# AMSR-2 OBSERVATIONS OF HURRICANE DORIAN

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**ABSTRACT**

Operational weather analysis, forecasting, and warning utilize a wide variety of data products and tools, including satellite imagery and derived products. Satellite observations provide information where in-situ measurements are lacking or not readily available. Passive microwave satellite observations are routinely exploited by forecasters at the National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) in the United States (U.S.) to support their weather analysis and forecasts. In this paper, we present examples of hurricane Dorian observations from Advanced Scanning Radiometer –2 (AMSR-2) on the Global Change Observation Mission (GCOM), which is part of the Japanese Aerospace Exploration Agency (JAXA). We compare NOAA AMSR-2 ocean EDR products with storm finding documented within National Hurricane Center Dorian discussions from Aug 24th through September 9th, 2019. NOAA AMSR-2 products are part of NWS forecasting product suite and are regularly used in daily operations. While Microwave Imagery product has been used the most for hurricane forecasting we examine usefulness of other ocean products by following Hurricane Dorian from its formation on August 24th to its demise on September 6th.
.***Index Terms***— Radiometer, High Winds, Hurricanes, GCOM, ASMR2

## 1. INTRODUCTION

Over the past three decades, scientific and operational users have come to rely more on satellite microwave remote sensing to provide vital measurements of geophysical parameters for weather and climate applications. These spaceborne microwave sensors have been highly successful in measuring global synoptic sea surface parameters under all weather, day/night conditions with reasonable spatial and temporal sampling.

Passive microwave satellite observations are routinely exploited by forecasters at the National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) in the United States (U.S.) to support of their weather analysis and forecasts. In this paper, we present examples of ocean measurements and derived products from Advanced Scanning Radiometer –2 (AMSR-2) on the Global Change Observation Mission (GCOM), which is part of the Japanese Aerospace Exploration Agency (JAXA) over Hurricane Dorian that supported critical forecasts. Following tropical discussion products issued by National Hurricane Center for Hurricane Dorian we show how AMSR-2 suite of ocean products can be used to validate issued forecasts and warnings.

## 2. HURRICANE DORIAN

Fig. 1. Hurricane Dorian track and intensity between August 24th through September 7th.
https://www.weather.gov/mhx/Dorian2019

Hurricane Dorian was the fourth named storm, second hurricane, and first major hurricane of the 2019 Atlantic hurricane season. Dorian formed on August 24, 2019 from a tropical wave in the Central Atlantic and gradually strengthened as it moved toward the Lesser Antilles, becoming a hurricane on August 28. Rapid intensification occurred, and on August 31, Dorian became a Category 4 hurricane. On September 1, Dorian reached Category 5 intensity, with maximum sustained winds of 185 mph, and a minimum central pressure of 910 mb (26.87 inHg) while making landfall in Elbow Cay, Bahamas. Dorian made another landfall on Grand Bahama several hours later. The ridge of high pressure steering Dorian westward collapsed on September 2, causing Dorian to stall just north of Grand Bahama for about a day. It is the strongest known tropical system to impact the Bahamas. A combination of cold water upwelling and an eyewall replacement cycle weakened Dorian to a Category 2 hurricane on the next day. On the morning of September 3, Dorian began to move slowly towards the north-northwest. Dorian subsequently completed its eyewall replacement cycle and moved over warmer waters, regaining Category 3 intensity by midnight on September 5. In the early hours of September 6, Dorian weakened to Category 1 intensity as it picked up speed and turned northeast. Dorian would pick up speed and move northeast along the North Carolina coast September 6, moving just south of the Crystal Coast, clipping Cape Lookout and eventually making landfall at Cape Hatteras.

## 2. AMSR-2 INSTRUMENT OVERVIEW

The GCOM program is part of the Japanese Aerospace Exploration Agency's (JAXA) broader commitment toward global and long-term observation of the Earth's environment. The GCOM-W project will have three satellites in series (GCOM-W1 launched in May 2012, GCOM-W2, and GCOM-W3), with 1-year overlap between them for inter-calibration. AMSR-2 was selected as a payload on GCOM-W1 mission to collect observations related to the global water and energy cycle [Overview of GCOM].

