Vieques Sound and Virgin Passage
2010-2011 Moored Array Transport Summary

NOAA Coral Reef Conservation Program
US Caribbean Coral Reef Ecosystem Connectivity:
Vieques Sound and Virgin Passage Transport Study
Project ID: 20416 - 2011

OVERVIEW:

As the primary component of the NOAA Coral Reef Conservation Program (CRCP) *US Caribbean Coral Reef Ecosystem Connectivity: Vieques Sound and Virgin Passage Transport Study*, an array of moored acoustic Doppler current profilers (ADCP) was deployed in the US Caribbean from March 3, 2010 through April 22, 2011. This array consisted of six moorings and was configured to quantify the volume transport of water across the costal shelf at two locations. Three moorings were deployed between the Puerto Rican islands of Vieques and Culebra at the eastern end of Vieques Sound (Fig. 1), and three moorings were deployed between the islands of Culebra, Puerto Rico and St. Thomas, United States Virgin Islands (USVI) in Virgin Passage (Fig. 2).

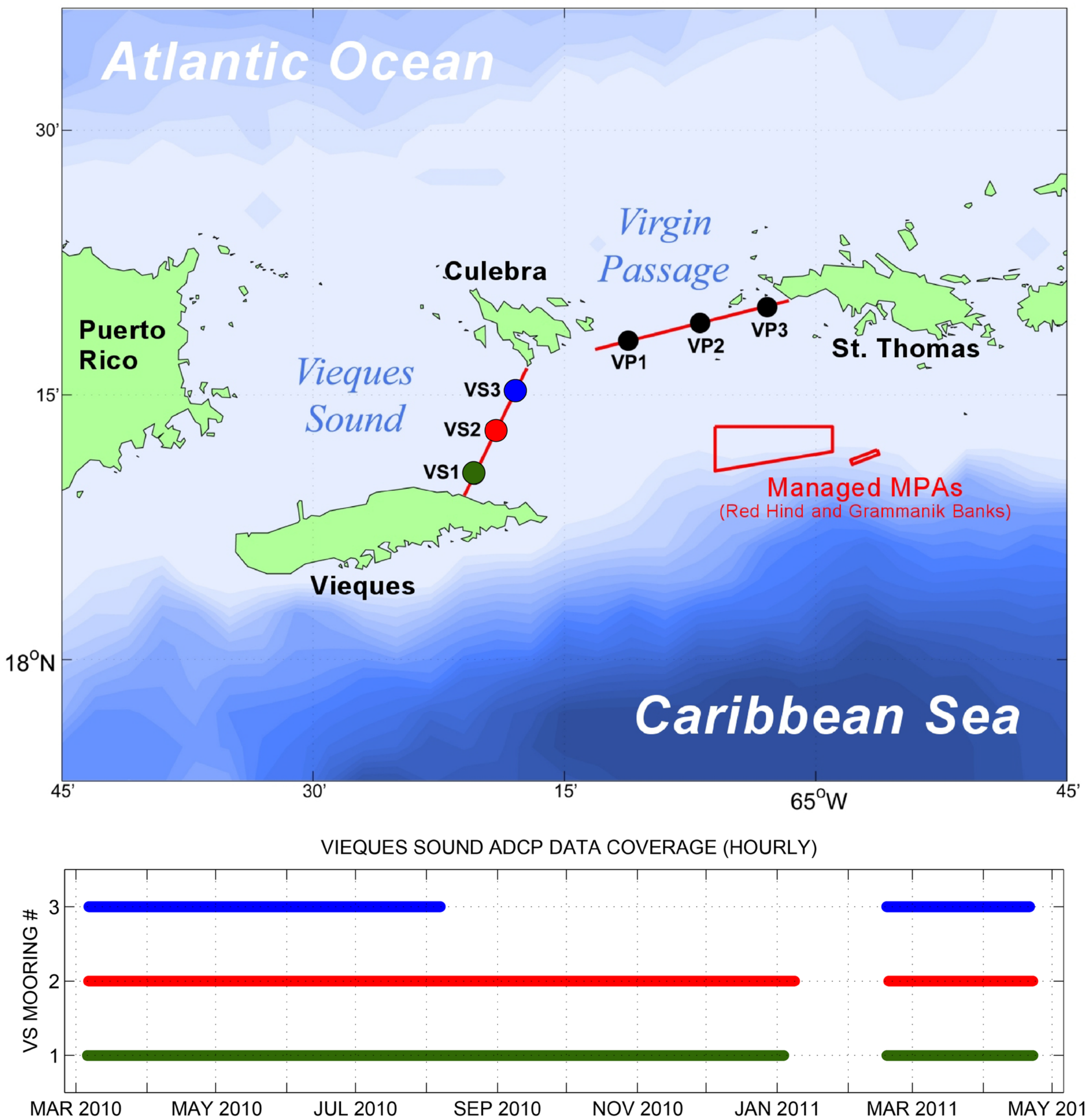
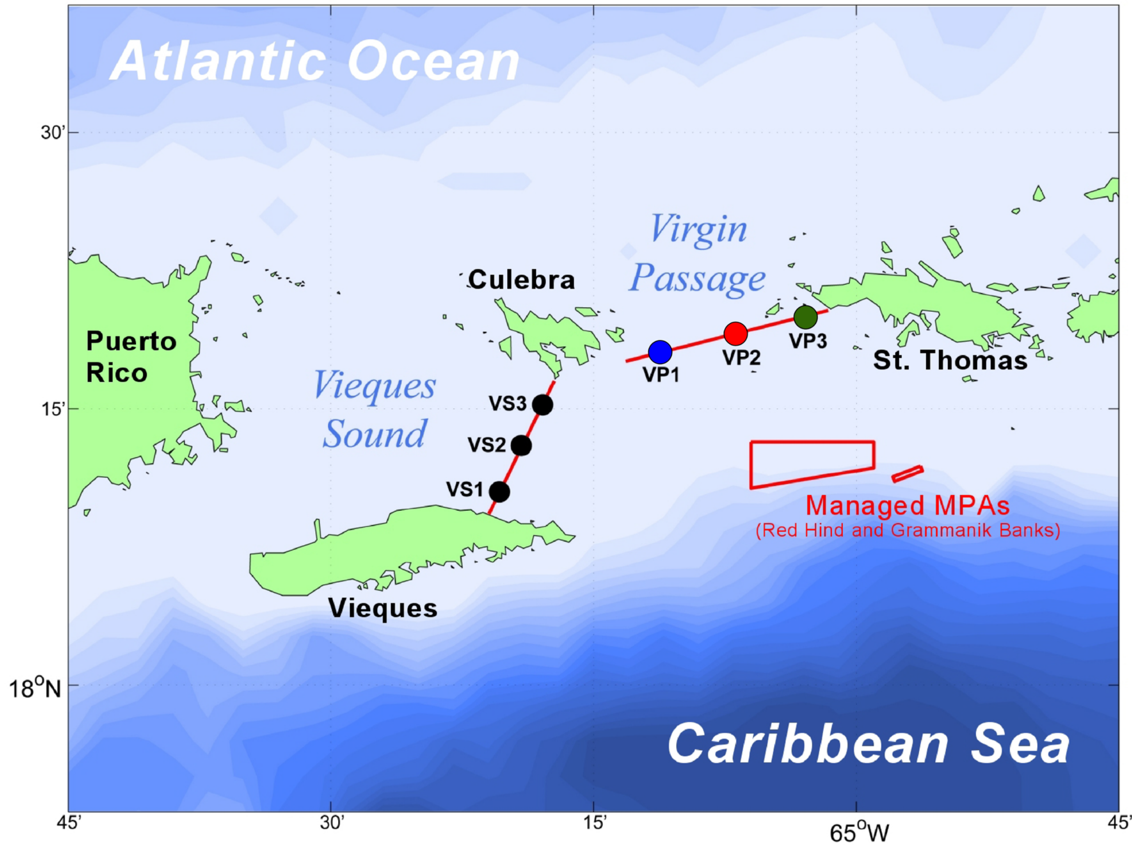


