LANDSAT SATELLITES
HISTORICAL, CURRENT AND FUTURE

The Landsat Project is the longest-running enterprise for acquisition of moderate resolution imagery of the Earth from space. The Landsat 1 satellite was launched in 1972 and the most recent, Landsat 7, was launched in 1999. The instruments on the Landsat satellites have acquired millions of images. These images form a unique resource for applications in agriculture, geology, forestry, regional planning, education, mapping, and global change research.

The data presented here on the historical aspects of the Landsat Program is a summary only and more details can be found on the web sites -
http://landsat.gsfc.nasa.gov/
http://landsat.usgs.gov/

LANDSAT PLATFORMS

Six Landsat satellites have now been successfully launched commencing with Landsat 1 in July 1972. All platforms have operated from a repetitive, circular, sun-synchronous, near-polar orbit and on each day-side pass, scan a ground swath 185km wide beneath the satellite. The first three satellites carried the Multispectral Scanner (MSS) as the main imaging instrument with a Retum Beam Vidicon (RBV) as a subsidiary. The paths of these satellites were inclined 99 degrees with an 18 day repeat cycle and an Equatorial crossing of between 8:30 and 9:30am local time. Landsats 4 and 5 have the Thematic Mapper (TM) as the main sensor together with an MSS. They were inclined 98 degrees, have a repeat cycle of 16 days and an Equatorial crossing between 9:30 and 9:45am local time. Landsat 6 was unfortunately lost on launch in 1993, however Landsat 5 continued to provide good data even after the launch of Landsat 7 in April 1999.

Current Landsat Sensors

Landsat 5 is 22 years old and no redundancy remains of most of its mission critical subsystems however it is still producing useful Thematic Mapper data. There have been some scares in the last few years, notably with the backup Solar Array Drive which malfunctioned in November 2005, however the problem was fixed by January 2006. There has also been some deterioration in the bumper mode operation which affects the locational accuracy of Landsat 5 systematic corrected imagery (ie Path Image and Map Image Products). This deterioration appears to have become worse for acquisitions after August/September 2006.

The Enhanced Thematic Mapper (ETM+) sensor on Landsat 7 developed an instrument malfunction on May 31, 2003 and this has severely limited the usefulness of the current data. The problem was caused by the failure of the Scan Line Corrector (SLC), which compensates for the forward motion of the satellite. Subsequent efforts to recover the SLC were not successful, and the problem appears to be permanent. Without an operating SLC, the ETM+ line of sight now traces a zig-zag pattern along the satellite ground track. Landsat 7 ETM+ is still capable of acquiring useful image data with the SLC turned off, particularly within the central portion of any given scene. Landsat 7 ETM+ therefore continues to acquire image data in the “SLC-off” mode. The SLC-off impacts are most pronounced along the edge of the scene and gradually diminish toward the center of the scene. The middle of the scene (approximately 22 kilometers with a 11G product) contains very little duplication or data loss, and this region should be very similar in quality to previous (“SLC-on”) Landsat 7 image data. Several different Level 1G ETM+ product options have been developed by EROS in order to increase the utility of the 11G SLC-off product. These options reflect the three different methods by which the original duplicated data may be replaced during processing.

Level 1G Standard - This product includes the original data gaps. Duplicated pixels have been replaced with null values (zero-fill) and the image will therefore contain alternating “stripes” of missing data.

Level 1G Interpolated - Maximum (15-pixel) interpolation provides a fully populated image, in which all missing pixels have been filled with DN values interpolated from neighbouring scan lines.

Level 1G Gap-filled - This product provides a fully populated image, in which all of the missing image pixels in the original SLC-off image have been replaced with histogram-matched data values derived from one or more alternative acquisition dates.

ACRES refers to the Gap-filled products as Composite images and now offers two types of products.

Landsat 7 SLC-Off ACRES Composite Product - one product made from the combination of several separate scenes (in an attempt to fill the gaps); Orthocorrected processing only; and

Landsat 7 SLC-Off Customer Composite Package - several separate products over the one area for customers to composite in their own way; Path Image processing only. (Recommended for experienced users only.)

To encourage use of Landsat 7 SLC-Off data, both of these options are provided at the same low price.

