Intelligent Sensorweb for Integrated Earth Sensing (ISIES)

Project Final Report

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TABLE OF CONTENTS

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LIST OF FIGURES

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LIST OF TABLES

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ACRONYMS AND ABBREVIATIONS

AAFC	Agriculture and Agri-Food Canada
ASAR	Advanced SAR
CASI	Compact Airborne Spectrographic Imager
CCRS	Canada Centre for Remote Sensing
CD ROM	Compact Disk Read-Only Memory
CHRIS	Compact High Resolution Imaging Spectrometer
CSA	Canadian Space Agency
ENVI	Environment for Visualizing Images
GIS	Geographic Information System
GML	Geography Markup Language
HH	Horizontal polarisation
ICT	Initial Cadre Training
ISIES	Intelligent Sensorweb for Integrated Earth Sensing
ISPRS	International Society for Photogrammetry and Remote Sensing
LAI	Leaf Area Index
MDA	MacDonald, Dettwiler and Associates Ltd.
MTVI2	Modified Triangular Vegetation Index
NOMAD	Networked On-line Mapping of Atmospheric Data
OGC	Open GIS Consortium
PAR	Photosynthetic Active Radiation
PDF	Portable Document Format
Precarn	Precarn Associates Inc.

R&D	Research and Development
R&D	Research and Development
RS	Radiated Susceptibility
SAD	System Architecture Document
SAR	Synthetic Aperture Radar
SLOC	Source Line of Code
SOMPAS	Soil Moisture Mapping Using Multi-Polarisation and Multi-Angle SAR
SOS	Sensor Observation Service
UTM	Universal Transverse Mercator
VSMB	Versatile Soil Moisture Budget
VV	Vertical Polarization

FACT SHEET

Project Name	Intelligent Sensorweb for Integrated Earth Sensing (ISIES)
Participants	MacDonald Dettwiler and Associates Ltd. Canadian Centre for Remote Sensing (CCRS) Agriculture and Agri-Food Canada (AAFC) York University Radarsat International (ICT group)
Start Date	August 1, 2003
End Date	March 31, 2006
Project Budget	$2,338,700
Project Description	ISIES system integrates an in-situ sensorweb, remote sensing data and Geographic Information System (GIS) data to provide superior estimates and predictions of biomass, yield, and drought through open and standard interfaces. During this project, an intelligent in-situ sensorweb was built that automatically acquires and transmits data in the field to a sensor server. Software was developed for the server to call the sensorweb, download data, and store them in a database. The In-situ data are then fused with remote sensing data to automatically predict yield and biomass using state-of-the-art plant models for a crop field and a rangeland. The plant growth model algorithms were also developed and integrated into the ISIES server. Also, an OpenGIS compliant viewer was developed to provide ISIES data and products through open and standard formats. Through several field trips, a comprehensive set of sensors was deployed in the fields.

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1 EXECUTIVE SUMMARY

MacDonald, Dettwiler and Associates Ltd. (MDA) has developed an innovative system, ISIES, to acquire in-situ data collected in the field by a set of sensors, perform data fusion operation to combine in-situ and remote sensing data, execute plant growth model algorithms to calculate yield and biomass estimates, and provide the results through an Open GIS Consortium (OGC) compliant visualization tool. Additionally, ISIES supported research in the area of soil moisture mapping and crop control by providing subject matter experts with in-situ as well as remote sensing data that were acquired through out the course of the project.

The main objective of this project is:

- To develop an intelligent sensorweb that integrates in-situ sensors with remote sensing and auxiliary data to provide superior prediction of crop and rangeland vigour.

Secondary objectives are:

- To develop data fusion techniques that will provide superior crop/rangeland yield prediction.
- To advance the current state-of-the-art in plant growth models.
- To validate soil moisture measurements extracted from remotely sensed Synthetic Aperture Radar (SAR) data.
- To deliver a working ISIES system to an end user.
- To develop and increase knowledge on OpenGIS, sensorweb technology, etc.
- To develop and maintain relationships between all of the project's participants.

There were a number of technical challenges that the team faced. Perhaps the greatest challenge was in maintenance of faulty sensors in the field that went down for various reasons. This problem was overcome by support from AAFC Lethbridge staff and also deploying multiple sensor platforms to ensure the collection of the necessary measurements.

There were a number of other technical challenges faced by the team:

- Work with less-than-perfect communication channels considering the small windows of opportunity for server-sensorweb connection set up and data download.
- Integration of the 2 selected plant growth model algorithms into the server. This required a significant code conversion from the original stand-alone Fortran code to Java, the language of choice for server development.
- Some data collection hardware that was deployed in the field (HOBO loggers) did not have proper remote connection capability and necessitated the manual download process as opposed to preferred automatic download.

The overall project was successful. ISIES server successfully connected and downloaded in-situ data from the Sensorweb and other field equipment for the most part of spring and summer of 2005.

The following are the major ISIES technical accomplishments:

- Successful design and implementation of a large and complex system that achieves all the required functionality to support crop monitoring.
- Successful design and manufacturing of Sensorweb hardware that functions as a data hub with wired connections to several sensors such as soil moisture probes and wireless dial up connection to the server.
- Generation of several Land Area Index (LAI) and Soil Moisture maps from remote sensing and ground data. These maps have various applications in the agriculture domain.
- An automated data collection system that downloads and stores in-situ data on the ISIES Database.
- Significant improvement in performance and accuracy of the 2 selected plant models which was made possible by using the in-situ and ground truth data that were acquired during this project.
- Successful integration of the Plant Growth Model algorithms with the server to allow automatic generation of Yield and biomass maps.
- Successful development of a geo-spatial viewer compliant with OGC standards namely SOS, WMS.

2 RESEARCH DESCRIPTION

2.1 Research Overview

ISIES tries to solve a combined temporal and spatial sampling problem for agricultural and drought monitoring applications. Ideally, ISIES would measure physical variables of interest in the lower atmosphere, at the earth surface, and the upper 1.5-meter soil-layer over large tracks of land at meter sampling distances and time intervals of tens of minutes nominally. Clearly, this is not practically achievable by using in-situ sensors alone given the equipment cost, land use issues, etc.

Thus, an alternative strategy was developed for ISIES that is affordable and technically reasonable. ISIES proposed to use a combination of in-situ sensors, remotely-sensed data, and model-driven interpolation to solve the sampling problem. The in-situ sensors are sparsely spatially placed but operate at relatively high temporal sampling rates. The remote sensing data provide dense spatial sampling and wide-area coverage but only very poor temporal resolution. Finally, a model-based approach is taken to combine in-situ and remotely-sensed data. The in-situ sensorweb measures relevant agricultural variables using three types of sensor nodes: Weather nodes, precipitation nodes, and soil moisture patches. This three-part distinction of sensor node types arises from the different spatial sampling required for accurate weather, precipitation, and soil moisture measurements, respectively.

In parallel with the main research objective as described above, other research was carried out by the participants including the processing of remote sensing data, investigation and integration of new OGC specifications (e.g. SensorML) and research on soil moisture measurement using remote sensing data.

The following table presents the structure of the ISIES team.

Table 2-1 List of ISIES Team Participants

Participant Organization	Role
Precarn	Funding
MacDonald, Dettwiler and Associates Ltd. (MDA)	Prime contractor, server development, soil-moisture extraction from remote sensing
Canada Centre for Remote Sensing (CCRS)	Sensorweb technology, design and deployment
Agriculture & Agri-Food Canada (AAFC)	Plant modeling, domain experts, test site maintenance, ground-truth sampling, LAI extraction, soil-moisture modeling
York University	Open GIS, Geospatial viewer and LAI extraction
Radarsat International (ICT group)	Commercialization

2.2 Research Methods

The ISIES research was centered on a 2-year field experiment. Two test sites in southern Alberta were selected. One site was a large wheat field close to Lethbridge, the other was a natural rangeland site in the vicinity of Brooks. The two test sites were equipped with in-situ sensors that wirelessly and periodically provided the ISIES server in Richmond, BC with measurements of key environmental variables.

In addition, several types of remote-sensing data were collected over the two test sites during the two growing seasons. After processing, the remote sensing data were stored on the ISIES server for integration with in-situ data for the purpose of plant models execution.

Much effort was spent on collecting ground truth for both test sites so that the accuracy of the ISIES results could be evaluated. The ground truth collected included LAI, biomass, yield, and soil water content.

The crop and rangeland growth models were developed in parallel to the field work and the ISIES server development. The models were improved using ISIES data, as well as the ground truth collected during the two-year campaign.

A very detailed description of the two test sites, and the location of the installed in-situ equipment can be found in the ISIES Field Test Sites Description document. Figure 2-1 shows the location of the two test sites, one near Lethbridge called Lanier and the other outside Brooks, Alberta called Antelope Creek. The Lanier site was planted with wheat and peas whereas the Antelope Creek site was a rangeland.

An exhaustive description of the in-situ data, the remote sensing data, the collected ground truth data, and miscellaneous ancillary data is provided in the ISIES Data Acquisition Plan document.

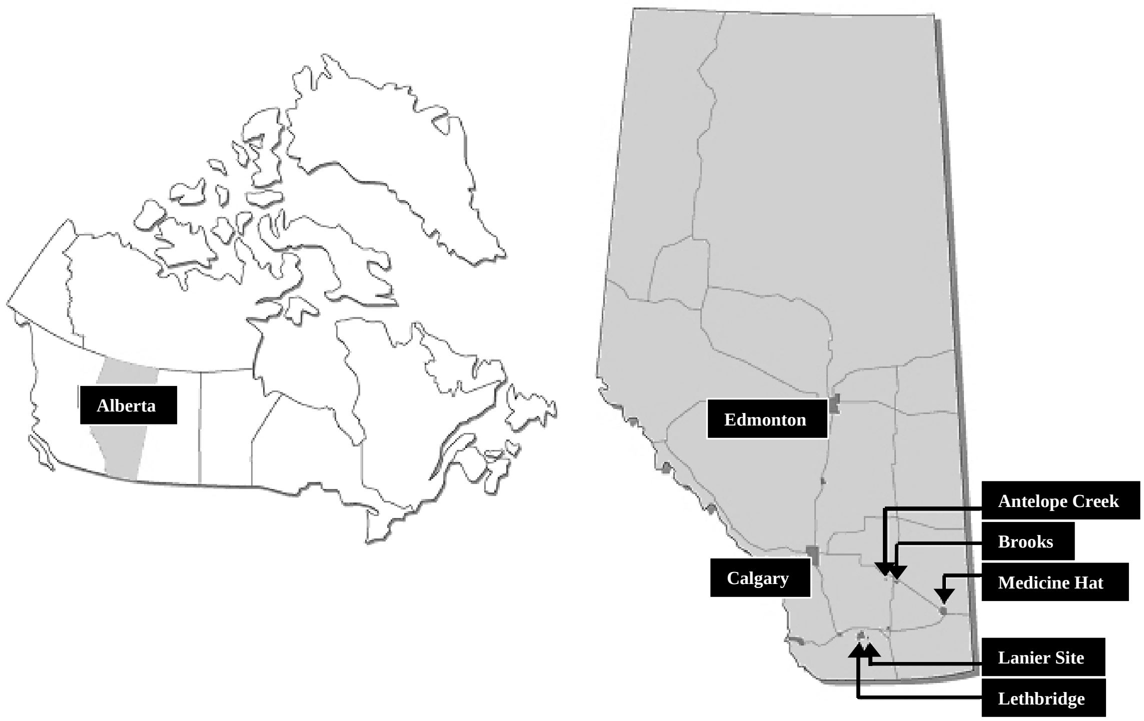


Figure 2-1 Locations of the ISIES Test Sites

2.3 Research Domain

The ISIES research encompassed seven main areas:

1. Integrated Earth Sensing Server
2. OpenGIS and Sensorweb visualisation
3. Sensorweb and in-Situ Sensor technology
4. Extraction of LAI for crops and range-land from Remote-Sensing imagery
5. Information fusion

6. Plant growth models for yield and biomass prediction
7. Extraction of soil moisture estimates from Remote-sensing imagery.

The team members are active researchers in all of these domains and this project provided an opportunity to collaborate to make integrated earth sensing a reality. It also provided an opportunity to go beyond the state-of-the-art in each of the research subtopics listed above.

MDA developed the ISIES server technology that integrated information from the sensor web, the remote sensing data, and the plant growth models, and presented the results via an openGIS interface. An information fusion module was developed to create the appropriate input sets for the plant growth models.

Dr. Vincent Tao and his team at York University in Toronto were developing the openGIS server technology and the openGIS display technology used by the ISIES server.

The CCRS under Dr. Phil Teillet was developing and researching the sensor web and the associated in-situ sensor technology.

Dr. Anne Smith and her team of the Sustainable Production Systems Section at the AAFC Lethbridge Research Centre Agriculture and Agri-Food Canada in Lethbridge, Alberta were researching the extraction of LAI for crops and rangeland from Remote-Sensing imagery. She collaborated for this work with Jim Freemantle from York University. Dr. Smith and her team were also instrumental in deploying and maintenance of equipment in the field, which was one of the most tedious tasks in this project.

Regarding the plant growth models, Dr. Gaétan Bourgeois and his research team at AAFC were researching crop models for yield, LAI and biomass prediction. They were using the LAI estimates produced by Anne Smith as input. Dr. De Jong with AAFC was researching models for estimating rangeland biomass and for modeling soil-moisture for natural rangeland.

MDA also carried out research in the extraction of soil moisture estimates from remote sensing imagery.

3 KEY RESEARCH RESULTS

3.1 ISIES Server

ISIES server contains four main components:

- ISIES database: this component hosts the in-situ data. A data model was constructed for the ISIES database that reflects the set of deployed hardware in the fields, namely sensors and loggers. Figure 3-1 shows the data model.
- Communication: encapsulates the functionality for connecting to the SmartCores at certain time periods and performing the automatic data download. The results of this component are consequently consumed by the Data ingest component. 5 Java classes containing close to 800 SLOC were designed and developed for this component. A COTS was also used for automatic download of Campbell Scientific weather node. This weather node was deployed as a parallel means of measuring and downloading data.
- Data Ingest: this component includes a data access layer, which was designed and developed in Java using JDBC technology. It interfaces with 3 data sources; SmartCore data that are downloaded automatically through the communication component, HOBO data files that are downloaded manually and sent to MDA, and Campbell Scientific weather node which was deployed in Lanier site. 31 Java classes containing more than 6500 SLOC were designed and developed for this component. A detailed class description is included in Appendix A.
- Plant Growth Models Wrapper (including the fusion module): this component integrates the two selected plant models, Maas for crops and VSMB for rangeland, into the server. The VSMB integration involved a complete code conversion from the existing Fortran code to Java. This task proved to be one of the most challenging and time consuming parts of the software development in this project. The Maas model was provided as an executable therefore only a wrapper was developed in Java. 17 Java classes containing close to 2000 SLOC

were designed and developed for this component. The result of plant model execution is a map in ENVI format. Further processing such as geotiff generation is performed manually using ENVI toolkit. Figure 3-2 is the data flow diagram for the plant models wrapper.

