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**Number 0103** **June 2001**

# GLOBAL SULFUR EMISSIONS IN THE 1990s

by

David I. Stern

CRES, ANU, Canberra ACT 0200, AUSTRALIA
Tel: +61 2 6249 4277
Fax: +61 2 6249 0757
E-Mail: dstern@cres.anu.edu.au
http://cres.anu.edu.au/anzsee/EEP.html

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# Global Sulfur Emissions in the 1990s

David I. Stern

June 2001

Centre for Resource and Environmental Studies, The Australian National University,
Canberra ACT 0200, Australia.

**Abstract**

This paper provides global and country by country estimates of sulfur emissions for the early and mid-1990s. Raw estimates are obtained in two ways. For countries with published data we compile that data from the available sources. For the remaining countries, we use either the decomposition model estimated by Stern (1999), the first differences environmental Kuznets curve model estimated by Stern and Common (2001), or simple extrapolation depending on the availability of data on the explanatory variables. We then examine the compatibility of these estimates with the ASL estimates for 1990. Based on these and other comparisons we construct a preferred database for 1850-1999 and discuss the main movements in the 1990s.

**Acknowledgments**

David Streets (Argonne National Laboratory), Allen Lefohn (ASL and Associates), Rachael Clarke (Environment Australia), Ketan Patel (U.S. EPA), and Cutler Cleveland (Boston University) helped me locate the available published data.

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Tel: +61 2 6125 0664, Fax: +61 2 6125 0757, E-Mail: dstern@cres.anu.edu.au

## 1. Introduction

Sulfur emissions are important in analyzing and understanding three important environmental problems: local air pollution and smog, acid rain and dry deposition, and global climate change. In the latter case, sulfate aerosols derived from emissions have a cooling effect on a continental scale due to the reflection and absorption of radiation by the aerosol particles. The nature of the climate change problem is such that there is a large amount of information in the most recent temperature data about the changes in climate (Kaufmann and Stern, 1997). Exploiting this data for the detection and attribution of climate change requires up to date data on the variables that may be causing changes in climate.

ASL and Associates (ASL and Associates, 1997; Lefohn *et al*., 1999) produced a data base of sulfur emissions on a country by country basis for the period 1850-1990 which has been used in a number of climate studies (e.g. Stern and Kaufmann, 2000). These estimates were more comprehensive in either the time or spatial dimension than all previous estimates published in the academic literature (e.g. Cullis and Hirschler, 1980; Möller, 1984; Varhelyi, 1985; Dignon and Hameed, 1989; Hameed and Dignon, 1992; Spiro *et al*., 1992; Kato, 1996; Stern and Kaufmann, 1996) and by national and international agencies. However, the cut-off point of 1990 is an impediment for continued use of these estimates in climate change research.

This aim of this paper is to provide global and country by country estimates of sulfur emissions for the early and mid-1990s which are compatible with the ASL database in order to extend its use to the analysis of the more recent climate data.

Raw estimates are obtained in two ways. For countries with published data we compile that data from the available sources. For the remaining countries, we use the decomposition model estimated by Stern (1999), the first differences environmental Kuznets curve model estimated by Stern and Common (2001) or simple extrapolation of the growth rate of emissions in the 1980s into the 1990s depending on the availability of data on the explanatory variables. These estimation methods are also used to update all countries for 1999 and for both 1998 and 1999 for the Asian group of countries which have published estimates up till 1997. We then examine the compatibility of these estimates with the ASL estimates for 1990 and earlier years and compile a preferred global estimate of sulfur emissions. Finally the main movements in emissions in the 1990s are discussed.

## 2. Compiling Published Estimates

All published estimates are first converted to the common unit of metric tonnes of sulfur. In total the published estimates cover 68 countries. The countries and sources are as follows:

**United States**. Source is US EPA (2000). The US EPA reports emissions in short tons of sulfur dioxide. There are 908 kilograms in a short ton and the mass of the sulfur content of sulfur dioxide is exactly half the total mass. These conversion factors are applied to the published data. Data is available through 1998.

**East and South Asia**. The source for 23 countries in East and South Asia: Bangladesh, Bhutan, Brunei, Cambodia, PRC, Hong Kong, India, Indonesia, Japan, North Korea, South Korea, Laos, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Vietnam, is Streets *et al*. (2000). The data are reported in Gg of $SO_2$. The period of the data is 1990-97.

**Europe**. Estimates for Europe are from the EMEP website: http://www.emep.int/emis_tables/tab1.html. As explained on the site: "the following tables include national anthropogenic emissions reported officially by the Parties to the Convention on Long-Range Transboundary Air Pollution. They are drawn from reports to the UNECE/EMEP Secretariat received by June 2000, approved by the Steering Body of EMEP in September 2000."

The following 33 countries have a full set of data for 1990-98: Armenia, Austria, Belarus, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Latvia, Lithuania, Luxembourg, Moldova, Monaco, Netherlands, Norway, Poland, Russian Federation, Slovakia, Slovenia, Sweden, Switzerland, Turkey, United Kingdom, Yugoslavia.
The following 3 countries have data for all years except 1998: Georgia, Italy, and Ukraine.

Portugal and Spain have data for 1990-96 and Liechtenstein and Romania only have data for 1990-94. Macedonia and Bosnia-Hercegovina have data for only one year each.

