Chapter 1
Introduction

The distribution and residence time of water on Earth in different resevoirs is shown in Table 1.1. The total volume of water on Earth is estimated to be $1.5 \cdot 10^9$ km^3.

Table 1.1 Distribution of water

	Volume (km^3)	**%**
Ocean	1 370 000 000	97.250
Polar ice caps, icebergs, glaciers	29 000 000	2.060
Ground water, soil moisture	9 500 000	0.674
Lakes and rivers	225 000	0.016
Atmosphere	13 000	0.001
SUM	**1 408 738 000**	**100.000**
Fresh water	36 020 00	2.600

Table 1.2 Fresh water as a % of its total

	%
Polar ice caps, glaciers	77.230
Ground water to 800 m depth	9.860
Ground water from 800 m - 4 km	12.350
Soil moisture	0.170
Lakes (fresh water)	0.350
Rivers	0.003
Hydrated earth minerals	0.001
Plants, animals, humans	0.003
Atmosphere	0.040
SUM	**100.000**

If all the water residing as groundwater was distributed uniformly over the Earth's surface, it would have a mean thickness of 16 m.

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River water is of great importance in the global hydrological cycle and for the supply of water to humankind. This is because the behavior of individual components in the turnover of water on the Earth depends both on the size of the storage and the dynamics of water movement. The different forms of water in the hydrosphere are fully replenished during the hydrological cycle but at very different rates. For instance, the period for complete recharge of oceanic waters takes about 2500 years, for permafrost and ice some 10 000 years and for deep groundwater and mountainous glaciers some 1500 years. Water storage in lakes is fully replenished over about 17 years and in rivers about 16 days. Table 1.3 shows the average residence time of water in various reservoirs and the equivalent thickness; calculated using $R_{earth} = 6371$ km, and surface area for water in the ocean as 70% of the total surface, water on land as 30% of surface, and atmosphere as 100% of surface [8, and many more].

Table 1.3 Residense time of water on Earth

Reservoir	V (%)	Residence time	Equivalent depth
Ocean	97.20	3700 a	3837 m
Ice	2.50	8600 a	190 m
Groundwater	0.63	5000 a	62 m
Surface water	10^{-2}	1 a	147 cm
Atmosphere	10^{-3}	10 d	25.5 mm

1.1 Hydrosphere

The hydrosphere is often called the “water sphere” as it includes all the earth’s water that is found in streams, lakes, the soil, groundwater, and in the air. The hydrosphere interacts with, and is influenced by, all the other earth spheres (Figure 1.1). The water of the hydrosphere is distributed among several different stores found in these other spheres. Water is held in oceans, lakes and streams at the surface of the earth. Water is found in vapor, liquid and solid states in the atmosphere. The biosphere serves as an interface between the spheres which aids in the movement of water between the hydrosphere, lithosphere and atmosphere. The hydrologic cycle traces the movement of water and energy between these various stores and spheres.

Definition 1.1. Hydrology is the study of water: occurrence, distribution, movement, and chemistry of water. *Hydrogeology* encompasses the interrelationships of geologic materials and processes with water.

Definition 1.2. The hydrological cycle refers to evaporation, condensation, rainfall, streams, infiltration, plants, and evaporation.

For all stores and spheres the *hydrologic equation*, or simply, the law of mass conservation, holds, [Inflow] = [Outflow] $\pm$ [Changes in storage].

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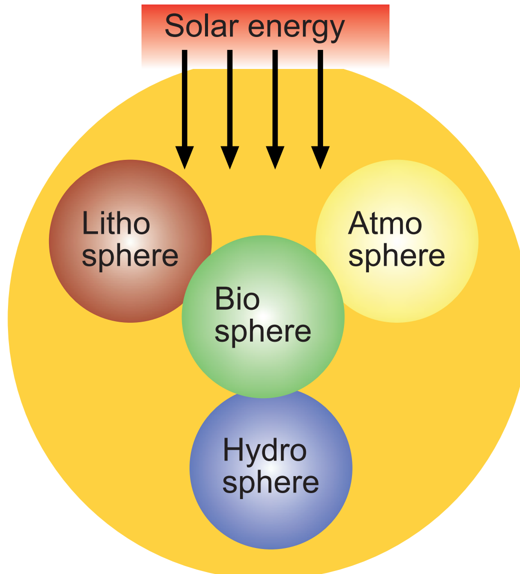

Fig. 1.1 The water-sphere receives energy from the sun. The water-sphere can be subdivided into different regimes, as shown in the figure.

