An Introductory Landsat Tutorial for Users of GeoCover Data

Welcome to the world of the Landsat Satellites and their view of the Earth we live on!

The images contained on this set of DVDs are from data obtained primarily by Landsat-5, one of a series of satellites built and launched by the National Aeronautics and Space Administration (NASA) of the United States of America. All Landsat images featured in this data set were processed for NASA by the Earth Satellite Corporation. The Landsat satellites observe the Earth, and the data that they collect have been used for over 30 years to study the environment, resources, and natural and man-made changes on the Earth's surface.

The Landsat series initiated the era of Earth observation from space for non-military purposes. *Landsat-type* data are now also collected by satellite systems built by other countries, yet Landsat data remain the standard for Earth observations, and Landsat is the only system of its type with the mission to collect, archive, and distribute data of <u>all</u> the Earth's land surface.

HISTORY

The first Landsat was launched on July 23, 1972. This satellite carried on board two instruments to look at the Earth's surface - a Return Beam Vidicon (RBV) and a Multi-Spectral Scanner System (MSS). Landsat-1, originally called the Earth Resources Technology Satellite (ERTS-1), was followed by Landsats-2, -3, -4, -5, and -7. Landsat-6 unfortunately failed to reach orbit. Return Beam Vidicons and Multi-Spectral Scanner Systems were flown on the first three Landsats. The MSS proved to be a more useful and reliable instrument that the RBV. Landsats-4 and -5 were equipped with an MSS and an improved version of the MSS, the Thematic Mapper (TM). Landsat-6 carried an "Enhanced Thematic Mapper" (ETM) only, and Landsat-7 is carrying an "Enhanced Thematic Mapper-plus" (ETM+). The operating dates of the Landsat satellites and the instruments on them are listed on Table 1 below.

Spacecraft	Launched	Out of Service	Instruments
Landsat-1 (ERTS-1)	July 23, 1972	January 6, 1978	RBV, MSS
Landsat-2	January 22, 1975	February 25, 1982	RBV, MSS
Landsat-3	March 5, 1978	March 31, 1983	RBV, MSS
Landsat-4	July 16, 1982	June 15, 2001*	MSS, TM
Landsat-5	March 1, 1984		MSS, TM
Landsat-6	October 5, 1993	October 5, 1993	ETM
Landsat-7	April 15, 1999		ETM+

Table 1: Landsat Satellites, their Operational Periods, and Their Instruments.

* The Landsat-4 science data telemetry system failed in August 1993; the satellite was later used for maneuver testing.

INSTRUMENTS

The TM instrument on Landsat-5 and the ETM+ instrument on Landsat-7 observe the Earth with 7 different filters or "bands". Bands 1, 2, 3, 4, 5, and 7 on both instruments are sensitive to light energy from the sun reflected by the surface of the Earth. Each band is sensitive to a different part of the reflected solar energy. The parts of the reflected energy are defined by the length of the light waves. Thus, band 1 of the TM and ETM+ instruments records reflected light energy only in the range of 0.45 microns (µm - a micron is one millionth of a meter long) to 0.52 µm. The human eye sees reflected light in that band of wavelengths as the color blue; hence, band 1 is sometimes referred to as the *blue band*. In a similar manner, bands 2 and 3 of the TM and ETM+ instruments record reflected green and red light, respectively.

TM and ETM+ bands 4, 5, and 7 record reflected light in wavelengths that human eyes cannot detect. These bands are referred to as *near infrared* (NIR, band 4) and *short wave infrared* (SWIR, bands 5 and 7).

Band 6 of the TM and ETM+ instruments is different from all the other bands because it does not record reflected light energy, but rather *heat* energy *emitted* by the Earth's surface. It is sometimes called the thermal infrared band (TIR band) or just the thermal band.

In addition to these bands, the ETM+ instrument on Landsat 7 also has an eighth band, called the panchromatic sharpening band. ETM+ band 8 is sensitive to reflected light energy across a broad range of wavelengths that includes blue, green, red and near infrared. Band 8 has a spatial resolution of 14.25 meters, rather than the 28.5 meters of bands 1, 2, 3, 4, 5 and 7. The sensitivities of RBV, MSS, TM, and ETM+ bands are listed in Tables 2 and 3 below.

Channel	RBV Spectrum	RBV Pixel Size	MSS Spectrum	MSS-Pixel Size
1	.48-.57 µm green	79 meters, 1.5 acres		
2	.58-.68 µm red	79 meters, 1.5 acres		
3	.69-.83 µm IR	79 meters, 1.5 acres		
4			.5-.6 µm green	79 meters, 1.5 acres
5			.6-.7 µm red	79 meters, 1.5 acres
6			0.7-0.8 µm IR	79 meters, 1.5 acres
7			0.8-1.1 µm IR	79 meters, 1.5 acres

Table 2: Landsat 1-5 Instrument Bands. IR = infrared; NIR = near infrared; SWIR = short wavelength infrared; TIR = thermal infrared (long wavelength); and µm = micron or micrometer.

Band	TM Spectrum	TM Pixel Size	ETM+ Spectrum	ETM+ Pixel Size
1	.45-.52 µm blue	28.5 meters, 0.2 acres	.45-.52 µm blue	28.5 meters, 0.2 acres
2	.52-.6 µm green	28.5 meters, 0.2 acres	.53-.61 µm green	28.5 meters, 0.2 acres
3	.63-.69 µm red	28.5 meters, 0.2 acres	.63-.69 µm red	28.5 meters, 0.2 acres
4	.76-.9 µm NIR	28.5 meters, 0.2 acres	.75-.9 µm NIR	28.5 meters, 0.2 acres
5	1.55-1.75 µm SWIR	28.5 meters, 0.2 acres	1.55-1.75 µm SWIR	28.5 meters, 0.2 acres
6	10.4-12.5 µm TIR	120 meters, 3.6 acres	10.4-12.5 µm TIR	57 meters, 0.9 acres
7	2.08-2.35 µm SWIR	28.5 meters, 0.2 acres	2.1-2.35 µm SWIR	28.5 meters, 0.2 acres
8	----	----	.52-.9 µm panchromatic	14.25 meters, 0.05 acres

Table 3: Landsat 4-7 Instrument Bands. IR = infrared; NIR = near infrared; SWIR = short wavelength infrared; TIR = thermal infrared (long wavelength); and µm = micron or micrometer.

TYPES OF COMPOSITE IMAGES

To what do the different bands respond? To see which features show up better in which band, examine the Landsat-7 images shown in Appendix 3. The individual band images appear as gray scale images - like old-fashioned black-and-white photographs. However, they can be combined to form composite images, with each gray scale image each adding a different color (typically a red-green-blue, or RGB combination). There are many band-color combinations that tell useful stories. Three different and often used composites are summarized below.

Figure 1: True Color.

For the true color rendition, band 1 (blue) is displayed in the blue color, band 2 (green) is displayed in the green color, and band 3 (red) is displayed in the red color. The resulting image is fairly close to realistic - as though you were riding in the satellite and took the picture with your camera. But it is also pretty dull - there is little contrast and features in the image are hard to distinguish.

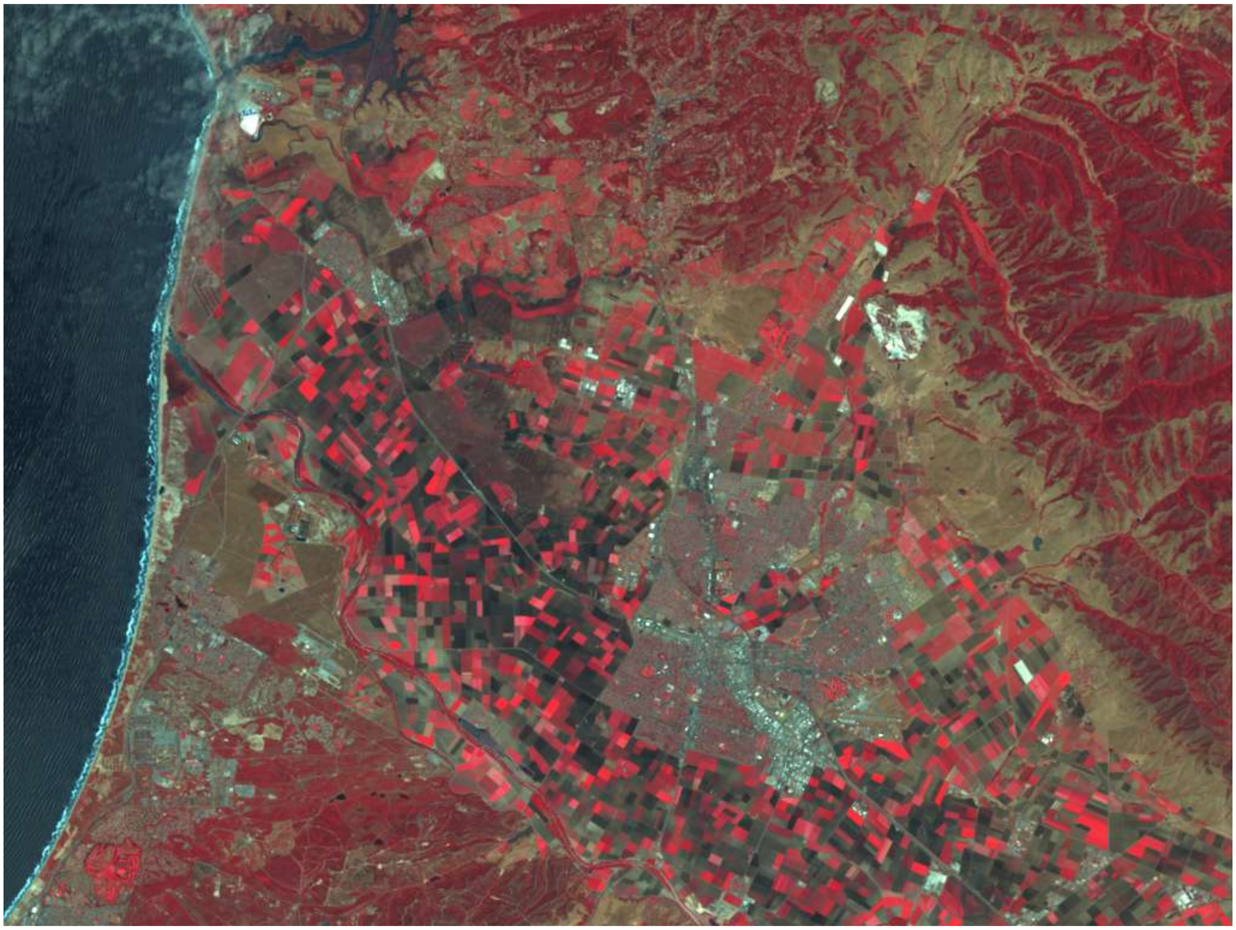

Figure 2: False-Color, also called Near Infrared or NIR.

In this image, band 2 (green) is displayed in blue, band 3 (red) is displayed in green, and band 4 (NIR) is displayed in red. This rendition looks rather strange - vegetation jumps out as a bright red because green vegetation readily reflects infrared light energy! It is similar to pictures taken from aircraft when using infrared film and is very useful for studying vegetation.

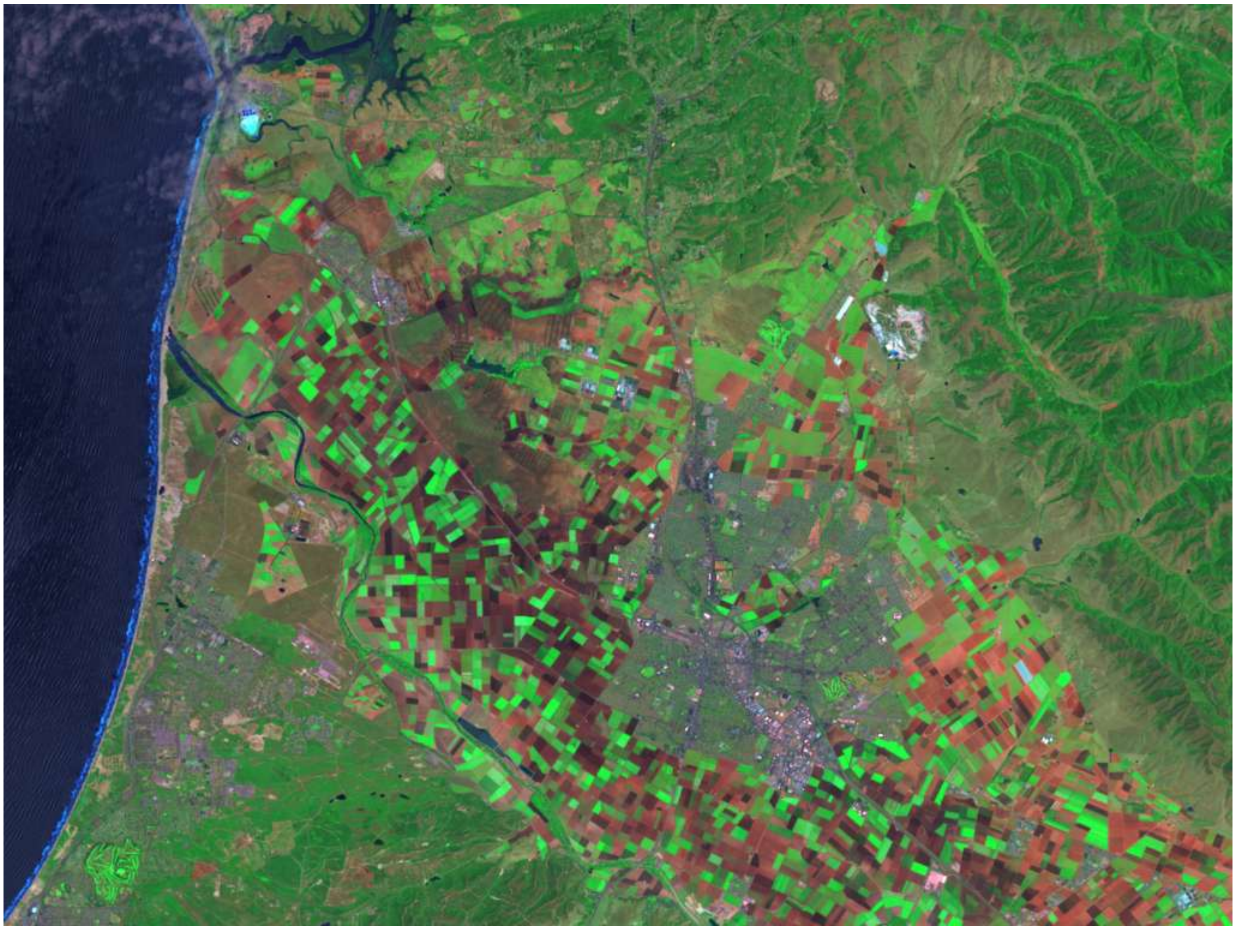

Figure 3: Short-Wavelength Infrared, or SWIR.

