

MODULE – 2 LECTURE NOTES – 3

RADIOMETRIC AND TEMPORAL RESOLUTIONS

1. Introduction

In remote sensing the term resolution is used to represent the resolving power, which includes not only the capability to identify the presence of two objects, but also their properties. In qualitative terms the resolution is the amount of details that can be observed in an image. Four types of resolutions are defined for the remote sensing systems.

- Spatial resolution
- Spectral resolution
- Temporal resolution
- Radiometric resolution

The previous lecture covered the details of the spatial and spectral resolution. This lecture covers the radiometric and temporal resolutions, in detail.

2. Radiometric resolution

Radiometric resolution of a sensor is a measure of how many grey levels are measured between pure black (no reflectance) to pure white. In other words, radiometric resolution represents the sensitivity of the sensor to the magnitude of the electromagnetic energy.

The finer the radiometric resolution of a sensor the more sensitive it is to detecting small differences in reflected or emitted energy or in other words the system can measure more number of grey levels.

Radiometric resolution is measured in bits.

Each bit records an exponent of power 2 (e.g. 1 bit = $2^1 = 2$). The maximum number of brightness levels available depends on the number of bits used in representing the recorded energy. For example, Table 1 shows the radiometric resolution and the corresponding brightness levels available.

Table 1. Radiometric resolution and the corresponding brightness levels

Radiometric resolution	Number of levels	Example
1 bit	$2^1 - 2$ levels	
7 bit	$2^7 - 128$ levels	IRS 1A & 1B
8 bit	$2^8 - 256$ levels	Landsat TM
11 bit	$2^{11} - 2048$ levels	NOAA-AVHRR

Thus, if a sensor used 11 bits to record the data, there would be $2^{11}=2048$ digital values available, ranging from 0 to 2047. However, if only 8 bits were used, then only $2^8=256$ values ranging from 0 to 255 would be available. Thus, the radiometric resolution would be much less.

Image data are generally displayed in a range of grey tones, with black representing a digital number of 0 and white representing the maximum value (for example, 255 in 8-bit data). By comparing a 2-bit image with an 8-bit image, we can see that there is a large difference in the level of detail discernible depending on their radiometric resolutions. In an 8 bit system, black is measured as 0 and white is measured as 255. The variation between black to white is scaled into 256 classes ranging from 0 to 255. Similarly, 2048 levels are used in an 11 bit system as shown in Fig.1.

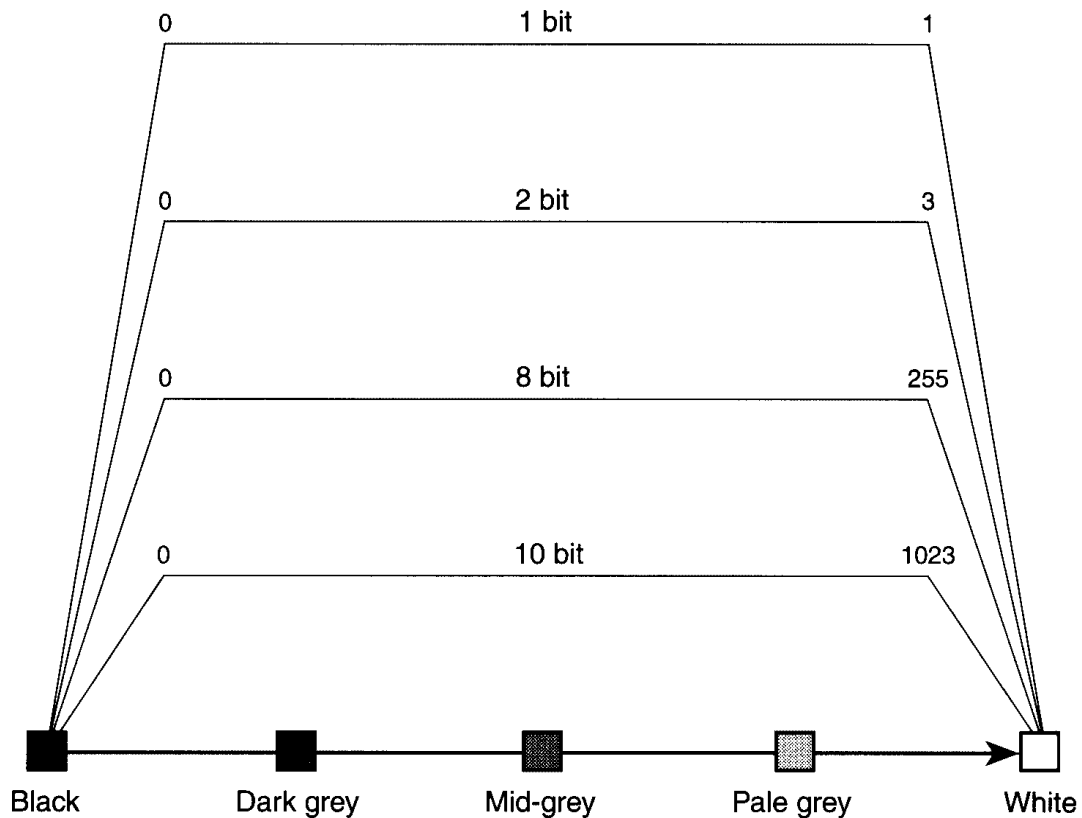


Fig.1 Variation in the brightness levels recorded at different radiometric resolution

