On the use of cross-polarized SAR and GPS-sonde measurements for wind speed retrieval in tropical cyclones

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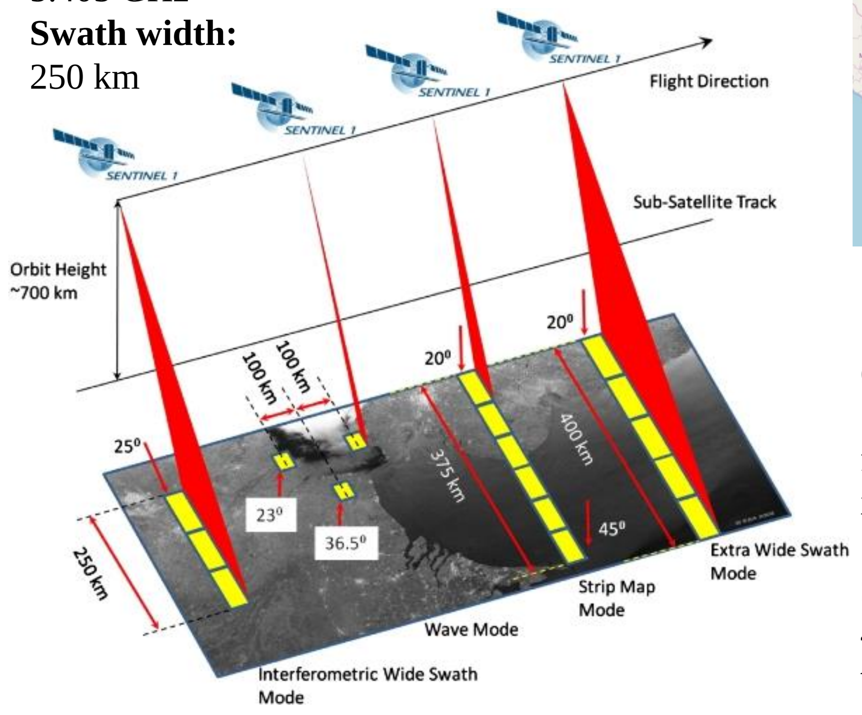
Summary. At present, the use of microwave methods for retrieval the tangential turbulent stress seems especially promising, since it is mainly related to the small-scale roughness defining the magnitude of the backscattered signal. The existing retrieval algorithms are not applicable due to the saturation of the scattered co-polarized microwave signal at wind speeds exceeding 20 m/s. However, recent studies showed found that the cross-polarized NRCS remain sensitivity to wind speed at high wind speeds. In this paper, we propose an approach for obtaining turbulent stress based on combined satellite cross-polarized SAR data and the measurement results from GPS-dropsondes.

Sentinel-1 acquisition modes

IWS mode
Resolution: 10 m
Incidence angle range: 29.1° - 46.0°
Centre frequency: 5.405 GHz
Swath width: 250 km



The location of images on the cross-polarization from the satellite Sentinel-1 for 2014 (left) and for 2015 (right), the areas of images are highlighted with red rectangles.

Radar measures Normalized Radar Cross Section (NRCS) of the water surface.

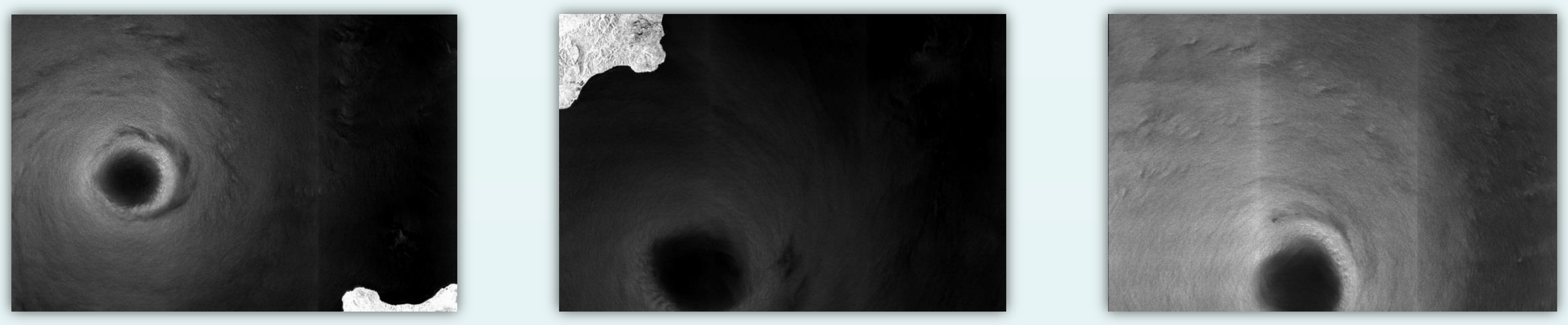
In the present work, we were able to collocate the date from the GPS-dropsondes and the cross-polarized SAR images of hurricanes from the Sentinel-1 (ESA).

