# CHAPTER 1
# INTRODUCTION

## 1.1. GENERAL

Tsunami is the Japanese word which is made up of two words: “*tsu*” means harbor and “*nami*” means waves. It means that Tsunami is the harbor gravity waves which propagate close to ocean facial. Tsunamis are long waves which have wavelengths order magnitude up to 10*km* and amplitude order of 1*m* in exposed Ocean, where they travel with the velocity of 700-800*km/h*. They can transfer the energy to the very far distance (Prins, 1958).

Most of the earthquakes generate tsunami as in the form of P- and N- types of seismic waves. Analytical and numerical models are always the handholding tools for the reporting of tsunamis near to the shorelines. The classical wave theory might turn out inappropriate for the model that runs for tsunami generation as well as wave propagation. Leading Dispersion N-waves (LDN) is assumed like the individual wave having dispersion trough in front that changes properties of individual waves. The dispersion ratio and the dispersive phenomenon of the waves carries the significance of dispersive wave number parameters *kd* for these kind of waves (Dean, 1974).

Tsunami travels with concurrently in the outwards directions from the generating region. Since its generation is due to the underwater explosion, hence, energy movements also take place in the direction of the propagation. The speed of the propagation depends on the depth of ocean. Inside the exposed and wide ocean, they transit at the speed between 500-1000*km/h*. These change occurrences take place for the tsunamis propagations from the deep water to the coastline because of nearshore bathymetry as well as coastal morphology. The most undeveloped part of the tsunami modeling is the run-up of the tsunami currents onto the land area (Barrick,1979).

Tsunamis have affected human cultures from the day it has started time to time. Their destructive force has notoriety in almost every civilization that borders the sea. These civilizations have documented the changes that take place after tsunami and how it affected them socially and economically. Tsunamis are a dangerous threat that has no warning, cannot be predicted, and result in significant casualties and loss of life.

Mostly the generation of Tsunamis takes place in the deep ocean due to the underwater plate tectonics movements or shifting of the ocean floor. Therefore, tsunamis are also known as seismic waves. Compared to the wind induced waves; seismic waves have higher magnitudes of energy and due to these phenomena, the wave characteristics changes continuously from the origin towards the direction of propagation at every instant of time (Ward, 1980).

Most tsunamis occurrences are due to the sudden shifts of sea bed tectonic plates. Seismic waves have their properties that, they could moves exceptionally high and more than ten times that of the wind generated waves in terms of the wavelengths and velocity of wave's propagation. The initial disturbance of free water surface lured from earthquakes having huge magnitude is N-waves comprising lengthy wavelengths along with smaller fluctuation in vertical direction *i.e* wave height. For such types of waves, dispersion number is the important parameter due to dispersion number $kd$ being $O$ ($10^{-2}$) to $O$ ($10^{-1}$) order. The dispersion number $kd$ is approximated in between 0.026 to 0.25, for the Indian Ocean tsunami (Zielinski *et.al.*,1983).

Tsunamis are the gravity waves which proliferate close to the surface of the ocean. These waves generated in tsunamis are as similar as the normal waves which propagate near to the surface. These kinds of waves have different generation modes and propagation characteristics such as time period, wavelength and velocity. Tsunami, which have a very long wavelength (10*m* to 100*km*) always travel shallow water even in deep ocean water depths. Tsunami springs from rapid displacements of ocean surface. The rapid displacements or movements could be underwater explosion, volcanic eruption, undersea landslides etc. Based on the various researches in the past, tsunamis are normally known to be as seismic waves. There are three phases of tsunami developments: creation of the focalized introductory disturbances, evolution close to shore and propagation of waves in exposed ocean and leaves all its energy to the shore from the deep water. The utmost familiar model applicable here for explaining tsunami generation, propagation and flooding in the continuous, shoal water, lengthy wave model which completely oversights the accouterments of Coriolis force and shore line effects for tsunami long travel (Dean *et.al*.,1984). Tsunami belongs to the same family as of the ocean waves which could normally be seen on to the beaches. The word shallow water wave explains the wave that has a wavelength higher than ocean base through which it is propagating (Okal, 1988).

When the tsunami waves reach the coast, they shallow and turn more dangerous. Reasonably, the most destructing belongings of natural hazards, but it are essential to save outlook. Tsunamis above a height of one or two meters are unusual caused by a underwater earthquake of magnitude above to *M*8.0. On an average, one *M*8.0+ earthquake happens per year, across the globe. Among these, 1-in-10 occurs below the ocean through a fault positioning supportive for tsunami generation. Hence, tsunamis which create extensive destruction number of almost three or four per 10 years. While one's ideas may be cast by infrequent "killer tsunamis", many more gentle ones are lost in shallow. Presently, bottom pressure sensors can sense a tsunami of a few meters fluctuations in the open sea. The reasonable (≈*M*6.5) earthquakes can bear waves of this size, "baby" tsunamis happen numerous periods per year. Except by scientists' observations, these are usually unobserved. At hand when a tsunami occurs is the physics surrounding the tsunami and its waves. The structure of the earth's bedrock, how the tsunami was created, and the topography of the ocean floor all contribute to a particular tsunami's characteristics. It is therefore necessary that these factors are explored in order to understand a tsunami and its properties.

