



Surface water volume changes in the Mackenzie Delta using satellite images and radar altimetry

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INTRODUCTION

Science III : Two decades of
continental water's survey
from satellite altimetry

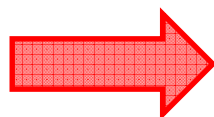
- **Ice melting** > discharge increases > **flooding** (Beltaos and Carter, 2009)
- **Increase** of Arctic rivers discharges from **18 to 70 %** from now to the end of the century (Peterson et al., 2002)
- Few *in-situ* gauges



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Mapping flooding extension at regional scale is an
important stake



REMOTE SENSING

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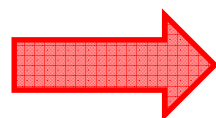
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wrmwater.com.au



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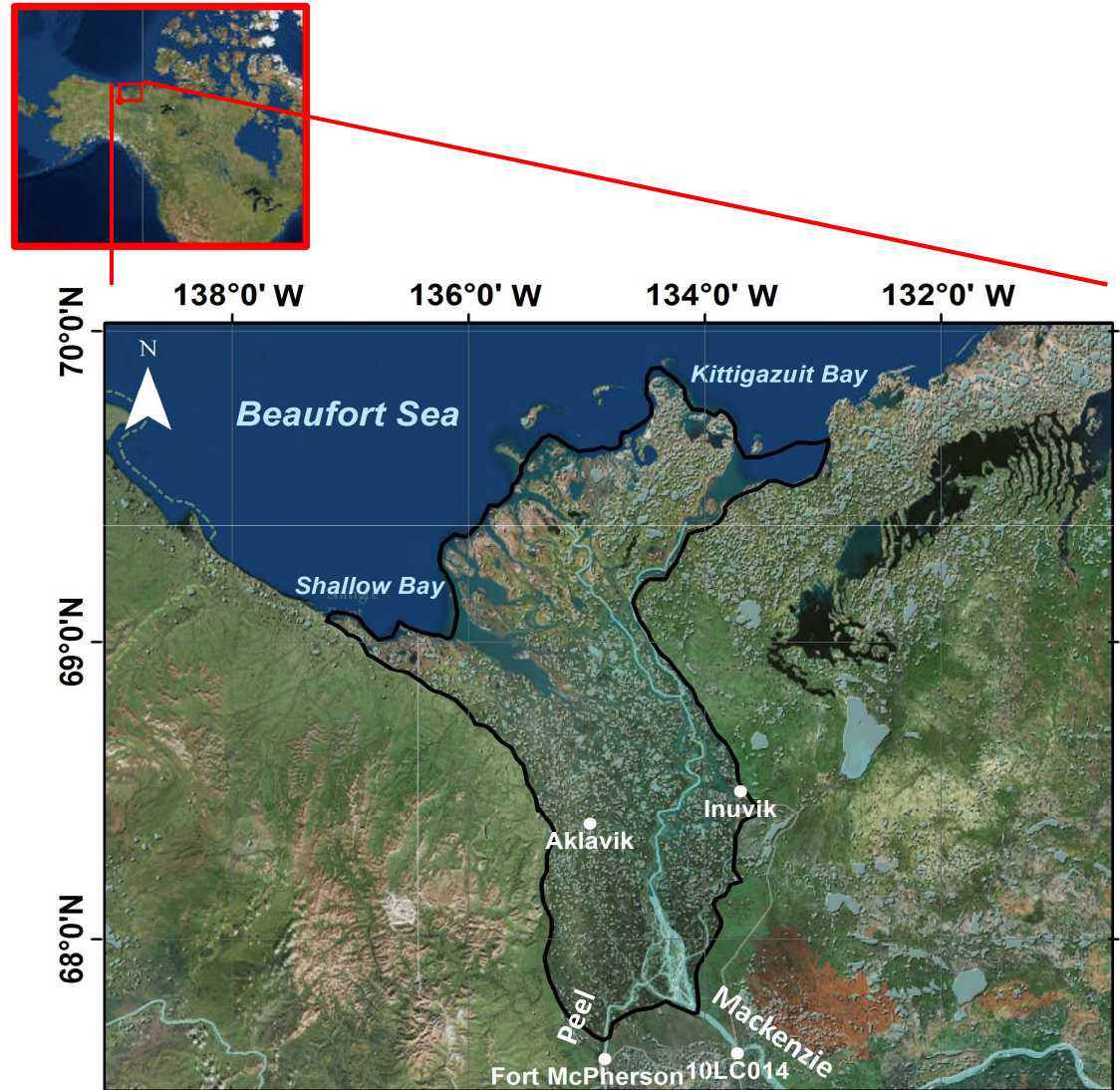
General scientific questions :

- What is the **amount** of **freshwater** stored in surface ?
- What is the **spatial** and **temporal variability** of freshwater stored in the world's terrestrial water bodies and their links with **climatic variability** ?

STUDY ZONE – Mackenzie Delta

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continental water's survey
from satellite altimetry

- $S = 13,000 \text{ km}^2$
- Length = 100 km
- Width = 80 km
- Flow of sediments = $130 \times 10^6 \text{ t.year}^{-1}$



