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**Passive Microwave Data Exploitation via the NRL Tropical Cyclone Webpage**

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Project Progress Semiannual Report
Year 2, Final Report

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 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-E/W has been processed and archived in near-realtime since June 2016. SSMIS, SAPHIR, GOES-16 have been added for the 2017 Hurricane Season. 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 99% complete. Components are set-up in processing system. Final completion pending additional 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 90% complete. Full dataset is staged. Cases are available for analysis, but full dataset hosting is pending new website delivery (JTWC FY18 project).
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 99% complete. Two rounds 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. Transition demonstration continues to run in near-realtime through NRL TC web. Section 2 provides examples for the continuing processing of the code for Atlantic hurricanes in September, 2017.

Project Timeline:

Notes: 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. Note that strikethrough text is completed and double-strikethrough red text is cancelled. Last two milestones are ongoing through current/future hurricane seasons. Venue for dataset delivery in Task 2 is still ongoing: new website creation is pending funding from JTWC FY18 project.

*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.
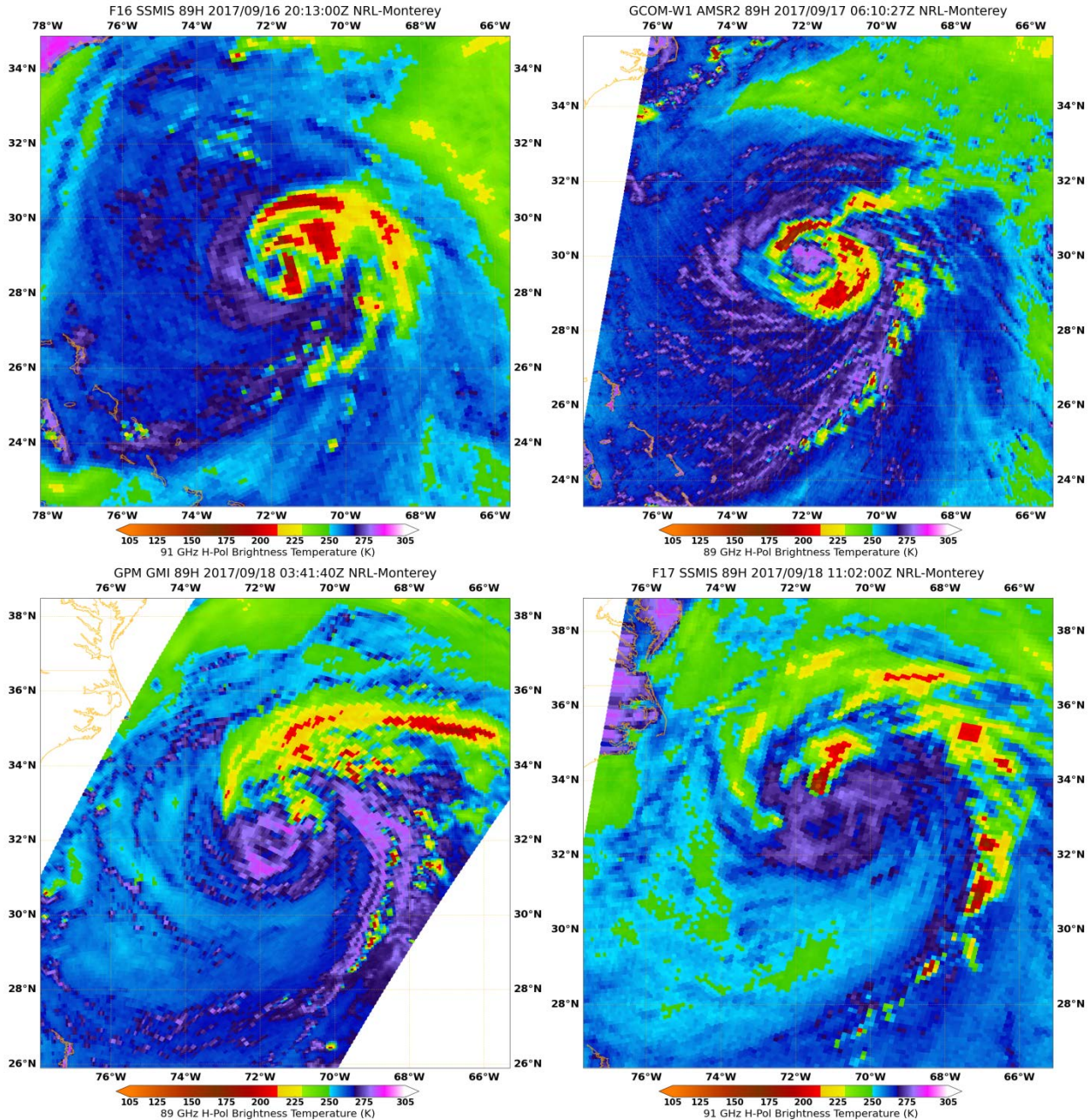

