ΧΑΡΑΚΤΗΡΙΣΤΙΚΑ ΔΟΡΥΦΟΡΙΚΩΝ ΕΙΚΟΝΩΝ LANDSAT TM & Sentinel 2

1) USGS: Από το Site http://earthexplorer.usgs.gov/

2) Site ESDI: http://glcfapp.glcf.umd.edu:8080/esdi/

3) **Δωρεάν εικόνες Landsat 8: Εικόνες Landsat μετά το 2013 : http://libra.developmentseed.org/**

Εγχειρίδιο για Landsat 8: http://landsat.usgs.gov/Landsat8_Using_Product.php

LANDSAT 4,5,7

Landsat is a set of multispectral satellites developed by the NASA (National Aeronautics and Space Administration of USA), since the early 1970's.

Landsat images are very used for environmental research. The resolutions of Landsat 4 and Landsat 5 sensors are reported in the following table (from http://landsat.usgs.gov/band_designations_landsat_satellites.php); also, Landsat temporal resolution is 16 days (NASA, 2013).

Landsat 4, Landsat 5 Bands	Wavelength [micrometers]	Resolution [meters]
Band 1 - Blue	0.45 - 0.52	30
Band 2 - Green	0.52 - 0.60	30
Band 3 - Red	0.63 - 0.69	30
Band 4 - Near Infrared (NIR)	0.76 - 0.90	30
Band 5 - SWIR	1.55 - 1.75	30
Band 6 - Thermal Infrared	10.40 - 12.50	120 (resampled to 30)
Band 7 - SWIR	2.08 - 2.35	30

The resolutions of Landsat 7 sensor are reported in the following table (from http://landsat.usgs.gov/band_designations_landsat_satellites.php); also, Landsat temporal resolution is 16 days (NASA, 2013).

Landsat 7 Bands	Wavelength [micrometers]	Resolution [meters]
Band 1 - Blue	0.45 - 0.52	30
Band 2 - Green	0.52 - 0.60	30
Band 3 - Red	0.63 - 0.69	30
Band 4 - Near Infrared (NIR)	0.77 - 0.90	30
Band 5 - SWIR	1.57 - 1.75	30
Band 6 - Thermal Infrared	10.40 - 12.50	60 (resampled to 30)
Band 7 - SWIR	2.09 - 2.35	30
Band 8 - Panchromatic	0.52 - 0.90	15

LANDSAT 8

The resolutions of Landsat 8 sensor are reported in the following table (from http://landsat.usgs.gov/band_designations_landsat_satellites.php); also, Landsat temporal resolution is 16 days (NASA, 2013).

Landsat 8 Bands	Wavelength [micrometers]	Resolution [meters]
Band 1 - Coastal aerosol	0.43 - 0.45	30
Band 2 - Blue	0.45 - 0.51	30
Band 3 - Green	0.53 - 0.59	30
Band 4 - Red	0.64 - 0.67	30
Band 5 - Near Infrared (NIR)	0.85 - 0.88	30
Band 6 - SWIR 1	1.57 - 1.65	30
Band 7 - SWIR 2	2.11 - 2.29	30
Band 8 - Panchromatic	0.50 - 0.68	15
Band 9 - Cirrus	1.36 - 1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100 (resampled to 30)
Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 (resampled to 30)

A vast archive of images is freely available from the U.S. Geological Survey . For more information about how to freely download Landsat images read this .

Τα φασματικά κανάλια των Δορυφόρων Landsat TM

Landsat 5 (TM sensor)	Wavelength (micrometers)	Resolution (meters)
Band 1	0.45 - 0.52	30
Band 2	0.52 - 0.60	30
Band 3	0.63 - 0.69	30
Band 4	0.76 - 0.90	30
Band 5	1.55 - 1.75	30
Band 6	10.40 - 12.50	120
Band 7	2.08 - 2.35	30

Landsat 7 (ETM+ sensor)	Wavelength (micrometers)	Resolution (meters)
Band 1	0.45 - 0.515	30
Band 2	0.525 - 0.605	30
Band 3	0.63 - 0.69	30
Band 4	0.75 - 0.90	30
Band 5	1.55 - 1.75	30
Band 6	10.40 - 12.5	60
Band 7	2.09 - 2.35	30
Pan Band	.52 - .90	15

Συνδυασμός καναλιών για εντοπισμό χρήσεων –καλύψεων γης

Land Cover Type	Spectral Band Combination
Water	Band 1, 4 & 7 / Band 1, 2 & 3
Urban	Band 1,4 & 7
Farmland	Band 1, 2 & 3
Forest	Band 1, 4 & 7
Salt Scald (αλάτι)	Band 1, 2 & 3
Remnant Vegetation (μικρά ίχνη βλάστησης)	Band 1, 4 & 7
Irrigated Vegetation (αρδευόμενη βλάστηση)	Band 1, 4 & 7

