# Rates of Mortality Improvement on the Lexis Surface — Visualizing Age-, Period-, and Cohort-Effects —

## Extended Abstract

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**Abstract**

We present surfaces of rates of mortality improvement. Based on two-dimensional plots of smoothed death rates, our "maps" depict the rate of mortality change over time. We argue that this approach provides an excellent exploratory tool to visually analyze mortality dynamics, in particular to detect age-, period-, and cohort-effects. International comparisons demonstrate that similar trajectories of life expectancy are not necessarily based on the same underlying mortality dynamics. For instance, minor life expectancy increases in the past were caused by cohort factors (e.g. Denmark) as well as by period factors (e.g. East Germany). An analysis by major causes of death for the United States shows that antagonistic cohort effects were instrumental for the slow life expectancy increase during the 1980s and the 1990s: If negative cohort effects of respiratory diseases and cancer had been absent, life expectancy would have increased much faster due to improvements in survival for heart diseases.

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# Introduction

Life expectancy has been increasing for more than 160 years in many high-income countries (e.g., Oeppen and Vaupel, 2002; Tuljapurkar et al., 2000; Vallin and Meslé, 2009; White, 2002). Best-practice life expectancy, i.e. the highest life expectancy recorded in a given year, increased by about 2.43 years per decade in an almost perfect linear manner (Oeppen and Vaupel, 2002). Albeit on a lower level, countries like France or Italy experienced a comparable trajectory as the respective record setting countries as illustrated for the last 50 years in Figure 1 on page 9. Other countries like the United States, Denmark or the former Eastern part of Germany experienced periods of stagnation, followed by a period of catching up.

The question whether period or cohort effects are the main driving force for these mortality dynamics is an ongoing discussion (e.g. Barbi and Vaupel, 2005; Barker, 1995; Doblhammer, 2004; Finch and Crimmins, 2004; Kannisto, 1994; Vaupel et al., 2003).

Various methods have been proposed to analyze these age-, period- and cohort-effects (see for an overview, comparisons, and recent developments, for instance, Wilmoth, 1990, 2006; Yang et al., 2004, 2008).

By plotting surfaces of rates of mortality improvement, we pursue a different approach in this paper. These plots build on Lexis surface maps pioneered originally in the mid-1980s (Caselli et al., 1985; Gambill and Vaupel, 1985; Vaupel et al., 1985).[1] Instead of plotting actual death rates, our maps depict annual rates of mortality change.

Our method can be considered as a descriptive, explorative tool. It is able to detect the predominant dynamics of mortality (or of any other phenomenon measured on the Lexis surface) and allows to generate hypotheses about the actual underlying factors. We think that our suggestion provides better insights into mortality dynamics than standard surface maps but is equally intuitively understandable. Of course, we also have to acknowledge the biggest drawback of our method: In contrast to other methods of APC analysis, our visual approach does not attribute any numerical values to the effects. Hence, one can neither compare various effects with each other nor is it possible to conduct significance tests.

[1] Caselli et al. (1985) point out that the first demographic surface map has been created by Delaporte in 1941.

# Data and Method

## Data

Country-specific deaths counts were downloaded from the Human Mortality Database (HMD) (2012).

Cause-specific death counts for the United States were extracted from the "Multiple Cause of Death Data" of the National Center for Health Statistics (2011), which are available online on the webpage of the National Bureau of Economic Research.

Exposure time for the different countries as well as for the analysis of cause-specific mortality were also obtained from the HMD (2012). The basic units of all analyses are these death counts and exposure times with a resolution of single years in the age dimension and single calendar years in the time dimension.

## Obtaining Surfaces of Rates of Mortality Improvement

Creating mortality surfaces of the raw data was the **first step** for creating surfaces of rates of mortality improvement in the end. The left panel in Figure 2 shows such a Lexis surface map of observed death rates of Danish women for the last sixty years. Clearly one can recognize random fluctuations in the data. To avoid spurious conclusions from such a surface, we smoothed in a **second step** the mortality surfaces following the $P$-spline approach of Eilers and Marx (1996) using the R package of Camarda (2009). An example for such a smoothed mortality surface is displayed in the middle panel of Figure 2.

In this paper we estimated rates of mortality improvement, $\rho$, by assuming a constant rate of change within a year. Hence, for annual data:[2]

$$\rho(x, t+1) = -\log_e \left( \frac{m(x, t+1)}{m(x, t)} \right).$$

The minus sign ensures to have positive numbers for survival improvements. We expressed the respective values for $\rho$ in percent. The right panel of Figure 2 illustrates this **third step** of this approach. No change or only little change for better or worse ($-0.5\% \leq \rho \leq 0.5\%$) is depicted in white. Slight improvements ($0.5\% < \rho \leq 2.0\%$) are shown in blue colors, better improvements in green colors ($2.0\% < \rho \leq 4.0\%$) and very strong improvements in red colors

[2]Thus, we used a continuous time version of calculating $\rho$ whereas Kannisto et al. (1994) and Rau et al. (2008) employed a discrete time approach.

($\rho > 4.0\%$). Please note that mortality is halved in less than 35 years with a value of $\rho$ of "only" two percent. For the case of a decline in survival chances, we used gray shades.

# Results

Some inferences about life expectancy and mortality dynamics among Danish women can already be made from the middle panel of Figure 2. A given color denotes a specific level of mortality. A color gradient for the same age over time indicates a change in mortality whereas the same color indicates no progress in survival.

