ÉVOLUTION CLIMATIQUE ET CANICULE EN MILIEU URBAIN

apport de la télédétection à l'anticipation et à la gestion de l'impact sanitaire

Rapport de projet soutenu par la Fondation MAIF (2008-2010)

Actions de valorisation

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Elle a été réalisée sous la co-responsabilité de Bénédicte DOUSSET, Responsable scientifique du projet et Chercheur associé au laboratoire Géomer et Chercheur à l'Université d'Hawaï, et Françoise GOURMELON, Directeur de recherche au CNRS et responsable du laboratoire Géomer.

Ont également participé à la recherche :

E. GIRAUDET, Ingénieur d'études CNRS, Géomer,
K. LAAIDI, Epidémiologiste, Institut national de Veille Sanitaire (InVS),
A. ZEGHNOUN, Statisticien, InVS.
P. BRETIN, Epidémiologiste, InVS,
S. VANDENTORREN, Epidémiologiste, InVS,

Fondation MAIF
Le Pavois
50, Avenue Salvador Allende
79000 Niort
Tél : 05 49 73 87 04
Fax : 05 49 73 87 03
http://www.fondation-maif.fr

Géomer UMR 6554, LETG, CNRS
Technopôle Brest-Iroise
Institut Universitaire Européen de la Mer
Place Nicolas Copernic
29280 Plouzané
http://letg.univ-nantes.fr

Institut de Veille Sanitaire
12, rue du Val d'Osne
94415 Saint-Maurice cedex
France
Tél : 33 (0) 1 41 79 67 00
Fax : 33 (0) 1 41 79 67 67
http://www.invs.sante.fr/

Le texte suivant est sous la seule responsabilité du Laboratoire Géomer

Les villes sont particulièrement vulnérables face aux événements climatiques extrêmes, tant sur le plan humain qu'environnemental et économique. La finalité du projet « Evolution climatique et canicule en milieu urbain » était de mieux comprendre l'incidence et l'intensité des canicules et leur impact sanitaire pour contribuer à l'anticipation et à la gestion des risques face à la récurrence des événements de chaleur extrême engendrés par le réchauffement des étés en Europe occidentale. L'analyse des images satellitaires de la région parisienne durant la canicule d'août 2003 à mis en évidence : i) le contraste entre la distribution des îlots de chaleur de jour et de nuit lié à l'occupation du sol et l'inertie thermique des surfaces; ii) l'atténuation de la chaleur par la végétation; iii) la relation entre l'augmentation des températures nocturnes et l'intensité de la canicule; iv) la variation spatio-temporelle des îlots de chaleur et des seuils critiques de température ; v) l'impact des températures nocturnes élevées et de la durée des vagues de chaleur sur les risques de mortalité des personnes âgées.

L'originalité du projet tient dans un jeu de données exceptionnel permettant pour la première fois l'analyse conjointe d'une série d'images thermiques et d'une étude de cas de mortalité de personnes âgées, sur une période continue de 13 jours. Les statistiques ont permis d'estimer, en un lieu donné, l'impact relatif d'exposition à la chaleur. Les résultats montrent qu'il est possible d'anticiper les risques sanitaires non seulement en termes de probabilité, mais aussi en termes de temps, lieu et magnitude.

L'adaptation au changement climatique implique de s'adapter également à de nouveaux concepts et à de nouvelles méthodes de mesures. De nombreux auteurs s'accordent sur le fait que la télédétection est décisive d'une part pour la compréhension fine des phénomènes physiques en milieu urbain et de leur impact sanitaire en période de canicule, et d'autre part pour le suivi des changements de température aux différentes étapes, avant, pendant et après les événements de chaleur extrême ; ce que les résultats acquis attestent.

- «Avant» implique l'anticipation des risques : l'amélioration des prévisions, la réduction des incertitudes et la résilience à l'événement par l'information et la prise de mesures préventives. Par exemple, dès le printemps, l'observation satellitaire à l'échelle régionale, de l'intensité et de la durée de la radiation, de la couverture nuageuse et de l'état de la végétation, permet de détecter les conditions de sécheresse favorables à une canicule et les régions les plus vulnérables. Une telle surveillance aurait peut-être permis d'anticiper les nombreux feux de tourbières dans la région de Moscou pendant les vagues de chaleur de juillet-août 2010 qui ont entraîné une surmortalité de 11000 personnes.
- «Pendant» implique la gestion de la crise : la délimitation des zones à forte chaleur, le lancement d'alertes localisées, l'assistance appropriée. Les mesures de température enregistrées dans un parc urbain ou un aéroport ne rendent pas compte des conditions d'exposition des habitants à la chaleur urbaine. Seule la télédétection permet le suivi du développement des îlots de chaleur, la localisation des secteurs vulnérables et des anomalies thermiques isolées pour faciliter l'information et les interventions locales. Ainsi l'usage des images satellitaires en région parisienne en août 2003, aurait probablement permis d'améliorer la gestion sanitaire de la canicule.

Dans le cadre de notre étude, un test de faisabilité de l'observation en temps réel sur la région parisienne avait été envisagé en collaboration avec le SATMOS (Service d'Archivage et de Traitement Météorologique des Observations Satellitaires – INSU-CNRS-Météo-France). Deux réunions avec le SATMOS ont eu lieu et un programme d'affichage des images satellitaires sur internet a été développé. Ce test de faisabilité a été reporté à la demande de l'InVS. Toutefois, le laboratoire Géomer a contribué par son expertise à un nouveau programme de surveillance satellitaire en temps réel de 10 grandes villes européennes, durant les mois d'été. Ce programme sur les îlots de chaleur et la thermographie urbaine, réalisé par un consortium de 5 instituts, est dirigé par l'Agence Spatiale Européenne. Les premiers résultats se sont avérés utiles durant les périodes d'extrême chaleur de l'été 2010 à Athènes (http://www.urbanheatisland.info).

- «Après» implique le suivi social et environnemental de la canicule et les retours d'expériences pour comprendre l'événement extrême afin d'améliorer son anticipation et sa gestion lors des prochaines vagues de chaleur. Après la canicule de 2003, de nombreuses analyses rétroactives ont été menées, certaines (comme la nôtre) utilisant l'imagerie satellitaire.

Des recherches sont en cours pour optimiser l'usage de la télédétection urbaine et en particulier assimiler les données radiométriques dans les modèles de couche limite urbaine, implémenter la surveillance climatique en temps réel, estimer l'exposition à la chaleur. De plus l'Agence Spatiale Européenne envisage le développement d'un capteur thermique à haute résolution spatiale qui serait principalement destiné à la surveillance des climats urbains.

Les résultats de nos travaux ont été communiqués dans différents contextes afin de contribuer aux échanges dans les domaines de la recherche sur le changement climatique et la santé publique, et dans ceux de la gestion des risques sanitaires et de l'adaptation au changement climatique, en particulier en milieu urbain. Les pages suivantes comprennent la liste des actions de valorisation ainsi que quelques exemples de publications dans des revues scientifiques, de communications à des colloques internationaux ou des séminaires et de citations dans les médias suite à une conférence de presse.

1. Publications

a. Revues scientifiques à comité de lecture

- International Journal of Climatology, Vol. 31, p. 313-323 February 2011.

Dousset B., F. Gourmelon, K. Laaidi, A. Zeghnoun, E. Giraudet, P. Bretin, E. Mauri, S. Vandentorren. 2010. "Satellite monitoring of summer heat waves in the Paris metropolitan area".
http://onlinelibrary.wiley.com/doi/10.1002/joc.2222/abstract

- Environmental Health Perspectives (manuscrit soumis le 7 février 2011)

Laadi K., A. Zeghnoun, B. Dousset, P. Bretin, S. Vandentorren, E. Giraudet, P. Beaudeau. "Heat islands impacts on human health in Paris during the August 2003 Heat wave".

b. Autres publications

- Cahiers de la solidarité

Europe et risques climatiques. 2009, "Evolution climatique et canicule en milieu urbain: apport de la télédétection à l'anticipation et à la gestion de l'impact sanitaire". Laboratoire Géomer UMR 8554-LETG-CNRS / Institut Européen de la Mer-UBO, *Cahiers de la solidarité* n°18, p82-83, édité à l'occasion des 20 ans de la Fondation MAIF.
http://www.pourlasolidarite.eu/Europe-et-risques-climatiques?lang=fr

- Vidéo : La recherche au service de la prévention

B. Dousset, 2009. "La recherche au service de la prévention: Evolution climatique et canicule en milieu urbain", CD-ROM-Agence interne multimedia MAIF.

2. Conférences internationales

a. communications orales

- The 89th American Meteorological Society annual meeting, Eight Symposium on the Urban Environment

Phoenix (USA), January 10-16 2009
Session 4 : Biometeorology and Public Health In Urban Area
B. Dousset, F. Gourmelon, E. Giraudet, K. Laaidi, K. Zeghnoun, and P. Bretin
Heat waves, urban heat stress and mortality: a satellite surveillance system
http://ams.confex.com/ams/89annual/techprogram/programexpanded_522.htm

- Seventh International Conference on Urban Climate ICUC-7

Yokohama (Japan), June 29 - July 3 2009
Session Urban remote sensing
B. Dousset, F. Gourmelon, K. Laaidi, A. Zeghnoun, E. Giraudet, P. Bretin, S. Vandentorren
Satellite monitoring of summertime heat waves in the Paris metropolitan area
http://www.ide.titech.ac.jp/~icuc7/extended_abstracts/pdf/384388-1-090518140731-002.pdf

- ***Séminaire Risques climatiques, quels enjeux pour l'Europe ?***
  Bruxelles (Belgique), 28 octobre 2009
  Comité Economique et Social Européen, *Fondation MAIF* et *Pour la Solidarité* : conférence et table ronde sur la dimension européenne des risques climatiques.
  B. Dousset
  Risques climatiques et vagues de chaleur dans les villes européennes
  http://www.pourlasolidarite.eu/IMG/pdf/Programme_20ans_EN.pdf

- ***American Geophysical Union Fall Meeting***
  San Francisco (USA), December 13-17, 2010
  Biogeosciences : session B2, Urban Areas and Global Change
  B. Dousset, F. Gourmelon, E. Giraudet, K. Laaidi, A. Zeghnoun, P. Bretin, S. Vandentorren
  Climate change and heat waves in Paris and London metropolitan areas
  http://www.agu.org/meetings/fm10/program/index.php

- ***AGU Conférence de presse*** : «New Views of Urban Heat Islands» Dec. 13 2010
  B. Dousset
  http://www.agu.org/meetings/fm10/newsmedia/press_conference_schedule.php

b. communications posters

- ***Scientific International Congress on Climate Change***
  Global risks, Challenges and Decisions, *Copenhagen March 10-12 2009*
  Session 42 - Adaptation and Climate Risk Insurance
  B. Dousset, F. Gourmelon, K. Laaidi, H. Oliviero, A. Zeghnoun, E. Giraudet, P. Bretin, S. Vandentorren
  A contribution of an insurance fondation to the study of urban heat waves and their societal impact
  http://iopscience.iop.org/1755-1315/6/42/422010

- ***Health Protection 2009*** *- Warwick, 14 -16 Septembre 2009*
  Session: Emergency preparedness and response
  K.Laaidi, A. Zeghnoun, B. Dousset, P Bretin, S. Vandentorren, E. Giraudet, F. Gourmelon,
  Health impact of heatwaves: the use of remote sensing in defining a new indicator of urban surface temperature
  http://www.healthprotectionconference.org.uk/

- ***Atelier européen "Workshop on Public Health Surveillance and Climate Change".***
  Institut de veille sanitaire (France). 25 – 26 mars 2010
  K.Laaidi, A. Zeghnoun, B. Dousset, P Bretin, S. Vandentorren, E. Giraudet, F. Gourmelon
  (même poster que pour le Health protection 2009)

- ***Joint Conference of International Society of Exposure Science & International Society for Environmental Epidemiology***
  Seoul (South Corea), August 28 –September 1, 2010.
  Theme : Technology, Environmental Sustainability and Health
  K. Laaidi, A. Zeghnoun, B. Dousset, P. Bretin, S. Vandentorren, E. Giraudet, F. Gourmelon
  Health impact of heatwaves in urban heat islands: how to estimate the exposure of the population ?
  http://www.isesisee2010.org

c. communications à venir

- *European Geosciences Union General Assembly*
Vienna (Austria), April 03-08, 2011
Session CL2.16 Urban climate, urban heat island and urban biometeorology
B. Dousset, F. Gourmelon, K. Laaidi, A. Zeghnoun, E. Giraudet, P. Bretin, S. Vandentorren.
Summer warming trends, heat waves and health impact in the Paris metropolitan area

- *19th International Congress of Biometeorology*
The University of Auckland (New Zeeland), December 5 – 9, 2011,
Theme : "Climate and Society", Congrès tri-annuel de la "International society of Biometeorology.
K.Laaidi, A. Zeghnoun, B. Dousset, P Bretin, S. Vandentorren, E. Giraudet, F. Gourmelon

3. Citations dans la presse à l'issue de la session Urban Areas and Global Change et de la conférence de presse de l' "American Geophysical Union Conference" *(San Francisco déc.13, 2010), quelques exemples :*

- EOS Transactions American Geophysical Union : Urban Areas and Climate Change. E Tretkoff, Vol. 91 N°51 page 503, Dec 21, 2010
- Discovery News : Nighttime Makes Urban Heat Waves Deadly. JD Cox, Dec 14, 2010
- NASA Earth Features : Heat Islands Sprawl, Dec 14, 2010
- Urban Climate News : "In the News", Satellites Pinpoint Drivers of Urban Heat Islands, International Association For Urban Climate N°38, Dec 2010

4. Annonces et parutions sur des sites internets

http://www1.nasa.gov/topics/earth/features/heat-island-sprawl_prt.htm

http://news.discovery.com/earth/nighttime-makes-urban-heat-waves-deady.html

http://www.physorg.com/news/2010-12-satellites-drivers-urban-islands-northeast.html

également sur : *RedOrbit News, SpaceMart, SpaceDaily, IceCap, Softpedia, Nano Patents and Innnovations ….*

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Satellite monitoring of summer heat waves in the Paris metropolitan area

