MSS Radiometric Calibration Handbook," final report to EROS Data Center, 1993.

PARTIAL LIST OF GRANTS OBTAINED

"Imaging and Modeling of Coupled Environmental Processes," NSF EPSCoR, 1995-1998, total amount $940,188.
"TM Radiometric Calibration," an unsolicited proposal submitted to NASA Goddard Space Flight Center, 3 years, funded, total amount $183,027.
"Characterization of Landsat 7 Geometry and Radiometry for Land Cover Analyses," Co-I with Jim Vogelman (PI), EROS Data Center, Wayne Boncyk, EROS Data Center, and Jim Merchant, University of Nebraska-Lincoln, 3 years, total amount to SDSU $241,225.
"Certification and Operational Development of an Ethanol Powered Aircraft," submitted to the South Dakota Corn Utilization Council, Jim Behnken, SDSU, Co-I, 4 years, funded, total amount $152,986.
"Thematic Mapper Radiometric Calibration Study," an unsolicited proposal submitted EROS Data Center, U.S. Geological Survey, funded, 1 year (continuation), total amount $14,986.
"Relative Radiometric Calibration of the Landsat Archive Year 2," $65,868, funded by: EROS Data Center, USGS, 1993-4.
Relative Radiometric Calibration of the Landsat Archive, $50,648, funded by: EROS Data Center, USGS, 1992-3.
Initiation of Machine Vision research at SDSU, $1992, SDSU Research Support Fund, 1992-3.
Landsat TM and MSS Relative Radiometric Calibration Study, $27,006, funded by: EROS Data Center, USGS, 1991-2.
CCD Detector Noise Removal, $1500, funded by: EROS Data Center, USGS, 1991-2.
Removing SPOT Panchromatic Noise, $20,728, funded by: EROS Data Center, USGS, 1990-1.
LAS Display R & D, $2000, funded by: EROS Data Center, USGS, 1990-1.
Deswathing of Thematic Mapper Data, $13,629, funded by: EROS Data Center, USGS, 1989-90.
Engineering/EROS Equipment Capacity Building, $18,000, funded by: CITE Grant, Governor's Office of Economic Development, 1990

Member of
IEEE: Institute of Electrical and Electronic Engineers

David Edward Clay

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South Dakota State University
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Education

B.S.	Soil Science, Natural Resources, University of Wisconsin, Madison, WI, 1976.
M.S.	Soil Science, Soil Fertility, University of Idaho, Moscow, Idaho, 1984
Ph.D.	Soil Science, Soil Biochemistry, University of Minnesota, St. Paul, 1988.

Post Doc., Water Quality Center, University of Minnesota, St. Paul, 1988-1990.

Experience and Responsibilities

8/86-5/88	Graduate RA, Soil Science Depart., University of Minnesota, St. Paul MN
8/89-6/95	Asst. Prof. Soil Biogeochemistry, 90% research and 10% teaching, South Dakota State University, Brookings, SD
8/96-present	Assoc. Prof., Soil Biogeochemistry, 90% research and 10% teaching, South Dakota State University, Brookings, SD
4/94-10/97	Newsletter editor of South Dakota Professional Soil Scientist Association
6/95-present	Director of South Dakota State University Ratio Mass Spectrometer Laboratory
3/98-7/98	Member of USDA-CSREES-NRI water resource and assessment Panel.
12/99-present	Chairman Editorial Board, Site-Specific Management Guidelines.
10/98-10/99	Chairman of NC180 and Agronomy Society Div. A-9, American Society of Agronomy Site-specific Management Symposium.
10/99-10/00	Co-chairman of Agronomy Societies division A-9, Electrical conductivity symposium.
10/99-	Associate editor, ASA Precision Farming Symposium, Precision Agriculture
5/00-	Associate editor, Agonomy Jounal

Regional and National Professional Memberships

- NC218 (Past Chairman)- N recommendation for manured land,
- NCS5 (Past Chairman)- North Central Region Water Quality Planning,
- Chairman of the planning committee for Precision Farming Guideline manual,
- South Dakota Pesticide Ground Water Management Group,
- South Dakota Professional Soil Science Association, (Past Editor of the Newsletter)
- Sigma Xi, (Past Chairman of Graduate Student Proposal Writing Contest),
- Member of Agron. Soc., Amer. Soc, Soil Sci., Gamma Sigma Delta, and Sigma Xi
- NC180, Site-specific management committee.

Publications and Proceedings:Over 60 paper since 1995

Grants: Over 4 million dollars since 1990

Presentations: Over 120 invited and volunteered talks since 1990

Graduate students: Current 2 Doctoral students and 3 Masters students

KEVIN DALSTED

South Dakota State University
PO Box 2220, Harding Hall, Brookings, SD 57007-0199
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TITLE

Director, Engineering Resource Center (1998 – Present)
Associate Director S. D. Space Grant Consortium (1997- present)

EDUCATION

NORTH DAKOTA STATE UNIVERSITY
B. S. and M. S., Soils, 1974 and 1977
Thesis Title: The Use of Remote Sensing Technology to Detect Saline Seeps

EXPERIENCE

SOUTH DAKOTA STATE UNIVERSITY
Remote sensing and GIS for natural resources and agricultural applications. Amalgamation of information systems and resource investigations. Administration of ERC (outreach department for College of Engineering).

PROJECT PARTICIPATION

- Detection of saline seeps with multispectral remote sensing data (VIS., NIR, and TIR)
- State applications projects under the NASA Applications Grant (1977 to 1981)
- Microwave remote sensing of wet and saline soils
- Soil survey leader for Landsat reconnaissance mapping in Mauritania, West Africa
- Researcher, responsible for work on two chapters in Volume 8, of the South Dakota superconducting supercollider proposal (1987)
- Developed a MOU between the SDSU and the USGS EROS Data Center (EDC)
- USAID Title XII projects for Somalia, Jordan, Botswana, Senegal, Mauritania, and a campus colloquium and conference series
- Leafy spurge detection from aerial photography
- Participant researcher in user needs assessment for a computerized, statewide Geographical Information System
- Co-Principal Investigator in Phase 2 Implementation Plan for South Dakota statewide Geographic Information Systems
- Consulting remote sensing and GIS lecturer for Asian Development Bank
  In-house Seminar: Environmental Techniques and Analysis in Bank Project (Feb. 1989)
- Over 40 reports and publications in remote sensing and geographic information systems
- Satellite analysis for cropland use intensity for 20 African countries and North Korea (1991 – 00)
- Upper Midwest Aerospace Consortium investigator developing remote sensing applications for precision agriculture (!997-present) including ESIPS project and UMAC projects at SDSU
- Coordinator for SDSU NASA EPSCoR planning grant

SOCIETY AND ORGANIZATION MEMBERSHIPS

American Society of Photogrammetry and Remote Sensing
Alpha Zeta

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South Dakota State University
Brookings, SD 57007
Home: (605) 693-3380, Work: (605) 688-5918, FAX: (605) 688-5878
Email: stephen_schiller@sdstate.edu

Professional Positions:

Dates	Institutions or Organizations	Nature of Duties
August 1997 - present	South Dakota State University	Professor
August 1995 - present	NSF EPSCoR Program	University Fellow in Research
June 1992 - 1996	NASA/JOVE Initiative	NASA University Fellow in Research
June 1991 - August 1991	NASA/USRA Summer Faculty	Research at Marshal Space Flight Center
June 1990 - August 1990	NASA-ASEE Summer Faculty	Research at Stennis Space Center
August 1993 - 1997	South Dakota State University	Associate Professor
August 1987 - May 1992	South Dakota State University	Assistant Professor
May 1986 - August 1987	University of Calgary	Postdoctoral Fellow

Education:

1981 – 1986 University of Calgary, Calgary, Alberta Degree: Ph.D. in Astrophysics.
Thesis: Eclipsing Binaries in Open Clusters: Observations and Analyses of HD 27130 and DS Andromedae

1978 – 1981 Ohio State University, Columbus, OhioDegree: M.Sc.in Astronomy
Thesis: Objective-Prism Survey of M-Giant Stars in the Region of the South Galactic Pole

1972 – 1977 Walla Walla College, College Place, Washington Degree: B.Sc.in Physics

Publications and Conference Proceedings (Since 1999):

Brown, S.W., Johnson, C., Thome, K., Schiller, S.J. 1999, "Radiometric Characterization of Field Radiometers in Support of the 1997 Lunar Lake, Nevada Experiment to Determine Surface Reflectance and Top-of-Atmosphere Radiance". Submitted to Journal of Oceanic and Atmospheric Technology.

Schiller, S.J., "A performance Evaluation of Commercial Shadowband Radiometers", 1999, Conference on Characterization and Radiometric Calibration for Remote Sensing. Space Dynamics Laboratory, Utah State University, Nov. 9-11, 1999.

Black, S.E., Schiller, S.J. and Helder, D.L., 2000, "Iradiance-based Cross Calibration of Landsat-5 and Landsat-7 Thematic Mapper Sensors" Submitted to International Journal of Remote Sensing.

Milone, E.F., Williams, M.D., McClure, M., Kallrath, J., and S.J. Schiller 2000, "Simulations of Transits in the Stars of the Globular Cluster 47 Tucanae", Poster Proceedings of IAU Symposium 200, Birth and Evolution of Binary Stars, pp 181-183.

Milone, E.F., Schiller, S.J., Munari, U., and Kallrath J., 2000, "Analysis of the Currently Non-Eclipsing Binary SS Lacertae or SS Lac's Eclipses", Astronomical Journal, **119**, 1405

Schiller, S.J. and Luvall, J.C. 2000, "Description and performance demonstration of the Portable Ground-Based Atmospheric Monitoring System (PGAMS) for optimal radiative transfer modeling, atmospheric correction, and vicarious calibration", Proceedings of the Worshop on Multi/Hyperspectral Sensors, Measurements, Modeling, and Simulation, November 7-9, 2000, Redstone Arsenal, AL. In press.

Rickman, D.L., Schiller, S.J. Luvall, J.C. 2000,"An Algorithm for atmospherically correct visible and thermal airborne imagery", Proceedings of the Worshop on Multi/Hyperspectral Sensors, Measurements, Modeling, and Simulation, November 7-9, 2000, Redstone Arsenal, AL. In press.

Thome, K., Arai, K., Conel, J., Gauthier, R., Schiller, S., and Tsuchida, S., 2000, "Results of the 1997 Joint EOS International Vicarious Calibration Campaign to Lunar Lake, Navada.", Submitted to International Journal of Remote Sensing.

Dr. Sharon A. Clay

Current appointment: Professor, Weed Science, SDSU Plant Sci. Dept., 80% research, 20% teaching

Education:

BS	University of Wisconsin	Horticulture	1977
MS	University of Idaho	Plant Science	1983
PhD	University of Minnesota	Agronomy	1986

Professional experience:

Professor, Plant Sci. Dept., 7/98-current
Associate Professor, Plant Sci. Dept., SDSU 7/93-6/98
Assistant Professor, Plant Science Dept., SDSU, 8/89-6/93
Research Agronomist - USDA-ARS, Soil & Water Management Research Unit, St Paul, MN. 7/86-8/89

Awards:

Edminster Award, USDA-ARS, 1987
Gamma Sigma Delta Research Award, SDSU Chapter, 1996
Dean's Award for Excellence, Teaching and Research, SDSU, 1997
F.O. Butler Foundation Award for Excellence in Research, 1997
Sigma Xi Research Award, 1999
Gamma Sigma Delta Teaching Award, SDSU Chapter, 2000

General Research Interests:

Site specific weed management, identifying weed management zones using remote sensing with multiband and hyperspectral data, integrating weed ecology into management decisions, weed competition in crops, and biological control of range weeds.

Selected Recent Publications:

Clay, S.A., T.M. DeSutter, and D.E. Clay. Herbicide concentration and dissipation from surface wind-erodible soil. Weed Sci. (Accepted)

Ellsbury, M.M., S.A. Clay, S.J. Fleischer, L.D. Chandler, and S.M. Schneider. 2000. Use of GIS/GPS systems in IPM: Progress and Reality. Pg. 419-438. In: Kennedy, G.C. and T.B. Sutton. Emerging technologies for integrated pest management: concepts, research, and implementation. APS Press. St. Paul, MN

Clay, S.A., R.H. Dowdy, J.A. Lamb, J.L. Anderson, B. Lowery, R.E. Knighton, and D.E. Clay. Herbicide movement and dissipation at four midwestern sites. J. Environ. Sci. Health, B35:259-278.

Cole, C., S.A. Clay, K. Dalsted, and G.J. Lems. 1999. Estimation of weed infestation levels through integration of landscape position, weed ecology, and remote sensing. Pecora Conference, Denver. Dec. 1999. (abstr.)

Chang, J., D.E. Clay, C.G. Carlson, J. Lee, D.D. Malo, S.A. Clay, and M.M. Ellsbury. 1999. Selecting precision farming soil sampling protocols: Part 1. Grid distance impact on semivariogram and estimation variances. Precision Agric. 1:277-289.

Clay, S. and G. Johnson. 1999. Scouting for weeds. In Clay, D.E. et al. (ed) Site specific management guidelines. SSMG-15. PPI, Norcross, GA.

Clay, S.A., G.J. Lems, D.E. Clay, F. Forcella, M.M. Ellsbury, and C.G. Carlson. 1999. Sampling weed spatial variability on a field-wide scale. Weed Sci. 47:674-681.

DeSutter, T., S.A. Clay, and D.E. Clay. 1999. Agrichemical concentration on wind blown sediments. J. Environ. Health Part B33:683-691.

Broulik, B.L., K.J. Dalsted, S.A. Clay, D.E. Clay, C.G. Carlson, M.M. Ellsbury, and D.D. Malo. 1999. Weed detection in field corn using high resolution multispectral digital imagery and field scouting. 1998 Precision Agricultural Conference. St. Paul, MN ASA, Madison, WI pg. 1409 (abstr.)

