Atmospheric boundary layer parameters retrieval from Stepped Frequency Microwave Radiometer measurements in tropical cyclones

Nikita Rusakov, Evgeny Poplavsky, Olga Ermakova, Yuliya Troitskaya, Daniil Sergeev, and Galina Balandina
nikitarusakov228@yandex.ru
Institute of Applied Physics of the RAS, Department of Nonlinear geophysical processes research, *Nizhny Novgorod, Russian Federation*

Summary

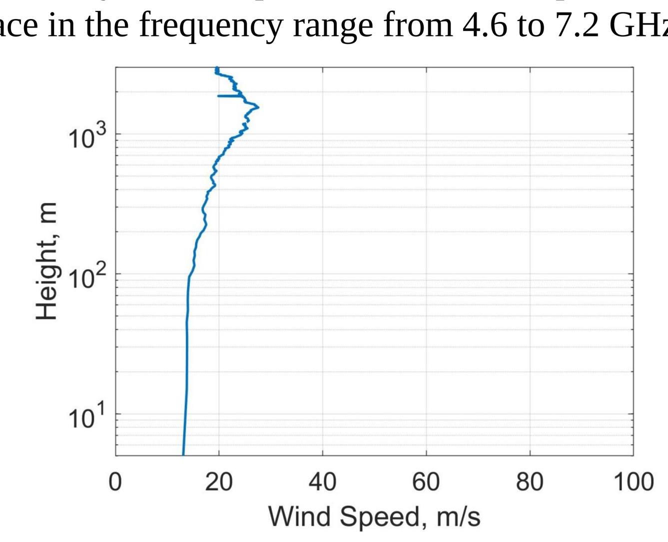
The retrieval of the NRCS dependence on the wind speed and other parameters of the atmospheric boundary layer is an important problem of remote sensing. Such dependences are used to construct geophysical model functions (GMF), allowing to restore the wind speed U_{10} from remote sensing data. However, there is a problem is associated with the saturation of the scattered co-polarized microwave signal at high wind speeds , which is solved by using cross-polarized signal receive. To construct these dependences, it is necessary to calibrate satellite data for field measurements. However, the collocation of remote sensing data and sub-satellite measurements is difficult due to the small amount of data. In this work, we use SFMR data, the main advantage of which is a large data set and its compatibility with the measurement from GPS-dropsondes.

Data sources from NOAA missions for analysis

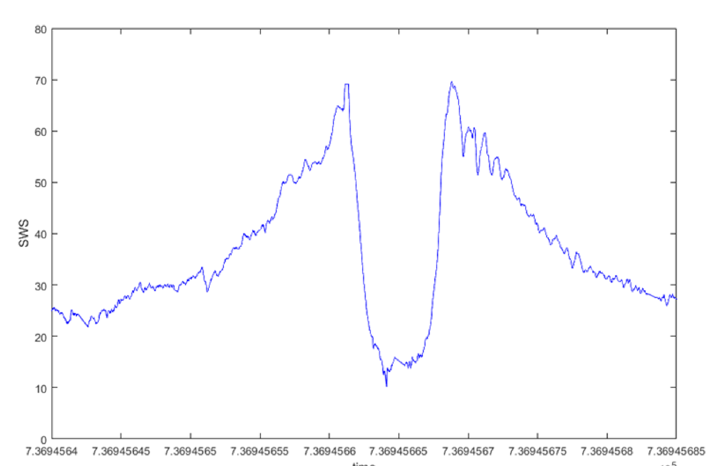
Radiometer under the wing of the aircraft NOAA

GPS-dropsonde

In this work, we used the Stepped Frequency Microwave Radiometer (SFMR) measurements and data from GPS-dropsondes, launched in hurricanes. Measurements from GPS-dropsondes are an array of data with wind speed, altitude, temperature, coordinates, etc., restored with a frequency of 2 Hz, publicly available on the site Hurricane Research Division: http://www.aoml.noaa.gov/hrd/. The scattered signal from the water surface is determined by its roughness, which is mainly related to the wind friction velocity. This parameter can be obtained from the vertical wind speed profiles measured by GPS-dropsondes. SFMR is a passive radar instrument that measures microwave emission from a water surface in the frequency range from 4.6 to 7.2 GHz. SFMR provides data on wind speed at a height of 10 meters.