Συμπεριφορά χρήσεων- καλύψεων γης στα 7 φασματικά κανάλια των εικόνων Landsat TM

Terrain Feature	Reflectance Response
Water Bodies	Generally reflect high in the visible spectrum, however, clearer water has less reflectance than turbid water. In the Near IR and Mid-IR regions water increasingly absorbs the light making it darker. This is dependent upon water depth and wavelength. Increasing amounts of dissolved inorganic materials in water bodies tend to shift the peak of visible reflectance toward the red region from the green region (clearer water) of the spectrum.
Soil	Northern latitudes have black soils and tropical regions have red soils. Soil reflectance decreases as organic matter increases. As soil moisture increases, reflectance of soil decreases at all wavelengths. Texture of soil will cause increased reflectance with decreased particle size, i.e., the bigger particles (rocks, sand, and soils) basically cast a larger shadow. **Καθώς η οργανική ουσία του εδάφους αυξάνει η ανάκλαση ελαττώνεται. Καθώς η υγρασία αυξάνει η ανάκλαση ελαττώνεται σ΄όλα τα μήκη κύματος.**
Vegetation	The spectral reflectance is based on the chlorophyll and water absorption in the leaf. Needles have a darker response than leaves. There will be various shades of vegetation based on type, leaf structure, moisture content and health of the plant. **Πευκοβελόνες έχουν σκουρότερη απόχρωση από τα φύλλα. Υπάρχουν διάφορες σκιάσεις ανάλογα με τον τύπο της βλάστησης τη δομή του φύλλου την υγρασία και την υγεία του φυτού.**
Man-Made Materials	Concrete and asphalt both display spectral curves that generally increase from the visible through the Near IR and Mid-IR regions. However, as concrete ages, it becomes darker and as asphalt ages it becomes lighter. Το τσιμέντο και η άσφαλτος έχουν αύξηση στην ανάκλαση από το ορατό στο υπέρυθρο. Όμως καθώς περνάει ο χρόνος το τσιμέντο φαίνεται σκουρότερο και η άσφαλτος πιο ανοιχτή
Snow and Ice	Old snow may develop a compacted crust and the moisture content increases which make it less reflective in the Near IR and Mid-IR region. It is possible to compare old and new snow by its Mid-IR reflectance.

Χρησιμότητα των χρωματικών απεικονίσεων στων εντοπισμό χρήσεων –καλύψεων γης

R, G, B	Potential Information Content
4,3,2	The standard "false color" composite. Vegetation appears in shades of red, urban areas are cyan blue, and soils vary from dark to light browns. Ice, snow and clouds are white or light cyan. Coniferous trees will appear darker red than hardwoods. This is a very popular band combination and is useful for vegetation studies, monitoring drainage and soil patterns and various stages of crop growth. Generally, deep red hues indicate broad leaf and/or healthier vegetation while lighter reds signify grasslands or sparsely vegetated areas. Densely populated urban areas are shown in light blue. This TM band combination gives results similar to traditional color infrared aerial photography. Η βλάστηση είναι σε αποχρώσεις του κόκκινου οι αστικές περιοχές σε κυανό και τα εδάφη ποικίλουν από σκούρο – ανοιχτό καφέ. Τα κωνοφόρα είναι σκούρο κόκκινο ενώ τα πλατύφυλλα πιο ανοιχτά. Είναι ο πιο δημοφιλής συνδυασμός. Χρήσιμος για μελέτες βλάστησης, αποστράγγιση, τύποι εδάφους και διάφορα στάδια ανάπτυξης των φυτών. Γενικά η βαθιά κόκκινη χροιά δείχνει υγιείς βλάστηση ενώ το πιο φωτεινό κόκκινο χορτολιβαδα ή διάσπαρτη βλάστηση.
3,2,1	The "natural color" band combination. Because the visible bands are used in this combination, ground features appear in colors similar to their appearance to the human visual system, healthy vegetation is green, recently cleared fields are very light, unhealthy vegetation is brown and yellow, roads are gray, and shorelines are white. This band combination provides the most water penetration and superior sediment and bathymetric information. It is also used for urban studies. Cleared and sparsely vegetated areas are not as easily detected here as in the 4 5 1 or 4 3 2 combination. Clouds and snow appear white and are difficult to distinguish. Also note that vegetation types are not as easily distinguished as the 4 5 1 combination. The 3 2 1 combination does not distinguish shallow water from soil as well as the 7 5 3 combination does.
7,4,2	This combination provides a "natural-like" rendition, while also penetrating atmospheric particles and smoke. Healthy vegetation will be a bright green and can saturate in seasons of heavy growth, grasslands will appear green, pink areas represent barren soil, oranges and browns represent sparsely vegetated areas. Dry vegetation will be orange and water will be blue. Sands, soils and minerals are highlighted in a multitude of colors. This

