

Introduction

Greenhouse Effect, Ozone Hole and Air Quality

The term of *air pollution* is often used in a misleading way. Actually, air pollution covers many phenomena which are driven by distinct processes and sometimes coupled:

- greenhouse effect due to the so-called greenhouse gases (e.g. carbon dioxide and methane) and the resulting climate change;
- destruction of stratospheric ozone (especially over the South Pole, “ozone hole”) catalyzed by chlorofluorocarbons (CFCs);
- air quality with topics ranging from photochemical pollution (ozone, nitrogen oxides and volatile organic compounds¹) to particulate pollution, acid rains (due to sulfur dioxide and sulfate aerosols), more generally transboundary pollution;
- impact of accidental releases (chemical and biological species, radionuclides) into the atmosphere.

All these topics have in common their strong link to the *chemical composition of the atmosphere* and to *atmospheric dispersion* of pollutants. The emission of *trace species*, with very low concentrations, may strongly alter the atmospheric behavior and the life conditions at the Earth’s surface. Considering the pollutant properties, and the space and time characteristic timescales of the processes which govern their atmospheric “fate” makes it possible to *classify* these topics.

Brief History

Air pollution is mentioned in very old texts, even if not named as such. Since Antiquity, a few authors, such as the Chinese philosopher Lao Tzu, were concerned by the impact of anthropogenic activities on environment (especially air). A Roman

¹In the following, NO_x will stand for nitrogen oxides, VOCs for volatile organic compounds, SO₂ for sulfur dioxide and O₃ for ozone.

lawyer regulates emissions from a number of activities in York (UK) in the IVth century (Table 0.1).

Historical studies usually focus on the works of the physician and philosopher Moses Maimonides (1135–1204), as giving a precise description of air quality: “*the air becomes stagnant, turbid, thick, misty and foggy*” (using the modern translations, [122]).

Regulatory rules against the use of *sea coal* in the vicinity of the King’s Castle are contained in an edict of Edouard I (“*whosoever shall be found guilty of burning coal shall suffer the loss of his head*”). At a larger scale, Richard II regulates the use of coal in London ([143]).

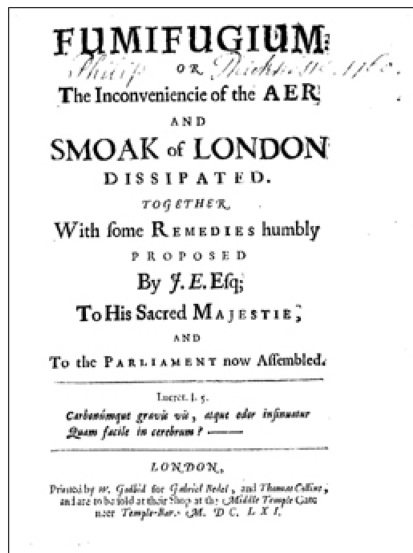
John Evelyn’s book, *Fumifugium or the Inconvenience of the Aer and Smoak of London Dissipated* (Fig. 0.1), is published in 1648 while Europe and England both had many other concerns. This book is often presented as the first one which is specifically devoted to air pollution. Actually, the historical British context is a bit more complicated (namely the Restoration of King Charles II, which lowers the environmental focus of the book, [34, 70]). Nevertheless, this book is a good illustration of the starting “industrial prerevolution” with an increasing use of coal for industries and heating, and of the resulting environmental damages (see the astonishing book of Peter Brimblecombe, *The Big Smoke: A History of Air Pollution in London since Medieval Times*, [20]).

While the previous texts were mainly focused on the description of *sanitary* effects, the investigation of the atmospheric chemical composition really starts with Robert Boyle in his book *General history of the Air* (1692), in which *nitros et salinos-sulphurus spiritus* is described. Stephen Hales (*Vegetable Statics*, 1727)

Table 0.1 A brief history

–500	Lao Tzu describes the impact of anthropogenic activities on environment.
300	Local regulation in York (UK, Roman empire).
1200	Moses Maimonides describes air pollution.
1272	Edouard I forbids the use of <i>sea coal</i> in the vicinity of his castle.
1390	Richard II regulates the use of coal in London.
1648	<i>Fumifugium</i> of John Evelyn.
1692	<i>A general history of the Air</i> of Robert Boyle.
1727	Stephen Hales observes the acidity of dew (<i>Vegetable Statics</i>).
1840	Christian Schönbein identifies ozone.
1852	Robert Angus Smith distinguishes different pollution regions.
1872	Robert Angus Smith writes <i>Air and Acid Rain</i> .
1905	Harold Antoine des Vœux introduces the term of <i>smog</i> .
1930	Sidney Chapman formulates a mechanism for stratospheric ozone.
1950s	Arie Jan Haagen-Smit studies the photochemical <i>smog</i> of Los Angeles.
1970s	Mechanisms for stratospheric ozone (Crutzen, Rowland, Molina).
1980s	Understanding of the processes driving the stratospheric “ozone hole”.
1990s	Convergence of topics related to atmospheric chemistry, greenhouse effect and climate.

Fig. 0.1 Fumifugium or the Inconvenience of the Aer and Smoak of London dissipated together with some remedies humbly proposed by J. Evelyn Esq. to His Sacred Majesty, and to the Parliament now assembled (1648). A key historical reference (see [34, 70] for the historical context)



studies the acidity of dew on vegetables: “the air is full of acid and sulphurus particles”.

