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Monitoring cumulus clouds using global horizontal irradiance data

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Cb formation stages

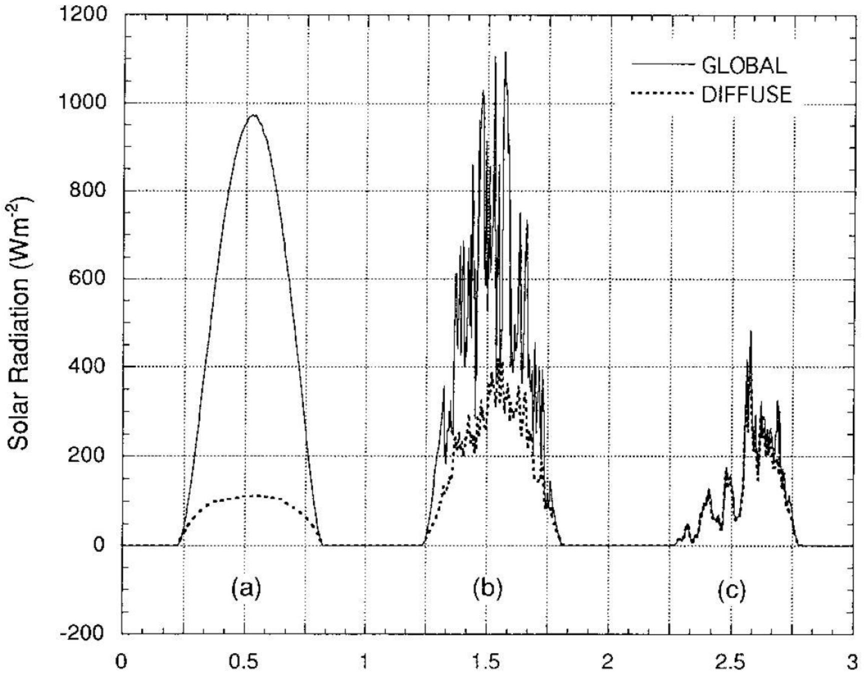
Cb are sources of dangerous meteorological phenomena (showers, thunderstorms, squalls, etc.) and form from *Cu*. Continuous *Cu* monitoring can predict *Cb* formation.

www.clouds-online.com
www.dreamstime.com

Common method for estimation cloud type using *GHI* data

Global Horizontal Irradiance (***GHI***) is the sum of Direct Normal Irradiance (***DNI***) (at some Sun altitude *h*) and Diffuse Irradiance (***DI***):

