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Volume and Heat Transports of the Florida Current: April 1982 Through August 1983

Abstract. *Absolute velocity and temperature profiles are used to estimate the volume transport through the Straits of Florida and, in combination with historical midbasin data, to estimate the total meridional heat flux through a section at 27°N. The mean annual volume transport of the Florida Current from April 1982 through August 1983 is 30.5 (± 1) × 10^6 cubic meters per second. The net northward heat flux through the 27°N section is 1.2 (± 0.1) × 10^{15} watts. The volume transport is characterized by high values in the late spring and early summer and low values in the late fall and early winter. There is a similar cycle in total heat flux.*

Vertical profiles of horizontal velocity components and temperature obtained during the Subtropical Atlantic Climate Studies (STACS) from April 1982 through August 1983 are used to estimate the mean annual and seasonal cycle of the volume and temperature transports of the Florida Current. Although similar profiler data have been obtained in the past (*1–3*), these historical data were collected intermittently during different seasons over many years. The STACS data were collected at approximately 2-month intervals from April 1982 through August 1983. The mean annual heat and volume transports as measured during STACS are similar to the historical data; a seasonal signal in heat transport is also exhibited.

The data were collected with a current profiler called Pegasus (*4*). A series of nine Pegasus stations is maintained across the Straits of Florida at 27°N (*5*). The Pegasus cruises were designed (i) to observe the annual cycle in volume and heat transport, (ii) to resolve important scales of motion with periods between 2 days and 2 weeks, and (iii) to provide calibration data for the remote-sensing techniques being tested concurrently as monitoring tools (*5*). Pegasus operations provide continuous data in the vertical at relatively closely spaced stations (~10-km separation), but the data are obtained only during relatively short (~2 week) cruises.

Data from nine cruises have been analyzed for use in this report. Two ships were used during the April, June, and September 1982 cruises and one ship during the November 1982 and February, April, May, July, and August 1983 cruises. Cruise length varied because of ship availability, weather conditions, and instrument problems. The typical cruise length was 8 to 14 days. Various sampling strategies were tested, but during a typical cruise continuous west-to-east station occupation was followed by east-to-west station occupation. This procedure resulted in unequal time intervals between occupation of the same station. A complete crossing of the section typically required 16 hours.

The raw Pegasus data were edited and interpolated to 10-m values (*6, 7*). Depth-averaged values of temperature and the velocity components were computed for each station. Daily values of depth-averaged temperature and the north component of velocity were obtained by means of an interpolation scheme in time which also smoothed the raw time series. Missing daily values were filled in with the use of linear regression relations with adjacent stations.

Sampling and instrument errors are present in the various transport estimates. The Pegasus internally records temperature, pressure, and travel times to two bottom-mounted transducers. If the geometry of the transducers relative to geographical coordinates is known, the trajectory of the Pegasus can be computed as it sinks and rises through the water column. Horizontal velocity components can then be determined. Inaccurate positioning of the transducers or poor positioning of the Pegasus relative to the transducers when launched can cause errors in the velocity components (*4, 6*).

Velocities can be computed from data collected during both the up- and the downcasts. Differences between up- and downcast north component of speed and temperature (Table 1) provide a measure of the repeatability of the Pegasus observation. The largest differences and standard deviations in speed and temperature typically occur at the boundary stations. At these stations transports are smallest, and thus the effects of velocity errors on total section transport are relatively unimportant. Comparison of two Pegasus vertical profiles of current with profiles obtained from a relative current profiler shows no systematic differences in the vertical structure (*8*).

A trapezoidal-rule integration formula was used to determine total section volume transport from the daily station transport values. We tested the adequacy of this formula qualitatively by assuming a representative cross-stream velocity structure and then moving this structure relative to the fixed station positions. Maximum errors related to the integration formula are of the order of 1 × 10^6 m^3/sec.

Sampling errors are related to the inability of the observing strategy to resolve higher frequency motions. If not adequately resolved, energy at these higher frequencies can be "folded" back into estimates of energy at lower fre-

Table 1. Comparisons of up- and downcast values of the north component of velocity from data collected during September and November 1982 and April and August 1983 and of temperature from data collected during September and November 1982 and April 1983 (a faulty temperature sensor was inadvertently used during August 1983).