All through the XIXth century, pollution fogs characterize London. Charles Dickens describes the *London particular* and *pea soupers* in his novels. Claude Monet, in the early XXth century, paints a series of oils in London, with a focus on the Parliament buildings, which illustrates the persistence of fog. These paintings can even provide elements to investigate *a posteriori* the atmospheric conditions over London in this period ([12]).

In 1852, Robert Angus Smith gives a description of pollution over Great Britain in a very precise way, on the basis of observational data and with particularly *modern* words. He notices that the pollution type may differ, depending on its distance from the emission sources:

[...] we may therefore find easily three kinds of air, [...], that with carbonate of ammonia in the fields at a distance, [...], that with sulfate and ammonia in the suburbs, [...] and that with sulphuric acid, or acid sulphate, in the town (from [44]).

The concept of *acid rain* is the subject of his book *Air and Acid Rain: the Beginnings of a Chemical Climatology* (1872). As a General Inspector in charge of the application of the *Alkaly Act*, he organizes an extended monitoring network, which can be viewed as a “precursor” of the modern air quality monitoring networks.

In 1905, the scientist Harold Antoine des Vœux introduces the term of *smog* to describe “a fog intensified by smoke” (there are possibly earlier uses). This term is widely used after his study of the pollution event over Glasgow (autumn 1909).

At the scientific level, the accelerating advances in physics and chemistry result in a finer and finer understanding of atmospheric processes. Meanwhile, the increase in anthropogenic emissions, due to growing industrial activities and birth of the automobile era, contributes to the emergence of environmental concerns.

Ozone is measured in the second half of the XIXth century (following its identification by Christian Schönbein, due to its characteristic odor). Atmospheric chemical mechanisms are formulated all through the XXth century to explain the atmospheric chemical composition. In the early 1930s, Sidney Chapman proposes the first chemical mechanism for stratospheric ozone. Arie Jan Haagen-Smit describes the possible composition of the photochemical smog over Los Angeles in the early 1950s, namely a mixture of ozone, nitrogen oxides and volatile organic compounds.

New topics are added to these “classical” pollutions (London and Los Angeles smogs) from the 1960s: acid rains, transboundary pollution, stratospheric ozone destruction, greenhouse effect (and resulting climate change), and more generally the study of the atmospheric chemical composition.

Viewing the atmosphere as a chemical reactor is definitely accepted after the works of P. J. Crutzen, M. J. Molina and F. S. Rowland, among many other scientists, sharing the Nobel prize in 1995 “*for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone*”.

Accidents, Impacts and Regulatory Context

Simultaneously with this increasing understanding, the pollution manifestations have sometimes resulted in spectacular impacts (Table 0.2). When specific emission and meteorological conditions are met, a few pollution events may result in hundreds or thousands of deaths in a few days (*Great Smog*, also referred to as *Big Smoke*, of 1952 in London: 4000 deaths from 5 to 9 December, Fig. 0.2).

The impacts of air pollution are not limited to health impacts. The works of Arie Jan Haagen-Smit were initially focussed on the impact of photochemical smog on agriculture. In the 1960s and 1970s, acid rains are indirectly observed by their impact on ecosystems (forests, lake eutrophication, soil acidity). Interactions between

Fig. 0.2 *Great Smog* (London, December 1952): evolution of mortality, sulfur dioxide concentration (SO₂) and smoke (“PM” stands for particulate matter). The concentration unit is mg m⁻³ (a scaling factor up to 100, as compared to the “modern” concentrations!). Sources: [20] and [156]

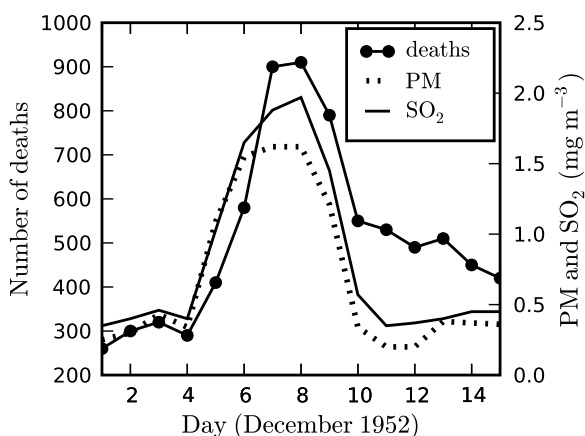


Table 0.2 A few historical “accidents” related to air pollution. For example, see [98] for the study of the Meuse Valley smog

1873	London	1000 deaths (?)	London smog
1909	Glasgow	1000 deaths	London smog
1930	Meuse Valley (Belgium)	60 deaths	London smog
1948	Donora (USA)	20 deaths	London smog
1952	London <i>Great Smog</i>	4000 deaths	London smog
1962	London	750 deaths (?)	London smog
1966	New York (24–30 November)	168 deaths	London smog
1984	Bhopal (India)	2000 deaths	chemical accident
1986	Chernobyl (USSR)	?	nuclear accident

SO₂, particulate matter and atmospheric water result in the black alteration of building surfaces.

