

# DEVELOPMENT OF OGC FRAMEWORK FOR ESTIMATING AIR TEMPERATURE FROM MODIS LST AND SENSOR NETWORK

S. Ninsawat<sup>a</sup>, H. Yamamoto<sup>a</sup>, R. Nakamura<sup>a</sup>, A. Kamei<sup>a</sup>, S. X. Kato<sup>b</sup> and S. Tsuchida<sup>a</sup>

<sup>a</sup> National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan,  
email: sarawut.ninsawat@aist.go.jp

<sup>b</sup> Hyogo University of Health Sciences, Liberal Arts Center, Kobe, Japan, e-mail: katosi@huhs.ac.jp

## Commission IV, WG IV/5

**KEY WORDS:** Interoperability, Web based, Distributed, Sensor, Temperature

### ABSTRACT:

While the satellite data and meteorological measurement are more easily available, there is a lack of comprehensive framework that provides an estimated air temperature map with ease of use to the end-users. This study focus on the developing of a comprehensive web based framework for estimating air temperature map from MODIS LST evaluated relationship with *in-situ* data collected over a distributed sensor network of ground sites. The development is based on various open standards of OGC (Open Geospatial Consortium) Web Service specifications such as Web Processing Service (WPS), Sensor Observation Service (SOS), Web Mapping Service (WMS) and Web Coverage Service (WCS). The availability of high temporal measured air temperature by sensor network provides as a superior ground based data source for estimating air temperature from satellite observation. The MODIS LST dataset as a data source from WMS server was evaluated relationship with near surface air temperature of Live E! Project sensor network weather station from SOS server to calculate air temperature map with on-demand processing capability of developed WPS server requesting satellite data source from WCS server. The developed OGC specification compliance system, that supports interoperability, scalability and robust platform, shows its powerful potential for standard data sharing and on-demand processing interfaces on satellite image and sensor observation data.

## 1. INTRODUCTION

The spatial and temporal variability of air temperature near the Earth's surface is an important and necessary parameter in several environmental, ecological, public health and especially agriculture applications (Sarriko, 2000 and Yun, 2003). Usually crop-growth modelling requires spatially weather variables for whole study area while the available weather information offers represented observe values of limited area near by meteorological station. In most case, a spatial interpolation of observed air temperature at single or multiple meteorological stations is carried out to estimate whole over area of interest. Due to, the limited density of meteorological station or rarely design to cover the range of climate variability with in region, thus uncertainly spatial information available of air temperature is often present. Consequently the output of uncertainly estimate for weather variables over study area can cause an inaccurate results when applying crop-growth models over regional area.

On the other hand, satellite remote sensing image is fundamentally design to offer spatially distributed information over earth observation. Nevertheless near surface air temperature (measured at two meter above ground) is scarcely obtained from direct satellite observation which mainly targets to the earth surface observation. While modern remote sensing platform like Moderate-resolution Imaging Spectroradiometer (MODIS) can estimates Land Surface Temperature (LST) using a generalized split-window technique of Thermal Infra-Red (TIR) channels (Wan and Dozier, 1996). Many scientists have studied and reported a strong correlation between LST and near surface air temperature. Mostovoy et al., 2006 and Vancutsem et al., 2010 demonstrates the derivation of near surface air

temperature from LST observed by satellite remote sensing through various regression and statistical analysis. Additionally, De Wit et al., 2008 shows the realistic simulations of crop potential production using the satellite-derived meteorological variables in Belgium. The results show slightly better than the results that use spatially interpolated variables from meteorological stations.

While the satellite data and meteorological measurement are more easily available, there is a lack of comprehensive framework that provides an estimated air temperature map from satellite remote sensing image with ease of use to the end-users. Previous study of many scientists shows that vast of time-series weather observed data and satellite remote sensing images are required to find a correlation between LST and near surface air temperature. There is a huge required effort for users to prepare, analyse and process both of datasets to achieve final results. Not only the task of acquisition, archive and manipulate high temporal dataset of weather station (from every minute to five minutes interval) is a time-consuming but also the acquiring and processing of satellite remote sensing data requires more user skill and sufficient computer hardware and software support system. It is a big challenge to develop the Spatial Data Infrastructure (SDI) for both of datasets and also a robustness on-demand processing framework for a real practical system publish satellite-derived air temperature to communities.

