Operational Use of Near-Real-Time Sea Surface Directional Wave Spectra Generated from NOAA Scanning Radar Altimeter Range Measurements

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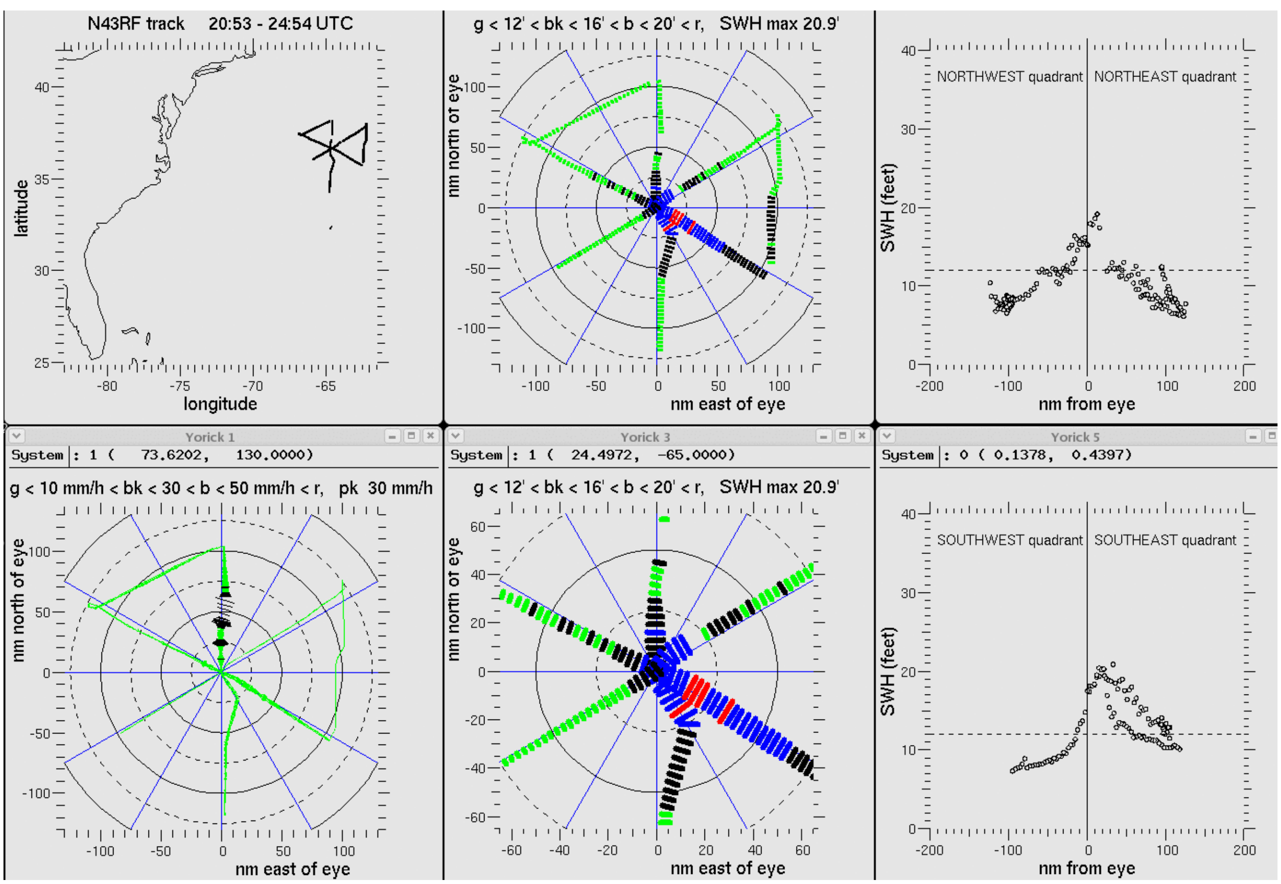
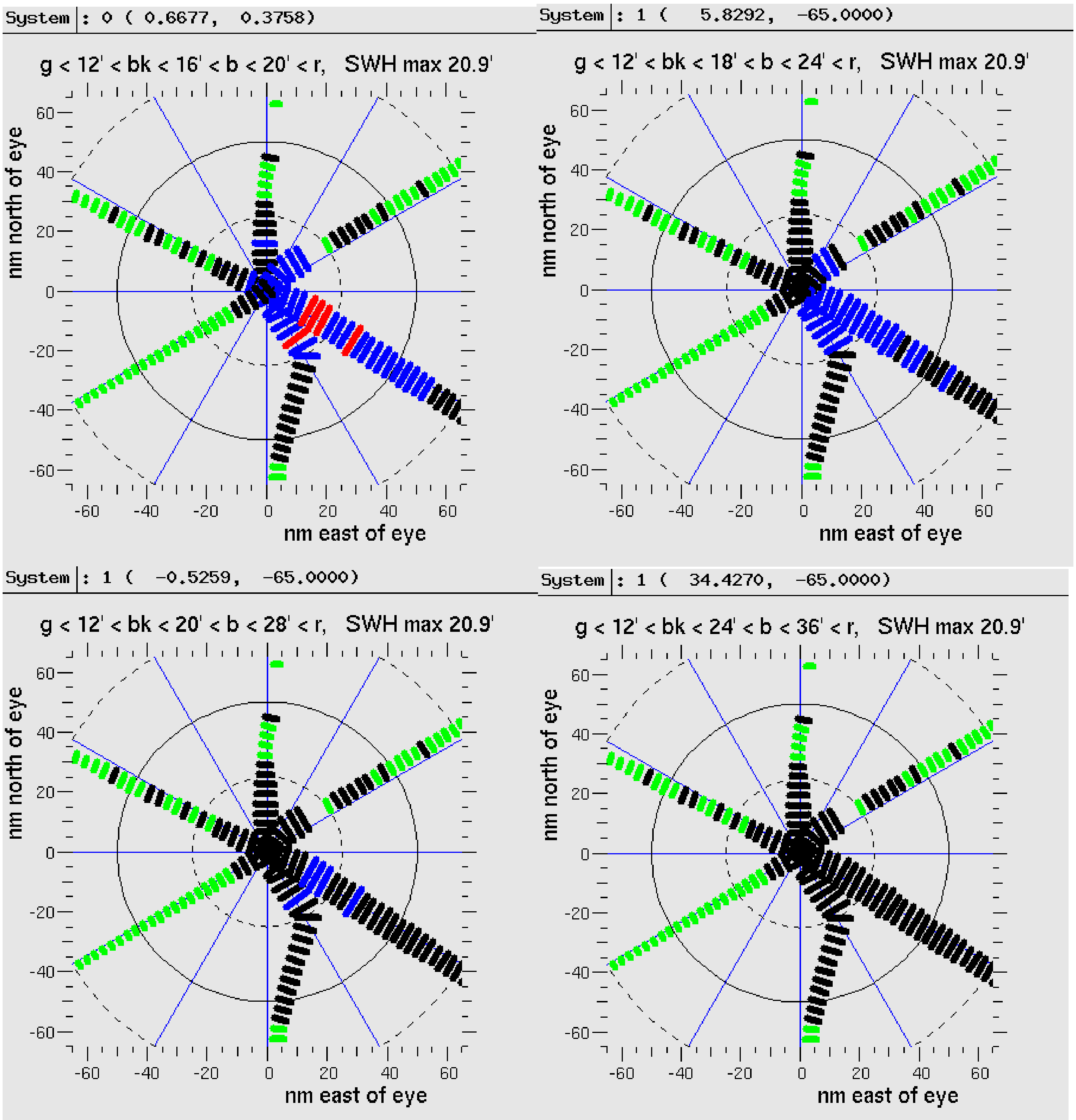
October 16, 2007 - Mid-Year Report

I have been trying to follow the schedule agreed upon in May (refer to first page of Appendix) despite delays in both the administrative and hardware areas that I had no control over. Because the MOU (Memorandum of Understanding) between NOAA and NASA that was completed in September stipulates that John Gaynor should receive copies of the Progress Reports, I have attached to this Mid-Year Report my Progress Report of August 1, 2007 (starting on the second page of the Appendix). For John Gaynor's benefit, the present report also summarizes the considerable interactions with the Points of Contact at Joint Hurricane Testbed (JHT) since the August Progress Report because he was not CCed on any of that correspondence either.

