NOAA/Joint Hurricane Testbed

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Guidance on Observational Undersampling over the Tropical Cyclone Lifecycle

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Mid-Year Report

Final Annual Report: No

1. ACCOMPLISHMENTS

a. Project Goals and Planned Activities

The intensity of a hurricane is defined by the maximum one-minute average wind speed that is associated with the storm. Recent studies using high-resolution hurricane simulations with very frequent output have explored the relationship between the highest directly observed wind speed and the contemporaneous maximum 1-minute wind. These studies, one using SFMR data from simulated reconnaissance flights (Uhlhorn and Nolan 2012, hereafter UH2012), and another for simulated surface observations (Nolan et al. 2014), both show that the peak reported winds generally underestimate the actual peak winds. For SFMR, UH2012 found that the inherent undersampling of the highly variable hurricane wind field causes the highest observed wind to underestimate the actual intensity by 7-10%. However, these results were drawn from a single high-resolution simulation of Hurricane Isabel (2003), using only the period when the storm was intense, highly symmetric, and in steady state. Given the significant asymmetries in the wind fields of most tropical cyclones, the underestimates for more complex systems could be considerably larger. Indeed, the Nolan et al. (2014) study that simulated surface observations found that the underestimates depended also on the size and asymmetry of the storm. These more diverse structures were sampled from a high-resolution simulation of the complete life cycle of an Atlantic hurricane.

The goal of this study is to compute systematic underestimates of hurricane intensity as measured by airborne SFMR instruments, satellite-borne scatterometers, and dropsonde estimates of minimum central pressure. The underlying data sets are very high-resolution, high-quality simulations, the realisms of which have already been well documented: Hurricane Nature Run 1 (HNR1) and Hurricane Nature Run 2 (HNR2). In Year 1, three additional simulations were generated that are representative of storm structures that are not available from the first two cases: these include a simulation of Hurricane Bill (2009) and two idealized hurricanes that achieve Category 2 and Category 5 intensity.

The deliverable product will be guidance for forecasters and for post-season analysts as to how to interpret SFMR, scatterometer, and point measurements of surface winds and pressure for differing classes of tropical storms and hurricanes.

b. Year 2 Activities and Results

In the first half of Year 2, we continued to refine our methods to improve and clarify our results regarding undersampling of surface winds as measured by the SFMR instrument. For example, we recomputed most of the results using repeated, rotated figure-4 patterns as well as single figure-4s. Immediately repeating a figure-4 (after rotating downwind) does improve the undersampling rate by a few percent, but not by as much as might be expected. This may help to inform NHC and/or the aircraft crew as to whether an additional figure-4 pattern is worthwhile, in contrast to some other flight pattern. Some of these results are shown in Table 1.

	Single Figure-4 (Avg. 6-hr %)	**Rotated Figure-4 (Avg. 6-hr %)**
HNR1	11.4 ± 0.8	9.1 ± 0.7
HNR2	16.0 ± 1.9	14.4 ± 1.5
HNR1 (TS)	12.7 ± 6.2	9.9 ± 5.5
HNR1 (RI)	13.3 ± 5.7	11.8 ± 5.6
HNR1 (Small)	12.4 ± 1.8	8.2 ± 1.3
HNR1 (Mature)	10.8 ± 1.1	8.3 ± 0.8
HNR1 (Recurving)	11.5 ± 2.0	9.9 ± 1.6

Table 1. Average underestimations of maximum surface winds for various tropical cyclone simulations are provided based 6-hour mean model maxima of 1-min surface wind. Average values are presented in m/s and as a percentage of the respective model maxima with 95% confidence intervals also indicated. The left column shows results for a single figure-4 pattern, whereas the second column shows the accumulated result over a repeated, rotated figure-4.

Another major activity of the first half of Year 2 is the development of similar methodologies to simulate undersampling of peak surface winds by satellite-borne scatterometers. Our approach is similar: we simulate the surface footprint of the scatterometer retrieval (see Figure 1), using either 12.5 km or 25 km resolution as the basic pixel size; note that the true pixel size varies with distance from nadir. The reported winds for each pixel are based on a weighted average of the 1-km model data using a realistic weighting function based on the properties of the ASCAT instrument (Figa-Saldana et al. 2002). Examples for the wind field from a single output time from Hurricane Nature Run 1 (HNR1) while it was an intensifying tropical storm are shown in Figure 2 for both resolutions. Preliminary results find that the underestimates for both 12.5 km and 25 km resolution scatterometers are not very different, ranging from 15-25% for tropical storm and category 1 cyclones. The undersampling rates are greater for stronger storms, but scatterometer wind fields are not typically used for such storms.