Broulik, B.L., C.L. Reese, S.A. Clay, D.E. Clay, and M.M. Ellsbury. 1999. Evaluation of General weed management (GWM) model: A computerized bioeconomic weed decision aid for row crops.1998 Precision Agricultural Conference. St. Paul, MN ASA, Madison, WI pg. 1615 (abstr.)

Broulik,B.L., J. Lems, S.A. Clay, D.E. Clay, and M.M. Ellsbury. 1997. Analysis of spatial distribution of Canada thistle (*Cirsium arvense*) in no-till soybean (*Glycine max*). South Dakota Acad. Science.

Tagir G. Gilmanov
Department of Biology and Microbiology, South Dakota State University
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Academic training:

Degree	Year	Institution	Major
M.S.	1972	Moscow State University	Soil Ecology/Math. Modeling
Ph.D.	1976	Moscow State University	Soil Ecology/Math. Modeling
Dr. Sci.	1992	Moscow State University	Systems Ecology

Professional experience:

Year	Position	Institution
1975-1977	Research Fellow	Dept. of Soil Science, Moscow State University
1977-1979	Post-doctoral Fellow	Dept. Biology, Moscow State University
1979-1983	Assistant Professor	Dept. Biology, Moscow State University
1983-1989	Senior Scientist	Dept. Biology, Moscow State University
1989-1992	Senior Scientist	Dept. Biology, Moscow State University
1992-1995	Head of Laboratory	Center for Ecology and Productivity of Forests, Russian Academy of Sciences
1992-1996	Visiting Scholar	Global Change Research Group, Dept Biology, San Diego State University
1996-1997	Visiting Scholar	Department of Rangeland Resources, Utah St.University
1997-present	Assistant Professor	Dept Biology/Microbiology, South Dakota State University

Professional and Honorary Societies, Committees:

USSR/IBP Grassland Ecosystems Committee (1970-1974)
SCOPE/ICSU Commission on Simulation Modelling (1973-1976)
USSR/SCOPE Commission on Simulation Modelling, Member and Scientific secretary (1973-1976)
"Znanie" ("Knowledge") Society of Russia (1975-1990)
Specialized Council on Ecology and Hydrobiology at Moscow State University for Ph.D. and Dr.Sci. dissertations (1987-1991)
SCOPEGRAM (SCOPE/ICSU Grassland Modeling Group) (1989-1992)
Moscow Society of Naturalists (full member: 1985-1992)
ARCSS LAII Flux Study Modeling WG, member (1992-1996)
USDA/ARS Rangeland CO2 flux WG, member (1997-present)
Ecological Society of America, member (2000 - present)

Teaching Experience:

General Ecology	Moscow State University
Ecological Bioenergetics	Moscow State University
Systems Ecology	Moscow State University
Advanced Ecological Modeling	Moscow State University
Systems Ecology	San Diego State University
Ecological Modeling	South Dakota State University
Introduction to Env. Science	South Dakota State University
Integrated Natural Res. Mgnt.	South Dakota State University

Supervision: 11 M.Sc. students; 10 Ph.D. students

Publications: 40+ scientific publications, including 3 books; 20+ Invited Seminars and Presentations since 1989

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Specialization: Solid state device Fabrication, Characterization and Production Techniques

Education:
B.S. Engineering Physics, South Dakota State University (1975)
M.S. Materials Science, University of Wisconson-Madison (1981)
PhD. (ABD), Materials Science, U of Wisc-Madison

Experience:

South Dakota State University, Brookings, SD (1993-present)
Assistant Professor of Physics

McDonnell Douglas Corp, St. Louis, MO (19898-1992)
Lead Engineer in Product Development Group. Work involves Developing, characterizing and improving performance of high power laser diodes for commercial and military applications.

South Dakota State University, Brookings, SD (1986)
Visiting Assistant Professor in Department of Electrical Engineering

University of Wisconsin, Madison, WI (1979-1989)
TA Electrical Engineering
RA & Dissertation studying amorphous binary metallic alloys in thin film form.

IBM Rochester, MN (1977-1979)
Associate Engineer designing and evaluating custom analog integrated circuits.

SDSU Brookings, SD (1974-1977)
Set up EPR spectrometer, RA Thermal mapping for remote detection of groundwater

Professional Societies:
Materials Research Society, American Vacuum Society, Tau Beta Pi, Phi Kappa Phi

Patent: D.B. Aaron and J.D. Wiley, US Patent #4,865,710 "Magnetron with Flux Switched Cathode and Method of Operation" Sept. 12, 1989.

Publications:

M.F. Chisholm, D.B. Aaron, J.D. Wiley, J.H. Perepezko, *Electromigration Studies in Amorphous and Polycrystalline Alloys,* Appl. Phys. Lett., **53**, 102 (1988).

R. E. Thomas, K. J. Guo. D. B. Aaron, E.A. Dobisz, J. H. Perepezko, J.D. Wiley, *Investigation of Amorphous Ni60Nb40 Diffusion Barriers,* Thin Solid Films, **150**, 245 (1987).

E.A. Dobisz, D.B. Aaron, K. J. Guo, J. H. Perepezko, R.E. Thomas, J.D. Wiley, *Thermal Stability of Amorphous Ni, Nb on Semiconductor Substrates,* Fifth Intl. Conference on Liquid and Amorphous metals, Los Angeles, CA (August 15-19, 1983).

D.B. Aaron, R.E. Thomas, J.D. Wiley, *Calculation of Temperature Profiles in Radiantly Heated and Cooled Silicon Wafers,* J. Appl. Physics, **54**, 3632 (1983).

R.E. Thomas, E.A. Dobisz, D.B. Aaron, D.E. Madisen, *Amorphous Metal Diffusion Barriers,* Proc. 2nd Conference on High Temperature Electronics and Instrumentation, Houston, TX (December 7-8, 1981).

D.B. Aaron, J. A. Tunheim, D.G. Moore, *Soil Temperature Fields Associated with Saline Seeps,* Proc. SD Academy of Science, **55**, 25 (1976).

Suzette R. Burckhard
Civil and Environmental Engineering
South Dakota State University
Brookings, SD 57007-0495 Brookings,
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Research Interests:
Fate and transport of contaminants in the environment; hytoremediation; water quality; geochemical modeling; remote sensing.

Education:
Ph.D. Civil Engineering, Kansas State University, August 1997.
Dissertation title: The Impact of Vegetation on the Transport of Heavy Metals in Contaminated Soils.
M.S. Chemical Engineering, Kansas State University, May 1993.
Thesis title: Hot Filament Assisted Chemical Vapor Deposition and Characterization of Diamond Films.
M.S. Physics, Kansas State University, May 1992.
Thesis title: Morphology of Thin Gold Films Prepared from a Non-Aqueous Colloidal Solution.
B.S. Engineering Physics, South Dakota State University, May 1986.
minors: Computer Science and Mathematics.

