The Mortality Impact of the August 2003 Heat Wave in France[1]

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In August 2003 Western Europe suffered from a deadly heat wave. An estimated 15,000 people died in France from the direct effect of the heat wave. The total number of person-years lost has not yet been estimated. Applying an indirect estimation technique to the monthly number of deaths by sex, age and place of residence for the period 1997-2003, a method that can easily be reproduced in other contexts, we estimate the number of years that would have remained to those who died from the heat wave had they been spared. The paper also evaluates the role of the 2003 heat wave "harvesting" effect in explaining the deficit of deaths recorded in 2004 (estimated at 27,500 out of a total expected 535,000 deaths).

In August 2003, France suffered from an unprecedented heat wave with temperatures reaching the high 30s in Celsius degrees for a record of twelve successive days and little differences between day- and night-time. Consequences were deadly for the population: an estimated 15,000 of the total 56,500 deaths recorded during that month have been attributed to the direct effect of the heat wave. The crisis had a major socio-political impact with the calling into question of the responsibility of the highest authorities, which lead to the resignation of the Minister of Health and the transfer of a number of high-ranking officials in that ministry, as well as the organisation of the French health care system and the responsibility of individual families. The outrage was such that major resources were promised by the government to prevent such a crisis to occur again in the future.

A better understanding of the crisis was regarded as the first step to designing effective preventive measures and numerous reports were requested from specialised agencies. This paper specifically aims at measuring the long term mortality impact of the August 2003 heat wave in France and at describing the demographic characteristics of the victims. One aspect of the debate in the literature centred around the question of whether those who died were particularly vulnerable persons who were expected to live only a few more days or weeks independently from the heat wave or whether the heat wave killed randomly among the general population. Considering that this issue has not yet been properly addressed, an additional purpose of this paper is to estimate to which extent the unusually low mortality recorded in 2004 is the result of an harvesting effect of the August 2003 crisis.

After providing some background on the French heat wave of August 2003 and demonstrating how unusual this episode has been in the demographic history of the past fifty years, the paper describes the specific hypotheses investigated in the analyses as well as the data and methods used. It then present the results of the statistical analyses and ends with a discussion of the findings.

Background

The French crisis was remarkable to the extent that no other Western countries has experienced such a high level of excess mortality due to heat waves, neither in the recent past

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nor in 2003 (for the United States, see for instance Greenough *et al.*, 2001, and Semenza *et al.*, 1996).

Historical comparison

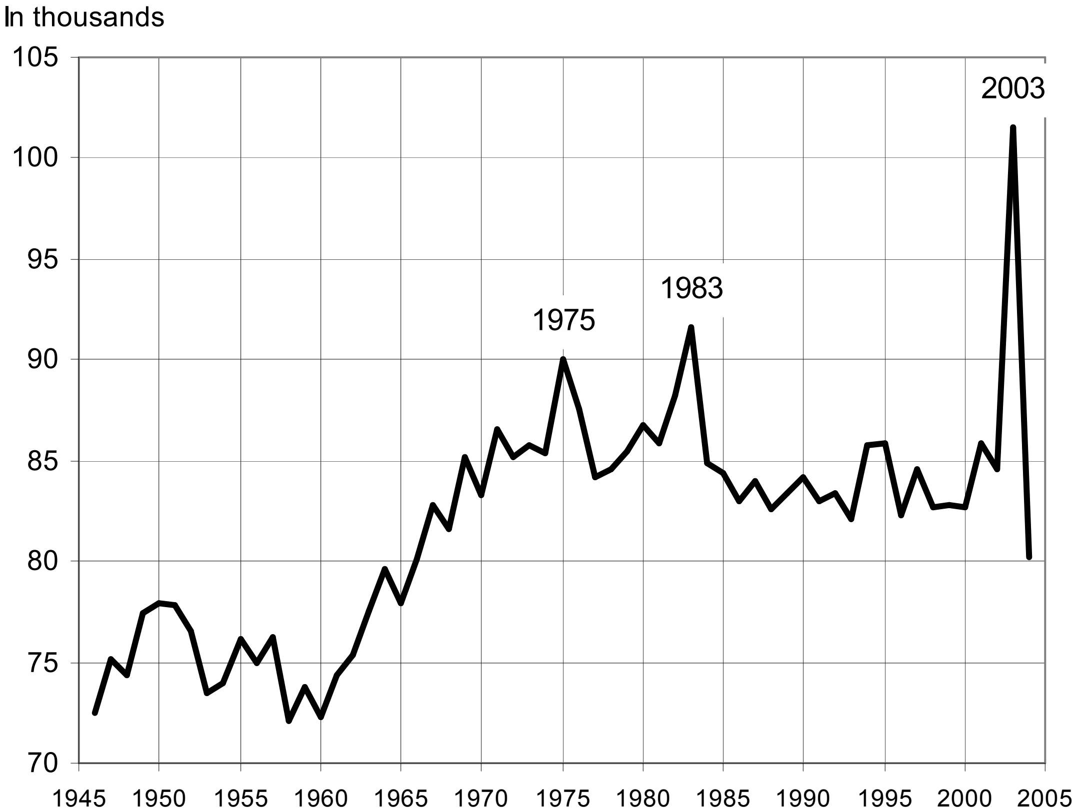
The August 2003 heat wave was clearly unusually intense. A recent study ordered by the French Government to determine temperature thresholds at which to trigger a health alert and activate a hot weather response plan found that, in Paris for instance[2], the best indicator was a succession of three days with all minima above 20 Celsius degrees and all maxima above 35 Celsius degrees. When looking back since January 1st, 1880, the first day of operation of the Paris meteorological station up to the present, one found a total of only six qualifying episodes but while the August 2003 episode lasted for an entire ten days, the next longest one (which took place in 1957) lasted for six days. In the Paris metropolitan area, the most severely hit region in 2003, temperatures reached a high of 35 Celsius degrees during day-time starting on August 3 and they remained above that level until August 14 when they declined below 30. Throughout this period, the lowest temperatures recorded at night never fell below 20, preventing any physiological recuperation to occur.

As indicated on Figure 1, which shows the number of deaths during the months of July and August over the past 30 years in France, other such episodes have occurred in the past but never with such a strong impact: in 1976 as in 1983, the number of extra deaths can be estimated at around 5,000 deaths[3]. In other Western countries, none of the Summer heat waves recorded over the past thirty years killed more than 2,000 people (Institut national de veille sanitaire, 2003). The most documented one was undoubtedly the Chicago heat wave of 1995 to which fewer than 800 deaths were attributed (Klinenberg, 2003 ; Benbow, 1997)

[2] The study also found that levels of minima and maxima temperatures showing an association with excess mortality vary from region to region.

[3] These numbers are estimated using the same methodology as the leading to an estimated 15,000 excess deaths during the Summer 2003, i.e. by comparing the observed number of deaths in July and August of each given year by the average number of deaths during the same months over the three preceding years.

Figure 1. Number of deaths in July and August from 1946 to 2004. France



Characteristics of the French 2003 heat wave

Such a large number of excess deaths as that recorded in France in August 2003 is clearly unusual during the Summer months in Western countries. Indeed, the month of August appears as the month typically characterised with the lowest level of mortality in recent demographic history (Figure 2). By contrast, it is not uncommon to observe episodes of large excess mortality during the Winter months in France as in other northern countries. Indeed, when looking at detailed mortality trends, episodes of excess of over 10,000 deaths due to flu epidemics are far from unusual.

Figure 2. Total number of deaths per month, January 1990 to March 2005, France

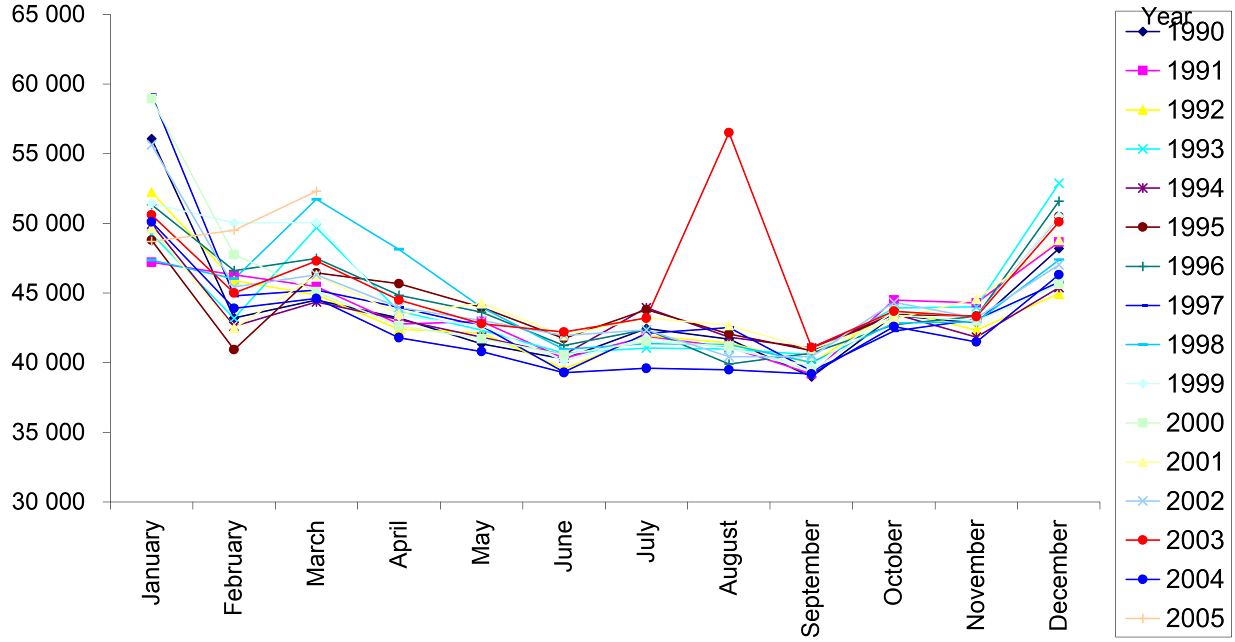


Figure 3 presents the daily number of deaths in France main cities. It shows that deaths are more numerous during the winter but that many summers are characterized with a few days when the number of deaths is significantly higher than average. However, the 2003 heat wave appears truly exceptionnal for two reasons: the maximum number of deaths reached more than four times the usual number of deaths, and the number of days with an excess number of deaths is remarkably large since the heat wave lasted for nearly two entire weeks.

Some of the reasons why these episodes have not elicited such public outrage as the August 2003 crisis is probably due to the fact that these are expected, that they are accompanied by much public health warnings and encouragements for the elderly to get vaccinated, but probably also by their very diffuse impact, since the deaths attributable to flu epidemics are usually spread over several weeks, if not months. By contrast, the 2003 episode took everyone by surprise, in large part because of its suddenness, as most of the 15,000 excess deaths occurred over a ten day period, from August 6 to August 15 (Figures 3 and 4).

