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# Volume Transport Through Tidal Channels in the Middle Florida Keys

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**ABSTRACT**

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Shipboard acoustic Doppler current profiler (ADCP) data from six synoptic surveys are combined with current meter, bottom pressure and wind data to describe tidal and low-frequency exchanges through four tidal channels in the Middle Florida Keys. ADCP crossings provide transport rates for Channel 2, Channel 5, Long Key Channel and the Seven Mile Bridge channels. Predictions of tidal current speed and water level provide mid-channel, vertically-integrated transport for times corresponding to total channel transport given by the ADCP data. For Channel 2, Channel 5 and Long Key Channel, flood and ebb tide data are separated, and results from the surveys are pooled. Total channel transport is regressed against mid-channel transport, and the slope of the regression equation serves as a conversion factor to translate time series of mid-channel transport into time series of total channel transport. Tidal transport is estimated for the principal tidal constituents in each channel. $M_2$ total flood and ebb discharges vary from 13.13 $\times$ $10^6$ $m^3$ for Channel 2 to 122.60 $\times$ $10^6$ $m^3$ for the Seven Mile Bridge channels. Time series of mid-channel current speed and bottom pressure from Long Key Channel are used to investigate the response to wind forcing. The mean mid-channel current speed is an inflow of 2.4 cm $s^{-1}$, and the mean transport is an inflow of 32 $m^3$ $s^{-1}$. Both are the result of forcing by strong east-northeasterly winds typical of the fall season.

**ADDITIONAL INDEX WORDS:** *Tidal transport, wind-driven transport, acoustic Doppler current profiler, Florida Keys.*

## INTRODUCTION

An understanding of circulation patterns in the Florida Keys is an important prerequisite to a broader understanding of the region's ecosystem because of the role currents play in transporting dissolved and suspended material. Over the past several years, one objective in a series of circulation studies has been to quantify tidal and low-frequency exchanges through passes that connect Florida Bay on the Gulf side of the Keys with Hawk Channel on the Atlantic side (Figure 1). Environmental stressors in Florida Bay have contributed to seagrass die-offs (ROBBLEE *et al.,* 1991; THAYER *et al.,* 1994; TOMASKO and LAPOINTE, 1994), as well as to a decline in recreational gamefish populations (TILMANT, 1989). Thus, there is concern that Florida Bay water moving through tidal channels will expose the reef tract on the Atlantic side of the Keys to larger salinity ranges, higher nutrient and turbidity levels, and lower water temperatures in winter (VOSS, 1973; LIDZ and SHINN, 1991).

Early studies conducted in five major tidal channels of the Middle Keys (SMITH, 1994) suggested that vigorous tidal exchanges were superimposed onto a long-term net outflow from Florida Bay. Time series measurements of currents in mid channel could not be used to quantify the outflow through four of the five channels, however, because water level data were not available to quantify the effect of current and water level interactions on volume transport. Bottom pressure data were available from Bahia Honda Channel (see Figure 1) for a 39-day study in October and November, 1990. Direct read-out flow meter data from five anchor stations helped define flood and ebb dominant parts of the channel relative to flow at a reference station, and these relationships were used to make volume transport estimates (SMITH, 1994). The local interaction of the tidal rise and fall in water level with the ebb and flood of the current in Bahia Honda Channel suggests a tide-induced residual transport into Florida Bay at a rate of +72 $m^3$ $s^{-1}$. Calculations using observations that included both tidal and nontidal variations in current and water level, however, revealed an average outflow of −620 $m^3$ $s^{-1}$. It was hypothesized that mean sea level differences on the order of several centimeters between the Gulf and Atlantic explained part of the outflow (CHEW *et al.,* 1982; LEE and SMITH, in press). In addition, a tide-induced residual transport, as described by WANG *et al.* (1994), has been suggested for forcing Gulf water through Florida Bay (SMITH, 2000).

