Can we use Spot 5 Take 5 to monitor dissolved organic carbon in the Arctic river Yenisei?

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Context

✓ + 5°C in high-latitudes
✓ 1/3 of the organic carbon in permafrost
✓ organic carbon drained by great Arctic rivers → dissolved organic carbon (DOC)
✓ Yenisei river is the greatest contributor to Arctic Ocean
Context

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Yenisei, 22/05/2015 (crédit : TOMCAR-Permafrost)
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- 80% of DOC fluxes in the peakflow period
- Logistical problems to sample DOC
  - Remaining ice-breaks
  - Very short-period (a few weeks in May and June)
- Lack of knowledge on DOC spatial patterns at largest scales and on DOC temporal dynamics
Context – Remote sensing could be a precious tool

- 80% of DOC fluxes in the peakflow period
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Background

- Satellite acquisitions
- Optical satellite images
- 1st statistical relationship
- 2nd statistical relationship
- DOC retrieval
- In situ DOC measurements
- CDOM measurements
- Visible absorption
- Infrarouge absorption

Yenisei, 22/05/2015 (crédit : TOMCAR-Permafrost)
Background

✓ Numerous CDOM retrieval algorithm have been developed in oceans, lakes and more recently on Arctic rivers (for a review: Zhu et al, 2014; Brezonik et al, 2015)

✓ 2 major approaches to explore relationships between CDOM and optical signal

Empirical models

- Easy to calibrate
- Current problems of linear regression (outliers, overfitting)

Process-based model

- Best description of the processes
- Input data rarely available
Background

✓ Numerous CDOM retrieval algorithm have been developed in oceans, lakes and more recently on Arctic rivers (for a review: Zhu et al, 2014; Brezonik et al, 2015)

✓ 2 major approaches to explore relationships between CDOM and optical signal

Empirical models vs. Process-based model

✓ Geographic-area dependent
✓ Spectral band combinations are effective (band ratio or band multiplication)
✓ namely shorter and longer wavelengths combination
Issues

✓ Low- spatial resolution sensors are effective to monitor CDOM in oceans or lakes but high-spatial sensors are more suited for Arctic rivers:

→ to evaluate the spatial heterogeneity of DOC

→ to characterize the river during the ice-break period or between clouds

→ for their atmospheric corrections

✓ Available high- spatial resolution sensors (Landsat, Spot) have a too low repeat-cycle orbit:

→ to evaluate DOC dynamics in the freshest period

→ to have an acceptable number of spatial acquisitions
Goals

✓ Developing a CDOM algorithm retrieval at high spatial and temporal resolution to:

→ to evaluate the **DOC dynamics during the open water season** with a special focus on the **freshest period**

→ to evaluate the **spatial heterogeneity of DOC** in the river channel

✓ Specific objectives are:

→ finding an optimal **spectral bands configuration**

→ evaluating the **predictive performance** of the developed model

→ discussing the **potentiality of high spatio-temporal optical remote sensing**

→ **Preparation for Sentinel 2 data**
Study site – Yenisei river (Igarka – Take 5 Site)

- Discontinuous permafrost
- High-flow period lasts from mid-May to mid-July
- Peak-flow period in late May-early June
Methodological flowchart

Optical satellite acquisitions

Draw an extraction mask

Extract water surface reflectances

Spectral variables

Multiple Linear regression

Linear regression

BD in-situ « DOC »

BD in-situ « CDOM »

Correlation ?

[KO]

[OK]

DOC model retrieval

CDOM model retrieval

CDOM prediction

DOC prediction
**Methodological flowchart**

Optical satellite acquisitions

- Draw an extraction mask
- Extract water surface reflectances

**Step 1**

- BD in-situ «DOC»
- BD in-situ «CDOM»

Linear regression

- [KO]
- [OK]

Spectral variables

- Multiple Linear regression
- CDOM proxy

DOC model retrieval

- DOC prediction
- CDOM prediction

CDOM model retrieval
**Methodological flowchart**

1. **Optical satellite acquisitions**
   - Draw an extraction mask
   - Extract water surface reflectances
   - Spectral variables

2. **Spectral variables**
   - Linear regression
   - Multiple Linear regression
   - Correlation?
   - [OK]
   - CDOM proxy
   - CDOM model retrieval
   - CDOM prediction
   - DOC prediction

3. **BD in-situ « DOC »**
   - BD in-situ « CDOM »
   - DOC model retrieval
   - DOC prediction

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Methodological flowchart

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Step 4

DOC model retrieval

CDOM model retrieval

CDOM prediction

DOC prediction
**Linear regression**

**CDOM proxy**

Introduction

Data and Methods

Results

Conclusion

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**Methodological flowchart**

- Optical satellite acquisitions
- **Step 1**
  - BD in-situ «DOC»
  - BD in-situ «CDOM»
  - Linear regression
  - Correlation?
    - [KO]
    - [OK]
- **Multiple Linear regression**
- CDOM proxy
- DOC model retrieval
- CDOM model retrieval
- CDOM prediction
- DOC prediction
Synchronisation of in-situ measurements and Spot 5 Take 5 acquisitions

- 25 ST5 scenes from 09/04/2015 to 06/09/2015
- 41 field-samples in 2014 and 28 in 2015 (DOC, CDOM, TSS)
Synchronisation of in-situ measurements and Spot 5 Take 5 acquisitions

