Cross-Calibration of Landsat and IKONOS Sensors for Use in Precision Agriculture

TAC - July 31, 2003

PI: Dennis Helder

A select few of the many scientists, researchers and students involved:

Plant Science Group:

David Clay	Sharon Clay	Cheryl Reese
et. al.		

IP Group:

Jim Dewald	Tim Ruggles	Jason Choi
Esad Micijevic	et. al.	

Satellite Calibration Group:

David Aaron	Larry Leigh	Beth Rybak
Young Sun Lee	Sara Landau	

(continuation of Steve Schiller's work).

Grateful appreciation to the Stennis Space Center's: Vicki Zanoni, Bob Ryan, Mary Pagnutti, et al, and the University of Arizonas Remote Sensing's Kurt Thome, Stu Biggar, Chris Cattral, Rob Kingston, et. al.

Background: Precision Ag

- The use of DGPS (differentially corrected global positioning systems) and GIS (geographic information systems) to vary management within fields for return optimization.
  - Use remote sensing (particularly satellite based) as a primary information input tool.
  - Information must be accurate and timely

Background: Precision Ag (cont)

- Satellite imagery is readily available from a number of sensors
  - Landsat TM (NASA)
  - Landsat ETM+ (NASA)
  - IKONOS (Space Imaging)
  - Quickbird (Digital Globe)

- Information content has varying spatial and spectral resolution (depending on sensor).

- 'Top of Atmosphere (TOA)' in-band pixel intensity is a function of many parameters (next slide)

- Building any Precision Agriculture system will require a comprehensive understanding of data systems and content.

Parameters Affecting TOA Measurement

- Satellites ‘look’ down and measure the upwelling radiance.

- In the simplest form (consider a crop site):
  - Direct downwelling irradiance comes from the sun
  - Transmitted through the atmosphere
  - Reflects from the crop canopy
  - Transmitted (upwelling now) through the atmosphere
  - Transmitted through the sensors optical system
  - Converted on a pixel by pixel based to a voltage signal
  - These voltage signals are downlinked and converted to 2D spatial images

- NOTE the word ‘simplest’ above

Focus on this Simple model

- Downwelling irradiance
  - Easy. Solar output is very constant, only concern is that the earth to sun distance varies over an annual cycle
- Transmission through the atmosphere
  - More complex. Numerous absorptions and reflections take place due to gases and aerosols in the atmosphere. This is a dynamic system.
- Reflection from the crop canopy
  - Again complex but this is exactly what we want to utilize. If healthy crop versus stressed crop versus weeds have differing spectral reflectances, the measured reflected radiance can be used to spatially pinpoint areas of concern.

Focus on this Simple model (cont)

- Upwelling Transmission through the atmosphere
  - Same complex form as downwelling (note: can we call it symmetric?)
- Sensor Optical System
  - Generally considered a ‘fixed’ system for any given sensor
    - IP lab monitors and models
- Radiance to voltage conversion at Focal Plane
  - Again generally considered a known
    - SDSU IP (Image Processing) lab monitors and models

Project Objectives

- Conduct cross-calibration of satellite sensors (in conjunction with ground based sensors)
  - crop based targets
  - evaluate atmospheric corrections
- Develop/Evaluate rules to identify the ‘best’ sensor for a given agronomic application

Project Components

- Devise/Implement/Evaluate atmospheric correction algorithms for each sensor and the sufficiency of scene based atmospheric corrections
  - MODTRAN
  - 6S
  - Stand Alone

- Develop models relating spectral characteristics to crop health (and/or invasive plant species)
  - Primary features
  - BRDF (Bi-directional reflectance distribution function)

- Integrate and validate the atmospheric correction algorithms and the spectral identification models

Project Status: Summer 2003

- Field work initiated in the summer of 2002, continuing in summer of 2003

- 2002 Procedure development and cross calibrations were the primary constituents
  - Develop & document procedures for
    - Site and targets
    - Equipment calibration
    - Data acquisition
    - Data validation
    - Data reduction
    - Data analysis
    - Report Generation

Project Status: Summer 2003

- Validate cross cal of ground based instrumentation
  - Analytic Spectral Devices FS FR 638 (hyper-spectral)
  - Crop Scan 2 (16 channel banded)
- Cross cal of satellite sensors
  - Landsat 5
  - Landsat 7
  - Ikonos
  - Quickbird ('new' satellite, not in original proposal)

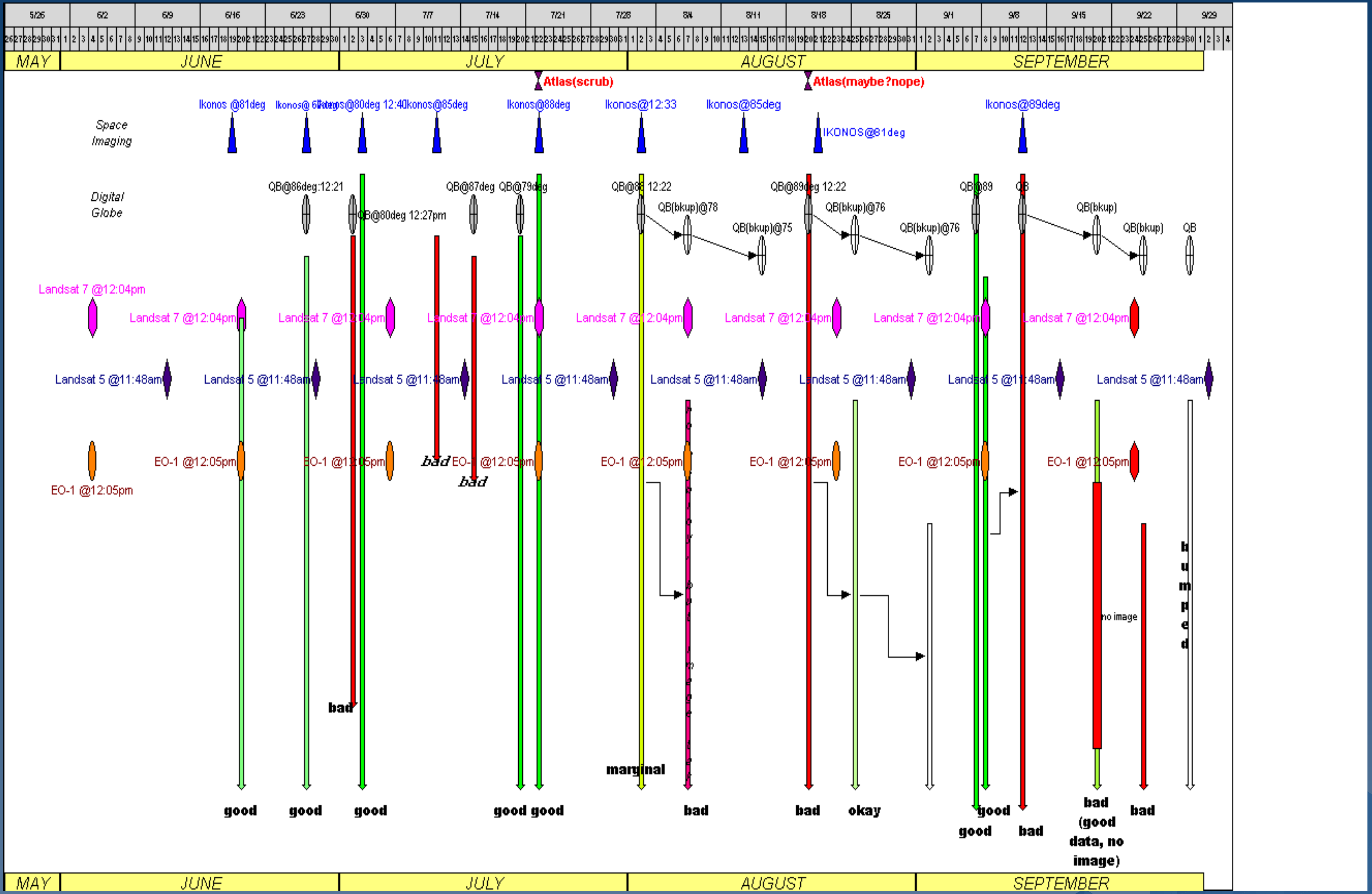
- Multi-tasking operation, work done in conjunction with:
  - EDC, Stennis Space Center JACIE group, UA RSG

Summer 2002

- WHAT A YEAR FOR MY INTRODUCTION INTO THIS PROJECT!