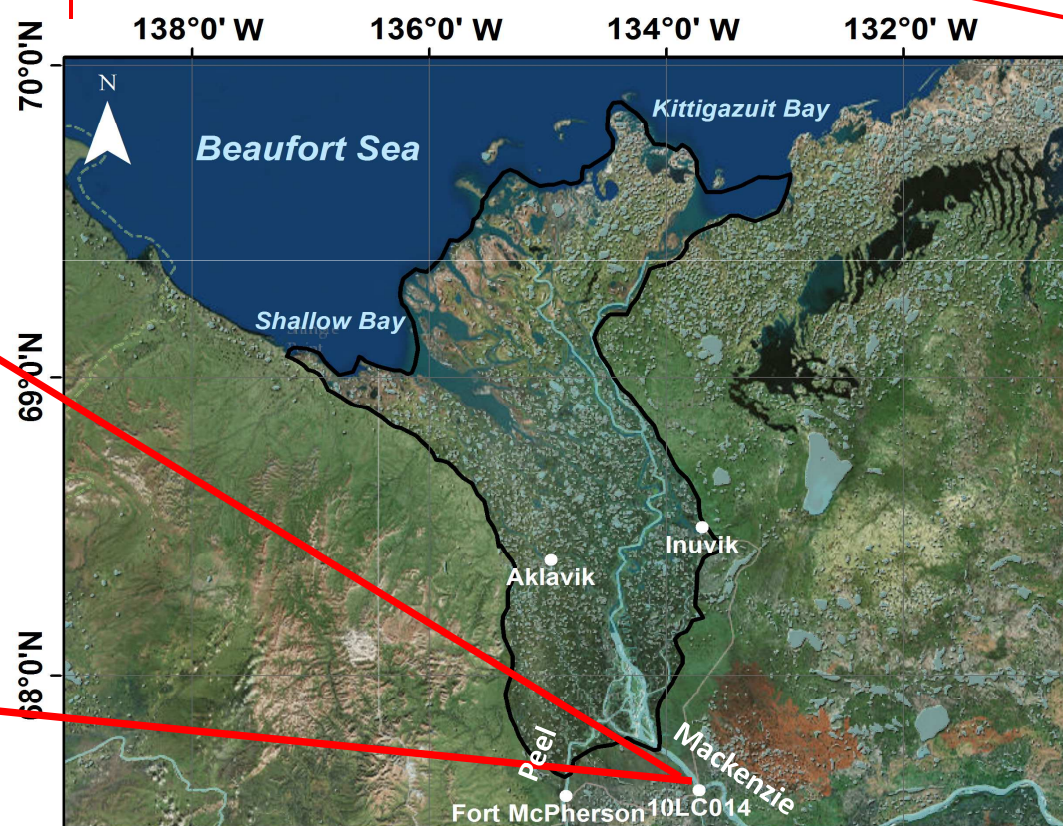
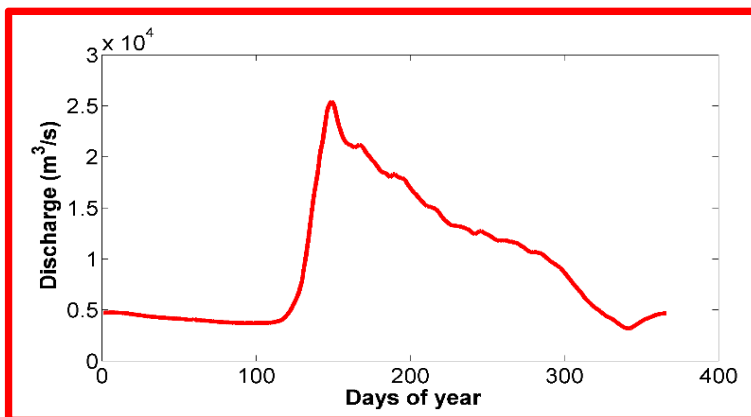
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In-situ gauge – 10 LC014



DATASET - MODIS Terra (MOD09A1)

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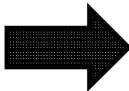
- **USGS** : United States Geological Survey

➤ <http://earthexplorer.usgs.gov/>



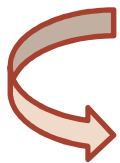
- **MODIS Terra (MOD09A1)**

- Composites products 8 days
- Spatial resolution of 500 m
- Atmospheric corrections
- BOA reflectances in 7 spectral bands

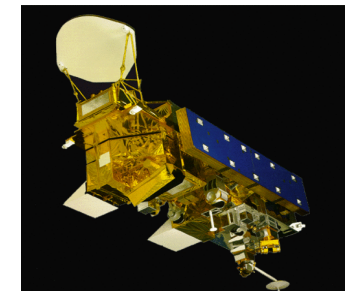


Band number	Wavelength (m)	Color	Spatial resolution (m)
1	620-670	Red	250
2	841-876	NIR	250
3	459-479	Blue	500
4	545-565	Green	500
5	1230-1250	MIR	500
6	1628-1652	SWIR 1	500
7	2105-2155	SWIR 2	500

- **2002 – 2015 : from June to September**



175 composites



Terra

6

DATASET – ENVISAT RA-2, SARAL, ERS-2

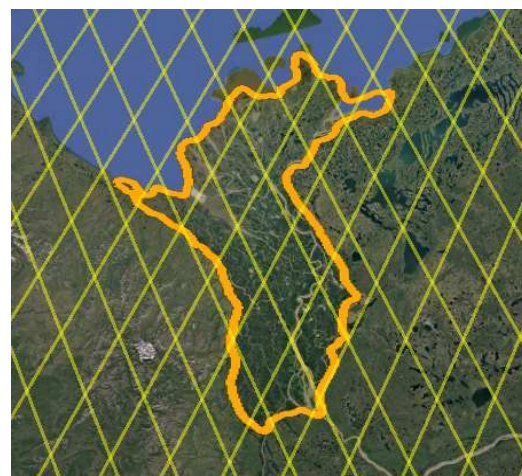
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from satellite altimetry

- **CTOH** : French Observation Service dedicated to satellite altimetry studies at LEGOS-OMP

- Altimetry data : <http://ctoh.legos.obs-mip.fr/products/>
- Altimetric tracks :
<http://www.aviso.altimetry.fr/fr/donnees/outils/localiser-une-demi-orbite.html>



- ENVISAT RA-2 : 2002 - 2010
- SARAL : from 2013 to now
- ERS-2 : from 1995 to 2003



Altimetry tracks

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DATASET – Complementary data

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continental water's survey
from satellite altimetry

<i>Sources</i>	<i>Parameters</i>
Laser altimetry ICESat/GLAS NASA, Hall et al., 2012 GLAS/ICESat L2 Global Land Surface Altimetry data (HDF5) V034	Heights for in-situ stations levelling
In-situ data Canada government http://wateroffice.ec.gc.ca/	Discharges Water levels Levelling levels

