Mapping Radial Ocean Currents During Hurricane Maria from Synthetic Aperture Radar Doppler Measurements

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Abstract

In this study, for the first time, we attempt to retrieve radial current velocities from Sentinel-1A SAR Doppler shifts acquired over Hurricane Maria. The retrieved radial current velocities are compared with collocated high-frequency radar measurements, and show a bias of 0.02 m/s and a root-mean-square error (RMSE) of 0.19 m/s. These results suggest that there is a potential to retrieve reliable radial current velocities under high wind conditions, as the contributions of non-geophysical terms and sea state to the Doppler shifts can be accurately estimated and removed.

Index Terms—**Doppler shift, hurricane, ocean surface current, synthetic aperture radar (SAR)**

Introduction

- ❑ Spaceborne synthetic aperture radar (SAR) Doppler shift measurements have been used to remote sensing of ocean surface currents under low and moderate winds.
- ❑ Mapping of strong currents under storm conditions is still a challenging and unsolved issue.

Objections

- ❑ We aim to retrieve radial ocean surface current (OSC) velocities from Sentinel-1 SAR Doppler shifts acquired over Hurricane Maria (2017).

Methods

SAR-measured Doppler shifts are expressed by:

$$f_{dc} = f_{att} + f_{elec} + f_{sca} + f_{osc} + f_{ss} + \Delta f$$

where f_{att} is the Doppler shift caused by the satellite attitude variation, f_{elec} is the Doppler shift arising from antenna electronic miss-pointing, f_{sca} is the Doppler shift related to the scalloping effect in the azimuth direction. f_{osc} and f_{ss} are Doppler shifts induced by surface current and sea state, respectively. Δf is the total residual error and other unknown biases.

In order to obtain a reliable estimate for the OSC velocity, the non-geophysical Doppler shifts (f_{att}+f_{elec}+f_{sca}), sea sate induced Doppler shift (f_{ss}) and residual biases (Δf) need to be precisely estimated and removed.

