Vieques Sound and Virgin Passage Transport Study

Model Results

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1 Introduction

Current velocity measurements collected on National Oceanic and Atmospheric Administration (NOAA) ship surveys of the US Virgin Islands (USVI) and Puerto Rico (PR) coastal ocean agree with drifter and model data suggesting strong linkages between MPAs south of St. Thomas and near-shore areas east of PR and north of St. Thomas. These regions are connected by Vieques Sound and Virgin Passage. In 2010, NOAA's Coral Reef Conservation Program (CRCP) funded NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) to moor instrumentation across these waters to assess biological connectivity over the USVI and PR shelf in support of adaptive management. Sustainable fisheries require effective resource management.

Protective measures must address overfishing and habitat protection, and they must be appropriately targeted. There is general agreement that assessment of the effectiveness of existing USVI and PR MPA management actions should be evaluated based upon analysis of biophysical data collected from the region, and that in order to develop improved adaptive management strategies for the future, a more comprehensive understanding of relevant larval recruitment pathways and region-wide habitat connectivity is required. These needs, have previously been articulated in USVI Coral Reef Management Priority Setting Process Objectives 4.12, MR15, and national objectives F1.1, F1.3, F1.6, F2.4, F2.5, and I1.5,

Building upon collaborative work in the region, AOML and the Southeast Fisheries Science Center (SEFSC) seek to quantify ichthyoplankton flux across the PR and USVI shelf, from known regional spawning aggregation sites to other near-shore habitats, through the collection of moored time-series data and model implementation. Here we present the model results as a comparison with the observed flow measured during occupation of Vieques Sound and Virgin Passage sections (Figure 1). This modeling work was also funded CRCP.

2 North Eastern Caribbean Model

The Regional Ocean Modeling System (ROMS), a coastal-scale hydrodynamic model, was implemented to simulate the circulation in the northeastern Caribbean Sea. The model domain encompasses east of Hispañola, Puerto Rico, the US and British Virgin Islands, and some of the Leeward Islands. The simulation consists of three embedded grids. The highest resolution grid is centered on St. Thomas and its shelf (Figure 2).

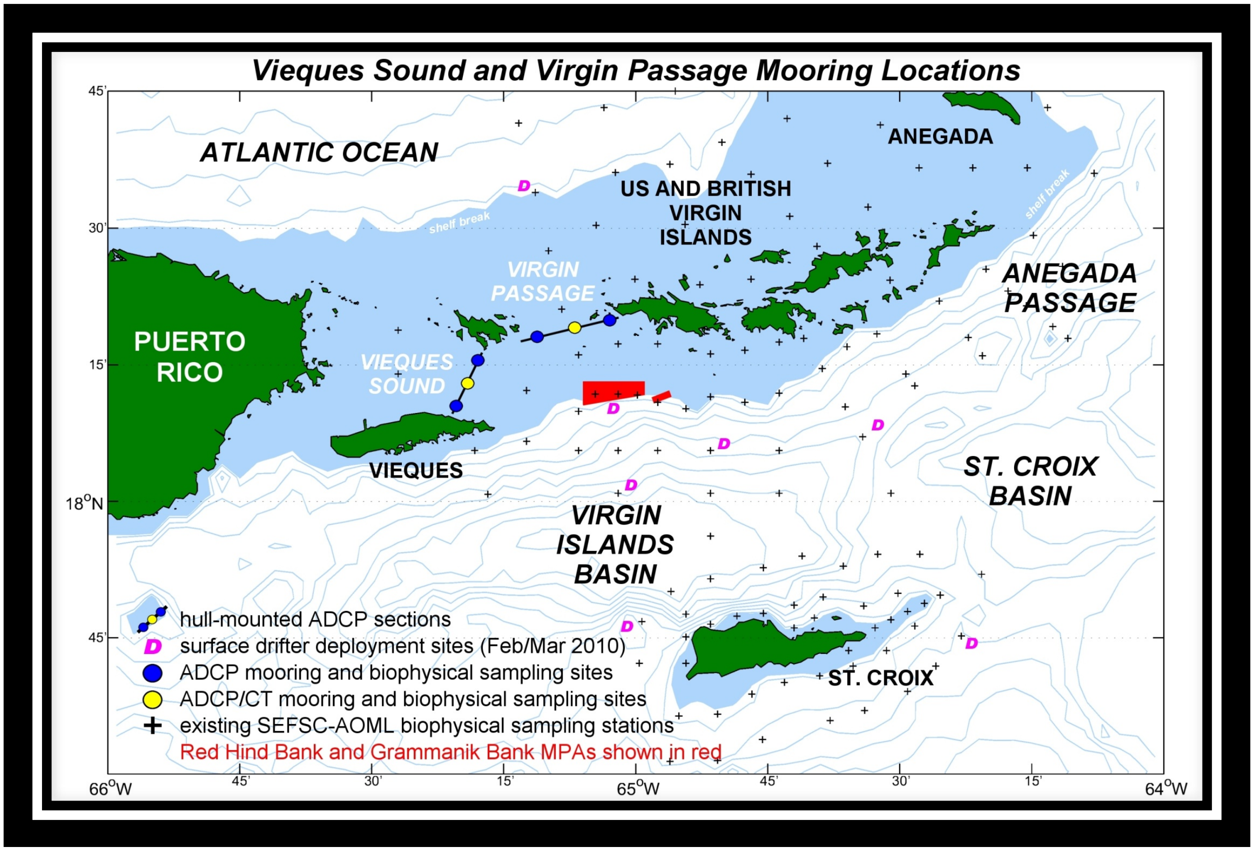


Figure 1: Map showing the sections occupied and the different types of measurements.

