A Statistical Analysis of Gulf Stream Variability from 18+ Years of Altimetry Data

John L. Lillibridge
NOAA Laboratory for Satellite Altimetry
Silver Spring, MD

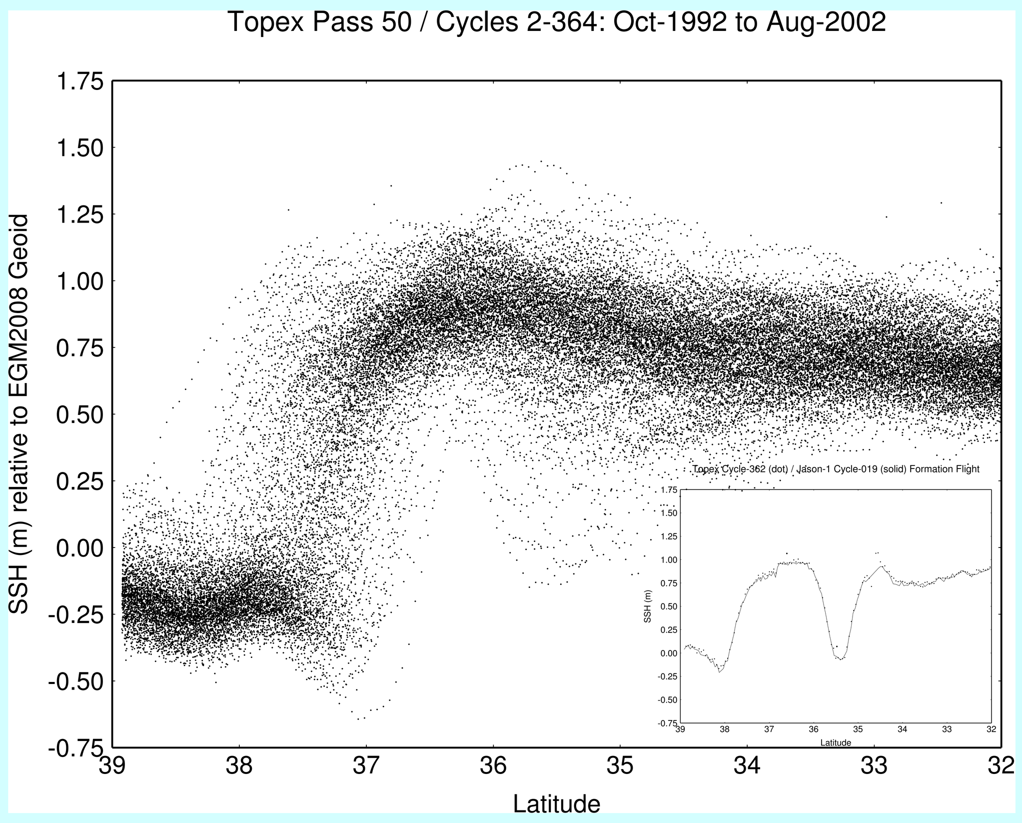
Arthur J. Mariano
Univ. of Miami, RSMAS/MPO
Miami, FL