Jose Salazar was able to run the SRA display program I sent him on the JHT server using dummy files I supplied and reproduced Figure 8 of August Progress Report. After Ivan PopStefanija, who is leading the SRA hardware development, projected that the NOAA SRA might not be able to provide the SRA backend computer, where my analysis programs will run, with the SFMR rain rate and wind speed in real-time, I modified the original SRA display program (SRAdisplay.i) to display a spatial map of the SRA rain rate (lower left panel below) similar to the upper middle panel for wave height instead of the scatter plot of SRA rain rate versus SFMR rain rate that occupied the lower left hand panel of the original display (Figure 8 of August Progress Report).



After Dan Brown asked if it was possible to change the significant wave height color ranges to accommodate storms of different intensities, I moded the display program to incorporate five options (four shown below) to tailor the color bar to the range of wave heights to provide a better impression of the wave height spatial variation. For a Cat 1 like Humberto the lowest range (upper left panel below) looks the most interesting.



I set up SRAdisplay3.i so that each time it is run it will produce the following screen query:

What wave height should be coded red? Enter 1 for 20', 2 for 24', 3 for 28', 4 for 32', 5 for 36'

It will then wait for one of those 5 numbers to be entered, so the operator has control. As an afterthought, I also generated SRAdisplay4.i. When it is run, it finds the maximum significant wave height (SWH) automatically and make the waves red at the 16', 20', 24', 28', 32', or 36' level, depending on the maximum level the wave height exceeds. So unless the waves are lower than 16', the display will always contain all the colors (green, black, blue, red). This is probably the best display to run routinely since it doesn't require an operator input.

Mark Willis had a discussion with Jose Salazar about the best way to get the SRA data into the N-AWIPS system. Mark indicated they were presently viewing wave height data from the Jason satellite altimeter as a swath of numbers and found the display of exact wave height values along the satellite track very useful. He sent an example from Hurricane Flossie and indicated that implementing something similar for the SRA would allow people to directly overlay the SRA observations on top of wave model output, which he considered extremely important. He also indicated that displaying the SRA wave spectra data in a similar fashion to how Hendrik Tolman displays the WaveWatch III (WW3) spectral quantities is in text bulletins would be useful. He said Hendrik had mentioned a couple months earlier that it would be possible for NCEP on a case by case basis to turn on WW3 wave spectra along a track in order to get a direct comparison with the SRA observed spectra.

I indicated to Mark that the best entry point into the N-AWIPS system would probably be from the JHT computer after the SRA data arrived from the aircraft, and that Jose would be the expert on that. Whatever software generated the Flossie display could be fed with the data in the SRA header files since each line contains latitude, longitude and total wave height. The Flossie display would be a little cleaner with the decimal point and two zeros deleted since the wave heights were quantized to a foot and higher resolution doesn't really matter anyway. Mark indicated that Chris Lauer was responsible for getting the Jason data into N-AWIPS so the forecasters would have the ability to view that data and any other data they wish to overlay.

Mark and I also discussed implementing a storm-relative N-AWIPS display. A satellite altimeter zips over a hurricane in a few seconds, essentially providing an instantaneous snapshot of the wave heights along a very narrow swath, but it will generally not track over the eye. In contrast, the SRA takes about 5 hours to provide good azimuthal coverage within about 200 km of the eye while the storm moves significantly. Once the SRA header files have been fed into the N-AWIPS system, a display program could be set up to query the operator for the present eye location. Then the program could develop pseudo lat and lon values from the storm-relative coordinates in the header file to generate a storm-relative wave display to overlay satellite wave or wind data.

Mark had a brief conversation about the SRA with Chris Lauer recently, but I have not yet contacted him myself. With the SRA hardware not yet installed and the season winding down, these developments might better be reserved until late November when Chris and Jose would not be as busy.

In the August Progress Report, I pointed out that the development I had proposed could not proceed independently of the SRA hardware development that NOAA had funded separately at ProSensing of Amherst, Massachusetts (prosensing.com) under its Small Business Innovation Research (SBIR) program. The hardware development has been slower than anticipated, which is not unreasonable since the NOAA SRA system design is much more complex than the original NASA SRA to achieve the benefits of significantly improved data quality while reducing size, weight, power and rain attenuation. I spoke to Ivan PopStefanija today and he indicated that the completed system would be shipped to the NOAA Aircraft Operations Center in Tampa by the end of this week. If the tropics remain quiet and all goes well, the installation on N43RF could be completed by the end of next week. Even if no hurricanes develop after the P-3 installation, a test flight would still provide complete information on system performance, antenna beam boresights, pitch and roll mounting biases, and data quality in general. An update will be issued after the first SRA flight and an analysis of system performance will be presented at the 62^{nd} Interdepartmental Hurricane Conference in Charleston in March.

Ed Walsh

APPENDIX

From	')">"Shirley.Murillo" <Shirley.Murillo@noaa.gov>
Sent	Friday, May 11, 2007 8:20 am
To	Edward Walsh <Edward.Walsh@noaa.gov>
Cc	Jiann-Gwo Jiing <Jiann-Gwo.Jiing@noaa.gov> Chris Landsea <Chris.Landsea@noaa.gov>
Bcc	
Subject	Revised JHT timeline

Ed Walsh,
Your JHT timeline was reviewed by the Points of Contacts and JHT staff. Minor changes were made. Below is the revised timeline. Let me know if there are any changes you wish to make. If I don't hear from you by 18 May, I'll assume this is the final year one timeline for your project.

Best regards,
Shirley
JHT Admin. Asst.

Project: Operational Use of Near-Real-Time Sea Surface Directional Wave Spectra Generated from NOAA Scanning Radar Altimeter Range Measurements
Principal Investigator: Ed Walsh
Affiliation: NASA/GSFC
Project Start Date: April 16, 2007

Year one timeline:

August 1 - Aircraft data processing computer programs completed, documented and training material provided. JHT/NHC display programs for wave field parameters and rain rate completed, documented, and training material provided.

