Surface Seiching in Quesnel Lake, British Columbia

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Introduction

Barotropic seiching in simple enclosed basins is straightforward to understand, and the fundamental period of oscillation can be determined easily using Merian's formula. For more complex geometries, such as multi-armed lakes, numerical models are typically required, but these only produce results on a case-by-case basis. Through the developlment of a simplified analytical model for multi-armed lakes, we seek to better understand the effect of geometry on seiche response. The model is compared to observational and numerical results in a test case: Quesnel Lake, British Columbia.

Methods

Site Descripton and Field Measurement

Quesnel Lake is a deep, fjord-type lake located in the Interior Plateau and Cariboo Mountain regions of British Columbia (see Fig. 1a). Moorings have been installed throughout the lake, and the Water Survey of Canada (WSC) has a long-term station (see Fig. 1b and Tab. 1).

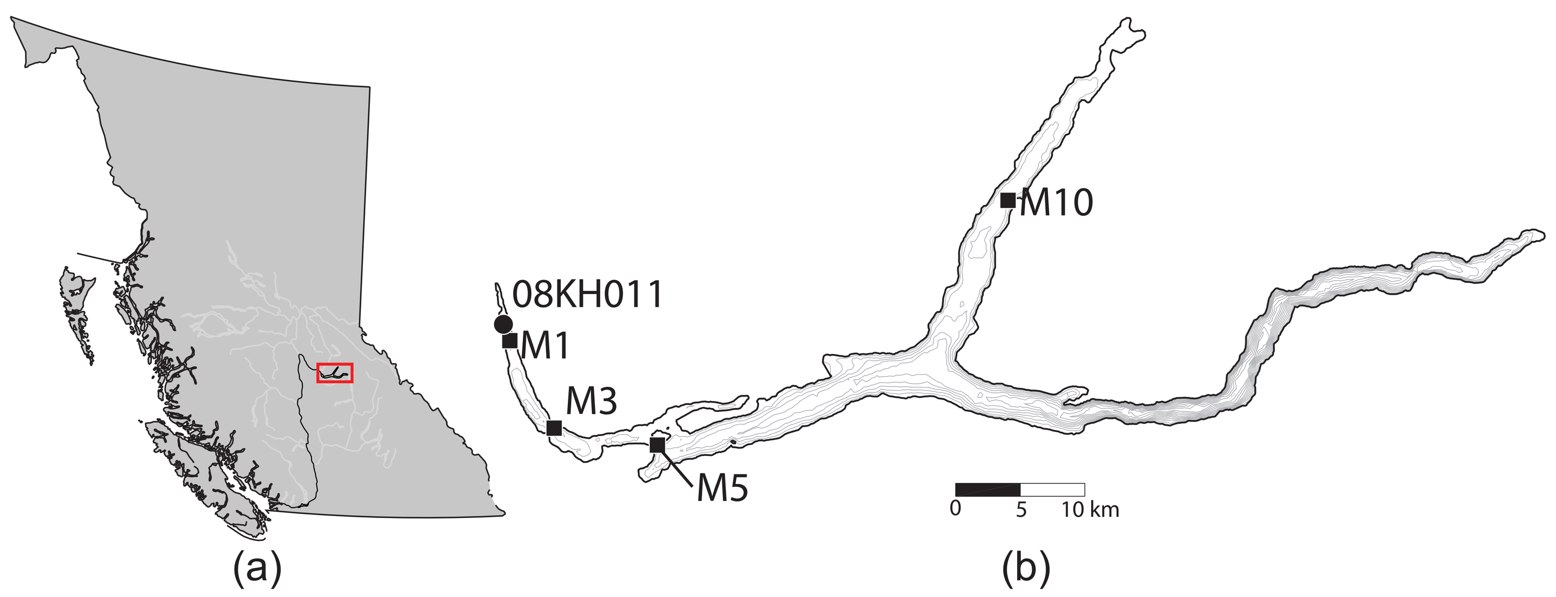

Figure 1: (a) The location of Quesnel Lake in British Columbia and it's connection to the Fraser River System. (b) Map of Quesnel Lake showing the locations of moorings. Bathymetric contours are draw every 50 m.

