remote sensing

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Technical Note

The Customized Automatic Processing Framework for HY-2A Satellite Marine Advanced Products

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Abstract: HY-2A, as the first Chinese ocean dynamic environment satellite, provides an effective and efficient way of observing ocean properties. However, in the operational stage, some inconveniences of the existing ground application system have appeared. Based on the review of users' requirements for data services, the Customized Automatic Processing Framework (CAPF) for HY-2A advanced products is proposed and has been developed. As an extension of the existing ground application system, the framework provides interfaces for adding customized algorithms, designing on-demand processing workflows, and scheduling the processing procedures. With the customized processing templates, the framework allows users to easily process the products according to their own expectations, which facilitates the usage of HY-2A satellite advanced products.

Keywords: ocean remote sensing; HY-2A satellite; radar data processing; radar altimeter; microwave scatterometer; microwave radiometer; on-demand processing; web services

1. Introduction

Marine ecosystems are important for human beings. However, due to the fact that the marine environment is dynamic and covers approximately 70% of the Earth's surface, it is difficult to observe and monitor the global ocean by using traditional means. In contrast, satellite remote sensing possesses some significant advantages. It is an effective and efficient way of observing the ocean all day and in almost all weather conditions. Furthermore, with high-frequency revisit times and long-term service life, it can easily collect the data of dynamic ocean characteristics covering a large area for years. These merits of the technology provide the possibility of further studying, developing and utilizing ocean resources [1].

Since the 1970s, many countries have launched their own ocean satellites to collect information of ocean properties. According to the different electromagnetic spectrums that they use, the onboard sensors can be categorized into two groups: ocean color and temperature instruments, and ocean dynamic environment instruments. The ocean color and temperature instruments usually depend on the visible spectrum to observe the color changes associated with phytoplankton and sediment concentrations within the euphotic depth, and the infrared spectrum to detect the blackbody radiation emitted from the top few micrometers of the water column. For example, the United States launched the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) instrument on the SeaStar satellite, the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the TERRA and AQUA satellites, and the Visible/Infrared Imager/Radiometer Suite (VIIRS) on the Suomi-NPP (National Polar-orbiting Partnership) satellite. The European Space Agency (ESA) also launched the European Medium Resolution Imaging Sepctrometer (MERIS) on the ENVISAT satellite

(Enviromental Satellite). Afterwards, the ESA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) launched the Ocean and Land Colour Instrument (OLCI) on the Sentinel-3A satellite and the Advanced Very High Resolution Infrared Radiometer (AVHRR) on the METOP-series satellites (Meteorological Operational satellite programme). For the ocean dynamic environment instrument, the onboard sensors usually can be a microwave scatterometer, a radar altimeter, a microwave radiometer or synthetic aperture radar. In the long microwave wavelengths, these active and passive observation instruments can use the backscatter of the waves at the sea surface and blackbody radiation naturally emitted from the sea surface to retrieve information on the ocean. For example, the United States and France have the JASON-series satellites (Joint Altimetry Satellite Oceanography Network) to produce sea surface topography data. EUMETSAT has the METOP and the Sentinel series for observations of ocean winds and sea surface temperature. Canada has the RADARSAT synthetic aperture radar satellites. On the other hand, by using the data derived from these sensors, researchers conducted many studies on the remote sensing applications, such as ocean color [2,3], sea surface temperature [4,5], and sea surface height [6,7].

China has its own plan for building ocean satellites dedicated to ocean color and temperature, ocean dynamic environment and ocean surveillance, and has launched three satellites called HY-1A, HY-1B and HY-2A. The first ocean satellite, which is HY-1A, was launched in 2002. It was used to detect ocean color and temperature. The satellite carried two sensors. The first is an ocean color scanner with 10 bands and the second is a coastal zone color scanner with four bands. The major mission of the satellite is to detect ocean color environmental properties, including chlorophyll concentration, suspended sediment content, dissolved organic matter, sea surface temperature, and shallow water depth and topography [8]. HY-1A operated for more than two years. Subsequently, HY-1B was launched in 2007. This satellite was a substitute for HY-1A and its accuracy was improved. HY-2A was launched in 2011. It is the first Chinese ocean dynamic environment satellite. The onboard instruments consist of a radar altimeter, a microwave scatterometer, a scanning microwave radiometer, and a calibration microwave radiometer. Ever since the ground application system was built in 2012, the data processed by the system has been able to derive various ocean properties, such as sea surface wind field, swell field, marine gravity field, ocean circulation and sea surface temperature [9]. However, during the operational stage, we found that a gap still remained in closing the "last mile" of data delivery to the users. The derived data do not always satisfy users' expectations, and the system is not flexible in responding to the changing demands of processing customized products. The HY-2A Customized Automatic Processing Framework (CAPF) addresses these challenges. It is applied for providing a solution for meeting the diversity of users' personalized needs for advanced products and expanding the breadth of data applications. The framework is the complement to the existing ground application system.

The remainder of the article is organized as follows. Section 2 reviews the HY-2A onboard sensors and their corresponding products, the existing ground application system, the relevant research on remote sensing data services and the challenges we are facing. Section 3 presents the technical solution to address the challenges of adapting users' changing demands for a diversity of data applications. Section 4 demonstrates the feasibility of the framework using some of case studies. The article ends with a discussion on future activities and conclusions.

2. Products and Related Work

This section reviews the sensors carried on HY-2A satellites and their products, and the existing ground application system. It also discusses the relevant research on remote sensing data services over the past decades and the problems that we are concerned with.

