How the environment works 2

TURNOVER OF MATTER AND ENERGY

 The Earth as seen from the Moon. (Courtesy of NASA's Earth Observatory)

"We're not passengers on spaceship earth, we're the crew. We're not just residents on this planet, we're citizens. The difference in both cases is responsibility."

Russell Schweikart, Apollo 9 Astronaut.

Planet Earth, unique in the solar system, has been able to develop and support life since the beginning of the history of the solar system, more than 4 billion years ago. This chapter describes the basic conditions for life on our planet.

Evolution of life has taken place on our planet's surface, a thin, skin-like crust. A large part of the surface is covered by water. In fact, the volume is so large that if all the water was evenly spread out, the whole planet would be covered with a layer 3 km deep. Presently, the Earth's crust is folded by geological processes and 30% of the surface reaches up above the water, making up land surfaces. Rocks that make up the crust are turned into fine-grained soil by physical and chemical weathering processes. The soil, accumulating in valleys and on plains, is the substrate on which life flourishes.

We live on the top of an immense globe that has a radius of about 6,400 km, and at the bottom of an immense "ocean" of air that reaches up about 1,600 km. The *hydrosphere,* water, the *atmosphere*, air, the *pedosphere,* soil and the *lithosphere,* rock, are components of the system collectively called the *ecosphere*, in which life thrives and develops.

All life depends on energy from the sun. At the outer reaches of the atmosphere, the sun shines on the planet with an average intensity of about 1,330 Watts per square metre. Close to half of this is reflected back into space by the atmosphere, partly by the surface of the Earth due to its reflectivity, or *albedo*. About half of the rest heats up the atmosphere and give rise to the weather phenomena. The other half reaches the surface of the Earth. The long wave back-radiation, i.e. heat from the Earth, is absorbed by the atmosphere. This process is called the *greenhouse effect*, which makes the planet about 35 degrees Celsius warmer than it would otherwise be.

The life forms on Earth have interfered very dramatically in the physical processes of the planet. They are part of the large turnover of material between the different components of the system. Since life has existed, these immense material flows have added up to an amount equivalent to the weight of the planet itself. These material flows are called the bio-geo-chemical cycles, a name that indicates their complex character. Carbon, nitrogen, phosphorus, sulphur and other materials move between biota, the atmosphere, oceans and the Earth's crust, in flows that uphold life and at the same time are generated by living organisms.

In many ways, man has intervened in large global processes and caused very harmfull results.The composition of the atmosphere has been changed through large fluxes of carbon dioxide which in turn change the energy exchange; and surface water has been changed through addition of nitrogen and phosphorus. These additional flows often become linear in contrast to the cyclic flows in nature, and interfere with stable biogeochemical cycles.

It is possible to define the conditions that humankind has to fulfil in order not to disturb the systems of our planet. The productivity of the ecosphere must not be systematically deteriorated. Materials in the lithosphere (such as carbon) must not systematically accumulate in the ecosphere. Synthetic materials and chemicals, must not systematically accumulate in the ecosphere. Finally, resources of the ecosphere should be used efficiently and justly.

The future of humankind requires respect for these basic rules, and protection of the rich and beautiful mosaic of life forms on this unique planet.

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How the environment works

Turnover of matter and energy

Planet Earth

Atmosphere and hydrosphere

Life forms and the large material flows

The planet and society

Planet Earth

Earth – a living planet

Seen from outer space, planet Earth appears unique in our solar system. It looks like a blue pearl floating in space, with atmospheric movements that make it look dynamic even from a distance.

The Earth has been able to develop and support life since the very beginning of the history of the solar system, almost 4 billion years ago. Life formed when the temperature on the surface of the planet allowed water to exist in liquid form, and the original intense frequency of meteorite impacts abated. Basic conditions for the development of life existed already then. The Earth is located in the ecosphere of the solar system, the region that is not too close to the sun to be burnt during the day, and not too far away to have too little influx of solar energy, (Fig. 2.1).

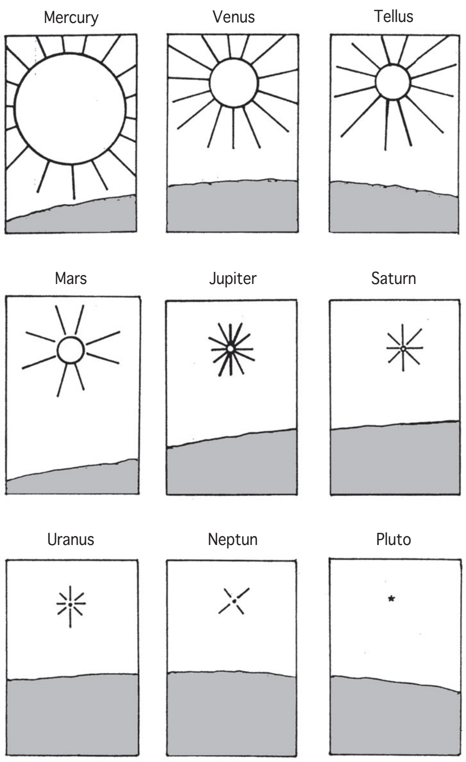
The planet Mars was probably also situated in the ecosphere. It is possible that life forms once existed there. If so, it does not seem that life has been able to develop there.

We do not know how unique the Earth is in the universe. During the 1990s, a series of planets around other stars than the sun were identified. All of these are very large, like Jupiter in our solar system, and it is not likely that they host life forms. However, several more planets could exist in these solar systems. It is very likely that there are many millions, of sun-like stars in our galaxy, the Milky Way. Many of these may certainly have planets, but it is difficult to estimate how likely it is that there is life on the planets.

We live on a planet uniquely endowed with a rich and beautiful mosaic of live forms, and we also have the unique responsibility of protecting and taking care of this mosaic. We are not separate from the environment, but part of it.

This chapter describes the Earth from the perspective of its physical systems and material flows. These systems and flows form the basis of the life support systems that made, and continue to make, life possible on the planet.

Figure 2.1. The ecosphere of our solar system. The Earth's sun seen from the planets in the solar system. The distance from a planet to its sun is crucial for life to evolve. The region where it is possible for life to exist is called the *ecosphere* of a solar system. Earth (Tellus), Mars, and possibly Venus, are found within the ecosphere of our solar system. If the sun was bigger, the ecosphere would extend to planets further away. For Mercury the distance from the closest point to the sun (perhelium) is used. (after Johansson et al., 1978.)



Structure of the planet

The planet itself has a sophisticated structure from which we have direct experience of only a minor part. The radius of the Earth is about 6,370 km. The Earth consists of an intensely hot *core* (diameter close to 7,000 km) made up mostly of iron, (Fig. 2.2). The inner part is molten while the outer core is semi-solid. The core is identifiable since it generates the Earth's magnetic field. The heat in the inner part of the planet comes mostly from radioactive decay. The heat from the Earth is used in many forms of technical heating systems, and provides a sustainable source of energy.

Around the inner core is the *mantle*. It floats on top of, or outside, the core since it consists of light elements such as silica, oxygen, magnesium, aluminium, sodium and potassium, forming a more or less molten, pliable rock. The mantle reaches down to a depth of about 2,900 km. During eruptions of volcanoes it appears on the surface as a floating molten rock material, called magma.

Outermost, on top of the magma, is the *crust* of the planet. This is the solid rock with which we are familiar. It is in this perspective quite thin. Under the oceans it reaches about 10 km in depth and on the continents up to 40 km in depth, which is from 0.2 to 0.7% of the distance to the centre. The crust is like a layer of skin on the planet.

The crust is brittle and floats on the magma. It is made up of several *tectonic plates*, huge blocks that move in relation to each other, sometimes colliding, sometimes breaking up in smaller pieces. Their movements explain the formation

Planet Earth

Age	4,600,000,000 years
Radius at equator	6,378 km
Radius at poles	6,357 km
Surface area	510,100,000,000 km^2
Mass	5,974,000,000,000,000 gigatonnes (5.974 · 10^{24} kg)

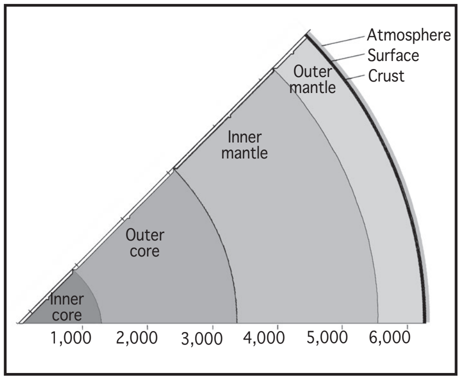
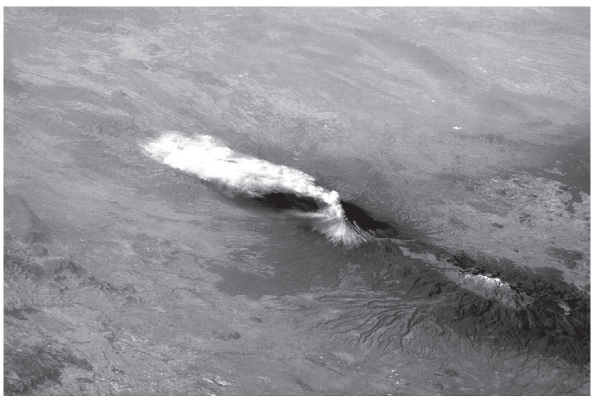


Figure 2.2. Structure of the Earth. The four major components of the planet are the inner and outer core and the inner and outer mantle, together constituting some 99.5% of the radius. On top of these is the outermost layer, the crust. It spans from 10 km in depth (under the oceans) to 40 km in depth (under the continents). The layer of soil on the surface of the crust on which life depends is, in this perspective, a minute and vulnerable outer skin.

