Determination of Minimum Sun Angle for Digital Aerial Image Acquisition

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1. Introduction

The Chief Directorate: National Geo-spatial Information (CD: NGI) - a component of the Department of Rural Development and Land Reform - is responsible for the national mapping programme, geodetic control network, collection of spatial information and aerial imagery in South Africa. Since 2008, all imagery is acquired digitally with multispectral large format digital aerial sensor systems. The CD: NGI aims to capture about 400km² of imagery annually (⅓ of R.S.A.).

In order to obtain quality output from the imagery, images must be captured in accordance with the Standard set by CD: NGI. The Standard specifies, among other things, the flying times for capturing of the images. The norms however were adapted from analogue aerial photography, without any scientific basis, and were not verified for digital imagery. For decades, the accepted practice is to obtain imagery with the sun angle being greater than 30º above the horizon.

The project, for which the authors were responsible, was initiated to provide answers to the questions of whether flying at lower solar elevations is relevant to the CD: NGI and what impact it would have on its various Divisions.

2. Project Objective and Scope

To investigate and summarize the behaviour, in the South African context, of the solar elevation against three variables:

1) Time of the day
2) Date/season of the year
3) Geographic location

The aim of the project was to revisit and review the flying times, prescribed by the current "Standard for the Acquisition of Digital Aerial Imagery" (version 1 of 14 December 2010). The research and recommendations were limited to digital aerial acquisition with an Integraph DMC camera, at nominal 0.5m Ground Sample Distance (GSD), i.e., ground pixel = 0.5m. If an acceptable flying window allows longer flying time, especially in winter, it will decrease the total cost and speed up the acquisition process of the imagery.

3. Discussion and Methodology

Sun angles were calculated and tabulated using the Natural Resources Canada (NRCAN) web-based utility (Natural, 2012). These angles were calculated for the 21st day of a particular month. The months January, April, July, and November were chosen to correspond to summer, autumn, winter and spring, respectively. Here, it should be mentioned that the current CD: NGI Standard did not take into account the seasons that fall between summer and winter, i.e. autumn and spring.

The latitudes: 20°, 25°, 30°, 35° South were chosen and were later adopted in the flying times' table in the version 2 of the "Standard for the Acquisition of the Digital Imagery" (CD: NGI, 2013). Although the latitude of 25° was not covered in the previous Standard, it was covered in this project's calculation as there is a significant gap between the latitude of 20° and 30°. The longitudes of 19°, 25° and 31° East were used in the calculations. These longitudes represent, in the best way, the extent of South Africa.

With respect to the minimal sun angle for digital image acquisition, several articles and publications that relate to digital image acquisition were studied to obtain an idea of what the recommended minimum solar altitude is. However, there was no comprehensive research found which would be applicable to the South African environment. For instance, the investigation was conducted in Finland with imagery acquired in the morning and noontime, at a latitude of 62°N (Honkavaara et al., 2012). Another study was performed with 0-degree-sun angles. However, it was for a disaster management purpose, where the quality of the ortho-rectified imagery was of not great importance and "may not meet mapping specifications" (Corbley et al., 2012).

In order to acquire more practical information, the CD: NGI commissioned, through its acquisition contractor ("Geospace"), to fly two pilot areas in and north of Pretoria:

1) The "Pretoria" test area (urban): jobs 2528C_SOLAR_AM and 2528C_SOLAR_PM, each consisting of two strips, namely 5 and 6, of the previously flown job 2528C_2012_495 (flown on 26, 27 May 2012).
2) The "Waterberg" test area (mountainous): jobs 2427B_SOLAR_AM and 2427B_SOLAR_PM, each consisting of two strips, namely 10 and 11, of the previously flown job 2427B_2012_474 (flown on the 2nd of May 2012).

These areas were chosen by CD: NGI and approved by "Geospace". Each area was flown in the morning and in the afternoon (hence the use of AM & PM), where the solar altitude was around 20º. (Generally, the minimum angle that other jobs are flown at is 30º).