Interferometric Wide Swath mode was analyzed for VH SAR-images taken above the sea surface at angles 29.1 ° - 46.0 ° during the 2017 hurricane season (from June 1, 2017 to November 30, 2017) in the Atlantic basin.

It was found that the "eye" of the hurricane is registered for the following hurricanes:

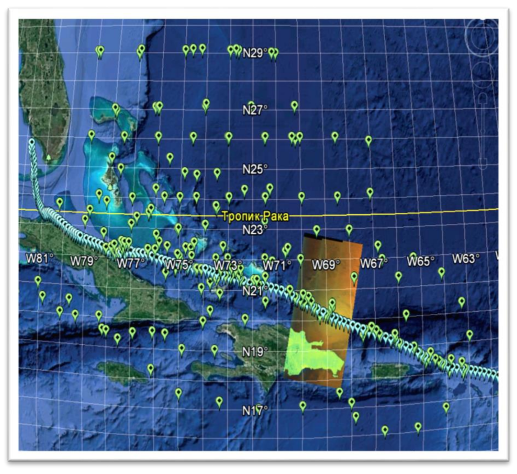
Irma	(2017/09/03 - 2017/09/10, 5 category (SSHS))
Maria	(2017/09/18 - 2017/09/27, 5 category (SSHS))
Jose	(2017/09/09 - 2017/09/20, 4 category (SSHS))

An array of data from NOAA for the 2017 hurricane season in the Atlantic basin was used to combine remote sensing and measurement data from the GPS-dropsondes. As a result, it was found that the combination of data can be made only for Hurricane Irma 2017/09/07 and Maria 2017/09/21 and 2017/09/23 because the snapshot of the "eye" of the hurricane and measurements from the GPS-dropsondes were the closest in time and space.



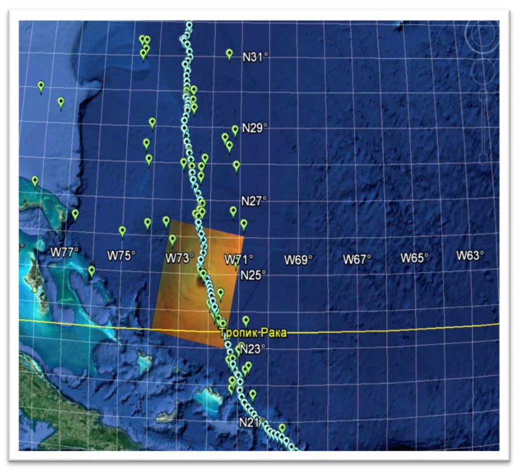
(a) Irma 2017/09/07 (b) Maria 2017/09/21 (c) Maria 2017/09/23

Collocation of the SAR data and the NOAA GPS-dropsondes



For each image, we analyzed the array of measurement data from GPS-dropsondes collocated with it in time and space. It should be noted, however, that the GPS-dropsondes were launched for a rather long period (6-10 hours), not always coinciding exactly with the time of the image acquisition. Therefore, we assume that there is a certain period of time for a full-fledged cyclone for which some of its characteristics can be considered quasistationary. To verify this assumption, we analyzed the dynamic characteristics of hurricanes: minimum sea level pressure (MSLP), maximum surface wind speed (MWS). It can be seen from the figures below that during the launch of GPS-dropsondes these characteristics change slightly. It makes possible the collocation of satellite data and the data from GPS-dropsondes during this period.