Figure 2.3. Satellite photo of the vulcanoe Popocatepetl in Mexico. Volcanoes demonstrate dramatically how the inside of our planet is magma, which wells up from the earth's molten inner mantle from a depth of several hundred km. (Courtesy of NASA's Earth Observatory.)



of dramatic mountain regions, such as the Himalayas and the Tatras. They move in geological time, but such dramatic events have never happened during the history of mankind. However, smaller scale dramas, like earthquakes, take place more often at plate borders. The tectonic areas, i.e. plate borders, closest to the Baltic region are found to the northwest in Iceland, and to the south in Turkey and Greece. Iceland is situated on a plate border and experiences dramatic volcanoes and earthquakes. Iceland also has an ample supply of geothermal energy, which is an environmentally sound, sustainable energy source.

Rock and soil

The most common type of rock on Earth formed from solidified magma and is called *igneous rock*. Included in this category are the fine-grained rocks from magma that cooled quickly after a volcanic eruption, such as basalt; and coarse-grained rock from slowly cooling magma, such as granite and gabbro.

Rock that has been modified by heat, pressure and chemical reactions, as exerted, for example, by tectonic movements or the weight of sediments, is called *metamorphic rock*. Common metamorphic rocks include marble, formed from limestone; and quartzite, formed from sandstone.

Most rocks are very durable but exposure to air, water, and temperature variations eventually cause them to finally break up in the process of *weathering*. Examples of mechanical weathering are when water between fragments freezes, expands and causes a physical break; or simply when pieces are rubbed against each other during movements, e.g. by inland ice during glaciation. Chemical weathering occurs when a chemical reaction such as oxidation, or acidification caused by carbon dioxide, dissolves a component of the rock.

The particles created by weathering constitute *the soil*, and are transported by wind and water in the process of *erosion*. Finally, the particles are deposited in low parts of the landscape in the process of sedimentation, which creates valley bottoms and plains. Common soil types include till (rock-debris deposited by retreating continental ice), loess (very fine particles transported by wind), the coarse sand and gravel transported by water in rivers and brooks, and finally the sand, silt and very fine particles of clay that are deposited as sediment from the water column in lakes and oceans and thus make up ocean and lake bottoms. Soil is found in valleys and plains, but also in other places where particles are kept from being carried away in the process of erosion.

The sediments, e.g. in ocean bottoms, solidify due to the high pressure created by the continuous addition of new sediments. This rock forming process forms *sedimentary rock*. Examples of sedimentary rock are shale, sandstone, and conglomerates (aggregates of sand and gravel).

The creation of soil suitable for plants to grow in is thus based on very slow geological processes. Compared to the size of the planet, the layer of arable soil is small and sensitive. It is often not more than a few metres deep, and sometimes only a few centimetres deep, but it plays an important role in the geological formation of the surface of the Earth. Humankind needs to consider how to keep the soil layer in a state where it can continue to support life processes.

The landscape

The landscape on the planet – the valleys and mountains, water and land, and rock outcrops and soil – is the result of recent processes in terms of geological time, and occurred in the Quaternary period (the last 1.6 million years). In the Baltic region, there is a dramatic difference between the landscape in the north and south. The north part was shaped by a very recent glaciation in geological terms, and the more mature south was levelled off by a glaciation that occurred longer ago. The rivers flow majestically through large plains in Germany and Poland, and dramatically over waterfalls in the north.

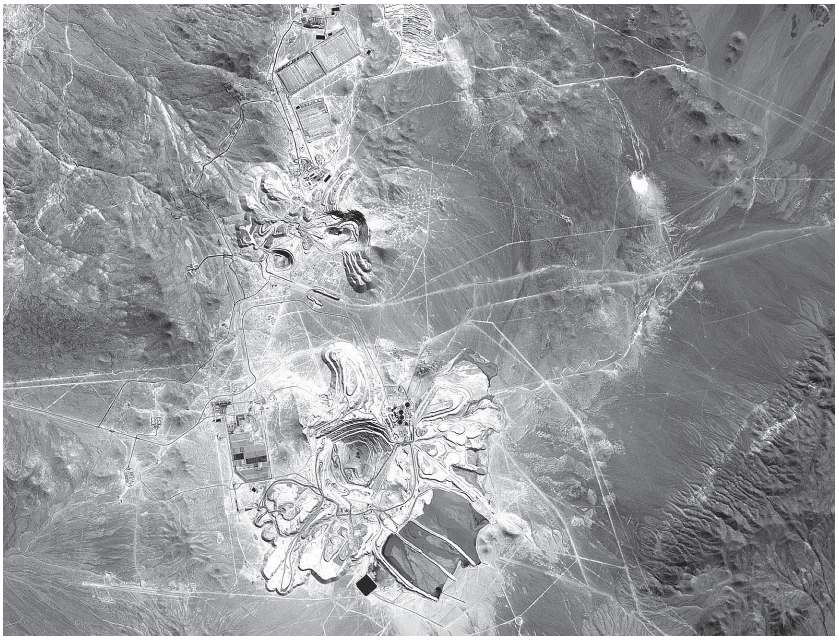


Figure 2.4. A copper mine in Chile seen from above. The earth's crust contains rare accumulations of metals. (Courtesy of NASA's Earth Observatory.)

Man has made major changes to the landscape, especially during the last few generations. Examples are deforestation, drainage operations, and construction of infrastructure such as large dams for hydropower.

The amount of material involved is large. It has been estimated that by building excavations, road building, and mining operations man moves about 35 gigatonnes of material per year world-wide. Sediments in rivers hold another 10 gigatonnes of material added by man per year. Other than plate tectonics, these man-made operations are the largest geological processes on Earth.

Man, however, does not interfere in large geological processes on the scale of tectonic plate movements. The forces of nature dwarf even nuclear weapons. There are, however, some instances when geology is sensitive to man's intervention, such as the process of erosion. Biological processes slow down erosion, especially since plants bind soil in areas where it would otherwise be lost. However, if plants are removed by human intervention, erosion is speeded up. Erosion occurs whenever land is made barren of plants. The amount of soil moved by erosion from agricultural land is massive. Farmland is extremely sensitive to erosion by rain and wind when left in fallow for long periods. This is a major threat towards the productivity of large areas. The soil ends up in rivers where it is transported to lakes and oceans, adding to sediments and magnifying natural processes.

Rock and soil as resources

The Earth's crust contains minerals, metals, and other materials that are essential to human society. In fact, civilisations have been named after metals extracted from the lithosphere, the crust. Stone, bronze (made up from copper and tin), and iron have been used to name periods of human history.

In modern times, hundreds of different materials are extracted from the Earth's crust. The amounts of metals most extracted are 740 megatonnes iron, 40 megatonnes aluminium, 22 megatonnes manganese, 8 megatonnes copper, and 8 megatonnes chromium. However, the largest amounts are extracted of sand and gravel, used for example in brick, concrete and other forms of building material. As well, large amounts of limestone are used to produce concrete. In addition, considerable amounts of other materials are moved in connection with mining.

Figure 2.5. **The atmosphere of the Earth** contains large amounts of water. At 60° N latitude, in the middle of the Baltic Sea region, water content is on average 10 kg/m^3 or, measured in the same units as rain, about 10 mm of water. The amount increases by about 4 times at the equator and falls towards the north. As a whole, the atmosphere stores the same amount of water as all freshwater lakes on Earth. Atmospheric water finally condenses as clouds, and eventually reaches the surface as precipitation. (Source: Eriksson, 2000. Photo: Inga-May Lehman Nådin.)

Atmosphere and hydrosphere

The evolution of the atmosphere

We live on top of an immense layer of solid material, measured from the centre of the Earth. We also live at the bottom of an immense "ocean" of air, the *atmosphere,* that reaches up about 1,600 km. It is composed of gaseous elements, many of which are essential to life on Earth (Ahrens, 1998).

When the Earth cooled some 4 billion years ago, the gases in the atmosphere were very different from those present today. The gases present then were part of the formation of the planet, mainly hydrogen and helium, and water vapour as an important ingredient. The atmosphere also contained gases resulting from the processes that occurred on the surface of the planet. For example, oxygen was consumed and gases such as methane were released.

Much has changed after four billion years of evolution. Almost all of the lighter gases, hydrogen and helium in particular, have vanished into space through diffusion. As a result of volcanic activity, nitrogen, carbon, sulphur, and many other elements have been added to the atmosphere. However, even if photosynthetic processes were most likely present since the early beginning, the atmosphere stayed reductive (meaning with very little oxygen), up to about 1 billion years ago. Since then, its oxygen content has slowly been built up. The present oxygen content of 20% was probably reached about 300 million years ago. Simple oxygen breathing, mono-cellular organisms have been present for more than a billion years. The large animals, which require a higher oxygen concentration, appeared on a geological scale rather abruptly some 670 million years ago. Human beings can not function well with a much lower oxygen concentration than is currently present. This can easily be experienced during high altitude mountain climbing.

