The Global Warming Crisis

Geography 630
WI'06

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"This is an excerpt from group project term paper with two other students, which includes only the sections I wrote." –K. Ski

1. Introduction

Human activities have greatly increased the greenhouse gas (GHG) concentration in the atmosphere. These GHGs have been positively correlated with global warming. There are expected to be serious consequences from global warming for the entire biosphere. It could ultimately lead to mass extinctions, great loss of biotic diversity, warmer oceans, glacial melting, costal flooding and an increase in tropical storm severity.

Human industrial activity, fueled by consumerism and fossil fuels, is the root cause of the rapid growth in GHG emissions. Development practices and economic policies promoted extensive use of personal automobile transportation over long distances, which further exacerbated the problem. Global politics involving organizations like the World Trade Organization (WTO) have also played a role in hindering effective outcomes with regards to GHG emissions and the global environment.

Humanity must take action to decrease GHG emissions, especially $CO_{2,}$ through effective global policies that focuses on reducing the dependency on fossil fuels producing GHGs. This must be augmented by grassroots and government funded efforts to develop and implement alternative ways to meet human needs for food, transportation, energy and building materials. Effort must also be directed at educating citizens about conserving energy, by improving efficiency and changing lifestyle practices, if things are to improve in a meaningful way.

2. The Development of the Science of Global Warming

The Earth is growing warmer. What discoveries lead to this revelation? Over a hundred years ago, two Swedish chemists made great progress at understanding how carbon dioxide (CO_2) cycles through natural geochemical processes and that CO_2 increasing in the atmosphere from the increase in the burning of fossil fuels will cause it to hold in more heat from the sun. Avid Högbom worked out the process of CO_2 cycling through the earth system. He described the way CO_2 is taken up by plants and the ocean. These are now termed a carbon sinks. He estimated the amount of CO_2 being released into the atmosphere from industrial processes and natural processes like volcanoes. His estimates lead him to believe that industrial processes would have very little effect on the atmosphere due to the small quantity being released, in comparison to the amount being release through natural processes.[1]

At the end of 1894, the idea that variations in CO_2 could be linked to changes in climate came to Svante Arrhenius after he heard Högbom lecture at the Swedish Society of Chemists. He disagreed with the conclusion of the lecture by Högbom. He set out to investigate what changes in the level of CO_2 in the atmosphere might do to the temperature of the earth. After a year of exhausting work, he concluded that if the CO_2 in the atmosphere were to double, the mean global temperature would increase by 6 degrees C. In addition if the amount of CO_2 in the atmosphere were to decrease by one half, it would cause a decrease in global temperature enough to bring on an ice age. His work also explained the winter/summer variation of CO_2 caused by the uptake of plants during the growing season. Based on the amount of CO_2 being released into the atmosphere from the burning of fossil fuels in industrial processes, he thought that the time it would take to double the amount of CO_2 in the atmosphere would be some 3000 years hence.[2] In 1904, Arrhenius noted that the yearly burning of fossil fuels which he had estimated at 900 million tons had almost doubled from his estimates in 1896. The quantity of CO_2 could undergo considerable change in the course of a few centuries from the influence of industry.[3] Over the course of just 8 years, he had realized that his original estimate for the time frame in which this warming would be felt was more like a few centuries instead of millennia.

This idea was not well received by the epistemic community of scientists at the time. Arrhenius was up against the hegemonic view of the world at the time known as the “Balance of Nature”. Spencer Weart, a historian, describes “This view of Nature-suprahuman, benevolent, and inherently stable-lay deep in most human cultures. It was tried up with a religious faith in the God-given order of the universe, a flawless and imperturbable harmony."[4] Several scientists disputed Arrehnius's work with research of their own. "Arrhenius the Erroneous" was the nickname he picked up for his idea of global warming. His work and ideas laid on the back burner for many years.

Weart explains, through out the first half of the twentieth century, climatologists were oriented around tracking the annual rainfall and temperatures year after year. The data tracking was based on the premise that the statistics of the past could describe what could be expected for many decades into the future. Climate was by definition considered stable, so there were no real climatology departments in universities. It wasn't until the 1950's that research of climate really took off. Research supported by the US Air Force, who had a real need to understand wind and weather, was fostered in hopes of gaining better weather prediction. The hope was that someday we might possibly be able to actually control weather.