**Canada**. Canadian data are also reported on the site providing the European estimates.

**Australia**. Estimates are based on Australian Greenhouse Office (2000). However, we believe that only the 1995-98 estimates are relatively comprehensive and reliable. We interpolate estimates between ASL's estimate for 1990 and the AGO estimate for 1995. This is done separately for emissions from energy and emissions from metal processing. For metal processing we carry out a linear interpolation between the two figures. For energy we estimate an emissions coefficient of sulfur per tonne of CO2 emitted in 1990 and 1995 and then linearly interpolate the coefficient. The interpolated coefficients are multiplied by CO2 emissions in the intervening years to estimate sulfur emissions for those years. AGO estimates of emissions from international bunkers are added to the national emissions total.

## 3. Estimating Emissions in the Remaining Countries and Years

In this section we first describe the various estimation methods used and then the sources of data. Finally we list in which countries and years we used the various methods.

### *i. Methods*

#### *a. Decomposition Method*

We use the decomposition model described in Stern (1999) to estimate emissions. We estimate the changes in emissions over the 1990s assuming that the residual in 1990 was zero. This is necessary for the countries not in the Stern (1999) study because we do not have an estimate of the country fixed effect. But we also used this approach when we did have an estimate of the country fixed effect because of changes and differences in the data used. This model uses data on output composition: agriculture, non-manufacturing industry, manufacturing, services; energy input composition: coal, oil, natural gas, hydroelectricity, nuclear electricity; GDP per capita, and population. We assume the rate of technical change in the prediction period is the same as the mean over the estimation period.

### *b. First Differences EKC Method*

For all remaining countries with published estimates and some missing years of data we estimated the missing years using the fixed effects global estimate of the environmental Kuznets curve in first differences provided by Stern (1999). We choose this estimate as it only includes data from 1973 to 1990. Stern and Common (2001) show that the global time effects are increasing before the oil crisis and decreasing after it. Assuming that the rate of technical progress is the sample mean, the rate of change of sulfur emissions is given by:

$$\Delta \ln(S/P) = -0.01158 + 1.5729\,\Delta \ln GDP/P - 0.05722\,\Delta((\ln GDP/P)^2)$$

where GDP/P is in 1985 PPP dollars per capita.

### *c. Growth Rate Method*

This method projects the mean growth rate of sulfur emissions in the previous decade into the 1990s.

### *ii. Data*

The data source for population is International Financial Statistics (IMF, various issues) and in some cases the World Bank sources used for the output structure. Where PPP GDP per capita estimates are available from a consistent set of estimates for 1990-96 provided by an online version of the World Development Indicators (IBRD, various years) these are used and in some cases an online version of the Penn World Table (Summers and Heston, 1991). Otherwise International Financial Statistics (IFS) data is used to estimate changes in PPP income per capita. Estimates of PPP GDP per capita for 1997-99 are updated using IFS data or growth rates of GNP per capita from the World Development Report. Occasionally interpolations of growth rates were used. In all cases PPP data are deflated into 1985 PPP dollars using the US GDP deflator. Output structure is from the World Bank Development Report (IBRD, various years) and online version of the World Development Indicators. Energy data is from OECD (International Energy Agency, various years).

### *iii. Coverage*

In this section we note which of the three methods was used in each country in each year. When not otherwise specified the data are from ASL, EMEP, or Streets et al.

#### *a. Decomposition Method*

1991-93 UAE
1991-94 New Zealand
1991-95 Bahrain, Kuwait, Iran
1991-97 Mexico, Trinidad and Tobago, Ethiopia, Gabon, Zaire
1991-1998 Algeria, Argentina, Bolivia, Brazil, Cameroun, Chile, Colombia, Costa Rica, Cote d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Ghana, Guatemala, Honduras, Jamaica, Jordan, Kenya, Lebanon, Morocco, Mozambique, Nigeria, Panama, Paraguay, Peru, Saudi Arabia, Senegal, South Africa, Tanzania, Tunisia, Uruguay, Venezuela, Yemen, Zambia, Zimbabwe
1998 Bangladesh, China, Hong Kong, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Thailand

#### *b. First Differences EKC Method*

1959-99 Guyana
1960-64 and 1980-99 Togo
1961-99 Cape Verde
1962-99 Rwanda and Burundi - emissions in 1961 for the joint territory in the ASL database are allocated to the two countries according to relative GDPs.
1972-99 Haiti
1979-99 Uganda
1982-88 Liberia

1983-99 Antigua and Barbuda

1984-99 Angola

1985-95 The Bahamas

1988-99 Oman

1989-99 Congo

1991-99 Albania, Barbados, Fiji, Israel, Madagascar, Malawi, Malta, Mauritania, Mauritius, Namibia, Niger, Papua, New Guinea, Qatar, Sierra Leone, Sudan, Surinam, Swaziland, Syria

1994-99 UAE

1995-99 New Zealand, Romania

1996-99 Bahrain, Kuwait, Iran

1997-99 Portugal, Spain

1998 Zaire

1998-99 Bhutan, Cambodia, Ethiopia, Gabon, Georgia, Italy, Japan, Laos, Mexico, Mongolia, South Korea, Trinidad and Tobago, Ukraine, Vietnam

