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Evaluation of the Innovation of Observation Efficiency in Satellite Oceanography and Meteorology by New Onboard Sensors

Pedro Reis*
Instituto de Educação, Universidade de Lisboa, 1649-004 Lisbon, Portugal

***Corresponding author:** Pedro Reis, pedroreis@epfl.ch

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Abstract:

This paper aims to evaluate the innovative effect of new onboard sensors on the observation efficiency of satellite oceanography and meteorology. Through the introduction and analysis of various new onboard sensors, their applications and advantages in the fields of oceanography and meteorology are expounded. Relevant data are combined to illustrate how these sensors improve the observation efficiency, providing more accurate and abundant data support for oceanographic and meteorological research and applications. At the same time, the existing problems and future development directions are also pointed out.

Keywords:

New onboard sensors
Satellite oceanography
Meteorology
Efficiency evaluation

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1. Introduction

Satellite oceanography and meteorology observations play a crucial role in many aspects such as global climate change research, marine resource development, and meteorological disaster early-warning. With the continuous progress of science and technology, the emergence of new onboard sensors has brought new opportunities and changes to the observations in these two fields. These new sensors, with their unique technical advantages, can obtain more accurate and detailed oceanographic and meteorological data, thus greatly improving the observation efficiency and providing more powerful support for related research and applications.

2. Overview of new onboard sensors

2.1. Synthetic Aperture Radar (SAR)

Onboard synthetic aperture radar plays an important role in space-based ocean observation with its working characteristics of all-weather, all day, and being unaffected by clouds and rain. With its high spatial resolution, multi-polarization, and multi-imaging-mode features, it shows its unique charm in the inversion of ocean dynamic elements and the research of multi-scale dynamic processes in the ocean. For example, C-band Sentinel-1 and RADARSAT-2 VV-polarized SAR images can be used for marine oil spill monitoring. By accurately marking and analyzing 15,774 oil-spill samples in 1,786 such images, and training relevant models, the detection accuracy and recall rate of oil-spill location can reach 89.23% and 89.14% respectively, and the accuracy and recall rate of oil-spill segmentation can reach 87.63% and 86.59% respectively [1].

2.2. Onboard lidar

Passive remote sensing has certain principle-based limitations, such as the inability to conduct three-dimensional space measurements, being restricted by the sunlight source and unable to detect well at night and in high-latitude regions, and the mutual interference of various components within the same observation integration pixel. Lidar can obtain the vertical profile information of substances along the laser emission path. With an active laser light source, it can achieve good detection at night and in the polar regions, effectively supplementing the Earth's environmental monitoring capabilities [2]. Onboard lidar can provide data such as carbon dioxide concentration, cloud-aerosol, cloud vertical profile, wake vortex, and planetary boundary layer characteristics, which is of great significance for predicting and warning of air pollution, understanding the formation mechanism of atmospheric particulate matter, and improving the quantitative remote-sensing service capabilities. For example, the CALIPSO satellite launched by the United States in 2006, carrying the CALIOP lidar, provided important data support for atmospheric detection. In April 2022, China successfully launched the Atmospheric Detection Lidar (ACDL) developed by the Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences. It is the world's first onboard carbon-dioxide-detecting lidar and the first high-spectral-aerosol-detecting lidar [2].

2.3. Onboard infrared hyperspectral sensor

This sensor is widely used in various observation modes, including nadir observation, occultation observation, and limb observation. Internationally, seven well-known sensors such as IMG, AIRS, and IASI, as well as China's Fengyun series and Gaofen series of atmospheric detection satellites, are equipped with such advanced sensors. In the nadir observation mode, it can provide temperature products within a 1 km range in the vertical direction with an accuracy of less than 1K. The TES sensor in the limb observation mode can provide tropospheric temperature profile products with an accuracy of up to 0.5K, both meeting the accuracy requirements of numerical weather prediction (NWP).

2.4. New-generation ocean color observation satellite sensor

On November 16, 2023, China successfully launched a new-generation ocean color observation satellite. The satellite is equipped with new detection instrument payloads, including a watercolor and temperature scanner, a medium-resolution programmable imaging spectrometer, and a coastal zone imaging spectrometer. The key performance indicators of these instruments, such as resolution, in-orbit calibration accuracy, and signal-to-noise ratio, have been significantly improved [3]. The number of imaging spectral bands of the satellite has increased from the original 16 to 46, enabling the spatial resolution of global ocean water color and temperature observation to be improved from 1100 meters to 500 meters. At the same time, the spatial resolution of coastal zone environmental observation has been increased from 50 meters to 20 meters. In addition, the satellite also has the ability to detect the panchromatic information of ground objects with a spatial resolution of 5 meters, further enhancing the observation accuracy.

