THE BENEFITS OF THE
EIGHT SPECTRAL BANDS
OF WORLDVIEW-2

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WorldView-2 Introduction

With the launch of the WorldView-2 satellite, DigitalGlobe is offering significant new capabilities to the marketplace: a large collection capacity of high-resolution 8-band multispectral imagery.

WorldView-2 is DigitalGlobe's second next-generation satellite, built by Ball Aerospace, and leveraging the most advanced technologies. Like WorldView-1, WorldView-2 is equipped with state-of-the-art geolocational accuracy capabilities and will be only the second commercial spacecraft–after WorldView-1–equipped with control moment gyros, which enable increased agility, rapid targeting and efficient in-track stereo collection. This advanced agility combined with an operating altitude of 770 km will enable it to collect nearly 1 million km^2 of high-resolution imagery per day, and offer average revisit times of 1.1 days around the globe.

Complementing the large-scale collection capacity is WorldView-2's high spatial and spectral resolution. It is able to capture 46 cm panchromatic imagery, and is the first commercial satellite to provide 1.84 m resolution, 8-band multispectral imagery. The high spatial resolution enables the discrimination of fine details, like vehicles, shallow reefs and even individual trees in an orchard, and the high spectral resolution provides detailed information on such diverse areas as the quality of the road surfaces, the depth of the ocean, and the health of plants. The additional spectral bands will also enable WorldView-2 to more accurately present the world as the human eye perceives it, creating a more realistic "true color" view of the world.

This paper focuses on how WorldView-2's unique combination of high spatial and spectral resolution will provide improved visual reality, enhance remote sensing applications and give rise to many practical applications.

The Eight Spectral Bands of WorldView-2

WorldView-2 is the first commercial high-resolution satellite to provide eight spectral sensors in the visible to near-infrared range. Each sensor is narrowly focused on a particular range of the electromagnetic spectrum that is sensitive to a particular feature on the ground, or a property of the atmosphere. Together they are designed to improve the segmentation and classification of land and aquatic features beyond any other space-based remote sensing platform.
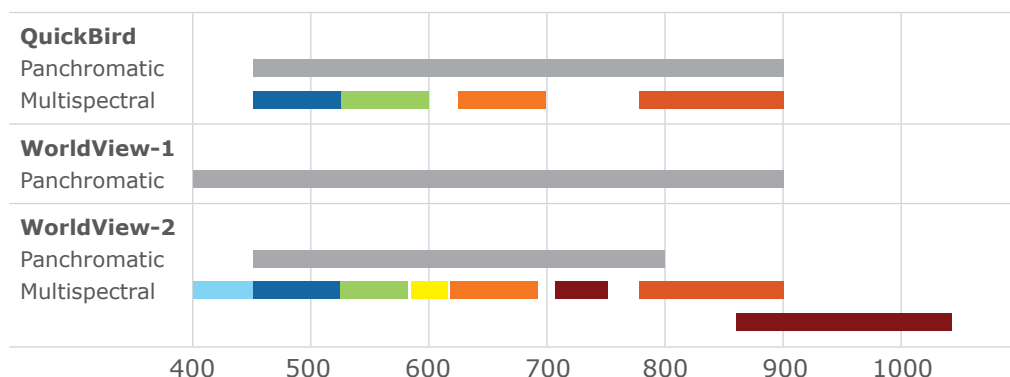
Worldview-2 Quick Stats	
Resolution	50 cm
New Spectral Bands	Coastal, yellow, red edge, NIR2
Slew Time	300 km in 9 seconds
Swath Width	16.4 km at nadir
Collection Capacity	550,000 km^2/ day
Average Revisit	1.1 days

The Role of Each Spectral Band

Coastal Blue (400-450 nm)

- New band
- Absorbed by chlorophyll in healthy plants and aids in conducting vegetative analysis
- Least absorbed by water, and will be very useful in bathymetric studies
- Substantially influenced by atmospheric scattering and has the potential to improve atmospheric correction techniques

Blue (450-510 nm)

- Identical to QuickBird
- Readily absorbed by chlorophyll in plants
- Provides good penetration of water
- Less affected by atmospheric scattering and absorption compared to the Coastal Blue band

Green (510-580 nm)

- Narrower than the green band on QuickBird
- Able to focus more precisely on the peak reflectance of healthy vegetation
- Ideal for calculating plant vigor
- Very helpful in discriminating between types of plant material when used in conjunction with the Yellow band

Yellow (585-625 nm)