Professional Experience:
Asst Professor, Civil and Environmental Eng.,SDSU, 1/97 to present
Conduct and develop research on hydrological processes, contaminant transport, stochastic modeling, and water resources management; Teach undergraduate and graduate coursework.
Visiting Scientist, USGS EROS Data Center, 8/97 to present
Conduct research related to remotely sensed data for assessing vegetation on disturbed lands and phytoremediation field sites.
Research Assistant, Civil Engineering Department, Kansas State University, Manhattan, KS, 6/93 - 12/96.
Designed and evaluated laboratory and modeling studies related to the fate of heavy metals in contaminated soils including; characterization of heavy metal contaminated soils by selective chemical extraction techniques; evaluation of the effect rhizosphere organic acids have on the transport of heavy metals in contaminated soils; predicting the amount of heavy metal solubilized from contaminated soils by rhizosphere organic compounds using computer geochemical modeling techniques.

Invited Articles:
Satellite Sensing in Assessment of Phytoremediation Field Sites, published in February/March 1999 issue of “Soil & Groundwater Cleanup Magazine”
Remote Sensing Tools for Phytoeremediation Site Assessment, published in October 1998 issue of EPA Tech Trends newsletter (EPA 542-N-98-009).

Articles and Presentations:
Over 10 papers and conference abstracts

1.0 Abstract

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, June-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, and LANDSAT ETM+ to predict the yield limiting factors. Findings from this study will be used to develop precision farming guidelines for selecting remote sensing information sources.

2.0 Proposed Research Plan

2.1 Introduction

Precision farming uses global positioning systems (GPS) and geographic information systems (GIS) to manage yield, weed, insect, and soil nutrient content variability. Precision farming applies the right management, at the right time, in the right way, targeting specific areas without providing excesses or deficiencies. Research conducted by the authors of this proposal has shown that precision agriculture in South Dakota can reduce the amount of herbicides and fertilizers applied to soil (Chang et al., 2000). Reducing agrichemical inputs can improve water quality.

Precision farming may also improve management decisions because crops harvested with combines equipped with yield monitors and differentially corrected global positioning systems (DGPS) have shown that fields previously considered uniform actually contain large amounts of variation (Fig.1). Understanding the causes of yield variability for management purposes as well as predicting final yields prior to harvest are critical for improving profitability. Information derived from remote sensing data can be used to address both issues (Fig. 2). For example, when remote sensing information is superimposed on topography maps, factors causing yield variability can be ascertained. As shown in Figure 1 and Figure 2, low reflectance values in the summit area resulted from low biomass yields. Yields in these areas were limited by water stress (Clay et al., 2000). Under water stress conditions, research conducted by the authors of this proposal has shown that adding fertilizer will have little influence on increasing yields, whereas weeds stress in these areas will have a large impact on yield (Clay et al., 2001). However, in non-water stressed areas nutrients limitations can drastically reduce yields while weeds stress has a smaller impact on yield.

Yield variability is not the product of random events, but is the result of predictable interactions between climate and biology and the soil forming processes (climatic characteristics, parent materials, vegetation, topography, and time). For example, the prairie glacial till soils in eastern South Dakota were formed in low rainfall environments (30 year average precipitation < 55 cm) which resulted in footslope areas with pH values ranging from 7.5 to 8.5, free calcium carbonates, and electrical conductivity (EC) values ranging from 0.4 to 1.5 dS/m. Summit soils, on the other hand, have pH values ranging from 6 to 6.5, do not contain free calcium carbonates, and have EC values ranging from 0.2 to 0.4 dS/m (Malo and Worchester, 1975). Topographic variations also result in large soil moisture differences, with summit soils being drier than footslope soils (Clay et al., 2000).

Differences in chemical properties at the different landscape positions are attributed to water leaching the salts out of summit soils and capillary flow transporting water and salts from subsurface to surface soils in toeslope areas. Many plants and are adapted to specific environments, and therefore landscape induced changes in water content, soil pH, EC, water drainage, water-holding characteristics, and redox potential influence weed and insect population dynamics, microbial activity, and nutrient availability will interact to produce yield variability.

One of the difficulties with precision farming has been collecting and interpreting spatial information. Remote sensing linked to decision support models has the potential to fill this gap (Moran, 2000; Clevers et al., 1994). *For remote sensing to be consistently integrated in precision agriculture, the information must be accurate, delivered to land managers relatively quickly, and contain information that can be used directly by decision support systems.* In other words, the remote sensing data must be radiometrically and geometrically corrected, and cross-calibrated to other sensors being used by the grower, available in a timely manner, and corrected for atmospheric distortions.

Different problems will require different sensors. For example, if the purpose is to identify weed patches then 4 m data may be needed. However, if the purpose is to evaluate regional hail damage, grass hopper migration, or yield variability then 30 m data may be adequate. Matching the information source to the problem is critical to facilitate the adoption of remote sensing as a decision tool.

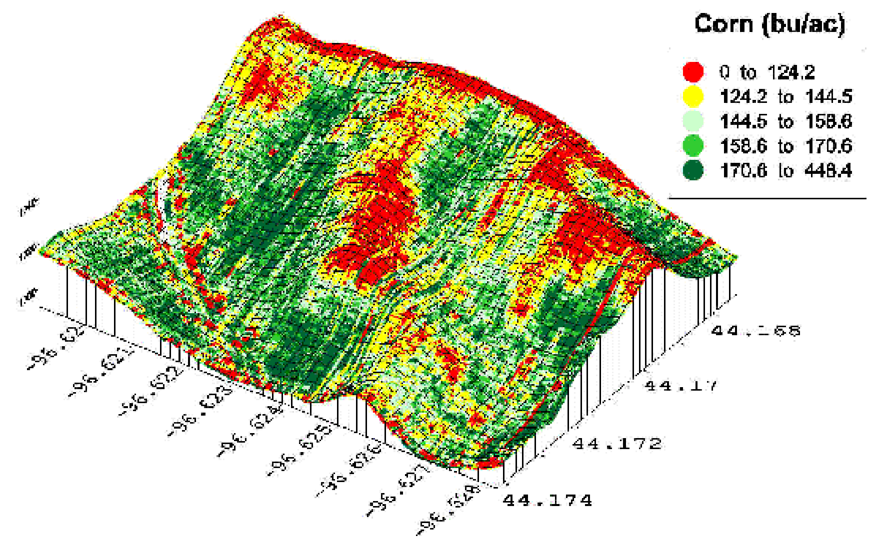

Figure 1. 1999 corn yield in a Moody County, South Dakota corn field (65 ha) derived from a yield monitor.

