04.06 Surface Temperatures Day and Night (Edition 1993)

Overview

The inclusion of climatological aspects in evaluating environmental situations of urban metropolitan areas and their spatial planning requires a definition of the term **urban climate**. Urban climate is understood, according to Schirmer et al. 1987, to be "the strongly modified mesoclimate (local climate) of cities and concentrated industrial areas in comparison to their surrounding areas. It encompasses the entire volume of near-surface air layers above and in the direct vicinity of the city and its urban borders. It is caused by the type and density of building, the heat storage capacity of the soil, a lack of vegetation, a changed water balance and increased emissions of waste gasses, aerosols, and heat wastes."

Definite limit values and guidelines for evaluating climate situations are lacking. The ideal urban climate to be striven for is one largely free of pollutants. It offers its inhabitants as great a diversity of atmospheric conditions as possible, and avoids extremes (cf. Deutsche Meteorologische Gesellschaft 1989 - German Meteorological Society 1989).

The classical climatological research methods for surveying urban climate are mobile field surveys, both vehicular and pedestrian (cf. Maps 04.02 - 04.05). Another method is the calculation of individual surface element temperatures (roofs, streets, tree crowns, etc.) by means of **Thermal-Infrared (IR) Imaging**. It proceeds from the physical principle that all objects give off **heat radiation** corresponding to their surface temperatures (cf. Methodology).

Heat radiation, and thus surface temperature as component of an object's heat balance, is of great importance as a control quantity for the heat balance of the earth's surface. The primary daytime determinant is the **short wave** radiation spectrum, particularly the direct irradiation of solar energy onto an object's surface, and the absorption or reflection of this energy (reflection = albedo, cf. Table 1). The only influence affecting the thermal radiation behavior of an object at night is the **long wave** spectrum and the soil heat flux.

Tab. 1: Albedo (Reflective Capacity) of Various Surfaces (Nachbarschaftsverband - Neighborhood Association, Stuttgart 1992)	
Surface Type	Reflective Capacity (%)
Black earth, dry	14
Black earth, wet	8
Light sand	30 – 40
Snow, clean	99
Surface waters	5 – 15
Green grass	26
Wheat	10 – 25
Concrete	14 – 22
Walls, white	65 – 80
Walls, yellow	35 – 50
Walls, gray	20 – 45
Asphalt	12 – 25
Gravel	5 – 10
Average value of earth's surface	35

Tab. 1: Albedo (Reflective Capacity) of Various Surfaces (Nachbarschaftsverband - Neighborhood Association, Stuttgart 1992)

Different types and compositions of surfaces can produce considerable differences in surface temperature (cf. Fig. 1), given equal irradiative (ingoing) and radiative (outgoing) conditions.