- New band
- Very important for feature classification
- Detects the "yellowness" of particular vegetation, both on land and in the water

Red (630-690 nm)

- Narrower than the red band on QuickBird and shifted to longer wavelengths
- Better focused on the absorption of red light by chlorophyll in healthy plant materials
- One of the most important bands for vegetation discrimination
- Very useful in classifying bare soils, roads, and geological features

Red-Edge (705-745 nm)

- New band
- Centered strategically at the onset of the high reflectivity portion of vegetation response
- Very valuable in measuring plant health and aiding in the classification of vegetation

NIR1 (770-895 nm)

- Narrower than the NIR1 band on QuickBird to provide more separation between it and the Red-Edge sensor
- Very effective for the estimation of moisture content and plant biomass
- Effectively separates water bodies from vegetation, identifies types of vegetation and also discriminates between soil types

NIR2 (860-1040 nm)

- New band
- Overlaps the NIR1 band but is less affected by atmospheric influence
- Enables broader vegetation analysis and biomass studies

Multispectral imagery has provided great value in helping to understand the earth and the impacts of natural processes and man-made activities. In this paper we will look at three major categories of remote sensing applications: feature classification, bathymetric measurements and vegetative analysis and explore how they can be enhanced with the increased spatial resolution, spectral fidelity, and collection capacity of WorldView-2.

Feature Classification

The growth in agriculture, increased urbanization and natural processes all contribute to the changing nature of land use and land cover around the globe. Remote sensing has been identified as a critical tool in understanding changes on a large and small scale, and currently several satellites are being employed to monitor and study the globe. With eight tightly focused spectral sensors ranging from visible to near infrared, combined with 1.8 meter spatial resolution, WorldView-2 will bring a high degree of detail to this classification process, enabling a finer level of discrimination and improving decision-making in both the public and private sector.

Cathedral of St. André,
Bordeaux, France
May 20, 2009

Land Use/Land Cover Classification and Feature Extraction

Land Use/Land Cover (LULC) classification can be seen on a continuum, starting with a basic estimation of land cover through broad categories, like farmland, and urban areas, to feature extraction, like road networks, buildings, and trees. A typical classification system might segment urban areas in the following manner:

Level 1	Level 2	Level 3	Level 4
• Urban or built-up	• Residential	• Single-family Units • Multi-family Units • Group Quarters • Residential Hotels • Mobile Home Units • Transient Lodging • Other	• Single Story Units • Two or More Story Units

Current satellite-based remote sensing techniques are most effective at classifying LULC on a large scale. Lower resolution multispectral satellites like Landsat are very effective at mapping LULC at the first two levels, by identifying the spectral signature of a particular type of feature, and broadly classifying areas that contain that spectral pattern. With spatial resolutions of 15-30 m, Landsat can classify forests, grasslands and urban developments using the different spectral reflectance of each type of land cover. However, finer details cannot be reliably differentiated at these resolutions. Higher resolution multispectral satellites with traditional visible to near infrared (VNIR) bands are increasingly able to discern fine scale features. With spatial resolutions of 0.5-1 meter, these satellites have consistently demonstrated the ability to classify features at the third level, for example, discriminating between grasses vs. trees in an orchard, segmenting urban areas by housing types, and discriminating between paved and unpaved roads.

In order to effectively classify LULC beyond the third level, analysts have investigated airborne hyperspectralsensors, which have spatial resolutions in the 4-5 m range. Even with a decrease in spatial resolution over the highest resolution satellite imagery, the increased spectral fidelity has enabled them to extract fourth level features, like roof types and road conditions.

The increased spectral fidelity of WorldView-2, combined with very high spatial resolution, will provide the additional data necessary to address the feature classification challenge. A pilot study conducted for DigitalGlobe has demonstrated an overall improvement in classification accuracies when comparing traditional VNIR multispectral imagery with simulated WorldView-2 8-band imagery. In some critical areas the improvements are dramatic, highlighting the importance of the additional bands in the classification of specific features.

For example, when looking at land classes, WorldView-2 is expected to deliver a 10-30% improvement in accuracy compared with traditional VNIR imagery overall. Specifically, the ability to accurately classify roads was shown to improve from around 55% to over 80%. Similar improvements were demonstrated when segmenting cultivated fields from other forms of vegetation. These dramatic improvements are due to the increased sensitivity to plant material and soil types provided by the addition of the Red-Edge, Yellow and NIR2 bands. In contrast, the classification of water bodies is expected to improve from 85-90% with traditional VNIR imagery to between 95-98% with WorldView-2. This suggests that while traditional VNIR multispectral imagery is very capable at classifying water types, the additional spectral bands of WorldView-2 will provide an incremental improvement in this area as well.

