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Verification of global radiation fluxes forecasted by numerical weather prediction model AROME for Hungary

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Abstract— Global radiation output fluxes predicted by numerical weather forecast model AROME were verified by using measured high accuracy global radiation data from the 19 most reliable network stations of the Hungarian Meteorological Service. Three suitably-selected months (April, June, August) from 2013 were used for the study. Differences between observed and forecasted values were analyzed separately for all cases, overcast cases, and cloudless (clear-sky) cases. It was found that AROME performs well for clear cases, and its goodness decreases as cloudiness increases. For cloudless cases, using aerosol optical depth, graybody optical depth, and relative global radiation to represent radiative transmission condition of the atmosphere, it was found that AROME overestimates atmospheric radiation transmission for cases of high turbidity and underestimates it for very clear conditions. It means that radiation transmission scale of the atmosphere produced by the model is more narrow than that of true atmosphere.

Key-words: verification, solar radiation, global radiation, observed data, radiative transmission of the atmosphere, optical depth

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1. Introduction

The aim of this study was to obtain detailed quantitative information about quality of predicted global radiation fluxes of numerical weather forecast model AROME. To know the performance of the predicted global radiation values is of primary importance not only to know how the model itself performs, but because using global radiation prediction starts to become more and more important in the solar energy sector mainly for providing the possible most effective operation of photovoltaics.

In addition to the use of forecasted global irradiance values coming from numerical weather prediction models, there have been developments to produce forecasted global radiation data by empricial models, but very few verification results have been published despite its crucial importance. An example for published results of verification of two empirical models is paper of Foyo-Moreno et al. (*Foyo-Moreno et al.,* 1990).

We have some previous experiences concerning verification of predicted solar radiation fluxes that comes from verification of predicted direct, global, and diffuse radiation fluxes of ALADIN model (*Tóth,* 2002), consequently it was approximately known what the expected strengths and weaknesses can be and where they are mainly found. AROME is a limited-area, high-resolution, non-hydrostatic, mezoscale weather forecast model. It has been developed since 2000 by coordination of MeteoFrance (*Seity et al.,* 2011; *Szintai et al,* 2015). It contains 59 layers between the surface and the level of 2.7 hPa pressure, while its horizontal spatial resolution is 2.5 km. AROME is run eight times a day at the Hungarian Meteorological Service. It uses the radiative trasfer model of the ECMWF. The quantitative background for it is given by both the model of Fouquart and Bonnel (*Fouquart* and *Bonnel,* 1980) for the short-wave range of the spectrum and the radiative transfer model RRTM for the long-wave range (*Mlawer et al.,* 1997) to produce radiation output quantities. Global radiation and short-wave net radiation are default output quantities of AROME, while some modifications in the code are needed to obtain predicted direct and diffuse radiation fluxes.

2. Data and method

2.1. Predicted data

Outputs from running of model AROME LAM and measured values from 21 selected stations of the global radiation monitoring network of the Hungarian Meteorological Service (OMSZ) were used for the verification. The study was performed both for daily and half-day (morning and afternoon) totals. The two half-days were separated at 12 h Central European Time (UT+1 h) instead of 12 h true time. It was reasonable, because the forecasted values were available in UT that means mean time setting similarly to CET. It can result in negligible error in the half-day global radiation values due to equation of time is not significant in magnitude as compared with a half-day interval.

Since predicted global radiation values are not archived in the operational practice, the model was to run again separately for this study. It requires long computer time, and because the re-running could be performed only on the computer of the OMSZ on which the operational forecast is run, the verification could be performed for a limited temporal interval that means three months only.

Due to this obligate limitation, a simple pre-study has been made to select the sufficient months instead of consecutive months. The reason for it was to provide, on the one hand sufficient number of completely clear sky day for the study, on the other, to provide higher diversity of weather conditions: more variable and more stabil periods, more rainy and drier periods, periods being richer in thunderstorms, etc. Suitably-selected months can meet these requirements with far higher reliability than months selected without pre-determined criteria. Considering these facts, April, June, and August of 2013 have been selected for the study, so the re-running of AROME has been done for the months in question.

2.2. Measured data as reference values

Global radiation monitoring network of the OMSZ consists of 40 stations using Kipp&Zonen pyranometers. Operational measurements at the OMSZ are carried out in ISO QA/QC system, so the suitable calibration of the radiometers and routine check of the measured values are continuously operationally provided according to the concerning working instructions of the OMSZ. This fact gives base to use measured data as reference for the verification without any separate study carried out to check reliability of measured data. Still, to obtain the possible highest quality results, and, in the same time, not to considerably enhance the number of data used, a ’sub-network’ of stations were selected including approximately half of the total number of the stations. 19 stations have been selected for the study by a method that had developed to determine quantitatively the reliability of each station and so to keep the reliability of the global radiation network continuously on the possible highest level. *Table 1* shows the stations and their coordinates used for the study.

2.3. ’Goodness’ of the forecast

’Goodness’ of the forecast was represented by the relative error of deviation of forecasted values from the measured value. Forecasted value valid for a given station was taken into consideration as it is usually estimated in the practice to minimize the uncertainty: it is that the forecasted value for a grid quadrat containing the given station is not the value itself forecasted for the given grid quadrat, but is the mean of the forecasted values for the neighboring grid quadrats. It was performed both for four neighboring quadrats and eight neighboring quadrats, but goodness of the forecast did not show any increase in case of averaging from eight values, so four neighboring values were used for the study.

Table 1. Geographical coordinates of the stations used for the study

Station	**φ (°)**	**λ (°)**
Agárd	47.19	18.58
Budapest-Pestszentlőrinc	47.43	19.18
Debrecen	47.49	21.61
Eger	47.90	20.39
Győr-Likócs	47.71	17.67
Kecskemét K-Puszta	46.97	19.55
Keszthely	46.74	17.27
Kékestető	47.89	20.01
Kunmadaras	47.47	20.89
Nyíregyháza	47.96	21.89
Pápa	47.36	17.50
Pécs-Pogány	46.00	18.24
Püspökszilágy	47.73	19.31
Sopron-Fertőrákos	47.71	17.67
Szeged-külterület	46.26	20.09
Szentkirályszabadja	47.08	17.97
Szolnok	47.12	20.23
Szombathely	47.20	16.65
Tápiószele	47.36	19.89

The verification was performed for (i) all cases, for (ii) totally clear and (iii) overcast cases. To perform the verification for completely cloudless cases is important, because it represents ’purely’ the radiative part of the forecast. Due to the very strong effect of cloudiness on the radiative transfer in the atmosphere, verification of the global radiation forecast of the model for cloudy cases becomes, actually, a kind of verification of cloudiness forecast and parametrization of cloud microphysics, except the slightly cloudy cases.