2.   PRODUCTS



Figure 1: Updated 89 GHz horizontal polarization visualization to track the two day evolution of
Hurricane Jose from an elliptical closed eye core to an asymmetric convective comma. Uses F16
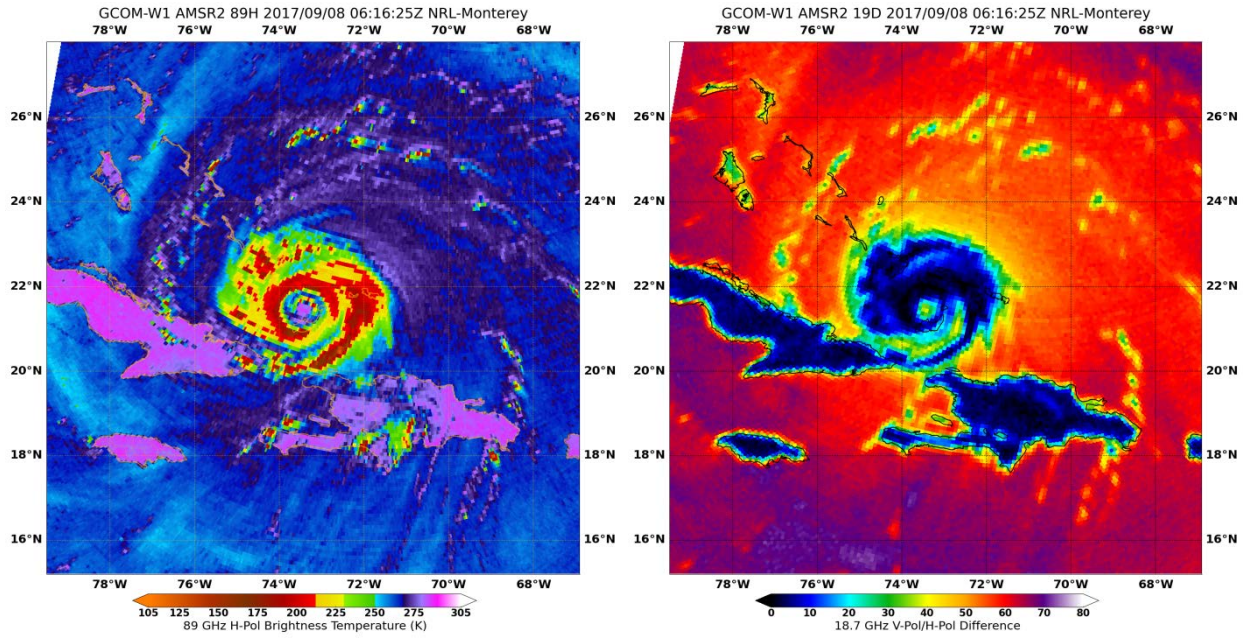SSMIS, AMSR2, GMI, and F17 SSMIS respectively