Table 1: Details of the two classes of measuring stations shown in Fig. 1b.

	Field Measurement Stations	
	■	●
Instrument	RBR duo T.D.	WSC Station
Variable	Pressure	Water Elevation
Sampling Rate	1 min	5 min
Recording Interval	Nov. 2014 - Sept. 2016	Jan. 2011 - Sept. 2016

Simplified Analytical Model (S.A.M.)

In the simplified model, the 2D domain is modeled as a set of 1D domains along the local thalweg of each arm (see Fig. 2).

Figure 2: Schematic of simplified analytical model

The shallow water wave equations are applied in each arm. Boundary conditions at the confluence act to couple the equations. This results in the following equation for determining modal frequecies (ω_n):

$$\sqrt{gH_1}\tan(\omega_n\tau_1)+\sqrt{gH_2}\tan(\omega_n\tau_2)+\sqrt{gH_3}\tan(\omega_n\tau_3)=0$$

in terms of the parameter $\tau_i{=}L_i(gH_i)^{-1/2}$ which has the physical interpretation of the travel time of a wave in a given arm, and here a constant depth, H_i, has been used for each arm

The mode shapes predicted by the simplified model are compared to those determined using the numerical model (compare Fig. 4a-d with e-h).

Methods, continued

Numerical Model

We use a 3D prognostic model, the Finite Volume Community Ocean Model (FVCOM), to characterize the free response of Quesnel Lake. Starting from rest, non-flat elevation fields were imposed and the model was allowed to relax freely. Spectral analyses were performed for each mesh point to determine periods of oscillation (see Tab. 2), and, using these, a harmonic analysis was done to determine the corresponding mode shapes (see Fig. 4a-d).

Results: Frequency Response

The mooring data show consistent low amplitude (~0.05-0.15 dbar) oscillations of the pressure record. Spectral analysis of these pressure signals presents a number of strong spectral peaks (see Fig. 3). These periods correspond to those predicted by FVCOM. The S.A.M. is able to reproduce the first two periods, but is unable to accurately predict higher modes (see Tab. 2).

Table 2: The observed and modelled barotropic periods for Quesnel Lake.

	Modal Periods [min]		
n	Observed	FVCOM	S.A.M.
1	73-78	78.5	75.3
2	59-64	63.6	63.0
3	44-48	46.6	33.6
4	33-35	35.5	24.9