2.1 Description

The larger model domain (parent grid) is centered on Puerto-Rico (14-22°N; 70-62°W). The first child grid is centered on St. Thomas, but encompasses all the Virgin Islands, eastern Puerto-Rico and St. Croix (17.3-19.2°N; 66-63.8°W). The second child grid is also centered on St. Thomas and encompasses only its shelf (18.13-18.6°N; 65.18-64.73°W). The model was spun up from 3August 2006 to 30 November 2006 with atmospheric climatology. Starting 1 December 2007, realistic forcing was applied. The temporal coverage is from January 2007 to December 2010.

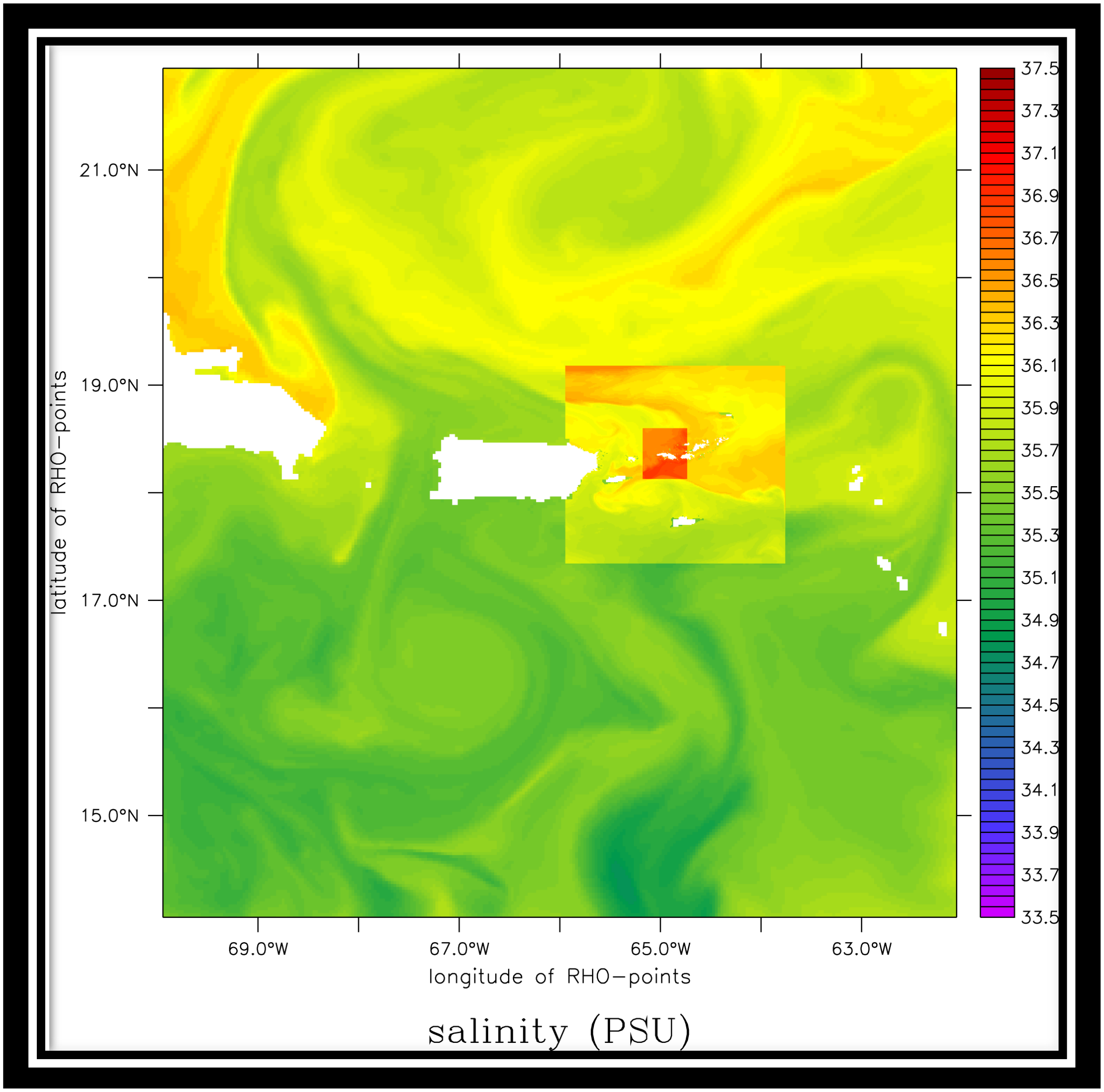


Figure 2: Model surface salinity and grid domains. Salinity is offset in each grid in order to show their respective domain.

2.2 Resolution:

The horizontal resolution of the parent grid is 2.862-km and the minimum depth is 8-m. The first child grid's horizontal resolution is 970-m and the minimum depth 5-m. The second child grid's horizontal resolution is 325-m and the minimum depth 2-m. All grids have 32 vertical layers.

2.3 Nesting

The parent and child models are run simultaneously and nested one way (no feed back of the child to the parent) using the AGRIF package. The parent model is nested off-line within the outer model. The model uses a weekly relaxation to the high-resolution (1/12°) Global HYCOM ocean state fields. Tides are set at the boundaries of the parent model by the TPXO7 global tide model.

2.4 Atmospheric forcing

4xdaily net surface shortwave and longwave heat fluxes, as well as the net shortwave radiation are obtained from the NCEP/NCAR reanalysis. 6xdaily air temperature, latent heat flux, sensible heat flux, precipitation rate, the relative and specific humidity are obtained from the North American Regional Reanalysis (NARR). Other surface variables include daily night SST from AVHRR Pathfinder SST v5 and monthly Sea Surface Salinity from NCEP Global Ocean Data Assimilation System (GODAS). 4xdaily zonal and meridional wind speed are obtained from NARR and converted into wind stress using the ROMS bulk flux formulation.

