WHITE PAPER

REMOTE SENSING

DigitalGlobe™

Remote Sensing Technology Trends and Agriculture

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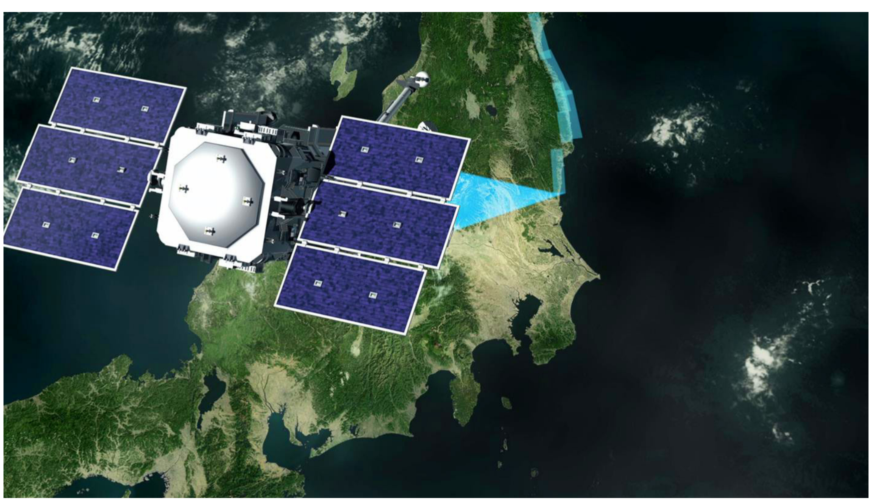
Introduction

The commercial remote sensing industry has turned a corner in capabilities that can address a variety of global applications including food security, global conflict, environmental issues, land sustainability, and more. This evolution can be primarily attributed to technological developments in the remote sensing industry as well as development of critical technologies such as increased computing power, mobile technology adoption, efficient distributed computing and dissemination, advanced pattern recognition technologies from medical imaging, robotics and machine learning, and others. The key catalysts that have transformed the geospatial industry include: the widespread acceptance of GPS technologies, smart phones, and mapping services offered by a variety of mapping portals such as Bing Maps, Google Earth/Maps, Nokia Maps, Baidu, and others globally. It is estimated that over two billion people on this planet are users of remotely sensed data and geospatial datasets, which includes data from a variety of geospatial technologies such as GPS, GIS, Remote Sensing, and CAD/BIM. Further, a recent report on the geospatial industry claims that geospatial technologies are an integral part of today's global economy, affecting 10% of global GDP.

Today's commercial remote sensing industry is primarily comprised of a variety of platforms including satellites, aerial, UAV's, and terrestrial sensors. Remotely sensed imaging is done using passive instruments that rely on reflected sun energy as well as active sensors that use their own energy such as RADAR, LIDAR and Sonar technologies. This paper will cover the trends, primarily passive remote sensing platforms, and will discuss trends of satellite, aerial and UAV platforms.