AMSR-2 is a passive microwave radiometer system that measures dual polarized [vertical (V-pol) and horizontal (H-pol)] radiances at 6.9, 7.3, 10.65, 18.7, 23.8, 36.5, and 89.0 GHz. It is a sun-synchronous orbiter (local time of ascending node 13:30) that acquires microwave radiances by conically scanning the Earth's surface to obtain measurements along a semicircular pattern in front of the spacecraft. It operates at a nominal earth incidence angle (EIA) of 55º resulting in a wide swath of 1,450 km

### 2.1. NOAA AMSR-2 Ocean Product Suite

NOAA near-real time AMSR-2 Ocean EDR processor produces six ocean EDRs: Calibrated Microwave Brightness Temparatures for all AMSR-2 frequencies, Total Precipitable Water (TPW), Cloud Liquid Water (CLW), Rain Rate (RR), Sea Surface Temperature (SST) and Wind Speed (WS). The inferred parameters were validated with other numerical model, satellite products and in-situ measurements to show that they meet measurement requirements [1]. Beside these products we also produce two derived products SST anomaly and TWP percentage normal.

### 2.2. AMSR-2 Calibrated Microwave Brightness Temperature Products

Perhaps the best-known and most used product from microwave radiometer sensors, when it comes to forecasting Tropical Cyclones, is Microwave Brightness Temperature (MBT) product. This product is used to assess the current structure of the tropical cyclone, rain band patterns and detect cyclones center position. On August 24th, NHC used AMSR-2 Tb's to assess cyclones position, size and help estimate its intensity. At that point NHC upgraded storm from tropical depression state to tropical cyclone Dorian: "A 1705Z AMSR-2 overpass showed the development of tightly curved bands and a 10 mile wide eye-like feature. In addition, a 1935Z SSMI/S microwave pass revealed a tightly curved band in 91 GHz data that wrapped almost 75 percent around the center. Based on the much improved inner-core structure and 33-kt wind vectors in an earlier ASCAT-B pass, the depression has been upgraded to Tropical Storm Dorian on this advisory."

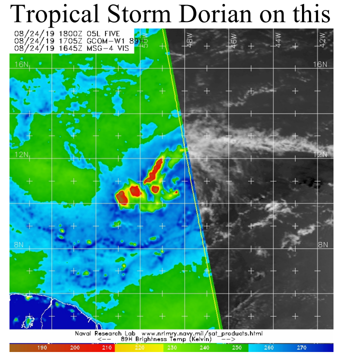

Fig 2. AMSR-2 89Ghz Tb over Tropical Cyclone Dorian on Aug 24th, 2019 at 17:05Z. Development of tight rain bands as well as small 10mi eye is visible on this imagery produced by Naval Research Laboratory using NOAA AMSR-2 calibrated Tb's product

### 2.3. AMSR-2 TPW, TPW Anomaly and Rain Rate products

Microwave TPW product is part of base NOAA AMSR-2 Ocean suite products. TPW is the source of atmospheric convection and cloud formation and it plays a crucial role in precipitation processes. The TPW algorithm makes use of Tb measurements from 4 AMSR2 channels (23 GHz, and 36 GHz channels, horizontally and vertically polarized [H- & V-pol]). The algorithm is statistical based that consists of multiple steps to infer TPW [2].

TPW anomaly product help forecasters compare the present distribution of the amount of TPW in a given region with a climatological normal produced from the NASA Water Vapor Project that used LEO microwave-derived TPW from satellites between 1988 and 1999. The forecaster's attention is drawn to percentage values of much below (less than 25% below normal), below (between 25 and 90% of normal), near normal (90 to 110% of normal); above (110 to 200% of normal) and much above normal (greater than 200% of normal). High percentage values indicate a strong potential for heavy precipitation and flooding, especially when precipitable water is released either by convection, orography or large-scale lifting initiated by an upper level jet, diffluence and/or a baroclinic disturbance (a tight upper trough, vorticity advection).

In the first several days of Dorian's development cyclones intensity forecast was difficult due to "battle between an increasingly conducive oceanic and shear environment versus plentiful dry air in the mid-levels of the atmosphere" (NHC discussion Aug 5th, 2019 5am). Fig 3 shows ASMR-2 derived TPW (left) and TPW anomaly (right) products from pass that went over the storm on Aug 25th, 2019 around 5:22UTC. While microwave TPW represents the water vapor levels in the lower part of the atmosphere it is still indicative of the environment encountered by the TC on the larger scale. Large area of 35-45mm$^2$, TPW values are observed especially West to South-West from the storm. Corresponding TWP anomaly product is showing percentage normal ranges between 50-80%, which was bellow normal for the area at that time of the year. Plots on Fig 4 show that TPW was staying in the bellow normal ranges during next two days along Dorian's path on Aug 26th and 27th.