As a consequence, a regulatory corpus (in a more systematic way than the aforementioned cases) is established (Table 0.4). Local rules may originate in the Middle Ages: they often focus on chimney heights. In Great-Britain, there is a growing initiative to regulate smoke emissions (*smoke abatement*) in the first half of the XIXth century. The so-called Mackinnon committee (including the scientist M. Faraday) is actually the *Committee for Means and Expediency of preventing the Nuisance of Smoke arising from Fires or Furnaces* (1843). Several regulatory texts are proposed but are subject to strong opposition of industrialists. As a result, only a “dampened” text is added to the *Public Health Act* in 1846. In 1853, more constraints are detailed in the *Smoke Nuisance Abatement Metropolis Act*. Other amendments will be added in the *Public Health Act* of 1875. A specific focus is put on the saponification industry, which emits chloride compounds, with the *Alkaly Act* of 1863 (it will result in a decrease of about 95% of chloride emissions).

In 1895, the United States of America start to regulate the emissions related to ...automobiles to decrease “*the showing of visible vapor as exhaust from steam automobiles*”.

The increasing number of smog events over Los Angeles results in the creation of the first modern air quality monitoring network in 1947 (*Los Angeles Air Pollution Control District*). Following the Great London Smog, the *British Clean Air Act* (CAA) is enacted in 1956 ([157] for an historical perspective). A similar regulation is taken in 1963 by the USA, with a specific part for traffic-induced emissions in 1965. While air quality monitoring was previously mainly in charge of states, a few amendments (CAAA, *Clean Air Act Amendments*) establish in 1970 the role of a federal agency, the *Environmental Protection Agency* (US EPA), and define federal guidelines for six pollutants (NAAQS, *National Ambient Air Quality Standards*).

The assessment of the acid rain impacts in North America results in a regulation devoted to sulfur dioxide emissions (a specific item is included in the 1970 CAAA). Persistency of acid rains on a few sites (as evaluated by NAPAP, the *National Acid Precipitation Assessment Program*) leads to the establishment of an emission trading market of dioxide sulfur emissions (title IV of the *US Clean Air Act*, 1990, and

Table 0.3 CLRTAP

protocols. EMEP is the technical center in charge of evaluation, measurements and modeling (*Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air pollutants in Europe*)

1984	Long-term funding of EMEP.
1985	Reduction of sulfur dioxide emissions of 30%.
1988	Control of NO _x emissions and transboundary fluxes.
1991	Control of VOC emissions and transboundary fluxes.
1994	Supplementary reduction of sulfur dioxide emissions.
1998	Persistent organic pollutants (POPs).
1998	Heavy metals.
1999	Acidification, eutrophication and ozone.

Acid Rain Program). North-American electric companies, strongly based on coal combustion, are mainly concerned.

In Europe, from 1967, the Swedish scientist Svante Oden investigates the impacts of sulfur dioxide emissions on rain acidity. In spite of an initial skepticism toward the possible long-range impact of emissions, transboundary pollution is recognized as a key concern in the 1970s:

[...] air quality in any European country is measurably affected by emissions from other European countries ...[and] if countries find it desirable to reduce substantially the total deposition of sulphur within their borders, individual national control programmes can achieve only a limited success (OECD Convention on Long-Range Transboundary Air Pollution, 1977).

In 1979, the *Convention on Long-Range Transboundary Air Pollution* (CLRTAP, see Table 0.3) is established by the United Nations. A few key concepts stem from this framework, such as the *critical load*, defined as “a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge”.

Many directives of the European Union will be issued during the following years: for sulfur dioxide in 1980 (80/779/EEC), for nitrogen oxides in 1985 (85/203/EEC), for ozone in 1992 (92/72/EC), etc. A global policy devoted to air quality control is initiated with the framework directive of 1996 (96/62/EC), which results in many “daughter” directives: particulate matter, sulfur, lead and nitrogen oxides in 1999 (99/30/EC), carbon monoxide and benzene in 2000 (2000/69/EC), ozone in 2002 (2002/3/EC), heavy metals, mercury and PAH (polycyclic aromatic hydrocarbons) in 2004 (2004/107/EC).

One of the most spectacular consequences of this intensive regulatory activity is related to lead. The decrease by a scaling factor greater than 2 of the authorized lead content in gasoline, in 1985 (directive 85/210/EEC), quickly results in a similar decrease in the air concentrations. The use of lead for gasoline will be forbidden in 2000.

Overcoming the fragmented approach which follows the 1979 convention (a few protocols devoted to specific pollutants, Table 0.3), the Göteborg Protocol, in 1999, adopts a global approach with a multipollutant and multimedia (water, air and soil) focus. The European Union initiates thereafter a process to decrease the regulated