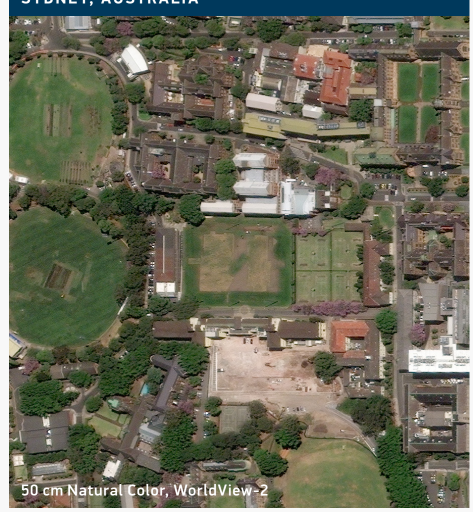
WEIZ, AUSTRIA

30 cm Natural Color, Aerial

PATTAYA, THAILAND

40 cm Natural Color, WorldView-2

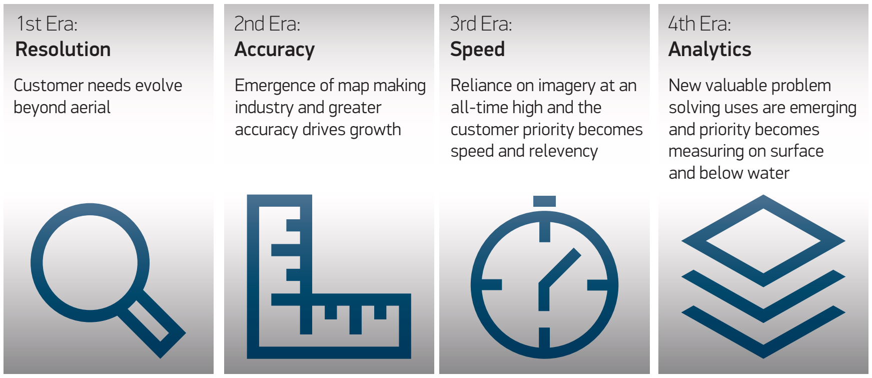
SYDNEY, AUSTRALIA



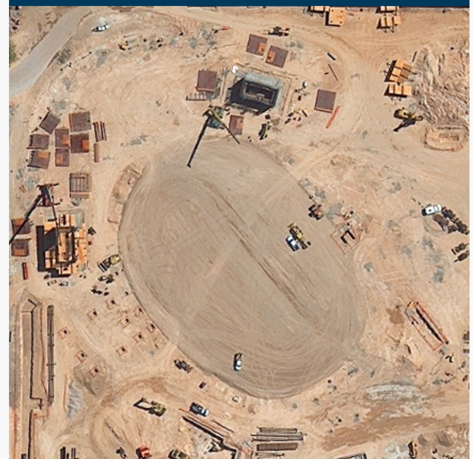
50 cm Natural Color, WorldView-2

Remote Sensing Trends

Global adoption of mapping and navigation applications by billions of users has transformed the remote sensing industry in the past decade. The transformation of the industry can be captured in 4 trends: Resolution, Accuracy, Speed and Analytics. The following sections detail the trends:



LAS VEGAS, NEVADA, USA



40 cm Natural Color, WorldView-3

Spatial Properties

Spatial resolution trends encompass advances in spatial, spectral, temporal and radiometric resolutions of various imaging sensors and platforms. Today's commercial remote sensing industry, especially the satellite industry, is comprised of sources from commercial as well as government, that make the imagery available for public consumption. In the following sections, we will discuss the trends of these commercial sensors and their impacts on agriculture.

Spatial quality

Spatial resolution is typically referred to by GSD (Ground Sampling Distance) or pixel size of the remotely sensed imagery. GSD is the minimum size that can be detected of the features on the ground. There are several standards that are used for representing spatial resolution, and NIIRS (National Imagery Interpretation Rating Scale) is one of the widely accepted schema that explains various features that can be distinguished based on panchromatic visible imagery as a function of effects such as pixel resolution, sharpness, noise, and contrast in (Table below). These effects can be caused by system parameters (e.g., optical quality, focal plane characteristics), acquisition conditions (e.g., sun angle, atmospheric haze, aerosols, water vapor), and exploitation conditions (e.g., duplicate film quality, softcopy monitor quality).

Civilian NIIRS rating	Features that can be distinguished
Rating Level 0	Interpretability of the imagery is precluded by obscuration, degradation, or very poor resolution.
Rating Level 1 (< 9 meters)	Distinguish between major land use classes (e.g., urban, agricultural, forest, water, barren). Identify large area drainage patterns by type (e.g., dendritic, trellis, radial).
Rating Level 2 (4.5-9 meters)	Identify large (i.e., greater than 160 acre) center-pivot irrigated fields during the growing season.
Rating Level 3 (2.5-4.5 meters)	Detect large area (i.e., larger than 160 acres) contour plowing. Distinguish between natural forest stands and orchards.
Rating Level 4 (1.2-2.5 meters)	Identify farm buildings as barns, silos, or residences. Count unoccupied railroad tracks along right-of-way or in a railroad yard. Detect jeep trails through grassland.
Rating Level 5 (0.75 – 1.2 meters)	Identify Christmas tree plantations. Distinguish between stands of coniferous and deciduous trees during leaf-off condition. Detect large animals (e.g., elephants, rhinoceros, giraffes) in grasslands.
Rating Level 6 (0.4 – 0.75 meters)	Detect narcotics intercropping based on texture. Distinguish between row (e.g., corn, soybean) crops and small grain (e.g., wheat, oats) crops. Detect foot trails through barren areas.
Rating Level 7 (0.2 – 0.4 meters)	Identify individual mature cotton plants in a known cotton field. Detect stumps and rocks in forest clearings and meadows.
Rating Level 8 (0.1 – 0.2 meters)	Count individual baby pigs. Identify a USGS benchmark set in a paved surface. Identify individual pine seedlings. Identify individual water lilies on a pond.
Rating Level 9 (< 0.1 meters)	Identify individual grain heads on small grain (e.g., wheat, oats, barley). Identify an ear tag on large game animals (e.g., deer, elk, moose).