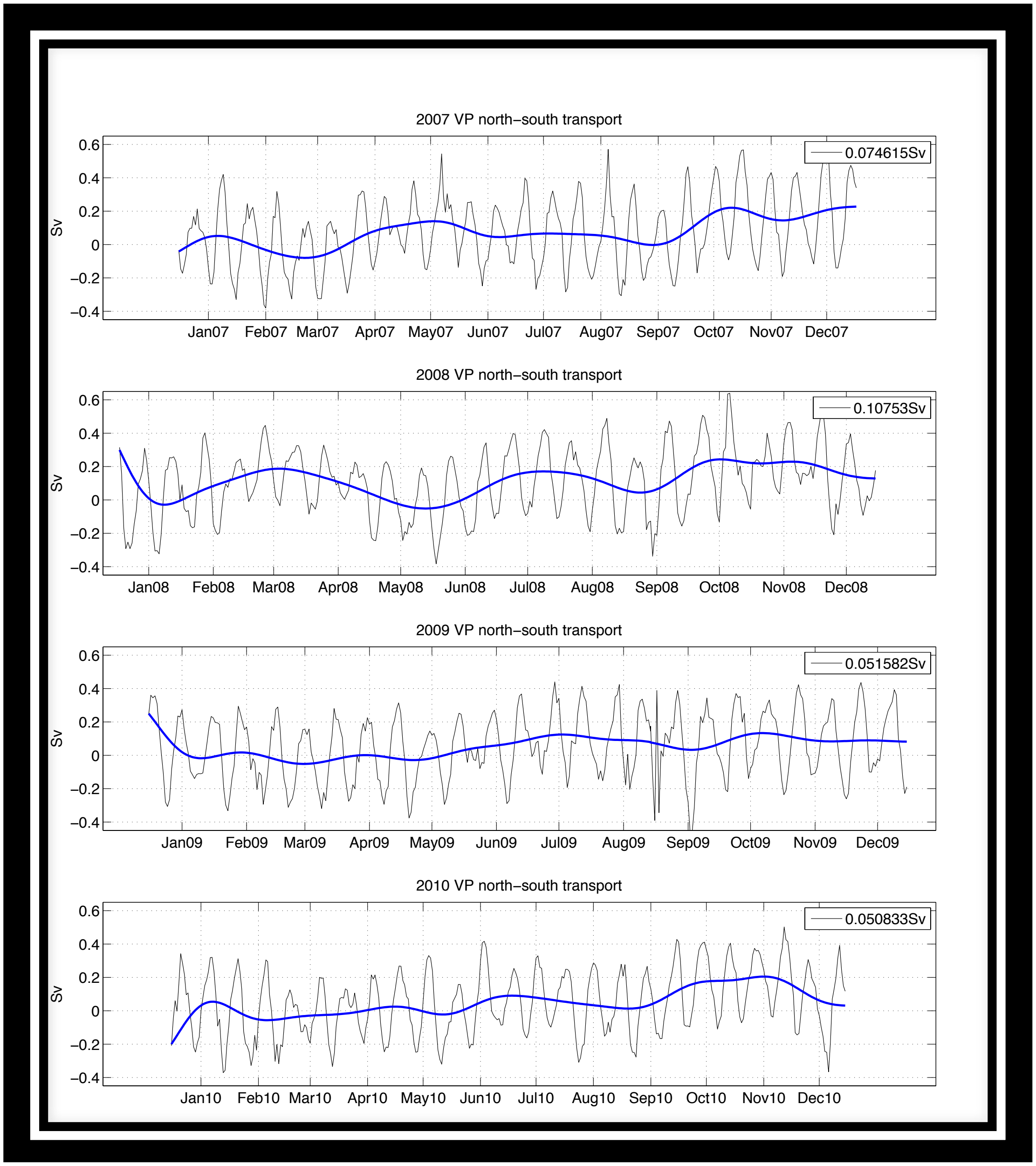
3 Outflow transport

Transport was calculated as the flow through the sections shown in Figure 1. Here we show the model time series for the 4-year simulation and we evaluate the model performance by comparing the observed flow measured during occupations of the sections to daily model outputs.

3.1 Virgin Passage

Daily transport from the model (Figure 3) shows bi-weekly fluctuations of the transport that are associated with the neap-spring tide cycle. No clear seasonal variability is present in the annual time series. However, the mean transport (net transport) is outside the Caribbean Basin and of the order of 0.075 ± 0.25 Sv, which is the order of magnitude observed during the Virgin Passage occupation (Fig. 4a). Model sections for transport similar to the one measured show similarities with observed sections, although the observation sections are not synoptic. The flow may have changed by the time the section was completed. We show here sections for the same day as when the survey was conducted (29-30 July 2013).

The model outflow at midnight on 31 July was about 0.25 Sv (Fig. 5a). The current cross-section showed a maximum core situated about 15 km from the east side of the passage (Fig. 5b). The occupation of the Virgin Passage on 30 July at midnight showed also a 0.26 Sv outflow (Fig. 5c). The current cross-section showed a double maximum core structure, one them located also 15 km from the east side of the passage. On 30 July, the model showed the same double core structure although the transport was only about 0.2 Sv (not shown).



2007 VP north–south transport

2008 VP north–south transport

2009 VP north–south transport

2010 VP north–south transport

Figure 3: Daily model transports from 2007 to 2010 across the Virgin Passage.