The classification of deep and coastal water waves are identified using the respective correlations between water depth ($d$) verses wavelength ($L$). If $d/L<1/20$, water is known as shallow water condition. If ratio varies from $1/20$ to $1/2$, water is known as intermediate water. If the ratio is more than $1/2$, the oceanic region is defined as to be for deep water. Howsoever, the Tsunami waves generate from deep ocean and reaches to the coastal regions. The impact at the coastal region is extremely high because a significant wave height increases to the maximum extent due to the variation of bathymetry geophysical tectonics (Craig *et.al*., 1993).

With increased experience in tsunami analysis and measurements resulted in a deep-rooted realization and consensual opinion that near-real-time deep-sea and mid-ocean sea-level movements, which are free of coastal contamination, are vital for realistic tsunami forecasting and source identification. The initial displacements of the free surface of the different water wave's conditions are induced by the larger earthquake with the magnitude of more than 9.0 onto the Richter scale in which the generation of N-type waves are higher in quantity (Tadepalli, 1994).

In general, the earthquakes produce tsunamis as a kind of N-wave, the consistency of the analytical and numerical models are first applied to the deep and exposed ocean then runs up to the beaches. The tsunami events are normally explained by means of the individual wave theory based on the classical approach. The profile of N-waves is distinct by the water depth ($d$) and wave height-depth ratio $H/d$. In general, the initial surface displacement induced by the earthquake provides the high probability impact due to the seismic activity. Under these conditions the N-waves have longer wavelength and smaller amplitude. For these kinds of waves the dispersion is the significant parameters because the dispersive number $kd$ varies from 0.01 to 0.1. (Tadepalli *et.al*.,1994 and 1996).

Tsunamis are of the family same as that of the common sea waves which can be easily observed at near to the beaches. Most of the major tsunamis have been generated by the undersea earthquakes. The impulsive seafloor movement causes the sudden deformation of water surface instantaneously. The sudden gain potential energy is converted to kinetic energy by restored gravitational forces (Kânoglu,1998).

Presently, ocean base pressure sensors may sense a tsunami of some centimeter heights in exposed sea. In the first few time, the tsunami wave signatures are rely on number of seismic earthquake *e.g*., magnitude, water depth, location to determine whether the tsunami is really have been generated. Tsunami is a system of ocean gravity waves formed as a result of large scale disturbance of the sea bed. (Geist, 1998). For the practical applications, linear water wave problems and modeling along with the Boussinesq equations are well developed and suitable for the recent tsunami studies and analysis. It is supposed and proposed that the Boussinesq equations could be used to study the generation, propagation and run-up of the tsunami wave mechanics (Kanogho *et.al*., 1998 and Liu *et.al*., 1995). A tsunami's motion in water is different from other waves because the wave's motion occurs throughout the entire water column, from the surface to the ocean bottom. This phenomenon causes a tsunami to take on the shape of a solitary wave in shallow water. Little energy is dissipated because the wave's motion involves the entire water column, especially on steep coasts (Bryant, 2001).

Eigen functions are the parameters involved in the study of distribution of tsunami wave motions with respect to the variation of depth at a particular angular frequency of operation. The values of the orbital velocity and distribution varied from deep ocean to the coastal regions (Eze *et.al*., 2009).

The characterizations of tsunamis are bit different in terms of their mode of generation, propagation, wavelength, time period, velocity and distribution from the distinct oceanic region to the coastal areas for the particular region of interest. Thus tsunamis are having different consequences than do their common field of wave propagation. For linear problem, free surface disturbance generated by seabed movements can be analyzed using various analytical and mathematical models such as potential theory (Hamack, 1973), power series solutions of Laplace Transforms (Zhao, Wang and Liu, 2009) and Fourier Laplace Transform (Todorovska and Trifunac, 2001). For the practical applications, linear *kdv* equation and the Boussinesq equations are much suitable for modelling the wave propagation in exposed ocean (Bingham and Liu, 2002), when waves propagate to the near shore area and run-up on the beach, nonlinearity plays an important role. The Boussinesq model (Madesen *et.al*., 2002 and 2008) results have shown the excellent linear and non-linear properties, such as linear dispersion, shoaling, subharmonics and super harmonics transmissions (Filloux,1970).

The generation stage of the tsunami includes the formation and evolution of initial ocean surface displacements due to the large earthquake triggered at the bottom of seafloor. The generated water surface is transformed to the long gravity waves which radiates from the earthquake source where it occurred at the time of evolution. The modeling of the tsunami is carefully related with the further readings on the earthquake tools.

The early detection and warning systems have shown and proven an ultimate importance, especially after the destructive tsunami that hit Japan in March 2011. The purpose of this research is to notify and enhance the existing tsunami results for the detection and early warning prediction with the suitable accuracy (Morissay, 2005). The various parameters have been analyzed and resulted out such as the marine debris in the region of japan coastal area which contains the post analysis activity using SAR datasets over the various processing cycle of the satellite movements. The purpose of this research is to notify and enhance the existing tsunami results for the detection and early warning prediction with the suitable accuracy. The real-time interpretations and monitoring of a tsunami have been narrow to deep water pressure sensor interpretations of variation in the sea-level deviations. The coastal based radar monitoring systems are implemented in various countries to detect the tsunami wave's arrival near to the coast and to analyze and present the report to the disaster management team for the quick and sudden action to save various lives. An empirical model for the recognition of the early influx of a tsunami, and validate its use with outcomes from data restrained by fourteen high frequency radar sites in Japan and USA following the *M* 9.0 earthquakes off Sendai, Japan, on 11 March 2011 [Arii. *et. al*.,2014].

