Environmental Science 6hp ECTS

Physics and Applications

Photograph: NASA

Course contents

The course in *Environmental Science* 6p is divided into two parts of 3p each. *Part I* gives an Introduction to Environmental science and deals with the Swedish environmental goals, pollutants, physical modelling, poisonous substances, Atmospheric and water pollutants, pollutants of the Baltic, International environmental standards, basic physical models of radiation, energy balance of the Earth, basics of the greenhouse effect, greenhouse gases and the carbon cycle**.** These subjects make a foundation for further studies of Environmental science and physics.

Part II describes more in detail radioactivity and its interaction with Nature, physical models of the atmosphere and the oceans, energy problems, thermodynamics, electricity, heat pumps, various fuels and their efficiency, solar cells, fission plants and fusion.

Within each chapter there are numerous examples with solutions.

The total 6 p course is tested by 10 Multiple choice questions, by 5 short problems, and 5 more extensive problems. (Maximum credits: 10+5+20 cr =35 cr, Pass: 17 cr).

The parts of the course can be tested separately: *Part I*, with 5 Multiple choice questions, by 2 short problems, and 2 more extensive problems. (Maximum credits: 5+2+8 cr = 15 cr, Pass: 8 cr) and *Part II*, with 5

Multiple choice questions, by 3 short problems, and 3 more extensive problems. (Maximum credits: 5+3+12 cr = 20 cr, Pass: 9 cr)

This course is based upon Environmental Physics courses given at KTH (F) Engineering Physics and KTH (Open) and at Stockholm University since the end of 1990 and has continuously been upgraded with recent research from many disciplines.

Course goals

* To give an insight in the influence of the society on the environment
* To give an introduction to the use of physical models applied on environmental issues
* To give knowledge about physical measuring methods and instrumentation within environmental science
* To give knowledge about technical solutions concerning environmental science
* To be able to solve simplified technical environmental problems

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Lars-Erik Berg 2009-05-08

Part I

Chapter 1

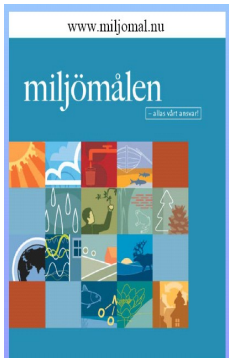
1 Introduction

In this chapter we will discuss general goals to obtain a better and cleaner environment. We will start with the aims of Sweden, that are quite similar in other countries as well. We will also discuss various pollutants and substances that are poisons to mankind.

All of us, as well as the society want to preserve the Nature although we also can consider it as a resource for mankind. In the picture below there are several examples showing how we use the environment to extract valuable resources for the community.

There are many examples like mining, farming, foresting etc., that are to some extent dangerous to the society, since it can create large damages of the Nature for future generations. However, many of these examples can give us a much richer society and means to hinder unjustices in the society and make it healthier by stronger support to health care etc. Much effort has to be taken in order to preserve the Nature in a way that we find acceptable for the future. The challenges are enormous.

1.1 The National Swedish Environmental Goals



As in any other country environmental goals are set to stop polluting the environment, both in the neighbourhood, as well as in a global perspective. The Swedish government has set 16 environmental goals, that can be studied in detail via the link:

http://www.miljomal.se/Environmental-Objectives-Portal/

1. Reduced climate impact
2. Clean air
3. Natural acidification only
4. A Non-Toxic Environment
5. A protective ozone layer
6. Safe radiation environment
7. Zero Eutrophication
8. Flourishing lakes and Streams
9. Good-quality Groundwater
10. A balanced marine environment
11. Thriving wetlands
12. Sustainable forests
13. A varied agricultural landscape
14. A magnificent mountain landscape
15. A good built environment
16. A rich diversity of plant and animal life

We will discuss most of these issues in the course.

1.2 Pollutants

A pollutant by definition, is the addition of a substance or energy by man, to parts of the echo system that at the end harm man (or the echo system).

