Final Progress Report

Title: Integration of an Objective, Automated TC Center-fixing Algorithm Based on Multispectral Satellite Imagery into NHC/TAFB Operations

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Summary

This project's primary objective was to implement the ARCHER algorithm into NHC's operational environment for real-time testing and evaluation of its multispectral satellite center-fixing guidance. Performance metrics show that ARCHER provides statistically robust center-fixing information and can complement the task of an operational analyst.

Accomplishments

<u>1. ARCHER algorithm development</u>

The project began with a prior version of the ARCHER algorithm (Version 1), optimized only for 85-92 GHz passive microwave imagery. Over the course of the JHT project, we revised this algorithm into the current Version 2, and calibrated it for application to 85-92 GHz imagery, 37 GHz imagery, ASCAT ambiguity vectors, and Geostationary (GOES-East) Visible, IR and Near-IR imagery.

A key addition to this latest ARCHER output is the center-fix expected error ("certainty estimate"). This is a well-calibrated, automated estimate of the center-fix accuracy based on the quality of the center-fix scoring field. It can also adjust this fix certainty over 0-9 hours before or after the time of the analyzed satellite image as new information comes in.

With these new elements (multi-platform center-fixing, expected error), ARCHER can display the results of a time series of fixes as an organized track of the highest confidence positions ("ARCHER-Track"). This can serve as an intuitive guide for forecasters and analysts (Figures 1 and 2).

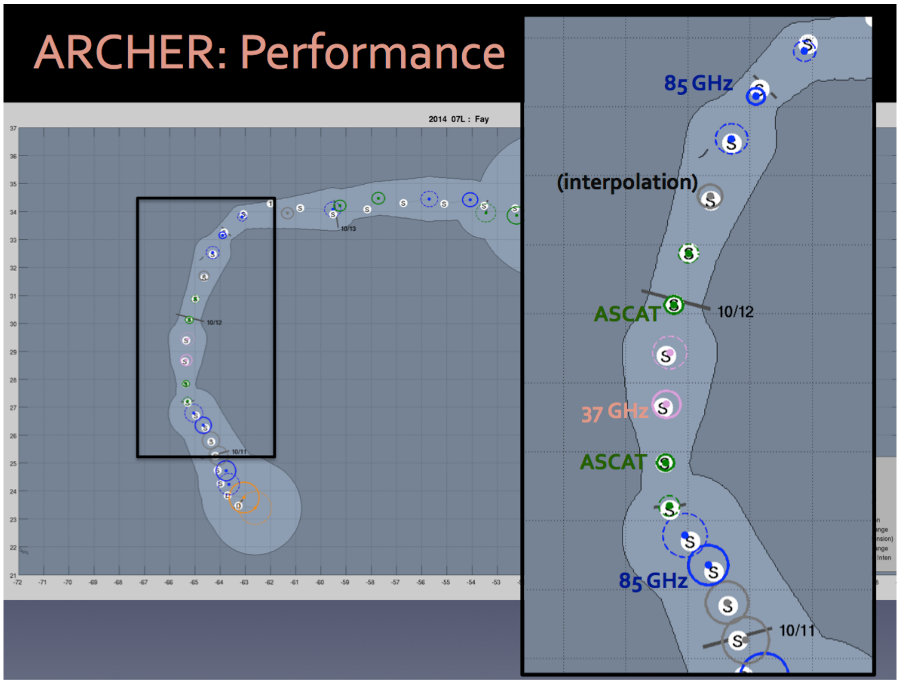

Figure 1. Example of ARCHER track visualization display for Hurricane Fay (2014). Colored dots are the corresponding ARCHER center-fixes, the rings of the same color are the range of 50% certainty (expected error), and the gray region is the range of 95% certainty.