It is important to underline that the imagery used in this study was taken during winter, in August 2012. In summer, the image quality is usually expected to be better than the one obtained during winter. Thus, the study was supposed to be conducted under the worst case scenario. The pilot jobs were treated as real tasks. They went through the entire imagery value chain, from image acquisition to ortho-rectification as well as image utilization.

4. Project Management Team Structure

The project instruction was received from the Director: Geo-spatial Information and Professional Support, in July 2012. The project team consisted of the two authors, three of their colleagues from the Division of Professional Support and Scientific Services, and the Managers of seven Divisions of the CD: NGI. The involvement of these various divisions was important in the success of this research.

- Field Surveys

This division is responsible for the survey of the Photo Ground Control points (PGC's), which are used for aerial triangulation. The impact of the sun angle on PGC's identification was examined.

- Imagery Acquisition and Analysis, Professional Support and Scientific Services

In these divisions the job was evaluated with respect to ancillary data, including external orientation and calculations of air-stations for GNSS assisted aerial photography.

- Reprographic Services

In this division the job was examined visually by the reprographic staff. This is where shadows, colours, contrast, cloud sharpness and histograms were checked. After the ortho-rectification process, the job was sent back to this division for a secondary visual check on the images.

- Aerial Triangulation and Elevation Capture

The job was processed on the available ground control, obtainable from the "main" jobs: 2528C_2012_495 and 2427B_2012_474, respectively. No extra cross-strips were flown and no additional photo ground control points were fixed. This division checked if the auto-correlation was affected during the process. The elevation data was then extracted.

- Orthophoto Production

After the ortho-rectification process, the job was evaluated with regard to the problems in relation to seam-line creation, mosaicing, and colour-balancing.

- Topographical Compilation (Divisions: A and B)

The images were checked with regard to their use for extraction of information and for topo-compilation. These were manual processes.

- Professional Support and Scientific Services

Lastly, the images were checked with regard to their use in the process known as automatic feature extraction, which is one of the applications of remote sensing.

All the above divisions wrote a report on the factors discussed and any other comments that were related to the image quality. (The summary from these reports are later quoted).

5. Analogue and Digital Flying Times

5.1 Analogue Imagery

The time intervals, before or after local noon, as indicated in Table 1, are cited from the "Standard for the Acquisition of Film-based Aerial Photography" (CD: NGI, 2008). The sun angles were obtained from the NRCAN web utility. The angles in brackets are the maximum sun angles (reached by the sun at noon) at specific latitudes, at a longitude of 25° East. Here, the sun angle obeys a rule of 30° as a minimum angle for image acquisition, whereas in mid-summer and in the average terrain the sun angle is at a minimum of 27°.

Thus in mid-winter, in the lower parts of SA, such as at a latitude of 35° South, there were only two hours available for flying in both the average and the mountainous terrain. However, in the digital Standard (CD: NGI, 2010), as demonstrated in Table 2, this was increased to a total flying time of three hours and four hours for the mountainous and the average terrain respectively.

Table 1. Relationship between flying times and the corresponding sun angles for analogue imagery

HOURS BEFORE OR AFTER LOCAL NOON **Solar Angle: Min [Max]**				
Latitude South	**Average Terrain**		**Very Mountainous Terrain**	
	Mid Summer	**Mid Winter**	**Mid Summer**	**Mid Winter**
35°	4½ 29 [76]	1 33.8 [35.4]	3 47.6 [76]	1 33.8 [35.4]
30°	4½ 28.6 [80]	2 32.2 [39.4]	3 48 [80]	1 37.6 [39.4]
20°	4½ 27 [88]	$2^3/_4$ 32 [47.4]	2½ 54.7 [88]	1 45.2 [47.4]

5.2 Digital Imagery

The values of the time intervals (Table 2) are extracted from the version 1 of the "Standard for the Acquisition of Digital Aerial Imagery" (CD: NGI, 2010). They show that the flying time for both terrains has been reduced for mid-summer and increased for mid-winter. That made the minimum sun angle to be significantly above 30° for mid-summer for both terrains and below 30° for mid-winter for the average terrain. Thus, the minimum sun angle for mid-summer, on the average terrain, was increased significantly from the analogue to the digital era. However, it was decreased for the mid-winter season, on the average terrain.

