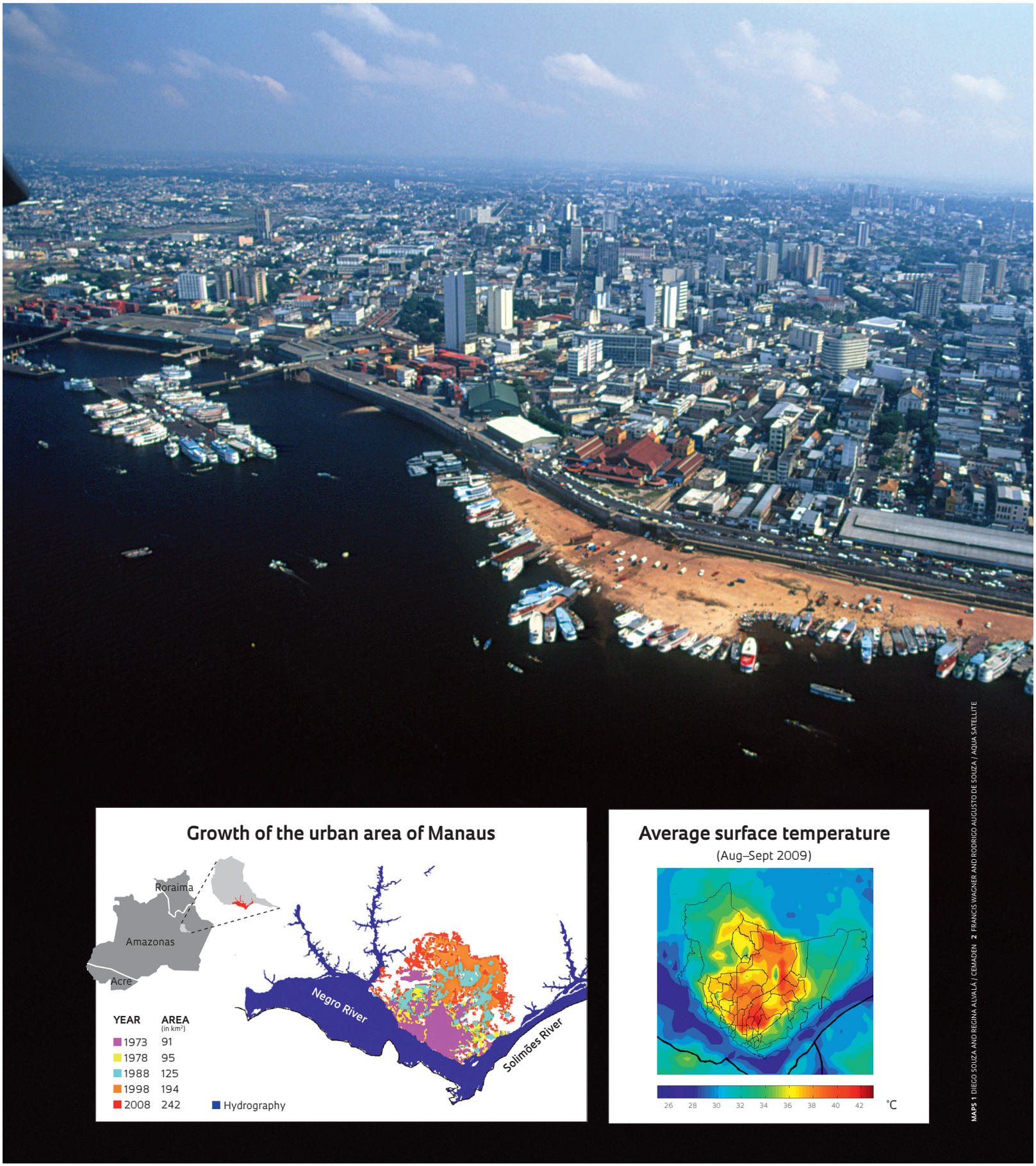

MAPS 1 DIEGO SOUZA AND REGINA ALVALÁ / CEMADEN **2** FRANCIS WAGNER AND RODRIGO AUGUSTO DE SOUZA / AQUA SATELLITE

PHOTO AFP IMAGEFORUM

The capital of the state of Amazonas: increases in concrete and asphalt make the city warmer