In this SWIR image, band 2 (green) is displayed in blue, band 4 (NIR) is displayed in green, and either band 7 or band 5 (SWIR) is displayed in red. This rendition looks like an exaggerated true color rendition - one with more striking colors.

The SWIR combination is the band combination that was used in the GeoCover data set. It is built into the GeoCover data and cannot be changed. Furthermore, the contrast and brightness of individual scenes have been altered to make a more consistent overall mosaic.

INTERPRETATION OF THE GEOCOVER COMPOSITE IMAGES

Table 4 summarizes the appearance of various surface features in different composite images.

	True Color **Red: Band 3** **Green: Band 2** **Blue: Band 1**	**False Color** **Red: Band 4** **Green: Band 3** **Blue: Band 2**	**SWIR (GeoCover)** **Red: Band 7** **Green: Band 4** **Blue: Band 2**
Trees and bushes	Olive Green	Red	Shades of green
Crops	Medium to light green	Pink to red	Shades of green
Wetland Vegetation	Dark green to black	Dark red	Shades of green
Water	Shades of blue and green	Shades of blue	Black to dark blue
Urban areas	White to light blue	Blue to gray	Lavender
Bare soil	White to light gray	Blue to gray	Magenta, Lavender, or pale pink
Clouds	White	White	White-pink-lavender
Snow/Ice	White	Light green-blue	Medium blue

Table 4: Appearance of Features on Composite Images.

To help understand the value of the different color composites, a set of sample images has been collected for this tutorial. Each sample data set is from the Landsat-7 satellite and includes 3-color composite images created following the recipes above. You can display the images and look at common features in each to see which composite makes finding each feature easier. If you like, you can follow the recipes above and build them yourself (see Appendix 3). The sample data sets are listed in Table 5 below.

Area	**Country, (State)**	**Features**
Albertville	France	Towns, mountains, snow, clouds
Denver-Northeast	USA, Colorado	City, airports, plains
Geneva	Switzerland	City, airport, roads, lake, rivers
Lyon	France	Major city, airports, roads, rivers
Salinas	USA, California	Town, farmland, valley, rivers, mountains, ocean, golf courses, lakes/ponds, roads, airport

Table 5: Sample Landsat-7 Data Sets.

The Landsat-7 data sets are from 1999 and 2003, not 1990, and are not orthorectified (i.e., they may not perfectly overlay the 1990 GeoCover data, which has been orthorectified). There will be some noticeable changes that have occurred during the decade between them. Look at the ****-742.tif images from Landsat 7 (the sample data) and the corresponding locations in the GeoCover data set. Some differences are due to natural changes and some were man-made. For example, examine the Denver-Northeast data set from 1999 (the Landsat-7 sample data set) and find the same area in the 1990-era GeoCover data set. Denver is located in tile N-13-35 on the North American DVD, near the top, in the center (around longitude 105 degrees West and latitude 39.7 degrees North, or UTM Zone 13 North, Easting 500000 meters and Northing 4394000 meters). It is the purple area to the right of the dark green mountains, some of which have snow on them. A major new public transportation facility (Denver International Airport) was added to the Denver area in the 1990's. It appears in the 1999 data but is absent in the GeoCover 1990 data.

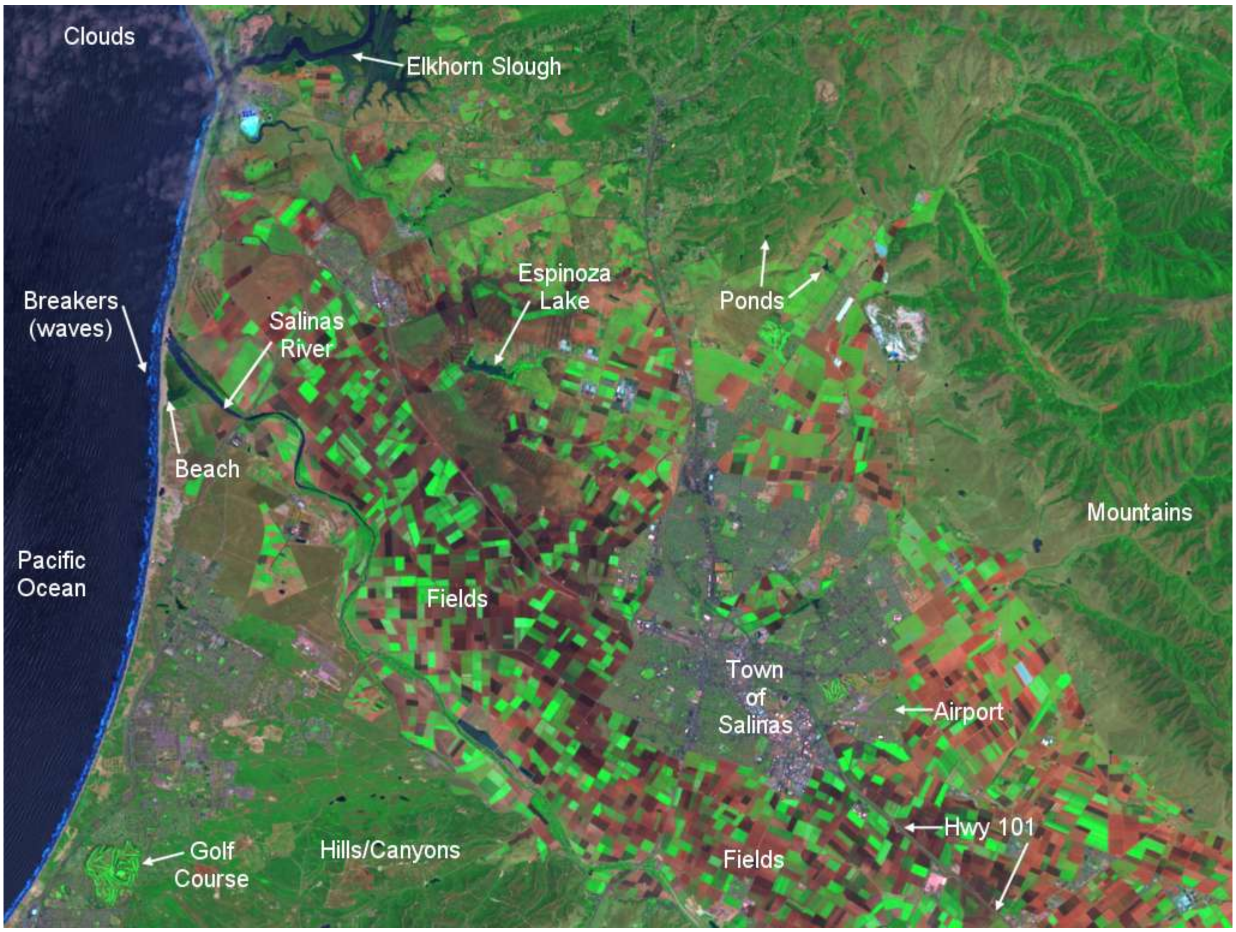

Figure 4: Annotated SWIR image of Salinas, California.

The Salinas, California data set includes an additional image labeled "Salinas-A.tif" which has some features annotated on it (see figure 4 above). These annotations will help you interpret (identify) features in the images. Shape and size distinguish features as well as their color and their relationship to other features around them. For instance, both agricultural fields and tree covered neighborhoods in a town or city may be rectangular in shape. But city blocks are usually a different color, they are much smaller than agricultural fields, and they typically are in a systematic, rectangular grid. Fields tend to follow the terrain and form polygons more often than city blocks. Sometimes you can be misled. The only real truth is what is called *ground truth* - when you visit a place and see what is actually there!

After you have gained some understanding of the Landsat images by studying Figure 4, try exploring familiar places - such as where you live. If there are prominent features - geological (mountains, deserts, lakes, rivers, volcanoes, etc.) or man-made (major highways, large bridges, golf courses, cities or towns, airports, etc.), look for them in the GeoCover data set.

If you are unfamiliar with an area, a map can be helpful. Maps are representations of a geographic area and may emphasize different features, sometimes at the cost of omitting others. A map showing political boundaries may not show the terrain and its elevations or the vegetative cover of the area - and vice-versa. Also, the geography may have changed since the map was made or the satellite images were taken. Cities grow, and monitoring urban growth worldwide is one of the uses of the Landsat satellites. The same holds true for deforestation (the clearing of forests) and reforestation (the regrowth of forests). Landsat does an excellent job of observing forest changes (see the web sites for examples). Nonetheless, maps can be powerful tools to help you understand what you are seeing from space. Some simple maps are included with the sample data sets. You may want to look up the sample areas in a road atlas and compare the atlas to the Landsat image.

Maps can help you to locate where you want to go - start by looking for the very large features like cities, lakes, and major rivers. Once you locate yourself in the big picture, zoom in (magnify) your area of interest. If you zoom in too soon, you may get lost in unfamiliar details and have a difficult time finding what you are looking for.

DATA SET ORGANIZATION

These data, called the GeoCover 1990 data set, cover most of the land surface of the Earth (missing are occasional scenes here and there, much of Eastern Siberia, and all of Antarctica). This data set was derived from observations acquired primarily by Landsat-**5**. Because of satellite scheduling constraints and cloud cover obscuring the ground, the scenes in the GeoCover data set were not all observed (acquired) on the same day or within the same month, but include scenes acquired within a year or two of 1990. The data set was produced for NASA by the Earth Satellite Corporation (EarthSat, at www.earthsat.com and www.geocover.com) and contains approximately 7600 TM images, or scenes. Per the standard Worldwide Reference System-2 (WRS-2) used for Landsats 4,5, and 7, each Landsat scene is about 180 kilometers long (along the orbit path) and 185 kilometers wide (across the orbit path), or about 97 nautical miles long and 100 nautical miles wide, or 112 statute miles long and 115 statute miles wide. To enable reasonably sized data files, the Earth's land surface was broken up into areas called *tiles* or *mosaics*. Each tile covers an area roughly 6 degrees wide by 5 degrees tall and consists of a number of Landsat scenes seamlessly joined together (mosaicked). Each tile was then compressed using the MrSID compression technique (http://www.lizardtech.com). This entire data set can be contained on 6 DVDs (Figures 5a and 5b and Table 6) or 39 CD-ROMs (Figures 5c and 5d and Table 7).

Within each tile or scene, the smallest picture element, or pixel, covers a square 28.5 meters (94 feet) on a side, or about 0.08 hectare (about one fifth of an acre). No matter how much you zoom in on an image, the smallest square that you can see will be 28.5 meters on a side - even if there are only a few big squares on your screen. The TM pixel size enables observation of large natural features, such as volcanos, rivers, and forests, and large man-made features. Major highways, airports, large office buildings (such as the Pentagon or US Capitol building in Washington, D.C.), football stadia, city parks, golf courses, agricultural fields, major bridges, and dams are apparent, but narrow streets, creeks and streams, individual houses, and automobiles cannot be resolved.

Each tile covers an area of 6 degrees of longitude (12 degrees of longitude at latitudes above than 60 degrees, affecting only Arctic data since there are no Antarctic data in this data set) by 5 degrees of latitude, with some overlap into adjacent tiles. Each 6 degree of longitude-wide, north-south oriented swath is called a"zone" in the Universal Transverse Mercator (UTM) projection used to display these data (see Appendix 2).

The UTM zones are numbered 01 to 60, starting at 180 degrees of longitude and counting eastward. The latitude of each tile is identified by the latitude closest to the equator. The hemisphere (northern or southern, not eastern or western) is indicated by the letter N (northern) or S (southern). Each tile is identified by giving its hemisphere (N or S), then its UTM zone (01-60), and finally its equatormost latitude. For example, Ecuador straddles the equator at about 78 degrees West longitude. The northern tip of Ecuador is in tiles N-17-00 and N-18-00, while the southern portion is in tiles S-17-00 and S-18-00.

