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An Overview of the CBERS-2 satellite and comparison of the CBERS-2 CCD data with the L5 TM data

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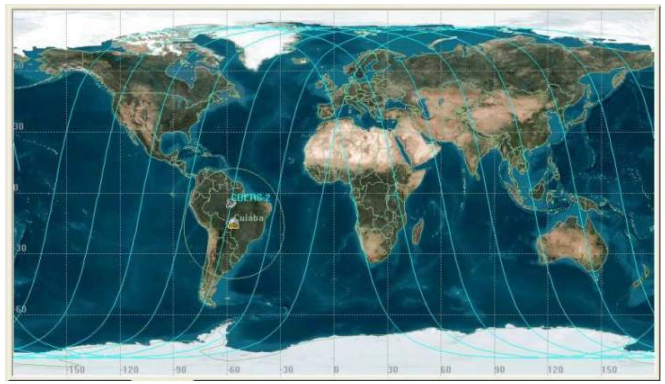
Outline

- Background
- Orbit and Payload
- Sensor Overview
- RSR Profiles comparison
- Data Products
- Conversion to Radiance
- Calibration based on image statistics
- References

CBERS:
China-Brazil Earth Resources Satellite

- **CBERS-1, was launched on Oct. 14, 1999**
  - The spacecraft was operational for almost 4 years
  - The CBERS-1 images were not used by user community
  - On Aug. 13, 2003, CBERS-1 experienced an X-band malfunction causing an end of all image data transmissions
- **CBERS-2 (or ZY-1B) was launched successfully on Oct. 21, 2003 from the Taiyuan Satellite Launch Center**
  - The spacecraft carries the identical payload as CBERS-1
- **CBERS Orbit**
  - Sun synchronous
  - Height: 778 km
  - Inclination: 98.48 degrees
  - Period: 100.26 min
  - Equator crossing time: 10:30 AM
  - Revisit: 26 days
  - Distance between adjacent tracks: 107 km



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CBERS- Sensor Compliment

- **CBERS satellite carries on-board a multi sensor payload with different spatial resolutions & collection frequencies**
  - HRCCD (High Resolution CCD Camera)
  - IRMSS (Infrared Multispectral Scanner)
  - WFI (Wide-Field Imager)
- **The CCD & the WFI camera operate in the VNIR regions, while the IRMSS operates in SWIR and thermal region**
- **In addition to the imaging payload, the satellite carries a Data Collection System (DCS) and Space Environment Monitor (SEM)**

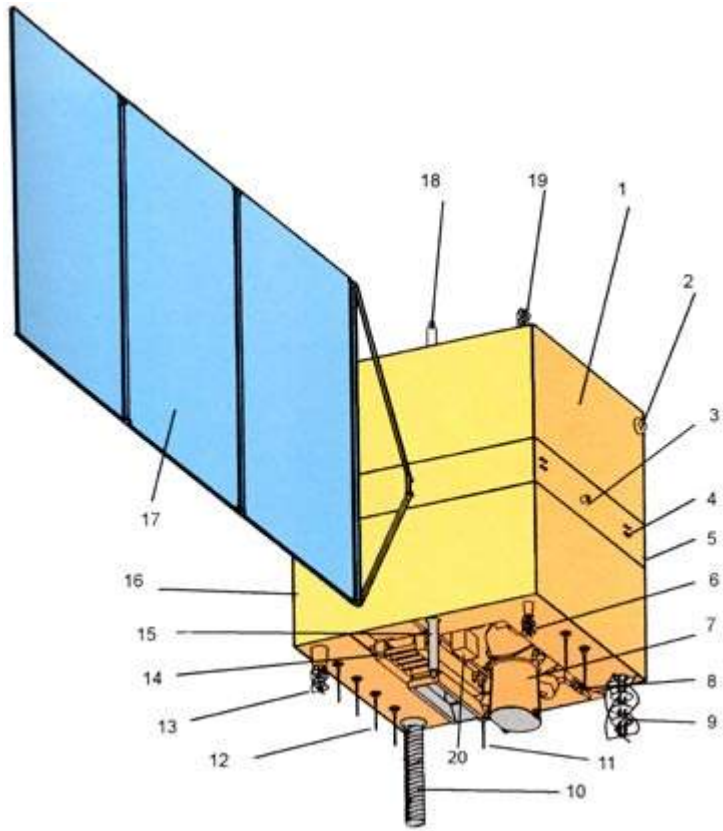
Work Share (70% China, 30% Brazil)

Pay load Module (16)

CCD (14)	China
IRMSS (7)	China
WFI (20)	Brasil
Data Transmission	China
Data collection	Brasil

Service Module (1)

Structure	Brasil
Thermal Control	China
Attitude and Orbit Control	China
Power supply	Brasil
On-board computer	China
Telemetry	Brasil



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High Resolution CCD (HRCCD)

- **The HRCCD is the highest-resolution sensor offering a GSD of 20m at nadir (Pushbroom scanner)**
- **Quantization: 8 bits**
- **Ground swath is 113 km with 26 days repeat cycle**
  - Steerable upto +/- 32^{o} across track to obtain stereoscopic imagery
- **Operates in five spectral bands - one pan & four VNIR**
  - CCD has one focal plane assembly
  - The signal acquisition system operates in two channels
    - Channel 1 has Bands 2, 3, 4
    - Channel 2 has Bands 1,3,5
    - Four possible gain settings are 0.59, **1.0**, 1.69 & 2.86

Infrared Multispectral Scanner (IRMSS)

- **The IRMSS is a moderate-resolution sensor offering a GSD of 80m (pan/SWIR) & 160m (thermal)**
- **Quantization: 8 bits**
- **Ground swath is 120 km with 26 days repeat cycle**
- **Operates in four spectral bands - one pan, two SWIR & one thermal**
  - The four spectral bands has eight detector staggered arrays mounted along track
  - IRMSS has three focal plane assemblies
    - The Pan band (Si photodiodes detectors) is located on the warm focal plane
    - The SWIR bands & the thermal band (HgCdTe detectors) are located on cold focal planes with cryogenic temps of 148K & 101K respectively
    - Four of eight thermal detectors are spare

IRMSS On-board Calibrator

- **The IRMSS incorporates an onboard radiometric calibration system**
- **Internal Calibrator (IC) and a Solar calibrator**
  - The IC includes cal lamp & blackbody that acquire real time cal data during the scan-turn around interval
    - During that time a rotating shutter is driven to prevent the Earth flux from being incident on the focal plane and the flux from calibration lamp and blackbody is reflected to the focal plane
    - The lamp calibrator has 4 operation states corresponding to different flux output (each state lasts about 16 seconds)
  - The solar calibrator is designed to provide cal reference with the Sun upon ground command
    - As the satellite passes over the north polar regions, the solar cal collects the solar flux & reflects it onto the Pan/SWIR band detectors
    - The solar calibration also provides a check on the stability of the on-board lamp calibration (It is performed once every 13 day)

Wide-Field Imager (WFI)

- **The WFI camera provides a synoptic view with spatial resolution of 260m**
- **Ground swath is 885km with 3-5 days repeat cycle**
- **Operates in two spectral bands – (Band 3 & 4)**
  - 0.63 - 0.69 µm (red) and 0.77 - 0.89 µm (infrared)
  - Similar bands are also present in the CCD camera providing complementary data

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Overview of the CBERS instruments

Parameter	HRCC	IRMSS	WFI
Spectral Bands (µm)	0.51 - 0.73 (PAN)	0.50 - 1.10 (PAN)	0.63 - 0.69
	0.45 - 0.52	1.55 - 1.75 (SWIR)	0.76 - 0.90
	0.52 - 0.59	2.08 - 2.35 (SWIR)	
	0.63 - 0.69	10.4 - 12.5 (TIR)	
	0.77 - 0.89		
Spatial Resolution	20 m	80 m (PAN & SWIR) 160 m (TIR)	260 m
Swath Width (FOV)	113 km (8.32°)	120 km (8.78°)	885 km (60°)
Temporal Resolution	26 days	26 days	3-5 days
Cross-Track Pointing	±32°		
Data Rate	2 x 53 Mbit/s	6.13 Mbit/s	1.1 Mbit/s
Carrier Frequency (X-band)	8.103 and 8.321 GHz	8.216 GHz	8.203 GHz
EIRP	43 dBm	39.2 dBm	31.8 dBm
Modulation	QPSK	BPSK	QPSK
Tracking Beam Frequency	8.196 GHz	8.196 GHz	8.196 GHz

Spectral Range (um) and Ground Sample Distance (m)							
	Landsat		CBERS			SPOT-4	IRS-P6
Band	L5 TM	L7 ETM+	HRCC	IRMSS	WFI		LISS-III
RC	16	16	26	26	5	26	24
1	0.450-0.520 (30)	0.450-0.515 (30)	0.45-0.52 (20)				
2	0.520-0.600 (30)	0.525-0.605 (30)	0.52-0.59 (20)			0.50-0.59 (20)	0.52-0.59 (23.5)
3	0.630-0.690 (30)	0.630-0.690 (30)	0.63-0.69 (20)		0.63-0.69 (260)	0.61-0.68 (20)	0.62-0.68 (23.5)
4	0.760-0.900 (30)	0.775-0.900 (30)	0.77-0.89 (20)		0.76-0.90 (260)	0.79-0.89 (20)	0.77-0.86 (23.5)
5	1.550-1.750 (30)	1.550-1.750 (30)		1.55-1.75 (80)		1.58-1.75 (20)	1.55-1.70 (23.5)
6	10.40-12.50 (120)	10.40-12.50 (60)		10.4-12.5 (160)			
7	2.080-2.350 (30)	2.090-2.350 (30)		2.08-2.35 (80)			
Pan		0.520-0.900 (15)	0.51-0.73 (20)	0.50-1.10 (80)		0.51-0.73 (10)	0.50-0.75 (5.8)

