Oceanic and Atmospheric Research (OAR) Office of Weather and Air Quality (OWAQ)
National Oceanic and Atmospheric Administration (NOAA)
Department of Commerce

Federal Grant Number: NOAA-OAR-OWAQ-2015-2004200

Passive Microwave Data Exploitation via the NRL Tropical Cyclone Webpage

Principle Investigator:
Josh Cossuth, Joshua.Cossuth@nrlmry.navy.mil, 831-656-4618
Meteorologist, Naval Research Laboratory, Marine Meteorology Division, Monterey, CA

Submitted:
March 30, 2017

Recipient Organization:
Office of Weather and Air Quality R/WA
NOAA Office of Oceanic and Atmospheric Research
1315 East-West Highway
Silver Spring, MD 20910

Project/Grant Period:
September 1, 2015 – August 31, 2017

Reporting Period End Date:
February 28, 2017

Project Progress Semiannual Report
Mid-Year 2

1. ACCOMPLISHMENTS

This project provides multiple thrusts towards implementing upgrades of microwave imagery processing in the Naval Research Laboratory's Tropical Cyclone Webpage (NRL TC web; http://www.nrlmry.navy.mil/TC.html), which provides a near-realtime demonstration of research and operational meteorological satellite observations centered on TCs. Project work so far has involved the implementation and near-realtime demonstration of the multi-platform analysis standardization procedure as well as new product delivery, through visualizing new channels, color tables, and product fusions. Statistics on brightness temperature distributions in the climatological data have been calculated to facilitate new product visualizations. Imagery from AMSR2, GMI, Himawari, and GOES has been processed and archived in near-realtime since June 2016. All TC cases globally in that time period have available imagery produced to be evaluated. The following tasks represent this effort:

1. Enhancement of the near-realtime 37 and 85/89/91 GHz H/V/PCT/color imagery products for all global TCs is proposed. This includes recalibration of the ice scattering channels to 89 GHz to reduce bias between sensors, bi-cubic spline interpolation, and CIMSS ARCHER recentering. A streamlined and cleaner python based processing and plotting.
    a. Task is 95% complete. Components are set-up in processing system. Final completion pending any feedback from POCs.
2. To complement Task 1 upgrades, this task aims to populate an archive of historical passive microwave data since 1987. Using a similar methodology as in the near-realtime upgrades, a standardized database of both digital data and image products will be generated and made available to the TC community to compliment the near-realtime data.
    a. Task is 70% complete. Historical test cases are being analyzed for analysis QC. Full dataset is staged and ready for processing.
3. Parallax of the storm based on feature heights and sensor scan angle can misrepresent the TC position. A study and application of a more sophisticated parallax correction scheme is proposed to provide increased confidence in the initialization of the TC center. This work will be achieved by analysis of TC centering and eye structure in co-located satellite radar vertical profiles and passive microwave imagery.
    a. Task is cancelled at 25% completion. Preliminary results showed ability to correct for parallax would not improve centering beyond current operational uncertainty. POCs request moving any further time devoted to Task 3 into Task 4.
4. The color tables used to visualize the TC were subjectively developed based on a small sample of cases observed by the SSM/I. Resolution and frequency changes since that time necessitate an expanded and quantitative revisiting of this visualization. Availability of improved resolution has suggested revisiting other channels for possible operational utility. Interaction with the JHT POCs has emphasized ability to process other frequencies (such as 18 and 166 GHz) as well as improve RGB false color product fusion between frequencies.
    a. Task is 90% complete. Another round of new products have been developed and demonstrated (see Section 2 for examples). Final list of 6 new products were developed based on user needs. Final task completion is pending any further iterative feedback from POCs on request improvements.

Results have been indicated through JHT POC interaction site visits and conference presentations at the American Geophysical Union Fall Meeting, the American Meteorological Society Annual Conference, the PACOM Joint Tropical Cyclone Forecasting Forum, and the Interdepartmental Hurricane Conference (see Section 2 for more information). Transition demonstration has been provided via near-realtime product development through NRL TC web (see Section 2 for more details).

