

12.307 Project 1: Weather and Extremes

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1 Hurricanes- analysis of scatterometer data

1.1 Theory- reminder

Radial force balance for atmospheric vortices. The radial force balance in atmospheric vortices is very similar to the radial force balance in the radial inflow experiment. Again, the balance is between a pressure gradient force, a centripetal acceleration, and a Coriolis acceleration such that

$$\frac{v_{\theta}^2}{r} + f v_{\theta} = \frac{1}{\rho} \frac{\partial p}{\partial r}. \quad (1)$$

Here, v_{θ} is the azimuthal velocity, r is the distance from the vortex center, ρ is the density of air, and p is pressure. The main difference from the radial inflow experiment is that the Coriolis parameter is given by $f = 2\Omega \sin \phi$, where $\Omega = 2\pi/T$ is Earth's rotation rate, T is Earth's rotation period (1 day = 86400 s), and ϕ is latitude. The Coriolis parameter is modified because Earth is a rotating *sphere*, and the radial force balance in atmospheric vortices is affected by the component of the rotation vector orthogonal to Earth's surface.

Rossby Number. As for the radial inflow experiment, we can use the radial force balance to define a Rossby number

$$Ro = \frac{|v_{\theta}|}{fr} \quad (2)$$

that characterizes the relative magnitude of the centripetal acceleration v_{θ}^2/r and the Coriolis acceleration $f v_{\theta}$. Again, the size of the Rossby number allows us to reason about dominant terms in the radial force balance, and about whether the flow is significantly influenced by Earth's rotation.

1.2 Scatterometer data

Satellite scatterometers—instruments that use measured radar backscatter from the ocean surface to infer surface roughness and wind speed—can provide detailed maps of the near-surface wind field in hurricanes. In this assignment we will work with scatterometer data to analyze real hurricanes. Analyzing hurricane winds during the data lab will require using data from the QuickScat scatterometer instrument (which operated from 1999-2009)—so this assignment checks that you can read and plot the QuickScat data.

1. Go to the "Weather & Extremes" Project page (\rightarrow Observation Data \rightarrow scatterometer-instructions) on the course site and download `qscat_20080711v4` (zip file) and one of `qscathurr.m` (for MATLAB users) or `readscat.py` (for Python users). Put all of these files in the same directory and unzip the two `.gz` files. (Mac users can use the Archive Utility; Windows users can use 7-Zip.) For those who prefer to work with Excel, you can also download the MATLAB script `Transfer_data_to_Excel.m` (which, if run after the `qscathurr.m` file, will convert the output the Excel sheets where you can do further analysis).
2. Run the MATLAB/Python script. It will read scatterometer data from the `qscat` file and plot a variety of fields centered around 29°N , 297.7°E . These should show an anti-clockwise circulation produced by Hurricane Bertha (Figure 1).

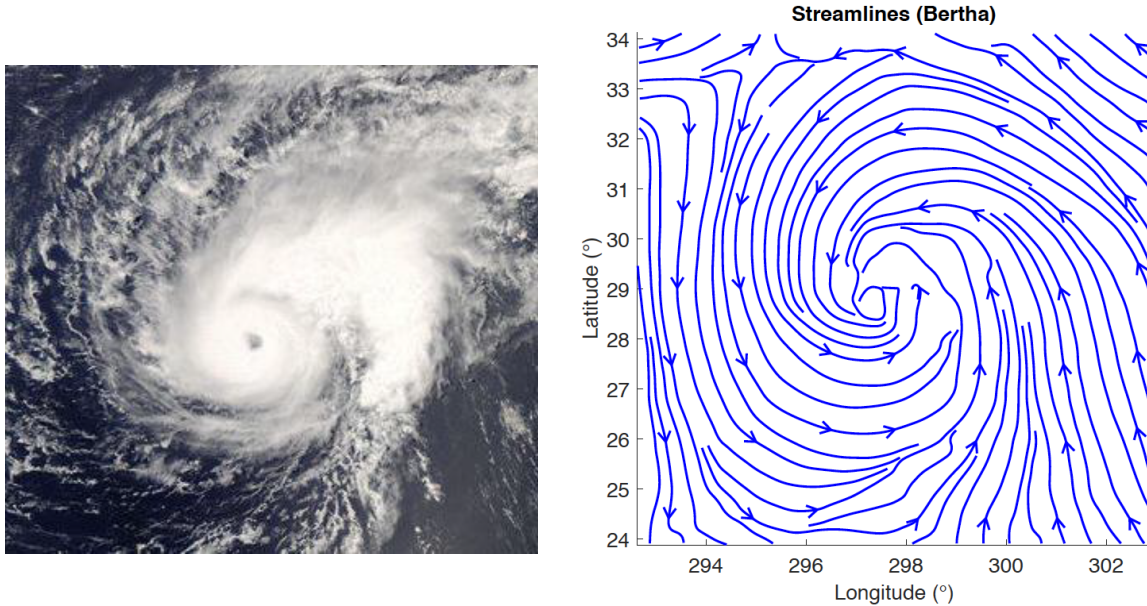


Figure 1: Satellite image of Hurricane Bertha on July 11, 2008 (left) and streamlines (trajectories of particles following the instantaneous flow) constructed from scatterometer winds for Hurricane Bertha. Scatterometer winds for Hurricane Bertha are from the QuickScat instrument on July 11, 2008.

- Investigate the plots: What does the streamline plot show? Where is the maximum wind speed? How does that value compare to typical ‘everyday’ winds? How does wind speed vary with radius? How about the azimuthal wind speed? Briefly comment on the contour plots of radial and azimuthal winds.