Figure 3. Number of deaths per day in August 2003 compared with the average daily number of deaths during the months of August 2000 to 2002 (France)

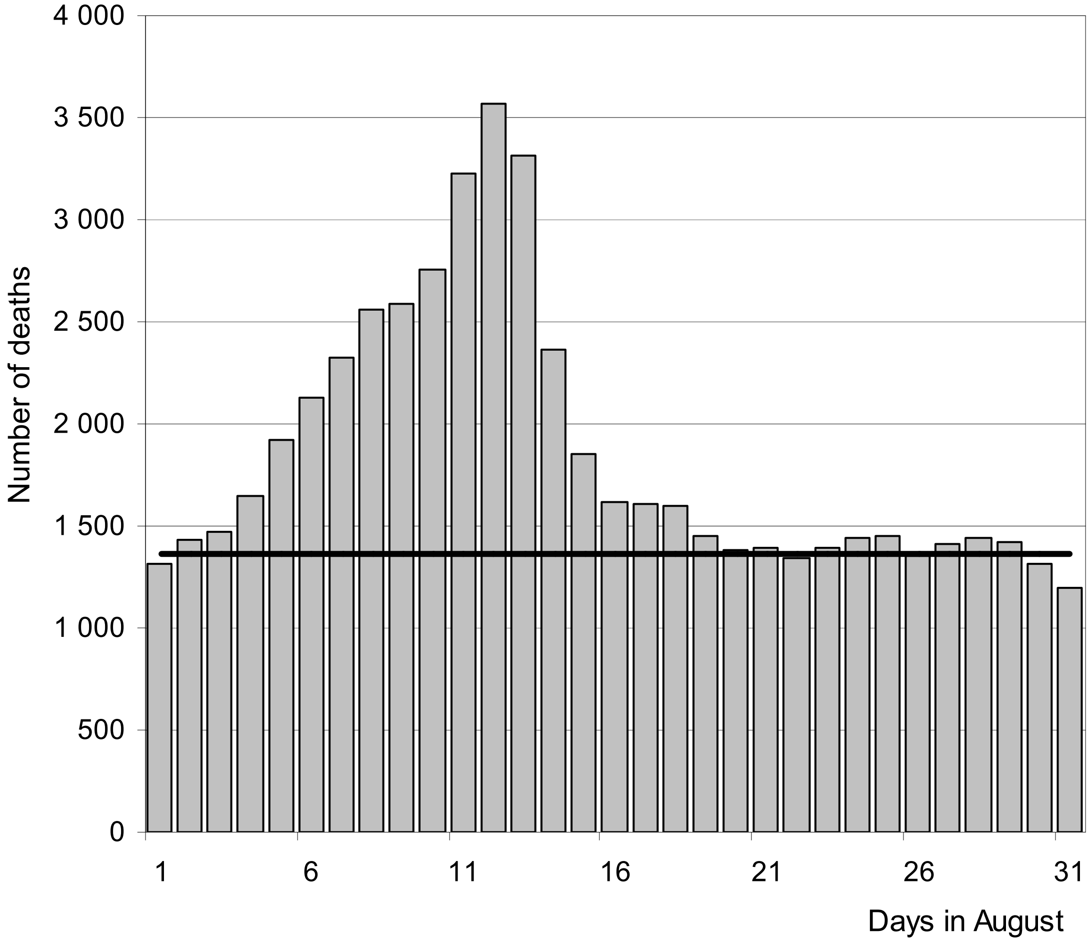
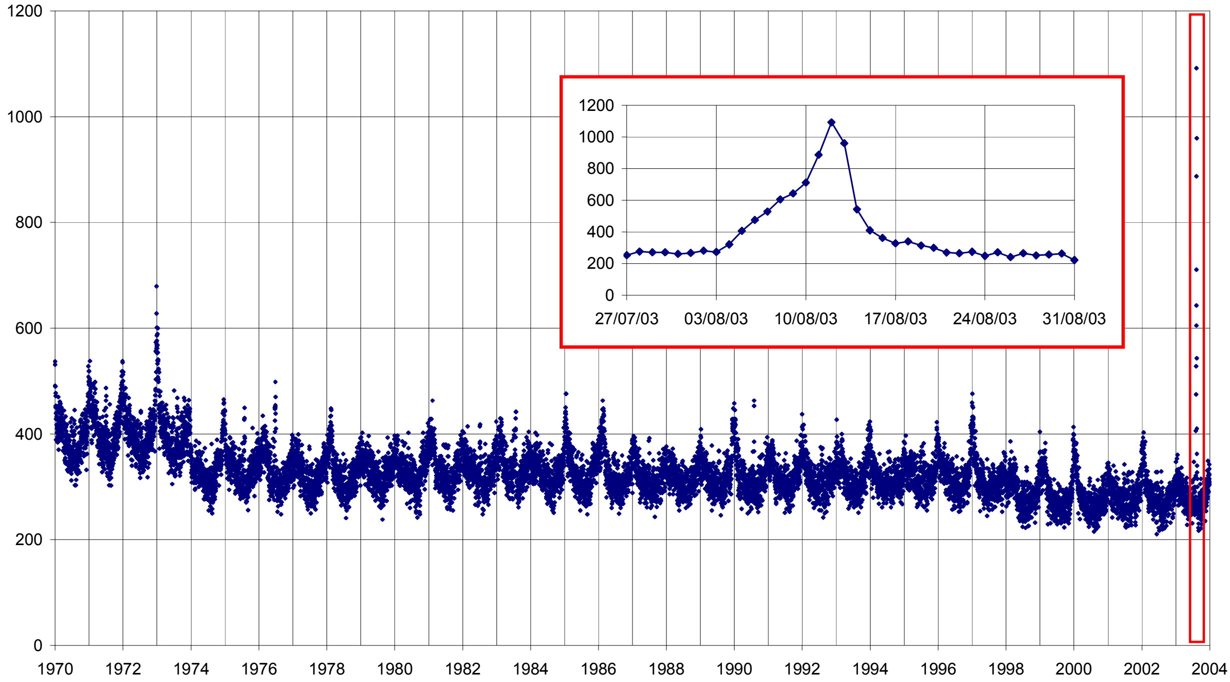
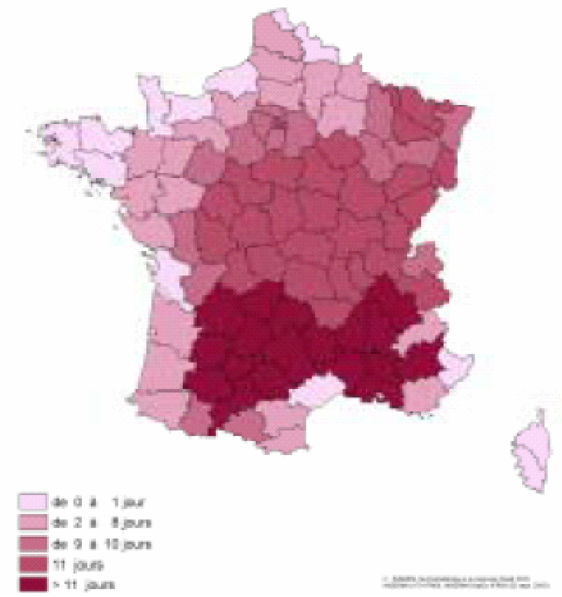


Figure 4. Number of deaths per day in 28 major cities of France, 1970 to 2004

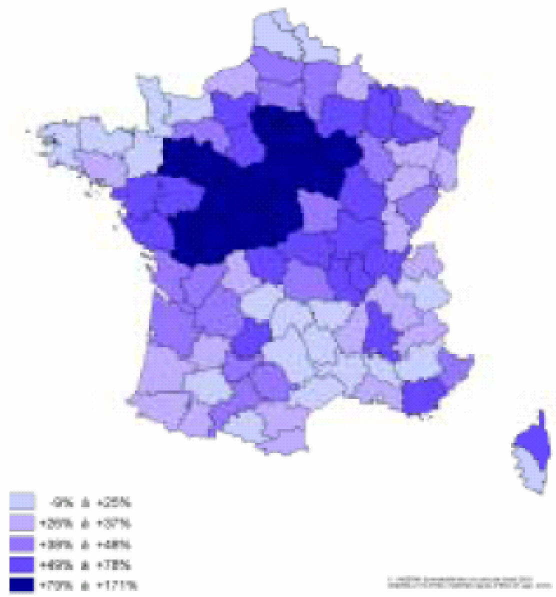


Another characteristic of the 2003 mortality crisis is its high geographic concentration. As indicated by Map 2, only a relatively small number of départements[4] were hit, though those happened to be disproportionately populated. Indeed, the four départements with the highest excess mortality, that is more than 85% excess deaths during August 2003 compared to August 2000 to 2002, include 10.5 percent of France total population but more than 25 percent of all excess deaths. These four départements are located in the Paris metropolitan area (départements number 75, 92, 93 and 94). The geographic concentration of the health crisis is particularly striking considering the relative lack of correlation between objective measures of temperatures and excess mortality (see Maps 1 and 2). If all the départements in which a significant level of excess mortality was recorded also experienced record-high levels of night and day temperatures during that period, there is also a number of départements which experienced higher levels of temperature for a longer duration but hardly any excess mortality, in the South of France in particular.

Map 1. Number of days when the temperature has exceeded 35°C between 1 and 20 August 2003



Map 2. Excess mortality by département from 1 to 20 August 2004



Source: reprint from Hemon-Jougla, 2003, maps III.1.a and III.1.b

Previous studies on this issue have all found that the heat wave crisis has been associated with a strong harvesting effect: as heat waves kill the frailest people, the number of deaths is lower in the subsequent period as, by definition, those who died during the heat wave would have lived for only a short additional period in the absence of the heat wave. Most of their conclusions were brought about by the large deficit of deaths observed throughout 2004, interpreted as the rebound effect of the August 2003 harvest. These findings, however, are based on either incomplete or wrong data. Our paper aims at carefully revisiting the issue by a detailed analyse of precise and up-to-date data on mortality trends and patterns before, during and after the heat wave.

[4] Mainland France includes a total of 95 *département*, the *départements* being one of the most basic administrative units.

Data

Individual records of death with information on day, month and year of occurrence as well as year of birth, sex and *département* of residence (the basic French administrative unit) of the deceased has been provided to us for the period 1996-2003 by the *Institut National de la Statistique et des Etudes économiques* (Insee), the institution in charge of collecting and analysing civil registration data in France. We also used life tables published by the latter institution for France for the periods 1997-1999 and 2000-2002 as well as population by sex and year of age on January 1st 2003 and January 1st 2004. As no reliable data is yet available at the individual level for 2004, we used the monthly total number of deaths by département for 2004[5]. Ideally, we would have liked to use an indicator of frailty but there is no information on civil registration records that could be used as such. The frailty effect has thus to be estimated indirectly.

