

INSTRUMENTATION FOR COASTAL ZONE MANAGEMENT.

Antony Joseph K.

National Institute of Oceanography, Dona Paula, Goa.

1. Introduction

Coastal zones are, in general, heavily populated regions largely because of their agricultural and fisheries potential. Their navigational potential render some coastal areas to be good trading centres. Coastal ocean being the ultimate disposal ground for liquid effluents many industries as well as thermal and power plants began to be established in the vicinity of sea coasts. Whilst such establishments are necessary for the overall prosperity of a nation they also pollute the marine environment, destroying precious, and often exotic, marine life and thereby adversely affecting the marine ecology.

Pollutants of various types render many beautiful beaches unusable for recreational purposes, adversely affecting the tourism industry. Oil slicks of various dimensions cause varying degrees of mortality of marine life. Remains of oil slicks and other organic wastes deposited in water get trapped in coastal waters for long periods of time, often giving rise to the occurrence of minute tar balls during certain phases of tide. This causes nuisance to swimmers. Even small quantities of organic substances on the ocean surface may be found as highly dispersed monolayers or in some cases they may exist as a film. These surface films can dramatically affect the physico-chemical processes at the sea/air interface.

Natural and man-made changes in the coastal environment may cause sedimentation, siltation, coastal accretion or erosion, resulting in undesirable changes in the topography of the coastal zone. Implications of major shoreline erosion include loss of historical sites and artifacts, disputes of ownership boundaries, and construction of development facilities. The capability to document changes in shoreline configuration on a regular basis would be useful for coastal zone management.

Generation of circulation cells in the surf zone of a beach causes danger to the lives of even experienced swimmers. Timely warning of the generation of these dangerous circulation cells and locating the position of rip currents will help save the lives of many tourists visiting the beaches.

For an effective management of coastal zone the factors affecting this zone must be detected using suitable instrumentation so that appropriate remedial measures could be implemented.

2. Instrumentation.

Because coastal zone encompasses a large area with routine fishing activity, deployment of instruments and their retrieval on a routine basis from this zone is impractical. Any decision relating to coastal zone management must rely on scientific data collected from a sufficiently large area in this zone. Logistic and financial involvements in the collection of such data using a large array of insitu measuring devices would be prohibitive. Further, deployment and collection of data from most of these devices would be difficult in severe sea conditions, during which time data is most needed. Inevitably, with any piece of equipment in the coastal zone environment there are severe problems to be overcome. A more realistic approach for routine monitoring of large areas of coastal zone would be the use of remote sensing techniques. For this reason, discussion in this paper is limited to some remote sensing techniques which can provide a synoptic coverage of the coastal zone. Specific topics covered are techniques for detection of coastal zone related factors such as presence of organic surfactants, shoreline changes, and coastal circulation.

(i) Remote detection of organic surfactants.

Pollution of coastal waters is a worldwide problem of high social relevance. One of the frequently occurring pollution problems arises from spilling of crude oils in coastal waters. It is necessary to first locate the region of pollution and assess the trend of movement of the slick before any sort of pollution combating measures can be initiated. As a first step in this direction many countries are considering the use of regular airborne coastal patrol remote sensing systems to survey coastal waters.

Conventionally used remote sensing techniques for detection of oil slicks are imaging by real- and synthetic- aperture side-looking active microwave radars popularly known as RAR and SAR respectively. Passivemicrowave radiometers and laser-induced fluorescence techniques are also rarely used (Alpers et al.1982, Blume et al.1983, Huhmerfuss et al.1986, and Camagni et al.1986). The advantage of an imaging radar is its potential for surveying large sea surfaces.

Imaging radars detect oil slicks based on the principle that the presence of slick reduces the roughness of the sea surface by virtue of a strong wave damping ability of oil in the short gravity wave range. A RAR is generally operated from an aircraft flying at heights as large as 10,000 feet, with rather steep depression angles, whereas a SAR is usually flown on polar orbiting satellites although SARs are rarely flown on aircrafts as well. The side-looking active microwave imaging radar is a sensor which measures the microwave reflectivity pattern of the ground.