Project Timeline:

The remainder of parallax work from Task 3 has been cancelled for this project, with remaining efforts being moved into Task 4 to further optimize new product development based on JHT POC discussion. Beyond that, task development remains on schedule. Note that strikethrough text is completed, underlined text is underway, and double-strikethrough red text is cancelled. The timeline continues to be flexible and subject to refinement given JHT POCs requests. Steps are continuing along the following revised timeline (amended using JHT POC feedback):

2015

~~Sep-Dec:~~	~~(Tasks 1 and 2) Process historical images and T_B statistics~~
~~Nov:~~	~~Interact with POCs at NOAA/NHC to assess operational needs~~

2016

~~Jan-Apr:~~	~~(Task 4) Perform statistical analysis on historical T_B distributions and formulate revised color table and ranges~~
~~March:~~	~~Present Mid-Year 1 results and collaborate at IHC~~
~~April:~~	~~Present and collaborate at AMS Tropical Conference~~
~~May-Aug:~~	~~(Tasks 1 and 4) Provide demos of standardization process, new color products, and new channels for transition to realtime datasets.~~
~~Aug-Dec:~~	~~(Tasks 1 and 4) Real-time tests of standardized data on NRL TC webpage~~
~~Sep-Dec:~~	~~(Task 3) Find, gather, and process all cases with satellite radar passes through TC center.~~
~~Nov:~~	~~Interact with POCs at NOAA/NHC to evaluate updated goals~~
~~Nov-Dec:~~	~~(Task 4) Revise, finalize color tables, ranges based on POC/IHC feedback~~

2017

Jan-Sep:	(Tasks 1 and 4) Provide a second round of realtime demos for standardization process, new color products, and new channels.
Feb-Apr:	(Task 2) Quality control and apply standardization process to historical data archive.
~~March:~~	~~Present Mid-Year 2 results and collaborate at IHC~~
~~March-May:~~	~~(Task 3) Develop statistics on radar profiles and microwave T_B, feature height parallax~~
May:	(Task 2) Populate ftp archive with climatological netCDFs, images
July-Sep:	(Task 3 and 4) Real-time tests of revised color tables and parallax correction scheme on real-time NRL TC page images.

2. PRODUCTS

- Examples from the second round of real-time product demonstration, performed from Tasks 1 and 4 is shown with the case study product descriptions below. Similar case studies have begun with Task 2, but are omitted to preserve space.
- This case shows an overpass of 04S Carlos in the South Indian Ocean from GCOM-W1 AMSR2, 2239 UTC February 5th, 2017. These are examples of realtime deliverables demonstrated in FY17 using the new methodology from this study:

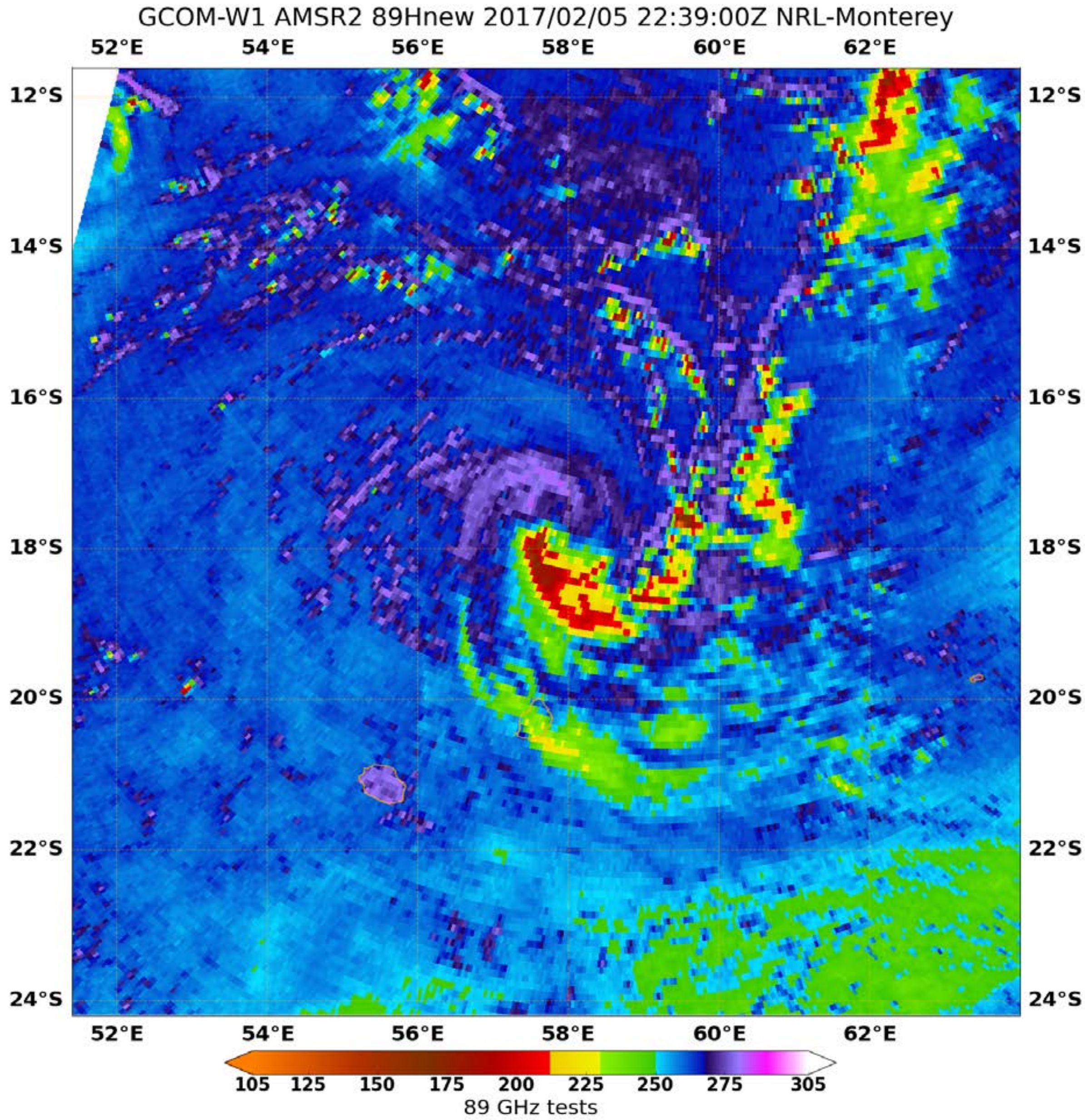

Figure 1: 89 GHz Horizontal Polarization. This is updates a currently operational product that provides information about convective vigor by expanding the dynamic range for intense

convection (< 200 K) and adding details for low level liquid water emission (purples and pinks, > 265 K). Convective ice is shown in a radar-like color scale with heavier convection indicated by lower brightness temperatures. Environmental stability is inferred with the middle-upper end of the scale, with lighter blues to greens indicated a more stable outer environment. The purples and pinks indicate liquid water emission from low level clouds as well as the land surface.