Station	Mean difference in northward speed (cm/sec)	Standard deviation (cm/sec)	Mean difference in temperature (°C)	Standard deviation (°C)	Volume transport uncertainty (×10^6 m^3/sec)
0	−0.9	5.5	1.5	1.4	0.04
1	−0.6	4.0	1.5	1.5	0.08
2	3.4	4.9	1.4	1.1	0.16
3	1.2	2.4	1.2	1.1	0.09
4	−1.6	2.2	0.8	0.8	0.13
5	0.5	1.7	0.8	1.2	0.13
6	−1.5	4.0	0.5	0.2	0.28
7	0.0	1.2	0.2	0.1	0.08
8	0.3	4.2	1.0	0.2	0.20

quencies. Earlier velocity observations in the Straits of Florida contain considerable energy at the tidal frequencies (*9*). Transports associated with these motions are greater than the amplitude of the seasonal signal (*1*). The part of the tidal energy in the depth-averaged or barotropic northward component that is coherent with sea-level data at nearby shore stations (about 70 percent of the total variance in the diurnal and semidiurnal bands) has been removed from the profiles by means of a response method (*10*). This component of the tidal signal is found to be essentially in phase across the Straits and, if not removed, could account for up to 5.1×10^6 m^3/sec of tidal transport. The residual (primary baroclinic) tidal energy not accounted for by the response method translates to maximum likely errors in total section transport of 1.5×10^6 m^3/sec. The actual error is less, as the section takes most of one diurnal tidal period to complete.

Daily total section volume transports are shown in Fig. 1a. Means by cruise were determined and then, because of the small number of samples, were averaged over three 12-month intervals to provide some qualitative confidence in the mean annual values given in Table 2. These intervals overlap, and thus the mean annual values are not independent. On the basis of errors given in Table 1 and other errors due to integration and the aliasing of tidal energy, maximum uncertainties in the total transport are about 2.5×10^6 m^3/sec. However, as noted by Larsen and Sanford (*11*), comparisons of Pegasus and cable estimates of transport suggest that the actual errors are probably of the order of 1×10^6 m^3/sec. The mean annual transport values observed during 1982 and 1983 are, within these uncertainties, equivalent to the mean annual transport given by Niiler and Richardson (*2*) (Table 2).