The atmospheric layers

The atmosphere is structured in four rather distinct layers. Closest to the surface of the Earth is the *troposphere*. It reaches up at the most 18 km at the equator and 8 km at the poles. The troposphere contains most, about 75%, of the mass of the atmosphere, simply caused by gravitation. The troposphere is where the weather phenomena occur. It is therefore very thoroughly stirred and, thus, has a quite uniform composition of gases. The temperature decreases throughout the entire troposphere by about 1° C per 100 metres, and is about –60° C at the top.

The *stratosphere* reaches from the troposphere up to an altitude of about 50 km. The border between the two layers is called the tropopause. The stratosphere is much thinner than the troposphere. The composition of the gases here is similar to the lower layer with some important exceptions. First, the water content is much lower, 1,000 times lower. Secondly, the oxygen in the stratosphere is converted to ozone through the influence of high energy ultraviolet radiation, so called UV B. Ozone is a form of oxygen that has three atoms per molecule, instead of two atoms as in ordinary oxygen. Ozone is quite opaque to UV radiation. This makes the stratosphere a large filter for UV radiation, essential for life on Earth, for which UV radiation is detrimental. The ozone is distributed equally throughout the stratosphere and thus extremely thin. If all ozone had been collected to a single layer at the pressure we have at the surface of Earth, its thickness would be only a few millimetres. It is clear that the recently discovered anthropogenic destruction of stratospheric ozone is a serious threat to life on Earth.

The next layer is the *mesosphere*, or middle layer. The border between the stratosphere and the mesosphere, characterised by an abrupt change in the

Gas	Concentration (%)	Turnover time	Variation
Nitrogen, N_2	78.08	millions of years	constant
Oxygen, O_2	20.95	thousands of years	constant
Argon, Ar	0.93	millions of years	slow increase
Carbon dioxide, CO_2	0.036	5-10 years	accumulation 0.4%/year
Water, H_2O	varies	days	

Table 2.1. Composition of the atmosphere. Concentration in percentage by weight, rate of turnover, and variation of concentration of the major gases.

temperature gradient, is rather sharp and called the stratopause. In the mesosphere, the temperature decreases from about 0° C at a height of about 30 km to about -80° C at a height of about 80 km.

At this altitude of about 80 km there is the mesopause, which marks the beginning of the forth and outermost layer, the *thermosphere*. In the thermosphere, gases are highly ionised, that is, electrically charged by the impact of high-energy solar UV radiation, the charge being maintained by the low concentration. This also causes temperature to increase with altitude and reaches above 100° C at 1,600 km, the outermost part. The lower part of the thermosphere is called ionosphere. This is where the northern lights, or Aurora borealis, occurs.

Solar radiation and the global heat balance

The sun shines on the planet with an intensity of about 1,330 Watts per square metre at the outer reaches of the atmosphere, and varies according to location and time of year. How much of this reaches the surface of the planet?

Reflectivity, or the so called *albedo*, is an important phenomenon. About 25% of incoming solar radiation is reflected by the clouds and the atmosphere and does not contribute to the heat balance of the planet. The atmosphere and clouds absorb another 25%. Only half of the solar radiation thus reaches the surface of the Earth, some being again reflected, or backscattered. If the surface is covered by clean snow the albedo is very high, about 90%, while black soil, which hardly reflects light at all, has an albedo close to 0%. The Earth on average has a 5% albedo – mostly since the oceans, which cover large areas, absorb much of the sunlight. The 25% reflected by clouds in the atmosphere should be added, to make up a total albedo of 30% for Earth as a whole.

About 45% of incoming radiation is finally absorbed by the surface of the planet. This energy is used for e.g. evaporation of water. All of it is, however, in the end radiated back to maintain heat balance. However, since the outgoing radiation comes from the colder Earth it is very different from the incoming radiation. It is mostly low energy, longer infrared wavelength radiation (heat radiation). The atmosphere is much less transparent to outgoing heat radiation than it is to the incoming solar light. Thus, much of the energy is used to heat up the lower atmosphere and indirectly the surface of the Earth. This effect contributes to the heat balance of the planet with about 35° C. Without this effect, the Earth would not harbour life as we know it.

The heating through absorption of infrared back radiation is called the "greenhouse effect," comparing the atmosphere to the glass in a greenhouse that makes the inside warmer by absorbing outgoing radiation (Boeker & van Grondelle, 1996). The most important component in the Earth's atmosphere that absorbs the infrared light from the Earth is water vapour. However, any gas that absorbs infrared light contributes. Most important are carbon dioxide and methane. The concentrations of each of these gases are decisive for the heat balance of the planet. The present dramatic increase of carbon dioxide and other greenhouse gases is obviously influencing this balance and causes a shift towards a warmer climate.

The energy available for processes on the surface of the Earth, such as the hydrologic cycle, photosynthesis and heating of soil layers and vegetation, is called the net radiation. This is the net income of energy to the Earth's systems. Net radiation consists of the nets of long-wave and short-wave radiation. In the

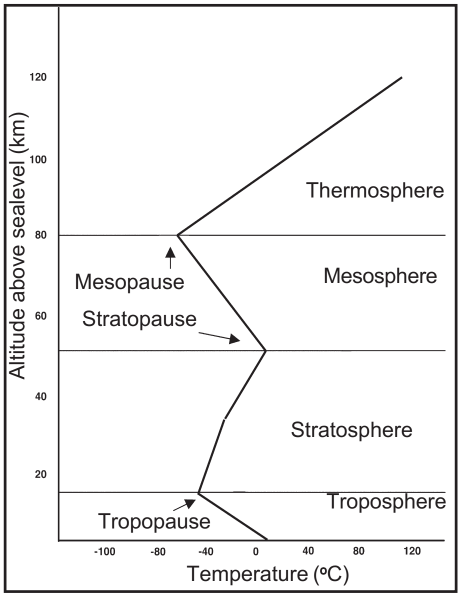


Figure 2.6. Structure of the atmosphere. The solid line shows how temperature varies with height up to about 130 km. The temperature diagram defines four sections of the atmosphere, the troposphere, stratosphere, mesosphere, and thermosphere. The interfaces between the layers are the tropopause, stratopause and mesopause. The air we breath is in the troposphere. The stratosphere is important to life as its ozone filters low wavelenght UV radiation.

Table 2.2. Solar radiation. Incoming solar radiation to Earth is either reflected (50%) or adsorbed (50%). The adsorbed radiation is used in a number of processes of which heating takes about half and movement of water, air and ocean currents the other half. A very small portion is used in biological or technical processes.

Incoming solar radiation	%
Reflected by clouds and the atmosphere	25
Absorbed by the atmosphere and clouds	25
Reflected by the surface	5
Absorbed by the surface	45

Use of solar input	%
Heating the surface	50
Evaporation of water from the surface, running the hydrological cycle	23
Convection in the oceans, currents	20
Winds	7
Photosynthesis	0.1
Human energy turnover	0.01

energy balance of the Earth's surface the net radiation is distributed between sensible heat flux (heating air and vegetation), latent heat (evapotranspiration) and ground heat flux (heating the ground).

The weather and movement of air and water

The sun heats the atmosphere unevenly. First of all the incoming radiation is much stronger closer to the equator than at the poles. The energy differences and thus temperature differences cause large movements of air and ocean water over the planet. Some of these movements are rather regular. They lead to a movement of warm tropical air towards the poles, but not all the way. The system breaks down in a number of so-called cells in which air circulates. Another example is the Gulf Stream, that redistributes warm water from the Gulf of Mexico northwards into the Atlantic Ocean.

An important component of the air is water evaporated from the surface of the Earth and carried by the wind, as described below.

The winds over the oceans have been used by man for sailing for thousands of years. Some winds are very regular and may thus be counted on for long voyages between continents; other winds fluctuate. In the Baltic region, the weather is dominated by western winds, which bring in warm air from the Atlantic Ocean.

On a global level, about 30% of the solar energy is used for the transport of air and water. The rest, about 20%, corresponds to movement of water in the oceans, the ocean currents.

The water planet

The third crucial component of the planet is water, or the *hydrosphere*. Water is a very special substance. It is part of all living cells. On average, about 70% of a living organism is water. It is a perfect solvent for all kinds of ions, charged molecules and many of the chemicals that make up the fundament of living cells. Water constitutes a liquid in a temperature range that is perfect for life, and in fact is the only substance with such properties. When it solidifies to ice it becomes slightly lighter and thus floats on liquid water, a behaviour which is also quite unique. It takes a considerable amount of energy to vaporise water, and thus it stays liquid over an unusually wide temperature range.

There is about 1,403 million km^3 of water on the Earth. If this was evenly spread out over the planet, and if the surface was smooth, it would cover the whole Earth in a layer about 3 km deep. The surface is of course not smooth and about 70% of the surface of the planet is covered by water.