	band combination provides striking imagery for desert regions. It is useful for geological, agricultural and wetland studies. If there were any fires in this image they would appear red. This combination is used in the fire management applications for post-fire analysis of burned and non burned forested areas. Urban areas appear in varying shades of magenta. Grasslands appear as light green. The light-green spots inside the city indicate grassy land cover - parks, cemeteries, golf courses. Olive-green to bright-green hues normally indicate forested areas with coniferous forest being darker green than deciduous. Η υγιής βλάστηση είναι ανοιχτό πράσινο ενώ τα χορτολίβαδα πράσινα. Αγονη γη χρώμα ροζ ενώ με πορτοκαλί – καφέ η αραιή βλάστηση. Εάν υπάρχουν περιοχές με φωτιά χρώμα κόκκινο. Εντοπισμός καμένων μη καμένων εκτάσεων. Αστικές περιοχές χρώμα μαντζέντα. Το σκούρο πράσινο δείχνει κωνοφόρα ενώ το ανοιχτό φυλλοβόλα.
4,5,1	Healthy vegetation appears in shades of reds, browns, oranges and yellows. Soils may be in greens and browns, urban features are white, cyan and gray, bright blue areas represent recently clearcut areas and reddish areas show new vegetation growth, probably sparse grasslands. Clear, deep water will be very dark in this combination, if the water is shallow or contains sediments it would appear as shades of lighter blue. For vegetation studies, the addition of the Mid-IR band increases sensitivity of detecting various stages of plant growth or stress; however care must be taken in interpretation if acquisition closely follows precipitation. Use of TM 4 and TM 5 shows high reflectance in healthy vegetated areas. It is helpful to compare flooded areas and red vegetated areas with the corresponding colors in the 3 2 1 combination to assure correct interpretation. This is not a good band combination for studying cultural features such as roads and runways. Η υγιής βλάστηση εμφανίζεται σε αποχρώσεις του κόκκινου, πορτοκαλί, κίτρινο. Τα εδάφη είναι πράσινα – καφέ. Αστικές επιφάνειες άσπρες, κυανό, γκρι. Ανοιχτό μπλε δείχνουν πρόσφατα κομμένες εκτάσεις ενώ οι κοκκινωπές περιοχές δείχνουν νέα βλάστηση μάλλον διάσπαρτα χορτολίβαδα. Ανιχνεύει διάφορα στάδια ανάπτυξης του φυτού. Προσοχή στη υγρασία. Πρέπει να γίνεται ερμηνεία της περιοχής και με τη βοήθεια του 3,2,1 συνδυασμού. Όχι καλό για δρόμους
	This combination of near-IR (Band 4), mid-IR (Band 5) and red (Band 3) offers added definition of land-water boundaries and highlights subtle details not readily apparent in the visible bands alone. Inland lakes and streams can be located with greater precision when more infrared bands are used. With this band combination, vegetation type and condition show as variations of hues (browns, greens and oranges), as well as in tone. The 4,5,3 combination demonstrates moisture differences and is useful for analysis of soil and vegetation conditions. Generally, the wetter the soil, the darker it appears, because of the infrared absorption capabilities