Automated Feature Extraction

Increasingly, scientists are experimenting with techniques for automating feature extraction, including neural net, machine vision and object oriented approaches. These methodologies rely not only on the spectral signal of individual pixels, but how pixels with a similar spectral signal are grouped together into recognizable features and how computer algorithms are refined to more accurately extract these features. For example, an asphalt road and asphalt roof shingles may have virtually identical spectral signatures, but by factoring in the shape of the cluster of pixels–long and narrow, or small and rectangular – an automated classification system can distinguish between the two. These various techniques are dependent on the combination of high spectral and spatial resolution, and are proving to be an effective solution to the feature classification challenge.

The increased spatial resolution of WorldView-2 is also expected to improve the efficiency of automated classification techniques. Studies using 2 m resolution 4-band multispectral aerial data have shown that object oriented techniques significantly improved classification accuracies without any manual intervention. The increased classification accuracies that can be achieved with eight bands have already been demonstrated; therefore we expect that the combination of the increased spectral and spatial resolution will be particularly effective in automated feature extractions.
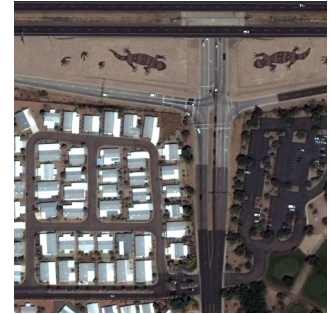
Original Image
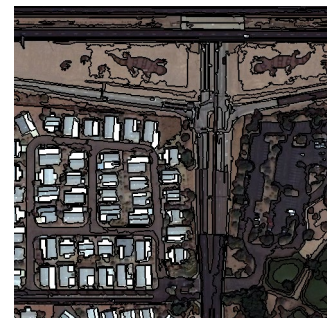
Converting to Objects

Object-Only Image

Feature Classification Applications

Highly detailed and comprehensive multispectral data is empowering feature classification and extraction analyses that bridge the gap between scientific studies and practical applications.

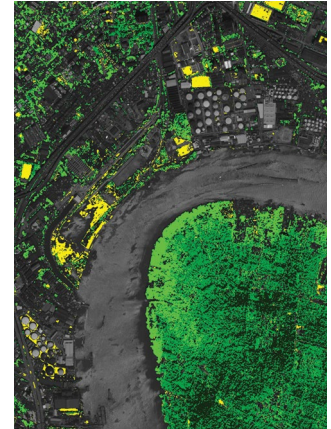**Mapping invasive species with biofuel potential**
Invasive plants are a serious environmental problem around the globe. They can choke out native vegetation, devastate wetlands, and dramatically impact croplands. However, some species such as Chinese Tallow may have the potential to be the next source of biofuel if their oil rich seeds can be effectively harvested.

Remote sensing is a critical tool for understanding and mapping invasive species. Scientists can use detailed species classification and extraction to better understand how invasive species have penetrated native plant populations, in order to identify harvestable populations or to monitor eradication projects, and ensure the complete removal of a target species.

Managing city services and LULC based taxation
Understanding LULC in urban environments is critical for maintaining city services, managing resources and collecting tax revenue. From maintaining degrading road networks, to monitoring water consumption to tracking the conversion of open space into impermeable surfaces, civil governments are constantly in need of continuously updated, detailed information.

WorldView-2 enables agencies to synoptically map an entire urban area, and with increasingly automated feature extraction and classification capabilities, derive actionable information for managing scarce resources. Through a combination of spectral signatures and objected oriented methodologies, roads can be extracted and even classified by when they will need resurfacing. Storm water management fees, based on changes to the amount of impermeable surfaces, can be accurately measured, and properly assessed without the need for expensive ground-based surveying projects. Spectral changes in urban areas can also indicate construction projects such as the addition of sheds, decks and other outdoor structures that may not be properly permitted.

Bathymetric Measurements

Coastlines, shoals and reefs are some of the most dynamic and constantly changing regions of the globe. Monitoring and measuring these changes is critical to marine navigation and an important tool in understanding our environment. Near shore bathymetry is currently calculated using high-resolution multispectral satellite imagery. However, with the introduction of WorldView-2's higher resolution, increased agility and Coastal Blue band (400-450 nm), bathymetric measurements will substantially improve both in depth and accuracy.