Figure 2: Updated 89 GHz horizontal polarization (right) and 19 GHz polarization difference (left) for Hurricane Irma as seen by AMSR2. Note the secondary eyewall structure visible in the ice scattering signal at 89 GHz is not present in the 19 GHz lower level liquid water emission.
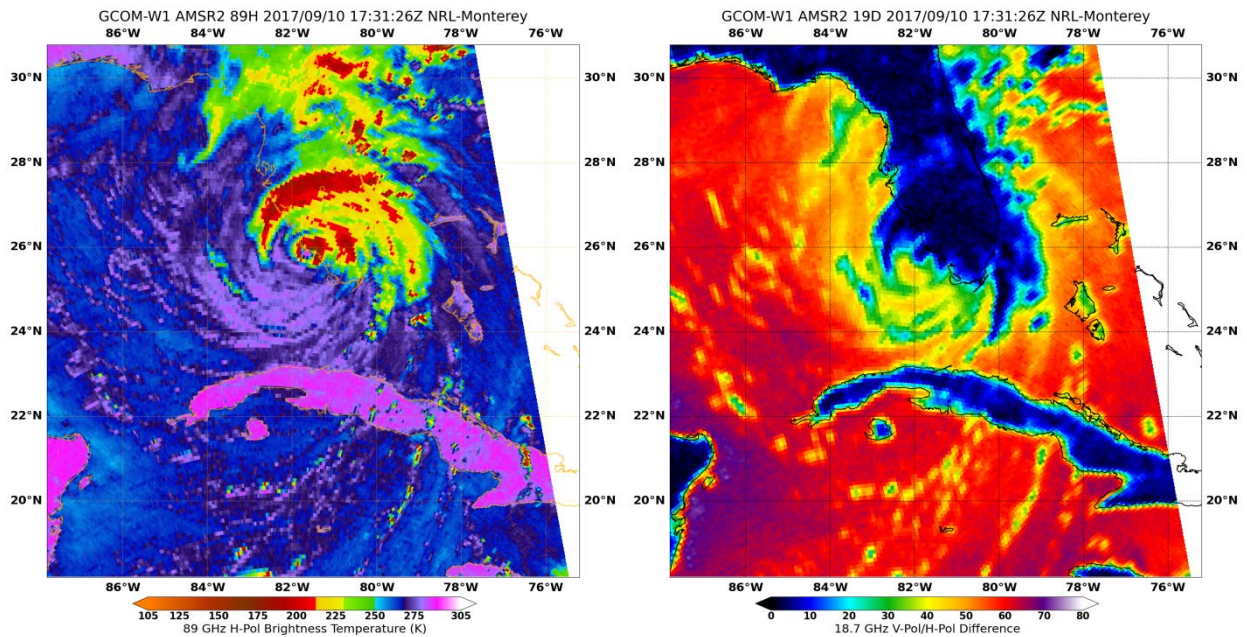