METHODS – Flooded areas using satellite imagery

Science III : Two decades of continental water's survey from satellite altimetry

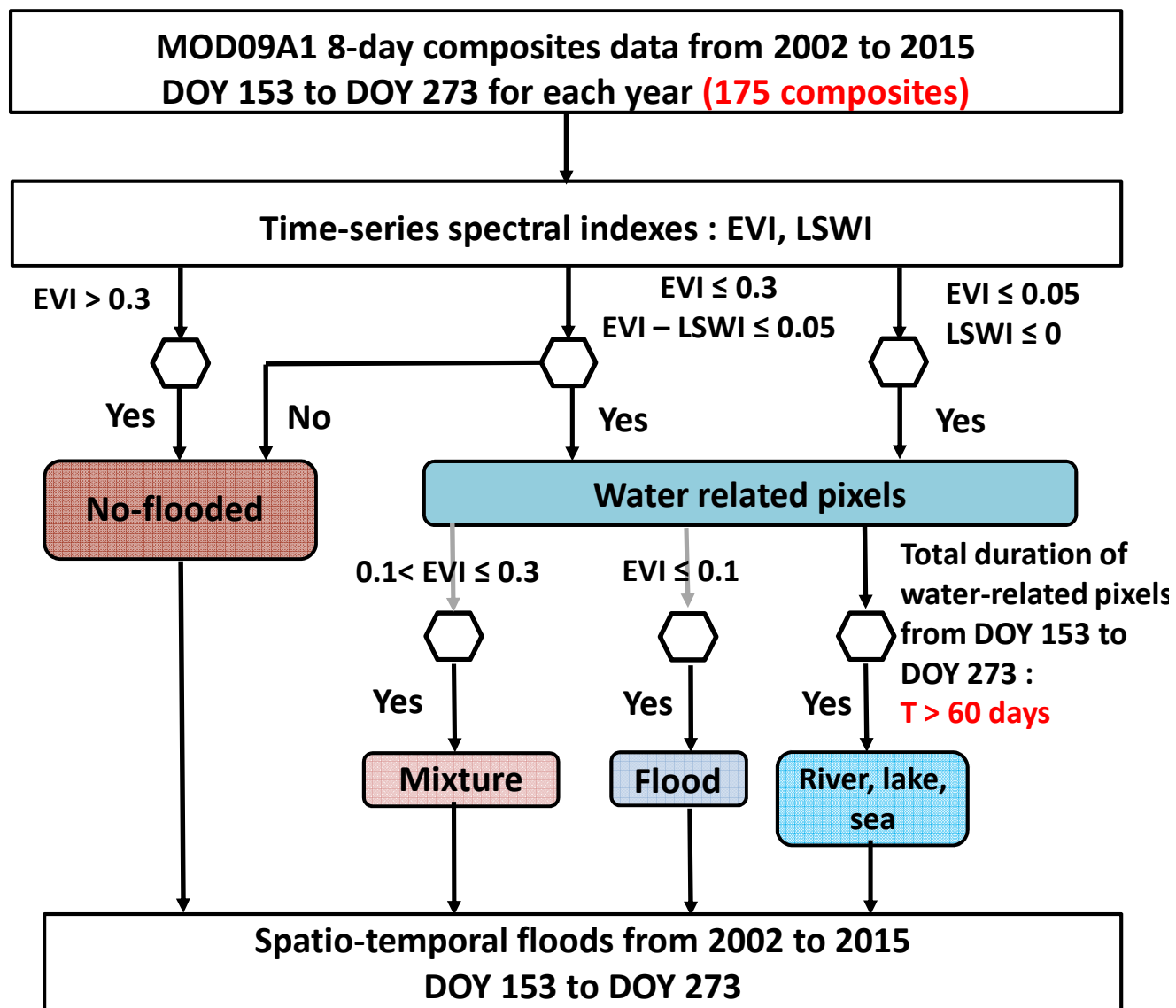
- Sakamoto *et al.*, 2007, modified

$$EVI = 2.5 \times \frac{NIR - RED}{NIR + 6 \times RED - 7.5 \times BLUE + 1}$$

$$LSWI = \frac{NIR - SWIR}{NIR + SWIR}$$

Where :

- NIR is the surface reflectance value in the near infrared (841-875 nm, band 2)
- Red (621-670 nm, band 1)
- Blue (459-479 nm, band 3)
- SWIR (1628-1652 nm, band 6)



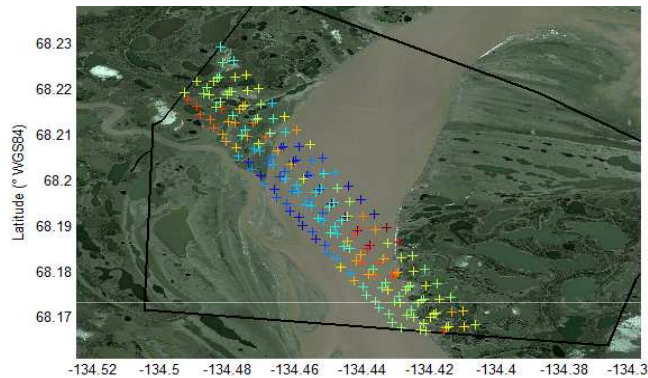
METHODS – MAPS (Multi-Mission Processing Software)

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Virtual stations (VS) created using MAPS

Frappart *et al.*, 2015

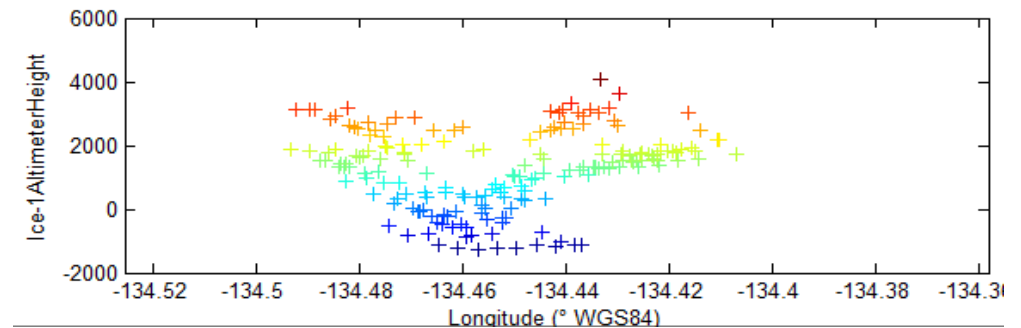
1. Data selection



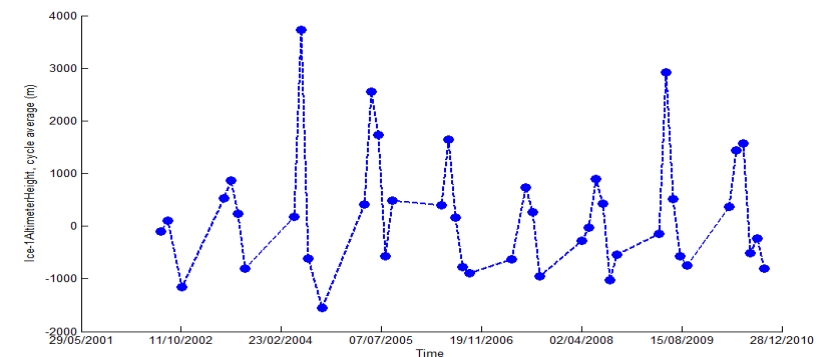
- ENVISAT-RA2 : 28 VS
- SARAL : 25 VS
- ERS-2 : 23 VS