2.1. The Onboard Sensors of HY-2A Satellite and Their Products

As mentioned in the previous section, there are four kinds of sensors onboard the HY-2A satellite. On the one hand, the two active microwave sensors are a radar altimeter and a microwave scatterometer.

On the other hand, the two passive microwave sensors are a scanning microwave radiometer and a calibration microwave radiometer [10].

The radar altimeter on HY-2A is mainly used to measure the sea surface height and the significant wave height. The radar altimeter is an active microwave sensor that emits short electromagnetic bursts vertically downward to the ocean surface and receives the reflected signal. By calculating the time difference between the transmitted and received signals, the distance between the satellite and the sea surface can be measured. With the precise orbit determination by the laser ranging, the Global Positioning System and the geoid, these observations can determine the changes in sea surface height to an accuracy on the order of a few centimeters, and the altimetry data can provide critical information on ocean circulation and dynamics [11]. In addition, the shape of the return signals yields the significant wave height and the magnitude yields the scalar wind speed [12]. The products derived from the radar altimeter divide into three levels. The level-1 products have geometric corrections applied. The level-2 products are the geophysical records derived by different processing methods. The level-3 products include gridded products, seasonal and annual products. Additional details of the radar altimeter carried on board HY-2A are given below in Table 1.

Table 1. The detailed information of the radar altimeter of HY-2A.

Frequency (GHz)	Swath Width (km)	Accuracy of Sea Surface Height at the Nadir Point (cm)	Range of the Significant Wave Height (m)
13.58/5.25	≤2	≤8	0.5–20

As the other microwave sensor, the scatterometer mounted on HY-2A is used to provide observations of vector wind at the sea surface. With a rotating dish antenna that can generate a pair of conically scanned pencil beams at two incidence angles, it takes multiple looks at the same sea surface area by transmitting pulses and receiving the returns either from different directions or at different polarizations. From the backscatter returns, the value of surface scattering cross section σ0 can be derived. With the geophysical model function (GMF), a functional relation between σ0 and the near-surface winds can be determined. In other words, the wave properties and the σ0 are functions of wind speed and the azimuthal difference between the wind direction and the scatterometer look angle. Therefore, such multiple measurements of σ0 can provide the wind speed and direction [12]. The scatterometer-derived wind products are also divided into three levels. The level-1 products are corrected by geometric correction and instrument noise removal, and calculated to the data of Kp coefficient, backscatter coefficient, etc. The level-2 products have two sub-levels: 2A and 2B. The 2A products are derived from correcting the return for atmospheric interference and mask processing, and the 2B products are wind velocity products. The level-3 products are the gridded products that are separated into ascending and descending passes. The technical specifications of HY-2A microwave scatterometer can be briefly summarized in Table 2.

Table 2. The technical specifications of HY-2A microwave scatterometer.

Frequency (GHz)	Polarization	Ground Resolution (km)	Swath Width (km)	Accuracy of Wind Speed (m/s)	Range of Wind Speed (m/s)	Accuracy of Wind Direction (°)
13.256	HH and VV	better than 50	H polarization 1350, V polarization 1700	2	2–24	20

The scanning microwave radiometer is a multi-channel imager with center frequencies at 6.6, 10.7, 18.7, 23.8 and 37 GHz. Both vertical and horizontal polarizations are used for all channels except the 23.8 GHz, which only has the vertical. With the calibrated brightness temperatures and retrieval algorithms, the radiometer can retrieve surface and atmospheric variables, such as water vapor, cloud liquid water, wind speed, and sea surface temperature. Because the emissivity or transmissivity associated with each atmosphere or oceanic constituent has a different frequency dependence, the variables can be retrieved from a set of multifrequency, multivariable simultaneous equations. The products of the scanning microwave radiometer are also processed into three levels. The level-1 data are the antenna temperatures after a series of calibration procedures including geolocation analysis, attitude adjustment, along-scan correction and so on. The level-2 products are various geophysical measurements derived from the calibrated brightness temperatures in level 1, including sea surface temperature, water vapor, cloud liquid water and wind speed. The level-3 products are daily and monthly gridded products at global or polar regional scale. The detailed parameters of the radiometer are listed below in Table 3.

Table 3. The detailed parameters of the scanning microwave radiometer.

Frequency (GHz)	Polarization	Swath Width (km)	Ground Resolution (km)	Noise-Equivalent Sensitivity (K)	Dynamic Range (K)	Calibration Precision (K)
6.6	VH	1600	100	Better than 0.5	3–350	1.0 (180–350 K)
10.7	VH		70			
18.7	VH		40			
23.8	V		35			
37	VH		25	Better than 0.8		

The calibration microwave radiometer is mainly used to provide the essential calibration parameters for water vapor processing of the scanning microwave radiometer and the radar altimeter. With fewer channels and better sensitivity, it can process the atmosphere parameters in real-time. The products can be categorized into two levels. The first level is similar to the corresponding products of the scanning microwave radiometer. The second level is the derived geophysical measurements. The detailed information is listed in Table 4.

Table 4. The detailed information of the calibration microwave radiometer.

Frequencies (GHz)	Polarization	Noise-Equivalent Sensitivity (K)	Dynamic Range (K)	Calibration Precision (K)
18.7	linear polarization	0.4	3–300	1.0 (180–320 K)
23.8		0.4		
37		0.4		

A few studies have been conducted on the quality assessment of HY-2A data. Xing et al. [13] compared the data of HY-2A with the data of the NDBC (National Data Buoy Center) of the National Oceanic and Atmospheric Administration (NOAA), the data of the European Centre for Medium Range Weather Forecasting (ECMWF), and the data of the advanced scatterometer (ASCAT). The result shows that the quality performances of the HY-2A near-real-time wind vector data (especially the wind speeds) were satisfactory throughout the service period. A cross comparison with JASON-2 data over the same period has been performed in order to compare the sea surface height and sea level anomaly of the HY-2 altimeter [14]. In that paper, Bao et al. found that the precision of HY-2 sea surface height is the same as that of JASON-2.