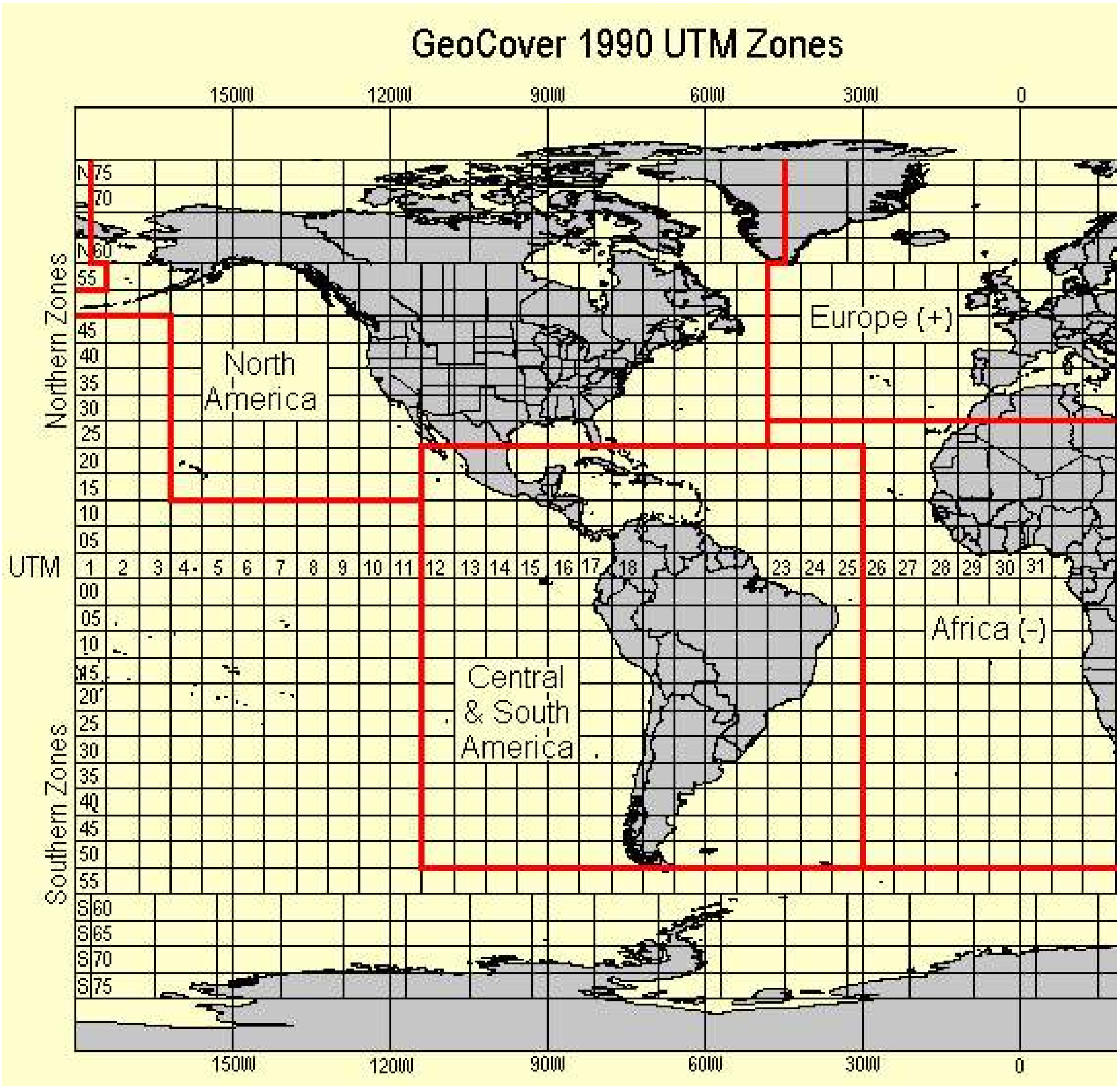

Figure 5a: The GeoCover 1990 Data Set Divided into 6 DVD's – Western Hemisphere.

DVD	Area Covered
1	North America, including Aleutian and Hawaiian islands, and Western Greenland
2	Central and South America, or America south of 25 degrees North latitude
3	Europe, including Eastern Greenland, Northern Africa, and the Middle East
4	Africa, excluding the area along the Mediterranean and Red Seas
5	Siberia and Western Asia
6	Eastern Asia and the Pacific, excluding Hawaii

Table 6: The 1990 GeoCover data set distributed over 6 DVD's.

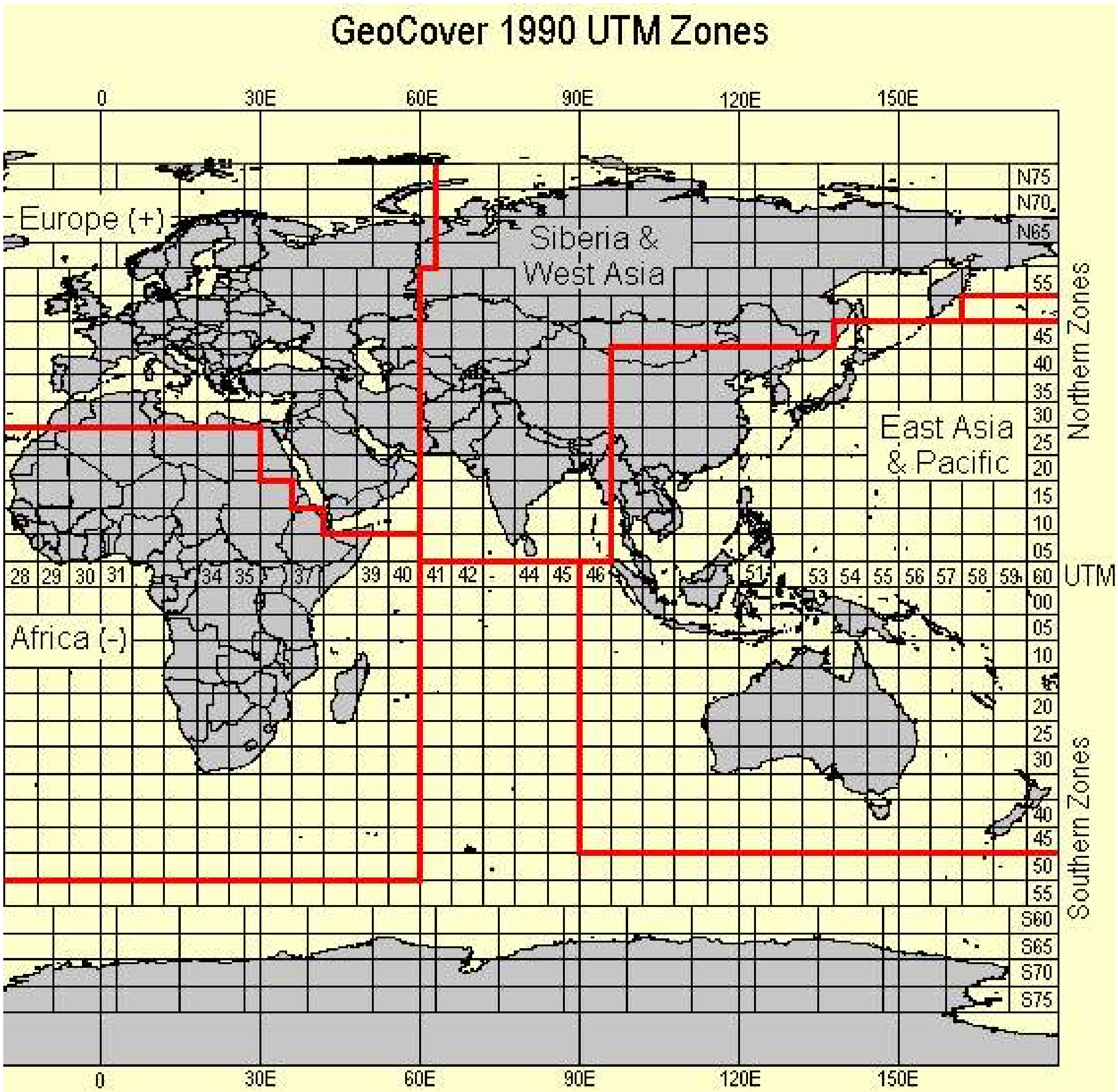

Figure 5b: The GeoCover 1990 Data Set Divided into 6 DVD's –Eastern Hemisphere.

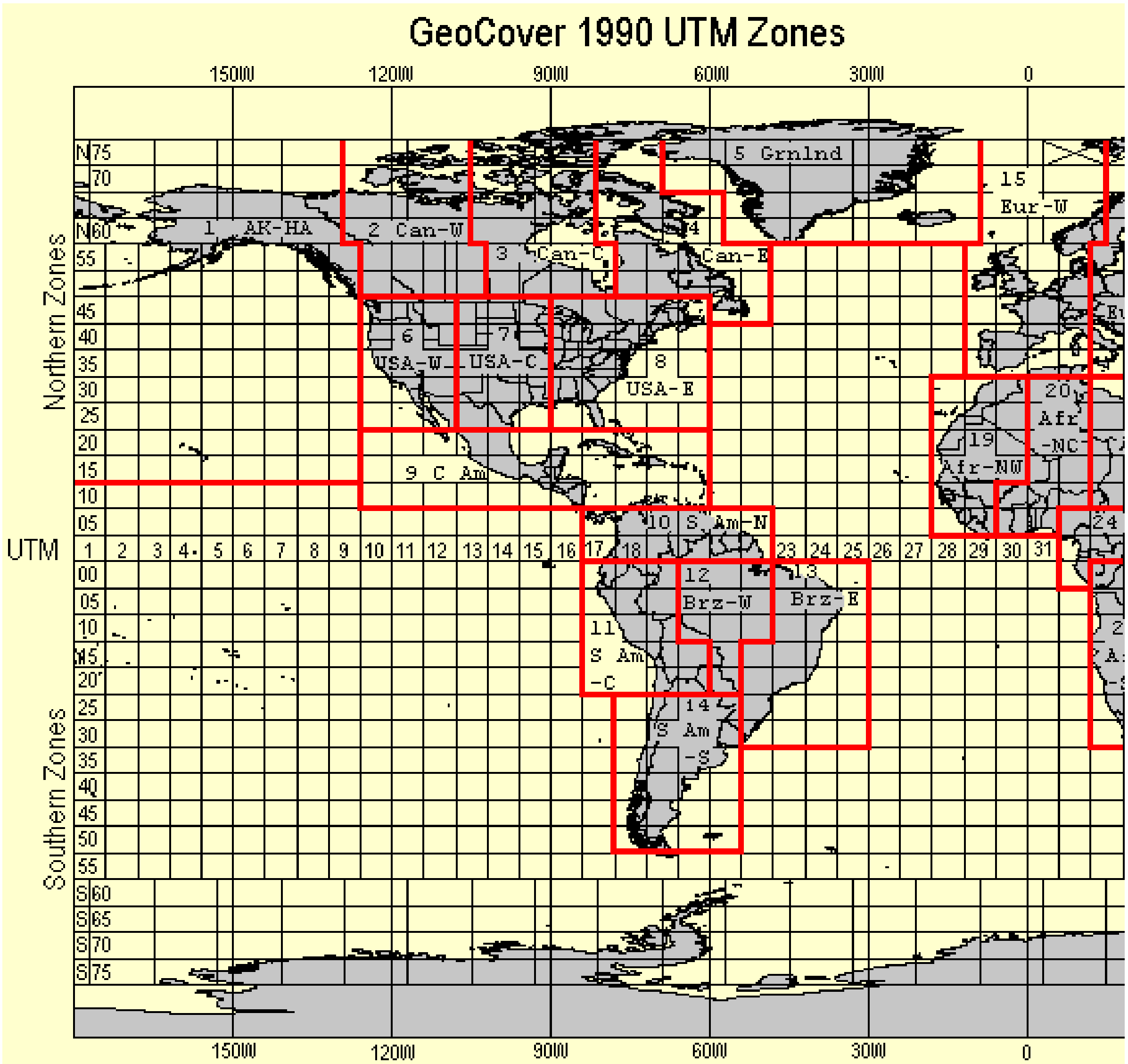

Figure 5c: The GeoCover 1990 Data Set Divided into 39 CD's – Western Hemisphere.

CD	Area Covered	CD	Area Covered
1	Alaska and Hawaii	8	Eastern United States of America
2	Western Canada	9	Central America
3	Central Canada	10	Northern South America
4	Eastern Canada	11	Central South America, Pacific Coast
5	Greenland	12	Western Brazil
6	Western United States of America	13	Eastern Brazil
7	Central United States of America	14	Southern South America

Table 7a: The 1990 GeoCover Data Set Distributed over 39 CD's– Western Hemisphere.

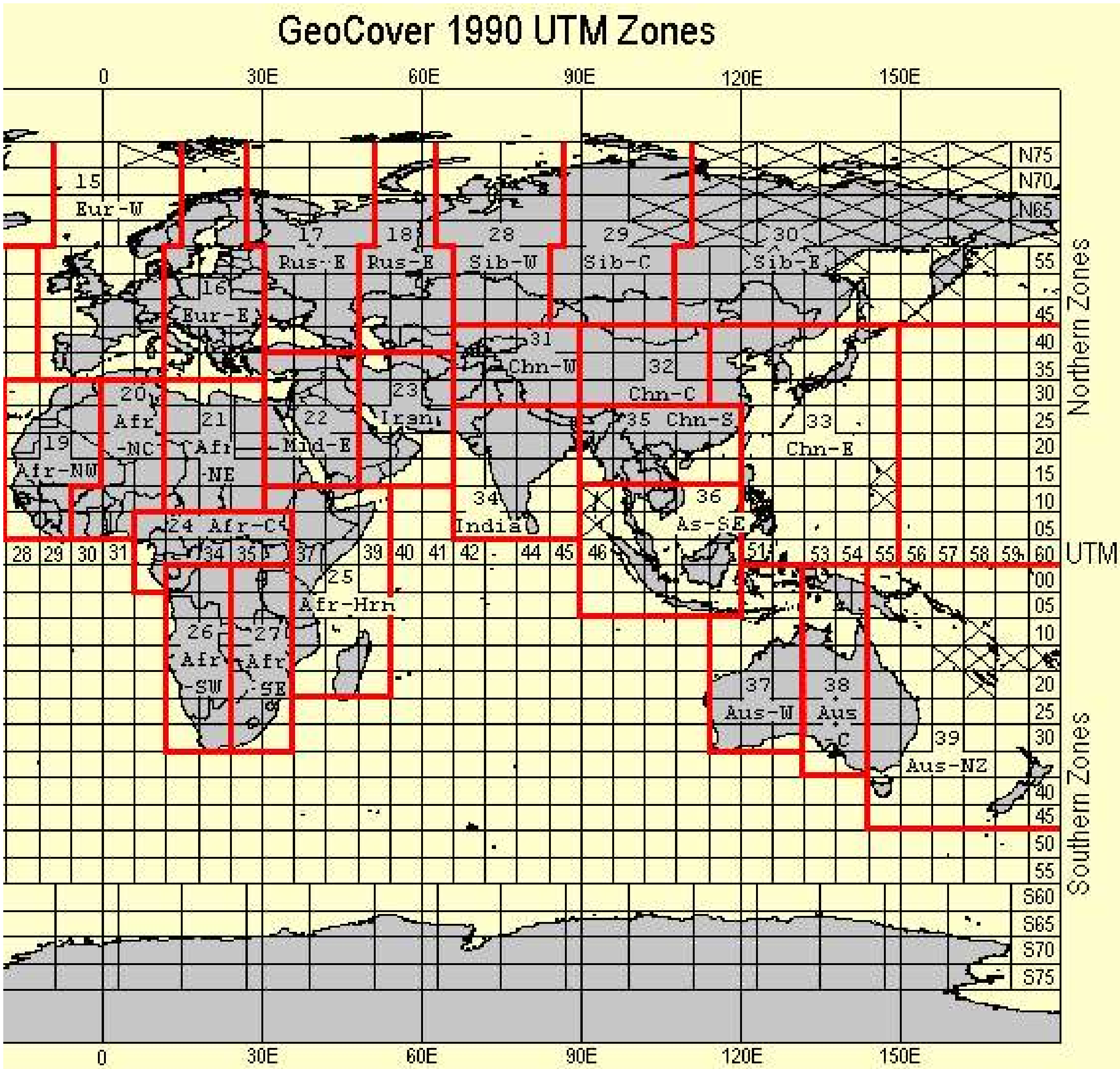

Figure 5d: The GeoCover 1990 Data Set Divided into 39 CD's – Eastern Hemisphere. "X'd" tiles have no data, as do most tiles over the oceans.