$$Q = S \cdot \sin h + D.$$

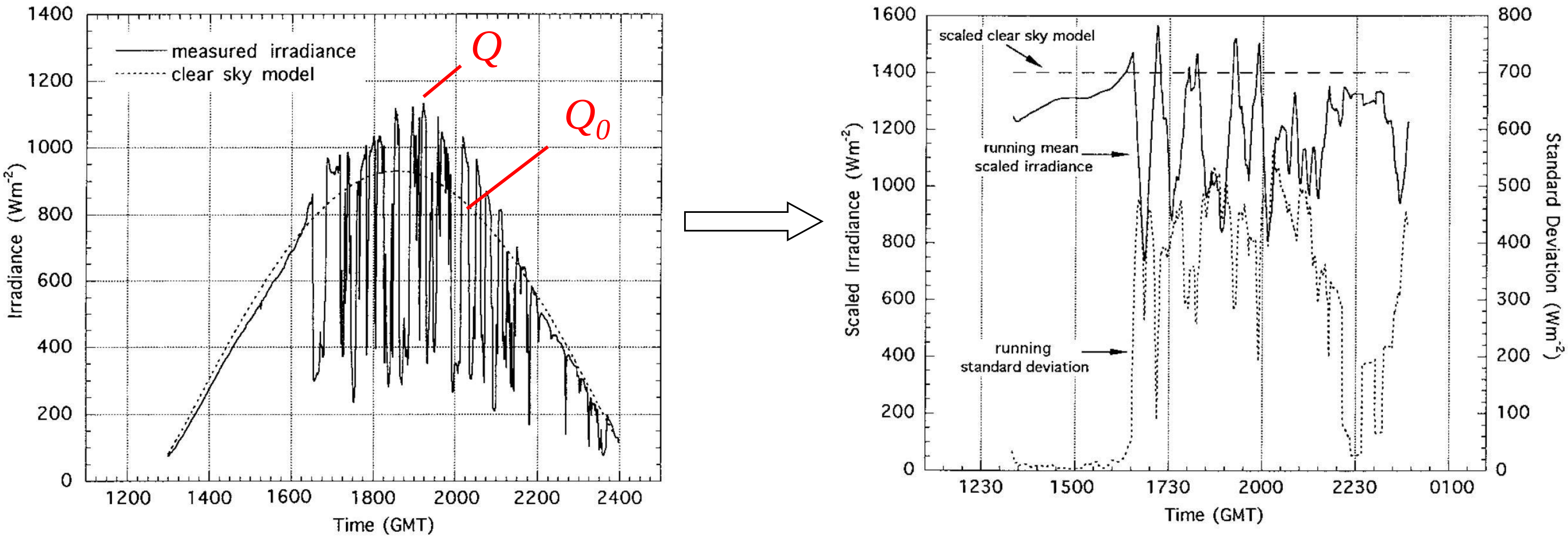


Procedure for determining the cloud type:

1. Estimation of the average value of the analyzed GHI window.
2. Estimation of the GHI standard deviation of the analyzed window.

Duchon 1999

Common method for estimation cloud type using *GHI* data

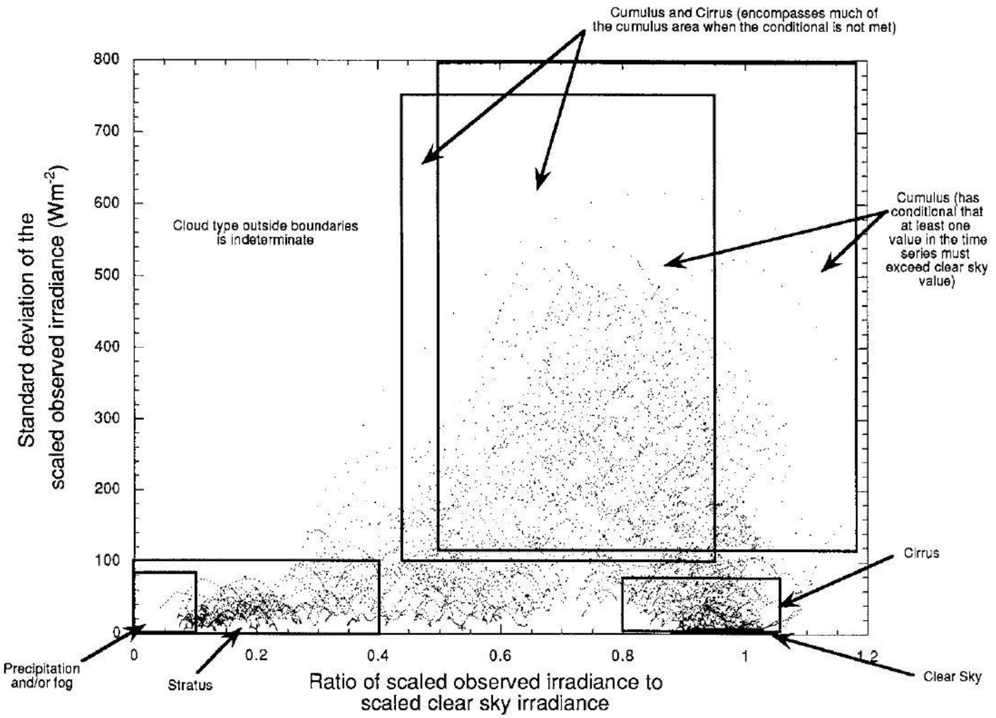


At first, non-stationary *GHI* time series is converted to stationary using any clear sky model Q_0.

