Overview of an Intelligent Sensorweb for Integrated Earth Sensing Project

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ABSTRACT

This paper outlines research and development efforts towards an Intelligent Sensorweb for Integrated Earth Sensing (ISIES). After introducing the integrated Earth sensing concept and summarizing some prototype in-situ sensorweb demonstration projects, the paper goes on to describe the key aspects and early results of the ISIES project. The objective is to develop an intelligent sensorweb system that integrates in-situ sensors with remote sensing and auxiliary data to provide improved predictions of crop and rangeland yield. The ISIES topics include test sites, sensorweb, data collection, plant models, host server, viewer and server software, and products.

Keywords: Earth observation, remote sensing, in-situ sensing, sensorwebs.

1 INTRODUCTION

The advanced technologies of today make it possible to develop integrated approaches to Earth sensing that encompass both remote and in-situ sensing. This paper provides an overview of the integrated Earth sensing concept and describes some initial steps towards building an integrated Earth sensing capability. It highlights a research and development project on an Intelligent Sensorweb for Integrated Earth Sensing (ISIES), an on-line system that integrates an in-situ sensorweb, remote sensing imagery and Geographic Information System (GIS) data to provide superior estimates and predictions of biomass, crop yield and drought severity through open and standard interfaces.

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2 INTEGRATED EARTH SENSING

At the 2002 World Summit on Sustainable Development, the point was made that "… space-derived information generally needs to be combined with in-situ measurements and models to obtain a holistic picture of the Earth's environment. … There is no Sustainable Development without adequate information about the state of the Earth and its environment" (Josef Aschbacher, European Space Agency (ESA)). At the World Space Congress 2002, a Panel convened to explore "An Integrated Approach to Monitoring Planet Earth" noted that ground-based (in-situ) monitoring systems are inadequate by several orders of magnitude. The majority of space agencies represented on the Panel stated that an integrated approach to monitoring the Earth demands that the in-situ sensing be a funded part of the solution offered by space agencies. This is in keeping with the integrated approach proposed for the Global Earth Observation System of Systems (GEOSS) (http://www.cgeo-gcot.gc.ca/). Indeed, the confluence of advanced technologies for Earth-based sensorwebs [1], Earth science satellite webs [2,3], and the power of the Internet will soon provide a kind of global virtual presence [4] or integrated Earth sensing [5,6].

3 PROTOTYPE IN-SITU SENSORWEB DEMONSTRATIONS

As opposed to other distributed sensor networks, sensors in a sensorweb share information with each other and modify their behaviour based on collected data. In the in-situ context, a "sensorweb" consists of an autonomous wireless network of smart sensors [7] deployed to monitor and explore environments or, more succinctly, "a macro-instrument for coordinated sensing" [8]. A network of collaborating satellite platforms and sensors can be referred to as a satellite web or a sensorweb. The essential features in the satellite case are reconfigurable and interoperable satellite platforms and sensors that can decide amongst themselves when and how to acquire and downlink pertinent Earth imagery. With the capability of providing an ongoing virtual presence in remote locations, many sensorweb uses are being considered in the context of environmental monitoring. Sensorwebs could have as much impact on the uses of sensor technology as the Internet did on the uses of computer technology.

The ISIES project builds on earlier in-situ sensorweb demonstrations. In 2002, an initial prototype sensorweb was deployed and tested at Bratt's Lake Station in Saskatchewan [9]. The sensorweb operated autonomously and standard meteorological parameters and soil moisture measurements were accessed remotely via satellite from the Integrated Earth Sensing Workstation (IESW) at CCRS in Ottawa. A second demonstration involved a second prototype in-situ sensorweb in remote operation in support of flood forecasting [10]. A five-node sensorweb prototype was developed and deployed in the Roseau River Sub-Basin of the Red River Watershed in Manitoba, Canada in September 2002 and remained there throughout the spring flood season until the end of June 2003. The sensorweb operated autonomously, with soil moisture and soil temperature plus other meteorological and climate measurements accessed remotely from the IESW. Independent soil moisture data were acquired on the days of Radarsat and Envisat SAR acquisitions. The in-situ data were used to validate spatial soil moisture estimates from the remotely sensed SAR data for use in a hydrological model for flood forecasting.

4 THE ISIES PROJECT

A new project was initiated in late 2003 to build an Intelligent Sensorweb for Integrated Earth Sensing (ISIES). The ISIES objectives are to:

- Develop an intelligent sensorweb system that integrates in-situ sensors with remote sensing and auxiliary data to provide improved predictions of crop and rangeland yield.
- Develop data fusion techniques that will provide superior crop/rangeland yield prediction.
- Advance state-of-the-art plant growth models.
- Validate soil moisture measurements extracted from remotely sensed Synthetic Aperture Radar (SAR) data.
- Deliver a working ISIES system to an end user.
- Develop and increase knowledge on OpenGIS and Sensorweb technology.

