EVAPORATION FROM THE SURFACE OF THE GLOBE

V.I. Babkin
State Hydrological Institute, St. Petersburg, Russia

Keywords: Evaporation of water, water vapor, water surface, ocean, continent, land, distribution, method, mountains, desert, zone.

Contents

Summary

Evaporation of water from the surface of the Earth is the main process providing water vapor transport to the atmosphere. On average 1130 mm (or 577 000 km^3) of water are evaporated from the surface of our planet during a year. Most of this amount, 505 000 km^3, is evaporated from the surface of the World Ocean and only 72 000 km^3 from land. The evaporated moisture is condensed and falls as precipitation. Maximum evaporation from the ocean is observed in both hemispheres in the zone of trade winds in the latitudinal zones 10 to 20^{o}N and 10 to 20^{o}S. Southward and northward of the trade wind

zones evaporation tends to decrease in both directions. Regular changes in evaporation by zones are disturbed by warm and cold currents in the ocean.

Though evaporation from Asia is not great, 400 mm only, about 18 100 $km^3$of water, i.e. about 25% of the total water amount evaporating from land are transported during a year to the atmosphere from this continent, which is the largest on the globe. More than 65% of the total water evaporating from land to the atmosphere is due to evaporation from three continents (Asia, Africa and South America). The zones of evaporation of different water quantities from the continents are most often explained by the amount of precipitation there, the amount of solar radiation and the relief of the terrain. Distribution of evaporation during a year from different land surfaces depends on the previous and current moistening and solar radiation.

1. Introduction

Evaporation of water from the surface of the World Ocean and land of the planet is the main process providing water vapor transport to the atmosphere. Evaporation of water takes much heat (1.26 x 10^{24} joules), or about 25% of all the energy received at the Earth's surface. Therefore, evaporation is a very important factor of energy and water balances of the atmosphere and the Earth's surface. Evaporation provides the return of most precipitation into the atmosphere in the form of water vapor.
Evaporation of water occurs at any absolute temperature of a water surface above 0 ^{o}C. It is a process involves many factors, and it is affected by numerous factors. For example, evaporation from a free water surface depends on the difference between the water vapor viscosity at the water surface and in the nearest air layers; it depends on the air and water temperatures, on wind velocity, atmospheric pressure and water quality.

Evaporation from the soil surface depends on soil moisture content. When the soil surface is saturated with water, the evaporation rate does not differ from evaporation from a water surface, if the temperature is similar. If the soil surface is not saturated with water, evaporation rate is limited by the rate of moisture migration into the surface soil from the lower soils and subsoils.

Some of the precipitation onto the land surface does not penetrate into soil but stays on the surfaces of plants. This water evaporates and returns to the atmosphere. As the surface of the leaves and bark of bushes and trees is very large the evaporation rate from a unit area overgrown with forest greatly exceeds the evaporation rate from a unit area of water. Water from the surfaces of trees and bushes evaporates quickly. But the water intercepted by thick grass evaporates slower, because air motion in the grass cover is difficult and the difference in the values of the water vapor viscosity is about zero.

The process of water transport from plants to the atmosphere in the form of water vapor is transpiration. Soil moisture is the source of water for transpiration. Therefore, the transpiration rate is restricted by the capacity of the roots to supply plants with water.

Data on evapotranspiration are required to study water balances of river basins, regions, countries, islands and continents. Evapotranspiration is the amount of water lost from the study area for transpiration and evaporation from the surfaces of land, swamps, water, snow, ice and top cover.

Individual types of evaporation (evaporation from water, snow, soil, swamps, transpiration, irrigated land, etc.) can be measured by pans (installed on the land surface or water surface), evaporimeters and lysimeters of different designs. In many countries, however rather few of these instruments are available. Therefore, during hydrological studies the data obtained from such instruments are used to establish empirical dependences of different types of evaporation or evapotranspiration on determining factors. Sometimes such data are used to estimate evaporation, though these estimates are not very reliable. Design methods based on the laws of water mass and energy conservation are usually applied to estimate evaporation from large surfaces. The following methods are most often applied: the method of water balance, energy balance, turbulent diffusion method, joint solution of water and energy balance equations, equations of relations, empirical formulas and graphs.

