



Community geometric standards for remote sensing products

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vEGU21

29 April 2021

The European Geosciences Union (EGU) General Assembly, 2021

Programme Group: ESS1.19

Stability and Accuracy of Earth satellite measurements through calibration and validation

15:35–15:37 | EGU21-1327

How to cite: Lin, G. (., Wolfe, R., Tan, B., and Nickeson, J.: Community geometric standards for remote sensing products, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-1327, <https://doi.org/10.5194/egusphere-egu21-1327>.



Collaboration with ESA on *Guidelines*



Early form



As of 3 March 2021, still evolving



Context of Geometry in remote sensing

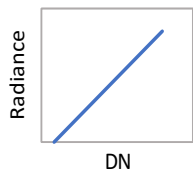
- Spectral banding:: essence of remote sensing

- Central wavelength or frequency & band width, in-band response, out-of-band response (suppressed?), etc.



- Radiometric calibration:: major part of CalVal

- Dynamic range, digitizing depth, calibration scaling (linear?), signal-to-noise ratio(SNR)/noise-equivalent-delta-temperature (NE Δ T), temporal stability, etc.



- Geometry:: (is important!) location, location, location!

- System spatial response → instrument resolution & image quality

- point spread function (PSF), line spread function (LSF), field of view (FOV) = full width at half maximum (FWHM) of PSF/LSF, modulation transfer function(MTF)

- Band-to-band co-registration (BBR) → affects data retrievals

- Alignment, pointing (star trackers, gyros, etc) → geolocation





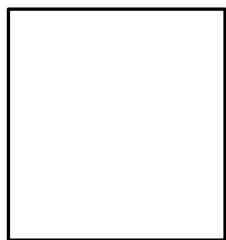
Spatial response

- System point spread function (PSF):: response to impulse functions at all possible (along-track, cross-track) locations
 - Often can be decomposed into two orthogonal line spread functions (LSFs)
 - Serves as a weighting function for a detector to collect energy from targets
- LSF in “slow” motion direction:: $\sim$ instantaneous LSF
 - Determined by detector size, convolved/smeared by optical PSF
- LSF in “fast” motion direction:: $\sim$ dynamic LSF
 - Determined primarily by detector size and convolved with motion (motion smear)

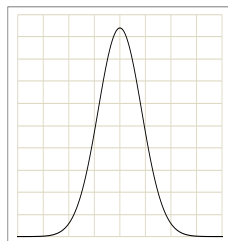


Spatial response [Cont.]

