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FIELD SENSOR VIRTUAL ORGANIZATION INTEGRATED WITH SATELLITE DATA ON A GEO GRID

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ABSTRACT

Remotely sensed satellite data can provide spatial and temporal coverage for global environmental monitoring. Calibration and validation are very important for more accurate satellite products and can contribute to the detection of climate changes on earth. Calibration and validation of satellite products normally use both ground-based and satellite-based data, which have geospatial metainformation and various data policies. Our proposal adopts both the Open Geospatial Consortium (OGC) standards and the virtual organization (VO) concept to develop a calibration and validation system for satellite products. In this research, we construct the Field Observation Network (FON) VO, which provides an interoperable system for various ground-based and satellite-based data by using the OGC standards Sensor Observation Service (SOS). FON VO also makes it possible to protect data policies. Ground-based and satellite-based atmospheric and ground physical parameters are the focus of this study.

Keywords: Ground-based data, Satellite-based data, Calibration and validation, Surface reflectance, OGC standards, Sensor Observation Service (SOS), Virtual organization (VO), ASTER/Terra, MODIS/Terra

(Note: Acronyms in the running text are shown in the Appendix.)

1 INTRODUCTION

The Kyoto Protocol came into effect in 2005. Moreover, the 10-Year Implementation Plan of the Global Earth Observation System of Systems (GEOSS) was adopted in 2005. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that "An increasing body of observations gave a collective picture of a warming world and other changes in the climate system" (Houghton et al., 2001). This report indicates that in-situ and satellite observation data for the atmosphere, land, ocean, and cryosphere need to be integrated. The integrated ground and satellite observation data will contribute to the prediction of global climate change.

Remotely sensed satellite data can provide spatial and temporal information for global environmental monitoring. Many recent studies have used this technology as an attractive tool for global environmental research. In addition, many studies have provided information for the integration of various satellite data and products. For example, the Long Term Data Record (LTDR) project, which was funded by NASA, is trying to generate a long-term dataset using AVHRR/NOAA and MODIS onboard the Terra and Aqua satellites and the next-generation VIIRS onboard the NPP and NPOESS satellite (Pedelty et al., 2007). The LTDR project will also reprocess the data from AVHRR sensors onboard the NOAA satellites from 1981 to the present. "Data compatibility" and "Data continuity" are very important objectives for generating the long-term dataset by integrating satellite data, including the LTDR project. Each satellite's sensor data should be well calibrated and validated for quality, compatibility, and continuity. This means that an inter-comparison is needed among the various levels of satellite products, and the functionality of different algorithms must be compared.

The integrated ground-based and satellite-based observation data is expected to contribute to the understanding of global climate change. Generally, satellite projects provide various types of products for earth science. For example, surface reflectance products derived by optical satellite sensor data are basic parameters of higher-level products. Surface reflectance is calculated by atmospheric correction, which often uses the radiative transfer model with auxiliary data, such as ground-based and/or satellite-based atmospheric parameters obtained by simultaneous observation. The higher-level products should be applied to a General Circulation Model (GCM), such as the global climate model (Figure 1). It is assumed that the accuracy of L1 or L2 satellite products affects the detection of environmental change. Therefore, calibration and validation of L1 or L2 satellite sensor products are very important.