Figure 1. Vieques Sound mooring locations and temporal data coverage.



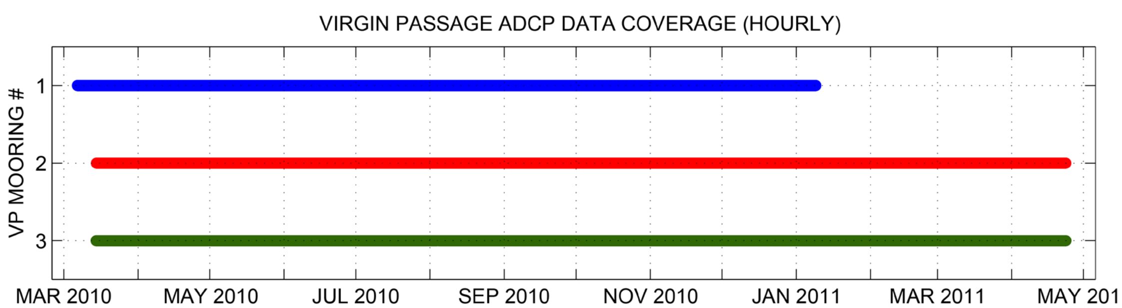


Figure 2. Virgin Passage mooring locations and temporal data coverage.

Hourly velocity data recorded by each moored instrument were combined to create hourly velocity sections for each passage. The Vieques Sound sections produced from these data are 15.2 km wide with cross-sectional areas of 0.38 km^2. These sections are oriented at a bearing of 25° from Vieques towards Culebra, approximately normal to the axis of Vieques Sound (Fig.1). The sections produced for Virgin Passage are 22.5 km wide with cross-sectional areas of 0.59 km^2. These sections are oriented along the sill of the passage, at a bearing of 77° from Culebra towards St. Thomas (Fig. 2). The maximum depth of the Vieques Sound sections is 29 m; the maximum depth of the Virgin Passage sections is 32 m. Velocity observations were rotated to yield the component of flow crossing each section. Hourly volume transport calculations were made from the velocity sections generated where all three moorings were reporting (see temporal data coverage in Figs. 1 and 2). These transports are referenced as either ***inflow*** or ***outflow***. For our purposes, inflow refers to flow entering the Caribbean Sea (specifically the Virgin Island Basin) from either Vieques Sound (in the case of Vieques Sound section) or the Atlantic Ocean (in the case of Virgin Passage section). Outflow refers to the volume transport out of the Virgin Island Basin (VIB) across these two sections. This document summarizes the flows observed by project moorings over the deployment period in 2010 and 2011.

METHODS:

The Nortek Aquadopp 600 kHz ADCP was selected for use on the project due to its appropriate range given the water depth, its portability, and due the fact that a regional partner, the University of the Virgin Islands (UVI) maintained an existing stock of the instruments in St. Thomas (Fig. 3). Combining UVI instrumentation with two project ADCPs provided a total of six Aquadopps for the study. Each instrument was configured to record and save hourly velocity averages from sixty samples measured during the hour (one per minute). The ADCPs were also set up to provide measurement coverage from the sea floor to the sea surface at one-meter intervals (known as bin size).

Mooring bases were fabricated from concrete and PVC (Fig 3.) and were deployed, serviced, and recovered by the NOAA Ship *Nancy Foster* during regional oceanographic surveys. A UVI small boat, the R/V *Garuppa*, was also used to service the instruments. In addition to the installation and recovery of the moorings, project divers serviced each instrument two additional times during the March 3, 2010 through April 22, 2011 deployment period.

