The Past, Present and Future of Satellite Earth Observation for Environmental Monitoring: a Canadian Perspective

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Outline

- Birth of modern satellite earth observation (EO)
- Four decades of innovation and application
- What’s next: New satellite missions
- Priority environmental issues facing Canada
- The challenge: from space assets to societal benefits
- How the GoC EO community is responding
- Concluding remarks
Birth of Modern Satellite Earth Observation in Canada

- 1971: Canada Centre for Remote Sensing (CCRS) founded
  - "to produce in a timely and effective manner, remotely sensed data and derived information needed for the management of Canada's natural resources and environment, and to perform and support research and development on the collection, processing and interpretation of such data."

- 1972: 1\textsuperscript{st} Canadian EO data receiving facility established at Prince Albert

- 1972: Received 1\textsuperscript{st} Landsat-1 image (USA Earth Resources Technology Satellite 1)
The 1970’s: Established Canada as 1\textsuperscript{st} US partner & leading nation in satellite EO

- 1\textsuperscript{st} country to join in the USA’s earth observation program
- Contributing to developing Landsat & SPOT (Système Probatoire d'Observation de la Terre) processing systems
- Active member of the Landsat Ground Station Operations Working Group
- Developed several leading-edge methods for geometric and atmospheric calibration and information extraction
- Produced Landsat Thematic Mapper (TM) images of Canadian capital cities and other important Canadian cities
- Developed standard products from Landsat TM for forest, crops, and geological mapping.
The 1980’s: The beginning of operational remote sensing

- Completed the first operational crop area estimation of potatoes in 1980 for Statistics Canada
- USA Department of Agriculture adopted CCRS methods for crop area estimation
- Operated the Digital Image Correction System (DICS) which geocoded digital products of Landsat data
- Produced remote sensing tutorials used worldwide
- Began Radarsat preparatory R&D:
  - SAR processing
  - Ice and geological applications
The 1990’s: Operational ice monitoring, SAR applications R&D & national scale products

- Methods and tools for ice monitoring using Radarsat-1– Canadian Ice Centre
- SAR technology and applications developed and transferred to over 30 countries
- National scale information and products for environmental monitoring, e.g.
  - land cover, albedo
  - leaf area index, wildfire
- Developed the first image processing and display package for hyperspectral images
- Transferred numerous technologies to industry.
Entering the 21st Century: Flourishing of EO applications...

- Long Terms Satellite Data Records (LTSDR)
- Land surface parameters and processes, e.g.
  - Ecosystem net primary productivity
  - Evapotranspiration
- SAR for monitoring
  - Flooding
  - Landslide
  - Permafrost-related infrastructure
- EO for supporting environmental data
  - Urban map updating
  - High-res DEM

Summer ice extent in Arctic

Trichtchenko 2008
Land cover and land use mapping for environmental assessment

- Circa 2000 land cover map at 30m resolution, used for
  - forest biomass estimation
  - Agricultural land use inventory
  - Greenhouse gas accounting

- Land cover and land use information for biodiversity assessment

- Continental land cover map at 250m resolution, supporting NAFTA environmental assessment

Land cover map, Latifovic et al. 2010 (CCRS)
Operational monitoring of water clarity and marine ecosystem productivity

- EC: operational remote sensing of water color for selected Canadian inland waters in near-real-time

- DFO: operational remote sensing of chlorophyll concentration and surface temperature to derive marine ecosystem primary productivity
What next: New EO satellite missions for environmental monitoring

- Planned operational satellite missions: improved spatial, temporal and spectral resolutions
  - RCM
  - Sentinels 1, 2, 3,
  - Landsat Data Continuity Missions (LDCM)
  - ALOS2
  - EnMAP
  - GRACE-2
  - JPSS

- New frontiers:
  - Closing the water cycle: total water storage, soil moisture, water level, precipitation
  - Source GHG: CO2, CH4, SO2, NO2
The Global Challenge: Transforming space assets into concrete societal benefits

- Agriculture
- Biodiversity
- Climate
- Disasters
- Energy
- Ecosystems
- Health
- Weather
- Water
Canada’s specific challenge landmass and coastline vs GDP
Satellite EO is essential

<table>
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<th>Region</th>
<th>GDP  ($billion)</th>
<th>Land (million km²)</th>
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<td>The USA</td>
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Priority environmental issues in Canada: Climate change

- The drivers and mitigation
  - Greenhouse gas emissions
  - Land use change
- The impacts and adaptation
  - Water resources
  - Extreme events: droughts, floods
  - Biomass resources: productivity vs. disturbance (fire, pest)
  - Potential permafrost thawing
    - Release a large storage of methane
    - Jeopardize infrastructure
  - Ecosystem services
    - Human health
    - Biodiversity

Permafrost thawing, Zhang et al. (CCRS)
Wildfire monitoring, Landry et al. (CCRS)
Priority environmental issues facing Canada: Effective and efficient regulatory regimes

- Canada is branded as global energy and resources leader
- Tremendous potential for economic prosperity but also potential of environmental liability
- Environmental and social pressures converge
- Effective and efficient regulatory regime – key to responsible resource development
- Environmental monitoring – essential input into regulatory frameworks
And improved regulatory regimes require...