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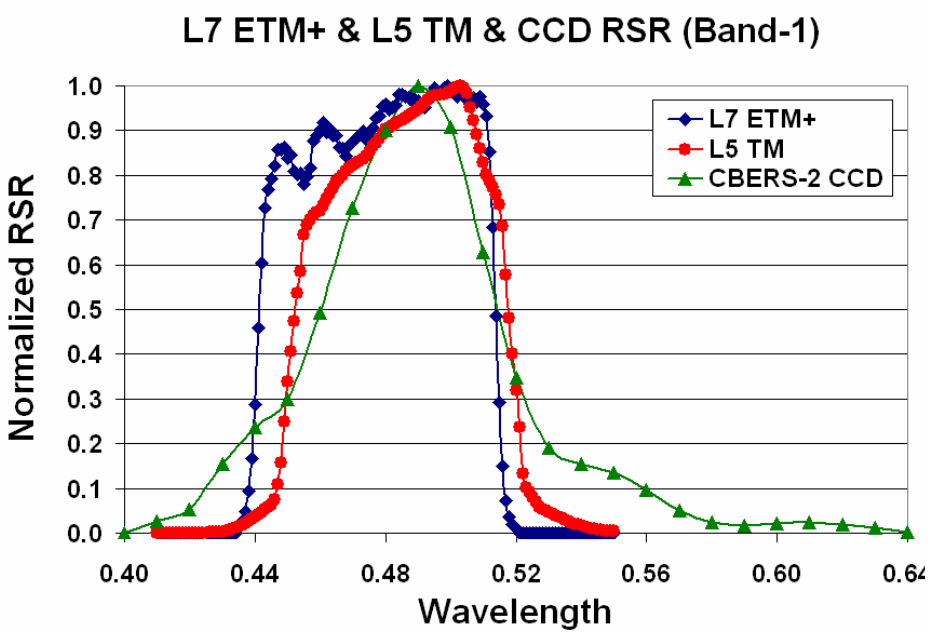
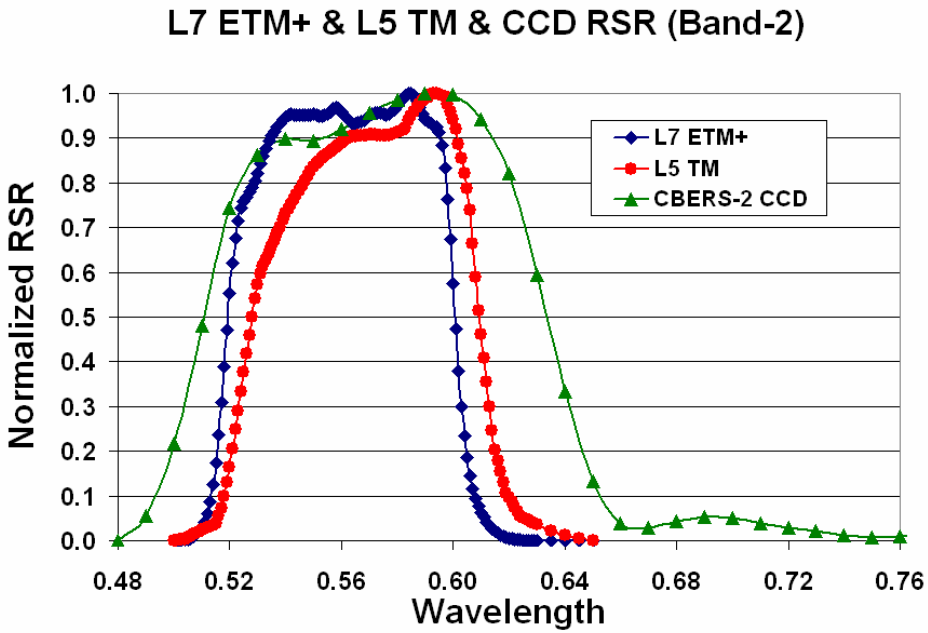
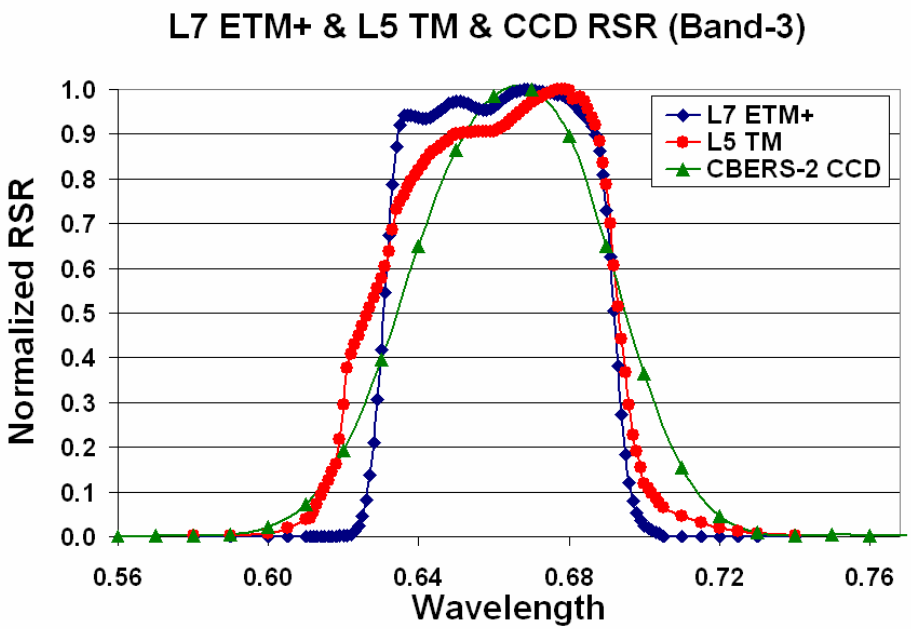
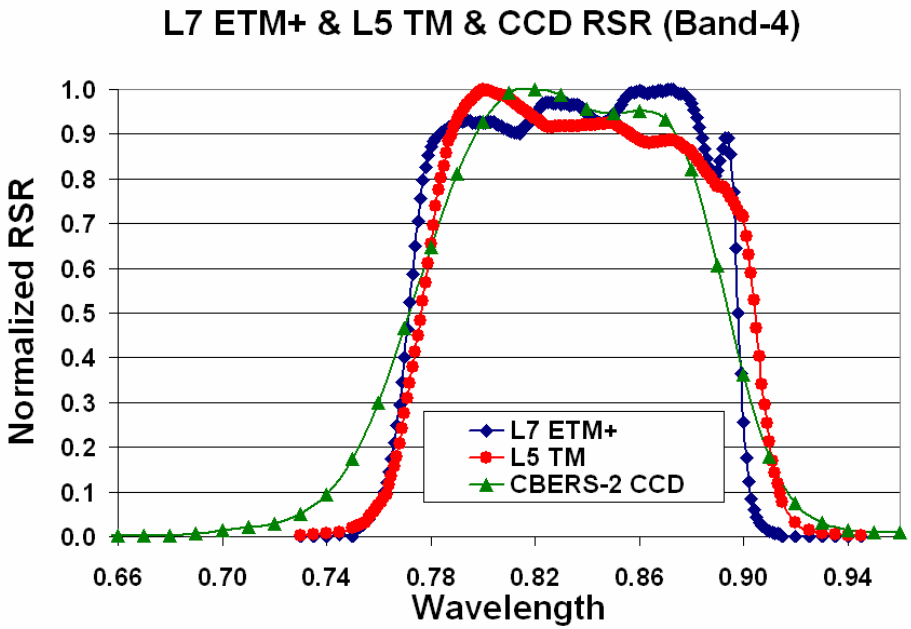
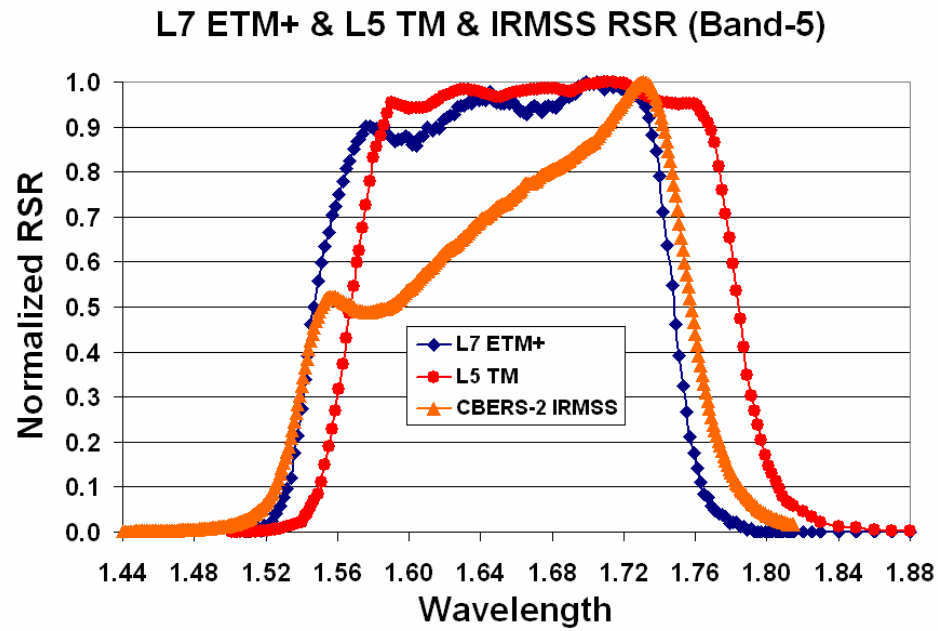
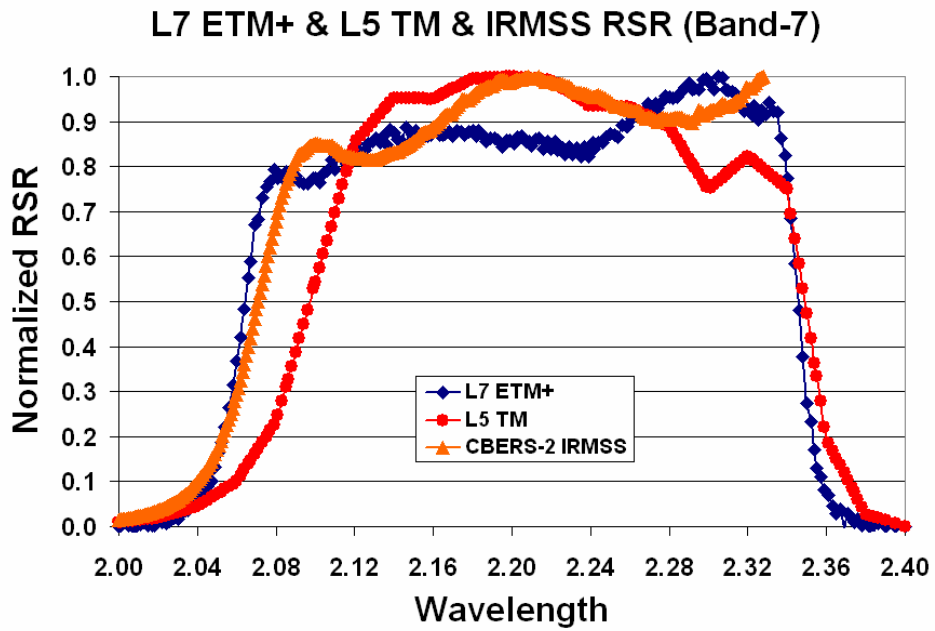

L7 ETM+ & L5 TM & CCD RSR (Band-1)
Normalized RSR
Wavelength
L7 ETM+
L5 TM
CBERS-2 CCD
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.40
0.44
0.48
0.52
0.56
0.60
0.64

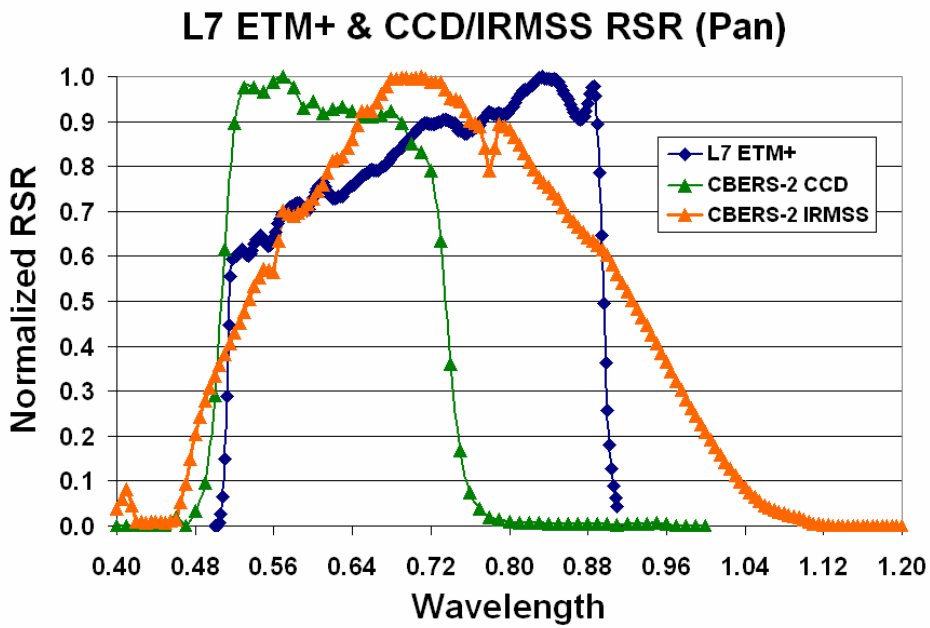

L7 ETM+ & L5 TM & CCD RSR (Band-2)
Normalized RSR
Wavelength
L7 ETM+
L5 TM
CBERS-2 CCD
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.48
0.52
0.56
0.60
0.64
0.68
0.72
0.76