CD	Area Covered	CD	Area Covered	CD	Area Covered
15	Western Europe	24	Central Africa	33	Eastern China, Japan, Philippines
16	Eastern Europe	25	Horn of Africa - Madagascar	34	India and Sri Lanka
17	Western Russia	26	Southwestern Africa	35	Southern China
18	Eastern Russia	27	Southeastern Africa	36	Southeast Asia and Indonesia
19	Northwestern Africa	28	Western Siberia	37	Western Australia, Islands
20	North-Central Africa	29	Central Siberia	38	Central Australia, Islands
21	Northeastern Africa	30	Eastern Siberia	39	Eastern Australia, New Zealand, and Islands
22	Middle East	31	Western China		
23	Iran	32	Central China		

Table 7b: The 1990 GeoCover Data Set Distributed over 39 CD's – Eastern Hemisphere.

Technically speaking, these data were orthorectified (geometrically corrected so that they would appear as they would on a map, always looking straight down and not from off to a side). Then the data were projected (displayed) using the Universal Transverse Mercator projection to minimize the distortion caused by taking a piece of a sphere and flattening it. Individual scenes were then mosaicked together to form the tiles. To insure overlap with its neighbors, each tile (mosaic) extends at least an extra 50 kilometers east and west, and at least 1 kilometer extra north and south. A list of the scenes embedded in each tile is given in an accompanying metadata file (identified as N-ZN-EL.met or S-ZN-EL.met, where ZN is the UTM zone number and EL is the equatormost latitude).

Data for individual Landsat scenes incorporated into this data set, each orthorectified but not mosaicked into a single large tile, can be ordered from the USGS's EDC (http://edc.usgs.gov/products/satellite.html) or downloaded at no cost from http://glcf.umiacs.umd.edu/index.shtml. But beware that the files are large - 28.5 meter resolution scenes are typically 57 Megabytes (25 Megabytes compressed), and a high speed (broadband) communications line is essential. Each Landsat 7 scene contains six 28.5-meter resolution files (at 25 or 57 Megabytes each), plus two 57-meter resolution files (5-15 Megabytes each), plus a 14.25-meter resolution file (90-250 Megabytes). Each scene typically is delivered on one CD-ROM by the USGS EROS Data Center. Two compressed scenes downloaded from the University of Maryland web site can usually fit on one CD-ROM.

HOW CAN LANDSAT DATA BE USED?

Finally, why be concerned with Landsat data? What can they tell us? Where can we use them productively? Most items on following list of applications for Landsat data date from 1982 (the era of Landsats-2 and -3) and are still valid.

Agriculture, Forestry, and Range Resources:

- Determining soil conditions and association
- Discriminating vegetative types: Crop types, Timber types, Range vegetation.
- Measuring crop acreage by species
- Determining vegetation vigor (estimating crop yields)
- Determining vegetation/crop stress
- Mapping plant communities for invasive species management
- Measuring timber acreage and volume by species (monitoring forest harvest)
- Assessing grass and forest fire damage
- Determining range readiness and biomass

Land Use and Mapping:

- Cartographic mapping and map updating (e.g., security, public health, air quality uses)
- Classifying land uses
- Categorizing land capability
- Studying changes in land cover/use associated with water and wind erosion
- Mapping land-water boundaries
- Mapping fractures
- Separating urban and rural categories (monitoring urban growth)
- Studying land use efficiency in large urban areas (e.g., traffic and pollution)
- Regional planning
- Mapping transportation networks

Geology:

- Recognizing rock types
- Mapping of major geologic units
- Identifying and mapping regional structures
- Mapping linears
- Revising geologic maps
- Delineating unconsolidated rock and soils
- Mapping igneous intrusions
- Mapping recent volcanic surface deposits
- Mapping predicted and actual volcanic flows
- Mapping landforms
- Searching for surface guides to mineralization

Water Resources:

- Determining water boundaries and surface water area and volume
- Conducting an inventory of lakes
- Mapping of floods and flood plains
- Determining areal extent of snow and snow boundaries (estimating snow melt runoff)
- Monitoring seasonal fluctuations in reservoir levels
- Measuring glacial features
- Measuring sediment and turbidity patterns
- Assessing water quality
- Determining water depth
- Identifying and mapping irrigated fields

Oceanography and Marine Resources:

- Determining turbidity patterns and circulation
- Studying eddies and waves
- Detecting and mapping shoreline changes (tracing beach erosion)
- Mapping of shoals and shallow areas
- Mapping coral reefs
- Detecting living marine organisms
- Mapping ice sheet activity in Antarctica
- Mapping of ice for shipping

Environment:

- Assessing carbon stocks (via vegetation)
- Mapping and monitoring of water pollution (e.g., tracing oil spills, oil slicks, and other pollutants)
- Detecting of air pollution and its effects
- Identifying and mapping areas at risk for disease outbreaks
- Mapping and determining the effects of natural disturbances and disasters (floods, tornadoes, and volcanos)
- Monitoring environmental effects of man's activities (e.g., lake eutrophication, defoliation, etc.)
- Quantifying and evaluating the effects of land use change
- Mapping and monitoring desertification
- Monitoring surface mining and reclamation
- Supporting wetland identification and restoration.
- Contributing to endangered species conservation
- Supporting the tracking of animal migrations

A very good source of information about Landsat and its uses is the Landsat internet site at NASA's Goddard Space Flight Center, at:

http://landsat.gsfc.nasa.gov/

This site also has links to other tutorials related to using Landsat data.
If you want to find current Landsat data, go to the United States Geological Survey (USGS) Landsat-7 internet site at:

http://landsat7.usgs.gov

USGS browse images are on the web and may be downloaded (free) by going to the above USGS Landsat-7 web site, clicking on "search archives", and then on "Visit EarthExplorer." These browse images are in JPG format and typically are around 100 kilobytes in size. They do not have the full Landsat resolution, however, as each pixel represents about 240 meters, not 28.5. Otherwise the files would be around 13 megabytes in size (171 megabytes if a TIFF)! EarthExplorer also allows you to obtain browse images of earlier Landsat data.

ACKNOWLEDGEMENTS

This tutorial was written by Charles Wende of NASA Headquarters with help and advice from numerous members of the Landsat community, in particular Ed Sheffner of NASA Headquarters; Darrel Williams, Jim Irons, and Laura Rocchio of the NASA Goddard Space Flight Center; and Jon Dykstra of the Earth Satellite Corporation. The summary GeoCover images overlaid with maps that are included with each GeoCover tile were produced by Sarah Neuman.

C.D.W.
April, 2004

APPENDICES

APPENDIX 1: LOCATING A PLACE IN THE GEOCOVER IMAGES

If you know the latitude and longitude of your place of interest, skip to step 2.

Step 1: Finding the place's latitude and longitude

If you need to find the latitude and longitude of a place of interest, consult a gazetteer. A gazetteer is a geographical index listing names and locations, usually listing the locations as latitudes and longitudes.

There are two sources of such gazetteers on the Internet.

For places in the United States and Antarctica, the source is the United States Geological Survey (USGS) at URL:

http://geonames.usgs.gov/index.html

This gazetteer is available for query on the web, or you may download the data via FTP (http://geonames.usgs.gov/geonames/stategaz/index.html) and use them later. If you are downloading files for future use, download either the ones with the "XX_deci.zip" ending (where XX is the 2-letter abbreviation for the state) and unzip them on your computer, or download the "yyyy.txt" files, where yyyy is the state name. Either should work.

For other areas of the world, go to the National Imagery and Mapping Agency's (NIMA's) web site at:

http://www.nima.mil/gns/html/index.html

NIMA uses 2-letter abbreviations for country files (the abbreviations are standard and documented on the NIMA web site.).

The NIMA web site will also give you the choice of entering a query on the web site or downloading a database via FTP (unzip them after you download them).

Step 2: Finding the appropriate tile

Noting that the UTM coordinate system divides the Earth into longitude swaths 6 degrees wide (see Figure App1-01), you should be able to find the UTM zone you desire. The map below (figure App1-01) shows the UTM zone grid. The first northern row of tiles is labeled N-ZN-00, where ZN is the zone number. The first southern row of tiles is labeled S-ZN-00. On the map, the UTM zone numbers appear in the N-ZN-00 zones. At high latitudes (above 60 degrees), the odd-numbered zones are split between adjacent even numbered zones.

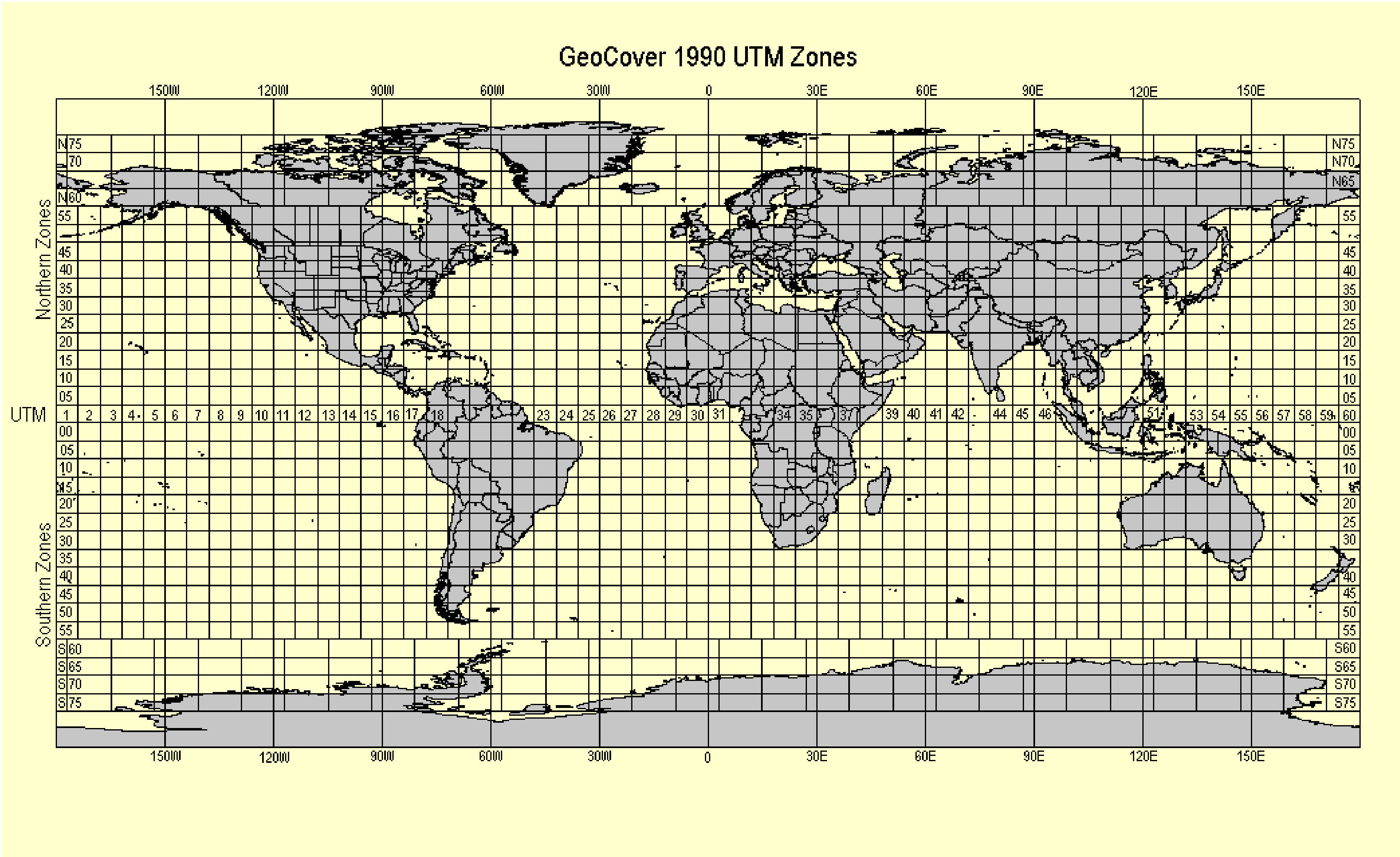

Figure App1-01: The UTM Grid System Used for GeoCover Data.

The swath numbers along the left axis of Figure App1-01 indicate the southernmost latitude in the northern hemisphere, and the northernmost latitude in the southern hemisphere.

Step 3a: A quick approach

If you have saved the gazetteer from either the USGS or NIMA on your hard drive and you have a DLGV32PRO or GlobalMapper viewer, you can simply:

1. load the appropriate GeoCover tile into DLGV32PRO or GlobalMapper,
2. load the gazetteer on top of the GeoCover tile (you may have to identify the USGS gazetteer file as a GNIS file when asked), and then
3. run a search on the place name (use the search tab at the top of the screen, type in the place name, double click on the place you desire).

4) DLGV32PRO/GlobalMapper will then center the image over the desired location. To zoom in without moving the map and losing the location, click on the magnifying glass with the red "+"inside it.

Note that you may search for another location listed in the gazetteer without first zooming out, and the image will move to the new location. If you moved into a nearby (not necessarily adjacent) tile and you see the place name on a light yellow background, you may add the needed GeoCover data by loading the appropriate tile. Usually you will not need to clear all the data and start again.

Step 3b: Matching viewers and coordinates.

If you are using a viewer that displays latitude-longitude information (e.g., GlobalMapper, DLGV32PRO), you simply load the tile containing the location you desire and find the latitude-longitude of your chosen location.

