Preface

We are living on “a blue planet”—more than 70% of the Earth surface is covered by the world’s oceans. The importance of the world oceans is tremendous for the planet—for food supply, transportation, recreation, etc. About 44% of the global population lives within 150 kms from the sea.

First and foremost, the world oceans, as a whole, control the global climate. On the other hand, they are responsive to ongoing changes in the atmosphere and continents, and trigger a chain of feedback interactions leading to far-reaching environmental effects including those related to aquatic ecosystem transformation (Pozdnyakov et al. 2007), degradation of biodiversity (Beaugrand et al. 2002) and depletion of living resources (Jackson et al. 2001).

Importantly, the influence exerted on the world oceans encompasses their both central and peripheral areas. The narrow interface between the land and the oceans, the coastal waters, whose seaward boundary is topologically determined by the continental shelf at a 200 m depth (Pernetta and Milliman 1995), are the arena of a concerted influence of external physical and biogeochemical forcings exerted by the contiguous pelagic waters and the land. Although the fringes of the oceans (encompassing continental shelves, continent-bound seas and estuarine systems) account for only $\sim$ 10% of the surface area of the world oceans, they accommodate approximately 90% of all marine living species and presently contribute about 40% of the total global aquatic primary production (Jickells 1998). Thus, the role of coastal/shelf waters for the humankind is crucial.

The consequences of impacts produced by human activities and climate change on marine waters are multifaceted, including eutrophication of coastal zones, acidification, toxic contamination, man-made depletion of living resources (Jackson et al. 2001), hydrological alterations (e.g., enhanced suspended matter, nutrients and contaminants delivery (Howarth et al. 2000), significant water level and hydrological cycle variations (Najjar et al. 1999), increased frequency and intensity of storms/flooding events), introduction of pathogens and non-endemic/alien (introduced) aquatic species due to transport with, e.g., ballast water (Carlton 1996), temperature growth above and beneath the air–water surface interface, ice cover extent and duration decline, etc. Such impacts are bound to affect a multitude of processes ranging from marine hydrodynamics, biogeochemistry and aquatic ecology to socio-economic dimensions.

The vitally important role of the worlds' oceans warrants the efforts at national and international levels to achieve sustainable management of aquatic resources. These are the major foci identified in SOER2015—The European environment-state and outlook 2015, the European Earth observation programme Copernicus, European Marine Strategy and International Ocean-Colour Coordinating Group (IOCCG) documents (for refs. see Pettersson and Pozdnyakov 2013).

The contemporary concept of studying natural waters implies a combination of observations both in and above the waters and 3D-biogeochemical mathematical modeling. Aquatic ecology simulations provide a deep insight into the intricacy of processes controlling the current state of the aquatic ecosystem including physical, biological and chemical processes and interactions. However, this can only be attained via using *observation data* as input and validation information. Given some well-based scenarios of variations in physical and anthropogenic forcings, 3D ecological modeling is appropriate to forecast the future status of the water body, and therefore presents a powerful tool for pursuing the policy of sustainable development, including extraction of natural aquatic resources.

Regarding *observation data*, historically, shipborne/field campaigns are the major means of acquisition/collection of the data reflecting changes occurring in natural waters. The accuracy of data of this nature can be very high, provided the accuracy of employed instrumentation and analytical methodologies are high. However, *in situ* measurements suffer from low spatial and temporal resolution. This problem especially aggravates when the targeted water body has large dimensions and the measured parameters vary significantly both in space and time.

From this perspective, generally, *satellite remote sensing* has a capacity of providing data on a certain number of aquatic ecology-relevant variables at the required spatio-temporal resolution, primarily only covering the upper surface layer of the ocean. However, being an indirect method, remote sensing does not yield the values of desired environmental parameters but rather their proxies, which can be further related to the parameters *per se*. The relation can only be established making use of synoptic and co-located *in situ* measurements of the pursued characteristics. If only because of this indirect/mediated approach, remote sensing data are sensibly less accurate compared to their *in situ* counterparts. Besides, unlike *in situ* measurements, remote sensing data on aquatic environments are typically restricted to a relatively thin surface layer or the actual surface skin boundary between the atmosphere and the ocean. For optical remote sensing the depth of remotely probed layer depends on water clarity and is particularly reduced in turbid/highly productive coastal waters subject to significant land runoff, land erosion, river discharge and anthropogenic emissions of nutrients.

Thus, a synergistic combination of *in situ*, simulated and remotely sensed data constitutes a most efficient and contemporary tool for studying the intricacy of relationships between hydrodynamic and biogeochemical processes under conditions of physical/climatic and/or anthropogenic forcings.

In the context of ecological studies of natural waters, the term "synergistic approach" is more complex than a mere use of harmonized in time and space modeling and *in situ* plus remote sensing observations. Remote sensing data obtained in different spectral regions, i.e., visible, infrared and microwaves, also can be combined and used synergistically.