3. Applications and efficiency improvements of new onboard sensors in oceanography

3.1. Monitoring of ocean dynamic elements

Onboard synthetic aperture radar (SAR), with its unique technical advantages, can accurately observe key information such as sea-surface roughness, and then effectively invert ocean dynamic elements such as high-resolution sea-surface wind fields. The multi-polarization and multi-imaging-mode characteristics of SAR greatly improve the observation accuracy and detail of mesoscale dynamic processes such as ocean internal waves, laying a solid data foundation for in-depth exploration in the field of ocean dynamics [4]. Taking China's independently constructed "Nüwa Constellation" as an example, this constellation is successfully formed by the networking of 12 commercial radar remote-sensing satellites. Under complex and changeable weather conditions, it can still stably perform high-precision measurement tasks, continuously providing high-resolution earth-observation images for ocean observation, and strongly promoting the development of ocean environmental monitoring, accurate typhoon-path prediction, and prevention and control of marine pollution incidents to a new level.

3.2. Monitoring of marine ecological environment

The new-generation ocean color observation satellite, with its significantly expanded imaging spectral bands, has excellent data-collection capabilities. It can not only accurately obtain more comprehensive and detailed water-color data but also simultaneously collect multiple information such as the atmosphere, vegetation, and pollutants. Thus, it can achieve large-scale, continuous, and dynamic monitoring of key elements such as water color, water temperature, sea ice, suspended substances, and the water ecological environment in the global ocean, offshore areas, coastal zones, islands, and port areas [5]. This feature shows extremely high application value in fields such as marine pollution monitoring, disaster early-warning, and biodiversity assessment, specifically covering aspects such as real-time tracking of the outbreak of harmful algal blooms in the ocean, fine-scale monitoring of estuary and harbor water quality, and precise control of the degree of offshore environmental pollution.

3.3. Marine oil-spill monitoring

Onboard synthetic aperture radar has unique advantages in ocean observation. Its observation efficiency is not restricted by weather conditions and lighting conditions, so it has great potential as a microwave sensor in the field of marine oil spill monitoring. The intelligent detection strategy of SAR marine oil spills based on deep-learning models innovatively integrates advanced algorithm architectures. Among them, the Faster R-CNN algorithm is used to accurately locate the oil-spill position, and the UNet network is used to finely segment the oil-spill dark spots. Thus, in the entire SAR image, the rapid and high-precision identification of marine oil-spill positions and the division of oil-spill dark spots can be achieved, effectively meeting the stringent requirements of current operational practices in marine oil-spill detection [6].

4. Applications and efficiency improvements of new onboard sensors in meteorology

4.1. Detection of atmospheric temperature profile

Onboard infrared hyperspectral sensors, with their diverse observation modes, demonstrate excellent performance in the detection of atmospheric temperature profiles, providing high-precision data support for related research and applications. The temperature products obtained from its nadir and limb observation modes have excellent accuracy performance, fully meeting the accuracy standards set by numerical weather prediction (NWP), and have become a key basis for weather forecasting and in-depth climate change research. Taking the TES limb observation mode as an example, the tropospheric temperature profile products it produces can reach a peak accuracy of 0.5K. This outstanding advantage has achieved a qualitative leap in the accuracy of weather forecasting, enabling more accurate capture of subtle changes in atmospheric temperature, providing a solid data foundation for many key decisions in the field of meteorology, and helping the meteorological science to move to a new stage of development.

4.2. Monitoring of air pollution

Onboard atmospheric lidar, with its advanced detection technology, can accurately obtain key data such as carbon dioxide concentration and cloud-aerosol, which is of great significance for the prediction and warning of air pollution and the in-depth analysis of the formation mechanism of atmospheric particulate matter. For China's independently developed Atmospheric Detection Lidar (ACDL), it uses a laser beam to detect along the satellite's orbit, has excellent high-resolution vertical-profile detection capabilities, and can accurately capture the fine-structure information of atmospheric aerosols and clouds globally. Thus, it builds a data foundation and provides strong and reliable support for many fields such as atmospheric environmental monitoring, the formulation of environmental governance strategies, and in-depth climate-change research, strongly promoting the development of related disciplines [7].