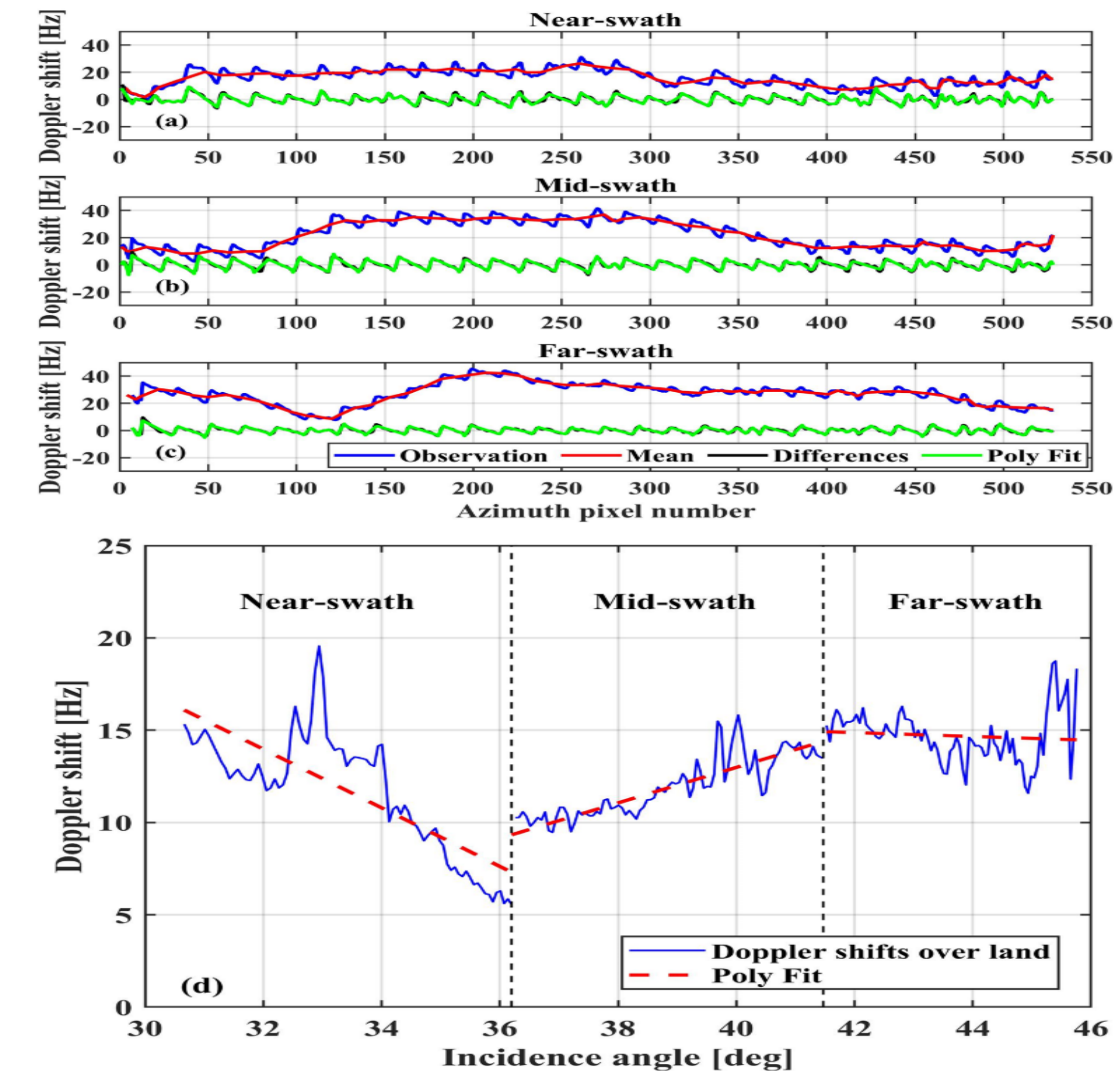

Fig. 1. Doppler shift profiles extracted from Sentinel-1A SAR Interferometric Wide (IW) scene: azimuth (along-track) Doppler shift profiles from observations (blue solid line), mean of the observations (red solid line), differences (observations – mean) (black solid line), and Doppler error due to the scalloping effect, estimated from a linear fit method (green solid line), for (a) near-swath, (b) mid-swath, and (c) far-swath, respectively. (d) Range (across-track) Doppler shift profile from observations (blue solid line) over the land within the SAR scene, and Doppler error (red dashed line) due to the antenna electronic miss-pointing and residual error estimated from the linear fit method for near-, mid-, and far-swaths, respectively.