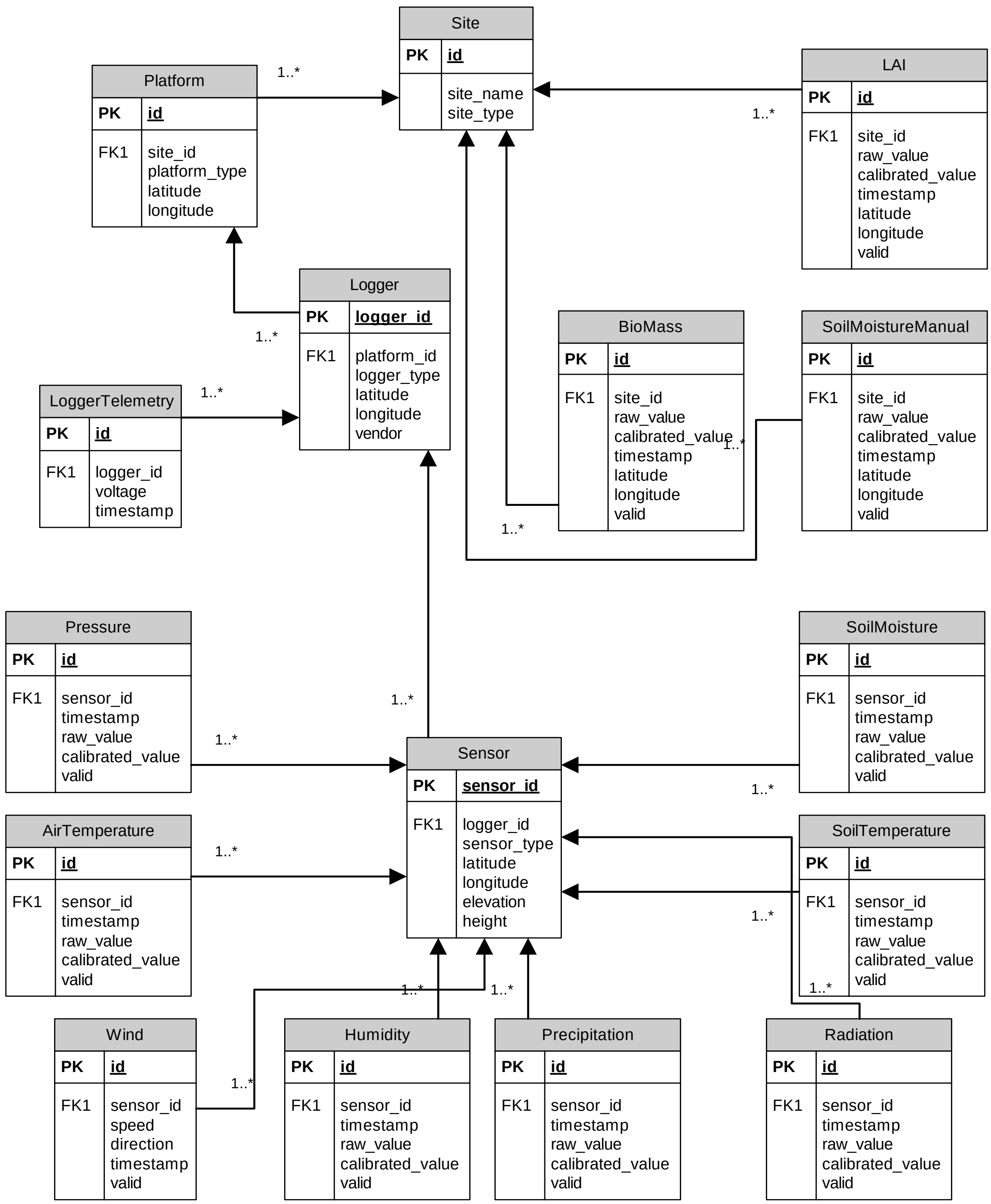


Figure 3-1 ISIES Server Data Model

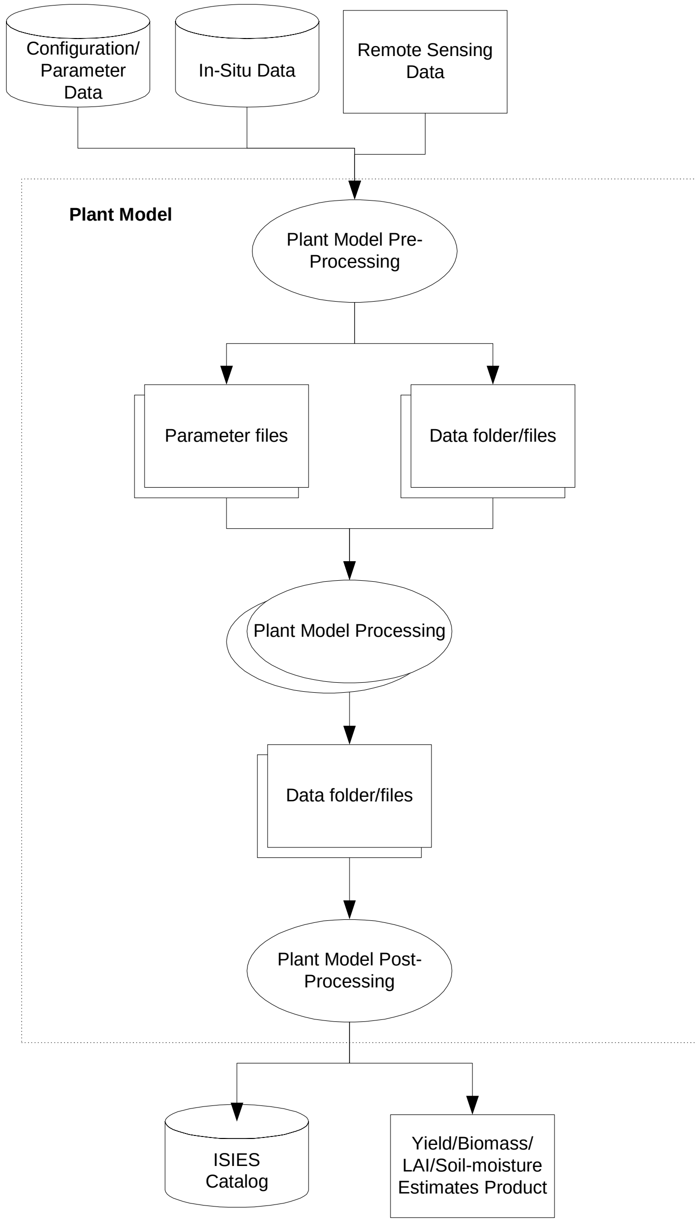


Figure 3-2 Plant Model Data Flow

One major module within the plant growth model wrapper component is the fusion module. Plant models take in a set of in-situ and remote sensing data. Remote sensing data have high spatial value and in-situ data have high temporal value. Considering the fact that the in-situ data are only collected for few points in the field and the desired result of the plant model execution is a yield/biomass map, a need for developing a spatial interpolation module was identified. This module is part of the plant model post-processing step in Figure 3-2.

3.1.1 Data fusion

The following is a discussion of the spatialization schema that was developed as part of the data fusion module.

We only have finite number of weather stations in any test site. Let's assume this number is 3, located at the map co-ordinates x1, x2, and x3. Only at these 3 locations we do know the weather values v1, v2, v3, respectively. Now we want to interpolate the data such that we get a value for all other locations at the test site.

The adopted approach is to find the value v4 at location x4 using the following formula:

$$v(x4) = w1(x4) * v1 + w2(x4) * v2 + w3(x4)*v3$$

where the weights w1, w2, w3 could, for example, be set as follows:

$$gn = 1/(a*|xn-x4| + b)$$

$$s = \Sigma(g1 + g2 +g3)$$

$$wn = gn/s;$$

'a' is positive and 'b' is small and positive. |xn-x4| is the euclidean distance between point xn and point x4. Euclidean distance is the straight line distance between two points. In a plane with p_1 at (x_1, y_1) and p_2 at (x_2, y_2), it is $\sqrt{((x_1 - x_2)^2 + (y_1 - y_2)^2)}$.

We used the same schema for all types of geophysical parameters (temperature, moisture, solar radiation, etc) as a proof of concept. However, in a real operational system, this may not be the most efficient schema for all the parameters. This topic by itself could be the subject of a big research project.

We continue with a discussion of the input/outputs for the plant models that were integrated into the server. This subject also touches on the fusion of data in order for the plant models to run properly. Note that Section 3.5 covers the plant growth models from the scientific point of view as the following discussion is more related to server integration of the plant models.

The plant model component integrates in-situ data with remote sensing and GIS data, and generates yield and biomass estimates. There may be multiple plant models, and each plant model includes a legacy model, which was originally written in FORTRAN and VB. The models to be used for ISIES are the VSMB and Maas models.

3.1.1.1 VSMB

In order to better interface with VSMB, a Java version of the model was developed, and all subsequent modifications to the original code were mirrored in the Java edition. Consequently, there is full control of all the configuration and parameters data used by the program. Additionally, the code was customized to better integrate the use of the ISIES in-situ and remote sensing data and improve software performance. Most noticeably, file I/O routines were bypassed when possible in order to reduce execution time.

Inputs

The inputs to the VSMB model include 3 different types of data:

- Daily weather data from the current simulation year – provided by the collected in-situ data
- Long-term historical climate data – archive weather data stored in files
- Soil and management data – includes all configuration parameters need to run the model, these data are provided by crop specialists and data analysts

Outputs

The outputs from the VSMB model consist of 3 different types of data:

- Daily output data – contains measured daily data for soil water contents and various water levels
- Miscellaneous output data – includes data regarding all measured soil water contents and data pertaining to each specified soil zone
- End-of-year biomass output data – contains all biomass calculations and predictions

Plant Model Algorithm for Estimating Yield

In order to make yield and biomass predictions, the plant model takes in 31 years of historical data, along with weather data for the current simulation year. In a single iteration, the current simulation data is combined with a single year's historical data to produce weather for each day of the year. The algorithm is then executed, and an estimate for the year-ending yield is made. 31 such iterations take place, as there are 31 years of historical data. The final estimate is obtained by taking the average of all 31 initial estimates.

Significant Changes to Original Fortran Code

- Daily weather data was provided by the calling method in the form of 2-dimensional arrays, instead of from a data file
- Historical data was read into memory once, and subsequent data requests were read from memory, instead of from a data file
- None of the outputs are written to files; instead, yield forecasts were returned to the calling method

3.1.1.2 Maas

Due to various constraints, a Java mirror of the Maas model could not be developed. Therefore, interfacing with this model required strict adherence to the input and output specifications of the original version.

Inputs

The Maas model demanded 4 different types of input data, each of which is stored in its own separate file:

- LAI observations – contains all remote sensing data
- Growth parameters – includes data that is specified by plant modellers and experts
- Daily weather data – contains all in-situ data that are used by this model
- Setup data – contains information specifying the source of all the above data and other configuration information

As can be seen in the above list, LAI observations come from remote sensing sources. However, the rest of the parameters are in-situ which requires the fusion of the multi-source data. After the in-situ values are processed through the spatialization module as described above, we can generate a set of data values for each location of the map for which we aim to generate a yield/biomass map.

Outputs

This model produces only 1 output file per location. Among the outputs are green LAI, living aboveground dry mass, and yield (living aboveground dry mass partitioned to grain) calculations and estimations.

3.1.2 Server Generated Results

Figure 3-3 and Figure 3-4 show two maps for the Lanier site as an example. The LAI map was generated from CHRIS remote sensing data. These data were then fused with in-situ data that were collected semi-automatically from the field sensors. The data fusion was part of the plant growth model algorithm that resulted in the yield values. The correlation between LAI and yield is clearly evident. A histogram of the yield data is presented in Figure 3-5.

Figure 3-3 Lanier LAI Map Generated from Remote Sensing Data. The brighter areas indicate higher LAI values.

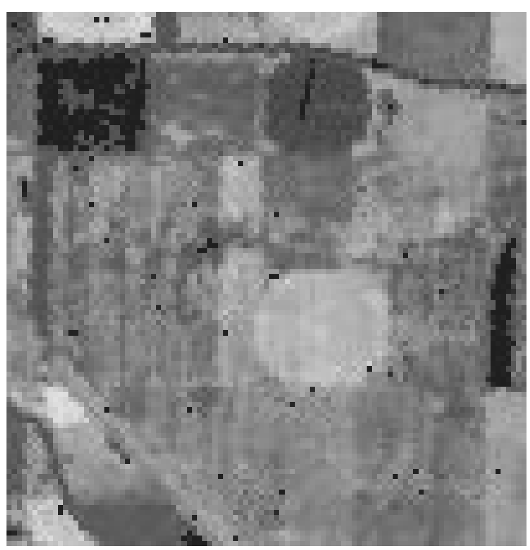


Figure 3-4 Sample Lanier Yield Map Generated by ISIES Server. The brighter areas indicate higher yield values.

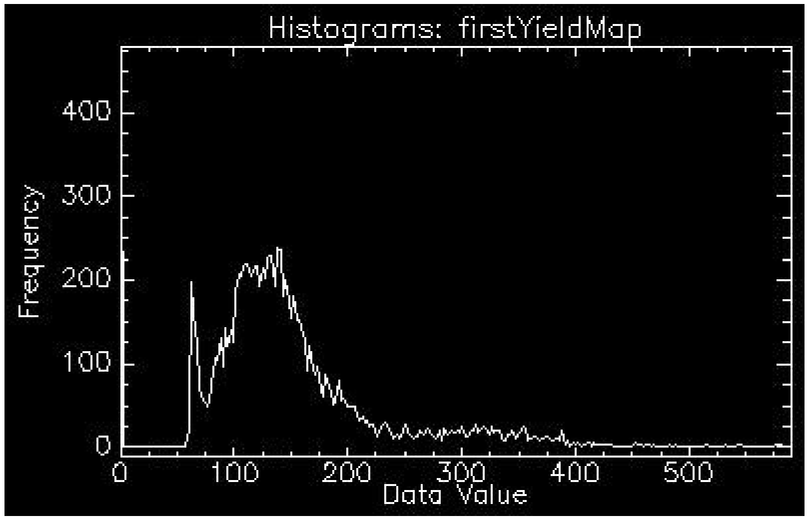


Figure 3-5 Histogram of the Lanier Yield Map. (Data values are in g/m²) Open GIS and Sensor Information Modeling

During the two year span of ISIES project, the most significant contribution to the project and research community in information modeling and openGIS category was the first international open geospatial sensing standard: OGC Sensor Observation Service (SOS). Steve Liang, a PhD student under ISIES project, joined OGC Sensor Web Working Group, and is one of the major contributors of SOS specification. York University has also implemented the world's first integrated sensor web geospatial viewer, and is well recognized by OpenGIS community.

The software developed by York University has a user-friendly fly-through feature with the capability of utilizing high-resolution imagery. Figure 3-6 is a snapshot of the user interface.

The viewer, through its interface, allows viewing of the in-situ data (also known as observations in OGC world) in tabular as well as graphical format. Figure 3-7 is an example of a graph for air temperature. It also presents the sensor meta-data using the SensorML standard in a human readable format. Various maps and imagery, including the yield, biomass, and LAI maps can be viewed on the viewer client as well.