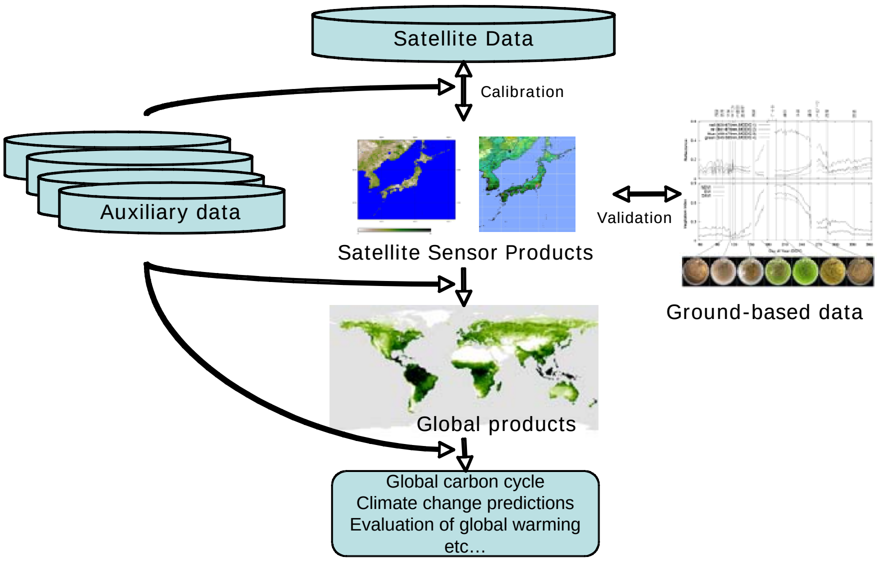


Figure 1. Integration of satellite-based and ground-based data for earth science

2 OBJECTIVE

The GEO Grid project is primarily intended to provide an e-Science infrastructure for the worldwide earth sciences community (AIST, 2007). One of the main contents of this project is data obtained by ASTER (Yamaguchi et al., 1998) and MODIS (Justice et al., 2002). These data require a huge storage volume; therefore, such data sets should be available for users with minimum time delays for managing both storage capacities and near-real-time distribution. To achieve size scalability in near-real-time data handling and distribution, data grid middleware called Gfarm has been adopted as a cluster file system to store and deliver satellite data (Sekiguchi et al., 2008). In addition, OGSA-DAI (Grant et al., 2008) is used to provide metadata of the satellite data for database federation, uniform access to heterogeneous databases, and a database processing service that supports third-party delivery interfaces. The most important characteristic of GEO Grid is it introduces the concept of virtual organization (VO), in which necessary data and applications are provided as "services" via standard protocols and APIs. Such services are provided for users through an appropriate access control to comply with the owner's publication policies for the data and applications. For example, the ASTER data policy is different from that of MODIS because MODIS data are free of charge, but payment contracts are needed for ASTER data. Therefore, the VO concept is an absolutely essential service for the simultaneous use of ASTER and MODIS data that have different data policies. Ground-based data also have different data policies, and they should be protected in their community. In the GEO Grid project, Business, IT, GIS (BIG) VO, Geohazard (GHZ) VO, and Environmentally COnscious (ECO) VO have been created and are in operation (AIST, 2007), and the Field Observation Network (FON) VO developed in this study is the fourth VO for the calibration and validation of satellite products.

Ground-based and satellite-based data are distributed geospatially. The Open Geospatial Consortium (OGC) is an international standards organization that encourages development and implementation of standards for geospatial content and services and for GIS data processing and exchange (OGC, 2008). These geospatial standards are very useful to integrate scientific earth data because of their general versatility, extensibility, and interoperability. The OGC defines many standards related to geospatial information, and the WMS, WFS, and WCS are the most popular web service standards. WPS is a remote processing service that can describe any calculation and/or processing through the Internet. CSW can access catalog information. SWE is one of the standards for making all types of sensors, transducers, and sensor data repositories discoverable, accessible, and useable via the Web (Botts et al., 2007). SOS includes OpenGIS Standards in the SWE framework (Na & Priest, 2007). This standard provides an API for managing both ground-based and satellite-based observation sensors. Recently, various communities have adopted these OGC standards for the integration system of ground-based and satellite-based data. Generally, ground-based and satellite-based scientific earth data have geospatial metadata including the location, time, sensor name, measurement items, and so on. The OGC standard is very adequate for integrating these satellite-based and ground-based data. However, the OGC standards do not support the VO concept that is being adopted in the GEO Grid system.

Surface reflectance products are the focus in this research because this is a very basic parameter for scientific earth research. As mentioned above, we need the calibration and validation system of atmospheric parameters and surface reflectances obtained by ground-based and satellite-based measurements, which have their own data policies. In this research, we construct the Field Observation Network (FON) VO, which makes it possible to easily inter-compare ground-based and satellite-based data, to evaluate multiple satellite products by using the OGC SOS standards, and to protect data policies. Until now, there has not been a calibration and validation system that adopts both SOS standards and VO concepts. Our proposed system adopts not only the OGC standards but also the VO concept. The objective of this research is to develop and evaluate our proposed system. The final goal of our proposed system is to construct an interoperable integrated calibration and validation system that can use both ground-based and satellite-based data and apply various correction algorithms to satellite products.