2. Wrong points removal



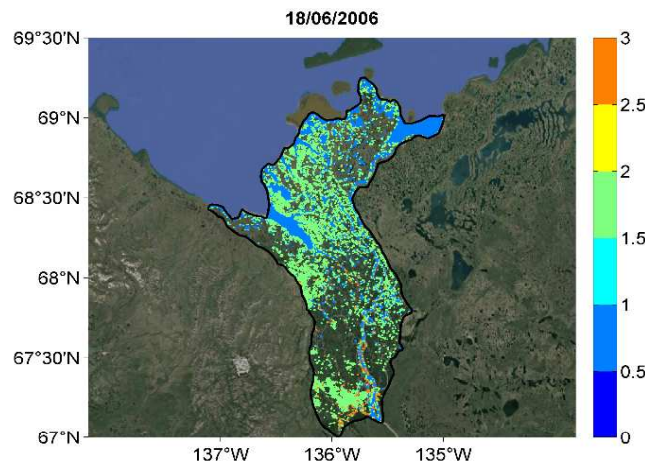
3. Water levels time-series



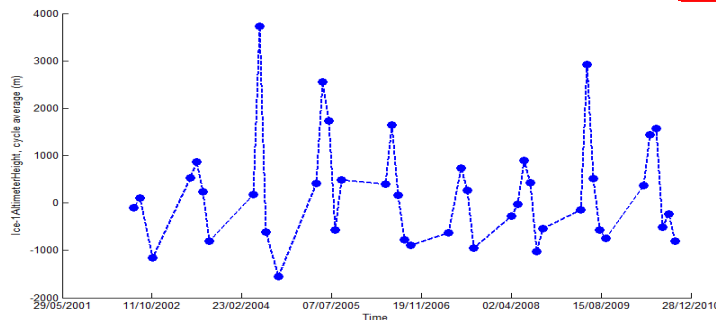
METHODS – Water level maps

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INUNDATED
SURFACE

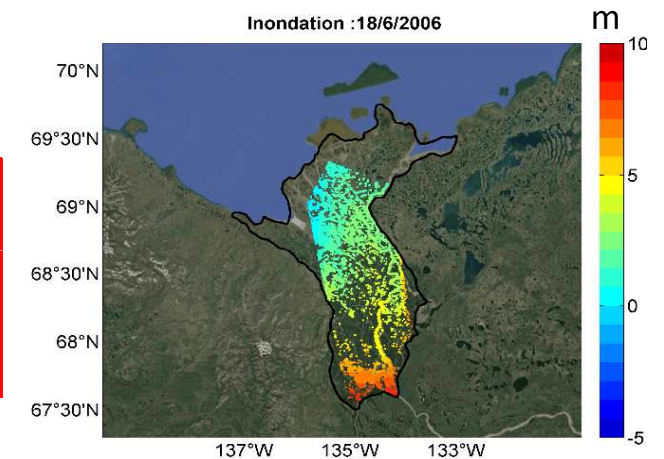


WATER
LEVELS



Opposite
interpolation to the
nearest virtual station
distance

WATER LEVELS MAPS



For each inundated pixel, **minimal**
water level was determined $h_{\min}(\lambda_j, \varphi_j)$

- At drainage basin scale, time series of surface water storage are calculated using :

$$V = \sum [h(\lambda_j, \varphi_j, t) - h_{\min}(\lambda_j, \varphi_j)] \cdot \Delta S$$

Surface water storage (km³)

Water level for the pixel (λ_j, φ_j, t) at instant t

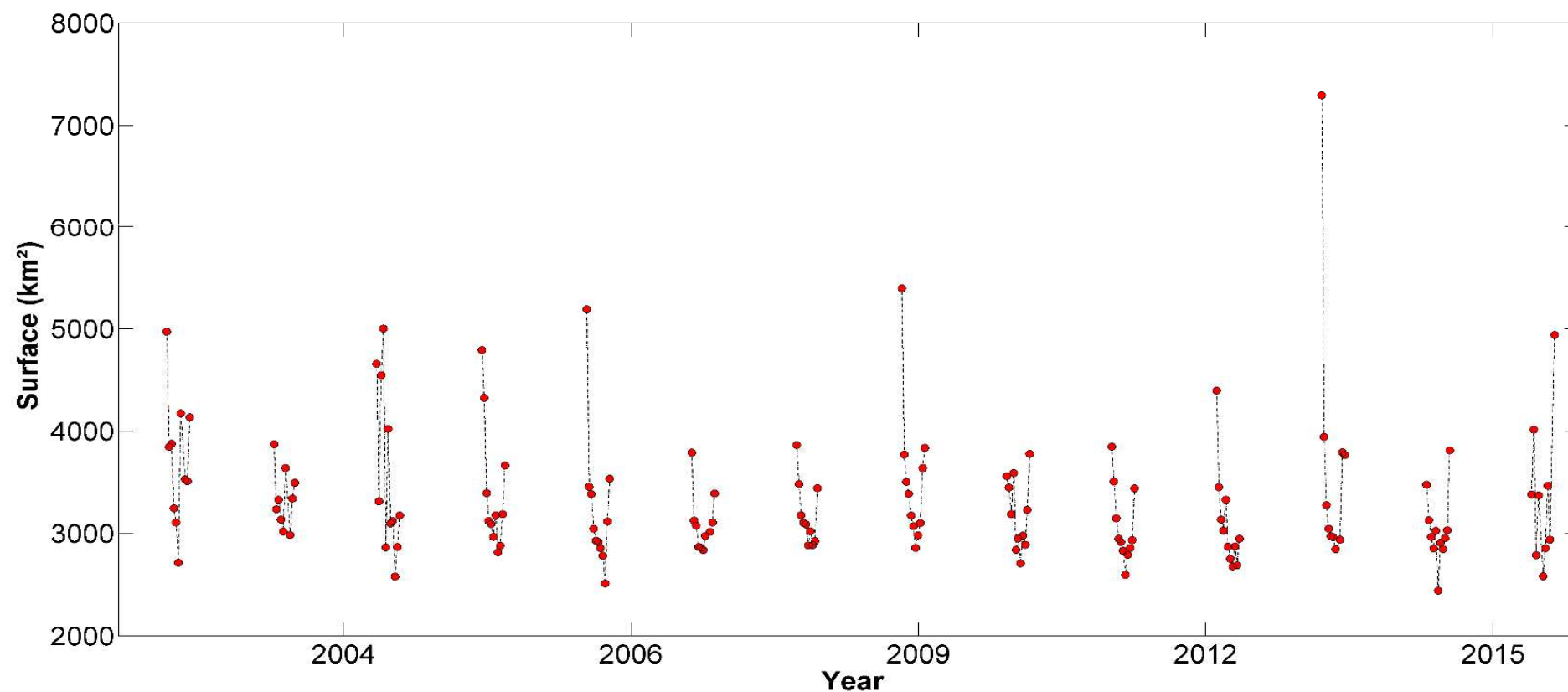
The minimal water level for the pixel (λ_j, φ_j)