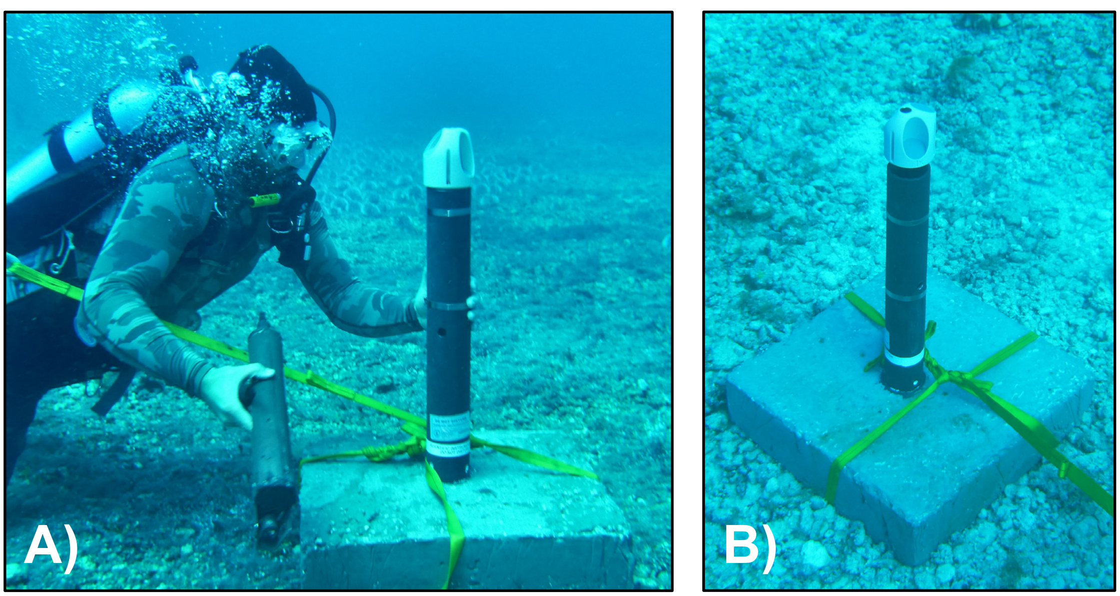


Figure 3. A project diver installs an Aquadopp 600 kHz ADCP in Virgin Passage.

As previously mentioned, three ADCP moorings were placed across the eastern end of Vieques Sound between Vieques and Culebra (Fig. 1), and three ADCP moorings were placed across Virgin Passage between Culebra and St. Thomas (Fig. 2). Mooring sites were selected to be roughly equidistant from each other across each channel (Table 1).

Name	Latitude	Longitude	Depth	Section
VS1 ADCP	18.1749°N	65.3396°W	25.7 m	Vieques Sound
VS2 ADCP	18.2168°N	65.3187°W	27.9 m	Vieques Sound
VS3 ADCP	18.2583°N	65.2984°W	29.7 m	Vieques Sound
VP1 ADCP	18.3013°N	65.1865°W	33.0 m	Virgin Passage
VP2 ADCP	18.3181°N	65.1150°W	30.3 m	Virgin Passage
VP3 ADCP	18.3330°N	65.0482°W	24.6 m	Virgin Passage

Table 1. Project mooring site names, locations, and depths.

Data recovered from each mooring were processed to remove bad values and to correct for regional magnetic variation. Data were then 40-hour low-pass (40HLP) filtered to remove the regional tides. While overall the moored ADCPs performed quite well, a few logistical and instrument battery problems resulted in some data loss over the 415-day deployment (see temporal data coverage in Figs. 1 and 2).

For each section, where all three mooring sites recorded data, the hourly processed velocity profile from each site was incorporated into a transport calculation for the section. These velocities were rotated to reveal along-channel flow components. The rotated data were linearly interpolated onto a uniform grid comprised of grid cells 100 m wide by 10 m high. A bathymetry mask was applied to the velocity grid, and a volume transport was computed. In the case of Vieques Sound, 3-mooring data coverage allowed for an hourly section transport to be calculated 51.8% of the time (~215 days). In Virgin Passage, 3-mooring data coverage yielded hourly section transports 72.2% of the time (~300 days).

Gridded velocities, extending beyond either outer mooring in a passage, were linearly extrapolated to the passage boundary to a value 0.1 times the corresponding velocity at the respective outer mooring. This extrapolation, mimicking a flow reduction at the boundary, is only an estimate of flow across these areas based on the data collected by the mooring closest to the boundary. Often, this is and accurate representation of flow across these relatively short distances. However, small narrow jets and flow reversals have been observed in these passages and could be missed by this extrapolation method. For this reason, two hourly velocity grids and transport estimates were computed: one including a linear boundary extrapolation and one without.

For each section, a mean transport across the section was calculated. For the Vieques sound section, this mean was based on 5157 hourly section transports. For the Virgin Passage section, this mean was based on 7193 hourly section transports.

FINDINGS:

Figures 4 and 5 show the non-rotated 40HLP depth-averaged velocity vectors for each mooring across the Vieques Sound and Virgin Passage sections. At both sections, the largest velocities were observed at the moorings located closest to the center of the channels. However, overall the magnitude of the flows observed in Virgin Passage were found to be approximately 1.8 times the magnitude of the flows observed at Vieques Sound. This is likely due to friction associated with the shallow depths of the Sound to the northwest (between Puerto Rico and Culebra) and to the southwest (between Puerto Rico and Vieques) of the section. The largest velocities observed across the Vieques Sound section were found at the two northern mooring sites (VS2 and VS3).

In addition to stronger flows observed across Virgin Passage, the directionality of these velocity data (Fig. 5) were less uniform than observations in Vieques Sound (Fig. 4). This is likely due to influences of bathymetry on the eastern end of the section near St. Thomas.