3 RELATED WORK

Understanding carbon circulation is very important for earth climate change detection. FLUXNET is a global network of micrometeorological tower sites that measures the exchanges of carbon dioxide, water vapor, and energy between the biosphere and atmosphere and provides an infrastructure to compile, archive, and distribute these data for the scientific community. This network has a huge in-situ and map layers database. ORNL DAAC developed the WebGIS and Spatial Data Access system that provides various kinds of geospatial data for FLUXNET sites using the OGC Web services, WMS, and WCS. This WebGIS and Spatial Data Access system uses a simple HTTP interface for requesting geo-registered interoperable map images and/or "coverage" of the actual data from one or more distributed geospatial databases, and it is easily linked to the ground-based data of each site.

FLUXNET focuses on the arrangement and integration of land observation. However, observation of the oceans, which cover 70% of our planet, is also important for understanding the carbon cycle. Ocean studies often conduct buoy measurements, and the data also contain geospatial metainformation. Therefore, an integrated interoperable system using the OGC standard architecture has recently started to gather attention in oceanology. OOSTethys is one of the communities of software developers and marine scientists who develop open source tools to integrate ocean observation systems. OOSTethys encourages input to the OGC Ocean Science Interoperability Experiment (Oceans IE), which brings together the ocean-observing community to advance the interoperability of ocean observation systems by using the OGC Standards. The Southeastern Universities Research Association (SURA), a consortium of over sixty universities across the US, is one of Oceans IE initiators, and The SURA Coastal Ocean Observing and Prediction (SCOOP) program is a virtual community of scientists with the tools and resources. The SCOPE program provides the OpenIOOS Interoperability Test Bed, which includes more than 1000 platforms with real-time data (Bermudez et al., 2006). The main characteristic of this system is adoption of the OGC SWE initiative, especially SOS.

The FLUXNET WebGIS Spatial Data Access system handles both ground-based and satellite-based data, and various geospatial data can be accessed easily because of the OGC WMS and WCS. At the present time, however, ground-based data are only linked to the arranged directories of each site, and interoperability is difficult for other ground-based databases. In contrast, OpenIOOS uses the OGC SOS standards, and the OOSTethys community has been making positive efforts to promote other OGC standards (e.g., WMS, WCS, WFS). However, these kinds of data are restricted to charge-free data of the oceanological geospatial data and satellite products. If the data have any policies, these data are difficult for the FLUXNET WebGIS Spatial Data Access system and OpenIOOS systems to integrate.

4 OBSERVATION DATA ON FON VO

Initially, FON VO used ground-based data obtained by the Phenological Eyes Network (PEN) (Nishida, 2007; PEN, 2008). PEN is a network of ground observatories for long-term automatic observation of vegetation dynamics (phenology), vegetation optical properties (such as spectral reflectance), and atmospheric optical properties (such as aerosol optical thickness). Satellite remote sensing represents a strong methodology in the study of terrestrial ecosystems. Remote sensing methodology has not been checked sufficiently or validated from an ecological standpoint. Detailed information about the PEN system is described in many articles.

FON VO uses three kinds of data, which include Automatic-capturing Digital Fisheye Camera (ADFC) data, HemiSpherical Spectro-Radiometer (HSSR) data, and sunphotometer (SP) data. These are derived as sky and ground photographs, ground reflectances, aerosol optical depths, and Angstrom exponents. PEN has many sites in Japan. In contrast, FON VO focuses on three sites: TGF (Grassland; Terrestrial Environment Research Center, University of Tsukuba), TKY (Forest; Takayama Flux Site), and FHK (Forest; Fuji-Hokuroku) because data are now acquired continuously at these sites. “Raw” data obtained at each site are collected in each site server and automatically stored on the GEO Grid cluster by rsync and wget. Then, the surface reflectance, aerosol optical depth, and Angstrom exponent are calculated automatically from these “raw” data. Sky and ground photographs are related to the aerosol optical depth, Angstrom exponent, and surface reflectance data.