2.2. The Ground Application System

The ground application system is used for receiving, processing, calibrating and validating the data of HY-2A satellite, and is responsible for data applications. Along the data processing chain, the system consists of a mission control subsystem, a data preprocessing subsystem, a processing subsystem, a precise orbit determination subsystem, a calibration and reality check subsystem, a data archiving and distribution subsystem, and a data application subsystem [15].

The data preprocessing subsystem is composed of three HY-2 ground receiving stations and a suite of data preprocessing software deployed at the National Satellite Ocean Application Service

(NSOAS) located in Beijing. Once these ground stations receive the real-time or delayed data, these satellite downlinked data will be transferred to the data preprocessing software for further processing. According to the commands from the mission control subsystem and the parameters from the calibration and reality check subsystem, the data preprocessing software converts the raw data to level-1 products [16].

The processing subsystem has four processing modules that are used to derive the corresponding data from the radar altimeter, the scatterometer, the microwave radiometer and the calibration microwave radiometer. By using the existing mature geophysical retrieval algorithms and the related ancillary data from the precise orbit determination subsystem, the data can be processed into level-2 and level-3 products which contain the geophysical measurements for different applications [16].

The data archiving and distribution subsystem mainly provide two functions that can automatically archive the various levels of data, and easily disseminate them to designated users. In order to ensure the data security, the archived data are physically separated from the data distribution system by a network gap. The data archiving module, which is deployed in the inner network, is responsible for automatically collecting the data derived from the data preprocessing subsystem and processing subsystem, and storing them on the data repositories and cataloging them in a spatial database. By synchronizing the cataloging information between inner network and outer network, a user can search and order their desired data by using a data distribution module. As soon as the desired data are ready, users can obtain the data by several means, such as File Transfer Protocol (FTP), Email or CDs [17].

The data application subsystem has identified six key categories of potential applications of HY-2A data. They are the sea level rise assistant decision-making system, the ocean storm surge monitoring application system, the sea ice monitoring and forecasting system, the marine gravity field application system, the ocean-atmosphere interaction application system, and the ocean fisheries business application system.

2.3. Related Work and Problems

Over the past decades, with the advances of the Earth Observation (EO) technology, remote sensing data have accumulated to a considerable degree. In order to ease and increase the use of these remote sensing data, many data agencies set up their own data service platforms, such as the Multi-Satellites Data Service system operated by the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (RADI) [18,19], the Land Observation Satellites Data Service platform from the China Centre for Resources Satellite Data and Application [20], the Data Service platform from Remote Sensing Technology Center of Japan [21], the GISTDA Data Service system from Geo-Informatics and Space Technology Development Agency of Thailand [22], and the Earth Online platform from the European Space Agency [23]. These systems and platforms provide catalogue access and data distribution services for standard remote sensing products, which are similar to the HY-2A ground application system. On the other hand, because of the new open data policy adopted by the United States Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA) in 2008, remote sensing data usage exploded [24]. Afterwards, ESA adopted the similar strategies. Today, more than 250,000 images are downloaded each month through two online platforms, the USGS Global Visualization Viewer (GloVis) [25] and the Earth Explorer system [26]. In addition, there is an obvious shift of service model from "provider push" to "user pull", which can facilitate scientists and the public to access remote sensing data [27,28]. Therefore, many data providers have developed a series of online tools for users to visualize and analyze the data [29–31]. In the marine field, the Giovanni data service platform [32] provides an integrated interface for users to plot high-level marine products and download the datasets directly. The Sentinels Scientific Data Hub provides complete, free and open access to Sentinel-series products [33]. The AVISO data service platform (Archiving, Validation and Interpretation of Satellite Oceanographic data) [34] and the Copernicus

Marine Service platform [35] also provide a reference portal for users to access, read and visualize the datasets derived from different sensors.

While the existing ground application system supports the routine business of the HY-2A satellite mission, there are some problems exposed in practice because of the unique characteristics of ocean remote sensing data. At first, the archived data are limited to the satellite geometry defined by the standard pass, which is a long north–south track covering a large area. However, especially for the level-2 and level-3 products, users always want to extract an area of interest (AOI), which may be larger or smaller than a standard satellite pass. The existing system does not provide corresponding tools for users to effectively obtain their desired results. In addition, the existing ground application system uses different data formats to store data from the HY-2A satellite. For example, the products of the scatterometer, the scanning microwave radiometer and the calibration microwave radiometer are stored in the HDF5 format developed by the Hierarchical Data Format (HDF) group [36], and the products of the radar altimeter are stored in the network Common Data Form (NetCDF) format developed by the University Corporation for Atmospheric Research (UCAR) [37]. These formats can be used to store and organize large volumes of numeric data into a multi-dimensional structure that needs specialized tools to deal with, such as the HDF Viewer [38]. However, because these tools only provide a limited number of functions to browse and edit the data, it is difficult for users to compare, analyze and visualize data, precluding the usage of HY-2A satellite data. Moreover, the existing processing procedures in the processing subsystem are designed as a fixed number of steps, which is not easily modified. Users cannot replace the current algorithms with their own methods. Furthermore, because the volumes of ocean remote sensing data have been increasing drastically, it is impossible for users to download and process them on their premises, especially for time-series analysis. More and more users are asking for an interaction platform to browse the data, design their own processing procedures and view results on the fly. Apparently, the existing ground application system cannot meet this kind of requirement.

