

# **Data Continuity of Landsat-4 TM, Landsat-5 TM, Landsat-7 ETM+, and Advanced Land Imager (ALI) sensors.**

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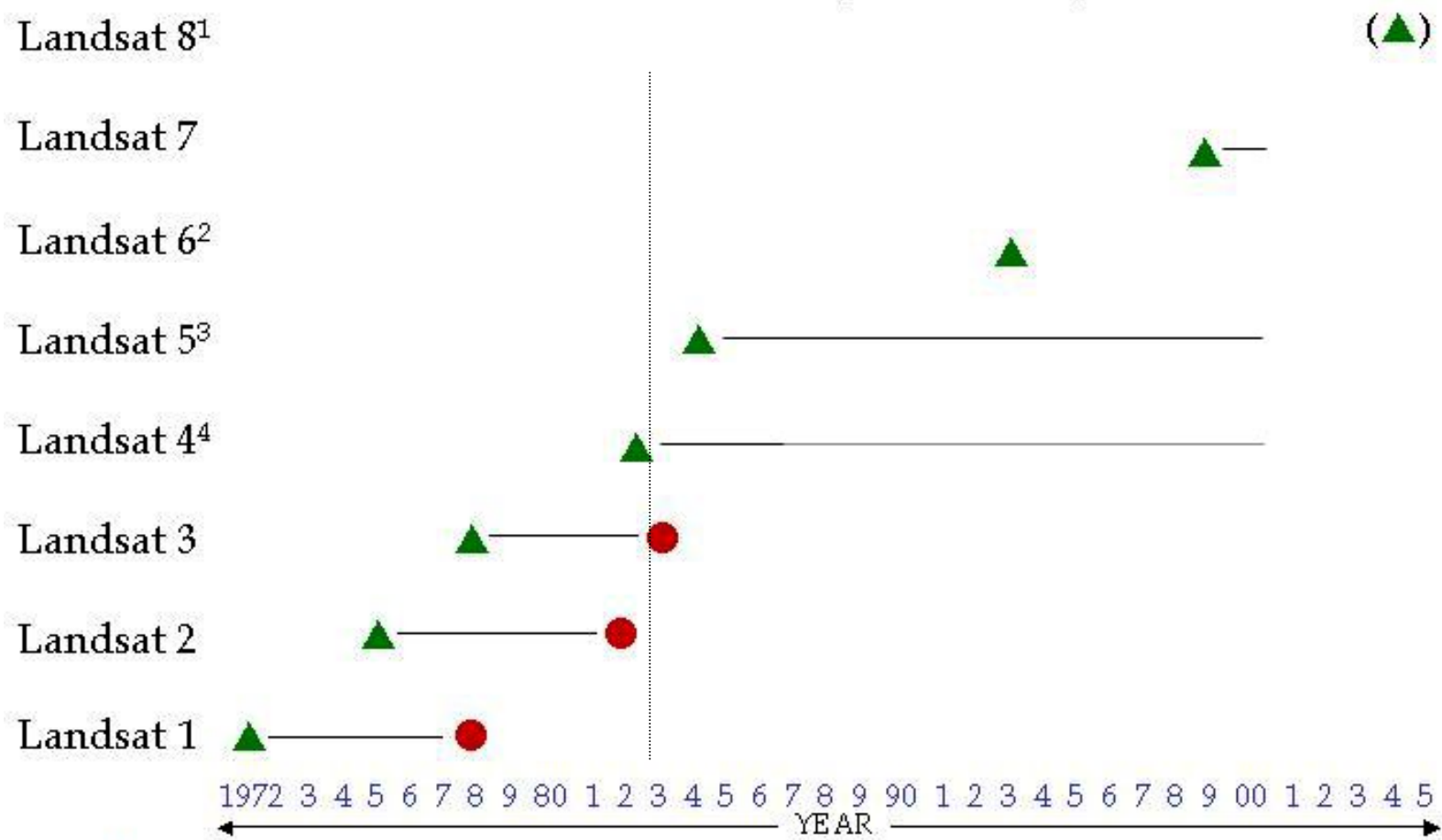
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Tucson, AZ 85721**



# Outline

- 1. Data Continuity of Landsat-4 TM, Landsat-5 TM, Landsat-7 ETM+, and Advanced Land Imager (ALI) sensors.**
- 2. Qualitative Analysis of ALI band 5p**
- 3. Comparison of ALI bands 4 and 4p to ETM+ band 4**
- 4. Field work in Argentina.**
- 5. Additional comparison of ALI and ETM+ band from Argentina image.**
- 6. CO<sub>2</sub> study using images from TM5 and ETM+**
- 7. Future work.**

# Landsat Coverage History



▲ Launch

● End of Service

<sup>1</sup>ETM+ follow-on instrument on EOS AM-2.

<sup>2</sup>Failed to obtain orbit.

<sup>3</sup>Data transmission by directdownlink only.

<sup>4</sup>No longer transmitting TM data.

# EO-1 Advanced Land Imager

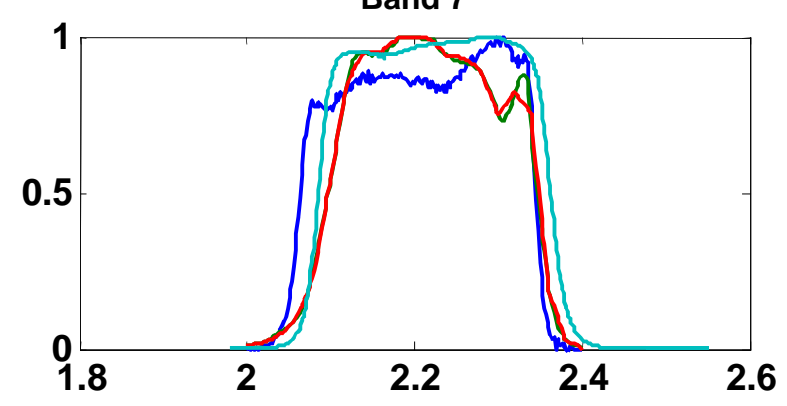
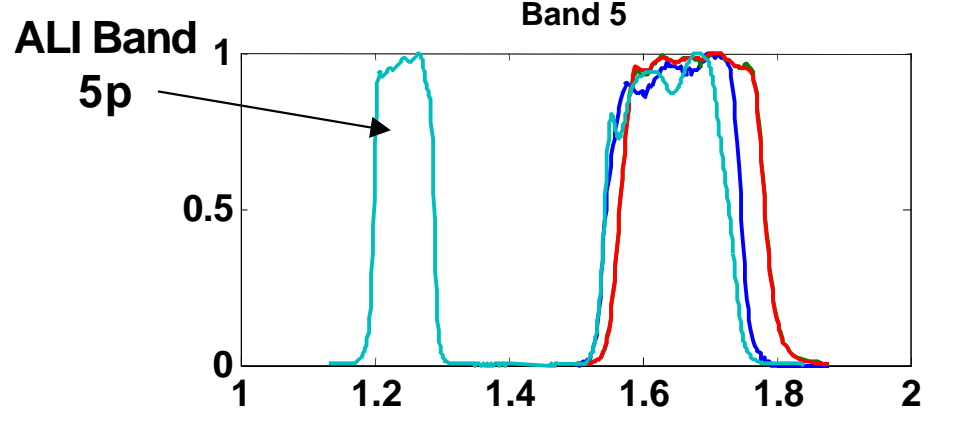
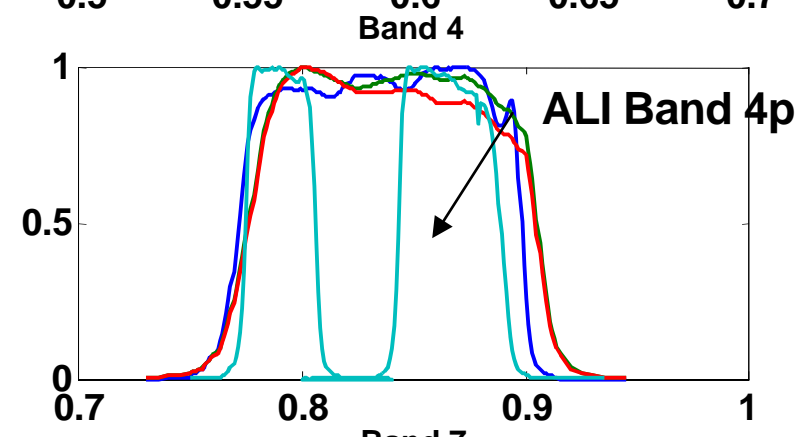
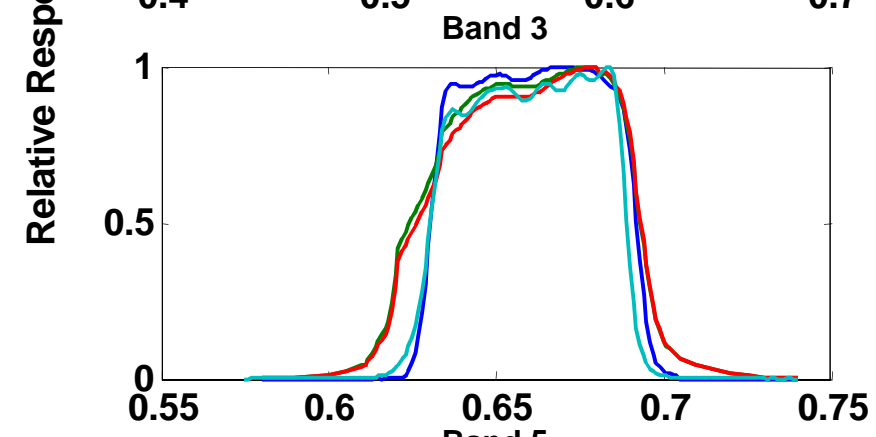
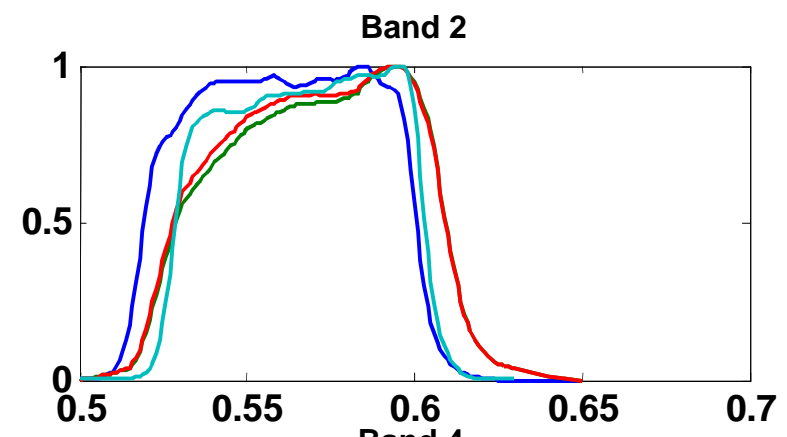
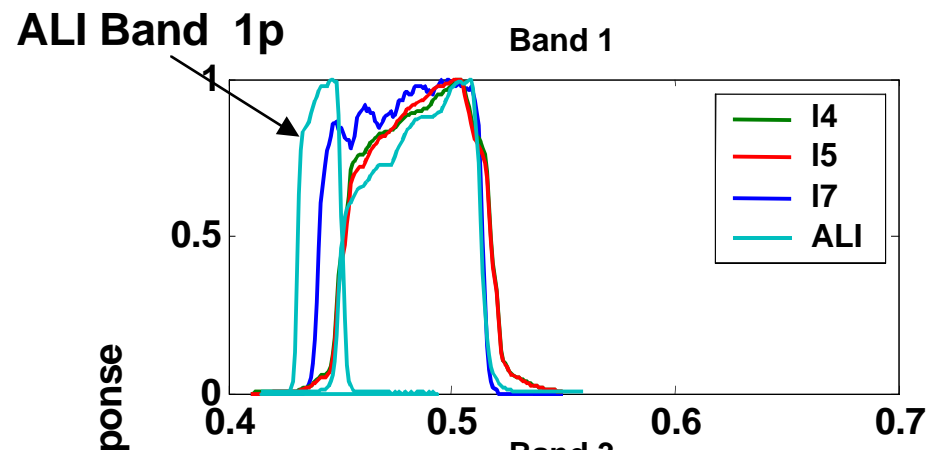
**EO-1 Advanced Land Imager (ALI) is a technology verification project designed to demonstrate comparable or improved Landsat spatial and spectral resolution with substantial mass, volume, and cost savings.**



