GULF STREAM PATHWAY AND TRANSPORT VARIATIONS; OBSERVATIONS AND MODELING

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Introduction

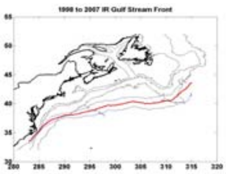
Modeling the Gulf Stream, its separation from the coast, open ocean pathway and transport, represents a major challenge for Ocean General Circulation Models

Western boundary currents represent a major challenge for ocean general circulation models (OGCM). Many factors control the behavior of the western boundary current, such as barotropic and baroclinic instability of the flow, interaction with the recirculation gyres, interaction with the deep flows (Hurlburt and Hogan, 2008), and interaction with the thermohaline circulation (meridional overturning circulation). To assess the performance of OGCMs in simulating the western boundary current, we need quantifiable measures of the transport and variability of the western boundary current and techniques to estimate the same measures in the OGCMs. We will use satellite sea surface temperature (SST) and sea surface height (SSH) plus in situ current observations from the volunteer observing ship MV Oleander transits to estimate the statistics of the Gulf Stream pathway and transport. We will compare these statistics to the output from three global simulations using the Hybrid Coordinate Ocean Model (HYCOM). The three simulations are: 1) Global model forced by an ECMWF climatology designated as HYCOM 9.4, 2) Global model forced by NOGAPS analyses for 2003 to 2007 designated as HYCOM 9.7, and 3) Global data assimilative model forced by NOGAPS analyses for 2003 to 2006.

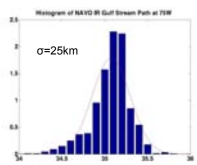
Satellite SST Analyses

North wall of the Gulf Stream can be located from the maximum SST gradient using the NAVO IR frontal position analyses

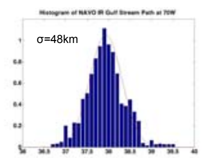
The Naval Oceanographic Office (NAVO) has produced daily analyses of the frontal positions from the Advanced Very High Resolution Radiometer (AVHRR) infrared sea surface temperature for the past decade. The mean Gulf Stream north wall from the NAVO IR analyses separates from the coast at Cape Hatteras (35.25N,75.5W). The meander amplitude grows from at minimum of 25 km at 75W to 100 km just west of the New England Seamount Chain (NESC). The path of the Gulf Stream is nearly due east from there to the Newfoundland Rise (NFR) at 48W with a nearly uniform meander amplitude of 100 km. East of NESC, the position of the Gulf Stream is normally distributed about the mean path.



Mean IR path and 85% confidence limits

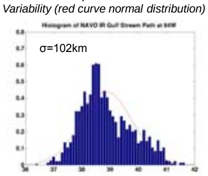


PDF of GS position at minimum Variability (red curve normal distribution)

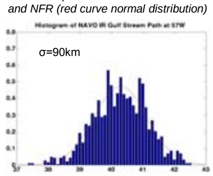


PDF of GS position between minimum and NFR (red curve normal distribution)

Standard deviation of GS path (°latitude)



PDF of GS position west of NESC (red curve normal distribution)

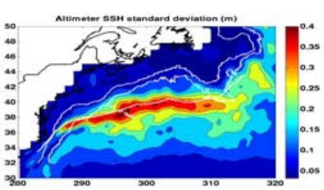


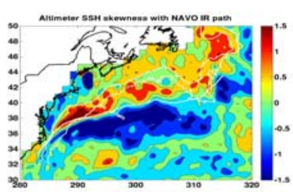
PDF of GS position between NESC and NFR (red curve normal distribution)

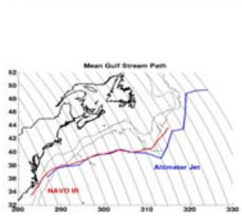
Satellite SSH Analyses

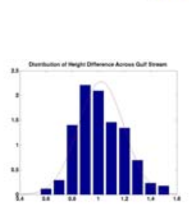
The path and transport of the Gulf Stream can be located using a gaussian jet model to find the location of the flow and the intensity and width of the jet