In this study, two major tasks have been carried out: (1) To compute the tsunami wave parameters specially Eigen functions such as water wave number, angular frequency, horizontal and vertical orbital velocity and acceleration, celerity of the waves (2) The idea for the investigation of its early warning using radar data processing with the *q*-factor estimation. Since the work is primarily concerned with the development of radar remote sensing techniques for naval applications in tsunami detection and investigation of its early warning using remote sensing techniques, the designed system may further be said as Integrated Tsunami Warning System (ITWS).

## 1.2 TSUNAMI MODELING

Globally, numerous models are being preferred (Zakharov, 1968, Titov & Gonzalez, 1997) for calculation of stationary sea bottom distortion for calculation of basic boundaries needed to propagate tsunami. Numeral modeling for calculating possible approaches and floods from a regional or remote tsunami is acknowledged as meaningful along with essential tool, as information from previous tsunamis are mostly not sufficient for planning approaching calamity relief as well as management strategies. Models are digitized with possible unfavorable situations for tsunami origins or for waves precisely offshore for determination of corresponding influence on neighboring shores. Models might even be computed with tiny origins to know acerbity of disaster for lesser intense but more persistent events. This data then transforms foundation to create tsunami drainage maps and methodologies. Authentic modeling methods are matured lately, and these models need decent inputs on elaborated bathymetry and topographic information for modeled region. Most of the tsunami models frequently employ various numeral methodologies applied to numerous segments of overall set of problems beginning from tsunami propagation, generation and approach on coastal regions *e.g.*, many numerical tools have been used to pretend the communication of tsunamis for islands. (Imamura, 1996)

The accuracy of model predictions is directly related to the quality of the data used to create the bathymetry and topography of the model area. Coastal Bathymetry is the prime determinant of the height of the tsunami wave or storm surge as it approaches the coast. High resolution coastal bathymetry is thus the key input for various tsunami and storm surge prediction models. Bathymetric data provided by the National Hydrographic Office (NHO) has been used in tsunami modeling. In addition, bathymetric survey is conducted for a few vulnerable areas of the Indian coast. For modeling coastal inundation, topography of the entire coastline of the country is required at 1:5,000 scales with contours at intervals of 0.5 *m* for a stretch of at least 1-3 *km* from the coastline in general and for 10-25 *km* at selected areas near coastal water bodies (*e.g.*, estuaries, backwaters). The National Remote Sensing Centre (NRSC) has completed the mapping of topography for 3,300 $Km^2$ out of about 15,000 $Km^2$ areas with airborne Light Detection and Ranging (LIDAR) and Digital Camera data in conjunction with Global Positioning System (GPS) control survey. CARTOSAT-1 data is being used for generating Digital Elevation Model (DEM) of the coastal region. Tsunami Modeling is classified in to three stages: (i) generation, (ii) propagation (iii) run-up (Inundation). The guidelines and varieties of models engaged at these stages vary and depend on experimental site parameters (Josheph,2008).

### 1.2.1 Generation

The generation phase of tsunami development comprises the creation of an early disruption at the surface of ocean due to the earthquake generated distortion on the sea floor. This early water surface disruption is biased in to the long gravity wave searing from the source of earthquake. The Modeling of early phase of the tsunami undulation is carefully linked to various studies of earthquake tools. The basic parameters required for the modelling of earthquake and tsunamis are fault area (length and width), angle of strike, dip, depth of fracture and the moment of magnitude (*M*). The wave form generated varied with these parameters and hence, the parameters play a key role in this study (Hammack, 1973, Todorovska, 2001).

### 1.2.2 Propagation

Tsunami propagates outward in all the directions from starting zone, along the course of the main dynamism propagation normally being orthogonal to the course of earthquake breakage. Their speed depends on water depth, the wave's experiences acceleration and retardation in passing over an ocean bottom of varying depth. In the deep and exposed ocean, they travel at speeds of 500 to 1000 *km/h*. The distance between successive crests can be as much as 500 to 650 *Km.* (Wu, 2001 and Madese *et.al*., 2010).

### 1.2.3 Run-up (Inundation)

The spreading tsunami wave from the deep water undergoes a change, causing increase in the wave height at the coast due to the near shore bathymetry and coastal morphology such as inlets, sand dunes, water bodies, etc. The run-up of the tsunami on land is the most undeveloped part of the tsunami model, primarily because of lack of two major aspects high quality field measurements for testing the models and fine resolution bathymetry or topographic data (Titov & Synolakis, 1997 and Synolakis, 1987). Studies have been carried out to validate the model results with December 26, 2004 Sumatra earthquake that indicated an 80% match. This model has been run for five historical earthquakes and the predicted inundation areas are being overlaid on cadastral level maps of 1:5,000 scale. (Kawata, *et.al*., 2004 and Lay, *et.al.*,2005)