20/05/2015

5 days

25 ST5 scenes from 09/04/2015 to 06/09/2015

15/09/2015

+ LANDSAT 8 acquisitions

✓ 25 ST5 scenes from 09/04/2015 to 06/09/2015

✓ 41 field-samples in 2014 and 28 in 2015 (DOC, CDOM, TSS)
Synchronisation of in-situ measurements and Spot 5 Take 5 acquisitions

- 25 ST5 scenes from 09/04/2015 to 06/09/2015
- 41 field-samples in 2014 and 28 in 2015 (DOC, CDOM, TSS)
- Only 6 ST5 scenes and 6 L8 scenes selected (clouds, hazing effects, acquisitions during the ice-period, too large gaps)
- 6 dates during the peakflow period (namely 22/05)
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**Time-series**

![Time-series images](image)

**Image corrections**

- Surface reflectance products were used
  - MACCS processor (Hagolle et al, 2015)
  - L8SR (L8SR Product Guide)

**Field sample treatments**

- Field measurements concern DOC (mg/L), CDOM (m\(^{-1}\)) and TSS (mg/L)
- Absorbance at 440 nm was chosen (Brezonik et al, 2015)
Methodological flowchart

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Optical satellite acquisitions

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Spectral variables

Step 3

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BD in-situ « CDOM »

Linear regression

Correlation?

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[OK]

Multiple Linear regression

CDOM proxy

Step 2

CDOM model retrieval

CDOM prediction

DOC model retrieval

DOC prediction

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### CDOM as a proxy to retrieve DOC concentrations?

- All field-samples were used \((N = 69)\)
- Goal: More robust statistical relationship

### Extraction of water surface reflectances

- A water extraction was defined:
  - 15 km North-South
  - from 300 m to river banks
- Goal: increasing the possibility to have cloud-free pixels
- \([\text{Min}, \text{max}, \text{mean}, \text{std}]\) in Green and Red channels of each spatial scene
Methodological flowchart

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Correlation ?

[KO]

[OK]

BD in-situ «DOC»

BD in-situ «CDOM»

DOC model retrieval

CDOM model retrieval

CDOM prediction

DOC prediction

Step 4
CDOM algorithm development and statistical analyses

✓ Based on existing models developed for oceans, lakes or rivers

✓ Kutser (2005) on Swedish lakes

→ green-red ratio

✓ Griffin (2011) on Kolyma river (Northern-Siberia)

→ green-blue ratio + red

✓ Spectral band multiplications were also tested (interaction term)

✓ Goodness of fit was examined with R² and Root Mean Square Error (RMSE)
CDOM can be used as a proxy to retrieve DOC concentrations in the Yenisei river.

![Graph showing correlation between CDOM and DOC](image)

$$R^2 = 0.84$$
$$p < 0.001$$
$$N = 69$$
The CDOM model developed shows high performances

\[
\text{CDOM} = -681.4 \times \text{[Green]} + 16410.9 \times \text{[Green:Red]}
\]

- \( R^2 = 0.76 \quad p < 0.001 \)
- \( \text{RMSE} = 1.2 \quad N = 12 \)

- \( R^2 = 0.79 \quad p < 0.001 \)
- \( \text{RMSE} = 1.4 \quad N = 12 \)
Shorter and longer wavelengths interaction to retrieve DOC concentrations

\[ \text{CDOM} = 681,4\cdot\text{[Green]} + 16410,9\cdot\text{[Green:Red]} \]
Shorter and longer wavelengths interaction to retrieve DOC concentrations

\[ \text{CDOM} = -681.4 \times [\text{Green}] + 16410.9 \times [\text{Green:Red}] \]

✓ Negative relationship between CDOM and [Green]
✓ Expected relationship
Shorter and longer wavelengths interaction to retrieve DOC concentrations

\[ \text{CDOM} = -681.4 \times \text{[Green]} + 16410.9 \times \text{[Green:Red]} \]

- Negative relationship between CDOM and [Green]
- Expected relationship
- Relationship between [Green] and CDOM depends on red reflectance values
- TSS strongly reflects light in red band
Shorter and longer wavelengths interaction to retrieve DOC concentrations

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\text{CDOM} = -681.4 \times \text{[Green]} + 16410.9 \times \text{[Green:Red]}
\]

- Negative relationship between CDOM and [Green]
- Expected relationship
- Relationship between [Green] and CDOM depends on red reflectance values
- TSS strongly reflects light in red band

→ For high values of TSS (> 15 mg/L), statistical relationship between shorter wavelengths and CDOM is noised
Mapping DOC concentrations during a whole open-water season

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If combined with high-spatial resolution, multi-temporal remote sensing data are precious to retrieve DOC in Arctic rivers.

☑ DOC evaluations:
  - To evaluate DOC in a hot-moment
  - To evaluate the spatial variability of DOC at largest scales

☑ Methodologically
  - To increase the possibility to have cloud-free scenes
  - To select pixels between cloud or ice-breaks
  - To apply more accurate atmospheric corrections
If combined with high-spatial resolution, multi-temporal remote sensing data are precious to retrieve DOC in Arctic rivers

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Sentinel 2/Landsat 8 synergies are promising to retrieve DOC in Great Arctic Rivers
Conclusion

✓ An effective CDOM retrieval algorithm with six dates in the freshest period
✓ Additional dates in the model will be needed (only 12 dates)

✓ Shorter and longer wavelengths combinations are powerful
✓ Potential TSS perturbations have to be taken into account

Perspectives

✓ Low and High spatial resolution could be complementary
✓ Sentinel 2 acquisitions in Igarka:
  ➔ Surface reflectance products will be delivered
  ➔ New field campaigns will be driven
  ➔ Further studies are coming…
Thanks!

Questions ?