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Forest Estate Mapping Using RapidEye

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Provision & Ownership of Data

It should be recognised that the spatial datasets used in this report have been provided by Rayonier, and as such are bound by the terms and conditions of the data licence agreement between Rayonier and FFR. Specifically, this agreement limits the use of the data to this study. Any maps published outside of this report must be appropriately acknowledged as follows.

"The representation of stands shown on this map was derived from data supplied by Rayonier New Zealand Limited as manager to Matariki Forests"

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SUMMARY

The applications outlined in this report link a combination of existing remote sensing techniques and principles that are well proven in the literature. It was not until recently that these techniques became operationally cost-effective. This is attributed to decreasing costs of data, improvements in spatial resolution, scene extents and temporal frequency.

The purpose of this study was to evaluate RapidEye imagery (5 m) to assist with broad-scale (1:25 000 scale) forest planning. The work recognises that almost all forest areas have already been mapped using high-resolution ortho-photography. The focus was therefore switched to complementing this base rather than trying to replace it.

Several objectives were established with the imagery evaluated for its ability to detect forest change activities such as harvesting, monitoring plantation establishment and growth progression, and to provide frequent updates and identify inconsistencies in existing GIS representations. The evaluation used repeat acquisitions approximately 6 months apart (October 2010 and March 2011) acquired over forests located in Canterbury and Hawke's Bay.

The approach adopted was to link existing remote sensing principles and translate these into a series of semi-automated mapping methods and processes. The routines have been adapted to run in ArcGIS software.

It should be noted that several of the image pre-processing steps (atmospheric and terrain correction) are not readily implemented in mainstream software packages.

The exclusion of the image pre-processing steps, however, does not preclude the processes from being applied. A significant amount of information can be derived from an uncorrected scene, especially in evaluating gross changes like forest to non-forest which show a very strong change in spectral signature.

Results

The following table outlines the study outcomes and potential industry applications as matched to the eight study objectives.

Table 1-1: Study Objectives & Outcomes

Ref:	Objective	Study Outcome	Application
1	Determine the age at which the plantation crop can be detected.	Establishment detected within 2 years of planting and mapped within 3-5 years of planting.	Satellite data is better suited to providing stand boundary updates for early to mid-rotation adjustments.
2	Identify areas of non-forest i.e. harvesting or gaps using a single image (T1).	Forest gaps or harvest areas (>200 m^2) that show a bare soil signature are detected. Manual editing of the results are required to remove noise and fragmented polygons.	Single date satellite imagery could be used to detect harvest areas and gaps.
3	Identify areas of harvesting through subtraction of an image pair separated in time (T1 – T2).	Forest gaps or harvest areas (>200 m^2) that show a bare soil signature are detected. Less manual editing of the results is required, as only areas of change are detected.	Repeat satellite coverage could be routinely used to assist in providing harvest updates.
4	Identify areas of soil disturbance caused by harvesting or roading operations.	Areas of soil disturbance are more difficult to delineate confidently due to their scale, variation in reflectance and fragmentation.	Potentially some application to identify and map larger heavy traffic areas.
5	Identify stands with variable establishment or growth variation *For this objective it is recommended that additional image pre-process steps be applied*.	An initial relationship between age and reflectance established that this provides a means to map variation in reflectance at the stand-level and within stands against a benchmark 'global value'.	Satellite data could be used to monitor stand development and identify gaps and anomalies in the stand GIS.
6	Evaluate the completeness of the GIS representation – including the accuracy of boundaries, detection of gaps.	This is achieved in Obj. 4	This is achieved in Obj. 4
7	Identification of areas with significant weed problems.	This was not assessed, but it is likely that stands that do not fit the expected reflectance values will be flagged.	Not assessed
8	Potential identification of areas with significant disease.	Not assessed and is expected to be evaluated in a further study	Not assessed

Limitations

Prior to pre-processing the images, several quality control (QC) checks were conducted. The images passed all the QC checks with the exception of the accuracy of the geo-referencing. During the course of the study RapidEye released improvements to the dataset. These included replacing the 90-m digital terrain model (DTM) with the NZ 25-m DTM and updating the existing set of ground control points (GCPs) using 15 m Landsat imagery.

These improvements have reduced the 'shift' between base GIS and RapidEye datasets. This has reduced the mis-classification error of the routines developed.

It is recommended that the current GCPs (about 2500 points) be updated using available high-resolution images to further improve the image registration. This recommendation has been lodged with RapidEye.

Operational Considerations

One of the main advantages of satellite imagery is that it can be directly integrated into GIS systems. Users have two options; they may opt to interpret the images visually and update the base GIS manually, or implement the semi-automated methods outlined in this study. In applying satellite imagery several aspects need to be considered. These include;

- **Stand Variation Model** – The lookup values used to develop the reflectance / age class relationship (stand variation model) were drawn from a single image (62 500 ha) and are specific to *P.radiata*. It is recommended that additional lookup tables be developed to account for regional variations in plantation development rates. These values could be added to the global lookup table or retained as regional tables.

- **File sizes** – although not a large issue, the multi-spectral nature and increased dynamic range (i.e. 16 bit) of satellite data does increase the file size. A delivered ortho-corrected tile (25 x 25 km) is approximately 250 MB. If additional quantitative analysis is undertaken and the tile is processed to reflectance, the file size increases to approximately 480 MB.
- **Image acquisition** – the optimal timing for acquisition is when the sun elevation[1] is above at 35°. This ensures that the effects of topographic shadow are minimised, which increases the useable area on the image. Ideally images should be acquired from October to mid-April.
- **Ordering Images** – The basic RapidEye cost model for archived imagery prices the imagery at 0.95 euro/km^2 with the minimum order value of €475 (~NZD 850).

If satellite data are not available from the online archive (www.eyefind.rapideye.de) then the imagery must be tasked. The minimum order is 250 000 ha (2 500 km^2) which is equivalent to approximately $4 000 NZD. A number of licensing options are available that enable data sharing. This presents the opportunity for resource managers to collaborate by placing joint tasking orders.

[1] The sun elevation angle (used interchangeably with altitude angle) is the angular height of the sun in the sky measured from the horizontal. The elevation is 0° at sunrise and 90° when the sun is directly overhead (which occurs for example at the equator on the spring and autumn equinoxes).

1. BACKGROUND

An up-to-date forest description is a key requirement to ensure resources are effectively managed and monitored.

Traditionally the benchmark for mapping and planning in forestry has been aerial photography. It is also generally accepted that visual interpretation and digitising of high resolution aerial photography (~0.25 m) provides a more accurate representation of boundaries, gaps and changes due to silvicultural tending or harvesting than automated delineation.

Typically aerial photography is routinely flown to update or remap areas after the following events:

1. Post establishment (to determine stocked area)
2. Early or mid-rotation inventory (adjustment of boundaries to account for area change)
3. Prior to pre-harvest inventory
4. After harvesting

For first rotation stands differential Global Positioning System (GPS) is often recommended so to set a solid spatial representation for future mapping. Post establishment updates often use aerial photography once the trees can be identified. Ongoing mapping is often also required to update areas prior to inventory or to track harvesting.

Recent advances in satellite technology mean that this technology offers a range of benefits to resource managers who require timely information to assist in broad-scale (1: 25 000 scale) planning. It is especially effective when combined with existing GIS stand boundaries that have been mapped from ortho-photography. In this environment satellite imagery provides a cost-effective option that allows for frequent monitoring and updating of forest mapping.

While this study focuses on RapidEye imagery, it is important to also consider alternative sensors that can be used to assess forest condition or monitor forest change. Table 1-2 provides an overview of sensors that are capable of providing this information.

Table 1-2: Selected Satellite Sensors & Characteristics

Sensor	Spatial resolution (m)	Pan resolution (m)	Temporal resolution (days)	Scene extent (km)	Cost per km^2 (USD)[2]	Available Bands		
						RGB[3]	NIR	Pan
SPOT 5	10	5	2-3	60 x 60	1.33	RG	Yes	Yes
Ikonos	4	1	3	11 x 11	20.00	RGB	Yes	Yes
GeoEye1	2	0.4	2-8	9 x 9	25.00	RGB	Y	Y
Quickbird	3	0.7	1-3.5	16 x 16	34.00	RGB	Y	Y
RapidEye	6.5	n/a	1-5.5	70 x 70	1.37	RGB	Y	N
FORMOSAT-2	8	2	1	24 x 24	8.97	RGB	Y	Y

The summary presented points to a number of functional differences between these sensors in terms of resolution (temporal, spectral and spatial) and cost. When these characteristics are compared it is possible to further refine the selection.

[2] Prices are based on images available in the archive and are correct as at September 2011
[3] Red, green and blue : NIR - near infrared : Pan - Panchromatic

In practical terms, for area-based applications the selected platform must satisfy the following criteria:

Table 1-3 Sensor Selection Criteria

Attribute	Requirement
Spatial resolution	<10 m (1:25 000 or better)
Temporal resolution (daily revisit)	1-2 days
Spectral resolution	Spectral bands sensitive to vegetation vigour
Image cost	Low cost to facilitate frequent acquisition
Meets user requirements	GIS ready (ortho-corrected) with minimal level of pre-processing and wide image extent to reduce the number of scenes. Minimal cloud-cover thresholds (<20%).

If the goal is stand-based assessment, then based on this selection criterion the currently available sensors (as at 2011) are limited to the SPOT 5 or RapidEye.

2. OBJECTIVES

The approach taken in this project was to make use of existing GIS representations and to develop methods that could be used to provide updates or flag areas of inconsistency.

In providing these updates users may opt to visually interpret the images and make changes manually, or follow semi-automated methods.

The satellite imagery selected is RapidEye, as it is cost-effective, and at 5 m resolution is suitable for stand-level mapping and monitoring (forest change detection).

The aim of the study was to evaluate the ability of 5 m satellite imagery to detect forest change activities such as harvesting, monitoring plantation establishment and growth progression and to provide frequent updates and identify inconsistencies in existing GIS representations.

The evaluation used repeat acquisitions approximately 6 months apart (October 2010 and March 2011) acquired over forests located in Canterbury and Hawke's Bay. The inclusion of separate sites and different image dates enables the repeatability of the process to be assessed.

The study set eight objectives, with six of the eight evaluated. Objectives seven and eight were not evaluated due to the lack of field observations:

1. Determine the age at which the plantation crop can be detected
2. Identify areas of non-forest i.e. harvesting or gaps using a single image (T1)
3. Evaluate images from two periods (T1 & T2) to identify areas of forest change caused by harvesting
4. Identify of areas of soil disturbance caused by harvesting or roading operations
5. Identify stands with variable establishment or growth
6. Evaluate the completeness of the GIS representation – including the accuracy of boundaries and detection of gaps
7. Identification of areas with significant weed problems
8. Potential identification of areas with significant disease (successful detection depends on the scale and prevalence of the disease).

Where possible the objectives have been evaluated using semi-automated mapping methods and processes. These have been adapted to use routines available in software such as ArcGIS (including the spatial analyst extension), and are implemented using the ArcGIS model builder application or custom python geo-processing scripts. To run the routines users are required to define the relevant GIS and image datasets manually.

Several of the image pre-processing steps (atmospheric and terrain correction) are not readily implemented in mainstream software packages. The implementation of these processes is considered best practice when comparing multiple images to detect change – due to changes in either growth or harvesting. Effectively the corrections reduce the variation between image pairs by accounting for differences in atmospheric conditions and solar illumination.

The exclusion of the image pre-processing steps however does not preclude the processes from being applied. A significant amount of information can be derived from an uncorrected scene, especially in evaluating gross changes like forest to non-forest, which show a very strong change in spectral signature.

However, it limits the ability to directly compare results from multiple time periods as the values are not calibrated to each other. Also, the derived products such as Normalised Vegetation Index (NDVI) or Enhanced Vegetation Index (EVI) can be affected significantly by atmospheric water vapour and/or aerosols, and therefore caution needs to be taken in interpreting the actual values of the derived product.

2.1 Datasets

Imagery for two areas was acquired for this study, and covered forests located in Canterbury and Hawke's Bay (Figure 2-1). The forest areas comprised a range of age-classes, species and operational activities distributed over a 100 000 ha area. The project objectives have been evaluated using a single 25 x 25 km tile (62500 ha) over Hawke's Bay.

Figure 2-1: Coverage and Study Area

2.2 Data Characteristics

A general description of the data characteristics for RapidEye is provided in Table 2-1. Further details that describe the sensor are provided in Appendix (4). There are five satellites in the constellation that have the same orbital path, which allows a daily overpass at about 11 a.m. each day. The overpass time is selected to coincide closely with solar noon when the sun is highest in the sky. The timing is designed to minimize the impact of shadow and maximize spectral reflectance from vegetation.

Two RapidEye products are available, Level 1B and 3A. The 1B product is not suitable for direct integration into the GIS as it is not referenced to a map coordinate system.

The 3A product has undergone a range of pre-processing stages that include the application of radiometric, sensor, and geometric corrections. It is also aligned to a cartographic map projection (usually UTM) with the default geometric correction based on GCPs derived from the Landsat ETM 15 m GLS2005 mosaic, and a (Shuttle Radar Topography Mission (SRTM) 90 m Digital Elevation Model (DEM). The intention of the ortho-correction process is to remove distortions inherent in imagery. The process ensures the satellite image conforms to a map projection, and includes correcting for terrain displacement.

Table 2-1: Data Characteristics

Product	RapidEye Satellite Imagery
Product Level	Level 3A – RapidEye Ortho
Currency	October 2010 – March 2011
Accuracy	<30m CE90* refer notes below
Pixel Size	5.0m in Level 3A Ortho product (rescaled from 6.5 m)
Bands	5-Bands: Blue, Green, Red, Red-Edge and Near Infra-Red
Bit Depth	12-Bit, scaled to 16-bit dynamic range for delivery – the dynamic range determines the number of discrete levels of information. A 16-bit image provides 65536 levels whereas an 8-bit image records only 256 levels
Imaging Angle	<20 degrees off-nadir (the sensor is able to point from orbital path to image objects off-nadir)
Projection / Datum	5-Band GeoTiff: WGS84 UTM
Tile / Mosaic	The sensor images a 70-km-wide swath that is processed into a 5-Band GeoTiff: 25km x 25 km tiles (*24km + 500 m tile overlap*). Each tile is approximately 250 mb.
Radiometry / Color Balance	5-Band GeoTiff: Calibrated Radiance-at-Sensor (Watt/m^2 sr^{-1} μm^{-1})
Cloud Cover	<20% per tile (for tasked imagery there is no obligation to purchase images with >20% cloud cover)
File Format	5-Band GeoTiff (~250 mb/tile)
Media	FTP

The imagery is delivered in a Geo-Tiff format that may be directly integrated into the GIS and overlaid with existing GIS datasets (by applying the appropriate coordinate transformation). Unlike conventional aerial photography, the Geo-TIFF file is scaled to 16-bit and contains five spectral bands, blue, green, red (as with photography), the red edge[4] and near infrared.

These bands measure discrete band widths (wavelengths) that are positioned to minimise atmospheric effects and are optimised to allow water penetration, discrimination of vegetation types and vigour[5].

The spectral reflectance patterns of forest in the visible spectrum are generally controlled by the absorption features related to chlorophyll content. In contrast, the spectrum in the near-infrared region is generally influenced by water content and the contribution of other organic materials.

When these principles are applied to a plantation situation, green healthy vegetation in the visible bands (blue, green and red) strongly absorbs the incoming radiation (as used for photosynthesis) resulting in a low percentage of the radiation being reflected back to the sensor. Conversely, reflectance increases at longer wavelengths (700-1300 nm). Should vegetation become stressed, reflectance increases across all bands when compared to healthy vegetation.

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[4] The red edge marks the transition between the visible spectral region, where plant pigments absorb most of the incident energy, and the near-infrared, where reflectance is high from plant canopies. Its position shifts according to changes of chlorophyll content, leaf area index, biomass, age, plant type, species, health levels and seasonal patterns.

[4] The decision of where to measure individual spectral bands was based on analysis of early satellite data such as from Landsat MSS (launched in 1972).

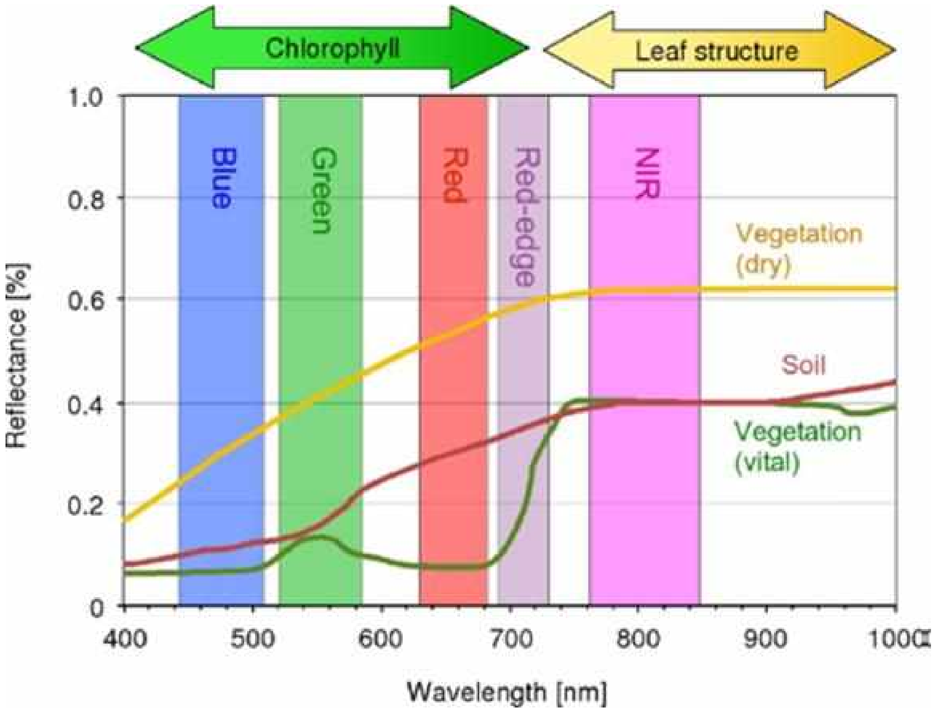


Figure 2-2: Spectral Response Curves with RapidEye Spectral Bands

The apparent shift in the spectral response of vegetation between the visible and NIR bands has been exploited by the computation of several spectral ratios. The Normalised Vegetation Index (NDVI) or derivatives (Enhanced Vegetation Index) are commonly applied to separating forest from non-forest and for monitoring plantation vigour. The application of ratios is further discussed in Section 2.12

2.3 Quality Control of Imagery

Prior to pre-processing the images, several quality control (QC) checks were conducted. These checks were made to ensure the images conformed to the RapidEye product specifications and the project requirements. The checks included:

1. Image tiles covered the project extent and were geo-referenced
2. All bands were present and contain five bands (red, green, blue, red edge and near infrared)
3. Spatial resolution equals 5 meters
4. Cloud cover threshold of <20% was met
5. Associated metadata file existed
6. Geo-referencing of the imagery is coincident with the GIS stand boundaries
7. Multi-temporal coincident tiles were offset no more than one pixel.

The images passed all the QC checks with the exception of points 6 and 7 which relate to the accuracy of the geo-referencing.

Consequently, offset issues were noted between the image tiles and the vector stand boundary layer provided. The offset was typically to the north/south with a range between 3-7 pixels offset. Much of the variability appears to be related to terrain. Attempts to correct the imagery using standard image co-registration techniques proved only partially successful due to the variability of the geo-registration offset, as shown in Figure 2-3.

(a) (b)

Figure 2-3: Geo-registration offset (a) before co-registration to base map (b) after co-registration to base map

Offsets between coincident RapidEye tiles from different data were also identified. These offsets showed a similar terrain-based variability, and therefore the tile to tile co-registration of coincident tiles proved only partially successful.

From documentation and correspondence with RapidEye it is understood that during product processing, all RapidEye ortho-products have to pass a system threshold value of 30.34 m CE90, or better. The CE90 or circular error at 90% refers to the radius of a circle that represents a 90% probability of position confidence.

This accuracy is determined per image taken (date), whereby a separate set of GCPs might be deployed by RapidEye for Level 3A geometric processing across adjacent tiles from different acquisition dates. This means that the geometric solution might differ across these tiles, dependent upon the accuracy and precision of the GCPs applied in each instance. These accuracies are valid for RapidEye imagery collected at nadir over flat (<10^{o} slope) terrain.

When two images are subtracted from each other the offset or shift can result in false change. This occurs close to non-forest edges where one image shows forest and due to the offset the other bare ground. The magenta colour on **Figure 2-4** shows areas of change detected as a result of the shift between coincident scenes.

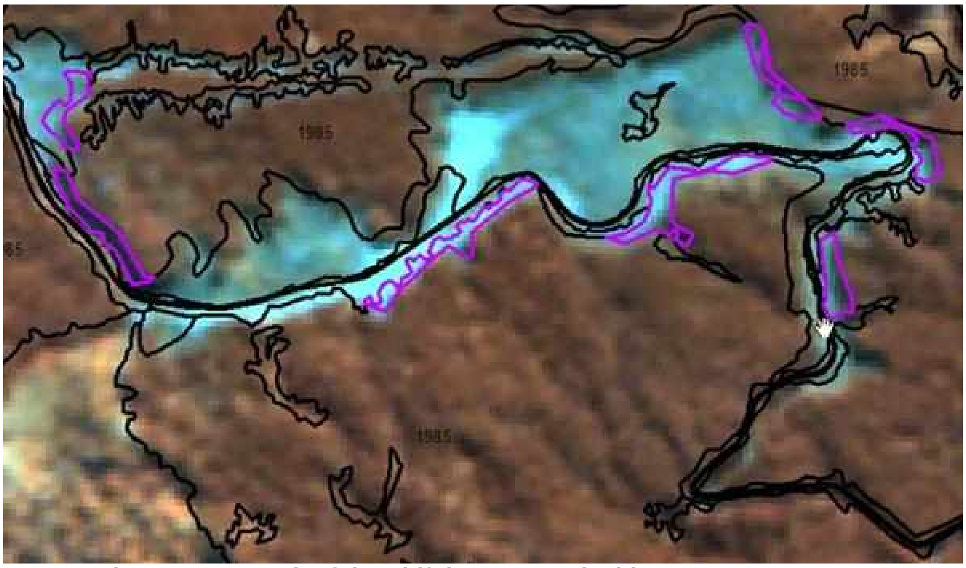


Figure 2-4: Result of the Shift between Coincident Images

2.4 Resolution of Positional Accuracy Issues

The geo-registration problems are related to the low resolution 90 m SRTM DTM used and the accuracy of the ground control points applied in RapidEye's ortho-rectification process.

In September 2011 RapidEye replaced the 90 m DEM with the 25 m National DEM[6] as developed by Landcare Research. The intention is that all further products supplied by RapidEye will be provided ortho-corrected using the 25 m National DEM.

Figure 2-5: Comparison of Ortho-correction using 25 m DTM

As an example, the improvement in the imagery is shown in **Error! Reference source not found.**, which plots the original 90 m DTM (left) against the 25 m DTM (right) over the Southern Alps. A greater level of distortion or warping is observed over the ridge in the centre scene in the 90 m DTM compared to the 25 m DTM.

The GCPs, the other error source, have not been updated and further improvement is warranted in this area. The update process would involve repositioning the national set of GCPs approximately 2500 points using available high resolution datasets such as aerial photography.

[6] (http://lris.scinfo.org.nz/#/layer/131-nzdem 25-metre

3. METHODOLOGY

The methods used sought to utilise off-the-shelf software packages, and where possible the routines were developed in a GIS environment (ArcGIS with spatial analyst) and added as a customised toolbox and implemented from ArcToolbox. The four geo-processing tools included:

- Detection of harvested and bare soil areas from a single image
- Detection of harvested and bare soil areas from a time series
- Mapping of crop variation at the stand-level
- Mapping of crop variation within stands.

Prior to running the GIS routines, several pre-processing steps are recommended, such as atmospheric corrections and corrections for topographic shadow (explained in section 4). These routines require specialist remote sensing software (ENVI or GRASS), and knowledge of satellite data and other atmospheric datasets (ozone and water vapour).

It should be noted that for change detection applications (i.e. harvest detection), the spectral ratio selected (Enhanced Vegetation Index (EVI)) is relatively robust, so the pre-processing steps are less critical. However, for variation mapping it is important that images are standardised so as to effectively detect change in the vegetation spectral response. The following process diagram shows the method adopted and inputs (left) and outputs from each process. Each part of the process is described in Sections 4.1 & 4.2.