## 1.3 CHARACTERISTICS OF TSUNAMIS

Tsunamis characteristics are generally defined based on the classical theory envision a rigid seafloor overlain by an incompressible, homogeneous and non-viscous ocean which continuously subjected to the constant gravitational field. As per the classical theory (Ward, 1980 and Geist, 1998), the celerity $c$, and group $u$ velocity of the surface gravity waves with the uniform ocean depth of $d$ are

$$c = \sqrt{\frac{gh\tanh(kd)}{kd}} \tag{1.1}$$

and

$$u = c\left[\frac{1}{2} + \frac{(kd)}{\sin(2kd)}\right] \tag{1.2}$$

Here, $g$ is the acceleration due to gravity and $k$ is the wave number associated with the sea wave of frequency $\omega$. Wave number is correlated with the wave length as given by

$$L = \frac{2\pi}{k} \tag{1.3}$$

Wave number also satisfies the dispersion relationship which is one of the basic and important equation used in the study of wave hydrodynamics specially to analyze the various types of waves and is given as

$$\omega^2 = gk \tanh(kd) \tag{1.4}$$

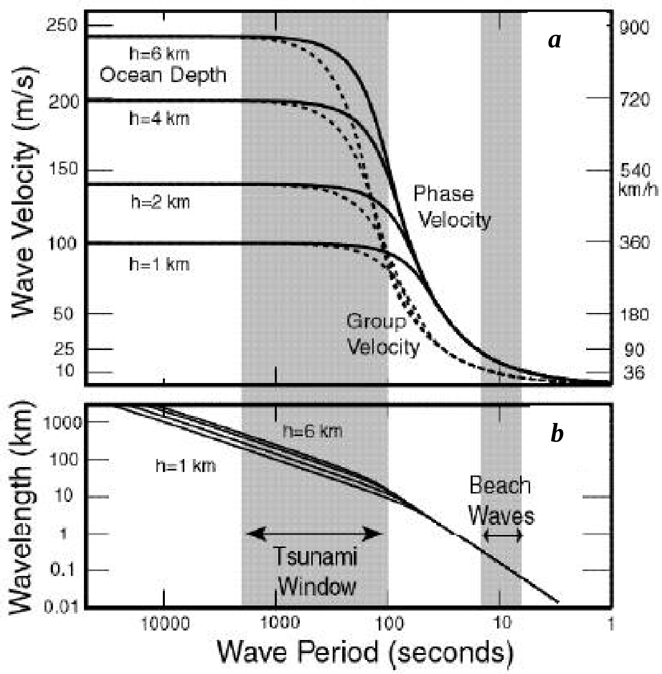



**Figure 1.1** (*a*) solid line indicates the phase velocity and dashed line represents group velocity of tsunami waves in ocean for various depths of 1,2,4, and 6 km depth, (*b*) shows the variation of wavelength with wave period, tsunami windows appeared [Dean, 1980]

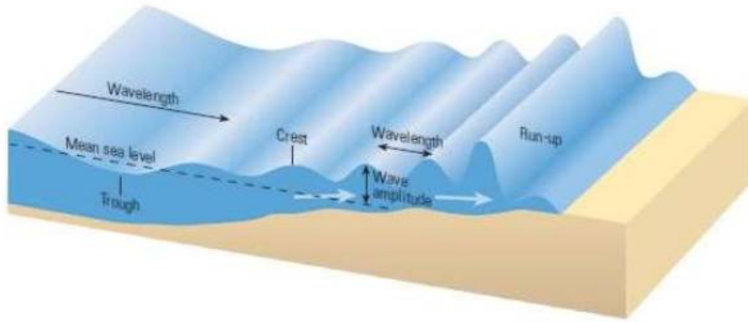



**Figure 1.2** Tsunami Shoaling from deep to coastal region (Ward, 1980)

Tsunamis are generated by seafloor shifts, must have wavelength greater than almost three times that of the ocean depths. The greatest earthquake deforms a region of 500*km* across. As shown in Figure 1.1, the left gray band shows the 'tsunami window' (*L*=10*m*-500*km*) that spans 100 to 2000*s* period. Waves in the tsunami windows travel rapidly, reaching speeds to 160-250*m/s* (600-900*km/h*) in the exposed sea, which is equivalent to the speed of commercial jet aircraft (Zielinkski and saxena, 1983). The basic ocean bathymetry geometry is as shown in Figure 1.2.
The wave approximations are given below for the ocean waves,
Long wave approximation: $L>>d$, $1/k>>d$, $kd \rightarrow 0$
Short wave approximation: $L<<d$, $1/k<<d$, $kd \rightarrow \infty$
Waves in tsunami window have intermediate character, behaving like shallow water waves at their longest periods and like deep-water waves at their shortest period.

### 1.4 TSUNAMI EIGEN FUNCTIONS

Many properties of tsunamis can be understood by examining their Eigen functions. An Eigen function describes the distribution of motion in a tsunami mode of a particular frequency. Consider coordinate system *(x, y, z)* .Vertical ($u_z$) and horizontal ($u_x$) components of tsunami Eigen functions normalized to unit vertical displacement at the sea surface are

$$u_z(\omega, z) = \frac{kg}{\omega^2}\frac{\sinh[\mathrm{k}(d-z)]}{\cosh[kd]}e^{i[kx-\omega t]} \tag{1.5}$$

$$u_z(\omega, z) = \frac{-ikg}{\omega^2}\frac{\cosh[\mathrm{k}(d-z)]}{\cosh[kd]}e^{i[kx-\omega t]} \tag{1.6}$$

Figure 1.3 indicates the tsunami Eigen functions versus depth in a 4*km* deep ocean at long (1500*s*), intermediate (150*s*) and short (50*s*) periods. The little ellipses can be thought of as tracing the path of a water particle as a wave of frequency $\omega$ passes. At 1500*s* period, the tsunami has a wavelength of $L$=297*km* and it acts like a long wave. The vertical displacement peaks at the ocean surface and drops to zero at the seafloor. The horizontal displacement is constant through the ocean column and exceeds the vertical component by more than a factor of ten.

