Radar Investigations of Ocean Surface Geometry and Dynamics

Stuart J. Anderson

ISR Division
Defence Science and Technology Organisation
Adelaide, Australia
stuart.anderson@dsto.defence.gov.au

***Abstract*— Radars can be used to measure and characterise the shape and motion of the ocean surface. Recent developments in our understanding of the geometry and dynamics of the surface can be exploited to enhance radar performance generally, as well as suggesting new capabilities.**

I. INTRODUCTION

The geometry and dynamics of the ocean surface dictate its radar scattering behaviour, yet, for many practical radar applications, a detailed knowledge of the surface is not essential. For instance, the presence of a target may often be established simply by detecting an outlier in the observed distribution of resolution cell power returns, without regard to the mathematical form of that distribution or its relationship with the sea surface shape and movement. Alternatively, a parametric form may be assumed, fitted to the measurements and used to set detection thresholds. It may even be that the parametric form is derived from a physical model of some kind, be it one describing the sea surface such as the Pierson-Moskowitz spectrum for surface gravity waves, or one relating to the interaction of the radar signal with the surface, such as the Bragg scattering process.

This paper considers the complementary class of problems, where the detailed structure and evolution of the surface is of primary concern. There are many reasons why one should wish to know the details of the water body geometry and dynamics, and not just its radar signature. Perhaps the most important is the desire to understand the sea surface from a scientific perspective, so that the predictive power of science can be applied to good effect. Then there are specific problems relating to the interaction between the sea and man-made structures, such as ships, offshore drilling platforms, breakwaters and so on. Yet another motivation stems from the fact that mass, momentum and heat are exchanged between the atmosphere and the ocean, with vital implications for weather and climate. And of course, there is the need to validate or at least justify descriptive models such as those referred to in the preceding paragraph. In all these cases, there can be no substitute for a fundamental examination of the underlying physics.

II. FORMULATION OF THE RADAR OBSERVATION PROCESS

The relationships between the components of the radar observation process are shown in Fig. 1. Of paramount importance is the choice of representation of the surface; this may be deterministic or stochastic as appropriate. Once adopted, each instantiation of a representation will correspond to some equivalence class of actual sea surfaces, since the number of parameters involved in such a description is necessarily finite.

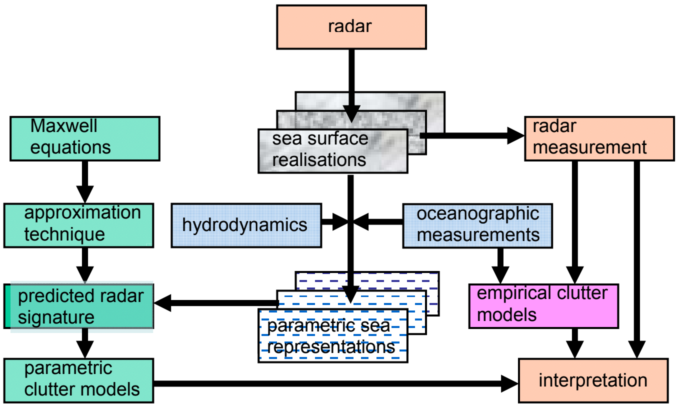

Fig. 1 The functional relationship between the physical and modelling domains relevant to radar oceanography

Once a surface has been defined in this way, it can be used to complete a sufficient set of boundary conditions for Maxwell's equations and hence, in principle, lead to a solution for the scattered field. In practice the equations can never be solved exactly, so some approximation technique must be employed. The choice of technique should be matched to the spatial and temporal scale sizes involved. In the case of the sea surface, this is nontrivial, to say the least, because of the rich variety of hydrodynamic phenomena, some of which are identified in Fig. 2.

