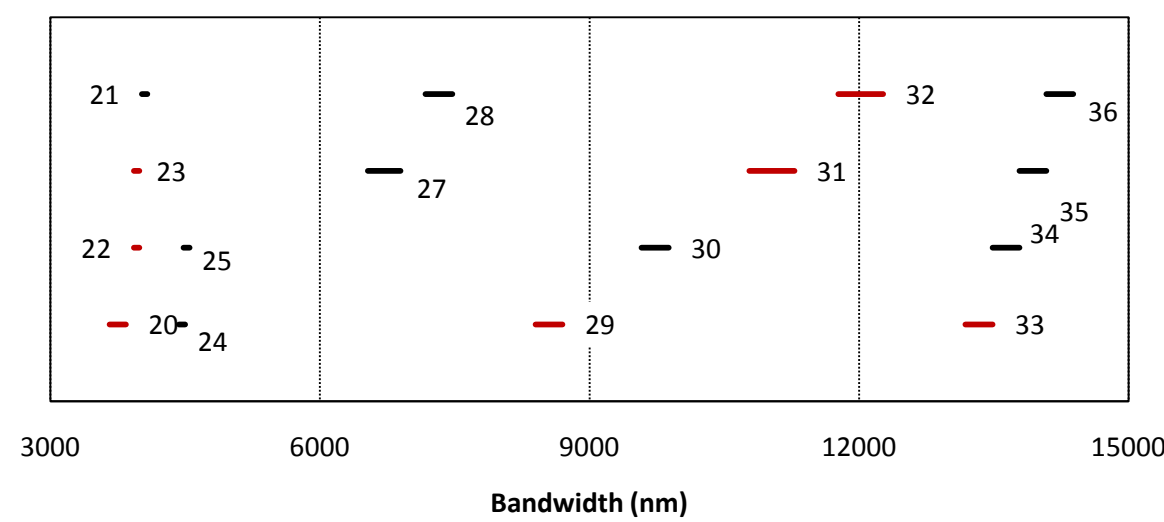# Satellite- and ground-based temperature observations used in assessing the urban heat island phenomena

