Storm surge observed by Chinese HY-2A satellite radar altimetry

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Abstract. HY-2A is the first Chinese ocean dynamic environment monitoring satellite, which was launched in August 2011. The satellite repeats its ground track every 14 days. It plays an important role in global monitoring of sea surface winds (especially extreme winds like typhoons and hurricanes), ocean waves, currents, eddies, and extreme events like storm surges by using its four major payloads, i.e. radar altimetry, microwave scatterometer, scanning microwave radiometer and calibration microwave radiometer. The HY-2A data are obtained from China’s National Satellite Ocean Application Service (NSOAS). We use 1 s along-track data with a nominal spatial resolution of about 7 km. For example, a storm surge induced by tropical cyclone Funso in the Southwest Indian Ocean near Mozambique in January 2012 is observed by HY-2A satellite altimetry. The storm surge magnitude is estimated to be 0.49 m and the cross-shelf e-folding decay scale to be 92 km. The present study shows that the HY-2A satellite altimetry is a useful tool for monitoring storm surges and their impacts in the Indian Ocean.

1. Introduction

Storm surge induced by an intense tropical cyclone (or typhoon/hurricane) is often the greatest threat to life and property of coastal areas. Intense Tropical Cyclone Funso (Category 4) was a powerful tropical cyclone which produced flooding in Mozambique and Malawi in January 2012 (figure 1). It is the first storm to affect Mozambique since Jokwe in 2008.

Satellite altimetry is a useful tool for observing and studying storm surge features. Scharroo et al. [2005] reported for the first time the altimetry observation of a storm surge in the Gulf of Mexico associated with Hurricane Katrina. Han et al. [2012] demonstrated the utility of satellite altimetry in observing and studying storm surge features and understanding dynamic mechanisms off Newfoundland and in the Gulf of Mexico. Lillibridge et al. [2013] and Chen et al. [2014] analyzed the HY-2A captured storm surge (with a surge magnitude of about 1.83 m at the coast and a cross-shelf decaying scale of 68 km) which was induced by Hurricane Sandy off New York. They pointed out that the along-track surge profile was approximately linear over the continental shelf. One of the key components in the e-Surge initiative is to integrate satellite altimetry and other space observations into monitoring and forecasting of storm surges.

2. Data and Method

2.1. HY-2A Data
The HY-2A sea surface height data and sea surface wind field data are obtained from China’s National Satellite Ocean Application Service (NSOAS). The satellite repeats its ground track within ±1 km every 14 days.

2.2. Other Data
We also use 3-hourly pressure fields from the North American Regional Reanalysis (NARR) project. The NARR is a high-resolution extension of the National Centers for Environmental Prediction (NCEP) Global Reanalysis over the North American Region.

3. Method
We use 1 s along-track data with a nominal spatial resolution of about 7 km. The altimetry data are corrected for wet tropospheric (based on the onboard calibration microwave radiometer) and ionospheric path delays, and for ocean, solid earth and pole tides [NSOAS, 2011]. The inverse barometric correction is not applied, unless specified otherwise. During Cycle 9, HY-2A flew over Quelimane, Mozambique at 15:32, 25 January 2012 UTC. Along-track data from 5 October 2011 to 26 December 2012 UTC are processed for track 127 from 18° to 30° S. There are a total of 32 cycles of good data.

Figure 1. Map showing the study area between Mozambique and Madagascar, and sea surface wind fields retrieved from microwave scatterometer on board HY-2A at 15:32, 25 Jan 2012, UTC. Intense tropical cyclone Funso track and locations at specific time are shown as black lines and dots. Red line is the HY-2A satellite ground track.
Dry tropospheric delays are corrected based on the sea level pressure field described in section 2.2. Ocean wave effects are not corrected. To suppress range noise in the HY-2A altimetry data, we applied a 50 km Butterworth low-pass filter, following Lillibridge et al. [2013]. The data from the other 31 cycles are linearly interpolated onto the data locations (based on latitude) of Cycle 9. Mean sea level for the satellite data period from 5 October 2011 to 26 December 2012 UTC is then calculated by averaging sea levels of all cycles at each location. Finally sea level anomalies are obtained by subtracting the mean sea level from sea levels of each cycle.

Continental shelf waves, with its sea surface height decaying exponentially across the shelf, could be generated by passing hurricanes [LeBlond and Mysak, 1978]. Thus, we fit the altimetry along-track sea surface height anomalies corrected for the inverse barometric effect at Cycle 9 to an exponential function with the maximum value at the coast. It is important to remove the inverse barometric effect before the exponential fitting so that shelf wave properties can be retrieved better. The inverse barometric effect is determined based on the atmospheric pressure data. The coastal surge is then determined by adding the fitted value to the inverse barometric effect at the coast. Different offshore extents are considered. The sea level anomalies corrected for the inverse barometric effect are expressed as

\[ S(x) = S_0 + S_1 \exp(-x/L) \]  

(1)

where \( S \) is the sea level anomalies, \( x \) is the coordinate in the cross-shelf direction (positive offshore) with the origin at the coast, and \( S_0, S_1, \) and \( L \) are constants to be determined. \( L \) is the cross-shelf e-folding scale associated with a continental shelf wave. The fitted coastal value is calculated as

\[ S(0) = S_0 + S_1 \]  

(2)

The phase speed \( c \) for the continental shelf wave can be obtained as

\[ c = L f \]  

(3)

where \( f \) is the Coriolis frequency.

Finally the total surge magnitude can be determined by adding the inverse barometric effect to \( S(0) \).

4. Results and Conclusions

For the impacts of storm surge, we will focus on the satellite-derived sea surface height anomalies relative to the mean sea surface profile estimated using HY-2A data. The storm surge magnitude at the location closest to the coast (about 6.2 km away) is 0.49 m from satellite data (figure 2).
shore decay scale is estimated to be 92 km on average, with a standard deviation of 20.5 km with respect to fitting segments (table 1). In comparison, the shelf width of Mozambique Channel is about 200 km. The phase speed based on the altimetry data is 4.34 m/s from equation (3). The extrapolated surge magnitude corrected for the inverse barometer effect is, on average, 0.51 m at the coast, with a standard deviation of 0.00 m with respect to fitting segments (table 1). Therefore, the total coastal surge magnitude with the inverse barometer effect included is 0.43 from HY-2A. This estimated surge magnitude is also subject to the uncertainty associated with the exponential fitting, which is calculated as the root-mean-square (RMS) differences between fitted values and altimetry data. The RMS difference is 0.00 for each segment (table 1). The storm surge magnitude is estimated to be 0.49 m and the cross-shelf e-folding decay scale to be 92 km. It shows that the HY-2A satellite altimetry is a useful tool for monitoring storm surges and their impacts in the Indian Ocean.

![Figure 2](image)

Figure 2. Altimetry-derived sea surface height anomalies along Track 127 across part of Mozambique Strait, observed by HY-2A. Blue: Cycle 9, shortly before the landfall of Tropical Cyclone Funso. Red: Cycle 8. Black: Cycle 10. The sea surface height anomalies corrected for the inverse barometric effect (magenta) are also shown for Cycle 9, along with fitted values (green crosses) by the exponential fitting to the anomalies over 18.77°S - 20.36°S.

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