However, a pollutant in one environment can be a useful substance in another environment. We can take ozone as an example. Ozone is hazardous in our neighbourhood and affects both plants, animals and humans, if the concentrations are too high. Ozone (O_3) in the stratosphere between 20-40 km above the surface of the Earth, hinders the dangerous ultraviolet radiation to reach the surface of the Earth and protects us and animals as well as plants from the UV radiation below 300 nm.

As an example of pollutant problems we can study an article of the Swedish journal *Svenska Dagbladet (SvD)* of May 18, 2003 (translated to English):
"*Time consuming work to save Stockholm from pollutants*. Now, the poisons of hundreds of ground areas in Stockholm have to be examined. The government is examining industry after industries that have left polluted ground behind. So far they have found some 4,000 spots in Stockholm where the ground is polluted or is suspected to be polluted. The work takes a very long time and at the same time the contributions for these types of investigations have been cut. Some 30 companies working with preserving wood with different chemicals have been contacted and where the ground has to be investigated. Some areas have been pointed out as risk areas for pollutants. The next step is to determine who is responsible for the damage, if it is the industry or the owner of the land, and who has to pay for the examination, says the environmental investigator Cecilia Obermüller of the Government. If there is none to blame, there are Government funds to use. In the Stockholm area they estimate the number of polluted areas to be between 7,000 and 8,000. At the same time investigations are going on in the whole country in order to achieve the environmental goals, Poison-free environment."

The Environmental Department, "Naturvårdsverket" has listed three fields of pollutants responsible for the damages:
* *Pesticides*
* *Industrial chemicals*
* *Products from industrial processes and burning*

For more information visit: www.naturvardsverket.se

Pesticides
Classical toxides are pesticides as DDT, toxafene, chlordane and hexachloro-cyclo-hexane (HCH) have been spread over rural ares but have successively been stopped in Sweden and in many other countries. However, they are still in use in the Tropics. In the Swedish environment they can still be found, and also substances that have never been used here, but have been transported here by the wind.
In todays Swedish agriculture one uses substances that are more or less broken down when chemicals are used to attack insects. However, such substances can spread outside the fields. Low, but not negligible concentrations of pesticides and rests of these can be detected in streams and in the ground water.

Bromated agents to protect from fire.
These agents are quite similar to *PCB* and are long-lived and can be spread over large distances. They can be enriched in animals especially in the tissues containing fat. The agents can influence both the liver and the pituitary gland, but also hinder the growth of the brain. Other agents as PBDE, polybromated biphenyl ethers, are found in humans. If this development increases, levels in humans and animals can reach concentrations that can cause

effects on the health. This substances are not produced in Sweden, but are imported for instance in cables. They can be found in electronic components as in computers, TV and in cars, but also in furniture.

Industrial chemicals.
Substances like industrial chemicals can also spread in the environment. PCB is the most well known example. Other substances are PCN, poly-chlorated naphthalenes. Some industrial agents are not produced any more. Some chemicals have shown to be harder to be replaced by non hazardous substances.
There are also kinds of chemicals that are produced during production or when burning processes are at hand. Agents such as HCB, hexa-chloro-benzene, PAH, polycyclic aromatic hydrocarbons are formed in processing. Some of these substances can be produced naturally, but the agents produced by man have been reduced considerably.

1.3 Atmospheric pollutants

Dry air consists of about 78 % nitrogen (N_2), 21 % oxygen (O_2), argon (Ar) 0.9 %, carbon dioxide (CO_2) 360 ppm and the rest is around 30 ppm. However, the atmosphere always contains varying amounts of water vapor (up to 4 %), which means that the above gas concentrations will be slightly reduced for moist air. We will discuss more in detail the atmospheric constituents in chapter 2.4.