2. Evaporation from the surface of the World Ocean

The World Ocean offers a single water surface whose area equals 361.3 million km^2. It is usually subdivided into four oceans, i.e. Atlantic, Arctic, Pacific and Indian oceans. The Pacific Ocean occupies about a half of the World Ocean surface area. The surface of the Atlantic Ocean is about half the area of the Pacific, and 1.2 times greater than the Indian ocean. The surface of the Arctic Ocean is about ten times less than that of the Pacific ocean. Having large areas of water surfaces, the oceans are gigantic evaporimeters of water which is transported to the atmosphere. The amount of evaporated water from the surface of the World Ocean and from the surfaces of each ocean is usually estimated by design methods.

2.1. Method for evaporation calculation

To estimate evaporation from the surface of the World Ocean methods are applied which are based on the following formula:

$$E = \xi * u * (q_S - q) \qquad (1)$$

where $q_S - q$ – is specific humidity deficit calculated from the temperature of the water surface;
u – is wind velocity;
ξ - is parameter of evaporation.

Dependence of this parameter on wind velocity, on the difference between water and air temperatures and on humidity deficit has been established at the Main Geophysical Observatory. The parameter of evaporation is estimated from mean monthly observation data from a boat taking account of the structure of meteorological fields at low and medium wind velocities. During storms the evaporation parameter increases greatly. Therefore, its values for storm wind velocities are expressed within the bands 17 – 21; 21 – 24; and 24 – 30 m/s, incorporating velocity probabilities within the above intervals. This method has been applied to estimate mean monthly evaporation from the surfaces of oceans, seas, bays and straits, taking account of both conditions of stratification of the air layer adjacent to the water surface and storms.

2.2. Distribution of evaporation from the water area of the World Ocean

Mean monthly evaporation from the surfaces of the oceans have been estimated for 722 design points. In accordance with the latitudinal distribution of the total solar radiation on the Earth, total annual evaporation from the surface of the World Ocean tends to a zonal decrease from low latitudes to high latitudes. Under the effect of atmospheric circulation and sea currents, however, the latitudinal distribution of evaporation is slightly disturbed. Within the limits of low latitudes annual evaporation from the World Ocean equals 1600 to 2400 mm. There are areas, however, with lower evaporation values in subequatorial regions in the east Atlantic and Indian Oceans as well as on the western and eastern margins of the Pacific. In these regions equatorial air masses with low wind velocities and higher moisture content reduce evaporation from the ocean surface for most of the year.

In the regions of the trade winds in both hemispheres, higher wind velocities and drier air masses are observed in association with anti-cyclonic weather regimes. Intensive evaporation is therefore observed in high tropical latitudes. Total annual evaporation here exceeds 2000 mm. On the margins of the oceans at these latitudes evaporation is affected by warm and cold currents.
In western parts of the oceans within the Antilles current, Brazil current, Mozambique current and to some extent the East Australian current, annual evaporation exceeds 2000 mm, because the values of water temperature here are higher.

In eastern areas of the oceans within the cold Benguela and Peru currents, annual evaporation is reduced to 1200 mm and lower.

Great differences in evaporation from west and east ocean areas are observed in the subtropical zone of the northern hemisphere. In the western part of this zone in the Atlantic, evaporation attains 3200 mm, and 2400 mm in the Pacific. On the eastern side the total annual evaporation from these oceans decreases to 1000 mm.

The intensive evaporation in the west of the oceans is explained by the interaction of the warm water surface of the Gulf Stream and Kuroshio Current, in winter, with cold air masses from the continents of North America and Asia. These air masses are transformed greatly when they reach the eastern part of the study zone. Therefore, the evaporation rate here is reduced.

In the subtropical zone of the southern hemisphere annual evaporation varies from 800 mm to 2000 mm.

In the temperate latitudes of the northern hemisphere total annual evaporation varies from 2000 mm to 400 mm. Distribution of evaporation over the Atlantic in this zone is explained by the prevailing currents. In the open ocean evaporation tends to reduce from south to north because of the lower intensity of the North Atlantic drift. Within the area of the cold Labrador Current lower evaporation values are observed all over the route of the current.

In the temperate latitudes of the north part of the Pacific evaporation exceeds 1000 mm per year; these are the highest evaporation values observed in the far southwest of the zone. In the other parts of this zone total annual evaporation from the Pacific varies from 400 to 800 mm.

In the temperate latitudes of the southern hemisphere annual evaporation from the open ocean surfaces varies from 400 to 1000 mm. Total annual evaporation from those parts of the oceans covered by ice for some months is close to 200 mm.

South of 45°S in the Atlantic and Indian Oceans there is an area of lower evaporation values. This is explained by lower water temperatures and by intrusion of warm air masses from low latitudes.