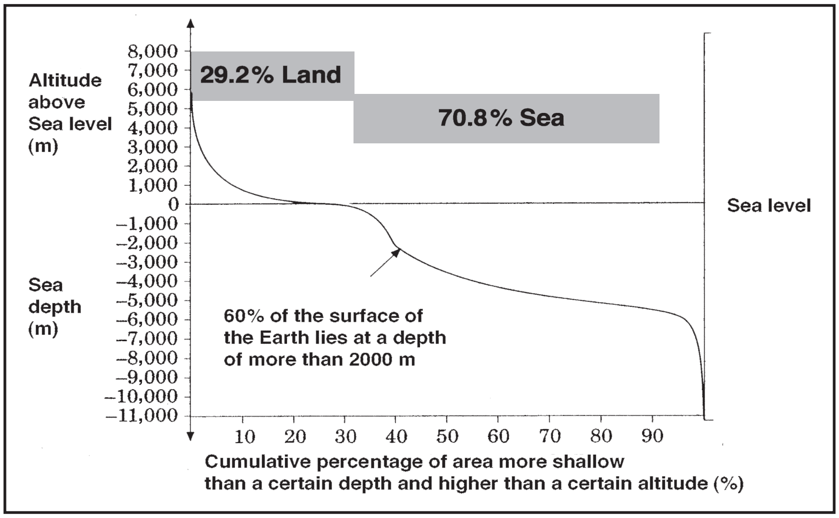


Figure 2.7. The hypsographic curve shows the distribution of altitude (above sea level) and depth (under sea level) on Earth as cumulative percentage of its surface. The highest mountain regions are on the left in the diagram and the deepest part of the oceans to the right. Land accounts for about 30% and water for about 70% of the total surface.

Most water on Earth is not immediately useful to us (Mays, 2001). Ocean and saline water accounts for about 97.6% of all water on Earth. The rest, 33,400 km^3, is fresh water. Most of this is bound in ice and glaciers. Liquid fresh water makes up 4,400 km^3. It is distributed between about 4,000 km^3 of ground water and smaller amounts of surface water. Lakes, rivers and brooks, wetlands, etc., contain about 130 km^3 on the Earth as a whole, and the atmosphere holds about 13 km^3. Considerable amounts are contained in biota (65 km^3) and soil moisture (65 km^3).

Figure 2.8. Planet Earth is a water planet more than a land planet. Sunset at the Bothnian Sea, north of Hudiksvall on the Swedish coast. (Photo: Inga-May Lehman Nådin.)

The hydrological cycle

Surface water is constantly re-circulated in what is called a natural *hydrological cycle*. Water evaporates from land, surface water and organisms. It enters the atmosphere and forms clouds as it condenses. It is transported by the winds and as it cools, especially at higher altitudes over mountains, it precipitates as rain and snow. Back on the ground it flows by gravity, coming back to the sea (See e.g. Hornsberger et al., 1998 for details).

The water flow described involves a considerable amount of energy. Mass (here water) present at higher altitudes contains *potential energy*, i.e., the flow down to lower levels represents an enormous amount of energy, which is used in e.g. hydropower plants.

Evaporation of water from land surfaces and transpiration from plants, called evapotranspiration, constitutes a considerable flow of water. Sublimation should also be included here. Sublimation is evaporation directly from the solid form of the substance without becoming a liquid first, e.g. snow, can sublimate on sunny winter days. Water as vapour, in a gaseous form in air, constitutes the humidity of the air.

In the reverse process, *condensation,* water vapour forms droplets of liquid water. Most often, condensation leads to cloud formation. When it occurs on ground or plant surfaces the water that appears is called dew. Some plants get all their water from dew.

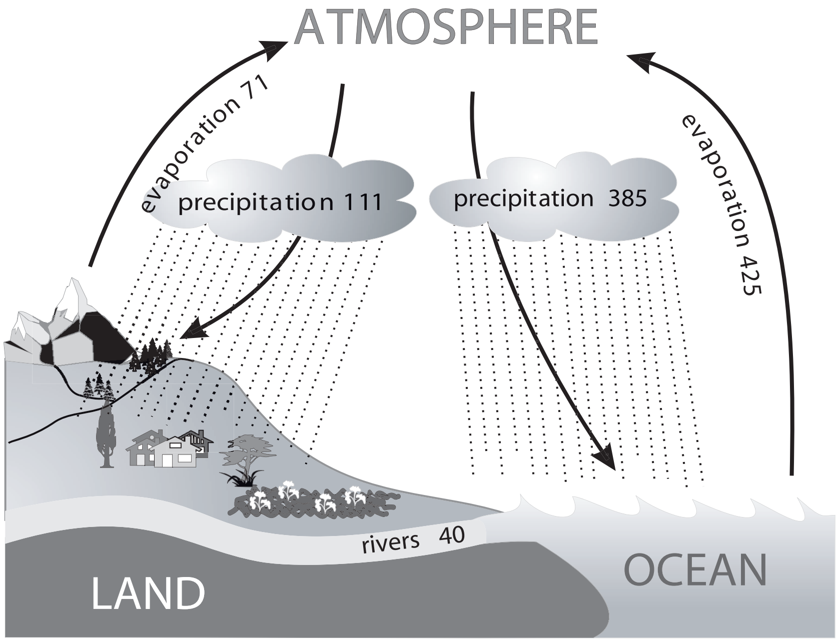


Figure 2.9. The hydrological cycle. Water evaporates from the oceans and land, is transported in the atmosphere, condenses as clounds and finally precipitates and runs through rivers back to the oceans. The numbers in the Figure are millions of Mtonnes of water per year globally. (Based on Karlsson, 1997.)

Precipitation occurs when water condensed in clouds forms large enough water droplets. Precipitation varies over the globe from several thousand millimetres per year down to almost zero. In the Baltic Sea region, the Norwegian mountains have a very large amount of annual rainfall, while many areas further south, e.g. in Poland, get smaller amounts. As a whole, the Baltic Sea basin receives 450 km^3 of water per year. This corresponds to 40 cm of water if spread out evenly over the entire region, or 1.2 m on the Baltic Sea itself. This is the potential annual runoff from the region. Subtracting the annual evapotranspiration gives the actual yearly runoff. The *water balance* can thus be formulated as: runoff is equal to precipitation minus evapotranspiration.

The hydrologic cycle includes the slow movement of ground and soil water. Here, movement is typically in the order of metres per year, as compared to metres per second for streams and metres per days for lakes. The storage of water in the ground and soil functions to even out water supply in nature. Even after prolonged draughts, some water is left in the soil and as ground water.

There are two implications of these aspects of water storage. First, seasonal water balances must include changes in the amount of water stored in the ground and soil. Second, polluted ground water moves slowly and may remain a problem even for future generations.

The water balance is connected to the heat balance by evapotranspiration. Net radiation is the driving force and sets the limit for evapotranspiration. In this way, the hydrological cycle is powered by precipitation which is the mass income, and net radiation is the power source.

The hydrological cycle thus constitutes a large solar powered pump that moves water and substances carried by water. Water evaporates in warmer areas, is transported by weather systems and precipitates in other colder areas. Many organic pollutants are in this way transported from southern Europe to the northern Baltic region and even further north, to e.g. Greenland, which thus receives pollutants that did not originate locally.

Life forms
and the large material flows

The planet and the biosphere

The part of the surface of the Earth that is moved by solar energy and that hosts life forms is called the *biosphere* or the *ecosphere*. It is a highly dynamic system that integrates all living species, which is referred to as the *biota*, and its environment, which consists of the *atmosphere* (air), the *hydrosphere* (water and oceans) and the *pedosphere*, which is the free layer of soil on the ground.

We may also discuss the whole system that is involved in material flows. This is the *geo-biosphere* which contains in addition to the *ecosphere,* the *cryosphere* (the ice on Earth e.g. in the regions of the north and south poles), and the *lithosphere,* that is the crust of the planet.

Originally, life was only present in water. About 350 million years ago life forms came up on land. At that time the circumstances needed for life on land were present, such as the oxygen in the atmosphere and the UV protecting shield of ozone in the stratosphere. Since then, life has resulted in an increased amount of organic materials on the surface of the Earth. These materials contain carbon, as well as oxygen, hydrogen, nitrogen, phosphorus, and sulphur, in addition to smaller amounts of other elements. Biomass constitutes a material pool of great importance.

The material flows that occur independent of life are limited. They are driven by e.g. volcanism, and chemical reactions caused by e.g. lightning. Life processes have increased these material flows enormously and, since their beginning, have been integral parts of all the major material flows on Earth. That is why these flows are called the *bio-geo-chemical* flows. Through photosynthesis and the coupled carbon dioxide fixation, life has moved masses in the ecosphere which, since the beginning of life, is estimated to be of the same order of magnitude as the mass of the Earth itself. Today's global net primary production (NPP) of biomass is estimated at 50 gigatonnes carbon/year for the continents and about half that amount for the oceans.

The turnover of matter from the lithosphere to the ecosphere is mediated by the extremely important thin layer of soil. The ecosphere is thus of ultimate concern for environmental protection and sustainable development.

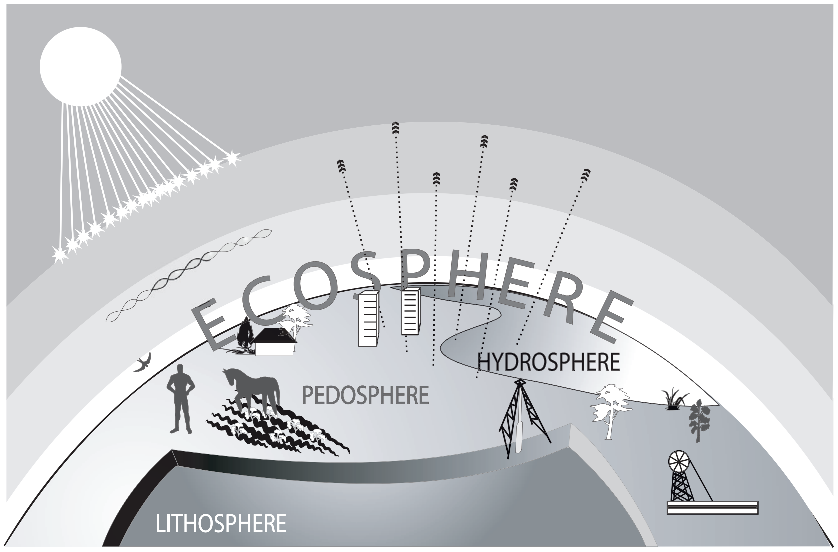


Figure 2.10. Spheres of the Earth. The *ecosphere*, also called the *biosphere*, contains all living organisms (the biota), and consists of three parts: the atmosphere, hydrosphere and free layer of soils above the bedrock, called the pedosphere. The *lithosphere* denotes the rest of the Earth, or the non-ecosphere, with three parts: the core, mantle and crust. It is in the crust, or bedrock, that mining takes place, e.g. for metals and fossil fuels. The mantle is the region of the Earth's interior between the crust and the core. (Based on Karlsson, 1997.)