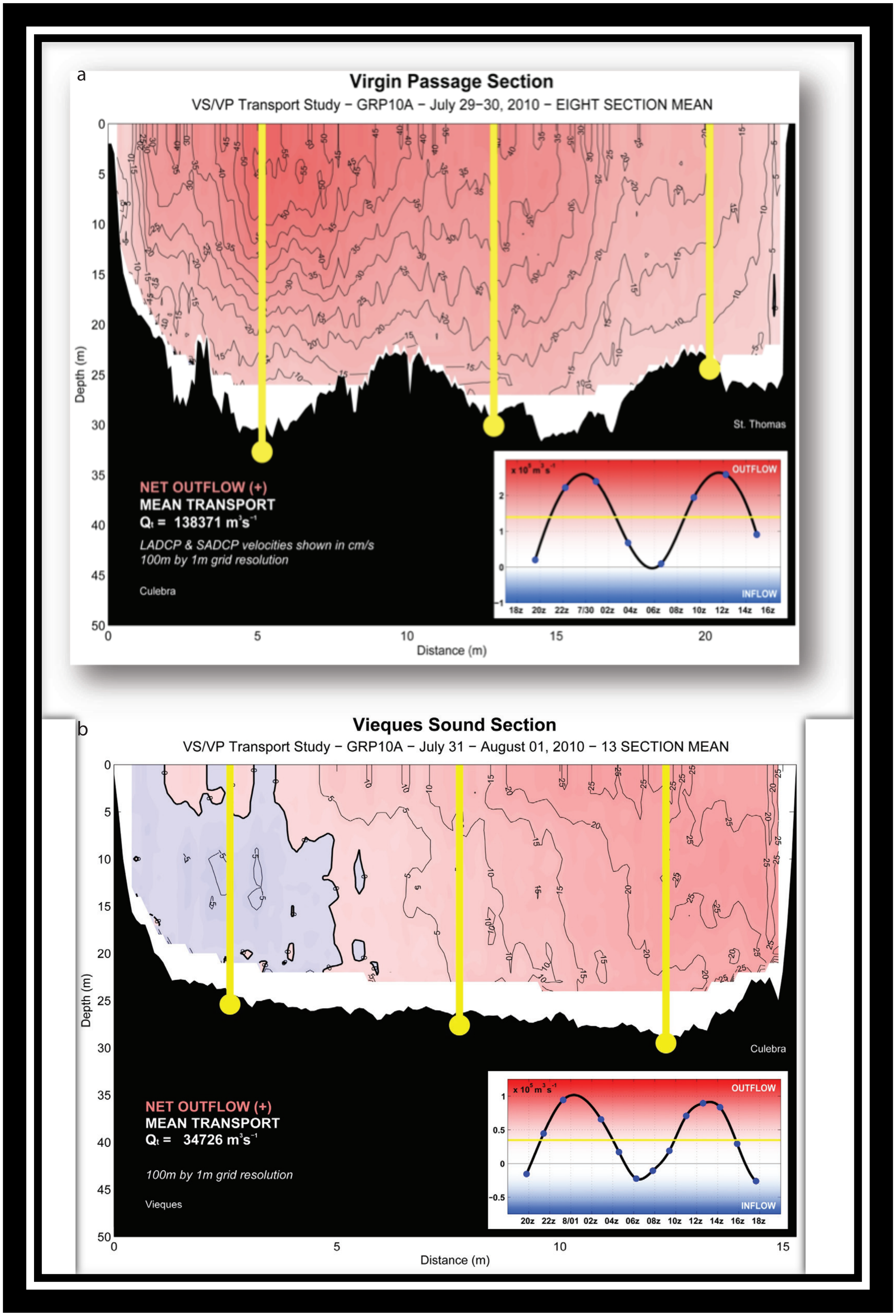


Figure 4: Mean transport from (a) the 20-hour occupation of the Virgin Passage and (b) from Vieques Sound section.