The project has built a smart sensorweb prototype that autonomously acquires meteorological and soil moisture data and transmits them wirelessly to a central server at MDA. Sensorwebs have been deployed at two test sites in southern Alberta: a crop field (1.6 km by 1.6 km in area) near Lethbridge (one section of wheat in 2004) and a native rangeland site at the Antelope Creek Ranch (4 km by 4 km in area) near Brooks. The server incorporates OpenGIS compliant web services to provide ISIES data and products through open and standard formats. The server is being developed to enable users to accurately and automatically predict biomass and crop yield using state-of-the-art vegetation models that integrate in-situ, remote sensing and GIS data. Remote sensing data types used for soil moisture and leaf area index (LAI) estimates include imagery from the Radarsat-1 SAR, the Envisat Advanced SAR (ASAR), and the Compact High-Resolution Imaging Spectrometer on the Project for On-Board Autonomy small satellite (CHRIS-PROBA).

5 ISIES TEST SITES

Two contrasting test sites, annual cropping and rangeland, were selected in southern Alberta (Figure 1). The annual crop site located near Lethbridge (Latitude 49°43' N, Longitude 112°48' W, Elevation 937 m ASL) represents a dryland zero-till management system. Annual average precipitation (1971-2000) is 380 mm with 270 mm falling from April-August; average minimum and maximum temperature ranges from -13.1 °C and -1.8 °C in January to 10.8 °C and 25.8 °C in July, respectively. The soil of the area is a Dark Brown Chernozemic (Typic Haploborall) clay loam belonging to the Lethbridge series. The parent material is lacustrine. The landscape is flat. As the crop rotation is typically a cereal-broadleaf, two adjacent fields of approximately 250 hectares (~600 acres) are being used to obtain data for two years of wheat.

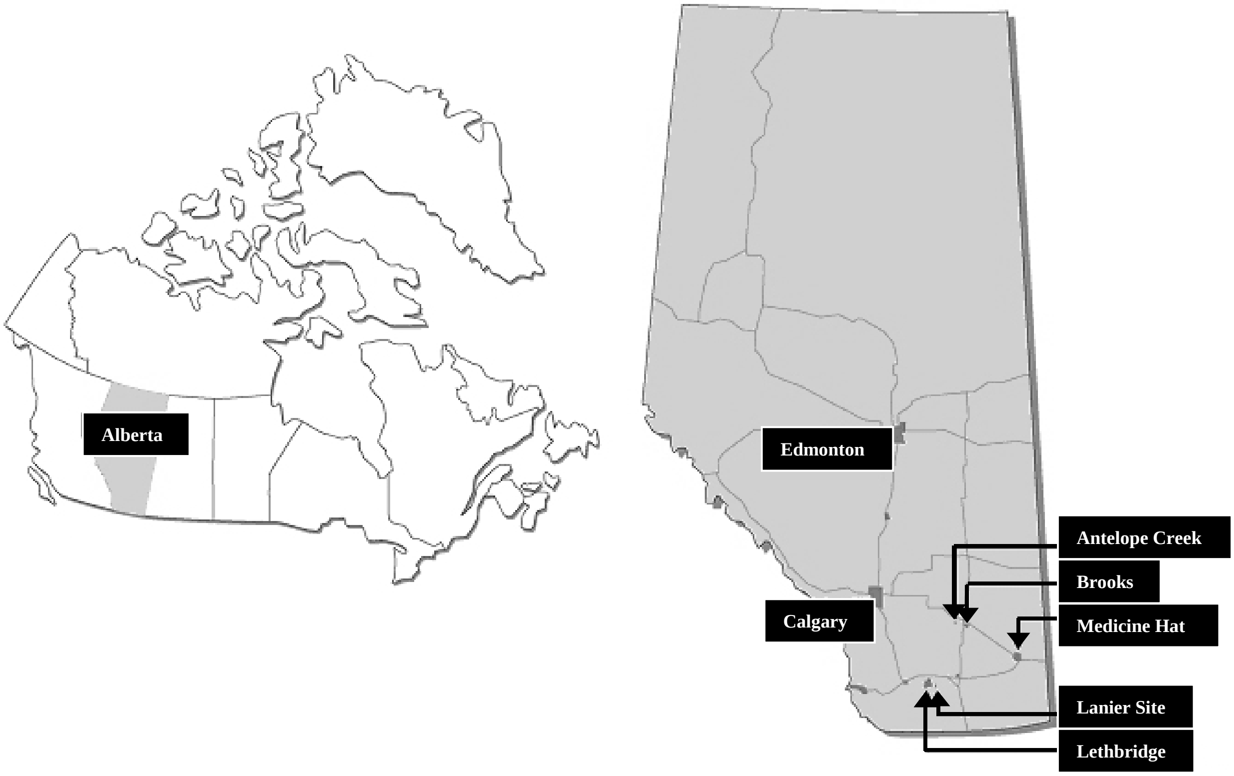

Figure 1. ISIES test site locations in Alberta.

