Exploring the Earth with Remote Sensing: Tucson

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1. Introduction

In this laboratory you will explore Tucson and its surroundings with *remote sensing*. Remote sensing is the use of information gathered from an object or place (the *target*), without physically touching it, to learn about it. One common example is using images of the Earth's surface, taken from aircraft or satellites, to explore places that are difficult to reach on the ground. This method is also used to learn about other planets, using images taken through telescopes, from satellites, or by surface landers.

Images of the target may be taken in visible light and shown in the colors we would see if we were there. These are called *true color* images. They may also be taken at wavelengths outside the range of human vision, selected to give particular kinds of information. In this case the image is displayed using *false color*. The invisible wavelengths are shown in a color that the eye can see, but the resulting color image is not how the target would look to our eyes if we were there.

This exercise uses images of the Tucson region taken by the Landsat 5 spacecraft. The Landsat satellites were designed to use remote sensing to characterize the natural environment of the entire Earth, and to monitor the planet for environmental changes. The images include true color and false color images. Since the spacecraft was intended to look for large scale characteristics and changes taking place over large regions, the images don't have fine detail.

The information in a remote sensing image may not always be completely certain. The image may be blurry, and different kinds of surfaces or objects may show the same color and shape. An important part of remote sensing is using *ground truth* to help understand what an image is showing us. This means visiting a target in person, to compare what is actually there to its appearance in a remote-sensing image. In this exercise, the ground truth will come from your personal knowledge—you live here!

Sometimes one uses ground truth from a target that is readily accessible to help understand images of another target. This is one way in which images of the planet Mars, taken from satellites and landers, are being interpreted—by comparison with features on Earth. We can't go to another planet in your class, but we can remotely explore another part of the Earth. In the last part of this exercise, you will use what you have learned to interpet images of a region in Chile, South America. Students in Chile are doing a similar lab, looking at images of southern Arizona. At the end of the lab, each group will use "robot landers" at the other location to take close-up photos of features that are unclear or mysterious in the Landsat images.

2. Orientation and scale

Accompanying this lab are three Landsat images of Tucson and one of a remote location. Two of the Tucson images are in false color, and one is in true color. The color images may be available on your computers. You will also have black and white or colored paper copies. You'll explore the meaning of the false colors in Section 4. Right now, we will think of each image as a map, and determine orientation (which way is north), scale (how big a real distance on the ground is on the map), and identify some major landmarks.

Begin with Figure 1, Tucson False Color Large. This is a false color image. This image is about 65 kilometers across left to right, and 45 kilometers top to bottom. It shows the major geographic features of the area. The city is the blue-green area in the center.

2.1 This image, like most maps, has North at the top, South at the bottom, East to the right, and West to the left. Write North, South, East, and West in the correct places on your paper copy.

Tucson is in a valley bounded by the Santa Catalina Mountains on the north, the Tucson Mountains on the west, and the Rincon Mountains on the east. The mountains look rough and wrinkled in the image (because they are rough and wrinkled!). Interstate 10 goes northwest to Phoenix between the Catalinas and the Tucson Mountains.

2.2 Label the Catalina, Tucson, and Rincon Mountains on your paper copy. Label Interstate 10 on your paper copy.

The Rillito River crosses this image from east to west, across the northern edge of the city, and south of the Catalina Mountains.

2.3 Label the Rillito River on your paper copy.

Now look at Figure 2, Tucson False Color Image Small, another false color image. This is zoomed in to show the city with more detail, and you'll be examining it closely. Around the edges of the image there is a grid of lines. These divide the image into blocks, The grid is labelled with letters (A-N) in the up-down direction and with numbers (1-19) in the left-right direction. These will be used to locate areas in the image.

For example, grid location I-11 is a block near the center of the image which contains a large, solid green area.

2.4 Find block I-11 on the image. Check here when you're sure you have found it. ________

Tucson streets are laid out on a very regular grid pattern. The major streets are 1.6 kilometers apart, east-west and north-south, over most of the city. They show up in the image as prominent straight dark lines that form a grid pattern. Use the street grid to estimate distances.