- SUBTITLE:
How to plan for more hours of work than there is in any given week

2002 Satellite Collection and Results Schedule



Summer 2002

Collections in support of Landsat, EO-1, Ikonos, and Quickbird

June 20 thru Oct 1

- 18 Attempts
  - 8 'good' collects
  - 1 'fair' collect
  - 1 'marginal'

2002 Summer Data Collections

Laboratory Objectives:

Institute and implement a ground data collection plan in support of:

- Vicarious calibration
- MTF assessment via edge techniques
  - ‘tarp on grass’
  - ‘pavement to grass’
  - ‘52% to 3.6% tarps’ (Courtesy SSC)
- MTF assessment via ‘point source’ method
- Geospatial image assessment

Primary Site: "3M"

North of Edgebrook Golf Course
Brookings SD

- Maintained 250 X 150m 'grass' site (approx)
  - rotated 6 degrees off N-S
  - NW corner:
    - Lat: 44°17'31.12383"N
    - Long: 96°45'59.33636"W
  - SE corner:
    - Lat: 44°17'25.14555"N
    - Long: 96°45'48.70484"W
  - Maximum measured elevation change = 4.89 meters

Differential GPS values measured by the Stennis GRIT Staff

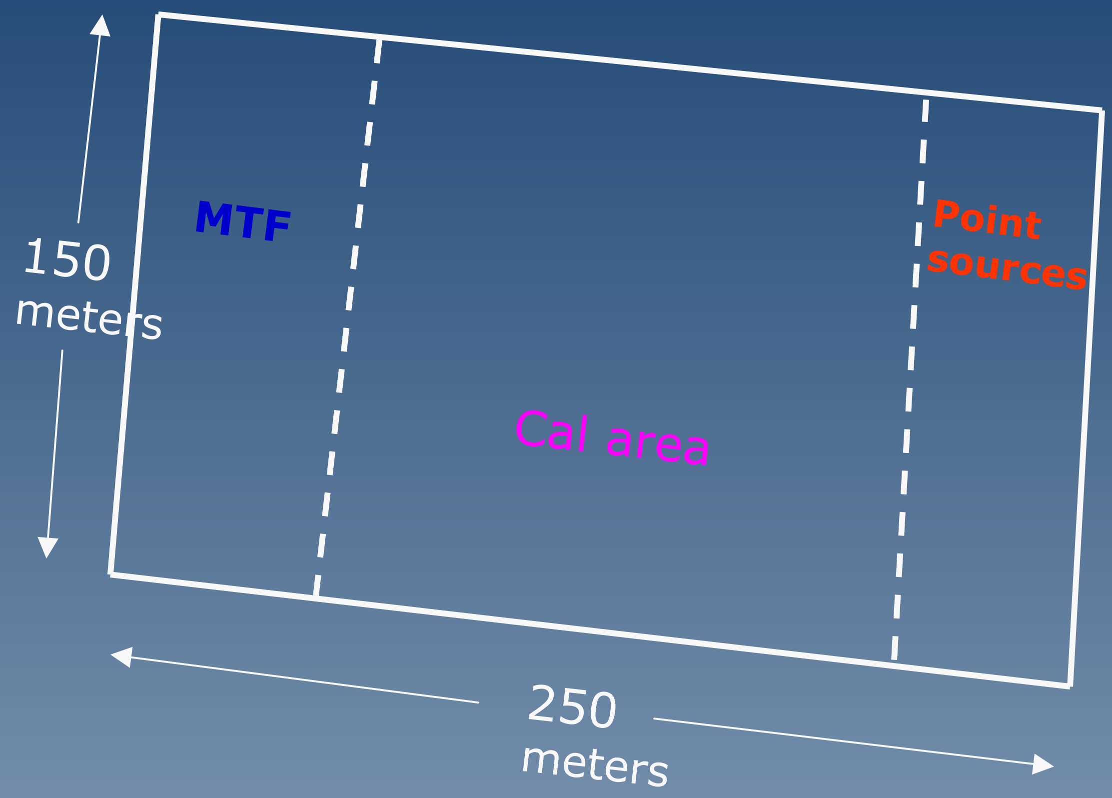
Secondary Sites:

- Parking Lot 1
  - MTF concrete to grass transition
- Parking Lot 2
  - MTF concrete to grass transition
- CEH Rooftop
  - Atmospheric monitoring site
    - ASR 08 (by U of A)
    - MFR Shadowband Radiometers
- Various Ground control points in and around Brookings

Primary Site Contains 3 Target Areas

- 10 Row Radiometry Site (details next slides)
  - Rough Grasses and weeds
- MTF Site
  - Blue MTF Tarps
  - Stennis MTL 3.6% & 52% STEP TRANSITION
- Point Source Site
  - Array of up to 20 convex mirrors

Base layout: grass site



Site Maintenance

- 9+ Acre Site (250m EW by 150 NS rotated 6^o E of N)
- Site Consists of rough grasses and weeds (primarily Canadian thistle)
- To increase homogeneity the site was regularly maintained
  - mowed (rotary mowers) about every 2 weeks depending on growth
  - height maintained at roughly 10 cm.
  - West 70m and East 30m, clippings were bagged & removed

- Site also has numerous rodent holes and mounds
  - spectrally ‘clay’
  - some of were filled and leveled (primarily a safety concern)

- Site selection included sloped areas (BRDF effects)
  - elevations were measured by Stennis GRIT team

Instrumentation and Collection Methodology

- Atmospheric Measurement: Automated Sun Radiometer
  - ASR unit #08 by University of Arizona
  - Sited on CEH rooftop

- Upwelling Radiance: Spectroradiometer
  - ASD FS FR unit 638 Cal 8
    - 8 degree optic
    - height 1.5 – 2 meters above ground (~25 cm static sample D)
    - generally 20 spectra/file
      - produces 50 files per 140 meter row
  - Spectralon (99%) panel 18”
    - BRDF Characterized
    - Take White reference every other row

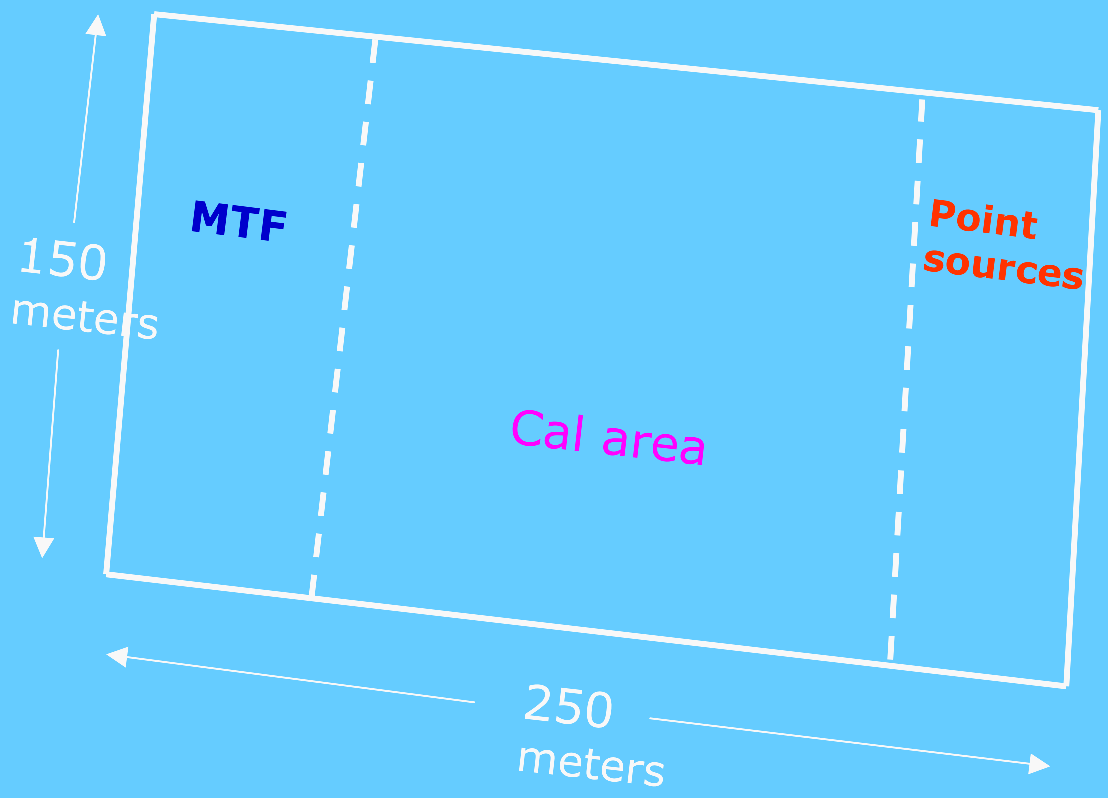
Support Instrumentation

- MFR-7 Shadowband Radiometers (YES)
  - Deploy one in field and one on CEH rooftop
- Pyranometer (YES TSP-700)
  - Field deploy
- Weather station, cameras, lots of sunscreen, water, Purina gopher chow, etc.

