Developing a Hydrologic-Hydrodynamic Flood Forecasting System for Lake Champlain

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Introduction

Lake Champlain is a binational lake bordered by New York on the west side, Vermont on the east side, and Quebec to the north (Fig.1). In recent years, severe floods caused by intense rain events and spring runoff caused significant destruction of property and infrastructure in the Lake Champlain Basin. In addition, high lake water levels (Figs.2-3) provided conditions for more shoreline destruction by wind waves and storm surges. The objective of this project is to develop a real-time flood forecast modeling system for the Lake Champlain-Richelieu River basin. This system will inform operational flood forecasts for the Lake Champlain-Richelieu River system (LCRRS) and enable the development of inundation mapping. It will also support other forecast needs such as recreational activities and search and rescue efforts. The flood modeling system will serve operational needs of the National Weather Service (NWS; includes Weather Forecast Office Burlington and the Northeast River Forecast Center) and the U.S. Coast Guard. It will provide input, particularly water levels, for Canadian flood models of the Richelieu River to enable improved flood forecasting.

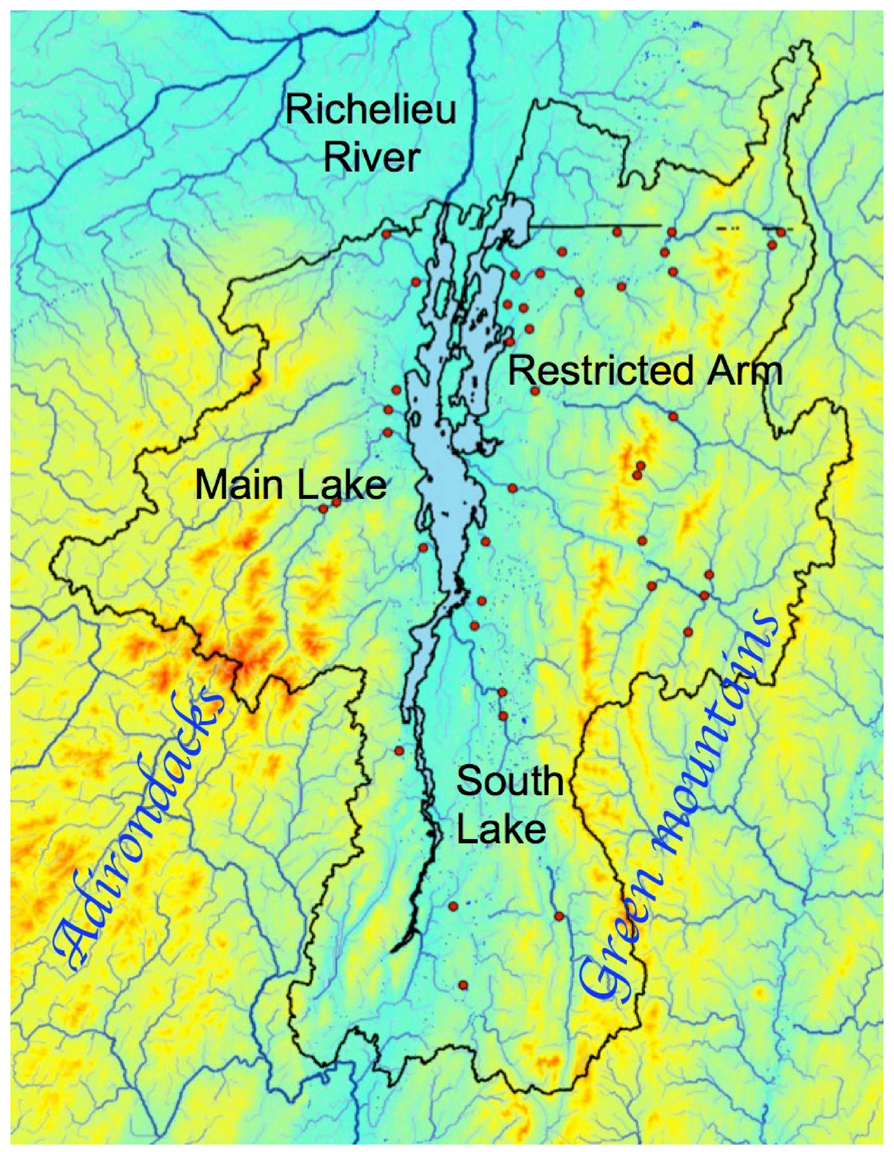


Figure 1. Lake Champlain watershed.