Bénédicte Dousset,[a,b]* Françoise Gourmelon,[b] Karine Laaidi,[c] Abdelkrim Zeghnoun,[c] Emmanuel Giraudet,[b] Philippe Bretin,[c] Elena Mauri[d] and Stéphanie Vandentorren,[c]
[a] *Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, Hawaii, USA*
[b] *Géomer, UMR-6554 LETG CNRS, IUEM Plouzané, France*
[c] *Institut de Veille Sanitaire, Saint Maurice, France*
[d] *Istituto Nazionale di Oceanografica e di Geofisica Sperimentale, Trieste, Italy*

ABSTRACT: Summer warming trends in Western Europe are increasing the incidence, intensity and duration of heat waves. They are especially deadly in large cities owing to population density, physical surface properties, anthropogenic heat and pollutants. In August 2003, for 9 consecutive days, the Paris metropolitan area experienced an extreme heat wave that caused 4867 estimated heat-related deaths. A set of 61 NOAA-AVHRR (advanced very high-resolution radiometer) images and one SPOT-high resolution visible (HRV) image were used to analyse the spatial variations of land surface temperature (LST) over the diurnal cycle during the heat wave. The LST patterns were markedly different between daytime and night-time. A heat island was centred downtown at night, whereas multiple temperature anomalies were scattered in the industrial suburbs during the day. The heat wave corresponded to elevated nocturnal LST compared to normal summers. The highest mortality ratios matched the spatial distribution of the highest night-time LSTs, but were not related to the highest daytime LSTs. LSTs were sampled from images at the addresses of 482 elderly people (half were deceased persons and half were control ones) to produce daily and cumulative minimal, maximal and mean thermal indicators, over various periods of time. These indicators were integrated into a conditional logistic regression model to test their use as heat exposure indicators, based on risk factors. Over the period 1–13 August, thermal indicators taking into account minimum nocturnal temperatures averaged over 7 days or over the whole period were significantly linked to mortality. These results show the extent of the spatial variability in urban climate variables and the impact of night-time temperatures on excess mortality. These results should be used to inform policy and contingency planning in relation to heat waves, and highlight the role that satellite remote sensing can play in documenting and preventing heat-related mortality. Copyright © 2010 Royal Meteorological Society

KEY WORDS urban climatology; heat waves; satellite thermal IR sensing; heat stress; mortality

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1. Introduction

Observations and reconstructions of global temperature evolution indicate a pronounced warming during the last 150 years, with an increase in the occurrence of so-called heat waves, which are extended periods of anomalously high summertime temperatures (Schär *et al.*, 2004). In the last decade, numerous heat waves occurred in Western and Central Europe and in the Mediterranean regions (2003, 2006 and 2007). Climate models for the 21st century suggest that the year-to-year variability of summer temperatures might experience a pronounced increase in response to greenhouse gases, affecting the frequency, intensity and duration of heat waves (Meelh and Tebaldi, 2004; Tebaldi *et al.*, 2006). By the end of the century, if greenhouse gas emissions are not reduced, the fraction of days with temperatures above 30°C in France might equal that currently experienced further south in Spain and in Sicily (Beniston *et al.*, 2007).

Heat waves are especially deadly in cities due to population density and urban surface characteristics. Urbanization drastically modifies the partition of the heat fluxes compared to suburban or rural surroundings, generating a differential temperature effect called an *urban heat island*. The main contributing factors are (1) changes in the physical characteristics of the surface such as *albedo*, emissivity or thermal conductivity owing to the replacement of vegetation by asphalt and concrete, and consequently changes in the radiative fluxes; (2) a decrease in surface moisture available for evapotranspiration; (3) changes in the near-surface flow, owing to the complicated geometry of streets and tall buildings; and (4) anthropogenic heat. At night, urban areas gradually release the heat accumulated in structures during the day, whereas rural areas cool off by unobstructed outgoing radiation. As is demonstrated below, it is the lack of relief at night, rather

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*Correspondence to: Bénédicte Dousset, Hawaii Institute of Geophysics and Planetology, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, 680 East-West Road, Honolulu, Hawaii 96822, USA. E-mail: bdousset@hawaii.edu

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than high daytime temperatures, that threatens people's health. The elderly, infants, young children, and people with chronic health problems such as asthma and cardiac diseases are more vulnerable. Air pollution, enhanced by high temperatures, further exacerbates the adverse health effects by stressing the respiratory and circulatory systems (Basu and Samet, 2002).

In August 2003, a persistent anticyclone over Western Europe blocked rain-bearing depressions from the Atlantic Ocean and advected dry air from Northern Africa. The average summer temperatures exceeded the 1961–1990 mean by ∼3 °C, an increase of up to 5 standard deviations (Schär and Jendritzky, 2004). These anomalous conditions resulted in a heat wave of exceptional strength and duration and a death toll estimated to have exceeded 70 000 (Robine *et al.*, 2008). In France, this extreme heat wave event was preceded by an unusually warm and dry spring. Rainfall deficit and high net radiation enhanced by clear skies contributed to early green-up and drying of the soil by evapotranspiration (Zaitchik *et al.*, 2006; Fischer *et al.*, 2007). From March to August, temperatures exceeded the 1971–2000 long-term mean by 4.7 °C in June, 1.8 °C in July and 4.4 °C in August (Bessemoulin *et al.*, 2004).

From 4 to 13 August, the Paris metropolitan area experienced 9 consecutive days with maximum air temperatures above 35 °C, reaching 39 °C at the peak of the heat wave on 12 August. Minimum temperatures steadily increased from 20 to 25.7 °C on 11 and 12 August. The atmosphere was very stable, the wind speed fluctuated between 1 and 4 m/s and the relative humidity and potential evapotranspiration were, respectively, below and above those of normal summers. From the start of the heat wave to its peak, the relative humidity decreased from 38% to 18% during daytime, and from 78% to 58% during night-time. Relative humidity regulates the rate of latent heat transfer from the human body, through perspiration, and high humidity augments the likelihood of heat stress and disorders. Clear skies intensified radiative forcing and strong sunlight triggered the photochemical production of ozone and its accumulation (Tressol *et al.*, 2008). However, in Paris the levels of humidity or ozone had little influence on the excess mortality, which was mainly attributable to temperature (Filleul *et al.*, 2006). The excess mortality reached +141% in the Paris region, resulting in an estimated 4867 heat-related deaths (Hémon and Jougla, 2003). Figure 1 shows the maximum and minimum air surface temperatures and associated mortality rate in summer 2003 in the Paris region. It indicates a short time lag between temperature increase and death, particularly during 11–13 August at the peak of the heat wave.

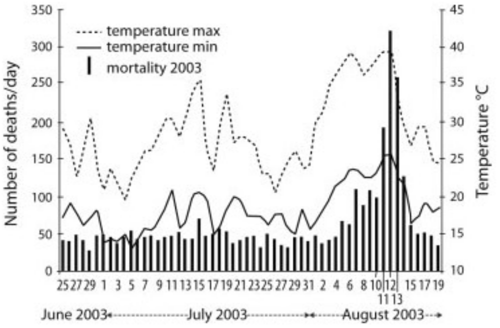

Figure 1. Maximum and minimum surface air temperature at the Paris weather station in the Montsouris Park (right scale) and mortality (left scale), from 25 June to 19 August 2003 (after InVS 2003).

Summer warming trends and increased weather variability in Western Europe have important implications for human health, particularly in large cities (Kalkstein and Green, 1997). Health risks increase with heat intensity, relative humidity, time exposure and high minimum night-time temperatures. Following the 2003 heat wave, the French Institut de Veille Sanitaire (InVS), which is a public health surveillance agency, in cooperation with Météo-France implemented a heat–health warning system based on biometeorological indicators, operating from 1 June to 31 August (Pascal *et al.*, 2006). This alert system allows people to enact management and prevention measures when the thresholds are reached. However, the available information does not take into account the intraurban temperature variations, which would enable one to take not only emergency measures but also long-term ones concerning urban planning. For synoptic purposes, most weather stations are situated in parks and airports, away from the effects of built environments. In Paris, the reference weather station is located in the Montsouris Park and its measurements may underestimate the temperatures experienced by people living downtown, or working in suburban industrial areas by several degrees. Furthermore, the weather station network is too sparse to record smaller scale variations in temperatures that may pose an increased risk to human health and which are best resolved using satellite thermal infrared sensing.

Applications of remote sensing in urban climatology have demonstrated the relationship between sprawling conurbations and complex patterns of surface temperature and heat islands (Dousset and Gourmelon, 2003; Streutker, 2003; Kato and Yamaguchi, 2005; Nichol, 2005; Hung *et al.*, 2006). Satellite monitoring of extreme heat events in urban areas (Dousset *et al.*, 2007; Cheval *et al.*, 2009) and estimations of associated public health impact (Johnson *et al.*, 2009) are recent developments. The objectives of this research were first, to monitor and analyse the spatial gradient of radiometric surface temperature over the diurnal cycle during the 2003 heat wave; second, to implement indicators of heat exposure for the elderly to better represent the risks of heat stress and mortality and third, to demonstrate the use of satellites for monitoring summer heat waves. This article is divided into four parts. Data acquisition and processing are described in part two. The LST spatial variability over the diurnal cycle, the comparison with the summer

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of 1998, the relation to land use/cover, and new indicators of heat exposure are presented in part three. The results are discussed in part four.

2. Methods

2.1. The Paris metropolitan area

Paris (2° 20′E, 48° 50′N) is located in a sedimentary basin on the Seine River. The regional climate is moderated by the oceanic influence of the mid-latitude Westerlies. The Paris Basin is relatively flat with low relief hills, which may produce significant low-level atmospheric motions, although orography has little impact on the thermal parameters (Troude *et al.*, 2002). The metropolitan area is characterized by compact urbanization, with a population of nearly 12 million and a high density of ∼20 000 inhabitants/km^2 in the city.

2.2. Remotely sensed data

2.2.1. NOAA-AVHRR acquisition and processing

Two high-resolution thermal images were available during the 4–13 August 2003 heat wave, one from the Landsat-5 Thematic Mapper (TM) (9 August) and another from Terra-ASTER (10 August). However, monitoring requires repetitive imaging to resolve the diurnal cycle and high resolution to observe spatial variability. Geostationary satellites have frequent sampling, but their coarser spatial resolution is insufficient for urban observations. These are best resolved by 1.1-km resolution images from sun-synchronous polar orbiting satellites, such as NOAA, Terra and Acqua, that pass twice daily. In summer 2003, the simultaneous operation of satellites NOAA 12, 16 and 17 provided good coverage with a 4–6 h revisit period.

Eighty-four images, which were sensed from 21 July to 21 August by the advanced very high-resolution radiometer (AVHRR) on board NOAA satellites, were acquired by the high-resolution picture transmission (HRPT) receiving station at the Istituto Nazionale di Oceanografica e di Geofisica Sperimentale, in Trieste. Seventy-six scenes were selected according to clear sky, image quality and small satellite-zenith viewing angle to ensure ground resolution close to 1.1 km and minimize both atmospheric attenuation and anisotropic effects. The images were geometrically corrected for earth rotation and curvature, orthorectified and interactively referenced to a Lambert projection. The AVHRR scans in six spectral channels centred at 0.62 μm (ch. 1), 0.91 μm (ch. 2), 1.61 μm (ch. 3A) and 3.74 μm (ch. 3B), 10.8 μm (ch. 4) and 12 μm (ch. 5). Land albedo and daytime cloudiness were derived from channel 2, and night-time cloudiness from the difference between channels 3 and 4. Cloudy pixels were flagged according to a threshold derived from the histograms of cloud-free images. Normalized difference vegetation indices (NDVI) were computed from the visible and near-infrared channels (ch. 1 and ch. 2). Calibrated brightness temperature was inferred using the internal black-body references of the satellites. The main constraints in retrieving LST from infrared satellite images are (1) the partial absorption of black-body radiation by water vapour and other gases in the atmosphere; (2) the surface emissivities being less than 1 and spatially and spectrally variable (Becker and Li, 1995; Dash *et al.*, 2002; Gustafson *et al.*, 2006); (3) sub-pixel variations of surface temperature and hot spots averaged nonlinearly through Planck's law (Dozier, 1981, Dousset *et al.*, 1993); (4) urban canyons trapping radiant and incident energy, increasing the pixel-averaged emissivity and (5) directional and anisotropic effects due to satellite viewing angles and urban structures (Voogt and Oke, 1998; Lagouarde *et al.*, 2004).

In August 2003, the air was dry and the differential atmospheric attenuation from thermal channels 4 and 5 yielded negligible water vapour corrections equivalent to errors less than 1 °C at night and 1 °C to 1.7 °C during the day for brightness temperatures between 30 and 40 °C, respectively. Uncertainties related to radiosounding and modelling of atmospheric transmittance to account for atmospheric absorption would exceed actual errors, and this correction was not justified. The correction for time-independent emissivity was also neglected, because the objective was to study the relative temporal variations of surface temperatures. Most images with satellite-zenith angles higher than 35° were rejected; however, a few were kept and empirically corrected based on consecutive images with smaller satellite-zenith angles (Roujean *et al.*, 1997; Lagouarde *et al.*, 2004). Median LST images were constructed from 50 NOAA-AVHRR images over six time intervals of satellites passes (i.e. 1–3, 4–7, 9–12, 12–15, 15–18 and 20–23 UTC) during the 9-day heat wave episode. Figure 2 shows the diurnal distribution of the 50 images, and Figure 3 displays the six median LST images, each averaged over six to ten individual images.

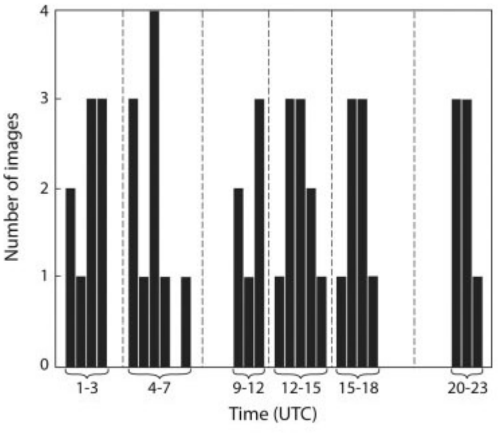

Figure 2. Temporal distribution of 50 images sensed by NOAA satellites 12, 16 and 17 over the region of Paris from 4 to 13 August 2003.