These radars are positioned so that their antenna faces to one side of the aircraft or satellite which carry them. In operation, a short electromagnetic pulse is transmitted through the antenna to the ground at an angle. The strength of the received back-scattered radiation depends mainly on the roughness of the ground within the footprint of the antenna beam. The time-dependent received signal gives the information of the microwave roughness characteristics of the ground in the cross-track direction, and is processed to give one image line. Processing for the next image line starts when the radar platform (i.e., aircraft or satellite) has moved a certain distance ahead. Repeating this process enables a complete image to be produced, which resembles an optical image, but in fact represents a different physical phenomena.

The advantage of microwave systems is that ground imaging can be conducted in nearly all weather conditions and also during night. The operation of an aircraft-borne imaging radar system is schematically shown in Fig.1(a). The smooth surface of the sea, where oil slick is present, reflects most of the incident radiation away from the radar receiver whereas the rough surface of the sea, where there is no oil slick, scatters the incident radiation so that a portion of which is received back by the antenna. Relative strength of the received signal from a sea surface with and without oil slick is schematically shown in Fig.1(b). Because the strength of the return signals from oil slick surfaces is extremely weak compared to that from slick-free surfaces the oil slick areas will be seen as dark in the microwave image of the radar footprint on the sea surface. In an aircraft-borne radar the sea surface roughness image can be seen by the operator on a video monitor screen. For future scientific evaluation, the data is digitised and stored in a high density storage medium so that digital image processing techniques can be applied.

A series of measurements during 'Archimedes' experiments for detecting and discriminating oil spills and sea slicks have shown that microwave radars can detect and image extremely thin layers (less than 1 micrometre) as well as thick layers of a slick (Witte, 1986). This poses the problem of discrimination between spilled crude oil slick layers and very thin layers of biogenic origin which can naturally appear at the water surface but do not pose any environmental hazard. Further, an unequivocal classification of the organic material on the sea surface cannot be achieved by means of the radar data (Huhnerfuss et al.1986). It is important to distinguish between different types of films to avoid false alarms.

There are indications that passive microwave radiometers are usable for volume and quality estimation, though it is not very effective for principal detection and contour estimation (Gruner et al.1986).

An exciting new technique recently developed for detection of organic surfactants on the water surface is a highly surface-selective non-invasive remote sensing technique known as 'reflected optical second harmonic generation' (SHG). As a surface probe, it has several attractive features (Shen, 1989). Being a laser-excited coherent optical process, surface SHG is highly directional. It is therefore suitable for non-detrimental, in-situ remote sensing studies and can be used for monitoring surfaces in a real environment. Sub-picosecond laser pulses can be used for probing, giving the technique the potential for sub-picosecond time resolution and making it useful for in-situ real time probing of fast surface dynamics such as on the ocean surface. Because laser excitation is capable of high spatial and spectral resolutions, it also allows in-situ mapping of the molecular arrangement and composition of a surface monolayer. This means that there is a possibility that the composition of the surfactant can also be remotely detected by an SHG probe. These advantages make SHG a unique and versatile tool for ocean surface studies.

The SHG technique is based on the principle that an optical wave at frequency ω impinging on a medium induces a dipole oscillation of each molecule in the medium. Because a molecule behaves like an anharmonic oscillator, overtone oscillations are excited at frequencies 2ω , 3ω and greater. Oscillating dipoles emit electromagnetic radiation. Thus, the medium impinged by the laser beam emits radiation at frequencies ω , 2ω , 3ω and so on. In the SHG technique, attention is focussed on the frequency 2ω because at an interface, where optical inversion symmetry is broken, radiations at all frequencies, except those at frequency 2ω , are very weak. Hence SHG is highly surface specific. This process is not applicable for bulk of media, but is applicable on the scale of a laser beam diameter where there is no bulk contribution to the SHG signal.