Example of the wind speed profile, measured by GPS-dropsonde



SFMR provides surface wind speed at a height of 10 m

Obtaining wind friction velocity and U_{10}

$$U_{max} - U(z) = \begin{cases} u_*\left(-\frac{1}{\kappa}\ln(z/\delta) + \gamma\right); z/\delta < 0.3, & \text{-logarithmic part} \\ \beta u_*(1 - z/\delta)^2; z/\delta > 0.3. & \text{-"wake" part} \end{cases}$$

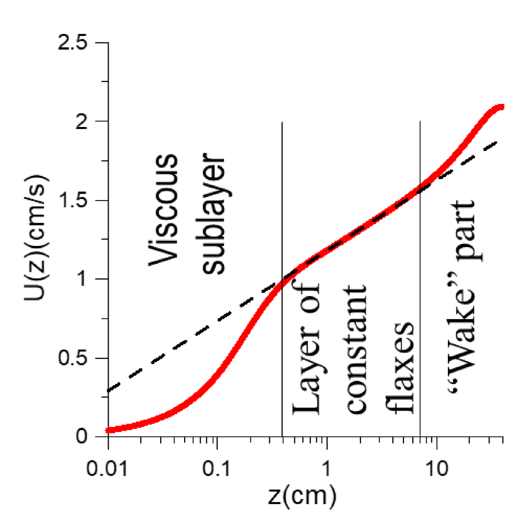
$\kappa = 0.4$

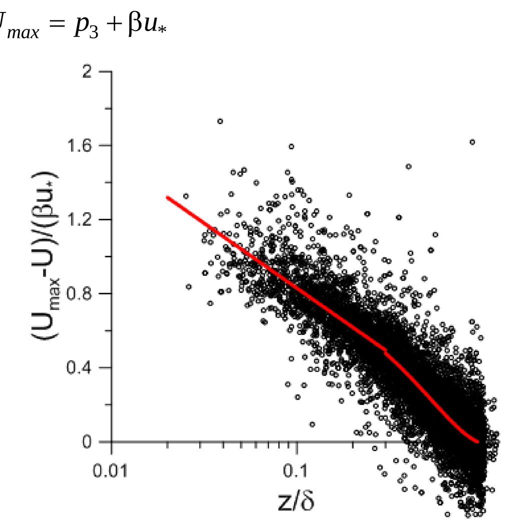
$$U(z) = p_3 + p_2 z + p_1 z^2$$

- approximation of the "wake" part by a polynomial of the second degree

$$\beta u_* = -\frac{p_2^2}{4p_1} \qquad \delta = -\frac{p_2}{2p_1} \qquad U_{max} = p_3 + \beta u_*$$

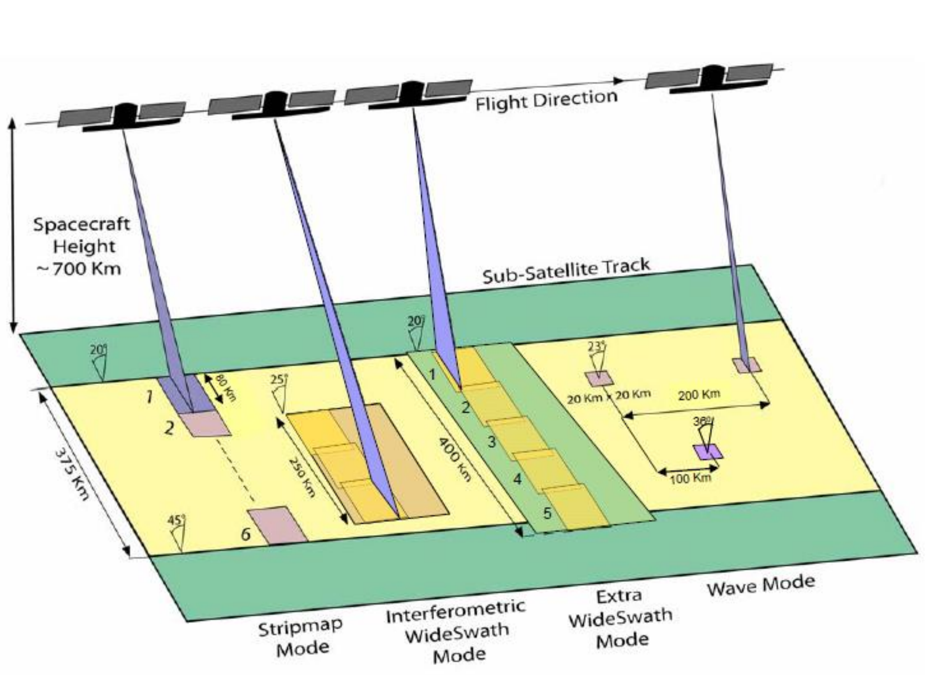
-boundary layer parameters in a hurricane derived from approximation