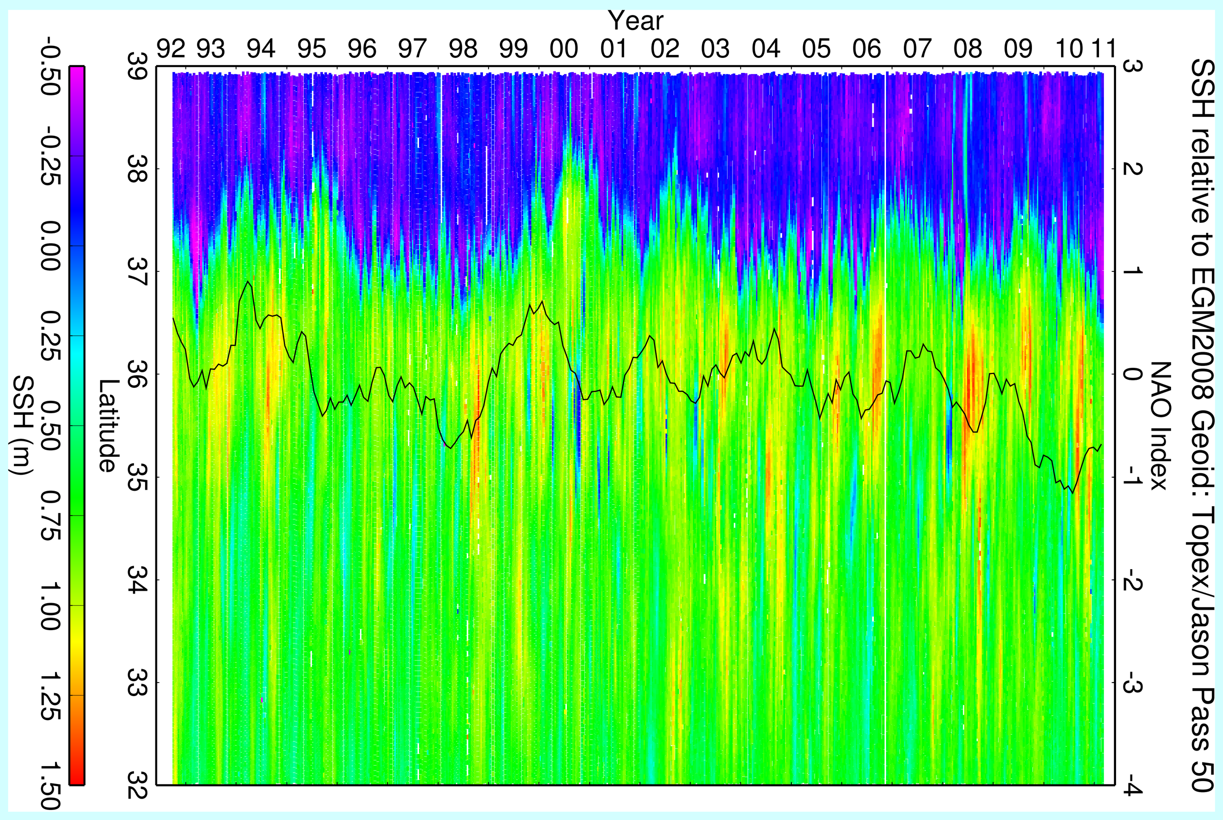
ABSTRACT: Seasonal variations in the Gulf Stream were analyzed using 18+ years of altimetry data from Topex, Jason-1, and Jason-2, spanning Topex cycle-2 (04-Oct-1992) through Jason-2 cycle-98 (02-Mar-2011). Reference mission pass #50, which brackets the core of the Gulf Stream between 32-39°N and 68-72°W, were analyzed in terms of absolute sea surface height differences, SSH, referenced to a geoid model and sea surface height anomaly differences, SSHA, referenced to a global mean sea surface. Indices for geostrophic velocity, baroclinic transport, and average position of the Gulf Stream were also calculated and analyzed.