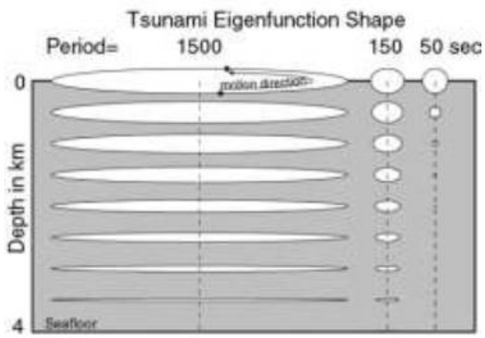



**Figure 1.3** Tsunami Eigen functions in a 4 *km* deep ocean at periods 1500*s*, 150*s* and 50*s*. Vertical displacements at the ocean surface have been normalized to 1*m* in each case (Ward, 2002)

## 1.5 MICROWAVE REMOTE SENSING: GEOMETRY AND PARAMETERS

SAR is able to achieve high azimuth resolution by storing and reconstructing all the returned signals in the "synthesized aperture". By moving the radar antenna while illuminating the target and coherently processing the returned signals, a large radar aperture is synthesized and thus achieved with high azimuth resolution. RADAR systems offer unique high spatial resolution regardless of the other environmental conditions, with wide area of coverage over swaths up to 500*km* across. The imaging geometry of a radar system is different from the framing and scanning systems commonly employed for optical remote sensing. Imaging radar such as SAR is a side-looking, that is, radar antenna beam is pointed sideways, nearly perpendicular to the flight direction of the spacecraft. Radar/SAR data can be acquired with great reliability to enable precision monitoring of Earth's surface. Most of the earth remote sensing radars operate in a part of the microwave region (1*m*-to-1*mm* wavelength) of electromagnetic spectrum specifically L-(24*cm*), C-(6*cm*), S-(10*cm*), and X-(3*cm*) band regions respectively.

A complete RADAR/SAR design must be considered as an "end-to-end" set of choices or decisions linking the radar and image signal processing. Elements that must be considered include the moving satellite platform, transmitted signal, propagation effects, complex target interactions (including motion), received signals, data recovery and on-board or ground-based signal processing. SAR system geometry is shown in Figure 1.4 (left panel) and SAR imaging output of the ocean surface objects are indicated in Figure 1.4 (right panel). Brighter signal signature indicates the hard targets (high backscatter response) while the dark background signal (low backscatter signal) represents the background ocean surface. The SAR systems generate large amount of data necessitating extensive process to produce images with required resolution. The process is usually performed and stored in ground stations.

The design of a SAR system is generally dependent on the application for which it is intended. Typically, specifications are provided to the design engineer by the end data user, such as resolution, incidence angle, swath width, wavelength, polarization, signal-to-noise ratio (SNR) and so on. The final design is the result of an iterative procedure, balancing performance characteristics among subsystems to achieve the optimal design. No single algorithm can be defined that will optimize the design across the wide range of applications, since the priority ordering of the system performance parameters depends on the data utilization.

**Table 1.1** Sensor parameters of various SAR systems

| Parameters | SEASAT | ERS-1,2 | ENVISAT-ASAR | TerraSAR-X | ALOS-PALSAR | Radarsat-2 |
|---|---|---|---|---|---|---|
| Launch year | 1978 | 1991,1995 | 2002 | 2005 | 2006 | 2007 |
| Frequency (GHz) | 1.27 | 5.30 | 5.30 | 9.65 | 1.27 | 5.40 |
| Wavelength (*cm*) | 23.50 | 5.60 | 5.60 | 3.11 | 23.60 | 5.60 |
| Resolution (*m*) | 25 | 30 | 30 | 1-18 | 10-157 | 3-100 |
| Swath (*km*) | 100 | 100 | 150-1000 | 5-100 | 70-350 | 10-500 |
| Look angle (degrees) | 23 | 23 | 20-50 | 20-55 | 10-51 | 20-50 |
| Polarization | HH | VV | HH,VV | Quad | quad | quad |

### 1.5.1 SAR Signal Processing Techniques

Signal processing can be any technique that changes the characteristics of the signals such as amplitude, phase, frequency, and polarization. Modern SAR systems use the digital signal processing technique to improve the azimuth and range resolutions. The image generation is always in a raw form. Signal processing techniques can be broken into two phases: range and azimuth compression (Cumming and Wang, 2005). The azimuth compression is based on the fact that each echo reflected from a single point target has a different phase shift. The azimuth compression operation focuses the echo signal in such a way that a zero phase shift remains and integrates the focus echo. As a result the azimuth resolution is improved. A number of algorithms have been developed to effectively process the SAR data from its raw signal into the well-focused images. The most common SAR processing algorithm is the range Doppler algorithm, which accurately and effectively accommodates the range varying parameters such as Doppler Centroid, azimuth frequency modulation rate, and range cell migration (Munson and Visentin, 1989). RADAR is an active sensor which self-illuminates the target area by transmitting pulses of microwave energy. These beats of radar signals are scattered from the target and the response is recaptured by receiving antennas. By exactly determining the pulse difference time in between the transmitted and backscattered signals, radar is able to determine the slant-range of the target. Various SAR systems and satellite sensor parameters are provided in Table 1.1 which could be useful in the application of various oceanographic phenomena such as tsunami modeling, wind wave direction measurements, target detections, Doppler shifts estimations.