The rangeland study site is the Antelope Creek Ranch (Latitude $50^o37'$ N, Longitude $112^o10'$ W, Elevation ~780 m ASL) approximately 15 km west of Brooks, Alberta. Antelope Creek Ranch, established in 1986, is a multi-disciplinary, multi-agency research site. The ranch serves as a demonstration to producers and resource managers in the mixed grass region that range improvement through specialized grazing systems benefits both livestock and wildlife. The ISIES project focuses on four native grassland fields (each ~450 ha in size), which are used in a deferred, rotational grazing pattern. The vegetation represents the *Stipa-Bouteloua-Agropyron* community of the mixed grass prairie ecoregion. Annual precipitation averages 340 mm with 240 mm falling from April-August; average temperature ranges from -12.5 ^oC in January to 18.4 ^oC in July. The soils of the area are Brown Solodized Solonetz (Acridic Natriboroll) and Solonetzic Brown clay loam to loam. The parent material is mainly glacial till. Approximately 30 % of the area has eroded pits or areas of patchy micro-relief due to differential soil erosion. The B-horizon is exposed in some eroded pits, and plant growth is usually very sparse.

6 ISIES SENSORWEB

The key component of each sensorweb is a SmartCore device designed by CCRS prior to the ISIES project and built during the ISIES project. The SmartCore is a compact device that essentially controls sensor data traffic autonomously and communicates with the central server wirelessly in two-way mode. Its main characteristics are: modules for data processing and RF or satellite communication; digital I/O, analog I/O, RS232, I2C, and SPI interfaces; and flexibility in terms of power requirements, sensor interfacing and programmability. The main functionalities of the current SmartCore prototype are listed in Table 1.

Figure 2 presents a schematic of the sensorweb layouts at the two test sites in 2004. The crop site has one so-called "soil moisture patch", whereas the larger Antelope Creek site has three. Each soil moisture patch is 100 m long and contains three sensor nodes that communicate via short-range RF to one SmartCore. Each sensor node encompasses an area of approximately 25 m by 25 m and includes multiple sensors (at least five). These nodes have a mix of mostly surface soil moisture probes (Decagon Echo probes) and a few Decagon soil temperature probes and Decagon precipitation gauges. In particular, the current equipment is such that five individual sensors are hard-wired to a radio transceiver, which communicates with the SmartCore nearest to that soil moisture patch. All soil moisture patches also have one or more sets of sensors deployed vertically in the ground to capture a depth profile of soil moisture. Additional weather and precipitation nodes round out the complement of data acquired at each test site, some routing through SmartCores, others not.

Each SmartCore can send sensor data autonomously and wirelessly to the central server at MDA and also can be prompted to send data by the central server. The SmartCore devices can be programmed locally or remotely to carry out aggregate calculations in the field and also to send special event alerts to the central server. It is in these respects that ISIES constitutes a smart sensorweb that can act as a macro-instrument capable of making decisions (simple ones for now in the proof-of-concept mode) based on distributed, hierarchical sensor nodes. The current SmartCore configuration uses digital cellular modems but the configuration can be changed easily to use satellite modems.

An additional "device" being tested with a SmartCore, but not yet deployed in Alberta, is a set of upward- and downward-looking microspectrometers in order to test the possibility of monitoring surface reflectance estimates. The SmartCore has been programmed to put together automatically the visible and near-infrared spectral radiance spectra (which come from separate microspectrometers) and compute the spectral reflectance spectrum from the two radiances (the upward-looking sensor looks through a diffuser). The use of webcams is also being considered.

7 ISIES DATA COLLECTION

Various in-situ data were acquired in 2004 at both of the test sites and data collection will continue in 2005. Some data were collected automatically by the sensorweb (weather and soil moisture) and some manually (leaf area index (LAI), biomass and soil moisture). Several types of remote sensing images were acquired over the two test sites. The main source of optical hyperspectral imagery is the CHRIS sensor, while the Envisat Advanced Synthetic Aperture Radar (ASAR) is used for the SAR imagery. Some Radarsat-1 SAR, QuickBird and Envisat Medium-Resolution Image Spectrometer (MERIS) images continue to be acquired. GIS data were collected for both of the test sites. Some of these data layers were updated and upgraded to improve their accuracy. Ancillary data were also collected, including, yield data from the crop test site. LAI maps were generated from cloud-free CHRIS imagery. The ASAR imagery was calibrated and geo-referenced. Preliminary soil moisture maps were produced based on the combination of satellite radar imagery and in-situ measurements (cf. Section 11).

