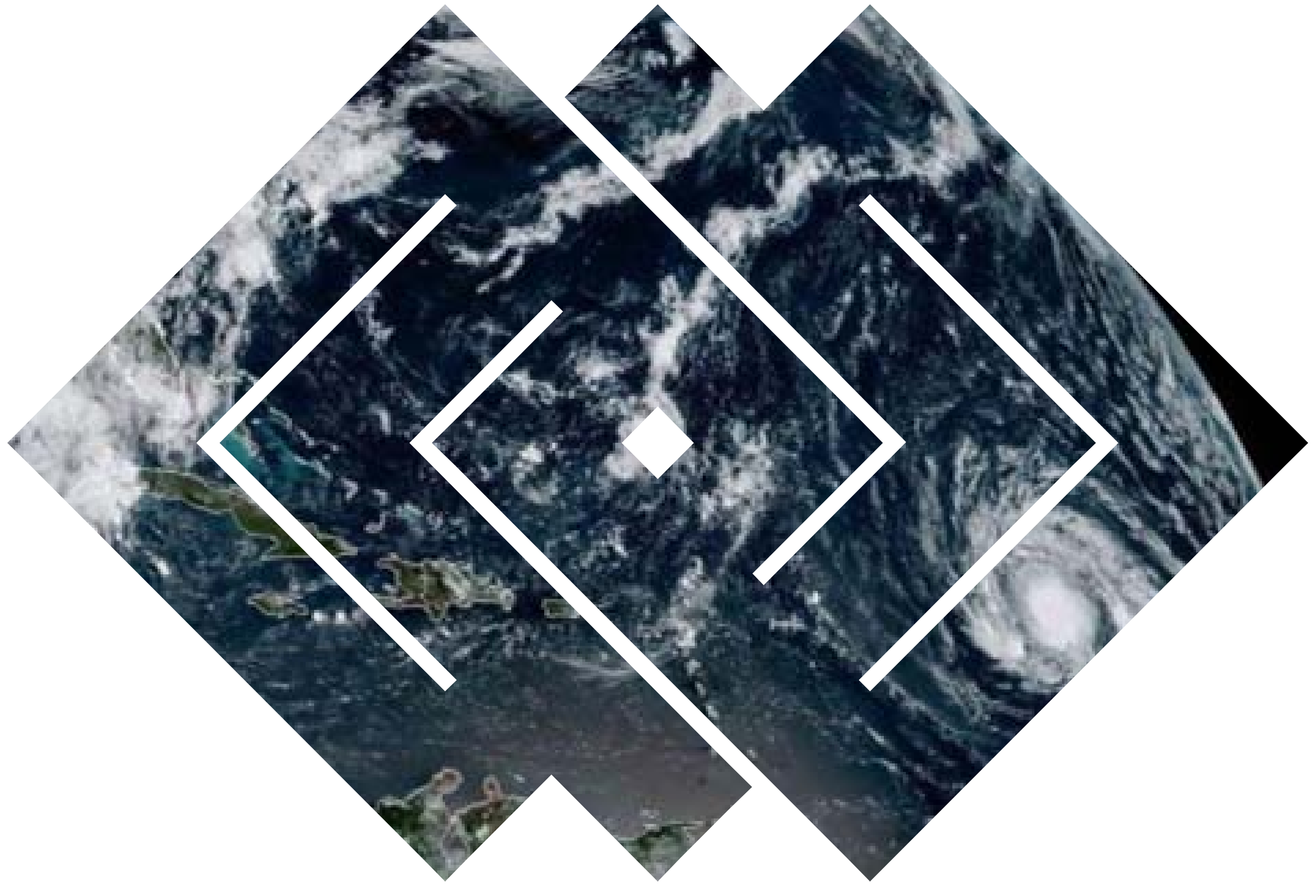

Exchange coefficients derived from GPS-sonde and SFMR measurements in hurricane conditions

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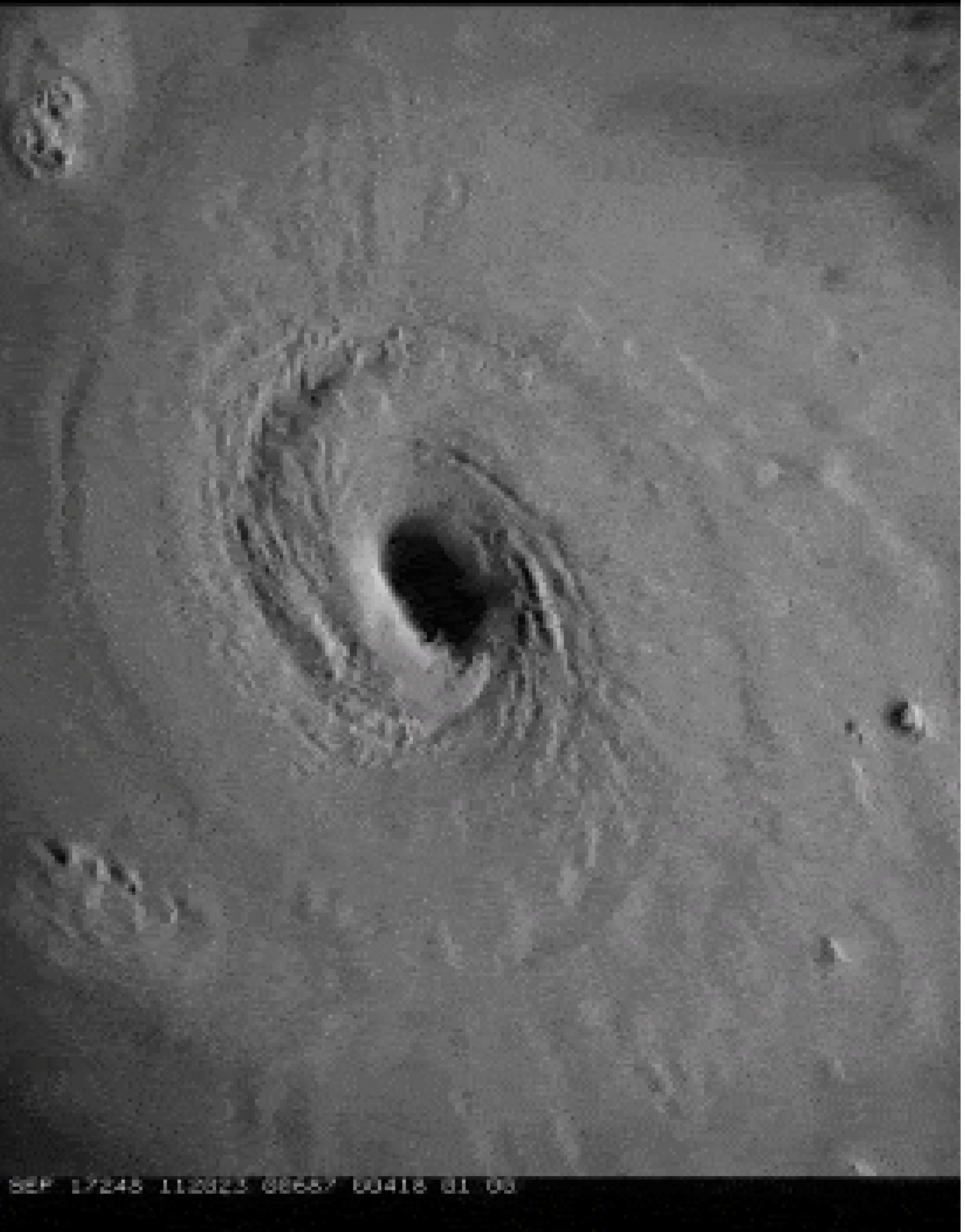