3. The Components of HY-2A CAPF

In order to address the problems stated previously, it is necessary to propose a new interactive data service framework to complement the existing ground application system. This section discusses the high-level components of the framework. By reviewing a large number of users' requirements, the user community can be categorized into two groups: the professional staff from State Oceanic Administration (SOA) and researchers. The professional staff are able to access the archived data in an intranet environment, and they use the framework to complete their daily work, so the framework should allow users to start the pre-defined batch processing workflows and schedule these workflows according to their requirements. For researchers, they can access the data from the internet according to authorization rules, and they always want to adapt the framework to test their own algorithms. The framework should provide tools for these users to design on-demand processing workflows and generate proper products based on the pre-defined processing algorithms and their own algorithms. Hence, as shown in Figure 1, the framework can be divided into three parts: the routine customized processing subsystem, the on-demand customized processing subsystem, and the integrated algorithmic environment.

3.1. The Routine Customized Processing Subsystem

The routine customized processing subsystem is a web application deployed in an intranet environment and can be accessed by staff of the SOA. With the pre-defined processing workflows, the subsystem can access the HY-2A level-2 data and automatically generate the daily, weekly, monthly, seasonal and annual statistics products of marine dynamic environments. Because these products are applied for the regular business, the batch processing programs of the workflows are relatively stable. Once a staff defines a batch processing program, it can be validated and deployed into the framework by a system manager. After users define the statistic period and set the area of interest with the Quartz Job Scheduling Library [39], the subsystem can automatically start tens-of-thousands of jobs and can schedule the jobs in the future when the more recent data is ready. Each job corresponds to a pre-defined batch processing workflow. The backend of the subsystem can execute the batch processing workflows on time. It accesses the archived data by a web service from the existing data archive and distribution system. Once data are within the statistic period, the subsystem will download the data directly from the data repository and start the processing workflows in parallel. As soon as the products are successfully generated, they will be archived to the existing data archive and distribution system. Users can download them directly. The detailed flow chart is shown in Figure 2.

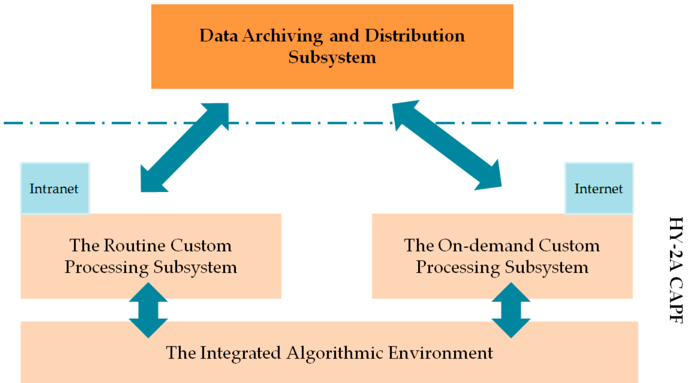

Figure 1. The components of the HY-2A Customized Automatic Processing Framework (CAPF).

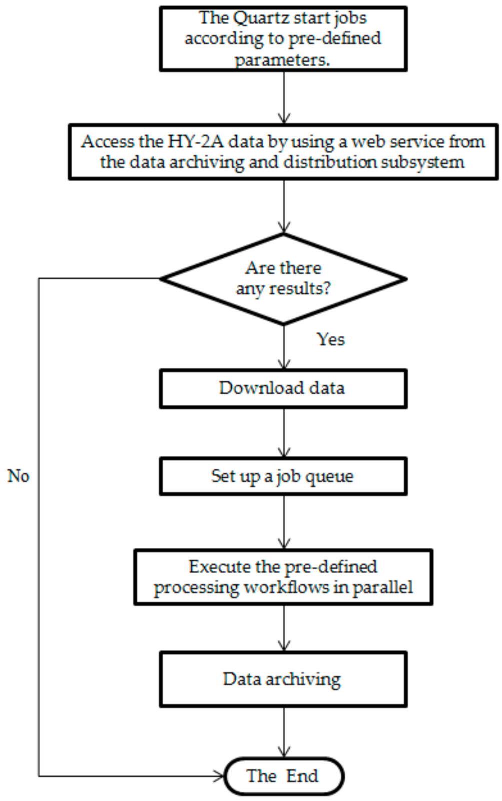

Figure 2. The flow chart of the routine customized processing.

3.2. The On-Demand Customized Processing Subsystem

In order to increase the use of HY-2A satellite data, the on-demand customized processing subsystem is used to support data services to the public, especially for researchers. Hence, the subsystem is able to be accessed via the internet. By using the subsystem, users can upload and register their own algorithms, design processing workflows with registered algorithms, run and test these processing workflows, and search and download the products derived from these workflows. Accordingly, the subsystem consists of four modules: the algorithms and workflows management module, products order module, processing module, data search and downloading module.

The algorithm and workflow management module provides a Graphical User Interface (GUI) for users to register algorithms, manage algorithmic parameters, and design processing workflows. Before users register their own algorithms, they need to add the required attributes of the parameter types for these customized algorithms. The attributes of a parameter type can be used to validate the input values. For example, if an algorithm has an input, which should be a file in HDF5 format, the user should define the type name and type definition at first. With such information, the subsystem can provide the prompt message when users edit the algorithm and validate the values at once. Once users upload their scripts or executables to the framework, they need to register the algorithms. Such information includes the name of the algorithm, version number, provider, parameters, etc. With these registered algorithms, users can design their own processing workflows by using the design panel and save them as processing templates for later use. Figure 3 shows the GUI for designing an on-demand customized processing workflow. Part 1 is a toolbox that lists the registered algorithms; Part 2 is a table where users can fill the overview information of a workflow, such as template name, version number, etc.; Part 3 is a designer panel in which users can drag the algorithms from the toolbox on the left and connect them as a sequence; Part 4 is an algorithm panel that shows the corresponding information of the algorithm that is being clicked in the designer panel. Users can edit the information of the algorithm that is being clicked in the designer panel; and Part 5 is a navigation bar that indicates the steps used to design a processing workflow and which step one is in.