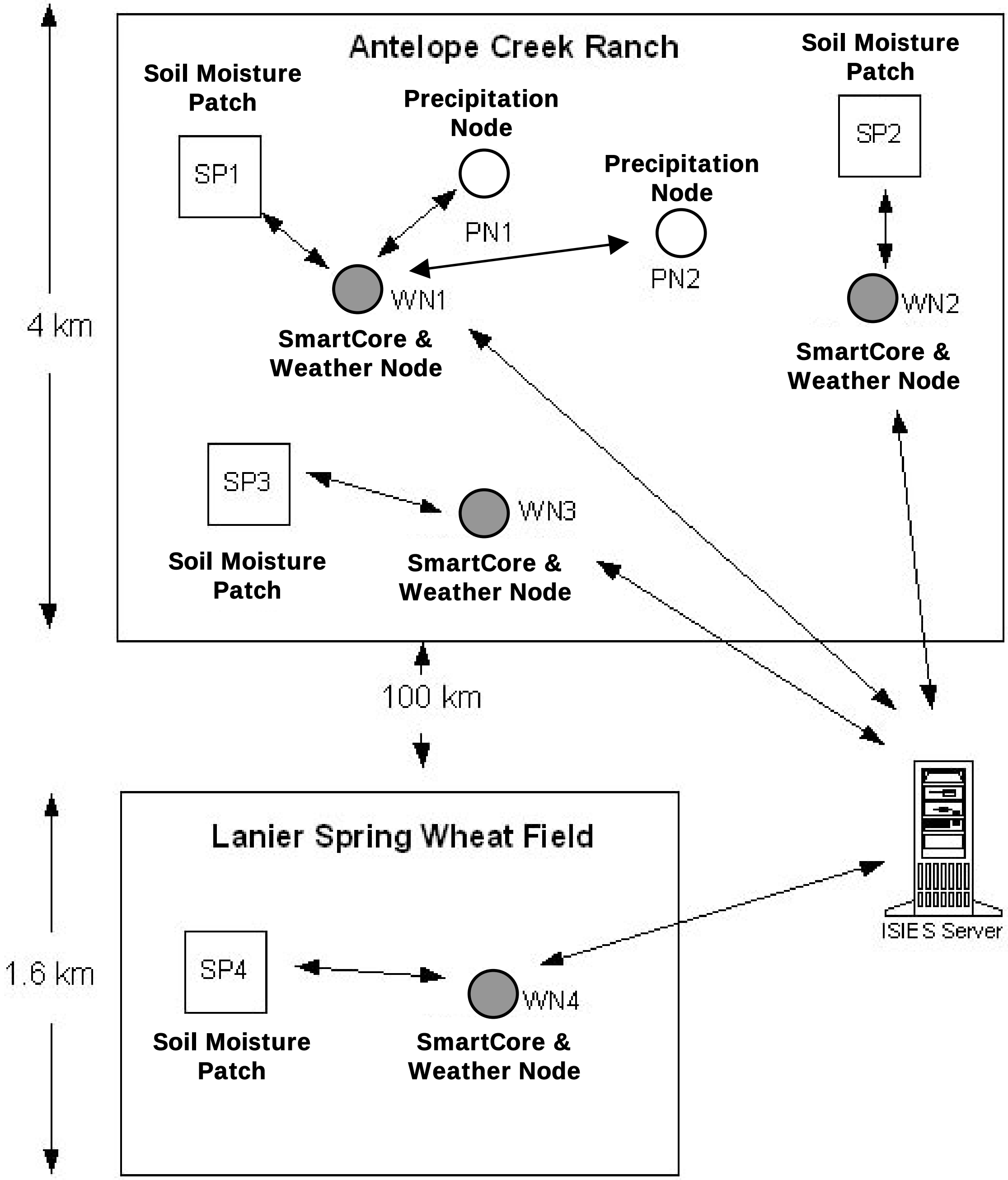

Figure 2. Conceptual sensor node distribution at each test site. The SmartCore devices are collocated with the weather nodes.

Table 1. List of SmartCore device functionalities.

SmartCore Functionalities
Communications
Support dial-in modem connection
Support direct serial connection
Support dial-out modem connection
Hardware
5 separate serial connections
5 (jumper) selectable 7- or 12-volt switches
15 analog to digital converters
Dual purpose reset button (to force clean boot)
Battery back-up real time clock
Event Monitoring
Remotely configurable events
Automatic event notification
Power Management
Remotely configurable awake/sleep period
Power monitoring and automatic shutdown
Remotely power activation and shutdown
Sampling
Remotely configurable device sampling period
New drivers for virtual devices
Remotely configurable device list
In-field sensor data aggregations (time and space)
Spectrometer reflectance calculation
On-demand device sample acquisition

CHRIS is a hyperspectral sensor developed by Sira electro-optics. The spectral range is 0.4 to 1.05 micrometers in up to 63 spectral bands with a spatial ground resolution of 34 m. The spectral sampling ranges from 2-3 nm in the blue to 12 nm at the shortwave infrared. The PROBA platform allows both along-track and across-track pointing of the CHRIS sensor. CHRIS data were chosen for several reasons. The spectral bands are close to those of the Compact Airborne Spectrographic Imager (CASI) used during the development and testing of the LAI algorithms. The pointing capabilities of PROBA enabled the collection of a greater number of images during the growing season than potentially available from most other sensor systems. CHRIS data are also delivered in a very timely manner after data acquisition.

Plant biophysical data were acquired at test sites during the course of the growing season to characterise growth and provide verification data for (a) the remote sensing derived LAI products and (b) the plant growth model for growth stage and above-ground biomass predictions.

In the wheat field, crop growth staging [11] and LAI measurements (using a LAI-2000 plant canopy analyzer) were made at 16 pre-determined sites every two weeks. Approximately every three weeks, to coincide with remote sensing image acquisition biomass measurements were also taken. Destructive LAI sampling was done on May 17. The leaf area of the plants harvested for the biomass estimates was measured using a LI-3100 Leaf Area Meter (LiCor, Lincoln, Nebraska). The values were converted to LAI using the following formula:

$$\mathrm{LAI} = \text{leaf area } (\mathrm{cm}^2)/\text{sample area } (\mathrm{cm}^2)\ . \qquad (1)$$

All other LAI measurements were made using an LAI-2000 Plant Canopy Analyzer (Li-Cor, Lincoln, Nebraska). The LAI-2000 was configured for analyzing row crops, one reading was taken above the canopy, followed by four readings below the canopy in a diagonal transect between two rows. This was done twice and the readings combined to give a one reading per sample site.