In prognostic models that evaluate the evolution of hurricane intensity, in addition to drag coefficients, thermodynamic exchange coefficients are also involved. Arrays of data obtained from NOAA GPS sondes carry information on wind speed, humidity, temperature and pressure, which allow to calculate specific enthalpy:

$$k = \Big((1-q)C_p + qC_{liq}\Big)\theta + qL_v$$

here q is the specific air humidity,

C_p and C_{liq} are the heat capacity of air and water,

ϑ is the potential air temperature,

L_v is the vaporization temperature.

Data for statistical analisys

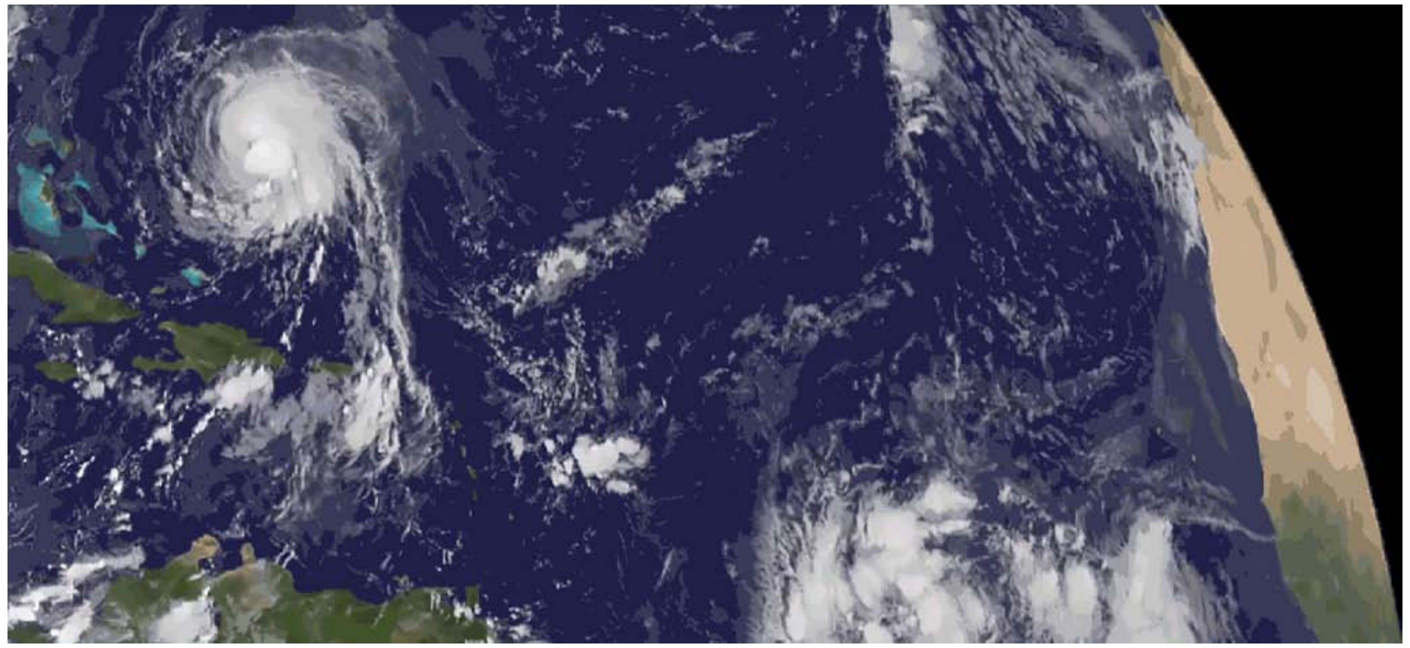
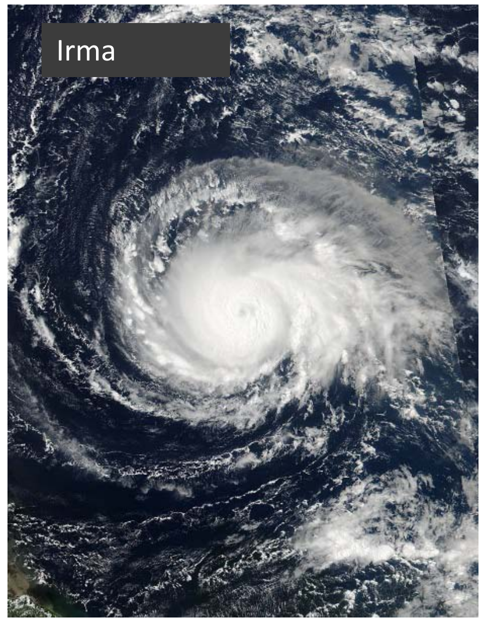


Image of hurricanes Irma, Maria and Harvey, data from GOES-13 satellite for the period September 15-19, 2017

Image of hurricane Irma, satellite data GOES-13 for the period 03/05/2017

No	*Hurricane*	*Data of drop-sonde measurments*	*Category*
1	Irma	2017/09/03-2017/09/10	5
2	Dean	2007/08/16-2007/08/22 (кроме 2007/08/18)	5
3	Isabel	2003/09/12-2003/09/18	5
4	Ivan	2004/09/07-2004/09/15 (кроме 2004/09/08)	5
6	Katrina	2005/08/26-2005/08/29	5
7	Maria	2017/09/18-2017/09/27	5
8	Matthew	2016/09/29, 2016/10/01-2016/10/08	5
9	Rita	2005/09/19-2005/09/24	5
10	Wilma	2005/10/18, 2005/10/20-2005/10/24	5



Statistical analysis

Velocity profiles

The typical profiles of wind speed in a hurricane (Fig.1(a)) are similar to the profiles obtained in the wind-wave flume (Fig.1(b)) (Troitskaya et al, 2017). The role of the cap restricting the flow of air mass from above is played by the atmospheric “inversion cap”.