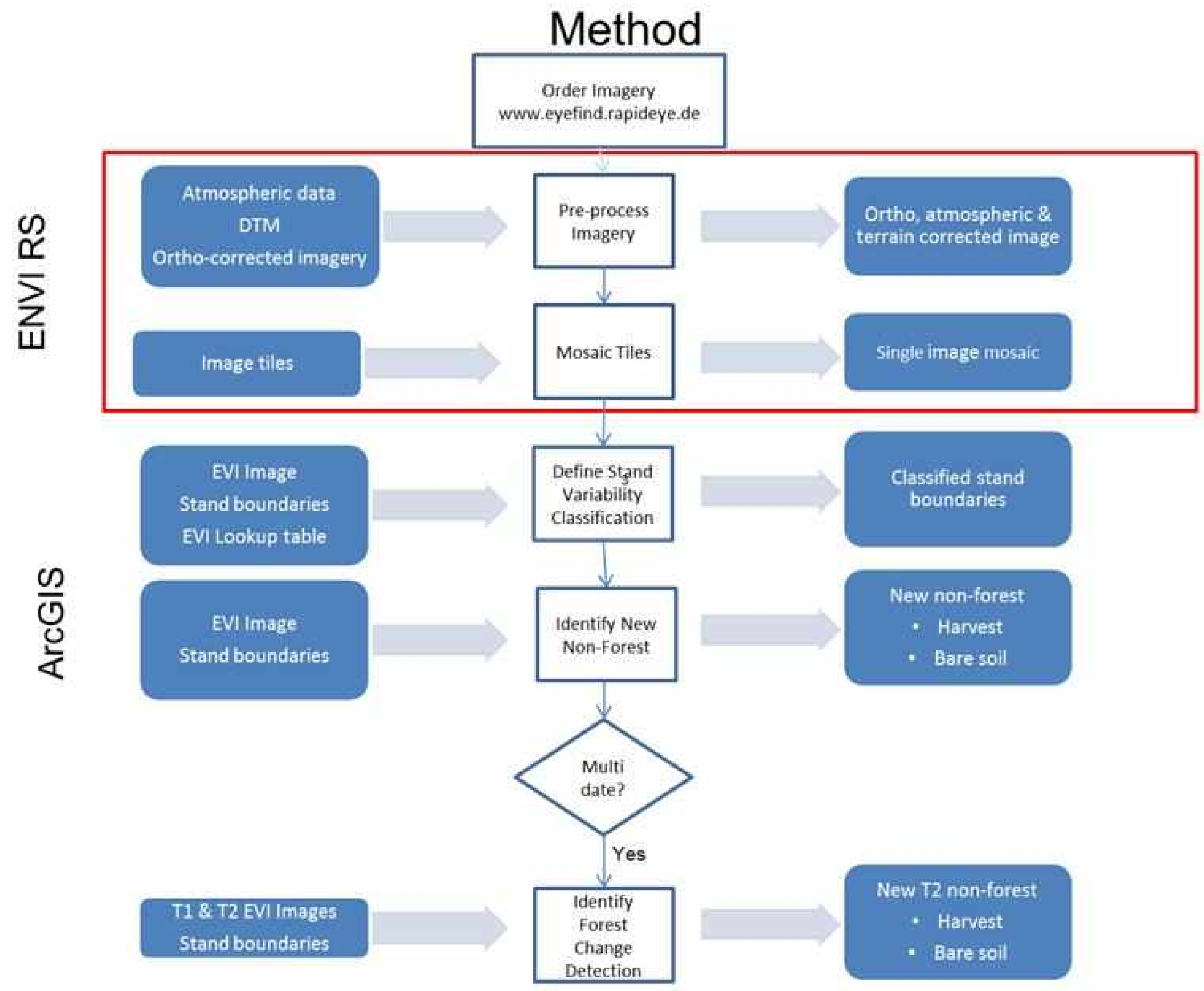


Figure 3-1: Process Flow & Methodology

4. IMAGE PROCESSING

For the selected image tiles, several pre-processing steps such as ortho-correction, atmospheric and topographic corrections are required prior to analysing satellite images. These processes were undertaken in ENVI and GRASS and are designed to produce standardised image products from which quantitative analysis such as land cover mapping, monitoring, and detection of change can be performed.

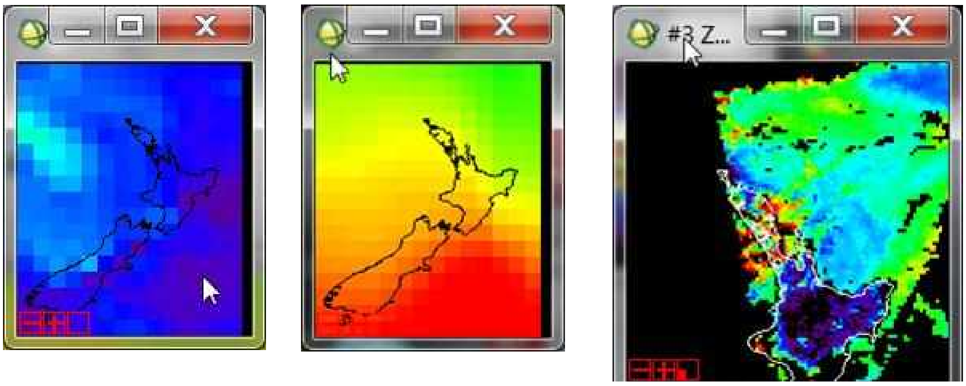
4.1 Atmospheric Correction

RapidEye imagery is provided scaled to 16 bit unsigned integer values. This is then converted to reflectance using available parameters. The resulting image represents calibrated energy returned from the field of view as detected at the top of the atmosphere (TOA).

In order to compare multi-temporal satellite imagery and adjacent scenes accurately, the surface reflectance must be calculated. The surface reflectance represents the energy returned at the ground surface after removing the scattering and absorption effects of the atmosphere.

The 6S (Second Simulation of a Satellite Signal in the Solar Spectrum) algorithm developed by Vermonte (2009) is used to correct for atmospheric effects. The 6S simulates satellite observations, accounting for varying target heights of a realistic molecular/aerosol/mixed atmosphere, and calculation of gaseous absorption.

The 6S implementation allows the definition of custom or standard atmospheric, aerosol and visibility models. Variables for defining these models for a specific date and time are generated from a number of remote sensing sensors (e.g. MODIS, AIRS, and MISR).



(a) (b) (c)

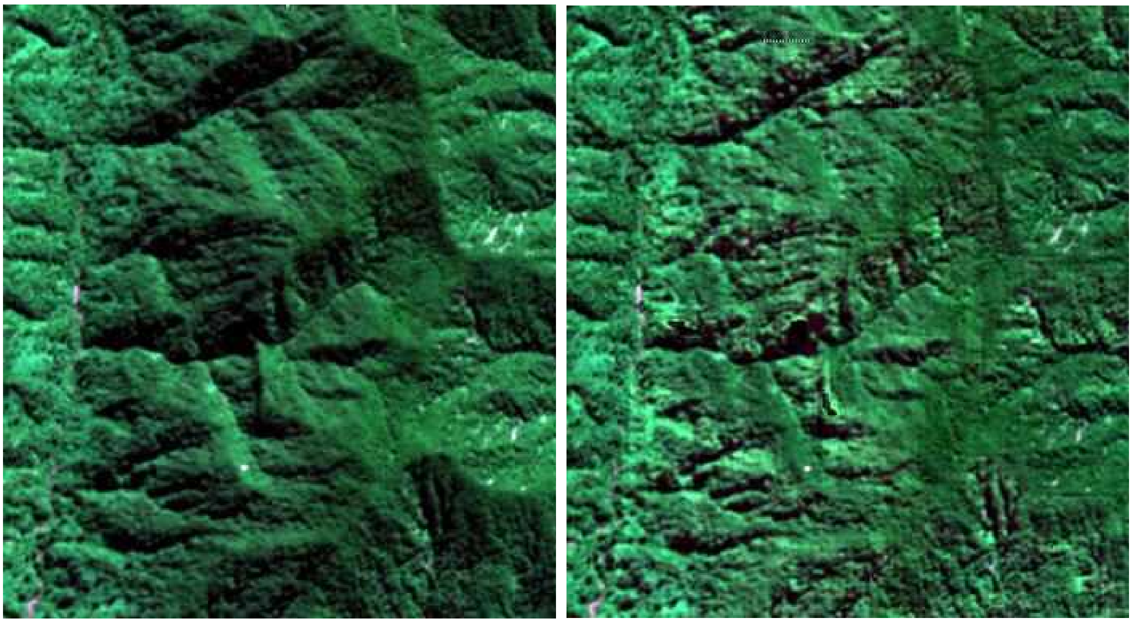
Figure 4-1: Sample inputs to Atmospheric Correction. (a) Water Vapour, (b) Ozone, and (c) Aerosol Optical Depth

Atmospheric conditions are simulated for the image date using a customized atmospheric model defined by the mean water vapour and ozone values over the scene from the daily atmospheric data collected for the image date. The visibility is defined using the mean aerosol optical depth (AOD) value over the scene from the daily atmospheric data collected for the image date.

4.2 Topographic Correction

In addition to atmospheric effects, topographic effects in hilly or mountainous terrain impact on the reflectance due to differences in terrain slope and aspect, viewing angle and sun position. These topographic effects can be reduced by applying a correction to adjust the reflectance for each pixel to a horizontal surface.

Corrections for topographic effects are applied using the C-correction method defined in Riano (2003). The available DEM is resampled to match the 5-metre RapidEye image using bilinear interpolation. Slope and aspect are derived from the DEM for input into the C-factor correction. These parameters are entered into a correction tool developed in ENVI to apply the topographic correction to each band in a selected RapidEye scene. Figure 4-2 shows the results of before (a) and after (b) the application of the correction – in this image the impact of shadowing is reduced.



(a) (b)

Figure 4-2: Correction for Topographic Effects. Uncorrected image (a) Topographically Corrected Image (b)

At the completion of the pre-processing the individual image tiles were mosaicked to produce a single coverage which can then be ingested into Arcmap and used as inputs to run the customised ArcGIS routines. For an overview of the routines developed for Arctool box, see Appendix 2.

5. RESULTS

To meet the study objectives the analysis used a combination of visual interpretation of the images and quantitative analysis. Generally the image composites are more easily interpreted when overlaid with GIS, the stand boundaries and the corresponding attribution. To assist, a basic image interpretation guide is provided in Appendix (1).

The quantitative analysis focused on the refinement of established remote sensing methods used to identify areas of change and also monitor plantation development. The change detection method adopted uses the EVI (band ratio) while the variation mapping routine establishes the relationship between the image reflectance and stand age. Both methods are further explained in section 5.2.

5.1 Monitoring Plantation Establishment

An evaluation of the March 2011 RapidEye imagery using the stand boundary layer and the year of establishment indicates that establishment can be detected within 2 years of planting and mapped within 3-5 years of planting.

This is demonstrated in Figure 5-1, which shows the false colour composites (using NIR, RE and Green bands) from the March 2011 RapidEye image for different stands established since 2005.

Bare ground or disturbed soil appears bright blue (2010 example) and green vegetation appears in shades of red, orange and brown. As the canopy closes the transition from bare ground (blue) to plantation (orange to brown) becomes quite apparent (2005 showing 5 years' growth).

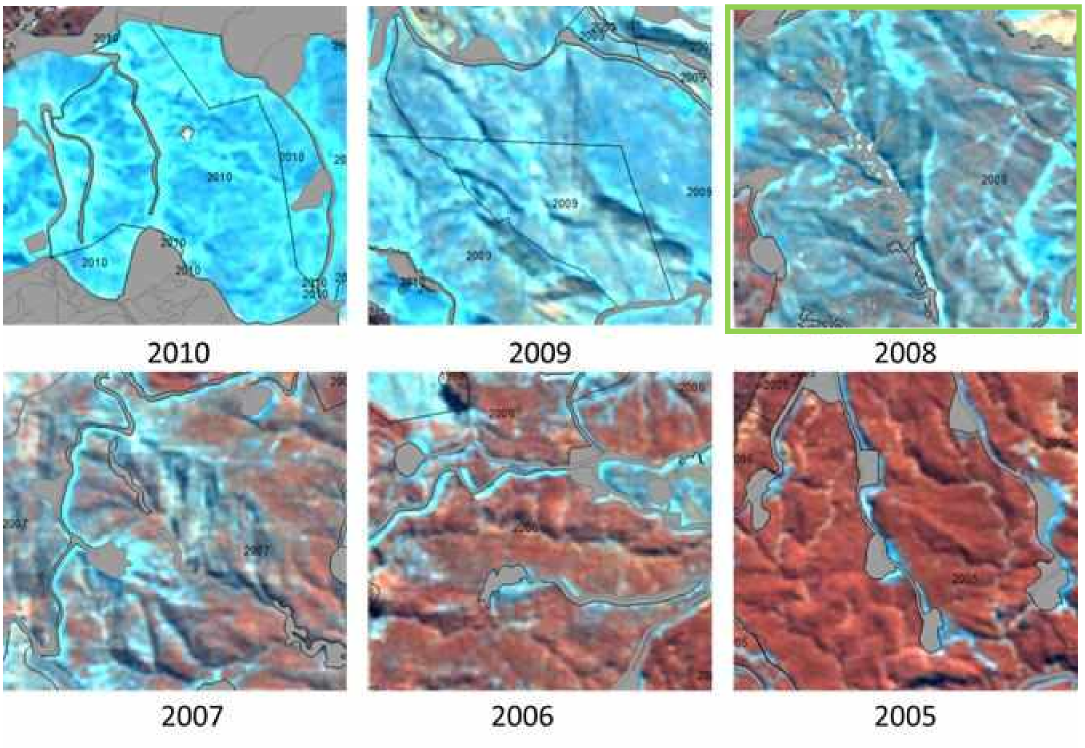


Figure 5-1: Monitoring Plantation Establishment (by Year of Establishment)

This trend is well known and has a physical basis, as reflectance is known to decrease in certain spectral bands as the canopy closes. This means that the trend observed should be transferable to other sites that are managed using a similar regime.

5.2 Detecting Harvest Areas and Mapping Plantation Variability

Previous research has shown that individual spectral bands such as the green, red and spectral ratios that include NIR correlate well with the degree of canopy closure, and are effective for separating forest from non-forest.

For this study band ratios are of particular interest as they provide an effective way to correct for variations in the reflectance values that may be caused by differences in atmospheric or sun illumination conditions. This partially negates the need to conduct pre-processing steps such as atmospheric corrections.

The Normalized Difference Vegetation Index (NDVI) is one the most widely used ratios for identifying areas of vegetation cover and bare ground. The difference in reflectance from the near infrared and red bands is divided by the sum of the two reflectances. This compensates for different amounts of incoming light and produces a number between 0 and 1. The typical range of actual values is about 0.1 for bare soil to 0.9 for dense vegetation.

For this study an alternative to the NDVI, the Enhanced Vegetation Index (EVI) ratio was used. The ratio was originally developed to help correct for certain atmospheric effects (using the blue spectral band) and soil background signals that potentially influence the NDVI values. The benefit of this ratio is that it provides a more robust method for separating non-forest (i.e. harvest areas) from established plantations. The EVI is calculated using the following equation:

$$\mathrm{EVI} = 2.5\left(\frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + 6\rho_{RED} - 7.5\rho_{BLUE} + 1}\right) \quad [1]$$

The following example (Figure 5-2) illustrates how the EVI can be used to identify harvested areas. On the greyscale EVI image, lighter shades of grey indicate high levels of vegetative cover (values close to 1) while darker areas indicate lower levels or none (black – values close to 0). On the EVI image the bare soil, skid sites, roads and harvesting are all clearly visible.

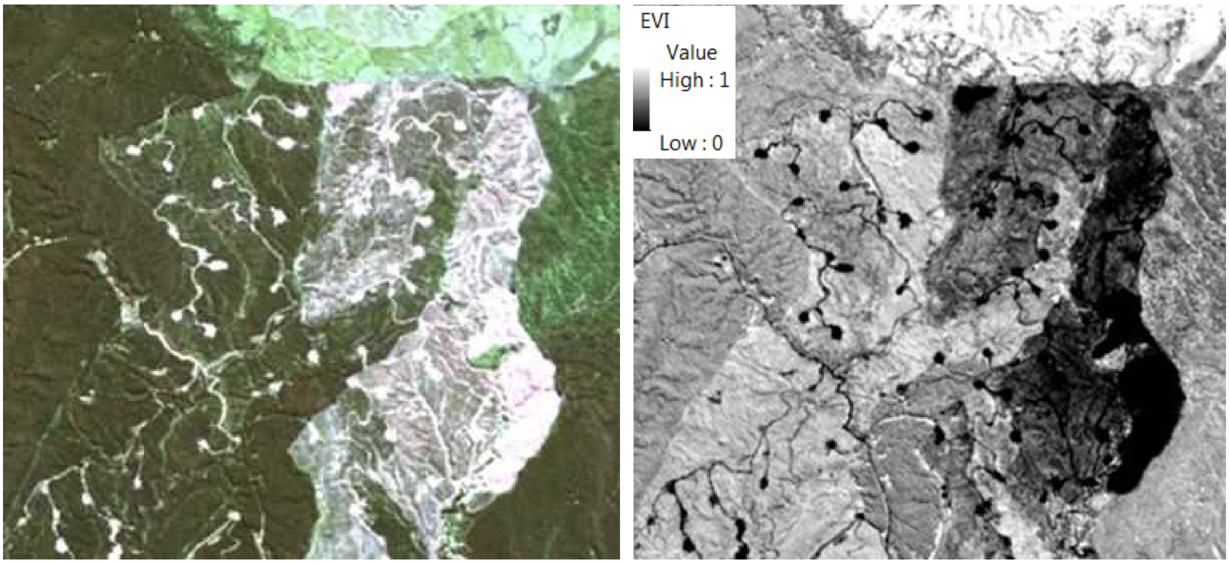


Figure 5-2: (a) True Colour Image & (b) Greyscale EVI image

Using this information, harvested, cleared areas or gaps that meet a user-defined threshold can be extracted from the imagery. The EVI ratio values are used as the basis for the harvesting and gap detection routines developed.

The development of the stand variation routines also relies on the relationship between the EVI ratio and age. Here, age is used as a proxy for establishment success.

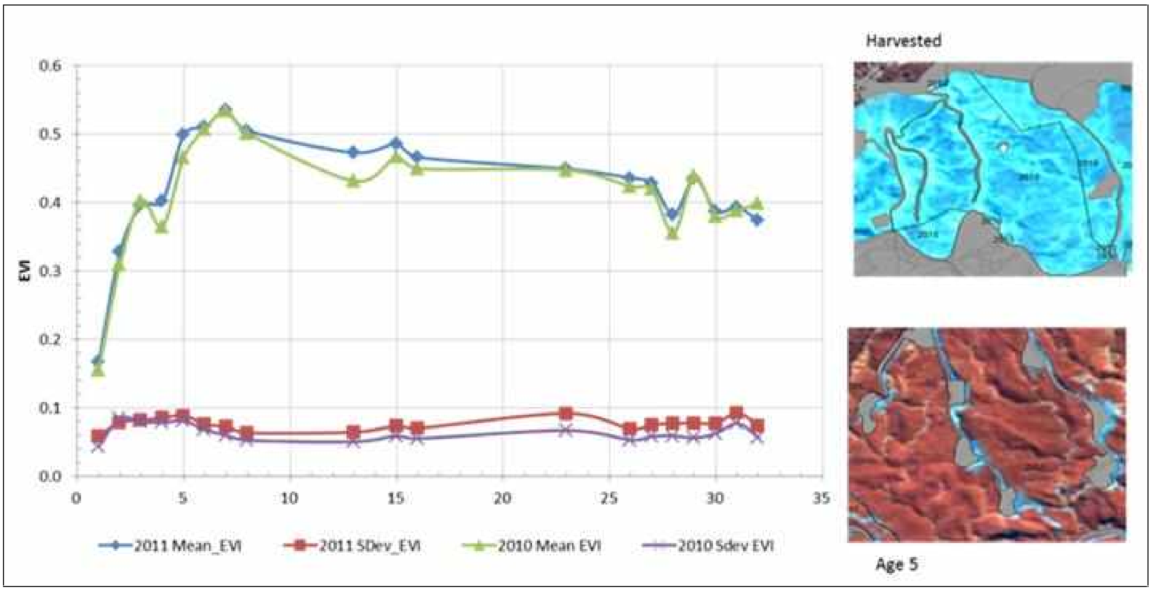
The following relationship was developed by averaging the reflectance values over 4000 *P.radiata* stands for the images acquired for two time periods (2010 and 2011). While minor differences are observed between the curves, the relationship is very similar. This is also indicated by the low standard deviation between the relationships.

Overall it tracks the trend discussed earlier whereby as the canopy closes the EVI values increase rapidly (from 0.15 to 0.5) and plateau at about age 7. Between these points a dip is observed which may correspond to the first thinning. Little variation is observed after age 7, with the EVI relatively stable. The oscillations at the tail of the curve reflect the different harvesting ages.

Practically this means that reflectance can be used to track crop development up to the point of canopy closure, as the reflectance values are changing rapidly. However, beyond this point there is little variation in reflectance, which limits its application.

Other research has sought to transfer this relationship and use it as a basis to estimate biophysical measurements such as canopy height.

Table 5-1: Relationship between Mean Stand-level EVI & Age (years)



The EVI and stand age relationship form the basis for the development of the stand variation routine as outlined in sections 6.3 & 0.

6. APPLICATIONS

The four routines developed are accessed via the ArcTool box menu (Figure 6-1) and apply the principles presented in the Results Section 5.2. The routines are designed to be flexible enough to utilise a range of satellite sensors (i.e. IKONOS, SPOT[7] or Landsat) and to be able to ingest GIS representations with a range of attribution structures[8]. To implement the applications users must have access to the spatial analyst extension.

It is also important to note that the outputs may need additional editing to meet the end users' mapping standards. This is especially true if stands have been mapped from high resolution (0.25 m) ortho-photography.

Figure 6-1: Toolbar Menu

For the change detection functions to be effective, the satellite images from different periods and the GIS need to overlay. If they do not then potentially any offset will be identified as change. Additionally, if imagery is not cloud-free then cloud will be detected as change, as its signature is similar to bare ground. All of these anomalies can be eliminated manually during post-processing of the resulting GIS layers.

6.1 Identification of Non-forest Areas

The purpose of this function ('T1_ForestChange') is to identify all non-productive areas or harvest areas from a single image. Optionally, areas of high soil disturbance (landings or heavy traffic areas) are also delineated. The inputs to run the routine include a single RapidEye image, and as an option the stand GIS.

The current routine is most effective for delineating those areas with a bare soil signature. The routine will not extract vegetated gaps – i.e. grass-covered areas.

The process steps are outlined in Figure 6-2. First, the enhance vegetation index (EVI) ratio is created using the RapidEye NIR, Red and Blue bands (i.e. bands 5, 3, and 1, respectively).

This process partitions the image into the forest and non-forest components. During the processing only non-forest components that meet the prescribed EVI threshold value (set at 0.25[9]) are retained. These areas are filtered to remove isolated or disjointed areas and then converted to GIS polygons. Optionally, the GIS polygons can also be further classified into areas of high soil disturbance.

During the final stages of extraction the gaps or harvested areas are clipped to the stand GIS. This means that any areas that have already been mapped out in the GIS as harvest or as gaps are ignored.

[7] If SPOT sensors are used then the EVI ratio will need to be replaced by the NDVI ratio which does not require the blue spectral band.

[8] It should be noted that they are provided 'as is' and no support or modifications are offered as part of this contract. The applications are available to FFR members only.

[9] The user may alter the default value based on experience which provides flexibility if pre-processing steps are not implemented.

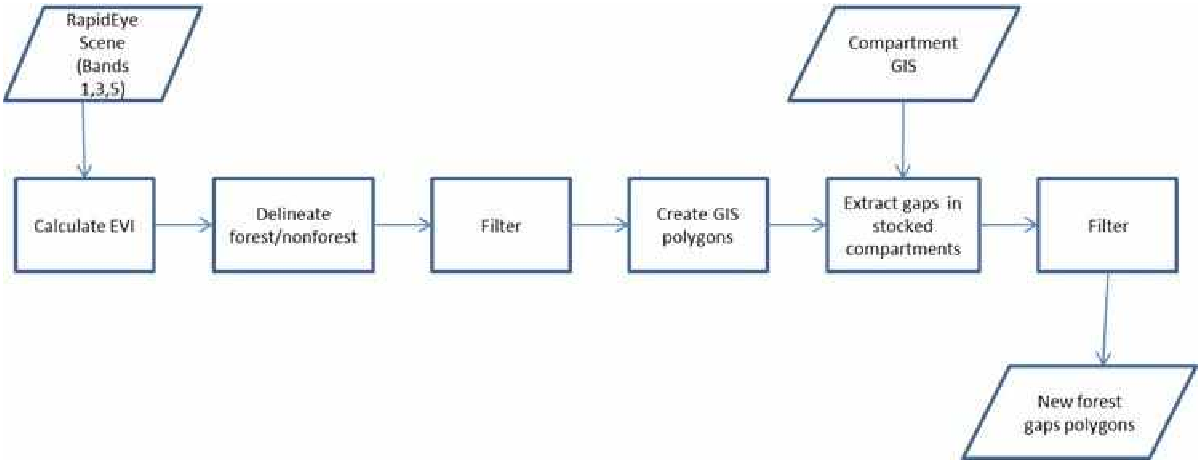


Figure 6-2: Non-forest Detection & Mapping Process

The output of the non-forest mapping routine is illustrated in Figure 6-3 where new harvest areas that have not yet been recorded in the GIS are displayed.

Figure 6-3: Detection of Recent Harvesting

shows the same area which has been further divided into either disturbed soil or harvest.

