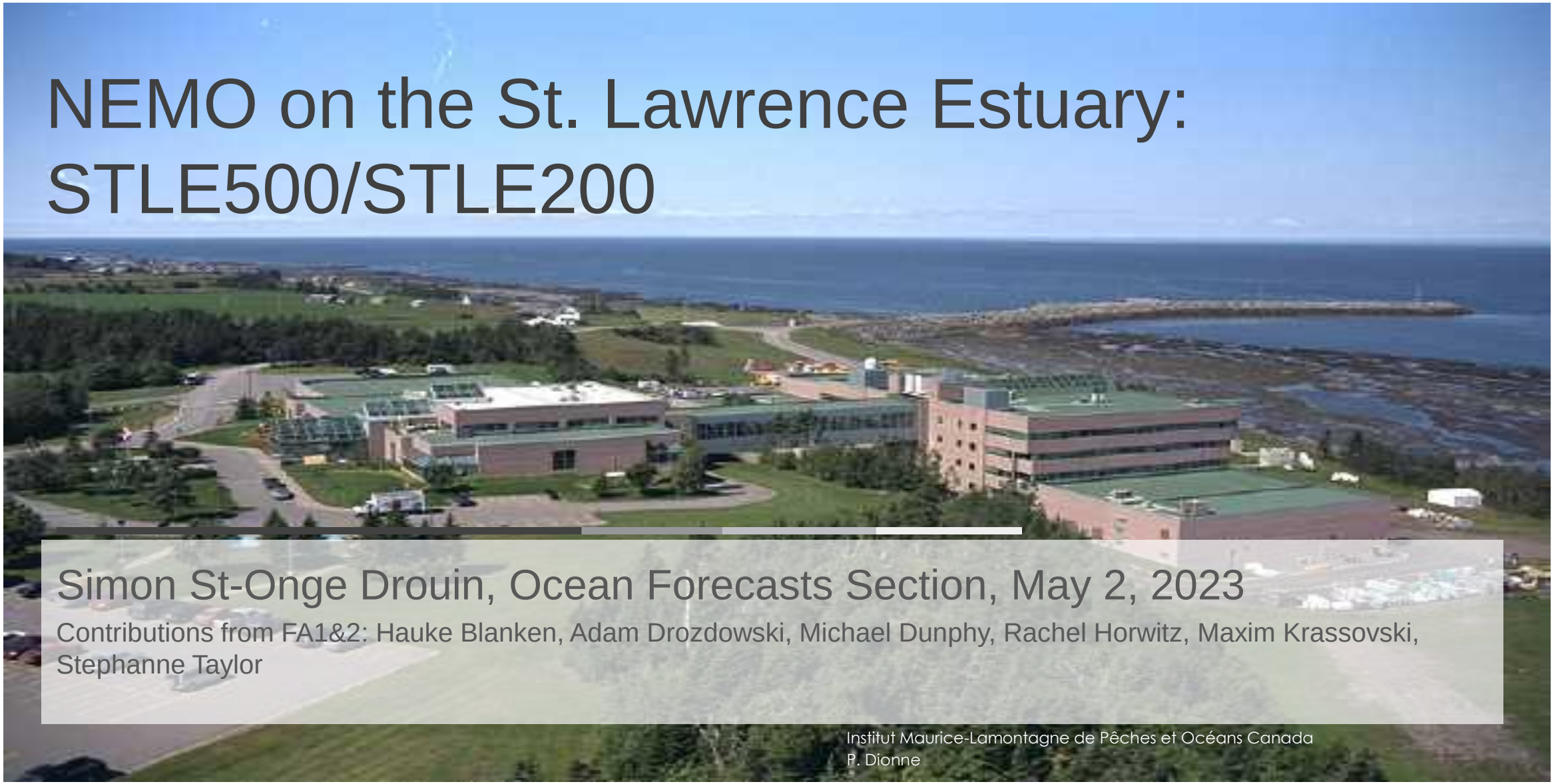
NEMO on the St. Lawrence Estuary: STLE500/STLE200



Simon St-Onge Drouin, Ocean Forecasts Section, May 2, 2023

Contributions from FA1&2: Hauke Blanken, Adam Drozdowski, Michael Dunphy, Rachel Horwitz, Maxim Krassovski, Stephanne Taylor

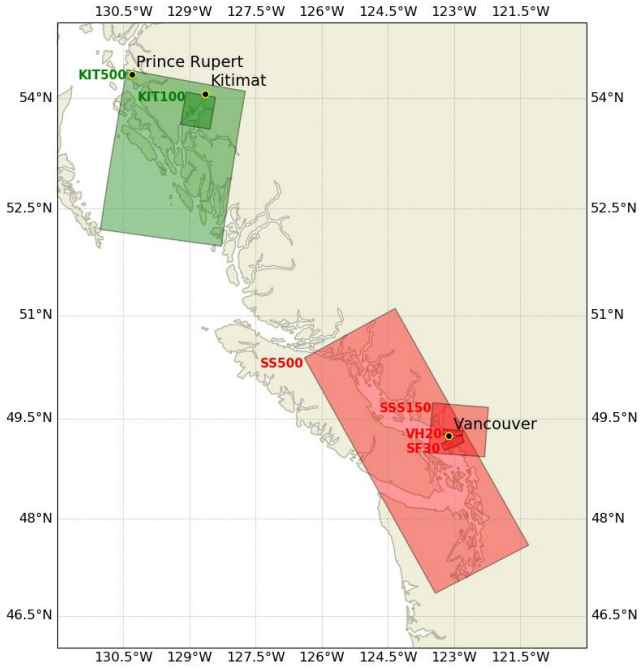
Institut Maurice-Lamontagne de Pêches et Océans Canada
P. Dionne