We argue that the underlying mortality dynamics are easier to detect in the right panel depicting rates of annual mortality improvements. The main reason for the stagnation in Danish life expectancy is a strong cohort effect as indicated by the gray area on the 45 degree line. This gray area corresponds to women born between the two world wars who were the first generation to have a relatively high proportion of smokers (Jacobsen et al., 2002). Danish life expectancy began to increase again in the late 1990s (see Figure 1). This coincides with the disappearance of the gray cohort effect.

The period of minor increases in life expectancy in the Eastern part of Germany during the 1970s and 1980s (see the line in magenta in Figure 1) was not caused by a cohort effect — as in the Danish case — but by a period effect. Figure 3 (page 11) shows that no or only minor improvements were characteristic for all ages during that period. Within less than 15 years after reunification in 1990, life expectancy among East German women converged with West German levels (see the lines in magenta and red in Figure 1). The vertical patterns clearly support the view that period effects were instrumental for the rapid increase in life expectancy. The most likely explanations for this pattern are improved medical technology, a better health care system and changes in economic conditions (Diehl, 2008).

Russia's mortality dynamics are also governed by period factors. Figure 4 (page 12) illustrates clearly that the fluctuations in Russian life expectancy (yellow line in Figure 1) are the outcome of increases and declines in mortality, which affect all ages in a given period.

The general pattern of the United States is comparable to the one of Denmark (see the two blue lines in Figure 1), especially with the period of only minor improvements in life expectancy during the last two decades of the twentieth century, followed by years of increases in life expectancy comparable to the record-setting country Japan. The underlying dynamics of mortality change are more complicated for women in the United States than in Denmark, though, as

shown in Figure 5 (page 13). In the 1970s, survival improved due to period factors whereas the period of small life expectancy increases from the mid-1980s until the early 2000s were governed by cohort effects. The crucial role of cohort effects for mortality dynamics in the US during the last decades of the twentieth century has previously already been pointed out by Yang (2008).

In Figures 6–9 we investigate the pattern of female mortality in the US further by analyzing four major causes of death: heart diseases, cerebrovascular diseases, malignant neoplasms (cancer) and respiratory diseases. Strong positive period effects can be found in the 1960s for heart diseases and cancer, and in the late 1970s for cerebrovascular diseases. The (period) improvements in cancer during the 1960s were counteracted by a strong negative period effect during the early 1970s. The analysis by cause of death in Figures 6–9 supports the view that the slow increase of female life expectancy in the United States in the 1980s and 1990s is the outcome of antagonistic effects in the cohort direction. The blue and green colors for heart diseases — the largest cause of death category — and to a lesser degree for cerebrovascular diseases would have suggested an increase in life expectancy. The gray areas for respiratory diseases and cancer for the same cohorts prevented larger life expectancy improvements, though. The comparable pictures at ages 50 and higher during the 1980s and 1990s for cancer and respiratory diseases suggests a strong effect of smoking.

## Future Steps

Our goal is to analyze more countries and to include not only women (as we have done so far) but also men in our paper. For the United States, we will investigate the patterns of more causes of death. Since cohort smoking histories are associated with the slow increase of life expectancy of women during the 1980s (e.g. Pampel, 2002; Preston and Wang, 2006; Wang and Preston, 2009), the development of lung cancer mortality is particularly important. It has also been argued that Alzheimer's disease could have played an important rule for life expectancy in the United States since the 1980s (Meslé and Vallin, 2006). Similar to the aforementioned negative effects of smoking in Denmark and the United States, we need to investigate what the actual underlying factors for the observed period and cohort effects in other countries are.

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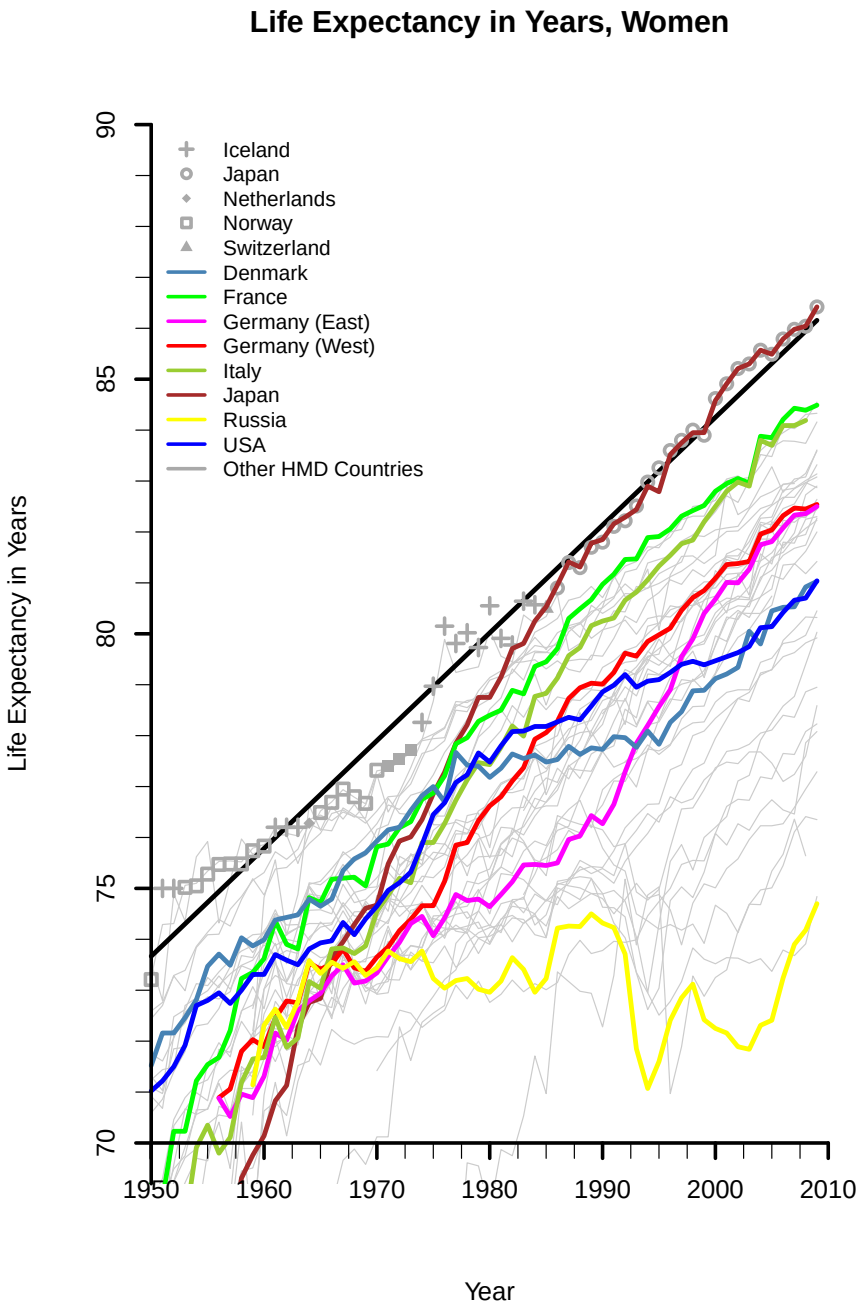