(Source: Gibson 2000)

Finer the radiometric resolution, more the number of grey levels that the system can record and hence more details can be captured in the image.

Fig.2 shows the comparison of a 2-bit image (coarse resolution) with an 8-bit image (fine resolution), from which a large difference in the level of details is apparent depending on their radiometric resolutions.

As radiometric resolution increases, the degree of details and precision available will also increase. However, increased radiometric resolution may increase the data storage requirements.

2 Bit Data (Coarse)



8 Bit Data (Fine)



Fig.2 Comparison of a coarse resolution 2-bit image with a fine resolution 8-bit image

In an image, the energy received is recoded and represented using Digital Number (DN). The DN in an image may vary from 0 to a maximum value, depending up on the number of gray levels that the system can identify i.e., the radiometric resolution. Thus, in addition to the energy received, the DN for any pixel varies with the radiometric resolution. For the same amount of energy received, in a coarse resolution image (that can record less number of energy level) a lower value is assigned to the pixel compared to a fine resolution image (that can record more number of energy level). This is explained with the help of an example below.

Example: A RS system with a radiometric resolution of 6 bits assigns a DN of 28, 45 and 48 to three surfaces. What would be the equivalent DNs for the same surfaces if the measurements were taken with a 3 bit system?

The DN's recorded by the 3-bit system range from 0 to 7 and this range is equivalent to 0-63 for the 6 bit system.

0	1	2	3	4	5	6	7	(3 bit)
0	9	18	27	36	45	54	63	(6 bit)

Therefore a DN of 28 on the 6-bit system will be recorded as 3 in the 3-bit system. A 6-bit system could record the difference in the energy at levels 45 and 47, whereas in a 3-bit system both will be recorded as 5.

Therefore when two images are to be compared, they must be of same radiometric resolution.

3. Temporal Resolution

Temporal resolution describes the number of times an object is sampled or how often data are obtained for the same area

The absolute temporal resolution of a remote sensing system to image the same area at the same viewing angle a second time is equal to the **repeat cycle** of a satellite.

The repeat cycle of a near polar orbiting satellite is usually several days, eg., for IRS-1C and Resourcesat-2 it is 24 days, and for Landsat it is 18 days. However due to the off-nadir viewing capabilities of the sensors and the sidelap of the satellite swaths in the adjacent orbits the actual revisit period is in general less than the repeat cycle.

The actual temporal resolution of a sensor therefore depends on a variety of factors, including the satellite/sensor capabilities, the swath overlap, and latitude.

Because of some degree of overlap in the imaging swaths of the adjacent orbits, more frequent imaging of some of the areas is possible. Fig. 3 shows the schematic of the image swath sidelap in a typical near polar orbital satellite.

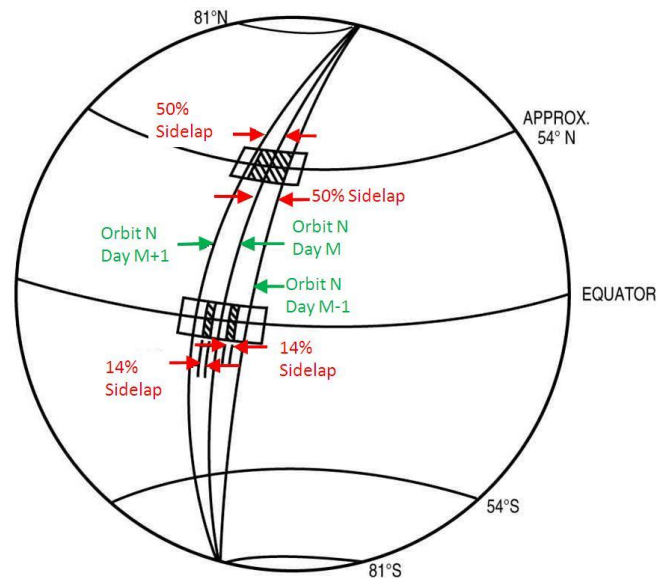


Fig.3 Sidelap in a typical near polar satellite orbit (Source: <http://eros.usgs.gov/>)

From Fig.3 it can be seen that the sidelap increases with latitude. Towards the polar region, satellite orbits come closer to each other compared to the equatorial regions. Therefore for the polar region the sidelap is more. Therefore more frequent images are available for the polar region. Fig. 4 shows the path of a typical near-polar satellite.