To categorize the cases, the so-called relative global radiation (RELG) was used. RELG for a certain time is defined as the ratio of measured value to the calculated possible maximum value for the time in question. The possible maximum value was taken into consideration as the highest value ever occured in a thirty year interval (1967–1996) of our global radiation database for the certain time that has been selected by a statistical method (*Nagy*, 2005). A study has been performed to obtain empirical relationship between RELG and cloudiness. Cloudiness values for the study have been taken from cludiness observations operationally carried out in the Marczell György Main Observatory and from satellite cloud estimations performed operationally in the Unit of Remote Sensing of the OMSZ. The results have yielded the following values: RELG values higher than 0.85 correspond completely clear sky and RELG values lower than 0.25 correspond overcast cases, with high reliability. The verification thus was performed for those three RELG categories.

Simple relative error (RE) was used to represent goodness of the forecasted global radiation values, as it was mentioned above. RE was calculated in the usual way:

$$RE = \frac{G_{FOR} - G_M}{G_M} 100, \qquad (1)$$

where RE is the relative error (%), $G_{FOR}$is the forecasted global radiation value in J/cm^2, and G_M is the measured global radiation value in J/cm^2.

Relative errors were categorized to intervals of 5%, and their relative frequencies were analyzed.

3. Relative error for all cases

3.1. Daily totals

Results for daily totals can be seen in *Fig. 1*. Shape of the relative frequency for April and June is reasonably similar, but differs for August. It reflects the different weather situation in respect of solar radiation. The number at the upper righ corner of the figures indicates the percentage rate of the cases when difference relative error was lower than 15% in absolute value. According to this indicator (that can be called as somewhat ’general monthly goodness’, it is clear that the model performed, in general, most accurately for August (75.7%) and least accurately for June (68.6%). This behavior can be resulted in by the more frequent occurence of cloudless or slightly cloudy cases and the small number of thunderstorm situations, while April characterized by very rapidly varying weather. Modality of the frequency distribution that can be produced from the frequencies is somewhat close to the Gaussian curve, but the number of extremely high overestimations (>50%) is big enough to deform it for each month. Assymetry is resulted in by the positive range (0–5 %) both for June and August, while for April it is caused by the negative range (–5– 0%). As it is clear from *Fig. 1*, frequency of very high overestimations (>50%) almost equals for June and August (5 and 6%, respectively), but considerably higher for April (10%). This phenomenon can be resulted in by the fact that the weather has higher and more rapid variability in April than in the other two months, and the model can track it with less reliability. It can seem to be a contradiction that the number of very high overestimation was lower in June, when the general goodness of the forecast was the lowest, than in April. The reason probably is that the model can predict the rainy and showery situations with a bit higher reliability than the rapidly and highly fluctuating ones.