Figure 1: Life Expectancy at Birth for Women in Selected Countries. Authors' Illustration Based on Data from the HMD (2012)

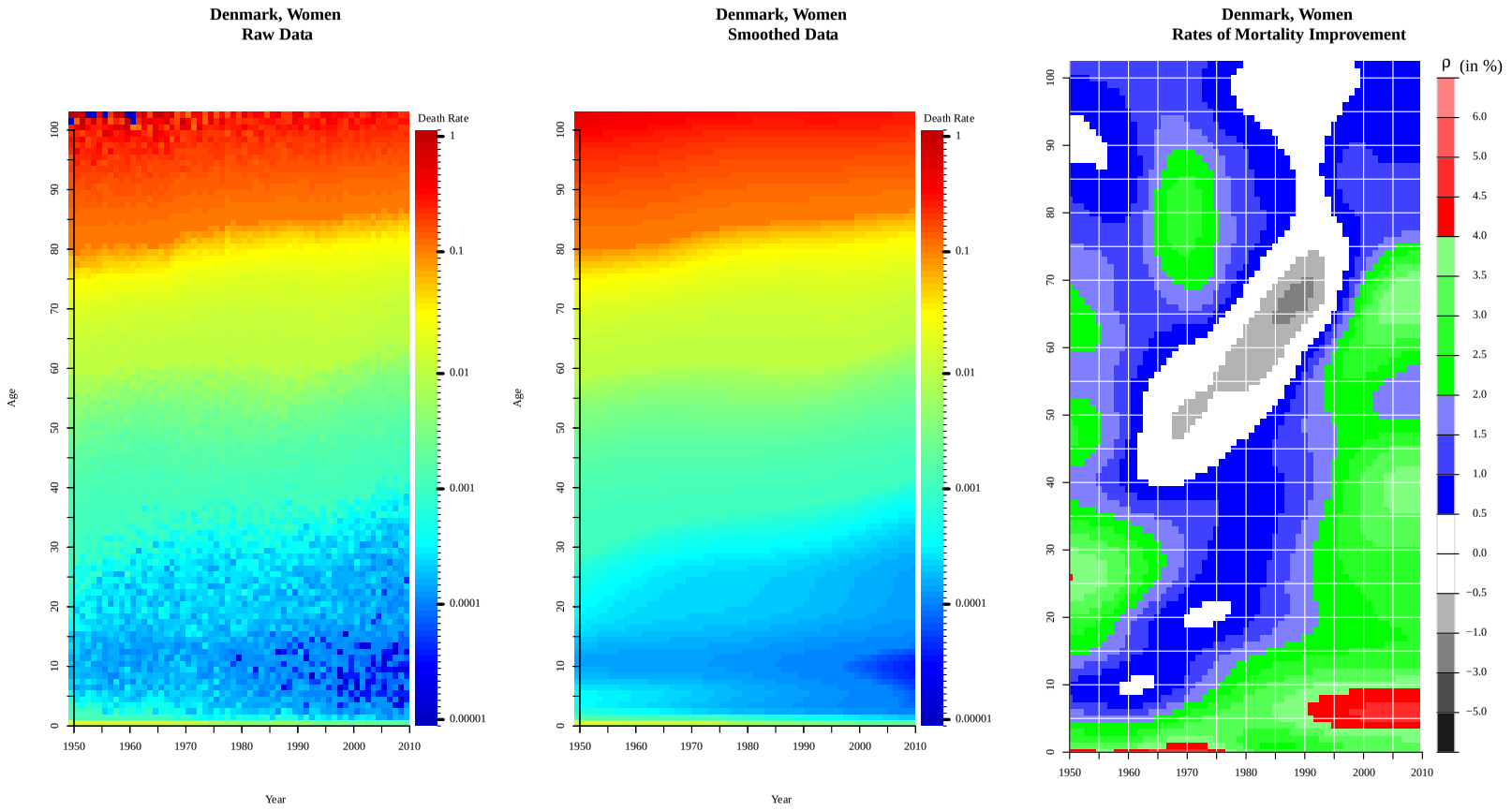


Figure 2: Step-by-Step Procedure to Obtain Surfaces of Rates of Mortality Improvement Using Data for Danish Women from the HMD as an example