Modeling Framework

The modeling framework will consist of a hydrodynamic lake model based on the Finite Volume Community Ocean Model (FVCOM) driven by hydrologic runoff from the Weather Research and Forecasting-Hydrologic distributed model (WRF-Hydro) and wind wave model based on the WAVEWATCH III model. Meteorological forcing will come from historical reanalysis and operational NWS forecasting models and products, depending on the simulation. Throughout the model development process, the models' configuration will be adjusted to meet operational requirements for accuracy, timeliness, and robustness. The hydrodynamic modeling system will be developed to be implemented in a manner similar to the Great Lakes Operational Forecast System (GLOFS, Anderson et al, 2010) that runs within NOAA's operational supercomputer. The hydrologic modeling system will be developed to be implemented within NOAA's National Water Model (NWM) framework. The resulting models will be designed to provide real-time forecasts on a sub-daily basis to predict flooding, waves circulation, and water temperature. Following model calibration and validation, a pre-operational demonstration of the hydrodynamic forecast system will be implemented by NOAA/GLERL with output made available in real-time on the web.

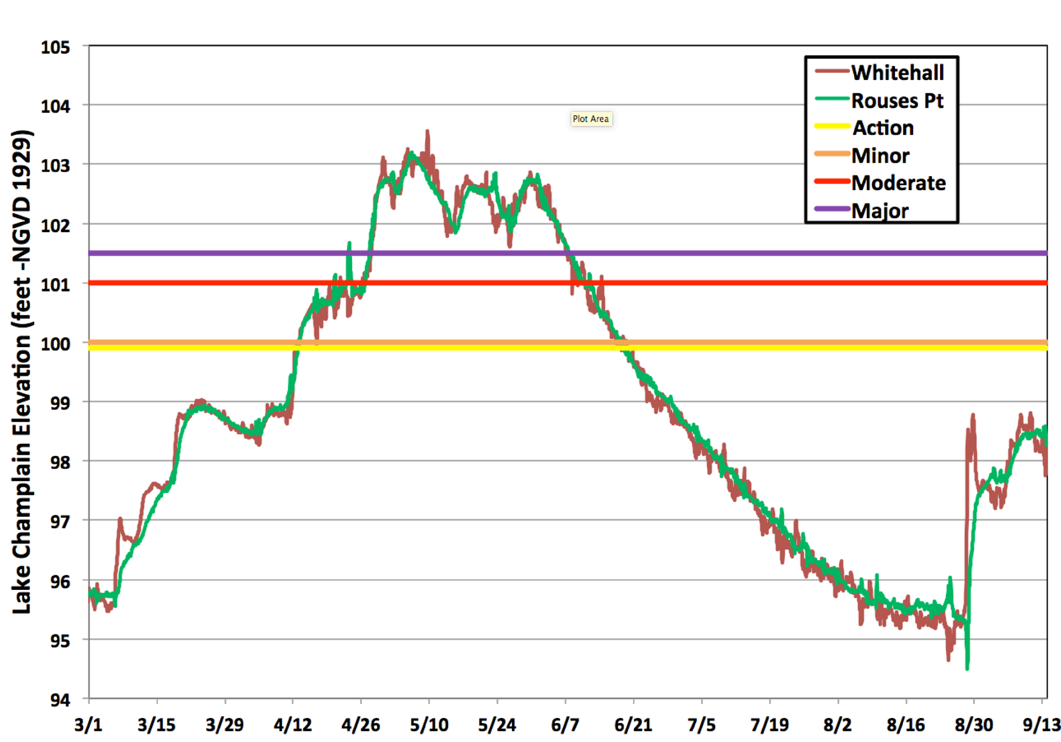


Figure 2. Lake Champlain water levels during 2011 flood.

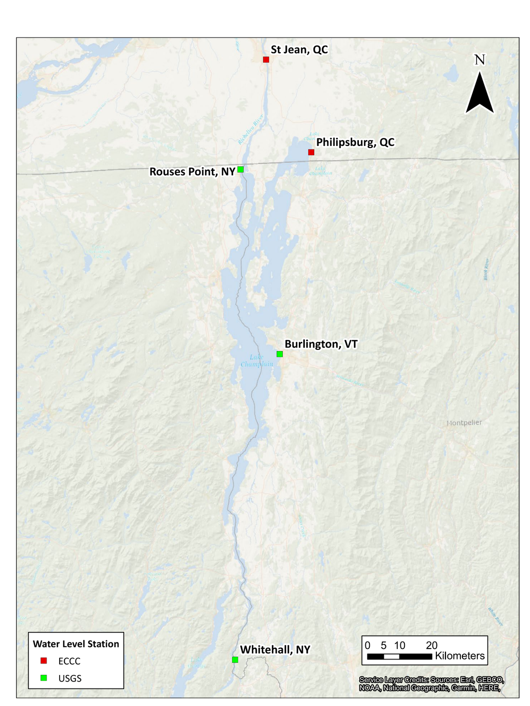


Figure 3. Water level gages.