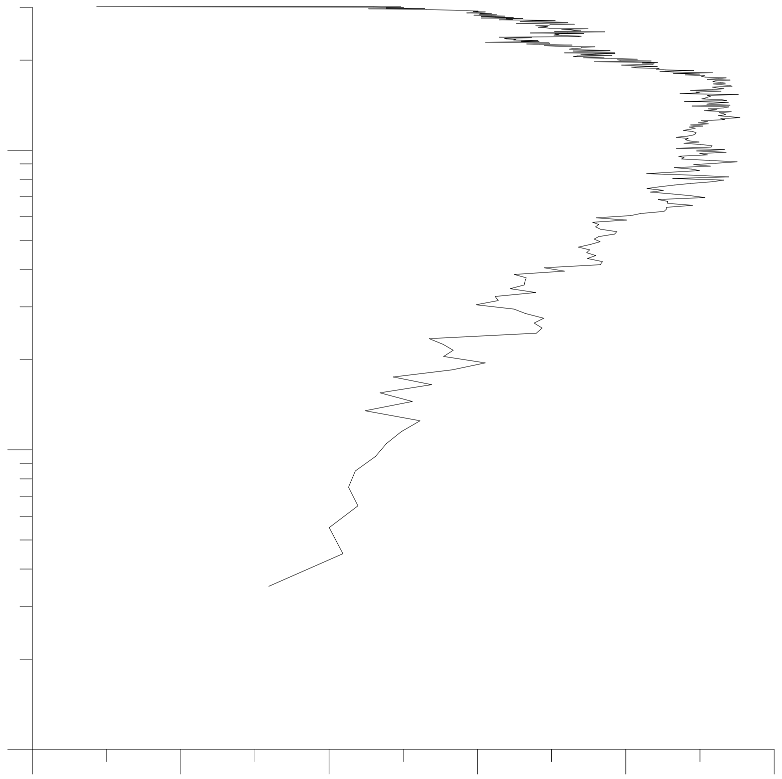


Fig.1(a)

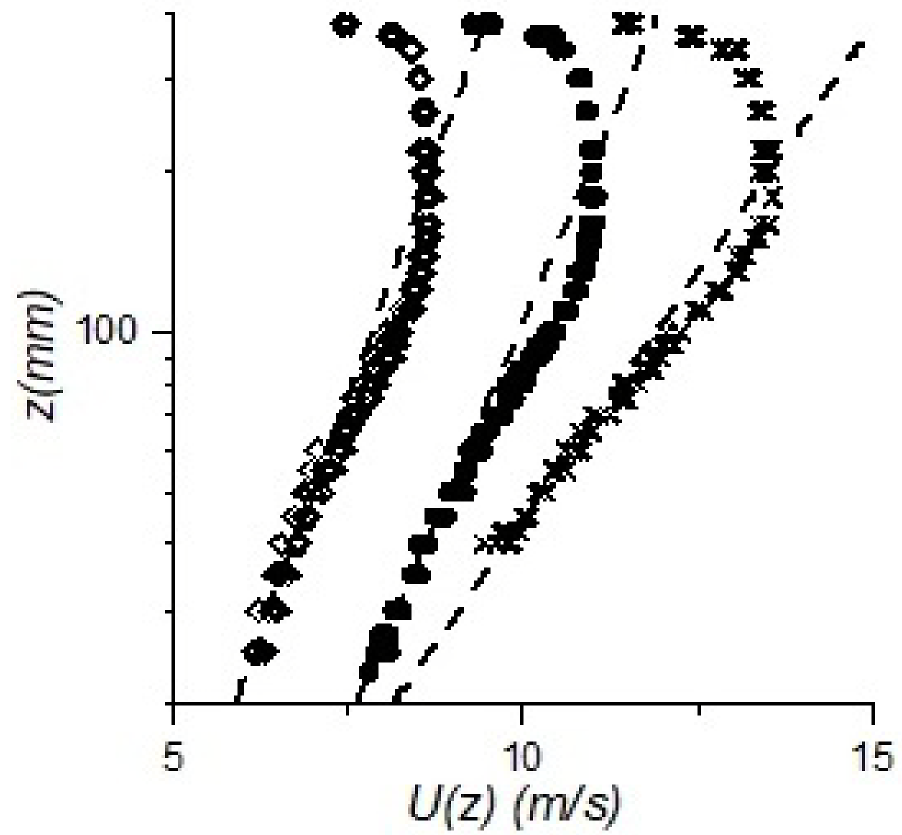


Fig.1(b)

Taking into account he self-similarity property of a velocity defect profile, we proposed the following expression for wind profiles:

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

For the wake part of profiles the following approximation was used:

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

Boundary layer parameters obtained from approximation:

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

u_*

Statistical analysis

Velocity profiles

$$\frac{U_{\max}-U(z)}{\beta u_*}=\begin{cases}\dfrac{1}{\beta}\left(-\dfrac{1}{\kappa}\ln\dfrac{z}{\delta}+\gamma\right);\ z/\delta<0.3\\[2mm] \left(1-\dfrac{z}{\delta}\right)^2;\ z/\delta>0.3\end{cases}$$

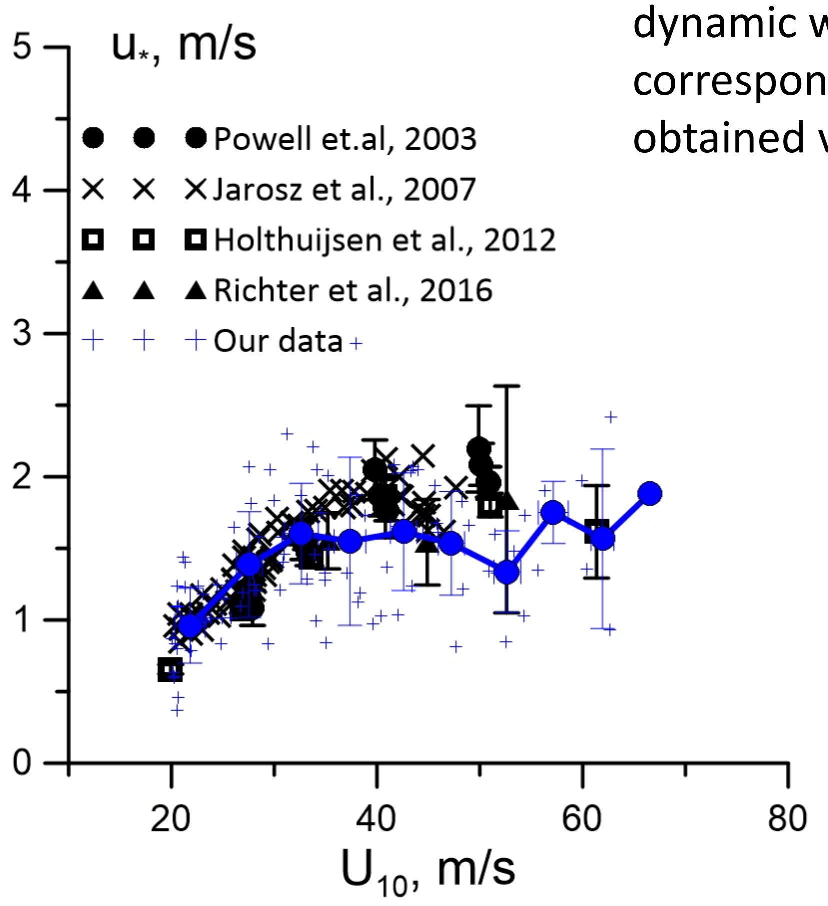
In accordance with this approximation, the parameters β and γ were obtained and, as a result, the boundary layer parameters were estimated:

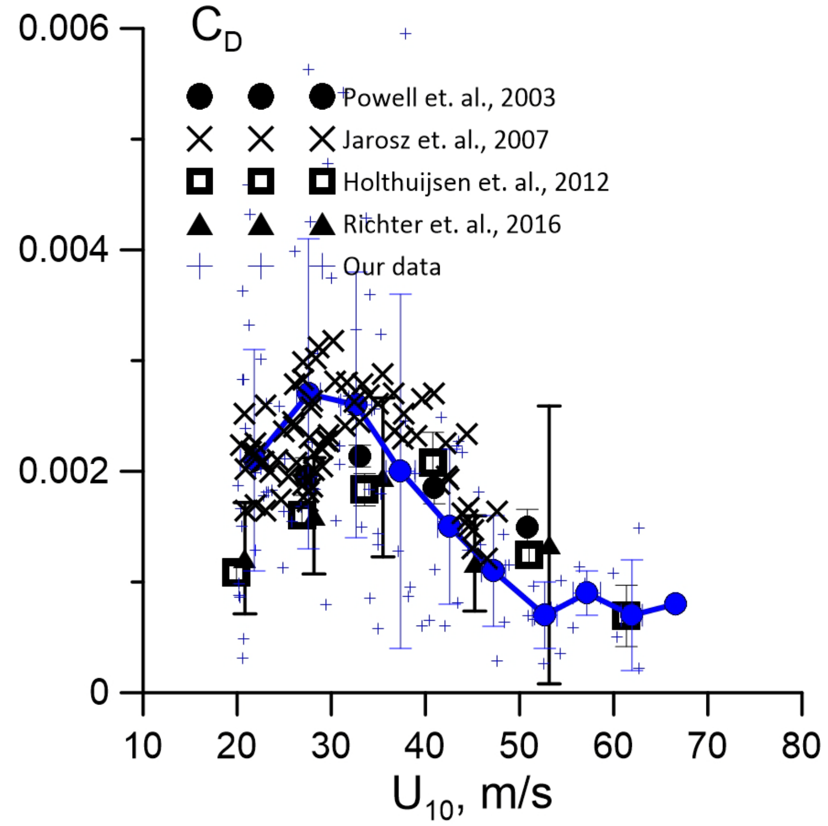
$$z_0=\delta\exp\left(-\kappa U_{\max}/u_*+\alpha\kappa\right)$$ - roughness height

$$U(z)=\frac{u_*}{\kappa}\ln\left(z/z_0\right)$$ - logarithmic profile for estimating speed U_{10}

$$C_d=\frac{\kappa^2}{\left(\kappa U_{\max}/u_*-\gamma\kappa+\ln\left(H_{10}/\delta\right)\right)^2}$$ - the drag coefficient of the water surface

The azimuth averaged dependences of aerodynamic drag coefficient and dynamic wind speed. The blue curve corresponds to the approximation of the obtained values at confidence intervals

