Architecture, implementation and application of soil moisture in-situ sensor network across Canadian agricultural landscapes

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Agenda

- Business requirements
- In-situ sensor network design and implementation
- Sensor calibration and QA/QC
- Data management and access
- Application and use cases
Business requirements

• Departmental needs
  Cost-effectively validate SAR derived soil moisture map
  Provide representative soil moisture data to modellers

• Added business case for NASA field campaign for SMAP cal/val

• Producers would like to access the data collected from their farms via Internet or smart phone.

• To meet departmental priorities in the area of Science and Innovation
In-situ sensor network design and implementation
Sensor Web architecture

- AAFC Ontario
- University Calgary
- AAFC Manitoba
- Nipissing Sensor net
- Others sensor net
- EC Saskatchewan

Web based PC access
- WAP based mobile access to most current data
- SMS/E-Mail warnings
- Server-to-server data replication
- A2A ASCII export server
- addUPI XML based third-party application connectivity

In-situ sensor net/web servers with OGC sensor web protocol suit
Architecture of our use case

Public users

Other sensor web servers

Nipissing University sensor web server

U. Of Calgary GeoSENS server

AAFC sensor web server
Star-network based insitu-senor web
Descriptive view of the system

**4 SK Stations**
- 15min data: 16 hydra probes, met data (rain, air temp, RH, wind)
  - SK Campbell logger & Bluetree modem (Sell)

**9 MB Stations**
- 15min data: 15 hydra probes, met data (rain, air temp, RH, wind)
  - MB Campbell logger & Raven X modem (Rogers)

**5 ON Stations**
- 15min data: 9-15 hydra probes, rain data
  - ON ADCON Radio Telemetry Unit (Rogers)

**AAFC Firewall**
- Top of hour: Data transmitted to AAFC server in MB with LoggerNet. Manual data transmission & battery power check
  - Top of Hour: Data transmitted to ADCON Gateway inside AAFC firewall

**AAFC Server in ON at 5min past the hour:** Automated script retrieves raw data, applies calibration equations to SM data, applies automated QC & generates data flags. Weekly or monthly manual QC (depends on season and issues). Currently, no way to add flags after manual QC

**AAFC External Server**
  - Cloud Server at 11min past the hour: Sensor Observation Service (SOS) of Open Geospatial Consortium (OGC) standard

**GeoCENS web service:** Geospatial Cyberinfrastructure for Environmental Sensing

Accessible by NASA, other users and web portals
In-situ station design
In-situ sensor station installation
Notes on installation and site configuration
Sensor calibration and QA/QC
Four calibration methods have been studied in Casselman site

**Hydroa probe default loam setting**
uses a calibration equation and the coefficients for the equation are averages of the coefficients from 20 soils.

**Site specific calibration**
a regression for each soil (Kennedy et al. 2003), to transform the real dielectric constant values to more closely match the gravimetrically determined volumetric moisture content value.

**Soil texture and pedology based empirical method**
uses calibration curve for each soil class on the soil texture triangle (Bellingham, 2007), was used to obtain the volumetric soil moisture from real dielectric constant

**Using model developed by Peplinski et al., 1995**
A semi-empirical dielectric mixture model
Notes on calibration

Based on our calibration test, the performance of Bellingham method is comparatively better than other methods and the Bellingham method can be used to convert soil moisture station real dielectric readings to volumetric moisture content.

<table>
<thead>
<tr>
<th>Location</th>
<th>Sand %</th>
<th>Clay %</th>
<th>Silt %</th>
<th>Stevens’s texture class</th>
<th>Calibration equations</th>
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</thead>
<tbody>
<tr>
<td>S1 - 5cm</td>
<td>8.26</td>
<td>53.06</td>
<td>38.67</td>
<td>Clay</td>
<td>VMC = (0.0032414 RDC^3 - 0.2464 RDC^2 + 6.553 RDC - 20.93) / 100</td>
</tr>
<tr>
<td>S1 - 20cm</td>
<td>8.64</td>
<td>52.23</td>
<td>39.13</td>
<td>Clay</td>
<td>VMC = (0.0032414 RDC^3 - 0.2464 RDC^2 + 6.553 RDC - 20.93) / 100</td>
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<tr>
<td>S1 - 50cm</td>
<td>28.42</td>
<td>41.67</td>
<td>29.91</td>
<td>Clay/Clay loam</td>
<td>=0.1033 SQRT(RDC) - 0.1768</td>
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<tr>
<td>S2 - 5cm</td>
<td>34.70</td>
<td>19.87</td>
<td>45.43</td>
<td>Loam</td>
<td>=0.108 SQRT(RDC) - 0.179</td>
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<td>S2 - 20cm</td>
<td>36.48</td>
<td>17.60</td>
<td>45.92</td>
<td>Loam</td>
<td>=0.117 SQRT(RDC) - 0.1847</td>
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<td>S2 - 50cm</td>
<td>68.23</td>
<td>6.11</td>
<td>25.66</td>
<td>Sandy loam</td>
<td>=0.1017 SQRT(RDC) - 0.1786</td>
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<td>S3 - 5cm</td>
<td>23.83</td>
<td>43.79</td>
<td>32.38</td>
<td>Clay</td>
<td>VMC = (0.0032414 RDC^3 - 0.2464 RDC^2 + 6.553 RDC - 20.93) / 100</td>
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<tr>
<td>S3 - 20cm</td>
<td>24.38</td>
<td>46.11</td>
<td>29.51</td>
<td>Clay</td>
<td>VMC = (0.0032414 RDC^3 - 0.2464 RDC^2 + 6.553 RDC - 20.93) / 100</td>
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<td>S3 - 50cm</td>
<td>2.42</td>
<td>52.23</td>
<td>45.34</td>
<td>Silty clay</td>
<td>=0.1088 SQRT(RDC) - 0.1738</td>
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</table>
Notes on calibration
Data management and access
Data access via Sensor Web