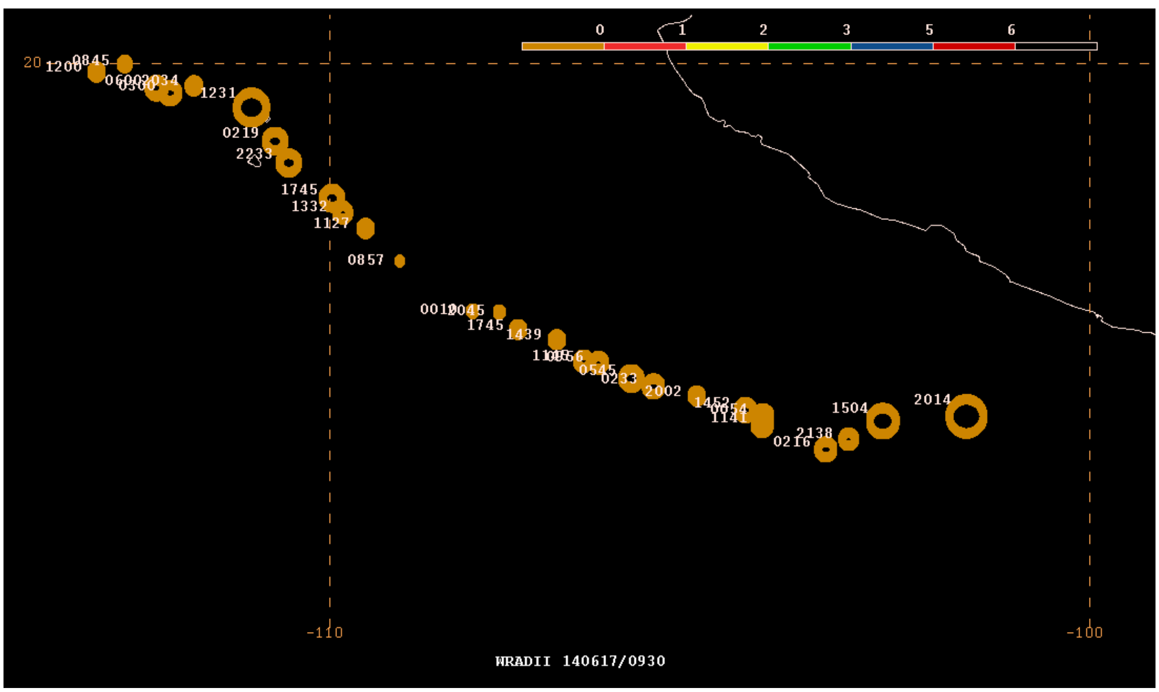

Figure 2. Example of NMAP2 display of Hurricane Christina (2014) using real-time, online ARCHER results. The size of the rings indicate the range of 50% certainty (expected error).

We have also written up this work for publication in the Journal of Applied Meteorology and Climatology (Wimmers and Velden, 2016), to be published next year (using other project funding).

2. Algorithm validation

In this project we initially validated the algorithm with a dataset from the 2012 North Atlantic storm season. We later addressed a request from NHC to perform a similar validation with the 2014 North Atlantic storm season, which was presented in the Year 2 Progress Report and is summarized here.

The following table presents the error statistics in terms of the “% Solved” and the mean error with respect to the best track (Table 1). The statistic “% Solved” describes the fraction of observation times in which either ARCHER, SAB or TAFB provide fixes for that set of times. (Note that the cases in which ARCHER lacks a solution are due to the lack of a confident center fix on any real-time source, whereas the no-solution cases for SAB are due to the 6-hourly reporting period, and the no-solution cases for TAFB are due to gaps in the record.)

Table 1. Error statistics of ARCHER combined-sensor center-fix w.r.t. the NHC Best Track (2014 dataset).

	TD – Cat 1			Cat 2-5		
	N	**% Solved**	**Mean error**	**N**	**% Solved**	**Mean error**
ARCHER Real-Time	103	95%	52 km	50	100%	17 km
ARCHER Near Real-Time	103	100%	40 km	50	100%	15 km
SAB	103	50%	32 km	50	50%	15 km
TAFB	103	79%	29 km	50	90%	15 km

From a straight comparison of average error, the SAB/TAFB positions are closer to the best track than ARCHER positions, as expected, by 30-40% on average for weaker storms. This was also the result of the 2012 validation. However, as noted during the 2012 validation, this result can be expected from an algorithm designed to complement the existing forecasting process rather than substitute for it. Table 2 addresses ARCHER’s relevance as a forecasting/diagnostic tool more directly.

Table 2. Comparison of ARCHER Real-time ("ArRT") and ARCHER Near Real-time ("ArNR") with SAB/TAFB (2014 dataset).

