DEVELOPMENT AND EXPERIMENTAL VERIFICATION OF KEY TECHNIQUES TO VALIDATE REMOTE SENSING PRODUCTS

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ABSTRACT:

Validation of remote sensing land products is a fundamental issue for Earth observation. Ministry of Science and Technology of the People's Republic of China (MOST) has launched a high-tech R&D Program named 'Development and experimental verification of key techniques to validate remote sensing products' in 2011. This paper introduces the background, scientific objectives, research contents of this project and research result already achieved. The objectives of this project include (1) to build a technical specification for the validation of remote sensing products; (2) to investigate the performance, we will carry out a comprehensive remote sensing experiment on satellite - aircraft - ground truth and then modify Step 1 until reach the predefined requirement; (3) to establish a validation network of China for remote sensing products. In summer 2012, with support of the Heihe Watershed Allied Telemetry Experimental Research (HiWATER), field observations have been successfully conducted in the central stream of the Heihe River Basin, a typical inland river basin in northwest China. A flux observation matrix composed of eddy covariance (EC) and large aperture scintillometer (LAS), in addition to a densely distributed eco-hydrological wireless sensor network have been established to capture multi-scale heterogeneities of evapotranspiration (ET), leaf area index (LAI), soil moisture and temperature. Airborne missions have been flown with the payloads of imaging spectrometer, light detection and ranging (LiDAR), infrared thermal imager and microwave radiometer that provide various scales of aerial remote sensing observations. Satellite images with high resolution have been collected and pre-processed, e.g. PROBA-CHRIS and TerraSAR-X. Simultaneously, ground measurements have been conducted over specific sampling plots and transects to obtain validation data sets. With this setup complex problems are addressed, e.g. heterogeneity, scaling, uncertainty, and eventually to fulfill the purpose of validation of remote sensing land products at pixel scale over heterogeneous surfaces.

1. INTRODUCTION

With the development of remote sensing technology, massive remote sensing data are made available for monitoring Earth surface. Correspondingly, a variety of land remote sensing products (RSPs) have been developed and operationally disseminated (e.g. de Jeu et al., 2008; Justice et al., 2002; Mu et al., 2007, 2011; Myneni et al., 2002; Wan, 2009). However, researchers from all over the world have long been concerned with the need to quantify the accuracies of remote sensing based land surface products, and this error determination process is herein defined as 'validation' (Justice et al., 2000).

Validation is an indispensable step in quantitative remote sensing and it involves several key components, e.g. ground measurement, simultaneous observation, modelling, object's information extraction, obtaining of RSPs and scale transformation (Zhang et al., 2010). In practical applications, validation refers to assessing the uncertainties of remotely sensed estimates and satellite sensor derived products by comparing against ground truth or some equivalent information, which is presumed to represent the target value (Justice et al., 2000).

In conventional validation means, a homogeneous land surface is commonly selected as the validation field where ground observation data are collected and then used to validate the RSPs. This kind of validation scheme, however, might cause two problems: (1) due to the heterogeneity characteristics of land surfaces, while the homogeneous land surface is rare in nature; (2) the validation result obtained with homogeneous conditions can not be applied to the heterogeneous conditions. Thus, these products may not sufficiently fulfil terrestrial hydrological and ecological applications at local-, watershed- to regional-scale because their resolutions are not fine enough (e.g. Cescatti et al., 2012; Wang et al., 2012). Especially, obtaining the ground truth at pixel scale over heterogeneous land surfaces is a fundamental task to be investigated urgently.

2. VALIDATION INITIATIVE

Upon this background, since 2011 we have been working on an initiative, named ‘Development and experimental verification of key techniques to validate remote sensing products’, which is funded by the Ministry of Science and Technology of the People’s Republic of China (MOST) High-tech R&D Program. This project is mainly attempt to: (1) establish recognized guidelines, standard procedures and technical systems that can be fittingly applied to direct validation activities for a variety of long-term watershed and regional scale terrestrial eco-hydrological RSPs; (2) to inspect the validity and performance of the recommended guidelines and procedures, we will carry out integrated airborne, satellite-borne and ground-based remote sensing experiment and then modify the Step 1 until reach the predefined requirement; (3) and to design and coordinate a nationwide distributed validation network composed of a certain amount of well characterized reference sites for RSP validation in China.

2.1 Key scientific issues

In this section, the key scientific issues will be addressed such as how to develop, design and conduct suitable validation schemes at pixel scale with heterogeneous land surfaces. In this paper, we will discuss how to obtain ground truths at pixel scale based on the observations provided by wireless sensor network (WSN), field measurements with footprint dimension and airborne remote sensing.