One if the recipients of the research money made available by the government was Gilbert Plass. He was funded to study infrared radiation at John Hopkins University. While he was working on this project, he came across the "much discredited" research of Arrhenius, and took up studying the effects of how CO_2 in the atmosphere absorbed infrared radiation in his spare time. His work differed from previous work in this field in two ways. He now had access to precision measurement technology and could use this technology to study the CO_2 in the atmosphere above the surface levels at which it was studied in the past. He also had access to new computer technology to perform the calculations for his research. Arrhenius had been refuted on the basis that CO_2 was already saturated in the atmosphere. The results of Plass's study were published in 1956. He demonstrated that increasing or decreasing CO_2 in the atmosphere could change the amount of radiation that escaped the Earth back into space, because the amount of CO_2 in the upper atmosphere was not saturated. He announced that human activity would raise the temperature of the earth by "1.1 degree C per century."[5]

The next step needed was to prove that CO_2 actually accumulated in the atmosphere as a result of industrial processes. This work was taken up by Dr. Charles D. Keeling, another recipient of the research money made available by the government for climate studies. He developed an extremely accurate instrument to measure CO_2 in the atmosphere and then managed to get instruments placed in Antarctica and in Mauna Loa, Hawaii. His relentlessness at tracking down sources of variations in the data from machinery in Antarctica and volcanic emissions in Hawaii enabled him to nail down a very precise baseline measurement of CO_2 in the atmosphere. His continued work in the Mauna Loa Observatory over the next 50 years has produced what is now known as the "Keeling Curve" [6] (Figure 1). The annual seasonal variation, which was described by Arrhenius, is clearly indicated. This cycle, known as biotic respiration, is the process by which plants take up CO_2 through the summer and release it through decay in the winter.

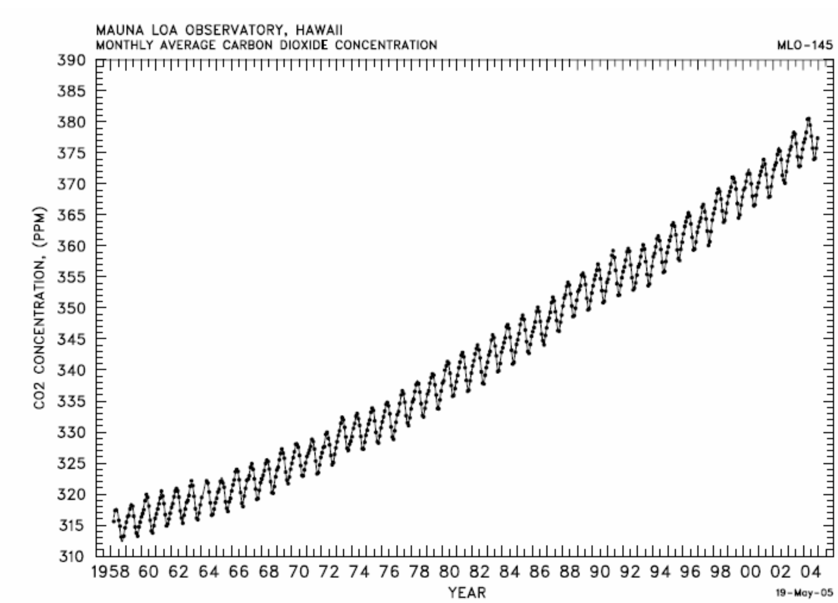


Figure 1: The Keeling Curve

Now that we have this record of current CO_2 data, we can compare it with historical data. For that information, we turn to glacial science. Polar ice cores have been extracted from Antarctica, Greenland and other glaciers around the world. The most famous work in this field comes from the Soviet Vostok Station in Antarctica. The 3363 meter ice core extracted by a French-Soviet drilling team gave us historical data stretching back over 400,000 years. It wasn't until 1980, that scientists learned how to extract the trapped air bubbles in an ice core to get accurate atmospheric data. The international team of scientists, working with the Vostok core, have been able to reconstruct a record of temperature and CO_2 variations over the entire time period. This data (see Figure 2) clearly shows that the current level of CO_2 in the atmosphere of over 380 ppmv is completely unprecedented in the historic record of the last 400,000 years.