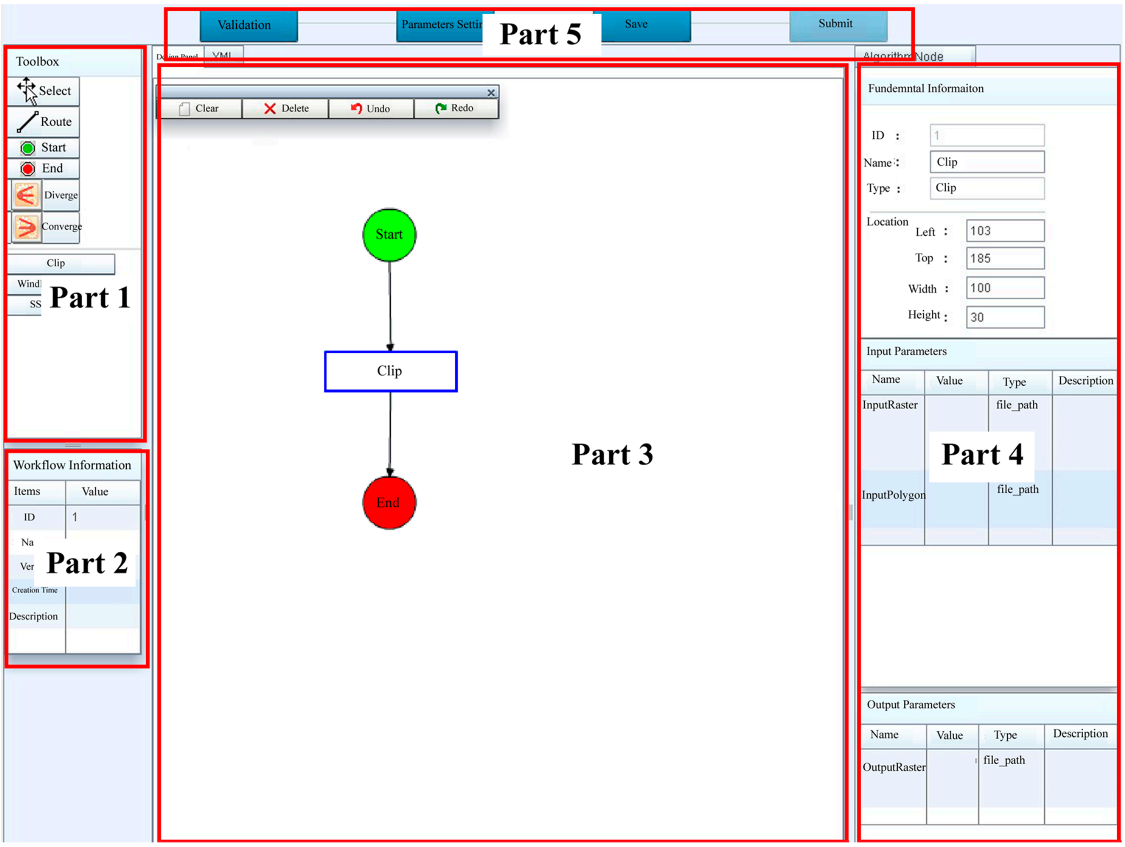

Figure 3. The Graphical User Interface (GUI) of designing a customized processing workflow.

Once a user completes the design of a customized processing workflow, he or she can start to run and test the workflow by submitting an order in the product order module. As shown in Figure 4, the processing workflows are listed as processing templates in the drop-down menu. Users can choose one of them, and set the period and priority of the task execution. The module is able to show a form with the input parameters according to the definition of the processing templates, and provide a GUI for users to fill in the form. For example, users can search the archived data and extract a region of interest interactively. In addition, users can set some additional parameters if necessary. For example, if the processing template can make a thematic map, the module allows users to set the title of the thematic map. Once the order has been submitted, the module can convert the information of the order into an XML file and send it to the processing module.