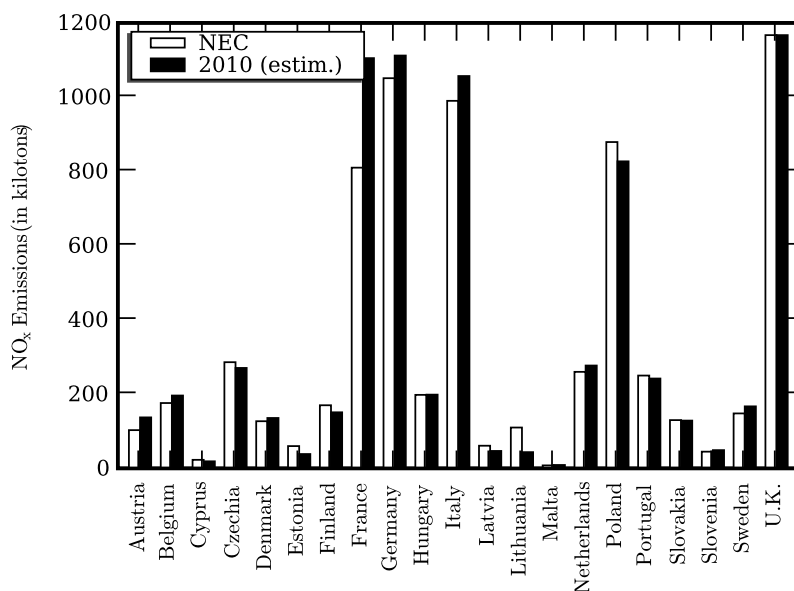


Fig. 0.3 NO_x national emission ceilings for 2010: comparison between the value of the NEC directive and the estimations (2006) of a few national plans. Source: [37]

concentrations (CAFE, *Clean Air For Europe*). In 2001, the NEC directive (National Emissions Ceilings, 2001/81/EC) defines for each country emission ceilings for 2010, for four pollutants: NO_x, SO₂, VOCs and ammonia (NH₃). As an illustration, Fig. 0.3 shows the evaluation, in early 2007, of the ability of countries to achieve the targets for NO_x (the most challenging issue, especially for France and Germany, because it is related to traffic-induced emissions).

At the global scale, the understanding of the chemical mechanism of stratospheric ozone destruction and the observation of the antarctic “ozone hole” in 1985 (a decrease by a factor 2 of the ozone column as compared to the 1960s) result in a series of international conferences to address this issue. The decision of reducing emissions of a few pollutants (e.g. CFCs) is taken by the Montreal Protocol in 1987. The extension to other species and to more drastic reductions is carried out by the London (1990), Copenhagen (1992) and Vienna (1995) protocols. The noticeable fact is that there are *only* a few years from the understanding of the adverse role of CFCs (on stratospheric ozone destruction) to the regulatory consequence (namely the progressive CFC emission ban).

Meanwhile, a strong increase in the atmospheric CO₂² is measured, especially by Charles Keeling (Hawaii, Mauna Loa) in the 1960s. The possible resulting perturbation in the radiative behavior of the atmosphere (“additional” greenhouse effect)

²More generally of a few greenhouse gases, defined as gases which absorb terrestrial infrared radiation (Chap. 2).

Table 0.4 A brief history of air quality reglementation

1853	Smoke Nuisance Abatement Metropolis Act.
1863	Alkaly Act (Great Britain).
1895	Regulation of automobile exhaust smoke (USA).
1947	Los Angeles Air Pollution Control District.
1956	British Clean Air Act.
1963	US Clean Air Act (US CAA).
1965	Title II US CAA (Motor Vehicle Air Pollution Control Act).
1970	Clean Air Act Amendments and creation of the US EPA (USA).
1979	Convention on long-range transboundary air pollution (Geneva).
1980	SO ₂ directive (European Union).
1987	Montreal Protocol (stratospheric ozone).
1990	Title IV US Clean Air Act (acid rains).
1992	Ozone directive (European Union).
1996	Framework directive for air quality (European Union).
1997	Kyoto Protocol.
1999	Göteborg Protocol (multipollutants, multimedia).
2001	NEC directive (National Emissions Ceilings; European Union).

and in the climate becomes a major concern in the 1990s. Following a cycle of international conferences, the Kyoto protocol (1997) determines emission reductions for a few countries. At the same time, the IPCC works (*Intergovernmental Panel on Climate Change*, for example [106]) result in a better understanding of the underlying processes and a finer evaluation of the possible impacts.

A Multiplayer Game

This framework drives the issues to be addressed and the strategies to be taken by the different “players” (public authorities and emission sectors).

A key question for the public authorities, at national and international levels, is the appropriate choice of emission reductions: how to define emission ceilings for a transboundary pollution, how to allocate emission reductions per country and per emission sector? Once an emission reduction is fixed, the issue of *monitoring* (namely of the monitoring networks to be deployed) becomes a prevailing issue. What pollutants should be measured (when possible)? How to reduce the cost of monitoring networks (trade-off between a large number of “coarse” stations and a smaller number of fine “supersites”)? For example, Fig. 0.4 shows the evolution from 1991 to 2001 of the French monitoring network devoted to ozone observation (a “continental” pollutant); meanwhile, the number of measurement stations for less classical pollutants has not significantly increased.

