Chapter 1

Introduction

Glacier Bay National Park (Fig. 1.1), located in southeast Alaska, attracts the attention of the public and the scientific community alike. For the public, the draw usually includes the mountains, the tidewater glaciers, and the wildlife. For the scientist, the attraction has many facets. First, Glacier Bay represents a nexus of freshwater, marine, and terrestrial environments. This variety of environment leads to a similarly rich variety in marine mammals, seabirds, and fishes.

As described by Etherington *et al.* (2007), Glacier Bay is also a unique environment due to the rapid deglaciation (Figs. 1.2-1.3) that has occurred over the past century. This rapid retreat has clearly had significant changes (for example, the bathymetry) on the estuarine environment of Glacier Bay.

Finally, the Bay's status as a national park brings with it a unique status, in terms of fisheries activity. Motivated by the desire to protect resident and sensitive species and to provide opportunities for science benefitting fisheries and marine ecosystems, legislation in the late 1990's established immediate and phased closures of the Bay proper to commercial fishing activity.

1.1 Oceanography of Glacier Bay

From an oceanographic point of view, Glacier Bay is exceptionally complex. For a full discussion of the oceanographic processes in Glacier Bay, the reader is referred to reports by Hooge & Hooge (2002) and Etherington *et al.* (2004). Several valuable reports, data, and analysis tools are found at http://www.absc.usgs.gov/glba/oceanography/index.htm.

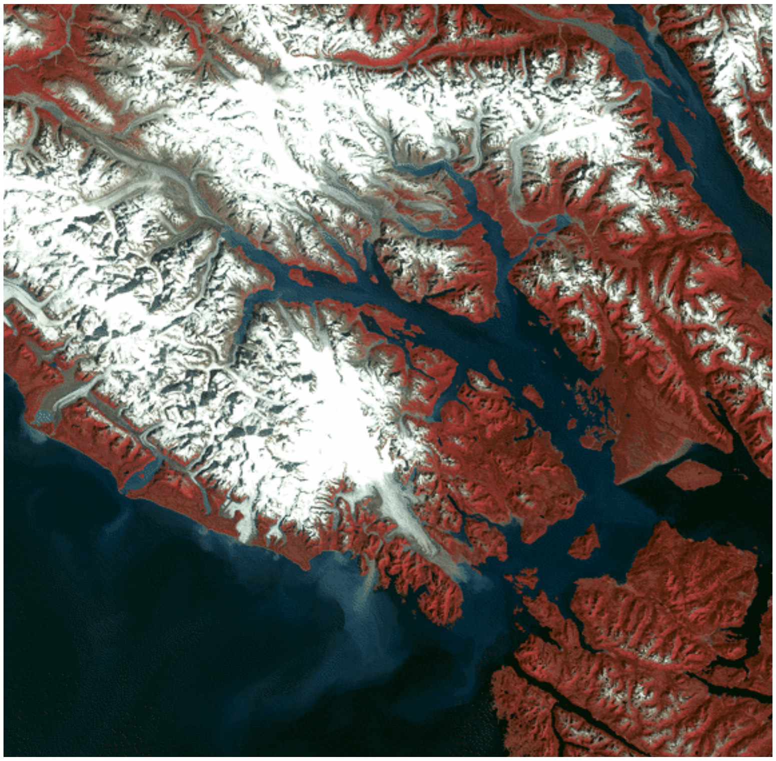

Figure 1.1: Satellite image of Glacier Bay National Park. Photo credit: NASA (http://glacier-bay.gsfc.nasa.gov/).

Briefly, Glacier Bay is a fjord estuarine system subject to large values of freshwater input, sedimentation, and tidal range. There are many deep basins, with depths on the order of 500 m, and many shallow sills, with depths on the order of 25 m. The steep gradients in bathymetry, along with the vigorous tidal currents, yield regions of significant turbulent mixing of bay waters.

In addition to the spatial complexity of the bay's physical environment, there is significant temporal complexity as well. The annual variation in precipitation, solar radiation, and (air) temperature lead to strong variations in salinity and (water) temperature, and therefore density. The annual hydrograph (runoff) is further complicated by the strong input due to meltwater. A cartoon of these and other major processes operating in the bay is given in Fig. 1.4.