Having established a methodology for computing the radar signature for a given sea surface, or boundary layer in the general case, one can begin to address the inverse problem of interpretation of radar echoes to retrieve the surface geometry and, where the radar measurements are suitably designed, the dynamics. In some situations the problem can be linearised with little sacrifice of fidelity, which simplifies the inversion somewhat, but in general hydrodynamic nonlinearity cannot be neglected. Again, the development of robust inverse techniques should be based on full exploitation of the constraints imposed by the physics involved.

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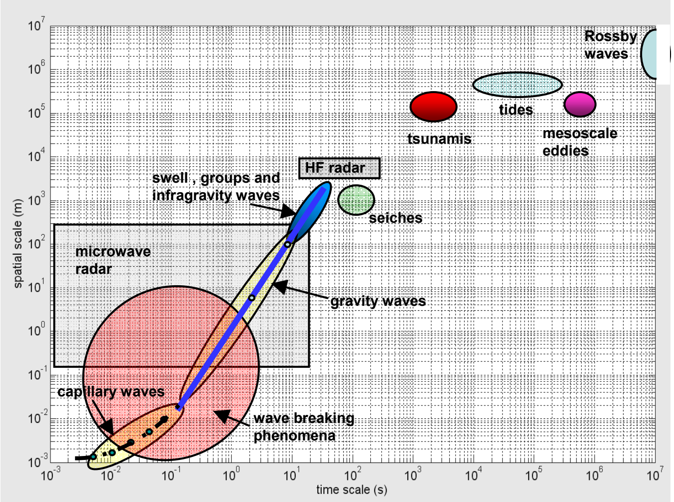

Fig. 2 Spatial and temporal scales of major oceanic wave phenomena

III. OCEANOGRAPHIC PHENOMENA

A conventional starting point for a description of the ocean surface is the adoption of a progressive wave ansatz. By rather brutal approximation of the Navier-Stokes equation for conditions corresponding to roughly the centre of Fig. 2, one obtains the surface elevation and velocity potential for the Airy wave in water of depth D :

$$\eta = a\cos(\kappa x - \omega t)$$

$$\phi = \frac{ga}{\omega}\sin(\kappa x - \omega t)\frac{\cosh(\kappa(z+D))}{\cosh(\kappa D)}$$

With this primitive model, we can explore ocean surface behaviour on length scales in the range $10^{-1} - 10^{3}$ m. Some of the phenomena which can be examined include :

- spectral representations
- wave groups
- wave-atmosphere coupling
- the consequences of nonlinearity
- wave instabilities
- wave breaking
- surfactant effects
- ship wakes
- internal waves

The step to greater length scales necessarily involves a more general form of the equation of motion, with solutions corresponding to phenomena such as :

- Rossby waves
- meso-scale eddies
- current filaments
- tides
- tsunamis

If we consider structures on the smaller length scales of Fig. 2, we find the need to extend the range of geometrical structures employed so as to describe :

- fragmentation of the water body (spray and spume)
- two-phase media (foam)
- multi-valued surfaces (over-turning and wave breaking)

IV. RADAR SYSTEMS AND TECHNIQUES FOR OCEAN SURFACE STUDIES

A wide variety of radar systems have been applied to the problem of sea surface characterisation, including :

- shore-based high resolution fully polarimetric, microwave radars
- shore-based, high resolution, fully polarimetric, mm wave radars
- satellite altimeters
- satellite scatterometers
- conventional shipborne X-band radars
- HF skywave radars
- HF surface wave radars
- airborne polarimetric electronically-scanned array radars
- fully polarimetric microwave radars
- airborne and spaceborne SAR-mode microwave radars
- laser radars (lidars)

using a variety of scattering mechanisms, including :

- reflection
- refraction
- diffraction
- interferometry
- tracer-following
- absorption

and combinations thereof. The resulting characterisations of specific phenomena can be exploited to enhance radar performance in operational roles.

V. CONCLUSION

There can be little argument with the assertion that understanding the physics of the ocean surface and exploiting this knowledge in radar design and deployment will lead to improved radar performance, even in applications where a useful capability can be achieved without adopting a knowledge-based approach.

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