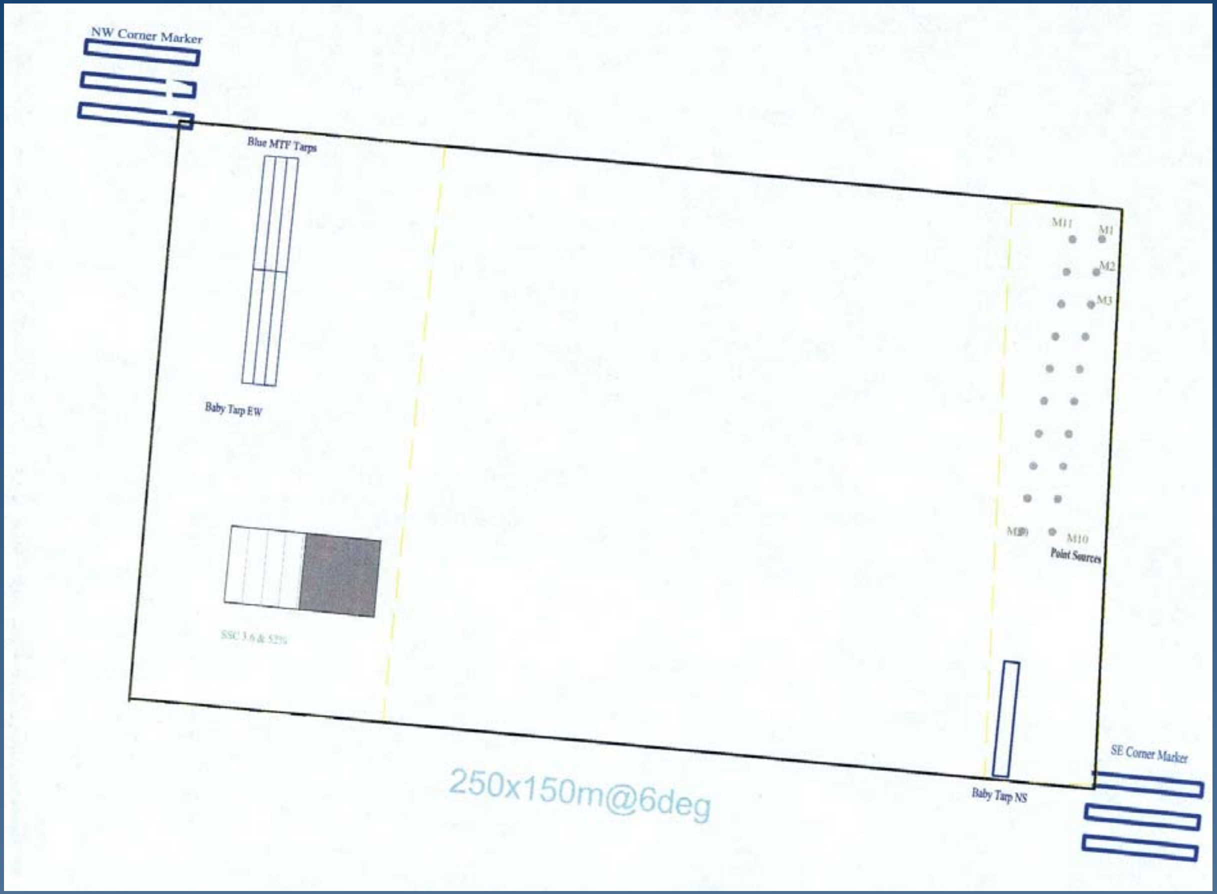
Site Shot

Sept 07, 2002 (Quickbird pan image)