L7 ETM+ & L5 TM & CCD RSR (Band-3)
Normalized RSR
Wavelength
L7 ETM+
L5 TM
CBERS-2 CCD
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.56
0.60
0.64
0.68
0.72
0.76

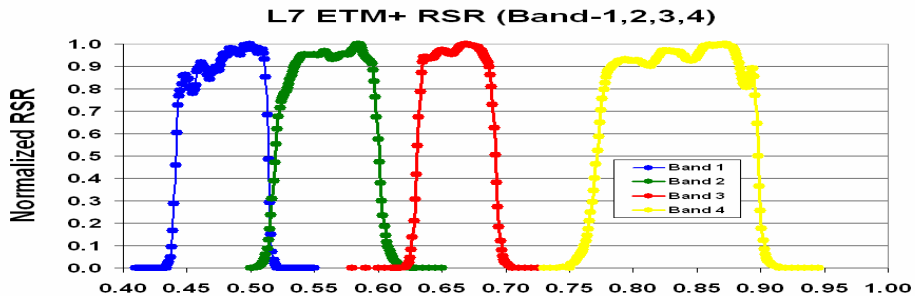

L7 ETM+ & L5 TM & CCD RSR (Band-4)
Normalized RSR
Wavelength
L7 ETM+
L5 TM
CBERS-2 CCD
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.66
0.70
0.74
0.78
0.82
0.86
0.90
0.94

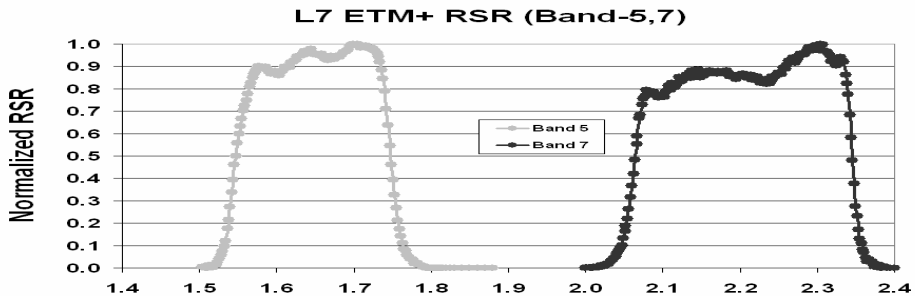

L7 ETM+ & L5 TM & IRMSS RSR (Band-5)
Normalized RSR
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.44 1.48 1.52 1.56 1.60 1.64 1.68 1.72 1.76 1.80 1.84 1.88
Wavelength
L7 ETM+
L5 TM
CBERS-2 IRMSS

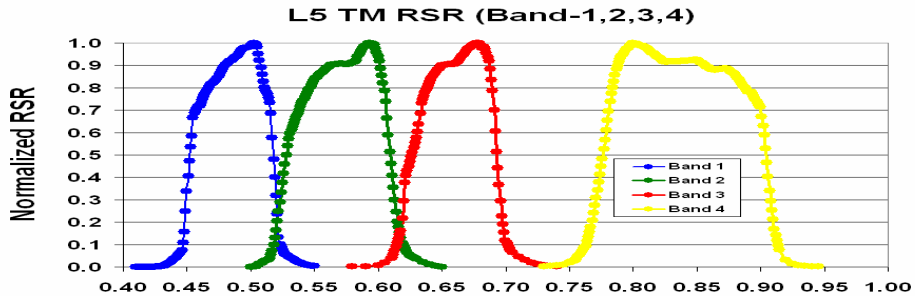

L7 ETM+ & L5 TM & IRMSS RSR (Band-7)
Normalized RSR
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2.00 2.04 2.08 2.12 2.16 2.20 2.24 2.28 2.32 2.36 2.40
Wavelength
L7 ETM+
L5 TM
CBERS-2 IRMSS

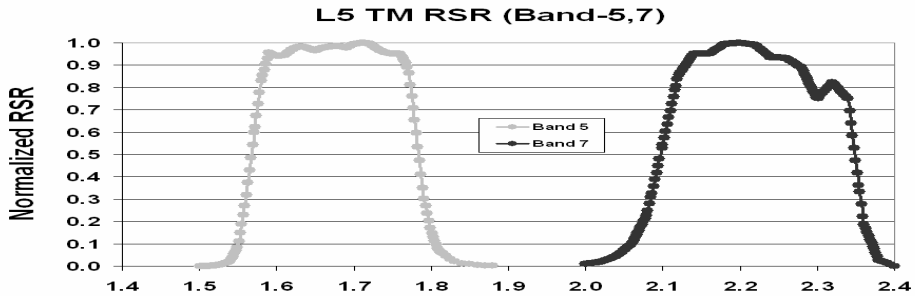

L7 ETM+ & CCD/IRMSS RSR (Pan)
Normalized RSR
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.40 0.48 0.56 0.64 0.72 0.80 0.88 0.96 1.04 1.12 1.20
Wavelength
L7 ETM+
CBERS-2 CCD
CBERS-2 IRMSS

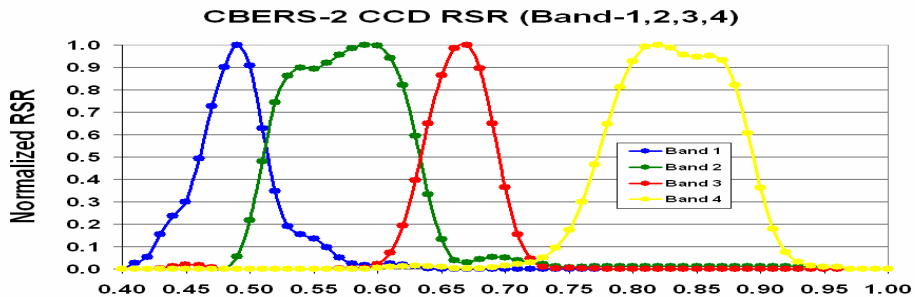
Relative Spectral Response (RSR) Profiles

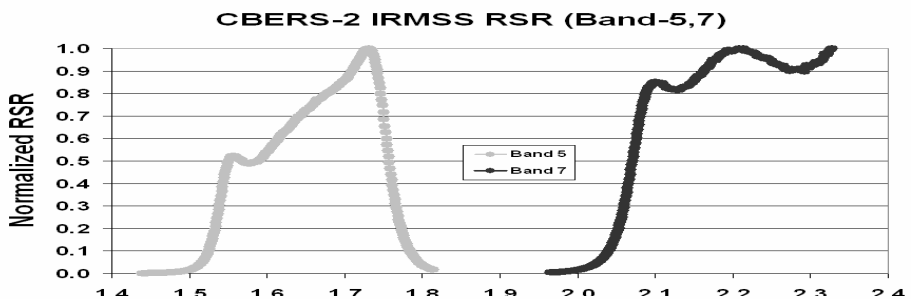


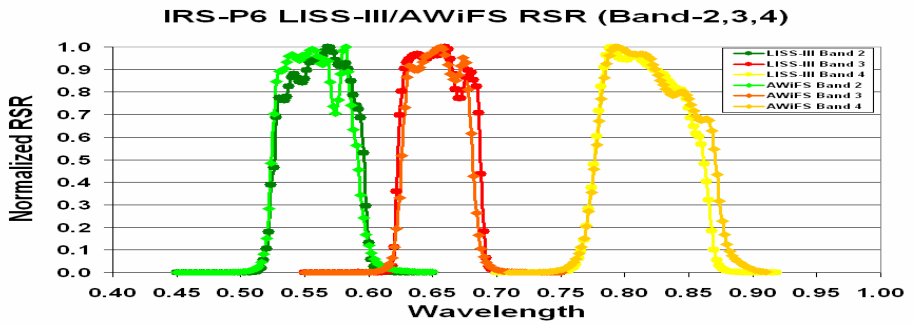


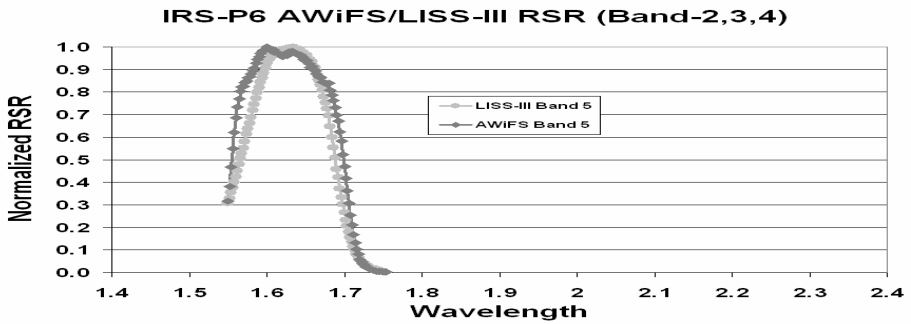












CBERS-2 Data Product Levels

Product Level	Product Level Explanation
Level 0	Not corrected raw data
Level 1	Radiometrically corrected and geometrically raw data
Level 2	Radiometrically and geometrically corrected using system model
Level 3	Radiometrically and geometrically corrected using Ground Control Points (GCPS)
Level 4	Radiometrically and geometrically corrected using GCPS and Digital terrain Model (DTM) for terrain
Level 5	Deeply processed remote sensing thematic mapper and image
Output Media	4-mm tape, 8-mm tape, 9-track CCT, CD-ROW

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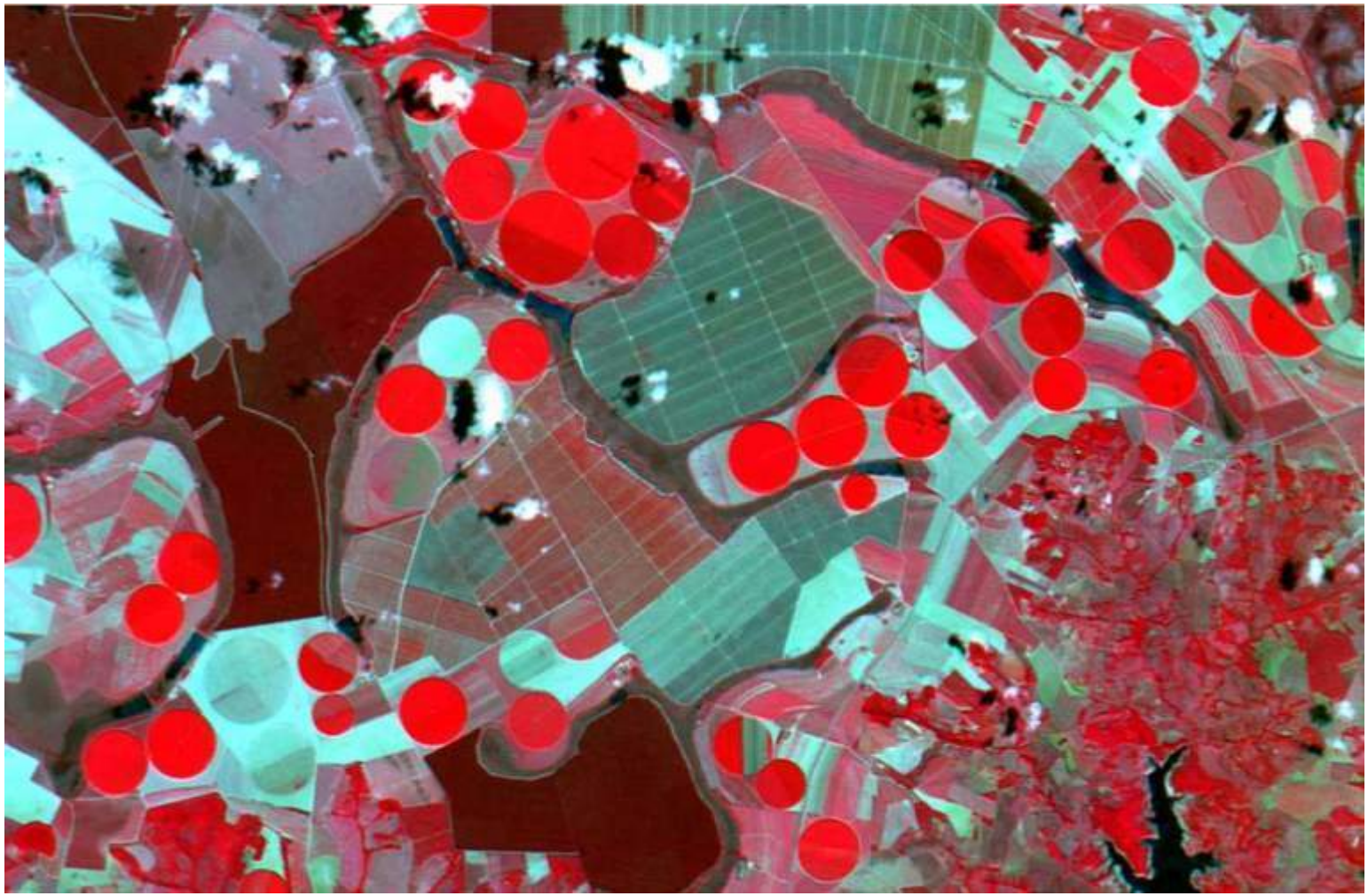
CBERS-2 CCD, Minas Gerais, Brazil