If your viewer only displays UTM, you must first convert the latitude-longitude data you found in the gazetteer into UTM coordinates (Easting and Northing). See Appendix 2 for instructions. Then load the appropriate tile and zoom in on the Easting and Northing of your chosen location.

APPENDIX 2: THE UTM COORDINATE SYSTEM

Most people are familiar with the latitude-longitude system of defining coordinates on the Earth. Latitude runs north and south from the equator, with the equator at 0 degrees latitude, the north pole at 90 degrees north latitude, and the south pole at 90 degrees south latitude (sometimes given as -90 degrees). Longitude runs east and west from an arbitrary starting point running through Greenwich, England. The western hemisphere, which contains most of the United States, lies to the west of Greenwich England. Longitudes in the western hemisphere must be either demarcated with a negative sign (i.e., as negative degrees of longitude) or explicitly stated as "west longitude" or"degrees west." It is also possible to give a longitude based on 360 degrees (e.g., Washington, DC's longitude would be 283 degrees rather than 77 degrees west, or -77 degrees). The approximate locations of some cities are given in table App2-01.

Table App2-01 gives the locations in two coordinate systems: the latitude-longitude system most of us know, and the ***Universal Transverse Mercator*** (UTM) system used by the GeoCover data set. The Mercator system in common use distorts the geography severely near the poles, but is good near the equator. It was developed as an aid to navigation, but at the expense of substantially distorting areas far from the equator - for example, Greenland appears larger than Africa on a Mercator projection, but in reality it is much smaller.

The UTM system takes advantage of the fidelity of the Mercator system near the equator by dividing the world into strips oriented perpendicular (transverse) to the equator. Then the whole Mercator coordinate system is rotated 90 degree so the "equator"now runs north-south instead of east-west. Each strip is only 6 degrees wide, so with the "equator" rotated and centered in the strip, the "polar" distortion is minimized - the worst distortion/inaccuracy is only one part in 2500. Then distances are given in meters from the equator (Northings) and distances off the central axis of the strip (Easting, since an offset always provides positive numbers increasing eastward). The conversion software used to generate the table gives coordinates in meters - while cities themselves encompass many square miles. Therefore the last three digits, and sometimes four digits, in the rightmost columns of the table are not very useful, if not meaningless. Unfortunately, most of the viewers can display the coordinates only in UTM.

The Universal Transverse Mercator coordinate system is apparently not exactly universal - there are variations. Per the original definition, the Earth was divided into zones 6 degrees wide along the equator, starting at 180 deg. of longitude and working Eastward. The center of zone 1 is at longitude -177 deg., or 177 deg. W (zone 1 covers from 180 deg. W to 174 deg. W). The center of zone 2 is at 171 deg. W (zone 2 covers from 174 deg. W to 168 deg. W); etc. These zones originally ran from 80 deg. South latitude to 84 degrees North latitude. At higher latitudes UTM coordinates were not used.

City	Lat. (deg.)	Long. (deg.)	UTM Zone	Easting (meters)	Northing (meters)
Honolulu, HA	21.5 N	158 W	4	603583	2377817
Fairbanks, AK	64.8 N	147.7 W	6	466744	7186349
Seattle, WA	47.6 N	122.3 W	10	552619	5272081
San Francisco, CA	37.7 N	122.4 W	10	552893	4172700
Salinas, CA	36.7 N	121.7 W	10	618060	4064520
Los Angeles, CA	34 N	118.2 W	11	389180	3629133
Salt Lake City, UT	40.8 N	111.8 W	12	432516	3629133
Denver, CO	39.7 N	105.0 W	13	500000	4394461
Dallas, TX	32.8 N	96.8 W	14	705998	3631258
Mexico City, Mexico	19.4 N	99.1 W	14	485418	2148874
Chicago, IL	41.8 N	87.7 W	16	441846	4627808
Miami, FL	25.8 N	80.2 W	17	580198	2853779
Quito, Ecuador	0.2 S	78.5 W	(S) 17	778239	-23867
Ottawa, Canada	45.6 N	60.0 W	18	445125	5029477
New York, NY	40.8 N	74.0 W	18	584419	4491505
Washington, DC	38.9 N	77.0 W	18	326565	4307580
Caracas, Venezuela	10.5 N	66.9 W	19	728014	1161458
Santiago, Chile	33.4 S	30.6 W	(S) 19	350541	-3708583
Punta Arenas, Chile	53.0 S	71.0 W	(S) 19	371824	-5890673
Buenos Aires, Argentina	34.6 S	58.7 W	(S) 21	346681	-3828433
St. John's, Newfoundland, Canada	47.5 N	52.7 W	22	371702	5267563
Rio de Janeiro, Brazil	23.0 S	43.2 W	(S) 23	681239	-2533537
Recife, Brazil	8.0 S	54.0 W	(S) 25	290645	-890312
Reykjavik, Iceland	64.1 N	22.0 W	28	162393	7132187
Dakar, Senegal	14.6N	17.4 W	28	237609	1622790
Marrakech, Morocco	31.6N	0.0 W	29	594791	3500289
London, England	51.5 N	0.1W	30	699787	5709356

Table App2-01a: Approximate Locations of Some Major Cities (West Longitudes).

City	Lat. (deg.)	Long. (deg.)	UTM Zone	Easting (meters)	Northing (meters)
Paris, France	48.9 N	2.3 E	31	451098	5412863
Lagos, Nigeria	6.5 N	3.4 E	31	543746	713333
Libreville, Gabon	0.4 N	9.5 E	32	550073	42391
Stockholm Sweden	59.4 N	18.0 E	33	670606	6581037
Berlin, Germany	52.5 N	13.4 E	33	391502	5819708
Cape Town, South Africa	34.0 S	18.4 E	(S) 34	261499	-3756284
Istanbul/Constantinople, Turkey	41.0 N	29.0 E	35	665173	4542821
Amman, Jordan	32.0 N	57.0 E	36	777258	3538675
Cairo, Egypt	30.0 N	31.2 E	36	331288	3325631
Moscow, Russia	55.7 N	37.6 E	37	413066	6179472
Nairobi, Kenya	1.2 S	18.4 E	(S) 37	257031	-141961
Riyadh, Saudi Arabia	24.6 N	46.8 E	38	679160	2725133
Teheran, Iran	35.7 N	51.9 E	39	538392	3947656
Islamabad, Pakistan	33.7N	73.2E	43	330092	3730412
New Delhi, India	28.6 N	77.2 E	43	715128	3165658
Calcutta, India	22.5 N	88.4 E	45	648096	2496163
Bangkok, Thailand	13.8 N	100.5 E	47	663978	1520609
Ulan Bator, Mongolia	47.9 N	106.9 E	48	643202	5308836
Hanoi, Viet Nam	21.0 N	105.9 E	48	588322	2326102
Jakarta, Indonesia	6.1 S	106.8 E	(S) 48	702428	-682838
Beijing, China	39.9 N	116.4 E	50	447653	4420104
Manila, Philippines	14.6 N	121.0 E	51	284576	1617719
Tokyo, Japan	35.7 N	139.7 E	54	387017	3949748
Sydney, Australia	33.9S	151.3 E	(S) 56	335098	-3750660
Wellington, New Zealand	41.2 S	174.8 E	(S) 60	314406	-4574457

Table App2-01b: Approximate Locations of Some Major Cities (East Longitudes).

The variation used in the GeoCover data set uses the same zone definition along the equator (i.e., the zones are 6 degrees of longitude wide at the equator), but these zones only run from 60 deg. S to 60 deg. N. At higher latitudes (i.e., North of 60 deg. N and South of 60 deg. S) the zones are widened to 12 degrees of longitude by splitting the odd-numbered zones into east-west halves which are joined to their even-numbered neighbors. For example, the tile covering the Alaskan Arctic from 162 deg. W to 150 deg. W (the eastern half of zone 3, all of zone 4, and the western half of zone 5 at lower latitudes) and 70 deg. N to 75 deg. N would be labeled N-04-70. The next two Easternmost high-latitude tiles would be N-06-70 and N-08-70. Further, to insure overlap with neighboring zones, each tile (mosaic) extends at least an extra 50 kilometers east and west, and at least 1 kilometer extra north and south.

The tiles or mosaics in the original definition are 8 degrees of latitude high. In the GeoCover data set, each tile is 5 degrees of latitude high. The latitude swath is identified by the equatormost latitude, rounded down to 5 degree increments.

The GeoCover tiles (mosaics) follow the 3-element naming convention given below:

The first element is the hemisphere: N (northern) or S (southern);

The second element is the UTM zone number: 01 to, and including, 60; and

The third element is latitude of the equator-most edge of the tile, rounded down in 5 degree increments:

In the northern hemisphere, it is the latitude (degrees) of the southern edge of the tile, and

In the southern hemisphere, it is the latitude (degrees) of the northern edge of the tile.

For example:

"N-13-25" names a mosaic/tile in the northern hemisphere, in UTM zone 13, extending between 25 and 30 degrees north latitude. In the same UTM zone, a latitude of 15.25 degrees North (15 deg. 15 min. 00 sec.) would be in tile N-13-15, as would a latitude of 17.5 degrees north and 19.7 degrees north, etc. A latitude of 20.1 degrees north would fall in tile N-13-20. A latitude of 3 degrees north would fall in tile N-13-00.

"S-21-10" names a mosaic/tile in the southern hemisphere, in UTM zone 21, extending between 10 and 15 degrees south latitude. In the same zone, a latitude of 3 degrees south (-3 degrees) would fall in tile S-21-00. A latitude of 46 degrees south would fall in tile S-21-45.

In short: the tiles (individual pieces of the overall mosaic) are 6 degrees of longitude wide, as measured at the equator, and 5 degrees of latitude tall - until you get above 60 degrees of latitude north or below 60 degrees of latitude south. Then the tiles are 12 degrees of longitude wide, but still 5 degrees of latitude tall.

At high latitudes the odd-numbered zones are divided into east-west halves, and the halves are combined with the even-numbered tiles on both sides.
Two tiles in the same zone and neighboring latitudes may combined if the resulting data set is still reasonably sized. For example, Hawaii is in a tile labeled N-04-15-20, indicating it is zone 4, with pieces from latitudes 15-20 deg. N. and 20-25 deg. N. Occasionally, a boundary of a tile may be extended to include a small land mass in a neighboring tile. For example, tile N-18-35 (the states of Delaware, Maryland, Virginia, and most of North Carolina in the U.S.A.) includes a small northern piece of what would technically be tile N-18-30 (the southeast portion of North Carolina).

The coordinates themselves are displayed in terms of "Eastings"(X, or horizontal distance) and "Northings" (Y, or vertical distance) away from a reference position. These Eastings and

Northings are usually given in meters, although some viewers allow you to change these units to kilometers or miles. However, these Eastings and Northings may not be zero at the westernmost edge (Eastings) or the equator (Northings). Frequently "false Eastings" and "false Northings" are used so that all X's increase as you go eastward, and all Y's increase as you go northward, and both X's and Y's may be adjusted to be positive numbers. These units are as defined as follows:

Northern Hemisphere:

> The False Eastings (X) are referenced by setting the central meridian (the line going up and down the center of each zone) to 500,000 meters (or 500 kilometers) and increasing as you move eastward. That means that whenever you are exactly in the east-west center of a zone, x is 500,000 meters. West of the central meridian, X is less than 500,000 meters; east of the central meridian, X is larger than 500,000 meters.
>
> The Northings (Y) are referenced to the equator being set to 0 (zero) meters and increasing northward.

Southern Hemisphere:

The False Eastings (X) are referenced by the same scheme used in the northern hemisphere.

> The Northings (Y) are sometimes referenced to setting the equator to a value of 0 meters, but in this case Y becomes more negative the further south you go. Another approach uses False Northings (Y') which are referenced by setting the equator to 10,000,000 meters (or 10,000 kilometers) and still increasing northward. That means that all False Northings in the Southern Hemisphere are between 0 meters and 10,000,000 meters (10,000 kilometers). When False Northings are used, the southern hemisphere is sometimes identified by assigning it a negative zone number.

An illustration of a part of Zone 18 in the northern hemisphere is given below:

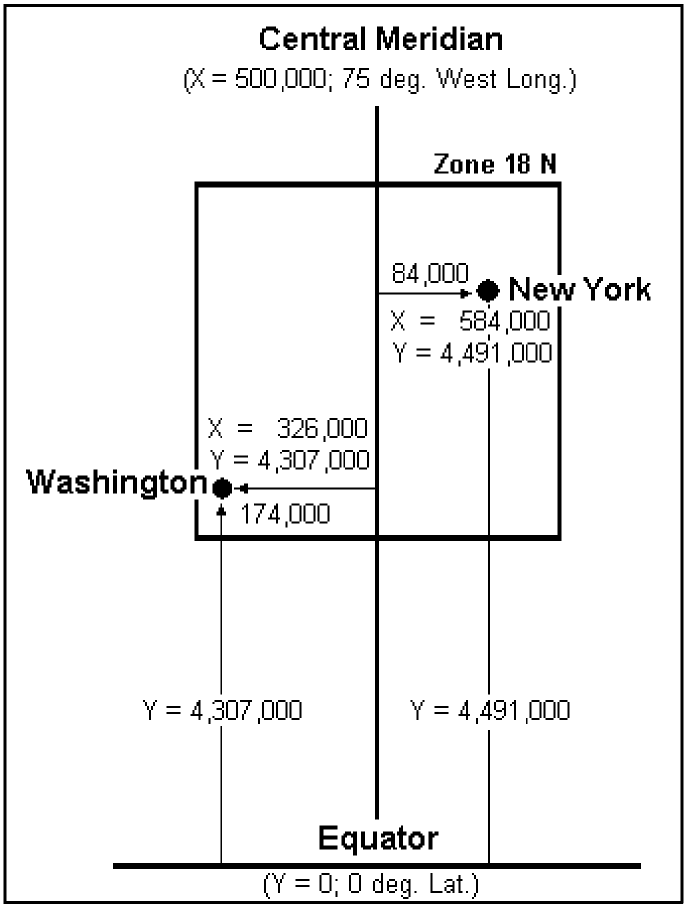

Figure App2-01: Zone 18, Northern Hemisphere (not to scale).