A second series of field studies during 1994–96 included the mid-channel current meter data and bottom pressure

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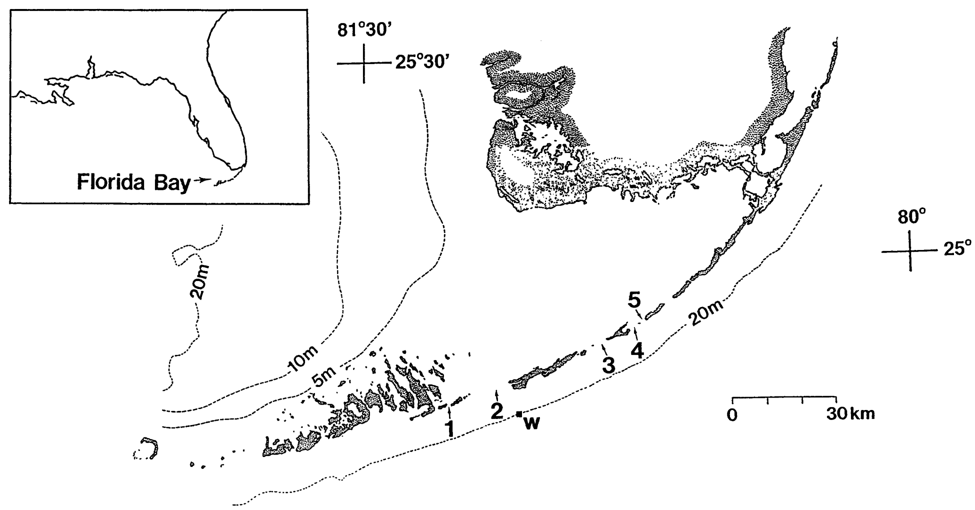


Figure 1. Map of the Florida Keys, showing locations of (1) Bahia Honda Channel, (2) the Seven Mile Bridge channels, (3) Long Key Channel, (4) Channel 5, (5) Channel 2 and (6) the C-MAN weather station at Sombrero Key. Insert shows the study area south of the Florida Peninsula.

measurements needed to estimate volume transport in Channel 2, Indian Key Channel, Whale Harbor Channel, Snake Creek and Tavernier Creek (SMITH, 1998). The methodology was similar. Channel calibration data were obtained from single flood or ebb tide cycles, and lateral resolution provided by flow meter data from 3–7 anchor stations was poor.

This paper describes results from a third study that integrate historical time series of currents and water levels with data from a boat-mounted acoustic Doppler current profiler (ADCP). Using ADCP data, lateral resolution is improved substantially, and several crossings during a semidiurnal tidal cycle provide much better temporal resolution than did the single flow meter measurements during flood or ebb conditions. We focus on the four channels with the largest transports in the Middle Keys. The primary purpose of the paper is to present improved estimates of half tidal-cycle volume transport and long-term tidal residual transport through these channels. A secondary purpose is to characterize the low-frequency response to wind forcing in Long Key Channel. Results provide a better under-standing of how Florida Bay water is exported to the reef tract.

Table 1. *Net total channel volume transport over a semidiurnal period, net nontidal volume transport, and net tidal residual transport. All transports are in m³.*

| Date | Channel | Total | Nontidal | Tidal |
|---|---|---|---|---|
| Feb 23 96 | Long Key | −987 | −909 | −78 |
| Feb 22 96 | 5 | −230 | −322 | +92 |
| Feb 22 96 | 2 | −174 | −189 | +15 |
| Total | | −1391 | −1420 | +29 |
| Jun 16 96 | Long Key | −1379 | −495 | −884 |
| Jun 15 96 | 5 | −110 | +81 | −191 |
| Jun 15 96 | 2 | −177 | −40 | −137 |
| Total | | −1666 | −454 | −1212 |
| Oct 24 96 | Long Key | +50 | −390 | +440 |
| Oct 23 96 | 5 | −52 | −148 | +96 |
| Oct 23 96 | 2 | −83 | −133 | +50 |
| Total | | −85 | −671 | +586 |
| Feb 27 97 | Long Key | −346 | −140 | −206 |
| Feb 26 97 | 5 | +286 | +266 | +20 |
| Feb 26 97 | 2 | +144 | +145 | −1 |
| Total | | +84 | +271 | −187 |
| May 20 97 | Long Key | −993 | −670 | −323 |
| May 21 97 | 5 | −356 | −200 | −156 |
| May 21 97 | 2 | −280 | −170 | −110 |
| Total | | −1629 | −1040 | −58 |
| Jul 15 98 | Long Key | −541 | −615 | +74 |
| Jul 14 98 | 5 | −344 | −343 | −1 |
| Jul 14 2 | 2 | −306 | −282 | −24 |
| Total | | −1191 | −1240 | +49 |