Figure 3-6 Snapshot of the GeoTango Viewer

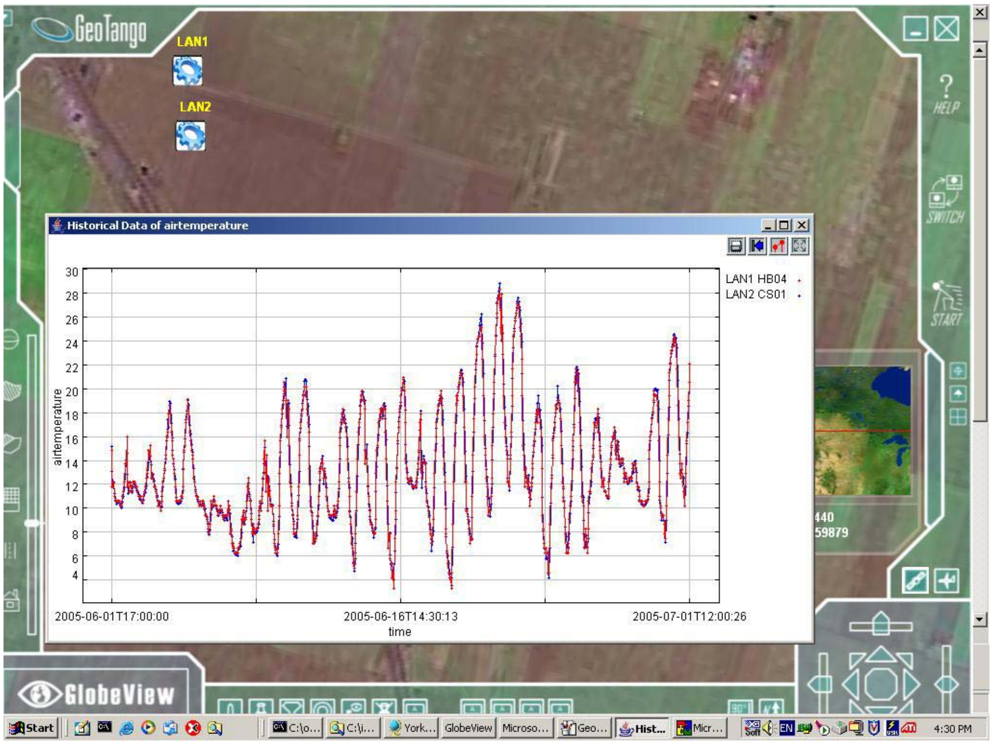


Figure 3-7 Data Visualization in GeoTango Viewer

3.2 Sensorweb and In-Situ Sensor Technology

Research in this area involved both hardware and software design and development. In the core of the Sensorweb, SmartCore, developed by CCRS, plays a key role. It functions as a hub to collect data from loggers and sensors. It also handles the wireless communication with the ISIES server. Figure 3-8 presents the original hardware design of the Sensorweb.

Sensors and loggers that were deployed as part of the Sensorweb collect soil moisture at different depths, precipitation, air and soil temperature, wind speed, air pressure and PAR.

Due to some technical difficulties that were encountered, the connection between HOBO loggers and the SmartCore did not materialise. Data downloads from the HOBO loggers were done manually. Also, a decision was made not to work on the spectrometer connectivity to SmartCore.

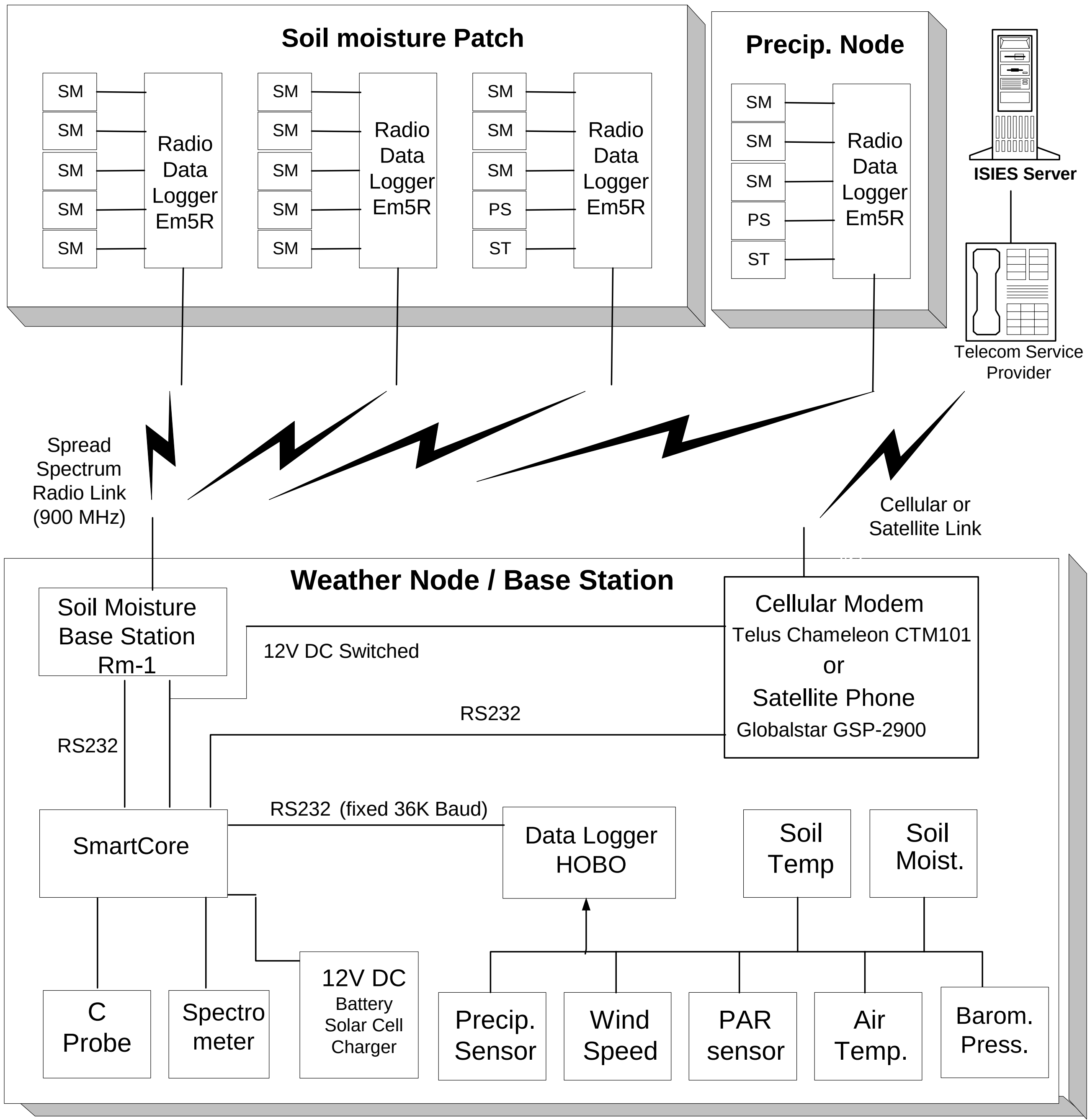


Figure 3-8 SensorWeb Hardware Design

The SmartCore software features are numerous. The following provides a high level view:

- Command line interface: SmartCore supports a wide set of commands that are accessible through a command line interface. A simple terminal session with either a direct RS-232 or modem connection is needed to access SmartCore. The complete set of commands is detailed in Section 4 of the SmartCore User Manual.

- Data logging: Various devices can connect to SmartCore. The latter maintains a list of devices in its internal memory along with the sampling period of each device. Note that devices are completely virtualized by SmartCore. SmartCore knows a device from its device driver. It is therefore easy to amalgamate various devices into a virtual device or even create a completely new virtual device.
- Power management: SmartCore includes functionality to monitor and preserve power in order to extend the life of deployed nodes.

Figure 3-9 Inside SmartCore

3.3 Data Acquisition

During ISIES project a number of data sets were collected from multiple sources. AAFC Lethbridge were instrumental in choosing the right test sites through negotiations with site administerators and owners, deploying the equipment, and also maintenance of the equipment. AAFC Lethbridge were also very active during ISIES project in collecting verification data (ground truth) which required several trips to the test sites and follow on lab work at their centre. Table 3-1 , Table 3-4, and Table 3-5 show the schedule for data collection which was carried out by AAFC Lethbridge team.

Table 3-1 Growth staging, LAI and Biomass Data Collection Schedule for the 2004 Season at the Lanier Spring Wheat Site (LAN-1)

Growth staging	Leaf area index	Biomass
May-17-04	May-17-04	May-10-04*
May-31-04	May-31-04	May-17-04*
Jun-08-04	Jun-08-04	Jun-03-04
Jun-14-04	Jun-14-04	Jun-22-04
Jun-23-04	Jun-23-04	Jul-13-04
Jun-29-04	Jun-29-04	Aug-03-04
Jul-08-04	Jul-8-04	Aug-16-04
Jul-13-04	Jul-13-04	
Jul-23-04	Jul-23-04	
Jul-28-04	Jul-28-04	
Aug-04-04	Aug-04-04	
Aug-10-04	Aug-10-04	
Aug-17-04	Aug-17-04	

* Destructive sampling

Table 3-2 Growth staging, LAI and Biomass Data Collection Schedule for the 2005 Season at the Lanier Spring DurumWheat Site (LAN-2)

Growth staging	Leaf area index	Biomass
May-09-05	May-09-05*	May-9-05
May-24-05	May-24-05	May 27-05
May-30-05	May-30-05	Jun-16-05
Jun-16-05	Jun-16-05	Jul-05-05
Jun-25-05	Jun-25-05	Aug-05-05
Jul-05-05	Jul-05-05	Aug-16-05
Jul-12-05	Jul-12-05	
Jul-19-05	Jul-19-05	
Jul-26-05	Jul-26-05	
Aug-04-05	Aug-04-05	

* Destructive sampling

Table 3-3 Biomass Data Collection Schedule for the 2005 Season at the Lanier Field Pea Site (LAN-1)

Biomass
Jul-07-05
Aug-08-05*

* Only partial harvest as producer had already combined ¾ of the field

At the Antelope Creek range site, plant samples were collected monthly throughout the growing season in three fields. In each field, ten sample points were established (Figure 3-10). The sample points were marked with a labeled survey flag, and the positions were recorded using a CDGPS connected to a Trimble GeoXM handheld unit. In each field, three sample points were located near the Hobo weather station, two sample points along the EM5R transect, and five other representative points were chosen. For the five representative sample points not at the HOBO or EM5R transect, duplicate samples were taken at each point. For the sample points located near the HOBO or along the EM5R transect only one sample was taken at each point. A total of 15 samples were collected per field on each harvest date.

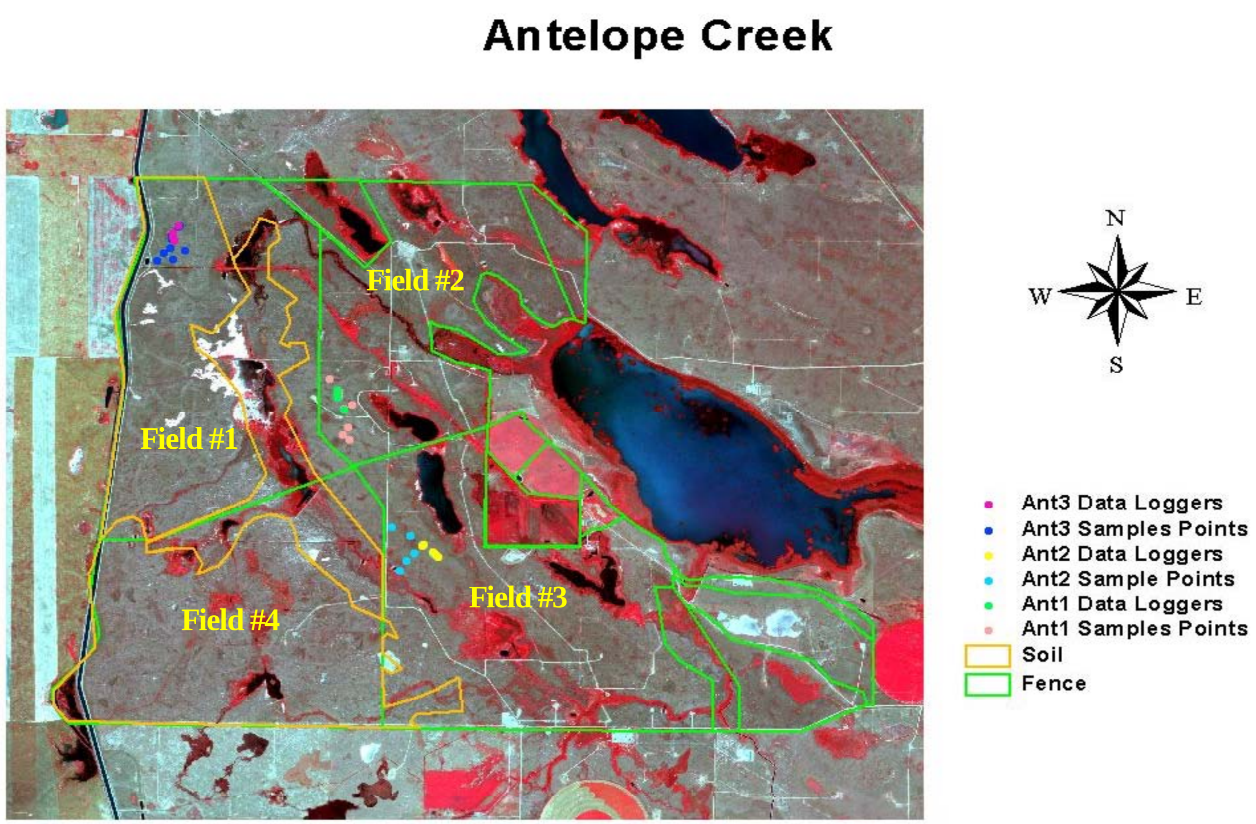


Figure 3-10 Location of LAI and Biomass Sampling Sites for the Antelope Creek Test Sit

The in-situ sensor network measures relevant agricultural variables using three types of sensor nodes: Weather nodes, precipitation nodes, and soil moisture patches. This three-part distinction of sensor node types arises from the different spatial sampling required for accurate weather, precipitation, and soil moisture measurements, respectively.

While weather and precipitation nodes take spatial samples at single points in space, the soil moisture patch design is intended to measure the average soil moisture over an area. This is required to reduce the impact of the high spatial variability of soil moisture, and the impact of speckle in Synthetic Aperture Radar (SAR) images used for soil moisture extraction. Soil moisture is also a special case because it needs to be sampled over a volume, rather than just over an area as the other quantities. This adds a soil depth dimension to the sampling requirements.

The following table presents different data sources and the corresponding parameters that were acquired and used in ISIES project.