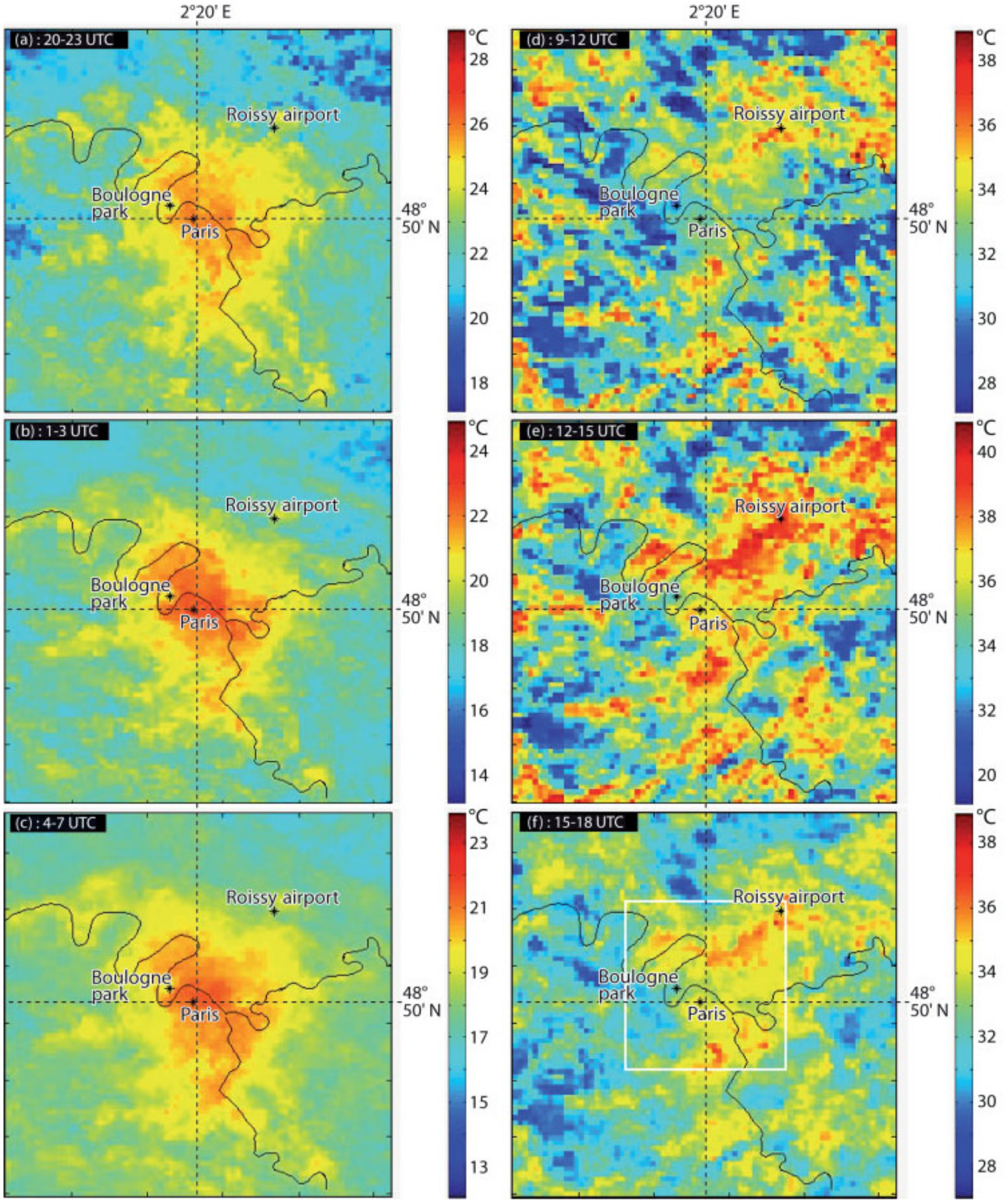

Figure 3. Average LST infrared images (see text) from 4 to 13 August 2003, for each of the diurnal time intervals shown in Figure 2. The colour scale (in degrees Celsius) is optimally enhanced separately for each image. The white square represents the enlarged area of Figure 4(a).

2.2.2. *SPOT HRV-4 acquisition and processing*

Surface characteristics and properties that govern the surface energy balance were extracted from a SPOT-4HRV multi-spectral image acquired on 13 July 2003, three weeks before the extreme event. The processing of the SPOT image included detector radiometric equalization, geometric processing to remove the earth rotation and resampling across-track to a uniform 20-m pixel size. Figure 4(a) represents the unsupervised land cover classification derived from the four visible and near-infrared channels, which yielded six classes corresponding to water, densely built urban areas, sub-urban residential areas, light bare soils, forest and lawns and fields. The classification was further validated using the NDVI, calculated from the SPOT visible and near-infrared channels. A geographic information system (GIS) was used to generate land use/cover fractional images and merge 20-m SPOT and 1-km AVHRR pixels. Ancillary data on urban administrative delineations,

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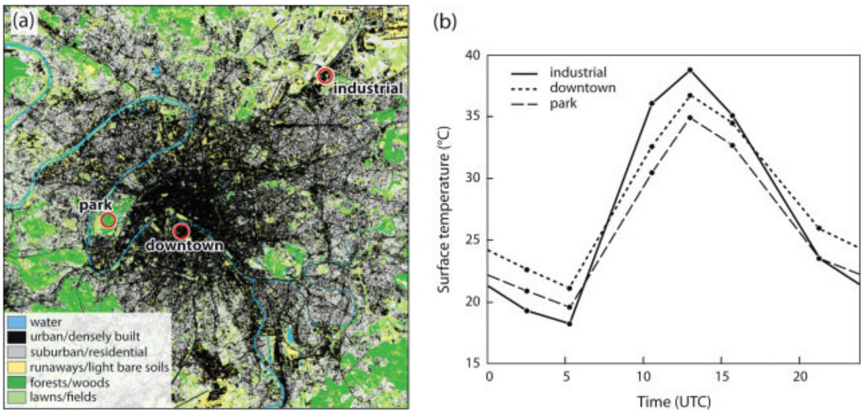

Figure 4. (a) Land cover classification of Paris derived from a SPOT-4 HRV image on 13 July 2003. The three locations used to construct the mean diurnal cycles of land surface temperature (LST) shown in (b) are indicated by circles. (b) Mean diurnal cycles of LST, constructed from 50 NOAA-AVHRR images, at an industrial site, in downtown Paris, and in an urban park (4–13 August 2003).

parks, rivers and industrial areas were obtained from the Paris Department of Planning (APUR) and integrated in the GIS database.

2.3. *In situ* meteorological data

The *in situ* meteorological data were recorded at the Paris automated weather station in Montsouris Park. Hourly data include surface air temperature (T_{air}) at 10 cm, 50 cm and 1.50 m above the surface, ground temperature at −10 cm, dew-point, wind speed and direction, relative humidity, water vapour and insolation and net radiation. Additional data at 00 : 12 UTC include ground temperatures at −20 cm, −50 cm and −1 m depth. Colocated *in situ* and remotely sensed data from Montsouris Park were used to interpret LST results, taking into account the different nature of these measurements.

2.4. Public health data

Following the summer of 2003, the InVS conducted a case–control study to identify the mortality risk factors for elderly people living in the Paris region during the heat wave (Ledrans *et al.*, 2005; Vandentorren *et al.*, 2006). The study included 241 people aged 65 and over, who died between 8 and 13 August and remained at home for at least 24 h before death or hospitalization. These 241 cases were matched with 241 controls, who were people living in a district of Paris under similar socio-economic conditions, having the same sex and age class as the cases, but survived the heat wave (Ledrans *et al.*, 2005). The surface temperature near the domicile of the considered cases and controls was one of the many risk factors related to death that were investigated. Other factors included age, sex, socio-economic conditions, family entourage, behaviour during the heat wave, mobility, health status, housing conditions and environment. In the previous work, LSTs on 200-m radius around the 482 addresses were derived from a single Landsat TM image at 10 : 17 UT on 9 August. Although the spatial resolution of this image is very high, this timing was not optimal to assess thermal patterns. Because the 16-day repeat cycle of the Landsat image precludes daily monitoring, thermal indices for this study were estimated from a time series of 61 NOAA-AVHRR images (1–13 August). The thermal index of an address corresponds to the LST of the pixel that contains the address. Different indicators of temperature exposure were constructed based on minimum and maximum LST, taking into account different lags between temperature and death, and daily temperatures as well as temperatures averaged over 3, 7 and 13 days, based on the knowledge of the lag between temperature extremum and health impact. These indicators were alternately integrated into the conditional logistic model of the previous case–control study, replacing the single indicator. This conditional logistic model (Breslow and Day, 1980) was adjusted for the same variables as in the previous study (age, sex, etc.) so that the relationship between thermal indicators and mortality could be tested.

3. Results

3.1. The LST diurnal cycle

Figure 3 shows six composite images of median LST, constructed from 50 images taken between 4 and 13 August. The LST spatial variability over the diurnal cycle is evident. The images reveal contrasting daytime and night-time heat island patterns, reflecting the different day and night rates of heating and cooling between urban and suburban areas, enhanced by the stable atmosphere that characterized the heat wave episode. The LST variability was analysed as a function of urban surface characteristics by merging data from the 20-m resolution classified SPOT image, and from APUR, with the 1-km resolution NOAA-AVHRR images (Dousset and Gourmelon, 2003).

At night-time, the images show strong urban heat islands of up to 8 °C over the 20–23 UTC and 1–3 UTC averaging periods (Figure 3(a) and (b)), and up to 6 °C over 4–7 UTC (Figure 3(c)). The LST distribution was well correlated with increasing built density from the suburbs to downtown. At the peak of the heat wave, low relative humidity of 27–40% in the evenings (20–23 UTC) in Montsouris Park suggests that vegetated areas in the residential suburbs and rural areas may have been conducive to evaporative and radiative cooling. In the rural areas north of Paris, LST decreased by ~4 °C, and remained constant the rest of the night. In downtown Paris, temperatures decreased slowly as the heat stored in buildings and trapped in urban 'canyons' was progressively lost and anthropogenic heat was continually produced. Eventually, the LST decreased after sunrise, both in the suburbs (~19 °C) and downtown (~22 °C) (Figure3(c)).

During the daytime, multiple temperature anomalies were scattered in the densely built and industrial suburbs, conveying mostly variations of the surface heat balance between dry and comparatively moist surfaces. In Montsouris Park, relative humidity dropped from 38% to 18% at the peak of the heat wave, and the wind fluctuated between ~0 and 2 m/s. From 9 to 12 UTC, the north-east region quickly warmed because of unobstructed field of view, low thermal inertia surfaces and anthropogenic heat produced by heavy traffic and industries. From 12 to 15 UTC (Figure 3(e)), heat islands up to 11 °C were observed between the industrial suburbs and the forests. The highest LSTs of 38–42 °C occurred in the suburbs: to the north in the industrial areas of St. Ouen, Aubervilliers, St. Denis and in the freight zones of Le Bourget, Garonord and Roissy airport; to the west in the industrial area of Argenteuil and to the south in the freight and industrial areas of Ivry-sur-Seine and the Orly airport.

Figure 4(b) displays the diurnal cycle of mean LST at three locations: downtown Paris, Garonord (industries near Roissy Airport) and the Boulogne park, shown in Figure 4(a). Urban canyons in downtown Paris consist of asphalt pavement, stone or concrete buildings of up to 7–10 floors and roofed with slate or zinc. The industrial area comprises large warehouses of 2–3 levels, with corrugated steel or fibre roofs, asphalt or concrete parking lots, and roads. The ~8 km^2 Boulogne Park is mainly composed of lawns, trees, bushes and a small lake. The mean diurnal cycles indicate a near-constant difference of ~1.5–2.2 °C between downtown and the park, but differences of +3 °C at night, and −3.5 °C at noon between downtown and the industrial area, and +4.5 °C at noon between the industrial area and the park (Figure 5). The industrial surfaces with lower thermal inertia and unobstructed sky view are consistently warmer at daytime and cooler at night-time than the downtown and park surfaces.

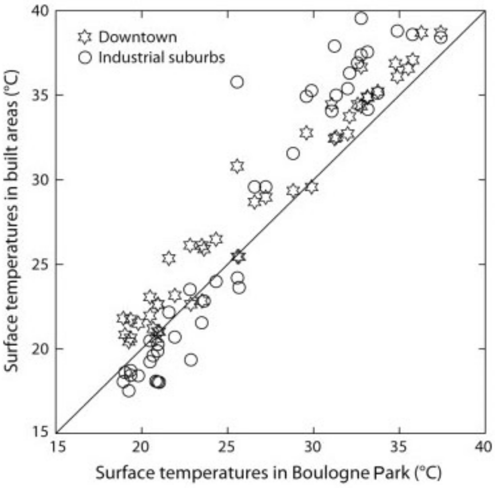

Figure 5. Scatter plot of satellite LSTs of built areas (contrasting downtown and industrial suburbs) against satellite LSTs in the Bois de Boulogne Park taken as reference.

3.2. Colocated satellite and *in situ* data in Montsouris Park

T_{air} and LST measurements are intrinsically different. The former corresponds to the ambient temperature at 1.50 m above the surface, whereas the latter represents the surface radiometric temperature averaged over a pixel, mostly composed of horizontal surfaces within different levels of the canopy layer. These measurements are complementary, because the sensible heat flux is determined by the temperature difference between the surface and the air immediately above it. Their correlation arises from the surface heat balance.

Figure 6(a) shows an hourly time series of T_{air} at 1.50 m and LST at the 4–6 h satellite sampling interval. Figure 6(b) and (c) shows the hourly time series of relative humidity and wind speed. Figure 6(d) and (e) shows the scatter plots of satellite LST *versus* T_{air} at night (01–06 UTC) and by day (12–15 UTC) for 1–13 August. Slopes and offsets of the linear regressions are shown in the respective figures. The linear correlation coefficient was 0.92 at night, but only 0.68 during the day, presumably reflecting stronger sub-pixel variations of surface cover and heat balance regimes. Minima of both T_{air} and LST occurred before sunrise at ~05:00 UTC, just before insolation resumed and net radiation ceased to be negative. At night, T_{air} was generally 1–2 °C higher than LST, except on 12 August at the peak of the heat wave, when the near-surface gradient reached 5 °C presumably because of lack of mixing. Maximum LSTs occurred at the time of maximum solar irradiance, while maximum T_{air} lagged typically by ~3 h. At ~13:00 UTC, T_{air}-LST varied from −2 to −4 °C, implying a significant near-surface temperature gradient due to intense radiative heating. Some residual difference may also be attributed to the effects of the satellite viewing geometry (Lagouarde *et al*., 2004).