There are two established techniques for calculating bathymetry using multispectral satellite imagery: a radiometric approach and a photogrammetric approach.

Vegetation Mapping

Urban Land Use Density

The Radiometric Approach

The radiometric approach exploits the fact that different wavelengths of light are attenuated by water to differing degrees, with red light being attenuated much more rapidly than blue light.

Analysts have leveraged existing multispectral satellites' ability to detect light in the blue (450 – 510 nm), green (510 – 580 nm) and red bands (630 – 690 nm) to achieve good depth estimates, in water up to 15 meters in depth. And, with the addition of sonar based ground truth measurements, they have achieved vertical and horizontal accuracies of less than 1 meter.

In order to improve bathymetric measurements, analysts have turned to airborne, high-resolution multispectral platforms. These sensors are able to detect light between 400 and 450 nm – the spectrum that provides the deepest penetration of clear water. Studies using these data have shown that accurate bathymetric measurements can be achieved up to 20 meters and deeper.

WorldView-2 is the first commercial high-resolution satellite to provide 1.84 m resolution multispectral imagery, plus a Coastal Blue detector focused on the 400 – 450 nm range. With the Coastal Blue band included in the mix, analysts expect to be able to calculate depths up to 20 m and potentially as deep as 30 m, by measuring relative absorption of the Coastal Blue, Blue and Green bands.

WorldView-2's large single-pass collection capabilities will also make the application of ground truth data more accurate and reliable. Multiple small collections contain differences in sun angle, sea state and other parameters and it is challenging to calibrate one series of measurements and then apply them across a broad area. Large synoptic collections, enabled by WorldView-2's agility and rapid retargeting capabilities, allow analysts to compare the differing absorption of the Coastal Blue, Blue and Green bands, calibrate their bathymetric estimations using a few known points, and then reliably extend the model across the entire collection area.

The Photogrammetric Approach

In this method, stereoscopic images are collected over the target area, and a data elevation model (DEM) of the shallow ocean floor is produced from the imagery. Early studies with both satellite imagery, and digital photography appeared promising, and demonstrate that this technique can be used to provide accurate bathymetric models of shallow environments without ground truth. However, the technique has not been widely studied due to limitations in the capabilities of current sensors.

The challenge with collecting stereoscopic imagery of the shallow ocean floor is in how light interacts with the air/water interface (Figure 1). At high angles of incidence, light is completely reflected off the surface of the water, preventing any sub-aquatic features from being observed. Current multispectral satellite sensors are not able to collect enough high-resolution stereoscopic imagery within the narrow angle necessary to penetrate the ocean surface. In addition, none of them are able to measure the shorter wavelength blue light necessary for maximum depth penetration.
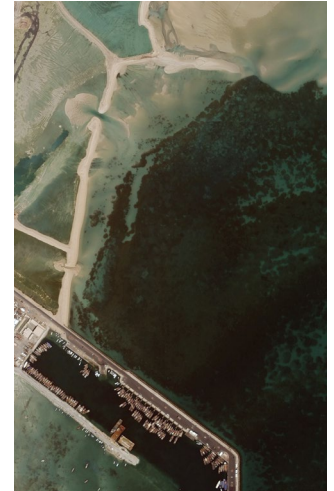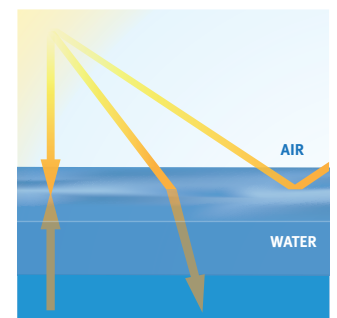

Al Wakrah Port, Qatar
April 5, 2009

Figure 1:
Light and the Air/Water Interface

WorldView-2 will make this new method for measuring bathymetry possible. The Coastal Blue band will deliver maximum water penetration, and WorldView-2's enhanced agility will enable the collection of large amounts of high-resolution in-track stereo imagery at the ideal angle for water penetration. The advantage of this approach is that multiple images can be registered using tie points that are visible on land and in the water, and the resulting stereo composite can be used to calculate water depth without relying on ground truth measurements. No other satellite is able to deliver this unique combination of high spatial and spectral resolution, agility and stereo collection capacity.