Two individual biomass samples were collected at each sampling site. Each individual sample consisted of all above-ground biomass in a 1m length of crop row. The biomass was harvested at ground level using hand shears and dried for four days at 60°C, and the dry weight was recorded. Once the crop had begun to head, the heads were separated from the stem prior to drying, and the stem and head dry weights of each biomass sample were recorded. As the row spacing for the wheat was 22.86 cm, the dry weight was converted to gm^{-2} by multiplying by 4.37.

At Antelope Creek, biomass samples were collected from 15 locations in each of the native grassland fields each month to coincide with remote sensing image acquisition. For each sample, a 0.5 m x 0.5 m quadrat was randomly selected within a 2 m radius of the sample point location. From the main 0.5 m x 0.5 m quadrat, a sub-quadrat of 0.2 m x 0.2 m was collected for separation into green (current year growth) and litter (past growth) material. All biomass was harvested using hand shears at ground level. All mosses and lichens were discarded. The ‘green’ and ‘litter’ sub-samples were each weighed and the leaf area in each fraction determined by running the plant tissue through a LI-3100 Leaf Area Meter. The LAI was calculated for the green as opposed to litter vegetation using the following equation:

$$\text{LAI} = \text{green leaf or litter area } (\text{cm}^2)/\text{sample area } (\text{cm}^2) \ . \qquad (2)$$

The remainder of the plant matter from the 0.5 m x 0.5 m quadrat was weighed and the amount of green and litter estimated using the fractions derived from the sub-sample from Antelope Creek.

8 ISIES PLANT MODELS

The importance of soil water in agriculture has long been recognized. Plant growth and crop yields are perhaps more closely related to soil water than any other single meteorological element, including rainfall. Consequently, estimating soil water status is an important component of crop yield modelling, especially in the semi-arid regions of the Canadian Prairies [12]. Crop growth models are useful for predicting variables like phenology (i.e., developmental stages), foliage characteristics (e.g., leaf area index), total biomass and yield. Input parameters are related to daily weather conditions (e.g., air and soil temperatures, precipitation, and solar radiation), soil characteristics (e.g., texture and soil available water-holding capacity), crop management (e.g., seeding and harvesting dates), and crop species characteristics. Crop growth models are well suited to the simulation of the temporal variability of a cropping system, where the variability is associated with climate and crop management.

On the other hand, the spatial variability observed at the field level is more complex to describe mathematically because many factors need to be taken into account, such as soil type, drainage, pH, nutrients, compaction, diseases, etc. We believe that remote sensing images offer an excellent potential to characterize this spatial variability. However, the frequency of image acquisition and the analysis of these images are limiting factors for adequate crop growth predictions. In order to characterize these spatial and temporal variabilities, the remote sensing and crop modelling approach proposed by Maas [13-18], as rendered in the FASMOD Fortran code, was selected for this project. The crop growth module in this code is relatively simple and offers excellent possibilities for adaptation to different crops. It was initially developed for cereals, like sorghum, corn, and wheat. An optimization technique is used for within-season calibration of leaf area index prediction with the field crop observations.

An updated version of the Maas-based model, FASMODVB written in Visual Basic, has been used to model spring wheat. Preliminary results show major limitations in the prediction of crop phenology and in the within-season estimation of initial parameters by mathematical optimization. Furthermore, the phenology module is specific to cereal crops and it needs to be redesigned for other types of crop (e.g., soybean, canola, beans, etc.). Consequently, a major update of the Mass software is required to improve phenology and biomass predictions for many different crops. The mathematical optimization module will also be updated to provide more accurate within-season estimations of initial parameters. These modifications are underway and this new version will be tested with wheat and rangeland data collected in Alberta in 2004 and 2005.

The Versatile Soil Moisture Budget (VSMB) model, as developed by Baier et al. [19], calculates the soil water balance within the rooting depth of the crop from precipitation, evapotranspiration and deep drainage data [20]. Water is withdrawn simultaneously, but at different rates, from different zones (depths) in the soil profile, depending on the rate of potential evapotranspiration, the stage of crop development, the water release characteristic of the soil and the available water content of the soil.

Several workers have determined the biomass yield and water use of forage crops (including rangeland) under a wide range of climatic, soil and management conditions in the Prairie region. By pooling the data and regressing yield versus water use, the average water use efficiency was calculated to be 112.8 kg ha cm^{-1}, with a minimum water requirement of 8.4 cm [21]. This simple regression model is currently being used to estimate aboveground dry matter production of rangeland from actual evapotranspiration data as calculated in the VSMB model. Water stored in the biomass is not included in this calculation. In order to predict year-end biomass production and its temporal variability during the early days of the growing season, long-term historical weather data from the nearby Brooks climatological station will be used.

