Spaceborne, airborne and seaborne hyperspectral remote sensing in optically shallow coastal waters: challenges and opportunities

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Outline

✓ What is hyperspectral and why?

✓ Ongoing projects and opportunities for hypersepectral development

✓ The WiSE-Man project

✓ The FORCSE infrastructure
What is Hyperspectral?

- Data cube concept (3D)
  - Space (2D)
  - Spectral (number of bands ~ > 50)
What is the water leaving radiance ($L_w$) and how it varies?

$L_w$ is the radiant energy exiting the water column (not equal to “surface” radiance), which contains the information of the water column.

In optically-deep waters, $L_w$ depends on the ratio of light scattering to absorption of seawater constituents known as Inherent Optical Properties (IOPs).

Constituents:
1. Phytoplankton (pigments)
2. Organic detritus and mineral (clay, silt)
3. Dissolved organic material
4. Water itself
Optically-deep versus -shallow waters

Optically-Shallow is when the bottom contributes to $L_w$ (some time only in the green!!)

- There is **not a single depth** to separate optically-deep and shallow waters

$\Rightarrow$ It depends on the water column attenuation ($K_d$), which is mainly driven by IOPs ($b_b + a$)

$\Rightarrow$ $1/K_d$ is a good approximation for delimiting shallow waters
What is the goal of shallow-water remote sensing?

• To retrieve
  - bulk water column IOPs or individual constituents (TSS, Chla, CDOM, DOC, POC, phytoplankton types, etc.)
  OR
  - The water depth or bathymetry (h)
  OR
  - The bottom type or habitat or bottom reflectance ($R_b$)
  OR
  - All of them!!
Why Hyperspectral?

- Atmospheric and air-sea interface contamination of the signal measured at the Top-Of-Atmosphere ($L_{TOA}$) or “at-sensor” is common to any remote sensing applications.
- The spectral water-leaving radiance ($L_{water}$), retrieved after applying atmospheric and surface corrections, contains information on
  A. the water-column’s inherent optical properties (IOPs)
  B. water depth ($h$)
  C. bottom reflectance ($R_b$).
- In general, to solve the problem using **multispectral imagery**, the retrieval of one of these requires the knowledge of the other two.
- From $R_b$, biological proxies may be derived (LAI, biomass) leading to development of applications.
- Unlike multispectral, **hyperspectral** has the potential to retrieve the three unknowns type with less a priori knowledge.
Challenges and opportunities for shallow-water hyperspectral remote sensing in Canada

1. Satellite borne:
   - WaterSat / COCI project (Canadian Space Agency)

2. Airborne:
   - Sensor developpement (Canadian Space Agency)
   - Airborne survey as part of DFO Ocean Protection Plan

3. Seaborne:
   - FORSCE project (Canadian Funds for Innovation)
In 2013, Canadian Space Agency (CSA), with the collaboration of several federal departments (DFO, DRDC, ECCC, PHAC and NRCan), launch a feasibility study (Phase 0) for the Watersat mission concept (hyperspectral imager) as part of the CSA’s Microsat Initiative.

- Contract awarded to MDA/ABB consortium => platform and payload’s specifications and design, cost evaluation, etc
- User requirements document (URD) led by CSA in close relationship with government and academic

The Watersat objective was « to monitor water quality and the productivity of aquatic ecosystems in Canadian coastal and inland waters to support environmental assessment, climate change monitoring, and economic and recreational activities”

Feasibility Study for WaterSat completed at the end of March 2016:
- Estimated at $98.8M (including risks); Too expensive with the current industrial set-up and approach;
In 2016, the opportunity to put the sensor (renamed **COCI: Coastal Ocean Colour Imager**) on PACE mission (Plankton, Aerosol, Cloud, ocean Ecosystem) was discussed with NASA-NRL

- PACE is a NASA/NRL project for a space-borne hyperspectral mission at low spatial resolution (1-km) for the global ocean
- CSA and NASA/NRL negotiated for ~ 1 year to put COCI on PACE platform (2016)
- In March 2017, not enough budget for the integration of COCI on PACE
In the mean time, CSA has been supporting sensors development in the context of WaterSAT/COCI mission concept

- A compact airborne demo, the **Watersat Imaging Spectrometer Experiment** (WISE), has been developed by **ITRES Research Ltd** (www.itres.com) and tested and a high performance breadboard started.

- WISE is now available commercially as “Enhanced CASI” sensor

- Performances have been confirmed through test flights in collaboration with the **National Research Council (NRC)** in late 2018 (Dr Leblanc’s team)
On November 7, 2016, the Canada’s Prime Minister launched a $1.5 billion national Oceans Protection Plan

- The Canadian Hydrographic Service (CHS) and various DFO, EC, Transport departments are receiving funds to map the coastal zones....
- Major airborne LiDAR survey along the EGSL coasts for the bathymetry of coastal zones and ecosystems mapping (coll. with CIDCO)
- In 2017, there was an opportunity to acquire hyperspectral imagery μCASI in coll with CHS and DFO science department
- Maurice Lamontagne Institute (MLI) leading and funding several projects between Tadousac and Pointe-des-monts, one of the region targeted by the OPP, to gather data to establish the base line
In fall 2017, CSA launch the **Fieldwork for the Advancement of Science and Technology (FAST-2017)** call

- Develop and maintain a critical mass of researchers and HQPs in space-related areas in Canada;
- Increase the level of **student employability** by exposing them to practical experiences that enable them to acquire space science and technology knowledge and skills sought by, among others, the industry; and
- Increase scientific knowledge and/or develop new technologies.
WaterSat Imaging Spectrometer Experiment (WISE) for optically shallow inland and coastal waters assessment (WISE-Man project) objective

The overall long-term objective of the project is to demonstrate the potential of WISE sensor, and more generally hyperspectral imagery, for mapping bathymetry, water column quality and bottom properties in order to fulfill the needs of science (e.g. ecology, geomorphology, coastal risk), resource management and defense operations.