Open Geospatial Consortium (OGC) has emerged as a major force in the trend towards openness, as a consortium of GIS vendors, government agencies, academic institutions and private entities. OGC has proposed a number of standards for geospatial data exchange, with the intention of promoting

interoperability through the use of web services as OGC Web Services (OWS). Several OWS specifications are available and practical implemented in many organizations to allow public community access huge dataset of geospatial data and geoprocessing functionalities. The development of interoperable, scalable and robust platform for management and on-demand processing of satellite image and sensor observation is promised by compliance with existing OWS specification.

This study focus on the developing of a comprehensive web based framework based on various open standard of OWS specifications for estimating air temperature from MODIS LST with *in-situ* data collected over a distributed sensor network of

weather station. The component of supported service and data are shown in Figure 1. The prototype web based application is developed to provide the ease of use to users through common web browser with the rich interactive web mapping client to visualize and facilitate on-demand processing. Current prototype application offers data only in Japan; however the scalability of developed framework is also possible for larger coverage. The detail of system development is presented in the architectures section. Then, the discussions about developed system for advantage, limitation and further development will be presented in conclusions part.

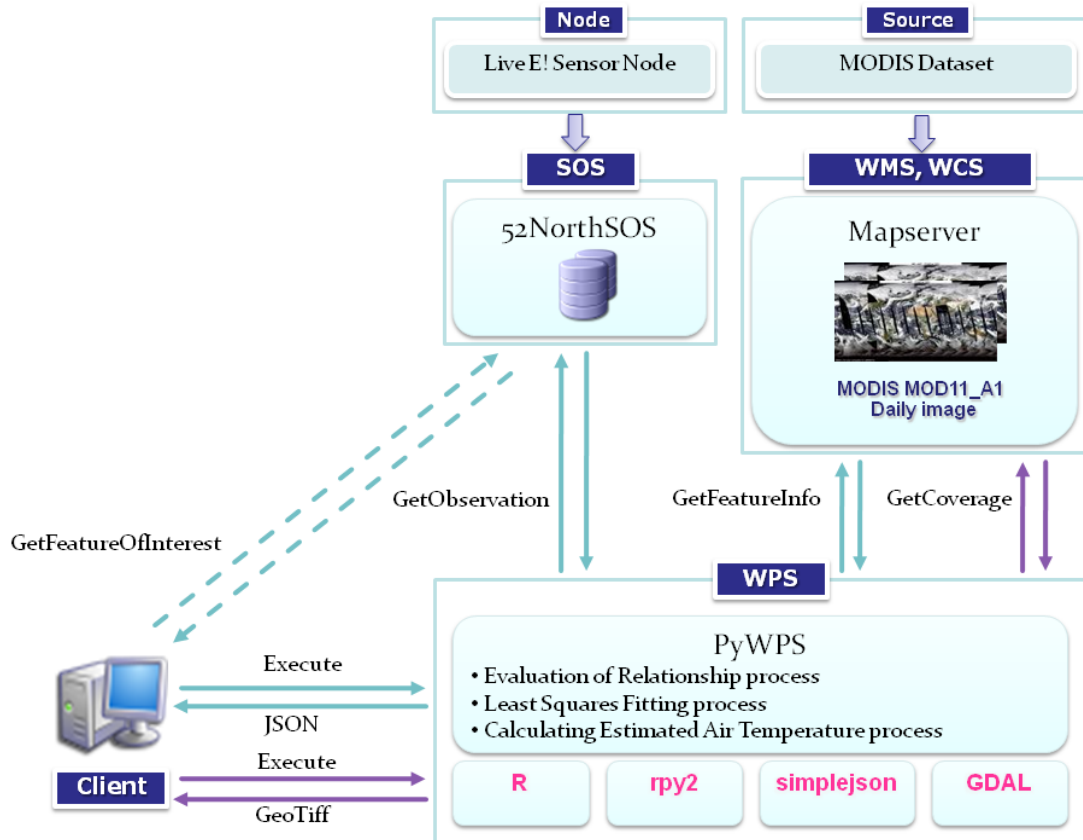


Figure 1. The service components in developed framework.