Table 2. Relationship between flying times and the corresponding sun angles for digital imagery Digital Standard (version 1 of December 2010)

HOURS BEFORE OR AFTER LOCAL NOON Solar Angle: Min [Max]				
Latitude South	**Average Terrain**		**Very Mountainous Terrain**	
	Mid Summer (January)	**Mid Winter (July)**	**Mid Summer (January)**	**Mid Winter (July)**
35°	4 35.2 [76]	2 28.8 [35.4]	3 47.6 [76]	1½ 31.7 [35.4]
30°	3½ 41.5 [80]	2½ 28.4 [39.4]	2½ 54.5 [80]	1½ 35.3 [39.4]
20°	3 47.8 [88]	3 30.8 [47.4]	2 61.7 [88]	2 38.8 [47.4]

5.3 Accepted Flying Times

The Standard stipulates that the minimum sun angle should be 30°. Mapping organisations around the world also adhere to this rule. The later chapters in this paper illustrate that a sun angle below 30° is not feasible for the CD: NGI. Therefore, it was decided to stick to the rule of 30° in the version 2 of the "Standard for the Acquisition of Digital Aerial Imagery" (CD: NGI, 2013). Table 3 below shows the accepted time intervals where the minimum solar angle of 30° has been achieved. Flying times at a latitude of 25°S were also introduced. The sun angles were calculated at a longitude of 25° East, similarly as it was done on the previous tables.

Table 3. Relationship between flying times and the corresponding sun angles for digital imagery Digital Standard (version 2 of December 2013)

HOURS BEFORE OR AFTER LOCAL NOON Solar Angle: Min [Max]				
Latitude South	**Average Terrain**		**Very Mountainous Terrain**	
	Mid Summer (January)	**Mid Winter (July)**	**Mid Summer (January)**	**Mid Winter (July)**
35°	4 35.2 [76]	1½ 30.7 [35.4]	3 47.6 [76]	1 32.8 [35.4]
30°	4 31.8 [80]	2 30.4 [39.4]	3 48 [80]	1½ 35.3 [39.4]
25°	4 31.1 [85]	2½ 32.2 [44.4]	3 48 [85]	1½ 39.8 [44.4]
20°	4 30.2 [88]	3 30.8 [47.4]	3 47.5 [88]	2 40.4 [47.4]

Table 4. Represents the time, gained or lost, in hours, between version 2 and 1 of the Standard

TIME GAINED / LOST				
Latitude South	**Average Terrain**		**Very Mountainous Terrain**	
	Mid Summer (January)	**Mid Winter (July)**	**Mid Summer (January)**	**Mid Winter (July)**
35°	0	-1/2	0	-1/2
30°	+1/2	-1/2	+1/2	0
25°	N/A	N/A	N/A	N/A
20°	+1	0	+1	0

Table 5. Local noon in South Africa, at various longitudes and seasons

LOCAL NOON				
Longitude	**Mid Summer (Jan/Feb)**	**Mid Autumn (April/May)**	**Mid Winter (July/Aug)**	**Mid Spring (Oct/Nov)**
19°	13:00	12:45	12:45	12:30
25°	12:30	12:15	12:30	12:00
31°	12:00	12:00	12:00	11:45

5.4 Thirty Degrees (30°) as a Minimum Solar Altitude

In order to prove the correctness of the proposed flying times, as shown in table 3, the flying times were calculated using the Canadian web-based utility for a solar altitude of 30°. The calculations were done for January and July corresponding to the middle of summer and winter respectively. The longitudes of 19°, 25° and 31°E were used in order to cover the E-W extent of South Africa. The local noon is written in brackets next to each longitude. The latitudes 20°, 25°, 30° and 35°S were used, as to cover the N-S extent of South Africa.