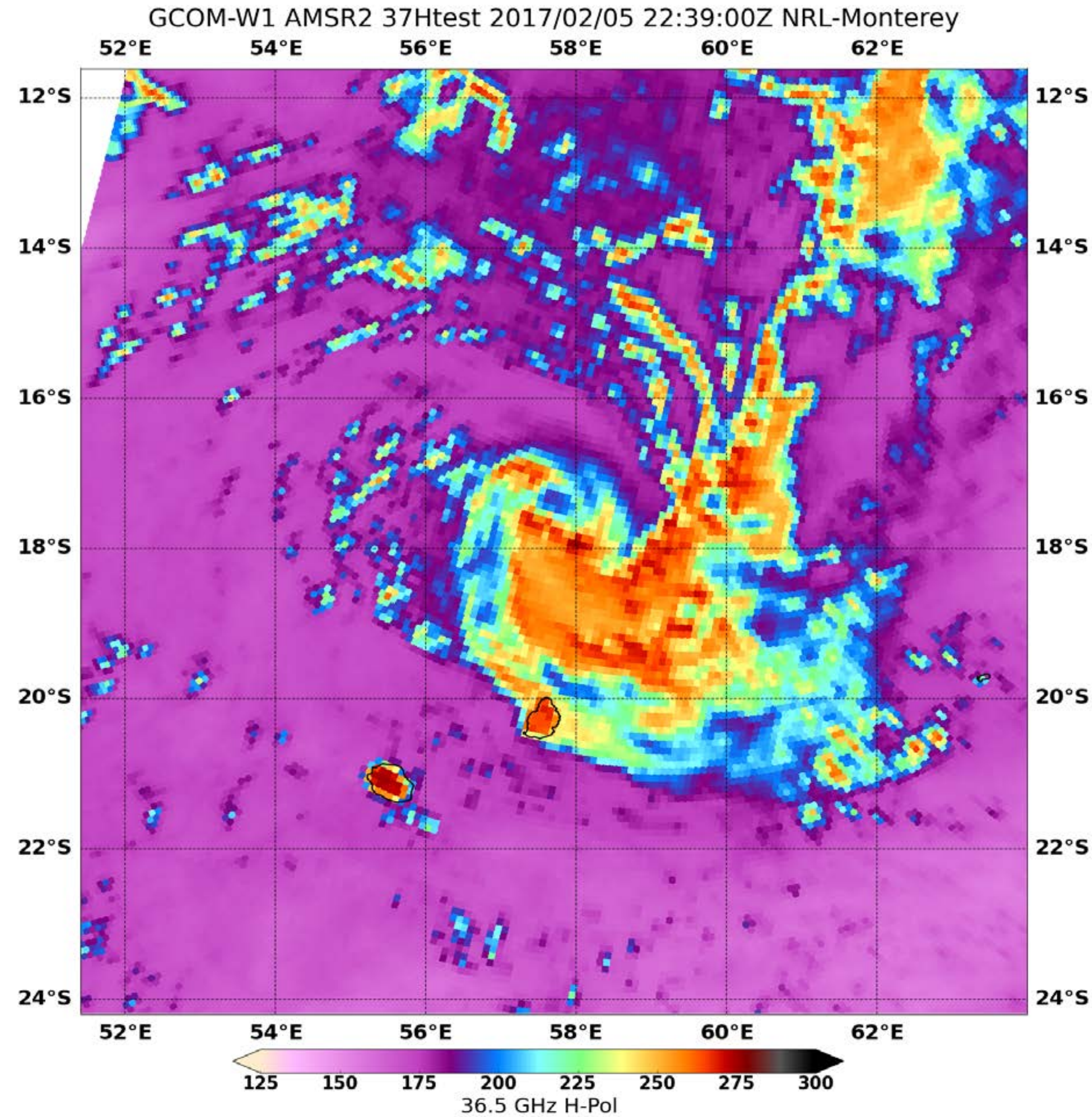

Figure 2: 37 GHz Horizontal Polarization. This updates a currently available product that provides information about lower tropospheric liquid cloud water content. The dynamic range and color distribution is amended to allow better interrogation of low level structure detail. Note that scattering is not mitigated at this frequency, such that intense convective ice will mask low level details (compare to Figure 1).