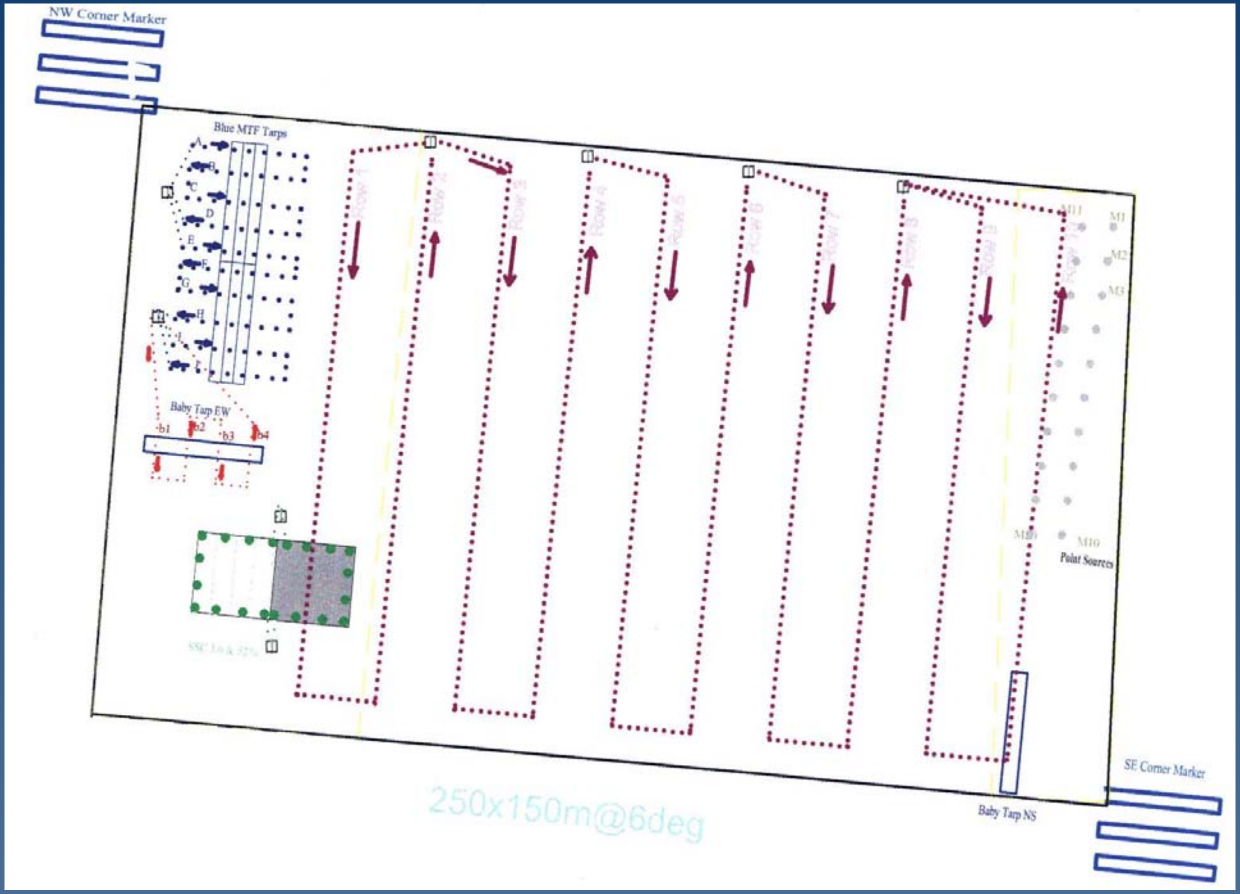
2002 Maintained Grass Site



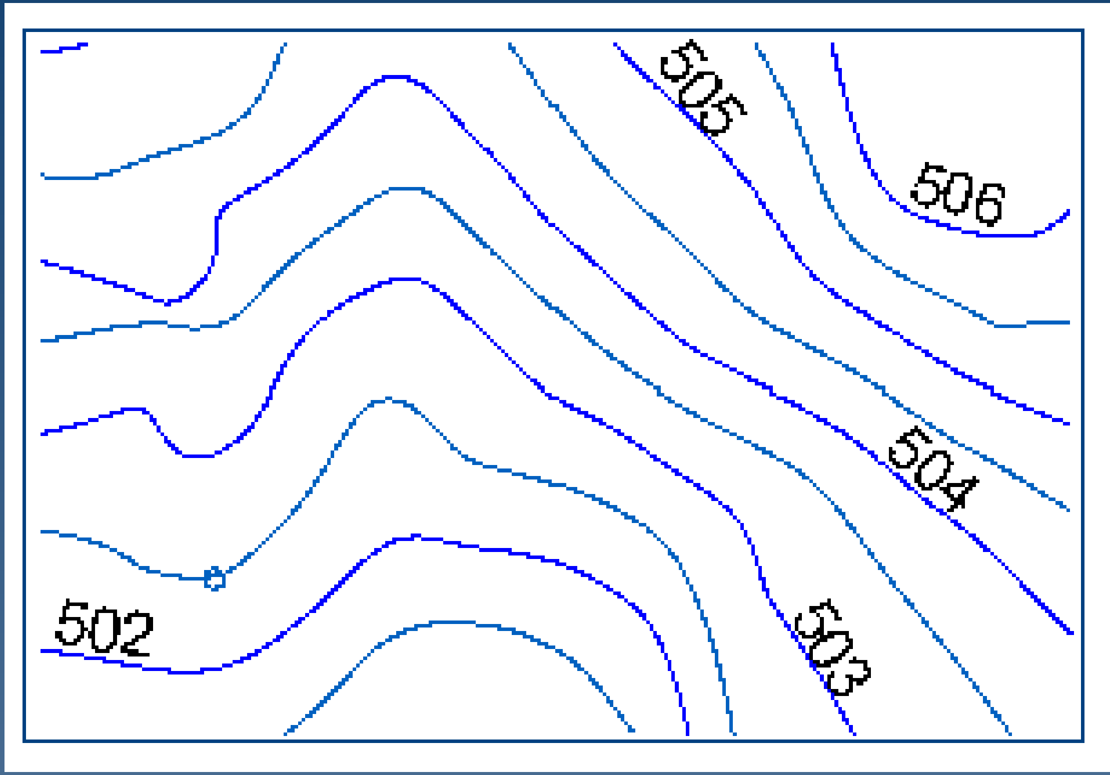
Calibration and MTF Targets
SDSU 2002



ASD Data Acquisition Paths



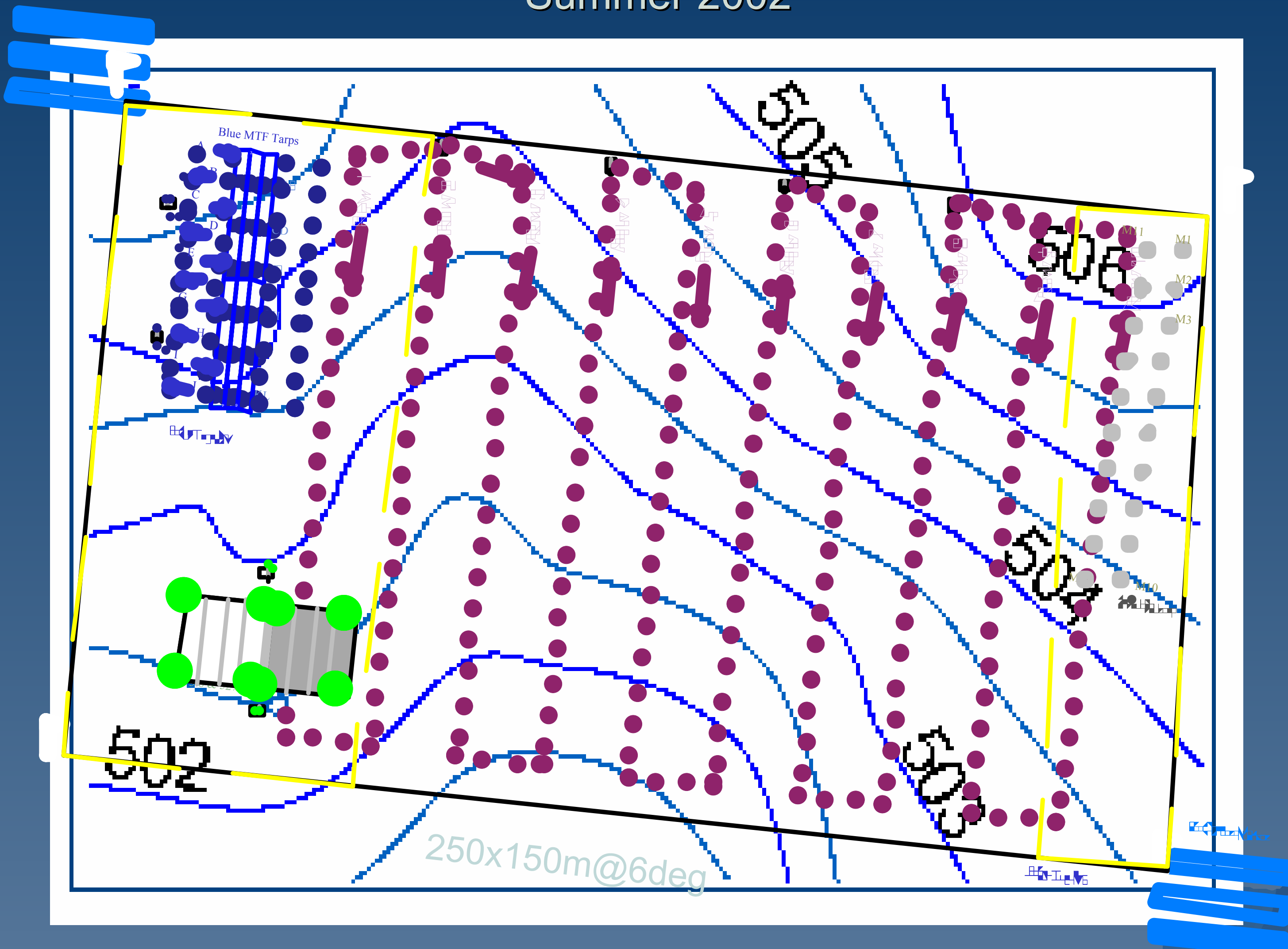
0.5 Meter Elevation Contours
(Mean Sea Level Meters)