2.1.1 Estimation of pixel-scale ground truth based on WSN: By adopting newly developed spatial sampling theories, and employing novel observation sensors, as well as considering distinct features of different RSPs, we will devise corresponding ground sampling scheme. Subsequently, wireless sensor network will be deployed in accordance with the sampling scheme, and upscaling technique towards heterogeneous land surfaces will be used to derive ground truths at pixel scale. Meanwhile, uncertainties within these processes can also be estimated.

2.1.2 Estimation of pixel-scale ground truth based on footprint observation data: Previous studies have demonstrated that ground measurements at large scales, e.g. from scintillometer and cosmic-ray soil moisture observing system (COSMOS), agree with remote sensing retrievals much better than point scale observations. However, the footprint or domain that these instruments perceived dose not fully coincide with remote sensing pixel in spatial. Therefore, the spatial/scale approach aiming at transforming such ground measurements from footprint to real pixel domain is urgently needed, and this kind of conversion is greatly related to footprint models with respect to various instruments. To develop such scale transformation method is pivotal and will be greatly emphasised in our project.

2.1.3 Estimation of pixel-scale ground truth based on airborne remote sensing: Airborne mission is capable of bridging the scale mismatch between ground-based measurements and satellite observations. Compare to space-borne platform, the similarity is aerial remote sensing can only deliver indirect measurements, remote sensing product can then be obtained after retrieval and upscaling, uncertainty will be yielded during these processes. The differentia is because airborne mission has the edge of good controllability and very high resolution observation capability, retrieval and upscaling efforts can be achieved under more favourable condition and dependent on more accurate *a prior* information, resulting in smaller uncertainty in the derived results. Studies on how to manage this kind of uncertainty as small as practical is still a subject for further research.

2.2 Strategy of validation

2.2.1 General flowchart: The validation initiative will be conducted with the framework consisting of the following components, i.e. theory and method, technical specification, experimental verification and establishing validation network. As showed in Figure 1, the standard specifications and technical systems are the top-level designs of all validation activities. Since we will devote to building of a national distributed validation network, and in this aspect, several anchor sites which bear solid observational facilities will be initially selected to inspect the validity of the specifications and technical systems, together with a comprehensive remote sensing experiment. This can also lay a foundation for uniting more sites and stations, as to constitute a recognized nationwide remote sensing validation network. After performing such reiterative efforts can help to constantly improve and mature those principles and guidelines. The following subsections will give more details.

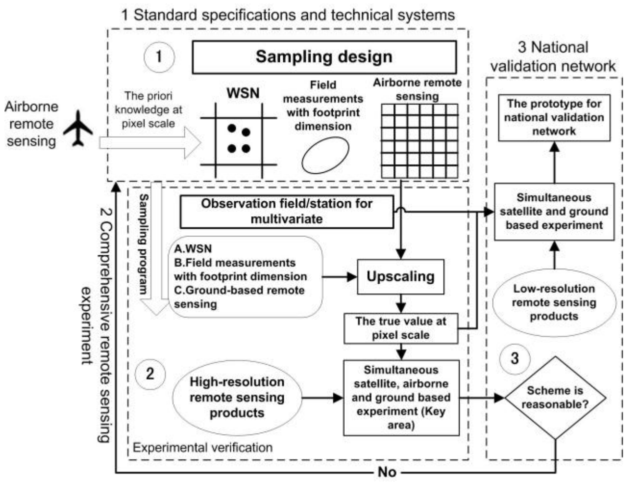

Figure. 1 The general flowchart of the validation strategy

2.2.2 Technical specification: First of all, based on previous research achievements in remote sensing validation, as well as referring to relevant national and industrial standards, the preliminary version of the general guidelines will be drafted according to the characteristics of different products derived from different sensors dependent on spectral region, spatial and temporal resolution. The drafted specifications will then be validated and improved in the practice of the remote sensing experiment and the prototype of the nationwide validation network. The ultimate goal is to build a set of well recognized guidelines and standard procedures that can be fittingly applied to direct validation activities. The flowchart of building of the technical specifications can be seen in Figure 2.