A heat island in the Amazon

The urban area of the city of Manaus is 3°C warmer than the surrounding forest

Marcos Pivetta

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The cities of Manaus and Belém, centers of development in the immense, hot, humid tropical forest of the Brazilian Amazon, are beginning to manifest the climate changes typical of large cities. From 1961 to 2010, the average temperature in Manaus rose by 0.7 degrees Celsius (°C) to 26.5°C, according to data from the National Institute for Space Research (INPE). During the same period, the average temperature in Belém rose by 1.51°C to 26.3°C. In both cases, the increase was due principally to the growth of urban areas in the cities, a process that has intensified in recent decades, although aggregate effects related to climate changes on a larger scale may also have had some impact. In 1973, the urban areas of the Manaus and Belém metropolitan regions covered 91 and 76 square kilometers, respectively. By 2008, these numbers had risen to 242 and 270 square kilometers, respectively (*see the charts on pages 42 and 45*).

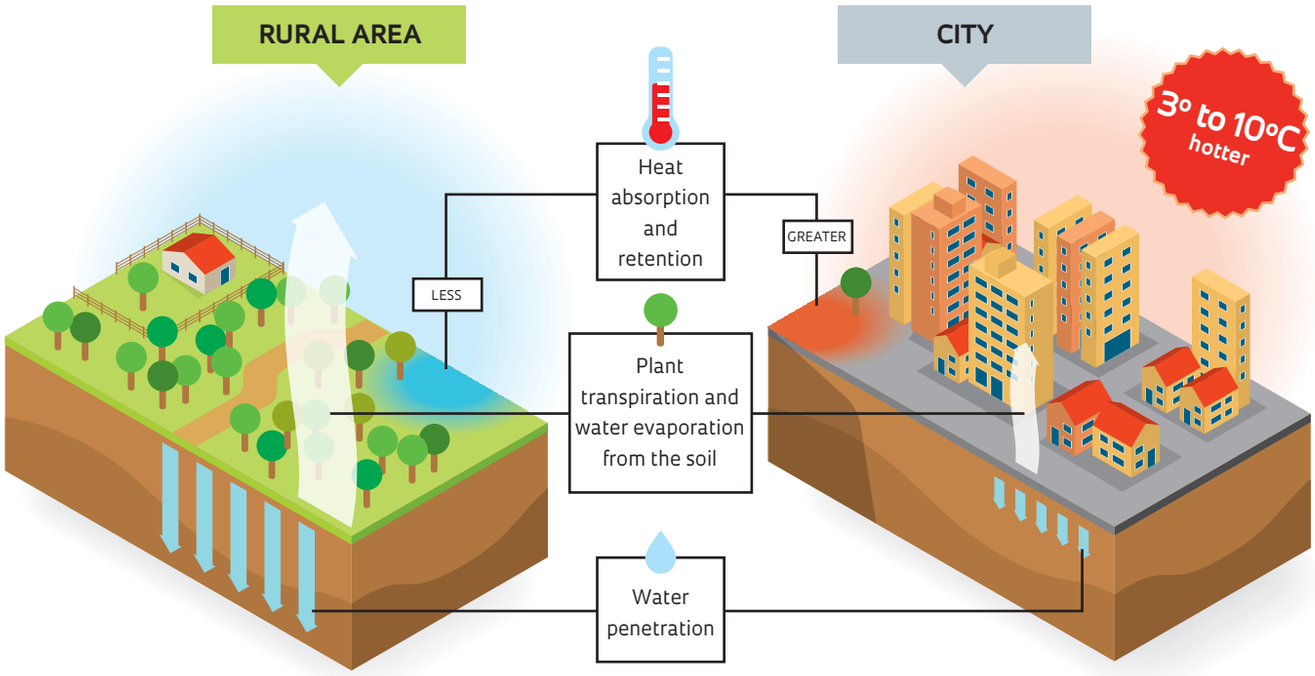
With more buildings and concrete and asphalt taking the place of native vegetation, what is known as the urban heat island effect – a phenomenon long known to the residents of São Paulo and Rio de Janeiro – has also taken hold in the two main cities of Brazil's north. At any time of day, the temperature in the most densely populated areas of these cities is consistently higher than that in nearby rural areas, where forest remains. Heat island data are clearer in the case of Manaus, today the seventh most populous Brazilian city, with over 1.8 million residents. Its population has surpassed those of northeastern state capitals such as Recife and major cities in the south such as Porto Alegre and Curitiba. The temperature difference between the more urbanized parts of the Amazon metropolis of Manaus and an area of Amazon forest approximately 30 kilometers away, the Cuieiras Biological Reserve, peaks at more than 3°C in five of the twelve months of the year.