Methods

We first sought to estimate the number of heat wave related deaths by département and, separately, by sex and age. This estimation is based on a comparison between the actual and the expected numbers of deaths for each département and for each sex and year of age. Expected mortality is based on the trend calculated from the previous six years (1997-2002). We then investigated the relationship between the excess mortality of August 2003 and the deficit recorded over the following period (September 2003 to December 2004). The two contrasting hypotheses we sought to test were the following: the existence of a short term, mortality harvesting effect and the absence of such an effect, i.e. heterogeneity versus homogeneity of the population in each sex and age group. The first hypothesis assumes that the heat wave killed the frailest individuals, who only had a few more weeks or months to live even without the hot weather episode. The second one assumes that the heat wave killed indiscriminately and that its victims would have lived as long as anyone else in their sex and age group in the absence of the August 2003 heat wave.

The mortality impact of the heat wave under hypotheses 1 and 2 can be described in terms of the number of deaths recorded in the subsequent months, in terms of life expectancy at birth, and in terms of spatial correlations between the excess mortality of August 2003 and the deficit recorded in 2004 at the level of the départements.

Comparing the age and sex structure of the August 2003 excess deaths with that of the 2004 missing deaths

We sought to estimate the age and sex structure of the excess deaths from the heat wave as well as that of the "missing" deaths of the following period. Large variations in the number of deaths at each age are expected from one year to the next due to the very irregular shape of the French age pyramid (Figure 5). These variations reflect France demographic history over the past century. Because the heat wave killed mostly among the elderly, the impact of the First World War on the age pyramid is particularly detrimental. Indeed, the main demographic impact of the war was to prevent and delay a large number of births so that those cohorts born in 1914-1918 are particularly small. Individuals aged 90 to 94 in 2004 are consequently much fewer than those in the surrounding age groups. Consequently, we cannot limit the analysis to a comparison of the average number of deaths in 2000-2002 with August 2003 for each sex and single year of age as previous studies have done but need to take into account the large independent variations in the size of the population at risk.

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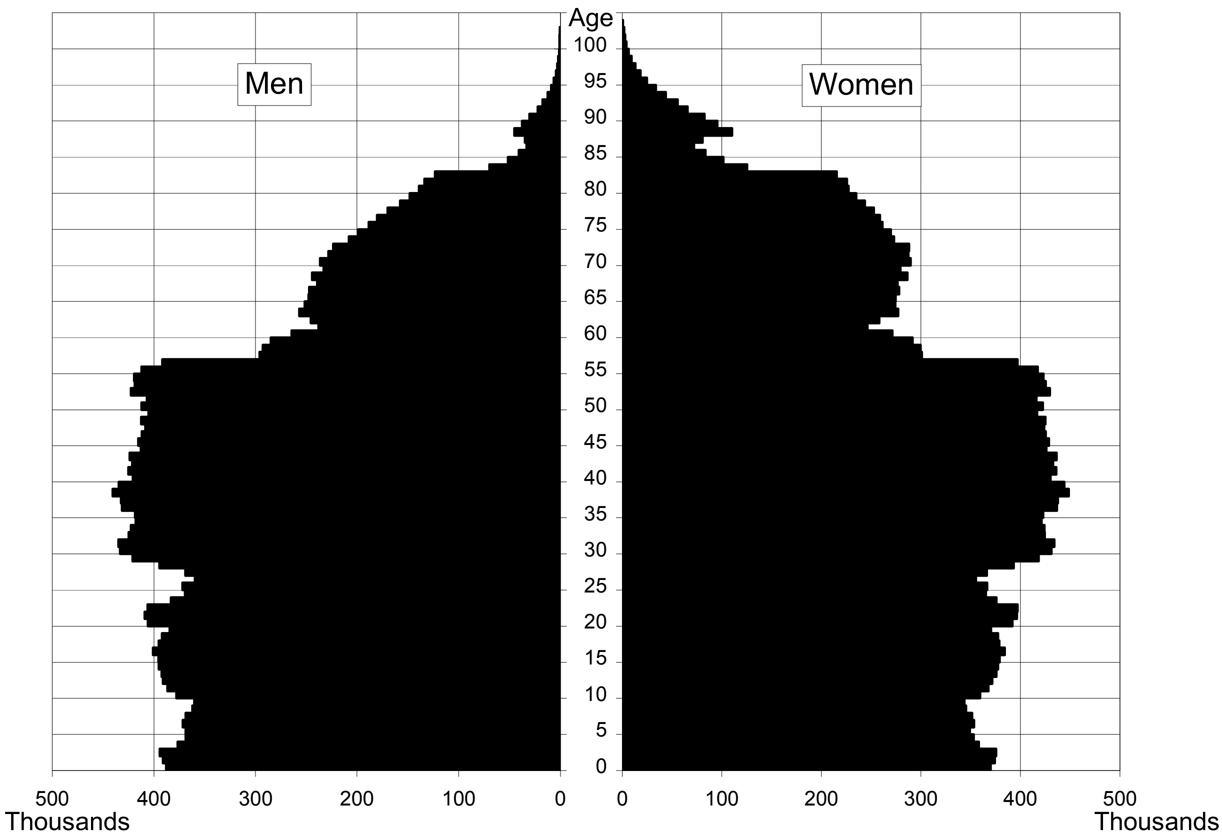
[5] We thank our colleages Catherine Beaumel, Aline Desesquelles, Guy Desplanques and Lucile Richet-Mastain, from Insee, *Département de la démographie,* for having provided us with all the data used in this paper.

Figure 5. Population pyramid at 1-1-2003. France



The method we followed was to compare observed and expected probabilities of death by sex and age, rather than the absolute number of deaths, for August 2003. To estimate our expected probabilities of death, we started by estimating the trend in the probabilities of death by sex and year of age between the two life tables 1997-1999 and 2000-2002. The trend was continued to construct a series of expected probabilities of death by sex and year of age separately for 2003. The expected probabilities of death by sex and year of age for the month of August 2003 were then estimated by assuming stability in the seasonality observed during the period 1997-2002. The resulting probabilities were applied to the number of births in 2003 and to the population by sex and year of age on January 1st 2003 to estimate the number of deaths that would have been expected in August 2003 in the absence of a heat wave. The difference between the observed and the estimated numbers of deaths by sex and year of age in August 2003 provides a distribution by sex and year of age of the heat wave related deaths.

A similar estimation (by continuing the trend observed from 1997-1999 to 2000-2002 in the probabilities of death by sex and year of age up to 2004) was carried out to estimate the distribution of the "missing" deaths by sex and year of age in 2004. However, instead of applying the probabilities thus found to the observed population on January 1st, 2004, we added to the later the number of heat wave related deaths found for August 2003 in each sex and single year of age category, since our estimate was carried out to reconstruct the number of deaths which would have occurred in 2004 in the absence of the August 2003 heat wave.

Estimating excess mortality in August 2003 and under-mortality in 2004 in the départements

The small number of deaths recorded on average in a large number of French départements and the large ensuing random variations from a year to the next did not allow for detailed calculations by sex and age. To estimate both the number of excess deaths in August 2003 and the deficit of 2004 at the level of the départements we thus resorted to a rather crude method of estimation based on the comparison between the total number of deaths recorded in August 2003 and the average number of deaths recorded in August 2000, August 2001 and August 2002 (used as the expected number of deaths) in each department[6]. Similarly, the under-mortality of the months following the heat wave was estimated by comparing the total number of deaths from September 2003 to the end of 2004 with the adjusted average number of deaths in 2000, 2001 and 2002 in each département.

The difference between the actual and the expected number of deaths in August 2003 for each département was then regressed on the difference between the actual and the expected numbers of deaths in September 2003-December 2004 after dividing both parts of the equation by a scaling factor (i.e. the average monthly number of deaths in each département) in order to evaluate the level of correlation between both phenomena at the département level. While a high level of correlation is expected under hypothesis 1 (total harvesting effect), that is those départements which exhibited the largest number of excess deaths in August 2003 should also be those exhibiting the largest number of "missing" deaths in the months following the heat wave, no correlation is expected under hypothesis 2 (no harvesting effect) since there would then be no reason to expect any relation at the département level between the excess mortality of August 2003 and the deficit recorded in the following months or year.

Results

Age and sex characteristics of the August 2003 heat wave related deaths

Following the aforementioned methodology, we find that the excess mortality due to the heat wave in August 2003 reaches 14,748 deaths. This number is very close to the number estimated in a more rudimentary fashion (14,800) published in the first public report (as early as September 2003) by calculating the difference between the number of death recorded in August 2003 and the average number of deaths recorded in August 2000, August 2001 and August 2002 (Hémon and Jougla, 2003), which lends credit to our method of calculation. By contrast with the authors of this report, however, our method has allowed us to estimate in details the sex and age distribution of the deceased.

When using the most rudimentary method, the two most striking characteristics of the deceased are found to be, first, that over 90 percent of the victims were aged 65 and above and, second, that women represented 65 percent of the deceased while men represented only 35 percent of them. The over-representation of women among the heat wave victims was particularly striking because of its scope and also because it is opposite of what was found in some other of the most documented heat wave mortality crises such as in the United States for instance (Benbow, 1997). Our detailed analysis shows that the large sex differential found in France is, for the most part, not due to the differential age structure of the male and female population. Indeed, when adjusted by exact year of age, the difference is only slightly reduced, so that women still account for 60 percent of all excess deaths. As indicated by Figure 6, showing the ratio of the actual to the expected probabilities of death by sex and year of age in August 2003, the sex differential is mostly significant after age 60 and increases progressively afterwards.