The NIIRS schema allows for picking the right source of imagery based on the application. It is important to keep in mind that NIIRS rating for a given sensor might be different from NIIRS grouping due to the quality of the sensor characteristics as discussed above.

Since the 1972 launch of Landsat by NASA, the commercial remote sensing industry has seen a proliferation of satellites with varying spatial resolutions. The spatial resolution trends fall into 4 classes: Low Resolution (pixels of 30 m or worse), Medium Resolution (5 m to 30 m), High Resolution (1 m to 5 m), and very high resolution (1 m or better). For agricultural applications, there are a wide range of platforms providing imagery at multiple resolutions and frequency at the global and local scale. The following sections will discuss the sensors and sources of various satellite, aerial, and UAV platforms.

TOKYO, JAPAN

60 cm Natural Color, Quickbird

Low spatial resolution sources (> 30 meters)

Today's low resolution sensors are typically launched by governments to monitor the environment and global changes in natural resources and agriculture. These sensors typically have large swath widths and provide global coverage on a daily basis. The following table summarizes existing sources of low resolution and may specify a time window of up to 14 days, with which DigitalGlobe can conduct a feasibility assessment. However, once the order is placed, satellites image the AOI regardless of cloud cover at the time. Customers may cancel Single Shot orders up to 24 hours before the acquisition.

Satellite/Instrument	Resolution	Country
Aqua & Terra/MODIS	250-1000 meters	USA
Terra/Aster	15, 30, 90 meters	USA - Japan
Landsat 1, 2, 5	30 meters, 120 meters	USA
IRS-1/LISS	32.74 meters	India

MEXICO CITY, MEXICO

30 m Natural Color

Medium resolution satellite (5-30 meters)

There are several medium resolution sensors that are operational today. The operators of these sensors include a wide range of providers from government sources to the commercial industry. The medium resolution industry is on the cusp of a revolution, where commercial startups such as Planet Labs from the United States are planning to launch a constellation of micro satellites, or small sats, with a vision to make space satellites cheap and accessible. While these micro satellites are designed for a short life of 3 years or less, they can take advantage of changes in new sensor technologies and replenish the constellation with new capabilities, as compared to very high resolution satellites. Further, the constellation approach of medium resolution satellites offers a unique revisit for broad crop monitoring area on a daily basis. One of the disadvantages with micro satellites is the lack of pointing accuracy that results in poor positional accuracy on the ground.

Satellite/Instrument	Resolution	Country
SPOT 1, 2, 3, 5	5, 10, 20 meters	France
Rapid Eye (5 Satellites)	6.5 meters	Germany
PlanetLabs	3-5 meters (planned)	USA
IRS 1C-1D, RESOURCESAT-1	6 meters	India
DMC	22 meters	UK (launched for several countries including Nigeria and Algeria
GMES Sentinel-2-a/2b	10, 20 meters	European Union

BERLIN, GERMANY

10 m Natural Color

High resolution industry (1-5 meters)

High resolution imagery providers include a combination of government owned satellites, as well as commercial vendors that provide imagery at multiple resolutions. Skybox imaging, a commercial company from the United States, plans to launch a fleet of satellites that revisit a given place on the globe multiple times a day. The planned Skybox constellation would include four planes of sun-synchronous orbits with six satellites in each plane. The descending equatorial crossing would occur at 9am, 11am, 1pm and 3pm local time of day. The imagery from Skybox imaging will be affected by the diurnal changes in the crop conditions, making it challenging to use the data for agriculture applications. The optimum time for viewing is about 10:30am for production agriculture because this allows for early morning fog to lift, lets plants reach their normal, unstressed metabolic state, avoids afternoon cloud buildup, and avoids thermal stress which occurs around 6pm on hot days. So only one fourth of the planned Skybox constellation does its collection at the optimal time for agriculture. But for “pattern of life” applications, the Skybox approach makes it possible to assess human activity at four times of the day.