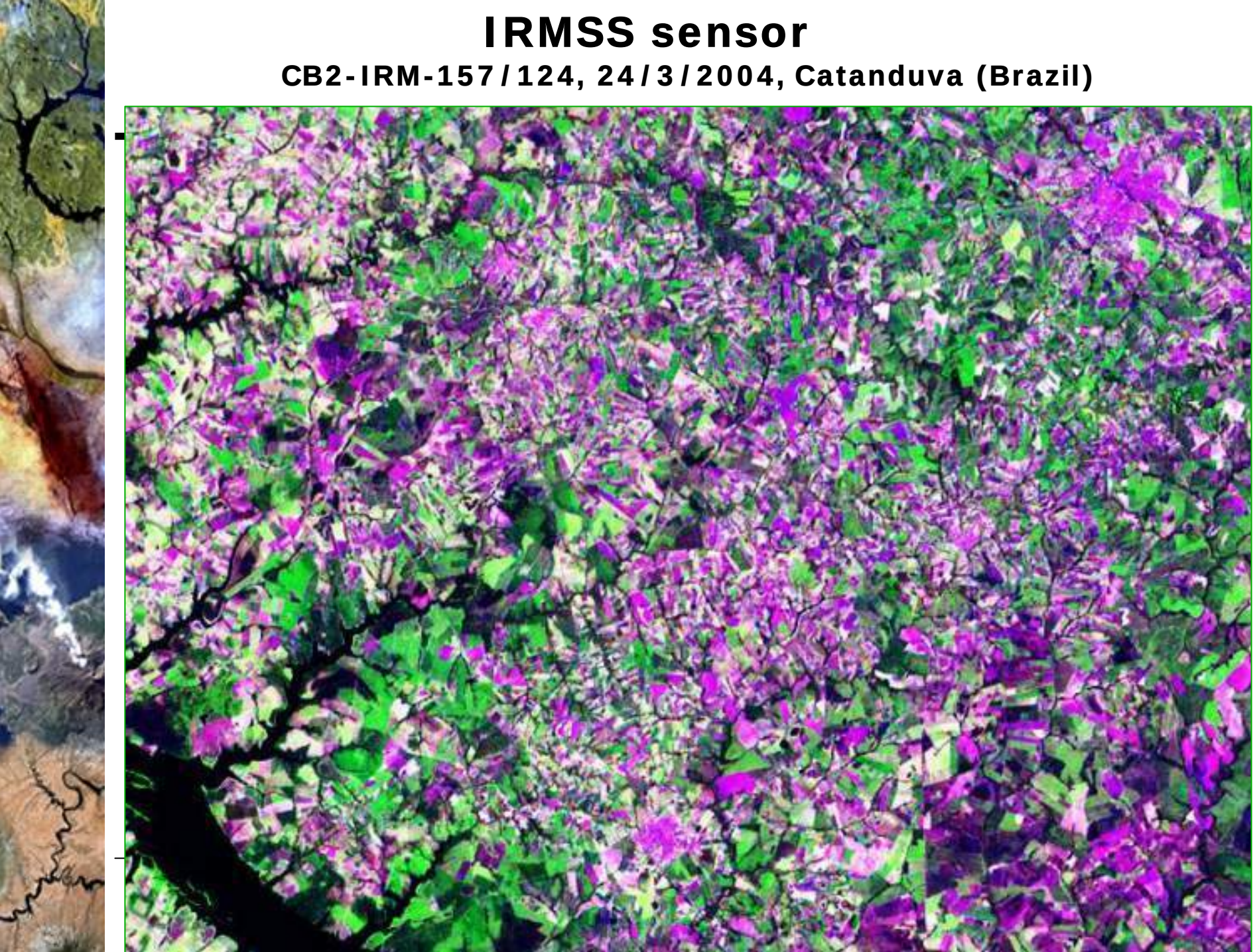


CBERS-2 CCD image, Louisiania

Obtained from on-board data recorder

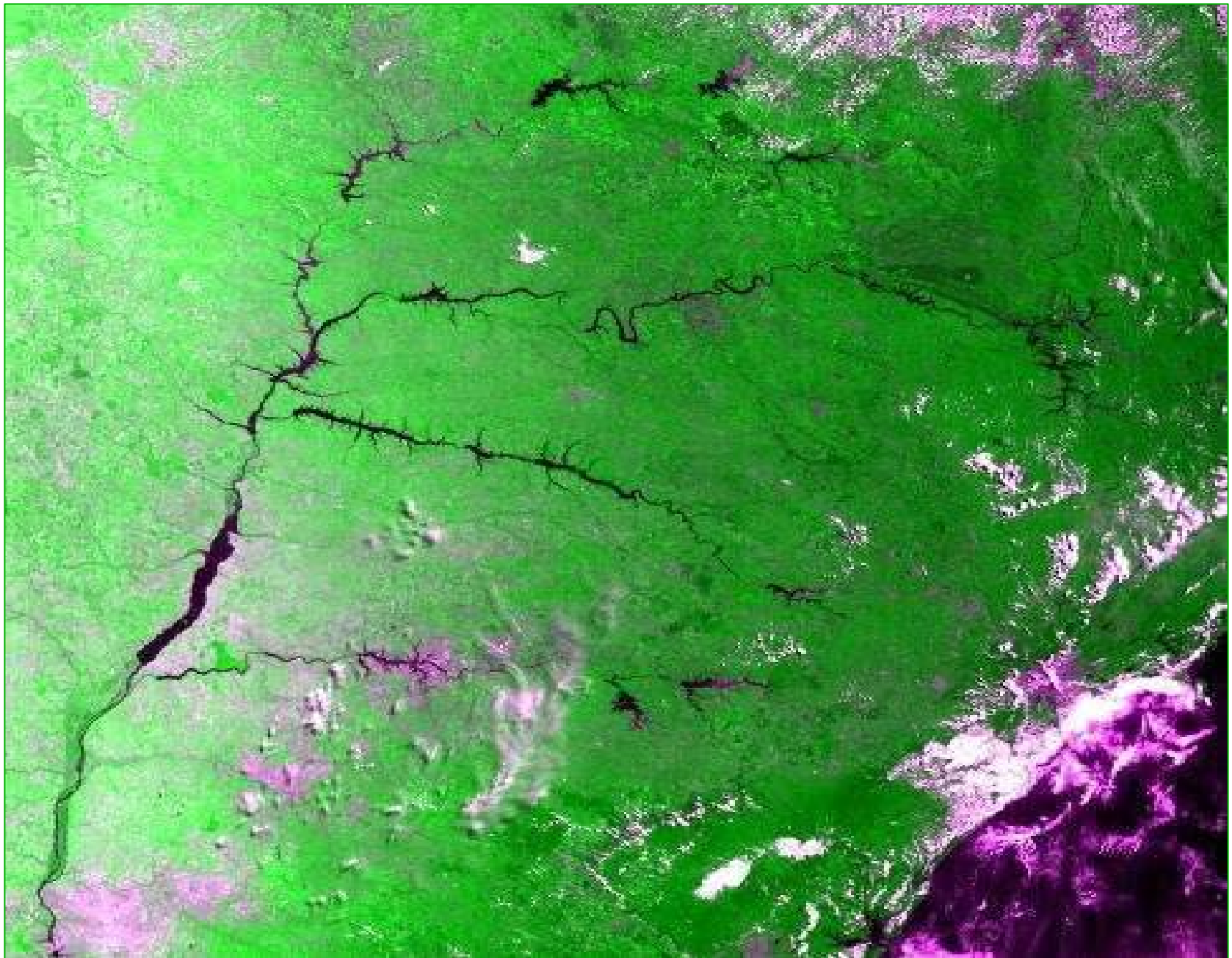
IRMSS sensor

CB2-IRM-157/124, 24/3/2004, Catanduva (Brazil)



WFI sensor

CBERS2-WFI – 157/124, 18/01/2004, São Paulo



HRCCD Detector Arrangment

- Focal plane has five spectral bands with three staggered CCD arrays, each with 2048 detectors
  - 2048 x 3 = 6144
- 14 pixels in the third array are not received by the station
  - 6144 – 14 = 6130
  - 6130 bytes are received in each line of the image
- There is a superposition region of 154 detectors
  - 154 x 2 = 308
- There is a dark current region of 8 detectors in each array
  - 8 pixels are dark (8 x 3 = 24)
- The final image contains 5798 pixels in a line
  - 6130-308-24=5798