There are two main ways that pollutants are spread or scattered in the atmosphere: a) By advection or by transport via the winds and b) by diffusion. If we look at diffusion we can regard a chimney emitting smoke gases as a point source. In that case we can use a Gaussian formed scattering pattern by using the Gauss function:

$$C(x,t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-x^2/2\sigma^2}$$

with

$$\sigma(t) = \sqrt{2Dt}$$

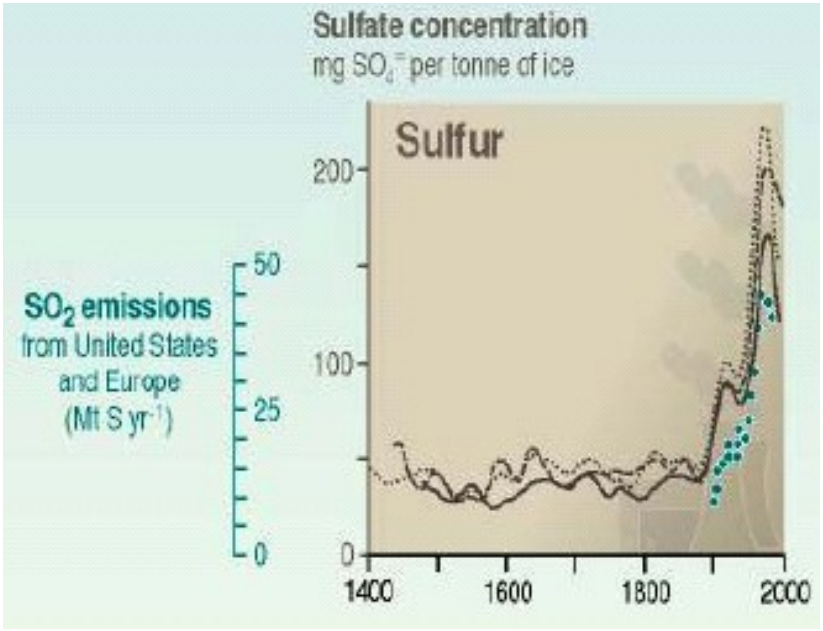
where *D* stands for the Diffusion coefficient or the diffusivity. This coefficient can be found in Chemical Tables and is different for various gases, depending on size, pressure etc. In the

expression above we have a linear dependency only in the x-dimension. This can be generalized to three dimensions.

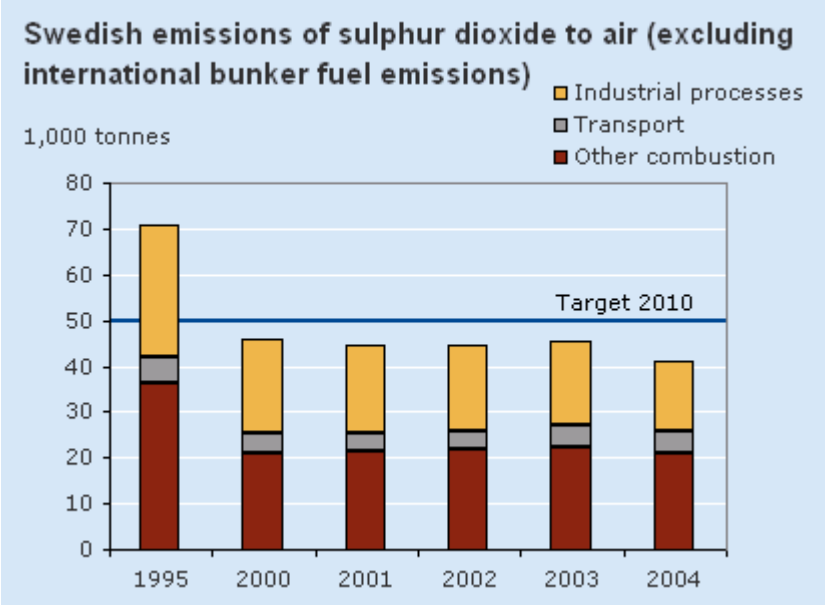
Example
Suppose we look at oxygen in the atmosphere, with diffusivity $D = 20.6\text{x}10^{-6}$ m^2/s and that we have a point source emitting the gas. Calculate the parameter C, i.e. how the gas spreads in 60 seconds if there is no wind at a distance of 1 dm.
Solution
First we calculate σ: $\sigma = (2Dt)^{1/2} = (2\text{x}20.6\text{x}10^{-6}\ \text{x}60)^{1/2}$ m = 0.050 m
This expression is put into the Gaussian and we get
$C(0.1,60) = \exp(-x^2/2\sigma^2)/\sigma(2\pi)^{1/2} = \exp(-0.1^2/2\text{x}0.05^2)/0.05(2\pi)^{1/2} = 1.1\ m^{-1}$.