Table 6. Represents the flying times at 30° solar altitude

Mid Summer (January)						
Latitude	**Lo 19° (13:00)**	**Hours from noon**	**Lo 25° (12:30)**	**Hours from noon**	**Lo 31° (12:00)**	**Hours from noon**
20°	8:45 - 17:00	4:15	8:15 - 16:45	4:15	8:00 - 16:15	4:00
25°	8:45 - 17:15	4:15	8:15 - 16:45	4:15	7:45 - 16:30	4:15
30°	8:30 - 17:15	4:30	8:15 - 16:45	4:15	7:45 - 16:30	4:15
35°	8:30 - 17:15	4:30	8:15 - 16:45	4:15	7:45 - 16:30	4:15
Mid Winter (July)						
Latitude	**Lo 19° (12:45)**	**Hours from noon**	**Lo 25° (12:30)**	**Hours from noon**	**Lo 31° (12:00)**	**Hours from noon**
20°	10:00 - 15:45	2:45	9:30 - 15:15	3:00	9:00 - 15:00	3:00
25°	10:15 - 15:30	2:30	9:45 - 15:00	2:45	9:30 - 14:30	2:30
30°	10:45 - 15:00	2:00	10:15 - 14:30	2:15	9:45 - 14:15	2:15
35°	11:15 - 14:15	1:30	11:00 - 14:00	1:30	10:30 - 13:30	1:30

It can be concluded from the above results that:

- The flying times (from local noon) vary in summer from 4 hours to 4.5 hours, which is in conformity with the flying times of 4 hours (from local noon), as shown in table 3.
- During summer the total flying times are almost the same at all the latitudes and longitudes.
- The flying times (from local noon) vary in winter from 3 hours to 1.5 hours, at the latitudes 20° to 35°S, respectively, which is in conformity with the flying times as shown in table 3.

6. Twenty Degrees (20º) as a Minimum Solar Altitude

6.1 Calculations for 20º as a Minimum Solar Altitude

In order to get an idea of how the flying times change and the total time gained if solar altitude is dropped from 30° to 20° (as shown in table 7), flying times were calculated in a similar way as described above, in 5.4. The calculations were done for January, April, July, and November, corresponding to the middle of summer, autumn, winter, and spring, respectively. Results for mid-summer and mid-winter are exposed below (Table 7).

Table 7. Represents the flying times at 20° solar altitude
(Local noon in brackets)

Mid Summer (January)									
Latitude	**Lo 19º (13:00)**	**Hours from noon**	**Total time gained**	**Lo 25º (12:30)**	**Hours from noon**	**Total time gained**	**Lo 31º (12:00)**	**Hours from noon**	**Total time gained**
20º	8:00 - 18:00	5:00	1:30	7:30 - 17:30	5:00	1:30	7:15 - 17:00	4:45	1:30
25º	7:45 - 18:00	5:15	2:00	7:30 - 17:30	5:00	1:30	7:00 - 17:15	5:00	1:30
30º	7:45 - 18:00	5:15	1:30	7:30 - 17:45	5:00	1:30	7:00 - 17:15	5:00	1:30
35º	7:45 - 18:00	5:15	1:30	7:15 - 17:45	5:15	2:00	7:00 - 17:15	5:00	1:30
Mid Winter (July)									
Latitude	**Lo 19º (12:45)**	**Hours from noon**	**Total time gained**	**Lo 25º (12:30)**	**Hours from noon**	**Total time gained**	**Lo 31º (12:00)**	**Hours from noon**	**Total time gained**
20º	9:00 - 16:45	3:45	2:00	8:30 - 16:30	4:00	2:00	8:15 - 16:00	3:45	1:30
25º	9:15 - 16:30	3:30	2:00	8:45 - 16:00	3:45	2:00	8:30 - 15:30	3:30	2:00
30º	9:30 - 16:15	3:15	1:30	9:15 - 15:45	3:15	2:00	8:45 - 15:15	3:15	2:00
35º	10:00 - 16:30	2:45	1:30	9:30 - 15:15	3:00	3:00	9:00 - 15:00	3:00	3:00

6.2 Findings Regarding Flying Times for 20º

- The flying times (from local noon) vary in summer from 4.75 hours to 5.25 hours.
- The flying times (from local noon) vary in winter from 2.75 hours to 3.75 hours.
- Due to the fact that the local noon comes earlier in the eastern parts of the country, there is about an hour difference in the local noon from east (longitude 31°E) to west (longitude 19°E).