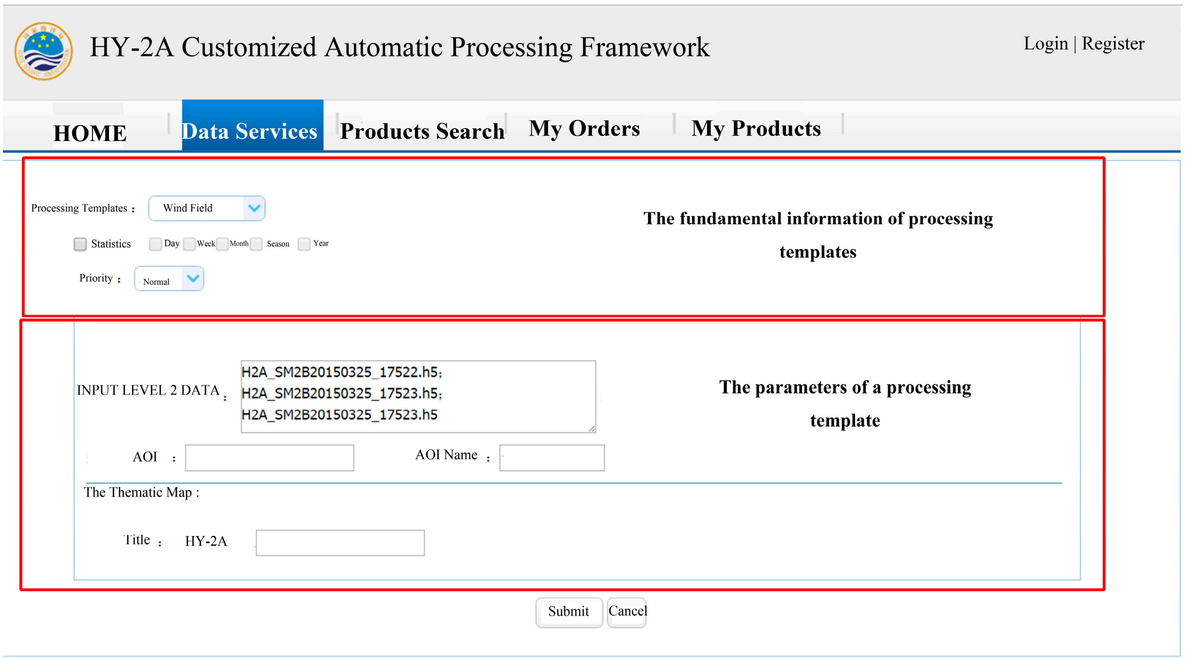

Figure 4. The GUI of the product order module for a customized wind field processing workflow.

The processing module will automatically interpret the XML file and execute the processing workflow step by step. Finally, the data search and downloading module will store the results in a temporary storage for users to access.

The architecture of the subsystem is implemented in three layers: the GUI layer, the services layer, and the data repository layer. The communication between the GUI layer and the services layer is based on Asynchronous Javascript and XML (AJAX) technology, whereas the communication between the services layer and the data repository layer depends on Representational State Transfer (REST) web services. The functions provided by the services layer are developed using Java programming language. The subsystem uses JSON and XML formats to exchange data between the server and a browser.

3.3. The Integrated Algorithmic Environment

The integrated algorithmic environment possesses a set of predefined algorithms, and offers a place to store users' customized algorithms. The predefined algorithms are developed in Python and can be used to generate typical ocean dynamic environment products, which will be discussed in the next section. On the other hand, in order to run algorithmic executables and scripts uploaded from users, the integrated algorithmic environment should provide different runtime environments to execute algorithms developed in different languages. The current version supports three runtime environments: Python, IDL and Windows Shell.

4. Case Studies

In order to validate the feasibility and functionality of the HY-2A CAPF, a set of predefined algorithms were developed. In this paper, a set of experiments were conducted to demonstrate the performance of the framework. These experiments represent the typical geophysical products that users want to generate.

4.1. Wind Field

The customized processing workflow of wind field consists of seven steps. The workflow has three inputs that are a file list of Level 2 data of the HY-2A scatteromter in HDF5 format, a polygon representing the AOI, and a name of the output thematic map, while the outputs of the workflow include a wind field product file in HDF5 format, a wind speed raster dataset in TIFF format, a wind field point feature class in Shapefile format, and a thematic map in JPEG format. The workflow reads the level-2 HDF files of the HY-2A scatterometer first, and converts the wind direction values and wind speed values to a point feature class. Then, it extracts the data based on the AOI. With the inverse distance weighted interpolation algorithm, the wind speed values and wind direction values are converted to raster datasets. If necessary, the workflow can mosaic the multiple raster datasets into a new raster dataset. Using a gridding algorithm with a 1/4-degree interval, the raster dataset can be mapped to a uniform grid. Finally, the thematic map can be exported for data visualization. Figure 5 shows a thematic map of a single HY-2A swath for 25 March 2015.

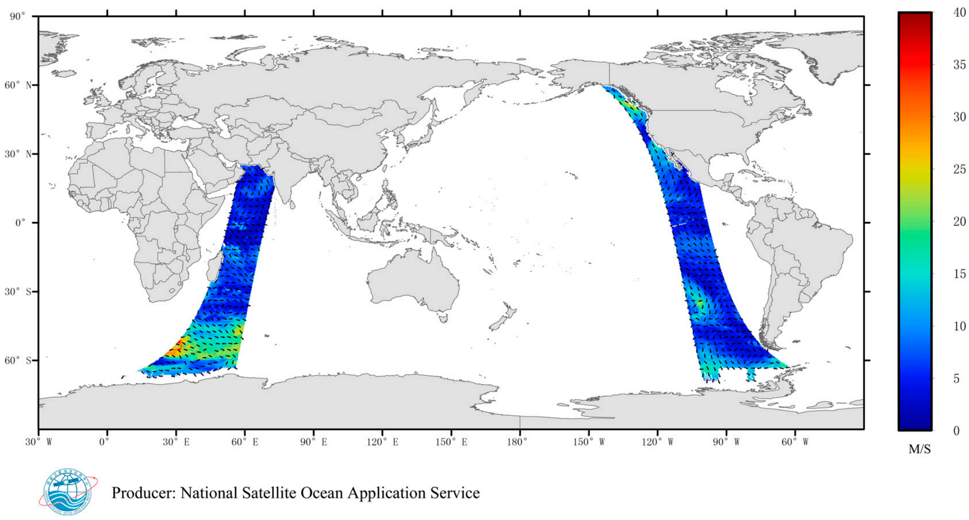

Figure 5. An Ocean Wind Field thematic map of a single HY-2A swath for 25 March 2015 derived from the HY-2A CAPF. The ocean wind vectors are mapped to a 0.25-degree grid. The lines and arrows show the wind direction; the colors show the wind speed.