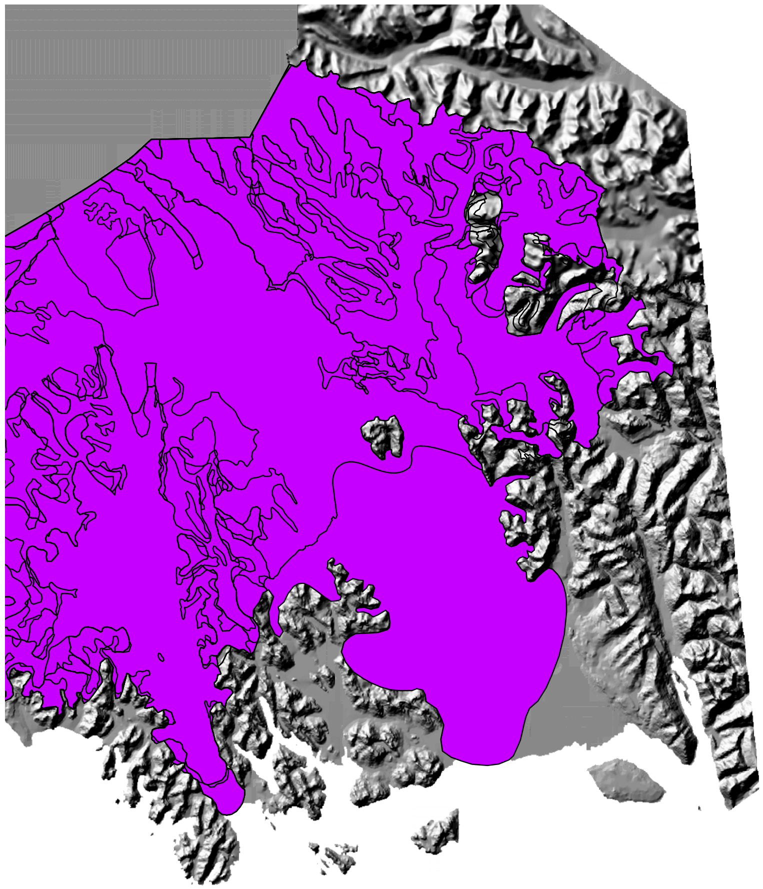

Figure 1.2: Glacier coverage in 1700; source: Glacier Bay Ecosystem CD.

1.2 Scope of Present Work

The work described in this report is intended to begin to fill an important gap in the knowledge of physical processes in Glacier Bay. As reviewed in Hooge & Hooge (2002), Etherington *et al.* (2004), and Etherington *et al.* (2007), there has been a great deal of effort invested in oceanographic data collection and analysis in the bay over the past 15 years. However, there has not been a similar effort invested in developing the ability to computationally model the tidal flows in the bay. The present report summarizes the initial steps that have been taken towards this goal.

The benefits of developing a computational model are myriad. Such a

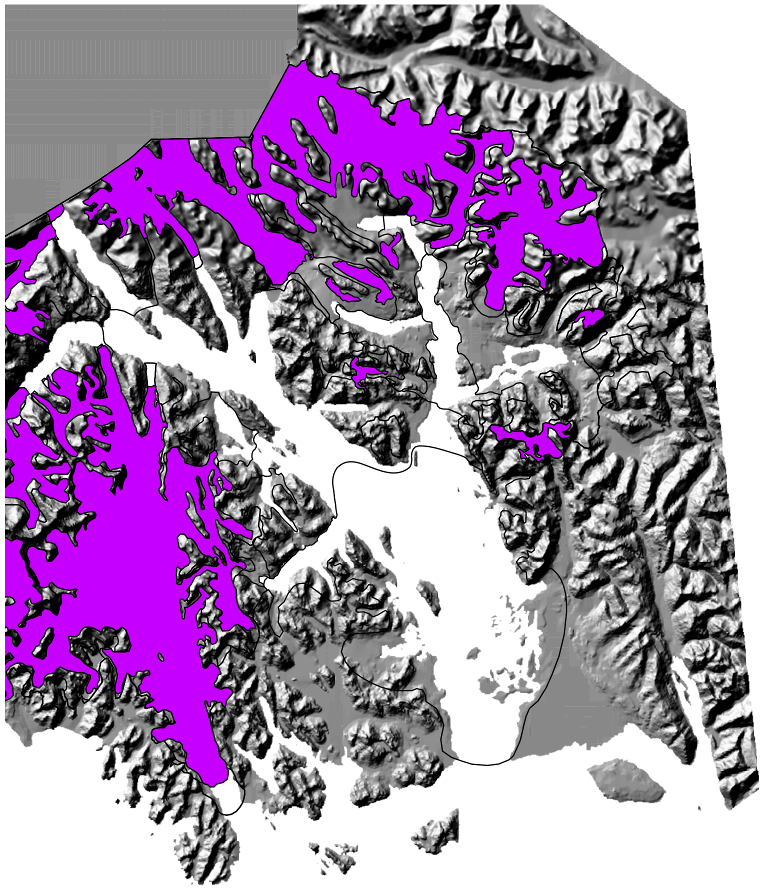

Figure 1.3: Glacier coverage in 1985; source: Glacier Bay Ecosystem CD.