**Launched from Vandenberg Airforce base, November 21, 2000**

## TM ETM+ ALI Comparisons

	Landsat 4,5 TM	Landsat 7 ETM+	EO-1
	<b>Thematic Mapper (TM)</b>	<b>Enhanced Thematic Mapper Plus (ETM+)</b>	<b>Advanced Land Imager (ALI)</b>
<b>Instrument(s):</b>	[scan mirror spectrometer]	[scan mirror spectrometer]	[Push broom radiometer/ spectrometer];
<b>Mass</b>	2200 kg	2200 kg	425 kg
<b>Swath Width</b>	185 km	185 km	37 km
<b>Revisit Interval</b>	16 days	16 days	ALI not applicable - experimental
<b>Orbit</b>	705 km, sun-synchronous, 98.2 degrees inclination, Equatorial crossing time = 9:30am +/- 15 min.	705 km, sun-synchronous, 98.2 degrees inclination; Equatorial crossing time = 10:00am +/- 15 min.	705 km, sun-synchronous, 98.2 degrees inclination; Equatorial crossing time = Landsat 7 + 1 min.
<b>Band</b>		<b>Spectral range (µm): Ground Res.(m)</b>	<b>Spectral range (µm): Ground Res.(m)</b>
1p			.433 - .453: 30
1	.450 - .515: 30	.450 - .515: 30	.450 - .510: 30
2	.525 - .605: 30	.525 - .605: 30	.525 - .605: 30
3	.630 - .690: 30	.630 - .690: 30	.630 - .690: 30
4	.750 - .900: 30	.750 - .900: 30	.775 - .805: 30
4p			.845 - .890: 30
5p			1.20 - 1.30: 30
5	1.55 - 1.75: 30	1.55 - 1.75: 30	1.55 - 1.75: 30
7	2.09 - 2.35: 30	2.09 - 2.35: 30	2.08 - 2.35: 30
pan		.520 - .900: 15	.480 - .680: 10
6 (thermal)	10.40 - 12.50: 120	10.40 - 12.50: 60	
<b>Launch Date</b>	1982	April, 1999	December, 1999



Wavelength (um)

## Location of sites



# EO-1 and Landsat Inter-Satellite Comparison at Two Established Arizona Field Sites

Maricopa Agricultural Center (MAC)



ARIZONA



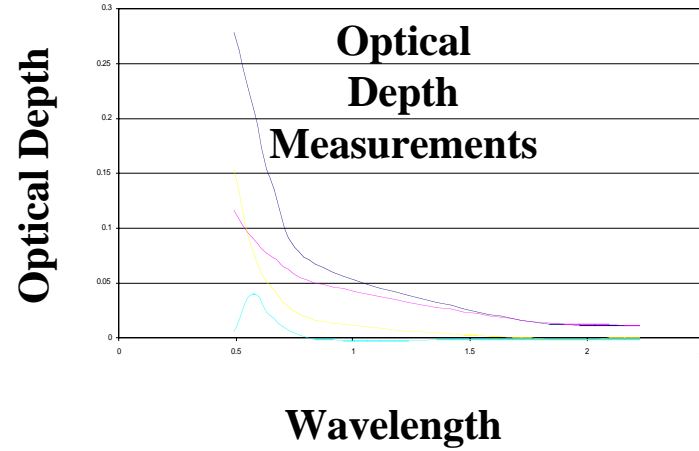
Walnut Gulch Experimental Watershed

# Approach

How do you make an independent verification using ground data?



Sun Photometer



→ **Radiative transfer code**



**Predicted at-sensor-reflectance (Atmospherically corrected) from sensor radiance**



**Each pixel contains radiance value for each band**

# How was ground data collected?

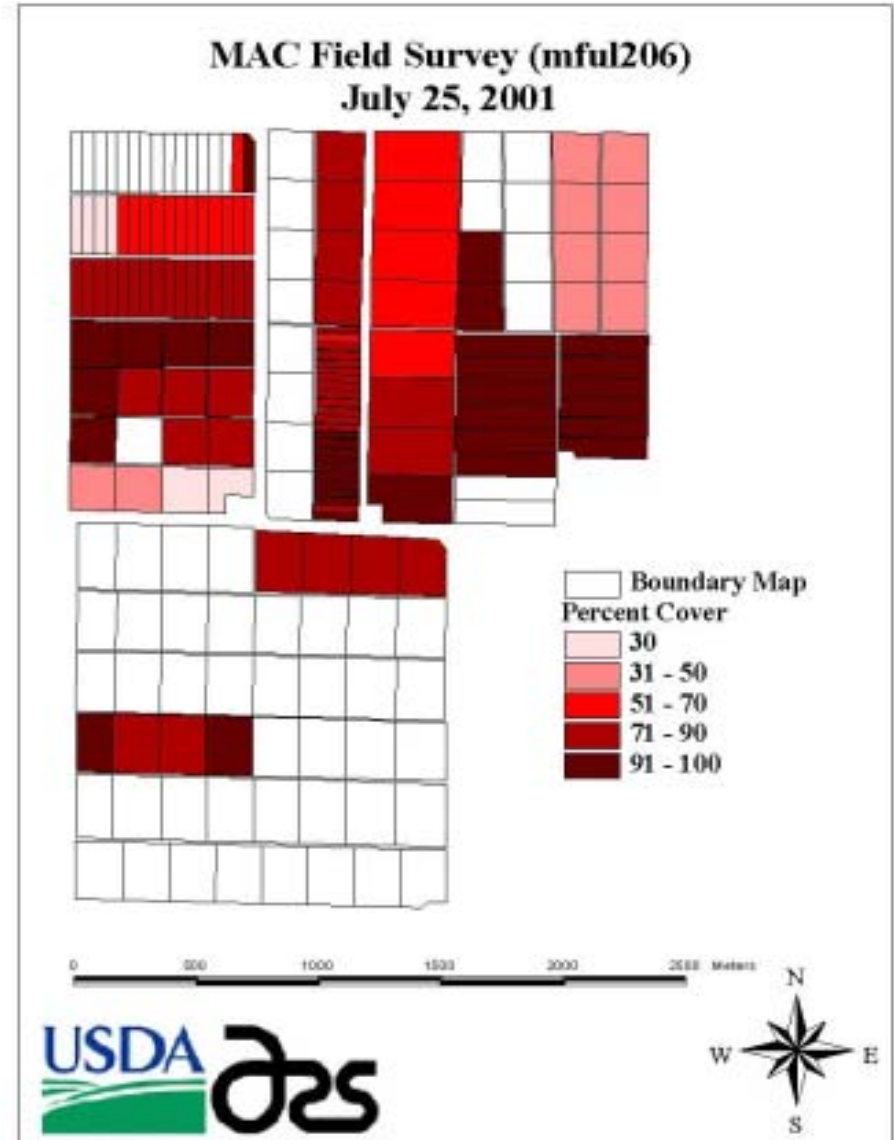
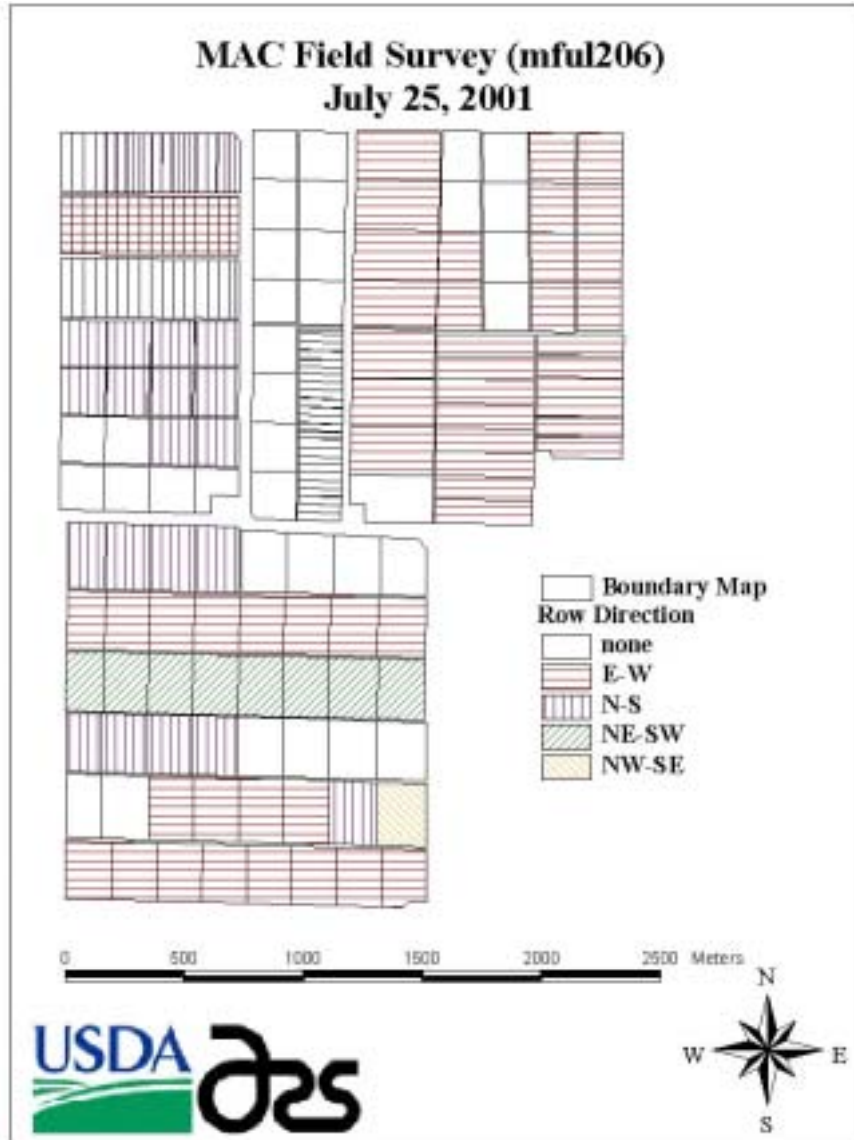
With a hyper-spectral radiometer (ASD FR) mounted on a powered parachute.

The ASD FR measures radiance from 0.35 to 2.5 micrometers.





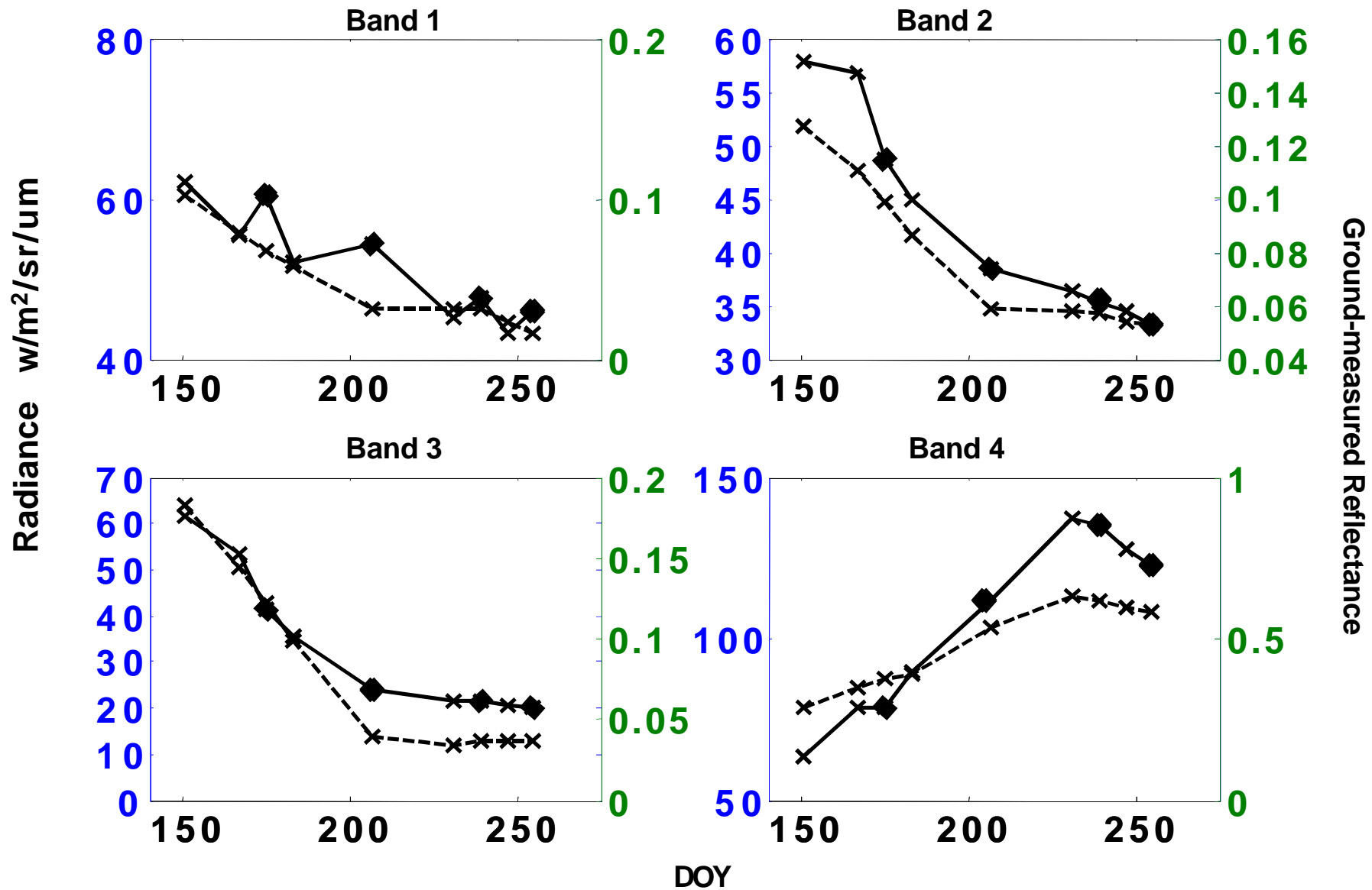
# Ancillary Data



# RESULTS

# Landsat 4 TM – 5 TM comparison

- Suffered from paucity of data.
- Had to take a semi-quantitative approach
- Had images of MAC farm for 1989 for both TM 4 and TM 5 but not on the same days
- During growing season bands 1,2,3      ↓      In reflectance value  
During growing season band 4      ↑      In reflectance value
- We looked at the pattern of the growing season of a cotton crop



Cotton field at MAC 1989.