These composite products and packages provide more useful Landsat 7 data because:

> Customers can choose SLC-off scenes acquired in the same season (subsequent passes) thereby reducing the ambiguity in interpretation due to temporal changes

> Customers can choose more than two SLC-Off scenes (maximum of five) to provide a greater chance of filling the data gaps

> One additional SLC-On scene can also be included to ensure there are absolutely no gaps in the final product. However this option is less useful for recent acquisitions because an SLC-On scene would now be several years old.

Full details of the Australian SLC-off products offered by ACRES can be obtained by contacting GEOIMAGE or from http://www.ga.gov.au/acres/referenc/slcoff_composite.jsp

Landsat Data Continuity Mission (LCDM)

Landsat 7 was launched in 1999 with a design life of five years. Early plans for Landsat data continuity after Landsat 7 were based on NASA purchasing data from a privately owned and commercially operated satellite system however these plans were cancelled in Sept 2003. Subsequent attempts to place Landsat-type sensors on National Polar-orbiting Operational Environmental Satellite System (NPOESS) platforms were also cancelled and in Sept 2005, NASA was directed to acquire a single Landsat data continuity mission in the form of a free-flier spacecraft. The instrument will collect land surface data similar to that of its Landsat predecessors. The data will be delivered to the U.S. Geological Survey who will be responsible for mission operations as well as data collection, archiving, processing and distribution. Current planning is for the satellite to be launched in July 2011 and after a successful launch it is anticipated that the sensor will be called Landsat 8.

<table>
<thead>
<tr>
<th>System</th>
<th>Launch (End)</th>
<th>Sensors</th>
<th>Resolution</th>
<th>Communication</th>
<th>Altitude (km)</th>
<th>revisit Days</th>
<th>Equatorial Crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 1</td>
<td>23 Jul 72</td>
<td>RBV</td>
<td>80</td>
<td>Direct Downlink</td>
<td>917</td>
<td>18</td>
<td>8.30 am</td>
</tr>
<tr>
<td>(6 Jan 78)</td>
<td>MSS</td>
<td>80</td>
<td>with Recorders</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 2</td>
<td>22 Jan 75</td>
<td>RBV</td>
<td>80</td>
<td>Direct Downlink</td>
<td>917</td>
<td>18</td>
<td>9.00 am</td>
</tr>
<tr>
<td>(25 Feb 82)</td>
<td>MSS</td>
<td>80</td>
<td>with Recorders</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 3</td>
<td>5 Mar 78</td>
<td>RBV</td>
<td>30</td>
<td>Direct Downlink</td>
<td>917</td>
<td>18</td>
<td>9.30 am</td>
</tr>
<tr>
<td>(31 Mar 83)</td>
<td>MSS</td>
<td>80</td>
<td>with Recorders</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 4</td>
<td>16 Jul 82</td>
<td>MSS</td>
<td>80</td>
<td>Direct Downlink</td>
<td>705</td>
<td>16</td>
<td>9.45 am</td>
</tr>
<tr>
<td>(5 Aug 82)</td>
<td>TM</td>
<td>30</td>
<td>TM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 5</td>
<td>1 Mar 84</td>
<td>MSS</td>
<td>80</td>
<td>Direct Downlink</td>
<td>705</td>
<td>16</td>
<td>9.45 am</td>
</tr>
<tr>
<td>(1 Aug 88)</td>
<td>TM</td>
<td>30</td>
<td>TDRSS (Failed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 6</td>
<td>5 Oct 93</td>
<td>ETM+</td>
<td>15 PAN</td>
<td>Direct Downlink</td>
<td>705</td>
<td>16</td>
<td>10.00 am</td>
</tr>
<tr>
<td>(1 Oct 93)</td>
<td>30 MS</td>
<td>with Recorders</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landsat 7</td>
<td>15 Apr 99</td>
<td>ETM+</td>
<td>15 PAN</td>
<td>Direct Downlink</td>
<td>705</td>
<td>16</td>
<td>10.00 am</td>
</tr>
<tr>
<td>(2 Oct 99)</td>
<td>30 MS</td>
<td>Solid State Recorders</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Level 1G Standard - This product includes the original data gaps. Duplicated pixels have been replaced with null values (zero-fill) and the image will therefore contain alternating “stripes” of missing data.

