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EXAMINATIONS ON THE METEOROLOGICAL FACTORS OF URBAN HEAT ISLAND DEVELOPMENT IN SMALL AND MEDIUM-SIZED TOWNS IN HUNGARY

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Abstract: The thermal difference between the settlements and their environment is called urban heat island (UHI). Potential UHI intensities are determined by the size, population and built-up structure of settlements, while meteorological conditions have a determinant impact on the development of the heat island at a certain moment. However, not much attention is paid to medium-sized and small towns from this aspect in International and Hungarian studies. Consequently, this study has been focused on the development of UHI in such an environment in Hungary. Settlements, located near the city of Debrecen (cca. 220000 inhabitants) in East Hungary, with population of about 30000, 20000 10000 and 1000 were chosen for the research. Data were collected in two one-year-long mobile measurement campaigns. Spatial characteristics of UHI have been described. Results have proved the existence of UHI even in the smallest settlement under suitable weather conditions. Effects of cloudiness and wind speed have been revealed as well. Stratus clouds have proved to be the most effective in preventing the formation of UHI. Wind speed had a strong impact on the strength of the heat island, while wind directions affected its shape merely.

Keywords: urban heat island, different sized settlements, East Hungary, Synoptic conditions, mobile measurements

1. INTRODUCTION

Settlements create a special local climate called urban climate. One of its most remarkable features is urban heat island (UHI), the thermal difference between settlements and their environment. Potential urban heat island intensities are determined by the size, population and built up structure of the settlements basically (Oke, 1973; Landsberg, 1981a; Feng & Petzold, 1988). It means that great cities with rather compact built up structures generate stronger heat islands than the small ones. Actual UHI intensities in a given settlement at a given point of time are determined by synoptic weather conditions (wind speeds and cloudiness) on the other hand. International and Hungarian studies deal with metropolises and big cities usually; much less attention is paid to medium sized and small towns. For this reason this study has been focused on the meteorological conditions of UHI formation in the typical sized Hungarian settlements.

2. METHODS

UHI measurements were carried out in typical small and medium sized settlements (Table 1) in the Eastern part of Hungary. 24 and 20 measurements were carried out during 2 one year term campaigns in 2003-2004 and 2008-2009.

The main aim of our research was to get abundant data on the role of various weather types in heat island development among different sized settlements. For this reason the measures were carried out in fourteen days intervals under diverse synoptic weather conditions during the research period.

Measurement route crosses the typical built-up types of the settlements involved in the study from rural grasslands to their centres (Fig. 1).

Mobile techniques were used in order to get abundant comparable data for Debrecen and the settlements involved in the research. A digital thermometer was mounted on a car at a height of 170cm.

Table1. Population of the settlements involved in the study.

	Debrecen	Hajdúböszörmény	Hajdúnánás	Hajdúdorog	Hajdúvid
Population	217000	31993	18185	9595	809