2.5 How large is Tucson, east to west ____________ km, and north to south __________ km.

2.6 Multiply the two dimensions from question 2.5 to get an estimate of the area of Tucson in square kilometers. ________ km X ___________ km = _____________ km^2

2.7 The most recent census indicates that about 500,000 people live in this area. What is the *population density*, the number of people per square kilometer? _____________________

2.8 New York City has a population density of 10,300 people per square kilometer. How does the population density of Tucson compare to that of New York?

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This image is composed of many small square *picture elements* or *pixels*. You may be able to detect something smaller than a pixel, but you can't see any detail in it—it will blur out to fill the whole pixel. We'll use the regular street grid again to determine the size of a pixel on the ground.

Pick an area near the image center where the square grid of major streets is easily seen. Now zoom the image on the computer screen until the individual pixels are visible between two of the major streets. In the sample image shown here, these would be the pixels between the heavy dark vertical line on the left, and the one on the right.

Sample image

2.9 Count the pixels in the image from one major street to the next one. This is a distance of 1.6 kilometers. How many pixels do you count in this distance? ___________

2.10 This distance equals 1600 meters. How big is a pixel, in meters? ____________

2.11 List three things found around you that are much larger than you are, but smaller than a single pixel in this image. You can't see any detail in the image for things of this size.

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3. Relief

Vertical relief is the variation in height of objects and terrain. This is easy to estimate from ground level. We can easily see that houses are taller than people, trees are taller than houses, and mountains are much taller than city buildings. However, relief can be difficult to determine in Landsat images. Shadows are the principal clue to height in downlooking images. Taller things cast longer shadows. But Landsat images are taken looking straight down and with the Sun nearly overhead, to minimize shadows. Only major features like mountains are tall enough to show shadows that indicate vertical relief in the images you are using.

Fig. 2 includes most of the Tucson Mountains on the left, and part of the Catalinas in the upper right corner. Examine these mountainous areas. Most of the very dark areas are shadows.

3.1 Where is the highest terrain in Fig. 2? ___________________________________

3.2 What are the reasons for your answer? __________________________________

When you are outdoors on a sunny day, your shadow lies on the opposite side of you from where the Sun is. Look at which side of the mountains their shadows lie.

3.3 From what direction was the Sun shining when this image was taken? _________________

On less steep terrain than mountains, there are indirect clues to vertical relief. Look at the urban area that occupies the central part of the image. Notice how straight the streets are. It's hard to build a street in a straight line up and down steep hills or across canyons.

3.4 What does this suggest about the terrain in the Tucson valley? _______________________

Look at how the major rivers and washes connect to each other.

3.5 Which direction does water flow as it crosses the Tucson valley? _____________________

3.6 What does this suggest about the overall tilt of the Tucson valley? ____________________

4. False color

Now you'll investigate what can be learned from the colors in Fig. 2. It is a false color image, created by combining separate black-and-white images in blue-green visible light, near infrared radiation just beyond the red end of what our eyes can detect, and mid infrared radiation at about four times the wavelength of visible light. The translation to false color is

visible light	→	blue in Fig. 2
near infrared	→	green in Fig. 2
mid infrared	→	red in Fig. 2

These wavelengths were chosen because they are known to give information about different sorts of things on the Earth's surface, such as the presence of vegetation, or the kinds of minerals in the soil.

The individual colors show the amount of sunlight reflected by a surface at each wavelength. Reflected light reaches your eyes (or the Landsat cameras). Light that hits a surface and is absorbed disappears.

For example, if an object reflected most of the visible light that fell on it, but absorbed the infrared wavelengths, it would show up as bright blue in the Landsat false color image.

4.1 What color would an object be in this image if it absorbed visible and near infrared light, but reflected mid infrared light? __________________

4.2 What color would a surface be if it absorbed all the energy that fell on it and reflected nothing? ___________________________

Now you'll use ground truth—your knowledge of what some things in the image actually are—to see what information can be gotten from colors in the image. Recall that more than one sort of surface may show up as the same color.