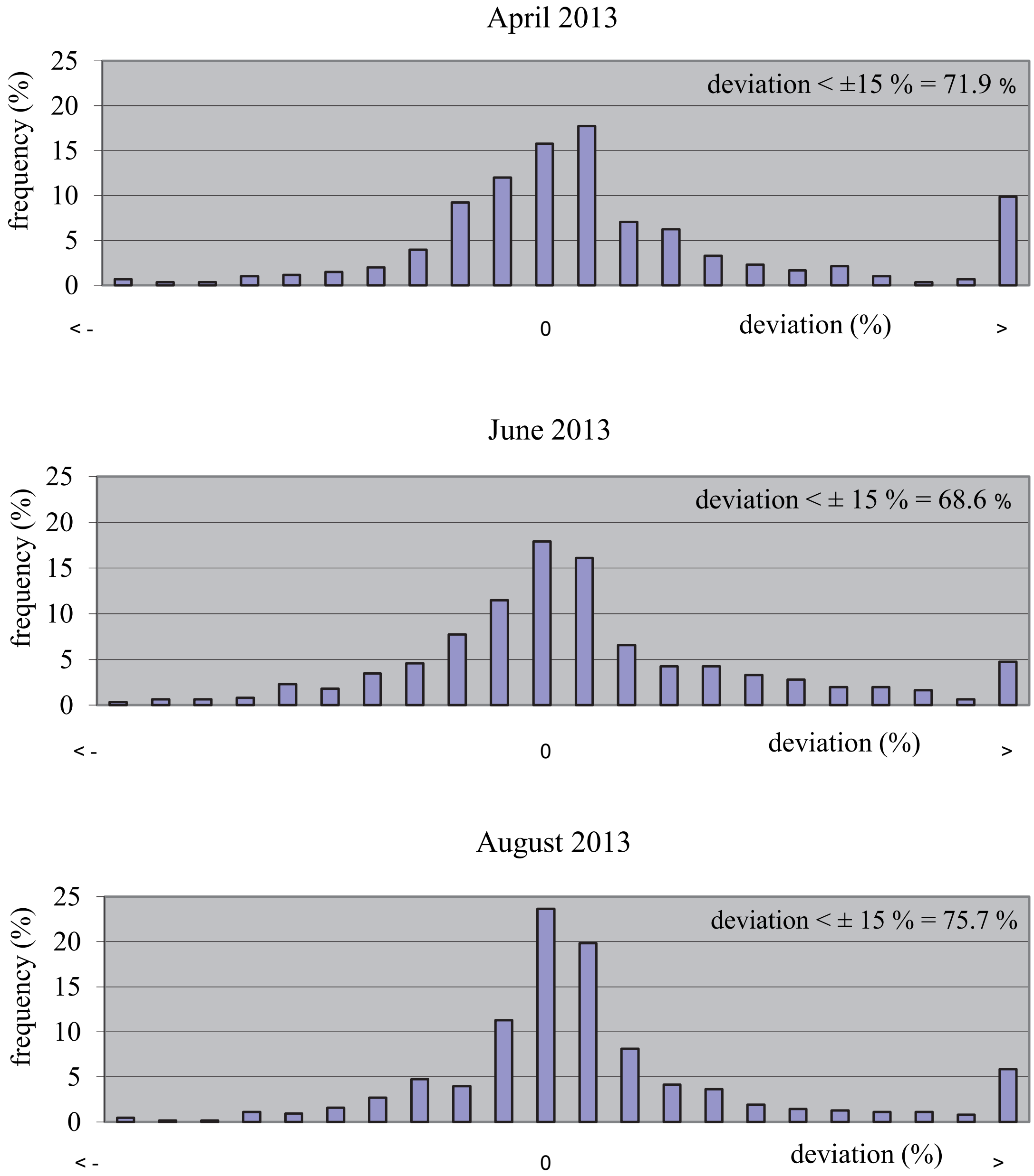


Fig. 1. Frequency of the relative error for daily totals

3.2. Half-day totals

Concerning first half-day (morning) totals, characteristics of the errors essentially similar to those obtained for the daily totals, as it can be seen in *Fig. 2*. April considerably differs from June and August in shape, and the goodness is highest for August (70.6%) and the lowest in June (65.5%). It is clear from the figure that frequency of cases when relative error was higher than 50 % was higher than in case of daily totals.

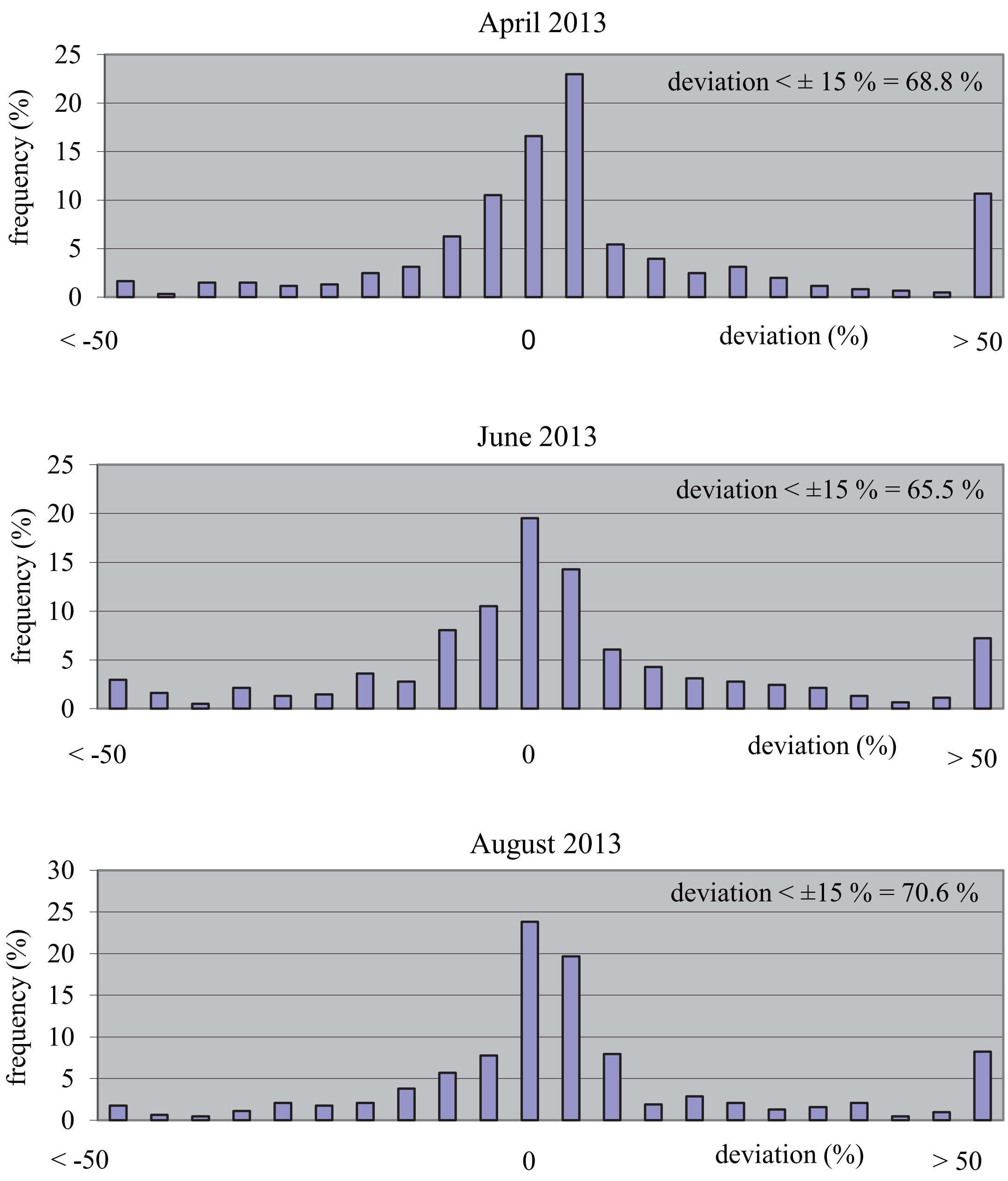


Fig. 2. Frequency of the relative error for first half-day totals

Accuracy of the forecasts was found to be the lowest for the second half-days (*Fig. 3*). Here the shape of the frequency distribution for April does not even approach the Gaussian function, unlike for June and August, and because the skewness is resulted in at the negative part of the *x* axis, an inclination for underestimation can be concluded. This effect is stronger for the second half-days, so it can be assumed that either the sky was less cloudy in reality than it has been forecasted or the radiation transmission of the realistic clouds has been higher than that of the model clouds. The general goodness indicator values are considerably lower than those for the first half-day totals for each months: it is 60.6 for April, as against the 68.8 for morning half day totals, and 58.0 for June (65.5 for morning). It is interesting that the two values completely equal for August (69.9). The difference between the goodness values for the two half-days for the corresponding months can be resulted in by the fact that the atmosphere is generally more instable in afternoon, but, at the same time, the differences seem to be too high to be explained solely by the different stability. One can assume that an effect of non-representative sampling can contribute to it: the number of days is presumably not sufficiently high to reduce the effect of special, uncharacteristic weather situations on the statistics, and involving more (at least three or four) of each month in the study can maybe decrease the difference in question.