This figure shows the positions and coordinates of

Washington, D.C (latitude 38.9 deg. North, longitude 77 deg. West), and

New York, NY (latitude 40.8 deg. North, Longitude 74 deg. West), U.S.A.

An example from the southern hemisphere is given in Figure App-2-2. Note that the equator is assigned a Y' value of 10,000,000 meters while the X value of the central meridian of each zone is still 500,000 meters.

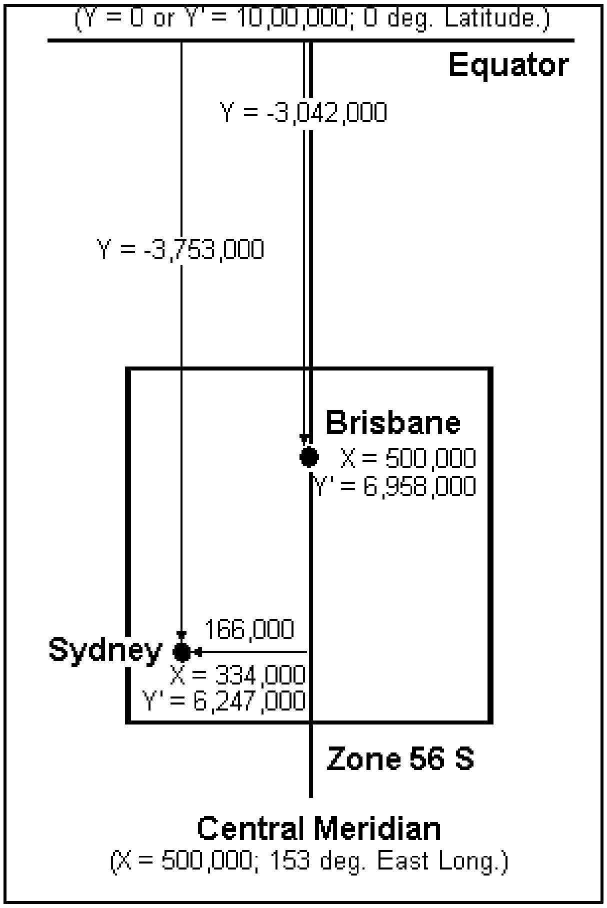

Figure App2-02: Zone 56 South (not to scale).

This figure shows the positions and coordinates of

Brisbane (latitude 27.5 deg. South, Longitude 153 deg. East) and

Sydney (latitude 33.9 deg. South, Longitude 151.2 deg. East) Australia.

In both figures, as you go northward Y (northern or southern hemisphere) or Y' (southern hemisphere) increases in value; and as you go eastward, X increases in value. In the southern hemisphere, Y is negative.

Software that converts between UTM and latitude-longitude can be found on the web (see the references). When using such software, use the WGS 84 geodetic system to correct for the fact that the earth is not an exact sphere.

Table App-2-02 lists Northings for every 5 degrees of latitude. Each degree of latitude is about 110 - 111 kilometers, or about 68-69 miles. However, because the earth not a perfect sphere, the number of kilometers/degree (or miles/degree) varies slightly with latitude. Hence, the reference to WGS 84 above. Each degree of longitude is around 110-111 kilometers at the Earth's equator and decreases as you move poleward.

Latitude (Degrees)	Northern Hemisphere Northing (y, meters)	Southern Hemisphere False Northing (y', meters)	Southern Hemisphere Northing y (meters)	Left Edge False Easting (meters)	Full Width (km)
0	0	10,000,000	0	166,021	668.0
5	552,644.3	9,447,355.7	-552,6544.3	167,286	665.4
10	1,105,412.5	8,894,587.5	-1,105,412.5	171,071	657.9
15	1,658,326.0	8,341,674.0	-1,658,326.0	177,349	645.3
20	2,211,481.3	7,788518.7	-2,211,481.3	186,074	627.9
25	2,764,947.7	7,235,052.3	-2,764,947.7	197,181	605.6
30	3,318,785.4	6,681,214.6	-3,318,785.4	210,590	578.8
35	3,873,043.1	6,126,956.9	-3,873,043.1	226,202	547.6
40	4,427,757.2	5,572,242.8	-4,427,757.2	243,900	512.2
45	4,982,950.4	5,017,049.6	-4,982,950.4	263,554	472.9
50	5,538,630.7	4,461,369.3	-5,538,630.7	285,016	430.3
55	6,094,791.4	3,905,208.5	-6,094,791.4	308,124	383.6
60	6,651,411.2	3,348,588.8	-6,651,411.2	165,410	669.2
65	7,208,454.6	2,791,545.4	-7,208,454.6		
70	7,765,873.1	2,234,126.9	-7,765,873.1		
75	8,323,606.8	1,676,393.2	-8,323,606.8		
80	8,881,585.8	1,118,414.2	-8,881,585.8		

Table App2-02: Latitudes and their Equivalent Northings.

APPENDIX 3: IMAGES OF SALINAS, CA IN BANDS 1-8

The following set of sample images are for the Salinas, California area south of San Francisco. It includes a sample from each individual band, although only one of the two band 6 images is presented. When comparing images, pick a few specific features to compare, such as:

The ocean (Light or dark, textured or smooth?)

The breakers along the beach (Visible or invisible?)

Various fields (Are they the same shade of gray?)

The lakes/ponds and rivers (clear and distinct, or hard to find?)

The airport (Do the runways stand out or fade away?)

The major highways (Are they sharper in some bands than others?)

The town of Salinas (Is it lighter or darker than the surrounding area?)

Then look for the same feature or features in the images from two or more different bands.

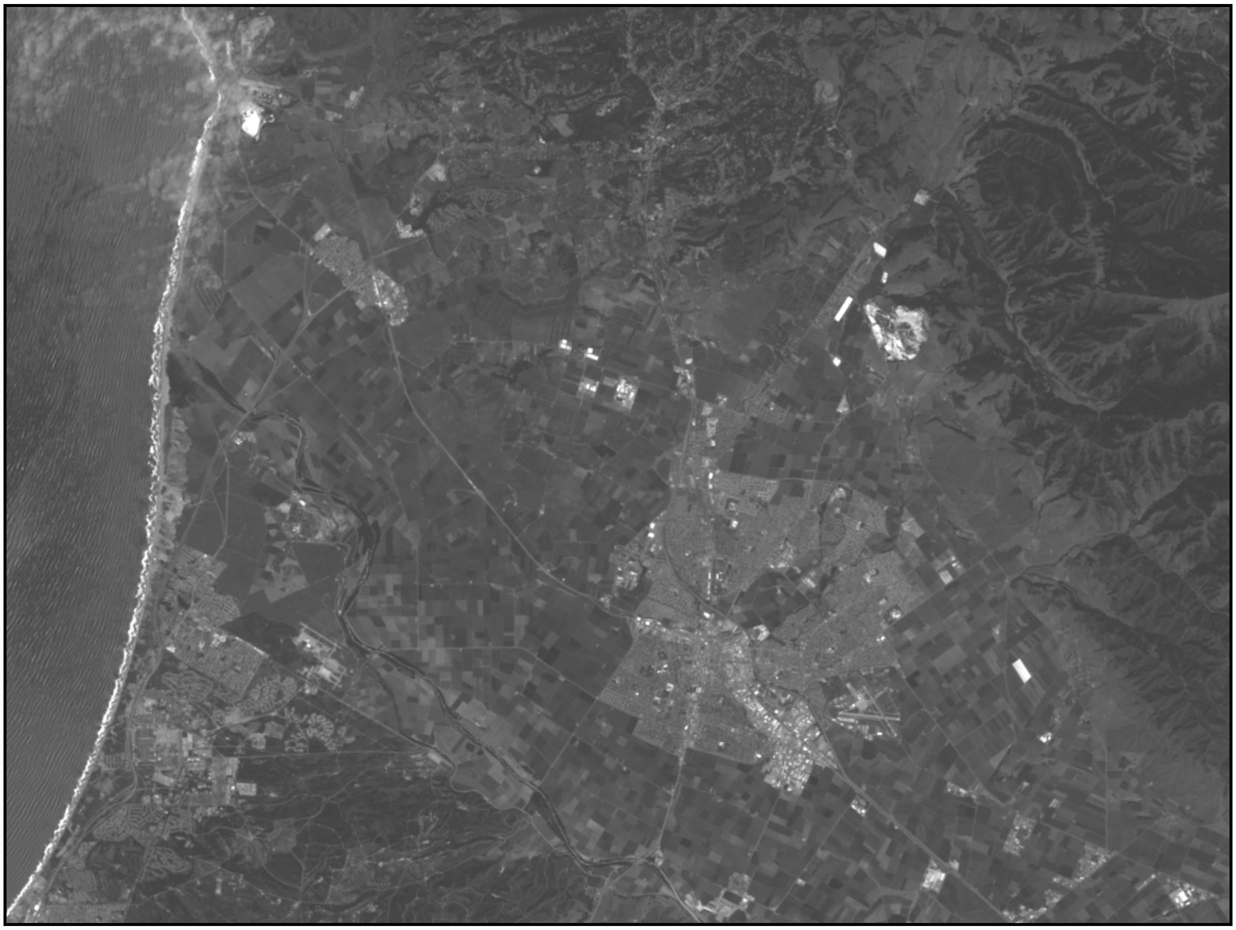

Figure App3-01: Band 1, Blue/Blue-Green.

Blue/Blue-green light (0.4-0.5 microns) is scattered by the atmosphere and illuminates material in shadows better than longer wavelengths (remember, blue is the short-wavelength end of the spectrum). Blue penetrates clear water better than other colors - note the texture of/in the water along the shore. It is absorbed by chlorophyll, and so plants don't show up very brightly in this band. That is why the fields all look drab and washed out. However, it is useful for soil/vegetation discrimination, forest type mapping (deciduous from conifer forests), and identifying man-made features, such as the airport in the lower right area of the image.

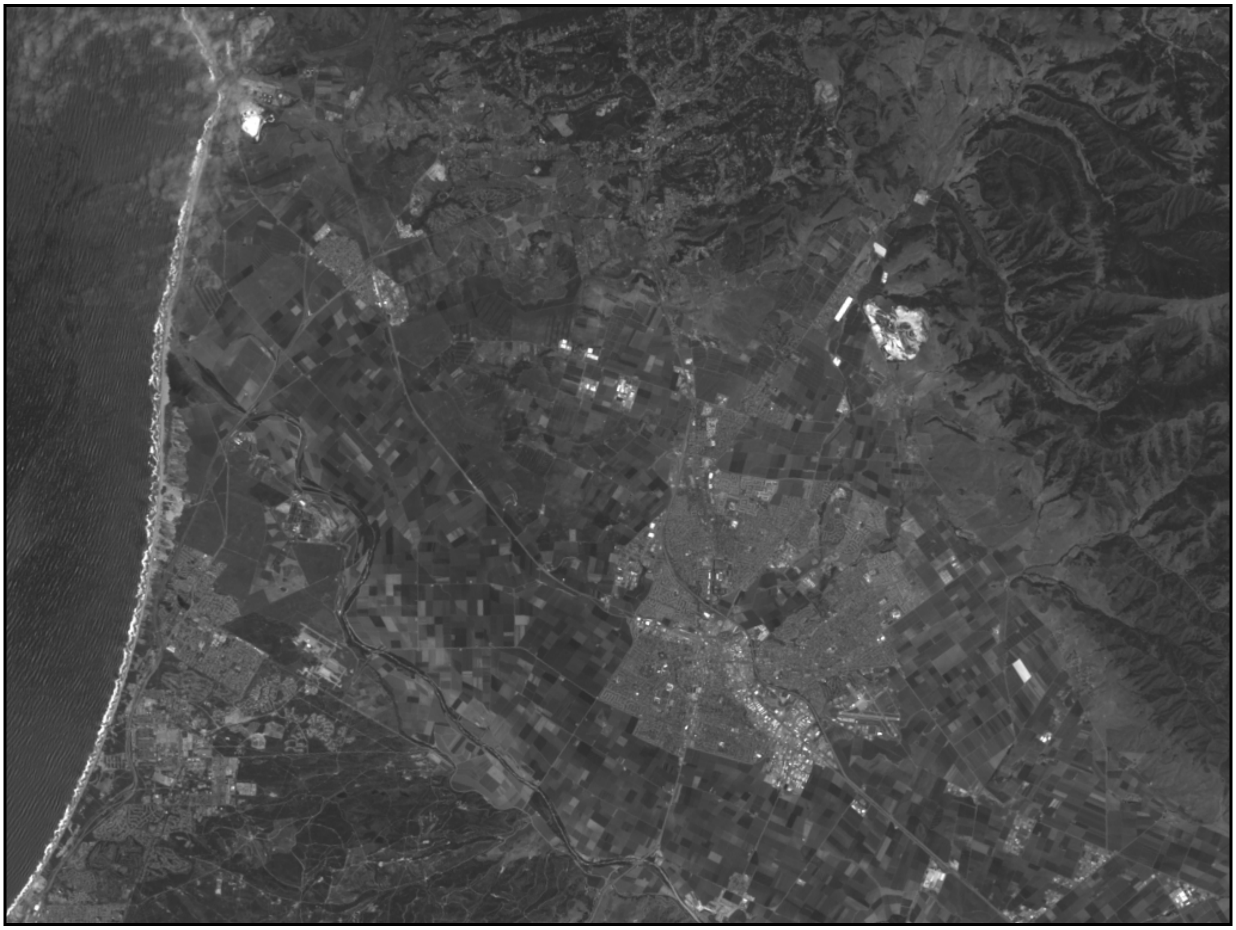

Figure App3-02: Band 2, Green.

Green light (0.5-0.6 microns) penetrates clear water fairly well, and gives excellent contrast between clear and turbid (muddy) water. It helps find oil on the surface of water. Vegetation (plant life) reflects more green light than any other visible color, and this band can be used to assess plant vigor (health). Man-made features are still visible (note the airport).