## DATA

Volume transports were measured over semidiurnal tidal cycles on six occasions in Long Key Channel, Channel 5 and Channel 2 (Table 1); and on a single day in the Seven Mile Bridge channels. A RDI 600 kHz direct reading broadband ADCP with a 20° beam angle was mounted forward of the bow between the hulls of a shallow-draft catamaran to make continuous vertical profiles of horizontal currents while crossing the channels. The instrument was set up in the bottom-tracking mode for channel depths that are characteristically between 0.5 and 3 m. Currents were profiled in 0.25 m depth bins, and standard deviations were kept less than 1.5 cm $s^{-1}$ by averaging 30 pings to obtain an average profile every minute. The RDI Transect software computed total volume transport for each crossing. Transects were made between start and end points located close to bridge abutments on the Florida Bay side of each channel. Transects were made every 1–2 hours over a semidiurnal tidal cycle. It took approximately 5, 10 and 25 minutes to complete transects at Channel 2, Channel 5 and Long Key Channel, respectively. Transects across the Seven Mile Bridge channels took approximately one hour.

Mid-channel current and water level records were assembled from a series of unrelated field studies from 1990–99

Table 2. *Historical current meter and bottom pressure records from Channel 2 (Ch2), Channel 5 (Ch5), Long Key Channel (LKC) and Moser Channel (MCh) used to determine harmonic constants of the principal tidal constituents. Starting and ending dates are given as month/day/year.*

| Channel | Current Measurements | Pressure Measurements |
|---|---|---|
| Ch2 | 1/28/1994–7/25/1994 | 1/28/1994–4/13/1994 |
| Ch5 | 8/3/1990–1/3/1991 | 1/18/1990–8/12/1990 |
| LKC | 10/12/1992–11/20/1992 | 10/12/1992–10/12/1992 |
| MCh | 10/22/1998–7/8/1999 | 10/22/1998–7/8/1999 |

(Table 2). Strong tidal currents scour unconsolidated sediments, and channel bottoms are primarily encrusted limestone. Thus, channel topography changes little from year to year. Mid-channel water depth was approximately 4 m in all channels, and current meters were moored 1.5 m above the bottom. General Oceanics Mark II current meters were used in Channel 2, Channel 5 and Long Key Channel. The speed and direction accuracies of Mark II current meters are ±1 cm $s^{-1}$ for currents between 10 and 60 cm $s^{-1}$ and 1°, respectively, according to instument specifications. A SonTek Argonaut acoustic current meter was in Moser Channel, the largest of the Seven Mile Bridge channels. Current speed and direction accuracies are ±1% of the current speed and ±2°.

Sea Data TDR-3 pressure recorders in Channel 2, Channel 5 and Long Key Channel provided information on the tidal and nontidal rise and fall of sea level. The accuracy and resolution are 0.012 and 0.005 db, respectively. Bottom pressure readings in Moser Channel were provided by the Argonaut current meter with an accuracy and resolution of 0.025 and 0.001 db, respectively.

An Endeco Type 174 SSM current meter was in Long Key Channel for a 39-day period from October 12 to November 20, 1992, recording time-averaged speeds and directions over 20-minute sampling periods. Speed and direction accuracies are 0.8 cm $s^{-1}$ and 5°. Hourly TDR-3 pressures were subsampled using a cubic spline fit to obtain values coinciding with current observations. Wind speed and direction, air temperature and atmospheric pressure data were recorded at a Coastal-Meteorological Automated Network (C-MAN) tower at Sombrero Key, 32 km southwest of the study site.