1.3 Accessing scatterometer data

Scatterometer data is available at <https://www.remss.com/tropical-cyclones/storm-watch/>. When searching for a hurricane to analyze, scroll down to find a list of past named storms, organized by year. Choose a hurricane case from the Storm Archive between 1999 and 2009 (recent data is not as good due to instrumentation problems). Click on the name of a storm. This will bring you to an interface for viewing scatterometer wind fields over that storm’s lifetime (example in Figure 2). Finally, click on different locations in the upper bar to view scatterometer data from different days. Try to find a storm and a day where scatterometer data is available (i.e., where wind barbs are visible) over most of the region shown in the left-most panel.

After finding a suitable storm, note down the year, month, day and pass of the event. Download scatterometer data from <https://data.remss.com/qscat/bmaps.v04/> and unzip into your working folder. Avoid the 3 day average files (i.e., download files that end in “v4.gz”, not “3day.gz”).

To plot the downloaded data, you’ll have to modify the `filename` variable in your Matlab/Python script to read from the right file. You’ll also have to re-center plots around the center of the storm by modifying the `cntr` variable—you can estimate the approximate center from the online viewer, and tune it once you have initial plots. Finally, each file you download will contain data from two passes of the satellite, and you’ll have to select the right pass by modifying the `pass` (MATLAB) or `ipass` (Python) variable so that your plots match the online viewer.

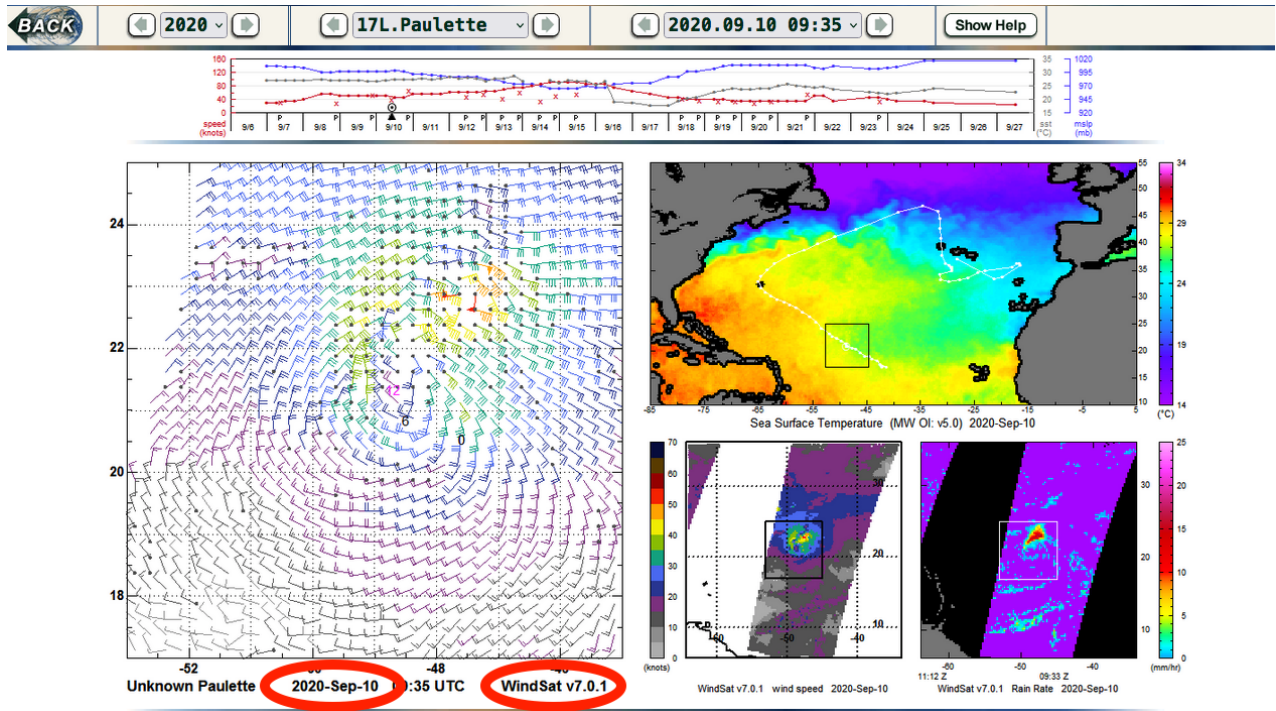


Figure 2: Interface for viewing scatterometer data from the REMSS storm archive. The scatterometer wind field is shown in the left panel, and the date and instrument are circled in red.

1.4 Your tasks

Analysis of hurricane wind fields.

During the data lab, you will analyze the balance of forces in hurricanes using scatterometer wind measurements.

1. Modify the readscat script to compute Rossby numbers (see section 1.1) from scatterometer data for Hurricane Bertha, and plot Rossby numbers as a function of radius.
2. Compare this plot with a prediction for the Rossby number as a function of radius based on angular momentum conservation. (Note: there's not a clear "correct" value for r_1 when analyzing hurricane winds. Instead, you should treat this value as a tunable parameter, and adjust it to see if you can obtain a good fit.)
3. Download scatterometer data for a different tropical storm (see instructions for accessing scatterometer data below) and repeat steps 1-2.
4. Discuss your results, particularly in relation to the radial inflow experiment. How does the Rossby number vary with radius, how does this compare with results from the tank experiment, and what does this imply about the balance of forces at various radii within a hurricane? Does theory based on angular momentum conservation predict $Ro(r)$ equally accurately for the lab experiment and the hurricane, and if not, why might that be?