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Satellite tools to monitor and predict Hurricane Sandy (2012): Current and emerging products

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A B S T R A C T

Hurricane Sandy – a tropical cyclone that transitioned into an extratropical cyclone near the time of landfall along the east coast of the United States – caused historic damage in many regions which rarely receive such a direct hit from a storm of this magnitude, including many of the large metropolitan areas along the U.S. eastern seaboard. Specifically, Sandy generated record low-pressure, a large wind field with corresponding storm surge and copious amounts of precipitation in some areas, including record snowfall in mountainous regions. Sandy presented several forecast challenges to the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS). Satellites played an integral role in the analysis and forecast of Sandy's track and intensity. The NOAA National Hurricane Center, Ocean Prediction Center, and Weather Prediction Center all relied on information from satellites to make critical warning decisions using various satellite products that assist with diagnosing tropical cyclone intensity, surface winds over the ocean, and heavy precipitation. All of the skillful global forecast models used satellite data for initiation to better forecast the track and intensity of Sandy. As part of the Geostationary Operational Environmental Satellite — R-series (GOES-R) and Joint Polar Satellite System (JPSS) Proving Ground activities, new satellite products were available to forecasters at these national centers in experimental form to assist with observing this unique, high impact event. This paper will demonstrate how the current satellite products assisted NOAA forecasters during Sandy and introduce some new satellite products that could be used to analyze and predict future high impact weather systems.

1. Introduction

From a meteorological perspective, Hurricane Sandy (henceforth simply referred to as Sandy) was a "perfect storm". The convergence of several synoptic features phased together along the U.S. Mid-Atlantic coastline to create record low-pressure, a huge wind field with corresponding storm surge, and copious amounts of precipitation in some areas, including record snowfall. Sandy caused over 250 deaths and upwards of $70 billion in damage and economic loss during its trek from the Caribbean northward to the mid-Atlantic and Northeastern United States (Blake et al., 2013).

Satellite data are utilized in three primary ways for tropical cyclone (TC) analysis and prediction. First, they are used for situational awareness. For example, water vapor imagery loops from geostationary satellites are often used subjectively to assess the flow in the cyclone environment. Second, quantitative satellite products are used for storm analysis, such as satellite-based cyclone position and intensity estimates and sea surface temperature analyses. Third, satellite data are assimilated into numerical forecast models. All three of these applications were heavily utilized in Sandy. For example, numerical weather forecasts were generally very good, with models such as the National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Prediction's (NCEP) Global Forecast System (GFS) and

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the European Centre for Medium-Range Weather Forecasts' (ECMWF) global model forecasting Sandy's intensity and track several days in advance. Satellite products aided the National Hurricane Center (NHC) with monitoring TC position and intensity, and column water vapor and precipitation estimates helped in assessing the location, duration and trends of the heaviest precipitation, especially when Sandy was offshore and out of radar range. Other satellite products such as sea surface temperature, oceanic heat content, and ocean surface vector winds also provided vital information to the forecasters. This paper illustrates many of the products that were available during Sandy and introduces proxy products demonstrating capabilities of future satellite missions.

Section 2 summarizes the life cycle of Sandy, Section 3 describes how satellite data and products contributed to the operational analysis and forecasting of Sandy's track, intensity, structure and precipitation, and Section 4 presents some emerging satellite capabilities. A summary and conclusions are presented in Section 5.

2. The life cycle of Sandy

Sandy's evolution is described in detail in the NHC Tropical Cyclone Report for this cyclone (Blake et al., 2013). Fig. 1 shows the track and intensity of Hurricane Sandy. Sandy originated from a tropical wave that left the west coast of Africa on 11 October. By 1200 UTC on 22 October, a surface circulation and banding features became organized enough about 560 km south-southwest of Kingston, Jamaica to be classified by the NHC as a tropical depression.

The depression rapidly organized in the next 6 h and was classified as Tropical Storm Sandy around 1800 UTC on 22 October. Steady strengthening occurred over the next 42 h and Sandy became a 36 m s^{-1} (70-kt) hurricane at the 1200 UTC NHC advisory on 24 October just before its first landfall in eastern Jamaica. After crossing Jamaica, Sandy continued to strengthen up until a second landfall in eastern Cuba as a 52 m s^{-1} (100-kt), Category 3 hurricane at 0525 UTC on 25 October. Sandy maintained hurricane intensity through the central Bahamas, though it did weaken after traversing the rugged terrain in Eastern Cuba and encountering southwesterly shear associated with an upper-level low to the southwest. Following this interaction, Sandy took on a hybrid-like structure from 26 October to 27 October as the storm encountered dry air and increased vertical wind shear, briefly losing its hurricane status in the process (0000 UTC 27 October to 1200 UTC 27 October). Early on 28 October 2012, the hurricane's outflow wrapped around the southwest quadrant and the effects of the upper-low diminished. This allowed Sandy to re-intensify over the warm Gulf Stream waters east of North Carolina.