1999 Algeria, Argentina, Armenia, Australia, Austria, Bangladesh, Belarus, Belgium, Bolivia, Brazil, Bulgaria, Cameroun, Canada, Chile, China, Colombia, Costa Rica, Cote d'Ivoire, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Finland, France, Georgia, Germany, Ghana, Greece, Guatemala, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Ireland, Italy, Jamaica, Jordan, Kenya, Latvia, Lebanon, Lithuania, Luxembourg, Malaysia, Moldova, Morocco, Mozambique, Myanmar, Nepal, Netherlands, Nigeria, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Russian Federation, Saudi Arabia, Senegal, Singapore, Slovakia,, South Africa, Sri Lanka, Sweden, Switzerland,, Tanzania, Thailand, Tunisia, Turkey, Ukraine, United Kingdom, United States, Uruguay, Venezuela, Yemen, Zambia, Zimbabwe

### *c. Growth Rates Method*

1956-1960 Cape Verde

1969-1999 Gibraltar

1973-1999 Faeroe Islands

1975-1999 Bermuda

1977-1999 Saint Pierre and Miquelon

1984-1999 Guam using a moving average of the ten-year growth rate

1984-1999 Macau

1985-1999 Greenland

1989-1999 Liberia

1991-1999 Afghanistan (using growth rate from 1986-1990), Cuba, Iraq, Libya, Martinique, Netherlands Antilles and Aruba, New Caledonia, Puerto Rico, Somalia, US Virgin Islands.

1996-1999 Bahamas

1998-1999 Brunei, North Korea, Taiwan

1999 (using one year growth rate) Bosnia and Herzegovina, Cyprus, Croatia, Liechtenstein, Macedonia, Monaco, Slovenia, Serbia-Montenegro, Zaire.

## 4. Comparing the Raw Estimates to the ASL Data for 1990

For 49 countries it is possible to compare the 1990 estimates from the ASL database with the published estimates (Table 1). The two sets of estimates differ widely (and even wildly!). On the whole the published estimates are lower than the ASL database and some deficits are substantial. The largest deviation - that in the former Soviet Union - is partly explained by the fact that the figure we have compiled from the published estimates does not include the Asian part of the Russian Federation or the 5 central Asian republics (Kazakhstan, Tadjikistan, Turkmenistan, Uzbekistan, and Kirghizstan) and Azerbaijan. Omission of Siberia clearly eliminates many important emission sources. LeFohn *et al*. (1999) note the following discrepancies in other countries:

USA: While the 1990 estimates differ significantly, ASL's and EPA's estimates are very close in 1985 so that they argue that the discrepancy reflects changes after 1985.

Japan: Both Streets *et al*. (2000) and Kato (1996) report much lower estimates for Japan. As shown by Streets *et al*. (2000), these are close to official government estimates for Japan as are their other estimates for Asia. LeFohn *et al*. (1999) note that they did not consider coal washing which may explain part of the difference in emissions.

*A priori*, our preference is for the reported or Streets *et al.* estimates rather than the ASL estimates, for the following reasons:

a. Individual country estimates take account of more detailed data than used by ASL. This is a point essentially conceded by LeFohn *et al.* (1999). For example, ASL assume that the sulfur content of fuels is constant in each country over time, with the exception of the US. ASL estimates for many developing countries do not include emissions from oil burning and therefore are lower than other estimates.

b. The published estimates take into account some changes in data over time. For example, the collapse of economic activity in the former Soviet Union, Yugoslavia, and some other eastern European countries comes right at the end of the ASL database. There have likely been adjustments to past estimates of energy production and use.

c. Streets *et al.* (2000) show that their estimates for Asia are congruent with official estimates for those countries and previous estimates for the region by for example Kato (1996).

## 5. Adjustment of ASL Data to Conform to Recent Estimates

Due to the above discrepancies we conducted further comparisons. The aim of these comparisons is to decide on adjustments to the earlier ASL data so that a smooth time series results. Readers who do not wish to rely on these adjustments can of course use our 1991-99 estimates separately and use the unadjusted ASL estimates for previous years.

**USA**. We compare EPA and ASL estimates for 1940-1990. EPA estimates ranged from 83% to 121% of the ASL estimate. The closeness of the estimates for 1985 turned out to be a pure coincidence. However the average ratio is 98% over the 50-year period. We choose to use the EPA data for the period 1940-1998. For periods before 1940 we scale ASL's estimate to make it comparable with the EPA's 1940 estimate. This means multiplying the ASL data by 0.86177546.

**Asia** We compared the ASL estimates with the Streets et al. (2000) estimates for 1985-1990 and Kato's (1996) estimates for 1975 and 1980. The ratio of the two (Streets and Kato relative to ASL) is remarkably constant in China - varying from 78% to 83%. The Streets and ASL data are almost equal in each year for India. In fact the ratio relative to ASL is fairly constant for most of the countries in the Streets dataset. For some countries there are sharp differences between the ratios of the Streets and Kato datasets to the ASL data. We decided to treat all the countries in the Streets dataset with the exception of Japan uniformly. For 1985 to 1997 we use the Streets dataset, for previous years we use the percentage rates of change in the ASL dataset to project the Streets data back into the past.

We note that: for Brunei the only ASL data is for 1931-1949 so we just used that data without any change. Similarly for Cambodia, the only ASL data is for 1926-1950 and 1964-1972. Malaysia includes Sarawak when this state is listed separately by ASL

We make separate projections for Bangladesh and West Pakistan from 1950 to 1971 based on the interpolated shifts in their shares in the Pakistan total over the period.