In the SHG technique a narrow laser pulse is incident on the sea surface. Intensity of the beam is maintained at a sufficiently low level so that it is non-destructive to the organic film of the surfactant. By the above-cited non-linear response of the molecules on the first several layers of the air/sea interface to the impinging laser beam an SHG signal of half the wavelength (i.e., frequency 2ω) of the incident laser beam is generated in the first several layers of the air/sea interface. This non-linear optical process is instantaneous, and is easily detected for incident laser energies very well below the damage threshold of the interfacial molecules. The backscattered SHG signal possesses the same temporal pulse shape as the incident laser pulse. Intensity of the backscattered SHG signal is dependent on the surface tension of the sea surface, and is proportional to the square of the intensity of the incident laser beam. This feature enables trouble-free detection of the SHG

signal. Increasing surface concentration of organic matter of the ocean surface results in a decreasing surface tension for sea water, and a corresponding decrease in the SHG signal strength. Since surface films or sea 'slicks' modifies the surface tension of the air/sea interface layer, variations in the intensity of the backscattered SHG signal is a measure of the concentration of organic slicks on the water surface. Thus, an SHG probe can remotely detect natural and man-made slicks on the ocean, and can monitor small changes in concentration of surface organic material.

Field measurements by Korenowski et al (1989) on the coastal ocean waters off Cape Henry in the Atlantic ocean from the Chesapeake Light Tower at a height of approximately 25 metres above the ocean surface demonstrated that SHG is a viable remote sensing probe for detection of natural and man-made slicks on the ocean, and for monitoring of concentration changes of surface organic material. In this slick detection experiment a narrow laser beam of 532 nanometre (nm) wavelength was directed to the ocean surface, which produced a second harmonic response at 266 nm wavelength [in the ultra-violet range]. The laser beam divergence produced a 3 cm diameter spot on the ocean surface. When a large area coverage is intended, as is usually the case in a typical remote sensing scenario, it becomes necessary to perform scanning of the laser beam. This is achieved by directing the laser beam to the ocean surface via a prism controlled by a stepper motor. The controlled prism allows precisely pointing the laser beam on to the ocean surface. A telescope signal-collection system receives the backscattered SHG signal. The received signal is amplified by a high-gain photo-detector such as a photo-multiplier or a similar system to achieve monolayer sensitivity, and the necessary filtering and signal-conditioning are performed subsequently. The large difference in frequency between the fundamental (w) and the second harmonic ($2w$) makes filtering of the SHG signal against unwanted background noise straight forward. Because the output is highly directional, spatial filtering can be used effectively to block most of the fluorescence or stray light from the sample area.

Repeated experiments by Korenowski et al (1989) at varying sea-states demonstrated that the SHG probe can remotely detect organic films on the ocean surface at sea conditions ranging from glassy calm to breaking waves. These findings show that the SHG technique has the potential to be used as a true remote sensing probe to monitor the sea surface layer. It is expected that land-based and aircraft-borne SHG devices will become a routine slick monitoring device in the near future.

Detection of organic slicks will enable suitable preventive measures to be undertaken to destroy the slick. A group of microbiologists at this Institute are currently working on the development of some bacteria suitable for biodegradation of or-

ganic slicks and minute tar balls in the ocean surface waters. It is hoped that the product will become a practical tool to combat the menace of frequently occurring oil spills in the coastal waters of many countries.

(ii) Remote detection of shoreline changes.

Erosion and sedimentation are problems that are usually observed in coastal zones. In some coastal areas accretion processes also take place during some seasons. Knowledge of these processes and the factors which affect them are of importance in devising shoreline protection measures. To detect changes in shoreline, it is necessary to have an inventory of periodic maps of the coastal zone. Generation of coastline maps on a seasonal basis permits determining the types and extent of changes in the shoreline environment, delineating active erosion zones, identification of potential sources of future erosion, and defining those problems which are technically treatable. Coastline detection using remote sensing methods falls in the category of boundary detection problems.