1.2 The Earth's Water Budget

Water covers 70% of the earth's surface, but it is difficult to comprehend the total amount of water when we only see a small portion of it. Figure 1.2 displays the volumes of water contained on land, in oceans, and in the atmosphere. Arrows indicate the annual exchange of water between these storages [2].

The largest container of water is the oceans containing about 97.5% of the earth's water. Most of this water is salt water. Ice caps like that found covering Antarctica and glaciers that occupy high alpine locations compose a little less than 2% of all water found on earth. Seemingly a small amount, the water stored as ice in glaciers would have a great impact on the environment if it were to melt into a liquid. One fear is that global warming will cause the melting and collapse of large ice sheets resulting in sea level rise of 77 m if all ice melts [5]. Rising sea levels could devastate coastal cities, displace millions of people, and wreak havoc on freshwater systems and habitats.

Water beneath the surface comprises the next largest store of water. Groundwater and soil water together make up about .5% of all water (by volume). There is a difference between ground water and soil water. Soil water is the water held in pore spaces between soil particles. Soil pore spaces usually are usually partially void of water most of the time but fill with water after a rain storm. Groundwater, on the other hand, is found where earth materials are saturated throughout the year. That is, the pore spaces are always occupied with water. Both soil and groundwater are very important sources of water. Soil water is available for plants to extract and use. Groundwater is an important source of water for irrigation and drinking water supplies.

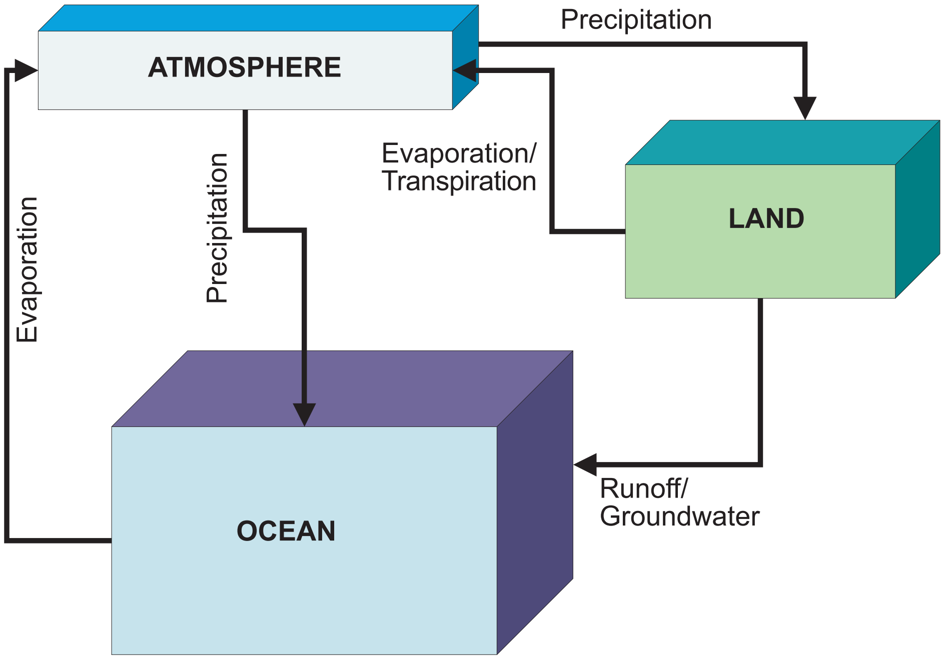

Fig. 1.2 Movement of water between the main reservoirs. Starting with the oceans (1350×10^{15} m^3) there is evaporation (361×10^{12} $m^3 a^{-1}$) that leaves, but direct precipitation from the atmosphere (324×10^{12} $m^3 a^{-1}$) and runoff/groundwater (324×10^{12} $m^3 a^{-1}$) enter. Part of the water in the atmosphere (0.013×10^{15} m^3) falls as precipitation on the ocean, and part on land (99×10^{12} $m^3 a^{-1}$). From the land there is an input to the atmosphere from evaporation and transpiration (62×10^{12} $m^3 a^{-1}$). Finally, the land surface (33.6×10^{15} m^3) gives up water as groundwater to the ocean, and evaporation/transpiration, and receives precipitation from the atmosphere (adapted from [2]).

Above the surface water is found stored in streams, rivers and lakes. One might expect that given the large rivers that flow across the earth and the huge numbers of lakes we have that this store would be rather large. Instead, streams, rivers and lakes only comprise .02% of all water in the earth system.