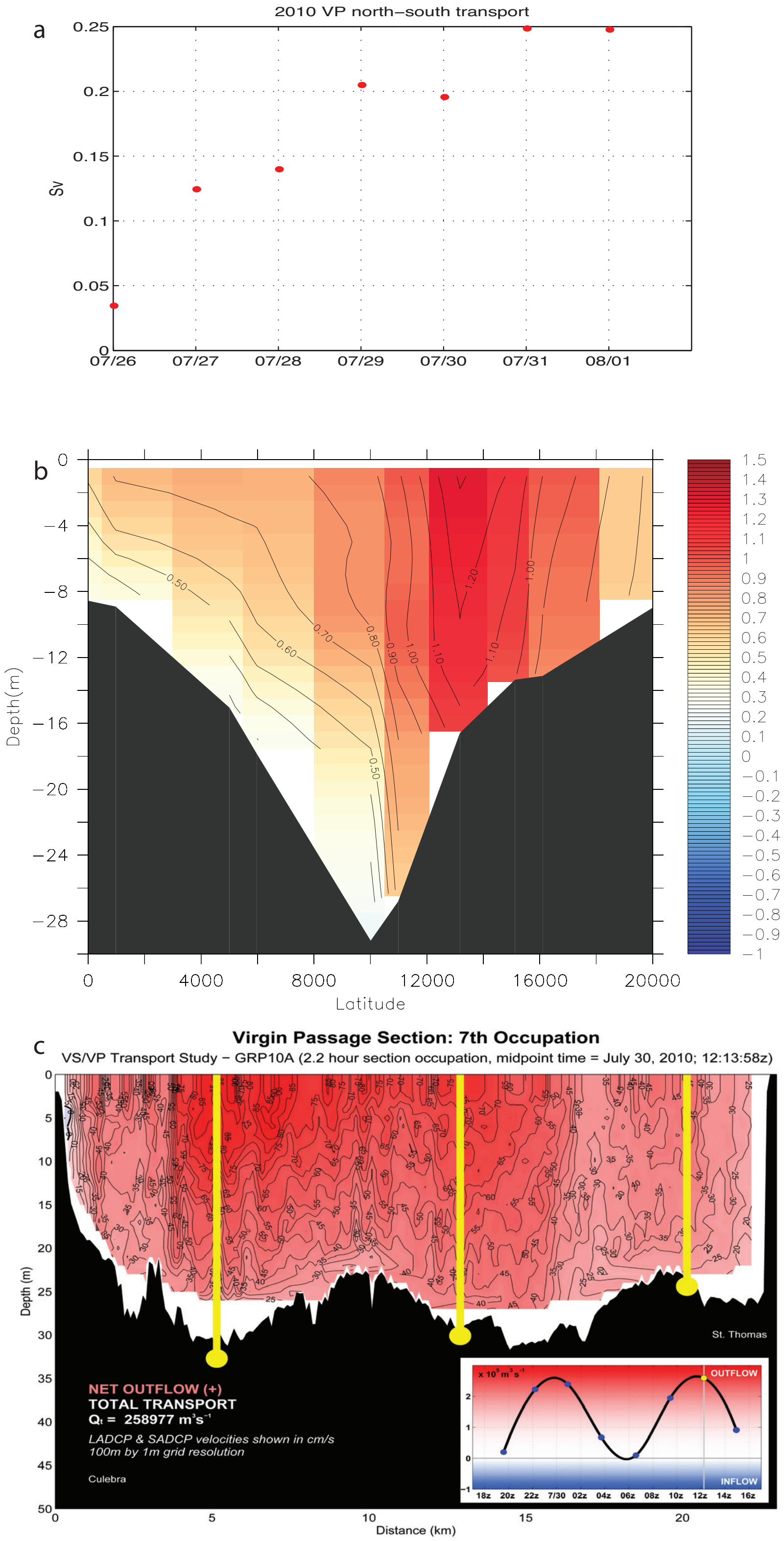


Figure 5: Virgin Passage outflow. (a) 26-31 July model transport time series. (b) Model current cross-section in m s^{-1} on 31 July. (c) Current cross-section from passage's occupation on 30 July 2013 at 12:14z. Yellow lines show the acoustic current profiler locations.

3.2 Vieques Sound

Model daily transport through Vieques Sound is shown for model years 2007 to 2010 in Figure 6. Similarly to the Virgin Passage, the transport exhibits no seasonal variability although the mean annual transport can be extremely variable (0.006 – 0.096). The mean transport from the 22h occupation is a net outflow of 0.035 Sv (Fig. 4b). This value is within the annual transport range and is consistent with the net transport being an outflow from the Caribbean Sea to the Atlantic Ocean.