**Ugly black diamonds represent Landsat 4 measurements.**

**Dashed line = ground measurements**

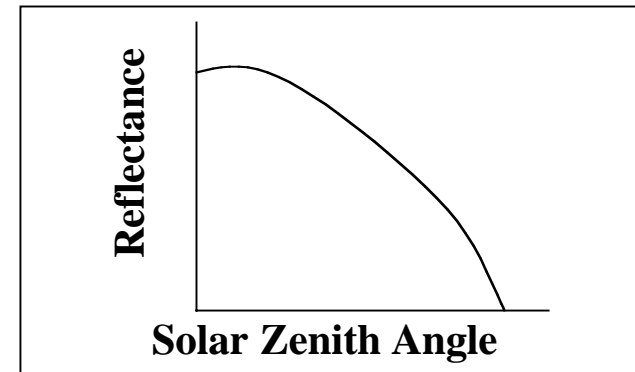
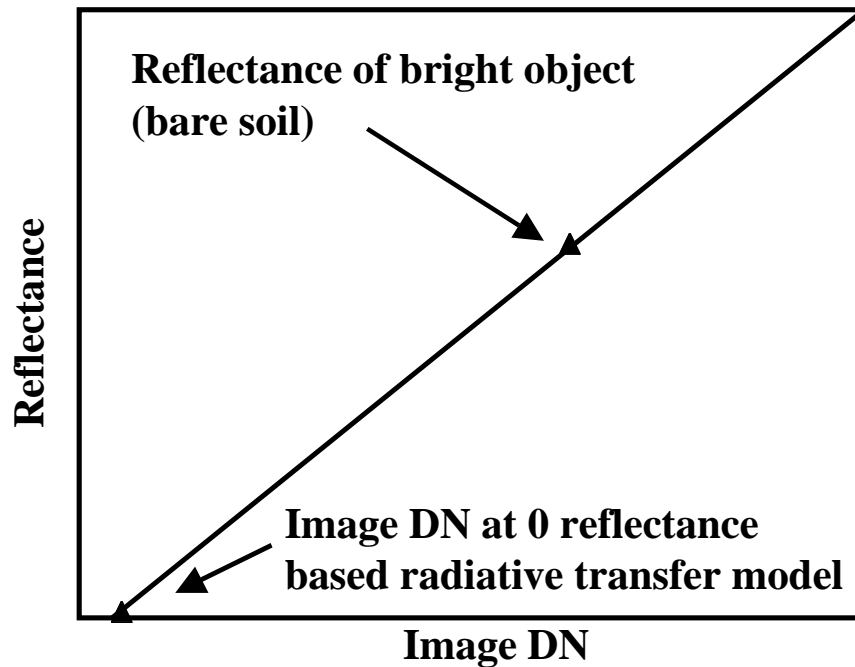
# **How do you account for radiance discrepancies between images?**

- One way is to use an image based approach for determining reflectance.**
- The Refined Empirical Line (REL) is such an approach.**

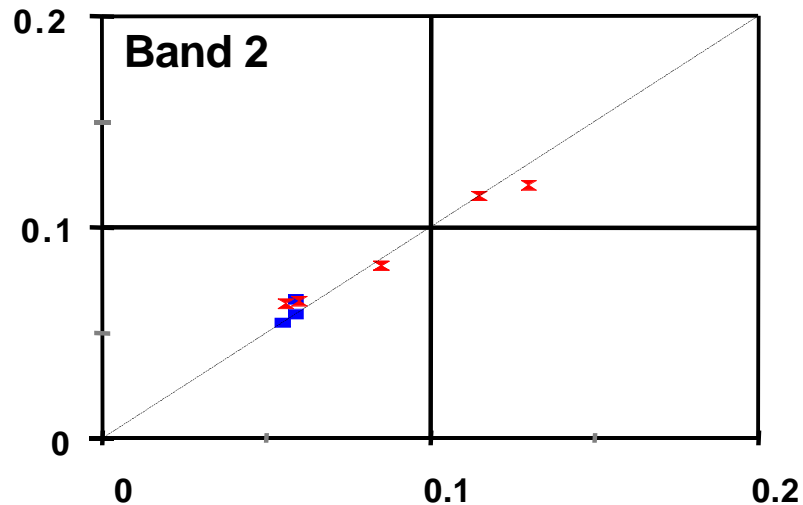
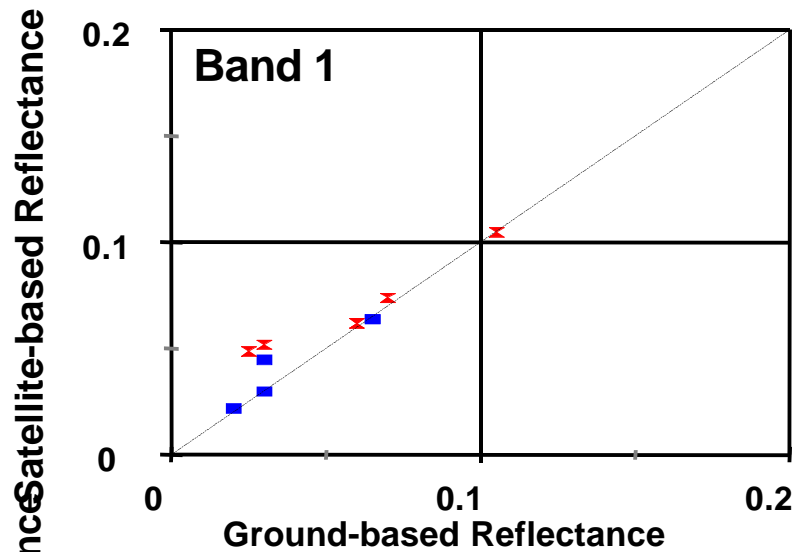
# Refined Empirical Line Approach

→ Reflectance of bright object is measured at different solar zenith angles

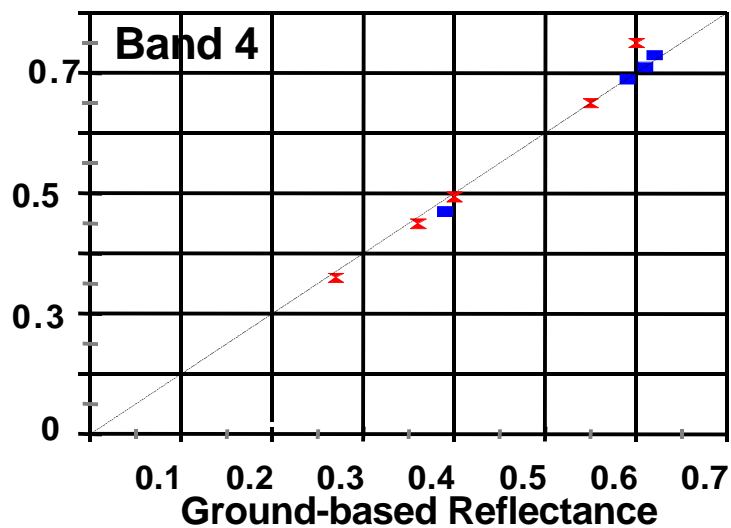
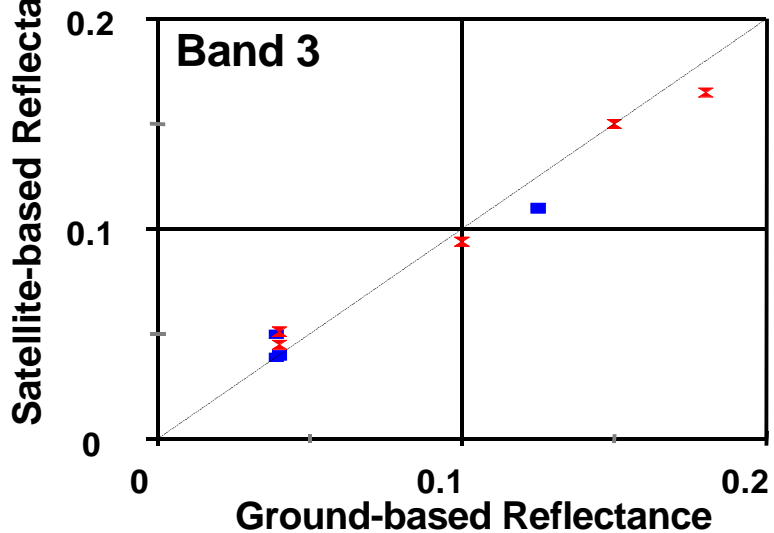
→ Relationship between solar zenith angle and reflectance of object is developed.



Then you have equation to convert bright object to reflectance at any solar zenith angle



■ L4 TM  
 × L5 TM



■ L4 TM  
 × L5 TM

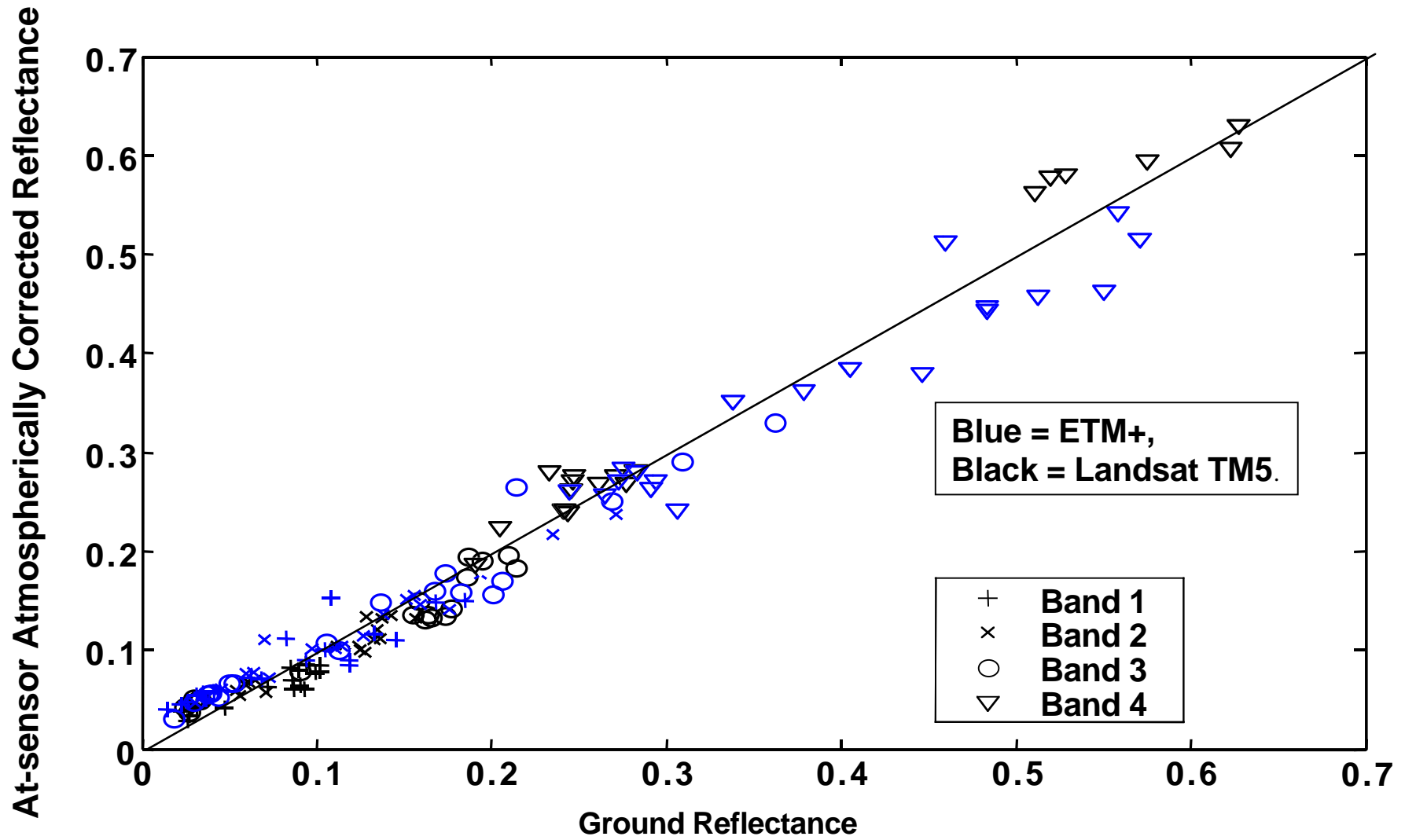
**RMSE**



	Band 1	Band 2	Band 3	Band 4
Landsat 4 TM	0.008	0.006	0.009	0.011
Landsat 5 TM	0.015	0.006	0.009	0.023