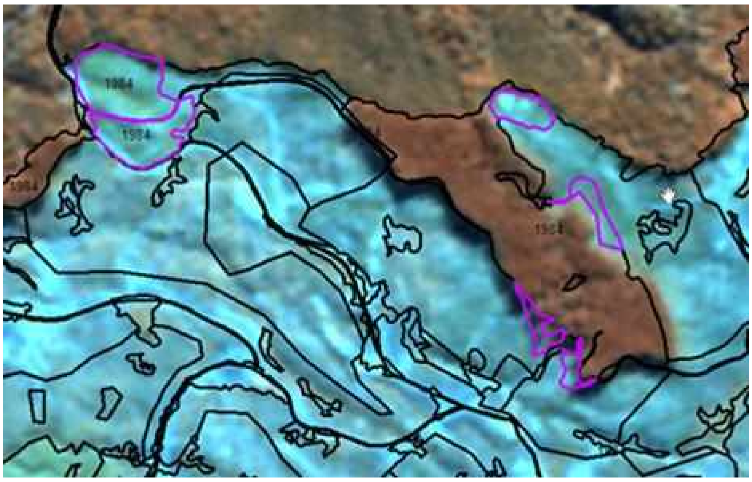


Figure 6-3: Detection of Recent Harvesting

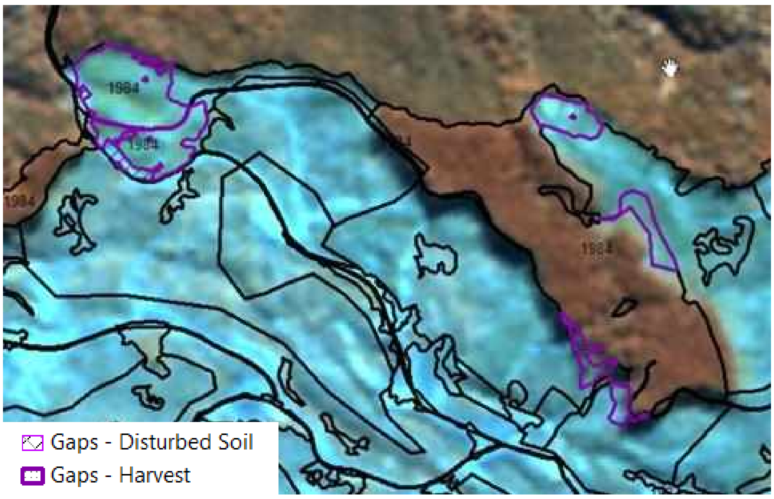


Figure 6-4: Harvest Area Classified by Harvest and Soil Disturbance

The detection and delineation of the area of soil disturbance (brighter blue areas) is possibly more subjective as it depends on the degree of disturbance and the time elapsed between the image acquisition and harvest activity.

6.2 Multi-temporal Forest Change Detection

The multi-temporal forest change detection process (T1_2_ForestChange) is similar to the T1_ForestChange routine. The main difference is that changes are identified by subtracting images taken from two different time periods. This has the advantage of identifying only those areas that have changed from forest to non-forest – potentially this can include harvest areas, areas of soil disturbance or forest gaps that have not already been mapped out.

The process runs by generating an EVI image for each of the time periods. This process partitions the image into the forest and non-forest components. The earliest image is often referred to as T1 and the second as T2.

The two EVI images are differenced, thresholded and filtered to identify areas of change. After converting the change areas to GIS polygons, the GIS stand boundaries are applied to identify and extract areas of harvesting and soil disturbance. This means that any areas that have already been mapped out in the GIS as harvest or as gaps are ignored. The process is outlined in Figure 6-5.

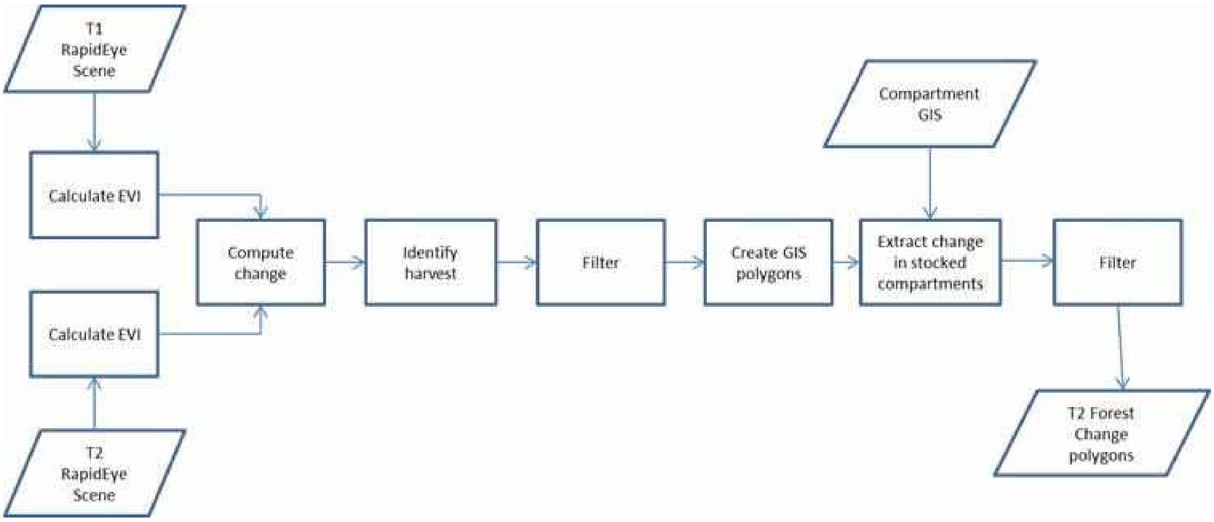


Figure 6-5: Multi-temporal Change Detection Mapping Process

The following examples show the same area with the stand GIS overlaid, before and after harvesting. Red coloured pixels identify areas of forest and the blue coloured pixels denote areas of harvest.

The two areas detected as harvested are highlighted in magenta. It is possible that the area detected may need additional editing to better define the harvest boundary to meet established mapping standards. Often this is the case if the area is small or fragmented and the resolution of the imagery is not high enough to define the edge of the harvesting accurately.

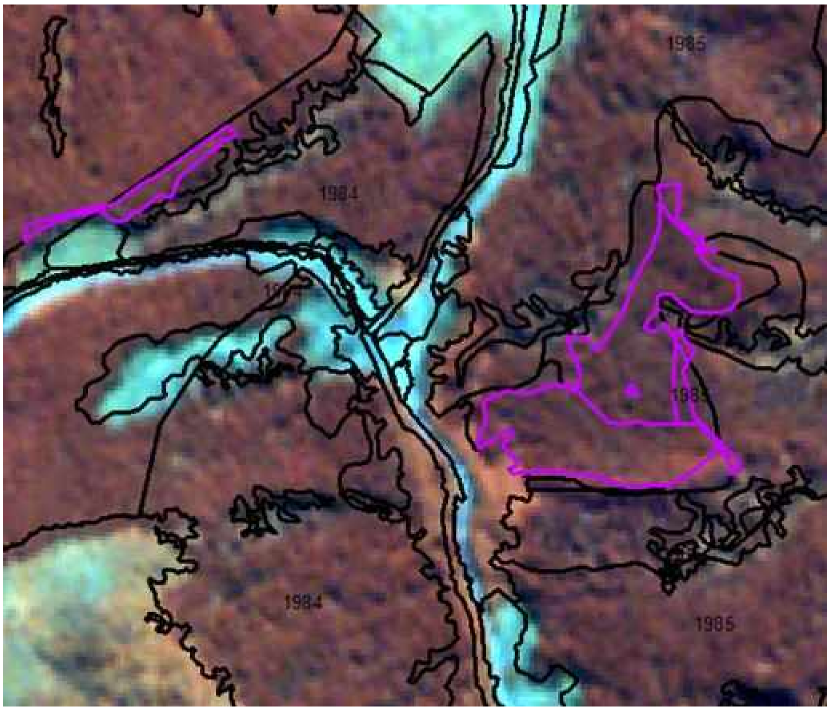


Figure 6-6: Pre Harvest Image (12-10-2010)

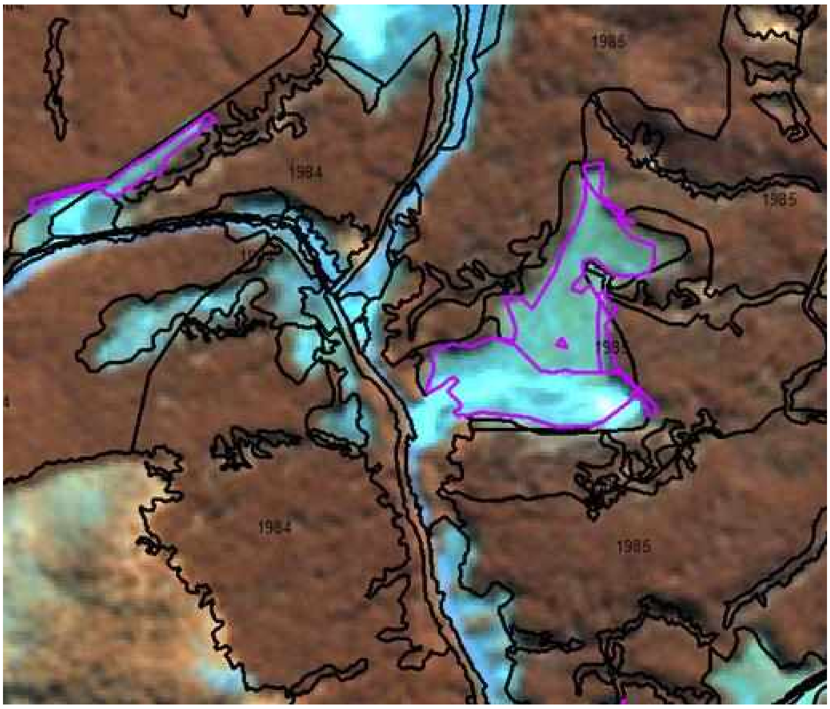


Figure 6-7: Post Harvest Image (22-03-2011)

The advantage of this routine over the single date 'T1_ForestChange' method is that only new changes that have occurred between the two image are identified. This will result in fewer potential change polygons for the operator to assess, attribute and integrate with the stand GIS.

6.3 Stand-Level Variation

The purpose of the stand variation routine ('StandLevelVariation' tool) is to provide a rapid method of identifying those stands that vary from what is expected. Differences could be related to either:

- variations in growth development across the stand;
- unmapped forest gaps such as wind damage or erosion; or
- areas that have not been updated in the stand GIS – i.e. new harvesting or roads.

It should also be noted that there are several factors that may influence the results, such as the effects of topography or cloud on the spectral response of the forest, and mis-registration of the GIS and image datasets. These factors are summarised as follows:

- A mismatch between the satellite and the stand GIS, or vice versa. These areas will appear as 'slithers' along the edge of the stand GIS.
- The topographic orientation of the stand relative to the sensor. In this case areas pointing towards the sensor will be illuminated and opposing areas will be in shadow. These areas will appear in line with the topographic aspect of the terrain and can be identified by producing a hillshade surface from the DTM that mimics the sun azimuth and elevation of the RapidEye image.
- Any cloud or cloud-shadow and potentially hazy areas. In both cases the results will appear in the shape of the cloud feature so can be easily eliminated.

The semi-automated nature of the method allows users to evaluate the results and retain only those areas that provide additional information. In this context the application is designed to augment existing mapping taken from higher-resolution data sources.

The variation routine is based on the relationship between the stand age-class and mean EVI outlined in Section 5.2. Using this relationship, a global lookup table was developed and populated with expected reflectance values for each age-class[10]. This is used to compare how individual stands vary from the overall mean, and is classified based on its standard deviation.

The variation for each stand is allocated based on its standard deviation using the following thresholds (Table 6-1). This is input as an additional column in the attribute table. Negative classes (-2 to -4) indicate those stands that plot lower than the expected reflectance value for that age-class. The higher the class value the greater the standard deviation. Positive classes (2 to 4) indicate those stands that plot higher than the expected reflectance value. In terms of development these areas are generally tracking ahead of the mean.

Table 6-1: Variation Thresholds

Class	Description	Threshold
4	Stand above normal – variation class 4	mean EVI > +3 stdev
3	Stand above normal – variation class 3	+3 stdev >= mean EVI < +2 stdev
2	Stand above normal – variation class 2	+2 stdev >= mean EVI < +1 stdev
1	**Normal**	**+1 stdev >= mean EVI < 0 stdev**
-1	**Normal**	**0 stdev >= mean EVI < -1 stdev**
-2	Stand below normal - variation class 2	-1 stdev >= mean EVI < -2 stdev
-3	Stand below normal - variation class 3	-2 stdev >= mean EVI < -3 stdev
-4	Stand below normal - variation class 4	-3 stdev >= mean EVI

The process used to classify the variability within stocked stands is shown in Figure 6-8.

[10] The global look up table is based on *P.radiata* stands and is drawn from the Hawke's Bay study area only. The sample size is 4000 stands covering a range of age-classes.

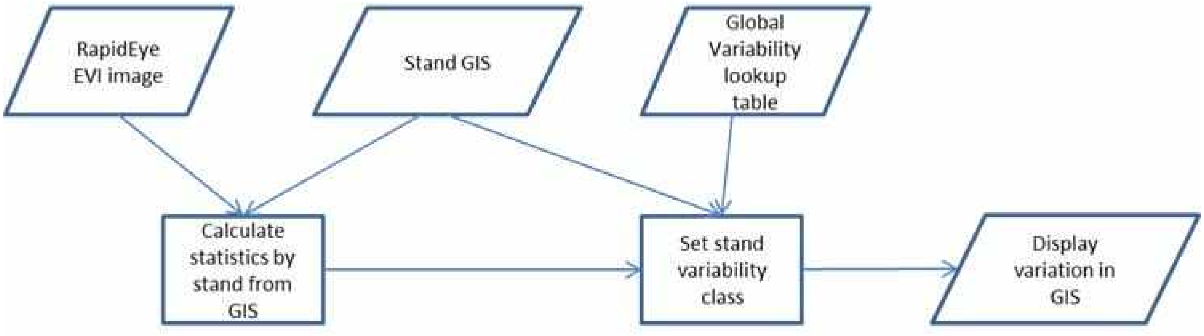


Figure 6-8: Stand-level Variability Classification Process

First the mean EVI value from the input image is calculated for each stocked stand in the stand GIS register. Next, the mean stand-level EVI value is calculated and linked with the age-class and compared to the mean EVI and standard deviation values held in the global lookup table.

Each stand is assigned a stand-level variability classification code based on the number of standard deviations from the global lookup mean EVI value.

The result of the stand variability analysis over the study area (62 500 ha) ha is highlighted in Figure 6-9 where stands exhibiting variability above or below the lookup mean are outlined in cyan.

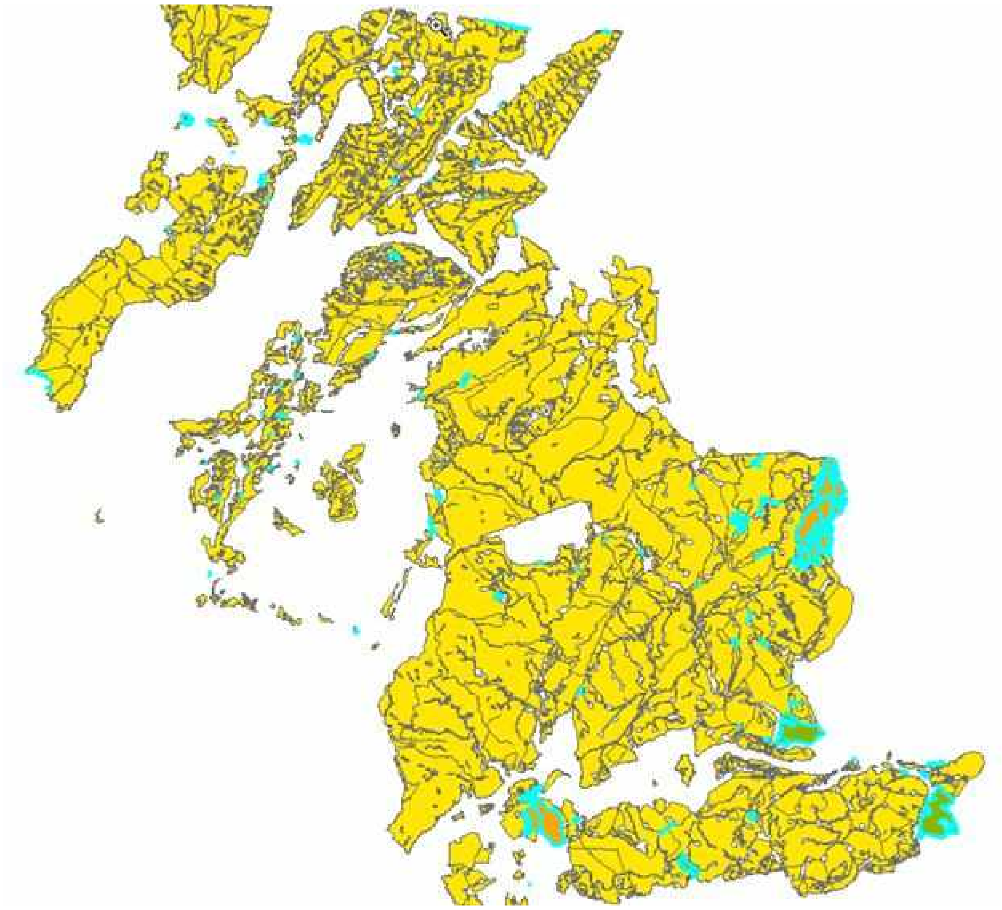


Figure 6-9: Stands Exhibiting Variability (cyan outline)

A further example with variation classification overlaid is shown (Figure 6-10) along with the RapidEye image displayed as a false colour composite.

The classification identifies a stand established in 2008 that falls two standard deviations (orange area) below the expected mean. The corresponding RapidEye image indicates that across the stand there is some variation in establishment. This is caused by a higher proportion of bare soil which lowers the reflectance values across the stand. The remainder of the stand (yellow area) falls within the expected reflectance range.

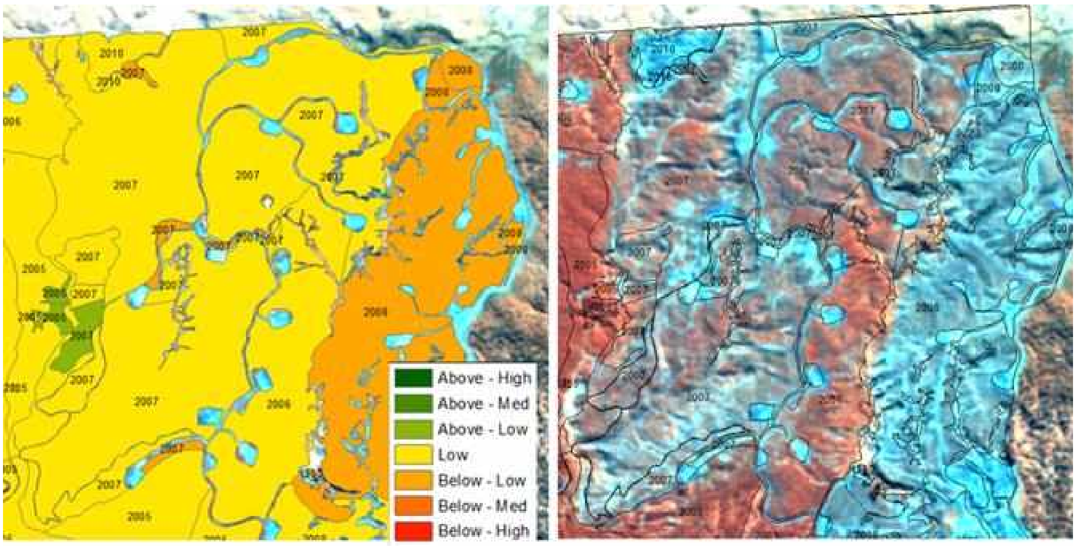


Figure 6-10: Stand Variability

The second example (Figure 6-11) shows an area planted in 1984 that has already been harvested. Due to harvesting the reflectance value (from soil) of the stand is much lower than the global lookup value. Accordingly, the stand is allocated a high standard deviation (coloured red) relative to the mean value for a stand of this age.

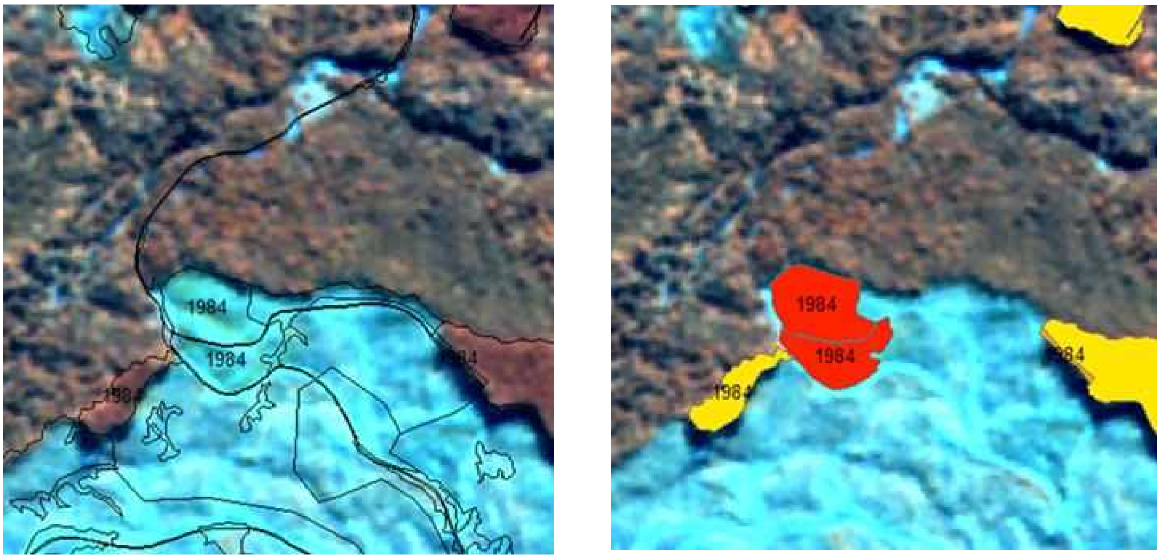


Figure 6-11: Identification of Update Errors in the GIS

6.4 Intra-stand Variation

The purpose of the intra-stand variation routine ('IntraStandVariation' tool) is to identify within-stand variation. This provides a way to pinpoint areas of anomalous growth or identify attribute discrepancies in each stand.

The routine uses the same relationship developed between image reflectance and age used for stand-level analysis which can be applied to identify the variation within stands.

The intra-stand variability routine compares the EVI value of each pixel against the global lookup value for that age-class. The following figure (Figure 6-12) shows the resulting classification for a stand and the corresponding RapidEye image. In this example a majority of the stand plots are coloured yellow, which indicates that the stand is tracking as expected as it falls within the reflectance bounds for its age.

Areas of red signify areas of high variation relative to the global look up values.

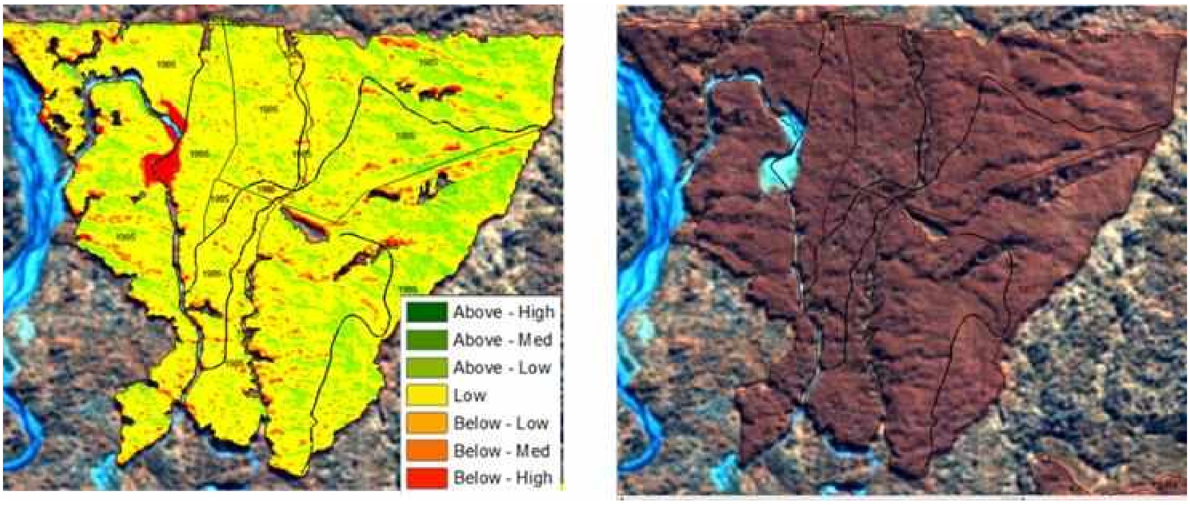


Figure 6-12: Intra-Stand Variability

These areas are identified as:

- A recent harvest area that has not be updated in the GIS
- A potential area of erosion close to the river
- Additional gaps that have not been excluded from the net stocked area
- Areas of shadow on the satellite imagery due to the topographic aspect
- Potential registration errors in the satellite image relative to the stand GIS

Areas that appear to be performing better than expected are coloured green. Some of these areas may be valid, but may also be caused by bright sunlit areas that are orientated directly towards the sensor.

The two variation routines developed – stand-level and intra-stand provide a means of identifying those stands that vary from 'normal' reflectance values. The stand-level routine provides a high-level assessment across all stands. In large stands the variation (measured as the s.d. from the mean) may be masked. This would occur if areas of high and low standard deviation were present across the stand in equal measure.

This situation would be countered by the intra-stand level routine which identifies anomalous areas at a 5-m scale (i.e. the pixel level).

7. RAPIDEYE IMAGE COST

In many situations a combination of archived (i.e. images already collected) and tasked acquisitions improves the forest harvest detection and forest monitoring process. This is achieved by identifying a cloud-free base image in the archive against which all subsequent changes can be compared.

In July 2011 RapidEye released a modified cost model for archived and tasked imagery. In particular the cost model applied to archive imagery provides a more cost-effective option for geographically scattered forests. The current archive spans from October 2010 to September 2011 with full national coverage until March 2011 (see Appendix 3).

Archive Imagery

The basic RapidEye cost model for archived imagery prices the imagery at 0.95 euro/km^2 with the minimum order value of €475 (~NZD850) for one contiguous area. While multiple areas can be ordered, the minimum of any single area of interest (AOI) is assumed to be greater than 125 km^2.

Smaller AOIs are priced at €8 per km^2 with a minimum order of €950 applied. RapidEye have indicated that they will assess any given area and may buffer it accordingly to simplify the extent.

Table 7-1 provides an overview of the cost structure in euro and estimated NZD equivalent.