The atmosphere holds less than .001%, which may seem surprising because water plays such an important role in weather. The annual precipitation for the earth is more than 30 times the atmosphere's total capacity to hold water. This fact indicates the rapid recycling of water that must occur between the earth's surface and the atmosphere.

Each year 120 cm evaporate from the sea surface. Rainfall over the sea surface is $\sim$107 cm a^{-1}, the rest as runoff. Precipitation over land $\sim$75 cm a^{-1} ($112 \cdot 10^3$ km^3). On land water has two chances out of three of being reevaporated before reaching the ocean [8].

To visualize the amount of water contained in these storages, imagine that the entire amount of the earth's annual precipitation over land fell upon Iceland. If this was to occur, every square meter of Iceland would be under ∼960 meters of water! Also, there is enough water in the oceans to fill a 13 107 km deep container having a base area equal to the surface area of Iceland (103 000 km^2).

Figure 1.3 that most of the fresh water is locked up as ice.

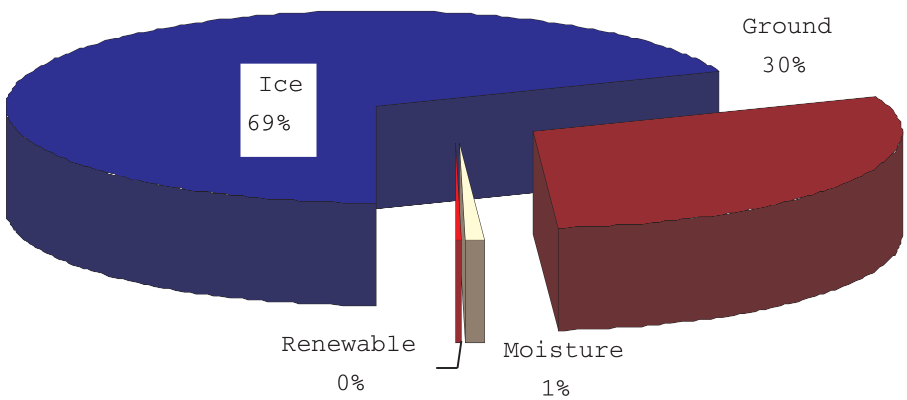

Fig. 1.3 Most of the fresh water is locked up in the ice sheets.

1.3 Distribution of snow and ice on Earth

Snow and ice distribution (coverage) changes considerably with season. Satellite data can show the distribution at various times and seasonal averages. Figure 1.4 shows the global average snow depth in January and June over a 10 year period (1993 - 2003). Sea ice also has a great seasonal variation (see Chapter 9).

1.4 Physical properties of water

Phase transitions, or phase changes, is used when materials, like water, changes from solid to liquid, liquid to gas, or directly from solid to gas, or in the other direction. Figure 1.5 shows the possible pathways, and their names. It is possible to add another layer, plasma above the gas phase, through ionization (deionization).

The water molecule is composed of two hydrogen atoms (H) and one oxygen atom (O) and has the familiar formula H_2O. Figure 1.6 shows the arrangements of the atoms.

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Fig. 1.4 Average snow depth in January (top) and June (bottom) for the years 1993 - 2003. Maximum (black) in January is 1841 mm, and in June it is 1641 mm (data from from NASA ISLSCP GDSLAM Snow-Ice-Oceans: Global data sets).

Water has some peculiar properties, such as high surface tension, high soluability, and is liquid at room temperatures.

The density of water is at maximum at 4°C, see Figure 1.7.

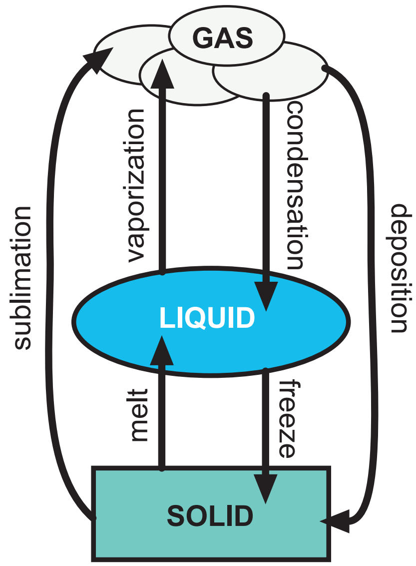

Fig. 1.5 Materials undergo phase changes when the temperature, and/or pressure, is changed significantly eneough This figure shows the nomenlecture used for the phase changes when going from solid (s), liquid (l), and gas (g). Melting refers to the phase change from s → l, freezing going from l → s, vaporization going from l → g, condensation going from g → l, sublimation going from s → g, and deposition going from g → s.