4,5,3	of water. Ικανότητα εντοπισμού λεπτομερειών. Εντοπισμός λιμνών – ποταμών. Διαχωρισμός της βλάστησης με χρώματα καφέ – πράσινο – πορτοκαλί. Αποτύπωση υγρασίας. Το γόνιμο έδαφος πιο μαύρο.
7,5,3	This band combination also provides a "natural-like" rendition while also penetrating atmospheric particles, smoke and haze. Vegetation appears in shades of dark and light green during the growing season, urban features are white, gray, cyan or purple, sands, soils and minerals appear in a variety of colors. The almost complete absorption of Mid-IR bands in water, ice and snow provides well defined coast lines and highlighted sources of water within the image. Snow and ice appear as dark blue, water is black or dark blue. Hot surfaces such as forest fires and volcano calderas saturate the Mid-IR bands and appear in shades of red or yellow. One particular application for this combination is monitoring forest fires. During seasons of little vegetation growth the 7 4 2 combination should be substituted. Flooded areas should look very dark blue or black, compared with the 3 2 1 combination in which shallow flooded regions appear gray and are difficult to distinguish.
5,4,3	Like the 4 5 1 combination, this combination provides the user with a great amount of information and color contrast. Healthy vegetation is bright green and soils are mauve. While the 7 4 2 combination includes TM 7, which has the geological information, the 5 4 3 combination uses TM 5 which has the most agricultural information. This combination is useful for vegetation studies, and is widely used in the areas of timber management and pest infestation. Υγιής βλάστηση φωτεινό πράσινο και τα εδάφη με μωβ. Αυτός ο συνδυασμός κατάλληλος για αγροτικές μελέτες. Διαχείριση ξυλείας και μόλυνση.
5,4,1	This will look similar to the 7 4 2 combination in that healthy vegetation will be bright green, except the 5 4 1 combination is better for agricultural studies.
7,5,4	This combination involves no visible bands. It provides the best atmospheric penetration. Coast lines and shores are well defined. It may be used to find textural and moisture characteristics of soils. Vegetation appears blue. If the user prefers green vegetation, a 7 4 5 combination should be substituted. This band combination can be useful for geological studies.
5,3,1	This combination display topographic textures while 7 3 1 may display differences in rock types.

Περιγραφή των 7 καναλιών Landsat TM

Landsat Thematic Mapper (TM)

Band 1 (0.45 - 0.52u m): provides increased penetration of water bodies and also capable of differentiating soil and rock surfaces from vegetation and for detecting cultural features.

Band 2 (0.52 - 0.60u m): it is sensitive to water turbidity differences; it highlighted the turbid water in the Barkley Lake. Because it covers the green reflectance peak from leaf surfaces, it has separated vegetation (forest, croplands with standing crops) from soil. In this band barren lands urban areas and roads and highways have appeared as brighter (lighter) tone, but forest, vegetation, bare croplands, croplands with standing crops have appeared as dark (black) tone. Also the Kentucky Lake has appeared as black tone.

Band 3 (0.63 - 0.69u m): senses in a strong chlorophyll absorption region and strong reflectance region for most soils. It has discriminated vegetation and soil. But it couldn't separated water and forest. Forest land and water both have appeared as dark tone. This band has highlighted barren lands, urban areas, street pattern in the urban area and highways. It has also separated croplands with standing crops from bare croplands with stubble.

Band 4 (0.76 - 0.90u m): operates in the best spectral region to distinguish vegetation varieties and conditions. Because water is a strong absorber of near IR, this band has delineated water bodies (lakes and sinkholes), distinguished between dry and moist soils (barren land and croplands). In this band croplands and grasslands have showed higher reflectance (brighter tone) than the forest. This band has also separated croplands from bare croplands. Since standing crops (vegetation) has higher reflectance in the near IR region, they have appeared as brighter tone and due to presence of moisture content in the bare croplands, they have appeared as darker tone. In the band 4 barren lands, urban areas and highways have not been highlighted and they appeared as dark tone. Band 4 is useful for crop identification and emphasizes soil-crop and land-water contrast.

Band 5 (1.55 - 1.75u m): is sensitive to the turgidity or amount of water in plants. Band 5 has separated forest lands, croplands, water body distinctly. Forests have appeared as comparatively darker tone than the croplands (light gray).Band 5 has separated water body (dark tone) from barren lands, croplands, and grass lands (lighter tone). Since urban area and croplands have responded almost in same spectral reflectance band 5 could not be able to separate these areas.

Band 7 (2.08 -2.35u m): has separated land and water sharply. Band 7 has strong water absorption region and strong reflectance region for soil and rock. Urban area, croplands, highways, bare croplands have appeared as bright tone and water body, forest have appeared as dark tone.

Ratio transformations of the remotely sensed data can be applied to reduce the effects of environment. Ratios also provide unique information and subtle spectral-reflectance or color differences between surface materials that are often difficult to detect in a standard image. It is also useful for discriminating between soils and vegetation.

The number of possible ratio combinations for a multispectral sensor with P bands is n= P(P-1). Thus for the TM's six reflectance bands there are thirty different ratio combinations - 15 original and 15 reciprocal. For the purpose of this study ten band ratios were examined to identify **the LULC features**.

TM3/TM4: This ratio has defined barren lands and urban area uniquely. But it could not define water body, forests and croplands.

TM4/TM3: This ratio distinguished vegetation, water and croplands. It has enhanced forests, barren lands. Because forests or vegetation exhibits higher reflectance in near IR region (0.76 -0.90u m) and strong absorption in red region (0.63-0.69u m) region. This ratio uniquely defines the distribution of vegetation. The lighter the tone, the greater the amount of vegetation present.