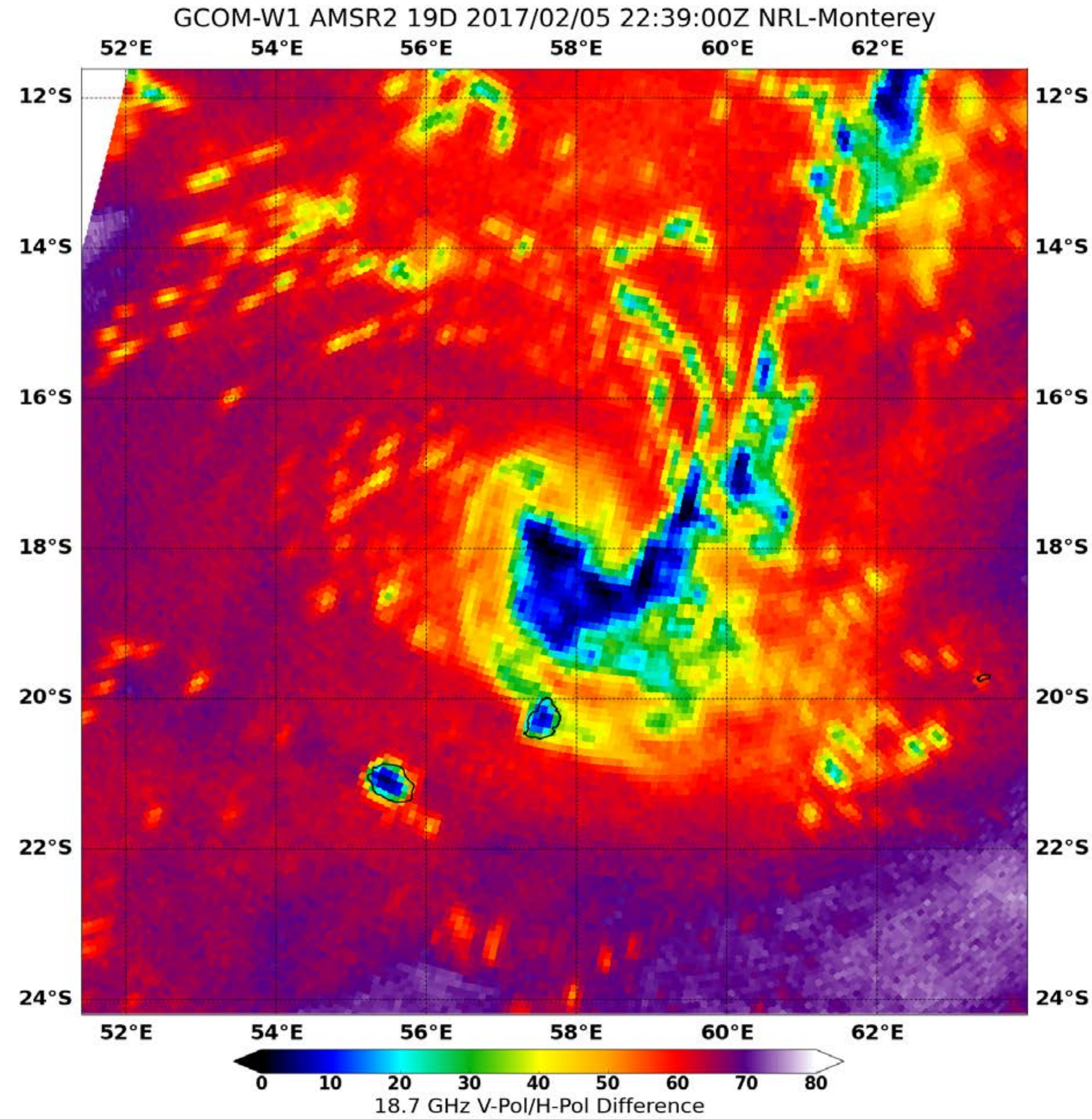

Figure 3: 19 GHz Polarization Difference. This is a new proposed product that takes the difference between the Vertical and Horizontal polarizations at 19 GHz, allowing differential ocean emission to be maximized. This provides an assessment of cloud water content – the closer to zero, the more that surface emission is masked. Unlike 37 GHz, there is much less ambiguity of signal due to scattering by ice. This allows a more robust analysis of low level structure (e.g., the closed eyewall in this example) to infer trends in intensity and structure change. However, also compared to 37 GHz, precipitating cloud is much more prominent, with less detail for non-precipitating liquid cloud. Note that this analysis cannot be provided over land and that SSM/I and SSMIS are too coarse to provide useful structure analysis.