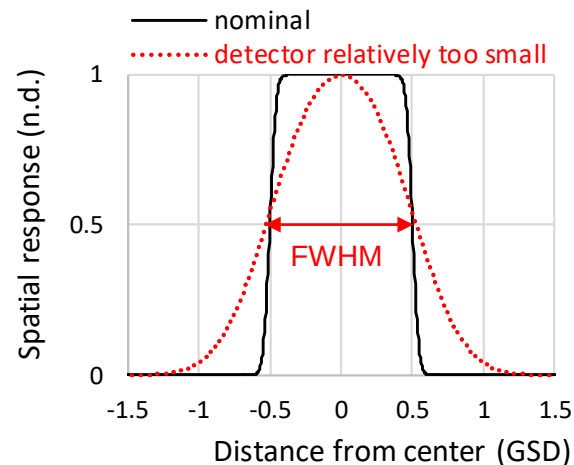
- Instantaneous LSF



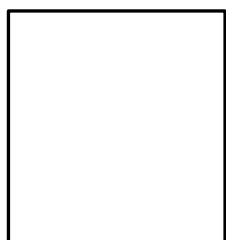
Detector size



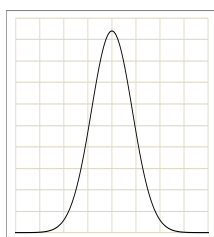
Optical blur



- Dynamic LSF



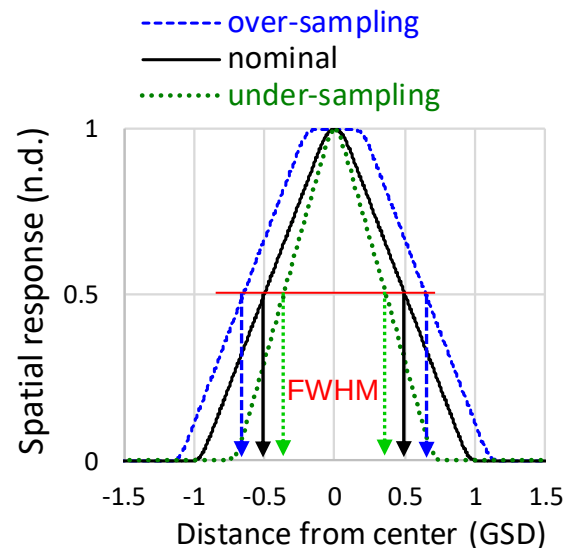
Detector size



Optical blur



motion blur



convolution

FWHM: Full-width at Half-Maximum
GSD: Ground Sample Distance



Spatial response [Cont.]

- Footprint: Full-Width at Half-Maximum (FWHM) of LSF
→ ground field of view (GFOV)
 - Instrument resolution $\left\{ \begin{array}{ll} \text{under-sampling,} & \text{GFOV} < \text{GSD} \\ \text{Nyquist sampling,} & \text{GFOV} = \text{GSD} \\ \text{over-sampling,} & \text{GFOV} > \text{GSD} \end{array} \right.$
 - Over-sampling yields un-sharp images but better signal-to-noise ratio, GFOV/GSD ratio in a range of 0.75 to 1.5 is usually required
- In gridded products, “resolution” → “grid”/ “cell”/ “pixel” size
 - they may $\neq$ GFOV $\neq$ GSD
- Modulation transfer function (MTF) – image quality, contrast reduction
$$MTF(\omega) = \frac{|FourierTansform(LSF)|}{|FourierTansform(LSF)|_{\omega=0}} \left\{ \begin{array}{l} = 0.63 \text{ @NF for square LSF} \\ = 0.40 \text{ @NF for triangular LSF} \\ > 0.2 - 0.3 \text{ @NF is usually required} \end{array} \right.$$

ω fraction of Nyquist frequency (NF)

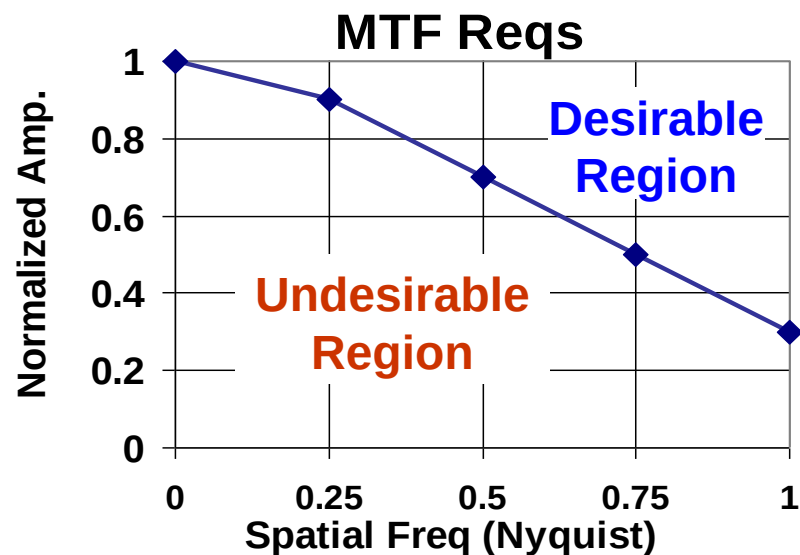


Spatial response, VIIRS example

- GFOV specification is tailored to detector designed value + margin
 - $GFOV_{design} = \text{detector_size} / \text{effective_focal_length} * \text{altitude}$
 - $GFOV_{spec} < GFOV_{design} + 10\%$ for imagery bands (375 m @ nadir)
 - $GFOV_{spec} < GFOV_{design} + 5\%$ for moderate resolution bands (750m @ nadir)
- The MTF requirements are to exceed values specified at fractional Nyquist frequency, which is the spatial frequency two horizontal sampling intervals (HSI) apart

$$f_{nyquist} = \frac{1}{2 * HSI}$$

Nyquist Freq. Fraction	MTF
0.00	1.0
0.25	0.9
0.50	0.7
0.75	0.5
1.00	0.3





Band-to-band co-registration (BBR)