Table 3-4 Data sources in ISIES

Sensorweb Data	Precipitation
	Air temperature
	Soil temperature
	Wind speed
	Wind direction
	Solar radiation
	Soil moisture
	Barometric pressure
	Relative Humidity
	Colour image (camera) [optional]
	Spectrum (spectrometer) [optional]
Verification Data	Biomass measurements
	Yield measurements
	LAI measurements
	Soil moisture measurements
Remote Sensing Data	LAI (from optical RS data)
	Vol. Soil Moisture (from SAR data)
Ancillary data (time dependent)	Weather Forecasts
	Yield Forecasts [optional]
	Seed time map
	Grazing time map
Ancillary data (time independent)	Soil Maps
	Elevation Maps [optional]
	Nutrient Maps [optional]
	Historical Yield Maps [optional]
	Historical Weather Data [optional]
	Weather Normals

3.4 Extraction of Leaf-Area-Index (LAI)

The leaf area index (LAI) is a key input to the ISIES crop model which in turn predicts the biomass and the yield of an agricultural area. Remote sensing was used to extract LAI in an economical manner. The extracted LAI estimates were compared to in-field measurements to verify the accuracy of the derivation. As mentioned before, the test sites and the data are described in ISIES Field Test Sites Description document and in the ISIES Data Acquisition Plan.A number of empirical relationships have been developed between LAI and vegetation indices. The majority of these indices are based upon the same wavelengths as the normalized difference vegetation index and constitute a "family" of indices. Inherent in these indices are the confounding factors of plant health or "greenness" and amount of plant material as well as the problem of signal saturation at higher LAI values. Recently, a novel algorithm for estimating LAI that decouples plant "greenness" from the amount of plant material was proposed. The algorithm was developed at an Ontario site using select crops and a Compact Airborne Spectrographic Imager (CASI) airborne dataset. The objective for the ISIES LAI work reported here is to evaluate the use of these algorithms with data from the Compact High Resolution Imaging Spectrometer (CHRIS) system aboard the PROBA satellite to estimate LAI of wheat and also rangeland vegetation. The success of integrating remote sensing information into crop models depends crucially upon the accurate estimate of LAI.

A total of 14 CHRIS images were acquired at the crop and rangeland sites in 2004. The images were of 36 m spatial resolution, 14 x 14 km area and 62 spectral bands. The optical data were atmospherically corrected using the CAM5S radiative transfer code to yield spectral reflectance images. The aerosol optical depths used in the corrections were estimated using climatological averages provided by the Networked On-line Mapping of Atmospheric Data (NOMAD) database maintained by the University of Sherbrooke. LAI images were created using the methodology of Haboudane et al. The method involves the Modified Triangular Vegetation Index (MTVI2).

The derived LAI images were georeferenced to WGS-84, Universal Transverse Mercator (UTM) 12N, pixel size 36 x 36 m, using a minimum of 20 GCPs. The georeferencing threshold was set at RMS < 0.20 and the images were warped using 1^{st} order polynomial, nearest neighbour resampling. The respective sampling points were overlain on the LAI derived images and the values extracted for a three by three window of pixels at each sample point.

The LAI exctraction task was performed by Jim Freemantle. The georefencing task was mostly carried out by AAFC Lethbridge.

The methodology required to process CHRIS imagery involves the following steps:

- Downloading of the CHRIS HDF files from the CHRIS data archive ftp://80.176.0.46/HDF_Image_Files/.

- Unzip the HDF files and determine the nadir image.
- Convert the nadir HDF image to PCIDSK format (use hdf2pci_chris written by author).
- Remove vertical stripes (columns), and line drop outs (see appendix).
- Atmospheric corrections and reflectance calculations (Freemantle, unpublished) using methodology to correct CASI images provided by York University.
- Quality assurance of the reflectance images.
- Process reflectance image to LAI map using methodology of Haboudane et al. 2004, provided by York University.

To perform these processing tasks some ancillary data are needed, namely:

Atmospheric conditions over the observed site: aerosol optical depth, visibility, etc. This ancillary data is required to derive reflectances. In this project the aerosol optical depth has been estimated using a handheld solar photometer provided by CCRS or visibility measurements obtained from meteorological data provided by Environment Canada. Aerosol optical depth was measured on April 21, 23 and June 11, 23 at Lanier site.

Crop Test Site

The LAI maps derived from the CHRIS imagery showed a progression similar to the ground-based data, as LAI increased to mid-July and then decreased. Although a reasonable relationship was found between the ground based and image derived LAI values ($r^2 = 0.70$), there was no data acquisition in 2005 between June 3 to June 28 when the crop was most actively growing and LAI increase form <1 to ≥ 3. There was a tendency for the measured LAI to exceed the CHRIS derived LAI values, particularly later in the season. This could be attributed to the LAI-2000 measuring total LAI and the remote sensing data capturing only green vegetation. The LAI predicted from the FASMOD crop model throughout the growing season showed a similar trend to the ground-based LAI, with peak growth in both instances being in mid-July. The LAI maps derived from the remote sensing imagery matched well with the crop modeled data.

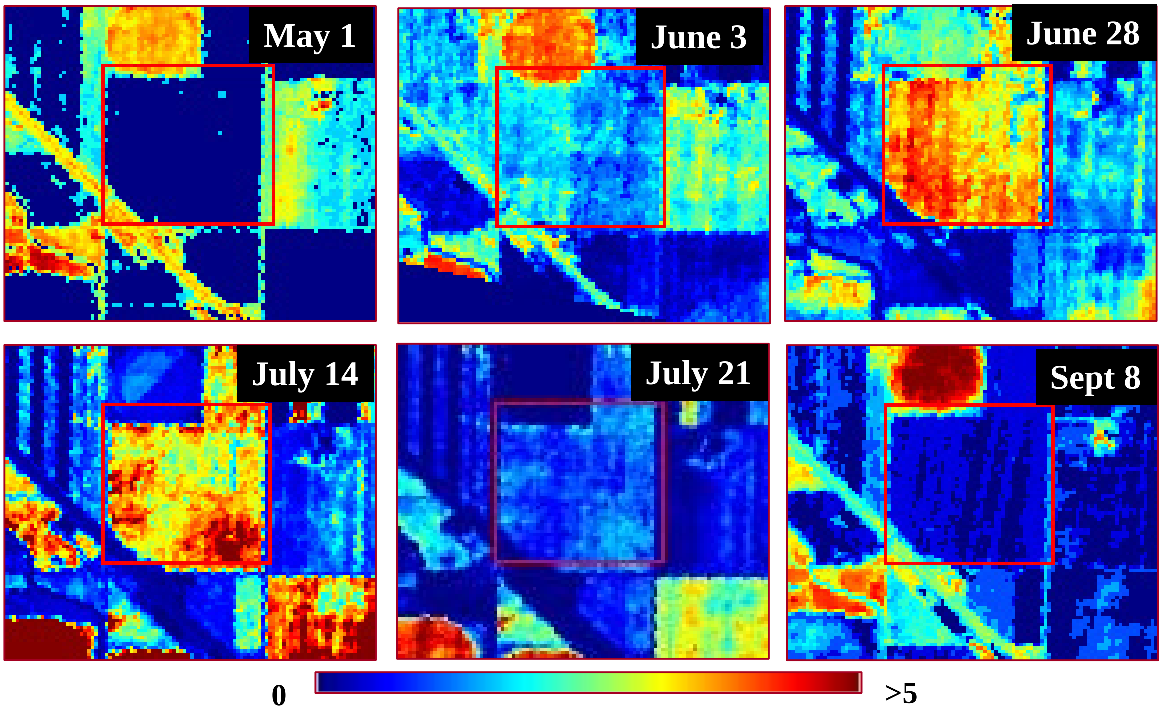


Figure 3-11 The Seasonal 2004 LAI Maps Derived from the CHRIS Imagery for the Annual Cropping Site

Range Land Test Site

The rangeland site is of low productivity and exhibited significant variation in the ground-based LAI measurements both within site and across fields. The ground-based and CHRIS LAI values remained fairly constant from June through September. In October, the ground based LAI tended to decrease but the CHRIS LAI did not. There was a good relationship between the CHRIS derived and ground-based LAI mid-season, but at the beginning and end of the season the LAI estimates from the CHIRS data exceeded those of the ground-based measurements. The actively growing green plant matter early and late in the season is often masked by the plant litter (senescent vegetation from past and current growing seasons), which may impact the derivation of LAI from remote sensing imagery and lead to the differences observed.

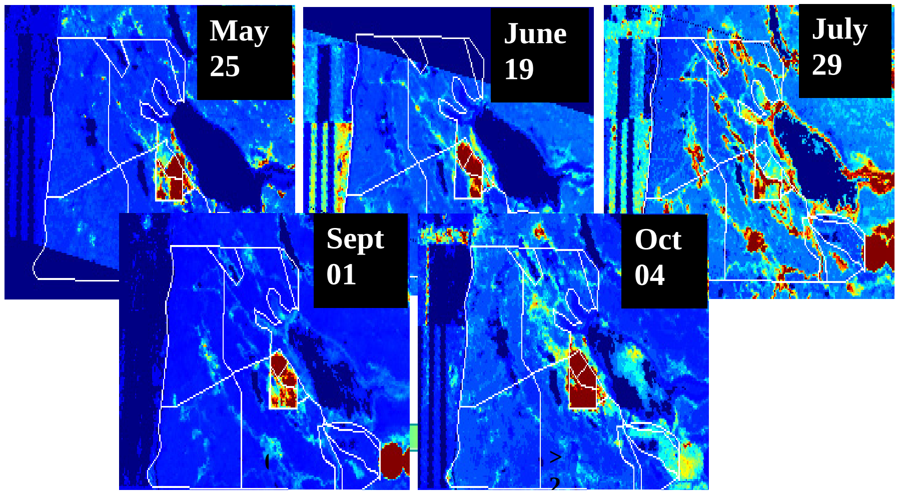


Figure 3-12 The 2004 Seasonal LAI Maps Derived from the CHRIS Imagery for the Rangeland Site

The results to date suggest that wheat LAI can be successfully estimated using CHRIS satellite imagery and that the LAI could potentially be fused with in situ weather data and crop modeling to spatially extrapolate crop growth. In rangeland systems of very low productivity, the estimation of productivity in terms of LAI was adequate mid-season, which is the time of highest productivity, but the presence of plant litter may limit the accurate determination of production.

A detailed account of the LAI work can be found in the 2005 and 2006 papers by Anne Smith et al.

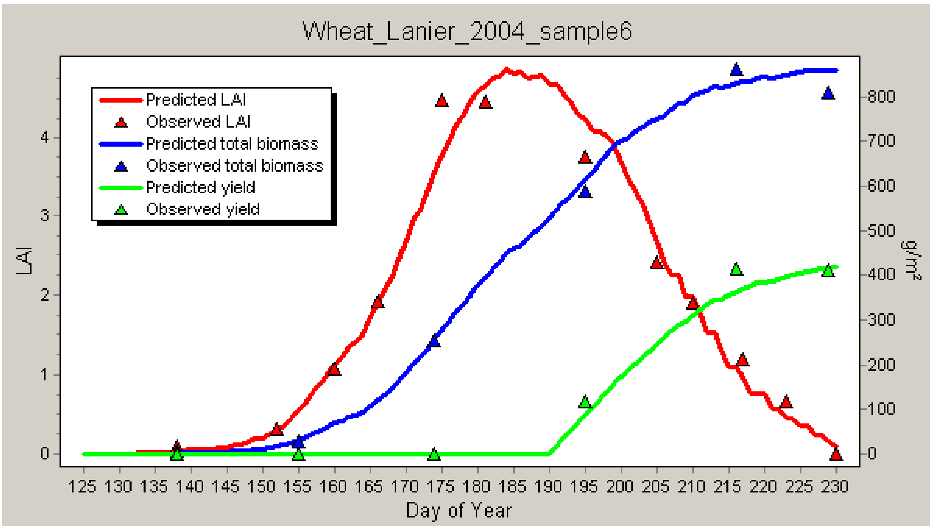
3.5 Plant Growth Models

Crop Model

The crop growth model Fasmod, developed by Maas in Texas, was translated from the Fortran programming language to Visual Basic to facilitate implementation and updates in MS Windows environment. Major improvements were obtained in the calibration process with the introduction of a correction function for the measured wheat LAI obtained with the optical instrument LAI-2000. In fact, the model is predicting green LAI and the field measurements obtained with the LAI-2000 are total LAI. The correction function transforms total LAI in green LAI based on wheat phenology. After these corrections, the processes of calibration and sensitivity analysis resulted in much improved predictions of green LAI, biomass, and yield for the Lanier wheat crop in 2004 and 2005. The results obtained in these analyses confirm the potential of this crop modeling approach. However, it also showed the importance of using total vs green leaf area for coupling remote sensing information with crop growth modeling predictions.

Wheat yield predictions in 2004 were excellent with an average absolute difference of 532 kg/ha between predicted and observed yields, which represents 13% of the average observed wheat yields. In 2005, wheat yield predictions were more variable with an average absolute difference of 1224 kg/ha which represents 19% of the average observed wheat yields. For this last year, more instability in predicting green LAI was obvious with the FasmodVB5. To improve this situation, algorithms to predict leaf area development, biomass production, and leaf senescence may have to be modified.

Figure 3-13 shows examples for the yield prediction and model fit for the 2004 and 2005 data.



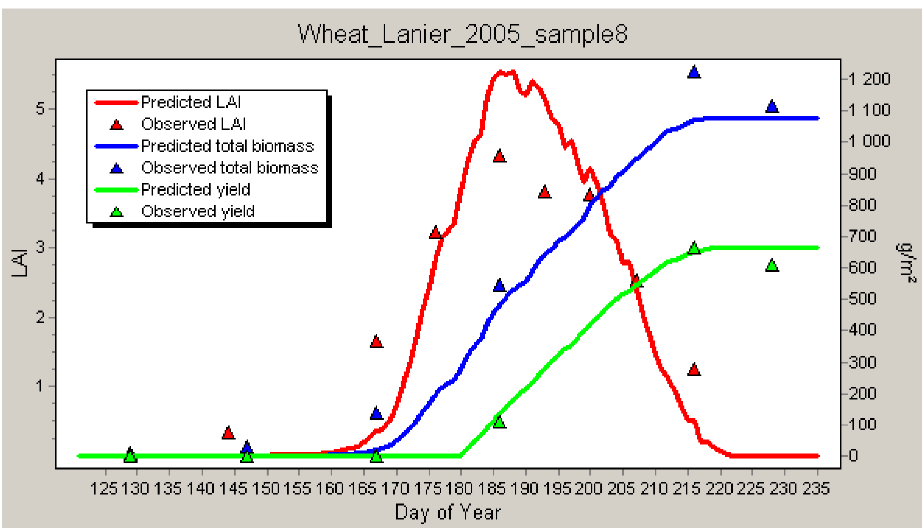


Figure 3-13 Examples of yield prediction and model fit for 2004 and 2005

Further improvements in the modules of the crop growth model and the coupling with remote sensing information will result in better biomass and yield predictions. In terms of crop growth modeling, the following improvements are proposed:

1. An improved predictive generic phenology module that will drive crop physiological events and will allow rapid adaptation to other crop species
2. A redesigned structure to predict both total and green LAI
3. Adaptations to improve biomass and yield predictions
4. A more effective optimization method (e.g. genetic algorithm) that can be used at any level in the crop growth model
5. A new module that will integrate the effect of soil moisture on crop phenology and growth

Some of these updates are already completed or in progress. The extensive data sets on wheat and native rangelands acquired during this project will provide essential information and details for future developments of these crop growth models.

Rangeland Model

Introduction

The southern Canadian prairies are predominantly semi-arid and as a result much more water is required by perennial native forage crops than is provided by the growing season precipitation alone. Several studies, ranging from simple regression analyses (Smoliak 1986) to detailed physical/biological modelling (Wight and Skiles 1987) have attempted to relate rangeland production to meteorological and soil moisture conditions. While the modelling approach is preferable in terms of transportability across large regions, the drawback is that this requires inputs that are often not readily available. We adapted a hybrid approach: the water balance was simulated with a physical based model that computed evapotranspiration, which in turn was used to estimate rangeland production with a local regression model.

