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WWF Remote Sensing Resources: satellite data for forest mapping, monitoring and REDD+

Background

WWF-Germany's Remote Sensing Centre of Excellence is providing the WWF network with detailed information on satellite imagery sources, data selection support and analysis methods relevant for forest mapping, monitoring and change detection, specifically relevant to REDD+ applications, and monitoring, reporting and verification (MRV). Please use this factsheet for project planning and background. For more information, please contact Aurélie Shapiro.

Available Data

There is a large variety of available satellite data to suit nearly every project need and budget. In order to select the appropriate sensor, there are three main considerations:

Spatial Resolution: also referred to as the pixel size, what is the smallest object that the data can discern? Or how large are the objects of interest? Individual trees or a forest? What area is intended to be covered? A landscape or a country? Low resolution (large pixel size) is coarse, only for detecting large objects. High resolution (small pixel size) is detailed, for viewing smaller objects.
Spectral resolution: satellites observe at various wavelength ranges of the electromagnetic spectrum: red, blue, green, infrared. Green, red and NIR are most useful for forest mapping. Radar sensors detect long wavelengths that can penetrate clouds.
Temporal resolution: How often does the satellite capture an image of a location? How often are repeat measurements or reporting required? Some satellites capture every few days, others months or years.

Other geographic elements to consider:
Scale: how big is your map compared to reality, or how much detail do you need?
Extent: how large is the area being mapped?

The cost is also an essential element to consider when planning a monitoring project. Prices vary widely, from entirely free to thousands of €. A list of available data, including WWF pricing are in the Appendix.

Trade-offs
These geographic elements are important because they act oppositely. It is very difficult to obtain very high resolution (low scale) over large areas for many reasons:
The data volume can simply be unmanageable; higher resolution sensors have a smaller footprint, which require mosaicking of data taken at different times and the fine details of objects (shadows, presence of people, cars, different trees species) can make mapping simple land cover (forest) or land use (urban) quite difficult. Finally, higher resolution satellites often collect less often, the cost and altitude prohibit high frequency; whereas coarse resolution sensors capture more frequently.

Image licensing
For commercial imagery, especially high resolution data, come with strict licensing regulations. Please read these closely. There are restrictions for sharing, publishing and posting data online.

Resolution

The resolution of data for a map or analysis must be defined *a priori*, to best suit the needs and budget of the project. It is a very common misconception that higher resolution is better. Higher resolution can in fact result in lower accuracy, higher costs, more difficult processing, and inconsistent results over time –therefore, only the appropriate resolution should be selected.
The following data sets are recommended for mapping at scale

Global/Regional Scale mapping (250m-1km resolution)
Large extent mapping at the regional or global scale is best achieved with low resolution, high frequency such as from the MODIS platform. These data are collected twice daily by the Aqua and Terra sensors and can be downloaded for free. File sizes are reasonable, and the data are consistent, can be mosaicked and averaged or composited to overcome cloud cover. In addition, there is a good spectral resolution for vegetation, a number of derived indices such as normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI) and Vegetative Continuous Fields (VCF) data which have proven useful for monitoring. The satellite was launched in 2000, providing a long time series for monitoring over time, and works well for automated alert systems. Finally, a suite of free tools including Modis Reprojection Tool (MRT) and MODIS Land Data Operational Product Evaluation (LDOPE) software tools support automated processing.
More information:
MODIS data : http://modis.gsfc.nasa.gov/
MODIS Reprojection Tool: https://lpdaac.usgs.gov/lpdaac/tools/modis_reprojection_tool
MODIS Reprojection Tool Web interface: http://mrtweb.cr.usgs.gov
LDOPE tools: https://lpdaac.usgs.gov/tools/ldope_tools

National/Landscape level mapping (20-100m resolution)
Medium resolution sensors, such as Landsat, ALOS Palsar are suitable for mapping at the national or landscape level. Data in the 20 to 100m resolution range provide optimal forest information for REDD+ projects, and national baselines. The Landsat sensor has been the veritable workhorse for medium resolution mapping, acquiring data since 1982 at spectral bands particularly useful for vegetation, with large footprints worldwide and generally free of charge. While the Landsat sensor is currently inoperable, a new mission planned in 2013, which will expand the archive, with free data that is processed to basic levels. The ASTER satellite is collecting imagery globally at 15m resolution, and geo-positioned jpgs are available worldwide, relatively up to date for free. Other sensors in this range include the SPOT constellation, which is still operating several satellites, collecting at 2.5m-20m resolution worldwide, with a similar long historical archive, but smaller footprint and reduced spectral range compared to Landsat.
In the radar domain, the ALOS Palsar satellite has collected valuable data between 2007 and 2010 that is free at 50m resolution that has been mosaicked, with terrain-corrected processing for tropical regions. A new mission is planned in 2013 which will provide additional annual mosaics for tropical regions and wetlands at 50m resolution. These data have been used successfully for mapping forest/non-forest and estimating biomass in low biomass vegetation types (<100 tons C/ha).
More information:
USGS data archive for Landsat, Aster data : http://glovis.usgs.gov
SPOT sirius archive: http://sirius.spotimage.fr
JAXA ALOS Palsar mosaics: http://www.eorc.jaxa.jp/ALOS/en/kc_mosaic/kc_mosaic.htm