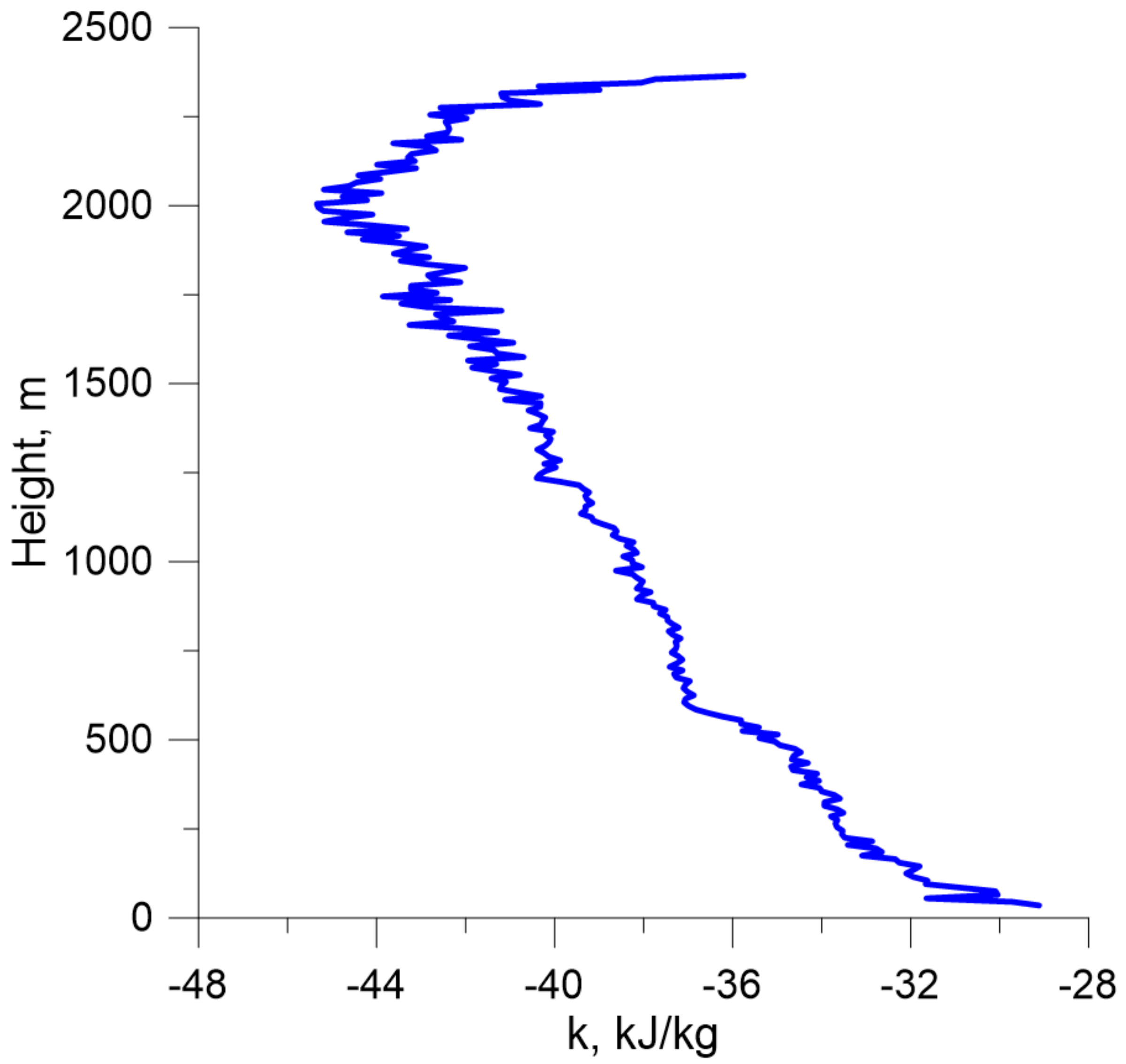


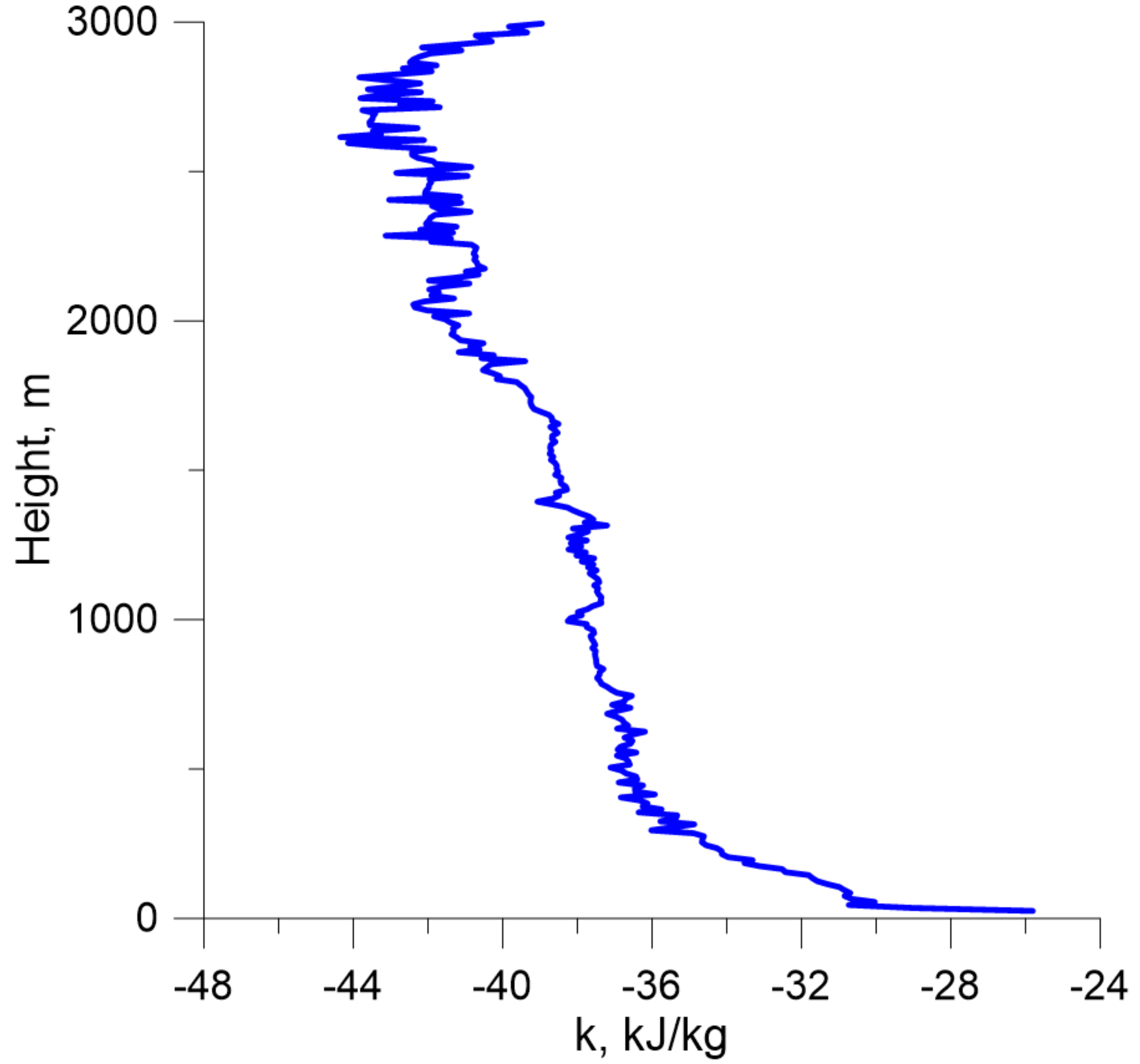


Statistical analysis

Enthalpy profiles

Ensembles for enthalpy averaging were grouped for the same hurricanes from the previous slides, profiles grouped by distance were used to calculate wind parameters





Averaged enthalpy profiles for the hurricane Irma, 2017.09.08, the distance from the center of the hurricane is 70-80 km and 80-90 km, respectively

The profiling method used above to reconstruct the aerodynamic drag coefficients and the friction velocity is also suitable for calculating the thermodynamic exchange coefficients:

We assumed, that dependence of the enthalpy defect profile is self-similar, to approximate it, the following expression was proposed:

$$k_{\max} - k(z) = \begin{cases} k_* \left(-\dfrac{1}{\kappa} \Pr \ln \dfrac{z}{\delta} + \alpha \right); z/\delta < 0.15 \\ \beta k_* \left(1 - \dfrac{z}{\delta} \right)^2; z/\delta > 0.15 \end{cases}$$