- A band pair BBR is a statistical collection of detector-to-detector co-registration (DDR), the overlap of footprints of corresponding detectors for a pair of different spectral bands.

$$DDR_{i,j} = \iint_{(x,y)} |PSF_i - PSF_j| / 2 \, dx dy, \quad \text{where } \iint_{(x,y)} PSF \, dx dy = 1.$$

- Practically,

$$DDR_{i,j} \approx \begin{cases} 0, & \Delta S_{i,j} > L_S \text{ or } \Delta T_{i,j} > L_T \\ \left(1 - \frac{\Delta S_{i,j}}{L_S}\right) \left(1 - \frac{\Delta T_{i,j}}{L_T}\right), & \text{else} \end{cases}.$$

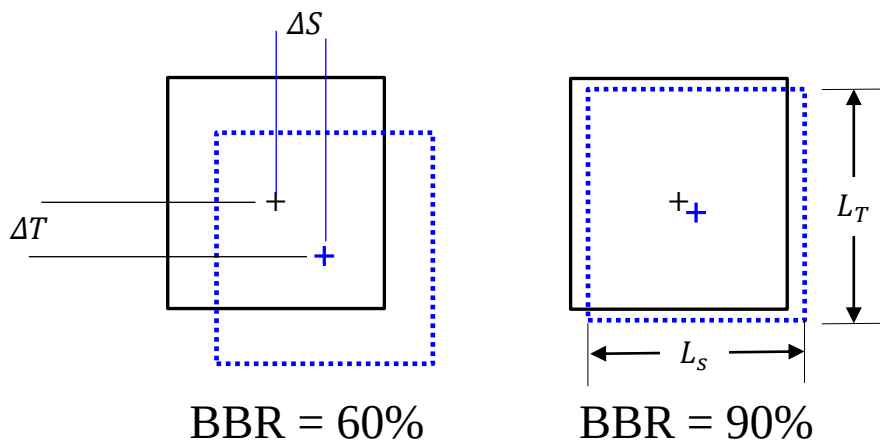
$\Delta S_{i,j}$ and $\Delta T_{i,j}$ are offsets in absolute values and L_S and L_T are the length scales approximating the equivalent area of PSFs in the cross-track (S) and along-track (T) directions, respectively. L_S and $L_T \sim \text{GFOV}$, and may be simplified to GSD.

- BBR > 60% to 90% is usually required



BBR [cont.]

- Good BBR is critical for biogeophysical parameter retrievals that use data from multiple spectral bands, especially in heterogeneous areas.
- Good BBR is achieved mainly by shifting bands in time/space, mostly in pre-launch testing.
- BBR is affected by many factors, such as focal plane clocking/tilting, adjustable time delay, scan rate for whiskbroom sensor, spacecraft speed for pushbroom or frame sensors, AND focal length.
- BBR in pictures, 60% or 90%





BBR, VIIRS example

Band-to-Band Co-Registration (BBR) Specification

“At least 99.7% of corresponding pixel samples”

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	I1	I2	I3	I4	I5
M1		0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
M2			0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
M3				0.64	0.70	0.64	0.64	0.64	0.64	0.64	0.70	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
M4					0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
M5						0.64	0.80	0.64	0.64	0.64	0.70	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
M6							0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
M7								0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
M8									0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
M9										0.64	0.64	0.80	0.80	0.80	0.80	0.80	0.64	0.64	0.64	0.64	0.64
M10											0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
M11												0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
M12													0.80	0.80	0.80	0.80	0.64	0.64	0.64	0.64	0.64
M13														0.80	0.80	0.80	0.64	0.64	0.64	0.64	0.64
M14															0.80	0.80	0.64	0.64	0.64	0.64	0.64
M15																0.80	0.64	0.64	0.64	0.64	0.64
M16																	0.64	0.64	0.64	0.64	0.64
I1																		0.80	0.80	0.80	0.80
I2																			0.80	0.80	0.80
I3																				0.80	0.80
I4																					0.80
I5																					