Figure 3 is a true color image of the central part of Fig. 2. It shows things in the colors your eye would actually see. It also has a little more detail than Figure 2. It's included for comparison, to help you understand what the false color image is showing. The questions below refer to Figures 1 and 2. You may want to examine Figure 3 to help you answer some of the questions.

In Fig. 2, look at the large, bright green rectangle in location I-11. This is Randolph Golf Course.

4.3 What covers the surface of a golf course? ___________________

Go back to Fig. 1 and look at the highest part of the Catalina Mountains, in the upper right corner.

4.4 What color is it? How does this compare to the golf course? ____________________

4.5 What covers the tops of the mountains, that we don't have down in the desert?

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Near infrared radiation, represented as green in this image, is highly reflected by *chlorophyll* in the leaves of green plants. The visible light and mid-infrared wavelengths are mostly absorbed. So any kinds of plants—grass, trees, bushes, orchards, or leafy field crops—will show up as bright green. We can't always tell the difference between different kinds of vegetation, only that some kind of vegetation is present. And these areas would *not* look such a bright green to our eyes—remember, green in this image means reflectance of wavelengths we can't see at all.

Return to Fig. 2. There are patches of green, smaller than Randolph Golf Course, scattered throughout the city. Examples are at E-10 and I-15.

4.6 Find two more examples. Write their coordinates here. ____________ _______________

4.7 Suggest some possibilities about what these might be. More than one thing is possible. Think about their *size*, *shape*, and *location*. These may indicate the more likely possibilities. You may know exactly what one of these is already—that's OK, that's ground truth!

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4.8 Go back to Fig. 1 and examine the green shapes in the extreme upper left corner. These are far outside the city. Think about their size, shape, location, and the shapes around them in other colors. What might these green areas be?

____

Tucson streets are paved with asphalt, which is grey-black in visible light.

4.9 What color are the streets in these images? ___________________________

4.10 What does that tell you about the reflectance of asphalt beyond the visible spectrum, in the infrared? ____

There is a small lake in Kennedy Park. It shows up in Fig. 2 as a dark blotch at grid location K-5/6 (right on the line between 5 and 6). Zoom in on this area in the image.

4.11 What does this tell you about the reflectance of water in this image?

____

Size, shape, and location are other clues that can be combined with color to figure out what you're looking at. There are dark rectangular shapes next to streets all over the city. An example is at H-13.

4.12 Are these more likely to be water or asphalt? ______________________________

What do you think they are? _____________________________________

Much of the area of central Tucson, where the square street grid is, is covered with houses and yards, small office buildings, and stores. This is a typical urban environment.

4.13 What is the dominant color of this area? ____

Since everything inside a pixel blurs together, this color represents the average reflectance of the mixture of surfaces found in the city.

The Rillito River was dry when this image was taken. We know it has a sandy bed without much vegetation.

4.14 What color is it? This is the color of bare sandy soil in this image. __________________

4.15 What color would the river be if water was flowing in it? ____________________________

Zoom in on grid location H-11, just north of Randolph Golf Course. There is a blocky white shape inside a dark rectangle, in the middle of the city, next to a street.

4.16 What is the approximate size, in meters, of the white object (remember how large a pixel is)?

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4.17 What do you notice about its shape or outline? _______________________________

4.18 Do you think this is just a big patch of sandy ground? What else might it be? __________

____

4.19 What do you think the big dark rectangle around it is? __________________________

To end this section, use what you've learned above to complete the table below. It will be a useful guide to using false color, shape, size, and location as clues to what you are seeing in an unfamiliar, remote location. *Color* is the color you see in Figs. 1 and 2. *Shape* is a description such as round, rectangular, long and thin, irregular, etc. *Size* should be estimated in meters, using the size in pixels and the meters per pixel from Question 2.10. This doesn't need to be exact; it just sorts out large, medium, and small things. *Location* is what you notice about the placement of something relative to other things. *Surface* is what kind of surface is reflecting the light to produce the false color, and *target* is what the object actually is. You've figured these out by working through the questions in Section 4. The first entries of the table have been completed as an example, and there are clues for some of the other entries. There are extra blank rows where you can add things if you want to.