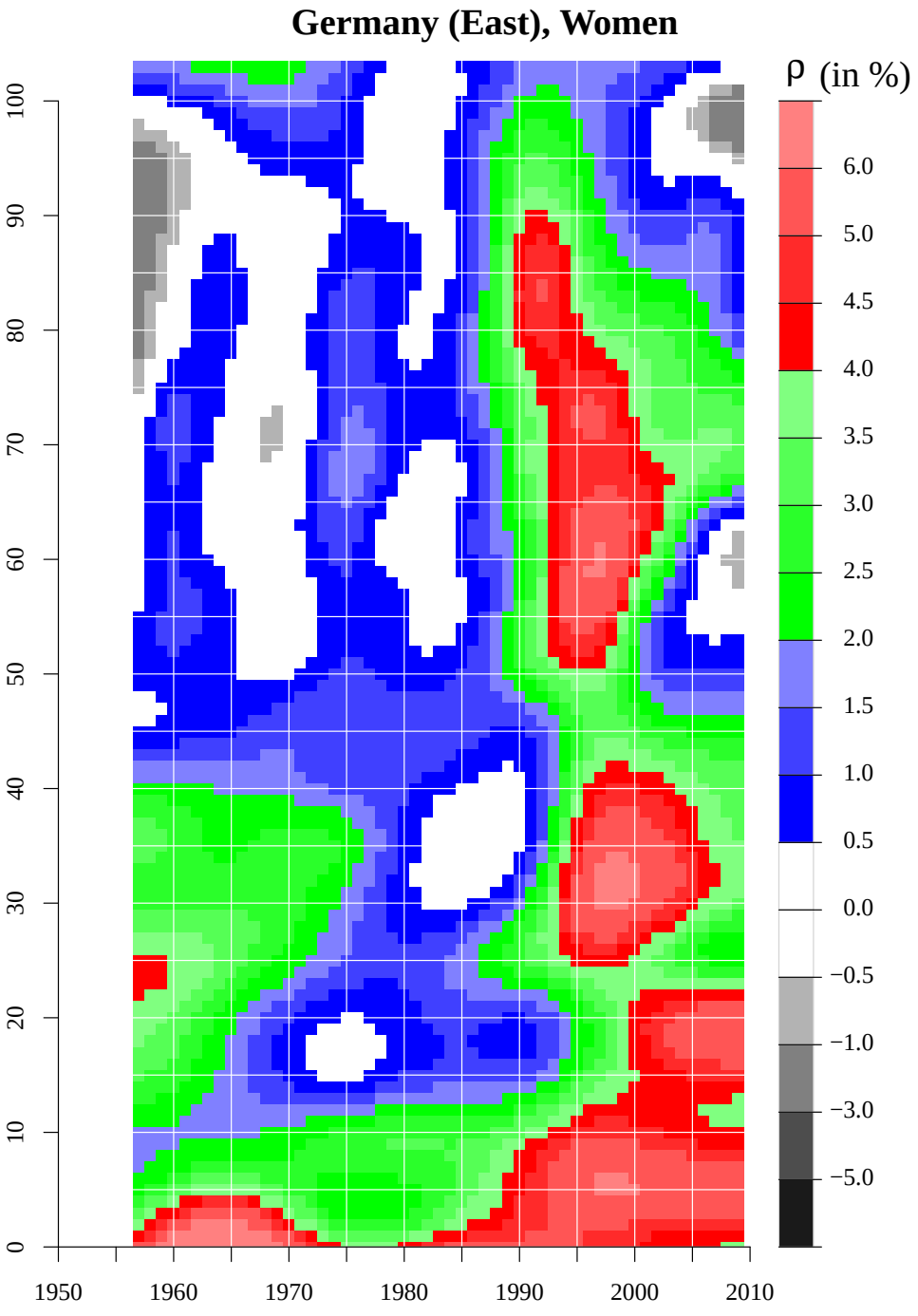


Figure 3: Rates of Mortality Improvement for Women in East Germany

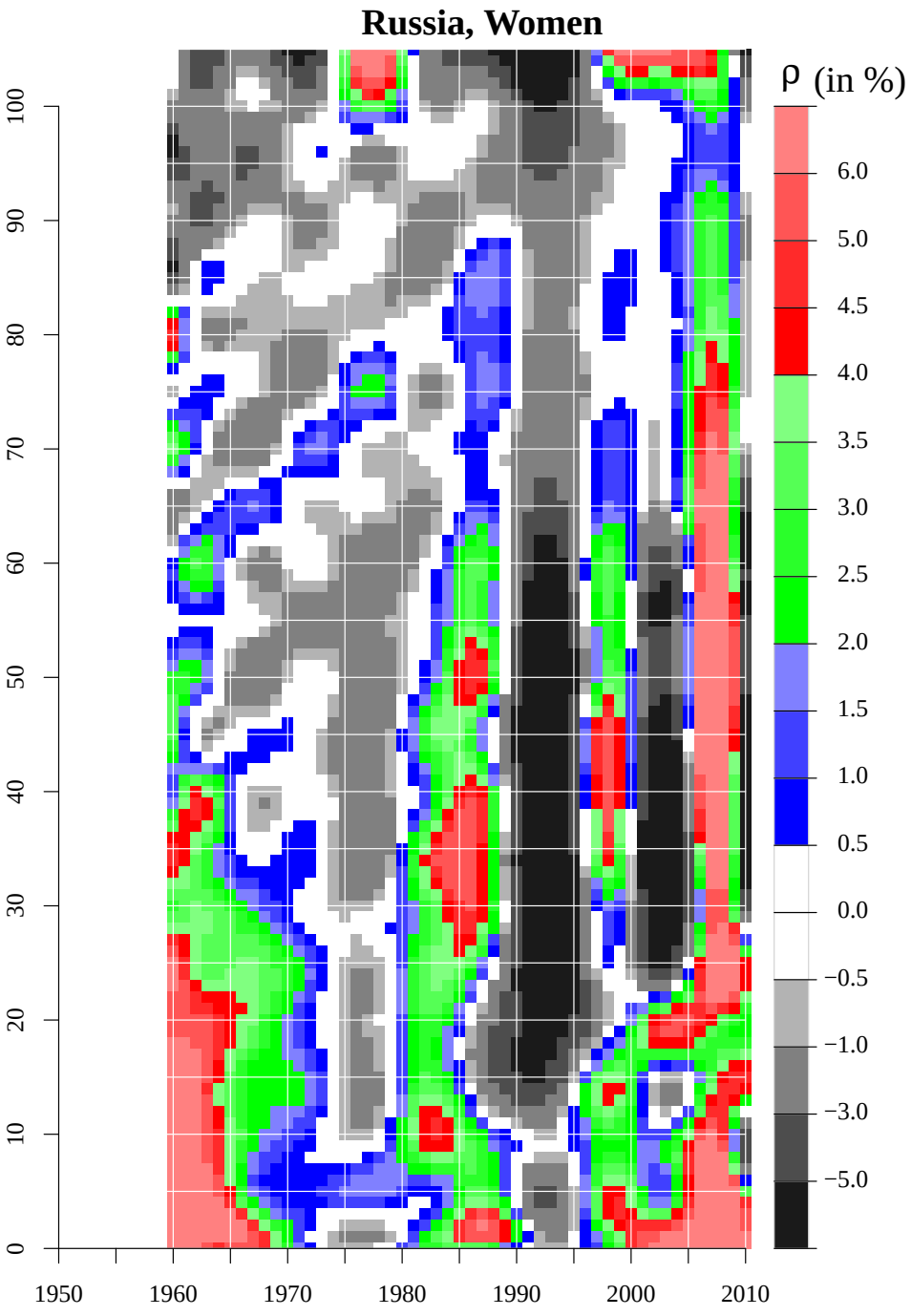