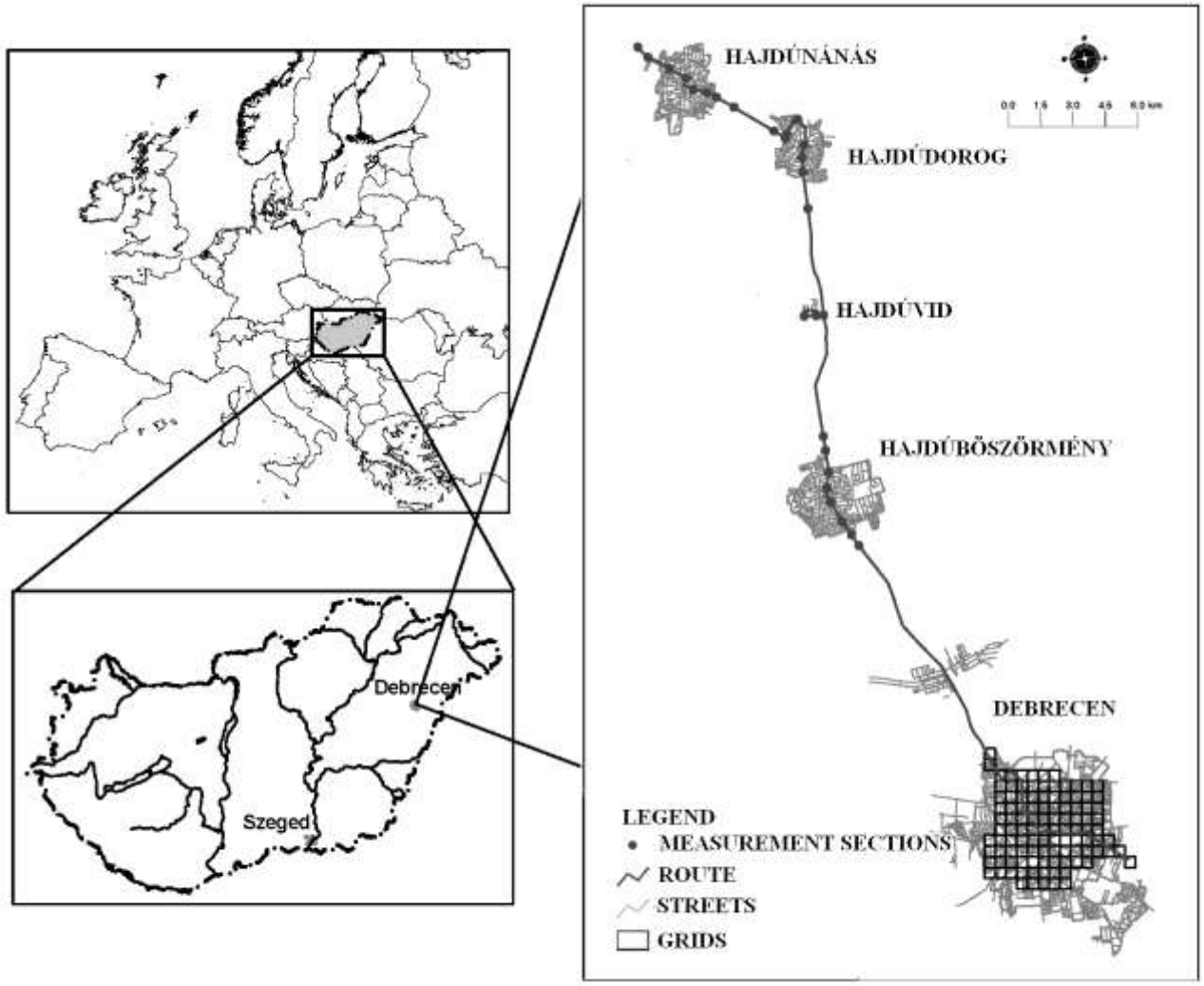

Figure1. Location of the study area

The thermometer had a thermal shield to eliminate radiant heat from the engine of the car. Data were recorded on a Logit digital data logger, sampling interval was set to 10 seconds. In order to get comparable temperature data during the measurements we visited each grid two times: first on the way to the end of the route and the second time on the way back. This way we got two temperature values for each grid. Since the grids were visited in reversed order on the way back, calculating averages for the grids we gained values for the same time (the reference time). The reference time was four hours after sunset since according to the literature (Landsberg, 1981a, 1981b; Unger et al., 2001) the heat island intensity reaches its maximum 3-5 hours after sunset.

Wind speeds were measured at a height of 2 meters using anemometers while wind directions were determined visually at the beginning, the halfway and the end of the rout. Additionally, wind speed and wind direction datasets of the agrometeorological observatory of the University of Debrecen were used as well. The meteorological parameters 72 hours before each measurement were also taken into account. Cloudiness was also determined using datasets of the agrometeorological observatory, which is located in the vicinity (500 meters) of the rout between Debrecen and Hajdúböszörmény.

Wind speeds and directions were measured at a height of 2 meters at the beginning, the halfway and the end of the rout. Cloudiness was determined visually. Datasets were processed using Excel for Windows; maps were made using Geomedia softwares.