# Images for Landsat TM 5, Landsat 7 ETM+ comparison

Location	DOY	Sensor	Date
Maricopa	79	Landsat 5 TM	3/20/1985
Maricopa	204	Landsat 5 TM	7/23/1985
Maricopa	220	Landsat 5 TM	8/9/1985
Maricopa	300	Landsat 5 TM	10/27/1985
Maricopa	111	Landsat 5 TM	4/21/1986
Maricopa	175	Landsat 5 TM	6/24/1986
Maricopa	151	Landsat 5 TM	5/31/1989
Walnut Gulch	114	Landsat 5 TM	4/23/1992
Walnut Gulch	162	Landsat 5 TM	6/10/1992
Walnut Gulch	194	Landsat 5 TM	7/12/1992
Walnut Gulch	274	Landsat 5 TM	9/30/1992
Walnut Gulch	306	Landsat 5 TM	11/1/1992
Walnut Gulch	322	Landsat 5 TM	11/17/1992
Maricopa	267	Landsat 7 ETM+	9/24/1999
Walnut Gulch	269	Landsat 7 ETM+	9/26/1999
Walnut Gulch	208	Landsat 7 ETM+	7/26/2000
Walnut Gulch	256	Landsat 7 ETM+	9/12/2000
Maricopa	270	Landsat 7 ETM+	9/26/2000
Walnut Gulch	272	Landsat 7 ETM+	9/28/2000
Maricopa	112	Landsat 7 ETM+	4/22/2001
Maricopa	144	Landsat 7 ETM+	5/24/2001
Walnut Gulch	146	Landsat 7 ETM+	5/26/2001
Maricopa	208	Landsat 7 ETM+	7/27/2001
Maricopa	240	Landsat 7 ETM+	8/29/2001
Maricopa	272	Landsat 7 ETM+	9/29/2001

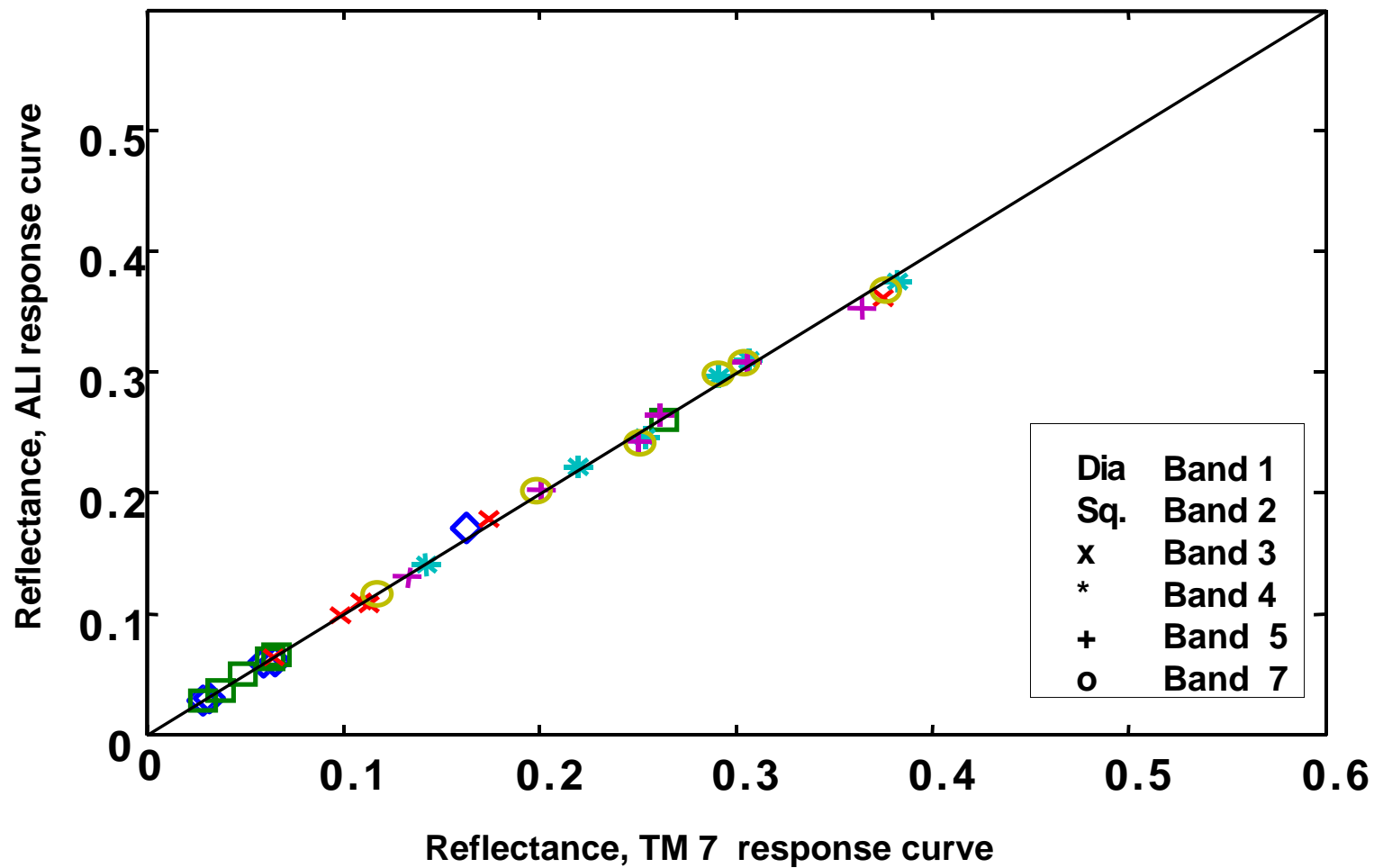


**RMSE** →

	Band 1	Band 2	Band 3	Band 4
Landsat 5 TM	0.017	0.016	0.022	0.027
Landsat 7 ETM+	0.022	0.018	0.022	0.038

# **ETM+ ALI band comparison**

Just to be sure, we compared ETM+ bands with ALI bands using ground reflectance data acquired with an the ASD FR.

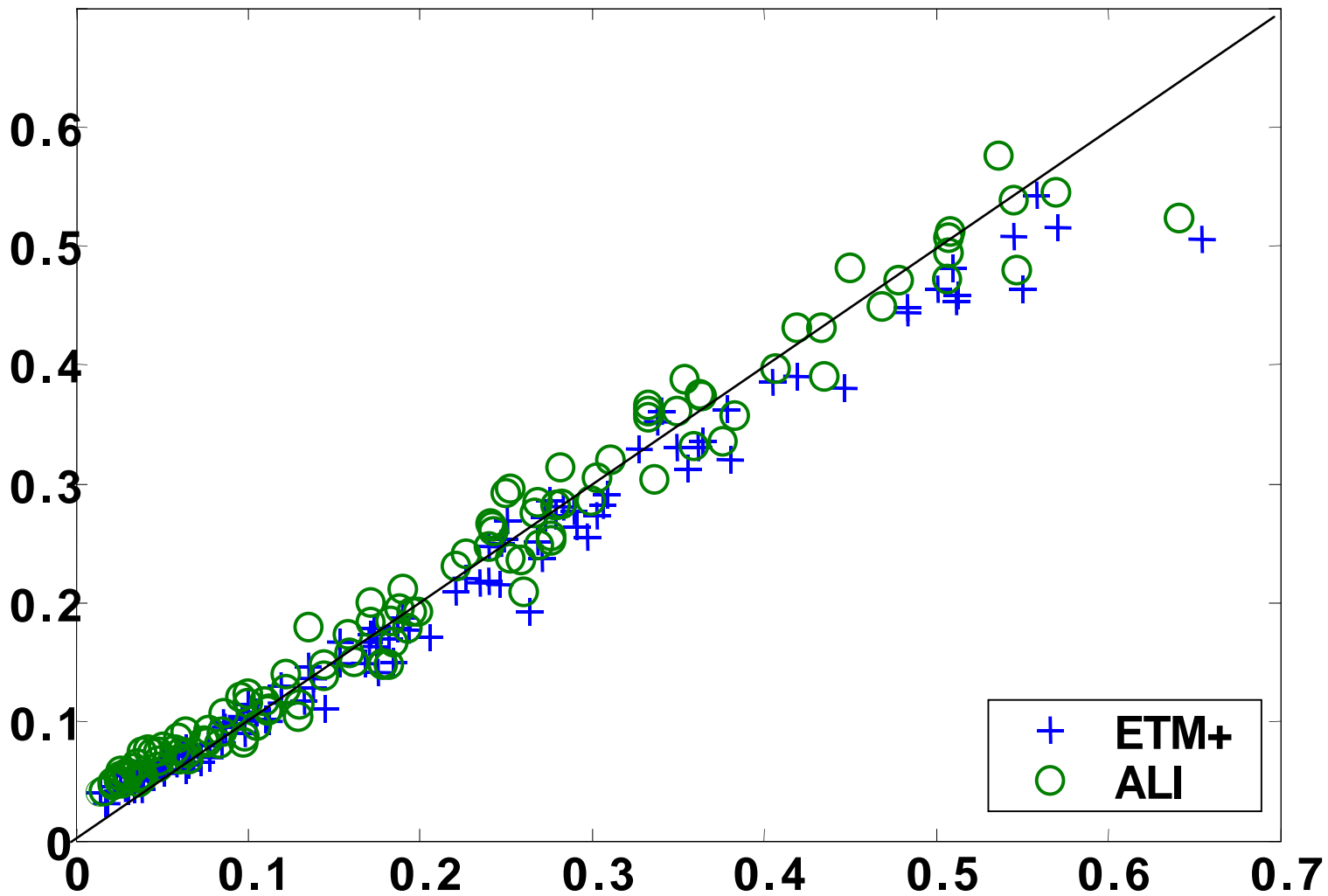


**Ground-based reflectance calculated with Landsat 7 ETM+ and EO-1 ALI response curves at Walnut Gulch, Arizona, 9/28/00.**

# ALI ETM+ Data Set

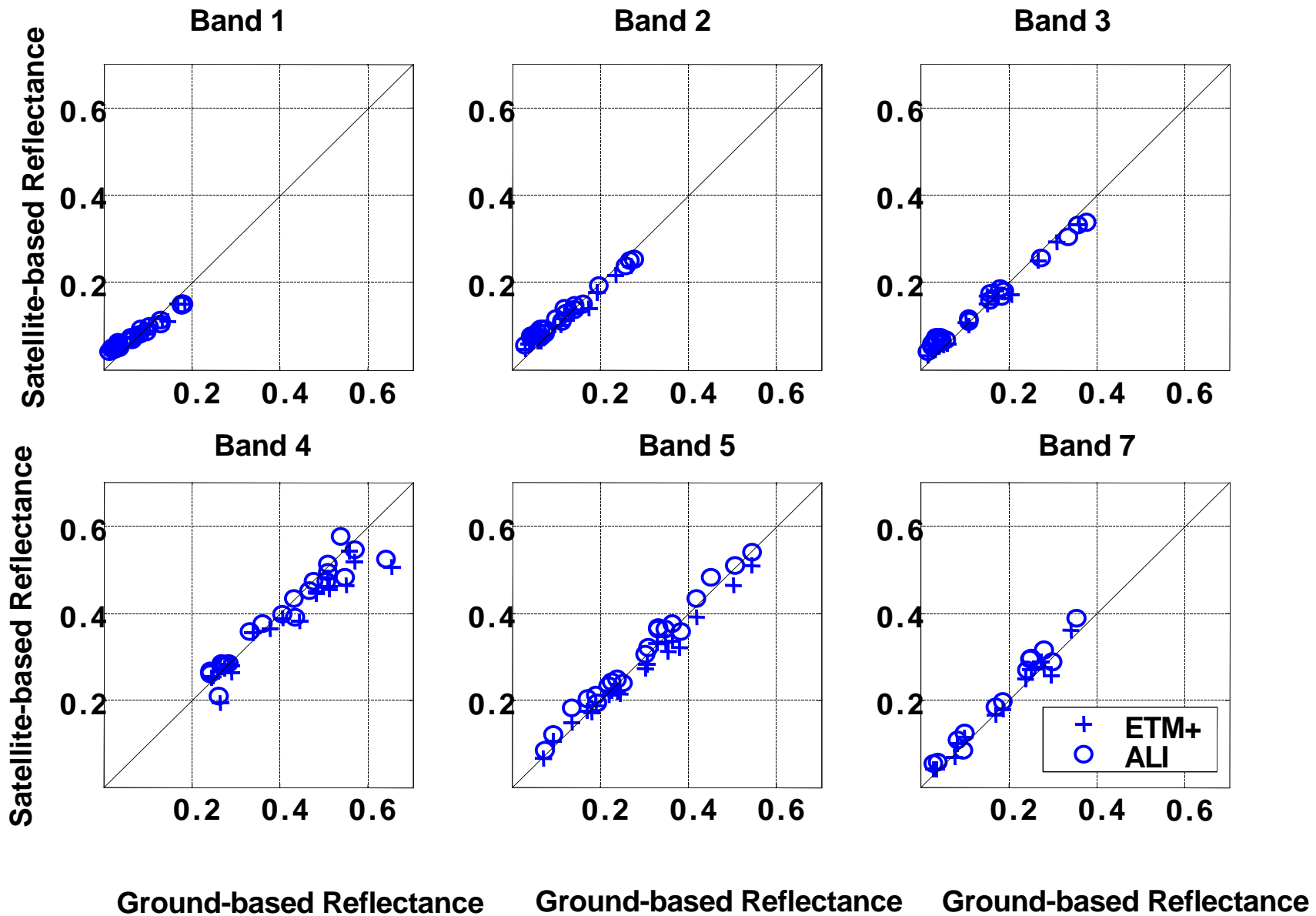
<b>Date</b>	<b>DOY</b>	<b>Location</b>	<b># of ground data readings</b>
<b>4/22/2001</b>	<b>112</b>	<b>Maricopa</b>	<b>4</b>
<b>5/24/2001</b>	<b>144</b>	<b>Maricopa</b>	<b>4</b>
<b>5/26/2001</b>	<b>146</b>	<b>Walnut Gulch</b>	<b>5</b>
<b>7/27/2001</b>	<b>208</b>	<b>Maricopa</b>	<b>4</b>
<b>8/29/2001</b>	<b>240</b>	<b>Maricopa</b>	<b>2</b>
<b>9/29/2001</b>	<b>272</b>	<b>Maricopa</b>	<b>2</b>
			<b>Total = 21</b>