model will allow park managers to obtain information about physical conditions in park waters at temporal and spatial resolutions that would be prohibitive, in terms of data collection. Additionally, a computational model allows the user to computationally explore the linkages between input and output variables, thereby helping to better understand what variables are of primary controlling importance. Finally, a model will allow users to make and test hypotheses based upon expected future conditions in the bay. For example, if glacial retreat (and hence freshwater input) accelerates, what effect will this have on tidal elevations and current patterns in the bay?

The development of a computational tidal model in no way diminishes the importance of or serves to replace regular data collection. First of all,

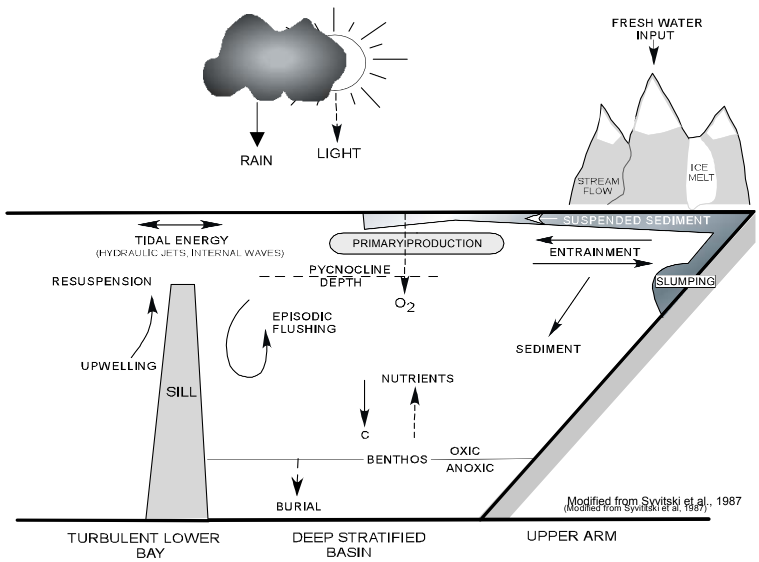

Figure 1.4: Conceptual model of the major oceanographic processes in Glacier Bay. Figure is reproduced from Hooge & Hooge (2002), and is based upon a figure from Syvitski *et al.* (1987).

data are required in order to validate the output of models. Second, no model will ever capture the entire range of processes in the bay. In order to keep computational costs reasonable, it is inevitable that compromises (for example, in how well resolved the bathymetry and coastline are) are made. An important point to keep in mind is that the data are the true picture of the bay's environment and that any model will be, at best, an approximation to this reality.

1.3 Study Approach

The approach taken by the author has been one of striking a balance between accuracy, pragmatism, and accessibility. The ultimate goal, or course, would be a low-cost computational model that fully resolves all of the fine-scale bathymetric and topographic features of the bay. In addition, the model is desired to be fully three-dimensional and baroclinic (resolving the vertical density profile). Finally, the model would be forced with spatially variable meteorological input and freshwater inflows.

The reality is that this would be an excessively onerous computational task and would result in a product that the author, but perhaps no one else, would be able to make use of. The author has therefore taken steps to keep computational requirements modest and to make the end product accessible to a generalist. One aspect of this is the choice between commercial and open-source software. The core model used by the author (and discussed in the following chapter) is available as part of a commercial and expensive software package. The chief benefits of this package are useful graphical user interfaces (GUIs) for pre- and post-processing. However, the 'engine' itself (the tidal hydraulics code) is open-source and is distributed freely (without the GUIs) for research purposes. Therefore, the author has taken the approach of working with the freely-available code and developing Matlab-based supporting tools to aid the user.

To summarize the present capabilities of the tidal model:

1. Determination of tidal stage and two-dimensional (depth-averaged) velocities.

2. Inclusion of meteorological (wind and pressure) forcing.

3. Inclusion of freshwater input.

4. Harmonic analysis (this allows for the determination of tidal datums such as mean higher high water (MHHW), mean sea level (MSL), etc.).

5. Two-dimensional dispersion of passive tracers.

6. Calculation of pathlines (this traces the path taken by a surface drifter buoy, for example).

7. A domain that includes the bay proper, as well as Icy Strait and Cross Sound.