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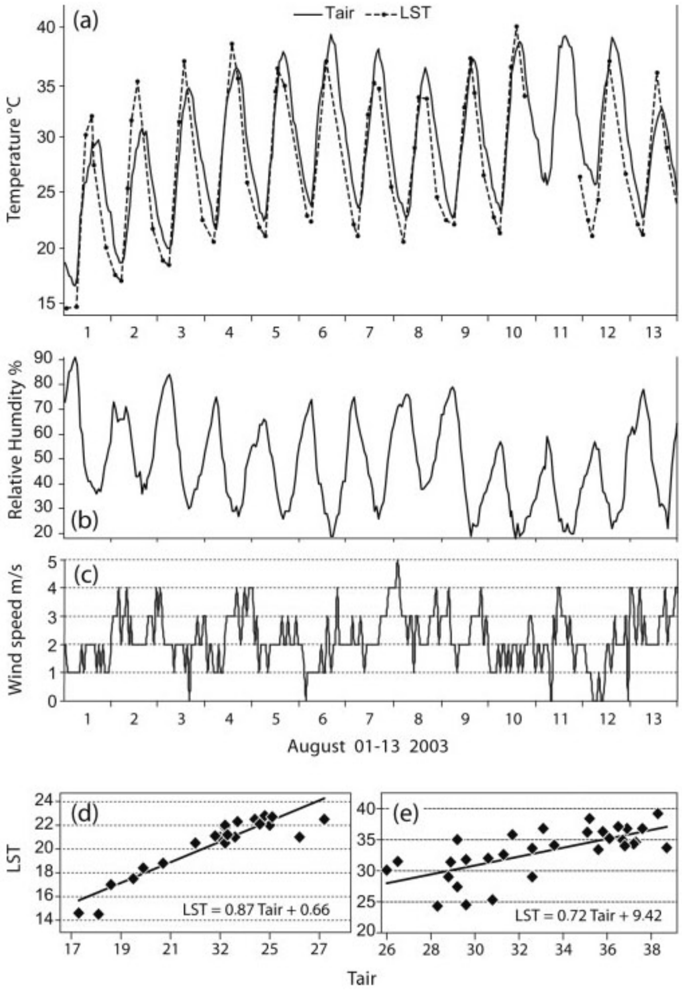

Figure 6. Colocated satellite and *in situ* data from the weather station in the Montsouris Park: (a) hourly T_{air} at 1.50 m and LST at the 4–6-h satellite sampling interval, (b) hourly relative humidity, (c) wind speed, (d) scatter plots of satellite LST *versus* T_{air} at night *(01–06 UTC)*, (e) and at daytime (12–15 UTC) for 1–13 August. Mid-day LST appears lower than T_{air} for 5–8 August due to a lack of data.

3.3. LST comparison of the August 2003 heat wave with August 1998

The time series of images of August 2003 were compared with those of August 1998, previously analysed by Dousset and Gourmelon (2003). The comparison indicates a large difference in the vegetation indices and high minimum temperatures. The metropolitan area is surrounded by fields and forests, and the city comprises a dozen small parks (0.1–0.6 km^2), and two large ones (8–10 km^2) at the west and east edges. In spring 2003, strong incident radiation and large precipitation deficit forced an early spring green-up and progressively reduced the soil moisture. Consequently, the vegetation index of August 2003 is lower than normal summers and evidences a significantly increased drought and reduced primary productivity (Ciais *et al.*, 2005; Zaitchik *et al.*, 2006). Figure 7 represents the bivariate histogram of the composite afternoon LST (12–15 UTC) *versus* the mean NDVI for 4–13 August 2003 (a) and its distribution (b). The figure indicates a significant negative correlation with a slope of $\sim -0.2\,°C/\%NDVI$ that illustrates the importance of vegetation in the partitioning between latent and sensible surface heat fluxes. Analysis and manual sampling of individual images indicate that the LST is 2–3 °C lower in small parks than in their built surroundings and 4–5 °C lower in large ones.

Figure 8 shows median LST diurnal cycles over the Paris metropolitan area, one from 5 to 11 August 1998, and the other from 1 to 13 August 2003. In 1998, the period from 5–11 August was relatively warm, with area-mean maximum LSTs between 28 and 36 °C, and LSTs for 4 consecutive days were over 35 °C. However, the highest area-mean minimum LSTs never exceeded 15 °C, thus averting the occurrence of a heat wave. In 2003,

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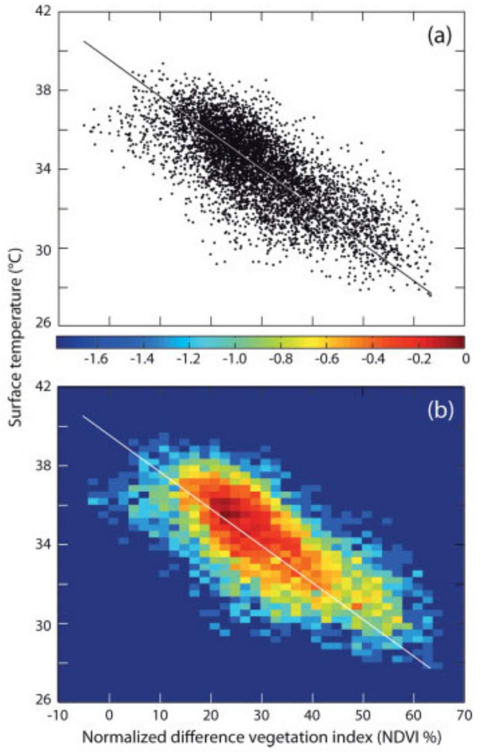

Figure 7. Scatter plot and bivariate histogram of LST-averaged 12–15 UTC (4–13 August 2003) *versus* the averaged NDVI. The colour bar shows the log 10 of the bivariate distribution normalized by the largest value. The principal mode of variance has a slope of −0.186 °C/%NDVI.

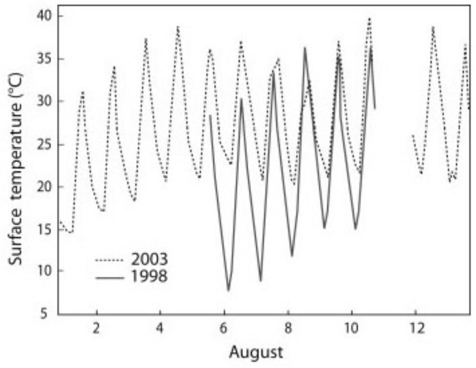

Figure 8. Median LST diurnal cycles over the Paris metropolitan area, from 5 to 11 August 1998, and from 1 to 13 August 2003. Mid-day LSTs that appear lower on 7–9 August 2003 than 1998 are due to a lack of data.

the diurnal amplitude was 5 °C lower (16 °C *vs* 21 °C) than that in 1998, and the mean minimum was 8 °C higher which confirms the impact of night-time minimum temperature on the heat wave. For two consecutive nights, on 10–11 and 11–12 August, stable meteorological conditions and low winds prevented convective mixing. At 05 : 00 UTC (07 : 00 local time), the minimum T_{air} was 25.7 °C for both nights. On 11 August, night-time LSTs were still 21.5 °C in Montsouris Park and 25–26 °C in downtown Paris. These high minimum night-time temperatures contributed to a lack of night rest for vulnerable people and to 500 excess deaths in the Paris region, on these two particularly deadly days during the heat wave (Figure 1). On the 13th, both temperatures and mortality excess began to decrease, and returned to normal on the 19th.

3.4. LST and mortality

Multilayer maps were generated over the six composite thermal images to identify risk factor areas. Standard layers, which were selected first, included surface albedo, percentage of built and vegetated surfaces, hydrology, population density, industrial areas and transportation.

Figure 9(a) represents the LST from 01 to 03 UTC and Figure 9(b) that of 12 to 15 UTC, with some of the land use overlays. Although the 1-km spatial resolution of the infrared images may be coarse for urban climate analysis, the overlays demonstrate the high sensitivity of the signal, such as a 1.5 °C decrease or increase attributable to the Jardin des Plantes Park and to the Palais du Louvre, respectively. At night, in the 20–22 UTC and 0–3 UTC composite images, the spatial distribution of the highest LSTs of 24 °C to 26 °C in the districts south and northeast of the Seine River matched the spatial distribution of the highest mortality ratios described in Cadot and Spira (2006), which were not related to the highest daytime LSTs. These maps would be useful for taking preventive measures to reduce strenuous activities in industrial areas north of Paris, where LST reached 40 °C in the afternoon, and assist elderly people living in the southern districts, where LST remained 25 °C at night.

Figure 10 displays the spatial distribution of the 482 cases and control addresses over Paris and the department of Val de Marne, in the suburbs of Paris. A total of ∼29 000 individual LST measurements were extracted at these addresses, using 61 satellite images recorded between 1 and 13 August.

Table I lists the adjusted odds ratio (OR) of mortality for the different thermal indicators (OR adjusted on age, sex, socio-economic conditions, family entourage, behaviour during the heat wave, mobility, health status, housing conditions, and so on). The OR is a relative measure of risk, which indicates the probability for someone exposed to a given factor to develop the outcome, as compared to someone with less or no exposure. If exposure is not linked to health impact, the OR is close to 1. If exposure is positively linked to health impact, OR >1. If exposure is negatively linked to health impact (protective effect), then OR <1. OR is given with a confidence interval (CI): if the value 1 is included in the CI, the result is not statistically significant. Table I shows that thermal indicators taking the average or maximum daytime temperatures into account were not significantly

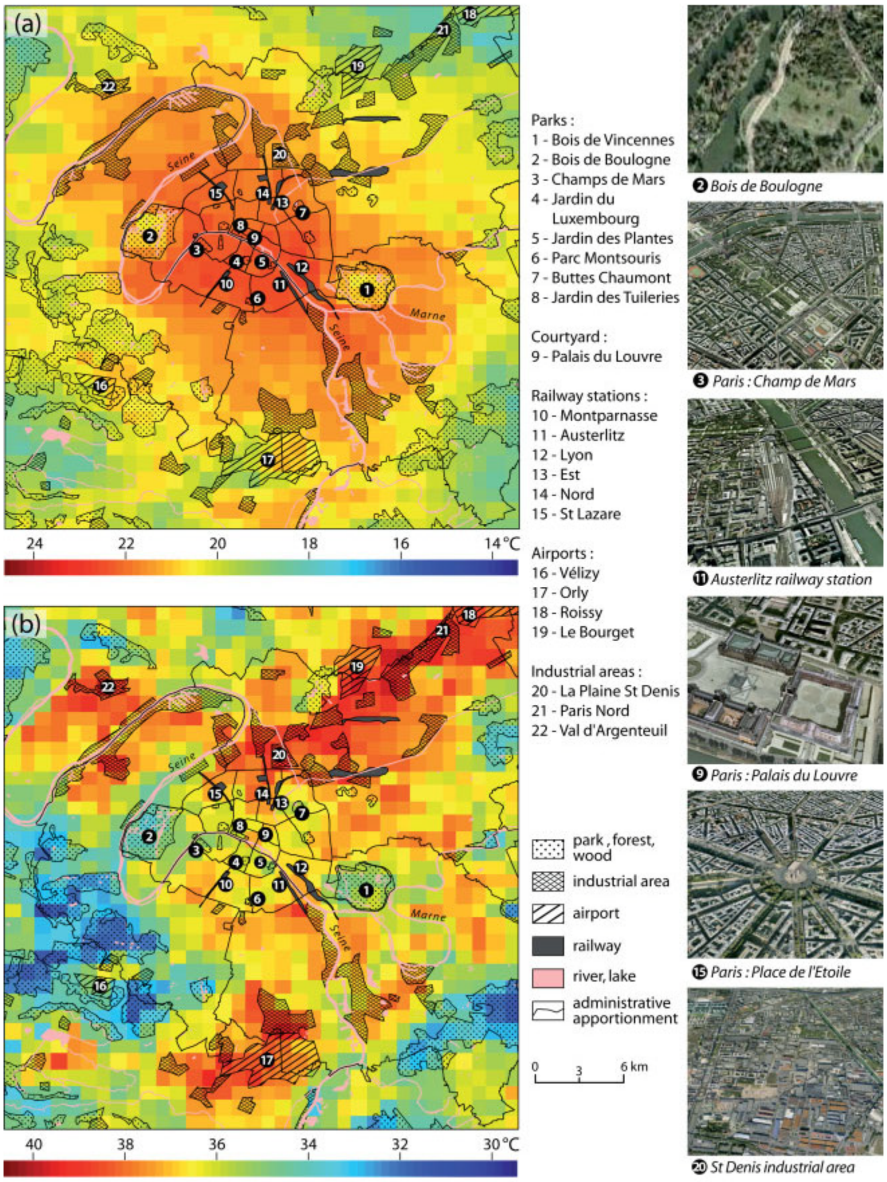

Figure 9. LST composite images of the Paris region from NOAA-AVHRR, under a land cover/use information layer; (a) at night (01–03 UTC); (b) by day (12–15 UTC). The thumbnail pictures display areas cooler and warmer than their surroundings (images from 2010 Aerodata International Survey, Google 2009).

linked to deaths. However, those taking minimum nocturnal temperatures into account were significantly linked to death. For example, for the mean minimum nocturnal temperature in the 7-day interval until the date of death, the OR associated with a 0.5°C LST difference between cases and controls was 2.2, indicating a death risk more than twice as high. This value of 0.5°C corresponds to the 90th percentile of the distribution of the differences between the cases and controls for this indicator.

4. Discussion and conclusion

This study documented the satellite monitoring of a 9-day heat wave over a metropolitan area and the associated epidemiological risk and time lag of death for elderly persons at given locations. The thermal images showed contrasting night-time and daytime heat island patterns, which were related to surface characteristics and land uses. The results confirm the influence of nocturnal temperatures on heat wave intensity and excess mortality,

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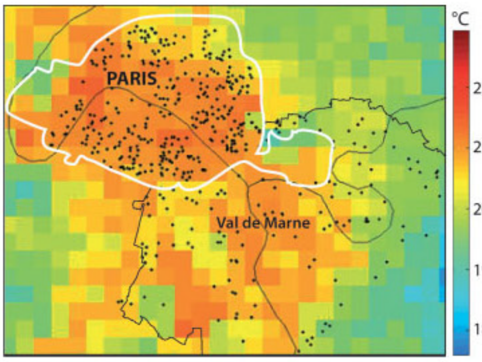

Figure 10. Spatial distribution of the 482 cases and control addresses in Paris and the Val de Marne department, over the NOAA-AVHRR thermal image of 7 August at 04 : 50 UTC.