The relative general stability of weather in August as compared with the two other months involved in this study can be the reason why no goodness difference between the two half-day for August was found.

Different behavior was found for the extremely high range (>50%) of errors. All of these very high errors are overestimations and their frequency is the same for both half-days for April and August, but, however, considerably differs for June: its value is between 7% and 8% for the first half-day totals, as against the value between 10% and 11% for the afternoon totals. It cannot be decided if either real atmospheric physical processes have resulted in these differences completely or also insufficient number of data contribute to the effect, as it was supposed in case of general goodness.

Based on the results shown above, it is, as a general rule, to be concluded that the model more poorly performs on shorter time scales.

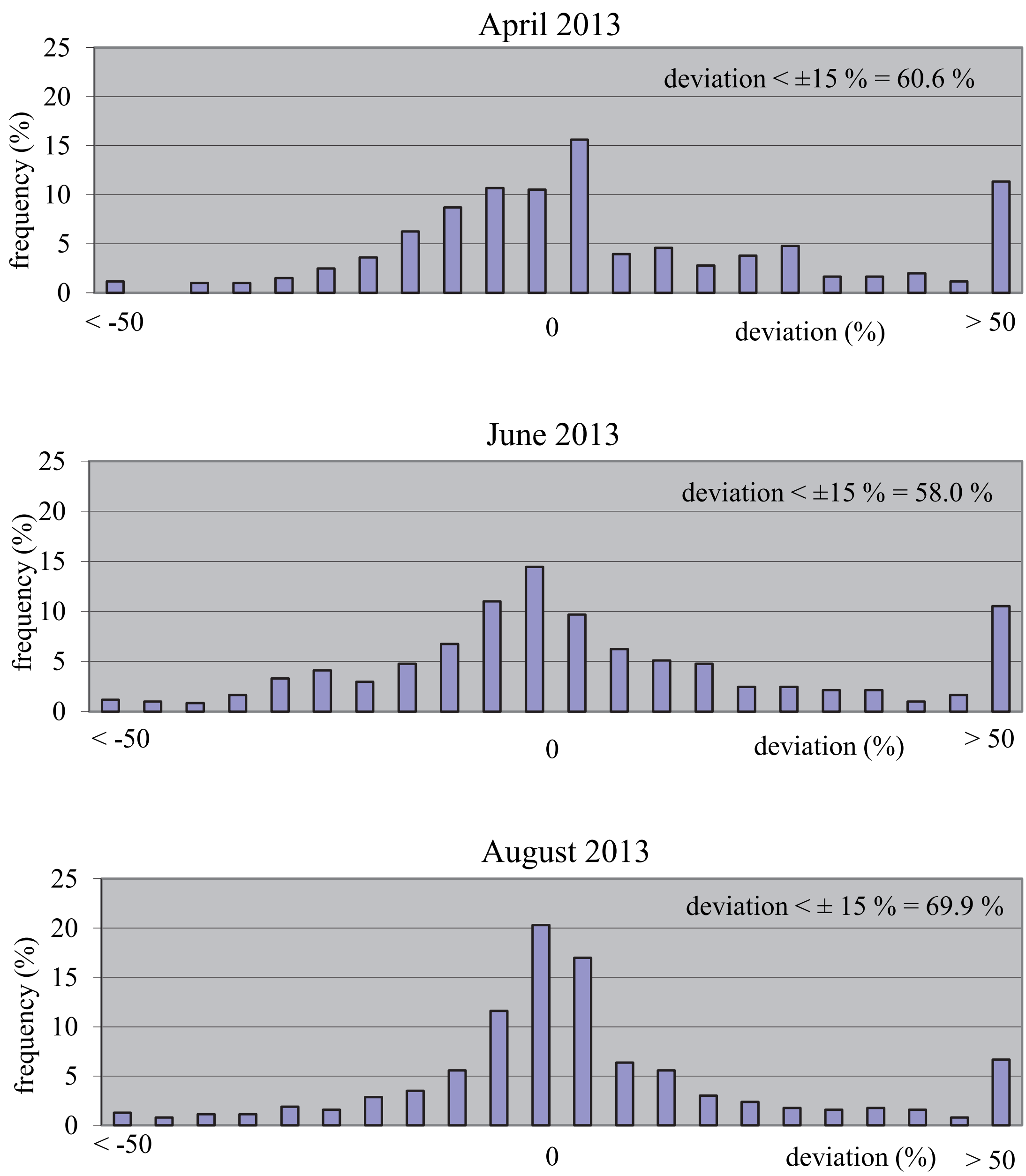


Fig. 3. Frequency of the relative error for second half-day totals

3.3. Cloudless and overcast cases

To know the goodness of the model for overcast cases (RELG < 0.25) is of primary importance, because it is a well-known fact that the cloud forecast is one of the most unreliable part of the numerical forecast models due to that the basic energetics in cloud microphysics is not completely clear even theoretically. To study completely clear cases (RELG < 0.85) is important for the reasons mentioned in Section 2. Results are shown for daily totals.

Fig. 4a shows the results of the study in question. As it has been expected, the model can accurately predict daily totals in cloudless cases as the relative error is lower than 5% in approximately half of all cases, and lower than 15% in almost 90% of all cases, with an error distribution approaching the Gaussian function well. The model, however, performs very poorly in overcast cases with a very special error distribution (*Fig. 4b*). Two peaks can be observed in the frequency distribution of error: one falls in one of the 'very good' range (between 0 and +5%) and the other is in the range of extremely high overestimations (> 50%) with a value of 30–30%, which means that errors fall in these two categories in 60 % of the cases. Relative error was lower than 15% in almost 40% of all cases, based on which, one could conclude that the model performs relatively well, if it would not higher than 50% in 30% of all cases. The error is distributed considerably uniformly in the whole error range. This behaviour means almost a two-state system: the forecast was either highly accurate or highly overestimated daily total. The reason supposed is that two types of cases dominates the producing conditions:

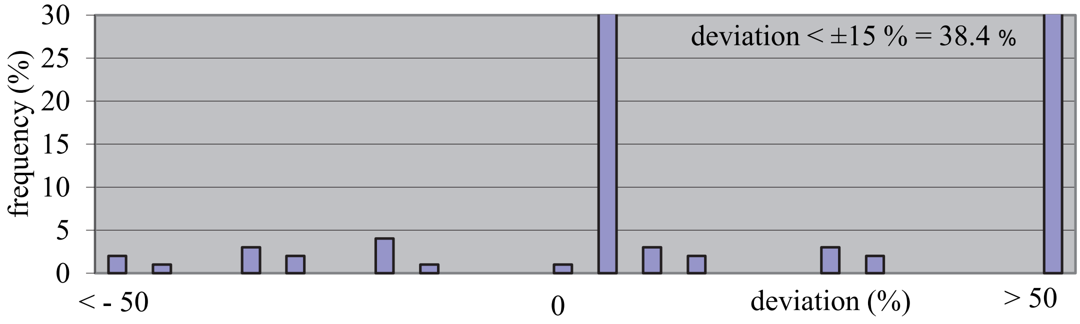
(i) Cases when the sky is uniformly covered by non-fluctuating, permanent, thick cloudiness. In these cases, the global radiation can be precisely forecasted. This type of cloudiness generally exists for longer periods, so neither some temporal inaccuracy in the forecast can result in considerable error in most of the cases.

(ii) To explain the very high frequency of extreme overestimations is difficult. However, due to the fact that frequency of extreme underestimation is very low, the reason can presumably be that the AROME clouds are more transparent than the realistic clouds in a considerable part of the cases. Considering the fact that these situations occured at very low global radiation values, these magnitudes of errors do not mean inexplicably high inaccuracy.

Nevertheless, to find out the reasons more precisely, the study should be performed again for higher number of months.

Dependence of relative error on atmospheric radiation transmission were also studied, and the results are described and analyzed separately in Section 4.

a) **Overcast cases (RELG < 0.25), April, June, August, 2013**



b) **Clear cases (RELG > 0.85), April, June, August, 2013**

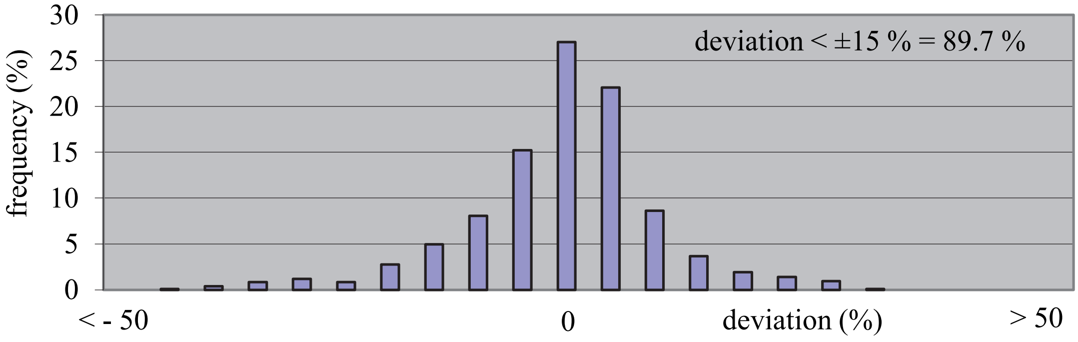


Fig. 4. Frequency of the relative error for daily totals

4. Verification for cloudless cases – dependence of relative error on shortwave radiative transmission of the atmosphere

As it was mentioned in Section 2, it is important to know how accurately the model performs in cloudless cases for different radiative transfer situations, when the relatively high uncertainty of cloud forecast does not affect the modeled radiative transfer. Number of completely clear days was, unfortunately, very low, that means altogether a bit more than 20 on average, during the period studied. But less were suitable to use, because the days that were cloudless, but the model, however, has predicted them cloudy, were to be omitted. This has resulted in about 15–20% decreasing in number of days used. Due to low number of suitable days, to show all precise statistics is not reasonable, so main chacteristics of forecast's behavior are shown only.

Two types of studies were carried out. In the first segment, dependence of relative error on the shortwave radiation transmission was studied. As a second part, temporal course of the relative error was investigated.

To characterize radiative transmission of the air column at the time of the measurement, any optical depth-like quantity is the most suitable, because, due to its physical definition, it indicates the radiative transmission conditions of any medium (like terrestrial atmosphere) more accurately than any other quantity that can be used for it (*Smietana et al*., 1984; *Tóth,* 2008). In our study, aerosol optical depth (AOD), and graybody (broad band) optical depth (GBOD) were used for Budapest, and relative global radiation (RELG) was used for the other (countryside) stations where no spectrophotometric or pyrheliometric measurements are carried out. Decision concerning in which case which quantity is to be used, depends on the measured quantities available, the effects to be traced, or circumstances affecting the results. Determination of AOD is well-known (*Alföldy,* 2007; *Tóth,* 2008, 2013), but, however, because GBOD is rather rarely-used quantity, its definition is shown in details in Section 4.1. It is to be noted that AOD for 500 nm is used for the study. Due to the inevitable high autocorrelation of the AOD values in one AOD spectrum, any AOD can be used without any selection effect, but 500 nm is the generally and widely used to characterize AOD in radiative transfer codes.

AOD is available from operational measurements with sumphotometer SP02 both in Marczell György Main Observatory in Budapest and in Kékestető station, and with sporadic checking measurements in cloudless days with LI-1800 spectroradiometer. In lack of pyrheliometric and spectrophotometric measurements at the other stations, RELG was used for the other sites involved in the study to characterize atmospheric transparency.

4.1. Determination of graybody (broad band) optical depth

GBOD is a very useful quantity to characterize the general shortwave radiation transmission of the atmosphere. Though it is in close relationship with AOD, they are different and the center of gravity of their sensitivity differs. While AOD is influenced by the absorption and scattering coefficient of aerosol, GBOD is influenced all absorption and scattering occuring in a very broad spectral range, practically in the sensitivity range of the pyrheliometers. Thus, it gives the rate of spectrally-averaged radiation attenuation for the spectral range in question.