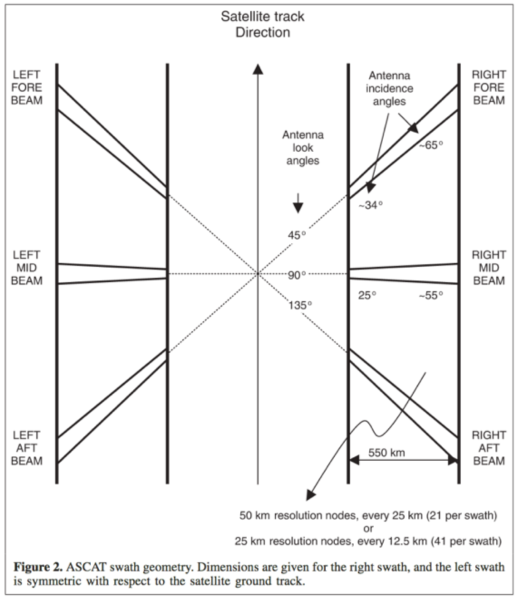

Figure. 1: Figure 2 from Figa-Saldana et al. (2002), showing the two swaths of view of the ASCAT instrument.

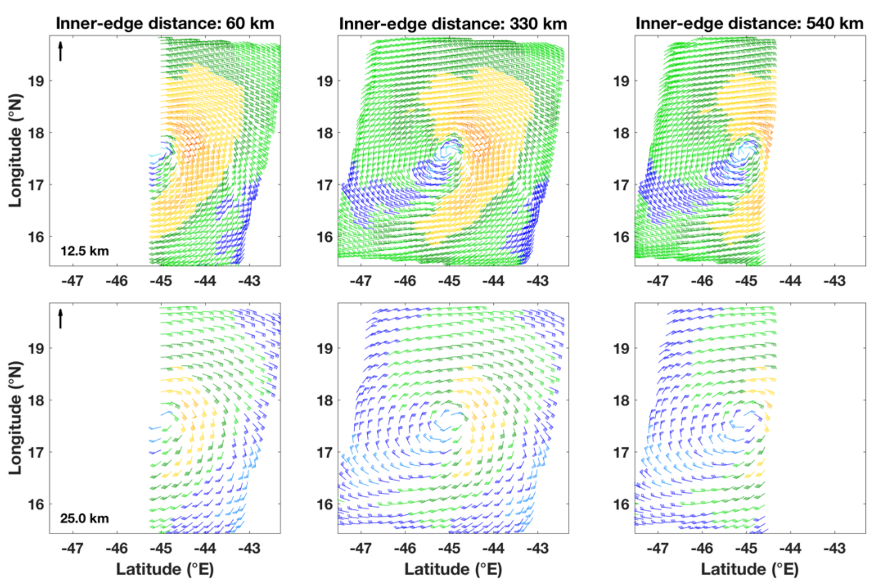

Figure 2: Simulated ASCAT wind swaths generated from HNR1, at 12.5 km resolution (top row) and 25.0 km resolution (bottom row).

Finally, in this period we have developed ideas for how to make these findings available and usable by NHC forecasters in real time. As noted in the previous report, our SFMR results show that the undersampling rate, as a percentage, is greater for larger storms and more asymmetric storms, and less for stronger storms. However, the dependence on asymmetry is not very strong, and since it is difficult for forecasters to accurately assess the asymmetry of the surface wind field in real time, we first limit the undersampling analysis to depend only on storm size (as measured by the radius of maximum surface winds) and storm intensity (as defined by category). Table 2 shows the results of all undersampling rates averaged over results from all 5 storms divided into size and intensity categories, along with the number of samples and the 95% confidence intervals.