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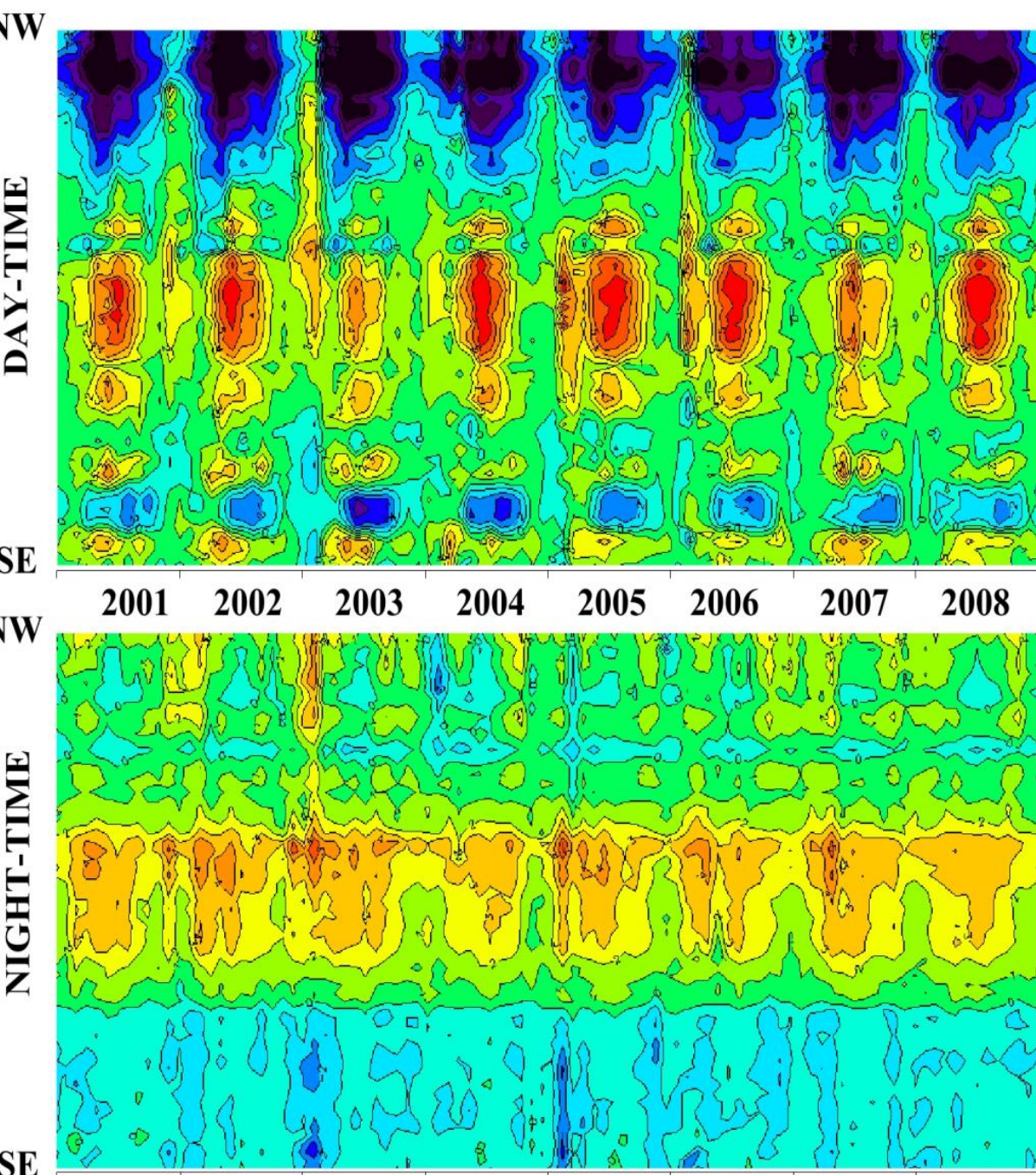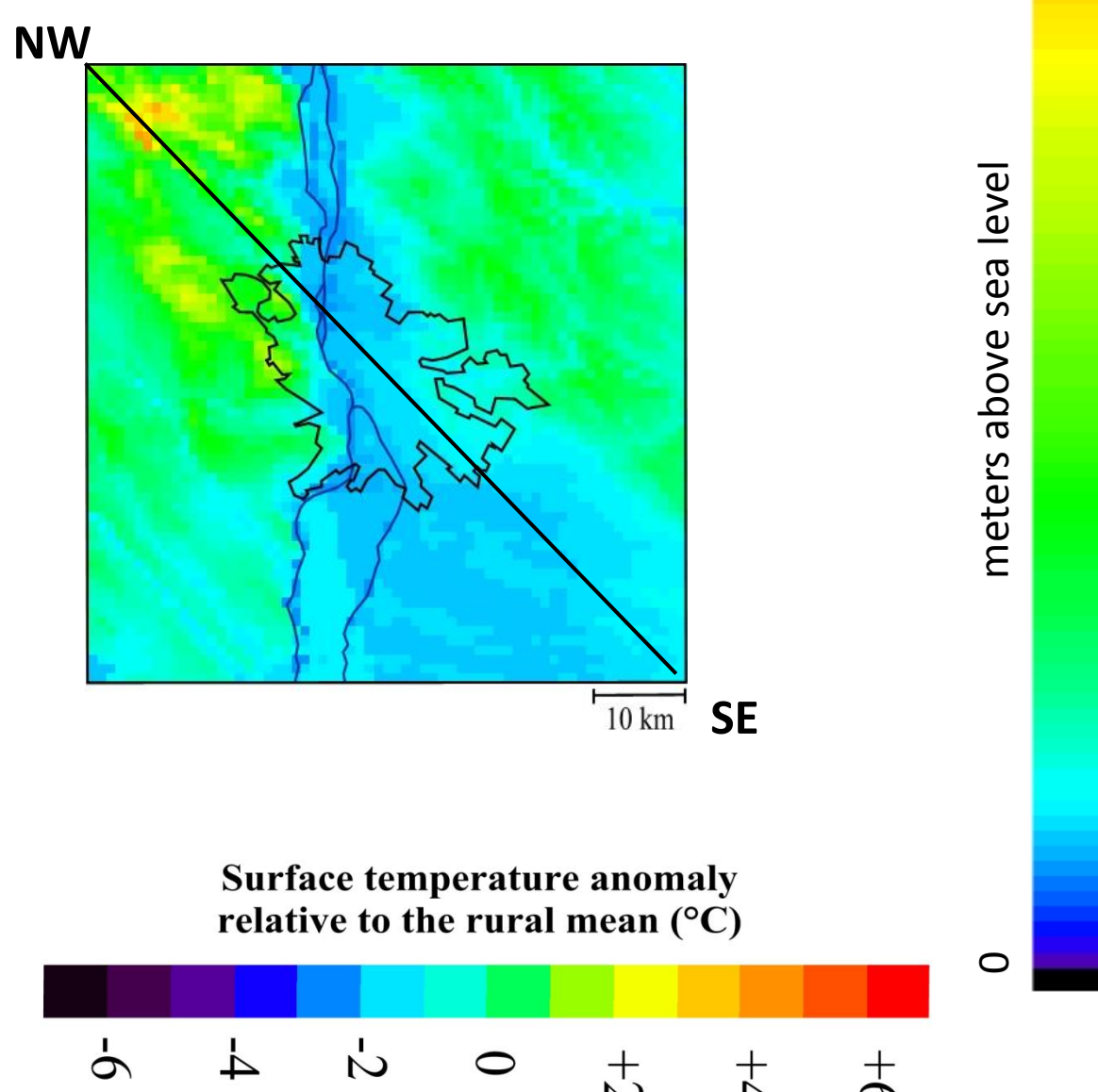E-mail: lelovics@zivatar.hu, prita@nimbus.elte.hu, bari@ludens.elte.hu

