

The status of aerial photogrammetry in South Africa: a transition to digital imagery system

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Abstract

The digital image camera technology has revolutionized the aerial imagery capture throughout the world. It has provided high spatial and spectral resolution together with superior efficiency and reliability compared to the traditional analogue aerial imagery method. In so doing, this has provided great accuracy in various photogrammetric applications. The South African survey and mapping organisation currently known as Chief Directorate: National Geospatial Information (CD: NGI) has been capturing aerial photography dating back as early as the 1930s. However, from 2008 CD: NGI embraced a transition to digital aerial imagery capture at 50cm Ground Sample Distance (GSD) (from 2008 to 2016) and 25cm GSD (as from 2017 till date). This has resulted to 1370 digital aerial imagery already captured (this number will continue to change as there are jobs that are still being flown which are yet to be recorded). The continuous enhancement of digital camera technology opens for more possibilities of national aerial imagery capture at even greater spatial resolution such as 10cm GSD in the foreseeable future.

However, the continuous digital imagery capture has not been without challenges such as the current global Covid-19 pandemic which has resulted in budget reprioritization, the organisation's technical knowledge transfer from one generation to another together with the determination of the CD: NGI requirement for digital imagery specifications. The organisation values stakeholders' engagement to ensure relevance, completeness and consistency on the data produced. This is possible through collaboration and partnership between State institutions, the private sector, research, and tertiary institutions through sharing of resources.

1. Background

The year 2020 marked the completion of a centenary of surveys and mapping under the Chief Directorate: National Geospatial Information (CD: NGI) within the National Geomatic Management Services (NGMS) branch in the Department of Agriculture, Land Reform and Rural development (DALRRD). These 100 years also represent the fruition of research, science and technology in South Africa. As the organisation celebrates its centenary year in the Geomatics field in South Africa, vast literature reviews on the history and achievements of the organisation dating back from its 90th

celebration have been well documented (Wonnacott, 2010; Zakiewicz, 2008; Voster, 2003). Consequently, this paper does not seek to replicate what has already been published and archived by the organisation but rather provides an in-depth perspective on the transitioning to digital imagery acquisition in the country.

Since its establishment, the office of surveys and mapping has evolved with time and thus adapting to changing environment and political landscapes. The name of the organisation has evolved from Trigonometrical Survey Office (TSO), through to Chief Directorate: Survey and Land Information (CDSLI); Chief Directorate: Surveys and Mapping (CDSM) to now the Chief Directorate: National Geo-spatial Information (CD: NGI). However, the founding principles of surveys and mapping remain the same - to provide geospatial information particularly geodetic and topographic survey information for the country. These are further entrenched in the Land Survey Act (Act no 8 of 1997) which stipulates the following main functions of CD: NGI as Survey and Mapping Organisation: to maintain and further develop the national control survey system, to collect geospatial information and revise maps of the national topographic mapping, to acquire aerial photography and other earth observation imagery for the State and, lastly, to provide advisory and other specialised services in the surveys and mapping field.

The geospatial information, by virtue of its ubiquity, has taken a central dominant position with the changing world due to its vast applications in assisting in decision-making from environmental, economic, social and political activities. Furthermore, geospatial information has been strengthened by its incorporation on the development, implantation and evaluation of policies (Avignon, 2012). Today, government, businesses and the general community rely on geospatial information for practical daily management of amenities. To illustrate this assertion, Mcdougal *et al.*, (2007) deliberate that, in an emergency services and disaster management, the value of accurate and relevant information such as location address, vehicular access, property ownership, climate and topography are crucial for directing and managing response efforts.

South Africa has also recognised the importance of geospatial information. This has been supported through the Spatial Data Infrastructure Act No 54 of 2003 (SDI Act, No 54, 2003). The aim of this Act is to establish a Committee for Spatial Information (CSI), to provide guidance for the determination of standards and geospatial information sharing, to develop electronic metadata catalogue for avoidance of geospatial data duplication and to deal with all unforeseen matters related to geospatial data. The CSI is a functional legal, institutional and technical framework of the South African Spatial Data Infrastructure (SASDI) and is aligned to the Global Spatial Data Infrastructure (GSDI). It is responsible, amongst others, to advise the Minister, the Director-General and other organs of State on matters regarding the capture, management, integration, distribution and utilization of geospatial information. The CSI further appoints the nominated organ of State as either base data custodians or contributor for a specific geospatial dataset. The base data custodian would be the organ of State responsible for oversight of specific dataset while the base data contributor would be any organ of State, contributing information towards such dataset. The custodians of the fundamental geospatial datasets are the producers of the base data, which is defined by the ECA (2007): “*as the*