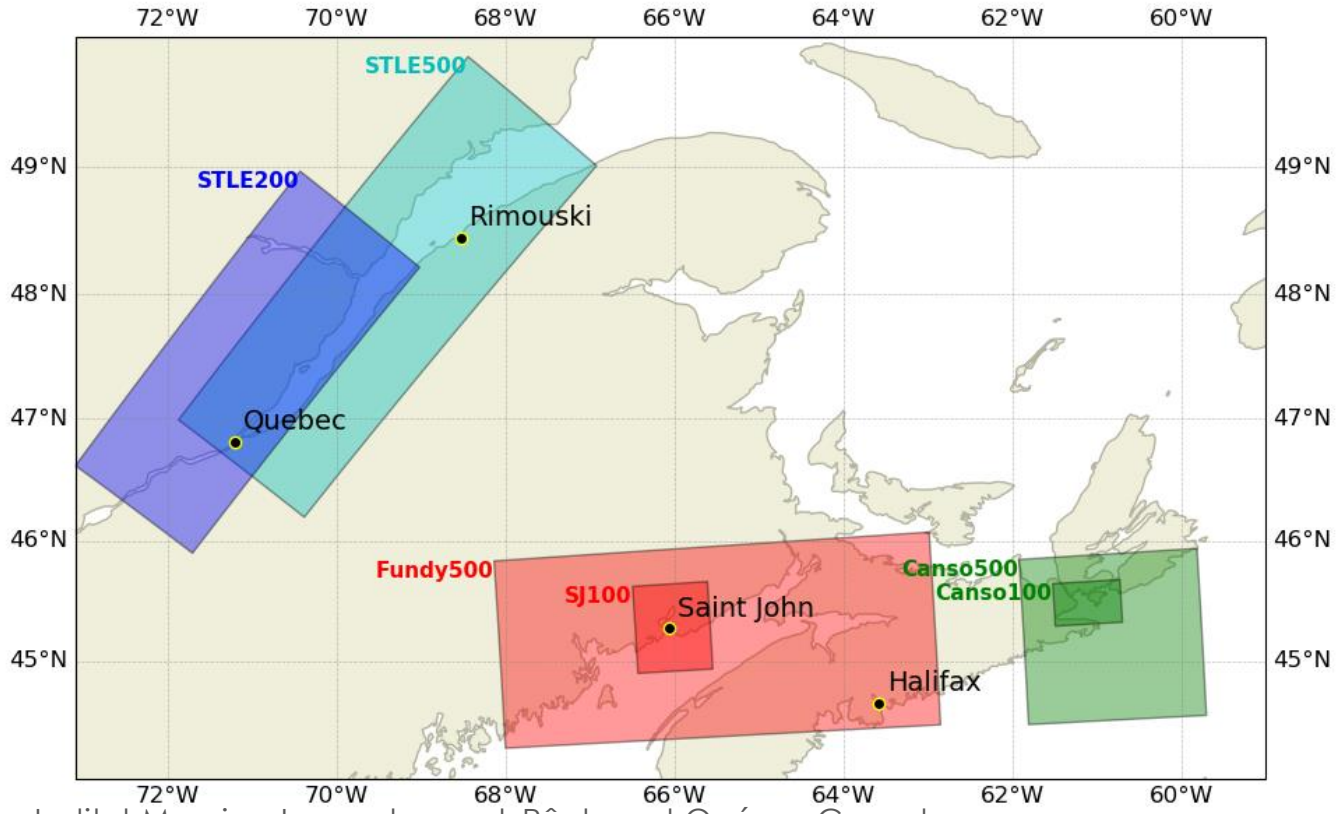
Presentation Plan

1. Context and Model description
2. Water level evaluation
3. Water velocity evaluation
4. Forecast evaluation

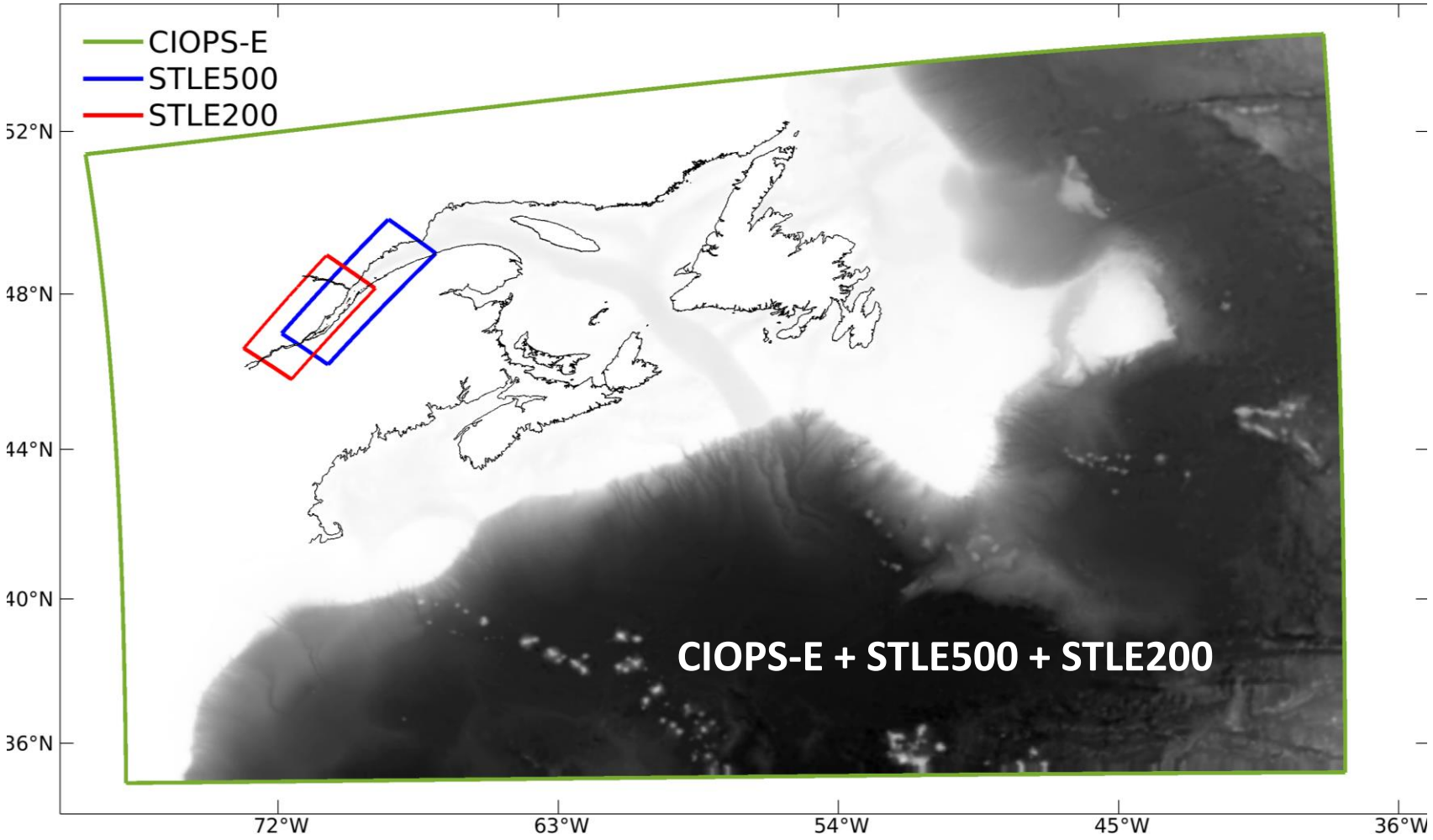
POPS: Port Ocean Prediction Systems developed under Ocean Protection Plan (OPP)

(1) Enhanced environmental protection and marine safety applications (e.g., drift prediction for oil spills)
(2) Enhanced safety for navigation and related activities (hydrographic e-navigation).