Satellite/Instrument	Resolution	Country
SPOT 5, 6	2.5 & 1.5 meters	France
Dove (Skybox imaging)	1 meter	USA
Cartosat 1, 2	2.5 & 1 meter	India
Ziyuan-2	3 meters	China
CBERS-2	2.7 meters	China/Brazil
THEOS	2 meters	Thailand
Kompsat-1	1 meter	South Korea

NORFOLK, VIRGINIA, USA

1 m Natural Color, WorldView-2

Very high resolution industry (< 1 meter)

The successful launch of Ikonos in 1999 formally signaled the start of the very high resolution commercial satellite imagery market at 1 meter resolution or better spatial resolutions. The past decade has seen an increase in satellite spatial resolutions that are positioned to compete with the traditional aerial markets. Today the very high spatial resolution market is primarily serviced by commercial industry, but there are a few government satellites, designed for military applications, that contribute excess capacity. These very high resolution imagery datasets are ideally suited for addressing small holder agriculture problems. In order to impact global agricultural issues, the agriculture industry will benefit from the planned constellation(s) increases that can provide essential global coverage and frequent revisits.

Satellite/Instrument	Resolution	Country
Ikonos, QuickBird, WorldView-1, Geoeye-1, WorldView-2, WorldView-3 (DigitalGlobe)	0.8, 0.6, 0.46, 0.41, 0.46, 0.3 (planned) meters	USA
Cartosat 2, 3	1, 0.25 (planned) meters	India
Pleaides 2A, 2B (Airbus)	0.7 meters	France
Kompsat 3	<1 meter	South Korea

Very high resolution imagery from aerial sources is currently being used for precision agriculture applications. These sources are well suited for local and regional agriculture applications. Piloted aircraft are substantially more expensive than other approaches. Low cost autonomous drones and remotely-piloted vehicles (RPV) are being tested in a number of application areas. But there are substantial regulatory and economic challenges that remain before we are likely to see significant adoption. Once these challenges are worked out, these devices will find many applications and will likely be cued by smarter systems to collect information that is infeasible and not economically viable, from space. Autonomous drones will have better economics than remotely-piloted vehicles (RPV) that need substantial ground crew involvement for operation. Hand Held Devices are already ubiquitous and can take very detailed pictures of agriculture fields. Smart phones enabled with personal navigation can be used to cue humans to very specific locations to then capture sub-millimeter color imagery. Smart phone imagery can then be sent to experts and machines for interpretation and diagnosis.

BARCELONA, SPAIN

40 cm Natural Color, WorldView-3

RWANDA, BUYOGA

50 cm Natural Color, WorldView-2

Zoom Levels

Recent years have seen a new terminology for representing spatial resolutions, called Zoom Levels. Bing Maps and Google Earth have created a zoom level nomenclature that is based on a mathematical model of the earth and is now widely accepted by the mapping portals, especially for visualizing 3D earth. The table to the right shows the Bing Maps definition of zoom levels and associated pixel resolution.

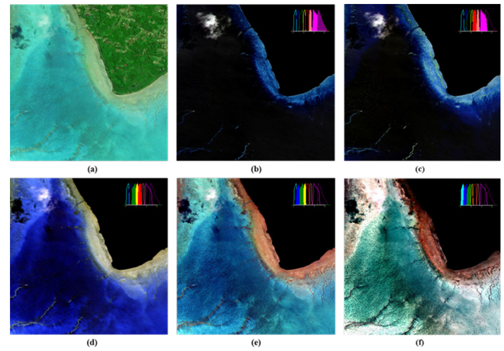
Most of the very high resolution and high resolution imagery providers are now providing imagery at multiple resolutions/zoom levels for their customers. This offering provides a unique opportunity to study agriculture problems at macro, regional, and micro levels by using imagery at various zoom levels. This schema of zoom levels is poised to replace the current nomenclature of spatial resolutions in the remote sensing industry.