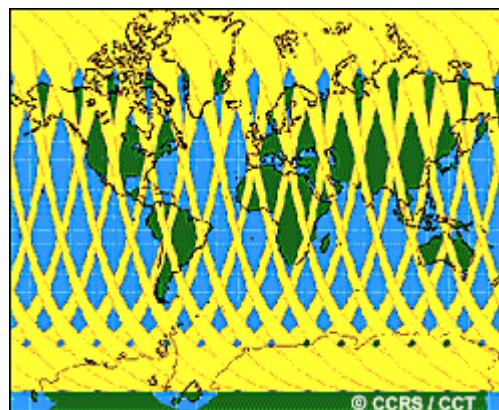


Fig.4. Orbit of a typical near-polar satellite (Source: <http://www.nrcan.gc.ca/earth-sciences>)

In addition to the sidelap, more frequent imaging of any particular area of interest is achieved in some of the satellites by pointing their sensors to image the area of interest between different satellite passes. This is referred as the off-nadir viewing capability.

For example: using pointable optics, sampling frequency as high as once in 1-3 days are achieved for IKONOS, whereas the repeat cycle of the satellite is 14 days.

Images of the same area of the Earth's surface at different periods of time show the variation in the spectral characteristics of different features or areas over time. Such multi-temporal data is essential for the following studies.

- Land use/ land cover classification
- Temporal variation in land use / land cover
- Monitoring of a dynamic event like
 - Cyclone
 - Flood
 - Volcano
 - Earthquake

Flood studies: Satellite images before and after the flood event help to identify the aerial extent of the flood during the progress and recession of a flood event. The Great Flood of 1993 or otherwise known as the Great Mississippi and Missouri Rivers Flood of 1993, occurred from April and October 1993 along the Mississippi and Missouri rivers and their tributaries. The flood was devastating affecting around \$15 billion and was one of the worst such disasters occurring in United States. Fig.5 shows the landsat TM images taken during a normal period and during the great flood of 1993. Comparison of the two images helps to identify the inundated areas during the flood.

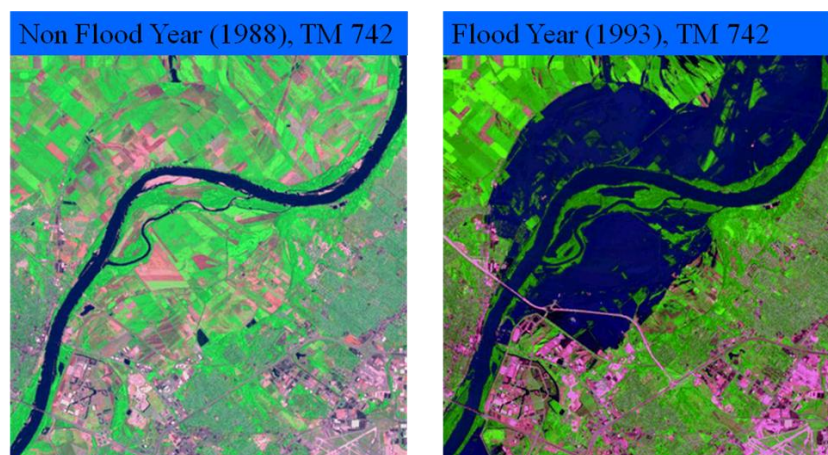


Fig.5 Landsat TM images of the Mississippi River during non-flood period and during the great flood of 1993

Land use/ land cover classification: Temporal variation in the spectral signature is valuable in land use/ land cover classification. Comparing multi-temporal images, the presence of features over time can be identified, and this is widely adopted for classifying various types of crops / vegetation. For example, during the growing season, the vegetation characteristics change continuously. Using multi-temporal images it is possible to monitor such changes and thus the crop duration and crop growth stage can be identified, which can be used to classify the crop types viz., perennial crops, long or short duration crops.

Fig. 6 shows the MODIS data product for the Krishna River Basin in different months in 2001. Images of different months of the year help to differentiate the forest areas, perennial crops and short duration crops.