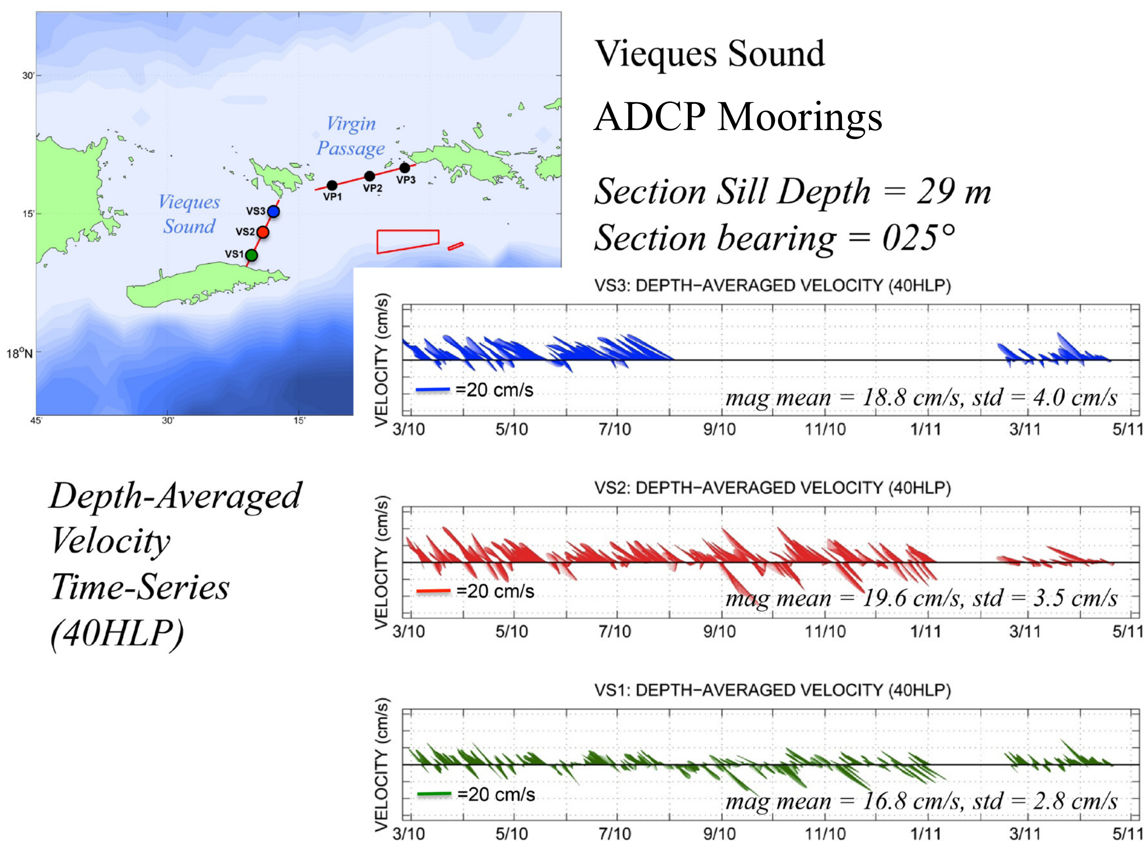


Figure 4. 40HLP depth-averaged velocity vectors produced from each moored ADCP across the Vieques Sound section.

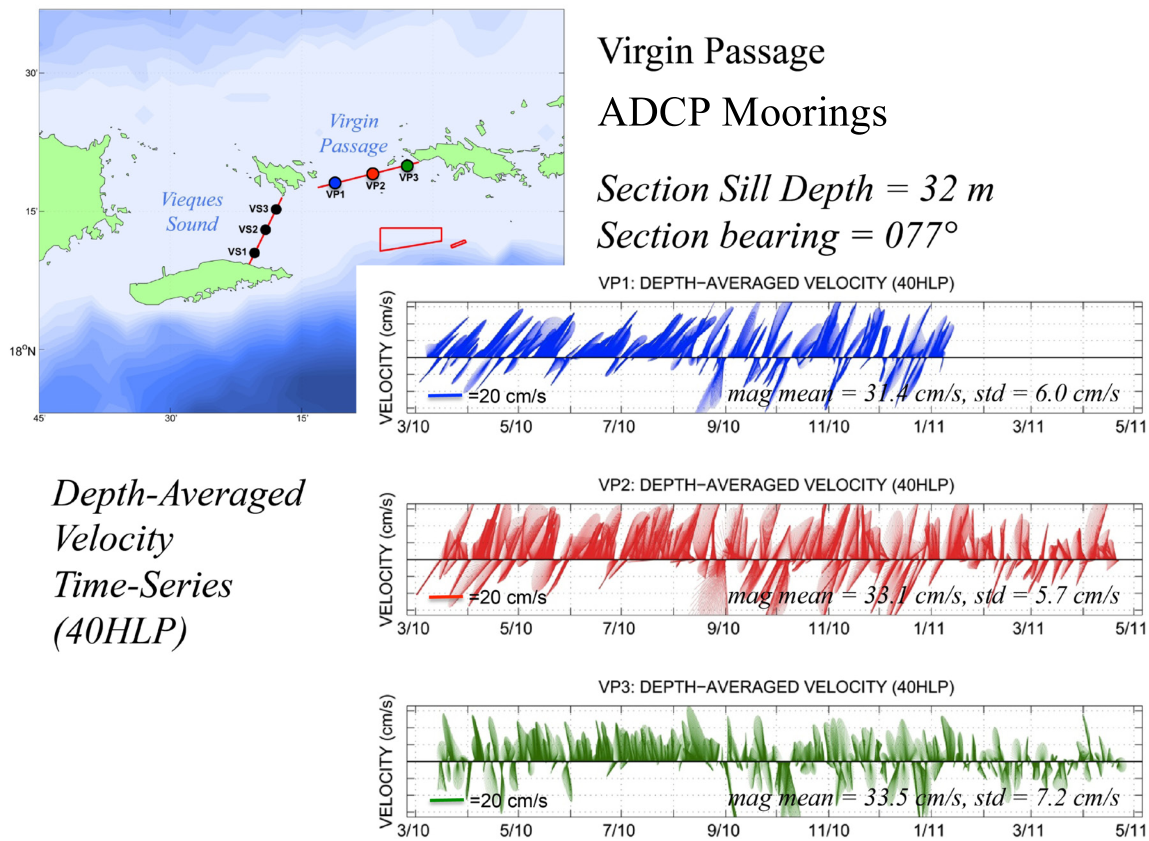


Figure 5. 40HLP depth-averaged velocity vectors produced from each moored ADCP across the Virgin Passage section.