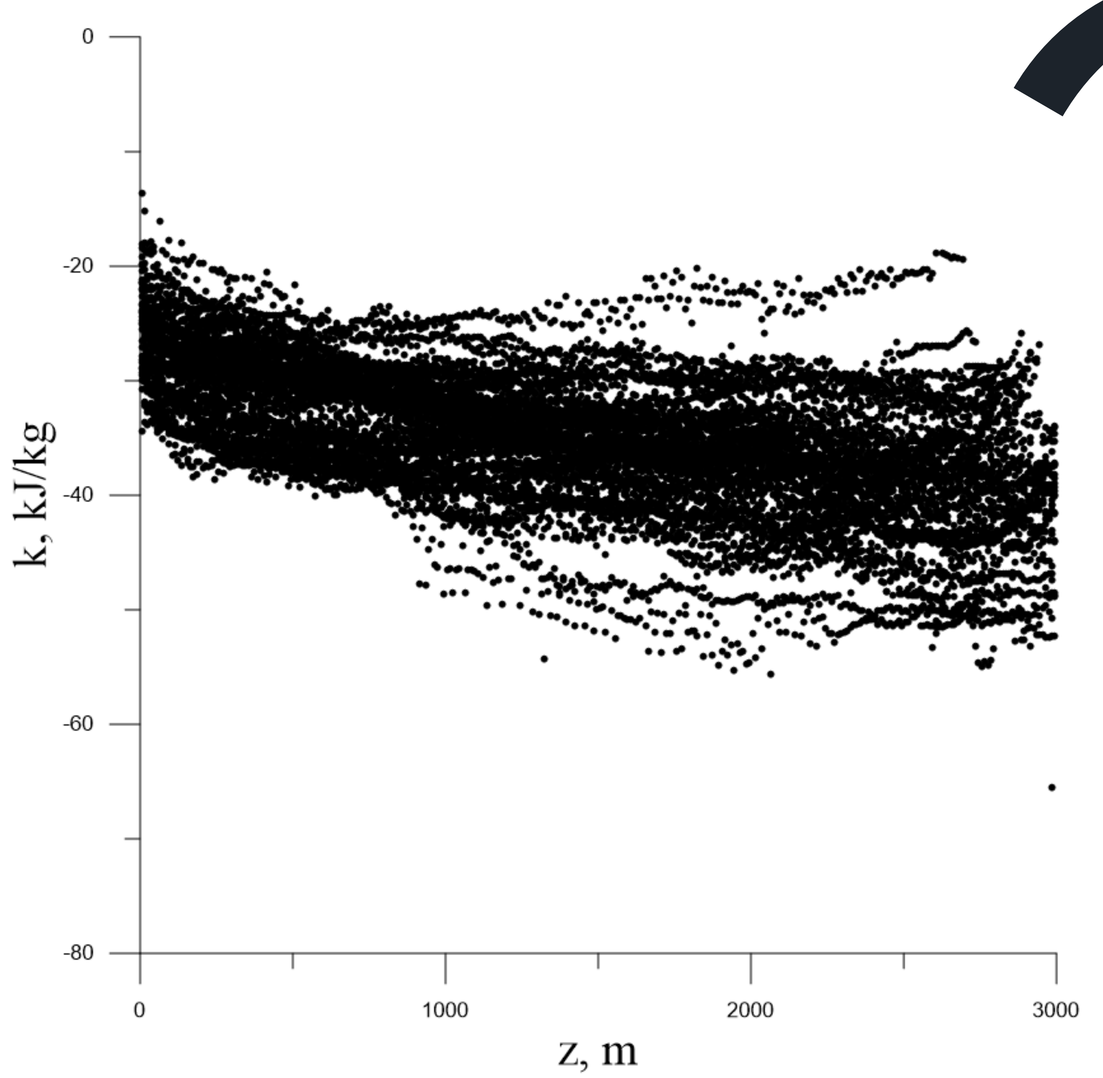
The enthalpy profiles averaged over the selected ensembles in the wake part of the boundary layer were approximated by a second degree polynomial:

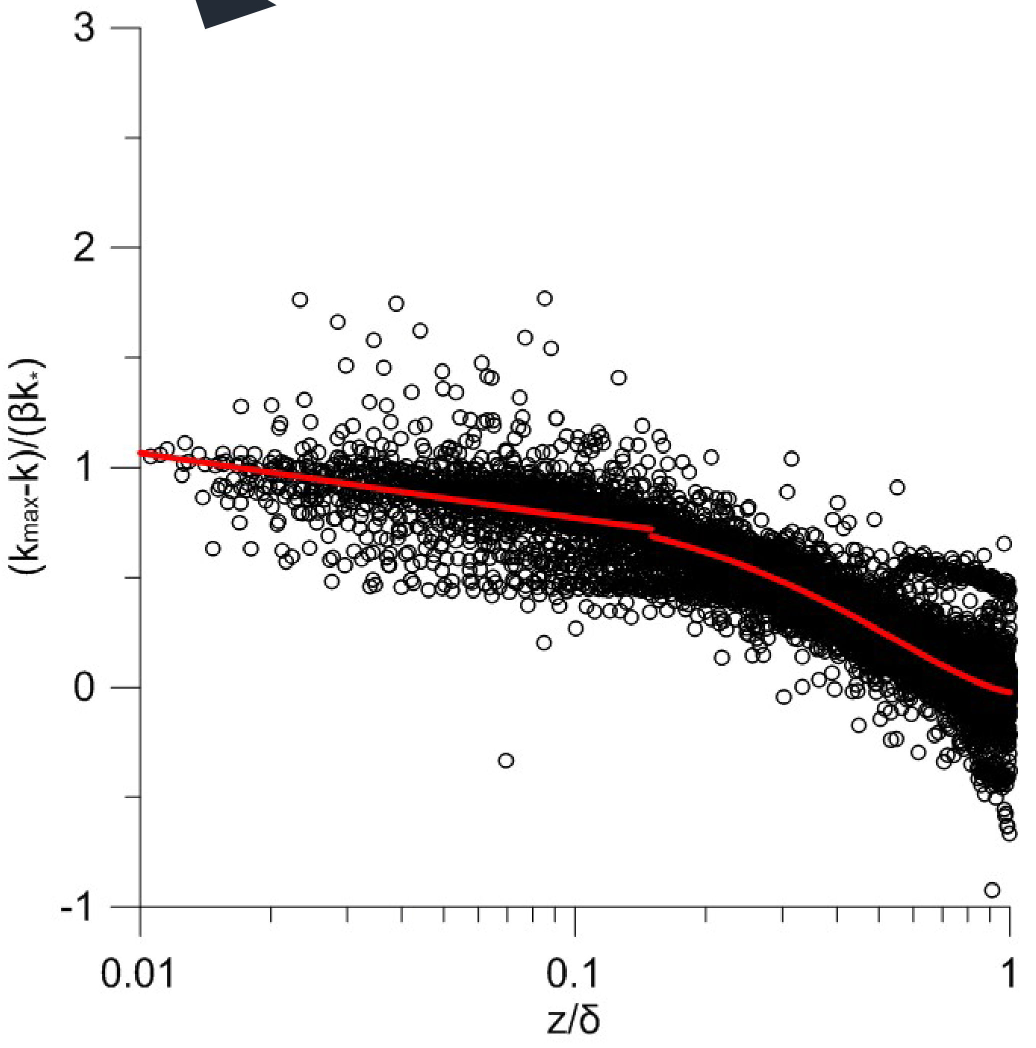
$$k(z) = p_3 + p_2 z + p_1 z^2$$

Due to this parabolic approximation, the following parameters of the enthalpy profile are calculated:

$$\beta k_* = -\frac{p_2^2}{4 p_1}; \delta = -\frac{p_2}{2 p_1}; k_{\max} = p_3 + \beta k_*$$

Using the calculated parameters, the profiles in physical variables are reduced to dimensionless





Ensemble of enthalpy profiles in physical and self-similar variables

Normalization demonstrates that experimental data are grouped around a curve described by the expression:

$$\frac{k_{\max}-k(z)}{\beta k_*}=\begin{cases}\frac{1}{\beta}\left(-\frac{1}{\kappa}\Pr\ln\frac{z}{\delta}+\alpha\right); z/\delta<0.15\\ \left(1-\frac{z}{\delta}\right)^2; z/\delta>0.15\end{cases}$$

The approximation of the logarithmic part of the profile gives the values of the slope and the constant component and allows us to calculate the values of the friction coefficient of the enthalpy k* for each ensemble.