As part of the CSA FAST initiative and supported by OPP
Man = Manicouagan Peninsula

Eelgrass beds

Credits photo: Mathieu Cusson Carlos Araujo

River plumes

Saltmarshes

Sandy beaches and Eelgrass beds tidal flats

Rocky coast with macroalgea

Landsat 8 image composite

Vecteur 2019
The WISE-Man team

**Academia**

Bélanger UQAR: Remote sensing of coastal and inland waters
Bernatchez UQAR: coastal geomorphology, FORSCE
Cusson UQAC: Benthic vegetation ecology
Huot, UdeS: Optics, phytoplankton, Lake Pulse leader
Nozais, UQAR Benthic Ecology

**MPO-Sciences et gestion (IML) (Desjardins, Gendreau, Proulx)**
Main interests: Habitats or ecosystems mapping

**MPO – Télédétection (BIO) (Devred, Fuentes-Yaco, ...)**
Main interests/expertise: water colour remote sensing

**DRDC (Fournier, Ardouin, ...)**
Main interests/expertise: Hyperspectral remote sensing and inversion for bathymetry and water visibility; Optical sensors development

**SHC (Chenier, Côté, ...)**
Main interests/expertise: acoustic, LiDAR and satellite bathymetry mapping

**CNRC-Ottawa (Leblanc, Soffer, Ifimov)**
Main interests/expertise: airborne hyperspectral data acquisition and processing

**CIDCO (Gauthier, Laflamme)**
Main interests/expertise: acoustic and LiDAR

**International collaborators:**
Clémence Goyens, RBINS: Atmospheric correction
John Hedley, RTE and swallow water inversion
Fichot, U Boston, Bio-geo-optics, in situ optics
Project’s work packages (WPs)

- WP1 : WISE data acquisition, calibration and corrections (Leader: Leblanc)

- WP2 : Hyperspectral inversion for bathymetry, water constituents and bottom type mapping (Leader: Bélanger)

- WP3 : Development and exploitation of novel in situ platforms for EO validation (Leader: Bernatchez)

- WP4 : EO applications to coastal ecosystems discrimination and assessment (Leader : Cusson)
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WISE – WaterSAT Imaging Spectroscopy Experiment

- Technology Readiness Level (TRL) development:
  - Development of a new high performance (modified) Dyson Spectrometer
    - Improved SNR
    - Reduced volume
    - Reduced mass
    - Tight stray light control
    - Tight Spatial and Spectral distortion specifications (Smile/Keystone)
Airborne Hyperspectral Imager

WISE
WaterSAT Imaging Spectroscopy Experiment
Vis/NIR (360 nm - 992 nm)
40° FOV
2.2 nm spectral sampling interval
4.2 – 6.0 nm spectral resolution
1.3 – 1.9 pixels spatial resolution
1500 image pixels
288 spectral channels
WISE Test Imagery – Lake Ontario, Prince Edward County

Altitude @ 3048 m
IT @ 100 ms
Ground Speed @ 90 knots

Raw Along/Cross Track Resolution - 6.5/1.5 m

Resampled Resolution - 4.5 m

Sept. 13, 2018

Raymond Saffer
Noise removal algorithm to improve the quality
Validation

- 11 stations with in situ hyperspectral (no water sampling)
- 6 stations with IOPs, MS light profiles and water sampling (Chla, CDOM, TSS)
- No bottom reflectance
Challenges for airborne HS imagery

• Beside atmospheric and glint correction, Signal-to-Noise ratio (SNR) of most commercial HS imager (such as µCASI) maybe a limitation for waters remote sensing

• Acquisition of in situ measurements to assess the quality of the $L_w$ retrieval is generally limited to a few stations....
Flotte Opérationnelle de Recherche en Sciences côtières et Environnementales (projet FORSCE) (cf Bernatchez et al.)

• Multibeam and sediment profiler: bathymetry, lithostratigraphy, sediment budget
• Underwater camera: Characterization of the seabed and habitats.
• Seabird CTD-pH-O2 probes, hyperspectral radiometers, CDOM and Chla fluorescence, backscattering: optical applications (satellite validation), biogeochemical fluxes, water quality, oil slick detection.
Articulated arms

Hydrodynamic cover to protect the instruments

Data logger and computer

Multibeam
2 in-water radiometers (HyperOCR, Satlantic) will be placed at two different depths (~10-cm and 30-cm) allowing the calculation of the diffuse attenuation of upwelling radiance ($K_{Lu}$) and water-leaving radiance ($L_w$).

This will allow extensive validation of WISE-derived $L_w$...
LED based active sensors for turbidity, CDOM, CHL-a, $b_{bp}(700)$, fluorescence for cyanobacteria detection

This will allow extensive mapping of the water-column IOP-s (or optical proxies)
WISE-Man project time line

• 2019 field sampling:
  • Benthic Characterization and Bathymetry: August 11 to 28, 2019
  • Airborne hyperspectral data acquisition: 4 hours flight between August 18 and 28, 2019
  • Column of water: 18 and August 28, 2019

• 2020-2022 : Data analysis, algorithm development, thesis and paper publication
Summary

• Optically shallow ecosystems are extremely difficult to monitor and HS imagery has to potential to greatly improve our capability to monitor these rich ecosystems

• The Canadian Apace Agency (CSA) is very much interested in the development of a strong hyperspectral community for water applications

• Several opportunities to develop our expertise in that field came up during the last few years, which led to WISE-Man
  ✓ FAST program
  ✓ FORSCE
  ✓ OPP
  ✓ RQM
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