4.20 Summary table for Section 4.

Color	Shape	Size, meters	Location	Surface	Target
Very dark purple	thin straight line	1000's	in city	asphalt	streets
	round or irregular	about 100	edges of city	water	small lakes
	rectangular	50-200	in city next to streets	asphalt	parking lots
	irregular	100 's - 1000's	in mountains	not a surface	shadows
Bright green	rectangular		in city		
	irregular		in city		
	irregular		edges of city		
Whitish	long, thin, wavy				
	rectangular				
Light blue	can't tell	fills many pixels			

5. Exploring a remote location

Now you'll take what you have learned by exploring Tucson in Landsat images and apply it to another place. Figure 4 is a Landsat image of the region around the cities of La Serena and Coquimbo, in the Atacama Desert of Chile. Tucson and La Serena have many similarities. They are both in desert regions, have mining and tourism as major economic forces, and are centers for astronomy due to their clear skies. You will explore some of the natural and manmade features in Figure 4. It has the same size and scale as Figure 2 of Tucson. Use what you have learned about the clues provided by color, size, shape, and location, to figure out what you are looking at.

Let's start with the large scale geographic features.

5.1 Give the general locations of mountainous areas in Figure 4. You can use grid coordinates, or, since the mountains cover a lot of area, general terms like "left middle" or "lower right".

____

5.2 Find two rivers in the image. Describe where they are, and which way you think water flows in them.

____

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5.3 Did these rivers contain water when the image was taken? How can you tell?

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5.4 What do you think is the large dark area on the left side of the image? Why?

____

5.5 What is the dominant color over most of the image, outside of the city area? What do you expect to find there, from this color?

____

5.6 The area around La Serena is a desert. What might produce this coloring near the city?

____

5.7 Where are the urban areas? Are the cities of La Serena and Coquimbo, together, larger or smaller in size than Tucson?

____

5.8 The population of Tucson is about 500,000 people. How many people do you think live in the La Serena-Coquimbo urban area? ____

5.9 What color are the urban areas? Is this the same as for Tucson (Fig. 2)? What differences between the cities does this suggest?

____

5.10 In Fig. 2, Interstate 10 crosses Tucson from N-13 to A-2/3. It connects Tucson to other cities. Find a road in Figure 3 that passes through La Serena and Coquimbo, and looks like a major highway. Locate it with grid coordinates.

____

5.11 There are rectangular areas of different colors outside the cities, around N-8 and G-12 in Fig. 3. What do you think these are? Why?

____

5.12 Look at the blocky white shapes in a dark patch at G-7. What do you think this is? Why?

____

5.13 There is a white patch at the end of a long dark streak in the upper left-hand corner of H-8. What do you think this is? Why? Is there more than one possibility?

____

5.14 Look at the long dark streak from G-11/12 to I-14 in Figure 3. Is there anything like it in the Tucson image (Fig. 2)? What do you think it might be?

____

5.15 There is a golf course near La Serena. Can you find it? If you can't find it, what is giving you trouble?

____

So far, you have examined La Serena from a satellite in orbit above it. Now imagine that you have commanded a lander to land on the surface and send out a robot. You can send the robot to take pictures of things close up, and transmit the pictures back to you. Locate something in Figure 3, using grid coordinates and description, that you want your robot to investigate. This should be something you're not entirely sure about. What do you think it may be? What is uncertain?

5.16 Target location and description: ____

5.17 Your initial guess about what it may be: ______________________________________

Your "robot" will be a student in La Serena who will go to the location you've specified, take pictures with a digital camera, and send them to you. The La Serena students are doing the same lab, with Tucson as their remote location, so you will be robots for them.

5.18 What did your target turn out to be? Did you guess more or less correctly? If not, what new information did the robot photo provide that cleared up this mystery?

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