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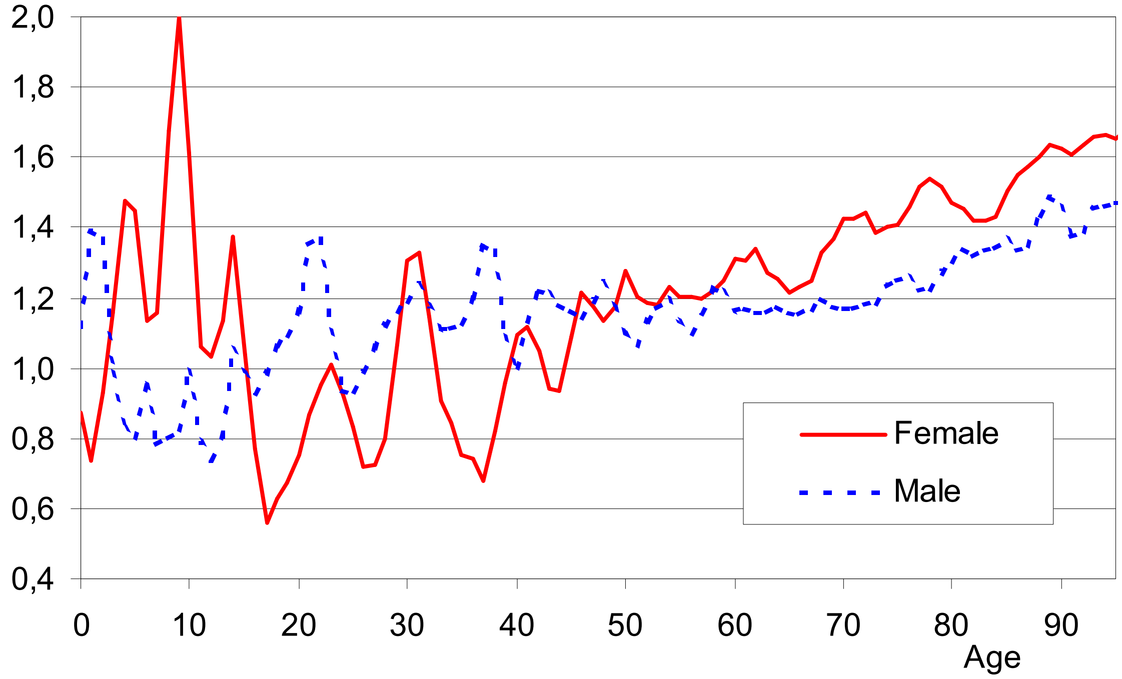
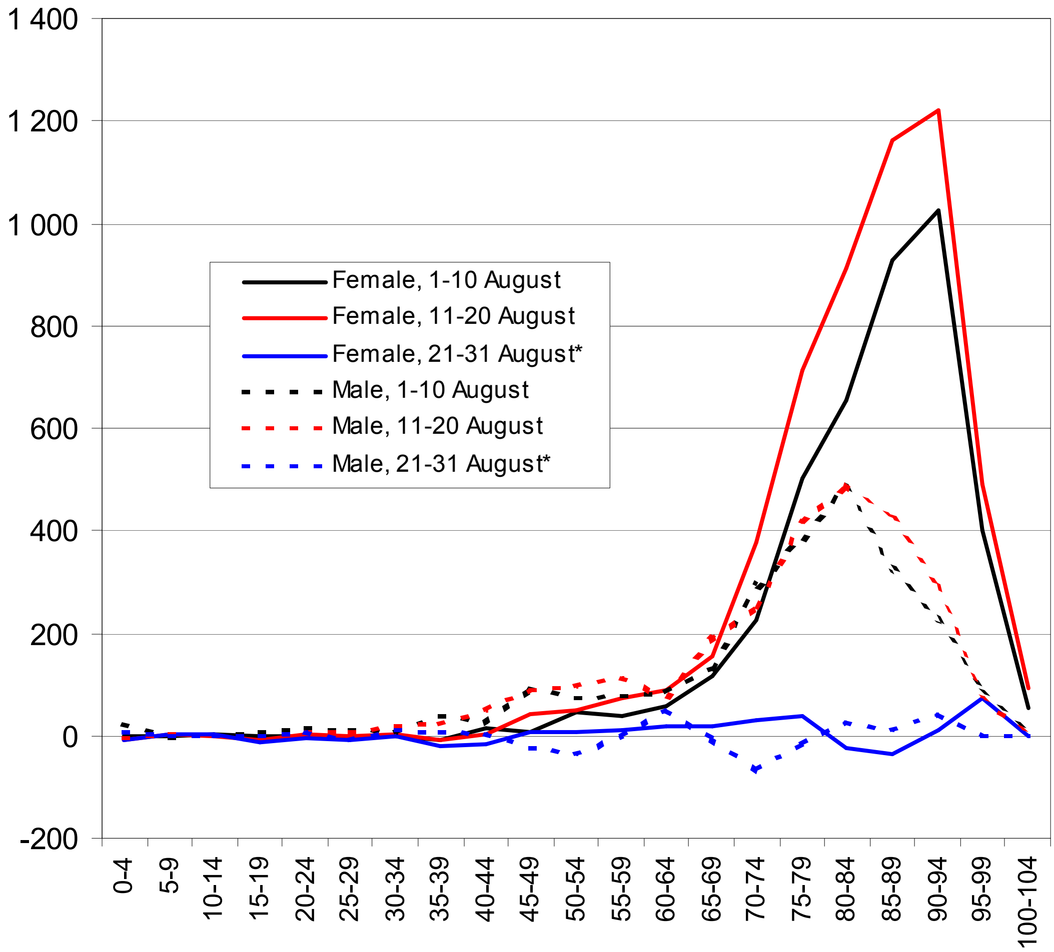
[6] This method has been proved to be robust at the departement level, compared to more sophisticated methods based on populations and probabilities of death by sex and age (Hémon, Jougla 2003).

Figure 6. Ratio of observed to expected probabilities of death by sex and age in August 2003



Considering the harvesting hypothesis, we also estimated the age and sex structure of the heat wave victims distinguishing between three periods, i.e. August 1-10, August 11-20 and August 21-31. Indeed, if a frailty effect related to age had been operating, we would expect the frailest, assumed to be the oldest, to have died first, followed during the later days of the heat wave by less frail, thus younger, victims. Under the harvesting hypothesis, we thus expected to find that those deceased during the first ten days of August to have been older on average than those who died during the following ten days. Similarly, the structure of mortality for the last days of August should have been even younger than expected since many of the elderly at risk would have died during the first three weeks of the month. The comparison is based on the average daily number of deaths by sex and age expected in August 2003 when projecting the trends in the probabilities of death observed from 1997-1999 to 2000-2002. Figure 7 shows the overall distribution of deaths by age and sex and for each of the three time periods.

Figure 7. Number of heat wave related deaths (O-E) by sex, August 2003



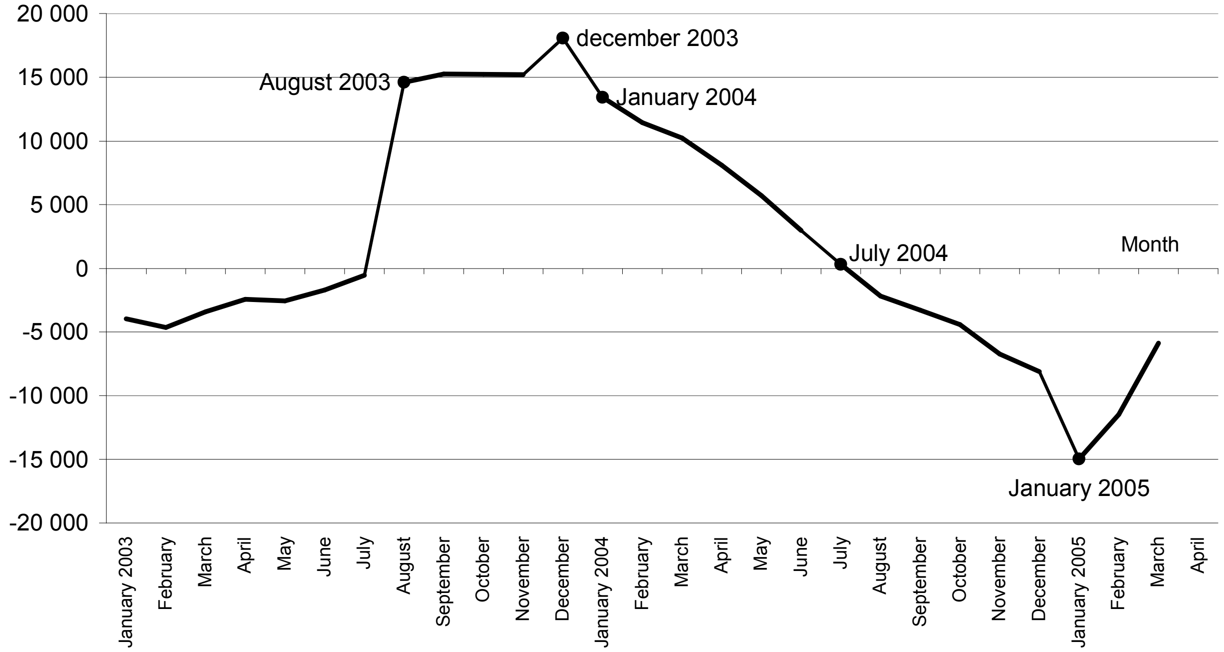
**Note: The 21-31 august period was adjusted for the sake of comparison to take account of its longer duration compared to the two previous periods.*

The results provide evidence against the frailty hypothesis to the extent that the distribution of deaths by sex and age for the first ten day period of August 2003 is not significantly different from that of the following ten day period. The average age at death is 71 years for men and 81 years for women during both periods. Furthermore, the distribution of deaths by sex and age during the later ten days of August, after the end of the heat wave crisis, shows no differences with the expected distribution while we would have expected fewer deaths in the age groups most affected by the heat wave under the harvesting hypothesis. The later hypothesis cannot however be ruled out to the extent that frailty might not be properly captured by the age variable. In other words, those people who died during the first few days of the heat wave were indeed more vulnerable than those who died later but because of the independence between frailty and age, a comparison of the deceased in both periods based on age and sex only is unable to distinguish between the frail and the robust. An alternative hypothesis would be that some harvesting did occur, but was compensated by delayed deaths, some people having been weakened by the heat wave and dying in the following days. If such delayed deaths did occur in the days or months after the heat wave, the harvesting effect could be difficult to isolate in the short term.

To further investigate this issue, we compared the number of deaths for every single month of 2003 and 2004 with that recorded during the same month of the previous three years. Figure 8 presents the cumulated number of deaths from January 2003 to March 2005, compared to the corresponding months of 2000-2002. In January and February 2003, the number of deaths has been smaller than in the same months of 2000-2002, and nearly 5,000 fewer than expected deaths were counted. From March to July, however, the monthly number of deaths was a little larger, and at the end of July 2003 the cumulated number of deaths was very similar to the corresponding figures in 2000-2002. Again, after August 2003 and its 15,000 excess deaths, the numbers of deaths in September, October and November were very similar to the previous years. In December, we find an excess number of 3,000 deaths, so that the cumulated number of excess deaths reached a maximum of 18,000 at the very end of the year 2003.