- October 16, 2007 - Mid-year report due

- March 2008 - Interdepartmental Hurricane Conference

- April 16, 2008 - Year one progress report/renewal proposal due

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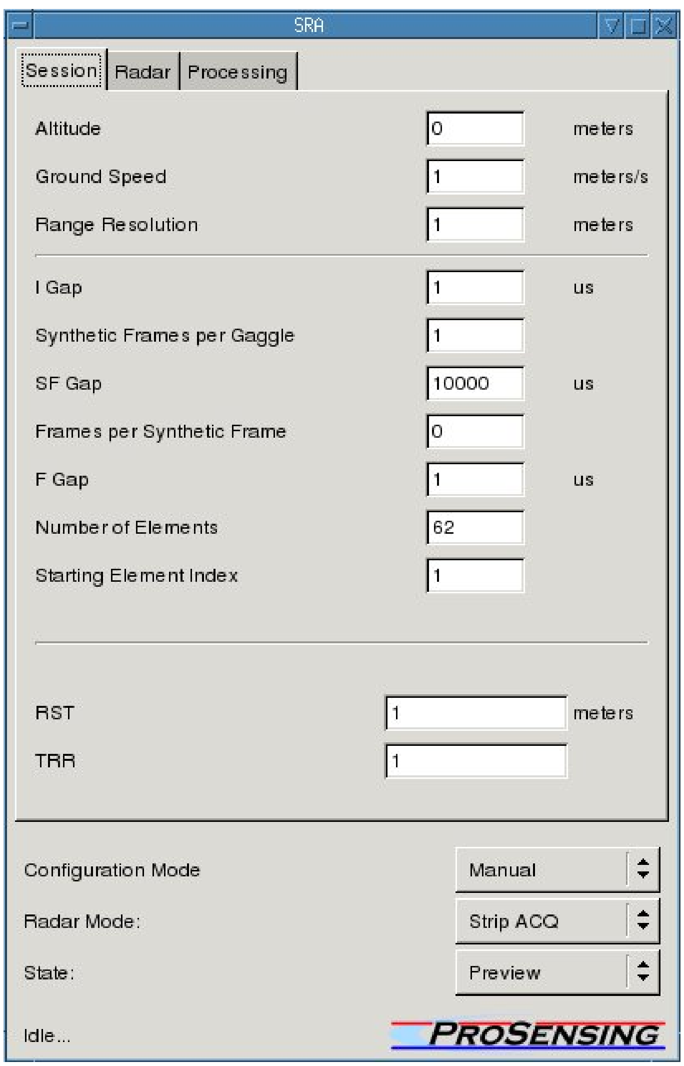
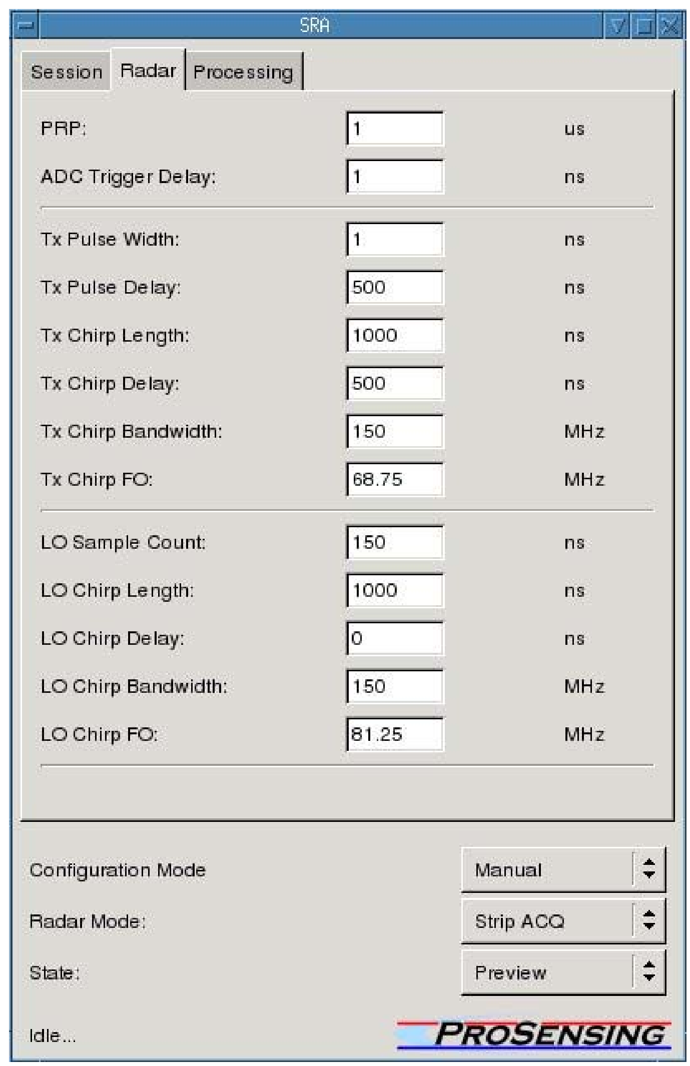
August 1, 2007 - Progress Report

HARDWARE STATUS

In working towards my own milestones, I have been consulting with Ivan PopStefanija of ProSensing, who has the 2-year contract from the NOAA SBIR program to design and build the NOAA Scanning Radar Altimeter (SRA) hardware. This has produced a better perspective on the overall schedule of the SRA development. Below are screen shots of two aspects of the ProSensing graphical user interface (GUI) indicating variable parameters for configuring the radar. All parameters are tied by equations to the first three: altitude, ground speed, and range resolution. I have supplied ProSensing with typical altitude and ground speed ranges, but their equations are based on assumptions that need to be optimized by observing changes in system performance as the parameters are varied about their nominal values during data acquisition under various flight and sea state conditions.





The development I proposed can not proceed independently of the SRA hardware development since the quality of the sea surface wave topography and directional wave spectra are dependent on the availability and quality of the range measurements being made by the SRA. The NOAA SRA will do what the NASA SRA did, but in a much more complex fashion. The NASA system operated at 36 GHz and transmitted a short pulse of 6 ns duration (0.9 m range extent). The NOAA SRA will operate at 16 GHz, less subject to rain attenuation, and transmit a much longer, chirped pulse that will need to be compressed digitally. This technique allows elimination of the expensive, high-powered klystron, but adds an additional level of complexity to the signal processing.

The NASA antenna system used a simply rotating mirror to scan a beam formed by a lens. The NOAA antenna uses no moving parts and forms the various beams digitally. This should provide much greater stability in the incidence angles of the beams, but the data processing is much more complex. ProSensing is also investigating the possibility of using synthetic aperture processing to narrow the along-track beamwidth which would improve the spatial resolution and the quality of the wave topography measurements. Since the digital processing of the NOAA SRA can support a much higher pulse repetition frequency (PRF) than the NASA SRA, they are also planning to incoherently average the synthetic aperture processed returns to produce an output cross-track scan rate of 10 Hz at 3 km altitude to further improve data quality. As their development has progressed, ProSensing has decided to focus on recording all the raw data for the 2007 hurricane season, as they tweak the various system parameters, so they can analyze on a post-flight basis the effect of trade-offs in bandwidth, frame rate, range window extent and coherent and incoherent averaging. They consider it critical to have this information available to optimize and finalize the hardware design for the 2008 hurricane season.

The barrel that will house the SRA radar hardware has undergone installation on WP-3D aircraft N43RF at the NOAA Aircraft Operations Center (AOC) in Tampa and has been returned to ProSensing in Amherst, MA. ProSensing received the microstrip antenna panel on July 27 and will be attaching the 64 cables to control the antenna during the week of July 30. After testing the antenna by itself and in conjunction with the radar, it will be mounted on a fairing that has been previously used on N43RF, so there should be no unexpected problems in installing the system on the aircraft at AOC. The SRA installation is now projected to take place in mid- to late-August.

ProSensing has ordered the back-end analysis computer that the software I am developing will run on, but it has not yet arrived. Once ProSensing has implemented and tested the software on their front-end radar data acquisition computer, they will develop a client-server protocol for transferring the output 10 Hz scan rate centroid ranges and backscattered power data from the 80 cross-track beam positions of the SRA along with aircraft flight parameters to the back-end data analysis computer, and the SRA data output will be automated.

Due to the complexity of the NOAA SRA hardware and everyone’s lack of experience with it, it does not seem reasonable at this point to expect that SRA data products will be routinely available at NHC during the 2007 hurricane season. I am now planning to fly with the system to aid ProSensing in their assessment of system performance and to establish and test the end-to-end processing and data links for transferring SRA output data products to NHC during the flights. Unattended operation may not occur until the 2008 season after the SRA hardware and processing have been finalized during the off-season.