GBOD can be determined if definition of monochromatic optical depth is extended to a wider spectral range if irradiances measured at the surface are available (*Tóth,* 2008, 2013). Consequently, the GBOD will then be determined in the following way. If $I_{\lambda 0}$ is the irradiance coming onto the top of the atmosphere at wavelength λ and I_λ is the irradiance measured at the surface by a pyrheliometer in case of relative optical air mass *m*, then:

$$\int_{S_{PYR}} I_\lambda d\lambda = \Big(\int_{S_{PYR}} I_{\lambda 0} d\lambda \Big) e^{-m\delta_{GB}} , \tag{2}$$

where δ_{GB} is the GBOD and S_{PYR} is the sensitivity range of the pyrheliometer.

Thus, GBOD is given by the following equation if direct solar irradiance (denominator of the fractional) is measured:

$$\delta_{GB} = \frac{1}{m} \ln \frac{\int\limits_{S_{PYR}} I_{\lambda 0} d\lambda}{\int\limits_{S_{PYR}} I_{\lambda} d\lambda} . \qquad (3)$$

It is clear that dependence of relative error on both optical depths is reasonable to study. To know dependence on AOD is reasonable, because AROME uses AOD in its radiative transfer code, while to know dependence on GBOD is important due to the fact that the verified forecasted quantity is global radiation which is influenced by every circumstance affecting radiative transfer and fine structure of the spectrum, namely each gaseous absorption, aerosol extinction, Rayleigh scattering, etc.

4.2. Dependence of relative error on atmospheric transparency

4.2.1. Dependence on GBOD and AOD

Results are shown and discussed for daily values only, because in this case there is no real importance to analyze them for the both half-days, too. However, the results are shown and discussed both for Budapest and Kékestető separately, because the latter is a mountain station where model outputs can behave in different way as they do for stations close to the sea level.

Figs. 5 and *6* show the dependence of the relative error of the foreacst on daily mean GBOD for Budapest and Kékestető, respectively. It can be seen in case of both stations, that the model tends to overestimate with higher probability with the increasing GBOD (decreasing atmospheric transparency). This dependence is more stressed and has higher correlation for Kékestető. This means that the model cannot simulate the more extreme radiative transmission situation sufficiently precisely, namely it smooths and avarages: it tends to underestimate the incoming radiation in case of extemely transparent (least polluted) cases, while tends to overestimate it in the less transparent (highly polluted) cases. This phenomenon was found for the other stations where RELG was used to characterize transparency of the atmosphere, as it can be seen in *Fig. 9* and discussed in *4.2.2*.

During the three months of the present study, forecasted AOD field was not applied in AROME, but an AOD climatology only: it means that monthly AOD fields were used as input AOD field.

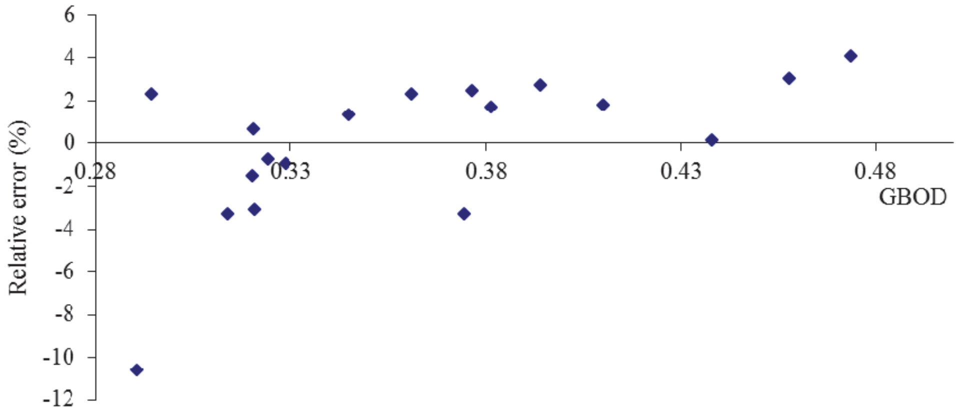


Fig. 5. Dependence of relative error on daily mean GBOD for Budapest

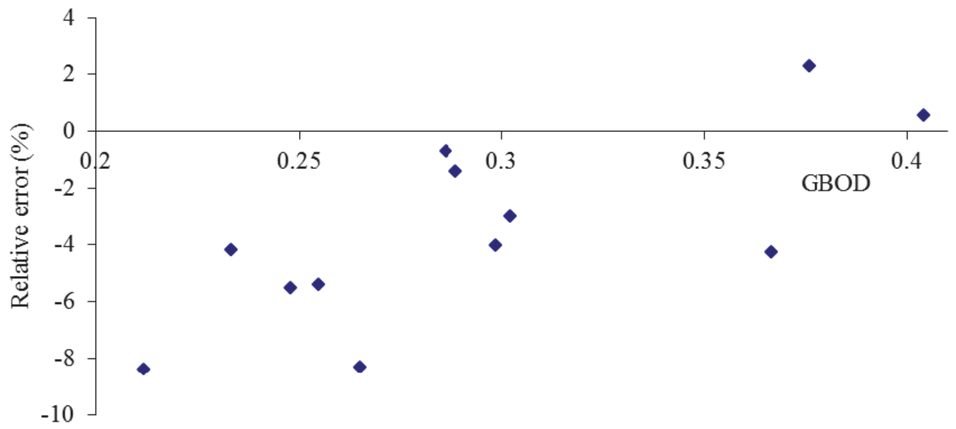


Fig. 6. Dependence of the relative error on daily mean GBOD for Kékestető

Dependence of the relative error of the forecast on daily mean AOD is shown in *Figs. 7* and *8* for Budapest and Kékestető. The relationship differs only a bit from those found for the dependence on GBOD. The correlation is a bit lower here that can be resulted in, on the one hand, by the less number of days used for the study, on the other hand, by the fact that global radiation is a broad spectral band quantity, so its given value that can be measured at the surface at a moment depends on several factors, and aerosol amount is only one of them. The averaging of the model can also be observed for the AOD dependence as it was found for the GBOD dependence. This fact suggests that the model would underestimate global radiation for the very clear cases and would overestimate it for the most polluted cases even in the case when predicted AOD field would be set, but expectably the ’averaging’ would be more moderate.