Duchon 1999

Common method for estimation cloud type using *GHI* data

Then, using a 21-minute moving window (±10 minutes near the point of analysis), its variation and amplitude characteristics are determined.



And finally, the analyzed point is assigned a cloud type according to the decision criterion.

For *Cu*: $\sigma = 100 \div 800$ W/m^2

$Q/Q_0 = 0.4 \div 1.2$

Duchon 1999

Difficulty of clear sky irradiance modeling

To compute the clear sky model

$$Q_0 = S_0 \cos\Theta_z T_R T_g T_w T_a$$

a large dataset of measurements and reference data (8 parameters in total) are required:

$$T_R T_g = 1.021 - 0.084[m(949p \times 10^{-5} + 0.051)]^{0.5},$$

$$m = 35(1224 \cos^2\theta_z + 1)^{-0.5}$$

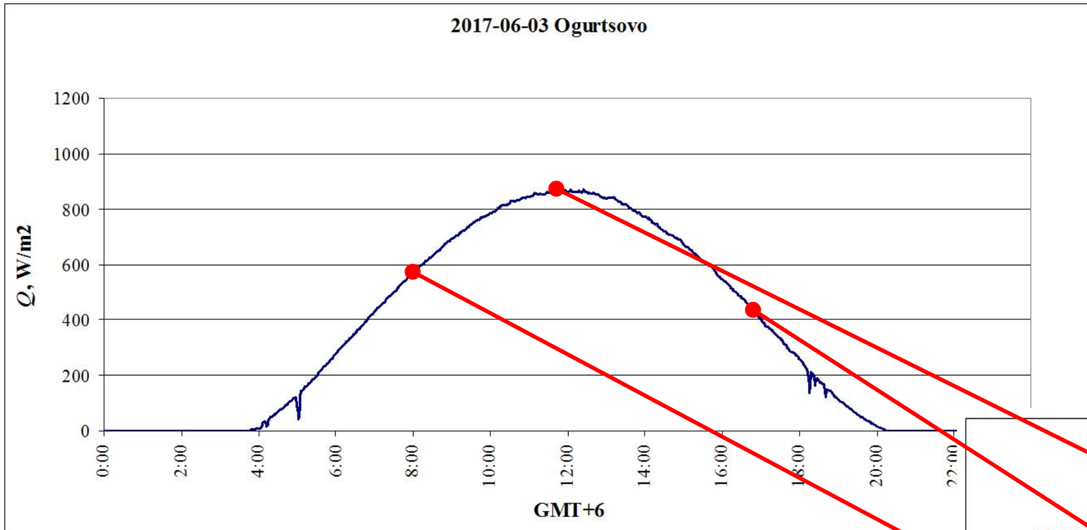
$$T_w = 1 - 0.077(um)^{0.3},$$

$$u = \exp[0.1133 - \ln(\lambda + 1) + 0.0393 T_d],$$

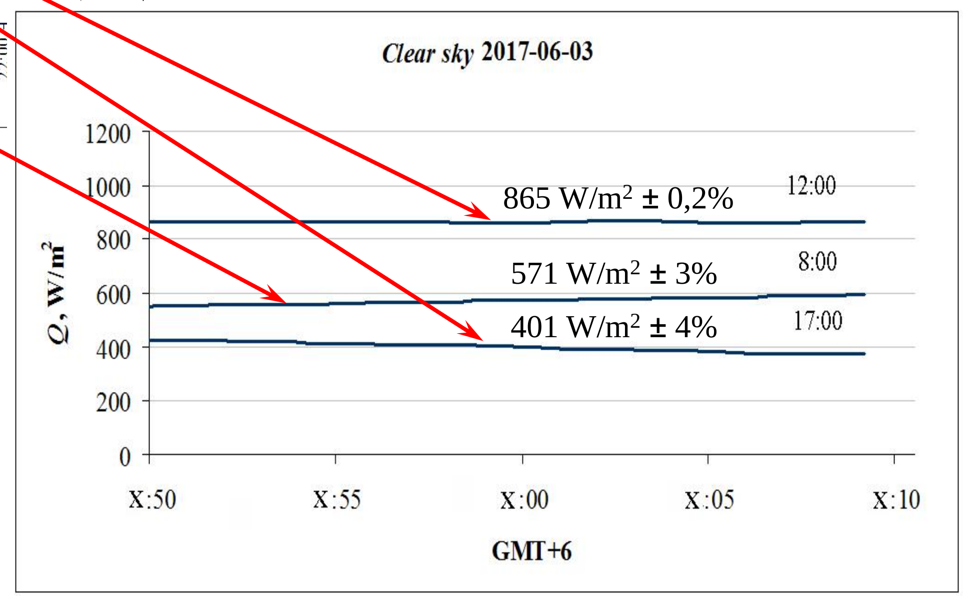
$$T_a = x^m$$

Duchon 1999

Stationarity of short GHI samples



Short 21-min samples of the GHI time series can be considered as stationary.



No clear sky model needed.

The coefficient of variation (CV) $V = \dfrac{\sigma}{Q_{AV}}$ is used instead of the standard deviation σ.

WMO 29638. 2017-06-03

Specific features of *Cu*

1. Dense opaque clouds.

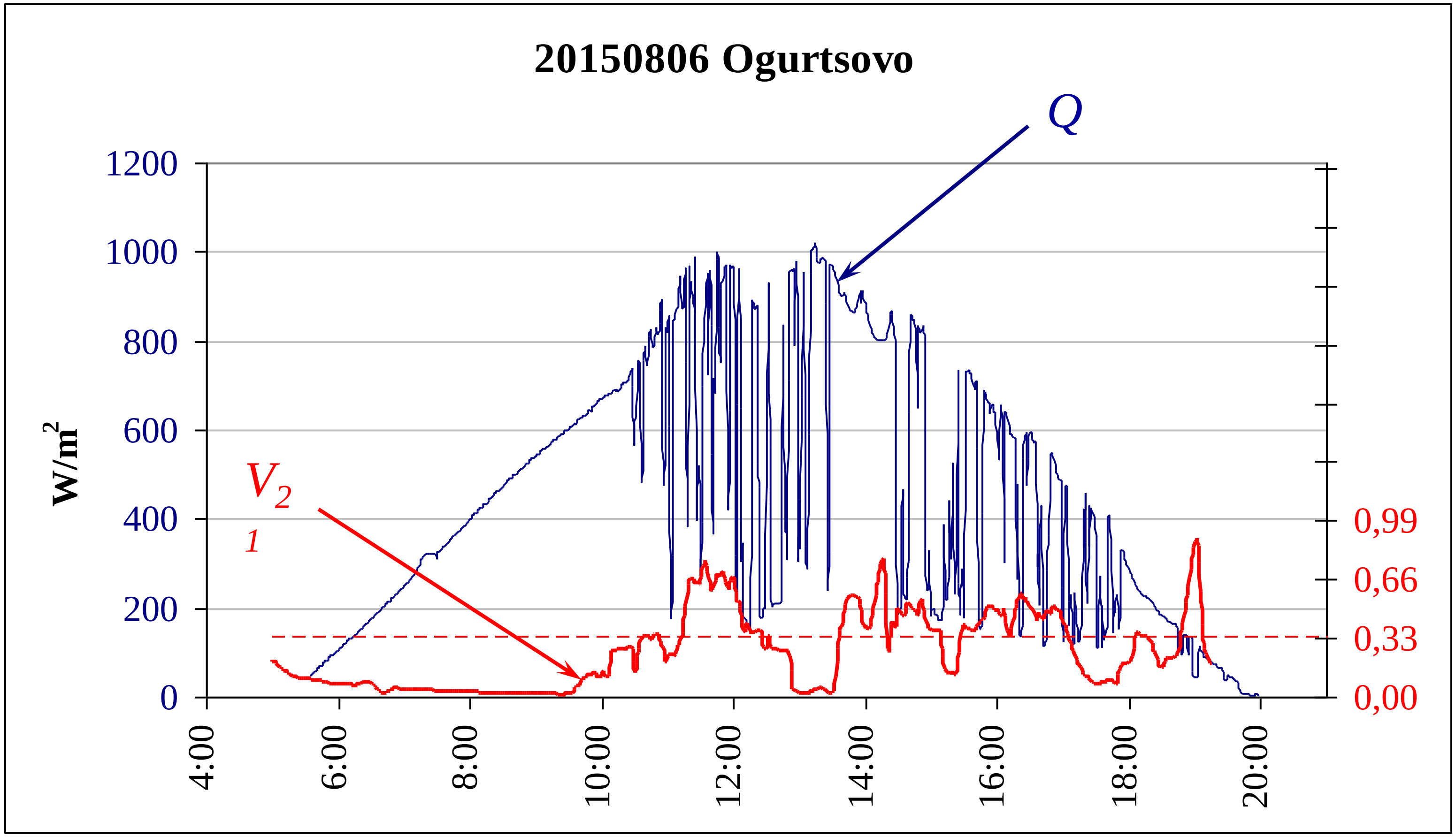
2. Clear skies between separate clouds.