Methodology

The Versatile Soil Moisture Budget (VSMB), developed by Baier et al. (1979), Baier and Robertson (1966) and modified by Akinremi et al. (1996) was used in this study. The VSMB essentially treats the soil profile as a series of buckets (layers) into which water, i.e. precipitation, flows until they are filled-up. Excess water is then treated as either surface runoff (from the uppermost layer) or as drainage into the underlying layer. Actual evapotranspiration (AET) is calculated in terms of potential evapotranspiration (PET), reduced according to the prevailing soil water conditions via a set of empirical soil and root coefficients.

Potential evapotranspiration was calculated from on site measurements of daily maximum and minimum air temperatures and solar radiation (Baier and Robertson

1965). The air temperatures were also used to separate the on site measured precipitation into rain and/or snowfall (Belanger et al. 2002). The crop coefficients reflect crop cover and root distribution patterns which change over time and with depth. For the 2004 and 2005 rangeland simulations we used the crop coefficients derived by De Jong and MacDonald (1975) for a native grassland site at Matador, Saskatchewan. According to the Soil Survey of the County of Newell, Alberta (Kjeargaard et al. 1983), there are three major soil types present at Antelope Creek Ranch, namely Cecil, Halliday and Hemaruka. They are Brown Solonetzic, medium textured soils. The soil physical characteristics required as input to the VSMB, were extracted from the Soil Layer File of the Canada Soil Information System (CanSIS) (Soil Landscapes of Canada Working Group 2005). The Z coefficients represent empirical drying curves, relating the ratio of AET/PET to the amount of water left in the soil.

Preliminary research showed that the model would significantly overestimate surface soil water contents, especially on days with little (< 5 mm) precipitation. To remedy this problem, we portioned the precipitation into crop interception and throughfall, as a function of the daily precipitation rate (Rijtema 1965; Couturier and Ripley 1973). It was assumed that intercepted precipitation would evaporate freely, i.e. at the potential rate.

The relationship between end-of-season biomass and water use, (i.e. accumulated actual evapotranspiration between the start and the end of the growing season) was obtained from native rangeland data collected during 1968 - 1971 at Matador, Saskatchewan (Coupland 1973). The water use efficiency was estimated to be 1.68 g^{C2} mm^{-1}, with the intercept at - 193.0 g^{C2}:

$$BM^{EoS} = -193.0 + 1.68 \; 3 \; AET \qquad (R^2 = 0.98) \qquad (1)$$

where BM^{EoS} (g^{C2}) is the end-of-season estimated biomass and 3 AET (mm) is the growing season accumulated actual evapotranspiration. The major limitation of this model is that it does not estimate biomass accumulation throughout the growing season.

The VSMB model, combined with Eqn. (1), was further modified to predict end-of-season biomass using currently available weather data (i.e. up to a given date within the simulation year) and historic long-term (1971 - 2000) weather data from nearby Brooks, Alberta. Sample simulations were carried out with April 8 to May 31, 2005 on site weather data, followed by one year historic weather data from June1 to the end of the growing season. The procedure was iterated thirty times to give potential biomass predictions as a function of current weather and historic weather. In a subroutine of the model, these predicted biomass yields were subjected to a probability analysis according to the procedure described by Spiegel (1961).

Results

In 2004, the model was run at each of the three sites (ANT1, ANT2 and ANT3, each with its own on site measured temperature and precipitation data). At site 3, we did not use the Cecil soil type, because it is not present at that site. The model was calibrated by adjusting the drying curve at each site and then comparing the estimated end-of-season biomass (mean of the three soil types) with measurements (Table 3-5). The measurements are the mean of five replicates, taken from the ungrazed part of each site. A satisfactory calibration agreement was obtained: at sites 1 and 2, the difference between estimated and measured means is less than 1%. At site 3, the model underestimates the biomass yield by 17%, but even here the model estimates are within one standard deviation of the measurements.

Table 3-5 Calibrated end-of-season biomass yield (g $^{-2}$) in 2004

Soil	Site		
	ANT1	ANT2	ANT3
Cecil	92.0	210.8	
Halliday	100.9	221.2	96.2
Hemaruka	100.8	220.2	98.3
Estimated mean	97.9	217.4	97.3
Measured mean*	98.4	217.0	116.7
Standard deviation	16.0	71.8	25.8

* Average of five ungrazed measurements (incl. green and litter material)

The data from 2005 were used to test the calibrated model, i.e. no further adjustments were made to the drying curves. The year 2005 was an anomalous weather year with growing season precipitation well above the normal (in nearby Brooks, normal 1971 - 2000 April to September precipitation is 242 mm, while in 2005 it was 468 mm) and consequently the measured end-of-season biomass yields were considerably higher, and also more variable, in 2005 as compared to 2004. Despite these abnormal weather conditions, the model performed remarkably well (Table 3-6). At site 1, the model overestimated the end-of-season biomass by 23%, at site 2 it underestimated the biomass yield by 7% and at site 3 the difference between estimated and measured biomass yield was only 1%. At all three sites were the model estimates within one standard deviation of the measured data.

Table 3-6 End-of-season Biomass Yield (g $^{-2}$) Simulated using the 2004 Soil Drying Curve Calibration Parameters

Soil	Site		
	ANT1	ANT2	ANT3
Cecil	212.7	270.2	
Halliday	216.7	277.3	166.5
Hemaruka	223.4	290.6	190.9
Estimated mean	217.6	279.3	178.7
Measured mean*	177.6	301.1	176.9
Standard deviation	68.9	68.3	77.8

* Average of five ungrazed measurements (incl. green and litter material)

An example of simulating actual evapotranspiration using current (April 8 to May 31, 2005) and long-term historic weather data for site 2 is given in Figure 3-14. Precipitation between the start of the growing season and May 31, 2005 was low (23 mm) and consequently the cumulative AET on May 31 was relatively low (48 mm). From June 1 on, we simulated 30 years with a wide range of weather conditions, leading to a wide range in cumulative AET values. The resulting end-of-season biomass predictions ranged from 52 g ^{C2} (using 2005 and 2000 weather data) to 436 g ^{C2}, using 1993 weather data. The probability analysis of the biomass yields is shown in Figure 3-15. On June 1, 2005, the model predicted an average (50% probability) end-of-season biomass yield of 235 g ^{C2}, considerably lower than the estimate (279 g ^{C2}) or measured (301 g ^{C2}) mean in Table 3-5. This might be contributed to the fact that most (95%) of the 2005 growing season precipitation (453 mm) fell after June 1, a fact not anticipated by the model. On the other hand, the model did predict at the 75% probability level (i.e. 1 year in 4) a biomass yield of 287 g ^{C2} or less.

Implementation

The rangeland models are based on the VSMB model that was adapted for ISIES requirements. The initial adaptation was called RANGE-4. The program models soil-moisture as well as biomass for natural rangeland. A nice fit between ground measurements and surface soil moisture content was achieved as shown in Figure 3-16.

Further research and development was carried out to improve the accuracy of the model and add an important feature to the algorithm to be able to predict the biomass at the end of the growing season. This improved version called RANGE-8 was tested by the plant modeller and also integrated into the ISIES server. Figure 3-17 shows the estimates for biomass at the Antelope Creek site generated by the VSMB model that was integrated into the server. The values are estimates of end of season biomass calculated at a particular day of the year.

Conclusion

Based on the limited number of local data collected, the model performed well. More data, from the Antelope Creek Ranch and from surrounding sites in southern Alberta and Saskatchewan are required to further test and validate the model. A serious limitation of the model is, that it does not simulate within season variations of biomass yield. While a more physical/biological based crop growth model might be able to simulate such variations, it will be hampered by additional model input requirements.