minimum primary sets of data that cannot be derived from other data sets, and that are required to spatially represent phenomena, objects, or themes important for the realisation of economic, social and environmental benefits consistently, locally, provincially and nationally”. The CD: NGI has been capturing and contributing to fundamental dataset for years, since the 1920s and was thus officially appointed as the base data custodian and base data coordinator for aerial imagery, geodesy, and national land cover geospatial datasets.

2. Introduction

The geospatial datasets generated and processed by the CD: NGI are stored, maintained and managed in the integrated topographic information system (iTIS) database. The geospatial dataset entails topographic vector data, aerial raw imagery, orthorectified imagery, flight index and footprint, aerial triangulation, geo-names, digital elevation model (DEM) and land cover data (Figure 1).

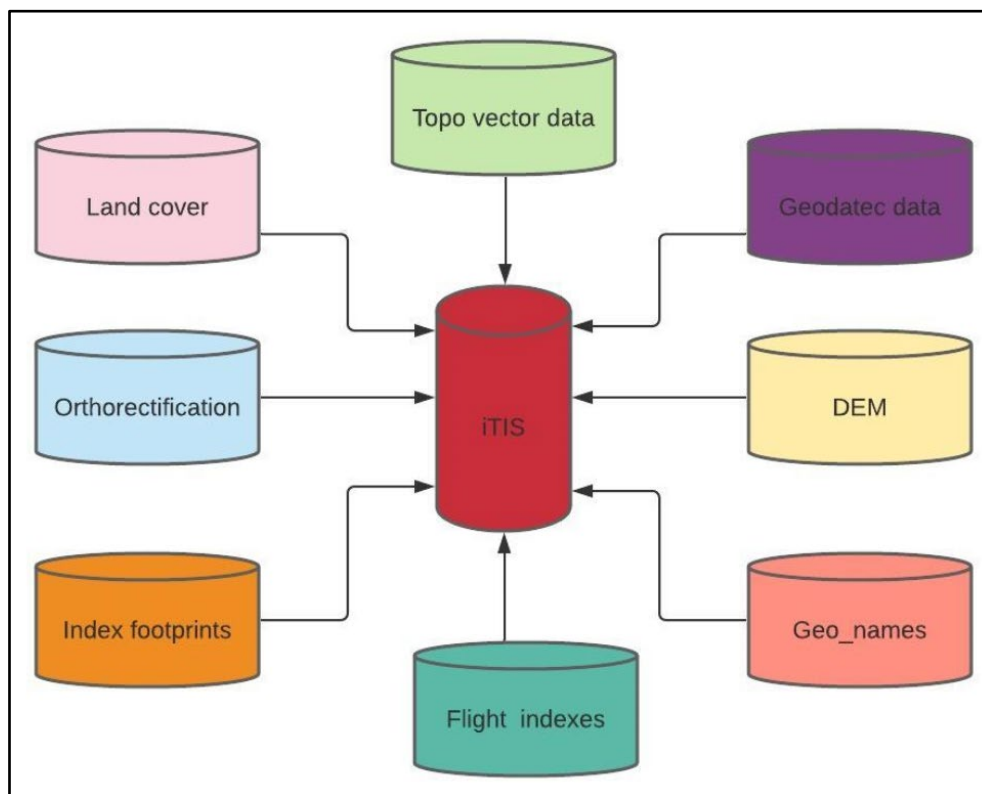


Figure1: Example of the CD: NGI geospatial datasets stored and maintained through its integrated topographic information system (iTIS) database.

In South Africa, the first aerial imagery coverage of the whole country took more than twenty years from 1930s to 1950s using traditional analogue cameras (Zakiewicz, 2008; Wonnacott, 2010). This rather long span was due to several factors including high costs for aerial imagery capture and pre-processing over the vast land area of South Africa and limited required expertise. Thus, leading to the acquisition of aerial imagery with the analogue technology of the time done over selected areas

of interest until 2008. The traditional analogue system is a frame-based photochemical process of developing hard copy imagery, which must be scanned for further digital analysis.