Table 7-1: Basic RapidEye Cost Model

Actual AOI Size (km^2)	Billed AOI Size (km^2)	Billed AOI Size (ha)	Price/ km^2 (€)	Approx. Price/km^2 (NZD)[11]
< 25	25	2 500	8	13.60
25-125	actual area	2 500-12 500	8	13.60
> 125	500	50 000	0.95	0.85

In some circumstances it may be better value to order a larger area rather than just a single small area. Coordination between resource managers may further reduce costs.

To assist in explaining the cost model, three scenarios are presented for the purchase of existing archive imagery. The scenarios provide an estimate of imagery costs to cover a small block (2500 ha), a series of scattered small blocks and a series of scattered medium-sized areas. It should be noted, however, that RapidEye will determine the final current costing for any order.

Scenario 1: Single Small Block

In the first example a single block of 2500 ha is ordered. The size of the order means it is priced at 8€/km^2. The total cost is €200. This falls below the minimum order so the total for the order is €950 (~$1700 NZD).

Table 7-2: Scenario 1: Single Small Block

Area Ref:	Km^2	ha	Cost (€)	Total (€)	Actual/best value (€)
Area 1	25	2 500	8	200	950

[11] Exchange rate estimated as at September 2011 –www.xe.com

Scenario 2: Three Small Blocks

For the second scenario three areas ranging from 1 000 to 7 500 ha are ordered. In this case the most cost effective option is to go for €8/km^2 as the total order exceeds the minimum €950 order size.

Table 7-3: Scenario 2: Three Small Blocks

Area Ref:	Km^2	ha	Cost (€)	Total (€)	Actual/best value (€)
Area 1	65	6 500	8	520	520
Area 2	10	1 000	8	80	80
Area 3	75	7 500	8	600	600
Total	150	15 000	8		
Order Cost (€)				1200	1200

In this case the cost to cover 15 000 ha is around NZD2 000.

Scenario 3: Three Blocks Scattered Across the Country

In the final scenario three scattered blocks ranging from a minimum of 1 000 to 13 500 ha are ordered. For areas 1 and 3 the most cost-effective option is to default to the minimum order of €950.

This option actually allows a larger area of 100 000 ha surrounding each of areas 1 & 3 to be ordered. Since the second area is only 1 000 ha the €8/km^2 rate is applied.

Table 7-4: Scenario 3: Three Blocks Scattered Across the Country

Area Ref:	Km^2	ha	Cost (€)	Total (€)	Actual/best value (€)
Area 1	125	12 500	8	1 000	950
Area 2	10	1 000	8	80	80
Area 3	135	13 500	8	1 080	950
Total	270	27 000			
Order Cost (€)				2160	1980

The total combined order is approximately NZD3 300.

Satellite Tasking

For new image tasking there is no increase in the price/km^2, but it attracts a minimum order cost of €2 375 (~NZD4 000). This equates to coverage of 250 000 ha (2 500 km^2). It should be noted that only imagery collected during the tasking that meets the cloud cover threshold (<20%) is delivered. The opportunity exists to reduce the costs through collaboration between resource managers.

8. OPERATIONAL CONSIDERATIONS

The applications outlined in this report link a combination of existing remote sensing techniques and principles that are well proven in the literature. It is not until recently that these techniques could be applied in an operational context. Previously, the main limitations of high- resolution imagery have included high cost, small scene extents and the inability of satellites to provide timely coverage.

Sensors such as RapidEye or SPOT 5 now offer large area coverage at low cost with frequent revisit capability with a series of spectral bands sensitive to vegetation change. One of the main advantages is that the imagery can be directly integrated into GIS systems.

Users have two options; they may opt to visually interpret the images and make changes manually, or follow semi-automated methods to produce outputs.

While there are many similarities to other image sources such as digital aerial photography, there are a number of aspects of the data that warrant further discussion. These are discussed below:

8.1 Additional Processing Requirements

Unlike aerial photography, satellite imagery often requires correction for atmospheric and topographic influences – this requires access to specialist software. To mitigate these influences the routine developed for harvest detection uses spectral ratios to provide a relatively robust method that does not require additional corrections.

The variation mapping routines, however, would benefit from inclusion of these corrections, as the spectral changes are likely to be more subtle. This is an important consideration if the intention is to monitor forest areas long-term.

8.2 Refinement of Lookup Tables

The lookup values used to develop the reflectance / age class relationship (stand variation model) were drawn from a single image (62 500 ha) and are specific to *P.radiata*. It is recommended that additional lookup tables be developed to account for regional variations in plantation development rates. These values could be added to the global lookup table or retained as regional tables.

8.3 Geometric Accuracy

To be effective the satellite images and the base GIS datasets need to overlay. If they do not, any shift in the datasets will be appear in the outputs. This increases the level of manual editing required. Geometric errors can be present in both the GIS and image datasets. It is recommended that if offsets are observed, then GPS sources such as roads be used as the point of comparison.

To further minimise errors it would appear that improvements in the accuracy of the RapidEye GCP dataset should also be conducted.

8.4 Increased File Sizes

Although not a large issue, the multi-spectral nature and increased dynamic range (i.e. 16 bit) of satellite data does increase the file size. A delivered ortho-corrected tile (25 x 25 km) is approximately 250 MB. If additional quantitative analysis is undertaken and the tile is processed to reflectance, the file size increases to approximately 480 MB. For this reason the datasets are best retained as 25 x 25 km tiles rather than attempting to mosaic adjacent tiles.

8.5 Optimal Time for Acquisition

The optimal time for satellite acquisition is when the sun elevation[12] is above at 35°. This ensures that the effects of topographic shadow are minimised, which increases the useable area on the image.

Figure 8-1 plots the sun elevation over the year. To achieve best results images should be acquired from October to mid-April. Outside of these months the sun elevation is too low, which leads to increased shadow – especially in steep areas.

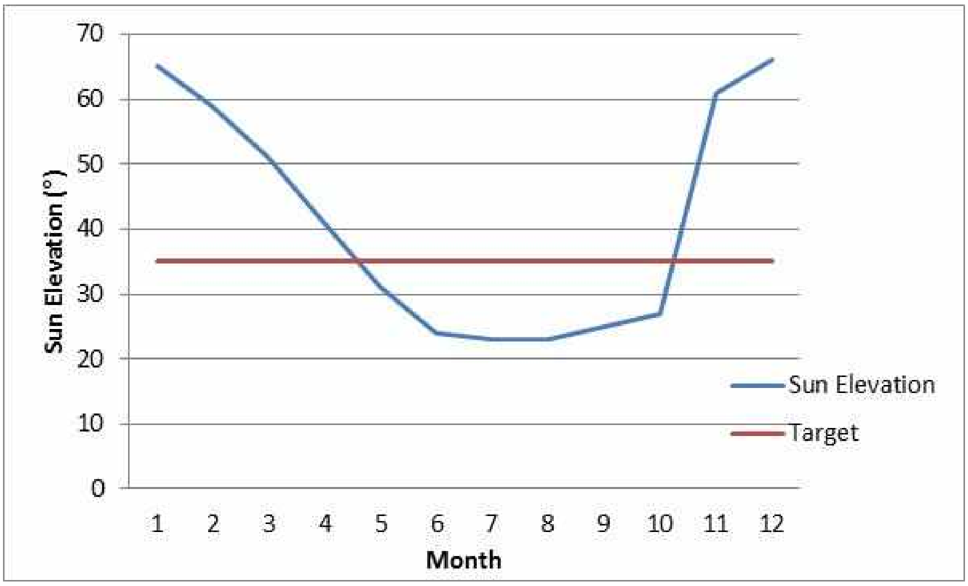


Figure 8-1: Sun Elevation by Month

8.6 Tasking and Image Ordering

If satellite data are not available from the online archive (www.eyefind.rapideye.de) then the imagery must be tasked. The minimum order is 250 000 ha (2 500 km^2) which is equivalent to approximately $4000 NZD. The actual tasking period is calculated based on cloud cover predictions and other tasking requests over the same orbital path. Successful image takes are typically delivered within seven days via FTP.

A range of licensing options is available (single or multiple user), which presents the opportunity for resource managers to collaborate by placing joint tasking orders.

[12] The sun elevation angle (used interchangeably with altitude angle) is the angular height of the sun in the sky measured from the horizontal. The elevation is 0° at sunrise and 90° when the sun is directly overhead (which occurs for example at the equator on the spring and autumn equinoxes).

Appendix 1

Interpretation Guide to Satellite Imagery

Spectral Characteristics Land Cover

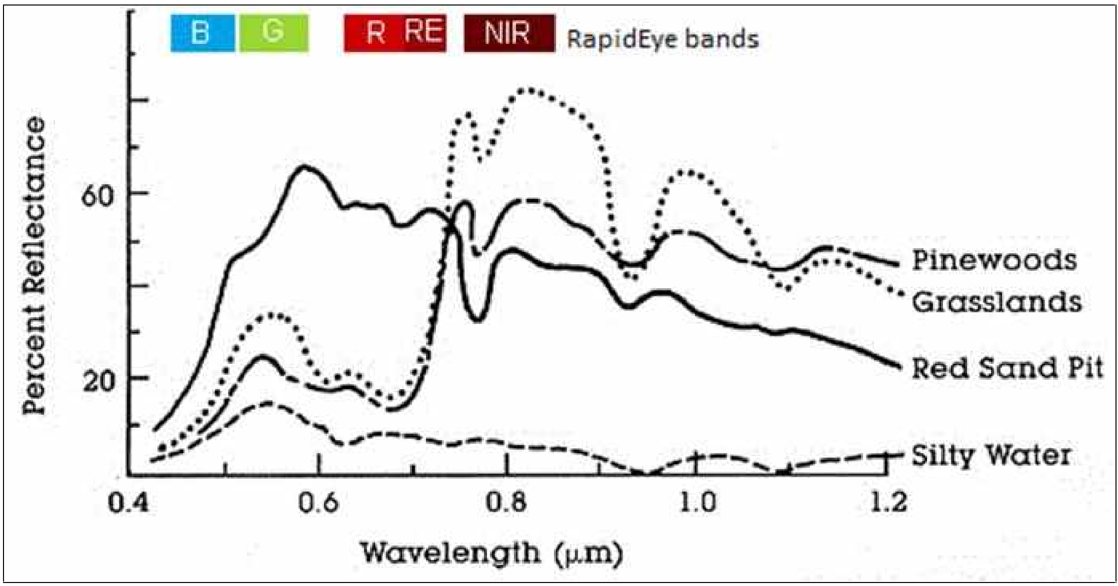
The basis for remote sensing is that different land-cover types respond differently to incoming solar radiation and produce different spectral responses.

The decision of where to measure individual spectral bands was based on analysis of early satellites such as Landsat MSS (launched in 1972). Many satellites measure discrete band widths that are positioned to allow water penetration the discrimination of vegetation types, and enable plant and soil moisture measurements3. In addition, atmospheric effects determine the placement of bands in the spectrum.

Spectral reflectance patterns of forest vegetation in the visible spectrum are generally controlled by the absorption features related to chlorophyll content. In contrast, the spectrum in the near-infrared region is generally influenced by water content and the contribution of other organic materials.

As shown in the following graph, land-cover types also have their own unique spectral response. Depending on the spectral and spatial resolution of a sensor, differences in spectral response can be used to separate and identify land-cover types.

Spectral Response Curves for Different Targets



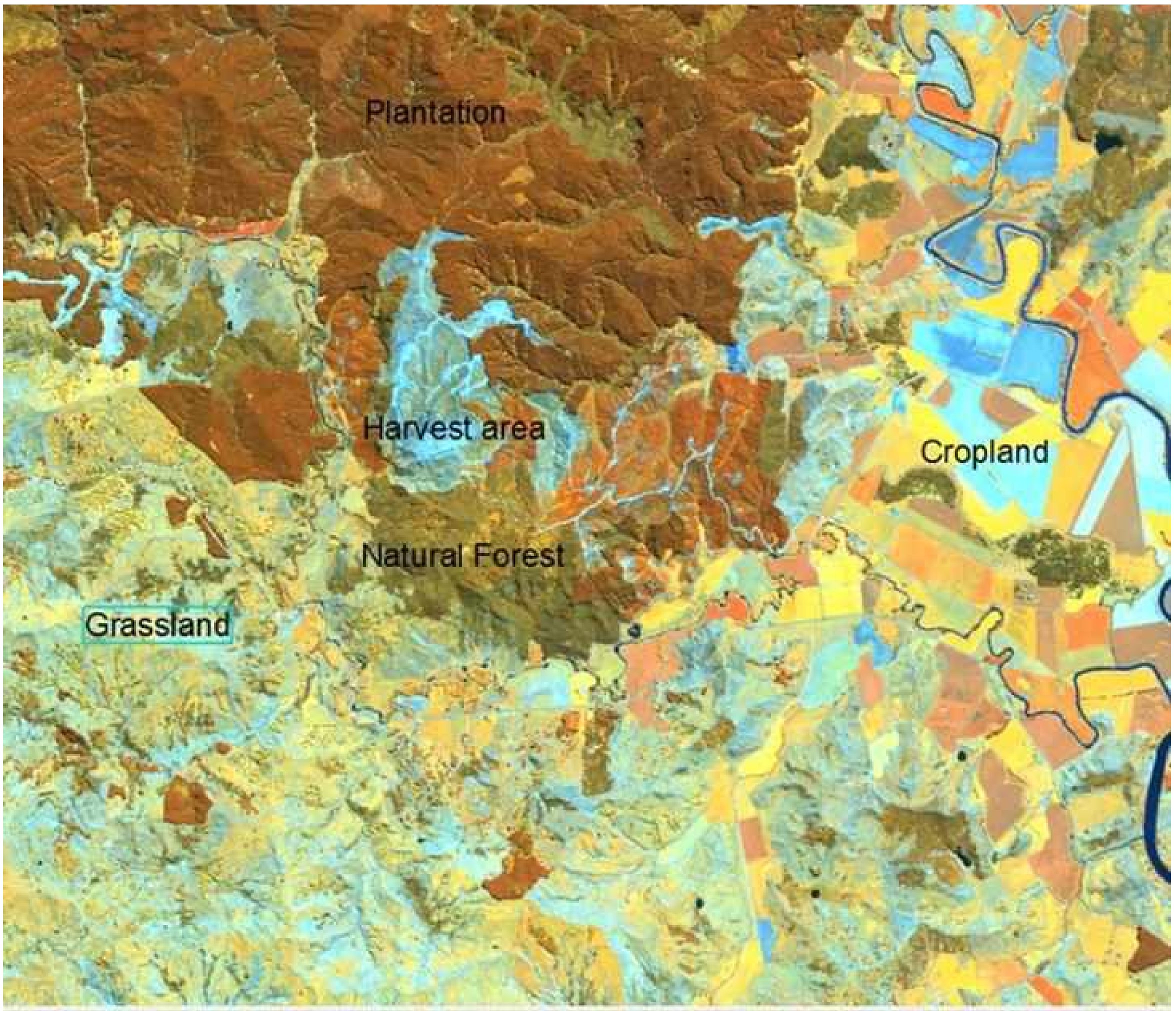
The expected response from green vegetation is that it absorbs strongly in the visible light wavelengths (400-700 nm), and therefore produces a weak signal to a sensor observing in those wavelengths. On the other hand green vegetation reflects strongly in the NIR wavelengths (700-1300 nm), so produces a strong signal in those wavelengths.

One band of particular interest is located around the red edge. The red edge marks the transition between the visible spectral region, where plant pigments absorb most of the incident energy, and the near-infrared, where reflectance is high from plant canopies. Its position shifts according to changes of chlorophyll content, leaf area index, biomass, age, plant type, species, health levels and seasonal patterns.

The following examples provide a description of the different spectral responses from vegetated and non-vegetated targets typically observed in a forestry context. Images are shown as false-colour composites whereby plantations are displayed in varying tones of red. Light red tones indicate vigorously growing vegetation with darker tones more mature plantations. Tones or spectral signatures also differ between forest species with natural forest olive.

Cropland is a mosaic of colours and the response depends on the crop grown and the development stage. Bare ground areas are depicted as tones of blue (including harvest areas and recently cultivated land). Brighter responses indicate exposed soil.

Spectral Characteristics of Different Land Cover



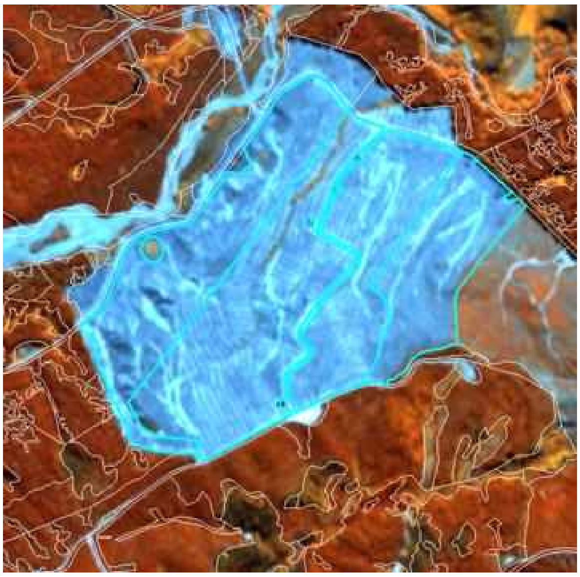
Plantation Establishment:

The following series shows the satellite image displayed as a false-colour composite using the near-infrared, red edge and red bands.

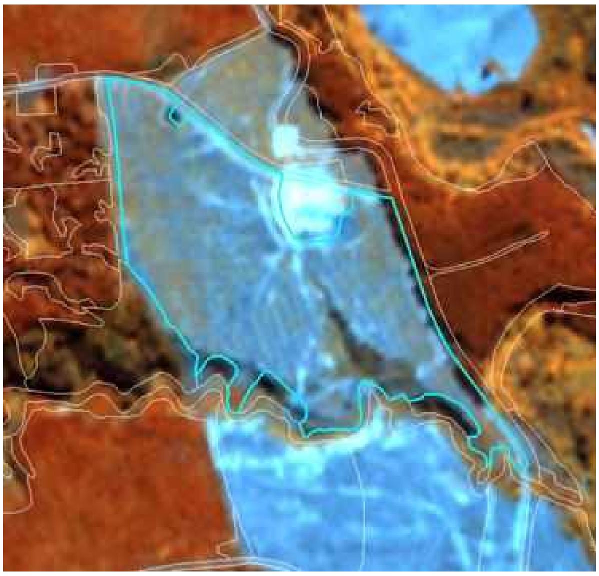
1. Distinctive is the blue colouration of the bare ground as a result of all vegetation being cleared from the site.

2. Harvest skid sites still apparent but some signs of new plantings or the site being captured around the edges of the harvest area.

3. Site captured and establishment clearly detected. Areas of bare ground evident which indicates skid sites or harvest roads, but may also indicate variable establishment.



1. Harvested – roading and landings observed



2. Year 1 – new / emerging establishment

3 Year 2 – establishment detected

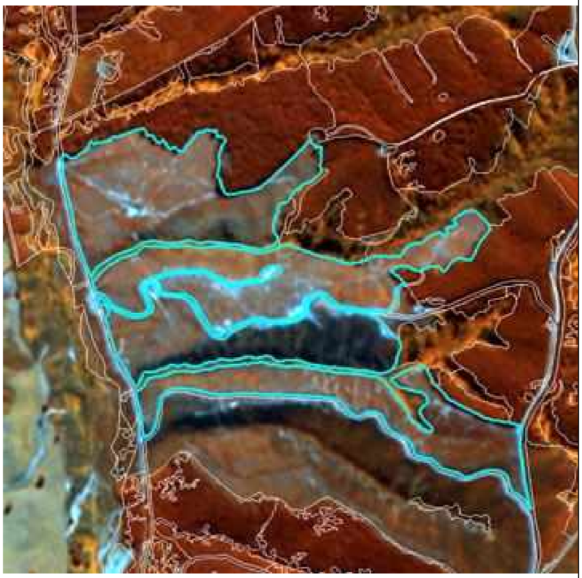
Plantation Species (*P. radiata*)

The following series shows the satellite image displayed as a false-colour composite using the near-infrared, red edge and red bands.

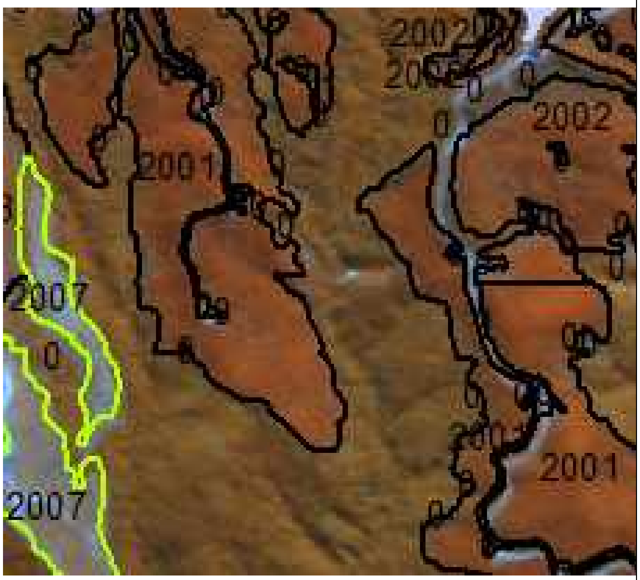
1. Roads and skid sites still apparent, but signs of establishment as the site transitions from an exposed soil signature (blue) to site capture. Slower developing areas also apparent.

2. Canopy closed – crop is uniform but still actively growing. Features such as forest roads and crop boundaries easily identified

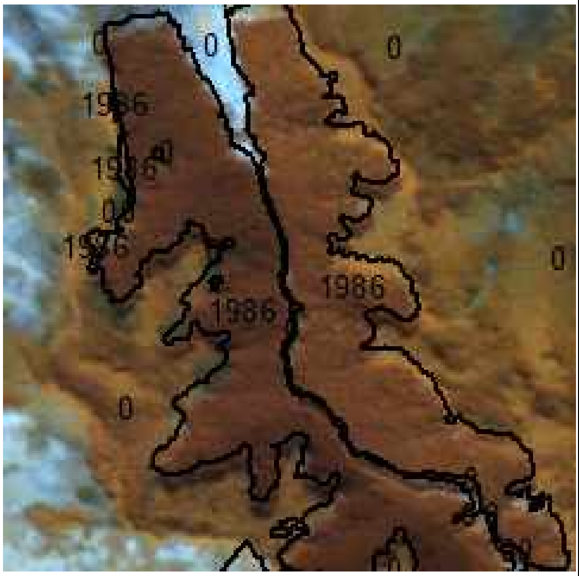
3. Canopy closed – a decrease in reflectance apparent with the canopy colour change to darker brown colour.



1. Newly established radiata pine (approx. 2 years)



2. Canopy closed (approx. 9 years)



3. Mature radiata pine (approx. 24 years)

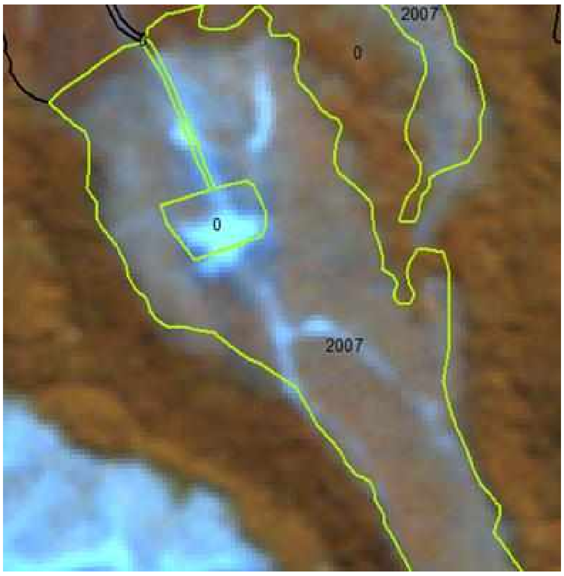
<u>Other species (D.fir)</u>

The following series shows the satellite image displayed as a false-colour composite using the near-infrared, red edge and red bands.

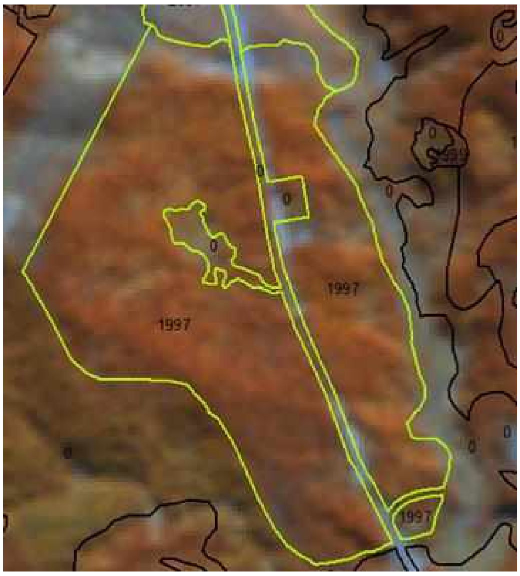
1. Emerging crop with the site starting to be dominated. Bare soil still apparent around skid sites and heavy traffic areas. The reflectance is different from *P.radiata*.

2. Site captured, although small gaps and un-stocked areas detected**.** This is shown as a combination of uneven spectral response and texture.

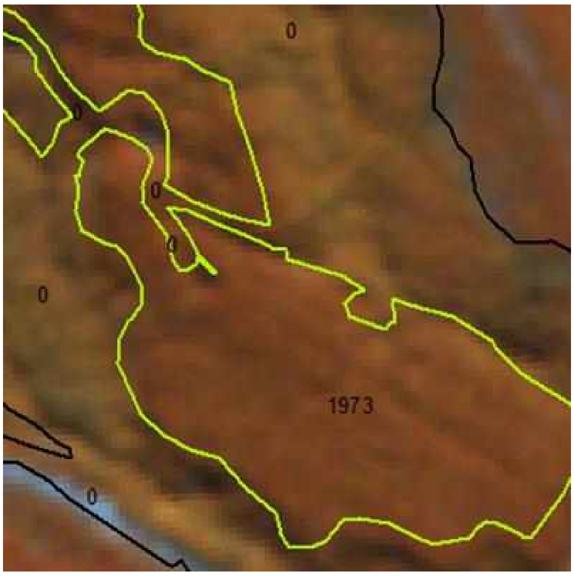
3. Site captured with a uniform spectral response across the stand.