Table I. Results of the logistic model showing adjusted odds ratios of mortality for different thermal indicators. The rows *italicized* indicate significant results. The odds ratios were adjusted for age, sex, socio-economic conditions, family entourage, behaviour during heat wave, mobility, health status and housing conditions.

Land surface temperature indicators from NOAA-AVHRR images	OR (CI 95%)
Mean of the minimal temperatures for 7 days (day of death and 6 preceding days)	*2.22 (1.03–4.81)*
Mean of the maximal temperatures for 7 days (day of death and 6 preceding days)	0.96 (0.69–1.33)
Mean of the minimal temperatures from 1 to 13 August	*2.57 (1.17–5.64)*
Mean of the maximal temperatures from 1 to 13 August	1.14 (0.77–1.67)
Mean of the average temperatures from 1 to 13 August	2.07 (0.91–4.70)

OR, odds ratio; CI 95%, 95% confidence interval.

and show the contribution of urban heat islands in intensifying the heat wave by absorbing heat during the day and progressively raising minimum nocturnal temperatures linked with heat stress and mortality. Urban parks had a significant impact on surface temperature with a 0.2 °C LST decrease per %NDVI, despite a prior warm and dry spring that lowered moisture availability.

The effect of urban heat islands on mortality is well known and the variability of death risk within cities has been investigated (Canouï-Poitrine *et al.*, 2006). Some studies (Vandentorren *et al.*, 2006; Johnson *et al.*, 2009) have integrated societal factors with LST derived from a single Landsat TM image. This study, consisting of the joint analysis of a large time series of thermal images and of colocated validated cases of elderly mortality, allowed us to infer the relative impact of heat exposure on elderly population at given locations and assess the time lag between heat exposure and death. It demonstrated the predominance of mean minimum nocturnal temperature, where a 0.5 °C increase doubles the risk of death, in the temperature range of the heat wave period.

There are implications regarding temperature monitoring and public health surveillance that are key issues in Europe given the summer warming trend and the resulting increase in heat wave incidence, duration and intensity, and also the aging of the population, which brings greater physiological and social vulnerability. Heat-related deaths are more frequent in large cities. In France, in 2003, the excess mortality was 40% in small towns, but 80% in Lyon and 141% in Paris (Vandentorren *et al.*, 2004). An analogous heat wave in USA would result in a mortality rate of +150% for New York City (Kalkstein *et al.*, 2008).

Satellite monitoring of summer heat waves provides surface temperature values that can be merged with urban databases to identify risk areas at the scale of a district or a neighbourhood, and supply criteria for adaptation strategies. Satellite monitoring can provide data to substantially improve understanding of urban surface processes and societal vulnerabilities to near-term climatic changes. Although Paris was chosen as a case study, having recently experienced an extreme heat wave with well-documented health consequences, the methods used in this study are general and should be applicable to other cities as well.

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Résumé de l'article soumis au journal "Environmental Health Perspective" le 7 février 2011

The impact of heat islands on human health in Paris during the August 2003 heatwave

Karine Laaidi[1], Abdelkrim Zeghnoun[1], Bénédicte Dousset[2], Philippe Bretin[1],
Stéphanie Vandentorren[1], Emmanuel Giraudet[2], Pascal Beaudeau[1]
[1] Institut de veille sanitaire, France
[2] Laboratoire Géomer, France.

Abstract :

Background. Heatwaves have a drastic impact on urban populations, which could be reinforced by climate change.

Objectives. The objective of this study was to evaluate new indicators of elderly people's exposure in Paris using satellite thermal images, from a public health prevention perspective.

Methods. A time series of 61 NOAA-AVHRR images from August 1 to 13, 2003, was used to produce thermal indicators of minimal, maximal, and mean surface temperatures, and diurnal amplitude, with different lags between the meteorological data and the health impact. Health data came from a case-control study involving 241 people who died during the heatwave in the Paris area and 241 controls, aged 65 years and over. For each person, the thermal indicators were integrated in a conditional logistic regression model, adjusted on risk factors such as age, sex and residence area.

Results. Odds ratios were computed comparing the 90th and 50th of the temperature differences indicators between cases and controls. These differences were around 0.5°C. Mortality risk was significantly associated with exposure for two indicators: minimal temperatures averaged from August 1 to 13, and minimal temperature averaged on the day of death and the six preceding days (OR 2.17 and 2.24, respectively).

Conclusions. These results confirmed the importance of night temperatures on the health impact of heatwaves in urban areas. Urban heat exposure indicators based on satellite imagery have the potential to highlight areas with higher risk of death, which could inform intervention decisions by key stakeholders.

Europe et risques climatiques

Cahiers de la solidarité n°18, p82-83, édité à l'occasion des 20 ans de la Fondation MAIF.

7. Évolution climatique et canicule en milieu urbain : apport de la télédétection à l'anticipation et à la gestion de l'impact sanitaire

Laboratoire Géomer UMR 8554 - LETG - CNRS/ Institut Européen de la Mer-UBO

L'évolution climatique et en particulier l'augmentation des températures de fin de nuit pourrait faire doubler en moins de vingt ans la mortalité attribuable à la chaleur en particulier dans les grandes agglomérations (Besancenot, 2002). Comme 73% de la population européenne (77% de la population française) vit dans des zones urbaines, il est impératif de limiter les conséquences sanitaires des épisodes caniculaires.

Après la canicule de l'été 2003, l'Institut de veille sanitaire en collaboration avec Météo-France, a construit un système d'alerte à partir d'une analyse rétrospective des données sanitaires et météorologiques dans 14 villes pilotes.

L'étude a permis de retenir un indicateur mixte représenté par la moyenne, sur trois jours des températures minimales et maximales, tenant compte de la persistance de la chaleur et des températures nocturnes. Des incertitudes demeurent cependant car le système d'alerte repose sur les températures enregistrées dans des parcs ou des aéroports, à l'écart des zones bâties, et de plus le réseau est trop lâche pour estimer les gradients d'amplitude du cycle diurne.

Ces incertitudes relatives au système d'alerte et aux conditions thermiques locales peuvent être réduites par l'utilisation de l'imagerie satellitaire. L'application de la télédétection thermique satellitaire permet l'observation de variations spatiales des températures urbaines à 1 km de résolution et la mise en évidence de leur relation avec l'occupation des sols (Dousset et Gourmelon, 2003).

Cette étude permettra de proposer de nouveaux indicateurs plus représentatifs de l'hétérogénéité du milieu urbain et de la variation des microclimats, et de tester la pertinence de leur utilisation comme facteurs d'exposition à ces microclimats. Ils pourront être testés en période de canicule pour affiner l'alerte.

Cette surveillance satellitaire permettra d'estimer l'intensité et les variations spatiales des ilots de chaleur au cours de la journée et de la nuit. Et d'adapter les consignes sanitaires en fonction des zones à plus gros risque, afin d'anticiper et de gérer des situations de crises dans les mégapoles françaises, voire européennes.

Climate Change: Global Risks, Challenges and Decisions IOP Publishing
IOP Conf. Series: Earth and Environmental Science **6** (2009) 422010 doi:10.1088/1755-1307/6/2/422010

P42.03

A contribution of an insurance foundation to the study of urban heat waves and their societal impact

Bénédicte Dousset(1), K Laaidi(2), H Oliviero(3), A Zeghnoun(2), E Giraudet(1), F Gourmelon(1), P Bretin(2), S Vandentorren(2)
(1) Laboratoire Géomer UMR 6554 CNRS, Institut Universitaire Européen de la Mer, Plouzané, France
(2) Institut de Veille Sanitaire, Saint Maurice, France
(3) Fondation MAIF, Le Pavois, Niort, France

Among its prospective activities, the MAIF insurance company (Mutuelle Assurance des Instituteurs de France) has created an independent foundation of public interest, in order to research and develop risk prevention and adaptation. Since, climate change has important implications on insurance industries, the MAIF Foundation is supporting projects on extreme weather events, their related risks and societal impacts. According to climate models for the XXI century, summer warming trends might increase the incidence, intensity and duration of heat waves, particularly in western and central Europe, the Mediterranean regions and the western and southern regions of the United States. Heat waves are especially deadly in cities due to the physical characteristics of their surfaces and the production of anthropogenic heat and pollutants. At night, while temperatures may decrease in rural areas, cities release the heat stored in the buildings, inducing a lack of relief and increasing the risk of heat stress and mortality for the more vulnerable population (the elderly, infants and people with chronic diseases). The assessment of heat stress and vulnerability requires high resolution meteorological observations that are currently unavailable, since urban weather stations are located in parks or airports, away from the built environment. The objectives of the project were to demonstrate the application of remote sensing techniques on three main levels: firstly, to monitor urban surface temperatures, their diurnal variation and the distribution of their amplitude during heat waves; secondly, to estimate the associated heat stress and to help vulnerable people in adjusting their behavior; and thirdly, to improve heat alert systems. The study is based on the extreme heat wave of August 2003, that persisted for nine consecutive days in the Paris metropolitan region, resulting in 4,867 heat related deaths. The satellite observations indicate large surface temperature gradients and contrasted daytime / nighttime heat islands patterns. The relatively small temperature amplitude in reference to normal summers confirms the impact of high minimum temperatures on the heat wave process, the lack of nighttime relief and the subsequent heat tress and mortality.

Maps of temperature thresholds were generated and areas most vulnerable to heat stress were delineated. The remote sensing data was then applied to a control case study of persons aged 65 and over (residing at home) to estimate the spatial variability of heat stress factors and improve the current health alert system in Paris. Based on summertime satellite surveillance, a near real time website is being designed to inform the local public and authorities on extreme surface temperatures and related heat stress for the French cities of Paris, Lyon and Marseilles. This project also demonstrates the significant contribution of insurance companies in promoting applied research of climate change, prevention and adaptation decisions, and urban risk management.

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A contribution of an insurance foundation to the study of urban heat waves and their societal impact

B. Dousset [1,2], K. Laaidi [3], H. Oliviero [4], A. Zeghnoun [3], E. Giraudet [1], F. Gourmelon [1], P. Bretin [3], S. Vandentorren [3]
[1] *Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI, USA.*
[2] *Laboratoire Géomer, UMR6554 LETG CNRS, Institut Universitaire Européen de la Mer, Plouzané, France.*
[3] *Institut de Veille Sanitaire, Saint Maurice, France.*
[4] *Foundation MAIF, Le Pavois, Niort, France.*

Rationale

Climate change implies new risks and challenges for insurance industries. Among its prospective activities the MAIF Foundation is supporting researches in climate change, societal impact, risk prevention and adaptation.

According to climate models for the XXI century, summer warming trends might increase the occurrence, intensity and duration of heat waves, **Fig.1**. Those are especially deadly in cities due to surfaces characteristics, anthropogenic heat and pollutants, e. g. the extreme 2003 heat wave in western Europe, **Fig.2**, has resulted in 4,867 heat related deaths in the Paris region, **Fig.3**. Urban heat stress and vulnerability studies require high spatial resolution meteorological observation that is unavailable from synoptic weather stations located in parks or airports **Fig.4**, away from the built environment **Fig.5**.

Objectives

Using time series satellite thermal IR images:
- to observe the urban surface temperature gradients
- to produce thermal indices and anticipate urban heat stress
- to implement health alert systems

Data and results

- 85 NOAA AVHRR images, Jul. 20 Aug. 20 2003, 1 km resolution
  albedo, vegetation index & radiant surface temperature
- 1 SPOT4 HRV image, Jul. 13 2003, 20m resolution
  albedo, vegetation index & land use classification
- Public health data : heat stress and mortality *(IVS)*

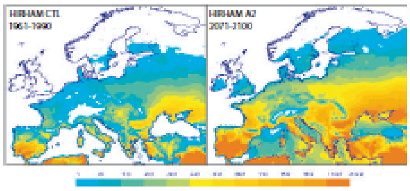


Fig.1 : Heat waves, mean number of days / Year > 30 °C *(Beniston et al., 2007 ; DMI)*

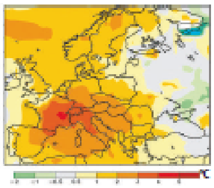


Fig.2 : Temperature anomaly June - Aug. 2003 vs. 1988-2003, in-situ and satellite observation *(NOAA)*.

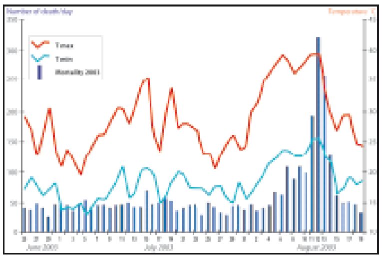


Fig.3 : Air temperature and mortality, June 25 - Aug.19, 2003 *(IVS)*.
Heat wave of 9 consecutive days : August 4-13 2003
High minimum temperatures > **4867 heat related deaths**

Fig.4 : The Paris weather station in a Park.

Fig.5 : The Paris built environment

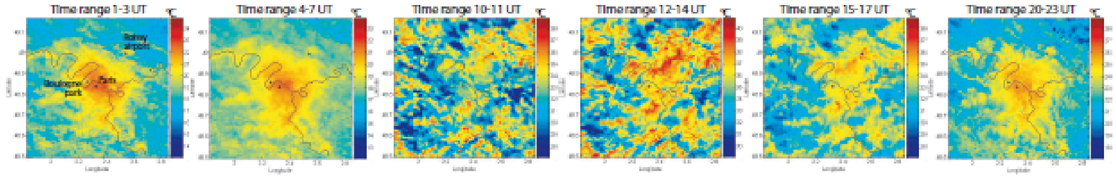


Fig. 6 : Land Surface Temperature during the August 4-13 2003 heat wave at times of satellites pass. The composite thermal infrared images are built from a 50 NOAA AVHRR image series.

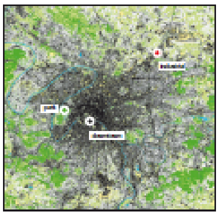


Fig.7 : Land cover classification of Paris from a SPOT-4 HRV image, July13 2003.