Rotated 40HLP depth-averaged velocity time-series (normal to their respective section) are plotted for Vieques Sound and Virgin Passage in Figures 6 and 7. Once rotated inflows and outflows are easily referenced. As previously mentioned, for our purposes, inflow refers to flow entering the VIB from either Vieques Sound or the Atlantic Ocean (via Virgin Passage), while outflow refers to the flow exiting the VIB across either of the two sections. Outflows from the VIB into Vieques Sound dominated the moored record (Fig. 6). The northernmost Vieques Sound mooring (VS3) recorded the most prevalent flow into the Sound.

Outflow through Virgin Passage, from the VIB to the Atlantic Ocean, was also observed to be the most dominant sub-tidal circulation feature (Fig. 7). However inflow events were more prevalent and in greater magnitude than those observed across the Vieques Sound section.

The rotated velocity time-series plots also reveal the influence of synoptic weather events on the regional circulation. Events such as the passage of Hurricane Earl in 2010 stand out clearly in the velocity records. Earl passed to the north of St Thomas on August 30, 2010 (within 100 km) driving strong inflow to the VIB across both sections.

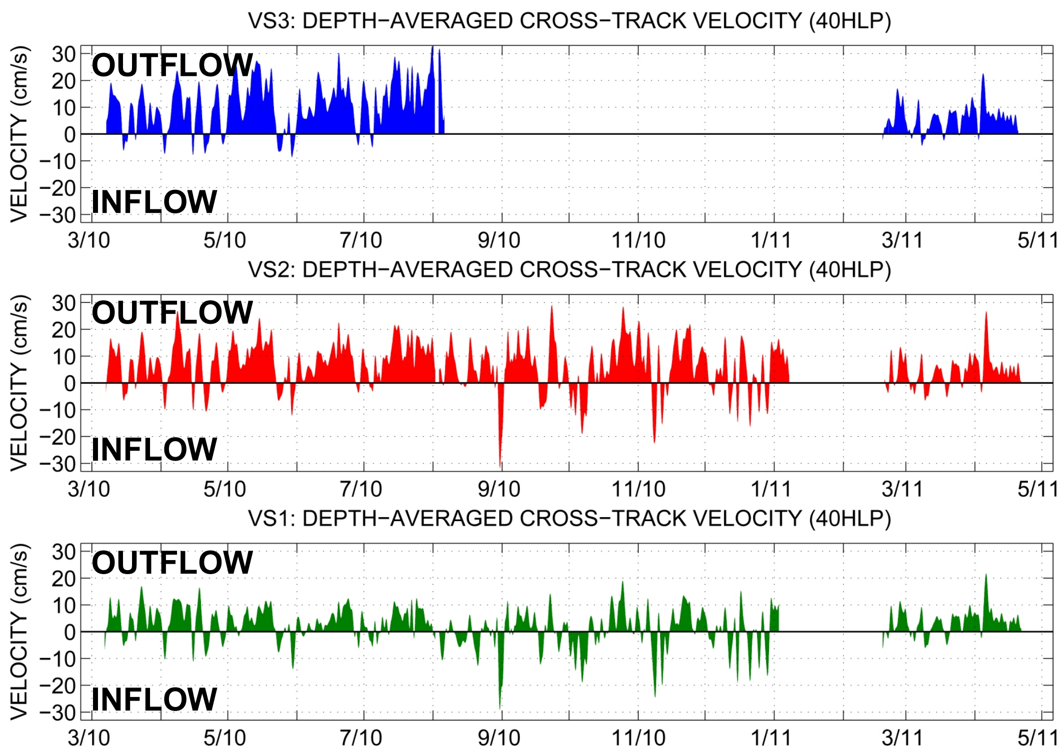


Figure 6. Rotated 40HLP depth-averaged velocity time-series for Vieques Sound.

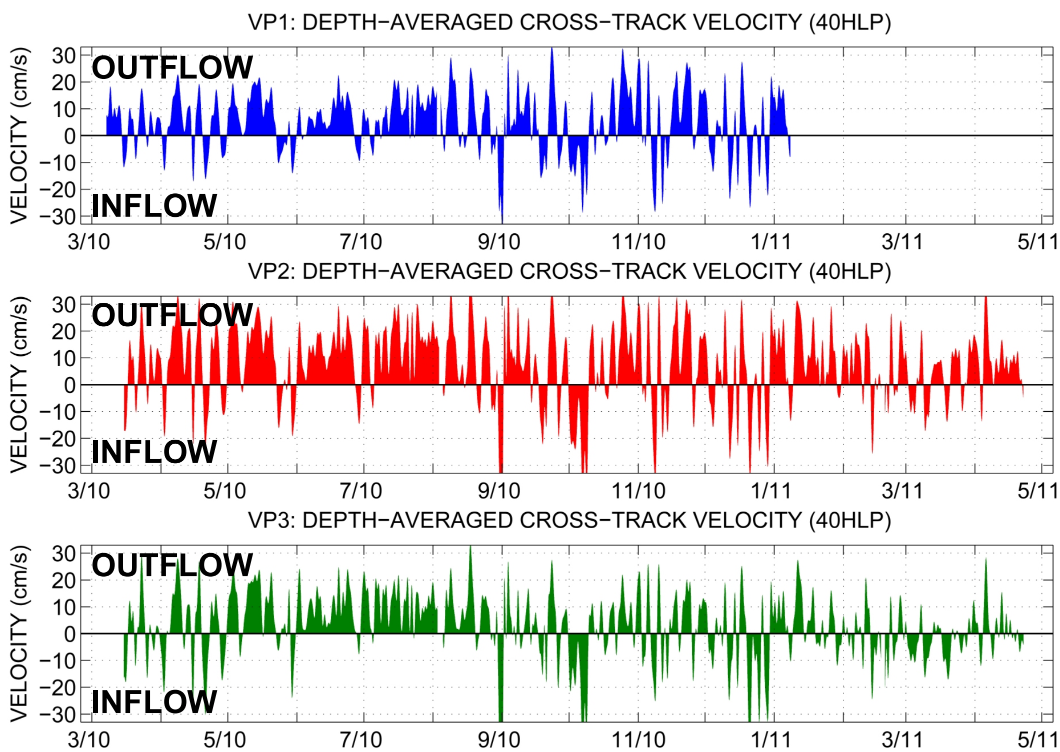


Figure 7. Rotated 40HLP depth-averaged velocity time-series for Virgin Passage.