## 2. DATA

### 2.1 MODIS Sensor Data

The data of MODIS sensor boarded the National Aeronautics and Space Administration (NASA), Earth Observing System (EOS) Terra and Aqua satellite is selected as satellite remote sensing dataset in this study. With two corresponding of Terra and Aqua satellite polar-orbiting, four time observations for each day are available (around 10:30 am/pm of local solar time for Terra satellite and around 1:30am/pm of local solar time for Aqua satellite). Since this study focus on the estimated air temperature, MODIS LST product version 5 was used. The daily LST of day and night time with a measurement in degree Kelvin unit at one km. resolution of Terra satellite is available in MOD11A1 dataset and MYD11A1 dataset for Aqua satellite. In each tile coverage of each Satellite (Terra and Aqua), same enclosed location on earth was observed and recorded in separate individual file for each day. In this study, the tile coverage of h28v05 and h29v05 cover whole Japan territories

have been downloaded from the Land Processes Distributed Active Archive Center (<https://lpdaac.usgs.gov>).

### 2.2 Live E! Weather Station Data

In this study, *in-situ* near surface air temperature observation was obtained from weather ground station of Live E! Project sensor network. In the Live E! Project, the networkable weather station are setup in nationwide over Japan or even also in other country such as China, Thailand etc. Since the system is mainly designed to utilize network infrastructure to share the digital information related with earth to public society (Matsuura et al., 2007). Thus, the weather observation, which is composed of air temperature, relative humidity, pressure, wind direction, wind speed and rain fall, is discoverable, accessible and useable via the web connection. The periodical air temperature measurements in degree Celsius unit of every five minutes from eight weather stations in various geographic conditions were used in this prototype application.

### 3. ARCHITECTURES

#### 3.1 Satellite Data Service

To encourage more utilization of satellite remote sensing data, users could be able to extract precisely desired information (parameters, time period and area of interest) for their interest from data center through network connection. OGC have specified the Web Mapping Service (WMS) and Web Coverage Service (WCS) in OWS specification allow user to discover and access satellite remote sensing data with a specific users requirement through common web browser or thin GIS client application. In this study, WMS and WCS (supported specification version 1.1.0) server were implemented with MapServer version 5.4.2 (<http://mapserver.org>) which is a free and open source software development environment for building spatially-enabled internet application.

**3.1.1 Web Mapping Service:** The utilization of WMS has been well-known by the capability that returns a dynamic creation map-like view image or vector-based graphical element in Scalable Vector Graphics (SVG) assembling from multi-sources over web connection with GetMap operation. Since the mainly utilization of GetMap request is used for graphical visualization purpose, thus the rendered map-like view image is only a representation of an actual data with range value in color space. In order to access to actual information at specific features (with the x,y image pixel position), the GetFeatureInfo, that is an optional operation in WMS, can be invoked. The GetFeatureInfo request returns as text-based formats, for example HyperText Markup Language (HTML), Extensible Markup Language (XML), JavaScript Object Notation (JSON) and simple plain text, which have been defined by each WMS server as state in GetCapabilities request. To perform WMS request, the client has to send the parameters to specify the desired map, for example, the name of the layers, the geographical coordinate of bounding box to be show, the projection and coordinate system, the raster format, the display size and so on. The additional parameter of request that user can send in WMS request is a time dimensions parameter which is very helpful for a time-series data like remote sensing image.