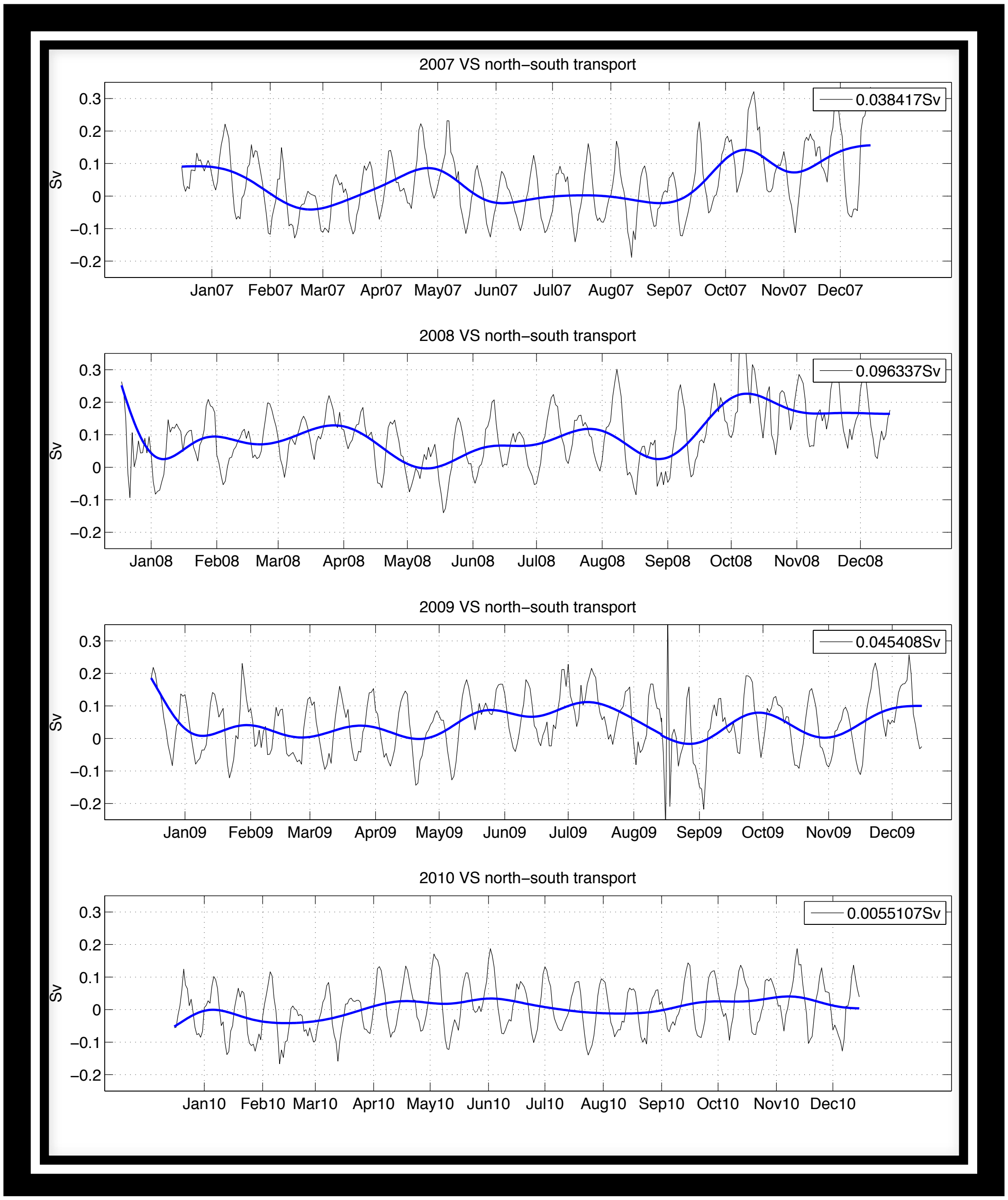


Figure 6: Daily model transports from 2007 to 2010 across Vieques Sound.

We compared now the model flow structure to the observations at similar date and time, namely 31 July 2010. The transport estimated from the model, 0.082 Sv (Fig. 7a) and the measurements 0.094 Sv (Fig. 7c) are very close. The model shows similar velocity and structure, the lowest velocity being on the western side of the passage.

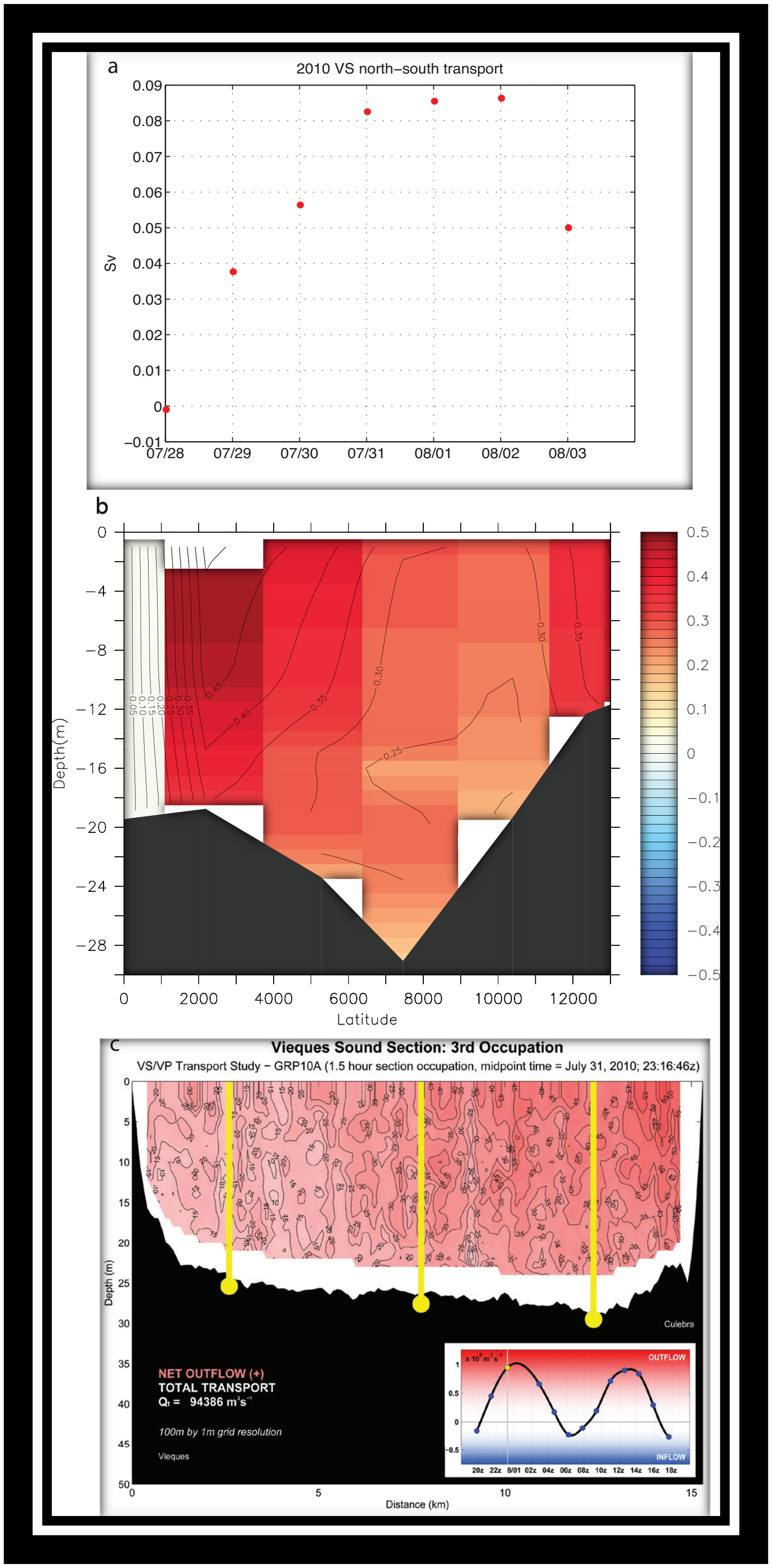


Figure 7: Vieques Sound outflow. (a) 28 July – 03 August 2010 model transport time series. (b) Model current cross-section in m.s^{-1} on 31 July. (c) Current cross-section from passage's occupation on 31 July 2013 at 23:16z. Yellow lines show the acoustic current profiler locations.