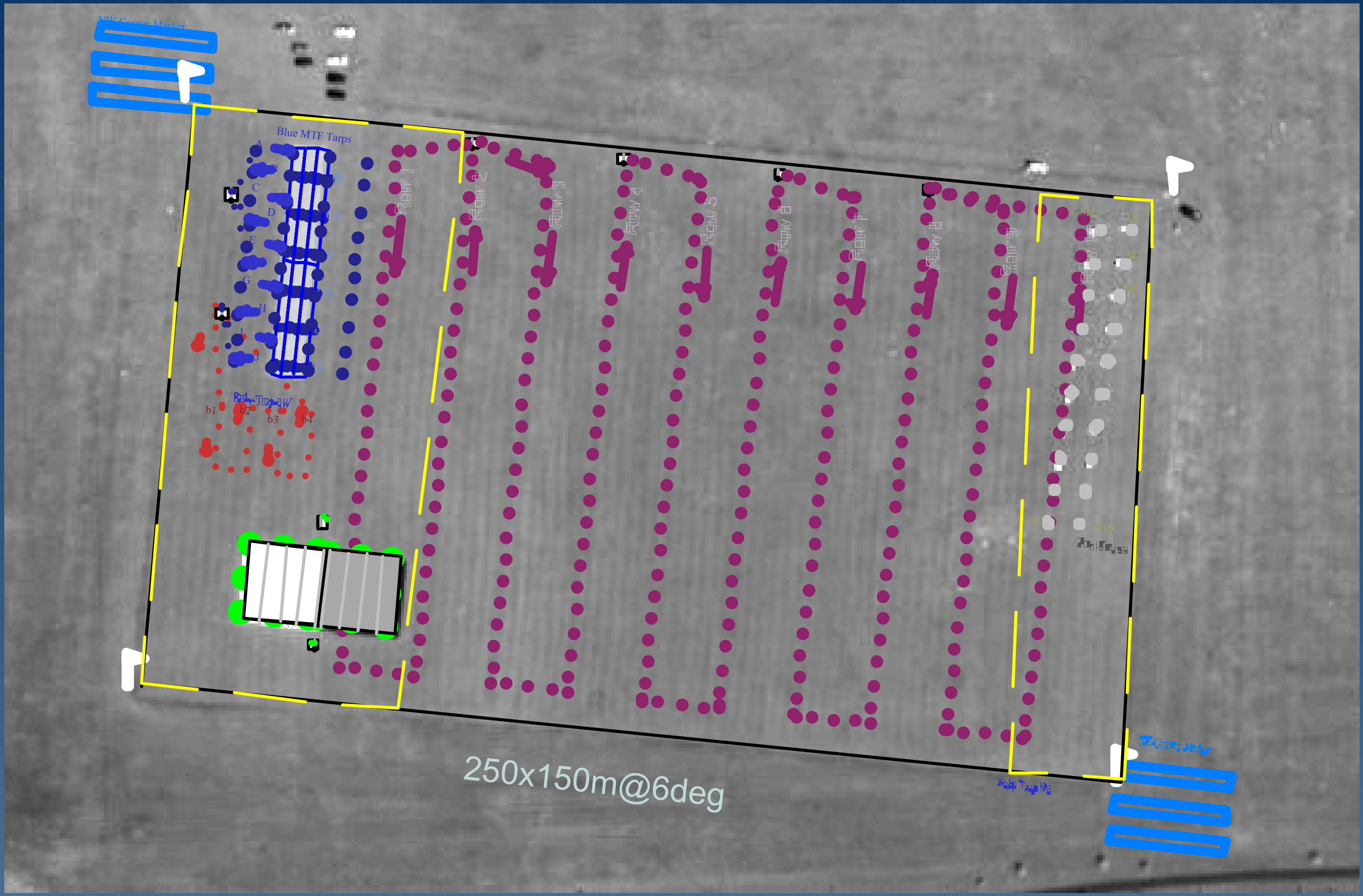


GPS points courtesy of SSC GRIT Staff

Primary Site Paths with Elevations

Summer 2002

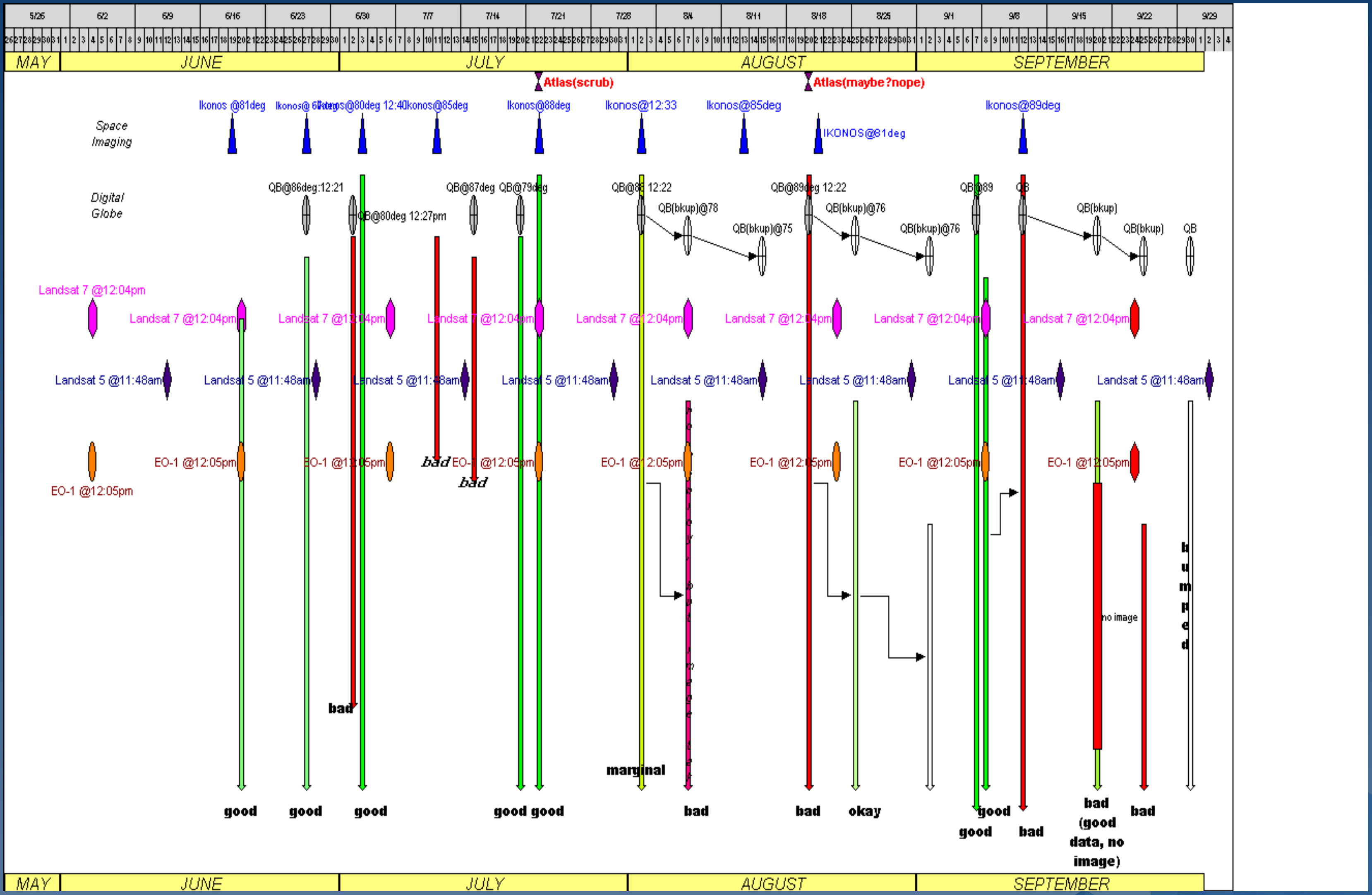




Grass Site with ASD paths 9/07/02

Note: Landsat 7 ‘Good’ collect 9/08

2002 Satellite Collection and Results Schedule



Summary of SDSU Landsat Data Collects

Generally 12:04 CDT overpass

June 20: Landsat 7 (& EO-1)

- Good collect
- Light Cirrus Wisps
- Walked Main Grass Site
- Deployed Blue MTF tarps (Ikonos width)
- Ground ASD Reflectance Uniformity of:
  - 6.2% 450-1350nm
  - 6.9% 1410-1800nm
  - 10% 1940-2470nm

(2002 Landsat Collects)

July 22: Landsat 7; EO-1 and Ikonos

- Good collect
- Good weather, slightly hazy
- Stennis Tarps Deployed
- Blue MTF deployed
- Mirrors Deployed
- Also deployed (N of maintained area), Plant Science '4 reflectance tarps'
- ASD data from Stennis also
- Good weather data
- Also extensive Cropscan II data

(2002 Landsat Collects)

Sept 8: Landsat 7; EO-1 (note Quickbird collect on the previous day)

- Good collect
- Hot & humid so somewhat hazy
- Only corner marker tarps deployed
- Recorded ancillary data on spots usually covered by Stennis & MTF tarps
- Ground ASD Reflectance Uniformity of:
  - 5.4 % 450-1350nm
  - 6.3% 1410-1800nm
  - 14.3% 1940-2470nm

Summary of SDSU Landsat Data Collects

Generally 12:04 & 12:05pm CDT overpass

June 20: Landsat 7 & EO-1

- Good collect
- Light Cirrus Wisps
- Walked Main Grass Site
- Deployed Blue MTF tarps (Ikonos width)
- Have only minimal weather data
  - (temp/pressure/humidity at overpass)
- Ground ASD Reflectance Uniformity of:
  - 6.2% 450-1350nm
  - 6.9% 1410-1800nm
  - 10% 1940-2470nm

(2002 Landsat Collects)

July 22: Landsat 7; EO-1 and Ikonos

- Good collect
- Good weather, slightly hazy
- Stennis Tarps Deployed
- Blue MTF deployed
- Mirrors Deployed
- Also deployed (N of maintained area), Plant Science '4 reflectance tarps'
- ASD data from Stennis also
- Good weather data
- Also extensive Cropscan II data

(2002 Landsat Collects)

Aug 7: Landsat 7; EO-1 and Quickbird

- Basically cloudy day so no deploy; however brief opening at Quickbird overpass time so QB image was acquired.

Sept 8: Landsat 7; EO-1 (note Quickbird collect on the previous day)

- Good collect
- Reasonable weather, but hot & humid so somewhat hazy
- Only corner marker tarps deployed
- Recorded ancillary data on spots usually covered by Stennis & MTF tarps
- Ground ASD Reflectance Uniformity of:
  - 5.4 % 450-1350nm
  - 6.3% 1410-1800nm
  - 14.3% 1940-2470nm

Landsat & EO-1 Collects
Summer 2002

Platform	Date	overall data	weather	Grass ASD	ASR	MFR	Other	Imagery
7 & EO-1	6/20	good	scattered cirrus	good	good	good	MFR; Blue MTF tarps deployed	
7 & EO-1 Ikonos	7/22	good	slight haze	good	good	good	SSC Tarps, Blue MTF tarps, Plant Science Tarps deployed	
7 & EO-1 Quickbird	8/7	none	cloudy exc at QB overpass	none	none	none	QB image obtained in ‘clear’ window of ~1/2 hour.	
7 & EO-1	9/8	good	hot & humid	good	good	good		
Landsat 5							Attempts Scheduled 6/27 thru 10/2 no successful collects	