	TD – Cat 1		Cat 2-5	
	N	**% Improved by ARCHER**	**N**	**% Improved by ARCHER**
ArRT vs. SAB	48	42%	25	44%
ArNR vs. SAB	51	45%	25	52%
ArRT vs. TAFB	76	33%	45	40%
ArNR vs. TAFB	81	43%	45	56%

As this shows, ARCHER improved on the fix estimates of operational analysts between 33-45% of the time on weaker storms and ~50% of the time on well-developed storms. It may be worth noting that this comparison does not include cases in which ARCHER "wins by default" because of a missing operational fix. (While this would increase ARCHER's improvement percentages by ~15% versus TAFB, it would only address operational constraints and not the relative accuracy.)

3. Real-time product delivery and website development

Since 30 June 2014, we have maintained an online site (http://tropic.ssec.wisc.edu/real-time/archerOnline/web/index.shtml) with a number of real-time supporting products for each tropical cyclone identified by the NHC or the JTWC. (Observations of tropical cyclones outside the purview of the NHC are a useful fringe benefit, and also have greatly accelerated the troubleshooting process for this project.) Although the project is now at a close, the operation of the real-time algorithm at CIMSS is ongoing.

The real-time supporting products include:

- The ARCHER **summary table**, in html and text format (for automated ingestion into the NMAP2 framework);
- The ARCHER **track image** (Figure 1), which visually summarizes the ARCHER-derived optimal storm track with the corresponding forecast center's forecast/analysis track included for reference;
- **Diagnostic plots** (Figure 3) for each satellite source image, to guide the user through the ARCHER centering process;
- **Comparison plots**, which shows the collection of ARCHER center-fixes for each 3-hour window; and
- **Reference material in a local collection of wiki pages**, described below.