## METHODOLOGY

The channel calibration procedure involved establishing a relationship between mid-channel, surface-to-bottom transport, in $m^2\ s^{-1}$, and total channel volume transport, in $m^3\ s^{-1}$. The conversion factor, in m ($m^3\ s^{-1}$ per $m^2\ s^{-1}$), could then be used with time series of mid-channel current speed and water level to calculate time series of channel volume transport.

Mid-channel measurements were not being made at the time of the ADCP crossings, thus predicted tidal water levels and currents (SCHUREMAN, 1958) were substituted for measured values. Tidal predictions with six constituents ($M_2$, $S_2$, $N_2$, $K_1$, $O_1$ and $P_1$) include the spring-neap and tropic-equatorial transitions and the diurnal inequalities seen in the ADCP observations. Harmonic constants needed for tidal predictions were obtained from 29-day harmonic analyses of the historical data listed in Table 2 (DENNIS and LONG, 1971). Mid-channel, surface-to-bottom transport was obtained by extrapolating the mid depth predicted tidal current to the bottom and to the surface. Calculations assumed that the vertical current profile was described by the power-law formula

$$u_z = u_{ref}\left(\frac{z}{z_{ref}}\right)^p, \tag{1}$$

where z is the height above the bottom and $u_{ref}$ is the current speed at a reference height of $z_{ref}$. A value of 0.16 was used for the exponent, p, as recommended by CHEN (1991) for fully rough flow. This produces a profile that is similar to a log-law profile with a roughness length, $z_o$, of 0.015 m. Mid-channel transport, T, was then given by the depth-integrated current speed

$$T = \int_0^Z u_z\,dz = \frac{u_{ref}}{z_{ref}^p}\frac{Z^{p+1}}{p+1}. \tag{2}$$

where the total water depth, Z, is the sum of the mean depth and the predicted rise and fall of the tide.

Linear regression analysis established the relationship between mid-channel and total channel transport. When mid-channel transport calculated from tidal predictions is regressed against total channel transport, the slope of the regression line relates mid-channel tidal transport with the tidal component of the total channel transport. For Long Key Channel, Channel 5 and Channel 2, several crossings during each of the six synoptic surveys provided samples of V-T pairs for both flood and ebb conditions, and they were analyzed individually. Having conversion factors for both ebb, $CF_E$, and flood, $CF_F$, conditions allows for the possibility that the center of the channel does not carry the same fraction of the total transport under flood and ebb conditions. Flood and ebb transport values could not be separated for the Seven Mile Bridge channels because data were available from only one synoptic survey, and the sample size was too small.

The slope obtained from linear regression analysis can be used to quantify both total and tidal volume transport. When measured water levels and currents are used in (1) and (2) to calculate the mid-channel transport, the slope provides the total transport for the channel. Alternately, when predictions for the six principal tidal constituents are used for water level and current speed, and if the prediction extends over many tidal cycles, results can be used to calculate the tide-induced residual flow. Nontidal, residual transport was obtained as the difference between the total, ADCP transport and the transport calculated from tide predictions.

Given a long time series of tidal transport, a second harmonic analysis produced harmonic constants for the principal tidal constituents. They, in turn, were used to quantify the total transport over the flood or ebb half of the tidal cycle for each constituent. The amplitude, A, of a tidal constituent, converted to $m^3\ hr^{-1}$, combined with its period, P, in hours, provides an estimate of the volume of water exchanged each half tidal cycle:

$$V = \frac{AP}{\pi}, \tag{3}$$

To investigate wind-forced exchanges over time scales of

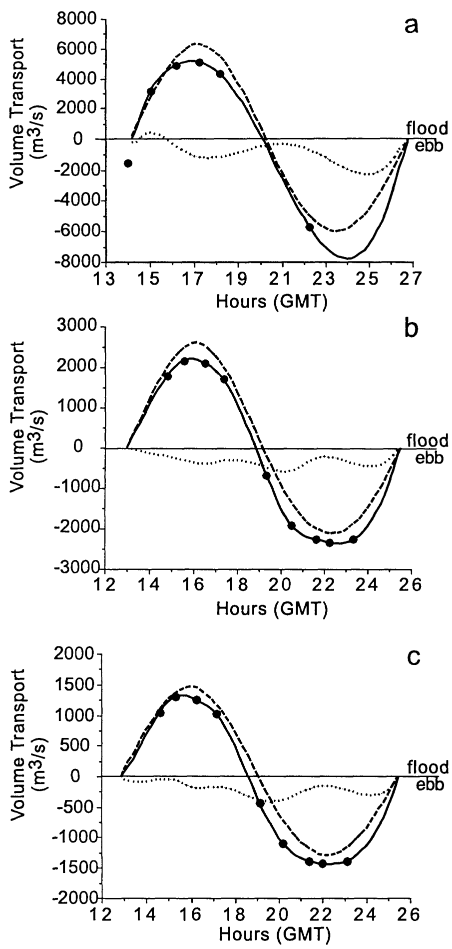


Figure 2. Shipboard ADCP derived volume transports for Long Key Channel on February 23 (upper panel) and for Channels 5 and 2 on February 22, 1996 (middle and lower panels). Included are the measured transports (solid triangles), the spline fit through the measured transports (small solid circles), tidal transports (small open squares) and nontidal transports (large open squares). Positive transport indicates water flooding into Florida Bay.

the order of several days to weeks, current meter and bottom pressure data from Long Key Channel were converted to total channel transport and compared with wind stress calculated from weather data recorded at Sombrero Key, 31 km southwest of Long Key Channel (Figure 1). Wind stress was calculated using the drag coefficient recommended by WU (1980). Winds recorded 48 m above the sea surface were reduced by 15% to obtain a value representative of the 10 m level. This assumes a power-law profile similar to (1), but with an exponent of 0.1 (SMITH, 1988). To focus on wind forcing over longer time scales, both records were smoothed with a low-pass filter (BLOOMFIELD, 1976). The filter passes 10, 50 and 90% of the variance of sinusoidal fluctuations at periods of 30, 37 and 48 hours, respectively. Linear regression was used to determine the component of the wind stress vector that was most highly correlated with low-frequency flow through the channel. The serial correlation coefficient reached 0.90 with the 285–105° component.

Table 3. *Conversion factors, CF, in $m^2 s^{-1}$ per $m^2 s^{-1}$, for estimating channel volume transport from mid-channel surface-to-bottom transport. SS is the sample size, $r^2$ is the square of the correlation coefficient and SE is the standard error of the estimate, in $m^3 s^{-1}$.*

| Channel | SS | CF | $r^2$ | SE |
|---|---|---|---|---|
| Channel 2 | | | | |
| a. Ebb | 29 | 476.1 | 0.73 | 182.5 |
| b. Flood | 25 | 658.4 | 0.77 | 235.1 |
| Channel 5 | | | | |
| a. Ebb | 30 | 1689.6 | 0.79 | 307.2 |
| b. Flood | 25 | 1963.1 | 0.74 | 390.6 |
| Long Key Channel | | | | |
| a. Ebb | 26 | 2917.0 | 0.87 | 618.2 |
| b. Flood | 25 | 2790.8 | 0.78 | 874.5 |
| Seven Mile Bridge Channels | | | | |
| a. Ebb and Flood | 10 | 3321.9 | 0.97 | 1242.6 |

## RESULTS

### Shipboard Transports

Examples of shipboard derived total transports are shown in Figure 2 for Long Key Channel (a), Channel 5 (b) and Channel 2 (c). The data (filled circles) are fit with a cubic spline to interpolate transports every 12 minutes (solid lines). Times of predicted slack tide define start and end times of the semidiurnal tidal cycle and thus the averaging period for determining net residual transport. Also shown are predicted tidal transports (dashed lines) and nontidal transports (dotted lines) determined as the difference of total and tide-predicted transports. Negative values indicate flow into Hawk Channel and toward the reef tract.

Peak transports in Long Key Channel range from 5000 to $-8000$ $m^3 s^{-1}$, which are 2–4 times larger than peak flows in Channel 5 and 3–6 times larger than peak flows in Channel 2. Measured transports in all three channels indicate a significant net transport out of Florida Bay toward the reef tract. This is seen in both the longer duration of the ebb cycle and the greater magnitudes of the ebb flow. Transport calculated from predicted tidal currents and water levels, however, indicates a tide-induced net inflow to Florida Bay through all three channels (Figure 2). Nontidal transports show a persistent outflow resulting in mean discharges of $-909$, $-322$ and $-198$ $m^3 s^{-1}$ through Long Key Channel, Channel 5 and Channel 2, respectively.