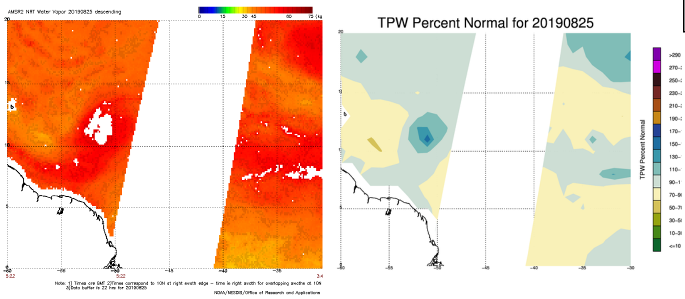


Fig 3 AMSR-2 TPW (left( and TPW anomaly (right) products depicting drier air surrounding Dorian on Aug 25th, 2019

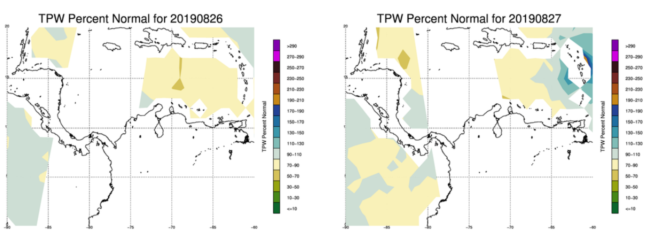


Fig 4. TPW anomaly from AMSR-2 measurements on Aug 26th and 27th in front of Dorian's path depicting dryer then normal air for the area at this time of the year

NHC Dorian discussions on Aug 25th on 11am states that while vertical wind shear is decreasing over Dorian, the cyclone still appears to be ingesting dry air based on the ragged convective pattern. Some dry air entrainment is expected to continue for the next few days, and based on this the new intensity forecast again calls for gradual strengthening through 72 h. Several hours later Dorian still appeared to be ingesting dry air based on the somewhat ragged convective pattern as shown in AMSR-2 rain rate product on Fig 5.

NHC discussion continue to point to changes in the storm patterns: "Aug 26th 5pm Dorian's convective pattern has waxed and waned this afternoon due to intrusions of dry mid-level air while the upper-level outflow pattern has continued to expand and become more symmetrical". This pattern can be seen on Fig 6 showing AMSR-2 MBT and rain rate product corresponding to NHC discussion

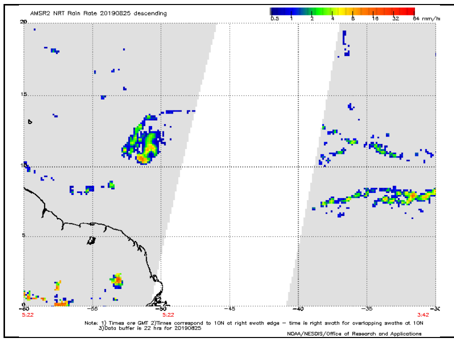

Fig 5. ASMR-2 Rain rate product showing ragged convective pattern on Aug 25th, 2019 during 5:22UTC early morning pass.

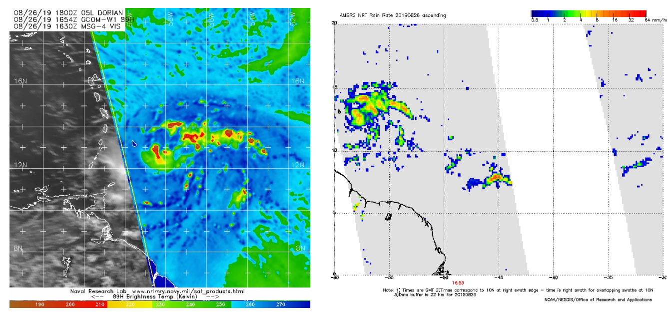

Fig 6. AMSR-2 Tb and rain rate product are showing shows a persistent low-level eye-like feature and ragged rain patterns on Aug 26th, at 16:53UTC

### 2.4. AMSR-2 Sea Surface Wind Product

Among all sea surface parameters, the sea surface winds (SSW) is considered the largest source of momentum for ocean surface. They affect the full range of ocean movement from individual surface waves to complete current systems. They also regulate the interaction between the atmosphere and the ocean via modulating the air-sea exchanges of heat, moisture, and gases. Despite all the success spaceborne microwave sensors have achieved, their SSW estimates in extreme weather events have limitations, which impede their performance and accuracy. Many of these limitations can be attributed to uncertainties in the sensors' measurements due to their characteristics (e.g. calibration and spatial resolution), and the effect of the intervening atmosphere on the propagating electromagnetic (EM) signal (e.g. precipitation) and how this was handled in the retrieval algorithms used in the inversion process. NOAA's AMSr-2 SSW product is derived through multiple regression schemes in which all microwave frequencies except 89GHz were used; the highest weight is given to the lower frequency channels in order to maximize surface signal detection in the precipitation [2]. While SSW product is accompanied with quality control flag that questions all retrievals in the precipitation careful examination of the data has shown that majority of high wind retrievals within TC core are still very much valid and useful especially for 50 and 64kt wind radii determination. Between August 25th and September 7th AMSR-2 observed Dorian 20 times.