Bathymetry Applications

Current, accurate, and easily updatable bathymetric models will be an effective tool for gaining a clearer understanding of the world's waterways, and improving the safety of marine navigation.

Natural disasters increase marine navigational hazards
In the aftermath of Hurricane Katrina, massive amounts of debris washed off shore and settled in the Mississippi Sound, becoming a serious threat to commercial and recreational boaters. As part of a NOAA funded project, five ships were sent to the area, and conducted multiple sonar surveys over the span of several months. These ships surveyed approximately 114 square nautical miles and identified over 1300 sonar contacts. Many of the identified objects were tens of meters across and pose a significant hazard to ships navigating throughout the Sound.

Satellite derived bathymetric measurements could provide a tremendous boost to the efficiency of this kind of project. The entire region could be imaged in a short amount of time, and bathymetric measurements could be made quickly in order to identify potential marine hazards. Ships could then be directed to investigate the objects that presented the greatest threat, and conduct sonar measurements that could be used to refine the satellite derived bathymetric measurements to create a current and more reliable nautical chart.

Accurate bathymetry helps to anticipate risk
In order to understand the impact on coastal communities from destructive marine forces, such as tsunamis, high-wave flooding, coastal inundation, and storm surges, specialists must have precise land-to-shore depth and elevation data. However maps and charts of coastal areas are typically generated from different data sources, and depict information about either the land, or the water. The lack of a seamless high-resolution map that extends from the land through the shoreline and beneath the water has been identified as a major hindrance in the efforts to accurately assess the nature of these threats.

By applying WorldView-2 and the photogrammetric methods, a contiguous elevation model could be created that encompassed the land and water interface. This seamless DEM would be an invaluable tool for modeling storm surge, and more accurately determining the risk to people and property.

Orange Beach, Alabama, U.S.A.
September 24, 2008

Vegetative Analysis

Vegetative analysis has been a mainstay of the satellite remote sensing community for decades. While the traditional Normalized Difference Vegetation Index (NDVI) method of measuring plant material has been very successful, there is increasing evidence that the addition of the Red-Edge spectral band can improve the accuracy and sensitivity of plant studies. WorldView-2 is the only commercial multispectral satellite to provide global, high-resolution access to the Red-Edge spectral band.

Measuring Plant Material

The NDVI is a well established mechanism for calculating vegetation. It relies on the principle that the chlorophyll in living plant material strongly absorbs visible light, and strongly reflects near-infrared light. Several multispectral satellites, including QuickBird, IKONOS, GeoEye-1, Spot-5 and LandSat-7, provide two bands, a red band (RED) in the 610 nm to 680 nm range, and a near infrared band (NIR) in the 750 nm to 890 nm range that are routinely used to calculate the the NDVI ratio: NIR-RED/NIR+RED. This ratio has been effective in calculating plant vigor, and is used around the globe to evaluate forest and crop heath and monitor environmental changes.

With the increasing availability of hyperspectral sensors that can measure dozens or hundreds of spectral bands, scientists have been evaluating the Red-Edge region of the spectrum (between 680 nm and 750 nm), which is the transition region between the minimum and maximum reflectance. Researchers have shown that a RED to Red-Edge comparison is more sensitive to subtle changes in plant health than NDVI.

A RED to Red-Edge comparison is better able to discriminate between healthy trees, and those impacted by disease. In addition, the Red-Edge band has been shown to reveal differences between young and mature plants, enhance the ability to segment between conifers and broad leafed plants and even discriminate between species of weeds in crop fields. It is clear from the research that including the Red-Edge band enables far more sensitive and sophisticated analyses.

Until now, the only satellite imagery available that contains Red-Edge data is medium to low resolution (5-30 m). It can provide some insights into the conditions of an entire field, but is unable to provide the segmentation necessary to evaluate small scale details, like the health of individual trees in an orchard, or map the impact of irrigation and fertilization within a field.

Airborne hyperspectral sensors are available and contain both the spatial and spectral resolution necessary to make fine scale evaluations, but collecting this imagery requires extensive planning, and is cost prohibitive for very large projects that require a high rate of revisit.

Red River, Vietnam
September 23, 2007

Red Edge Measurements with WorldView-2

WorldView-2 is the first commercial high-resolution satellite to provide a Red-Edge sensor as part of its 8-band multispectral capabilities. The detector is focused on a narrow band of radiation from 705 to 745 nm, allowing for very sensitive measurements of Red-Edge reflectance. And, at 1.84 m spatial resolution, Worldview-2's multispectral imagery is more comparable to airborne sensors than other satellites. This combination of spatial and spectral resolution will enable the greater segmentation of physical features and more granular measurements of plant vitality.