With the history of traditional analogue system well documented in literature (Wright, 1987; Light, 1996; Collier, 2002; Neumann, 2008), the 1990s and early years of 2000s saw evolution of earth observation at a quick pace due to great technological developments, with consequent development of digital aerial imagery. Acknowledging such technological developments in aerial photography, Wonnacott (2010) asserted that the future of geospatial topographic mapping hinged on embracing the digital developments of aerial and satellite imagery capturing. Thus, this paper focuses on the status of digital aerial imagery capture and future strategy by the CD: NGI.

3. Digital Aerial Imagery Capture

In keeping with developments, in 2008 the CD: NGI embarked on the new era of digital aerial imagery capture. The airborne digital sensor (digital aerial camera) provides an improved image accuracy and quality. The use of advanced automated operations offered by digital imagery capture facilitates increase in the number of flight hours per day and lessens number of days of aerial photography per year, thus reducing cost. The high radiometric competence capability to carry out flights even under weak light conditions or at low sun angles and still meet the image quality requirements for mapping is an added advantage (Verovencii, 2007; Ahmad, 2006; Kang *et al.*, 2008; Trinder, 2009). This renders digital aerial imagery to be more effective and efficient than the traditional analogue imagery.

In embarking on the transition to digital aerial camera, the CD: NGI's first task was the choice of suitable digital camera to use amongst the variety available on the market. The whole project of purchasing the camera was quite complex not only due to finances but mainly from the technical and operational points of view (Zakiewicz, 2008). The new methodology had to be suitable for immediate incorporation within the existing organisational mapping system. Furthermore, adjustments and adaption to the new technology were required from the staff. The purchase of the camera was done through a tender process with specification that the processing workflow of the potential camera should be seamless and compatible with existing photogrammetry workflow process of the CD: NGI. The preferred digital aerial imagery was frame-based because it was considered a close and natural follow-on to the historical analogue technology that was in operation (Zakiewicz 2008). Other technologies like push-broom and Bayer filter were deemed not suitable for seamless workflow within the organisation. They (push-broom and Bayer filter) would require a complete and expensive re-organisation of the production process workflow and, therefore, were not acceptable. With the frame-based aerial digital cameras, however, the following sensor technical specifications were required: The digital sensor had to be capable of capturing panchromatic and at least four multispectral bands, namely red, green, blue (RGB) and the near-infrared band (NIR) simultaneously. It had to be able to produce high spatial resolution in a range of 0.25m – 0.75m ground sample distance (GSD). Also it had to capture imagery with a minimum of 12-bit radiometric resolution

which afterwards could be re-processed to 8 bit resolution for each spectral sensor; the accuracy of the focal length should not be less than 1 micron; a certificate confirming its radiometric and geometric calibration had to be provided; the camera should operate within global navigation satellite system (GNSS) and inertial navigation system (INS) to collect data on the position and exterior orientation of the imagery. Lastly, the system should be able to provide an image footprint coverage width equivalent to a traditional large format aerial film camera's (Zakiewicz, 2008).

The Intergraph's Digital Mapping Camera version 1 (DMC1) was deemed suitable camera and purchased by the CD: NGI. The camera specifications entail the following: *it is a large format (13 824 * 7 680 pixels) metric frame camera; Custom optics by Carl Zeiss (F = 120mm and FOV = 70° * 42°); Nominal ground resolution of 65cm; Electronic forward motion compensation; Radiometric resolution is 12-bit; Frame rate is 2.1 sec / image; 4 spectral bands (Red, Green, Blue & NIR), pan-sharpened.* However, due to lack of capacity to operate the newly acquired aerial digital camera, coupled with lack of suitable aircraft, the only option was to outsource the camera operation through a partnership program. Though, this could be viewed as a controversial decision, the CD: NGI at the time had to encourage the South African market to invest in digital aerial imagery, and then take significant steps to grow the field. Due to the challenging nature of selecting the right camera specification to address CD: NGI requirements, this exercise was deemed necessary. It would serve to pave the way for interest groups to purchase digital cameras with the requisite specifications to enable them to embark on future CD: NGI contractual work.