As expected, the issues are quite different for the emitting sectors and, as a result, the corresponding industries. How to forecast and to apply regulatory constraints

Fig. 0.4 Evolution from 1991 to 2001 of the number of measurement stations for ozone in France. Source: ADEME (French environmental protection agency)

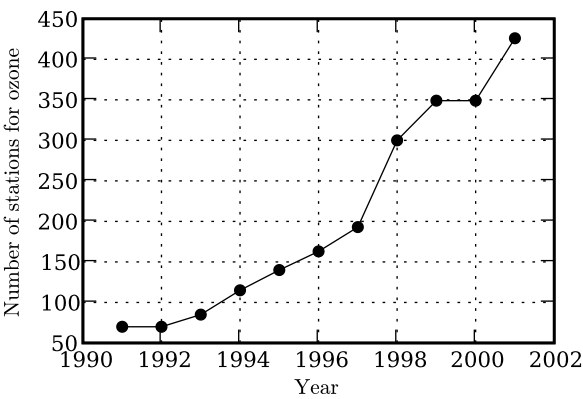


Table 0.5 Evolution (in %) of SO₂ emissions from 1980 to 2000 in Europe. The estimated range of uncertainties is indicated between brackets. Source: [1]

Country	Evolution (in %)	Country	Evolution (in %)
Austria	−90	Netherlands	−[85, 90]
Denmark	−90	Poland	−[60, 65]
France	−80	Switzerland	−[80, 85]
Germany	−90	Sweden	−[85, 90]
Italy	−75	Great Britain	−90

Table 0.6 Evolution (in %) of NO_x, VOCs and CO emissions from 1990 to 2002, in Europe and in the USA. Source: [72]

Region	NO _x	VOCs	CO
Europe (EU25)	−31	−39	−45
USA	−16	−16	+14

which have been dramatically increased for many pollutants? What are the consequences for investments and the choice of R&D projects to initiate? Table 0.5 details the decrease between 1980 and 2000 of SO₂ emissions for a few European countries. The corresponding industrial sector is that of electric power production (accounting for up to 80%). For example, in the case of thermal power plants for electric production, the innovative techniques which make it possible for such a decrease in emissions are FGD (for *fuel gas desulfurization*) and SRC (*selective reduction catalysis*; see e.g. [103]). Illustrative costs are about 100 millions of euros and 50 millions of euros for a power plant of 600 megawatts. As an illustrative case, Poland spent more than 8 billions of euros in the 1990s to reduce its annual emissions of SO₂ and NO_x of 800 kt (kilotons) and 300 kt, respectively ([71]).

Similarly, another most impacted sector is the automobile sector, which comprises both car and oil industries. The evolution of reglementations devoted to unitary emissions (emissions for a given vehicle) has impacted gasoline quality and the design of car engines. Figure 0.5 shows the evolution of the so-called Euro norms from 1993 to 2005 for a gasoline-fueled vehicle. In spite of the increase in traffic,

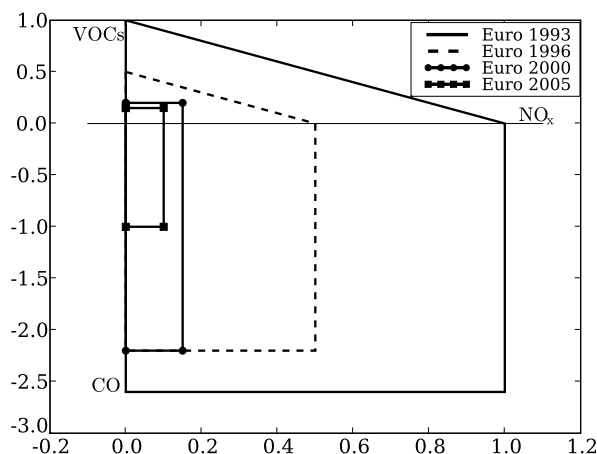


Fig. 0.5 Evolution of the European regulation for unitary emissions of gasoline vehicles (Euro 1993–2005 norms). The values are dimensionless. The polygon of “regulatory constraints” is defined by NO_x for positive abscissae, by VOCs for positive ordinates and by CO for negative ordinates

this results in a strong decrease in the emissions of ozone precursors (nitrogen oxides and volatile organic compounds). We can refer to Table 0.6, which indicates a reduction ranging from 30 to 40% between 1990 and 2002 in Europe.

Reductions of CO_2 emissions for cars is another example. In 1998, the ACEA (European Automobile Manufacturers’ Association) signed an agreement with the European Union to reach a mean CO_2 emission of 140 g km^{-1} for new cars in 2008. Such an effort underlies many changes in the automobile sector (increase in number of diesel vehicles, introduction of new fuels, technological improvement of engines). Note the strong differences among manufacturers (Table 0.7). ACEA predicts that the target of the European Union for 2012 (130 g km^{-1}) cannot be achieved with only technological approaches (position paper dated 7 June 2007, [6]). Moreover, another tough point for the evaluation of the 1998 agreement is related to the impact of the so-called *external factors* (changes in the automobile market, regulatory framework, etc.).

A key point is the difference between an emission reduction and an atmospheric concentration reduction due to the long-range transport of pollutants and the formation of secondary pollutants through chemical and physical processes (Fig. 0.6, Chap. 5).