For **Japan** we find that the ratio relative to the ASL estimate is constant at between 24% and 26% in the Streets dataset. In the Kato dataset the ratios are 40% for 1980 and 66% for 1975. This suggests that ASL do not pick up sulfur reduction methods introduced in the 1970s. We assume that the ratio is 100% in 1970 and adjusts linearly from 1970 to 1985. We then apply these ratios to the ASL data. Note that Japan includes the Ryuku Islands when these are listed separately by ASL.

**Australia** As described above, the Australian estimates are merged smoothly into the ASL data.

**Canada** ASL estimates vary between 65% and 84% of the EMEP database estimates during 1980-1990. The 84% value occurs in 1990. Between 1980 and 1989 the maximum value is 74%. We used the growth rates in ASL data to project the EMEP data backward from 1980. Newfoundland data are included in Canada when they are listed separately by ASL.

**Europe** Again, there is great variation in the ratio of the ASL estimates to the EMEP estimates. For the three biggest emitters with data in both data sets: Germany, United Kingdom, and Poland the ratio is very close to unity and almost constant over the decade of the 1980s. For Czechoslovakia, the fourth greatest emitter, the ratio varies from 1.19 to 1.33. Overall the ratio rises from 91% in 1980 to 117% in 1990. This suggests that, again, the ASL database is not picking up the full extent of sulfur reduction measures. Therefore, for the following group of countries we use the EMEP data for 1980-98 and use the growth rates in the ASL data to project back emissions into the past: Austria, Belgium, Bulgaria, Cyprus, Czechoslovakia, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland, Turkey, United Kingdom. For a number of smaller and east European countries some interpolation is needed. We interpolate the relative ASL/EMEP ratio and then use the ASL data to reconstruct estimates.

For Liechtenstein and Monaco there is no ASL data so we simply use the EMEP data for the years available.

For the **former Yugoslavia** we interpolate values for Croatia for 1981-89 and for Bosnia and Macedonia for 1980-89 as a constant proportion of Serbia-Montenegro's EMEP emissions. In the 1990s we assumed that emissions in Macedonia and Bosnia-Hercegovina in the missing years changed at the same rate as the mean of the rate of change in Croatia and Yugoslavia. We report estimates for these countries separately from 1980 on. ASL emissions are then used to project back Yugoslavian emissions to 1920. ASL estimates for Serbia for 1851 to 1912 are used unmodified.

For the **former USSR** we first interpolate some EMEP data for Estonia and Latvia based on changes in emissions in Lithuania. We then assume that the deficit between total EMEP USSR and ASL emissions in 1990 is due to the Asian USSR regions missing from EMEP. We assume that emissions in this Asian region decline at the same rate as in the 9 European and Trans-Caucasian republics included in EMEP. This is probably the biggest data lacuna in the estimates presented here. High emissions from Siberia are supported by Spiro *et al*. (1992). We report the 9 republics and one region separately from 1980 on and as the USSR in previous years.

From 1986 we report the Czech Republic and Slovakia separately and as a single country before 1986. Germany is reported as a single country for all years.

For all **other countries** the estimates are from our own models based on ASL data and therefore there is no need to compare them to the ASL data.

## 6. Preferred Global Aggregate Estimates

Our aim is to produce continuous and reasonably smooth time series of emissions for each country for use in global climate modeling. There are numerous periods of missing data within the ASL estimates and we first interpolate these using the simple formula $E_t = 0.5 E_{t-1} + 0.5E_{t+1}$. We also extrapolated estimates for each country back in time to 1850.

For this computation we first extrapolated any countries with estimates for 1851 but not 1850 back to 1850 using the growth rate from 1851 to 1852. Then we grouped the data into the following regions:

W. Europe, E. Europe and the Soviet Union, Middle East and North Africa, Asia, Africa, Oceania, Anglo America, Latin America

In addition to the modifications of country definitions mentioned above we also added together or reattributed the estimates for some further countries in the ASL database:

We added Cape of Good Hope to the estimates for South Africa between 1926 and 1935.
French Equatorial Africa is attributed to Gabon during 1950-57. French-Indo China refers to Laos. Emissions for French West Africa are attributed to Senegal. Estimates for the Leeward Islands are attributed to Antigua and Barbuda. Rhodesia-Nyasaland is added to Zimbabwe from 1950 to 1963.

The regions include the following countries:

**W. Europe:** Austria, Belgium, Cyprus, Denmark, Faeroe Islands, Finland, France, Germany Unified, Gibraltar, Greece, Greenland, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, United Kingdom

**E. Europe and the Soviet Union:** Albania, Armenia, Asian USSR, Belarus, Bosnia And Herzegovina, Bulgaria, Croatia, Czech Republic, Czechoslovakia, Estonia, European Russia, FYR Macedonia, Georgia, Hungary, Latvia, Lithuania, Moldova, Romania, Serbia, Serbia-Montenegro, Slovakia, Slovenia, Ukraine, USSR, Yugoslavia

**Middle East and North Africa:** Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Turkey, UAE, Yemen United, Yemen Democratic, Yemen North

**Asia:** Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, China, Hong Kong, India, Indonesia, Japan, Korea, Laos, Macau, Malaysia, Mongolia, Myanmar, Nepal, North Korea, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, Vietnam

**Africa:** Angola, Botswana, Burundi, Cameroun, Cape Verde, Congo, Cote d'Ivoire, Ethiopia, Gabon, Ghana, Kenya, Liberia, Madagascar, Malawi, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Rwanda-Urundi, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zaire, Zambia, Zimbabwe

**Oceania:** Australia, Fiji, Guam, New Caledonia, New Zealand, PNG

**Anglo America:** Bahamas, Bermuda, Canada, Puerto Rico, St Pierre et Miquelon, USA, US Virgin Islands

**Latin America:** Antigua and Barbuda, Argentina, Barbados, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Rep., Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles and Aruba, Nicaragua, Panama, Paraguay, Peru, Surinam, Trinidad, Uruguay, Venezuela

The extrapolations for each country were based on the growth rate of the aggregate emissions for the region. This problem was solved iteratively in Microsoft Excel.