The *visible* radiation, appreciably penetrating into the water column, can provide information about the water color/water composition of colour producing agents (CPA) within the light penetration depth ie. the integrated signal over the light penetration depth. The remotely sensed signal leaving the water column in the *infrared* spectral range is formed exclusively by an infinitesimally thin surface layer —the skin layer. It represents a measure of the temperature, which ultimately can be related to the water temperature of the subsurface top layer.

The water surface leaving signal in the *microwave spectral region* can be efficiently used, e.g., for the detection of ice-free zones and classification/mapping of various types of ice cover, surface temperature, winds, etc. The nature of the instrumentation and signal implies that the information is obtained at a coarse spatial resolution. In the case of *active microwave* remote sensing (performed with, e.g., a Synthetic Aperture Radar—SAR), the signal returning from water surface caries information about the water surface micro-scale roughness that is generally driven by such factors as wind forcing, waves, surface currents, presence of surfactants (e.g. oil and algae biomass), water temperature and hydrodynamic processes.

Therefore, harmonized in space and time spaceborne signals in three spectral regions can significantly extend the scope of information about the targeted water body, and the synergy in this sense is undoubtedly highly warranted. Challenges remain although with relation to spatial and temporal scales of variability of the marine ecology, as well as the sensor mapping capabilities and coverage.

Presently, the state of the art of the three components of aquatic ecology studying/monitoring arsenal has already attained a high degree of maturity and efficient applications have been developed and validated. In terms of observation means, the maturity is not solely confined to sensor technology, but also to data retrieval and integration methodologies. For instance, regarding satellite remote sensing in the visible, the developed bio-optical retrieval algorithms are in a state that they are capable of adequately portraying spatial and temporal distributions of water-quality related parameters not only in clear off-coastal marine waters but also in coastal waters that are generally optically complex, and therefore challenging for discrimination of the signal contributions from the various optically active water constituents (e.g., Parslow et al. 2002; Carder et al. 2004; Pozdnyakov et al. 2005; Doerffer and Schiller 2007; Korosov et al. 2009b; Pettersson and Pozdnyakov 2013). The algorithms developed for the retrieval of sea surface temperature (SST) are robust and close to four decades of consistent sea surface temperature data are available for the world oceans. For near real-time monitoring applications it is also important that the retrieval algorithms are fast enough to qualify as veritably operational tools. Through e.g. the Climate Change Initiative (CCI) of the European Space Agency (ESA) several long time series of satellite Earth

Observation (EO) data have recently become available for use in science and environmental assessment.

In combination with a synergistic data approach, these achievements paved the way to comprehensive studies of natural waters including optically complex waters of large spatial extension, and/or remotely located and inaccessible that previously has been a major obstacle. This is further favoured by increased and continuous availability of several series of satellite Earth observation sensors daily covering the Earth surface providing data for operational and research studies (e.g., Traon et al. 2015) for refs. see Johnsen et al. 2011; Kuenzer and Dech 2013; Jackson and Apel, 2004). Recently the European Copernicus Marine Environment Monitoring Service (CMEMS) published the first Ocean State Report for addressing the state and health of the European regional seas and the global oceans (von Schuckmann, et al, 2016).

We openly admit that the present book was largely spurred up by our own results of the concerted studies performed during last two decades under a number of national and international projects performed in cooperation between the two Nansen Centres in St. Petersburg, and in Bergen respectively. Their concise description of 25 years of international cooperation between Russia, Norway and others countries is given in this book.

This book does not aim at a voluminous overall review of what has been done so far in the area of optical remote sensing of marine environmental ecological studies: only those papers are discussed/cited here, on which we either based some of our simulations or found as substantiating our results. The extent of case studies described and discussed herein varied so that the chapters and separate sections are different in terms of their size, comprehensiveness and sophistication. The structure of the book is not very strict: a general description of the water bodies is given only when we believed it necessary; besides, the methodological issues are not only collected in a dedicated chapter, but on some (but rare) occasions are additionally discussed in other chapters/sections. For the various marine environments encompassed by our studies some concise descriptions of their geographical lay and general oceanographic and ecosystem characteristics are provided. This is done in the view that this may help the readers from different regions of the world get a better insight into both the specific features retrieved in the research carried out by us and our respective interpretations.

In the course of preparing the book its scope became widened through the inclusion of studies that proved to be conceptually very close. We believed that, jointly, the included materials illustrates more fully the feasibility of the employed synergistic approach but also present some valuable scientific results shedding new light onto the intricate mechanisms of marine coastal ecosystems subjected to external forcing. To those who accepted the nature of our endeavor, we welcome to *Exploring the Sea Ecology from Space*.

Finally, we would like to emphasize that the research results presented in this book were the outcomes of many research projects funded by both national research agencies (e.g., Research Council of Norway, Norwegian and European Space Agencies and Russian Foundation for Basic Research) and programs and initiatives of the European Commission, such as INTAS (The international association for the

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