1.4 Pollutants of water
The scattering in water is due to advection and diffusion. Pollutants can spread *directly* from industries and the society via the water pipes and then to the sea, lakes and other water streams. *Indirectly* pollutions can spread via the atmosphere and through rain over large areas.

Acid rain
Sulphur dioxide, SO_2, can be transported in the atmosphere over long distances and will fall down as H_2SO_3 and H_2SO_4. Also nitric oxides from high temperature burning will contribute to acid rain in the form of HNO_3. We can have reactions as:
$2SO_2 + 2H_2O + O_2 \longrightarrow 2H_2SO_4$.
Normal rain has pH = 5-7. Minerals in the soil neutralizes the natural rain, but SO_x, reduces the value of pH. Fish can handle a pH around 5, but not too much lower. Another effect of acid rain and acid water and ground water is that heavy metals as cadmium (Cd) can be extracted from the soil. The concentrations of SO_2 have increased during the years. Measurements have been in the polar ices and extrapolated during long times. One observes the increase in sulphur in recent years as is shown in the figure below:



The SO_4^{2-} concentrations per tonne of ice are shown in the figure. The increase from around the year 1900 is 4-fold. However, there is a decrease in the concentrations due to the efforts made after 1950 through international agreements. This can be seen in the figure below:



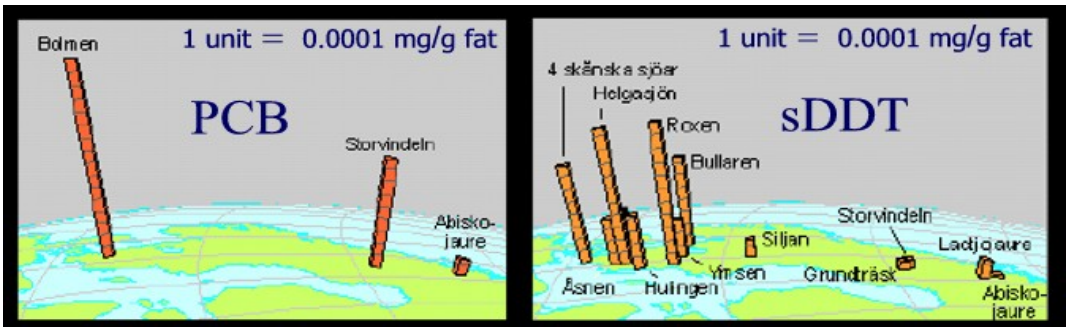
Sulphur deposition in Sweden has declined by about 60 percent between 1990 and 2004. Deposition of nitrogen, a contributory cause of acidification, has declined by 30 percent. However, emissions of these substances must be reduced still further to stop acidification.