Landscape/project level mapping (<10m resolution)
Very high resolution should be reserved for very small areas, or for validation, verification purposes (determining accuracy, ground-truthing other data). Very high resolution data is voluminous and requires high end hardware and software. Data can be used to visualize local scale degradation (logging) canopy gaps and forest types. Satellites from Digital Globe (which provide preferred pricing for WWF) and Geo-Eye lead the high resolution market. These however, only collect intermittently on demand. RapidEye AG, with a constellation of 5 satellites is filling the temporal gap and overcoming cloud cover by collecting data daily, at 6m resolution, with a special red-edge band useful for vegetation studies.
More information:
Digital Globe Image Finder: http://browse.digitalglobe.com/imagefinder/main.jsp?
GeoEye Search and Discovery Platform: http://geofuse.geoeye.com/landing/Default.aspx
RadidEye image search: http://eyefind.rapideye.de/

Table 1. Summary of sensor types for different scales of analysis

Scale	Recommended resolution	Satellite sources	Notes
Global/regional	250m-1km	MODIS, MERIS	MERIS mission ended in 2012, MODIS is still collecting twice daily since 2000. Additional derived products (vegetation indices) are useful for forest monitoring, alert systems
National/Landscape	20-100m	Landsat, ASTER, ALOS Palsar, SPOT	Landsat and ALOS Palsar missions are not operational; new missions planned. SPOT and Aster data provide an in-between resolution optimal for forest monitoring
Landscape/project	<10m	Geo-Eye 1, IKONOS, Quickbird, Worldview-1, Worldview-2, RapidEye	These satellites afford detailed views of canopies, forest types. Not recommended for large areas.

Obtaining imagery

After deciding on a resolution and mapping frequency, consult the data table for appropriate satellite imagery. Not all satellites collect everywhere, nor are there always cloud-free images available, so you need to search for useable data. Define an area of interest in Google Earth or ArcGIS (WGS 84 projection), and use that to search the archives.
You should also ask partners, universities or local institutes or governments who may have already obtained satellite imagery for your area of interest.
Some imagery can be obtained at no cost after submitting a proposal to a company or foundation (i.e. Planet Action). These submissions should highlight the innovative quality of the research, and the communications, publications benefits for the data donor. It is very important to budget time and resources for reporting and feedback to the image donor - this is crucial in helping to maintain WWF's good standing and cooperation with these organizations – failure to provide reporting can affect other WWF projects seeking donations.
More information:
Astrium Geo Planet Action Foundation: http://www.planet-action.org/
GeoEye Foundation: http://www.geoeyefoundation.org/

Satellite-Derived products

You can save a lot of time and money by using already processed, or "GIS-ready" satellite-derived products, which are often free. In addition, proxy data, such as night-lights or fires can provide additional information concerning human activities or threats.
These derived products include:

MODIS Vegetation Continuous Fields (VCF)
These data are free of charge, 250m resolution, derived from MODIS, and provide an estimate for forest cover from 0-100% for each pixel. Available globally, consistently, annually from 2000 to 2010. Data products also include a cloud cover layer, quality control and a standard deviation (to describe seasonality of inter-annual variation). Annual products can be used to assess general trends. WWF-Germany is processing these products for all WWF priority ecoregions.
More information:
MODIS vegetative continuous Fields:
https://lpdaac.usgs.gov/products/modis_products_table/vegetation_continuous_fields/yearly_l3_global_500m/mod44b

MODIS Vegetation Indices
Available at multiple resolutions (250m, 500m, 1km) as well as multiple temporal resolutions (16 day or monthly composites).these products are automated, consistent, atmospherically corrected

products which allow for comparison of vegetation. The enhanced vegetation index is adapted to dense vegetation conditions. Data can be downloaded free of charge.
More information:
MODIS Vegetation data products:
http://modis.gsfc.nasa.gov/data/dataprod/dataproducts.php?MOD_NUMBER=13