FON VO uses the satellite-based products of ASTER and MODIS data onboard the Terra satellite and focuses on surface reflectance. We have already developed the generating system of ASTER/MODIS surface reflectance in-house products in the visible and near infrared bands (Yamamoto et al., 2008). Our atmospheric correction algorithm derives the ground surface reflectance by removing the effects of Rayleigh scattering, ozone absorption, and water vapor absorption and by using MODIS atmosphere products and EPTOMS/Aura OMI total column ozone products. The surface reflectance products should be validated by ground-based data such as PEN data and inter-compared with other satellite reflectance products. FON VO uses MODIS surface reflectance, which is known as MOD09 (Vermote & Vermeulen, 1999) and is freely provided by the Land Processes Distributed Active Archive Center (LPDAAC) of NASA; the latest version is MOD09GA Collection 5. Since 2000, MOD09GA Collection 5 products have been automatically downloaded on the GEO Grid system. Originally, MODIS science products were designed for the atmosphere, land, ocean, and cryosphere. Therefore, MODIS offers not only surface reflectance products but also many kinds of products for earth science. One of these products, MOD08_D3, is an L3 global gridded product that is generated from four kinds of L2 products: aerosol, water vapor, cloud, and atmosphere profile products (Hubanks et al., 2008). These products are freely provided by the L1 and Atmospheres Archive and Distribution System (LAADS) of NASA and downloaded automatically on the GEO Grid. The water vapor parameter contained in MOD08_D3 products is used in our algorithm. Earth Probe TOMS (EPTOMS) (McPeters et al., 1998) and Aura OMI (Bhartia, 2002) products are used for ozone absorption for the atmospheric correction. As mentioned above, ground-based measurement data include surface reflectances, aerosol optical depths, and Angstrom exponents; therefore, the satellite-based surface reflectance derived from MOD09GA products and aerosol optical depth/Angstrom exponents derived from MOD08_D3 products are shown in the FON VO proposed in this study. All values at each site are derived from MOD08_D3 and MOD09GA products by using GRASS (Neteler et al., 2007), which is well-known GIS software.

5 ARCHITECTURE OF FON VO

First, ground-based and satellite-based “raw data” at each site are stored on the GEO Grid system. These “raw” data are automatically synchronized with the site server by rsync or wget and processed automatically on the GEO Grid system. In addition, the ground-based and satellite-based surface reflectances, aerosol optical depths, and Angstrom exponents are calculated. These processed data are registered in the PostGIS/PostgreSQL object-relational database. Registration written by a PHP4 script is run as “cron.” However, if users are assigned to observation periods, sensors, and site locations after login, the FON VO portal sends requests to MapServer, which is also a well-known open source development environment for building spatially enabled web applications. MapServer supports the OGC standards (OGC, 2008), including W*S (WMS, WFS, WCS, etc.) and the OGC SWE (Botts et al., 2007), and works with the PostGIS/PostgreSQL extension. As mentioned above, SOS is used for FON VO, and so it can be said that FON VO has general versatility and expendability with the addition of other sites’ data and systems implemented in the OGC architecture. MapServer can also search the user assigned data and return XML as an SOS response with the GetCapabilities request. Then, the data view service receiving this XML response from the SOS server can visualize the data that the user assigned. In this research, we used MapServer 5.2.0 and SOS 1.0.0.

FON VO targets TGF (Grassland: Tsukuba, Japan), TKY (Forest: Takayama, Japan), FHK (Forest: Fuji-Hokuroku, Japan), and MSE (Rice field: Tsukuba, Japan); these are defined as “offerings.” Sensors include SP (ground-based atmospheric information), SR (ground-based ground surface information), MOD08_D3 (satellite-based atmospheric information), and MOD09GA (satellite-based ground surface information); these are defined as “procedures.” The observation items, which are defined as “ObservedProperty,” are shown in Table 1. Many ground-based original data are obtained within one day; however, only one or a few MODIS products can be obtained within one day. Therefore, we conduct temporal aggregation for ground-based and satellite-based data (daily, eight days, and monthly) because MODIS products are often used as daily, eight day, and monthly products. This offers not only the reduction of incidence for drawing graphs but also the possibility of comparison with public satellite products by other providers.

Figure 2 shows the SOS architecture of FON VO. Users can understand the results of the inter-comparison between ground-based and satellite-based measurement data by this architecture. Moreover, FON VO has a satellite data-search function. Therefore, the user can search and obtain ASTER and MODIS products for the period of interest. We have already developed the system to generate the radiometrically and atmospherically corrected reflectance products of the ASTER and MODIS products. Currently, our atmospheric correction algorithm uses only satellite-based products; however, ground-based data will also be applied to the reflectance products in the near future. The aerosol optical depth and Angstrom exponent data obtained by PEN SP have the potential to be input into satellite reflectance products. This functionality can be even more flexible for satellite products by adjustment of the input parameters. Users will be able to search, generate, and refine the satellite products after recognition of the difference between the ground-based and satellite-based parameters.