The lower than expected mortality of January and February 2003 and the higher than expected mortality of December 2003 is explained by the pattern of the flu epidemics during the period 2000-2003. Indeed, the mortality effect of flu epidemics is typically spread over the entire Winter months (December through February). However, Winter 2002-2003 was one of the few Winters exempted from the epidemics, so that there were hardly any flu victims in both January and February 2003 compared to the previous years. In addition, most of the flu epidemics of the following Winter, that is Winter 2003-2004, took place in the early season, i.e. December 2003, which then exhibited a high level of mortality relative to the previous years. The lower than expected number of deaths in January and February 2004 could also be explained by the same reason. However, one cannot rule out the possibility that one reason why there were relatively few flu victims in the early weeks of 2004 was because of the unusually small size of the population at risk due to the heat wave crisis. This assumption is further supported by the fact that mortality was continuously lower than would be expected from previous mortality trends throughout the rest of 2004 and up to the end of January 2005, so that by the end of July 2004, the number of "missing" deaths was equal to the number of excess deaths estimated for 2003. It becomes negative for subsequent months of 2004, reaching a minimum of -15,000 at the end of January 2005. A flu epidemics took place in February and March 2005, later than in typical Winters, which, again, explains the increase in mortality during those two months.

Figure 8. Monthly cumulated number of deaths, relative to the same months of years 2000-2002

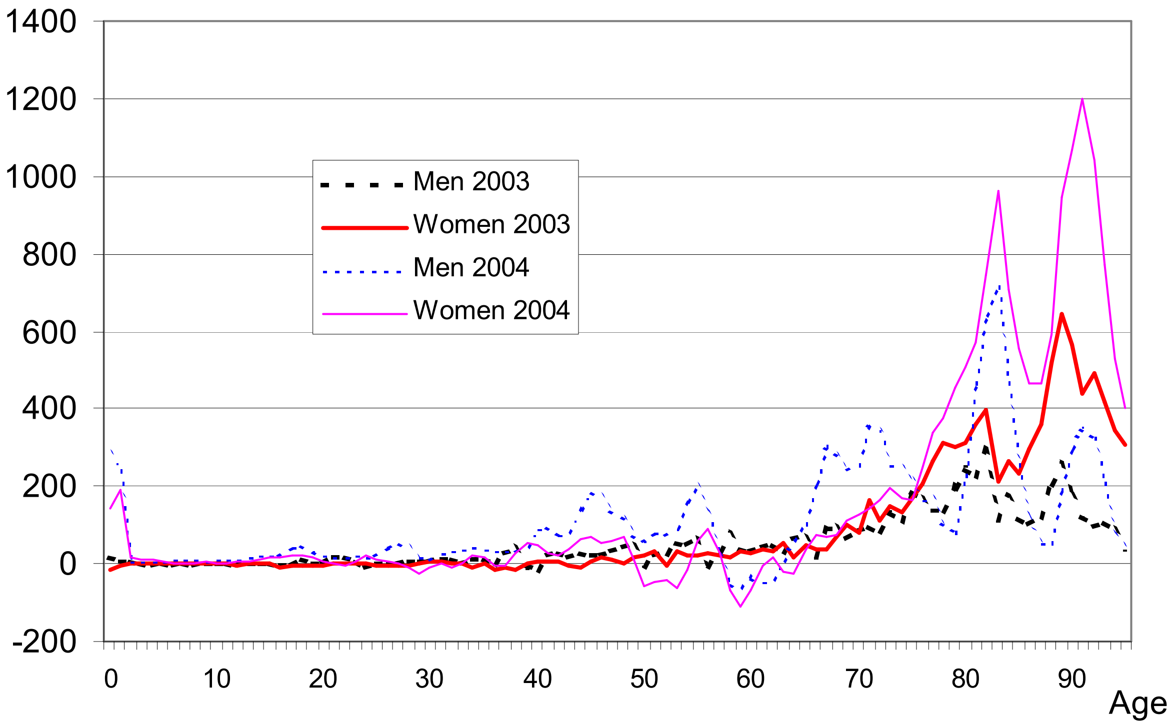


These results justify looking at the potential harvesting rebound of the August 2003 crisis over the entire 2004 year.

Age and sex characteristics of the " missing" deaths of 2004

As previously explained in details, we applied the probabilities of death projected from the trend observed between 1997-1999 and 2000-2002 to the population by sex and year of age on January 1st, 2004 to which we added the 15,000 victims of the heat wave, to estimate the life expectancy that would have been expected in the absence of the 2003 exceptional episode of hot weather. The actual number of deaths recorded in 2004 shows a deficit reaching about 27,000 compared to the expected number of deaths. Figure 9 shows how these "missing" deaths are distributed by sex and age.

Figure 9. Distribution by sex and age of heat wave related deaths (august 2003) and of the missing 2004 deaths



The above figure shows that, for men, the deaths missing for the year 2004 are way above the number of 2003 excess deaths for every single year of age from about 17 to 88 and, for women, the gap is even larger, starting at 65. In other words, the age and sex structure of the deaths "missing" in 2004 is far from simply mirroring the age and sex structure of the heat wave related deaths. However, we cannot discount the possibility that the "missing" deaths of 2004 actually include all of the heat wave related deaths in addition to others of unknown origin.

The construction of a distribution by sex and year of age of the heat wave related victims let us estimate the number of years lost under hypothesis 2, that is assuming no frailty effect, i.e. those who died would have lived as long as those who did not in the same sex and age groups. The expectation of life of the deceased under hypothesis 2 is calculated by applying the survival probabilities estimated as previously described to the sex and age structure of the deceased. This method yields an expectation of life of 11.8 years for men and 8.0 years for women (9.3 years for both sexes). The calculation implies that given their sex and age, under hypothesis 2,450 of the victims were expected to die before the end of 2003 and about 1,500 during the year 2004 (details not shown) while, by definition, under hypothesis 1, all of the victims would have died between August 2003 and the end of 2004.

Impact on expectation of life at birth by sex in 2003

Another way to look at the impact of the heat wave on life expectancy in 2003 is to estimate the difference between the expectation of life for the year 2003 as calculated from the observed deaths and as estimated without the heat wave related deaths and in the absence of any harvesting effect or delayed deaths. The latter is estimated assuming the same monthly probabilities of death by sex and age as observed in 2003 except for the month of August, for which we recalculated probabilities of death by sex and age after removing all the heat wave deaths previously estimated. The result shows that while the expectation of life calculated for the year 2003 using the actual number of deaths reaches 75.80 for men and 82.87 for women, it would have been 76.00 and 83.15, a difference of 0.2 and 0.28 years, respectively, for men and women.

Impact on expectation of life at birth by sex in 2004

The impact of the August 2003 mortality crisis on the expectation of life in 2004 is very simple under the no-harvesting hypothesis. Due to the heat wave, fewer people are alive at the beginning of 2004 and, consequently, fewer people are expected to die during the following 12 months. However, because those who died are supposed to have been randomly selected in each sex and age group, they would have had by definition the same probabilities of death at every age as those who survived, so that life expectancy would have been the same as that actually recorded for 2004. If, by contrast, we assume that all of the heat wave victims were doomed to die during the year 2004 in the absence of a hot weather episode (a complete harvesting effect), then two compensating phenomena should have occurred. On the one hand, the excess deaths at any age x lead to missing deaths at age x+1: the mirror effect takes place with a lag of one year of age, and the overall effect would be to increase life expectancy by a lower amount than it was depressed in 2003 since the older the deaths, the lower the impact on life expectancy at birth. On the other hand, life expectancy is more sensitive to a decline in the number of births than to an excess of deaths. Some simulations (not shown) indicate that all in all the mirror effect should be nearly perfect: if N excess deaths at time t induce a decline in life expectancy of d years at t, equivalent missing N deaths at time t+1 (at ages lagged one) lead to an increase in life expectancy of d. In other words, life expectancy observed in 2004 should be equal to the expected life expectancy estimated following our method accrued by the number of years lost in 2003 due to the heat wave, that is 0.2 year for men and 0.28 years for women (Table 1).

In fact, expectation of life at birth jumped to 76.69 years for men and to 83.81 years for women in 2004 according to the latest Insee estimates (Richet-Mastain, 2005), an excess of 0.5 years above an expected level that would continue the trend observed over the period 1997-2002 (estimated through linear regression). This result indicates that the gain in 2004 is much higher than would have been expected even with the most extreme hypothesis of a complete harvesting effect from August 2003 to the end of 2004. Though it tends to favour hypothesis 1 over hypothesis 2, it does not run counter to the former considering that those factors responsible for the unexplained increase, in excess of the full recovery from the August 2003 crisis, could very well also explain some of the apparent result of a harvesting effect. Further analysis is thus warranted to conclude in favour of one or the other of our two working assumptions.

Table 1. Estimated and observed life expectancy at birth by sex, in 2003 and 2004

	Women		Men	
	2003	2004	2003	2004
1.Observed life expectancy	82.87	83.81	75.80	76.69
2.Estimated without heat wave	83.15	83.31	76.00	76.22
3.Impact of the heat wave	-.28		-.20	
3.Estimated with complete harvesting		83.59		76.42
4.Difference remaining (1.-4.)		.22		.27

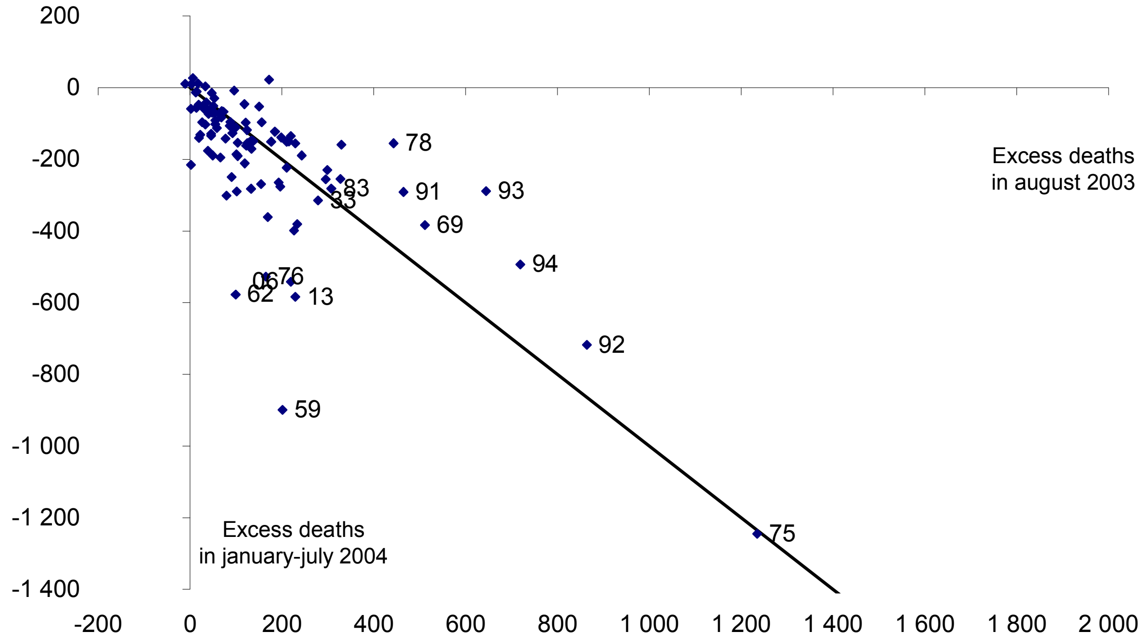
Considering that we have been warned by Insee about the provisional nature of the data provided to us for 2004, we have to be careful about interpreting these results. However, if the exact values remain to be assessed, there is very little reason to believe that, considering its size, the direction of these findings will be reversed when more accurate data are available.