Remote sensing techniques are used to generate maps of the coastal zones more accurately in short periods of time than resorting to conventional time-consuming land survey techniques. Superposition of suitably enlarged aerial photographs or imageries, of a given coastal zone, onto the terrain maps prepared in previous years based on land surveys or previous photographs will provide a quantitative estimate of the geomorphological processes in a given shoreline and deviations, if any, in the water/land interfaces. Aerial photographs and imageries can be complemented by limited field work. Multispectral scanner (MSS) data obtained from Spot satellite was used by Markon (1989) to document shoreline erosion along the northern Alaskan Arctic coastal plain. Luu (1989) used data from Landsat, Soyuz, and Spot satellites and applied remote sensing techniques to study shoreline changes in Vietnam. The Spot satellite data is suitable for detecting shoreline configuration greater than 20 m (the resolution of the data). Aerial photographs and Landsat images were used by Hizal (1986) to devise cost-effective methods to stabilize the coast of Kocaeli peninsula in Turkey.

Satellite-derived multispectral data is classified based on the spectral properties of a scene. A maximum likelihood algorithm is then applied to produce a classification containing several different classes. Two techniques are in common use for the classification of remotely sensed imagery, namely; (i) supervised classification and (ii) unsupervised classification. In the former the analyst provides information about the locations and characteristics of known regions. In the latter the analyst labels regions that the algorithms have identified as homogeneous. The maximum likelihood algorithm assigns every pixel in the data set to one of the spectral classes, producing class-

ification where each pixel represents a water or land cover class. The classes coming under land coverage can further be divided into areas having vegetation, areas with no vegetation, or muddy land. The classification is geo-coded and then converted into a map coverage. Digital map coverages of the same regions, generated for different seasons or dates, are then graphically displayed to show the location and amount of change which occurred between these seasons or dates. These procedures also provide information on the depletion or enhancement of vegetation or forest cover in coastal or other regions.

A drawback of aerial photography and optical-wavelength radiometry is their inability to operate during nights and cloudy days. Although microwave imaging radars, with their all-weather capability, are effectively used for imaging sea surface features on an operational basis, they are yet to become powerful tools for land mapping applications. Although microwave radar images show apparent similarities with aerial photographs, radar image interpretation for land use studies is a comparatively young and not thoroughly understood field of remote sensing. Understanding radar images is difficult in that they are non-optically generated and do not present ground reactions of optical wavelength but of microwaves, which are not a component of primary human experience (Kessler, 1986). Radar image interpretation for purposes of land use inventory requires well skilled interpreters who must have fundamental experience in both the physics of the system and the science of the particular discipline sought to be investigated using microwave imagery. Error in microwave image interpretation for shoreline mapping will be particularly severe when considering the fact that the return from the wind-roughened and wave-modulated surf-zone waters can frequently equal or exceed the return from a nearby land area, resulting in inadequate contrast for unambiguous separation of land from the sea (Lee et al.1989). Furthermore, presence of speckle effect, generated by the coherent signal scattering within SAR resolution elements complicates the detection problem.

(iii) Remote detection of surf zone circulation paths.

Remote sensing of circulation patterns in the surf zone (the region between wave breaking zone and the shoreline) is important for a realistic management of a coastal zone. In the study of fluid motion, flow visualization techniques are often used in order to detect the location and the spatial dimensions of the flow field. Visible wavelength photography and active microwave imaging are two powerful techniques used for detection of vortices and a dangerous coastal current known as 'rip current'. Information on the dimensions and locations of surf zone circulation cells are valuable to give warning to swimmers in a beach which is characterized by this dangerous circulation.

The signature exploited in the detection of surf zone cir-

ulation cells is roughness contrast. Surface regions dominated by intense currents are often marked by a roughness contrast of the sea surface compared to adjacent regions of no significant currents. These contrasts can be seen in ocean surface imageries. These imageries permit, therefore, identification of circulation paths. This is one of the principles behind remote detection of ocean surface circulation using visible wavelength photography and active microwave imageries.