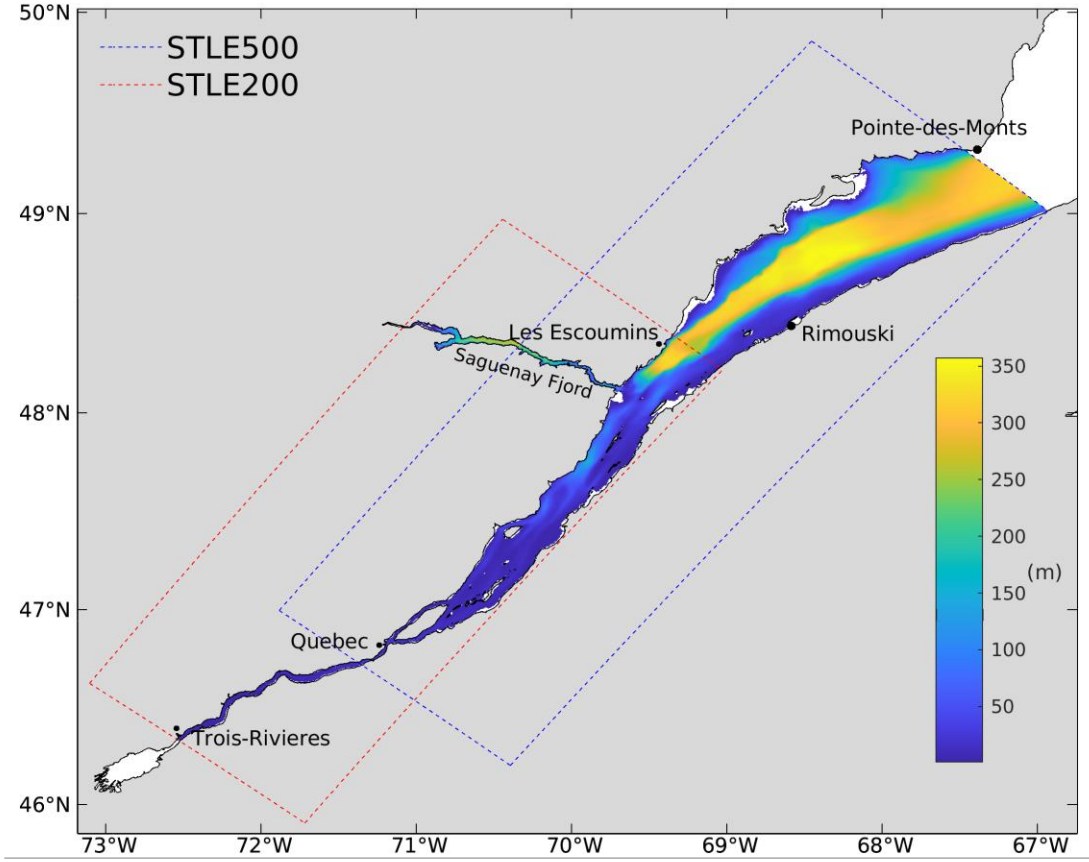


St. Lawrence modelling systems



Model domains, general informations

STLE500 (blue box) extends from Pointe-des-Monts to Québec (just east of Québec's bridge).
STLE200 (red box) extends from Les Escoumins to Trois Rivières.

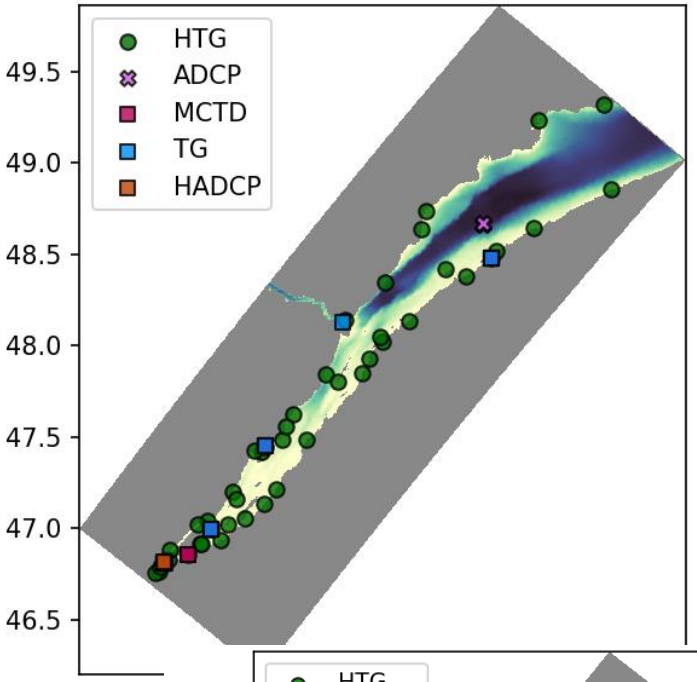


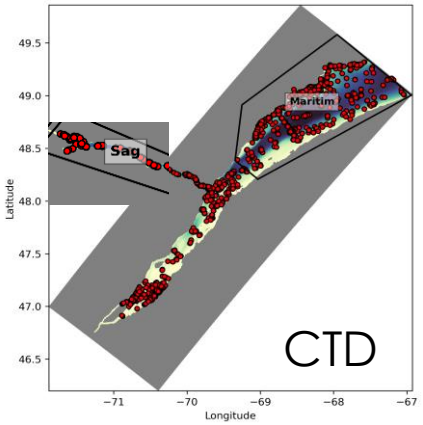
	STLE200	STLE500
Horizontal resolution	200 m	500 m
Time step	8 s	30 s
Vertical resolution, first layers	3m	1m

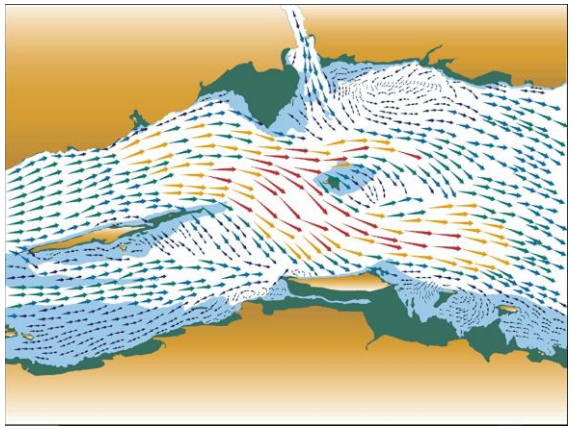
- NEMO 3.6, CONCEPTS version
- Tides are provided by OTPS at the eastern boundary of both models
- Both models are coupled to a 1-D model in a 2-way nested mode at their western boundary in order to modulate St. Lawrence runoff and correctly propagate the tidal wave

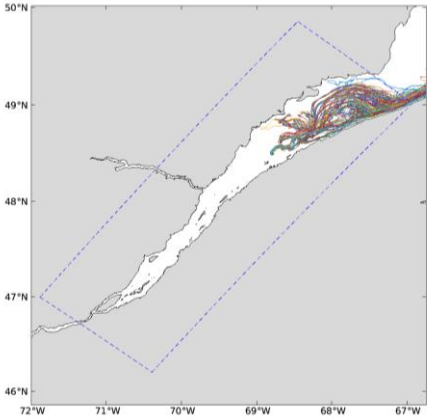
Maps of observations

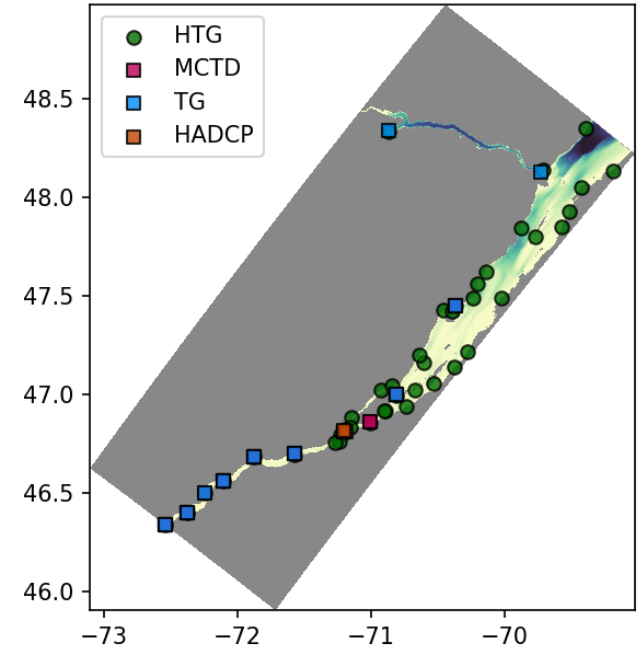
- Multiple observations and products were used to validate the models: CTDs, moored CTDs, ADCPs, HADCPs, historical tide gages, drifters, tidal atlas, storm surge evaluation.