Role of Scientific Expertise

In such a context, scientific and technical expertise plays a leading role. Classically, this concerns:

- understanding of the underlying phenomena for the adverse effects on health and environment to evaluate the contribution of anthropogenic activities;

Table 0.7 CO₂ emissions for new gasoline and diesel vehicles in the European Union with 15 countries (EU-15). Value in 2003 (in g km⁻¹) and evolution from 1995 to 2003, depending on the manufacturer origin (ACEA for European manufacturers, JAMA for Japanese manufacturers and KAMA for Korean manufacturers). Source: [2]

	Global		Gasoline		Diesel	
	2003	1995–2003	2003	1995–2003	2003	1995–2003
EU-15	164	−11.8%	171	−9.5%	157	−12.3%
ACEA	163	−11.9%	171	−9.0%	154	−12.5%
JAMA	172	−12.2%	170	−11.0%	177	−25.9%
KAMA	179	−9.1%	171	−12.3%	201	−35.0%

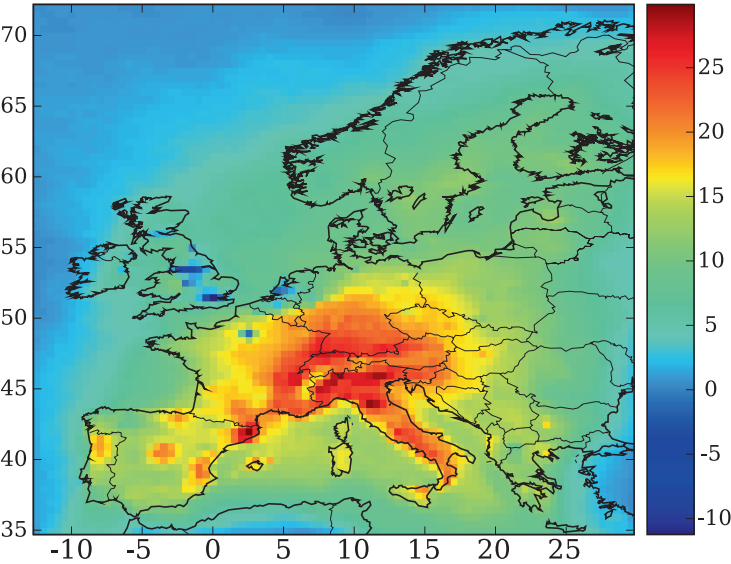


Fig. 0.6 Contribution (in %) of traffic-induced emissions to the ozone peaks (Europe, summer 2001). The estimation is carried out by comparing a reference simulation with a simulation without traffic-induced emissions. The simulation configuration does not take into account the nonlinear effects of photochemistry (Chap. 4). Simulation with the POLYPHEMUS system. Credit: Yelva Roustan, CEREAs

- definition of appropriate monitoring networks to supply regulatory decisions or to improve scientific knowledge (satellite observation of the atmospheric chemical composition).

During the last decade, numerical models have become a decisive tool, with many applications:

- *process studies* (to improve scientific understanding);

- *environmental forecasting*: how to forecast a photochemical pollution event, how to estimate the dispersion of an accidental release (Fig. 0.7 for the assessment of the Chernobyl accident)?
- *impact studies*: how to assess the impact of emission reduction scenarios at the European scale (national emission ceilings; Fig. 0.6) or at the local scale (impact of changes in traffic management)?
- *long-term climate studies* of the atmospheric chemical composition (greenhouse effect and climate change);
- *inverse modeling of emission fluxes*: how to estimate poorly accurate emissions (possibly regulated) from observational data of atmospheric concentrations?

Atmospheric Dilemma

In many cases, environmental policy decisions face a dilemma because the improvement of a given criterion may result in a *disbenefit* of another. Investigating all possible consequences of changes in emissions requires therefore scientific expertise, as illustrated by the four following examples.

Ozone concentration depends on the emissions of precursors, (VOCs and NO_x) in a complicated (nonlinear) way. Depending on the *chemical regime*, emission reduction may lead to an increase in ozone concentration (see the North-American case in the 1980s, Chap. 4)!

Similarly, the introduction of a new engine or of a new fuel for car traffic may result in adverse effects, whose prior evaluation is challenging. *Mass* reduction of *emitted* particles may result in an increasing number of fine particles which are *formed* in the atmosphere (the most adverse ones at the sanitary level, Problem 5.4).

Another example is provided by the introduction of biofuels (ethanol) whose prior motivation is the decrease in emitted fossil carbon. Based on a lifecycle analysis, the resulting impact should be positive by reducing the net budget of greenhouse gas emissions. However, there are at least two concerns. First, the impact on air quality could be negative, similarly to the first previous example (Exercise 4.7). Second, the extension of agro-biofuels is expected to generate concomitant emissions, especially of nitrogen peroxide (N_2O , Exercise 4.7), a strong greenhouse gas, which could negate the expected gain.

Last, the improvement of air quality, due to the decrease in sulfate particulate pollution in the Northern Hemisphere during the last two decades, results in a reduction of the cooling effect of particles with respect to solar radiation (Chap. 2), which can be viewed as the annealing of the counterbalance to the greenhouse effect.