END-TO-END SIMULATION

I have developed an end-to-end simulation of the NOAA SRA that includes a front-end program that generates return waveforms from a simulated sea surface and then runs them though a back-end analysis program to produce and display wave topography, directional wave spectra, mean square slope (mss), and rain rate. If ProSensing can transfer the 10 Hz scan line centroid ranges and powers and aircraft parameters to the back-end computer even intermittently during the initial flights, my displays of sea surface topography will allow assessment during the flights of data quality as a function of radar input parameters that should make the process much more efficient.

In my simulation I have assumed the SRA antenna produces raster scan lines at a 10 Hz rate from 80 beams of 1° (two-way) width, generating 80 ranges to the sea surface across the swath for incidence angles between ±28.2° (for 0° aircraft roll) spaced at equal intervals in the sine of the angle from the antenna boresight. (This may need modification once the SRA antenna characteristics are measured on an antenna range by ProSensing.) That would make the angular increment 0.775° between beams 1 & 2 at the left edge and 79 & 80 at the right edge and 0.686° between beams 40 & 41 straddling nadir, fairly close to the 0.703° uniform increment for the NASA SRA.

I assumed that the interrogated range window is 320 m wide with 320 independent samples at 1 m range intervals (150 GHz bandwidth) and when the aircraft is at 3 km height, the near edge of the window is positioned at a range of 2980 m, 20 m above mean sea level (msl). In this regard, I have pointed out to ProSensing that, if they can implement a mode where the SRA range window is positioned by adding a constant, but operator controlled, bias to the aircraft radar altimeter measurement, it will greatly increase their efficiency in acquiring data.

My simulation adds random fluctuations to the power returned from the simulated sea surface and adds a random noise baseline. It then finds the range to the peak value in each of the 80 return waveforms. Then it places a small window centered on the peak whose width depends on the aircraft height and the angle off-nadir and finds the centroid of the returned power within the small window, re-centering the small window on the initial centroid range and recomputing the centroid and integrating the total power within the small window. I have assumed that the data acquisition computer will send the data analysis computer the values of the centroid range and total power from each of the 80 cross-track positions for each scan line (cross-track sweep) along with various parameters from the aircraft RS232 data link in the following format.

(1) seconds of the day (at least to 0.1 s resolution, but 0.01 s would be better)
(2) latitude from the aircraft RS232
(3) longitude "
(4) north component of ground speed (m/s)
(5) east component of ground speed (m/s)
(6) aircraft heading
(7) pitch
(8) roll
(9) aircraft radar altitude
(10) wind direction
(11) wind speed (m/s)
(12) SFMR wind speed (m/s)
(13) SFMR rain rate (mm/hr)
(14) - (93) centroid ranges from cross-track positions 1 – 80
(94) - (173) total powers from cross-track positions 1 – 80

Item (1) would be the time each scan line sweep is initiated and items (2) – (13) would be sampled from the aircraft RS232 data distribution system at that time. All that information could be dumped into a 173-by-300 array in the data analysis computer every 30 seconds and set a flag to tell it to process it into wave topography and spectra, etc. Items (2) – (13) are only 1 Hz data, but sampling and sending them with each scan line instead of in a separate file increases the data rate by less than 7% and eliminates the need for the analysis computer to do a temporal interpolation between the RS232 file and the SRA centroid range and total power file. These are the kind of details that ProSensing is not thinking about in their focus to get the radar front-end processing going.

Figure 1 shows 300 raster scan lines of the simulated sea surface, which has waves of 300 ±50 m length propagating toward 340° ±20° and waves of 100, 150 and 200 m length propagating toward 265°. A scan rate of 10 Hz was assumed and a 130 m/s ground speed with 15° drift angle at 3 km height. A large aircraft roll variation of ±11° was assumed to demonstrate some of the processing problems to consider when trading off range window extent with other system parameters.

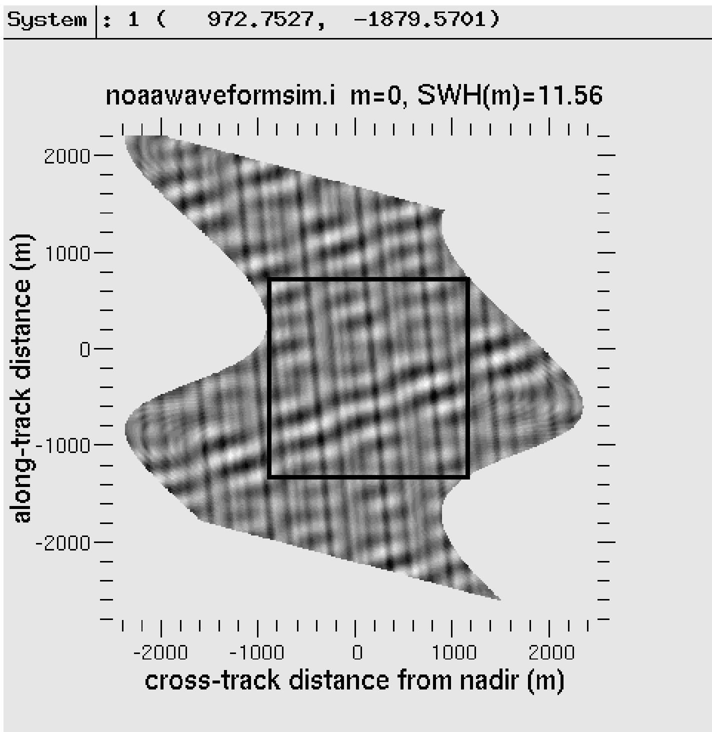


Figure 1. Simulated sea surface.

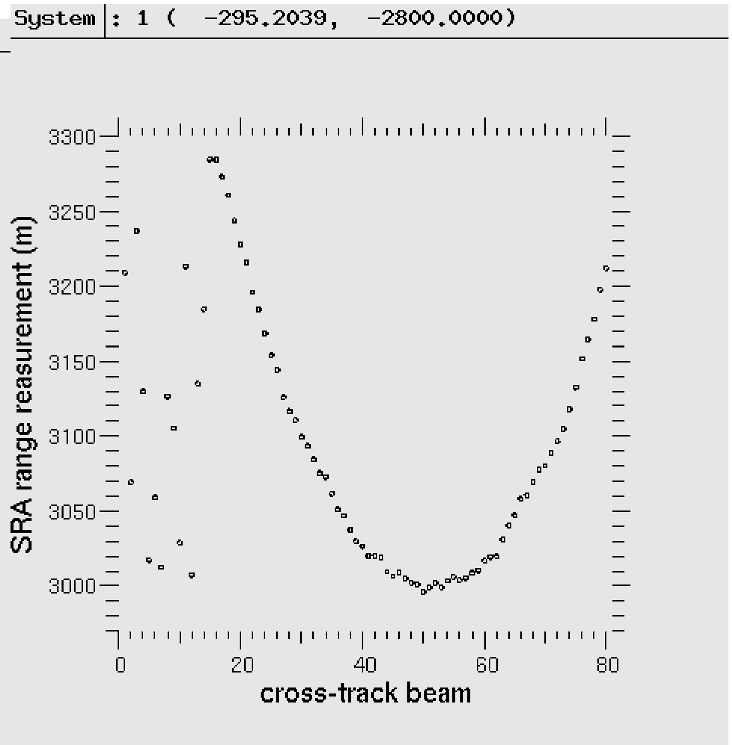


Figure 2. Simulated centroid range measurements.

