MODIS Spatial Calibration – Methodology and Performance On-orbit

MODIS Characterization Support Team (MCST)

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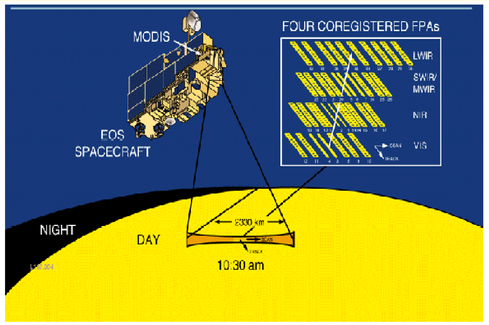
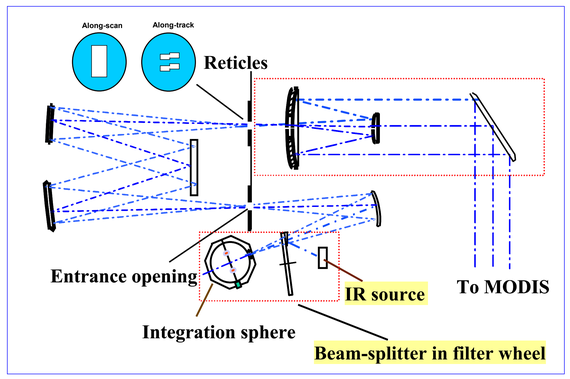
Introduction

- The MODIS 36 bands are located on four Focal Plane Assemblies (FPAs): VIS, NIR, SMIR, and LWIR with detector sizes of 0.25km, 0.50km, and 1.00km (IFOV).
- The MODIS spatial characterization was measured prelaunch by an Integration & Alignment Collimator (IAC) at SBRS.
- On-orbit spatial characterization is performed using an on-board calibrator: Spectro-Radiometric Calibration Assembly (SRCA).
- The SRCA is operated in spatial mode with two reticles (one for along-scan and another for along-track) alternately located at the focal plane of the SRCA collimator.
- The SRCA measures changes of Band-to-Band Registration (BBR) along-scan (each detector) and along-track (band) for all 36 bands (the measured BBR is relative to band 1).

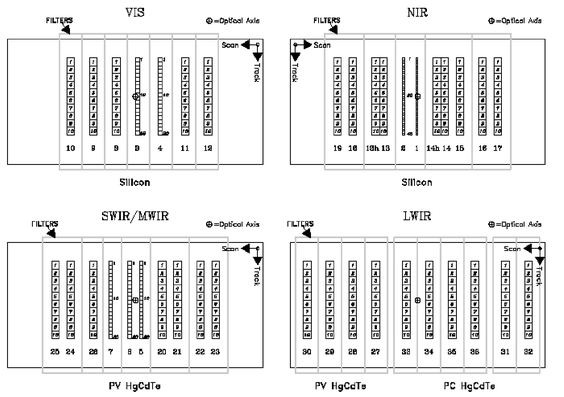
MODIS



SRCA layout in spatial mode



MODIS Focal plan layout



SRCA operation on-orbit

TERRA

No.	Year	Day	No.	Year	Day
1	2000	46	21	2002	73
2	2000	48	22	2002	135
3	2000	60	23	2002	205
4	2000	68	24	2002	255
5	2000	75	25	2002	318
6	2000	89	26	2003	22
7	2000	96	27	2003	72
8	2000	118	28	2003	149
9	2000	131	29	2003	211
10	2000	159	30	2003	259
11	2000	187	31	2003	322
12	2000	215	32	2004	13
13	2000	308	33	2004	79
14	2001	8	34	2004	99
15	2001	67	35	2004	147
16	2001	131	36	2004	189
17	2001	192	37	2004	259
18	2001	256	38	2004	328
19	2001	326	39	2005	13
20	2002	31			

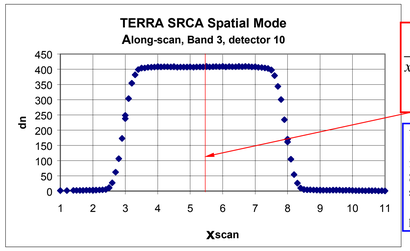
AQUA

No.	Year	Day	No.	Year	Day
1	2002	170	10	2003	273
2	2002	206	11	2003	328
3	2002	241	12	2004	14
4	2002	267	13	2004	85
5	2002	316	14	2004	146
6	2003	20	15	2004	188
7	2003	104	16	2004	258
8	2003	140	17	2005	13
9	2003	204			

SRCA spatial mode is operated bi-monthly on-orbit.