Figure 4: Rates of Mortality Improvement for Women in Russia

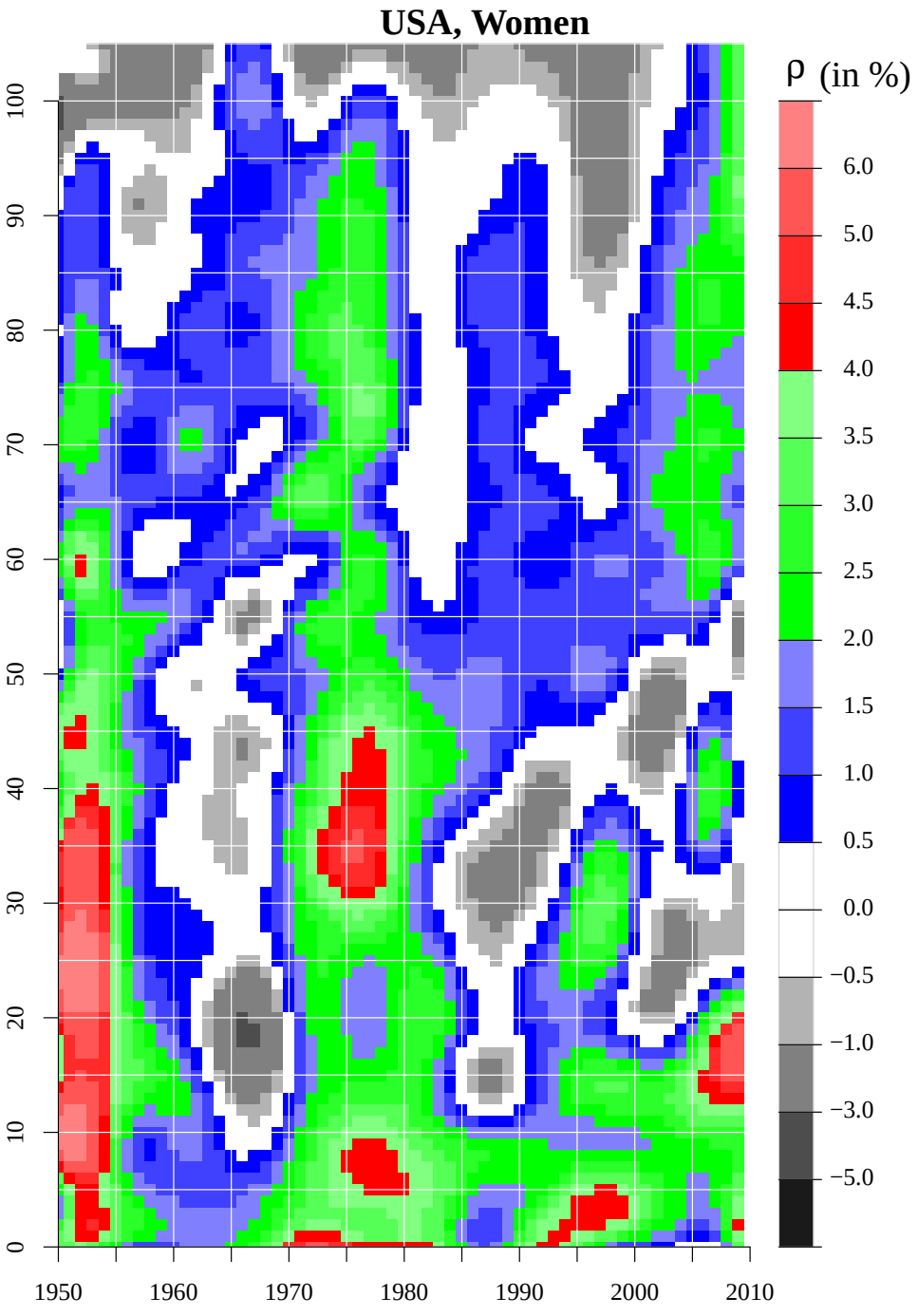


Figure 5: Rates of Mortality Improvement for Women in the United States