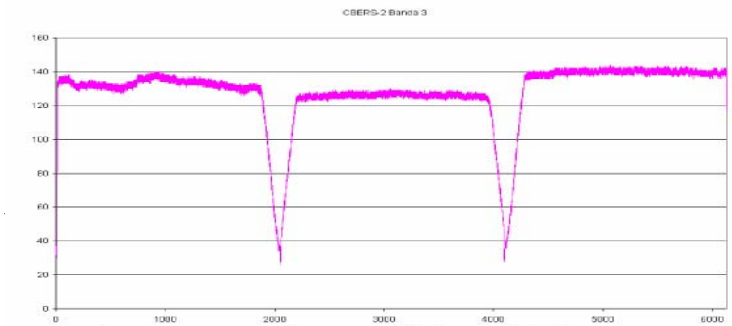
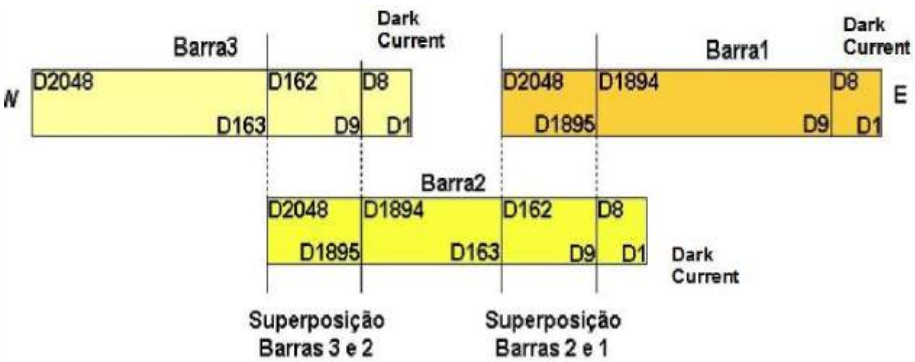
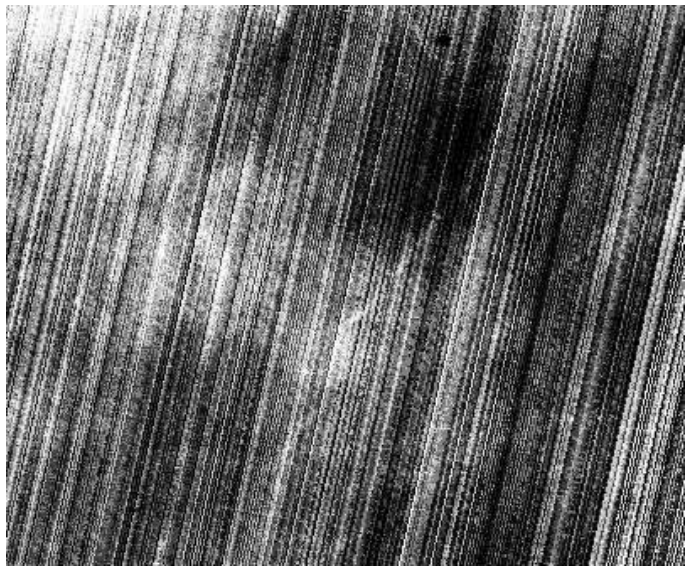


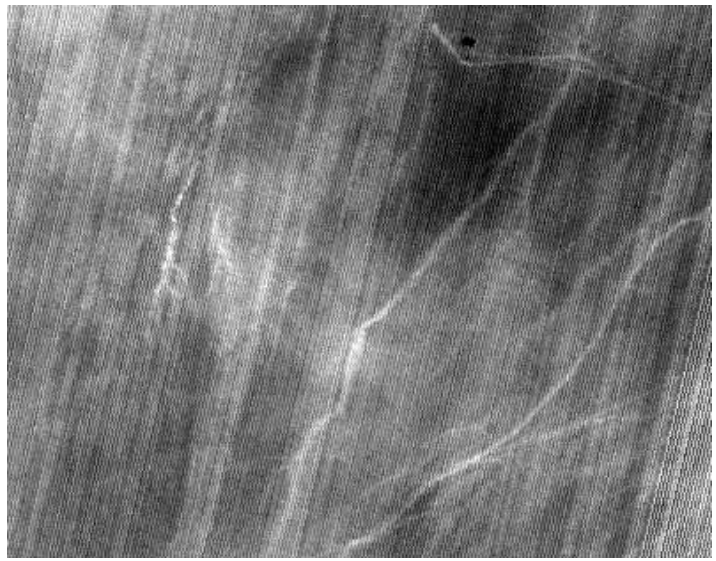
Figure 1.5.1 – CBERS2-CCD: Responses of the detectors in the three arrays.



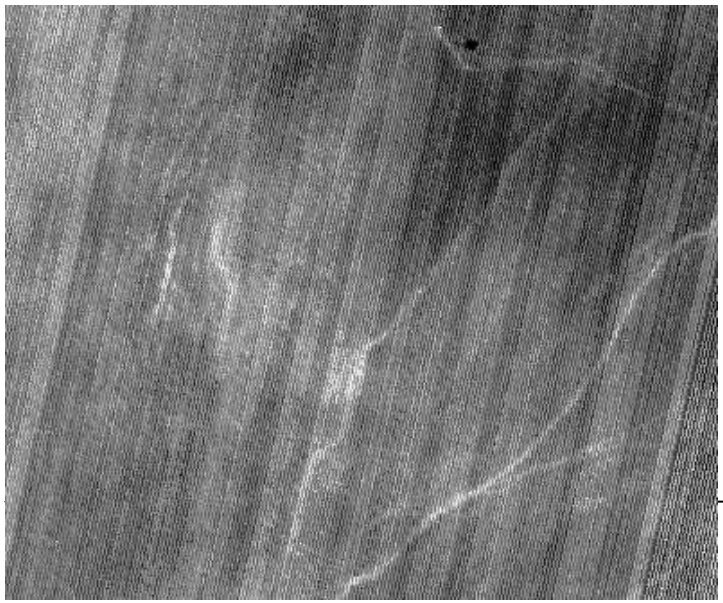
Striping in the CCD data



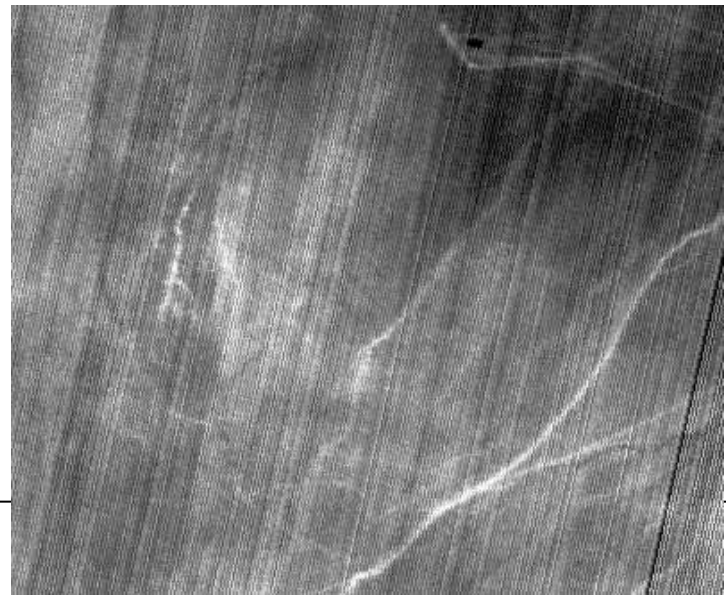
B1



B2

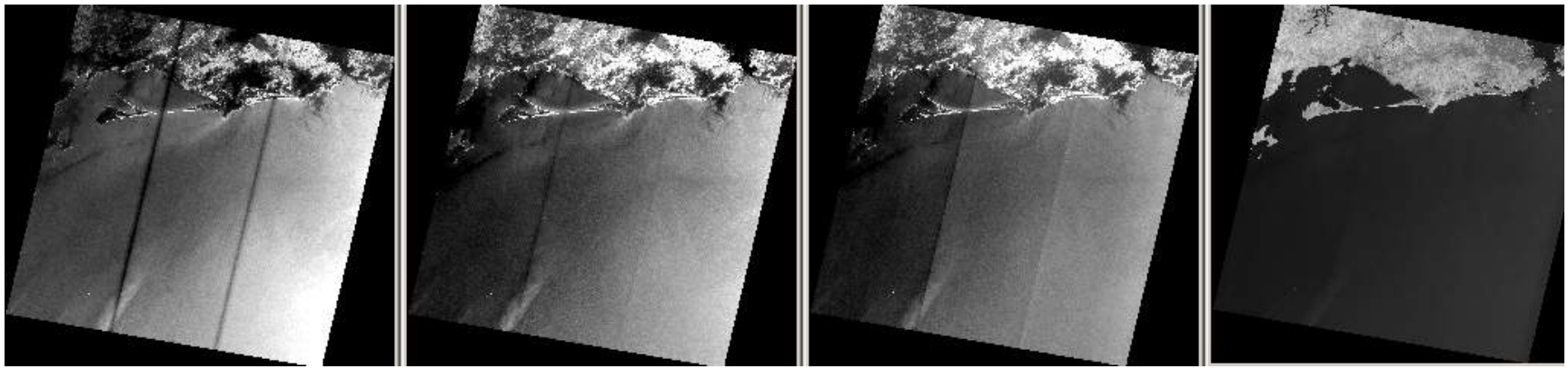


B3



B4

Black lines in the CCD INPE data



Band 1 | Band 2 | Band 3 | Band 4

- **CBERS-2 images processed from INPE have black lines**
  - The problem is worse in B1 and B3, sometimes in B2
  - INPE has tried several relative calibration tables to avoid these black lines, in some cases they disappear completely!
- **CBERS-2 images from CRESDA do not have black lines**
  - CRESDA uses scene dependent relative calibration techniques
  - They process the images one by one.
  - Each image (path/row) has its own relative calibration table

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Calibration issues with CCD camera

- **Spectral range for band 2 is broader than specs**
  - Specification = 0.52 – 0.59 um / Measurement = 0.515 – 0.635 um
    - Technical difficulties in meeting the project specification by CAST
  - The wider the spectral band the greater the radiance seen by detector
    - Decreases the instrument dynamic range in the spectral band
    - Thus, saturation is reached much lower than expected
- **Signal to Noise Ratio (SNR)**
  - Bands 1,3,4 has SNR 4 db, 2 db and 1 db lower than specifications
  - Max spectral radiance values for all bands are lower than specs
  - The random noise level measured was 2.7mV (equivalent to 0.7DN)
  - Therefore, saturation level is reached lower than expected
- **CCD images (band 4) has high saturation problem**
  - Due to high gain determined during prelaunch

Absolute Calibration Coefficients

- **Independent studies are carried out by INPE & CRESDA**
  - INPE used calibration sites in the west part of State Bahia
  - CRESDA used Gobi desert (Dunhuang) test site in China

L* = DNn / CCn

Where

L* = spectral radiance at the sensors aperture W/(m2.sr.um)

DN = Digital number extracted from the image in band n

CCn = absolute calibration coefficient for band n

CBERS-2 CCD Vicarious Absolute Calibration Coefficients (CCn)						
	Test-Site	**CCD_1**	**CCD_2**	**CCD_3**	**CCD_4**	**CCD_Pan**
Pre-launch		0.9800	1.5900	1.2000	2.2900	1.2500
Brazil						
25th June 2004	Bahia	1.228	2.357	1.215	2.553	1.628
16th August 2004		1.0090	1.9300	1.1540	2.1270	1.4830
Oct_3th New		0.862	1.544	0.874	1.933	0.995
Oct_3th Old		0.978	1.721	1.057	1.936	1.223
Oct_6th New		0.84	1.558	0.89	2.095	1.03
Oct_6th Old		0.97	1.74	1.083	2.105	1.263
China						
19th August 2004		0.9917	1.6761	1.0096	2.0613	
25th August 2004	Dunhuang	1.0292	1.7254	1.0356	2.1515	
24th August 2005	Dunhuang	1.0288	1.8096	1.1079	2.2783	

Radiance to TOA Reflectance

$$\rho_p = \frac{\Pi \bullet L_\lambda \bullet d^2}{ESUN_\lambda \bullet \cos\theta_s}$$

ESUN Units = W/(m^2.um) from INPE				
CCD_1	CCD_2	CCD_3	CCD_4	CCD_Pan
1934,03	1787,10	1548,97	1069,21	1664,33
IRMSS_1	IRMSS_2	IRMSS_3		
1347,75	222,32	83,46		
WFI_1	WFI_2			
1563,95	1068,25			