In this study, the GetFeatureInfo operation was used as a main interface to collect a time series of LST data from MODIS dataset. The return result as JSON format is composed of data values of LST and local solar time of LST observation at specific location during particular time period. The daily local solar time of LST observation is also provided as an essential information that enables to request *in-situ* ground based air temperature as closed as possible to the moment of the satellite overpass since Terra and Aqua orbit always cover same location at varied local overpass time (usually differ from 30 minutes to 60 minutes). The extending of common GetFeatureInfo interface has been implemented in this prototype application provides more specific request to allow user to filter data with a post production quality assurance (QA) information of MOD11A1 and MYD11A1 dataset which is mainly indicated by cloud condition. In this study, QA flag filter for only good data quality type and all measurement are supported.

Not only GetFeatureInfo operation is utilized in this developed framework, but also the GetMap operation is used to present a graphical rendered image map of estimated air temperature from processing service. Users can easily examine the final result from a preview map before make a decision to download actual result data to operate for further analyze at local machine.

**3.1.2 Web Coverage Service:** The WCS server that provides a standard access procedure for exchanging geospatial data as coverage (such as satellite image, aerial photography and elevation data) was implemented in this study. Rather than static maps (server-rendered images) which are generated by WMS, geospatial coverage contains raw values or properties of geographic locations can be obtained via a standard interface request of GetCoverage. Access to unrendered geospatial information is truly needed for client-side that input requested data into scientific models and other rich clients beyond simple viewers. Any desktop GIS application or image processing software could be used to access the requested data and make any further analysis on the data set.

GetCoverage request syntax and semantics is nearly same as a GetMap request in WMS but several extensions support the retrieval of subset defined range set or dimensions of coverage data. Similar to previous implemented WMS, the time dimension request is also supported in this implemented WCS. But in this case, the time instant format is specified to retrieve a desired date observation of MODIS LST coverage. While the day and night LST measurement are presented in separate image band (which usually define as range in terms of WCS specification), thus the desired period of observation (day or night) can be specified in the "PARAMETER" key in GetCoverage request. Processing service will send a request to WCS server with a specific time instance and then process a retrieved LST data to estimated air temperature map.

#### 3.2 Weather Data Service

Nowadays the earth has been observed for *in-situ* measurements by millions of sensors which are various different types and architectures. The lack of integration and communication between these networks is a challenge to fully utilize ground-based measurement information. Therefore, Sensor Observation Service (SOS) standard was proposed by OGC as a component of a Sensor Web Enablement (SWE) specification. SOS is a meant to facilitate the development with standard interface to allow users access, filter and retrieve archiving measurement data from distributed heterogeneous sensor network. The core interfaces in SOS request includes the three mandatory operations GetCapabilities for requesting a description of the service and the sensor data offering, DescribeSensor for retrieving the metadata documents of the sensors and GetObservation for querying observations of certain sensors or phenomena using combination of spatio-temporal and filters for observation values. Moreover, the station name and coordinate value of available weather station can be queried with specific expression using the GetFeatureOfInterest operation. In this study, SOS server of near surface air temperature measurement data was established to provide a ground-based dataset observed by Live E! sensor network project in support of an evaluation of relationship with MODIS LST dataset. The observed near surface air temperature from SOS was requested between 30 minutes interval to the satellite overpass which was gathered from WMS server. The result of request that is encoded in XML following the OGC's Observations & Measurements (O&M) schema will be aggregated as a representative measurement value comparable with daily LST in Processing service. The open source software 52North SOS (<http://52north.org/sos>) was used to implement SOS server (supported specification version 1.0.0) in this prototype framework.

### 3.3 Processing Service

Instead of providing the access to archived geospatial data as same as WMS, WCS and SOS, Web Processing Service (WPS) provides an effort to enable on-demand processing capability over the network connection as a web service, which can utilize various data sources at local server or distributed network. In this study, WPS server (supported specification version 1.0.0) was established by PyWPS version 3.1.0 (<http://pywps.wald.intevation.org>) software. WPS itself does not offer computational capabilities but the sequence task of computer programming or legacy software performs the analytical functionalities in the background. Three processes were developed to fulfil an estimated air temperature framework.