Figure 3: As in Figure 2, except at Florida landfall. Note the closed eye at 89 GHz is open to the south at 19 GHz.
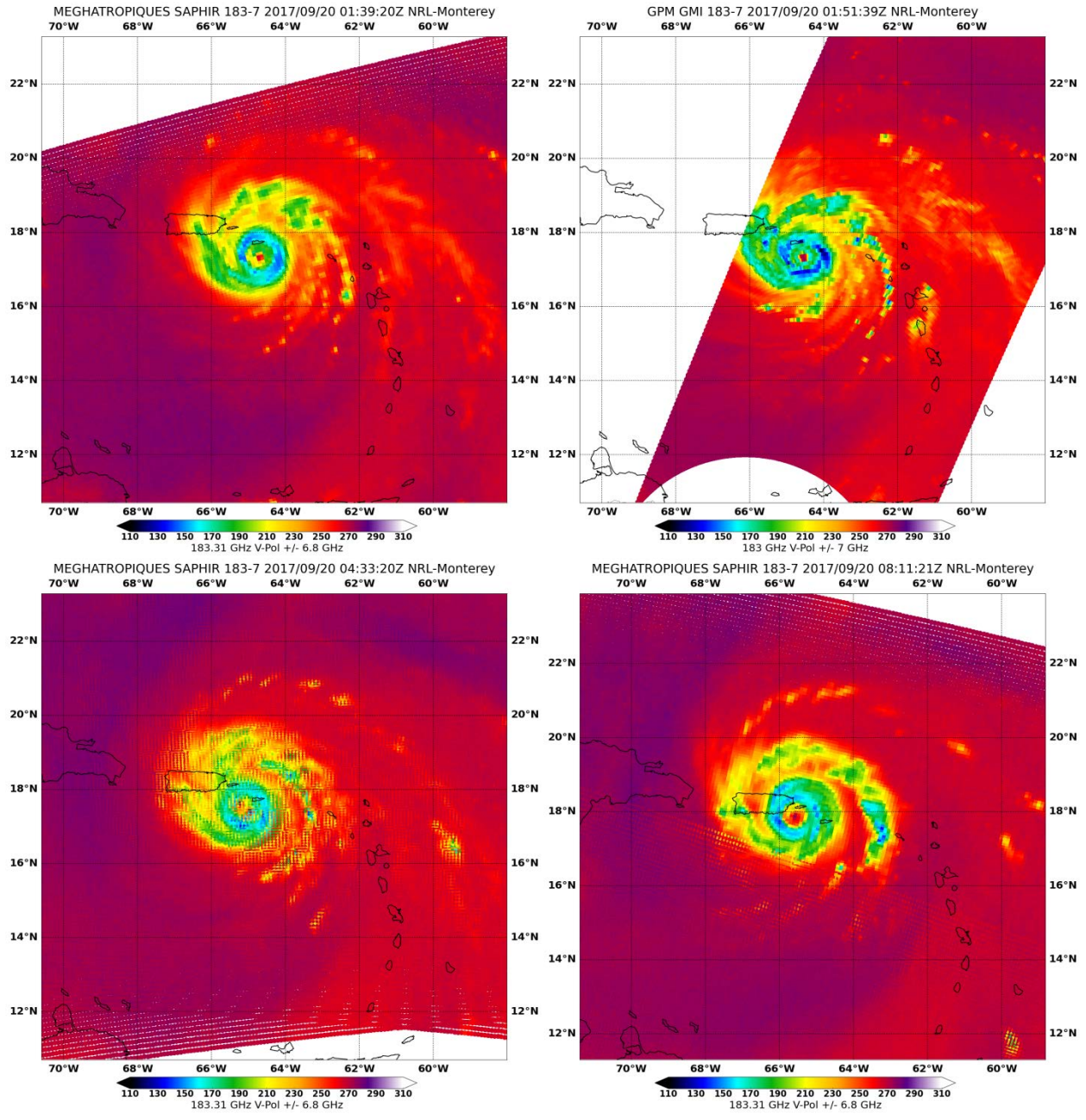
Figure 4: 183 +/- 7 GHz Vertical Polarization. The convective envelope and surrounding mid-level water vapor signal of Hurricane Maria is tracked by GMI and SAPHIR on its approach to Puerto Rico. Note that differences in signal magnitude between sensors are due to resolution and frequency.
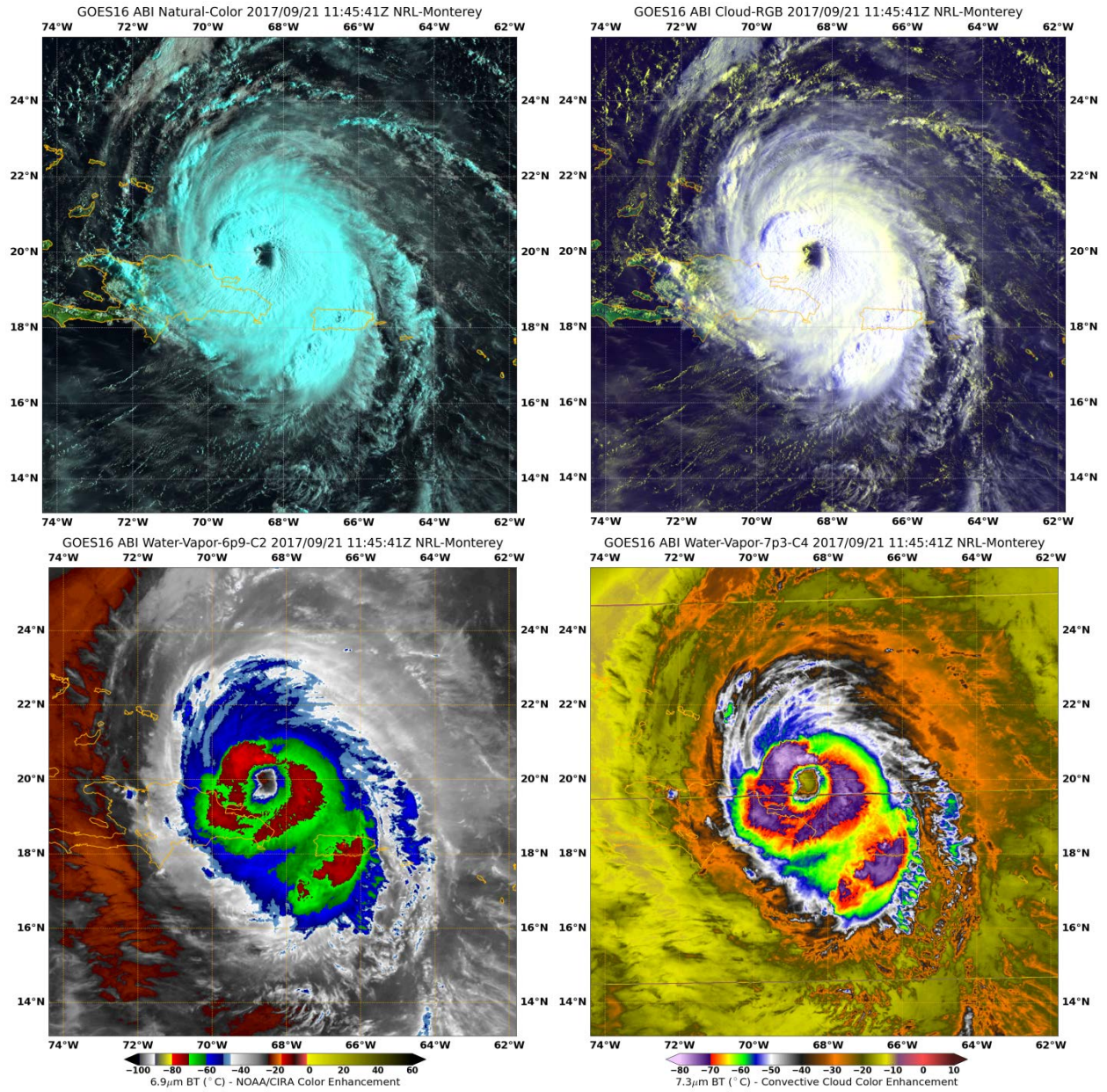
Figure 5: GOES-16 of Hurricane Maria after crossing Puerto Rico. Top left image is the EUMETSAT Natural Color RGB; top right image is the Cloud RGB; bottom left is the mid-level water vapor with NOAA/CIRA color enhancement; bottom right is the low-level water vapor with NRL Convective Cloud enhancement.