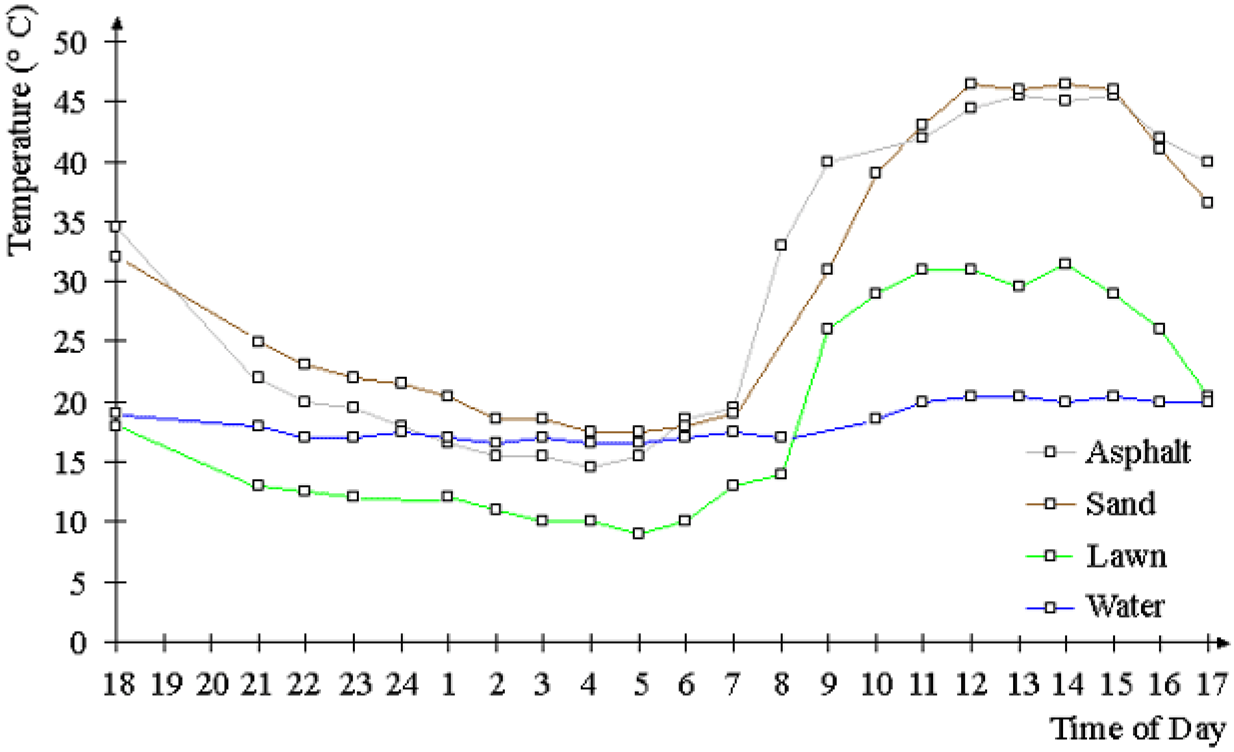


Fig.1: Surface Temperatures of Various Structures (Kessler 1971 in Mählenhoff 1989

The primary usefulness of thermal maps for (urban) climate analysis is their **digitally-processable information regarding the total area**. There is a differentiation between infrared photos taken by thermal imaging from aircraft, and data supplied from satellites. The Environmental Atlas Maps are based on **satellite data**.

The almost 2,000 km² size of Greater Berlin and its immediate surroundings means that only a satellite-based process is capable of the almost **simultaneous recording** of the longwave radiation of the earth (surface temperature) on consecutive nights and days. Satellite orbits and times cannot be changed however, and in this case they were regarded as not being optimal for the Berlin area (cf. Statistical Base).

The interpretation of IR thermal imaging also allows qualitative classifications of the thermal properties of individual surface elements and spatial units. The conversion of this data, however, requires extremely specialized knowledge of climate, as well as the use of other basic data, such as use maps and relief maps. Surface temperature in any given thermal image is influenced by various use structures. Surface temperature is always the result of complex physical processes, which include horizontal and vertical heat flows, and energy exchange turnovers such as evaporation and condensation. The inclusion of further climatological parameters, like air temperature and wind velocity, allows the use of surface temperature maps in determining **climate function areas** (cf. Map 04.07).

Statistical Base

Earth resource information satellites have been operated by space agencies since the beginning of the 70's. The US **Landsat-5** remote-sensing satellite orbits the earth in an almost-true polar orbit at an altitude of 705 km. Landsat 5 carries a multi-spectral scanning system called the "Thematic Mapper" (TM). The satellite images a 185 km-wide strip along the earth during each orbital cycle of 1-1/2 hours. The entire surface of the earth is thus surveyed in 16 days. The satellite passes over Berlin and environs in about 20 seconds. Data is digitalized and radio-transmitted to ground stations, which record it on magnetic tape. The satellite's thermal resolution quality about 1,500 points, or pixels, per line. Each point equals a surface area of 120 m x 120 m. Flight patterns during the day and night are not identical, resulting in different image sectors in the resulting maps. Night scans of this area must be specially ordered by way of the ground station of the European Space Agency (ESA) in Italy.

The seven total spectral ranges of the Landsat-TM are in wavelengths from the 0.45 μm of blue-green light, to the 12.5 μm of heat-infrared.

The **longwave** spectrum between 10.4 and 12.5 μm was selected for the imaging of surface temperatures. This portion of longwave radiation emanating from the earth itself can pass relatively undisturbed through the atmospheric layers. It is called the "infrared window".