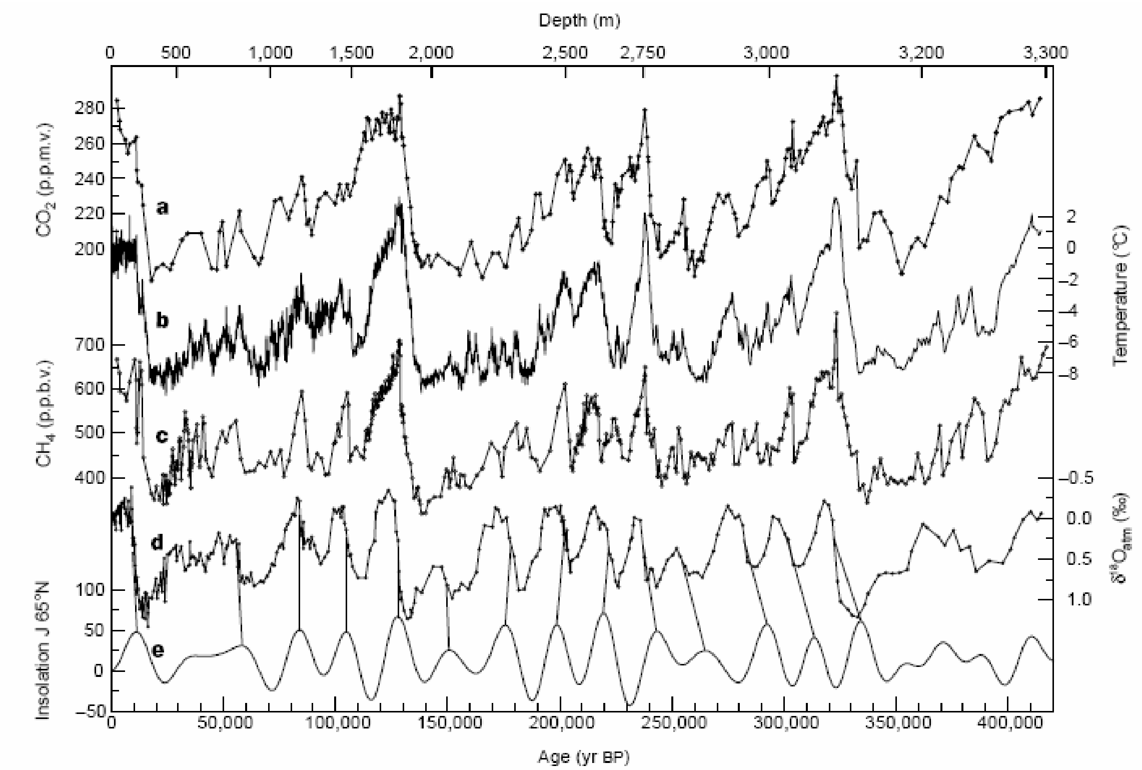


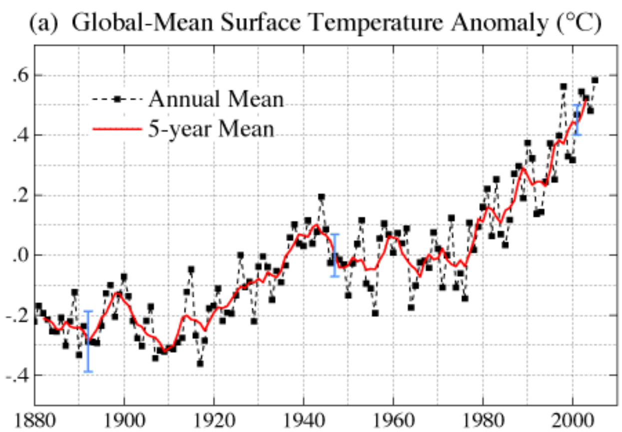
Figure 2: Vostok Ice Core Data

The highest value of carbon dioxide found in the ice core was approximately 300 ppmv about 330,000 years ago. In addition, it was found that the carbon dioxide variations were highly correlated ($r^2 = 0.71$) with the temperature changes. The final conclusion from this research was "greenhouse gases did contribute significantly to global temperature change."[7]

