CHAPTER 1

INTRODUCTION

1.1 REMOTE SENSING

Remote sensing is the art and science of sensing the information of an object without coming into physical contact. Remote sensing refers to sensing of the parameters of the surface of the earth as well as of the atmosphere by using sensors working in different frequency ranges or bands of the electromagnetic spectrum. The most common types of bands used in remote sensing are- visible band, infrared band and microwave band [1, 8].

The types of remote sensing broadly include active and passive remote sensing. Active remote sensors have their own sources of illumination and detectors. The example of an active remote sensor is a Synthetic Aperture Radar (SAR). However, the passive remote sensors have only detectors to detect the radiation from the target. Example of a passive remote sensor is a radiometer [2].

The sensors used in remote sensing are installed on different platforms, such as- a spacecraft, an aircraft, a balloon, an Unmanned Air Vehicle (UAV) or ground based (sensor on a platform on the ground) [2].

Different bands as well as sensing platforms have different utilities. Depending on the sensitivity to various target features, the sensing mechanisms and configurations are selected.

One of the very important spectrums of frequencies in the electromagnetic spectrum is the Microwave range. The utility of the microwaves in remote sensing is different from optical as well as infrared remote sensing. The following section introduces this unique type of remote sensing called Microwave Remote Sensing and its basic principles.

1.2 MICROWAVE REMOTE SENSING

The microwave portion of the spectrum covers the range from approximately 1 cm to 1 m in wavelength. Because of their long wavelengths, compared to the visible and infrared ranges, microwaves have special properties that are important for remote sensing. Microwave remote sensing encompasses both active and passive forms of remote sensing. A special characteristic of microwaves is that the longer wavelength microwave radiation can penetrate through cloud cover, haze, dust, and all but the heaviest rainfall. This is possible due to the longer wavelengths of the microwaves, which are not susceptible to atmospheric scattering. Shorter optical wavelengths cannot do the same. This characteristic allows detection of microwave energy under almost all weather and all environmental conditions, and data can be collected at any time. Typical Microwave frequencies and their position in the electromagnetic spectrum are shown in Figure 1.1.

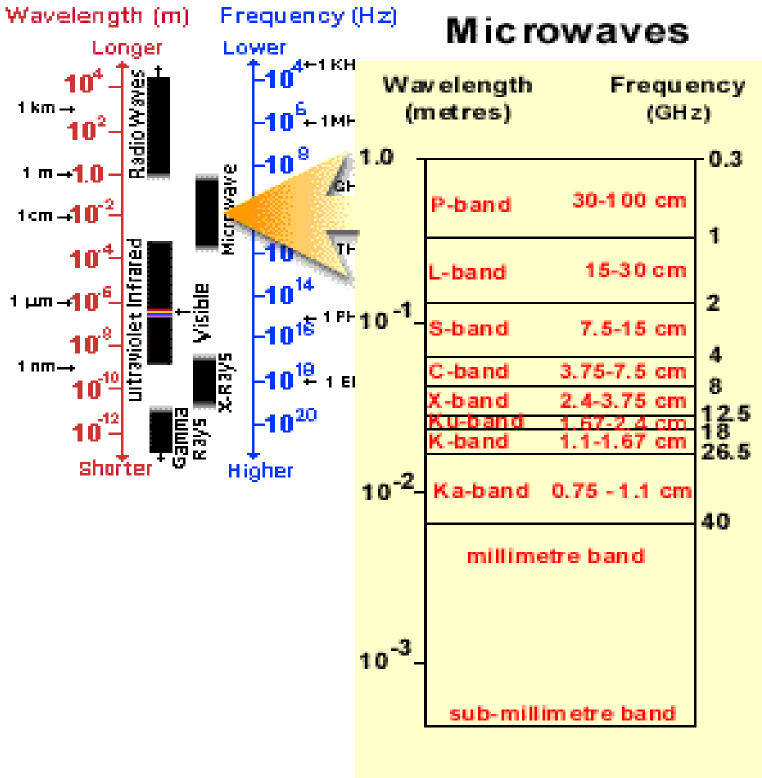

Figure 1.1: Position of Microwaves in the Electromagnetic Spectrum [62]

All objects emit microwave energy of some magnitude, but the amounts are generally very small. A passive microwave sensor detects the naturally emitted microwave energy within its field of view. This emitted energy is related to the temperature and moisture content of the emitting object or surface. Passive microwave sensors are typically radiometers or scanners and an antenna is used to detect and record the microwave energy emitted by the target.