Table 1. Registered ObservedProperty

	Ground-based		Satellite-based	
	Atmospheric	Ground surface	Atmospheric	Ground surface
	SP	SR	MOD08_D3	MOD09GA
Original	sp_original	sr_original	mod08_d3_original	mod09ga_original
Daily	sp_daily	sr_daily	---	---
Eight days	sp_eight	sr_eight	mod08_d3_eight	mod09ga_eight
Monthly	sp_monthly	sp_monthly	mod08_d3_monthly	mod09ga_monthly

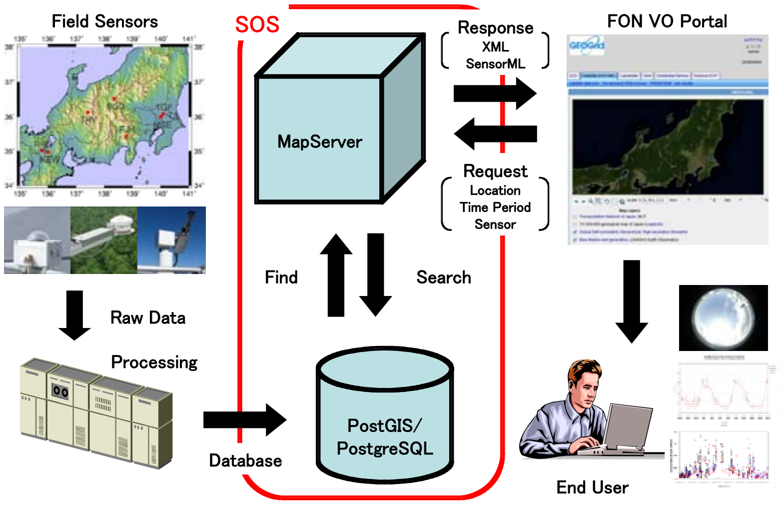


Figure 2. Architecture of FON VO

Figure 3 shows the initial display after the FON VO login. Users can input the observation period, observation site, and observation items for both satellite products and ground observation and select the items of interest, press the plot button, and the results are then shown as graphs. Figures 4 and 5 show example plots of the surface reflectance and Angstrom exponent, respectively. Each graph includes both the satellite-based and ground-based values. One characteristic is the display of sky and ground photos by mouse-over on the plot points. This is a very useful function because users can confirm both the measurement value and the actual condition. ASTER and MODIS products in the user-assigned period can also be searched after inter-comparison of the ground-based and satellite-based values (Figure 6). Then, reflectance products can be ordered (Figure 7), and satellite-based atmospheric products can be used as input parameters for atmospheric correction. Products for Rayleigh scattering, ozone and water vapor absorption corrected reflectance are available, and aerosol correction is currently not applied in this system; however, a new algorithm including aerosol correction will be implemented in the near future. The aerosol effects for these reflectance products can be confirmed because users can compare the ground-based atmospheric information, aerosol optical depth, and Angstrom exponent data. This functionality is very useful for the quality assurance of satellite products.