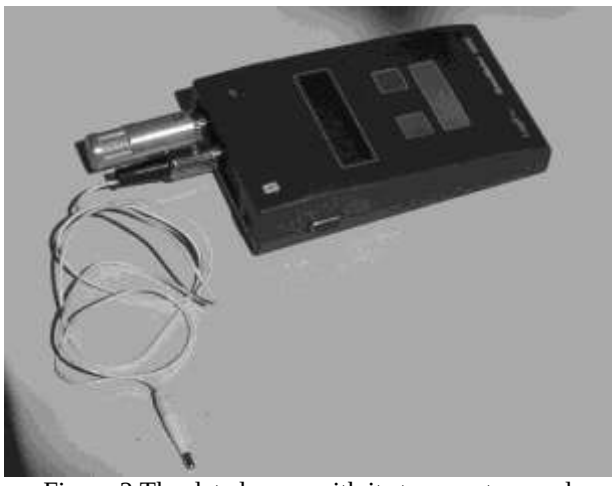

Figure 2.The data logger with its temperature and humidity sensors

3. RESULTS AND DISCUSSION

3.1. Seasonal patterns of the UHI

Results have proved the existence of the UHI even in case of the smallest settlement under suitable weather conditions. In cases when skies were clear all day and night and wind speed was under 0.3m/s at a height of 2m an 1.9°C UHI was detected in the smallest settlement studied here (Table 2). There have been stronger heat islands detected in the heating season (Table 2). UHI intensities show a decreasing trend with the decreasing settlement size. The only exception is Hajdúnánás where stronger heat islands were found in the non-heating season and in the whole year, than in the larger Hajdúböszörmény which has less compact structure.

Table 2. UHI intensities in the heating season, in the non heating season, in the whole studied period and the absolute maximum in the different settlement sizes (values in °C).

	Debrecen	**Hajdúböszörmény**	**Hajdúnánás**	**Hajdúdorog**	**Hajdúvid**
Population	217000	31993	18185	9595	809
Heating season	4.2	1.8	1.9	1.a0	0.3
Non heating season	3.9	1.5	1.4	0.5	0.2
Whole year	4.0	1.5	1.6	0.6	0.2
Absolute max.	6.9	5.8	2.6	1.9	1.9