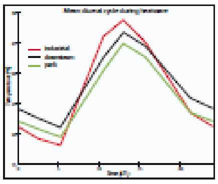


Fig.8 : Mean diurnal cycle of Surface Temperature at given locations, from 50 NOAA-AVHRR image series, Aug.4 -13, 2003.

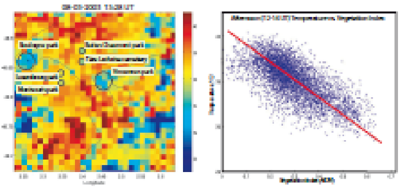


Fig.9-10 : Influence of Vegetation on Surface Temperature.

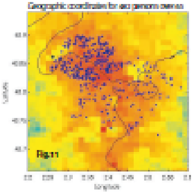


Fig.11 : Thermal conditions for 482 persons over 65. For each location, a thermal index is produced and integrated into a conditional logistic regression model to estimate the spatial variability of risk factors and to implement the health alert system.

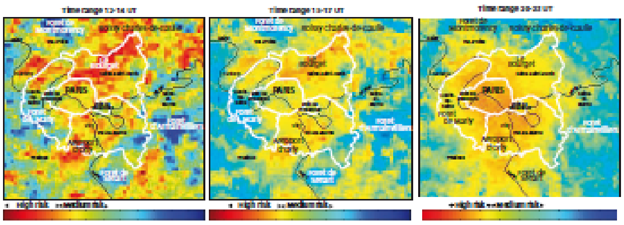


Fig.12 : Vulnerability - Surface Temperature thresholds.

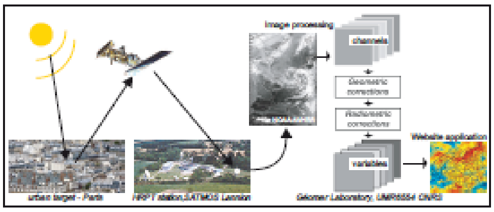


Fig.13 : Summertime satellite surveillance and near real time website to inform local public and authorities on extreme urban surface temperature and related heat stress.

SATMOS apur

CLIMATE CHANGE Global Risks, Challenges & Decisions - Copenhagen 2009 10-12 March
bdousset@hawaii.edu

Abstract :

Health impact of heatwaves: the use of remote sensing in defining a new indicator of urban surface temperature

K. Laaidi[1], A. Zeghnoun[1], B. Dousset[2], P. Bretin[1], S. Vandentorren[1], E. Giraudet[2], F. Gourmelon[2]

[1] *Institut de Veille Sanitaire, Saint Maurice, France;*

[2]*Laboratoire Géomer CNRS, Institut Universitaire Européen de la Mer Plouzané, France;*

Heat waves are especially deadly in cities due to the physical characteristics of their surfaces and the production of anthropogenic heat. But urban temperatures are not available through meteorological stations, which are located in parks or airports. A previous case-control study was conducted on the 2003 heatwave using a unique midday Landsat image to measure the surface temperature variability.

The objective of this project was to define a new indicator using night and day satellite images to estimate the different health impacts of urban heat.

The surface temperature of Paris, from August 1 to 13, was produced from NOAA-AVHRR satellite images, at 1 km resolution. A case-study was conducted using 482 people aged 65 and over, residing at home. Different exposure indicators were constructed based on minimum and maximum surface temperatures, and introduced into a conditional logistic regression model adjusted for confounding factors.

The results of the regression analysis were statistically significant for the average minimum temperature between the day of death and the six days preceding. The odds ratio associated with 0.5°C difference in surface temperature between cases and controls was 2.22 (CI95% = 1.03-4.81).

This study confirmed the importance of night temperatures upon health during heatwave episodes, the release of heat by buildings at night inducing a lack of relief for the population, and the usefulness of the NOAA-AVHRR satellites to estimate the diurnal cycle of heat islands. These results are helpful to improve the current heat health alert system, heat waves and urban risk management.

Health impact of heatwaves

The use of remote sensing in defining a new indicator of urban surface temperature

K.Laaidi[1], A. Zeghnoun[1], B. Dousset[2], P. Bretin[1], S. Vandentorren[1] E. Giraudet[2], F. Gourmelon[2],
[1] *Institut de Veille Sanitaire, Saint Maurice, France*
[2] *Laboratoire Géomer, UMR6554 LETG CNRS, Institut Universitaire Européen de la Mer, Plouzané, France*

Rationale

According to climate models for the XXIst century, summer warming trends might increase the occurrence, intensity and duration of heat waves. These are especially deadly in cities due to surfaces characteristics, anthropogenic heat and pollutants, as France experienced in August 2003, with 4,867 excess deaths in the Paris region and about 15,000 in all France.

Synoptic weather stations, often located in parks or airports away from the built-up environment, are not representative of urban temperatures. In 2003, a case control study was performed by the "Institut de Veille Sanitaire" to estimate the risk factors for the elderly during the heat wave. A Landsat satellite image of August 9 (10.07 am UT), at 50m resolution, was used to map the surface temperature. However only one high resolution image was available during the heat-wave

Objectives

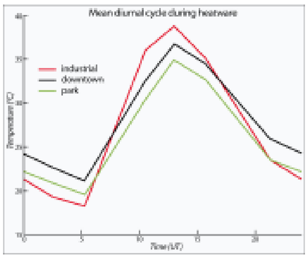
Using time series thermal infrared images, at 1 km resolution:

- To observe the urban surface temperature gradients during night and day
- To elaborate a methodology integrating satellite data, to estimate the health impact of heat stress in megacities

Data and Methods

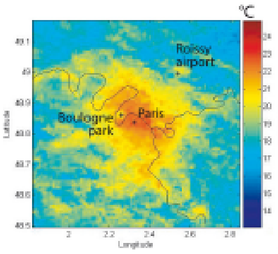
- 61 NOAA-AVHRR satellite images, at 1km resolution, from August 1 to 13th (day and night images)
- Health data concerning 482 people aged 65 or more (241 cases/deceased and 241 controls) who were residing in Paris (France) at the time of the heat-wave
- For each person, a thermal index was produced from the satellite images and integrated into a regression model to test its use as a heat exposure factor.
- The model was adjusted for risk factors (socio-economic conditions, self-care ability, behavioural adaptation to heat, health problems, housing), age, sex and geographical zone.
- The thermal indexes that were tested are the minimum, maximum, mean temperature and day-night temperature amplitude.
- The considered periods were: day of death, one day, 2 days, 6 days or 13 days preceding it.

Results

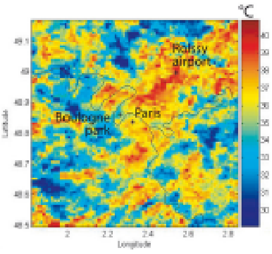


- Highest and lowest temperatures are observed in the industrial suburban area
- Highest night-time temperature in downtown leads to no heat stress relief for people
- Temperatures in the park are 2 to 3°C lower than in downtown over the diurnal cycle

Mean diurnal cycles of surface temperature in 3 locations, August 4-13 2003, constructed from 50 NOAA-AVHRR images



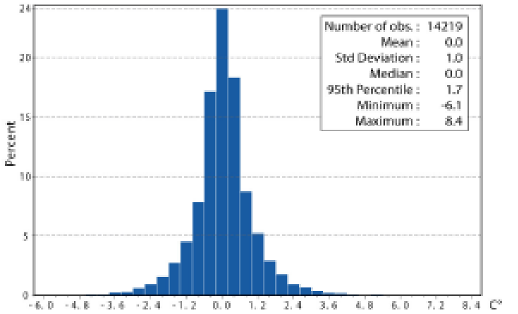
Composite image. Time range 1-3 UTC:
At night-time a significant (~8°C) heat island, due to built density and lack of evapotranspiration, develops in downtown Paris.



Composite image. Time range 12-14 UTC: By daytime multiple thermal anomalies (~ 10°C), due to surfaces low thermal inertia and unobstructed field of vision, scatters over industrial suburbs.

Results of the regression model showed that, for an increase of 0.5°C, the risk of dying is around two times higher, depending on the considered index (table below). Results are not significant for other indexes (not presented).

Satellite	Variable	OR (IC 95%)
Landsat	temperature 9 August 10.17 am	1.29 (1.08 – 1.55)
NOAA	Average Tmin 1st to 13th August	2,57 (1,17 - 5,64)
NOAA	Tmean 1st to 13th August	2,07 (0,91 - 4,70)
NOAA	Average Tmin from 6 days before death to the day of death	2,22 (1,03 - 4,81)



Distribution of differences between thermal indexes of matched cases and controls, from NOAA-AVHRR images (1st to 13st August).

Conclusion

These results demonstrate the importance of the night-time temperature impact on health (from heat stress to mortality), which was not possible with the Landsat image.

Now, we will have to evaluate the use of our results to improve public health protection, proposing urban-planning and architectural measures to decrease the temperature in the heat islands shown.

SATMOS

This study has been funded by the insurance foundation MAIF

Climate risk : what is at stakes for Europe ? – Brussels, October 28, 2009

SEMINAR

CLIMATE RISK: WHAT IS AT STAKES FOR EUROPE?

28th of October, Brussels

Program

Program

8:30 – 9:00 Registration

9:00 – 9:30 Welcome by **Stéphane Buffetaut**, president of the Sustainable Development Observatory, European Economic and Social Committee
Introduction by **Denis Stokkink**, president of the European Think Tank *Pour la Solidarité*, **Roger Belot**, president of MAIF and **Pierre Guillot**, president of MAIF Foundation

9:30 – 9:45 Presentation of MAIF Foundation's movie

9:45 – 10:30 Round table: Global warming and its consequences regarding dryness and heat waves in an urban environment
With: **Pascale Delecluse** (Centre National de Recherches Météorologiques), **Roger Cojean** (Laboratoire Géomatériaux et Géologie de l'Ingenieurie), **Bénédicte Dousset** (laboratoire Géomer) and **Philippe Tulkens**, GD Research, European Commission
Animation : **Caroline Grégoire**, environment consultant

10:30 – 11:00 Coffee break

11:00 – 11:45 Round table: The impact of global warming in Europe and the European policies developed to fight against it
With: **Guillaume Lapeyre** (Laboratoire de Météorologie dynamique), **Philippe Ciais** (CNRS), **Peter Gammeltoft**, GD Environment, European Commission, **Isabelle Durant**, Vice-president of the European Parliament
Animation : **Alexandra Debaisieux**, YTES consultant

11:50 – 12:40 Round table: Risk prevention and financial sector: what solutions?
With: **Jean-Luc de Boissieu** (GEMA), **Olivier Marquet** (Triodos), **Fiona Joyce** (Groupement européen des Caisses d'épargne) and **Catherine Hock** (AMICE)
Animation : **Denis Stokkink**, President of *Pour la Solidarité*

12:40 – 13:00 Conclusion by **Pierre Guillot**, president of MAIF Foundation

13 :00 Lunch

With the contribution of

Health impacts of urban heat island in Paris

K. Laaidi[1], A. Zeghnoun[1], B. Dousset[2], P. Bretin[1], S. Vandentorren[1], E. Giraudet[2], F. Gourmelon[2], P. Beaudeau[1]

1/ French Institute for Public Health Surveillance, Saint-Maurice, France
2/ Géomer Laboratory, UMR6554 LETG CNRS, European University Institute of the Sea, Plouzané, France

Rationale

In large cities, the distribution of surface heat fluxes is altered compared to natural areas, creating an urban heat island (UHI). Reducing the UHI is a key issue to adapt to climate change.

Following the 2003 heat wave, the French Institute for Public Health Surveillance conducted a case-control study to identify the main risk factors for the elderly living at home. Individual, social and environmental risk factors were investigated. A Landsat picture, acquired on 9 August 2003 at 10:17 UTC,, was used to construct ou get the UHI profile of the area around the homes during the heat wave. The temperature exposure indicator – calculated as the mean of the surface temperatures for a 200 m radius around the home – was a risk factor while the vegetation index was described as protective [1].

The Landsat picture had a good geographical precision (50m) but the long return period of the satellite prevents its use to assess the daily and cumulative minimal and maximal exposure to heat. The objective of this study is to reanalyse the data from the 2003 case-control study, using several indicators to characterise the UHI.

Materials and methods

- Study period: August 1st-13th 2003.
- Satellite data: for each day between the 1st and 13th/08, two to six thermal images at 1 km resolution were recorded, sensed by the NOAA-AVRR satellites. In total, 61 images were used.
- Health data: 482 persons aged 65 or more (241 cases/deceased and 241 controls), living at home in the Paris region (France). Cases: died during the mortality peak (8-13 August), used to live at home at least 24 hours before their hospitalization or death. Controls: lived at home from 8th to 13th August.
- Method:

  The place of residence was geocoded and the surface temperatures of the corresponding satellite pixel were used (Figure 1). For each person, several indices were built; daily minimum, maximum and mean temperature, day-night temperature amplitude, and cumulated indicators defined as the average of temperatures recorded between the 1st and the 13th/08.

  These indicators were introduced into a conditional logistic regression model, at lag 0, 1, 2 and 6. The model was adjusted on other risk factors such as age, sex, socio-economic conditions, autonomy, and behaviour of heat adaptation, health problems, housing, and geographical district [2].

FIGURE 1 NIGHT-TIME SURFACE TEMPERATURES AND GEOCODED ADDRESSES OF CASES AND CONTROL IN PARIS AND THE VAL DE MARNE DEPARTMENT (FRANCE).

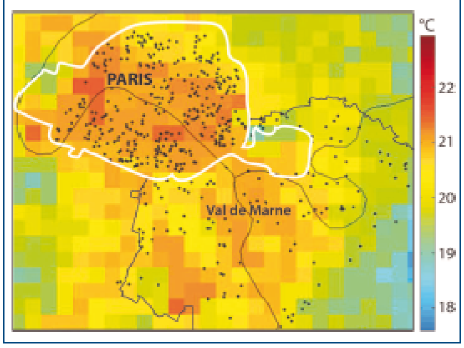
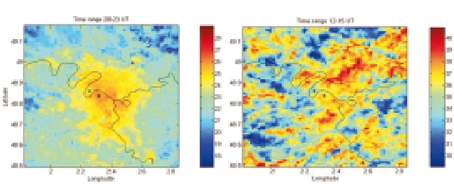


FIGURE 2 LOCALISATION OF THE URBAN HEAT ISLAND DURING NIGHTS (LEFT) AND DAYS (RIGHT)



For all cases and controls, surface temperatures ranged from 12.18 to 45.41°C with a median of 21.44°C by night (from 8 pm to 7 am) and 34.16°C by day (from 7 am to 8 pm).