Choices for the two imaging scans were coupled to the time periods that the satellite was over the Berlin area (the time periods could not be changed) during the early **evening** and the **morning** of the following day. The selection was also coupled to certain meteorlogical requirements. A recording of the behavior of surface structures as precisely as possible requires that there will be no influence on the area to be examined by clouds, previous precipitation, or too high wind velocity. Consideration of these requirements during the summer half-year of 1991 allowed usable images only during the time periods of the evening of **14 September 1991, 21:45** CET (Image 49-222), and the following day of **15 September 1991, 10:30** CET (193-23). The meteorlogical conditions measured at the Dahlem Station of the Free University of Berlin were:

- 14 Sept., 22:00 CET: Cloudiness, 0/8; wind velocity, 1.0 m/s; air temperature at 2 m altitude, 13°C
- 15 Sept., 10:00 CET: Cloudiness, 1/8; wind velocity, 2.5 m/s; air temperature at 2 m altitude, 23°C

A high pressure weather condition with weak winds prevailed before and during the time of overflights. The weather was characterized by extreme, continuing dryness, and hours of sunshine approaching those theoretically possible. This time period was very suitable for the survey.

A climate survey was conducted at the same time by the TU (Technical University Berlin) (Maps 04.02 - 04.05 and 04.07). This survey conducted mobile field surveys along selected routes. Measurements were taken of air temperature, wind, and vapor pressure at an altitude of 2 m. The surface temperatures of homogenous structures, such as surface waters and large-area parking lots, were determined by analog technology. It was thus possible to **compare calculated with actually measured surface temperatures**. This parallel measurement of climate parameters at an altitude of 2 m also facilitated the inclusion of surface temperature maps in preparing Climate Function Map 04.07.

Methodology

IR thermal imaging does not directly measure surface temperature. Surface temperatures are calculated from the longwave radiation emanating from structures. The **radiation temperature**, as it is called, is measured. Radiation temperature is a transport of energy by electromagnetic waves. Radiation is then defined as the flow of electromagnetic waves per given area during a given period of time. The **radiation** and **temperature** of an object's immediate surface are in a functional relationship to each other, as expressed in the Stefan-Boltzmann equation. This relationship occurs when the surface approaches its full emissivity (emissive capability) (theoretical emissive value = 1). Values are known for all important surface elements within the imaged wavelength spectrums of 10.4 to 12.5 μm, so that the influence of the atmosphere on measured emissive behavior remains minimal. The difference between the radiation temperature measured by satellite and the calculated surface temperature is then usually negligible. Only metal surfaces, such as used in flat roofs, deviate significantly with emissive values of 0.1. They must be given a special category during interpretation.

Of much greater significance is the degree of **spatial resolution** of the image elements in pixels of 120 m x 120 m. These are transposed into pixels of 30 m x 30 m before delivery by the ESA ground station. However, the larger initial size often means the registration of **mixed signals** which impedes the determination of traffic areas, smaller urban squares, or various vegetal structures. Each grid of approximately 14,000 m^2 can initially only be given an **average radiation temperature** integrating all the surface elements within the grid.

The initial material was digitally processed by ERDAS, an image processing system. It was necessary to first perform a geometric distortion correction before both images could be superimposed to generate a **Differential Map**. The low resolution of the initial pixels produced a large degree of mixed signals. A control reference value was needed. Surface waters were found to be suitable as reference values, for they are large homogenous areas, and the temperature difference makes it easier to distinguish them from their surrounding areas.

The conversion of the radiation amounts measured by satellite into **temperature values** resulted initially in a total of 53 gray scale values; each represented a temperature interval of about 0.5 °C. The lowest value was 4.3 °C at night, and the highest value was 28.9 °C during the day. Deviations for selected structures from those temperatures determined in the ground measuring program conducted at the same time led to a temperature classification in stages of 1°C. An easier overview of the amounts of data was made, without any great loss of information, by condensing the lowest and highest values into the open categories of < 8 and > 26 °C.

A combined qualitative gradation of temperature differences into 5 categories from "low" to "high" was made for the Differential Map. This scale was chosen in order to take into account the non-optimal time period of survey. Optimal overflight times would have given a stronger differentiation of the radiation behavior of surface areas during the day and at night, especially in the city center area. City center green spaces in particular would then, as more quickly cooling areas, be more intensely differentiated from densely built-up areas and industrial areas with high heat potential.

The map does not present statements regarding the level at which the temperature differences range, i.e., whether at relatively high or at lower surface temperatures. Figure 2 provides information about this.