These results are based on data collected hourly at four weather stations from 2000 to 2008 and reported in an article by Diego Souza and Regina Alvalá, former INPE researchers currently at the National Center for Natural Disaster Monitoring and Alerts (CEMADEN), in the city of Cachoeira Paulista, published on August 8 in the journal *Meteorological Applications*.

The study by Souza and Alvalá also indicates that the atmosphere of the urban areas of Manaus has become drier than that of the surrounding forests. During the period studied, the relative air humidity in the central areas of Manaus was, on average, 1.7% lower than that in the adjacent forest. The difference in relative humidity is greatest in February, in the middle of the rainy season,

Why the urban heat island effect occurs

GRAPHIC ALEXANDRE AFFONSO



when the relative humidity is 3.5% lower in the city than in the forest. "This data clearly shows the heat island effect in Manaus," according to Regina Alvalá, a cartographic engineer specializing in the mapping of land use and cover that is used in weather modeling.

The CEMADEN researchers were unable to determine the extent of the urban heat island effect in Belém due to the absence of long-term historical records containing daily averages based on hourly data for different parts of the city and its surrounding forested areas.. However, there is evidence that the heat island phenomenon in Belém – the eleventh most populous Brazilian city, with just over 1.4 million people – is most prominent during the night.

Although they may seem small to the millions of residents of Brazil's two megacities (São Paulo and Rio de Janeiro), Manaus and Belém have become large urban metropolitan areas by world standards. If they were, for example, French or Italian cities, they would be behind only Paris and Rome in terms of population.

TWO PEAKS

A unique and controversial point noted in the article by Souza and Alvalá was the identification of two daily peaks during which the heat island effect is exacerbated in Manaus: the first at approximately 8 am and the second between 3 pm and 5 pm. As the meteorologist Souza stated, "most cities have only one daily peak of the heat island effect, and it usually occurs at night or in the early morning." The researchers are not sure why the peaks in Manaus occur at these two times of day, but they speculate that they may be associated with rush hour traffic. The heat generated by fuel combustion is one of the factors that contribute to local warming of the atmosphere.

A study undertaken by Francis Wagner and Rodrigo Augusto de Souza, physicists at the Amazonas State University (UEA), also evaluated the heat island effect in Manaus. Not all of their findings concerning the characteristics of the phenomenon are consistent with the information in the CEMADEN article. However, in addition to methodological differences, the UEA researchers' work covered another time period. Between May 2010 and April 2011, air temperature data from four stations – two in urban areas and two in rural areas – were analyzed. Wagner and Rodrigo Souza found two peaks in the heat island effect, one at 7 am and another at 8 pm. The largest temperature difference between the urban and rural areas was on the order of 3.5°C.

From 1961 to 2010, the average temperature in Belém increased by 1.51°C to 26.3°C

Based on data from the environmental satellite Aqua, which scans the area with a spatial resolution of 1 x 1 km, UEA scientists estimated temperature variations on the ground in Manaus from August to September 2009, typically the driest months. The hottest areas were precisely the most urbanized, and the coolest were those with the largest quantity of preserved vegetation. On the ground, the temperature differences between areas covered by concrete and asphalt – such as the downtown area and the Cidade Nova and Petrópolis neighborhoods – and forested areas reached 10°C. "We're doing a study of the microclimate in the urban areas of Manaus to aid in creating a master plan for forestation and ecological zoning," stated Wagner, whose project is financed by the Manaus Municipal Development and Environment Fund.