The microwave energy recorded by a passive sensor can be- (1) emitted by the atmosphere, (2) reflected from the surface, (3) emitted from the surface, or (4) transmitted from the subsurface (Figure 1.2). Because the wavelengths are longer, the energy available is smaller compared to optical wavelengths. Thus, the fields of view must be large to detect enough energy to record a signal. Most passive microwave sensors are therefore characterized by low spatial resolution.

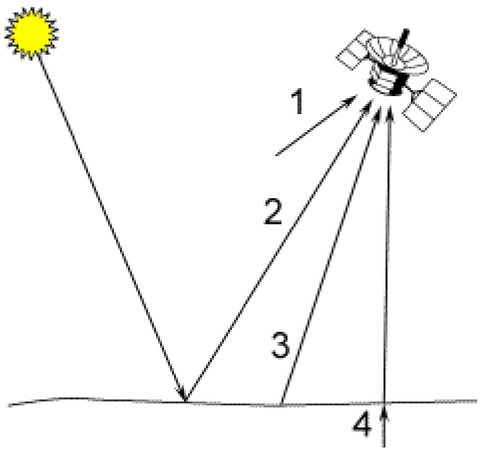

Figure 1.2: Passive Microwave Sensing

Applications of passive microwave remote sensing include meteorology, hydrology, and oceanography. By looking at or through the atmosphere, depending on the wavelength, meteorologists can use passive microwaves to measure atmospheric profiles and to determine water and ozone content in the atmosphere. Hydrologists use passive microwaves to measure soil moisture, since microwave emission is influenced by moisture content. Oceanographic applications include mapping sea ice, currents and surface winds as well as detection of salinity, pollutants, such as oil slicks and occurrence of events like cyclone etc.

Active microwave sensors provide their own source of microwave radiation to illuminate the target. Active microwave sensors are generally divided into two distinct categories: imaging and non-imaging. The most common form of imaging active microwave sensors is Synthetic Aperture Radar (SAR). The sensor transmits a microwave (radio) signal towards the target and detects the backscattered energy of the signal. The strength of the backscattered signal is measured to discriminate between different targets. Similarly, the time delay between the transmitted and reflected signals determines the distance (or range) to the target. A schematic diagram of an airborne active microwave sensor is shown in Figure 1.3.

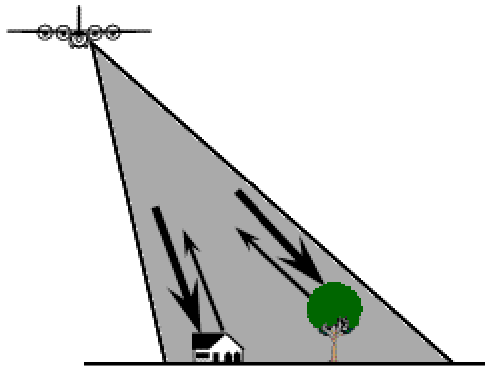

Figure 1.3: Airborne Active Microwave Sensing

Non-imaging microwave sensors include altimeters and scatterometers. In most cases these are profiling devices which take measurements in one linear dimension, as opposed to the two-dimensional representation of imaging sensors. Radar altimeters transmit short microwave pulses and measure the round trip time delay to targets to determine their distance from the sensor. Generally altimeters look straight down at nadir below the platform and thus measure height or elevation (if the altitude of the platform is accurately known). Radar altimetry is used on aircraft for altitude determination and on aircraft as well as satellites for topographic mapping, sea surface height estimation etc. Scatterometers are also generally non-imaging sensors and are used to make precise quantitative measurements of the amount of energy backscattered from targets. The amount of energy backscattered is dependent on the surface properties (roughness) and the angle at which the microwave energy strikes the target.