Model Development and Validation

1.WRF-Hydro Hydrofabric Development

Current version of NWM (version 2.0) does not include Richelieu River that is vital for accurate prediction of water level in Lake Champlain (Fig.4a). To address that issue two extended and refined hydrofabrics were developed for WRF-Hydro modeling and forecasting. Fine resolution hydrofabric based on the NHDPlus HR(beta) dataset (1:24,000) and moderate resolution hydrofabric is based on the NHDPlusV2 dataset (1:100,000). The latter (Fig. 4b) will be integrated in the next version of NWM (version 2.1).

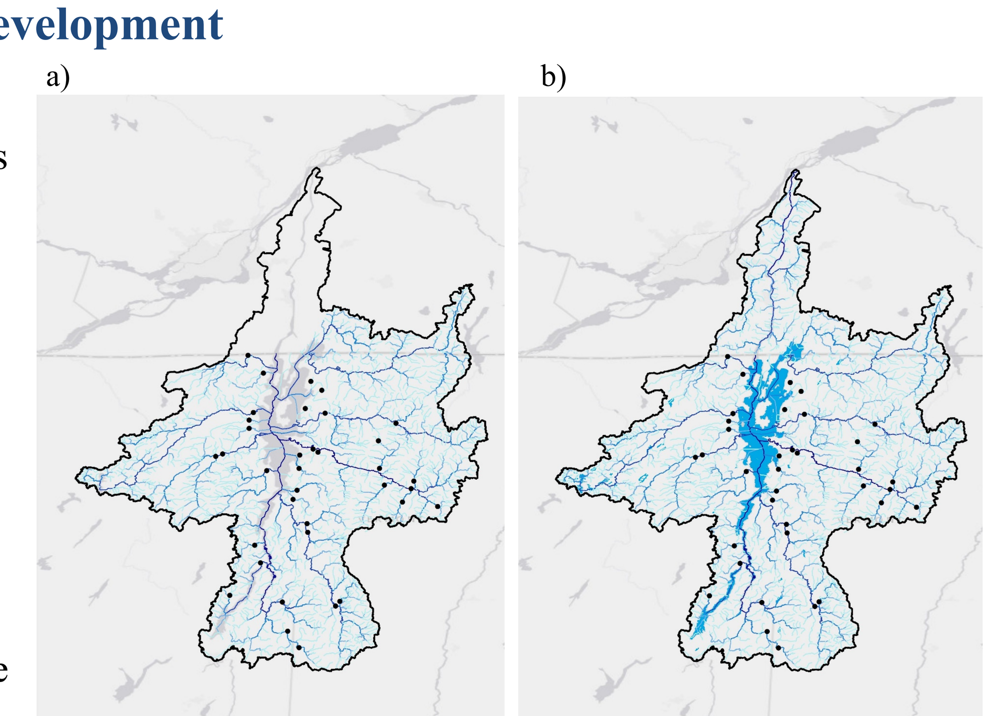


Figure 4. Lake Champlain-Richelieu River routing in NWM 2.0 (a) and NWM 2.1 (b). Horizontal resolution of water routing grid is 250 m.

2. Hydrologic Modeling

To predict hydrologic runoff, state of the art hydrologic model WRF-Hydro (Gochis et al, 2018) is used. Its main features:

- Distributed hydrologic model
- Modularized component model: includes Land Surface, Terrain Routing and Channel routing modules
- Multi-scale functionality to permit modeling of atmospheric, land surface and hydrological processes on different spatial grids

The following meteorological and precipitation forcing datasets were used for hindcasting of the 2011 flood season: NLDAS2 (North American Land Data Assimilation System phase 2) with 10 km resolution and ECCC CaPA (Canadian Precipitation Analysis) with 15 km resolution. In the forecasting mode HRRR (High Resolution Rapid Refresh model) 3 km output will be used to drive the model. WRF-Hydro was run in two configurations with moderate resolution and high-resolution hydrofabric. Overall, both NLDAS and CaPA performed favorably, CaPA slightly better (Fig. 5). High resolution hydrofabric performed better in smaller basins while moderate resolution hydrofabric performed better in larger basins.