So how much has this increase in greenhouse gases, particularly CO_2, affected the temperature of Planet Earth? Dr. James Hansen has been working on the topic of global warming since 1976 at the NASA Goddard Institute for Space Studies. His work on Greenhouse Gas Growth Rates indicates "Global surface temperature increased in the past century by >0.5ºC. This warming is, at least in part, a result of anthropogenic climate forcing agents. A climate forcing is an imposed, natural or anthropogenic, perturbation of the Earth's energy balance with space. Increasing anthropogenic greenhouse gases (GHGs) cause the largest positive (warming) forcing."[8] Of all the GHGs, Hansen reports that CO_2 has accounted for 90% or more of the increase GHG climate forcing. "In 2003, the proportions were CO_2 (90%), N_2O (5%), CH_4 (4%) and MPTGs and OTGs (1%)."[9] MPTGs are Montreal Protocol Trace Gases and OTGs are Other Trace Gases, these include the group of gases known as CFCs and HFCs. He concludes that "CO_2 increases are the main cause of the anthropogenic greenhouse effect, so efforts to mitigate global warming must focus on CO_2."[10]

3. The Geography and Consequences of Global Warming

The latest work by Hansen provides a very clear picture of just how much warming has occurred and where it is happening in the world today. 2005 was the warmest year ever recorded



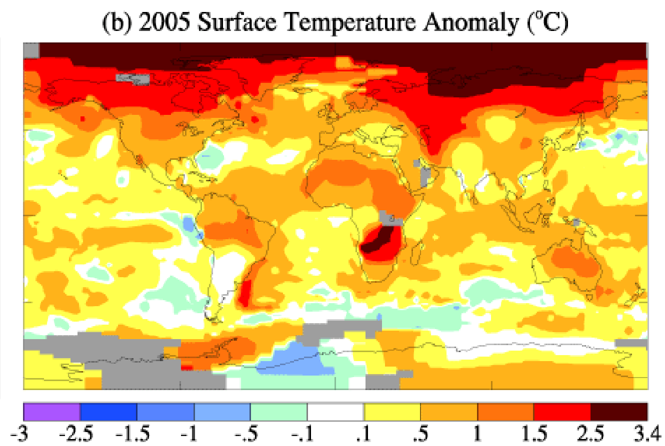


Figure 3: (Left) Global annual surface temperature relative to 1951-1980 mean based on surface air measurements at meteorological stations and ship and satellite measurements for sea surface temperature. Error bars are estimated 2σ (95% confidence) uncertainty. Figure 4: (Right) Temperature anomaly for 2005 calendar year. Gray areas indicate a lack of station data within 1200km. [11]

It is clear from Figure 3 that the global-mean surface temperature has now increased 0.8ºC during the last 120 years. Figure 4 shows the majority of the warming for 2005 happened in the northern hemisphere, with the hottest spot concentrated around at the North Pole.

This data is supported by the work of the scientists at the Byrd Polar Research Center at the Ohio State University. Dr. Jason Box has been studying the Greenland ice sheet surface mass balance (has the mass of the ice sheet increased or decreased). In his own words at the American Association of

Geographers meeting last year, “Greenland is Melting!”[12] Greenland’s runoff has increased 35% in the last 17 years and the outlet glaciers have been observed to accelerate rapidly during this period.[13] If Greenland were to melt completely the runoff water would raise the global sea level by 23 feet. Greenland’s melt water already accounts for one-fifth of the sea level rise each year. Greenland isn’t the only melting glacier in the world. The term galloping glaciers has become popular in the press to describe the speed of glacier movement increasing as melt water lubricates the bottom of the ice flow. If the present warming trend continues, all glaciers in Glacier National Park could be gone by 2030.[14]

The Consequences of Global Warming

Dr. Lonnie Thompson, another glaciologist at the Byrd Polar Research Center, indicates the loss of glaciers all over the world will effect fresh water sources for populations and crop irrigation, as well as the ability to generate hydroelectric power.[15] The addition of melt water to the oceans of the world and the expected increase in sea level due to warmer ocean temperatures (warm water expands), means that low lying countries, like Bangladesh, can expect their heavily populated coastlines to be overflowed with sea water. Other countries, like the Maldives, could disappear altogether.[16] The loss of glaciers also means the loss of the historic record of climate laid down year by year within the layers of ice.