Thematic Mapper Wavelengths

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Wavelength (μm)</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45 - 0.55</td>
<td>coastal water mapping, differentiation of soil from vegetation, has poor penetration through haze</td>
</tr>
<tr>
<td>2</td>
<td>0.52 - 0.60</td>
<td>vegetation vigour assessment</td>
</tr>
<tr>
<td>3</td>
<td>0.63 - 0.69</td>
<td>vegetation discrimination, also has high iron oxide reflectivity</td>
</tr>
<tr>
<td>4</td>
<td>0.76 - 0.90</td>
<td>determining biomass content and delineation of water bodies</td>
</tr>
<tr>
<td>5</td>
<td>1.55 - 1.75</td>
<td>(middle infrared)</td>
</tr>
<tr>
<td>6</td>
<td>10.40 - 12.50</td>
<td>(thermal infrared)</td>
</tr>
<tr>
<td>7</td>
<td>2.08 - 2.35</td>
<td>(middle infrared)</td>
</tr>
<tr>
<td>8*</td>
<td>0.52 - 0.90</td>
<td>(visible green - near infrared)</td>
</tr>
</tbody>
</table>

* Pan band only on Landsat 7
GEOIMAGE is pleased to undertake searches of Landsat data from the various worldwide archives and to provide price quotations for the purchase of the data and processing to the clients specifications. This section is aimed at providing brief details regarding the quality and the types of products available from the various sources.

**EROS DATA CENTRE**

The Center for Earth Resources Observation and Science (EROS) is a data management, systems development, and research field center for the U.S. Geological Survey’s (USGS) Geography Discipline. EROS is located near Sioux Falls, South Dakota and since it was established in the early 1970s has been the largest repository of worldwide Landsat imagery. GEOIMAGE is affiliated with the USGS through the Satellite Business Partner Program.

Data searching and ordering is performed through a variety of information management systems and interfaces, including Glovis and Earth Explorer.

The USGS Global Visualization Viewer (Glovis) [http://glovis.usgs.gov/](http://glovis.usgs.gov/) is a quick and easy online search tool for selected satellite data. GloVis provides greater data availability, allowing the user visual access to browse images from the Landsat 7 ETM+, Landsat 4/5 TM, Landsat 1-5 MSS, MRLC, and Landsat Orthorectified data sets, as well as ASTER TIR and ASTER VNIR browse images from the DAAC inventory.

**Map Oriented Image** - Map oriented data with systematic radiometric and geometric corrections applied to the data. The data is rotated to fit a specific Earth datum and map grid.

**Orthocorrected Image** - Map oriented data with systematic geometric corrections refined with the use of GCPs and the GEODATA 9 second DEM. This product is the most locationally accurate.

To define a variable window product in the ACRES digital catalogue a particular path and date of imagery is nominated and a rectangular window is specified by the latitude and longitude of the window centre with the window extent in kilometres. For example, a window product could be 150 by 150km.

**Window Size**

The product is extracted only from the window specified. If the nominated window extends outside the image swath, that area will be filled with blank pixels. The maximum size window that can be specified is 310 by 530km. The E-W extent is larger than the width of the available imagery due to the satellite path being tilted N-E by 9 to 13deg, depending on the latitude. Note that the maximum N-S extent is larger than the path oriented scene size of 184.8km. This allows for much more data to be ordered in a single data set.

**Pixel Sizes**

The imagery is resampled to square pixels which:

- are slightly smaller than the original imagery to avoid aliasing and loss of information in stretch band composites in ER Mapper or ECW compressed format with headers for display in MapInfo
- are multiples of each other to allow ready registration
- fit neatly into one hundred metre grid intervals

Pixel sizes for the Landsat MSS are:

- TM Multi: 25m
- ETM+ Pan: 12.5m
- ETM+ Multi: 25m
- ETM+ Thermal: 50m

**Sources of Landsat Data**

**How Can GEOIMAGE Help?**

- Landsat archive searches for data covering your AOI
- acquire the data and orthorectify to your datum/projection
- processing of ETM+ pan-sharpened bands
- processing of iron ratios, Lsfit predictions and stretched band composites in ER Mapper or ECW compressed format with headers for display in MapInfo
- supply of GeoCover and EarthSat Naturalvue Mosaics
- supply of digital data on DVD or for FTP download
- supply of normal or pseudo-stereo hardcopy prints.

For larger ETM+ or TM Images

Example window:

- MSS: 50m
- TM Multi: 25m
- ETM+ Pan: 12.5m
- ETM+ Multi: 25m
- ETM+ Thermal: 50m

**ACRES**

The Australian Centre for Remote Sensing (ACRES) is Australia’s major public satellite remote sensing organisation having begun operation as the Australian Landsat Station in 1979. ACRES is within the Geospatial and Earth Monitoring Division of Geoscience Australia (GA), which itself falls within the Australian Government Department of Industry, Tourism and Resources. The Centre routinely receives data from Landsats 5 and 7, RADARSAT 1, ERS 2, MODIS, NOAA 17 and 18 and ALOS. As well it has an extensive archive of Landsat MSS (extending back to 1979), TM and ETM+.