Zoom Level	Pixel Resolution (meters)
1	78271.52
2	39135.76
3	19567.88
4	9783.94
5	4891.97
6	2445.98
7	1222.99
8	611.50
9	305.75
10	152.87
11	76.44
12	38.22
13	19.11
14	9.55
15	4.78
16	2.39
17	1.19
18	0.60
19	0.30

Spectral Properties

Spectral resolution is an ambiguous term. Sometimes it refers to the number of spectral bands and the ranges within the electromagnetic spectrum imaging window where the information is captured within the sun/EM (Electro-Magnetic) spectrum. Sometimes it refers to the actual bandwidth of each band. Some systems have different bandwidths depending on the parts of the spectrum. Hyper-spectral instruments tend to have hundreds of contiguous bands across the VNIR and SWIR parts of the spectrum. Extensive research has gone into designing the spectral bands of Landsat satellites, and most of the current remote sensing systems leverage the Landsat pedigree in designing their spectral bands. The most common spectral bands used are Red, Green and Blue bands in the visible part of sun spectrum followed by a spectral band in the Near Infra-Red region. In addition, most of these systems typically have a high resolution panchromatic band that has a spectral range covering the entire visible part of the spectrum, with some panchromatic bands extending into the NIR spectrum as well. The spatial resolution of the panchromatic band is typically 4X the spatial resolution of visible and NIR (VNIR) bands, and data fusion techniques such as pan sharpening are typically employed to fuse VNIR bands with panchromatic band to achieve higher spatial resolution with some loss in spectral fidelity in the pan-sharpened color pixels.

Spectral sensors are typically categorized as multi, super or hyper spectral. Multi-spectral imagery refers to sensors with less than 10 bands, super-spectral resolution include sensors carrying 10-20 bands, and hyper-spectral sensors typically carry hundreds of bands. Landsat multi-spectral satellites carried 8 spectral bands that capture information in the Visible, Near Infra-Red, Shortwave Infra-Red, and Thermal regions of sun spectrum. Most aerial and UAV platforms carry 4 multi-spectral bands. The SPOT series of satellites carried a broad SWIR band which is now discontinued on the SPOT 6 satellite. DigitalGlobe's WorldView-2 satellite was designed with eight spectral bands in the VNIR region. The red edge band, yellow band, and additional NIR band were added to traditional 4 bands and are primarily designed for agriculture applications. The image above right illustrates the "walk-through" from the longest to the shortest wavelengths of the eight spectral bands of WorldView-2 over a coastal region. Image (a) shows the scene in true color. As displayed, different features appear with different band combinations. For example, wave refraction patterns appear, but submerged aquatic vegetation do not appear in 3-band combinations involving the NIR bands e.g., images (d), (e), and (f) whereas structural features are visible using shorter wave visible 3-band combinations such as coastal, blue and green channels.



Spectral information in various spectral bands on WorldView-2

Visible light (RGB) & Visible Near Infra-Red (VNIR)

Spectral Properties

DigitalGlobe's WorldView3 satellite is the first very high spatial resolution, super-spectral satellite, with 16 bands covering Visible, NIR, and SWIR parts of the sun spectrum. This satellite coupled with its 0.3 meter resolution is ideal for addressing small holder farmer applications. Two of the Short Wave Infra-Red bands are primarily designed to estimate crop canopy moisture, as well as measure soil residue, moisture content, and organic matter content that can be used for soil mapping as well as other applications.

With the exception of a few, special mission hyper-spectral imaging and thermal imaging aerial platforms, most of the satellite, aerial, and UAV platforms are trending towards multi-spectral imagery.

Radiometric Properties

Radiometric properties include radiometric resolution and dynamic range. Radiometric resolution of an imaging system describes its ability to discriminate very slight differences in measured energy. The dynamic range of an imaging system specifies the ratio of the highest energy pixel to the lowest energy pixel that can be captured (including detector noise).

The older systems had dynamic range of 256:1. For a digital system, these measurements could be stored as 8-bit data. Modern systems have dynamic ranges between 2048:1 (i.e., 11-bits) and 16,384:1 (i.e., 14-bits). An important operational goal in remote sensing systems is to be able to adjust the amplifier gain controls so that a 100% reflective object will produce the upper value permitted by the number of available bits in the dynamic range. Effectively, the instrument is just saturated by a 100% reflective object when the sun is the illuminator of the object. The challenge lies in the fact that the intensity of the sun varies considerably over an orbit range, generally producing smaller digital numbers (DN) the further the sensor is from sun's nadir on the earth.

