Example application of SeCoTide: water circulation within the Magdalen Island Archipelago

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1 Introduction

The analyzed system of basins and channels consists of two relatively long and narrow tidal basins within the Magdalen Island Archipelago (Gulf of Saint-Lawrence, Canada): the smaller Havre-aux-Maisons Lagoon (HML) to the south and the larger Grande-Entrée Lagoon (GEL) to the north. A schematic map of the area is shown in Fig. 1. The lagoons are connected by a very narrow inlet ('watershed' in the SeCoTide convention) with a bridge leaving only a 300-m^2 cross-section. The cross-sectional areas of the inlets connecting the lagoons to the Gulf of Saint-Lawrence are larger: 2960 m^2 for GEL and 620 m^2 for HML. The dimensions of the basins and inlets are listed in Table 1.

The physical oceanography and hydrodynamics of the area is described in detail in Koutitonsky et al. (2002) and Guyondet and Koutitonsky (2008). The water circulation in the lagoons is governed by the tides (of mainly semidiurnal type and amplitude of $\approx$0.5 m at spring tide) and meteorology; there is no river discharge and the spatial variability of the water density is insignificant in most cases, so that the water circulation can be regarded as barotropic. The hydrodynamics of the area, with emphasis on the residual circulation and harmonic analysis of water levels and currents, was investigated by Guyondet and Koutitonsky (2008) by means of a finite-element hydrodynamic model, calibrated based on observed water levels and currents from a number of measurement stations located in various parts of the study area. Here we use the water levels at Stations L1 and L9 (time series reconstructed from the dominant harmonic constituents) as open-sea forcing for SeCoTide simulations of the HML–GEL system. The results will be compared with measured water

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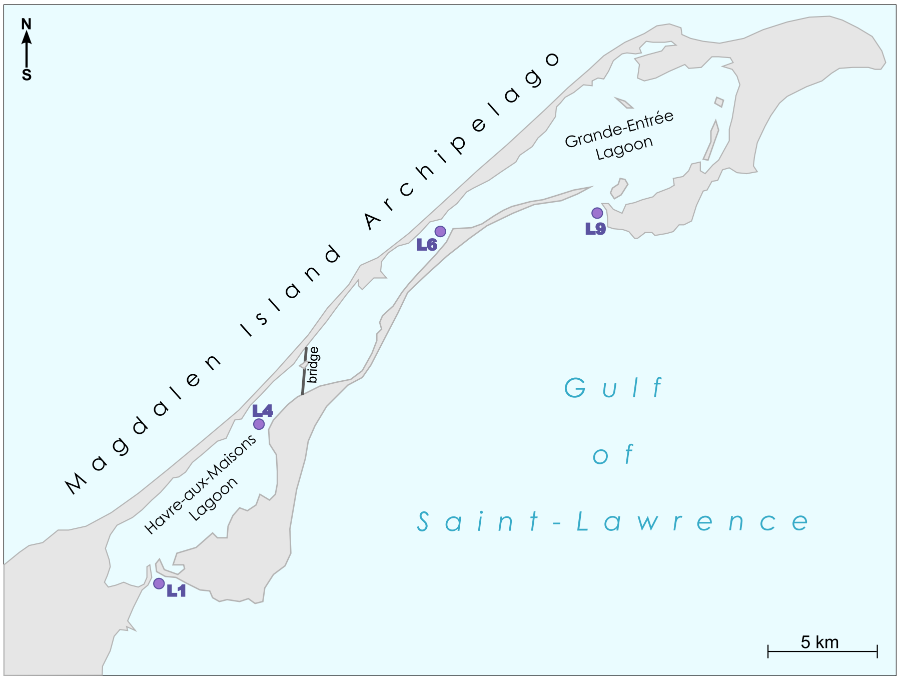

Fig. 1. Schematic map of the analyzed system of two lagoons (Magdalen Islands, Gulf of Saint-Lawrence, Canada). The locations of the water-level measurement stations are shown with dots, labeled as in Guyondet and Koutitonsky (2008).

Table 1
Model setting for the Magdalen Island example. Entries shown in a straight font are taken from Guyondet and Koutitonsky (2008); the remaining ones, shown in *italics*, have been set approximately based on an analysis of maps of the study area.

Parameter	HML	GEL	Parameter	watershed
$\bar{A}_b$ (km^2)	34	74		
$\bar{A}_c$ (m^2)	620	2960	$\bar{A}_w$ (m^2)	300
L_c (m)	700	2000	L_w (m)	*2500*
$R \approx \bar{h}_c$ (m)	4.1	3.8	$R \approx \bar{h}_w$ (m)	*1.0*
δ_c (m^{-1})	*0.006*	*0.004* (flood) *0.0015* (ebb)	δ_w (m^{-1})	*0.001*

levels at Stations L4 and L6 (regarded as representative for HML and GEL, respectively) and with the results of the calculations by Guyondet and Koutitonsky (2008) performed without meteorological forcing.