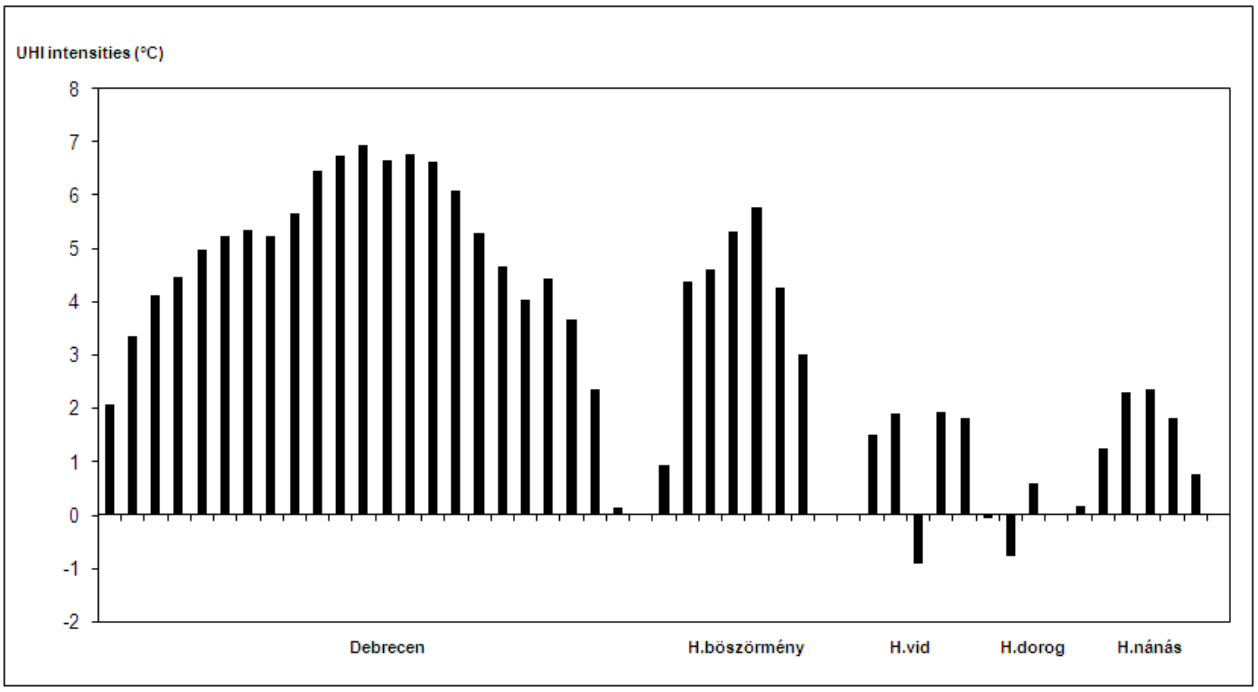

Figure 3. UHI intensities in the studied settlements on 18.02.2009

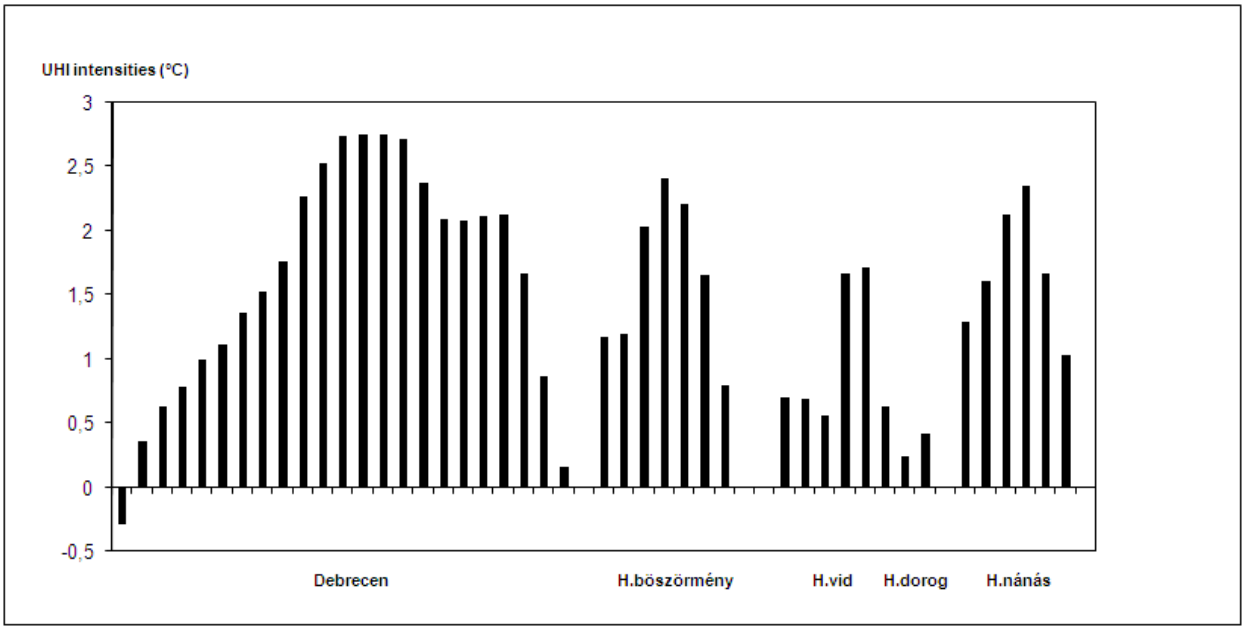

Figure 4. UHI intensities in the studied settlements on 29.05.2008

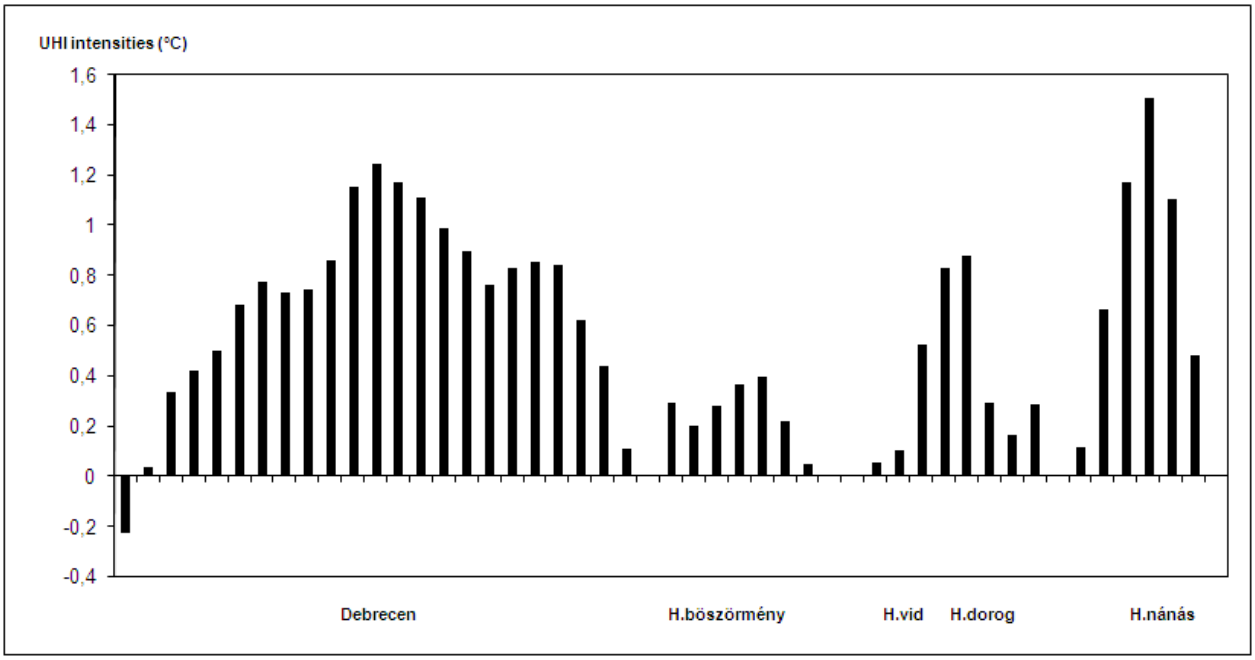

Figure 5. UHI intensities in the studied settlements on 06.01.2009

3.2. Effects of frontal activity on the development of the UHI

Strong UHIs developed under anticyclonic weather conditions with clear skies and low wind speed since strong frontal activity prevents the development of the heat island (Fig. 3).

In some cases within 24-48 hours after a cold front with 10-15mm of rain relatively strong heat islands developed in the settlements with more than 10000 inhabitants. The different heat balance of the natural and artificial surfaces manifested more clearly under such circumstances. There were sharp drops in the intensity curves at the borders of those surface types. It means that a fast moving cold front does not eliminate the development of UHI completely but its intensity decreases (Fig. 4).

Slow moving warm fronts could eliminate the development of the UHI or could destroy a well developed UHI more effectively. During or shortly after the passage of a strong warm front only weak heat islands were detected (Fig. 5).

3.3. Effects of cloudiness

To trace the impact of cloudiness on the

development of the UHI is rather complicated, because with the exception of radiative stratus (St) clouds, they usually appear in windy weather. From the cloud genera detected during the measurements St has proved to be most effective in preventing the formation of UHI. A St cover of 7-8 octas, 12-20 hours before the measurements could completely eliminate the thermal differences between the natural and artificial surfaces (Fig. 6).

Cirrus (Ci) type clouds had the weakest impact: they could prevent the formation of the heat island only in the smallest settlement involved in the study. In cases when favourable synoptic conditions prevailed within 48-72 hours before the measurements, but during the measurement cloudiness reached 4 octas strong UHI could not develop in any settlement, while over 6 octas only weak UHI could form in Debrecen. Over 7 octas there were no heat island found in any settlements involved here.

3.4. Effects of wind speed and directions

Wind speed had a strong impact on the strength of the heat island, while wind directions affected the shape merely. It was found that winds of 1-1.5m/s (measured at a height of 2meters) could prevent the formation of an UHI in settlements with 10000 inhabitants and under. In such cases in settlements with 20000-300000 inhabitants only medium intensity heat islands could develop and the intensity curve became asymmetric as the heat island was pushed towards the lee side. In case of stronger 2.5-3m/s winds, UHI could develop only in Debrecen. UHI intensities in such cases (2-3°C) reached only about the half of the characteristic intensities for ideal circumstances. The UHI was drifted strongly to the lee side usually. Over 3m/s wind speed at a height of 2m heat island could not develop in any settlements involved in the study. As a result we could determine the critical values of wind speed and cloudiness that can hinder the formation of UHI in the different sized settlements (Table 3).