	TS	**CAT 1-2**	**CAT 3-5**
Small $RMW_{10} < 30$ km	8.9% (n=7, σ=5.8%)	5.7% (n=16, σ=2.7%)	3.1% (n=29, σ=1.8%)
Medium 30 km to 60 km	14.0% (n=26, σ=3.4%)	10.6% (n=76, σ=2.8%)	6.1% (n=45, σ=2.0%)
Large $RMW_{10} > 60$ km	17.8% (n=51, σ=6.8%)	10.7% (n=17, σ=2.4%)	--

Table 2: Undersampling rates averaged over all 5 simulated storms, divided into bins defined by storm size and storm category.

At present, our plan for operational implementation is to provide a streamlined version of Table 2 to which NHC forecasters can easily refer in real time, to make quick adjustments to reported SFMR wind speeds. Rather than using the precise numbers above, we would adjust the numbers in some consistent fashion. For example, we could simply round the undersampling percentages down to their nearest whole number; an example of this is shown below in Table 3. A more conservative approach would be to adjust each value down to the lower limit of its 95% confidence interval, and then round up or down. For example, this would reduce the undersampling rate for medium-sized, category 1-2 storms from 10.6% down to 8%.

Presently we anticipate a similar approach for reporting the scatterometer results, providing a simple contingency table based on storm size and intensity. In our March meeting with NHC staff, we learned that scatterometer results are generally only reliable and only used for weaker systems such as tropical depressions and tropical storms. Therefore we expect the Table categories to be shifted towards weaker and larger storms. Depending on how the actual results come out, some other representation of the results may be more effective.

	TS	CAT 1-2	CAT 3-5
Small RMW_{10} < 30 km	9.0%	5.0%	3.0%
Medium 30 km to 60 km	14.0%	10.0%	6.0%
Large RMW_{10} > 60 km	17.0%	10.0%	8.0% *

Table 3: Example of an SFMR Undersampling Adjustment Table for peak SFMR winds resulting from a single figure-4 pattern. The value in the lower-right bin is an estimate.

c. Plans for the next reporting period

In the next 6 months, we will continue to work toward completion of this JHT project. In particular, we will finalize our methodologies and results for the SFMR undersampling, the scatterometer undersampling, and the dropsonde pressure estimate undersampling. We will continue to work with the NHC staff to determine the best way to make these results useful and usable in the real-time forecasting environment.

Please see the end of this document for the requested “Test Plan Outline.”

2. PRODUCTS

In Year 1 we gave a presentation at the IHC and we presented a poster at the AMS Conference on Hurricanes and Tropical Meteorology:

Klotz, B. W., D. S. Nolan, and E. W. Uhlhorn, 2016: Further studies in observational undersampling in flight-level and SFMR observations. Available from http://ams.confex.com.ams/32Hurr/webprogram/Paper293604.html

Presentations with more results were presented by the PI at the 2016 AGU meeting in San Francisco and at the 2017 AMS Meeting in Seattle. The latter is recorded and available online:

Nolan, D. S., and B. W. Klotz, 2017: Further studies of observational undersampling of the surface wind and pressure fields in the hurricane core. 97th Annual Meeting of the American Meteorological Society, Seattle, WA. Recorded presentation available from: https://ams.confex.com/ams/97Annual/webprogram/Paper306107.html

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

The PI, Dr. David Nolan, and Mr. Bradley Klotz of NOAA/HRD/CIMAS, have worked on this project.

Originally, Dr. Eric Uhlhorn of NOAA/HRD was also a PI for this project. However, he departed NOAA for private industry in November 2015. Mr. Klotz was assigned to replace him and to perform much of the analyses originally intended for Dr. Uhlhorn.

Other than UM/RSMAS/CIMAS and NOAA/HRD, no other organizations have been involved.

4. IMPACT

No impact at this time.

5. CHANGES/PROBLEMS

There have been no significant changes to the project plan or activities.

6. SPECIAL REPORTING REQUIREMENTS

At the present time the results from this project can be characterized by readiness levels RL3 and RL4.

7. BUDGETARY INFORMATION

With the departure of Dr. Uhlhorn, the funds originally intended for his salary were redirected to increase support at CIMAS for Mr. Klotz. No other changes were made to the budgets, and budget expenditures are on track.