TM5/TM7: This ratio separated land and water uniquely. Since soils exhibit strong absorption in the band 7 (2.08 -2.35u m) and high reflectance in band 5 (1.55 - 1.75u m), soil has been enhanced in this ratio. Land has appeared as lighter tone and water appeared as dark tone.

TM2/TM3: this ratio has distinguished croplands, barren lands sharply. But it hasn't separated croplands, forests and water body. Both forests and water body has appeared as lighter tone and barren land appeared has dark tone. It did not enhance urban area. Chlorophyll has strong reflectance in the band 2 (0.52 -0.60u m) region and strong absorption in the band 3(0.63 -0.69u m) region, vegetation has appeared as higher tone.

TM3/TM2: This ratio has separated forests and croplands. Because band 3 (0.63-0.69m m) is the red chlorophyll absorption band of healthy green vegetation and band 2 (0.52-0.69m m) is the reflectance band from leaf surfaces. This ratio can be useful to discriminate broad classes of vegetation. Croplands have appeared as lighter (brighter) tone and forests appeared as dark tone.

TM4/TM5: It enhances the water body, vegetation and presence of moisture content in the croplands. Water body has appeared as dark tone and vegetation as lighter tone. Because water is a strong absorber in near IR region (band4) and higher reflectance in band 5 region. It can be useful for discriminating water bodies from land.

TM5/TM4: It has separated water body from forest, barren lands and vegetation. In this ratio water has appeared as dark tone and forest, barren lands, bare croplands all have exhibited brighter tone.

TM5/TM7: It has separated water body from lands (soils). It has also enhanced presence of moisture in croplands. All water bodies appeared as dark tone. Both band 5 and band 7 are sensitive to moisture content variation in soils and vegetation. This ratio is useful for crop-drought studies and plant vigor investigations.

TM3/TM5: This ratio enhances barren lands, highways, street patterns within the urban areas and urban built-up or cemented areas. It could not enhance the clear water but it enhanced turbid water. This ratio is useful for observing differences in water turbidity. Barren lands, highways, urban and built-up areas have appeared as lighter tone and forests, water body and croplands appeared as dark tone.

TM7/TM2: This ratio has separated forests and croplands. But it could not separated forests from water body; both features have appeared as dark tone. It enhances highways, urban and built-up areas and croplands and all of them have appeared as lighter tone.

BACK

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Tutorial: Image interpretation quiz
Question 7

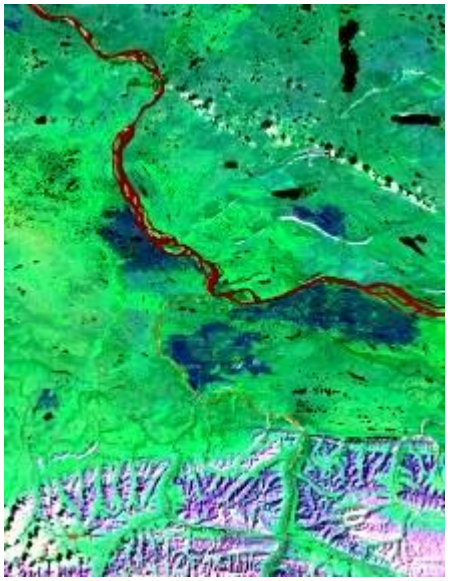
Match the band combinations with their respective images.

Landsat TM Band Combinations

- 3, 2, 1
- 3, 4, 5
- 4, 3, 2
- 5, 4, 3

Hints

A



Satellite image: Mackenzie River, N.W.T., LANDSAT TM

B

Satellite image: Mackenzie River, N.W.T., LANDSAT TM

C

D

Satellite image: Mackenzie River, N.W.T., LANDSAT TM Satellite image: Mackenzie River, N.W.T., LANDSAT TM

When looking at image "C": the dark brown areas in the middle of the image are forest fire scars, the white areas at the bottom of the image are snow-covered mountain tops, the light blue line across the middle of the image is a river. There is a diagonal line of small clouds (and cloud shadows) across the top right of the image. The small black areas are lakes.

Image Information

Mackenzie River, N.W.T.
LANDSAT TM

ΣΥΝΔΥΑΣΜΟΙ ΚΑΝΑΛΙΩΝ LANDSAT TM - ΧΡΗΣΙΜΟΤΗΤΑ

3, 2, 1
This combination is the only one that includes band 1 with its blue sensitivity. Therefore, this combination of bands and colour assignments is the closest that we can come to making a real-colour simulation.

TM band 1 is the band most affected by atmospheric scattering, so it shows clouds, haze and smoke the best.