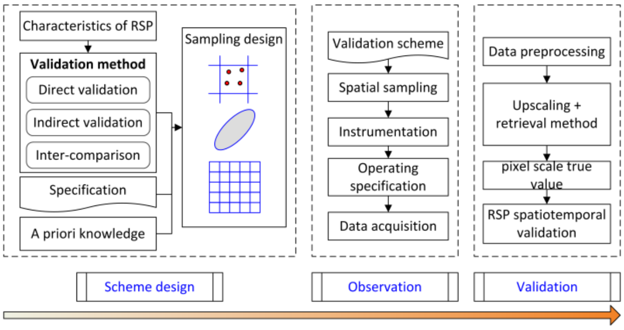

Figure. 2 The flowchart of building of the technical specifications

Due to the fact that both location and amount of sampling points within an image pixel domain directly affects the accuracy of estimated pixel scale ground truth, and generally speaking, the more samples, the higher accuracy. This is usually effective for non-heterogeneous surfaces. However, homogeneous land surface is rare in nature, thus it is not guaranteed that the estimated result is best and unbiased if traditional sampling theory and approach were used over complicated sub-pixel scenes. Hence, how can we use limited number of sampling points to optimize their spatial distribution and acquire accurate ground truths at pixel scale will be extremely stressed in the current study, because this is also a core mission in the top-level design. This will be investigated based on spatial sampling and statistical inference theories, as the latest realised mean of surface with non-homogeneity (MSN) spatial sampling optimization scheme (Hu and Wang, 2011; Wang et al., 2009) will be used to calculate the global mean and its variance, and through the relationships among quantity and location of sampling points and estimated variance, in association with optimal algorithms (e.g. particle swarm optimization), to seek optimum number and spatial location of samples within a pixel under given conditions.

Since different RSP has different spatial resolution, ground measurements are not able to cover all these scales, especially for coarse resolution observations. Therefore, validation of these coarse scale products should rely on upscaling techniques. Different scaling methods will be used according to the number of sampling points appeared in a pixel. For fewer points, due to weak statistical relationship, common scale transformation methods which are based on Taylor series expansion will be used; while if abundant samples were available, hierarchical Bayes models can be utilized, in association with auxiliary information and high resolution remote sensing observations. At the meantime, corresponding accuracies will be assessed in terms of large scale remote sensing experiment and synergistic measurements provided by the validation network. In this aspect, direct, indirect and inter-comparison validation methods will be used.

2.2.3 Comprehensive remote sensing experiment: Obviously, to achieve the aforementioned goal requires considerable resources and observation infrastructures and evidently a remote sensing campaign is preferred. Rich data sets acquired from multi-platform including satellite, aircraft and ground-based provide the possibilities to systematically verify and improve the drafted technical specifications, to quantitatively evaluate the uncertainties of various products, and to analyse the rationality of evaluation methodologies and indicators in the whole validation activities.

For this purpose, validation experiments were carried out within the framework of Heihe Watershed Allied Telemetry Experimental Research, a large scale remote sensing experiment (HiWATER, Li et al., 2013). It is a simultaneous air-borne, satellite-borne and ground-based remote sensing experiment aiming at improving the observability of hydrological and ecological processes and at enhancing the applicability of remote sensing in integrated eco-hydrological studies and water resource management at watershed scale. A wireless sensor network and flux observation matrix has been established to serve as validation applications. Figure 3 shows a typical observation scenario in HiWATER that is able to deliver multi-scale observations on land surface parameters. More details about HiWATER will be illustrated in Section 3.

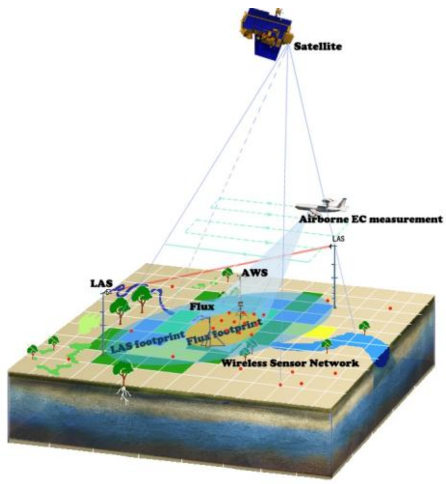

Figure. 3 The typical multi-scale observation characteristic in HiWATER

2.2.4 National validation network: Initially some existing stations/sites with sound observational foundations will be selected. As each of these observatories may have distinct local landscape features, accordingly, specific validation targeting variables will be focused. And on this basis, these stations/sites will be reconstructed as standard reference sites to be united as a prototype of the nationwide validation network. By subsequently following the proposed specifications and coordinating with the remote sensing experiment, individual validation efforts can be made towards specific product at each site, in order to demonstrate the reasonableness and operability of the advised standard validation guidelines, and to actively feedback to the whole system design to move forward the improvement and integration. The technical route on the establishment of the network can be seen in Figure 4.