- Baseline information for environmental impact assessment
  - Long term time series, with temporal resolution capturing environmental change
  - National coverage, with spatial resolution representing the targets
- Monitoring regulatory compliance
  - Infrastructure development
  - Tailing ponds
  - Reclamation
- Monitoring cumulative environmental impacts
  - Air
  - Water
  - Wildlife habitats and biodiversity
Challenges to satellite EO community: from space investment to societal benefits

- Satellite data receiving, archiving, processing, distribution
- Pre-launch application R&D
- Applications development
  - Issues-oriented R&D
- Transition to operations
  - Plug in to decision loops
  - Multi-disciplinary and trans-disciplinary approach
  - From “peer reviewed paper” to “product”
  - From “methods” to “capacity”
- Horizontal integration
  - Science level
    - satellite-in-situ; multi-disciplinary
  - Organizational level
  - Decision support level
The EO Community of the Canadian Federal Family is responding....
Operational monitoring of ecological integrity for national parks

- Operational EO tools and protocols developed and integrated into ecological integrity monitoring of national parks
  - Land cover
  - Leaf area index, biomass, foliage
  - Permafrost
- Results used in official reporting on the state of the national parks
- A model of multi-disciplinary approach to operationalize EO

Predictive ecosystem type map for Ivavik National Park. The 10 m resolution map was created using SPOT HRVIR multispectral satellite imagery and terrain attributes derived from a digital elevation model (Fraser et al. 2011 CCRS)
Integrated Satellite Tracking of Polluters (ISTOP)

Monitoring illegal oil discharges in Canadian waters
Satellite Ground Infrastructure: New GoC investment will provide sufficient coverage for Canada’s lands and waters.
Will implement a world-class, interconnected network of satellite facilities for EO data reception, archiving, processing and distribution
Satellite pre-launch application R&D

- RCM: Compact polarimetry applications
  - Surface water
  - Wetlands
  - River ice
  - Oil spill
  - Biomass
  - Land deformation
- Sentinels: applicability to Canadian priorities
  - Agriculture
  - Forest
- EnMAP
  - Tailing ponds monitoring
  - Ecosystem health
Supporting environmental stewardship
Example: oilsands

Regulatory compliance monitoring
for regulatory enforcement

- Compliance monitoring
- Performance monitoring
- In-situ sampling and upscaling
- Baseline monitoring
- Accumulated state monitoring
- Surveillance monitoring
- Cumulative effect monitoring

E.g. Monitoring acid-sensitive lakes
Sampling of hundreds of lakes by aircraft across AB, SK and MT as identified in IMP is costly, limiting monitoring. Remote sensing is a cost effective, powerful and complimentary monitoring tool.

Environmental impact monitoring
Supporting strategic policies
Change detection of man-made structures and related activities

- **Lead scientists:** Bert Guindon, Ying Zhang, CCRS
- **Alberta contact:** Energy Resource Conservation Board (ERCB)
- **Proposed outputs:**
  - Methods and tools for operational monitoring of infrastructure development and land disturbances using high resolution imagery
  - Information products for study sites or key oilsands region
  - Recommendations to integrate the outputs in compliance monitoring operations
- **Collaborators:** ERCB, AE, ESS-MIB

Extraction of Land Disturbances due to Infrastructure Development from High-Resolution Image
Steam injection monitoring from InSAR

- **Lead scientist:** Vern Singhroy, CCRS
- **Alberta contact:** ERCB
- **Proposed Outputs:**
  - InSAR deformation maps at sites with variable geology
  - Correlation of InSAR data with industry steam injection heave models
  - Building capacity at ERCB to support future operational use of InSAR.
- **Collaborators:** ERCB, Imperial Oil, ESSO, Exxon Mobil, Conoco Philips, Geological Survey of Canada, CSA
EO-based assessment and monitoring of land surface conditions