The various applications of Microwave Remote Sensing (MRS) of both active and passive types are experimented with, as discussed in the subsequent chapters. The comparison of MRS with traditional optical remote sensing is done in the next section.

1.3 COMPARISON OF OPTICAL AND MICROWAVE REMOTE SENSING FOR FLOOD AND SOIL MOISTURE STUDIES

In optical range of the electromagnetic spectrum, the viewing of earth's surface is obstructed by cloud cover. However, the microwave portion of the spectrum can penetrate through clouds and can be therefore used more effectively for change detection in tropical regions [15]. This is a major factor for selection of microwave remote sensing in place of optical range.

Another major factor is the economic consideration. Use of some of the very high resolution optical imageries such as IKONOS or SPOT 5 has not been very popular yet in the certain fields of applications of remote sensing such as flood management, due to their high price. Instead a majority of the researchers favour multi date radar imageries to observe a particular flood event [5]. Radar and Radiometer images are much cheaper in price and hence are preferred for multi-temporal studies.

Another parameter of comparison between optical and microwave remote sensing is their resolution. The spatial resolution of optical remote sensed images (in m) is much higher as compared to active (also in m) and passive (in km) microwave remote sensed images. On the other hand, the temporal resolution of passive microwave images is of the order of few hours, as compared to several days in case of optical as well as active microwave sensors.

Optical images are better to interpret by human eye. Microwave images even map the sub-surface parameters, hence are not directly interpretable by simple observation. Hence, visually optical remote sensing images are better to analyse as compared to microwave images.

Optical images are not very much affected by change of soil moisture. However, Microwave observations, in particular, are highly sensitive to soil moisture, since the presence of water strongly affects the dielectric constant (ε) and consequently affects the emissivity of land surfaces. Retrieval of Soil Moisture (*SM*) is considered as an open issue and is still regarded as a subject of extensive research. This parameter is an important state variable of the global energy, land and water resource management and an important boundary condition for our climate system.

Apart from its dominant role in the global climate system, soil moisture takes a fundamental role in climate-sensitive socio-economic activities like water management, agriculture planning, flood and drought hazards monitoring etc [56]. Among passive microwave frequencies, sensors operating at C- and X-band frequencies have been used successfully to estimate near-surface soil moisture from aircraft and satellite platforms [57].

1.4 DIELECTRIC PROPERTIES OF NATURAL EARTH MATERIALS AT MICROWAVE FREQUENCY

Natural earth materials exhibit dielectric property because of the molecular structure. In the molecules, the positive and negative charges move into opposite directions when an electric (E) field is applied. This phenomenon is referred to as polarisation. Under the influence of an external electric field, the positive and negative charges within the molecules move into opposite directions, forming electric dipoles. There are three ways by which polarisation may arise. The two of these ways involve distortion and one involves orientation. The types of polarisations are-

(i) Electronic polarisation: If the molecule has no permanent dipole, then polarisation occurs due to the relative movement of nuclei and electrons which is called as electronic polarisation.

(ii) Ionic polarisation: Polarisation may also occur due to relative movement of positive and negative ions in a solid which is called ionic polarisation.

(iii) Orientational polarisation: If the molecule has a permanent dipole, then the external field imposes a preferential direction. This type of polarisation is temperature dependent, since thermal agitation randomises the directions of the dipoles. In a high frequency oscillating field, the molecules cannot follow the polarity changes of the field. Hence, the orientational distribution disappears in general in the microwave region.

At low frequencies the three polarisation mechanisms may occur together. Ionic polarisation disappears in the infrared frequency and electronic polarisation disappears in the visible and infrared frequencies.