Late on 28 October 2012, the final in a series of shortwaves dropped from the Upper Plains of the U.S. toward the Carolinas and started to cut off an upper-low from the jetstream just west of Sandy. This allowed the upper-level low to capture Sandy early on 29 October 2012, resulting in a west-northwest motion toward the Mid-Atlantic coastline. Sandy was considered a hurricane up until the 2100 UTC 29 October 2012 NHC advisory when the storm merged with the upper-level low and transitioned into an extratropical storm (re-classified as post tropical — a storm that was once tropical and has since acquired non-tropical characteristics), including a warm seclusion structure surrounded by much colder air. Sandy continued west and made its final landfall in southern New Jersey with winds along the coast at hurricane strength (70-kt) with stronger wind gusts experienced well north of the landfall point. After landfall, Sandy moved into south-central Pennsylvania and fully occluded on 30 October 2012, slowly spinning down before being picked up by an upstream shortwave trough around 1 November 2012.

3. Satellite contributions to the analysis and forecasting of Sandy

The NHC provides a number of text and graphical products for tropical cyclones in the Atlantic and north East Pacific tropical cyclone basins. Details are available from www.nhc.noaa.gov. The primary forecast parameters are the latitude and longitude of the TC center, and maximum sustained surface winds, which are provided out to 120 h. Storm structure is represented by the radii of 34, 50 and 64 kt winds in four quadrants relative to the storm center (NE, SE, SW and NW). The 34 and 50 kt wind radii are forecasted out to 72 h and the 64 kt radii out to 36 h. The cyclone type (tropical, subtropical, extra-

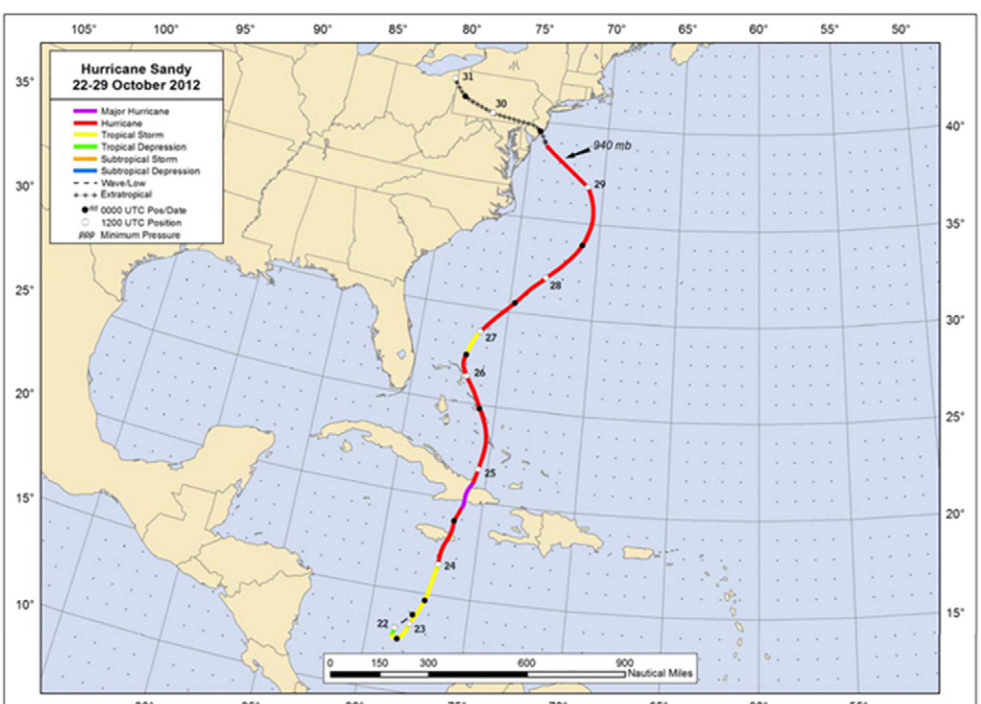

Fig. 1. The NHC best track and intensity of Hurricane Sandy.
From Blake et al., 2013 www.nhc.noaa.gov.