Ikonos Collects (attempted deploys also)
Summer 2002

Platform	Date	overall data	weather	Grass ASD	ASR	MFR	Other	Imagery
Ikonos Quickbird	6/27	good	hazy & scat cirrus	good	good			good
Ikonos	7/3	good	cirrus	okay	good	good		good
Ikonos	7/11	bust	clouds			good		
Ikonos L7 & EO-1 Atlas	7/22	good	slight haze	good	good	good	SSC Tarps, Blue MTF tarps, Plant Science Tarps deployed, scrubbed ATLAS	good
Ikonos Quickbird	8/2	marginal	cirrus	fair	fair early am	fair early		
Ikonos Quickbird	9/12	bust	clouds					

Quickbird Collects (attempted deploys also) Summer 2002

Platform	Date	overall data	weather	Grass ASD	ASR	MFR	Other	Imagery
Quickbird Ikonos	6/27	good	hazy & scattered cirrus	good	good			good
Quickbird	7/2	bust	clouds					
Quickbird	7/15	bust	clouds					
Quickbird	7/20	good	slight haze	good	good	good		good.
Quickbird Ikonos	8/2	marginal	cirrus	fair	fair early am	fair early		
Quickbird L7 & EO-1	8/7	none	clouds exc @ QB overpass	none				bracketed by cloudsa
Quickbird Atlas	8/20	bust	clouds					
Quickbird	8/25	fair	cirrus	fair	fair	fair		
Quickbird	9/7	good	very slight haze	good	good	good	Landsat 7 next day	
Quickbird	9/20	good but no image	good	good	good	good	Image not acquired by DG	none
Quickbird	9/25	bust	clouds					
Quickbird	9/30	bumped	excellent	none	good	good	Bumped by Digital Globe	none

2002 Results Summary

- Developed a ‘standard’ site plus several ancillary sites
- Calibrated and established standard procedures for equipment base
- Devised/developed standards for data acquisition
  - pre acquisition meetings
  - publish schedule and procedures for each acquisition
  - standardized run sheets
  - standardized files
- Initiated procedures and acquisitions to ensure data validity
  - goal of ‘more than one deep’
  - Implemented a data archiving system with RAID backup

2002 Results Summary

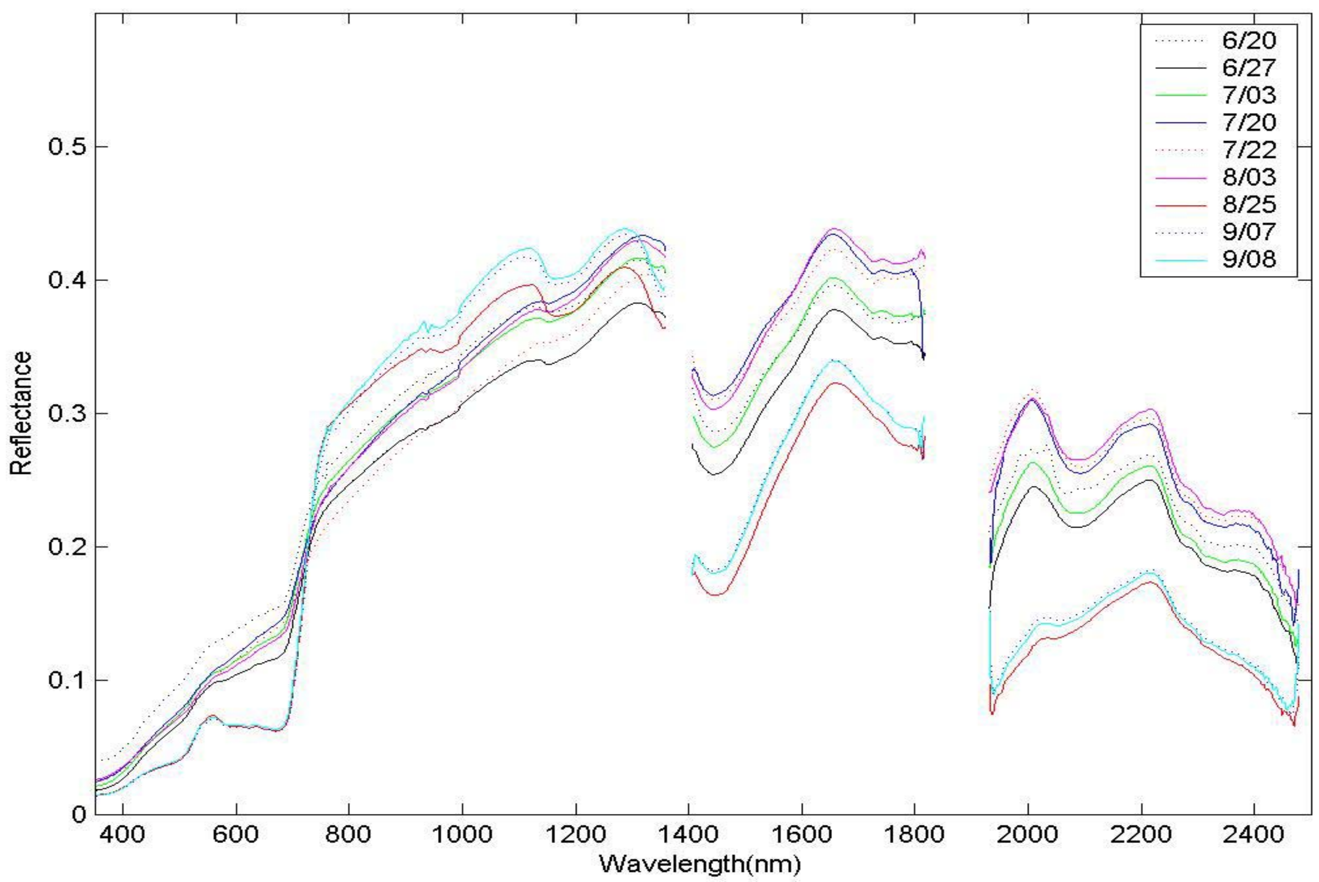
- Establishing standard reduction tools
  - MATLAB basis
  - Automated ground level reflectance extraction tool
    - Beth Rybak and Young Sun Lee
  - Sunphotometer Langley atmospheric analysis tool
    - Jim Dewald and Dave Aaron
  - Shadowband Langely atmospheric analysis tool
    - Beth Rybak and Sara Landau
  - Sunphotometer cloud extraction tool
    - Beth Rybak