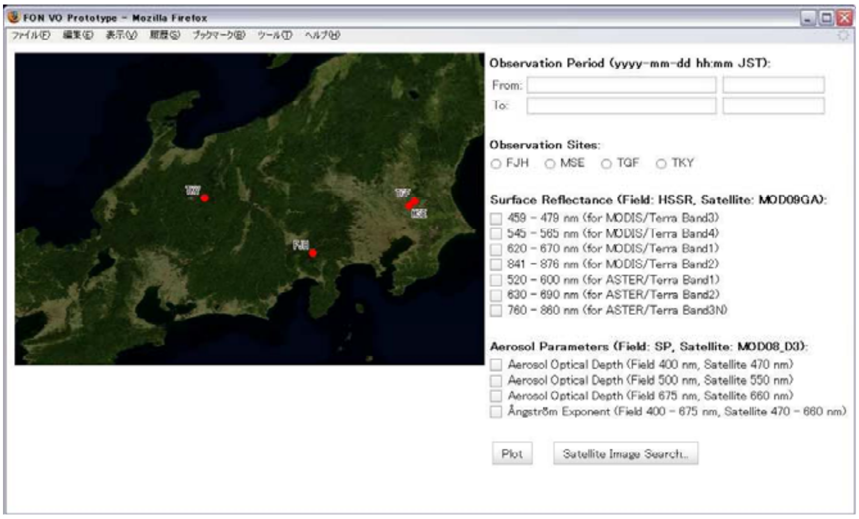


Figure 3. Initial page after FON VO login

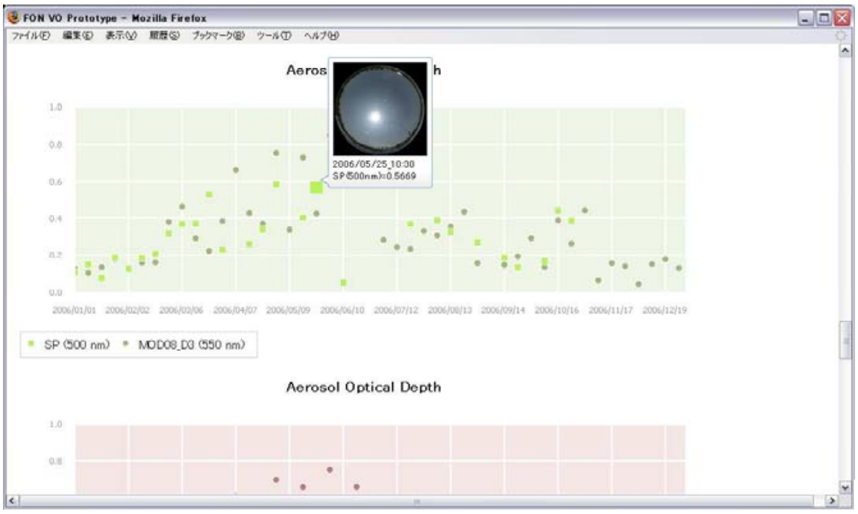


Figure 4. Example result of ground-based and satellite-based data plots for atmospheric profile