- Throughout the year, along the longitudes of 31°E, 25°E and 19°E noon occurs from 11:45 to 12:00, 12:00 to 12:30 and 12:30 to 13:00, respectively.
- Irrespective of longitude, the total flying times for a specific season are the same at a fixed latitude. In other words; the solar altitude, in the east-west direction, does not affect the total flying time in any given day, however, it affects the starting and finishing flying time.
- In autumn and winter, about two hours of the total flying time is lost from low to high latitudes. However, during spring and summer, the total flying times are almost the same at all the latitudes (as it is reflected in table 7).
- Using 20º as a reference/minimum solar altitude, imagery can be taken as early as 06:30 in spring in the most eastern parts of South Africa and in summer as late as 18:00 in the western parts of South Africa. It means that there would be a two-hour gain in total flying time (if 20º was accepted as a minimum solar altitude, instead of 30º).

6.3 Results from the Divisions of CD: NGI

6.3.1 Field Surveys

- The imagery flown at 20º solar altitude has longer shadows and makes the identification of photo ground control points difficult. This would affect production and costs as new appropriate ground control points would have to be surveyed. Also, a few of these newly surveyed points would be carried forward because of the position of the shadow changes depending on time of the day. This means that the capacity, in terms of human resource, would have to be increased in the field surveys, in order to keep up with the demand of surveying of new photo ground control points, whenever the area is re-flown (Snijders, 2013).
- In addition to the above statement, if the tie strips are be flown at the later time, it could also cause a few more points being unusable.
- An option would be to use the multi-ray photogrammetry technique, which does not require a significant amount of control points. With this technique, some points would still be identifiable as the side and forward overlap is 60% and 80%, respectively. Therefore each pixel would be covered by more than eight images (Vexcel).

6.3.2 Reprographic

- Generally, the imagery flown at a lower solar altitude (less than 30º), over the mountainous areas, does not look good visually due to the longer shadows (Hayman, 2013).
- Depending on the season, leafy trees may cast a far more extensive shadow than bare vegetation, and this may cause ambiguities on the ground.
- There is a loss of details because, in some images, shadows dominate the image to such an extent that the colour and the shape may not be easily identified. This degrades the overall quality of the image.
- If longer time windows are to be flown, then the area would have to be taken into account and examined more closely in the flight planning component of the job.

6.3.3 Aerial Triangulation and Elevation Capture

- Auto-correlation did not present problems in the AM imagery, except in the mountainous areas, where the shadows were too long. However, in the PM imagery the shadows were far greater than the AM imagery; hence manual measurements were required to complete the tie point matching process (Tang, 2013).
- The imagery, flown at a solar altitude of 20º, is sufficient for a quick DEM generation.
- For the morning AM imagery, the compilation of break-lines was successful in the non-shadow areas, and it was time consuming on the darker areas, as the operator was more involved in this case. Therefore, the elevation capturing process requires an experienced photogrammetrist, as putting break-lines in the dark may be complicated (Havenga, 2013).
- In the built-up areas, no problems were faced with elevation capturing, as there were many identifiable "bright" features with a regular shape.

6.3.4 Ortho-Rectification

- The ortho-rectified images for the SOLAR_AM & PM imagery were visually unappealing, as the shadows were exaggerated in comparison with the ortho-rectified images created from imagery flown during the standard specified times (Hugo, 2013).
- The shadows were more problematic in areas of high terrain variation. More manipulation of seam-lines was thus required.
- Greater terrain differences caused unpleasant problems with shadow matching and tonal/colour balancing, even along the vertical seam-lines, which usually do not need major manipulation.
- Furthermore, the software struggled to achieve an even tonal/colour balance due to the deep extensive shadows. In some cases these problems could not be resolved. These problems were far more noticeable in the 12-bit imagery, and less so in the 8-bit version of the imagery.