Pixel surface (0.25 km²)

RESULTS – Flooded surface time-series

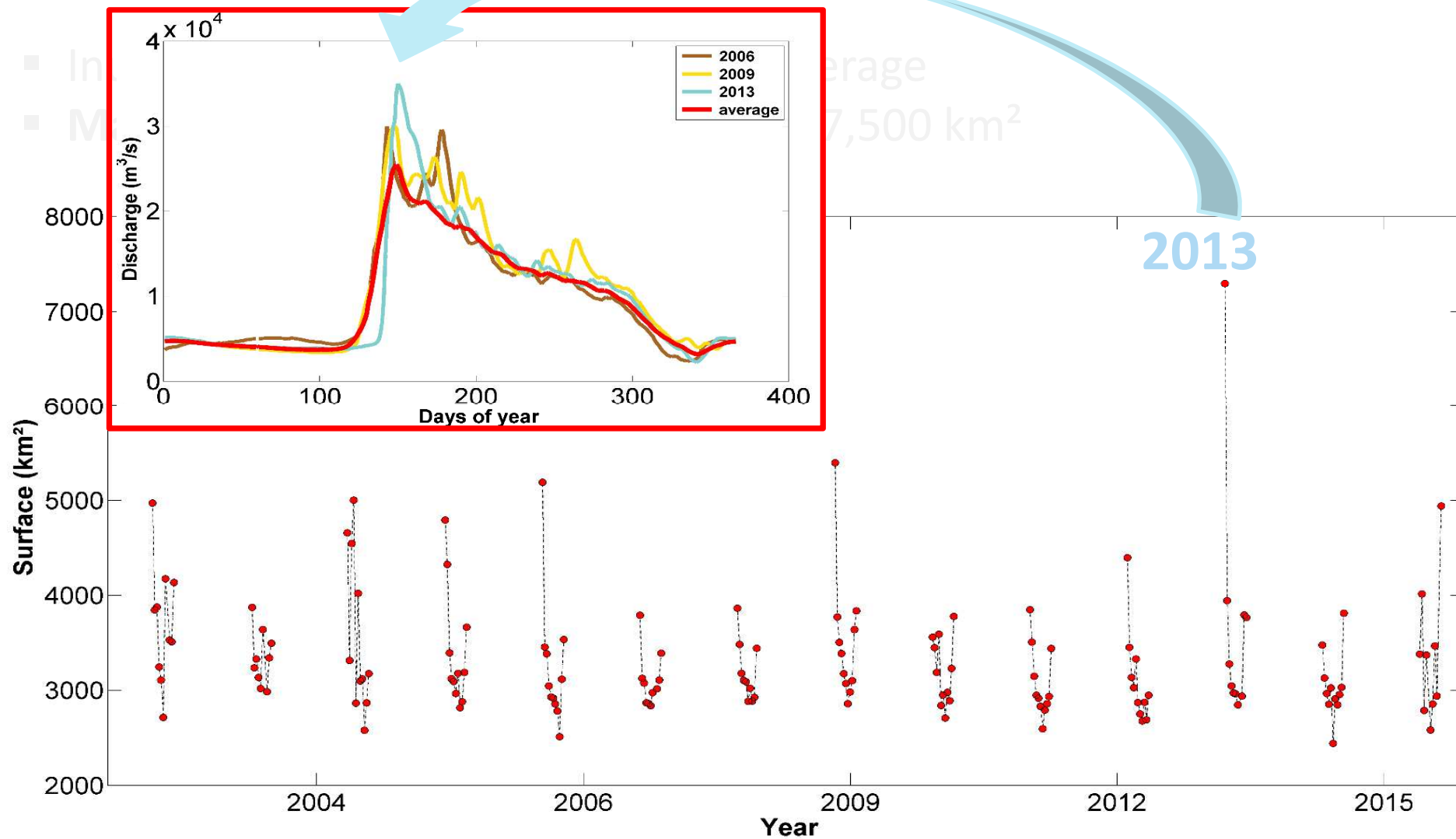
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- Inundated surface : ~ **4,000 km²** in average
- **Maximal** inundated surface in **2013** ~7,500 km²