The **possibilities and limits** of the survey technology and time periods described above should be mentioned again as a basis for the interpretation and comparative analysis of day and night levels:

- Small areas of differentiated horizontal and vertical structures, such as interior courtyards, street areas, and city squares, could be recorded only as mixed pixel images.
- The overflight times during the **morning** and early **evening** did not record the time periods of greater heating or greater cooling. Material-dependent heat conduction and heat storage exert a special influence. The dry sand soil, with high air content, of farmlands and dried-off vacant areas has a poor heat conductivity, particularly on sunny weather days with weak winds. This produces a quick morning heating and a quick evening cooling in the map image. Inversely, the high heat storage properties of building materials such as concrete, asphalt, and stone lead to a slower heating and cooling, and thus to a limited representation of "the urban heat-island".
- Seasonal changes in open areas are of great importance. Critical modifications in temperature behavior sometimes occur during harvest or large-scale dying of surface stocks, particularly in field areas and rough meadows.

Map Description

Map 04.06.1: Surface Temperatures in the Evening

Overflights took place at time periods of progressive cooling at different stages; the degree of cooling depended on the thermal behavior of individual objects. The first optical impression of the evening overflights is given by the coolest locations in the blue-purple spectrum. These areas are almost all at the edge of and outside the city, except for a few locations in the city center. They are mainly areas typical of the Berlin area, such as large **farmlands and sewage farms**, former and current. They form a ring around the city, although some are within the city, such as Karolinenhöhe in the west, and Lübars - Blankenfelde - Wartenberg in the northeast. Smaller, very cool and clearly defined areas include the farmlands of the Johannisstift in Spandau, Jagen 94 in Grunewald, the vacant areas southeast of Müggelsee Lake and the vacant areas of the airports. Among the quickly cooling areas west of the city is the Döberitz Heath, especially its hollows. The thermal behavior of these areas is not usually changed significantly by relief influences, in contrast to forested areas.

A size of at least several hectares and quick, high energy turnovers in the soil/air boundary layer are of prime importance for these areas named above. Neighboring structures exert no, or hardly any, influence. The **dry** soil allows only a minimal heat conductance. This isolating effect is most clearly seen in sandy soil with especially high air content. Bogs, in contrast, have a lesser rate of cooling, similar to the heat storage effects of large **water areas**. A similar behavior can be expected for the flooded areas of active sewage farms.

These locations are efficient "cold air production areas"; but they are especially emission-endangered from the air stagnation that develops during the night. The degree to which their equalizing effects can act on the climate-stressed areas of Berlin depends on the influence of emittents, and the spatial relationship to the stressed area.

The occasional large-areas of **flat metal-roof complexes** have to be considered separately; such as the Kanalstraße and Gradestraße in the Neukölln borough, around the Eichbornstraße area in the Reinickendorf borough, and the convention center/fairgrounds. Uncoated metal roofs have a greatly reduced emission value of under 0.1 and are given a special category. It is not possible to calculate their "true" surface temperature from the radiation temperatures in the thermal imaging (cf. Methodology). They appear too cold in the map. All other flat-roof complexes have predominantly horizontal orientations and possess very effective irradiation and radiation conditions. They reach very high daytime maximum temperatures and minimum night-time temperatures.

The thermic behavior of **allotment garden areas** and **parks with meadows** is basically similar to green land and field areas outside the city, and can be similarly categorized. They are, however, greatly influenced by their location in the city. Some examples of open-structured areas formed by lawns and trees with small crowns are the allotment gardens at the Südgelände; south of the Hohenzollern canal; around the Britz Garden; and the meadows at the Johannisthal waterworks.

In comparison to these surfaces, green areas with large amounts of **tree stocks** display thermic behavior like that of forested areas, but also like similar parks in the urban area. One example is the **Große Tiergarten**, of about 220 ha size. The Große Tiergarten, as a park in the center of the city, is exposed to the influence of the surrounding built-up area. This influence is directly clear in its thermal image, such as in the "heat wedge" west of the Brandenburg Gate. It can also be assumed that the radiation loss, especially of the forested area, is limited by the warmer surrounding air; more strongly by weather conditions with strong currents than by those with weak winds. Cold air layers above meadows build up relatively quickly, and their thickness increases during the night. Thermal imaging does not register the soil of predominantly closed forested areas, but rather the radiation at the height of the tree crowns. Heat stored in the crown and trunk prevents a quick cooling in the evening. The further course of events is an introduction of warm air from the vicinity. This warm air cools on the leaf surfaces and diverts into the trunk region. It is supplemented by warm air from the trunk region and/or the vicinity above the tree crowns, which then again supplies heat to the radiating leaf surfaces. This process ends only after a layer of cold air large enough to encompass the crown area has built up on the stock floor. The temperature gradient between meadow areas and tree areas in the Große Tiergarten which can be expected at the time point of greatest cooling is thus very strongly dependent on the height, type and density of tree stocks.