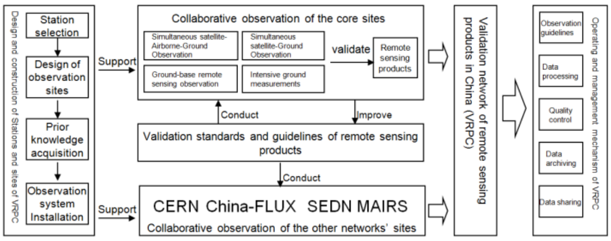

Figure. 4 The technical route on the establishment of the national validation network

In total, it is planned 12 anchor stations that located at 7 representative regions in China will be encompassed in the network (Figure 5). At each site, according to its typical land surface characteristic, 1-3 standard observation fields will be identified with the size of 3 km × 3 km. For the validation of soil moisture product derived from passive microwave observations, the field size can be expanded to 25 km × 25 km. Based on *a prior* information, *in situ* instrumentation will be deployed with the guidance of above mentioned pixel scale ground truth acquisition sampling scheme. To account for different resolution products, potential observation facilities will include WSN, scintillometer, eddy covariance (EC) system and point scale remote sensing instrument, to be able to realize nested multi-scale coverage.

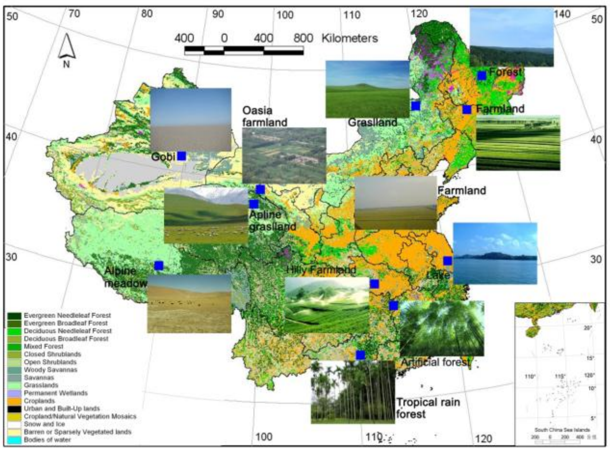

Figure. 5 Anchor sites and their vegetation types in the validation network in China

Being organized as a network and accounting for concrete observation requirements, all stations/sites will abide strictly by the unified standard technical specifications and systems in implementing validation attempts, e.g. selection of reference site, establishment of observation field, deployment of instrumentation, data processing procedure, data check, data quality control and data sharing. With practical endeavours, the standard principles and specifications can be constantly improved to form a mature institution on building of a Chinese validation network.

Besides, various observation campaigns will be conducted at every anchor stations, this can be accomplished coordinately or individually. Simultaneous remote sensing experiment flexibly combined with multi-platform will be performed and this can assist acquiring ground truths with different resolutions for a variety of key land surface variables.

3. REMOTE SENSING EXPERIMENT

3.1 Overview of HiWATER

As a critical juncture in our whole validation framework, HiWATER is a watershed-scale eco-hydrological experiment taking place in the Heihe River Basin (HRB), the second largest inland river basin in the arid regions in Northwestern China. It is designed from an interdisciplinary perspective to address complex problems, such as heterogeneity, scaling, uncertainty and closing water cycle at the watershed scale. The validation of RSPs from an experimental perspective is also a major objective of HiWATER. The design and implementation plan of HiWATER can be found at Li et al (2012; 2013) and a website (http://hiwater.westgis.ac.cn/english/).

3.2 Experimental design in relation to the validation of remote sensing products in HiWATER

As aforementioned, validation is a cardinal prerequisite to ensure the quality and reliability of RSPs. Specific schemes and exertions were conceived and having been conducted to be able to help us gain more insight into validation and its associated problems. These programs are outlined as following to delineate our view on validation from the perspective of experimental design and implementation.

3.2.1 Specific validation experiment: In HiWATER, a fundamental experiment has been tailored on cal/val activities. Some sampling plots and transects were particularly identified to carry out intensive *in situ* measurements concurrently with airborne and satellite overpasses aiming at key eco-hydrological parameters, e.g. land surface temperature, soil moisture, LAI, biomass. These point measurements will play a fundamental role in the validation of remote sensing retrievals derived from various sensor payloads.

3.2.2 Pixel scale ground measurements acquisition: Additionally, ground truths are not limited to be acquired only at point scale; they are also obtained at imagery pixel scale in terms of WSN and field measurements with footprint dimension.