1.4.1 Dielectric properties of Water

Amongst natural media on the earth, only liquid water shows orientational polarisation. The permanent dipole moment of water occurs due to the special structure of the H_2O molecules. The H_2O molecules are bent in structure as shown in Figure 1.4. Above a certain frequency, called relaxation frequency, the dipoles cannot follow the oscillations of the applied Electric (E) field any longer. Thus, the real part (ε') of the dielectric constant (ε) decreases. The equation 1.1 shows the real and imaginary parts of the dielectric constant. At the relaxation frequency the molecules behave like harmonic oscillators and absorption (ε'') of the energy due to high frequency wave is the highest. The dielectric constant of pure water obeys the relaxation spectrum of the Debye type, which is given by the expression-

$$\varepsilon = \varepsilon' + j\varepsilon'' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 - j.\frac{f}{f_0}} \qquad (1.1)$$

where, f is the frequency, f_0 is the relaxation frequency, ε_s is the static dielectric constant, and ε_∞ is the dielectric constant in the high frequency limit. The parameters are temperature dependent.

Figure 1.4 shows the variation of dielectric constant of water with frequency. The changes in both the real and imaginary parts are seen in the figure.

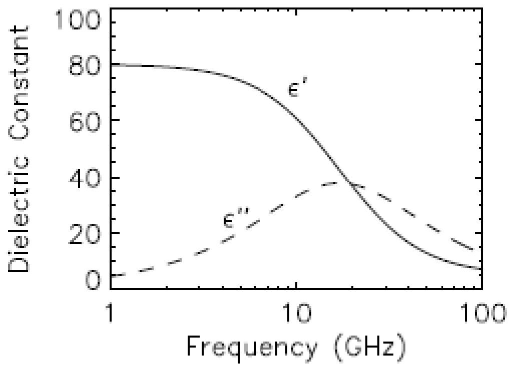

Figure 1.4: Dielectric constant ε of pure water versus frequency at 20^0 C

1.4.2 Dielectric properties of Soil

The term soil refers to the weathered and fragmented outer or upper layer of the earth's terrestrial surface. Soil consists of three phases: a solid phase made up of mineral and organic matter, a liquid phase consisting of soil water, and a gaseous phase. In the absence of water, the real part of the dielectric constant ε' varies over the range from 2 to 4. The imaginary part ε'' is typically lower than 0.05. For explaining the dielectric behaviour of wet soil the soil water is usually divided into two fractions according to the forces that are acting on the water molecules. The water molecules contained in the first molecular layers surrounding the soil particles are tightly held due to matrix and osmotic forces. This fraction is referred to as bound water and exhibits a dielectric dispersion spectrum that is very different from that of free water.

The dielectric properties of bound water are not known quantitatively, but it is apparent that with an increasing fraction of bound water ε' decreases. Therefore ε depends on the textural composition of the soil which determines the specific surface area of the soil particles. The term soil texture refers to the size range of particles in the soil. The array of possible particle sizes is divided into three fractions, namely sand, silt, and clay. Typically sand particles fall in the range from 2000 mm down to 50 mm, silt from 50 mm to 2 mm, and clay from 2 mm downwards. Figure 1.5 shows the dependence of the dielectric constant on soil wetness for a loamy soil with *Sand (Sa)* = 40% and *Clay (Cl)* = 20%. It can be seen that ε' increases from about 2.3 for a dry soil to 40 for a saturated soil surface [2].

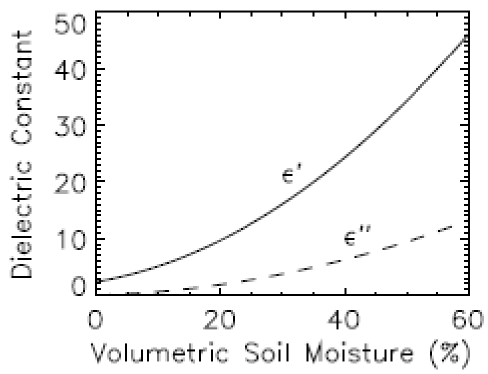

Figure 1.5: Dielectric constant ε for a loamy soil versus the volumetric soil moisture content in percentage

1.4.3 Dielectric properties of Vegetation

Direct measurements of oven-dried samples of various types of vegetation material show that the real part of the dielectric constant *ε'* is generally between 1.5 and 2, and *ε''* is below 0.1. Water may constitute between about 80 % and 90 % of the fresh weight of leave like plants. Therefore also *ε* of vegetation increases strongly with the water content. To estimate e of both the bound and free water components a dispersion model of the Debye type is employed. While the relaxation frequency of the free water component was assumed to be equal to that of pure water (17 GHz at 20°C), the relaxation frequency of the bound water component was estimated to be about 0.18 GHz by conducting dielectric measurements for sucrose-water mixtures. Figure 1.6 shows the variation of dielectric constant with the moisture content of vegetation [2].