Abstract

One of the most obvious and therefore studied characteristics of urban environment is the so-called urban heat island (UHI). UHI is the positive temperature anomaly occuring between built-in areas and their surroundings (Oke, 1982; Landsberg, 1985). There are several possible methods to determine UHI intensity and to measure temperature from which UHI intensity can be calculated. (1) The often used method is to observe air temperature by using fixed weather stations. (2) Another possibility is to use remotely sensed technique, e.g., a multispectral radiation sensor called MODIS. Seven infrared channels of MODIS can be applied to calculate surface temperature: 3660-3840 nm [20], 3929-3989 nm [22], 4020-4080 nm [23], 8400-8700 nm [29], 10,780-11,280 nm [31], 11,770-12,270 nm [32], 13,185-13,485 nm [33].

Satellite-based temperature observations provide information with fine spatial resolution over a large area, without any large time-lag. On the other hand, satellite-based measurements result in surface temperature while ground-based observations at the weather stations provide air temperature data. Naturally, these two variables are different, their spatial and temporal distributions are also different. Moreover, the spatial resolution of the satellite- and ground-based observations are also different. The ground-based temperature represents only the local surrounding of the weather station, while one grid point value of the satellite-based temperature dataset represents a larger area, e.g., 1 km² in case of MODIS.

The purpose of our research is to analyse similarities and differences between temperature values observed by ground-based and satellite-based instruments. In the current analysis temperature datasets for 2001-2008 have been evaluated using ground-based temperature data from four weather stations of the Hungarian Meteorological Service in Budapest and satellite-based MODIS surface temperature (NASA, 1999) for the nearest grid points.

We calculated monthly, seasonal and annual mean temperature values. The results suggest that daytime/night-time satellite-based surface temperature is higher/lower than ground-based air temperature (especially, in summer/winter). This can be explained by the faster warming and cooling of the surface than those of the atmosphere.

Comparison of the two observing methods

	Satellite-based	Ground-based
Observation type	Remotely sensed	In-situ, using WMO standards
Spatial resolution	1 km × 1 km, sinusoid projection	Limited number of observation points
Observed area	Large area	Surrounding of the weather station
Measured or calculated meteorological variable	Surface temperature	Air temperature
Availability	In case of clear condition only	Any time
Temporal resolution	When satellite passes over the region	Continuously
Number of data available in one particular day	Maximum 4	144
Duration of observation	Almost immediately on large region	-
Measuring institute	NASA, processed: Eötvös Loránd University (Dezső et al., 2005)	Hungarian Meteorological Service