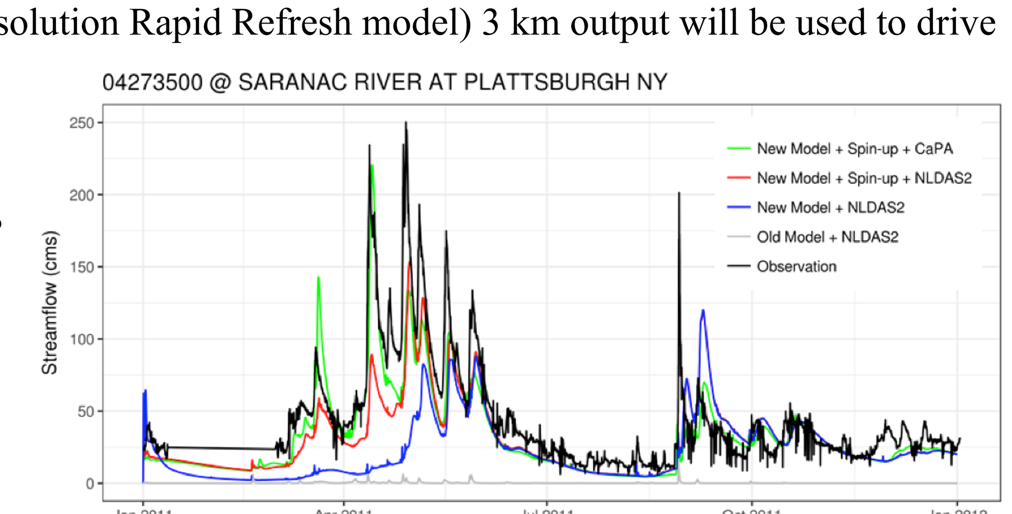


Figure 5. WRF-Hydro 2.0 (uncalibrated) validation with stream gage data.

3. Hydrodynamic Modeling

State of the art hydrodynamic model FVCOM (Chen et al., 2003) is used to predict water levels and lake circulation. FVCOM features:

- 3D unstructured hydrodynamic model
- Terrain following (sigma) vertical coordinate
- Vertical turbulence model (Mellor-Yamada model).
- Wetting-drying capability

Horizontal resolution of FVCOM ranges from 50 to 350 m (Fig. 6), 20 vertical levels are uniformly distributed over the water column. HRRR meteorological forcing is available only in recent years, therefore to simulate 2011 conditions GEM (Global Environmental Multiscale) model forcing with 2.5 km resolution, NLDAS2 forcing and observed mid-lake winds (at Colchester Reef) were used. Observations of streamflows at 13 major tributaries were used to specify inflows in FVCOM in 2011, while water level observations at St. Jean were used as downstream boundary conditions.

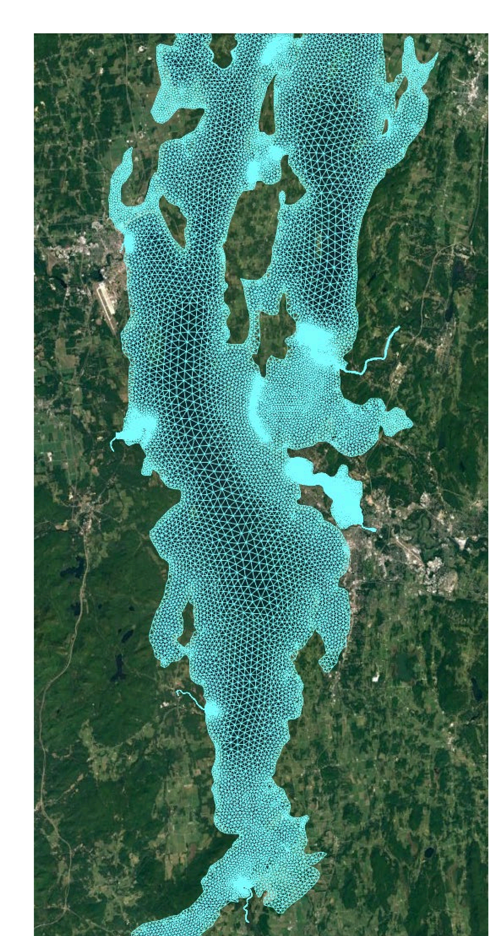


Figure 6. FVCOM grid (central portion).