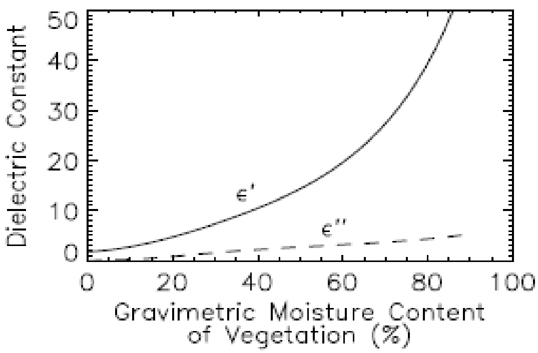

Figure 1.6: Dielectric constant (*ε*) of vegetation versus the gravimetric soil moisture content in percentage

1.4.4 Dielectric properties of Ice and Snow

Over the whole microwave frequency range *ε'* of ice is relatively constant, *ε'* = 3.17±0.03. Ice has a remarkable property in the microwave range. For frequencies below 10 GHz *ε''* is lower than 10^{-3}. These losses are amongst the lowest of condensed matter and consequently the penetration depth of microwaves into ice is on the order of meters. Snow is a mixture of ice, air, and water, depending on the temperature. For dry snow *ε'* is lower than about 1.7. The magnitude of the imaginary part *ε''* of dry snow is not much different from that of ice. When temperatures approach 0°C, liquid water is formed and the dielectric properties are changed significantly. The penetration depth decreases rapidly with increasing water content and consequently dry and wet snow show distinctly different backscattering behaviour. Variation of dielectric constant with the volumetric fraction of water in snow is shown in Figure 1.7 [2].

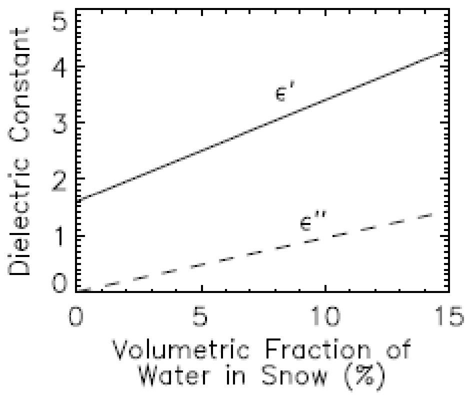

Figure 1.7: Dielectric constant ε of snow versus the volume fraction of water in percentage

1.5 MICROWAVE BRIGHTNESS TEMPERATURE AND ITS DERIVED PARAMETERS

The brightness temperature (T_B) recorded by a microwave radiometer due to emissions from the earth's surface is given by-

$$T_B = eT_S \ \text{(K)} \qquad (1.2)$$

where, e is the emissivity of the surface and T_S is the surface soil temperature in Kelvin.

Microwave emissivity (e) is related to reflectivity (r) as in the following.

$$e = (1 - r) \qquad (1.3)$$

The reflectivity at horizontal polarization (r_H) as well as at vertical polarization (r_V) are related to dielectric constant of soil (ε) as shown in equation (1.4) and (1.5) by the well known Fresnel equations [2].

$$r_H = \left|\frac{\cos\theta - \sqrt{\varepsilon - sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - sin^2\theta}}\right|^2 \quad (1.4)$$

$$r_V = \left|\frac{\varepsilon\cos\theta - \sqrt{\varepsilon - sin^2\theta}}{\varepsilon\cos\theta + \sqrt{\varepsilon - sin^2\theta}}\right|^2 \quad (1.5)$$

where, θ is the incidence angle of the radiometer.

The value of ε has a large contrast between dry soil (~5) and liquid water (~80). As soil moisture increases, the change in ε value leads to increase in soil reflectivity (r_H and r_V) or decrease in emissivity (e). When soil is completely or partially inundated, e changes significantly because of this reason.