1. Newly established Douglas-fir (approx. 3 years)



2. Established Douglas-fir (approx. 13 years)



3. Mature Douglas-fir (approx. 37 years)

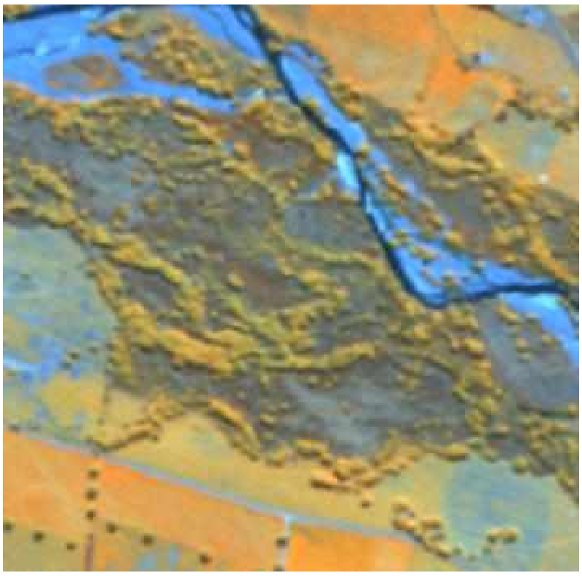
Other forest and land use

The following series shows the satellite image displayed as a false-colour composite using the near-infrared, red edge and red bands.

1. Poplar or willow planted along the river shown in yellow. The blue colouration indicates non-vegetated bare ground (i.e. shingle).

2. Natural forest and scrub (green colour) area around a river catchment surrounded by grassland (grey colour). Top right side shows the edge of an established *P.radiata* plantation.

3. Natural forest area shown in brown tones



1. Riparian plantings – poplar / willows

2. Natural forest area around a stream

3. Natural forest area

Other land uses & Erosion

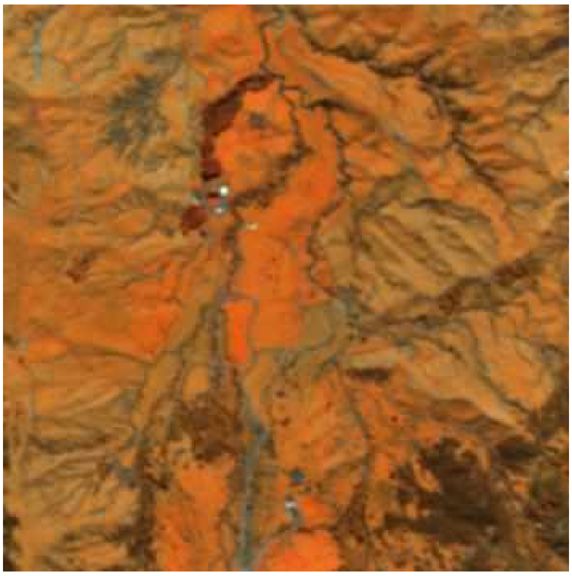
The following series shows the satellite image displayed as a false-colour composite using the near-infrared, red edge and red bands.

1. Cropland areas showing a range of crops at different development stages. Blue areas identify area of bare soil.

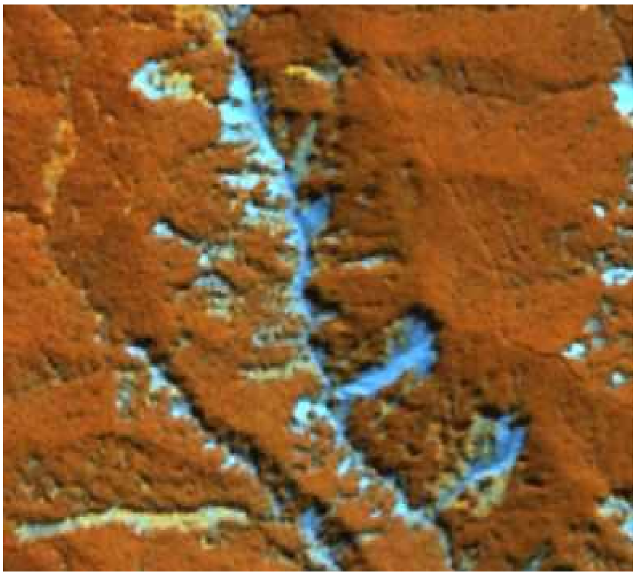
2. Grassland areas with brighter orange areas in the centre of the image showing areas of improved grassland.

3. *P.radiata* plantation and eroding land (East coast – Gisborne)

1. Agricultural cropland



2. Grassland improved and unimproved



3. Gully erosion within established plantations

Appendix 2

ArcGIS Toolbar Documentation

IAP SAT TOOLS TOOLBOX

Installation Toolbox

Copy the following files to your custom Toolbox directory (e.g. “C:\Users\<username>\AppData\Roaming\ESRI\Desktop10.0\ArcToolbox\My Toolboxes”)

1. ExtractNewForestGaps.py
2. ExtractT2PlantationChange_v2.py
3. IAP_Sat_Tools.tbx
4. IntraCompartmentStockVarAnalysis.py
5. StockVarAnalysis.py

Start ArcMap and open ArcToolbox. Right-click on the ArcToolbox as shown in Figure 1. Navigate to the IAP_Sat_Tools.tbx file (Figure 2) and click Open. The IAP_Sat_Tools Toolbox will be added to the Tools (Figure 3). Depending on where the Toolbox was installed, you may need to update the path of the individual tools by right-clicking on the tool, selecting properties and then navigating to the correct location of the .py file (Figure 4 and Figure 5).

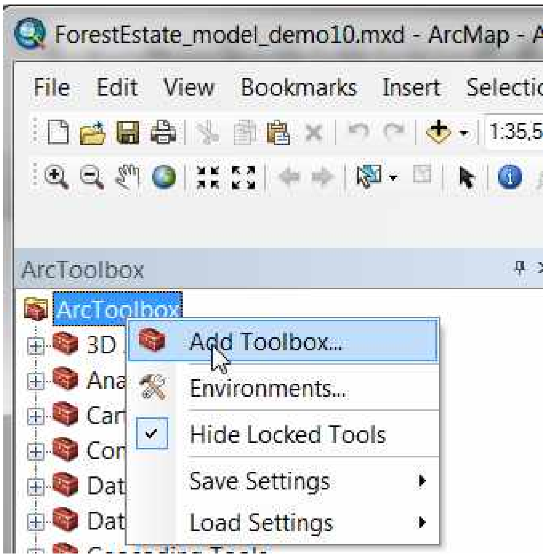


Figure 1: Add a custom Toolbox

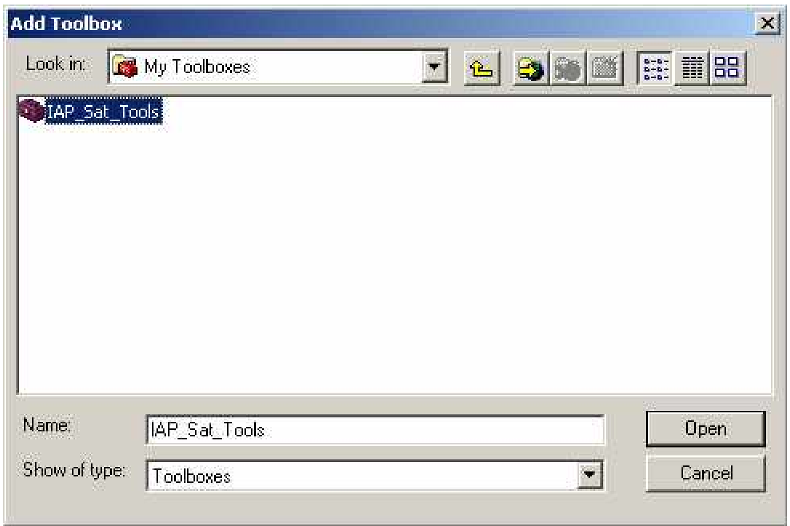


Figure 2: Locate the custom IAP Sat Tools toolbox file

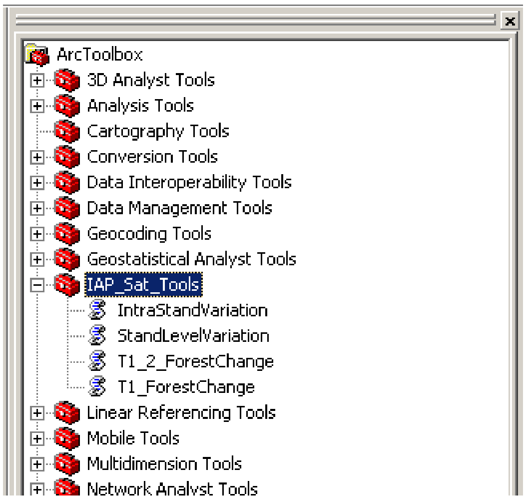


Figure 3: New Toolbox added to ArcToolbox

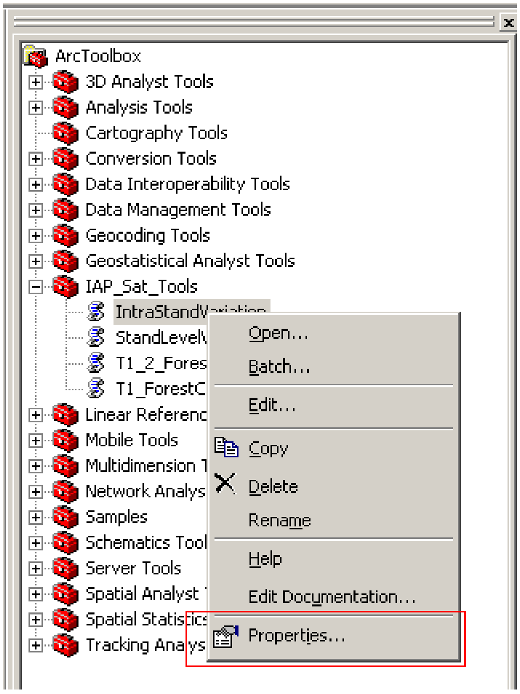


Figure 4: Change location of tool source.

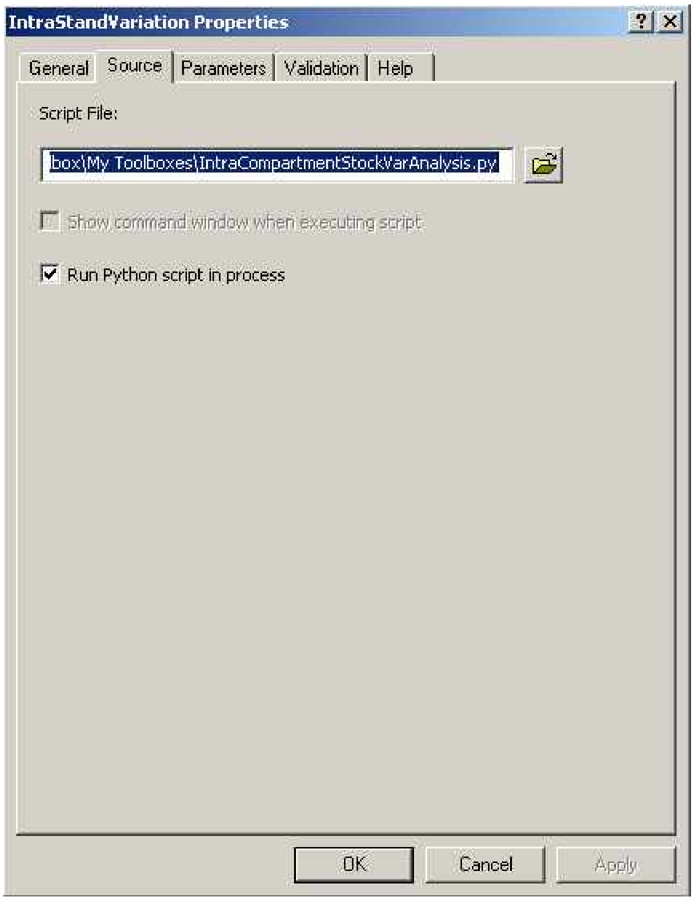


Figure 5: Navigate to the correct location of the python script file

Forest Change Mapping

T1_ForestChange

The purpose of this function is to identify all non-productive areas or harvest areas from a single RapidEye image. Optionally, areas of high soil disturbance (landings or heavy traffic areas) are also delineated. Only non-contiguous gaps greater than the minimum mapping unit (0.1ha) are mapped. These gaps are classed as either "disturbed soil" (GapClass=1) or "harvest" (GapClass=2). The stocked field value should be set to 1 to indicate compartment contains stocked forest.

Input data sets

- RapidEye image
- Compartments boundary polygon shapefile

Output data

- Polygon shapefile created in user-specified output directory

T1_2_ForestChange

The forest change detection process is similar to the T1_ForestChange routine. The main difference is that changes are identified by subtracting EVI images taken from two different time periods. This has the advantage of identifying only those areas that have changed from forest to non-forest – potentially this can include harvest areas, areas of soil disturbance or forest gaps that have not already been mapped out. Only non-contiguous gaps greater than the minimum mapping unit (0.1ha) are mapped. These gaps are classed as either "disturbed soil" (GapClass=1) or "harvest" (GapClass=2). The stocked field value should be set to 1 to indicate compartment contains stocked forest.

Input data sets

- Time 1 RapidEye image
- Time 2 RapidEye image
- Compartments boundary polygon shapefile
- Polygon shapefile output from *T1_T2_ChangeDetection*

Output

- Polygon shapefile created in user-specified output directory

Stand Variability Classification Mapping

StandLevelVariation

The purpose of the stand variation routine (‘StandLevelVariation’ tool) is to provide a rapid way to identify those stands that vary from what is expected. It assigns a stand variability classification to each stocked compartment based on the local mean EVI value relative to a global mean EVI value from a lookup table.

Input data sets

- EVI image
- Lookup Table with mean/stddev EVI statistics
- Stand boundary shapefile

Output

The StVarClass field in the Compartment boundary shapefile is updated (of added if it does not already exist).

IntraStandVariation

The purpose of the intra-stand variation routine (‘IntraStandVariation’ tool) is to identify within-stand variation. This provides a way to pinpoint areas of anomalous growth or identify attribute discrepancies in each stand. It classifies intra-stand variation based on an EVI image and global forest age mean and standard deviation values within a lookup table. The variation of each pixel within a compartment is classified based on the amount of deviation from the global mean.

Input data sets

- EVI image
- Lookup Table with mean/stddev EVI statistics
- Compartments boundary polygon shapefile

Output

The StVarClass field in the Compartment boundary shapefile is updated (or added if it does not already exist)

Appendix 3

NZ RapidEye Satellite Coverage 2010-11

RapidEye satellite coverage commenced in October 2010. All tiles < 20% cloud cover. The five orbiting satellites follow the same track allowing for daily data acquisition. The area imaged in one overpass is 70 km wide. These swaths are divided into 25 x 25 km tiles for delivery. If satellite data is not available from the online archive (www.eyefind.rapideye.de) then the imagery must be tasked.

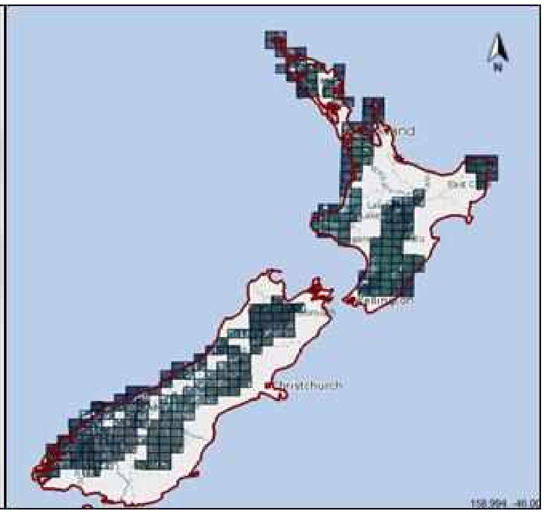
Two RapidEye products are available, Level 1B and 3A. The 1B product is not suitable for direct integration into the GIS as it is not referenced to a map coordinate system.

The 3A product has undergone a range of pre-processing stages that include the application of radiometric, sensor, and geometric corrections. It is also aligned to a cartographic map projection (usually UTM).

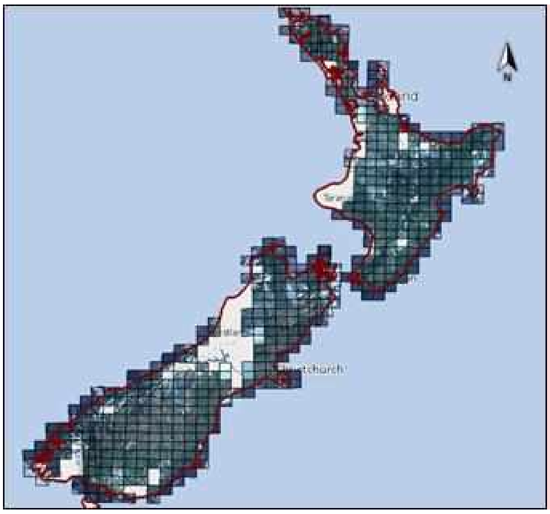
The following series of maps shows the monthly image coverage over New Zealand that spans from October 2010 to September 2011. The coverage is on-going with newly acquired scenes added to the online archive.

Coverage October 2010

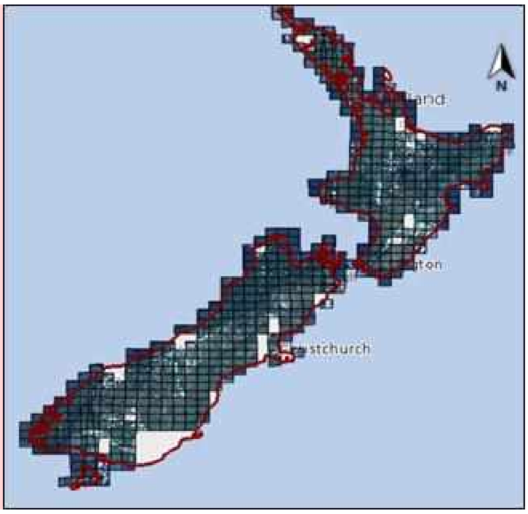
Coverage November 2010



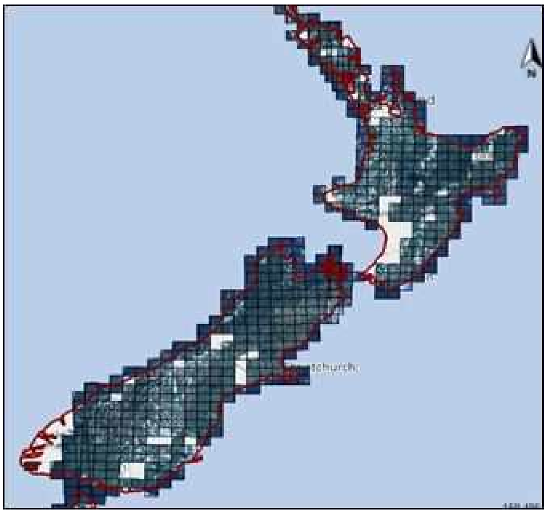
Coverage December 2010



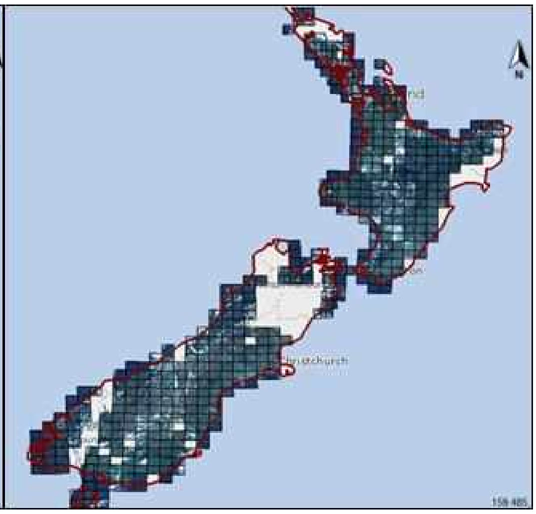
Coverage January 2011



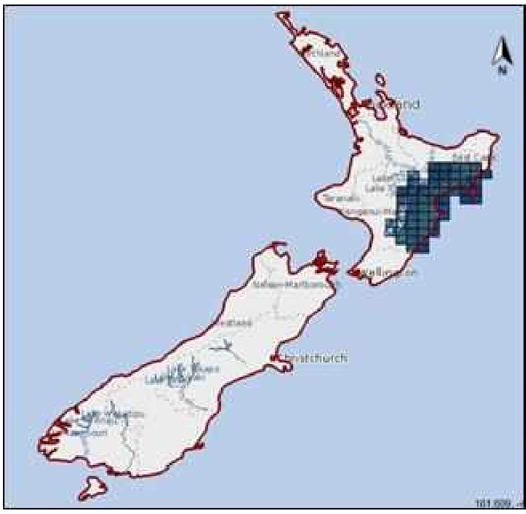
February 2011



March 2011



May 2011



July 2011

August 2011

September 2011

Appendix 4

RapidEye Documentation

RapidEye Standard Image Product Specifications

Version 3.0

May 2010

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Abbreviations

DEM	Digital Elevation Model
DTED	Digital Terrain Elevation Data
GCP	Ground Control Point
GS	Ground Segment
JFIF	JPEG File Interchange Format
JPEG	Joint Photographic Experts Group
IFOV	Instantaneous Field of View
ISD	Image Support Data
MTF	Modulation Transfer Function
N/A	Not Applicable
NIR	Near Infra-red
NMAS	National Map Accuracy Standards
NITF	National Imagery Transmission Format
RPC	Rational Polynomial Coefficients or Rapid Positioning Coordinates
SRTM	Shuttle Radar Topography Mission
TBC	To Be Confirmed
TBD	To Be Defined
TIFF	Tagged Image File Format
UDM	Unusable Data Mask
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
WGS	World Geodetic System

1. Introduction

RapidEye offers image users a data source containing an unrivaled combination of large-area coverage, frequent revisit intervals, high resolution and multispectral capabilities. For the first time, there is a constellation of five earth imaging satellites that contain identical sensors, that are in the same orbital plane and are calibrated equally to one another. This means an image from one RapidEye satellite will be identical in characteristics to an image from any of the other four satellites, thus allowing the user access to an unprecedented amount of imagery collected on a frequent basis.

RapidEye Standard Image Products are offered at two different processing levels to support the varied needs of the customer: 1) RapidEye Basic (Level 1B) products are sensor level products with a minimal amount of processing (geometrically uncorrected) for customers who prefer to geo-correct the images themselves; and 2) RapidEye Ortho (Level 3A) are orthorectified products with radiometric, geometric and terrain corrections in a map projection. Please see Section 3 for detailed descriptions of each image product type.

This document provides detailed information on the following subjects related to the RapidEye Standard Image Products:

RapidEye Satellite Constellation: RapidEye's 5 satellite constellation offers something new and unique to the world of commercial remote sensing.

Product Level Descriptions: RapidEye offers two different processing levels which are described in detail. Attributes related to product quality are also discussed.

Product Ordering: RapidEye offers three different way to order Standard Image Products. The details of each method are described is this section.

Product and Delivery Options: Each image data product is offered with several processing and delivery options.

Product Licensing: RapidEye offers customers several licensing options to ensure that all users who need to use the imagery may do so.

Product Naming: Provides a description of the product naming convention used for the RapidEye Standard Image Products.

Image Support Data: All images are supported with several different metadata files to aid the customer with the use and analysis of the data.

2. RapidEye Satellite Constellation

The RapidEye constellation of five satellites stands apart from other providers of satellite-based geospatial information in their unique ability to acquire high-resolution, large-area image data on a daily basis. The RapidEye system will be able to collect an unprecedented 4 million square kilometers of data per day at 6.5 meter nominal ground resolution. Each satellite measures less than one cubic meter and weighs 150 kg (bus + payload), and has been designed for at least a seven-year mission life. All five satellites are equipped with identical sensors and are located in the same orbital plane.

Table 1 below outlines general mission characteristics for the RapidEye system.

Mission characteristic	Information
Number of Satellites	5
Spacecraft Lifetime	7 years
Orbit Altitude	630 km in Sun-synchronous orbit
Equator Crossing Time	11:00 am (approximately)
Sensor Type	Multi-spectral push broom imager
Spectral Bands	Capable of capturing any of the following spectral bands: Name — Spectral Bands (nm) Blue — 440 – 510 Green — 520 – 590 Red — 630 – 685 Red Edge — 690 – 730 NIR — 760 – 850
Ground sampling distance (nadir)	6.5 m
Pixel size (orthorectified)	5 m
Swath Width	77 km
On board data storage	Up to 1500 km of image data per orbit
Revisit time	Daily (off-nadir) / 5.5 days (at nadir)
Image capture capacity	4 million sq km/day
Dynamic Range	Up to 12 bit

Table 1: RapidEye System Specifications

3. RapidEye Standard Image Product Specifications

RapidEye Standard Image Products are available in two different processing levels to be directly applicable to customer needs. Table 2 summarizes the various processing levels of image products.

Level	Description
1B	**RapidEye Basic Product** - Radiometric and sensor corrections applied to the data. On-board spacecraft attitude and ephemeris applied to the data.
3A	**RapidEye Ortho Product** – Radiometric, sensor and geometric corrections applied to the data. All products have been rectified using a DTED Level 1 SRTM DEM or better, and with appropriate ground control can meet an accuracy of 6m 1-sigma (12.7 m CE90). The highest accuracy achieved by these products will meet 1:25,000 NMAS standards

Table 2: RapidEye Standard Image Product Processing Levels

3.1 RapidEye Basic – Level 1B Product Specification

The RapidEye Basic product is the least processed of the available RapidEye image products. This product is designed for customers with advanced image processing capabilities and a desire to geometrically correct the product themselves.