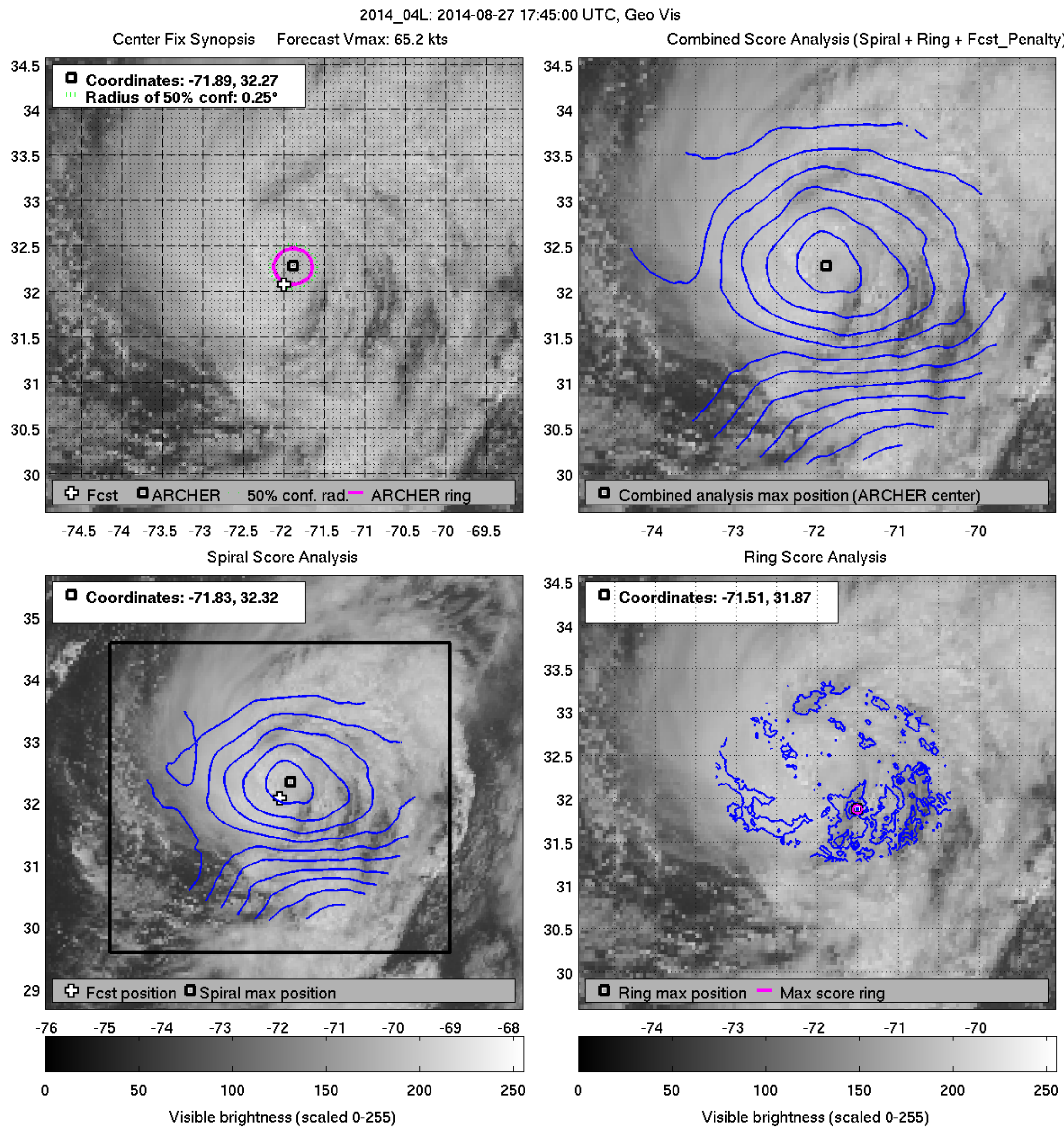

Figure 3. ARCHER single-image diagnostics for a GOES-East Visible channel analysis, showing the components of the ARCHER algorithm: the center-fix synopsis, combined score analysis, spiral score analysis and ring score analysis.

We have compiled several wiki-format webpages of reference material, linked from the main page of the ARCHER website: https://groups.ssec.wisc.edu/groups/archer/archer-product-description. It is designed to give an overview of the ARCHER system and forecasting process in the course of a 5-20 minute read (depending on the user's time commitment).

4. Incorporate new findings

In follow-up discussions with our colleagues at NHC, we agreed to give priority to the following topics in our remaining project time: a) Incorporate RapidSCAT ambiguities, b) Revise ARCHER to re-ingest data from 6 hours before a TC is initially declared in order to increase coverage, and

c) Improve ARCHER performance by increasing the resolution of the Visible channel input data. Our further progress on these areas is as follows:

a) During the 2015 storm season we incorporated RapidSCAT ambiguities into the product suite. However we have observed that the quantitative center-fixing from this source is inferior to that of the ASCAT sensor. As a result, we have decided to keep this source on the website for viewing, but it will not be used in the multi-sensor center-fix track.

b) We have also revised ARCHER to re-ingest all available data before the earliest time of the TC reported track (which sometimes stretches 6-12 hours before the initial designation). This has led to a significant reduction in center-fix uncertainty in the first 6-12 hours of a TC track (Figure 4) since June 2015. We also see improved continuity in the ARCHER center-fix track as a result.