UHI locations dramatically differ from day to night. At night, the UHI is localised at the city centre. During the day, several smaller UHIs are scattered over the city (Figure 2).

Odds ratios (OR) were computed for a difference of temperature between cases and controls corresponding to the OR where this difference goes from the 50th to the 90th percentiles of the distribution of the temperatures difference. Only statistically significant results are presented in Table 1. The most significant results correspond to a night-time exposure, cumulated over time (Table 1).

TABLE 2 ODD RATIO ASSOCIATED TO A TEMPERATURE DIFFERENCE BETWEEN CASES AND CONTROLS.

Thermal indicator	OR (IC 95%) p50/p90	T°C difference
Average Tmin 1st to 13th August	2.17 (1.14 – 4.16)	0.41
Average Tmean 1st to 13th August	1.71 (0.94 – 3.11)	0.37
Average Tmin from 6 days before death to the day of death	2.24 (1.03 – 4.87)	0.50

Discussion

Our results confirm that the UHI creates important differences in exposure, and that the UHI is dramatically different between night and day.

Using NOAA satellites images allowed taking into account this feature. The night UHI, cumulated over several days, was the best thermal indicator.

Such data could be used for long term prevention, including urban planning, and to target areas for interventions.

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1. Vandentorren S, Bretin P, Zeghnoun A, Mandereau-Bruno L, Croisier A, Cochet C, et al. August 2003 heat wave in France: risk factors for death of elderly people living at home. Eur J Public Health 2006 Dec;16(6):583-91.

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August 2010 – ISEE-ISES, Seoul

Contact: Karine Laaidi (ka.laaidi@invs.sante.fr) – French Institute for Public Health Surveillance – 12, rue du Val d'Osne 94415 Saint-Maurice – France – Tél. : +33 (0)1 55 12 53 22 – Fax : +33 (0)1 41 79 67 68

Climate change and heat waves in Paris and London metropolitan areas

Bénédicte Dousset,[a, b] Françoise Gourmelon,[b] Karine Laaidi,[c] Abdelkrim Zeghnoun,[c]
Emmanuel Giraudet,[b] Philippe Bretin,[c] Stéphanie Vandentorren,[c]

[a] *Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu USA;*
[b] *Géomer, UMR-6554 LETG CNRS, IUEM Plouzane, France;*
[c] *Institut de Veille Sanitaire, Saint Maurice, France.*

Abstract

Summer warming trends in Western and Central Europe and in Mediterranean regions are increasing the incidence, intensity, and duration of heat waves. Those extreme events are especially deadly in large cities, owing to high population densities, surface characteristics, heat island effects, anthropogenic heat and pollutants. In August 2003, a persistent anticyclone over Western Europe generated a heat wave of exceptional strength and duration with an estimated death toll of 70,000, including 4678 in the Paris region. A series of NOAA-AVHRR satellite thermal images over the Paris and London metropolitan areas, were used to analyze Land Surface Temperature (LST) and its related mortality. In the Paris region, LSTs were merged with land use and cover data to identify risk areas, and thermal indicators were produced at the addresses of ~ 500 elderly people to assess diurnal heat exposure. Results indicate: (i) contrasting night time and daytime heat island patterns related to land use and surface characteristics; (ii) the relation between night-time heat islands and heat waves intensity; (iii) the impact of elevated minimal temperatures on excess mortality, with a 0.5 °C increase doubling the risk of death, (in the temperature range of the heatwave); iv) the correlation between the spatial distribution of highest night-time LSTs and that of highest mortality ratios; and v) the significant impact of urban parks in the partitioning between latent and sensible surface heat fluxes, despite a prior warm and dry spring. Near-real time satellite monitoring of heat waves in urban areas improve our understanding of the LST processes and spatial variability, and of the related heat stress and mortality. These observations provide criteria for warning systems, contingency policies and planning, and climate adaptation and mitigation strategies.

EOS, Transactions of American Geophysical Union, Vol. 91, N° 51, 21 December 2010

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White House Issues Scientific Integrity Policies

PAGE 503

On 17 December the White House issued its long-awaited guidelines on the Obama administration's scientific integrity policy.

The new memorandum to heads of departments and agencies of the U.S. federal government "describes the minimum standards expected as departments and agencies craft scientific integrity rules appropriate for their particular missions and cultures, including a clear prohibition on political interference in scientific processes and expanded assurances of transparency," according to Presidential Science Advisor John Holdren, who released the guidelines. Holdren also is the director of the White House Office of Science and Technology Policy (OSTP). The guidelines require "that department and agency heads report to me on their progress toward completing those rules within 120 days."

The guidelines, which come in response to the White House memorandum on scientific integrity that was issued on 9 March 2009, specify that agencies should develop policies that ensure a culture of scientific integrity; strengthen the actual and perceived credibility of government research; facilitate the free flow of scientific and technological information, consistent with privacy and classification standards; and establish principles for conveying scientific and technological information to the public.

In addition, the guidelines indicate that agencies "should develop public communications policies that promote and maximize, to the extent practicable, openness and transparency with the media and the American people while ensuring full compliance with limits on disclosure of classified information."

Concerning the use of federal advisory committees (FACs), the guidelines state, among other things, that the recruitment process for new FAC members should be as transparent as practicable and that the selection of FAC members should be based on expertise, knowledge, and contribution to the relevant subject areas.

The guidelines also call for establishing policies that promote and facilitate the professional development of government scientists and engineers.

Each department or agency may require distinct mechanisms to implement the guidelines. Also, the guidelines note that the director of the White House Office of Management and Budget will issue guidance to OMB staff regarding the review of draft executive branch testimony on scientific issues prepared for presentation to Congress.

In issuing the guidelines, Holdren noted that "although this Memorandum is new, scientific integrity has been a White House priority since Day One of this Administration."

For more information see http://www.whitehouse.gov/blog/2010/12/17/scientific-integrity-fueling-innovation-building-public-trust.

—Randy Showstack, Staff Writer

Urban Areas and Climate Change

PAGE 503

Half of the world's population lives in urban areas today, and 80% of the world's population is predicted to be city dwelling by 2030. The urban heat island effect, in which cities are several degrees warmer than their surrounding areas, is therefore likely to increase along with increasing urbanization.

Scientists at the 2010 AGU Fall Meeting last week discussed new research on urban areas and climate change. A.-L. Beaulant of Centre National de Recherches Météorologiques (CNRM), Météo-France, used modeling studies to predict characteristics of future heat waves in the Paris metropolitan area. In a scenario in which emissions continue to rise, she found that there could be three heat waves per year on average between 2075 and 2099. With some emissions mitigation, there might be two heat waves per year during that time, compared with only one heat wave every 4 years on average now.

Benedicte Dousset of the University of Hawai`i reported on satellite thermal imagery studies of Paris during the August 2003 heat wave that killed thousands of people across Europe. Her observations of temperatures during the night and day over the city showed that even small parks in the city were 2°–3°C cooler than surrounding areas covered with buildings; larger parks within Paris were 4°–5°C cooler. In addition, she suggested that a 1% increase in vegetation index in the city could lead to as much as 0.2°C of cooling. Satellite monitoring can help identify areas of risk at a local scale and provide data for adaptation strategies, Dousset said.

Ping Zhang of NASA Goddard Space Flight Center focused on the characteristics of a city that contributes to the heat island effect. Zhang studied satellite data comparing 42 cities in the northeastern United States. Unsurprisingly, larger cities and more densely populated ones have greater heat island effects. The type of land surrounding the city is also a key factor in the urban heat island. Cities that are surrounded by forest tend to be several degrees warmer than their surrounding areas, while cities surrounded by desert can actually be cooler than their surroundings. Cities surrounded by farmland are in between. Replacing forest with buildings and pavement creates a stronger heat island than replacing desert or grassland, Zhang concluded.

Cities not only affect the temperature of their areas, but they can also affect rainfall patterns. Dev Niyogi of Purdue University presented observations indicating that rainstorms sometimes split in two when they reach a city and then intensify downwind of the city. He noted that about 60% of storms changed composition upon hitting an urban area. "There were significant changes in storm characteristics due to urbanization," he said. He also noted that monsoon rains in India have increased more in urban areas, such as Mumbai, than in rural areas in recent years, another indication of the effect that cities have on weather.

—Ernie Tretkoff, Staff Writer

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2010 AGU Fall Meeting

Press Conference Schedule

The following schedule of press conferences is subject to change, before or during Fall Meeting. Press conferences may be added or dropped, their titles and emphases may change, and participants may change. All updates to this schedule will be announced in the Press Room (Room 3001A, Moscone West, Level 3, adjacent to the Level 3 lobby). Press conferences take place in the Press Conference Room (Room 3000), diagonally across the hall from the Press Room.

Times for press conferences are Pacific Standard Time. Session numbers at the end of each press conference listing may show only the first in a series of related sessions on the topic.

(Note to Public Information Officers: If you have prepared press releases or other handouts for press conferences listed below, please email electronic copies of the documents to Peter Weiss (pweiss@agu.org) so they can be made available online to reporters calling in from outside the meeting.)

Eruptions from the Far-Side: New Global Views of the Sun

Monday, 13 December
1000h

New observations of the Sun indicate that the search for the factors that play a role in the initiation and evolution of eruptive and explosive events, sought after for improved space-weather forecasting, requires knowledge of much, if not all, of the solar surface field. The combination of observations from two NASA missions, the Solar Dynamics Observatory (SDO) and the Solar TErrestrial RElations Observatory (STEREO) enable us to view much of the solar surface and atmosphere simultaneously and continuously for the first time. These near-global observations often show long-distance interactions between magnetic areas that exhibit flares, eruptions, and frequent minor forms of activity. These interactions were previously suspected, but have never been observed until now. We analyzed a series of flares, filament eruptions, coronal mass ejections, and related events which occurred on 1–2 August 2010. These events extended over a full hemisphere of the Sun, only two-thirds of which is visible from the Earth's perspective.

Participants:
Karel Schrijver
Research Scientist, Lockheed Martin, Palo Alto, California, USA;
Alan Title
SDO AIA principal investigator, Professor of Physics, Stanford University and Senior Fellow, Lockheed Martin Advanced Technology Center, Palo Alto, California, USA.
Madhulika Guhathakurta
SDO program scientist, NASA Headquarters, Washington DC, USA;
Rodney Viereck
Chief, Space Weather Services Branch, NOAA Space Weather Prediction Center, Boulder, Colorado, USA

Sessions: SH11B, SH13A

New Views of Urban Heat Islands

Monday, 13 December
1100h

Weather watchers have long noted that city centers tend to be warmer than their surrounding environs. These "urban heat islands," which are produced when pavement and other city infrastructure replaces open land and vegetation, can boost temperatures by a few degrees and in some cases by as much as 11 °Celsius (20 °Fahrenheit) or more. Recent findings, based on satellite data, offer new insight into how heat islands can vary across cities, threaten public health, and increase air conditioning usage in ways that might inadvertently exacerbate dangerous heat waves.

Participants:
Ping Zhang,
Research Scientist, NASA Goddard Space Flight Center/Earth Resource Technology, Greenbelt, Maryland, USA
Benedicte Dousset
Researcher, Hawai`i Institute of Geophysics and Planetology, University of Hawai`i at Manoa, USA
Cécile De Munck
Scientist, National Centre of Meteorological Research (CNRM), Météo-France, France.

Sessions: B11J, B21E

DiscoveryNews.

Nighttime Makes Urban Heat Waves Deadly

By John D. Cox | Tue Dec 14, 2010 01:43 PM ET

The extreme daytime temperatures of an urban heat-wave may be hard to ignore, but really, scientists say, it's the nights that kill you.

The tragedy of Paris in 2003 -- the deaths of 5,000 vulnerable people in the first two weeks of August -- spawned a raft of new studies on the subject of death-by-weather, a researchers presented their findings this week at the annual meeting of the American Geophysical Union in San Francisco.

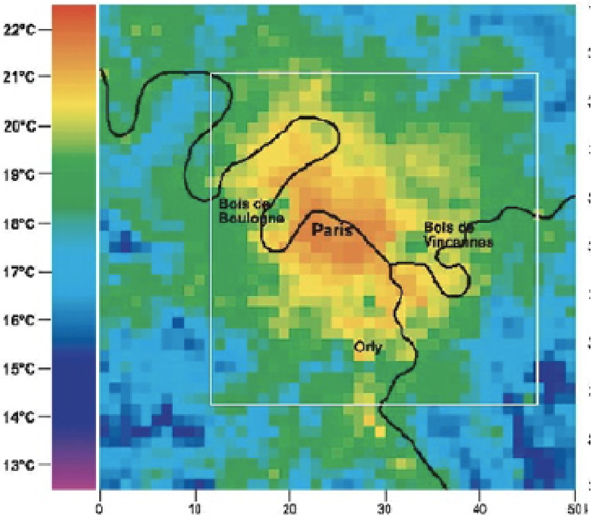
SEE ALSO: Summer Heat Waves to Increase

Half of us live in cities, and just 20 years from now 80 percent of us are expected to be urban dwellers. Cities are the lifeblood of the modern economic times, no doubt about it, but they are also the boiler rooms. And the rising frequency of lethal heat waves across the globe is prompting a more detailed look at the "urban heat island" effect.

Using satellite data, Ping Zhang and colleagues at NASA's Goddard Space Flight Center compared the different heat-generating signatures of thousands of cities around the planet, and their findings confirm that the strongest heat islands are the larger, most densely developed cities.

SEE ALSO: Is Global Warming Causing the Heatwave?

This probably goes some way toward explaining why about 600 people died in sprawling, greener London during the same heat wave that killed 4,867 people in densely developed Paris.



"Exposure to high temperature during several nights, especially consecutive nights, can double the risk of death for the most vulnerable people -- people over 65 years of age or young infants, and also people with chronic health problems," researcher Benedicte Dousset told a news conference.

SEE ALSO: Heatwaves: They Don't Call it Global for Nothing

The University of Hawaii researcher and French colleagues studied satellite-derived thermal images of Paris on a neighborhood-by-neighborhood scale, noticing subtle temperature difference depending on vegetation and development-density.

Average afternoon temperatures from Aug. 1-13 carried a heat-island effect of 18 degrees Fahrenheit, she reported, while average nighttime temperatures measured a 15-degree F heat island.