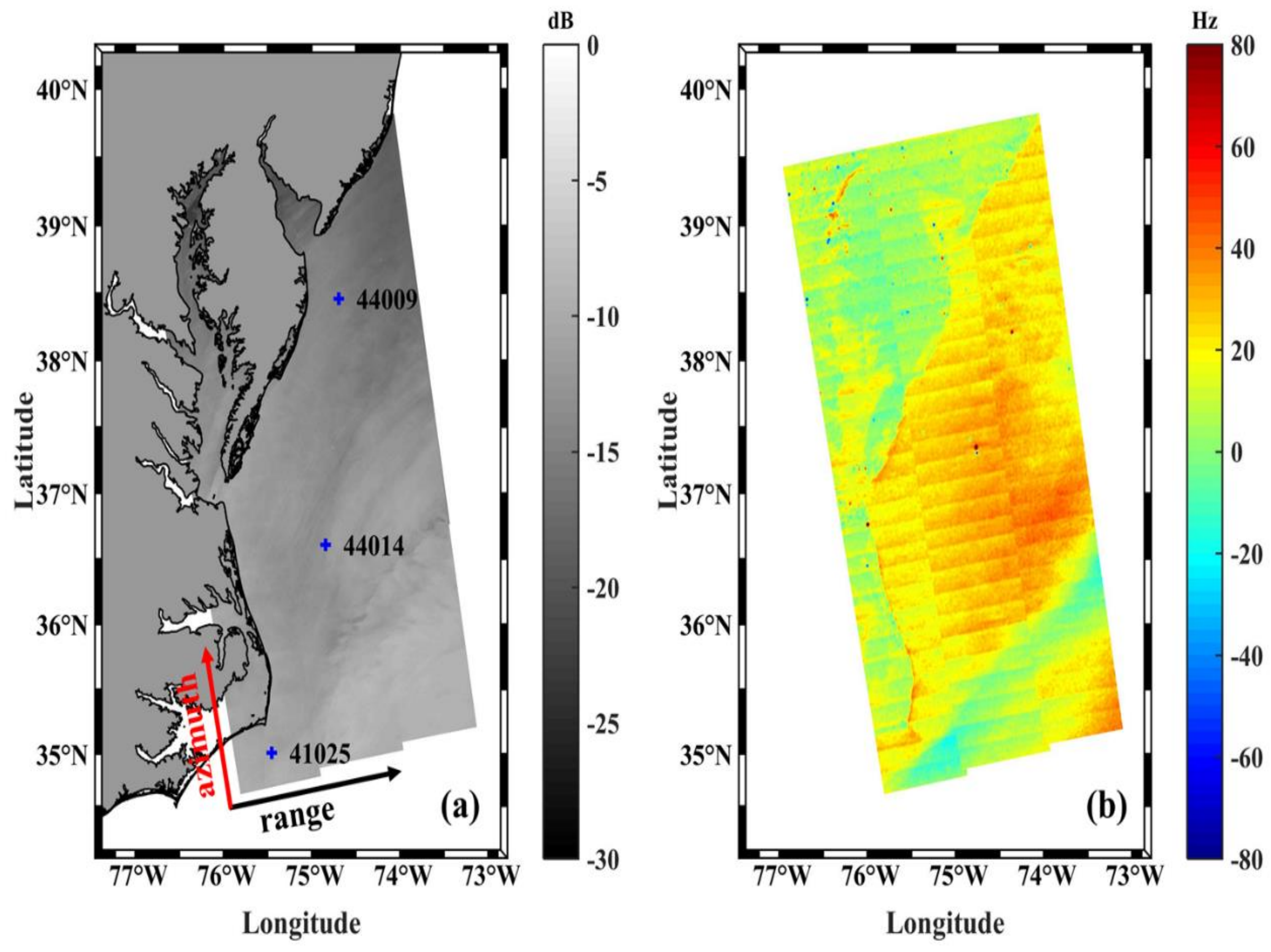

Fig. 2. (a) C-band Sentinel-1A VV-polarized SAR image acquired in Interferometric Wide (IW) swath mode over Hurricane Maria on September 26, 2017 at 22:57 UTC. Blue plus sign (+) represents the locations of the three NDBC buoys (#44009, #44014 and #41025). Red and black arrows denote azimuth and range directions, respectively. (b) Sentinel-1A SAR-measured Doppler shifts.