Setting the sensor gain to prevent saturation (i.e., exceeding the highest recordable number) at the sun's nadir point on the earth means that points at higher latitudes will not even come close to using all of the available bits. So, for the older system with 8-bits, this means effectively that the energy at those higher latitude targets are restricted to perhaps 5-bits of dynamic range. That means that reflectance values for objects at those locations are spread across 32 DNs. That usually means that the smallest discernable difference in reflectance is about 3%. Thus the red band, which is an essential part of vegetative indices like the Normalized Differentiated Vegetative Index (NDVI), becomes almost useless for detecting levels of stress in crops.

Modern systems can adjust their dynamic range for latitude ranges. In the case of systems with 11-bits of dynamic range, the effective dynamic range can be on the order of 9-bits (or better) with discernable differences in reflectance of about 0.2% (or smaller), making them ideal for measuring very subtle changes in stress in crops. High effective radiometric resolution is paramount for agriculture applications, especially to accurately model crop vigor and health issues at an early stage, as well as to identify subtle changes on soils for moisture and organic matter mapping. These increased capabilities have resulted in superior information quality of the images and, subsequently, the ability to extract information from them accurately and in an automated fashion.

Temporal Properties

Temporal resolution is characterized by the revisit frequency of the platforms for a given spot on the earth. Over the last decade, significant progress has been made in developing and launching satellites in constellations that can provide daily revisits across the globe. Large amounts of data are being acquired by these systems globally to include images from newer and more complex platforms such as WorldView-1, WorldView-2, GeoEye-1, and the more recent Pleiades-1A and Pleiades-1B. Currently, the potential global capacity of very high spatial resolution imaging satellites is greater than 1.8 billion square kilometers per year, which corresponds to more than 12 times the land surface area of the earth. This capacity could potentially increase to more than 2.4 billion square kilometers per year (about 16 times the land surface area of the earth) in the near future. Other than the areas that are under permanent cloud belts, commercial remote sensing industry can provide the revisit to support precision agriculture and small holder farmer agriculture practices globally.

In the past, spatial resolutions, spectral content, field-of-view, revisit frequencies, and multi-temporal consistency of these government satellites have only been sufficient for doing “passive observation”. The new systems can enable “active management” of areas in a way that sustainably addresses land, water, food, and natural resource challenges given current population projections over the next thirty years. The center column of the chart below shows major elements needed for active management.

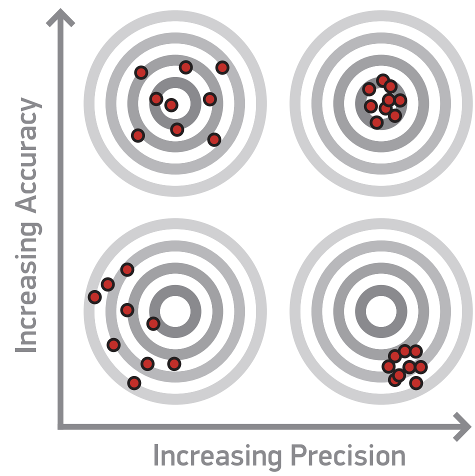
Active management	Major elements for active management	Passive observation
» Higher quality » Higher cost » Higher value » More focused, frequent revisit » Find problems early, when smaller » Change the outcome	» Detect long term trends » General land use and land cover » Provide context and orientation » Detect interesting anomalies » Measure current states » Diagnose current states » Predict future states » Compare alternative actions » Implement action plans » Change future states	» Lower quality » Lower cost » Lower value » Less focused, frequent revisit » Find problems late, when bigger » Stuck with outcome

System capabilities are evolving from passive, low-value observation in the past, to active, high-value management of natural resources