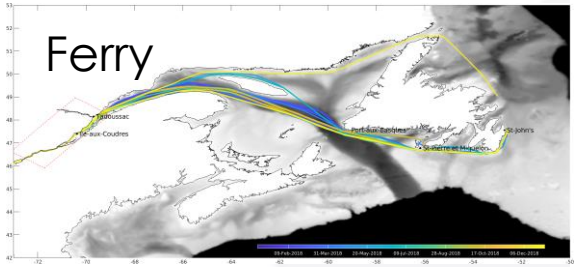




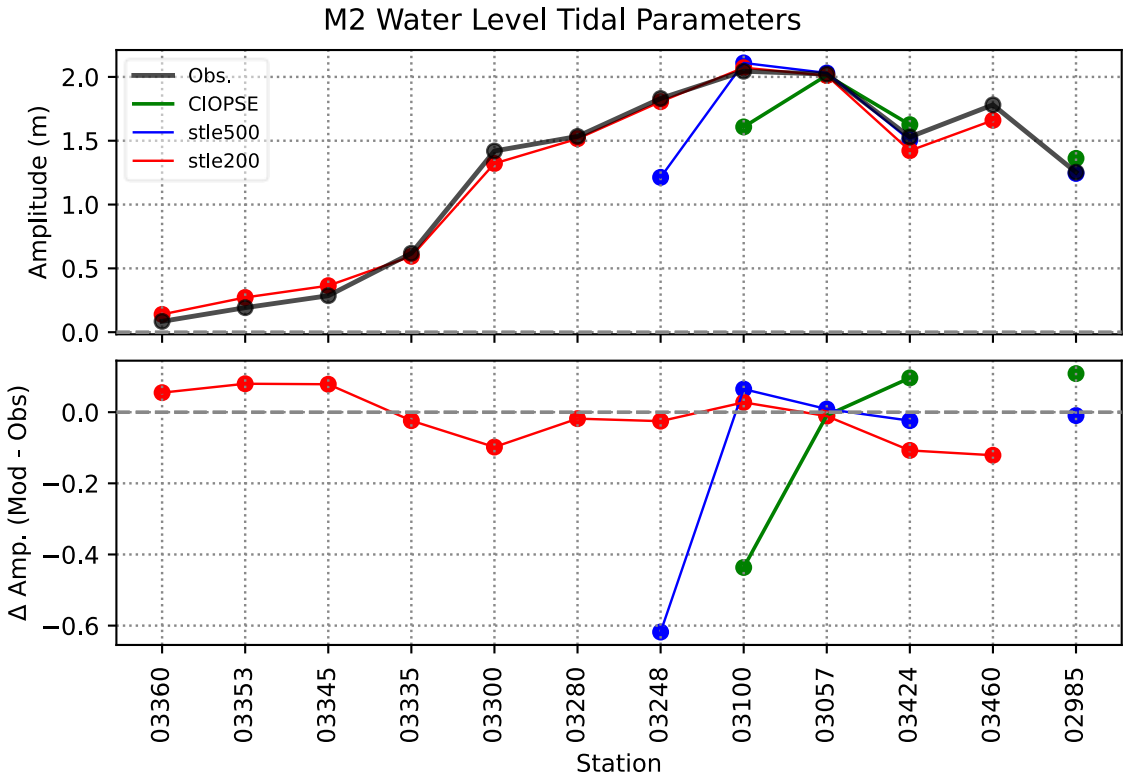


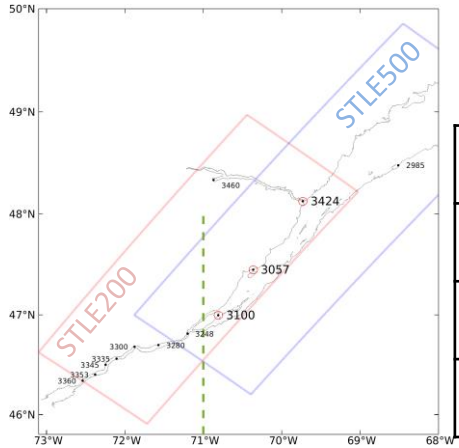






Water Level – Tides M2





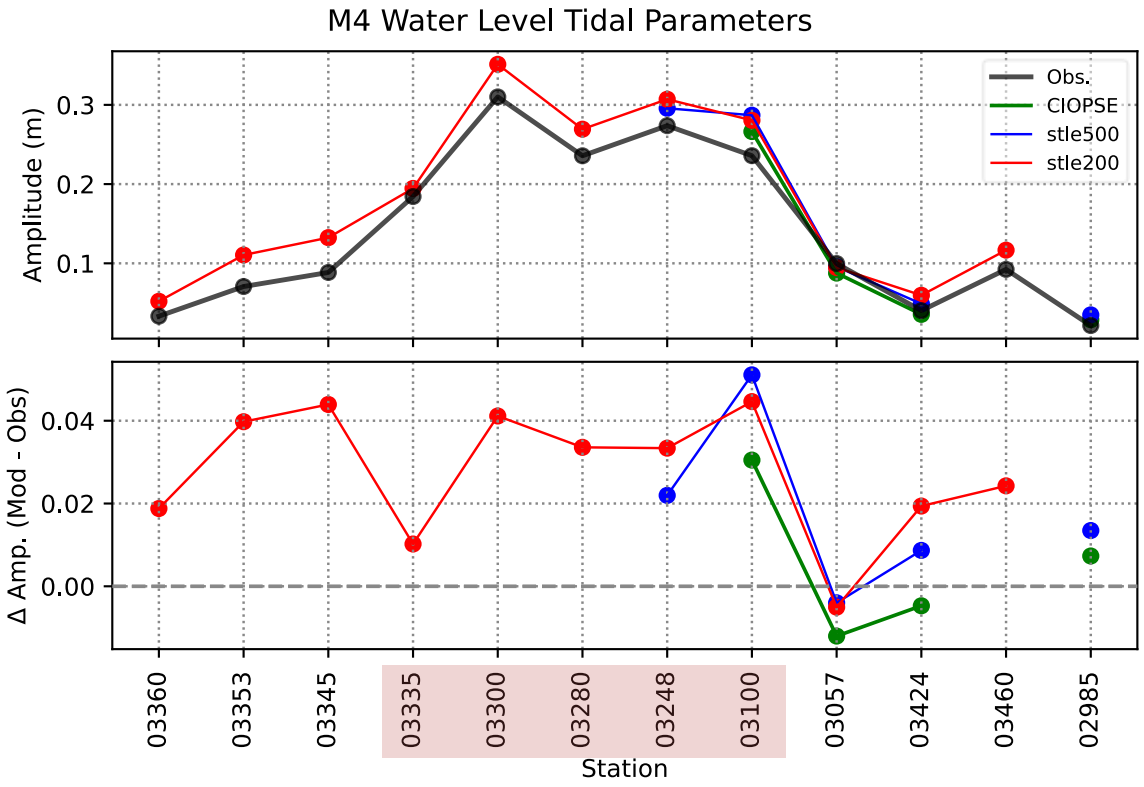
Tidal error (cm)