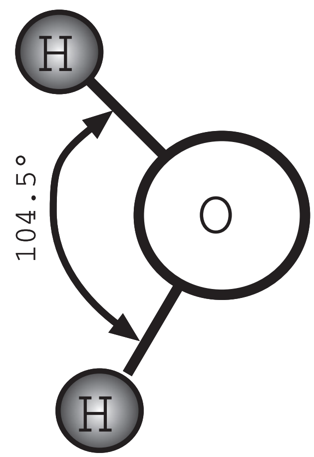

Fig. 1.6 The water molecule. The angle between the two hydrogen atoms is 104.5°.

Surface tension

Surface tension is an effect within the surface layer of a liquid that results in a behavior analogous to an elastic sheet. The effect of surface tension permits insects to walk on water and for drops of water to bead up.

Surface tension results from an imbalance of molecular forces in a liquid, see Figure 1.8. At the surface of the liquid, the liquid molecules are attracted to each other and exert a net force pulling themselves together. High values of the surface tension means the molecules tend to interact strongly. Lower values mean the molecules do not interact as strongly.

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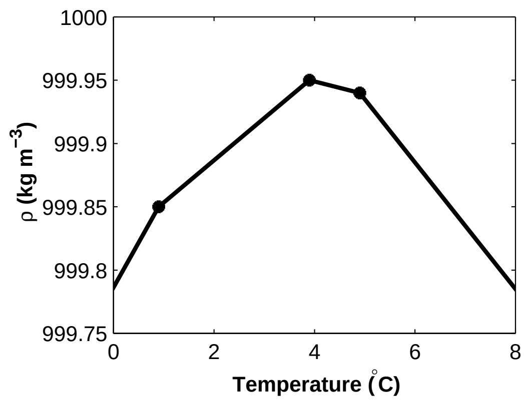

Fig. 1.7 The density of water as a function of temperature. The maximum density occurs at 4°C, which has a great impact on life in lakes, rivers and so on.

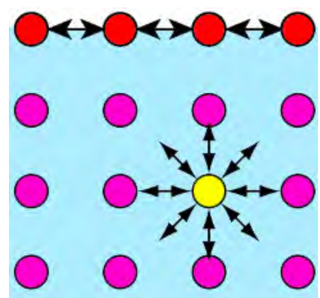

Fig. 1.8 Surface tension forces. Molecules in the interior experience an attractive force from neighboring molecules which surround on all sides, while molecules on the surface have neighboring molecules only on one side (the side facing the interior) and thus experience an attractive force which tends to pull them into the interior.

Water has a very high value of surface tension because of hydrogen bonding, which insects utilize as seen in Figures 1.9 and 1.10. In surface science, surface tension is measured in newtons per meter and is often represented by σ.

Ice

Ice I_h crystals are hexagonal (Fig. 1.11) and their faces are shown in Figure 1.12.

Humidity

At any given temperature, air can hold a maximum amount of vater vapor, called the saturation humidity, see Figure 1.13. The relative humidity is the percentage ratio of the absolute humidity to the saturation humidity at the given air temperature. As the relative humidity approaches 100%, evaportation ceases [4].

Fig. 1.9 The waterlily leaf beetle *Pyrrhalta* feeds upon the plant for which it is named. The larva is a poor swimmer, making travel between lily pads difficult. It uses a special meniscus-climbing technique to close in on emerging overhanging vegetation. The deformation of the water surface near the head and tail of the larva is clearly visible (http://www-math.mit.edu/ dhu/Climberweb/climberweb.html).

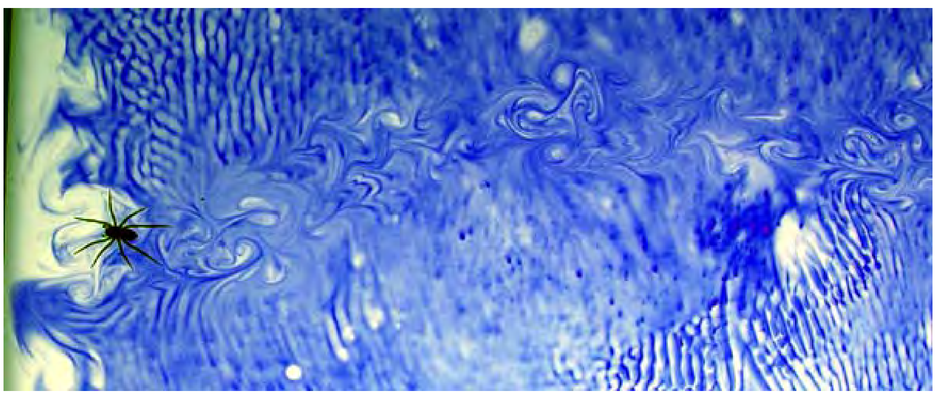

Fig. 1.10 Freshwater spider *Dolomedes* running along the surface, leaving vortices behind its four pairs of stroking legs. More wonderful pictures at http://www-math.mit.edu/∼dhu/Striderweb/striderweb.html.