**At-sensor Atmospherically Corrected  
Reflectance**



**Ground Reflectance**

# Ground based reflectance vs. satellite-based reflectance, ETM+ and ALI

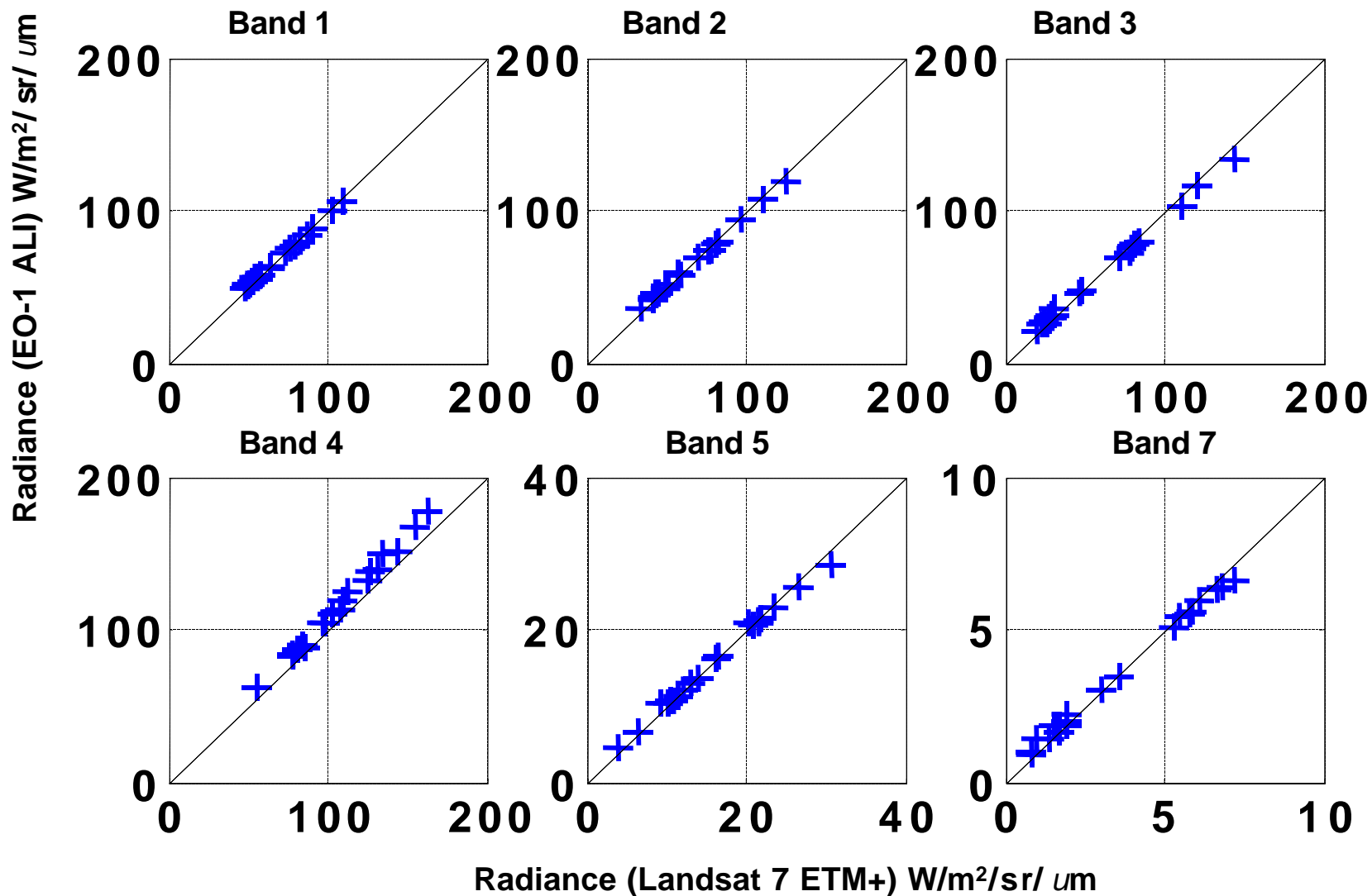


**Root mean squared error between atmospherically corrected satellite based reflectance and ground reflectance for Landsat 7 ETM+ and ALI.**

<b>Sensor</b>	<b>Band 1</b>	<b>Band 2</b>	<b>Band 3</b>	<b>Band 4</b>	<b>Band 5</b>	<b>Band 7</b>
<b>Landsat 7 ETM+</b>	<b>0.023</b>	<b>0.024</b>	<b>0.027</b>	<b>0.057</b>	<b>0.032</b>	<b>0.013</b>
<b>EO-1 ALI</b>	<b>0.021</b>	<b>0.020</b>	<b>0.023</b>	<b>0.037</b>	<b>0.020</b>	<b>0.020</b>

**Since we we had coincident ETM+ and ALI images we were able to make direct sensor to sensor comparisons by comparing radiances of each band**

# At Sensor radiances retrieved from Landsat 7 ETM+ and EO-1 ALI, by band.



Band	Slope	Offset
1	0.911	5.528
2	0.912	4.655
3	0.901	4.209
4	1.090	-1.875
5	0.928	0.922
7	0.904	0.282

**x= ETM+ at sensor radiance**  
**y= ALI at sensor radiance**

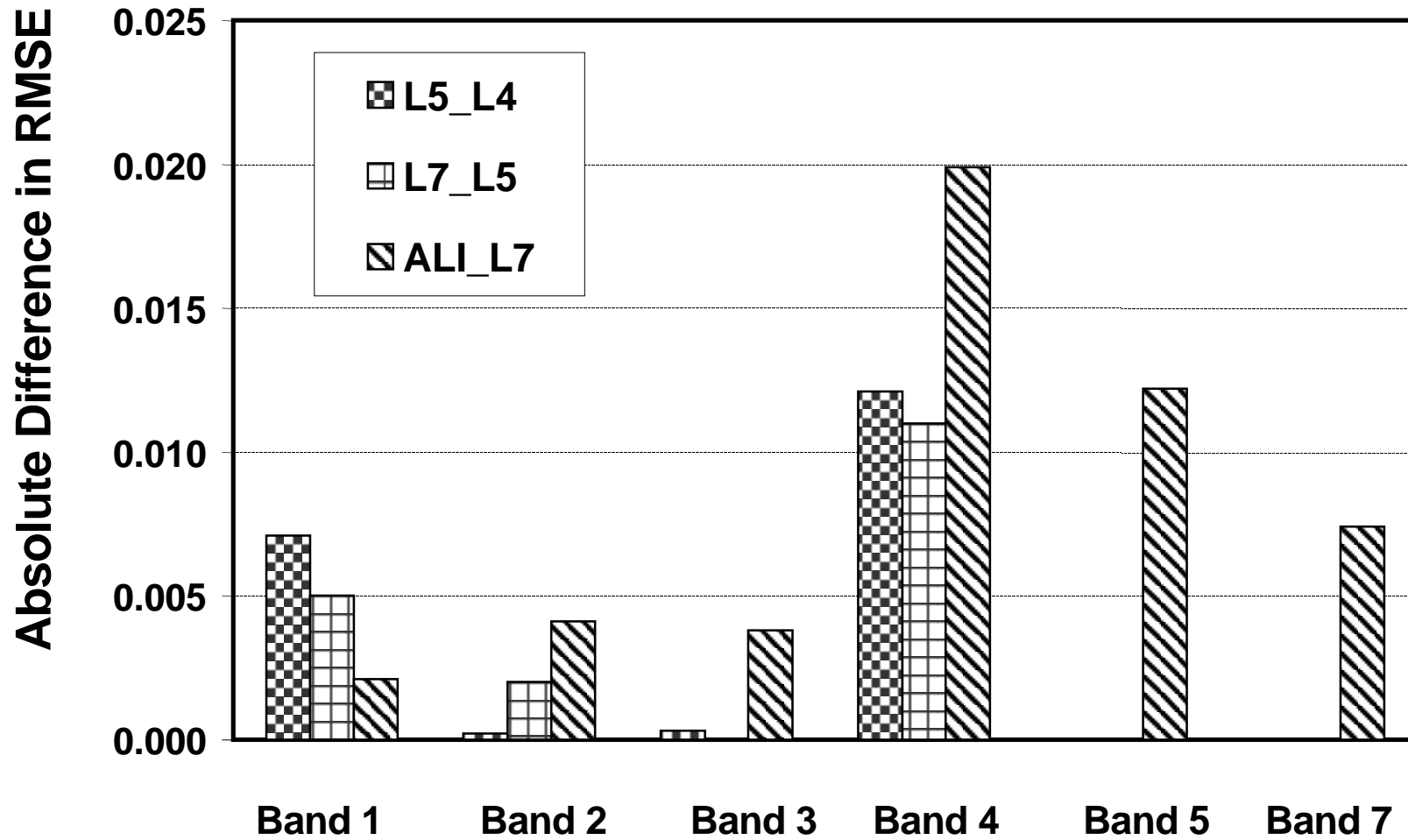
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**Root mean squared error  $RMSE_s$  radiance for Landsat 7 ETM+ and radiance for EO-1 ALI.**

Sensor	Units	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
ALI-ETM+	W/m <sup>2</sup> /sr/um	2.02	2.58	4.02	8.52	0.67	0.25
ALI-ETM+	As a percent of average radiance	3.0%	4.1%	7.2%	7.6%	4.2%	7.1%

## **Data continuity across all sensors**

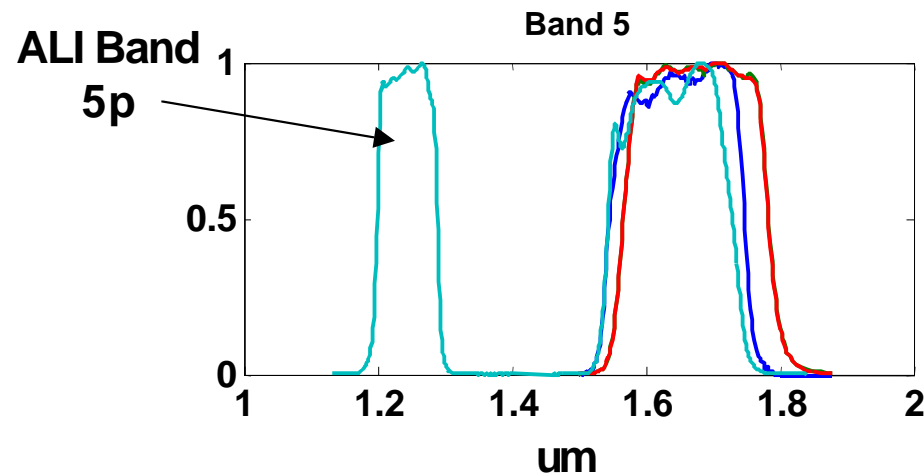
To evaluate the data continuity of all four sensors over time and minimize the method-induced differences, the absolute difference of the RMSE between sensor pairs was determined.



**Quick look at new ALI bands, 4 and 4p, 5p**

# ALI Band 5p

- One of the new ALI bands, 5p is a new SWIR band.
- There is an atmospheric window in this part of part of the spectrum and there is some speculation that it might be useful for deriving new information for agriculture.
- Our study was primarily a data continuity study so we did not collect ground data for a rigorous analysis of band 5p.