As the aircraft rolls back and forth, the range to the sea surface varies greatly in each of the 80 beams. Figure 2 shows the centroid ranges from the 80 beams when the aircraft roll attitude was about 7°. The shortest range is at the nadir point which is at cross-track position (beam) 50 instead of straddling beams 40 and 41 when the roll attitude is zero. The range variation in beams 16 through 80 is approximately quadratic with incidence angle, although the ranges are also affected by the surface elevation and noise in the measurement process. The ranges in beams 1 – 14 are random because the 320 m range window does not intercept the sea surface and the radar only sees system noise. Beam 15 is in transition with just a fraction of the sea surface within the beam.

Figure 3 shows the boundaries of a range interrogation window of 320 m extent in the cross-track plane when its near edge is positioned 20 m above msl at nadir for aircraft roll attitudes of 0° and 7°. The 80 dots indicate the positions of the 80 cross-track beams. For the roll attitude of 7°, the range window for the first 14 beams from the left does not intercept msl and the radar will see only system noise. Even for an aircraft roll attitude of 0°, the range window will be above msl for the five beams nearest both edges of the swath.

This range window limitation did not exist with the short pulse technique used by the NASA SRA but the NASA system frequently did not have useful signals near the edge of the swath due to power limitations. The range window extent of the NOAA SRA is one of the system parameter trade-offs being studied by ProSensing. My back-end analysis software goes through a series of steps using the ranges near nadir to make a determination of the aircraft roll attitude. There is enough torsion in the aircraft airframe that the roll attitude measured by the Inertial Navigation System (INS) located near the cockpit is different than the roll attitude at the SRA antenna located near the rear of the aircraft. The back-end program initially uses the INS roll attitude to avoid the corrupted range measurements and iteratively solves for an antenna roll attitude to use in generating the sea surface topography.

I learned on July 30 that ProSensing has settled on 398 m for the extent of their range window and planned to offset the near edge of that window 100 m above mean sea level (msl). That would allow the radar to see 298 m beyond the range to msl at nadir, about the same situation portrayed in Figures 2 and 3 for my assumption of a 320 m range extent with the near edge positioned 20 m above msl.

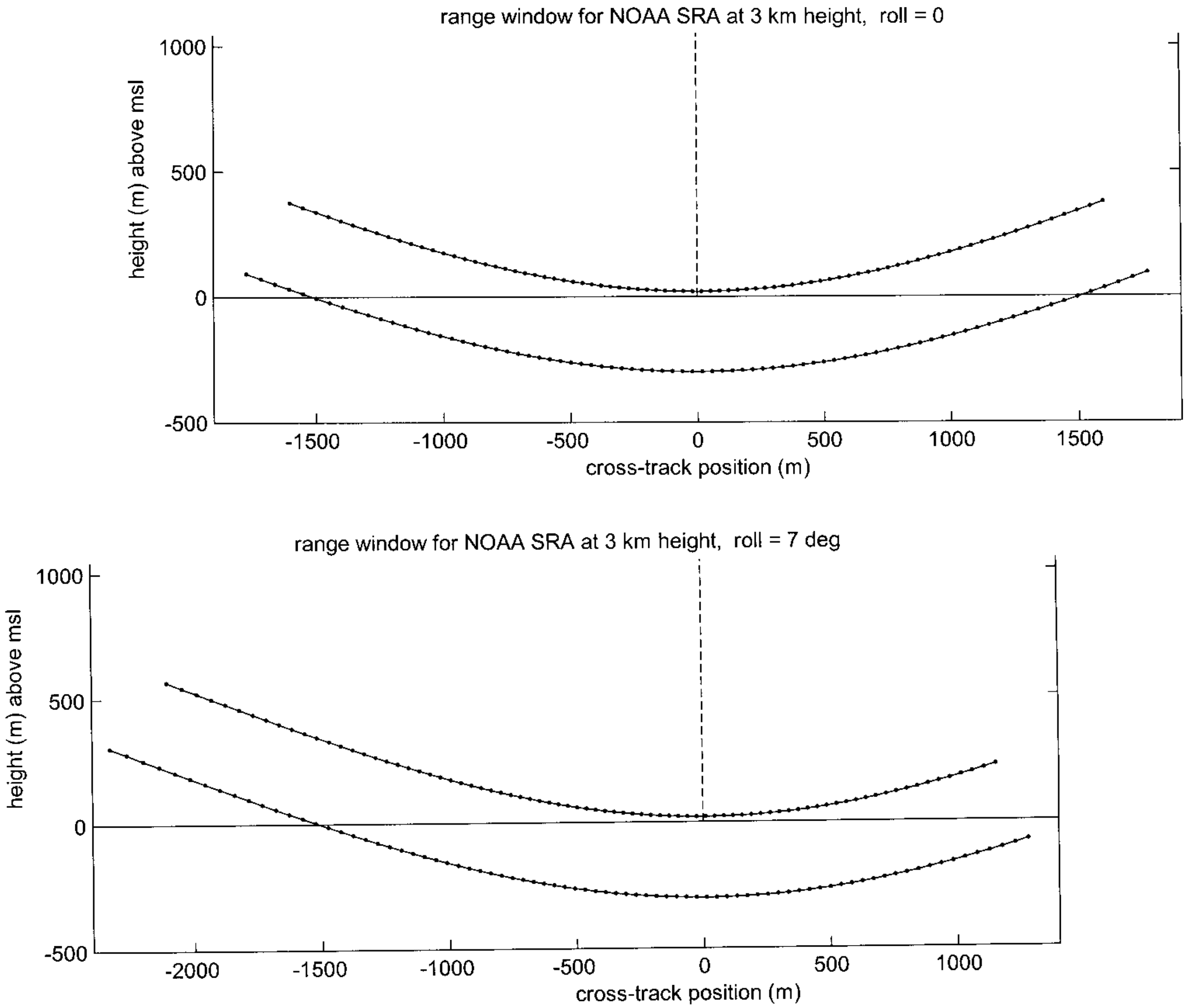


Figure 3. Range window position relative to msl for aircraft roll attitudes of 0° and 7°.

I recommended that ProSensing modify their GUI to incorporate an operator-controlled bias that could be added to the aircraft radar height to position the near edge of the window between 0 and 100 m above msl. This would compensate for any plumbing biases in the absolute height determination between the aircraft radar and the SRA. It would also allow the near edge of the window to positioned only 20 m above msl at nadir and push the far edge of the window to 378 m past msl instead of my 300m assumption in Figures 2 and 3, partially mitigating the problem they indicate. All beams would then view the sea surface for a 0° roll attitude and an additional 5 beams would view the sea surface near the left side of the swath for a 7° roll attitude, which would improve the antenna roll attitude determination. Of course, the number of beams included in the determination is fewer than the nominal because it considers potential deviations of the sea surface from msl due to the waves and initial uncertainty in the roll attitude.

Once the antenna roll attitude is determined the sea surface elevations and their locations are computed using the SRA range measurements and the aircraft flight parameters and the sea surface topography is interpolated to an 8-by-8 m NS-EW grid.