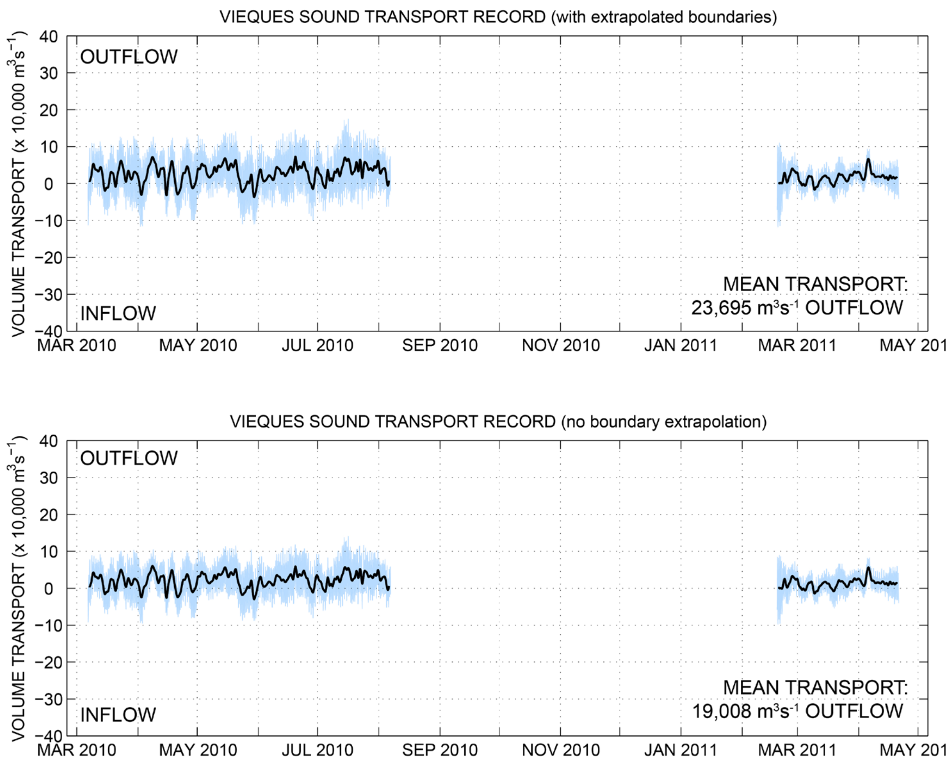


Figure 8. Vieques Sound transport time-series (black line = 40HLP).

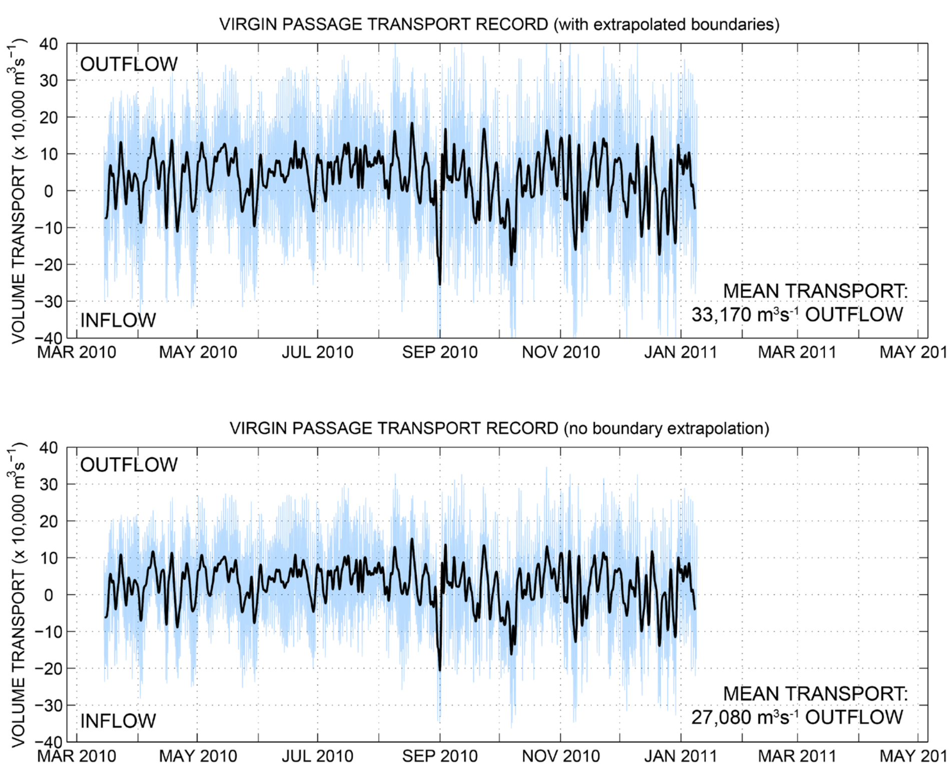


Figure 9. Virgin Passage transport time-series (black line = 40HLP).

Volume transport time-series for the Vieques Sound and Virgin Passage sections are shown in Figures 8 and 9 respectively. Transports calculated with and without the boundary extrapolation described in the previous section are plotted in each figure. For the Vieques Sound section, the extrapolated boundary region accounts for 28.3% of the total cross-sectional area (0.11 km^2). In Virgin Passage, boundary extrapolated regions include 30.9% of the total cross-sectional area (0.18 km^2).