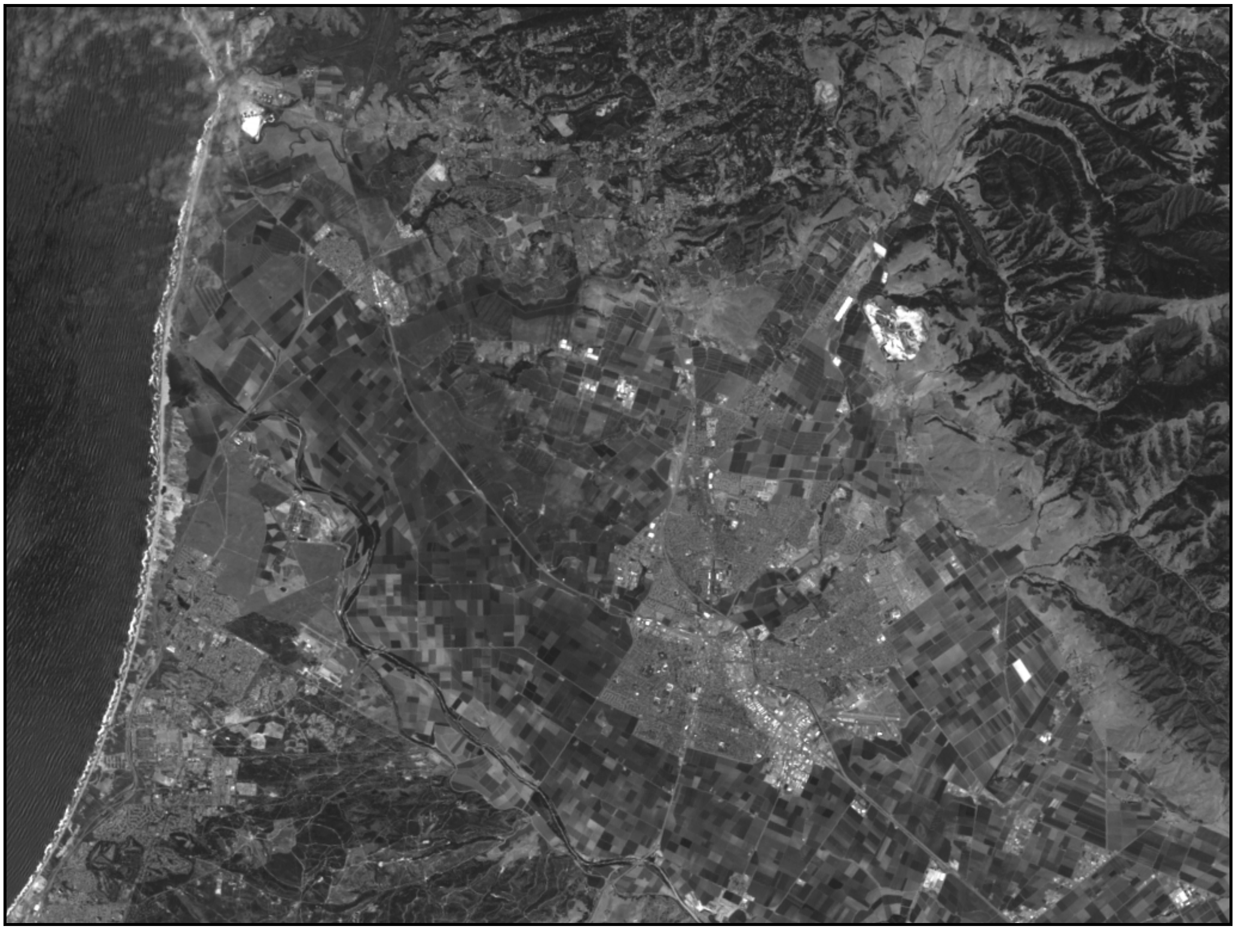

Figure App3-03: Band 3, Red.

Red light (0.6 - 0.7 um) has limited water penetration. It reflects well from dead foliage, but not well from live foliage with chlorophyll. It is useful for identifying vegetation types, soils, and urban (city and town) features.

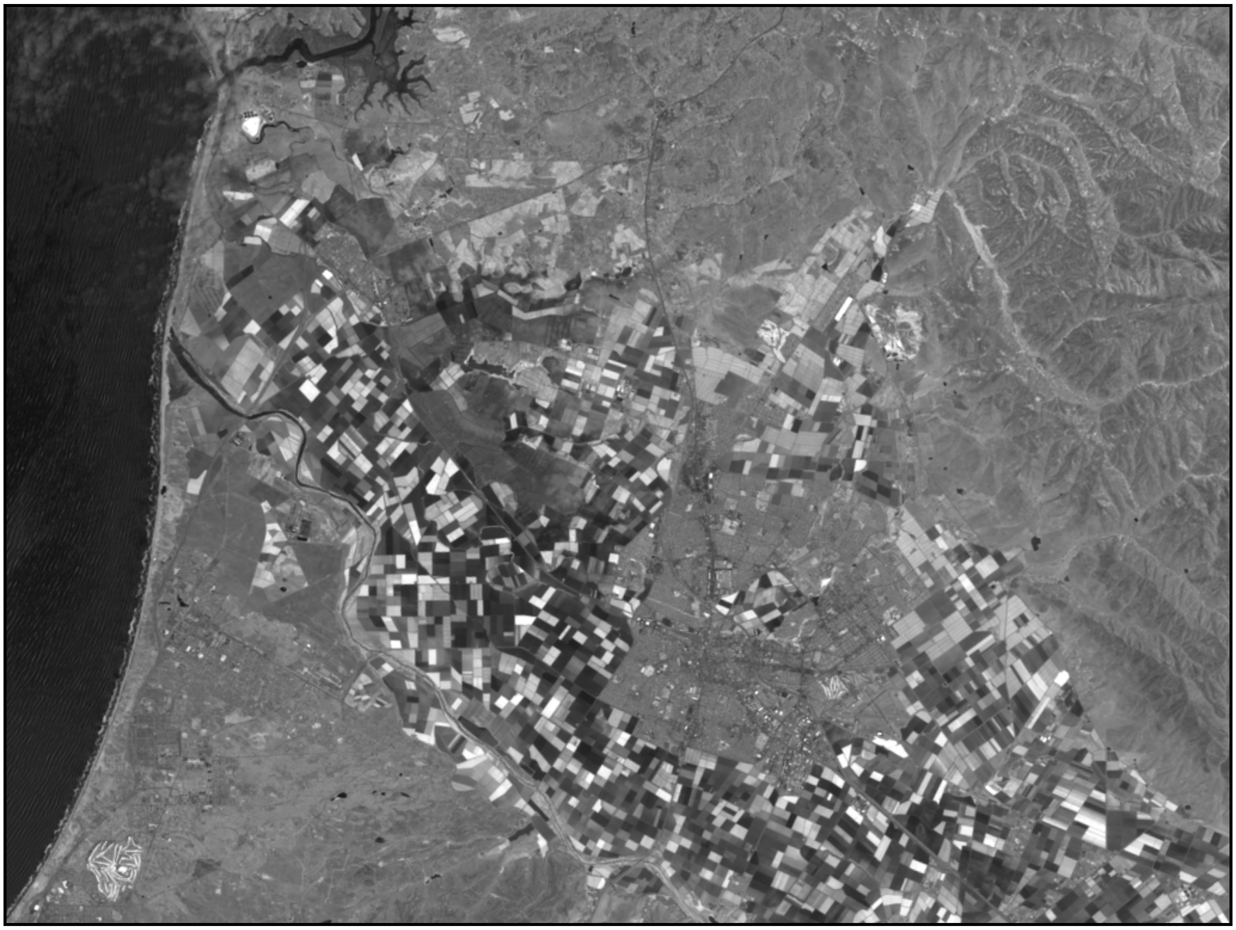

Figure App3-04: Band 4, Near Infra-Red.

The near infra-red (NIR, .7-1.2 microns, redder than red, but not visible) is good for mapping shorelines and biomass content. It is very good at detecting and analyzing vegetation. See how the fields that looked almost the same in bands 1, 2, or even 3 have changed dramatically in band 4. But the airport has darkened.

Figure App3-05: Band 5, The Short Wavelength Infrared.

The short wavelength infrared (SWIR, 1.55 - 1.75 microns, even redder than NIR) has limited cloud penetration and provides good contrast between different types of vegetation. It is also useful to measure the moisture content of soil and vegetation. It helps differentiate between ice, snow, and clouds.

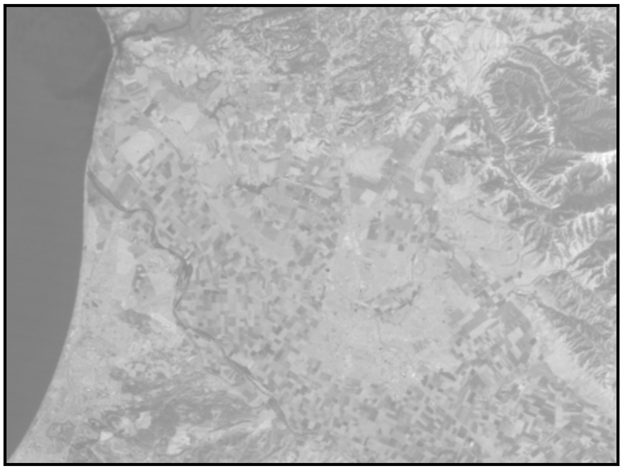

Figure App3-06: Band 6, Thermal infrared.

The thermal infra-red (TIR, 5.0 - 14.0 microns, so red it "sees" warm objects; also called long-wavelength infrared (LWIR) or thermal IR) is useful to observe temperature and its effects, such as geothermal activity and daily and seasonal variations. It is also useful to identify some vegetation density and stress, soil moisture, and cover type. This image has only 57-meter pixels, so it is not as sharp as the other images. It is also one half the height and one half the width. Band 6 pixels on Landsat-5 are 120 meters.

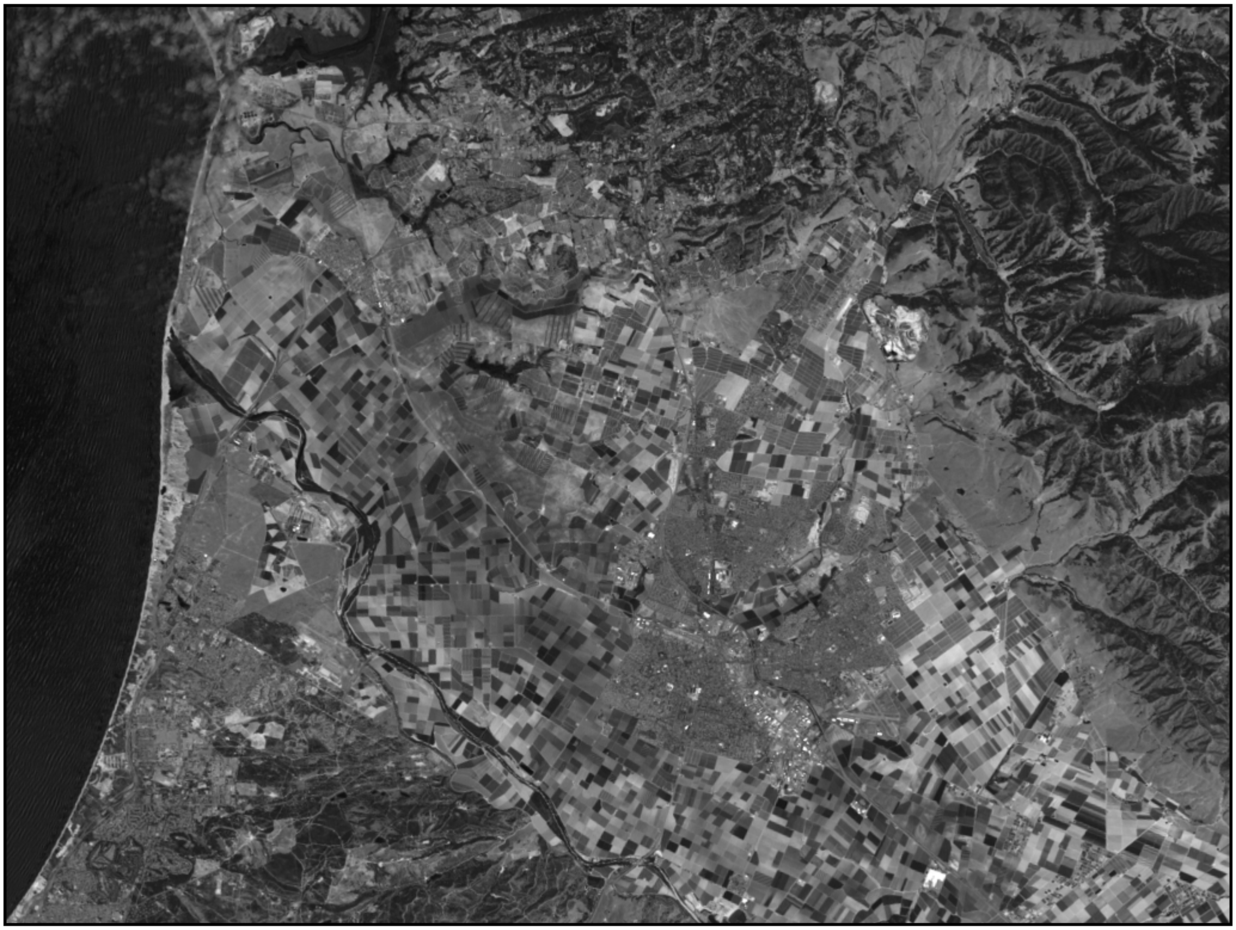
Figure App3-07: Band 7, Another short wavelength infrared band.

This band (SWIR, 2.08 - 2.35 microns, although somewhat longer wavelength than Band 5) has limited cloud penetration and provides good contrast between different types of vegetation (compare to vegetation in bands 4 and 5) and different geologic rock formations. It is also useful to measure the moisture content of soil and vegetation. It helps differentiate between snow and clouds.

Figure App3-08: Band 8, Panchromatic Sharpening Band (Landsat 7)-partial image.

The wide, panchromatic sharpening band covers the spectrum from green to NIR (0.52 - 0.9 microns), and was not carried on Landsats 1 through 5. This image should be twice the height and width of the visible-SWIR band images (bands 1-5, and 7). Hence, only the lower left-hand portion of the image is shown in Figure App3-08.