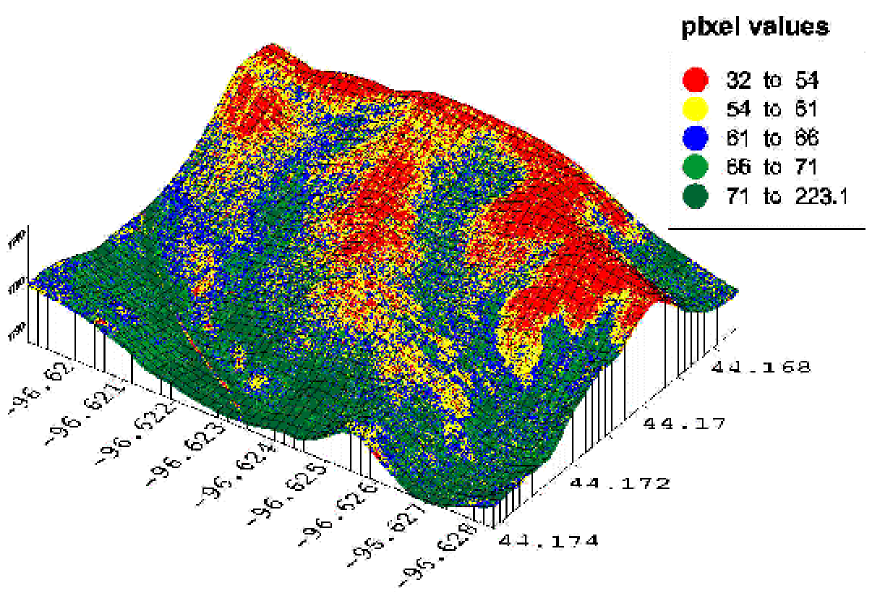

Figure 2. September 28, 1999 near infrared image of Moody County, South Dakota field draped on a 3-d perspective (1 m pixel data from a multispectral aerial digital camera).

Remote Sensing Sensors

With the launch of Landsat 7, the ability to obtain accurate satellite imagery of the Earth's land surfaces entered into a new era. The Enhanced Thematic Mapper Plus (ETM+) sensor on Landsat 7 is perhaps the most accurately calibrated land surface sensor in space at this time. It contains three on-board calibrators: the internal calibrator (IC); the partial aperture solar calibrator (PASC), and the full aperture solar calibrator (FASC). In addition, research conducted by the authors of this proposal have conducted ground calibration of the instrument (Helder et al., 1997a; Helder et al.,1998). Results from calibration studies have shown that radiometric calibration of this sensor is known to within 5% (unpublished results presented at November, 2000 Landsat 7 Science Team meeting by Helder). In addition, its spatial and geometric properties are also well understood with results showing that all specifications for the instrument are being met (unpublished results presented at November, 2000 Landsat 7 Science Team meeting).

Over the past 5 years an effort has also been in progress to provide a high degree of radiometric calibration for the Landsat 5 Thematic Mapper (TM) (Helder et al., 1997a, Helder et al., 1997b, Helder et al., 1998). A web page for Landsat TM calibration is also maintained (http://iplab2out.sdstate.edu/tmcal).

Cross calibration of Landsat 5 and 7 was conducted by matching the orbital paths of the two satellites during the initial check out period for Landsat 7. At this time, the two instruments imaged the same portions of the Earth's surface within 30 minutes of each other. Initial results from these data analysis show that vicarious ground calibration of Landsat 5 and cross-calibration with Landat 7 may agree to less than 5% (unpublished results presented at November, 2000 Landsat 7 Science Team meeting). This method of cross-calibration provides an upper limit of the effects due to the slight differences that exist in the spectral response functions of the two instruments.

The significance of this work is twofold: first, it provides data continuity between the two instruments. Since Landsat 5 was launched in 1984, a record of the Earth's land cover is available that spans 16 years. Secondly, and more important to this project, repeat time for imaging a selected location is halved. The orbits of these two instruments are spaced exactly eight days apart. Thus, any site may be potentially imaged on nearly a weekly basis. This type of coverage is, of course, cloud dependent. But it is also at a temporal scale to provide timely input to the needs of precision agriculture.

Published ground calibration information for IKONOS is not currently available. However, research conducted by the authors of this proposal began work in May, 2000. Preliminary findings substantiate the radiometric, spatial, and geometric accuracy of this instrument. This sensor provides 1 meter panchromatic and 4 meter multispectral imagery with repeat times of less than 4 days with non-nadir viewing. Spatially and temporally speaking these data are ideal for many applications within precision agriculture. However, the field of view is small and the cost is high. Thus, it is imperative to cross-calibrate this system to the Landsat instruments at isolated locations.

Previous work done by the authors of this proposal has indicated that applications using remote sensing are influenced by errors that occur during calibration (Vogelman, 2001). Vogelman (2001) reported that the largest source of error in image classification was relative mis-calibration of the sensor. This was followed by atmospheric induced errors and instrument artifacts. In this project similar sensitivity analysis will be conducted. It will be necessary to perform this analysis especially for the IKONOS instrument because its method of image formation is significantly different than that of Landsat. For example, IKONOS uses a pushbroom scanner technology as opposed to Landsat's whiskbroom scanner approach. Thus, the number of detectors in the IKONOS instrument numbers in the thousands as opposed to the approximately 100 detectors used in thematic mappers.

An additional bonus to this project may occur with the successful launch and deployment of the EO-1 satellite by NASA. This platform carries an instrument known as the Advanced Land Imager. The technology demonstrated by this instrument may become part of future land imaging systems launched by NASA (although this is undecided at this time). Part of the team for this project (Helder/Schiller) are members of the EO-1 Science Validation Team. As part of that project, ALI imagery will be collected during the summer 2001 growing season. This imagery will provide another opportunity to assess Landsat style imagery utility to precision agriculture. If the data sets are acquired, a cross-calibration to Landsat 7 will be performed and ALI data will be used in precision agriculture modeling.

Objectives

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 and evaluate rules for identifying the "best" sensor for given agronomic applications, including applying various levels of atmospheric correction to the sensor data.

2.2 Methods

Field research will be conducted in 2001, 2002, and 2003. In each year, cross calibrations will be conducted three times (May-June, June-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 needed to transform at-sensor radiances to surface reflectance for the different sensors will be determined.
- 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 capability of IKONOS, LANDSAT TM, and LANDSAT ETM+ to predict/estimate the yield limiting factors. Findings from this study will be used to develop precision farming guidelines for selecting remote sensing information sources by application. Coordination will take place with the other funded SD NASA EPSCoR activities. This will insure that common practices and techniques will be used for data collection and analyses, to the extent possible.

Component 1

Equipment available at SDSU will be used for cross-calibration and to determine atmospheric correction of Landsat and IKONOS data. All radiometric instrumentation used by the team will be cross-calibrated on standard reflectance panels.

Equipment that will be used includes shadowband radiometers, sunphotometers, field spectroradiometers, and Portable Ground-based Atmospheric Monitoring System. The shadowband (MFRSR) is a ground-based instrument for simultaneously measuring total horizontal, diffuse horizontal, and solar direct normal irradiance in seven wavelength passbands that span the spectral region from 400 to 1000 nm. One channel is a broadband measurement and the other six are 10 nm full width half maximum (FWHM) bandwidths. In each passband, three components of solar short-wave irradiance is measured with the same filter-detector using the shadowband technique. In this technique, total horizontal and diffuse horizontal irradiance are measured by a sensor collecting radiation over 2π steradians with a nearly Lambertian response. The sensor is alternately shielded and unshielded from direct solar radiation by a metal shadowband that blocks a strip of the sky with a 3.3^{o} umbral angle. Two additional observations 9^{o} east and west of the sun are made to correct for excess sky that is blocked by the shadow band when it occults the sun. From these measurements, direct normal solar radiation is calculated. The shadowband is controlled and the data are acquired by a microprocessor that obtains a complete measurement sample in 15 seconds. Data are retrieved through either a direct serial connection or a telephone modem.