MODIS Fire Data
1km resolution, real-time fire data derived from MODIS is provided by the University of Maryland Fire Information for Resource Management System. This website provides daily updates, email alert for areas of interest, as well as calibrated archive data for the entire world.
More information:
Fire Information for Resource Management System: http://earthdata.nasa.gov/firms

Night Lights Data
This 1km resolution data is a cloud-free composite of night time data that can serve as a proxy for developed areas, or infrastructure. Data are standardized, available globally for free for 1992-2010. These could be valuable for looking at the threats from human settlements over time, but only applicable for areas with significant urban or city-light infrastructure.
More information:
Night Lights data: http://www.ngdc.noaa.gov/dmsp/downloadV4composites.html

Forest Fragmentation Index (from Riitters et al., 2000)
A simple technique for estimating fragmentation and connectivity has been developed by Kurt Riitters, USGS. This algorithm classifies a forest map into categories based on location: core, patch, edge, transition and perforation. Monitoring these categories over time with updated forest maps can meet the basic needs for monitoring degradation.
More information:
Global Scale Patterns of Forest Fragmentation http://www.ecologyandsociety.org/vol4/iss2/art3/

Forest Monitoring and Change Detection

Forest monitoring or mapping is most efficiently be achieved over time by analyzing satellite imagery, which can be done using a number of different methods. For REDD+ and other goals, the monitoring must be consistent, transparent and repeatable in order to be accepted for reporting. The following rules should be considered when selecting a method for monitoring forests over time:
The method utilized must be *simple and repeatable* – complicated methods tend to increase cost, as well as the difficulty to produce accurate, consistent results over time
Semi-automated or *fully automated* procedures are better than completely manual methods – a method that only experts or few people in-country with specialized skills can reproduce is not reliable or affordable over time. In addition, each operator has different skills, accuracy; manual methods must account for operator differences.
The method *cannot be sensor dependent* – satellites eventually fail, new missions come onboard, therefore any procedure must be able to adapt to different sensors.

A summary of suggested methods for change detection are listed below. This list is not exhaustive; appropriate literature review of methods should be conducted to determine if the method is appropriate for the sensor, region, and forest type:

Post-classification change
Classifying 2 images from different dates in forest/non-forest, or other applicable land cover types. The benefit of this method is that results are clear and straightforward, provide, however, there is significant error propagation with this method, where the classification errors (which can be reasonable for 1 image alone) are in fact, multiplied through the change analysis. This method is recommended for areas where good classifications are possible, with fewer categories (forest/non-forest; mangrove) or classifications from radar imagery.

Multi-date stack
A multi-date stack is a combination of images from several dates, and the differences and similarities are identified to create maps of persistence and change. The benefit of this technique is that

multiple (i.e. more than 2) dates can be incorporated, as well as different sensor types. However, images must be well co-registered, and change must be readily visible.

Principle Components
Principle components analysis (PCA) is a common data reduction technique to reduce dimensionality. Analyzing the 2nd, 3rd bands of PCA from a multi-date stack is a simple, automated method for determining change. This method can overcome certain overall differences between images (atmosphere or differences in brightness). However, a user must still determine the criteria and threshold for identifying change, which can introduce variability, or subjective error.

Object-based segmentation
Object-based analysis techniques are a growing realm of expertise in remote sensing, affording the combination of raster spectral data with vector analysis. With object-based analysis, pixels from an early data raster image are grouped based on color, shape and texture and spectral variations of the later date image within these segments can be analyzed for change.

High Temporal Resolution Time Series
Using the long time series of high temporal resolution data such as MODIS, detailed trends at multiple temporal scales can be determined – separating seasonal and annual trends from anomalies due to land cover change. These techniques are commonly used for alert systems, and real time change detection. These require advanced analysis capabilities, but free tools are becoming more accessible for analysis time series.

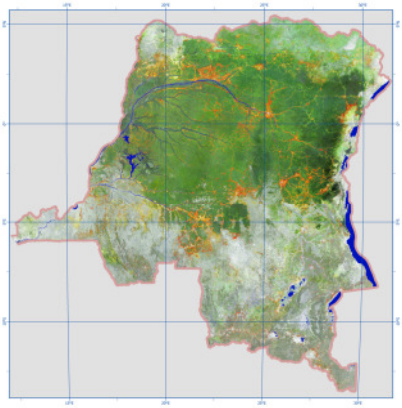
Hybrid Approaches
The best approaches combine different techniques, tailored to the needs and geographic region of analysis. Coarse alert systems combined with traditional change techniques are increasingly common, or automated classification with manual editing can be very accurate. The best approach will be derived after repeated testing and validation.