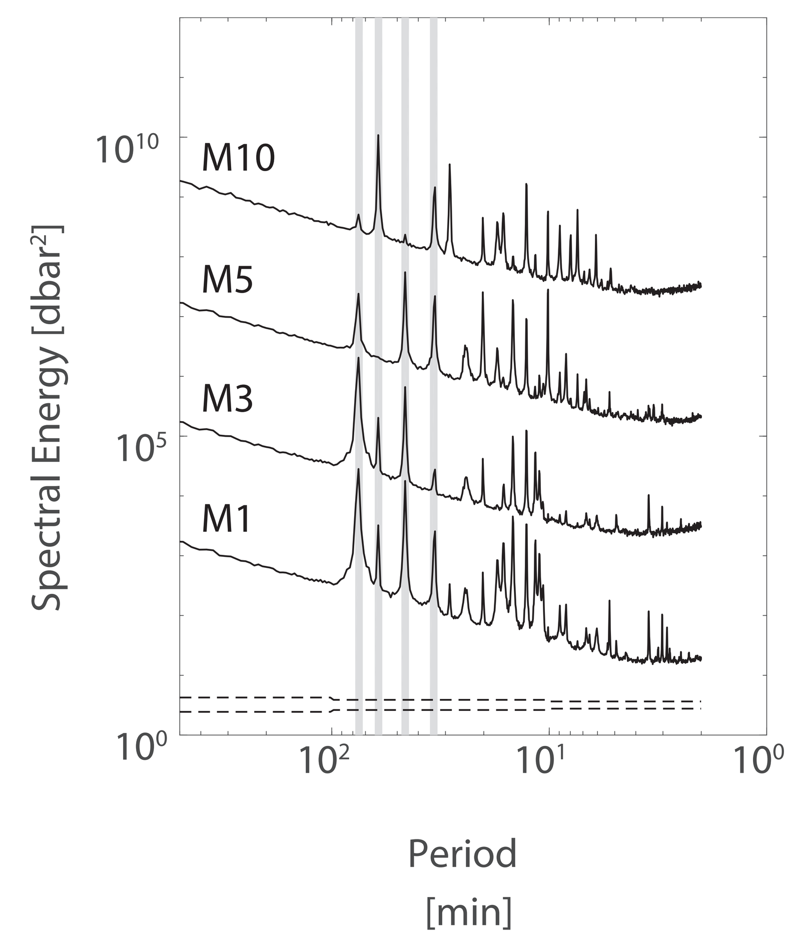

Figure 3: Spectral analysis of observed pressure data. Dashed lines represent 95% confidence bounds.

Discussion

Simplified Analytical Model

The solution presented for the simplified analytical model is based on the assumption that $\tau_1 \neq \tau_2 \neq \tau_3$

If instead $\tau_1{=}\tau_2{=}\tau_3$, then the model predicts a different response: namely, there will be a multiplicity of mode shapes for a given period. In each mode shape, there will be only two active arms, while the third arm will not oscillate. While this decoupled response does not occur (and is not expected to occur) in Quesnel Lake, the model provides a framework for understanding other multi-armed lakes.

Seasonal Patterns

A spectrogram of the water elevations from the WSC station reveals an interesting seasonality to the signal that appears to be tied to regional wind patterns (see Fig. 5). The variation in signal strength corresponds to changes in the wind intensity, and we are still seeking an explanation for the seasonal curvature in the excited frequency bands.