The data being accumulated by the United Nations Framework Convention on Climate Change created in 1992, indicates the loss of biotic diversity is another effect expected from global warming. “Numerous plant and animal species already weakened by pollution and habitat loss are not expected to survive the next hundred years.”[17] Humans will face difficulties as well. Scientists have been developing global climate models (GCMs) for a number of years to help predict what we can expect for climate changes across the globe as the Earth warms up. The results vary from one GCM to another but in general they expect a temperature increase of 1.4 to 5.8 degrees C by the year 2100. Although they cannot say for certain what will happen when, they do agree that we can expect more frequent extreme weather events, including floods, droughts, heat waves, and tropical storms. All of these will contribute to a drop in agricultural production effecting world food supplies. "The range of tropical diseases like malaria may expand as well."[18]

The Worlds Largest Contributors of CO_2 to the Atmosphere

The data from the Carbon Dioxide Information Analysis Center (CDIAC) at Oak Ridge National Laboratory in TN was made available online in 2005.[19] This research by G. Marland, T. Boden and R. Andres, indicates that there have been significant emissions of CO_2 going back as far as 1750. The amount of CO_2 released into the atmosphere has been calculated from fossil fuel consumption figures which were gathered on a country by country basis.[20] See Figure 5 and Table 1 below.

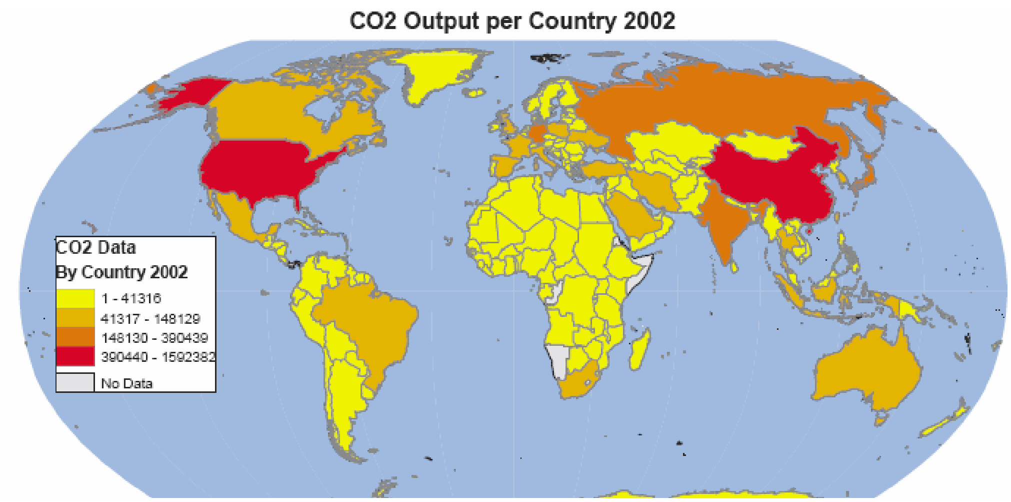


Figure 5: CO_2 Production by Country for 2002 (CDIAC data)

Table 1: The Top 10 CO_2 Emitting Countries for 2002

Rank	Country	Total CO2 emissions from fossil-fuels (thousand metric tons of C)	Per capita CO2 emissions (metric tons of carbon)
1	United States of America	1592382	5.52
2	People's Republic of China (Mainland)	967398	0.74
3	Russian Federation	390439	2.69
4	India	332667	0.32
5	Japan	327939	2.57
6	Germany	219270	2.66
7	United Kingdom	148129	2.50
8	Canada	140915	4.49
9	South Korea	121578	2.55
10	Italy	117989	2.05

However, when the data is standardized by looking at the amount of CO_2 produced by country per person, the result is seen below in Figure 6. The highest emission per capita countries are a much different group, including many very small countries with low populations. It is easy to see how just talking total CO_2 output verses per capita output makes a big difference in how one looks at the problem of global warming world wide.