**3.3.1 Evaluation of relationship process:** It is an initially process of whole implemented framework that be invoked from client application to WPS server. First, WMS's GetFeatureInfo operation is requested with supplement parameters for time-series satellite LST observed values subsequently SOS's GetObservation operation is performed to retrieve near surface air temperature according to the satellite overpass time which is extracted from WMS result. Then an O&M document is parsed and aggregated as a representative of period value to comparable with LST measurement. Since the value of LST in MODIS dataset is recorded in degree Kelvin unit, thus the unit conversion to degree Celsius is must performed. Both of dataset are used to produce time-series plot and scatter plot graph feature encoded in JSON format which will be rendered as interactive graphic features on client application as a purpose to analyse relationship.

**3.3.2 Least Square Fitting process:** The main purpose of this process is to perform a basic linear least squares regression between MODIS LST and ground-based air temperature measurement which are available in the drawing scatter plot graph feature. The least squares fitting is a standard approach to the approximate solution by minimized the sum of squared residuals between an observed value and value provided by a model. In this process, the main functionality is operated by free and open source statistical R software (<http://www.r-project.org/>). The results of fitting process which are composed of slope and intercept value of fitting line, fraction of variance ( $R^2$ ) parameter and start and end point pair value of fitting line are returned to client.

**3.3.3 Calculating Estimated Air Temperature process:** After the analysis of relationship and linear fitting between both of datasets were performed. The MODIS LST would be ready to convert to estimated air temperature map. At first, a desired MODIS LST data is requested as a GEOTIFF image format from WCS server. Then the MODIS LST is calculated with the input of slope and intercept value from fitting process to estimate air temperature. The calculation is done by the python programming implemented with Geospatial Data Abstraction Library (GDAL) (<http://www.gdal.org>). The output result encoded in GEOTIFF format is stored in the web accessible connection which allows users to download for further analysis.

## 4. PROTOTYPE APPLICATION

In order to demonstrate the operation of developed framework, the prototype web based application was developed. The

developed web client application enables users to visualize, analyze the spatial-temporal relationship between satellite-measurement LST and ground-based measurement near surface air temperature with the ease of use by a rich interactive of web client. Afterwards the result of relationship analysis will be used in the process of calculating estimated air temperature from MODIS LST dataset. The web mapping client functionality was developed with the OpenLayers Javascript library (<http://www.openlayers.org>) allows user to examine the map and define a study area by using a drawing tool. The defined area will be used as a reference bounding box to query for available weather stations that will be used for evaluating relationship. The returning of GetFeatureOfInterest operation from SOS server is composed of name and coordinate of available weather stations. The coordinate values of each station are essential information in GetFeatureInfo request to specify the spatial location in satellite observation data.

Subsequently, users have to define time period range of relationship study which is necessary in WMS and SOS operation to query only measurements in a period of study from whole dataset. To improve the reliability of evaluation of relationship, users can also specify finer filter of satellite data with QA filter parameter. After all requirement parameters are collected, the Execute operation is send to WPS server with asynchronous connection. The series of task will be done as describe in detail of the evaluation of relationship process. The returning results encoded in JSON format will be rendered as graphical time-series and scatter plot chart allow user to examine and analyse the relationship. Multiple time-series chart will be presented according to the number of available weather station in defined area. As shown in figure 2, two time-series charts in same time period for each weather station are presented with a plot of satellite LST and near surface air temperature. In the scatter plot chart as shown in figure 3(a), the pair values of all MODIS LST measurement and near surface air temperature value from every station are plotted. But in figure 3(b), only good quality of MODIS LST data are presented as user can specify QA parameter in client.