The raw hourly volume transports for these plots are shown in light blue and can give one a sense of the transport magnitude associated with the tidal component of the flow. Despite a net transport outflow from the VIB through both of these sections, each section typically experiences an inflow period during the course of a tidal cycle. Similar to the velocity magnitudes observed in the individual ADCP time-series records, the magnitudes of the hourly transports calculated for Vieques Sound are less than those calculated for Virgin Passage. The 40HLP transports are represented with a black line in each plot. When averaged over the transport record length, these time-series yield the mean volume transport for each transect.

The mean transport for the Vieques Sound section, calculated without extrapolated boundaries, was found to be an outflow (from the VIB into Vieques Sound) of 19,008 m^3s^{-1}. With boundary extrapolation, the outflow was larger at 23,695 m^3s^{-1}. In Virgin Passage, the mean transport, without extrapolated boundaries, was found to be an outflow of 27,080 m^3s^{-1}. With boundary extrapolation, mean outflow through Virgin Passage was calculated to be 33,170 m^3s^{-1}.

Mean velocity sections associated with each of these four mean transports are contoured in Figures 10-13. The locations of the moored ADCPs are indicated with yellow markers. All contours are plotted in cm s^{-1}, with outflow represented as positive values. Despite the strongest current magnitudes being observed at the center mooring of each channel, one can see from these section plots that the northern end of the Vieques Sound section and the western side of the Virgin Passage section yield the strongest mean transports (both outflows).

The volume transport data described in this summary will be used in conjunction with larval fish abundance data for the region to calculate larval flux across the Vieques Sound and Virgin Passage sections. This topic will be to focus of a separate report titled: *Vieques Sound and Virgin Passage Larval Flux Assessment.*

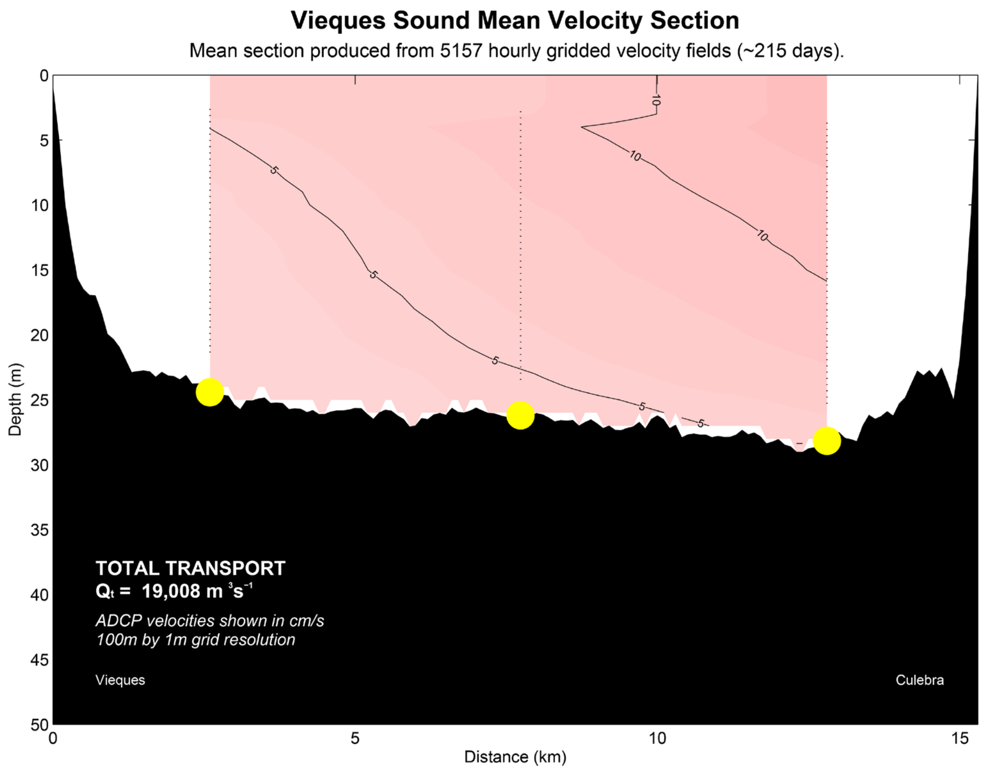


Figure 10. Vieques Sound mean velocity section without boundary extrapolation.

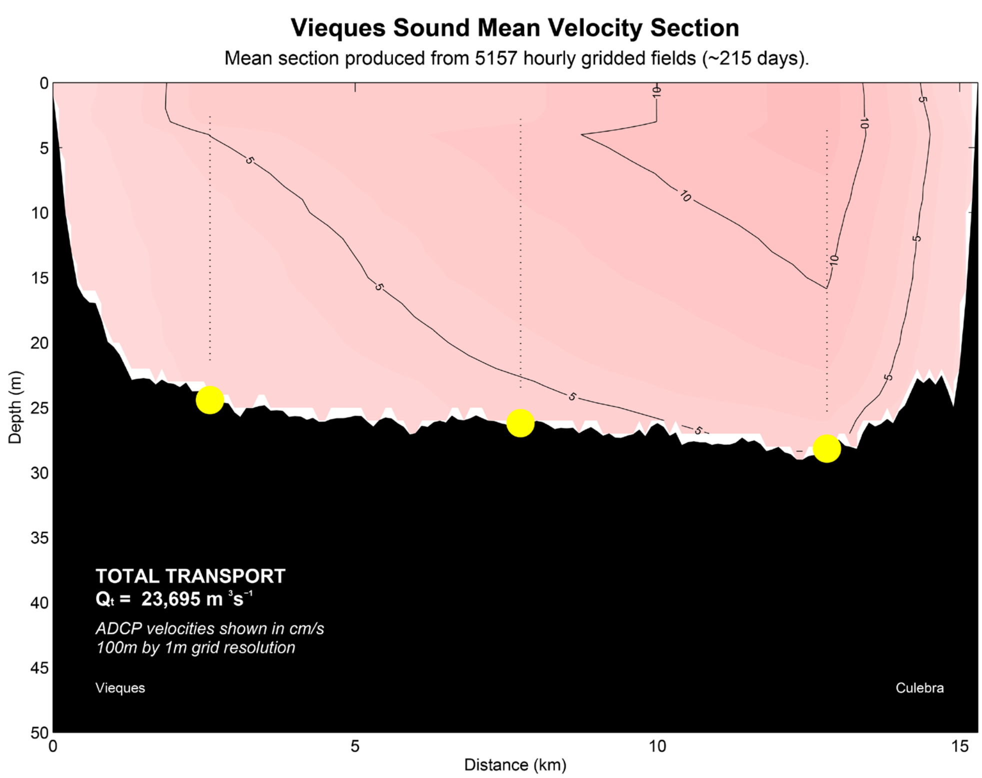


Figure 11. Vieques Sound mean velocity section with boundary extrapolation.