This latter example provides a typical case of links between scientific expertise and decision-making. It also illustrates the temptation of *atmospheric engineering* (*geo-engineering*). A classical case in meteorology (whose effects are controversial) is *cloud seeding* (particles are used to initiate precipitations, Chap. 5). In the context of atmospheric chemistry, P.J. Crutzen questions the possible injection of

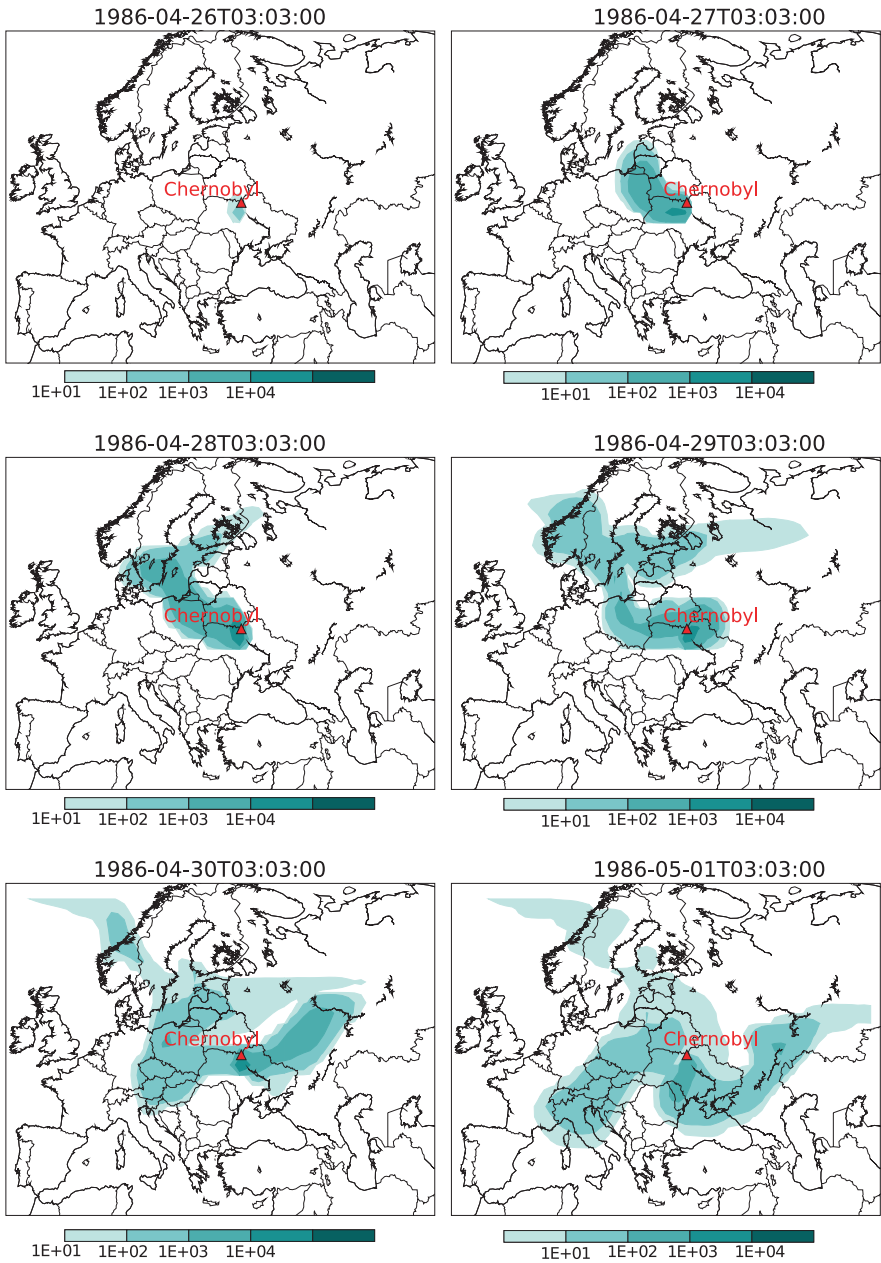


Fig. 0.7 Simulated evolution of the radionuclide plume over Europe following the Chernobyl accident (marked by a triangle). From left to right and from top to bottom: field of cesium 137 (in becquerel) at 3:00 (TU) from 26 April to 1 May 1986. Simulation with the POLYPHEMUS system. Credit: Denis Quelo, CERE/Institute of Radiological Protection and Nuclear Safety. Source: [115]

sulfate particles into the stratosphere to increase the planetary albedo³ and, thus, to compensate the reduction in particulate burden (Exercise 2.9):

[...] this can be achieved by burning S_2 or H_2S , carried into the stratosphere on ballons and by artillery guns to produce SO_2 [...] and this has to be viewed] as an escape route against strongly increasing temperatures ... ([26]).

Apart from a “general” position toward such projects, resulting negative effects of such projects have of course to be carefully estimated (e.g. possible increasing destruction of stratospheric ozone).

Book Objectives and Organization

This book aims at giving the key elements to understand *atmospheric pollutions* (Table 0.8).

The objective of this book is not to give a global and comprehensive overview of issues, which would require the knowledge of many scientific fields (fluid mechanics, atmospheric chemistry, radiative transfer, aerosol and cloud physics, etc.). Reference textbooks, more or less easy to read, are available (see the bibliographical references at the end of this chapter). This book is based on these references, especially for a few exercises.

Complementary to these comprehensive monographs, this books aims at giving a few “rules of the (scientific) game”, beyond the rule of the thumb.