3,4,5
The red-sensitive band (#3) that has a little water penetration ability is coded as red in this band combination. The other two bands have no significant water penetration ability, so any sediment-laden water body should appear as red.

4,3,2
This is the simulation of the traditional of false-colour infrared film which shows healthy vegetation in shades of red.

5,4,3
The red-sensitive band (#3) which has a little water penetration ability is coded as blue in this band combination. The other two bands have no significant water penetration ability, so any sediment-laden water body should appear as blue.

An Introductory Landsat Tutorial

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

The images contained on this set of CD-ROMs were obtained 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. The Landsat satellites observe the Earth, and the data that they collect have been used for almost 30 years to study the Earth's 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 collected by satellite systems built by other countries and commercial enterprises, but Landsat data are the standard for Earth observations, and Landsat is the only system of its type with the mission to collect, archive, and distribute data of all the Earth's land surface.

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," or ETM+. The operating dates of the Landsat satellites and the instruments on them are listed on Table 1.

	Launched	**Retired**	**Instruments**
Landsat-1 (ERTS-1)	July 23, 1972	January, 1978	RBV, MSS

Landsat-2	January 22, 1975	July, 1983	RBV, MSS
Landsat-3	March 5, 1978	September, 1983	RBV, MSS
Landsat-4	July 16, 1982	June, 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 sensors were not operational after July, 1987; the satellite was later used for maneuver testing.

The data on these CD-ROMs, called the GeoCover data set, cover the United States of America, including Alaska and Hawaii. The data set was produced by the Earth Satellite Corporation for NASA and contains approximately 900 TM images, or scenes. Each Landsat scene is about 115 miles long and 115 miles wide (or 100 nautical miles long and 100 nautical miles wide, or 185 kilometers long and 185 kilometers wide). This data set covers the United States around 1990 and came from observations acquired by the**Landsat-5 satellite**. 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. Within each image or picture, the smallest picture element, or pixel, covers a square 28.5 meters on a side. 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. That data square is about 94 feet on a side, or an area of about one fifth of an acre or about 0.08 hectare. The TM pixel size enables observation of large natural features, such as volcanos, rivers, and forests, and large man-made features. Major highways, office buildings (such as the Pentagon or US Capitol building), city parks and agricultural fields, airports, major bridges and dams are apparent, but narrow streets, creeks and streams, individual houses, and automobiles cannot be discerned.

Since the data are spread over 4 CD-ROMs, the United States was broken up into smaller areas called *tiles* or *mosaics*. Collections of tiles were put on each CD - one CD-ROM covers the eastern United States, another covers the central United States, a third CD-ROM covers the western United States, and one final CD-ROM covers Alaska and Hawaii. Each tile covers an area of 6 degrees of longitude (12 degrees of longitude at latitudes above than 60 degrees, affecting only Alaskan data) by 5 degrees of latitude. A description of the tiling scheme can be found in the GeoCover Product Description Sheet (GeoCover.doc; also Appendix 3.). 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.

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.

In addition to these bands, the ETM+ instrument 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. This panchromatic band has a spatial resolution of 15 meters, rather than the 28.5 or 30 meters of bands 1, 2, 3, 4, 5 and 7. The sensitivities of MSS, TM and ETM+ bands are listed in Table 2.