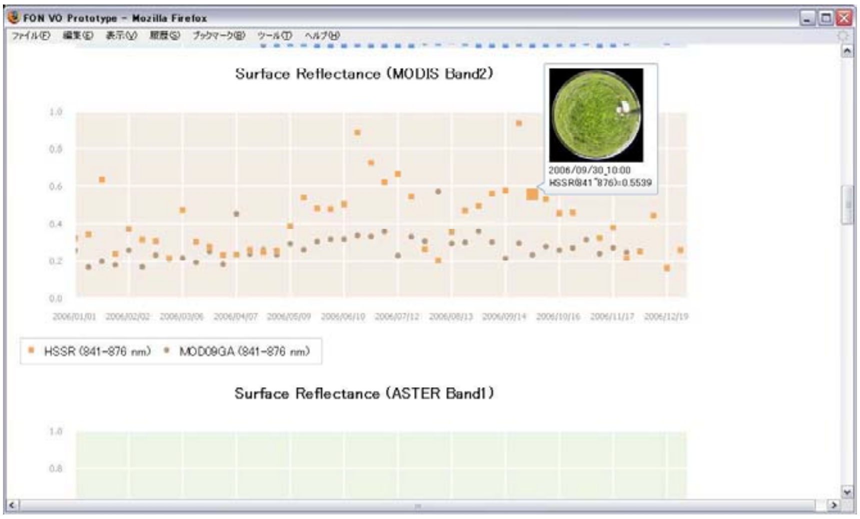


Figure 5. Example result of ground-based and satellite-based ground data plots

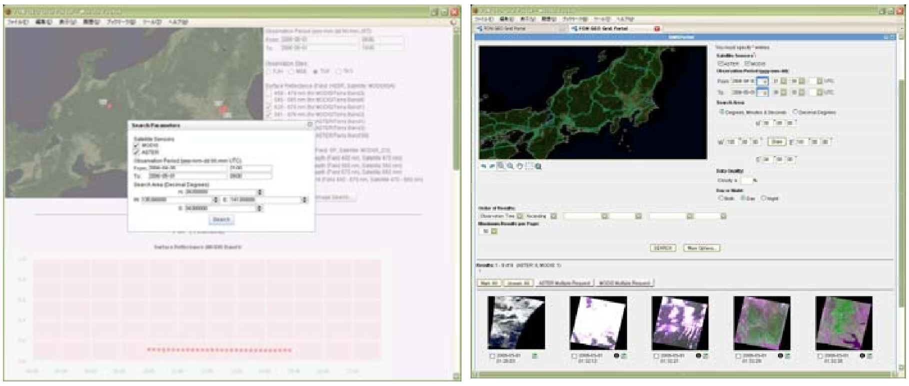
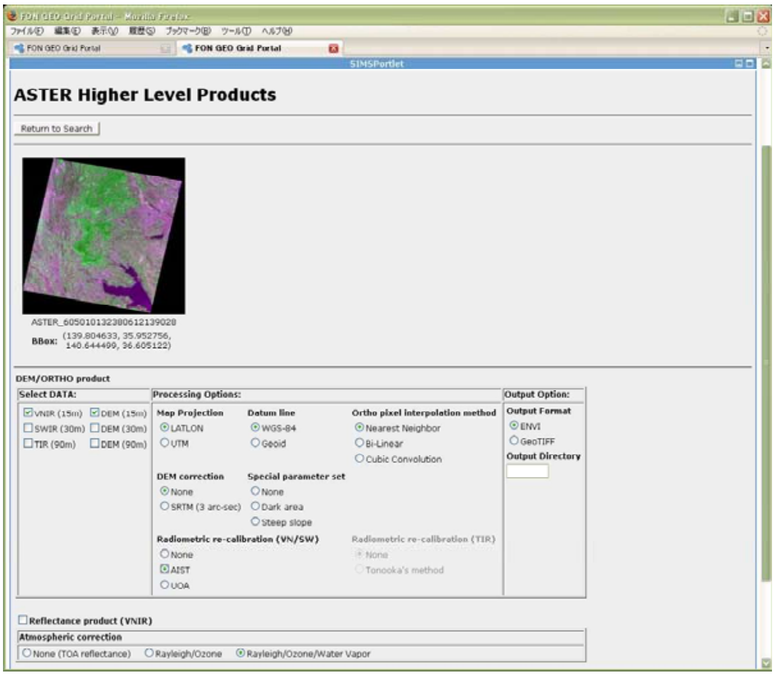


Figure 6. Satellite data search



ASTER Higher Level Products

ASTER_605010132380612139028
BBox: (139.804633, 35.952756, 140.644499, 36.605122)

DEM/ORTHO product

Select DATA:
☑ VNIR (15m) ☑ DEM (15m)
☐ SWIR (30m) ☐ DEM (30m)
☐ TIR (90m) ☐ DEM (90m)

Processing Options:
Map Projection: ● LATLON ○ UTM
Datum line: ● WGS-84 ○ Geoid
Ortho pixel interpolation method: ● Nearest Neighbor ○ Bi-Linear ○ Cubic Convolution
DEM correction: ● None ○ SRTM (3 arc-sec)
Special parameter set: ○ None ○ Dark area ○ Steep slope
Radiometric re-calibration (VN/SW): ○ None ● AIST ○ UOA
Radiometric re-calibration (TIR): ● None ○ Tonooka's method

Output Option:
Output Format: ● ENVI ○ GeoTIFF
Output Directory:

☐ Reflectance product (VNIR)
Atmospheric correction: ○ None (TOA reflectance) ○ Rayleigh/Ozone ● Rayleigh/Ozone/Water Vapor

Figure 7. Reflectance product order page

6 CONCLUSION

This research constructed FON VO, which is a basic system that makes it possible to conduct quality checks and quality assurance of satellite products by using ground-based measurement data. This is the first calibration and validation system adopting both the VO concept and OGC standard SOS. This system is focused especially on calibration and validation for surface reflectance products obtained by optical sensors of ASTER and MODIS onboard the Terra satellite. Generally, the provided surface reflectance products show large differences from the ground-based measurement data. This system can perform factor analysis for the differences between the satellite products and ground measurement data. The atmospheric and ground surface information obtained by PEN is used as the ground-based data. However, the general ground-based and satellite-based data have different data policies. This problem is solved by adoption of the VO concept in the GEO Grid system.

Figure 8 shows the entire schematic flow of FON VO. On the current FON VO, both ground-based/satellite-based ground surface and atmospheric parameters can search and order the ASTER/MODIS surface reflectance products, which reflect satellite-based atmospheric parameters. Previously, calibration and validation of various levels of satellite products were conducted by trial-and-error efforts using various ground-based data. The VO concept protects the data policies of the data providers. Interoperability of the geospatially distributed data using the OGC standards is important because of the increasing field sensor network. We plan to add the following functions to the system proposed in this research.