• World Wide Web provides enormous distributed computing resources.

• Sensor Web leveraging Internet protocols connects distributed and networked heterogeneous in-situ and remote sensors.

• An effective Sensor Web should be constructed using interoperable protocols and application interfaces.

• A Sensor Web is achieved by connecting to information centers/servers/nodes that store, disseminate, exchange, display, and manage the sensed information.
The **Sensor Observation Service** (SOS) is a web service to query real-time sensor data and sensor data time series and is part of the [Sensor Web](#).

- The offered sensor data comprises descriptions of sensors themselves, which are encoded in the Sensor Model Language ([SensorML](#)), and the measured values in the [Observations and Measurements](#) (O & M) encoding format.

- The web service as well as both file formats are open standards and specifications of the same name defined by the [Open Geospatial Consortium](#) (OGC).

This XML file does not appear to have any style information associated with it. The document tree is shown below.

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</sos:Capabilities>
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GeoCENS Portal—a SOS use case

• Created and maintained by ServerUp
• [http://aafc.geocens.ca/](http://aafc.geocens.ca/)
• Current contract with ServerUp includes improving data downloading capability and generating a data summary window when viewing latest data from a station
The data summary table will be achievable and downloadable and will contain something like the following data:

Date/time of last reading: June 14, 2013 14:00 CST or EST

Current Conditions (past hour):
- Air Temp: 25.3 °C
- Relative Humidity: 50%
- Wind Direction: WSW / 241 °
- Wind Speed: 19 km/h
- Max Wind Speed: 30 km/h
- Min Wind Speed: 12 km/h
- Precip, past hour (or 15 min): 0 mm
- Precip, since midnight: 2.1 mm

Conditions Previous 24 Hours or previous day (June 13, 2013)
- Total Precip: 1.4 mm
- Min Air Temp: 13.1 °C
- Max Air Temp: 27.3 °C
- Ave Air Temp: 20.2 °C
- Ave RH: 60.3%
- Ave Wind Direction: SW / 240 °
- Ave Wind Speed: 20.1 km/h
Data access: download

- The archived summary data can be downloaded by the general public.
- The complete data set can currently be downloaded by the public as long as they register and log in.
Application and use cases
**Objectives:** SMAP will provide global measurements of soil moisture and its freeze/thaw state. These measurements will be used to enhance understanding of processes that link the water, energy and carbon cycles, and to extend the capabilities of weather and climate prediction models. SMAP data will also be used to quantify net carbon flux in boreal landscapes and to develop improved flood prediction and drought monitoring capabilities.

**Observatory:** The SMAP observatory employs a dedicated spacecraft with an instrument suite that will be launched on an expendable launch vehicle into a 680-km near-polar, sun-synchronous orbit, with equator crossings at 6 am and 6 pm local time.

**Instrument:** The SMAP instrument includes a radiometer and a synthetic aperture radar operating at L-band (1.20-1.41 GHz). The instrument is designed to make coincident measurements of surface emission and backscatter, with the ability to sense the soil conditions through moderate vegetation cover. The instrument measurements will be analyzed to yield estimates of soil moisture and freeze/thaw state. The measurement swath width is 1000 km, providing global coverage within 3 days at the equator and 2 days at boreal latitudes (>45 degrees N).

**Operations:** SMAP science measurements will be acquired for a period of three years. A comprehensive validation program will be carried out after launch to assess the accuracies of the soil moisture and freeze/thaw estimates. Data products from the SMAP mission will be made available through a NASA-designated data center.
Soil moisture maps retrieved from RADARSAT-2 image pairs using the hybrid inversion method.

A. Merouki, H. McNairn, X. Geng, P. Rollin, R. Han, 9th Advanced SAR Workshop, 15-18 October 2013, Montreal
SAR derived soil moisture validation

Temporal evolution of soil moisture data sets for each *in situ* station.

A. Merzouki, H. McNairn, X. Geng, P. Rollin, R. Han, 9th Advanced SAR Workshop, 15-18 October 2013, Montreal
Extended in-situ sensor for pivot monitoring
Thank you!

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