Investigating spatial correlations between the excess mortality of August 2003 and the 2004 deficit

In order to investigate the harvesting hypothesis , we now look at the number of excess deaths in August 2003 by *département* of residence at the time of death, and the corresponding figure for the subsequent period, that is from September 2003 to December 2004. We first looked at the relationship between the August 2003 excess mortality and the deficit in deaths from January through July 2004, the period in which occurred a complete recuperation of the 2003 mortality excess as previously demonstrated.

In the Île-de-France region, corresponding to the larger Paris metropolitan area, the départements with a large excess number of deaths also exhibit a comparable number of missing deaths during the first part of 2004 (Figure 10) [développer quand même en une phrase sur la droite de régression de la figure ci-dessous]. However, no such systematic pattern is found for the other départements in which a similar dramatic decline in the number of deaths was recorded during the first seven months of 2004: in Northern France (départements 59 and 62), in the South (13, 06) and in the West (76), none of the départements had experienced a significant excess of deaths during the August 2003 heat wave (Map 2).

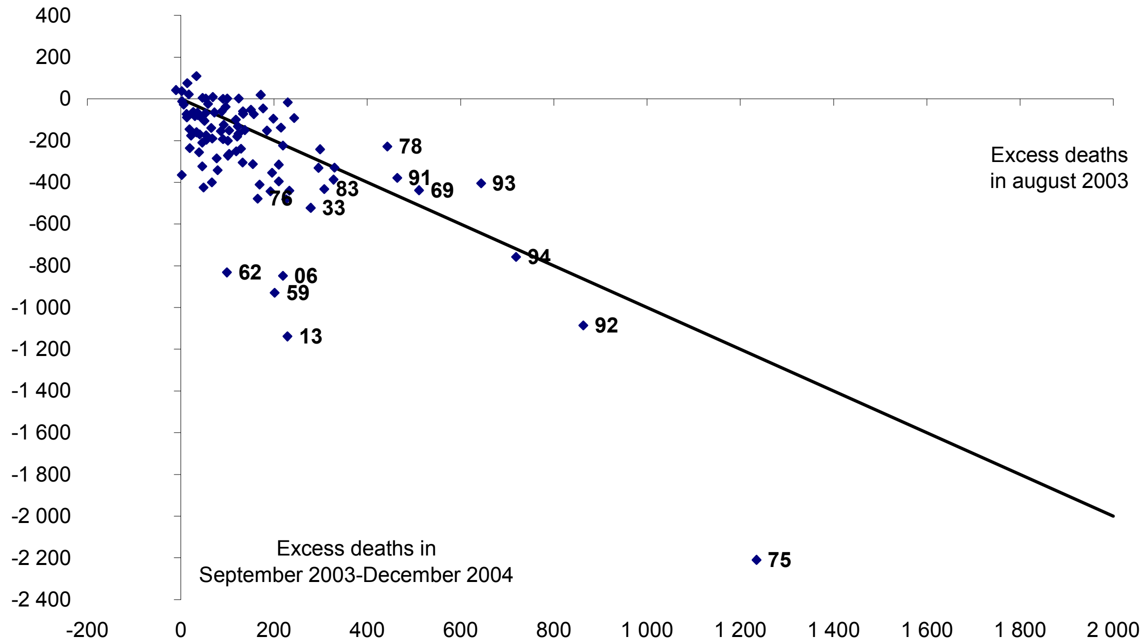
Figure 10. Joint graph of excess deaths in January to July 2004 (vertical axis) and excess deaths in August 2003 (horizontal axis), by *département*



Note: the line (y=-x) represents hypothetical perfect harvesting.

The negative correlation with August 2003 is weaker for the period September to December 2003, as well as for the period August 2004 to December 2004. Looking at the months from September 2003 to December 2004 as a whole, we obtain the following figure :

Figure 11. Joint graph of excess deaths in September 2003 to December 2004 (vertical axis) and excess deaths in August 2003 (horizontal axis), by *département*



The relation seems to be strong for the *départements* of Paris larger metropolitan area (78, 91, 92, 93, 94) and the city of Lyon (69). However, for the city of Paris (75), the decline in 2004 is much larger than the number of excess deaths in August 2003: 2,200 vs. 1,200. Again, the large deficit in the North (59, 62) and the south (13, 03) appears to be largely unrelated to the small number of excess deaths during the heat wave.

In the previous two graphs, no account has been taken of possible size effects. Considering that those départements most affected by the mortality impact of the heat wave are also the most populated, we re-estimated the correlation with a scaling factor, by dividing both indicators (the excess number of deaths in August 2003 and the deficit in September 2003 to December 2004) by the mean monthly number of deaths for each département during the years 2000-2002. This technique enables a direct comparison, for each département, of excess deaths during august 2003 and missing deaths during the subsequent period.

Indeed, let's consider one *département*.
D(m,t) is the number of deaths during month m of year t.
"*base*" is the mean number of deaths in 2000-2002,
so that *D(m,base)* is the mean number of deaths during the month(s) *m* of 2000-2002.
D(base,base) is the mean monthly number of deaths in 2000-2002 .
X is the difference between the number of deaths during August 2003 and the usual number of deaths in august: $X=D(8,2003)-D(8,base)$.
Y is the difference between the number of deaths from September 2003 to December 2004 and the usual number of deaths in that period, so that:

$$Y=D([8,2003] \text{ to } [12,2004])-D([1,base] \text{ to } [12,base])- D([8,base] \text{ to } [12,base])$$

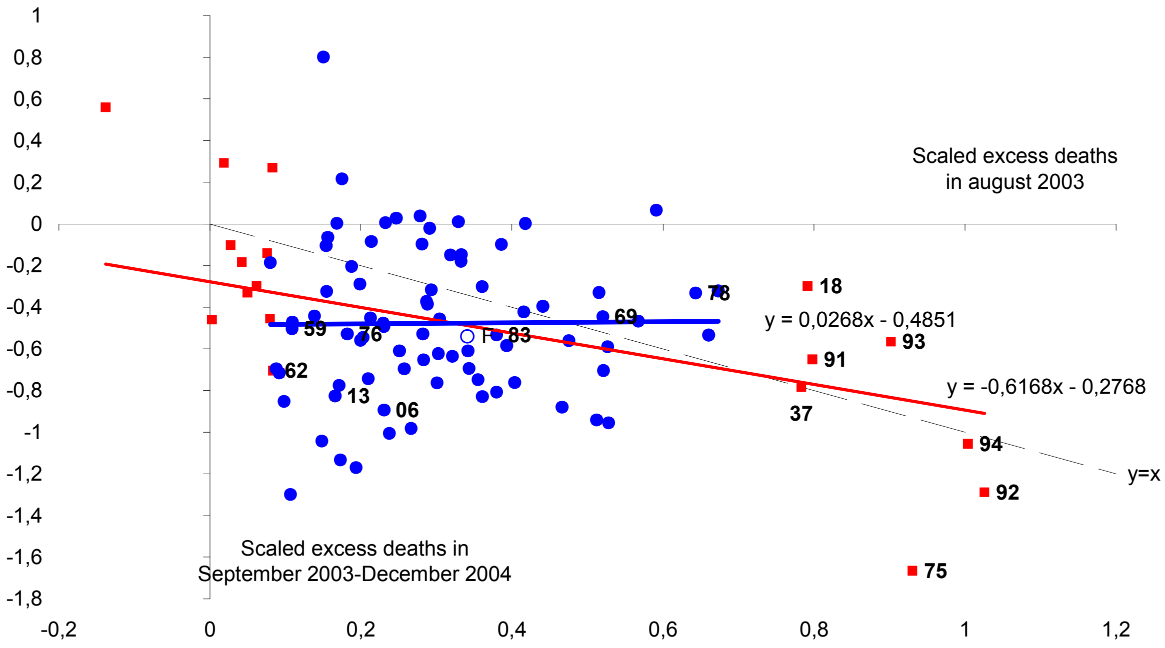
Y and *X* are scaled by the mean number of deaths:

$$x=X/D(base,base) \text{ and } y=Y/D(base,base).$$

x and *y* are then directly comparable, so that in case of a complete harvesting effect (and no other change)

$$y=-x.$$

Figure 12. Joint graph of scaled* excess deaths in September 2003-December 2004 (vertical axis) and excess deaths in august 2003 (horizontal axis), by *département*.



** The difference between observed and expected deaths is standardised by the mean number of monthly deaths in 2000-2002.*

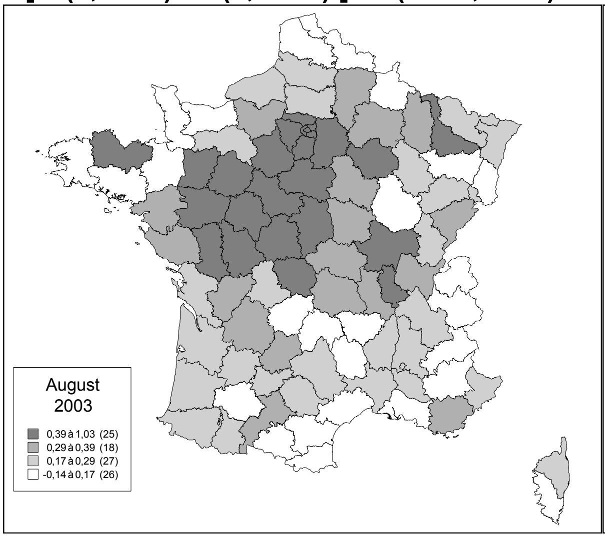
As showed on Figure 12, the relationship is slightly modified when département data are scaled. Two *départements* from the Center of France, i.e. *Indre-et-Loire* (37) and *Cher* (18), appear to have suffered from a large excess number of deaths during the heat wave. However, the overall picture remains unchanged: the départements with the largest absolute number of excess deaths are those located in the larger Paris metropolitan area (75, 91, 92, 93, 94).
The following maps confirm that the correlation is far for complete. The map on the left hand side shows the number of death during August 2003 standardized by the mean number of deaths in the three August months of 2000-2002. The right hand side map shows the difference between the number of deaths from January to July 2004, relative to the same months of August 2000-2002, plotted with an inverse scale to increase the comparability: the two maps would look similar if the under-mortality of early 2004 mirrored the excess number of deaths in August 2003[7].