Using the formula for the enthalpy difference:

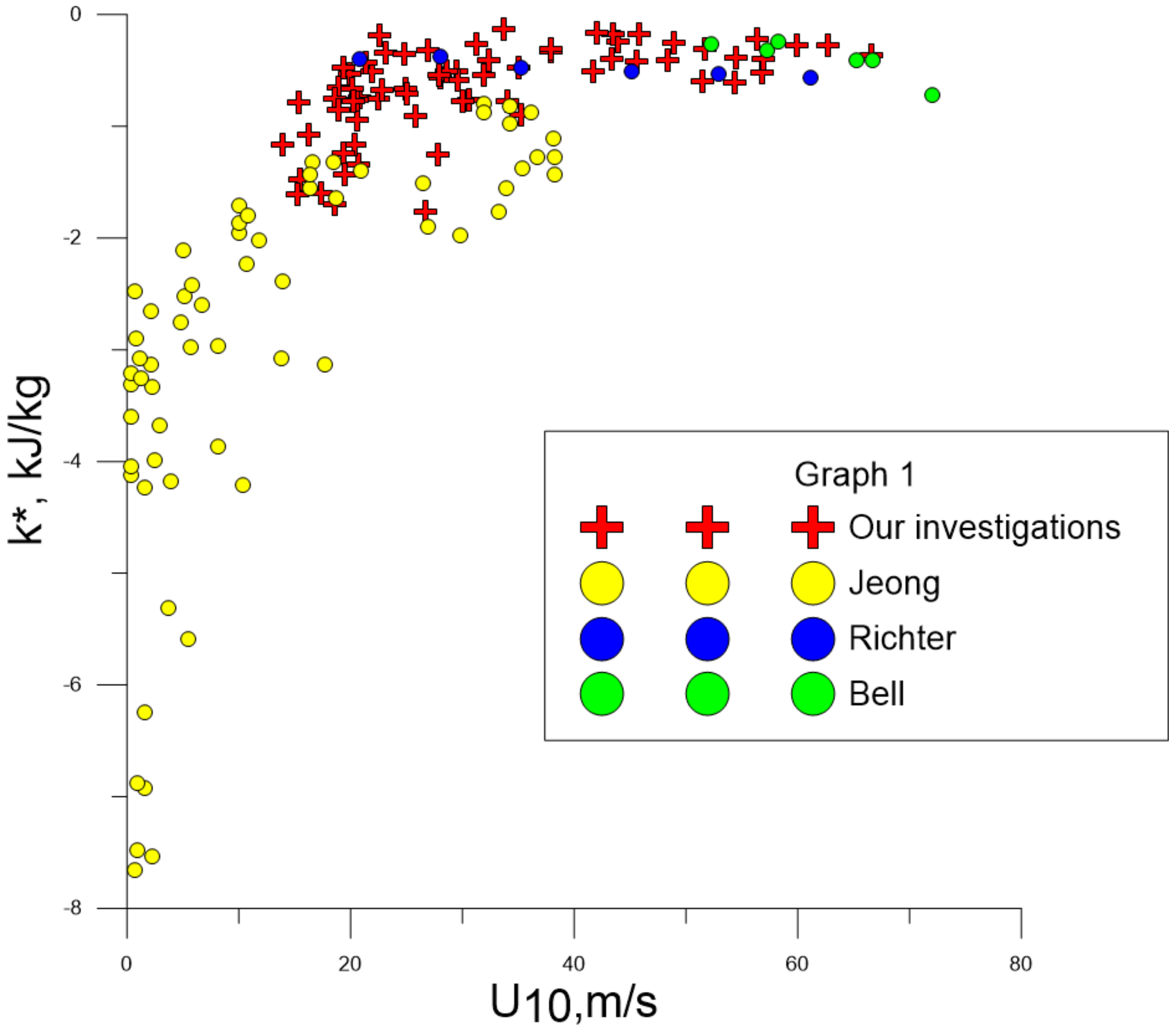
$$k(z)-k(0)=\frac{k_*}{\kappa}\Pr\ln\frac{z}{z_0}$$

here z_0 is the enthalpy roughness parameter reconstructed by the formula:

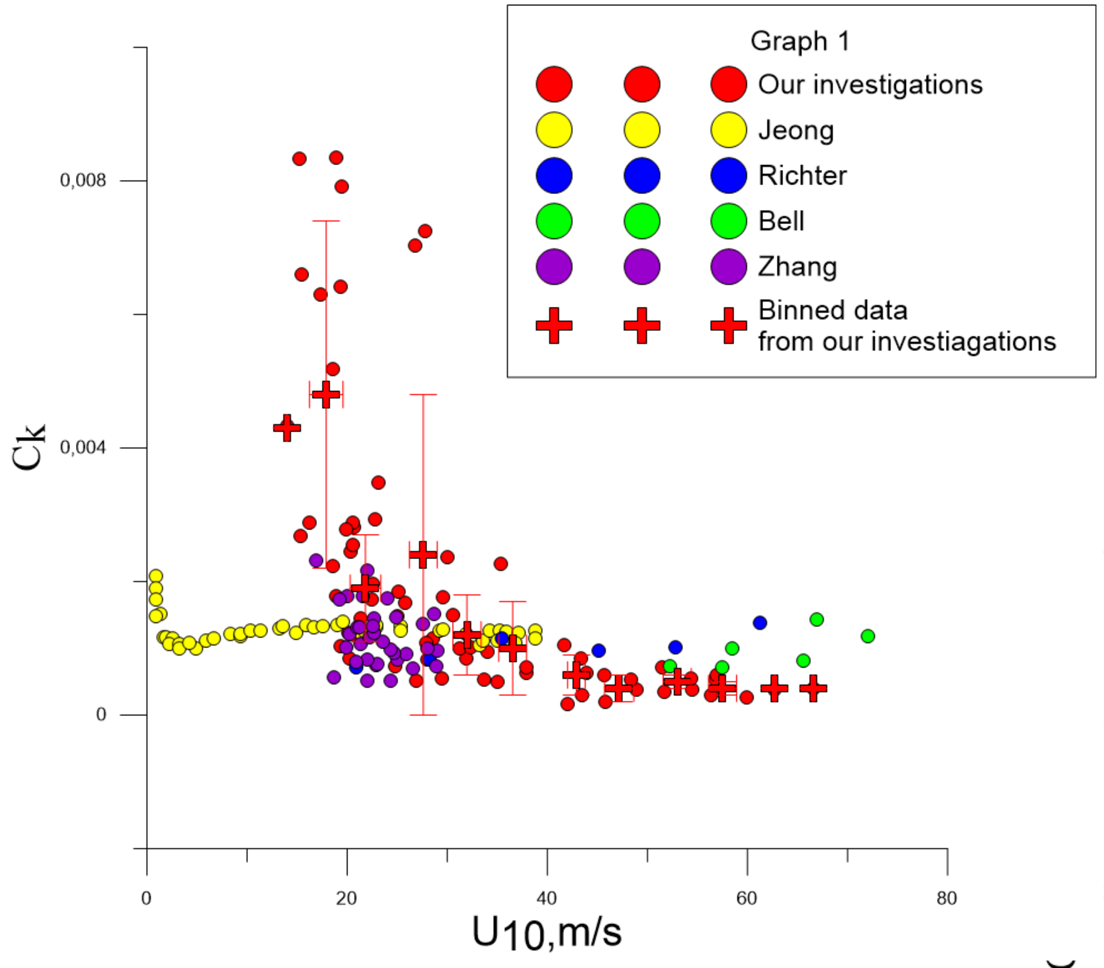
$$z_0=\delta\exp\left(-\frac{\kappa k_{\max}}{\Pr k_*}+\alpha\kappa\right)$$

enthalpy exchange coefficient C_k, which is responsible for the increase in the intensity of the hurricane due to the heat coming from the ocean surface