Urban pixels
Rural pixels
Built-in area
10 km

River Danube
County border
Budapest
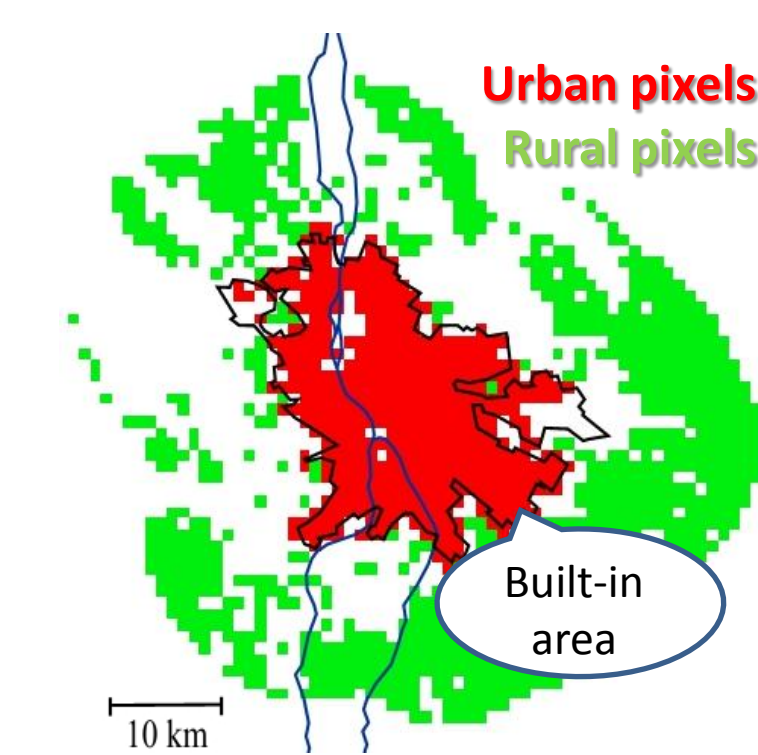
Satellite-based observations
- 2 polar-orbit satellites of NASA Earth Observing System
-- Terra: 09-10 UTC and 20-21 UTC measurements from 2001
-- Aqua: 02-03 UTC, 12-13 UTC measurements from 2003
- Surface temperature is calculated from spectral observations of sensor MODIS