The RapidEye Basic product is radiometric and sensor corrected, providing imagery as seen from the spacecraft without correction for any geometric distortions inherent in the imaging process, and is not mapped to a cartographic projection. The imagery data is accompanied by all spacecraft telemetry necessary for the processing of the data into a geo-corrected form, or, when matched with a stereo pair, for the generation of digital elevation data. Resolution of the images is 6.5 meters GSD at nadir. The images are resampled to a coordinate system defined by an ideal basic camera model for band alignment.

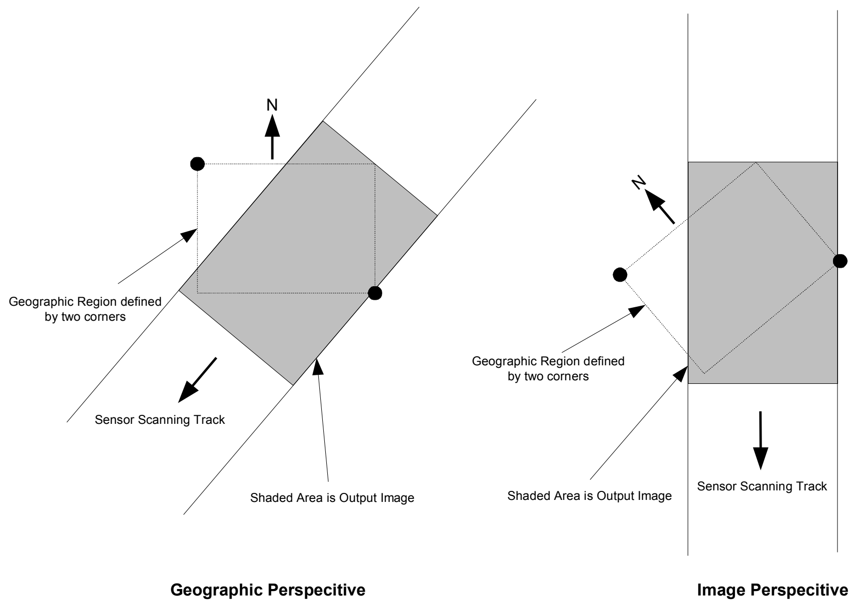
The radiometric corrections applied to this product are:

- Correction of relative differences of the radiometric response between detectors
- Non-responsive detector filling which fills nulls values from detectors that are no longer responding
- Conversion to absolute radiometric values based on calibration coefficients

The geometric sensor corrections applied to this product correct for:

- Internal detector geometry which combines the two sensor chipsets into a virtual array
- Optical distortions caused by sensor optics
- Registration of all bands together to ensure all bands line up with each other correctly

Table 3 lists the product attributes for the RapidEye Basic product.

<table>
<tr><th>Product Attribute</th><th>Description</th></tr>
<tr><td>Product Components and Format</td><td>RapidEye Basic image product consists of the following file components:
• Image File – Image product delivered as a group of single-band NITF 2.0 files with associated RPC values. Bands are co-registered.
• Metadata File – XML format metadata file. Metadata file contains additional information related to spacecraft attitude, spacecraft ephemeris, spacecraft temperature measurements, line imaging times, camera geometry, and radiometric calibration data.
• Browse Image File – JPG format
• Unusable Data Mask (UDM) file – GeoTIFF format</td></tr>
<tr><td>Product Orientation</td><td>Spacecraft/sensor orientation</td></tr>
<tr><td colspan="2">Product Framing
Geographic based framing – a geographic region is defined by two corners. The product width is close to the full image swath as observe by all bands (77 km at nadir, subject to minor trimming of up to 3 km during processing) with a product length of between 50 and 300 km.


</td></tr>
<tr><td>Pixel spacing</td><td>Native camera pixel spacing, nominally 6.5 m at nadir.</td></tr>
<tr><td>Bit Depth</td><td>For radiometrically corrected products, 16-bit unsigned integers.</td></tr>
<tr><td>Product Size</td><td>Variable number of pixels (less than 11980 per line) and up to a maximum of 15384 lines per band.
462 Mbytes/25 km along track for 5 bands. Maximum 5544 Mbytes.</td></tr>
<tr><td>Geometric Corrections</td><td>Idealized sensor, orbit and attitude models. Bands are co-registered.</td></tr>
<tr><td>Horizontal Datum</td><td>WGS84</td></tr>
<tr><td>Map Projection</td><td>n/a</td></tr>
<tr><td>Resampling Kernel</td><td>Cubic Convolution (default), MTF, or Nearest Neighbor</td></tr>
</table>

Table 3: Product attributes for RapidEye Basic products

3.2 RapidEye Ortho – Level 3A Product Specification

The RapidEye Ortho product offers the highest level of processing available for RapidEye Standard Image Products. This product was designed for a wide variety of applications that require imagery with an accurate geolocation and cartographic projection. It has been processed to remove any distortions caused by terrain and can be used for many cartographic purposes.

The RapidEye Ortho product is radiometric, sensor and geometrically corrected and aligned to a cartographic map projection. The geometric correction uses fine DEMs with a post spacings of between 30 and 90 meters. Ground Control Points (GCPs) are used in the creation of every image and the accuracy of the product will vary from region to region based on available GCPs. RapidEye Ortho image products are output as 25 by 25 kilometer tiles reference to a fixed, standard RapidEye image tile grid system (see Appendix B).

Table 4 lists the attributes for the RapidEye Ortho product.

Product Attribute	Description
Product Components and Format	RapidEye Ortho image product consists of the following file components: • Image File – GeoTiff file that contains image data and geolocation information • Metadata File – XML format metadata file • Browse Image File – JPG format • Unusable Data Mask (UDM) file – GeoTIFF format
Product Orientation	Map North up
Product Framing	Image Tile (image tiles are based on a worldwide, 24km by 24km fixed grid system (see Appendix B for full tile grid definition). To each 24km by 24km grid square, a 500m overlap is added to produce a 25km by 25km image tile. Image tiles that are only partially covered by an image take will be black-filled in areas with no data).
Pixel spacing	5m
Bit Depth	For radiometrically corrected products, 16-bit unsigned integers.
Product Size	Tile size is 25km (5000 lines) by 25km (5000 columns). 250 Mbytes per Tile for 5 bands at 5m pixel spacing.
Geometric Corrections	• Sensor-related effects are corrected using sensor telemetry and a sensor model, bands are co-registered, and spacecraft-related effects are corrected using attitude telemetry and best available ephemeris data. • Ortho-rectified using GCPs and fine DEMs (30m to 90m posting)
Horizontal Datum	WGS84
Map Projection	Universal Transverse Mercator (UTM)
Resampling Kernel	Cubic Convolution (default), MTF, or Nearest Neighbor

Table 4: Attributes for RapidEye Ortho Products

3.3 Product Quality Attributes

The following sections detail the quality attributes related to all RapidEye Standard Image products.

3.3.1 Geometric Product Accuracy

3.3.1.1 RapidEye Basic (1B) Accuracy

The RapidEye Basic (1B) products are geometrically corrected to an idealized sensor and satellite model, and band aligned. They are delivered as NITF (National Imagery Transmission Format) files together with Rapid Positioning Capability (RPC) described by rational functions. The horizontal accuracy of Level 1B products is determined by satellite attitude (which is adjusted by pre-marking Ground Control Points during image cataloging) and ephemeris as well as terrain displacement, since no terrain model is used in the processing of the 1B products. The worldwide RapidEye Ground Control Point database has been mainly populated with GCPs derived from the GeoCover 2000 Landsat mosaic, along with other reference data of higher accuracy to create the available GCPs used during cataloging and processing. Moving into the future, the GCPs created from the GeoCover 2000 mosaic will be replaced with points derived from the GLS 2000 Landsat mosaic. The replacement process with start in areas with the largest deviation between the two datasets.

The default accuracy of the Basic product, using GCPs derived from the Landsat mosaic, is 45m CE90 (RMSE 1-D = 21m) or better. In the case where GCPs of better accuracy are available, such as in the United States, this accuracy will not exceed 23m CE90 (RMSE 1-D = 11.00m) These geo-location accuracies are valid for image collected at Nadir over flat (< 10^{o} slope) terrain.

3.3.1.2 RapidEye Ortho (3A) Accuracy

The accuracy of the RapidEye Ortho (3A) products depends on the quality of the reference data used (GCPs and DEMs). Additionally, the roll angle of the spacecraft during the image acquisition and the number as well as the distribution of GCPs within the image will impact the final product accuracy.

In general, GCPs derived from the Landsat mosaic and the CGIAR SRTM 90m DEM are used to produce the Ortho products. The CGIAR SRTM 90m DEMs have an accuracy of 16.0m LE90 and 20.0m CE90. The Landsat GCPs may have an accuracy as low as 50m CE90 in places. However, in selected locations (the United States and parts of Europe) the GCPs are derived from different, more accurate sources.

During product processing, all RapidEye Ortho products have to pass a system threshold value of 30m CE90 (15m 1-D) or better using GCPs derived from the Landsat mosaic. It is possible to achieve an accuracy of one pixel or less, meaning a product accuracy of 14m CE90 (RMSE 1-D = 6m) or better with the most accurate GCP and DEM sources. These accuracies are valid for image collected at Nadir over flat (< 10^{o} slope) terrain.

3.3.2 Cloud Cover

Cloud detection in the RapidEye processing system is being conducted in two different stages of the processing chain:

1) Cataloging Time: for each acquired image received on the ground, the system performs a cloud detection and provides an Unusable Data Mask (UDM) for each tile in the image (see

Appendix B for a description of the tile grid); the result of this assessment is used to determine whether each tile can be accepted or whether a new collection is required.

Moreover, in order to facilitate their ordering processes, RapidEye provides selected Partners with the Library contents (i.e. the System Catalog) which includes meta-data, UDM and browse products.

2) Processing Time: for each product generated (i.e. L1B or L3A) the system performs a cloud detection and produces a UDM file for that product. This is provided to the Customer as part of the Image Support Data (ISD) metadata files.

The algorithm used in the RapidEye processing system to detect the clouds is based on a band threshold analysis combined with simple object recognition techniques to improve the classification accuracy. In fact, it identifies potential cloud pixels by comparing the DN pixel values in the Red band with a given threshold value.

This cloud detection technique has a number of known limitations:

1) haze and cloud shadow are not detected
2) snow/ice may be incorrectly classified as clouds
3) very bright features (e.g. desert sand) may be incorrectly classified as clouds
4) “darker” and/or “small” clouds may be undetected
5) small “popcorn” type clouds might remain undetected

Due to the vast amount of tiles collected on a daily basis (on average ~4,000 per day), the cloud detection in both stages is the result of a fully automatic process and thus there is no “manual” quality control of the UDMs.

Standard cloud cover for all RapidEye Standard Image Products is considered 20% over the Area of Interest (AOI) of the order.

The projection of the UDM file is identical to the projection of the parent image, however there are some differences between the two files for the L1B Basic product. The UDM file for a L1B Basic product is the standard GeoTiff format for the UDM, whereas the L1B image is in NITF format. This difference in formats leads to slightly different georeferencing between the two files and may lead to the UDM file not exactly overlaying the image file at the right location. For the L3A Ortho product both the UDM and image files are in GeoTiff format, so the UDM overlays the image tile exactly.

3.3.3 Band Co-registration

The focal plane of the RapidEye sensors is comprised of five separate CCD arrays, one for each band. This means that the bands have imaging time differences of up to three seconds for the same point on the ground, with the blue and red bands being the furthest apart in time. During processing, every 1B and L3A product is band co-registered using a DEM to roughly correlate the bands to the reference band (red-edge), then a final alignment is done using an auto-correlation approach between the bands. For areas where the slope is below 10°, the band co-registration should be within 0.2 pixels or less (1-sigma). For areas with a slope angle of more than 10° and/or areas with a very poor image structure (e.g. Sand dunes, water bodies, areas with significant snow cover) the co-registration threshold mentioned above may not be met.

The separation between the RapidEye spectral bands leads to some effects that can be seen in the imagery. In a regular RapidEye scene with clouds, the cloud may show a red-blue halo around the main cloud. This is due to the fact that the red and blue bands are the furthest apart on the sensor array, and the cloud cannot be fully co-registered due to its movement during the time between the two bands, and also due to the fact that clouds are not reflected within the DEM. If the same scene is viewed as a color-infrared composite (Near infrared, red and green) the clouds will appear with smaller halos of green, because the green band is closer in time to the red and near-infrared than it is to the blue band. The same effect is visible for jet exhaust trails and flying planes. Bright vehicles moving on the ground will also look like colored streaks due to the image time differences.

3.3.4 Product Radiometry and Radiometric Accuracy

Significant effort is made to ensure radiometric image product quality of all RapidEye Standard Image Products. This is achieved through a vigorous sensor calibration concept that is based on regular checks of the statistics of all incoming image data, additional regular acquisitions over selected temporal calibration sites, and additional absolute ground calibration campaigns.

The long term stability and inter-comparability among all five satellites is done by monitoring all incoming image data, along with regular, frequent acquisitions from a number of calibrations sites located worldwide. Statistics from all collects are used to update the gain and offset tables for each satellite on a periodic basis. These statistics are also used to ensure that each band is within a range of $\pm$ 2.5% from the band mean value across the constellation.

All images are collected at 12 bit and stored on-board the satellites with a bit depth of up to 12 bit (the effective bit depth of the image can be determined from the “shifting” field in the XML metadata file). During on-ground processing radiometric corrections are applied and all image are scaled up to 16 bit dynamic range. The scaling is done with a constant which converts the (relative) pixel DNs coming directly from the sensor into values directly related to absolute radiances. The scaling constant has been determined during pre-launch absolute radiometric calibration for each sensor element of each band. These scaling factors are applied so that the resultant single DN values correspond to 1/100th of a Watt/m^2 sr^{-1} μm^{-1}. The conversion factor between DN values for any given pixel and absolute radiance in Watt/m^2 sr^{-1} μm^{-1} is adjustable, and is shown in the “radiometricScaleFactor” field for each band in the XML metadata file.

The digital numbers of the RapidEye image pixels represent

- absolute calibrated radiance values for non atmospheric corrected images
- reflectance values for atmospheric corrected images (currently not offered for delivery)

To convert the Digital Number (DN) of a pixel to radiance it is necessary to multiply the DN value by the radiometric scale factor, as follows:

$$RAD(i) = DN(i) * radiometricScaleFactor(i)$$

The resulting value is the Top of Atmosphere (TOA) radiance of that pixel in watts per steradian per square meter (W/m^2 sr μm).

Reflectance is generally the ratio of the reflected radiance divided by the incoming radiance. Note, that this ratio has a directional aspect. To turn radiances into a reflectance it is necessary to relate the radiance values (i.e. the pixel DNs) to the radiance the object is illuminated with. This is often done by applying an atmospheric correction software to the image, because this way the impact of the atmosphere to the radiance values is eliminated at the same time. But it would also be possible to neglect the influence of the atmosphere by calculating the Top Of Atmosphere (TOA) reflectance taking into consideration only the sun distance and the geometry of the incoming solar radiation.

The formula to calculate the TOA reflectance not taking into account any atmospheric influence is as follows:

$$REF(i) = RAD(i) \frac{\pi * SunDist}{EAI(i) * \cos(SolarZenith)}$$

with:

i: Number of the spectral band

REF: reflectance value

RAD: Radiance value

SunDist: Earth-Sun Distance at the day of acquisition in Astronomical Units

Note: This value is not fix, it varies between 0.983 289 8912 AU and 1.016 710 3335 AU and has to be calculated for the image acquisition point in time.

EAI: Exo-Atmospheric Irradiance

SolarZenith: Solar Zenith angle in degrees (= 90° – sun elevation)

For RapidEye the EAI values for the 5 bands are:

Blue: 1997.8 W/m²µm

Green: 1863.5 W/m²µm

Red: 1560.4 W/m²µm

RE: 1395.0 W/m²µm

NIR: 1124.4 W/m²µm

Results from an on-orbit absolute calibration campaign have been used to update the pre-launch absolute calibration of all five sensors. This calibration change applies to all imagery acquired after January 1, 2010, but was only effective on or after April 27, 2010. Changes to the calibration will be documented in a forthcoming technical document on the subject.

The radiometric sensitivity for each band is defined in absolute values for standard conditions (21. March, 45° North, Standard atmosphere) in terms of a minimum detectable reflectance difference. This determines the already mentioned bit depth as well as the tolerable radiometric noise within the images. It is more restrictive for the red, red-edge and near-infrared bands, compared with the blue and green bands. During image quality control a continuous check of the radiometric noise level is performed.

4. Product Ordering

RapidEye Standard Image Products can be purchased through the RapidEye Geodata Kiosk, the RapidEye Library or by using the RapidEye On-Demand Service to task the satellite constellation. This section provides a detailed overview of RapidEye order types and requirements for specifying an Area of Interest (AOI), Time of Interest (TOI) and placing an order.

4.1 The RapidEye Geodata Kiosk

RapidEye offers an easy on-line platform for purchasing satellite imagery, for more information see www.geodatakiosk.com. This option allows customers to conveniently purchase level 3A data over small or large areas with flexibility and immediate turn around.

4.2 RapidEye Library Orders

RapidEye offers imagery for sale from a rapidly growing indexed archive. Both Level 1B – Basic and Level 3A – Orthorectified products are available for purchase. For more information please contact your local distributor. If a distributor does not exist in your region, you may contact RapidEye directly at sales@rapideye.de or call (49) 3381 8904 ext 555.

4.3 RapidEye On-Demand Service

RapidEye offers on-demand tasking of the satellites for both the Level 1B – Basic and Level 3A – Orthorectified products.

When RapidEye prepares its collection plan, many factors are given consideration. The historical cloud cover statistics are given consideration during this planning and the customer's specified imaging window is accounted for. RapidEye will image on a “best effort” basis.

4.3.1 Tasking Parameters

- Tasking is available for RapidEye level 1B Basic product and level 3A Ortho product.
- The minimum size for the RapidEye On-Demand Service is a contiguous Area of Interest (AOI) of 5,000 km².
- Pricing is dependent on the specified date and duration (Time of Interest) of the order. The tolerance for cloud cover and desired license type will also influence the final pricing.
- There is no differentiation between the cost of level 1B and Level 3A data. However, if you intend to purchase both processing levels over the same AOI with the same TOI, you will be charged once for each product.
- If you desire a pricing quote for a potential tasking order, please contact your local distributor. If a distributor does not exist in your region, you may contact RapidEye directly at sales@rapideye.de or call (49) 3381 8904 ext 555.

4.4 Area of Interest (AOI) Polygons

RapidEye prefers to receive an ESRI shapefile of the Area of Interest (AOI). The ESRI shapefile must have polygon topology (not line or point topology). RapidEye will also accept a KML file or geographic coordinates with a specified buffer size to be applied. Projection should be in UTM or Geographic coordinates, WGS 84 datum.

The Area of Interest must be one contiguous area meeting the minimum size requirements specified for tasking or archive orders. If the polygon does not meet the size requirement, you will be charged the minimum list price. If the area is not contiguous, each area will be treated as a separate AOI and will be held to the same specifications of minimum size and pricing.

4.5 Requesting Quotations

To request a quote or place an order for library or on-demand tasking data, contact your local distributor. Please see http://www.rapideye.de/home/about-us/distributors/index.html for a list of distributors in your area. If a distributor does not exist in your region, you may contact RapidEye directly at sales@rapideye.de or call (49) 3381 8904 ext 555.

To request a quotation, please provide us with the following information:

1. Definition of AOI (Area Of Interest)

   Please see specifications above. Note that the minimum area size for tasking orders is 5,000 km², for ordering data from the RapidEye library the minimum size of the AOI must be 2,500 km²

2. Definition of TOI (Time Of Interest)

   The TOI should be defined by the exact start and end date of the desired acquisition window.

   If a tasking order is requested, the first possible date to start the image collection will be 2 days after receiving the request.

3. Definition of Products

   Our Standard Image Products, taken by our satellite constellation, can be purchased in two product levels (3A ortho product and 1Bbasic product) depending on the task at hand. Please see our website for details:

   http://www.rapideye.de/upload/documents/PDF/RE_Product_Specifications_ENG.pdf

4. Definition of License Type

   RapidEye grants the right to use the Products under a standard End-User License Agreement (EULA). RapidEye offers several licensing options to address the needs of end-users. Please see our website for more details:

   http://www.rapideye.de/upload/documents/PDF/RE_EULA_ENG.pdf

5. Definition of maximum Cloud Coverage Tolerance

   Standard cloud cover tolerance for all RapidEye Standard Image Products is equal to or less than 20% over the Area of Interest (AOI). Please specify a cloud cover tolerance if less than 20% is desired. Please note that RapidEye does not offer data with a cloud coverage of 0% for tasking orders.

6. Use Case of the requested Data

   A short description of the data's end use will help us to optimize the acquisition planning and the processing according to your needs.

4.6 Placing an order

To place an order, please assure that all information is correct on the quotation provided, sign the form and fax to +49 3381 8904 555 or email to support@rapideye.de.

4.6.1 Delivery of the Data

The collected imagery will be delivered within 72 hours of image acquisition. The image products will be delivered to a secure ftp account, unless otherwise specified. The customer service representative will provide login credentials via email.

5. Product and Delivery Options

Table 5 summarizes the product options available for all RapidEye Standard Image Products.

Processing Option	Discussion
Processing Kernels	Nearest Neighbor, Cubic Convolution (default), or MTF
Image File Formats	• GeoTIFF (default for level 3A); • NITF (default for level 1B);
Projection (only for 3A products)	UTM WGS84
Delivery	• FTP Pull • DVD • CD

Table 5: Product Processing and Delivery Options

6. Product Licensing

RapidEye grants the right to use the Products under a standard End-User License Agreement (EULA). RapidEye offers several licensing options to address the needs of end-users. Customers select the type of license when placing an order by identifying the end-users of the Products. The number of end-users identified by the customer during order placement determines the license type acquired. The following licensing options are available:

License Type	Number of Users	Conditions
Single-User	Permits use by one (1) end-user.	License is non-exclusive and non-transferable. Permits limited use by contractors and consultants. Permits creation of value-added products for internal use. See the EULA for terms and conditions.
Multi-User	Permits use by two (2) to five (5) end-users.	License is non-exclusive and non-transferable. Permits limited use by contractors and consultants. Permits creation of value-added products for internal use. See the EULA for terms and conditions.
Enterprise	Permits use by six (6) to ten (10) end-users.	License is non-exclusive and non-transferable. Permits limited use by contractors and consultants. Permits creation of value-added products for internal use. See the EULA for terms and conditions.
Expanded Enterprise	Permits use by eleven (11) or more end-users.	License is non-exclusive and non-transferable. Permits limited use by contractors and consultants. Permits creation of value-added products for internal use. See the EULA for terms and conditions.
StateCiv	Multiple (1+)	All state/provincial/local government agencies/offices
FedCiv	Multiple (1+)	All federal civilian government agencies/offices
AllCiv	Multiple (1+)	All civilian government agencies/offices
MOD/Title50	Multiple (1+)	All departments/offices of a defense ministry/agency

Table 6: License Types

The inclusion of the imagery or data contained in the RapidEye Products in any product by an end-user is considered value-added work. Resale or distribution of these value-added products is not permitted under the standard EULA. To redistribute the Products or value-added products to third parties, the customer must request additional licensing from RapidEye. Licensing allowing additional use may be granted to the customer upon the conclusion of a license upgrade. Contact RapidEye for details.

7. Product Naming

The naming of RapidEye Standard Image Product provides important information about the image. This information includes acquisition date and time, satellite that acquired the image, product level, product description, product and order identification and file type and format. The name of each product is designed to be unique and is composed of the following elements:

<acquisition time>_<satellite>_<product ID>_<RE catalog ID>_<order number>_<band type>.<file extension>

For examples:

1B Product File Name = 2008-10-26T012345_RE3_1B-NAC_0123456789_9876543210_band1.ntf

or

3A Product File Name = 2008-10-26T012345_RE3_3A-NAC_0123456789_9876543210.tif

where:

<acquisition time>	=	2008-10-26 (date) T012345 (time in UTC)
<satellite>	=	RE3
<product ID>	=	<processing level>-<product description>
	=	1B (processing level) -NAC (product description)
<RE catalog ID>	=	0123456789
<order number>	=	9876543210
<file type>	=	band1 (only for L1B images)
<file extension>	=	ntf (NITF 2.0)

The expected values for the satellite, product ID (processing level + product description), file type and file extension fields are listed in Table 7.

Satellite	Product ID		File Formats	
	Processing Level	Product Description	File Type	File Extensions
1 - 5	1B = RE Basic 3A = RE Ortho	NAC = Non-atmospherically corrected	For Images : none for 3A GeoTiFF images or band*n* for 1B NITF images (where *n* = 1..5)	.tif = GeoTiFF .ntf = NITF2.0
			browse	.tif
			license	.txt
			metadata	.xml
			readme	.txt
			udm	.tif

Table 7: Expected product naming values by category

8. Image Support Data

All RapidEye Standard Image Products are accompanied by a set of five image support data (ISD) files. These ISD files provide important information regarding the image or are useful sources of ancillary data related to the image. The five ISD files are:

1. XML Metadata File
2. Browse Image File
3. Unusable Data Mask File
4. License File
5. Readme File

Each file is described along with its contents and format in the following sections. In addition to the XML metadata file, for RapidEye Basic products (L1B) further metadata information that may be of interest is located in the header of the NITF image file. A description of the header section of the Level 1B NITF image file can be found in Appendix C.