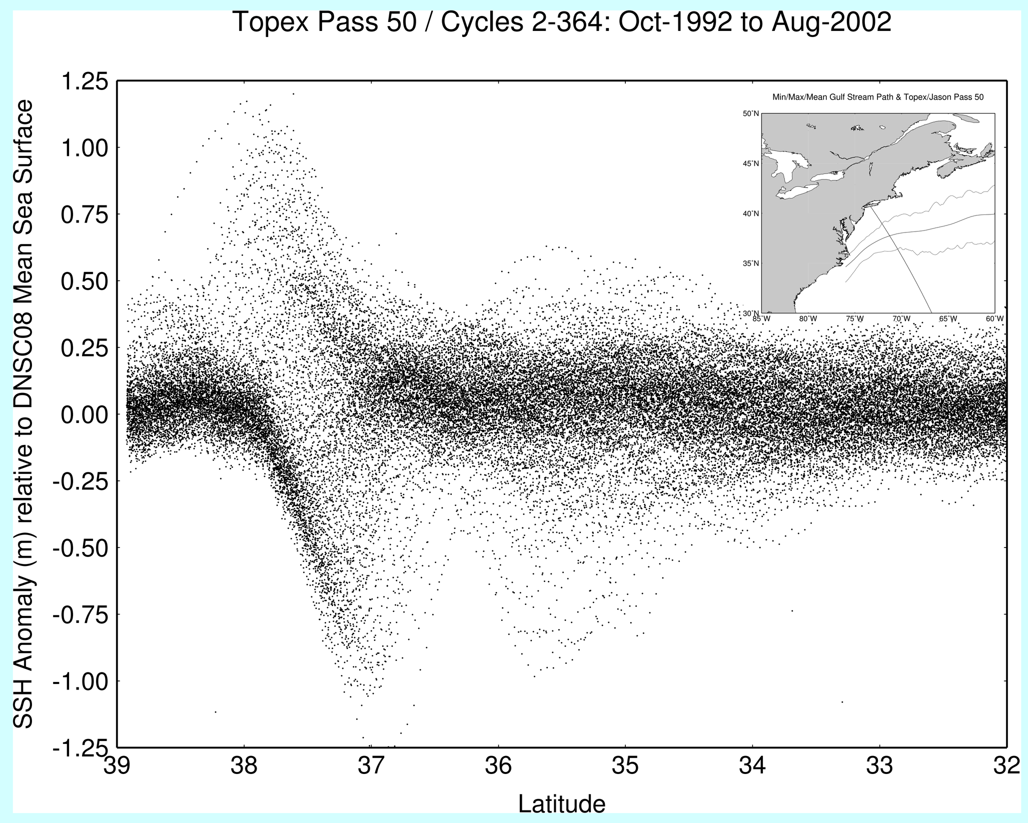
The three dominant periods for these variables, based on spectral and auto-covariance analyses, are SSH: 15-21 months, 7 months, 4 years; SSHA: 9 months, 21 months, 5-6 months; velocity index: 9 months, 21 months, 5 months; transport index: 11 months, 2-3 months, 1 month; and Gulf Stream position: 21 months, 13 months, 4-6 years. The average annual distribution of the variables slowly increases throughout the year to late summer and early fall, quickly decreases to a minimum in winter, and increases to a secondary maximum in early spring. Interannual variations exhibit a correlation with the North Atlantic Oscillation index.

The Gulf Stream behaves like a delayed nonlinear oscillator, with peak values in near-surface geostrophic velocity in early summer, maximum northward migration of the Gulf Stream path in August, and maximum baroclinic transport in the fall. After the transport reaches a maximum, the stream starts to move south faster than the seasonal northward migration. Both the velocity and baroclinic transport modes are dominated by a summer maximum, a secondary maximum in the spring, and a minimum in the fall.

Methodology: For Topex, Jason-1 and Jason-2 descending pass 50, compute absolute SSH with respect to the EGM2008 geoid and relative SSHA with respect to the DNSC08 mean sea surface. Calculate absolute height difference ΔSSH as the median of the highest 13 values – median of lowest 13 values. Calculate the relative height difference ΔSSHA as the average height from 33-34°N – average height from 38-39°N. The time series of absolute SSH correlates with a lagged North Atlantic Oscillation.