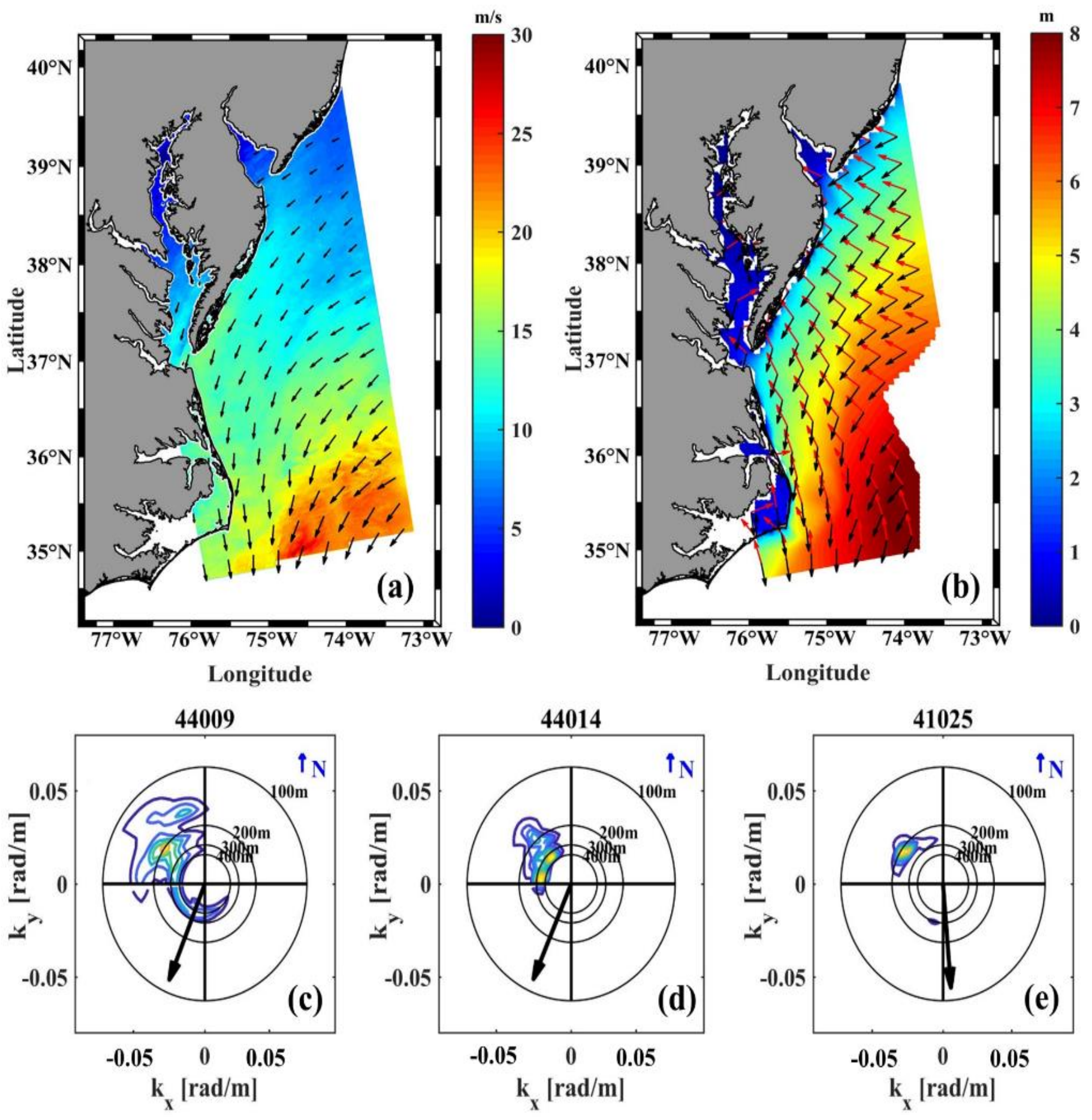

Fig. 4. (a) Ocean surface wind field retrieved from Sentinel-1A dual-polarization (VV, VH) SAR. (b) Significant wave height of Hurricane Maria derived from WAVEWATCH III (WW3). (c), (d) and (e) are directional wave spectra measured by NDBC buoys (#44009, #44014 and #41025 as shown in Fig. 2(a)).