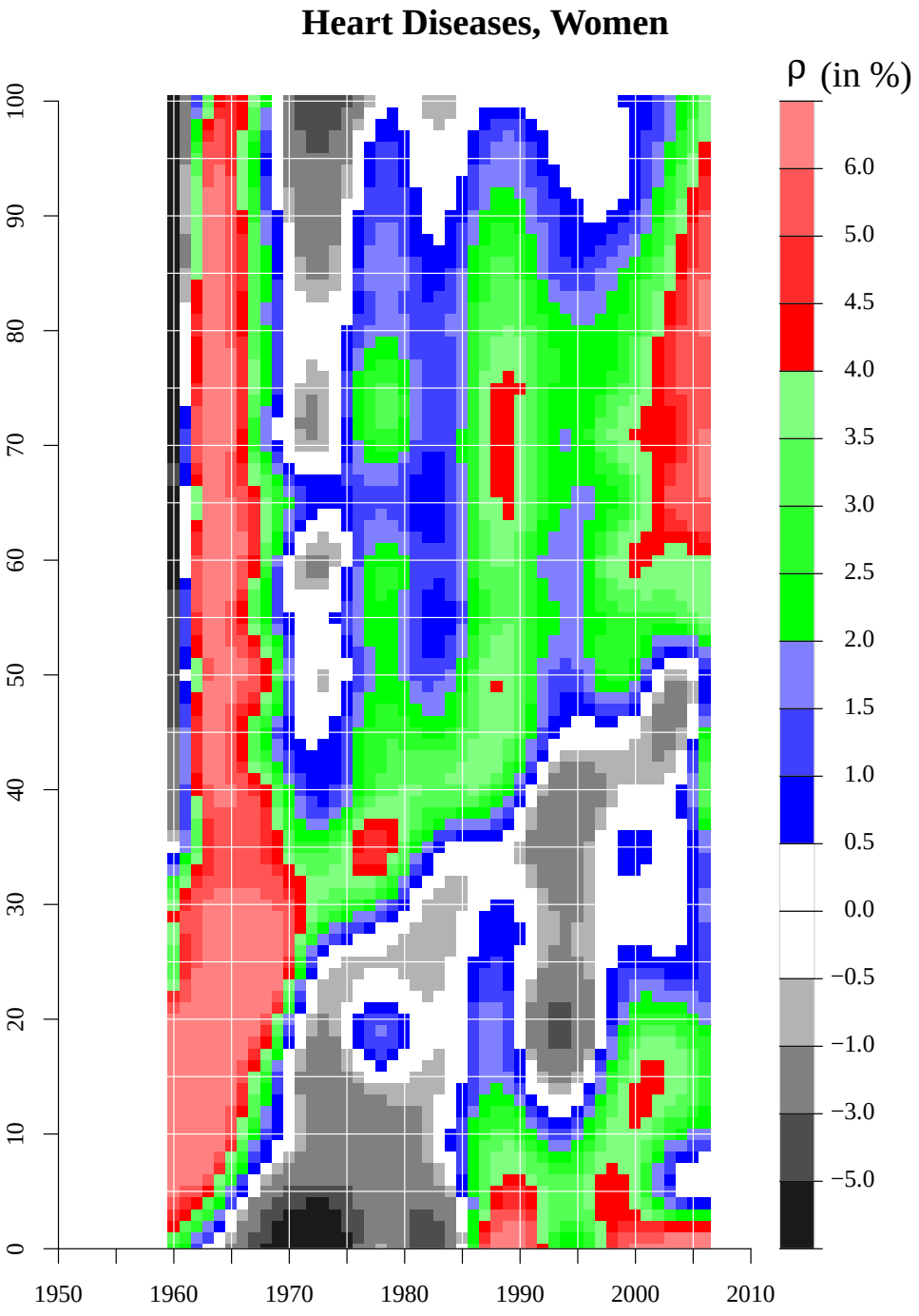


Figure 6: Rates of Mortality Improvement for Heart Diseases for Women in the United States