- Urban pixels: inside of the city border, in built-in area, where the altitude is not too far from the average (thus the hills and forests of the city were excluded)
- Rural pixels: out from the city, but not far from it, where the surface coverage is not built-in, and the altitude is close to the average (thus the hills and villages around Budapest were excluded)
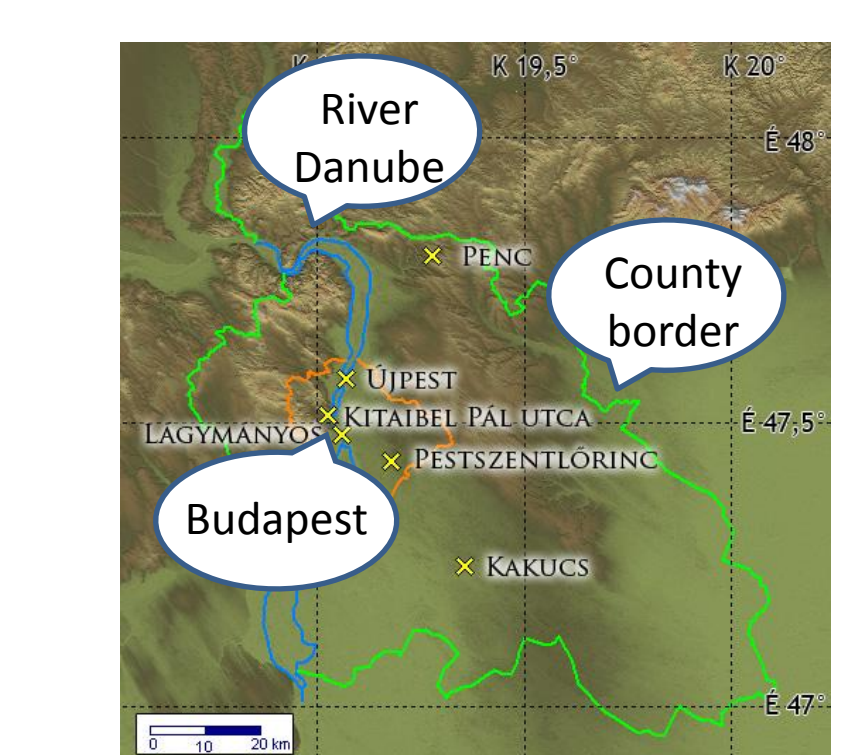
Ground-based observations
- 6 weather stations of the Hungarian Meteorological Service