1.5 Problems

Water budget problems

1.1. Find, at least 3 different, references for the global water budget, and the fluxes between water reservoirs. Note that different classifications are used, sometimes groundwater contains both proper groundwater and soil moisture, and sometimes just groundwater.

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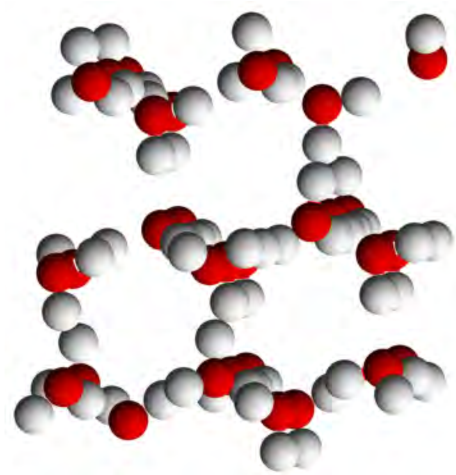

Fig. 1.11 The crystal structure of ice I_h. The red balls represent the oxygen atoms, and the white ones represent the hydrogen atoms.

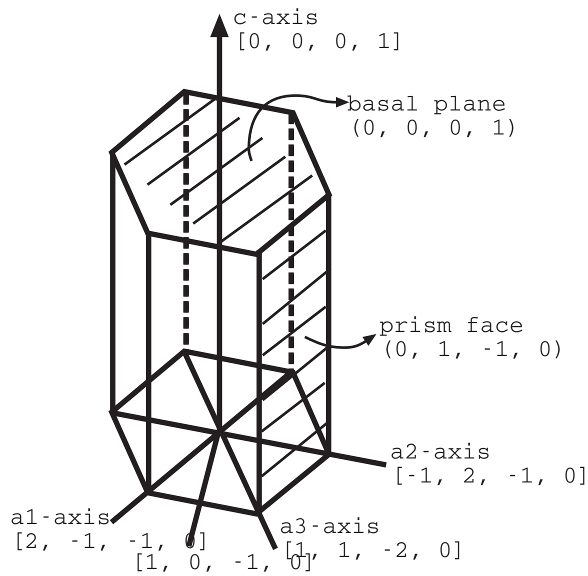

Fig. 1.12 The crystal faces and axes of ice I_h.

Present the values from the original source, in that format, using Excel (or other spreadsheets), and then in a coordinated way (that is, using the same categories for all data sources) to facilitate comparison.

Compare the differences (as total amount and percentage) in:

- Total water on earth
- Water content in each reservoir
- Fluxes between reservoirs


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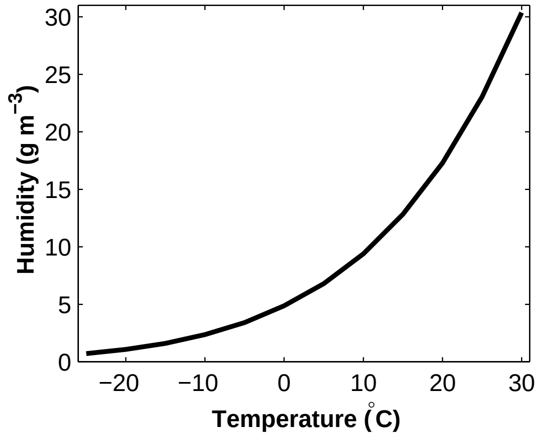

Fig. 1.13 The saturation humidity of air as a function of temperature.

Distribution problems

1.2. Why is the snow line lower at the equator than at 30?

1.3. The surface area of Iceland is about 103 000 km^2, and the total volume of ice is about 4 000 km^3 (glaciers cover about 11% of the surface of Iceland).

- What is the mean thickness of Icelandic glaciers?
- How thick would the ice cover be if the total volume were spread out over Iceland? Compare with known structures in Reykjavk.