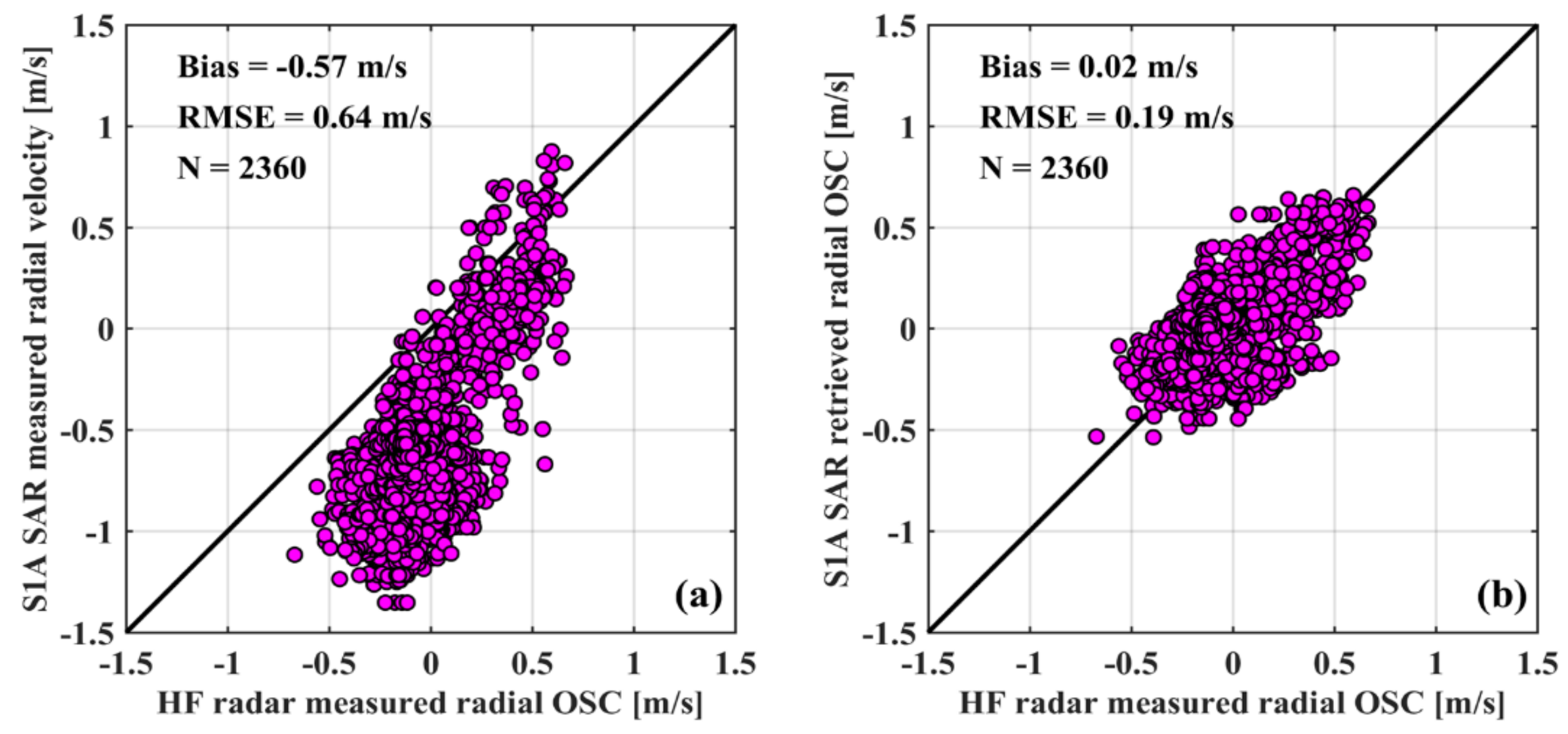

Fig. 6. Comparisons of SAR-retrieved radial ocean surface current (OSC) velocities and collocated HF radar measurements: (a) without and (b) with removal of sea-state-induced Doppler shift.

Results

- ❑ The bias and root-mean-square error (RMSE) significantly decrease after removing the effect of sea state, which are 0.02 m/s and 0.19 m/s, respectively
- ❑ Doppler shift induced by sea state need to be precisely estimated and corrected, in order to obtain reliable radial OSC velocity, especially under high wind conditions.

Discussions

- ❑ The differences between SAR retrievals and HF measurements are likely related to inaccurate Doppler shift corrections for non-geophysical and geophysical terms and uncertainty estimates for HF radar current observations.