2 Results

Fragments of the simulated time series of water levels and currents, shown in Fig. 2 (generated with the SeCoTide 'Plot' functionality), provide an overview

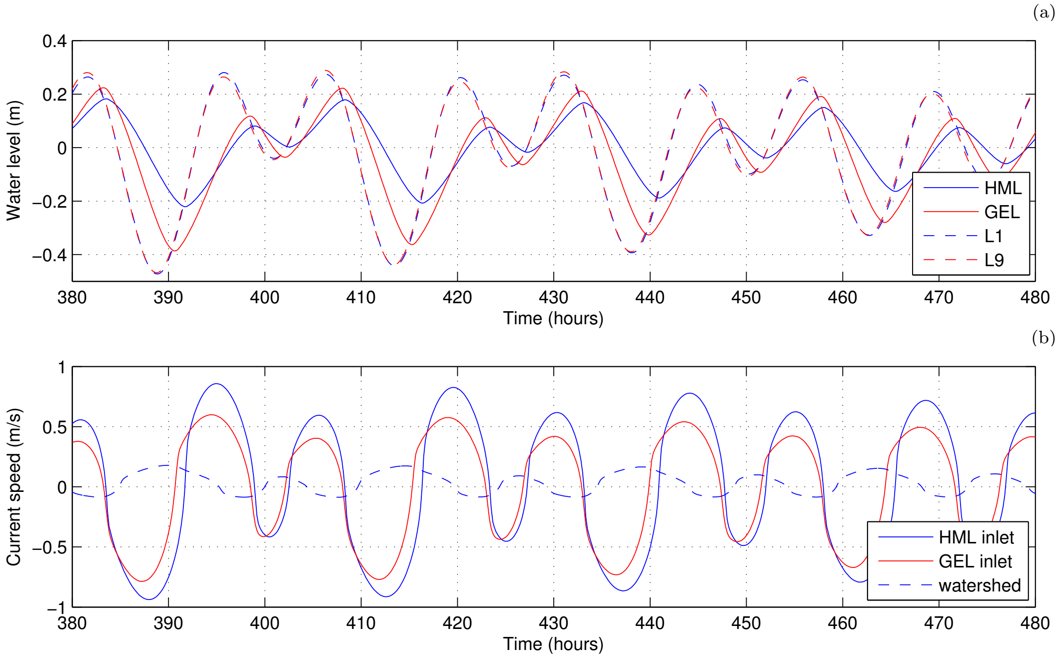

Fig. 2. Fragments of the time series of water levels (a) and currents (b) in the HML–GEL system simulated with SeCoTide. The figures were generated with the ‘Plot’ tool of the SeCoTide GUI.

of the SeCoTide performance. A number of general features of the water circulation in the HML–GEL system described by Guyondet and Koutitonsky (2008) are correctly reproduced by SeCoTide: the tidal oscillations in GEL have higher amplitude than in HML; the current speeds at the entrance to HML (at times reaching 1 m/s) are higher than those at the entrance to GEL; contrary to the HML inlet, which is neutral in terms of tidal asymmetry (ebb and flood currents of comparable amplitude), the GEL inlet exhibits a strong ebb dominance, with ebb currents exceeding 0.8 m/s and maximum flood currents below 0.6 m/s; the pressure gradient between the two basins changes direction during the tidal cycle: it is directed from GEL to HML during flood and in the opposite direction during ebb; the residual water level in HML is about 2 cm higher than in GEL; and, finally, the cumulative volume transport through the ‘watershed’ is directed from HML to GEL and has been estimated to lie in the range 1–8 m^3/s (current speeds of 3–27 mm/s), as compared to 2 m^3/s obtained by Guyondet and Koutitonsky (2008).

Two of the phenomena listed above require some comment. The first one is the ebb dominance of the GEL inlet. A series of a few tens SeCoTide simulations with varied parameters describing the geometry of the basins and inlets have shown that there is only one model configuration that can lead to a significant tidal asymmetry observed at GEL, namely one with different values of the head-loss damping coefficient for inflow and outflow conditions (see Table 1). A specific asymmetry in the geometry of the GEL inlet, with an island and a deep navigation channel on its inner side, leads to a different effective inlet length by ebb and flood, which in turn manifests itself in asymmetries in current velocities. This reason was suggested by Guyondet and Koutitonsky (2008) and SeCoTide, thank to its simplicity, enabled to clearly identify the source of the asymmetry. It is also worth noticing that this asymmetry remained almost unchanged in the results of an additional simulation in which GEL was modelled as a single basin: the differences in water levels and current speeds throughout the tidal cycle were lower than 1 cm and 4 cm/s, respectively.