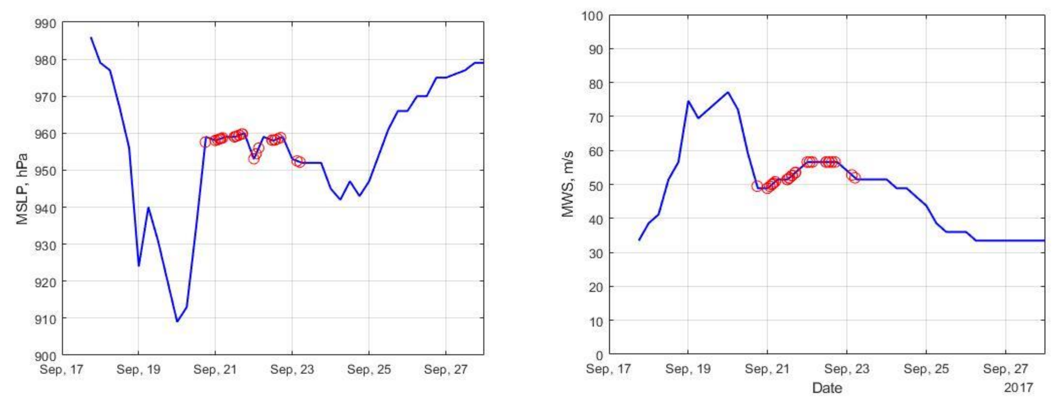
In this regard, an array of data from GPS-dropsondes launched 36 hours before and after the image was selected for analysis — while conserving of the hurricane dynamic characteristics was controlled.



GPS-dropsondes measures vertical profiles of wind speed, pressure, temperature and humidity during a fall with a frequency of 2 Hz.
www.aoml.noaa.gov/hrd/

Minimum sea-level pressure and maximum wind speed

Hurricane Maria



Hurricane Irma

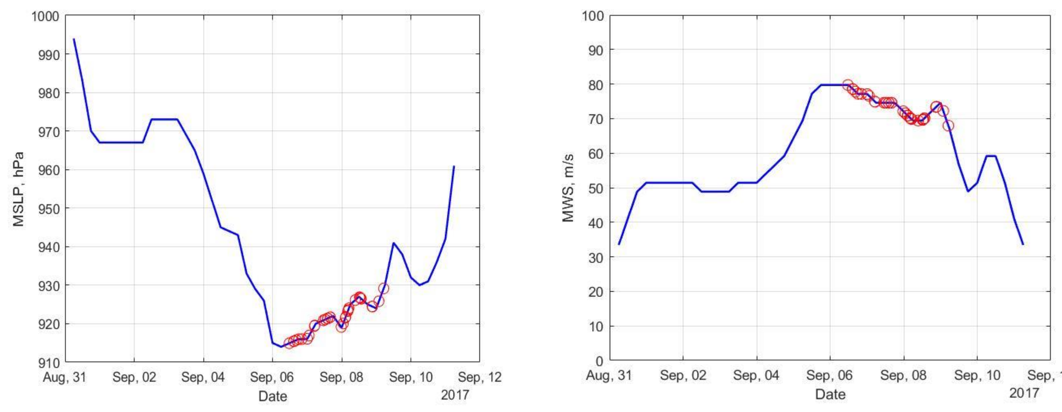
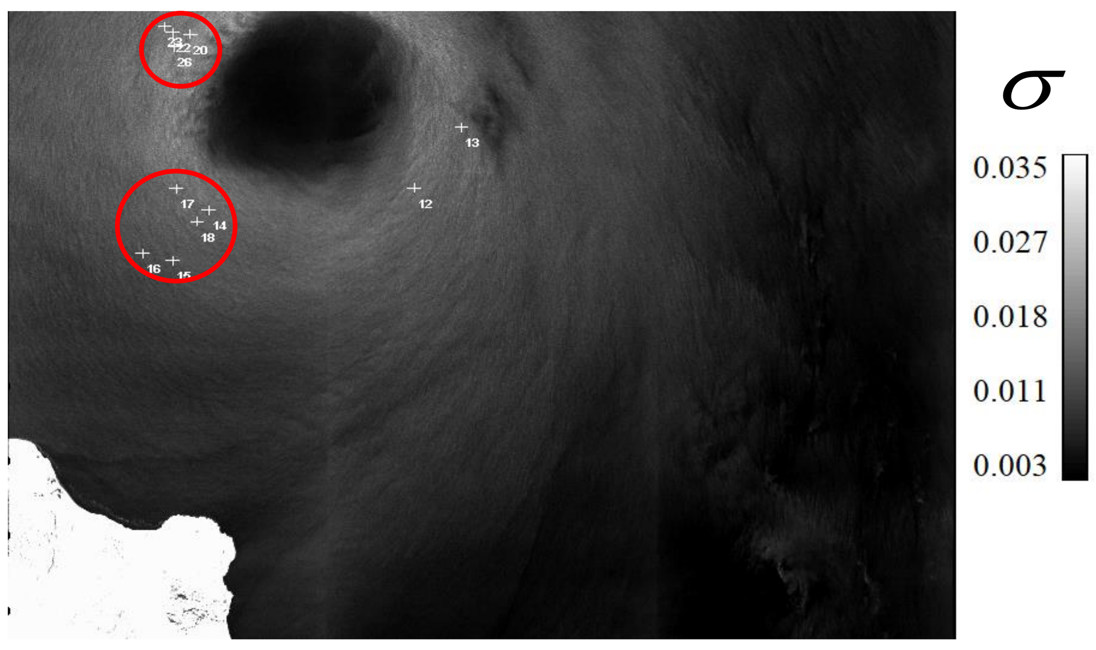