The actual estimates for countries and regions for all years are available on the web at:

http://cres.anu.edu.au/~dstern/EEP/datasite.html

## 7. Discussion and Conclusions

Figure 1 presents the global and regional totals for the full 1850-1999 period. Emissions peaked in 1989 at around 64 million tonnes. They declined in the following year but spike in 1991 due to the Kuwait oil fires. A precipitous decline resumes as the Soviet Union and Eastern European economies collapse till 1998 when the effects of the Asian crisis are felt. Emissions rise by just under 2% in 1999. Thus after going through a topping out period in the 1970s and 1980s the direction of change has reversed on a decadal scale. At the regional level, the 1990s continue the process of change already evident in the previous 140 years. In 1850 Europe accounted for more than 80% of emissions (Figure 2). The locus of emissions shifted first to North America, then the share of Eastern Europe and the Soviet Union increased followed by the rise of Asia as a substantial emitter. In the 1990s Asia became the largest source area. Chinese emissions overtook US emissions in 1988 to make China the largest single emitter. Chinese emissions peak in 1996 and then fall till 1998 before increasing again in 1999. Figure 2 also shows that emissions in the minor regions – Africa, South America, Middle East, and Oceania are also an increasing share of global emissions and this trend accelerated in the 1990s. Figure 1 clearly shows a massive decline in emissions in Western Europe in the 1990s extending the decline of the 1980s. The decline in North America appears more moderate while the decline in Eastern Europe is the initiation of a new trend. Asia’s emissions increase most significantly. Figure 3 presents regional estimates for just the 1980s and 1990s in order to show more detail of the regional changes. Among those features are the increase in emissions in North America since the mid-1990s, the Kuwait oil fires, and the Asian crisis. Also this chart makes clear that emissions in Western Europe and Latin America are now quite similar in magnitude.

Figure 4 presents pie charts of world emissions by region in 1990 and 1999. Again these demonstrate primarily the shrinking of Eastern and Western Europe and expansion of emissions in Asia as well as expansion in the shares of the Middle East, Latin America and Africa.

At first glance the reversal in emissions in Figure 1 might be thought to have negative implications for future climate change. That is, if sulfate aerosols will decline in future (and have already declined) their effect in offsetting future warming may be less than has been expected. In fact this is one key factor behind higher rates of temperature increase in the 21st century predicted in the latest IPCC Report (Schneider, 2001).

However, Figure 3 suggests that the rapid reductions in emissions may be over in both North America and Western Europe. Perhaps even in Eastern Europe the major cuts are behind us. The latter is a tentative comment based on 1999 alone. The reduction in emissions in Asia in 1997-98 is likely to be related to the economic crisis in that period. Hence global emissions may continue the renewed upward trend initiated in 1999. However, it might take longer than a decade to again reach the level of emissions seen in 1989.

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**Table 1**

**Comparison of ASL and Published Estimates for 1990**

| Country | Published Estimate | ASL | Percent | Deficit |
|---|---|---|---|---|
| Austria | 45.5 | 93.7 | 49% | -48 |
| Bangladesh | 49.9 | 10.9 | 459% | 39 |
| Belgium | 186.0 | 331.9 | 56% | -146 |
| Bhutan | 0.7 | 0.2 | 339% | 0 |
| Bulgaria | 1004.0 | 331.7 | 303% | 672 |
| Canada | 1618.0 | 1366.4 | 118% | 252 |
| China | 11112.7 | 14213.9 | 78% | -3101 |
| Cyprus | 23.0 | 3.9 | 592% | 19 |
| Czechoslovakia | 1209.5 | 1574.1 | 77% | -365 |
| Denmark | 91.5 | 138.5 | 66% | -47 |
| Finland | 130.0 | 126.6 | 103% | 3 |
| France | 634.0 | 626.3 | 101% | 8 |
| Germany | 2660.5 | 3218.3 | 83% | -558 |
| Greece | 253.0 | 552.8 | 46% | -300 |
| Hong Kong | 76.2 | 100.5 | 76% | -24 |
| Hungary | 505.0 | 495.1 | 102% | 10 |
| Iceland | 12.0 | 0.8 | 1523% | 11 |
| India | 2218.6 | 2192.6 | 101% | 26 |
| Indonesia | 280.9 | 194.0 | 145% | 87 |
| Ireland | 93.0 | 63.4 | 147% | 30 |
| Italy | 825.5 | 579.3 | 143% | 246 |
| Japan | 416.6 | 1578.6 | 26% | -1162 |
| Luxembourg | 7.5 | 2.2 | 338% | 5 |
| Malaysia | 127.9 | 55.0 | 233% | 73 |
| Mongolia | 40.5 | 115.3 | 35% | -75 |
| Myanmar | 9.6 | 4.1 | 232% | 5 |
| Nepal | 8.4 | 0.4 | 2133% | 8 |
| Netherlands | 101.0 | 366.0 | 28% | -265 |
| North Korea | 176.7 | 256.4 | 69% | -80 |
| Norway | 26.5 | 37.2 | 71% | -11 |
| Pakistan | 342.5 | 121.9 | 281% | 221 |
| Philippines | 205.9 | 193.2 | 107% | 13 |
| Poland | 1605.0 | 1681.0 | 95% | -76 |
| Portugal | 171.5 | 195.3 | 88% | -24 |
| Romania | 655.5 | 1337.9 | 49% | -682 |
| Singapore | 95.4 | 191.1 | 50% | -96 |
| South Korea | 853.2 | 576.8 | 148% | 276 |
| Spain | 1024.5 | 828.4 | 124% | 196 |
| Sri Lanka | 13.0 | 7.9 | 165% | 5 |
| Sweden | 59.5 | 178.8 | 33% | -119 |
| Switzerland | 21.5 | 17.2 | 125% | 4 |

