Florida Current Transport Variability: An Analysis of Annual and Longer-Period Signals

Christopher S. Meinen[1], Molly O. Baringer[1], and Rigoberto F. Garcia[2]
[1]Atlantic Oceanographic and Meteorological Laboratory, NOAA
[2]Cooperative Institute for Marine and Atmospheric Studies, Univ. Miami

Background

The subtropical gyre in the North Atlantic is unique both because of the large latitudinal breadth spanned by the gyre and because the horizontal wind driven gyre is embedded within (or embeds) a climatically important vertical gyre, the meridional overturning circulation or MOC. Decadal variations in the MOC, and the associated changes in ocean properties such as sea-surface temperature, have been tied in models to variations in precipitation over the neighboring continents and other socially important quantities (e.g. Zhang and Delworth, 2006). Recent observational analyses have shown that components of the MOC are much more highly variable at high frequencies than had previously been thought (e.g. Meinen et al., 2006), and in two recent papers illustrating the first ever basin-wide time series observations the total Atlantic MOC has been shown to exhibit strong variations at time scales ranging from a few days out to a few months (Cunningham et al., 2007; Kanzow et al., 2007). Analysis of longer-period variations of the MOC is challenging due to the paucity of long-term time series observations. Prior to the recent RAPID/MOCHA observations of the basin-wide MOC, time series data is generally available for only components of the MOC if at all.

One piece of the MOC circuit that has been observed more than most is the Florida Current. At 27°N the Florida Current passes through the northern Straits of Florida carrying both the bulk of the Subtropical Gyre western boundary current flow and the majority of the warm upper limb of the Meridional Overturning Circulation. The first observations of the Florida Current transport were made more than a century ago by a US Navy ship under the command of Lieutenant John E. Pillsbury between 1884 and 1888 (Pillsbury, 1887; 1890). Over the subsequent decades several additional attempts were made to collect data on the Florida Current transport, however the next repeated observations did not begin until 1964. In the 1960s and 1970s most (but not all) of the observations collected were made along 26°N between Miami and Bimini. By the 1980s all of the observations had shifted northward to 27°N, where observations are still collected today.

Observations of FC transport in the northern Florida Straits

The following types of observations have been made since 1964 and will be discussed herein –

Dropsondes – Free-falling float that provides estimate of vertical mean horizontal velocity, collected at multiple stations across FC
- *75 sections collected between 1964 and 1970 – Niiler and Richardson (1973)**
- *44 sections collected in 1974 – Brooks and Niiler (1977)**
- *178 sections collected between 1991 and the present – Ongoing NOAA Western Boundary Time Series program (e.g. Meinen et al., 2008)*

**Collected on the Miami – Bimini line: Increased by 2 Sv herein to account for flow through Northwest Providence Channel*

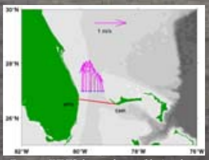

Figure 1: WBTS dropsonde sites (blue) and mean dropsonde meridional velocity for 1991 to 2007. Also shown is the approximate cable location (red line).

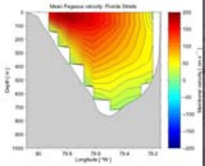

Figure 2: Mean STACS Pegasus meridional velocity for 60 sections collected in 1982-1984.

Pegasus – Acoustically-tracked free-falling float that provides a vertical profile of horizontal velocity
- *60 sections collected between 1982 and 1984, and an additional 9 sections collected in 1986-1988 where the Pegasus was used as a dropsonde, all now reprocessed using modern methodology – Joint NOAA and UM/RSMAS Subtropical Atlantic Climate Studies program (e.g. Molinari et al., 1985; Leaman et al. 1987)*

Submarine cable – Voltage induced on cable by electric field created by charged particles (ions) moving through the Earth's magnetic field
- *About 3 years of voltage data collected between 1970 and 1972 (calibrated into transport as part of this study) – (Sanford, 1982; see also Meinen et al., 2008)*
- *About 25 years of voltage/transport data collected between 1982 and the present – NOAA Western Boundary Time Series program (e.g. Larsen and Sanford, 1985; Larsen, 1992; Baringer and Larsen, 2001; Meinen et al., 2008)*

Figure 3: Cartoon illustrating cable technique.

Observed FC transport variability

Combining all of the data discussed above provides a fairly complete time series from 1964 to the present with two large gaps in 1975-1981 and 1998-2000. The agreement between the different measurement systems is generally quite good. The correlation between the Pegasus sections and the cable in 1982-1984 was better than r=0.9, and the correlation between the GPS-equipped dropsondes used in 2000 to the present is similar (see example in lower panel of Figure 4).

There is no sign of a long-term trend over the 40+ year record (and even the values from the 1880s were similar in the mean). Spectral analysis over the full cable record would not be very reliable due to the time gaps, but spectra of the different segments that are nearly continuous (Figure 5) illustrates the lack of any trend over the past 25 years in the spectral character of the flow variability. The distribution of variance in different time windows illustrates the high percentage (70%) of the total variance in transport that is at periods shorter than annual (see Table 1 above).

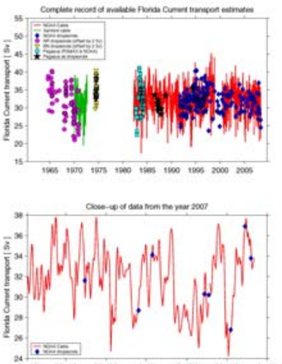

Figure 4: Upper panel – Time series of all observations of the Florida Current transport at 27°N. Lower panel – Close-up of data collected in 2007.