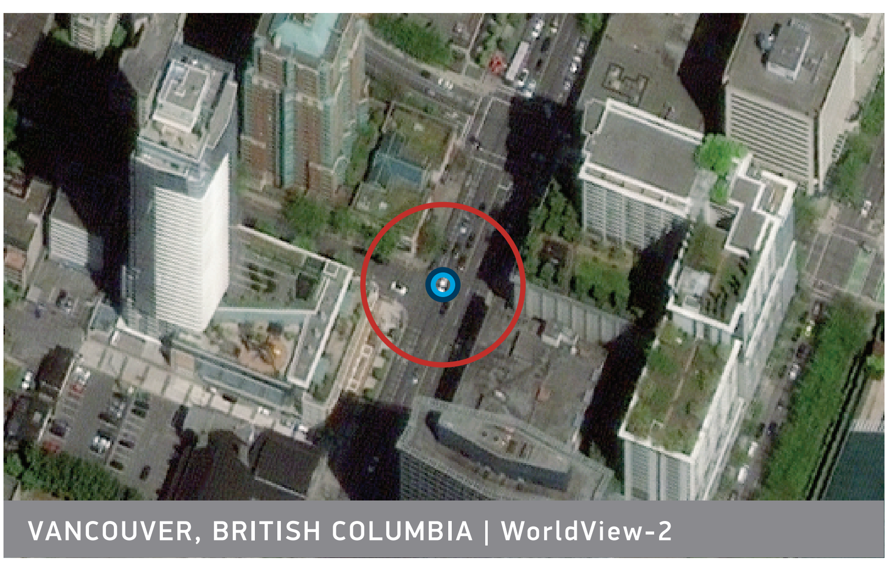
Precision/Information Accuracy

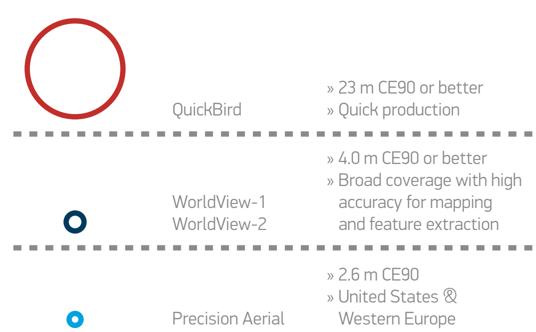
Postional accuracy

As location-based systems become an integral part of life, high accuracy and precision are two aspects needed to ensure that imagery and derived information can be used for actionable intelligence for a variety of applications including those used for agriculture. Imagery's positional accuracy has been steadily improving from error margins around 23 meters in the early 2000's to less than 3 meters today. Increased accuracy is primarily due to more stable satellite orbits and innovative post-processing techniques that reduce error margins. There are several technologies that enable efficient registration of data to a base map, showing both imagery as well as vector base layers. This practice is referred to as "second generation ortho" where a new image is registered to a base map that is, in turn, used for maintenance and updates of geospatial databases aligned to the base map. The coming years will see accuracies getting better with increased spectral resolution. Precision, on the other hand, refers to relative accuracy of images collected over time. This is an important aspect to consider when creating and maintaining multi-year geospatial databases. The diagrams below and right illustrate the concepts of accuracy and precision. As shown, newer platforms such as the WorldView series of satellites have an average accuracy of 4 meters which is comparable to the performance of precision aerial imagery.



Aerial and UAV platforms provide high spatial accuracy with improved IMU's/INU's on the systems. The advances in positional accuracy of GPS systems in mobile phones enable them to be effective tools for field scouting and ground truth collection in agriculture.





Increasing spatial accuracy of satellite imagery

Speed

Mapping large areas

Speed can also be assessed as a function of time relative to the mapping of large areas. Using traditional mapping techniques, cartographers typically take four to five years to create authoritative maps. These timelines are no longer acceptable for today's geospatial needs. The remote sensing industry has started leveraging high performance computing (HPC) and cloud computing to make these tasks faster and more efficient than ever. The images below illustrate three years worth of cloud-free imagery available over Mexico from the DigitalGlobe archive, and the corresponding orthomosaic of Northern Mexico at 50 cm resolution created by DigitalGlobe in less than three days. These technologies help with nationwide agriculture cadaster creation, update, and maintenance.

Three years worth of cloud-free imagery over Mexico and the corresponding orthomosaic of Northern Mexico at 50 cm resolution created in less than three days

Speed of Delivery

With the increasing network of global infrastructure, terrestrial as well as in space, the satellite industry can now provide information into the hands of the end user within just a few minutes of collection. Making the information available to agronomists and growers in a rapid fashion is one of the key factors for the adoption of remote sensed imagery and information for small holder farmers. It is important for growers and agronomists to be able to scout their fields shortly after anomalies are detected. Otherwise critical ground truth and samples needed for diagnosis, remediation planning, and decision support may be lost.

Analysis

High Performance Extraction (HPX) is defined to be very accurate classification of objects and/or estimation of object states from a single image or sequences of images by using ancillary information in various ways. HPX is often necessary for accurate and reliable "active management". For agriculture applications, normalizing the imagery for changing or spatially variable atmospheric conditions is foundational technology that is now a reality. The images below show an image with and without atmospheric correction.