In addition to the ISD files provided with every image, each order is accompanied by three sets of order support data (OSD) files. These OSD files provide information on AOI and an outline of the products delivered in the order. The three OSD files sets are:

1. AOI shapefile
2. Order summary shapefile
3. Order summary KMZ file

These OSD files sets are described in section 8.6 after the ISD files.

8.1 XML Metadata File

All RapidEye Standard Image Products will be accompanied by a single XML metadata file. This file contains a descriptions of basic elements of the image. The file is written in Geographic Markup Language (GML) version 3.1.1 and follows the application schema defined in the Open Geospatial Consortium (OGC) Best Practices document for Optical Earth Observation products version 0.9.3, see http://www.opengeospatial.org/standards/gml.

The contents of the metadata file will vary depending on the image product processing level. All metadata files will contain a series of metadata fields common to all image products regardless of the processing level. However, some fields within this group of metadata may only apply to certain product levels and are indicated as such in Table 8 . In addition, certain blocks within the metadata file apply to only to certain product types. These blocks are noted in the table.

8.1.1 Contents

Table 8 describes the fields present in the XML metadata file for all product levels.

Metadata File Field Contents			
Field	**Description**	**Range/Value**	**Conditions**
"metaDataProperty" Block			
EarthObservationMetaData			
identifier	Root file name of the image		
acquisitionType	Type of image acquisition	NOMINAL	
productType	Product level of image	L1B L2A L3A	
status	Status type of image, if newly acquired or produced from a previously archived image	ACQUIRED ARCHIVED	
downlinkedTo			
acquisitionStation	X-band downlink station that received image from satellite	Svalbard	
acquisitionDate	Date and time image was acquired by satellite		
archivedIn			
archivingCenter	Location where image is archived	BRB	
archivingDate	Date image was archived		
archivingIdentifier	Catalog ID of image within the RE DMS processing system		
processing			
processorName	Name of ground processing system	DPS	
processorVersion	Version of RE DPS software used to process image		
nativeProductFormat	Native image format of the raw image data		
license			
licenseType	Name of selected license for the product		
resourceLink	Hyperlink to the physical license file		
versionIsd	Version of the ISD		
orderId	Order ID of the product		
tileId	Tile ID of the product corresponding to the RE Tile Grid		Only for Level 2A and 3A products

Metadata File Field Contents			
Field	**Description**	**Range/Value**	**Conditions**
pixelFormat	Number of bits per pixel in the product image file.	16U – 16 bit unsigned 16S – 16 bit signed	16U for non-atmospherically corrected data 16S for atmospherically corrected data
“validTime” Block			
TimePeriod			
beginPosition	Start date and time of acquisition for source image take used to create product, in UTC		
endPosition	End date and time of acquisition for source image take used to create product, in UTC		
“using” Block			
EarthObservationEquipment			
platform			
shortName	Identifies the name of the satellite platform used to collect the image	RE	
serialIdentifier	ID of the satellite that acquired the data	RE-1 to RE-5	
orbitType	Orbit type of satellite platform	LEO	
instrument			
shortName	Identifies the name of the satellite instrument used to collect the image	MSI	
sensor			
sensorType	Type of sensor used to acquire the data.	OPTICAL	
resolution	Spatial resolution of the sensor used to acquire the image, units in meters	6.5	
scanType	Type of scanning system used by the sensor	PUSHBROOM	
acquisitionParameters			
orbitDirection	The direction the satellite was traveling in its orbit when the image was acquired	DESCENDING	
incidenceAngle	The angle between the view direction of the satellite and a line perpendicular to the image or tile center.	0.0 to 90.0	

Metadata File Field Contents			
Field	**Description**	**Range/Value**	**Conditions**
illuminationAzimuthAngle	Sun azimuth angle at center of product, in degrees from North (clockwise) at the time of the first image line		
illuminationElevationAngle	Sun elevation angle at center of product, in degrees		
azimuthAngle	The angle from true north at the image or tile center to the scan (line) direction at image center, in clockwise positive degrees.	0.0 to 360.0	
spaceCraftViewAngle	Spacecraft across-track off-nadir viewing angle used for imaging, in degrees with "+" being East and "-" being West		
acquisitionDateTime	Date and Time at which the data was imaged, in UTC. Note: the imaging times will be somewhat different for each spectral band. This field is not intended to provide accurate image time tagging and hence is simply the imaging time of some (unspecified) part of the image.		
"target" Block			
Footprint			
multiExtentOf			
posList	Position listing of the four corners of the image in geodetic coordinates in the format: ULX ULY URX URY LRX LRY LLX LLY ULX ULY where X = latitude and Y = longitude		
centerOf			
pos	Position of center of product in geodetic coordinate X and Y, where X = latitude and Y = longitude		
geographicLocation			
topLeft			
latitude	Latitude of top left corner in geodetic WGS84 coordinates		
longitude	Longitude of top left corner in geodetic WGS84 coordinates		

Metadata File Field Contents			
Field	**Description**	**Range/Value**	**Conditions**
topRight			
latitude	Latitude of top right corner in geodetic WGS84 coordinates		
longitude	Longitude of top right corner in geodetic WGS84 coordinates		
bottomLeft			
latitude	Latitude of bottom left corner in geodetic WGS84 coordinates		
longitude	Longitude of bottom left corner in geodetic WGS84 coordinates		
bottomRight			
latitude	Latitude of bottom right corner in geodetic WGS84 coordinates		
longitude	Longitude of bottom right corner in geodetic WGS84 coordinates		
“resultOf“ Block			
EarthObservationResult			
browse			
BrowseInformation			
type	Type of browse image that accompanies the image product as part of the ISD	QUICKLOOK	
referenceSystemIdentifier	Identifies the reference system used for the browse image		
fileName	Name of the browse image file		
product			
ProductInformation			
fileName	Name of image file.		For L1B images only the root file name is listed and not the individual band files
size	The size of the image product in kbytes		
productFormat	File format of the image product	GeoTIFF NITF2.0	
spatialReferenceSystem			

Metadata File Field Contents			
Field	**Description**	**Range/Value**	**Conditions**
epsgCode	EPSG code that corresponds to the datum and projection information of the image		EPSG code = 4326 for L1B images as images are unprojected
geodeticDatum	Name of datum used for the map projection of the image		Only for Level 2A and 3A products
projection	Projection system used for the image		Only for Level 2A and 3A products
projectionZone	Zone used for map projection		Only for Level 2A and 3A products
resamplingKernel	Resampling method used to produce the image. The list of possible algorithms is extendable.	NN = Nearest Neighbor CC = Cubic Convolution MTF = Modulation Transfer Function	
numRows	Number of rows (lines) in the image		
numColumns	Number of columns (pixels) per line in the image		
numBands	Number of bands in the image product	1 to 5	
rowGsd	The GSD of the rows (lines) within the image product		Only for Level 2A and 3A products
columnGsd	The GSD of the columns (pixels) within the image product		Only for Level 2A and 3A products
radiometricCorrectionApplied	Indicates whether radiometric correction has been applied to the image	true false	
radiometricCalibrationVersion	Version of the radiometric calibration file used to correct the file		
geoCorrectionLevel	Level of correction applied to the image	Sensor for L1B images Systematic Geocorrection for 2A images Precision Geocorrection for 3A images	

Metadata File Field Contents			
Field	**Description**	**Range/Value**	**Conditions**
elevationCorrectionApplied	Type of elevation correction applied to the image	false CoarseDEM FineDEM	
atmosphericCorrectionApplied	Indicates whether atmospheric correction has been applied to the image	true false	
atmosphericCorrectionParameters			Present only if atmospheric correction is performed
autoVisibility	Indicates whether the visibility was automatically calculated or defaulted	true false	
visibility	The visibility value used for atmospheric correction in km		
aerosolType	The aerosol type used for atmospheric correction	Rural Urban Maritime Desert	
waterVapor	The water vapor category used	Dry Mid-latitude Winter Fall US Standard Subarctic Summer Mid-latitude Summer Tropical	
hazeRemoval	Indicates whether haze removal was performed	true false	
roughTerrainCorrection	Indicates whether rough terrain correction was performed	true false	
bRDF	Indicates whether BRDF correction was performed	true false	
productAccuracy	Estimated product horizontal CE90 uncertainty, in meters		
mask			
MaskInformation			
type	Type of mask file accompanying the image as part of the ISD	UNUSABLE DATA	
format	Format of the mask file	RASTER	

Metadata File Field Contents			
Field	**Description**	**Range/Value**	**Conditions**
referenceSystemIdentifier	EPSG code that corresponds to the datum and projection information of the mask file		
fileName	File name of the mask file		
cloudCoverPercentage	Estimate of cloud cover within the image	-1 = not assessed 0-100	
cloudCoverPercentageAssessment Confidence	Estimate of cloud cover assessment confidence in percentage	70	
cloudCoverPercentageQuotationMode	Method of cloud cover determination	AUTOMATIC	
unusableDataPercentage	Percent of unusable data with the file		
The following group is repeated for each spectral band included in the image product			
bandSpecificMetadata			
bandNumber	Number (1-5) by which the spectral band is identified.	1 = Blue 2 = Green 3 = Red 4 = Red Edge 5 = Near IR	
startDateTime	Start time and date of band, in UTC		
endDateTime	End time and date of band, in UTC		
percentMissingLines	Percentage of missing lines in the source data of this band		
percentSuspectLines	Percentage of suspect lines (lines that contained downlink errors) in the source data for the band		
binning	Indicates the binning used (across track x along track)	1x1 2x2 3x3 1x2 2x1	
shifting	Indicates the sensor applied right shifting	none 1bit 2bits 3bits 4bits	
masking	Indicates the sensor applied masking	111, 110, 100, or 000	

Metadata File Field Contents			
Field	**Description**	**Range/Value**	**Conditions**
radiometricScaleFactor	Provides the parameter to convert the pixel value to radiance (for radiance product) or reflectance (for a reflectance product). To convert to radiance/reflectance engineering units, the pixel values should be multiplied by this scale factor. Hence the pixel values in the product are: **Radiance product**: (W/m^2 sr µm) / (Radiometric Scale Factor). The Radiometric Scale Factor is expected to be 1/100. For instance, a product pixel value of 1510 would represent radiance units of 15.1 W/m^2 sr µm. **Reflectance product**: Percentage / (Radiometric Scale Factor). The Radiometric Scale Factor is expected to be 1/100. For instance, a product pixel value of 1510 would represent 15.1% reflectance.		
The remaining metadata fields and sub-fields are only included in the file for L1B RapidEye Basic products			
spacecraftAttitudeMetadata			
attitudeMeasurement	Attitude measurements are provided for the time period during which the image data was captured. The time interval between measurements is 1 second		
measurementTime	UTC Time of measurement		
measurements			
roll	Roll attitude measurement in radians		
pitch	Pitch attitude measurement in radians		
yaw	Yaw attitude measurement in radians		
spacecraftEphemerisMetadata			

Metadata File Field Contents			
Field	**Description**	**Range/Value**	**Conditions**
ephemerisMeasurement	Ephemeris measurements are provided for the time period during which the image data was captured. The time interval between measurements is 1 second. The coordinate system for the ephemeris measurements is WGS-84 (Earth Centered Earth Fixed) Cartesian coordinates		
measurementTime	UTC Time of measurement		
position			
x	Position of x-axis, in meters		
y	Position of y-axis, in meters		
z	Position of z-axis, in meters		
velocity			
vx	Velocity of x-axis in meters/sec		
vy	Velocity of y-axis in meters/sec		
vz	Velocity of z-axis in meters/sec		
lineTimeMetadata – This group is repeated for each band present in the image product			
bandNumber	Band number of the spectral band	1 = Blue 2 = Green 3 = Red 4 = Red Edge 5 = Near IR	
lineInfomation	Record for each line in the image file for this band		
imagingTime	UTC Date/Time line imaged		
lineMissing	Indicates whether the line was missing from the input data	true false	
spacecraftTemperatureMetadata			
temperatureMeasurements			
averageFocalPlaneTemperature	Average temperature (over imaging time) from each of the temperature sensors on the focal plane. There are 4 temperature sensors		
averageTelescopeTemperature	Average temperature (over imaging time) from each of the temperature sensors in the telescope. There are 4 temperature sensor		
cameraGeometryMetadata			

Metadata File Field Contents			
Field	**Description**	**Range/Value**	**Conditions**
focalLength	Focal length of the idealized sensor model, in meters		
firstDetectorXCoord	First detector coordinate on the x-axis of the focal plane for the idealized camera model, in meters		
firstDetectorYCoord	First detector coordinate on the y-axis of the focal plane for the idealized camera model, in meters		
detectorPitch	Size of the detector, in meters		
radiometricCalibrationMetadata – This group is repeated for each band present in the image product			
bandNumber	Band number of the spectral band	1 = Blue 2 = Green 3 = Red 4 = Red Edge 5 = Near IR	
perDectectorData	Record for each detector		
gain	Identifies gain used to radiometrically correct the product		
offset	Identifies offset used to radiometrically correct the product		
deadDetectorIndicator	Indicates where the detector is performing outside of its specification and is considered to be dead	true false	

Table 8: XML Metadata File Field Descriptions

8.1.2 File Naming

The XML Metadata file will follow the naming convention described in Section 5.

Example:

2008-10-26T012345_RE3_1B-NAC_0123456789_9876543210_metadata.xml

8.2 Browse Image File

All RapidEye Standard Image products will be accompanied by a reduced resolution browse image file.

8.2.1 Contents

The browse image file contains a reduced-resolution representation of the product. It has the same aspect ratio and radiometric corrections as the product, but with a pixel resolution of roughly 48m. The GeoTiFF file will contain 1 or 3 bands and will be an 8-bit image that is georeferenced to a WGS84 Geographic (Latitude-Longitude) projection. The 3-band browse image contains the Red, Green, and Blue bands. The single band browse image will contain the first available band in the following list: Red, Red Edge, Green, Blue, NIR. Since the browse image is derived from the parent image, the re-projection into geographic coordinates may create areas of blackfill on the borders of the browse image that will not be present in the full resolution parent image.

8.2.2 File Naming

The Browse Image file will follow the naming convention described in Section 7.

Example:

2008-10-26T012345_RE3_1B-NAC_0123456789_9876543210_browse.tif

8.3 Unusable Data Mask File

All RapidEye Standard Image products will be accompanied by an unusable data mask file.

8.3.1 Contents

The unusable data mask file provides information on areas of unusable data within an image (i.e. cloud and non-imaged areas). The pixel resolution of the file will be roughly 48m. The UDM file has 11m or more of horizontal geolocational uncertainty and combined with its lower resolution cannot absolutely accurately capture the edges of areas of unusable data. It is suggested that when using the file to check for usable data, a buffer of at least 1 pixel should be considered. Each bit in the 8-bit pixel identifies whether the corresponding part of the product contains useful imagery:

- Bit 0: Identifies whether the area contains blackfill in all bands (this area was not imaged by the spacecraft). A value of “1” indicates blackfill.
- Bit 1: Identifies whether the area is cloud covered. A value of “1” indicates cloud covered. Cloud detection is performed on a decimated version of the image (i.e. the browse image) and hence small clouds may be missed. Cloud areas are those that have pixel values in the assessed band (Red, NIR or Green) that are above a configurable threshold. This algorithm will:
    - Assess snow as cloud;
    - Assess cloud shadow as cloud free;
    - Assess haze as cloud free.
- Bit 2: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in the **Blue** band. A value of “1” indicates missing/suspect data. If the product does not include this band, the value is set to “0”.
- Bit 3: Identifies whether the area contains missing (lost during downlink and hence blackfilled) or suspect (contains downlink errors) data in the **Green** band. A value of “1” indicates missing/suspect data. If the product does not include this band, the value is set to “0”.
- Bit 4: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in the **Red** band. A value of “1” indicates missing/suspect data. If the product does not include this band, the value is set to “0”.
- Bit 5: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in the **Red Edge** band. A value of “1” indicates missing/suspect data. If the product does not include this band, the value is set to “0”.
- Bit 6: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in the **NIR** band. A value of “1” indicates missing/suspect data. If the product does not include this band, the value is set to “0”.
- Bit 7: Is currently set to “0”.

Figure 1 illustrates the concepts behind the Unusable Data Mask file.

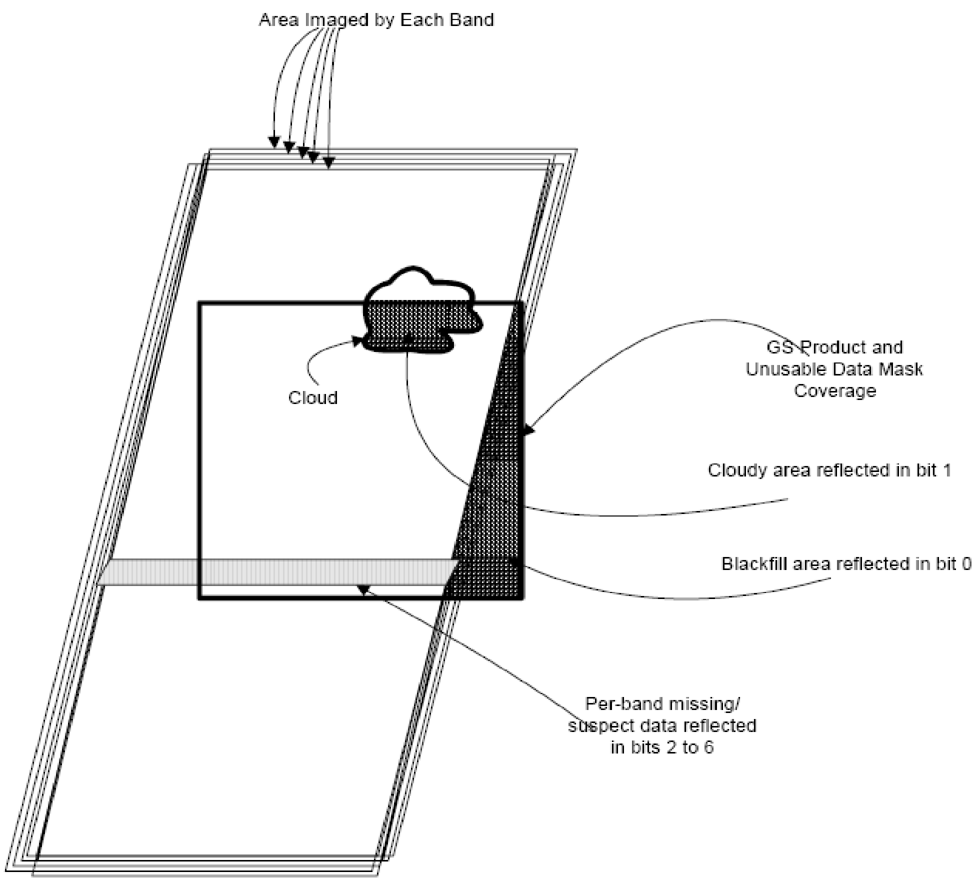


Figure 1: Explanation of Unusable Data Mask file

8.3.2 File Naming

The Unusable Data Mask file will follow the naming convention described in Section 7.

Example:

2008-10-26T012345_RE3_1B-NAC_0123456789_9876543210_udm.tif

8.4 License File

All RapidEye Standard Image products will be accompanied by a license file for the image.

8.4.1 Contents

The license file is a simple text file that contains the text of the license that was selected at the time the image order was placed.

8.4.2 File Naming

The license file will follow the naming convention described in Section 7.

Example:

2008-10-26T012345_RE3_1B-NAC_0123456789_9876543210_license.txt

8.5 Readme File

All RapidEye Standard Image products will be accompanied by a Readme file.

8.5.1 Contents

The Readme file is a simple text file that contains a number of fields with general information regarding the image and the files that accompany it. These field are described in Table 9.

Readme File Contents			
Field	**Description**	**Range/Value**	**Conditions**
ISD version	Version of the ISD		
Copyright Text	Copyright and restricted use text		
Product Generation Time	End time when the Image Product was generated		
Order Number	Order number that the image belongs to		
File List	A list of file names that accompany the image product file		
Product Type	Level of image product	L1B L3A	
Comments	comment field for customer comments or other information pertaining to the order		Empty if none supplied

Table 9: Readme File Contents

8.5.2 File Naming

The Readme file will follow the naming convention described in Section 7.

Example:

2008-10-26T012345_RE3_1B-NAC_0123456789_9876543210_readme.txt

8.6 Order Support Data

The following sections describe the possible Order Support Data (OSD) files that accompany each order delivery.

8.6.1 Area of Interest (AOI) Shapefile

Every delivery order will be accompanied by an AOI shapefile.

8.6.1.1 Content

The AOI shapefile consists of a vector polygon showing the outline of the order area or area of interest (AOI) for that order. The polygon is formatted as a series of files in ESRI® shapefile format and is in a WGS84 Geographic projection.

8.6.1.2 File Naming

The AOI shapefile will be named *aoi_<order_number>. ext*

Example:

aoi_1234567890.dbf
aoi_1234567890.prj
aoi_1234567890.shp
aoi_1234567890.shx

8.6.2 Order Summary Shapefile

Every delivery order will be accompanied by an order summary shapefile.

8.6.2.1 Content

The order summary shapefile consists of vector polygons showing the outline of each image delivered up to that time. If an order has multiple deliveries, this file will show the cumulative total of all images delivered for the order up to that delivery increment. The polygons are formatted as a single ESRI® shapefile in WGS84 Geographic projection. Each polygon within the shapefile will have the following fields of metadata information:

Name – name of the image product
Tile ID – the tile ID number only for 3A products
Order ID – ID number of the order to which the image belongs
Acq Date – date of acquisition of the image
View Angle – the spacecraft off-nadir view angle for the image
UDP – unusable data percentage, a combination of percentage original blackfill and clouds
CCP – cloud cover percentage, as a percentage of usable imagery
Cat ID – catalog ID of the image
Product – type of image product, i.e. 1B or 3A

8.6.2.2 File Naming

The order summary shapefile will be named *order_<order_number>_sum_<delivery-number>. ext*

Example:

order_1234567890_sum_3.dbf
order_1234567890_sum_3.prj
order_1234567890_sum_3.shp
order_1234567890_sum_3.shx

8.6.3 Order Summary KMZ File

Every delivery order will be accompanied by an order summary KMZ file.

8.6.3.1 Content

The order summary KMZ file consists of the order AOI and vector polygons showing the outline of each image delivered up to that time. If an order has multiple deliveries, this file will show the cumulative total of all images delivered for the order up to that delivery increment. The file is formated to work in any software that handles KMZ files.

When viewed in GoogleEarth® each image polygon will have a distinct RapidEye placemarker located in the center of the polygon. When the cursor is placed over the placemarker the tile ID will become visible. If the placemarker is selected with the left mouse button, a information bubble will appear which will contain the browse image of the product and the following metadata fields:

Name – name of the image product
Tile ID – the tile ID number only for 3A products
Order ID – ID number of the order to which the image belongs
Acquisition Date – date of acquisition of the image
View Angle – the spacecraft off-nadir view angle for the image
Usable Data – unusable data percentage, a combination of percentage original blackfill and clouds
Cloud Coverage – cloud cover percentage, as a percentage of usable imagery
Catalog ID – catalog ID of the image
Product Level – type of image product, i.e. 1B or 3A

8.6.3.2 File Naming

The KMZ file will be named *order_<order_number>_sum_<delivery-number>. kmz*

Example:

order_1234567890_sum_1.kmz

Appendix A – Glossary of Terms

The following list defines terms used to describe RapidEye image products.

Bidirectional Reflectance Distribution Function (BRDF)	• Describes the directional dependence of reflected energy (light). BRDF is a fundamental optical property. It characterizes the energy scattered into the hemisphere above a surface as a result of incident radiation.
Digital Elevation Model (DEM)	• A digital model of the terrain surface, usually derived from stereo imagery. A DEM is used to remove terrain distortions from the imagery for the geo-corrected products.
Digital Number (DN)	• The value assigned to a pixel in a digital image. This gray density value represents the intensity of reflected light from a feature collected by the sensor for a particular spectral range.
Dynamic Range	• The number of possible DN values for each pixel in a band of an image. RapidEye has an 12-bit dynamic range which translates into 4096 possible values.
Ground Control Point (GCP)	• A visible point on the ground with known geographic coordinates. GCPs can be planimetric (latitude, longitude) or vertical (latitude, longitude, elevation). GCPs can be collected from ground survey, maps, or orthorectified imagery.
Ground Sample Distance (GSD)	• The size of one pixel, as measured on the ground.
Instantaneous Field of View (IFOV)	• The area on the ground visible to the satellite.
Metadata	• Ancillary data that describes and defines the RapidEye imagery product. Metadata files differ for the two image processing types. See Section 6 for a complete breakdown of metadata files and the fields within them.
Nadir	• The point on the ground that is directly below the satellite.
Off-nadir Angle	• The angle between nadir and the point on the ground that the satellite is pointing to.
Orthorectification	• The correction of distortions caused by terrain relief displacement on the image.
Pixel	• The smallest element comprising a digital image.
Radiometric Correction	• The correction of variations in data that are not caused by the object or scene being scanned. These include correction for relative radiometric response between detectors, filling non-responsive detectors and scanner inconsistencies.

Resolution	• The resampled image pixel size derived from the GSD.
Revisit Time	• The amount of time it takes to image the same point on the ground.
Sensor Correction	• The correction of variations in the data that are caused by sensor geometry, attitude and ephemeris.
Sun Azimuth	• The azimuth of the sun as seen by an observer located at the target point, measured in a clockwise direction from the North.
Sun Elevation	• The angle of the sun above the horizon.
Sun-Synchronous	• An orbit which rotates around the earth at the same rate as the Earth rotates on its axis.
Swath Width	• The width of the ground area that is recorded by one image strip.
Terrain Correction	• The correction for variations in data caused by terrain displacement due to off-nadir viewing.

Appendix B – Tile Grid Definition

RapidEye image tiles are based on the UTM map grid as shown in Figure B-1 and B-2. The grid is defined in 24km by 24km tile centers, with 1km of overlap, resulting in 25km by 25km tiles.