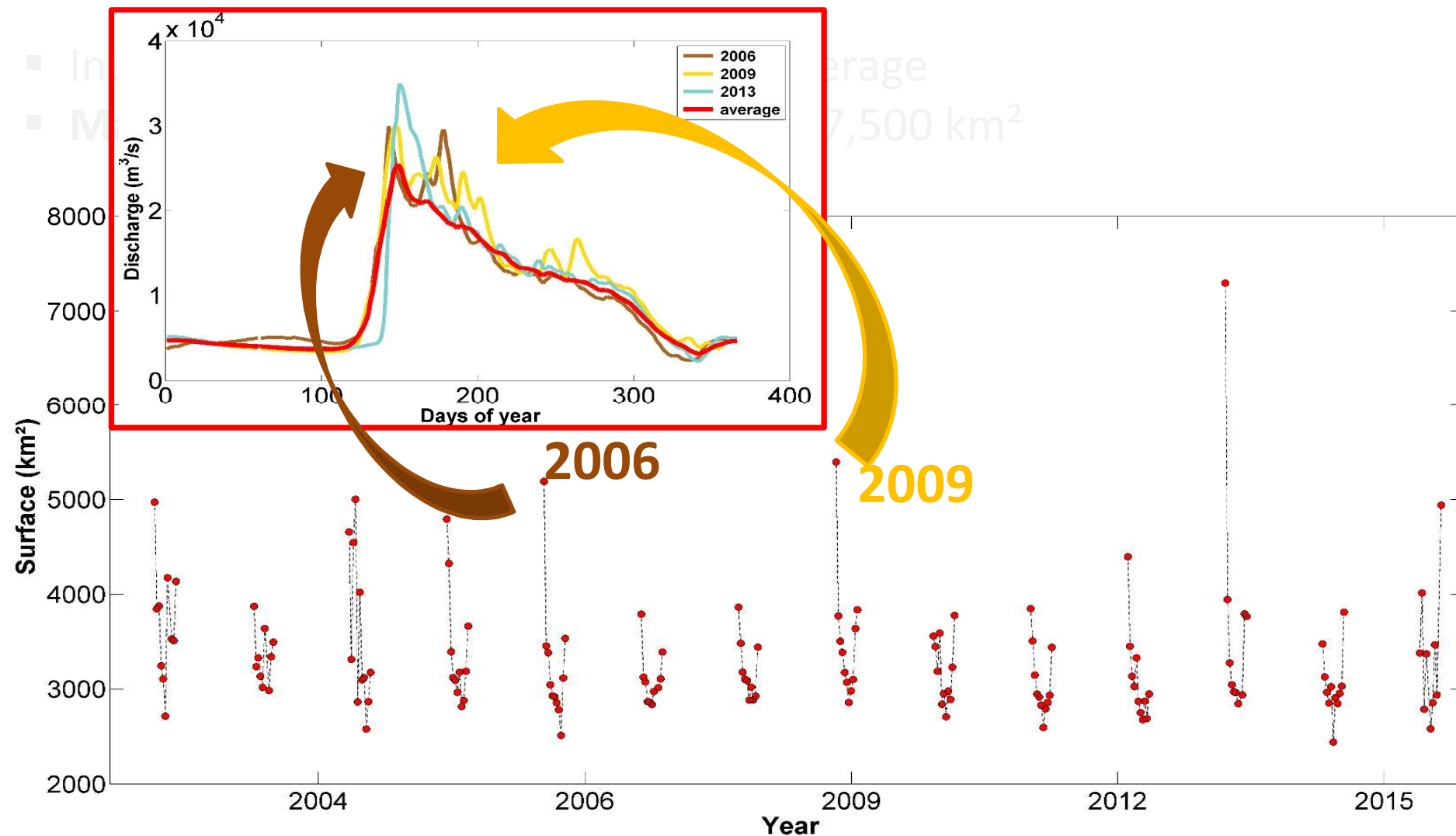
RESULTS – Flooded surface time-series

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RESULTS – Flooded surface time-series

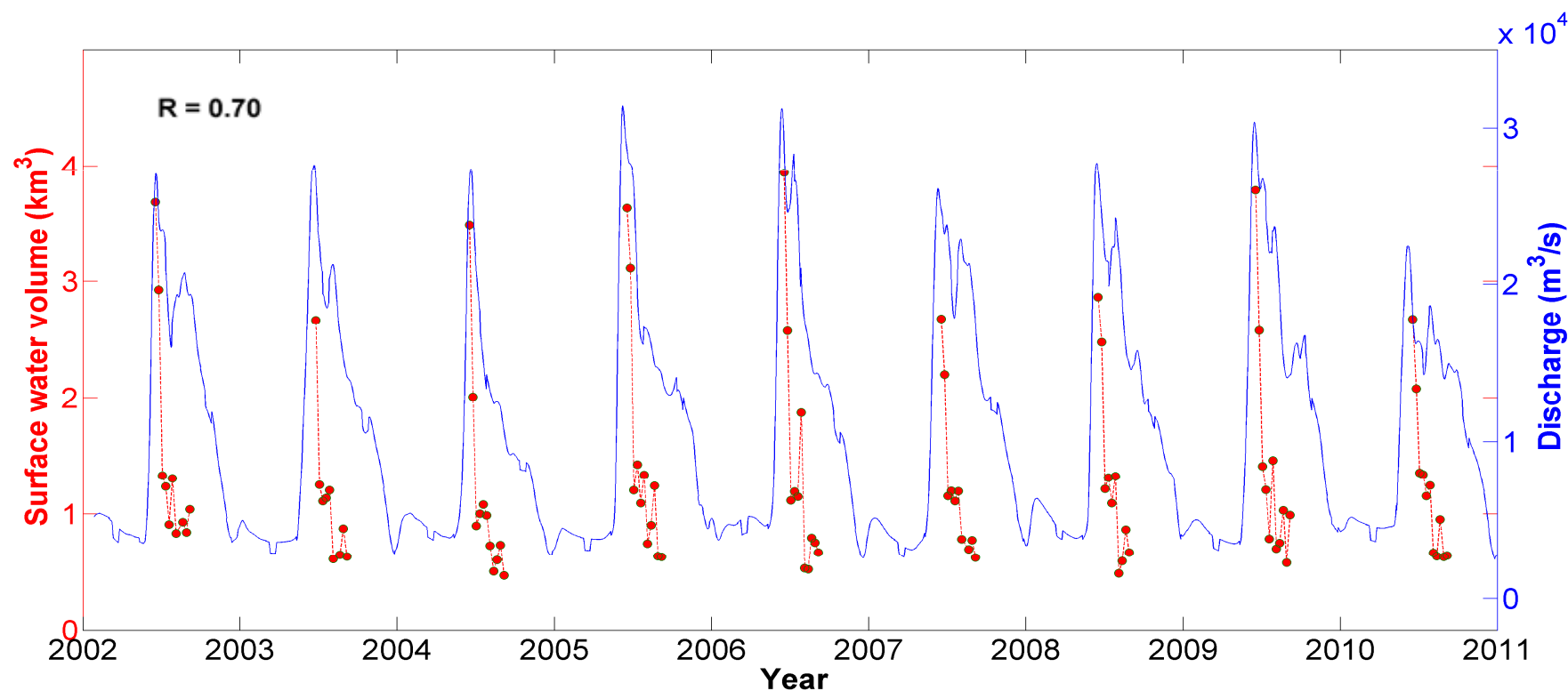
Science III : Two decades of
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RESULTS – Surface water volume time-series

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continental water's survey
from satellite altimetry

- From 2002 to 2010 : **ENVISAT**
- Surface water volume in June : $\sim 3 \text{ km}^3$
- **Maximal** surface water volume in **2006** : $\sim 4 \text{ km}^3$
 - large flood event in 2006 reported by Beltaos and Carter, 2009



CONCLUSION AND PERSPECTIVES

Science III : Two decades of
continental water's survey
from satellite altimetry

- Flooded surface : ~ **4,000 km²**
 - Surface water storage : ~ **3 km³**
 - Limits :
 - satellite imagery : spatial resolution of **500 m**
 - altimetry : **large footprint** (several km) + temporal resolution of **35 days**
-

- Measure impact of surface water volumes on **muddy plume** in the Arctic sea
- **Extending** study periods :
 - Altimetry : CryoSat-2 (since 2010), **Sentinel-3A** (2016), **3B** (2017)
 - Imagery : **impact of HR images** **Sentinel 2A** (June 2015) ~20m
 - Futur : **SWOT (2021)**. Cal/val future L2/L3 products?