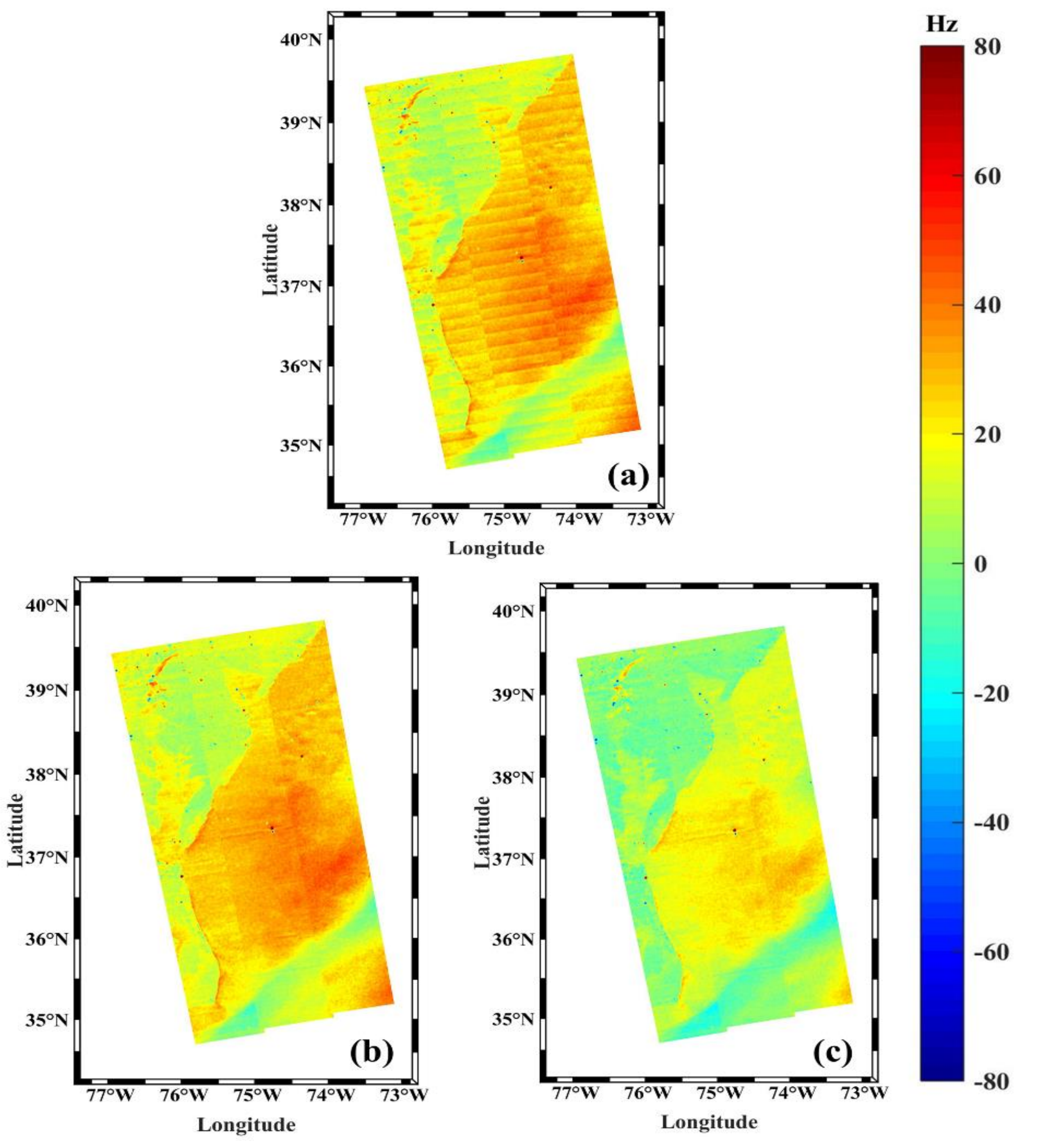

Fig. 3. (a) After removing the Doppler error due to the satellite attitude variations. (b) Doppler shifts after removing Doppler error due to the scalloping effect. (c) Doppler shifts after removing Doppler error caused by the antenna electronic miss-pointing and residual error.