8. PROJECT OUTCOMES

As of yet there are no project outcomes.

9. REFERENCES

Moon, Yumin, and David S. Nolan, 2015: Spiral rainbands in a numerical simulation of Hurricane Bill (2009). Part I: Structures and comparisons to observations. *J. Atmos. Sci*., **72**, 164-190.

Nolan, D. S., 2011: Evaluating environmental favorableness for tropical cyclone development with the method of point-downscaling. *J. Adv. Model. Earth. Syst*., **3**, Art. M08001.

Nolan, D. S., R. Atlas, K. T. Bhatia, and L. R. Bucci, 2013: Development and validation of a hurricane nature run using the joint OSSE nature run and the WRF model. *J. Adv. Model. Earth. Syst*., **5**, 1-24.

Nolan, D. S., and C. Mattocks (2014): Development and evaluation of the second hurricane nature run using the joint OSSE nature run and the WRF model. *Preprints, AMS 31st Conference on Hurricanes and Tropical Meteorology,* San Diego.

Nolan, David S., Daniel P. Stern, and Jun A. Zhang, 2009: Evaluation of planetary boundary layer parameterizations in tropical cyclones by comparison of in-situ data and high-resolution simulations of Hurricane Isabel (2003). Part II: Inner-core boundary layer and eyewall structure. *Mon. Wea. Rev.*, **137**, 3675-3698.

Nolan, D. S., J. A. Zhang, and D. P. Stern, 2009: Evaluation of Planetary Boundary Layer Parameterizations in Tropical Cyclones by Comparison of In Situ Observations and High-Resolution Simulations of Hurricane Isabel (2003). Part I: Initialization, Maximum Winds, and the Outer-Core Boundary Layer. *Mon. Wea. Rev*., **137**, 3651-3674.

Nolan, D. S., J. A. Zhang, and E. W. Uhlhorn, 2014: On the limits of estimating the maximum wind speed in hurricanes. *Mon. Wea. Rev*., **142**, 2814-2837.

Uhlhorn, E. W. and D. S. Nolan, 2012: Observational undersampling in tropical cyclones and implications for estimated intensity. *Mon. Wea. Rev*., **140**, 825-840.

TEST PLAN OUTLINE

I. What **concepts/techniques** will be tested? What is the scope of testing (what will be tested, what won't be tested)?

What will be tested is quantitative guidance for how to interpret and adjust in-situ measurements of wind speeds and pressures in tropical storms and hurricanes.

II. **How** will they be tested? What **tasks** (processes and procedures) and activities will be performed, what preparatory work has to happen to make it ready for testing, and what will occur during the experimental testing?

Our project results will be delivered in the form of contingency tables or similar simple guidelines, and they will be made available for the forecasters to use during the 2017 hurricane season.

III. **When** will it be tested? What are **schedules and milestones** for all tasks described in section II that need to occur leading up to testing, during testing, and after testing?

The guidance will be tested during the 2017 hurricane season.

IV. **Where** will it be tested? Will it be done at the PI location or a NOAA location?

Testing will occur at NHC.

V. Who are the key **stakeholders** involved in testing (PIs, testbed support staff, testbed manager, forecasters, etc.)? Briefly what are their **roles and responsibilities**?

The stakeholders are the PI, NHC, and its forecasters. The PI's role is to provide the most accurate undersampling estimates possible, and to provide them in a manner that is useful in real-time forecasting. The NHC role is to use the guidance and to assess its accuracy and utility.

VI. What **testing resources** will be needed from each participant (hardware, software, data flow, internet connectivity, office space, video teleconferencing, etc.), and who will provide them?

No resources are required.

VII. What are the **test goals, performance measures, and success criteria** that will need to be achieved at the end of testing to measure and demonstrate success and to advance Readiness Levels?

There will be two aspects of success: first, whether NHC forecasters actually use the guidance in real-time; and second, in post-season analysis, if the guidance appears to have had a positive impact in improving real-time analyses of tropical cyclone intensity (as compared to post-season, best-track analyses).

VIII. How will testing **results** be documented? Describe what information will be included in the **test results final report**.

After the hurricane season, we will meet with forecasters to discuss if and how they used the guidance; these findings will be put in the report.