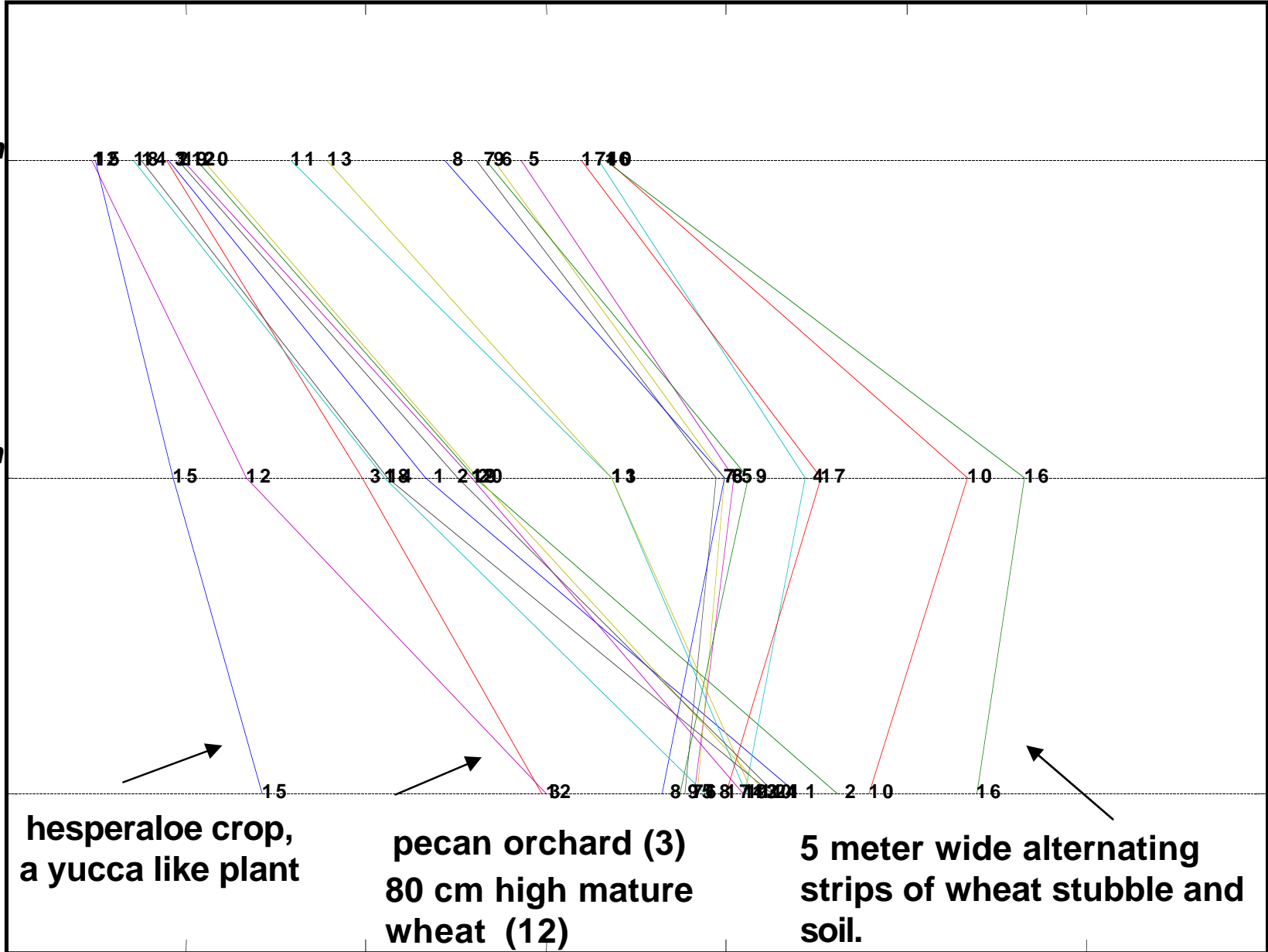
## Description of targets used in Landsat 7 ETM+ - EO-1 ALI analysis

Target #	DOY	Target description
1	144	alfalfa
2	144	alfalfa
3	144	pecan orchard
4	144	wheat , senescent
5	146	semi-arid grassland
6	146	semi-arid grassland
7	146	semi-arid grassland
8	146	semi-arid grassland
9	146	semi-arid grassland
10	240	alfalfa wet
11	240	wheat stubble
12	112	wheat
13	112	weeds
14	112	road
15	112	hesperaloe
16	208	wheat scencent
17	208	soil
18	208	cotton
19	208	alfalfa
20	272	alfalfa
21	272	alfalfa

**Band 7**  
**2.082-2.35  $\mu\text{m}$**

**Band 5**  
**1.55-1.75  $\mu\text{m}$**

**Band 5p**  
**1.2-1.3  $\mu\text{m}$**



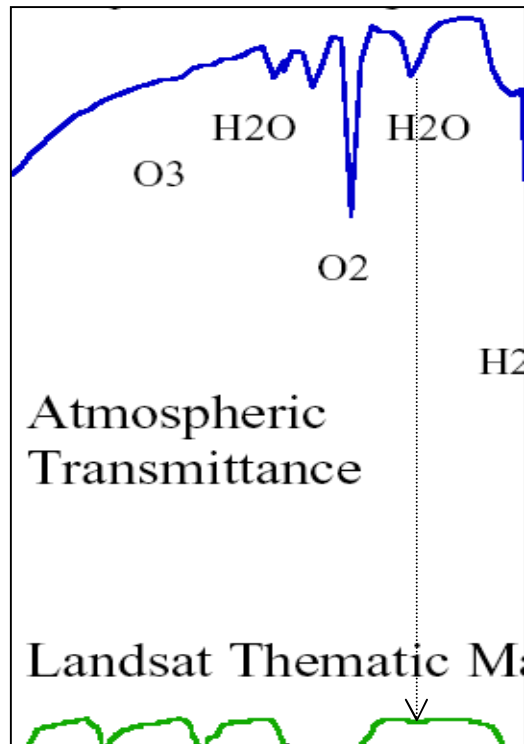
**hesperaloe crop,  
a yucca like plant**

**pecan orchard (3)  
80 cm high mature  
wheat (12)**

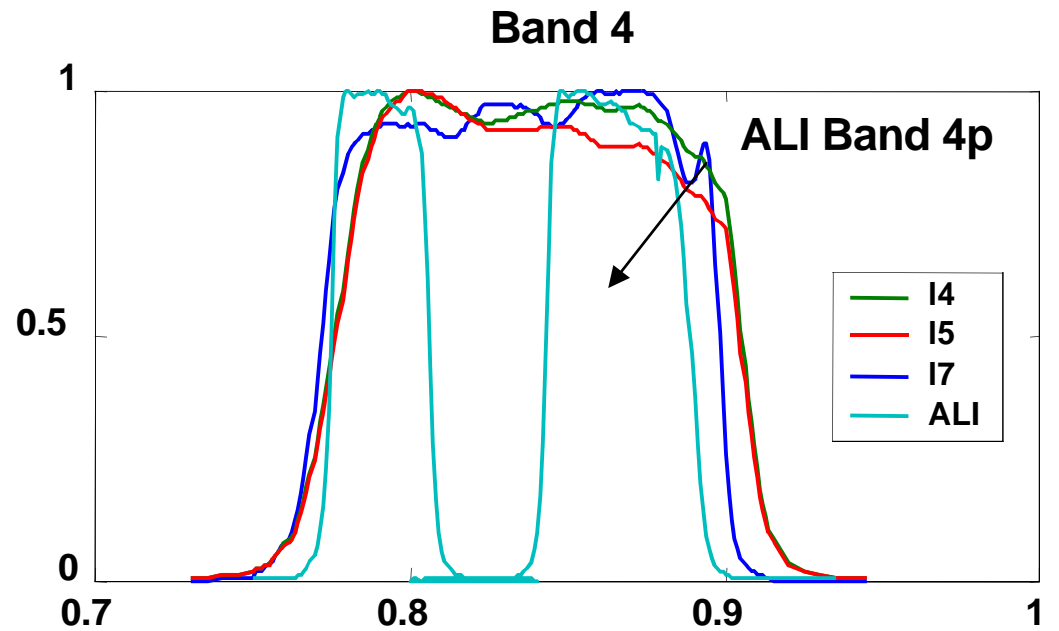
**5 meter wide alternating  
strips of wheat stubble and  
soil.**

**0 0.1 0.2 0.3 0.4 0.5 0.6 0.7**  
**Reflectance**

**ALI bands 4 and 4p were added to avoid atmospheric water absorption.**



ETM+ Band 4



RMSE

RMSE

atmospherically corrected satellite based reflectance and ground reflectance

Band	Without water vapor correction	With water vapor correction
ETM+ Band 4	0.078	0.057
ALI Band 4	0.052	0.041
ALI Band 4p	0.037	0.034

# Conclusions

- **Data continuity across Landsat 4 TM, Landsat 5 TM , Landsat 7 ETM+, and ALI is very good.**
- **For images where calibrations coefficients are unavailable or unreliable, an image based method such as the REL is recommended for conversion to reflectance.**
- **Coincident image comparison between ETM+ and ALI show excellent data continuity between the two sensors.**
- **ALI band 5p is interesting.**
- **ALI bands 4 and 4p are minimally affected by atmospheric water vapor.**