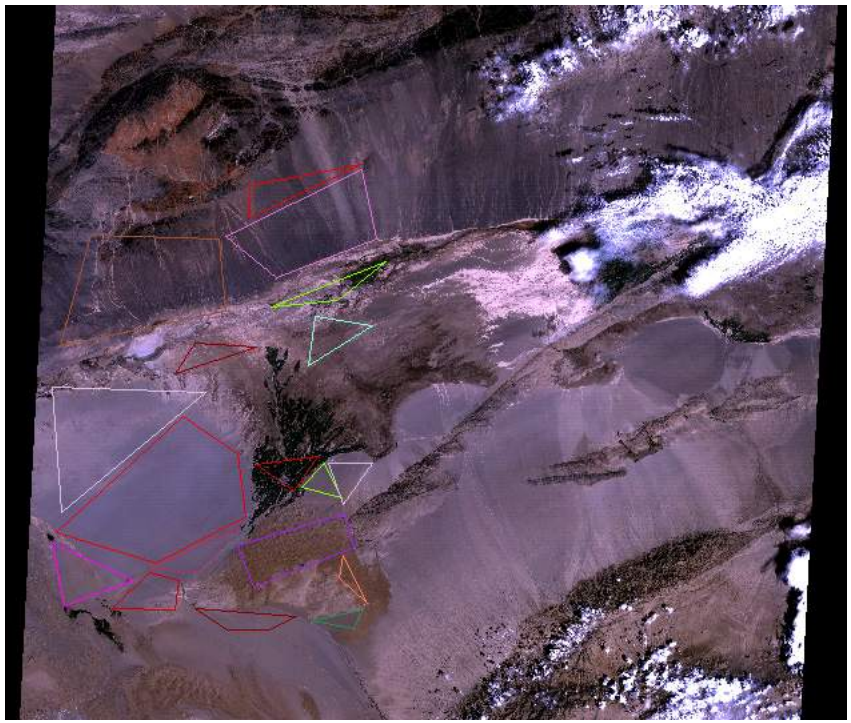
Solar Exoatmospheric Spectral Irradiances										
Units:	ESUN = W/(m^2.um)									
Model :	Neckel and Labs		Chance Spectrum CHKUR (MODTRAN 4.0)							
Band	L4 TM	L5 TM	L4 TM	L5 TM	L7 ETM+	E0-1 ALI	HRCCD	IRMSS	LISS-III	AWiFS
1	1958	1957	1957	1957	1969	1967.6	1928.18			
2	1828	1829	1825	1826	1840	1837.2	1799.51		1846.77	1849.82
3	1559	1557	1557	1554	1551	1551.47	1535.35		1575.5	1579.37
4	1045	1047	1033	1036	1044	1164.53	1053.38		1087.34	1075.11
5	219.1	219.3	214.9	215.0	225.7	230.03		220.11	270.66	254.24
7	74.57	74.52	80.72	80.67	82.07	79.61		83.3		
Pan					1368	1747.86				
1P						1851.8				
4P						957.46				
5P						451.37				

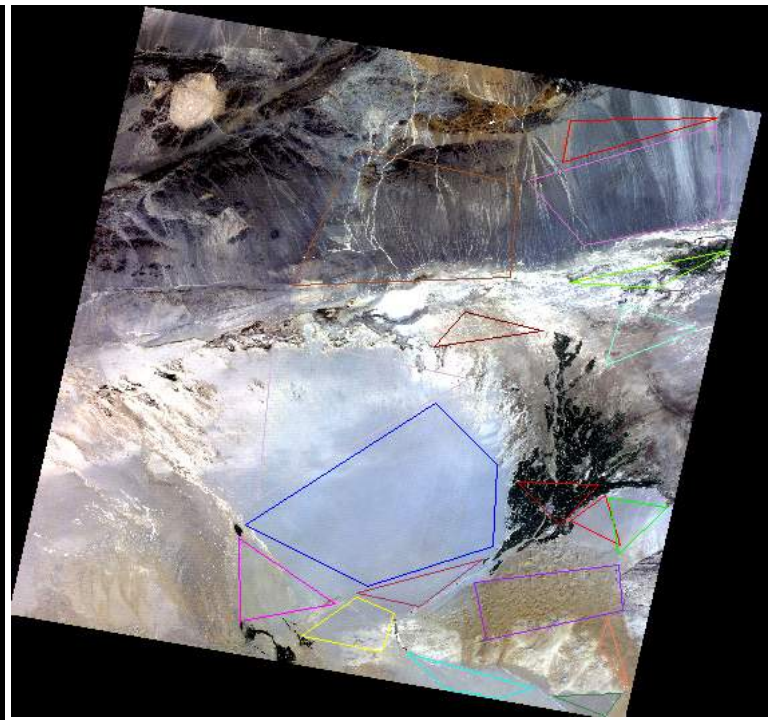
CBERS & Landsat coincident images

- It is very difficult to get image's from the two satellite at the same time
- CRESDA has collected a coincident image from L5 TM and CBERS-2 satellite on August 25, 2004 at the Gobi desert (Dunhuang) test site
  - Performed side-looking (off-nadir-look-angle=-6.0333) for CCD
  - No images from IRMSS (Nadir looking)
- Dunhuang test site is very big and homogenous. The atmosphere is mostly clear and the aerosol loading is typically low. It is a very well-characterized site, CRESDA has performed several field campaigns for various satellites (CBERS-1/2, SPOT, Landsat, a series of FY meteorological satellite etc.)
  - During the overpass, ground reflectance measurements were collected using ASD
  - A manual (CE317) photometer were used for tracking sun at regular intervals

Agency	Sensor	Date	DOY	Path	Row	Look angle	Sun Elevation	GMT
CRESDA	CBERS-2 CCD	8/25/2004	237	23	55	-6.03	56.60	
	L5 TM	8/25/2004	237	137	32	0.00	53.37	
INPE	CBERS-2 CCD	12/30/2004	365	154	126		64.23	13:14:15
	L5 TM	12/29/2004	364	219	76	0.00	59.32	12:50:15
INPE	CBERS-2 CCD	11/16/2005	320	151	126		66.47	12:58:05
	L5 TM	11/16/2005	320	217	76	0.00	63.03	12:40:25

L5 TM and CBERS-2 CCD Image Pairs





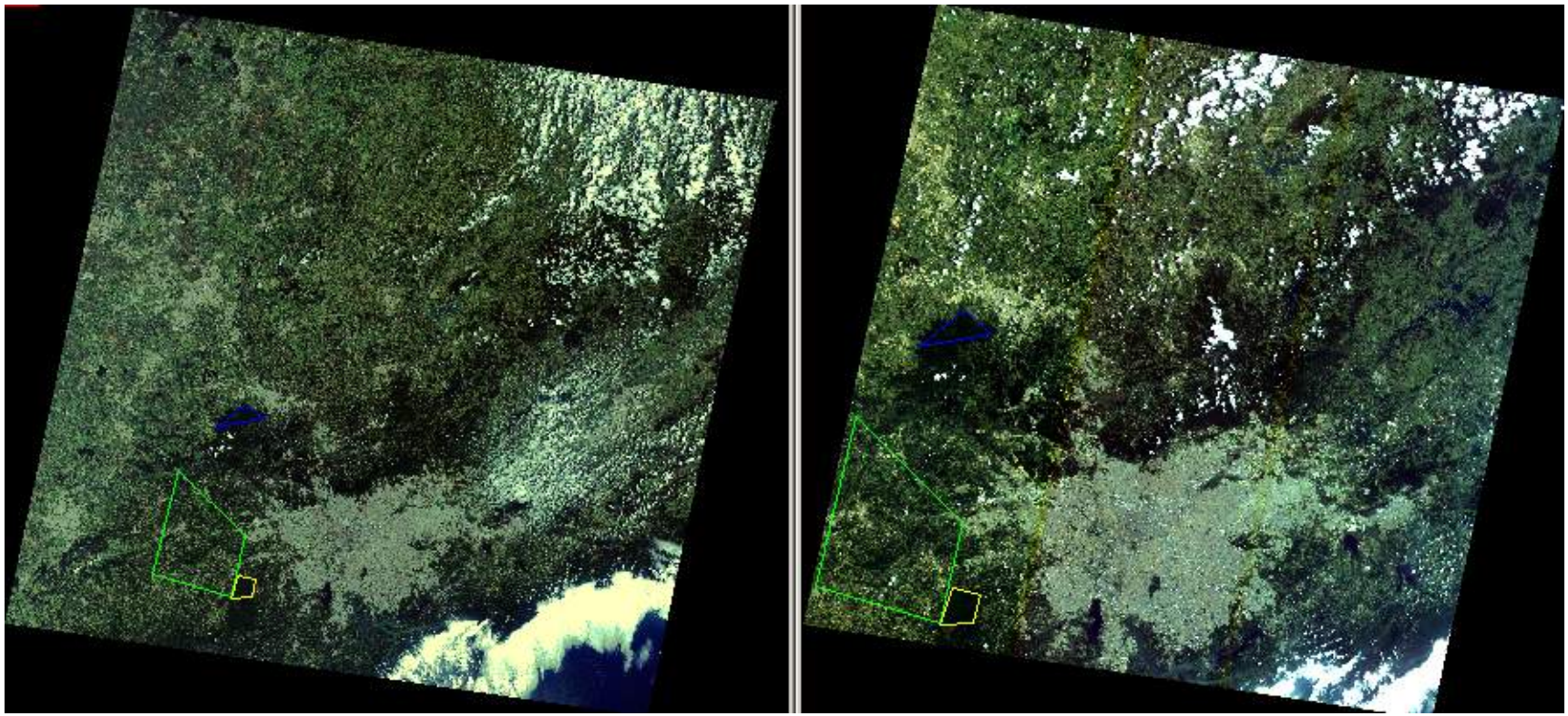
L5 TM
WRS Path = 137 Row = 032
Nadir looking

CBERS-2 CCD
Path = 23 Row = 55
side-looking (off-nadir-look-angle=-6.0333)

Gobi (Dunhuang) desert test site
Data acquired on Aug 25, 2004 (20 min apart)