Table 1 summarizes the total, nontidal and tidal volume transports through Long Key Channel, Channel 5 and Channel 2 for all six experiments. Total net transport for all three channels ranged from $-1420$ $m^3 s^{-1}$ in February 1996 to $+271$ $m^3 s^{-1}$ in February 1997, and it was directed toward the reef tract on five of the six experiments. Net tide-induced flows ranged from $+29$ to $-1212$ $m^3 s^{-1}$.

### Tidal Exchanges and Residual Tidal Transport

Results of regressions of ADCP data against mid-channel tidal transport are summarized in Table 3. Conversion factors of 476 and 658 $\times$ $10^6$ $m^3 s^{-1}$ for Channel 2 ebb and flood transport, respectively, suggest that a greater fraction of the

Table 4. *Half-tidal cycle transport, in $10^6$ m$^3$, and residual full tidal cycle transport rates, in m$^3$ s$^{-1}$, through Channel 2 (Ch2), Channel 5 (Ch5), Long Key Channel (LKC) and the Seven Mile Bridge channels (7MB). Positive transport indicates flow into Florida Bay.*

| | Tidal Channel | | | |
|---|---|---|---|---|
| Tidal Constituent | Ch2 | Ch5 | LKC | 7MB |
| $M_2$ | 13.13 | 23.91 | 62.94 | 122.60 |
| $S_2$ | 2.58 | 4.89 | 13.25 | 24.73 |
| $N_2$ | 2.47 | 4.18 | 12.05 | 18.72 |
| $K_1$ | 5.15 | 10.35 | 26.01 | 40.49 |
| $O_1$ | 4.86 | 10.28 | 28.62 | 35.59 |
| $P_1$ | 1.82 | 3.52 | 8.58 | 14.17 |
| Combined Residual | 128.94 | 64.53 | 70.21 | 199.28 |

ebb tide transport occurs in the middle of the channel. Thus, mid-channel ebb currents require a lower conversion factor than do flood currents to represent a given transport for the entire channel. Standard errors (HOEL, 1976) of 182 and 235 m$^3$ s$^{-1}$ for ebbs and floods indicate that in Channel 2 estimates of flood tide volumes based on mid-channel observations are less certain than are estimates of ebb tide volumes. The $r^2$ values indicate that tidal exchanges account for 73–77% of the variance in the total ebb and flood volume transport, respectively.

Channel 2 exchanges the least amount of water of the four channels included in this study (Table 4). For the $M_2$ constituent, approximately 13 × $10^6$ m$^3$ of water enter and leave over each half tidal cycle. Volume transport during peak flood and ebb (not listed in Table 4) reaches +923 m$^3$ s$^{-1}$ in both cases. The $K_1$ and $O_1$ constituents are the next largest, but individually they exchange less than half the amount exchanged by the $M_2$ constituent. The residual tidal transport associated with all six principal tidal constituents is into Florida Bay at a rate of 129 m$^3$ s$^{-1}$.

The larger conversion factors obtained for Channel 5 are consistent with the larger cross-sectional area (approximately 4540 m$^2$) relative to the cross-sectional area of Channel 2 (approximately 1730 m$^2$), but there are several similarities. Again, the larger flood tide conversion factor indicates that the center part of Channel 5 plays a greater role in removing water from Florida Bay on the ebb tide than in carrying water into the bay on the flood tide. Also, the $M_2$ constituent is similar in magnitude to the combined effect of the $K_1$ and $O_1$ diurnal constituents. In both Channel 2 and Channel 5, the magnitudes of the $K_1$ and $O_1$ constituents indicate that tidal exchanges can have large diurnal inequalities.

Data from Long Key Channel indicate that approximately 63 × $10^6$ m$^3$ of water move between Florida Bay and Hawk Channel over each $M_2$ half tidal cycle. This is about five times greater than the transport for either of the other semidiurnal constituents, and over twice as large as that associated with the two largest diurnal constituents. The long-term tide-induced residual transport, however, is the smallest of the four channels considered in this study.