 *link with **climatic variability** ?*

Canadian geographic

Canada government

**Thank you
for your attention!**

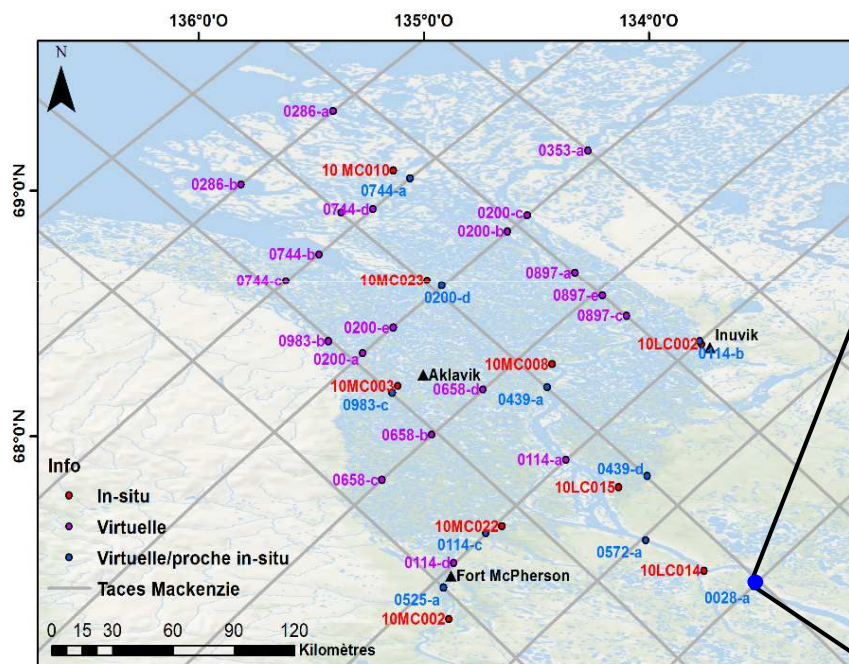
Canadian geographic

albertaoilmagazine

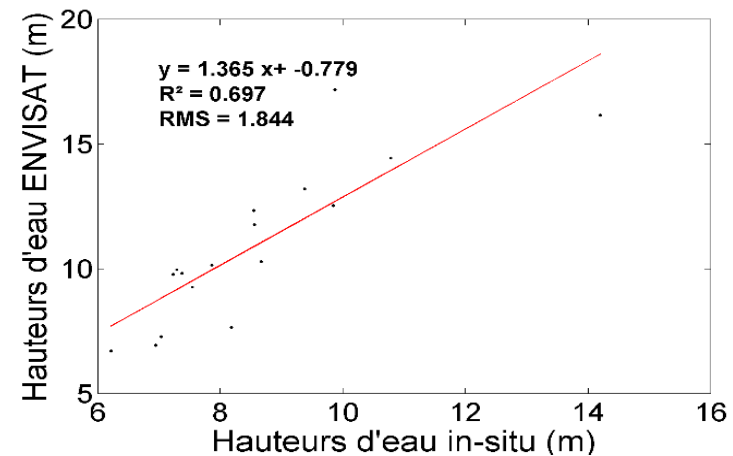
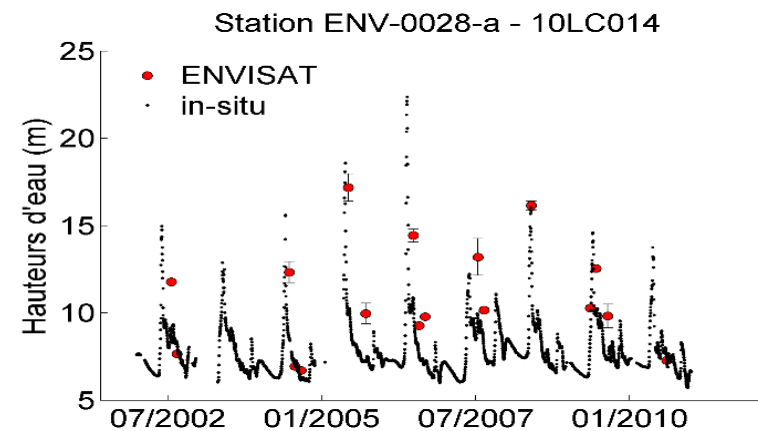
- Beltaos S., Carter T. Field studies of ice breakup and jamming in the Mackenzie Delta. CGU HS Committee on River Ice Processes and the Environment, 15th Workshop on River Ice, June 15-17, **2009**.
- Frappart, F., Papa, F., Santos da Silva, J., Ramillien, G., Prigent, C., Seyler, F., Calmant, S. Surface freshwater storage and dynamics in the Amazon basin during the 2005 exceptional drought. *Environmental Research Letters*, **2012**, 7, 044010.
- Frappart F., Papa F., Malbeteau Y., Gabriel Leon J., Ramilien G., Pigent C., Seoane L., Seyler F., Calmant S. Surface freshwater storage variations in the Orinoco floodplains using multi-satellite observations. *Remote sensing*, **2015**, 7, 89-110.
- Peterson B.J., Holmes R.M., McClelland J.W., Vorosmarty C.J., Lammers R.B., Shiklomanov A.I., Shilkomanov I.A., Rahmstorf S. Increasing river discharge to the Arctic Ocean. *Sciencemag*, **13 décembre 2002**, vol 298, 2171-2173.
- Sakamoto T., Nguyen N.H., Kotera A., Ohno H., Ishitsuka N., Yokozawa M. Detecting temporal changes in the extent of annual flooding within the Cambodia and the Vietnamese Mekong Delta from MODIS time-series imagery. *Remote sensing of environment*, **2007**, 109, 295-313.