4.2. Sea Surface Temperature

The customized processing workflow of sea surface temperature also consists of seven steps, three of which are the same as the ones in the wind field processing workflow. These are the clip algorithm, the interpolation algorithm and the mosaic algorithm. The workflow has three inputs that are a file list of Level 2 data of the HY-2A scanning microwave radiometer in HDF5 format, a polygon representing the AOI, and a name of the output thematic map. The outputs of the workflow include a sea surface temperature product file in HDF5 format, a sea surface temperature raster dataset in TIFF format, and a thematic map in JPG format. With similar processing steps, the workflow reads the level-2 HDF files of the HY-2A scanning microwave radiometer and validates the values. Afterwards, the data are extracted based on the AOI and interpolated into raster datasets. Followed by a gridding algorithm with a 1/4-degree interval, the data can be mapped to a uniform grid. The thematic map is shown in Figure 6.

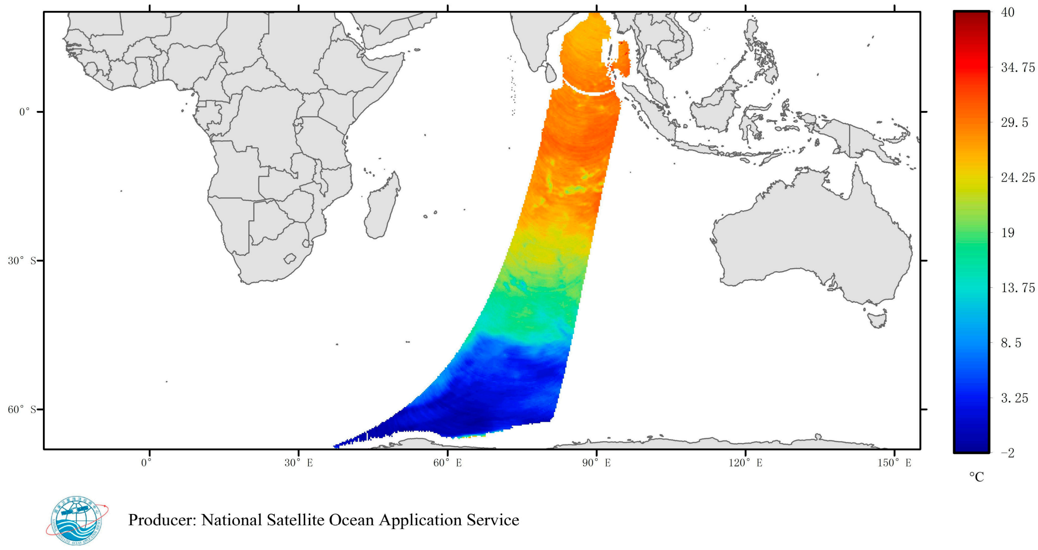

Figure 6. A Sea Surface Temperature thematic map of a single HY-2A swath for 25 March 2015 derived from the HY-2A CAPF. The sample points of sea surface temperature are mapped to a 0.25-degree grid. The colors correspond to the temperature scale.

4.3. Water Vapor

The customized processing workflow of water vapor is similar to the sea surface temperature. The only difference is the first step in which the workflow needs to read the water vapor dataset from the level-2 HDF file of the HY-2A scanning microwave radiometer. The thematic map is shown in Figure 7 following the remaining six steps.

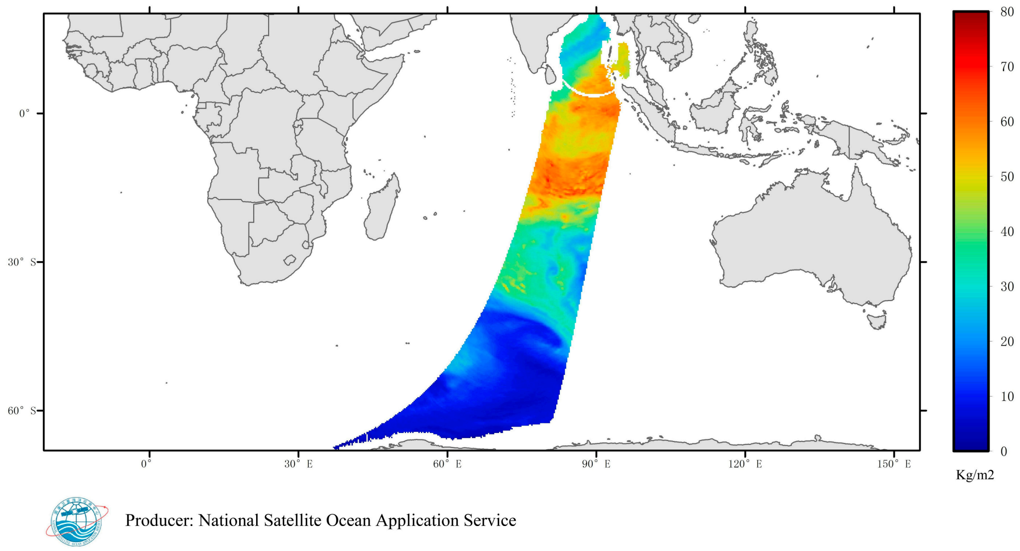

Figure 7. A Water Vapor thematic map of a single HY-2A swath for 25 March 2015 derived from the Customized Processing System. The sample points of water vapor are mapped to a 0.25-degree grid. The colors show the water vapor concentration.