VIIRS 22 Bands: 16 M-Band, 5 I-Band and 1 DNB		
VIIRS Band	Spectral Range (um)	Nadir GSD (m)
DNB	0.500 - 0.900	750
○ M1	0.402 - 0.422	750
○ M2	0.436 - 0.454	750
○ M3	0.478 - 0.498	750
○ M4	0.545 - 0.565	750
I1	0.600 - 0.680	375
○ M5	0.662 - 0.682	750
M6	0.739 - 0.754	750
I2	0.846 - 0.885	375
○ M7	0.846 - 0.885	750
M8	1.230 - 1.250	750
M9	1.371 - 1.386	750
I3	1.580 - 1.640	375
M10	1.580 - 1.640	750
M11	2.225 - 2.275	750
I4	3.550 - 3.930	375
M12	3.660 - 3.840	750
○ M13	3.973 - 4.128	750
M14	8.400 - 8.700	750
M15	10.263 - 11.263	750
I5	10.500 - 12.400	375
M16	11.538 - 12.488	750

○ Dual gain band

$BBR_{99.7\%} = \min(DDR_s)$ within band pairs in testing



Alignment, pointing & Geolocation

- 1) Alignment of various parts of the instrument, and various pointing sensors, such as star trackers, gyros, magnetometers and sun sensors on the spacecraft, need to be carefully designed, installed and tested (characterized and calibrated) at various stages of satellite build before launch.
- 2) After launch, an intensive calibration and validation (CalVal) campaign must be carried out that includes the pointing sensors on the spacecraft as well as the instrument. Earth-pointing instruments should perform pointing CaVal with ground truth (coastlines or ground control points).
- 3) Long-term monitoring and continuous CalVal must be performed to ensure temporal stability.
- 4) Geolocation accuracy is important for time series analysis of satellite data.
- 5) Geolocation accuracy is critical in synergizing different data sources for interoperability.