### 1.5.2 Synthetic Aperture Formation and Doppler Data Processing

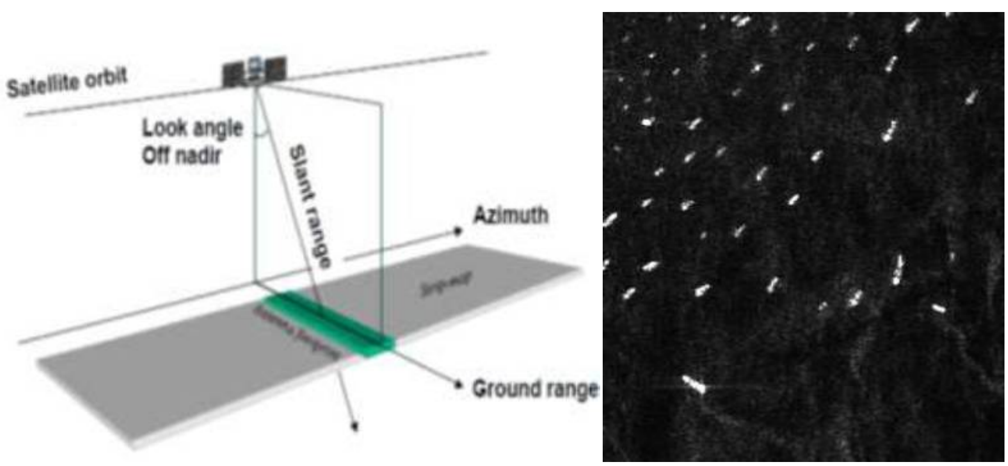
SAR achieves the high spatial resolution in the azimuth direction with help of the synthesized aperture formation. A synthetic aperture, or virtual antenna, consists of a long array of successive and coherent radar signals that are transmitted and received by a physically short (real) antenna as it moves along a predetermined flight or orbital path. Figure 1.5 shows the basic formation of SAR length, the aperture length is the distance between the point from where the SAR start looking to view the target and the point at which it stops to view the target. Ground covered by the SAR platform under the illumination of radar beams is known as a swath. SAR signals are stored in the form of in-phase ($a$) & quadrature ($b$) components, and these signals are subjected to range and azimuth components to obtain an image. SAR transmits the chirp signal and the equation of chirp signal can be expressed as,

$$s(t) = A.\exp\left(i.2\pi\left(f_c.t + \frac{\pi t^2}{2}\right)\right) \tag{1.7}$$

where $A$, $f_c$, $\tau$, and $t$ are the amplitude, signal carrier frequency, chirp slope, and time duration of pulses respectively.

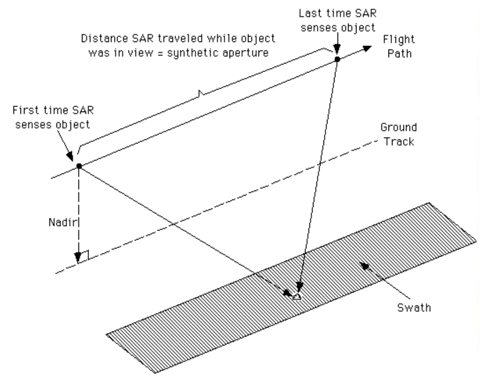
Due to relative motion between the target and spacecraft (or aircraft), the return signals from the target are frequency shifted (known as Doppler shift). The return signal frequency increases when the spacecraft approaches the target, and it decreases when spacecraft is going far away from the target. The Doppler frequency information is used to form a large aperture. The Doppler frequency shift is proportional to the rate, at which the range between satellite and the target changes and the governing equation can be defined as,

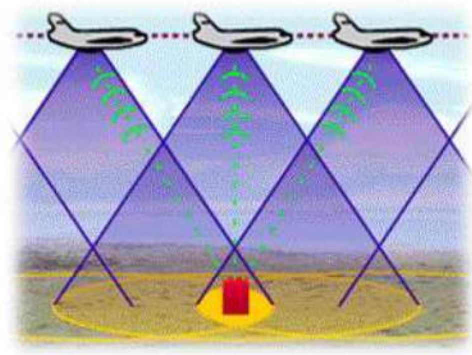
$$f_D = -\frac{2\dot{R}}{\lambda_r} = -\frac{2}{C}\dot{R}\, f_c \tag{1.8}$$




*a* *b*

**Figure 1.4** (*a*) Side looking SAR geometry and flight path, (*b*) SAR image consists of the hard targets (brighter pixels due to high backscattered response) and ocean background (dark pixels due to low backscattering response).



(*a*) (*b*)

**Figure 1.5** Synthetic aperture lengths (*a*), concept of array of real antenna positions forming a synthetic aperture (*b*).SAR beam interaction with target

Where $f_D$, $C$, $\lambda_r$, $f_c$, and $\dot{R}$ terms indicates Doppler frequency shift, speed of electromagnetic waves, radar wavelength, radar carrier frequency, and slant-range rate respectively. Along track geometry of SAR system is shown in Figure 1.6, where $V_s$ is the spacecraft velocity, $H$ is the altitude of craft above the globe, $R$ is the slant-range between the craft and target, $X$ is the along-track position of the target, $R_g$ is the across-track location of the target, $\theta_a$ is the along-track angular position of the target, $R_b$ is the broad-side range of the target and $s$ is slow (integration) time.