6.3.5 Compilation

- The longer shadows in the AM photography hide objects and were much darker. The PM images were too red in colour. The obscured objects, such as buildings, ruins, telecommunications poles, diggings etc, may be missed entirely. Also, the placement or shape of these objects may end up inaccurately captured. However, due to the longer shadows, walls or objects with depth were easier to identify on the AM and PM photography as shadows tend to emphasize a 3D view of the object (Swart, 2013).
- Based on the evaluation done by the Compilation Division, colours in the current specification photography ("main" job) are brighter, trees are greener, red roofs are redder, as compared to the AM and PM imagery. This was as the result of the brighter sunlight, or lack thereof (for AM and PM).

- The compilation process may be potentially faster if it is done in a 3D environment, but it is not always possible to work in a 3D environment due to the lack of resources. Furthermore, the rate of compilation would be affected as a constant swoop between 2D and 3D would be required.

6.3.6 Advanced Applications (Land Cover and Image Classification)

- The lack of rectified Near Infra-Red (NIR) band hindered the possibilities of classifying vegetation more accurately. This lack is because the Ortho-rectification Division focuses on rectifying the Red, Green and Blue (RGB) bands, due to the lack of capacity, amongst other factors.
- It was impossible to classify the urban area without the NIR band, even on the imagery captured during normal flying times.
- At a solar elevation of 20 degrees (i.e., imagery acquired at 8am and 4pm) the shadows are significantly greater than those in the standard imagery (solar elevation of 30 degrees). These large shadows make image classification difficult since much of the detail present in the image is obscured by shadows. The shadows result in the appearance of additional classes not present in the original imagery. In Figure 1, the difference in season is also clear (Duncan, 2013). Standard imagery shown in Figure (left) was acquired in May 2012, while the other images were captured in August 2012. The lack of vegetation in Figure 1 (right) can be seen when compared to that in Figure 1 (left). The shadow in the middle image in Figure 1 obscures the vegetation and built-up areas in the scene.

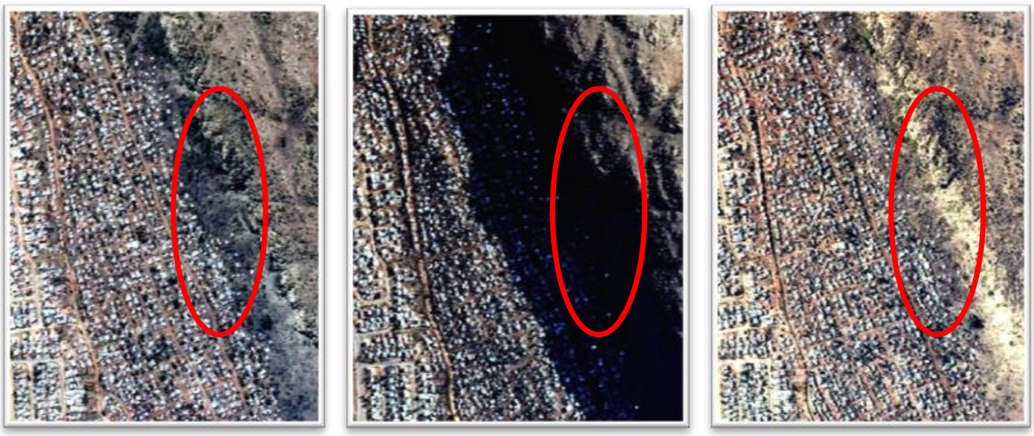

Figure 1. Portion of the urban scene (orthoimage 2528CB24);
left: Standard aerial imagery; middle: 8am imagery, right: 4pm imagery.

- As expected, the shadows are greater in the mountainous areas compared to the flatter regions, making image classification more difficult in these areas.
- Classifying imagery with significant amounts of shadow is possible (Figure 2 and 3), but would require manual intervention from the user to identify features hidden by shadow, and this is not optimal.