The low temperature of the air and the underlying surface explain to a great extent the low rate of evaporation from the central part of the Arctic Ocean. Southward of this area the warmer water of the Atlantic and Pacific Oceans flows. In accordance with the oceanic advection of heat northwards, the annual evaporation in the Bering Strait increases to 200–250 mm.

In the southeastern part of the Baffin Bay, within the area of the West Greenland current, annual evaporation increases to 300–350 mm. In the Norwegian and Barents Seas where they are free from ice, i.e. in places affected by the Murmansk and West Spitsbergen currents, total annual evaporation increases to 800–1000 mm. Evaporation from the surfaces of the Atlantic, Pacific, Indian and Arctic oceans as well as from the whole World Ocean by latitudinal zones is given in Table 1.

Latitude, in degrees	**Arctic Ocean**	**Atlantic Ocean**	**Indian Ocean**	**Pacific Ocean**	**World Ocean**
90-80NL	75				75
80-70	205				205
70-60	405	798		308	520
60-50	390	1100		565	795
50-40		1420		953	1150
40-30		1720		1560	1630
30-20		1840	1920	1810	1830
20-10		1950	2000	2020	2000
10-0		1720	1940	1810	1820
0-10SL		1640	1810	1630	1680
10-20		1700	2060	1900	1910
20-30		1560	1960	1890	1830
30-40		1350	1380	1530	1440
40-50		672	773	1100	876
50-60		409	569	735	598
60-70		239	372	409	355

Mean from the ocean	220	1360	1420	1510	1400

Table 1. Total annual evaporation from the surface of the oceans (mm)
(World Water Balance and Water Resources of the Earth, 1974)

It is evident from Table 1 that the maximum annual evaporation is observed in the zones of high atmospheric pressure in both hemispheres. Lower evaporation occurs at pre-equatorial latitudes. In the northern hemisphere beyond the equatorial latitudes, evaporation from the Atlantic Ocean is higher than from the Pacific because of the effect of the North Atlantic current.

Maximum annual evaporation is observed from the Indian Ocean at 30^{o}N to 30^{o}S. This maximum is explained by the high total solar radiation at these latitudes and by a greater dryness of air fluxes in the trade winds zone.

2.3. Distribution of evaporation from the surface of the World Ocean during a year

Total annual evaporation from most water areas of the World Ocean depends on the conditions during the autumn-winter period. During this time of the year the water surface is warmer than the air. Concurrently, the highest wind velocity above the water surface is observed during this period. The range of evaporation distribution during a year is especially wide at temperate latitudes and in the west of the subequatorial zone of the northern hemisphere. Cold and dry Arctic and continental air masses move onto warm water areas in these zones. Therefore, more water evaporates from the water surface during this time, i.e. up to 15–20% of annual evaporation during some months.

In summer the temperature differences between the oceans and the continents tend to be lower. In some areas of the ocean the water surface is cooler than the air. Therefore, evaporation at temperate and subtropical latitudes is lower. This evaporation decrease is also contributed by decreased wind velocities and lower storm activity. Monthly evaporation in summer may decrease to 1–5% of the total annual value. In summer time water vapor condensation may be observed in some areas within the study latitudes of the World Ocean when there is interaction between warm air masses and a rather cool oceanic water surface. But the layer of condensed moisture, if compared with annual evaporation, does not exceed a few percent.

In eastern areas of the oceans at temperate and subtropical latitudes, evaporation differs slightly during a year. This is explained by transformation of air masses during their transport over the oceans.

On oceanic water areas beyond the equatorial latitudes in both hemispheres, distribution of evaporation during the year is more even than evaporation distribution beyond the tropical latitudes. In autumn and winter the total monthly evaporation here is 10–14% of its annual value. In summer time total monthly evaporation attains 4 to 7% of its annual value. Southern latitudes of the trade winds zone in the northern hemisphere at latitudes beyond the equator, where the secondary summer evaporation maximum is observed, are the exception. This maximum is explained by the higher wind velocity in the

Atlantic and Pacific Oceans resulting from cyclone activity at tropical fronts, and in the Indian Ocean, by higher pressure gradients above South Asia. The centre of a great Asian depression in summer occurs close to the shores of the Indian Ocean. Therefore, wind velocity in the study zone tends to greatly increase at this time, explaining the high total evaporation, i.e. about half of the annual value during the three summer months.