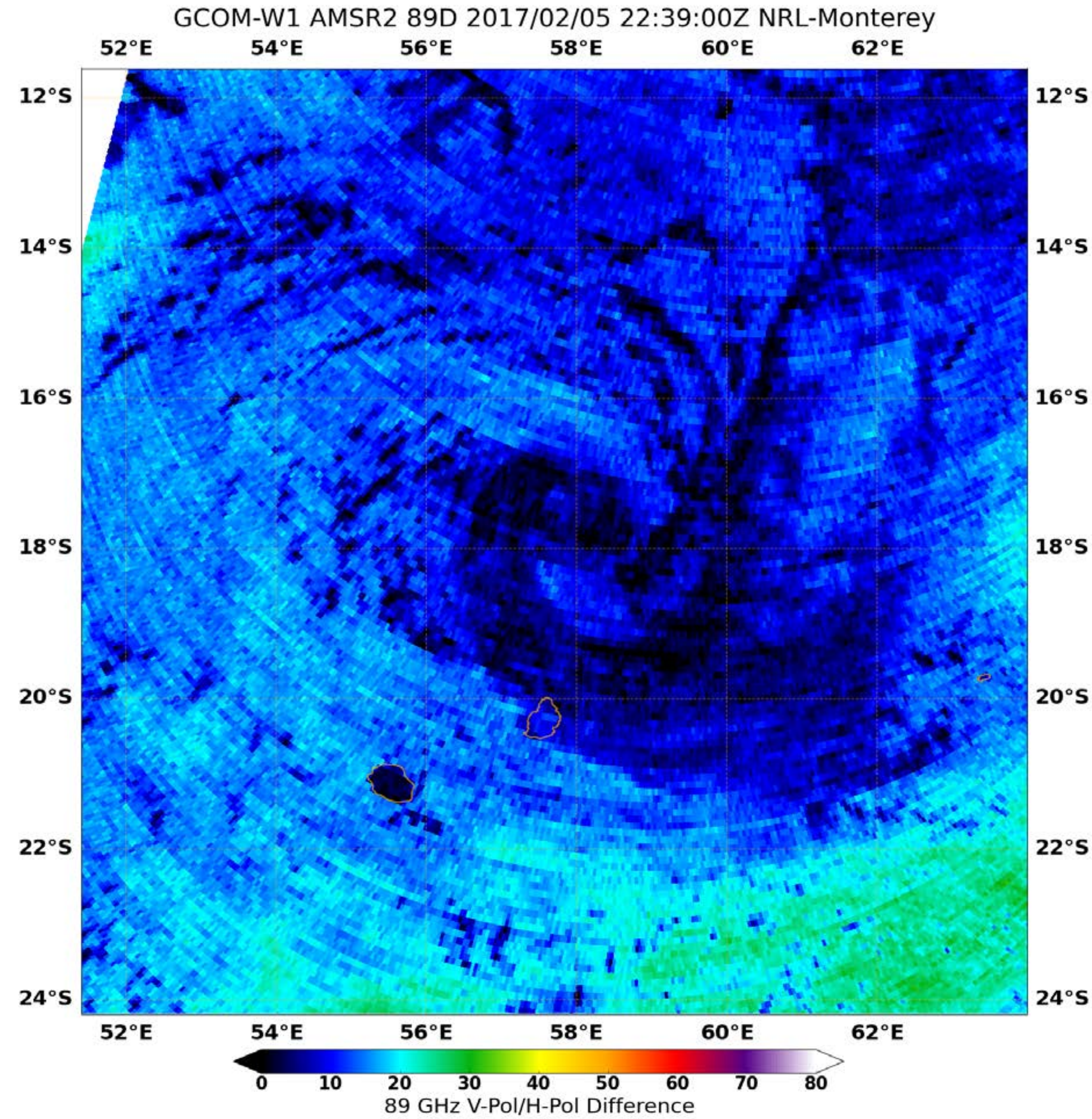

Figure 4: 89 GHz Polarization Difference. This is a new proposed product that takes the difference between the Vertical and Horizontal polarizations at 89 GHz, allowing differential ocean emission to be maximized – the closer to zero, the more that surface emission is masked. While 89 GHz is not strongly sensitive to liquid emission, the higher resolution allows a finer detail of structure compared to 19 and 37 GHz products. Note that ice scattering is still strongly present and not mitigated (Compare to Figure 1), thus is this more useful for center finding and spatial extent rather than structural diagnosis.