Dousset said a one percent increase of the "vegetation index decreases by 0.2 degrees C (about 0.4 F) the surface temperature of Paris in summer afternoons."

Studying the impact of air conditioning on the heat island of Paris, another team led by Cecile de Munck and French colleagues observed that air conditioning increases energy demand and the cooling systems themselves release heat onto city streets.

"It's a vicious circle," said de Munck, "temperature increase due to air condition will lead to an increasing air cooling demand."

Photo: People cool off in a Paris street, Saturday Aug. 9, 2003. credit: AP Photo/Franck Prevel; Surface temperature of Paris at night, courtesy B. Dousset, University of Hawaii.

Print Close

Feature

Satellites Pinpoint Drivers of Urban Heat Islands in the Northeast **12.13.10**

Cities such as New York, Philadelphia, and Boston are prominent centers of political power. Less known: Their size, background ecology, and development patterns also combine to make them unusually warm, according to NASA scientists who presented new research recently at an American Geophysical Union (AGU) meeting in San Francisco, Calif.

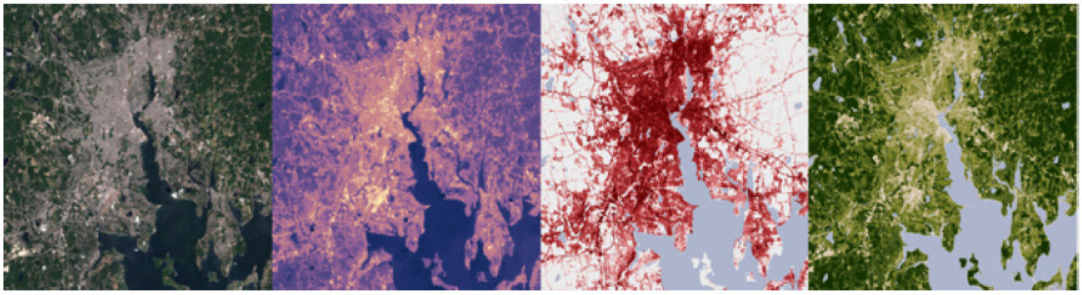
Summer land surface temperature of cities in the Northeast were an average of 7 °C to 9 °C (13°F to 16 °F) warmer than surrounding rural areas over a three year period, the new research shows. The complex phenomenon that drives up temperatures is called the urban heat island effect.

Heat islands are not a newly-discovered phenomenon. Indeed, using simple mercury thermometers, weather watchers have noticed for some two centuries that cities tend to be warmer than surrounding rural areas.

Likewise, researchers have long noticed that the magnitude of heat islands can vary significantly between cities. However, accurate comparisons have long eluded scientists because ground-based air temperature sensors tend to be unevenly distributed and prone to local bias. The lack of quantifiable definitions for urban versus non-urban areas has also hindered comparisons.

Satellite technology, which offers a more uniform view of heat islands, is in the process of changing this. The group of researchers from NASA's Goddard Space Flight Center in Greenbelt, Md., presented results based on a new method for comparing heat islands at the AGU meeting.

Providence, R.I.



Visible Light
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Surface Heat
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Developed Land
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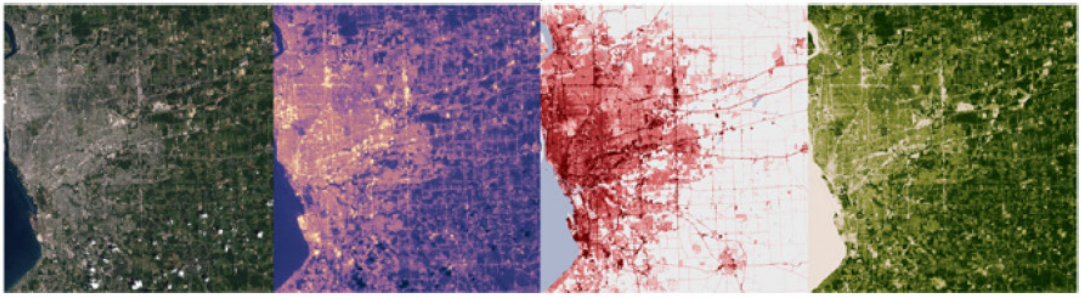
Vegetation Cover
› Larger image

Buffalo, N.Y.



Visible Light
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Surface Heat
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Developed Land
› Larger image

Vegetation Cover
› Larger image

Satellite-produced maps of Providence and Buffalo highlight the role that differences in development patterns and vegetation cover can have on the magnitude of a city's urban heat island. Though the two cities have the same approximate size, Providence has a significantly stronger heat island. **Credit:** NASA/Earth Observatory

› Larger images of Providence
› Larger images of Buffalo

"This, at least to our knowledge, is the first time that anybody has systematically compared the heat islands of a large number of cities at continental and global scales," said Ping Zhang, a scientist at Goddard and the lead author of the research.

Development produces heat islands by replacing vegetation, particularly forests, with pavement and other urban infrastructure. This limits plant transpiration, an evaporative process that helps cool plant leaves and also cools air temperatures, explained Robert Wolfe of Goddard, one of the scientists who developed the method.

Dark city infrastructure, such as black roofs, also makes urban areas more apt to absorb and retain heat. Heat generated by motor vehicles, factories, and homes also contributes to the development of urban heat islands.

A New View

The new method for comparing cities, which the team of scientists has honed for about two years, involves the use of maps of impervious surface area produced by a United States Geological Survey-operated Landsat satellite, and land surface temperature data from the Moderate-resolution Imaging Spectroradiometer (MODIS), an instrument aboard NASA's Aqua and Terra satellites.

Impervious surfaces are surfaces that don't absorb water easily, such as roads, roofs, parking lots, and sidewalks. Land surface temperatures tend to be higher and more variable than air temperatures, but the two generally vary in sync with each other.

By analyzing data from thousands of settlements around the world, the Goddard team has pinpointed key characteristics of cities that drive the development of heat islands. The largest cities, their analysis shows, usually have the strongest heat islands. Cities located in forested regions, such as the northeastern United States, also have stronger heat islands than cities situated in grassy or desert environments.

Most recently, the Goddard group has shown that a city's development patterns -- whether a city is sprawling or compact -- can also affect the strength of its heat island.

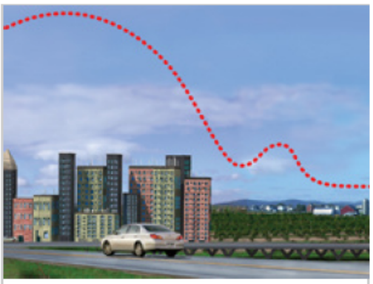
By comparing 42 cities in the Northeast, they found that densely-developed cities with compact urban cores are more apt to produce strong urban heat islands than more sprawling, less intensely-developed cities.

The compact city of Providence, R.I., for example, has surface temperatures that are about 12.2 °C (21.9 °F) warmer than the surrounding countryside, while similarly-sized but spread-out Buffalo, N.Y., produces a heat island of only about 7.2 °C (12.9 °F), according to satellite data. Since the background ecosystems and sizes of both cities are about the same, Zhang's analysis suggests development patterns are the critical difference.

She found that land cover maps show that about 83 percent of Providence is very or moderately densely-developed. Buffalo, in contrast, has dense development patterns across just 46 percent of the city. Providence also has dense forested areas ringing the city, while Buffalo has a higher percentage of farmland. "This exacerbates the effect around Providence because forests tend to cool areas more than crops do," explained Wolfe.

Cities in desert regions, such as Las Vegas, in contrast, often have weak heat islands or are actually cooler than the surrounding rural area. Providence, R.I.; Washington, D.C.; Philadelphia, Pa.; Baltimore, Md.; Boston, Ma.; and Pittsburgh, Pa.; had some of the strongest heat islands of the 42 northeastern cities analyzed.

"The urban heat island is a relative measure comparing the temperature of the urban core to the surrounding area," said Marc Imhoff, the leader of the Goddard research group. "As a result, the condition of the rural land around the city matters a great deal."



Land surface temperatures in cities, particularly densely-developed cities, tend to be elevated in comparison to surrounding areas -- a phenomenon called an urban heat island. **Credit:** NASA

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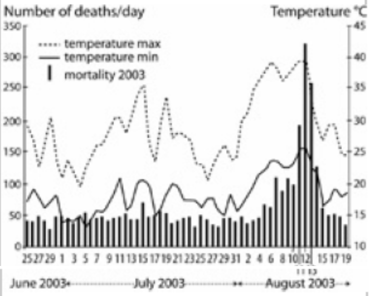

Heat islands can be deadly. This graph shows how the number of deaths spiked in Paris during a sweltering heat wave in 2003. **Credit:** University of Hawaii at Manoa/Benedicte Dousset

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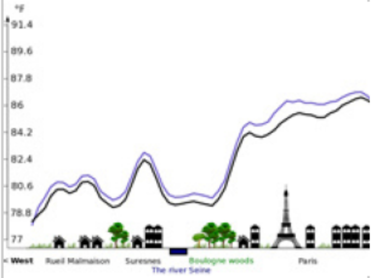

Air conditioning systems release waste heat into the atmosphere such that their widespread use can inadvertently elevate city air temperatures. This graph shows the result of a model that calculated the likely magnitude of the effect during the 2003 heat wave in Paris. **Credit:** Météo France/Cécile de Munck

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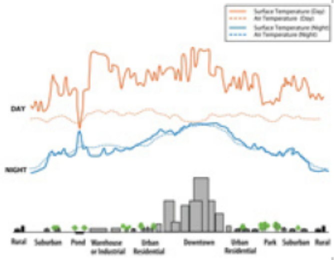

Surface temperatures vary more than air temperatures during the day, but they both are fairly similar at night. **Credit:** EPA

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Heat Island Impacts

Ratcheting up temperatures can have significant -- and deadly --
consequences for cities. Heat islands not only cause air conditioner and electricity usage to surge, but they also increase the mortality of elderly people and those with pre-existing respiratory and cardiovascular illness.

The U.S. Environmental Protection Agency estimates that, between 1979 and 2003, heat exposure has caused more than the number of mortalities resulting from hurricanes, lightning, tornadoes, floods, and earthquakes combined.

"It is the lack of cooling at nighttime, rather than high daytime temperatures, that poses a health risk," said Benedicte Dousset, a scientist from the University of Hawaii who also presented data about heat islands at the AGU meeting.

Dousset recently analyzed surface temperature images of Paris and showed the spatial distribution of heat-related deaths during a sweltering heat wave in 2003. Some 4,800 premature deaths occurred in Paris during the event, and excess mortality across Europe is thought to be about 70,000.

The risk of death was highest at night in areas where land surface temperatures were highest, she found. Buildings and other infrastructure absorb sensible heat during the day and reradiate it throughout the night, but the cooling effect of evaporation is absent in cities. The lack of relief, particularly among the elderly population, can be deadly, she explained.

Ramped up air conditioning usage may have even exacerbated the problem, other data presented at the meeting suggests. Cecile de Munck, of the French Centre for Meteorological Research of Meteo-France, conducted a series of modeling experiments that show excess heat expelled onto the streets because of increased air conditioner usage during heat waves can elevate outside street temperatures significantly.

"The finding raises the question: what can we do to design our cities in ways that will blunt the worst effects of heat islands?" said de Munck, who notes also that her research shows that some types of air conditioning exacerbate heat islands more than others.

Making sure cities have trees and parks interspersed throughout the compact urban cores can also help defend against heat islands. And studies shows that painting the surfaces of roads and buildings white instead of black and creating “green” roofs that include vegetation can soften urban heat islands.

"There's no one solution, and it's going to be different for every city," said Dousset. "Heat islands are complex phenomena."

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ISSUE NO. 38 DECEMBER 2010 • www.urban-climate.org • INTERNATIONAL ASSOCIATION FOR URBAN CLIMATE

In the News

Satellites Pinpoint Drivers of Urban Heat Islands in the Northeast

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While researchers have long noticed that the magnitude of heat islands can vary significantly between cities, accurate comparisons have long eluded scientists because ground-based air temperature sensors tend to be unevenly distributed and prone to local bias. The lack of quantifiable definitions for urban versus non-urban areas has also hindered comparisons.

Satellite technology, which offers a more uniform view of heat islands, is in the process of changing this. The group of researchers from NASA's Goddard Space Flight Center in Greenbelt, Md., presented results based on a new method for comparing heat islands at the AGU meeting.

"This, at least to our knowledge, is the first time that anybody has systematically compared the heat islands of a large number of cities at continental and global scales," said Ping Zhang, a scientist at Goddard and the lead author of the research.

The new method for comparing cities, which the team of scientists has honed for about two years, involves the use of maps of impervious surface area produced by a United States Geological Survey-operated Landsat satellite, and land surface temperature data from the Moderate-resolution Imaging Spectroradiometer (MODIS), an instrument aboard NASA's Aqua and Terra satellites.

By analyzing data from thousands of settlements around the world, the Goddard team has pinpointed key characteristics of cities that drive the development of heat islands. The largest cities, their analysis shows, usually have the strongest heat islands. Cities located in forested regions, such as the northeastern United States, also have stronger heat islands than cities situated in grassy or desert environments. Most recently, the Goddard group has shown that a city's development patterns -- whether a city is sprawling or compact -- can also affect the strength of its heat island. By comparing 42 cities in the Northeast, they found that densely-developed cities with compact urban cores are more apt to produce strong urban heat islands than more sprawling, less intensely-developed cities.

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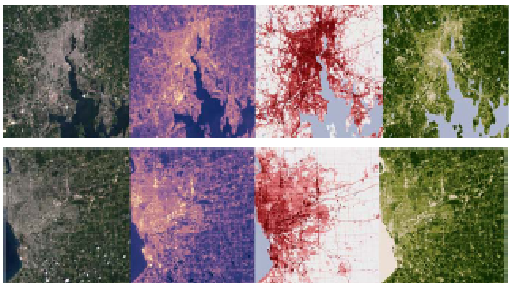

Satellite images of Providence, RI (top) and Buffalo, NY (bottom). The images show (from left to right): visible light, surface heat, developed land and vegetation cover. ***Source*****:** NASA

Ratcheting up temperatures can have significant -- and deadly -- consequences for cities. Heat islands not only cause air conditioner and electricity usage to surge, but they also increase the mortality of elderly people and those with pre-existing respiratory and cardiovascular illness.

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Source: http://www.nasa.gov/topics/earth/features/heat-island-sprawl.html