The organisation therefore embarked on a collaborative arrangement to ensure that 60% of the aerial imagery capture was done using the newly acquired digital aerial camera through private sector partnership. The remainder of the 40% was executed through open tender process for private sector with similar camera specifications but not limited to the use of Intergraph's DMC1 purchased by the CD: NGI. The first digital aerial imagery was captured at 50cm Ground Sample Distance (GSD). The first full country digital aerial imagery coverage at 50cm GSD was completed in 2012 and the second coverage in 2016 as per Figure 2 and Figure 3, respectively. There were 58 images captured during the first year in 2008 followed by 131 in 2009, 118 in 2010, with 105 in 2011 and 134 in 2012, thus resulting to 546 total imagery capture. The second digital aerial imagery cycle, still at 50cm GSD continued from 2013 to 2016, improving capture cycle to four years. There were 174 images captured in 2013, followed by 133 images in 2014, with 166 in 2015 and 152 in 2016, resulting in a total of 625 images captured. This resulted in certain parts of the country being recaptured. This was envisaged to contribute in reducing the number of years for a full country imagery capture. Through the National Imagery Mapping Advisory Committee (NIMAC), requests by other government entities to capture digital aerial imagery at a higher resolution were discussed. The increase in aerial imagery resolution or GSD also entails increase in the budget together with technological advancements. It also entails the increase in the number of aerial images to be captured to cover the whole country. During this time an all-inclusive cost benefit analysis on the continuous use of the aerial imagery capture of higher resolution with DMC1, through a partnership program, would be a costly operation compared with other available technologies. This provided a gap to explore the consequences of

increase GSD of digital aerial imagery capture as requested from the NIMAC discussions. The collaborative digital aerial imagery capture ended in 2016 thus resulting in the decommissioning of Intergraph's DMC 1 and its auction by the Department.

The year 2016 witnessed the capture of digital aerial imagery at 25cm GSD purely on digital cameras on the market that met the CD: NGI operational requirements mentioned earlier. This is regarded as the third digital aerial imagery coverage cycle. There were 152 images captured in 2016, followed by 88 images in 2017, with 82 images in 2018, with 16 in 2019 and 13 in 2020 (Figure 4). The total images captured at 25cm GSD was 351, with some parts of the country yet to be covered (Figure 5). Although there have been evident successes with the digital aerial imagery capture, they have not been without challenges such as meeting technical specifications requirements by the CD: NGI and the budget cuts which are taking place generally in the public sector. The aerial imagery acquisition plan had to be revised from a three-year (2016 - 2018) coverage to a five-year (2017-2021). The coronavirus pandemic (also known as Covid-19) has also affected the aerial imagery capture plan for 2020-2021 financial year. Six months in the capturing plan were lost. The plan for 2021-2022 financial year would provide a first cycle completion of 25 GSD country coverage.

The vast datasets of the CD: NGI are easily accessible at walk-in client centres in Cape Town, Pretoria and at offices of the various Surveyors General, via email request, through commercial vendors and through managed relationships with District Municipalities. Accessibility is further enhanced with the launch of the geoportal facility. The geoportal also provides the advantage of improved data accessibility from anywhere and by anyone, thus making the CD: NGI geospatial datasets readily available to users (cdngiportal.co.za/cdngiportal/). The organisation further participates in technical committees nationally, within the African continent and globally aligning itself with the implementation of geospatial information policies and governance. Such collaborations and participations enhance the continuous capacity-building and knowledge transfer. As the aerial imagery base data custodian and the base data coordinator, the CD: NGI in 2020 embarked on a collaborative role through the development of the South African aerial imagery committee. The collaboration seeks to develop the first South African digital aerial imagery capture standard with the aim of enhancing the quality of imagery capture for common use and for adaption by users of diverse background.

4. Conclusion

The potential value of geospatial information has vastly increased over the years. It is viewed as the capital that cannot be depleted, with immense theoretically unlimited range of applications (OECD, 2015). To continue with the geospatial data capture, the CD: NGI embarked on the transition journey from analogue to digital aerial imagery capture. This has been motivated by wide ranging advantages of digital aerial imagery technical developments such as high radiometric and spatial accuracy. The ability for on-site quality checking of aerial imagery especially in-flight restriction areas brings both time and cost savings. The year 2008 witnessed CD: NGI embarking on its first

digital aerial imagery capture at 50cm GSD, which was improved to 25cm GSD by 2016-2017 financial year to date.