Table 0.8 Classification of atmospheric pollutions. The *regional* scale corresponds to the meteorological meso scale (from a big city to the continental scale)

Pollution	Historical peak	Species	Scale	Regulation
<i>London smog</i>	London 1952	SO_2	local	CAA (1956)
Photochemistry	Los Angeles (1940s)	ozone, NO_x , VOCs	local, regional	O ₃ directive (1992)
Acid rains	USA (1960s)	SO_2	regional	US CAA (1970s)
Transboundary pollution	Europe (1970s)	sulfates, nitrates		CLRTAP (1979), Göteborg (1999)
Stratospheric ozone	antarctic hole (1980s)	CFCs	global	Montreal (1987)
Greenhouse effect and climate change	1990s	CO_2 , CH_4	global	Kyoto (1997)

³That is to say the ability of the Earth/atmosphere system to reflect solar radiation back to space.

The book organization is detailed in Table 0.9.

The fundamentals are given in Chap. 1, to be viewed as a short primer for the atmospheric chemical composition. Magnitudes of a few characteristic scales are calculated. The different atmospheric pollution types are classified by considering the impact scales.

Chapter 2 reviews the radiative issues with a focus on the atmospheric energy budget. The interaction between solar and terrestrial radiations and the atmospheric matter (gases, aerosols, cloud liquid water) is investigated. This provides an introduction to the greenhouse effect issue.

Atmospheric dynamics is briefly summarized in Chap. 3, with a focus on the *atmospheric boundary layer* (let us say the first kilometer just above the Earth's surface). Starting from bases of fluid mechanics, a few key meteorological models are presented. Attention is paid to the role of meteorological conditions in the development of a pollution event (stability and vertical mixing of pollutants).

Chapter 4 should be viewed as an introduction to gas-phase atmospheric chemistry, with applications to stratospheric ozone and to photochemical smog ("ozone peaks"). A few issues related to the oxidizing power of the atmosphere are also presented.

Multiphase processes are detailed in Chap. 5 with a focus on aerosols (atmospheric particles). The fundamentals of aerosol dynamics are given to understand their atmospheric evolution, the interactions with gas-phase species and with clouds.

Table 0.9 Questions, scientific fields and keywords for each chapter

Chap.	Issues
1	How to classify atmospheric pollutions? What are the characteristic scales? <i>Keywords:</i> bases of atmospheric sciences, emissions, residence time.
2	What is the impact of atmospheric chemistry on the atmospheric energy budget? What is the connection between air pollution and visibility degradation? <i>Keywords:</i> radiative transfer, greenhouse effect.
3	To what extent do meteorological conditions govern pollution? What are the urban specificities? <i>Keywords:</i> atmospheric boundary layer.
4	What are the main cycles of atmospheric chemistry? What is the genesis of a photochemical pollution event? What is the efficiency of emission reduction strategies? <i>Keywords:</i> gas-phase atmospheric chemistry.
5	What is the role of atmospheric particles (aerosols)? By what processes are their evolution governed? What is acid rain? <i>Keywords:</i> microphysics, aerosol dynamics.
6	What are the current state-of-the-science models? What are the applications and the limitations? <i>Keywords:</i> chemistry-transport models, numerical simulation.

Applications are related to acid rains, particulate pollution and scavenging by precipitation.

Last, numerical simulation is briefly introduced in Chap. 6 with the presentation of the *chemistry-transport models* (CTMs). Applications and current challenging issues are also illustrated.

Each chapter includes not only exercises for direct applications but also problems for more realistic issues. Constants, units, etc. may be found in the Appendix 1. A complete list of References, including the selected Bibliography below, and a comprehensive Index complete the book.

Bibliography

At least two comprehensive books give a nice general presentation of atmospheric chemistry and physics:

- J. SEINFELD AND S. PANDIS, *Atmospheric Chemistry and Physics*, Wiley-Interscience, 1998
- G. BRASSEUR, J. ORLANDO, AND G. TYNDALL, *Atmospheric Chemistry and Global Change*, Oxford University Press, 1999

For radiative transfer theory, classical references are:

- R. GOODY AND Y. YUNG, *Atmospheric Radiation. A Theoretical Basis*, Oxford University Press, 1986
- K. LIOU, *Radiation and Cloud Processes in the Atmosphere*, vol. 20, Oxford Monograph on Geology and Geophysics, 1992
- G. THOMAS AND K. STAMNES, *Radiative Transfer in the Atmosphere and Ocean*, Cambridge University Press, 1999

The study of the atmospheric boundary layer is detailed in:

- J. HOLTON, *An Introduction to Dynamic Meteorology*, Academic Press, 1992
- R. PIELKE, *Mesoscale Meteorological Modelling*, Academic Press, 1984
- R. STULL, *An Introduction to Boundary Layer Meteorology*, Kluwer Academic Publishers, 1988
- J. GARRAT, *The Atmospheric Boundary Layer*, Cambridge University Press, 1992

Numerical simulation is investigated in

- M. Z. JACOBSON, *Fundamentals of Atmospheric Modeling*, Cambridge University Press, New York, 1998
- B. SPORTISSE AND B. MALLET, *Introduction to Computational Atmospheric Chemistry: From Fundamentals to Advanced Applications of Chemistry Transport Models*, Springer Verlag, 2008

To end these references, a *marvelous* book, for its clarity and its concision, is:

- D. JACOB, *Introduction to Atmospheric Chemistry*, Princeton University Press, 1999

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