With wide-scale coverage and frequent revisit times, WorldView-2 will make Red-Edge data available on a global scale. Analysts can rely on current synoptic coverage of fields and forests with the most sensitive data available, allowing for the development of a new standard equation, similar to NDVI, but significantly more sensitive to subtle changes in plant health and growth states.

Vegetative Analysis Applications

Frequent and reliable access to Red-Edge data is enabling novel remote sensing applications that depend on the detection of subtle changes in plant health, offering more early-warning capabilities to a variety of industries that interact with, and depend on, the environment.

Identifying leaks in gas pipelines

Underground natural gas pipelines stretch across the globe, and travel through remote and inaccessible regions. When these pipelines develop leaks, the escaping natural gas causes stress to the surrounding vegetation. Using remote sensing techniques that rely on the sensitivity of the Red-Edge, scientists are able to identify plants that are experiencing physical stress, even in areas where the affects are not visible. By monitoring underground pipelines with high-resolution multispectral satellite imagery, utilities can identify potential gas leaks at their earliest stages, before they pose significant danger to people and the environment.

Monitoring forest health and vitality

Forest plantations are susceptible to wide-scale disease and pest infestations that can cause significant economical impact. Traditional monitoring techniques involve measurements using air and ground surveys; however they are costly and highly subjective. Red-Edge based remote sensing analyses were shown to be effective at identifying trees that were impacted by disease, and were able to provide quantitative information on the health of the trees. By using satellite-based remote sensing techniques that rely on the Red-Edge, large regions can be monitored synoptically. This represents a dramatic cost savings over the traditional monitoring techniques, and allows for more targeted and effective eradication strategies.

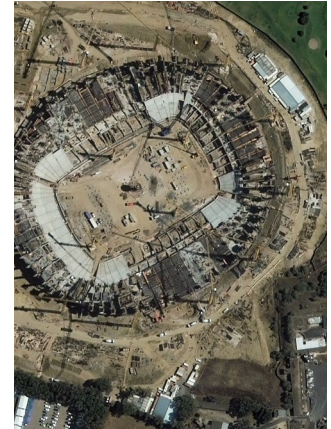## Improving Change Detection with WorldView-2

For decades, satellite based remote sensing has been an immensely valuable tool for detecting change. No other platform can consistently revisit an area and repeatedly quantify and classify LULC on such a broad scale. However, the current mix of satellites often cannot detect the subtle details that are so valuable in understanding and reacting to change. WorldView-2's eight spectral bands, 46 cm* panchromatic and 1.8 m multispectral resolution are able to reveal significantly more detail in the spectral changes of small ground features. Measuring the changes in road conditions, or the health of plants over an underground gas pipeline or the new location of a sandbar requires sensitivity that only WorldView-2 can provide. Increased sensitivity, however, is only part of the story. With WorldView-2's immense collection capacity and rapid revisit capabilities, large areas can be repeatedly imaged, providing the data necessary to conduct automated change detection.

Capetown, South Africa
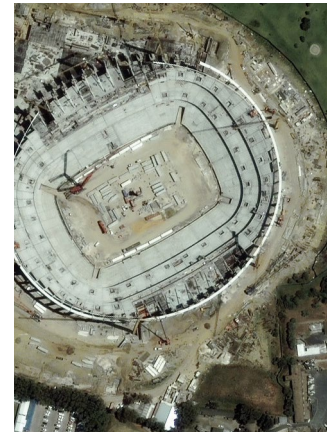March 5, 2008

Conclusion

As discussed, the eight spectral bands, high spatial resolution, and large-scale collection capacity of WorldView-2 will deliver deeper analysis and faster insights. We've presented some specific examples of how WorldView-2 will improve feature classification, bathymetric measurements, and vegetative analyses, but these are only a sampling of the new uses and improvements yet to be identified.

As the premier provider of high-resolution commercial imagery, DigitalGlobe is leading the way through technology to bring the most advanced imagery products to the marketplace. DigitalGlobe is committed to the practical solutions that can be derived from premium quality imagery, and how these solutions can be applied to challenges in governments, enterprises, and consumer applications.

Capetown, South Africa
November 25, 2008

* Distribution and use of imagery at better than .50 m GSD pan and 2.0 m GSD multispectral is subject
   to prior approval by the U.S. Government.