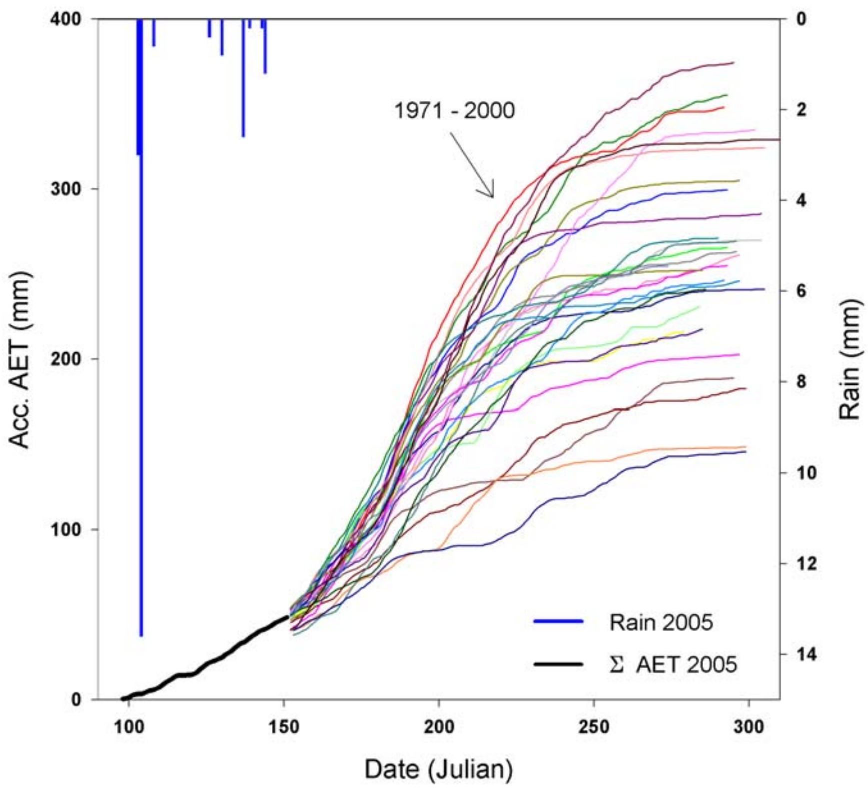


Figure 3-14 Simulation of Actual Evapotranspiration

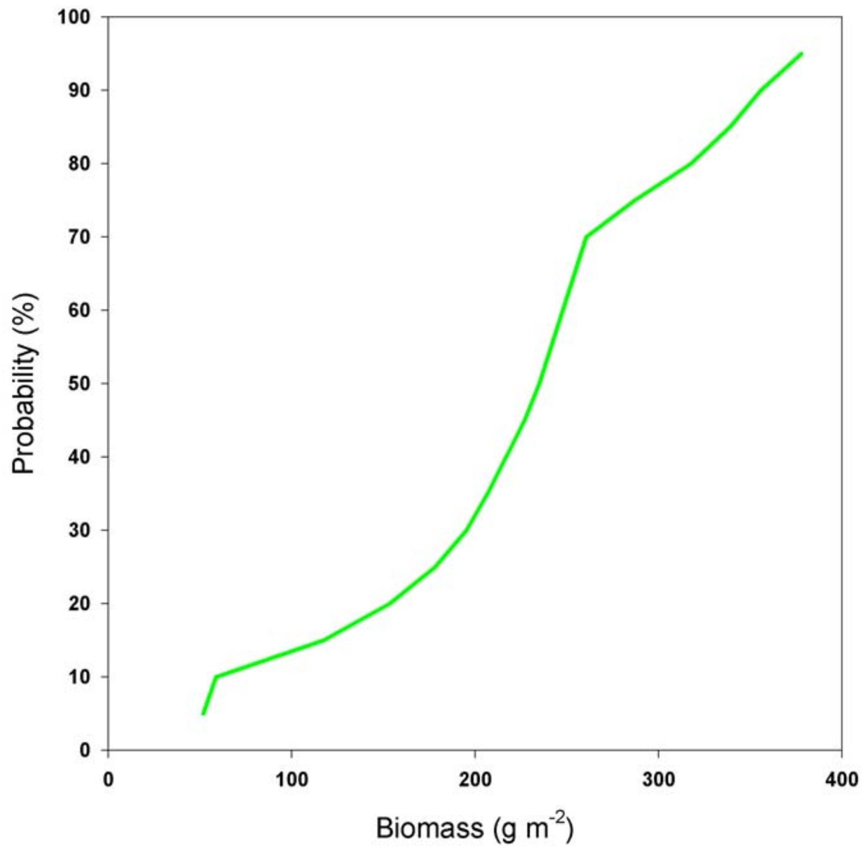


Figure 3-15 Probability Analysis of the Biomass Yields

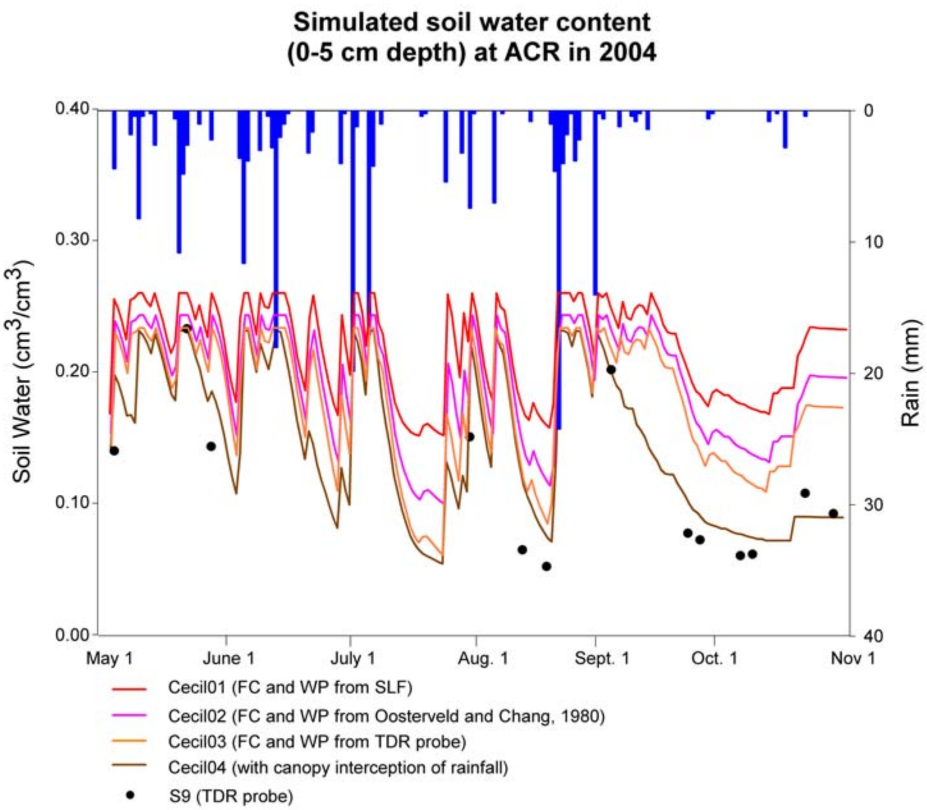


Figure 3-16 Fit of the RANGE-4 Soil Moisture Estimates to Measured Values

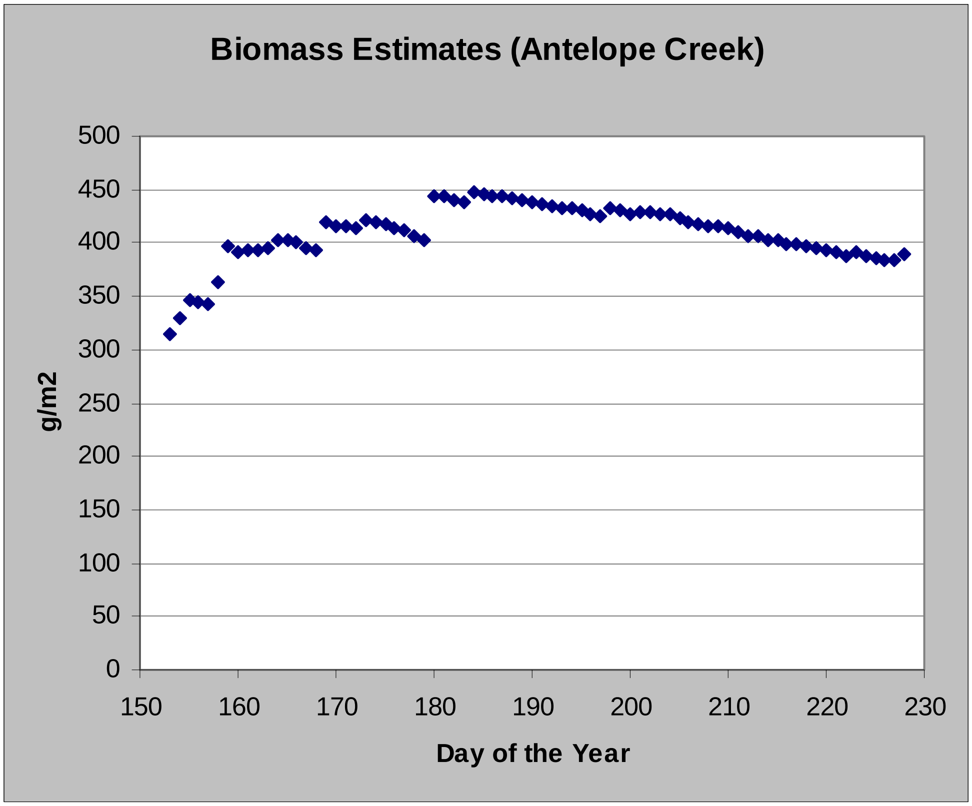


Figure 3-17 Biomass Estimates for Antelope Creek site using VSMB Model

References

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3.6 OGC Client/Server Tools

This section presents the work carried out mostly by York University in the area of geospatial visualization. As part of ISIES project, York University enhanced the design and development of their Sensor Observation Service (SOS) server. YorkU SOS is a Java servlet program for the implementation of OGC Sensor Observation Service Specification (SOS). It is designed for ISIES project to serve ISIES sensor observations. The design is general enough to accommodate databases other than ISIES database that stores sensor data. Its interfaces and architecture guarantee optimized interoperability due to the standards of OGC (Open Geospatial Consortium). YorkU SOS can be seen as an interoperable web interface that connects the proprietary sensor databases or sensorweb to the interoperable Spatial Data Infrastructure (SDI). YorkU SOS uses the following OGC standards:

1. OGC SensorObservation Service (SOS)
2. Observation and Measurements (O&M)
3. Geographical Markup Language (GML)
4. Sensor Markup Language (SensorML)
5. Unit of Measurement encoding (UoM), and
6. ISO 8601 Date and Time format.

The Following figure presents a tiered component diagram of YorkU SOS.

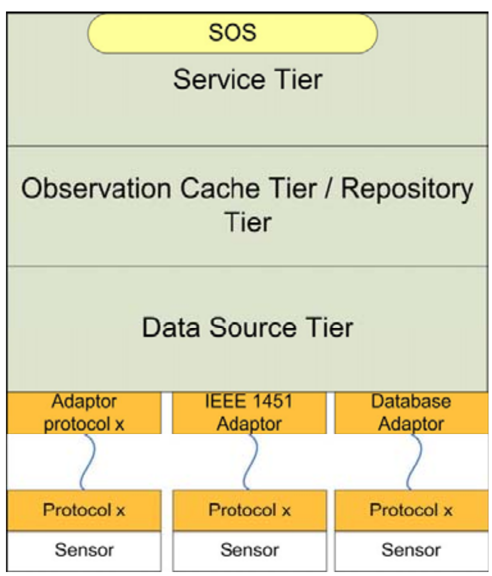

Figure 3-18 York University SOS server component diagram

The SOS server uses Apache/Tomcat web application server which is an open source tool.