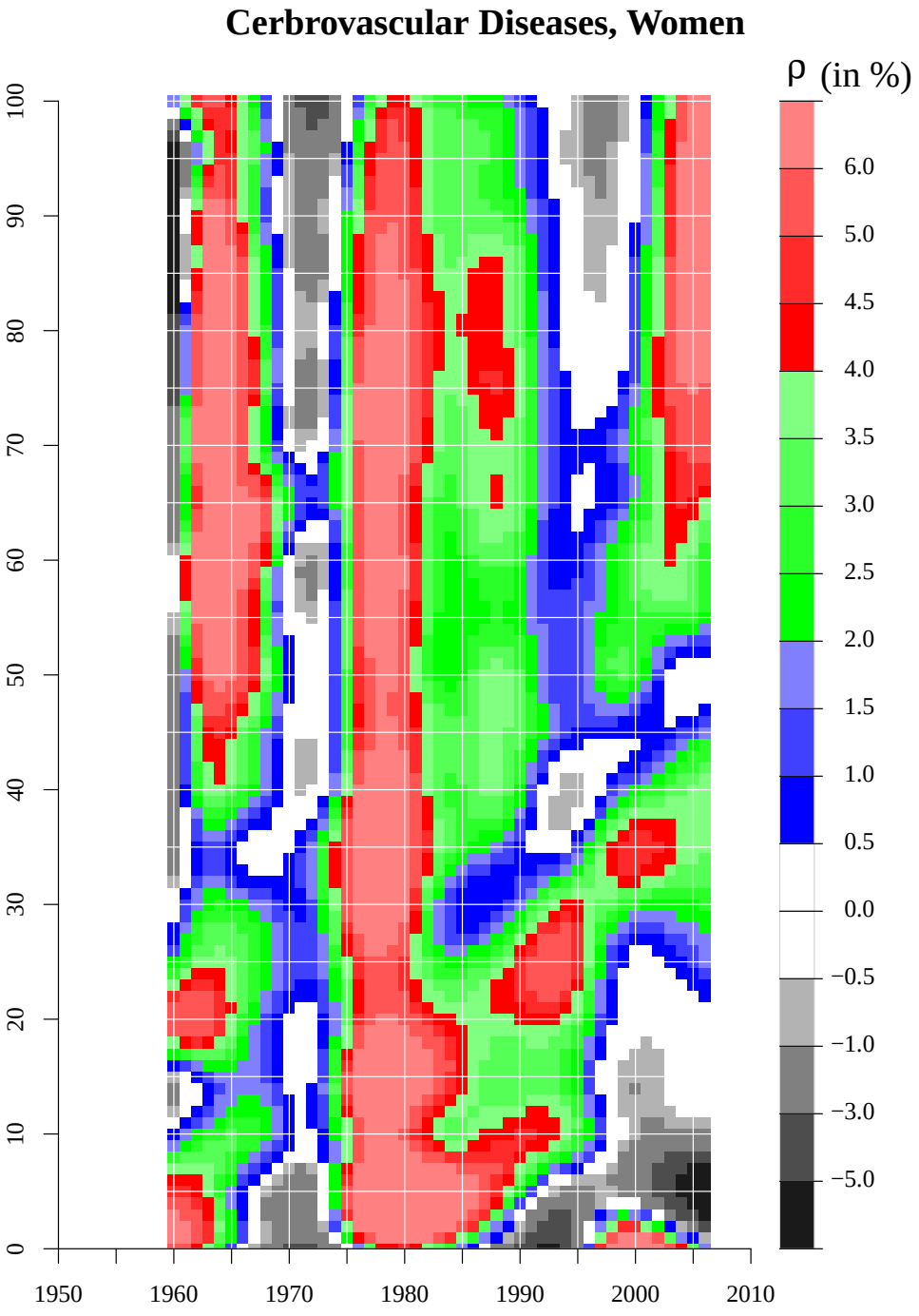


Figure 7: Rates of Mortality Improvement for Cerebrovascular Diseases for Women in the United States