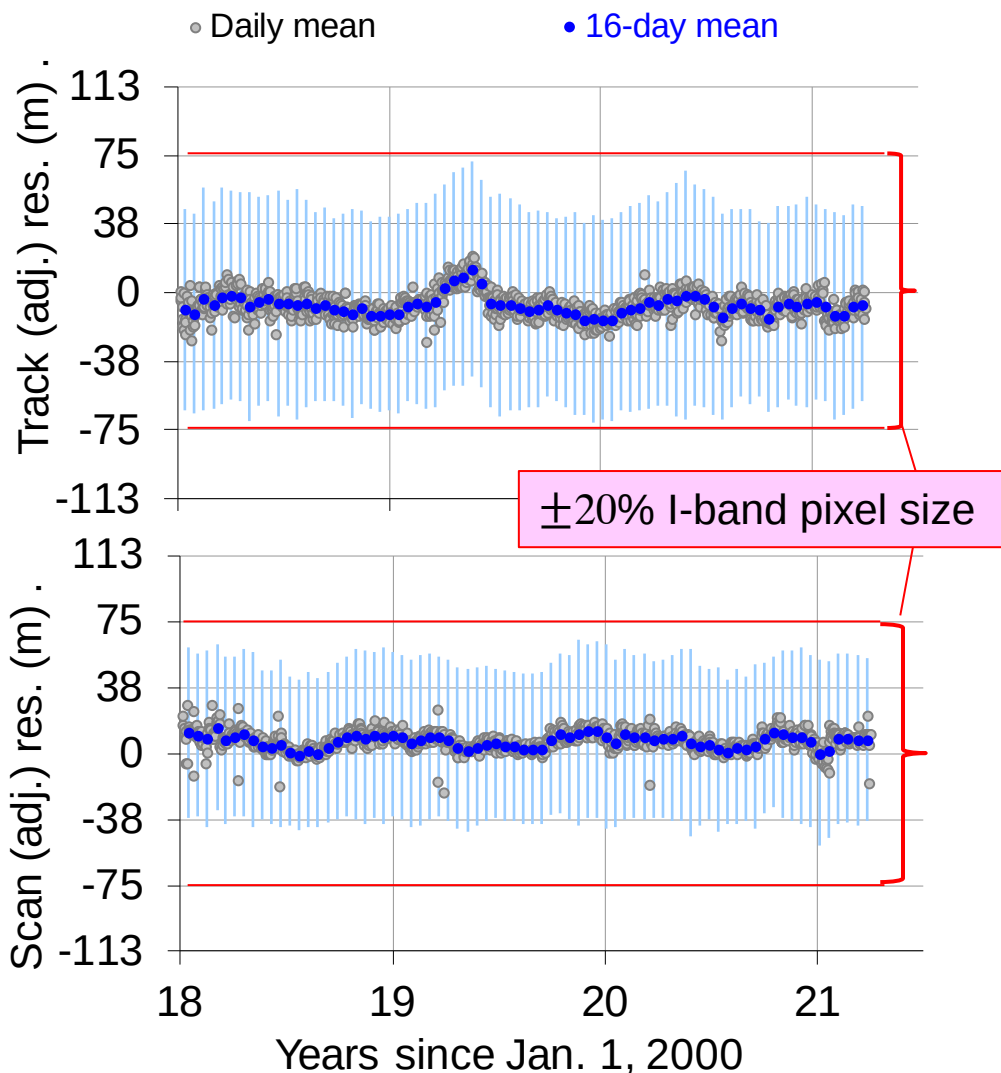
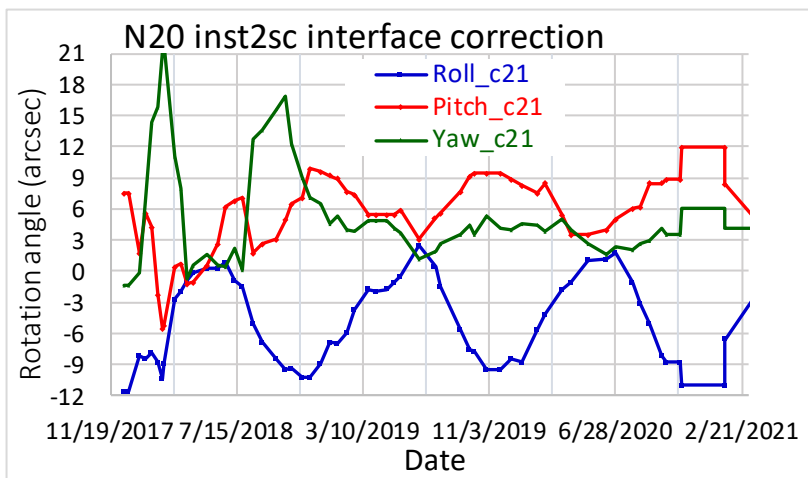
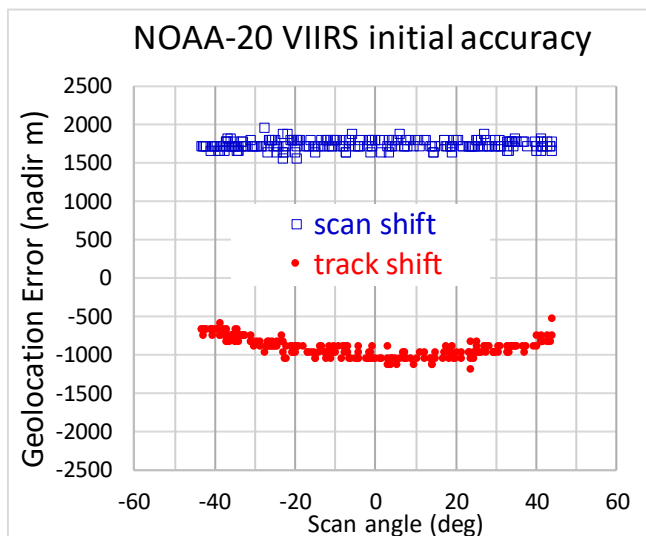