| | | | | |
|---|---|---|---|---|
| Taiwan | 252.3 | 312.4 | 81% | -60 |
| Thailand | 482.1 | 240.2 | 201% | 242 |
| Turkey | 416.5 | 1358.3 | 31% | -942 |
| United Kingdom | 1868.0 | 1762.6 | 106% | 105 |
| USA | 10741.6 | 12516.2 | 86% | -1775 |
| USSR | 5028.5 | 10910.3 | 46% | -5882 |
| Vietnam | 56.5 | 8.6 | 657% | 48 |
| Yugoslavia | 691.7 | 1817.4 | 38% | -1126 |

**Figure 1. Global and Regional Sulfur Emissions 1850-1999**

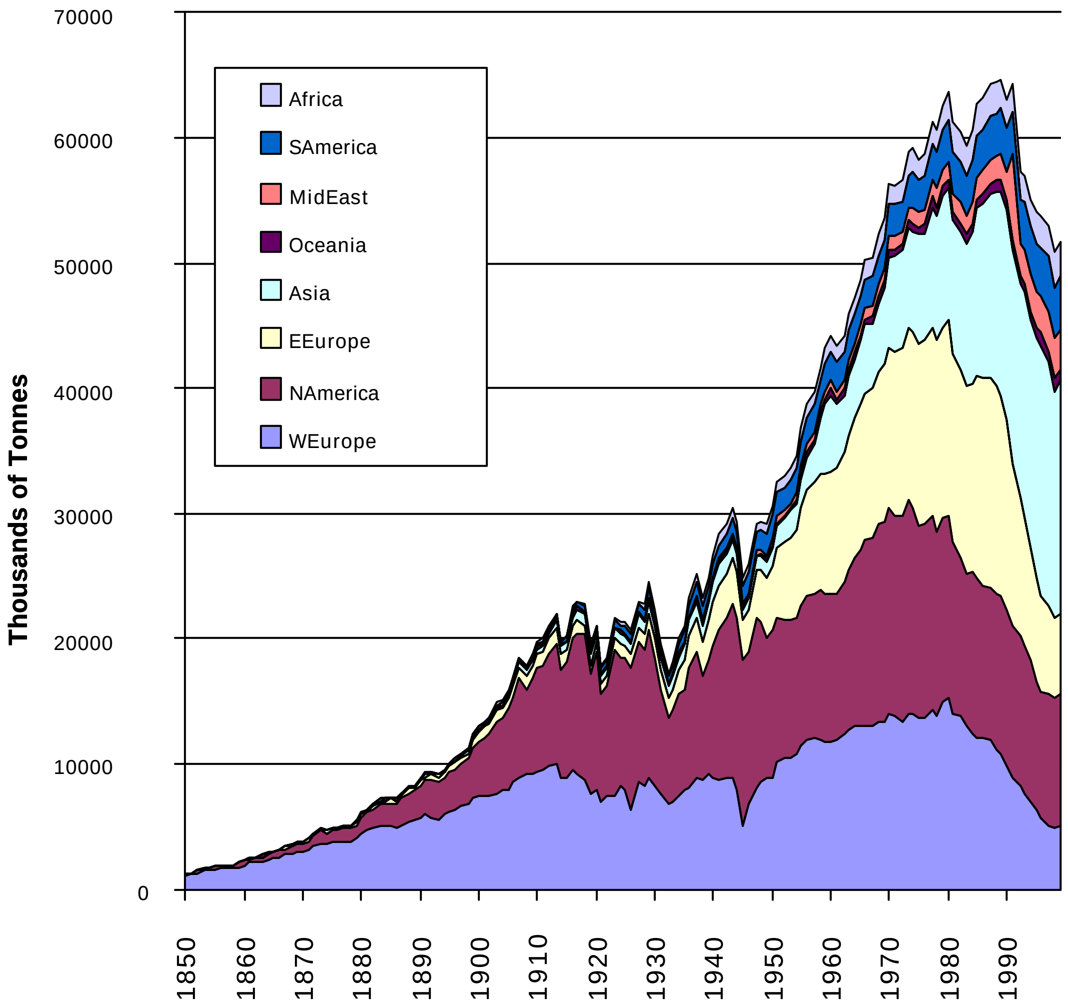


**Figure 2. Shares of Global Sulfur Emissions**

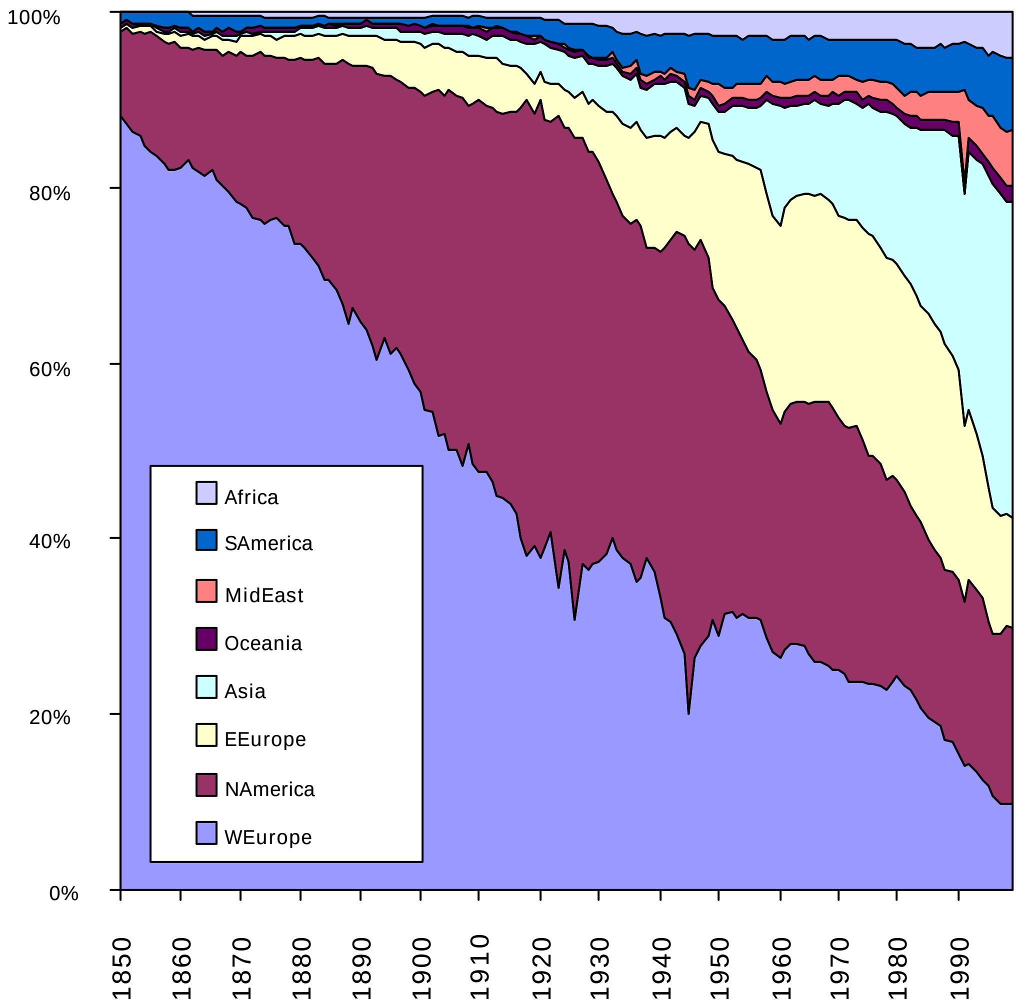