Meanwhile, the least squares fitting process is automatically invoked from web client after receives results from evaluation of relationship process. The list of pair values in scatter plot feature is submitted as a main parameter in this process. Then the statistical information from process's result will be presented beside the scatter plot chart as shown in figure 3 assist user to easily understand the relationship results. The statistical parameters will be recalculated instantly after scatter plot was manually modified by user via interactive tool.

Eventually, the estimated air temperature map can be retrieved from the WPS's calculating estimated air temperature process with the input of slope and intercept of fitting equation. The desired location and date observation of MODIS LST dataset will be decided by users and submit to the process. The web accessible link to map results encoded in GEOTIFF image format will be provided on the client. And also the preview of result map is presented in the map viewer part as shown in figure 4 which allow user to interactive examine a result by zooming and querying result before decide to download actual dataset for further analysis at local machine.

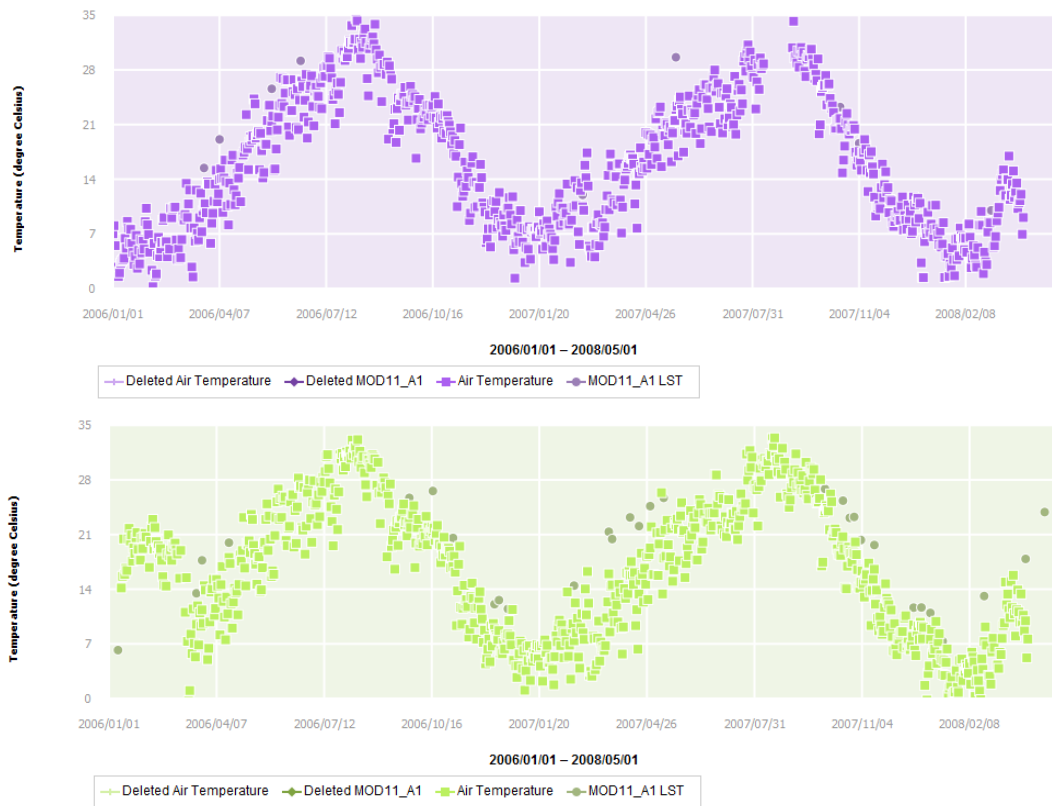


Figure 2. Time series charts (two weather stations) of MODIS LST and near surface air temperature measurement from January, 2006 to May, 2008.