The main Landsat processing levels provided by ACRES are:

1. **Path Image** - Satellite path oriented data with systematic radiometric and geometric corrections applied to the data. The data has been resampled in two dimensions to fit a specific Earth datum and map grid. These products are only available in full, double or triple scenes.
SPECTRAL PROCESSING

With six reflectance spectral bands, it is possible to make a total of 120 different 3 band colour composite images from a TM image. From a practical viewpoint however, the first three visible bands are very highly correlated as are bands 5 and 7 so the number of significantly different 3 band combinations reduces to only a few. The main ones being:

- Bands 147 or 247 in BGR simulated natural colour with the visible blue in blue, vegetation in green and iron oxides in red. This band combination usually has the least correlation between bands.
- Bands 345 in BGR is usually preferred for vegetation studies.
- Bands 123 in BGR is a natural colour image and although the bands are very highly correlated often shows a remarkable amount of detail.
- Bands 457 in BGR incorporates all the infrared bands and is useful in areas affected by haze.

Of course, the selection of the bands is only the first step and the selection of the type of histogram modification is just as important. This is especially so in the case of a bimodal histogram where separate enhancements may be necessary to give maximum information e.g. in a greenstone terrain with very bright granitic and very dark greenstone areas. Region of interest contrast stretching may be required where the image area used in the histogram generation is restricted to the immediate area of interest e.g. over a particular rocktype, so that the resulting contrast modification is maximised to show that particular rocktype.

In the case of Landsat 7 data, it is normal to pan-sharpen the 30m multispectral imagery with the 15m panchromatic band and this results in much sharper imagery and often highlights roads and tracks better.

BAND RATIOS

Ratios of bands are commonly used because they highlight the spectral differences between materials, at the same time decreasing the variations in surface brightness due to topography. For example, the ratio of bands 3/1 is often used to highlight iron oxide and 5/7 is used to highlight clays. Before ratios are calculated it is important to remove the effects caused by scattering of light in the atmosphere from each band. This effect which is highest in band 1 decreases to almost negligible values in bands 5 and 7. Theoretically the atmospheric effect would be the reflectance value in the image from a black body reflector on the earth’s surface. This might be expected to be the minimum value in any band however there may be noise in the image well below this value. The best method of estimating the value is to examine the histogram and select the value where the back slope of the band’s histogram intersects the zero reflectance. Use these values in the ratio and examine the image produced. If there is still topographic detail visible in the image slightly modify the subtraction values until it disappears. When there is minimal slope information visible in the image, you will know that the atmospheric corrections are correct. Ratios tend to highlight the noise in an image and this can be minimised using a median filter.

LSFIT

Most clay minerals have an absorption feature in the area covered by Landsat TM Band 7. Many techniques have been developed to highlight this effect and thus enable identification of areas of clay alteration indicative of mineralisation. The LSFIT technique developed by the Australian CSIRO is a linear regression technique that compares the predicted band 7 with the actual band 7 to identify areas of anomalously high absorption and hence infer the presence of clays.

SUMMARY

The above techniques are generally very important in providing information on the rock types and possible alteration from TM imagery prior to field visits. It is however important that the spectral techniques be applied properly and that common sense is used in their interpretation. For example, techniques that try to predict clays may also highlight water and snow as well as defining all playas with thin coatings of clay. For this reason, it is important to interpret such images in conjunction with a standard colour composite image of the same area.
INTERNATIONAL GROUND STATION (IGS) NETWORK

The maps below show the locations of ground stations operated by International Cooperator (IC) for the direct downlink and distribution of Landsat data. The red and green circles show the approximate area over which each station has the capability for direct reception of Landsat data. Landsat 5 initially had the capability of uplinking data to the TDRSS satellites however this capability failed so the data is now only available through direct downlink.

GEOIMAGE has established relationships with several of these stations to obtain Landsat data that is not available from EROS, and this is especially important in areas of high cloud cover such as the Amazonian Basin.