Although there have been great achievements in capturing digital aerial imagery by the CD: NGI, these have not been without challenges. Organisational transformation takes time, yet data may be required urgently (Light, 1996; Kedar, 2018). The CD: NGI has similar experiences with the organisation's technical knowledge transfer from one generation to another. The other challenge relates to budget limitation due to other more pressing needs the country experiences such as the current global Covid-19 pandemic which has resulted in budget reprioritization in South Africa. Above all, much has been attained such as data access. The service provided by CD: NGI is now accessible through geoportal (<http://www.cdngiportal.co.za/cdngiportal/>). The continuous thirst for still higher spatial resolution digital aerial imagery in the region of 10cm GSD is the future of aerial photography.

It is essential that the CD: NGI continues to embrace technology, research and development for robust methods for generation of geospatial information. Going forward, the organisation would engage its readiness regarding the evolution of big data, cloud storage, internet of things, artificial intelligence and geospatial convergence as part of its future strategy, as it provides national datasets and collaborates with various entities both locally and globally. The issues of data transmission, processing, integration and security are also of paramount importance. The value chain analysis provided through the National Imagery Mapping Advisory Committee (NIMAC) is vital in determining the impact of CD: NGI datasets to ensure usability, accessibility and availability. In so doing, the organisation's relevance and contribution through evidence-based decisions would be enhanced.