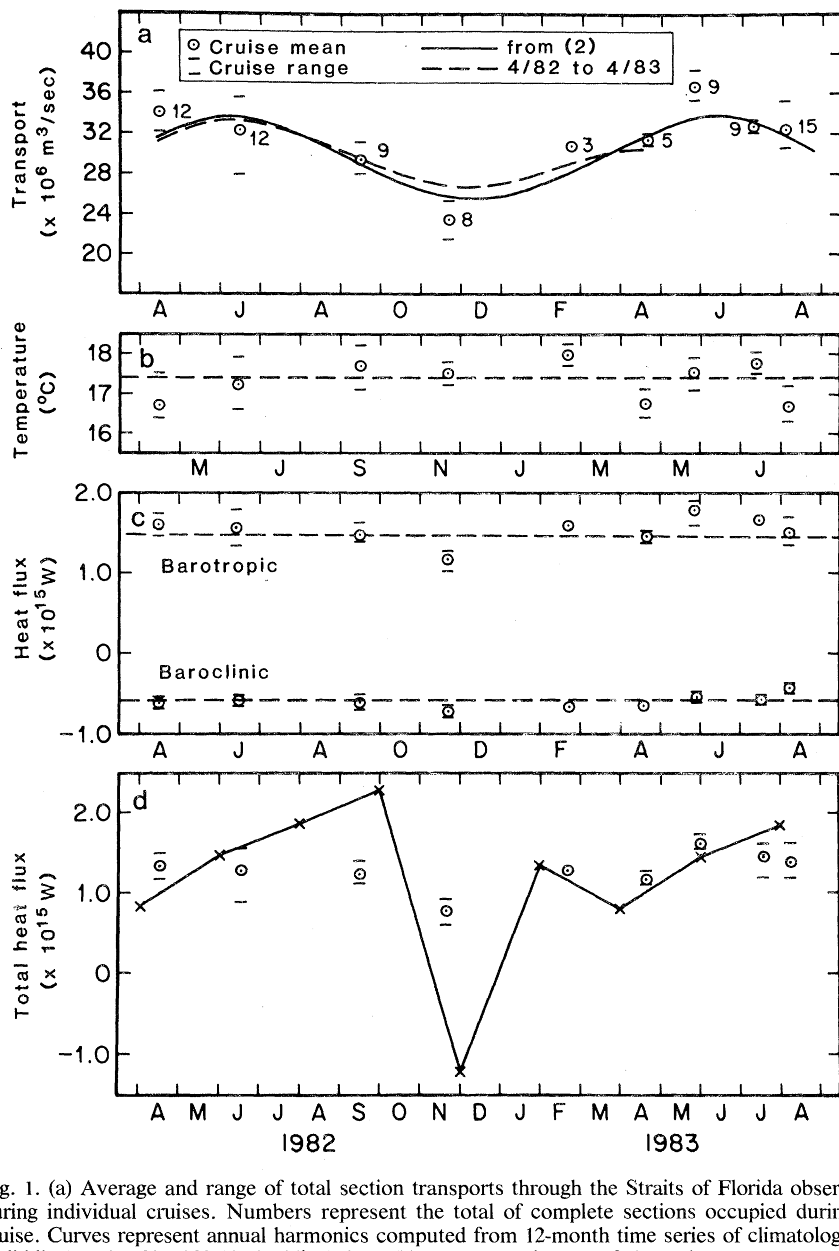

Fig. 1. (a) Average and range of total section transports through the Straits of Florida observed during individual cruises. Numbers represent the total of complete sections occupied during a cruise. Curves represent annual harmonics computed from 12-month time series of climatological (solid line) and 1982–1983 (dashed line) data. (b) Average and range of channel mean temperatures observed during individual cruises. The dashed line represents the 12-month average temperature (Table 2). (c) Net barotropic (depth-averaged) and baroclinic (geostrophic) components of heat flux through 27°N. See text for computational details. (d) Mean and range of net heat flux through 27°N computed from the 1982–1983 data and the bimonthly curve of heat flux through 25°N from Lamb (*16*).

The annual harmonic fits to the climatological volume transport data (*2*) and the 1982–1983 data are shown in Fig. 1a. As Larsen and Sanford have shown (*11*), the observed annual signal is quite asymmetric; the harmonic fit is applied here only for purposes of comparison with the climatological curve. The seasonal pattern of transports during 1982 and 1983 is similar to the climatological pattern in that highest transports occur in the late spring and early summer and lowest transports in the late fall and early winter. The variability observed during any one cruise is similar to the variability observed earlier at 26°N (*1, 2*) and has spatial and temporal characteristics similar to the continental shelf waves (*12, 13*).

The STACS Pegasus data permit computation of oceanic heat flux through a section at 27°N (the primary objective of STACS), provided that we have some information on midbasin temperature and velocity structure (*14*). Oceanic heat flux through a basinwide meridional section with zero net meridional transport is the areal integral of temperature (T) multiplied by the north component of the velocity (v)

$$Q = \rho c_p \int_0^X \int_0^H v\, T\, dz\, dx \qquad (1)$$

where ρ is the seawater density, c_p is the specific heat of seawater, X is the basin width, and H is depth. Velocity and temperature can be decomposed into depth-dependent and depth-averaged components, such that

$$Q = \rho c_p \left(\int_0^X \int_0^H v' T' dz\, dx + \int_0^X \bar{v}\, \bar{T}\, H\, dx \right) \qquad (2)$$

where the primes denote depth-dependent variables and the overbars depth-averaged variables. Historically, the decomposition was developed to permit estimation by conventional oceanographic observations of the various terms contributing to heat flux. The

Table 2. Average properties of the Florida Current (FC) and heat flux through 27°N.

Period	Number of cruises	Transport ($\times 10^6$ m^3/sec)	Temperature (°C)	Barotropic heat flux ($\times 10^{15}$ W) FC	Barotropic heat flux ($\times 10^{15}$ W) Midbasin	Baroclinic heat flux ($\times 10^{15}$ W) FC	Baroclinic heat flux ($\times 10^{15}$ W) Midbasin	Ekman heat flux ($\times 10^{15}$ W)	Total heat flux ($\times 10^{15}$ W)
4/82 to 2/83	5	30.05	17.41	2.12	−0.68	0.28	−0.93 (*15*)	0.42 (*15*)	1.21
6/82 to 5/83	6	30.68	17.44	2.17	−0.69	0.29	−0.93 (*15*)	0.42 (*15*)	1.26
9/82 to 8/83	7	31.02	17.42	2.19	−0.70	0.32	−0.93 (*15*)	0.42 (*15*)	1.30
Average		30.58	17.42	2.16	−0.69	0.29	−0.93	0.42	1.25
From (*2*)		29.50							
From (*15*)				1.88	−0.65	0.50	−0.93	0.42	1.22
From (*16*)									1.13