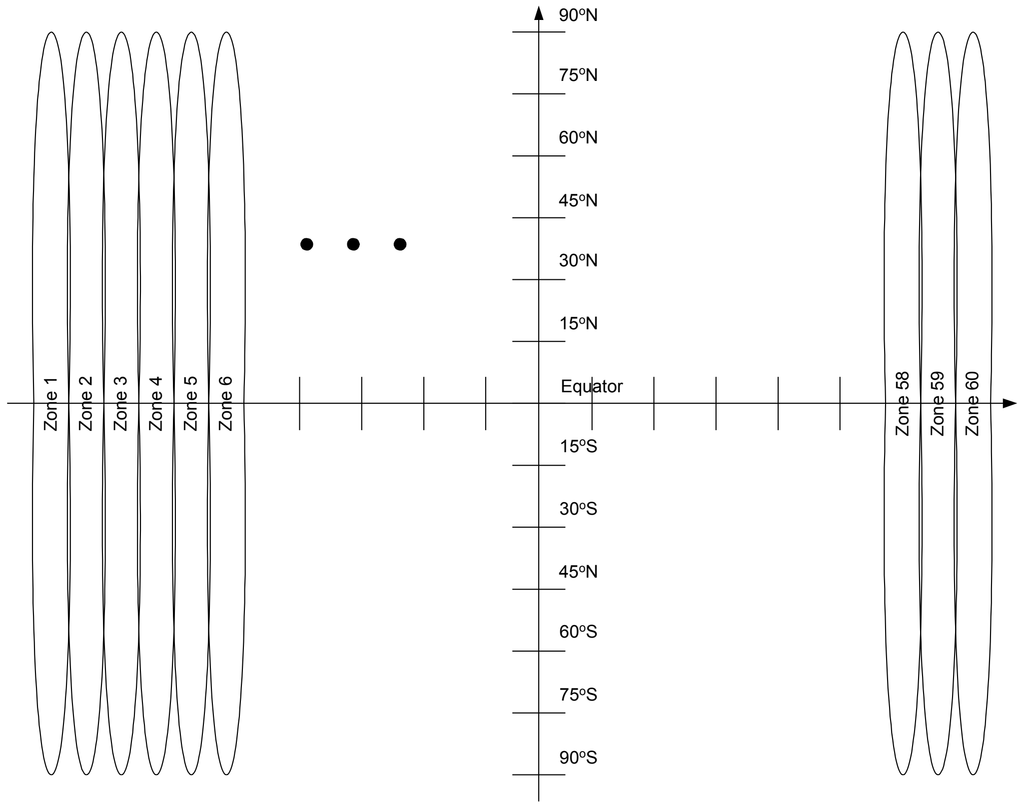


Figure B-1 Layout of UTM Zones

A tile is identified by the UTM zone number, the grid column number within the UTM zone, and the grid row number.

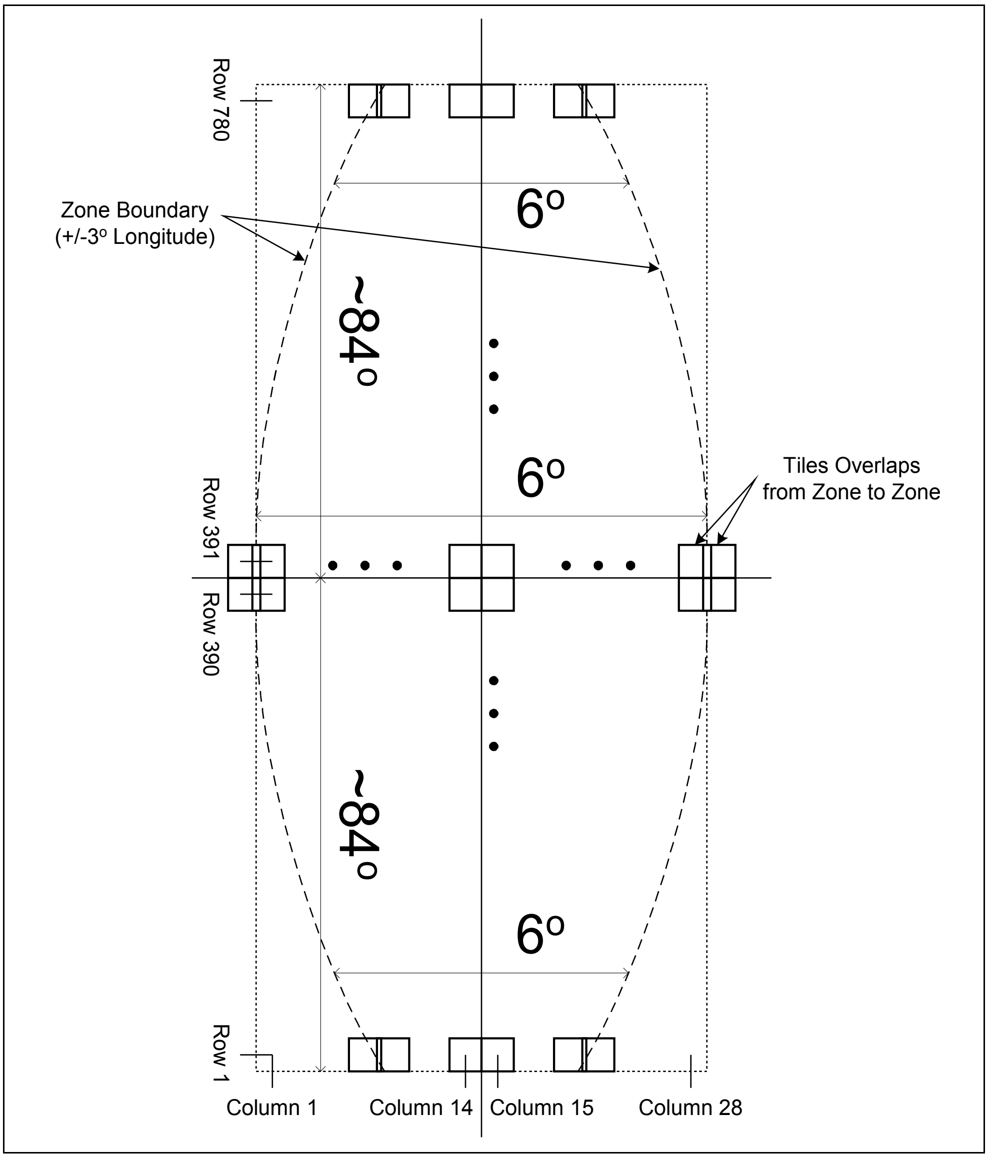


Figure B-2 Layout of Tile Grid within a single UTM Zone

Due to the convergence at the poles, the number of grid columns varies with grid row as illustrated in Figure B-3.

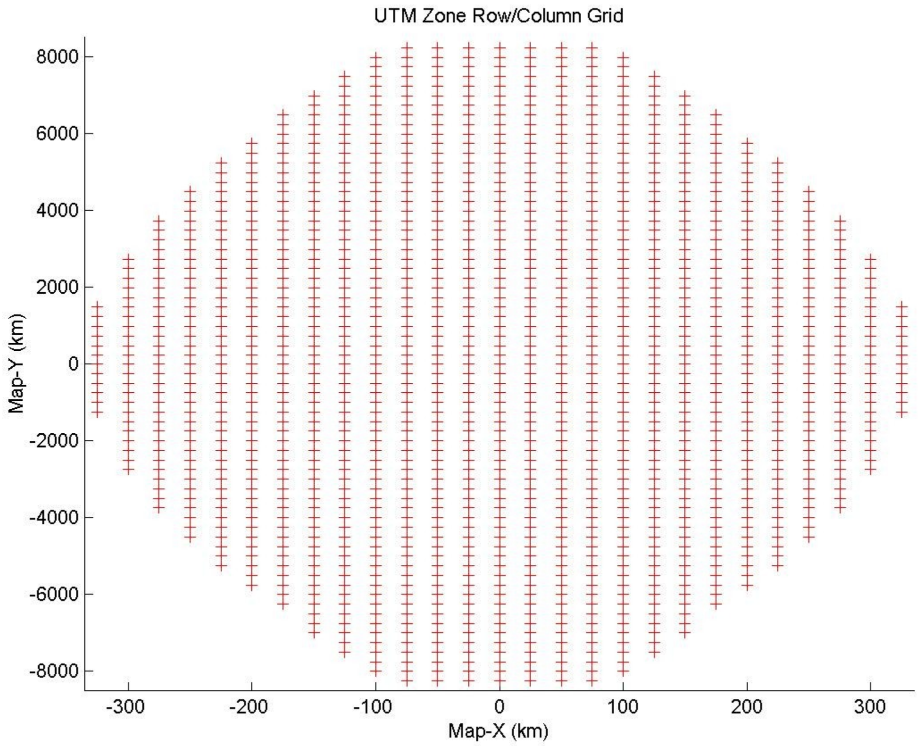


Figure B-3 Illustration of grid layout of Rows and Columns for a single UTM Zone

The center point of the tiles within a single UTM zone are defined in the UTM map projection to which standard transformations from UTM map coordinates (x,y) to WGS84 geodetic coordinates (latitude and longitude) can be applied.

col = 1..29

row = 1..780

X_{col} = False Easting + (col –15) x Tile Width + Tile Width/2

Y_{row} = (row – 391) x Tile Height + Tile Height/2

Where:

X and Y are in metres

False Easting = 500,000m

Tile Width = 24,000m

Tile Height = 24,000m

The numbers 15 and 391 are needed to align to the UTM zone origin.

Appendix C – NITF File Structure and Contents

The RapidEye Basic image product is delivered as a series of NITF 2.0 files. The NITF 2.0 file format contains image data and basic metadata about the image. The structure of the NITF file for the RapidEye Basic product are shown in Figure D-1.

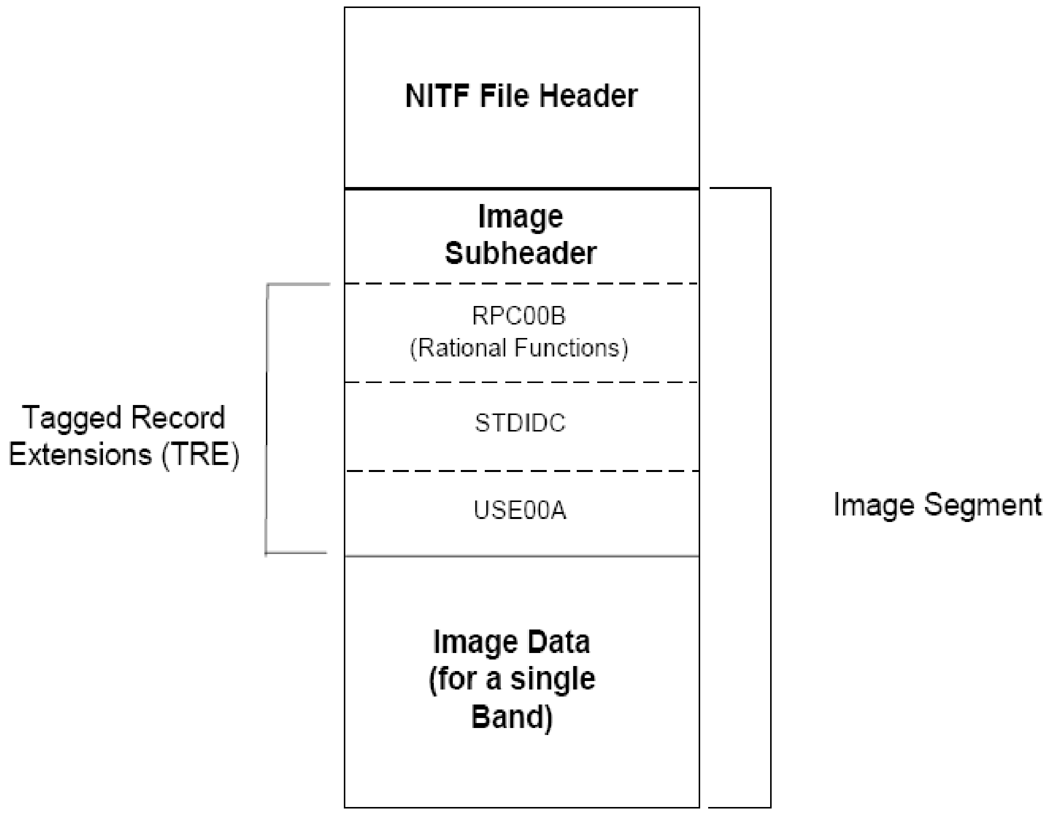


Figure D-1 Structure of NITF 2.0 File

The contents of the NITF File Header are detailed in the Table 10. The "Req" column indicates whether the field is required. Valid values are:

R = Required
C = Conditional
<> = null data allowed

NITF File Main Header Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
FHDR	File type and version	NITF02.00	R	
CLEVEL	Complexity level required to fully interpret all components of the file. Note: Multi-spectral products will have a minimum CLEVEL of 06. A CLEVEL of 99, as required by specifications, is assigned for imagery greater than 2GB, which may adversely affect some software packages.	03, 05, 06 or 99	R	
STYPE	Standard System type	" " (4 spaces)	R	
OSTAID	Originating station identification code	RE	R	
FDT	File date and time	DDHHMMSSZ MONYY	R	
FTITLE	File Title	"RE Image Data"	<R>	
FSCLAS	File security classification	U	R	
FSCOP	Copy number of the file. Message copy number. Not Used.	00000	R	
FSCPYS	Contains the total number of copies of the fileMessage number of copies. Not Used.	00000	R	
ENCRYP	Encryption '0' represents no encryption	0	R	
FBKGC	File background color in the order Red, Green, Blue. Set to a soft gray background	7E 7E 7E	R	
ONAME	Originator's name	RapidEye	<R>	
OPHONE	Originator's phone number	RapidEye Ag Phone Number	<R>	
FL	Length in bytes of the entire file, including all headers, subheaders and data	000000000388-999999999998, 999999999999	R	
HL	NITF 2.0 file header length	000404	R	
NUMI	Number of separate image segments in a file "1" is used for all products	001	R	
LISHn	Length of n-th image subheader, where n = NUMI	000439 to 999998,999999	C	This field occurs as many times as specified in the NUMI field

NITF File Main Header Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
LI00n	Length of n-th image segment, where n = NUMI	0000000001 to 9999999998, 999999999	C	This field occurs as many times as specified in the NUMI field
NUMS	Number of graphic symbols in file. Not Used.	000	R	
NUML	Number of labels. Not Used.	000	R	
NUMT	Number of text segments in file. Not Used.	000	R	
NUMDES	Number of data extensions segments in file. Not Used.	000	R	
NUMRES	Number of reserved extension segments (RES) in file. Not Used.	000	R	
UDHDL	User defined header data (UDHD) length. Not Used.	00000	R	
XHDL	Extended header data (XHD) length. Not Used.	00000	R	

Table 10: NITF File Main Header Contents

The contents of the NITF Image Subheader are detailed in the Table 11.

NITF File Subheader Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
IM	Identifies the subheader as an image subheader	IM	R	
IID	Image identifier	0000000 to 9999999	R	ID of Image Segment from which this image was extracted
IDATIM	Image Date and Time. The image acquisition date and time in GMT	DDHHMMSSZ MONYY	R	
ITITLE	Image Tile	"RE Image Data"	<R>	
TGTID	Target Identifier Where: BBBBBBBBBB = Basic Encyclopedia identifier OOOOO = facility OSUFFIX CC = country code Zero-filled	000000000000 000000	<R>	
ISCLAS	Classification level of image RE products are Unclassified ("U")	U	R	
ENCRYP	Encryption "0" represents no encryption.	0	R	
ISORCE	Image source	RE01-RE05	<R>	
NROWS	Number of significant rows in image	00000000 to 99999998, 99999999	R	
NCOLS	Number of significant columns in image	00000000 to 99999998, 99999999	R	
PVTYPE	Pixel value type	INT SI	R	INT for unsigned integer pixel values SI for signed integer pixel values
IREP	Image representation - "MONO" is used for single-band products - "MULTI" is used for multi-band products	MONO	R	

NITF File Subheader Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
ICAT	Image category	MS	R	
ABPP	Actual bits-per-pixel per band This is also related to the value in NBPP filed of the subheader	12 or 16	R	
PJUST	Pixel Justification Pixels will be right justified	R	R	
ICORDS	Image coordinate representation Geographic ("G") or MGRS ("U")	G	<R>	
IGEOLOn (where: n = 1..4)	Image Geographic Location. Represents the 4 corners of the image, and is presented in image coordinate order: (0,0), (0,NCOLS),(NROWS,NCOLS),(NROWS,0). When ICORDS = "G", IGEOLO is expressed as latitude and longitude and uses the format ddmmssXdddmmssY where "ddmmss" represents degrees, minutes, and seconds of latitude with "X" represents North (N) or South (S), and "ddmmss" represents degrees, minutes, and seconds of longitude with "Y" representing East (E) or West (W).	ddmmssXdddmmss	C	
NICOM	Number of free text image comments	1	R	
ICOMn	Image comments #n, where n = 1..5 Empty by default – configurable text.		C	
IC	Image compression form. Compression is not supported.	NC	R	
NBANDS	Number of data bands	1	R	
IREPBANDn	n^{th} Band representation, where n= 1..NBANDS Note: When NBAND in subheader = 1 this field contains all spaces	blank	<R>	
ISUBCATn	n^{th} Band subcategory – center wavelength of the band, where n = 1..NBANDS	RE spectral centers	<R>	
IFCn	n^{th} Band image filter condition, where n = 1..NBANDS N – no filters	N	R	

NITF File Subheader Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
NLUTSn	Number of LUTs for the nth Image Band, where n = 1..NBANDS Not used.	0	<R>	Required only if the PVTYPE is INT hence the inclusion
ISYSNC	Image sync code – reserved for future use	0	R	
IMODE	Indicates how image pixels are stored. "B" represents band interleaved by block, and is used on all products.	B	R	
NBRP	Number of blocks per row. Contains the number of image blocks (1 block = 1024 x 1024 pixels) in the horizontal direction	0001 - 9999	R	
NBPC	Number of blocks per column. Contains the number of image blocks (1 block = 1024 x 1024 pixels) in the vertical direction	0001 - 9999	R	
NPPBH	Number of pixels per block horizontal	1024	R	
NPPBV	Number of pixels per block vertical	1024	R	
NBPP	Number of bits per pixel per band. RE 12 bits product imagery is stored via 16.bit integers. This is also related to the value in ABPP of the subheader.	16	R	
IDLVL	Image display level. All products consist of a single level.	001	R	
IALVL	Attachment level of image. All products are created with the minimum attachment level.	000	R	

NITF File Subheader Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
ILOC	Image Location. This is the location of he first pixel of the first line of the image and is represented as RRRRRCCCCC, where RRRRR represents row values and CCCCC represents column values.	0000000000	R	Note: The coordinates are line/column numbers. Important when the image is a portion of a larger image (this is not the case for the RE Basic product so the field will always be constant 0000000000).
IMAG	Magnification factor of the image relative to the original source image. Set 10 1.0 to signify no magnification	1.0	R	
UDIDL	User defined image data length. not used.	00000	R	
IXSHDL	Image extended subheader data length. This is the sum of the length of all the Controlled Extensions (CETAG) appearing in the image plus 3:(sum(CEL + 11)) + 3, where 11 is the size of the extension header and 3 is the length of the IXSOFL field.	00003 - 99999	R	
IXSOFL	Image extended subheader overflow. Not used.	000	C	
CETAG	Controlled unique extension type identifier	RPC00B STDIDC USE00A	R	
CEL	Contains the length in bytes of the data contained in the CEDATA field 1041 = length of RPC00B data 89 = length of STDIDC data 107 = length of USE00A data	1041, 89 or 107	R	

Table 11: NITF Subheader Contents

The contents of the RPC00B portion of the NITF Image Subheader are detailed in the Table 12.

NITF RPC00B portion of the Subheader Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
FIELD1 (SUCCESS)		1	R	
FIELD2 (ERR_BIAS)	Error bias. 68% non time-varying error estimate assumes correlated images	0000.00 to 9999.99	R	
FIELD3 (ERR_RAND)	Error random. 68% non time-varying error estimate assumes uncorrelated images	0000.00 to 9999.99	R	
FIELD4 (LINE_OFF)	Line offset	0000000 to 9999999	R	
FIELD5 (SAMP_OFF)	Sample offset	0000000 to 9999999	R	
FIELD6 (LAT_OFF)	Geodetic latitude offset	±90.0000	R	
FIELD7 (LONG_OFF)	Geodetic longitude offset	±180.0000	R	
FIELD8 (HEIGHT_OFF)	Geodetic height offset	±9999	R	
FIELD9 (LINE_SCALE)	Line scale	000001 to 999999	R	
FIELD10 (SAMP_SCALE)	Sample scale	000001 to 999999	R	
FIELD11 (LAT_SCALE)	Geodetic latitude scale	±90.0000	R	
FIELD12 (LONG_SCALE)	Geodetic longitude scale	±180.0000	R	
FIELD13 (HEIGHT_SCALE)	Geodetic height scale	±9999	R	
FIELD14 (LINE_NUM_COEFF 1..20)	Line numerator coefficient: 20 coefficients for the polynomial in the Numerator of the r sub n equation All values are expressed in scientific notation.	-1.000000E+00 to +1.000000E+00	R	
FIELD15 (LINE_DEN_COEFF1 ..20)	Line denominator coefficient: 20 coefficients for the polynomial in the Denominator of the r sub n equation All values are expressed in scientific notation.	-1.000000E+00 to +1.000000E+00	R	

NITF RPC00B portion of the Subheader Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
FIELD16 (SAMP_NUM_COEF F1..20)	Sample numerator coefficient: 20 coefficients for the polynomial in the Numerator of the r sub n equation All values are expressed in scientific notation.	-1.000000E+00 to +1.000000E+00	R	
FIELD17 (SAMP_DEN_COEF F1..20)	Sample denominator coefficient: 20 coefficients for the polynomial in the Denominator of the r sub n equation All values are expressed in scientific notation.	-1.000000E+00 to +1.000000E+00	R	

Table 12: RPC00B (Rapid Positioning Capability) portion of the NITF Subheader Contents

The contents of the STDIDC portion of the NITF Image Subheader are detailed in the Table 13.

NITF STDIDC portion of the Subheader Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
ACQ_DATE	Date and time of image acquisition in GMT.	yyyymmddhhmmss	R	
MISSION	Identifies the specific RE vehicle as the source of image data	RE01 - RE05	R	
PASS	Identifies pass in the day of the image acquisition. A new day starts at 00:00Z	01 -16	R	
OP_NUM	Image Operation Number.	000	R	
START_SEGMENT	Start Segment ID. Identifies images as separate pieces (segments) within an imaging operation. This field will always contain AA.	AA	R	
REPRO_NUM	Reprocess Number. Indicates whether data is original or has been reprocessed or enhanced. We assume “00” for original data.	00	R	
REPLAY_REGEN	Replay/Regeneration. Indicates remapping or regeneration mode of imagery. We assume “000” as all images are produced from raw data.	000	R	
START_COLUMN	Starting Column Block. The first column block in the image. All products start at 1.	001	R	
START_ROW	Starting Row Block. The first row block in the image. All products start at 1.	00001	R	
END_SEGMENT	Ending segment ID of the file. This field will always contain AA.	AA	R	
END_COLUMN	Ending Column Block. The last column block in the image.	001 - 999	R	
END_ROW	Ending Row Block. The last row block in the image.	00001 - 99999	R	

NITF STDIDC portion of the Subheader Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
LOCATION	Location. Natural reference point (in WGS84) of the sensor, expressed as latitude and longitude The format used is ddmmXdddmmY, where "ddmmX" represents degrees and minutes of latitude with "X" representing North (N) or South (S), and "dddmmY" represents degrees and minutes of longitude with "Y" representing East (E) or West (W).	ddmmXdddmmY	R	

Table 13: STDIDC (Standard ID Extension Format) portion of NITF Subheader Contents

The contents of the USE00A portion of the NITF Image Subheader are detailed in the Table 14.

NITF USE00A portion of the Subheader Contents				
Field	**Description**	**Range/Value**	**Req**	**Conditions**
ANGLE_TO_NORTH	Angle to north. Angle to true north measured clockwise from first row of the image.	0 - 360	R	
MEAN_GSD	Mean Ground Sample Distance. The geometric mean of the cross and along scan center-to-center distance between contiguous ground samples, in inches.	000.0 to 999.9	R	
DYNAMIC_RANGE	Dynamic range of the pixels in image. "255" is used for 8-bit products, "4095" is used for 12-bit products, "65535" is used for 16-bit products. This corresponds to the bit-depth value in ABPP of the file subheader section.	00255, 04095 or 65535	<R>	
OBL_ANG	Obliquity angle. This is the angle between the local NED horizontal plane and the optical axis of the image.	00.00 to 90.00	<R>	
ROLL_ANG	Roll angle. Roll is the rotation angle about the platform roll axis. Roll is positive if the platform positive pitch axis lies below the NED horizontal plane.	±90.00	<R>	
N_REF	Number of reference lines in image.	00	R	
REV_NUM	Orbit revolution number at the time of exposure.	00001 to 99999	R	
N_SEG	Number of image segments. This value is always set to 1.	001	R	
MAX_LP_SEG	Maximum Lines Per Segment. This is the number of rows per image segment. This value is equal to NROWS value in subheader.	000001 to 999999	<R>	
SUN_EL	Sun Elevation. Degrees measured from the target plane at intersection of the optical line of sight with the earth's surface at the time of the first image line.	+90.0 or 999.9	R	
SUN_AZ	Sun azimuth. Degrees measured from true North clockwise (as viewed from space) at the time of the first image line.	000.0 to 359.0 or 999.9	R	

Table 14: USE00A (Exploitation Usability) portion of the NITF Subheader Contents