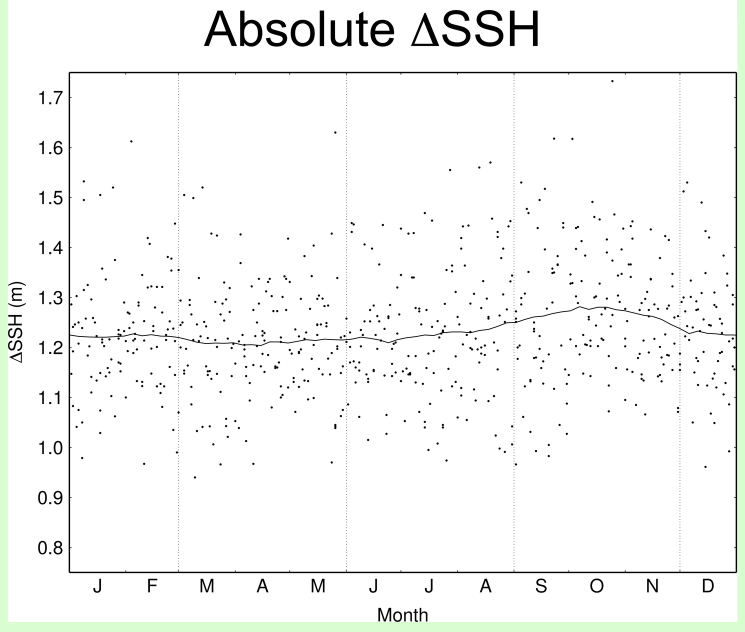




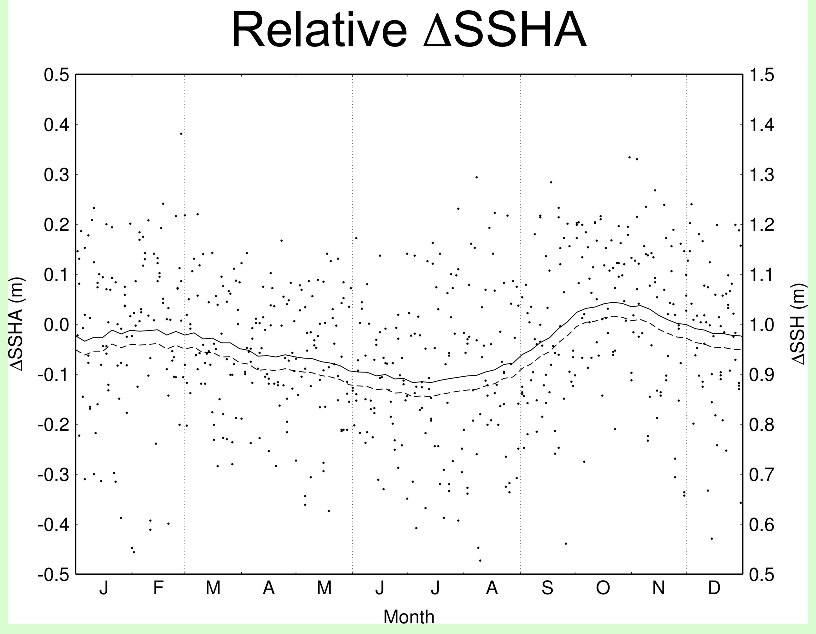


Seasonal Variations: Differences are formed across the Gulf Stream for five dynamical quantities for each pass and plotted as a function of year day. The 18+ years of data are averaged with a 60-day running mean over all years to estimate the "seasonal signal" in each quantity. The amplitude of the height variations are 8 and 16 cm for ΔSSH and ΔSSHA, respectively.