Forest areas basically follow the cooling schema described above. Cooling in uneven terrain is additionally delayed by cold air flows or cold air collections in hollows. The high temperatures in tree stocks in **ridge areas** (the hills of the Havel, Müggelberge, and Schäferberg) can be explained by the fact that here the build up of a cold air layer from the floor is prevented by a cold air flow following the slope. Inversely, the cold air produced is concentrated in the areas of hollows.

These influences in the boundary areas of **surface waters** overlap with higher temperature levels caused by the strong heat storage capabilities of water. The surface waters are very balanced in a day/night rhythm. The course of temperature is dependent on water depth, (a "warehouse" of stored heat) as well as direct anthropogenic influences. Return inflows of water used for cooling the Reuther thermoelectric plant and the Oberhavel power plant are clearly recognizable in the thermal imaging.

The course of temperatures in **built-up areas** is mainly a function of the built-up structures. The large amount of heat-storing materials, such as concrete, stone, and asphalt, leads to the expected highest temperature values, after wetlands and surface waters, in wide areas of the inner city, in core areas, as well as industrial areas. They can thus be called **extensive heat sources** which exert the greatest influence on the formation of the "heat-island effect".

The intensity of local cooling is influenced by the amount of construction materials with high heat-storage properties used in buildings, streets and city squares, as well as the more quickly and more strongly radiating surfaces of building roofs and green areas. There are differences in dense inner city locations between those dense block structures with a high portion of poor heat-conducting roof areas and interior courtyards closed off to sunshine, and those inner city areas which have more space and larger intervals between structures. It is just as difficult estimate the total climatic situation of these built-up areas as it is for comparable industrial areas. Individual cases require a strict differentiation of the temperature levels as registered in the thermal imaging.

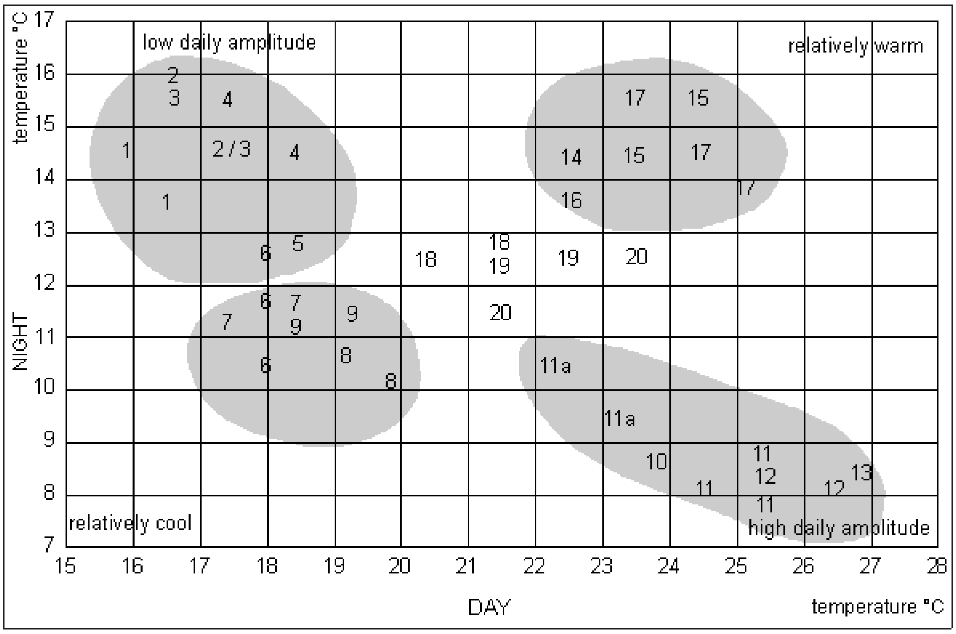
Areas subject to strong anthropogenic influences can be expected to display similar high cooling rates at all locations where no firm connection to the underground exists, such as the roadstone areas of **railway lines** and adjoining areas.