❖ Validation water levels method

ENV-0028-a / 10LC014

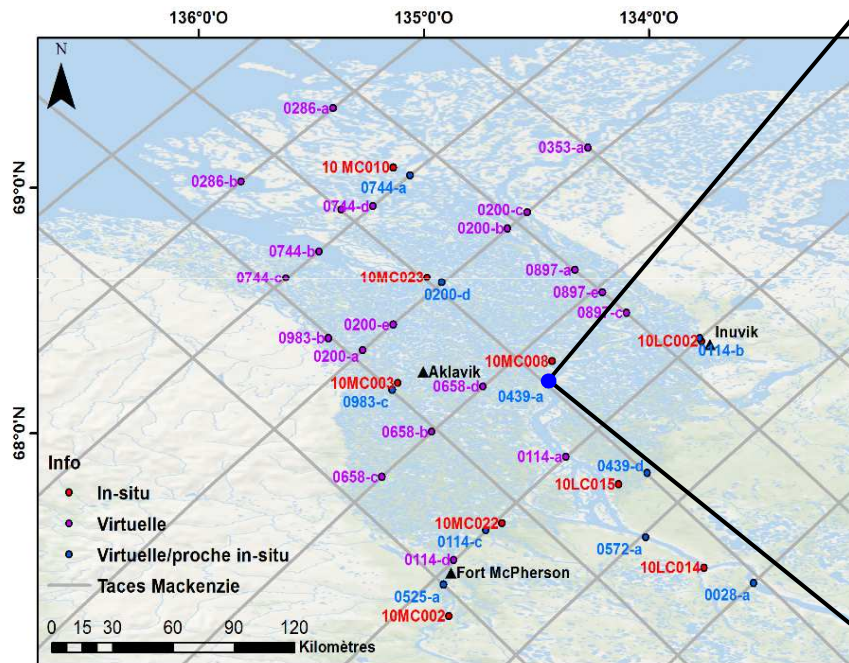


$r=0,83$

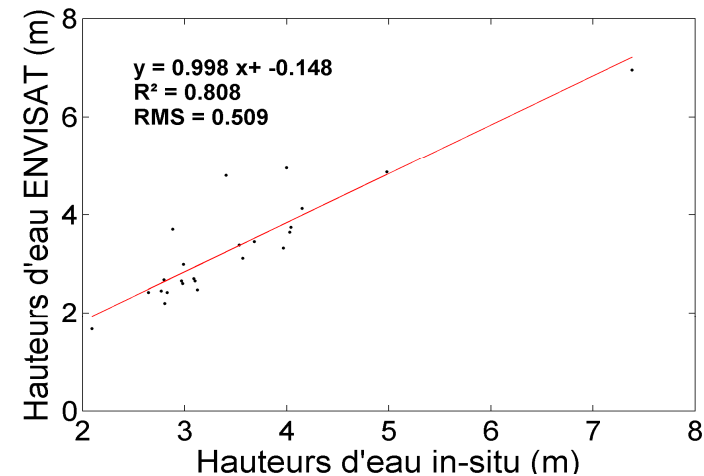
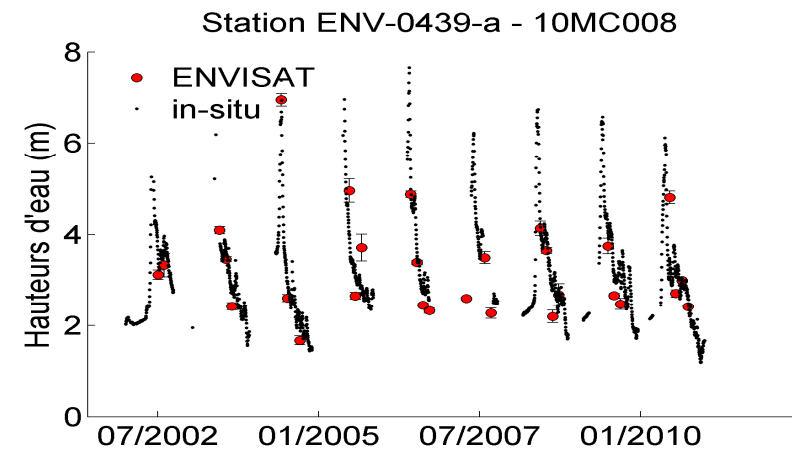


❖ Validation water levels method

ENV-0439-a / 10MC008

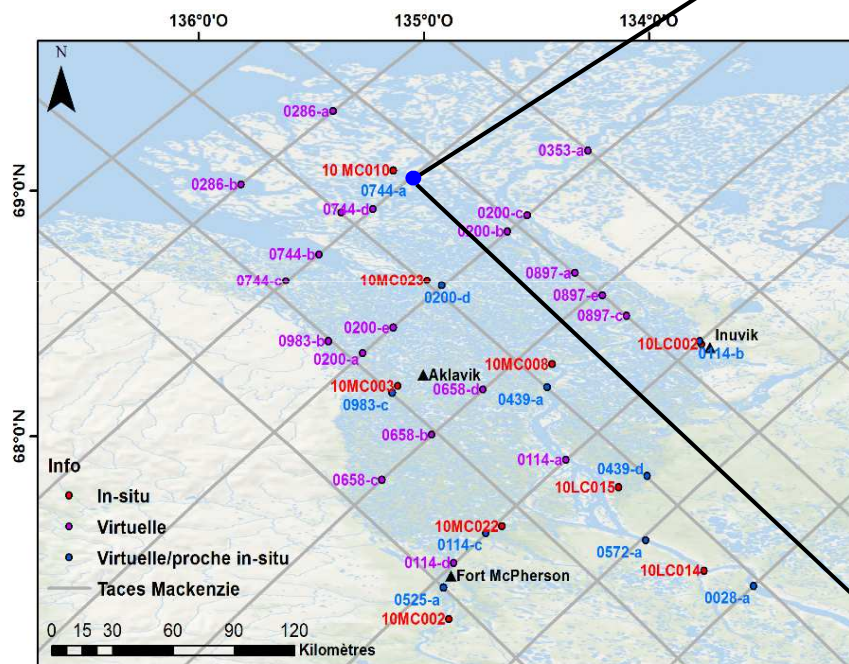


$r=0,90$



❖ Validation water levels method

ENV-0744-a / 10MC010



$r=0,83$