9 ISIES PRODUCTS

At this time, ISIES has a comprehensive dataset of in-situ data (weather, soil, biomass and more), remote sensing data (optical and SAR), Geographic Information System (GIS) data and ancillary data, such as actual crop yield, pertaining to the 2004 field season.

The nadir view CHRIS image layer was extracted and atmospherically corrected using the CAM5S radiative transfer code [22] with averages provided by the Networked On-line Mapping of Atmospheric Data (NOMAD) database maintained by the University of Sherbrooke [23]. LAI was retrieved using the Modified Triangular Vegetation Index (MTVI2) [24]:

$$MTVI2 = \frac{1.5*(1.2*(R_{800} - R_{550}) - 2.5*(R_{670} - R_{550}))}{\sqrt{(2*R_{800} + 1)^2 - (6*R_{800} - 5*\sqrt{R_{670}}) - 0.5}} \quad . \tag{3}$$

$$LAI\ MTVI2 = 0.2227*\exp(3.6566*MTVI2) \quad . \tag{4}$$

The coefficients in equation (4) were derived from simulated data and then validated using real imagery of corn, wheat and soybean [24].

During the 2004 season, 11 multi-angle, dual-polarization (HH and VV) Envisat ASAR images were collected over Antelope Creek Ranch. Similar data collection and analysis are planned for the 2005 season for additional validation of the results. The 2004 data were calibrated and co-registered, and then used as input to a Bayesian estimator that uses time series information to estimate surface soil moisture [25]. In particular, the estimator optimally fuses all available information, including the multi-polarization and multi-angle SAR measurements, the knowledge of radar backscatter behaviour, and coarse a-priori knowledge of the surface roughness and soil moisture in the area. This comprehensive fusion of all the available information sources provides a superior estimate of soil moisture content.

Preliminary LAI maps and soil moisture maps have been generated for Lanier (Figure 3) and Antelope Creek (Figure 4), respectively. The final output products of the ISIES system will be predicted yield and biomass maps for the ISIES test sites. The yield and biomass estimates will be calculated on the same pixel grid as the CHRIS imagery. The maps will be geo-corrected and will be available in a raster-based image and in a vector-based map. These products will be made available on the web using the OGC software described in Section 10. Smith et al. [26] describe the ISIES LAI work in greater detail.

As revealed by the ISIES trials, currently available technology can be easily exploited to assess agricultural conditions. However, pending further miniaturization and cost reductions arising from micro-electro-mechanical systems (MEMS) technology, the cost of populating sensorwebs throughout a region remains a challenge even though the individual components are fairly inexpensive. The implication is that, for now, sensorweb technology is more likely to be deployed in a small area or region to acquire information that can be used to validate satellite retrievals and/or as a guide to generate forecasts on crop or range conditions over a larger region where growing conditions, weather, soils and crops are fairly homogeneous.

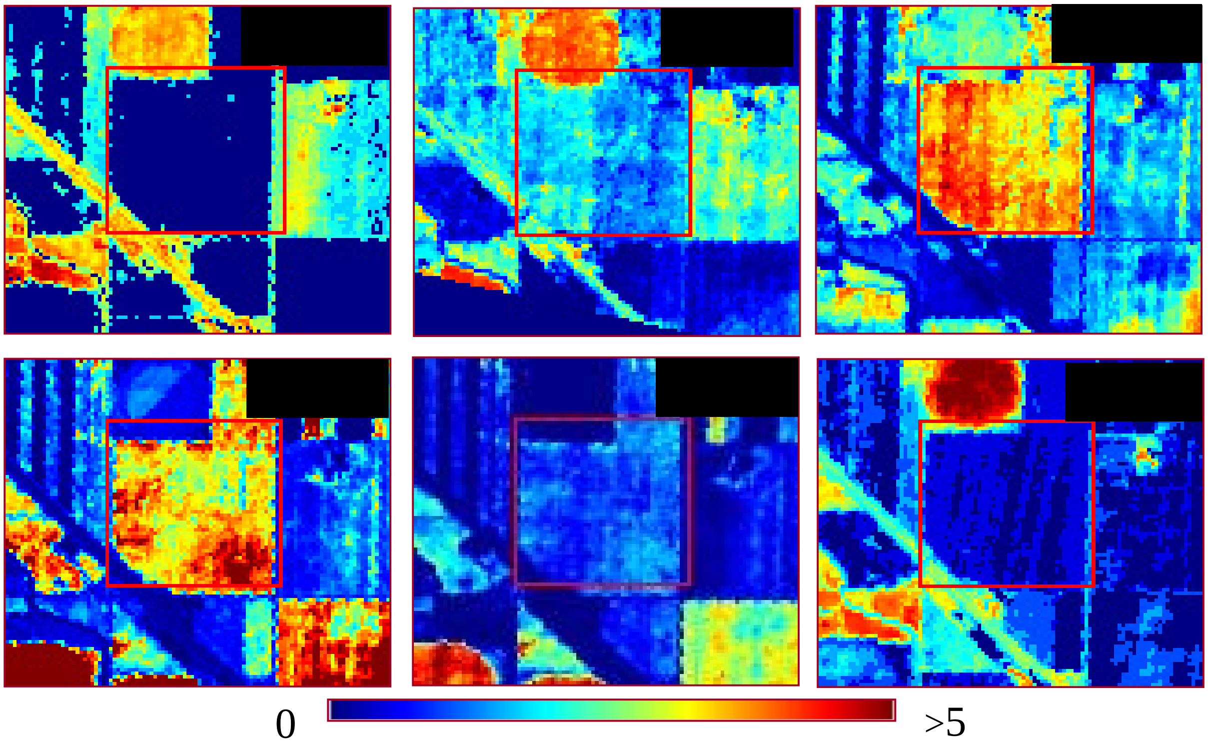

Figure 3. Time series of leaf area index (LAI) products derived from CHRIS imagery acquired in 2004 over the Lanier spring wheat test site.