Accuracy Assessment

All maps, including land cover, change must be appropriately validated, with Kappa metrics or user/producer error. A map without a standard accuracy assessment has zero value for any REDD+ activities. Standard accuracy assessment techniques exist, and are relatively easy to implement. When using field data for verification, an independent set of ground points (GPS, photos) must be set aside for accuracy assessment – these cannot be used for classifications or algorithm training. Additionally, Google Earth, or very high resolution data can be used as an alternative to field visits, when inaccessibility, or timing (i.e. validating a 10 year old map) require it.
More information:
Overview of Accuracy assessment:
http://biodiversityinformatics.amnh.org/index.php?section_id=34&content_id=131

Examples

Democratic Republic of Congo



In order to map forest cover change between 2000 and 2010 over the entire Democratic Republic of Congo, the University of Maryland, South Dakota State University and the Observatoire satellital des forêts d'Afrique centrale (OSFAC) developed a unique method to mine and analyze Landsat data. Over 8 thousand images with less than 50% cloud cover were processed and analyzed to generate seamless "wall-to-wall" forest cover and forest cover loss. Multiple images were combined to overcome cloud and data gaps. The advantages of this technique are near complete coverage of the entire country, at the medium scale 60m resolution, well suited to the small deforestation dynamics. The disadvantage is that exhaustive processing is need to radiometrically correct and standardize many images from different dates. Also, this method only assesses 3 types of forest cover: primary, secondary and woodland. These have widely varying accuracy. Finally, the Landsat

satellites are nearing the end of their life span, resulting in a data gap starting in 2010, and new methods must be applied to new data.

Borneo

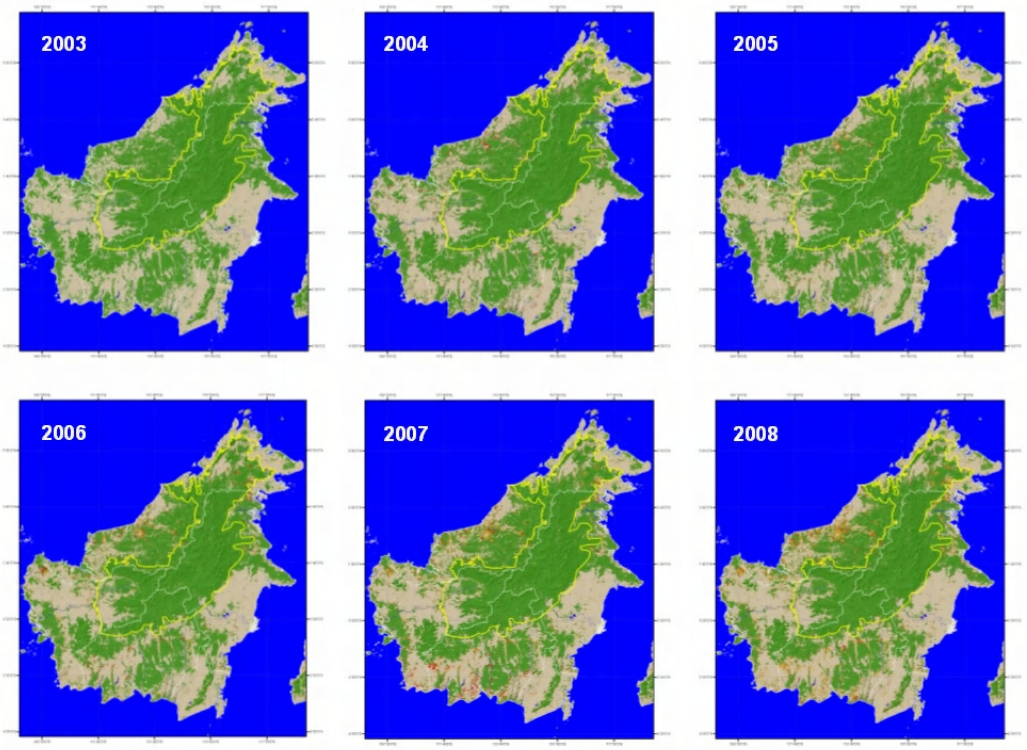
To monitor land cover over the entire island of Borneo, there are several issues to overcome:

a very large area, requiring consistent data over wide extent, large data volume, a lot of processing

persistent cloud cover makes optical remote sensing verv challenging

rapidly changing landscape means repeated updates are necessary

SarVision LLC overcame these issues by developing a robust, annual monitoring system using **MODIS** data. This is fairly low resolution (250m) but is more than adequate for a large area. In addition, the twice daily imagery collections can overcome persistent clouds in all but a few places. The spectral resolution of MODIS allows for multiple landcover types to be mapped, and the long time series provides repeated, annual updates. The downsides to this approach are the large volume of data, for which specialized software was needed to be developed in order to automate tasks on multiple images.