-- 2 in the downtown area of Budapest (Kitaibel Pál street, Lágymányos)
-- 2 in the suburbs of Budapest (Újpest, Pestszentlőrinc)
-- 2 small towns in the vicinity of Budapest (Penc, Kakucs)
- According to WMO standards, Vaisala MILOS-500 and QLC-50 automated instruments
- Air temperature is measured 2 m above the surface (standard height)
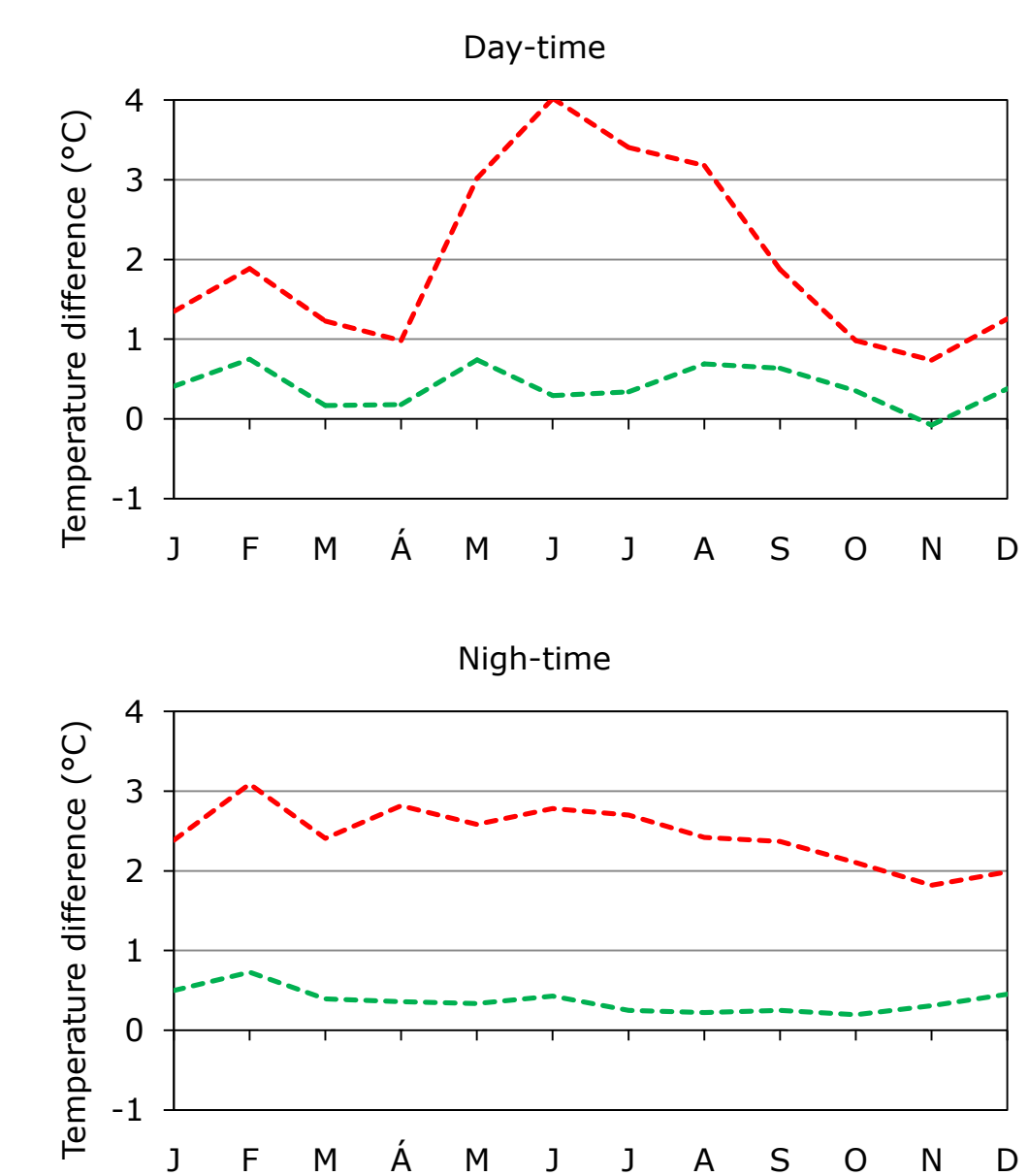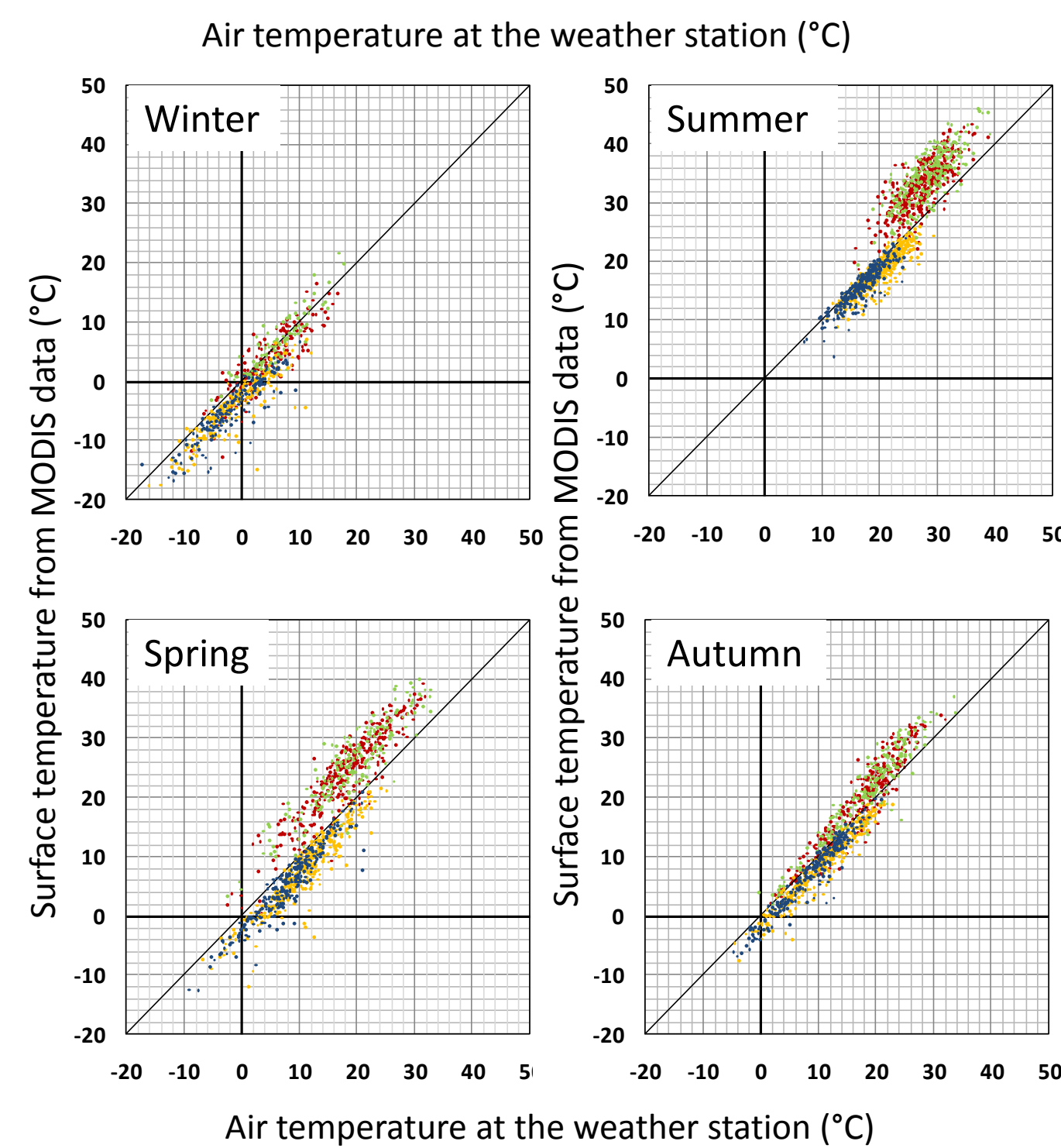- It represents only the surrounding of the measuring weather stations