Comparison of top-of-atmosphere (top) reflectance and surface reflectance (bottom) images

For remotely sensed information extraction for agriculture, several algorithms have been developed in the last four decades that have built on extensive remote sensing knowledge from scientists from NASA and other reputable institutions across the globe. In recent years, the remote sensing industry has also adopted technologies from machine learning, medical imaging, and artificial intelligence to exploit the maximum information from remotely sensed imagery. Recent technological developments that help with analysis include web based platforms that can compare a picture of a stressed leaf taken on the field with a library of similar photos and help enable a grower with diagnosing the problem. The advances in various geospatial technologies such as GIS, GPS, and remote sensing coupled with technological developments in cloud computing and storage, as well as mobile technologies, have resulted in the development of decision support systems that can integrate various remote observations with field measurements to provide actionable intelligence in the field.

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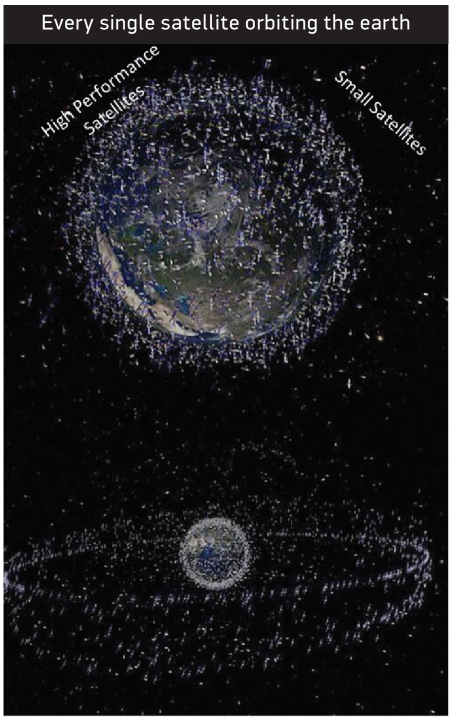
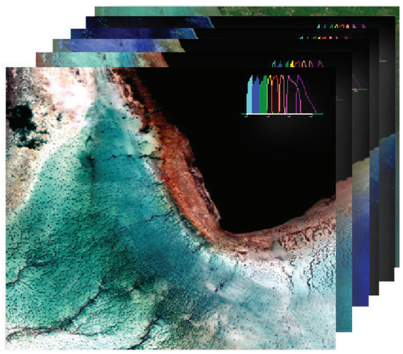
Summary

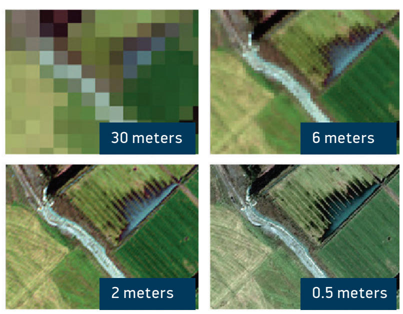
Technological advancements in remote sensing coupled with advances in IT, cloud computing, mobile technology, wide spread adoption of GPS, and digital technologies have created a unique opportunity for implementing smarter solutions for small holder farmers globally. The timing of the STARS project can leverage these advancements to uncover the long promised value of remote sensing to better the lives of small holder farmers with increased productivity, reduced resource consumption, and food security. The images below summarize satellite trends suitable for agricultural remote sensing applications.



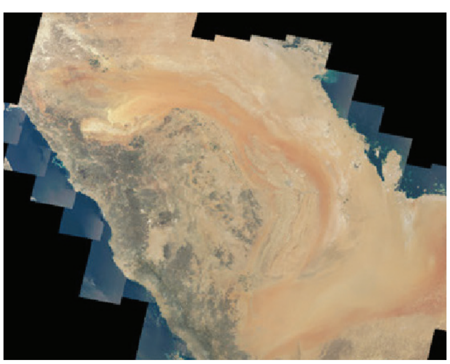
Increasing number of satellites data sources for agriculture applications



Increasing number of bands that help with vegetation inventory and health mapping



Increasing spatial resolution to help small holder farmers



Large scale computing and global infra-structure to process imagery and provide timely information for farmers

Global collection capacity and frequent refresh for agriculture monitoring

BILL & MELINDA GATES foundation

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