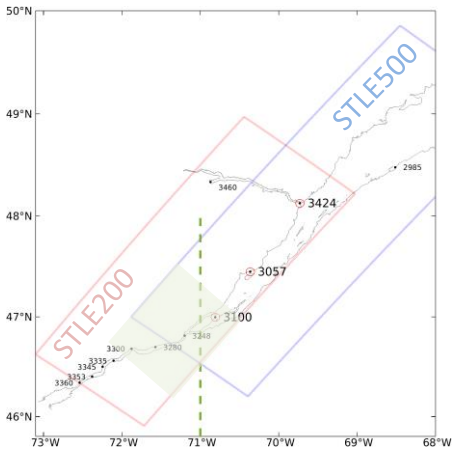
Stations	**CIOPS-E**	**STLE500**	**STLE200**
3100	32.5	13.8	2.0
3057	28.2	15.4	5.7
3424	30.6	19.1	8.2

- *Phase and amplitude are improved in STLE200*
- *Similar for all major constituents*

Tidal error: $D_\eta = \langle(\eta_o - \eta_m)^2\rangle^{1/2} = \left[\frac{1}{2}(h_o^2 + h_m^2) - h_o h_m \cos(\phi_o - \phi_m)\right]^{1/2}$ Cummins and Thupaki, 2018

Water Level – Tides M4

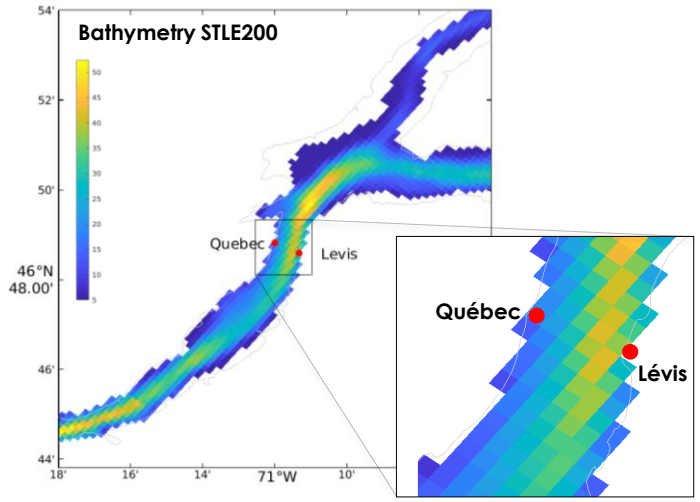


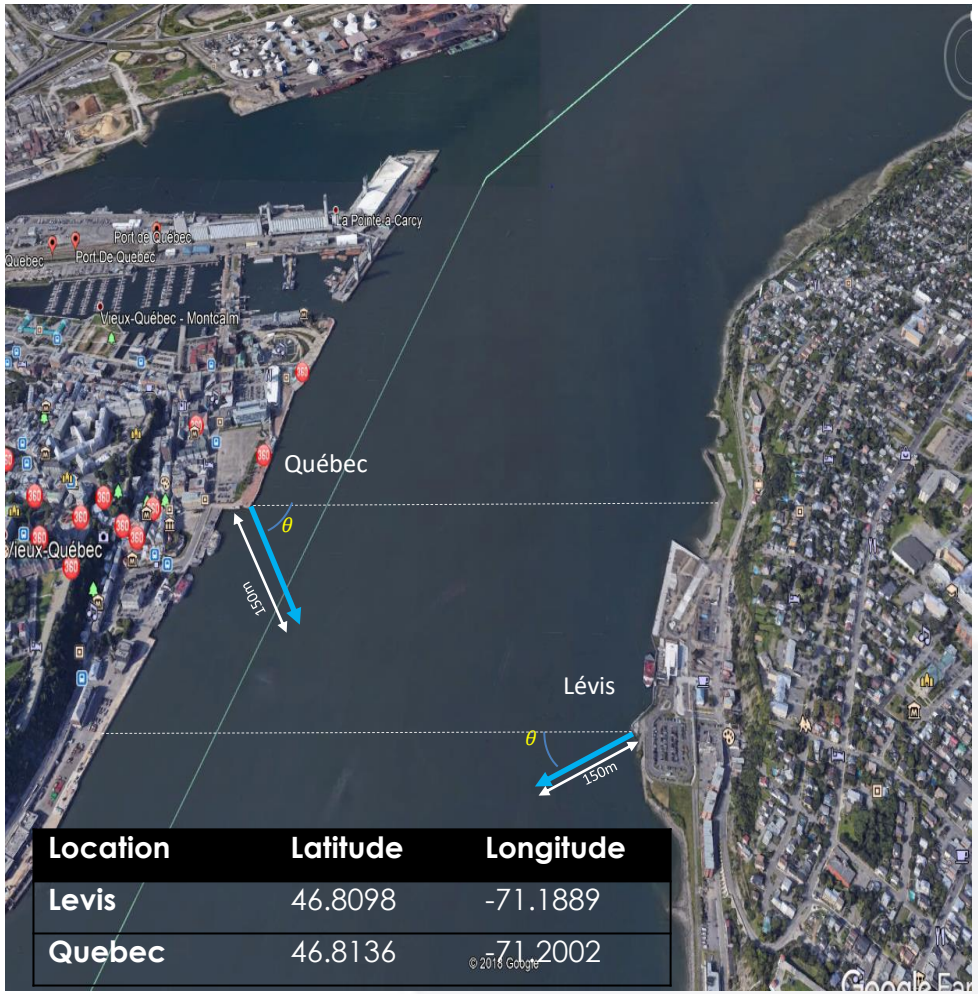


- *M4 quarter-diurnal component amplitude is significant from station 3100 to station 3335*
- *All the models reproduce this, but overestimate it's amplitude by ~4cm*