The Seven Mile Bridge channels collectively are the most important in terms of the volume of water exchanged between the Gulf and Atlantic sides of the Keys, and in terms of the tide-induced residual transport. Total $M_2$ transport during the flood and ebb is just over 123 × $10^6$ m$^3$. The long-term residual tidal transport is 199 m$^3$ into Florida Bay. The relatively large standard error (Table 3) may be due in part to the combining of flood and ebb conditions into a single regression equation.

### Wind-driven Transport through Long Key Channel

The plot at the top of Figure 3 shows low-pass filtered wind stress, calculated from observations made at Sombrero Key during October 12 to November 20, 1992. Axes have been rotated 285°, so that the positive y-axis represents the wind stress heading that is most highly correlated with inflow through Long Key Channel. A dominant feature of the plot is the period from October 20–22, when westward wind stress reached 2.5 dynes cm$^{-2}$. After a relatively calm period during the last week of October and the first week of November, a second period of energetic wind forcing began on November 10 and continued to the end of the study. Westward wind stress was especially strong during November 11–13.

Low-pass filtered transport through Long Key Channel is shown at the bottom of Figure 3. The slope of the regression equation obtained from the 285–105° wind stress components and along-channel flow indicates that an increase of 1 dyne cm$^{-2}$ in wind stress increases inflow by 766 m$^3$ s$^{-1}$. This is in good agreement with the low-pass filtered inflow of over 1500 m$^3$ s$^{-1}$ that occurred on October 20–21. Inflow occurred intermittently during the last half of the study, including a several day event in mid November that coincided with strong westward wind stress. This 39-day time period is anomalous, because the long-term net flow is into Florida Bay. The Eulerian mean current is a weak inflow of +0.24 cm s$^{-1}$, which is within the accuracy of the current meter. Longer records (SMITH, 1994) indicate a nontidal outflow through Long Key Channel that is strongest during winter and spring. The cumulative transport at the end of this time period was +253.7 × $10^6$ m$^3$. Dividing by the total time period gives an average transport into Florida Bay of about +75 m$^3$ s$^{-1}$, but the low-frequency variability about the mean is the most prominant feature of the plot.

## DISCUSSION

The integration of ADCP volume transport measurements with mid-channel time series of current speed and water level provides an improved understanding of the volumes of water moving through these channels with the ebb and flood of the tide. With the incorporation of regional wind data, results provide useful information regarding the response to wind forcing. The residual nontidal outflows calculated in Long Key Channel, Channel 5 and Channel 2 are consistent with results from previous studies (SMITH, 1994, 1998; LEE and SMITH, in press). Nearly all the tidal channels that have been investigated in the Middle and Upper Florida Keys show a long-term net outflow. Thus, while the local interaction of tidal currents and water levels acts to transport water into Florida Bay, nonlocal forcing is dominant and forces a long-term outflow.

The strong correlation between the 285–105° wind stress component and exchanges through Long Key Channel (Fig-