4 Inflow Transport

Transport was calculated as the flow through the sections shown in Figure 1. We evaluate the model performance by comparing the observed flow measured during occupations of the sections to daily model outputs.

4.1 Virgin Passage

Because of the phase of the tide, which yielded outflow around midnight on 29-30 July 2013 and because the model outputs were only at midnight, it is not possible to plot the model inflow during this time period. Therefore we used the model outputs when the inflow was around 12am, which is around 23 July 2013 (Fig. 8a). The model's transport showed in Figure 8a is in fact an outflow, but it is close to what the current structure looked like before turning into an inflow. The section occupations didn't record an outflow as shown in Figure 8c and 8d, although they seemed to be very close to the reversal point. Therefore, we chose to show that the current spatial structure in the model and the observations are relatively similar for a transport of 0.04 Sv in the model. The current exhibits an incoming flow at the bottom and an outgoing flow at the surface. In Figure 8c, the net transport is 0.067 Sv and when the occupation started the current was outgoing (left side of the plot). When the occupation ended the current was incoming (right side of the plot – Fig. 8c). Chances are that when the occupation ended, the current was then incoming at the other end where the occupation started, which is showed in Fig 8d at the bottom (left side of the plot). Although model and observations tend to agree on the west side of the passage, the model shows outflow while observations show inflow on the east side of the passage close to reversal time. Nonetheless, the fact that the comparison is made at a different phase of the tide (30 July for the observations, versus 20 July for the model) could explain that discrepancy. This could be verified against the ADCP measurements.

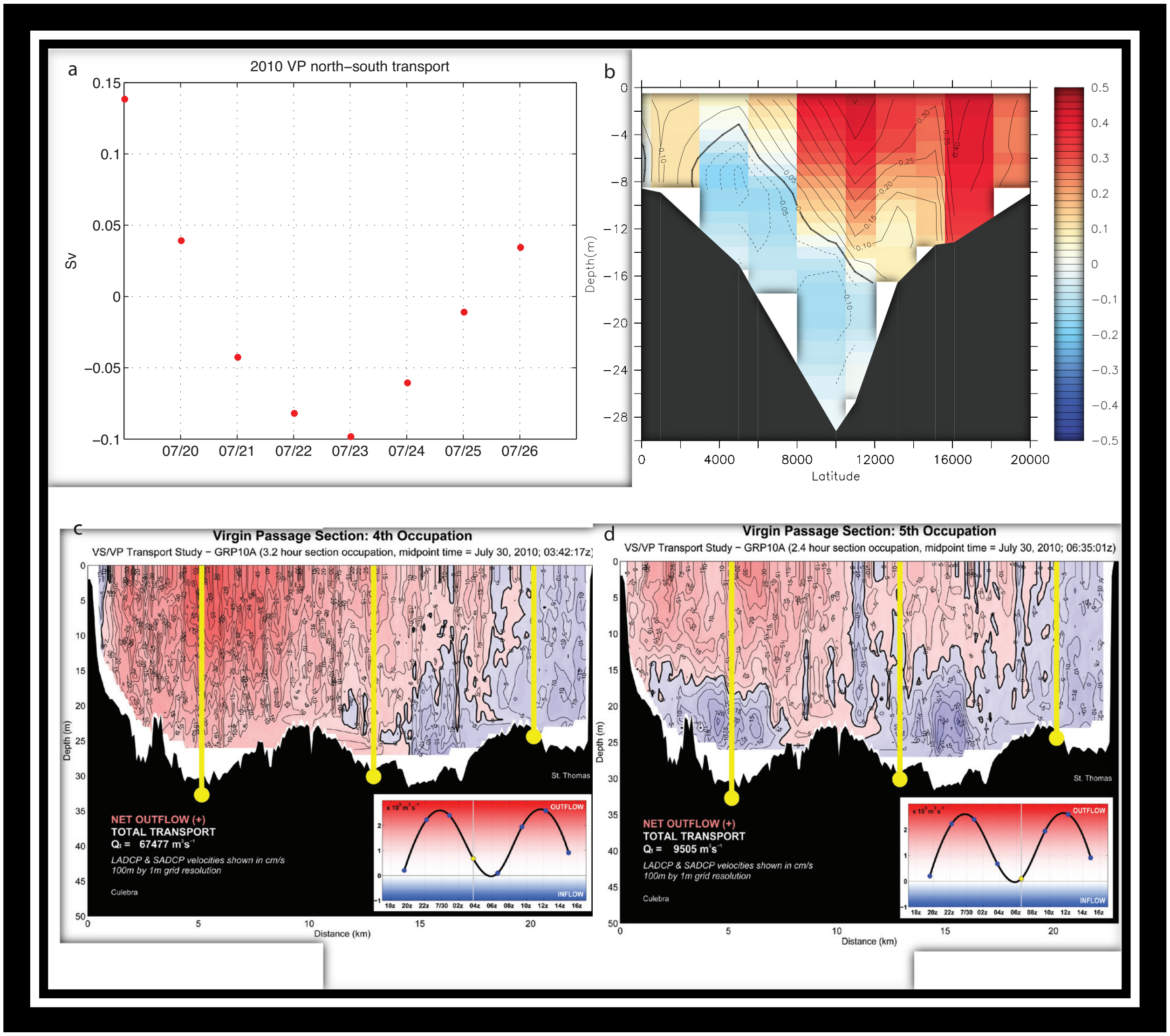


Figure 8: Virgin Passage transport close to reversal time. (a) Model transport time series for the period 20-26 July 2010. (b) Model current on 20 July 2010. (c) Section occupation on 30 July 2010 at 03:42z. (d)

Section occupation on 30 July 2010 at 06:35z. Yellow lines show the position of the acoustic current profilers.