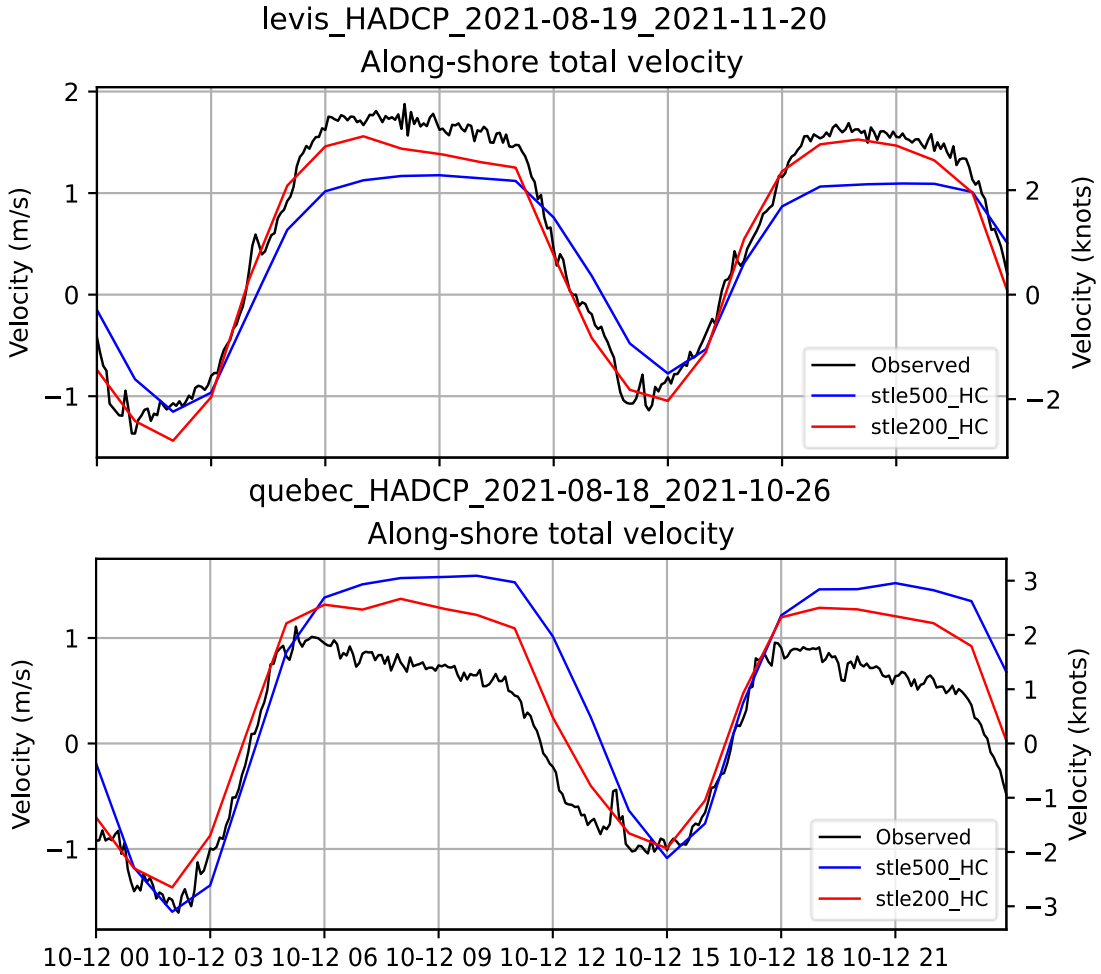
Water Velocity - HADCP

- Two HADCP have been deployed on each side of the St. Lawrence river, one at Lévis and one at Québec, for a ~2 months period in 2020 and 2021.



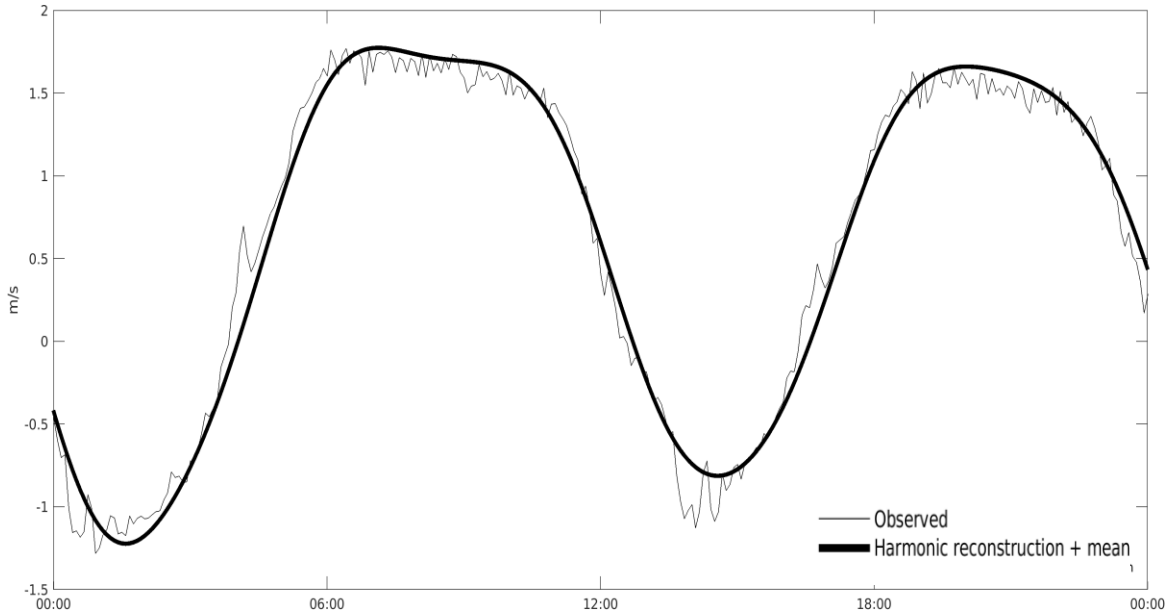


Water Velocity - HADCP



- *The improvement is clear at both ebb and flood tide from STLE500 to STLE200*
- *For both Québec and Lévis, the most striking characteristic of the signal is that it is **truncated during ebb tide**.*
- *Due to strong runoff and constriction upstream near Québec's bridge? Just tidal effect?*