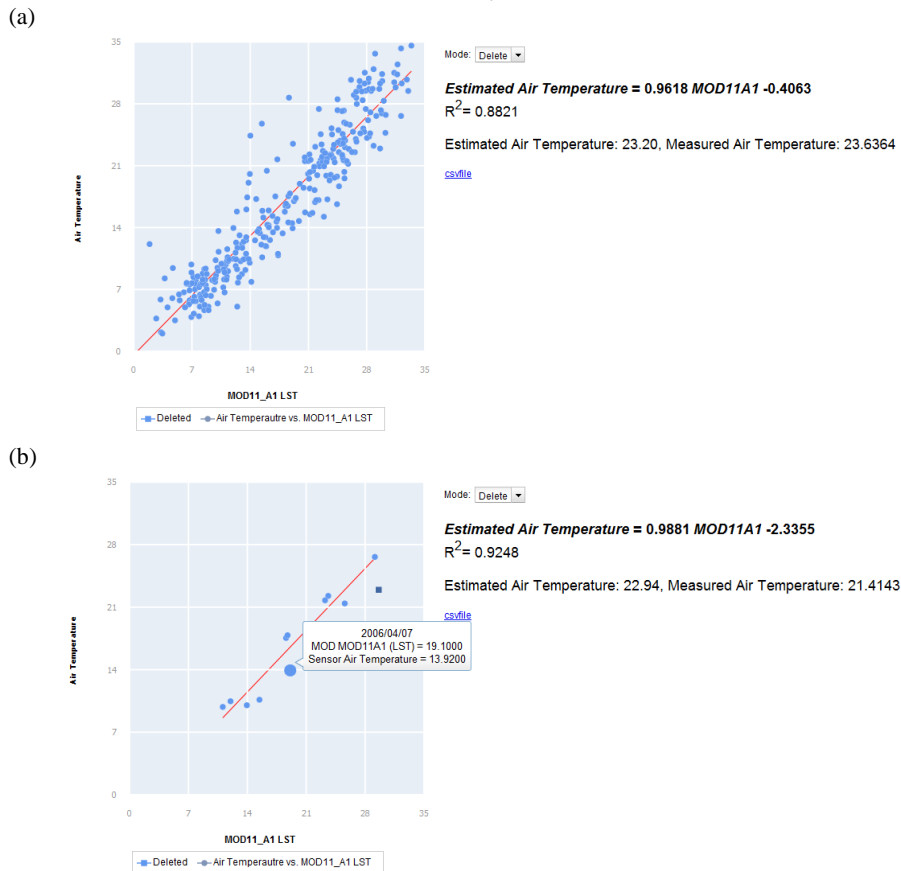


Figure 3. Scatter plot chart between MODIS LST and near surface air temperature measurement and related statistical information: (a) QA for all measurement from MODIS LST, (b) QA for only good quality MODIS LST.

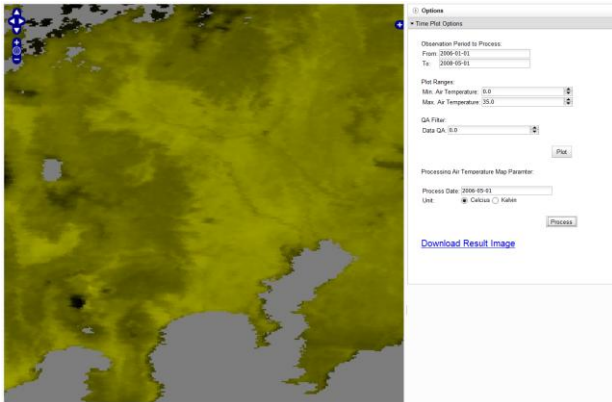


Figure 4. Results map display with WMS interface on client.

## 5. DISCUSSION AND CONCLUSIONS

The developed comprehensive web based framework demonstrates the utilization of integrated various standard of OWS to provide the ease of use of satellite observation data and *in-situ* measurement from sensor network to obtain an estimated air temperature map. The MODIS LST dataset as a data source from WMS server was evaluated relationship with near surface air temperature of Live E! Project sensor network weather station from SOS server to calculate air temperature map with on-demand processing capability of developed WPS server requesting satellite data source from WCS server.