USGS

L5 TM and CBERS-2 CCD Image Pairs

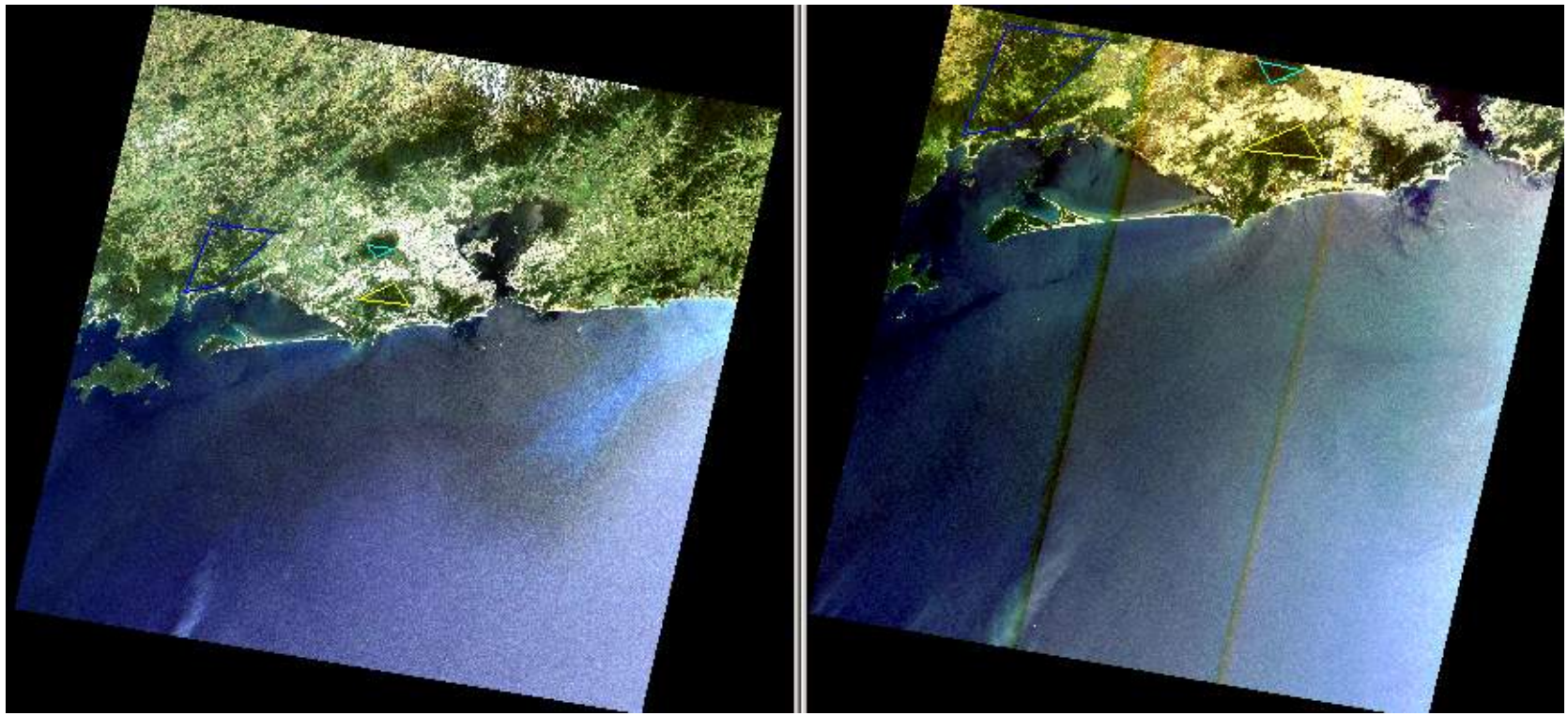


L5 TM
WRS Path = 219 Row = 076
Nadir looking
Acquisition Date: Dec 29, 2004

CBERS-2 CCD
Path = 154 Row = 126
Acquisition Date: Dec 30, 2004

USGS

L5 TM and CBERS-2 CCD Image Pairs

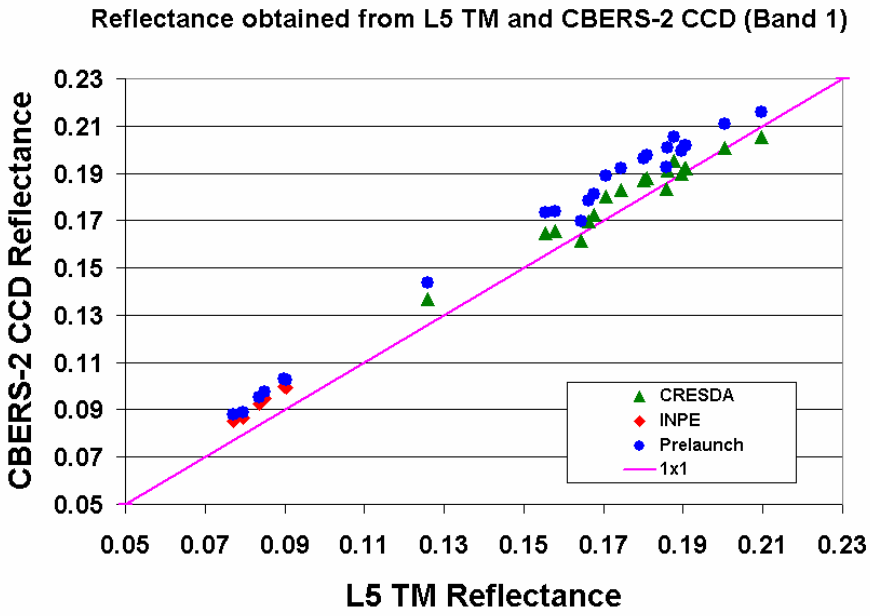


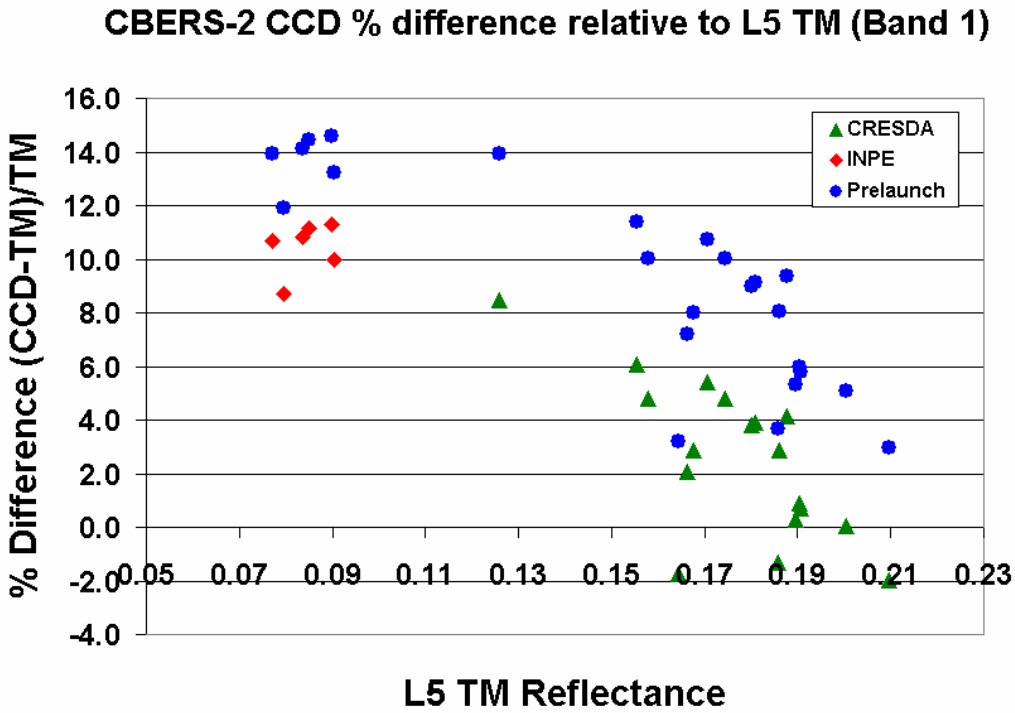
L5 TM
WRS Path = 217 Row = 076
Nadir looking
Acquisition Date: Nov 16, 2005

CBERS-2 CCD
Path = 151 Row = 126
Acquisition Date: Nov 16, 2005

USGS

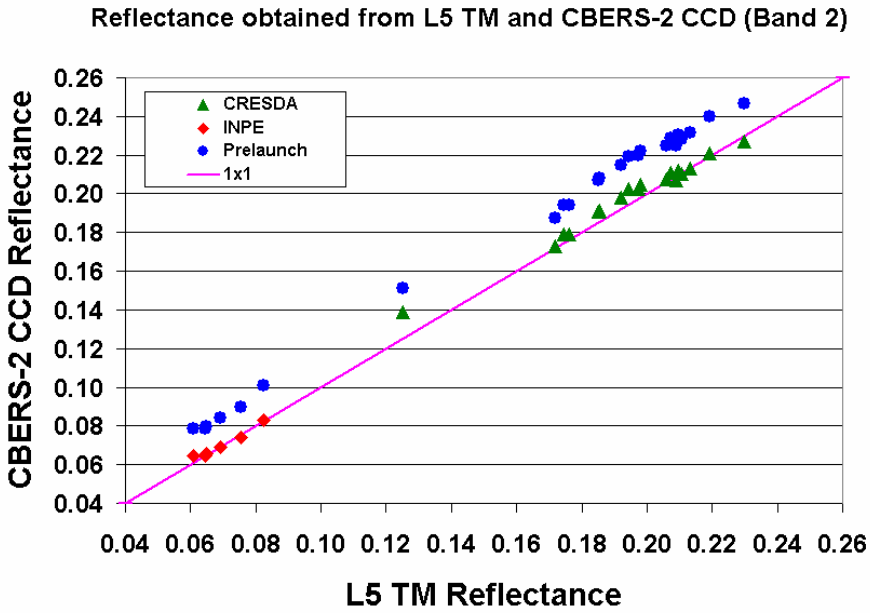
Band 1

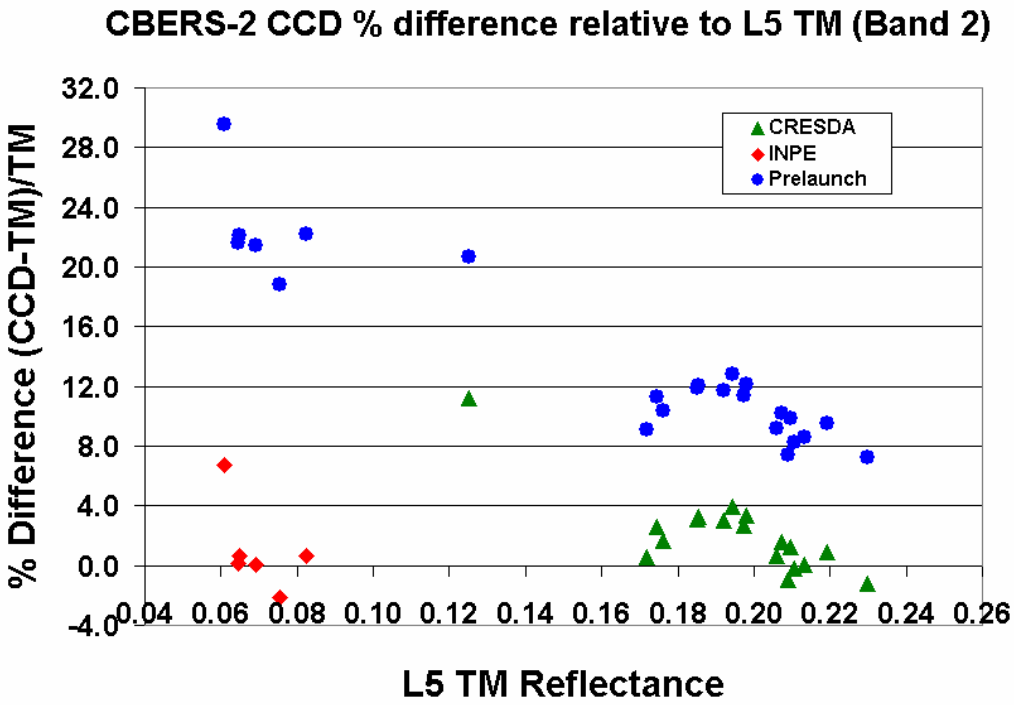

Reflectance obtained from L5 TM and CBERS-2 CCD (Band 1)
CBERS-2 CCD Reflectance
0.23
0.21
0.19
0.17
0.15
0.13
0.11
0.09
0.07
0.05
0.05 0.07 0.09 0.11 0.13 0.15 0.17 0.19 0.21 0.23
L5 TM Reflectance
CRESDA
INPE
Prelaunch
1x1


CBERS-2 CCD % difference relative to L5 TM (Band 1)
% Difference (CCD-TM)/TM
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
0.05 0.07 0.09 0.11 0.13 0.15 0.17 0.19 0.21 0.23
L5 TM Reflectance
CRESDA
INPE
Prelaunch