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Satellite Data Resources for WWF

List of available satellite data, sources, applications and cost

Low Resolution

Name	Source	Date	Resolution	Frequency	Spectral Bands	Uses, applications	Cost	Source
MODIS	NASA	1999 -	250m – 1km; ~10degree tiles	Twice daily	36 bands, for land, water, atmosphere	Fire detection, real time monitoring, daily snapshots, phenology, regional studies, long term trends, vegetation indices	FREE	Info on MODIS Data http://modis.gsfc.nasa.gov/data/ Search and download raw and derived data products from Reservb (need to register): http://reverb.echo.nasa.gov Or GLCF for derived products http://glcf.umiacs.umd.edu/data/modis
SeaWifs	NASA	1999-	9km	daily	8 bands	Water quality, chlorophyll, sediment	FREE	Data download from Oceancolor web (registration required) http://oceancolor.gsfc.nasa.gov/
SPOT-VGT	VITO	2002-2012	1km	daily	Red, blue, NIR, SWIR, Composite vegetation index	Surface mapping, basic vegetation and canopy	Synthesis products are FREE	Read documentation for how to convert DN Background information: http://www.vgt.vito.be/index.html free products: http://free.vgt.vito.be/
MERIS/ ENVISAT	ESA	2002-2012	300m; swath width 1150km	3 days	15 bands	Land and water mapping	Free through registration or application	Data access through ESA application, multiple web clients: https://earth.esa.int/web/guest/data-access/catalogue-access

Medium Resolution

Name	Source	Date	Resolution	Frequency	Spectral Bands	Uses, applications	Cost	Source
ALOS PALSAR	JAXA	2007-2010	25m, 50m resolution	Annual mosaics	HH, HV polarization	Forest mapping, biomass, change detection, cloudy areas	50m mosaics are free; other data can be negotiated	Processed mosaics for Africa and SE Asia available in GTIFF from WWF Germany. HDF 50m mosaics can be download from the K&C website: http://www.eorc.jaxa.jp/ALOS/en/kc_mosaic/kc_map_50.htm Additional requests for 25m data can be made through K&C
ALOS AVNIR	JAXA	2007-2010	10m; 70km swath	2 days	Blue, green, red, NIR	Land cover mapping, and quick disaster response	Cost varies	Search archive and order through Pegasus: http://en.alos-pasco.com/sample/pegasus.html
ASTER	NASA	1999-	15m/30m/90m ; 60kmx60km tile	weekly	15 bands: 4 visible and NIR; 6 Short wave IR, 5 thermal bands (90m); 1 stereo	Land cover mapping, change detection, real time monitoring	$0.02/km² ($80 for 60x60km)	Data can be browsed and downloaded from Earth Explorer http://edcsns17.cr.usgs.gov/EarthExplorer/ or Glovis http://glovis.usgs.gov list of ASTER Derived products: https://lpdaac.usgs.gov/products/aster_products_table
AWIFS	Indian Space Research Organization	2003-	56m; 370 x 370km	5 days	4 spectral bands, green, red, NIR, Mid-IR	Land cover mapping, change detection, crop yields, large scale analyses	$0.01/km² ($700/tile)	Data can be searched through the National Remote Sensing Centre of India http://218.248.0.130/internet/servlet/LoginServlet or through a reseller; data can be freely available for Amazon (Resource-Sat http://www.dgi.inpe.br/CDSR/)
Corona	USGS	1960-1972	10m; 22kmx22km	intermittent	Panchromatic camera	Historical mapping	$80/scene	Searchable via selecting Declassified Data in Earth Explorer: http://earthexplorer.usgs.gov/
ICESat/GLAS	NASA	2003-2010	60m granules/footprints	891 days	LiDAR: Altimetry, backscatter	Forest canopy height, elevation, sea ice thickness	FREE	Coverage is not continuous; data must be filtered for quality. http://nsidc.org/data/icesat/index.html

Medium Resolution cont...