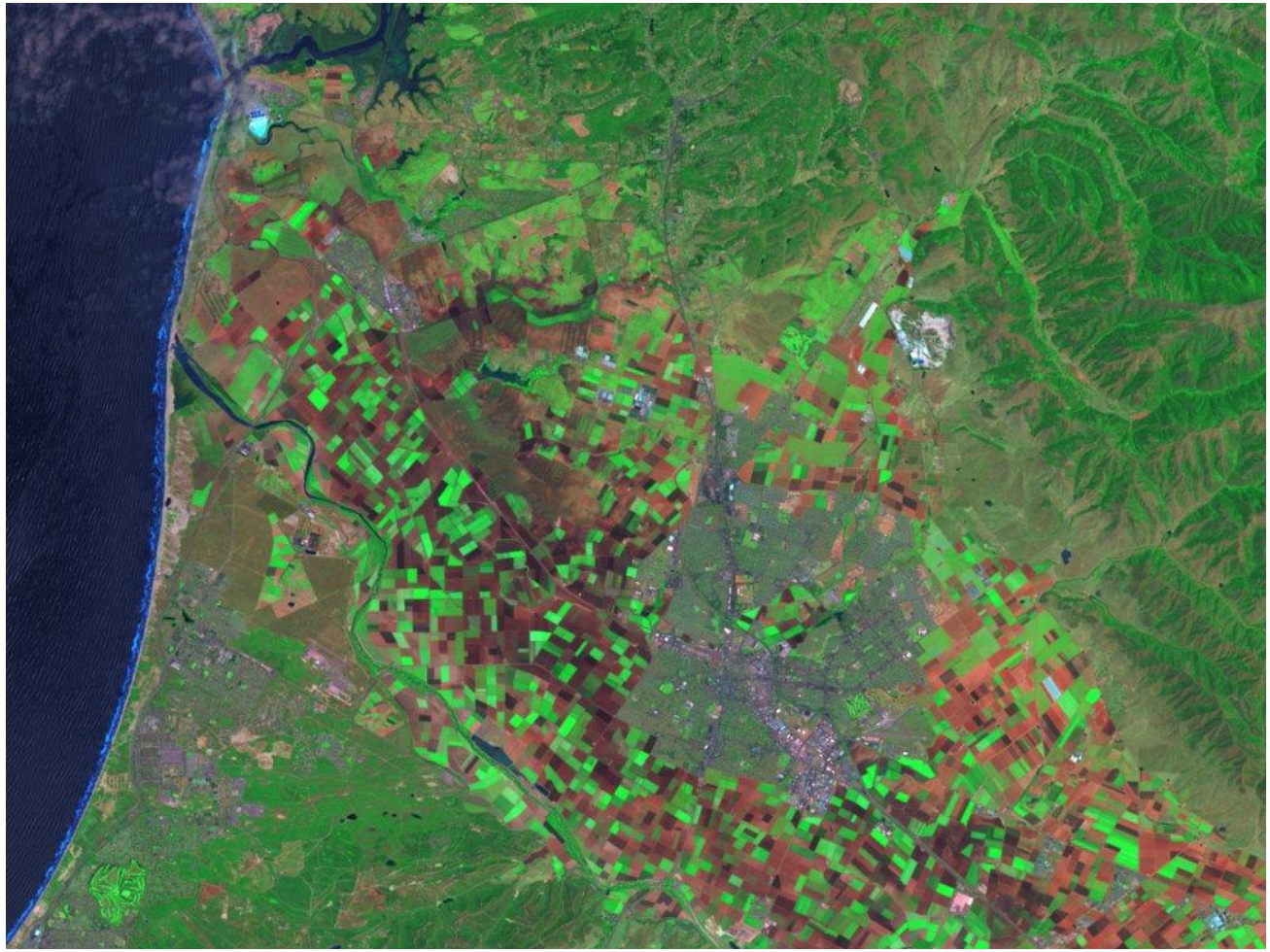
Band	RBV	MSS	TM	ETM+
1	.48-.57 µm green		**.45-.52 µm blue**	.45-.52 µm blue
2	.58-.68 µm red		**.52-.6 µm green**	.53-.61 µm green
3	.69-.83 µm IR		**.63-.69 µm red**	.63-.69 µm red
4		.5-.6 µm green	**.76-.9 µm NIR**	.75-.9 µm NIR
5		.6-.7 µm red	**1.55-1.75 µm SWIR**	1.55-1.75 µm SWIR
6		0.7-0.8 µm IR	**10.4-12.5 µm TIR**	10.4-12.5 µm TIR
7		0.8-1.1 µm IR	**2.08-2.35 µm SWIR**	2.1-2.35 µm SWIR
8				.52-.9 µm panchromatic

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

What do the different bands mean to us when we look at the data? To find out what each individual band sees best, or better than the others, check the Landsat-7 images shown in Appendix 2. 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 a different gray scale image feeding a different color gun (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.

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

False-Color, also called Near Infrared or NIR: In this image, band 2 is displayed in blue, band 3 is displayed in green, and band 4 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.



Short-Wavelength Infrared, or SWIR: In this SWIR image, band 2 is displayed in blue, band 4 is displayed in green, and band 7 (or 5) is displayed in red. This rendition looks like a jazzed up true color rendition - one with more striking colors.

This is the band combination was used in the GeoCover data set. It is built into the GeoCover data and cannot be changed. Further, the contrast and brightness have been altered in the GeoCover data set to make a more consistent overall mosaic.

The appearance of different surface features for the different composite images is summarized on Table 4.

	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

Table 4. Appearance of Features on Composite Images.