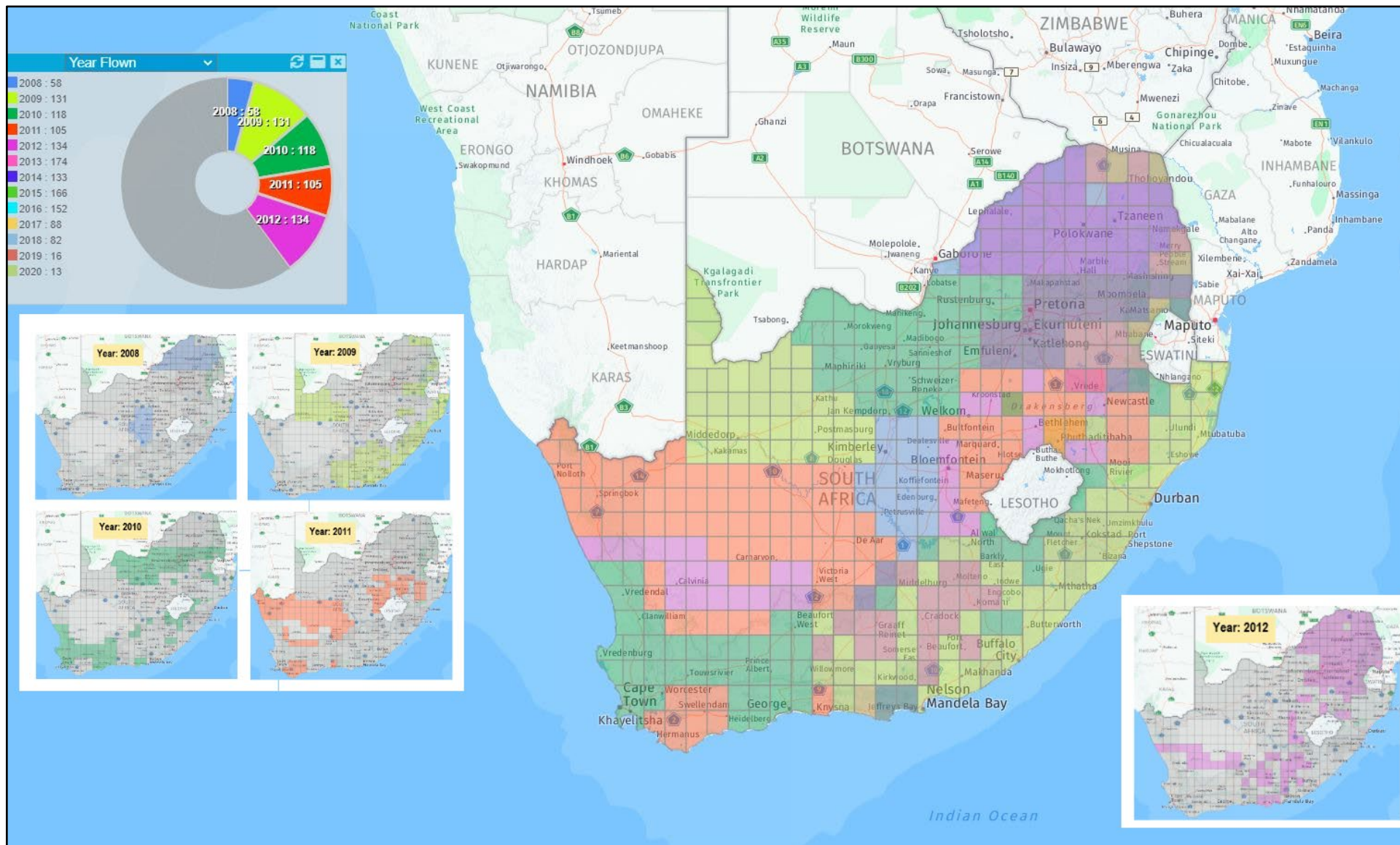


Figure 2: The first digital aerial imagery cycle at 50 cm ground sample distance (GSD) from 2008 to 2012 covering the country

