MAPPINGMATTERS

YOUR QUESTIONS ANSWERED

The layman's perspective on technical theory and practical applications of mapping and GIS

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QUESTION:

Q: Although we are using digital cameras with different focal lengths and configurations and therefore different flying altitudes to acquire imagery with a resolution of 10 centimeters, my client insist on applying the following rules in associating imagery resolution and final products scales and accuracies:

1. Mapping Scale = 7*aerial photo scale
2. Contour Interval = flying height / 1,800 to 2,100
3. For imagery with resolution of 10 centimeters, we have to provide the client with mapping products with a map scale of 1:1000 and positional accuracy of RMSE = +/- 20 centimeters in X, Y, or Z.

Is there a direct relationship between map scale and GSD? If so, what is the appropriate map scale that we can produce from imagery with resolution of 10 centimeters?

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Dr. Abdullah: Looking through the history of map making, one can easily notice the influence of hardcopy media, i.e. paper, that we used to publish and communicate all matters related to the maps, including positional accuracy. Because maps were only produced on paper, we needed to define map scale so users could measure the physical distance on a paper map and relate it to the actual distance on the surface of the earth. Map scale dictated the film-to-map enlargement ratio, flying altitude, map accuracy, etc. We used this association of paper map scale and all other subjects related to the map production for decades, and some users seem confused and unsecured during the transition period to digital imagery and digital map production workflow. The current reality of the new digital workflow used in almost all geospatial production processes makes it difficult to connect to the legacy paper maps workflow. Digital imagery and lidar produce digital maps and digital elevation data that are no longer associated or defined by map scale or contour interval. Digital imagery and other digital aerial products should not be labeled or associated with map scale, GSD, and/or contour interval. Map scale and contour interval were created to deal with the limitations of the mapping instruments and paper media at the time. They have no room in the all-digital workflow we are using today to produce digital geospatial products. Digital imagery with certain resolution, i.e. GSD, can be used to create maps with different GSD and accuracy. The new ASPRS Positional Accuracy Standard for Digital Geospatial Data (*PE&RS*, March 2015) is based on the latter understanding. In the new standard, accuracy is expressed independently from GSD, map scale or contour interval. The map can be produced and labeled according to the users need and not according to the imagery resolution or map scale. Today's digital workflow can achieve different end-user required accuracy by applying different stringency in the workflow. Users need to realize this new reality and start labeling products accuracy without thinking of paper map scale or contour interval. Your client criteria given in (1) above is expressing a film-to-map enlargement ratio of seven. With digital imagery, we do not use enlargement ratio. That was valid when we projected the film on a paper to enlarge it seven times to produce a paper map with a certain scale that is seven times larger than the negative (film) scale. Digital imagery is closely associated with the digital zoom on the screen. It is not limited to any map scale as it varies depending on the zoom level that the user selects. Scale for each zoom level can only be determined by measuring the physical distance on the computer or the tablet screen and

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comparing it to the distance on the ground—something that has never been done nor something anyone is intending to do in the future.