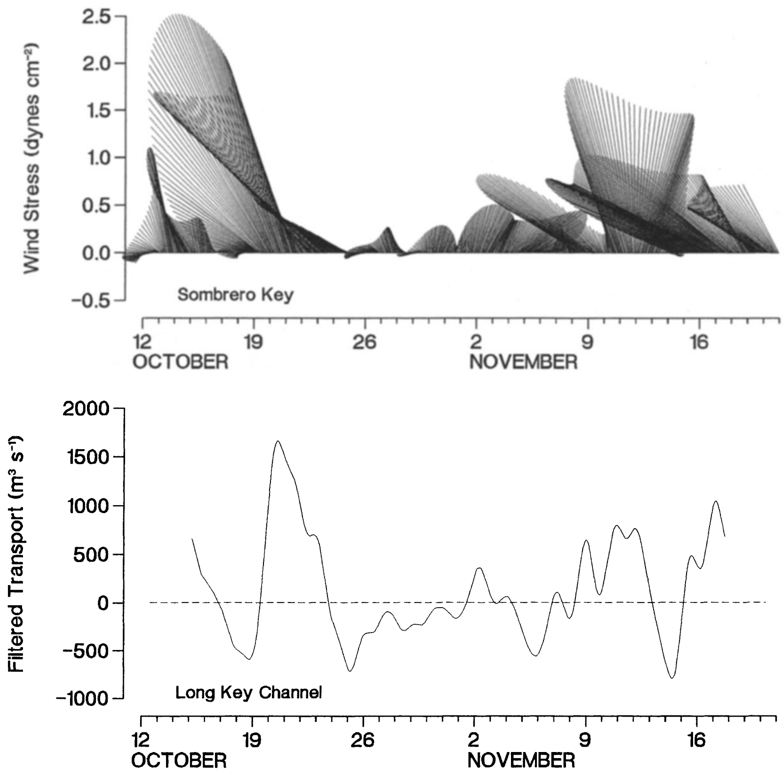


Figure 3. Wind stress calculated from Sombrero Key weather data (top) and cumulative net transport through Long Key Channel, October 12 through November 20, 1992 (bottom). Axes for the wind stress vectors have been rotated so that the positive y-axis is along a heading of 285°. Positive transport values indicate flow into Florida Bay.

ure 3), combined with the strong correlation between channel transport and sea level differences between Hawk Channel and Florida Bay (LEE and SMITH, in press), suggests that wind forcing produces significant sea level differences on the Gulf and Atlantic sides of the Keys, and that this in turn drives much of the low-frequency transport. Wind stress into the westerly quadrant is common throughout the year, although resultant wind stress is more commonly northwestward in summer and southwestward in winter and fall. Low-frequency deviations from monthly resultant wind stress vectors are greatest in winter (SMITH, 2001). Thus wind-assisted exchanges through Long Key Channel and subtidal transport into Florida Bay are probably greatest at that time of year.

Results from Long Key Channel, Channel 5 and Channel 2 can be compared with results from previous studies (SMITH, 1994), in which volume transport was calculated after channels were divided into 4–7 segments. Surface currents in each segment were measured with a flow meter and related to the surface current speed at a mid-channel reference station. In all cases, transport estimates from the present study, based upon ADCP measurements, are larger than transport estimates from previous studies, based upon flow meter data from anchor stations. In Long Key Channel, for example, and for the $M_2$ tidal constituent in particular, ADCP flood and ebb tide transports of $70.2 \times 10^6$ $m^3$ (Table 4) were about 20% larger than the values obtained using flow meter readings. Differences in magnitudes can arise from where the ADCP crossings start and stop, and from the mean segment depth used in the flow meter calculations. While the flow meter approach provides an opportunity to identify lateral structure in the flood and ebb tide currents, poor spatial resolution and the lack of repeated measurements over a semidiurnal tidal cycle are serious drawbacks to this approach.

Conversion factors for flood and ebb conditions in Channel 2, Channel 5 and Long Key Channel (Table 3) provide a convenient way to estimate total volume transport from vertically-integrated transport. They must be redetermined, however, if time series of current and water level are obtained from another study site in the channel, which could be located in a part that is more flood or ebb dominant.

The pooling of ADCP volume transport data and the regression against mid-channel vertically-integrated transport provide conversion factors which reduce considerably the error in channel transport estimates based on individual flow meter readings. Flow meter stations, occupied once within a flood or ebb tide cycle are at best comparable to a single ADCP crossing. The standard errors calculated from multiple crossings are typically several hundred $m^3$ $s^{-1}$, and conversion factors with these errors will introduce a significant systemmatic error in channel volume transport calculations.

While the Atlantic-to-Gulf net transport during the 39-day study of Long Key Channel was anomalous compared to longer measurement periods (SMITH, 1994; SMITH, in press; LEE and SMITH, in press), calculations of half-tidal-cycle transports (Table 4) show that even when the residual transport is into Florida Bay, tidal exchanges are sending pulses of Florida Bay water into Hawk Channel, thereby providing a mechanism for exporting water from the bay and into Hawk Channel in the direction of the reef tract.

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