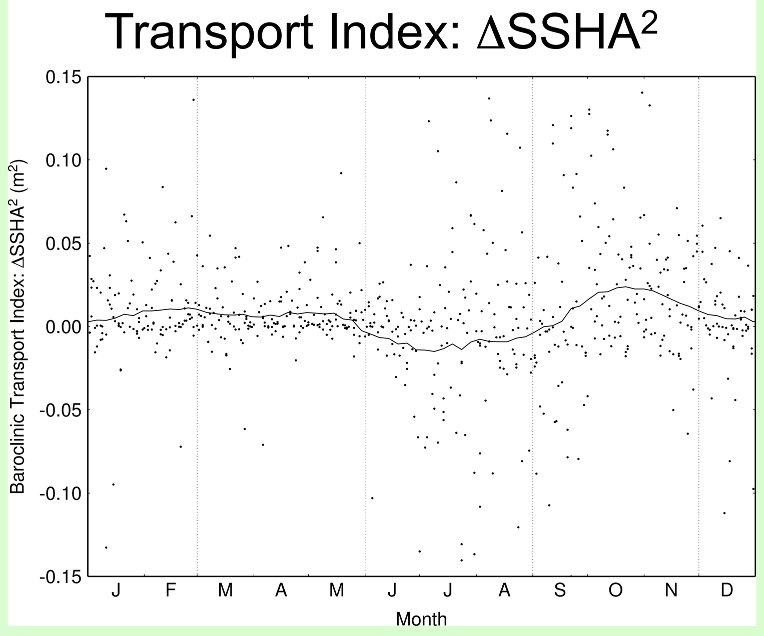
Absolute ΔSSH



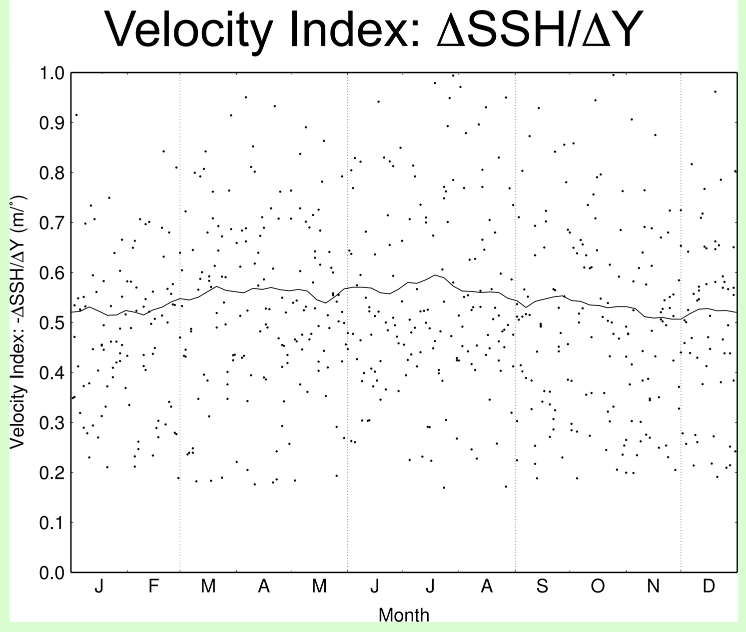
Relative ΔSSHA



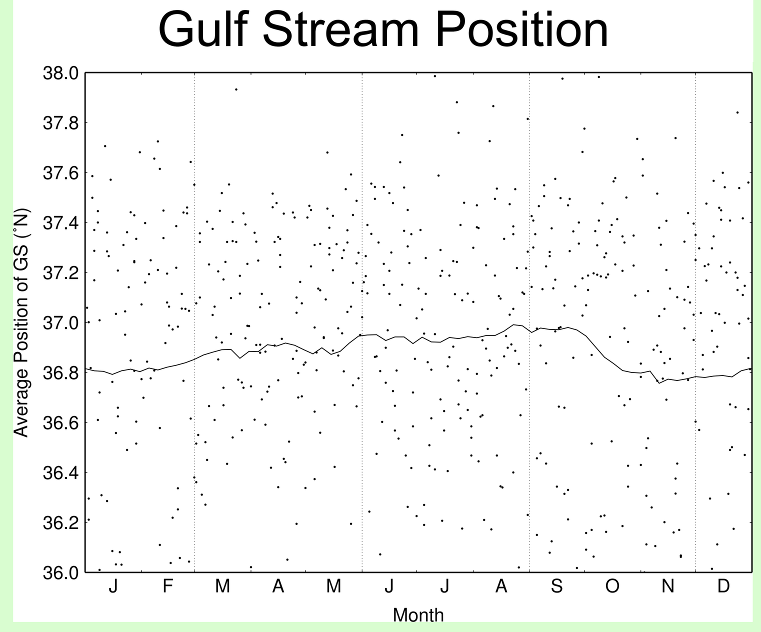
Transport Index: $\Delta SSHA^2$



Velocity Index: ΔSSH/ΔY



Gulf Stream Position



Statistical Analyses: Power spectra, autocorrelation, and EOF analyses were performed for each of the 5 variables (first and second mode monthly amplitudes and interannual principal components are shown by the solid and dashed lines, respectively, in the two right-hand columns). Examples are shown for ΔSSHA (top) and Gulf Stream position (bottom). The seasonal variability is not strongly sinusoidal, with ΔSSH, ΔSSHA, and transport index peaking in the fall when the Gulf Stream moves southward. The system behaves like a delayed nonlinear oscillator, with significant energy in the interannual, monthly, and weekly bands. Even though the underlying altimetry data are highly accurate, there are significant variations in the individual height estimates due to this broadband energy distribution.