GEOCOVER

NASA sponsored the creation of an orthorectified and geodetically accurate global land dataset of Landsat data from three time periods. These datasets incorporating Multi-spectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM+) data, from the 1970s, circa 1990, and circa 2000, respectively, were produced to support a variety of scientific studies and educational purposes. This is the first time a geodetically accurate global compendium of orthorectified multi-epoch digital satellite data, at the 30- to 80-m spatial scale spanning 30 years, has been produced for use by the international scientific and educational communities. These sets of orthorectified Landsat images are referred to as GeoCover and were compiled by EarthSat through NASA’s Commercial Remote Sensing Program. Full details of the data selection, orthorectification, accuracy, access, and other aspects are described in Photogrammetric Engineering & Remote Sensing Vol. 70, No. 3, March 2004, pp. 313-322.

Approximately 8,500 Landsat TM images were selected from each of the 1990 and 2000 epochs. The acquisition dates of these images were relative to a 1990 and 2000 acquisition baseline, and the images were either cloud-free or contained minimal cloud cover. In addition, TM images with a high quality ranking in regards to the possible presence of errors such as missing scans or saturated bands were selected. One of the selection criteria used by NASA was that scenes be selected during periods of peak greenness if possible.

The Landsat data were orthorectified, using geodetic and elevation control data, to correct for positional accuracy and relief displacement. Large blocks of Landsat data were adjusted through a patented procedure that uses pixel correlation to acquire tie-points within the overlap area between adjacent Landsat images. Ground control points were fixed, and images projected to the Universal Transverse Mercator map projection, using the World Geodetic System 1984 datum (WGS84). All bands are individually resampled, using a nearest neighbour or cubic convolution resampling. The result is a final product with a Root Mean Square (RMS) Error of better than 50m in positional accuracy. GEOIMAGE is a reseller of the GeoCover data and offers the following products. Please check with your local office for pricing.

GeoCover-Ortho Mosaics

GeoCover-Ortho Landsat mosaics are created by digitally suturing a group of juxtaposed Landsat scenes into a single seamless digital image. Mosaics are colour (3 band) products with Bands 2, 4 and 7 in blue, green, red (BGR). The stock mosaics have been prepared from both the 1990 and 2000 epoch GeoCover stock scenes and are “off-the-shelf” products with the following Specifications -

> Worldwide coverage of the Earth’s landmass
> Data set size based on 5 degree (N-S) segments of standard UTM
> UTM projection, WGS84 datum
> 50m RMS positional accuracy
> 28.5m pixel size - 1990 epoch
> 14.25m pixel size (Pan-sharpened) - 2000 epoch
> Contrast adjusted colour composite of TM bands 2, 4, 7 in BGR
> Cubic Convolution interpolation
> Compressed using MiSID or uncompressed GeoTIFF
> GEOIMAGE has compressed with ERMapper ECW compression.

GeoCover-Ortho Single Scenes

The stock scenes are “off-the-shelf” orthorectified full scene TM images for the 1990 epoch and ETM+ images for the 2000 epoch with the following product specifications -

> Worldwide coverage of the Earth’s landmass
> Data set size based on Landsat WRS (Path/Row) Reference system
> UTM projection, WGS84 datum

The stock scenes can be reprojected into any customer selected projection and/or datum. While the GeoCover scenes are a very cost effective dataset, it should be noted that for certain applications they may not be ideal. For example, because the data were preferentially selected when the vegetation growth was at a maximum, some scenes may not be suitable for applications such as mineral exploration where it is important to get maximum soil/rock exposure. In such cases, there may be better scenes available from the EROS archive.

EarthSat NaturalVue(TM)

This product is based on the 2000 epoch Landsat GeoCover imagery and is available for the same 6 by 5deg tiles as the GeoCover mosaics. The data has been processed using a propriety process developed by MDA Federal to produce a Simulated Natural Colour image which renders a pleasing green/brown/blue dominated colour pallet while at the same time preserving the textural and spectral information of the 14.25m Landsat data. This product therefore differs considerably from the NASA GeoCover B742 mosaic product described above which has the undesirable side effect of turning cultural features purple and vegetation a florescent green. The tiles are in Geographical projection WGS84 datum and the 0.5 arc second pixel size approximates to 15m. Each 6 by 5deg tile is delivered in four 3 by 2.5deg subtiles which are about 1.1Gb each in GeoTiff format. The NaturalVue product is a trademarked product developed by MDA Federal Inc. and is available from GEOIMAGE as a licensed distributor.