The criteria given in (2) which uses c-factor to determine the appropriate contour interval that can be generated from an elevation dataset, is no longer valid for digital cameras products and softcopy workflow. C-factor is a term developed to express the physical limitations of the mechanical movements of the analogue stereo plotters and its tolerance to the variation in terrain relief. It should not be used for all-digital workflow. We used the flying altitude in such formula when the aerial imagery was strictly done using one film camera geometry, and that is a 9x9-inch film format and a lens with 6-inch focal length. Flying altitude alone can no longer be used to determine products accuracy. Digital cameras of today come with different formats and lens focal lengths. Digital cameras such as UltraCAM Eagle with 210-millimeter lens or A3 from Vision Map with 300-millimeter lens are capable of acquiring high-resolution digital imagery from a very high altitude. An UltraCAM-210 camera for example is capable of acquiring imagery with a ground resolution of 15 centimeters from an altitude of 19,870 feet above ground level (AGL). Using film-based cameras, we use to acquire photography from an altitude of 3,600 ft. with a negative scale of 1:7,200 to obtain the same ground resolution of 15 centimeters after scanning the film with 21 micron/pixel. Using the above formula in (2) for both scenarios results in a product that meets 2-foot contour interval criteria from the film photography while it only meets 11-foot contour interval criteria from an UltraCAM-210 sensor. Such conclusion will be rejected by Vexcel, the manufacturer of UltrCAM, and all UltraCAM cameras owners who claim that their products from the UltraCAM-210 sensor can meet the highest accuracy requirements horizontally and vertically. As for the question on whether digital imagery with a GSD of 10 centimeters satisfies a certain map scale, I do not have a straight answer as there is none. However, I will provide some guidelines that may put you closer to what your client is trying to achieve. When we first transitioned to softcopy workflow in the early ‘90s, we scanned the film to convert it to a digital media. The main concern at the time was the scanning resolution needed to produce a certain map scale. There was no one answer and different companies used different scanning resolution. The most common scanning resolution adopted at the time was 1200 dots-per-inch (dpi) or 21-micron. Based on such scanning resolution, we developed the association between the film scale, GSD, and the resulting map scale provided in Table 1.

‘‘Digital imagery and lidar produce digital maps and digital elevation data that are no longer associated or defined by map scale or contour interval’’

When we transitioned to the digital imaging sensors, we were faced with the same challenge of deciding on which image resolution was suitable to produce a map or ortho photo with a certain map scale. As we were constrained by the users’ specifications and understanding, we tried to create such association, not based on any scientific merit, but according to what we practiced and learned from our experience during the transition from film to softcopy. We developed the association of digital imagery and map scale given in Table 2, based on what we learned from Table 1.

Table 2 represents how we interpreted the ASPRS legacy map accuracy standard of 1990 which is originally based on paper map scales to suite digital imagery. Again, the values

Table 1. Relationship between film scale and derived map scale.

	Common Photography Scales (with 9″ film format camera and 6″ lens)				Scanning Resolution (um)
Photo Scale	1″ = 300′	1″ = 600′	1″ = 1200′	1″ = 2400′	
	1:3,600	1:7,200	1:14,400	1:28,800	
Flying Altitude	1,800′ / 550 m	3,600′ / 1,100 m	7,200′ / 2,200 m	14,400′ / 4,400 m	
Approximate Ground Sampling Distance (GSD) of Scan	0.25′ / 7.5 cm	0.50′ / 0.15 m	1.0′ / 0.3 m	2.0′ / 0.6 m	21

Supported Map/Orthoimagery Scales and Contour Intervals

GSD	3″ / 7.5 cm	6″ / 15 cm	1.0′ / 30 cm	2.0′ / 60 cm
C.I.	1.0′ / 30 cm	2.0′ / 60 cm	4′ / 1.2 m	8′ / 2.4 m
Map Scale	1″ = 50′	1″ = 100′	1″ = 200′	1″ = 400′
	1:600	1:1,200	1:2,400	1:4,800

Table 2 Examples on horizontal accuracy for digital orthoimagery interpreted from ASPRS 1990 legacy standard.

Common Orthoimagery Pixel Sizes	Associated Map Scale	ASPRS 1990 Accuracy Class	Associated Horizontal Accuracy According to Legacy ASPRS 1990 Standard	
			$RMSE_x$ and $RMSE_y$ (cm)	$RMSE_x$ and $RMSE_y$ in terms of pixels
0.625 cm	1:50	1	1.3	2-pixels
		2	2.5	4-pixels
		3	3.8	6-pixels
1.25 cm	1:100	1	2.5	2-pixels
		2	5.0	4-pixels
		3	7.5	6-pixels
2.5 cm	1:200	1	5.0	2-pixels
		2	10.0	4-pixels
		3	15.0	6-pixels
5 cm	1:400	1	10.0	2-pixels
		2	20.0	4-pixels
		3	30.0	6-pixels
7.5 cm	1:600	1	15.0	2-pixels
		2	30.0	4-pixels
		3	45.0	6-pixels
10 cm	1:800	1	20.0	2-pixels
		2	40.0	4-pixels
		3	60.0	6-pixels
15 cm	1:1,200	1	30.0	2-pixels
		2	60.0	4-pixels
		3	90.0	6-pixels
30 cm	1:2,400	2	60.0	2-pixels
		3	120.0	4-pixels
		3	180.0	6-pixels
60 cm	1:4,800	1	120.0	2-pixels
		2	240.0	4-pixels
		3	360.0	6-pixels