The Arctic Ocean is characterized by three types of evaporation distribution during a year. The first type is observed on the central part of the ocean with permanent ice coverage. Here maximum evaporation occurs in June, and minimum evaporation is observed in January to March. The second type of evaporation distribution during a year is typical of the area of the ocean free from ice for some time (maximum evaporation is in winter and minimum is in summer). The third type of evaporation distribution during a year is characterized by two maxima and two minima of evaporation. Evaporation maxima are observed in spring and in autumn; the minima occur in winter and in summer. The third type of evaporation distribution during a year is characteristic of marginal seas with seasonal ice coverage.

The volume of evaporation from the surface of the World Ocean is about seven times greater than the volume of evaporation from land. Evaporation from continents, however, explains many of the processes of the hydrological cycle which are very important for human life and activity.

-
-
-

Bibliography

Andrejanov V.G. (1977). Improvement of methodology for water balance computations of watersheds on the basis of physical and mathematical model. – Trudy GGI, vol.241, p.56 – 75. Leningrad. [New methodology to estimate evaporation from land] (in Russian).

Atlas of World Water Balance (1976). Hydrometeorological Publishing House. The UNESCO PRESS, 65 pp. [Maps are gives on all water balance components from the world surface and from individual continents]

Babkin V.I. (1984). Evaporation from water surface. 72 pp. Hydrometeoizdat, Leningrad. [Molecular and kinetic theory of evaporation is presented] (in Russian)

Baumgartner A., Reichel E. (1975). The World Water Balance. – Vienna: R. Oldenbourg Verlag Munchen, 180 pp. [Methodology and data on water balance components of the world's continents are given]

Brutsaert W.H. (1985). Evaporation into the atmosphere. Translated from English. 351 pp. Gidrometeoizdat, Leningrad [This is about heat and energy theory of water evaporation]

Budyko M.I. (1971). Climate and life. 472 pp. Hidrometeoizdat,Leningrad. [This is about methods for estimation of all energy balance components of land] (in Russian).

Drozdov O.A., Vasilieev V.A., Kobysheva N.V., Raevsky A.N., Smekalova L.K., Shkolny E.P. (1989). Climatology, 567 pp, Leningrad [This describes principles of climatology and hydrometeorological processes and events on the Earth] (in Russian).

Zubenok L.I. (1976). Evaporation from continents. 264 pp. Gidrometeoizdat, Leningrad [This is about the use of the multipurpose (complex) method to estimate evaporation from the continents of the Earth] (in Russian).

Institute of Geography RAS (1998). Resources and Environment, World Atlas. Pt.I – Vienna: Ed.Holzel, 56pp. [Maps are presented showing the water balance components of the Earth]

Konstantinov A.R. (1968). Evaporation in nature. 532 pp. Gidrometeoizdat, Leningrad. [Results of theoretical and empirical studies of water evaporation are given] (in Russian).

Lvovich M.I. (1974). World water resources and their future. "Mysl", 448 pp. Moscow [Data are given on water resources and basic water balance components of the Earth] (in Russian).

Matveev L.T. (1984). A course of general meteorology. Physics of the atmosphere. Gidrometeoizdat, 751 pp. Leningrad [it is about physical principles of meteorology] (in Russian).

Mezentsev V.S., Karnatsevich I.V. (1969). Moistening of West Siberian Plain. 168 pp. Gidrometeoizdat, Leningrad [A heat balance method is suggested to estimate evaporation from land surface] (in Russian).

World Water Balance and Water Resources of the Earth. (1974). Gidrometeoizdat, Leningrad, 638 pp. [Methods and data are given on each water balance component of the Earth]

Penman H.L. (1968). Plant and moisture., 161 pp. Gidrometeoizdat, Leningrad. .[The use of heat balance method to estimate evaporation from land]

Shuleikin V.V. (1968).Physics of Sea. 1083 pp. "Nauka" Publishing House, Moscow. [This is about physical principles of oceanology and global hydrometeorological processes] (in Russian)

Biographical Sketch

Vladimir Ivanovitch Babkin was born in 1941. In 1965, he graduated from the Voronrzh State University. Since 1969 he has worked at the State Hydrological Institute. In 1970, Babkin defended his thesis for the degree of candidate of geographical sciences, and in 1984 a doctoral thesis in geography.

Since 1982, Babkin has been head of the laboratory "Water Resources and Water Balance" at the State Hydrological Institute, St. Petersburg.

He is the author of 130 scientific papers including seven monographs on hydrology, hydrophysics, and water balance and water resources. Most of his studies deal with hydrological cycle processes (evaporation, runoff, precipitation, and infiltration), developing methods for their estimation, as well as discovering global mechanisms of land moisturizing on the continents.