A Reagan Sunphotometer is a microprocessor controlled multichannel sunphotometer mounted on an active alt-azimuth solar tracker developed by John Reagan, University of Arizona. The sensors consist of 10 separate filter/detector channels in the UV, visible, and near infrared spectrum. The nominal wavelength of each channel is 370, 400, 440, 520, 610, 670, 780, 870, 940 and 1030 nm with FWHM transmission varying between 8 and 12 nm. The field-of-view (FOV) is fixed at 3.2$^{o.}$ A temperature stability circuit maintains each photodiode/op-amp combination at a temperature of about 43^{o}C. The filters are also stabilized by proximity to the detector. The automated tracking provided by a alt-azimuth mount is guided by a quadrant detector telescope assembly. The optical system automatically locks onto the sun when it is positioned anywhere in the quadrant detectors 34^{o} FOV. Once centered, a tracking accuracy of ± 0.05^{o} is maintained. Data collection is possible throughout the day, from sunrise to sunset, with observation intervals that are user set from 10 seconds to several minutes.

The FieldSpec FR records spectra over the full reflective solar spectrum from 350 nm to 2500 nm. This is done using a trifurcated fiber-optic cable that delivers radiation to the entrance slit of three separate spectrometers. The first spectrometer is very similar to the PS II covering the visible-near-infrared (VNIR) spectrum from 350 nm to 1000 nm. The short-wave infrared is recorded by two scanning spectrometers. Both employ light dispersal with holographic gratings and detection via thermoelectrically cooled InGAs detectors. One spectrograph covers the interval from 1000 nm to 1800 nm and the other from 1800 nm to 2500 nm. The spectrum sampling is 2 nm with a FWHM resolution of 10 nm. Foreoptics provide 1^{o}, 8^{o}, and 25^{o} FOV's. The system is controlled by a notebook PC recording the signal with 16 bit digitization. The integration time is fixed to less than 2 seconds and signal-to-noise is improved by co-adding large numbers of spectra. The FieldSpec can also be operated in only the VNIR mode with shutter controlled integration times from 14 ms to 25 minutes.

The Portable Ground-Based Atmospheric Monitoring System (PGAMS) is a hyperspectral radiometric system that has the ability to record high angular resolution measurements in both downward and upward looking hemispheres (Schiller and Luvall, 1994; Schiller et al., 1996). Though the scanning sequence is slower and the angular sampling density is lower, PGAMS can record observations similar to the Portable Apparatus for Rapid Acquisition of Bidirectional Observation of the Land and Atmosphere (PARABOLA) but with much higher spectral resolution. PGAMS is basically an ASD PS II spectroradiometer interfaced with a sophisticated Alt-Alt tracking system. The PS II is operated with 1^{o} FOV foreoptics co-aligned with a video camera that records spatial images of spectral targets and is used in altitude and azimuth calibration procedures. The tracking system makes it possible to conduct a highly flexible observing program. Capabilities include solar and lunar irradiance measurements, angular resolved sky path radiance and surface radiance measurements, interactive cloud tracking, automated satellite tracking, principle plane and almucantar radiance scans, and hemispherical sky radiance maps. These PGAMS operations can be carried out through automated control from command files or interactively with real time user control on site or through remote access. With manual assistance, the ASD FR spectroradiometer can also be operated from the PGAMS tracking system in order to obtain the same type of measurements but over the spectral range from 350 to 2500 nm.

On days when both IKNONOS and a Landsat instrument are collecting information at the site, a field campaign will be conducted. Measurements using the equipment described above will be used to determine surface reflectance and upwelling radiance. An atmospheric model will be developed from ground measurements using the Modtran radiative transfer code (Schiller and Luvall, 2000). This will allow removal of atmospheric effects. Then, using techniques similar to those employed by Teillet et al., (2001) spectral differences between the two sensors will be analyzed. IKONOS pixels will be aggregated up to Landsat pixel scales taking into account geometric and spatial responses of the instruments. These will be regressed to one another to develop a transfer calibration relationship. An error analysis will be conducted to assess the accuracy of the cross-calibration.

Since dates when both Landsat and IKONOS image near simultaneously are rare (especially for limited view angles and allowing for cloud cover), the above approach will be augmented through temporal interpolation. Several IKONOS scenes will be acquired during the course of a growing season (May-June, July-July, August). All available Landsat 7 imagery will also be acquired, along with as many available nearly cloud free scenes of Landsat 5 (a trade between number of scenes and cost may be dictated due to pricing structures for these data). On each overpass day, a field campaign will be conducted to measure atmospheric and ground radiances, irradiances, and reflectances. These data will be used to remove atmospheric effects. Time series will be constructed of the reflectances of test site locations imaged by all sensors. These time series will provide a consistency check over the course of a single growing season. Over the years that this project continues, a multi-year time series will also be developed.

Component 2

During coincident coverage by Landsat and IKONOS, field work will be conducted in a corner (10 ha) of each 65 ha field. In these locations approximately 100 spectra will be obtained and integrated to accurately characterize the reflectance properties of the crop being produced. GPS receivers will be used to accurately locate sampling locations in the grid throughout each field. These data will be collected with the FieldSpec FR (about 2 m above the crop canopy) along with a calibrated Spectralon reflectance panel. Upwelling radiance, measured with the spectroradiometer will be converted to reflectance using corresponding ASD radiance spectra of a NIST traceable spectralon reflectance standard. Both nadir and off-nadir look angles will be recorded to evaluate the effects of the bi-directional reflectance properties of the canopy. Calibration and atmospheric correction information obtained in Component 1 will be used to correct both Landsat and IKONOS information. To insure accurate geometric rectification between sensors, tarps will be deployed in corners of the study regions. This has been done routinely by project investigators for several years during radiometric calibration field campaigns. Over the course of a growing season, and through multiple years, the intense measurements made in each field will allow accurate calibration of each satellite sensor, as well as cross-calibration.

At the 100 sampling points, soil samples (0-15 and 15-60 cm) will be collected and analyzed for water and soil nutrients. Plant samples will be separated into weedy and non-weedy components, weighed to determine weed and crop biomass production, and analyzed on a ratio mass spectrometer to determine the $^{13}C/^{12}C$ ratio (Clay et al., 2000). The $^{13}C/^{12}C$ ratio has been used to characterize the impact of water and nutrient stress on yields (Clay et al., 2000). Based on this information, the influence of water, weeds, and nutrient stress on biomass production will be assessed. The amount of plant stress will be compared to ground measured spectral reflectance as well as atmospheric corrected IKONOS and LANDSAT TM, and LANDSAT ETM+ spectral radiance information. Findings from all sampling dates and sites will be used to build a spectral reflectance library (Gustafson et al., 2000) and construct a model relating crop reflectance to crop health by crop stage using the approach described in Thanapura et al. (2000).