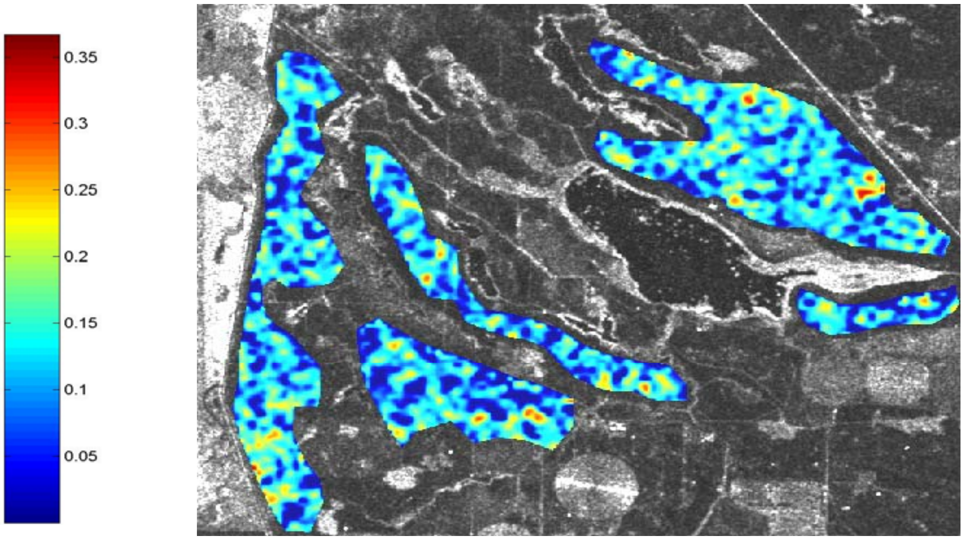

Figure 4. Estimated surface soil moisture map for the Antelope Creek Ranch, Alberta, derived from ASAR imagery acquired in 2004.

The other constraint on the wide-scale implementation of the technology, until it becomes more turnkey and off-the-shelf, is the uncertainty on the return on investment and the high cost of developing an information management system that satisfies end-users who are unlikely, for a variety of reasons, to gain significant economic value from the information derived from the sensorweb. From the end-users perspective, the marginal improvement in yield due to the deployment of the sensorweb technology might be inadequate compensation to recover the associated costs.

10 ISIES HOST SERVER

The ISIES host server is being designed and built to ingest data from the sensorweb, process it and store it in a relational database. It is the host of a relational database, built using Oracle 10g, and a file storage system that contains all ISIES data (remote sensing, GIS and in-situ). An automated communication module has been built to contact the SmartCore devices and retrieve the in-situ data on a daily basis. It will also be able to receive data and event alarms initiated by the sensorweb and communicated to the server by the SmartCore devices. The output files of this communication module are then parsed and the data are automatically stored in the relational database. A data fusion engine is being developed to automatically run the two plant models described in Section 8 using the in-situ and remote sensing data. These models will be run on a daily basis, shortly after the in-situ data are received. Yield and biomass maps will be produced for each of the test sites. A graphical user interface (GUI) will also be developed and will be used for the administration and configuration of the server and its various components.

The ISIES server is built around Java. All the APIs for serial communication (with data loggers in the field), XML processing module (JAXP), and database connectivity (JDBC) are Java-based. For the web-based features, Tomcat and Apache have been used. JDK 1.4 has been used as the development kit.

11 ISIES OPENGIS VIEWER AND SENSOR SERVER SOFTWARE

The focus of ISIES OpenGIS components is on interoperability among sensorwebs and their underlying information models. Currently, most research and development on sensorweb or sensor network implementations focus on sensor deployment, sensor communications, and context-specific applications. However, the information model underlying a sensorweb and the interoperability of the model are rarely addressed. Sensing information is disseminated within each sensorweb using proprietary formats and proprietary communication protocols. Proprietary designs result in poor interoperability among sensorwebs and make collaboration among sensorwebs very difficult.

York University's Geospatial Information and Technology (GeoICT) Laboratory is developing an *ISIES OpenGIS Viewer* and an *ISIES OpenGIS Sensor Server* [27]. These tools are the components of the ISIES sensorweb that address the issue of information models and interoperability. They link ISIES products (sensor observations, crop yield predictions and biomass predictions) with a global spatial data infrastructure, such as the Global Spatial Data Infrastructure (GSDI) or the Canadian Geospatial Data Infrastructure (CGDI) through open web service interfaces and standard information models for sensors. In order to accommodate various sensors in a sensorweb, standard information models play a vital role by making the whole architecture efficient, extensible, and interoperable. Table 2 lists the information disseminated within a sensorweb and the information that needs to be described in a standard way in order to build an interoperable sensorweb. It is envisioned that users will be able to assemble the interoperable components from different sensorwebs for use in their own applications. These interoperable components include the ability to task sensors, retrieve sensor observations, and utilize processing models within sensorwebs, etc.