3. The Sun is almost always at one of a stable states:

- completely closed and $Q_{min} = D$,
- completely open and $Q_{max} = S' + D$.

WMO 29638. 2015-08-06

Cu detector V_{21}



The result, under *Cu* form a very heterogeneous GHI time series. When the coefficient of variation (CV) for a 21-min. moving window $V_{21} > 0.33$, near analyzed point ±10 min. cumulus are present.

WMO 29638. 2015-08-06

Cu detector V_{21} problems

Similar variation characteristics also form under *St* and *Ns*.

This is due to the high sensitivity of CV to small changes of *Q* at its low average values.

For the detector V_{21} an additional criterion is required.

http://habr.com
http://travelask_ru

Cu detector $V_{21}+V_3$

The Sun is completely closed.

Transitional state of the Sun.

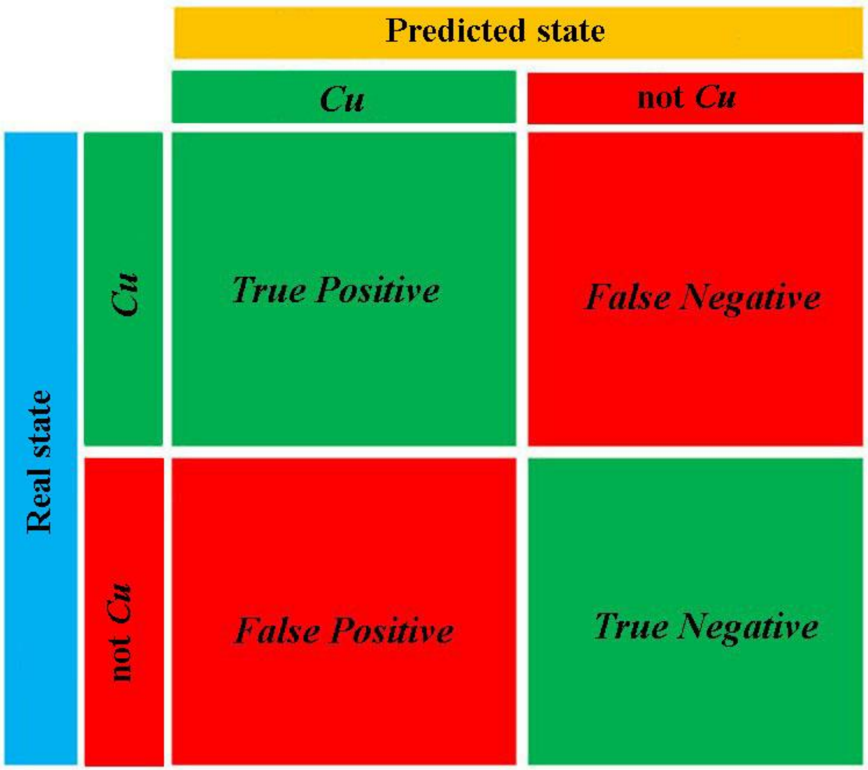
The Sun in completely open.