The model successfully reproduced water levels in 2011, including conditions during the height of 2011 flood (Fig. 7). It also showed considerable skill in reproducing water level fluctuations during wind events in 2017 (Fig.8) using HRRR forcing and 28 observation-based inflows.

Figure 7. Validation of seasonal water level dynamics in 2011.

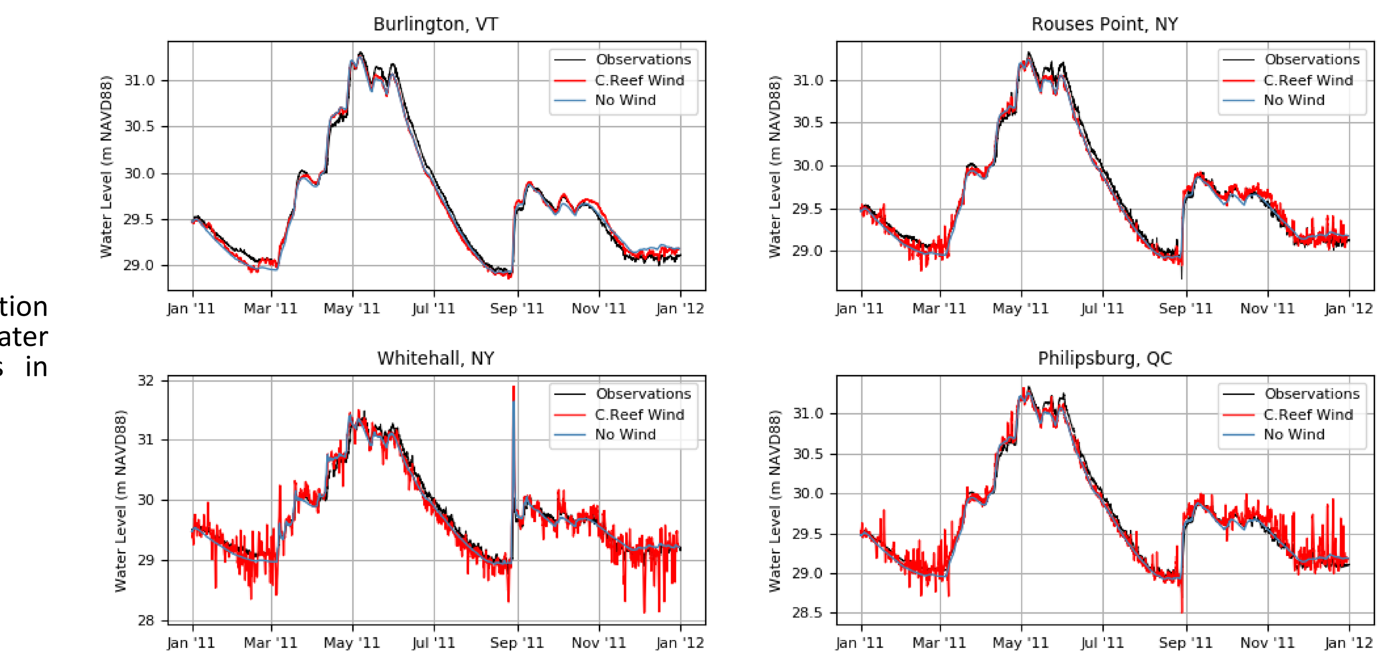
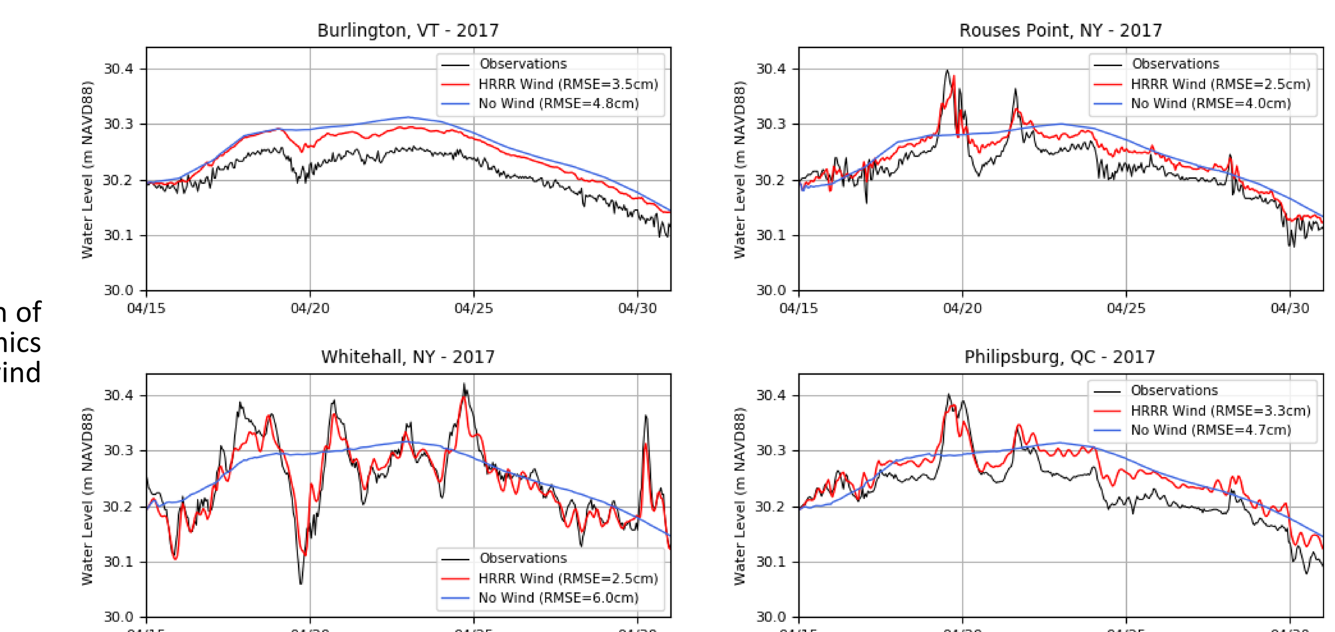