Case

Box 2.1

The Gaia hypothesis

In the 1960s, as part of the US space program the English analytical chemist James Lovelock, well known for his development of the gas chromatograph, was asked by NASA, to try to find out if there was life on Mars. This was part of the long process of preparation for landing a spacecraft on Mars. Lovelock, however, did not judge that it was necessary to land on Mars to find out about possible life on the planet. He used spectroscopic methods to analyse the composition of the atmosphere on Mars and compared it to the atmospheres on other planets including Earth. He found a high concentration, 95%, of carbon dioxide, no oxygen and some other gases, including water. The atmosphere of Venus also has 95% carbon dioxide.

The high concentration of carbon dioxide is consistent with an atmosphere in chemical equilibrium. Earth's atmosphere, with a carbon dioxide concentration at about 0.036% and high oxygen levels, is far from equilibrium. The life processes of photosynthesis maintain this state. In fact, life on Earth has created its own life conditions.

Lovelock continued to conclude that life also had established mechanisms for maintaining these conditions. If carbon dioxide levels increase, photosynthesis will increase (experiments confirm this) and if it decreases, respiration will increase.

Lovelock then investigated a series of other parameters and found out that these were also maintained at levels optimal for life. Oxygen levels in the atmosphere may not be very much higher than 21% because then the incidence of fires on Earth will increase, and thus oxygen decreases. The salt concentrations in the oceans is another parameter, and even the DMS (dimethylsulphide) synthesised by algae in the oceans might be part of the life maintaining mechanisms, as they regulate the albedo and thus influence the temperature of the Earth.

The concept of Earth as a liveable planet able to maintain optimal conditions for itself was named Gaia, after the Greek name for Godess mother Earth, by Lovelock (1987). His Gaia hypothesis was met with scepticism by the scientific community. In the early 1990s, however, the existence of the Gaia phenomenon has been accepted at several prominent scientific conferences. The idea that Gaia has some level of consciousness is not part of Lovelocks' theory, but a fascinating concept proposed by others.

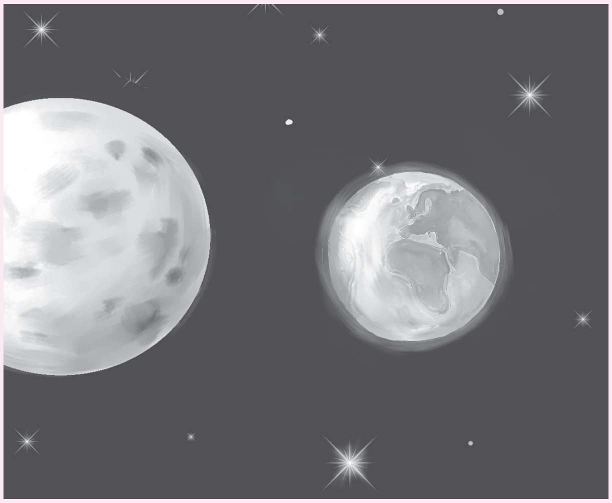


Figure 2.11. The Moon and the Earth as seen from space. The Gaia hypothesis maintains that several major geophysical properties of the Earth, such as temperature, oxygen concentration in the atmosphere and salinity in oceans, are self-regulating.

The carbon cycle

The carbon of the planet is found in the atmosphere as carbon dioxide, dissolved in ocean water, bound in biomass, and stored in the lithosphere as carbonate minerals. Although the atmosphere holds only 0.036% of CO_2 this substance is a key component in the physics of the planet since it interacts, as explained above, with the heat balance. It is also essential to all living cells as it is used when new biomass is built up in carbon dioxide fixation.

The carbon cycle starts when carbon dioxide in the atmosphere is formed from carbonates in the lithosphere. Carbon has been added to the atmosphere, through volcanic activities, throughout the history of the planet. An important part of the carbon flow is the formation of calcium carbonate in the seas especially as shells in marine organisms. As these die and their shells sink to the bottom, carbonate is transferred from the atmosphere to the sediments which finally become limestone rock, and thus return to the lithosphere. This slow, but in the history of the planet, major part of the carbon cycle, is estimated to have taken care of some 60 entire atmospheres of carbon dioxide, and that each carbon atom has made about 30 such round trips.

The absorption of carbon dioxide in ocean water is slow however, and in addition, limited by the slow mixing of the upper layer with the rest of the water in the oceans. An immediate component is the fixation of carbon dioxide to organic substances by living organisms during photosynthesis. As the biosphere builds up to considerable amounts of biomass, this constitutes a major carbon sink, not the least in the forests of the planet, but also organic material in soil.

Carbon dioxide fixation removes carbon from the atmosphere and respiration returns it back. In respiration organic molecules are oxidised with oxygen to provide energy to living cells. The by-products are water and carbon dioxide. All kinds of combustion and decay processes add to this flow.

Today, the comparatively immense utilisation of fossil fuels seriously disturbs the balance between natural processes. Modern combustion practices cause the concentration of carbon dioxide to increase. This increase is the key factor behind the enhanced greenhouse effect. The people of the Earth now consume 6 gigatonnes carbon/year, a mass that exceeds the mass of all the metals used by mankind during the period of time by a factor of ten! In addition, the handling of many fossil fuels involves flows of other matter than pure carbon, particularly sulphur (see below), which adds to the turnover of matter and many profound environmental stresses.

The nitrogen cycle

Nitrogen is found in the atmosphere at a concentration of 78%. It is present as a very stable diatomic nitrogen gas. This is natural in the oxidising atmosphere present today. However, it should be pointed out that when the atmosphere once was reductive, nitrogen was present as ammonium.

All life forms were, already from the outset, dependent on nitrogen, which is a component in such fundamental bio-molecules as proteins and nucleic acids. Ammonium can be used directly while molecular nitrogen cannot, but some life forms, special bacteria, have developed mechanisms to convert by reduction nitrogen to ammonium. These nitrogen fixing bacteria play a key role in maintaining life on Earth and manage the biological flow of nitrogen from the atmosphere pool back to life forms.

The flow of nitrogen is rather complex when seen in all its detail. The nitrogen fixing bacteria produce ammonium, which is easily oxidised to nitrite and nitrate. This is taken up from soil by plants. Certain plants, such as clover and alder trees, harbour their own "private" N_2-fixing bacterial strains. As plants are broken down to detritus, the soil content of nitrogen compounds increases.

Animals receive their nitrogen through food, especially animal food, and excrete this as urine, or for certain groups such as birds in other forms. This nitrogen may again be used by plants.

Finally, a series of bacteria uses nitrogen compounds as a source of energy and extracts this as they return the nitrogen to nitrogen gas. These denitrifying bacteria, present e.g. in many aquatic environments, work in oxygen depleted conditions.

In general, nitrogen is a limiting nutrient for plants. Since ancient times, "fossil" nitrogen, e.g. deep layers of bird droppings, have been used to provide agriculture with extra nitrogen as fertilisers. In the early part of the 20th century, an artificial method for reducing atmospheric nitrogen, the Haber-Bosch process, was developed. By using this process, modern industry has dramatically augmented the nitrogen flow by putting artificial fertilisers on the world market. Today, the amount of industrial nitrogen fixation is on the same size scale as biological fixation. It is not surprising to find that nitrous compounds have become so abundant that they have accumulated in natural ecosystems, not least in recipient aquatic systems, such as the Baltic Sea, resulting in eutrophication, algal growth and dead sea bottoms.

The phosphorus cycle

Phosphorus is another element essential to living cells. Phosphorus is common in soil and minerals, and the cycle begins when phosphorus is released from

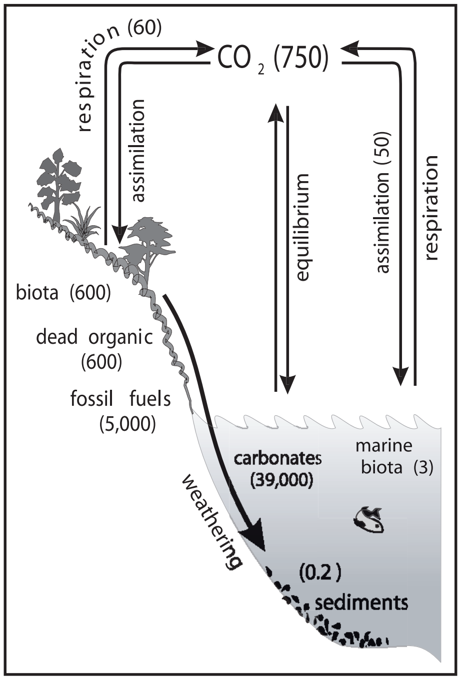


Figure 2.12. The natural carbon cycle. Carbon is available in the ecosphere as carbon dioxide in the atmosphere or dissolved in sea water as carbonates. A large amount is also present in organic form in living organisms or in dead organic matter in the soil and the sea. A rapid turnover between these two pools occurs through photosynthesis and respiration. The inorganic and organic pools correspond to around 400 and 20 years of photosynthesis, respectively. The carbon in fossil fuels, if used, is enough to significantly change the carbon concentrations in the atmosphere. The numbers denote for flows gigatonnes per year globally and for storages gigatonnes. (Based on Karlsson, 1997.)