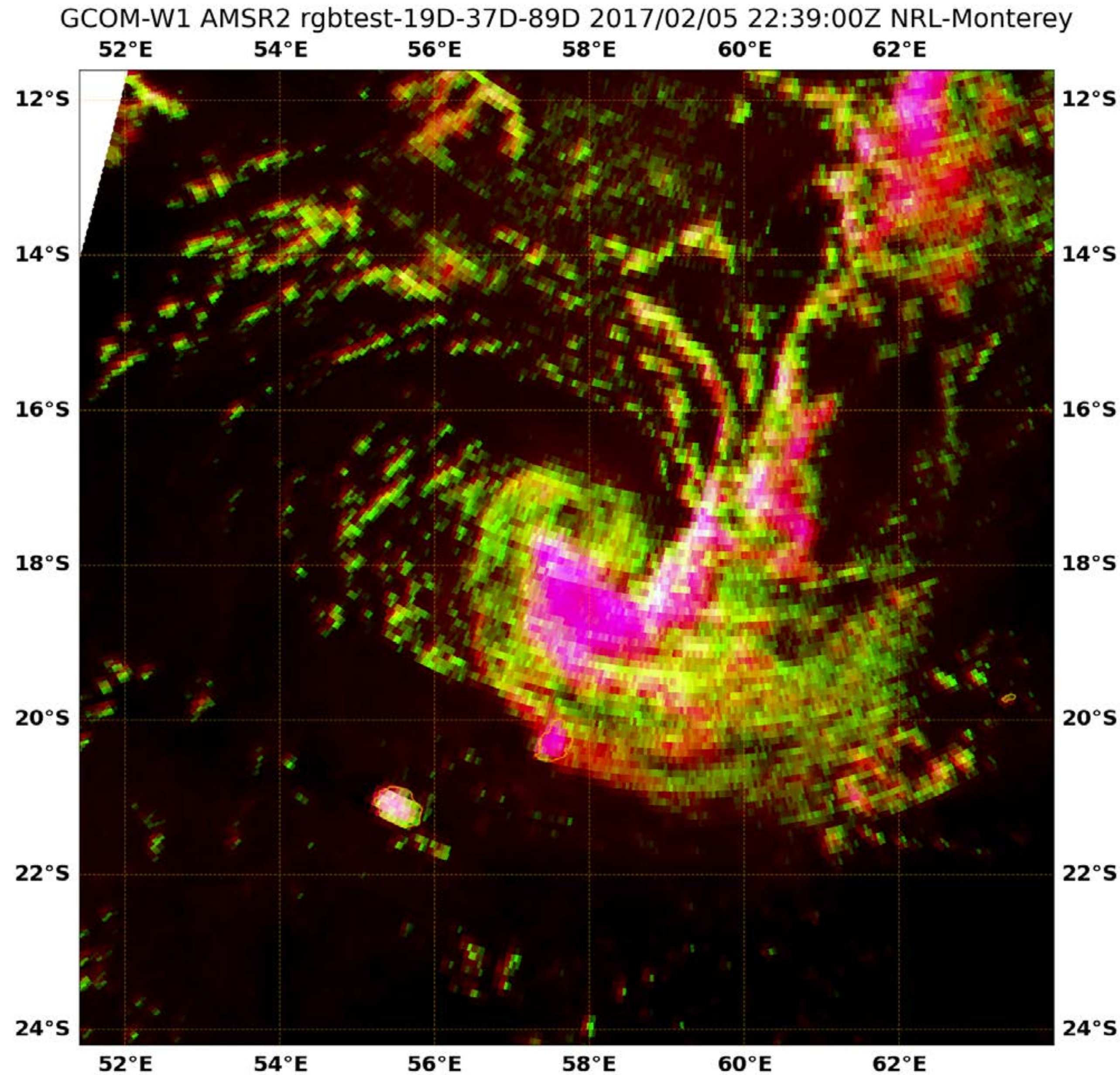

Figure 5: Low Level Structure False Color. This is a new proposed false color product that composites information from the 37GHz Polarization Difference (red gun), 89 GHz Polarization Difference (green gun), and 19 GHz Polarization Difference (blue gun). **Magenta**/**White** represents precipitating convective clouds as well as land surface. **Yellow**/**Green** pixels show lower tropospheric water emission. **Black** pixels represent hydrometeor-free oceanic background. This product is intended to highlight low level center of circulation and banding/inflow for weak and asymmetric storms. Note that the signal to noise ratio is low since 89 GHz emission signal is leveraged/emphasize to maximize spatial resolution/detail.

Publications, Conference Papers, and Presentations

Cossuth, J., R. L. Bankert, K. Richardson, and M. L. Surratt, 2016: Using Multispectral False Color Imaging to Characterize Tropical Cyclone Structure and Environment. Proceedings, 2016 AGU Fall Meeting, San Francisco, CA, Amer. Geophysical. Union, A52E-06. [Available online at https://agu.confex.com/agu/fm16/meetingapp.cgi/Paper/152588]

Bankert, R., K. Richardson, J. Cossuth, A. P. Kuciauskas, M. Surratt, and S. Yang, 2017: Exploiting Next Generation Satellite Data for Environmental and Tropical Cyclone Characterization at the Naval Research Laboratory. Proceedings, 28th Conf. on Weather Analysis and Forecasting, Seattle, WA, Amer. Meteor. Soc., P564. [Available online at https://ams.confex.com/ams/97Annual/webprogram/Paper304403.html]

Cossuth, J., 2017: NRL TC Web and CIMSS Updates for 2017. Joint Tropical Cyclone (TC) Forecasting Program Assembly, Camp Smith, HI, PACOM.

Cossuth, J., R. Bankert, K. Richardson, and M. Surratt, 2017: Passive Microwave Data Exploitation via the NRL Tropical Cyclone Webpage: JHT Project Status. 71st Interdepartmental Hurricane Conference/ Tropical Cyclone Operations and Research Forum, Miami, FL, OFCM/NOAA. [Available online at http://www.ofcm.gov/meetings/TCORF/ihc17/Session_09/9-7%20Cossuth_web.pdf.]

Website(s) or other Internet site(s)

- The Naval Research Laboratory's Tropical Cyclone webpage (NRL TC web; http://www.nrlmry.navy.mil/TC.html) continues to serve as the primary vehicle for near-realtime product demonstration and evaluation.
    - A beta product testing internet link through this web portal has been provided to project POCs for near-realtime development and evaluation. Public release of this link will be provided after evaluation by POCs.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Performers:
Naval Research Laboratory, Marine Meteorology Division, Monterey, CA
Richard Bankert, Richard.Bankert@nrlmry.navy.mil
Josh Cossuth, Joshua.Cossuth@nrlmry.navy.mil
Kim Richardson, Kim.Richardson@nrlmry.navy.mil
Mindy Surratt, Melinda.Surratt@nrlmry.navy.mil

- Project development has evolved in conjunction with collaborative discussions with Joint Hurricane Testbed (JHT) Points of Contact (POCs) at NHC (Avila, Blake, Roberts, and Landsea) and JTWC (Strahl), as well as other interested partners at NHC, JTWC, and CPHC.

4. IMPACT

- Evaluation of impact on meteorological analysis (both in realtime and research frameworks) is being investigated as the project continues.
    - The combined improvements in scientific understanding of satellite radiative properties as well as increased satellite observation capabilities have allowed new channels and products to be considered.
    - Production of processing code in an open source framework able to be transitioned and more quickly updated will help speed and efficiency of product analysis. This also fosters improved collaboration with other research agencies, allowing faster R2O and easier sharing of techniques.
    - Updated and efficient analysis will result more accurate tropical cyclone analysis, thus benefiting society through improved information from operational centers.