It has been found that the variation in T_B due to presence of water on top surface of earth is more when it is measured in the horizontal polarization, as compared to that in the vertical polarization. Therefore this variation can be detected by taking the difference between the two as in equation (1.6) in the following.

$$\text{Polarization Difference, } PD = T_{BV} - T_{BH} \quad (1.6)$$

where, T_{BV} is the brightness temperature measured in vertical polarization and T_{BH} is the brightness temperature measured in horizontal polarization.

PD will be high for soil having water cover, as compared to soil having some moisture. It is because the value of T_{BH} will increase more with the increase in soil moisture, as compared to T_{BV}. Therefore, the value of T_{BH} will be changing more with the change in land cover type, from dry soil condition to flooded condition, as compared to the change in value of T_{BV}. However, the variation in the values of brightness temperature may also take place due to the change in the surface temperature (T_S). Hence, it will not be clear from *PD* whether the variation in the brightness temperature has taken place due to the change in temperature or due to the change in land cover. Therefore to eliminate the effect of T_S in finding the brightness temperature difference, the polarization index (*PI*) is used, as in equation (1.7) in the following.

$$\text{Polarization Index, } PI = \frac{T_{BV} - T_{BH}}{T_{BV} + T_{BH}} \qquad (1.7)$$

The *PI* will thus give indication of difference in brightness temperatures due to land cover change as shown below.

$$PI = \frac{T_S(e_V - e_H)}{T_S(e_V + e_H)}$$
$$= \frac{(e_V - e_H)}{(e_V + e_H)}$$

The above relation shows that the *PI* will increase with the decrease in emissivity in horizontal polarization (e_H) due to increase soil moisture, while the vertical emissivity (e_V) does not change much with any change in the soil moisture. Thus this *PI* would be indicative of any increase in soil moisture value.

1.6 SCATTERING COEFFICIENT OF SYNTHETIC APERTURE RADAR

A synthetic aperture, or virtual antenna, consists of a long array of successive and coherent radar signals that are transmitted and received by a real, physically short antenna, as it moves along a predetermined flight or orbital path [65]. The synthetic aperture is formed by pointing the real radar antenna of relatively small dimensions, broadside to the direction of forward motion of that platform. The points at which successive pulses are transmitted can be thought of as the elements of a long synthetic array, which a signal processor will then use and process to generate a SAR image. This detailed array of radar signal data is the key to achieving high azimuth resolution.

The achievable azimuth resolution of a SAR is approximately equal to one-half the length of the actual (real) antenna and does not depend on platform altitude (distance) [8].

High range resolution is achieved through pulse compression techniques. In order to map the ground surface the radar beam is directed to the side of the platform trajectory; with a sufficiently wide antenna beam width in the along-track direction, an identical target or area may be illuminated a number of times without a change in the antenna look angle.

Scattering coefficient of SAR is the ratio of the average reflected electromagnetic wave power to the incident electromagnetic power, for distributed scattering targets [66]. Scattering coefficient ($\sigma°$) is a conventional measure of the strength of radar signals reflected by a distributed scatterer, usually expressed in dB. It is a normalised dimensionless number, comparing the strength observed to that expected from an area of one square metre. $\sigma°$ is defined with respect to the nominally horizontal plane, and in general has a significant variation with the following parameters-

(a) incidence angle,
(b) wavelength,
(c) polarisation,
(d) properties of the scattering surface itself.

Hence, keeping the incidence angle, wavelength and polarisation same, the SAR data can be used to measure $\sigma°$ for analysing the different scattering surface parameters. The surface parameters such as dielectric properties of the natural earth materials affect the value of $\sigma°$ measured from SAR images.

1.7 APPLICATIONS OF MICROWAVE REMOTE SENSING

The following table shows the typical applications of the different bands of microwave range in remote sensing. The applications listed in the table include both the passive as well as active types of remote sensing.