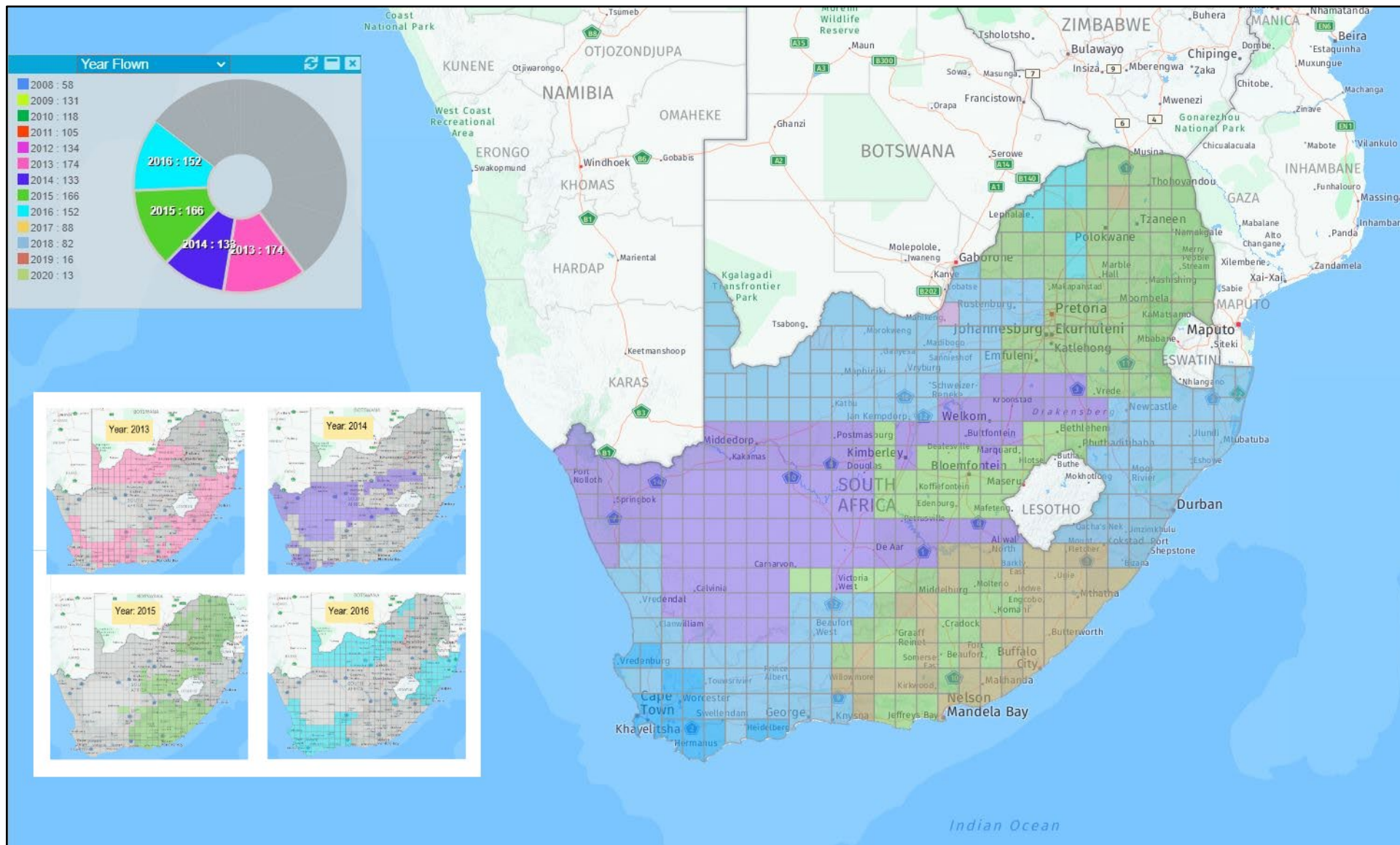


Figure 3: The second digital aerial imagery cycle at 50 cm ground sample distance (GSD) from 2013 to 2016 covering the country.