KOMPSAT	Korea Aero-space Research Institute	2006-	1m panchro-matic, 4m multispectral; 15km swath	14 days	Blue, green, red, NIR	Disaster surveillienace, vegetation and coastal monitoring	Price upon request; Free data via Planet Action, or ESA	http://www.kari.re.kr/data/eng/contents/Space_001.asp?catcode=1010111000&depthno=0 imagery donations for climate change projects from www.planet-action.org
Landsat	USGS	1982 - 2012	30m; 185kmx185km	14 days	Red, Green, Blue, NIR, mid-IR, ther-mal IR (60m); Land-sat 7 includes a panchromatic (15m) band	Land cover mapping, vegetation studies, change detection, long term studies, marine mapping	FREE	Landsat 7 ETM+ data collected after May 2003 has striping issues. Landsat 5 TM is still collecting, though not every-where. Data can be browsed and downloaded from Earth Explorer http://earthexplorer.usgs.gov/ or Glovis http://glovis.usgs.gov

High Resolution

Name	Source	Date	Resolution	Frequency	Spectral Bands	Uses, applications	Cost	Source
CBERS I &II	China-Brazil	1999-2010	20,80, 240m; swath is 113-1000km	3-26 days	Panchromatic + red, infrared, blue, green, nir, shortwave and thermal infrared, stereoscopic	Multiple resolution forest monitoring, especially for Amazon	Free for amazon, other places	More information on the different CBERS satellites: http://www.cbers.inpe.br/ingles/satellites/cameras_cbers1_2_2b.php Free data for Amazon, some other countries available: http://www.dgi.inpe.br/CDSR/
IKONOS, Geoeye-1	GeoEye	1999-	80cm-4m; 13km swath	On demand	Pan, blue, green, red, nir	Land cover mapping, marine mapping, high resolution detail, small area	$12-18/km²	Donation of 250km2 available from GeoEye Foundation www.geoeyefoundation.org Archive search online Google interface, or ArcGIS toolbar http://geofuse.geoeye.com/landing/Default.aspx
Pleiades-1	Astrium	2011-	50cm; 100kmx100km	daily	Green, blue, red, IR, panchromatic	High resolution mapping, validation	TBD	Data must be ordered through a reseller. Pleiades 2 will launch in 2012/2013
Quickbird, Worldview 1, 2	Digital Globe	2001-	<60cm – 2.4m;	On demand	Red, green, blue, nir, panchromatic; worlview 2 has additional 4 bands: yellow, coastal, red edge, NIR 2	Land cover mapping, marine mapping, high resolution detail, small area, vegetation and biomass	$3.6-5.25/km²	Can be tasked on demand for $5.25/km2; archive orders start at 3.60 km2 View the archive at http://browse.digitalglobe.com/imagefinder/ upload a shapefile, change search criteria, download results
RapidEye	RapidEye AG	2008-	6.5m 25km x 25km tiles; swath width 77km	daily	Blue, green, red, red edge, NIR	Land cover, vegetation mapping, change detection	0,9€/km2, minimum order	Archive search at http://eyefind.rapideye.de/ Images available for free to research institutions in Germany
SPOT	Astrium	1982	2.5-20m; 60kmx60km tile	2 days	Varies by satellite; pan, green, red, near IR, shortwave IR	Land cover mapping, vegetation and change detection	1000€+/scene < 20 tiles free via Planet Action	SPOT catalog: http://sirius.spotimage.com/PageSearch.aspx imagery donations for climate change projects from www.planet-action.org commercial SPOT imagery through regional reseller

Other resources

For all imagery orders, please register as a GIS user on the portal first. You may also use the portal to order software, find data sources and other GIS, remote sensing users

WWF GIS portal http://gis.panda.org

Useful table of derived products from MODIS and ASTER: https://lpdaac.usgs.gov/products

SPOT-VGT Vegetation archive 1km data http://free.vgt.vito.be/

A number of derived products from Geoland 2, medium resolution, global coverage data:
http://www.geoland2.eu/portal/service/ListService.do;jsessionid=C6BB68AAAE639ADBDA3AAAB05811CF4B?serviceCategoryId=CA80C981

Raw satellite data and derived products from the University of Maryland Global Land Cover Facility: http://glcf.umiacs.umd.edu/

3D land mapping with LiDAR and radar: http://lidarradar.jpl.nasa.gov/

INPE catalog with free imagery for Amazon: http://www.dgi.inpe.br/CDSR/