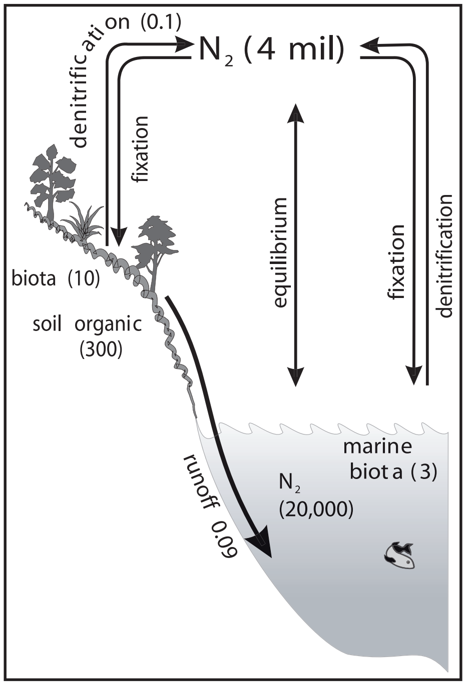


Figure 2.13. The natural nitrogen cycle. The Earth's crust contains relatively small amounts of nitrogen; most of the nitrogen in the ecosphere exists as the inert N_2 gas residing in the atmosphere, and only about 1% is dissolved in the oceans. From an environmental point of view, the interesting part of nitrogen is not this inert pool, but the chemically and biologically active part, the so-called "fixed nitrogen" in the ecosphere. Nitrogen is fixed and brought into the biogeochemical cycles mainly by certain specific nitrogen-fixing micro-organisms. A small amount of fixed nitrogen also comes from lightning, as atmospheric nitrogen is oxidized, as well as from volcanoes. The numbers denote for flows gigatonnes per year globally and for storages gigatonnes. (Based on Karlsson, 1997.)

soil through weathering processes. Phosphorus as phosphate is dissolved in water and absorbed by plants and in this way enters biological forms. It returns to inorganic phosphate as the organisms decay.

Phosphorous has no atmospheric form and it is thus directly transferred by water, mostly bound to fine particles in surface water where it is trapped in sediments and in this way returns to the lithosphere.

The phosphorous cycle is a very slow one. Man, however, dramatically speeds it up when phosphorus is mined, e.g. as phosphorites. Some of the richest phosphorite mines in the world are found in Estonia and in Northern Russia in the Murmansk region. The large amounts of phosphorous used as fertilisers in agriculture also add to eutrophication of surface waters, especially in lakes.

The sulphur cycle

Sulphur is a common element in many minerals and thus part of the lithosphere. It is released in weathering processes and dissolved in various forms in water. As such it is taken up by plants and bacteria and incorporated in several kinds of bio-molecules. It is essential for all life forms.

Sulphur has a complex chemistry and is available both as a dissolved substance in water, and in a gaseous form in the atmosphere. It has a capacity to form aerosols and droplets in air. Dimethylsulphide (DMS), formed by certain algae in the seas seems to have a role in climate regulation. DMS initiate aerosol formation and later droplets, which add to the albedo of the atmosphere above the oceans. Since it is formed when the water is warmer, it thus counteracts a temperature increase.

Sulphur is added to the atmosphere by volcanic activities. In the atmosphere, it is naturally oxidised to become sulphuric acid, a strong acid that is efficiently acidifying the water or soil where it finally precipitates. It is returned to the lithosphere as sediments.

Man has dramatically increased sulphur flow by burning fossil fuels, which often contain several percent sulphur. Again these artificial flows equal the natural flows.

The planet and society

Society and energy sources

Society is propelled by energy. We have seen that there is plenty of energy available on Earth, but still today the flows of energy are environmentally damaging. A very large share of energy use today is based on combustion of fossil fuel. It has already been noted that this is destructive to the environment since it influences the heat balance of the atmosphere and thus causes an enhanced greenhouse effect. What then are the alternatives that may be non-destructive?

Solar energy

All natural energy flows are based on solar energy. The sun provides the planet with energy that far exceeds what is being used today. The amount of energy is thus not the problem for environmental protection. It is the material flows connected to the energy flows that constitute the problem. Energy flows need to be dematerialised, in particular de-carbonised.

Review
Box 2.2

Satellites for global monitoring

ENVIronmental SATellite

Envisat – Europe's highly sophisticated global monitoring satellite – was launched by an Ariane 5 launcher from Europe's spaceport in French Guiana on 1 March 2002. Envisat will observe the Earth over a planned five-year mission using a combination of ten multi-disciplinary instruments.

Global data is recorded onboard the satellite and downlinked once per 100-minute orbit, to the Kiruna space station located in North Sweden. Experts across all Europe organised by the European Space Agency, ESA, are working together to process and interpret the data

ESAT Earth observation satellite has the size and weight of an ordinary bus, and is powered by a 14x4.5 m solar collector. Envisat circles the Earth at 100-minute intervals, 14 times a day, returning in a 35-day cycle to the same orbit, and in 3 days draws a complete map of the world.

The ten instruments on board Envisat, more than on any other satellite, cover a wide spectrum of phenomena, delivering evidence of the interactions between the atmosphere, the ocean and the surface of the earth.

Several other satellites are used by the European Space Agency to monitor the environment of the planet. Some of them are mentioned below.

Scanning the Earth's atmosphere

One of the instruments is the SCIAMACHY, the SCanning and Imaging Absorption spectroMeter for Atmospheric CartograpHY. It searches the atmosphere for trace gases, ozone and similar substances as well as clouds and dust particles, confirms the total amount of the gases and indicates the different altitudes. SCIAMACHY shows the consequences of forest fires, industrial emissions, arctic haze, dust storms and volcanic eruptions.

We will with Envisat be able to retain an overview, for example, of ocean water quality, of greenhouse gases or temperature distribution in the atmosphere, and to be able to establish the extent to which tropical forests are being cut down.

Scanning the land

On Envisat an imaging SAR radar penetrates the clouds and reveals land use. Comparisons of SAR images from different dates detect changes in the *land surface use*. A visible-infrared scanning radiometer gauges *vegetation growth* and also measures *surface temperatures*, often a symptom of land use, and reveals fires used to clear fields. Measurements of *soil moisture*, which is the key to the land's fertility, is also measured. It will be studied further by the presently planned satellite called SMOS

Scanning the sea

The oceans have been monitored from space since 1991 by ESA's ERS-satellite, and it will now continue with Envisat. It will measure sea-level changes and surface temperatures, and observe seasonal growth of plankton, while the role of ERS in gauging ocean winds (by radar scatterometer) will pass to the new weather satellite METOP (2003). Detection of variations in the thickness of the Greenland and Antarctic ice sheets, pioneered with the ERS radar altimeter, will be improved with twin radars on ESA's Cryosat (2003).

Satellites are also used to scan the surface of the sea for many different features. In Figure 2.16 an oil slick in the North Sea is detected by Tromsø Satellite Station (TSS) in norther Norway using SAR data. If an oil slick is discovered a communication is sent to the Norwegian Pollution Control Autority (SFT) by phone and fax.

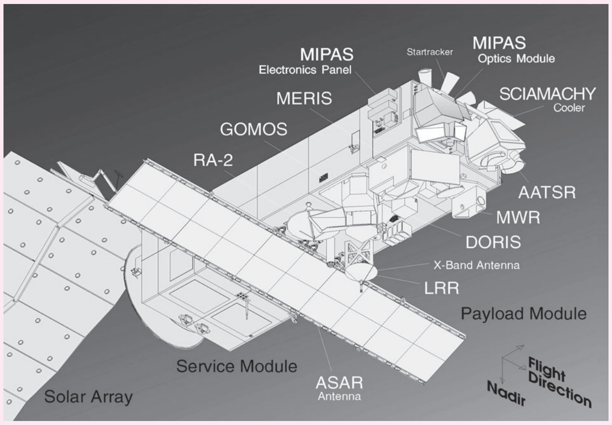


Figure 2.14. Envisat in detail. The "exploded" diagram shows the main strucutre of the satellite. (Source: ESA, European Space Agency, 2002. See further http://ravel.esrin.esa.it/images/envisat_detail.jpg.)

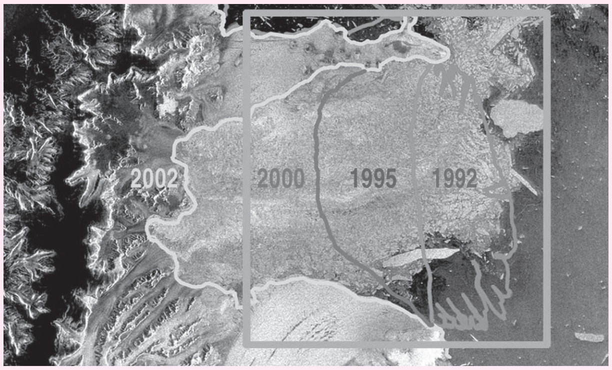


Figure 2.15. Global warming and the Antarctic. The Antarctic Peninsula has experienced exceptional atmospheric warming over the last decades, triggering the retreat and breakup of the ice-shelfs. On March 2002 Envisat observed the disintegration of the Larsen B ice shelf which has fractured into thousands of small icebergs. Calvings from earlier years are also shown in this image. (Source: ESA, 2000.)