The sample data sets included with this tutorial contain Landsat-7 scenes. The differences between Landsat-5 and Landsat-7 are:

- Landsat-7 has a 57-meter resolution thermal band (band 6), while Landsat-5 had a 120 meter thermal band;
- Landsat-7 has a additional 14.25-meter resolution panchromatic (wide-spectrum) band (band 8) which allows users to sharpen the 28.5-meter bands; and
- Landsat-7 data were taken about 10 years after the Landsat-5 (GeoCover 1990) data.

These data appear as a set of grayscale images. Since band 6 has only 57 meter spatial resolution, the image is half the height and half the width of the images for bands 1, 2, 3, 4, 5 and 7. Band 8 has 14.25 meter resolution and a broad spectral response. It is used to "sharpen" the 28.5 meter images. Since it has 14.25 rather than 28.5 meter resolution, its image is twice the height and twice the width of the images from bands 1, 2, 3, 4, 5, and 7.

As you look at the individual band images of the Salinas, California area (see above), you will observe that different features appear in the images from different bands. If you have image processing software that handles TIFF (or TIF) files on your computer, try loading the sample images into your computer and then experimenting with changing the brightness, and/or contrast, or other characteristics of individual band-images and see what you can bring out. Sometimes the results are surprising! Available image processing software includes (there are others):

- Adobe Photoshop (commercial software), and
- Jasc Software's Paint Shop Pro (shareware, 30-day free trial from the internet at www.jasc.com)

The following MrSID viewers include limited image enhancement capabilities:

- Geomatica's Freeview (freeware available from the internet at www.pcigeomatics.com), and
- Viewfinder and MapSheets Express (both freeware available from the internet at gis.leica-geosystems.com/erdascentral/).

Compositing: Next, try combining three single-band, gray scale images into a single color image. By choosing different band combinations, different land features are emphasized. If your computer software allows you to separate a color image into"red", "green", and "blue"black-and-white images and to recombine them into a color image, you can put together a synthetic color image, or composite image. First, go to the recombining step. Identify the "red"gray scale image (by file name) as band 3; identify the "green"gray scale image (by file name) as band 2; and identify the "blue"gray scale image (by file name) as band 1. Push the recombine button (or whatever your computer tells you to do) and you'll see a color image

Feature	Best Band	Gray-scale (black - white)	False Color, or NIR Composite Image
Clear Water	4	Black tone	Black
Silty Water	2, 4	Dark in 4	Bluish
Nonforested Coastal Wetlands	4	Dark gray tone between black water and light gray land	Blocky pinks, reds, blues, blacks
Deciduous Forests	3, 4	Very dark tone in 3, light in 4	Dark red
Coniferous Forest	3, 4	Mottled medium to dark gray in 4; Very dark in 3	Brownish-red and subdued tone
Defoliated Forest	3, 4	Lighter tone in 3, darker in 4	Grayish to brownish-red
Mixed Forest	2, 4	Combination of blotchy gray tones	Mottled pinks, reds, and brownish-red
Grasslands (in growth)	3, 4	Light tone	Pinkish-red
Croplands and Pasture	3, 4	Medium gray in 3, light in 4	Pinkish to moderate red, depending on growth stage
Moist Ground	4	Irregular darker gray tones(broad)	Darker colors
Soils –Bare Rock – Fallow Fields	2, 3, 4	Depends on surface composition and extent of vegetative cover. If barren or exposed, may be brighter in 2 and 3 than 4	Red soils and red rock in shades of yellow; gray soils and rock dark bluish; rock outcrops associated with large land forms and structure.
Faults and Fractures	3, 4	Linear (straight or curved), often discontinuous; interrupts topography; sometimes vegetated	
Sand and Beaches	2, 3	Bright in all bands	White, bluish, light buff
Stripped Land-Pits and Quarries	2, 3	Similar to beaches – usually not near large water bodies; often mottled, depending upon reclamation	
Urban Areas: Commercial	3, 4	Usually light tones in 3, dark in 4	Mottled bluish-gray with whitish and reddish specks
Urban Areas: Residential	3, 4	Mottled gray, street patterns visible	Pinkish to reddish
Transportation	3, 4	Linear patterns; dirt and concrete roads light in 3, asphalt dark in 4.	

Table App3-01: Appearance of Surface Features in Individual Bands and NIR Composite Images.

Table App3-01 summarizes what different features look like in different bands, in particular which individual band or bands are best used to look for a particular feature. It also tells what color the feature will appear to be in a false-color composite (not the GeoCover composite).

Sharpening: Landsat-7's band 8 is used to sharpen the images from bands 1, 2, 3, 4, 5, and 7. Sharpening enhances a lower resolution composite image by impressing a higher resolution panchromatic image upon it. You can follow the recipe below to try it yourself.

Begin by making a three-band RGB composite, such as the 7-4-2 combination used in the

GeoCover data set. How to do that is described above. If you have difficulty building a composite image, there are composite images included in each set of sample data.

Next, double the composite image size - from 1024 x 768 pixels to 2048 x 1536 pixels - using your software's resizing function. Now the enlarged composite image and the band 8 image should be the same size.

Then, separate the enlarged RGB composite using the hue-saturation-luminance (HSL) scheme, sometimes called the hue-saturation-intensity (HSI) scheme. Your software should tell you the names of the three new files - one associated with hue, another with saturation, and the third with luminance or intensity.

Then, reconstruct the image using the HSL scheme, but replacing the data in the luminance channel with the band-8 (14.25 meter) data file. You should have a sharpened image. In effect, the resulting image combines the spatial resolution of the 14.25 meter pan band with the color characteristics of the 28.5 meter data. There are examples given in the sample data sets (they have the ***-S.tif file name).

You may be wondering what is the difference between the RGB color scheme and the HSL color scheme. They represent different ways of describing what we call "color."

RGB (Red-Green-Blue) is the same scheme that is used in a color television set. Red, green, and blue colors, with various intensities, are added together to produce the final color that you see. If the red, green, and blue guns are all turned off (all intensities 0), then the color is black. Similarly, if they are all at their maximum, the resulting color is white. Various gun intensity combinations give the colors in between.

HSL (Hue-Saturation-Luminance) is a alternative color description. Hue is determined by the dominant wavelength that you see - red-orange-yellow-green-blue-violet, etc. Saturation specifies the purity of the color relative to a gray scale. Pastel colors such as pink are near the white end of the saturation scale and have low saturation. Vivid colors (e.g., crimson) are usually in the mid-range, and extremely saturated colors are nearly black (e.g., a very dark Burgundy red). Luminance refers to the total brightness, or intensity, of a color (like comparing a 5 watt light bulb to a 50 watt bulb to a 150 watt bulb, all through a filter giving the same hue and saturation).

By maintaining the hue and saturation of the 28.5 meter image (already colorized, so to speak, by adding together three black and white images fed through RGB filters) the color characteristics of the 28.5 meter composite image are carried forward. By replacing the luminance (intensity) with the 14.25 meter black and white image, the spatial character of the 14.25 meter image is imposed on the color character of the 28.5 meter image and a sharpened image results. For more information on sharpening, see pages 525 to 532 in the Lillesand and Keiffer book in the references.

APPENDIX 4: MrSID VIEWERS

There are several free **PC/Windows viewers** available from the internet, although most of these viewers only locate the cursor in the Universal Transverse Mercator (UTM) coordinate system (See Appendix 2). They are listed below in table App4-01, the first three being from the vendor of the MrSID compression software. They will all read GeoCover data in the MrSID format and allow you to zoom in and out, increasing the detail as you zoom in and decreasing the detail as you zoom out. Most will also read data in the GeoTIFF format used in the sample data sets.

For the **Macintosh**, a version of the MrSID viewer (formerly at URL: www.lizardtech.com) is included on the “United States of America Digital Landsat Mosaics” data set available from the EROS Data Center of the United States Geological Survey (see the "Viewers" folder on Disk 1).

Similarly, for **Linux**, **IRIS**, and **Sun Solaris 2.6**users, a MrSID viewer (formerly at URL: www.lizardtech.com) was also included on the “United States of America Digital Landsat Mosaics” data set available from the EROS Data Center of the United States Geological Survey (see the "Viewers"folder on Disk 1).

WARNING: Some image processing software (Paint Shop Pro, Irfanview, Xnview, and Polyview among them) mention the capability of importing or reading MrSID files. While this software can read in small files compressed using MrSID in the same sense that they can read a GIF or JPEG file, as of this writing they do NOT have the capability of reading a large area at coarse resolution and zooming in to smaller areas at finer resolutions. The MrSID viewers listed above have that capability. Further, the image processing software usually cannot handle MrSID files the size of those in this data set (typically 50 MB each). If you need to use the image processing features of these packages, you should first generate a TIF file of the area of interest (using, for example, the MrSID Viewer or GeoViewer). Then read the TIF file into the image processing software and proceed from there.

WARNING: Image processing software packages such as that mentioned above (e.g., (Paint Shop Pro, Irfanview, etc.) usually delete the GeoTIFF information when saving a TIF file, even if it was opened from a GeoTIFF file.

Name	URL	Comment
MrSID Viewer	www.lizardtech.com	Allows saving a section of the overall image as a TIFF file (obsolete, no longer offered)
GeoViewer 2.1	www.landsystems.com	Allows saving a section of the overall image as a GeoTIFF file (Trial version)
GeoExpressView (Win2K, XP)	www.lizardtech.com	Like GeoViewer (windows 2000/XP only), saves as BMP, JPG, and TIF with associated TAB, TFW, but not GeoTIFF(Trial version)
ArcExplorer 2 (not 4)	http://www.esri.com/software/arcexplorer/index.html	Scale bar available at bottom, add layers; save only in BMP, EMF, or internal format. Version 4 does not support MrSID.
Dlgv32pro, also available as GlobalMapper	mcmcweb.er.usgs.gov/drc/dlgv32pro/ www.globalmapper.com	Allows overlays, mosaics nearby images, can add lat.-long. or UTM grids. Limited capability is free; full capability (print, save in GeoTIFF, etc.) is less than $200 US.
EpiMap	www.cdc.gov/epiinfo/	Cannot subset MrSID files; saves in internal format or BMP.
Freeview 8.2	www.pcigeomatics.com/freeware	Allows changing brightness, contrast, equalization of image, but cannot save or print.
MapSheets Express 1.3	gis.leica-geosystems.com/erdascentral/	Allows changing brightness, contrast, add layers; saves and prints as HTML.
Viewfinder 1.1 (Win9x, 2K) Viewfinder 2.1 (NT/2K)	gis.leica-geosystems.com/erdascentral/	3 panels; adjust brightness, contrast, sharpen, etc.; save to clipboard image only for MrSID.

Table App4-01. Free MrSID Viewers Available on the Internet.

APPENDIX 5: BIBLIOGRAPHY

This bibliography is not intended to be complete. In particular, internet web sites are known to come and go, and may not last over a period of years. Rather, this bibliography was intended to give the readers a starting point from which to pursue further information.

Remote Sensing Textbooks:

Remote Sensing of the Environment, *An Earth Resource Perspective*, by John R. Jensen, Prentice Hall, Upper Saddle River, NJ, 07458, 2000, ISBN 0-13-489733-1, 544 pages

Remote Sensing and Image Interpretation, by Thomas M. Lillesand and Ralph W. Kiefer, 4th edition, John Wiley and Sons, Inc., New York, NY, 1999, ISBN 0-471-25515-7, 724 pages

Other useful texts:

The Landsat Tutorial Workbook, Basics of Satellite Remote Sensing, Nicholas M. Short et al, NASA Reference Publication 1078, Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 1982, 553 pages (dated but useful).

Geomorphology from Space, A Global Overview of Regional Landforms, edited by Nicholas M. Short, ST. and Robert W. Blair, Jr., NASA SP-486, available on CD-ROM via the Goddard DAAC Help desk at (301)-614-5224 or daacuso@daac.gsfc.nasa.gov. Web version available at:

http://daac.gsfc.nasa.gov/www/geomorphology/

Map Projections - A Working Manual, by John P. Snyder, U.S. Geological Survey Professional Paper 1395, U.S. Government Printing Office, Washington, DC 1987.

A particularly good reference to these data is:

"NASA's Global Orthorectified Landsat Data Set", by C.J.Tucker, D.M.Grant, and J.D.Dykstra, in *Photogrammetric Engineering and Remote Sensing*, Volume 70, Number 3, pp. 313-322, March, 2004.

Useful internet URLs:

Topic	**URL**	**Comment**
GeoTIFF	http://remotesensing.org/geotiff/geotiff.html	DOS software to read/edit geotiff headers embedded in a geotiff file
Landsat per se	http://landsat.gsfc.nasa.gov/	Information plus links to tutorials, and free/sample data
Landsat per se	http://landsat7.usgs.gov/	The public source for all Landsat data (not free)
Landsat per se	http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_toc.html	Landsat 7 Science Data Users Handbook
Landsat Data	https://zulu.ssc.nasa.gov/mrsid/	Free GeoCover data sets for downloading
Landsat Data	http://glcf.umiacs.umd.edu/index.shtml	Open source for free Landsat data
Landsat Data	http://dmc.ohiolink.edu/GEO/LS7/	Landsat images of Ohio for use by individuals for educational and research purposes
Landsat Data	http://landsat.org	Supports the purchasing, distribution, and sharing of Landsat 7 imagery; supports research centers, science teams, and educational organizations.
Landsat Data	http://aria.arizona.edu/	Arizona Regional Image Archive, includes links and a land cover change tutorial
Landsat Data	http://www.bsrsi.msu.edu/trfic	Tropical Rain Forest Information Center, some low cost Landsat imagery
Landsat Data	http://www.landsat4u.com/	Inexpensive images of the South Western USA
UTM	http://www.maptools.com/	Tools for UTM/MGRS and Lat./Long. coordinates; tutorials.
UTM	ftp://ftp.blm.gov/pub/gis	Software tools UTM2LL.ZIP and UTM.ZIP. See programs.txt
UTM	http://www.nps.gov/prwi/readutm.htm	**How to Read the UTM Grid**
UTM	http://maps.nrcan.gc.ca/maps101/utm.html	The UTM Grid
UTM	http://www.remotesensing.org/proj/	the PROJ.4 Projections library
UTM	http://www.colorado.edu/geography/gcraft/notes/coordsys/coordsys.html	Coordinate tutorial