NW-SE cross-section

- Satellite-based surface temperature values
- Surrounding of Budapest
- Blue line: river Danube
- Black line: border of the built-in area

NW
SE
10 km
meters above sea level

Surface temperature anomaly relative to the rural mean (°C)
-6 -4 -2 0 +2 +4 +6

NW
DAY-TIME
SE
NW
NIGHT-TIME
SE
2001 2002 2003 2004 2005 2006 2007 2008

Day-time:
- Cold in NW area (hills of Buda): -4; -6 °C below rural mean
- In the city +4; +6 °C above rural mean: stronger intensity than night-time
Night-time:
- Cold in SE area (plain): -2; -4 °C below rural mean
- More balanced temperature values

Annual distribution of difference between the urban/rural mean temperature and the average temperature value of Kakucs and Penc

Satellite-based temperature data
- The average temperature of the two used weather station is close to rural mean temperature
- The difference between them is above 1 °C
- Urban mean temperature is 3-4 °C higher then rural mean temperature

Day-time
Night-time
--- Urban --- Rural

Comparison of observed temperature values for Pestszentlőrinc site ▶ ▶ ▶

- Surface temperature values are more extreme: they are higher at day-time and lower at night-time than air temperature values
- There is a difference between night-time observed values: it is colder at Aqua passing time (02-03 UTC) than at Terra passing time (20-21 UTC)
- In case of higher temperature values the variance is larger then in case of lower values
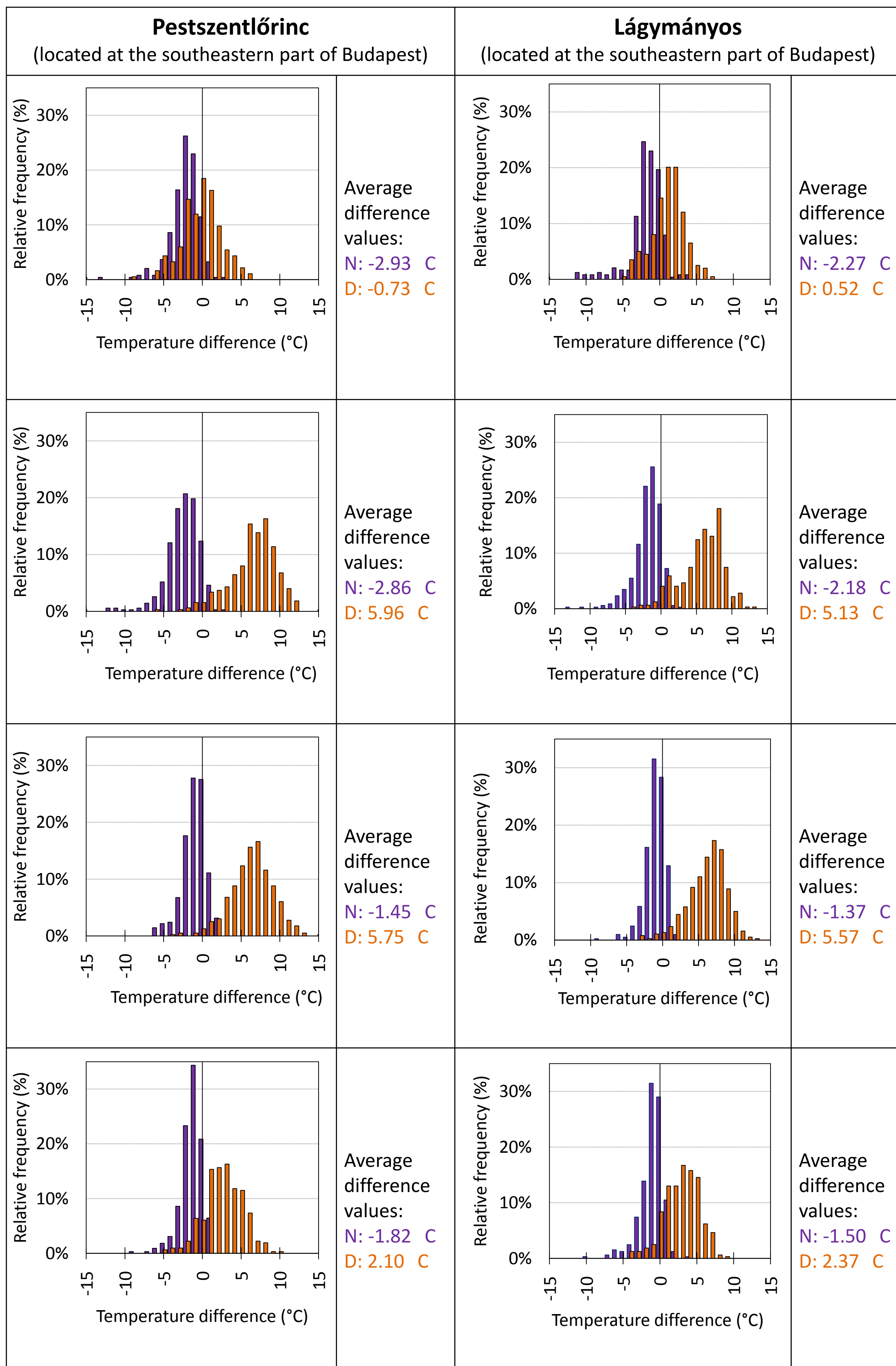
Air temperature at the weather station (°C)

Winter
Summer
Spring
Autumn

Air temperature at the weather station (°C)

Frequency distribution of difference between satellite-based surface temperature and ground-based air temperature ▾