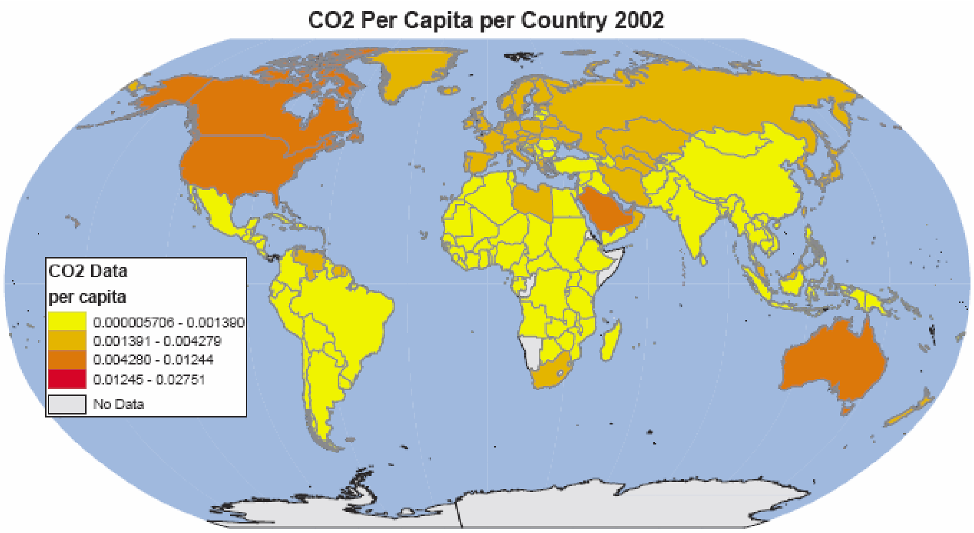


Figure 6: CO_2 Production by Country per Capita 2002 (CDIAC data)

Table 2: The Top 20 CO_2 Per Capita Countries for 2002 (CDIAC data)

Rank	Country	Total CO_2 emissions from fossil-fuels (thousand metric tons of C)	Per Capita CO_2 emissions (metric tons of carbon)
1	U.S. VIRGIN ISLANDS	2795	25.41
2	QATAR	9932	16.53
3	TRINIDAD AND TOBAGO	11231	8.8
4	UNITED ARAB EMIRATES	25657	8.74
5	BAHRAIN	5811	8.65
6	KUWAIT	16316	7.21
7	GUAM	1116	6.93
8	NETHERLAND ANTILLES	1345	6.14
9	LUXEMBOURG	2573	5.79
10	ARUBA	541	5.75
11	UNITED STATES OF AMERICA	1592382	5.52
12	MONTSERRAT	15	5.02
13	WAKE ISLAND	5	5.02
14	AUSTRALIA	97096	4.94
15	BRUNEI (DARUSSALAM)	1685	4.94
16	CANADA	140915	4.49
17	GIBRALTAR	123	4.24
18	SAUDI ARABIA	92794	4.22
19	FALKLAND ISLANDS (MALVINAS)	12	3.85
20	FAEROE ISLANDS	178	3.79

The Time Frame

The data presented in these maps and tables include all sources of CO_2 emissions. These sources are broken down into five categories: from gas fuels, from liquid fuels, from solid fuels, from cement production and from gas flaring. The only source which has shown any reduction in emissions is from gas flaring (see Table 3). It is clear that the start of the industrial revolution, which created the need for larger and larger energy inputs to drive the machinery, has been the driving force in the increase in CO_2 production world wide. More than half of the increase in CO_2 in the atmosphere has been added since 1980. In a tiny fraction of time, this release of carbon into the atmosphere, which had been stored for millions of years, is tipping the balance of the carbon cycle as never seen before in the history of our planet.

Table 3: The Global Historical Record of CO_2 Emissions by Decade in Millions of Metric Tons

Year	Total	Gas	Liquids	Solids	Cement	Flaring
1760	30	0	0	30	0	0
1770	30	0	0	30	0	0
1780	40	0	0	40	0	0
1790	50	0	0	50	0	0
1800	65	0	0	65	0	0
1810	95	0	0	95	0	0
1820	125	0	0	125	0	0
1830	173	0	0	173	0	0
1840	271	0	0	271	0	0
1850	429	0	0	429	0	0
1860	715	0	0	715	0	0
1870	1203	0	1	1199	0	0
1880	1902	0	16	1888	0	0
1890	2909	17	48	2846	0	0
1900	4270	22	116	4131	0	0
1910	6867	49	250	6569	0	0
1920	8876	92	495	8289	0	0
1930	9864	187	1225	8422	30	0
1940	10652	321	1856	8377	97	0
1950	13758	632	3010	9977	117	23
1960	21127	1638	6460	12407	308	312
1970	32476	3749	13101	14407	611	605
1980	48252	6412	22703	17111	1025	1001
1990	55552	8449	23106	22075	1371	553
2000	64149	11633	27048	23146	1949	375

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