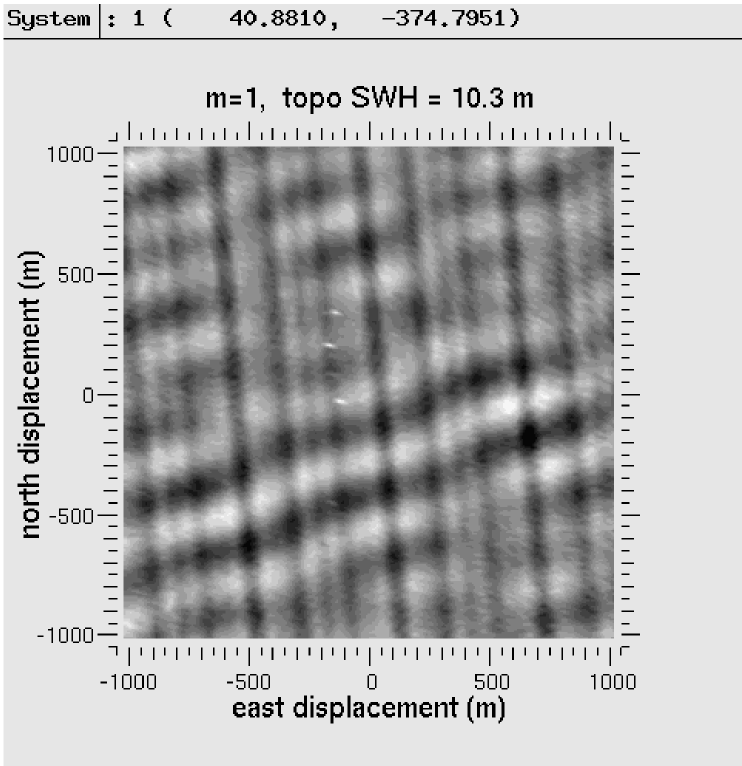


Figure 4. SRA measured wave topography.

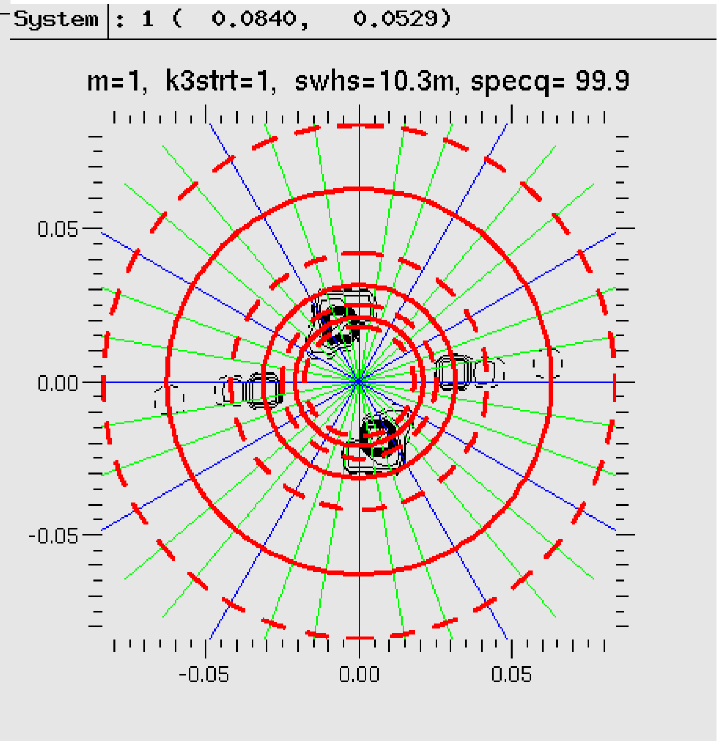


Figure 5. Directional wave spectrum from the SRA wave topography shown in Figure 4.

Figure 4 shows the output for the SRA measured wave topography corresponding to the simulation sea surface shown in Figure 1. Figure 5 shows the directional wave spectrum produced from the wave topography in Figure 4. When transforming wave topography there is a 180° uncertainty in the wave propagation direction and the artifact spectral lobes have not been deleted in the Figure 5 spectrum. A time history of the eye location is necessary to decide which spectral lobes are the artifacts and that final processing step would occur at half-hour intervals along with averaging the individual spectra determined from 2-by-2 km areas (Figure 4) into non-overlapping 5-spectrum averages covering a time interval of 50 s and an along-track distance of about 6 km.

SRA OUTPUT DATA

There will be three levels of data output by the SRA. The first will be the wave topography in the form of x, y, z values of the sea surface elevations and the backscattered power from the 80 SRA beams. This data would be useful in examining detailed wave scattering characteristics in support of other remote sensing missions and for looking at the characteristics of individual waves and wave groups and assessing the frequency of occurrence of rogue waves in hurricanes. But there would be no benefit to having it available in real-time. Those data could be copied onto a thumb drive and transmitted post-flight. The second level of data would be the directional wave spectra, and the third level would be the header file for the wave spectra. For each hour of data collected by the SRA there will be about 60 Mbytes of wave topography data, 1.22 Mbytes of wave spectra, and 0.025 Mbytes of header data.

Hendrik Tolman, NCEP, indicated that, due to network security and access issues, the best repository for the entire SRA data set might be the National Oceanographic Data Center (NODC) and he would like to participate in the discussions regarding its ultimate disposition. He suggested that for the 2007 hurricane season, while the initial assessment of data quality is being made, it would probably be best for the wave spectra and header files to be resident on a server at NHC.

When operational status is attained, pairs of files will be generated at about half-hour intervals for transmission to NHC which will contain information on 36 directional wave spectra (or fewer if not all the spectra are good). The header file would contain 36 lines of ascii scaled integers in 58I6 format (58 columns). Each spectrum will be a 65 by 65 array of integers with the peak normalized to 999. The spectrum file would contain 2340 lines (36*65) in 65I4 format. The header file columns will contain:

1	UTC seconds of the day
2	100* latitude
3	100* longitude
4	10* km north of eye
5	10* km east of eye
6	100* significant wave height (m)
7	10* dominant wavelength (m)
8	10* dominant wave propagation direction (degrees)
9	100* dominant wave height (m)
10	10* secondary wavelength (m)
11	10* secondary wave propagation direction (degrees)
12	100* secondary wave height (m)
13	100000* spectrum peak value
14	spectrum quality indicator
15	10* aircraft height (m)
16	10* ground speed (m/s)
17	10* ground track (degrees)
18	10* aircraft heading (degrees)
19	10* aircraft wind speed (m/s)
20	10* aircraft wind direction (degrees)
21-29	1000* wave numbers of components arriving from eyewall in 1,2,3,4,5,6,9,12,15 hours
30-38	10* directions of components arriving from eyewall in 1,2,3,4,5,6,9,12,15 hours
39-43	10000* SRA mean square slope (mss) values from 5 non-overlapping 10-s averages
44-48	10* SRA rain rate values from 5 non-overlapping 10-s averages
49-53	10* SFMR rain rate values from 5 non-overlapping 10-s averages
54-58	10* SFMR wind speed (m/s) values from 5 non-overlapping 10-s averages

DATA TRANSMISSION TO NHC

As a result of discussions with Jim Carswell of Remote Sensing Solutions, Jim has offered to use his high speed data protocol to transfer the SRA data to NHC. It will parse the SRA data and convert it down to a more efficient data stream, transferring it via the UDP Ethernet protocol, then recreate the file on the NHC computer. I have adopted a naming convention similar to the one used by Jim. Header and spectra files covering a data span which began at 16:20:36 UTC today would be called SRAheader-20070801162036.dat
and SRAspectra-20070801162036.dat

Eight each header and spectra files have been dummied up for a four hour interval using NASA SRA data from a flight in Hurricane Humberto on 24 September 2001 and sent to Jim for testing.