- Available input of ground-based atmospheric parameters into the atmospheric correction algorithm
- Support of OGC Sensor Alert Service (SAS) standards (Simonis & Echterhoff, 2007) for field sensor condition monitoring
- Support of OGC Web Processing Service (WPS) standards (Schut & Whiteside, 2005) for load balancing by workflow.

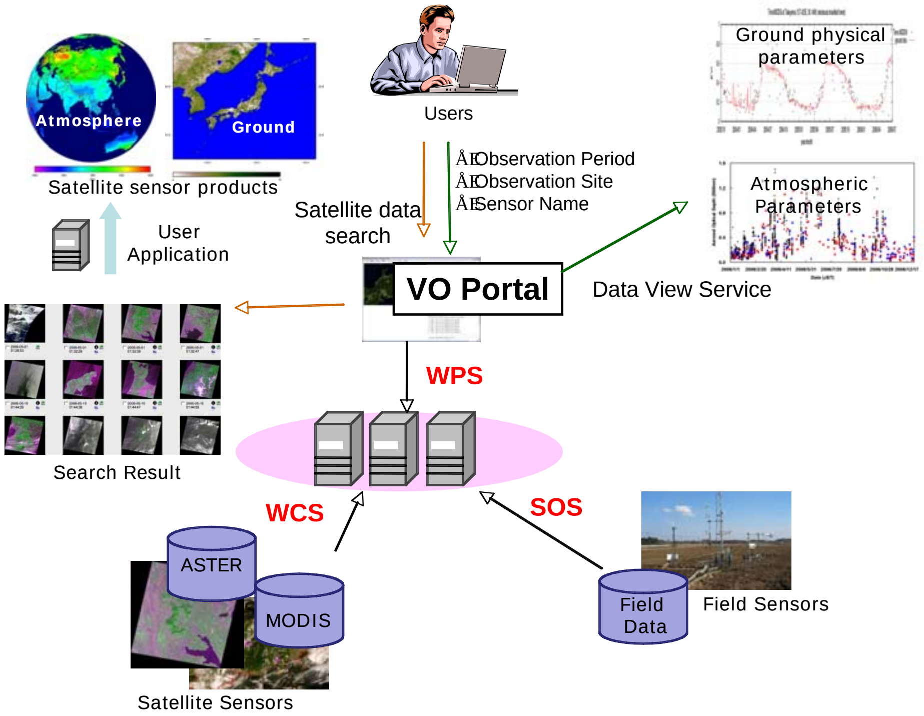


Figure 8. The schematic flow of FON VO in the future

7 ACKNOWLEDGEMENTS

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9 APPENDIX: Acronym List

Organization, Consortium, Provider, and Project

GEO Grid	Global Earth Observation Grid
IPCC	Intergovernmental Panel on Climate Change
LPDAAC	Land Processes Distributed Active Archive Center
LAADS	MODIS L1 and Atmospheres Archive and Distribution System
NASA	National Aeronautics and Space Administration
Oceans IE	Ocean Science Interoperability Experiment
OOSTethys	Ocean Observing System with Tethys
ORNL DAAC	Oak Ridge National Laboratory Distributed Active Archive Center
PEN	Phenological Eyes Network
SURA	Southeastern Universities Association
SCOOP	SURA Coastal Ocean Observing and Prediction

Information Technology acronyms:

API	Application Programming Interface
OGSA-DAI	Open Grid Services Architecture Data Access and Integration
VO	Virtual Organization
XML	eXtensible Markup Language

Geographic Information System acronyms:

CSW	Catalogue Service for Web
GIS	Geographic Information System
GRASS	Geographic Resources Analysis Support System
OGC	Open Geospatial Consortium
SWE	Sensor Web Enablement
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
WPS	Web Processing Service
SOS	Sensor Observation Service

Satellite mission name acronyms:

EP	Earth Probe
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project

Satellite-based sensors acronyms:

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
EPTOMS	Earth Probe TOMS
OMI	Ozone Monitoring Instrument
MODIS	Moderate Resolution Imaging Spectroradiometer
VIIRS	Visible Infrared Imaging Radiometer Suite
TOMS	Total Ozone Mapping Spectrometer

Ground-based sensors acronyms:

ADFC	Automatic-capturing Digital Fisheye Camera
HSSR	HemiSpherical Spectro-Radiometer
SP	SunPhotometer

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