Water Velocity – HADCP – Truncated ebb currents

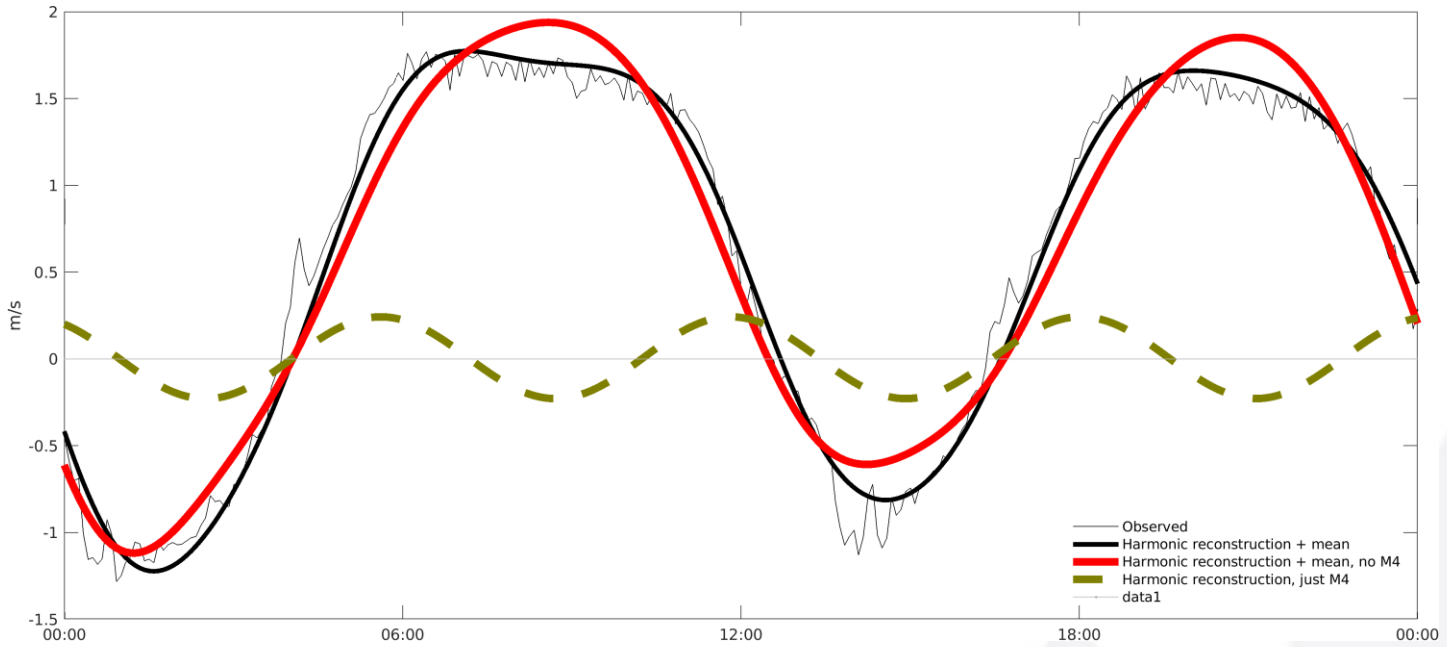


- *I used u_tide Matlab package (Codiga 2011) to analyse the signal and reconstruct it.*
- *The truncation during ebb tide is strictly due to tides*

Codiga, D.L., 2011. Unified Tidal Analysis and Prediction Using the UTide Matlab Functions. Technical Report 2011-01. Graduate School of Oceanography, University of Rhode Island, Narragansett, RI. 59pp.

Water Velocity – HADCP – Truncated ebb currents - Lévis

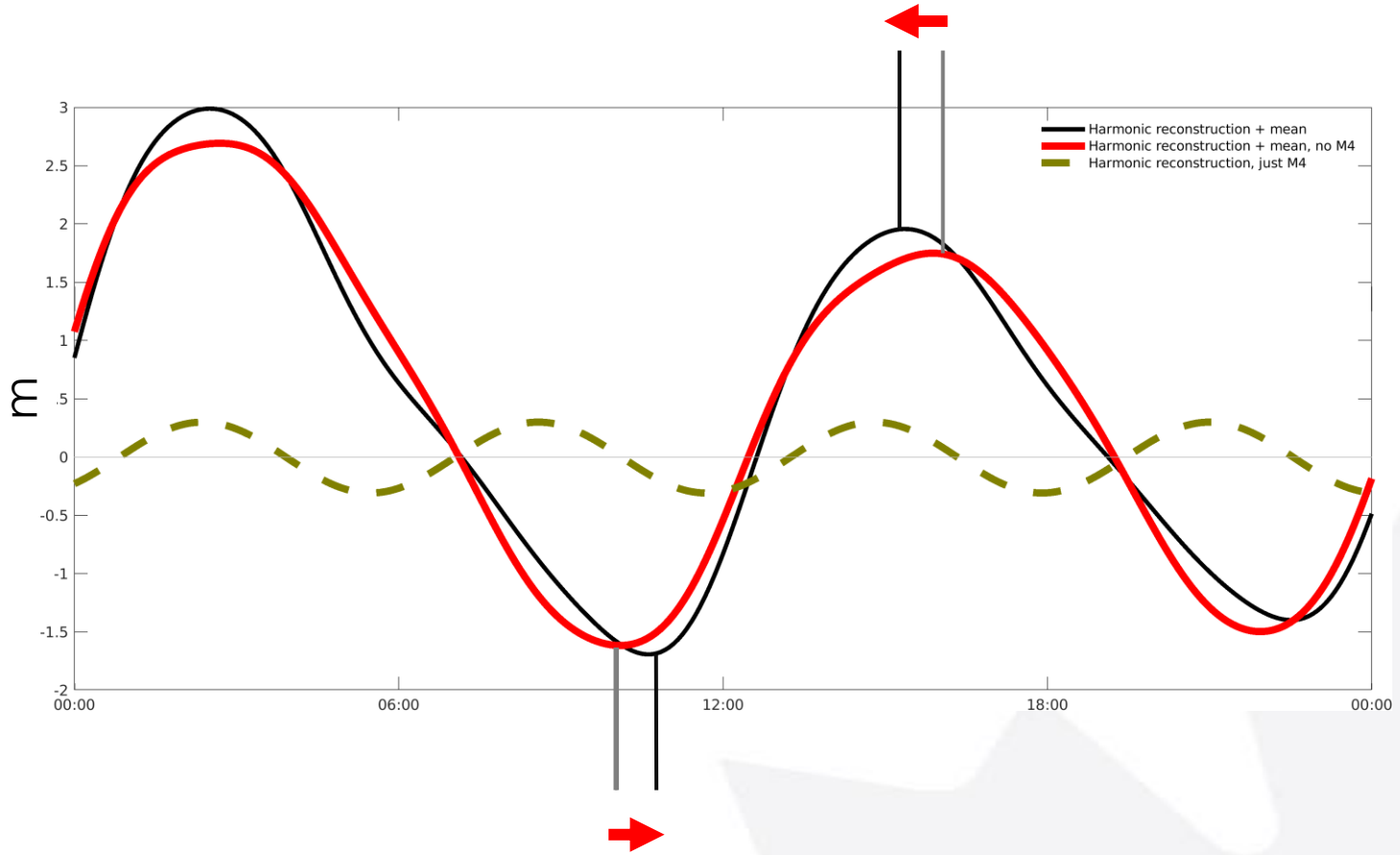
- Reconstructing the signal without the M4 quarter-diurnal constituent (red) removes the "flat top" of the signal
- Superimposing the M4 signal (green) makes it more intuitive to understand how the M4 constituent is having this effect on the surface current signal



Const.	Amp (m/s)
M2	1.31
S2	0.33
M4	0.24

Water Level - Lévis – modeled SSH

- The effect of M4 on SSH is to create an asymmetric signal: low tide is delayed, and high tide is advanced, which makes the flood tide shorter than the ebb tide.
- In the past, this asymmetry was commonly interpreted as an effect of the runoff of the St. Lawrence River.