depth-averaged or barotropic mode (the second integral in Eq. 2) is related to horizontal circulation within the subtropical gyre of the North Atlantic (*15*); it can be expressed as the volume transport of the Florida Current multiplied by the difference between the mean temperature of the Florida Current and the mean temperature of the southward midbasin compensatory flow. The depth-dependent mode (the first integral in Eq. 2) is related to both vertical overturning, the baroclinic mode, and direct wind-driven currents, the Ekman mode.

In order to evaluate the integrals in Eq. 2, we need, in addition to data from the Straits of Florida, data on the velocity and temperature structure between the Bahamas and Africa. These data, as far as we know, are not available during 1982 and 1983. Thus, values for various properties of the midbasin given by Hall and Bryden (*15*) are used to evaluate the integral (for example, the temperature of the southward midbasin barotropic flow is taken as 5.4°C).

An uncertainty of 0.1×10^{15} W in the Florida Current component of the net barotropic heat transport results from an error analysis based on the use of the values in Table 1. If errors in the baroclinic heat transport are as large as 100 percent, errors introduced in total Florida Current heat transport would be only about 15 percent. The largest uncertainty in the values given in Table 2 is obviously related to the large scatter observed during individual cruises (Fig. 1). The similarity of the estimates for the three periods considered as well as the results presented in the companion papers in this set provide support for the validity of these volume and heat transport estimates.

The mean annual total heat flux through 27°N is similar to that computed by Hall and Bryden (*15*) at 26°N (Table 2). The result should not be surprising as the mean Florida Current transport and temperature during 1982–1983 are very similar to those used by Hall and Bryden (*15*). The STACS data are valuable in that they were obtained over a continuous period rather than sporadically over many years. Thus, they suggest that the earlier results do not suffer from the smoothing problems inherent in averaging data from many years. In addition, the 1982–1983 values are within 10 percent of the heat flux at 26°N computed by Lamb (*16*) (Table 2). However, the barotropic temperature transport values in the Straits were somewhat higher and the baroclinic values somewhat lower in 1982–1983 than in the climatological data used by Hall and and Bryden (*15*). This apparent redistribution of heat transport is probably related to differences in bottom topography between 27°N and 26°N, where the earlier measurements were taken.

As the percent variability in volume transport is larger than that in temperature (Fig. 1, a and b), the seasonal cycle of the barotropic mode of net heat flux closely resembles the seasonal cycle of the former variable (Fig. 1c). Differences of about 0.8×10^{15} W between the spring 1982 and 1983 barotropic heat transports and the fall 1982 transport are observed. A similar cycle is observed in the Florida Current baroclinic mode of heat flux with a range of 0.2×10^{15} W.

Lamb (*16*) computed the annual cycle of heat flux through 25°N, using a somewhat different approach (one based on surface energy fluxes and oceanic heat storage) than that used by Hall and Bryden (*15*). His bimonthly heat flux values (Fig. 1d) show a seasonal range some three times that of the mean annual heat flux. We have computed cruise average heat fluxes through 27°N, using STACS values for barotropic and baroclinic fluxes, through the Straits and the mean annual values computed by Hall and Bryden (*15*) for the midbasin barotropic and baroclinic fluxes. These fluxes (Fig. 1d) indicate a much smaller annual cycle than given by Lamb (*16*). The difference can be attributed to either errors in the computations given by Lamb (*16*) or a large annual signal in midbasin fluxes, a signal that we cannot resolve without additional 1982–1983 data in that region.

In summary, the mean annual volume transport and seasonal cycle around this mean are quite similar to transports derived from historical data. Seasonal variability in total heat flux through 27°N is observed to be in phase with the seasonal variability in volume transport (largest values in the late spring and early summer and smallest in the late fall and early winter). The data presented above can be used to verify results from numerical models of the region. However, of greater significance is the fact that these data demonstrate that the cable and tide gauge systems can serve to monitor the Florida Current transport, eliminating the need for future labor- and funding-intensive Pegasus operations.

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