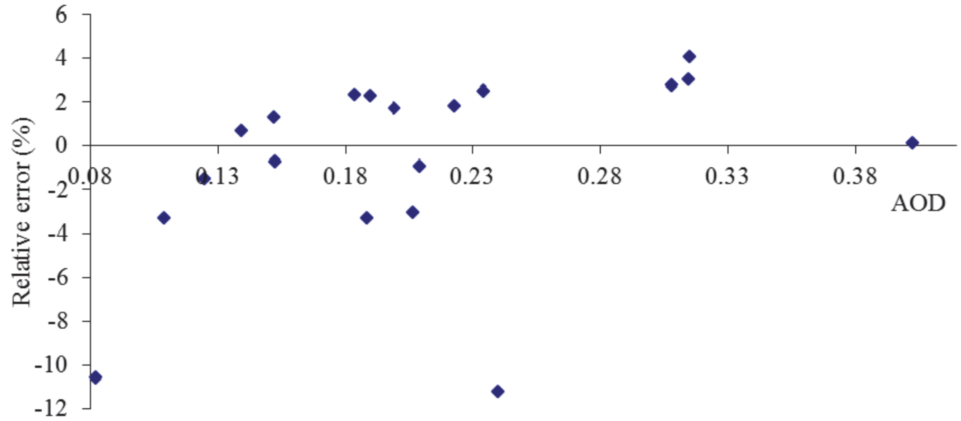


Fig. 7. Dependence of the relative error on daily mean AOD at 500 nm for Budapest

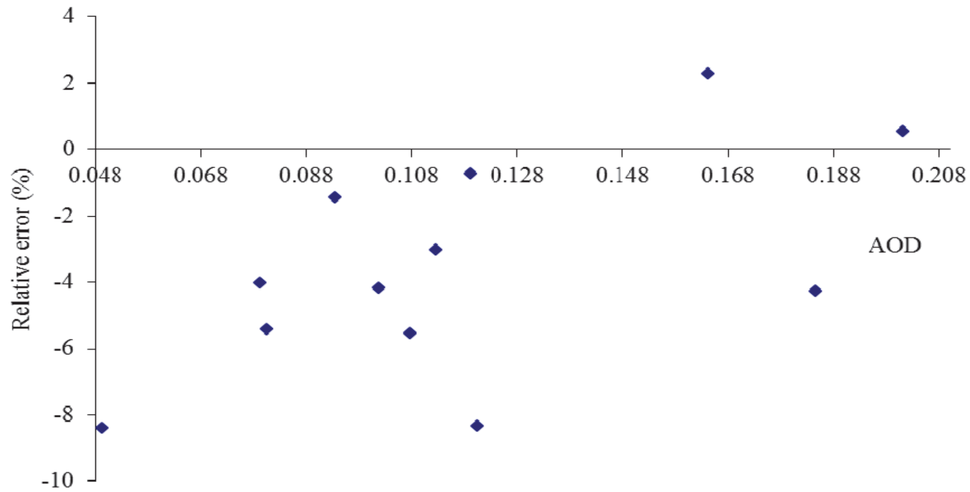


Fig. 8. Dependence of the relative error on daily mean AOD at 500 nm for Kékestető

4.2.2. Dependence on RELG

As it was noted above, RELG was used to characterize atmospheric transparency for the stations where only global radiation is measured and there is no possibility to estimate optical depths.

The result of the study performed for these stations is not shown station-by-station, because it has no high siginificance and only small differences were found for the different stations. The main shape of the relationship can be seen well if dots obtained for all stations and for all days are shown in one figure (*Fig. 9*). The pattern is similar to those found for Budapest and Kékestető: the model tends to underestimate better and better as RELG increases, namely atmospheric transparency increases.

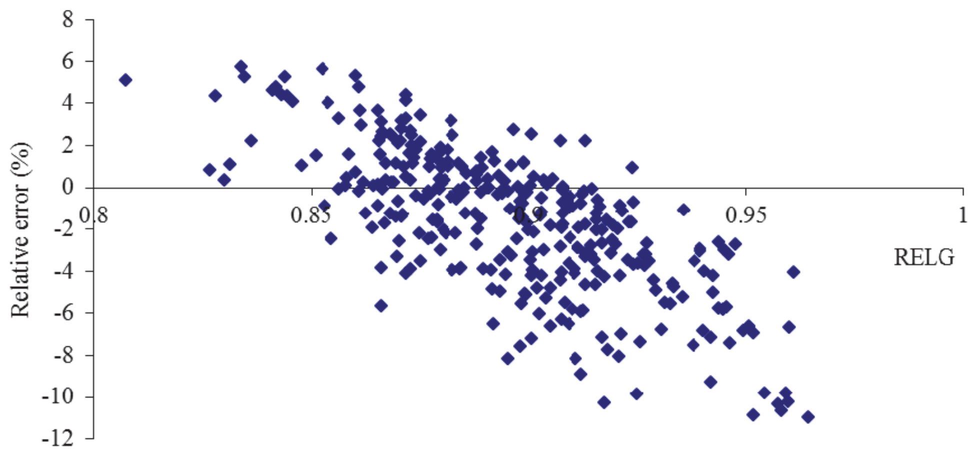


Fig. 9. Dependence of the relative error on RELG for all other stations where no spectrophotometric or pyrheliometric measurements are carried out

It can be concluded that the underestimation is typical in general. Because there is necessarily relatively good relationship between RELG and the two optical depth parameters, calculated AOD (AODC) and calculated GBOD (GBODC) can be produced by performing regressions for the two relationships in question. In this way, the dependence of relative errors on atmospheric transparency for the countryside stations, where AOD and GBOD values are not available, can be quantitatively compared with those for Budapest and Kékestető. The correlation coefficient for the relationship with GBODC is higher than that for relationship with AODC due to the different effect of the two optical depths on atmospheric transparency discussed above.

Considering the dependence of relative errors on AODC and GBODC for the countryside stations, this study shows that underestimation characterized the countryside stations, but its measure is lower than its measure for Kékestető. The fact, that overestimation is typical for Budapest, lower underestimation is typical for the countryside stations, and higher underestimation is characteristic for Kékestető, confirms that the model can describe the transparency with decreasing reliability towards the extremes, and it would behave in the same way, though expectably in a lower measure, in case when forecasted AOD field would be applied in the model.