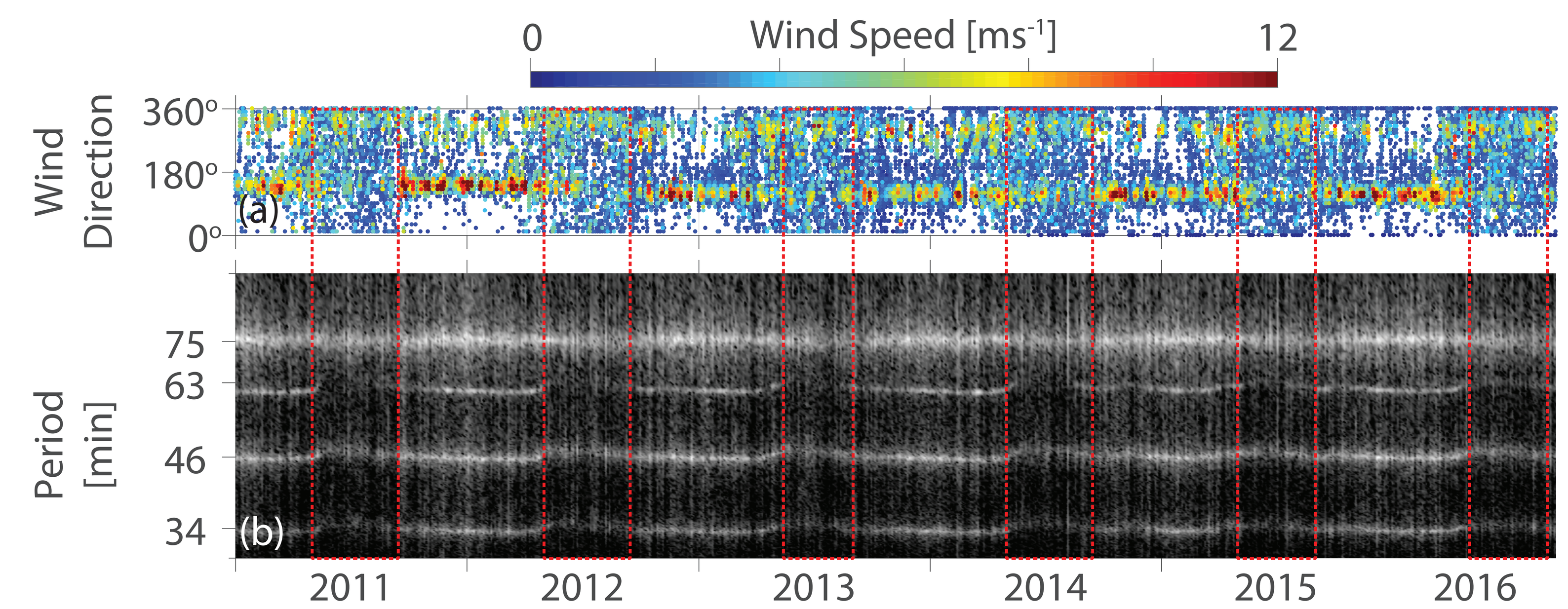

Figure 5: (a) Wind speed and direction at William's Lake Airport (approximately 60 km from Quesnel Lake). (b) Spectrogram of water elevation data collected at station 08KH011 (lighter shaded bands correspond to peaks in spectral density). Red dashed lines highlight the summer period where spectral energy decreases and some modes appear inactive.

Results: Predicted Modeshapes

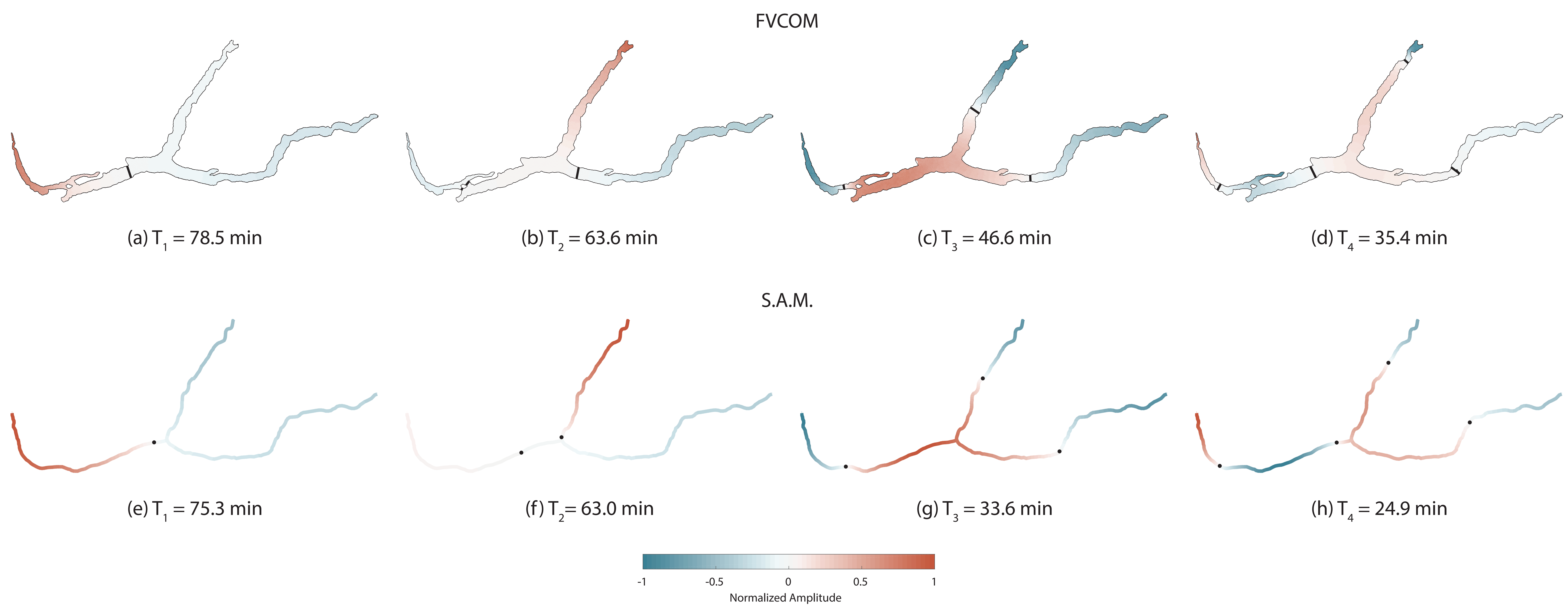

Figure 4: Mode shapes predicted by (a-d) FVCOM, and (e-h) the simplified analytical model, with their corresponding periods, T. Deflections are normalized between -1 (blue) and 1 (red), and nodes are indicated by black contours or dots.