GIS will be used to store rectified spatial databases for various GIS processes and geospatial and other modeling. ESRI and ERDAS software will be the primary tools used in this process. Through applying various questions/hypotheses to the data with ERDAS Imagine, spatial relationships can be ascertained, such as spectral radiance by slope, aspect, and landscape position against the occurrence of a particular weed species. These types of analyses will be undertaken with the agronomic data and remote sensing data to derive "best sensor" results by application.

Satellite data analysis will be initiated as each successful overpass is completed. Agronomic analysis will commence at the end of the growing season and when the calibrated satellite data become available. Year two and year three will build on results of the preceding year and develop refinements to the calibrations and modeling components of this study. Regression analysis will be used to determine the capability of IKONOS, LANDSAT TM, and LANDSAT ETM+ to predict various yield limiting factors. Findings from this study will be used to develop precision farming guidelines for selecting remote sensing information sources.

Component 3

Models (developed in component 1 and 2) will be validated on data collected from the remaining portion of each field (55 ha). At 150 selected sites, soil and plant samples, crop reflectance (measured with Cropscan Multispectral Radiometer and ASD Field SpecII) will be collected and analyzed as described above. Atmospheric cross-calibrated remote sensed information will be used input for the agronomic models.

Regression analysis will be used to compare agronomic model predicted results with ground-based measurements and with calibrated remote sensing data from satellite data. The results will be statistically compared and the role of the remote sensing data in precision agriculture will be evaluated.

Expected Results

1. Cross-calibration of the operational Landsat sensors with IKONOS will be achieved. Error bounds on the cross-calibration will be established theoretically as well as, to some degree, operationally. Cross-calibration will be optimized for typical agricultural use in eastern South Dakota.
2. An understanding of the capabilities and limitations of scaling IKONOS imagery to Landsat scales will be developed.
3. Remote sensing based agronomic models will be developed. These models will be used to help predict the yield limiting factors in field. This information can be used by decision support systems to develop cost effective management strategies.
4. A measure of the usefulness of satellite data for precision agriculture will be determined. Based on those results, scientific papers will be submitted to journals and symposia. Outreach programs will be developed building on the applicability of the results and delivered to end-users by Cooperative Extension staff experts.

Technology Transfer

Findings from this project will be published in appropriate journals as well as shared with land managers interested in utilizing remote sensing as a management tool. Funding for the technology transfer portion of this project will be provided by collaborating projects funded by the Potash and Phosphate Institute North Central Soybean Board, South Dakota Soybean Research and Promotion Council, SD Corn Utilization Council, USDA-CSREES, and SD Experiment Station. A critical component in training end-users in precision farming is to reduce startup costs, provide training, and use relatively simple packages where results can be obtained quickly. In other words keep it simple. The proposed project will develop outreach products that follow this principal. Specifically this project will develop:

- Knowledge that producers can use in combination with interactive decision support systems (DSS) to evaluate the impact of remote sensing on profitability and environmental quality.
- Whole system case studies illustrating the use of remote sensing as a tool for whole farm system analysis.
- A guideline paper that identifies the best remote sensing sensor for a given problem.

Findings will be shared with local communities through workshop and teacher training. The workshops will be targeted toward producers and consultants. Workshops will utilize research findings to demonstrate how GIS and DSS can be used as a visualization and management tools. To integrate research findings into K-12, workshops will be held for 6 grade teachers. In these workshops, teachers will develop GIS and precision farming modules that can be incorporated into 6 grade curriculums. The proposed project will utilize the infrastructure developed in collaborating projects and the extension service to deliver outreach materials to producers.

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2.3 Relevance to NASA Research Priorities

In order to support NASA's goal to involve a broader audience of users for their available remote sensing data, the EPSCoR team will investigate ways of evaluating these data for agricultural applications. Characterizations of satellite sensors including radiometry, spatial resolution, and geometry needs to be evaluated. We believe that a strong potential exists for agricultural applications. Emphasis will be placed on processed imagery available to the user and science community. A primary goal of this work will be to determine whether the product delivered by Landsat and IKONOS can be cross-calibrated and evaluated against the needs of agricultural producers, particularly those involved in site-specific farming.

2.4 NASA Interactions

The investigators in the project have had substantial interaction with the Landsat Project Science Office (Goddard Space Flight Center, Code 923) for the past five years. This has involved calibration of Landsat 4, 5 and 7 Thematic Mapper sensors with Dr. John Barker and Mr. Brian Markham. Discussions of precision agricultural applications have been recently been initiated with Dr. James Irons of the same branch through support of the NASA EPSCoR planning grant.

Over the past year, collaborations have been established with Dr. Robert Ryan, Ms. Mary Pagnutti, and Mr. Fritz Policelli of the Stennis Space Center. These efforts have been direct towards the evaluation of the IKONOS sensor for the Commercial Remote Sensing Program. A Science Data Buy has been funded for two data collection periods for use in precision agriculture work at SDSU with Mr. Polliceli as a contact.

These linkages will form the basis for continued collaboration on the proposed project. All the above-mentioned individuals will be directly associating with the investigators of this project with respect to the calibration of Landsat 5, 7 and IKONOS. In addition, more involved collaborations will be initiated with Dr. Jim Irons. These discussions will involve the application of Landsat data to the development of precision agriculture models. Dr. Iron's expertise in both remote sensing, particularly Landsat, and agriculture will play a major role in shaping the progress of this project.

2.5 Existing Research

SDSU has a long history in agricultural research and extension as a Land Grant College. Furthermore, remote sensing research began at SDSU with the establishment of the Remote Sensing Institute in 1969. Presently, SDSU is actively involved in remote sensing through an Image Processing Laboratory (Electrical Engineering), atmospheric characterizations (Dept. of Physics), precision agriculture (Plant Science), Office of Remote Sensing and GIS laboratory (Engineering Resource Center), among other entities. SDSU also works closely with the USGS EROS Data Center (EDC), which serves as a primary archive for land remote sensing imagery. The EDC's role with NASA and the user community has expanded greatly with the introduction of NASA's EOS system.

"Characterization of Landsat 7 Geometry and Radiometry for Land Cover Analyses," Co-I with Jim Vogelman (PI), EROS Data Center, 4 years
This project involves assessing the radiometric and geometric performance of Landsat 7, through vicarious calibrations of the sensor using the Brookings 3M test site.

Landsat TM Radiometry, Dennis Helder (PI), NAG5-3540, 5 years
This project has resulted in the definitive radiometric calibration of Landsat 4 and 5 Thematic Mapper sensors.

An integrated assessment of the Earth Observer –1 Instrument Suite and the Landsat 7 Enhanced Thematic Mapper Plus, Dennis Helder & Steve Schiller (CO-I's), Dave Meyer, EROS Data Center (PI), 1 year
This involves a comprehensive evaluation of the on –orbit performance of the Advanced Land Imager.

Radiometric, Spatial, and Geometric Characterizations of IKONOS, Dennis Helder (PI), 1 year, Stennis Space Center Commercial Remote Sensing Program
This project will ascertain whether imagery received from IKONOS meets the specifications set forth in the NASA Science Data Buy.