Table 1.1: Typical applications of the microwave bands in remote sensing [64]

Band	*Frequency range*	*Applications*
L	1 to 2 GHz	Soil Moisture mapping
S	2 to 4 GHz	Weather radar, surface ship radar
C	4 to 8 GHz	Soil Moisture, crop identification, flood mapping, geology, forestry, urban land use, hydrocarbons, wave direction spectrum, wave length, ocean circulation, oil pollution, imaging ocean and ice features etc.
X	8 to 12 GHz	Crop identification, Snow studies, Geology, Forestry, Urban land use, Ocean studies, flood mapping
Ku	12 to 18 GHz	Glaciology, Snow Cover Mapping
K	18 to 27 GHz	Airborne radar systems, Flood mapping
Ka	27 to 40 GHz	High Resolution Radars, Flood mapping, Atmospheric Studies
V	40 to 75 GHz	Instrumentation, wide band receiver applications, millimeter wave radar research
W	75 to 110 GHz	Atmospheric studies, flood monitoring, millimeter-wave radar research, military radar targeting and tracking applications
mm or G	110 to 300 GHz	Atmospheric studies, Radio astronomy, high-frequency microwave radio relay, millimeter wave scanner

The bands of frequencies having longer wavelengths in microwave range, such as L (1 - 2 GHz), S (2 - 4 GHz), C (4 - 8 GHz), X (8 - 12 GHz) and so on, have better cloud penetration capability and experience less atmospheric absorption. Hence, the passive sensing using the radiometer antennae for these bands are used more commonly for soil moisture mapping, flood monitoring and forecasting purposes [43- 50]. Flood extent can be detected in rural floods using low resolution microwave remote sensing (MRS) satellites including the passive MRS satellites, but the passive microwave images have too low resolution to detect flooded streets in urban areas. However, a number of SARs with spatial resolutions as fine as 3 m or better have been launched lately and are potentially capable of detecting urban flooding. They include TerraSAR-X, RADARSAT-2, and the four COSMO-Sky Med satellites [16]. Indian satellite RISAT-1 falls in that same category.

However, with a resolution of 10 km^2, one can hardly speak of flood extent mapping for the passive microwave sensor derived products. At best, the maps indicate areas where floods occur, not the precise extent. It is possible to indicate if the area around a town is flooded, but not whether the town is flooded. However, passive microwave sensing method provides maps with a high temporal resolution (1 day), which is suitable for mapping the dynamic aspects of floods, such as the downstream propagation or the growth and recession of flood waters [6].

1.8 NEED STATEMENTS

The need statements of the research work of the thesis can be stated as in the following.

(a) Traditional optical remote sensing methods fail to work in cloud covered regions. Hence microwave remote sensing is a potential alternative to optical remote sensing in such cases.
(b) Flood is a perennial problem in many places in the world. Some such places also do not have proper physically installed flood detection and monitoring sensor networks. In such places remote sensing of flood is a necessity.
(c) Flood prediction using remote sensing techniques is also an important activity. In cloud covered regions for prediction and early warning of flood, microwave remote sensing is a potential tool.
(d) Soil moisture is a closely associated parameter of flood occurrence. Soil moisture measurement using microwave remote sensing techniques are generally done successfully for places having small water bodies and vegetation. However, for places with dense vegetation and closely spaced large open water bodies, the existing soil moisture measurement techniques need modification. Therefore, there is a need for development of special techniques for soil moisture measurement in such regions using microwave remote sensing.

1.9 STUDY AREA

The study area selected for the research work is the state of Assam in the north eastern region (NER) of India. The rationale over selection of the region for the study is-

(a) Microwave remote sensing is critically needed for Assam and the NER, as the region is covered by cloud during most of the time of the year and particularly during the monsoon season. Typical optical remote sensing often fails to provide real time information in this region for flood studies.

(b) Very few microwave remote sensing based studies have been carried out, taking into consideration the typical parameters of NER, such as its typical soil type, high soil moisture level, dense vegetation, unique crop types, diverse hydrology and different weather conditions. There is ample scope as well as necessity of research focussing on such aspects in NER using microwave remote sensing.