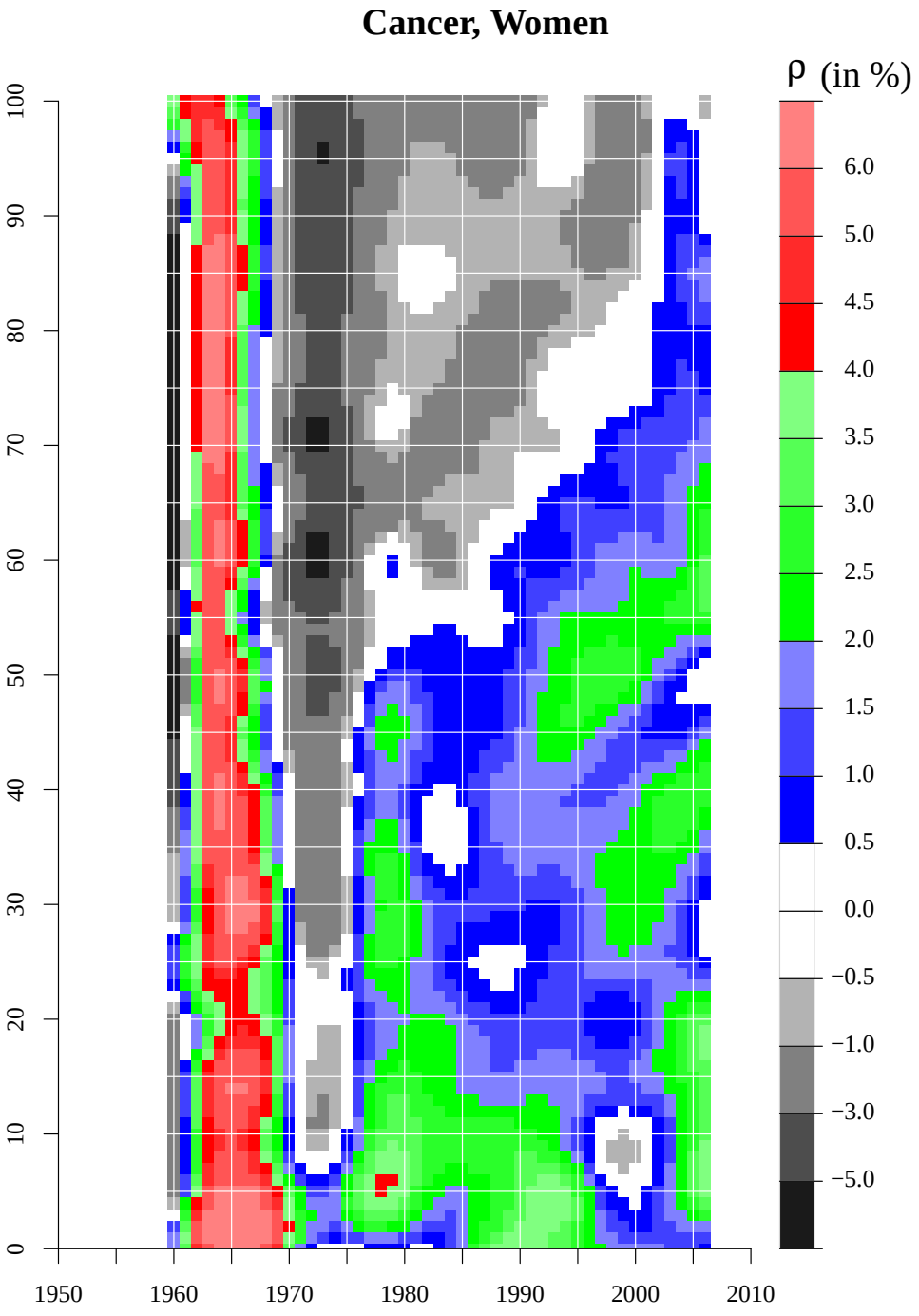


Figure 8: Rates of Mortality Improvement for Malignant Neoplasms for Women in the United States

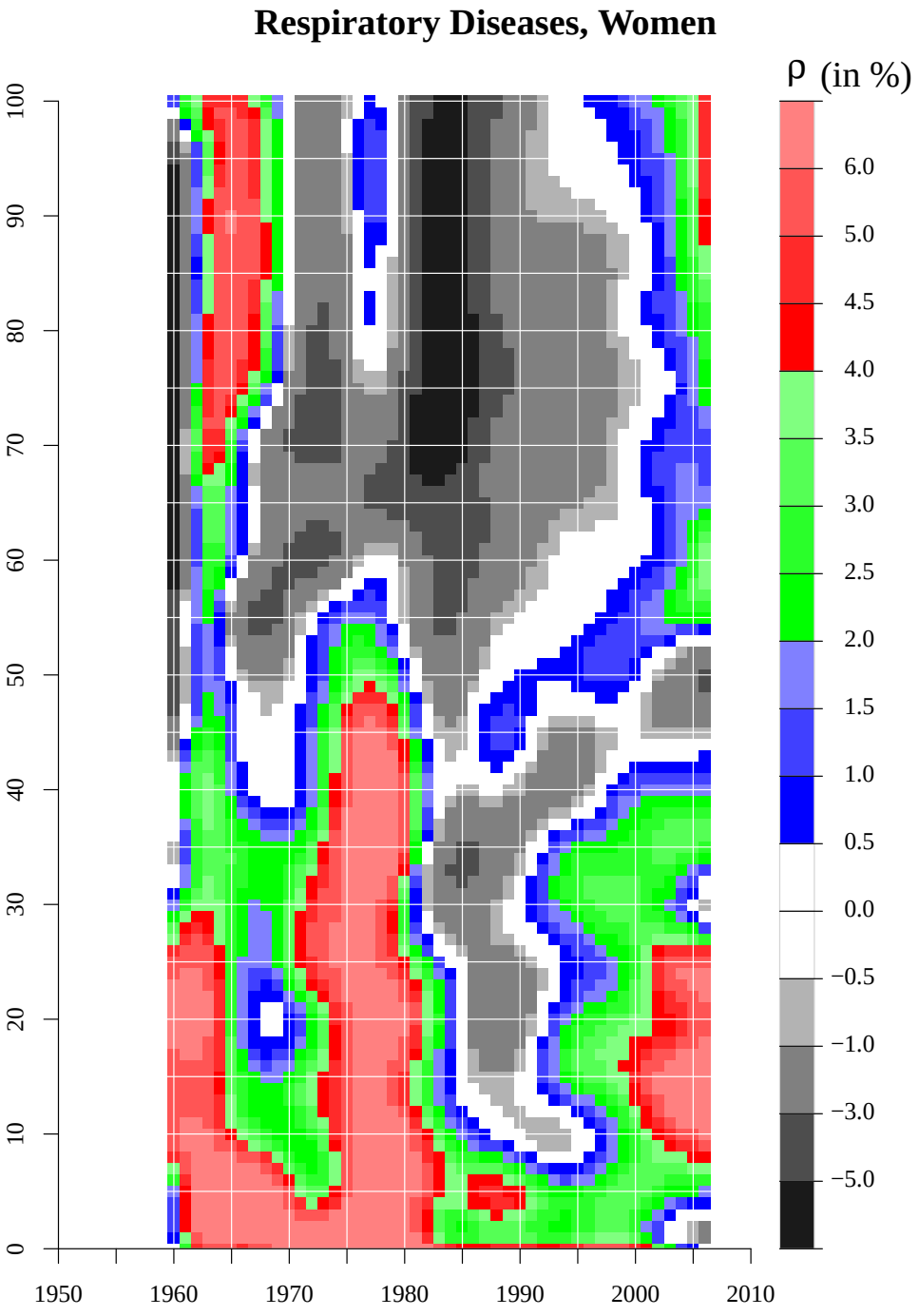


Figure 9: Rates of Mortality Improvement for Respiratory Diseases for Women in the United States