Comparison is accomplished for day-time and night-time

Using MODIS measurements of Terra satellite and ground-based measurements around Terra passing time
- In general positive differences are dominant in day-time and negatives are night-time, which implies that satellite-based surface temperature is larger/smaller during day-time/night-time than ground-based air temperature
- The smallest difference between the satellite- and the ground-based temperature values can be found in winter
- The largest difference between the satellite- and the ground-based temperature values is in spring and summer
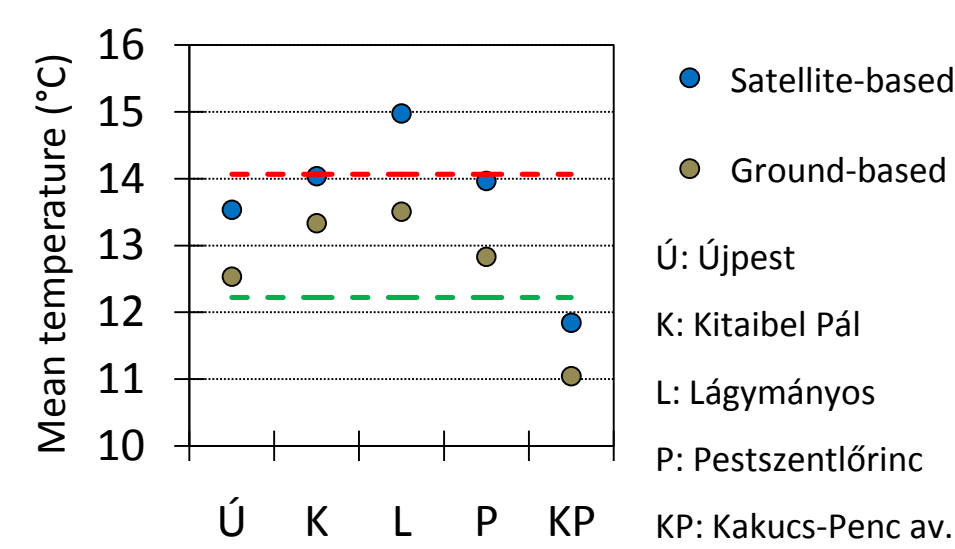

Pestszentlőrinc (located at the southeastern part of Budapest)

Average difference values:
N: -2.93 C
D: -0.73 C

Average difference values:
N: -2.86 C
D: 5.96 C

Average difference values:
N: -1.45 C
D: 5.75 C

Average difference values:
N: -1.82 C
D: 2.10 C

Lágymányos (located at the southeastern part of Budapest)

Average difference values:
N: -2.27 C
D: 0.52 C

Average difference values:
N: -2.18 C
D: 5.13 C

Average difference values:
N: -1.37 C
D: 5.57 C

Average difference values:
N: -1.50 C
D: 2.37 C

Temperature difference (°C)
Relative frequency (%)

Mean temperature ▶ ▶ ▶

- Green line: average rural temperature (satellite)
- Red line: average urban temperature (satellite)
- Generally, higher temperature is detected by the satellite-based method
- The difference between average temperature values detected by the two methods is around 1 °C.
- Higher temperature in the downtown (K, L) and lower around the city (KP)
- Satellite-based rural mean is almost the same as KP satellite-based surface temperature

Mean temperature (°C)
Ú K L P KP

- Satellite-based
- Ground-based
Ú: Újpest
K: Kitaibel Pál
L: Lágymányos
P: Pestszentlőrinc
KP: Kakucs-Penc av.

Difference between monthly mean temperature values observed with ground-based and satellite-based method ▶ ▶ ▶

From March until October:
- Surface temperature is higher than air temperature
- The warmest: Lágymányos, the coldest: Újpest
In winter:
- Air temperature is higher than surface temperature
- The two stations located in Buda (west from the river Danube) are warmer then the other ones in Pest (east from the Danube)

Results of the Welch-test: the difference between satellite-based and ground-based temperature values is not significant in spring and autumn. However, the two temperature values are significantly different in winter and summer.

Annual mean temperature: the surface temperature is generally higher than the air temperature at all stations

Linear relationship: correlation coefficients have been calculated between the temperature anomaly values using satellite-based and ground-based measurements. Use the anomaly values was necessery in order to avoid the characteristic annual distribution of temperature, thus we calculated the difference between the actual temperature values and the monthly average. The result suggests that the linear correlation is high (0.85-0.95) and significant. The largest correlation coefficients were found for Újpest and Pestszentlőrinc.

Satellite-based
Day-time
Night-time
Ground-based
Day-time
Night-time
Temperature difference (°C)
J F M Á M J J A S O N D

Újpest; **Kitaibel**; **Lágymányos**; **Pestszentlőrinc**; **urban mean**. These values are differences from Kakucs-Penc average.

Difference between downtown and suburb, according to satellite-based and ground-based measurements ▶ ▶ ▶

- We calculated the urban heat island intensity as the difference between the average urban and the average rural temperatures

- Day-time: heat island intensity is above 0 °C, it is higher in case of satellite-based temperature then ground-based air temperature values in this time
- Satellite-based average: 1.49 °C
- Ground-based average: 0.61 °C

- Night-time: heat island intensity is positive in case of both temperature observations. It is more intense using the air temperature than the surface temperature, but the difference is small
- Satellite-based average: 3.20 °C
- Ground-based average: 3.42 °C

- Maximum of the satellite-based intensity: in winter and summer, minimum in spring
- Maximum of the air-temperature-based intensity: in winter

Day-time
Night-time
Temperature difference (°C)
No. data
2001 2002 2003 2004 2005 2006 2007 2008

Number of data available --- Satellite-based --- Ground-based

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