4.3. Temporal course of the relative error

Temporal course of error of the forecasted values was also studied. Because data from only three months were available, yearly course could not be produced, while simple comparison of the three months was performed. It was found that standard deviation of the relative error was considerably different for the three months involved in the study for all three time scales. For daily totals, it was the highest for April (3.81), and was the lowest for June (2.58). Its value for August was 3.08. The effect is the same for both half-days, but with different values as it can be seen in *Table 2*. It is to be noted that the standard deviations are considerably higher for the afternoon totals. This can probably be resulted by the convection-caused reliability decrease of the model discussed above.

Table 2. Standard deviation of the relative error for the different months

	Apr	**Jun**	**Aug**
Daily totals	3.81	2.58	3.08
First half-day totals	3.53	2.20	2.34
Second half-day totals	4.46	3.63	3.98

4.4. Areal dependence of the relative error

Areal dependence of the relationship between the relative error of forecasted values and RELG was also investigated. It was performed in the way that, on the one hand, areal dependence of average and standard deviation of the set of dots calculated for the given stations was studied, on the other hand, areal dependence of parameters of linear fitting for the relationship between relative error of forecast and RELG was studied. No significant dependence was found for both daily and half-day totals.

5. Conclusions

5.1. General conclusions:

(i) The model performs well both in clear and not highly cloded situations. Relative error is lower than 15% in 89.7% of the completely clear cases, while in 38.4% of the cloudy cases. Its goodness decreases as cloudiness increases.

(ii) The goodness decreases with decreasing time scale.

5.2. Daily totals:

(i) No difference was found between the results obtained by using methods of 4 neighboring grids and 8 neighboring grids.

(ii) The model is the most accurate for August and the least accurate for June. The reason can be that more stable situations characterize August, while June is considerably variable, thunderstroms and precipitations can occur more frequently that can result in rapid alternation of clearer and more cloudy skies. April is generally very variable, but thunderstorms can occur very rarely and conditions with very high cloudiness can occur not so frequently.

(iii) Extremely high overestimations can occur most frequently in April. It can be resulted in by the fact that the unexpected situations are the most frequent in that month.

(iv) Parameterization of cloud mycrophysics and thunderstorms is not sufficiently accurate in the model.

5.3. Half-day totals:

(i) Accuracy of the global radiation forecast is a bit lower than in case of the daily totals.

(ii) The forecast is the most reliable for August and the least reliable for June. The reasons should be the same like those for the daily totals.

(iii) The model performs significantly better for the first half-day than for afternoon. The reason can be that convection appears and increases in the afternoons and the model cannot describe it sufficiently precisely.

(iv) Underestimation is the most characteristic for April, and is more stressed for the second half-day than for the first half-day.

The reasons can be as follows: (a) Certain physical processes showing seasonality and being characteristic for April are over-represented in the model that results in clouds in AROME that have higher extinction than realistic clouds have. (b) Effect of convection-caused mixing on radiative transfer is over-represented, and consequently, the AROME clouds appearing in the afternoon have higher optical depth than real ones have.

5.4. Dependence of the relative error on the radiative transmission of the atmosphere

(i) Relationship between relative error and atmospheric transparency has higher correlation for GBOD than for AOD. The reason should be that global radiation is a broad spectral band quantity, so its any given value that can be measured at the surface at a moment depends on several factors, and aerosol amount is only one of them.

(ii) Reliability decreases at the extreme ends of the radiative transmission scale: it underestimates the global irradiance in the extremely clear cases and overestimates it in the extremely polluted situations. One of the reasons is that the model did not use real AOD during the three months studied, but used AOD climatology varying on monthly base. However, this error should, in some measure, remain in the case of using forecasted AOD field, because dependence of the relative error on the atmospheric radiative transmission was found for GBOD also, which is formed by the forecasted compostion of the atmosphere.

5.5. Temporal course and areal dependence of the relative error

(i) Though three months are not sufficient to study seasonality, it is clear that considerable difference can be observed for those months, however, it cannot be ascertained if there is any regularity in the yearly course.

(ii) Standard deviations of relative error are typically the highest for April, which suggests that the model smooths: it describes the higher variability with less reliability.

(iii) Concerning daily and afternoon totals, lowest standard deviations are found for June. It is surprising at first, but it can resulted in by the fact that despite June is characterized by frequently cloudy and rainy cases, the circumstances have been considerably similar for clear cases.

(iv) Concerning aeral dependence of the relative error, no significant dependence was found for both daily and half-day totals.

5.6. Comparison of dependence of relative error on transparency for countryside measuring sites with those for Budapest and Kékestető

Concerning dependence of relative error on atmospheric transparency (indicated by calculated optical depth from relative global radiation) for the countryside measuring sites, it can be established that countryside stations are characterized by underestimation as it was found for Kékestető, but in a lower measure. Knowing that countryside stations, considering pollution circumstances, should fall statistically somewhere between Budapest and Kékestető, it should mean that the model pull the extremes towards the average situations. Consequently, applying forecasted AOD field instead of the monthly-based AOD climatology that has been used during the time of the study, would solve the problem of transparency-dependent reliability only partly.

6. Possible future studies

Though several basic properties of the forecast were studied in details, and the used three month were carefully selected by preconception set by reasonable and practical respects, a possible yearly course was not to detect. To ascertain if there is seasonality in the goodness of the forecast, at least twelve months would be needed for the study. However, because it can occur that weather circumstances of some months considerably differ from the usual behavior characterizing the certain months, rather three complete years would be prefered for a study.

To know sufficiently deeply the behavior of predicted global irradiance fluxes and to ascertain the reasons causing variablity of its reliability, verification of direct and diffuse irradiances would be also very useful in the future.

As the results show, relative error of the forecast depends on the atmospheric transparency, and that dependence differs a bit for the two optical depths used to indicate transparency, as it can be expected due to the facts discussed above. Recently, developments are in progress to produce predicted AOD field. When it will be applied in the operational use in the future, it would expectably improve the ability of the model to produce more realistic values for both most polluted and least polluted 'end' of the transparency scale in clear sky cases. It means that repeating the study is worth in the future for this reason also.

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