Illustration of the location of GPS-dropsondes on the example of hurricane Maria

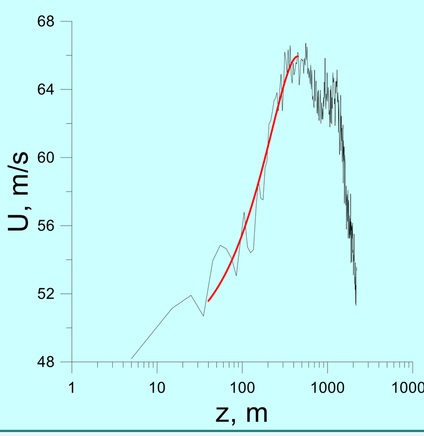


The GPS-dropsonde data were collected in such arrays was divided into groups constructed from closely spaced GPS-dropsondes. Within each of these groups, the profiles measured by GPS-dropsondes were averaged. From the averaged profiles, the values of the wind friction velocity u_* and the 10-m wind speed U_{10} were obtained based on the procedure described below.

The analysis was conducted in the period 2017/09/20-2017/09/22

Obtaining wind friction velocity and wind speed at meteorological height

Wind speed profiles obtained from GPS-dropsondes → Parabolic approximation of averaged profiles in accordance with the modified "wake law"



$$U_{max} - U(z) = \beta u_* (1 - z/\delta)^2$$

$$u_* = \sqrt{\tau_{turb}/\rho_{air}}$$

The value that determines the turbulent momentum flux in the vertical direction

Found u_*, U_{max} and δ

Unmeasured lower part of the profile is described by logarithm: $U_{max} - U(z) = u_*(-2.5\ln(z/\delta) + \gamma)$

The roughness height: $z_0 = \delta \exp(-\kappa U_{max}/u_* + \gamma\kappa)$

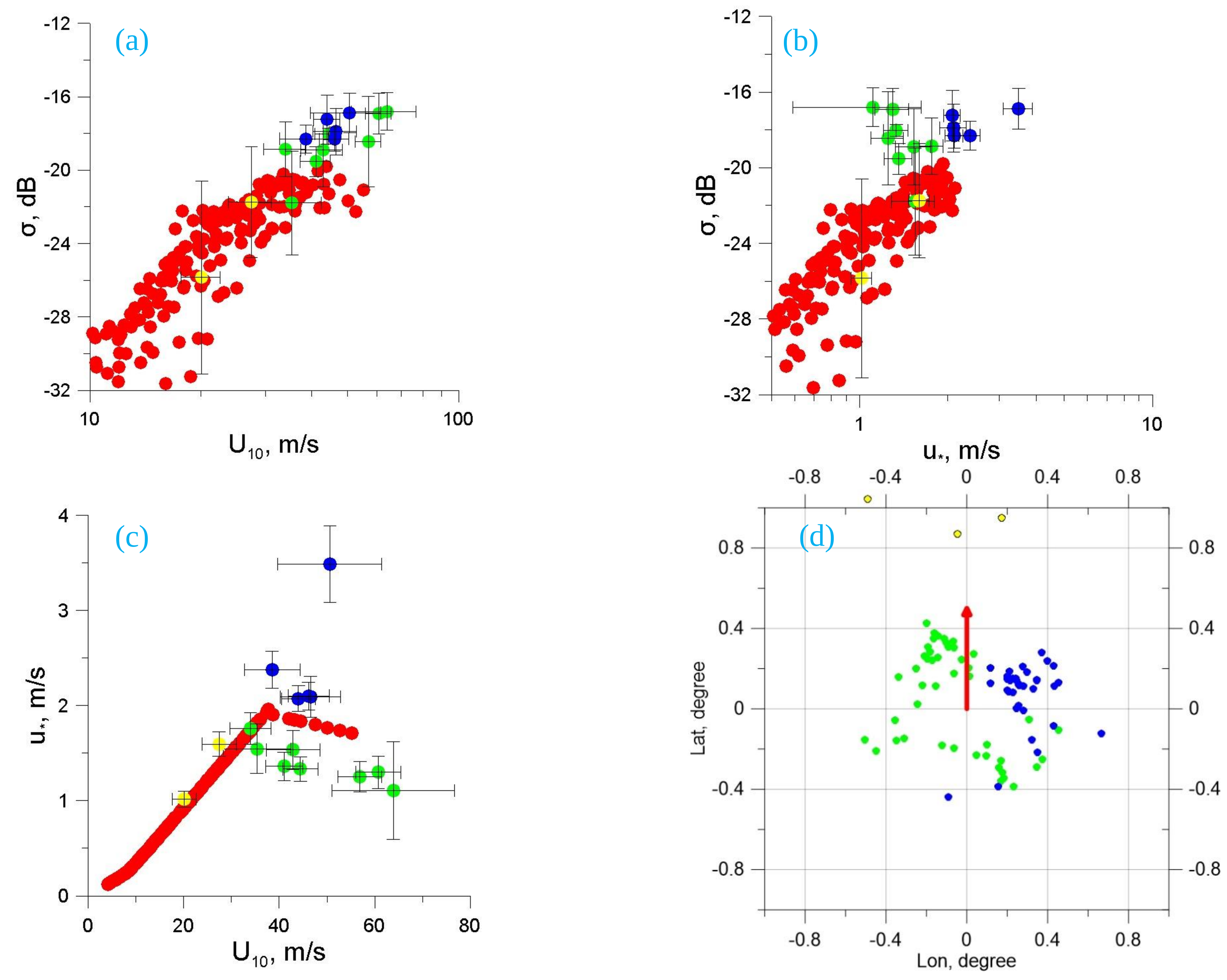
Logarithmic profile: $U(z) = 2.5 u_* \ln(z/z_0)$