4. CONCLUSIONS

Results have proved the existence of the UHI even in case of the smallest settlement under suitable weather conditions.

Synoptic conditions of 2-3 day long periods before the measurements are important since artificial surfaces accumulate significant amounts of heat from one day to another. Therefore the development of a strong heat island takes several days. For this reason a short unfavourable weather event (e.g. a cold front without heavy rainfall) cannot eliminate completely a well developed heat island. On the other hand, after 2-3 day long periods of disadvantageous synoptic conditions, only medium UHI intensities were found in the studied cases within a 24 hour long favourable period.

Different critical cloudiness and wind speed values that eliminate the formation of the UHI have been determined in different settlement seizes.

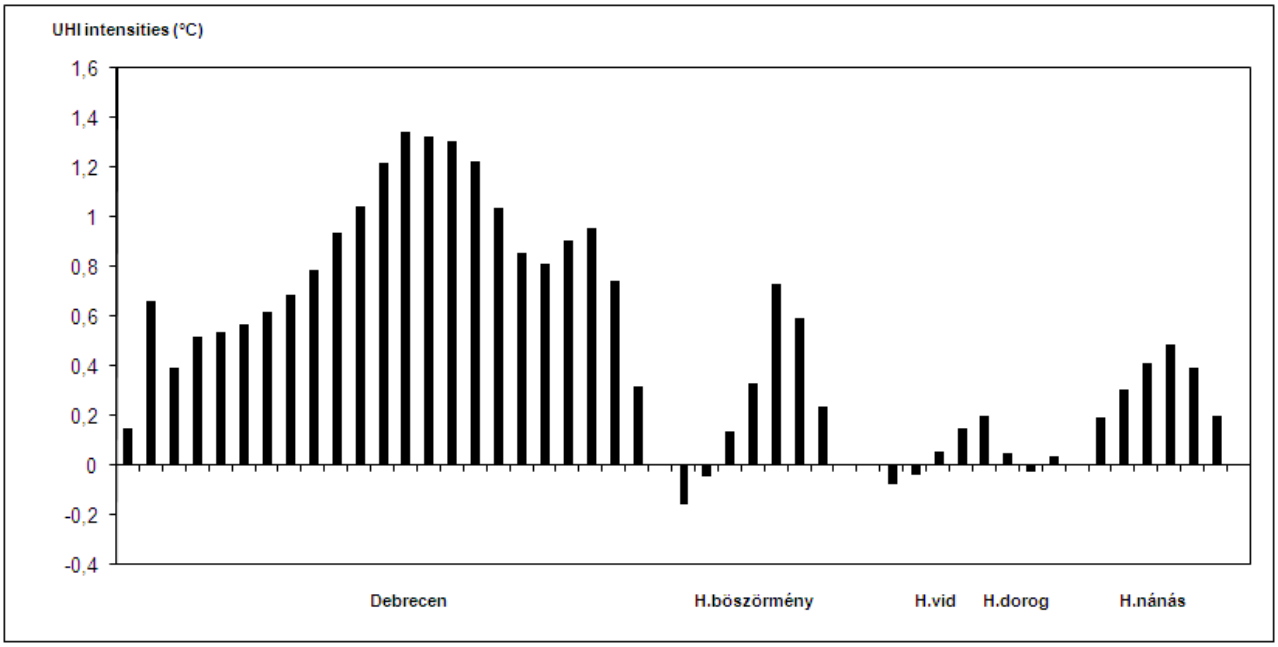

Figure 6. UHI intensities in the studied settlements on 17.07.2008

Table3. Critical wind speeds and cloudiness that eliminate the development of UHI in the different sized settlements.

	Debrecen	**Hajdúböszörmény**	**Hajdúnánás**	**Hajdúdorog**	**Hajdúvid**
Population	217000	31993	18185	9595	809
Critical wind speed (measured at 2 meters m/s)	4.0	3.0	2.5	1.0	0.5
Critical cloudiness (octas)	7	4	4	2	1

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