Continuous Streams of MODIS Data Products

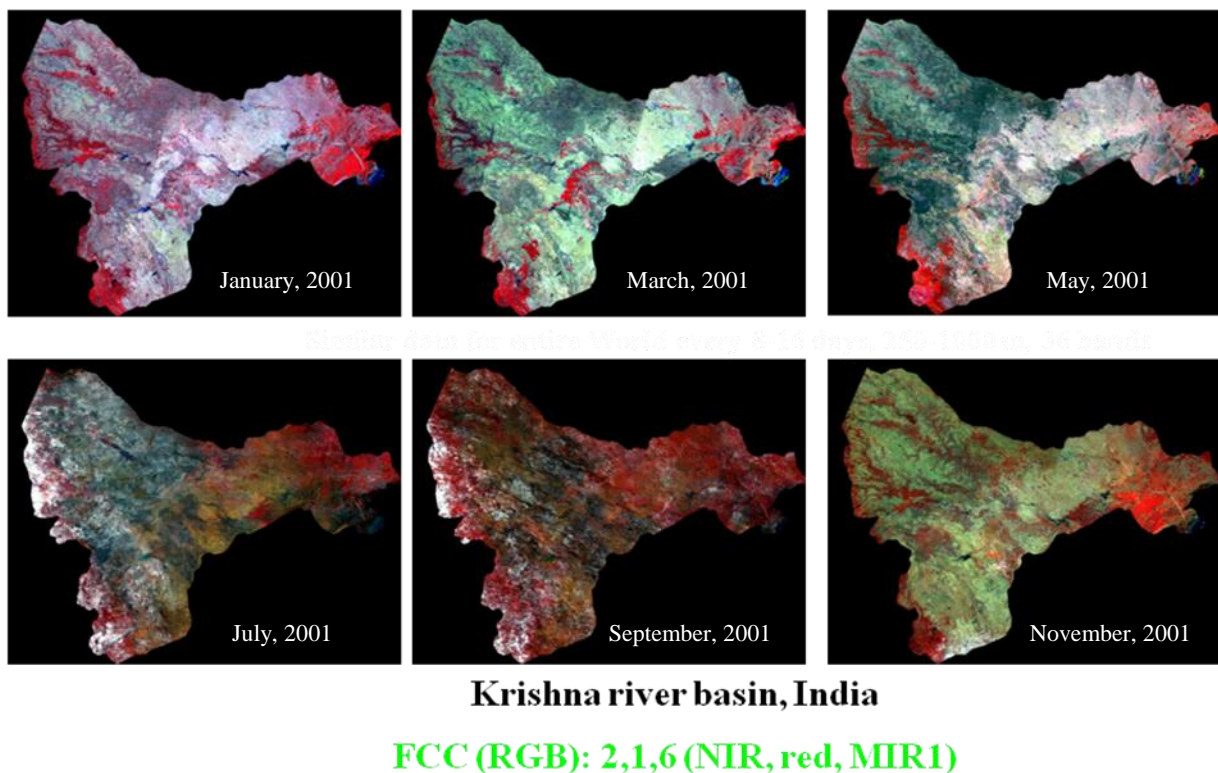


Fig.6 False Color Composites (FCC) of the Krishna River Basin generated from the MODIS data for different months in 2001.

The figure represents False Color Composites (FCC) of the river basin. The concepts regarding color composites have been explained in module 4.

4. Signal-to-Noise Ratio

The data recorded on a sensor are composed of the signal (say reflectance) and noise (from aberrations in the electronics, moving parts or defects in the scanning system as they degrade over time). If the signal-to-noise ratio (SNR) is high, it becomes easy to differentiate the noise from the actual signals. SNR depends on strength of signal available and the noise of the system.

Increasing the spectral and spatial resolution reduces the energy received or the strength of the signal. Consequently, the SNR decreases. Also, finer radiometric resolution results in larger number of grey levels and if the difference in the energy level between the two levels is less than the noise, reliability of the recorded grey level diminishes.

5. Trade-offs between spatial, spectral and radiometric resolution

In remote sensing, energy recorded at the sensor depends on the spatial and spectral resolution of the sensor.

Radiometric resolution of the sensor varies with the amount of energy received at the sensor. Fine spatial resolution requires a small IFOV. Smaller the IFOV, smaller would be the area of the ground resolution cell and hence less energy is received from that area. When the energy received is less, lesser would be the ability of the sensor to detect the fine energy differences, thereby leading to poor radiometric resolution.

Use of narrow spectral bands increases the spectral resolution, whereas it reduces the energy received at the sensor in the particular band. A wider band increases the reflected energy. To increase the amount of energy received and hence to improve the radiometric resolution without reducing the spatial resolution, broader wavelength band can be used. However, this would reduce the spectral resolution of the sensor.

Thus, there are trade-offs between spatial, spectral, and radiometric resolution. These three types of resolution must be balanced against the desired capabilities and objectives of the sensor.

Thus, finer spatial, spectral and radiometric resolutions of a system may decrease the SNR to such an extent that the data may not be reliable.

Bibliography / Further Reading

1. Gibson P.J (2000) “Introductory Remote Sensing- Principles and Concepts”
Routledge, London.