Visible wavelength photography was historically the first remote sensing technique developed to study the ocean from space. This is also one of the very few techniques which 'sees' directly from the surface layers of the sea down to a depth of several metres. The track of surface roughness contrast can be imaged in the visible-wavelength photography because the sea surface roughness variability alters the sunglint pattern. Inman et al. (1971) have shown that visible-wavelength photography is an excellent tool for detection of surf zone circulation cells consisting of longshore- and rip-currents. The spacing between successive rip current paths determines the longshore dimensions of the near-shore circulation cell.

Whilst visible-wavelength photography is an excellent tool for remote detection of the dangerous surf zone circulation cells and vortices, their efficiency is hampered during the periods when clouds are present or visibility is poor. Active microwave imaging radar systems permit detection of coastal circulation patterns regardless of weather and visibility conditions. However, as a result of poor resolution arising from the comparatively larger wavelength of the radar, the imagery obtained from radar systems do not generally match those obtained from photography in terms of quality.

A radar image of the sea surface is simply a pictorial representation of the backscattering properties of the sea surface at the radar wavelength. Alpers et al. (1981) have shown that aircraft- and satellite-borne sidelooking real- and synthetic-aperture radars are excellent tools for remote detection of surf zone currents. Since the high velocity regions of the surf zone have strong backscattering cross-section, one would expect that these regions will be seen brighter in the SAR image. On the contrary, longshore- and rip-current regions in the image are darker compared to the neighbouring areas. This 'blacking out' in the radar image occurs when the orbital velocities of the shoaling waves is of the order of its phase velocity (Alpers et al. 1981). In this case the azimuthal displacement of the moving facets can become so large that they are shifted completely out of the image if the azimuthal bandwidth of the radar is limited. It is surprising that image suppression arising from fast moving targets, an inherent defect of the SAR imaging process, has become a useful feature for detection of circulation patterns in the surf zone which has generally a bright microwave-background because of

strong backscattering cross-section of the breaking waves.

3. Conclusions.

Some remote sensing techniques for detection of coastal zone related factors such as presence of oil slicks, shoreline changes, and paths of surf zone circulation have been discussed briefly. The remote sensing devices discussed above can be borne on aircrafts or satellites. Because air patrolling of coastal zones are routinely undertaken by the coast guards, installation of these remote sensing devices on these aircrafts can be undertaken, and information required for efficient coastal zone management can be elicited cost-effectively.

REFERENCES.

Alpers, W., J.C. Blume, W.D. Garrett and H. Huhnerfuss (1982), The effect of monomolecular surface films on the microwave brightness temperature of the sea surface, *International Journal of Remote Sensing*, Vol.3, pp.457-474.

Blume, J.C., H. Huhnerfuss, and W. Alpers (1983), Variation of the microwave brightness temperature on sea surfaces covered with mineral and monomolecular oil films, *IEEE Transactions on Geoscience and Remote Sensing*, Vol.GE-21, pp.295-300.

Huhnerfuss, H., W. Alpers, O. Fast, P.A. Lange, A. Loffet, K. Richter, R.C. Schriel, N. Skou, and F. Witte (1986), On the discrimination between crude oil spills and monomolecular sea slicks by airborne remote sensors - Today's possibilities and limitations, *Proceedings of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS'86)*, Vol.3, pp.1359-1364.

Camagni, P., G. Colombo, C. Koechler, A. Pedrina, N. Omenetto, and G. Rossi (1986), Diagnostics of oil pollution by laser-induced fluorescence, *Proceedings of IGARSS'86 Symposium*, Vol.3, pp. 1365-1367.

Witte, F (1986), Oil slick detection with a sidelooking airborne radar, *Proceedings of IGARSS'86 Symposium*, pp. 1369-1374

Gruner, K., N. Bartsch, F. Witte, H. Schreiber, and W. Keydel (1986), Contributions to oil spill detection and analysis with radar and microwave radiometry, results of the Archimedes II campaign, *Proceedings of IGARSS'86 Symposium*, pp. 1375-1380.