- **Lead scientists:** R. Latifovic, D. Pouliot, R. Fernandes, CCRS
- **Alberta contact:** Alberta Environ. (AE)
- **Proposed outputs:**
  - Regionally consistent multi-sensor long term satellite data records (high temporal & 0.03-1km resolution)
  - Derived land surface indicators (land cover, LAI, fAPAR, snow, etc.) to establish baselines, analyze trends & support modeling (land surface/water/air processes)
  - Methods to enable near-real time land surface monitoring by regulators
- **Collaborators:** CFS, EC, PC, CSA, academia…
SAR for water level monitoring

- **Lead scientist:** Brian Brisco, CCRS
- **Alberta contact:** AE
- **Proposed Outputs – R&D:**
  - Evaluation of InSAR technology for water level estimation
  - SAR input to Wet Area Mapping tools and evaluation of the methodology
  - Recommendation for operational approach to water level estimation using SAR data
- **Possible collaborators:** EC, Ducks Unlimited Can, CSA, academia…

- Spring
- Summer

ERS-1/TM Wetland Classification
Polarimetric SAR for peatland monitoring

- **Lead scientist:** Ridha Touzi, CCRS
- **Alberta contact:** Sustainable Resource Development (SRD), ERCB, AGS, AE
- **Proposed outputs:**
  - Polarimetric SAR methodology for peatlands classification/change detection
  - Methods for monitoring long term changes in surface & sub-surface peatland water flow (Radarsat 2, ALOS)
- **Possible collaborators:** SRD, ERCB, AGS, AE, CSA…
G&C Project: Hyperspectral technology for ecosystem health monitoring

- **Lead:** University of Victoria
- **Participants:** U. of Calgary, U. of Alberta, U. of Lethbridge, Gov. of Alberta
- **Proposed outputs:**
  - Airborne multi-sensory, processed imagery for selected areas
  - Vegetation health indicators
  - Wetland conditions
  - Landscape reclaimation process
  - Upscaling to simulate requirements for space-based hyperspectral sensors
- **Collaborators:** NRCan (CCRS, CFS), Gov of Alberta (TecTerra), EC

Sites for hyperspectral studies

- Active mining
  - VNIR-SWIR
  - 1500 sq km - 5 days
  - VNIR-SWIR/LIDAR/photog
- Brett's Christina Lake
  - Brett's new polygon
- Industrial Heartlands
  - Potential Industrial VNIR/LiDAR/photos
  - 1-2 days
- Coal Valley - Shane
  - Coal reclaimation - Shane
- Wetlands - GoA-CCRS-VNIR
  - 1500 sq km Wetlands GoA (Sleep) and CCRS (Touzi)
- Air quality 2
  - Additional air quality - VNIR, LiDAR, photos
- Groundwater 1
  - 2000 km sq 4 days, VNIR
- Active Mining 2
  - Full range 2 - active mining
  - ca 2 days
- Wetlands 2
  - VNIR/LIDAR/photog
  - Wetlands, baseline premining
- Cold Lake - Trp Oil
  - VNIR(?), LiDAR, photos
  - in situ, Staenz

Canada
Opportunity to “-operationalize”: GRACE to characterize water storage change

- GRACE satellites take gravity measurements, which are proven capable of monitoring total water storage changes
- CCRS & GSD, under Earth Sciences Sector Groundwater program, has developed this technology in-house
- The Great Lakes example on right.
Opportunity to “operationalize”: Quantify water resource availability & change

- Long Term Satellite Data Records and Radarsat data are used to map surface water and land conditions; together with other data feeding to:
  - Water cycle estimation through physics-based integration,
  - Which can be validated by total water storage change derived from gravity-based estimates (GRACE)

Physics-based integration of multi-satellite and in-situ data for water cycle estimation (Wang et al. 2012, CCRS)
Opportunity to “operationalize”: Monitoring boreal habitat integrity

- Boreal caribou population is in decline; if triggered, SARA could impact many resource development projects
- EC has made significant investments in Boreal infrastructure mapping using Landsat; but the maps need updating
- CCRS has developed advanced methods and tools, which could be used to update the maps in a cost effective manner
- Again, partnership is essential
Strategic Partnerships

- Strategic partners:
  - CSA, EC, PC, AAFC, DND, DFO
  - Provincial/territorial governments
  - Academia
  - Industry

- International collaborations
  - NASA, NOAA, USGS,
  - ESA
  - German Space Agency (DLR)
  - Japan (JAXA)
  - China (CEODE, IRSA)
Earth Observations:

The *single most powerful source of information* for understanding and managing human impact on the planet

- The most cost effective
- Remote, synoptic, continuous

**worthless** if not "inside the decision loop" of users, clients, policy makers, regulators

Operational (vice science) EO missions

- Should be designed for these decision loops
- Should have the majority of the operational applications developed prior to launch