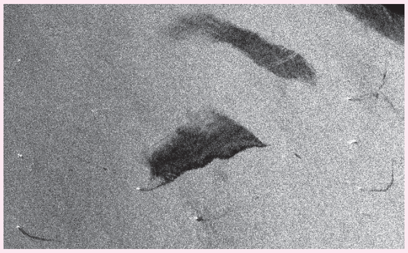


Figure 2.16. Oil slicks in the North Sea. An image area of 40 x 25 km. located northwest of Bergen, Norway in the North Sea was acquired from the European Space Agency's ERS-2 satellite on July 18 1996, by Tromso Satellite Station (TSS). In the image, there are two possible oil slicks of mean sizes 12 x 5 km and 14 x 3 km. Both slicks are diffuse and probably several hours old. Slicks can also be observed in connection with almost every oil platform (very bright points). (Source: ESA, European Space Agency, 2002. See further http://earth.esa.int/ew/oil_slicks/north_sea_96/_images/northsea.jpg.)

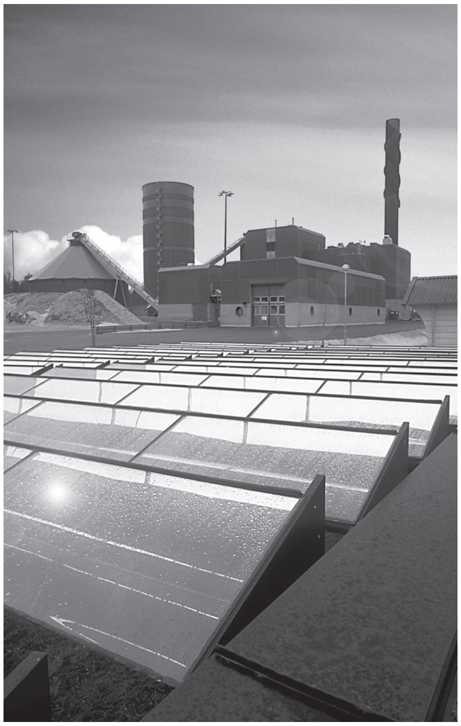


Figure 2.17. Direct use of solar energy. The flow of energy to a sustainable human society does not need to be severly limited. The amount used today, about 0.01% of the incoming solar radiation, is not by itself a problem. The problem is rather the large material flows presently linked to the energy turnover. If energy from the sun could be used directly, these problems would largely disappear. One possibility is to use heat from the sun in solar panels, as shown in this photo from Falun, Sweden. Other possiblites are to convert solar radiation to electricity in photovoltaic cells and to produce fuel, such as hydrogen, in solar synthesis. (Photo: Hans Blomberg, courtesy of Vattenfall.)

A large part of solar energy is captured in the atmosphere and creates the weather. This kind of energy generates *wind, waves, and flowing water.* Technology can convert the flowing, *kinetic*, energy in the wind into electricity with high efficiency or the *potential* energy of water at high altitudes into electricity. Energy from wind, waves, and flowing water is renewable, but at the same time environmentally problematic due to the infrastructure needed. Wind energy captured in a wind power plant has a large output of electric energy per surface area used for building the power station. For hydropower this is also valid, if we do not include the entire upstream area. If there is a reservoir, it may dramatically interfere with nature and ecosystems. The wave energy technology available today does not efficiently generate electricity.

The solar energy that reaches the ground may be captured as *heat*. This is used in e.g. solar panels on houses. Extra efficiency is gained if the solar panels are used as part of the roof construction. A problem with heat is that it is difficult to store. Large underground storage tanks are sometimes used.

Finally, *sun light* may be used directly in photovoltaic cells that convert the solar light into an electric current. Photovoltaic cell technology has improved dramatically in recent years and is now a viable option in some contexts for production of electricity.

Photosynthesis captures part of the solar energy and uses it to produce biomass. Biomass is thus a renewable source of "solar energy" on the time scale of years. The combustion of biomass, however, as all combustion processes, requires good technology so as not to produce air pollutants. Today, society harvests some 40% of all photosynthetic production on the land surface of the planet. It is probably close to the maximum possible. An interesting possibility is to develop synthetic photosynthesis to produce some other kind of reduced hydrocarbon, or even hydrogen gas. Research to develop this option has been taking place for some time. Hydrogen gas will probably play an important role in leaving the fossil fuel economy.

Peat, coal, oil and natural gas constitute stored photosynthetic products, old biomass. Of these coal, oil and gas are considered fossil, while peat is sometimes counted as fossil, and biomass is not. From the perspective of environmental protection and sustainability, any of these fuels may be used as long as the rate of harvesting does not exceed the rate of formation. The present rate of use of fossil oil in society exceeds that of formation by million of times. This of course leads to the accumulation of carbon in the atmosphere.

Geothermal energy

Another form of energy available on Earth is the heat from the ground, geothermal energy. This can be of great importance in areas close to tectonic plate borders, such as Iceland, and in other areas (e.g. in Poland and Denmark). Geothermal heat can be used for heating entire residential areas or individual buildings, as well as heat for heat pumps.

Nuclear energy

Radioactive decay gives rise to ionising radiation, a form of energy that may be captured, e.g. as heat. The fission of uranium is another process, which releases massive amounts of energy and can be used in nuclear weapons and nuclear power plants. Uranium, however is also a limited natural resource and therefore not renewable in the long run. Further, there are health and environmental impacts at every link in the nuclear fuel chain, e.g. uranium exploration, mining, milling, conversion, enrichment, fuel fabrication, fission in an nuclear reactor, spent fuel storage, and finally reactor decommissioning. The hazards of transportation of radioactive materials are also a concern. Further, spent nuclear

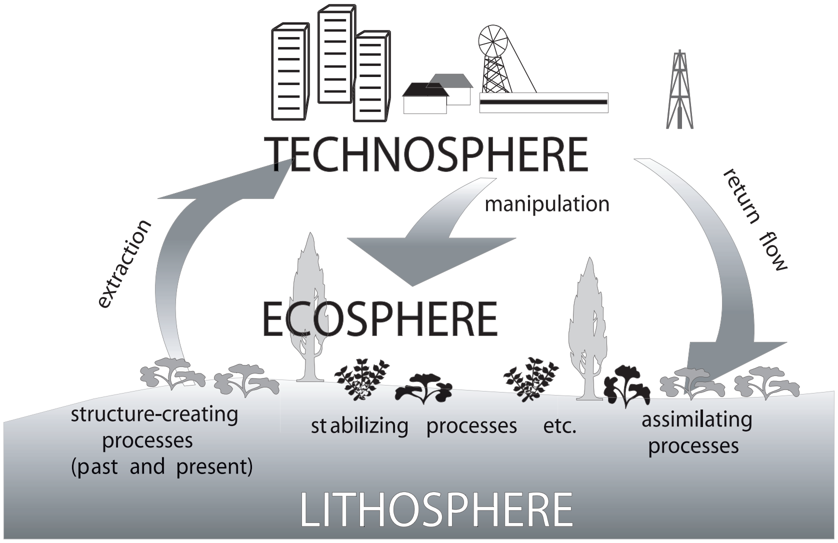


Figure 2.18. The planet and society. The relationship between human society and the planet can be illlustrated as a series of interactions between two major compartments or spheres. The *technosphere* denotes society (often described as the human sphere, that is people, and technical infrastructure). The planet is divided into the *ecosphere* and *lithosphere*, as illustrated in the Figure. Humans in the technosphere change the environment both through *extraction* of resources (creating new structures), the *return flow* (causing pollution), and other *manipulations* (landscape changes, building, etc.). (Based on Holmberg & Karlsson, 1992.)

fuel is one of the most toxic materials to life forms and is highly dangerous for hundreds of thousands of years.

Tidal energy

Tidal waves are a form of energy independent of the sun. They are caused by the gravitational influence of the moon. It is practically difficult to build a tidal power plant. The tidal movements are insignificant on the Baltic Sea coasts, but are very significant in other areas, e.g. in western Europe and North America.

Modern society and material flows

The natural nitrogen and carbon cycles have been disrupted by modern society, as have the natural cycles of phosphorus, sulphur, and many metals and chemical compounds. Historical changes in the turnover of matter is not only evident by the large amount of mass used by people, but also by the diversification of the quality and kinds of substances that have been extracted from the lithosphere. This has contributed to a deteriorated situation with regards to waste, pollution and scattering of contaminating and toxic substances. Effective machinery has been developed for fishing, forestry, and agriculture. Monocultures of crops, cattle and even fish have greatly increased and replaced older systems of self-sufficient households.

The results of the development of modern society are large factories, mines, cities and harbours, effective transportation lines in the form of roads, railways, airports, electric power lines, pipelines for oil and gas, and communication links of all sorts. Telephones and media services have partly moved away from electron carrying cables and poor radio wave transmissions to fibre optic cables and efficient satellite communication. The Earth is today a ball of yarn wound up by many different categories of transmission lines. This has lead to a highly diverse demand for combinations of rare natural substances.