4.2 Vieques Sound

Similarly to the Virgin Passage inflow comparison, we had to select another time period in the model, which was 24-29 July 2010. The model showed larger inflow than the maximum measured during the occupation, namely more than 0.06 Sv for the model versus 0.02 Sv in the observations (Fig. 9). The inflow structure in Vieques Sound model section (Fig. 9a) shows in inflow of 0.018 Sv that occupied the whole section except at the bottom, where the flow was out of the Caribbean Sea (Fig. 9b). Sections from the occupations showed instead, inflow on the western three-quarter of the section and outflow in the last quarter of the section and below the inflow toward the middle of the section (Fig 9c and d). Although the inflows were consistent between model and observations, their structures differed. This could be explained again by the lack of synopticity, although the current structure remains the same between the two occupations. On the other hand, because of the bottom topography smoothing in the model, the shape of the bottom, which differs from the real topography, may be responsible for this structure difference. Like the Virgin Passage, the tidal phase difference could also explain the current structure difference, which could be verified with the acoustic current profilers.

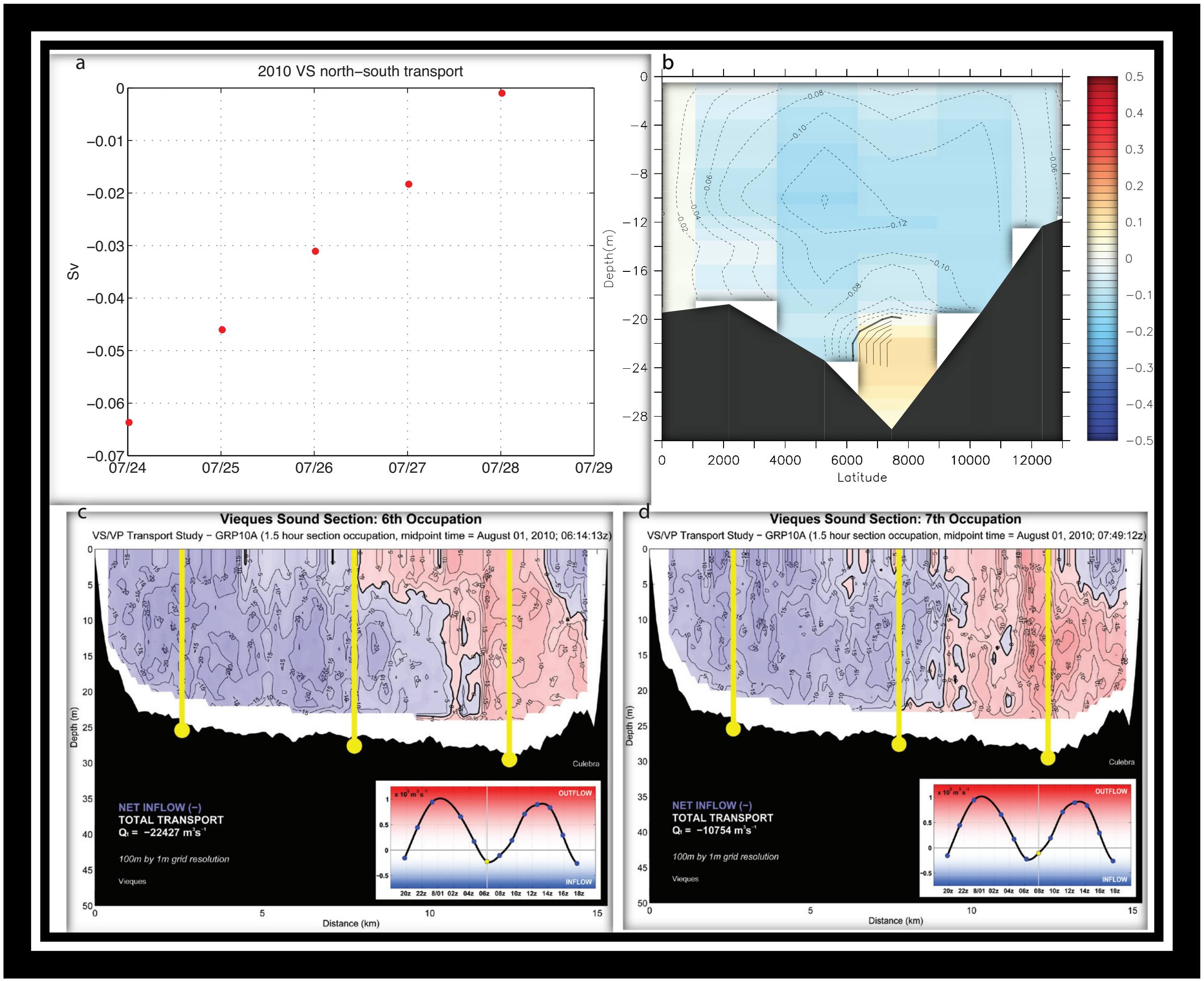


Figure 9: Vieques Sound inflow. (a) 24-29 July 2010 model transport time series. (b) Model current cross-section in m.s^{-1} on 27 July. (c) Current cross-section from passage's occupation on August 1 2013 at 06:14z. (d) Same as (c) on August 1 2013 at 07:49z. Yellow lines show the acoustic current profiler locations.

5 Conclusions

When in phase with the observations, the model shows similar transport magnitude and similar current structure. This suggests that the flow field surrounding the Virgin Passage and the eastern side of Vieques Sound is relatively realistic and can be used to estimate the water pathways that could connect different areas on the coastal shelf between the US Virgin Islands and Puerto-Rico.