(c) The typical characteristic of the river Brahmaputra and its valley prompts the need of a detailed remote sensing based study of the area. The river Brahmaputra has braided channels all along its course, with a narrow valley of long monsoon fed catchment. Microwave remote sensing based studies specific to such type of a valley is very rare.

The study area selected is shown in the map in Figure 1.8.

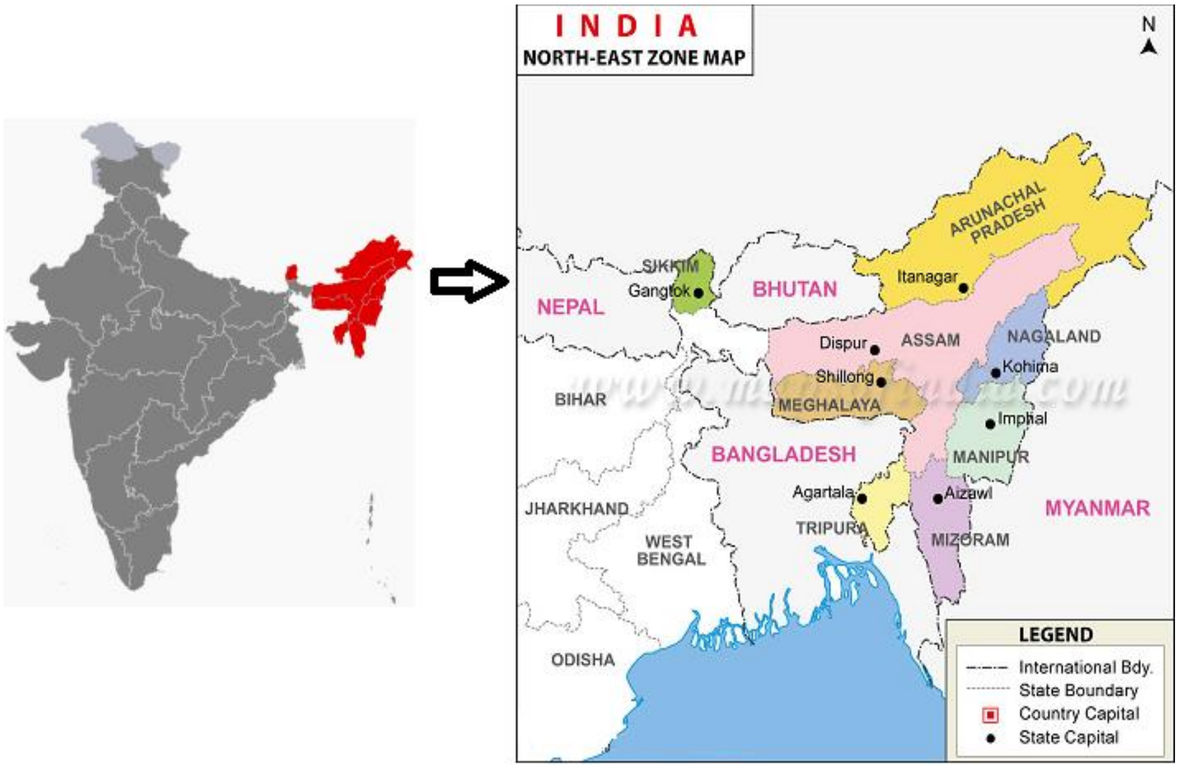

Figure 1.8: Study Area [Source: www.mapsofindia.com]

1.10 ORGANISATION OF THE THESIS

This thesis is organised into 7 chapters. Chapter 1 is the introduction to the topic of the thesis and the basic concepts associated with it. Chapter 2 is a detailed report of the literatures surveyed during the research work. Chapter 3 presents the objectives and methodologies for the work done. Chapter 4 presents a number of methods of flood detection and monitoring using passive microwave brightness temperature and active microwave backscattering coefficient. Chapter 5 presents several techniques of flood prediction based on passive microwave remote sensing data. Chapter 6 presents an Artificial Neural Network based system, designed for estimating soil moisture taking passive microwave brightness temperature and its derived indices as inputs. Chapter 7 is the concluding chapter, where conclusions derived out of the experimental works are summarized, along with a discussion on future scope of the research.