$$\frac{U_{max} - U(z)}{\beta u_*} = \begin{cases} -\frac{1}{\kappa\beta}\ln(z/\delta) + \frac{\gamma}{\beta}; z/\delta < 0.3, \\ (1 - z/\delta)^2; z/\delta > 0.3. \end{cases} \rightarrow \beta, \gamma \rightarrow u_*, U_{10}$$

Sentinel-1 acquisition modes

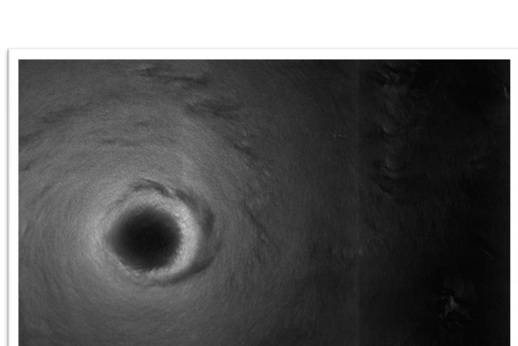


IWS mode

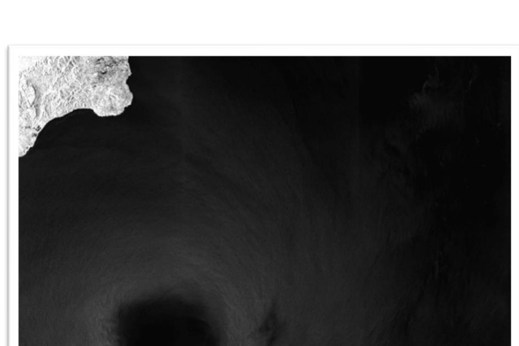
Polarization: VH, HV
Resolution: 10 m
Incidence angle range:
29.1° - 46.0°
Central frequency:
5.405 GHz
Measure Normalised Radar Cross Section (NRCS) of the water surface

In this work, we used SAR images of hurricanes at cross polarization, because cross-polarized NRCS is sensitive to wind speed at high wind speeds.

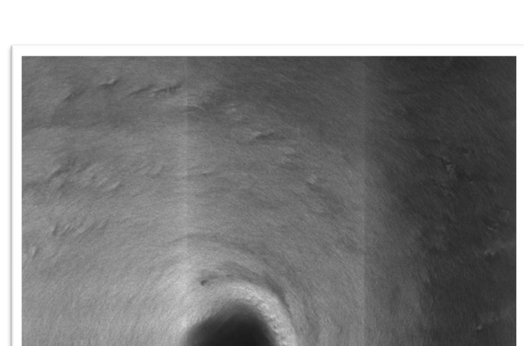
Examples of hurricane eye images for which a combination SAR and SFMR data was performed:



(a) Irma 2017/09/07



(b) Maria 2017/09/21

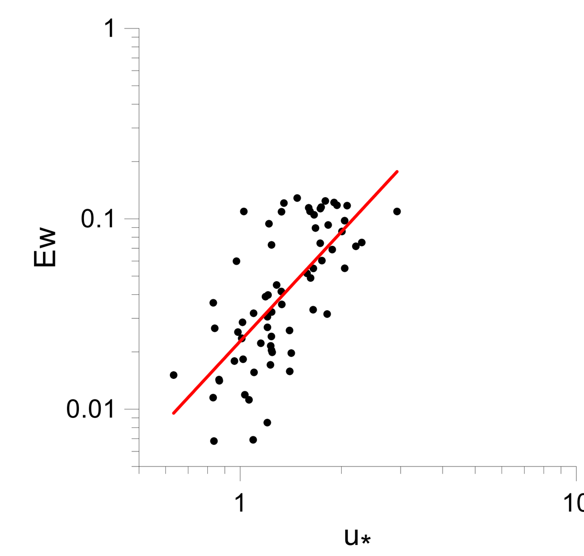


(c) Maria 2017/09/23

Calibration of emissivity on wind friction velocity obtained from GPS-dropsondes

$$E_w = \begin{cases} a_1 U_{10}, U_{10} \le 7\text{м}/c \\ a_2 + a_3 U_{10} + a_4 U_{10}^2, 7\text{м}/c < U_{10} \le 31.9\text{м}/c \\ a_5 + a_6 U_{10}, > 31.9\text{м}/c \end{cases}$$

- GMF, proposed by (Uhlhorn, 2007). This function describes the dependence of the emissivity on the wind speed U_{10} and is used in the SFMR. However, we need to restore the values of wind friction velocity.