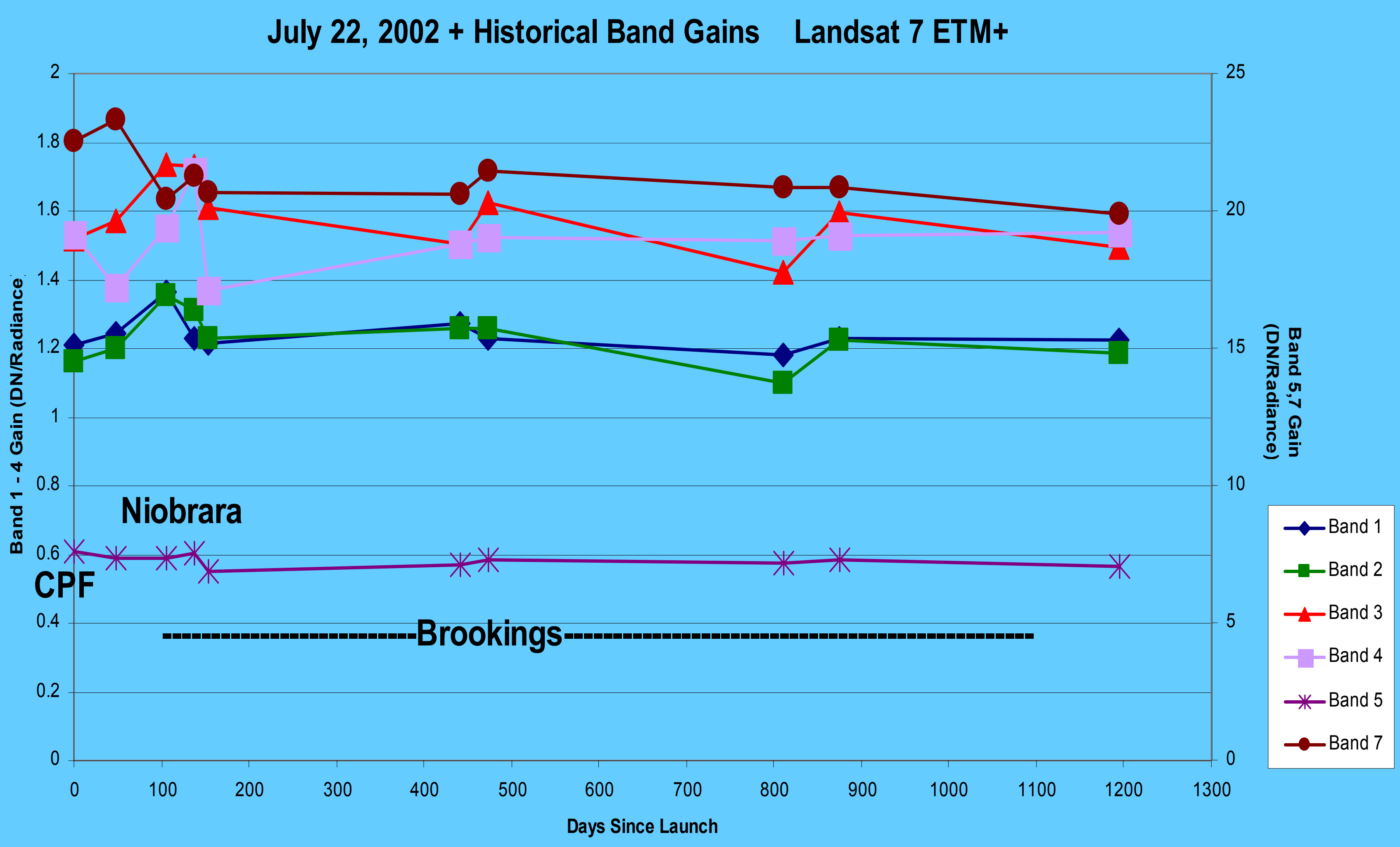
2002 Results Summary

- Began data analysis phase
  - Atmospheric analysis still being ‘outsourced’, begin pulling it in during the 2003 phase.
  - Tech transfer from the IP lab to the Sat cal group of methodologies for vicarious gain calculations
  - Established filter libraries and developed initial algorithms for ‘hyperspectral’ to ‘multispectral banded’ integrations
- Report generation protocols
  - In progress

2002 Grass Site Spectral Averages for dates with 'good' collections

(~1000 spectra per curve-ASD FR FS #638 cal 8)





July 22, 2002 + Historical Band Gains Landsat 7 ETM+
Band 1 - 4 Gain (DN/Radiance)
Band 5,7 Gain (DN/Radiance)
Days Since Launch
Niobrara
CPF
------------------------Brookings---
Band 1
Band 2
Band 3
Band 4
Band 5
Band 7
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
5
10
15
20
25
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300

2002-2003 Predictive Yield Modeling

Three different modeling approaches are being investigate as crop yield predictors based primarily on remote sensing technology.

1. Development of a predictive model based on principal component analysis of remote sensing data.
   - We just finished this work and the paper has been accepted for publication in the Agronomy Journal. (Chang, D.E. Clay)

Predictive Yield Modeling (cont)

2. Development has been initiated on predictive model for estimating yields (corn is the test vehicle).

This model taps into the soils data base as an adjunct to remote sensing data.

- Absolute radiometric calibration of the remote sensing data is required to temporally standardize the data sets.

- Data that will be used in this analysis includes archived Landsat, soils, and yield monitor data.
  - If successful this appraoch can be used as a marketing tool by producers, and can be used in Carbon sequestation studies that require estimates of biomass production. (D.E. Clay and K. Dalsted)

Predictive Yield Modeling (cont)

- 3. Development of a physiological model that uses remote sensing and water mass balance to estimate yields and potential future growth based on available water.
  - In this component soil water content, biomass production, leaf area, and reflectance are routinely monitored.
  - Since water is the primary limiting plant growth factor, this model can evaluate the potential benefit of management strategies.
    - For example, should additional N or herbicides be applied. (G. Carlson and T. Trooien)

Weed detection,

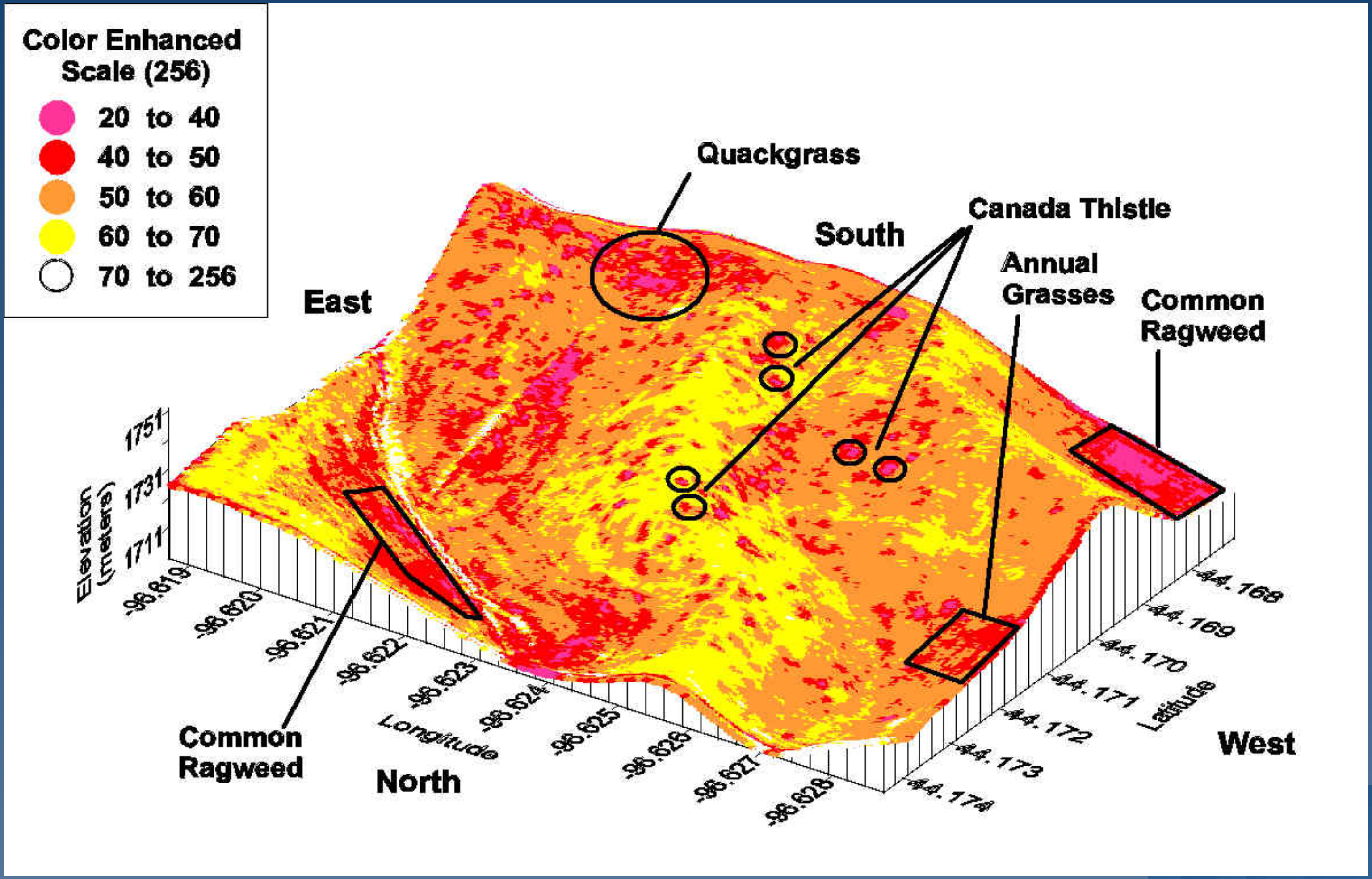
I. in 2002 an approach was developed to use remote sensing to detect and characterize weedy areas of fields.

- The basis of this model is the observation that plants reflect light differently than soil.
  - i.e. The greater the plants density is in an area (weeds plus crop plants) the more or less reflectance from the soil.
  - If no-tillage is used, then more plants will reflect less than the residue covered soil and if tillage is used then, more plants will reflect more than the bare soil.