Figure 2. Portion of the mountanious scene (orthoimage 2427BC21; left 8am and right 4pm)

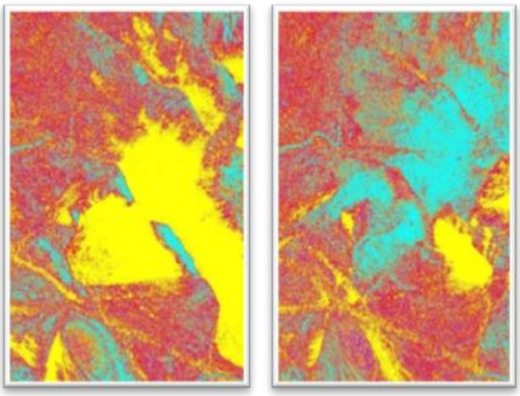

Figure 3. Portion of the mountanious scene in Figure 2 classified

- The problems experienced, such as the inability to distinguish inside shadows, may be diminished by using 12-bit imagery, but this was not included in the study, as it is not a standard CD: NGI product.
- When flying outside of the normal flying hours (i.e., imagery acquired at 8am and 4pm), the amount of mixed classes increases by over 20% (Verhulp, 2013). As a result, the software could not distinguish the differences between ground types with large shadows, which makes an unsupervised classification unsuitable (Figure 4).

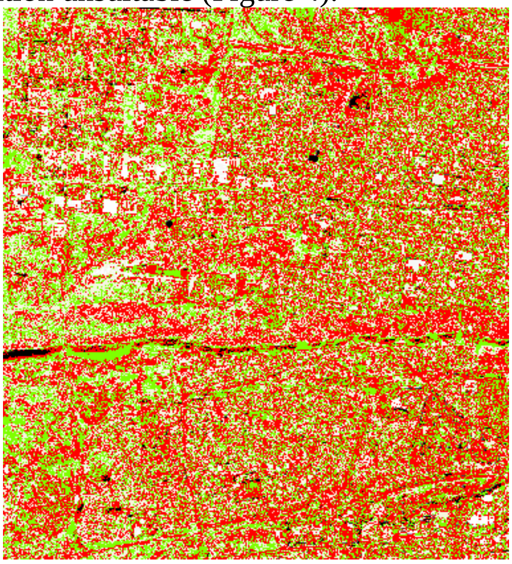

Figure 4. An example: Almost the entire image is mixed class (red)

6.3.7 Other Notes

- CD: NGI should look into increasing the forward and side overlaps to about 80% and 60% respectively, as this has proven that one object can be captured and viewed from many different angles. In that case, images covering the same area will have less shadow than others. Furthermore, as the technology advances, the use of 12-bit imagery will become possible and more information will be extracted, especially if the multi-ray photogrammetry is employed (Vexcel).

- The current Standard stipulates that the minimum sun angle should be 30°. Mapping organisations around the world also adhere to this rule. The chapters in this report illustrate that a sun angle below 30° is not feasible for the CD: NGI. Therefore, the flying times in the version 2 of the Standard were slightly modified, in order to adhere to the minimum solar angle of 30°. Flying times at a latitude of 25°S were also introduced, as explained previously (CD: NGI, 2013).

7. Final Conclusions

7.1 Advantages and Disadvantages

- The main advantage in using 20º as a reference/minimum solar altitude is that it increases the total daily flying time by about two hours.
- The main disadvantage in using 20º as a reference/minimum solar altitude is the extensive shadow. All the processes in the production line become affected and more difficult to perform. Imagery with too much shadow requires manual interference in all the Divisions, thus, slows down the production processes, such as the identification and survey of additional photo ground control points, photo interpretation, classification of imagery, compilation, rectification, etc.
- Also, the problem in using 20º as a reference/minimum solar altitude is that the ortho-rectified AM & PM imagery becomes visually unpleasant because of the exaggerated shadows.
- The ortho-rectified map sheet in the 1:10 000 map production processes uses the orth-rectified imagery as the background for its maps and the visual impact of the low sun angle will be very real for the end user of such maps (Kinsey, 2013).

7.2 Recommendations

- CD: NGI should continue to obey the 30º reference/ minimum solar altitude.
- CD: NGI should investigate using of the multi-ray photogrammetry technique.
- CD: NGI should consider using of 12-bit imagery.
- CD: NGI should consider rectifying the NIR band.

8. Acknowledgement

The authors are grateful to the Managers of the Divisions of the CD: NGI for their findings and reports, on which this research has depended and final recommendations delivered.

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