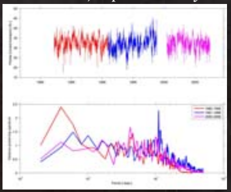

Figure 5: Upper panel – Florida Current transport determined from cable. Lower panel – Spectra of cable data separated into the color-coded segments.

	Less than 30 days	Month to 11 month	Annual	13 month to 42 month	Greater than 42 month
Variance (Sv^2)	2.4	4.6	0.9	1.3	0.8
% of total variance	24	46	9	13	8

Table 1: Variance of the Florida Current transport associated with different period bands as determined from the 1982-1998 cable time series. Variance calculated with 1982-1998 cable record where time gaps have been filled with simple interpolation. First row is the variance, second row is the variance as a percentage of the total variance in the 1982-1998 cable time series, which is roughly 10 Sv^2.

Extracting a FC annual cycle

Baringer and Larsen (2001) noted an apparent change in the annual cycle of the Florida Current between 1982-1990 and 1991-1998 using the cable data. Adding in the most recent data illustrates yet another radically different-looking annual cycle to the mix (Figure 6). This leads to the question of whether the annual cycle itself is changing over time or whether variance in other time scales is leaking into the mean annual cycles being defined.

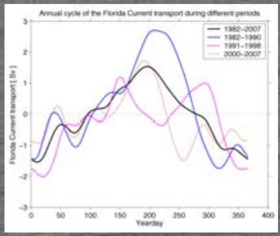

Figure 6: Annual cycle of Florida Current transport estimated from different segments of data from the cable (as noted in the legend).

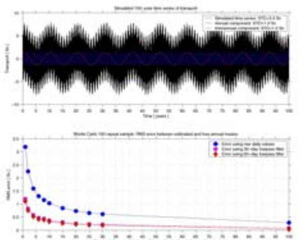

Figure 7: Upper panel – 100 year synthetic time series of Florida Current transport made up of an annual cycle, a 12 year cycle, and random noise. Lower panel – Monte Carlo style estimate of the root-mean-squared error in the predicted annual cycle signal for a day given the indicated number of years averaged together.

Building a simulated 100-year record using the observed amplitudes for the annual and long-period signals (Figure 7) and then applying a Monte Carlo style subsampling to the record leads to an estimate of the "error" associated with determining an annual mean from a limited length record when the annual cycle itself represents only a small percentage of the total variance. The results suggest that the different annual cycles determined from 8-year periods (Figure 6) are not statistically different from one another.

Extracting longer-period signals

A similar Monte Carlo style approach, in this case using the actual cable observations rather than a simulated record, has been used to quantify the accuracy to within which a monthly, annual, 3-year, or 5-year mean can be determined for a given number of observations. These results suggest that in order to obtain an annual, 3-year, or 5-year mean that is accurate (at the 67% confidence level) to better than 0.5 Sv more than 50 observations are required during the averaging interval. This presumes the distribution is random; else the errors are larger.

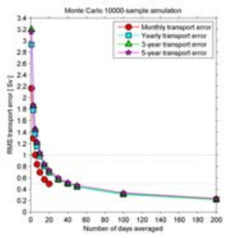

Figure 8: Monte Carlo style estimate of the root-mean-squared error in estimating a monthly, annual, 3-year, or 5-year mean based on the number of observations within the time period..

This does not imply that we cannot look at the long-period variability with this data, just that we need to understand the statistical accuracy of our data.

Baringer and Larsen (2001) and DiNezio et al., (2008) showed that over the 1982-1998 time period there was an anticorrelation between the FC and the NAO (and the wind stress curl over the basin interior along 26°N). The longer time series suggests that the relationship with the NAO is sporadic, while the wind stress curl versus FC relationship appears to be more robust.

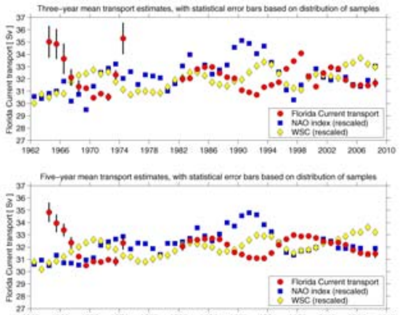

Figure 9: Upper panel – Three-year running-mean estimates of the Florida Current transport (red), the North Atlantic Oscillation (blue), and the wind stress curl integrated in three boxes in the interior and lagged based on fast Rossby wave translation speeds (yellow). Lower panel – Similar to top but for five-year means. Both panels display statistical error bars based on the number and distribution of samples. See DiNezio et al., (2008) for more detail on the wind stress curl calculation.

Conclusions

- *More than 40 years of Florida Current transport data are available for analysis and for comparison to other data sets and numerical model output (for model validation, etc.).*
- *Given the high percentage of sub-annual variance in the Florida Current, at least 25 years of data are required to obtain an annual cycle that is accurate to within 20%.*
- *Similarly, a robust annual (or 3-year, or 5-year) mean accurate to within 0.5 Sv only results from a large number (>50) observations spread evenly throughout the averaging period.*
- *The relationship between FC transport, the NAO, and wind stress curl over the interior is not stationary over the past 40+ years, implying multiple mechanisms that must control long-term FC variability.*

For further information:

Meinen, C.S., M.O. Baringer, and R. F. Garcia, *Florida Current Transport Variability: An Analysis of Annual and Longer-Period Signals*, J. Geophys. Res., (submitted), 2008.

DiNezio, P. N., L. J. Gramer, W. E. Johns, C. S. Meinen, and M. O. Baringer, *Observed Interannual Variability of the Florida Current: Wind Forcing and the North Atlantic Oscillation*, J. Phys. Oceanogr., (submitted), 2008.

Acknowledgements

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