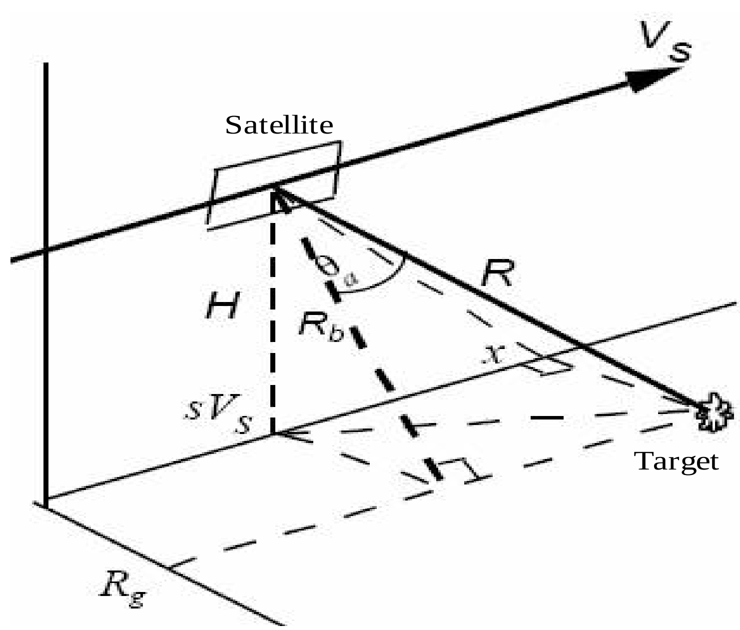



**Figure 1.6** Along track geometry of a SAR system.

The equation has been proposed by Curlander and McDonough (1991). Using Trapezoid properties (from Figure 1.6), it can be written as,

$$R^2 = (X - sV_s)^2 + R_g^2 + H^2 \tag{1.9}$$

From the above equation, the range rate can be calculated by an assumption of reference frame moving with spacecraft ($s$=0) and differentiating $R$ (*i.e.*, equation 1.9) with respect to $s$ as follows,

$$\dot{R} = -\frac{X}{R} V_s \tag{1.10}$$

Substituting the value from equation 1.10 in equation 1.8, we obtain the Doppler frequency as follows:

$$f_D = \frac{2V_s X}{\lambda_r R} = \frac{2V_s \sin(\theta_a)}{\lambda_r} \tag{1.11}$$

**Doppler Frequency Rate ($f_R$):** The rate at which the frequency of the return from a target changes as the target passes through the radar footprint is called the Doppler frequency rate, which can be expressed as,

$$f_R = \frac{2\ddot{R}}{\lambda_r} \tag{1.12}$$

Taking differentiation of equation 1.9 twice, we get,

$$\ddot{R} = \left( \frac{V_s X - V_s{}^2 s}{R^2} \right) \dot{R} + \frac{V_s^2}{R} \tag{1.13}$$

The first term is very less than the second term (from equation 1.13), we get,

$$\ddot{R} = \frac{V_s{}^2}{R} \tag{1.14}$$

**Doppler Centroid Frequency ($f_{DC}$)**

The frequency of the return from the target when it is located in the center of the radar beam is the Doppler Centroid Frequency ($f_{DC}$), which can be expressed by the following relation,

$$f_{DC} = -\frac{2\dot{R}_c}{\lambda_r} \tag{1.15}$$

The various equations have been derived in order to understand the physical phenomena of SAR signals under the relative motion between targets and satellite with the concept of Doppler's effect. The important properties which are achieved by the SAR in order to form an image can be described below.

### 1.5.3 Azimuth Resolution

The direction which is orthogonal to the radar beam is known the azimuth direction or cross range direction. It is defined as the resolution along with the direction of flight. The azimuth resolution depends on the antenna beam width ($\beta$), and ground range resolution ($R_g$). The well-known definition as shown below is described by Curlander and McDonough, (1991) among others, and began with the azimuth resolution for SAR. The resolution does not depend on the range and the radar wavelength. The azimuth resolution for the radar is defined as,

$$r_{ap} = \frac{d_a}{2} \tag{1.16}$$

where $r_{ap}$ and $d_a$ are the azimuth resolution and antenna aperture length respectively.

### 1.5.4 Range Resolution

Range resolution of radar is the ability to determine the minimum distance between two objects, if the targets are unglued from each other, each would then be placed in separate resolution cell, if this condition does note satisfies, radar reflection would be the complex grouping of backscattered energy from the two targets. For SAR sensors, the range resolution ($r_r$) can be expressed as,

$$r_r = \frac{Ct}{2\sin\theta} \tag{1.17}$$

where $C$ is the speed of electromagnetic waves, $\theta$ is the incident angle between radar beams and normal to Earth's surface and $t$ is the pulse duration. Correct and accurate pulse duration is needed to achieve a reasonable and sufficient echo signal-to-noise ratio (SNR). In practice, many factors can affect image quality by causing the signal amplitude or phase modulation.

## 1.6 SAR IMAGING OF OCEAN SURFACES

Since the microwave backscatter is from short scale ripples, the apparent modulation of the ripples by the longer waves renders the longer waves visible in SAR image. If the waves are long and not too high, the SAR imaging mechanism may be linear and it is possible to directly retrieve the directional spectrum from a SAR image spectrum. The sea surface is constantly moving and the mean wave structure includes a variety of motions with components along the line-of-sight to the radar (Vachon and Raney, 1991). These motions will induce small Doppler frequency shifts on the reflected signals. These shifts, and the resulting misregistration of scene scatterers, produce a smearing, or blurring effects in the azimuth direction and the amount of defocusing for optimum images depends only on the wave phase velocity and propagation direction (Krogstag, 1992).