A WSN has been established in HiWATER aiming to integrate a variety of hydrological, ecological and meteorological observation facilities (Figure 6). This provides possibilities to build up several ground-based validation fields with image pixel scale to furnish *a prior* spatial distribution information of soil moisture/temperature over heterogeneous surfaces to estimate evapotranspiration (ET) by remote sensed data, and to validate remote sensing retrievals and products related to eco-hydrological variables. More details can be found in Ge et al. (2012) and Jin et al. (2012).

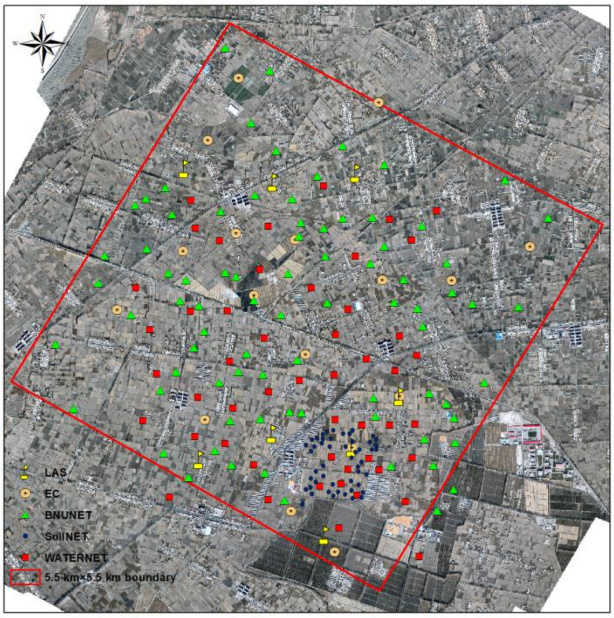

Figure. 6 The setup of the WSN deployed in the Yingke and Daman irrigation districts, the middle stream of the HRB

Besides, an observing matrix composed of EC system and large aperture scintillometer (LAS) has also been established in the middle stream of the HRB. This observing matrix provides multi-scale data sets of meteorological elements and land surface parameters for the estimation of regional ET over heterogeneous surfaces, to identify scale effects and to deliver ground truths that correspond to the development of the remote sensing models and scale transformation approaches in association with validation purposes (Liu et al., 2013; Xu et al., 2013).

3.2.3 Airborne mission: A multi-purpose, multi-sensor airborne remote sensing campaign with the payloads of CCD, visible near infrared (VNIR) imager, thermal infrared (TIR) camera, microwave radiometer and light detection and ranging (LiDAR) has been performed. Each flight was dedicatedly designed towards acquiring different resolutions of observations and therefore, some of them are comparable to the scale of satellite sensors imaging pixel size. Thus, through the implementation of airborne missions, on one hand, it can improve the remote sensing methods and algorithms for observing and retrieval of key eco-hydrological variables and parameters, on the other hand, it can also account for developing scale transformation approaches by acquiring multi-spatial resolution remote sensing data, and moreover, to bridge the scale divergence between ground measurements and satellite sensor observations.

4. CONCLUSION

During the last several decades, unprecedented advances in characterizing land surface parameters from satellite platforms have been achieved, resulting in an increase in satellite remote sensing data products for global change research and environmental monitoring. However, previous investigations have demonstrated that these products, while providing reasonable spatial and temporal coverage, are still sometimes questionable at local-, watershed- to regional-scale applications. On one hand, the accuracies of these products are not always satisfied when they are compared against various validation data sets, particularly in extreme environments such as cold and arid regions; on the other hand, these products may not sufficiently fulfill terrestrial hydrological and ecological applications at local-, watershed- to regional-scale because their resolutions are not fine enough.

In this paper, we introduced a validation project which is taking place in China. This project is initially to build a technical specification for the validation of RSPs. All other validation activities will be adhered to the proposed recognized guidelines and standard procedures to regulate our measures on the planning of sampling strategies, arrangement of resources, deployment of observation instruments etc. Besides, for the sake of the essential complicated heterogeneous characterization of land surfaces, novel spatial sampling methods and models will be developed and used based on spatial sampling theorems and geostatistical methodologies. This will be beneficial to quantitatively calculate various statistical indicators for the estimates acquired at pixel scale, to seek and finalize the optimized spatial layout of sampling points and therefore to obtain the best unbiased estimated ground truth at pixel scale over non-homogeneous scenes for validation purpose.

Additionally, a large-scale remote sensing experiment is taking place in the HRB to assist the validation studies, considerable research results have already yielded, e.g. a flux observation matrix composed of EC and LAS, and a densely distributed eco-hydrological wireless sensor network have been established to capture multi-scale heterogeneities of ET, LAI, soil moisture and temperature. Moreover, building of a nationwide validation network in China is being planned and organized.

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