4.4. Cloud Liquid Water

Because the cloud liquid water is also derived from the HY-2A scanning microwave radiometer, the customized processing workflow is similar to the previous two workflows. With the seven steps, the workflow can read the cloud liquid water dataset from the level-2 HDF file of the HY-2A scanning microwave radiometer. After extraction, interpolation and gridding, the data can be made as a thematic map, which is shown in Figure 8.

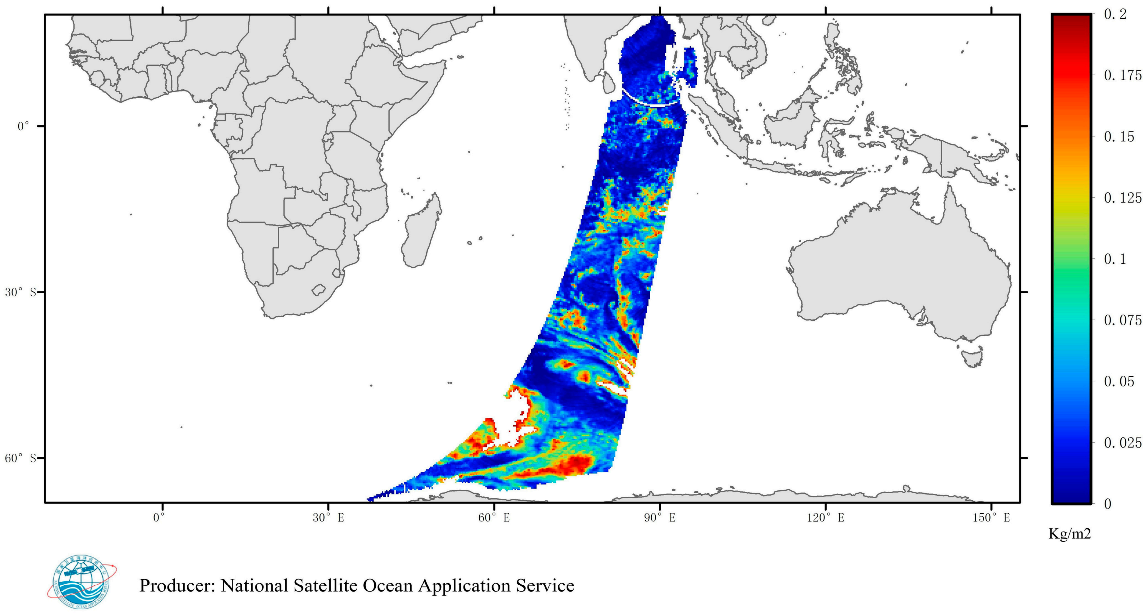

Figure 8. A Cloud Liquid Water thematic map of a single HY-2A swath for 25 March 2015 derived from the Customized Processing System. The sample points of cloud liquid water are mapped to a 0.25-degree grid. The colors show the cloud liquid water.

5. Discussion

As an extension of the existing ground application system, HY-2A CAPF enables users to efficiently and effectively work with HY-2A satellite data. With the capability of solving user's on-demand processing requirements, it has the potential to make a large ocean remote sensing dataset available to a wider user community.

A beta version of the framework was released to an intranet environment in September 2016. The framework helps users accomplish their daily work and greatly increases the work efficiency. According to user feedback, further iterations are being planned to expand the capabilities of the system. The first iteration will focus on developing more pre-defined algorithms to expand case studies and facilitate users to design their own processing workflows. For example, in order to help the Xue Long icebreaking research vessel explore the Polar Area, we need to develop the thematic mapping algorithms for the Xue Long vessel.

Furthermore, with the progress of cloud computing technology, it is necessary to follow the trend and adopt novel techniques of data analysis and data storage. As future work, we will take advantage of cloud storage to store processing results from researchers. Additionally, the integrated algorithmic environment should support more programming languages for users' customized algorithms.

It is expected that the framework can be applied to other domains. In other words, it is necessary to standardize the interfaces to access other remote sensing data from different agencies and platforms. For example, the meteorological remote sensing data from the China meteorological administration can be integrated into the framework to enrich the content and widen the user community.

6. Conclusions

The HY-2A CAPF is a significant contribution to expanding the usage of HY-2A satellite data. It focuses on upgrading the existing ground application system by addressing users' on-demand processing issues. Based on the review of users' requirements, the framework provides innovative ways to access and process the large ocean remote sensing data. For the staff of SOA, the framework offers pre-defined algorithms and processing workflows to automatically deal with daily work. For researchers, the framework offers a platform to easily translate their research into an operational processing workflow that can be used by other users. In the meantime, once a large number of use cases have been accumulated, more research and development activities are required to meet users' needs in order to enhance the framework usage.

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Abbreviations

The following abbreviations are used in this manuscript:

AJAX	Asynchronous Javascript and XML
AOI	Area of Interest
CAPF	Customized Automatic Processing Framework
CD	Compact disc
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FTP	File Transfer Protocol
GISTDA	Geo-Informatics and Space Technology Development Agency
GloVis USGS	Global Visualization Viewer
GMF	Geophysical Model Function
GUI	Graphical User Interface
HDF	Hierarchical Data Format
HH	Antenna that transmits and receives with an H-polarization
HY-2A	Hai Yang 2A Satellite
IDL	Interactive Data Language
JPEG	Joint Photographic Experts Group
JSON	JavaScript Object Notation
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Format
NSOAS	National Satellite Ocean Application Service
RADI	Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences
REST	Representational State Transfer
SOA	State Oceanic Administration
TIFF	Tagged Image File Format
USGS	United States Geological Survey
UCAR	University Corporation for Atmospheric Research
VV	Antenna that transmits and receives with a V-polarization
XML	eXtensible Markup Language

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