[7] The comparability between the two graphs results from the fact that August 2003=[August(2000-2002)+ August 2003-August(2000-2002)]

Maps 3 and 4. Excess mortality during the heat wave of August 2003 and subsequent decrease in January to July 2004, by *département*

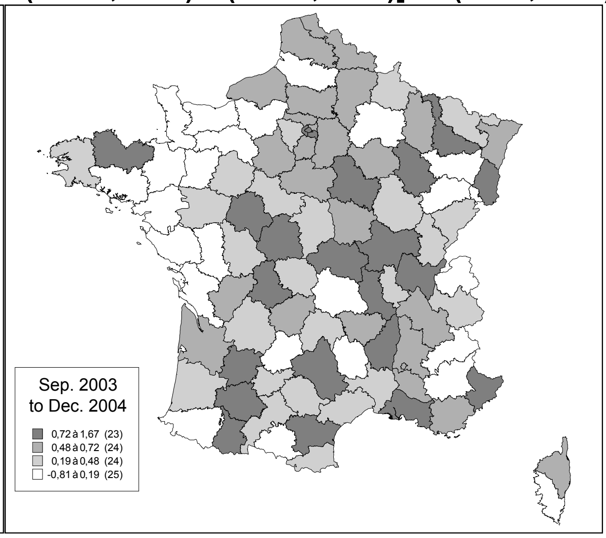
Map 3. Scaled excess mortality during August 2003

[D(8,2003) - D(8,base)] / D(base,base)



Map 4. Scaled missing deaths during September 2003 to December 2004 :

-[D(9,2003to12,2004) -D(9to12,base)-D(1to12,base)] / D(base,base)



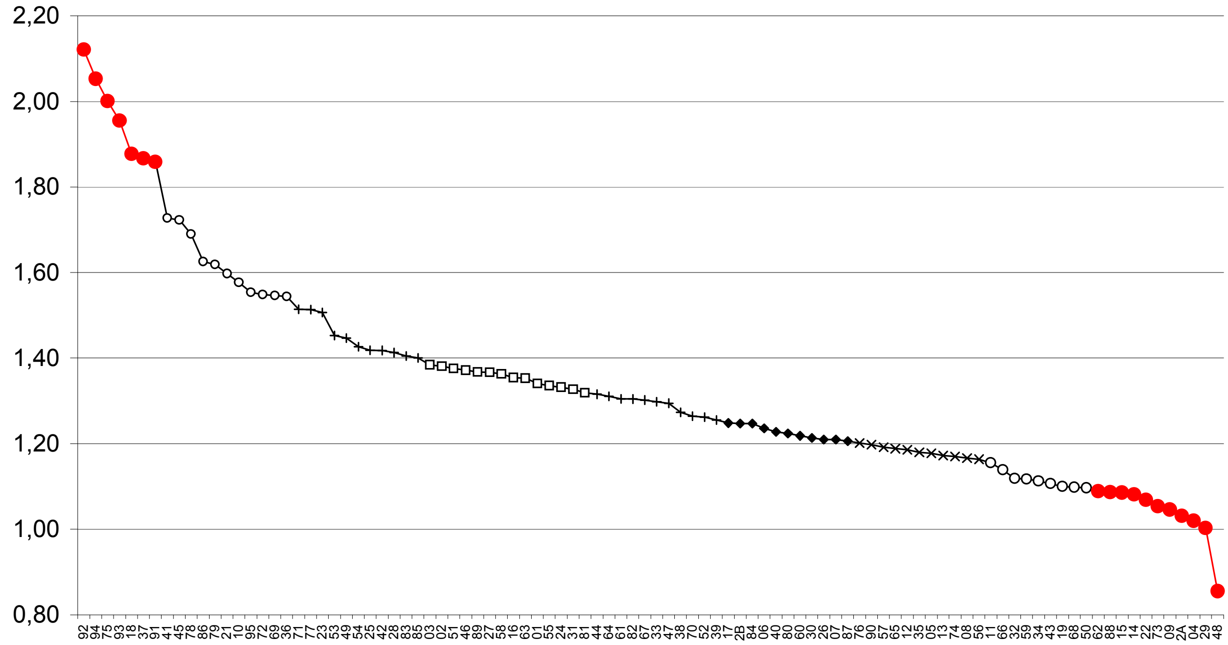
The regression line for all *départements* leads to the following equation

$$y=-0.28 + 0.62x$$

During the period September 2003-December 2004, France experienced 24,000 fewer deaths than "usual", estimated from the mean adjusted number of deaths in 2000-2002. Applying the results of the equation to the excess deaths of August 2003 for all départements, we could attribute 9,300 of the about 27,000 "missing" deaths in 2004 to a harvesting effect. However, the regression is unappropriate. Indeed, an order-three polynomial fits the data much better, with a large range of values for x for which y is not decreasing with x, the negative relation being restricted to the extreme values of x.

The excess relative mortality is largest for a group of seven départements, showed with red circles on Figure 13. These seven départements represent 60,000 annual deaths (2000-2002). For comparative purposes, we have first ranked all the other départements according to the relative mortality impact of the August 2003 heat wave (Figure 13) and regrouped them so that they average a similar number of total annual deaths, i.e. about 60,000, as the first group, for a total of nine groups.

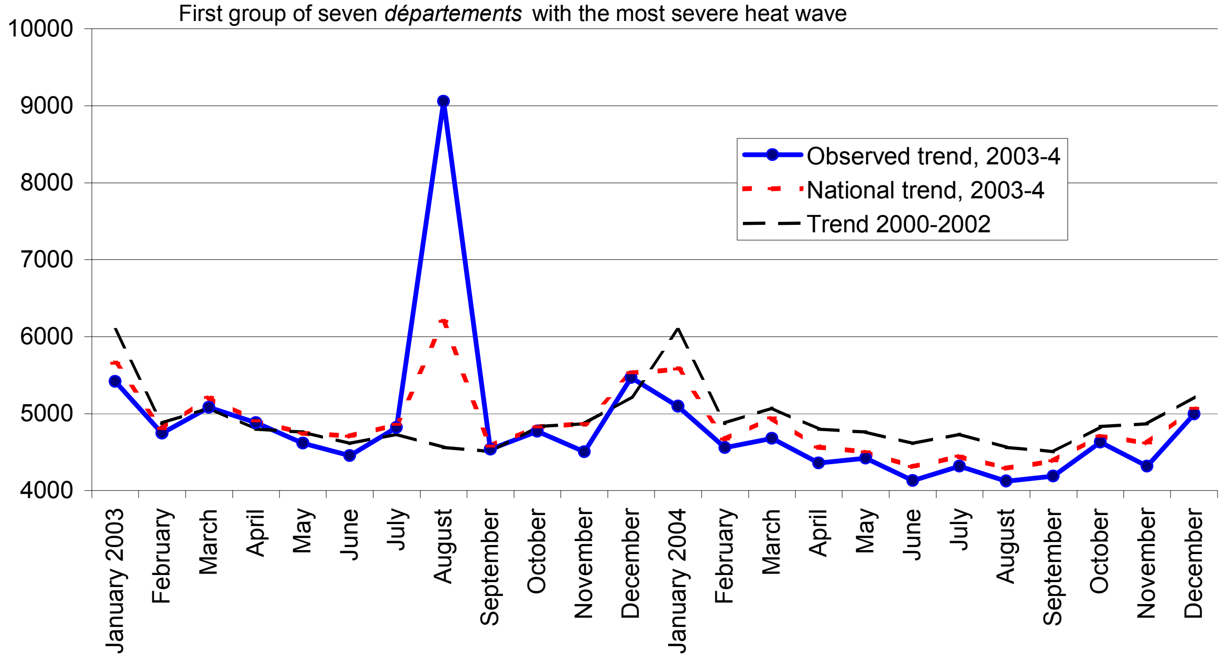
Figure 13. Excess mortality in August 2003, by *département*, relative to August 2000-2002 (O/E), sorted



The following graphs show the monthly trend in the number of deaths, for the first, second and eighth groups of départements. The blue curve presents the actual number of deaths per month from January 2003 up to Décember 2004. The black curve shows what the monthly number of death averaged over each month in 2000, 2001 and 2002 in the départements belonging to the group. Finally, the red curve represents the estimated monthly number of deaths at the national level for the period 2003-4, computed as the product of the observed deaths in 2000-2 in each département by the relative number of deaths at the national level in 2003 and 2004, compared to the mean 2000-2 for the country as a whole. The red curve can also be interpreted as the number of deaths in each group of départements if the trend between 2000-2002 and 2003-2004 had been the same in all the départements. The red curve is below the black curve when, at the national level, mortality is lower than expected from 2000-2002. The blue curve is below the red curve in the départements where the decline of mortality is larger than at the national level.

For the first group of departments (Figure 14.1), the number of deaths has pretty much double in August 2003 with an excess reaching 4,500 more deaths, compared to 2000-2002. In addition, in this group of départements, a strong harvesting effect is visible: the decline in 2004 is more pronounced that for the country as a whole: the blue curve is lower than the red one for nearly every month.

Figure 14.1. Monthly number of deaths, from January 2003 to December 2004.



This effect is no longer perceptible in any of the other groups. In particular, the second group of départements also experienced a large crisis in August 2003. Mortality increased by 60 percent, which represents a total of 3,400 excess deaths compared to 2000-2002, an effect nearly twice as large as the national average. However, even this group of départements does not exhibit a larger than average decline in the number of deaths in 2004. The same lack of correlation holds for the other groups: in the sixth, seventh or eighth groups of départements (Figures 14.1, 14.2 and 14.3), where the number of excess deaths were much less numerous than for France as a whole in August 2003, the decline in mortality observed in 2004 is as pronounced as elsewhere. It is only in the ninth group that the 2004 mortality decline is smaller than average (other groups not shown).

Figure 14.2. Monthly number of deaths, from January 2003 to December 2004.