of pixel size and map scale are based on what we developed for scanning an aerial film using 21micron/pixel scanning resolution. According to Table 2, imagery with a GSD of 10 centimeters is sufficient to produce a map with a scale of 1:800 with three different accuracies, RMSE = 20 centimeters or (2*pixel size) for class I, RMSE = 40 centimeters or (4*pixel size) for class II, or RMSE = 60 centimeters or (6*pixel size) for class III. In the new ASPRS standard, we are saying it is up to the user to request what accuracy he or she wants the products to be labeled as, without any reference to map scale, GSD, or contour interval. However, expecting the confusion that map users and producers may experience during the early stage of the new standard implementation, the new standard provided some guidelines and current best practices. Table 3 provides general guidelines to determine the appropriate orthoimagery accuracy class for three different levels of geospatial accuracy. The new standard states:

> *"The orthoimagery pixel sizes and associated $RMSE_x$ and $RMSE_y$ accuracy classes presented in Table 3 are largely based on experience with current sensor technologies and primarily apply to large and medium format metric cameras. The table is only provided as a guideline for users during the transition period to the new standard. These associations may change in the future as mapping technologies continue to advance and evolve."*

"Digital imagery and other digital aerial products should not be labeled or associated with map scale, GSD, and/or contour interval"

Table 3 Digital orthoimagery accuracy examples for current large and medium format metric cameras.

Common Orthoimagery Pixel Sizes	Recommended Horizontal Accuracy Class $RMSE_x$ and $RMSE_y$(cm)	Orthoimage $RMSE_x$ and $RMSE_y$ in terms of pixels	Recommended use
1.25 cm	≤1.3	≤1-pixel	Highest accuracy work
	2.5	2-pixels	Standard Mapping and GIS work
	≥3.8	≥3-pixels	Visualization and less accurate work
2.5 cm	≤2.5	≤1-pixel	Highest accuracy work
	5.0	2-pixels	Standard Mapping and GIS work
	≥7.5	≥3-pixels	Visualization and less accurate work
5 cm	≤5.0	≤1-pixel	Highest accuracy work
	10.0	2-pixels	Standard Mapping and GIS work
	≥15.0	≥3-pixels	Visualization and less accurate work
7.5 cm	≤7.5	≤1-pixel	Highest accuracy work
	15.0	2-pixels	Standard Mapping and GIS work
	≥22.5	≥3-pixels	Visualization and less accurate work
15 cm	≤15.0	≤1-pixel	Highest accuracy work
	30.0	2-pixels	Standard Mapping and GIS work
	≥45.0	≥3-pixels	Visualization and less accurate work
30 cm	≤30.0	≤1-pixel	Highest accuracy work
	60.0	2-pixels	Standard Mapping and GIS work
	≥90.0	≥3-pixels	Visualization and less accurate work
60 cm	≤60.0	≤1-pixel	Highest accuracy work
	120.0	2-pixels	Standard Mapping and GIS work
	≥180.0	≥3-pixels	Visualization and less accurate work
1 meter	≤100.0	≤1-pixel	Highest accuracy work
	200.0	2-pixels	Standard Mapping and GIS work
	≥300.0	≥3-pixels	Visualization and less accurate work
2 meter	≤200.0	≤1-pixel	Highest accuracy work
	400.0	2-pixels	Standard Mapping and GIS work
	≥600.0	≥3-pixels	Visualization and less accurate work
5 meter	≤500.0	≤1-pixel	Highest accuracy work
	1,000.0	2-pixels	Standard Mapping and GIS work
	≥1,500.0	≥3-pixels	Visualization and less accurate work