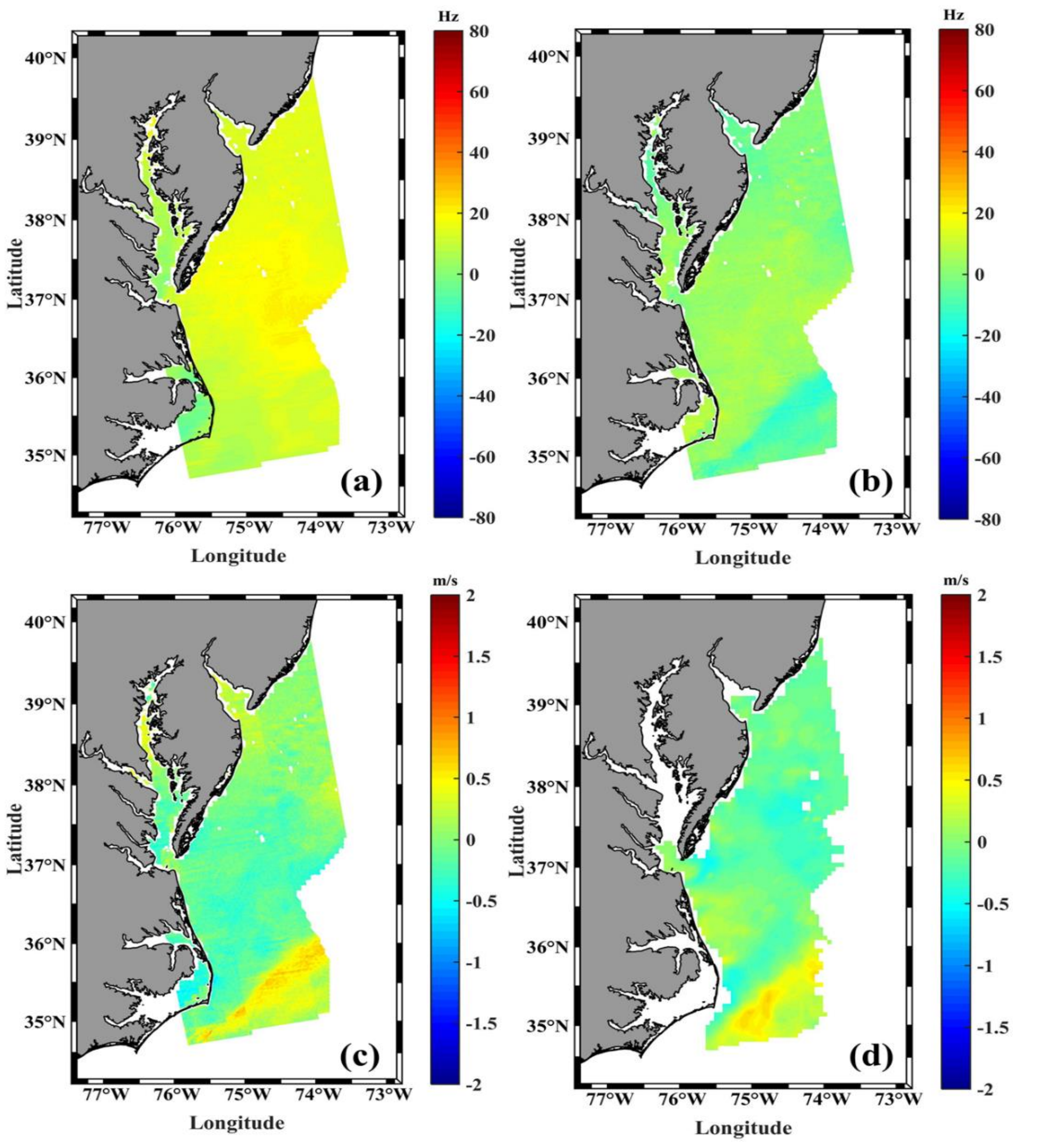

Fig. 5. (a) Estimated sea-state-induced Doppler shift using DPDop model, (b) Doppler shifts after removing sea state effect (wave bias correction) using the DPDop model, (c) Retrieved radial surface current velocities from Doppler shifts as shown in Fig. 5(b), and (d) HF radar-measured radial surface current velocities.

Conclusions

- ❑ This is a first attempt to retrieve radial OSC velocities under high wind conditions (<30 m/s).
- ❑ In the future, the wind speed range of the DPDop model will be extended and we plan to calculate sea-state induced Doppler shifts in the hurricane eyewall region. Thus, strong surface currents (~2 m/s) may be derived.

References

[1] V. Kudryavtsev, S. Fan, B. Zhang, B. Chapron, J. A. Johannessen, and A. Moiseev, "On the use of dual co-polarized radar data to derive a sea surface Doppler model –Part 1: Approach," *IEEE Trans. Geosci. Remote Sens*., vol. 61,2023.

[2] S. Fan, B. Zhang, A. Moiseev, V. Kudryavtsev, J. A. Johannessen, and B. Chapron, "On the use of dual co-polarized radar data to derive a sea surface Doppler Model – Part 2: Simulation and validation," *IEEE Trans. Geosci. Remote Sens*., vol. 61, 2023.