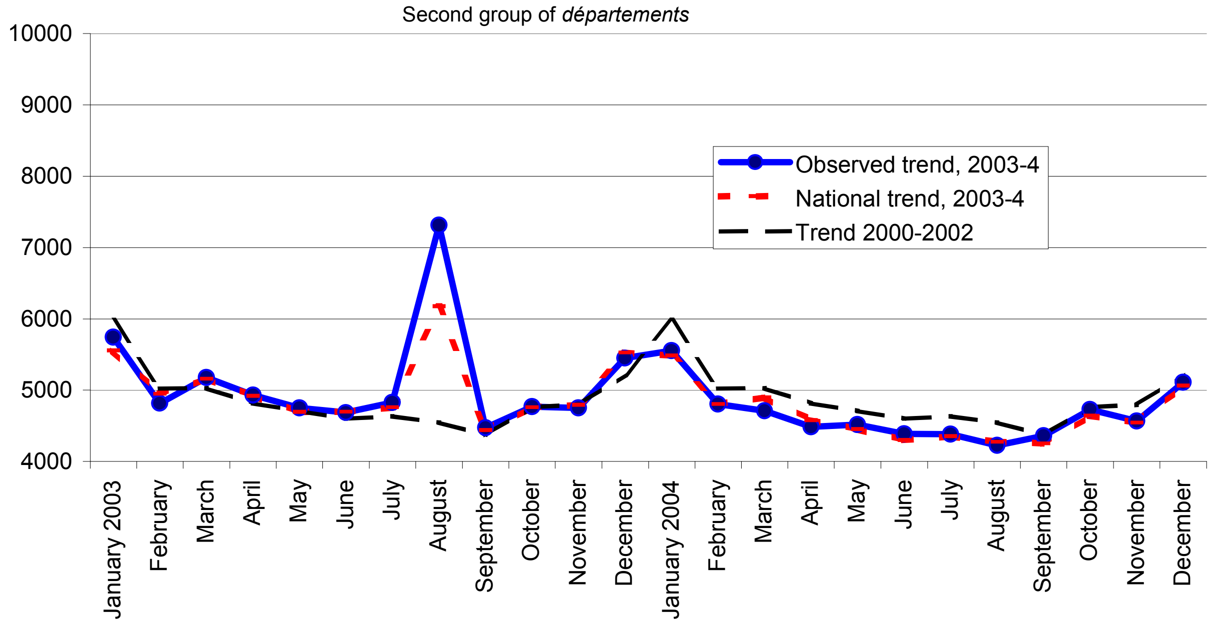
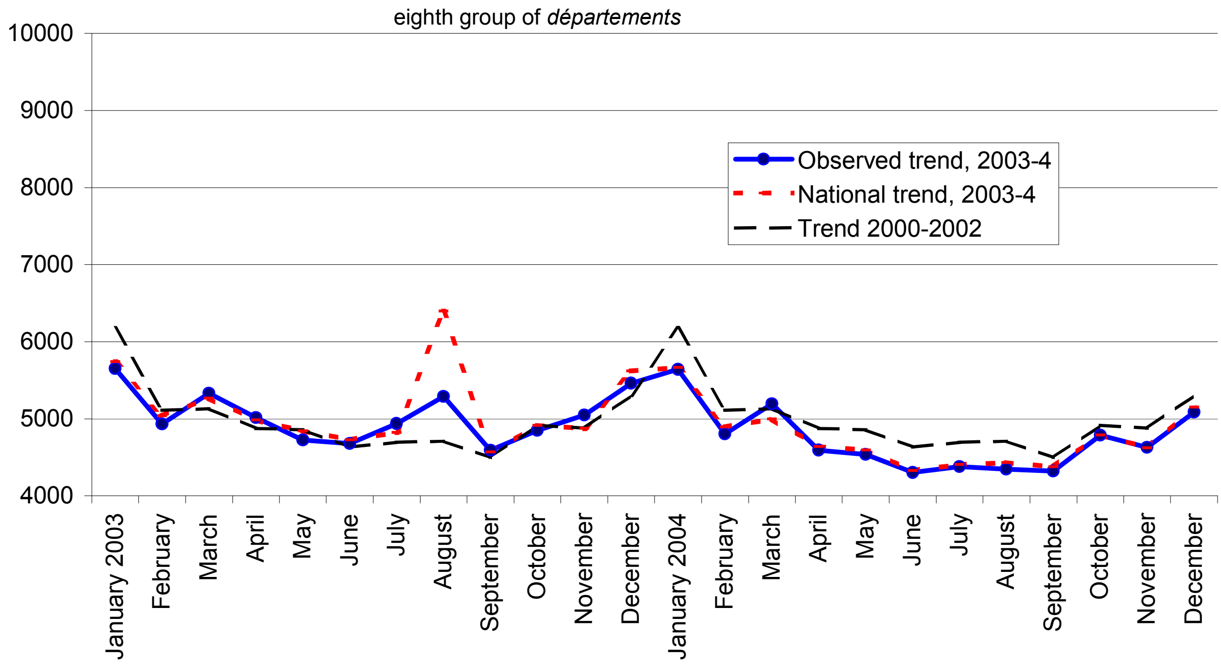


Figure 14.3. Monthly number of deaths, from January 2003 to December 2004.

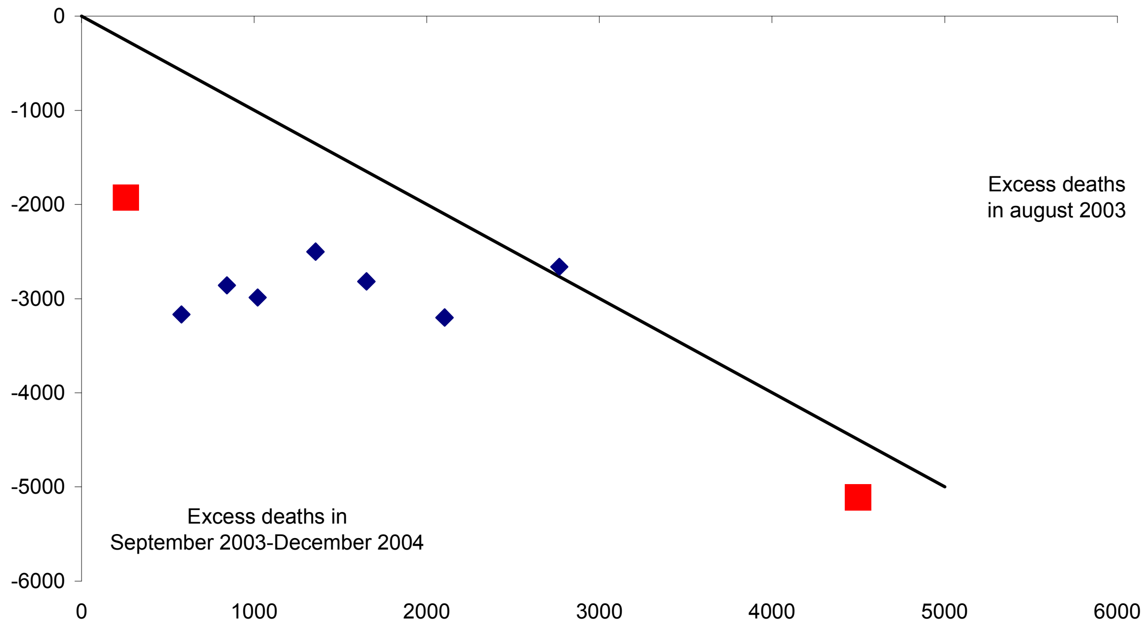


If we exclude the two extreme groups of *départements*, i.e. the first one, were there appears to be a strong correlation between the August 2003 mortality crisis and the remarkably low mortality of 2004, and the last one, in which there was no mortality increase in August 2003, the regression line no longer exhibits any negative relationship (Figure 15). The resulting equation is the following:

$$y=0.03x-0.49$$

The features of the *départements* exhibiting no excess mortality during the heat wave will be examined further when we obtain more accurate data so as to allow for an analysis of mortality by all three variables, i.e. age, sex and place of residence for 2004, but this goes beyond the aim of that paper. It is enough for us to remember that no harvesting effect is to be expected since there was no excess mortality in August 2003.

Figure 15. Relationship between the number of excess deaths in August 2003 (O-E) and the number of missing deaths in September 2003-December 2004, by group of *département* sorted by intensity of heat wave mortality



In conclusion, we are willing to assume a full harvesting effect in the seven *départements* were the August 2003 mortality crisis was the most severe, considering the strong correlation found between the 2003 mortality excess and the 2004 mortality deficit for this first group. By contrast, because the correlation between the excess mortality of August 2003 and the deficit of 2004 is nil, we decided to dismiss the possibility of any harvesting effect in explaining the low mortality of 2004 in all other départements. Consequently, we consider that only about 4,000 to 5,000 of the deaths "missing" in 2004 are due to the heat wave harvesting effect.

Conclusion

The 15,000 victims of the August 2003 heat wave are disproportionately found among the elderly and, more specifically, among elderly women. Nevertheless, the expected number of years lost for those people is not negligible. Assuming no harvesting effect, only about 2,000 of them would have died by the end of 2004. An hypothesis of full harvesting would imply that all 15,000 victims would have died by the end of 2004 in the absence of a heat wave. Among them, some would have been expected to die by the end of 2003. Since the number of deaths recorded in the period September 2003 to November 2003 does not exhibit any deviation from the pattern expected from the previous years, one has to assume either no harvesting effect or a full compensation of the harvesting effect and a phenomenon of heat wave related delayed mortality.

The spatial analysis of mortality comparing the excess number of deaths in August 2003 and the deficit in the subsequent period at the level of the départements shows that complete harvesting is not likely: if we exclude the seven départements where the heat wave was the most deadly and were a full harvesting effect might have occurred (4,500 deaths), no correlation is found between the high mortality of August 2003 and the low mortality of 2004 at the level of the départements. Consequently, only about 5,000 deaths missing in 2004 could be attributed to the heat wave harvesting effect, accounting for about one fifth of the decline observed between the period prior to 2003 and the year 2004. This estimate is very rough, but the order of magnitude must be accurate: the number of missing deaths of 2004 due to harvesting is less than half of the 15,000 excess deaths of august 2003, probably around one third.

Regarding the remaining 20,000 or so deaths "missing" in 2004, several hypotheses can be formulated, most unrelated to the 2003 heat wave. The most likely is the unusual absence of a flu epidemics which typically kills about 7,000 to 10,000 individuals over a single Winter. This absence of flu has been described by some as the direct consequence of the heat wave (Valleron 2004). Indeed, the age structure of the victims of flu epidemics resembles that of the heat wave related deaths. A harvesting effect is thus not to be completely excluded. However, we should then have found a significant negative spatial correlation at the level of the departments between the mortality of August 2003 and that of December 2003 when the flu typically starts.

The increasing cost of Alcohol and tobacco, as well as a severe policy measures against driving under the influence of alcohol, may have avoided an additionnal 2,000 to 5,000 deaths and would explain in particular the lower than expected level of mortality among young adult male.

All in all, 4,000 to 8,000 "missing" deaths thus remain to be explained. One hypothesis would be that a special effort has been made towards isolated elderly people as an indirect consequence of the heat wave. Indeed, in many urban areas, a special census of isolated elderly was conducted as part of a plan to prevent any future such crisis in case of extreme climatic episodes but also as part of the general effort to improve the conditions of life of the elderly. Since women in France are more often isolated at old ages than men (Désesquelles and Brouard, 2003), this effort could have led to a larger decline for older women in most *départements*, independently from the direct mortality impact of the 2003 heat wave, in perfect agreement with the observed trend.

A more precise analysis will be possible when we have detailed individual records for 2004, allowing to check whether the spatial correlation holds for all sex and age groups, but our main conclusion will remain unchanged.

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