A second asymmetry of the analyzed system concerns the average water level gradient HML→GEL and a related constant current through the watershed. The range of this residual volume transport given above reflects the results of SeCoTide simulations with some parameters of the watershed (those shown in italics in Table 1) varied within realistic limits. Remarkably, no model configuration resulted in negative residual volume transports.

The harmonic analysis of the results, performed with the `T_TIDE` MATLAB package by Pawlowicz et al. (2002), provides further insight. The four dominating tidal constituents, O_1, K_1, M_2 and S_2, are attenuated in both lagoons, as can be seen in Fig. 6. Although their amplitudes are the same at L1 and L9, they are damped stronger in HML than in GEL. The difference between the observed and simulated amplitudes lies within 2 cm for all four constituents (Table 2). When judging the SeCoTide performance, it must be remembered that the results of the finite-element model of Guyondet and Koutitonsky (2008) show that whereas the amplitudes and phases of both diurnal and semidiurnal constituents are almost uniform within HML, they vary within GEL (up to 20° in phase)—which means that the assumption of the uniform water level is only approximately true for GEL and one cannot expect that a perfect agreement exists between the observed phases and those simulated with SeCoTide. Contrary to the dominating constituents, SeCoTide fails to reproduce the compound MO_3 tidal component within the basins: the simulated amplitude of MO_3 in GEL is almost the same as in the forcing signal, whereas in HML MO_3 is attenuated, although in the observed time series a strong amplification is present. The simulated phases of MO_3 are also not satisfactory, contrary to the phases of the dominating components. In particular, for the M_2 component the simulated phases lie within the confidence bounds of the measured values.

An interesting question concerning the system behaviour is whether, and to what degree, the observed asymmetries are generated externally (due to the inhomogeneity of the forcing signal) or internally (due to the specific geometry of the system, as in the above-discussed case of the ebb dominance of the GEL inlet induced by its specific geometry). To investigate the issue in more detail, it is worthwhile to compare the results of the realistic simulations with those obtained for modified model settings. An inspection of the boundary conditions at Stations L1 and L9 (Table 2 and Fig. 2) shows that the inho-

Table 2
Amplitude and phase of the observed ('obs') and simulated with SeCoTide ('sim') tidal constituents at four stations within the study area (Fig. 5). Measured data from Guyondet and Koutitonsky (2008).

	L1	L4		L9	L6		difference L4−L6	
	obs	obs	sim	obs	obs	sim	obs	sim
				Amplitude (m)				
O_1	0.12	0.08	0.08	0.12	0.09	0.11	−0.01	−0.03
K_1	0.12	0.09	0.07	0.12	0.10	0.11	−0.01	−0.03
M_2	0.19	0.10	0.08	0.19	0.14	0.13	−0.04	−0.04
S_2	0.06	0.02	0.02	0.06	0.03	0.03	−0.01	−0.01
MO_3	0.009	0.010	0.005	0.007	0.013	0.006	−0.003	−0.001
				Phase (degr)				
O_1	220.1	266.4	277.6	224.3	254.0	261.6	12.4	16.0
K_1	247.0	295.7	301.9	247.7	280.0	284.5	15.7	17.4
M_2	285.9	351.8	352.1	282.7	328.9	329.8	22.9	22.4
S_2	329.4	046.2	057.8	329.2	025.7	035.7	20.5	22.1
MO_3	055.1	188.8	208.1	070.8	153.7	211.2	35.1	−3.2

mogeneity of the forcing concerns the phases, not the amplitudes, of the tidal components, mainly M_2 and O_1. To check whether this may have any influence on the behaviour of the system, we repeat the simulations two additional times: with equal phases of M_2 at L1 and L9 (taken as an average value of 284.3°) and with equal phases of O_1 at L1 and L9 (taken as an average value of 222.2°). As may be expected, both changes have rather limited influence on the results. The differences in water level amplitude in HML and GEL are smaller than 0.5 cm; the differences in current speed through the inlets and through the watershed are smaller than 6 cm/s and 7 cm/s, respectively. Interestingly, the change in boundary conditions leads to slightly higher net volume transport between the lagoons: the increase equals 2.4% if the phase of M_2 is modified and 4.0% if the phase of O_1 is modified.

References

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