NHC DISPLAYS

A great deal of consideration has been put into what quantities should be displayed at NHC. I have developed two types of displays that have been of great benefit in analyzing SRA data. Both can be plotted from the header file. The first type, shown in Figure 6, is optimum for comparing the wave characteristics measured by the SRA with the predictions of the WaveWatch III (WW3) model throughout a hurricane. The left side of Figure 6 compares the dominant wave direction of propagation (top), wavelength (middle), and wave height (bottom) for the SRA measurements (red) and WW3 (blue) as a function of time sequence (spectrum number) throughout

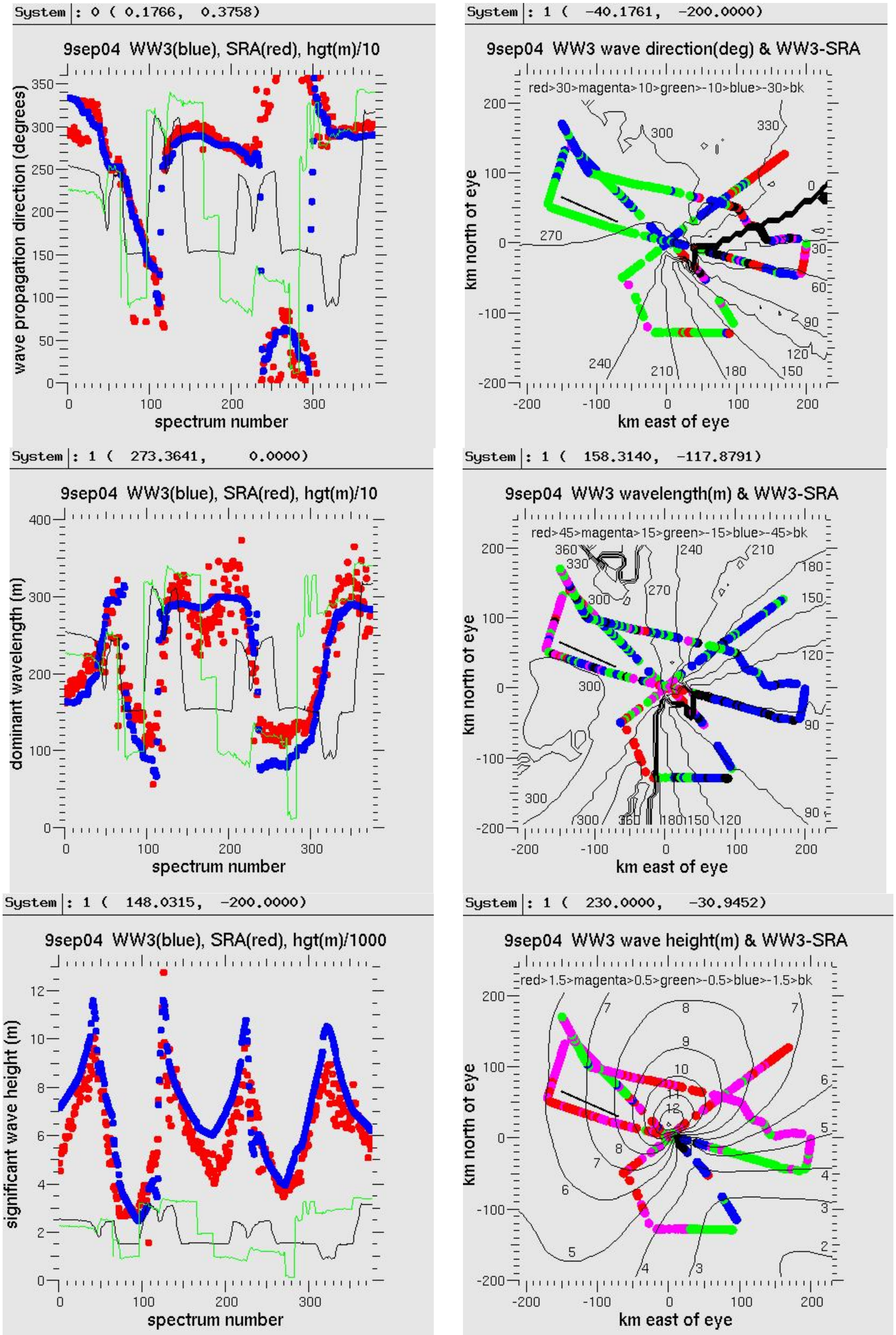


Figure 6. SRA wave field parameter comparison with WaveWatch III model output for Hurricane Ivan.

Hurricane Ivan on 9sep04. The right side color-codes the differences in the quantities from the left side on a plan view of the aircraft track superimposed in a plot of the WW3 prediction through the storm.

Figure 6 allows someone to see at a glance where the SRA and the wave model agree and disagree without having to sort through hundreds of spectra. This would be a valuable display if the SRA data and the WW3 model output were both available on the same computer, but such a detailed comparison might be of more interest to wave modelers like Hendrik Tolman (NCEP), Isaac Ginis (URI), and Shuyi Chen (RSMAS) than NHC forecasters.

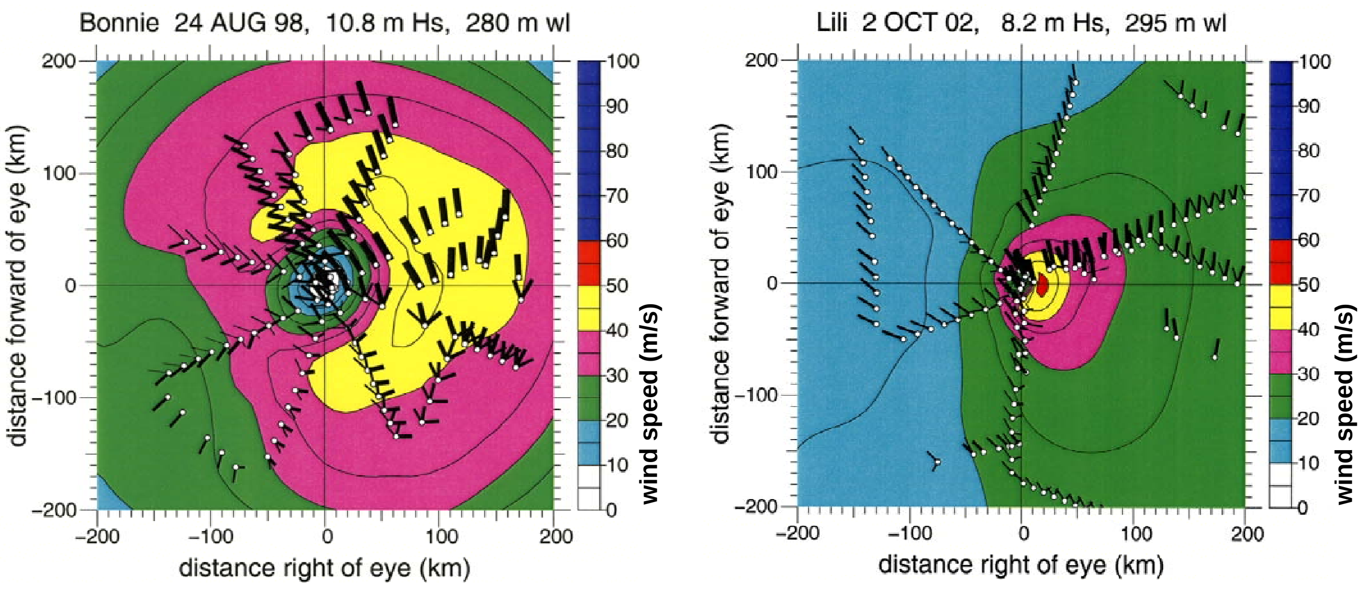
The second type of SRA display, shown in Figure 7, has been very insightful in demonstrating the effect of hurricane size on its wave field. It shows a plan view of the HRD H*wind field with superimposed radials extending from the SRA observation points in the wave propagation direction a distance proportional to the wavelength of the various wave components, and a width proportional to their wave height. The Hurricane Bonnie windfield did not exceed 46 m/s, but produced significantly larger waves than the more intense Hurricane Lili because of its much larger area of high winds.