15 years of repeat track altimetric sea surface height anomalies now exist. The mean position of the Gulf Stream can be estimated from the maximum variance of the SSH. Thompson and Demirov (2006) proposed that the skewness of the SSH could be used to locate the mean position of a meandering jet, since the probability distribution function (PDF) of the will be skewed towards negative (positive) anomalies on the northern (southern) side of the Gulf Stream leading to positive (negative) skewness. Neither of these techniques require knowledge of the absolute sea surface topography. Kelly and Gille (1990) proposed using a Gaussian jet model to estimate the position and intensity of the Gulf Stream. Averaging over all of the jet profiles can produce an estimate of the mean sea surface topography in the vicinity of the Gulf Stream. We have extended the model of Kelly and Gille to allow for multiple crossings of a meandering jet. The jet model requires the Gulf Stream to either meander, change its transport or change its direction. From the Gaussian jet analysis, we find that similar to the IR path position, the position of the jet is normally distributed about the mean path. Between the separation point and the NESC, the meander amplitude increases with distance from the coast with the same amplitude found from the IR path analysis. Between the NESC and NFR, the Gaussian jet meander amplitude is about 20% greater than the corresponding IR amplitude (120 km vs 100 km). The height difference across the Gulf Stream increases from 0.45 m near Cape Hatteras to about 1.7 m just before the NESC. After crossing the NESC the height difference decreases to about 1 m near 58W and then increases to nearly 2 m just before the NFR. After crossing the NFR the height difference decreases significantly. The height difference can be related to the mass transport. Johns et al (1995) found that the baroclinic transport of the Gulf Stream is nearly constant downstream from Cape Hatteras and the transport increase is primarily barotropic. Following Johns et al. we can estimate the Gulf Stream transport from the height difference. The transport increase from about 80 Sv near Cape Hatteras to 165 Sv at the NESC, dropping to 125 Sv at 58W and then increasing to 180 Sv

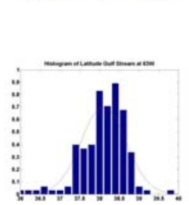




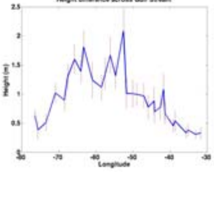


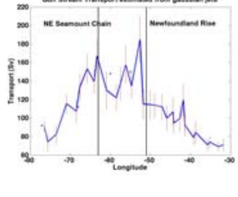


PDF of GS height difference west of NESC (red curve normal distribution)



PDF of GS position west of NESC (red curve normal distribution)





Ocean General Circulation Models

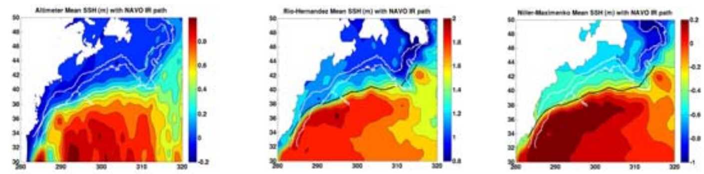
Modeling the Gulf Stream, its separation from the coast, open ocean pathway and transport, represents a major challenge for Ocean General Circulation Models

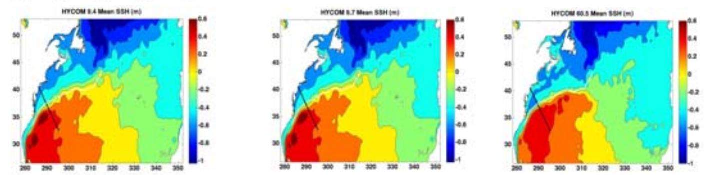
The Gulf Stream will be described in three different global simulations of the Hybrid Coordinate Ocean Model (HYCOM). All three models are run with 40 layers and a horizontal resolution of 0.08° (c.f. Hurlburt et al., 2008). The models are forced with realistic fluxes. The first model (HYCOM 9.4) is forced with the climatological fluxes from ECMWF. The second model (HYCOM 9.7) starts from the climatological model and is forced with NOGAPS fluxes from 2003 to 2007. The third model (HYCOM 60.5) is forced by NOGAPS fluxes and assimilates observations using the NCODA scheme of Cummings (1995).