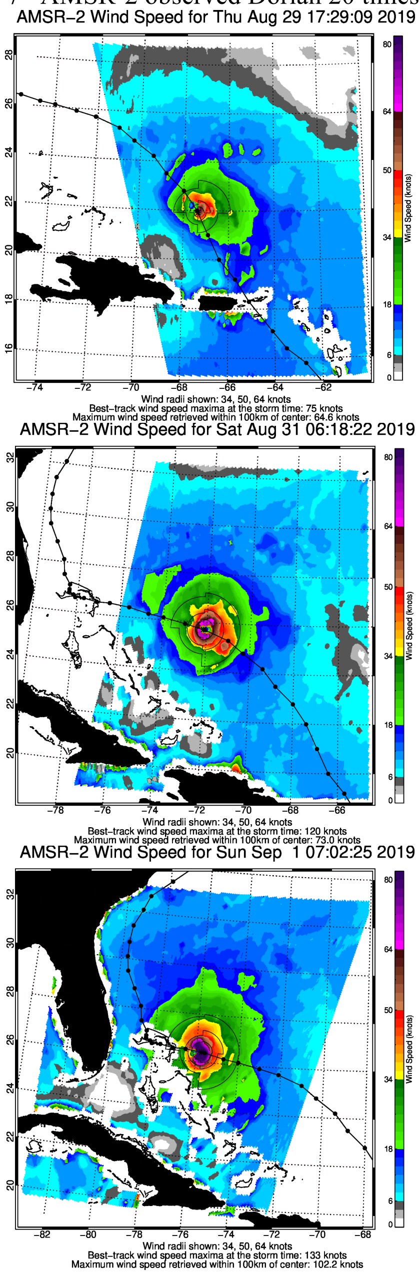


Fig 7. Rapid intensification of Dorian depicted in the wind field AMSR-2 product from Aug 29th through Sep 1st when Dorian has reached category 5 strength.

### 2.4. AMSR-2 SST and SST Anomaly products

Sea surface temperature (SST) is an essential component to understand air-sea interaction and climate variability. It plays a fundamental role in the energy and moisture exchange between oceans and the atmosphere. Moreover, SST influences the development of extreme wind events such as hurricanes and tropical cyclones. NOAA AMSR-2 SST product is based on lower frequency microwave Tb's as described in [3]. We have validated the retrieved AMSR-2 SST values, models (Reynolds' SST), buoys, and AXBTs. Results show that the retrieved SSTs are in excellent agreement with other measurement with a mean error of 0.2°C, and an RMS error of 0.6

Microwave SST's have been consistently used in blended SST products however they are showing increase utility for routine marine forecasts. Beside SST product we are producing SST anomaly calculated using the climatology from [4] An example of cooling SST's left behind Dorian has been depicted on Fig 8 by AMSR-2 SST surface anomaly product on September 6th, 2019.

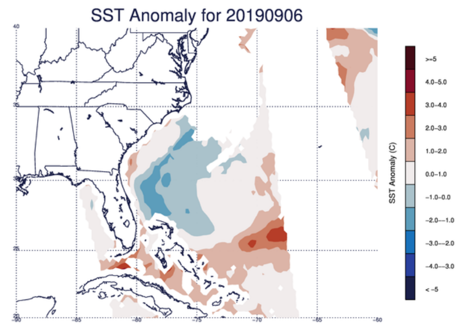


Fig 8 Cooling left by Dorian detected by ASMR-2 SST anomaly product

## 3. CONCLUSION

While ocean observations from passive microwave radiometers have been used for over four decades to document changes in the lower atmosphere and surface for both climatological purposes and marine warning and forecasting within NOAA NWS for TC observation mainly microwave brightness temperature products from 89 and 36Ghz have been used. In this paper following hurricane Dorian we show how other products from NOAA AMSR-2 ocean suite can be utilized to validate current conditions and help infer future storm development. We will present validation of AMSR-2 wind speed product within Dorian's core using aircraft SFMR measurements coincident with AMSR-2 passes as well as give additional examples of AMSR-2 products during Dorian's lifetime.

## 4. REFERENCES

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