Several NASA-sponsored research activities on precision farming currently are being conducted at SDSU:

ESIPS: weed mapping research with aerial, multispectral imagery and greenhouse characterization of several weed species,

RESAC: soil moisture and nutrient modeling with remote sensing data, UMAC (Upper Midwest Aerospace Consortium): work with agricultural producers to evaluate remote sensing data for precision agriculture.

On these projects SDSU scientists have used remote sensing data and GIS software to: (i) characterize aerial remote sensing data based on spectral response of different weeds (Gustafson et al., 2000); (ii) develop weed management maps; (iii) separate fields into 3 yield zones (high yield stable, low yield stable, and unstable yields) (Murphy, 2000); (iv) characterize areas of fields that should be planted with Phytothoria resistant and nonresistant soybean varieties; and (v) to determine the influence of different sampling techniques on the error associated with N and P site specific recommendations (Chang et al., 2000).

2.6 Personnel

Co-principal investigators for this project will be *D. Helder* and *D. Clay*. *D. Helder* will have the overall responsibility for satellite sensor characterization activities, and *D. Clay* will have the overall responsibility for agriculturally related activities. Other staff responsibilities (co-investigators) are listed below. *T. Gilmanov* and *S. Burckhard* will be responsible for developing crop models. *D. Clay* will be responsible for soil related measurement and for determining yield limiting factors in the fields. *S. Clay* will be responsible for characterizing weed stress and distribution. *K. Dalsted* will be responsible for GIS classification. *D. Helder* will be responsible for sensor cross-calibration analysis. *S. Schiller* and *D. Aaron* will be responsible for the collection of radiometric data of the atmospheric and surface, and for atmospheric modeling. *G. Carlson* will be responsible for farmer collaboration and agricultural outreach.

One post doctorate staff member will be hired to work full-time supporting the interdisciplinary nature of this study. This individual will ideally have a Ph.D. in an agricultural field with substantial experience with remote sensing and GIS. This position will report to *D. Helder* and to *D. Clay*. Two research associates will work on GIS and remote sensing image processing to support data rectification, database development, image classification and modeling. The associates will report to *K. Dalsted*.

Three graduate students will be employed to support work in cross calibration, atmospheric modeling, and agriculture/remote sensing guideline development for decision support systems. Three undergraduates will be hired to help in the collection and processing of field data.

3.0 Management and Evaluation

3.1 Research Program Management

Since the most active time period for this project is during the growing season in South Dakota, a planning meeting involving all project personnel will be scheduled each spring in March. This meeting will outline all major activities and responsibilities during the summer campaigns. In late October a post-campaign meeting will be held to evaluate the successes and shortcomings of the season and to develop procedures for reducing all data gathered during the summer and coordinate the generation of results. *D. Helder* and *D. Clay* will be responsible for sensor calibration and agronomic characterization work, respectively. Periodic meetings will take place during data collection periods and less frequently during the data analyses periods. Staff participants, graduate students and

Post-Doc seminars will be held at the end of each year to present results-to-date and to express needs for the upcoming campaign.

3.2 Program Evaluation

Timeline and Major Activities (Annually)

March: Spring Planning Meeting
May – October: Landsat data acquisition every 8 days, weather permitting
    Atmospheric data acquisition and Agricultural data acquisition
May – October: IKONOS acquisition monthly
    Atmospheric data acquisition and Agricultural data acquisition
Sept. – Oct.: Harvest of agricultural fields
    Agricultural data acquisition
July – Dec: Reduction of atmospheric data
    Reduction of agricultural data
October: Fall Planning Meeting
    Analysis of summer efforts and Planning of data reduction/analysis
January: Delivery of satellite sensor characterizations
    Cross-calibrations of Landsat and IKONOS
    Delivery of agricultural modeling results
    Evaluation of remote sensing inputs
February: Report generation

Coordination with the state NASA EPSCoR program will occur in March and October shortly after scheduled project planning meetings. Teleconferences and other meetings will also occur with the other State EPSCoR projects.

Program Metrics

<u>Field measurements</u>: All measured values will be calibrated against primary standards. Laboratory and field protocols will be stored with the data sets that will be accessible to all project collaborators.
<u>Performance</u>: The ability to meet the stated objectives as reported in the time table will be measured.
<u>Outreach</u>: Activities that will be tracked include: (i) number of times findings are reported in newspapers, TV, and radio programs; (ii) estimated viewership, viewer feedback, frequency and times of broadcast of each reporting will be noted; (iii) number and diversity of participants at workshops and changes in participants perceptions over time; (iv) case studies, fact sheets, farmer meetings, and farmer groups formed; (v) the adoption of precision farming techniques will be monitored by evaluating changes over time in pre and post workshop farm meeting exit surveys; and the (vi) number of webpage hits, as well as if information is downloaded from the webpage and length of time spent on the webpage.

As measures of the progress achieved by this project, the following milestones are indicated: annual calibration/cross-calibration of Landsat and IKONOS and annual evaluation of spectral variability of crops under study.

Models relating agronomic variables to remote sensing data will be evaluated annually. It will be the responsibility of the project PIs to ensure these goals are met annually.

3.3 Tracking of Program Progress

An enormous unmet need exists in agriculture for spatial information derived from calibrated remote sensing data. Numerous satellite sensors with increased spatial and spectral response are planned for the future. The need for cross calibration of these sensors will continue to grow as the demand for these sensor grows.

Self-sufficiency for this project will be gained through two means. First, as success in using remote sensing data for precision farming is developed, additional funding opportunities should develop from agricultural sources (USDA, commodity groups) as well as from traditional science agencies (NSF, NASA) to continue and expand the work. Additionally, as economic viability of this approach is developed through the technology transfer component outlined above, agriculture may quickly demand this kind of information and industrial support will likely follow. Towards this end, efforts will be directed towards both developing a scientific basis for this project and a practical interface to the farmers, crop consultants, extension agents, and other end-users.

The average area per Midwest farm increases every year. The need for more efficient land management follows this trend. The demand for calibrated remote sensing data and related decision support systems can only grow, particularly as precision agriculture techniques are adopted by more and more producers.

3.2 Facilities and Equipment

South Dakota State University has the equipment required to conduct the proposed research. Equipment available includes: shadowband radiometers, sunphotometers, field spectroradiaometers, Portable Ground-based Atmospheric Monitoring System Geonics EM38, Leica survey grade real time DGPS, Omnistar DGPS, weather stations, TDR, combines equipped with yield monitors and GPS, HPLC, GC, Europa ratio mass spectrometer, Astoria N analyzer series 300, computers with SSToolbox, GIS and ERDAS software, and a portable radiometer produced by CID that scans the 300 to 950 nm wavelengths. The remote sensing and GIS laboratories have 300 MHZ pentium PCS with windows NT operating systems and access to workstation versions of the software. Multiple copies of both ARC/Info and ERDAS software reside on PCs with University workstations. Supported hardware includes color plotters and printers, 8 mm tape drive, CDrom writers and access to other university resources. The SDSU Image Processing Laboratory includes six Unix and NT workstations with Matlab, IDL, and ENVI software, along with tape backup and 200 Gbytes of disk storage. Internet II connections are available to EROS Data Center, Goddard Space Flight Center, and Stennis Space Center.