The data assimilative model has a mean path nearly identical to the altimetric path with a very similar meander amplitude, although the SSH variance is weaker in the model than observed. The mean sea surface of the model has a weaker recirculation gyre which is confined much further to the west compared to the altimetric mean sea surface and the mean sea surfaces estimated by Niiler and Maximenko and by Rio and Hernandez. The PDFs of the Gulf Stream position and height difference are nearly normal similar to the altimetric SSH.

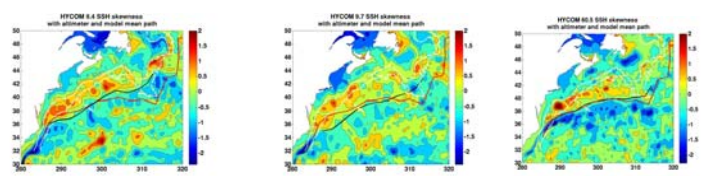
The climatologically forced model has a path south of the the observed pathway west of the NESC and slightly northwards to the east of the NESC. The meander amplitudes are greater in the model compared to the observations. The SSH variance and the recirculation gyre are strongly confined to the west. The PDF of position is substantially broader than a Gaussian distribution. The NOGAPS forced model has a mean path almost 2° south of the observed path west of the NESC. This model has the largest meander amplitude and substantial non-gaussian PDF. Similar to the climatological model, the SSH variance and recirculation gyre are strongly confined to the west.

Mean sea surfaces derived from observations. The altimeter surface shows the coarse track sampling and bias between ascencding and descending tracks

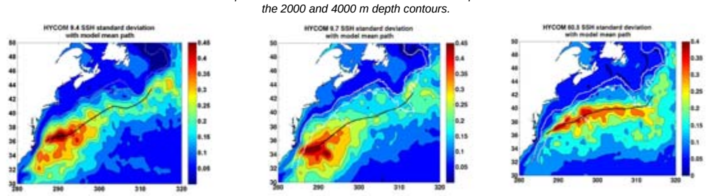




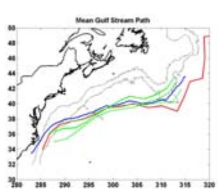
Model mean sea surfaces. Note the strong westward confinement of the SSH compared to the observations. The line on the figures Is the track of the MV Oleander with approximately weekly adcp transits.



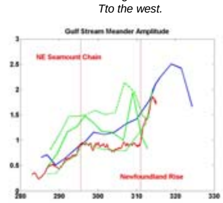
Model SSH skewness . The model mean path is shown in black and the altimeter mean path shown in red. The thin white lines are the 2000 and 4000 m depth contours.



Model SSH standard deviation. The model mean path is plotted as the black line. The data assimilative model (HYCOM 60.5) extends to the east as observed but has smaller variance. The climatologtical and NOGAPS forced models have the SSH variance confined Tto the west.



Mean Gulf Stream paths. Models are depicted by green lines.



Mean Gulf Stream meander amplitudes. Models are depicted by green lines.

Comparison of the height difference across the Gulf Stream along the MV Oleander transit line. The Oleander has much largerh height difference than the models or observations.

Conclusions

The models generate a Gulf Stream with very different characteristics than observed. The meander amplitudes and transport variability are normally distributed around the mean in the observations, but substantially broader than normal in the models. Data assimilation helps produce a more realistic Gulf Stream.

Several measures have been produced to describe the pathway of the Gulf Stream after it separates from shelf at Cape Hatteras. The mean pathway can be estimated from maps of the SSH variance and skewness. Using a Gaussian jet model of the velocity, instantaneous estimates of the location and height difference across the Gulf Stream can be made. In both the observations and HYCOM global model, the meander amplitude of the Gulf Stream increases downstream of Cape Hatteras until just west of the New England Seamount Chain (64W). The ECMWF climatologically forced and NOGAPS forced HYCOM models have a much larger meander amplitude than observed. East of the New England Seamount Chain and west of the Newfoundland Rise (49W) the meander amplitude of the models and observations are approximately constant. The observed meanders are nearly normally distributed around the mean pathway, while the non-assimilative models have a much broader distribution. The SSH variance and recirculation gyres are strongly confined to the west in the models. The observed and model transports increase downstream from Cape Hatteras until just west of the New England Seamount Chain. The observed transport has a minimum near 58 W before increasing towards the Newfoundland Rise at 49W. The observed transport fluctuations are nearly normally distributed about the mean transport.