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

Agriculture, Forestry, and Range Resources:

Discrimination of vegetative types: Crop types, Timber types, Range vegetation.
Measurement of crop acreage by species (estimating crop yields)
Measurement of timber acreage and volume by species (monitoring forest harvest)
Determination of range readiness and biomass
Determination of vegetation vigor
Determination of vegetation stress
Determination of soil conditions
Determination of soil association
Assessment of grass and forest fire damage

Land Use and Mapping:

Classification of land uses
Cartographic mapping and map updating
Categorization of land capability
Separation of urban and rural categories (monitoring urban growth)
Regional planning
Mapping of transportation networks
Mapping of land-water boundaries
Mapping of fractures

Geology:

Recognition of rock types
Mapping of major geologic units
Revising geologic maps
Delineation of unconsolidated rock and soils
Mapping igneous intrusions
Mapping recent volcanic surface deposits
Mapping landforms
Search for surface guides to mineralization
Determination of regional structures
Mapping linears

Water Resources:

Determination of water boundaries and surface water area and volume
Mapping of floods and flood plains
Determination of areal extent of snow and snow boundaries (estimating snow melt runoff)
Measurement of glacial features
Measurement of sediment and turbidity patterns
Determination of water depth
Determination of irrigated fields
Inventory of lakes

Oceanography and Marine Resources:

Detection of living marine organisms
Determination of turbidity patterns and circulation
Mapping shoreline changes (tracing beach erosion)
Mapping of shoals and shallow areas
Mapping of ice for shipping
Study of eddies and waves

Environment:

Monitoring surface mining and reclamation
Mapping and monitoring of water pollution (e.g., tracing oil spills and pollutants)
Detection of air pollution and its effects
Determination of effects of natural disasters
Monitoring environmental effects of man's activities (e.g., lake eutrophication, defoliation, etc.)

Table: 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).

Feature	**Best Band**	**Gray-scale (black and white)**	**False Color, or NIR**
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, relative to normal vegetation
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.	

Bibliography

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/DAAC_DOCS/daac_ed.html

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

Useful internet URLs:

Landsat: http://landsat.gsfc.nasa.gov/ (Information plus links to tutorials, and to some free/sample data)

http://landsat7.usgs.gov/ (Information plus it is the public source for all Landsat data, although it is not free)

Landsat Data:

http://zulu.ssc.nasa.gov/mrsid/ (Additional free GeoCover data sets for downloading)

http://dmc.ohiolink.edu/GEO/LS7/ (Landsat images of Ohio for use by individuals for educational and research purposes)

http://aria.arizona.edu/ (Arizona Regional Image Archive, includes links and a land cover change tutorial)

http://www.bsrsi.msu.edu/trfic (Tropical Rain Forest Information Center, some low cost Landast imagery)

http://www.landsat4u.com/Merchant/index.html (Inexpensive images of the SW USA)

SENTINEL 2

Sentinel-2 Bands	Central Wavelength [micrometers]	Resolution [meters]
Band 1 - Coastal aerosol	0.443	60
Band 2 - Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 - Red	0.665	10
Band 5 - Vegetation Red Edge	0.705	20
Band 6 - Vegetation Red Edge	0.740	20
Band 7 - Vegetation Red Edge	0.783	20
Band 8 - NIR	0.842	10
Band 8A - Vegetation Red Edge	0.865	20
Band 9 - Water vapour	0.945	60
Band 10 - SWIR - Cirrus	1.375	60
Band 11 - SWIR	1.610	20
Band 12 - SWIR	2.190	20

Sentinel-2 images are freely available from the ESA website https://scihub.esa.int/dhus/ .

Band combinations for Sentinel-2. They can be found in SNAP menu, the RGB composite is as follows:

Natural Colors: 4 3 2
False color Infrared: 8 4 3
False color Urban: 12 11 4
Agriculture: 11 8 2
Atmospheric penetration: 12 11 8a
Healthy vegetation: 8 11 2
Land/Water: 8 11 4
Natural Colors with Atmospheric Removal: 12 8 3
Shortwave Infrared: 12 8 4
Vegetation Analysis: 11 8 4

INDICIES

NOTE 3: The Normalized Difference Water Index (NDWI) proposed by McFeeters[2] is designed to: maximize the reflectance of the water body in the green band; minimize the reflectance of water body in the NIR band. McFeeters's NDWI is calculated as:

$$NDWI = \frac{Green - NIR}{Green + NIR} = \frac{B3 - B8}{B3 - B8}$$

NOTE 2: The most commonly used metrics for burned area and burn severity mapping, derived from satellite data, is the normalized burn ratio (NBR).

$$NBR = \frac{NIR - SWIR}{NIR + SWIR}$$

Healthy vegetation has very high near-infrared reflectance and low reflectance in the shortwave infrared portion of the spectrum. Burned areas on the other hand have relatively low reflectance in the near-infrared and high reflectance in the shortwave infrared band. A high NBR value generally indicates healthy vegetation while a low value indicates bare ground and recently burned areas.