5. CHANGES/PROBLEMS

- Interactions with the JHT POCs at NHC, JTWC, and CPHC occurred in November 2016 as well as February and March 2017. Input provided in these meetings resulted in another reassessment of work priorities and reorganization of timeline goals.
    - Further work on Task 3 has been cancelled. Preliminary work in this task has demonstrated an average improvement of center position from microwave imagery of about 0.1 degrees or less. Since the current uncertainty in the best track is this order of magnitude, it would not be operationally beneficial to continue this work. Remaining work time has been moved to continue improvements in Task 4 due to positive feedback from project POCs.
- Timeline modifications:
    - Remaining work milestones for Task 3 will no longer be performed.
- Visualization of JHT demonstration products is currently provided via the internet on a beta project directory. A new and enhanced NRL TC webpage has been developed, but remains on our development server due to logistical issues. We still aim to make this our

primary product evaluation portal, now targeted for the beginning of the 2017 Northern Hemisphere TC season.

- While current work is expected to continue at nominal pace, the details of this project are flexible so as to allow the JHT POCs breadth in pushing the work direction to prioritize certain operational needs. However, at this time, it is not expected that change in goals are needed.

6. SPECIAL REPORTING REQUIREMENTS

- Project components are currently being demonstrated in a real-time NRL environment, along with an archive of produced products for post-season evaluation. More information about testbed research and transition activities can be found in Section 1. An assessment of the project's Readiness Level is provided below.
    - Task 1: Standardized processing infrastructure has been integrated into the near-realtime demonstration environment and is underway.
    - Task 2: Development of reprocessed archive is staged with case studies using processing from Task 1 and Task 4 products being prototyped.
    - Task 3: Preliminary work begun, but initial analysis and discussion of NHC POCs indicates insufficient benefit to operations at this time. Time from Task 3 will be allotted to Task 4, which has demonstrated a large operational benefit.
    - Task 4: Second round of new products and alternate visualizations have been proposed and demonstrated. Final new product set proposed. Evaluation underway.

Task	**Start of Project RL**	**Current Project RL**
1) Standardized realtime python processing	3	8
2) Standardized archive creation	2	6
3) Storm parallax evaluation/correction	2	3
4) New product/color visualization	2	7

Readiness Levels (RLs) are defined below:

TRL 1: Basic research
TRL 2: Applied research
TRL 3: Development of proof-of-concept
TRL 4: Successful validation in experimental environment
TRL 5: Successful validation in relevant environment
TRL 6: Prototyping demonstration in a relevant end-to-end environment
TRL 7: Prototyping demonstration in an operational environment
TRL 8: Actual system completed through test and demonstration in an operational environment
TRL 9: Actual system deployment

- Outline of Test Plans for USWRP-supported Testbed Projects

*I.	What concepts/techniques will be tested? What is the scope of testing (what will be tested, what won't be tested)?*
New satellite passive microwave imager near-realtime processing code in open-source python will be tested, along with currently available and proposed products as shown in Section 2, as shown on the NRL TC demonstration website.

*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?*
Testing of the new code and products was performed for multiple case studies before being demonstrated with active TCs in near-realtime beginning in June 2016. All further testing and refinements are performed on the operationally running code set.

*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?*
Evaluation of the new processing has already begun as of June 2016 and will continue in perpetuity for operational use. New products and sensors are demonstrated and added incrementally to the near-realtime NRL TC web processing system as they are made available.

*IV.	Where will it be tested? Will it be done at the PI location or a NOAA location?*
This work is processed at the NRL TC webpage (as described in Section 2) and made available to JHT POCs (and eventually, pubically).

*V.	Who are the key stakeholders involved in testing (PIs, testbed support staff, testbed manager, forecasters, etc.)? Briefly what are their roles and responsibilities?*
Testing stakeholders include the PI and performers listed in Section 3 (who will continue research and operational testing of code/products) and the NHC/CPHC/JTWC forecasters who can monitor products for near-realtime cases and/or outside of operations to provide iterative feedback for improvements.

*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 additional resources are needed at this time.

*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?*
Products are already being delivered and new functionality will be added as made available. Success will be defined in terms of utility of new products, and ability to alter products such that the forecaster benefits from improving them.

*VIII.	How will testing results be documented? Describe what information will be included in the test results final report.*
An archive of all near-realtime processing is saved as products are created. Both near-realtime product usage and retrospective product analysis and comparison will determine the added utility

of new products compare to previous products, as well as where improvements can be made, as detailed in the final report.

7. BUDGETARY INFORMATION

- The project is currently on budget and progressing according to amended tasking priorities set by meetings with project POCs (see Section 5). No major budget anomalies or deviations from the original planned budget expenditure plan are noted or anticipated.

8. PROJECT OUTCOMES

- Current outcome is the production and near real-time demonstration of new tropical cyclone satellite microwave analysis process and product development, which are being demonstrated to project POCs. Determinations of added value, and possible areas of continued development, are assessed as products are generated and POCs acquire time to evaluate them.

- Performance of project goals and insight into possible improvement is achieved via communication with project POCs. Since this project is still active and being developed, assessment of performance measure achievement are ongoing.