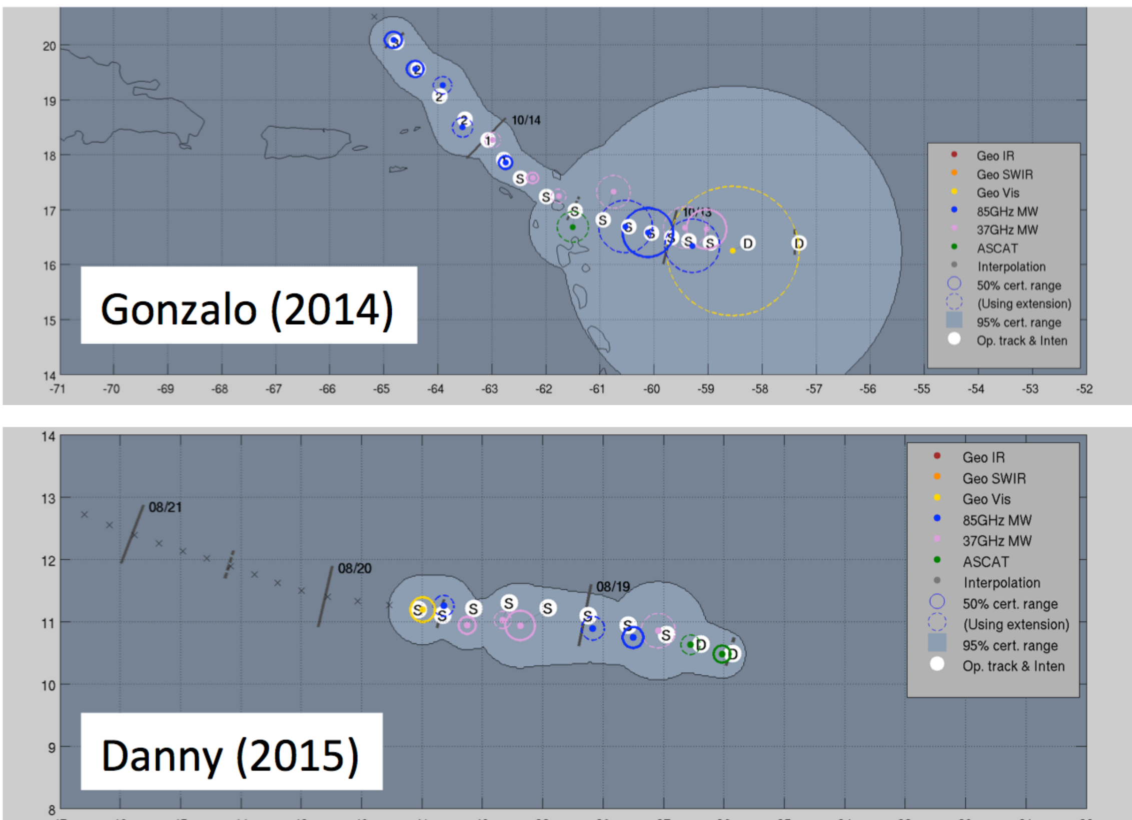

Figure 4. Top image: Early storm track display for Gonzalo (2014) before data “re-ingest” was implemented. The first two center-fixes are missing microwave or ASCAT data, leading to a high-uncertainty “bulb” at the start of the track. Bottom image: Early storm track display for Danny (2015) after re-ingesting was implemented. Since 2015, high-uncertainty “bulbs” are rare.

c) We have increased the operational resolution of the Visible channel application in ARCHER by a factor of 2, and determined in a retrospective run of 2012 North Atlantic imagery that it slightly improves the algorithm performance, and fits seamlessly into the multi-sensor system. The diagnostic imagery is noticeably improved, but the systematic errors such as feature displacements caused by shadows are unaffected. (However, this is still captured in the expected error calibration.) We have monitored the real-time operations and insured a full continuity of operations.

5. Explore strategies for recoding into real-time operations at NHC

ARCHER currently exists as a library of Matlab scripts, run from cron on a unix server at the University of Wisconsin. The data formats are currently Matlab-standard, although the graphical imagery is standard and shared online. In order to transition the algorithm to regular operations at NHC, it would require several modifications:

- Ability to work from a common data format of incoming TC imagery, pre-organized by each TC.

- Needs to operate in a free (non-licensed), open-source software language, and maintainable by knowledgeable technical support personnel.

- Produce output that is easily accepted into other current and future JHT MW-based algorithms.

In recent months, we have been in detailed discussions with colleagues at the Naval Research Lab (NRL) to use GeoIPS as a resource for initializing ARCHER and processing its outputs in a standard setting. This is a potential avenue for NHC assuming continued interest in integrating GeoIPS into their operations as a foundation for microwave-satellite based JHT research and applications. We are currently making plans to recode ARCHER into the version of Python used in GeoIPS, leveraged with support from the Office of Naval Research, and tested initially on the real-time NRL platform. This would enable a prototype microwave satellite image ingesting system with capabilities that feature ARCHER's center-fixing and center-fixing diagnostics.

We will continue to coordinate with NHC and NRL to refine or revise this strategy as necessary.

References

Wimmers, A. J. and C. S. Velden, 2016: Advancements in objective multi-satellite tropical cyclone center-fixing. *J. Appl. Meteor. Climatol.*, in press.