**Figure 3. Regional Trends in the 1980s and 1990s**

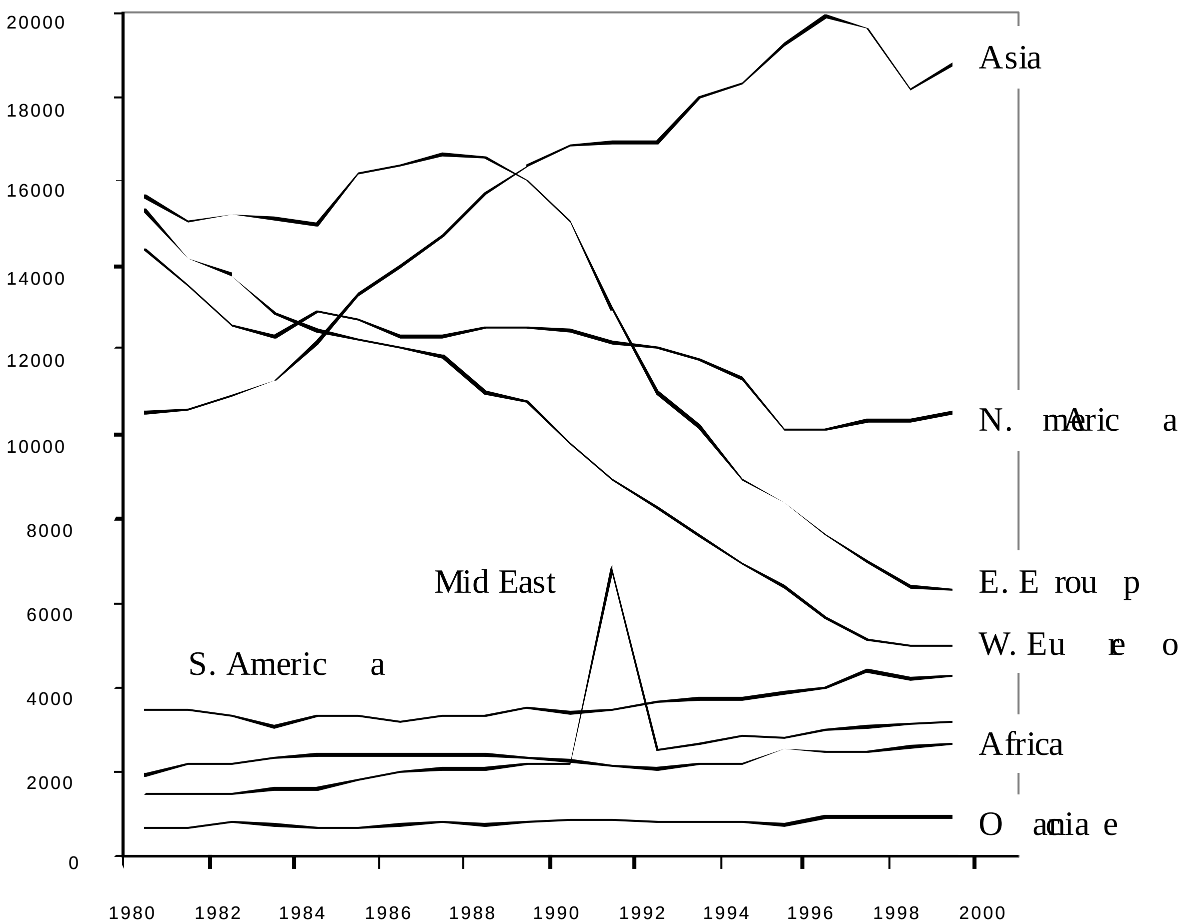
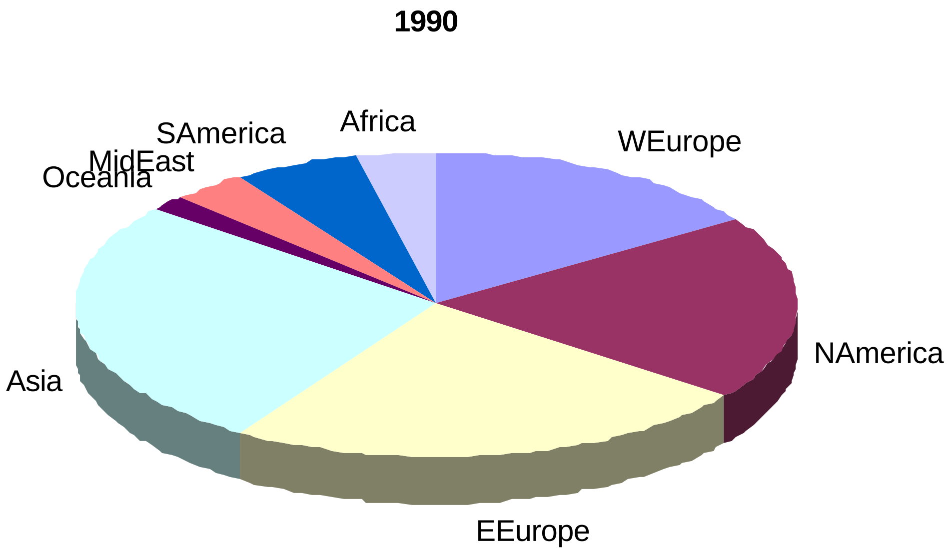
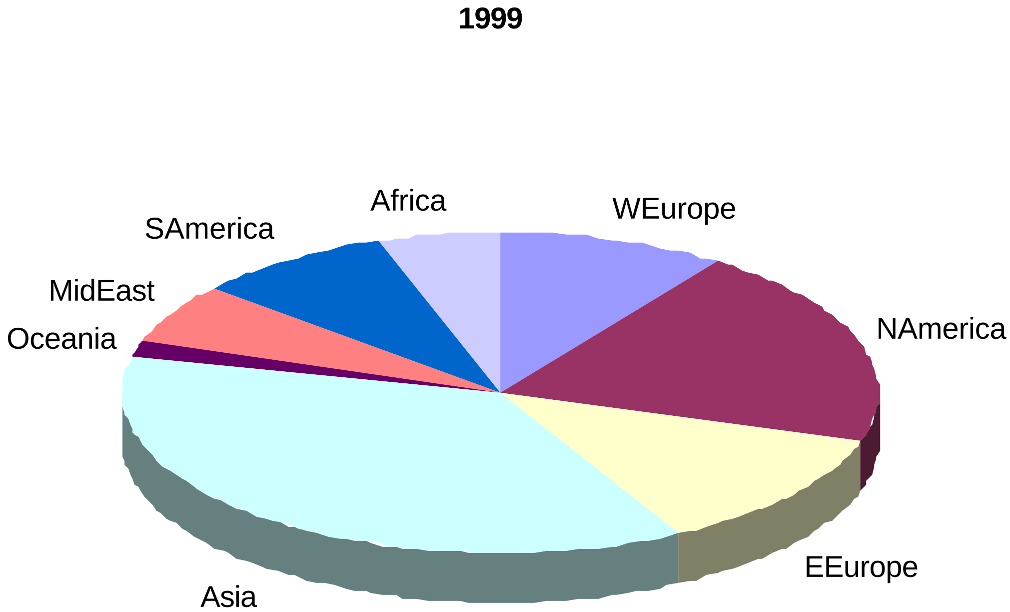


**Figure 4. Pie Charts of Emissions in 1990 and 1999**




1999
Africa
WEurope
SAmerica
MidEast
Oceania
NAmerica
EEurope
Asia