For the type of display shown in Figure 7 to be clear, the SRA data must be averaged over a considerably greater distance than the nominal 6 km spacing of the SRA output spectra. The spacing in Figure 7 is typically about 20 km. At 6 km spacing, the radials would tend to touch each other and obscure the results.

While the information on display in Figures 6 and 7 would be of great interest in detailed analyses of hurricane wave fields, it might not be highly useful to forecasters in real-time.

The hurricane wave field is determined by its size, intensity, and forward speed.

Hurricane Bonnie was Category 2, but because of its much larger size it had significantly greater waves than those generated by Category 3 Hurricane Lili.



Black radials extend in the wave propagation direction a distance proportional to the ocean wavelength (wl). Their width is proportional to the significant wave height (Hs). Wind contours at 5 m/s, color changes at 10 m/s intervals.

Figure 7. Comparison was NASA SRA wave field measurements in Category 2 and Category 3 hurricanes.

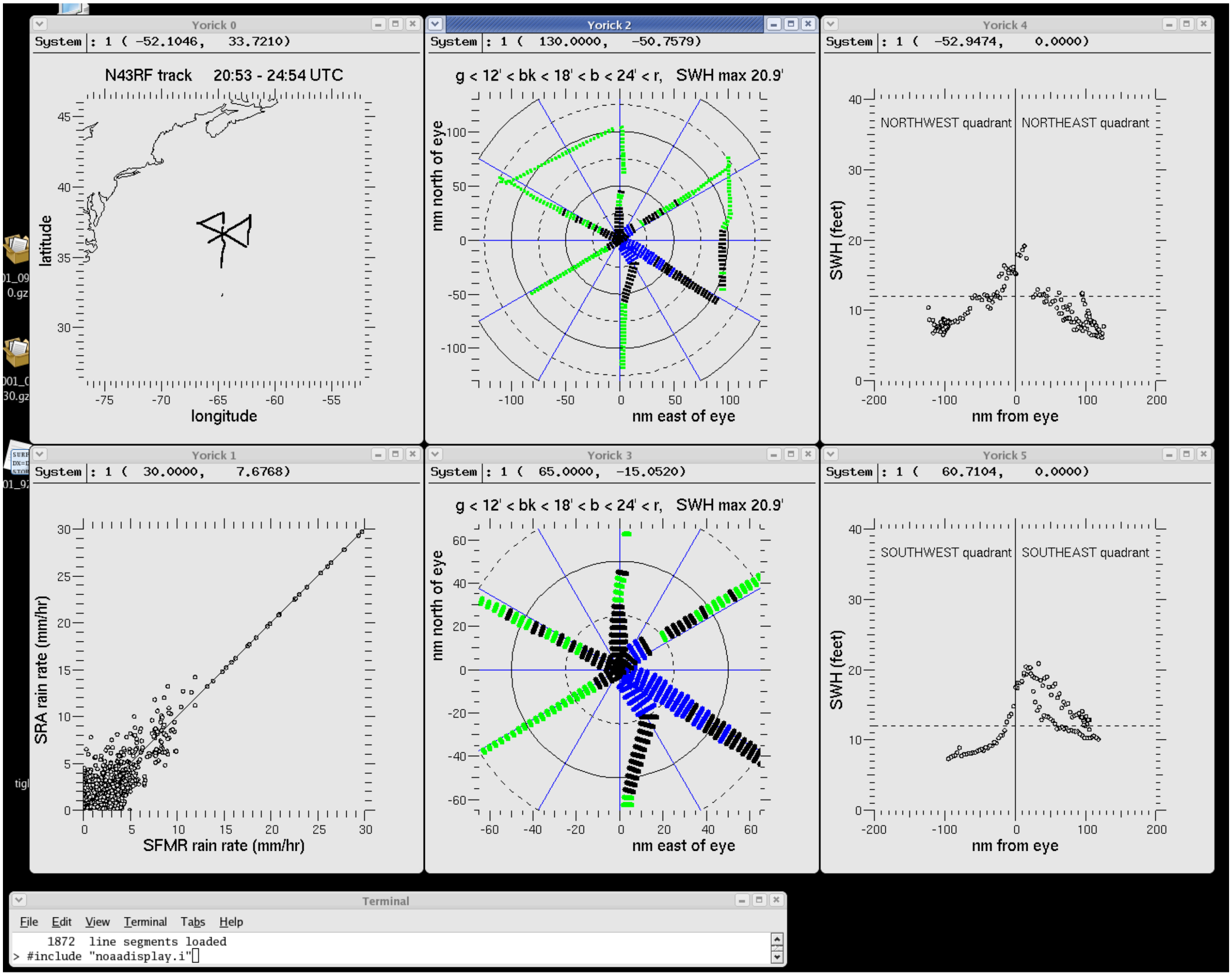


Figure 8. Recommendation for initial JHT display.

Figure 8 is my recommendation for the initial display of SRA data on the JHT computers. The top left panel shows a plan view of the aircraft track in lat/lon with a superimposed world map and indicates the time span of the data displayed. The top center panel shows a storm-relative view of the track within 130 nm of the eye, the typical limit of the aircraft flight track in the vicinity storms. The bottom middle panel is a blow-up of the top panel within 65 nm of the eye. These two panels indicate the maximum wave height observed by the SRA and the wave height at each measurement location indicated by a bar perpendicular to the aircraft track whose width is proportional to wave height and whose color indicates one of four wave height intervals: green for less than 12', black for 12' to 18', blue for 18' to 24', and red for > 24'. These panels show the spatial distribution of the SRA observations and the sharp contrast between green and black provides an immediate sense of the radius of 12 foot seas.

The two panels on the right side plot the individual wave height values as a function of their distance from the eye in the four quadrants for which the radius of 12' seas needs to be specified. In cases of stronger storms where the wave height along the aircraft track is always above 12', this will indicate how rapidly the wave height is decreasing with distance from the eye in the various quadrants and provide a sense of where it may fall below 12'.

The output rate for the wave data in the header and spectra files is 50 s. The bottom left panel of Figure 8 plots the rain rate determined by the SRA at 10 s intervals versus the rain rate from the SFMR averaged over the same

10 s interval. Rain rate from the NOAA SRA is an experimental product. The data used in Figure 8 were acquired by the NASA SRA during a flight into Hurricane Humberto on 24 September 2001. The NASA SRA operated at 36 GHz and its signal was subject to severe attenuation by rain. It provided high sensitivity to light rain, but rates above 13 mm/hr at the 1.8 km altitude of the Humberto flight were not consider reliable and were replaced by the SFMR value in the plot. For rates above 30 mm/hr the NASA SRA signal was totally attenuated as indicated by the gaps in the middle panels of Figure 8. The NOAA SRA operates at 16 GHz and its signal is much less attenuated by rain so it should provide measurements over the full range of rain rates. This panel would provide an immediate sense of how well the new measurement technique agrees with the standard.

The data displayed in Figure 8 were taken over a four hour interval and eight header and spectra files were generated from them in the format of the NOAA SRA. In an operational mode the output header and spectra files generated at half hour intervals will be transmitted to NHC and deposited in a directory on a JHT computer. Each time the display program is run, it will read in all the header files in the directory and plot the results in the display shown in Figure 8. If the program is run eight times at half-hour intervals during the course of the flight, the display will grow each time.

DISPLAY IMPLEMENTATION ON JHT COMPUTER

The display program and dummy files are ready for transfer to a JHT computer for testing. Yorick, the programming language the display program is written in, has been installed on the JHT computers and Jose Salazar has set up an account for me. But so far I have not been able to ssh into the JHT computers, apparently due to firewall issues. As soon as this problem is resolved, the display program and dummy files can be transferred and tested.

I would welcome any suggestions as to displays. This is a new capability and there will be an evolutionary period while people become aware of it.