ISIES OpenGIS Sensor Server is one of the first OGC (Open Geospatial Consortium) Sensor Collection Service implementations. It will connect to the database of the ISIES host server, access ISIES products (e.g., in-situ sensing data, remote sensing data, and/or plant model results), and serve ISIES products with OGC web service interfaces using the standard-based information models (GML, SensorML, and O&M). Table 3 lists the OGC web service interfaces of the server and descriptions of the interfaces. *ISIES OpenGIS Sensor Server* uses SensorML, GML, and O&M as standard-based information models for sensor information and observations. A SensorML instance is a self-description of a sensor, which contains sensor specifications, capabilities, geolocation, and history, etc. GML is a standard information model for spatial features. O&M is an information model for observations and measurements, including units of measurement, description of observed phenomenon, etc.

ISIES OpenGIS Viewer is built upon GSN 3D Globe, an interactive 3D globe client from GeoTango International Corp. GSN 3D Globe provides a unified global context within which users can access, visualize and analyze geospatial information from interoperable OGC web map servers (WMS), web coverage servers (WCS) and web feature servers (WFS). In addition to GSN 3D Globe's existing WMS, WCS and WFS functionalities, *ISIES OpenGIS Viewer* supports OGC Sensor Collection Service, SensorML and O&M. When first launched on a desktop computer by a user, the *ISIES OpenGIS Viewer* starts from a "zoomed out" view of the globe and allows the user to select a sensorweb site and "fly into it". While the user is "flying into" the sensorweb site, multi-resolution base maps (e.g., rivers, satellite images, etc) and terrain data are streamed to the viewer via open WMS/WCS/WFS interfaces from various OGC servers (e.g., Natural Resources Canada's WMS Server for Landsat mosaic data). While the user zooms in closer to the site location, the viewer displays high spatial resolution satellite imagery of the site as well as sensor nodes with symbols to denote sensor locations. The user can then mouse click on one of the sensor symbols to launch a sensor query dialog to obtain sensing information by spatial-temporal bounding box, sensor type and/or platform type. The user can choose to see query results in three different types of presentation: 1) a temporal plot of *in-situ* observations, 2) ISIES products encoded in GML/O&M, and 3) sensor metadata encoded in SensorML. For example, a user can request a temperature sensor plot as a function of time (JPEG format). A user can also choose to request the GML/O&M encodings of the observations, which contain richer information, such as the observations, units, accuracy, locations, targets of the observations, and the sensor that performed the measurements, etc. The GML/O&M response can direct the user to a detailed description of the sensor in SensorML, which contains the sensor's location, history, capabilities, coordinate reference systems, etc.

Table 2. Information disseminated within the sensorweb.

Types of Information	Examples
Sensor metadata	Capabilities, manufacturers, histories, owners, etc.
Sensor observations	Scalar values, aggregated values, etc.
Units of the observations	Degrees Celsius/Fahrenheit and conversion formulae.
Calibration formulae	Soil moisture calibration factors, etc.
Geophysical variables	Air temperature, soil moisture content, etc.
Associated sensor features	Road network intersection of a traffic webcam location.
Locations	Sensor locations, static, mobile, coordinates, etc.

Table 3. Web service interfaces of *GeoSWIFT Server*.

Requests	Responses
GetCapabilities	The GetCapabilities request XML response conforms to OGC service information model schema and provides detailed information for a client to access the service. The information provided includes service type, service instance, content type, and content instance.
GetObservations	The GetObservations request XML response is encoded conforming to GML and O&M schema. It contains values, units and locations of the requested sensor observations.
DescribePlatform	The XML response describes the sensor platform and conforms to SensorML schema. An example of a sensor platform can be an aircraft platform that carries a camera, several inertial sensors and meteorological sensors.
DescribeSensor	The XML response contains detailed information on sensor characteristics encoded in SensorML. The sensor characteristics can include lists and definitions of observables supported by the sensor.

12 CONCLUDING REMARKS

Earth science sensorweb data have the potential to become an integral part of government policy and decision support domains. The work reported in this paper has taken an initial step towards demonstrating approaches to the time-critical and cost-effective monitoring of complex and dynamic systems. Nevertheless, much more needs to be done to provide a more solid basis for issue-specific decision support, including smaller, smarter and cheaper sensor systems for monitoring, the integration of time-critical in-situ sensor data and/or metadata into on-line geospatial data infrastructures, and the generation of validated data and information products derived from the fusion and assimilation of in-situ and remote sensing data into models. Ongoing challenges in such endeavours are the early developmental stages of the rapidly advancing technologies involved, the lack of resources to put in place capabilities for integrated assessment, and the potential future shortfall of highly qualified science and technology personnel.

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