Map 04.06.2: Surface Temperatures in the Morning

Surface heating began with sunrise in this season at 6.00 CET. The thermic situation had only an intermediate differentiation at the 10.30 time of satellite scanning, depending on the materials heated.

Individual surfaces are **mirror images of the night survey**, in many cases, and will be mentioned only briefly.

The most conspicuous locations are the **open areas** of meadows, harvested farmlands, and areas of similar use, analogous to the night imaging. Their quick heating is due to high heat turnover on their surfaces resulting from reduced heat conductivity underground and a low heat storage capacity. The comparatively high volume of air in dry soil insulates the soil surface from deeper soil levels. Heat turnover between individual soil components is greatly hindered. This causes temperature differences of more than 20 °C between the day and night satellite images.



1 = Müggelsee Lake	6 = Forests Grunewald, Tegel, Spandau	11 = Agricultural Area	16 = Densely Built-Up Areas
2 = Havel	7 = Inner City Parks	12 = Sewage Farms	17 = Industrial/Small Business Areas
3 = Tegel Lake	8 = Allotment Gardens	13 = Airports	18 = Sparsely Built-Up Areas
4 = Rummelsburg Lake	9 = Single-Family Homes	14 = Freeway Interchanges	19 = Large Settlements
5 = Spree River	10 = Dahlem Feld	15 = Core Areas	20 = Railway Facilities

Fig. 2: Surface Temperature Behavior of Selected Surface Types and Individual Locations from Evening and Morning Imaging from 14-15 September 1991 (Horbert, Institut für Ökologie, TU-Berlin)

Surface waters, in contrast, only have a flat surface temperature gradient of about 2-3 °C between day and night, even if the water is shallow and thus has an increased energy turnover. Besides the high heat storage capacity there is, as in other moist areas, the temperature relieving effect of a high rate of evaporation in the daytime. The large surfaces of flat-roof complexes in industrial and small business areas also appear very cold (cf. Evening survey).

An influence on **park facilities with trees** and **forests** at the time of imaging was that the degree of cooling reached in the course of the night cooling phase acts as an initial buffer zone up to the level of the tree crowns. This buffer is reinforced by the evaporation beginning from the leaf masses (evaporative cooling). The forests also seem more homogeneous than in the evening imaging, since the effect of the cold air outflow is not an influence in knolls.

The **densely built-up** area can not yet act in the expected fashion as a central heat-island in the morning because of the effects of the described physical laws. Values approaching those of field areas and meadows are to be expected at a later point in time, with stronger radiation of stored heat.

Map 04.06.3: Surface Temperature Differential Evening-Morning

Temperature gradients chosen for the Differential Map were only qualitatively classified, as previously accented. Large portions of the area to be imaged remained within the range of medium temperature gradients due to the times of scanning. The only areas representationally presented are surface waters, with their low temperature fluctuations in day-night rhythm and, inversely, areas with maximum gradients (non-grown over or meadow-like structures).

The evaluation of the thermic effectiveness of surface structures is facilitated by interpretation of the respective **temperature levels** where fluctuations occur, and a qualitative presentation of day and night temperature differences. Figure 2 refers to selected surface types and individual locations, and orders them into a **day-night temperature matrix**.

Surface types with relatively high or low daily amplitude can be recognized here. Beside them are areas which are basically to be classified as very cool or very warm. This is of great significance for effects on air masses layered above the surface, whereby the horizontal air exchange can result in effects on air temperature. Various classifications of surface type characterize the **distribution of day and night surface temperatures**. Low day and night temperatures of forests, parks, allotment gardens and sparsely-built-up settlements at the city's edge contrast with high surface temperatures throughout the day at densely built-up inner city, traffic and industrial areas. Surface waters, with low day and night temperatures, show a greater flattening of the daily amplitude, due to higher capacities of heat storage and heat conductivity. This is transferred into the direct vicinity of the bank and shore areas. Agricultural areas, sewage farms, and railway facilities, in contrast, heat very quickly during the day and cool just as quickly in the night. The greatest amplitudes occur at these locations.

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