isiesDataStoreConfig.xml is YorkU SOS's server configuration file. It configures data sources, database connections, and database permission control. Significant amount of work was put into the enhancement and refinement of the schema for this configuration file. Figure 3-19 presents the configuration schema.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
  <xs:element name="GeoSWIFTDataStore">
    <xs:complexType>
      <xs:sequence>
        <xs:element name="ContentType" maxOccurs="unbounded">
          <xs:complexType>
            <xs:sequence>
              <xs:element name="Connection">
                <xs:complexType>
                  <xs:attribute name="url" type="xs:string" use="required"/>
                  <xs:attribute name="driver" type="xs:string" use="required"/>
                  <xs:attribute name="username" type="xs:string" use="required"/>
                  <xs:attribute name="password" type="xs:string" use="required"/>
                </xs:complexType>
              </xs:element>
            </xs:sequence>
            <xs:attribute name="name" type="xs:string" use="required"/>
            <xs:attribute name="tableName" type="xs:string" use="required"/>
            <xs:attribute name="type" type="xs:string" use="required"/>
            <xs:attribute name="valueField" type="xs:string" use="required"/>
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            <xs:attribute name="tableName" type="xs:string" use="required"/>
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    </xs:complexType>
  </xs:element>
</xs:schema>
```

Figure 3-19 Schema for SOS configuration file

On the client side (sensorweb viewer), York University also carried out some enhancement work within the context of the ISIES project. YorkU integrated sensorweb viewer is a 2D/3D geospatial information visualization system that will support OGC WMS, WFS, WCS, SOS, SensorML, and O&M specifications. YorkU sensorweb viewer provides a unified global context within which users can access, visualize and analyze geospatial information from standard-based interoperable OGC web services. Starting from a 'zoomed out' view of the globe, users can select an area of interest anywhere on earth, navigate to it, search and discover sensors and query the measurement results.

The visualization engine of YorkU sensorweb viewer uses GeoTango's GSN 3D Globe SCOTS software that supports WMS, WCS and WFS web services. YorkU sensorweb viewer is a thick client application that is able to render the entire Globe in 3D using multiple resolution data from OGC web services. The viewer is developed using Java, C++, and DirectX, and it runs under Microsoft Windows environment. Figure 1 shows a web interface diagram of YorkU sensorweb viewer. It shows that all information that can be queried or displayed are from distributed interoperable web services. For example, vector maps are from several WFS, raster maps are from several WMS or WCS, and sensor information and observations are from several SOS.

The features that were added to the viewer as part of the ISIES project are charting of the in-situ data, tabular representation of the in-situ data, the ability to save and print the charts and tables and also representation of the SensorML tags in a more user friendly format. The original SensorML information is in pure XML which is hard to read for humans.

3.7 Soil Moisture Estimates from RS Imagery

Soil moisture is a parameter of much importance in agriculture and rangeland applications. It is of particular interest in southern Alberta, where much of the agricultural output is water limited. In the worst case, droughts can arise and can cause huge economic damage. Since soil-moisture is a spatially highly variable quantity, remote sensing is basically the only economical way of measuring soil-moisture over large tracks of land. Thus, an important part of ISIES was to investigate how remote sensing can be used to measure soil moisture. Keeping with the ISIES integrated earth sensing approach, however, other information, including in-situ data, was fused with the remote sensing data to significantly improve the soil moisture estimates.

To conduct the study, we identified nine test sites in and around Antelope Creek Ranch, which is our previously mentioned ISIES rangeland test site in southern Alberta, close to Brooks. All ISIES test sites were natural, non-irrigated rangeland sites, covered with short prairie grasses. For each of the nine sites, a transect was defined along which surface soil moisture was measured using manual probes. This was done near-simultaneously with the acquisition of dual-pol Envisat Advanced SAR (ASAR)

(HH&VV,C-band) images. In this manner, we collected a times-series of 11 dates of ground truth and simultaneous Synthetic Aperture Radar (SAR) images for all nine test sites in 2004. This work was conducted synergistically with a Canadian Space Agency (CSA) study called SOMPAS.

It is known that soil moisture estimates can be retrieved from SAR data without ground measurements using multi-pol or multi-angle data. ISIES combined both schemes. It also used any additionally available information to help with generating better and more robust soil moisture maps. It used a Bayesian estimator to optimally fuse all available information. This includes the multi-pol / multi-angle SAR data, the knowledge of the data noise, the radar backscatter model and its uncertainties, and a-priori knowledge about surface roughness, as well as soil-moisture models and in-situ soil moisture measurements. This fusion of all the available information sources provided the best possible estimates of soil moisture.

An important reason for this success is that ISIES focuses more on long term monitoring applications where entire time series are of interest rather than just isolated individual measurements at a particular date. In particular, a-priori knowledge on the slow variation of surface roughness provides a powerful constraint that increases estimation accuracy significantly. Additional gains can be obtained by making assumptions about the dry-out behavior of the soil. This can be obtained from in-situ measurements and soil models. Combining multi-pol and multi-angle SAR measurements further improved the results.

ISIES was able to achieve an estimation accuracy exceeding 4% volumetric soil moisture for natural range land in southern Alberta. This compares to an accuracy of only 8-9% using the best existing conventional inversion techniques.

The soil moisture inversion is calculated for each pixels in the image, yielding soil moisture maps similar to the one shown in Figure 3-20. These maps could then become an input to calculate biomass and drought indicators.

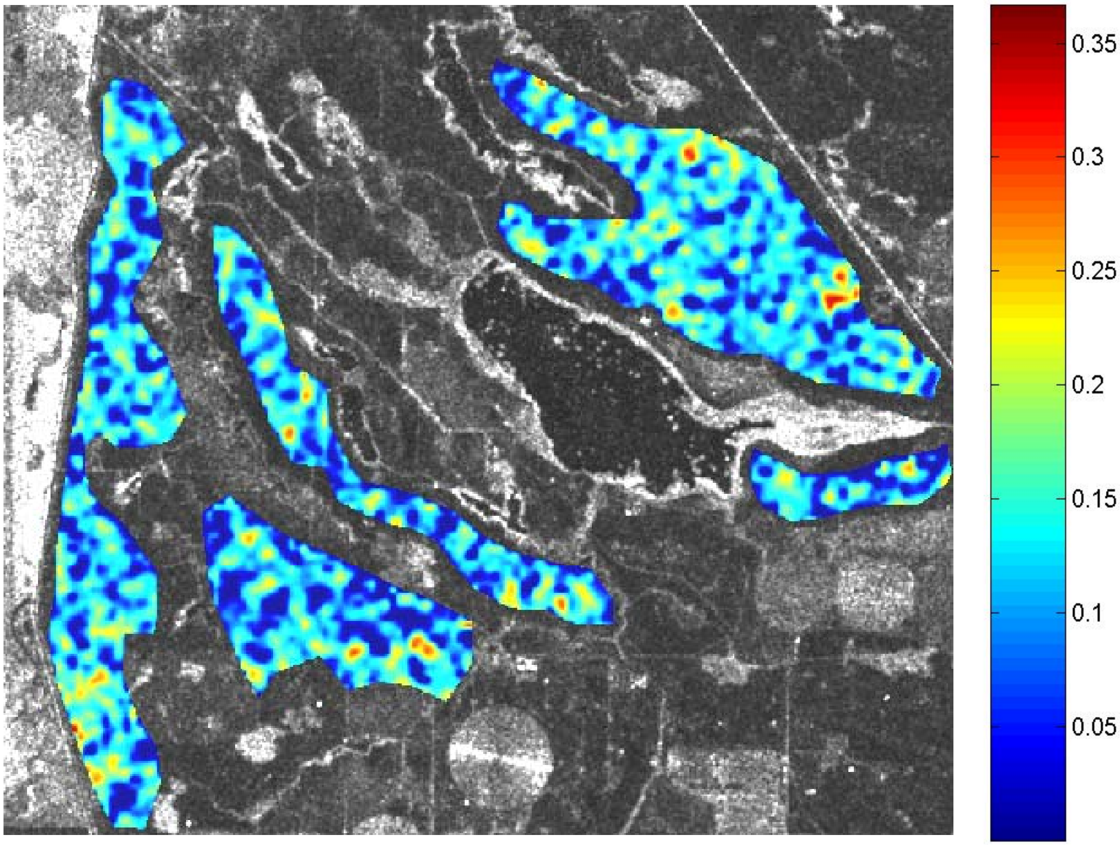

Figure 3-20 Soil moisture map [m^3/m^3] of natural range land on 18-Sep-2004 in Antelope Creek. The black-and-white areas are not natural non-irrigated range land.

3.8 Results Summary

The key strength of the ISIES technology is that it can be adapted to different applications other than agriculture modeling. The current project represents a small subset of the markets and applications that can be commercialized nationally and internationally.

Overall, ISIES project was a successful endeavour into new areas of science and technology. Having a big distributed team of experienced researchers was a challenging yet rewarding experience which has formed relationships that would last beyond this project. It added the intelligence aspect to the field of crop monitoring in two areas. First, the capability of the Sensorweb to monitor pre-programmed events and act accordingly when an event occurs (e.g. observed precipitation above a certain limit), second, the effective fusion of remote sensing, in-situ and GIS data to produce information products.

Highlights of the project are successful transfer of Sensorweb technology from CCRS to MDA, providing an intelligent decision-making framework to the subject matter experts, research in the area of geo-spatial information modelling and OGC standards and research in the area of plant growth model algorithms.

The ISIES project validated the vision that integrated earth sensing works. The fusion of in-situ data acquired by a sensorweb with Remote Sensing data and ancillary data such as GIS maps and weather normals, provides great benefits for crop yield and biomass prediction, and soil moisture assessment.

Like any other project, ISIES was not without shortcomings and unexpected problems. Smartcore could not be connected to HOBO loggers and the reason remained unclear for the team. The solution was to perform data downloads from HOBOs manually. Team members had different views as what exactly data fusion is. The idea was to combine in-situ data with remote sensing data and given that objective data fusion (combination) was realized. However, there are more scientific definitions of information fusion, which were not considered for ISIES project as it would have expanded the scope of the project beyond the available budget and resources. There are big projects focusing solely on information fusion techniques.

Co-ordination of a geographically dispersed team was time consuming.Staffing was another issue that slowed us down at times. MDA team got smaller as 2 of the management staff moved on to other tasks. Also AAFC Ottawa was not successful in hiring co-op student for the duration they wanted. CCRS contract with ACG Space Inc. terminated 9 months before the end of the project.

Given all the challenges of executing ISIES, this is our strong belief that the outcomes of this project were quite satisfactory and useful for further endeavours in the research as well as commercial domains.

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4 CONTINUATION OF RESEARCH

Earth science sensorwebs have the potential to become an integral part of scientific endeavours and government policy and decision support domains. The ISIES project has taken initial steps towards demonstrating approaches to the time-critical and cost-effective monitoring of complex and dynamic systems.

More needs to be done to provide a solid basis for issue-specific decision support, including:

- Generation of validated and consistent data and information products derived from the fusion of in-situ and remote sensing data and their assimilation into models
- Smaller, cheaper and smarter sensor systems for environmental monitoring
- Integration of time-critical in-situ sensorweb data and/or metadata into on-line geospatial data infrastructures

We believe the technology transfer from CCRS was successful. This puts MDA Research and Development (R&D) group in a desirable position to conduct further research concerning the above-mentioned issues.

Dr. Vincent Tao's research team and Mr. Steve Liang in particular will continue to be focused on OpenGIS standards and the development of OGC compliant viewer for various application domains. GeoTango company which is a spin off of York University has taken very successful steps towards commercialization of their software. A recent example is an interest expressed by software giant Microsoft in using GeoTango's technology in geospatial visualization.

AAFC team consists of a number of active researchers in the field of crop monitoring. All the senior members of AAFC team will continue their on-going research in fine-tuning their plant growth models by using the in-situ data collected during the course of this project. They are also planning on presenting their research results in future conferences and journals.

It is important to continue the research in identifying or even building cheaper and smaller sensor web hardware. By 2010, some futurists forecast that the unit price of a smart dust node will fall below $1.00. The term smart dust refers to tiny sensors, perhaps as small as one cubic millimeter. They would be scattered over an industrial space, for example, and would form an ad hoc wireless network to report back on conditions such as temperature or pressure in a production facility. Miniaturization and mass production, e.g. smart dust, are expected to lead to more economical deployments.

5 DELIVERABLES

The following table identifies all the deliverables of this project.

Table 5-1 Checklist of Project Deliverables

ID	Name	Date Delivered	Format	Contractual	Supplemental
1	Project Plan	Version 1/0, July 16, 2004 Version 2/0, Dec 14, 2004	Softcopy PDF and hardcopy document.	X	
2	Quarterly Progress Reports	Every two weeks following quarter end	Softcopy PDF and hardcopy document.	X	
3	SAD Document and Mid-Term Commercialization Plan	January 5, 2005	Softcopy PDF document.		X
4	Field Site Description	February 15, 2006	Softcopy PDF document		X
5	Data Acquisition Plan	February 15, 2006	Softcopy PDF document		X
6	Software Packages	March 15, 2006	Developed source code on CD ROM.		X
7	Commercialization Plan	February 1, 2006	Softcopy PDF and hardcopy document.	X	
8	Project Final Report	February 1, 2006	Softcopy PDF and hardcopy document.	X	

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6 CUMULATIVE STATISTICAL DATA AND IMPACTS

This section attempts to identify, quantify, and collect information related to the non-technical benefits and impacts of the Research Project.

Collaborations & Networking

This project created a unique opportunity to create collaboration among research groups within the government (CCRS, AAFC), industry (MDA), and university (York University).

OGC selected York University as a partner in defining international sensorweb standards. York University's experience with developing ISIES sensorweb server gave YorkU an advantage in this regard. Steve Liang contributed to three OGC sensorweb standards, namely OGC Sensor Observation Service, OGC Observation and Measurement, and OGC Transducer Markup Language.

York University's ISIES work also attracted CANARIE's attention. CANARIE is Canada's advanced Internet development organization. They envision sensorweb to be a major application for the next generation Internet. Web services for sensorweb will enable scientists to access and control sensorweb through GRID or Internet. YorkU's ISIES work fits nicely into CANARIE's web service architecture. Therefore, CANARIE invited Steve Liang and Dr. Vincent Tao to present YorkU's web services' research in sensorweb at two workshops. We expect further collaboration in sensorweb research between CANARIE and YorkU in the future.

Hiring & Training

ISIES project trained one PhD student and one research associate over project span of two years at York University. Steve Liang is the PhD student, and Jing Lu is the research associate. Steve was involved in the ISIES project since the beginning. Jing was involved in the last six months of ISIES project.

ISIES is a real world project that trained Steve Liang in both management and research skills. On management side, Steve managed YorkU's activities within the ISIES project. Steve composed YorkU's ISIES reports, and represented YorkU in ISIES monthly teleconferences, quarterly meetings. In February 2006, Steve organized the final workshop of ISIES. On the research side, Steve was the architect of ISIES OGC server and viewer. He designed the software architecture, and led YorkU and GeoTango team to implement ISIES OGC server and viewer. With the experiences learned from ISIES project, Steve contributed to the making of three international sensorweb standards.

Jing is a software developer and contributed to developing the communication module between ISIES sensorweb viewer and GeoTango's GlobeView™ geospatial viewer.

At AAFC, they had a number of students involved and trained through the project: 4 co-op students at Lethbridge (Don Iwanicka, David Rolfson, Ian Kehler and Nicole Daub), 2 co-op students at Saint-Jean-sur-Richelieu (Caroline Dubé and Olivier Gravell) and a compter specialist (Natalie Beaudry). As yet the co-ops have not found full time employment with AAFC. People currently on staff with AAFC also participated and learnt a number of skills during this project (Peter Eddy, Gary Larson and Danielle Choquette).

CCRS hired 1 scientific and 2 engineering staff from ACG Space Inc. One CCRS staff also worked part time on ISIES under the supervision of Dr. Teillet.

MDA also hired one coop student (Mike Cheung) who was actively involved in the development of the ISIES server. MDA extended Mike's co-op term to use the expertise he developed during his initial term of 8 months. During most of the ISIES life cycle, 3 engineering staff were involved.

Knowledge Dissemination & Intellectual Property

The AAFC researchers created IP in the Plant Growth Models domain, which they will own. MDA generated techniques related to soil moisture mapping, which it owns and CCRS generated IP with regards to the Smartcore device.

The ISIES team actively contributed to various scientific conferences and journals. The following is a list of all publications and contributions.

Conference attended:

- ISPRS XXth Congress, Istanbul, Turkey. July 12-23, 2004. Attendees: Vincent Tao and Steve Liang
- Geoinformatics 2005, Toronto, Canada. August 17-19, 2005. Attendees: Dr.Vincent Tao and Steve Liang

Workshop attended:

- 1st Geo Sensor Networks Workshop, Portland, ME, USA. October 9-11, 2003. Attendee: Dr.Vincent Tao
- Canarie C-4 Design Meeting, Ottawa, CANADA, Mar 24, 2004. Attendee: Steve Liang
- Canarie's advanced networks workshop 2004, Halifax, Nova Scotia, Canada. November 22-24th. Attendee: Dr.Vincent Tao.

International Standards:

- Open Geospatial Consortium Sensor Observation Service Specification. OGC Report 05-088r1 (Steve Liang is listed as one of the contributors.)
- Open Geospatial Consortium Observation and Measurement Specification. OGC Report 05-087 (Steve Liang is listed as one of the contributors.)
- Open Geospatial Consortium Transducer Markup Language Specification. OGC Report 05-085 (Steve Liang is listed as one of the contributors.)

Book chapter:

- Vincent Tao, Steve H.L. Liang, Arie Croitoru, Zia Haider, and Chris Wang (2004), GeoSWIFT: Open Geospatial Sensing Services for Sensor Web, *GeoSensor Networks*, eds. A. Stefanidis & S. Nittel, CRC Press, 2004, pp. 267-274 ISBN:2-88074-541-1

Journal publication:

- Liang, S.H.L., Coritoru, A., Tao, C.V. (2005), A Distributed Geo-Spatial Infrastructure for Smart Sensor Webs, *Journal of Computers and Geosciences* Vol.31(2) pp.221-231
- Liang, S.H.L., Tao, C.V., Croitoru, A. (2004), Sensor Web and GeoSWIFT - An Open Geospatial Sensing Service, *ISPRS XXth Congress*, Istanbul, TURKEY. July 12-23, 2004
- The following paper is being prepared for submission to a refereed scientific journal (likely the *Canadian Journal of Remote Sensing*):

- Teillet, P.M., A. Chichagov, G. Fedosejevs, R.P. Gauthier, G. Ainsley, M. Maloley, M. Guimond, C. Nadea, H. Wehn, A. Shankaie, J. Yang, M. Cheung, A. Smith, G. Bourgeois, R. de Jong, V. C. Tao, S. H.L. Liang, J. Freemantle, and M. Salopek, 2006, "An integrated Earth sensing sensorweb for improved crop and rangeland yield predictions", in preparation.

Conference publication:

- Liang, S.H.L., Tao, C.V. (2005), Design of an integrated OGC spatial sensor web client, *Geoinformatics 2005*, Toronto, CANADA. August 17-19, 2005

The following paper is being prepared for submission to IGARRS06/CRSS conference:

- Smith A.M.1, Bourgeois G.2, DeJong R.3, Nadeau C.4, Freemantle J.5, Teillet P.M.6, Chicagov A.6, Fedosejevs G.6 , Wehn H. 4, and Shankaie A. 4. REMOTE SENSING DERIVED LEAF AREA INDEX AND IT'S POTENTIAL APPLICATION IN CROP MODELING

The following papers that included aspects of ISIES appeared in conference proceedings:

- Teillet, P.M., A. Chichagov, G. Fedosejevs, R.P. Gauthier, G. Ainsley, M. Maloley, M. Guimond, C. Nadea, H. Wehn, A. Shankaie, M. Cheung, J. Yang, A. Smith, G. Bourgeois, R. de Jong, V. C. Tao, S. H.L. Liang, et J. Freemantle, 2005, « Prototype d'un webcapteur intelligent vers une observation intégrée de la terre », *Actes du Douzième Congrès de l'Association Québecoise de Télédétection*, Chicoutimi, Québec, 8 pages, in press.
- Teillet, P.M., G. Fedosejevs, R.P. Gauthier, J. Gibson, R.K. Hawkins, T.I. Lukowski, R.A. Neville, K. Staenz, Th. Toutin, R. Touzi, H.P. White, J. Wolfe, J. Brazile, Y.Carbonneau, R. Chénier, R. Filfil, K.P. Murnaghan, S. Nedelcu, N. Short, L. Sun, and B. Yue, 2005, "On Data Standardisation For Generating High Quality Earth Observation Products For Natural Resource Management", *Proceedings of the 98th Annual Conference of the Canadian Institute of Geomatics*, Ottawa, Ontario, on CD-ROM, 6 pages.