The returned energy over the sea surface is primarily scattered by the small wind induced surface waves. It is assumed that for moderate incident angles between $20^0$ and $60^0$ the Bragg resonance is the primary mechanism for SAR ocean surface imaging, *i.e.*, the incident radar waves are backscattered by short capillary wave components on the ocean surface. Backscatter increases with increasing the wind speed and vertical polarization returns are higher than the horizontal in several of dB except at the steepest of incidence angle ($0^0$~$20^0$). The noise floor, *e.g*. the termed as noise equivalent sigma naught ($\sigma^0$) of space-borne C-band SAR for the ocean surfaces is usually less than -20dB (*e.g*., -25dB for RADARSAT-2). Ocean returns which produce that level during the low wind condition and high incidence angles, may not produce the adequate signal above the noise floor, thus limiting the quantitative usefulness of measurement under those conditions. In SAR imagery, three major processes seem to exist that are considered to be responsible for the formation of the quasi-monochromatic images of the ocean waves are tilt, hydrodynamic and velocity bunching modulations (Hasselmann and Hasselmann, 1991).

## 1.7 RADAR REMOTE SENSING APPROACH FOR DETECTION OF TSUNAMI

Current tsunami sentry structures are created on computational databases that counsel alongside the probability of seismic activity-produced tsunami influences, and effort to forecast their power and influx times verses site built on the seismic activity appearances [Titov *et.al.*,2005, 2009]. These computational models comprise ocean-size shoreline and bathymetry geometries. A procedure exists for sudden dissemination of earthquake datasets and tsunami model early investigations in between foreign administrations but there are no structure exists for native recognition of an real inward wave with the substantial early warning competences (Wei *et.al.*, 2008). Tide-gauge sea heights at seaside locations nearer to the epicenter and do deliver useful measurable data for sites additional downstream, if they would able to transmit the datasets (Lipa *et.al.*, 2011). Tsunami which hited Japan in March 2011, the signal was detected by many high frequency radars round the Pacific ocean with strong consequences from locations in United States, Japan, and Chile [Hirofumi *et.al.*,2011). The high frequency radar systems currently function endlessly from numerous seaside sites around the world, measuring the ocean surface currents and waves. The radar locations around the globe are accessible on http://www.codar.com/ seasonde_world_locations.shtml.

Barrick, 1979 initially suggested the utilization of coastal based radar instruments for tsunami early monitoring. Furthermore, the investigation refined this idea and radar period pattern algorithm was proposed (Lipa *et.al.*, 2006 and Wei *et.al.*, 2008) which can be further be engaged using a single radar to detect a tsunami signals among the background wave currents. This algorithm was depends on the evidence that when wave velocity mechanisms perpendicular to the water depth contours are conquered by the tsunami waves, they will be intelligible over area bands parallel to the water depth subzones. The arrival of the tsunami is indicated by the commencement of distinctive current velocity oscillations [Barrick, 1979].

When water depth reduces, the height of tsunami decreases gradually, as the inverse $1/4^{th}$ order of water level. The Eigen function orbital velocity upsurges with higher values swiftly, as the inverse $3/4^{th}$ order of water level. Water wavelength reduces with the quantity of square root to the water depth.

## 1.8 OBJECTIVES AND SCOPES OF THE RESEARCH

### 1.8.1 Objective

This study consists of the two main focused objectives

- To compute and analyze the Tsunami wave parameters such as Eigen functions in terms of its angular velocity, orbital velocity, orbital acceleration, celerity of the waves and wave potential in deep, intermediate and shallow water regions.
- To compute the tsunami detection function (*q*-factor) using the radar remote sensing technique.

### 1.8.2 Scopes

- The overall scope of this work is to achieve the certain conclusion that, if the early warning systems can be designed and implemented, the concerned authority can be able to take the quick action against the region of interest which has been affected due to the waste tsunami disasters.
- The basic fault parameters of Tsunami generation such as fault length, width, area and displacement would be calculated with respect to the impact of earthquake magnitude.
- The measurement and analysis of tsunami Eigen functions such as orbital velocity, acceleration, wave potentials in the direction of propagation, vertical and resultant directions would be carried out using Airy's wave theory.
- Radar remote sensing approach specially the measurement of *q*-factor would be taken into consideration for Japan coast for which the datasets were provided when the tsunami occurred in March 2011 using two of the radar systems

## 1.9 ORGANISATION OF THE THESIS

The chapters of the thesis are organized in the following manner:

Chapter 1 introduces the brief outline of research and introduction of Tsunami wave parameters and microwave remote sensing (RADAR and SAR) with the various applications in ocean technologies.

Chapter 2 describes the various literature reviews to understand the previously developed models, techniques and methodology.

Chapter 3 provides detailed overview of the dataset description, methodology, results and discussion for the Tsunami Eigen function estimations in deep, intermediate and shallow water regions.

Chapter 4 gives detailed explanation on the investigation of early warning for the Tsunami wave parameters using radar remote sensing technique.

Chapter 5 presents a summary of the work carried out and important conclusions drawn.

## 1.10 SUMMARY

In summary, we explained the basic theory of Tsunami generation, propagation and run-up from deep to intermediate to coastal regions based upon the Airy's wave theory algorithms. RADAR imaging concepts of oceans have been explained and the investigation of early warning concept of Tsunami arrivals using radar has also been presented. The objective and scopes of the research has been drawn to work upon the work.