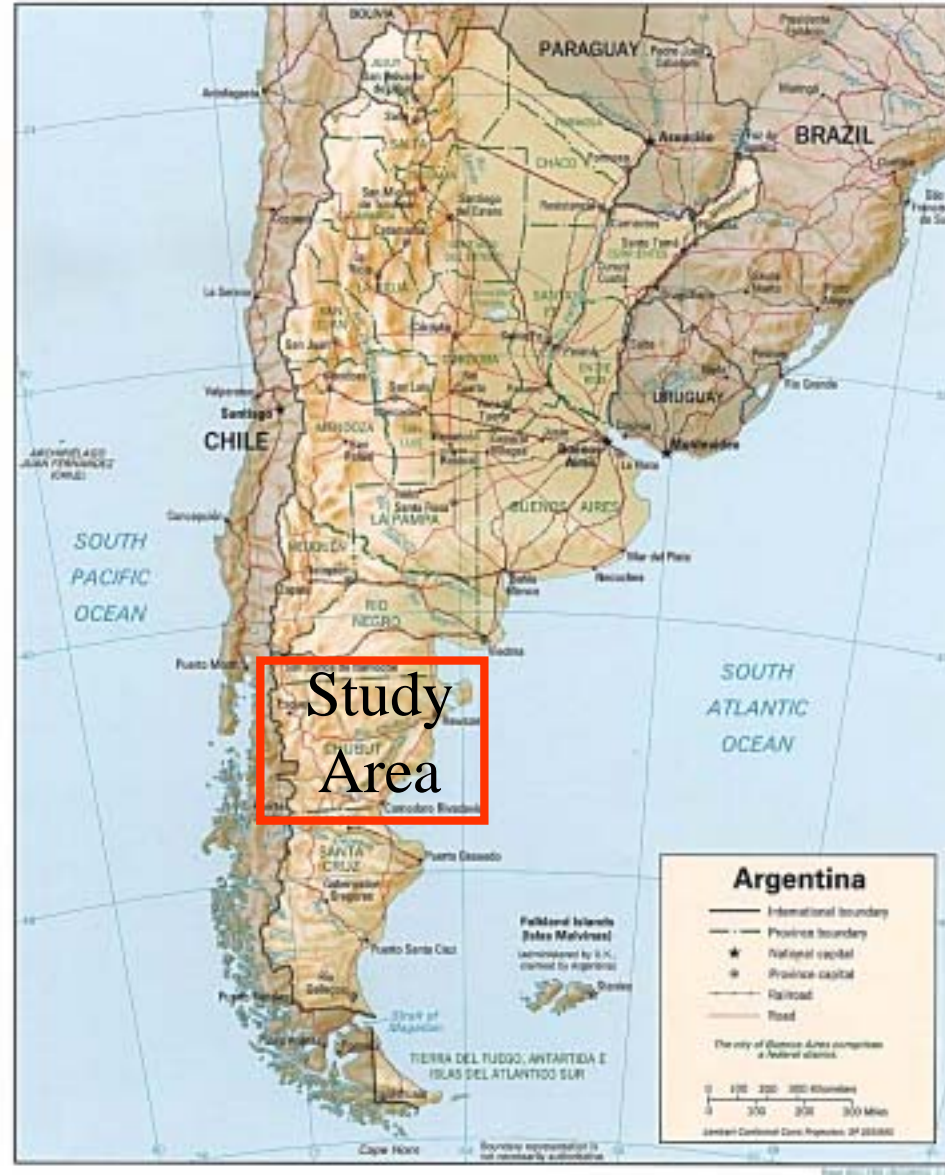
**Off to Argentina**

# **Research collaboration with Jose Paruelo at the the Universidad de Buenos Aires**

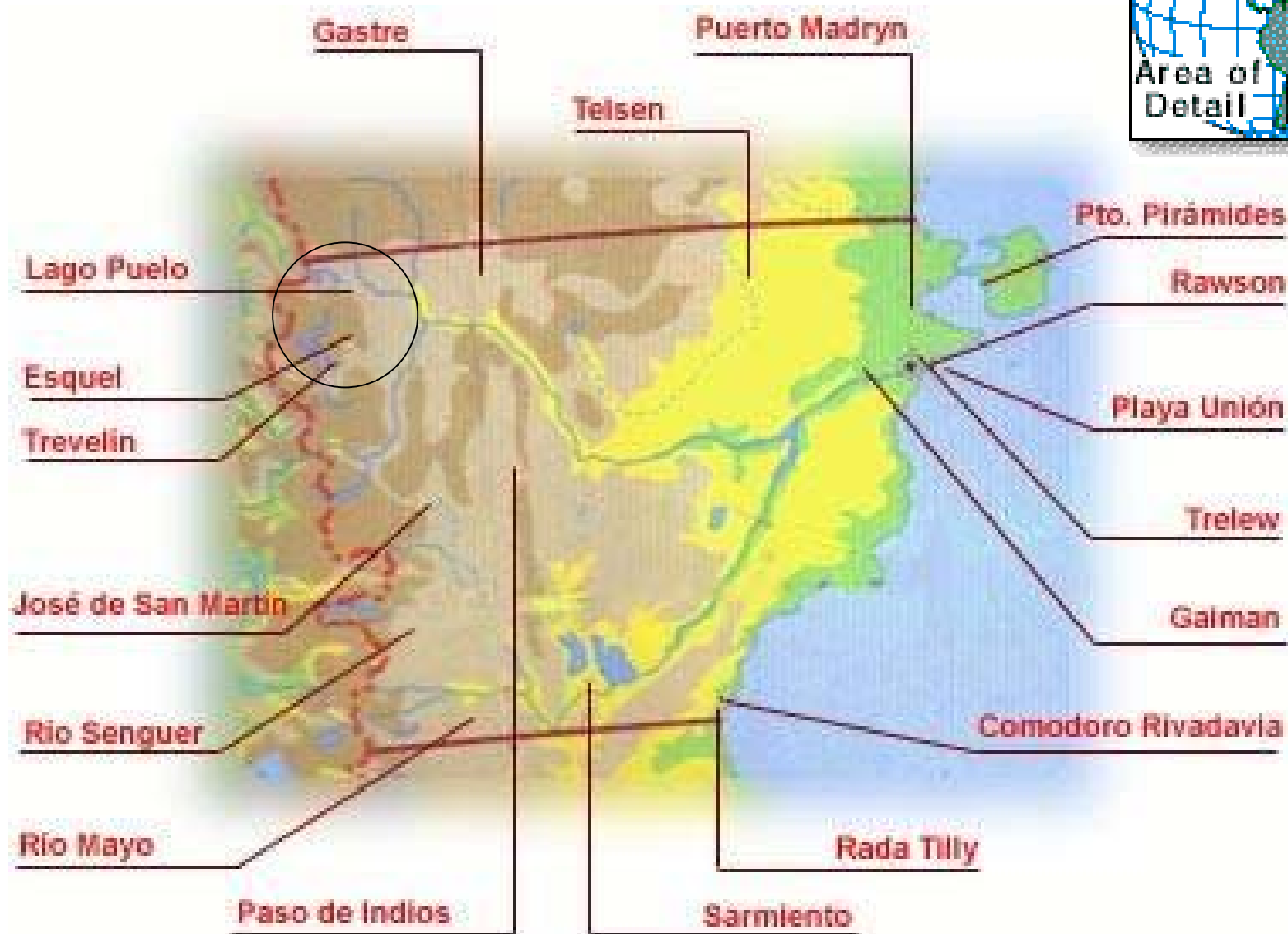
## **Objectives**

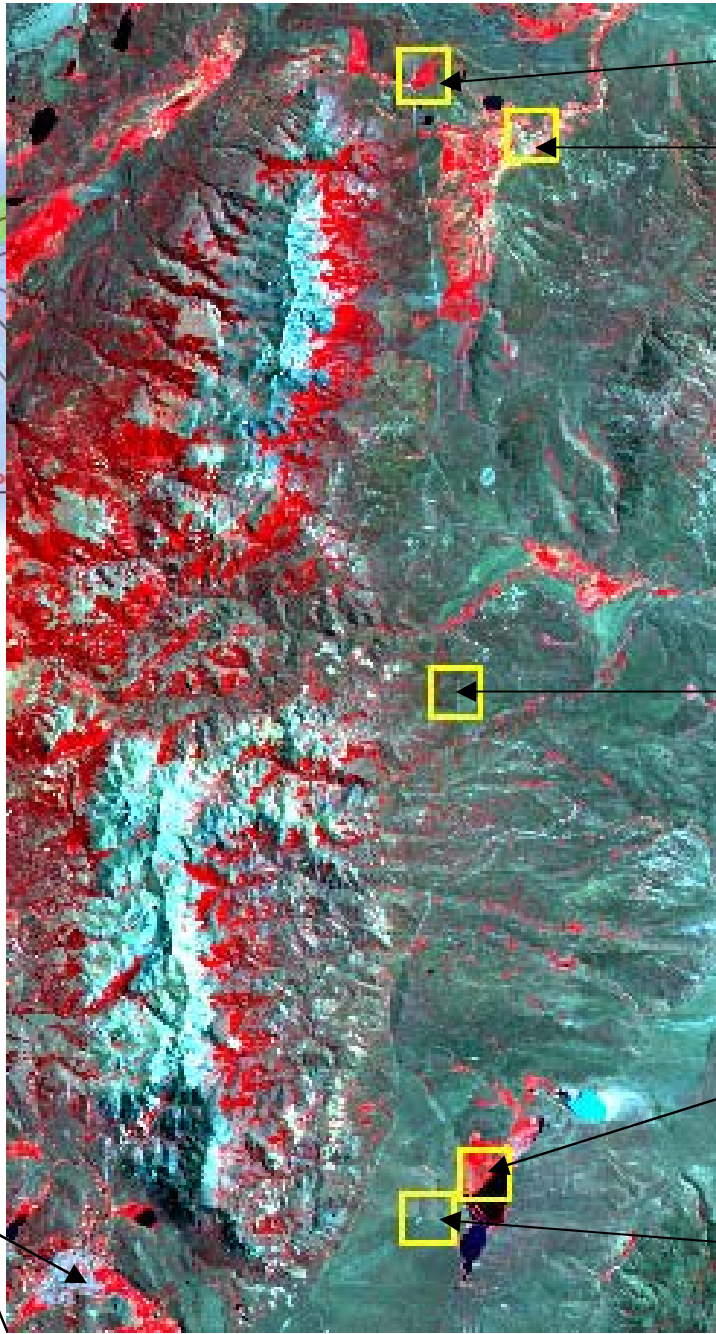
- **Assess the data continuity of a new satellite sensor (EO-1 ALI) with the conventional Landsat7 ETM+ sensor for naturally vegetated sites.**
- **Begin investigation of remote sensing applications at "twin" grassland sites in southeastern Arizona and the Patagonian region of Argentina.**

# Locator Map of Study Area in Argentina



# Locator Map of Chubut Province





Invernada chica

Galpon

Nevado

Laguna esquel

Burned & Unburned

Esquel



Collecting ASD measurements at invariant object site



Collecting field measurements



Collecting field measurements

# Grassland Vegetation at Patagonia Sites



Laguna Esquel



Burned Laguna



Invernada Chica



Nevado

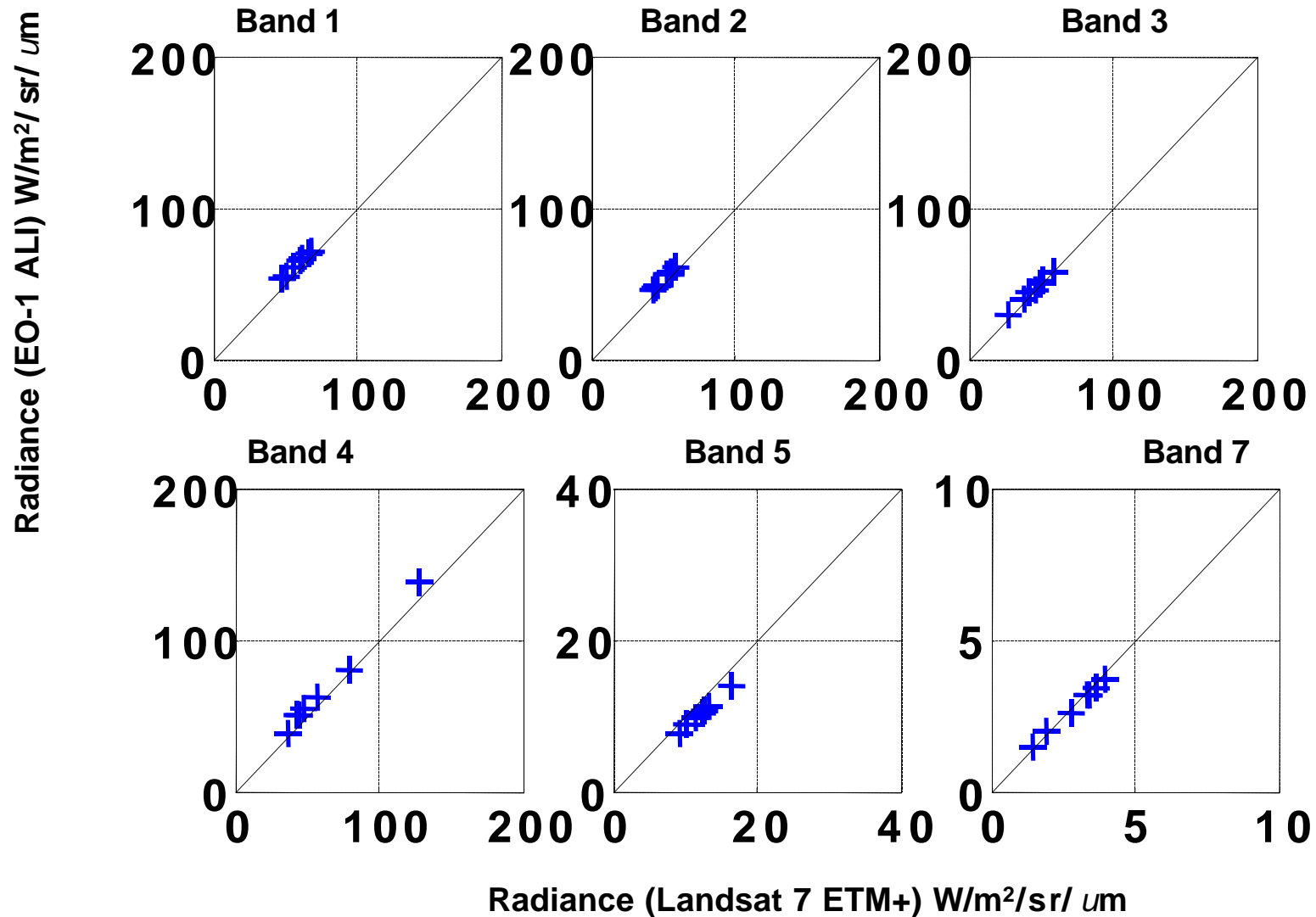


Unburned Laguna



Galpon de Esquila

# At Sensor radiances retrieved from Landsat 7 ETM+ and EO-1 ALI, by band.



## USA DATA 2001

Band	Slope	Offset
1	0.911	5.528
2	0.912	4.655
3	0.901	4.209
4	1.090	-1.875
5	0.928	0.922
7	0.904	0.282

**x= ETM+ at sensor radiance**  
**y= ALI at sensor radiance**

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## ARGENTINA DATA Jan 2002

Band	Slope	Offset
1	0.931	7.92
2	0.909	6.58
3	0.901	4.96
4	1.055	1.883
5	0.848	-0.077
7	0.861	0.235

**x= ETM+ at sensor radiance**  
**y= ALI at sensor radiance**

**Root mean squared error  $RMSE_s$  radiance for Landsat 7  
ETM+ and radiance for EO-1 ALI.**

**USA DATA 2001**

<b>Sensor</b>	<b>Units</b>	<b>Band 1</b>	<b>Band 2</b>	<b>Band 3</b>	<b>Band 4</b>	<b>Band 5</b>	<b>Band 7</b>
ALI-ETM+	$W/m^2/sr/um$	2.02	2.58	4.02	8.52	0.67	0.25
ALI-ETM+	As a percent of average radiance	3.0%	4.1%	7.2%	7.6%	4.2%	7.1%

**ARGENTINA**

<b>Sensor</b>	<b>Units</b>	<b>Band 1</b>	<b>Band 2</b>	<b>Band 3</b>	<b>Band 4</b>	<b>Band 5</b>	<b>Band 7</b>
ALI-ETM+	$W/m^2/sr/um$	3.87	2.11	1.25	6.1	1.98	0.28
ALI-ETM+	As a percent of average radiance	6.4%	4.1%	2.8%	9.4%	17.5%	7.6%

