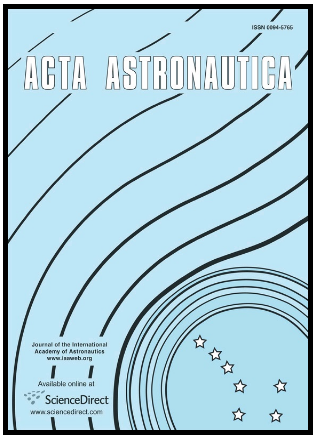

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On Small Satellites for Oceanography: A Survey

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Abstract

The recent explosive growth of small satellite operations driven primarily from an academic or pedagogical need, has demonstrated the viability of commercial-off-the-shelf technologies in space. They have also leveraged and shown the need for development of compatible sensors primarily aimed for Earth observation tasks including monitoring terrestrial domains, communications and engineering tests. However, one domain that these platforms have not yet made substantial inroads into, is in the ocean sciences. Remote sensing has long been within the repertoire of tools for oceanographers to study dynamic large scale physical phenomena, such as gyres and fronts, bio-geochemical process transport, primary productivity and process studies in the coastal ocean. We argue that the time has come for micro and nano satellites (with mass smaller than 100 kg and 2 to 3 year development times) designed, built, tested and flown by academic departments, for coordinated observations with robotic assets *in situ*. We do so primarily by surveying SmallSat missions oriented towards ocean observations in the recent past, and in doing so, we update the current knowledge about what is feasible in the rapidly evolving field of platforms and sensors for this domain. We conclude by proposing a set of candidate ocean observing missions with an emphasis on radar-based observations, with a focus on Synthetic Aperture Radar.

Keywords: Small Satellites, Sensors, Ocean Observation

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1. Introduction

Starting with **Sputnik**'s launch in 1957, more than 7000 spacecraft have been launched, most for communication or military purposes. Nevertheless, the scientific potential of satellites was perceived early on, and even though **Sputnik** did not have any instruments, the radio beacon it had was used to determine electron density on the ionosphere [1, 2]. A small percentage of the satellites were, and still are, dedicated to research (see Fig. 1). In particular, we focus on Earth observation and remote sensing satellites, as they have changed the way we perceive and understand our planet. This transformation started with the first dedicated weather satellite, **TIROS** (Television Infrared Observing Satellite) 1, launched 3 years after **Sputnik 1** [1].

Although the first satellites had mass smaller than 200 kg, consistent demand on performance led to a natural growth in spacecraft mass, with direct consequences to their complexity, design, test, launch, operation and cost. This reached a peak of 7.9 tonnes with ESA's **EnviSat** mission in 2002 [4]. With launch costs to low Earth orbit (LEO) being on average 21 k€/kg, and for geostationary Earth orbits (GEO) 29 k€/kg, for conventional satellites, the missions were mainly developed by national institutions or multi-national partnerships involving substantial investment [5]. However, several engineering problems arose from having different instruments (with different features and requirements) within the confines of a single spacecraft. Consequently, this rise in mass has stopped and spacecraft of about 1 tonne, with fewer instruments have been preferred by the European Space Agency (ESA) and the American National Aeronautics and Space Administration (NASA) in the last few years.

The cost of a spacecraft is not only linked to the launch, but also to its development time, so as to account for mission complexity, production and operation during its life-span [6]. Moreover, their design, development and subsequent operation require a substantial infrastructure to provide the end user with the desired data. Furthermore, project, planning and execution demands years of investment prior to a successful launch.

The revolution of very-large-scale integration, in 1970, opened the possibility of integrating sophisticated functions into small volumes, with low mass and power, which pave the way for the modern small satellite [5]. This concept was initially demonstrated in 1961 with the Orbiting Satellite Carrying Amateur Radio (**OSCAR**) 1, and kept growing in sophistication until **OSCAR-8**, at the end of the 1970s (although still without an on-board computer). In 1981, the launch of the **UoSAT-OSCAR-9** (**UoSAT-1**), of the University of Surrey, changed this, as it was the first small satellite with in-orbit re-programmable computers.

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