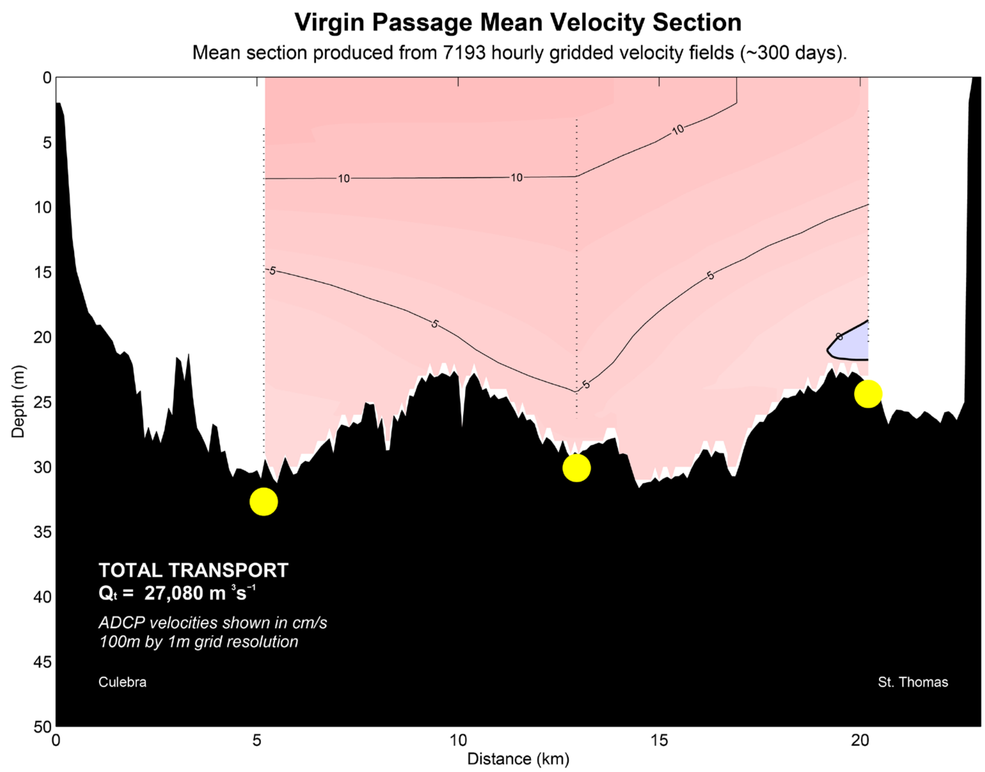


Figure 12. Virgin Passage mean velocity section without boundary extrapolation.

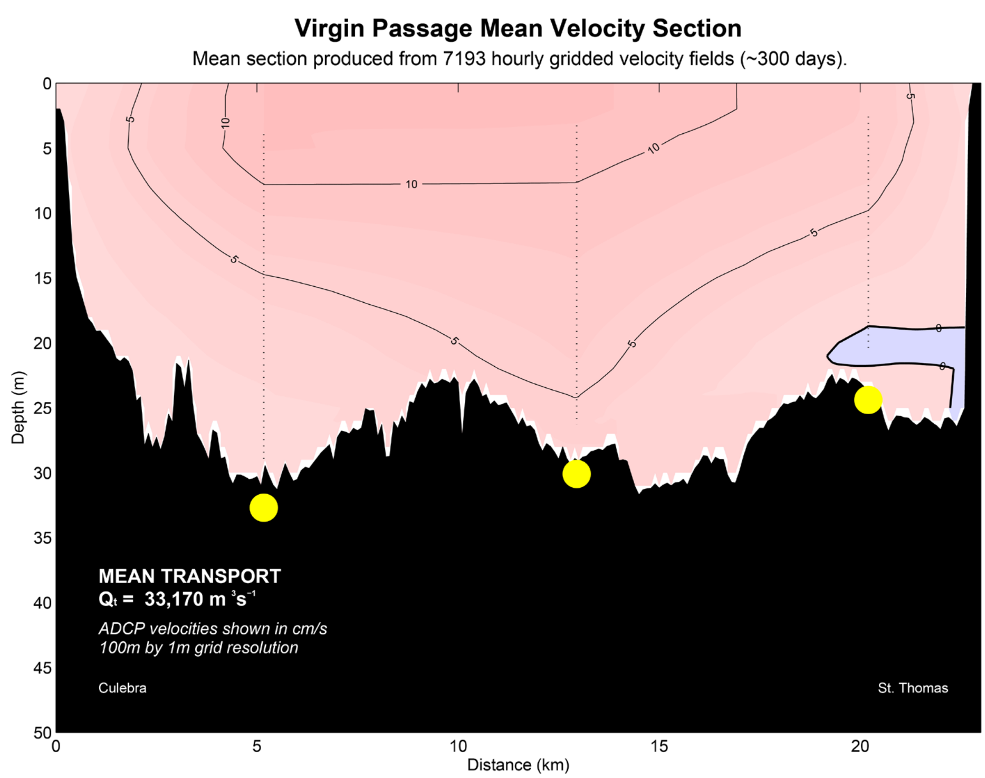


Figure 13. Virgin Passage mean velocity section with boundary extrapolation.

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