The algorithm of spatial calibration

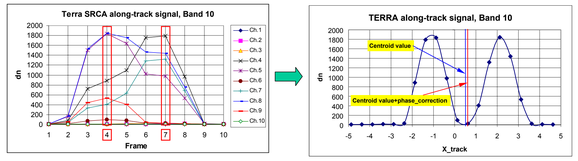
Along-scan (five phase-delays improve precision)



$$\bar{x}(b,ch) = \frac{\sum_{x=0}^{N_x} dn(b,ch,x)\cdot x}{\sum_{x=0}^{N_x} dn(b,ch,x)}$$

Where x=frame+(subframe-1)*size + 0.2*phase_delay
frame = 1 to 10
Size = 1, 0.5, and 0.25
subframe = 1, 2, 4 for 1, 0.5, 0.25km size detector
phase_delay=0 to 4

Along-track (unique reticle to measure band center shift)



$$\varphi_{bias}(b,m) = \left\{\left\langle x_{track,avg}(b,m)\right\rangle - \left\langle x_{track}\right\rangle\right\}\cdot\frac{2\pi}{d_{open}} + \gamma(b,m)$$

Set angle value for each detector

$$\theta_L(b,d,m) = \left[x_{track}(d) - \left\langle x_{track}\right\rangle - 0.5\cdot d_{step}\right]\cdot\frac{2\pi}{d_{open}} - \varphi_{bias}(b,m)$$

$$\theta_R(b,d,m) = \left[x_{track}(d) - \left\langle x_{track}\right\rangle + 0.5\cdot d_{step}\right]\cdot\frac{2\pi}{d_{open}} - \varphi_{bias}(b,m)$$

iteration

Fourier sine and cosine transform

$$S_x(b,m) = \sum_{d=1}^{N}\left\{dn(b,d,f^L,m)\cdot\sin\theta^L(b,d,m) + dn(b,d,f^R,m)\cdot\sin\theta^R(b,d,m)\right\}$$

$$S_y(b,m) = \sum_{d=1}^{N}\left\{dn(b,d,f^L,m)\cdot\cos\theta^L(b,d,m) + dn(b,d,f^R,m)\cdot\cos\theta^R(b,d,m)\right\}$$

Phase-angle

$$\gamma(b,m) = a\tan(S_x(b,m).S_y(b,m))$$

Using entire profile to calculate position to correct centroid results

$$\Delta x_{track}(b) = \frac{1}{2}\sum^{2}\frac{\varphi_{bias}(b,m)}{\gamma(b,m)}\cdot d_{open}$$

Band position along-track

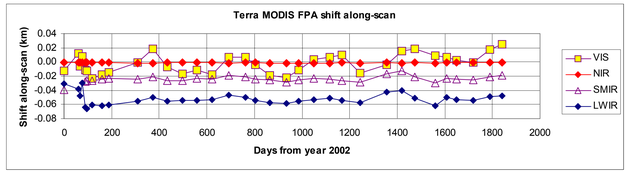
$\langle x_{track,avg}\rangle$ – average of two centroid values for curves from frame#4 and #7 $\langle x_{track}\rangle$ – ideal position along-track for all bands

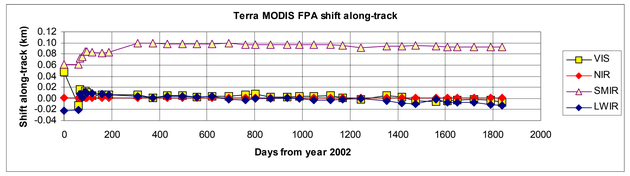
γ – phase angle $x_{track}(d)$ – detector number(see reticle figure) f^L, f^R – frame number corresponding to full open by left/right openings

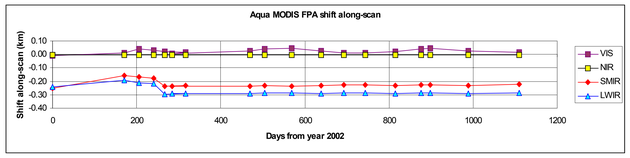
specifications

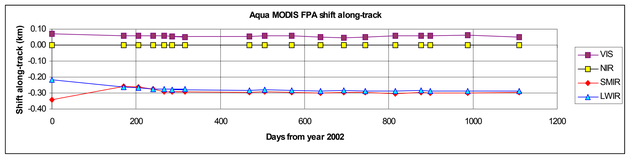
1. Instantaneous Field Of View (IFOV) should be within 0.94 of nominal size in both along-scan and along-track.
2. Band to Band Registration (BBR) should be within 0.2km between any two bands.
3. Modular Transfer Function (MTF) should be greater than 0.9, 0.7, 0.5, and 0.3 corresponding to F/F_NYQ = 0.25, 0.50, 0.75, and 1.00, respectively.