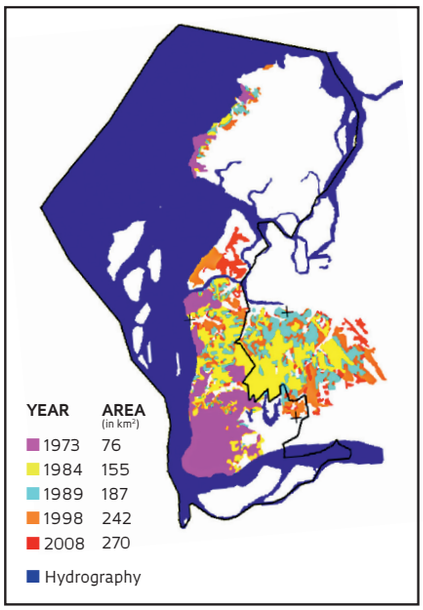
A possible result of the heat island effect is the alteration of rainfall patterns over the two Amazonian cities. For example, in São Paulo, the largest city in Brazil, the average annual rainfall has increased 30% over the past 80 years, and part of this increased rainfall, particularly in spring and summer, is attributed in some studies to increased urbanization. The results of high-resolution atmospheric modeling studies carried out by Souza and Alvalá indicate that if the urban areas of the two capitals continue to grow, there will be a downward trend in rainfall in Manaus, whereas Belém is expected to experience a slight increase in rainfall. "However, the changes in rainfall patterns do not seem to be very significant," according to Alvalá.

LONDON HEAT IN THE NINETEENTH CENTURY

Although it was not then known by that name, the urban heat island phenomenon has been studied since the early nineteenth century, when British scientist Luke Howard measured differences of almost 2°C at night between London, then the largest metropolis in the world, with more than 1 million inhabitants, and three rural locations nearby. Since then, the analysis of city climates has become an increasingly important research topic, especially in the twenty-first century, when, for the first time in history, more people are living in urban centers than are living in rural areas.

Enlargement of Belém

In 35 years, the size of the urban area of the metropolitan region has tripled



MAP DIEGO SOUZA AND REGINA ALVALÁ / CEMADEN

The building of cities radically alters patterns of land use and creates microclimates where heat islands almost become a natural law. Instead of exposed soil, grass and trees, which are rural features that mitigate high temperatures both at the ground level and in the air, the urban landscape is dominated by impermeable and heat-trapping materials that retain heat differently than vegetation. In the countryside, the presence of woody vegetation and scrub creates shadow zones that reduce soil temperature and subsequently reduce the atmospheric temperature. Green areas also contribute to the cooling of a locale's climate through evapotranspiration. This is the mechanism by which plants and soil release water to the air, dissipating heat from the environment.

In the most urbanized parts of a city, everything that makes the climate of the countryside milder is either scarce or absent. Rainwater barely penetrates the soil, there is less local moisture and the evapotranspiration process is less intense. In general, a city of concrete, asphalt, glass and metal tends to absorb and store twice as much heat as a neighboring rural area. Urban architecture, with its tall buildings and structures with surface textures different from those of the countryside, can also change wind patterns and intensify the sensation of heat. In megacities such as São Paulo or New York, the heat island effect may result in a difference of up to 12°C in air temperature between a densely urbanized area and a rural area or forest. If the comparison is made with ground temperatures, the differences tend to be even larger.

In Brazil, the effect of urban heat islands has been studied in many state capitals for some time. In the state of São Paulo, small and medium cities have also become the target of research on the phenomenon. A team of geographers from the Presidente Prudente campus of São Paulo State University (UNESP), led by João Lima Sant'Anna Neto and Margarete Amorim, measured the heat island effect in six municipalities in the inland regions of São Paulo state: Teodoro Sampaio, Euclides da Cunha, Jales, Rosana, and Birigui, and Presidente Prudente. They used data from the Landsat satellite thermal channel and from fixed and mobile weather stations to measure the phenomenon.

In Presidente Prudente, a city with 207,000 inhabitants, there were differences of up to 8°C between the more urbanized and rural areas, especially at night. The hottest areas in the city were the neighborhoods where government-built housing projects were located. Sant'Anna Neto notes that "in these places, the use of inappropriate building materials, such as fiber cement tiles, the high density of built area and the scarcity of green space is intensifying heat islands, since there are no large pollutant emissions from industry and vehicles." Even tiny towns, such as Alfredo Marcondes, a city with 3,800 inhabitants adjacent to Presidente Prudente, has suffered climate change. Differences of 2.5°C were measured between its urban and rural areas. "Heat islands are also a public health problem and predispose the elderly and children to respiratory and circulatory diseases," according to Sant'Anna Neto. ■

Scientific article

OLIVEIRA, D.O. and ALVALÁ, R.C.S. Observational evidence of the urban heat island effect in Manaus City, Brazil. **Meteorological Applications.** Published online. Aug. 3, 2012.