4.3. Early-warning of meteorological disasters

New onboard sensors, relying on cutting-edge technology, have strong data-collection capabilities and can capture more comprehensive and timely meteorological data, which plays a key role in improving the accuracy and timeliness of meteorological disaster early-warning. Taking typhoons, a highly destructive meteorological disaster, as an example, with the help of various new sensors carried by satellites, typhoons can be continuously monitored in real-time. During this process, the data obtained from multiple sensors are fully integrated, such as the atmospheric vertical-structure information provided by onboard atmospheric lidar and the temperature-humidity profile data fed back by onboard infrared hyperspectral sensors. Then, a more accurate typhoon dynamic model is constructed to achieve accurate prediction of typhoon paths, intensities, and landing times, reserving a more ample preparation window for disaster prevention and mitigation work and minimizing disaster losses.

5. Data comparison and analysis

5.1. Comparison of observation accuracy

In terms of observation accuracy, new onboard sensors show significant advantages over traditional sensors. In the field of ocean observation, the new-generation ocean color observation satellite has made breakthrough progress. Its spatial resolution for global ocean water color and temperature observation has been greatly increased from 1100 meters to 500 meters, and the spatial resolution for coastal zone environmental observation has been refined from 50 meters to 20 meters. This enables the monitoring of the marine environment to penetrate into a more microscopic level, capturing detailed information that was difficult to reach in the past [8]. In contrast, traditional ocean color observation satellites, limited by technological levels, have a low resolution and are at a loss when facing the complex and changeable marine environment, unable to meet the urgent need for fine-scale observation of the marine environment.

5.2. Comparison of observation range

From the perspective of the observation range, new onboard sensors show unparalleled advantages. They can cross geographical limitations and achieve comprehensive global observation of oceanography and meteorology. Taking China's "Nüwa Constellation" as an example, after the commercial remote-sensing satellites it contains are successfully networked, they operate in a global networking mode, like a tight and vast sky-net, comprehensively covering the Earth's surface, greatly expanding the breadth and depth of earth-observation. Whether it is the vast ocean depths, the inaccessible polar regions, or the mountainous areas with changeable climates, they can all be within its observation scope, and various key data can be collected in real-time [9]. In contrast, traditional ground-based observation stations, restricted by their fixed geographical locations, can only obtain data in the limited areas around the stations, and are out of reach for remote areas far from the stations, the central ocean, etc. Although aircraft observations have certain mobility, factors such as endurance and operating costs limit the continuity and coverage of observations, making it difficult to achieve large-area and long-term continuous observations.

5.3. Comparison of observation timeliness

In terms of observation timeliness, new onboard sensors show outstanding efficiency, with the excellent ability to obtain data in real-time or near-real-time, bringing a revolutionary improvement to oceanographic and meteorological research and applications. Taking onboard atmospheric lidar as an example, relying on the advanced technical architecture and the advantages of the satellite platform, it can continuously monitor the atmospheric environment at a high frequency. Once abnormal situations such as a sudden change in pollutant concentration occur in the atmosphere, it can quickly capture and promptly feedback relevant information, ensuring the timeliness and freshness of the data. In sharp contrast, traditional ground-based monitoring methods mainly rely on manual field sampling, and then transfer the samples to the laboratory for a cumbersome analysis process [10]. This process involves many links, from sample collection, transportation, to complex detection procedures in the laboratory. It is not only time-consuming and labor-intensive but also inevitably introduces a certain time lag. Often, when the data is finally produced, the atmospheric environment may have changed significantly, making the obtained data unable to accurately reflect the current actual situation. It is difficult to compete with new onboard sensors in terms of timeliness and cannot meet the urgent need to keep real-time control of the rapidly changing atmospheric environment.

6. Conclusion

The emergence of new onboard sensors has significantly improved the observation efficiency of satellite oceanography and meteorology, playing an important role in monitoring ocean dynamic elements, marine ecological environment, atmospheric temperature profiles, air pollution, etc. Through data comparison and analysis, their advantages in observation accuracy, observation range, and observation timeliness have also been proven. However, currently, there are still some technical problems and challenges, and continuous efforts are needed in aspects such as technological innovation, data quality control, and multi-sensor fusion. In the future, with the continuous progress of science and technology and the integrated development of multiple disciplines, new onboard sensors are expected to play a greater role in the field of satellite oceanography and meteorology observations, providing more powerful support for global climate change research, marine resource development, meteorological disaster early-warning, etc.

Disclosure statement

The author declares no conflict of interest.

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