MODIS FPA Registration Trending

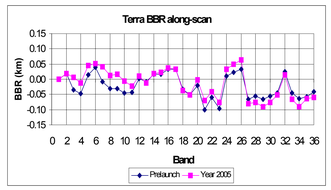


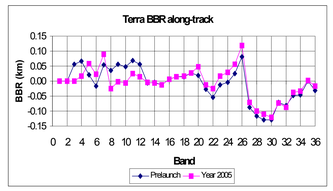


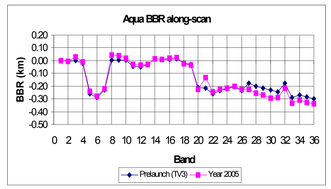


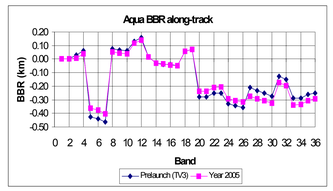


MODIS Band-to-Band Registration (BBR)









Summary

1. The SRCA has been shown to be a stable device according to the engineering parameters and on-orbit performance trending for both Terra and Aqua MODIS.
2. According to on-orbit trending and data analysis, the SRCA spatial mode has a precision of ±0.020km (along-scan) and ±0.010km (along-track), with an overall precision of ±0.022km.
3. FPA shifts were detected post-launch but has remained stable over time (less than ±0.030km for Terra and ±0.050km for Aqua except for SWIR bands).
4. Small but noticeable annual variation in FPA shifts are observed due to seasonal changes of instrument temperature.
5. The Band-to-Band registration for Terra MODIS meets the specification both along-scan and along-track except for a few bands along-track. For Aqua MODIS, significant mis-registration was detected pre-launch. On-orbit band/FPA mis-registration is at the same level as pre-launch.
6. The mis-registration for Aqua is mainly between VIS/NIR FPAs and SMIR/LWIR FPAs. Users should be cautious if images are constructed from bands on different FPAs.

Terra MODIS Pre-launch Spatial Characterization

RSB Key Spatial Parameters (Band Average Summary)

Band	IFOV (m) Specified @ Nadir	IFOV (m) Scan Direction	IFOV (m) Track Direction	Band Reg (m) Scan/Track	Re_Mis-Reg (m) Scan Direction	Re_Mis-Reg (m) Track Direction	MTF Specified	MTF Scan Direction	MTF Track Direction
1	250	266	248	50	0	0	0.3	0.35	0.43
2	250	255	247	50	24	2	0.3	0.38	0.47
3	500	536	496	100	13	4	0.3	0.38	0.55
4	500	525	498	100	6	8	0.3	0.39	0.56
5	500	521	502	100	61	68	0.3	0.26	0.49
6	500	530	496	100	78	40	0.3	0.27	0.50
7	500	533	510	100	43	97	0.3	0.36	0.48
8	1000	1047	996	200	19	-7	0.3	0.38	0.60
9	1000	1026	997	200	18	-15	0.3	0.40	0.61
10	1000	1039	996	200	9	-23	0.3	0.39	0.60
11	1000	1023	972	200	10	3	0.3	0.41	0.61
12	1000	1039	996	200	54	-1	0.3	0.40	0.60
13L	1000	1017	1000	200	3	-4	0.3	0.40	0.60
14L	1000	1023	1000	200	14	-16	0.3	0.40	0.60
15	1000	1021	1000	200	14	-26	0.3	0.41	0.60
16	1000	1024	1001	200	19	-27	0.3	0.41	0.60
17	1000	1031	1002	200	19	-29	0.3	0.40	0.60
18	1000	999	1001	200	-14	7	0.3	0.41	0.60
19	1000	1009	1002	200	-29	13	0.3	0.41	0.60
26	1000	1035	1003	200	81	84	0.3	0.40	0.58
13H	1000	1017	1000	200	3	-4	0.3	0.40	0.60
14H	1000	1023	1000	200	14	-16	0.3	0.40	0.60

TEB Key Spatial Parameters (Band Average Summary)

Band	IFOV (m) Specified	IFOV (m) Scan Direction	IFOV (m) Track Direction	Band Reg Scan/Track	Re_Mis-Reg Scan Direction	Re_Mis-Reg Track Direction	MTF Specified	MTF Scan Direction	MTF Track Direction
20	1000	1030.6	1005.5	200	39	51	0.3	0.40	0.51
21	1000	1015.6	998.3	200	-24	-16	0.3	0.38	0.58
22	1000	1021.3	1005.2	200	-3	-25	0.3	0.34	0.51
23	1000	1048.3	998.7	200	-38	17	0.3	0.40	0.56
24	1000	1034.2	1005.2	200	51	-10	0.3	0.40	0.58
25	1000	1018.7	1000.4	200	62	-3	0.3	0.41	0.59
27	1000	1074.3	1012.5	200	133	-71	0.3	0.33	0.58
28	1000	1074.8	1020.2	200	163	-90	0.3	0.37	0.57
29	1000	1085.7	1027.2	200	180	-103	0.3	0.35	0.57
30	1000	1065.2	996.5	200	168	-96	0.3	0.36	0.60
31	1000	1060.9	1006.0	200	-6	-21	0.3	0.33	0.54
32	1000	1018.5	986.7	200	41	-6	0.3	0.36	0.55
33	1000	1060.8	1005.2	200	1	20	0.3	0.33	0.54
34	1000	1080.0	1003.7	200	-6	32	0.3	0.32	0.52
35	1000	1075.7	994.7	200	-2	37	0.3	0.33	0.47
36	1000	1079.1	991.7	200	-48	49	0.3	0.32	0.47

MODIS BBR Trending