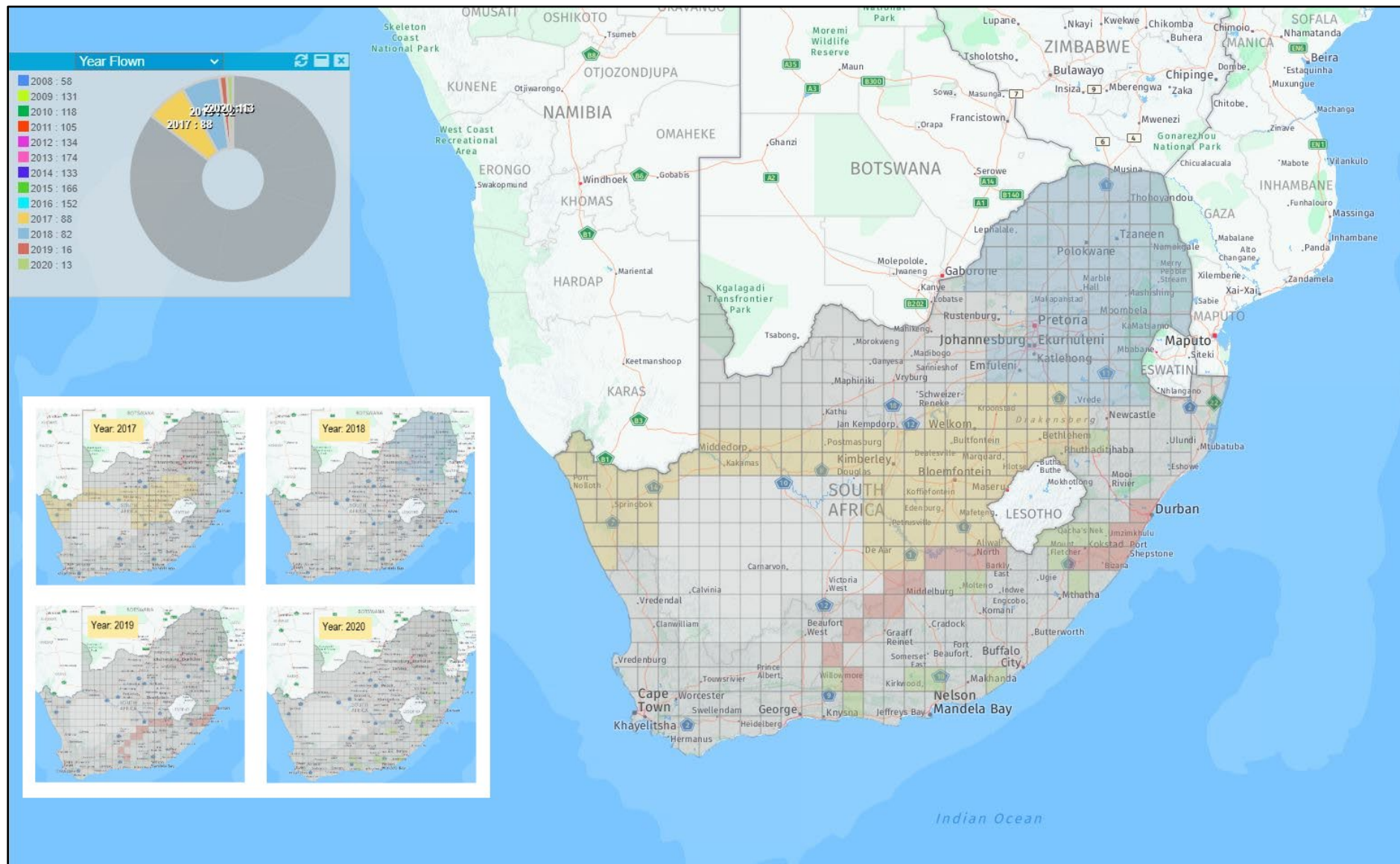


Figure 4: The third aerial digital imagery cycle at 25 cm ground sample distance (GSD) from 2016 to 2020; country coverage is not complete.

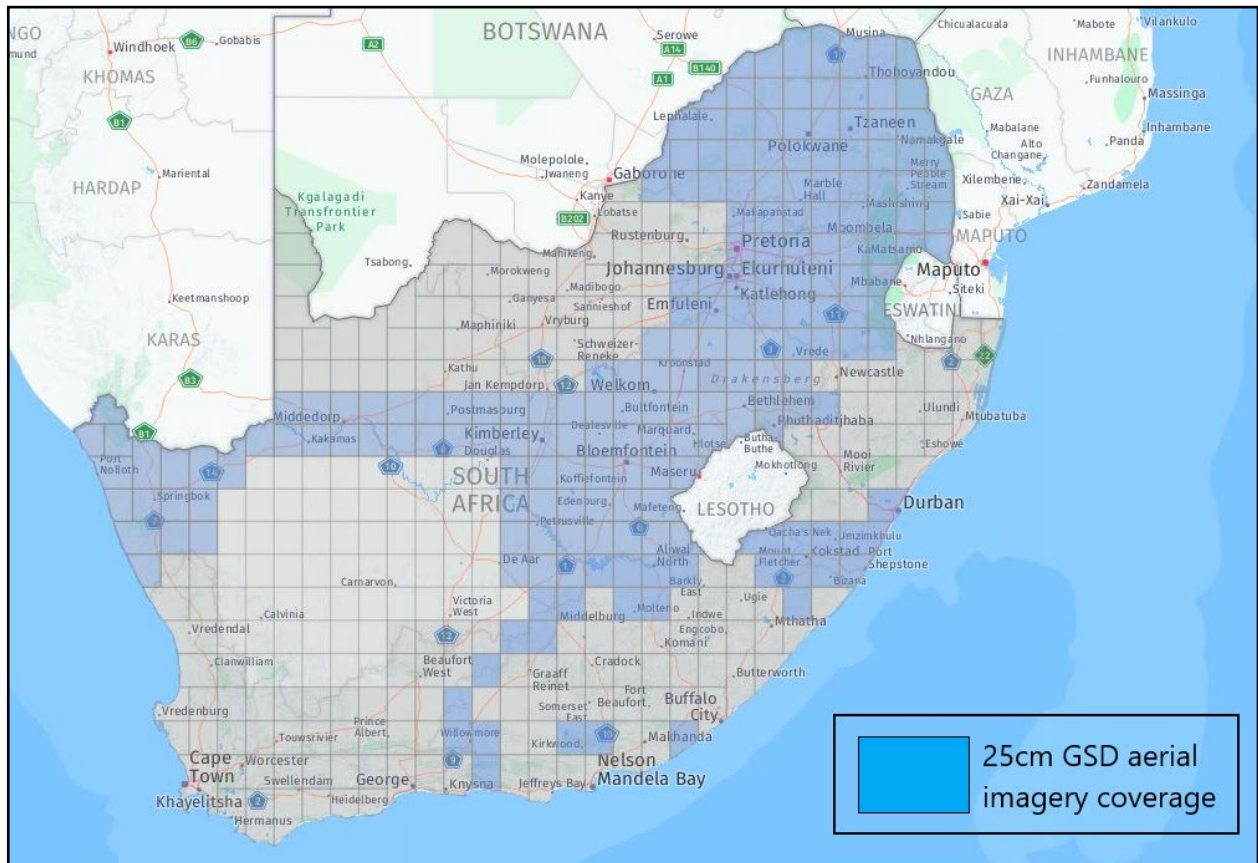


Figure 5: Current coverage of 25 cm ground sample distance of aerial imagery

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