"In the new standard, accuracy is expressed independently from GSD, map scale or contour interval. The map can be produced and labeled according to the users need and not according to the imagery resolution or map scale"

Table 4, provided by the new ASPRS standard, helps the users approximate an association between the new standard accuracy class, approximate GSD of source imagery, and equivalent map scale according to the legacy standards, NMAS and ASPRS1990. Table 4 provides some guidelines on approximating the map scale the 10-centimeter imagery may support according to the old practices. In reference to the values given in Table 4, the new standards states:

> *"The range of the approximate GSD of source imagery is only provided as a general recommendation, based on the current state of sensor technologies and mapping practices. Different ranges may be considered in the future depending on future advances of such technologies and mapping practices."*

Table 4. Horizontal accuracy/quality examples for high accuracy digital planimetric data.

ASPRS 2014				Equivalent to map scale in		Equivalent to map scale in NMAS
Horizontal Accuracy Class $RMSE_x$ and $RMSE_y$ (cm)	$RMSE_r$ (cm)	Horizontal Accuracy at the 95% Confidence Level (cm)	Approximate GSD of Source Imagery (cm)	ASPRS 1990 Class 1	ASPRS 1990 Class 2	
0.63	0.9	1.5	0.31 to 0.63	1:25	1:12.5	1:16
1.25	1.8	3.1	0.63 to 1.25	1:50	1:25	1:32
2.5	3.5	6.1	1.25 to 2.5	1:100	1:50	1:63
5.0	7.1	12.2	2.5 to 5.0	1:200	1:100	1:127
7.5	10.6	18.4	3.8 to 7.5	1:300	1:150	1:190
10.0	14.1	24.5	5.0 to 10.0	1:400	1:200	1:253
12.5	17.7	30.6	6.3 to12.5	1:500	1:250	1:317
15.0	21.2	36.7	7.5 to 15.0	1:600	1:300	1:380
17.5	24.7	42.8	8.8 to 17.5	1:700	1:350	1:444
20.0	28.3	49.0	10.0 to 20.0	1:800	1:400	1:507
22.5	31.8	55.1	11.3 to 22.5	1:900	1:450	1:570
25.0	35.4	61.2	12.5 to 25.0	1:1000	1:500	1:634
27.5	38.9	67.3	13.8 to 27.5	1:1100	1:550	1:697
30.0	42.4	73.4	15.0 to 30.0	1:1200	1:600	1:760
45.0	63.6	110.1	22.5 to 45.0	1:1800	1:900	1:1,141
60.0	84.9	146.9	30.0 to 60.0	1:2400	1:1200	1:1,521
75.0	106.1	183.6	37.5 to 75.0	1:3000	1:1500	1:1,901
100.0	141.4	244.8	50.0 to 100.0	1:4000	1:2000	1:2,535
150.0	212.1	367.2	75.0 to 150.0	1:6000	1:3000	1:3,802
200.0	282.8	489.5	100.0 to 200.0	1:8,000	1:4000	1:5,069
250.0	353.6	611.9	125.0 to 250.0	1:10000	1:5000	1:6,337
300.0	424.3	734.3	150.0 to 300.0	1:12000	1:6000	1:7,604
500.0	707.1	1223.9	250.0 to 500.0	1:20000	1:10000	1:21,122
1000.0	1414.2	2447.7	500.0 to 1000.0	1:40000	1:20000	1:42,244

If we assume that products from this imagery were produced to have an accuracy label of 10-centimeters according to the new ASPRS standard, then your recommendation for this imagery would be to support 1:400 scale map according to the legacy ASPRS1990-Class I. However, if the products were produced with an accuracy class of 20-centimeters, then your recommendation for this imagery would be to support 1:800 scale map according to the legacy ASPRS1990-class I, and so on.

"C-factor is a term developed to express the physical limitations of the mechanical movements of the analogue stereo plotters and its tolerance to the variation in terrain relief. It should not be used for all-digital workflow"

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