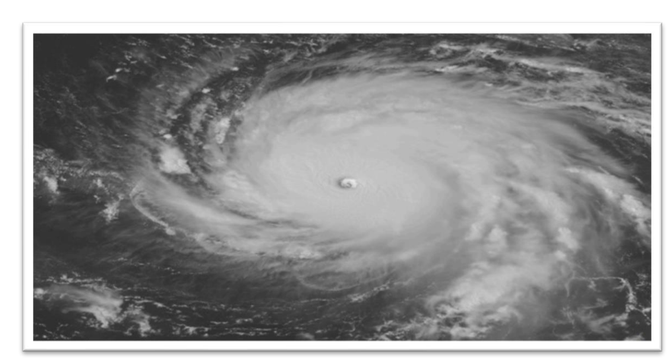


Using the combined data with SFMR and GPS-dropsondes, the emissivity was calibrated for wind friction velocity, the procedure for obtaining which was described earlier.

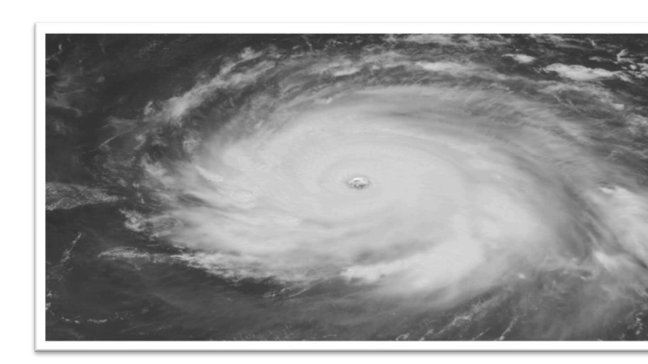
$$\ln(E_w) = A\ln(u_*) - B$$

$$u_* = \left(E_W \exp(B)\right)^{1/A}$$

It can be seen that the shape of the hurricane changes only slightly during the day, which means that the correct combination of satellite data and data from SFMR can be carried out. The preservation of the shape of the hurricane while strictly controlled. Optical images were made by geostationary satellite GOES-13.