USGS

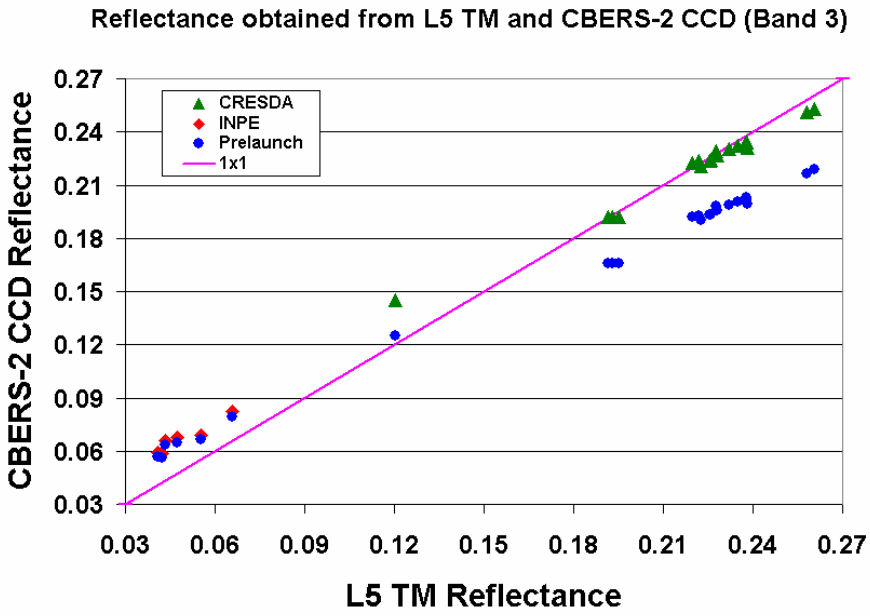
Band 2

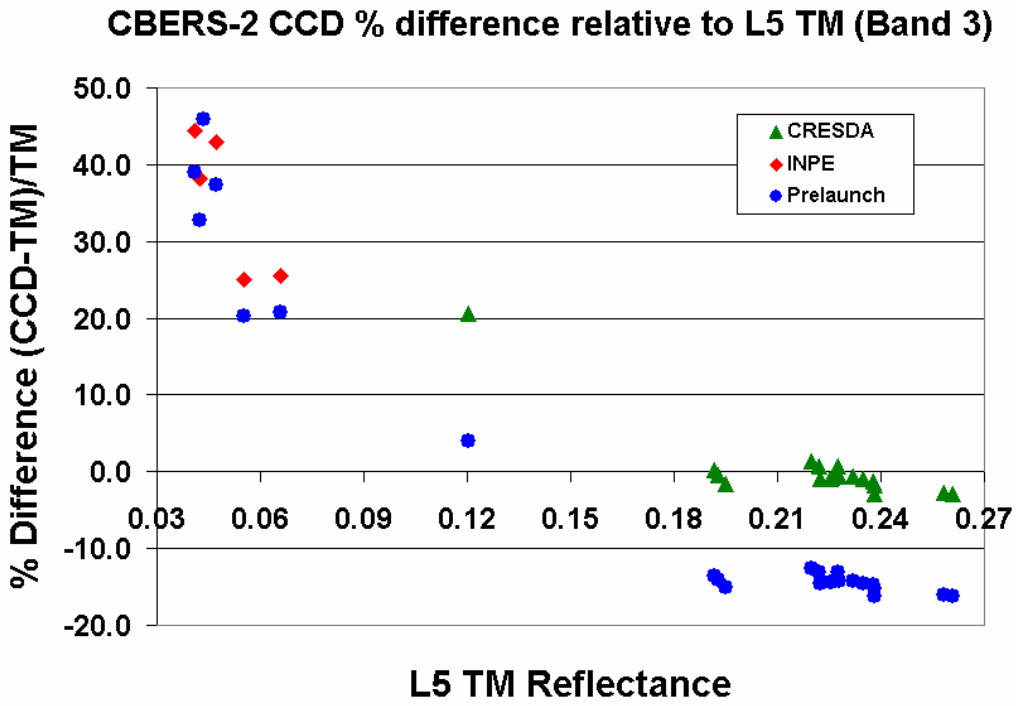

Reflectance obtained from L5 TM and CBERS-2 CCD (Band 2)
CBERS-2 CCD Reflectance
L5 TM Reflectance
CRESDA
INPE
Prelaunch
1x1
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26


CBERS-2 CCD % difference relative to L5 TM (Band 2)
% Difference (CCD-TM)/TM
L5 TM Reflectance
CRESDA
INPE
Prelaunch
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0.0
-4.0
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26

USGS

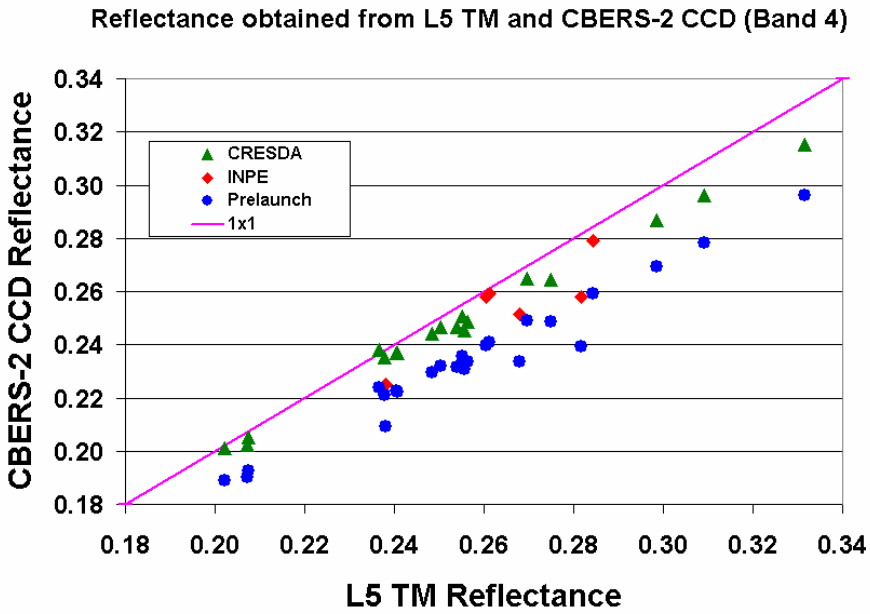
Band 3

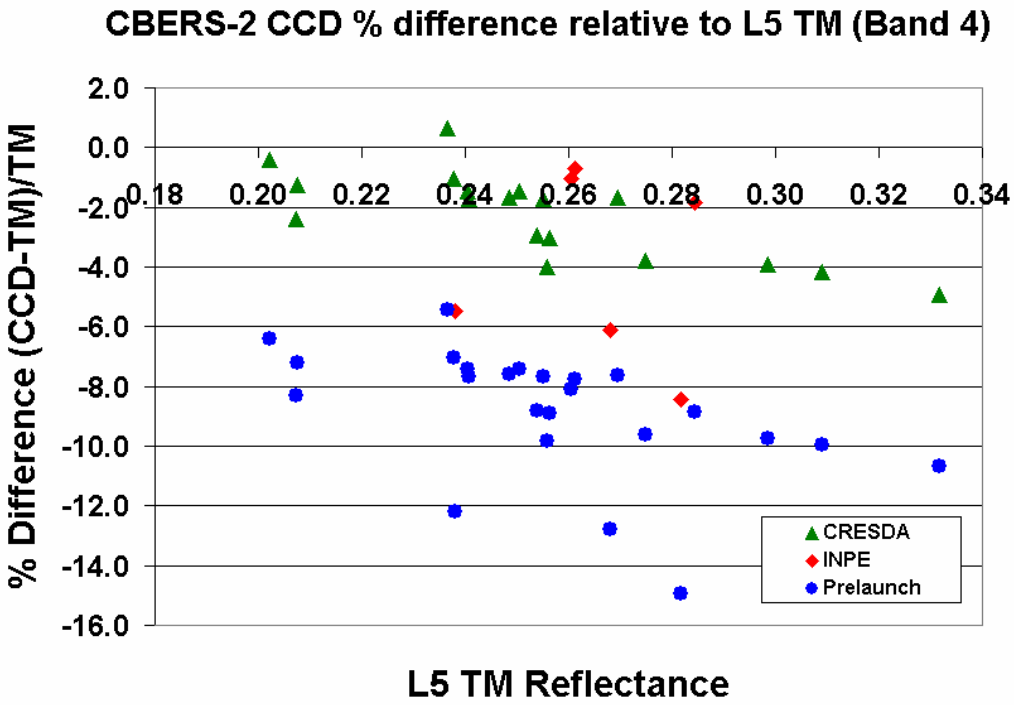

Reflectance obtained from L5 TM and CBERS-2 CCD (Band 3)
CBERS-2 CCD Reflectance
L5 TM Reflectance
CRESDA
INPE
Prelaunch
1x1
0.03
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.27


CBERS-2 CCD % difference relative to L5 TM (Band 3)
% Difference (CCD-TM)/TM
L5 TM Reflectance
CRESDA
INPE
Prelaunch
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
0.03
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.27

USGS

Band 4


Reflectance obtained from L5 TM and CBERS-2 CCD (Band 4)
CBERS-2 CCD Reflectance
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
CRESDA
INPE
Prelaunch
1x1
0.18 0.20 0.22 0.24 0.26 0.28 0.30 0.32 0.34
L5 TM Reflectance


CBERS-2 CCD % difference relative to L5 TM (Band 4)
% Difference (CCD-TM)/TM
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
-14.0
-16.0
0.18 0.20 0.22 0.24 0.26 0.28 0.30 0.32 0.34
CRESDA
INPE
Prelaunch
L5 TM Reflectance

USGS

CBERS-2 CCD absolute calibration accuracy relative to L5 TM

Root Mean Square Error (RMSE)				
	CCDB1	CCDB2	CCDB3	CCDB4
	Radiance			
CRESDA	5.88	5.38	6.03	3.69
Both	8.25	5.23	21.93	3.81
	Reflectance			
CRESDA	3.81	3.38	5.06	2.69
Both	6.19	3.26	20.08	3.38

- **Uncertainties in the cross-calibration results**
  - Differences due to the Relative Spectral Responses (RSR) were not taken into account
  - Atmospheric changes between the two image-pairs were not accounted
    - acquisition time between the two sensors were 20-min apart
  - Registration problems while selecting the regions of interest (ROI)
    - image statistics based on large areas in common between the image pairs
  - INPE scenes were acquired over dark regions and water bodies

Minutes from USGS-INPE meeting
São José dos Campos, April 22nd 2005 (XII BRSS)

- INPE and USGS jointly agreed to pursue the below three actions in the spirit of GEOSS and to hold further discussions that are directed towards long-term and open data exchange agreements
  - Trial data reception at Sioux Falls: USGS and INPE agreed on a trial reception of CBERS data at USGS ground station. INPE will provide the prototype data ingest system and data production software for this test
    - USGS received the bit-synch from INPE
    - Dr. Gilberto Camara is the new Director of INPE
  - USGS and INPE agreed on a joint calibration campaign
  - General information on CBERS program and data policy: INPE will provide further information to USGS on aspects related to CBERS data availability and ground station infrastructure

Challenges and Future Plans

Challenges

- **CBERS-2 High Density Data Recorder (HDDR) is not in use due to power limitations**
- **The IRMSS stopped working in Apr, 2005 due to power supply failure**
- **Limited coincident Landsat/CBERS image-pairs**
  - Limited data distribution policies outside the country
  - Limited documentation available
  - No L7 data downlink in Brazil

Future Plan

- **CBERS-2 test downlink at USGS EROS**
- **Evaluate the raw data (artifacts, noises)**
  - Evaluate the relative calibration of the CCD data
  - Evaluate Bias estimates
  - Night time acquisitions
- **Perform similar cross-calibration experiment**
  - Data processed from INPE
  - Data processed from CRESDA
  - Same datasets processed at INPE and CRESDA
  - Temporal scale (image pairs from 2003-2005)
- **Perform Vicarious calibration**

References

- **Personal communication**
  - Flavio Ponzoni (INPE)
  - Fu Qiaoyan (CRESDA)
- **World Wide Web (WWW)**
  - http://www.cbers.inpe.br/
  - http://www.cresda.com/
- **Documents**
  - **Radiometric Quality Assessment of CBERS-2**
  - **The CCD & IRMSS for CBERS**
  - **CALIBRAÇÃO ABSOLUTA DOS SENSORES CBERS-2**
  - **In-flight absolute calibration of the CCD/CBERS-2 sensor**