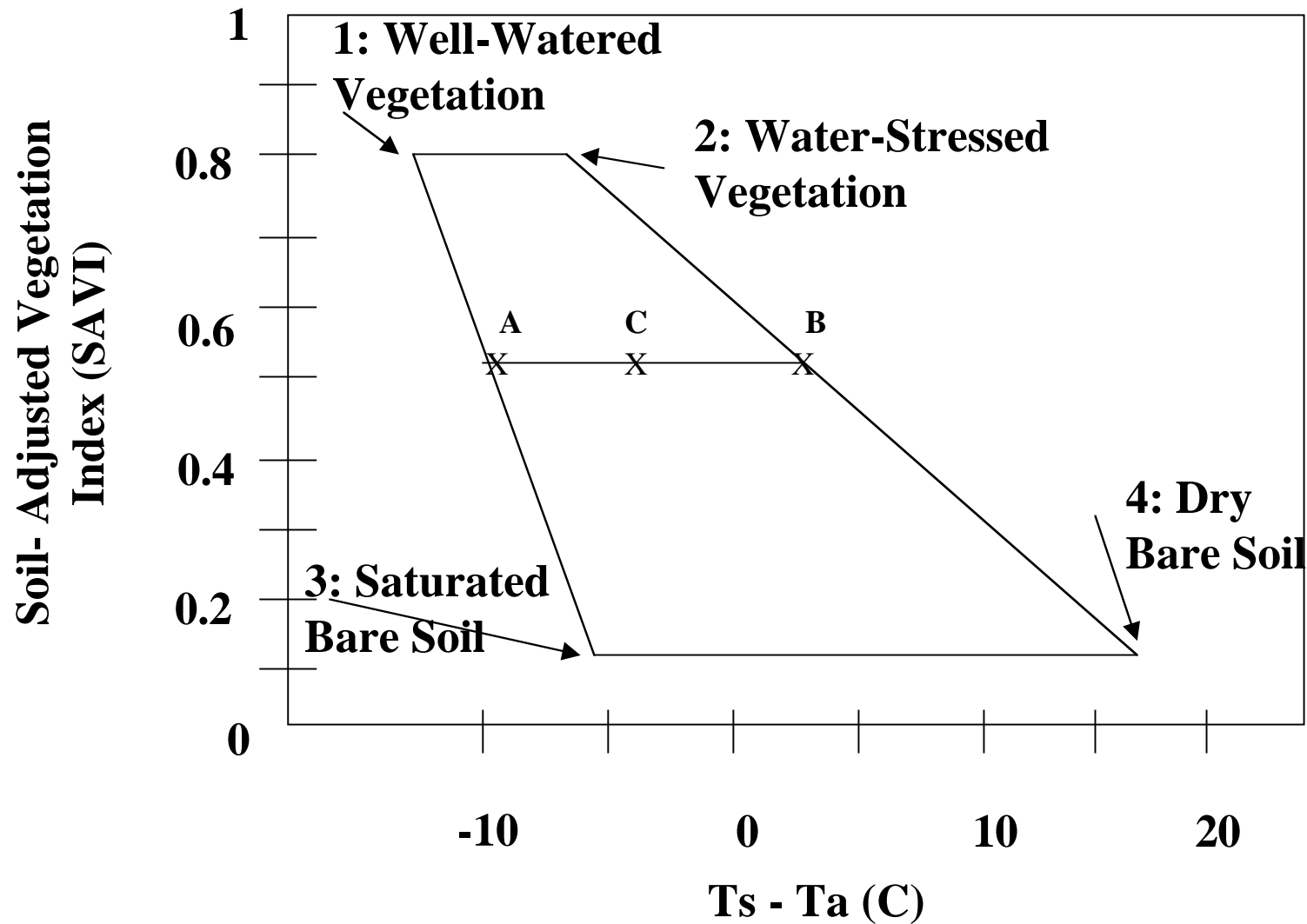
**An example of research  
using more than one  
Landsat sensor**

**CO<sub>2</sub> study by  
Chandra Holifield**

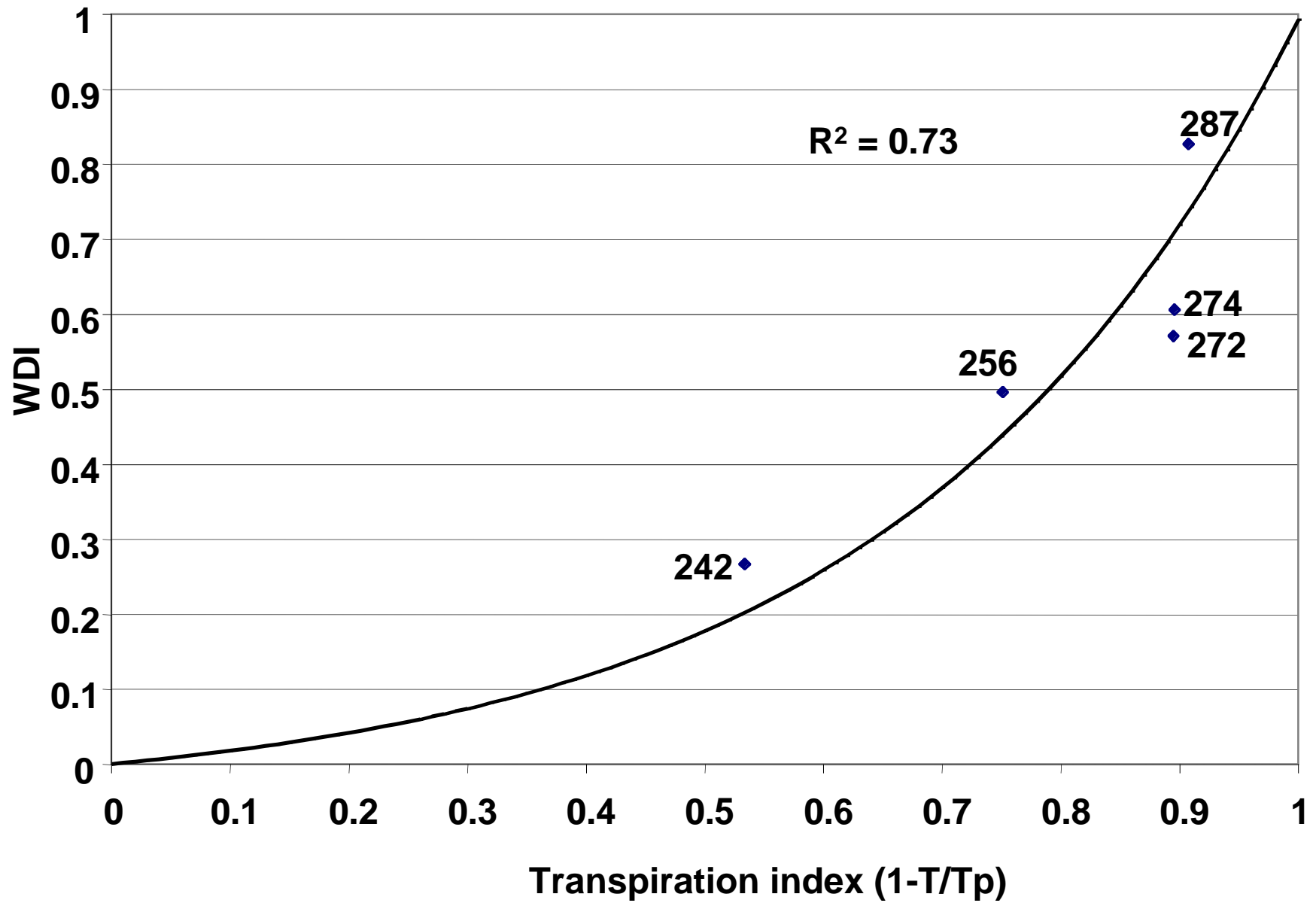
**Is it possible to derive a measurement of CO<sub>2</sub>  
flux from Landsat imagery?**

**Landsat images of the Walnut Gulch Experimental  
Watershed used for the study.**

<b>Landsat-5 TM</b>	<b>Landsat-7 ETM+</b>
<b>Oct. 14, 1997</b>	<b>Sept. 12, 2000</b>
<b>Aug. 30, 1998</b>	<b>Sept. 28, 2000</b>
<b>Oct. 1, 1998</b>	



The hypothetical trapezoidal shape that would result from the relation between surface minus air temperature and the Soil Adjusted Vegetation Index (ranging from ~ 0.1 for bare soil and ~ 0.8 for full-cover vegetation). The Water Deficit Index (WDI) is equal to the ratio of AC/AB.

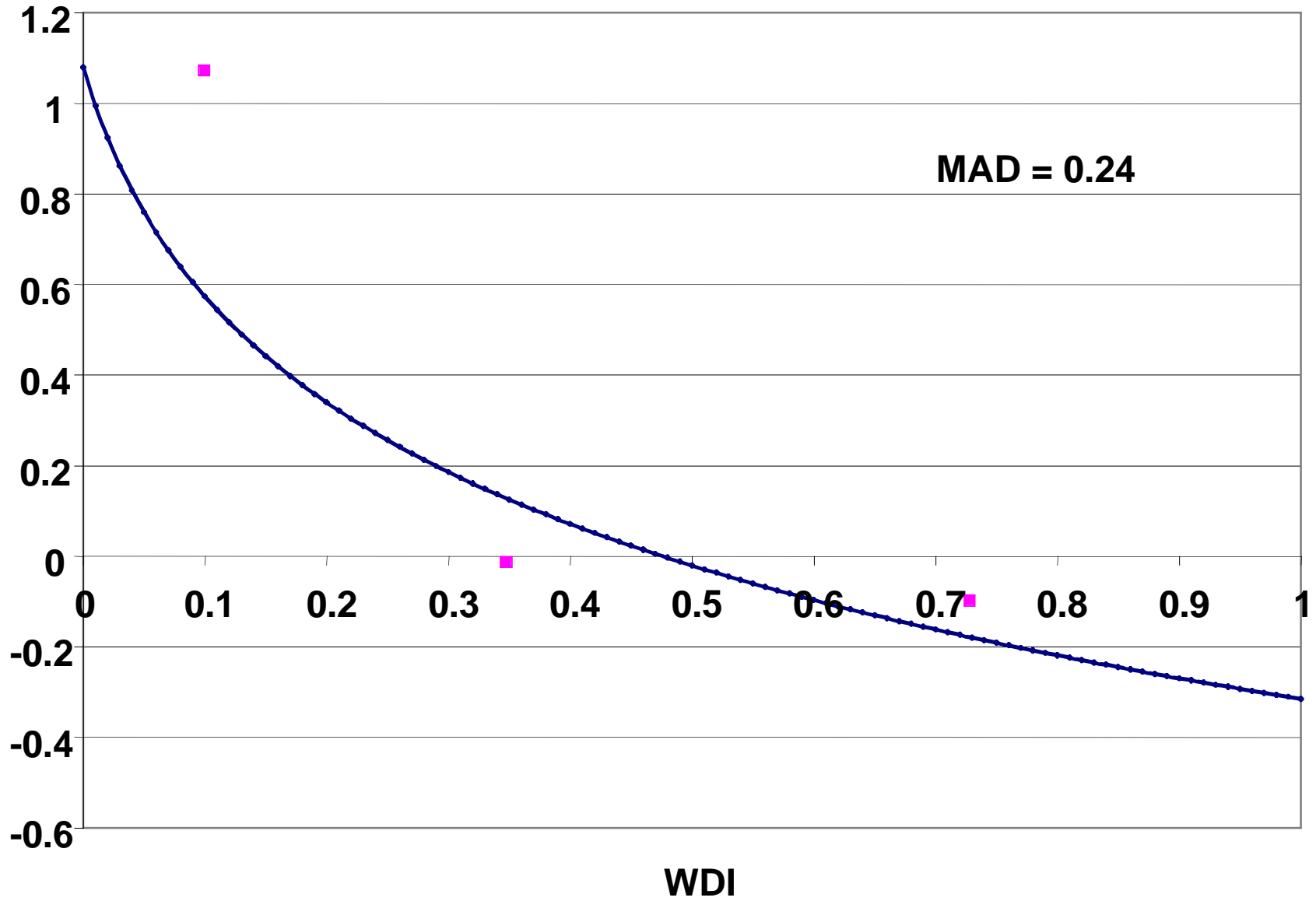




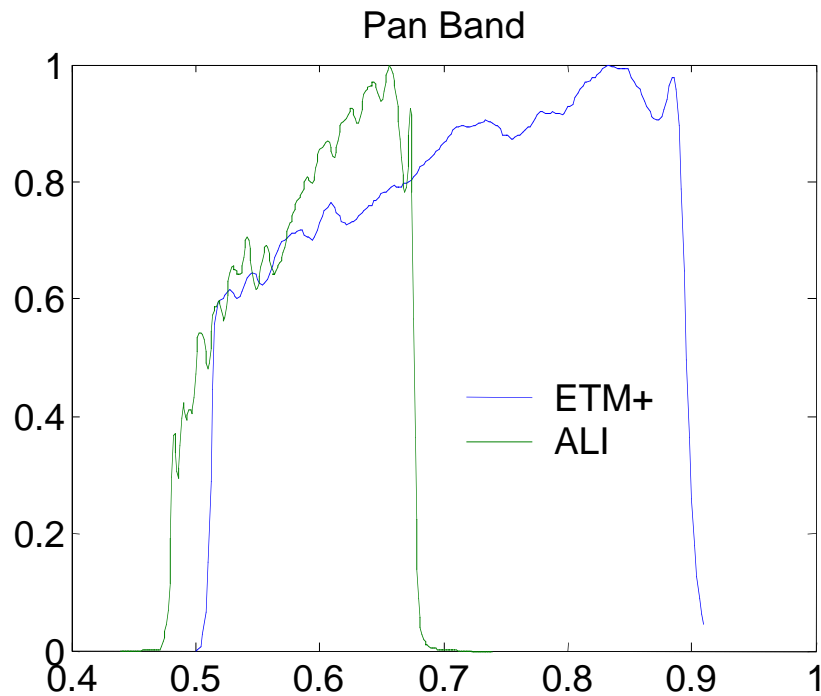
net CO<sub>2</sub> plant uptake

CO<sub>2</sub> (mg/m<sup>2</sup>/s) flux

net CO<sub>2</sub> loss from soil



# **Future Work**



## Compare ETM+ Pan band with ALI band

1. **Different response function**
2. **Higher resolution: 15m vs. 10m**
3. **Better quantization 8 bit vs. 12 bit**

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**Look at MODIS bands derived from Hyperion data to  
compare Normalized Difference Water Index (Gao, 1996)  
to WDI.**

$$\text{NDWI} = \frac{(\text{R857nm} - \text{R1241nm})}{(\text{R857nm} + \text{R1241nm})}$$

**MODIS NIR band 2 = 841 –876**

**MODIS NIR band 5 = 1230 - 1250**

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Questions?

Comments?