*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.
    - o 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.
    - o Demonstration of a new NRL TC website using this processing is pending follow-on maintenance funding.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Performers:
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- 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.
  o 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.
  o 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.
  o 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.
  o 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:
  o Remaining work milestones for Task 3 were canceled.
- 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 and funding issues. An FY18 project

sponsored by JTWC to maintain NRL TC web products will be used to facilitate development of a new website to continue real-time demonstration of this work.

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.
    - o Task 1: Standardized processing infrastructure has been integrated into the near-realtime demonstration environment and is underway.
    - o Task 2: Archive of cases have been processed via procedures from Task 1 and prototyped products via Task 4.
    - o 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.
    - o Task 4: Two rounds of new products and alternate visualizations have been proposed and demonstrated. Final new product set produced.
- Note: Readiness Levels for Tasks 1 and 2 remain at 8 until final delivery mechanism (new website interface) is provided via a follow-on FY18 JTWC maintenance project. Products continue to be produced, demonstrated, and archived online in near-realtime, but product deployment is not considered finished until this new vehicle is provided.

| Task | Start of Project RL | Current Project RL |
|---|---|---|
| 1) Standardized realtime python processing | 3 | 8 |
| 2) Standardized archive creation | 2 | 8 |
| 3) Storm parallax evaluation/correction | 2 | 3 |
| 4) New product/color visualization | 2 | 9 |

*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*

7. BUDGETARY INFORMATION

- The project is ending on budget. 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. 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. As this project closes, assessment of performance and measures achievement will continue beyond this funding vehicle through continued feedback for near-realtime product generation and use.