The anthropogenic turnover of matter can be simplified and expressed in kilograms of matter per capita per year. It has been estimated that in Germany at the end of the 20th century, the mass turnover was 60 tonnes of matter per capita per year, not counting the societal turnover of water which alone was about 15 times as much. This is obviously not sustainable, nor can it become sustainable without fundamental changes in the structures of society and practical habits. A reduction of the total turnover of matter by a factor of 10 (!) has been discussed among experts (see Chapter 25).

Review
Box 2.3

Physical conditions for sustainability

Starting with the requirement that the balanced material flows on the planet should be maintained, it is possible to summarise a few principles for sustainbility. They are based on work from the Department of Physical Resource Theory at Chalmers University of Technology (Holmberg, et al., 1994).

Principle 1. Substances extracted from the lithosphere must not systematically accumulate in the ecosphere. This principle is violated, for example, when fossil fuel is extracted and carbon dioxide accumulates, or when phosphorus is mined and accumulates in surface waters.

Principle 2. Human-made substances must not systematically accumulate in the ecosphere. The principle is violated when, for example, persistent organic pollutants accumulate or when human-made radioactive isotopes are disseminated in the environment.

The guiding principles for material flows can be used by planners and decision makers, and for environmental management in general. In summary, the physical conditions for sustainability requires respect for material cycles, recycling of resources, and minimisation of wastes.

Principle 3. The physical conditions for production and diversity within the ecosphere must not systematically be deteriorated. This principle is violated by, for example, deforestation and the resulting desertification which leaves land infertile.

Principle 4. The use of resources must be efficient and just with respect to meeting human needs. This is an ethical principle.

The qualitative innovations over the last hundred years involve elements like heavy metals and other metals, which may have important functions in modern technology, as well as hundreds of thousands of chemical compounds that have been comparatively recently synthesised for a diversity of purposes. Many of these, if not to say most of them, may be harmful in different respects and toxic to groups of life forms and species. The worst scenario is that some such consequences are still left to discover.

It is of note that the whole nuclear industry, both for civil and military purposes, as well as the phenomenon of radioactivity, were entirely unknown only 100 years ago. The generations living around the year 2000 certainly have an unprecedented task in taking measures with new goals for future development.

In summary, the physical conditions for sustainability requires respect for material cycles, recycling of resources, and minimisation of wastes.

Conditions for sustainability

We have described how man has interfered very dramatically in the physical processes of the planet, in particular in the large turnover of material, the bio-geo-chemical cycles. At the same time life – including man – constitutes an integrated part of these flows, but under conditions that have developed over millions and even billions of years. If those conditions are changed dramatically in the time span of a few human generations, the existing balance is disturbed. The material is accumulating in one compartment, since the incoming flow is much larger than the outgoing flow. In short, the man-made flows become linear, and lead to negative environmental effects.

It is possible to define the conditions necessary for society to thrive without damaging the ecological systems of the planet. First, the productivity of the ecosphere should not be systematically deteriorated, such as, for example, the systematic removal of soil from a large area. Deforestation can lead to erosion and eventually desertification. Farmland soil in the Baltic Sea region is systematically deteriorated, and is discussed in Chapter 18.

Second, materials in the lithosphere should not systematically accumulate in the ecosphere. The most clear-cut example is when mining and combustion of fossil fuels (e.g. coal and oil), leads to accumulation of carbon dioxide in the atmosphere. Another example is when phosphorus is mined and accumulates in water. Other examples are metals, such as lead as well as some less common metals, which are mined and accumulate in the environment. These constitute linear flows and will eventually become damaging. It is typical that the environmental damage becomes a problem long before the resource is depleted.

Thirdly, man-made (synthetic) materials and chemicals, should not systematically accumulate in the ecosphere. Again, such flows will become linear and thus sooner or later reach toxic levels. Examples are substances such as polychlorinated biphenyls (PCBs), which do not exist naturally.

Fourthly and finally, resources of the ecosphere should be used efficiently and justly. This is not a physical constraint, but rather a moral one.

The quest for natural resources in modern societies has put a great load on the turnover of matter in the ecosphere. In judging today's situation it should be kept in mind that profound global quantitative changes have occurred. Human population has grown enormously, especially during the last two centuries. Urbanisation has proceeded at an ever-increasing rate in most cultures of the world. The human demands of all kinds of modern utilities have risen in growth processes which have been mediated by an effective market place for exchange and distribution of goods and services. In parts of the world, basic human needs have been overshadowed by human *demands*, a term which is exclusively associated with the economic market. As Mahatma Gandhi stated, "nature has enough for everybody's need, but not for everybody's greed."

Review questions

1. Write a short history of planet Earth.
2. Describe the structure of the Earth.
3. Describe the composition and structure of the atmosphere.
4. Describe briefly how the solar influx in used, including weather, waves, water cycle, and photosynthesis.
5. Make a drawing defining the different components of the biosphere (ecosphere).
6. Describe the main components of carbon flow and how they are influenced by human activity.
7. Describe the main components of nitrogen flow and how they are influenced by human activity.
8. Describe the solar energy resources that can be used without disturbing the Earth's ecological systems.
9. Describe the non-solar energy resources and comment on if they may be used by man.
10. List the basic principles for sustainable use of materials.

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Internet resources

The Earth's Atmosphere
http://csep10.phys.utk.edu/astr161/lect/earth/atmosphere.html

The Earth Observatory
http://eob.gsfc.nasa.gov/

Earth's Weather
http://www.windows.ucar.edu/tour/link=/earth/Atmosphere/weather.html&edu=high

European Space Agency, Envisat
http://www.esa.int/envisat/

The Global Atmosphere Watch Programme
http://gaw.web.psi.ch/

Global Hydrology and Climate Centre
http://wwwghcc.msfc.nasa.gov/

A Goddess of the Earth? The Debate over the Gaia Hypothesis
http://www.sprl.umich.edu/GCL/paper_to_html/gaia.html

Hydrology and Water Resources Programme
http://www.wmo.ch/web/homs/hwrpdesc.html

Hydrology Web
http://terrassa.pnl.gov:2080/EESC/resourcelist/

MineNet!
http://www.microserve.net/~doug/index.html

The Nine Planets
http://www.nineplanets.org/

Nutrient Overload: Unbalancing the Global Nitrogen Cycle
http://www.wri.org/wri/trends/nutrient.html

The Phosphorus Cycle
http://www.bsi.vt.edu/chagedor/biol_4684/Cycles/Pcycle.html

Resource and Materials Use
http://www.igc.apc.org/wri/materials/project.html

Surface Meteorology and Solar Energy Data Set
http://eosweb.larc.nasa.gov/sse/

West's Geology Resources
http://www.soton.ac.uk/~imw/

The Woods Hole Research Center. Global Carbon Cycle
http://www.whrc.org/science/carbon/carbon.htm

Glossary

albedo
proportion of incident light or radiation reflected by a surface

atmosphere
layer of gas around the Earth

bio-geo-chemical flows
the flows of material between the different parts of the geo-biosphere

biosphere
all life forms and the surface of the Earth that hosts life forms

biota
all life forms

core
the innermost part of the Earth, intensely hot made up mostly of iron

crust
the outermost part of the Earth, the solid rock with which we are familiar, 10 to 40 km thick

cryosphere
the ice on the Earth e.g. glaciers and ice around the north and south poles

ecosphere
another term for biosphere

erosion
when particles, created by weathering, are transported by wind and water

geo-biosphere
the biosphere and the rock

greenhouse effect
heating the Earth through atmospheric absorption of infrared back radiation

hydrological cycle
the cycle in which water is constantly re-circulated as it evaporates, enters the atmosphere and forms clouds, is transported by the winds and precipitates back to land as rain and snow

hydrosphere
all liquid water on the Earth

igneous rocks
rocks from magma that cooled after a volcanic eruption, such as basalt, and granite

kinetic energy
energy in movements of mass, e.g. air, moved as wind; this energy is transformed in wind power stations

lithosphere
the crust of the planet, the rock

magma
fluid rock from volcanic activity originating form the mantle

mantle
the part of the Earth outside the core, consisting of lighter elements such as silica, reaching down to a depth of about 2,900 km

mesosphere
part of the atmosphere reaching from the stratosphere up to an altitude of about 80 km

metamorphic rock
rock modified through heat, pressure and chemical reactions, e.g. marble

pedosphere
the free layer of soil on the ground

photosynthesis
production of biomass by living cells using solar radiation

photovoltaic cells
technical components that converts solar light into an electric current

potential energy
energy of mass, e.g. as water, present on higher altitudes; the fall down to lower levels releases this energy which may be transformed in hydropower plants

sedimentary rock
rock formed when sediments on ocean bottoms solidify due to high pressure, e.g. shale

soil
smaller particles of rock, such as till, loess, sand, silt and clay

solar energy
the energy contained in solar radiation

stratosphere
part of the atmosphere reaching from the troposphere up to an altitude of about 50 km; the stratosphere contains the ozone that protects the Earth form ultraviolet light

tectonic plates
huge blocs of the Earth's crust that move in relation to each other, and lead to earthquakes, and in geological time, formation of mountains

thermosphere
the outermost layer of the atmosphere, with highly ionised gas molecules, giving rise to the northern lighta, Aurora borealis

troposphere
part of the atmosphere closest to the Earth, reaching up from 18 km at the equator and 8 km at the poles

weathering
break up of rocks through mechanical and chemical processes to form smaller particles