Shen, Y.R (1989), Surface properties probed by second-harmonic and sum-frequency generation, *Nature*, Vol.337, pp.519-525.

Korenowski, G.M., G.S. Frysinger, W.E. Asher, W.R. Barger, and M.A. Klusty (1989), Laser based nonlinear optical measure-

ment of organic surfactant concentration variations at the air/sea interface, Proceedings of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS'89), Vol.3, pp.1506-1509.

Markon, C.J (1989), Detection of coastal shoreline erosion using Spot MSS data and ARC/INFO., Proceedings of IGARSS'89 Symposium, Vol.3, pp.1656-1658.

Luu, D.N (1989), Shoreline changes in Vietnam using remote sensing techniques, Proceedings of IGARSS'89 Symposium, Vol.3, pp.1693.

Hizal, A (1986), The use of remote sensing (including aerial photographs) to devise cost-effective methods for soil conservation in the Kocaeli peninsula, Turkey, Proceedings of IGARSS'86 Symposium, Vol.3, pp.1247-1250.

Kessler, R (1986), Microwave remote sensing - its applicabilities and limitations in operational tasks of land use inventory and forest management, Proceedings of IGARSS'86 Symposium, Vol.1, pp.629-631.

Lee, J.S., and I. Jurkevich (1989), Unsupervised coastline detection and tracing in SAR images, Proceedings of IGARSS'89 Symposium, Vol.4, pp.2611-2614.

Inman, D.L., R.J. Tait, and C.E. Nordstrom (1971), Mixing in the surf zone, Journal of Geophysical Research, Vol.76, No.15, pp.3493-3514.

Alpers, W.R., D.B. Ross, and C.L. Rufenach (1981), On the detectability of ocean surface waves by real and synthetic aperture radar, Journal of Geophysical Research, Vol.86, No.C7, pp.6481-6498.

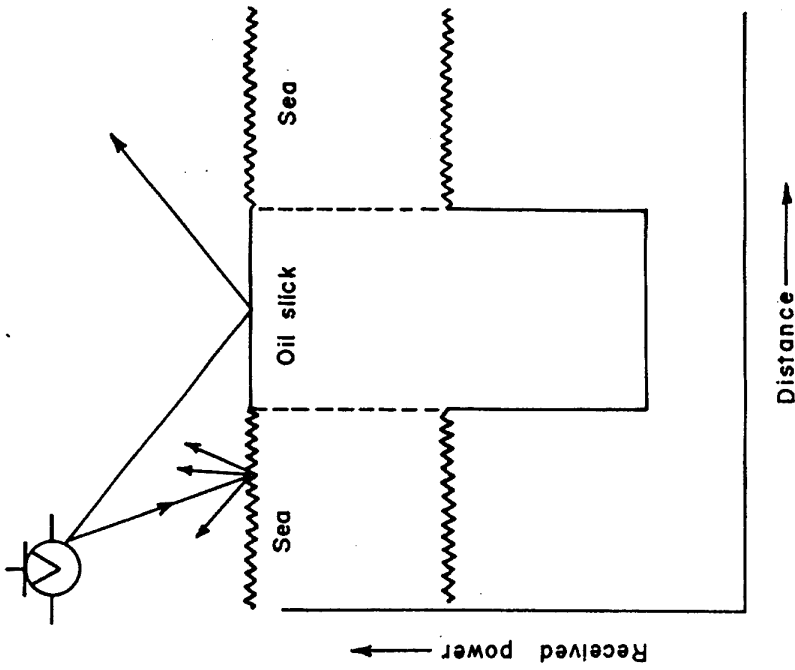


Fig. 1

(a) Microwave transmission from an aircraft-borne radar and backscattering and reflection from the sea and oil slick areas respectively.

(b) Received backscattered microwave power from sea surface.