$$U_{10} = 2.5 u_* \ln(10/z_0)$$

The cross-polarized NRCS versus wind speed and friction velocity in hurricanes Irma and Maria.

The collocated cross-pol NRCS were taken from the SAR-images of Sentinel-1. It should be noted, however, that significant fluctuations of the NRCS in each image were associated with the presence of surface waves. In this regard, the values of NRCS were averaged over the 2 × 2 km cells with the centers at points with the coordinates of the launched GPS-dropsondes. Afterwards, we found the NRCS averaged over the ensemble of these points. Examples of such ensembles were shown earlier.

For comparison, we used an array of data obtained on cross polarization in a wide range of wind speeds by (Hwang et al., 2015). In (Troitskaya et al., 2018) the authors used data from (Hwang et al., 2015) to retrieve the dependence of the NRCS on u_* (a, b). Obviously, the present data are in agreement with the dependence from (Hwang et al., 2015) and extend it to higher wind speed. At the same time, it is seen, that the dependence of NRCS on u_* becomes ambiguous for $u_* \sim 2$ m/s. An analysis of dependency u_* on U10 (c) and GPS-dropsondes distribution (d) showed that the data corresponding to different branches of the dependence belong to GPS-dropsondes fallen in left and right sectors of the hurricanes. It should be noted that for data obtained far from the center of the hurricane (yellow symbols on figures), where wind speeds are low, the sectoral dependence is not so obvious.



Red symbols - NRCS obtained according to the data from (Hwang et al., 2015, Troitskaya et al., 2018) (a), (b); red symbols on (c) show functional dependencies from (Troitskaya et al., 2018, Holthuijsen et al., 2012). Green and blue symbols – data obtained from left and right sector of hurricane, respectively. Yellow symbols – data from GPS-dropsondes fallen far from the hurricane center. Illustration of sectoral distribution of data in hurricanes Maria and Irma (d), where red arrow shows the direction of hurricanes motion.

Conclusions

The paper describes the first step towards development of GMF for retrieval wind speed and wind stress in hurricanes basing on calibration of the cross-polarized satellite SAR data from Sentinel-1 by the collocated NOAA GPS-dropsondes data. Procedure for collocation of the GPS-dropsondes data and the Sentinel-1 cross-polarized SAR data was suggested, based on the assumption that the shape of the hurricane remains unchanged during the time of field measurements. Basing on preliminary data processing, the dependencies of the cross-polarized NRCS on the wind speed and wind friction velocity were obtained. The NRCS dependence on u_* is ambiguous apparently due to dependency of u_* on the sector of the hurricane. The found peculiarities are the subject for further investigation.