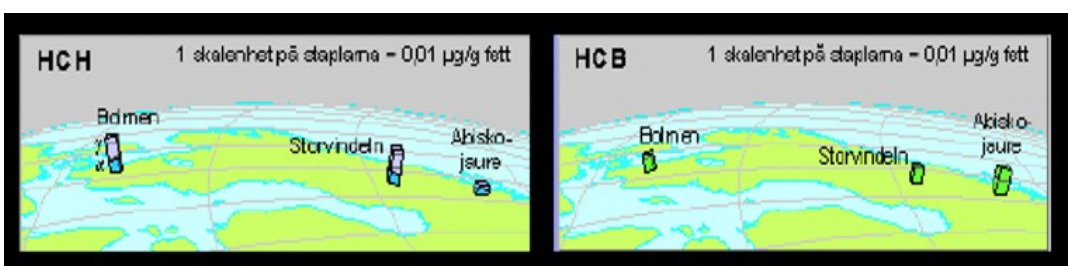
Environmental poisons in sweet water fish

When looking at the concentrations of the agents *PCB* and *DDT* in fish in lakes, one observes a decrease in concentrations from the South to the North, due to the much larger emissions in the southern part of Sweden.

Studies of Hexachloro-cyclo-hexane (*HCH*) and hexa-chloro-benzene (*HCB*) are found in just the same amounts in fish in the whole country. These substances are more easily evaporated compared to *PCB* and *DDT*, why they spread more easily into the atmosphere, and rather even all over the Earth. The analyses shown below are based on measurements on fishes from lakes.

This also illustrates how important it is to perform transport analyses and to make physical models of these phenomena.





Too much fertilizing leads to lack of oxygen
Bacteria use material in the lakes and is thus consumes oxygen and transforms it to carbon dioxide as shown below:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 4.7 \times 10^{-18}$ J

This leads to the death of fish and of the bottom of the lake or sea.

Examples are what have happened in the Laholm bay area and in large areas of the Baltic.

Pollutants reaching the Baltic
The amount of phosphor of the Baltic has increased 8-fold during 1900 and the amount of nitrogen around four times during the same period.
This leads to the fact that the alga with fine threads is dominating over seaweed and is making a kind of carpet along the shores above the seaweed.
Too much fertilizer also lead to more plankton in the seas that also have caused the sight of depth to decrease by at least 3 m since the beginning of the fifties. The death of the bottoms of the sea is increasing and the areas free from oxygen have increased from 20,000 km^2 in the fourties to around 70,000 km^2 today. Life is impossible if we exclude some bacteria living on sulphur. Too much fertilizer also lead to blooming along the coastlines, and in some cases the blooming has been hazardous.

Fertilizers in the Baltic
The mean salt concentrations of the Baltic vary between 0.2 to 1.0 %, There are also great variations both in time and in depth. There are layers that separate the fresh surface sweet water from the salt water in the deep. That is one reason for the limited number of species found in the Baltic if one compares with the North Sea. There are some 1500 species that can be seen with ones own eyes, to be compared with the some 70 species of the Baltic. Most species are sweet water species or salt-water species, which are stressed by the mixed nature of the Baltic, which results in a higher sensitivity for environmental poison.

Man has during the whole century of 1900 been taking tens of thousands of organic substances into account, some of which are environmental poisons. The concentrations of organic environmental poisons in the Baltic are high, which affects animals at the higher levels of the nutrition chain. The environmental substances *PCB* and *DDT* have for long been a threat for the reproduction of seals and eagles, but the situation is gradually getting better.

The change to unleaded fuel has resulted in a reduction of lead concentrations in the Baltic and also in the lakes. Measurements on small herring have shown a reduction of around 4% per year and in cod around 5% annually.

The cadmium concentrations are increasing in Baltic fish by around 5% annually and are some 3 times larger than in the beginning of the 1980-ties.
In perch, those are living close to the coastline, the concentrations rise even faster.

Also the concentrations of Cu and Sn are high, compared with the beginning of 1900.
Due to restrictions in copper and tin based boat color will hopefully reduce the concentrations in the future. However, more environmental poisons are being discovered. One of those agents contains bromine compounds used as fire retardants.

All this clearly shows that there is a need for international agreements for the Baltic.