- Teillet, P.M., A. Chichagov, G. Fedosejevs, R.P. Gauthier, G. Ainsley, M. Maloley, M. Guimond, C. Nadea, H. Wehn, A. Shankaie, M. Cheung, J. Yang, A. Smith, G. Bourgeois, R. de Jong, V. C. Tao, S. H.L. Liang, et J. Freemantle, 2005, "Overview of an Intelligent Sensorweb for Integrated Earth Sensing Project", *Proceedings of the 26th Canadian Symposium on Remote Sensing*, Wolfville, Nova Scotia, on CD-ROM, 13 pages.
- Smith, A., C. Nadeau, J. Freemantle, H. When, P.M. Teillet, I. Kehler, N. Daub, G. Bourgeois, and R. de Jong, 2005, "Leaf Area Index from CHRIS Satellite Data

and Applications in Plant Yield Estimation", *Proceedings of the 26th Canadian Symposium on Remote Sensing*, Wolfville, Nova Scotia, on CD-ROM, 15 pages.

- Teillet, P.M., G. Fedosejevs, R.P. Gauthier, J. Gibson, R.K. Hawkins, T.I. Lukowski, R.A. Neville, K. Staenz, Th. Toutin, R. Touzi, H.P. White, J. Wolfe, J. Brazile, Y.Carbonneau, R. Chénier, R. Filfil, K.P. Murnaghan, S. Nedelcu, N. Short, L. Sun, and B. Yue, 2005, "Recent Advances in Data Calibration and Standardisation in Support of Sustainable Development of Natural Resources", *Proceedings of the 2005 IEEE Geoscience and Remote Sensing Symposium (IGARSS 2005)*, Seoul, Korea, 4 pages.

Presentations:

The following presentations that included aspects of ISIES were made at conferences:

- Teillet, P.M., A. Chichagov, G. Fedosejevs, R.P. Gauthier, G. Ainsley, M. Maloley, M. Guimond, C. Nadea, H. Wehn, A. Shankaie, M. Cheung, J. Yang, A. Smith, G. Bourgeois, R. de Jong, V. C. Tao, S. H.L. Liang, et J. Freemantle, 2005, « Prototype d'un webcapteur intelligent vers une observation intégrée de la terre », Douzième Congrès de l'Association Québecoise de Télédétection, Chicoutimi, Québec, le 10 mai (presenté par Teillet).
- Teillet, P.M., G. Fedosejevs, R.P. Gauthier, J. Gibson, R.K. Hawkins, T.I. Lukowski, R.A. Neville, K. Staenz, Th. Toutin, R. Touzi, H.P. White, J. Wolfe, J. Brazile, Y.Carbonneau, R. Chénier, R. Filfil, K.P. Murnaghan, S. Nedelcu, N. Short, L. Sun, and B. Yue, 2005, "On Data Standardisation For Generating High Quality Earth Observation Products For Natural Resource Management", 98th Annual Conference of the Canadian Institute of Geomatics, Ottawa, Ontario, 14 June (presented by Teillet).
- Teillet, P.M., A. Chichagov, G. Fedosejevs, R.P. Gauthier, G. Ainsley, M. Maloley, M. Guimond, C. Nadeau, H. Wehn, A. Shankaie, M. Cheung, J. Yang, A. Smith, G. Bourgeois, R. de Jong, V. C. Tao, S. H.L. Liang, et J. Freemantle, 2005, "Overview of an Intelligent Sensorweb for Integrated Earth Sensing Project", 26th Canadian Symposium on Remote Sensing, Wolfville, Nova Scotia, 14 June (presented by Fedosejevs).
- Smith, A., C. Nadeau, J. Freemantle, H. When, P.M. Teillet, I. Kehler, N. Daub, G. Bourgeois, and R. de Jong, 2005, "Leaf Area Index from CHRIS Satellite Data and Applications in Plant Yield Estimation", 26th Canadian Symposium on Remote Sensing, Wolfville, Nova Scotia, 15 June (presented by Smith).
- Teillet, P.M., G. Fedosejevs, R.P. Gauthier, J. Gibson, R.K. Hawkins, T.I. Lukowski, R.A. Neville, K. Staenz, Th. Toutin, R. Touzi, H.P. White, J. Wolfe, J. Brazile, Y.Carbonneau, R. Chénier, R. Filfil, K.P. Murnaghan, S. Nedelcu, N.

Short, L. Sun, and B. Yue, 2005, "Recent Advances in Data Calibration and Standardisation in Support of Sustainable Development of Natural Resources", 2005 IEEE Geoscience and Remote Sensing Symposium (IGARSS 2005), Seoul, Korea, July (presented by Lukowski).

Potential Commercial Benefits:

Throughout Canada, the US and internationally, farmers are integrating a wide range of technologies such as Global Positioning System (GPS), Geographic Information Systems (GIS), and remote sensing with wireless access and intelligent technologies to increase their knowledge of crop conditions and to mitigate risk.

The Intelligent Sensorweb for Integrated Earth Sensing (ISIES) represents a solution to overcoming spatial temporal sampling. Using ISIES technology in conjunction with intelligent vegetation modelling agents, it will be possible to integrate relevant information to predict yield and assess the impact of relevant environmental and meteorological conditions or events.

Future Exploitation or Commercialization:

In Canada, federal and provincial governments subsidize multiple peril policies, so the producer often pays only 50% of the premium. Therefore, it is in the interest of both the farmer and agricultural officials to have relevant information on soil moisture, climatic conditions, etc. in a form that supports decision making. In brief, ISIES can offer significant efficiency and cost benefits related to the processing of insurance claims due to lost production because of climatic conditions or pest infestation.

ISIES fits nicely into the operational concepts of crop insurance adjusters. In addition, legislation is stimulating investment in technology that improves agricultural practices. In the U.S., the Agriculture Risk Protection Act of 2000 designated $8.2B to be spent on crop insurance reform between 2000 and 2005. Of this amount, $175 million was specifically designated for product development and R&D to improve claim processing and farm insurance management.

The economic and legislative climate is an encouraging indicator of future market potential. It is expected that similar economic and legislative initiatives in Canada and elsewhere will present a significant opportunity for companies such as MDA to establish a presence in the Sensorweb market and lead to demand for customized services based on ISIES or ISIES like technologies.

Provide details of exploitation (how the project participants were using the results themselves) and commercialization (how the technology will create additional business opportunities).

Impacts

There is great interest by the agricultural sector to use remote sensing information to determine the state of crop production and to evaluate risks.

- This project will position Canada at the forefront of the development and exploitation of the emerging Sensorweb technology. It combines off-the-shelf communications technology with fit to purpose soil moisture sensors, which respond to changing environmental conditions.
- The output is the fusion of in-situ and remotely sensed image data to reveal trends in productivity and forecasting models. The project increases the utility and economic value of the acquired data such that information previously available only to field users can be introduced into mapping products, GIS data layers, reports, and presentations and support operational activities.
- Significant economic and social advancements are expected to come about by developing more systematic capabilities for assimilating remote sensing observations and in situ measurements for use in models, at relevant scales, and as an integral component of general business and production operations.

The knowledge made available by using Sensorweb data has the potential to empower farmers, managers and decision-makers to act on critical climate, sustainable development, natural resource, and environmental issues.

ISIES technology has applications in the areas of flood prediction and meteorological monitoring.

A five-node Sensorweb was deployed in the Roseau Basin of the Red River in Manitoba, Canada in the autumn of 2002 and remained there throughout the flood season in the spring of 2003. The Sensorweb operated autonomously where soil moisture measurements and standard meteorological parameters were accessed remotely via satellite from the Integrated Earth Sensing Workstation (IESW) at the Canada Centre for Remote Sensing in Ottawa, Canada. Independent soil moisture data were acquired from actual grab samples and field-portable sensors on Radarsat and Envisat satellite SAR acquisition days. The in-situ data were then used to calibrate and validate spatial soil moisture estimates from the remotely sensed SAR data for use in a hydrological model for flood forecasting. [1]

[1] Soil moisture Sensorweb for use in flood forecasting applications, P. M. Teillet, R. P. Gauthier, T. J. Pultz, A. Deschamps, G. Fedosejevs, G. Ainsley, A. Chichagov, Natural Resources Canada (Canada); K. Best, B. D. Toth, J. Toyra, A. Pietroniro, National Water Resources Institute (Canada).

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A DATABASE ACCESS CLASSES

A1 DBInputSession

This class subclasses the generic *DBSession* class (defined below). It is responsible for performing all forms of data input, whether it is an insert, update or delete function (all invalidate methods represent a specific kind of update). Each of the aforementioned methods is defined for each table in the In-Situ database, and similar methods inherit from a generic method of the same type (for example, all insert methods inherit from a generic, hidden "insert" method). A call to each method returns an integer reflecting the number of rows affected in the database (a single successful insertion, update or delete counts as having affected 1 row). Before any input method can be called, one must call the *openStatement()* method that is responsible for preparing the necessary initialization tasks. After all calls to these methods, a final *closeStatement()* method call should be made in order to perform the necessary clean-up tasks. Both methods return a Boolean value indicating either successful or unsuccessful task completion.

Method	Return Type
closeStatement()	boolean
deleteAirTemperature(AirTemperature anairtemperature)	Int
deleteBioMass(BioMass abiomass)	Int
deleteHumidity(Humidity ahumidity)	Int
deleteLAI(LAI anlai)	Int
deleteLogger(Logger alogger)	Int
deleteLoggerTelemetry(LoggerTelemetry aloggertelemetry)	Int
deletePlatform(Platform aplatform)	Int
deletePrecipitation(Precipitation aprecipitation)	Int

Method	Return Type
deletePressure(Pressure apressure)	Int
deleteRadiation(Radiation aradiation)	Int
deleteSensor(Sensor asensor)	Int
deleteSite(Site asite)	Int
deleteSoilMoisture(SoilMoisture asoilmoisture)	Int
deleteSoilMoistureManual(SoilMoistureManual asoilmoisturemanual)	int
deleteSoilTemperature(SoilTemperature asoiltemperature)	int
deleteWind(Wind awind)	int
insertAirTemperature(AirTemperature anairtemperature)	int
insertBioMass(BioMass abiomass)	int
insertHumidity(Humidity ahumidity)	int
insertLAI(LAI anlai)	int
insertLogger(Logger alogger)	int
insertLoggerTelemetry(LoggerTelemetry aloggertelemetry)	int
insertPlatform(Platform aplatform)	int
insertPrecipitation(Precipitation aprecipitation)	int
insertPressure(Pressure apressure)	int
insertRadiation(Radiation aradiation)	int
insertSensor(Sensor asensor)	int
insertSite(Site asite)	int
insertSoilMoisture(SoilMoisture asoilmoisture)	int
insertSoilMoistureManual(SoilMoistureManual asoilmoisturemanual)	int
insertSoilTemperature(SoilTemperature asoiltemperature)	int
insertWind(Wind awind)	int
invalidateAirTemperature(AirTemperature anairtemperature)	int
invalidateBioMass(BioMass abiomass)	int
invalidateHumidity(Humidity ahumidity)	int
invalidateLAI(LAI anlai)	int
invalidatePrecipitation(Precipitation aprecipitation)	int
invalidatePressure(Pressure apressure)	int
invalidateRadiation(Radiation aradiation)	Int
invalidateSoilMoisture(SoilMoisture asoilmoisture)	Int
invalidateSoilMoistureManual(SoilMoistureManual asoilmoisturemanual)	Int
invalidateSoilTemperature(SoilTemperature asoiltemperature)	Int
invalidateWind(Wind awind)	Int
openStatement()	boolean

Method	Return Type
updateAirTemperature(AirTemperature anairtemperature)	Int
updateBioMass(BioMass abiomass)	Int
updateHumidity(Humidity ahumidity)	Int
updateLAI(LAI anlai)	Int
updateLogger(Logger alogger)	Int
updateLoggerTelemetry(LoggerTelemetry aloggertelemetry)	Int
updatePlatform(Platform aplatform)	Int
updatePrecipitation(Precipitation aprecipitation)	Int
updatePressure(Pressure apressure)	Int
updateRadiation(Radiation aradiation)	Int
updateSensor(Sensor asensor)	Int
updateSite(Site asite)	Int
updateSoilMoisture(SoilMoisture asoilmoisture)	Int
updateSoilMoistureManual(SoilMoistureManual asoilmoisturemanual)	Int
updateSoilTemperature(SoilTemperature asoiltemperature)	Int
updateWind(Wind awind)	Int

A2 DBOutputSession

This class subclasses the generic *DBSession* class (to be defined later). It is responsible for performing all forms of data extraction through various queries. All query methods inherit from a generic, hidden query method. A call to each query method returns a variable-sized array of objects of the requested data type.

Method	Return Type
queryAirTemperatureBySensorId(int aSensorId)	ArrayList
queryAirTemperatureByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList
queryBioMassByLatLong(double lat_one, double long_one, double lat_two, double long_two)	ArrayList
queryBioMassBySiteId(int aSiteId)	ArrayList
queryBioMassByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList
queryHumidityBySensorId(int aSensorId)	ArrayList
queryHumidityByTimestamp(Timestamp earliestTimestamp, latestTimestamp)	ArrayList
queryLAIByLatLong(double lat_one, double long_one, double lat_two, double long_two)	ArrayList
queryLAIBySiteId(int aSiteId)	ArrayList

Method	Return Type
queryLAIByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList
queryLoggerByLatLong(double lat_one, double long_one, double lat_two, double long_two)	ArrayList
queryLoggerByLoggerType(String aLoggerType)	ArrayList
queryLoggerByPlatformId(int aPlatformId)	ArrayList
queryLoggerTelemetryByLoggerId(int aLoggerId)	ArrayList
queryLoggerTelemetryByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList
queryPlatformByLatLong(double lat_one, double long_one, double lat_two, double long_two)	ArrayList
queryPlatformByPlatformType(String aPlatformType)	ArrayList
queryPlatformBySiteId(int aSiteId)	ArrayList
queryPrecipitationBySensorId(int aSensorId)	ArrayList
queryPrecipitationByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList
queryPressureBySensorId(int aSensorId)	ArrayList
queryPressureByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList
queryRadiationBySensorId(int aSensorId)	ArrayList
queryRadiationByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList
querySensorByLatLong(double lat_one, double long_one, double lat_two, double long_two)	ArrayList
querySensorByLoggerId(int aLoggerId)	ArrayList
querySensorBySensorType(String aSensorType)	ArrayList
querySiteBySiteName(String aSiteName)	ArrayList
querySiteBySiteType(String aSiteType)	ArrayList
querySoilMoistureBySensorId(int aSensorId)	ArrayList
querySoilMoistureByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList
querySoilMoistureManualByLatLong(double lat_one, double long_one, double lat_two, double long_two)	ArrayList
querySoilMoistureManualBySiteId(int aSiteId)	ArrayList
querySoilMoistureManualByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList
querySoilTemperatureBySensorId(int aSensorId)	ArrayList
querySoilTemperatureByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList
queryWindBySensorId(int aSensorId)	ArrayList
queryWindByTimestamp(Timestamp earliestTimestamp, Timestamp latestTimestamp)	ArrayList

A3 DBSession

This class represents the generic class subclassed by the two aforementioned classes. It is responsible for performing all database connections and generic environment configurations for data input or extraction. Before any method in either subclass is called, one must call the *openConnection()* method to establish a connection with the database. After all calls to subclass methods are made, a final *closeConnection()* method call should be made in order to close the database connection and perform all other necessary clean-up tasks. Both methods return a Boolean value representing either successful or unsuccessful task completion.

Method	Return Type
CloseConnection()	boolean
OpenConnection()	boolean

A4 Object Classes

The following classes represent the different object classes available. Each object class has 2 constructors: a public constructor used to perform data input, and a hidden constructor used by *DBOutputSession* to extract data from the database. The difference lies in the number of arguments the constructor receives. 'Get' methods are implemented for all applicable fields for getting the specific value of a particular object field.

A4.1 AirTemperature

Constructor	
AirTemperature(int sensor_id, Timestamp timestamp, double raw_value, double calibrated_value)	
Method	**Return Type**
getCalibratedValue()	double
getId()	int
getRawValue()	double
getSensorId()	int
getTimestamp()	Timestamp
getValid()	boolean

A4.2 BioMass

Constructor	
BioMass(int site_id, double raw_value, double calibrated_value, Timestamp timestamp, double latitude, double longitude)	
Method	**Return Type**
getCalibratedValue()	double
getId()	int
getLatitude()	double
getLongitude()	double
getRawValue()	double
getSiteId()	int
getTimestamp()	Timestamp
getValid()	boolean

A4.3 Humidity

Constructor	
Humidity(int sensor_id, Timestamp timestamp, double raw_value, double calibrated_value)	
Method	**Return Type**
getCalibratedValue()	double
getId()	int
getRawValue()	double
getSensorId()	int
getTimestamp()	Timestamp
getValid()	boolean

A4.4 LAI

Constructor	
LAI(int site_id, double raw_value, double calibrated_value, Timestamp timestamp, double latitude, double longitude)	
Method	Return Type
getCalibratedValue()	double
getId()	int
getLatitude()	double
getLongitude()	double
getRawValue()	double
getSiteId()	int
getTimestamp()	Timestamp
getValid()	boolean

A4.5 Logger

Constructor	
Logger(int platform_id, String logger_type, double latitude, double longitude, String vendor)	
Method	**Return Type**
getLatitude()	double
getLoggerId()	int
getLoggerType()	String
getLongitude()	double
getPlatformId()	int
getVendor()	String

A4.6 LoggerTelemetry

Constructor	
LoggerTelemetry(int logger_id, double voltage, Timestamp timestamp)	
Method	**Return Type**
getId()	int
getLoggerId()	int
getTimestamp()	Timestamp
getVoltage()	double

A4.7 Platform

Constructor	
Platform(int site_id, String platform_type, double latitude, double longitude)	
Method	**Return Type**
getId()	int
getLatitude()	double
getLongitude()	double
getPlatformType()	String
getSiteId()	int

A4.8 Precipitation

Constructor	
Precipitation(int sensor_id, Timestamp timestamp, double raw_value, double calibrated_value)	
Method	**Return Type**
getCalibratedValue()	double
getId()	int
getRawValue()	double
getSensorId()	int
getTimestamp()	Timestamp
getValid()	boolean

A4.9 Pressure

Constructor	
Pressure(int sensor_id, Timestamp timestamp, double raw_value, double calibrated_value)	
Method	**Return Type**
getCalibratedValue()	double
getId()	int
getRawValue()	double
getSensorId()	int
getTimestamp()	Timestamp
getValid()	boolean

A4.10 Radiation

Constructor	
Radiation(int sensor_id, Timestamp timestamp, double raw_value, double calibrated_value)	
Method	**Return Type**
getCalibratedValue()	double
getId()	int
getRawValue()	double
getSensorId()	int
getTimestamp()	Timestamp
getValid()	boolean

A4.11 Sensor

Constructor	
Sensor(int logger_id, String sensor_type, double latitude, double longitude, double elevation, int height)	
Method	**Return Type**
getElevation()	double
getHeight()	int
getLatitude()	double
getLoggerId()	int
getLongitude()	double
getSensorId()	int
getSensorType()	String

A4.12 Site

Constructor	
Site(String site_name, String site_type)	
Method	**Return Type**
getId()	int
getSiteName()	String
getSiteType()	String

A4.13 SoilMoisture

Constructor	
SoilMoisture(int sensor_id, Timestamp timestamp, double raw_value, double calibrated_value)	
Method	**Return Type**
getCalibratedValue()	double
getId()	int
getRawValue()	double
getSensorId()	int
getTimestamp()	Timestamp
getValid()	boolean

A4.14 SoilMoistureManual

Constructor	
SoilMoistureManual(int site_id, double raw_value, double calibrated_value, Timestamp timestamp, double latitude, double longitude)	
Method	**Return Type**
getCalibratedValue()	double
getId()	int
getLatitude()	double
getLongitude()	double
getRawValue()	double
getSiteId()	int
getTimestamp()	Timestamp
getValid()	boolean

A4.15 SoilTemperature

Constructor	
SoilTemperature(int sensor_id, Timestamp timestamp, double raw_value, double calibrated_value)	
Method	**Return Type**
getCalibratedValue()	double
getId()	int
getRawValue()	double
getSensorId()	int
getTimestamp()	Timestamp
getValid()	boolean

A4.16 Wind

Constructor	
Wind(int sensor_id, double speed, int direction, Timestamp timestamp)	
Method	**Return Type**
getDirection()	int
getId()	int
getSensorId()	int
getSpeed()	double
getTimestamp()	Timestamp
getValid()	Boolean

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