Figure 8. Validation of water level dynamics during strong wind events in 2017.



4. Wave Modeling

Third-generation community wave model WAVEWATCH III (WW3DG, 2019) is used to predict wave conditions in the lake. WAVEWATCH III features:

- Spectral wave model
- Supports structured and unstructured grids, as well as multi-grid setups
- Capable of wetting/drying in floodplain areas

Wave model was applied on the same grid as FVCOM and used the same HRRR forcing. The model wetting-drying scheme was shown to work well during flood conditions. Model was run for January-March conditions in 2017 and produced reasonable wave heights during strong wind episodes (Fig. 9). The model will be validated with observations that will be collected in 2020 in the Main Lake and in the Restricted Arm (Fig. 1).

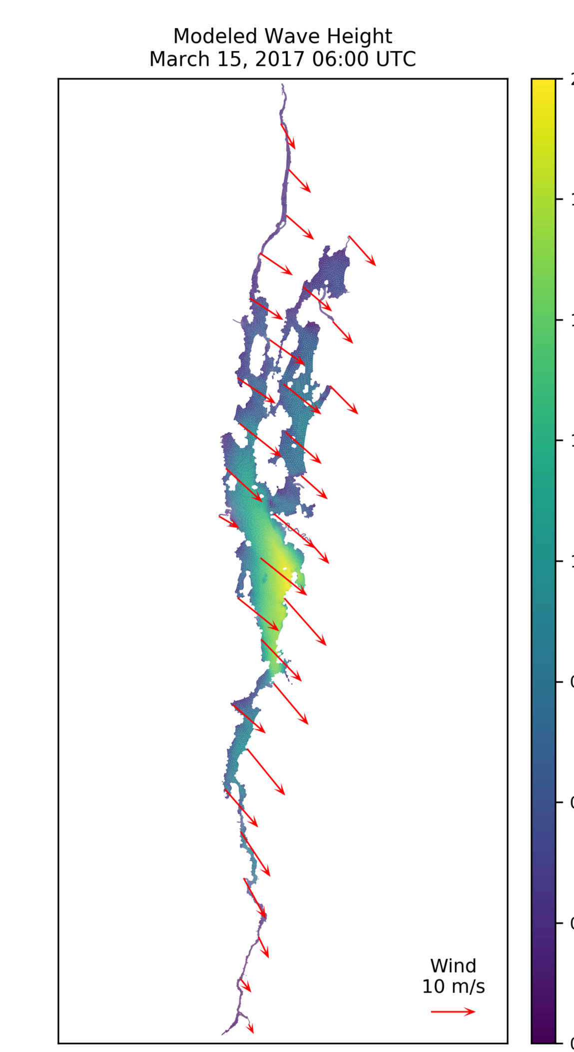


Figure 9. Modeled wave height during NW wind event, March 2017.

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