Traditionally, raw data of both dataset are required to manually discover the source, download and extract only necessary data during time period of study. In this developed framework, the implemented WCS, WMS and SOS server show their outstanding capabilities of SDI that enables standardized operation of discover, access and utilize geospatial data through web service connection. The data gathering and manipulating task is dramatically reduced with its standard data sharing operation and filter expression potential. Moreover the robustness dynamic on-demand processing of WPS server assists user to retrieve final results with customization input parameters. The result map is encoded in well-known format which allows any GIS software or OWS server to visualize or make further analyse for higher-level information. In this prototype application, the air temperature measurement of eight weather stations from Live E! Project sensor network was used during initial of developed framework. Since the SOS was originally proposed to interoperability and scalability support with the heterogeneous sensor network, therefore difference sensor network or other weather stations from Live E! Project sensor network can also be utilized to increase a reference data for evaluation relationship process. Also the same with WMS and WCS, difference satellite observed coverage or difference sensor data can be used also for example Meteosat dataset which routinely provides LST every 30 minutes.

The utilization of satellite observation gathering spatial continuous information of estimated air temperature was presented in this study. However, the limited utilization of optical/thermal wavelength satellite data is always constrained by the cloud contamination that makes unavailable or imprecise LST measurement. Neteler, 2010 presents novel algorithms to reconstruct incomplete MODIS LST dataset using time-series statistical analysis with volumetric spline interpolation

technique to fill all void pixels which were removed based on poor quality affected by cloud contamination. In further development, the process of calculating estimated air temperature could be performed with reconstructed MODIS LST data instead of original MODIS LST dataset to improve better quality of final map. However, the reconstruction of MODIS LST is required high processing power for complex process on large time-series dataset. Grid and parallel computing technology integrated with on-demand processing of WPS can overcome and contribute its efficient to enable more powerful framework. And also the implemented fitting algorithm was based on the basic linear regression empirical approach, in future the multiple regression or advanced statistical approach will be studied.

## 6. REFERENCES

- De Wit, A.J.W. and Van Diepen, C.A., 2008. Crop growth modelling and crop yield forecasting using satellite-derived meteorological inputs. *International of Journal of Applied Earth Observation and Geoinformation*, 10(4), pp. 414-425.
- Matsuura, S., Ishizuka, H., Ochiai, H., Doi, S., Ishida, S., Nakayama, M., Esaki, H. and Sunahara, H., 2007. Live E! Project: Establishment of Infrastructure Sharing Environmental Information. *In Proceedings of the 2007 International Symposium on Applications and the Internet*.
- Mostovoy, G.V., King, R.L., Reddy, K.R., Kakani, V.G. and Filippova, M.G., 2006. Statistical estimation of daily maximum and minimum air temperature from MODIS LST data over the state of Mississippi. *GIScience and Remote Sensing*, 43(1), pp. 78-110.
- Neteler, M., 2010. Estimating Daily Land Surface Temperatures in Mountainous Environments by Reconstructed MODIS LST Data. *Remote Sensing*, 2, pp. 333-351.
- Saarikko, R. A., 2000. Applying a site based crop model to estimate regional yields under current and changed climates. *Ecological Modelling*, 131(2-3), pp. 191-206.
- Vancutsem, C., Ceccato, P., Dinku, T. and Connor, S.J., 2010. Evaluation of MODIS land surface temperature data to estimate air temperature in difference ecosystems over Africa. *Remote Sensing of Environment*, 114(2), pp. 449-465.
- Wan, Z. and Dozier, J., 1996. A generalized split-window algorithm for retrieving land surface temperature from space. *IEEE Transaction on Geoscience Remote Sensing*, 35(4), pp. 892-905.
- Whiteside, A., 2006. OpenGIS Web Services Common Specification. *OGC® Implementation Specification*, Doc.No.06-121r3.
- Yun, J.I., 2003. Predicting regional rice production in South Korea using spatial data and crop-growth modelling. *Agricultural Systems*, 77(1), pp. 23-38.