Water Velocity – HADCP – Truncated ebb currents

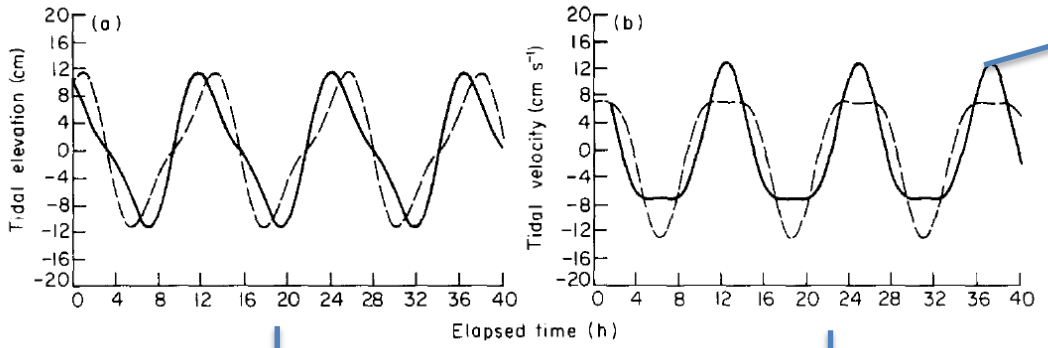
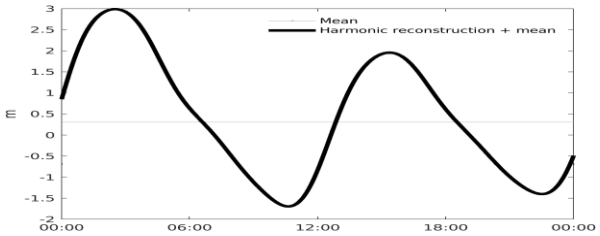


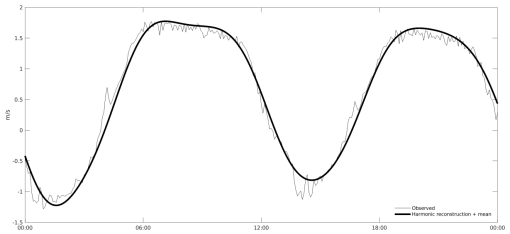
Figure 1. Examples of flood-dominated (stronger flood flow) and ebb-dominated (stronger ebb flow) distorted tides, for the case of $M_4/M_2 = 0.3$. (a) Distorted sea surface, with M_4 leading M_2 by 90° in ebb-dominated case. (b) Same as (a) but for depth-averaged velocity, where flood-dominant M_4 is in phase with M_2, and ebb-dominant M_4 is 180° out of phase with M_2, ——, flood dominant; – – –, ebb dominant.

It is the solid line that corresponds to the St. Lawrence case, but y-axis reversed.

Modeled ssh at Lévis



Observed surface currents at Lévis

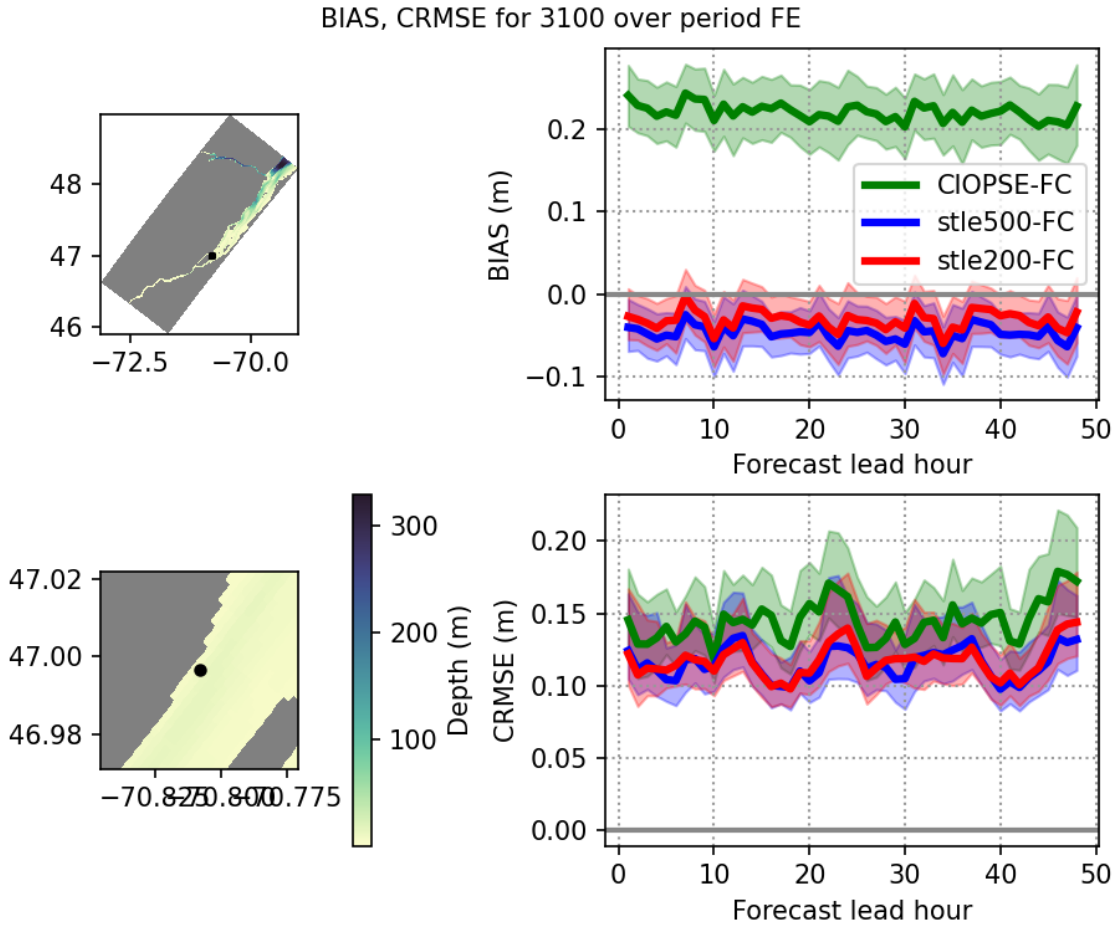


- *It is reported in litterature that strong quarter-diurnal tide (M4) result in similar signals: Aubrey and Speer, 1985*

- *M4/M2 = 0.3 (Aubrey and Speer 1985)*
- *M4/M2 = 0.19 (Obs. at Lévis)*
- *M4/M2 = 0.25 (Obs. at Québec)*

Aubrey, D. G., & Speer, P. E. (1985). A study of non-linear tidal propagation in shallow inlet/estuarine systems Part I: Observations. *Estuarine, coastal and shelf science*, *21*(2), 185-205.

Forecast Eval – Non-tidal water level, station 3100 (Saint-François)



- *We performed 48h forecast simulation every day for a 2 months period (Dec 2021 – Jan 2022) and compared the results with TG, SST and ADCP records, as a function of lead time.*
- *Bias is similar between STLE500 and STLE200 (around -4 cm), and bigger for CIOPS-E (around +22 cm)*
- *CRMSE is comparable for the 2 high-resolution models and bigger for CIOPS-E*

Aknowledgement

Thanks to Denis Lefaivre, all the OPP port leads group (Rachel Horwitz, Michael Dunphy, Stephanne Taylor, Adam Drozdowski, Maxim Krassovski and Hauke Blanken), François Roy and people at ECCC (Jean-Philippe Paquin, Greg Smith and Frédéric Dupont), Ji Lei (maestro support), Doug Schillinger (BIO), Félix St-Pierre and Michel Rousseau (tech at IML), Caroline Lafleur for her help with data in the St. Lawrence, Nancy Soontiens for her help with drift evaluation, and everybody that worked on collecting data that I have been using on this project.