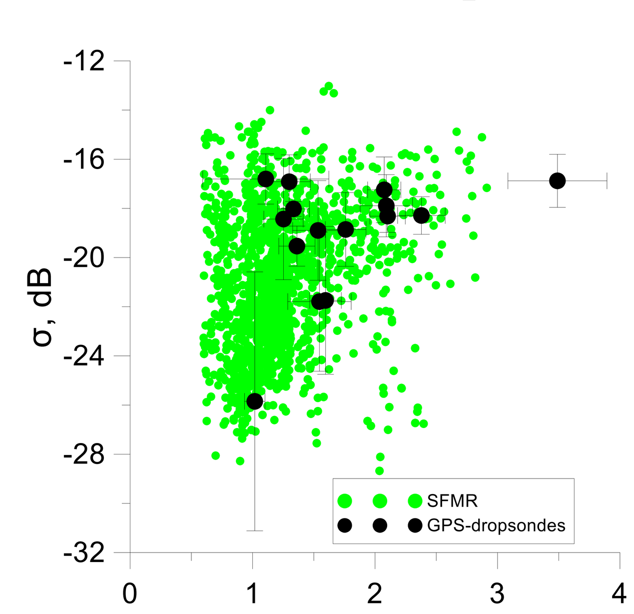
(a) Hurricane Irma
2017/09/06 18:15UTC

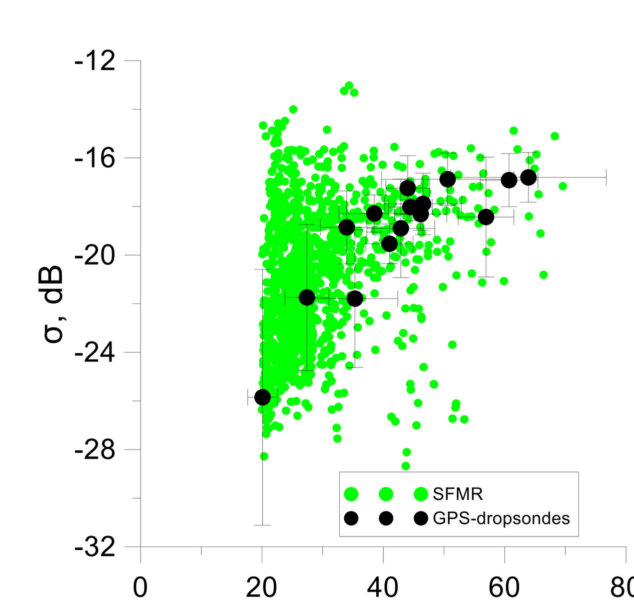


(b) Hurricane Irma
2017/09/07 16:15UTC

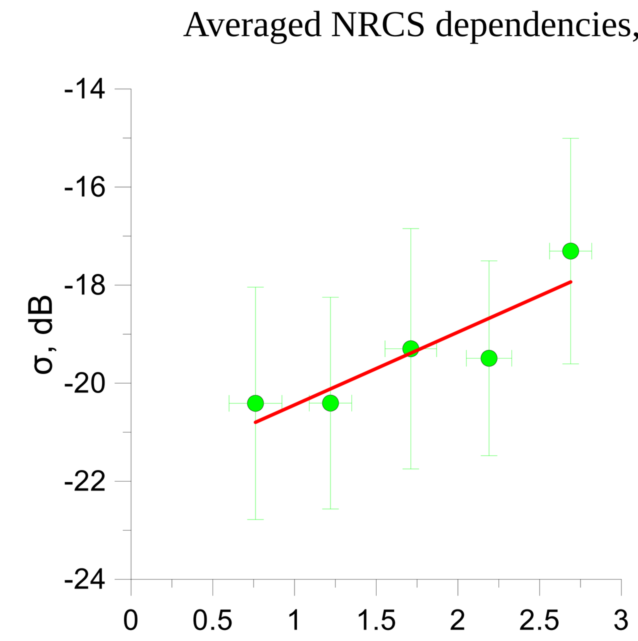
This allowed us to make the combination of SFMR and Sentinel-1 data. Flight track over Hurricane Irma (2017/09/07). The dots in the image indicate the places where the combination of NRCS and SFMR data (U_{10} and u_*) was made.

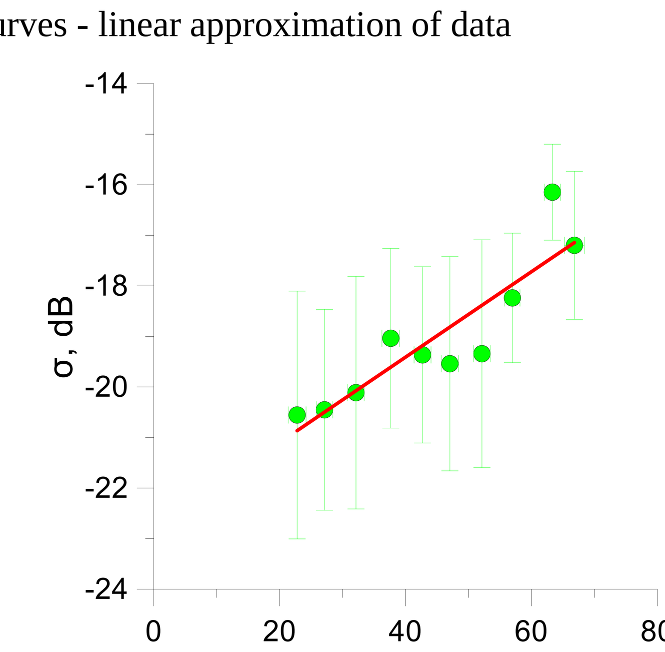
NRCS dependencies on wind friction velocity and U_{10}





Averaged NRCS dependencies, red curves - linear approximation of data





Conclusion

In our recent studies, SAR images from the Sentinel-1 satellite were combined with field data from NOAA GPS-dropsondes in hurricane conditions. Dependencies of NRCS on wind speed and wind friction velocity were constructed. However, in 2016-2017, only 3 SAR images were found, which became the motivation to supplement the data ensemble using SFMR measurements. The radiometric measurements of the emissivity were calibrated to the wind friction velocity obtained from vertical wind speed profiles. Using the assumption that the hurricane is quasistationary during the day, the SFMR data and SAR data of the Sentinel-1 satellite were combined.