Another specific feature of *Cu* is its distinct boundaries. Therefore, the change from one Sun stable state to another takes a short time (usually 1-2 min.). At the same time, sharp changes are formed between Q_{max} and Q_{min} at the GHI time series. This is an additional criterion, the analysis of the CV of a 3-minute window V_3 (±1 min. near the point of analysis), moving within the analyzed 21-min. window. If at least for one point $V_3 > 0.33$, then *Cu* are present.

Comparison of V_{21} and $V_{21}+V_3$ detectors

For compare the detectors, the GHI data of the CM-11 pyranometer (May-August 2018 for $h > 30º$) and the All-sky images of the MVK-1653c panoramic camera (IMCES SB RAS) are used.

Comparison of V_{21} and $V_{21}+V_3$ detectors



Detecting *Cb* as *Cu* was not considered a mistake.

The results were checked using a binary classifier (predicted / real state):

True Positive (*TP*) – *Cu* / *Cu*

False Positive (*FP*) – *Cu* / not *Cu*

False Negative (*FN*) – not *Cu* / *Cu*

True Negative (*TN*) – not *Cu* / not *Cu*

Positive Predictive Value $PPV = \frac{TP}{TP+FP}$

True Positive Rate $TPR = \frac{TP}{TP+FN}$

F-measure $F_1 = \frac{2 \cdot PPV \cdot TPR}{PPV + TPR}$

Comparison results

Month	Version	Total analysis points	*TP*	*FP*	*FN*	*PPV*	*TPR*	F_1
May	V_{21}	14806	2821	440	316	0,86	0,90	0,88
	$V_{21} + V_3$	14745	2051	191	390	0,91	0,84	0,88
June	V_{21}	13255	1885	723	677	0,72	0,74	0,73
	$V_{21} + V_3$	13201	1556	344	722	0,82	0,68	0,74
July	V_{21}	16913	2628	448	588	0,85	0,82	0,84
	$V_{21} + V_3$	16853	2621	230	668	0,92	0,80	0,86
August	V_{21}	14784	2562	592	913	0,81	0,74	0,77
	$V_{21} + V_3$	14732	1933	306	1037	0,86	0,65	0,74
Total (mean)	V_{21}	59758	9907	2203	2494	(0,81)	(0,80)	(0,81)
	$V_{21} + V_3$	59531	8188	1071	2817	(0,88)	(0,74)	(0,81)

The result of using the additional criterion:

1. Errors of *Cu* detection decreased by 50%;
2. The precision has increased by 7% with a decrease of the sensitivity by 6%.

Comparison results

Month	Version	Total analysis points	Total points *FP*				
			Ci fib.	*Ac cuf.*	*Sc cuf.*	*St*	*Ns*
May	V_{21}	14806	0	191	244	0	5
	$V_{21} + V_3$	14745	0	79	112	0	0
June	V_{21}	13255	125	365	223	0	18
	$V_{21} + V_3$	13201	17	233	94	0	0
July	V_{21}	16913	0	145	147	52	104
	$V_{21} + V_3$	16853	0	128	178	0	0
August	V_{21}	14784	24	206	455	0	73
	$V_{21} + V_3$	14732	5	167	139	0	0
Total	V_{21}	59758	149	907	895	52	200
	$V_{21} + V_3$	59531	22	607	442	0	0

3. Errors of *St* and *Ns* have completely disappeared.
4. Errors of *Ac cuf*. decreased by 30%;
5. Errors of *Sc cuf*. decreased by 50%;

To reduce errors of *Ac cuf*. and *Sc cuf*. further studies are required.

Conclusion

- The proposed method allows monitoring medium and high *Cu* amount at near real time.
- To realize the method does not require difficult calculations.
- Possibility to use the existing network of actinometric observations.
- Possibility of using simple PAR sensors.

Thank you for attention!

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