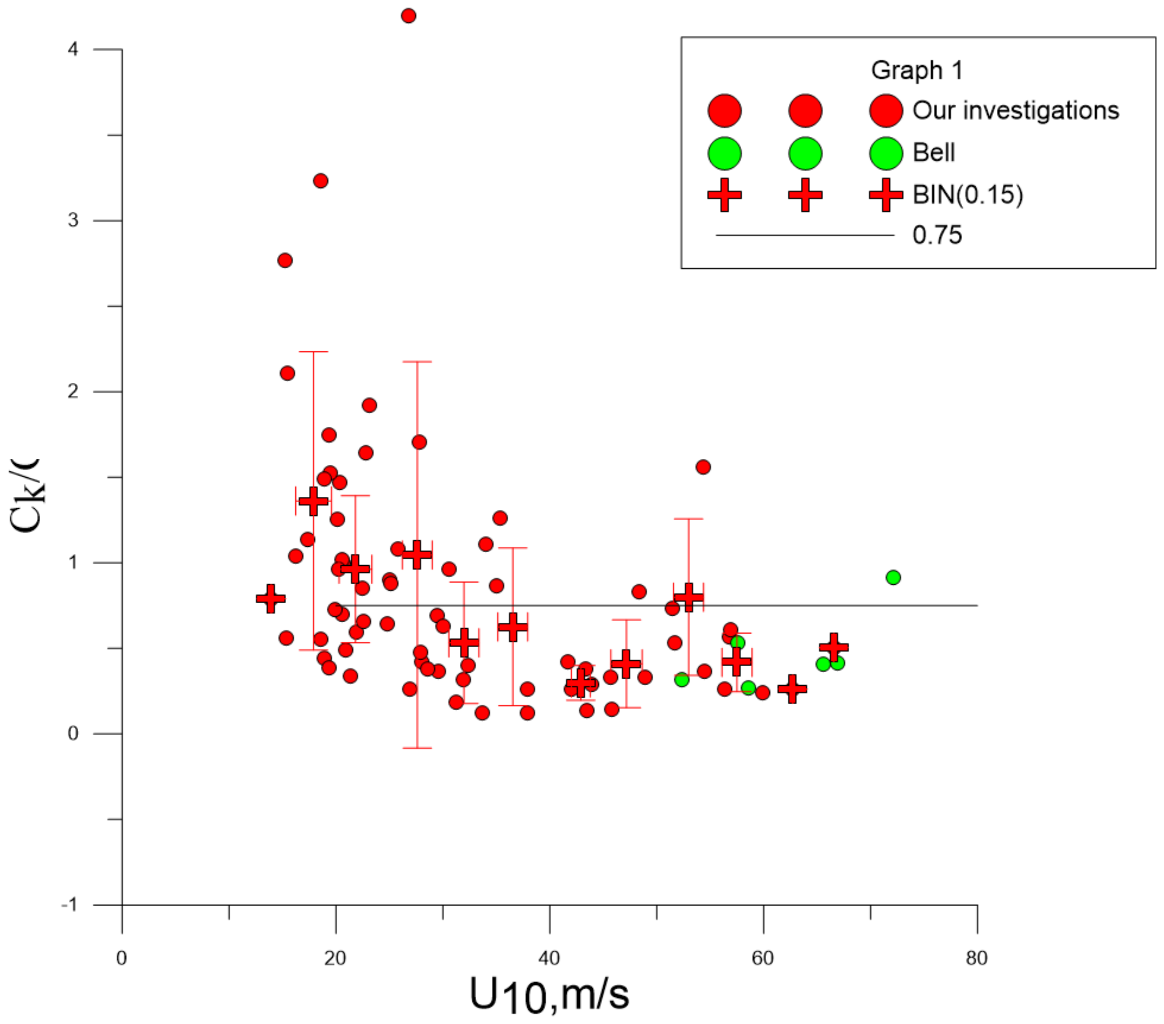
$$C_k=\frac{k_*\sqrt{C_d}}{k(10)-k(0)}$$



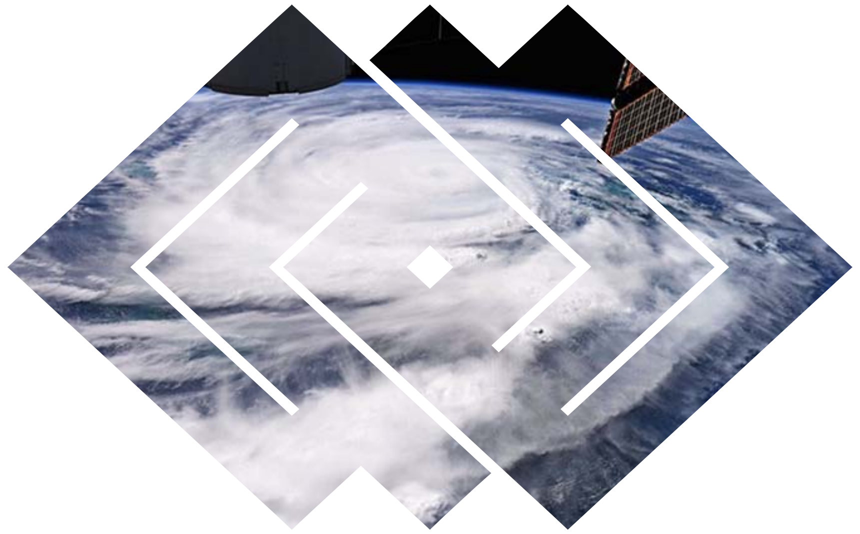
k_* dependence on wind speed at meteorological height in comparison with data from earlier studies (Bell et al, 2012, Richter et al, 2016, Jeong et al., 2012).



Dependence of the enthalpy exchange coefficient on wind speed in comparison with the values obtained from the studies Bell et al, 2012, Richter et al, 2016, Jeong et al., 2012)



The dependence of the ratio of these coefficients binned by wind speed with the step of 5 m/s and data from (Bell et al, 2012).



Conclusions

An approach is proposed for describing a turbulent boundary layer formed in hurricane conditions, based on the use of the self-similarity properties of a velocity defect in the boundary layer, which includes a constant-flow layer passing into its “wake” part. The advantage of this approach is the ability to use velocity profile measurements at a distance from the surface (in the “wake” part). This approach was applied to the thermodynamic parameters of the boundary layer to retrieve the enthalpy exchange coefficients, which play a significant role in predicting the intensity of a hurricane.