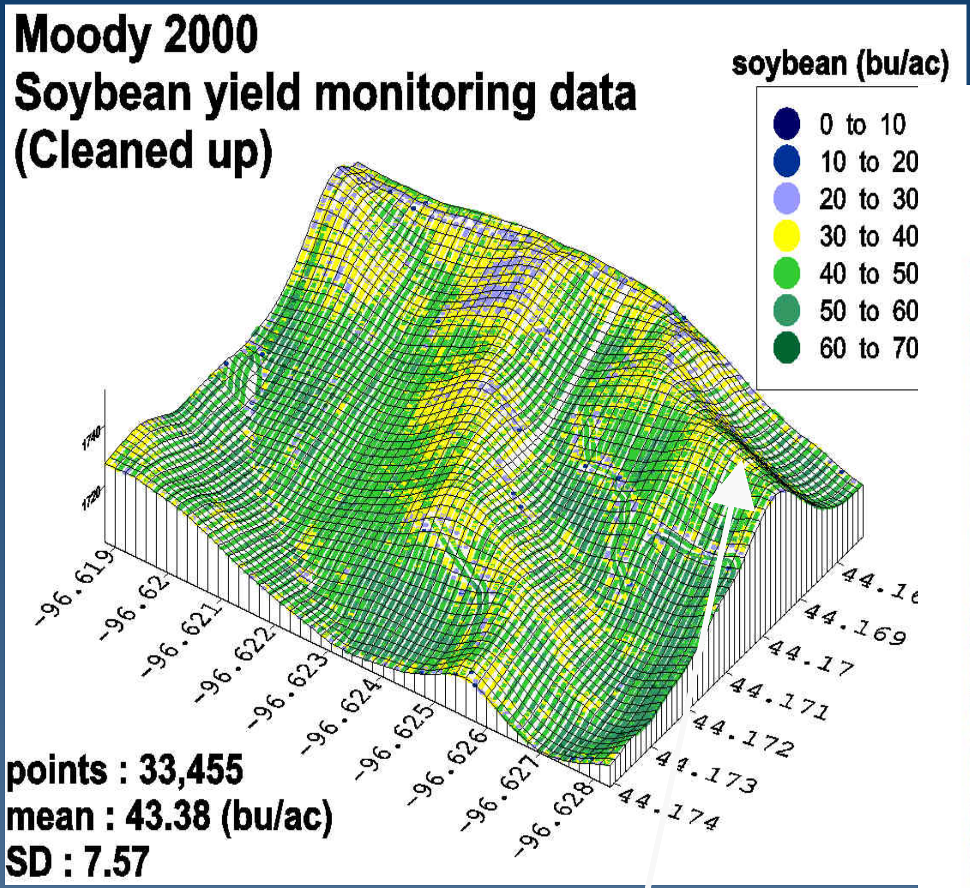
- During this study, reflectance was measured biweekly and weed and crop densities were measured at 3 different study sites.
  - This approach can be used by producers to determine when weed control is needed.

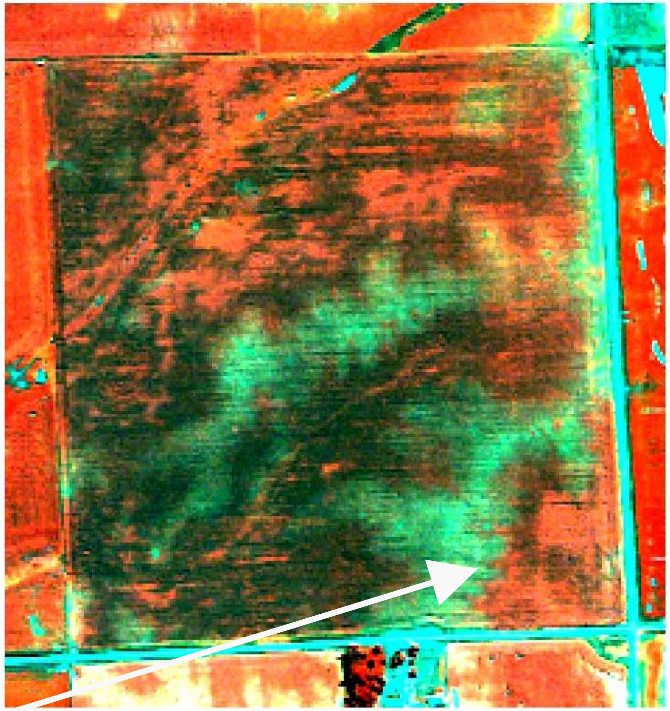
- (Chang and S.A. Clay). This data was written up and has been submitted to Weed Science for publication.

2002 Weed locations "Moody Field"



Moody field 2002 yield data





Same area

Correlation coefficients: Relationships between yield and index

	GDVI	NDVI	Green	Red	NIR
July	0.21	0.28	0.23	0.15	0.26
Aug	0.51	0.47	-0.48	-0.47	0.40

Publications and Grants: Plant Science Group

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

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

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

Grants

- Clay, D.E. C.G. Carlson. SD Corn Utilization Council (5 years project, year 1 funded) $23,000/$136,000 requested, Using deep tillage to improve corn profitability.

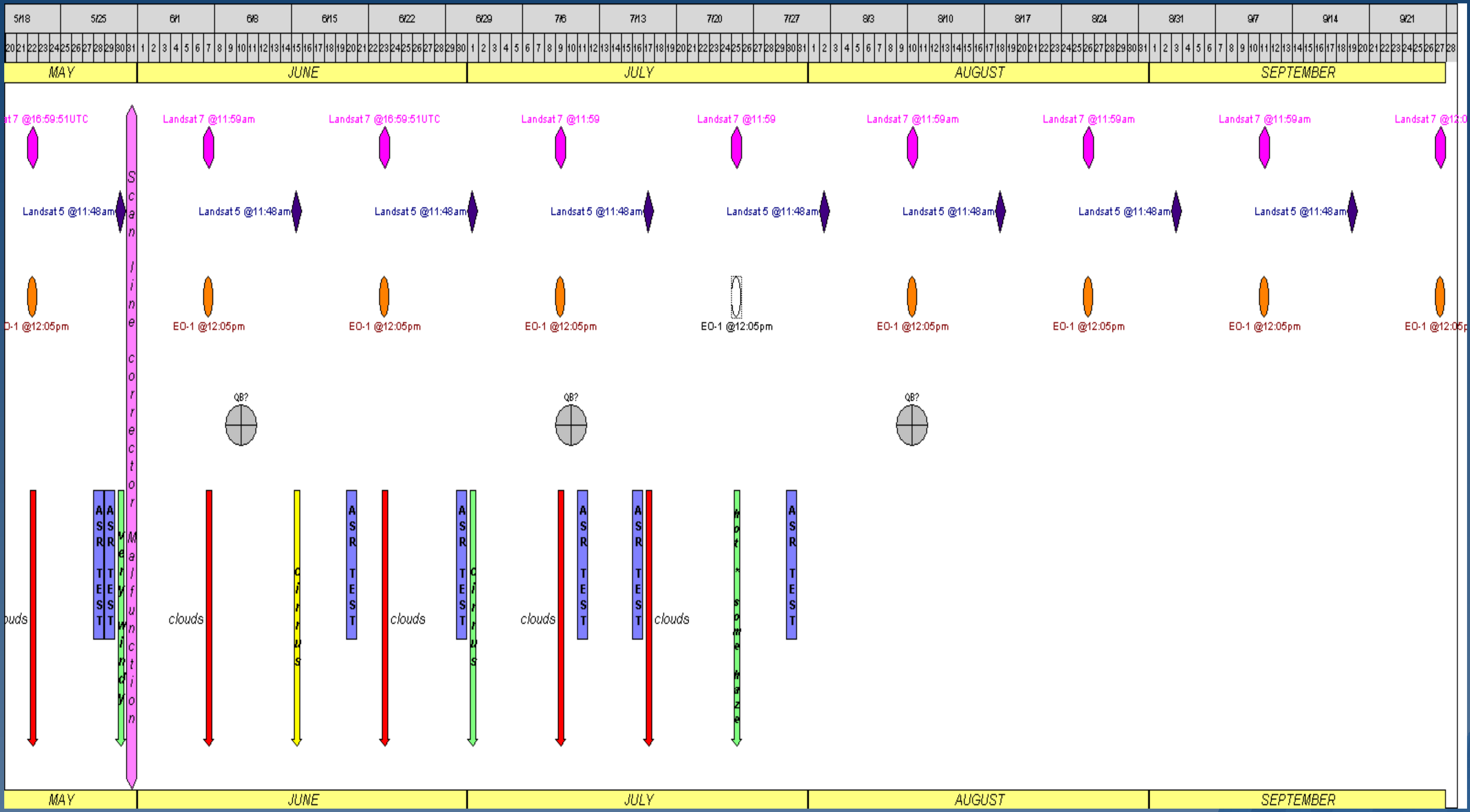
- Carlson, C.G, D.E. Clay, and S.A. Clay. $5,000, SD Soybean Research and Promotion Council. Year 1 of a 5 year project.

2003 Objectives: Cross Calibration

- Focus on Landsat 5 and 7
  - Corn on Corn-stubble Site ("Brookings Field")
    lat 44^0 13.7′ long 96^0 38.8′
    - 250 X 150m site walk 8 E-W rows
  - Reduced Grass site (120X210m)
  - Vicarious Calibration
  - modeling capability
    - MODTRAN
    - 6S
  - BRDF Modeling
  - BRDF Application

- Potential for 3 Quickbird Collections

2003 Collection Schedule




That's all for now!