Geolocation requirements, examples for VIIRS

- 1) *The known pointing of the VIIRS instrument boresight, referenced to the center of the effective field of view for any channel, prior to on-orbit calibration shall be **within 1200 m** (radial, 3 sigma) of the true location of that field of view, at nadir, on the WGS84 reference ellipsoid, at any time during nominal JPSS operations.*
 - 2) *The known pointing of the VIIRS instrument boresight, referenced to the center of the effective field of view for any channel, following on-orbit calibration shall be **within 375 m** (radial, 3 sigma) of the true location of that field of view, at nadir, on the WGS84 reference ellipsoid, at any time during nominal JPSS operations.*
- The 1st requirement allows more tolerance in static errors while the 2nd requirement dictates the removal of such static errors by on-orbit CalVal.
 - Actual initial post-launch VIIRS geolocation offsets could be > 1200 m.
 - There are non-static but slow-varying errors that may be removed.
 - Actual on-orbit VIIRS geolocation accuracy after calibration is better than 125 m (radial, 1 sigma), or 88 m (along-track and cross-track directions, 1 sigma), even better than **75 m (20% 375 m band GSD)**, see next slide.



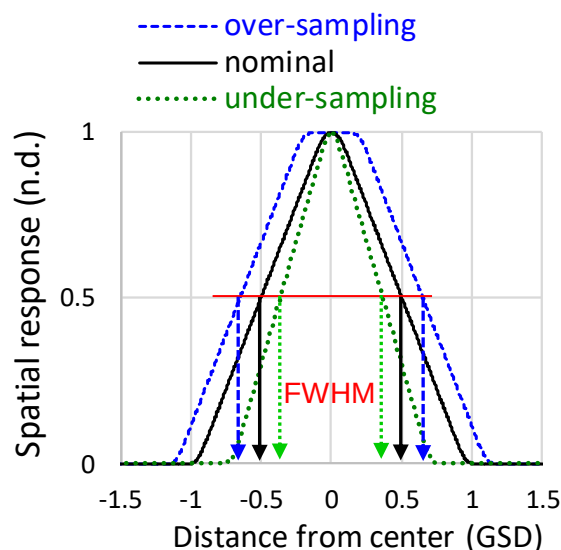
Geolocation accuracy, examples for VIIRS



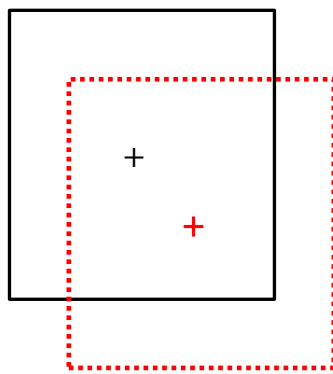
- A set of ground control points are used to detect and correct initial geolocation error $\sim 2\text{km}$ and temporal pointing variations. NOAA-20 is the name of JPSS-1 after successful launch.



Summary of proposed geometric standards for remote sensing products



Footprint of
band B1 or at time T1



Footprint of
band B2 or at time T2

Sensor Spatial Response (all detectors or $3-\sigma$)

Grade	Ratio of footprinting FWHM to GSD or pixel size	MTF at Nyquist Frequency
Basic	Footprint ratio < 1.5	MTF > 0.20
Intermediate	Footprint ratio < 1.3	MTF > 0.25
Goal	Footprint ratio < 1.1	MTF > 0.30

Band-to-band Registration (BBR) ($3-\sigma$)

Grade	Footprint overlap
Basic	BBR > 60%
Intermediate	BBR > 80%
Goal	BBR > 90%

Absolute Positional Accuracy ($1-\sigma$)

Grade	Ratio of circular error (CE) to GSD or pixel size
Basic	CE ratio < 80%
Intermediate	CE ratio < 50%
Goal	CE ratio < 30%